BJT:
Bipolar Junction Transistor

PRESENTED BY: CALLEN FISHER

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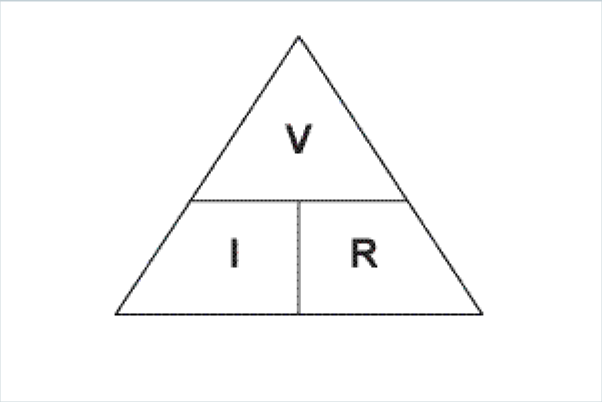
Previously

- Kirchhoff's Voltage law
- Kirchhoff's Current law
- Diode: single PN junction
  - Steering diode
  - Zener diode



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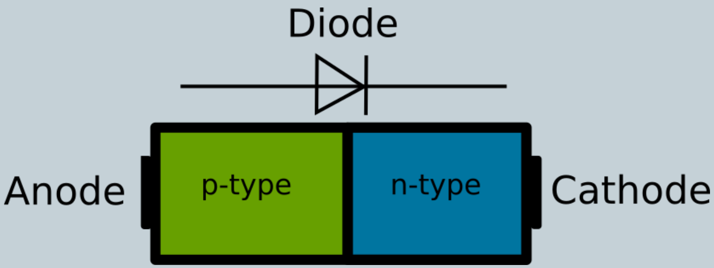
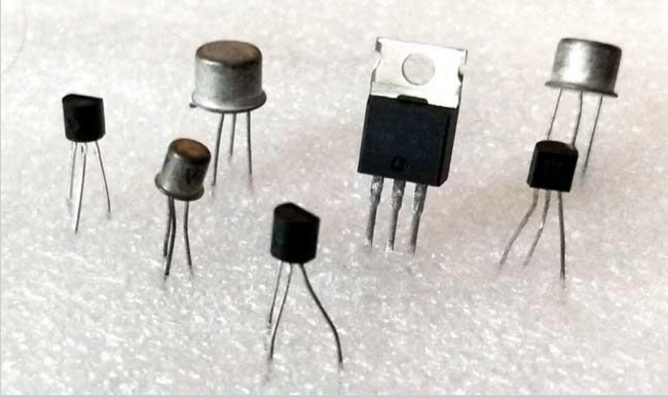


Today's Lecture

- Transistor basics!
  - Introduction to transistors
  - Current amplification (active mode)
  - Cutoff and saturation mode
- Basis of all electrical components



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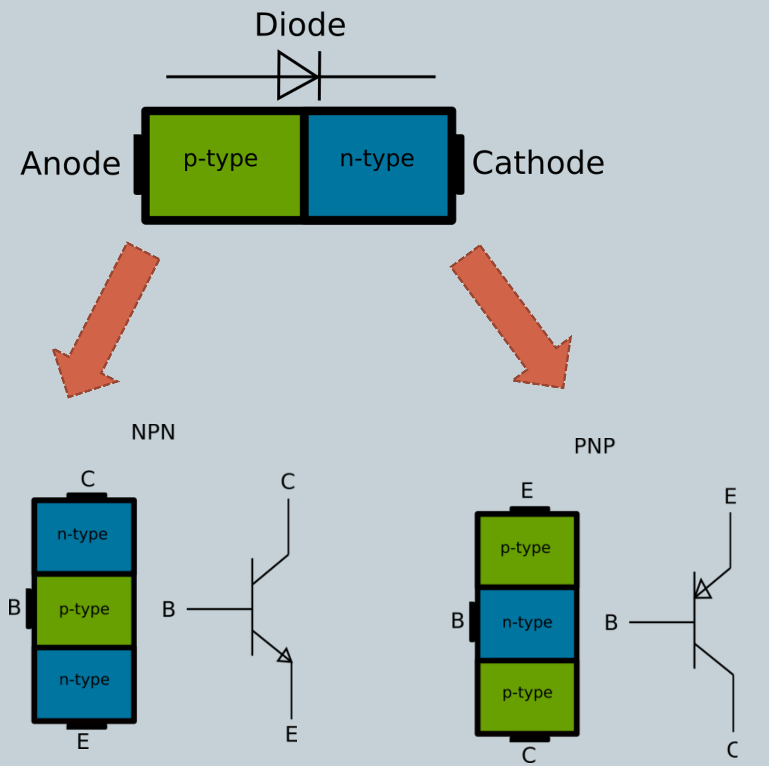
Bipolar Junction Transistor (BJT) Basics

