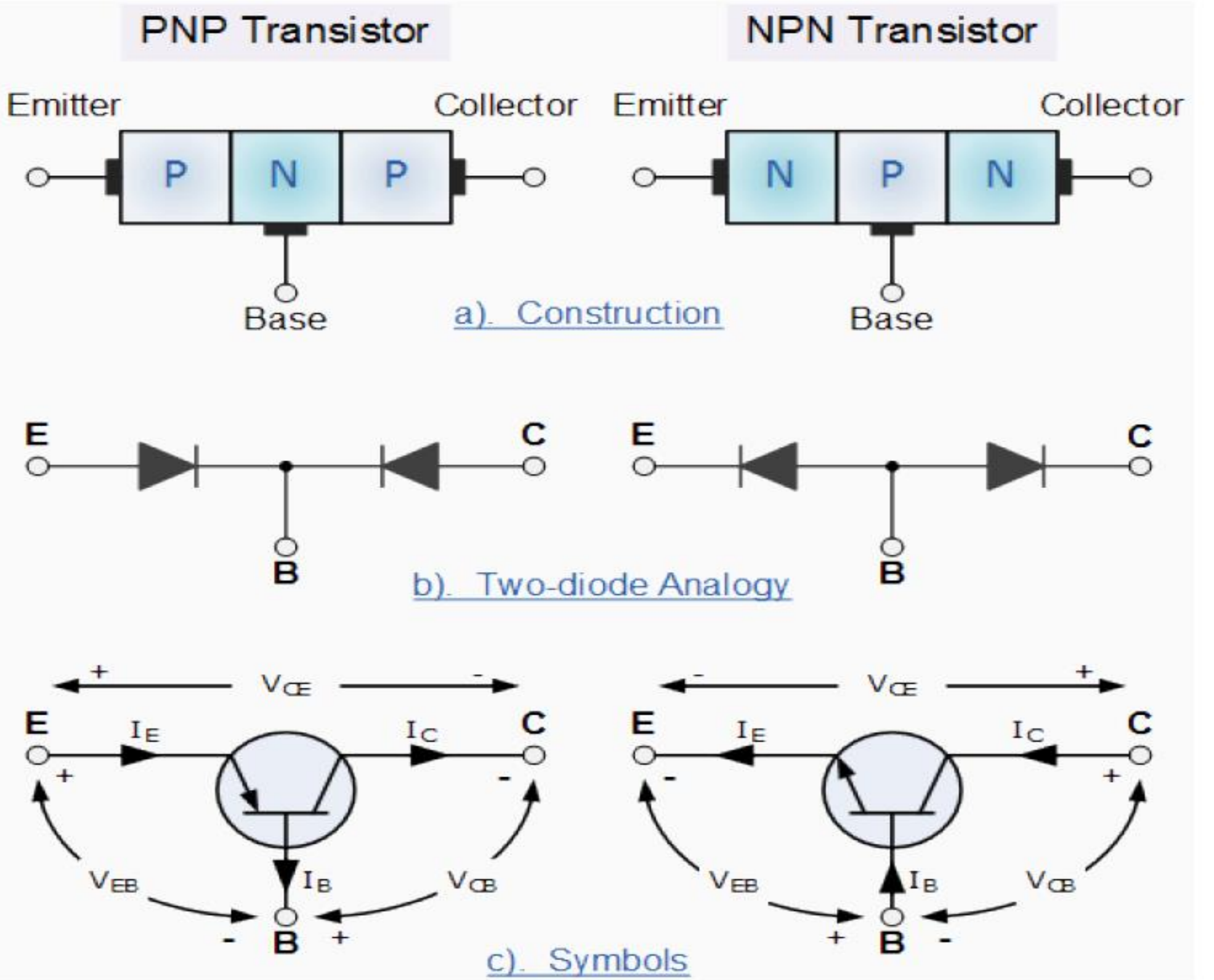
Embedded Hardware Design and Development

Unit 2-3

Dr. Dhanashri H. Gawali

Analog Circuit Design:

Transistors



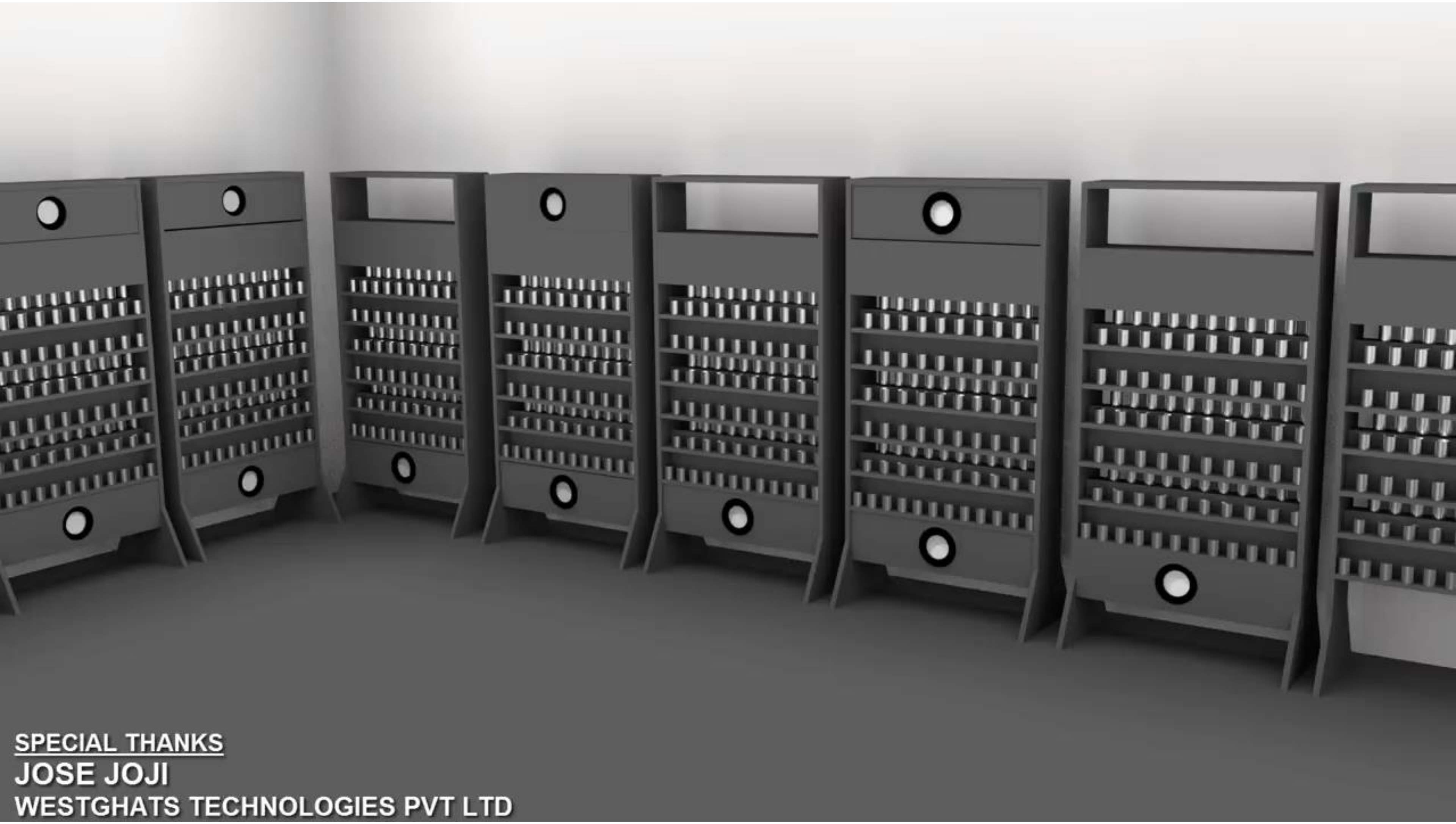
Transistor --
Transfer Varistor

Two types –
NPN and PNP

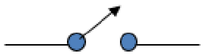
Three terminals --
Emitter (E),
Base (B),
Collector (C)

It is current-controlled device

Transistors : BJT



Transistor biasing

Sr. No.	Region of operation	Base emitter junction	Collector base junction	application
1	Cutoff region	Reverse biased	Reverse biased	
2	Saturation region	Forward biased	Forward biased	
3	Active region	Forward biased	Reverse biased	Amplifier

Bipolar Transistor Configurations

- 1. Common Base Configuration - has Voltage Gain but no Current Gain.
- 2. Common Emitter Configuration - has both Current and Voltage Gain.
- 3. Common Collector Configuration - has Current Gain but no Voltage Gain.

Characteristics of a transistor in CB configuration

- **The characteristics of a transistor help us to understand its behavior.**
- **The transistor characteristics are of three types :**

Characteristics of a transistor in CB configuration

- **The characteristics of a transistor help us to understand its behavior.**
- **The transistor characteristics are of three types :**

- **Input characteristics**

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- **The characteristics of a transistor help us to understand its behavior.**
- **The transistor characteristics are of three types :**

- **Input characteristics**

- **Output characteristics**

Characteristics of a transistor in CB configuration

- **The characteristics of a transistor help us to understand its behavior.**
- **The transistor characteristics are of three types :**

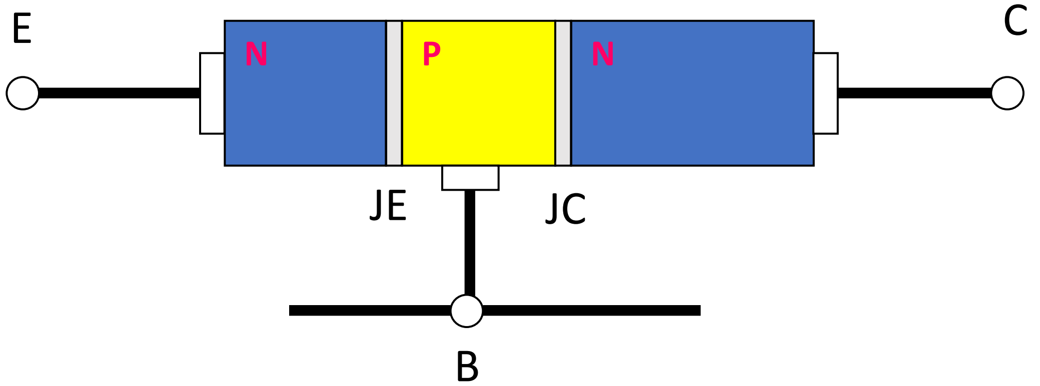
- **Input characteristics**

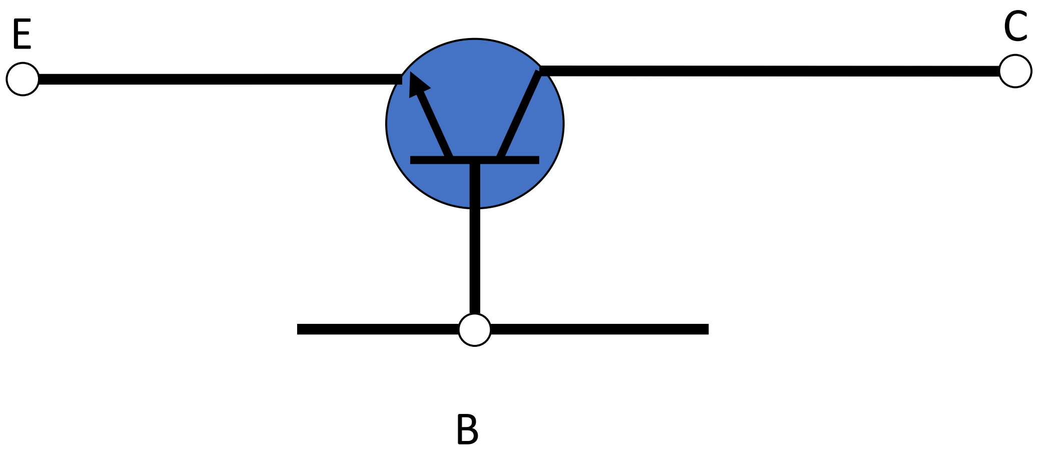
- **Output characteristics**

- **Transfer characteristics**

Characteristics of a transistor in CB configuration

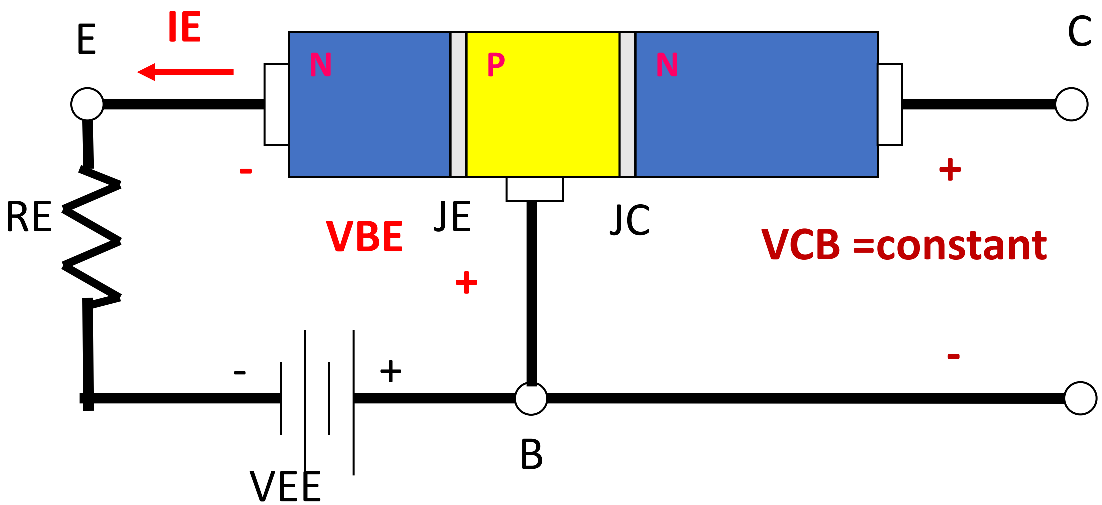
Input characteristics

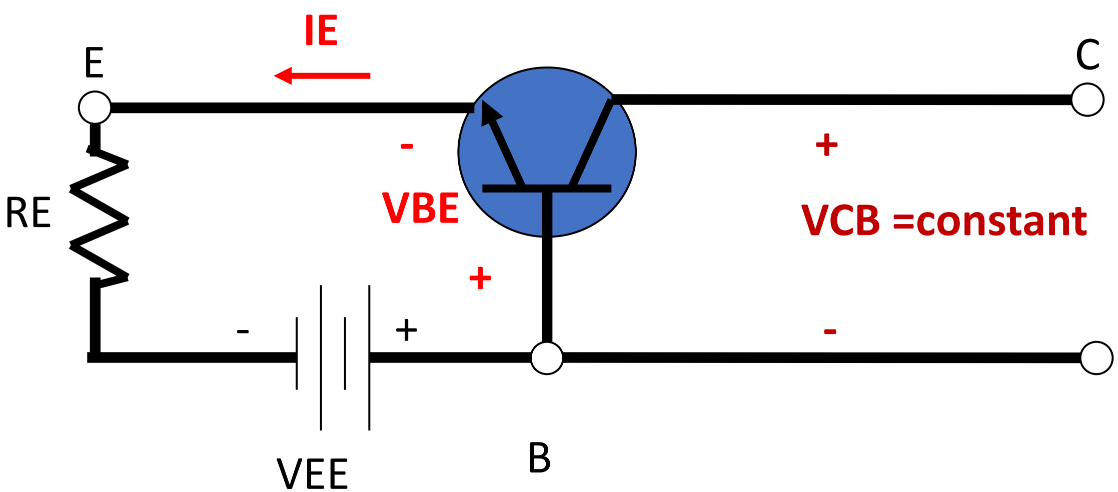




Characteristics of a transistor in CB configuration

Input characteristics

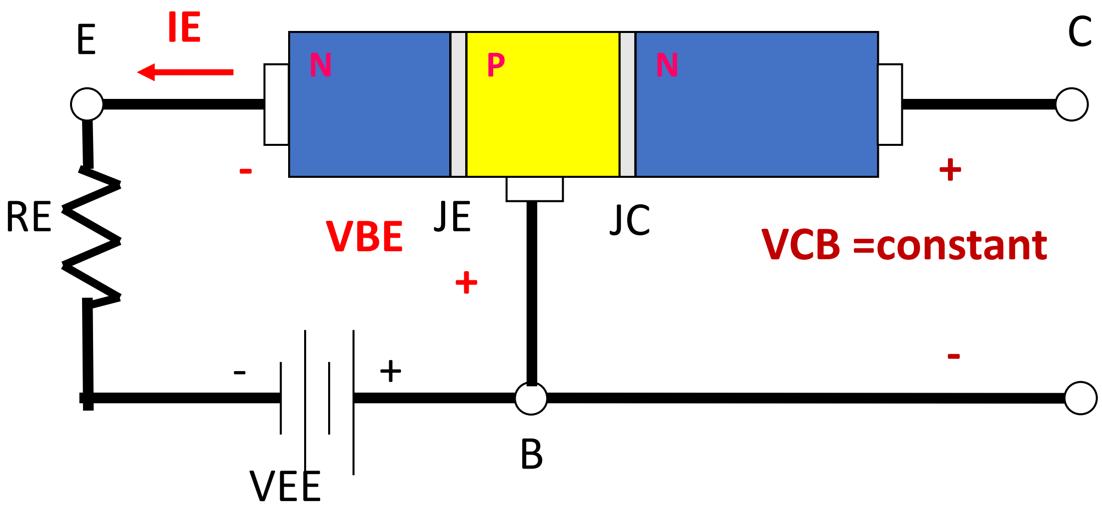


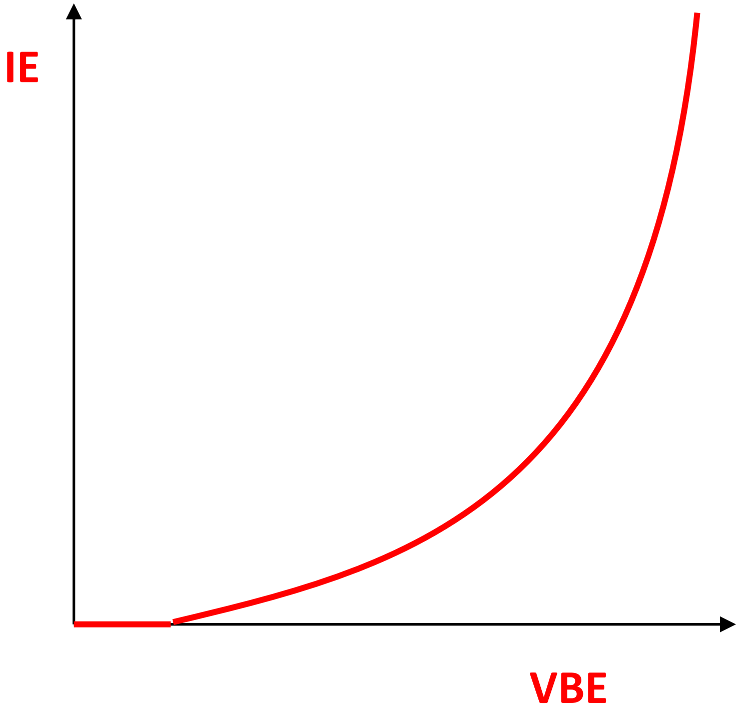


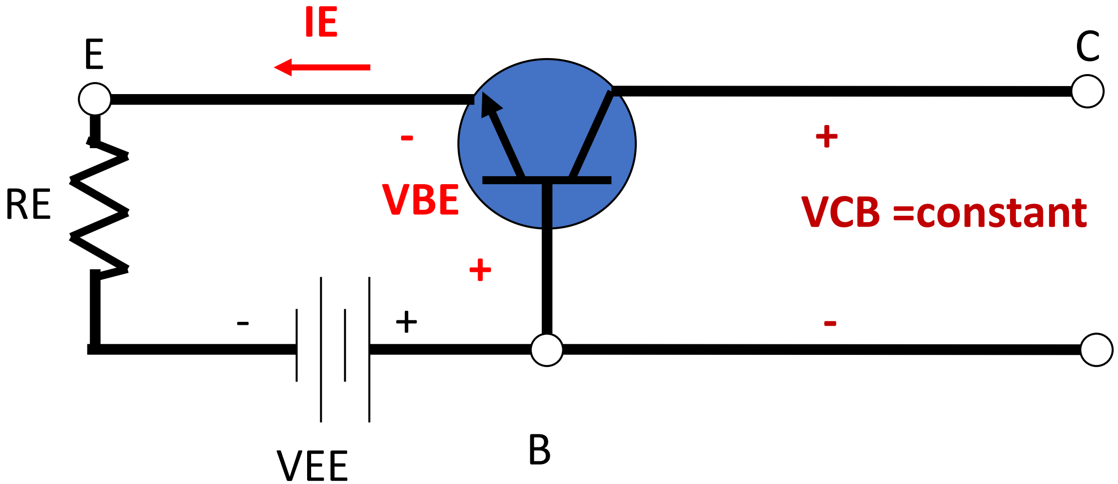
- Input characteristics is always A graph of input current versus Input voltage.
- For the CB configuration, input Current is **IE** and input voltage Is the emitter to base voltage **VBE**
- Input characteristics is plotted at a constant output voltage **VCB**

Characteristics of a transistor in CB configuration

Input characteristics

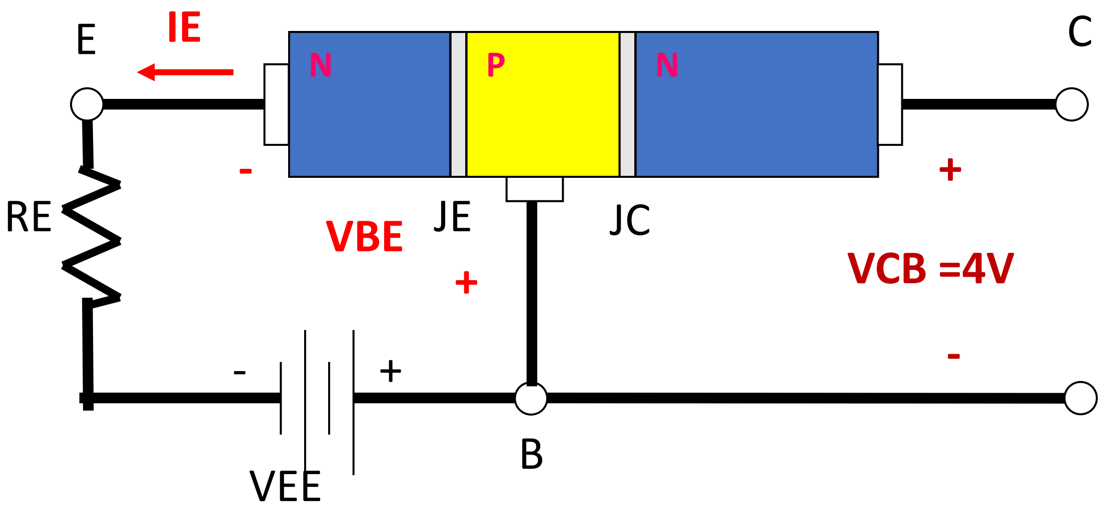


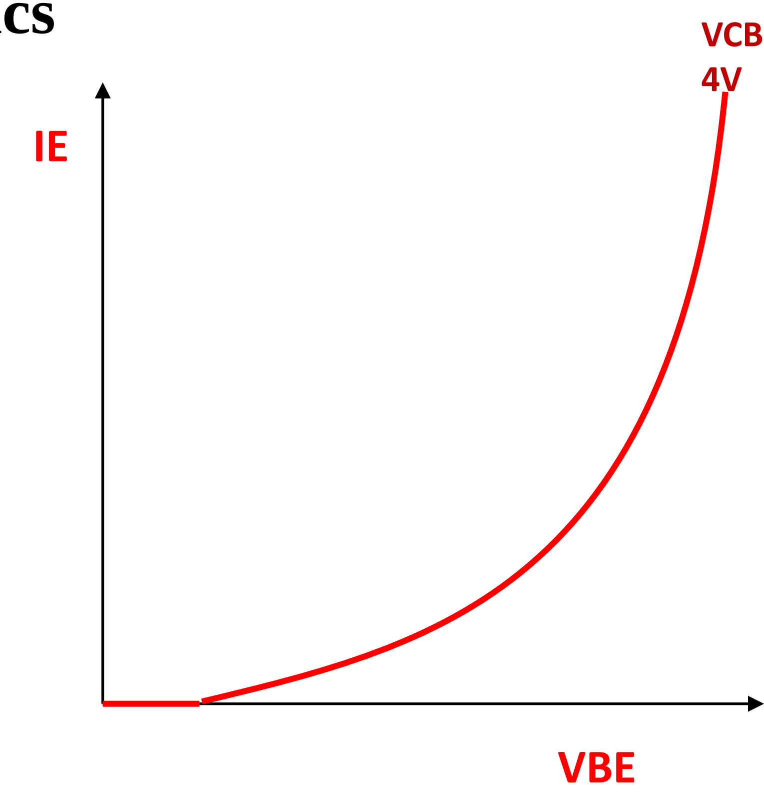


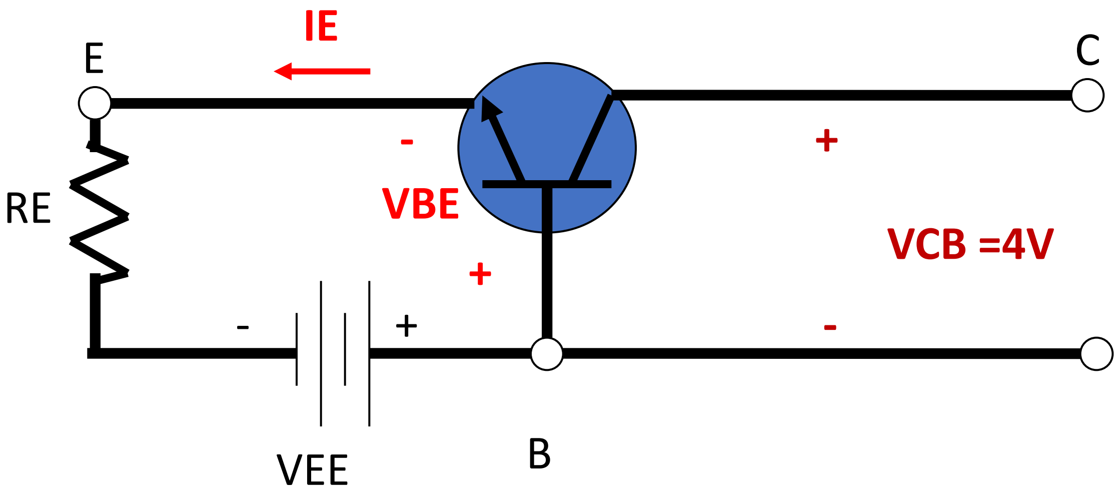


Characteristics of a transistor in CB configuration

Input characteristics

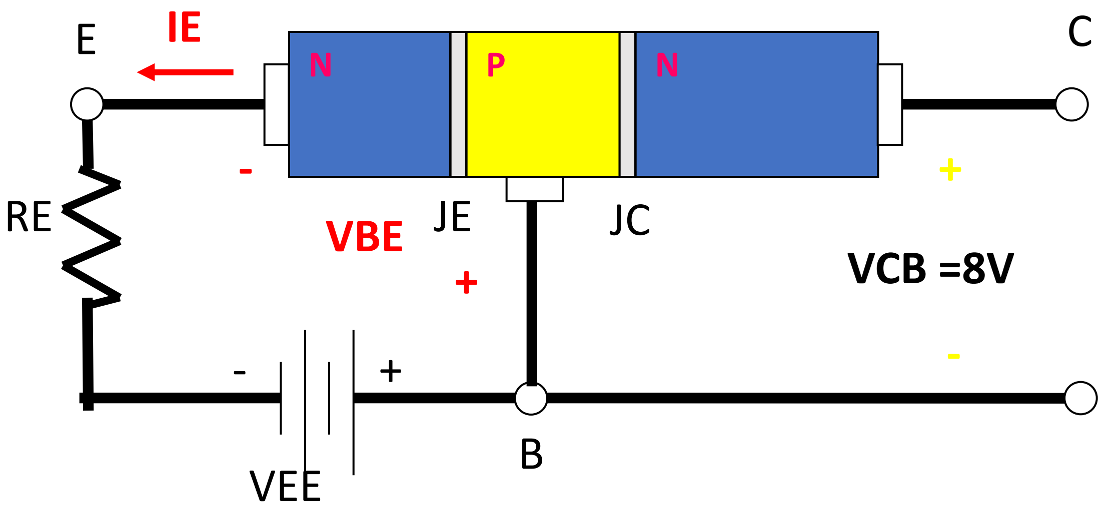


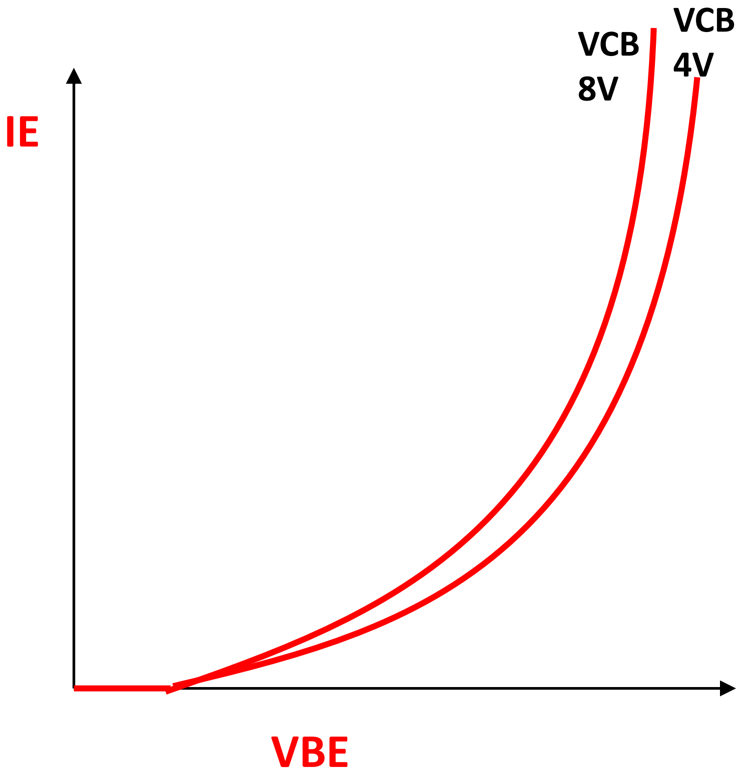


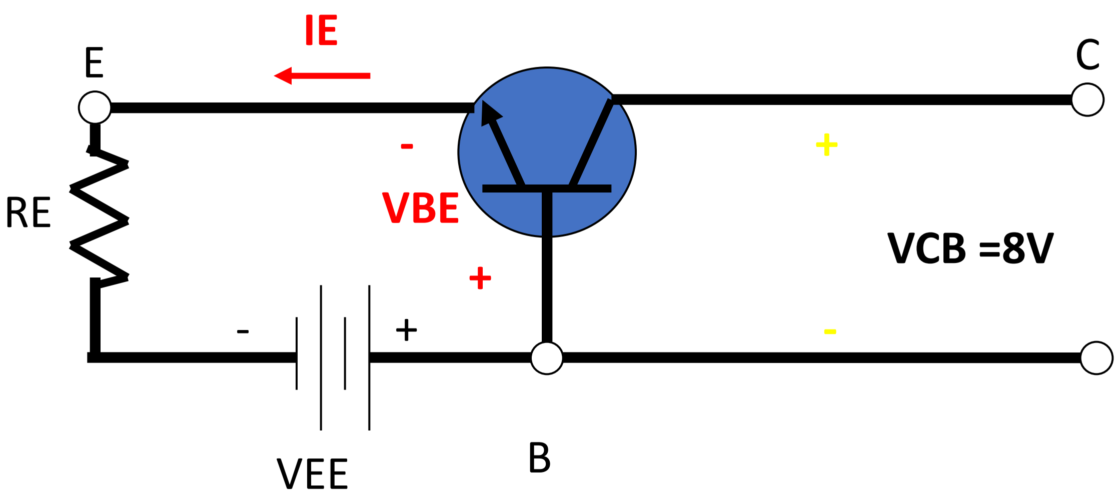


Characteristics of a transistor in CB configuration

Input characteristics

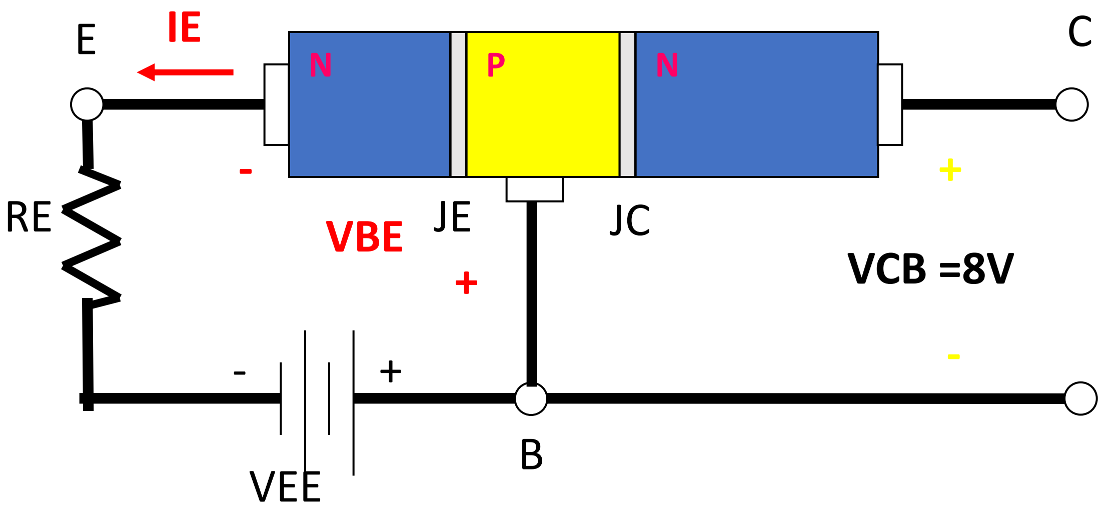


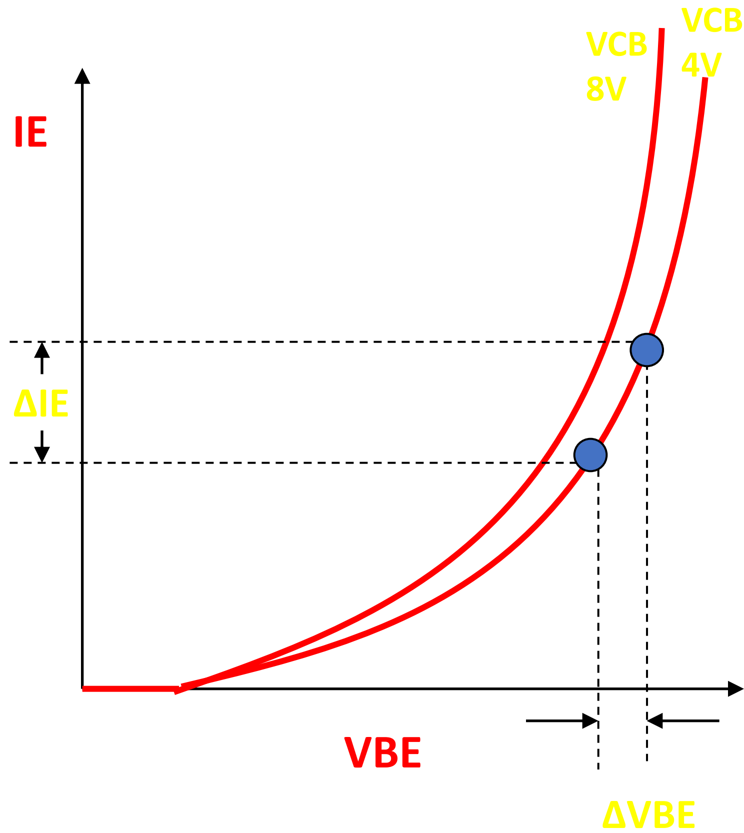


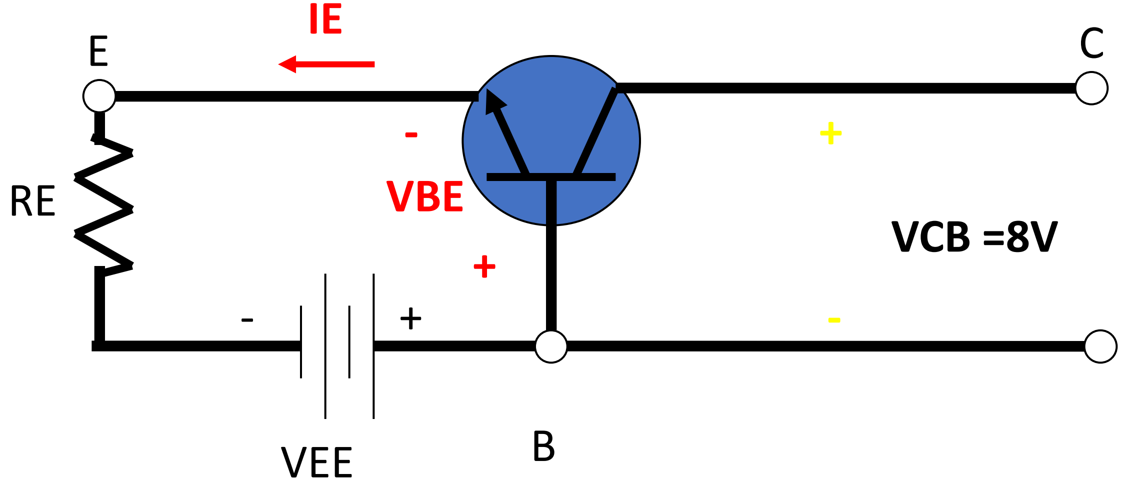


Characteristics of a transistor in CB configuration

Input characteristics







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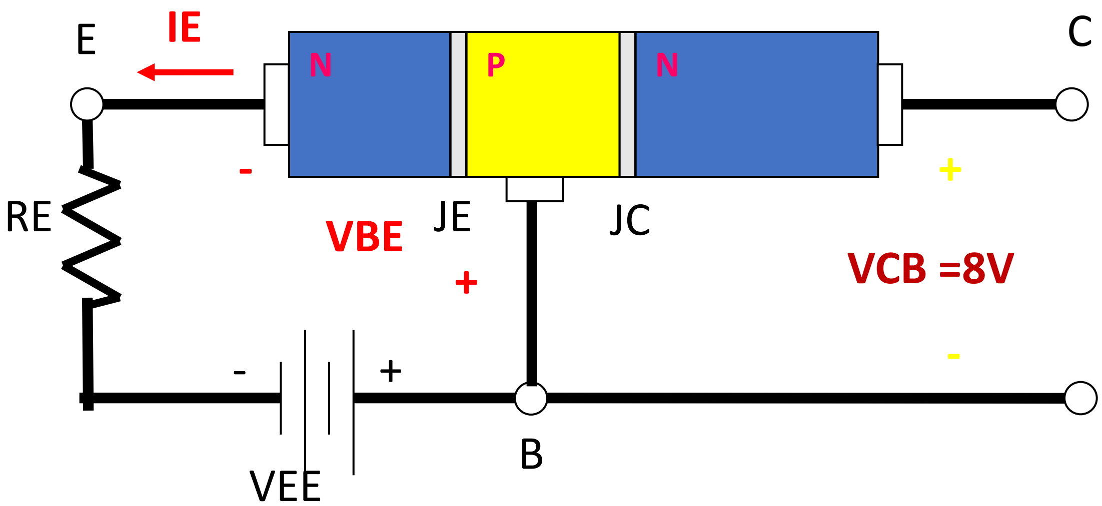
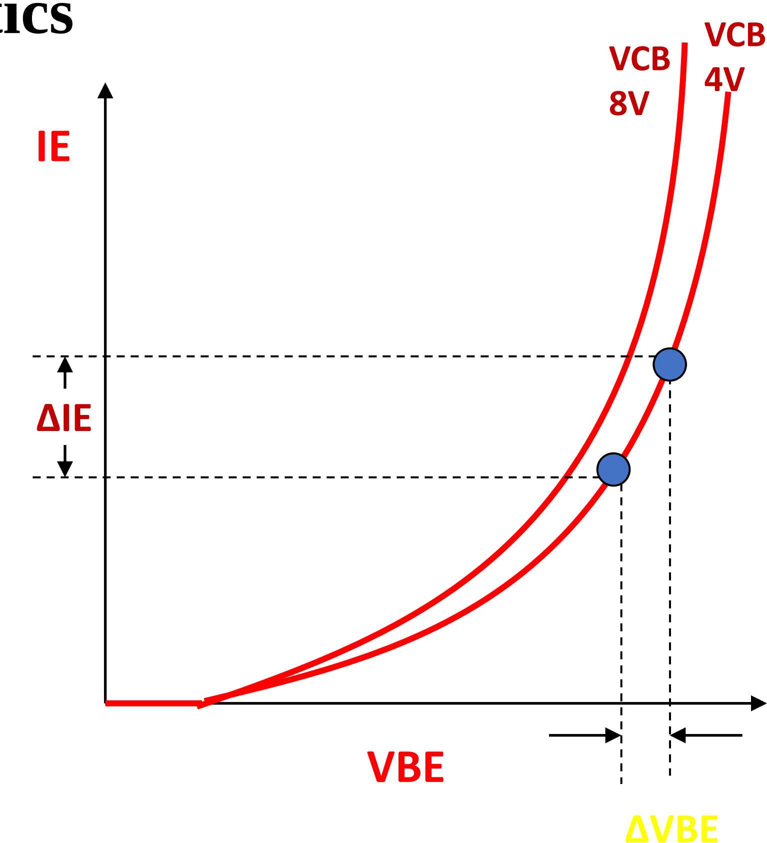
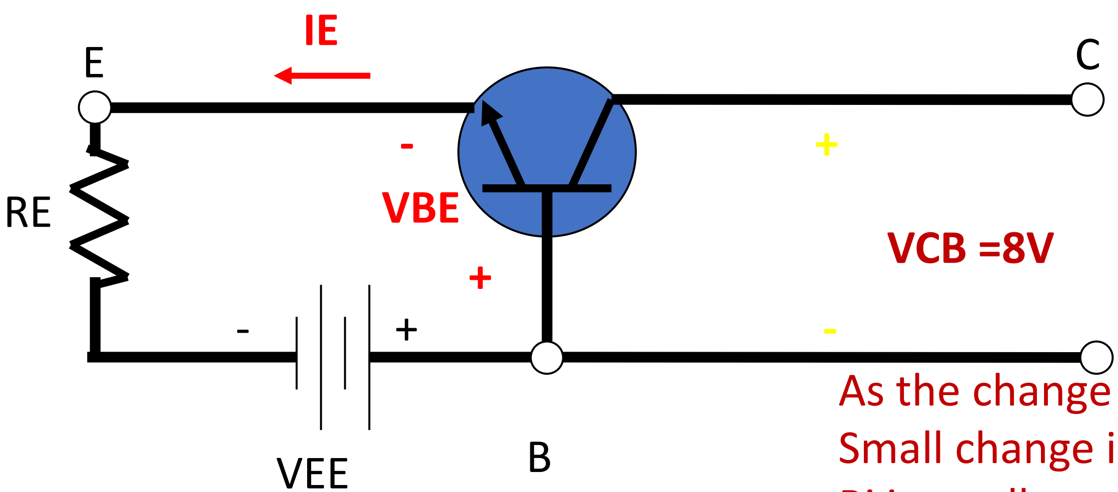






Input resistance

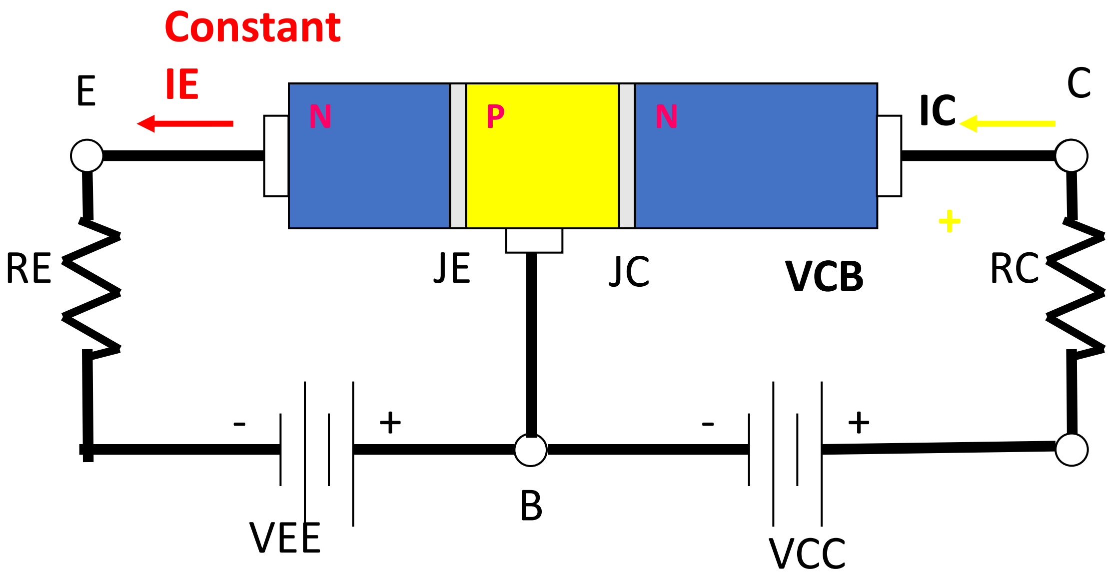
$R_i = \Delta V_{BE} / \Delta I_E$

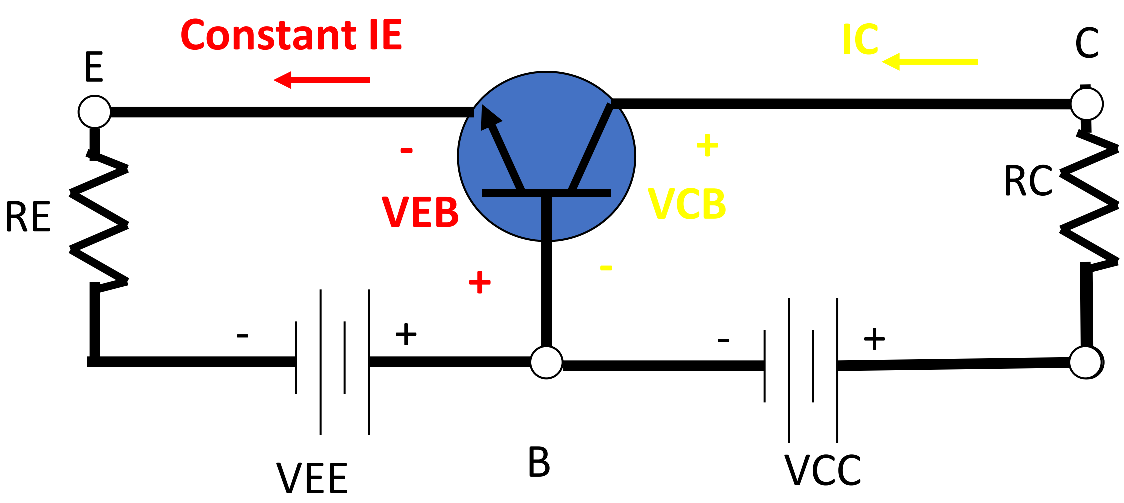
at constant VCB

As the change in emitter current is very large for a Small change in input voltage, the input resistance Ri is small

Characteristics of a transistor in CB configuration

Output characteristics





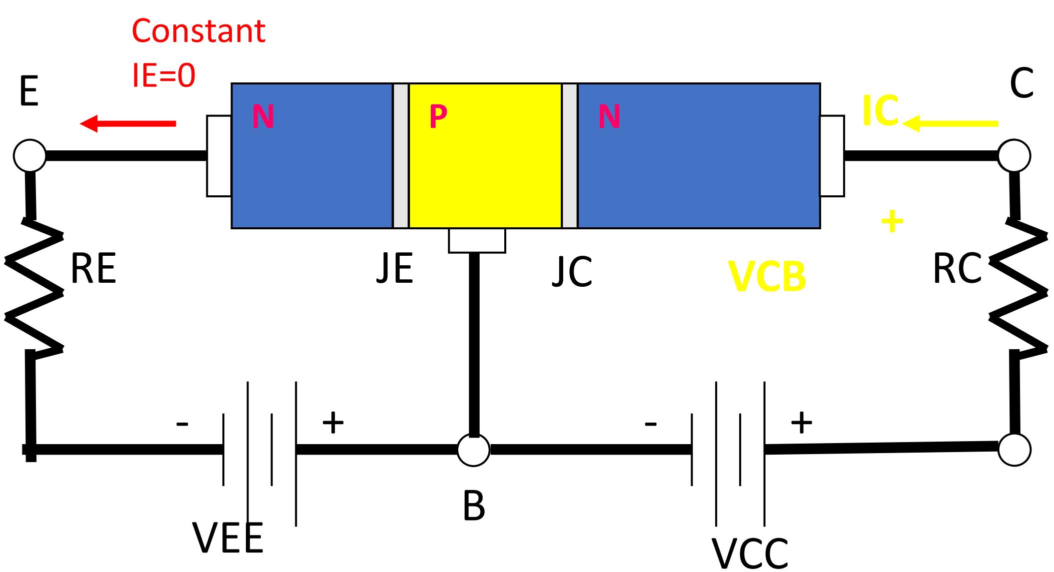
- output characteristics is always
A graph of output current versus
output voltage.

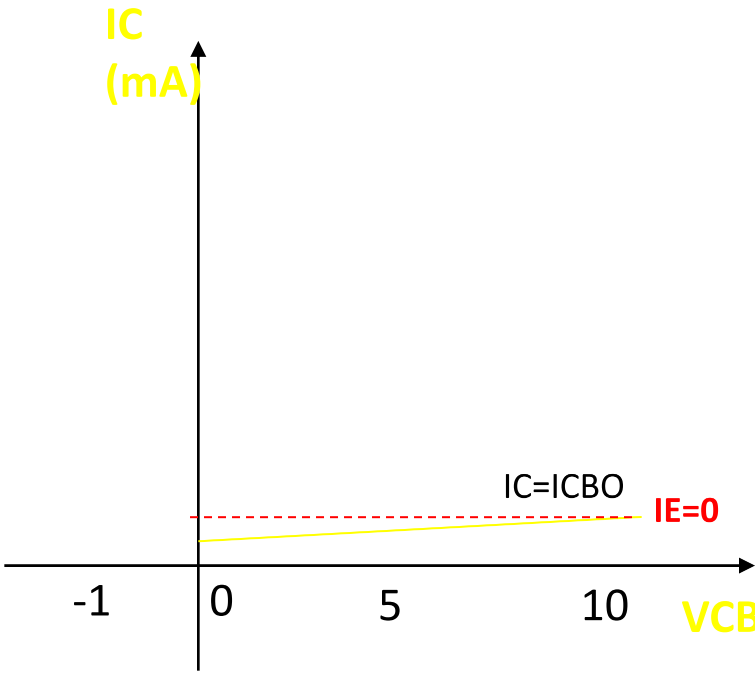
- For the CB configuration, output
Current is **IC** and output voltage
Is the collector to base voltage **VCB**

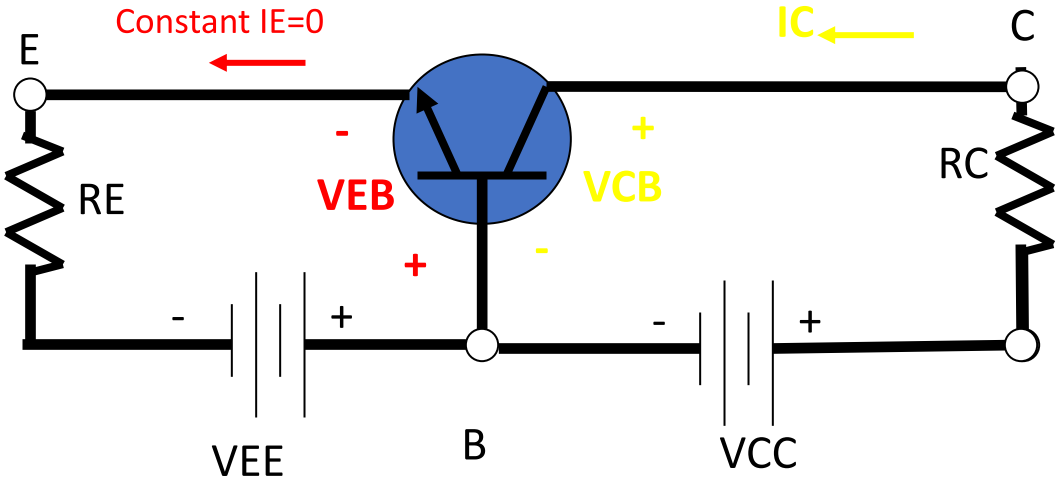
- Input characteristics is plotted at
a constant input current **IE**

Characteristics of a transistor in CB configuration

Output characteristics

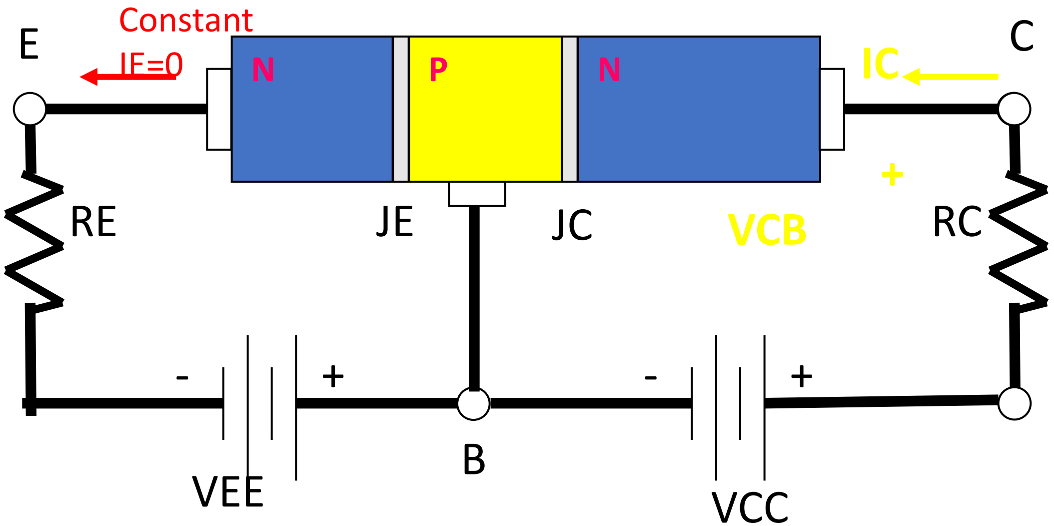


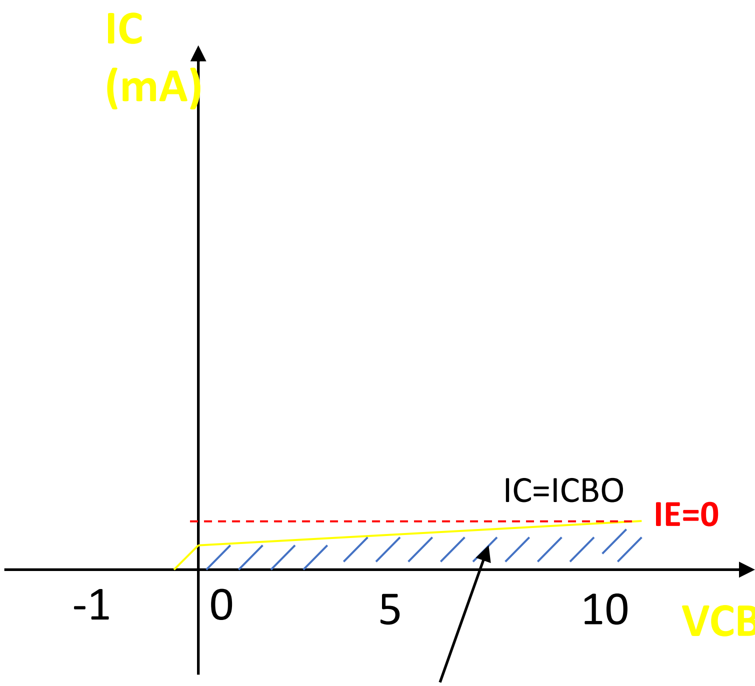




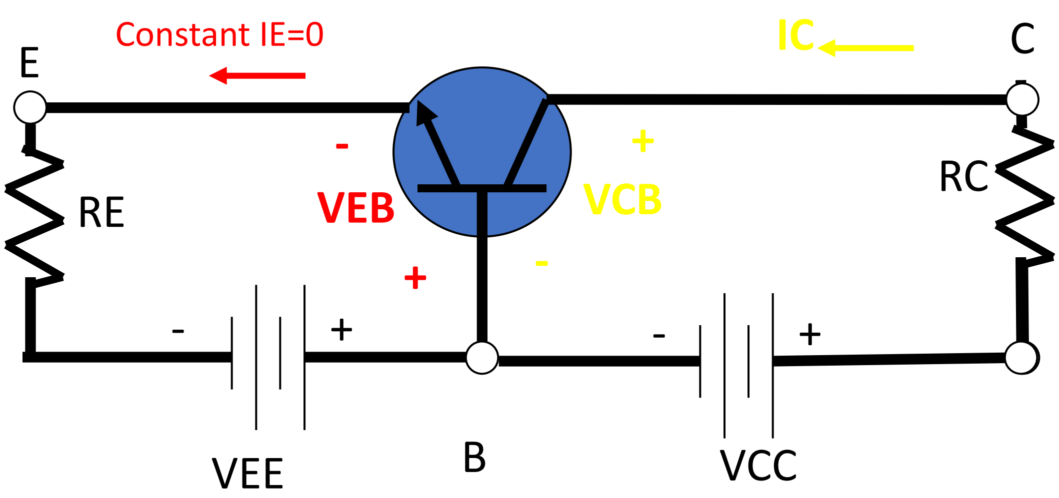
Characteristics of a transistor in CB configuration

Output characteristics





Cutoff region
Both the junction
Becomes reverse bias



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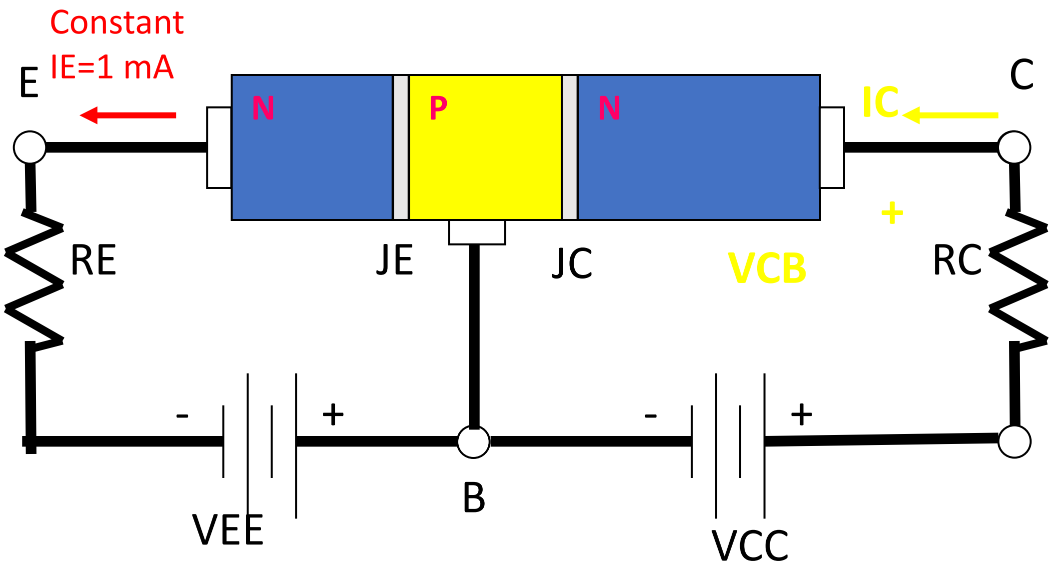

