Ministry of high Education and Scientific Research
Southern Technical University
Technological institute of Basra
Department of Electrical Techniques

Learning package

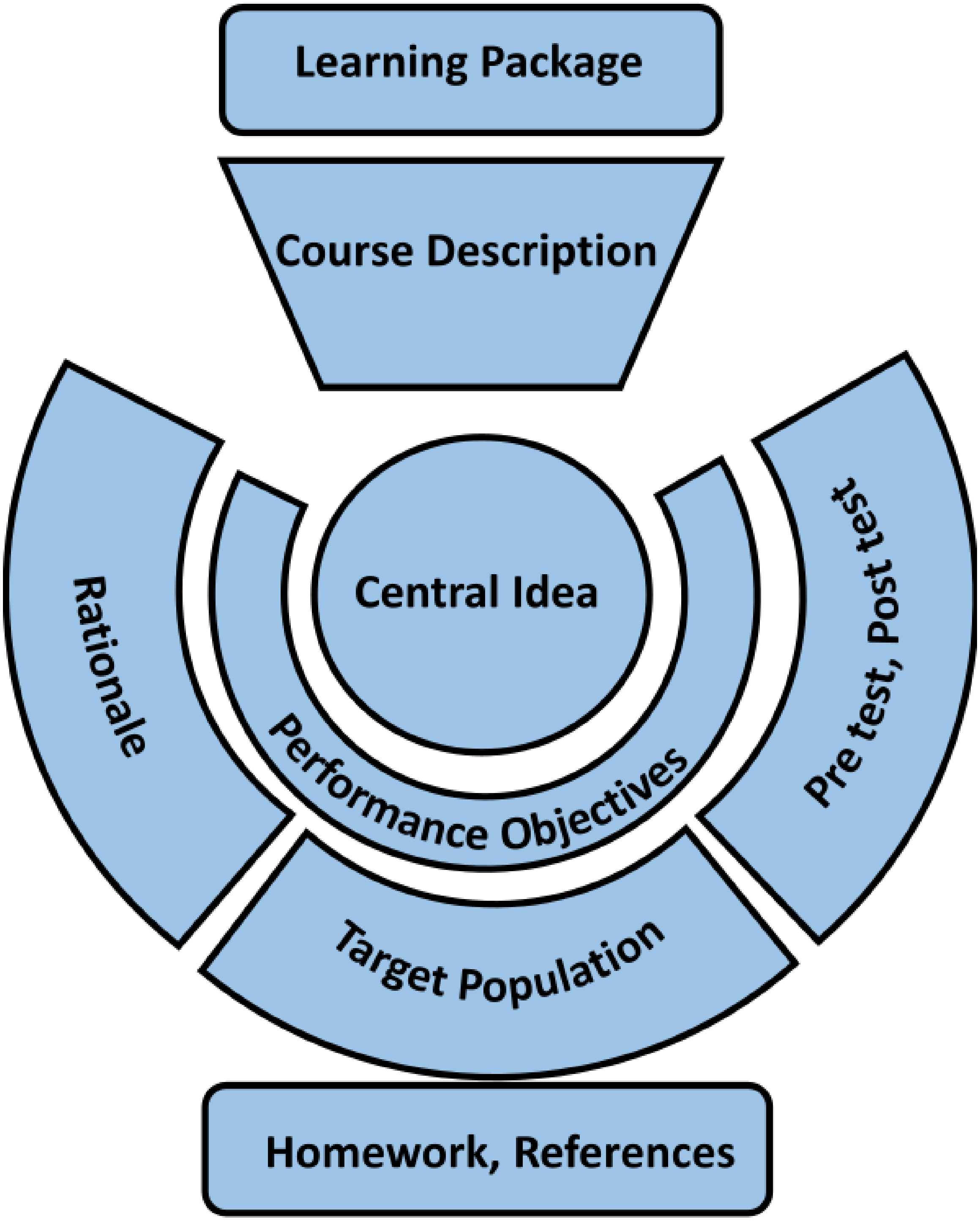
Power Electronics

For

Second year students

By

M.Sc. Humam Qahtan ALhassan
Dep. Of Electrical Techniques
2025



Course Description

Course Name:	
Power Electronics Princeples	
Course Code:	
Semester / Year:	
Semester	
Description Preparation Date:	
14/ 05/ 2025	
Available Attendance Forms:	
Attendance only	
Number of Credit Hours (Total) / Number of Units (Total)	
60 hours/4 hour weekly/4 unit	
Course administrator's name (mention all, if more than one name)	
Name: Humam Qahtan Email: humam.alhasan@stu.edu.iq	
Course Objectives	
❖ Differentiate between the general electronic circuits and power electronic devices. ❖ Understand the main functions of power electronics: Power control and Power conversion. ❖ Use the transistors for switching control. ❖ Understand the various applications of UJT and op-amp circuits. ❖ Learn the SCR structure, functions, circuits, and types. ❖ Understand and differentiate between the different kinds of power conversion: AC-DC (rectifiers), DC-DC (choppers), DC-AC (invertors), AC-AC (convertors). ❖ Connect the most important power electronic circuits in the Lab. and measure their parameters and characteristics.	• ..... • ..... • .....

Teaching and Learning Strategies	
1. Cooperative Concept Planning Strategy. **2.** Brainstorming Teaching Strategy. **3.** Note–taking Sequence Strategy.	

Course Structure

Weeks	Hours	Required Learning Outcomes	Unit or subject name	Learning method	Evaluation method
1 2 3 4 5 6 7 8 9 10 11 12 13 14	4hours 4hours 4hours 4hours 4hours 4hours 4hours 4hours 4hours 4hours 4hours 4hours 4hours 4hours	1- Differentiate between the general electronic circuits and power electronic devices. 2- Understand the main functions of power electronics: Power control and Power conversion. 3- Use the transistors for switching control. 4- Understand the various applications of UJT and op-amp circuits. 5-	Chapter 1: Power Electronic Devices Chapter 2: The Transistors Chapter 3: The Uni-Junction Transistor (UJT) Chapter 4: The Operational Amplifier (Op-Amp)	**1.**Conducting laboratory experiments to build and test digital circuits. This enhances theoretical understanding and develops practical skills. **2.**Seeking feedback from instructors and peers to identify strengths and weakness **3.**Reviewing concepts periodical and applying them to new problems to reinforce memory and understanding. **4.**Using educational software an interactive applications to bette understand concepts, s **5.**Encouraging self-research on r topics in electronics and explori recent 7e4t4developments.	Weekly, Monthly, Daily and Written Exams, and Final Term Exam.

Course Evaluation

Distribution as follows: 20 points for Midterm Theoretical Exams for the first semester, 20 points for Midterm Practical Exams for the first semester, 10 points for Daily Exams and Continuous Assessment, and 50 points for the Final Exam.

Learning and Teaching Resources

Required textbooks (curricular books, if any)	W.Shepherd,andL.Hulley,**PowerElectronicsandMotorControl**,2ndedition,CambridgeUniversityPress,1996.
Main references (sources)	T.L. Floyd, **Electronic Devices**, 9th edition, Merrill Publishing Company, 1988.
Recommended books and references (scientific journals, reports…)	M.H.Rashid,**Power Electronics Handbook: Devices,CircuitsandApplications**,2nd. AcademicPress:Elsevier,2007.
Electronic References, Websites	https://zlibrary-asia.se/

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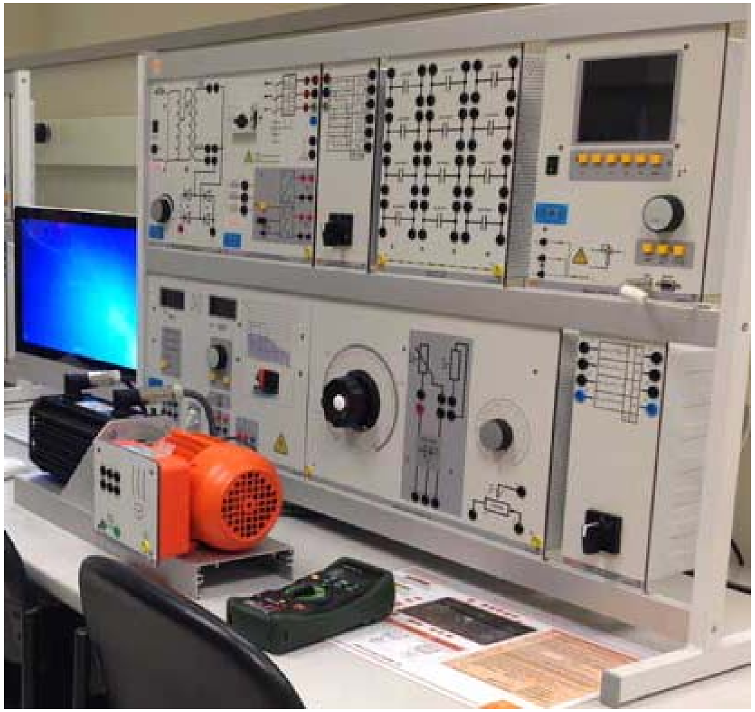
Chapter 1

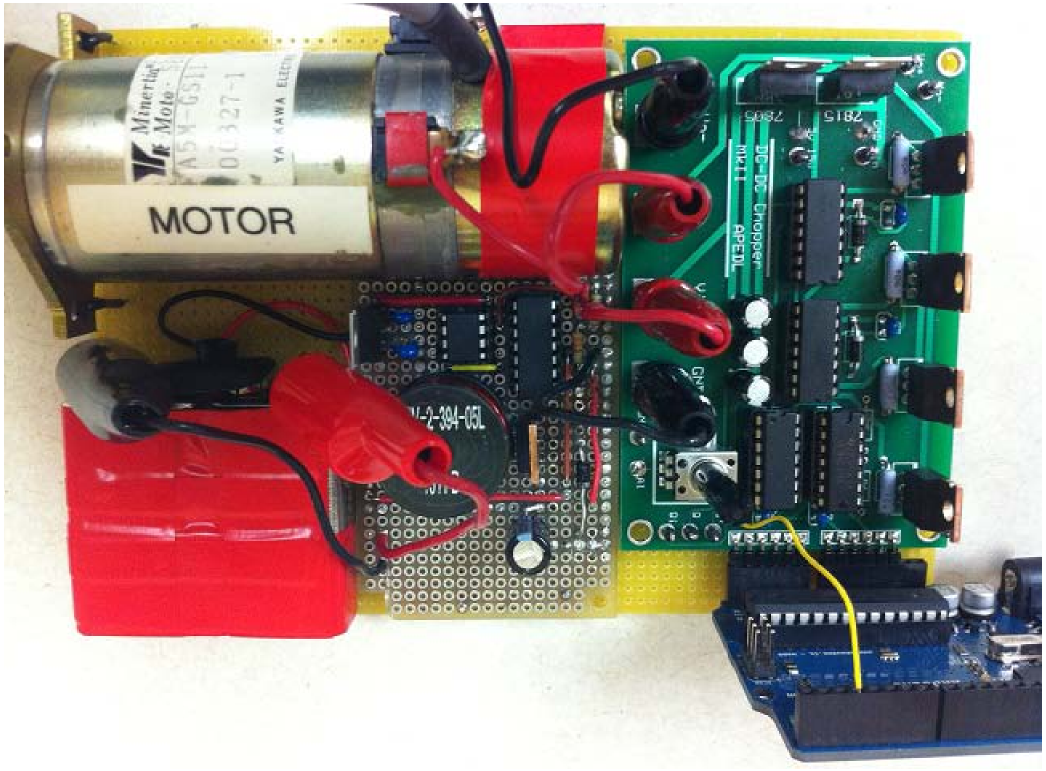
Power Electronic Devices

Introduction

Power Electronic Devices:

Any device that can be used in the power processing circuits to convert or control the electric power.





Classification of Power Electronic Devices

Uncontrolled device: diode
(Uncontrollable device)

has only two terminals and can not be controlled by control signal. The on and off states of the device are determined by the power circuit.

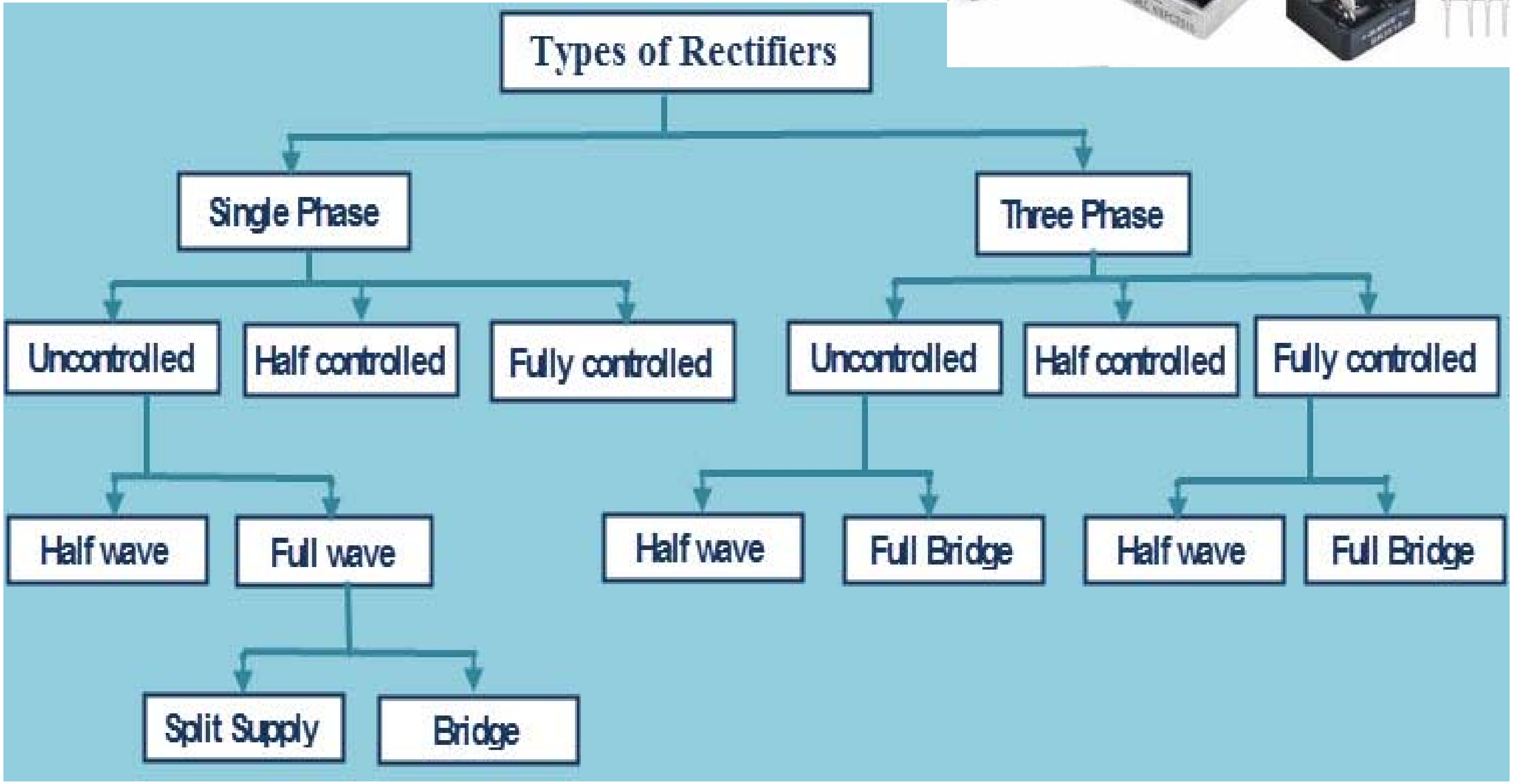
Half-controlled device: thyristor
(Half-controllable device)

is turned-on by a control signal and turned-off by the power circuit

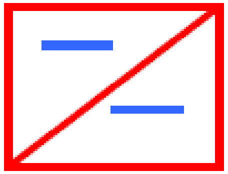
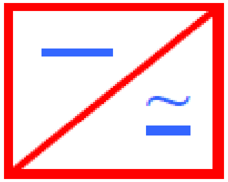
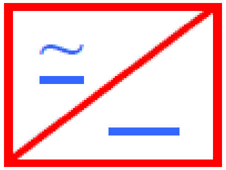
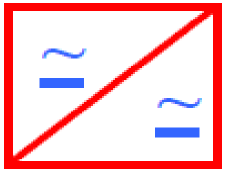
Fully-controlled device: Power MOSFET, IGBT,GTO, IGCT
(Fully-controllable device)

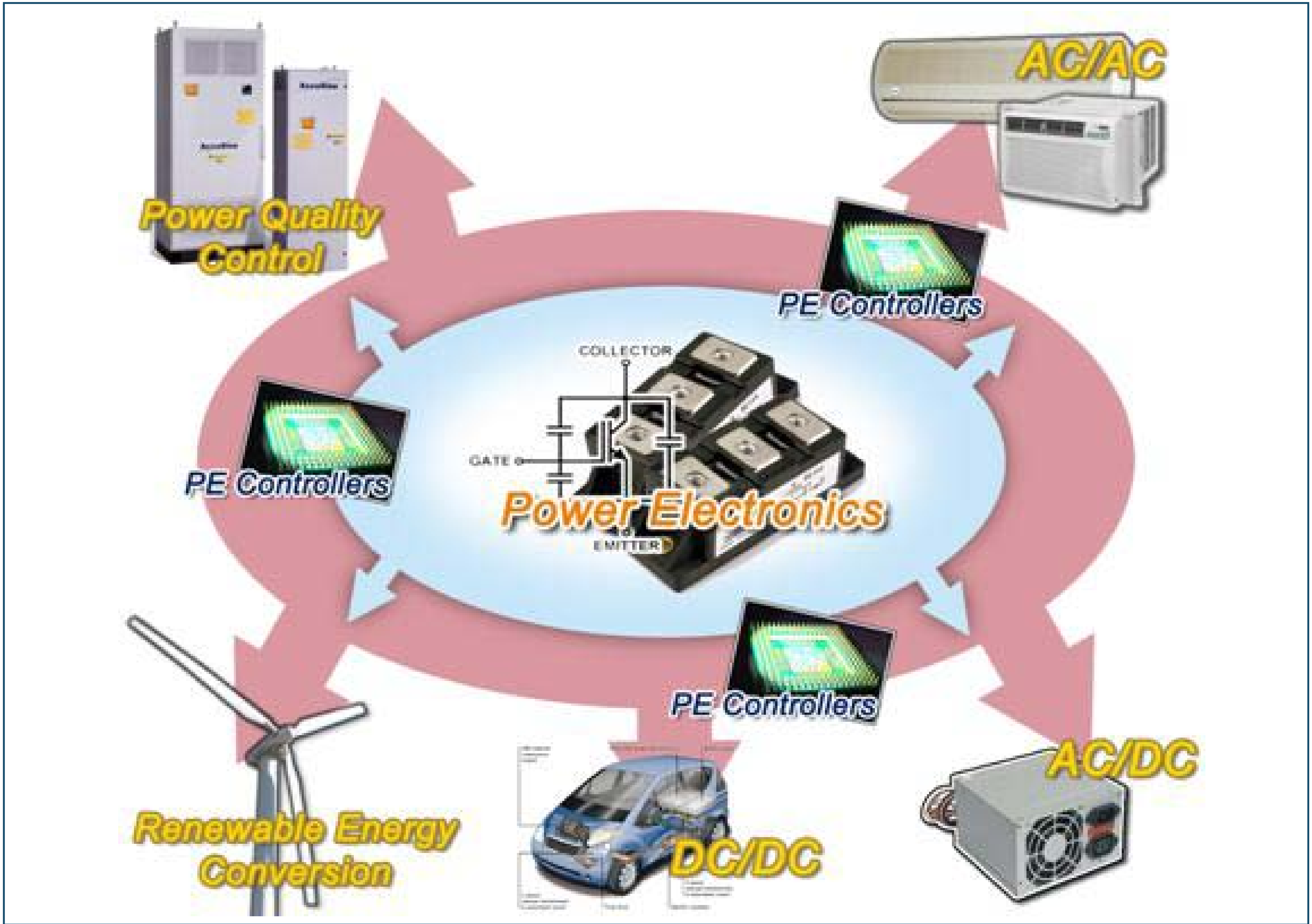
The on and off states of the device are controlled by control signals.

Types of Rectifiers



Power Conversion

CONVERSION FROM/TO	NAME	FUNCTION	SYMBOL
DC to DC	Chopper	Constant to variable DC or variable to constant DC	
DC to AC	Inverter	DC to AC of desired voltage and frequency	
AC to DC	Rectifier	AC to unipolar (DC) current	
AC to AC	AC controllers or AC Regulators	AC of desired frequency and/or magnitude from generally line AC	


Power Quality
Control
AC/AC
PE Controllers
COLLECTOR
GATE
PE Controllers
Power Electronics
EMITTER
PE Controllers
AC/DC
Renewable Energy
Conversion
DC/DC

Diode Circuits (Uncontrolled Rectifiers)

Rectification: The process of converting the alternating voltage to direct voltage.

Performance Parameters

Rectification Efficiency:

$$\eta = P_{dc} / P_{ac}$$

Form Factor:

$$FF = V_{rms} / V_{dc}$$

Ripple Factor:

$$RF = \frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{rms}^{2} - V_{dc}^{2}}}{V_{dc}} = \sqrt{\frac{V_{rms}^{2}}{V_{dc}^{2}} - 1}$$

$$RF = \sqrt{FF^{2} - 1}$$

Three Phase Half-Wave Uncontrolled Rectifier ($f_o = 3f_i$)

$$V_{dc} = \frac{3\sqrt{3}\ V_m}{2\pi} = 0.827V_m$$

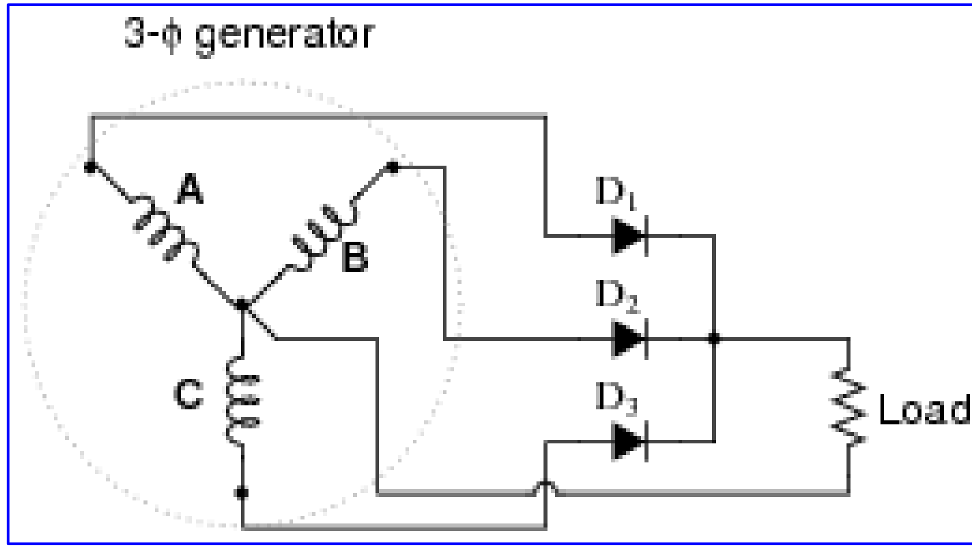
$$I_{dc} = \frac{3\sqrt{3}\ V_m}{2\pi R} = \frac{0.827V_m}{R}$$

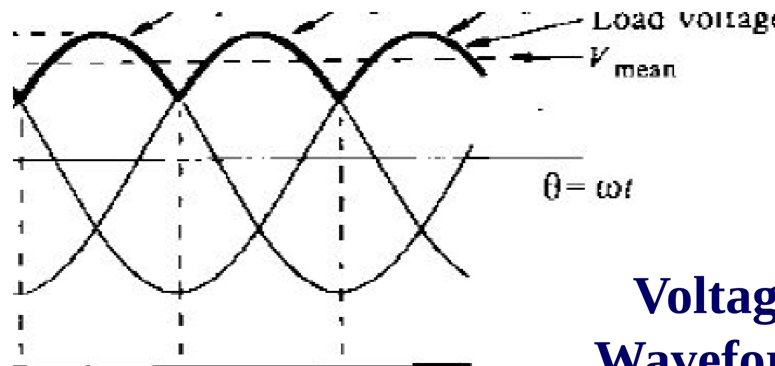
$$V_{rms} = \sqrt{\frac{1}{2} + \frac{3\sqrt{3}}{8\ \pi}} V_m = 0.8407\, V_m$$

$$I_{rms} = \frac{0.8407\ \ V_m}{R}$$

$$I_r = I_S = \frac{08407\ \ V_m}{R\ \sqrt{3}} = 0.4854\ \ \frac{V_m}{R}$$

$$Diode\ \ \text{PIV}\ = \sqrt{2} V_{LL} = \sqrt{3}\, V_m$$





Voltage Waveforms

Example 1

The rectifier shown above is operated from 460V/50 Hz supply at the secondary side and the load resistance is R = 20Ω. If the source inductance is negligible, determine: (a) Rectification efficiency, (b) Form factor (c) Ripple factor (d) Peak inverse voltage (PIV) of each diode.

Solution:

$$V_S = \frac{460}{\sqrt{3}} = 265.58 \text{ Volt} \quad ; \quad V_m = 265.58 \times \sqrt{2} = 375.59 \text{ Volt}$$

$$V_{dc} = \frac{3\sqrt{3}\, V_m}{2\pi} = 0.827 V_m \quad ; \quad I_{dc} = \frac{3\sqrt{3}\, V_m}{2\pi\, R} = \frac{0827 V_m}{R}$$

$$V_{rms} = 0.8407 V_m \quad ; \quad I_{rms} = \frac{0.8407\, V_m}{R}$$

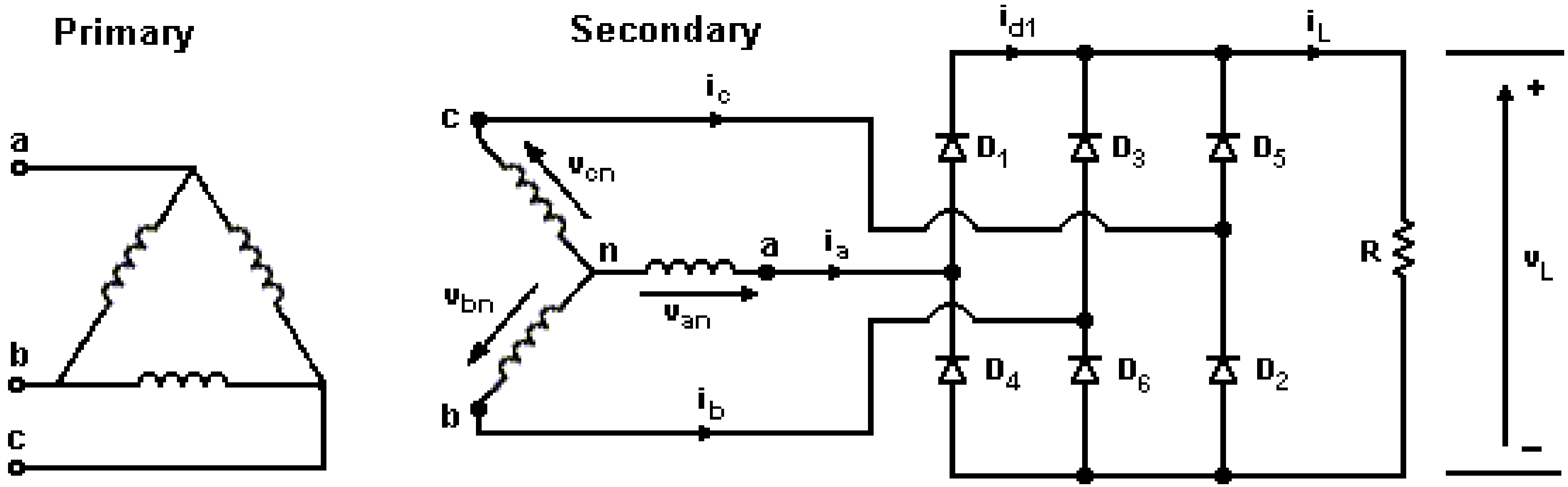
$$\Rightarrow \eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc}\, I_{dc}}{V_{rms}\, I_{rms}} = 96.767 \ \%$$

$$\Rightarrow FF = \frac{V_{rms}}{V_{dc}} = 101.657 \%$$

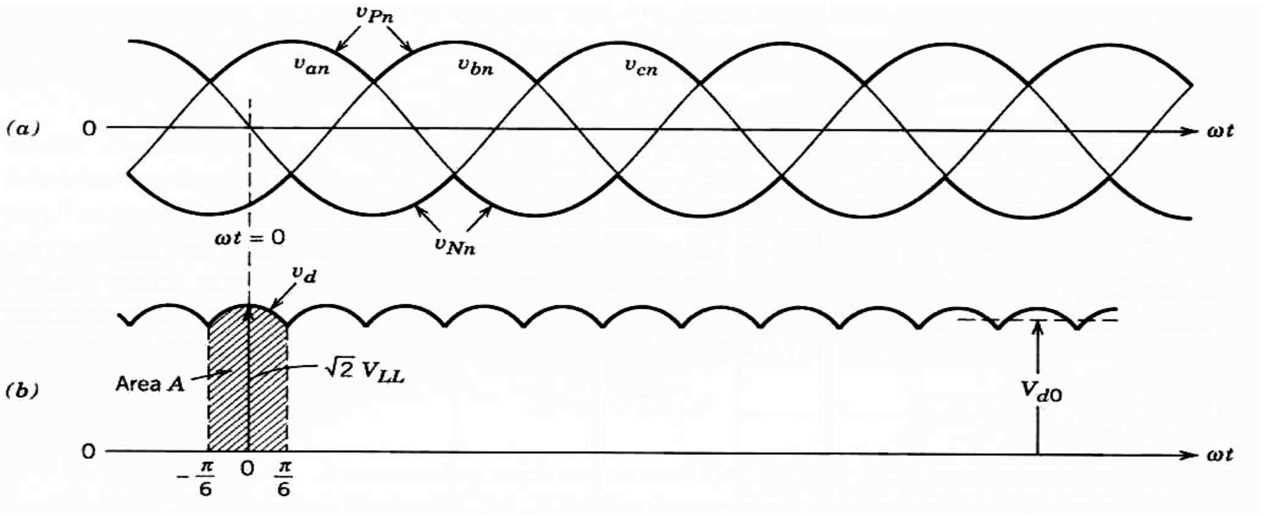
$$\Rightarrow RF = \frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}} = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1} = \sqrt{FF^2 - 1} = 18.28 \ \%$$

$$\Rightarrow PIV = \sqrt{3}\, V_m = 650.54 \text{ Volt}$$

Three Phase Uncontrolled Bridge Rectifier ($f_o = 6f_i$)



Voltage Waveforms



Three Phase Uncontrolled Bridge Rectifier ($f_o = 6f_i$)

$$V_{dc} = \frac{3\sqrt{3}\,V_m}{\pi} = \frac{3\sqrt{2}\,V_{LL}}{\pi} = 1.654V_m = 1.3505V_{LL}$$

$$I_{dc} = \frac{V_{dc}}{R} = \frac{1.654V_m}{R} = \frac{1.3505V_{LL}}{R}$$

$$V_{rms} = \sqrt{\frac{3}{2} + \frac{9\sqrt{3}}{4\pi}}\,V_m = 1.6554\,V_m = 1.3516V_{LL}$$

$$I_{rms} = \frac{1.6554\,V_m}{R}$$

$$I_r = \frac{1.6554\,V_m}{R\sqrt{3}} = 0.9667\frac{V_m}{R}$$

$$I_s = 0.9667\sqrt{2}\frac{V_m}{R}$$

$$Diode\ \text{PIV} = \sqrt{2}V_{LL} = \sqrt{3}\,V_m$$

Where:
$V_s = 0.707\,V_m$ is the rms voltage of transformer secondary;
$I_s = 0.7804\,I_m$ is the rms current of one line transformer secondary;
I_m = peak secondary line current.

