INTRODUCTION TO TRANSISTORS and common applications in mechatronics

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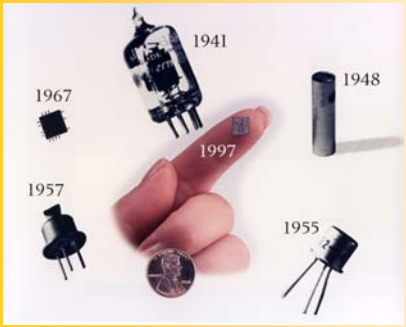
Outline

- History
- Theory
- Transistor Types
- Properties of BJT
- BJT applications
- FET and applications
- Power transistor and applications
- Summary
- References

What is a Transistor?

A Transistor is an electronic device composed of layers of a semiconductor material which regulates current or voltage flow and acts as a switch or gate for electronic circuit.

History of the Transistor



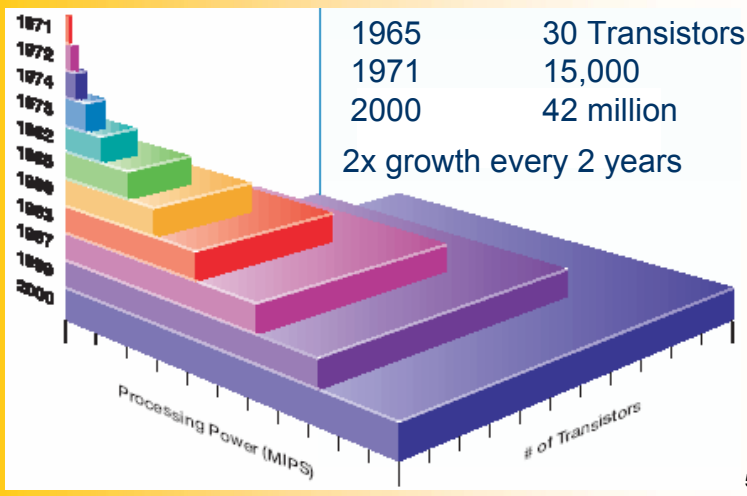
P-N Junction
Russell Ohl 1939

First Transistor
Bell Labs 1947
Shockley, Brattain, and Bardeen

First Solid State Transistor - 1951

History of the Transistor

Processor development followed Moore's Law



1965	30 Transistors
1971	15,000
2000	42 million

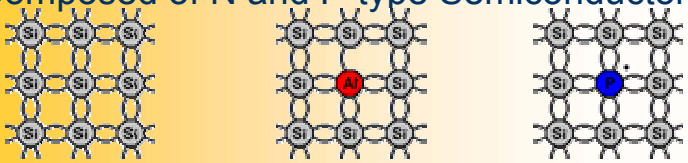
2x growth every 2 years

Applications

- Switching
- Amplification
- Oscillating Circuits
- Sensors

Transistor Physics

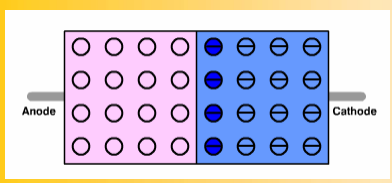
- Composed of N and P-type Semiconductors



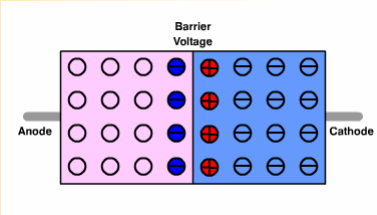
- N-type Semiconductor has an excess of electrons
  - Doped with impurity with more valence electrons than silicon
- P-type Semiconductor has a deficit of electrons (Holes)
  - Doped with impurity with less valence electrons than silicon

Transistor Physics

P-N Junction (Basic diode):
- Bringing P and N Semiconductors in contact
- Creation of a Depletion Zone