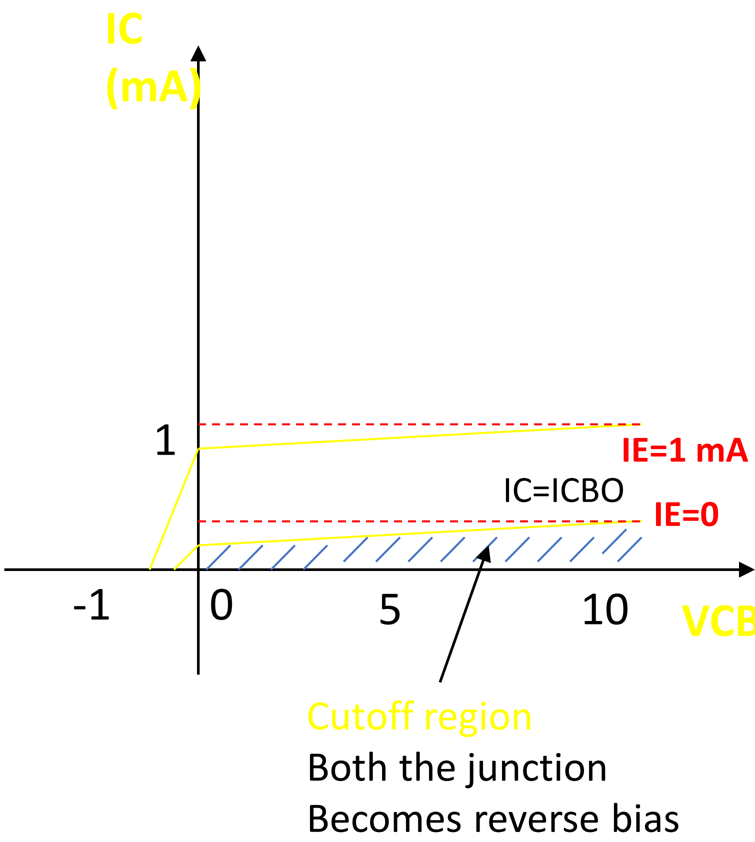

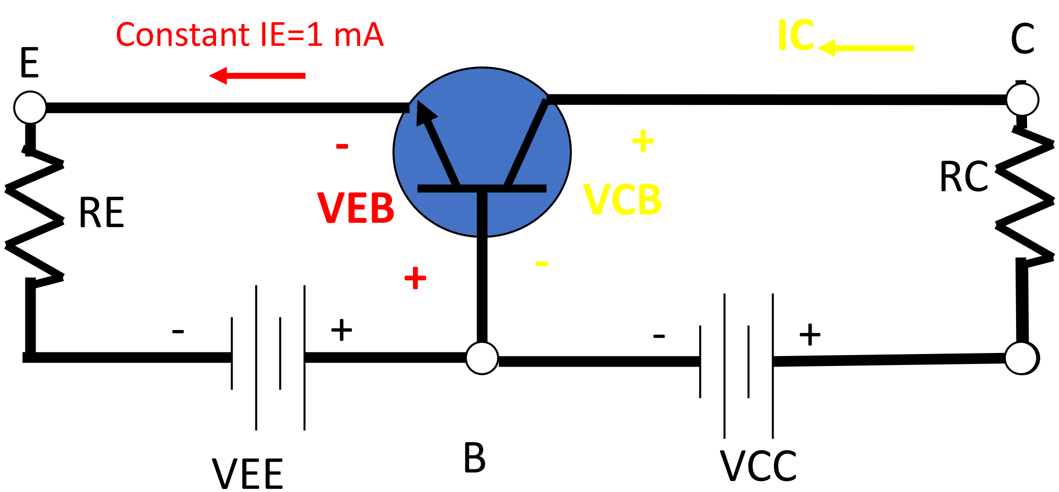

Characteristics of a transistor in CB configuration

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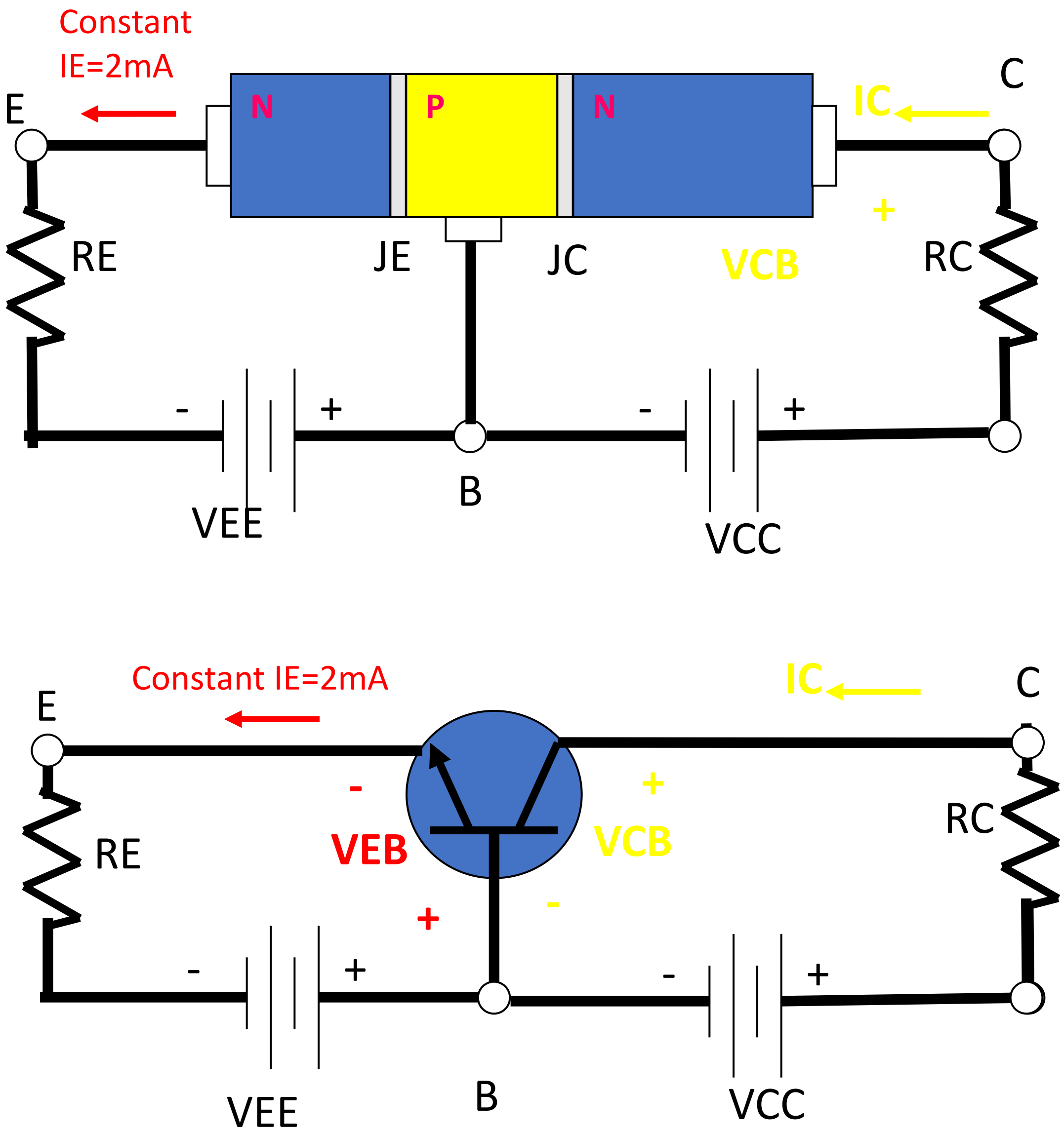

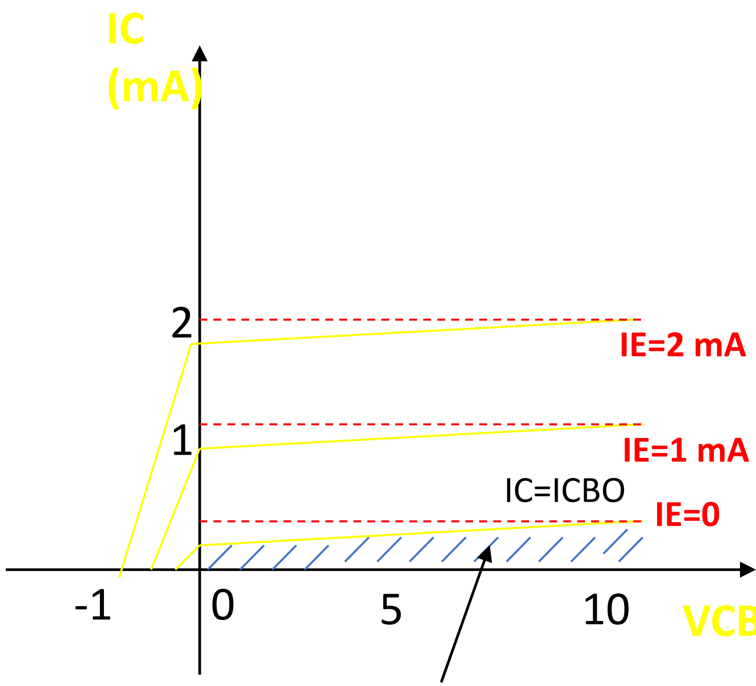

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Characteristics of a transistor in CB configuration

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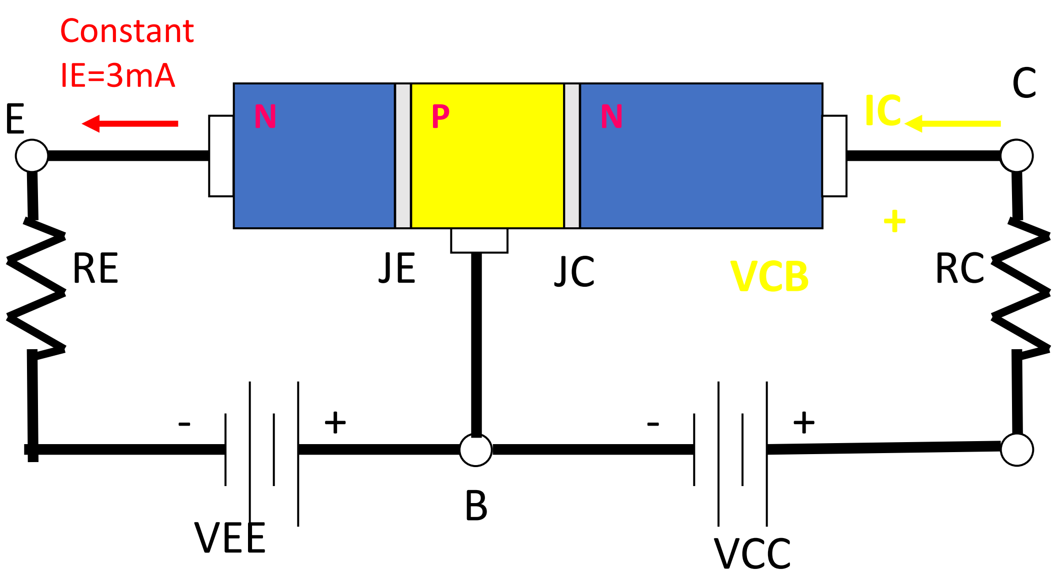

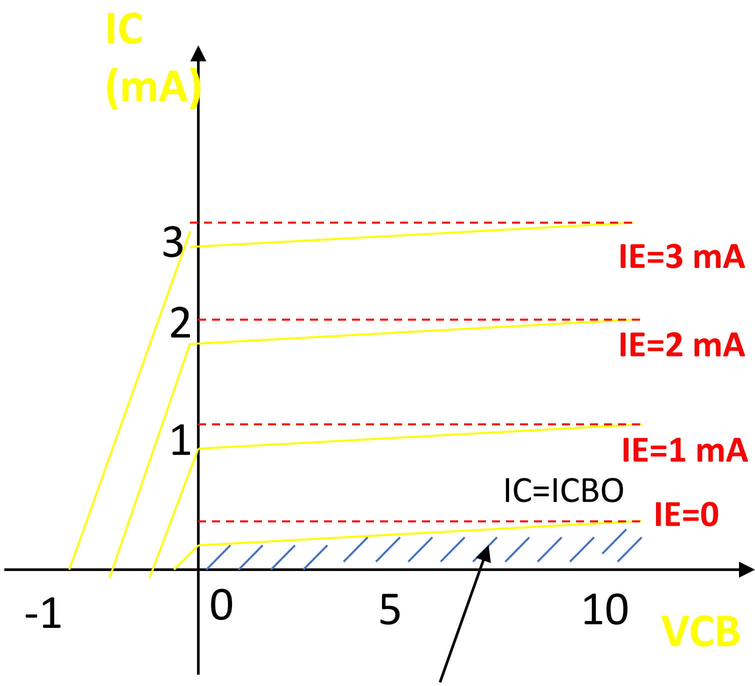

Cutoff region
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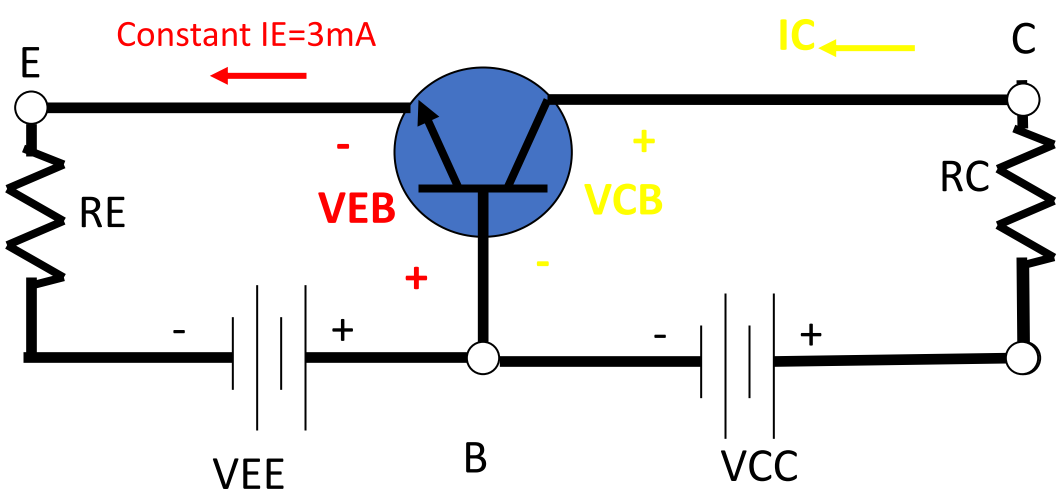

Characteristics of a transistor in CB configuration

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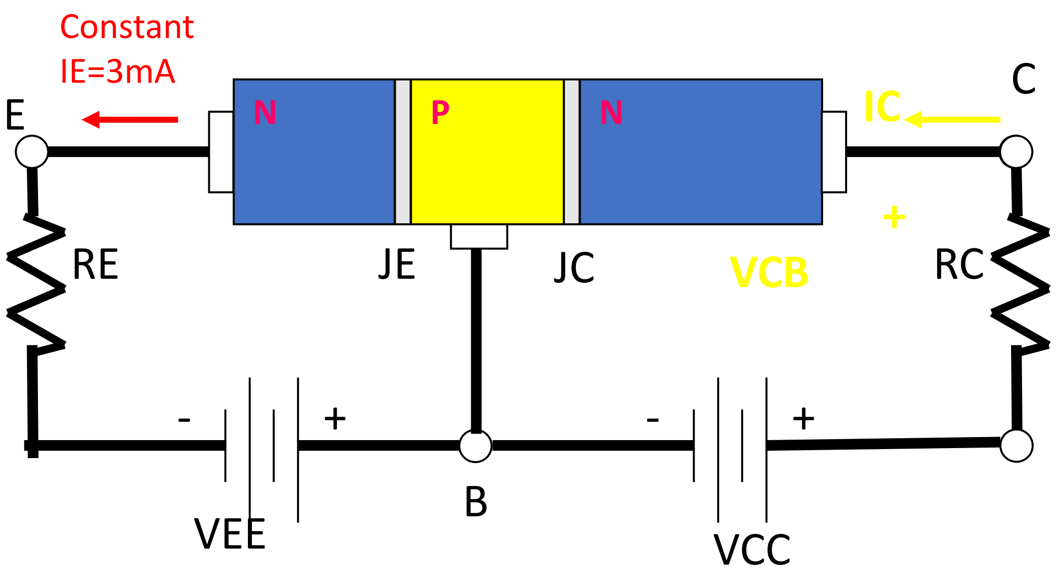
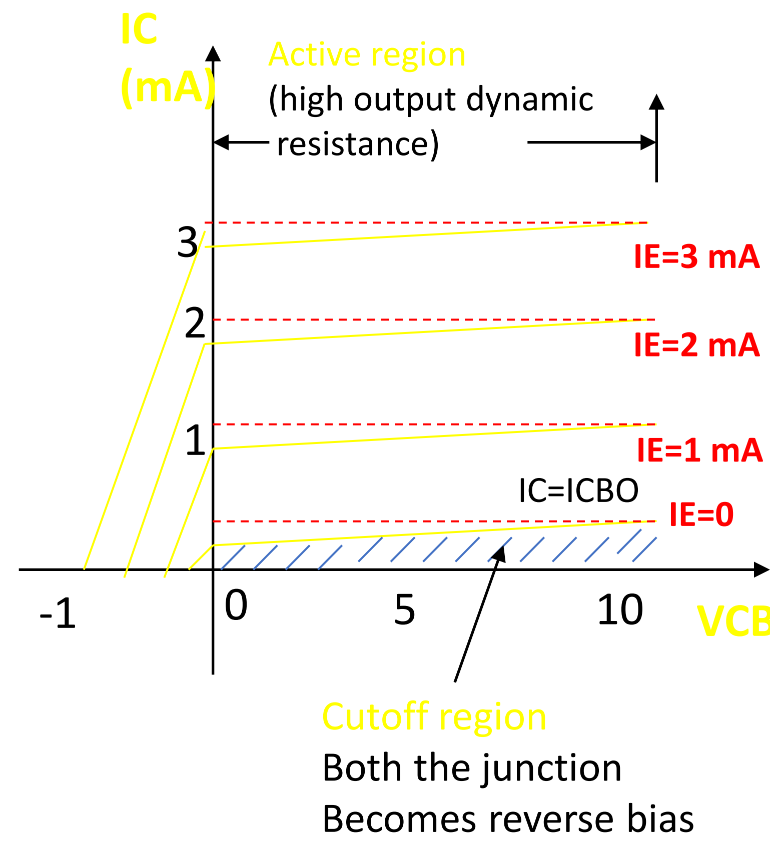
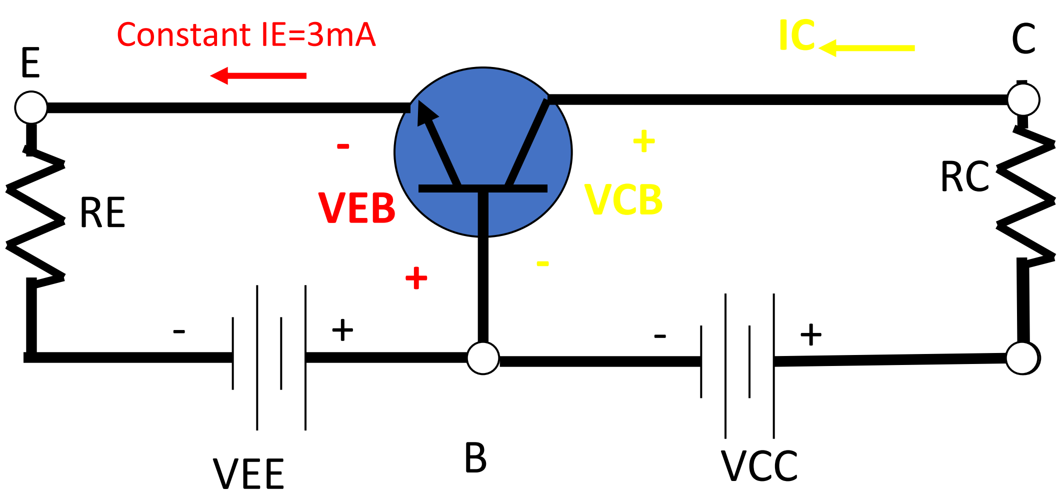
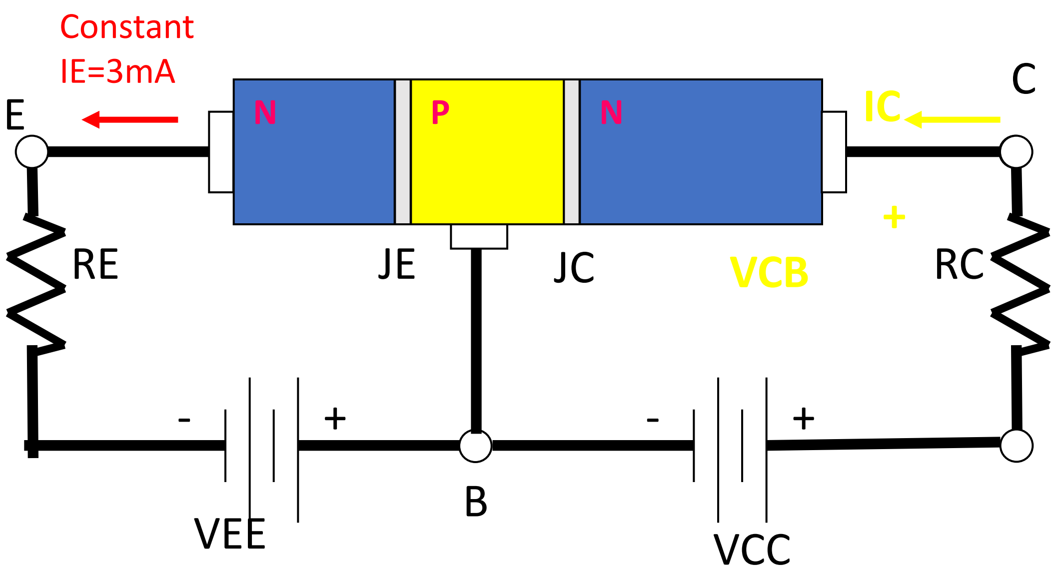


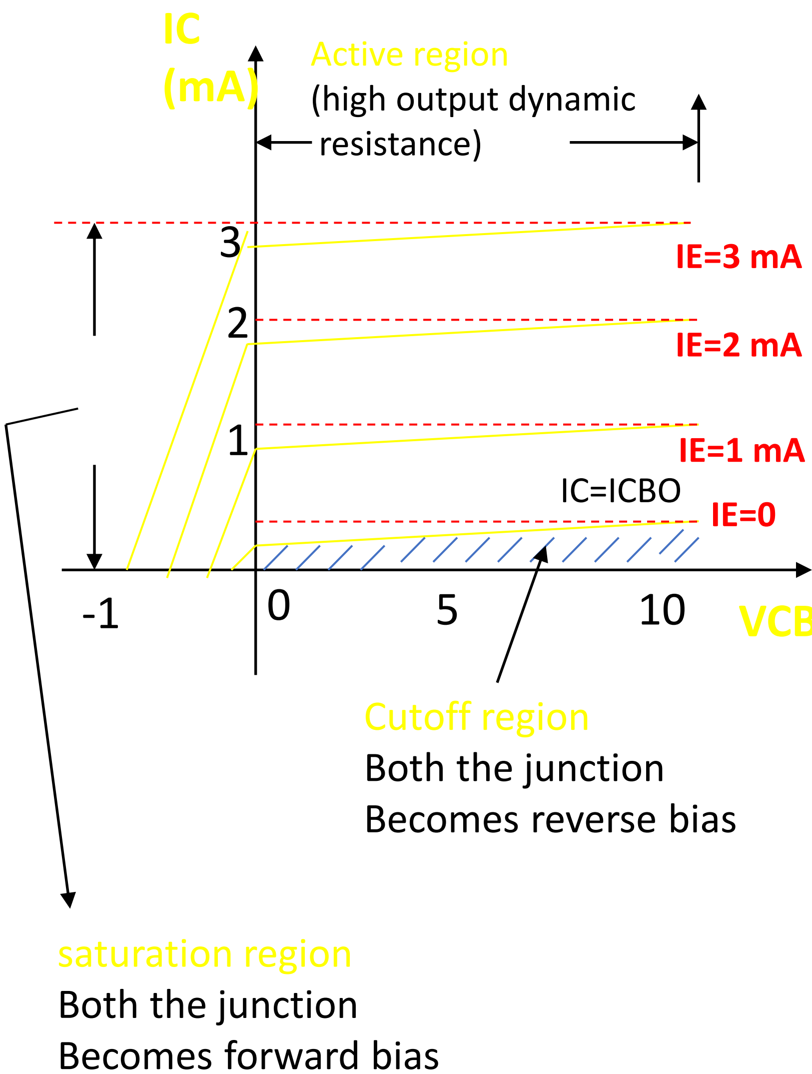


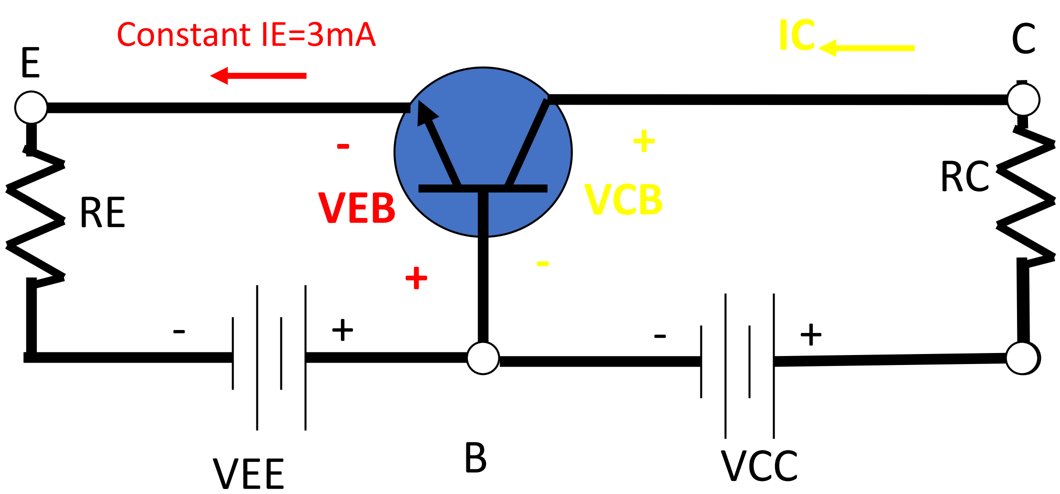


Characteristics of a transistor in CB configuration

Output characteristics







Characteristics of a transistor in CB configuration

Output characteristics

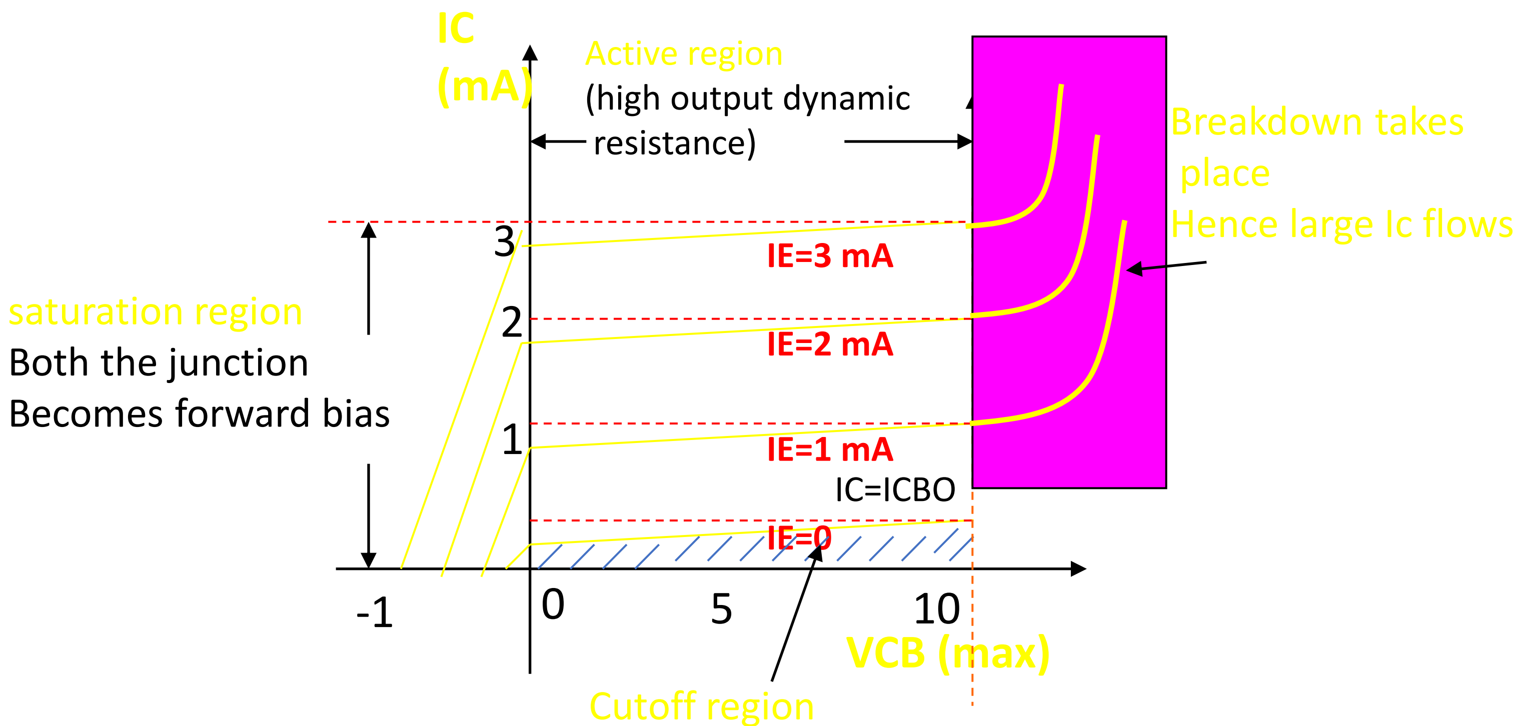
Dynamic output resistance of the transistor :

Ro = $\Delta V_{CB} / \Delta I_C$ ….. …………………… for I_E constant

- **This is nothing but the reciprocal of the output characteristics in the active region.**
- **Slope of the output characteristics in the active region is very small.**
- **Therefore the dynamic resistance Ro in the active region is high.**
- **That's why the voltage drop across the transistor is very large in active region**

Characteristics of a transistor in CB configuration

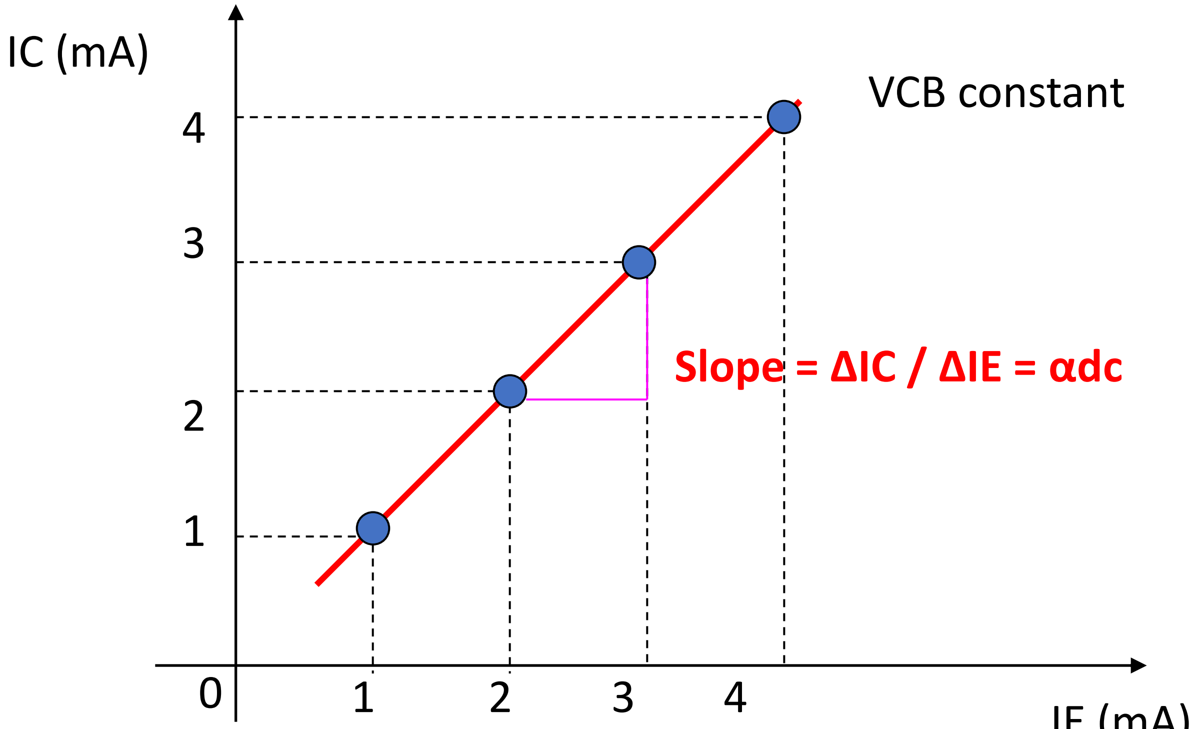
Output characteristics



- **Due to excessive heat produced by this current, the transistor may get damaged. The type of breakdown is avalanche breakdown.**

Characteristics of a transistor in CB configuration

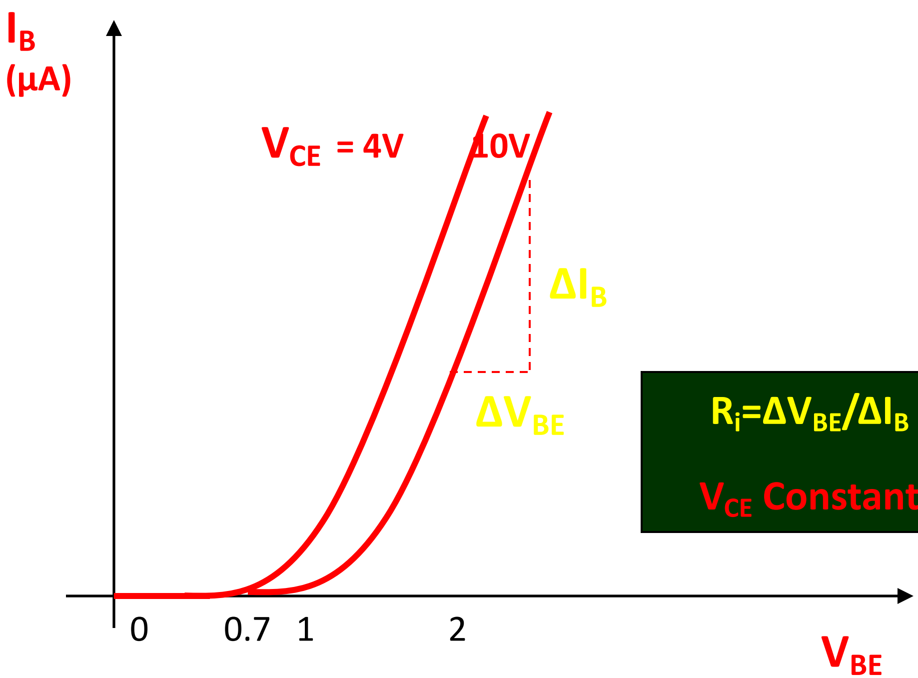
Transfer characteristics



α dc = ΔIC / ΔIE

Characteristics of a transistor in CE configuration

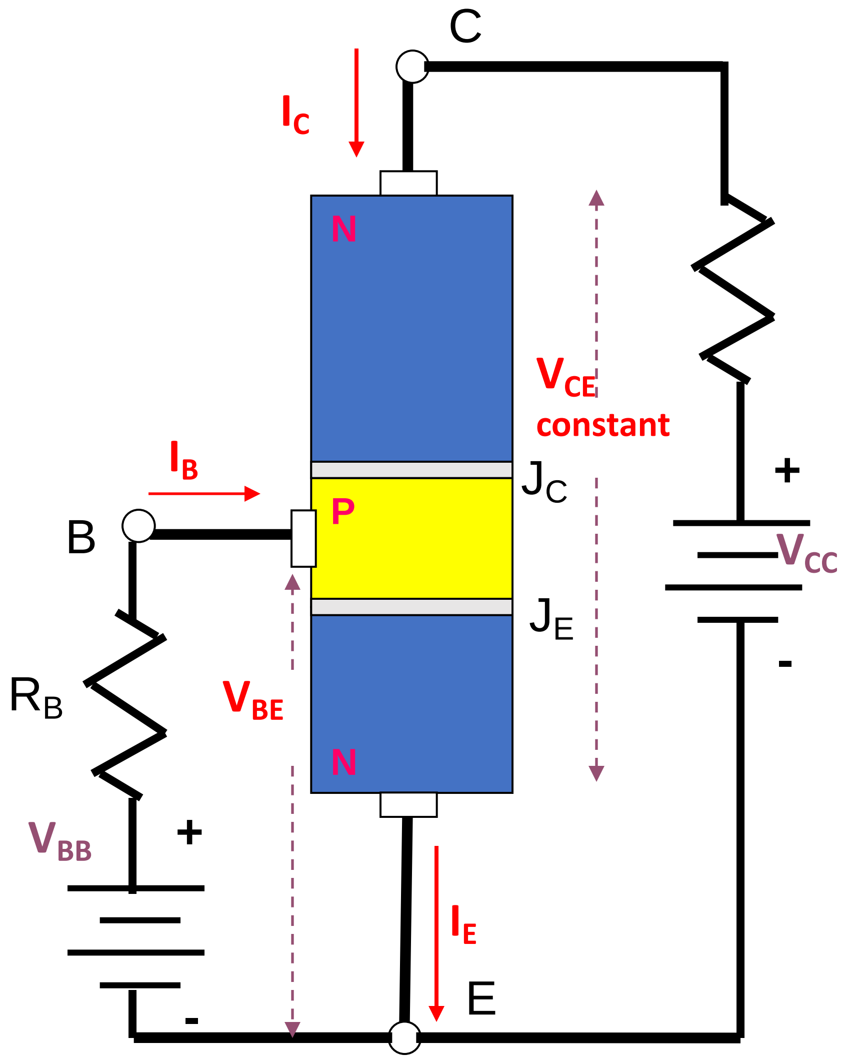
- **Input characteristics:**
- It is a graph of input current (I_B) versus input voltage (V_{BE}) at a constant output voltage (V_{CE}).



$R_i = \Delta V_{BE} / \Delta I_B$

V_{CE} Constant

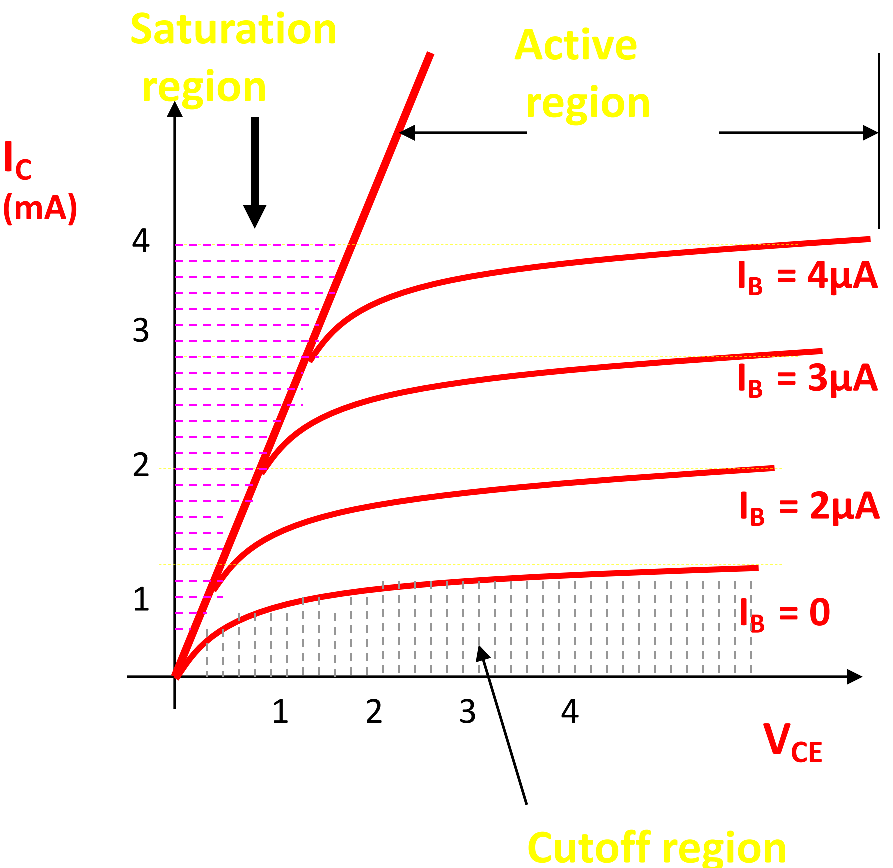
The value of dynamic input resistance "Ri" is low for CE

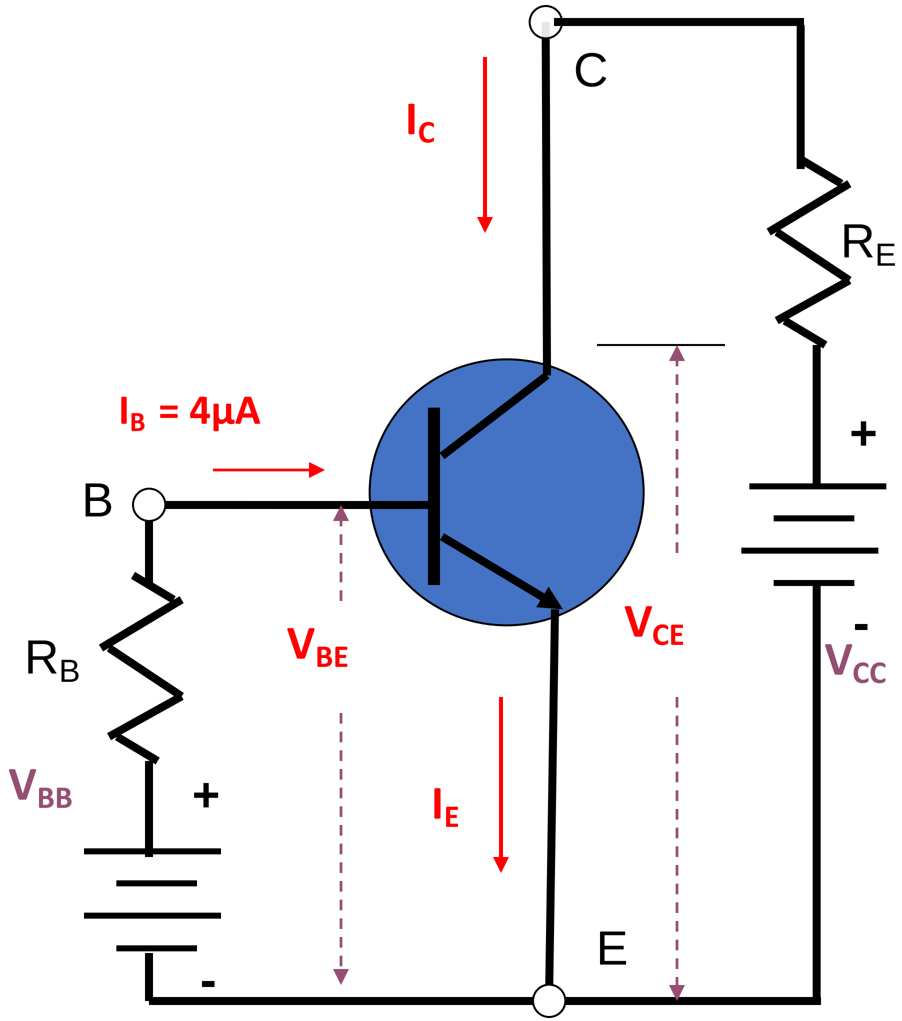


N-P-N Transistor

Characteristics of a transistor in CE configuration

- **Output characteristics:**
- It is a graph of output current (I_c) versus output voltage (V_{CE}) at a constant input current (I_B)

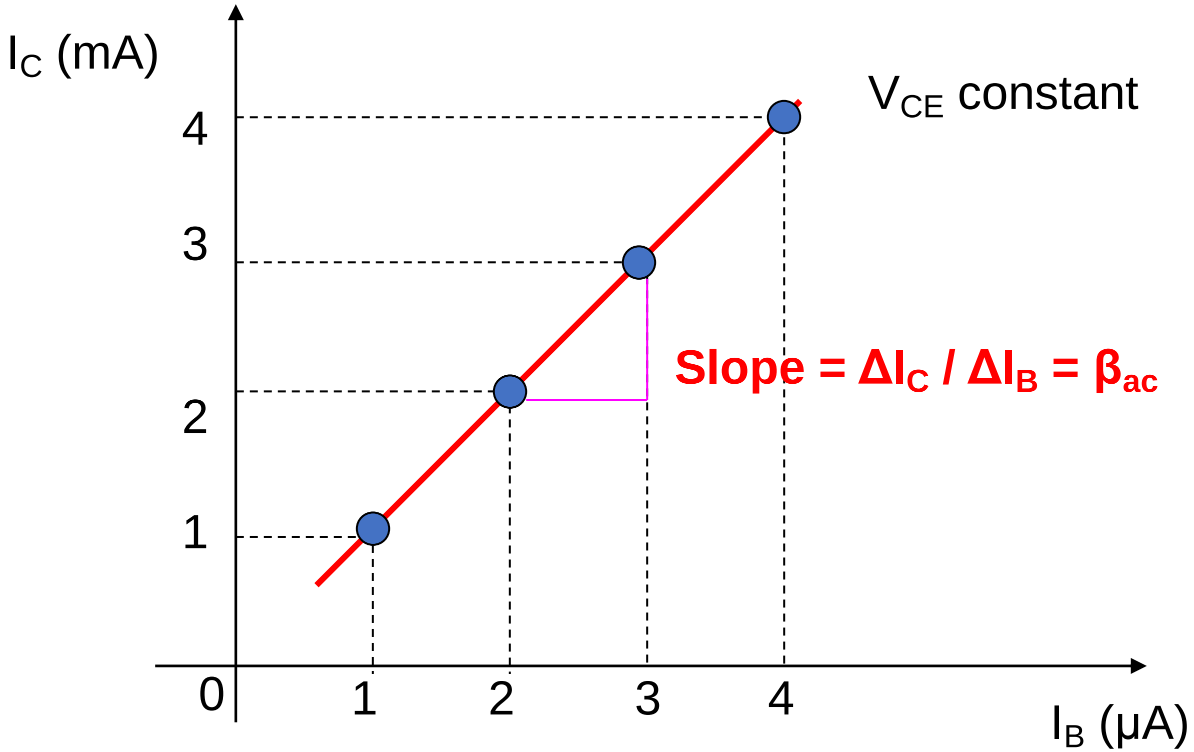




N-P-N Transistor

Characteristics of a transistor in CE configuration

Transfer characteristics



$$\beta_{ac} = \Delta I_C / \Delta I_B$$

$$\beta_{dc} = I_C / I_B \qquad V_{CE} \text{ constant}$$

Relationship between DC Currents and Gains

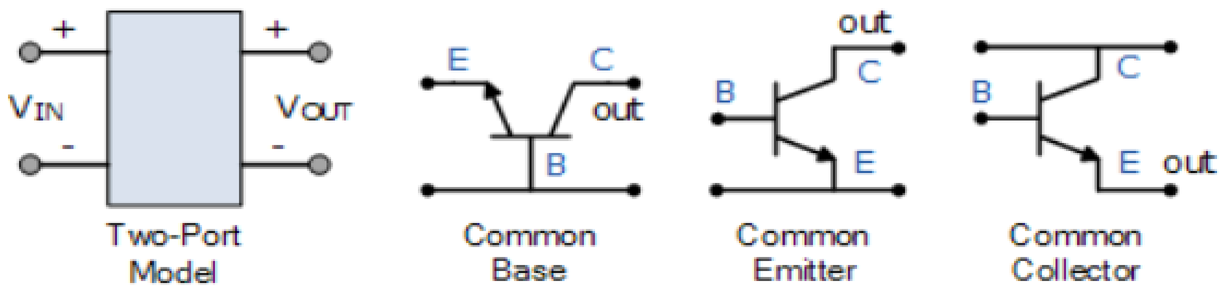
$I_E = I_B + I_C$ $I_C = I_E - I_B$ $I_B = I_E - I_C$	$\alpha = \dfrac{I_C}{I_E} = \dfrac{\beta}{1+\beta}$ $\beta = \dfrac{I_C}{I_B} = \dfrac{\alpha}{1-\alpha}$
$I_B = \dfrac{I_C}{\beta} = \dfrac{I_E}{1+\beta} = I_E(1-\alpha)$	
$I_C = \beta . I_B = \alpha . I_E$	$I_E = \dfrac{I_C}{\alpha} = I_B(1+\beta)$

Relationship between DC Currents and Gains

If NPN transistor IB =50uA and alpha=0.99 then IE= ??

In a transistor, IC = 100mA & IE =100.5mA . The value of β_{DC} = ??

Bipolar Transistor Configurations

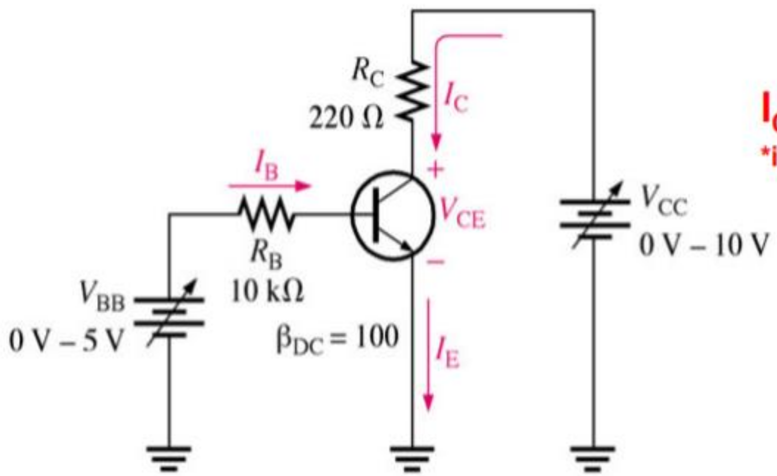


S .No	Characteristics	CB	CE	CC
1	Input impedance	Low	Medium	High
2	Output impedance	High	medium	low
3	Current gain	Low	High	High
4	Voltage gain	High	High	Unity
5	Power gain	Medium	High	Low
6	Phase reversal	No	Yes	No
7	application	AF amplifiers	Voltage & power amplifiers	Impedance matching

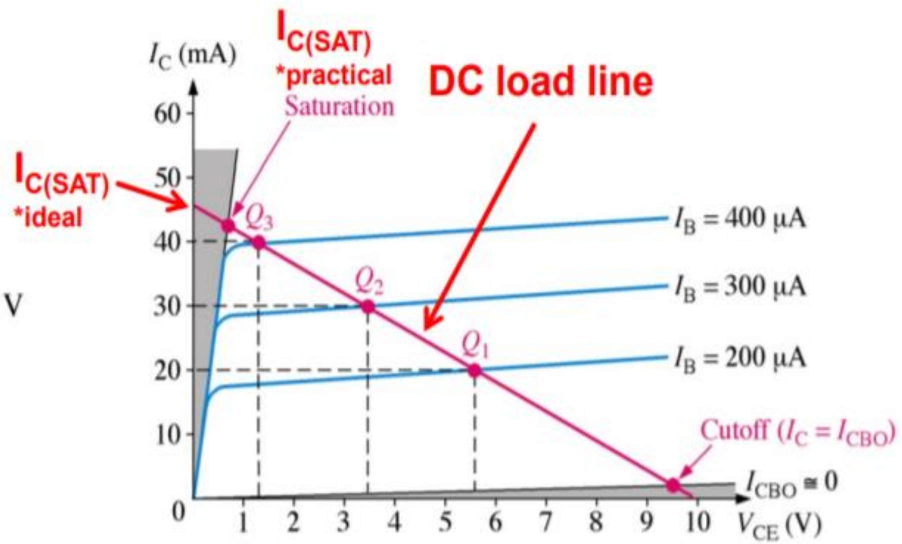
DC Load Line

For a transistor circuit to amplify it must be properly biased with dc voltages. The dc operating point between saturation and cutoff is called the **Q-point.** The goal is to set the Q-point such that that it does not go into saturation or cutoff when an a ac signal is applied.