Example 2 3ϕ Bridge rectifier is operated from 460V/50 Hz supply and the load resistance is R = 20Ω. If the source inductance is negligible, determine (a) The efficiency, (b) Form factor (c) Ripple factor (d) Peak inverse voltage (PIV) of each diode .

Solution:

$$V_S = \frac{460}{\sqrt{3}} = 265.58 \text{ Volt} \quad ; \quad V_m = 265.58 \times \sqrt{2} = 375.5 \text{ Volt}$$

$$V_{dc} = \frac{3\sqrt{3}\,V_m}{\pi} = 1.654V_m = 621.2 \text{ Volt} \quad ; \quad I_{dc} = \frac{1.654V_m}{R} = 31.0613 \text{ A}$$

$$V_{rms} = 1.6554\,V_m = 621.75 \text{ Volt} \quad ; \quad I_{rms} = \frac{1.6554\,V_m}{R} = 31.08 \text{ A}$$

$$\Rightarrow \eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc}\,I_{dc}}{V_{rms}\,I_{rms}} = 99.83\ \%$$

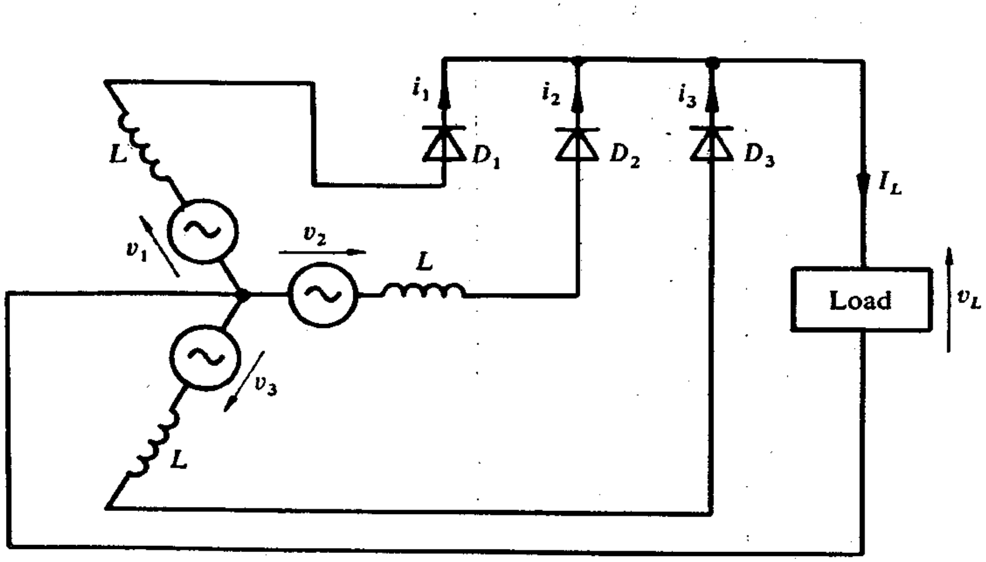
$$\Rightarrow FF = \frac{V_{rms}}{V_{dc}} = 100.08\%$$

$$\Rightarrow RF = \frac{V_{ac}}{V_{dc}} = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}} = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1} = \sqrt{FF^2 - 1} = 4\ \%$$

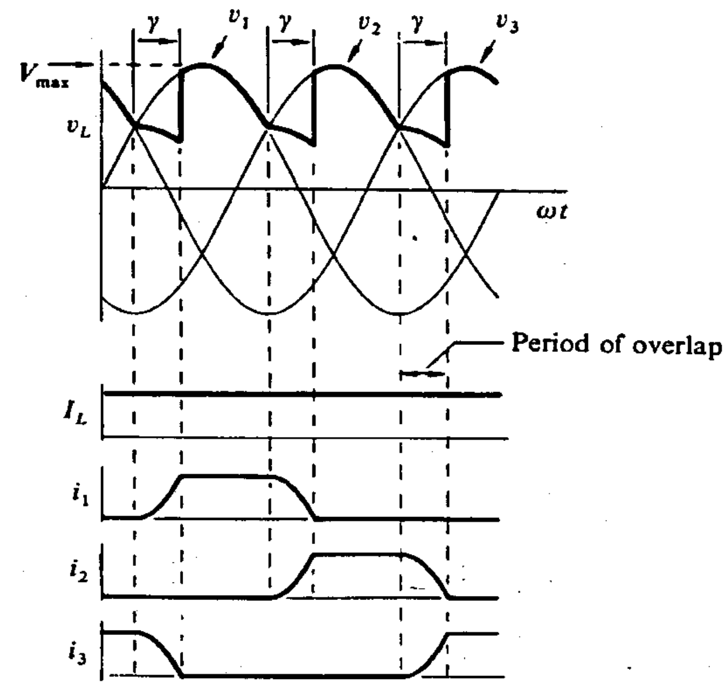
$$\Rightarrow PIV = \sqrt{3}\ V_m = 650.54 \text{ Volt}$$

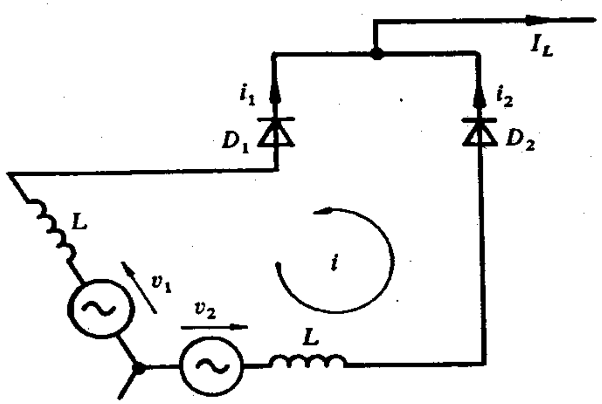
Overlap Phenomenon

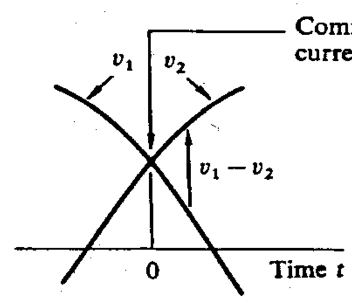
- Overlap is the phenomenon due to the effect of source inductance on the AC side.
- Commutation current is delayed due to the source inductance which is normally the leakage reactance of a transformer (as X >> R for a transformer, the source resistance is usually neglected).
- The waveforms with the commutation period, denoted by [γ] during which both the outgoing diode and incoming diode are conducting. This period is also known as “overlap” period.
- During the overlap period, the load current is the addition of the two diode currents, the assumption being made that the load is inductive enough to give a constant load current.
- The load voltage is the mean of the two conducting phases during overlap period.
- The effect of overlap is to reduce the mean output voltage.



(a)







A circulating current i can be considered to flow in the closed path formed by the 2 conducting diodes D1 and D2.

The average output voltage due to overlap:

$$V_{dc} = \frac{1}{2\pi/3}\left[\int_{\frac{\pi}{6}+\gamma}^{\frac{5\pi}{6}} V_m \sin\theta \, d\theta + \int_0^{\gamma} V_m \sin\frac{\pi}{6}\cos\phi \, d\phi\right] = \frac{3\sqrt{3}}{4\pi} V_m (1+\cos\gamma)$$

$$\boxed{V_{dc} = \frac{3\sqrt{3}}{4\pi} V_m (1+\cos\gamma)}$$

OR

V_{dc} = V_{dc} without overlap - reduction of V_{dc} due to overlap.

V_{dc} without overlap = $\frac{1}{2\pi/3}\int_{\pi/6}^{5\pi/6} V_m \sin\omega t \, d\omega t = \frac{3\sqrt{3}\,V_m}{2\pi}$

Example 3 A three-phase half-wave rectifier circuit is supplied from a [120/208] V, 3phase, 60 Hz source. Determine: 1) the average DC output voltage of the rectifier, 2) the conduction angle θ_C, 3) output frequency f_o.

Solution:

$$V_{ph} = \frac{208}{\sqrt{3}} = 120.2 \text{ Volt} \quad ; \quad V_{peak} = V_m = \sqrt{2} V_{ph} = 170 \text{ Volt}$$

$$1)\ V_{dc} = 3\sqrt{3} \times \frac{V_m}{2\pi} = 140.3 \text{ Volt} \quad ; \quad 2)\ \theta_C = \omega t_C = 2\pi f_i \times \left(\frac{1}{3f_i}\right) = \frac{2\pi}{3} = 120^o$$

$$3)\ f_o = 3f_i = 3 \times 60 = 180\text{Hz}$$

Example 4 3ϕ – Half-Wave rectifier with Δ-Y transformer is connected to 100Ω resistive load. For 220V secondary line to line voltage and 50Hz supply frequency. Calculate: 1) The dc load power, 2) The conduction time of each diode, 3) If the input transformer has leakage reactance which causes an overlap angle of 20° , calculate V_{dc} .

Solution:

$$1)\ V_{dc} = 0.827 V_m = 0.827 \times \sqrt{2} V_{ph} = 0.827 \times \sqrt{2}\frac{220}{\sqrt{3}} = 149 \text{ Volt}$$

$$\Rightarrow P_{dc} = \frac{V_{dc}^2}{R} = \frac{(149)^2}{100} = 222\text{W}$$

$$2)\ \theta_C = \omega t_C \quad \Rightarrow t_C = \frac{\theta_C}{\omega} = \frac{2\pi/3}{2\pi f_i} = 6.67m\sec \text{ OR } t_C = \frac{1}{f_o} = \frac{1}{3f_i}$$

$$3)\ \text{Due to overlap:} V_{dc} = 3\sqrt{3}\frac{V_m}{4\pi}(1 + \cos 20) = 144.1\text{Volt}$$

Problems and Solutions

Question 1 A three-phase half-wave rectifier circuit is supplied from a [220/380] V, 3phase, 60 Hz source. Determine : 1) The average DC output voltage of the rectifier, 2) The conduction time of each diode, 3) If there is an overlap phenomenon of 30° , find V_{dc} and the reduction of V_{dc} due to overlap.

Solution:

$$V_m = 380 \times \sqrt{2}/\sqrt{3} = 311 \text{ Volt}$$

1) $V_{dc} = 0.827V_m = 0.827 \times 311 = 212 \text{ Volt}$

2) $\theta_C = \omega t_C \Rightarrow t_C = \dfrac{\theta_C}{\omega} = \dfrac{1}{f_o} = \dfrac{1}{3f_i} = \dfrac{1}{3\times 60} = 5.56\text{msec}$

3) For an overlap angle of $30^o \Rightarrow V_{dc} = 3\sqrt{3}\dfrac{V_m}{4\pi}(1+\cos\gamma)$

$$\therefore V_{dc} = 3\sqrt{3}\frac{311}{4\pi}\left(1+\cos 30^o\right) = 198.2\text{Volt}$$

$\therefore$ the reduction in $V_{dc} = V_{dc}$ without overlap $- V_{dc}$ with overlap

$$V_{dc} = 212 - 198.2 = 13.8 \text{ Volt}$$

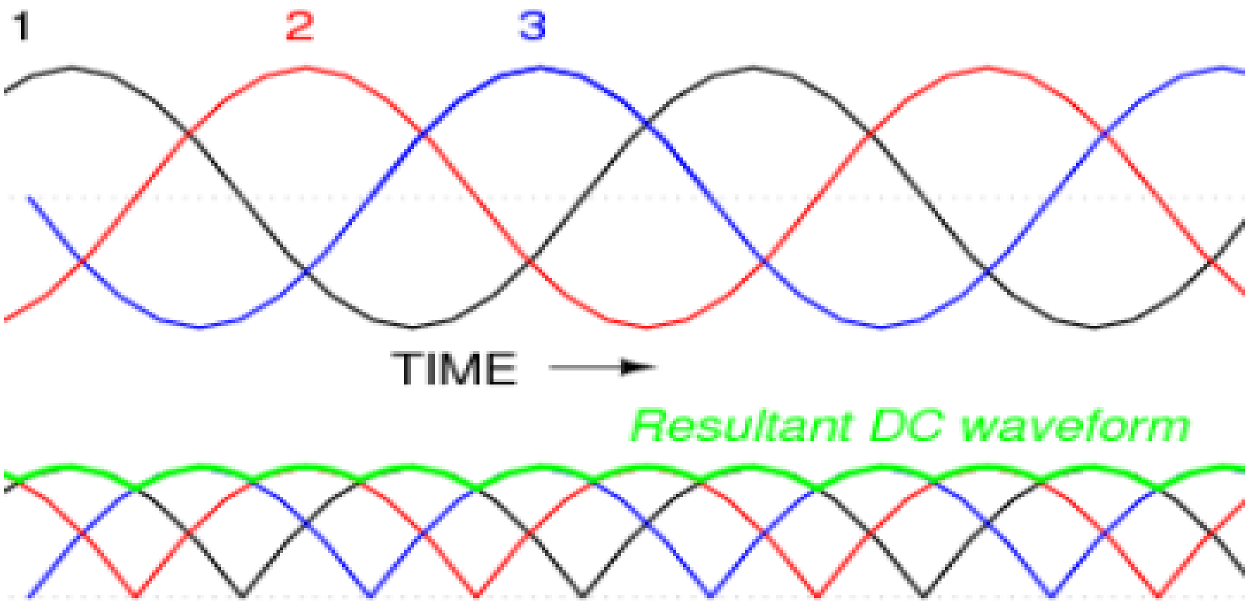
Question 2 A three-phase Bridge rectifier is supplied from a [220/120] V, 3phase, 60 Hz source. 1) Determine the average DC output voltage of the rectifier, 2) Sketch the load voltage and supply current waveforms.

Solution:

$$V_m = 120 \times \sqrt{2} / \sqrt{3} = 97.97 \text{ Volt}$$

1) $V_{dc} = 1.654 V_m = 1.654 \times 97.97 = 162 \text{ Volt}$

2) Load voltage and supply waveforms as below:



Question 3 3ϕ-Bridge rectifier with Δ-Y transformer and [1200w, 3Ω] resistive load. Find : 1) The secondary line voltage, 2) The Form Factor, and 3) The efficiency of rectification.

Solution:

1) $$P_{dc} = \frac{V_{dc}^2}{R} \Rightarrow V_{dc} = 3 \times \sqrt{1200} = 60 \text{ Volt}$$

$$V_{dc} = 1.654 V_m \Rightarrow V_m = \frac{60}{1.654} = 36.27 \text{ Volt}$$

$$V_{line} = \frac{\sqrt{3}\, V_m}{\sqrt{2}} = 44.26 \text{ Volt}$$

2) $$V_{rms} = 1.6554 V_m = 60.041 \text{ Volt}$$

$$\text{FF} = \frac{V_{rms}}{V_{dc}} = \frac{1.6554 V_m}{1.654 V_m} = 100.8\%$$

3) $$I_{dc} = \frac{V_{dc}}{R} = \frac{60}{3} = 20 \text{ A}$$

$$I_{rms} = \frac{V_{rms}}{R} = \frac{60.041}{3} = 20.014 \text{ A}$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{V_{dc}\, I_{dc}}{V_{rms}\, I_{rms}} = \frac{1200}{60.041 \times 20.014} = 99.86 \text{ \%}$$

Question 4 3ϕ – Half-Wave rectifier with Δ-Y transformer and [250w, 5A] resistive load. Find the value of the secondary line voltage.

Solution:

$$P_{dc} = V_{dc} \times I_{dc} = 250\text{W} \Rightarrow V_{dc} = 250/5 = 50\,\text{V} = 0.827V_m$$

$$\Rightarrow V_m = 60.5\text{V}\;;\; V_{ph} = V_m/\sqrt{2} = 42.79\text{V};\; V_{line} = \sqrt{3}V_{ph} = 74\text{V}$$

Question 5 3ϕ – Bridge rectifier with Δ-Y transformer is connected to 100Ω resistive load. For 220V secondary line to line voltage and 50Hz supply frequency, calculate: 1) The dc load power, 2) The conduction time.

Solution:

$$V_{dc} = 1.654V_m = 1.654 \times \sqrt{2} \times 220/\sqrt{3} = 297\,\text{V} \Rightarrow P_{dc} = V_{dc}^2/R = (297)^2/100 = 883\text{W}$$

$$t_C = \theta_C/\omega = 1/f_o = 1/6f_i = 1/(6 \times 50) = 3.33\text{msec}$$

Question 6 3ϕ – Bridge rectifier with Δ-Y transformer and [250w, 5A] resistive load. Find the value of secondary line voltage V_{ab}.

Solution:

$$P_{dc} = V_{dc} \times I_{dc} = 250\text{W} \Rightarrow V_{dc} = 250/5 = 50\,\text{V} = 1.654V_m$$

$$\Rightarrow V_m = 52.3\text{V}\;;\; V_{ph} = V_m/\sqrt{2} = 36.98\text{V};\; V_{line} = \sqrt{3}V_{ph} = 64\text{V}$$

Question 7 **Choose the correct or best alternative in the following:**

1) Power electronics is the application of……………..for the control and conversion of electric power.
   A. Conductors B. Transformer C. Inductive load **D.** solid-state electronics
2) Most power semiconductor devices are only used in ……………
   A. commutation mode B. Rectification mode C. Amplification mode D. Non of the above
3) The three phase half-wave rectifier with resistive has an average value = …………..
   A. 0.87 V_{ph} **B.** 1.17 V_{ph} C. 1.41 V_{ph} D. 1.99 V_{ph}
4) When voltage applied to a diode is more than PIV, it is likely to result in…………
   A. More distortion on output side B. Poor regulation C. Conduction in both direction **D.** Breakdown at the junction.
5) The ripple factor of a full-wave rectifier compared to half wave rectifier is …………
   A. half that of half -wave rectifier **B.** less than half that of half-wave rectifier
   C. equal to that of half -wave rectifier D. none of the above.
6) Switched mode power supplies are preferred over the continuous types, because they are……………and……………………..
   A. suitable for use in both ac and dc **B.** more efficient **C.** suitable for low-power circuits.
   D. suitable for high-power circuits.
12) Electric current is the flow of …………..
   A. Neutrons B. Photons **C.** Electrons D. none of the above

Question 8 Fill in the blanks with the appropriate words

1) In a rectifier, electrical power flows from the……………..side to the………………side.

2) Uncontrolled rectifiers employ………………whereas controlled rectifiers employ……………….

3) For any waveform “Form factor” is always……………..than or equal to unity.

4) Three phase half-wave uncontrolled rectifier uses……………….. diodes .

5) Three phase half-wave uncontrolled rectifier requires………… phase………. wire power supply .

Answers:

1) ac, dc
2) diodes, thyristors
3) greater
4) three
5) three , four

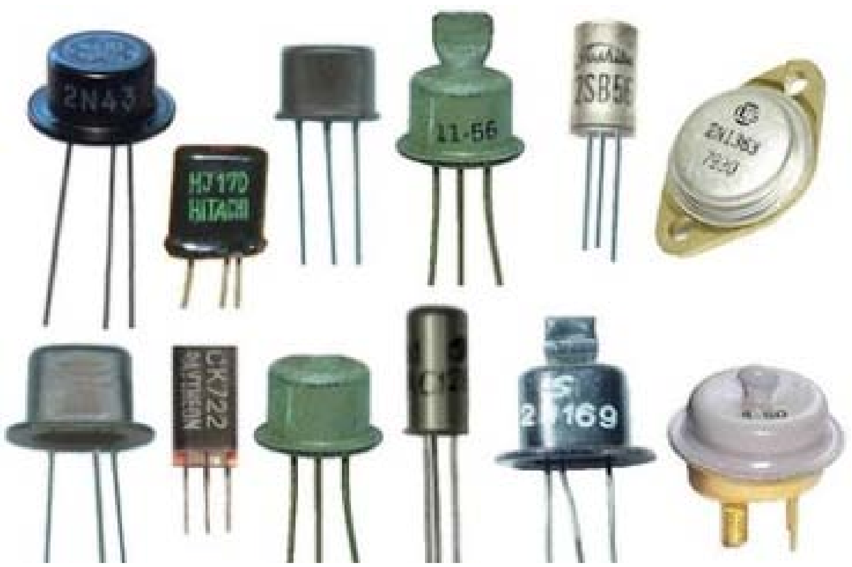
Chapter 2

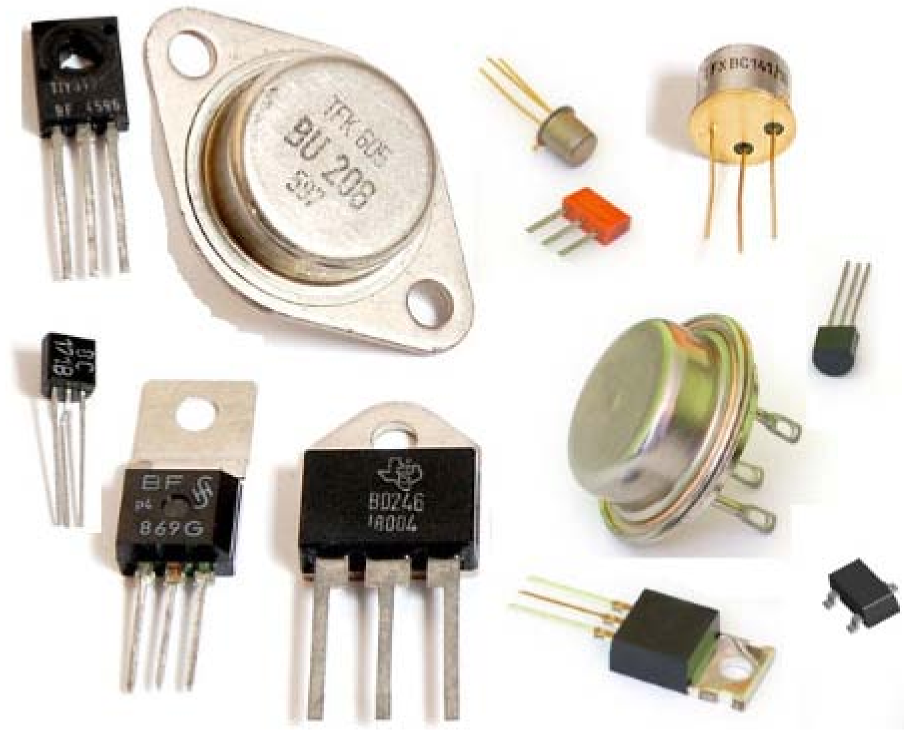
The Transistors

The Transistor

Transistor: It is a three-terminal, solid-state semiconductor device used to control the electric current or voltage between two of the terminals by applying an electric current or voltage to the third terminal.

- Transistor is an active component.

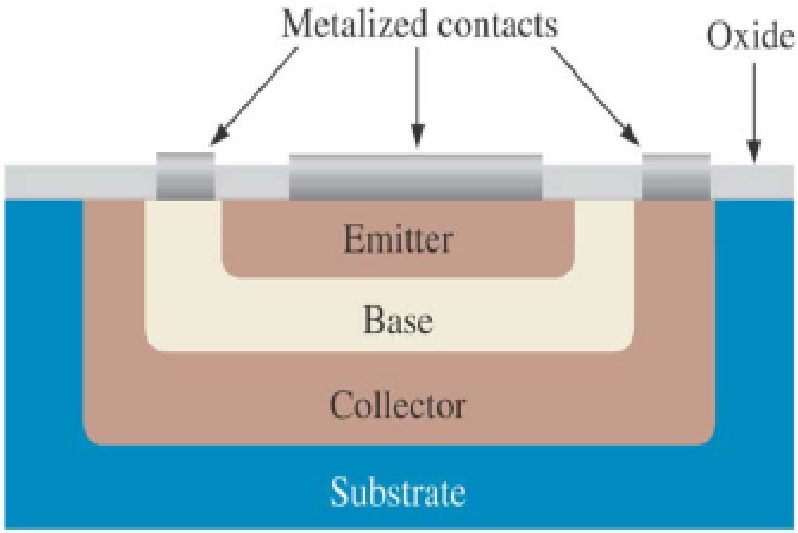




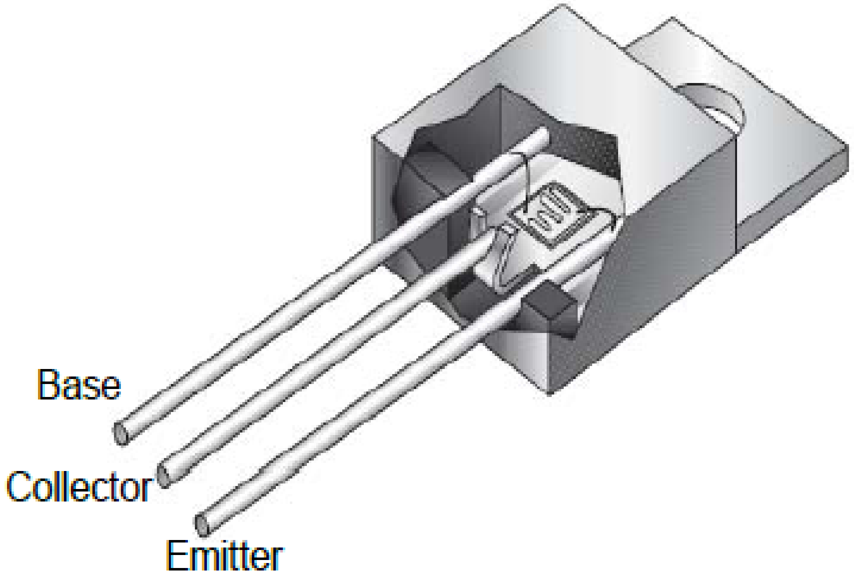
Examples of Different Transistors Packages

Bipolar Junction Transistor (BJT)

- It is constructed with *three* doped semiconductor regions separated by *two* PN junctions.
- The three regions are called **emitter**, **base**, and **collector**.
- The base is lightly doped and very narrow compared with the heavily doped emitter and moderately doped collector.
- It is used as an electrical signal amplifier or an electronic switch.
- Bipolar: refers to the use of both holes and electrons as current carriers.



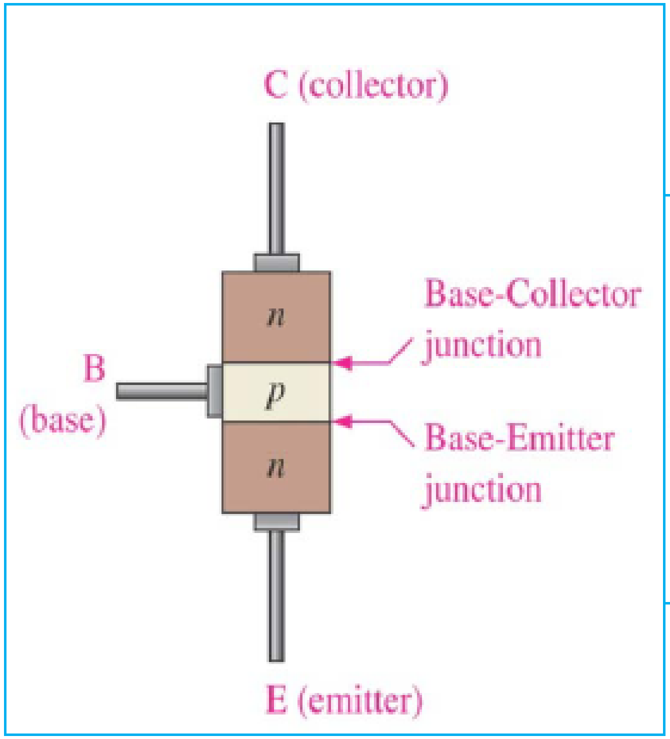
Basic BJT construction

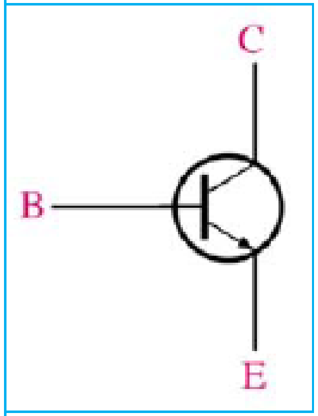


BJT package Example

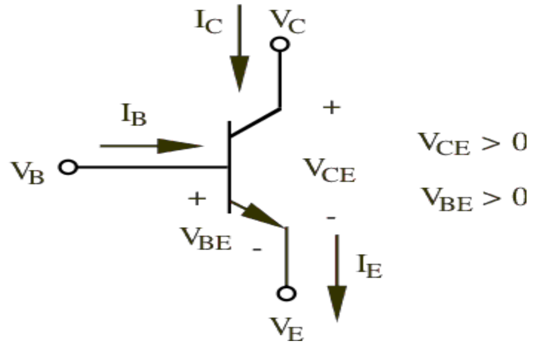
Types of BJTs

npn

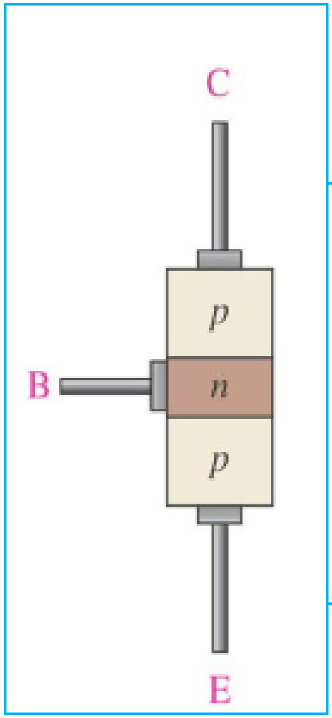


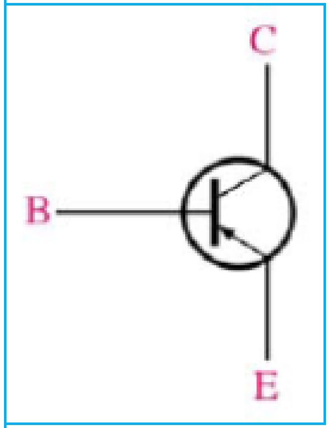


npn Symbol

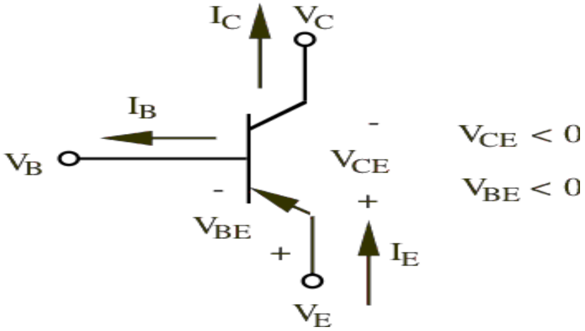


pnp





pnp Symbol



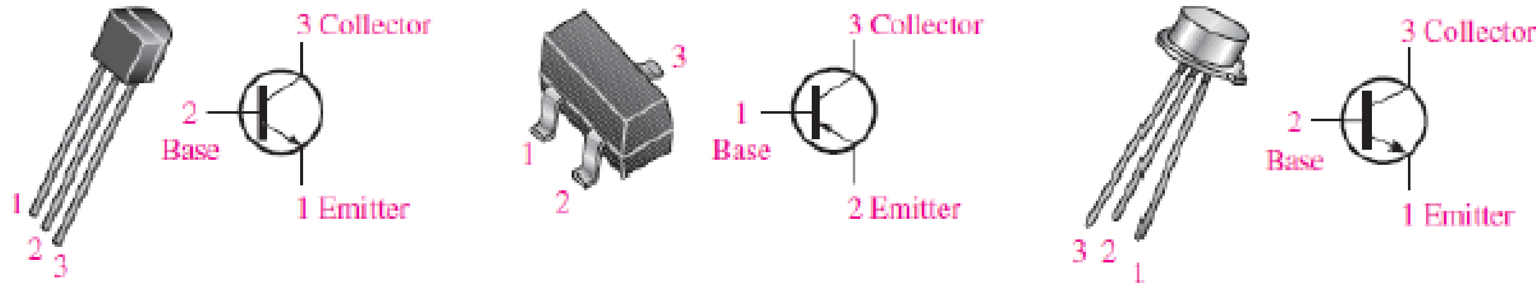
$$V_{BE} \simeq 0.7 \text{ V}$$

$$I_E = I_C + I_B$$

$$V_{BE} = V_B - V_E$$

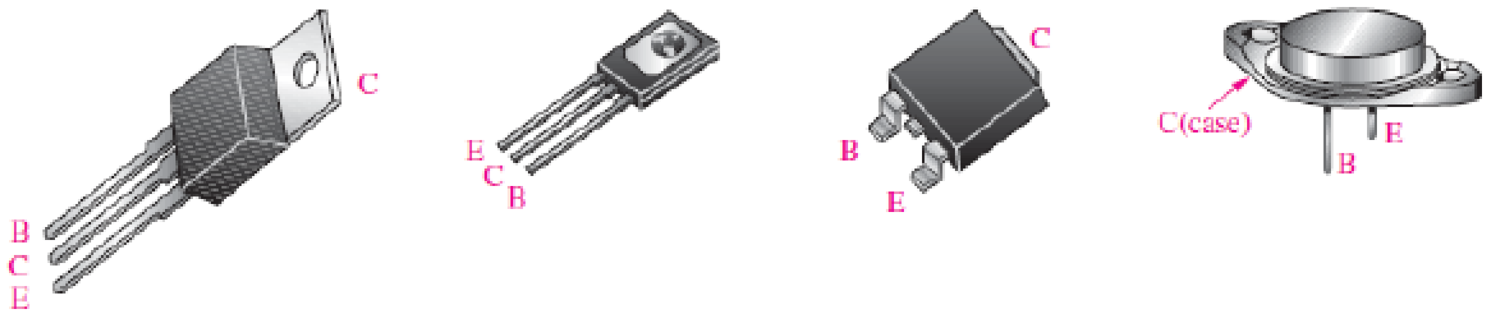
$$V_{CE} = V_C - V_E$$

Examples of BJTs



(a) TO-92 (b) SOT-23 (c) TO-18. Emitter is closest to tab.