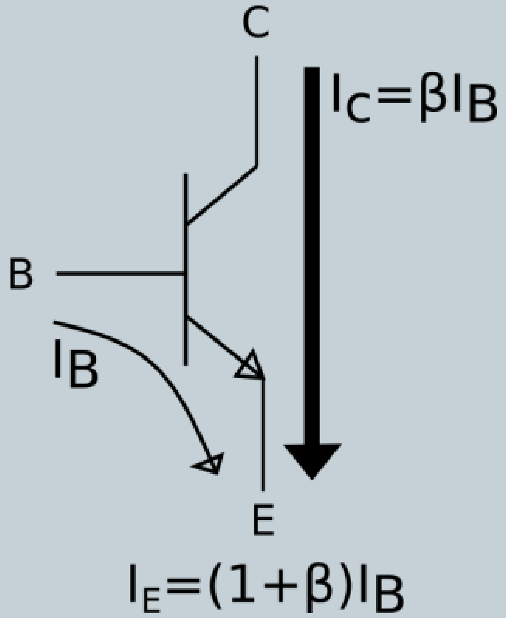
- Transistor:
  - Builds on from the diode model
  - Two PN junctions
  - Amplifies current
- Two types of BJT transistors
  - NPN
  - PNP
- Each layer has a name and a wire connected to it
  - Base
  - Emitter
  - Collector
- Arrow indicates what type of transistor it is



Rules for Amplification

1. To turn on the transistor (NPN):
   - $V_B > V_E + V_{SAT}$
   - What is V_{SAT}?
     - Saturation voltage

- Equations governing the transistor:
  1. $I_C = \beta I_B$
  2. $I_E = (1 + \beta) I_B$
  - What is β?
    - Also known as h_{FE}
    - It is the gain of the transistor



NPN Properties

Electrical Characteristics (T_a = 25°C unless specified otherwise)

Description	Symbol	Test Condition	Value		Unit
			Minimum	Maximum	
Collector Emitter Breakdown Voltage	BV_{CEO}	I_C = 10mA, I_B = 0	30	-	V
Collector Base Breakdown Voltage	BV_{CBO}	I_C = 10μA, I_E = 0	60	-	
Emitter Base Breakdown Voltage	V_{EBOf}	I_E = 10μA, I_C = 0	5	-	
Collector Leakage Current	I_{CBO}	V_{CB} = 50V, I_E = 0 V_{CB} = 50V, I_E = 0 T_a = 150°C	-	10 10	nA μA
Collector Emitter Saturation Voltage	$^*V_{CE\ (Sat)}$	I_C = 150mA, I_B = 15mA I_C = 500mA, I_B = 50mA	-	0.4 1.6	V
Base Emitter Saturation Voltage	$^*V_{BE\ (Sat)}$	I_C = 150mA, I_B = 15mA I_C = 500mA, I_B = 50mA	0.6	1.3 2.6	

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NPN Properties

Electrical Characteristics (T_a = 25°C unless specified otherwise)