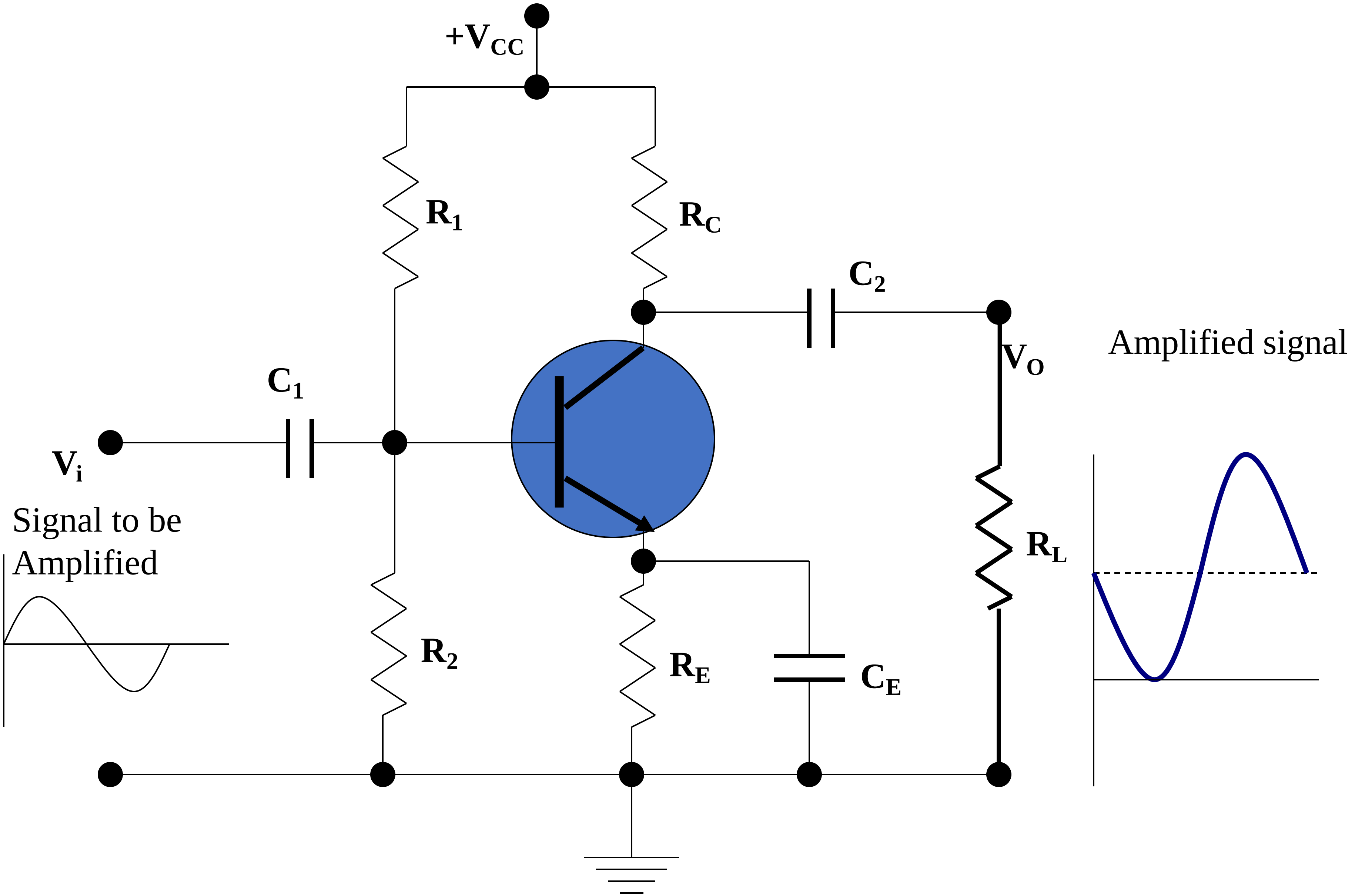
$$I_C = \frac{V_{CC} - V_{CE}}{R_C} = -\left(\frac{1}{R_C}\right)V_{CE} + \frac{V_{CC}}{R_C}$$



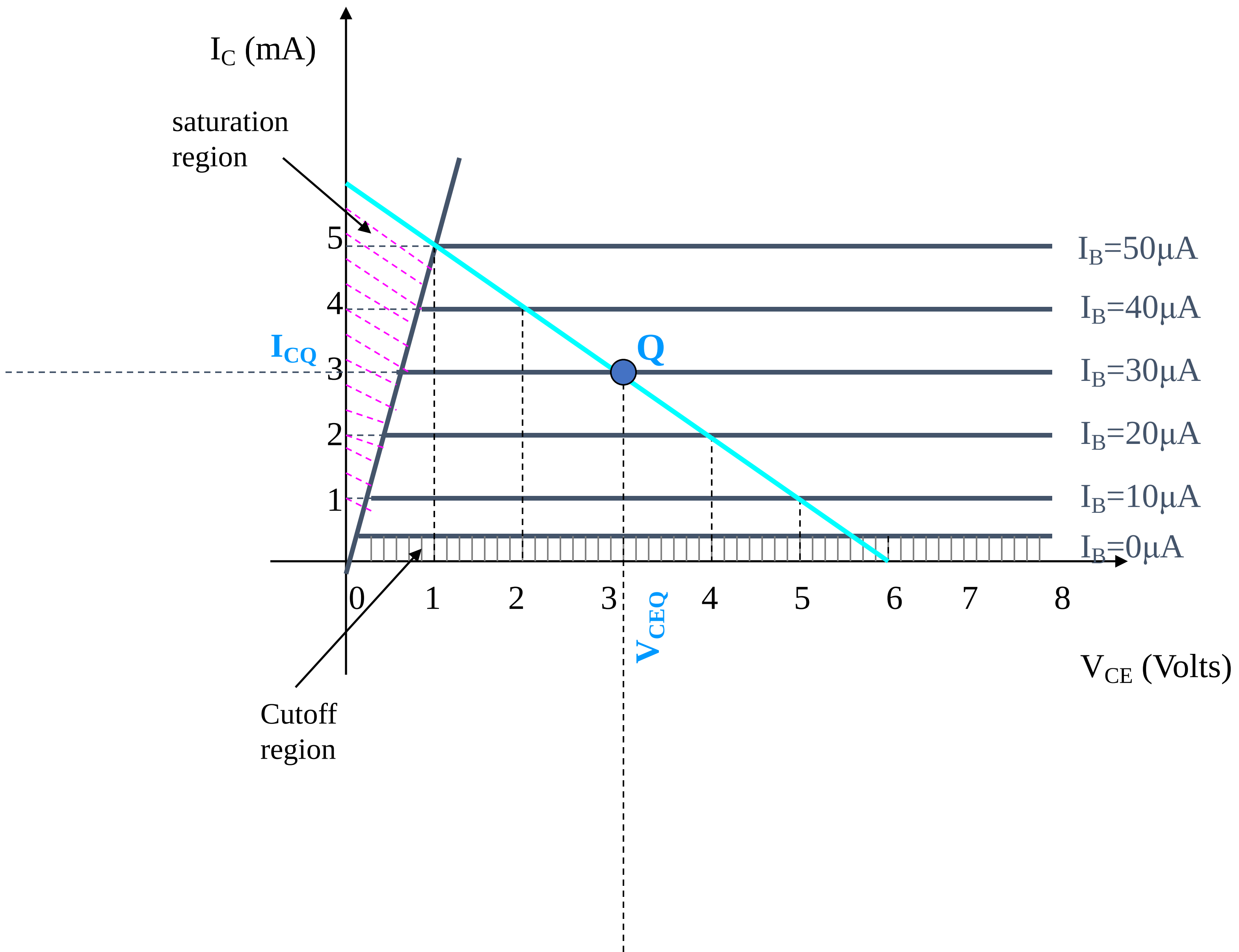
(a) DC biased circuit



Single stage RC coupled CE amplifier



Q- point at the center of DC load line



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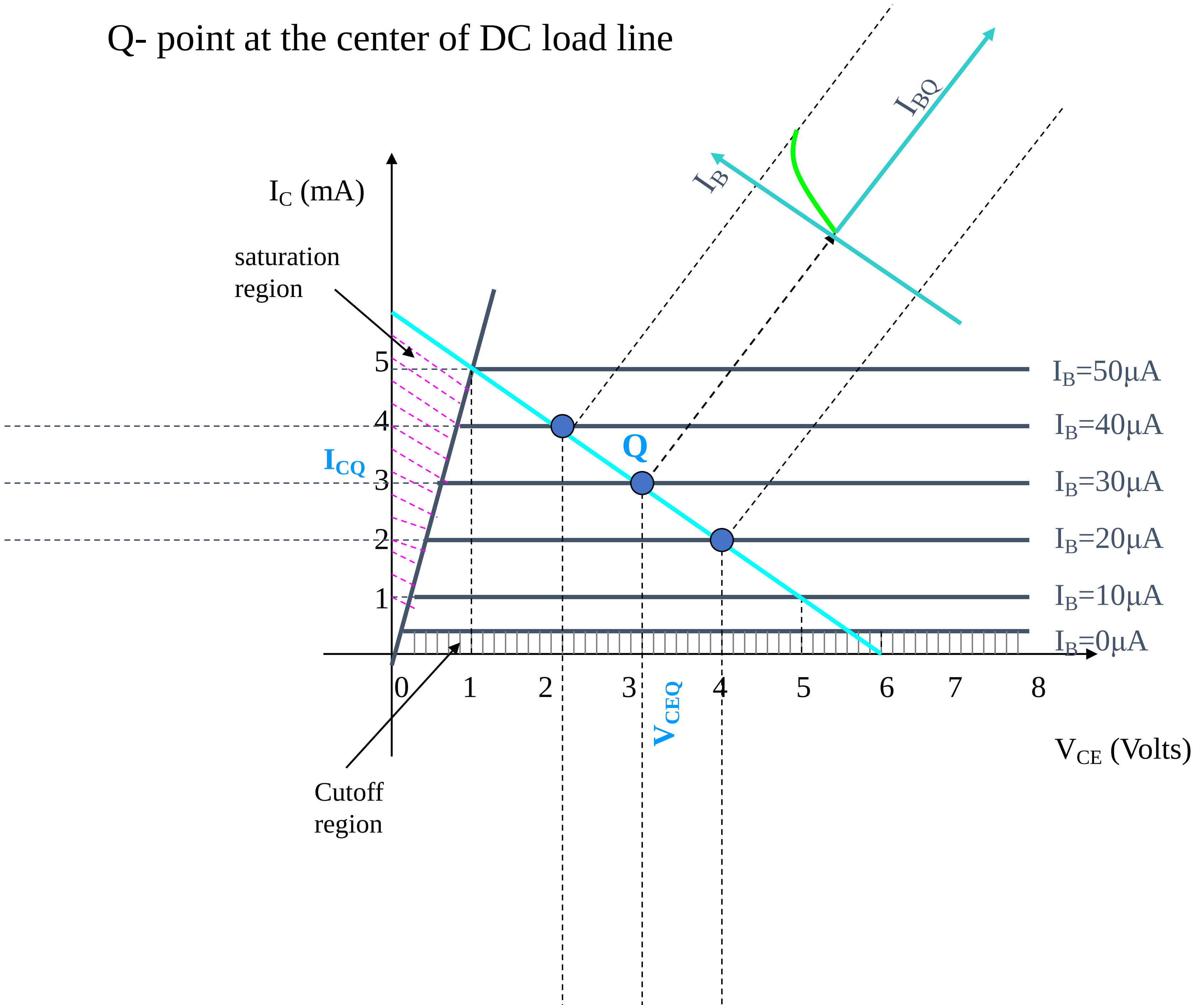

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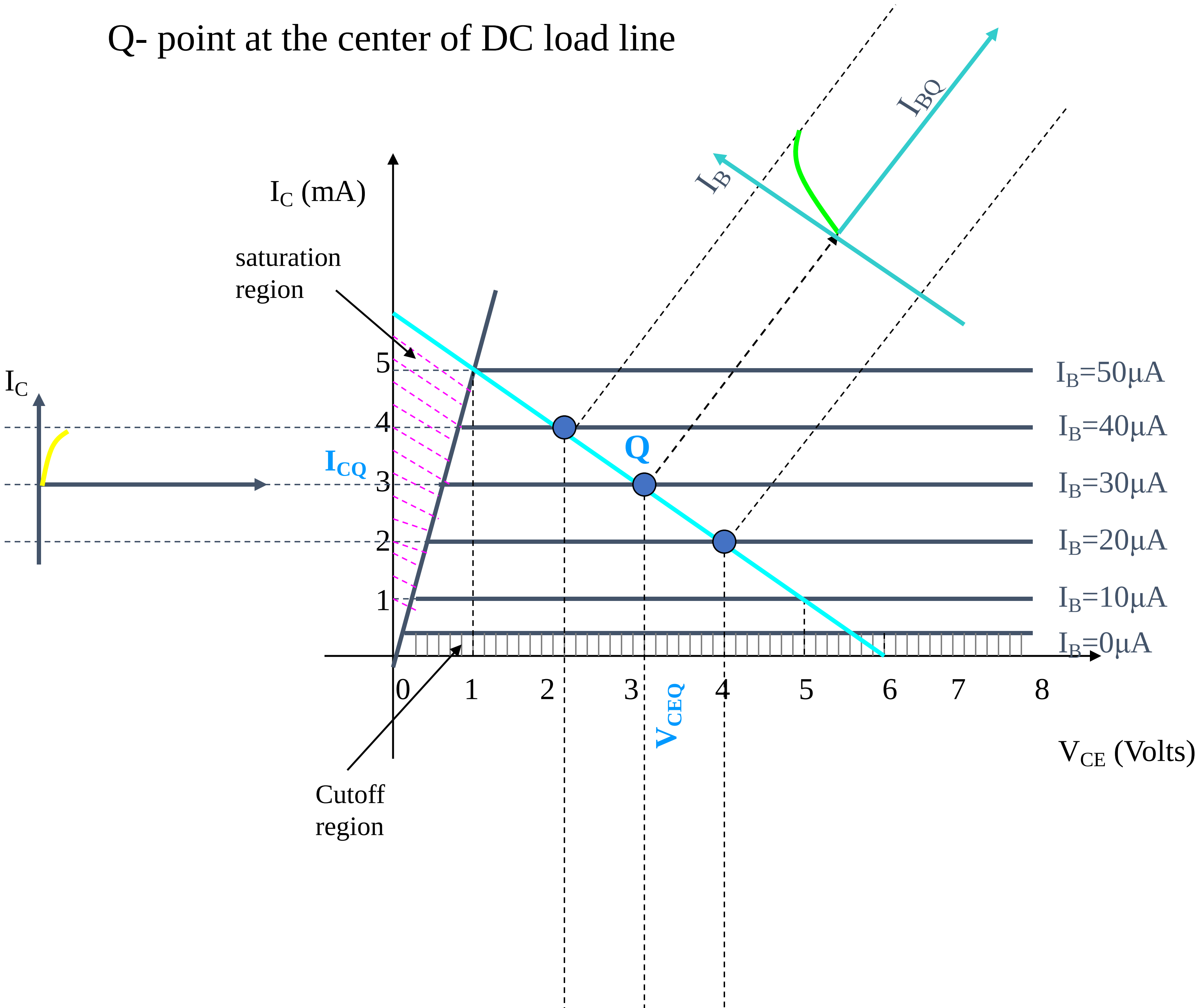

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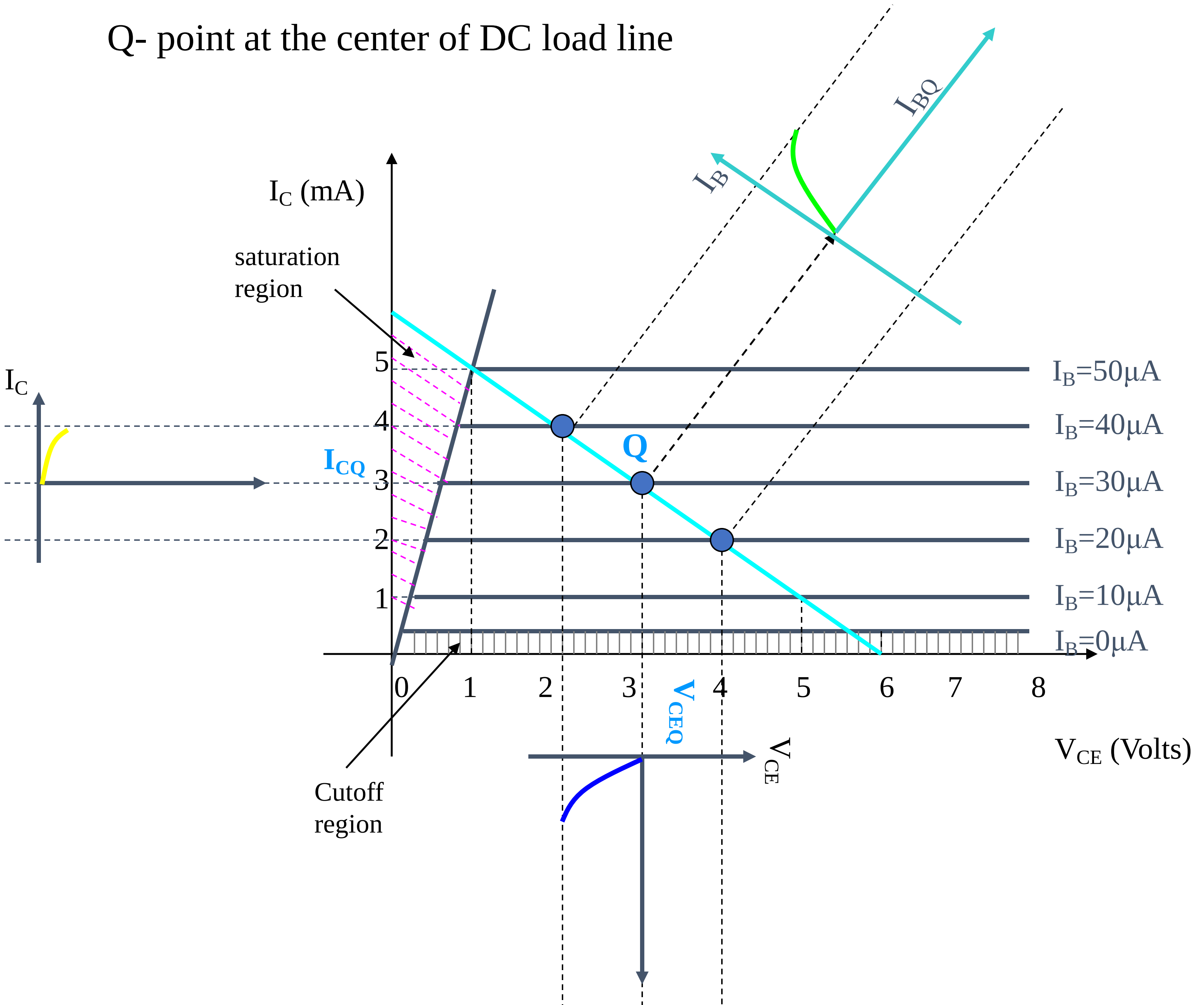

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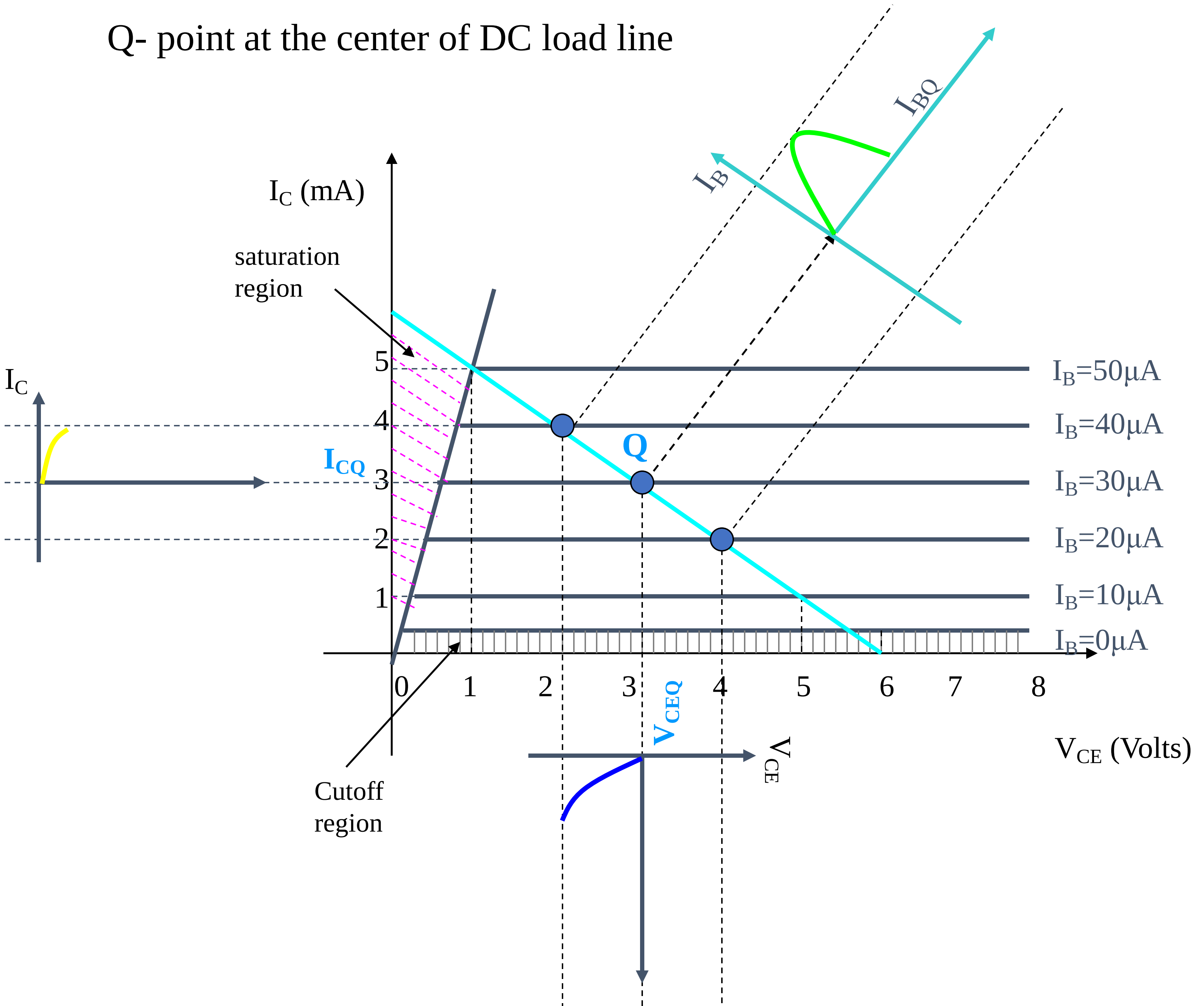

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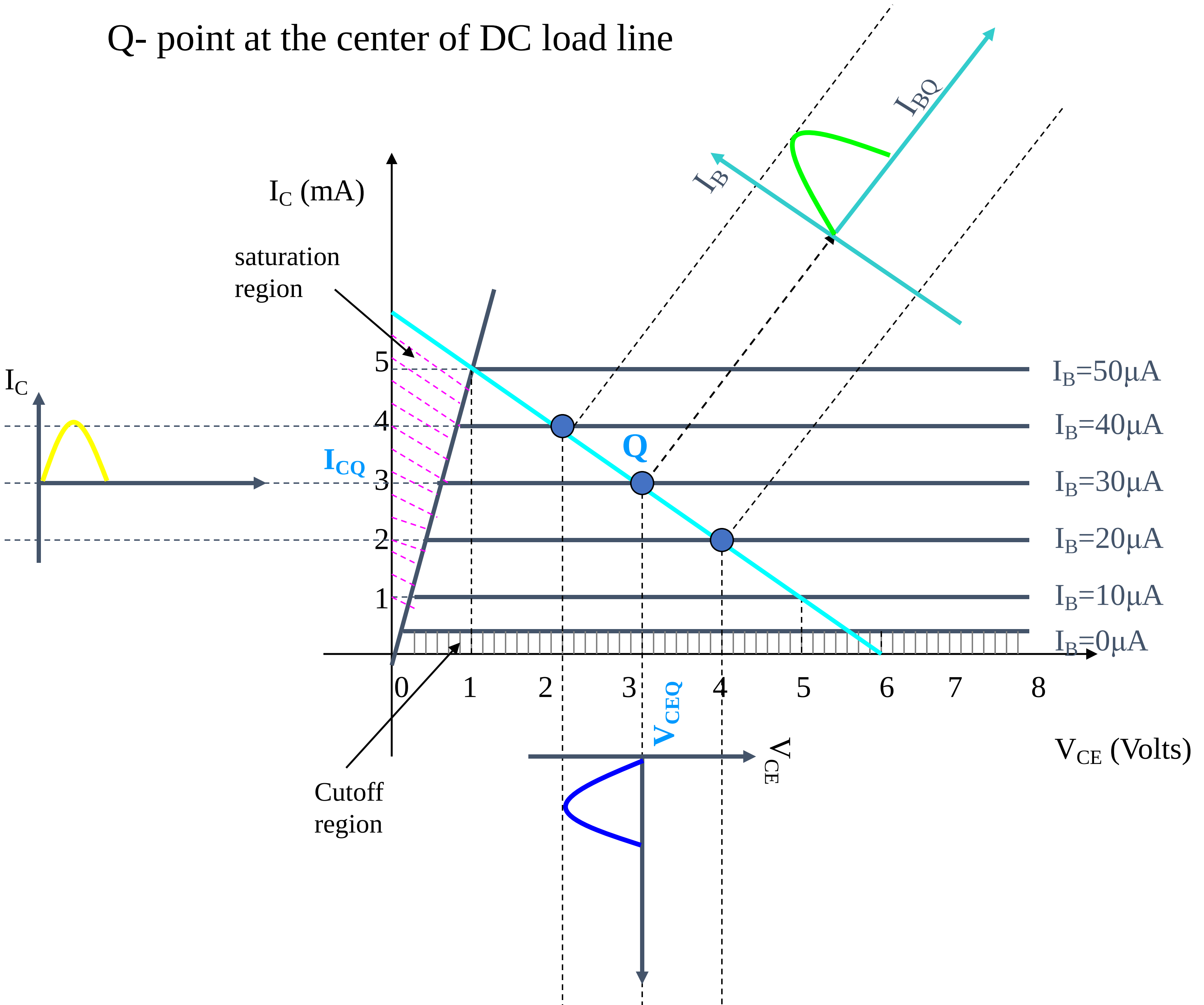
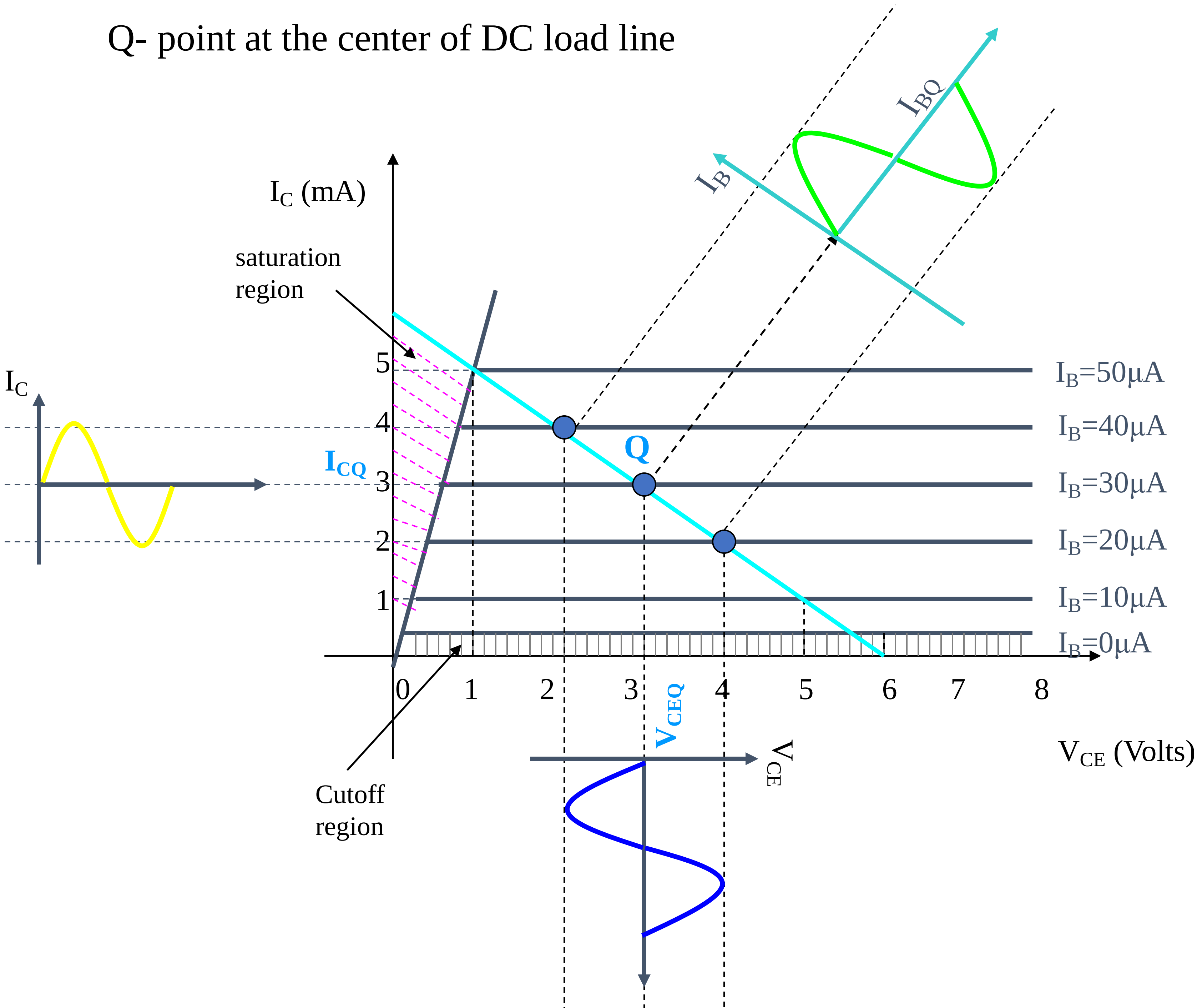
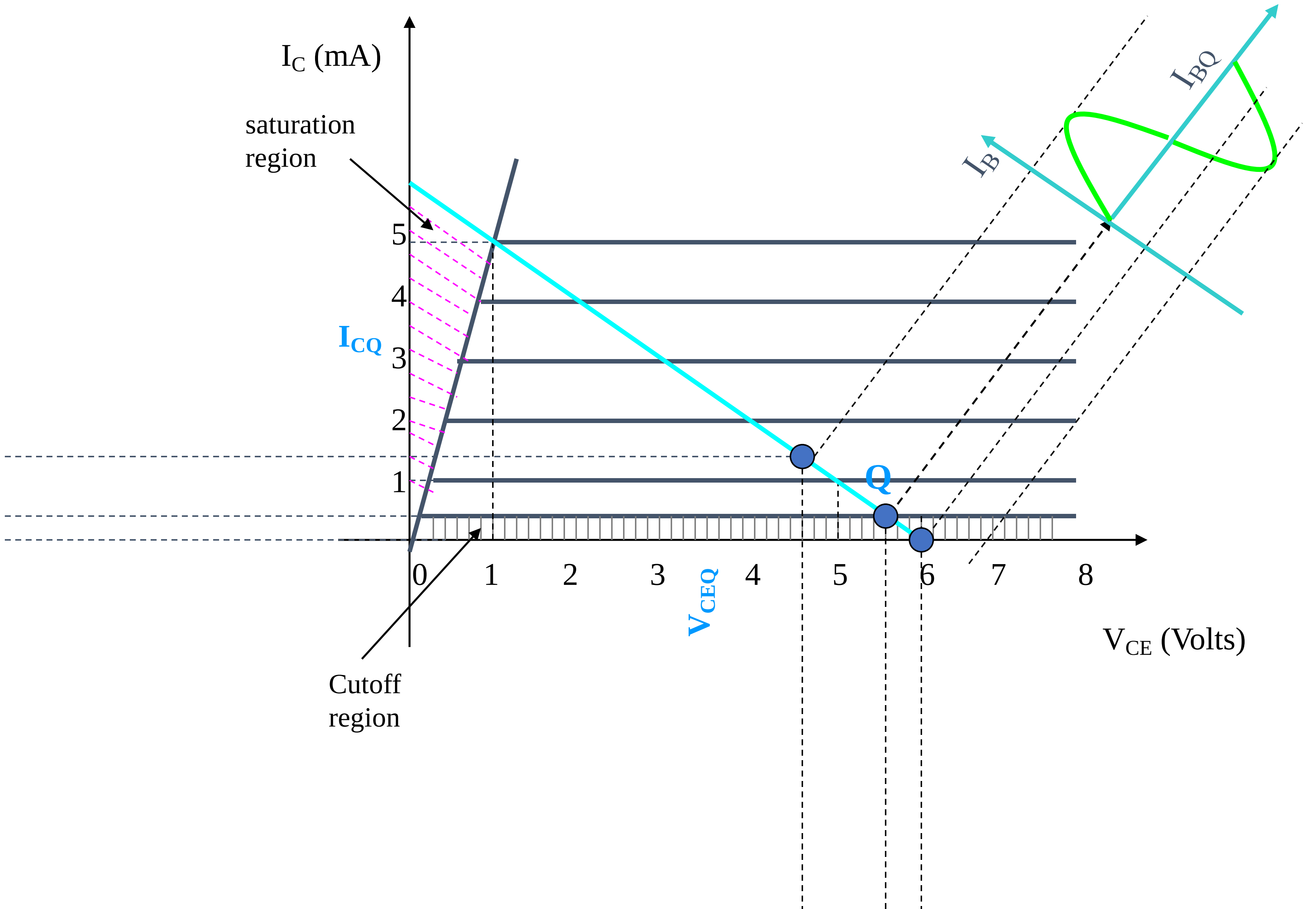


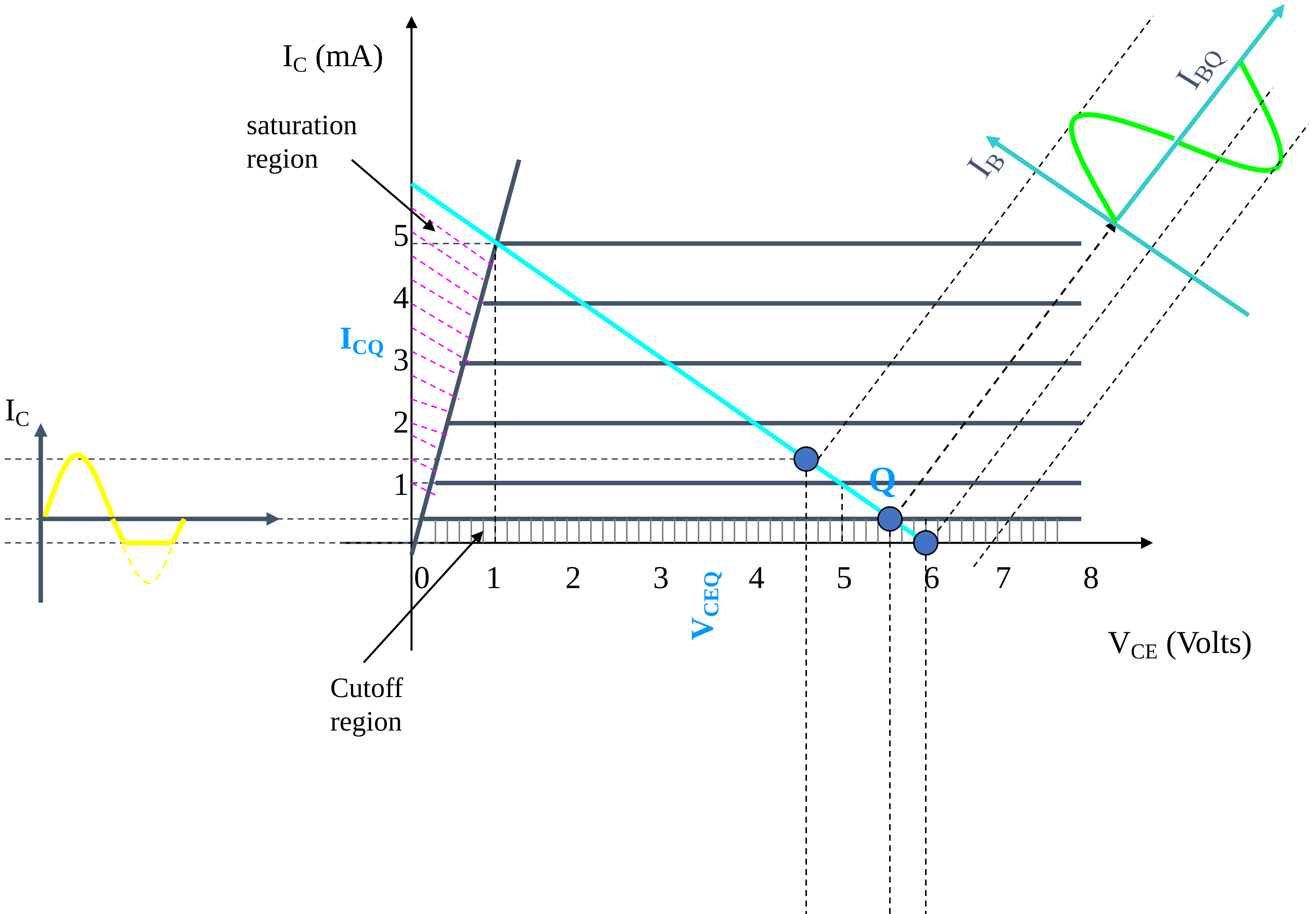
Q- point at the center of DC load line



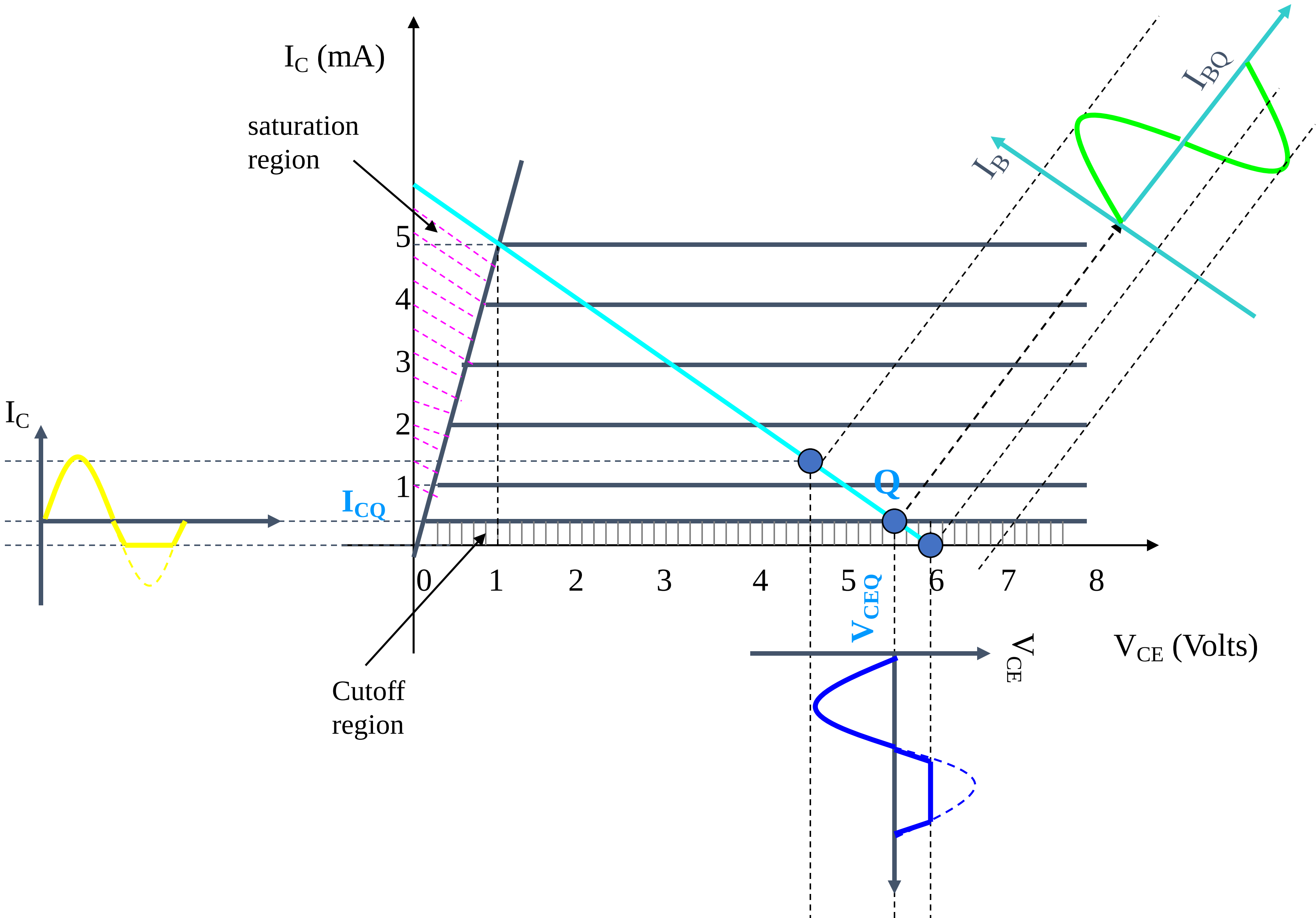
Effect of Q- point close to cutoff region



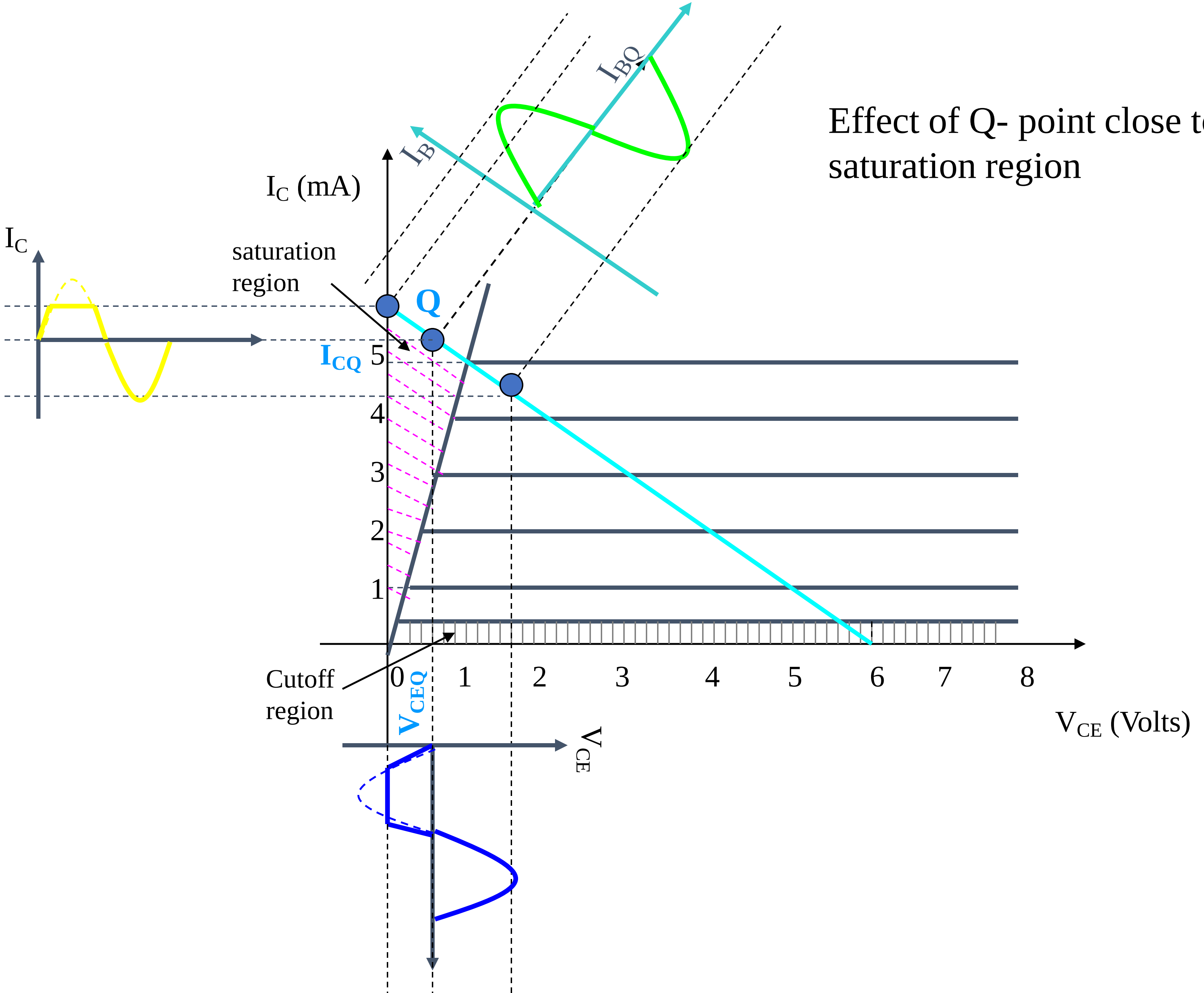
Effect of Q- point close to cutoff region



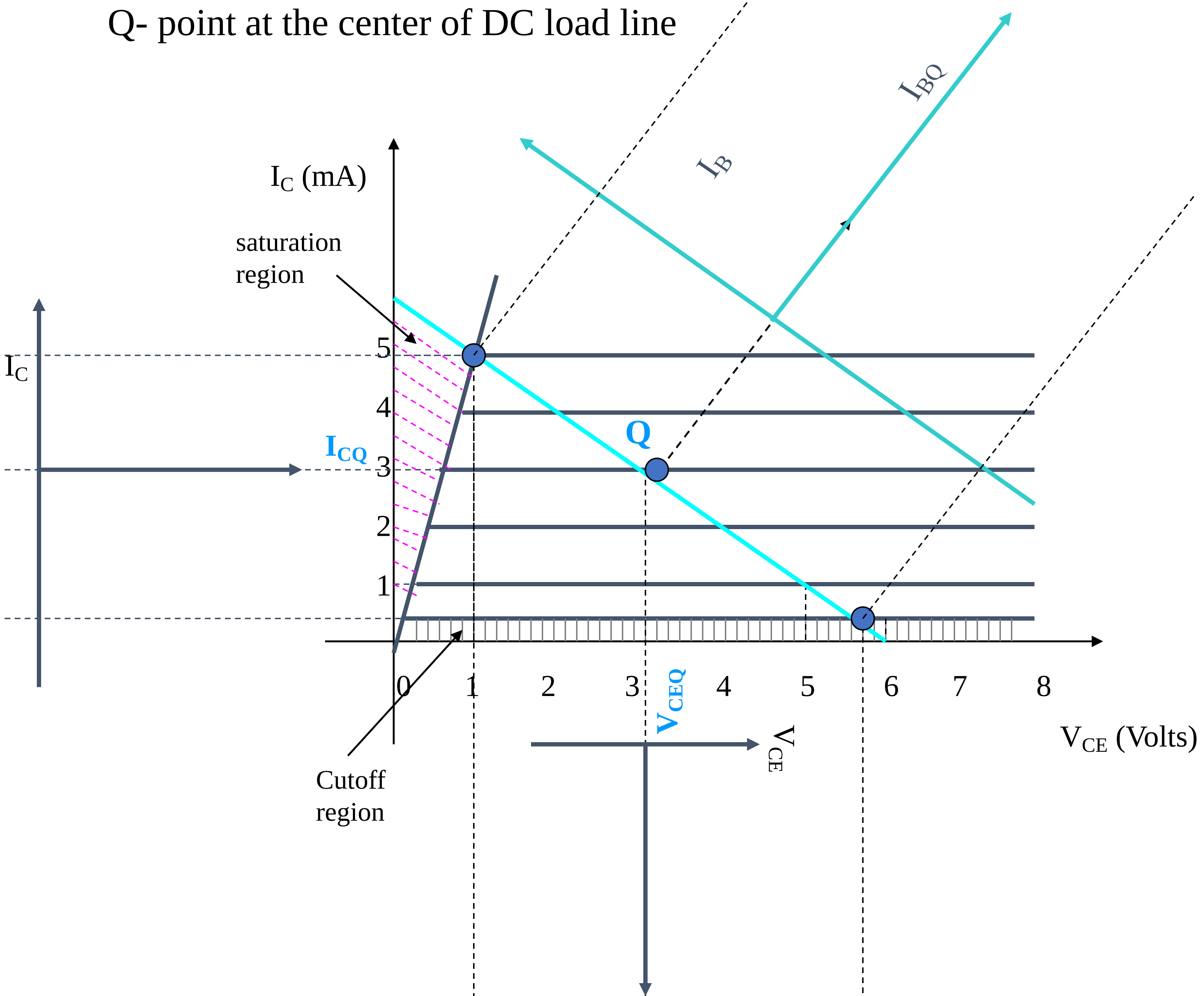
Effect of Q- point close to cutoff region



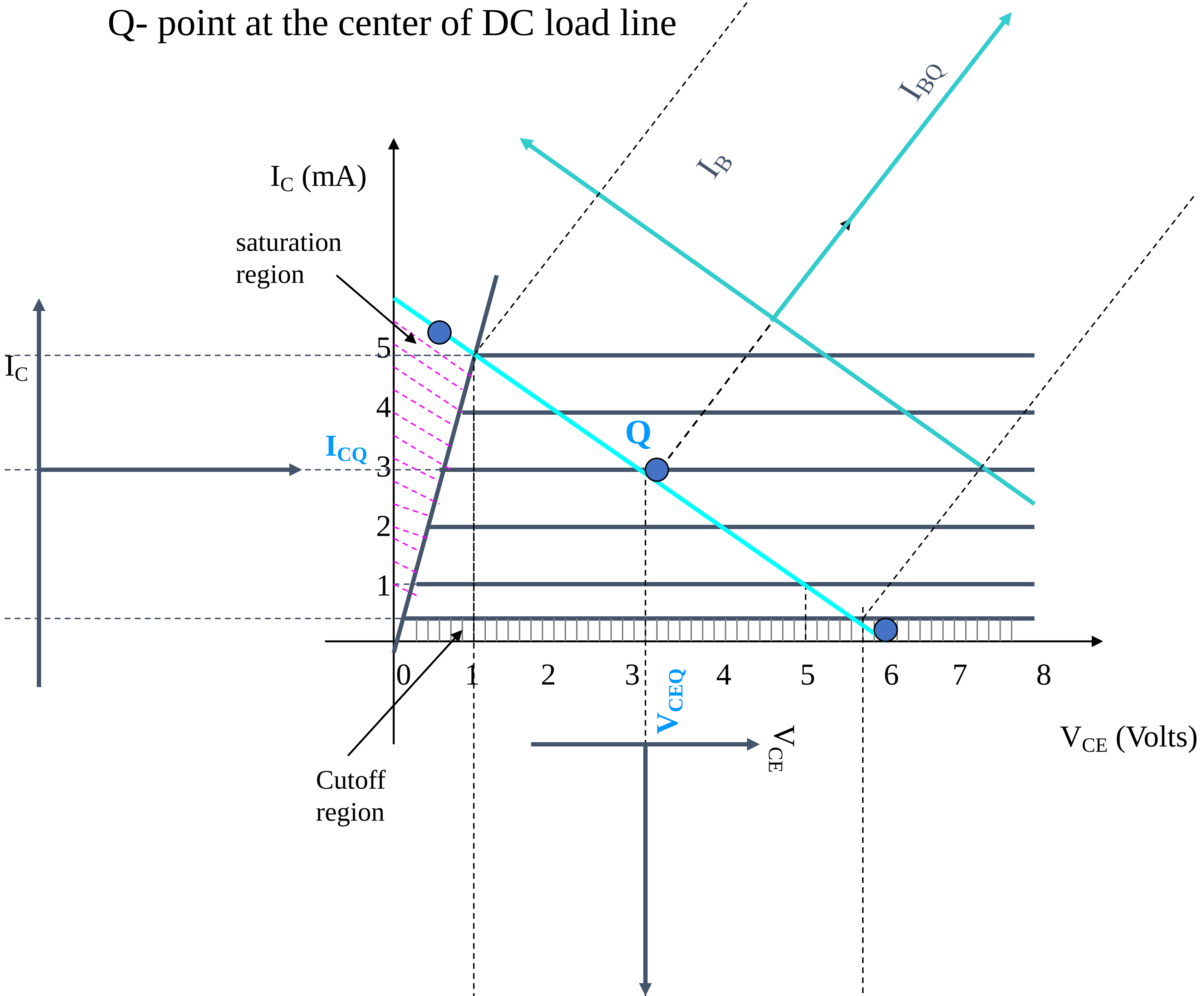
Effect of Q- point close to saturation region



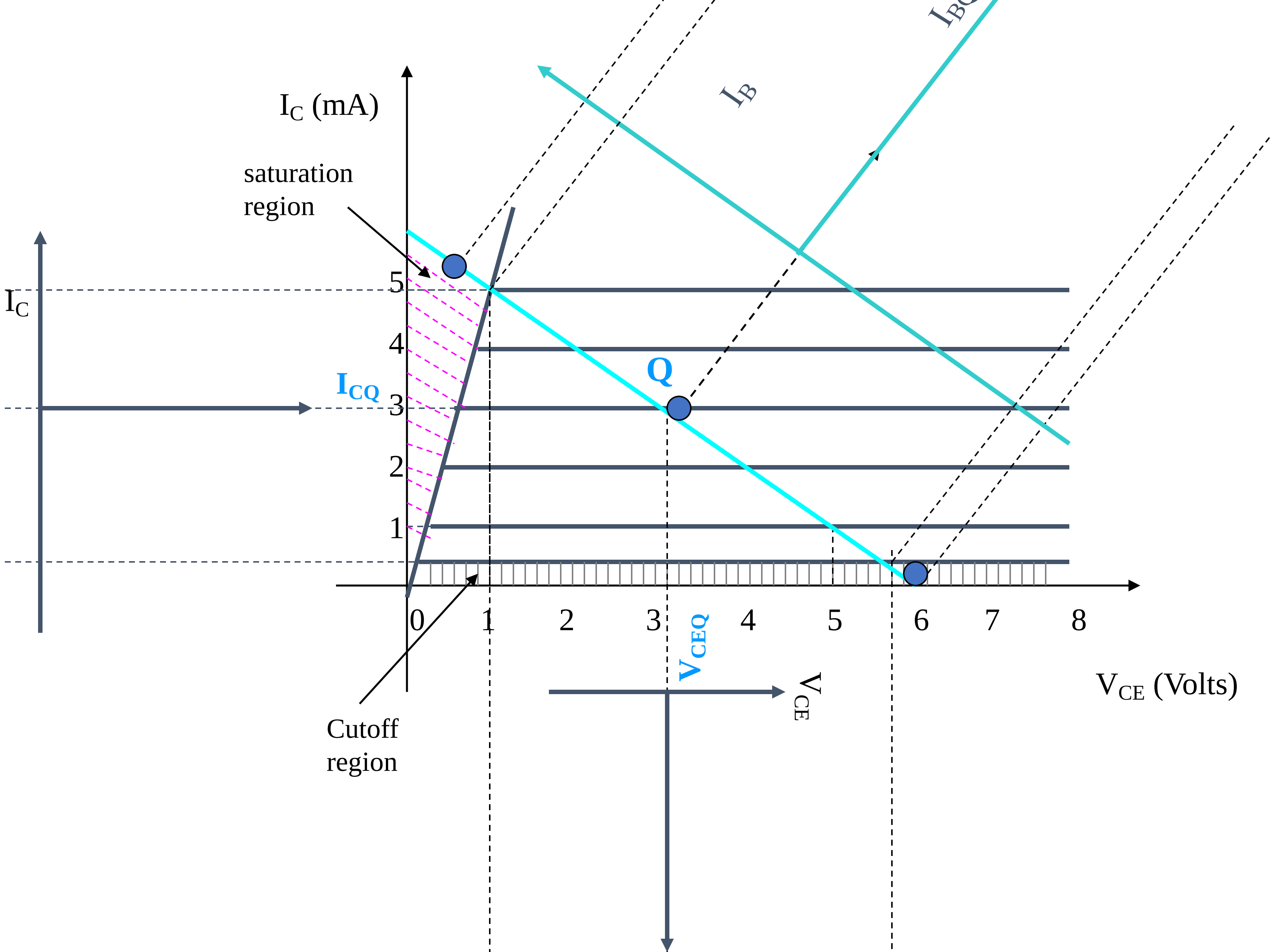
Q- point at the center of DC load line



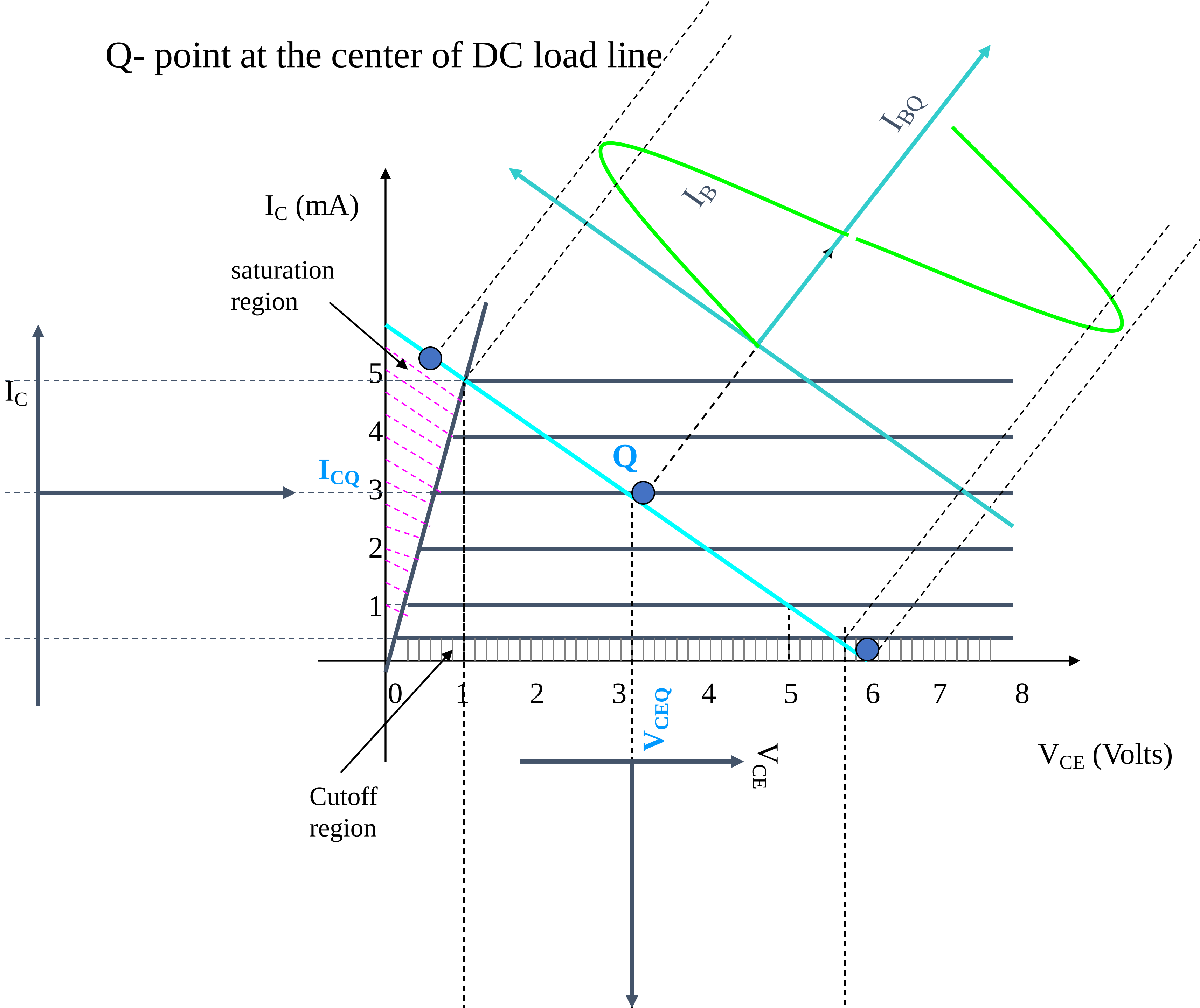
Q- point at the center of DC load line



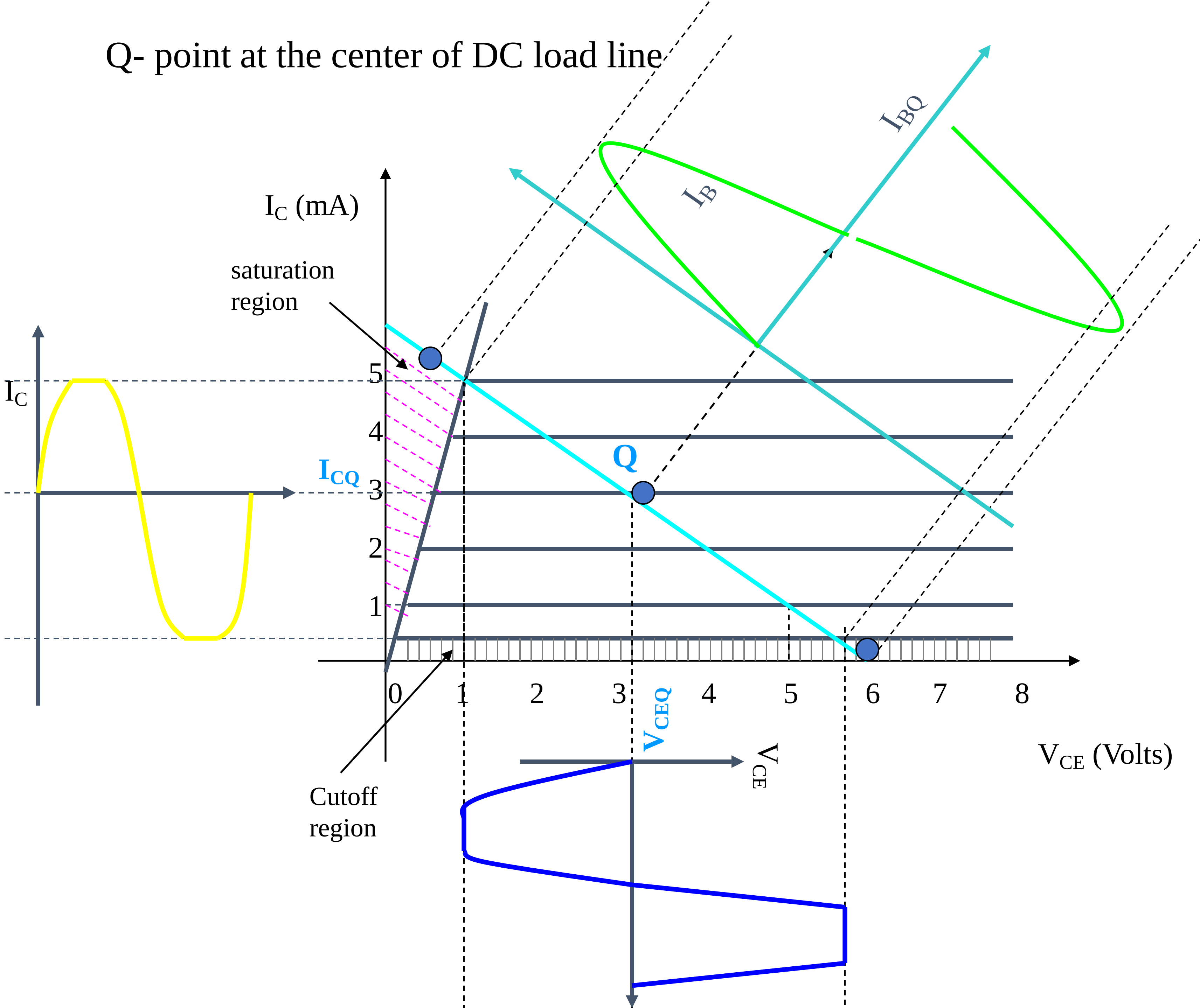
Q- point at the center of DC load line



Q- point at the center of DC load line

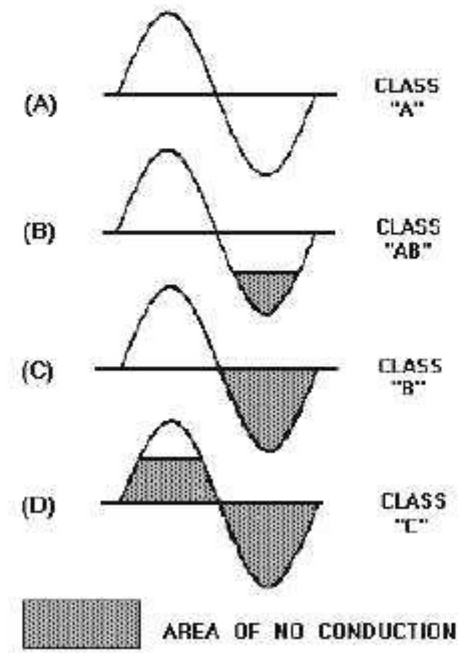


Q- point at the center of DC load line



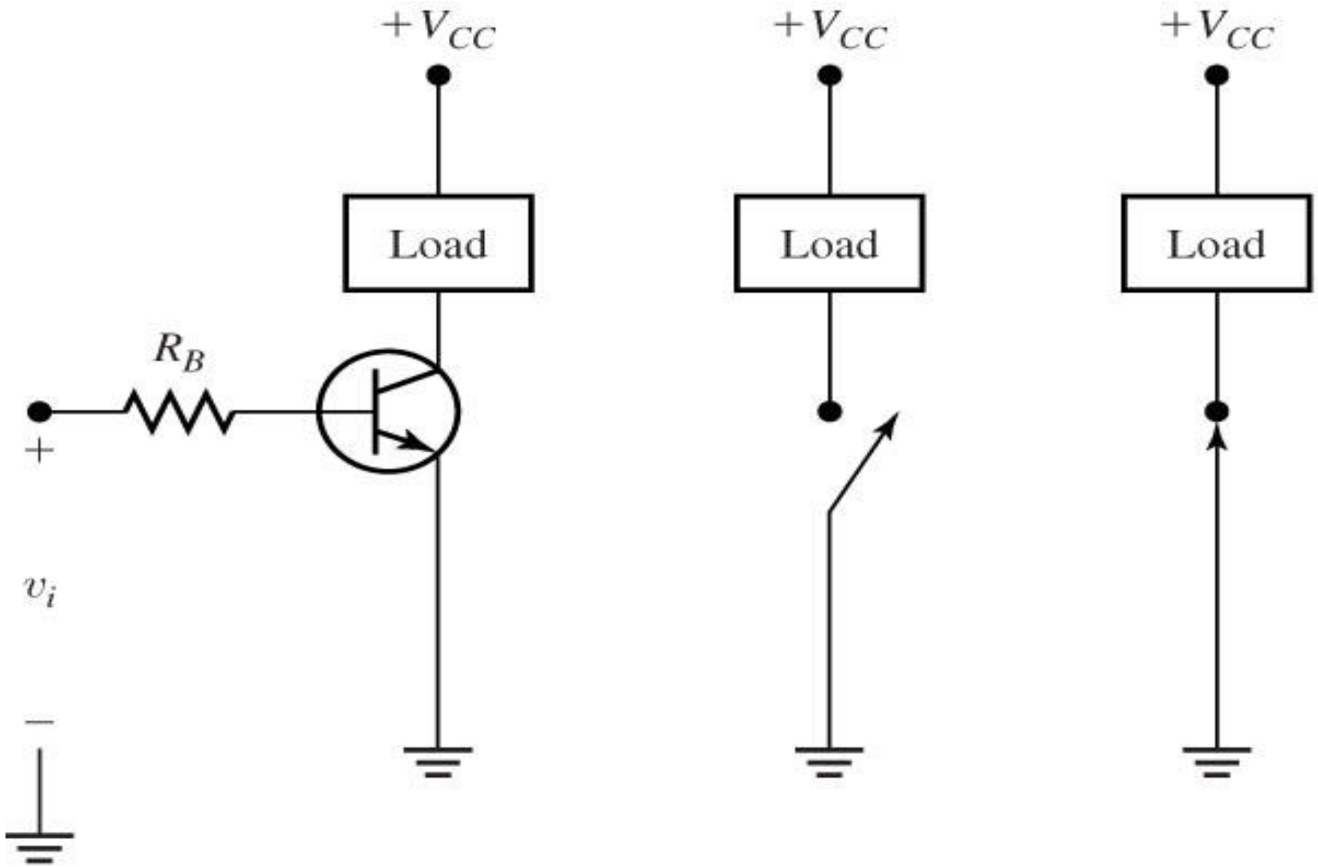
Amplifier Classes

Class	A	B	C	AB
Conduction Angle	360^0	180^0	Less than 90^0	180 to 360^0
Position of the Q-point	Centre Point of the Load Line	Exactly on the X-axis	Below the X-axis	In between the X-axis and the Centre Load Line
Overall Efficiency	Poor 25 to 30%	Better 70 to 80%	Higher than 80%	Better than A but less than B 50 to 70%
Signal Distortion	None if Correctly Biased	At the X-axis Crossover Point	Large Amounts	Small Amounts



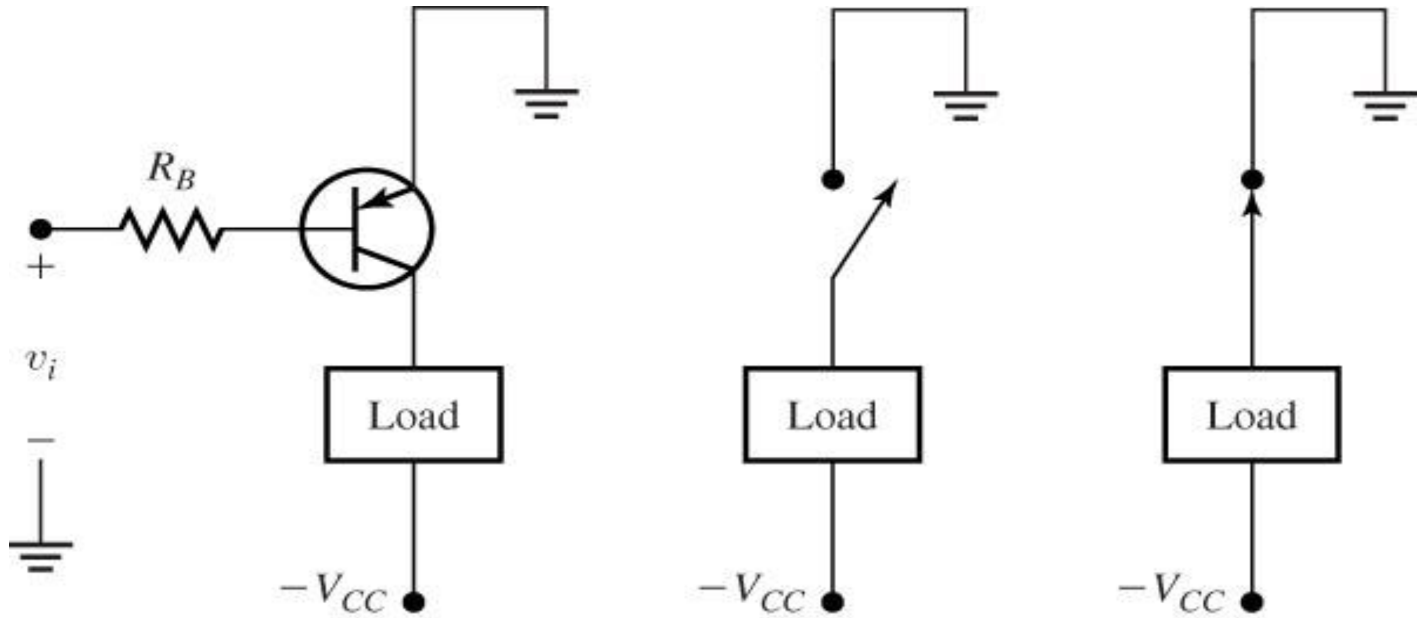
Load Switching

BJT switch using an NPN transistor.



