IIT Bombay

Makerspace (MS101)

2022-2023-II (Spring)

EE-Lecture-4

Introduction to transistor

Use of Bipolar Junction Transistor (BJT) as a Switch

Kushal Tuckley, Joseph John, PC Pandey and Dinesh K Sharma

Topics Covered Earlier

- Passive Electrical devices : Resistors, Capacitors, Inductors and Transformers
- Circuit Laws: Kirchhoff's Current and Voltage laws
- Power Sources: Dependent and Independent
- Diodes Types & applications: PN-junction, Zener, LED, Photodiode, Solar Cell
- Transformers and power conversions: Transformers, Rectifiers, Regulators etc.

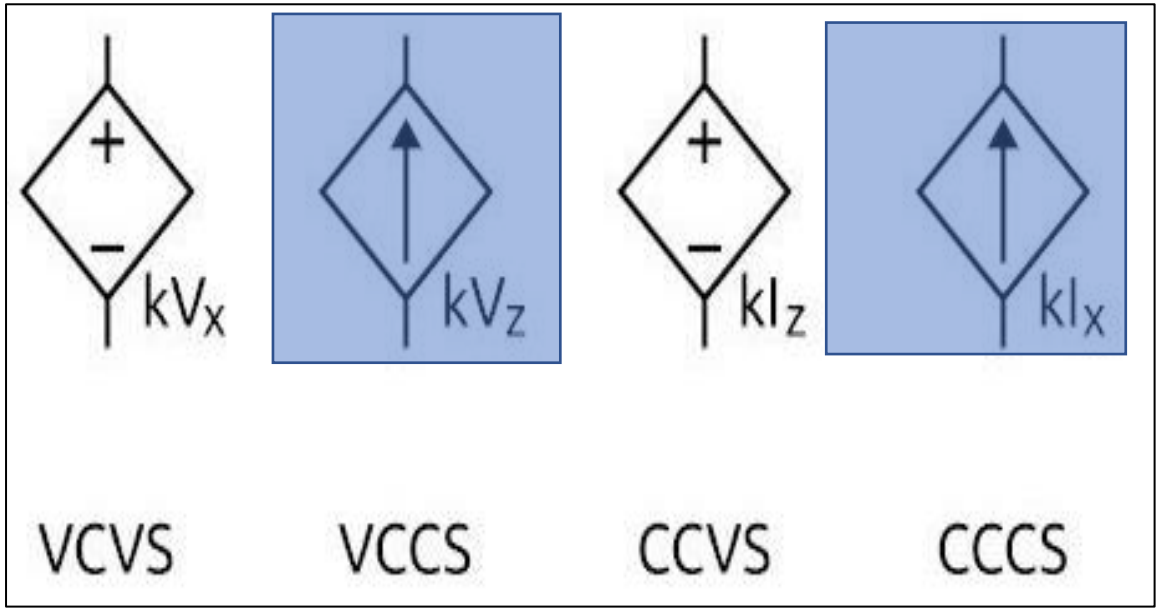
Transistors: Underlying Concepts

A transistor is a semiconductor device with three terminals, capable of showing 'Control Parameter Dependent changes' in the Circuit under consideration (Etymology: 'Transferred–Resistor')

Commonly used types of Transistors

(a) Bipolar Junction Transistor (BJT)

(b) Metal Oxide Field Effect Transistor (MOSFET)