Parameter	Symbol	Test Condition	2N2222 Minimum	2N2222 Maximum	Unit
DC Current Gain	h_{FE}	I_C = 0.1mA, V_{CE} = 10V* I_C = 1mA, V_{CE} = 10V I_C = 10mA, V_{CE} = 10V* I_C = 150mA, V_{CE} = 1V* I_C = 150mA, V_{CE} = 1V* I_C = 500mA, V_{CE} = 10V*	35 50 75 50 100 30	300	-
Dynamic Characteristics					
Transition Frequency	f_t	I_C = 20mA, V_{CE} = 20V f = 100MHz	250	-	MHz
Output Capacitance	C_{ob}	V_{CB} = 10V, I_E = 0 f = 100kHz	-	8	pF
Input Capacitance	C_{ib}	V_{EB} = 0.5V, I_C = 0 f = 100kHz	-	30	pF
Switching Characteristics					
Delay Time	t_d	I_C = 150mA, I_{B1} = 15mA	-	10	ns
Rise Time	t_r	V_{CC} = 30V, $V_{BE\ (off)}$ = 0.5V	-	25	ns
Storage Time	t_s	I_C = 150mA, I_{B1} = 15mA	-	225	ns
Fall Time	t_f	I_{B2} = 15mA, V_{CC} = 30V	-	60	ns

*Pulse Condition: Pulse Width ≤300µs, Duty Cycle ≤2%.

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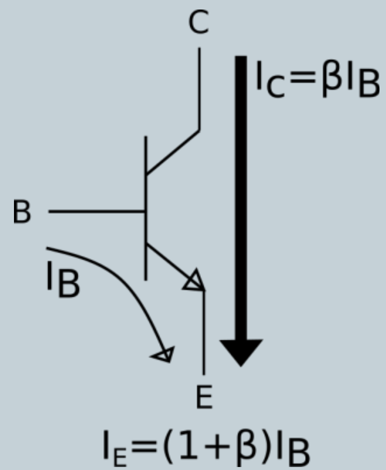
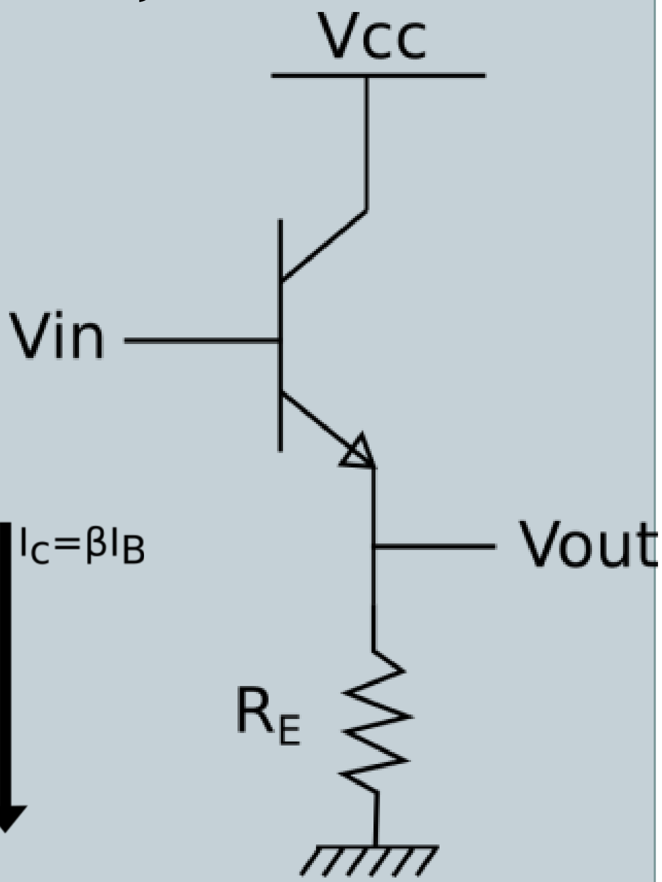
Common Collector (NPN)

- If: $R_E = 1k, V_{CC} = 5V$ (Often R_E is the load)
- According to rule 1:
  - $V_{out} = V_{in} - 0.6$
  - Can vary the voltage across the load
- If:
  - $V_{in} = 5V$
  - $V_{out} = V_{in} - 0.6$
  - $I_E = \frac{V_{out}}{R_E} = \frac{5-0.6}{1000} = 4.4mA$
  - $I_E = (1+\beta)I_B$
  - $\therefore I_B = \frac{I_E}{(1+\beta)} = \frac{0.0044}{101} = 43.6\mu A$
- What if $V_{in} = 3V$?