(a) (b) $v_i = 0$ (c) $v_i = V_i$

BJT switch using a PNP transistor.



(a) (b) $v_i = 0$ (c) $v_i = -V_i$

BJT as a switch

- In cut off region, both junctions BE & BC are reversed biased.
- Small reverse current flows through transistor.
- Voltage drop across transistor (VCE) is high.
- Hence transistor is like an open switch.
- Input voltage is zero so IB = IC = 0

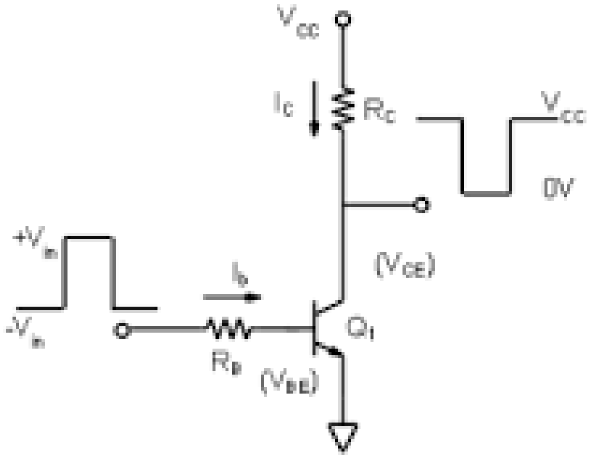
BJT as a switch

Applying KVL to collector ckt.

$$V_{cc} = IcRc + V_{CE}$$

$$Ic = 0$$

so , $Vcc = V_{CE}$



Voltage across transistor CE is very high, equal to Vcc & current Ic = 0

so

$$Vcc = Ic.R$$

$$R = \frac{Vcc}{Ic} = \frac{Vcc}{0} = \infty$$

Means if offers infinite resistance

∞ resistance means open switch.

Transistor in Saturation region

- High input voltage Vin is applied at the base.
- R_B value is adjusted such that it satisfies the condition,

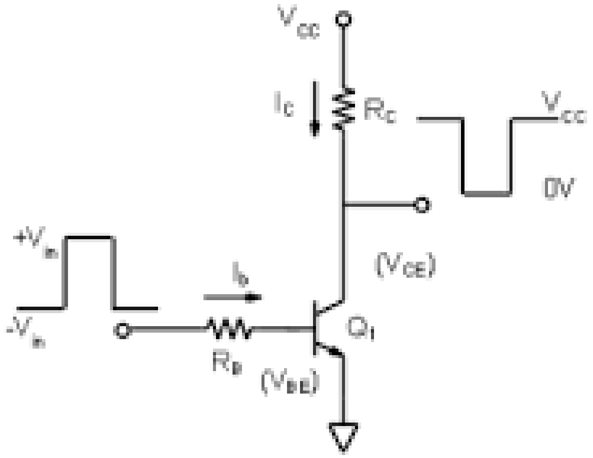
IB ≥ IC(sat)/ β

In saturation region, both junctions are FB, Voltage drop across transistor (VCE) is very small

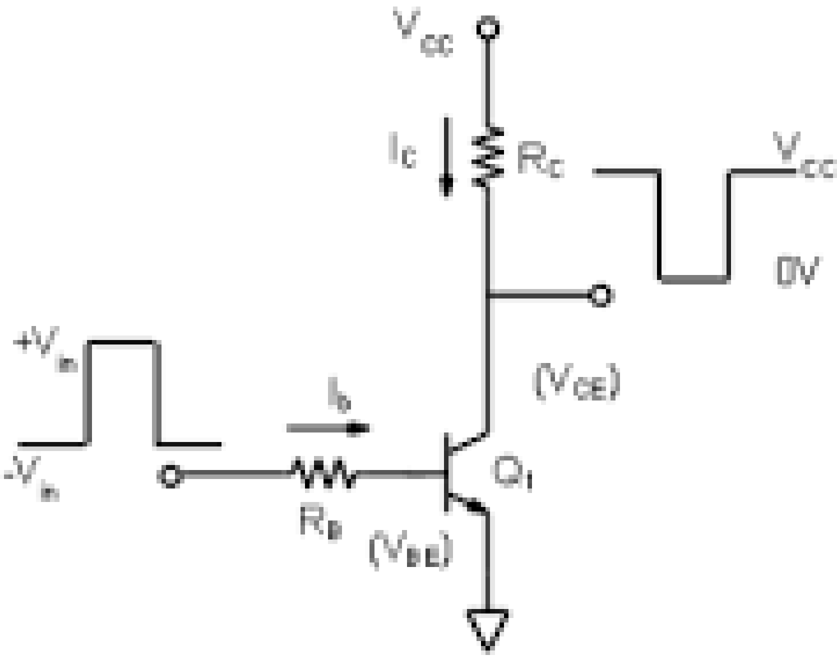
Low voltage drop, 0.2V (almost zero) & large current through it indicates zero resistance.

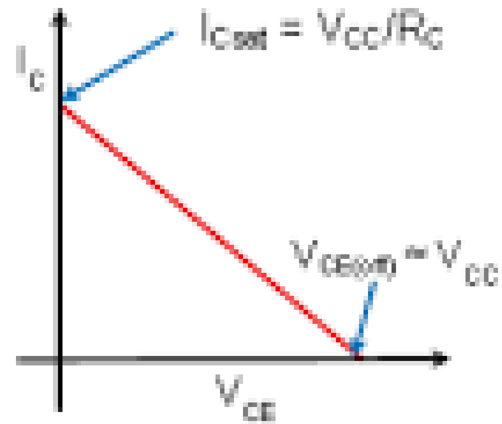
V = I. R

0 = I.R Hence R = 0 so transistor is equivalent to closed switch.



BJT as a switch



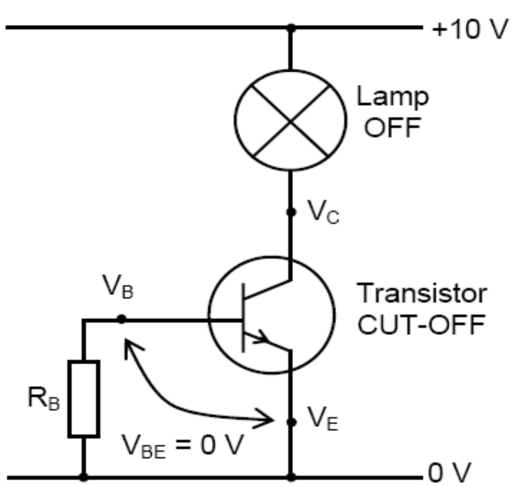


Load Line

Transistor as an Off switch

A switching circuit

i) Transistor as an OFF switch



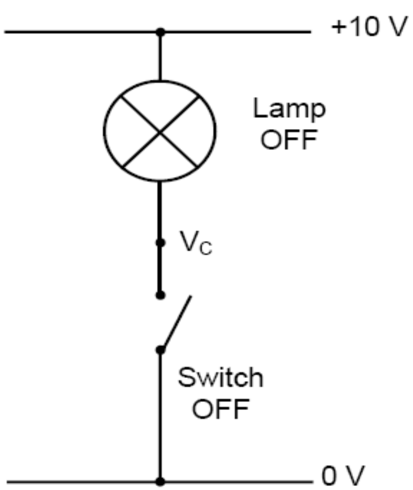


Fig. 5.25(a) – Transistor in CUT-OFF Condition (no current)

Fig. 5.25(b) – Transistor compared to switch

Transistor in Saturation region

ii) Transistor as an ON switch

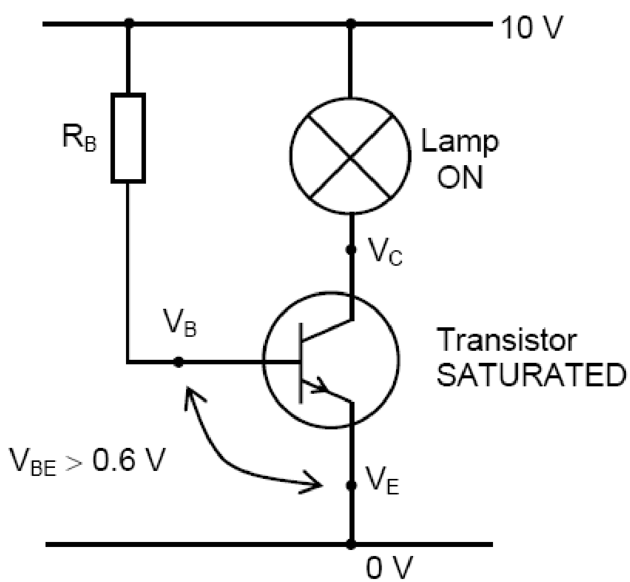


Fig. 5.26(a) – Transistor in SATURATED Condition (maximum current)

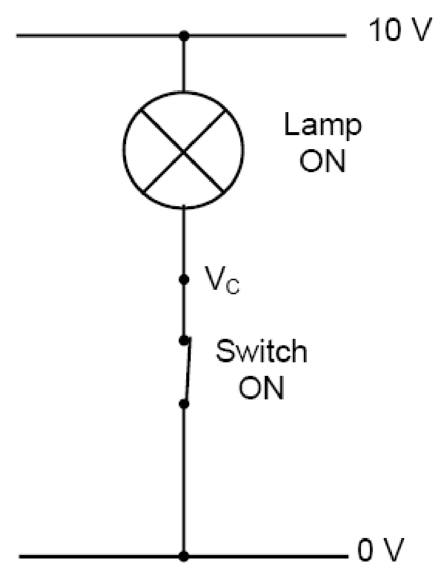
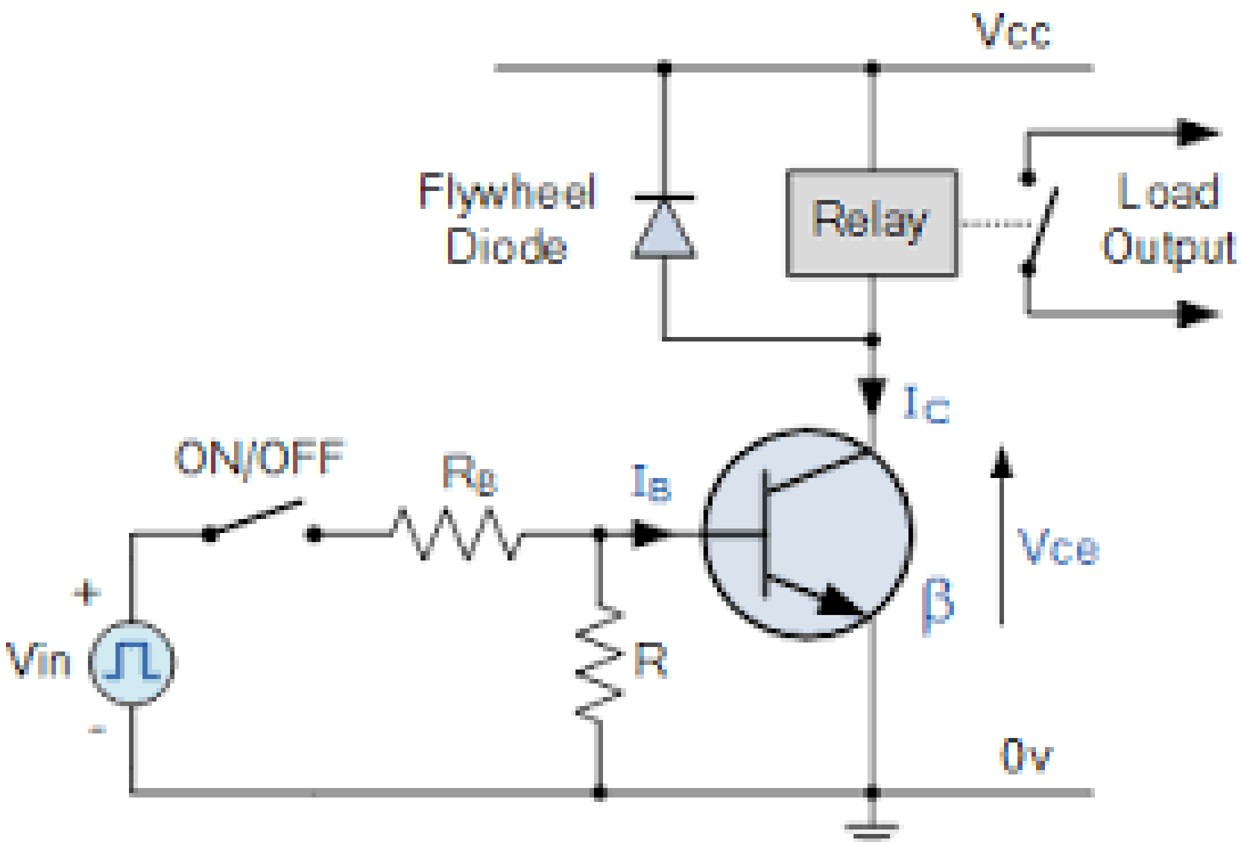


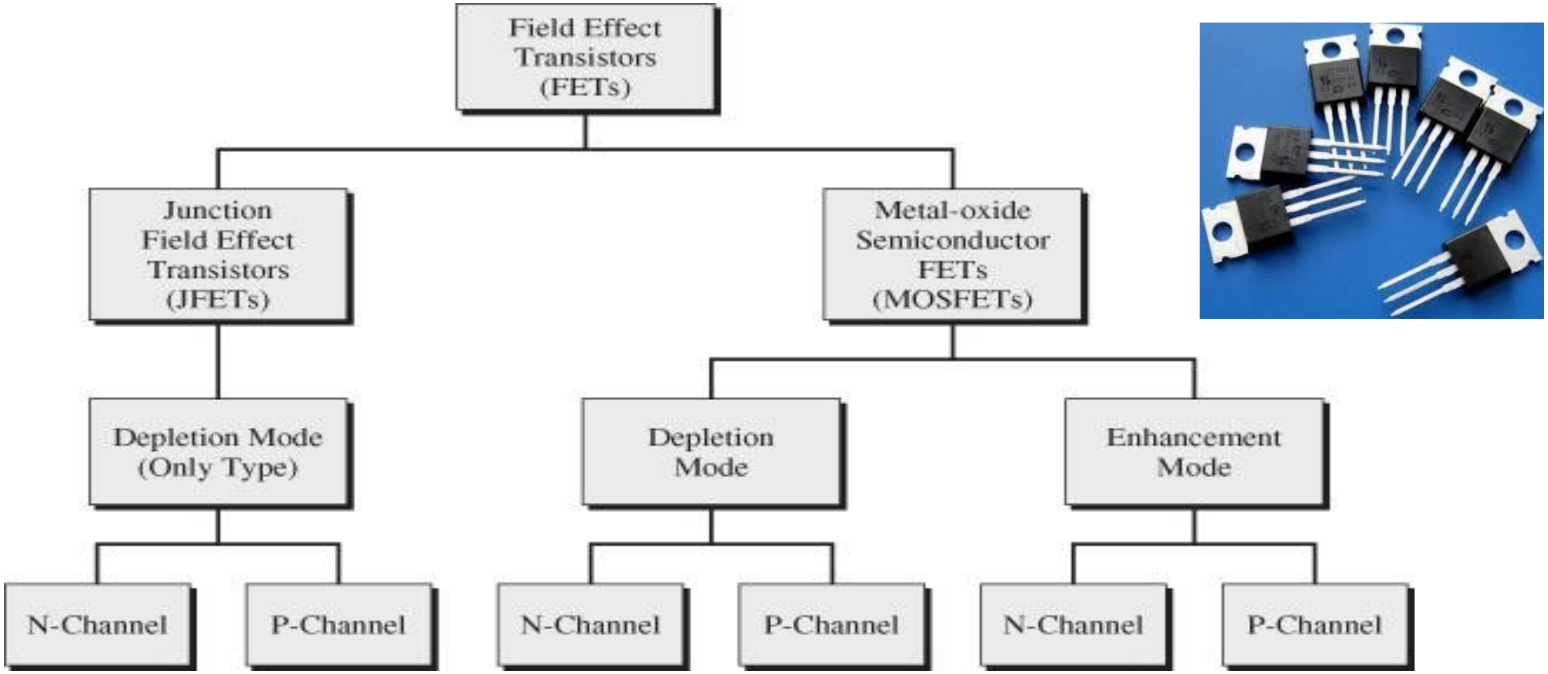
Fig. 5.26(b)

BJT as a switch

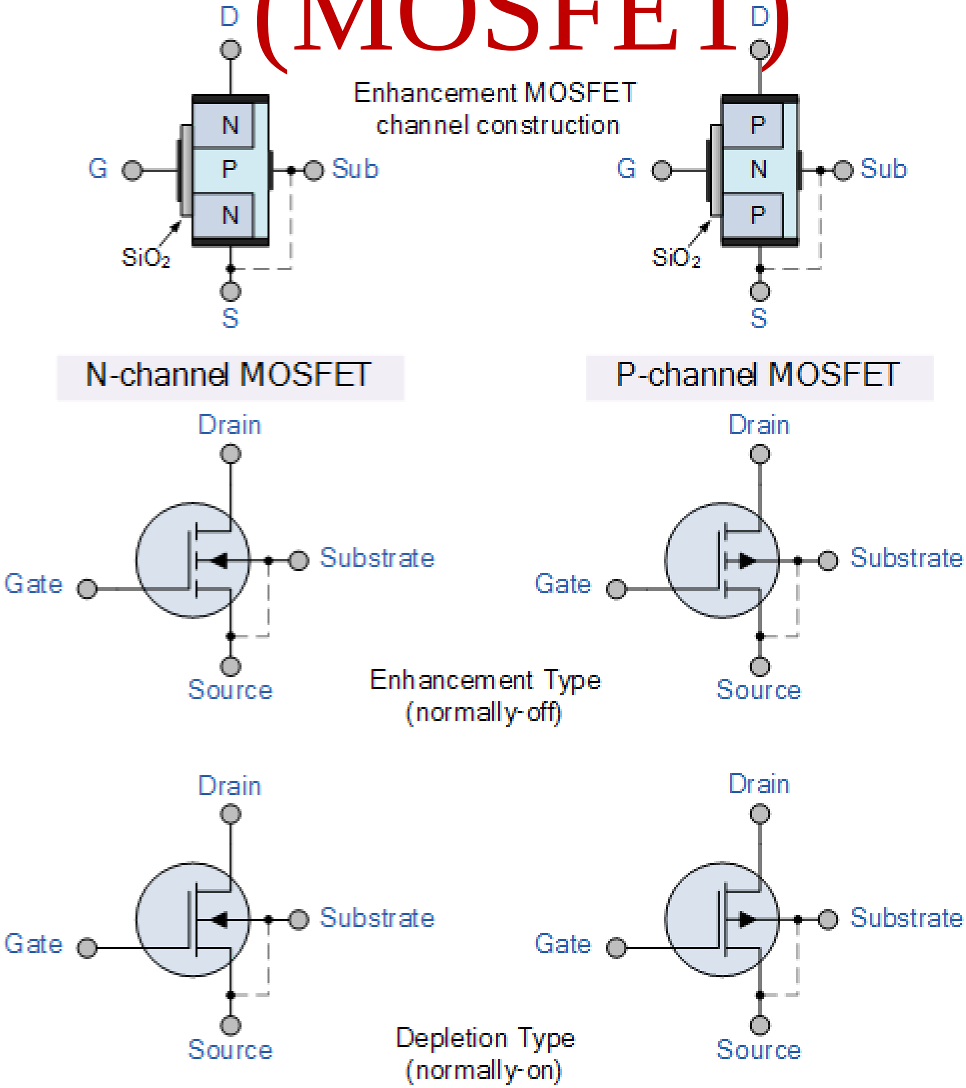


Field Effect Transistors (FET)

- An electronic device which uses an electric field to control the flow of current.
- FETs are devices with three terminals: *source*, *gate*, and *drain*.
- FETs control the flow of current by the application of a voltage to the gate, which in turn alters the conductivity between the drain and source.

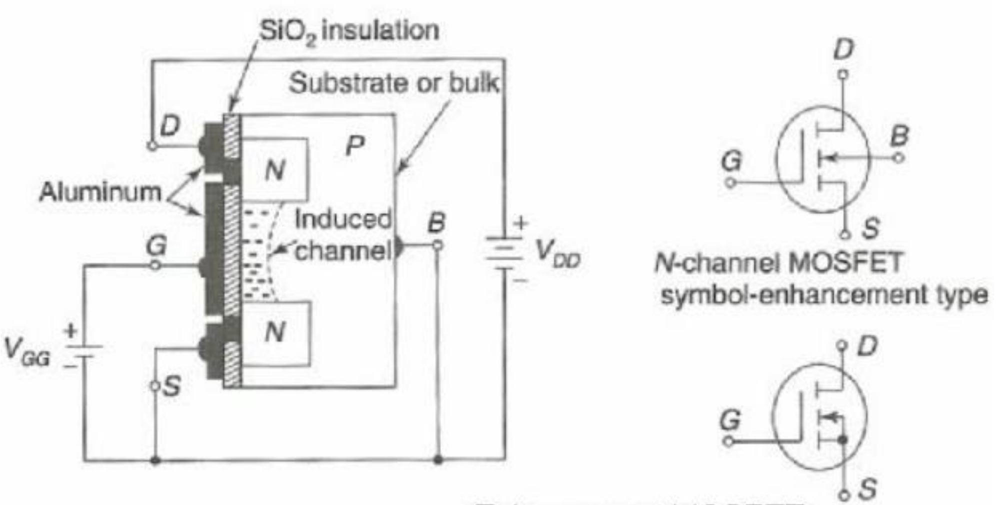


MOS Field Effect Transistors (MOSFET)

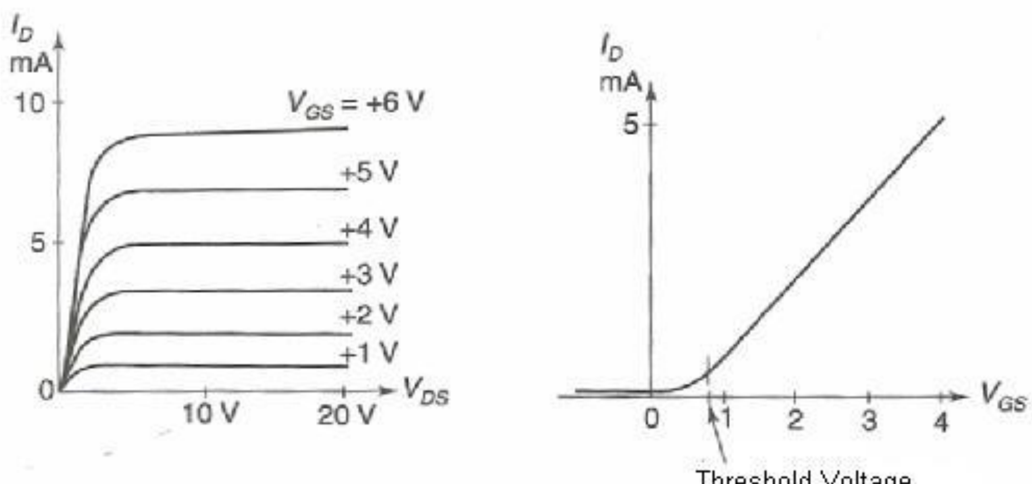


MOSFET

MOS Field Effect Transistors (MOSFET)



Enhancement MOSFET



Enhancement MOSFET Drain Characteristics

BJT Vs. FET

BJT	FET
High voltage gain	Low voltage gain
Low current gain	High current gain
Low input impedance	Very high input impedance
Low output impedance	High output impedance
Medium Noise Generation	Low Noise generation
Medium switching time	Fast switching time
Robust	Easily damaged
Requires zero input to turn it "OFF"	Some need an input to turn it "OFF"
It is a Current controlled device.	It is a Voltage controlled device.
Cheap	More expensive than BJT.
Easy to bias	Difficult to bias

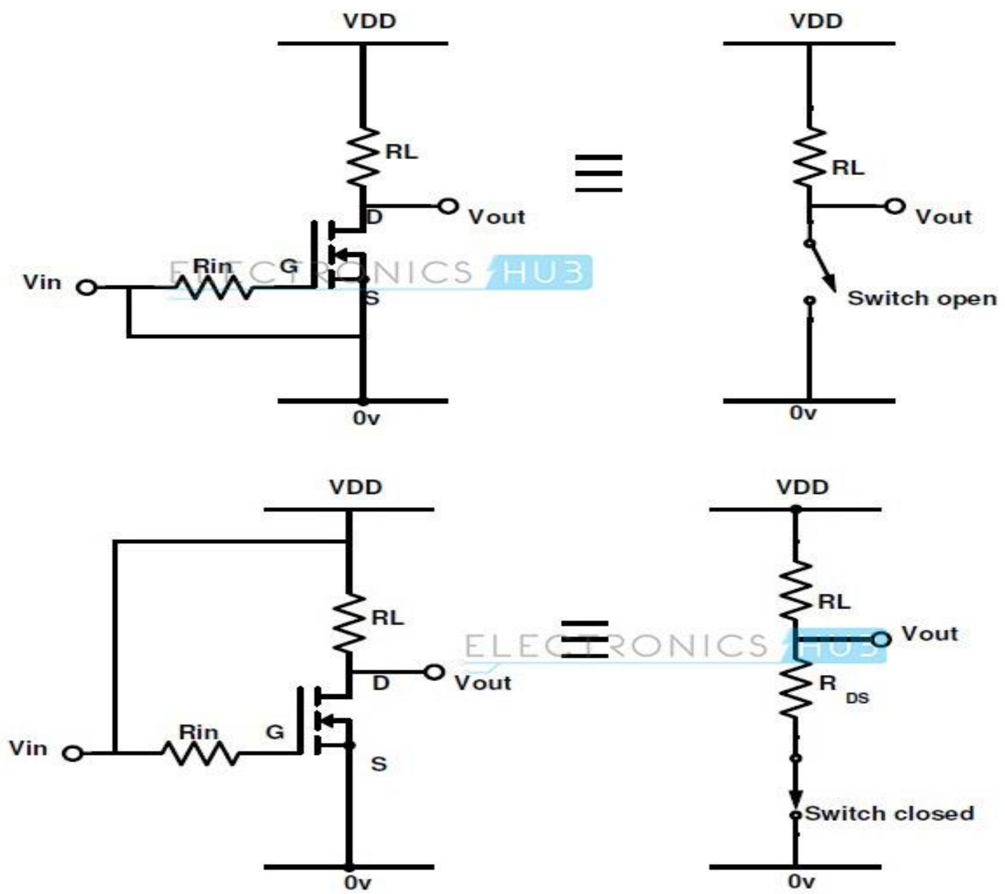
Checkpoint

Question	A	B	C	D	Answer
In semiconductor transistor to make proper heat dissipation from collector area ………..	Base area is greater than emitter area	collector of transistor is lightly doped	Base area is less than emitter area	emitter of transistor is heavily doped	
The doping concentration is highest in……………………………..region of BJT.	base	emitter	collector	none of these	
The ……………………… is current gain of CB configuration	α_{DC}	β_{DC}	Υ_{DC}	none of these	
What is the collector current for a C-E configuration with a beta of 100 and a base current of 30 μA?	30 μA	3 μA	3 mA	30 mA	
Transistor acts as open switch in…………………………region.	cut-off	active	saturation.	none of these	

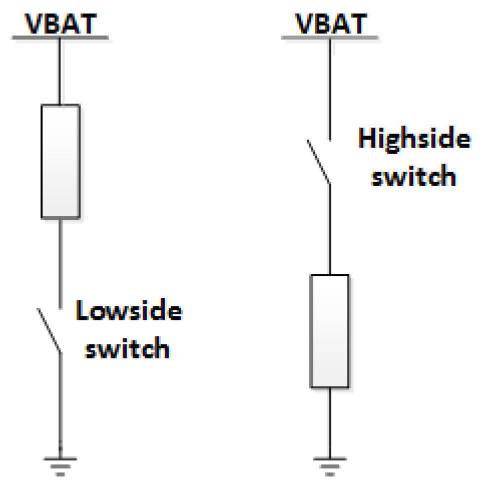
Checkpoint

Question	A	B	C	D	Answer
In semiconductor transistor to make proper heat dissipation from collector area ……….	Base area is greater than emitter area	collector of transistor is wider in size	Base area is less than emitter area	emitter of transistor is heavily doped	B
The doping concentration is highest in……………………………region of BJT.	base	emitter	collector	none of these	B
The ………………………… is current gain of CB configuration	α_{DC}	β_{DC}	Υ_{DC}	none of these	A
Transistor acts as open switch in…………………………region.	cut-off	active	saturation.	none of these	A

MOSFET as a Switch

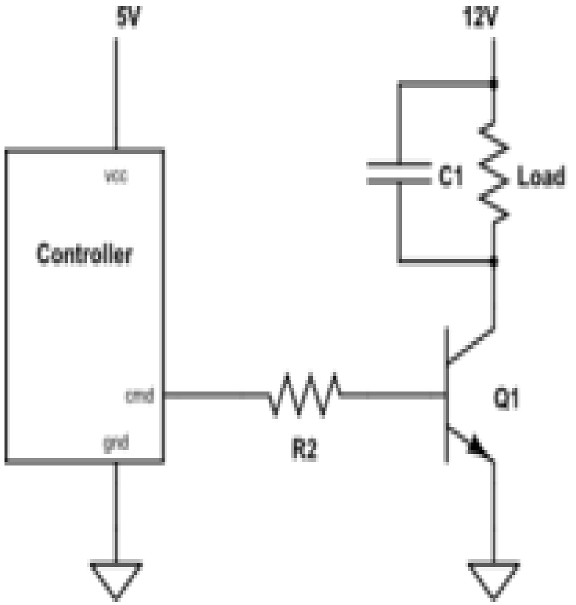


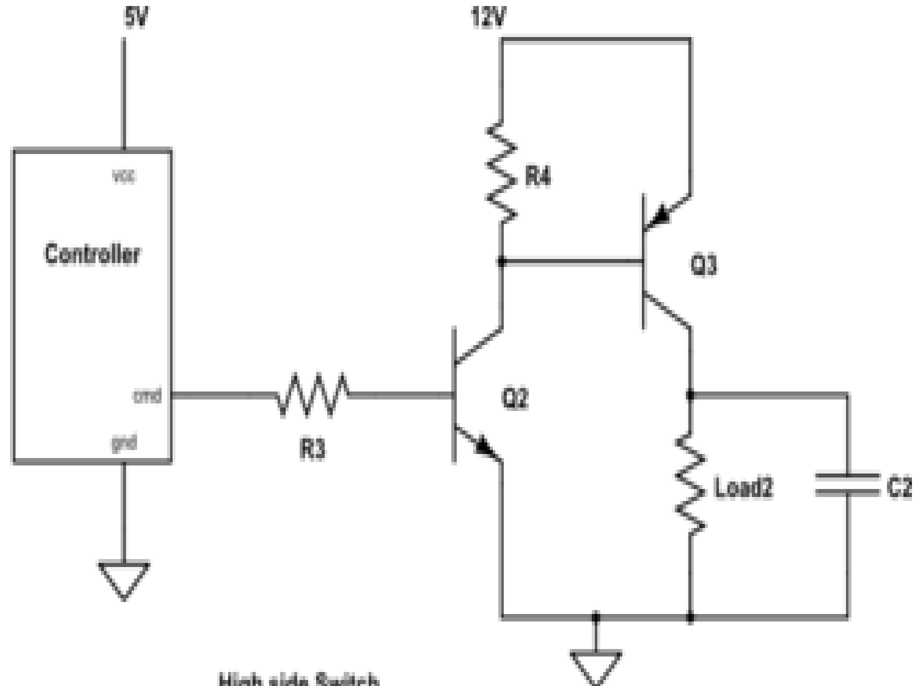
Load Switching



- A high side driver is one in which the switching element is between Vcc and the load.
- A low side driver is one in which the switching element is between the load and common.
- A self-contained load such as a DC motor, solenoid/relay, light or LED string, can usually be driven by either method.

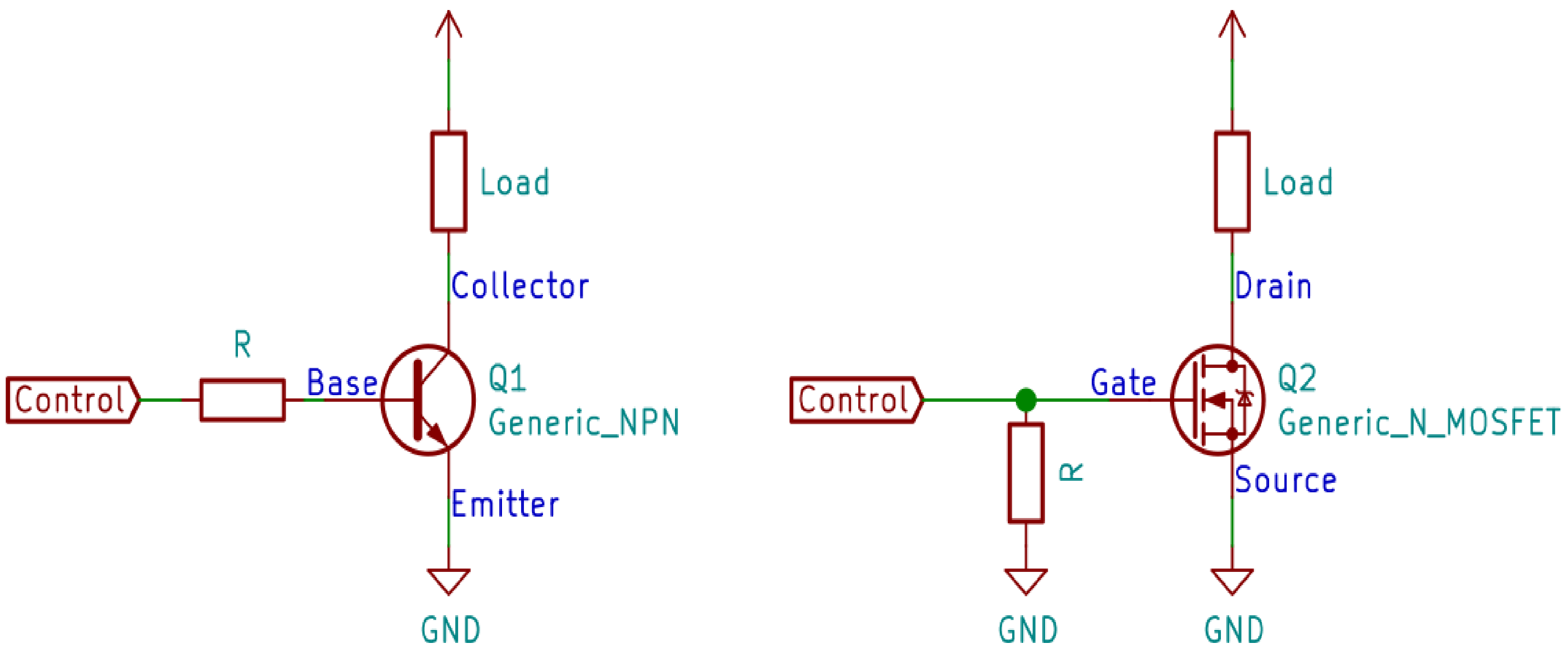
Load Switching



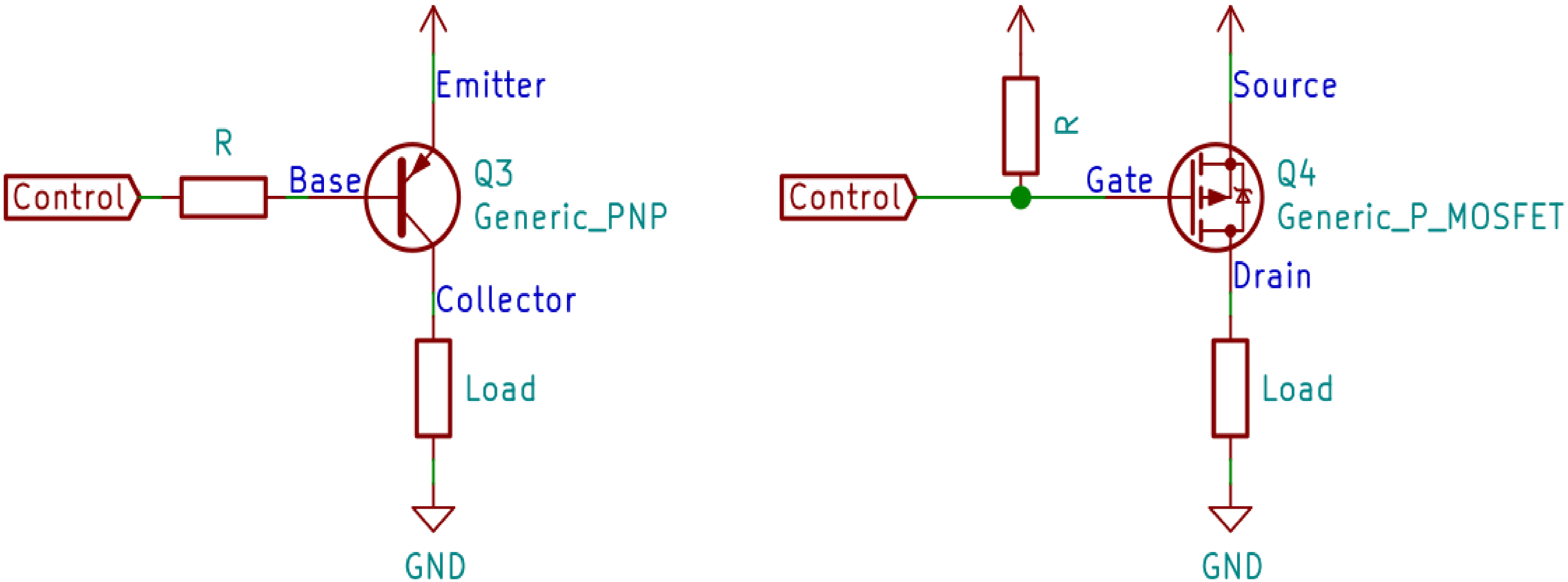

Low side Switch

High side Switch

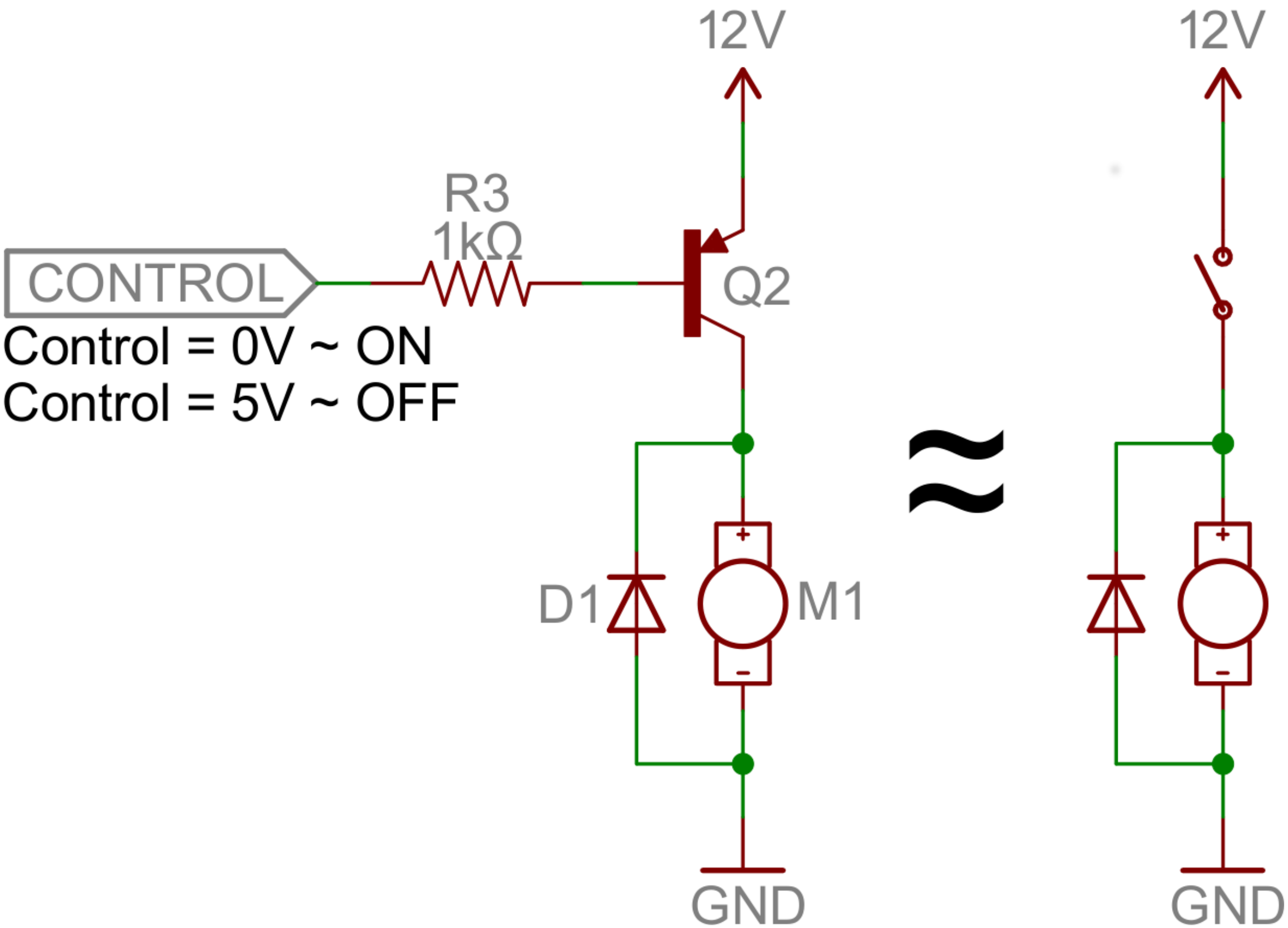
Low-Side Switching



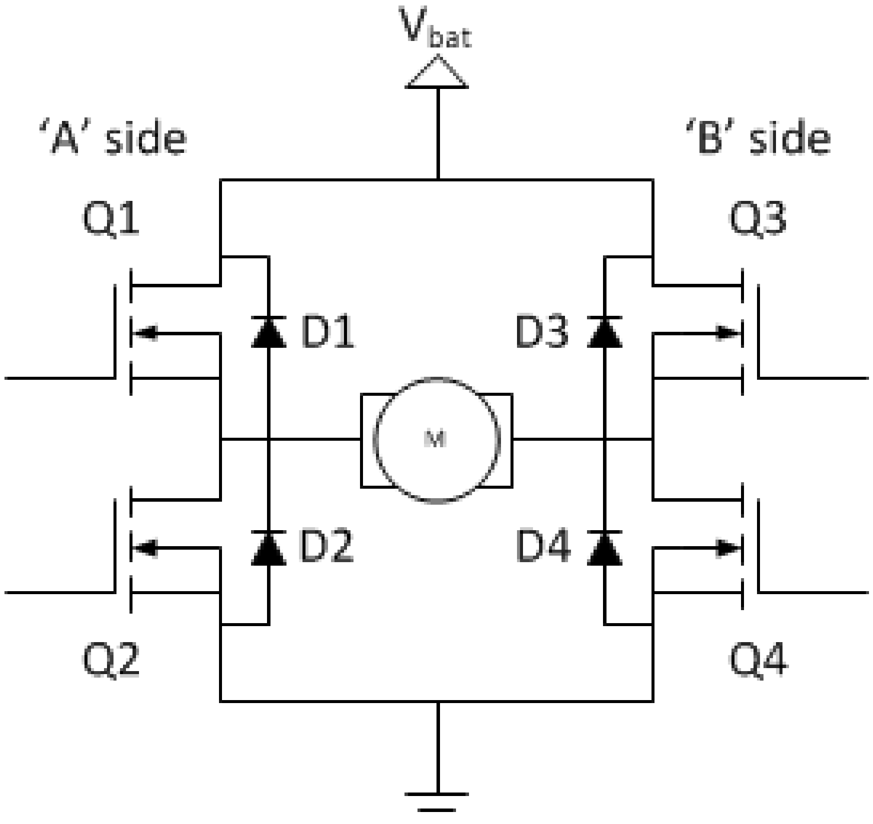
High-Side Switching



Load Switching



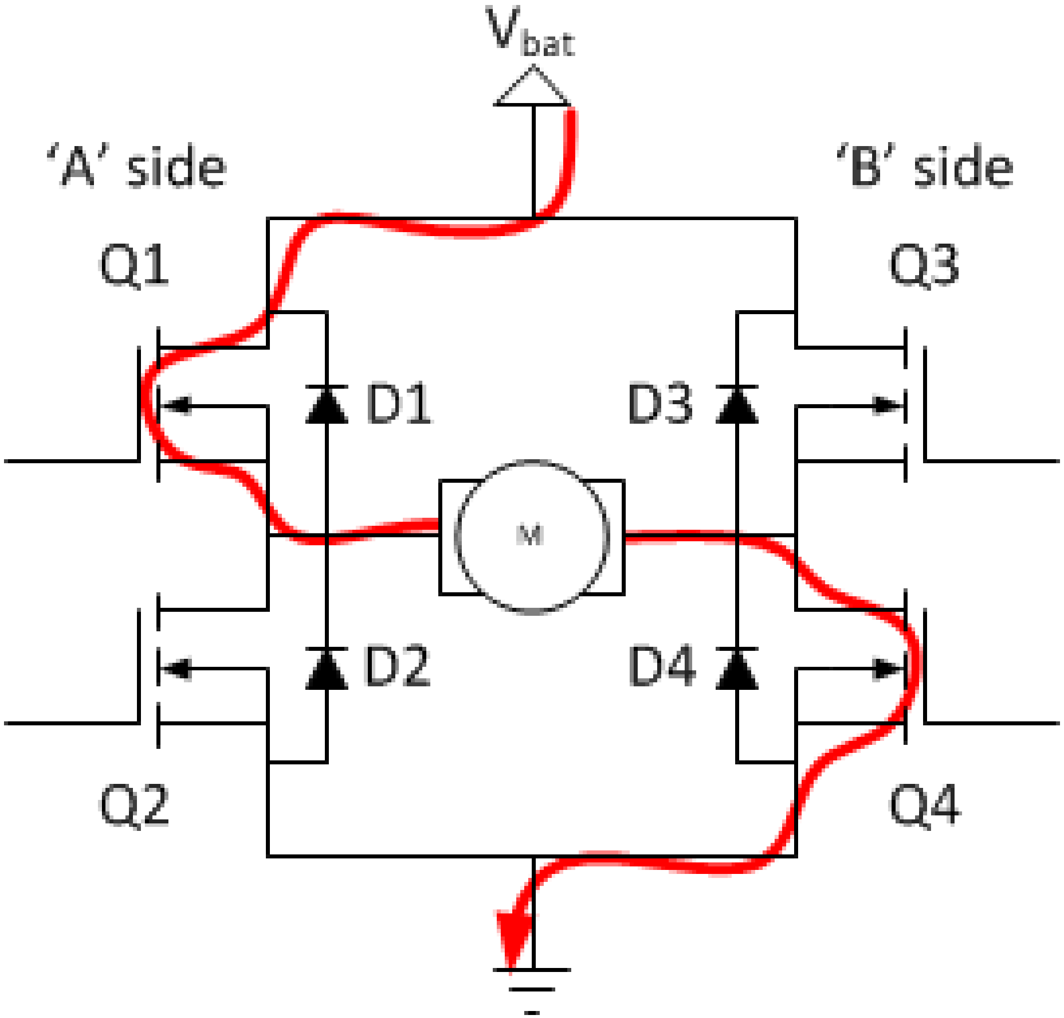
H Bridge



- Contains four switching element, with the load at the center

- The switching elements (Q1..Q4) are usually bi-polar or FET transistors
- Integrated solutions also exist

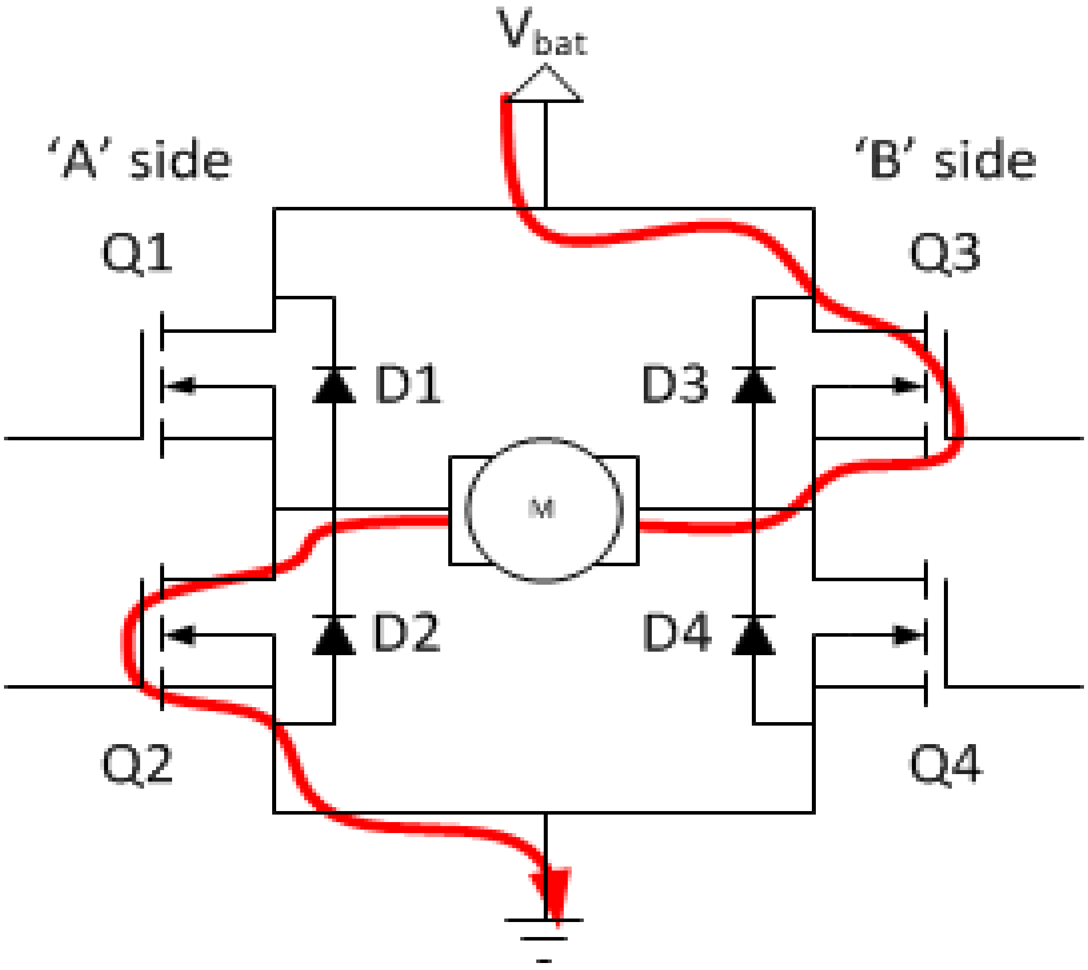
H Bridge



Q1 and Q4 are turned on

the motor starts moving in forward direction

H Bridge



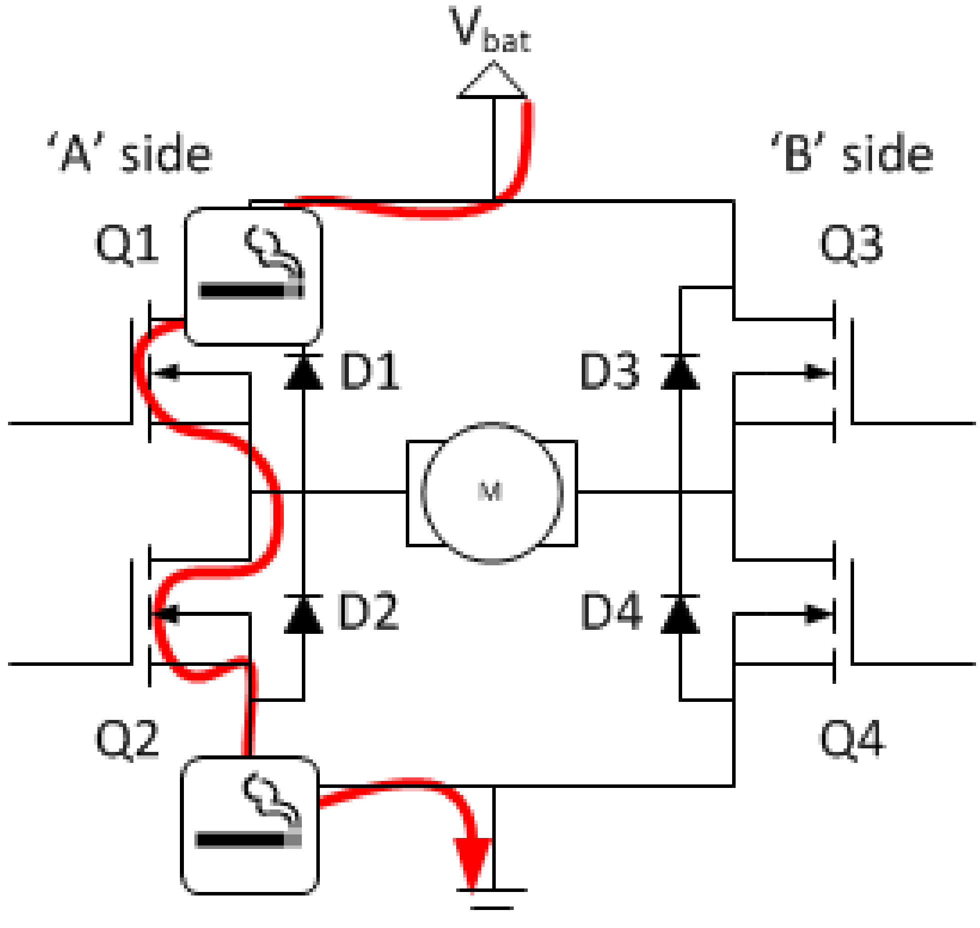
If Q2 and Q3 are turned on,

the motor gets energized in the reverse direction

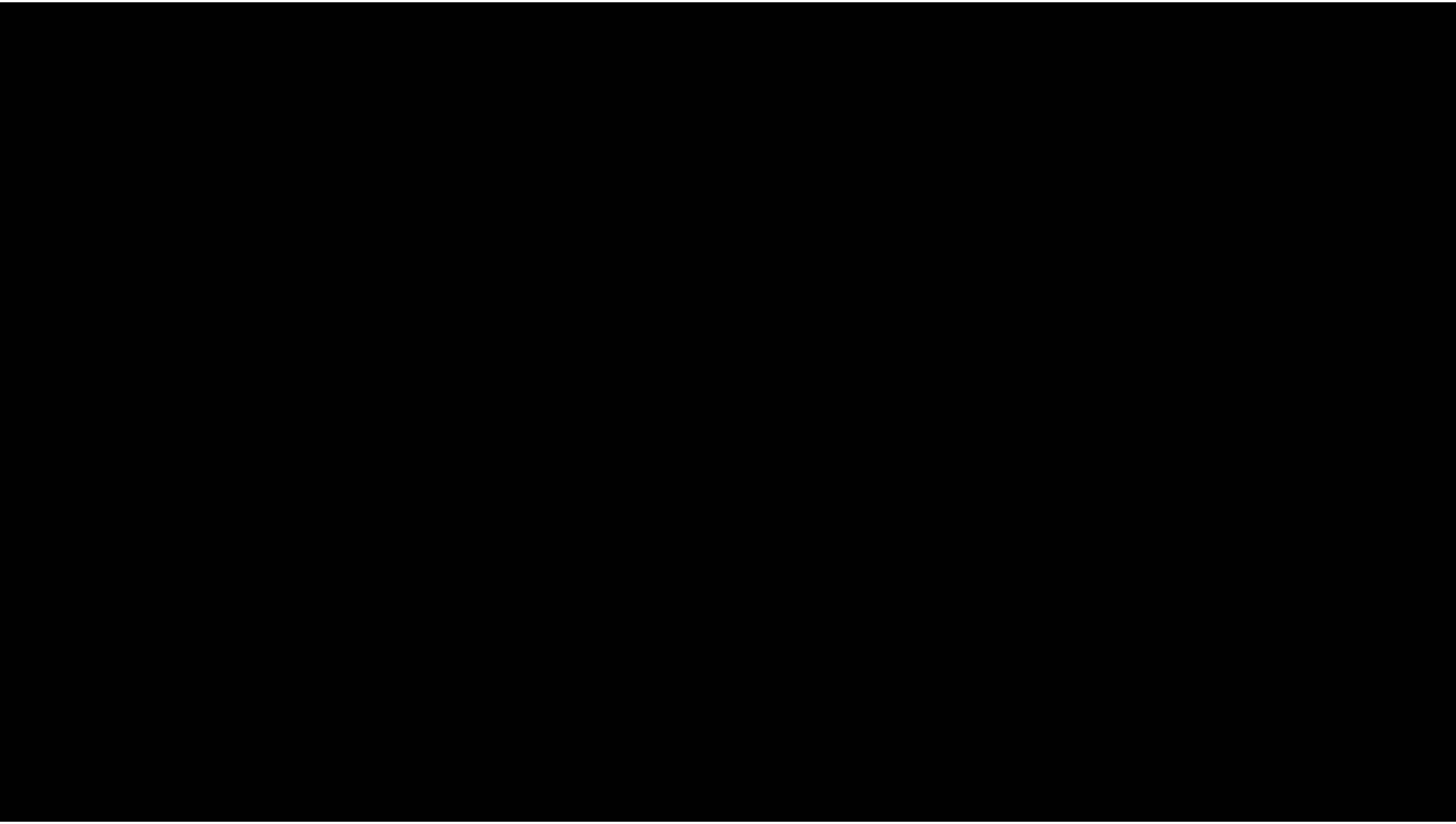
.