Dependent Sources

Exhibiting control by an external parameter

Transistors Behave as Dependent current sources

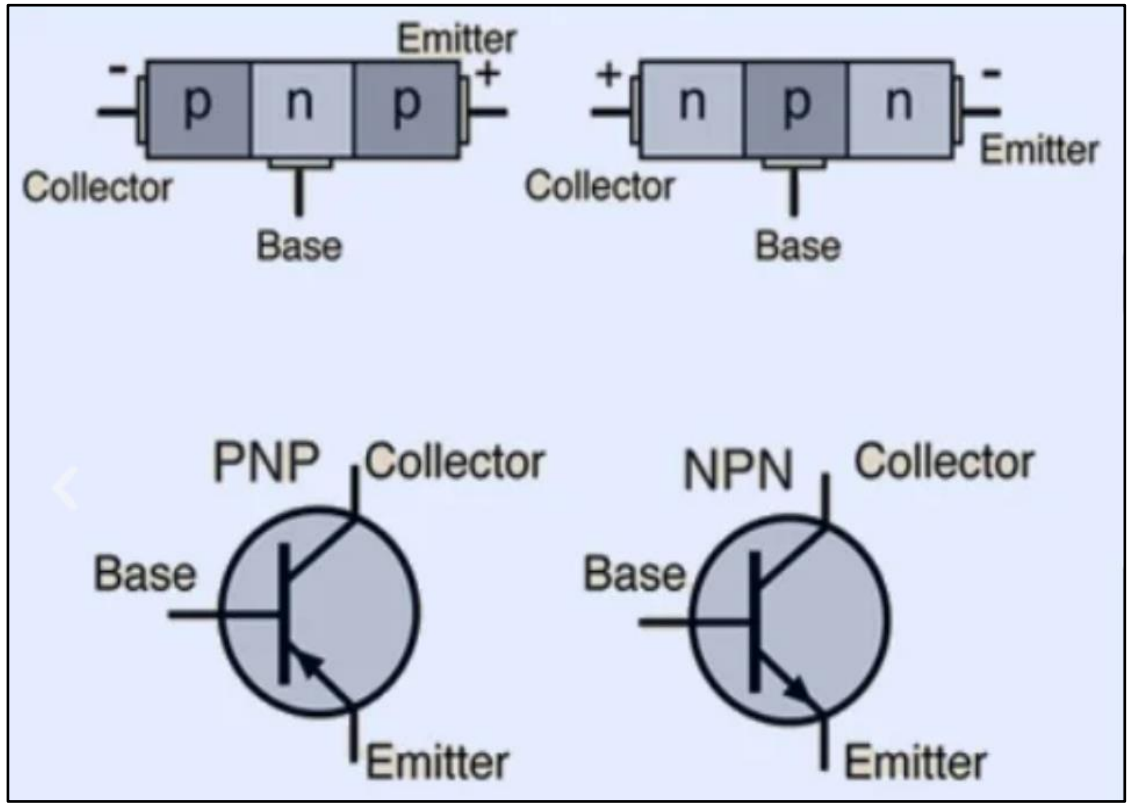
1. Bipolar Junction Transistor

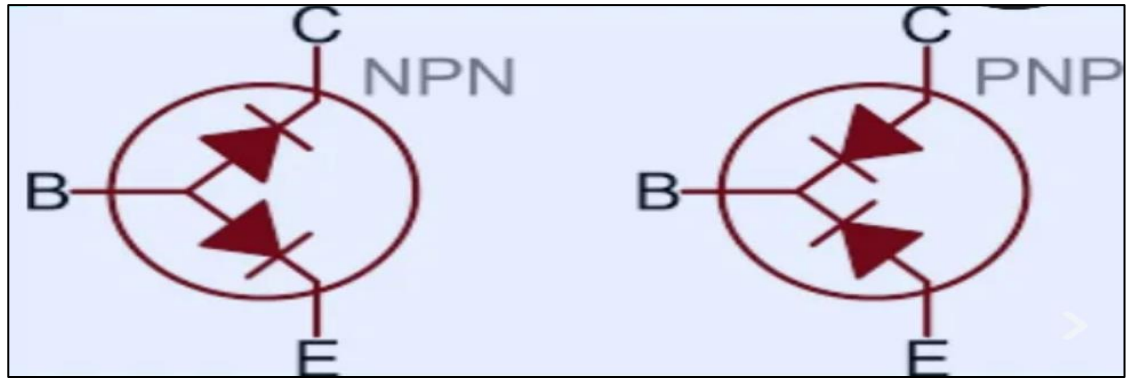
   (Current Controlled Current Source-CCCS)- **BJT**

2. Metal Oxide Semiconductor Field effect transistor

   (Voltage Controlled Current Source-VCCS) –**MOS FET**

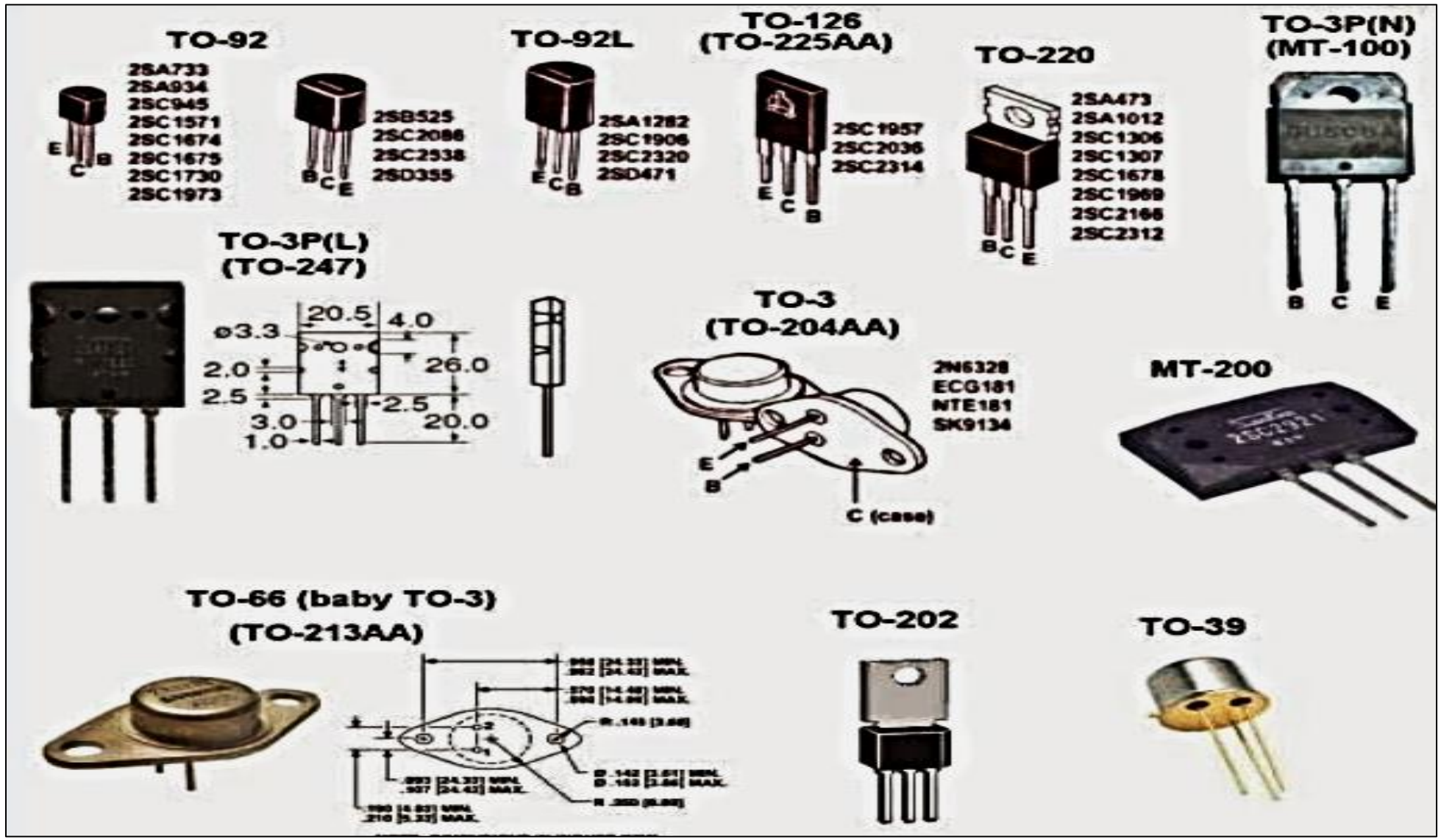
Bipolar Junction Transistor (BJT)