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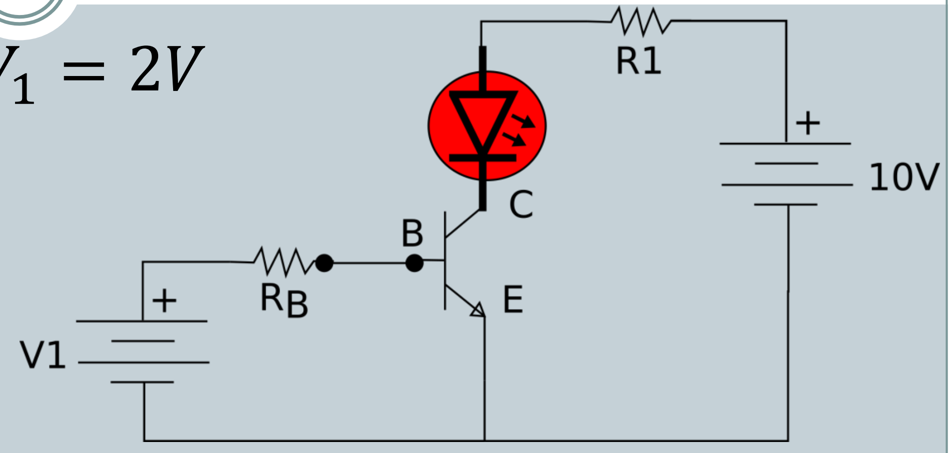
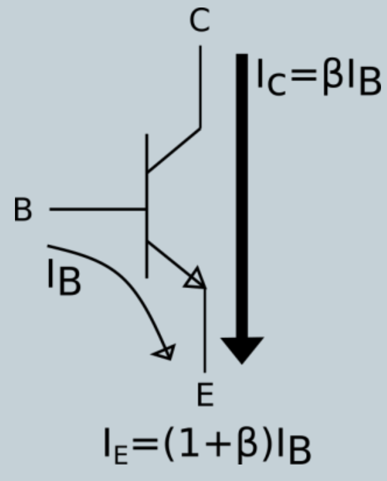
Common Emitter (NPN)

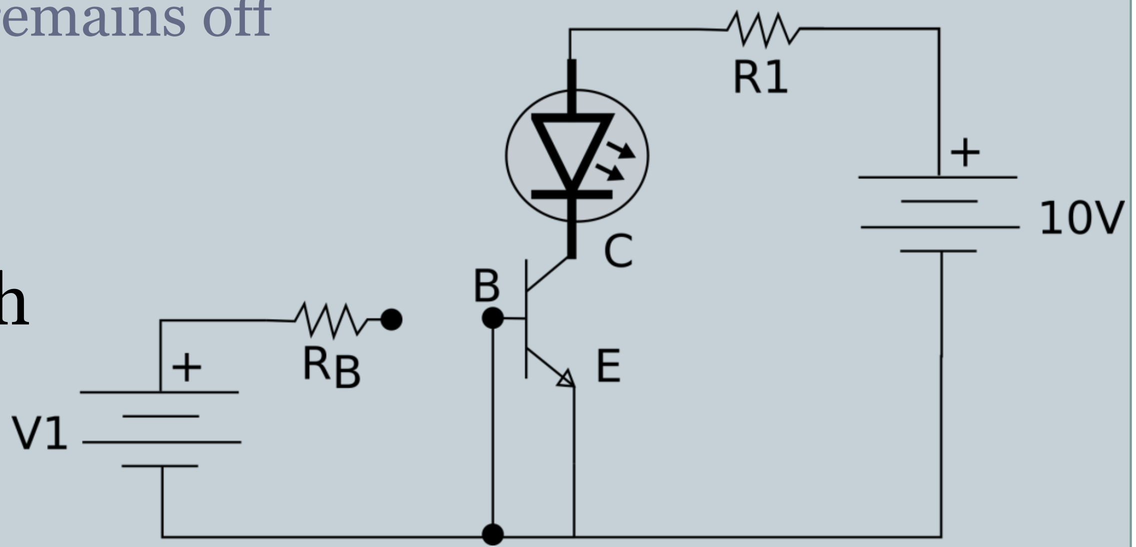
- If: $R_1 = 500\Omega, R_B = 10K\Omega, V_1 = 2V$
- $V_{Forward\ LED} = 1.5V$
- According to rule 1:
  - $V_B = V_E + 0.6 = 0.6V$
  - $\therefore I_B = \frac{V_1 - V_B}{R_B} = 14mA$
- According to governing equations:
  - $I_C = \beta I_B = 100 \times 14mA$ =1.4A
- Maximum current due to load:
  - $I_{max} \approx \frac{10 - V_{Forward\ LED}}{R_1} = 17mA$
- IMPOSSIBLE!
  - Transistor enters saturation mode!