H Bridge

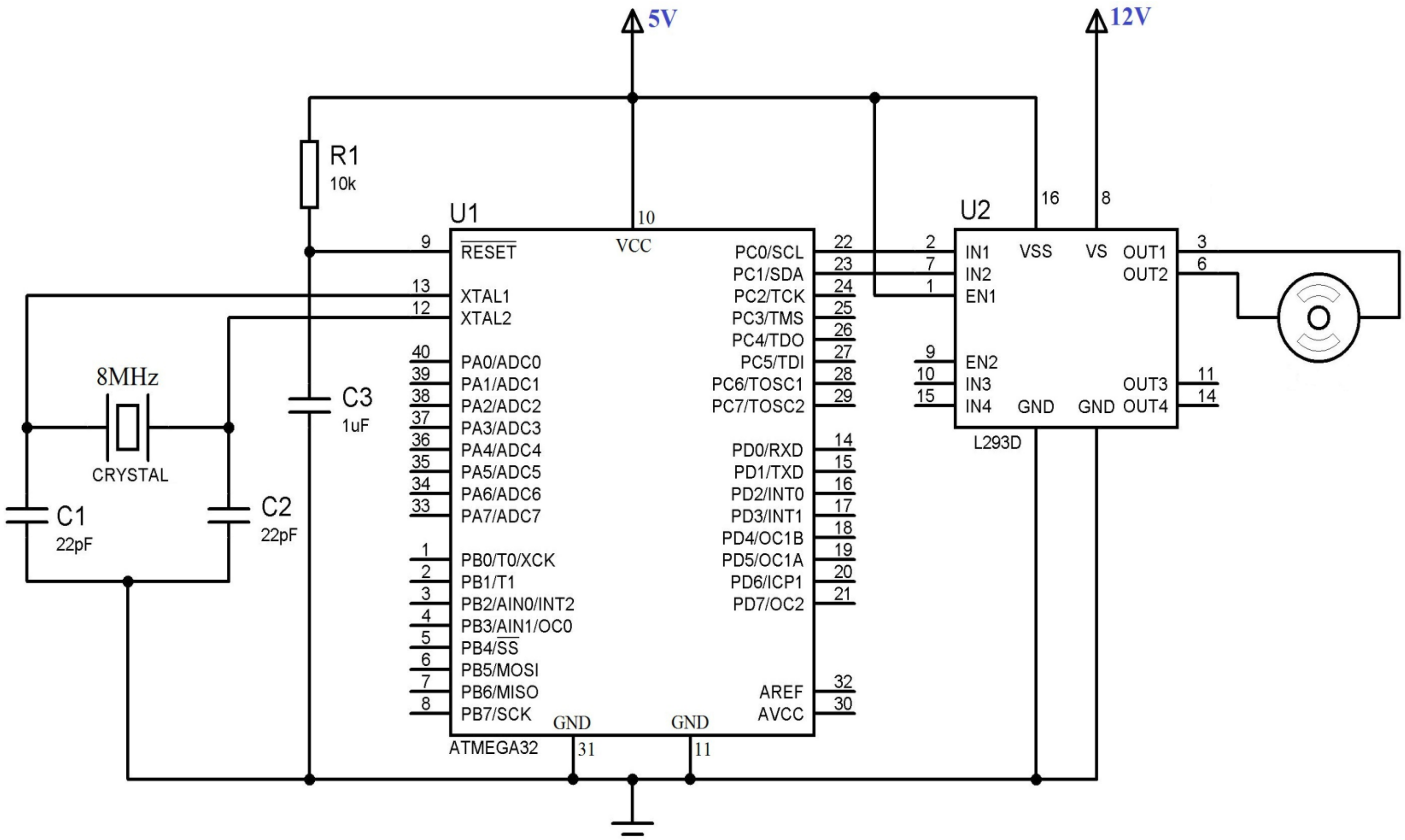
In a bridge, you should **never** ever close both Q1 and Q2 (or Q3 and Q4) at the same time.



H - Bridge Demo

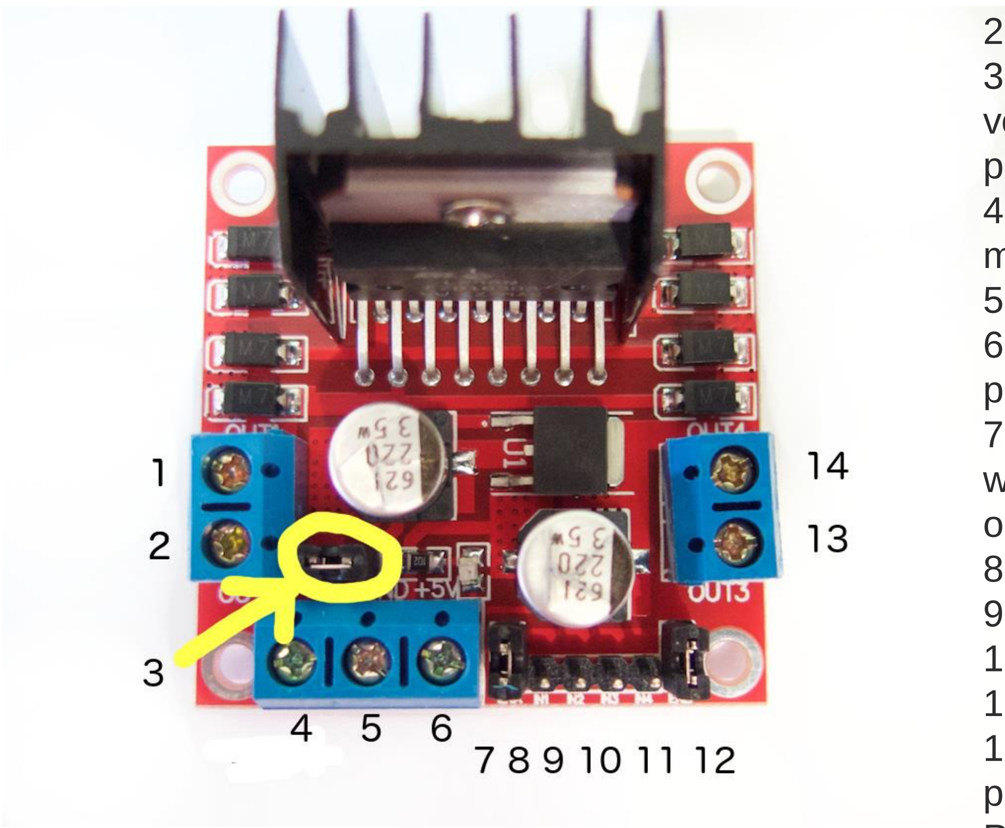


H Bridge IC



5V
12V
R1
10k
U1
U2
8MHz
CRYSTAL
C1
22pF
C2
22pF
C3
1uF
RESET
XTAL1
XTAL2
VCC
PA0/ADC0
PA1/ADC1
PA2/ADC2
PA3/ADC3
PA4/ADC4
PA5/ADC5
PA6/ADC6
PA7/ADC7
PB0/T0/XCK
PB1/T1
PB2/AIN0/INT2
PB3/AIN1/OC0
PB4/SS
PB5/MOSI
PB6/MISO
PB7/SCK
GND
GND
PC0/SCL
PC1/SDA
PC2/TCK
PC3/TMS
PC4/TDO
PC5/TDI
PC6/TOSC1
PC7/TOSC2
PD0/RXD
PD1/TXD
PD2/INT0
PD3/INT1
PD4/OC1B
PD5/OC1A
PD6/ICP1
PD7/OC2
AREF
AVCC
ATMEGA32
IN1
IN2
EN1
EN2
IN3
IN4
VSS
VS
GND
GND
OUT1
OUT2
OUT3
OUT4
L293D

H Bridge IC Module

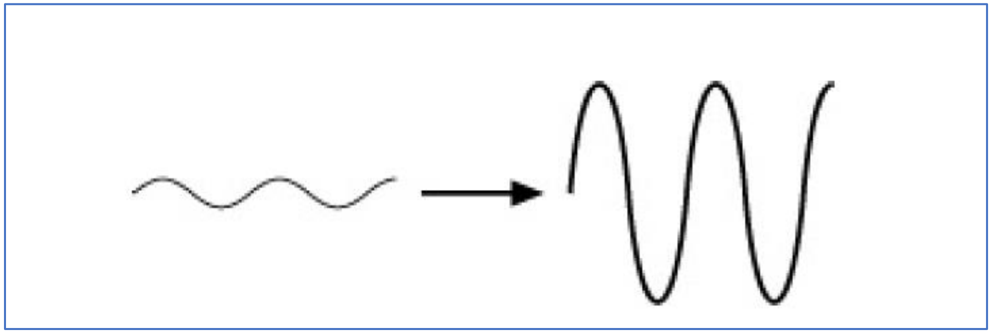


<u>L298N Dual H-Bridge Motor Driver Module</u>

1.DC motor 1 "+" or stepper motor A+
2.DC motor 1 "-" or stepper motor A-
3.12V jumper - remove this if using a supply voltage greater than 12V DC. This enables power to the onboard 5V regulator
4.Connect your motor supply voltage here, maximum of 35V DC.
5.GND
6.5V output if 12V jumper in place, ideal for powering your Arduino (etc)
7.DC motor 1 enable jumper. Leave this in place when using a stepper motor. Connect to PWM output for DC motor speed control.
8.IN1
9.IN2
10.IN3
11.IN4
12.DC motor 2 enable jumper. Leave this in place when using a stepper motor. Connect to PWM output for DC motor speed control.
13.DC motor 2 "+" or stepper motor B+
14.DC motor 2 "-" or stepper motor B-

Amplifier
Opamp Circuits

Amplifier

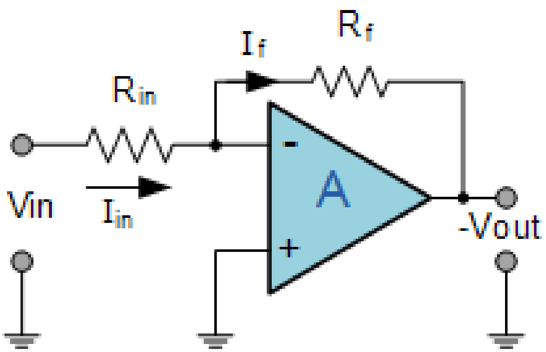


$$\text{Gain} = V_{OUT} / V_{IN}$$

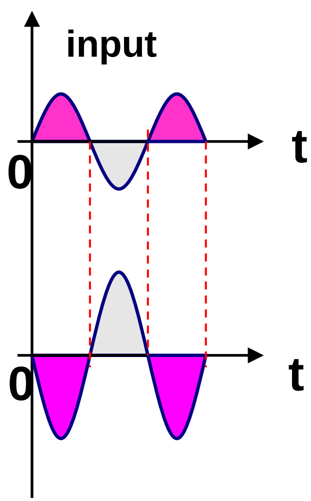
- An amplifier is a circuit that increases (or decreases) a given input voltage to produce an output voltage.
- If you had a sensor that produced a maximum output that was 5 mVpp, and this was to be interfaced to a sampling system that required an input signal of 5 Vpp.
- You would use an amplifier between the sensor and the sampling system to increase the sensor's output accordingly

Opamp Circuits

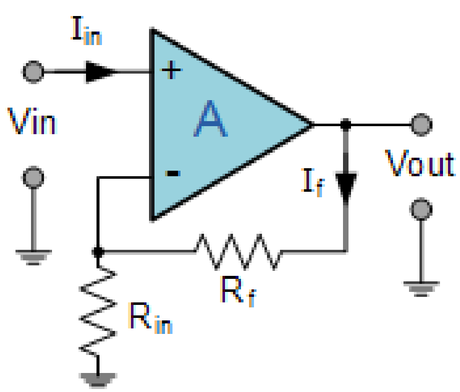
Inverting Op-amp



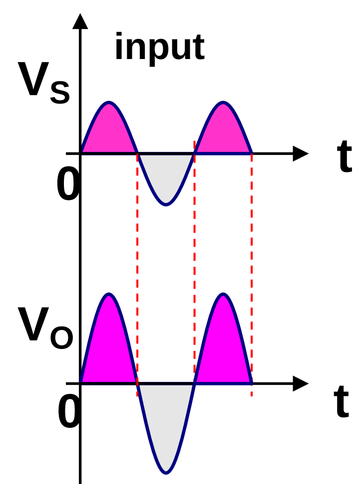
$$A = \frac{Vout}{Vin} = -\frac{Rf}{Rin}$$



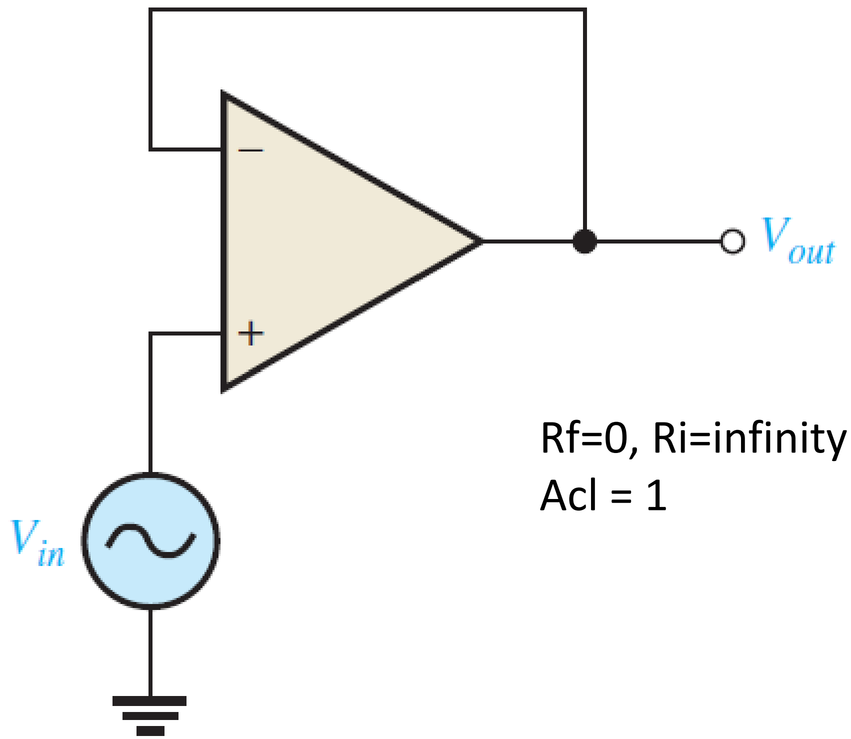
Non-inverting Op-amp



$$A = \frac{Vout}{Vin} = 1 + \frac{Rf}{Rin}$$



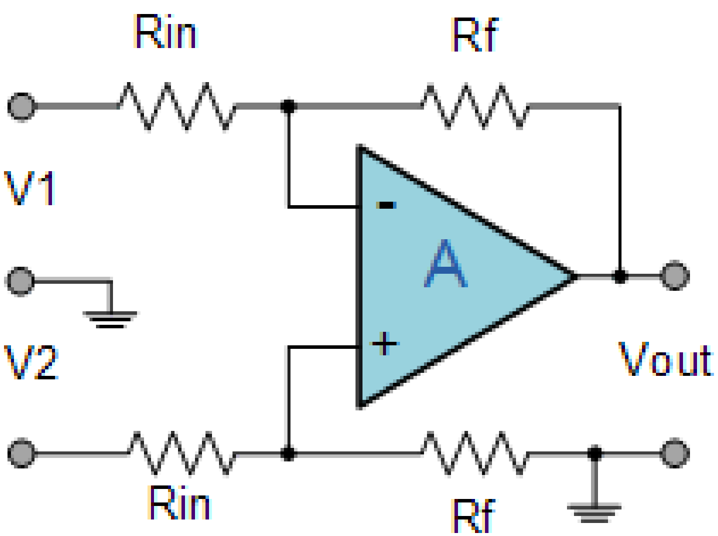
Opamp Circuits



Rf=0, Ri=infinity ohms
Acl = 1

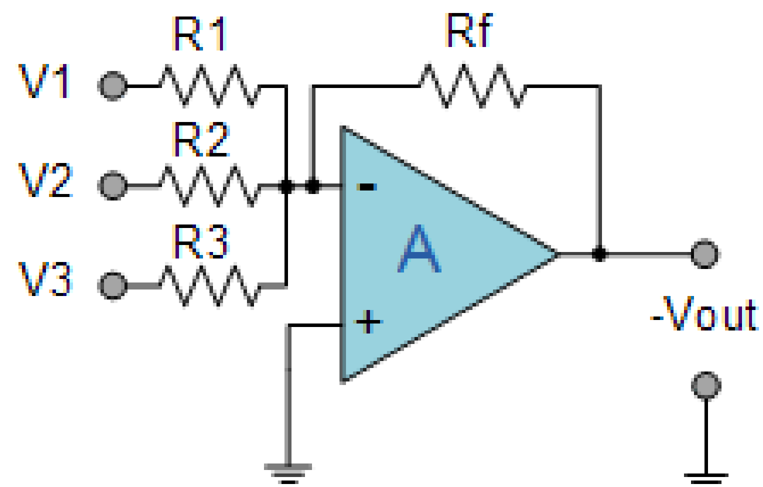
Opamp Circuits

Differential Op-amp



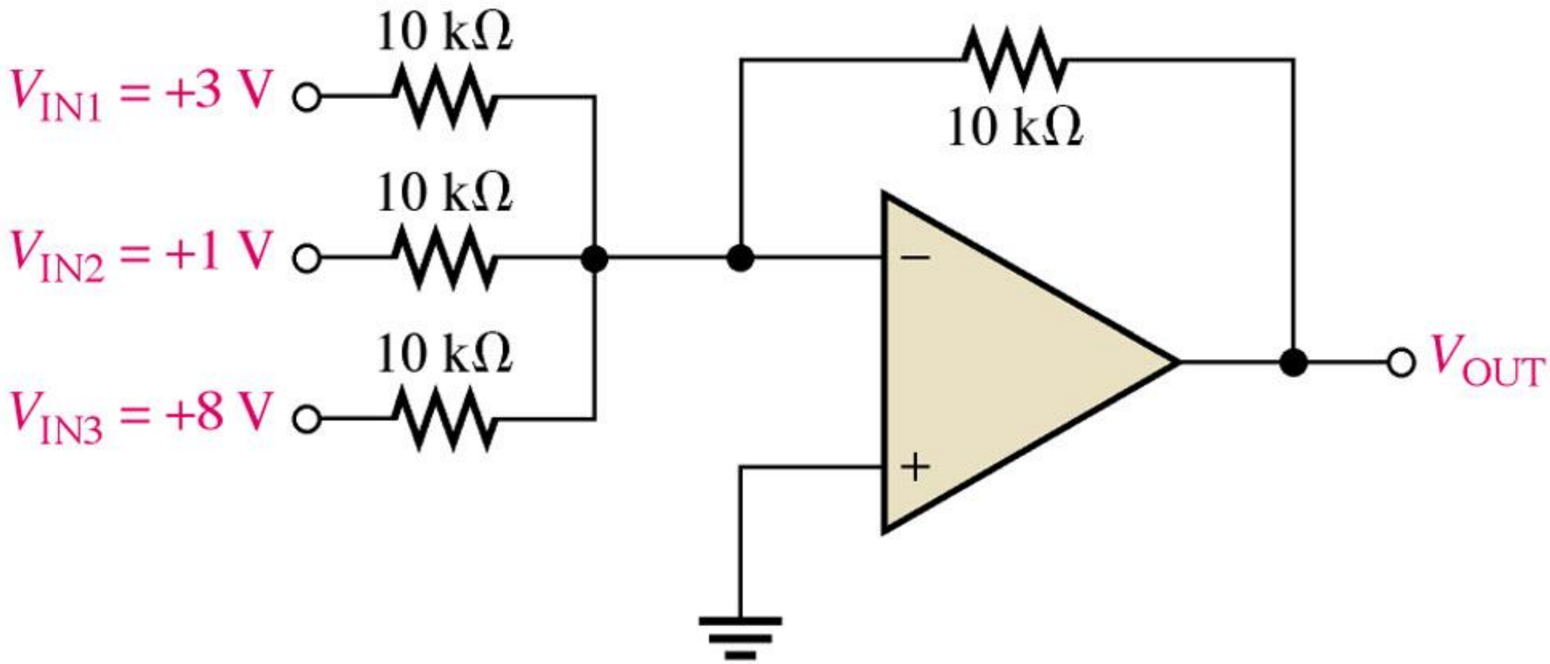
$$Vout = \frac{Rf}{Rin}(V2 - V1)$$

Summing Op-amp

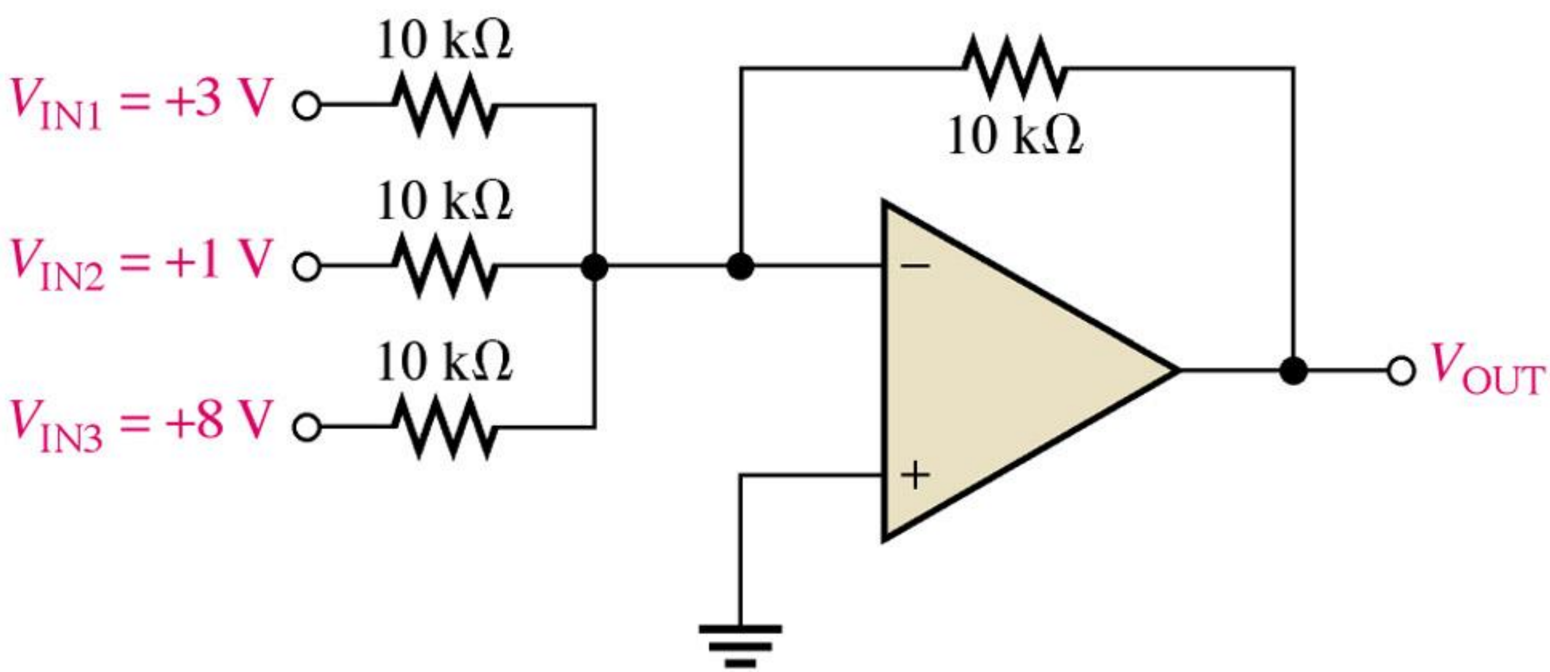


$$Vout = -\left(\frac{Rf}{R1}V1 + \frac{Rf}{R2}V2 + \frac{Rf}{R3}V3\right)$$

Determine the output voltage in given figure

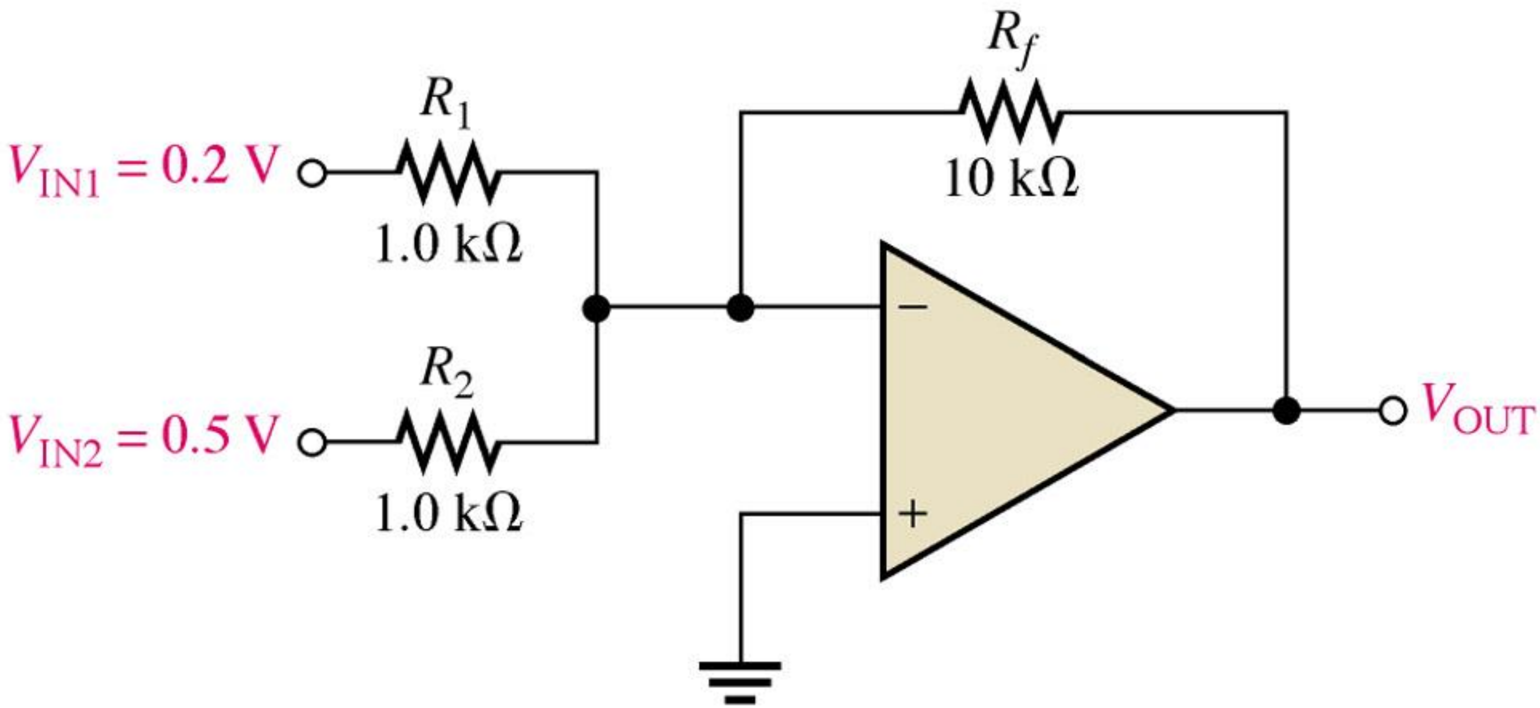


Determine the output voltage in given figure

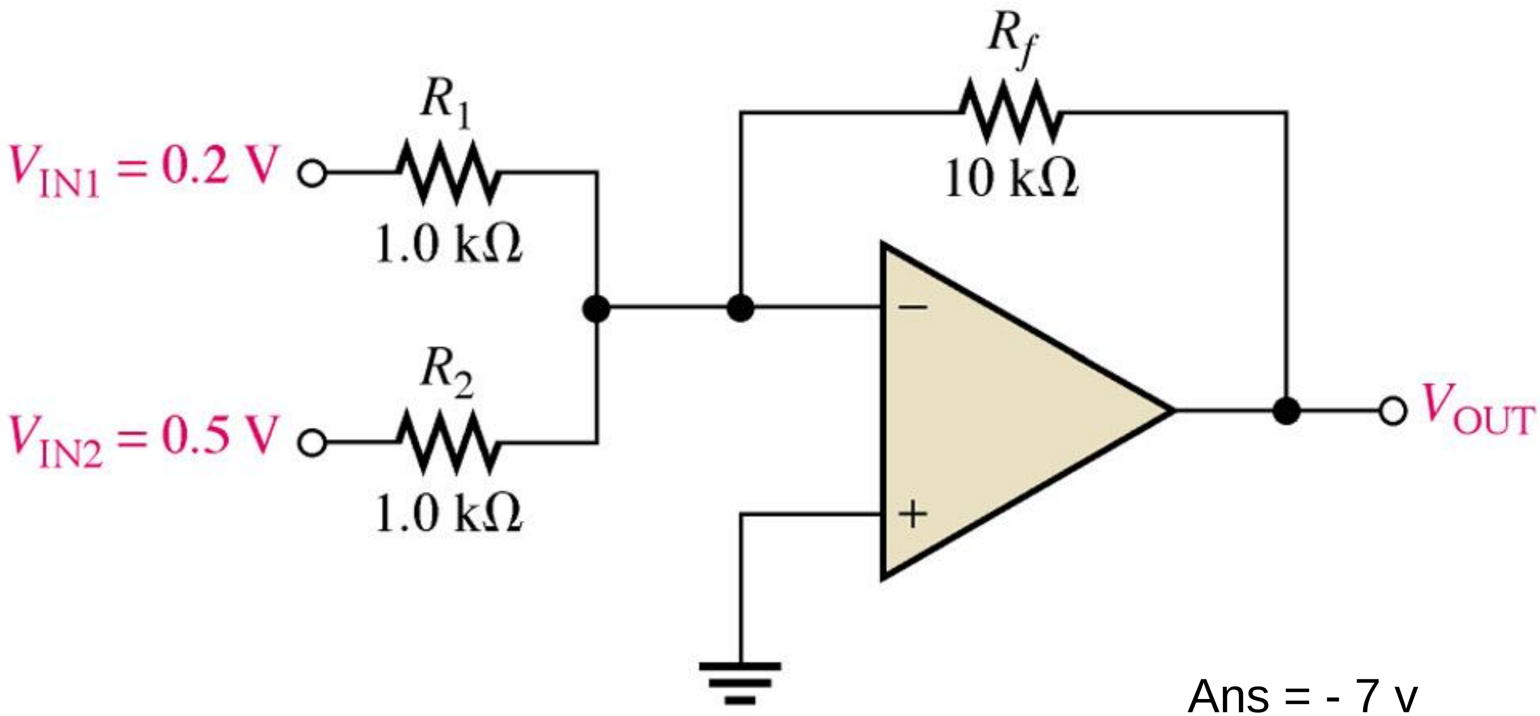


Ans = - 12V

Determine the output voltage in given figure

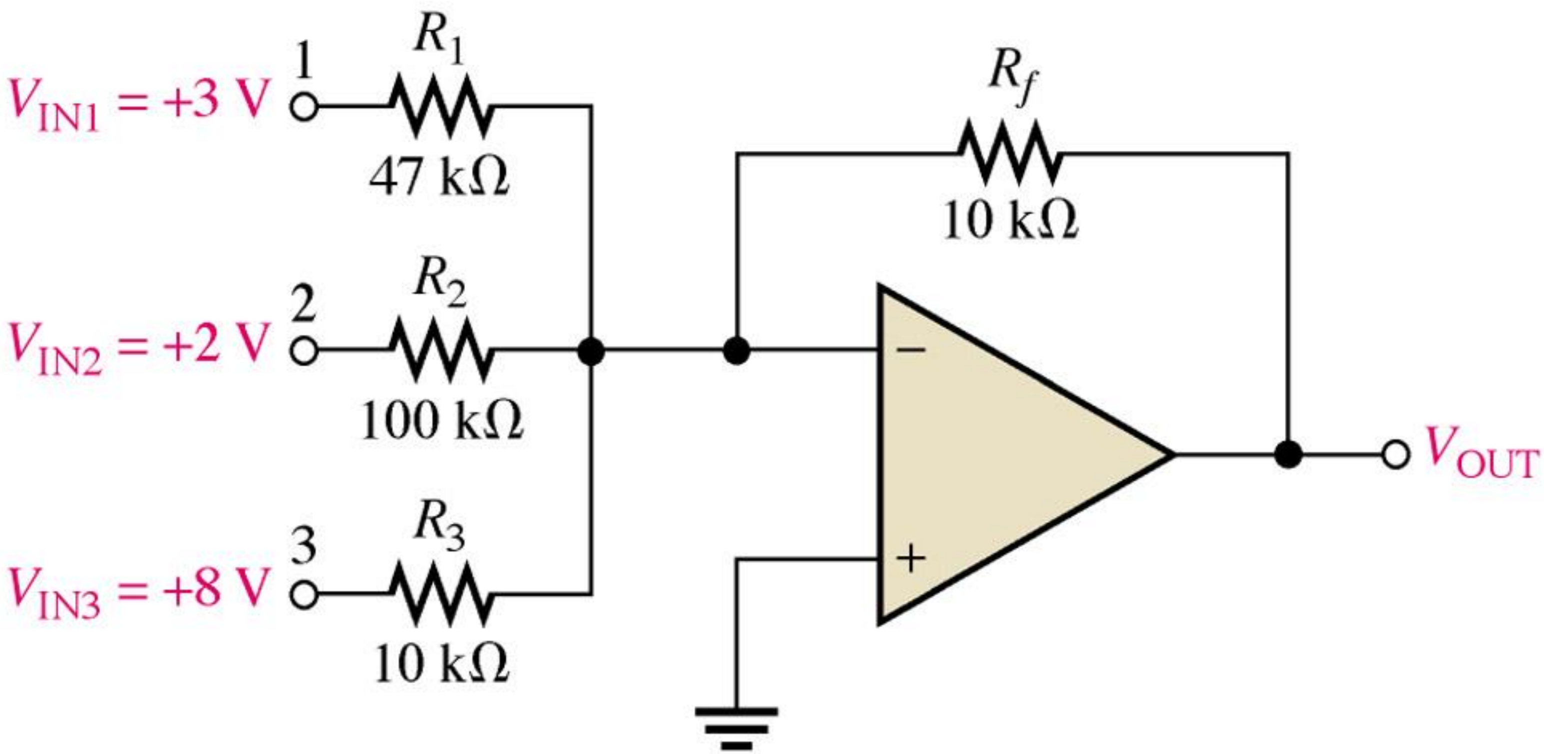


Determine the output voltage in given figure

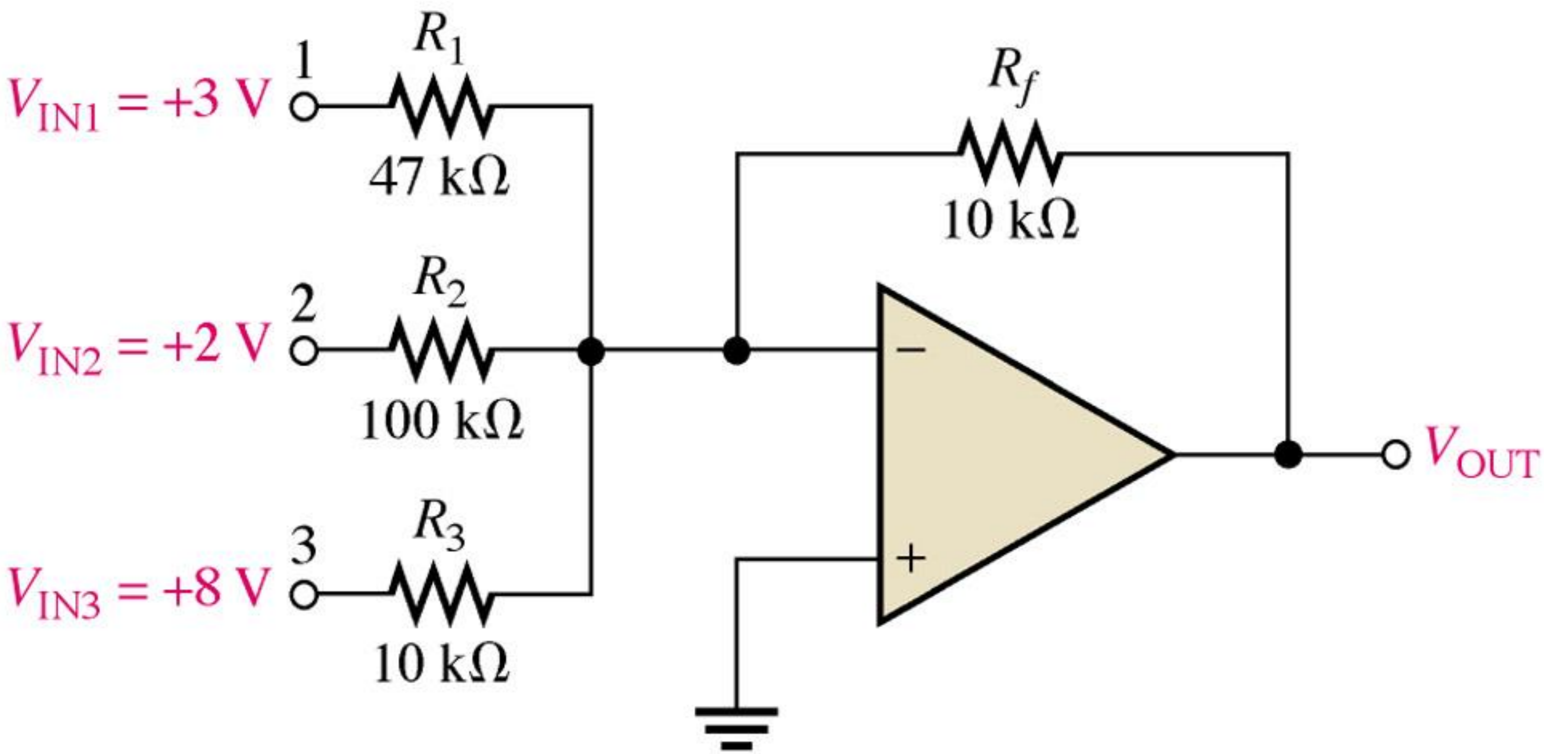


Ans = - 7 v

Determine the output voltage in given figure

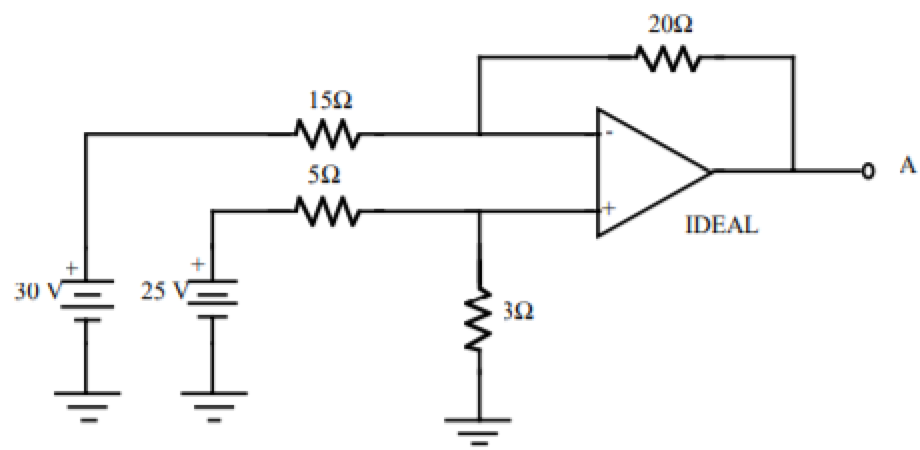


Determine the output voltage in given figure

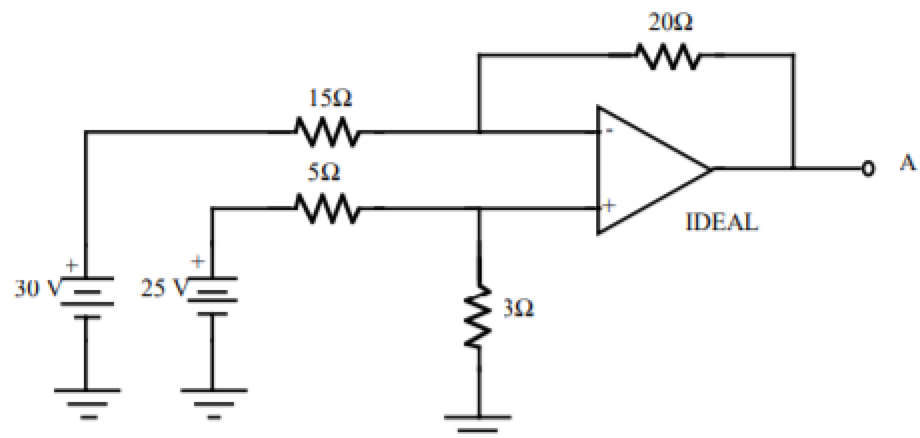


Ans = - 8.84 V

For the difference amplifier circuit shown, determine the output voltage at terminal A.



For the difference amplifier circuit shown, determine the output voltage at terminal A.



Solution:

By voltage division,

$$v_{in+} = 25V\left(\frac{3\Omega}{5\Omega + 3\Omega}\right) = 9.375V$$

By the virtual short circuit between the input terminals, $v_{in-} = 9.375$ V
Using **Ohm's** law, the current through the 15 Ω resistor is

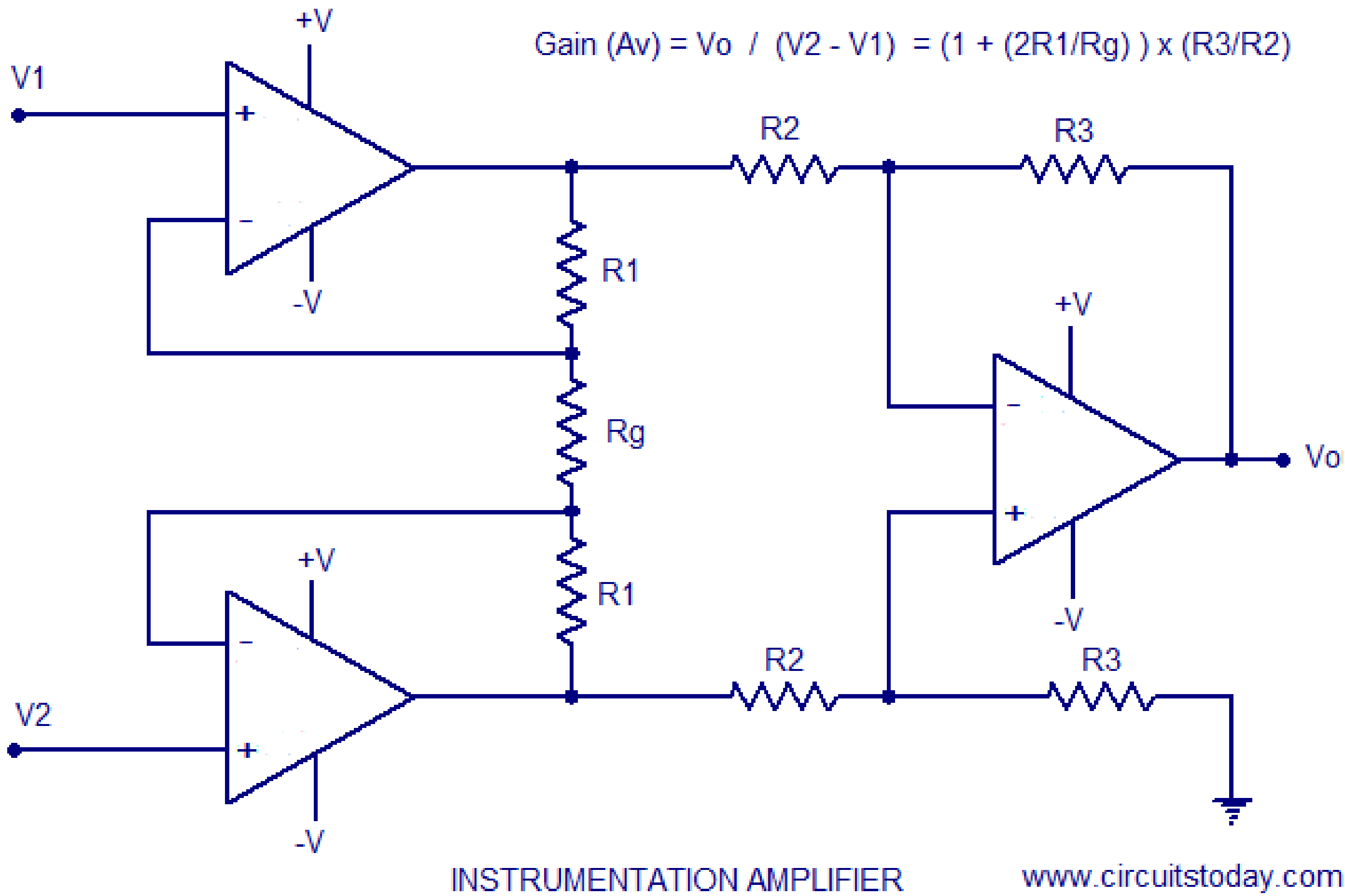
$$I_{15} = \left(\frac{30V - 9.375V}{15\Omega}\right) = 1.375V$$

The input impedance is infinite; therefore, $I_{in-}=0$ and $I_{15}=I_{20}$.

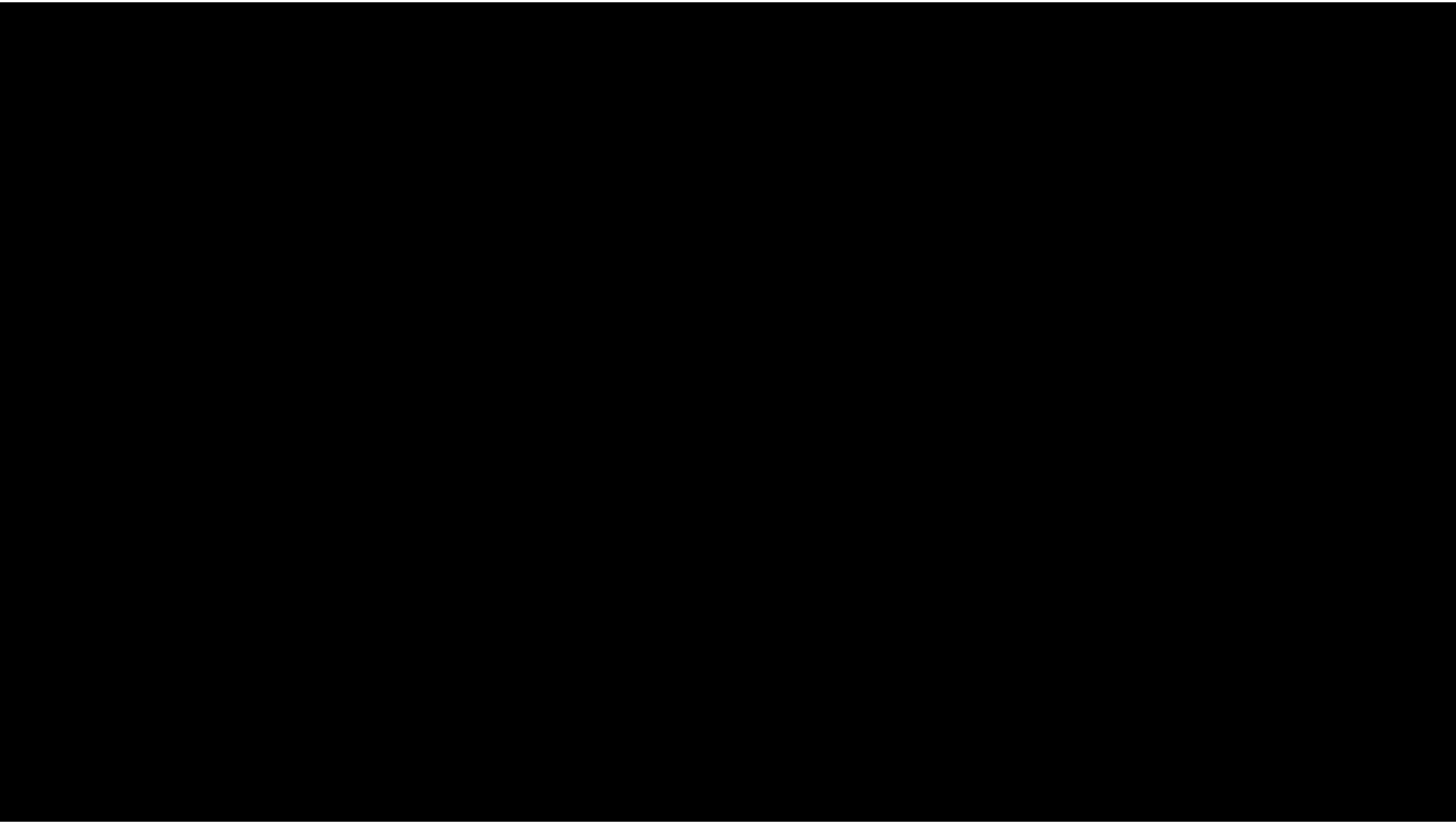
Use Kirchoff's voltage law to find the output voltage at A.

$v_A=v_{in-} - 20I_{20} = 9.375 \text{ V} - (20\Omega)(1.375 \text{ A}) = -18.125 \text{ V}$

Instrumentation Amplifier

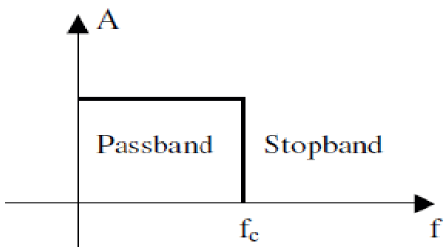


Opamp Demo

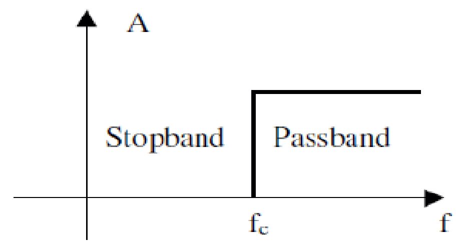


Filters

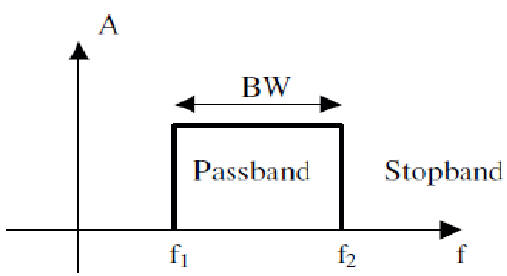
- To filter / cancel out unwanted characteristics of a signal



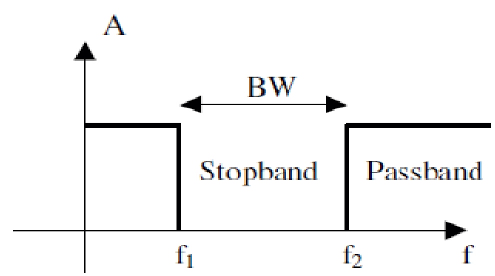
LOW-PASS FILTER RESPONSE



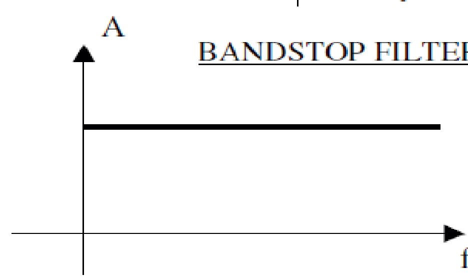
HIGH-PASS FILTER RESPONSE



BANDPASS FILTER RESPONSE



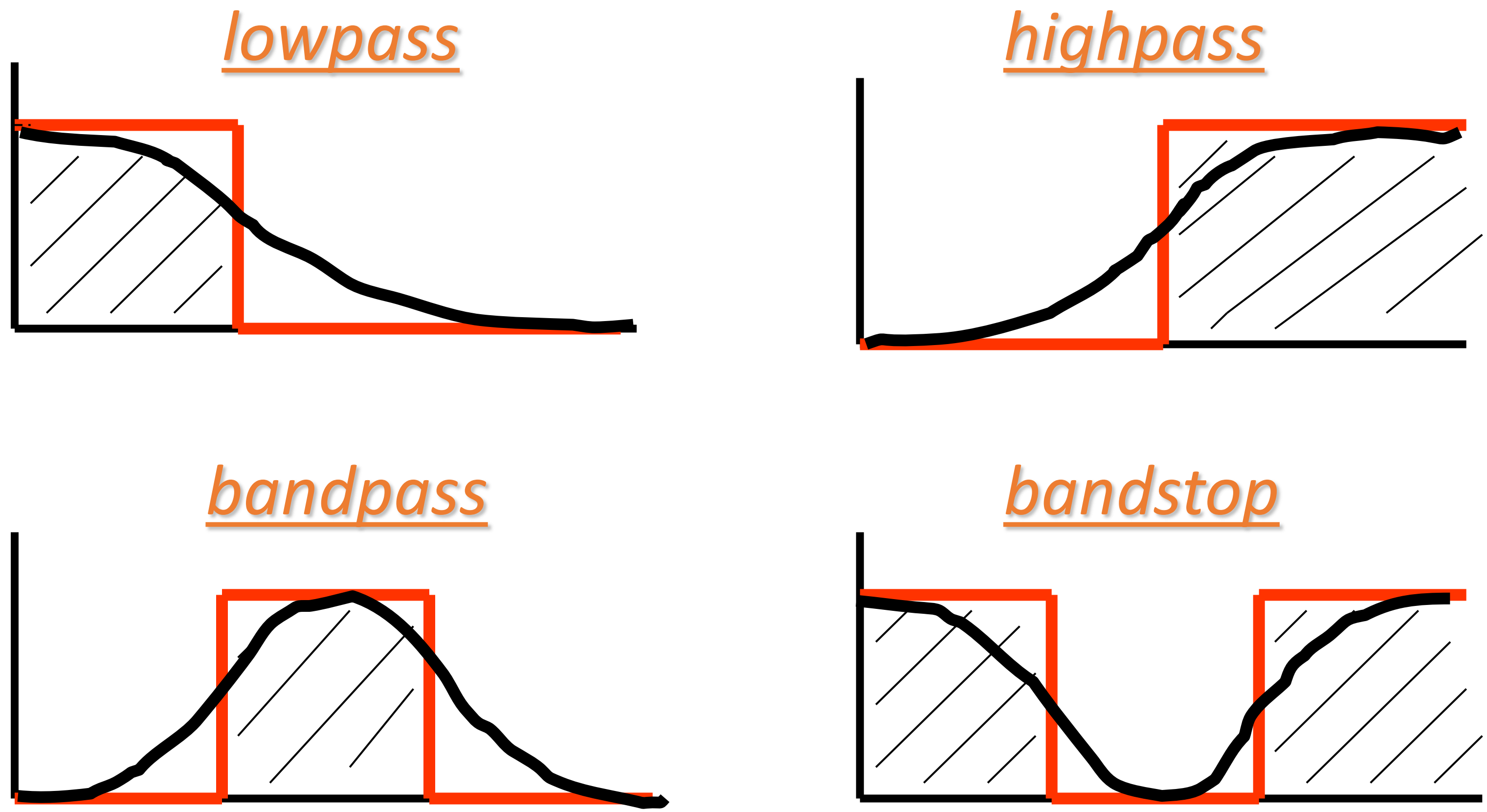
BANDSTOP FILTER RESPONSE



ALLPASS FILTER RESPONSE

Filters

- Realistic Filters



Filters

- Filters may be classified as either digital or analog.

- ***Digital filters*** are implemented using a digital computer

  or special purpose digital hardware.