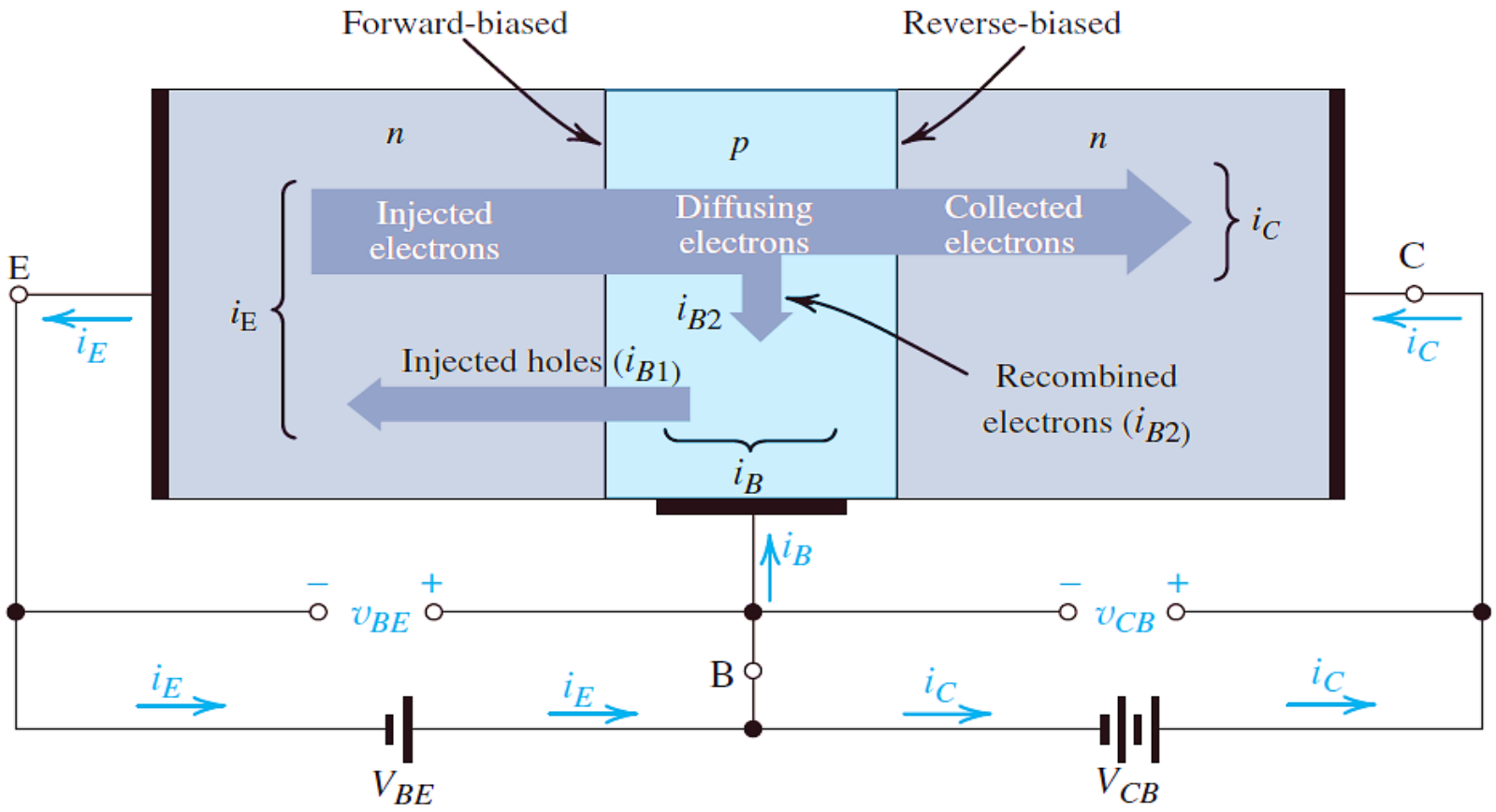


Parameter	BJT
Types	Based on the construction, BJTs are classified into two types: NPN and PNP
Terminals	BJT has three terminals viz. emitter, base and collector.
Controlling quantity	BJT is a current controlled device Base current ($\mathbf{I_B}$) controls the Collector Current ($\mathbf{I_C}$)
Applications	BJT is used in Following applications 1. Amplifiers 2. Oscillators **3. Switches** 4. Buffers

Commercially Available Transistor Packages



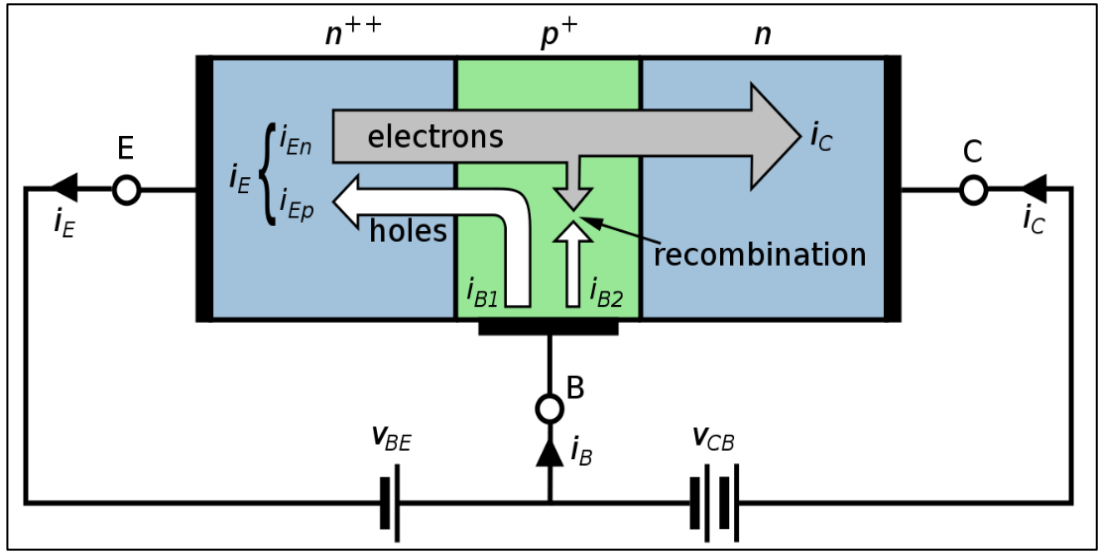
Bipolar Junction Transistor Operation

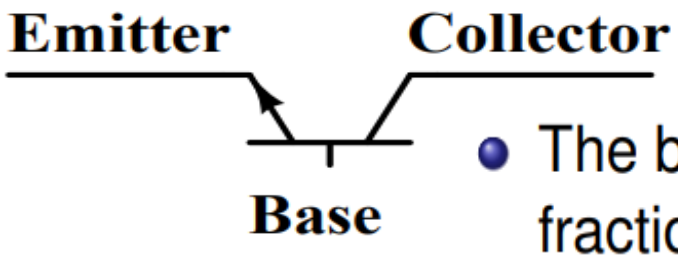


Current flow in an npn transistor biased in active mode

Source: Fig 6.3:-Sedra A S, Smith K C, "Microelectronic Circuits",Oxford University Press, 7Ed. ISBN: 9780199339136

BJT Operation: Cricket Analogy





- The emitter is the bowler who shoots electrons into the base.
- The base is the batsman – a tail-ender who swings away, but connects with no more than 1 to 2% of the incoming balls (electrons).
- Most of the balls are collected by the wicket keeper – the collector.

- The base current (rare balls connected by the batsman) is a fraction of the emitter current and the collector current is almost equal to the emitter current.
- Thus the collector current is 50 to 100 times the base current. Ratio of collector current to the base current is the current gain of the transistor.

Applications of BJT

- **BJT as Amplifier**

  Used as 'Small Signal' amplifiers in audio circuits & instrumentation applications

  Used as 'Large Signal' or power amplifiers in RF and microwave circuits

- **BJT as Oscillator**

  BJT circuits can also be used as oscillators for frequency generation.