General-purpose/small-signal transistors



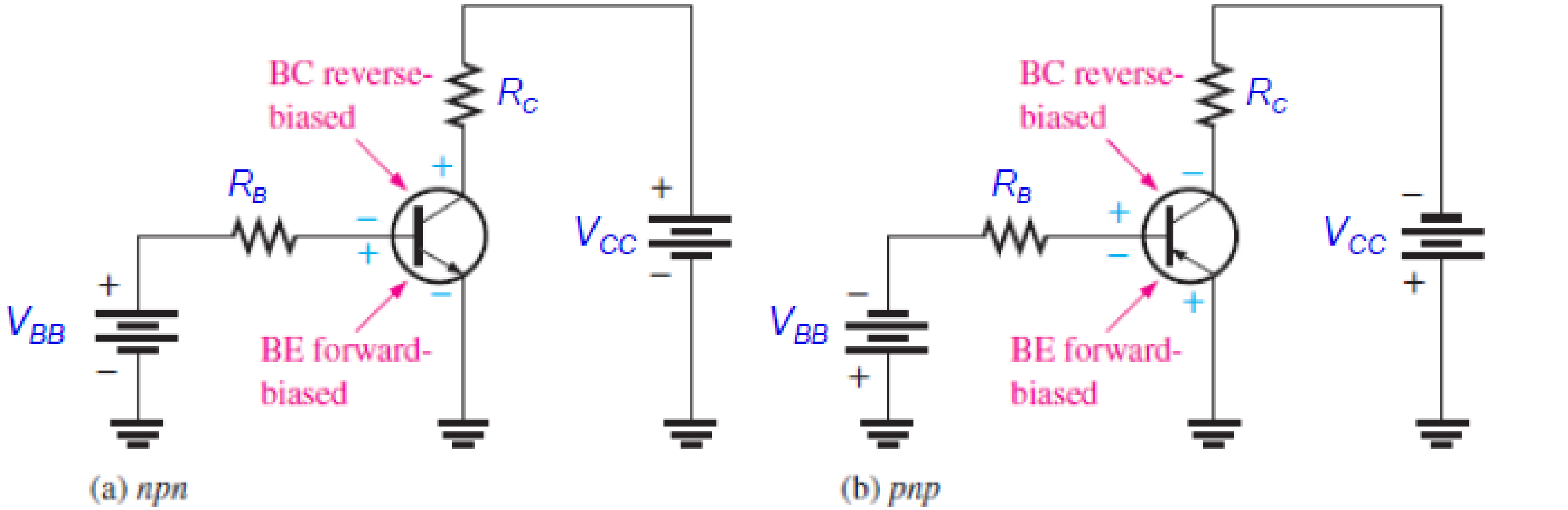
(a) TO-220 (b) TO-225 (c) D-Pack (d) TO-3

Power transistors

Common Emitter BJT Circuit

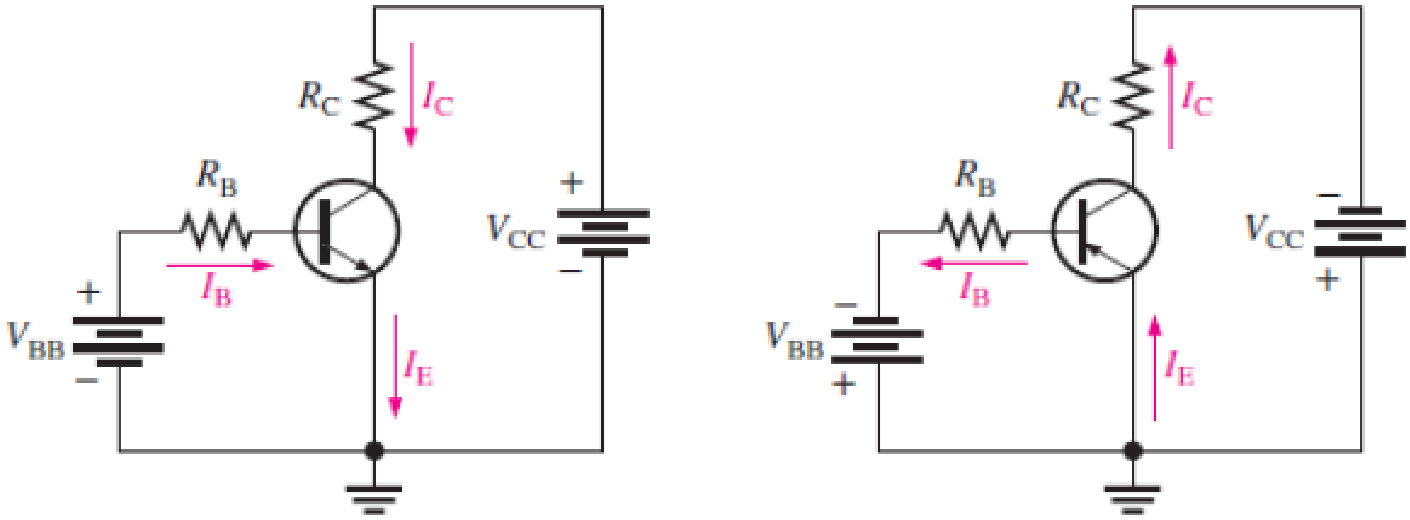
- In order for a **BJT** to operate properly as an amplifier, the two **pn** junctions must be correctly biased with external **dc** voltages.
- The operation of **pnp** is similar to the **npn** except that the roles of electrons and holes, bias voltage polarities, and current directions are all reversed.

Forward-Reverse Bias for BJT Operation as an amplifier



- The BE junction in both cases is forward-biased .
- The BC junction in both cases is reversed-biased.

BJT Currents



(a) *npn* (b) *pnp*

For Conventional current direction (holes current) we have:

$$I_E = I_B + I_C$$

I_B is very small due to light doping

$$I_E \simeq I_C$$

Collector current is much greater than base current and hence the current gain

BJT Parameters

DC Beta (β_{DC}) and DC Alpha (α_{DC})

- The **dc current gain** of a transistor ($\boldsymbol{\beta_{DC}}$) is the ratio of dc collector current (I_C) to the dc base current (I_B).

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

Typical values of $\boldsymbol{\beta_{DC}}$ from less than 20 to 200 or higher.

- In data sheets, the hybrid ***h***-parameters are used for transistors where $h_{FE} = \beta_{DC}$.

- α_{DC} is the ratio of dc collector current (I_C) to the dc emitter current (I_E).

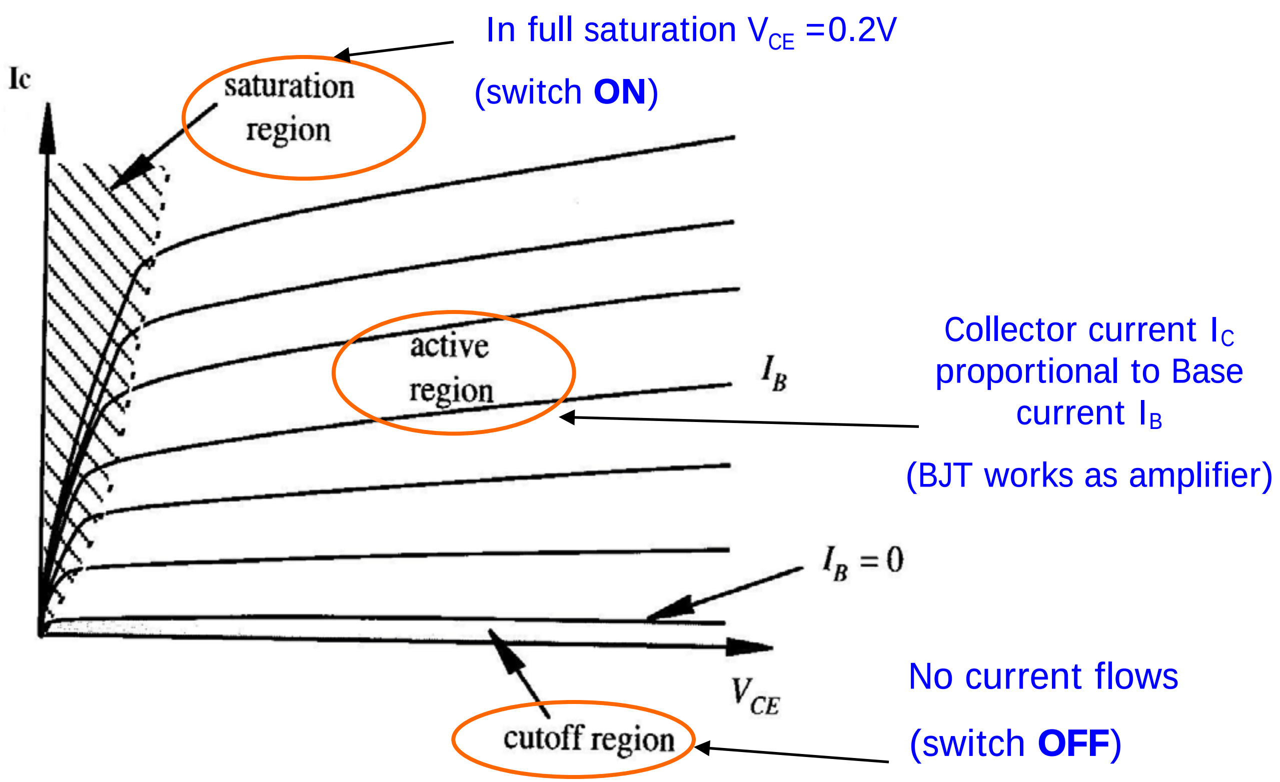
$$\alpha_{DC} = \frac{I_C}{I_E}$$

Typical values of $\boldsymbol{\alpha_{DC}}$ from 0.95 to 0.99 or less than 1.

BJT Operation

- Emitter is grounded and input voltage is applied to Base.
- Base-Emitter starts to conduct when V_{BE} is about 0.7V, I_C flows with $I_C = \beta_{DC} I_B$
- As I_B further increases, V_{BE} slowly increases to 0.7V, IC rises exponentially.
- As I_C rises, voltage drop across R_C increases and V_{CE} drops toward ground (transistor in saturation, no more linear relation between I_C and I_B)

Common Emitter Characteristics



BJT Operation

- Electrons diffuse from **E**mitter to **B**ase (from *n* to *p*) With $V_C > V_B > V_E$
- Depletion layer on the Base-Collector junction → no flow of electron allowed.
- The Base is thin and Emitter region is heavily doped → electrons have enough momentum to cross Base into Collector.
- Small base current I_B controls large current I_C through β_{DC} which functioning as a current gain of the amplifier.
- β_{DC} is temperature and voltage dependent.

Example 1

(a) For a given BJT: $I_B = 50\ \mu A$ and $I_C = 3.65$ mA . Find the dc current gain (β_{DC}), I_E , and α_{DC} .

(b) In a certain BJT: $I_B = 50\ \mu A$ and $\beta_{DC} = 200$. Find I_C , I_E , and α_{DC} . (HOME WORK)

SOLUTION

$$\beta_{DC} = \frac{I_C}{I_B} = \frac{3.65 \text{ mA}}{50\ \mu\text{A}} = \frac{3.65 \times 10^{-3}}{50 \times 10^{-6}} = 73$$

$$I_E = I_B + I_C = 50 \times 10^{-6} + 3.65 \times 10^{-3} = 3.7 \times 10^{-3} = 3.7 \text{ mA}$$

$$\alpha_{DC} = \frac{I_C}{I_E} = \frac{3.65 \text{ mA}}{3.7 \text{ mA}} = \frac{3.65 \times 10^{-3}}{3.7 \times 10^{-3}} = 0.986$$

DC Analysis of BJT Circuit

$$V_{R_B} = V_{BB} - V_{BE}$$

Also, by Ohm's law,

$$V_{R_B} = I_B R_B$$

Substituting for V_{R_B} yields

$$I_B R_B = V_{BB} - V_{BE}$$

Solving for I_B,

$$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

The voltage at the collector with respect to the grounded emitter is

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

Since the drop across R_C is

$$V_{R_C} = I_C R_C$$

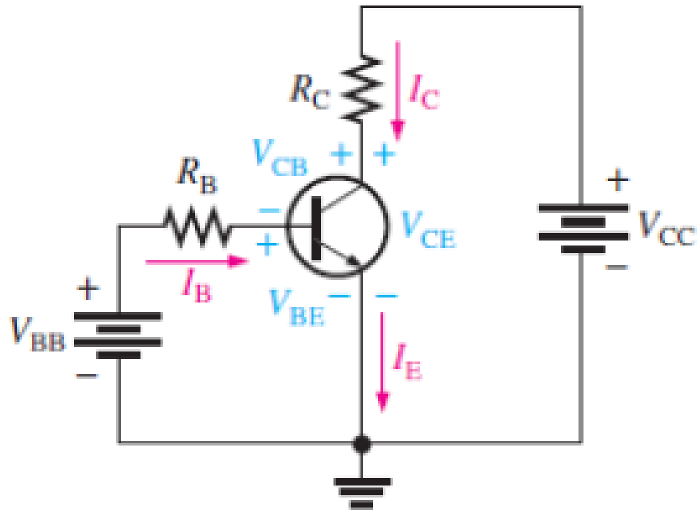
the voltage at the collector with respect to the emitter can be written as

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

where $I_C = \beta_{DC} I_B$.

The voltage across the reverse-biased collector-base junction is

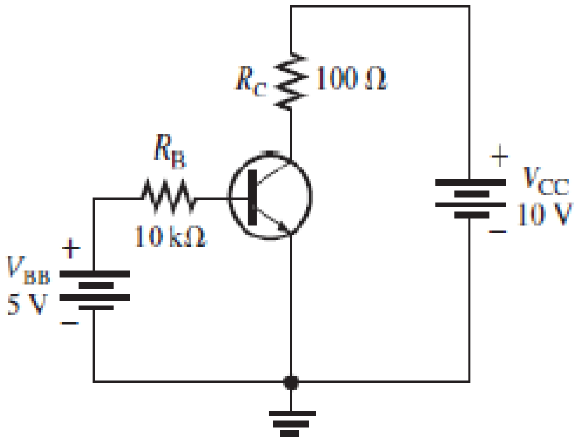
$$V_{CB} = V_{CE} - V_{BE}$$



DC Bias Circuit of *npn* Transistors

Example 2

1) For the given npn BJT circuit if $\beta_{DC} = 150$, find: I_B, I_C, I_E, V_{BE}, V_{CE}, and V_{CB}.
2) Repeat the problem if $\beta_{DC} = 90$, $R_B = 22\ k\Omega$, $R_C = 220\ \Omega$, $V_{BB} = 6V$, $V_{CC} = 9V$. (HOME WORK)



SOLUTION

$$V_{BE} \cong \mathbf{0.7\ V}$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5\ V - 0.7\ V}{10\ k\Omega} = \mathbf{430\ \mu A}$$

$$I_C = \beta_{DC} I_B = (150)(430\ \mu A) = \mathbf{64.5\ mA}$$

$$I_E = I_C + I_B = 64.5\ mA + 430\ \mu A = \mathbf{64.9\ mA}$$

Solve for V_{CE} and V_{CB}.

$$V_{CE} = V_{CC} - I_C R_C = 10\ V - (64.5\ mA)(100\ \Omega) = 10\ V - 6.45\ V = \mathbf{3.55\ V}$$

$$V_{CB} = V_{CE} - V_{BE} = 3.55\ V - 0.7\ V = \mathbf{2.85\ V}$$

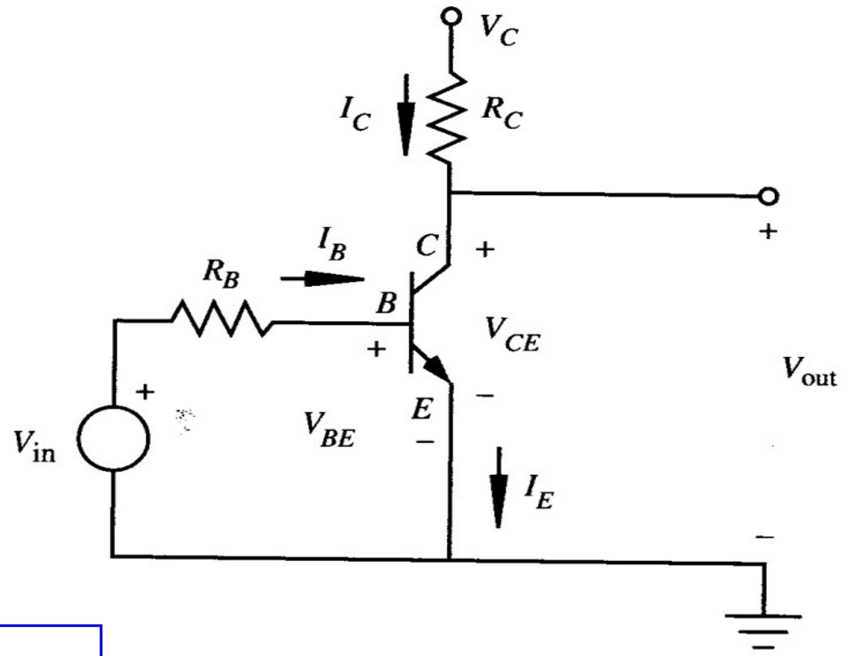
Since the collector is at a higher voltage than the base, the collector-base junction is reverse-biased.

BJT As Switch

OFF State

When $V_{in} < 0.7V$

- BE junction not forward biased
- **Cutoff state** of transistor
- $I_C = I_E = 0$
- $V_{out} = V_{CE} = V_C$
- V_{out} = High



ON State

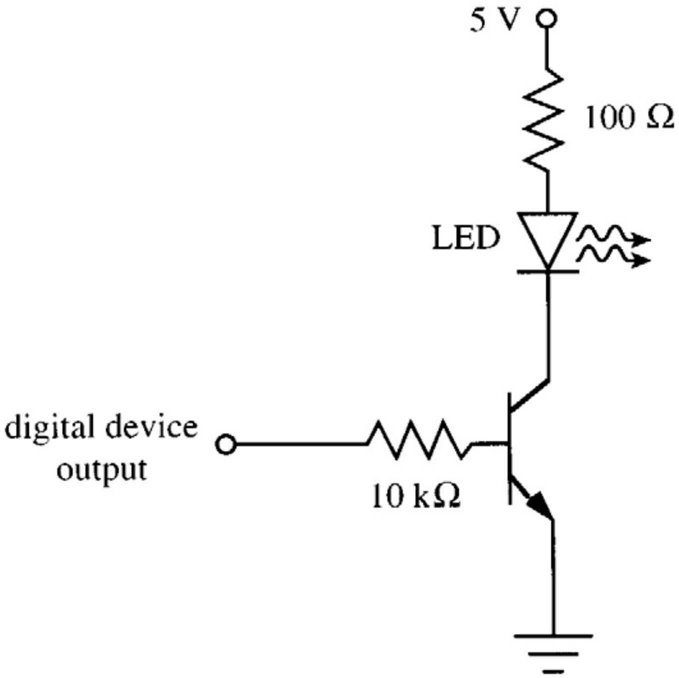
When $V_{in} > 0.7$

- BE junction forward biased (V_{BE} = 0.7V)
- $I_B = (V_{in} - V_{BE}) / R_B$
- **Saturation** region
- V_{CE} small (~0.2 V for saturated BJT)
- V_{out} = Low

Example 3

Practical LED Switch: For the given 2N3904 npn BJT circuit assuming the LED requires 20-40 mA to provide a bright display and has 2 voltage drop when forwarded biased. Find that the circuit works properly with ON and OFF states.

Solution



- When digital output is 0V, transistor is **OFF**.
- When digital output is 5V, the transistor is in **saturation** (**ON**), with base current:

$$I_B = (5V - 0.7V)/10K\Omega = 0.43\, mA$$

Collector current (LED current) is limited by collector resistor as:

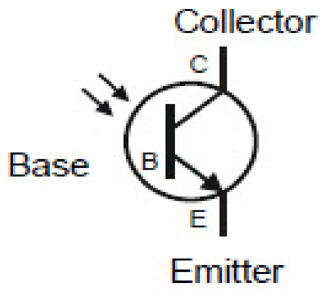
$$I_C = (5V - 2V - 0.2V)/100\Omega = 28\, mA$$

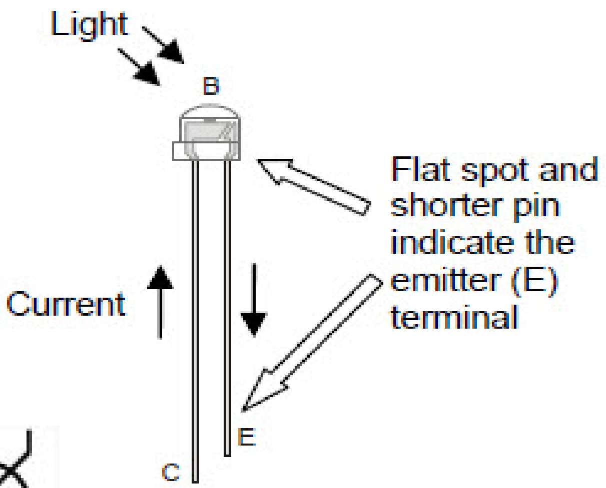
Hence: LED is lighted properly

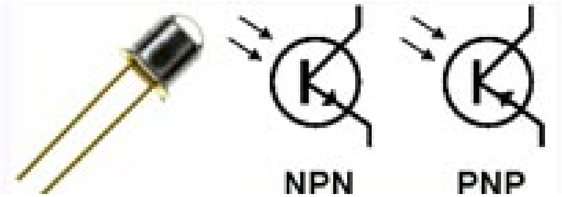
Phototransistors

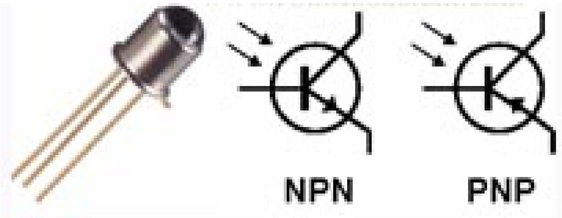
- **Phototransistors** are solid-state light detectors that possess internal gain.
- They are photodiode-amplifier combinations (2 or 3 terminals) integrated within a single silicon chip to overcome the major fault of photodiodes (unity gain).
- They can be used to provide either an analog or digital output signal.

NPN Phototransistors
0.25", small area, high speed
0.04", medium area, high sensitivity
0.05", large area, high sensitivity







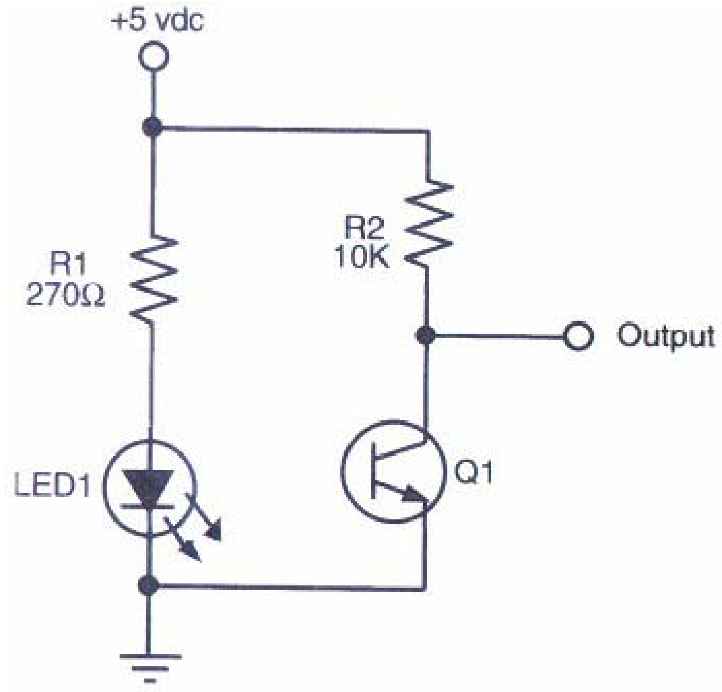


Two and Three Terminal Phototransistors

Features and Applications of Phototransistors

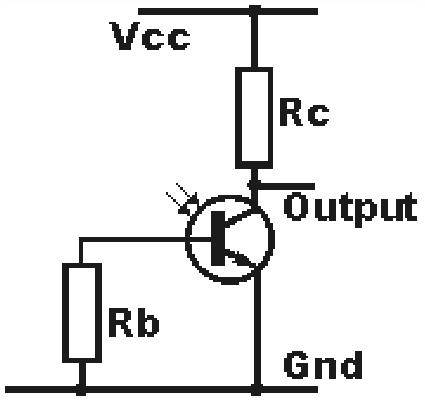
Features

- Low-cost visible and near-IR region.
- Available with gains from 100 to over 1500.
- Moderately fast response times.
- Available in a wide range of packages.
- Same general electrical characteristics as BJTs.



Applications

- Computer/business equipment: write-protect control and margin controls in printers.
- Industrial: security systems and safety shields.
- Consumers: coin counters, lottery card readers, audio/visual equipments, games, and camera shutter control.



Circuit Diagrams for Phototransistor Connections

Problems and Solutions

Question 1 Using ideal BJT switch of $\beta_{DC} = 200$, $V_{CC} = 10V$ and $I_B = 20\mu A$.

1) Find the value of base resistor R_B required to switch the load "ON" when the input terminal voltage exceeds 2.5V and $V_{BE} = 0.7V$.
2) Calculate R_C for point (1).
3) Find the minimum base current I_B required to turn the transistor "Fully-ON" (saturated) for a load that requires 200 mA when the input voltage is increased to 5.0V. Also calculate the new value of R_B.

Solution:

1) $$R_B = \frac{V_{in} - V_{BE}}{I_B} = \frac{2.5 - 0.7}{20\times 10^{-6}} = 90\ \text{k}\Omega$$

2) For ideal BJT at saturation $V_{CE} = 0$ Volt

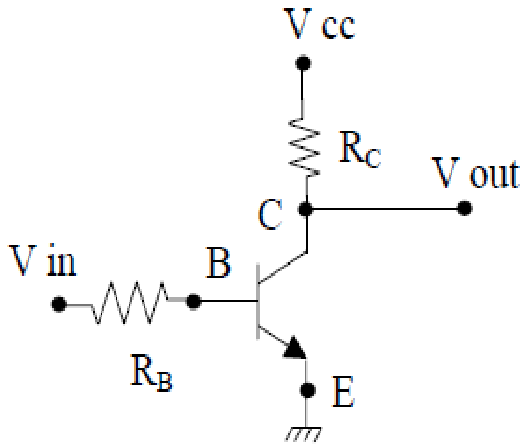
$$I_C = \beta_{DC} I_B = 200 \times 20 \times 10^{-6} = 4\ \text{mA}$$

$$R_C = \frac{V_{CC} - V_{CE}}{I_C} = \frac{10 - 0}{4\times 10^{-3}} = 2.5\ \text{k}\Omega$$

3) At ON state, the load current is equal to I_C

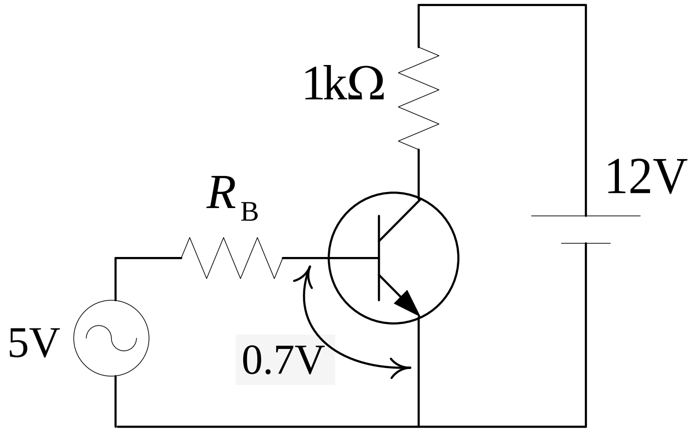
$$I_B = \frac{I_C}{\beta_{DC}} = \frac{200\ \text{mA}}{200} = 1\ \text{mA}$$

$$R_B = \frac{V_{in} - V_{BE}}{I_B} = \frac{5 - 0.7}{1\times 10^{-3}} = 4.3\ \text{k}\Omega$$



Question 2 The BJT in the given circuit has: $50 \le \beta_{DC} \le 150$, $V_{CC} = 12V$, $V_{BE} = 0.7V$, and $V_{CE} = 0.2V$. Find R_B that saturates the BJT with the so called Over Driven Factor (ODF) of at least 10.

Solution:



$$I_{Csat} = \frac{V_{CC} - V_{CE}}{R_C} = \frac{12 - 0.2}{1 \times 10^3} = 11.8 \text{ mA}$$

$$I_B = \frac{I_{Csat}}{\beta_{DC\,\min}} = \frac{11.8 \times 10^{-3}}{50} = 0.236 \text{ mA}$$

For OFD of at least10, we have:

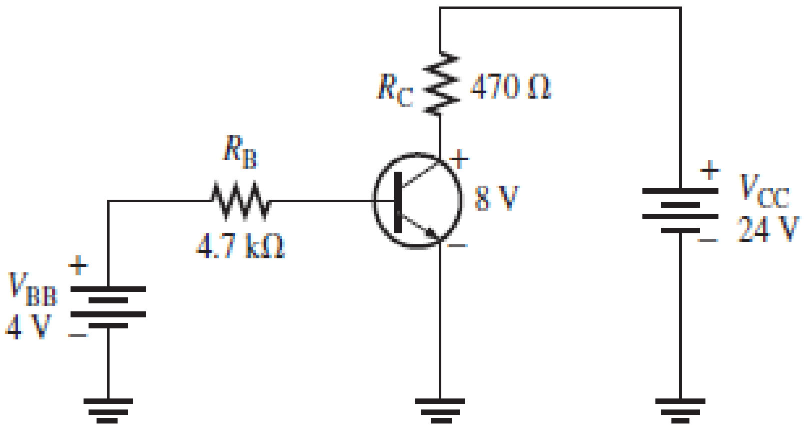
$$I'_B = 10 \times I_B = 10 \times 0.236 \times 10^{-3} = 2.36 \text{ mA}$$

$$R_B = \frac{V_{in} - V_{BE}}{I'_B} = \frac{5 - 0.7}{2.36 \times 10^{-3}} = 1.82 \text{ k}\Omega$$

Question 3 Find for the given npn BJT circuit: I_B , I_C , I_E , V_{CB} , β_{DC} , α_{DC}

<u>*Solution:*</u>

We have $V_{BE} = 0.7$ V and form the circuit $V_{CE} = 8$ V



$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{4 - 0.7}{4.7 \times 10^3} = 0.7 \text{ mA}$$

$$I_C = \frac{V_{CC} - V_{CE}}{R_C} = \frac{24 - 8}{470} = 34 \text{ mA}$$

$$I_E = I_B + I_C = 0.7 \text{ mA} + 34 \text{ mA} = 34.7 \text{ mA}$$

$$V_{CB} = V_{CE} - V_{BE} = 8 - 0.7 = 7.3 \text{ V}$$

$$\beta_{DC} = \frac{I_C}{I_B} = \frac{34 \text{ mA}}{0.7 \text{ mA}} = 48.57$$

$$\alpha_{DC} = \frac{I_C}{I_E} = \frac{34 \text{ mA}}{34.7 \text{ mA}} = 0.9798$$

Question 4 For the given BJT switch circuit: $\beta_{DC} = 100$, $V_{CC} = 5V$, $V_{BE} = 0.7V$, $V_{CE} = 0V$, $V_{LED} = 2V$ and $I_{LED} = 15mA$. Assuming the minimum average voltage of microcontroller I/O port V_{port} with logical "1" is about 4.2V.