Common Emitter (NPN)

- If: $R_1 = 500\Omega, R_B = 10K\Omega, V_1 = 2V$
- $V_{Forward\ LED} = 1.5V$
- $V_B = 0V$
  - $V_B \ngtr V_E + V_{SAT}$
  - Therefore transistor remains off
  - $I_C = 0A$
- Cutoff mode
- Operates as a switch



Summary

1. To turn on the transistor (NPN):
   - $V_B > V_E + V_{SAT}$
   - What is V_{SAT}?
     - Saturation voltage

- Equations governing the transistor:
  1. $I_C = \beta I_B$
  2. $I_E = (1 + \beta) I_B$
  - What is β?
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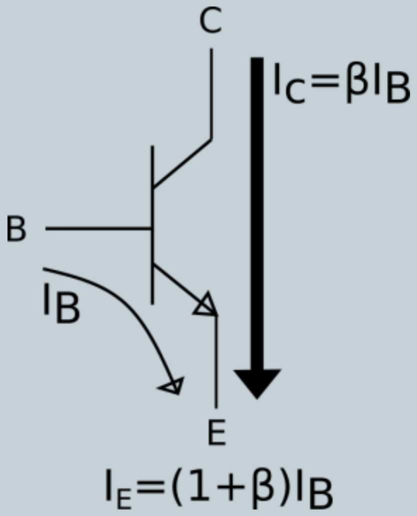
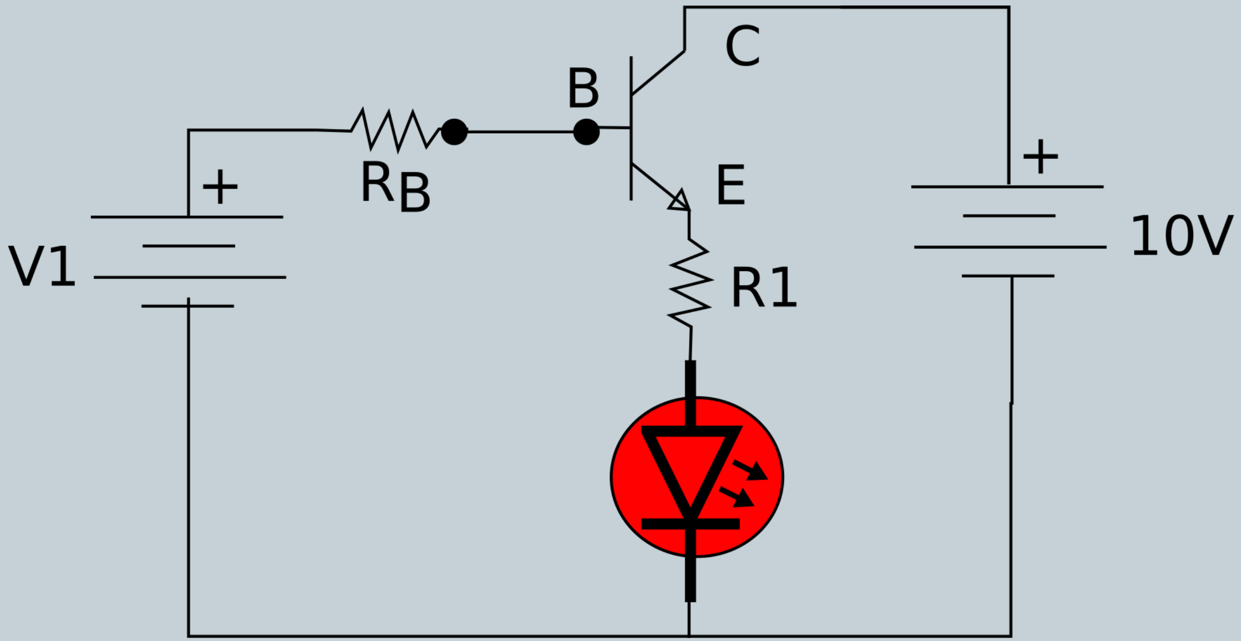