  These circuits are used in transmitting sources and timing circuits

- **Transistor as a Switch**

  Transistor (BJT or MOSFET) is most extensively used in Switching Application

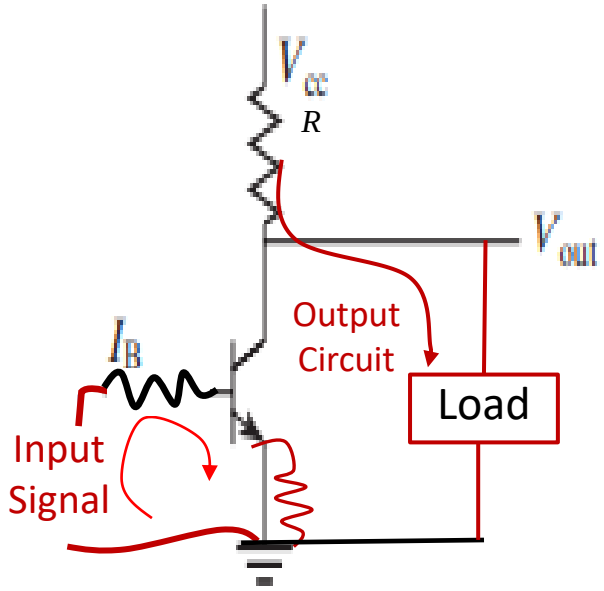
  Used in control electronics, indicators, conditional actions etc.

- **Transistor as a Buffer/**

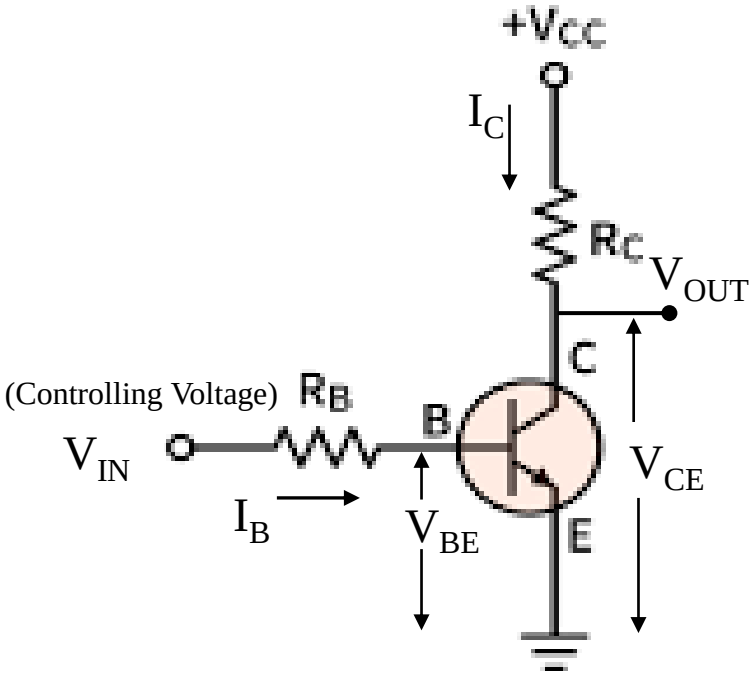
BJT in 'common base configuration' → Provides voltage gain at similar current levels

Enhances current driving capacity ← BJT in 'common collector configuration'

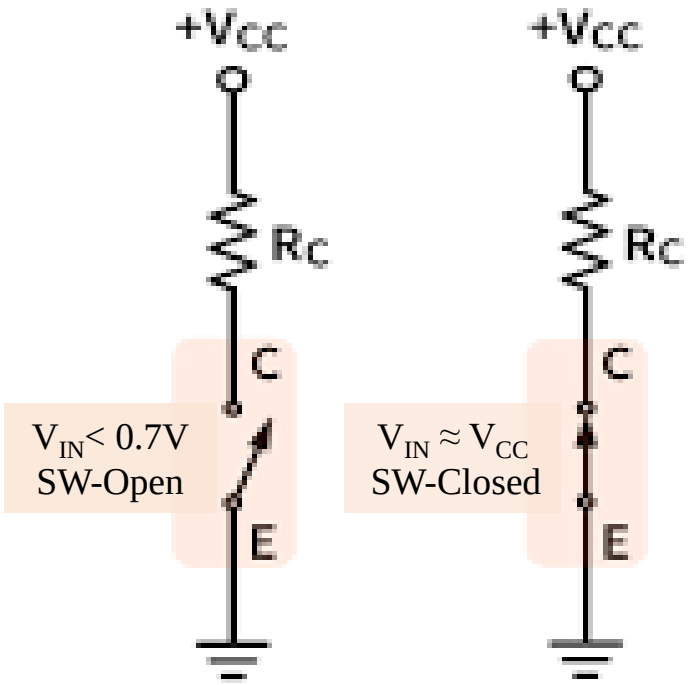
Operating Common Emitter Configuration for Switching



Common Emitter Configuration



Action



Common Emitter (CE) Current Gain: $\boldsymbol{\beta = I_C/I_B}$

$V_{IN} = I_B R_B + V_{BE}$

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

$V_{OUT} = V_{CE}$

Common Emitter Operation

- **Case-1** $V_{IN} < 0.6 - 0.7$ V (Less than PN Junction Cut-in Voltage)

  $I_B = 0, I_C = 0. \rightarrow V_{out} = V_{CE} = V_{CC}$ (Switch is OPEN; BJT is said to be Cut-off)

- **Case-2** $V_{IN} > 0.6 - 0.7$ V BJT Conducts, with $I_B > 0$

  $I_B = (V_{IN} - V_{BE})/ R_B$ and $I_C = \beta I_B \rightarrow V_{OUT} = V_{CE} = V_{CC} - I_C R_C$

  $V_{CEmin} = V_{CE\ Sat} = 0.2$ V $I_{CMax} = (V_{CC} - V_{CESat})/ R_C = \beta I_{BSat}$

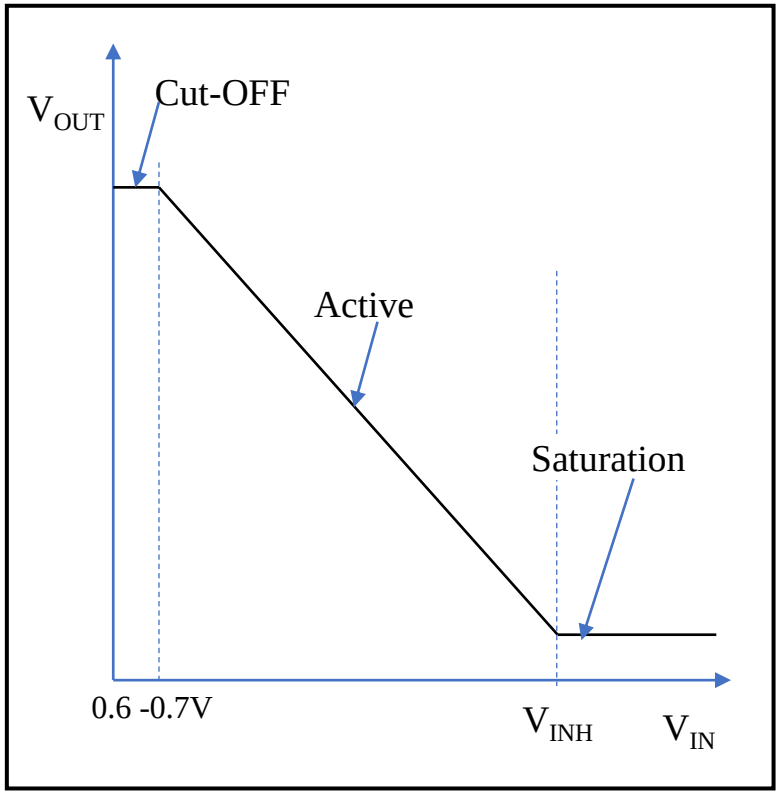
  At that point $V_{BESat} = 0.8$ V and Corresponding $V_{INH} = I_{BSat} R_B + V_{BESat}$