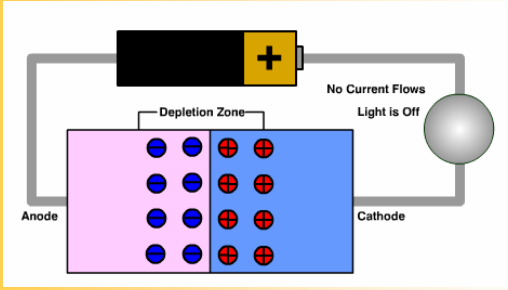


P-Type **N-Type**



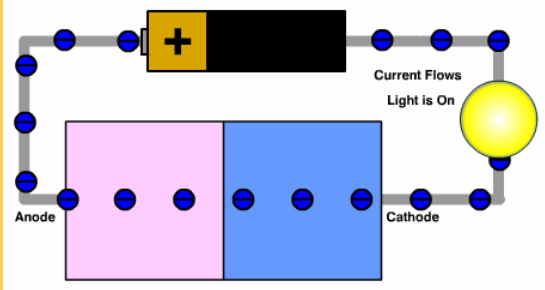
Transistor Physics

- P-N Junction
- Reverse Biased => No Current
- Applying –ve Voltage to Anode increases Barrier Voltage & Inhibits Current Flow



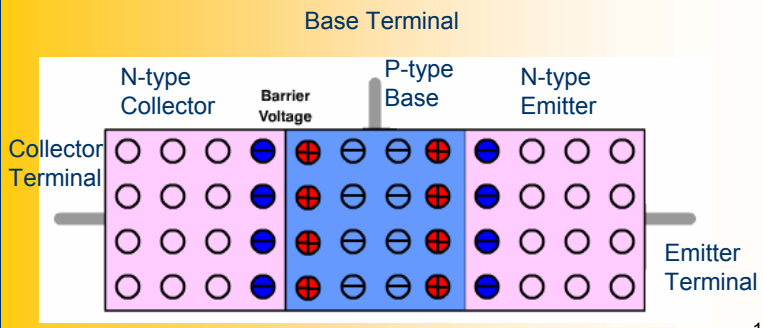
Transistor Physics

- P-N Junction
- Forward Biased => Current Flows
- Applying +ve Voltage > Barrier Voltage to Anode allows current flow