1) Find the value of R_B and R_C.
2) Calculate the power dissipation on R_B and R_C.

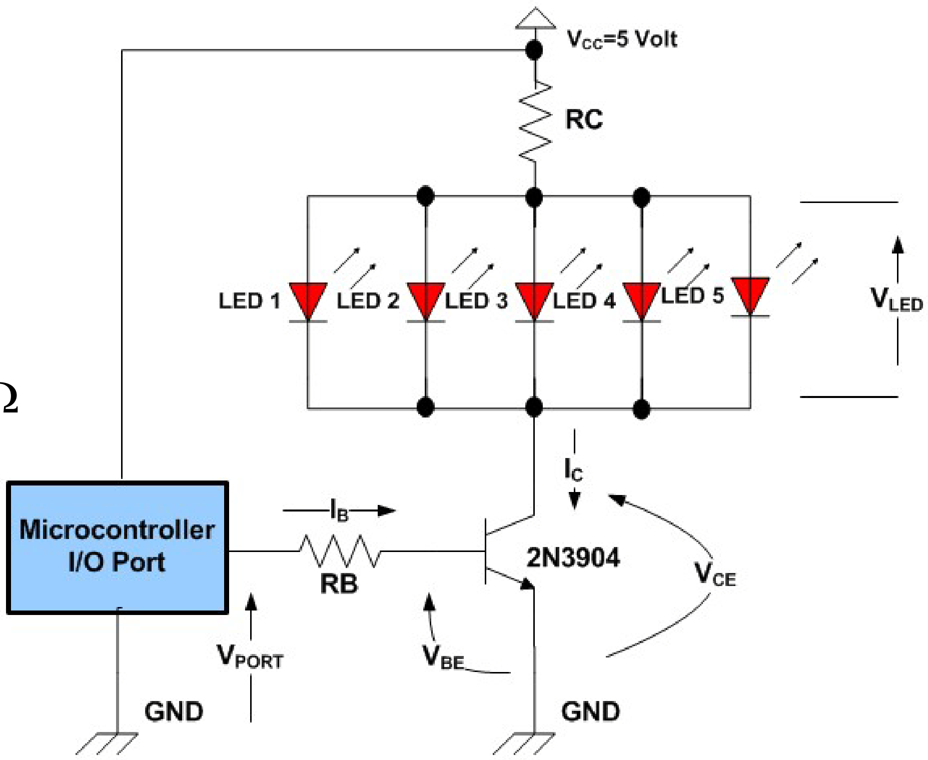
Solution:

1) $I_C = 5 \times I_{LED} = 5 \times 15 \times 10^{-3} = 75 \text{ mA}$

$$I_B = \frac{I_C}{\beta_{DC}} = \frac{75 \text{ mA}}{100} = 0.75 \text{ mA}$$

$$R_B = \frac{V_{port} - V_{BE}}{I_B} = \frac{4.2 - 0.7}{0.75 \times 10^{-3}} = 4.6 \text{ k}\Omega$$

$$R_C = \frac{V_{CC} - V_{LED} - V_{CE}}{I_C} = \frac{10 - 2 - 0}{75 \times 10^{-3}} = 40\Omega$$



2) Power dissipation on $R_B = I_B^2 R_B$

$$= \left(0.75 \times 10^{-3}\right)^2 \times 4.6 \times 10^3 = 2.58 \text{ mW}$$

Power dissipation on $R_C = I_C^2 R_C$

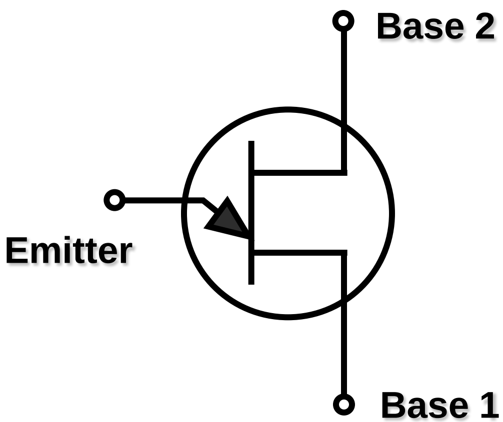
$$= \left(75 \times 10^{-3}\right)^2 \times 40 = 0.225 \text{ W}$$

Chapter 3

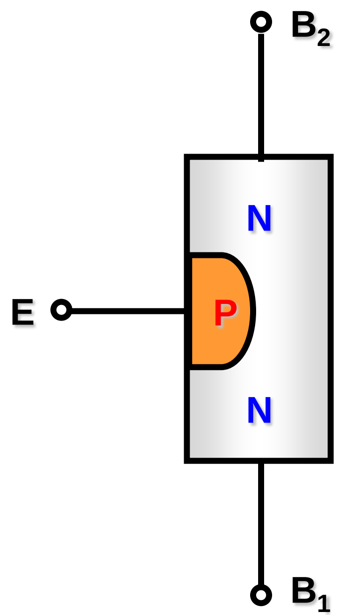
The Uni-Junction Transistor
(UJT)

The Uni-Junction Transistor UJT

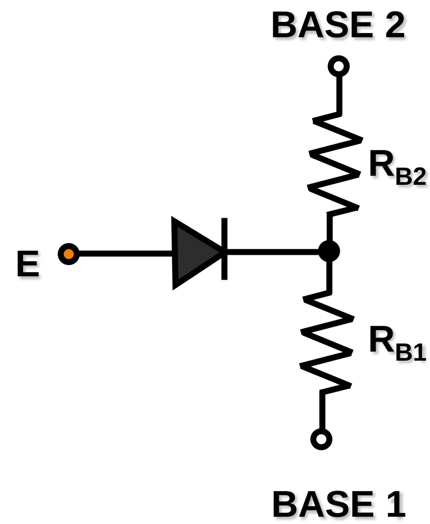
UJT is a semiconductor device having only one PN junction and three terminals, Base1, Base2, and Emitter.



Symbol



Structure

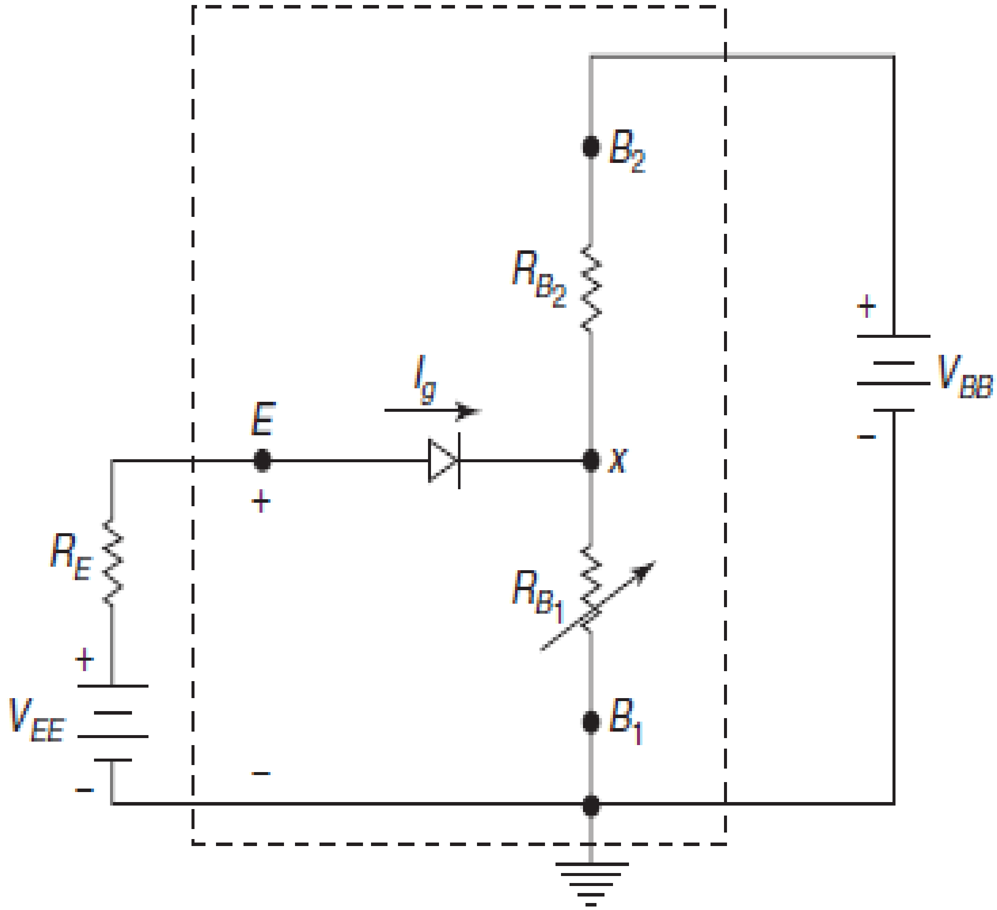


Equivalent Circuit

The Inter-Base Resistor: $R_{BB}=R_{B1}+R_{B2}$

Equivalent Circuit Of UJT

- The V_{BB} source is generally fixed and provides constant voltage from B_2 to B_1.
- The UJT is normally operated with both B_2 and **E** is positive biased relative to B_1.
- B_1 is always the UJT reference terminal and all voltages are measured relative to B_1.
- V_{EE} is a variable voltage source.



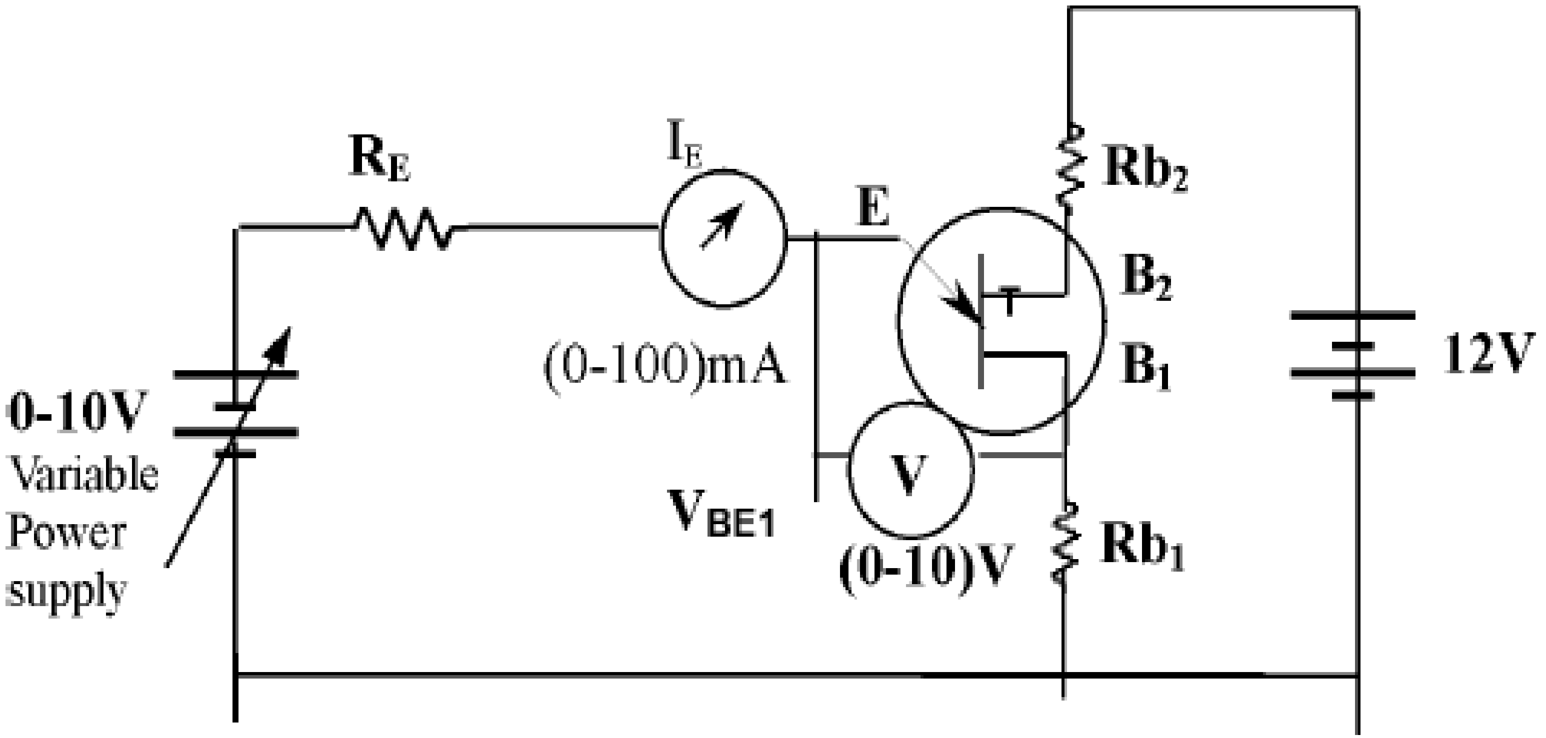
- η is the **Intrinsic standoff ratio**:

$$\eta = \frac{R_{B1}}{R_{B1}+R_{B2}} = \frac{R_{B1}}{R_{BB}}$$

$$R_{BB}=R_{B1}+R_{B2}$$

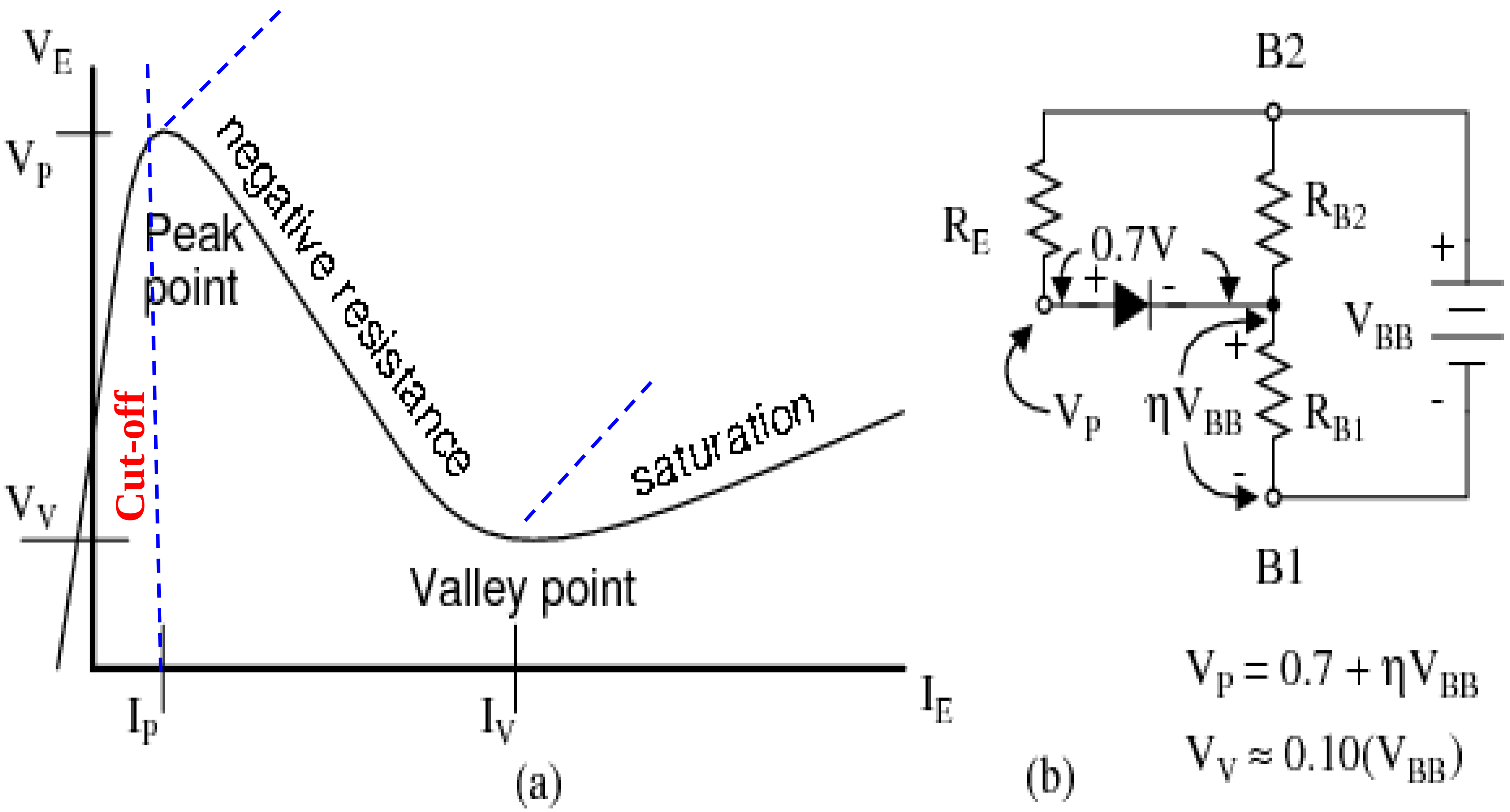
Input Forward Characteristics Of UJT

CIRCUIT DIAGRAM:



Standard values : R_E = 1KΩ, R_{b2}= 2.2KΩ, R_{b1} = 220Ω, **T= 2N2646**

Characteristic Curve



$V_P = 0.7 + \eta V_{BB}$

$V_V \approx 0.10(V_{BB})$

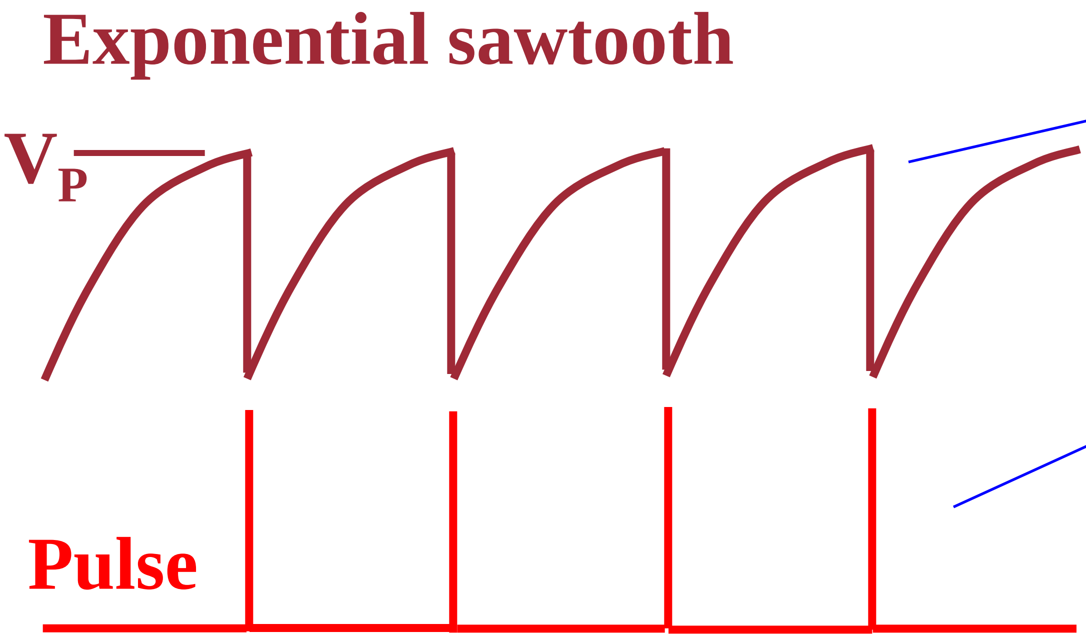
UJT Relaxation Oscillator

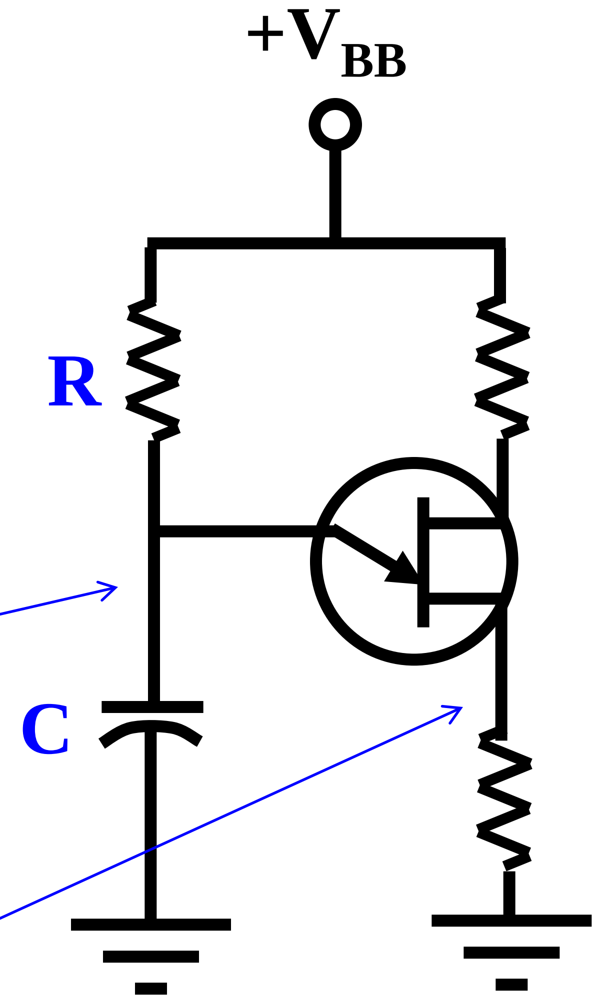
It provides two waveforms.

$$f \cong \frac{1}{RC \ln\left(\frac{1}{1-\eta}\right)}$$

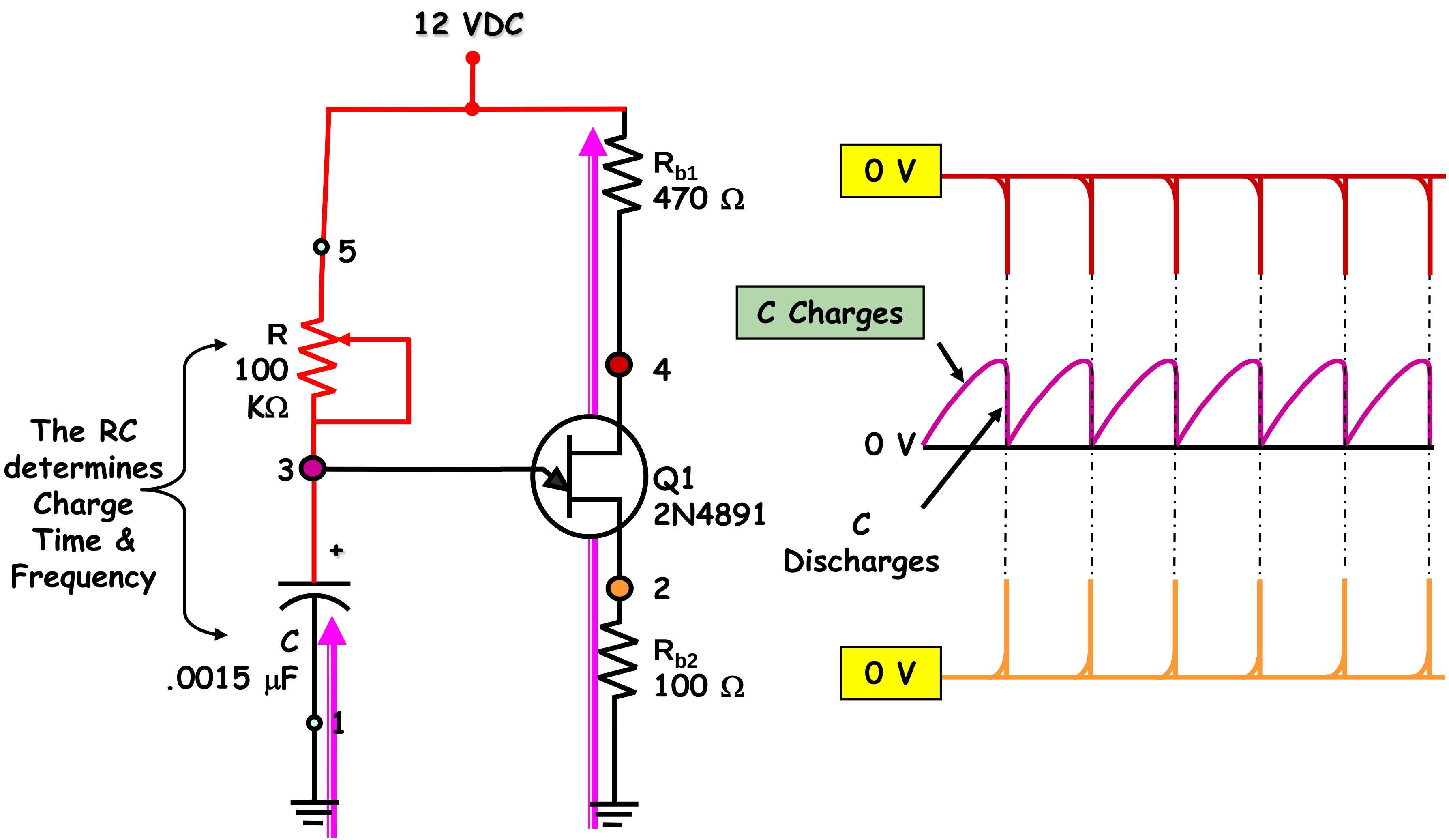
$$\eta = \frac{R_{B1}}{R_{B1} + R_{B2}}$$

$$\tau = RC$$

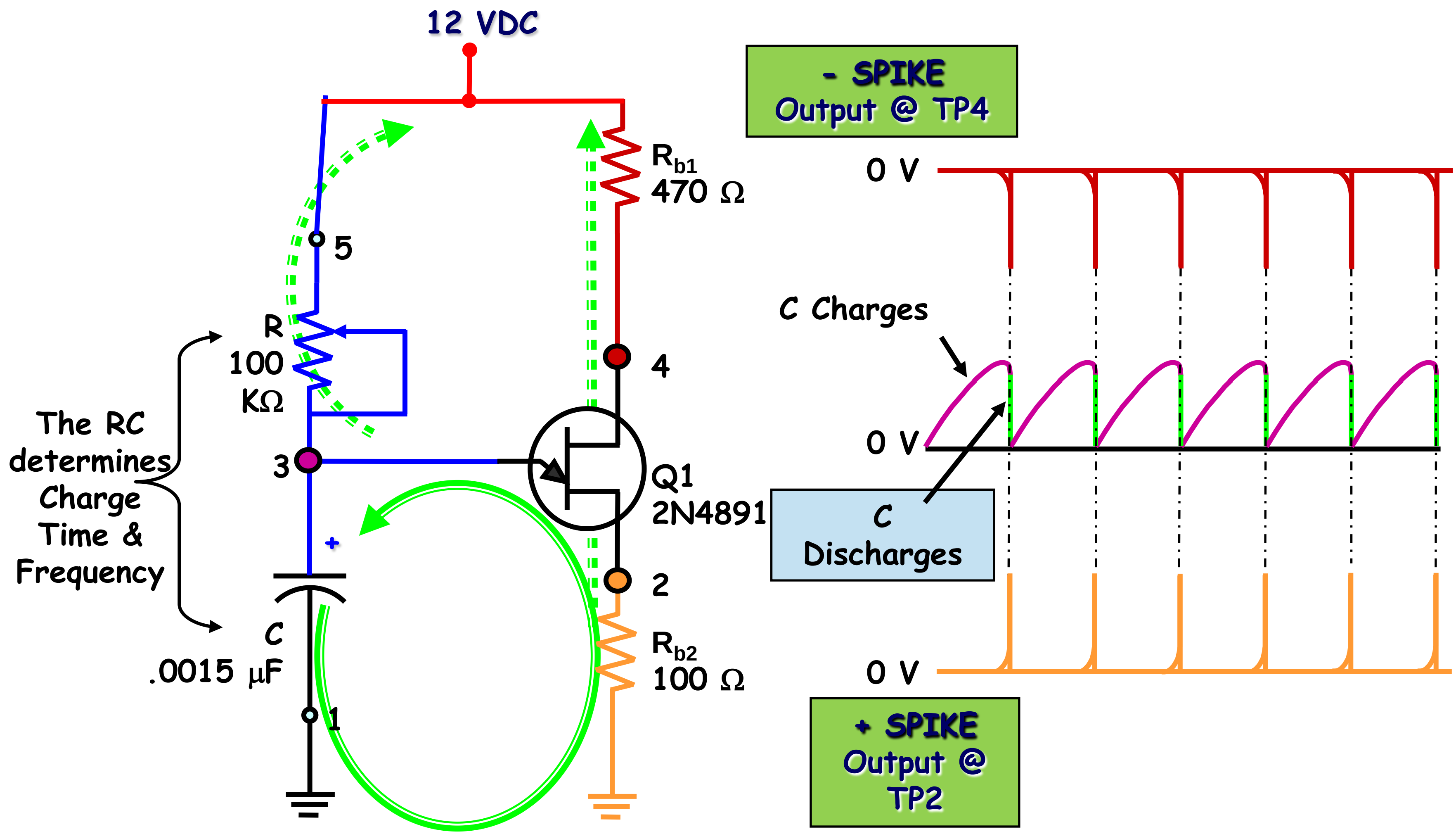




Operation of UJT Relaxation Oscillator: *C* charging



Operation of UJT Relaxation Oscillator: *C* discharging



Output; + & - Spikes and Sawtooth at TP3

Theory of operation as an oscillator

- For satisfactory operation, two conditions for the turn-on and turn-off of the UJT must be met as:

$$\frac{V_{BB} - V_V}{I_V} < R < \frac{V_{BB} - V_P}{I_P}$$

- The time period and, therefore, frequency of oscillation can be derived as below.

The voltage across the capacitor during charging is given as:

$$V_C = V_{BB}\left(1 - e^{-t/RC}\right)$$

$$V_P = V_D + \eta V_{BB}$$
$$= V_C = V_{BB}\left(1 - e^{-t/RC}\right)$$

$$V_{swing} = V_P - V_V$$

$$T = \frac{1}{f} = RC \ln\left(\frac{1}{1-\eta}\right)$$
$$= 2.3RC \log_{10}\left(\frac{1}{1-\eta}\right)$$

Example 1 Design a 1kHz relaxation oscillator using UJT with the following specifications: V_{BB} = 10V, η = 0.56 ~ 0.75, I_P = 5μA, and I_V = 4mA.