  (Active/ Linear Region Used for amplifier operation)

- **Case-3** $V_{IN} > V_{INH}$

  $I_B = (V_{IN} - V_{BESat})/ R_B$ and $I_C = I_{CMax}$ But $\mathbf{I_B \beta > I_{CMax}}$

  (Switch is CLOSED; BJT is said to be in Saturation)

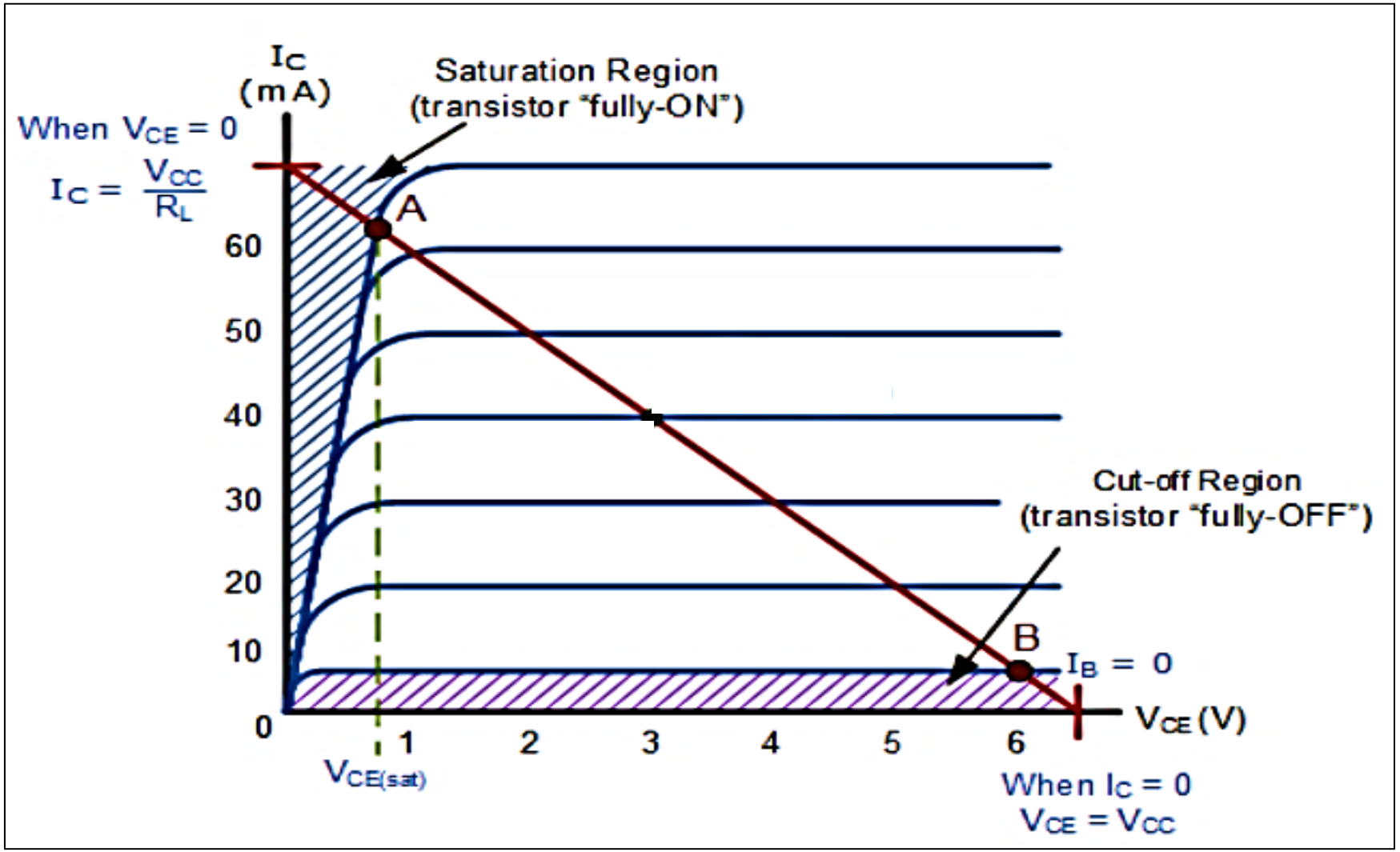


Switching Operation corresponds to **Case1** and **Case3**

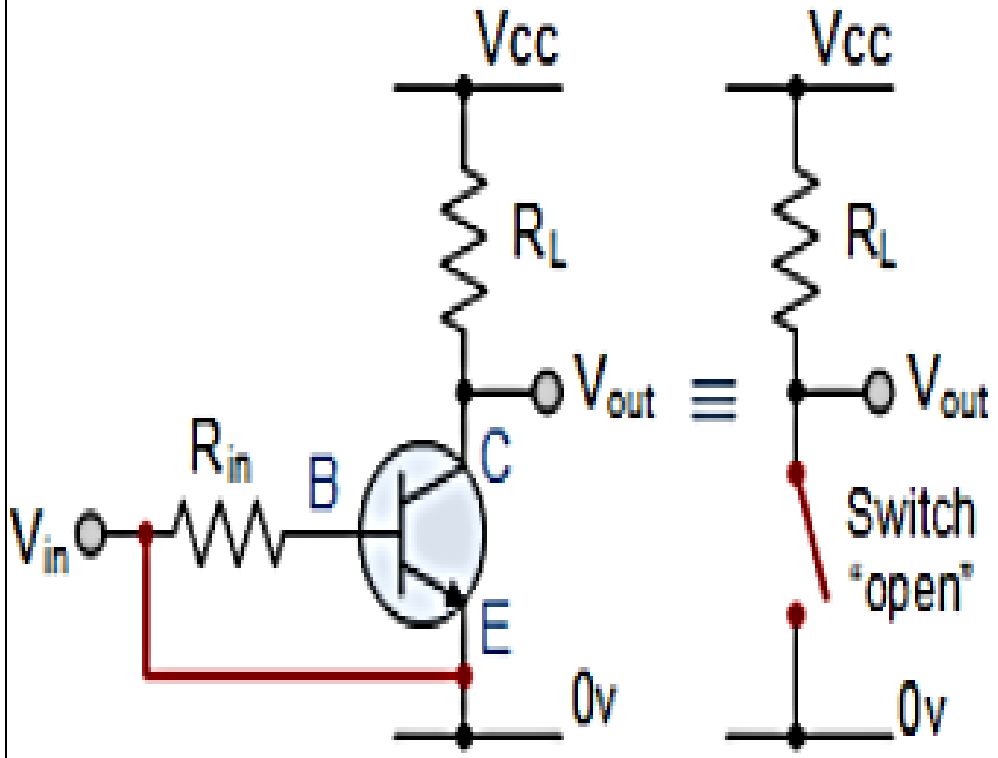
Conditions on (Vin)➔ **$V_{IN} < 0.6$ (Switch Open)** OR **$V_{IN} > V_{INH}$ (Switch Closed)**