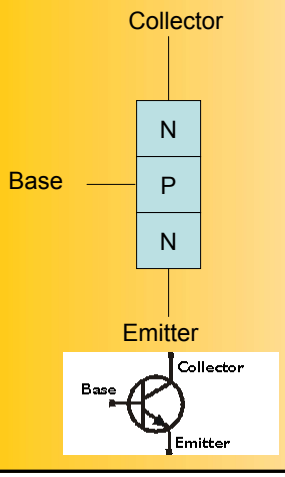
Transistor Physics

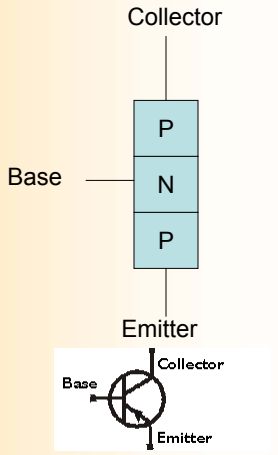
- Basic Transistor



Transistor Physics

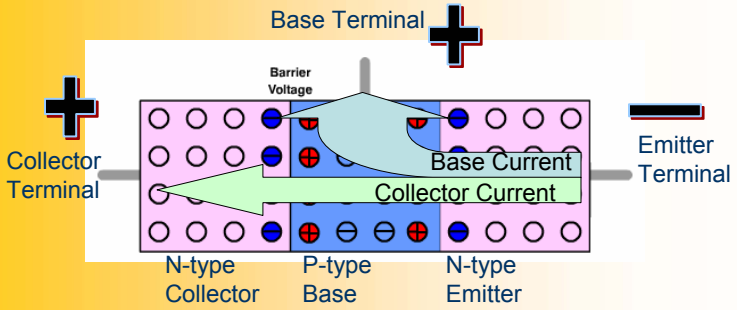
- Two Types - NPN and PNP



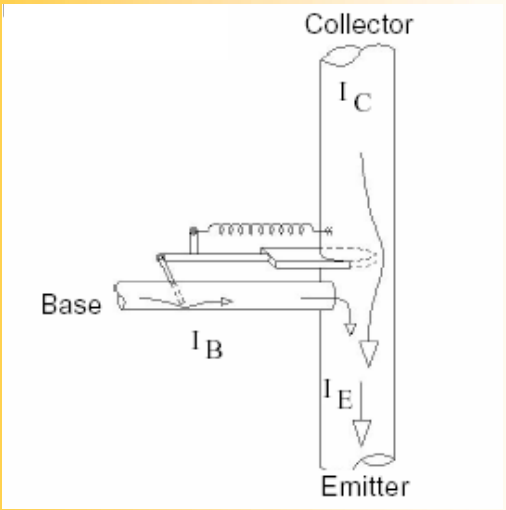


Transistor Physics

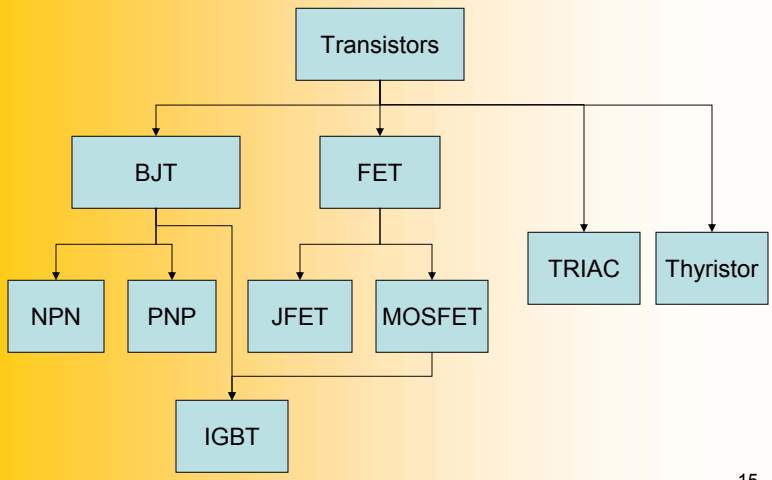
- Basic Transistor



Water pipe analogy

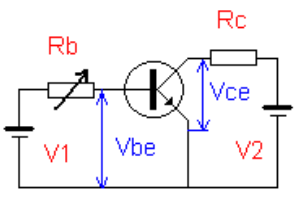


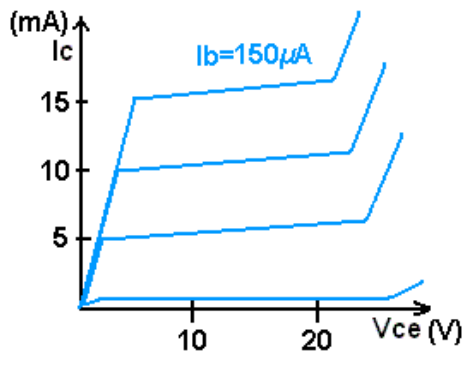
Types of Transistors



Properties of the BJT

Common emitter configuration





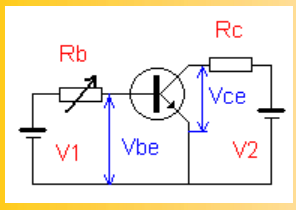
2 basic laws:

$I_e = I_b + I_c$

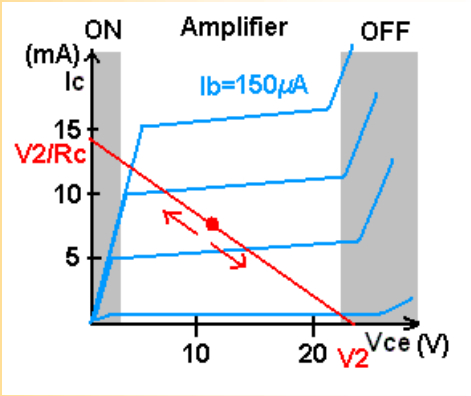
$I_c = \beta . I_b$ (β=10 to 100)