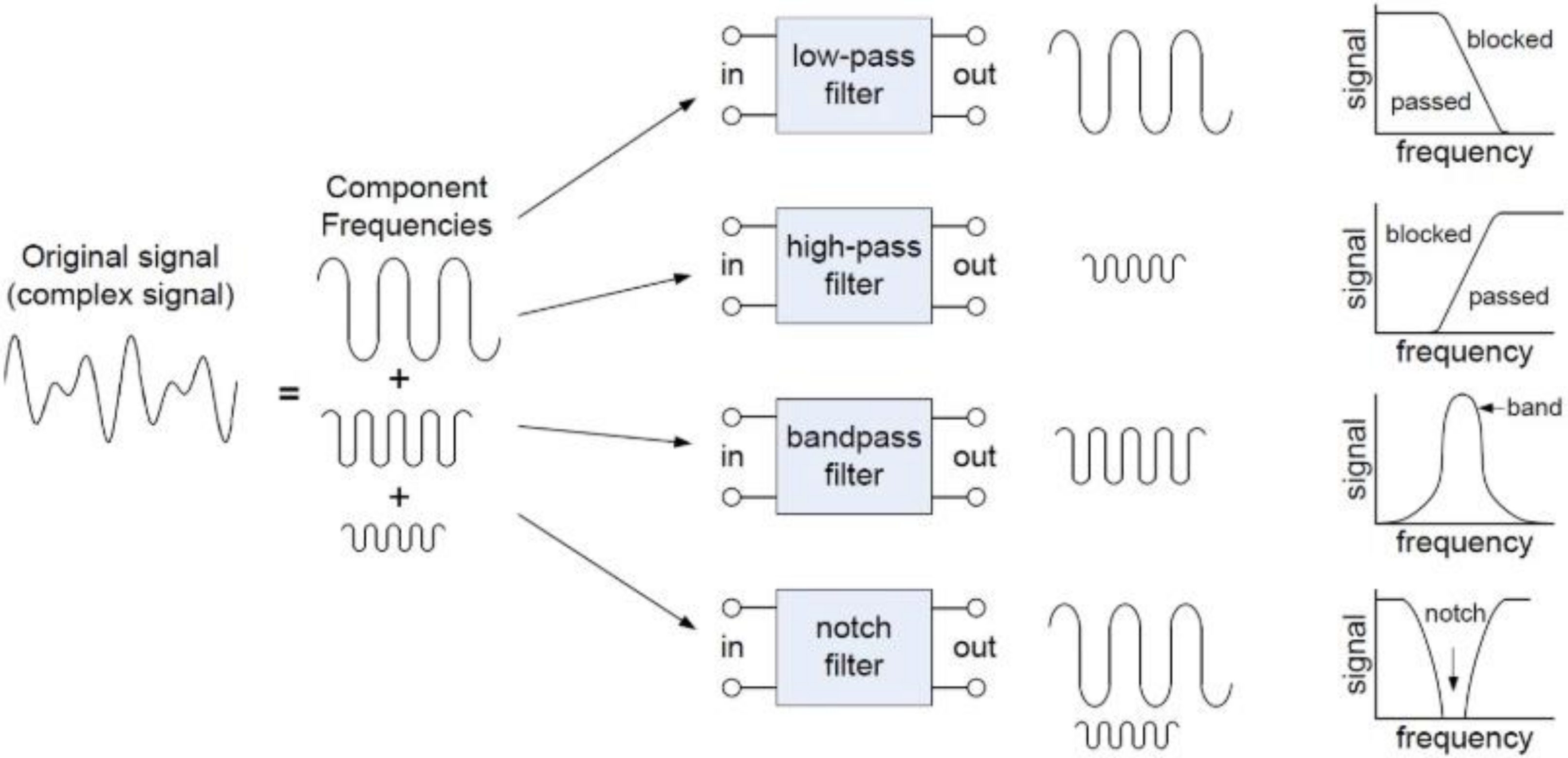
- ***Analog filters*** may be classified as either passive or active and are usually implemented with R, L, and C components and operational amplifiers.

Filters

- An ***active filter*** is one that, along with R, L, and C components, also contains an energy source, such as that derived from an operational amplifier.

- A ***passive filter*** is one that contains only R, L, and C components.
    - It is not necessary that all three be present.
    - L is often omitted (on purpose) from assive filter design because of the size and cost of inductors – and they also carry along an R that must be included in the design.

Filters

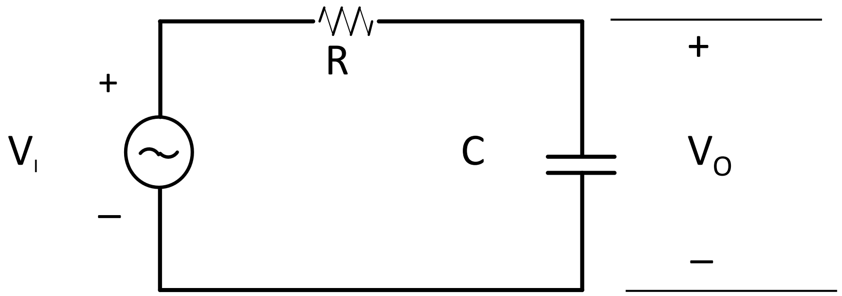


Original signal
(complex signal)
=
Component
Frequencies
+
+
in
low-pass
filter
out
in
high-pass
filter
out
in
bandpass
filter
out
in
notch
filter
out
signal
blocked
passed
frequency
signal
blocked
passed
frequency
signal
band
frequency
signal
notch
frequency

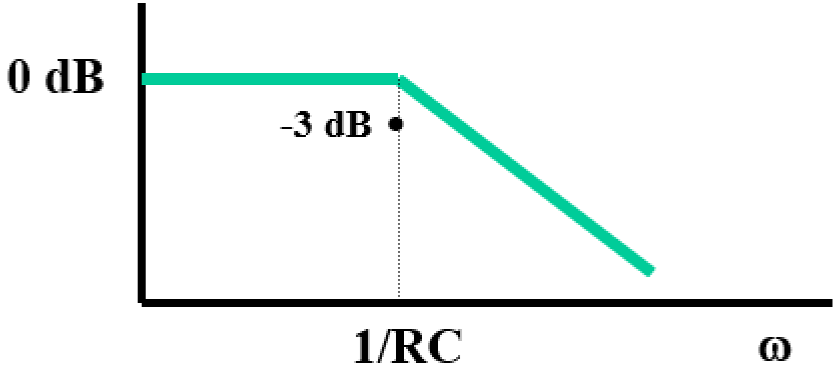
Filters

Low Pass Filter

Consider the circuit below.



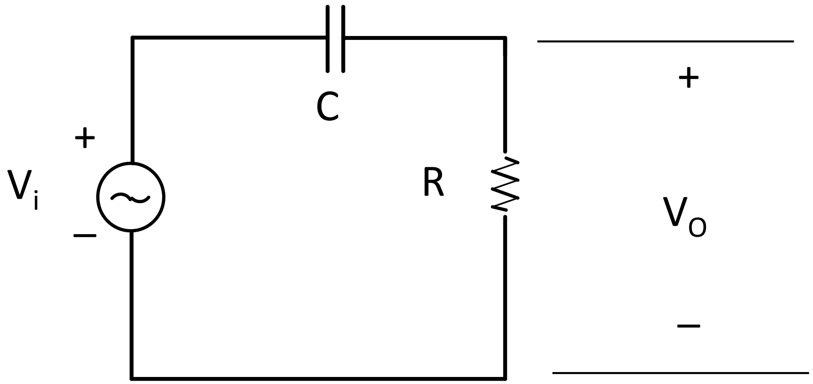
Low pass filter circuit



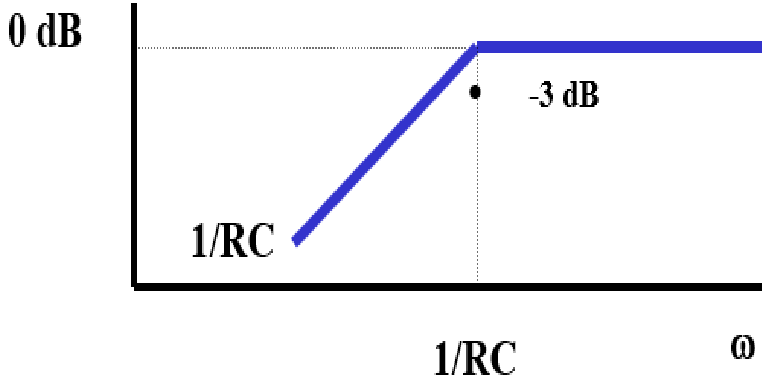
Filters

High Pass Filter

Consider the circuit below.



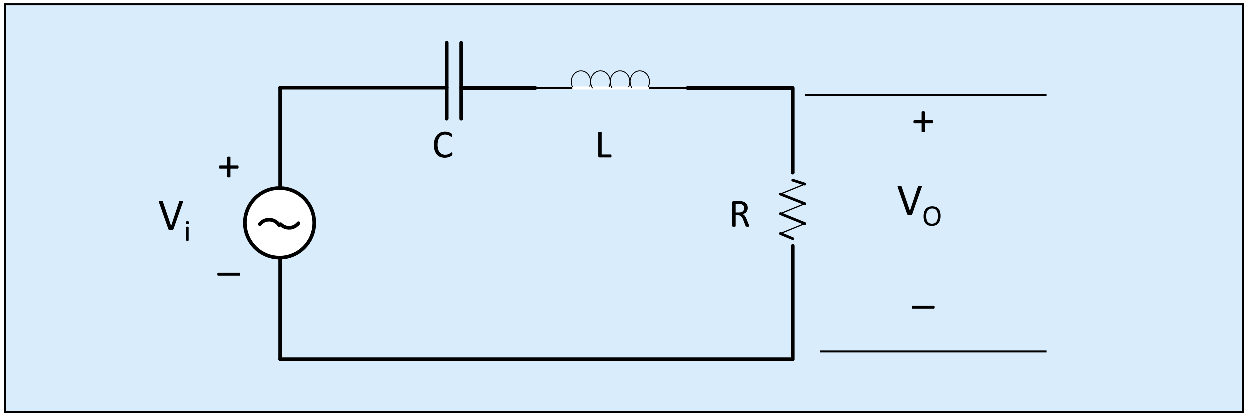
High Pass Filter

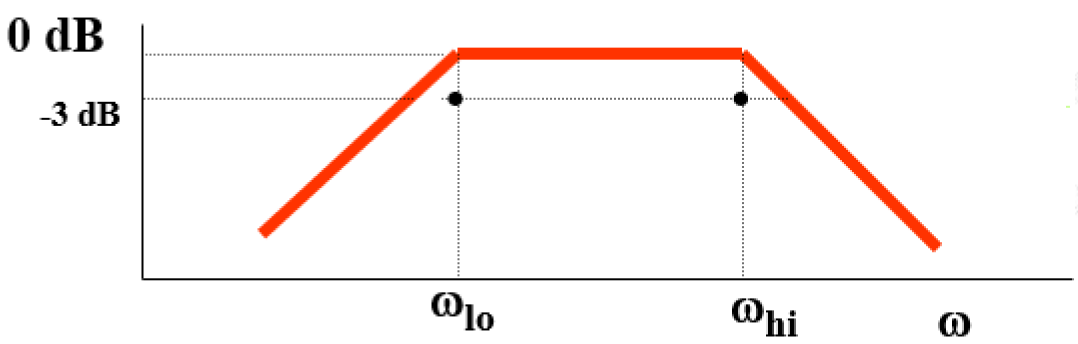


Filters

Bandpass Pass Filter

Consider the circuit shown below:





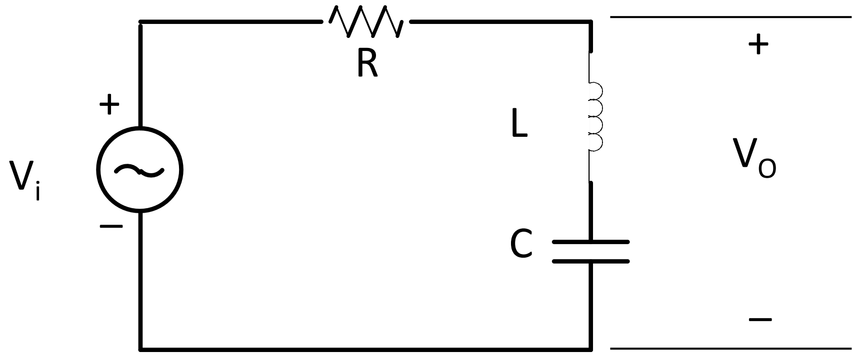
$$\omega_{c1} = -\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}}$$

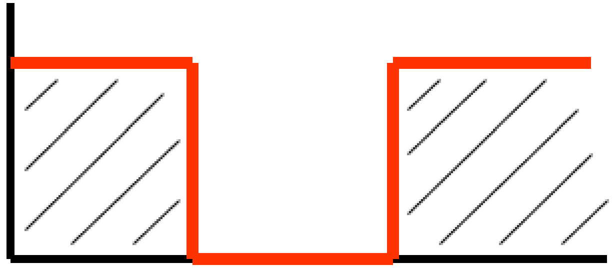
$$\omega_{c2} = \frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}}$$

Filters

RLC Band stop Filter

Consider the circuit below:

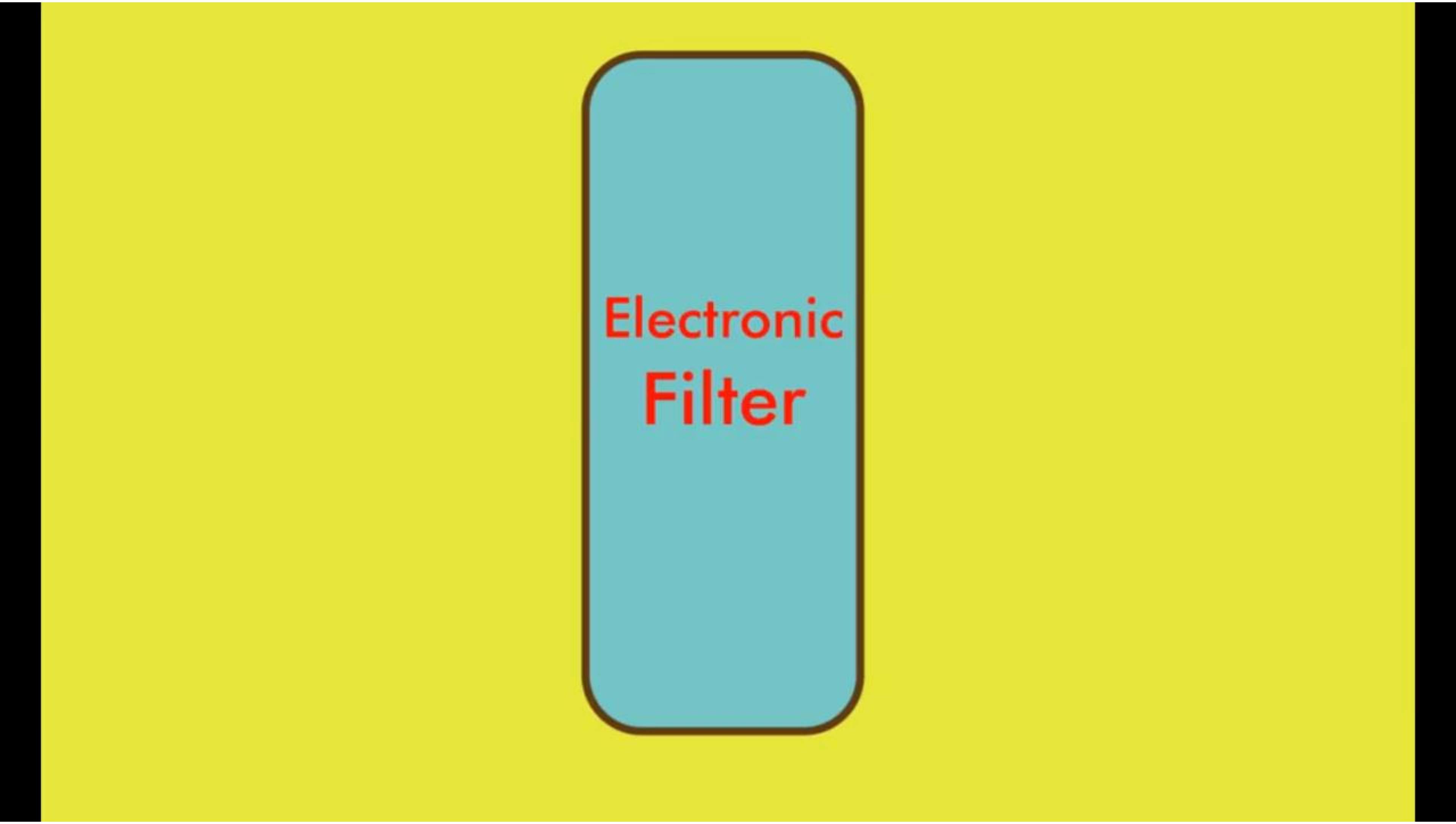




$$\omega_{C1} = -\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \left(\frac{1}{LC}\right)}$$

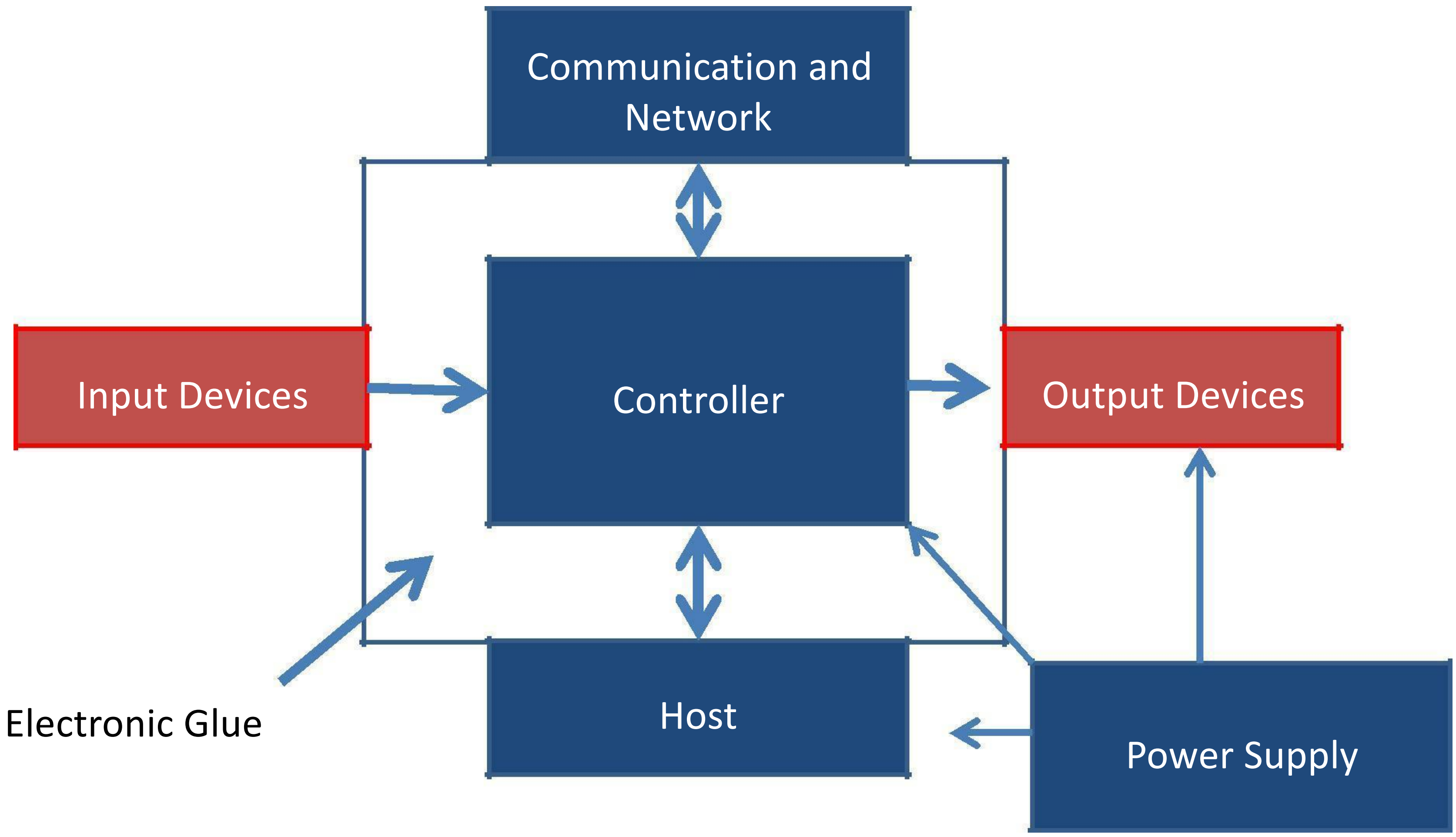
$$\omega_{C2} = \frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \left(\frac{1}{LC}\right)}$$

Filters Demo

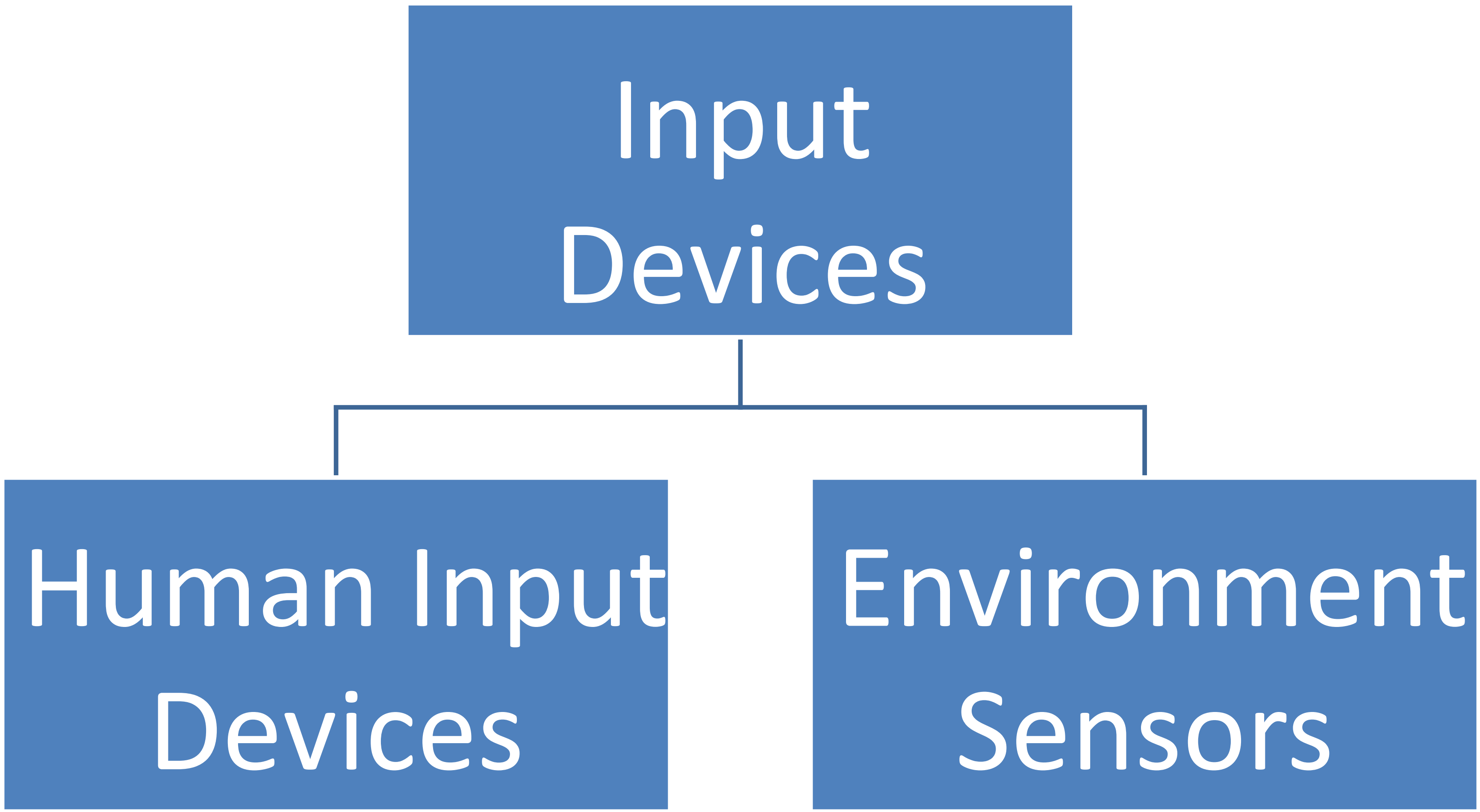


Input Output Devices

6-Box Model


Communication and Network
Input Devices
Controller
Output Devices
Electronic Glue
Host
Power Supply

Input Devices


Input Devices
Human Input Devices
Environment Sensors

Human Input Devices

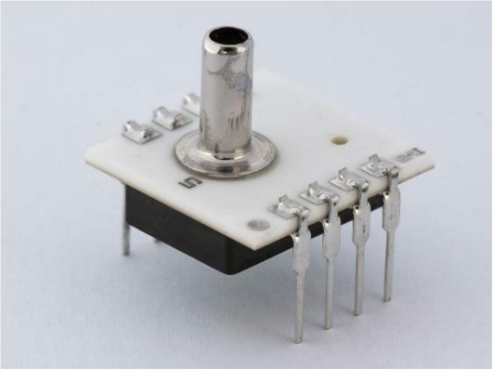
- Keyboards
  - Push button
  - Switches (DIP, Slide)
- Pointing device
  - mouse
  - touchpad
  - pointing stick
  - touchscreen
  - trackball

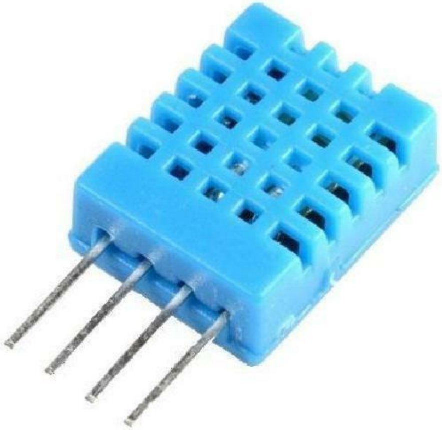
Human Input Devices

- Composite devices
  - Joystick controller
  - Gamepad (or joypad)
  - Paddle (game controller)
  - Jog dial/shuttle (or knob)
  - Wii Remote

Environment Sensors

- Sensors/Transducers
  - Temperature
  - Light
  - Humidity
  - Sound
  - Magnetic Field
  - Distance
  - Force/Stress/Strain
  - Position/Motion





Multimedia Input Devices

- Graphic input devices
  - Webcam
  - Video Camera
- Audio input devices
  - MIcrophone

Switches

- An electrical switch is any device used to interrupt the flow of electrons in a circuit.
- A *switch* is an electrical device, usually electromechanical, used to control continuity between two points.
- Binary devices: either completely on ("closed") or completely off ("open")

Switches

- Classification:
  - **Mechanical switches**
    - must be activated physically, by moving, pressing, releasing, or touching its contacts.

  - **Electronic switches**
    - do not require any physical contact in order to control a circuit.
    - These are activated by semiconductor action.

Switches

- Classification:
  - *Hand* switches: actuated by human touch.
  - *Limit* switches: actuated by machine motion.
  - *Process* switches: actuated by changes in some physical process (temperature, level, flow, etc.).

Switches

- Types
  - Push button switch
  - DIP Switch
  - Rocker Switch
  - Rotary Switch
  - Toggle Switch
  - Others..!

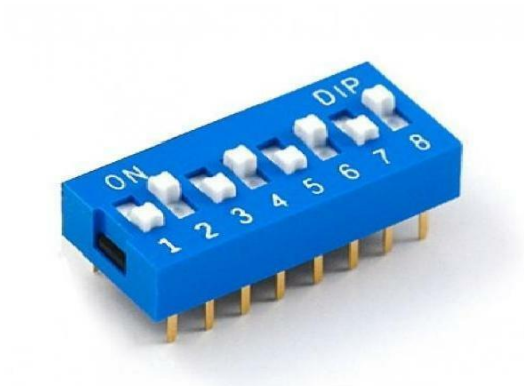
Push Button Switch

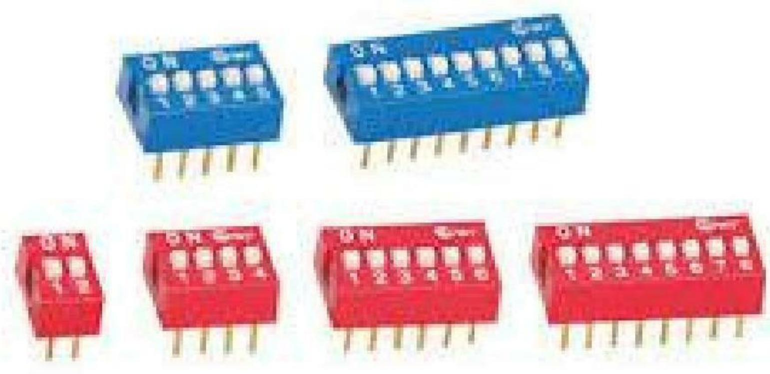
It is a momentary contact switch that makes or breaks connection as long as pressure is applied (or when the button is pushed).

Toggle Switch

These are used for switching high currents (as high as 10 A) and can also be used for switching small currents.

DIP Switches





Rocker Switch

- A **rocker switch** is an on/off **switch** that rocks (rather than trips) when pressed
- One side of the **switch** is raised while the other side is depressed much like a rocking horse rocks back and forth.

Rotary Switch

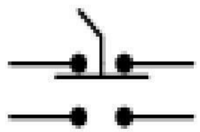
Limit Switch

- Switches are operated by the presence of an object or by the absence of objects or by the motion of machine instead of human hand operation.
- These switches are called as limit switches.
- These switches consist of a bumper type of arm actuated by an object.
- When this bumper arm is actuated, it causes the switch contacts to change position.

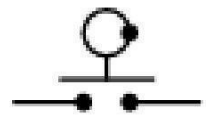
Limit Switch

Others..!

Selector switch

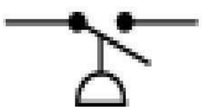


Joystick switch



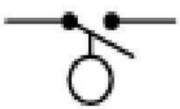
Liquid flow switch

Pressure switch



Temperature switch

Liquid level switch



Others..!

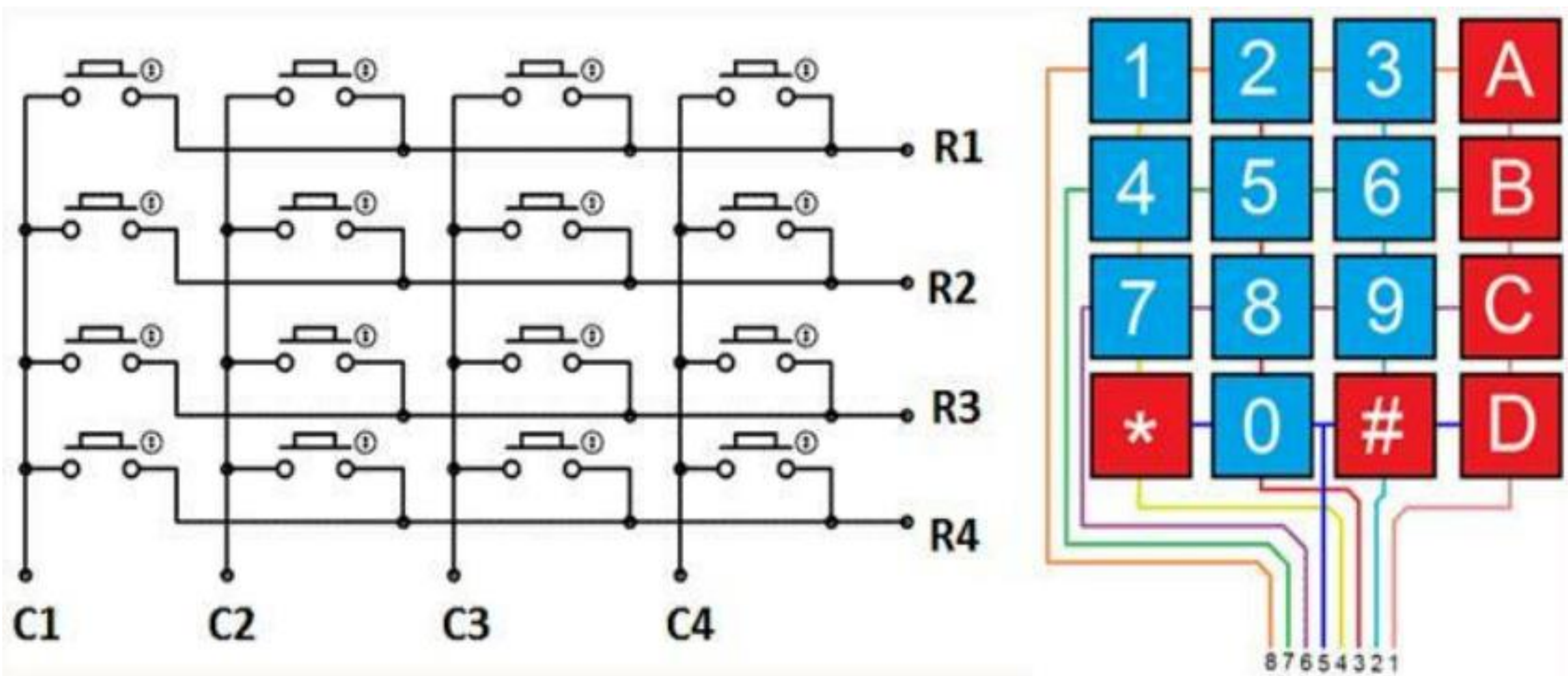
- **Float switches** are mainly used for controlling DC and AC motor pumps according to the liquid or water in a tank or sump.
- **Flow switches** are mainly used to detect the movement of liquid or air flow through a pipe or duct. The air flow switch (or a micro switch) is constructed by a snap-action.
- **Pressure switches** are commonly used in industrial applications in order to sense the pressure of hydraulic systems and pneumatic devices.
- The **temperature switch** contacts are operated when the temperature causes the strip to bend or wrap.
- **Joystick switches** are manually actuated control devices used mainly in portable control equipment's.
    - It consists of a lever which moves freely in more than one axis of motion.
    - Depending on the movement of the lever pushed, one or more switch contacts are actuated.

Keypad

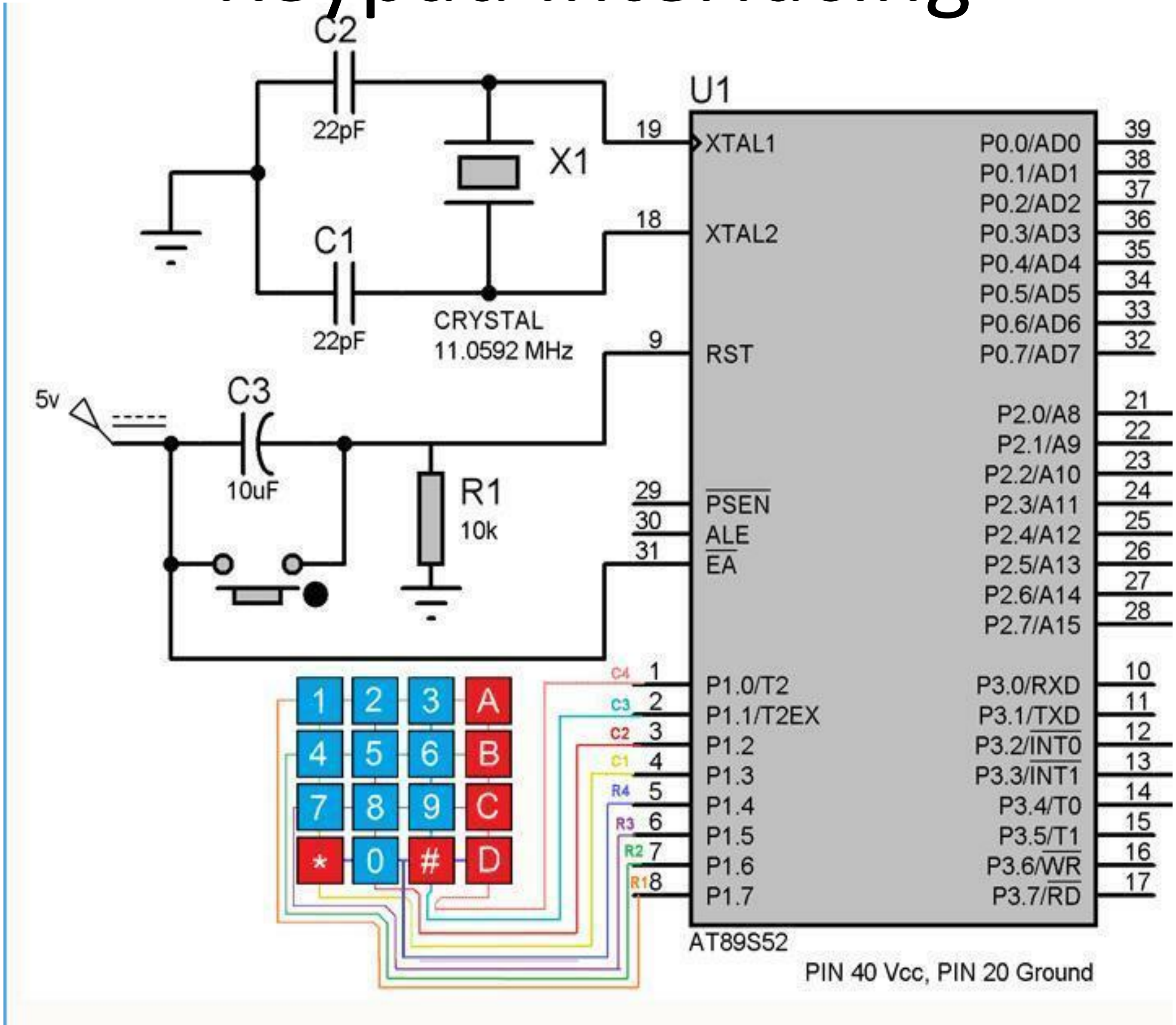
ABC
DEF
GHI
JKL
MNO
PRS
TUV
WXY
OPER

A
B
C
D
4x4 Matrix Keypad
EmbedJournal.com

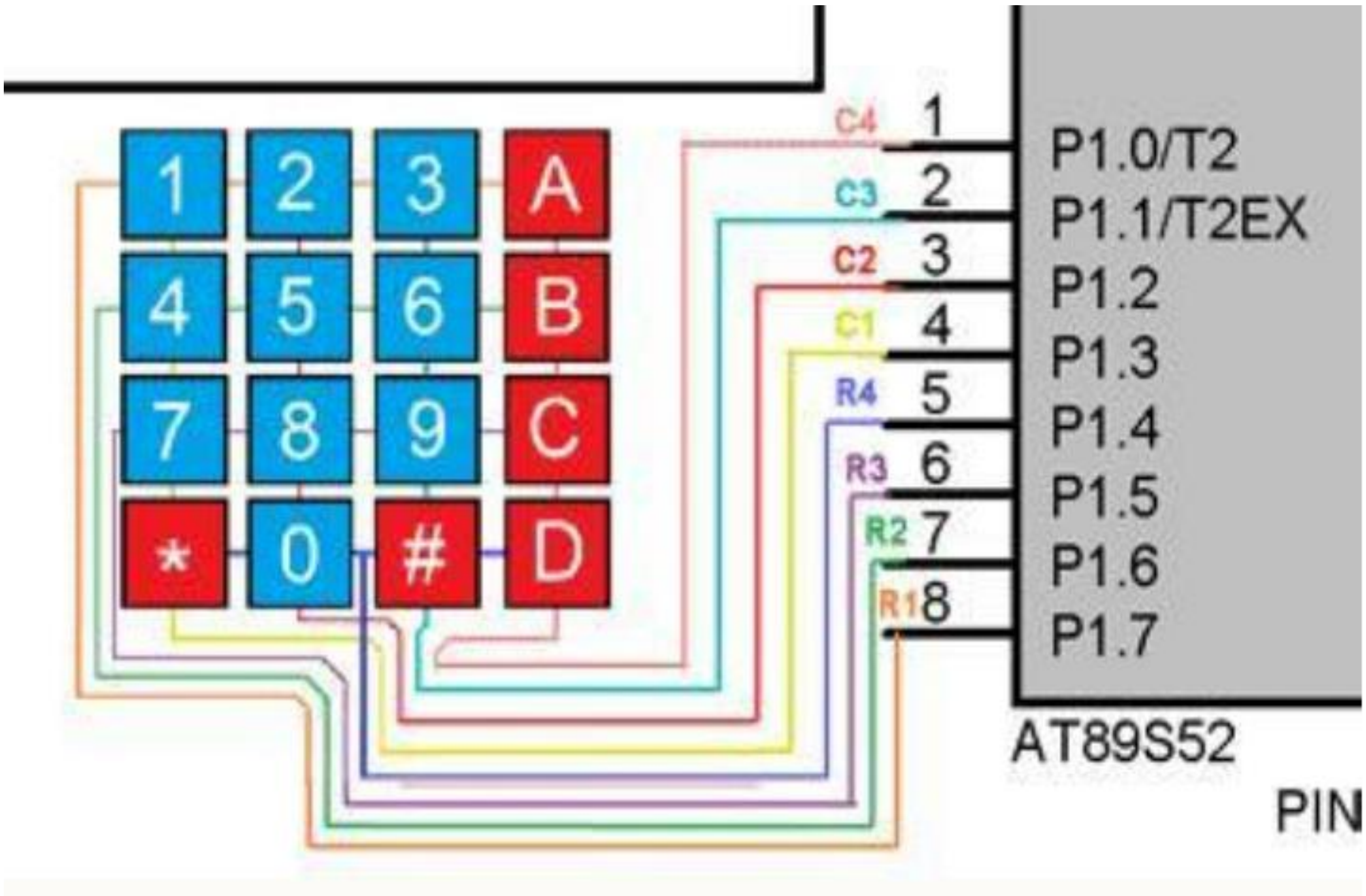
Keypad Interfacing



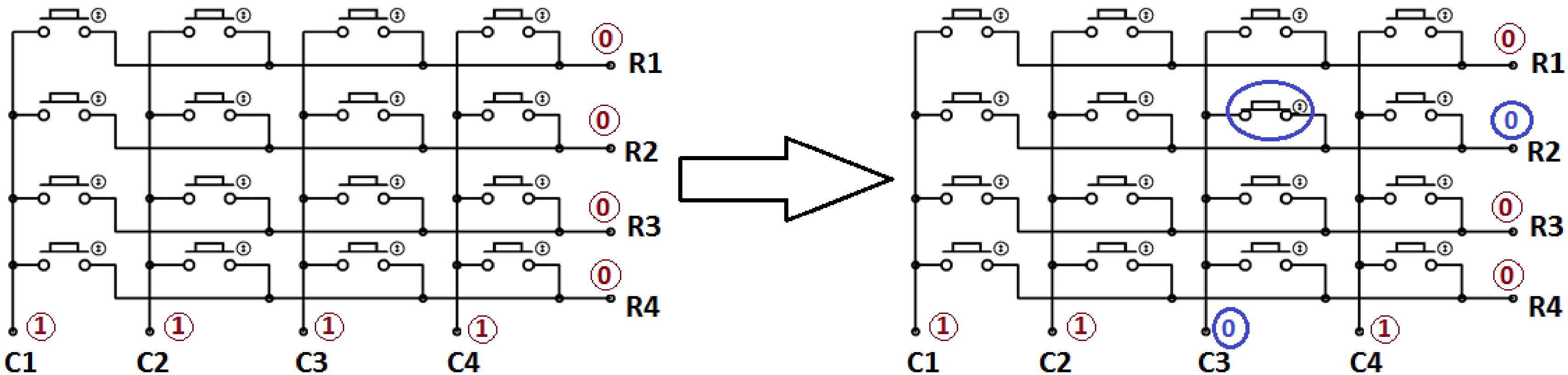
Keypad Interfacing



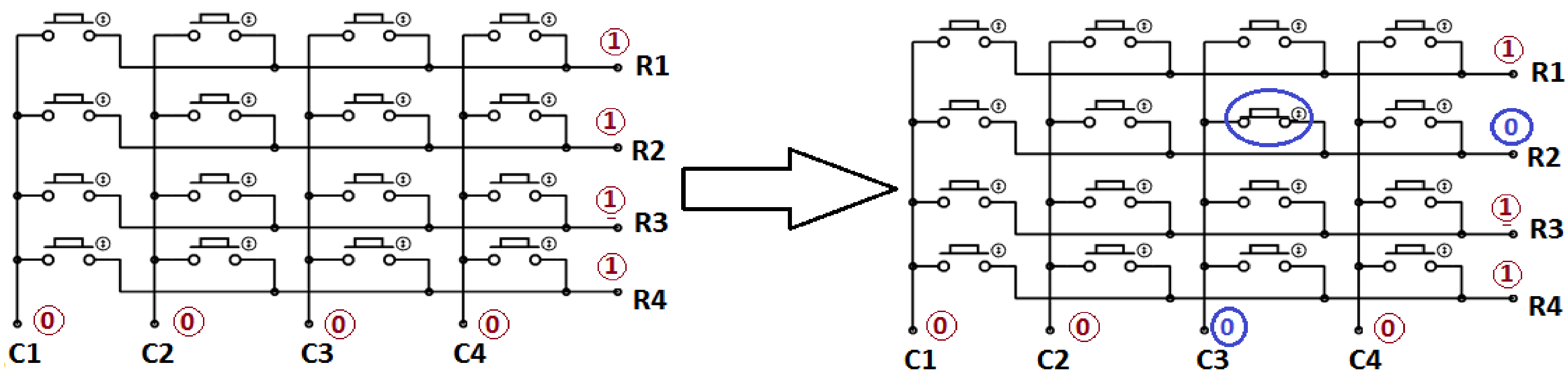
Keypad Interfacing



Keypad Interfacing



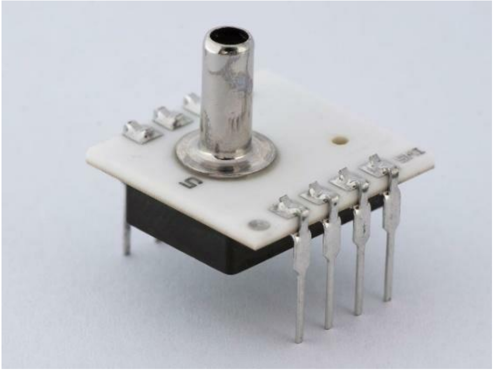
FINDING COLUMN No.

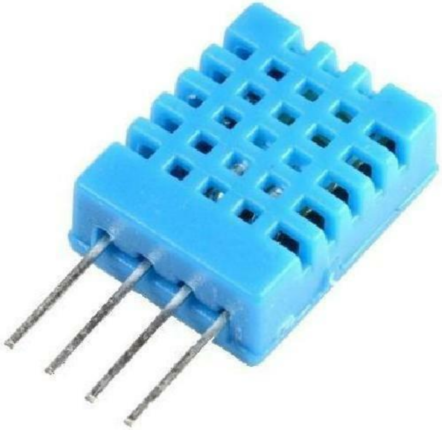


FINDING ROW No.

Environment Sensors

- Sensors/Transducers
  - Temperature
  - Light
  - Humidity
  - Sound
  - Magnetic Field
  - Distance
  - Force/Stress/Strain
  - Position/Motion





Temperature Sensors

1. Negative Temperature Coefficient (NTC) thermistor

- The effective operating range is -50 to 250 °C for glass encapsulated thermistors or 150°C for standard.

2. Resistance Temperature Detector (RTD)

- also known as a resistance thermometer
- across -200 to 600 °C.

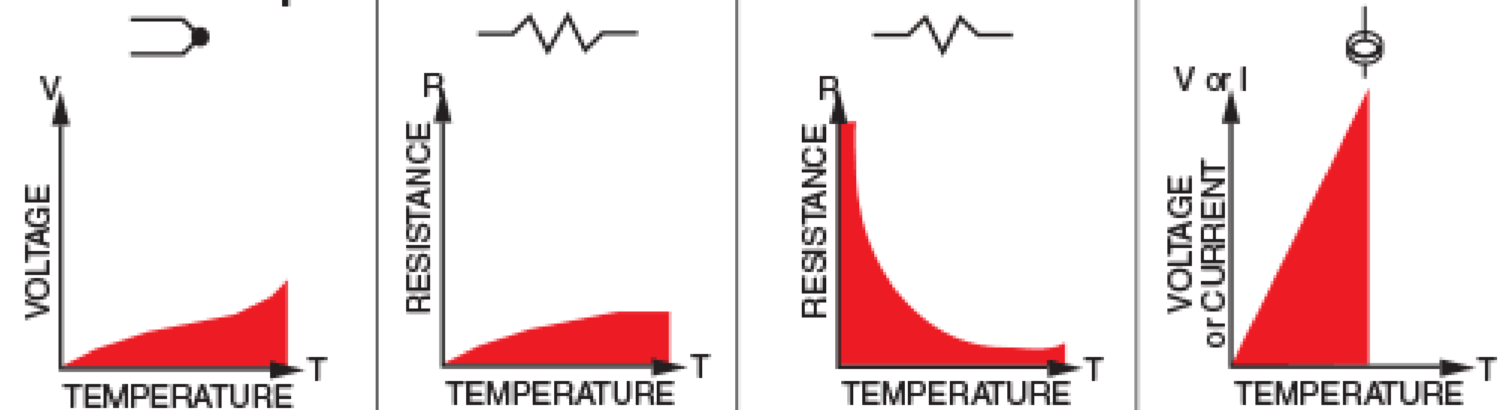
3. Thermocouple

- Consists of two wires of different metals connected at two points.
- The varying voltage between these two points reflects proportional changes in temperature.
- operate across the widest temperature range, from -200 °C to 1750 °C.

4. Semiconductor-based sensors

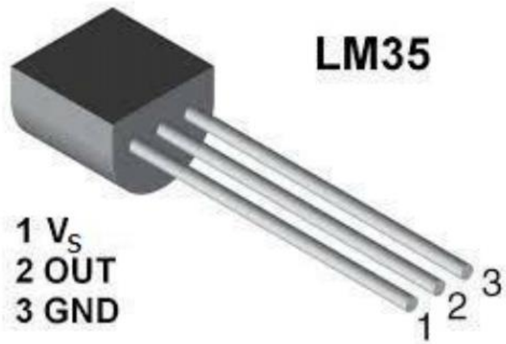
- A semiconductor-based temperature sensor is placed on integrated circuits (ICs).
- Two identical diodes with temperature-sensitive voltage vs current characteristics used to monitor changes in temperature.
- narrowest temperature range (-70 °C to 150 °C).

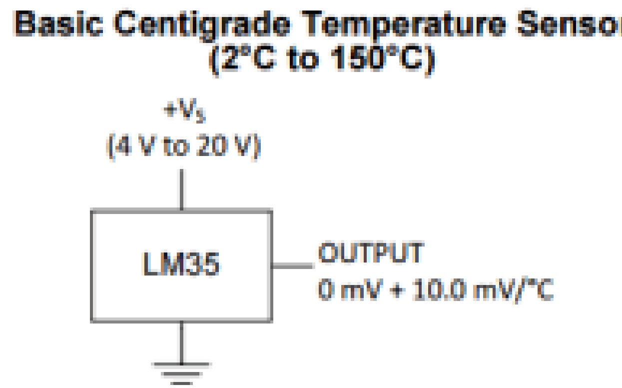
Temperature Sensors

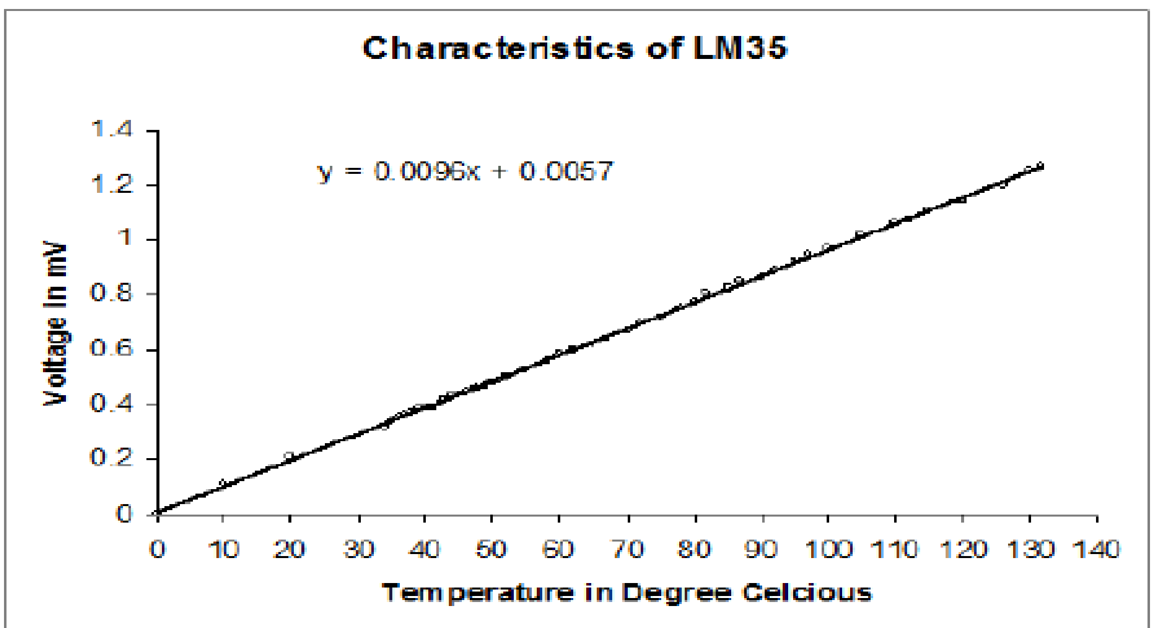


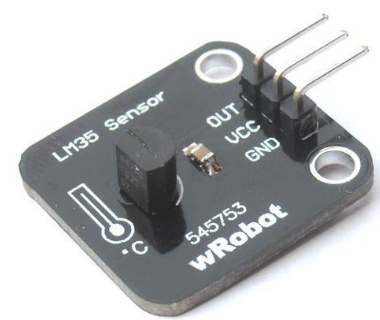
	Thermocouple	RTD	Thermistor	I. C. Sensor
Advantages	Self-powered Simple Rugged Inexpensive Wide variety Wide temperature range	Most stable Most accurate More linear than thermocouple	High output Fast Two-wire ohms measurement	Most linear Highest output Inexpensive
Disadvantages	Non-linear Low voltage Reference required Least stable Least sensitive	Expensive Current source required Small Δ R Low absolute resistance Self-heating	Non-linear Limited temperature range Fragile Current source required Self-heating	T<200°C Power supply required Slow Self-heating Limited configurations

Temperature Sensors

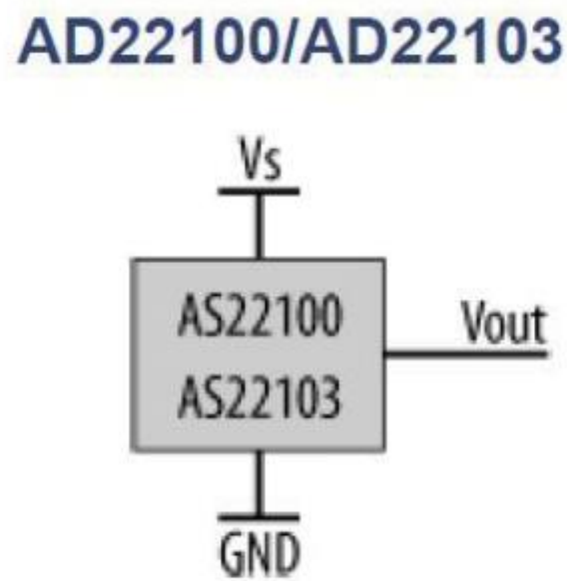








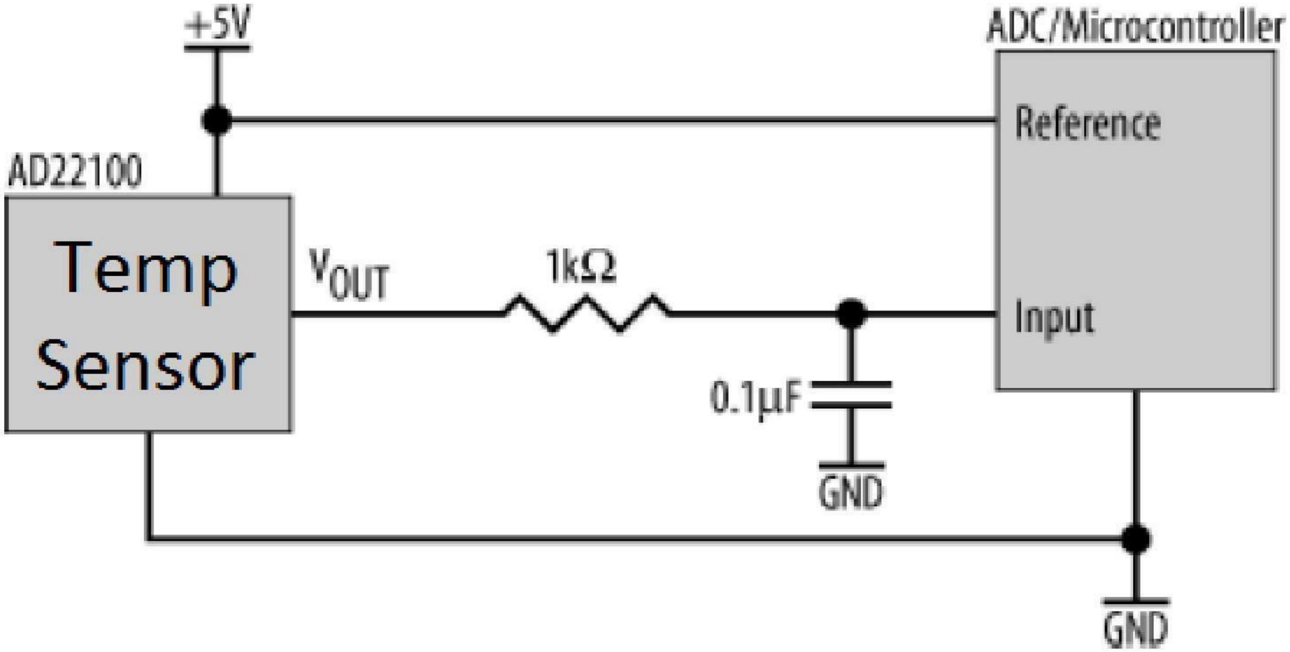
Temperature Sensors



$T_A = ((V_{out} \times 5 / V_s) - 1.375) / 0.0225$
----- for AD22100 (-50^oC to $+150\ ^oC$)

$T_A = ((V_{out} \times 3.3 / V_s) - 0.25) / 0.028$
----- for AD22103 (0^oC to $+100\ ^oC$)

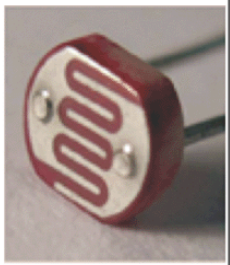
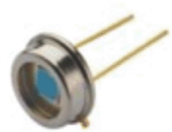
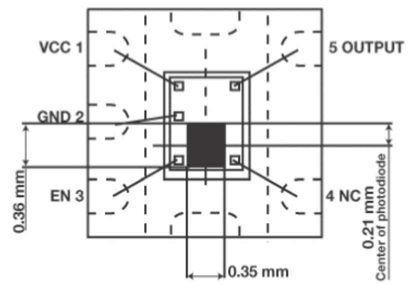
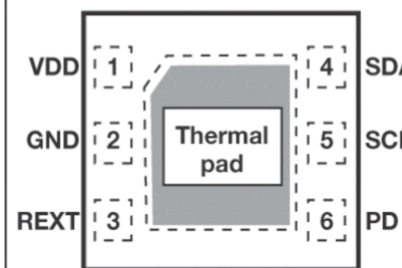
Temperature Sensors