Application of BJT: Switching

Switching Operation presented on V_{CE}-I_C Plane

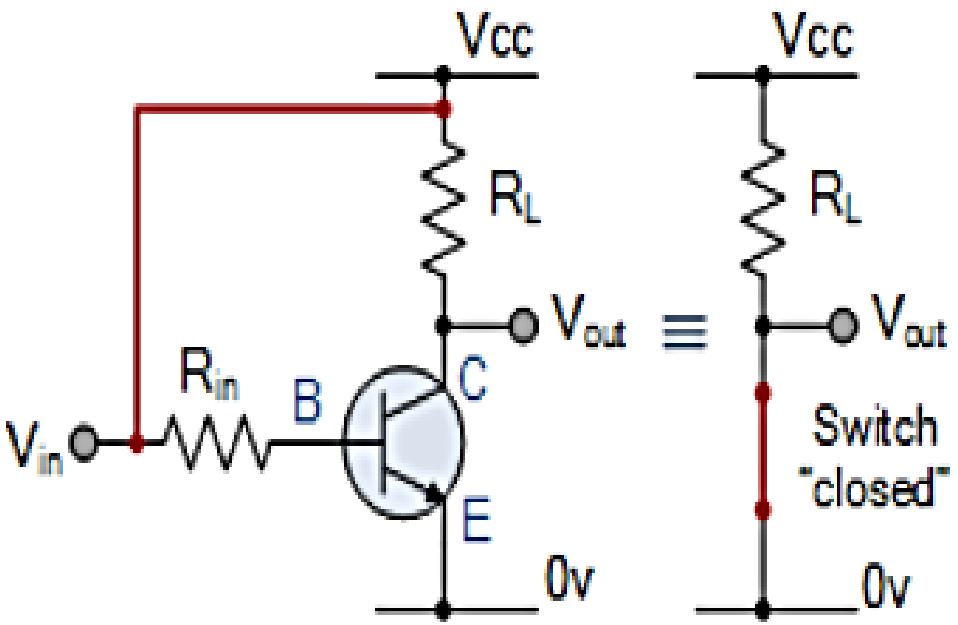


Vin< 0.7,≈ 0 V → BJT Switch is 'OPEN'



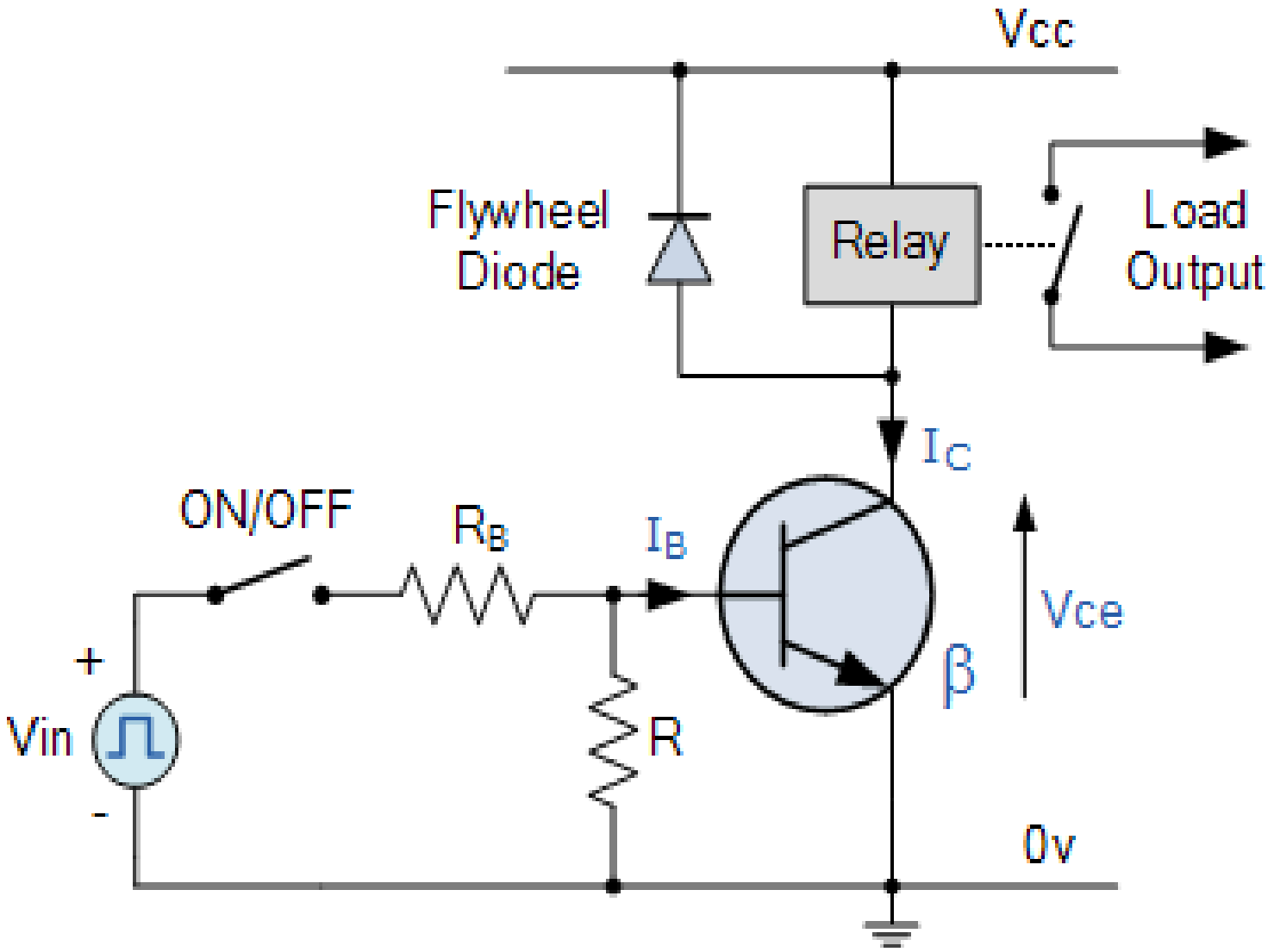
- The input and Base are grounded (0v)
- Base-Emitter voltage $V_{BE} < 0.7v$
- Base-Emitter junction is reverse biased
- Base-Collector junction is reverse biased
- Transistor is "fully-OFF" (Cut-off region)
- No Collector current flows ($I_C = 0$)
- $V_{OUT} = V_{CE} = V_{CC} = "1"$
- Transistor operates as an "open switch"