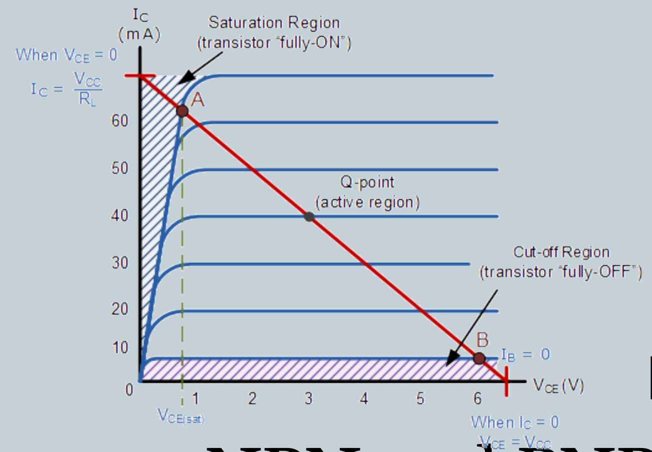
Homework

- We require 30 mA flowing through the LED (forward voltage of 1.5V), $R_1 = 100\Omega$
- Calculate:
  - V_1
  - R_B
  - I_B
  - I_C
  - I_E



Coming Next Lecture

- Investigate the Q-point:



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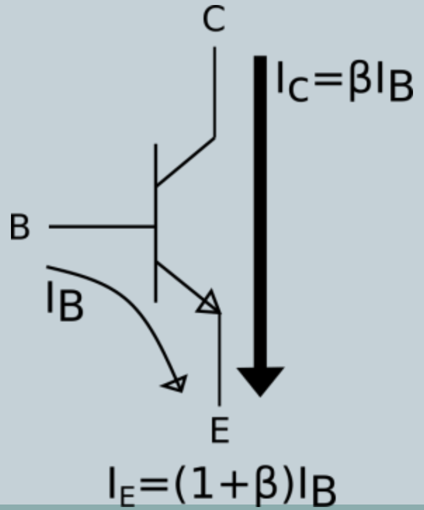
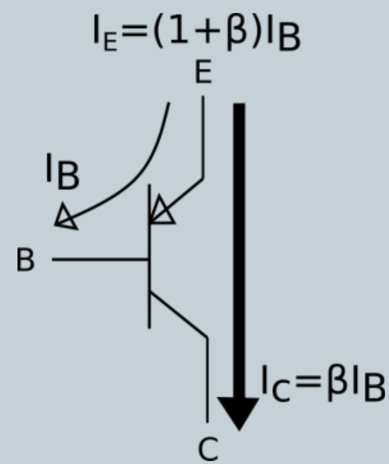
- Investigate the difference between NPN and PNP





References and Further Reading

- [1] http://www.bbc.co.uk/schools/gcsebitesize/design/electronics/calculationsrev1.shtml
- [2] https://circuitdigest.com/article/different-types-of-transistors
- [3] https://www.onsemi.com/pub/Collateral/ PN2222-D.PDF
- [4] https://www.electronics-tutorials.ws/transistor/tran_4.html
- Further reading:
  - Course notes
  - https://learn.sparkfun.com/tutorials/transistors/operation-modes
  - https://www.electronics-tutorials.ws/transistor/tran_4.html

Any Questions?

- Callen Fisher: FSHCAL001@myuct.ac.za