Operating Point

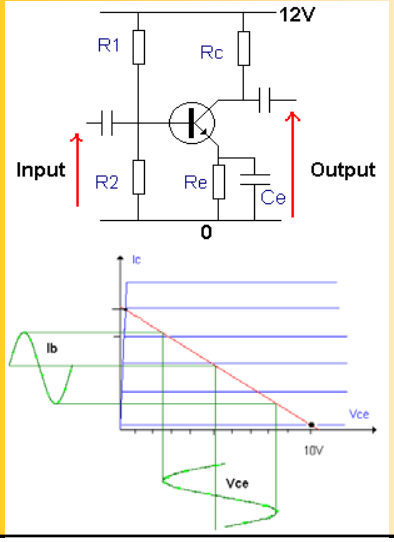
- Amplifier mode
- Switching mode



$$Ic = \frac{V2 - Vce}{Rc}$$



BJT Applications: Small signal amplifier



$$Vb = \frac{R2}{R2 + R1}.12$$

$$Ve = Vb - 0.7V$$

$$Ie = Ve / \mathrm{Re}$$

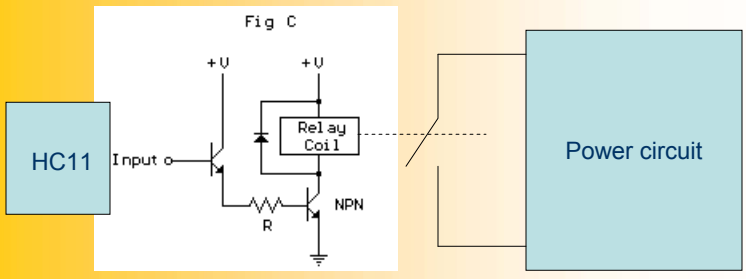
$$\mathrm{R'e} = \frac{25mV}{Ie}$$

$$Gain = -\frac{Rc}{\mathrm{R'e}}$$

Zin = R1//R2

Zout = Rc

BJT Applications: Darlington

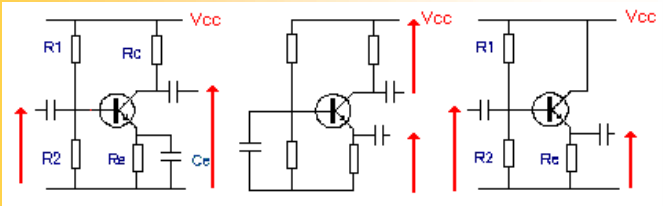


The overall current gain will be: β1*β2

R is chosen so that the saturation point can be reached: R = (V-2*0.7)/(Ib(in)* β1)

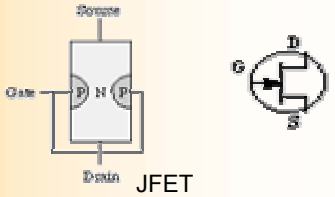
Basic Circuits

	Common Emitter	Common Base	Common Collector
Input Impedance	Medium, xkΩ	Low, xΩ	High
Output Impedance	Medium = Rc	Medium = Rc	Low, xΩ
Phase Shift	180°	0°	0°
Voltage gain	High	High	<=1
Usage	Useful for low frequency signal	More for HF since the bandwidth is larger	To adapt the impedance in a circuit



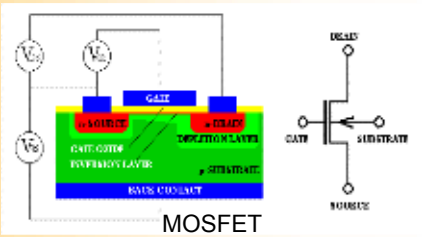
FET Basics

- Advantages
  - low power
  - high gate impedance
  - low S/D resistance
- Uses
  - amplifier
  - analog switch
- Design
  - gate==base
  - source==emitter
  - drain ==collector



JFET

http://encyclobeamia.solarbotics.net/articles/jfet.html



MOSFET

http://ece.colorado.edu/~bart/book/

FET Symbols

- Gate arrow --> n-type or p-type
- Gate/source separation --> MOSFET or JFET
- Broken source/drain line --> enhancement mode or depletion mode
- Gate line is offset towards the source

JFET
n-channel
depletion mode

JFET
p-channel
depletion mode

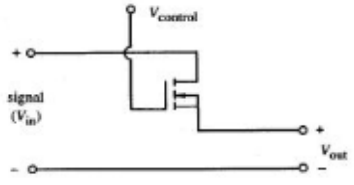
MOSFET
n-channel
enhancement mode

MOSFET
p-channel
enhancement mode

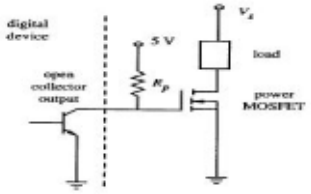
FET Applications

Analog Switch

Power Switch



Mechatronics (Histand & Alciatore, 1999)



Mechatronics (Histand & Alciatore, 1999)

Power Transistors

- Generally
  - Fabrication differences for dissipating more heat
  - Lower gain than signal transistors
- BJT
  - essentially the same as a signal level BJT
  - Power BJT cannot be driven directly by HC11
- MOSFET
  - base (flyback) diode
  - Large current requirements: use parallel MOSFETs