Vin > V_{INH}, ≈ VCC → BJT Switch is 'CLOSED'



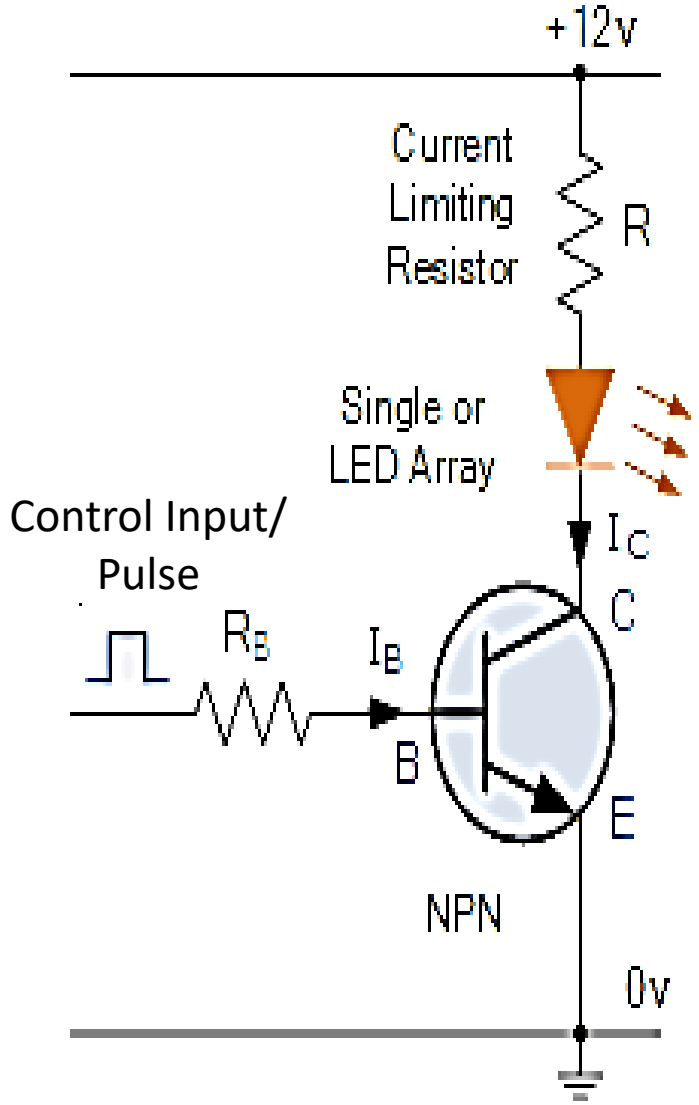
- The input and Base are connected to V_{CC}
- Base-Emitter voltage V_{BE} > 0.7v
- Base-Emitter junction is forward biased
- Base-Collector junction is forward biased
- Transistor is "fully-ON" (saturation region)
- Max Collector current flows ($I_C = Vcc/R_L$)
- $V_{CE} = 0$ (ideal saturation)
- $V_{OUT} = V_{CE} =$ "0"
- Transistor operates as a "closed switch"