Solution:

The value of ***R*** can be found using the following condition:

$$\frac{V_{BB} - V_V}{I_V} < R < \frac{V_{BB} - V_P}{I_P}$$

$$\therefore R_{max} = \frac{V_{BB} - V_P}{I_P} \quad \text{and} \quad R_{min} = \frac{V_{BB} - V_V}{I_V}$$

$$V_P = 0.7 + \eta V_{BB} \qquad V_V \simeq 0.1\, V_{BB} = 1\text{V}$$

For the given UJT, the average value of η can be found as: $\eta = \frac{0.56 + 0.75}{2} = 0.655$

$$\Rightarrow V_P = 0.7 + 0.655 \times 10 = 7.25\text{V}$$

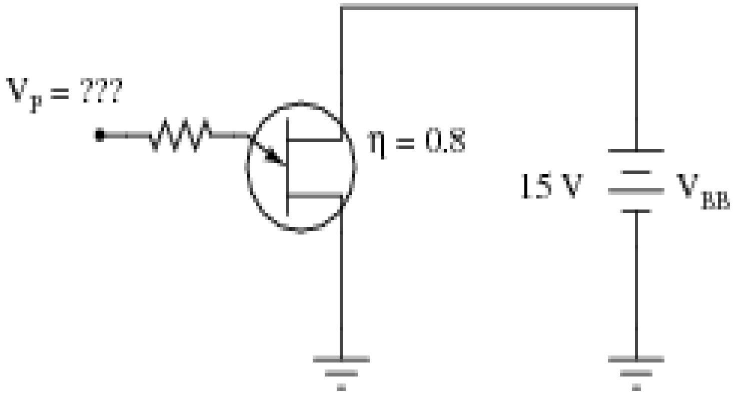
$$\Rightarrow R_{max} = \frac{10 - 7.25}{5 \times 10^{-6}} = 550\text{k}\Omega \qquad \Rightarrow R_{min} = \frac{10 - 1}{4 \times 10^{-3}} = 2.25\text{k}\Omega$$

Suitable value of ***R*** can be selected between $2.25\text{k}\Omega$ and $550\text{k}\Omega$ as: $R = 10\text{k}\Omega$

$$f = \frac{1}{RC \ln\left(\frac{1}{1-\eta}\right)} \qquad \Rightarrow C = \frac{1}{1 \times 10^3 \times 10 \times 10^3 \times \ln\left(\frac{1}{1 - 0.655}\right)} \approx 94\text{nF}$$

Example 2 A given UJT with an intrinsic standoff ratio ($\eta = 0.8$) is powered by a 15 volt DC source. Calculate the emitter voltage (V_P) needed to "trigger" this UJT into its conductive state.

Solution:



$$V_P = V_D + \eta V_{BB} = 0.7 + \eta V_{BB}$$

$$\Rightarrow V_P = 0.7 + 0.8 \times 15 = 12.7\text{V}$$

Example 3 A given UJT relaxation oscillator has the following: V_{BB} = 30V, V_D = 0.6V, R = 100kΩ, and η = 0.6. What is the value of C that gives 1kHz output frequency? Calculate the maximum value of capacitor voltage V_C.

Solution:

$$V_P = V_D + \eta V_{BB}$$

$$\Rightarrow V_P = 0.6 + 0.6 \times 30 = 18.6\text{V}$$

$$f = \frac{1}{RC \ln\left(\frac{1}{1-\eta}\right)}$$

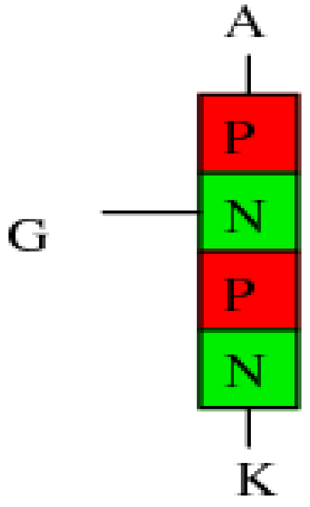
$$\Rightarrow C = \frac{1}{1\times 10^3 \times 100 \times 10^3 \times \ln\left(\frac{1}{1-0.6}\right)} = 1.09\times 10^{-6} F = 1.09 \mu F$$

$$(V_C)_{max} = V_P$$

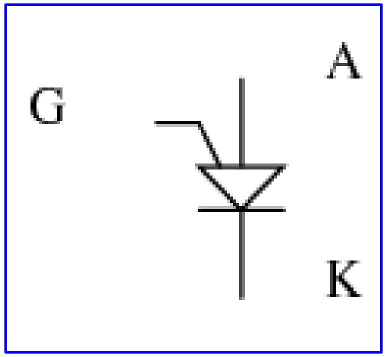
$$\Rightarrow (V_C)_{max} = 18.6\text{V}$$

Programmable Unijunction Transistor (PUT):

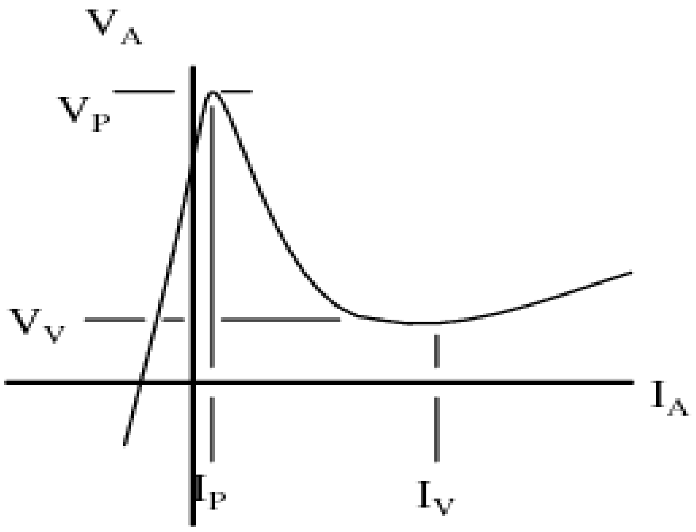
- Although UJT is expensive if obtained, the PUT is inexpensive and in production.
- PUT serves similar to the UJT, But it has three terminals as the thyristor.
- The PUT shares the four-layer structure typical of thyristors as shown.
- The gate, an N-type layer near the anode, is known as an “anode gate”.
- The gate lead on the schematic symbol is attached to the anode end of the symbol.



PUT Configuration

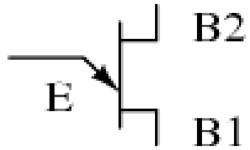


Symbol

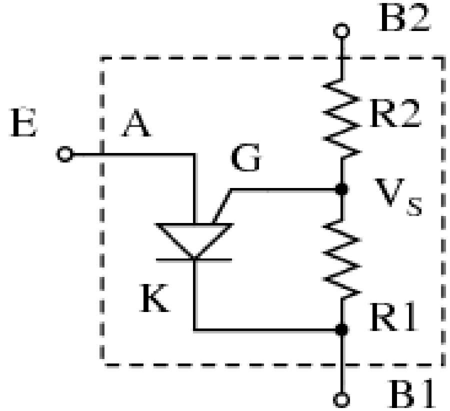


Input forward characteristics

PUT Equivalent Circuit



Unijunction



PUT equivalent

$$R_{BB0} = R1 + R2$$

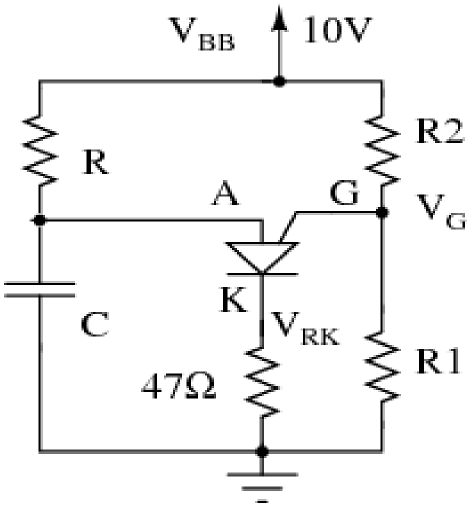
$$\eta = \frac{R1}{R1 + R2}$$

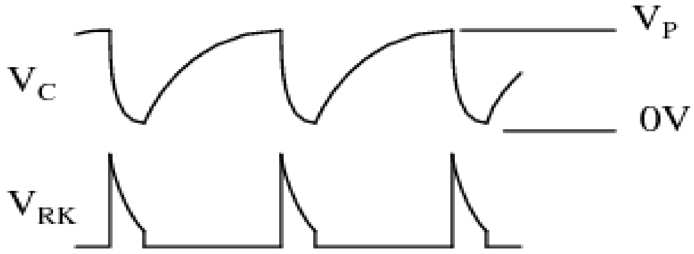
$$V_S = \eta V_{BB}$$

$$V_P = V_T + V_S$$

$$R_G = \frac{R1 \cdot R2}{R1 + R2}$$

PUT Relaxation Oscillator





Problems and Solutions

Question 1 For a given UJT of 180 mw power and inter-base resistor R_{BB} = 4kΩ , find the estimated value of maximum source voltage V_{BB}.

Solution:

$$\text{UJT Power} = \frac{V_{BB}^2}{R_{BB}}$$

$$\Rightarrow V_{BB}^2 = 180 \times 10^{-3} \times 4 \times 10^3 = 720$$

$$\therefore \ V_{BB} = \sqrt{720} = 26.8\text{Volt}$$

Question 2 For a given UJT, V_{BB} = 10 volts, η_{min} = 0.6, and η_{max} = 0.8, find the possible values of V_P.

Solution:

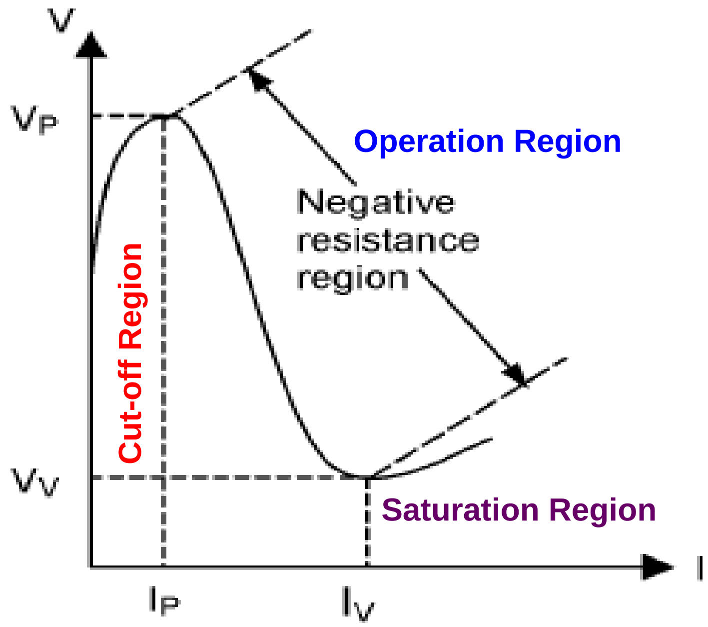
$$V_P = V_D + \eta V_{BB} = 0.7 + \eta V_{BB}$$

$$\Rightarrow (V_P)_{\min} = 0.7 + \eta_{\min} V_{BB} = 0.7 + 0.6 \times 10 = 6.7\text{Volt}$$

$$\Rightarrow (V_P)_{\max} = 0.7 + \eta_{\max} V_{BB} = 0.7 + 0.8 \times 10 = 8.7\text{Volt}$$

Question 3 Sketch the input forward characteristics curve of UJT and indicate the regions of operation.

Solution:



Input forward characteristics curve of UJT

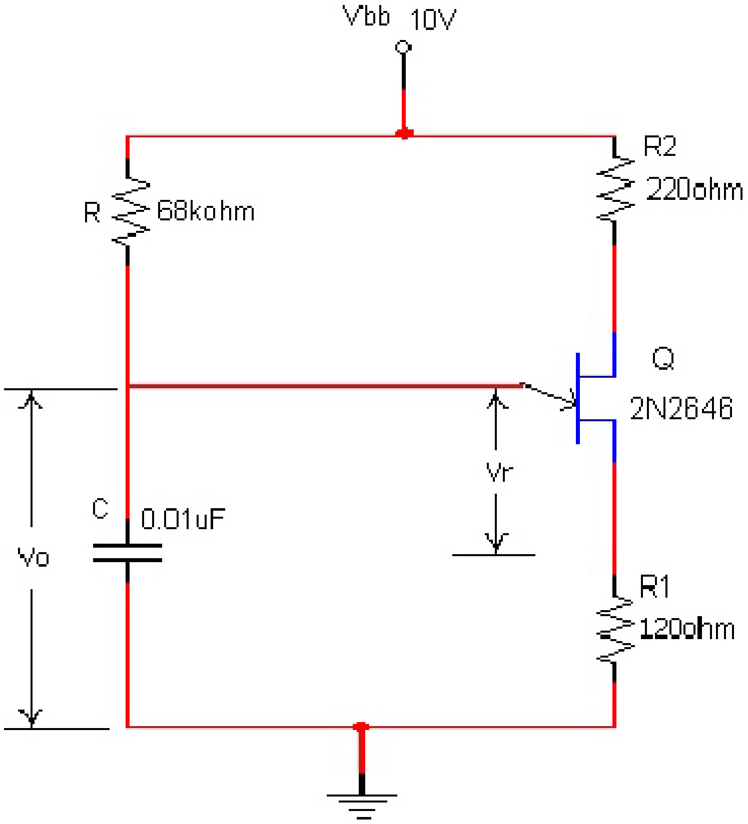
Question 4 Why a UJT oscillator called relaxation oscillator?

Solution:

Because the charging time constant ***RC*** is much greater than the discharging time. So the capacitor relax in charging state, and hence the name of relaxation oscillator.

Question 5 For the given relaxation oscillator: 1) find the output frequency if $\eta = 0.65$, 2) the maximum value of V_C , and 3) the value of V_C at half value of periodic time T.

Solution:



1)

$$f = \frac{1}{RC \ln\left(\frac{1}{1-\eta}\right)}$$

$$\therefore f = \frac{1}{68\times10^{3}\times0.01\times10^{-6}\times\ln\left(\frac{1}{1-0.65}\right)} = 1.4\text{kHz}$$

2)

$$V_P = V_D + \eta V_{BB} = 0.7 + \eta V_{BB}$$

$$\Rightarrow V_P = 0.7 + 0.65\times10 = 7.2\text{V}$$

$$(V_C)_{\max} = V_P \quad \Rightarrow (V_C)_{\max} = 7.2\text{V}$$

3)

$$V_C = V_{BB}\left(1-e^{-t/RC}\right)$$

$$\text{at } t = \frac{T}{2} = \frac{1}{2f} = \frac{1}{2\times1.4\times10^{3}} = 0.357m\sec \Rightarrow V_C = 10\left(1-e^{\frac{-0.357\times10^{-3}}{\left(68\times10^{3}\times0.01\times10^{-6}\right)}}\right) = 4\text{V}$$

Question 6 A given UJT relaxation oscillator has the following: V_{BB} = 20V, I_V = 10mA, I_P = 40 μA, C = 1μF, and η = 0.65. Find the value of maximum and minimum frequencies.

Solution:

$$V_P = 0.7 + \eta V_{BB} \quad \Rightarrow V_P = 0.7 + 0.65 \times 20 = 13.7\text{V}$$

$$V_V \simeq 0.1\, V_{BB} = 2\text{V}$$

$$f = \frac{1}{RC \ln\left(\frac{1}{1-\eta}\right)} \quad \Rightarrow f_{max} = \frac{1}{R_{min} C \ln\left(\frac{1}{1-\eta}\right)} \quad \text{and} \quad f_{min} = \frac{1}{R_{max} C \ln\left(\frac{1}{1-\eta}\right)}$$

$$\because R_{max} = \frac{V_{BB} - V_P}{I_P} \quad \text{and} \quad R_{min} = \frac{V_{BB} - V_V}{I_V}$$

$$\Rightarrow R_{max} = \frac{20 - 13.7}{40 \times 10^{-6}} = 157.5\text{k}\Omega \qquad \Rightarrow R_{min} = \frac{20 - 2}{10 \times 10^{-3}} = 1.8\text{k}\Omega$$

$$\therefore f_{max} = \frac{1}{1.8 \times 10^3 \times 1 \times 10^{-6} \times \ln\left(\frac{1}{1 - 0.65}\right)} = 529\text{Hz}$$

$$\therefore f_{min} = \frac{1}{157.5 \times 10^3 \times 1 \times 10^{-6} \times \ln\left(\frac{1}{1 - 0.65}\right)} = 6\text{Hz}$$

Question 7 For the given UJT relaxation oscillator, calculate the maximum and minimum frequencies if $\eta = 0.6$

Solution:

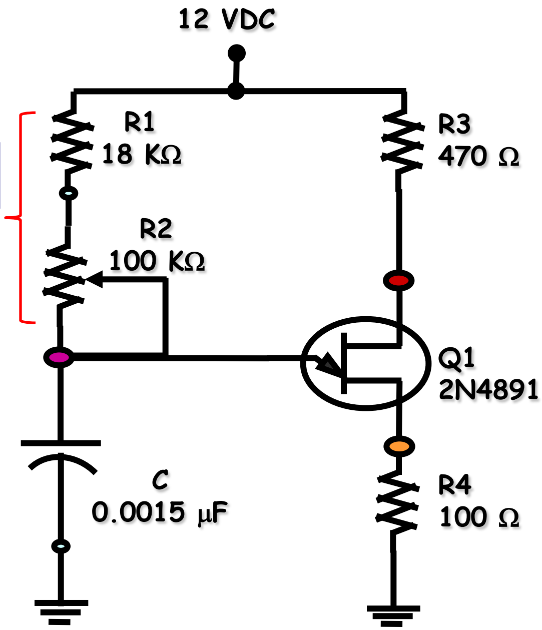
$$V_P = 0.7 + \eta V_{BB} \Rightarrow V_P = 0.7 + 0.6 \times 12 = 7.9\text{V}$$

$$V_V \simeq 0.1\, V_{BB} = 1.2\text{V}$$

$$f = \frac{1}{RC \ln\left(\frac{1}{1-\eta}\right)}$$

$$R_{max} = R_1 + R_2 = 118\text{k}\Omega$$

$$R_{min} = R_1 + 0 = 18\text{k}\Omega$$



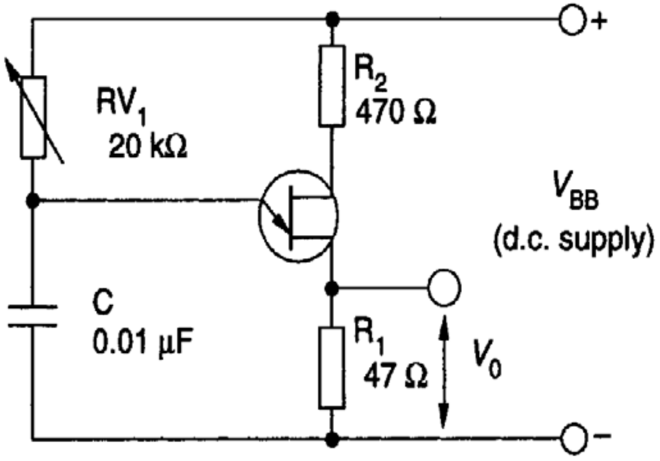
$$\Rightarrow f_{max} = \frac{1}{R_{min} C \ln\left(\frac{1}{1-\eta}\right)}$$

$$= \frac{1}{18 \times 10^3 \times 0.0015 \times 10^{-6} \times \ln\left(\frac{1}{1-0.6}\right)} = 40\text{kHz}$$

$$\Rightarrow f_{min} = \frac{1}{R_{max} C \ln\left(\frac{1}{1-\eta}\right)} = \frac{1}{118 \times 10^3 \times 0.0015 \times 10^{-6} \times \ln\left(\frac{1}{1-0.6}\right)} = 6.16\text{kHz}$$

Question 8 For the given UJT relaxation oscillator with V_{BB} = 30V and η = 0.6, calculate the output frequency and the voltage swing.

Solution:



$$V_P = 0.7 + \eta V_{BB}$$

$$\Rightarrow V_P = 0.7 + 0.6 \times 30 = 18.7\text{V}$$

$$V_V \simeq 0.1\ V_{BB} = 3\text{V}$$

$$f = \frac{1}{RC \ln\left(\frac{1}{1-\eta}\right)}$$

$$\Rightarrow f = \frac{1}{20\times10^{3}\times0.01\times10^{-6}\times\ln\left(\frac{1}{1-0.6}\right)} = 545\text{kHz}$$

$$V_{swing} = V_P - V_V \qquad \Rightarrow V_{swing} = 18.7 - 3 = 15.7\text{V}$$

Question 9 **Fill in the following blanks with suitable words.**

1) UJT is also called Double *Base Diode* .

2) Intrinsic standoff ratio is the coefficient of UJT that has typical values lie between *0.5* and *0.8*.

3) UJT interbase resistance of *N* block of several thousands of Ohms when positive voltage is applied to *B1* at *reverse biased condition of the pn junction*.

4) The condition of operation of UJT is: $V_E = 0.7 + \eta V_{BB}$.

5) The UJT has three operating regions as, *cut-off region*, *negative resistance region*, and *saturation region*.

6) The oscillation condition of UJT oscillator is: $\frac{V_{BB} - V_V}{I_V} < R < \frac{V_{BB} - V_P}{I_P}$

7) Capacitor voltage during charging time of UJT oscillator can be expressed as: $V_C = V_{BB}\left(1 - e^{-t/RC}\right)$

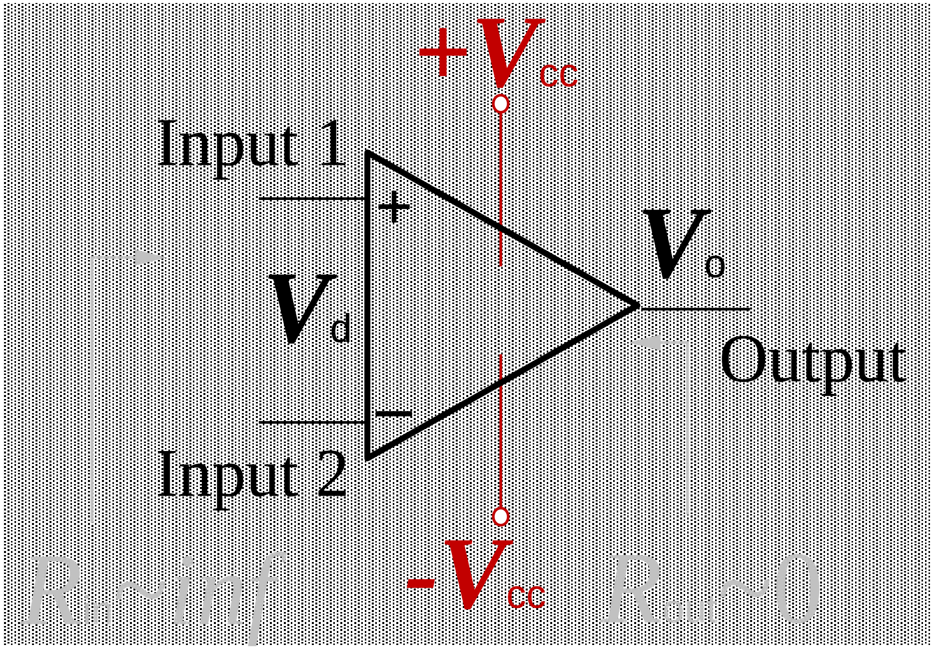
8) The negative resistance region in the characteristic of the *UJT* makes it useful for constructing *voltage oscillators*.

Chapter 4

The Operational Amplifier (Op-Amp)

The Operational Amplifier (Op-Amp)

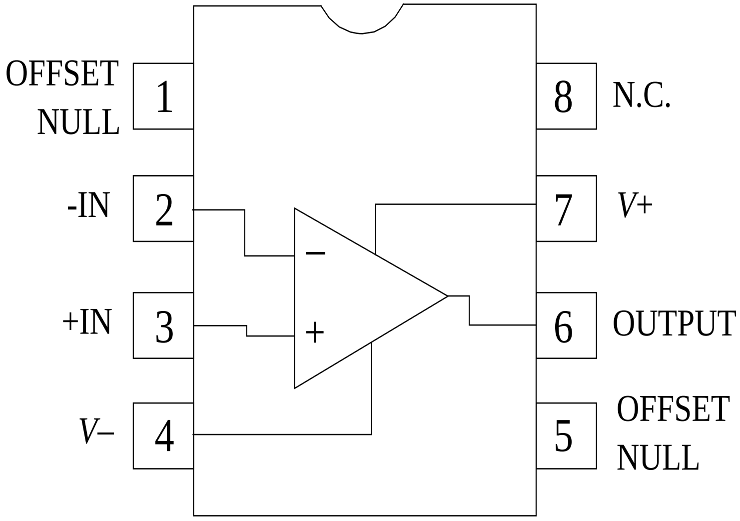
- Very high differential gain G_d .
- High input impedance R_{in} .
- Low output impedance $R_{out.}$
- Provide voltage changes (amplitude and polarity).
- Used in oscillator, filter and instrumentation.
- Accumulate a very high gain by multiple stages.



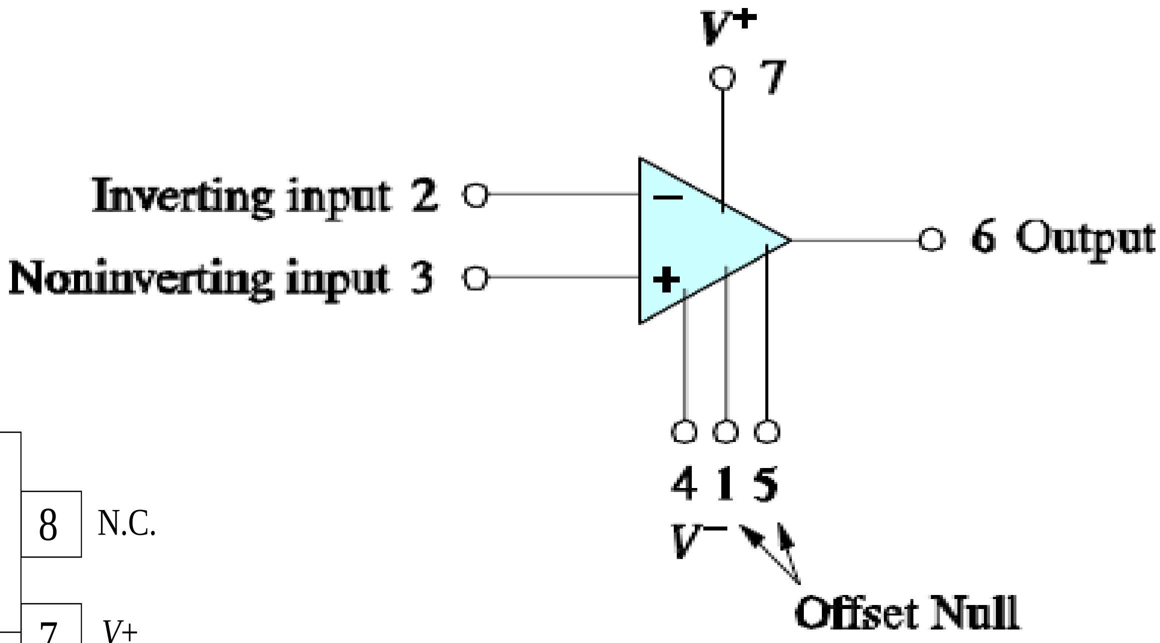
$$V_o = G_d V_d$$

G_d : differential gain normally very large about 10^5

The Op-Amp Symbol



DIP-741

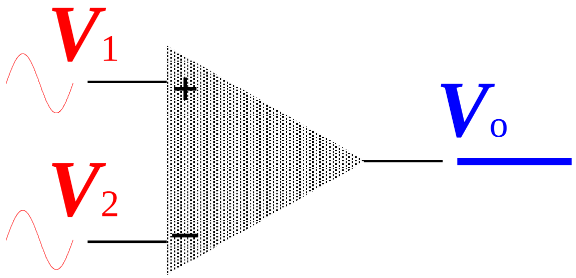


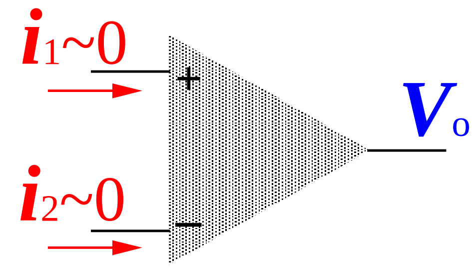
Op-Amp Properties

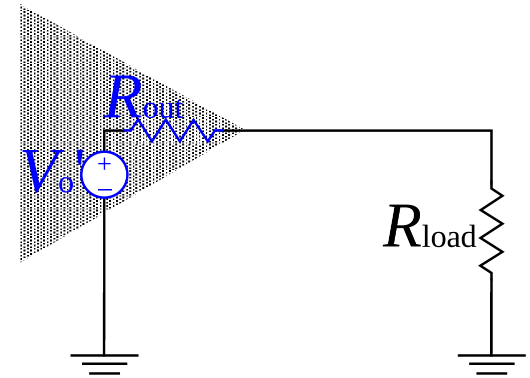
(1) Infinite Open Loop gain
- The gain without feedback equal to G_d.
- Zero common-mode gain.
- Practically, G_d = 20,000 to 200,000

(2) Infinite Input impedance
- Input current i_i , i_2 ~0A
- TΩ in high-grade op-amp
- mA input current in low-grade op-amp

(3) Zero Output Impedance
- act as perfect internal voltage source
- No internal resistance
- Output impedance in series with load
- Reducing output voltage to the load
- Practically, R_{out} ~ 20-100 Ω

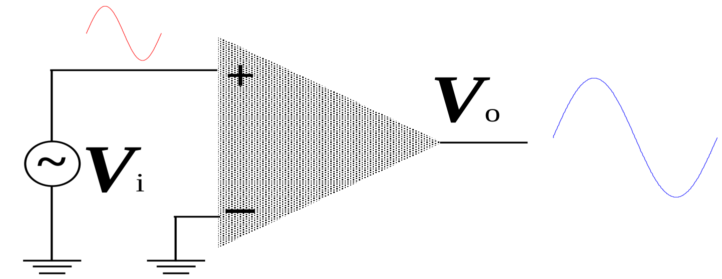




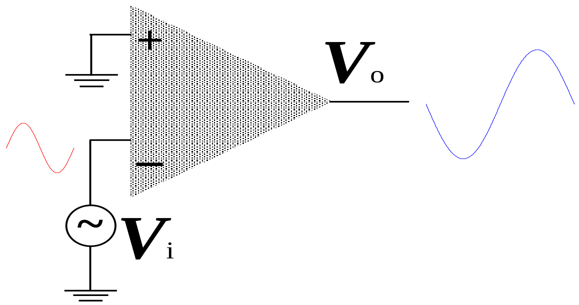


$$V_{load} = V_o' \frac{R_{load}}{R_{load} + R_{out}}$$

Single-Ended Input

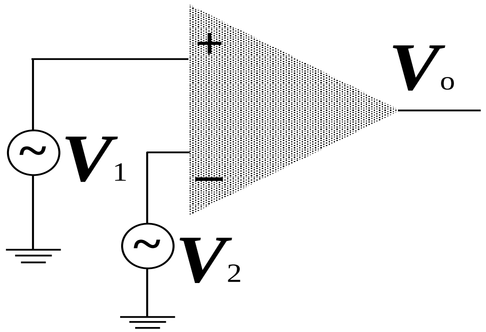


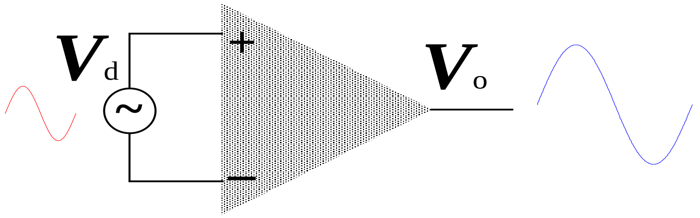
- + terminal : Source
- – terminal : Ground
- 0º phase change



- + terminal : Ground
- – terminal : Source
- 180º phase change

Double-Ended Input



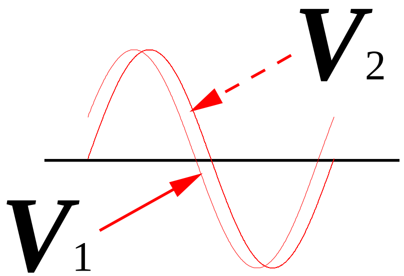


$$V_d = V_+ - V_-$$

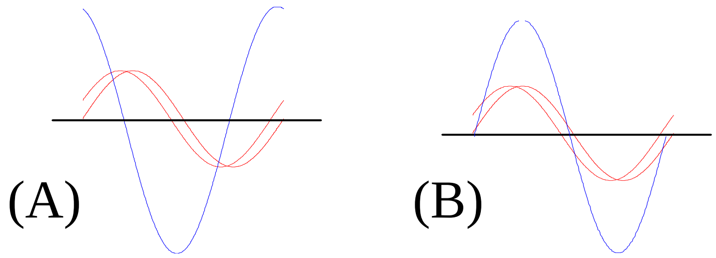
- Differential input V_d.
- 0º phase shift change between V_o and V_d

Question:

Which of the following (A or B) is the output voltage V_o if the input voltages is given as:



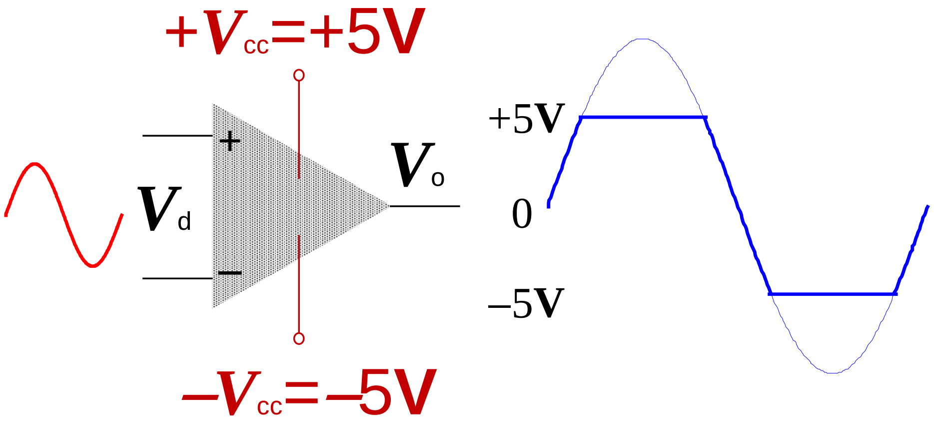
Input voltage



Output voltage (Aor B) ?