Temperature Sensors

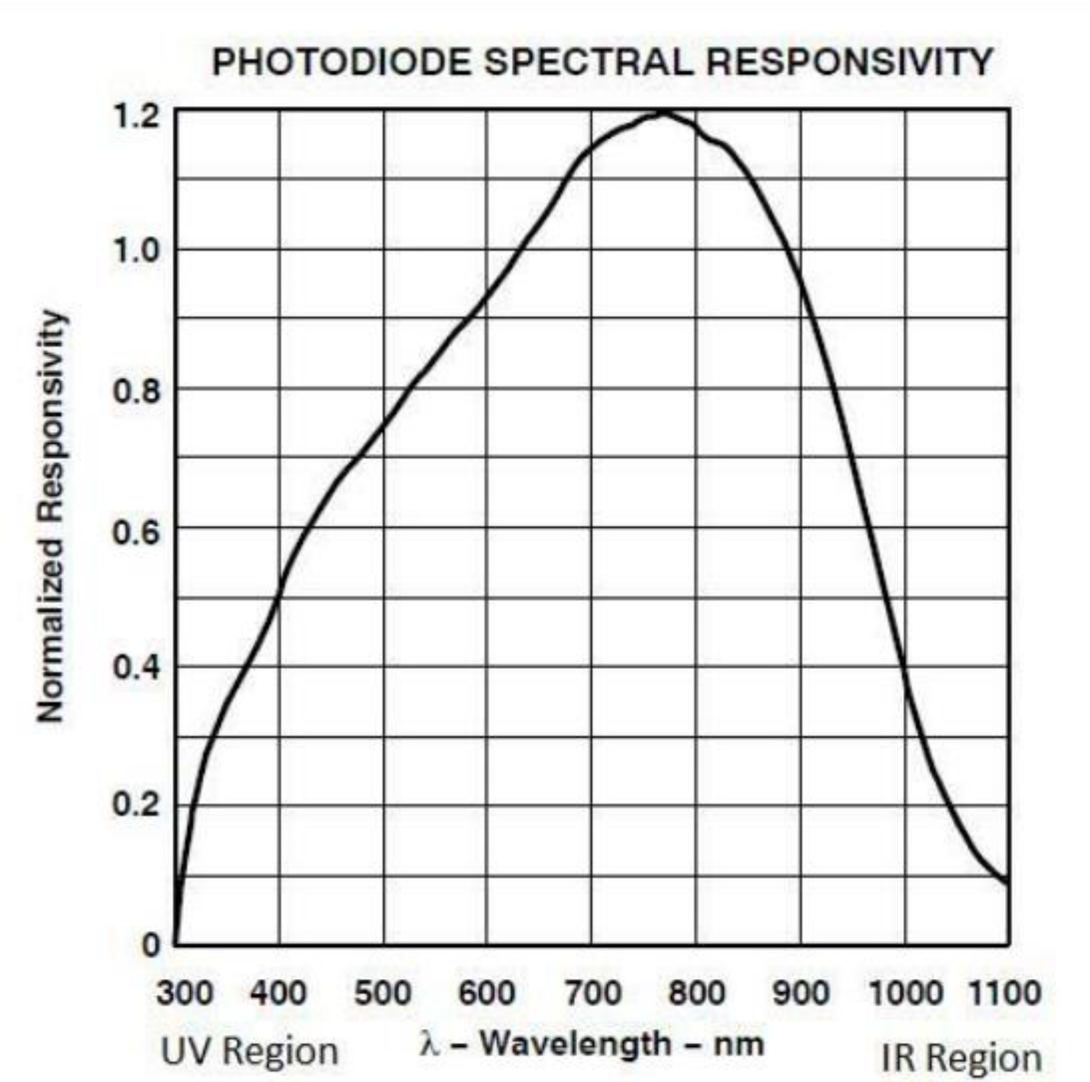
Manufacturer	Part Number	Output Type	Designation	Temp. Range	Accuracy (Typical)	Accuracy (Min)	Linear Temperature Slope	Input Voltage Range	Supply current	Output Voltage Range	Package	Datasheet
Analog Devices	AD590[8]	Analog	IC Temperature Transducer	-55 to 150 °C	+/-0.5 °C		1 µA / °K	4 to 30 V		298.2 µA @25 °C	TO52SO8 FLATPACK LFCSP	AD590
Analog Devices	AD592[9]	Analog	Precision IC Temperature Transducer	-25 to 105 °C	+/-0.5-2 °C	+/-1-3.5 °C	1 µA / °K	4 to 30 V	-	298.2 µA @25 °C	TO92	AD592
Analog Devices	AD22105[10]	Switch	Resistor Programmable Thermostatic Switch	-40 to 150 °C	+/-0.5 °C	+/-3 °C	-	2.7 to 7 V	120 µA max	-	SO8	AD22105
Dallas	DS18B20	Digital	Temperature Sensor with 1wire interface	-55 to +125 °C	+/-0.5 °C (@ -10 - +85 °C)	+/-2 °C		3 to 5.5 V	1 mA (active)		TO928 SO 8 FSOP	
Microchip	EMC1072[17]	Digital	SMBus / I2C Multi Temperature Sensor	-40 to +125 °C	0.25 °C	+/-1 °C		3.0 to 3.6 V	430 µA	-	MSOP8	EMC1072
Microchip	MCP9509[18]	Switch	Resistor-Programmable Temperature Switch	-40 to +125 °C	+/-1 °C	+/-4.5 °C	-	2.7 to 5.5 V	30 µA (50 µA max)	-	4 µASOT23-5	MCP9509
Microchip	MCP9700[19]	Analog	Voltage Temperature Sensor	-40 to +150 °C	1 °C	+/-4 °C	10 mV / °C	2.3 to 5.5 V	6µA (12 µA Max)		SC70-5SOT23-5 TO92	MCP9700
Microchip	MCP9700A[20]	Analog	Voltage Temperature Sensor		1 °C	+/-2 °C	10 mV / °C	2.3 to 5.5 V	6µA (12 µA Max)		SC70-5SOT23-5	MCP9700A
Microchip	MCP9701[21]	Analog	Voltage Temperature Sensor		1 °C	+/-4 °C	19.53 mV / °C	3.1 to 5.5 V	6µA (12 µA Max)		SC70-5SOT23-5 TO92	MCP9701
Texas Instruments	**LM35[31]**	**Analog**	**Analog Output Temperature Sensor**	**-55 to +150 °C**	**+/-0.5 °C**	**+/-1.5 °C**	**10 mV / °C**	**4 to 30 V**	**114 µA**		**S08TO92 TO220 TO-CAN**	**LM35**
Texas Instruments	LM50[32]	Analog	Analog Output Temperature Sensor	-40 to +125 °C	+/-2 °C	+/-4 °C	10 mV / °C	4.5 to 10 V	130 µA	100 mV to 1.750 V	SOT23	LM50
Texas Instruments	LM73[33]	Digital	Temperature Sensor with IC2/SMBus Interface	-40 to +150 °C	+/-1.0 °C	+/-2.5 °C	-	2.7 to 5.5 V	320 µA (2 µA Shutdown)	-	SOT (6 pin)	LM73
Texas Instruments	LM76[34]	Digital	Temperature Sensor with IC2/SMBus Interface	-55 to +150 °C	+/-1.0 °C		-	4.5 to 5.5 V	250 µA (8 µA max Shutdown)	-	SO8	LM76

Light Sensor

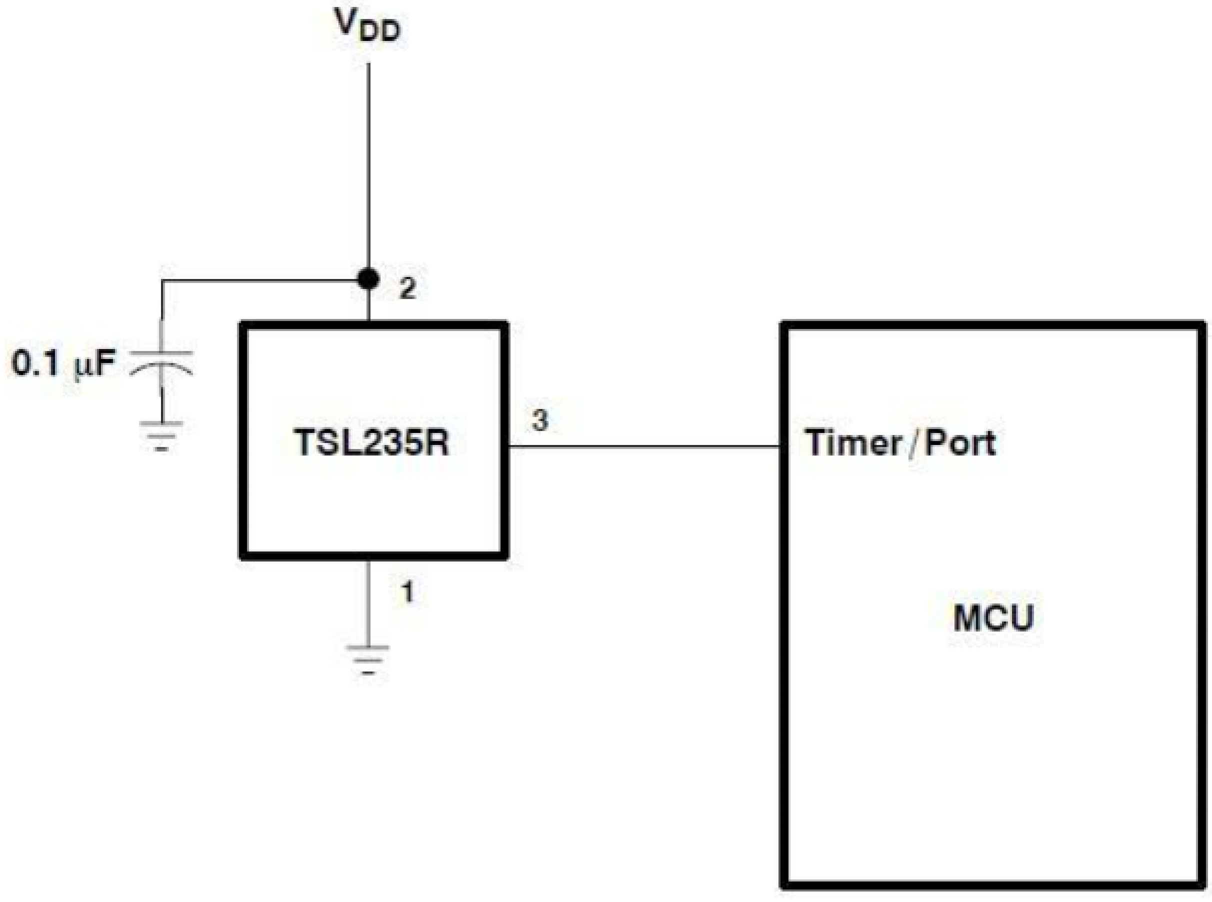
<table>
<tr><th>Device</th><th>Photo resistor</th><th>Photo diode</th><th>Photo transistor</th><th>Photo diode and current amplifier</th><th>Photo diode, current amp, ADC and filter</th></tr>
<tr><td>Referenced part #</td><td>PDV-P500X</td><td>Everlight DTD-15</td><td>Everlight DPT-092</td><td>EL7900</td><td>ISL29001</td></tr>
<tr><td></td><td></td><td></td><td></td><td>
</td><td>
</td></tr>
<tr><td>Accuracy</td><td>Not guaranteed</td><td>Not guaranteed</td><td>± 75%</td><td>± 33%</td><td>15-bit resolution</td></tr>
<tr><td>Current (1000 lux)</td><td>Varies</td><td>3 μA</td><td>2.6 mA (70 klux)</td><td>0.9 mA</td><td>0.3 mA</td></tr>
<tr><td>Range</td><td>1 to 100 lux</td><td>7 to 50 klux</td><td>1 k to 100 klux</td><td>1 to 100 klux</td><td>0.3 to 10 klux</td></tr>
<tr><td>Response time</td><td>55 ms</td><td>6 ns</td><td>15 μs</td><td>0.5 ms</td><td>100 ms</td></tr>
<tr><td>Enable function</td><td>No</td><td>No</td><td>No</td><td>Yes</td><td>Yes</td></tr>
</table>

Light Sensor

Light Sensor

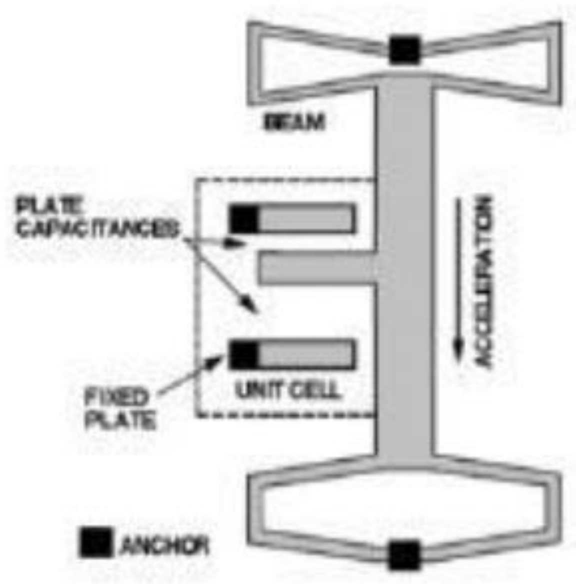


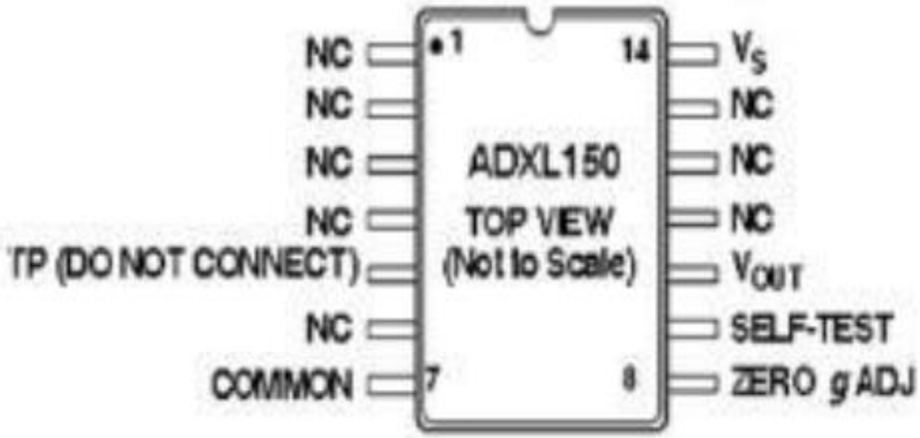
Light Sensor



Accelerometer

Accelerometer





Single / Dual Axis measurement **Obsolete**

ADXL335 - 3 axes Accelerometer

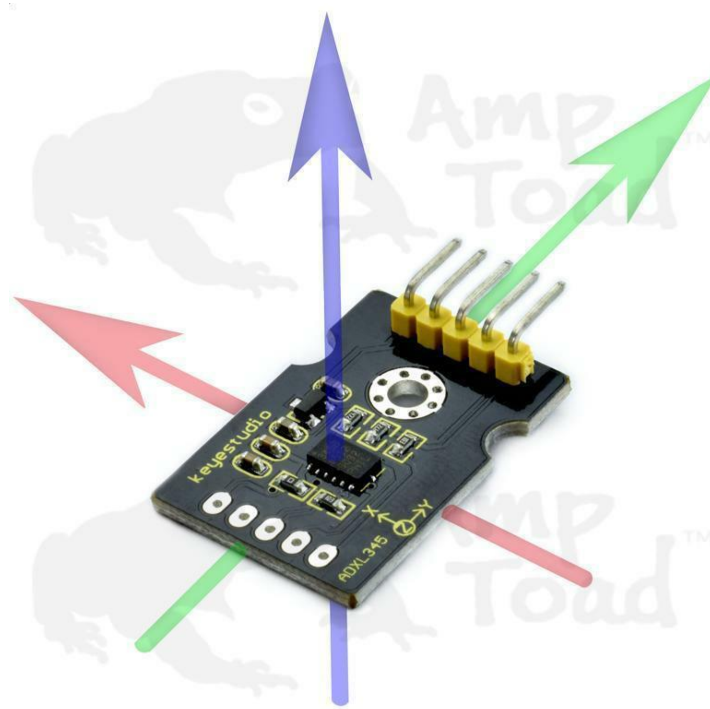
ANALOG DEVICES

FEATURES

3-axis sensing
Small, low profile package
  4 mm × 4 mm × 1.45 mm LFCSP
Low power : 350 µA (typical)
Single-supply operation: 1.8 V to 3.6 V
10,000 *g* shock survival
Excellent temperature stability
BW adjustment with a single capacitor per axis
RoHS/WEEE lead-free compliant

APPLICATIONS

Cost sensitive, low power, motion- and tilt-sensing
  applications
  Mobile devices
  Gaming systems
  Disk drive protection
  Image stabilization
  Sports and health devices



3 Axes Accelerometer

FUNCTIONAL BLOCK DIAGRAM

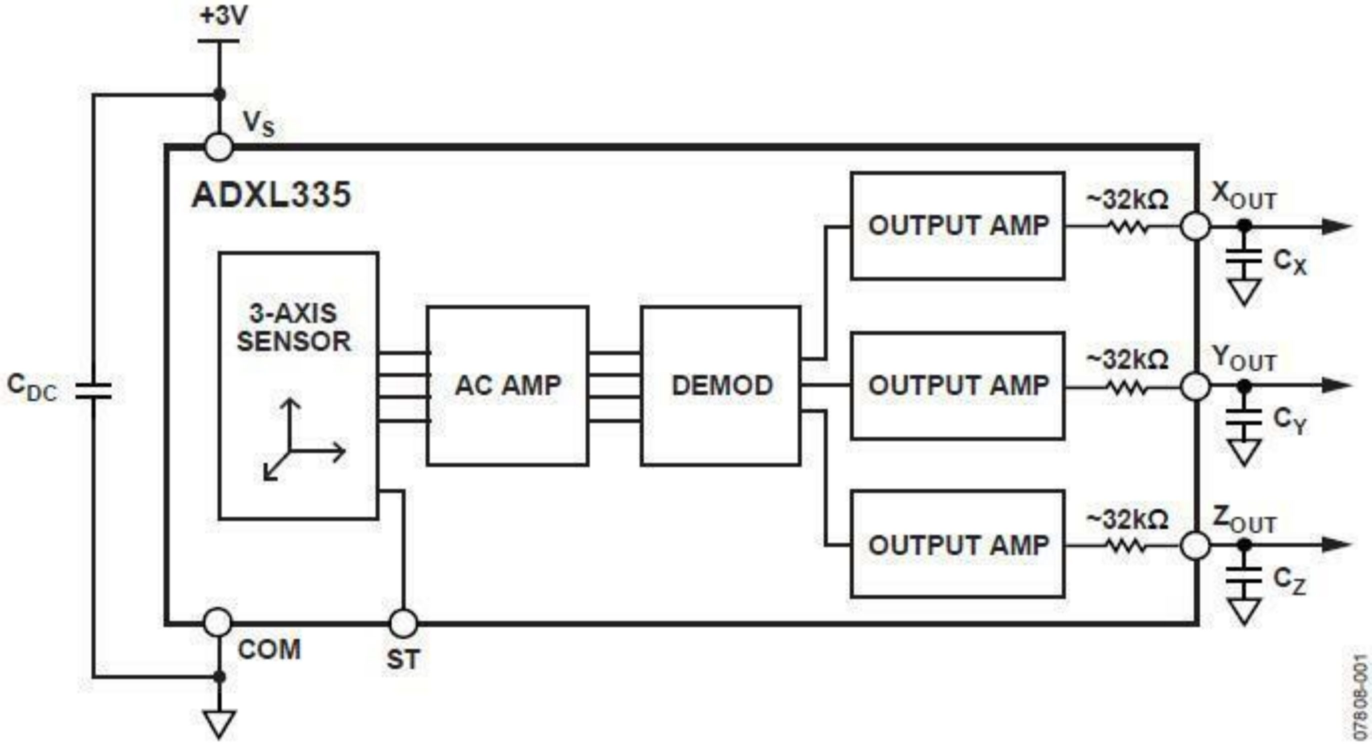
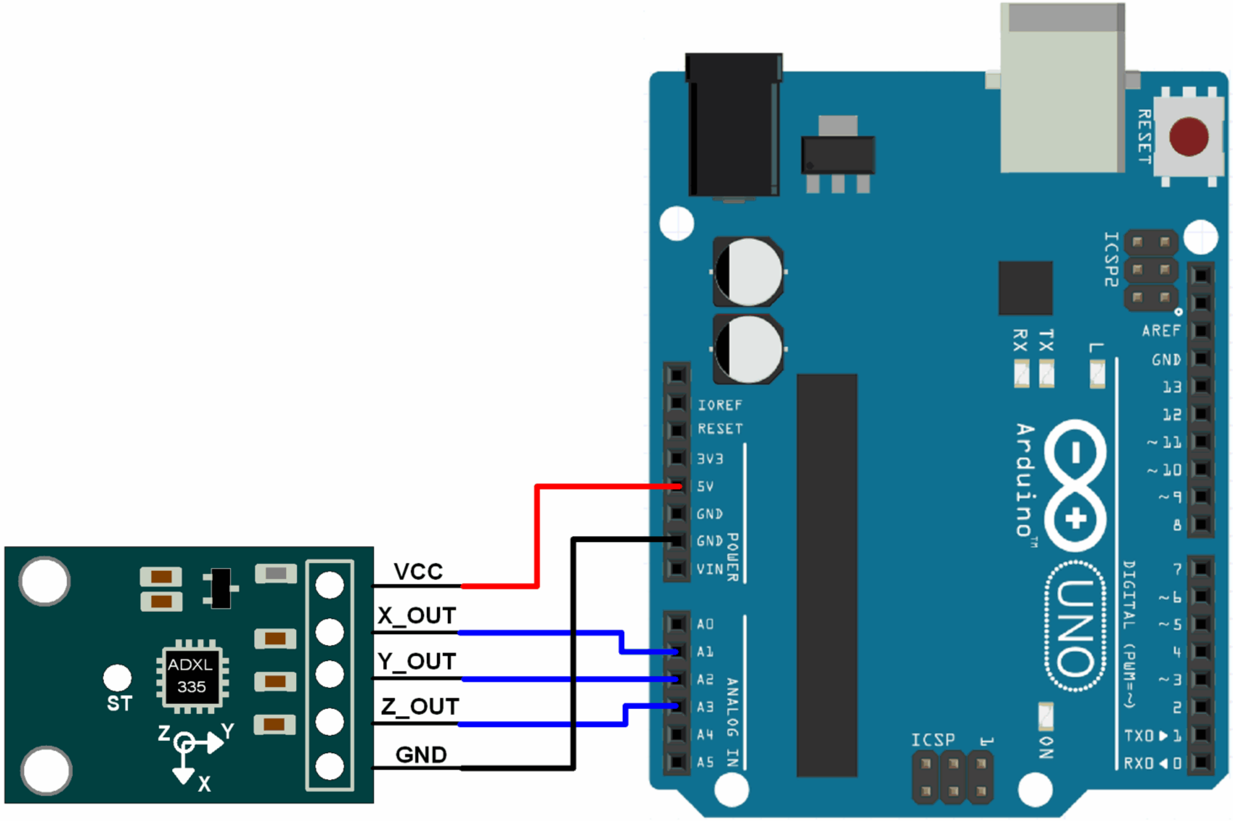
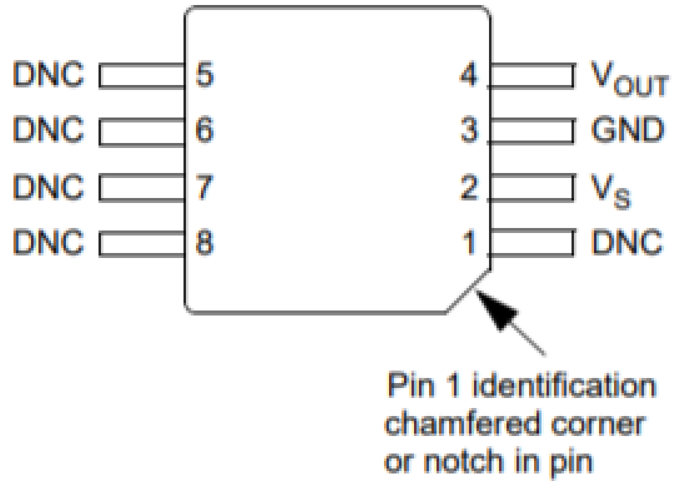


Figure 1.

3 Axes Accelerometer



Pressure Sensor

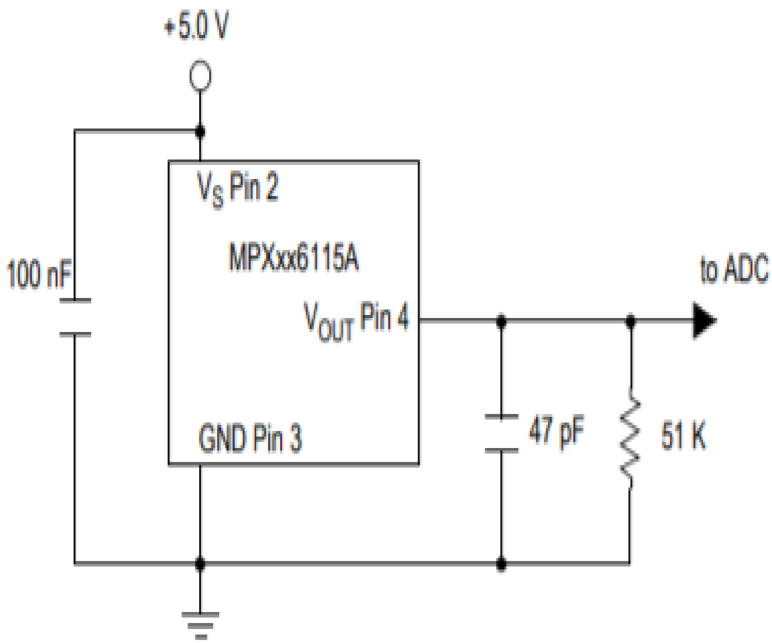


Pinout

Piezoresistive material based

A **pressure sensor** is a device for **pressure** measurement of gases or liquids.

Pressure Sensor



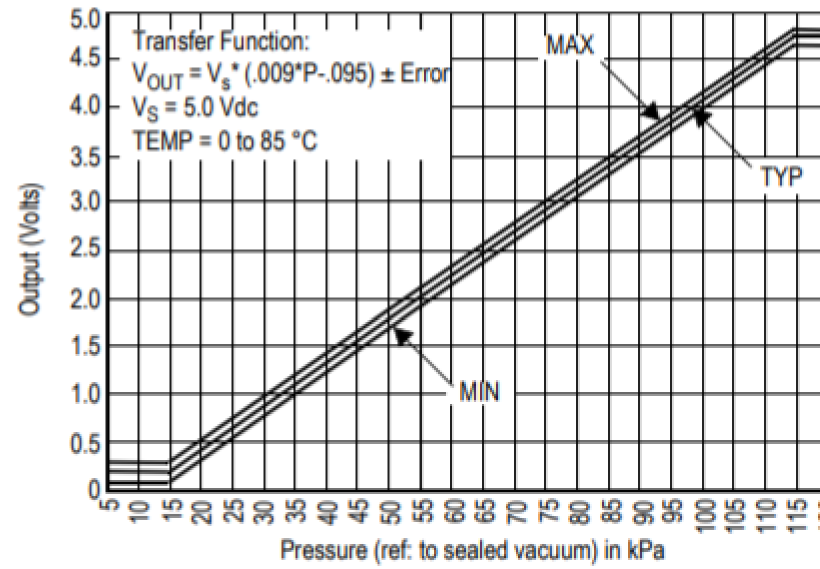
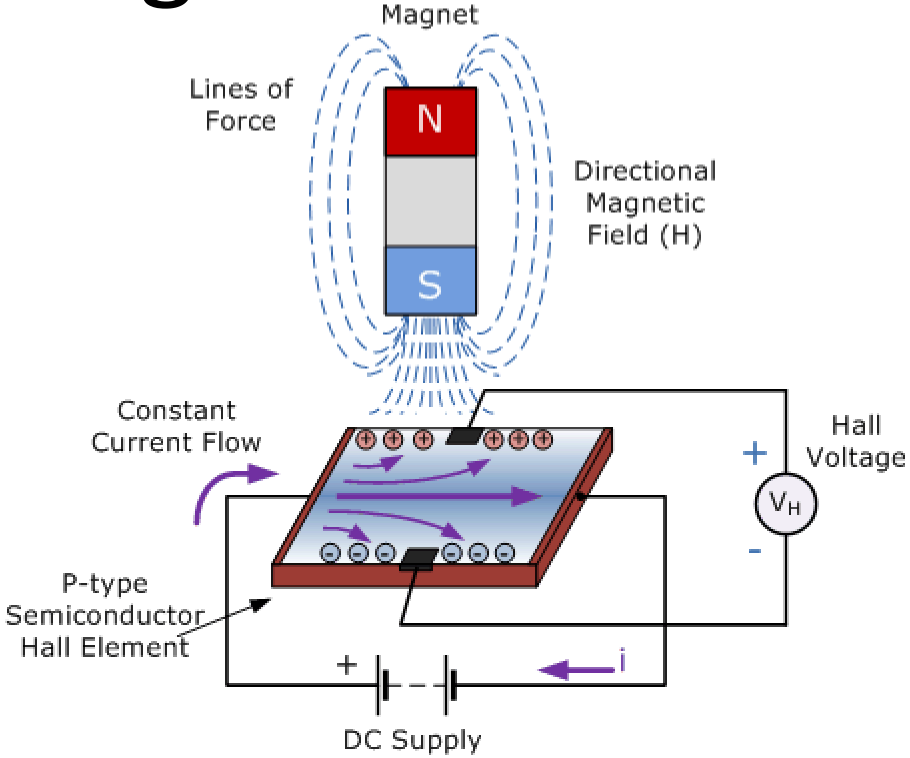


Figure 5. Output vs. absolute pressure

The MPXxx6115A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation

Magnetic Field Sensors

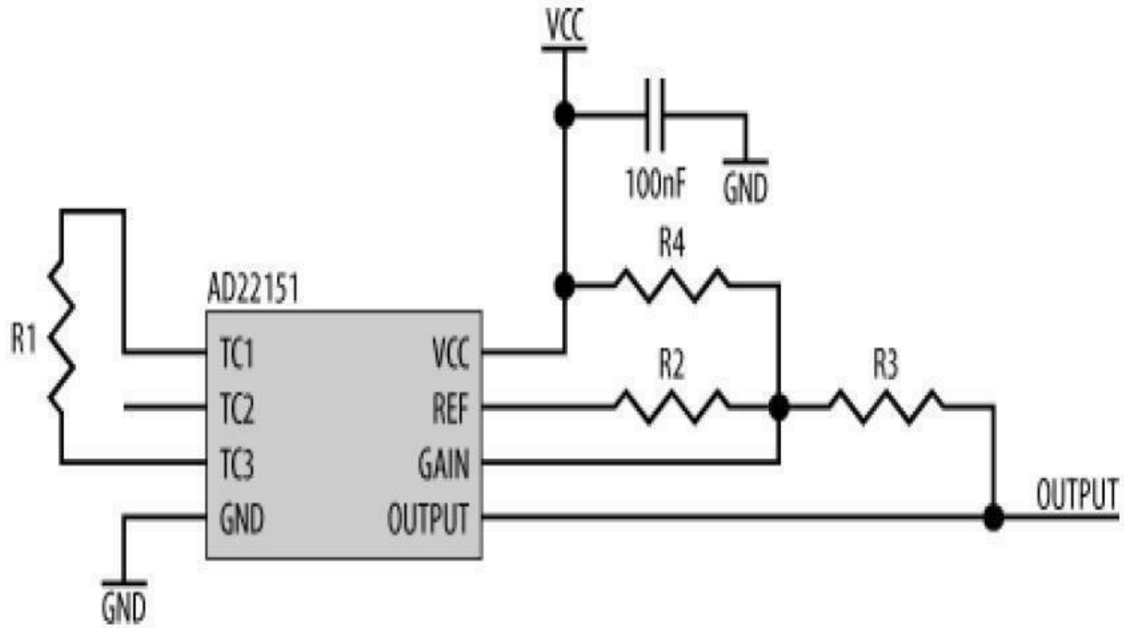


Working principle – Hall Effect

In the presence of a **magnetic field**, the electrons in the metal strip are deflected toward one edge, producing a voltage gradient across the short side of the strip (perpendicular to the feed current).

In its simplest form, the **sensor** operates as an analog transducer, directly returning a voltage.

Magnetic Field Sensors

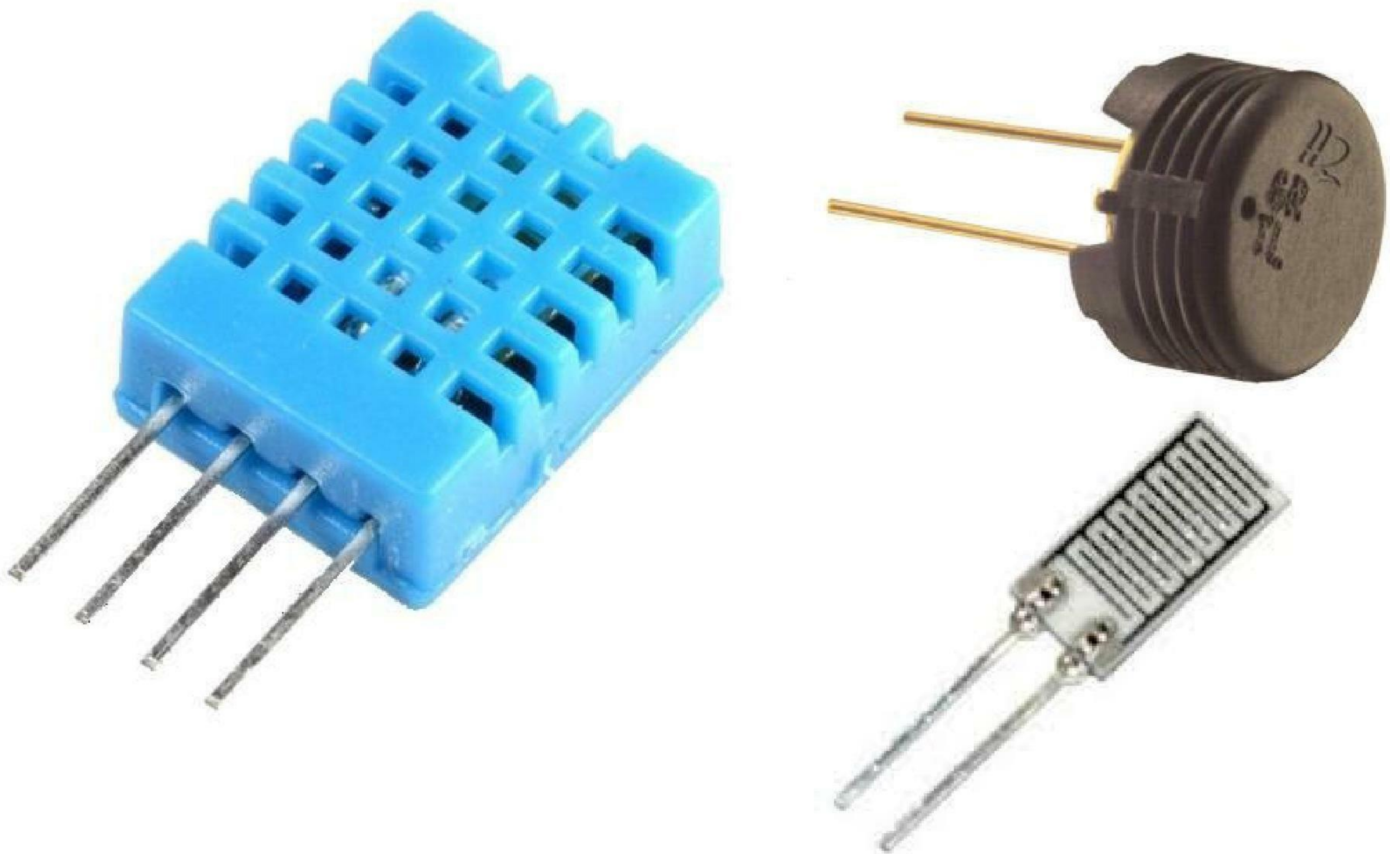


- Works on 5V Supply
- R1: Temperature Compensation Resistor
- R2, R3: Resistor to set the signal gain
- R4: Voltage offset resistor

Magnetic Field Sensors

Humidity Sensor

Humidity is defined as the amount of water present in the surrounding air.



Humidity Sensor

Absolute humidity

- It is the measure of water vapor (moisture) in the air, regardless of temperature.
- It is expressed as grams of moisture per cubic meter of air (g/m3).
- The maximum absolute humidity of warm air at 30°C is approximately 30g of water vapor - 30g/m3

$$\mathbf{AH = m/V}$$

Relative Humidity

- Ratio of the amount of water vapor actually present in the air to the greatest amount possible at the same temperature
- Relative humidity depends on temperature and the pressure of the system of interest.

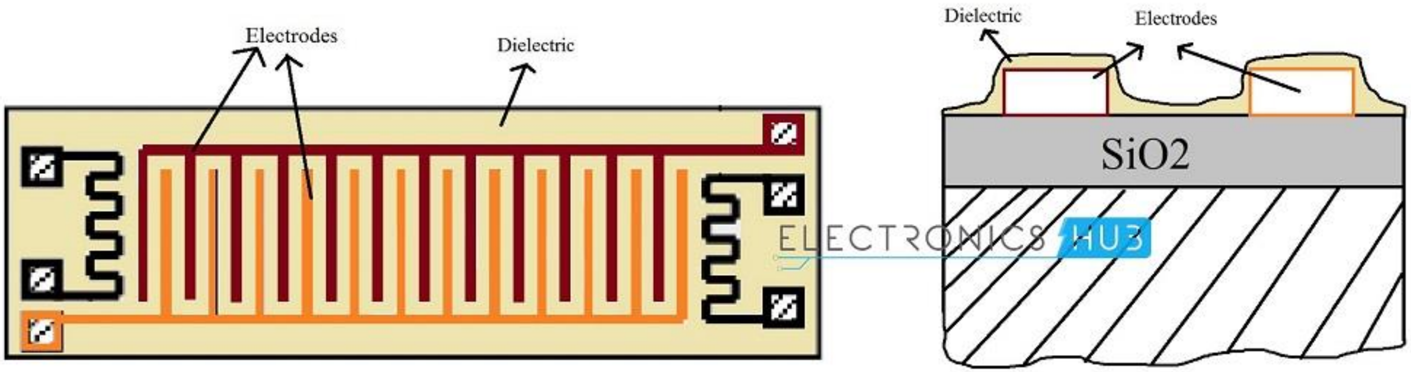
Humidity Sensor

Humidity sensors work by **detecting changes that alter electrical currents or temperature in the air**.

Types of humidity sensors:

- Capacitive
- Resistive
- Thermal

Humidity Sensor



Top View   Cross Section

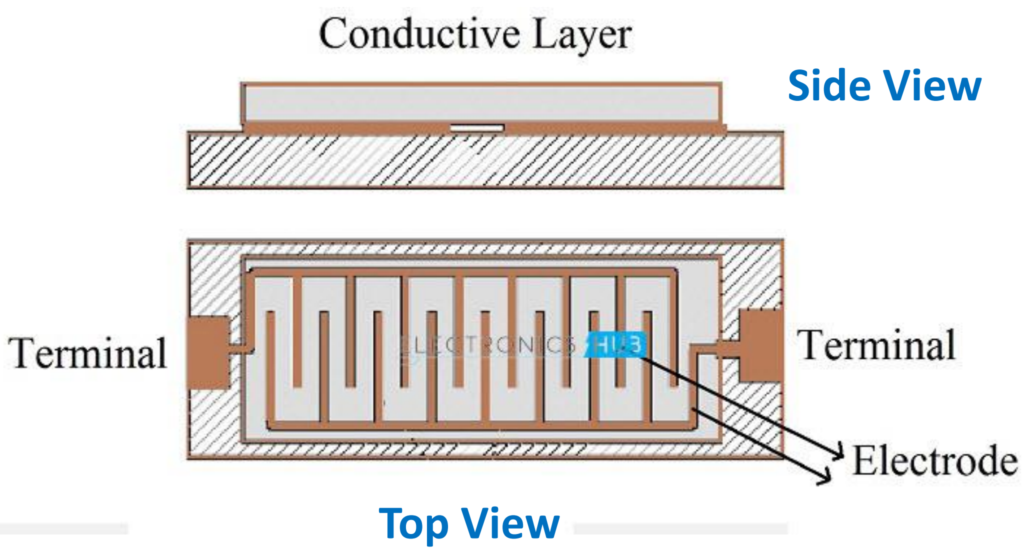
Capacitive

- Measures relative humidity by placing a thin strip of metal oxide between two electrodes.
- The metal oxide’s electrical capacity changes with the atmosphere’s relative humidity.
- The capacitive type sensors are linear and can measure relative humidity from 0% to 100%.
- These are the only types of full-range relative humidity measuring devices down to 0% relative humidity.

Humidity Sensor

Resistive

- The Resistive Humidity Sensor is usually made up of materials with relatively low resistivity
- The resistivity changes significantly with changes in humidity.
- The resistivity between the electrodes changes when the top layer absorbs water



Humidity Sensor

Thermal

- Two thermal sensors conduct electricity based upon the humidity of the surrounding air.
- One sensor is encased in dry nitrogen while the other measures ambient air.
- The difference between the two measures the humidity.

Humidity Sensor

DHT 11 Humidity & Temperature Sensor

- Digital temperature and humidity **sensor**.
- Uses a capacitive humidity **sensor** and a thermistor
- Gives out a digital signal on the data pin

Item	Measurement Range	Humidity Accuracy	Temperature Accuracy	Resolution	Package
DHT11	20-90%RH 0-50 ℃	±5%RH	±2℃	1	4 Pin Single Row

Typical Application

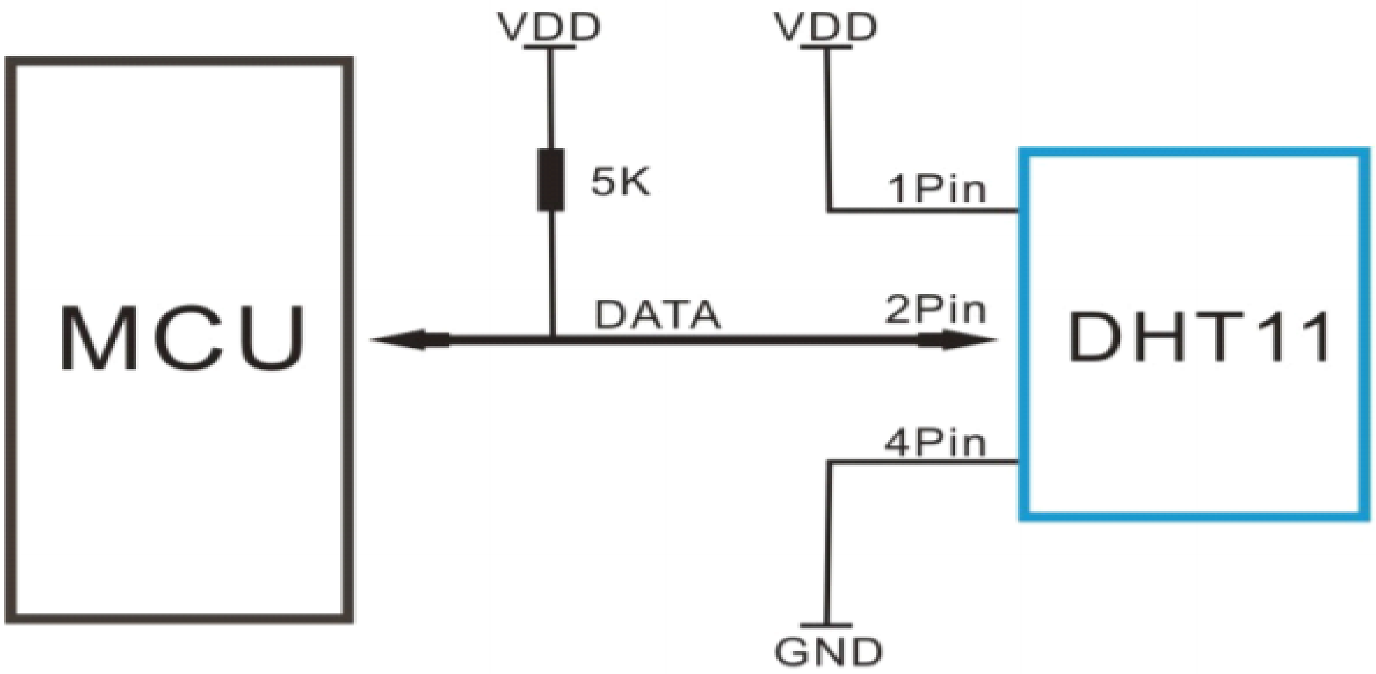


Figure 1 Typical Application

Note: 3Pin – Null; MCU = Micro-computer Unite or single chip Computer

Communication Process: Serial Interface (Single-Wire Two-Way)

Humidity Sensor

HIH-4000-001 by Honeywell

This thermoset polymer-based capacitive sensor offers accuracy: ±3.5% RH, humidity range 0 ~ 100% RH, operating supply current: 200 uA, operating Temperature: -40°C ~ 85°C, supply voltage: 4 V ~ 5.8 V, analog voltage output.

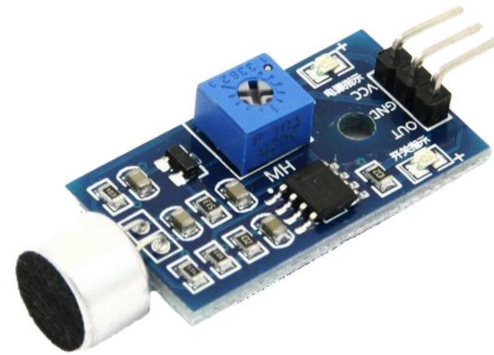
SHT15 by Sensirion

This digital output capacitive sensor offers accuracy: ±2% RH, humidity range 0 ~ 100% RH, operating supply current: 28 uA, operating temperature -40°C ~ 123.8°C, supply voltage: 2.4 V ~ 5.5 V, resolution 12 bit.

Humidity and Temperature Sensor Interfacing

Sound Sensor

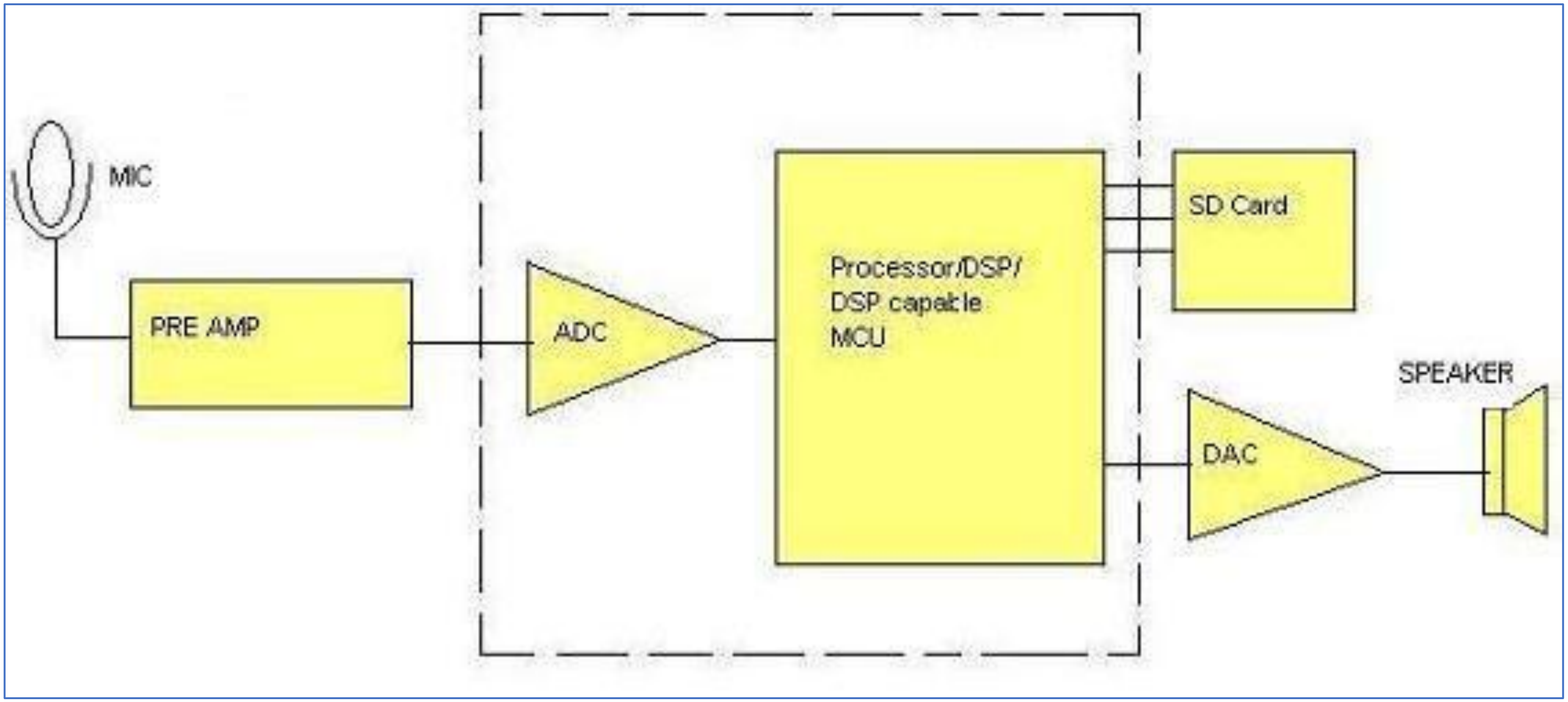
Microphone/ Mic



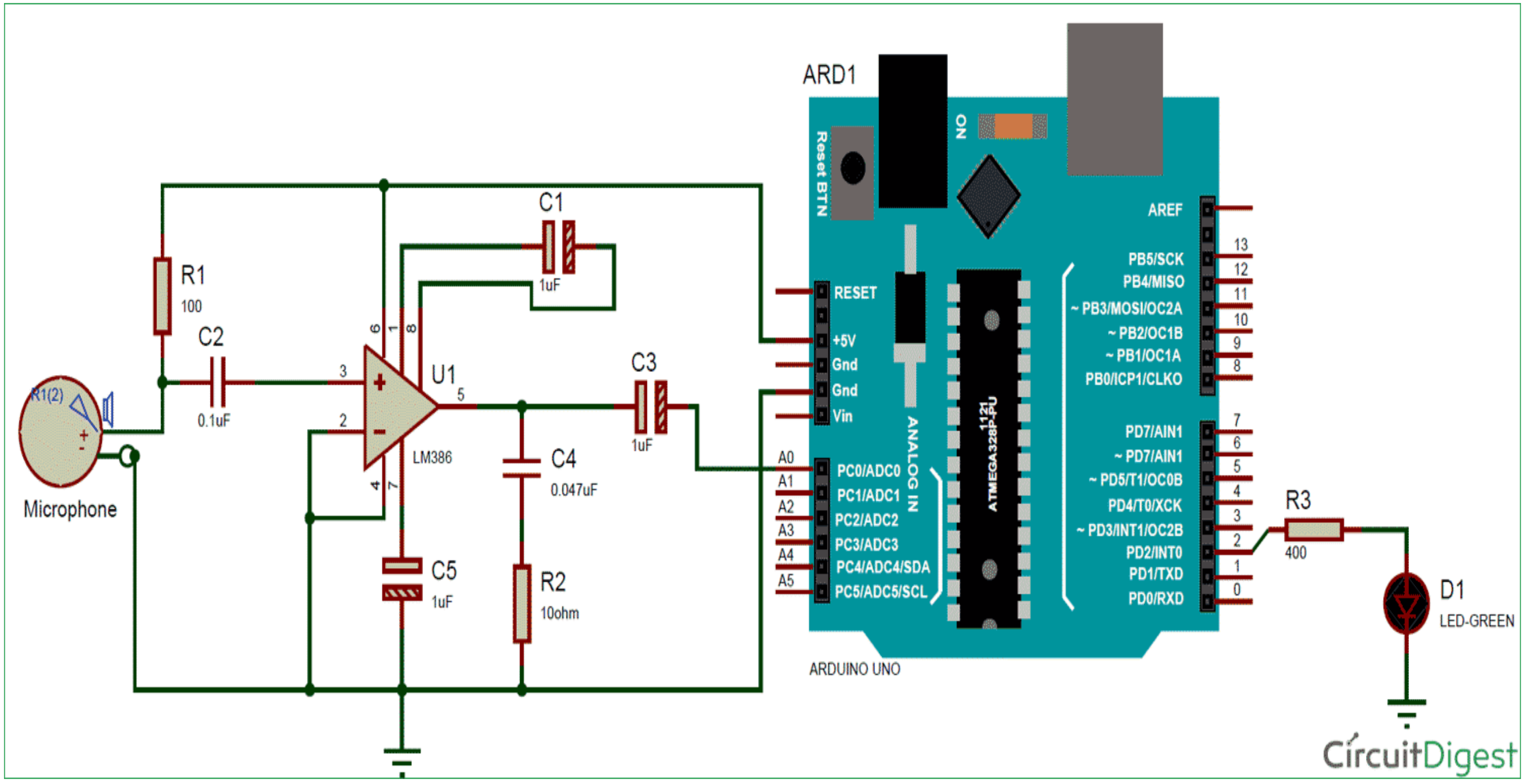
Sound Sensor Module

Condenser Microphone,
A parallel plate capacitor and works on the principle of a variable capacitance.
It consists of two plates, one fixed (called the back plate) and the other moveable (called Diaphragm) with a small gap between them.
An electric potential charges the plate. When sound strikes the diaphragm it starts moving, thereby changing the capacitance between the plates which in turn results in a variable electric current to flow.

Sound Sensor

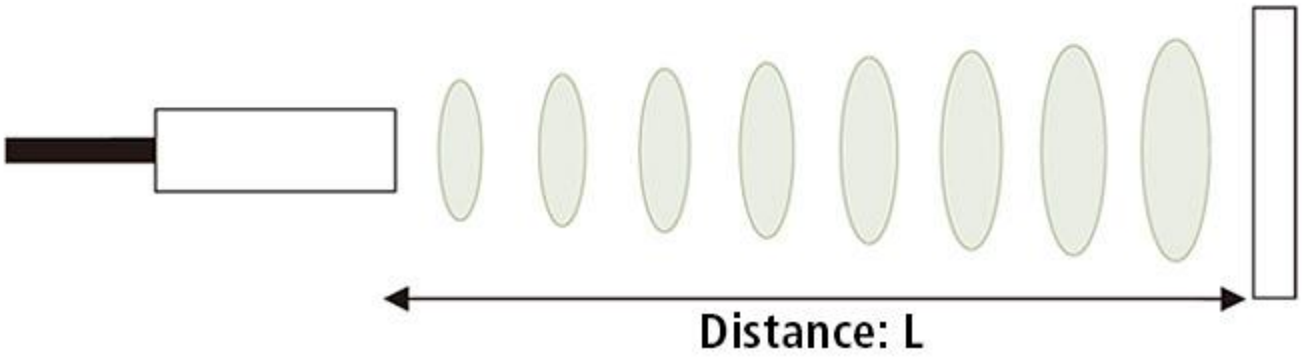


Sound Sensor



Distance Sensor

- Ultrasonic sensors measure distance by using ultrasonic waves. The sensor head emits an ultrasonic wave and receives the wave reflected back from the target.
- Ultrasonic Sensors measure the distance to the target by measuring the time between the emission and reception.



The distance can be calculated with the following formula:

Distance L = 1/2 × T × C

- L is the distance,
- T is the time between the emission and reception,
- C is the sonic speed.
- (The value is multiplied by 1/2 because T is the time for go-and-return distance.)

Distance Sensor

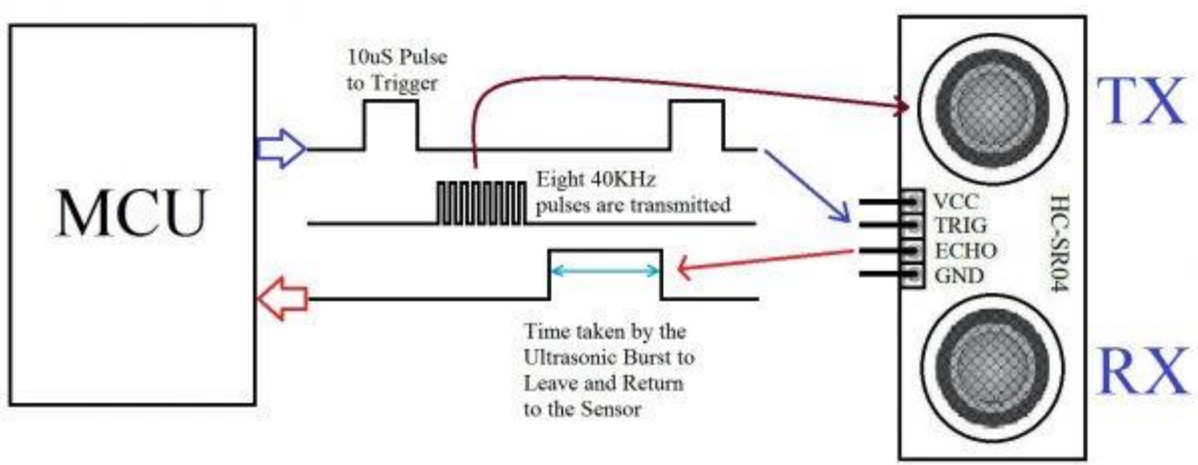
Sensor Module - HC-SR04

The Module automatically sends eight **40 kHz** and detect whether there is a pulse signal back.