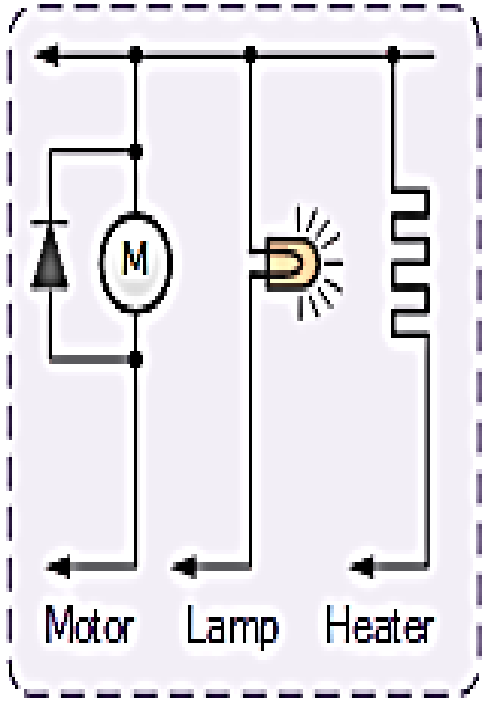
Relay Operation Using a BJT Switch



Source : https://www.electronics-tutorials.ws/transistor/tran_4.html

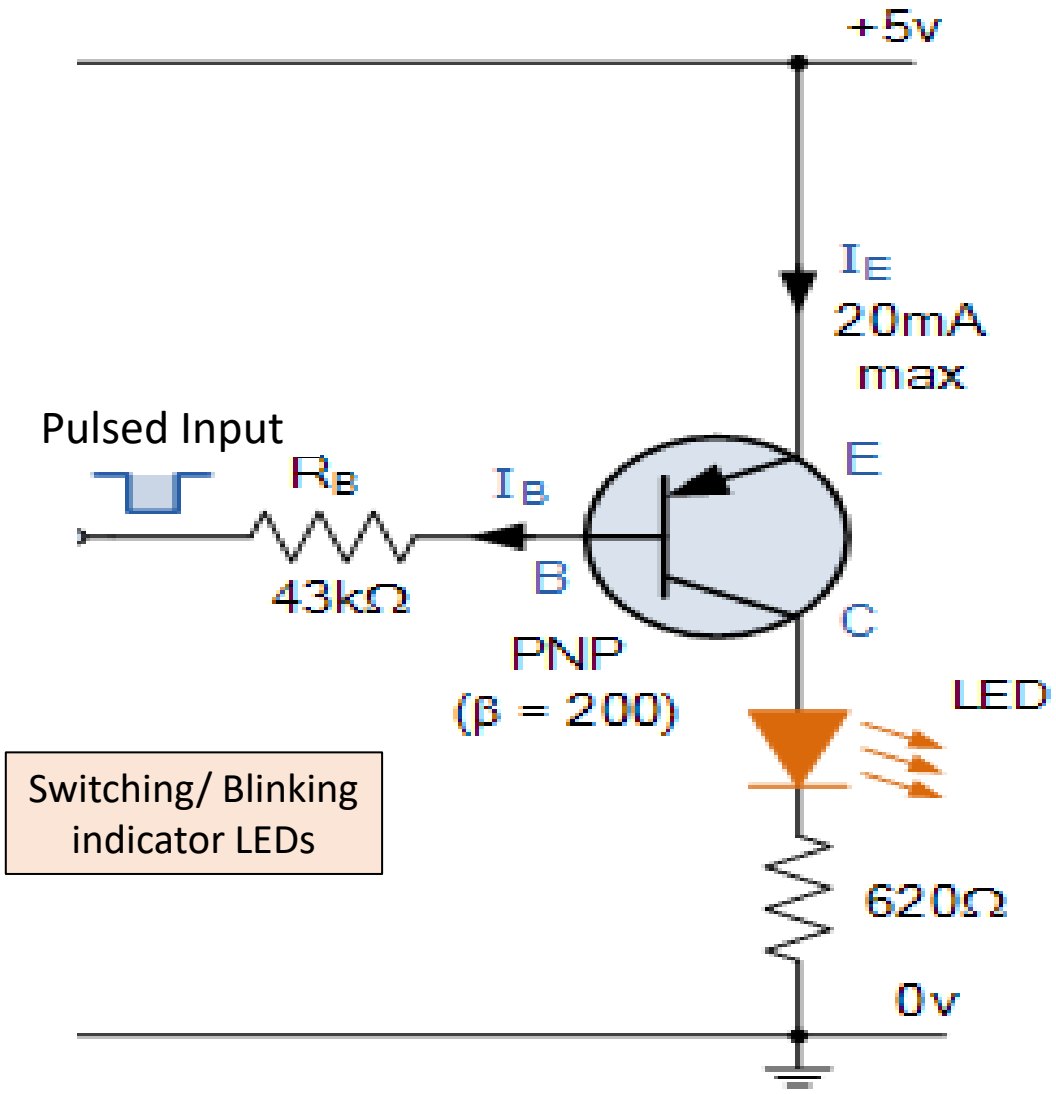
Operating Different Gadgets Using BJT-Switch





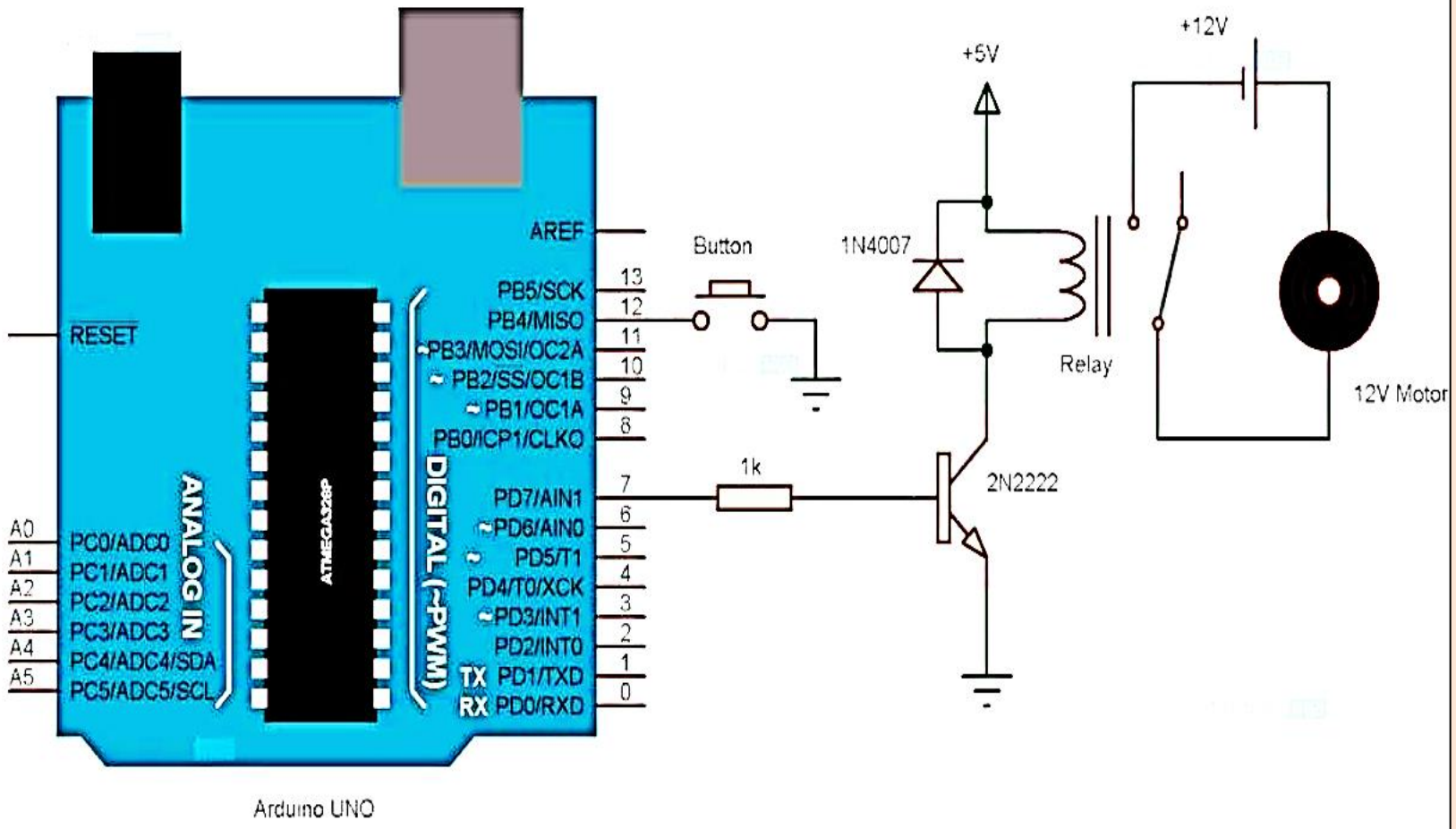
Different Collector Loads

Operating LED using PNP - BJT



Relay Switching Using Micro-Controller (Arduino)

Shall be discussed with Microcontroller Operation: Lectures 9 thro 12



Arduino Relay Control Circuit Diagram

This is a representative example of operating a relay with 'Arduino digital output pin. PD7 ' and PNP transistor (2N2222)

Parameters: Relay Coil Current ≈ **60 mA**, CE current Gain (β)≈ **50**.

Action: Set the pin PD7 to 'Hi'. This will conduct the transistor. The relay operation leads to closing the contact (Relay 'ON')

Relevant current computations: Current required to drive the transistor to ON (≈2 mA)

(Assume βmin=30→60/ βmin= 2)

Source: https://www.electronicshub.org/arduino-relay-control/

Questions and Discussions