Op-Amp Distortion

The output voltage never excess the DC biasing voltage of the Op-Amp.

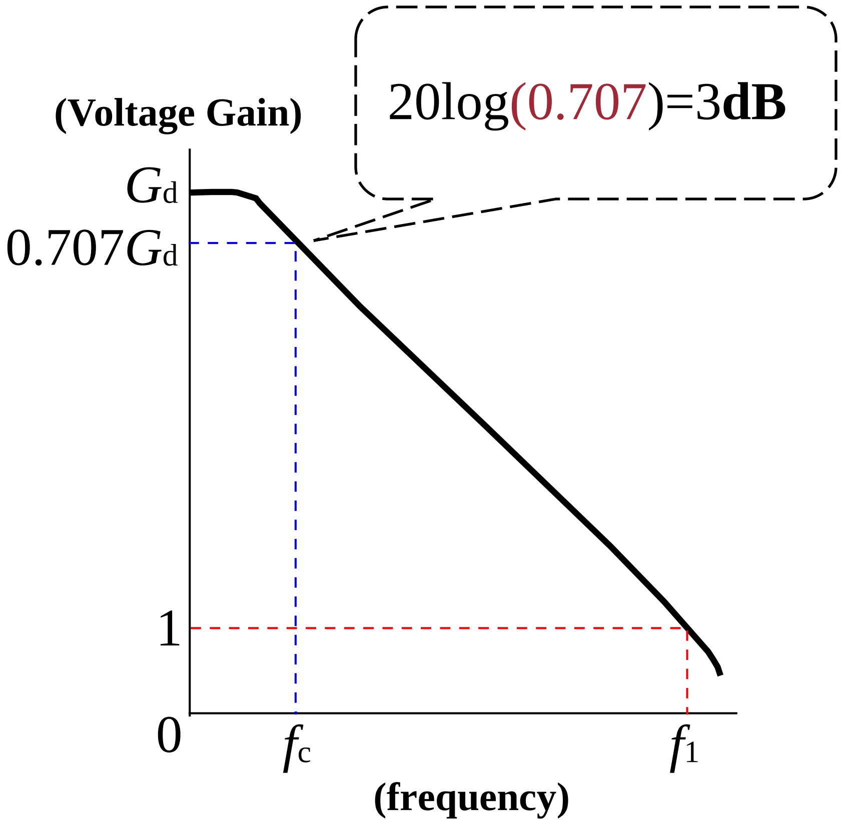


Frequency-Gain Relation

- Ideally, signals are amplified from DC to the highest AC frequency
- Practically, bandwidth is limited
- 741 family op-amp have an limit bandwidth of few KHz.

- Unity Gain frequency f_1: the gain at unity
- Cutoff frequency f_c: the gain drop by 3dB from dc gain G_d
- Gain Bandwidth (GB) product is represented as:

$$\text{GB Product} : f_1 = G_d\, f_c$$



Example 1: Determine the cutoff frequency of an op-amp having a unit gain frequency f_1 = 10 MHz and voltage differential gain G_d = 20**V**/m**V.**

Solution:

Since f_1 = 10 MHz

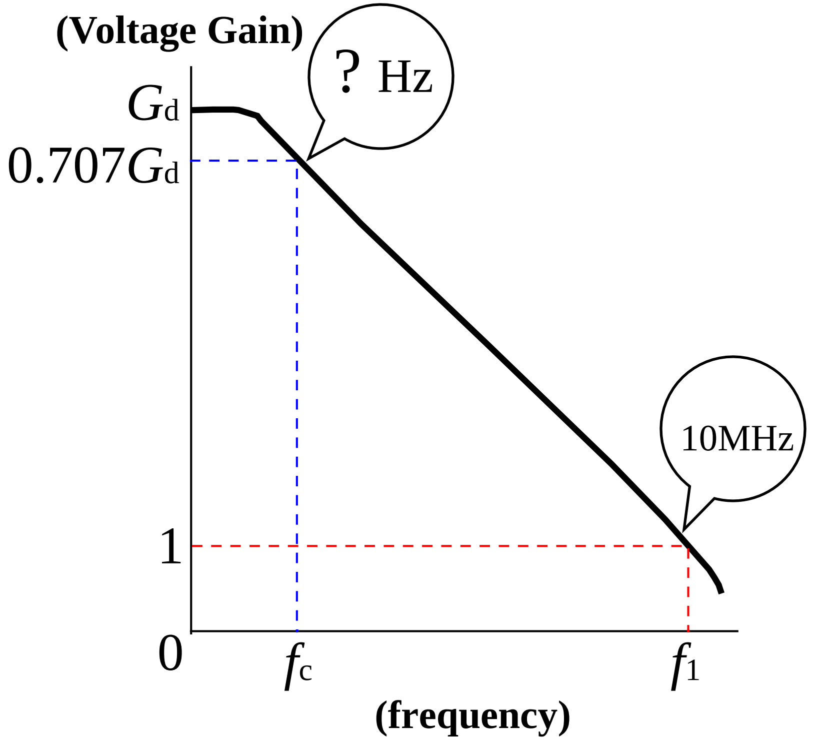
By using GB production equation

$$f_1 = G_d\, f_c$$

$$f_c = f_1 / G_d = 10\text{ MHz} / 20\text{ V/mV}$$

$$= 10 \times 10^6 / 20 \times 10^3$$

$$= 500\text{ Hz}$$



Ideal Op-Amp Applications

Analysis Method :

Two ideal Op-Amp Properties:

(1) The voltage between V_+ and V_- is zero $V_+ = V_-$

(2) The current into both V_+ and V_- terminals is zero.

For ideal Op-Amp circuit:

(1) Write the Kirchhoff node equation at the non inverting terminal V_+

(2) Write the Kirchhoff node equation at the inverting terminal V_-

(3) Set $V_+ = V_-$ and solve for the desired closed-loop gain

Non-Inverting Amplifier

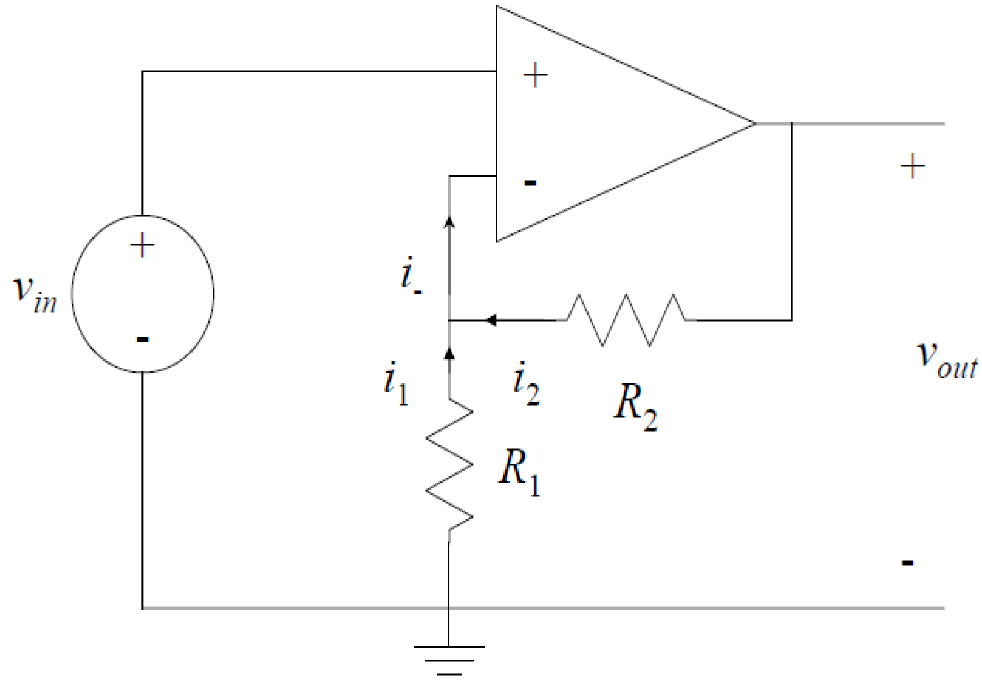
KCL at the Inverting Input

$$i_- = 0$$

$$i_1 = \frac{-v_-}{R_1} = \frac{-v_{in}}{R_1}$$

Since $v_- = v_+ = v_{in}$

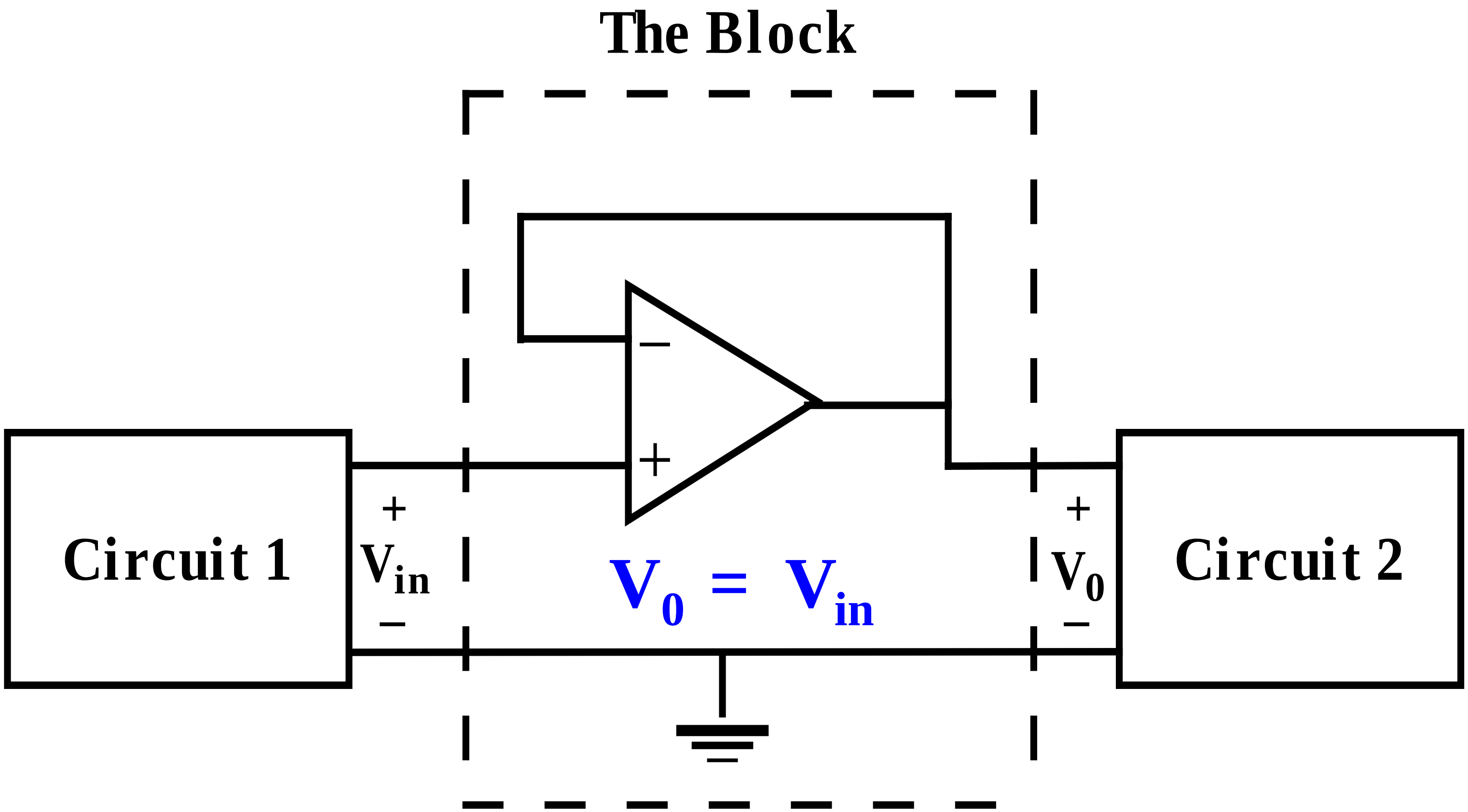
$$i_2 = \frac{v_{out} - v_-}{R_2} = \frac{v_{out} - v_{in}}{R_2}$$



Solve for V_{out}

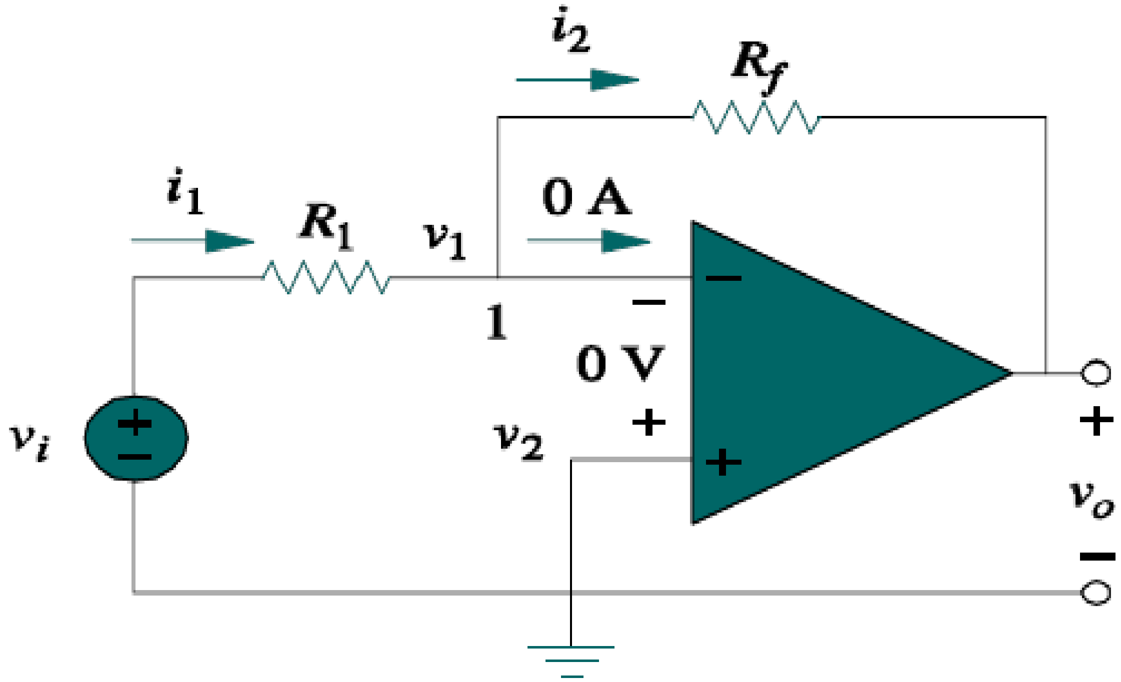
$$\frac{-v_{in}}{R_1} + \frac{v_{out} - v_{in}}{R_2} = 0 \quad \Rightarrow \quad v_{out} = v_{in}\left(1 + \frac{R_2}{R_1}\right)$$

Isolation or Voltage Follower



Circuit isolation with an op-amp.

Inverting Amplifier



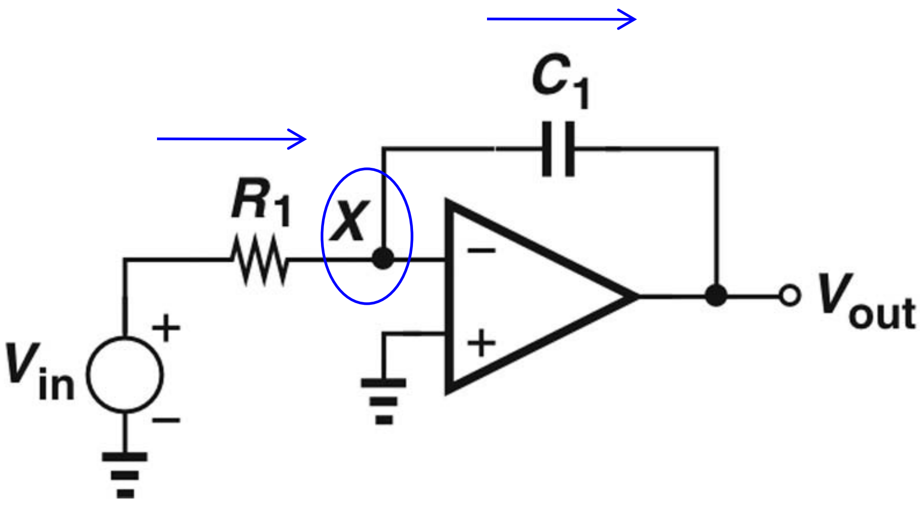
Since the noninverting terminal is grounded

$$v_1 = v_2 = 0$$

KCL at v_1: $i_1 = i_2 \Rightarrow \frac{v_i - 0}{R_1} = \frac{0 - v_0}{R_f}$ ⇒ $v_0 = -\frac{R_f}{R_1} v_i$

Op-Amp Integrator

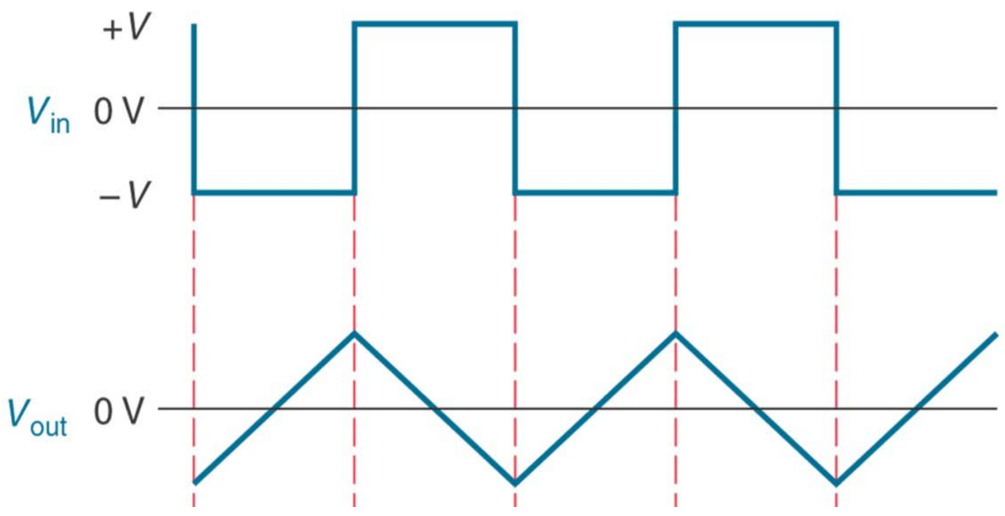
- The op-amp provides a constant-current source for the capacitor, causing it to charge at a linear rate.
- It is used as Low Pass Filter.



At point *X*

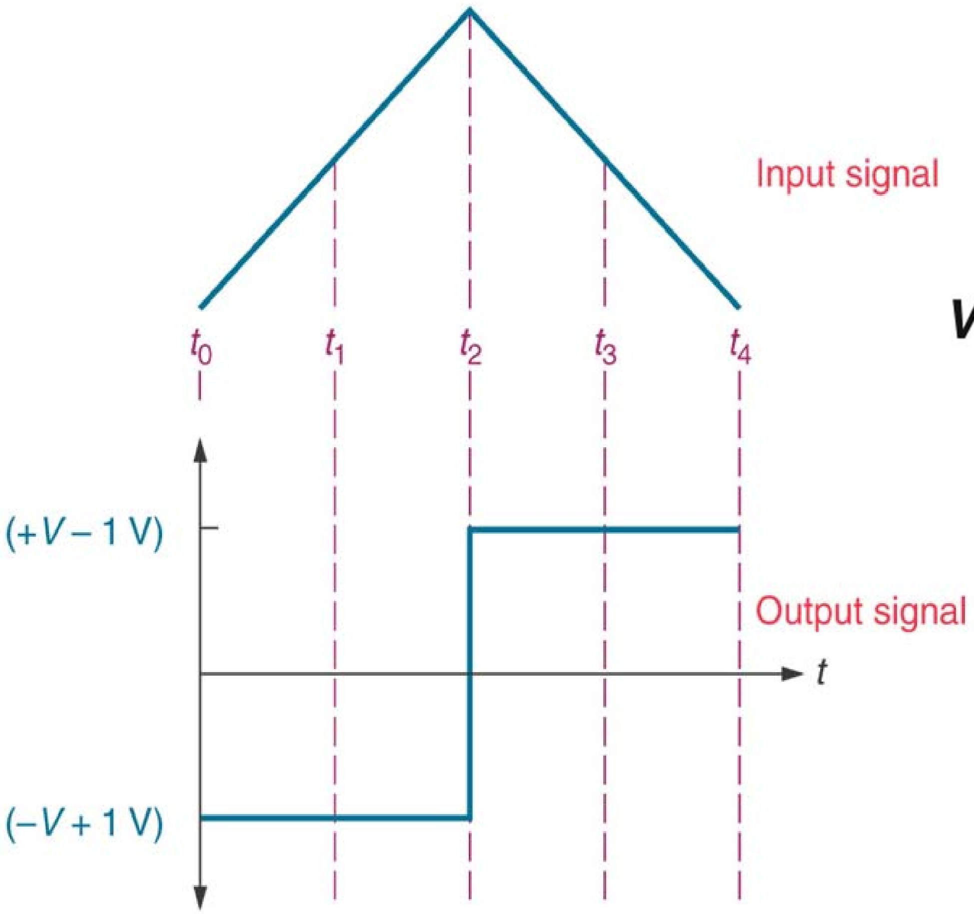
$$\frac{V_{in}}{R_1} = -C_1 \frac{dV_{out}}{dt}$$

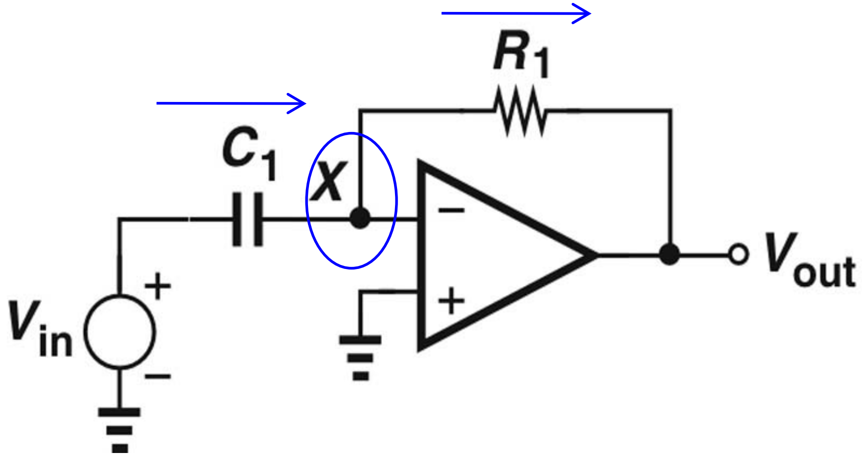
$$V_{out} = -\frac{1}{R_1 C_1} \int V_{in}\, dt$$



Op-Amp Differentiator

- The output signal is proportional to the rate of change of input signal.
- It is used as High Pass Filter.



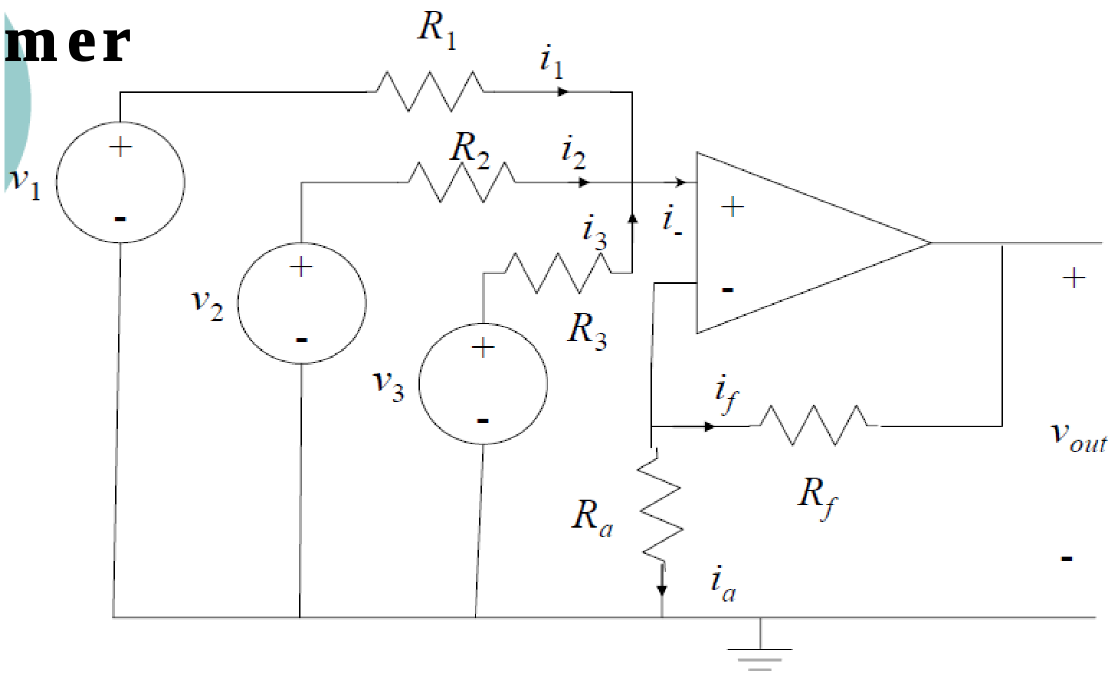


At point *X*

$$C_1 \frac{dV_{in}}{dt} = -\frac{V_{out}}{R_1}$$

Op-Amp with Multiple Inputs

Noninverting Summer



At the noninverting input:

$$i_1 + i_2 + i_3 = 0$$

$$i_1 = \frac{v_1 - v_+}{R_1}$$

$$i_2 = \frac{v_2 - v_+}{R_2} \qquad i_3 = \frac{v_3 - v_+}{R_3}$$

At the inverting input:

$$i_f + i_a = 0$$

$$i_f = \frac{v_- - v_{out}}{R_f}$$

$$i_a = \frac{v_-}{R_a}$$

$$v_- = \frac{R_a}{R_a + R_f} v_{out}$$

$$v_- = v_+$$

$$\frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_3}{R_3} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) v_+$$

$$\frac{1}{R_T} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$\frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_3}{R_3} = \frac{1}{R_T} \frac{R_a}{R_a + R_f} v_{out}$$

$$v_{out} = \left(1 + \frac{R_f}{R_a}\right)\left(\frac{R_T}{R_1} v_1 + \frac{R_T}{R_2} v_2 + \frac{R_T}{R_3} v_3\right)$$

Inverting Summer

KCL at the Inverting Input

$$i_1 = \frac{v_1 - v_-}{R_1} = \frac{v_1}{R_1}$$

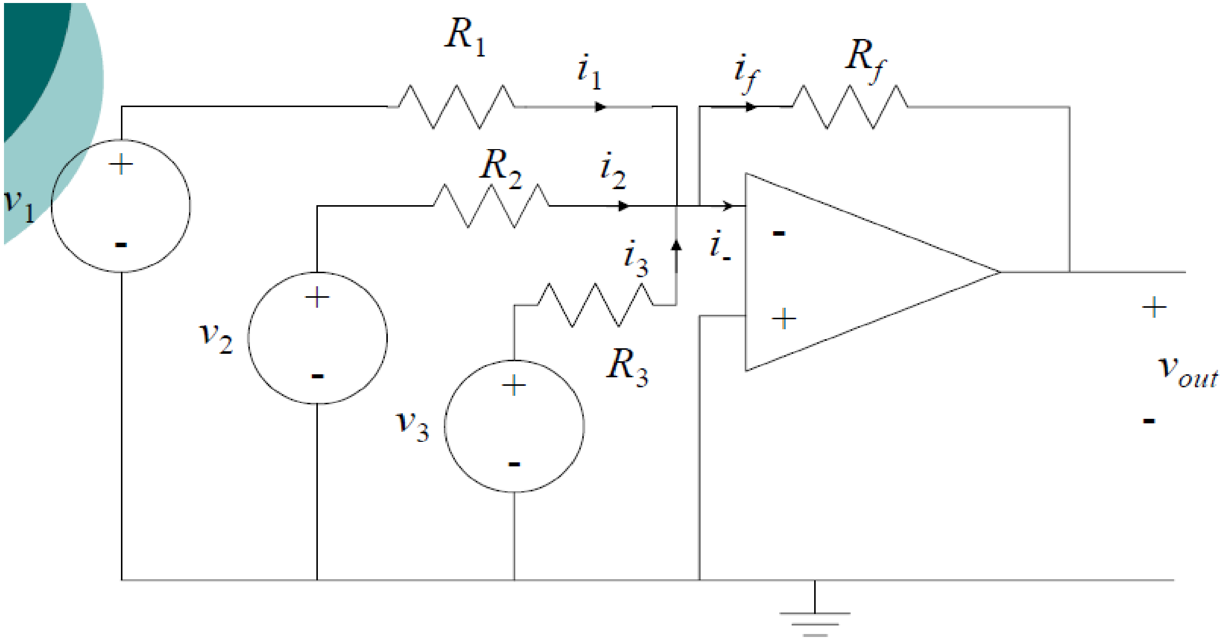
$$i_2 = \frac{v_2 - v_-}{R_2} = \frac{v_2}{R_2}$$

$$i_3 = \frac{v_3 - v_-}{R_3} = \frac{v_3}{R_3}$$

$$i_- = 0$$

$$i_f = \frac{v_{out} - v_-}{R_f} = \frac{v_{out}}{R_f}$$

$$\frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_3}{R_3} + \frac{v_{out}}{R_f} = 0$$



$$v_{out} = -\frac{R_f}{R_1}v_1 - \frac{R_f}{R_2}v_2 - \frac{R_f}{R_3}v_3$$

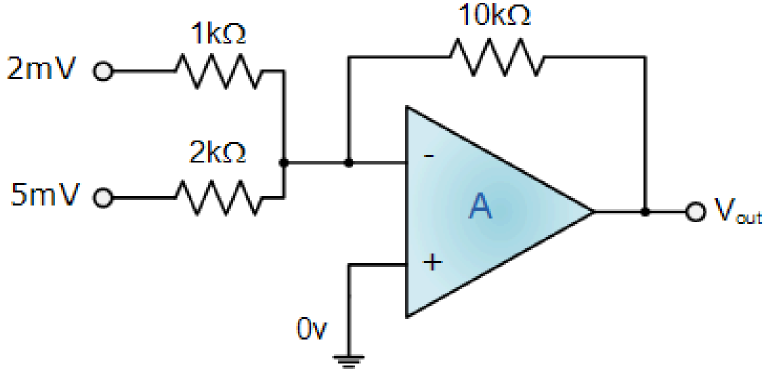
Example 2

Calculate V_{0ut} for the following summing circuit.

$$V_{out} = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} \right)$$

$$= -10\times10^3 \left(\frac{2\times10^{-3}}{1\times10^3} + \frac{5\times10^{-3}}{2\times10^3} \right)$$

$$= -10\times10^3 \left(2\times10^{-6} + 2.5\times10^{-6} \right) = 45\times10^{-3}\,\text{V} = 45\ \text{mV}$$



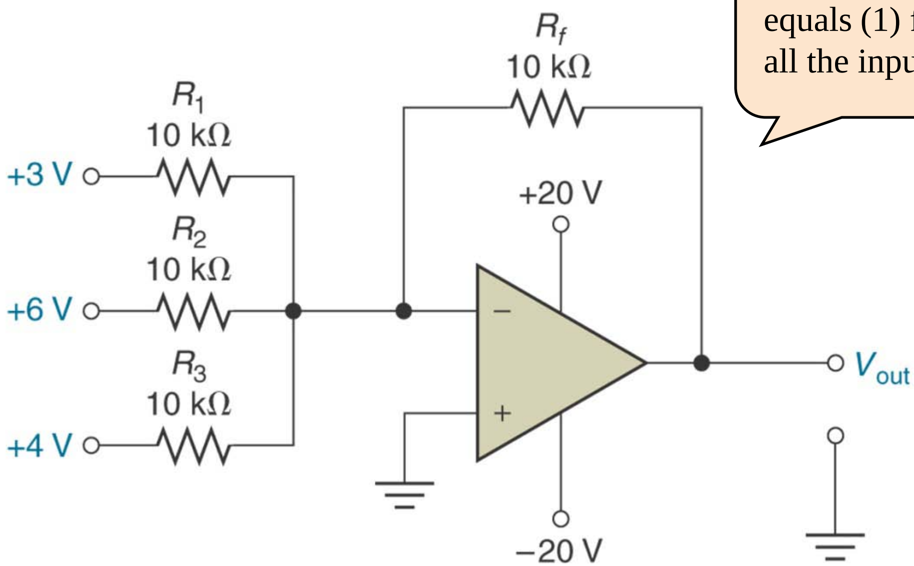
Example 3

Determine V_{0ut} for the following summing circuit.