Features

- Output: Digital
- Voltage: 5VDC
- Detection distance: 2cm-400cm (0.02M - 4.0M)
- Static current: < 2mA
- Level output: high-5V
- High precision: up to 0.3cm

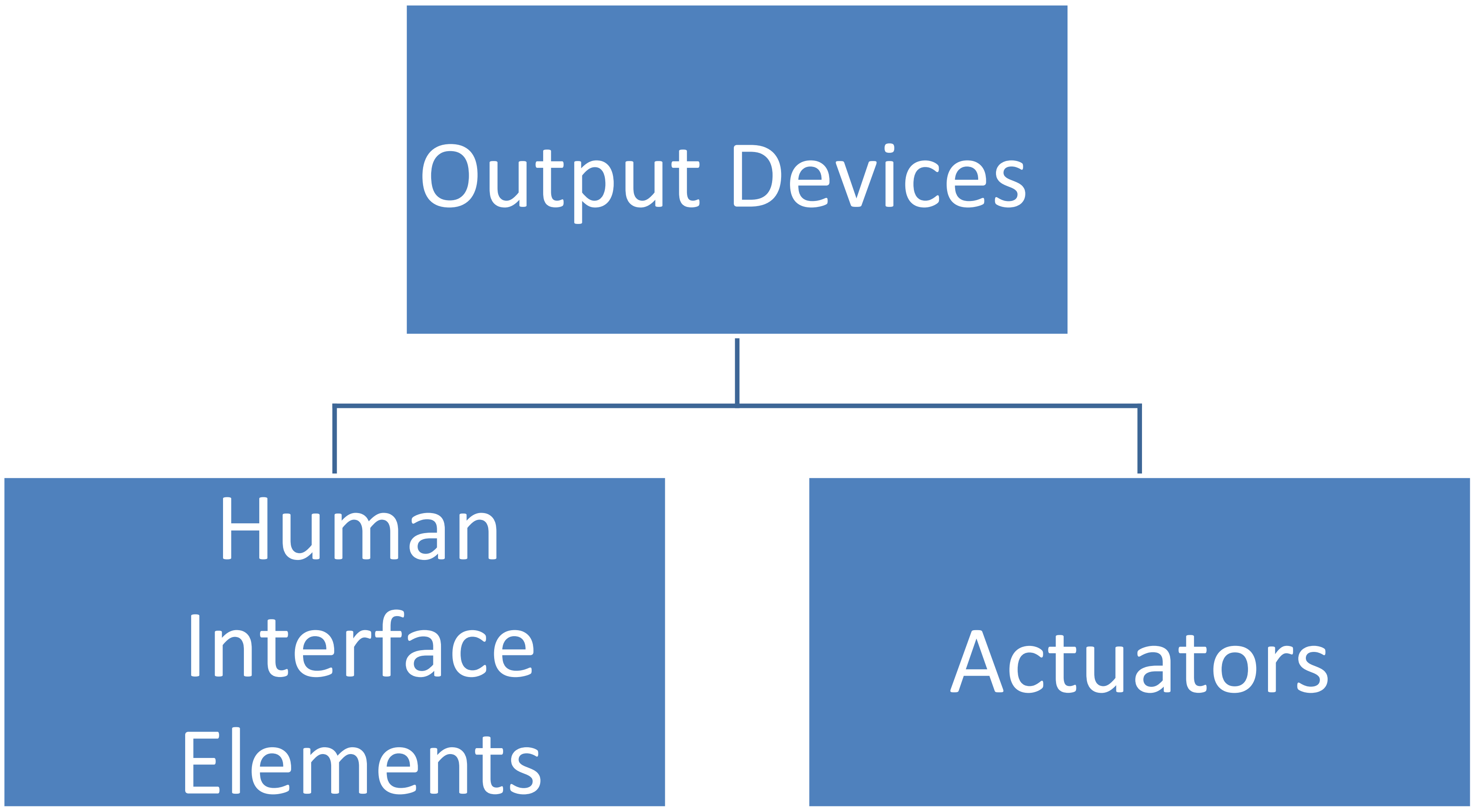
Distance Sensor



1.Provide TRIGGER signal
2.The module will automatically transmit eight 40KHz ultrasonic burst.
3.If there is an obstacle in-front of the module, it will reflect the ultrasonic burst.
4.If the signal is back, ECHO output of the sensor will be in HIGH state (5V) for a duration of time taken for sending and receiving ultrasonic burst.
Pulse width ranges from about 150μS to 25mS and if no obstacle is detected, the echo pulse width will be about 38ms.

Ultrasonic Sensor

Output Devices


Output Devices
Human Interface Elements
Actuators

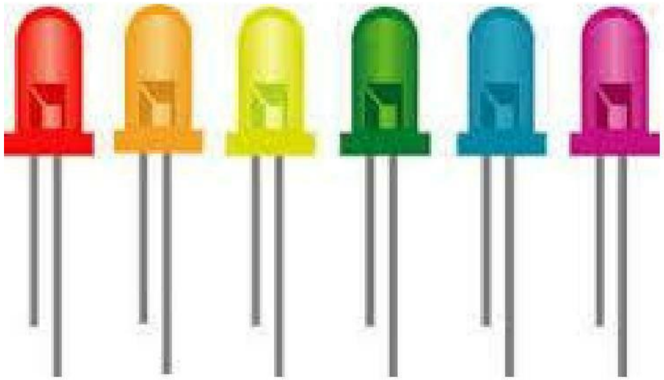
Output Devices

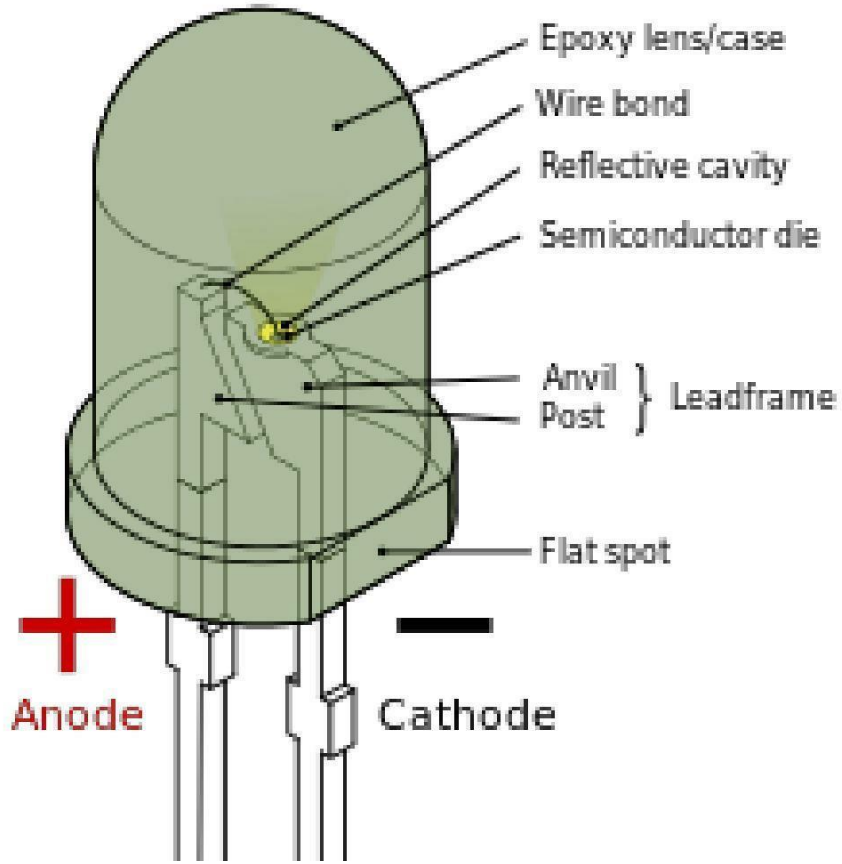
- Position
  - Motors
- Flow (valves)
- Audio
  - Speakers
  - Headphones
- Printer
  - Punched tape
  - Braille embosser
  - Plotter
- Temperature
  - Heating
  - Cooling

Output Devices

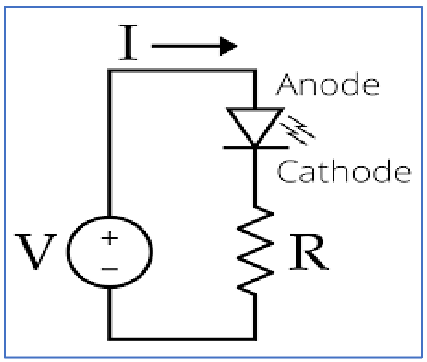
- Graphics
  - Screen (Monitor)
  - Automotive navigation system
  - LCD, LED
- Data through wired/wireless communication

LED

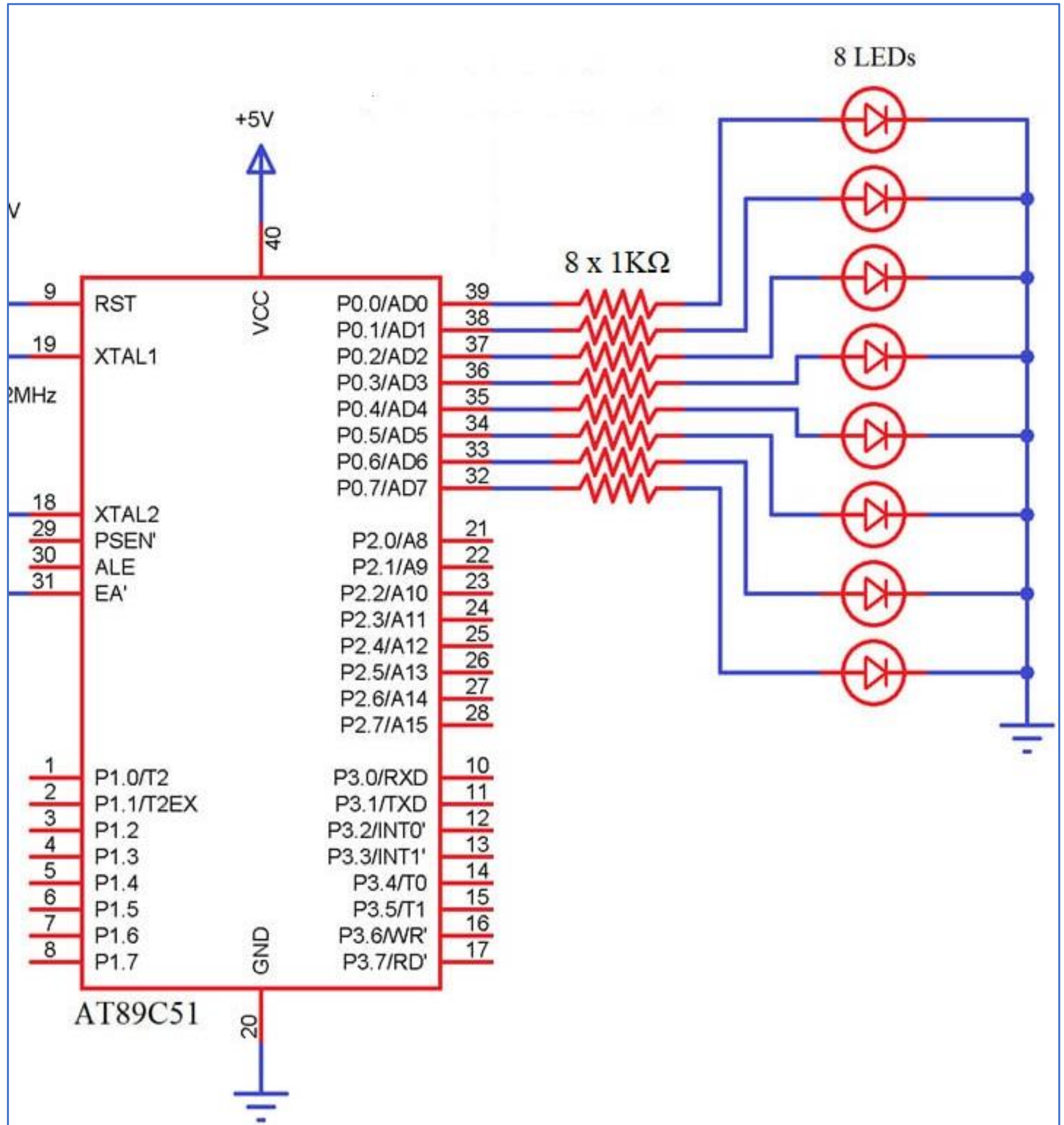



Epoxy lens/case
Wire bond
Reflective cavity
Semiconductor die
Anvil
Post
Leadframe
Flat spot
+
Anode
−
Cathode

LED

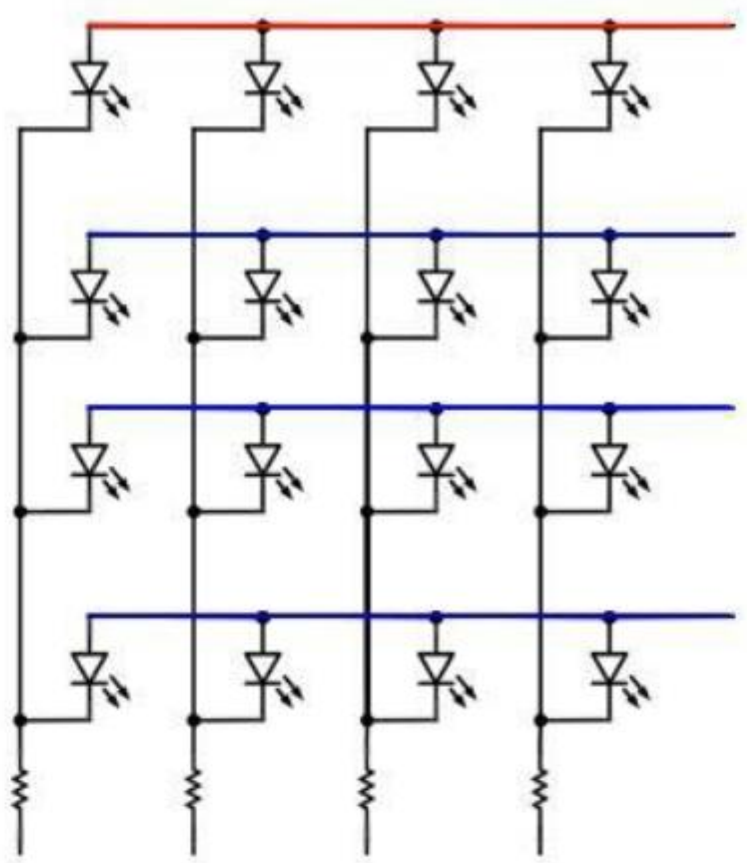


I
Anode
Cathode
V
R

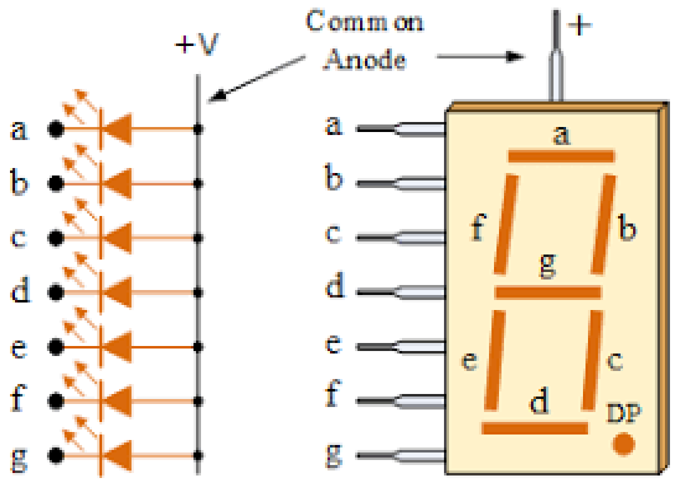


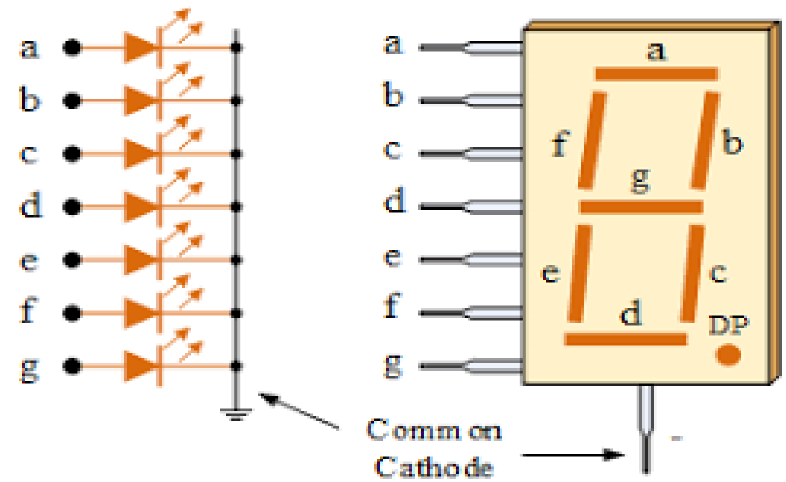
8 LEDs
+5V
8 x 1KΩ
RST
XTAL1
XTAL2
PSEN'
ALE
EA'
VCC
GND
P0.0/AD0
P0.1/AD1
P0.2/AD2
P0.3/AD3
P0.4/AD4
P0.5/AD5
P0.6/AD6
P0.7/AD7
P2.0/A8
P2.1/A9
P2.2/A10
P2.3/A11
P2.4/A12
P2.5/A13
P2.6/A14
P2.7/A15
P1.0/T2
P1.1/T2EX
P1.2
P1.3
P1.4
P1.5
P1.6
P1.7
P3.0/RXD
P3.1/TXD
P3.2/INT0'
P3.3/INT1'
P3.4/T0
P3.5/T1
P3.6/WR'
P3.7/RD'
AT89C51

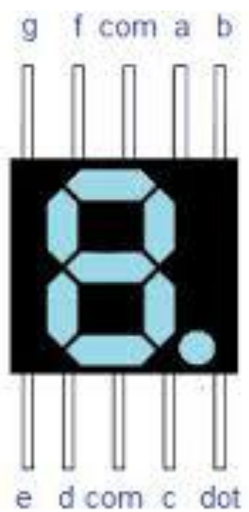
LED Multiplexing

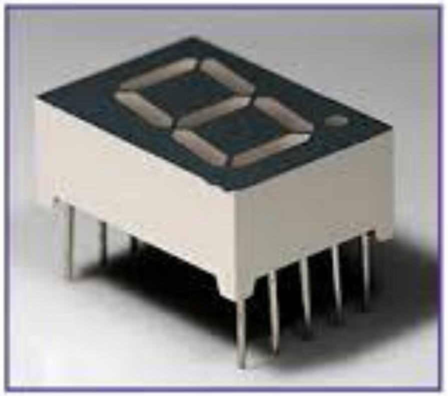


LED Multiplexing

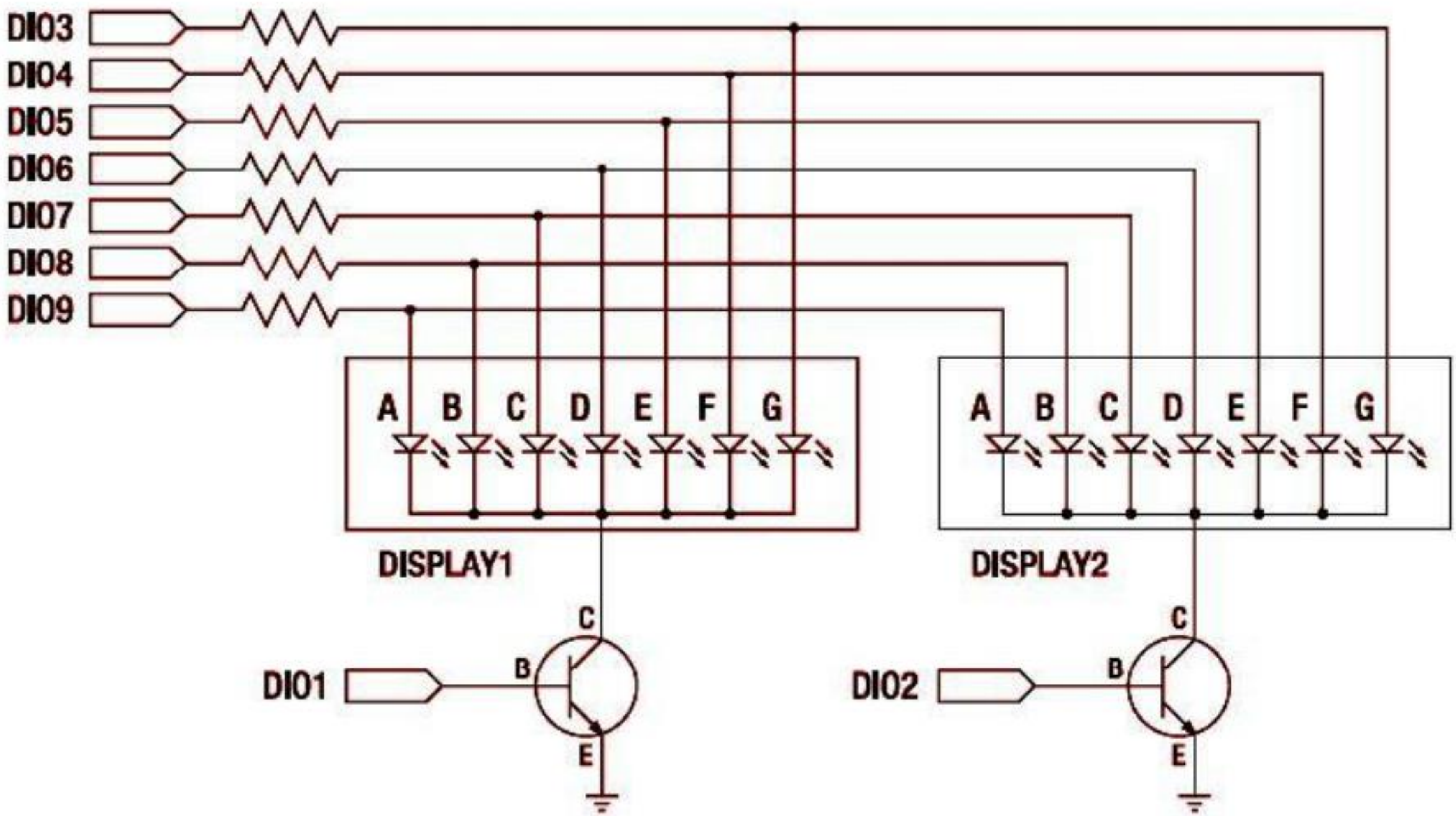








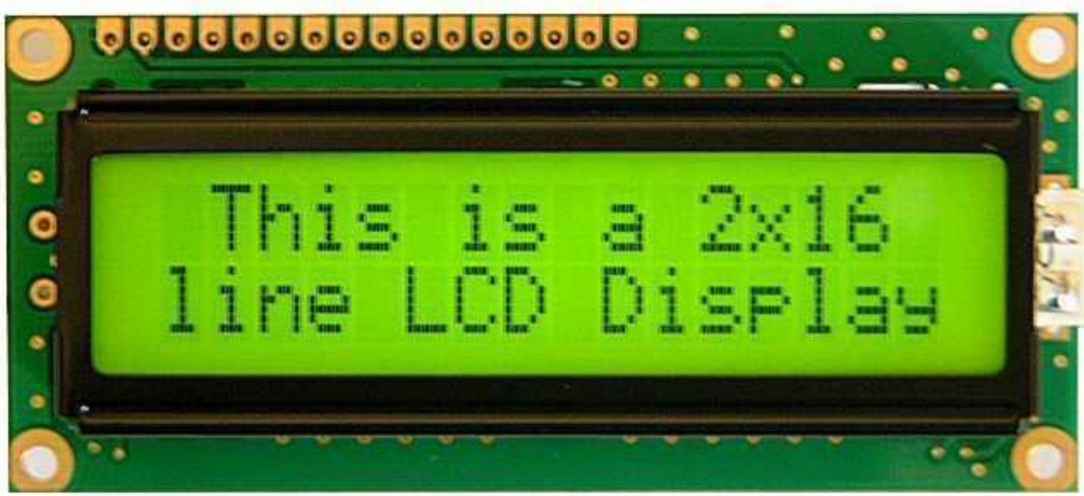
LED Multiplexing

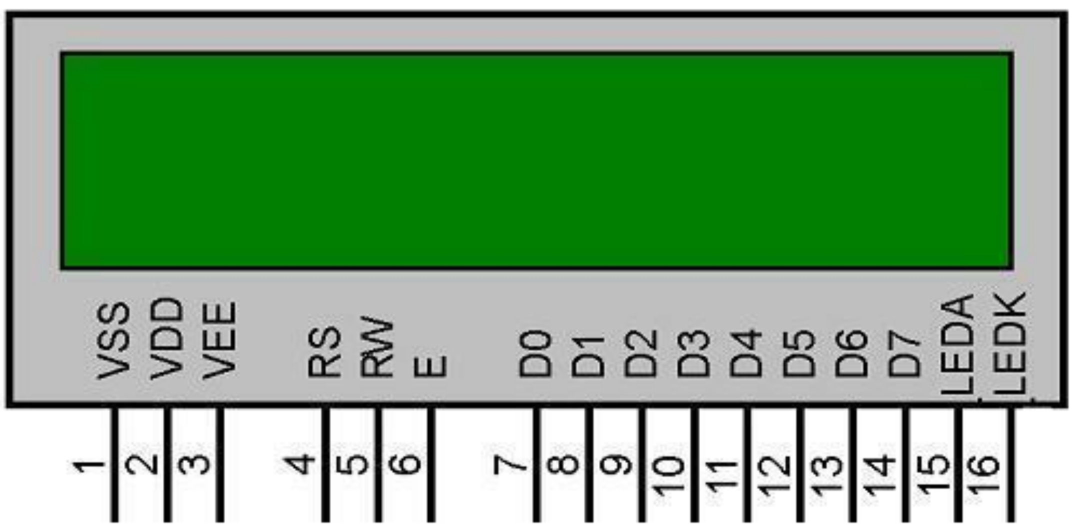


LED Multiplexing Demo

LCD

- •Operating Voltage is 4.7V to 5.3V
- •Current consumption is 1mA without backlight
- •Alphanumeric LCD can display alphabets and numbers
- •Consists of two rows and each row can print 16 characters.
- •Each character is build by a 5×8 pixel box
- •Can work on both 8-bit and 4-bit mode

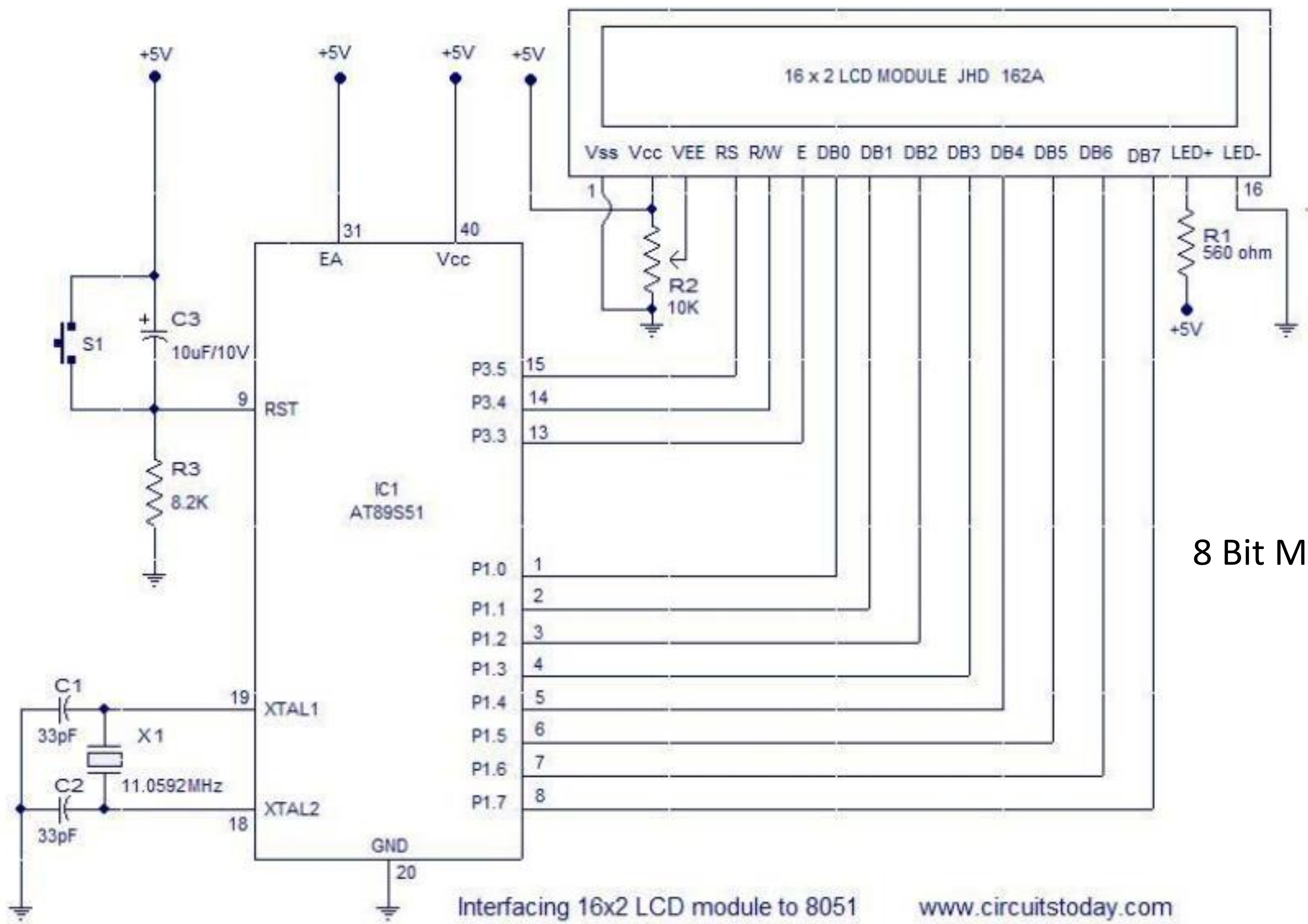




LCD

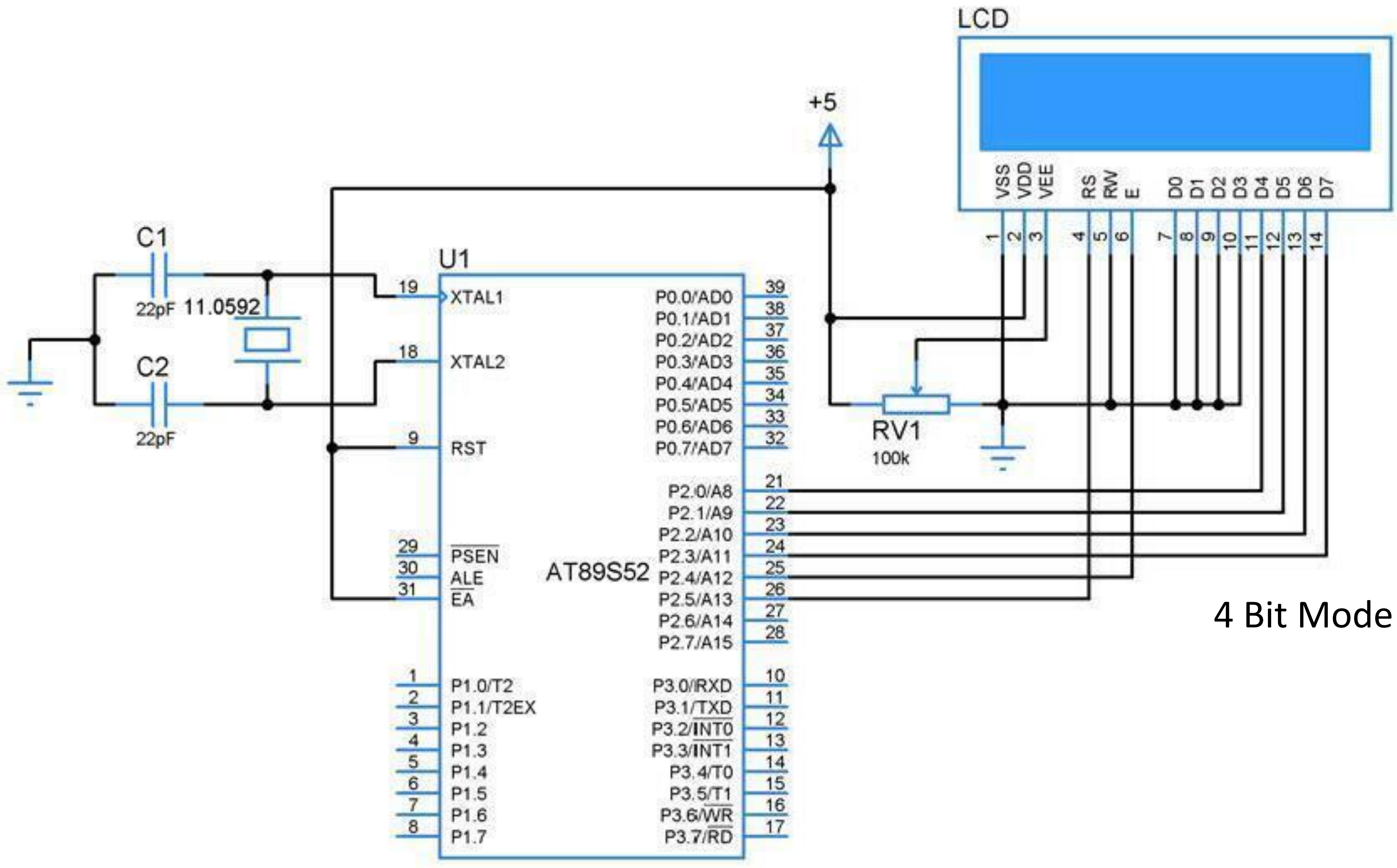
Pin No:	**Pin Name:**	**Description**
1	Vss (Ground)	Ground pin connected to system ground
2	Vdd (+5 Volt)	Powers the LCD with +5V (4.7V – 5.3V)
3	VE (Contrast V)	Decides the contrast level of display. Grounded to get maximum contrast.
4	Register Select	Connected to Microcontroller to shift between command/data register
5	Read/Write	Used to read or write data. Normally grounded to write data to LCD
6	Enable	Connected to Microcontroller Pin and toggled between 1 and 0 for data acknowledgement
7 -14	Data Pin 0 - 7	Data pins 0 to 7 forms a 8-bit data line. They can be connected to Microcontroller to send 8-bit data. These LCD's can also operate on 4-bit mode in such case Data pin 4,5,6 and 7 will be left free.
15	LED Positive	Backlight LED pin positive terminal
16	LED Negative	Backlight LED pin negative terminal

LCD Interfacing



8 Bit Mode

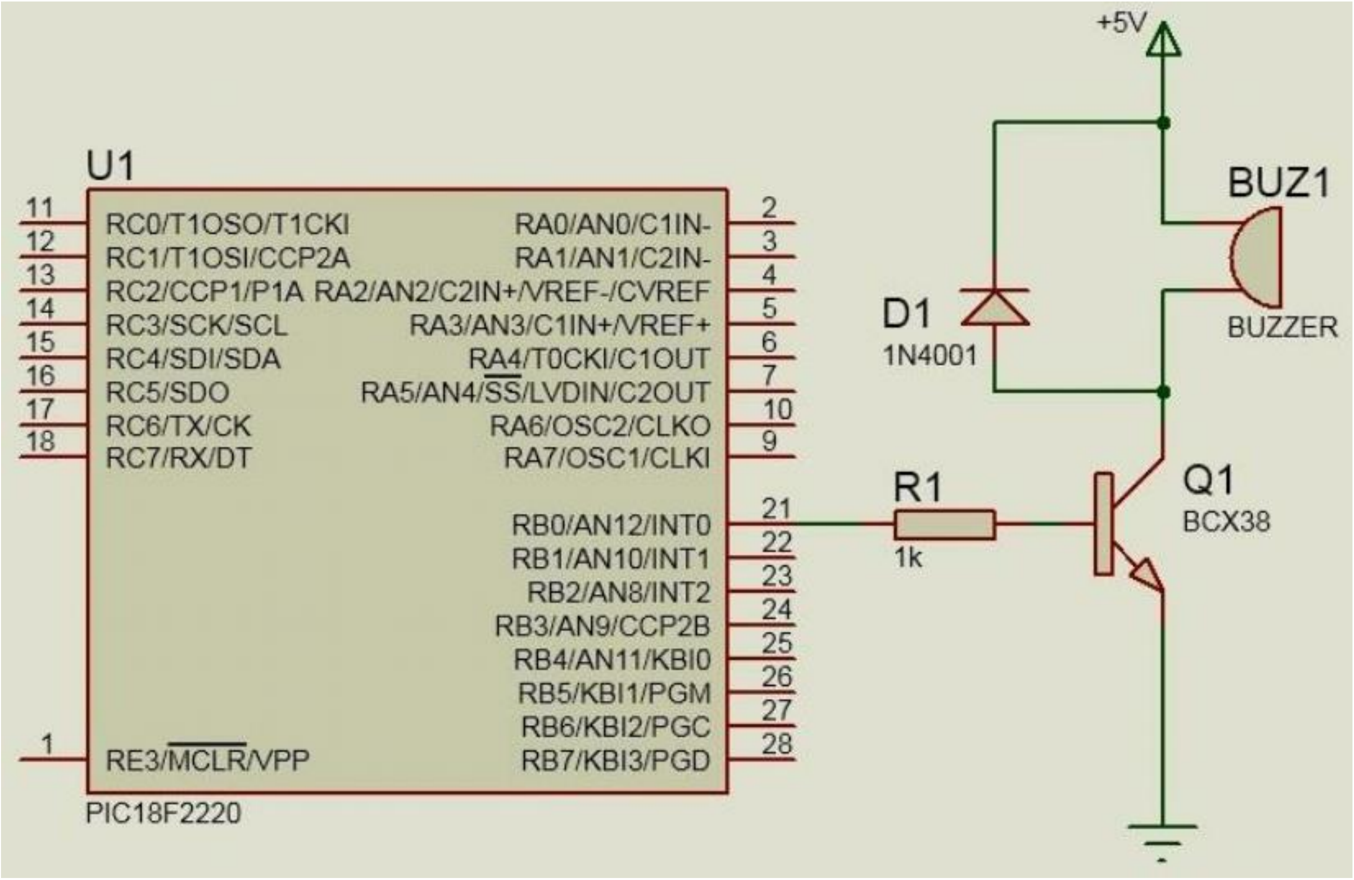
LCD Interfacing



4 Bit Mode

Buzzer

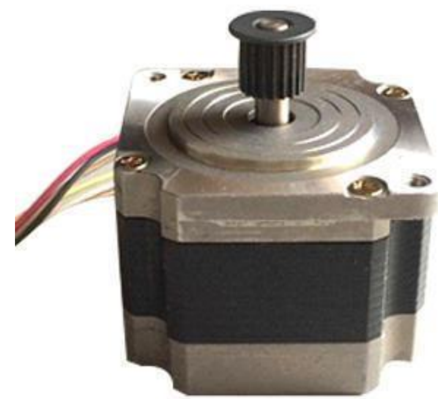
A **buzzer** or **beeper** is an audio signaling device



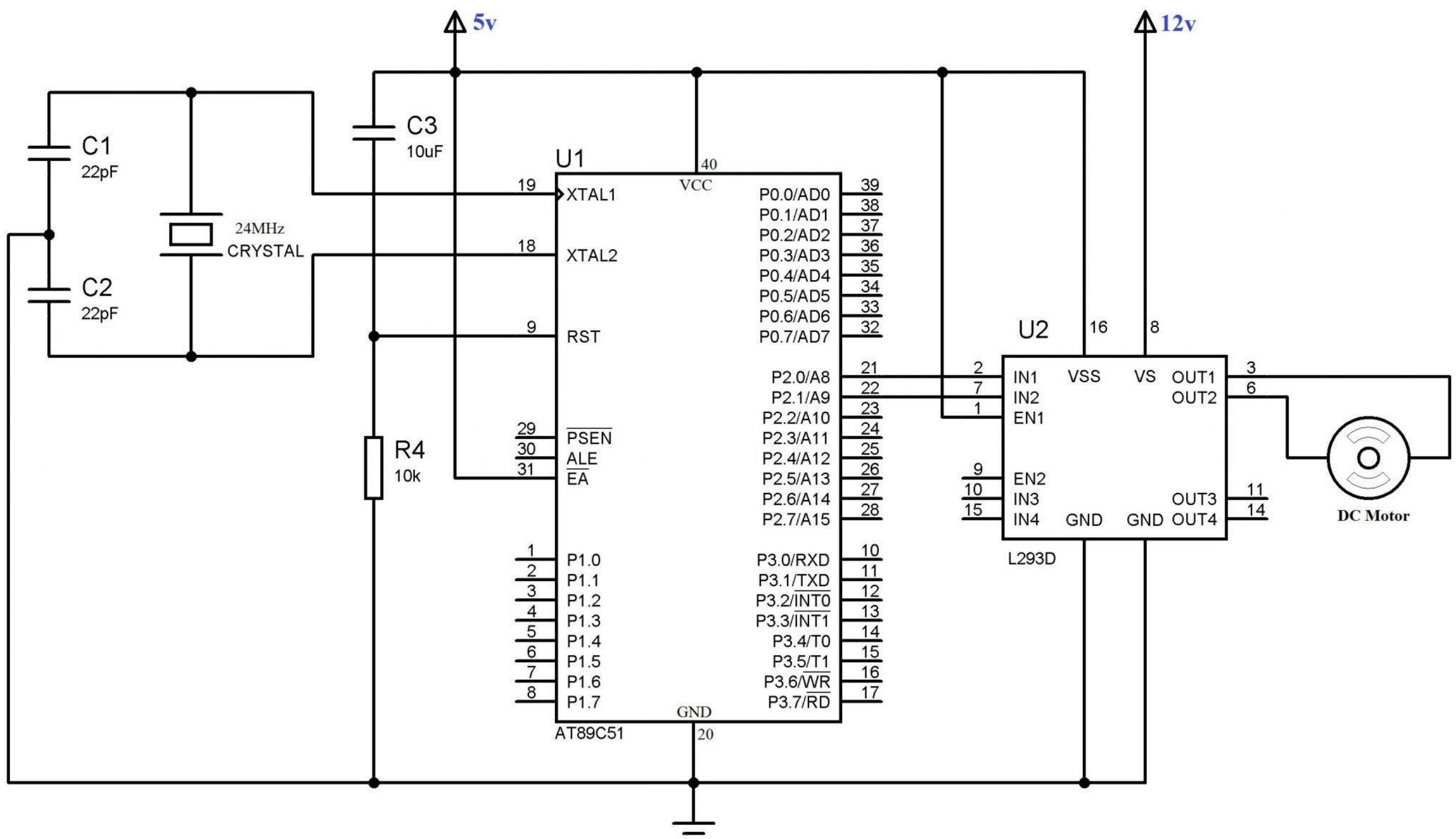
Motor

There are basically three types of conventional electrical motor available:

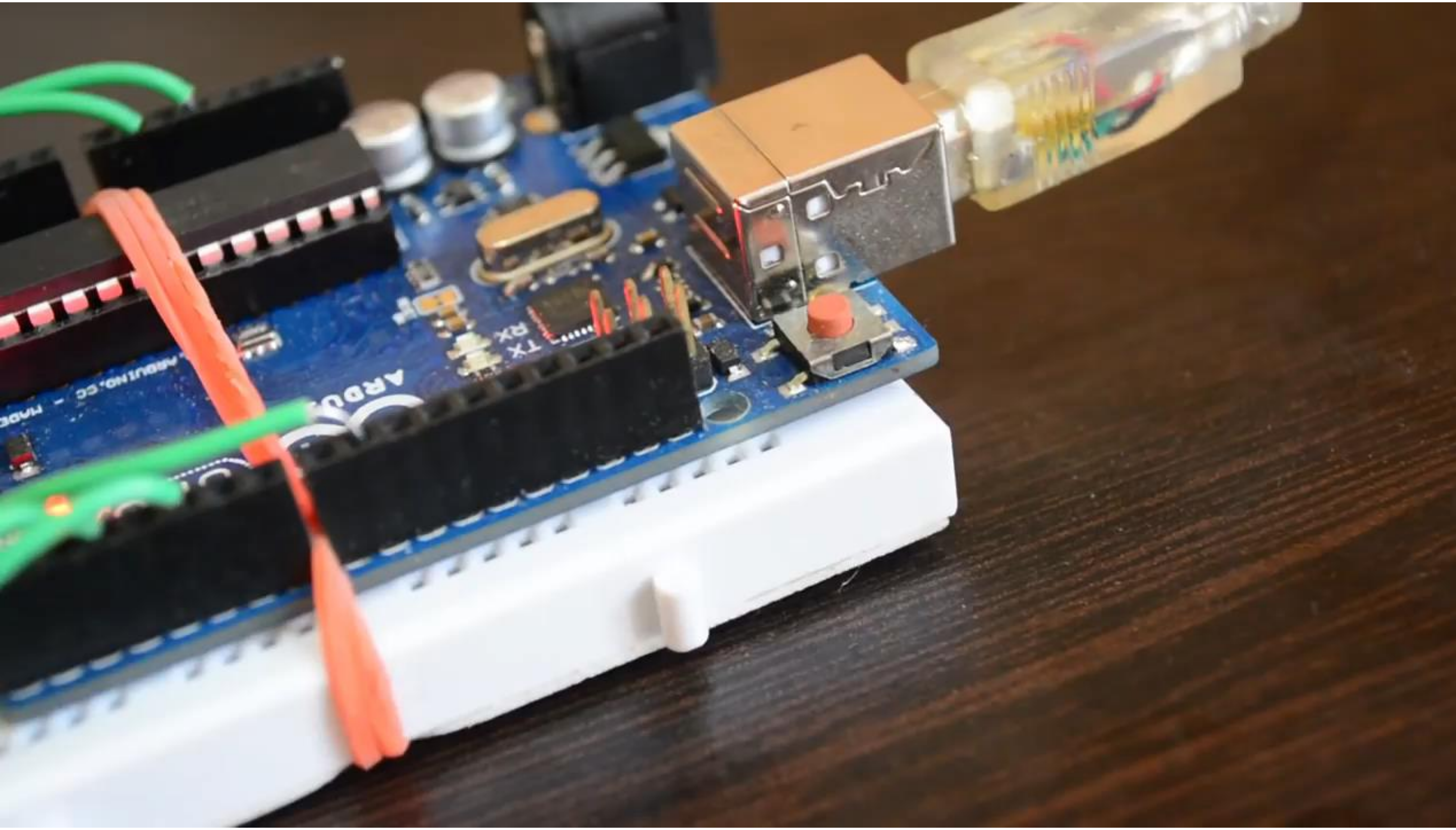
•A Typical Small DC **Motor**.
•Servo **Motor**.
•Stepper **Motor**.



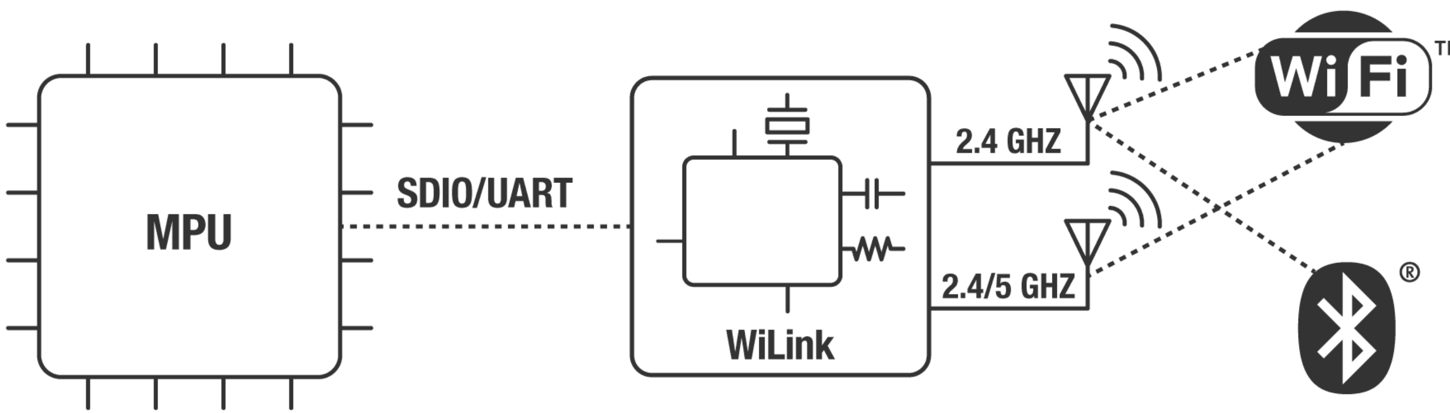
Motor Interfacing



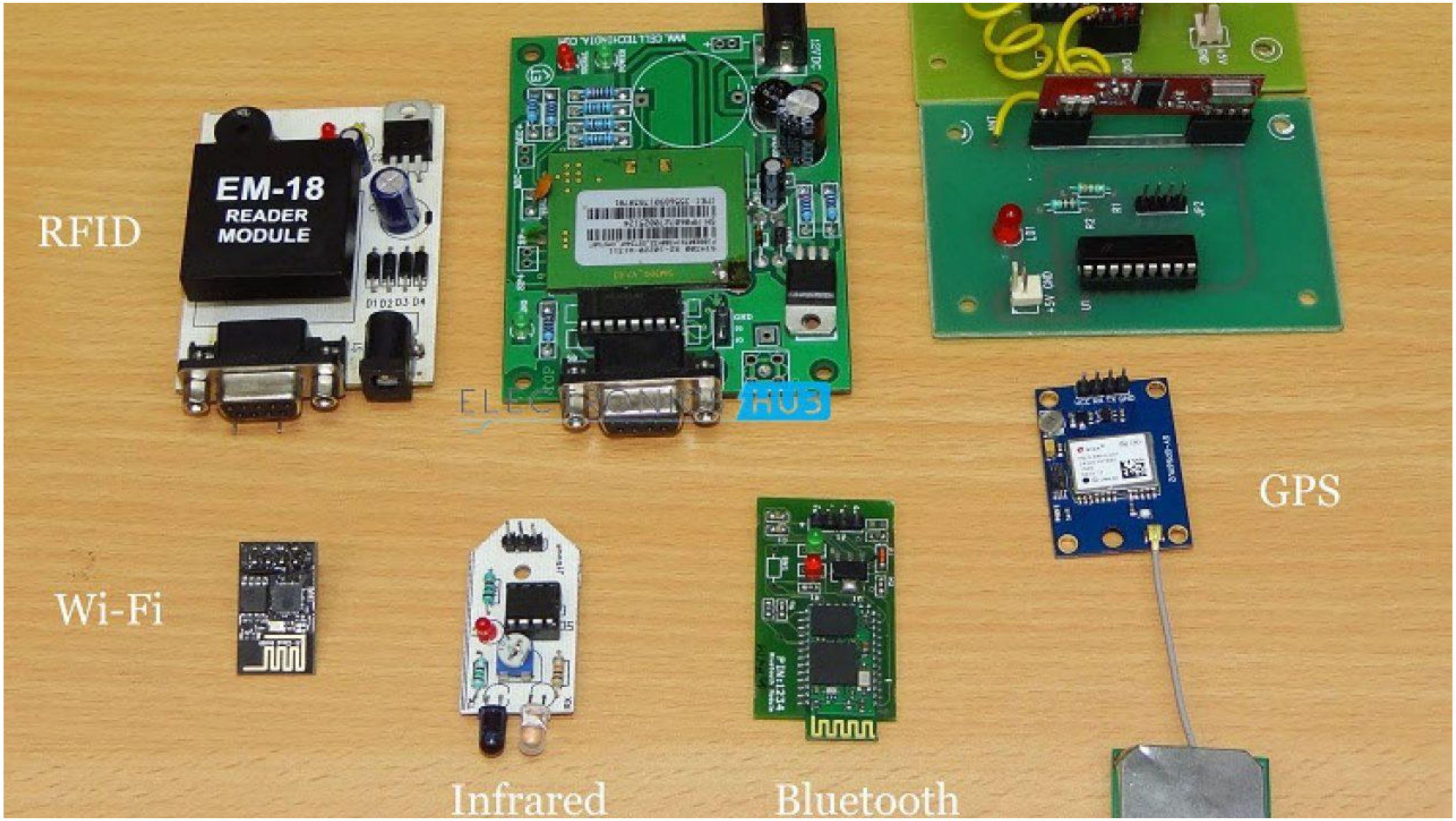
Motor Demonstration



Data Communication Devices

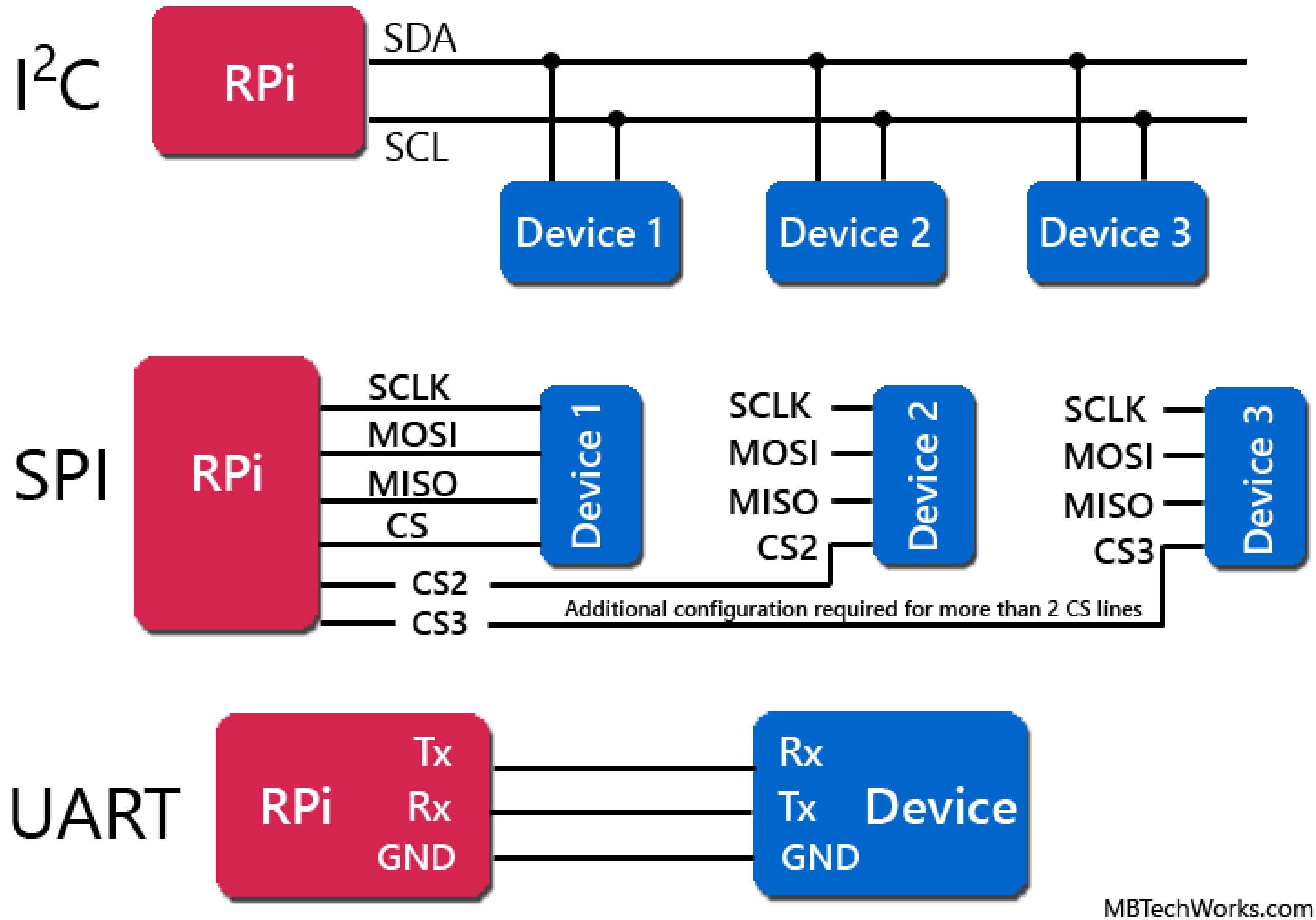


Data Communication Devices

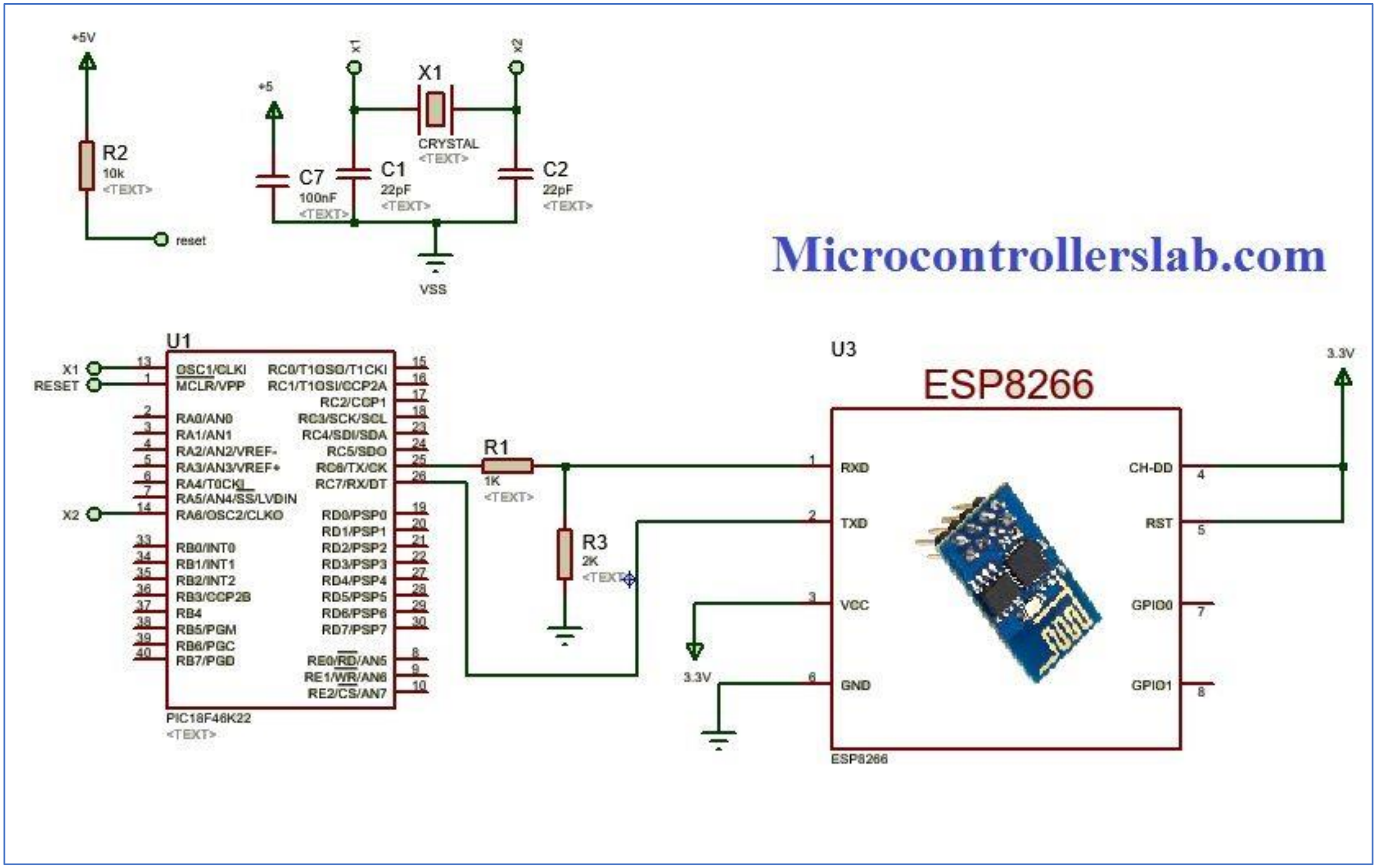


WIRELESS TECHNOLOGIES AT A GLANCE					
Technology	Frequency	Data rate	Range	Power	Cost
2G/3G	Cellular bands	10 Mb/s	Several km	High	High
802.15.4	2.4 GHz	250 kb/s	100 m	Low	Low
Bluetooth	2.4 GHz	1, 2.1, 3 Mb/s	100 m	Low	Low
LoRa	< 1 GHz	<50 kb/s	2-5 km	Low	Medium
LTE Cat 0/1	Cellular bands	1-10 Mb/s	Several km	Medium	High
NB-IoT	Cellular bands	0.1-1 Mb/s	Several km	Medium	High
SIGFOX	<1 GHz	Very low	Several km	Low	Medium
Weightless	<1 GHz	0.1-24 Mb/s	Several km	Low	Low
Wi-Fi (11f/h)	2.4, 5, <1 GHz	0.1-1 Mb/s	Several km	Medium	Low
WirelessHART	2.4 GHz	250 kb/s	100 m	Medium	Medium
ZigBee	2.4 GHz	250 kb/s	100 m	Low	Medium
Z-Wave	908.42 MHz	40 kb/s	30 m	Low	Medium

Data Interfaces



Wifi Module interfacing



Embedded System Demo

Embedded System Demo

System Components

Input Devices

Output Devices