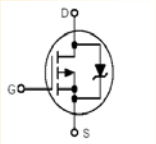
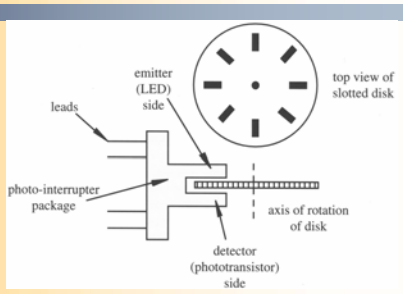
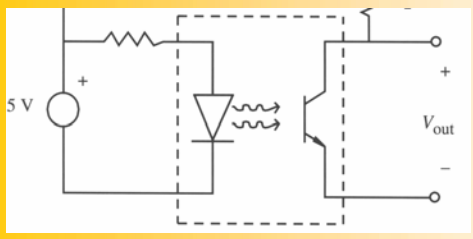


Photo Transistors

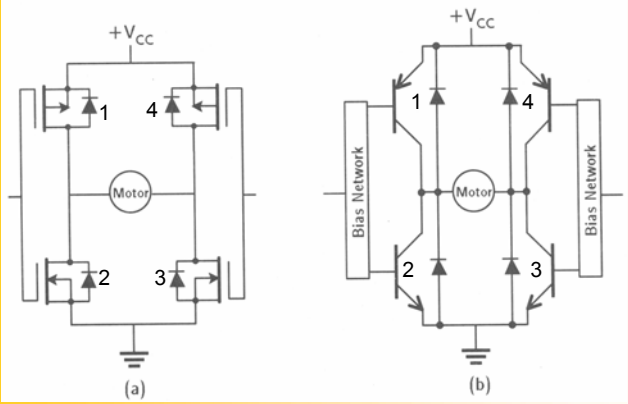
- Light acts as the base current





Opto-coupler

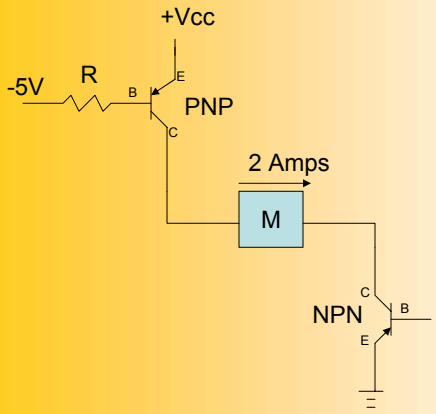
H-bridge example



Left side -5V, right side +5V → 1 & 3 on, 2 & 4 off

Left side +5V, right side -5V → 1 & 3 off, 2 & 4 on

H-bridge example – BJT



Size R so that PNP is in saturation:

Ic = -2 Amps

Hfe = β = 10

Ib = ic / β = -0.2 Amps

-5 = -0.2 * R

R = 25 Ω

Repeat for NPN…

H-bridge example – Summary

- BJT design:
  - Choose TIP31 (NPN) and TIP32 (PNP)
  - Must size R to provide sufficient base current to saturate the transistor
  - Controller must supply high current to BJT
- MOSFET design:
  - Choose FDN359AN(n-channel) and FDN360P(p-channel)
  - Less parasitic power loss than BJT
  - Just plug it in!
- HC11 issues:
  - HC11 can't supply negative voltage, so:
    - Use only NPN or n-channel
    - Control 1 & 3 together, 2 & 4 together

Synthesis

- **Application**
  - Switch for a digital signal: BJT or MOSFET
  - Switch for a analog signal: JFET
  - Switch for a power signal: Power MOSFET or BJT
  - Current controlled-current amplifier: BJT
  - Voltage controlled-current amplifier: JFET or MOSFET
- **Meet current & voltage requirements**
- **Speed: n-channel is faster than p-channel, npn is faster than pnp**
- **FET notes:**
  - Enhancement mode (default off) vs. depletion mode (default on)
  - For an n-channel JFET, the gate must always be at a lower potential than the source. Opposite for p-channel.
  - FETs are higher cost and easier to damage
  - Amplification is not linear

References

- *Mobile Robots: Inspiration to Implementation.* Jones, Seiger & Flynn. (1999).
- *Introduction to Mechatronics.* Histan & Alciatore. (1999).
- *The Art of Electronics.* Horowitz. (1980).
- http://Whatis.techtarget.com