Voltage gain equals (1) for all the inputs.

$$V_{out} = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right)$$

$$= -13\text{V}$$



Example 4

Design op-amp summing circuit to satisfy the following equation:
$V_{0ut} = 0.2\,V_1 + 0.25\,V_2 - V_3$. (Assume $R_f = 10k\Omega$)

Design steps:

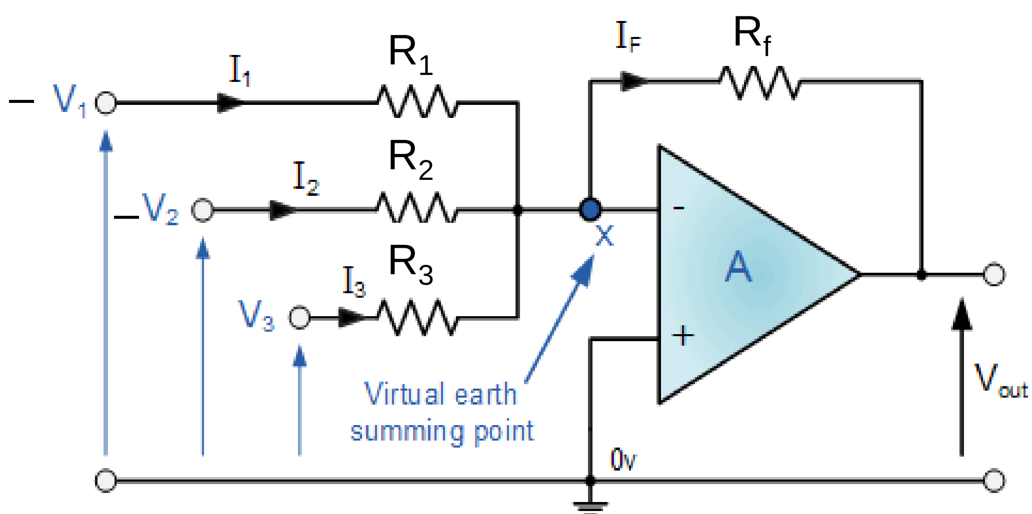
- Draw the summing circuit that has three input voltages and three resistances and reverse the sign of the three inputs as shown.
- Calculate the values of the three resistances by matching the summer equation with the given one as:

$$V_{out} = -\frac{R_f}{R_1}V_1 - \frac{R_f}{R_2}V_2 - \frac{R_f}{R_3}V_3$$

$$\frac{R_f}{R_1} = 0.2 \Rightarrow R_1 = \frac{10k\Omega}{0.2} = 50k$$

$$\frac{R_f}{R_2} = 0.25 \Rightarrow R_2 = \frac{10k\Omega}{0.25} = 40k$$

$$\frac{R_f}{R_3} = 1 \Rightarrow R_3 = \frac{10k\Omega}{1} = 10k$$



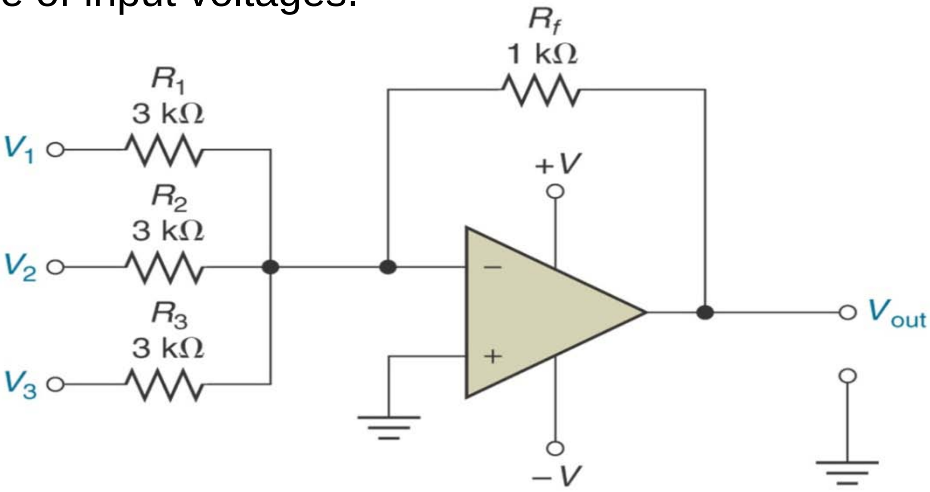
Averaging Amplifier

Averaging amplifier – is a summing amplifier with proper input and feedback resistors, that provides an output proportional to the average of input voltages.

Example 5

$$-V_{out} = \frac{1}{3}V_1 + \frac{1}{3}V_2 + \frac{1}{3}V_3$$

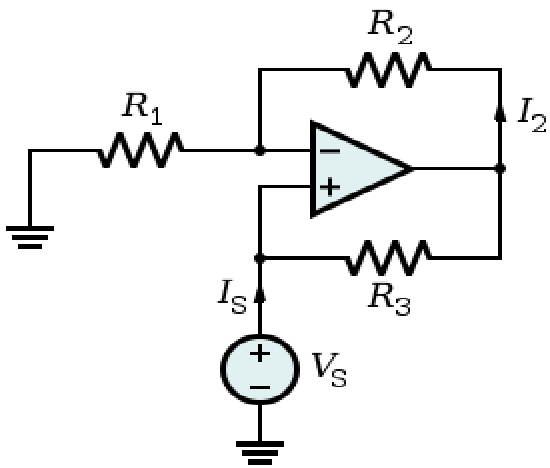
$$\therefore\ -V_{out} = \frac{V_1 + V_2 + V_3}{3}$$



Negative Impedance Converter NIC

- Creates a negative resistor for any signal generator.
- The ratio between input voltage and input current (input resistance) is given by:

$$R_{in} = -R_3\left(\frac{R_1}{R_2}\right)$$



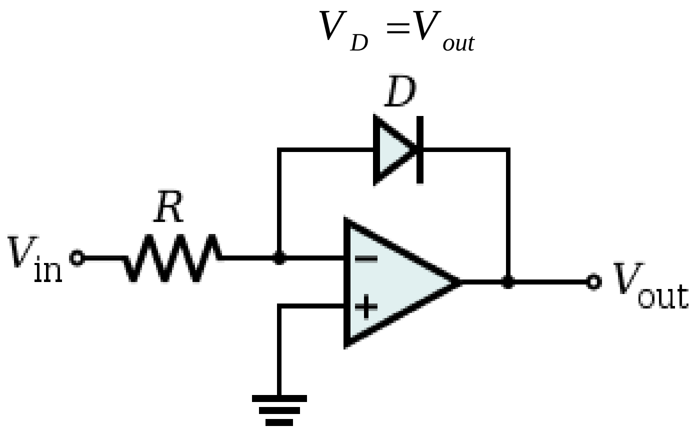
Logarithmic op-amp

$$\frac{V_{\text{in}}}{R} = I_R = I_D$$

$$I_D = I_S\left(e^{(V_D/V_T)} - 1\right) \simeq I_S e^{(V_D/V_T)}$$

$$V_{\text{out}} = -V_{\text{T}} \ln\left(\frac{V_{\text{in}}}{I_S R}\right)$$

Where: I_s is the saturation current and V_T is the thermal voltage.

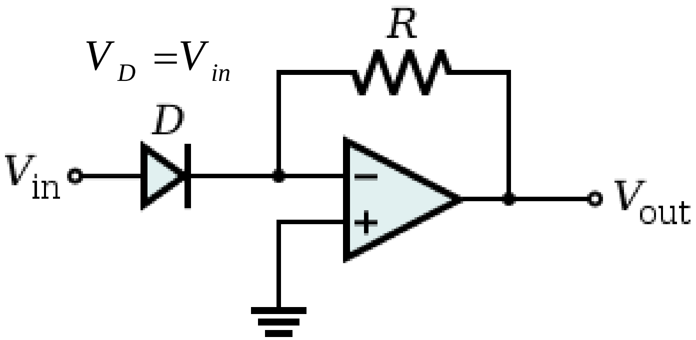


Op-amp Exponential Amplifier

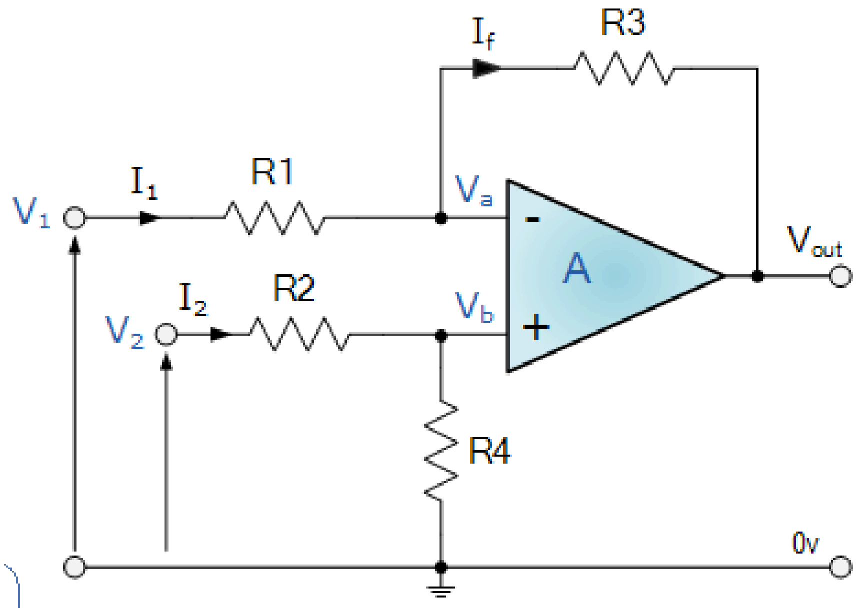
Considering ideal op-amp, the negative pin is virtually grounded, so the current through the diode is given by:

$$I_D = I_S\left(e^{(V_D/V_T)} - 1\right) \simeq I_S e^{(V_D/V_T)}$$

$$V_{\text{out}} = -RI_D = -RI_S e^{(V_{in}/V_T)}$$



Voltage Subtractor



$$I_1 = \frac{V_1 - V_a}{R_1}, \quad I_2 = \frac{V_2 - V_b}{R_2}, \quad I_f = \frac{V_a - (-V_{out})}{R_3}$$

Summing point $V_a = V_b$

If $V_b = 0$, then: $V_{out(a)} = -V_1\left(\frac{R_3}{R_3 + R_1}\right) = -V_1\left(\frac{R_3}{R_1}\right)$

If $V_a = 0$, then: $V_{out(b)} = V_2\left(\frac{R_4}{R_2 + R_4}\right)\left(1 + \frac{R_3}{R_1}\right)$

$$V_{out} = V_{out(a)} + V_{out(b)}$$

$$\therefore V_{out} = -V_1\left(\frac{R_3}{R_1}\right) + V_2\left(\frac{R_4}{R_2 + R_4}\right)\left(1 + \frac{R_3}{R_1}\right)$$

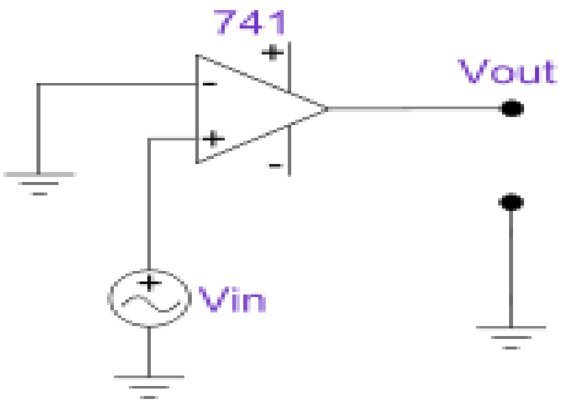
If $\mathbf{R_1 = R_2}$ and $\mathbf{R_3 = R_4}$

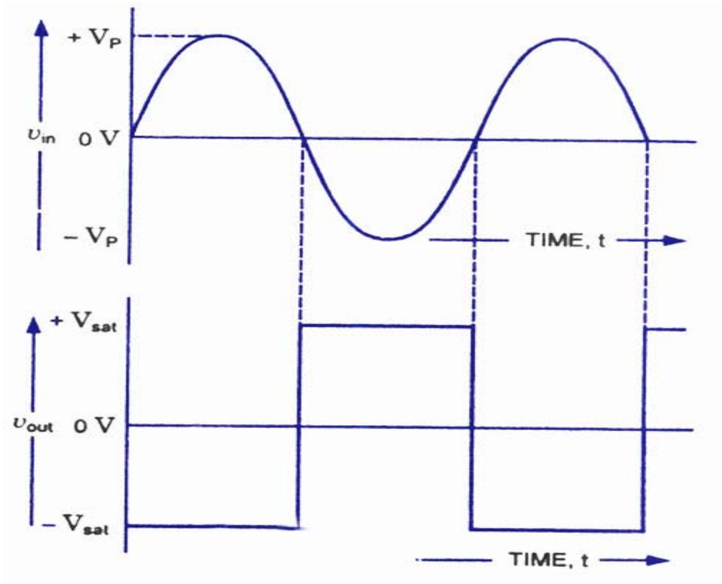
$$V_{out} = \frac{R_3}{R_1}(V_2 - V_1)$$

If $\mathbf{R_1 = R_2 = R_3 = R_4}$

$$V_{out} = V_2 - V_1$$

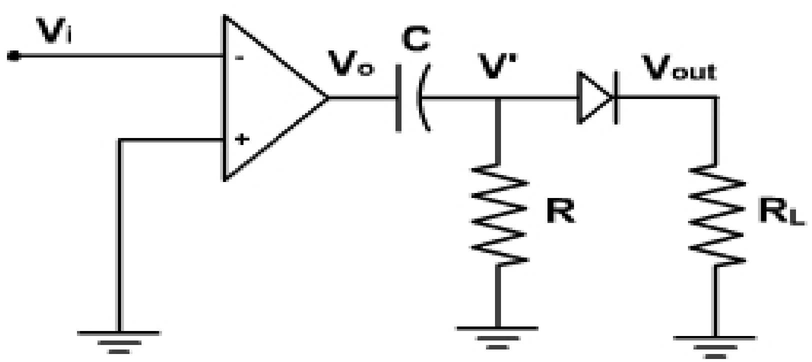
Zero Crossing Detector

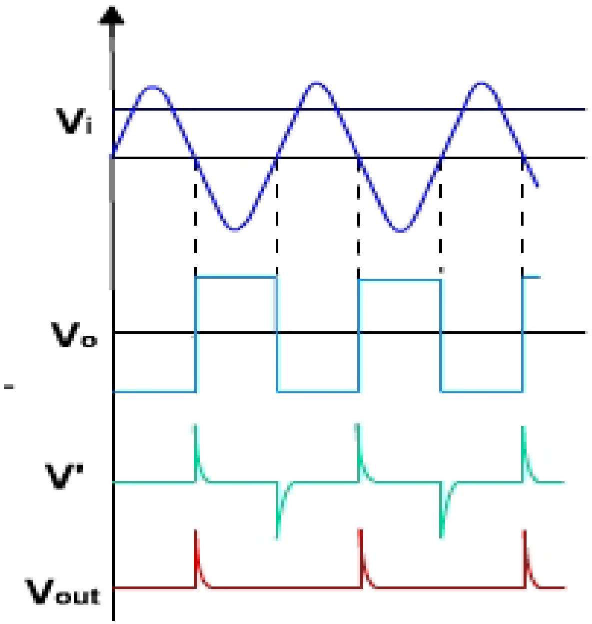




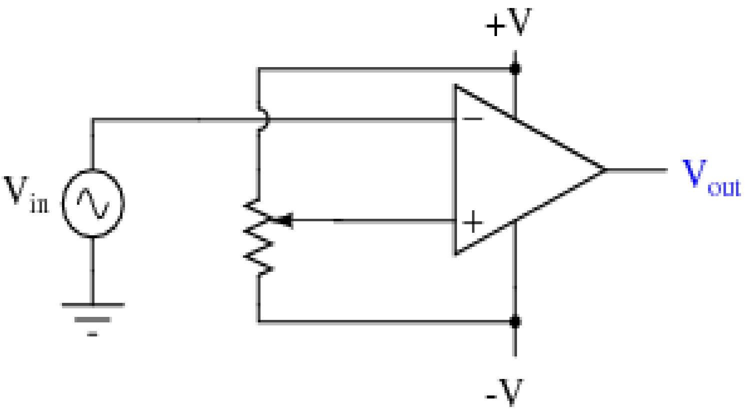
Input and Output Waveforms

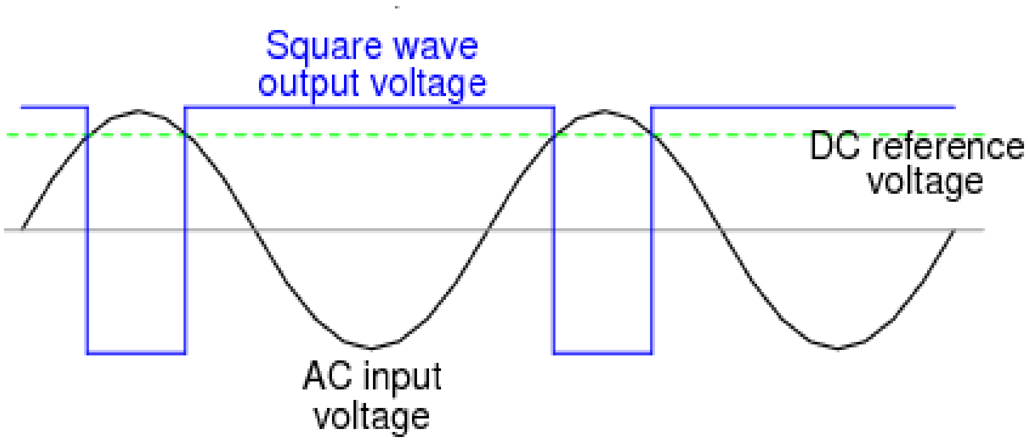
Zero crossing detector supplies trigger pulses





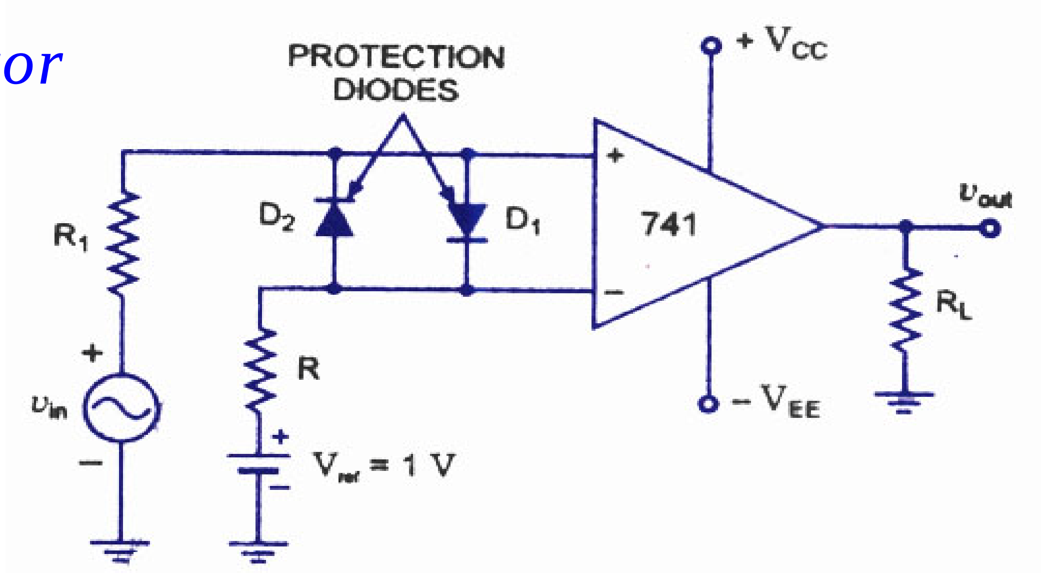
Inverting Comparator





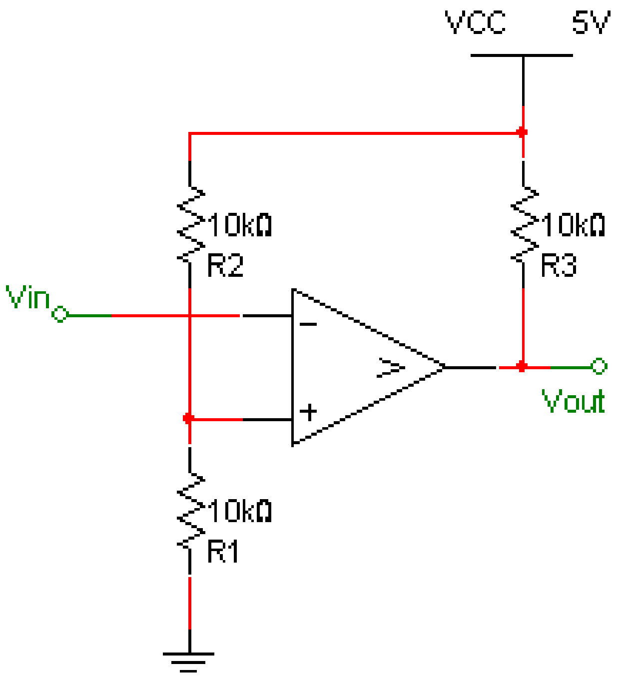
A "clean" AC input waveform produces predictable transition points on the output voltage square wave

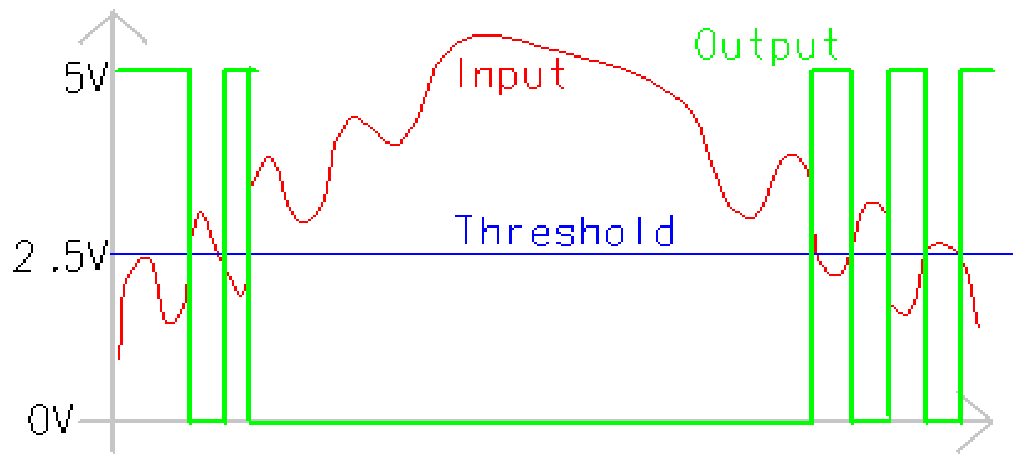
Noninverting Comparator



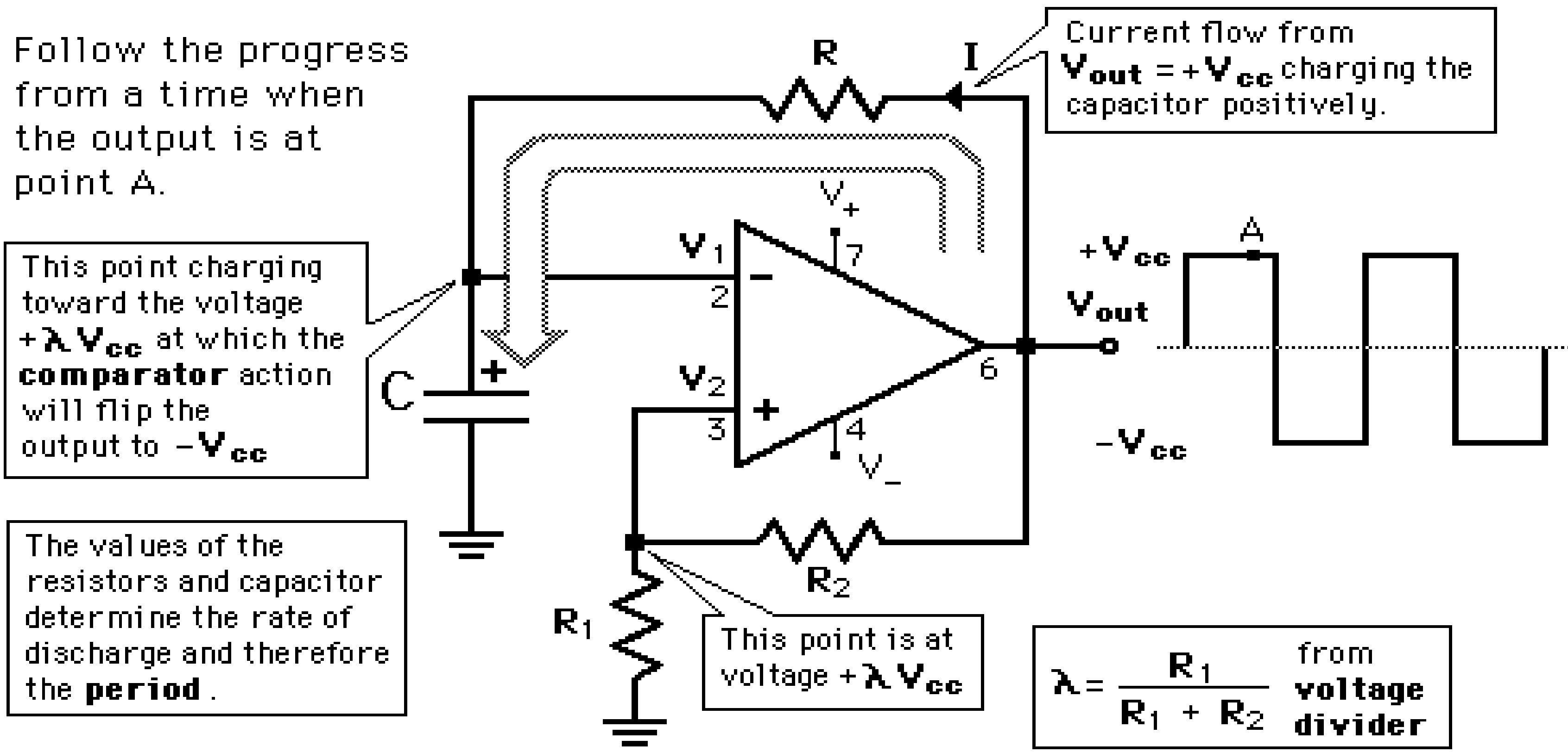
Example 6

Inverting comparator circuit using op-amp and threshold voltage of 2.5 volt.

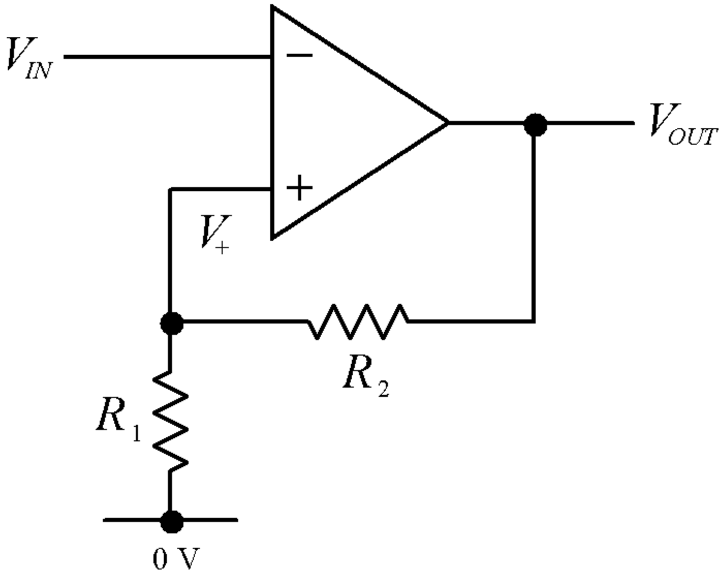




Square Wave Generator



Schmitt Trigger



Switching occurs when:

$$V_{IN} = V_- = V_+ = V_{OUT} \frac{R_1}{R_1 + R_2}$$

But,

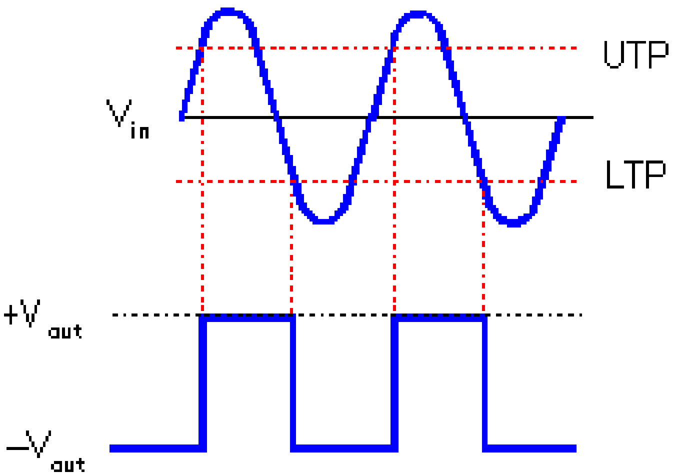
$$V_{OUT} = \pm V_{SAT}$$

∴ Threshold input voltage

for upper trigger point (UTP)

and lower trigger point (LTP)

$$V_{IN} = \pm V_{SAT} \frac{R_1}{R_1 + R_2}$$

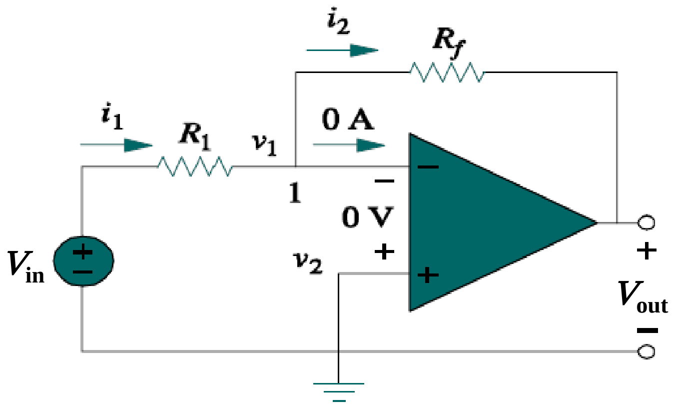


Problems and Solutions

Question 1

(a) Derive an expression for (V_{out} / V_{in}) for the inverting op-amp amplifier in terms of R_1 and R_f .
(b) Inverting op-amp amplifier with 1kHz sine wave input of 2 volts peak-to-peak, $R_1 = R_f = 10k\Omega$.
1. Calculate V_{out}. 2. Draw the input and output waveforms (V_{in} and V_{out}).

Solution:



(a) Since the non-inverting terminal is grounded:

$$v_1 = v_2 = 0$$

Also for the op-amp, we have: $i_- = i_+ = 0$

Using KCL at the node 1 we get:

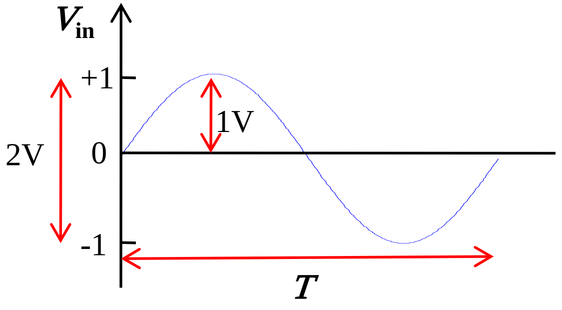
$$i_1 = i_2 \Rightarrow \frac{V_{in} - 0}{R_1} = \frac{0 - V_{out}}{R_f} \Rightarrow \boxed{\therefore \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_1}}$$

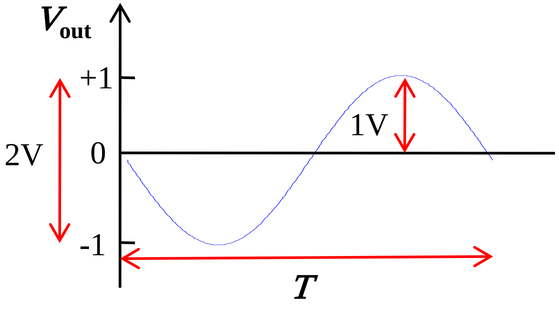
(b)

$$V_{out} = -\frac{R_f}{R_1} V_{in}$$

$$V_{out} = -\frac{10 \times 10^3}{10 \times 10^3} \times 2$$

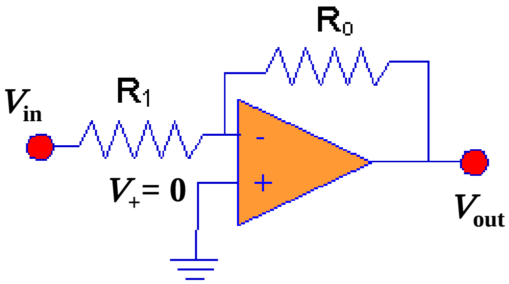
$$V_{out} = -2 \ volt$$





$$T = \frac{1}{f} = \frac{1}{1 \times 10^3} = 1m \sec$$

Question 2 For the following op-amp circuit with gain of A = -10, find the output voltage V_{out} if the input voltage V_{in} = 0.24 volt .



Solution:

$$V_{out} = -\frac{R_0}{R_1} V_{in} = -10 \times 0.24 = -2.4 \; volt$$

Question 3 Inverting amplifier with R_f = 4700Ω , find the value of R_1 that produce gain of A = -5.

Solution:

The gain of inverting amplifier is: $$A = -\frac{R_f}{R_1} \Rightarrow R_1 = -\frac{R_f}{A} = -\frac{4700}{-5} = 940\Omega$$

Question 4 An op-amp has a differential gain G_d = 250,000. If the output voltage V_{out} = 3.75 volt, find the difference between input voltages V_d.

Solution:

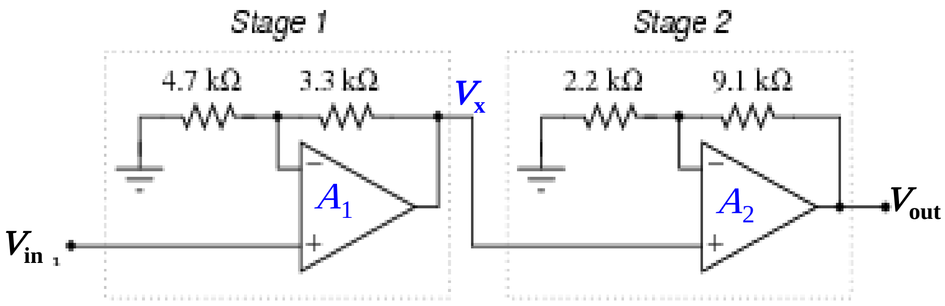
$$V_{out} = G_d V_{in}$$

$$V_{in} = \frac{V_{out}}{G_d} = \frac{3.75}{250,000} = 15 \times 10^{-6} \; volt = 15 \mu V$$

Question 5 Calculate the voltage gain for each stage (A_1 and A_2) of the given amplifier circuit and then find the overall voltage gain A.

Solution:

The gain of any single stage non-inverting amplifier is:



$$A = \frac{V_{out}}{V_{in}} = \left(1 + \frac{R_f}{R_1}\right)$$

The gain of stage 1 is:

$$A_1 = \frac{V_x}{V_{in}} = \left(1 + \frac{3300}{4700}\right) = 1.702$$

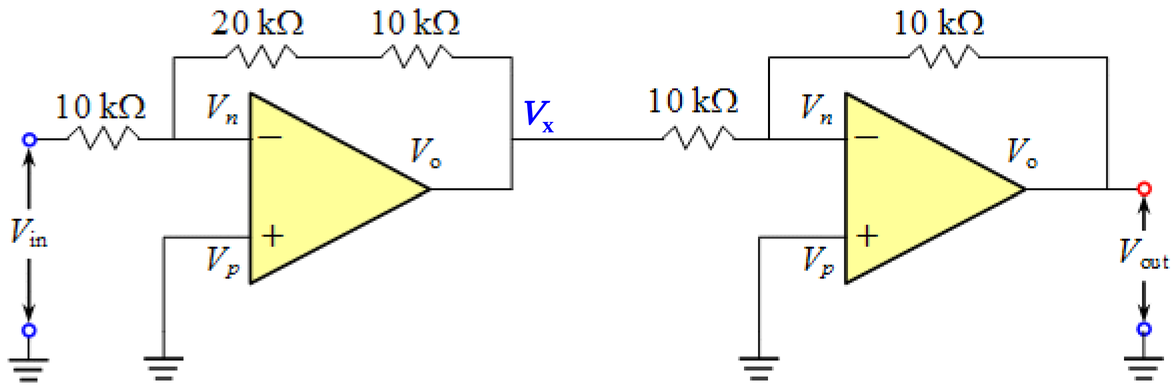
The gain of stage 2 is:

$$A_2 = \frac{V_{out}}{V_x} = \left(1 + \frac{9100}{2200}\right) = 5.136$$

Thus, the overall gain is:

$$A = \frac{V_{out}}{V_{in}} = \frac{V_x}{V_{in}} \times \frac{V_{out}}{V_x} = A_1 \times A_2 = 1.702 \times 5.136 = 8.74$$

Question 6 For the given circuit, calculate the output voltage V_{out} if the input voltage $V_{in} = 1.5$ volt .



Solution:

The gain of any single stage inverting amplifier is:

$$A = -\frac{R_f}{R_1}$$

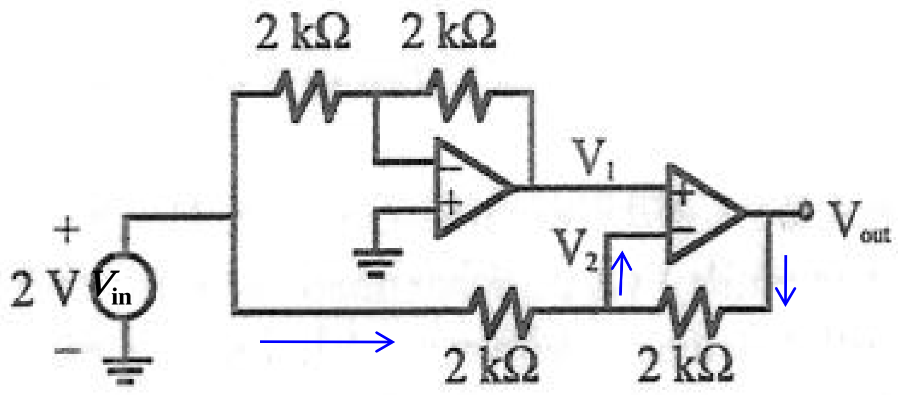
When $V_{in} = 1.5$ **V**,The output voltage of first stage is:

$$V_x = \left(-\frac{20\times10^3 + 10\times10^3}{10\times10^3} \right) \times V_{in} = (-3)\times1.5 = -4.5\text{Volt}$$

Therefore, the output voltage V_{out} at second stage is:

$$V_{out} = \left(-\frac{10\times10^3}{10\times10^3} \right) \times V_x = (-1)\times(-4.5) = 4.5\text{Volt}$$

Question 7 For the given circuit, determine V_1 and V_2, and the output voltage V_{out}.



Solution:

The gain of any single stage inverting amplifier is:

$$A = -\frac{R_f}{R_1}$$

$$\therefore\ V_1 = \left(-\frac{2\times10^3}{2\times10^3}\right)\times V_{in} = (-1)\times 2 = -2\text{Volt}$$

For ideal op-amp we have: $V_1 = V_2 = -2\text{Volt}$

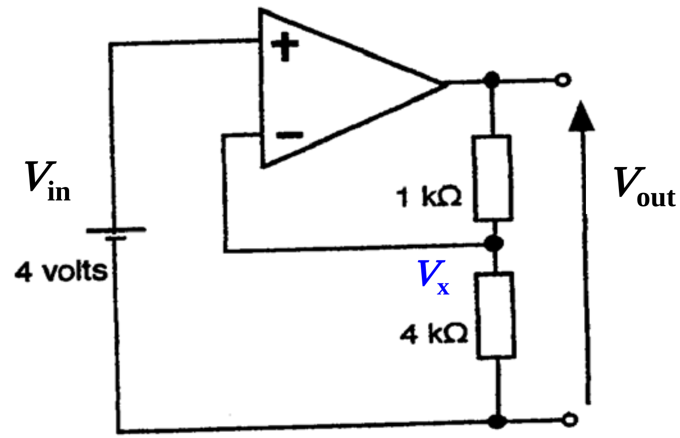
Also for the op-amp, we have: $i_+ = i_- = 0$

Using KCL at node V_2, we get:

$$\frac{V_{in} - V_2}{2\text{k}\Omega} + \frac{V_{out} - V_2}{2\text{k}\Omega} = i_- = 0$$

$$\therefore\ V_{out} = V_2 + V_2 - V_{in} = -2 - 2 - (2) = -6\text{Volt}$$

Question 8 For the given non-inverting op-amp, find the output voltage V_{out} .



Solution: $i_+ = i_- = 0$

$$v_x = v_- = v_+ = V_{in} = 4\text{Volt}$$

Using the voltage divider equation at node "V_x":

$$V_x = \left(\frac{4\text{k}\Omega}{4\text{k}\Omega + 1\text{k}\Omega}\right) V_{out}$$

$$\therefore \quad V_{out} = \frac{5}{4} \times V_x = \frac{5}{4} \times 4 = 5\text{Volt}$$

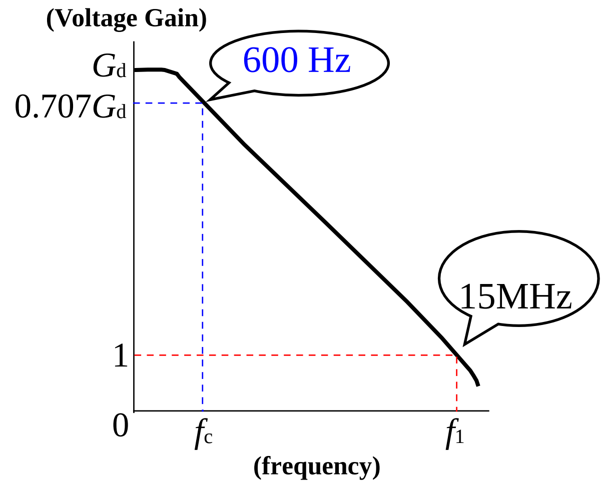
Question 9 Determine the cutoff frequency f_c of an op-amp having a unit gain frequency f_1 = 15MHz and voltage differential gain G_d = 25V/mV. Draw the frequency response.

Solution:

$$G_d = 25\text{V/mV} = \frac{25\text{V}}{10^{-3}\text{V}} = 25 \times 10^3$$

$$f_1 = G_d f_c$$

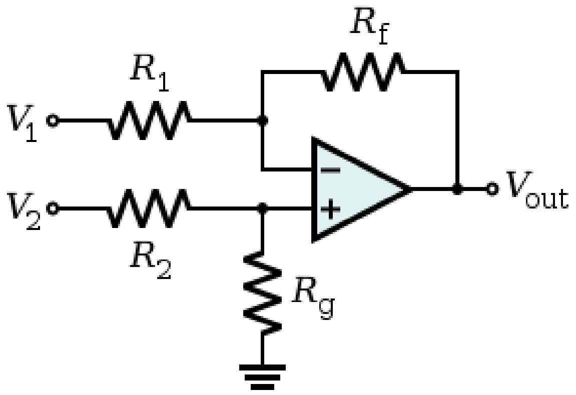
$$\therefore \quad f_c = \frac{f_1}{G_d} = \frac{15 \times 10^6}{25 \times 10^3} = 600\text{Hz}$$



Question 10 Design op-amp subtractor circuit to satisfy the following equation: $V_{out} = 2(V_2 - V_1)$ Assume the feedback resistance $R_f = 10\text{k}\Omega$.

Solution:

The circuit diagram of op-amp subtractor is shown as:



For good design $R_2 = R_1$ and $R_f = R_g$.

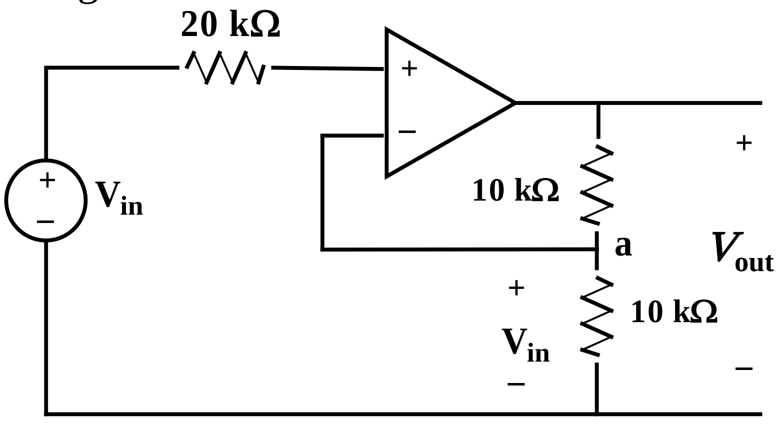
Then, the output voltage V_{out} is given as: $V_{out} = \frac{R_f}{R_1}(V_2 - V_1)$

And we have from the given question $V_{out} = 2(V_2 - V_1)$

Then by similarity of both equations, we get $\frac{R_f}{R_1} = 2 \Rightarrow \therefore R_1 = \frac{R_f}{2} = \frac{10\text{k}\Omega}{2} = 5\text{k}\Omega$

Question 11 Calculate the voltage gain A for the voltage follower circuit.

Solution:



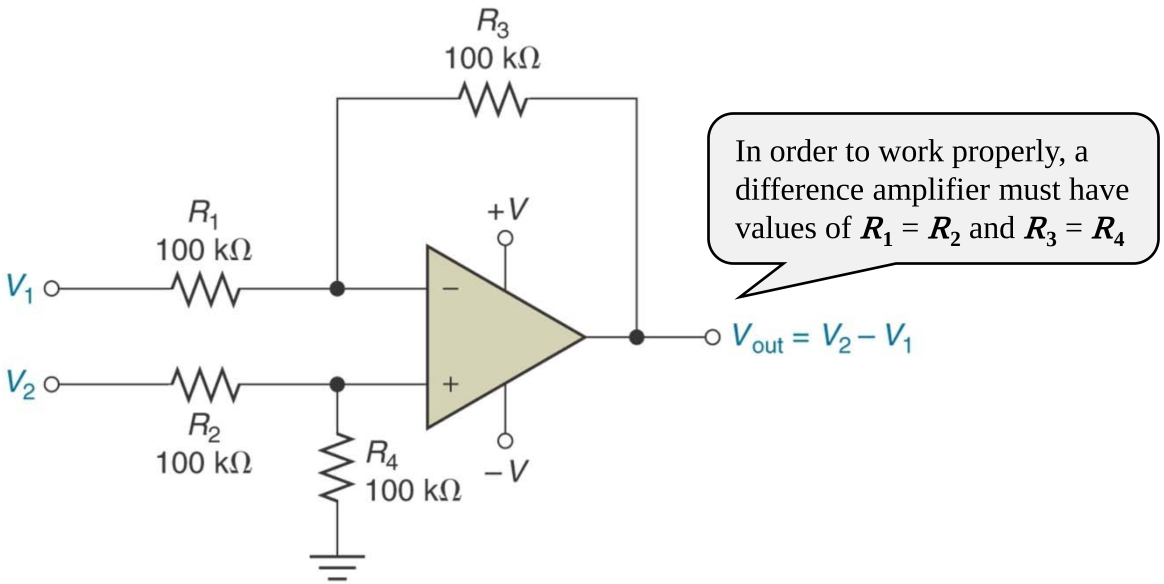
$i_+ = i_- = 0$

$v_a = v_- = v_+ = V_{in}$

Using the voltage divider equation at node “a”:

$$V_{in} = \left(\frac{10\text{k}\Omega}{10\text{k}\Omega + 10\text{k}\Omega}\right) V_{out} \Rightarrow \therefore \quad A = \frac{V_{out}}{V_{in}} = 2$$

Question 12 For the given difference amplifier (subtractor), write the equation of output voltage V_{out} .



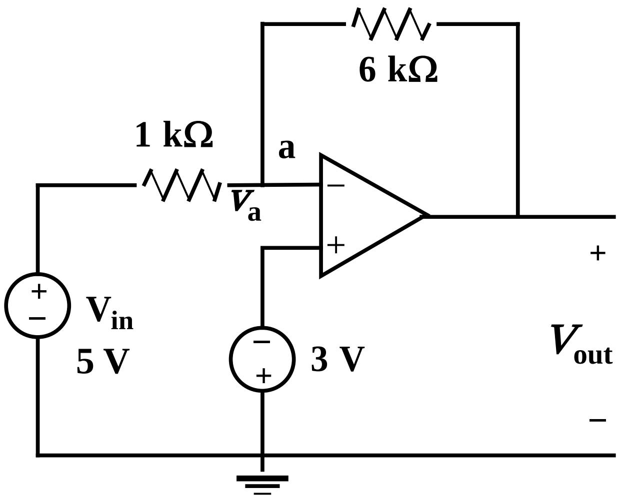
Solution:

$$V_{out} = \frac{R_3}{R_1}(V_2 - V_1)$$

$$V_{out} = \frac{100k\Omega}{100k\Omega}(V_2 - V_1)$$

$$\therefore V_{out} = V_2 - V_1$$

Question 13 Find V_{out} for the given op-amp circuit.



Solution: $i_+ = i_- = 0$

Since the non-inverting terminal is connected to +3 volts, we get

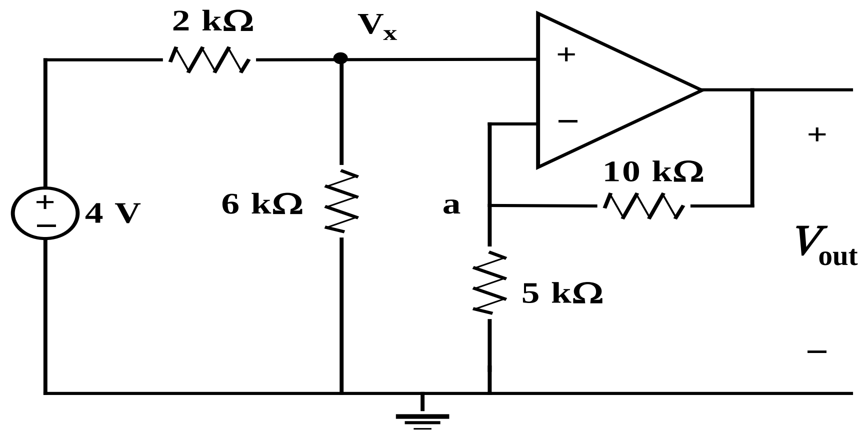
$$v_a = v_- = v_+ = -3 \text{ Volt}$$

Using KCL at the non-inverting node "a":

$$\frac{V_{in} - v_a}{1k\Omega} = \frac{v_a - V_{out}}{6k\Omega} + i_-$$

$$\therefore V_{out} = -51\text{Volt}$$

Question 14 For the given non-inverting op-amp, find the output voltage V_{out} .



Solution: $i_+ = i_- = 0$

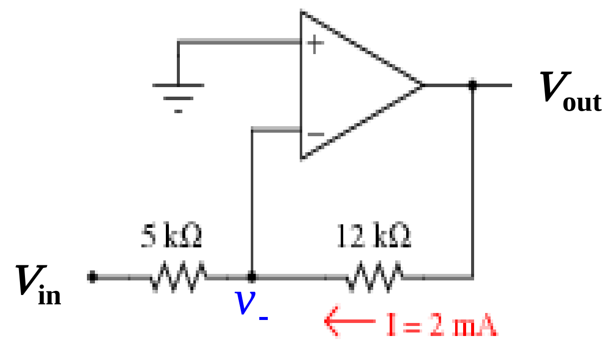
$$v_a = v_- = v_+ = V_x$$

$$V_x = \left(\frac{6k\Omega}{6k\Omega + 2k\Omega}\right) \times 4 = 3\text{Volt}$$

Using the voltage divider equation at node "a":

$$V_a = \left(\frac{5k\Omega}{5k\Omega + 10k\Omega}\right) \times V_{out} \Rightarrow V_{out} = 3 \times V_a = 9\text{Volt}$$

Question 15 Determine both of input voltage V_{in} and output voltage V_{out} for given circuit.



Solution: $i_+ = i_- = 0$

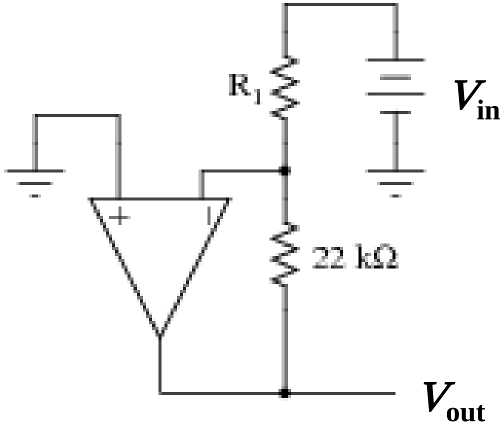
$$v_- = v_+ = 0 \quad \Rightarrow V_{out} = 2mA \times 12k\Omega = 24\text{Volt}$$

For the inverting op-amp we have: $V_{out} = -\frac{R_f}{R_1} V_{in}$

$$\therefore \; V_{in} = -\frac{R_1}{R_f} V_{out} = -\frac{5k\Omega}{12k\Omega} \times 24 = -10\text{Volt}$$

Question 16

Calculate R_1 to produce a voltage gain of $A = 15$ in the given op-amp circuit.



Solution:

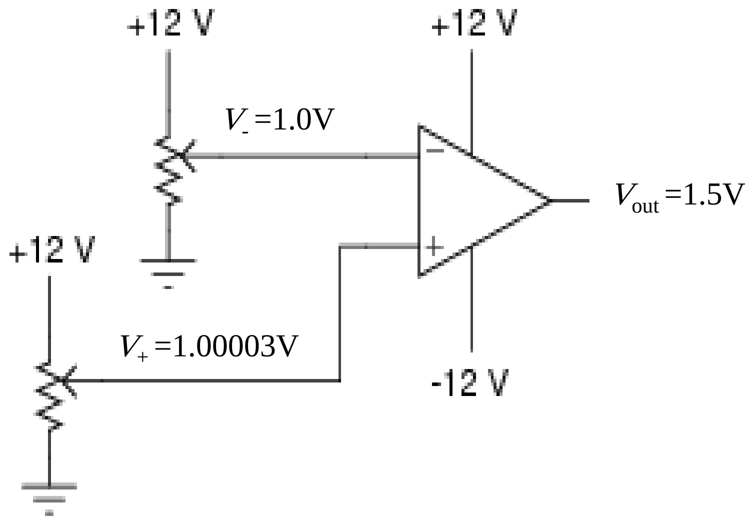
The voltage gain of inverting op-amp is:

$$A = \frac{R_f}{R_1}$$

$$\Rightarrow R_1 = \frac{R_f}{A} = \frac{22\text{k}\Omega}{15} = 1.46\text{k}\Omega$$

Question 17

For the given op-amp circuit with two different input voltages. Determine the differential voltage gain G_d of this op-amp.



Solution:

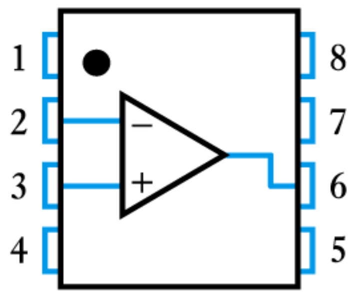
$$V_{out} = G_d V_d$$

$$V_d = V_+ - V_- = 1.00003 - 1 = 30\times10^{-6}\,\text{Volt}$$

$$\Rightarrow G_d = \frac{V_{out}}{V_d} = \frac{1.5}{30\times10^{-6}} = 50000$$

Question 18 **Choose the correct alternative for the following multiple choice questions.**

(1) What signal corresponds to pin 3 of this operational amplifier?



A- The non-inverting output. B- The positive supply voltage.

C- The non-inverting input. D- The inverting input

(2) What characteristics would characterize an ideal operational amplifier?

A- An infinite voltage gain, an infinite input resistance and an infinite output resistance.

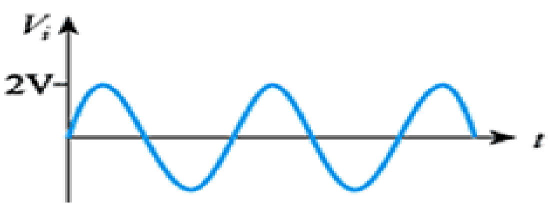
B- An infinite voltage gain, zero input resistance and an infinite output resistance.

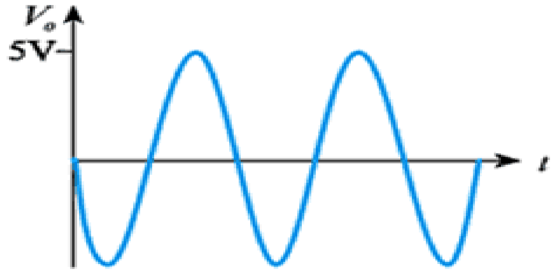
C-. An infinite voltage gain, zero input resistance and zero output resistance.

D- .An infinite voltage gain, an infinite input resistance and zero output resistance

(3) The graphs show input and output waveforms of an op-amp.
What is the gain of this circuit?

A) - 0.4 B) -2.5 C) 2.5 D) 0. 4

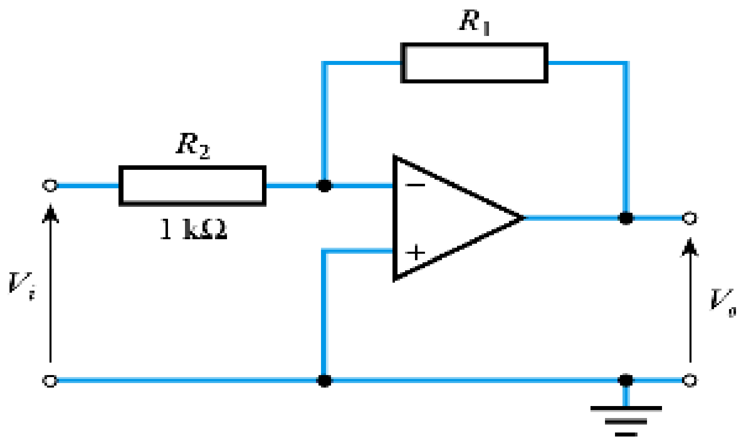




(4) A differential amplifier amplifies the ---------- between two input signals.

A- Addition B- subtraction C- multiplication

(5) In the given circuit, what value of R_1 is required to give a voltage gain of -50 ?



A) 49 kΩ B) 50 kΩ C) -50 kΩ D) -49 kΩ

(6) Frequency response of the differentiator is same as that of …………………

a) high pass filter b) low pass filter c) band pass filter

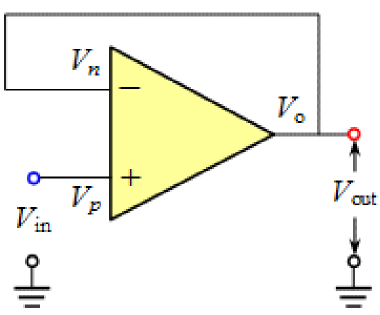
(7) What is the voltage gain of the unity follower?

a) 0 b) 1 c) –1 d) infinity

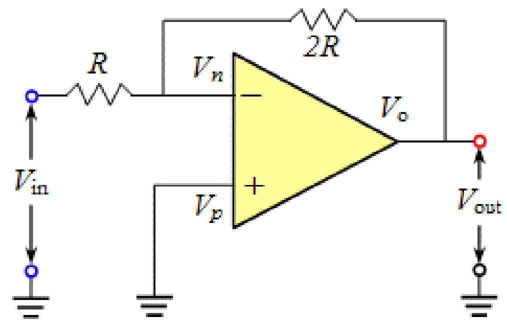
(8) What is the scale multiplier (factor) of a basic integrator?

a) R/C b) C/R c) –RC d) –1/RC

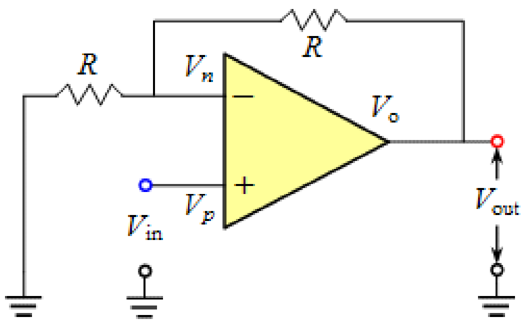
(9) Choose the circuit below that would take a DC input voltage V_{in} = 1 V and produce an output voltage V_{out} = 2 V.



(a)



(b)



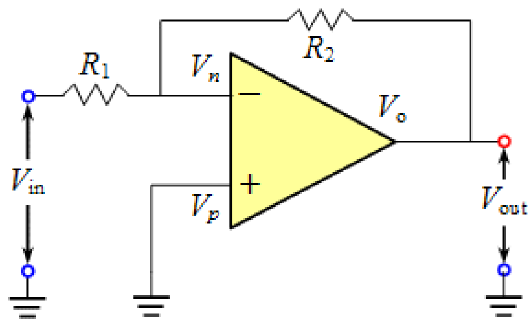
(c)

(10) If R_1 = 10 kΩ, and R_2 = 10 k Ω, this circuit would be…………….

A) buffer B) inverting summer C) inverter

D) inverting amplifier E) noninverting amplifier

F) low-pass filter G) high-pass filter



(11) If R_1 = 10 kΩ, and R_2 = 20 k Ω, this circuit would be…………….

A) buffer B) inverting summer C) inverter

D) inverting amplifier E) noninverting amplifier