Solid State Devices

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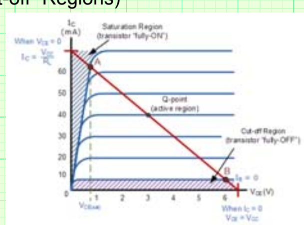
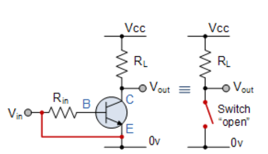
Transistors as a Switch

- In TECH 2821 (Solid State Technology) you used transistors (NPN/PNP) in the "Active" region as an amplifying device.
- But transistors can also be used as a switch (ie the "Saturation" and "Cut-off" Regions)



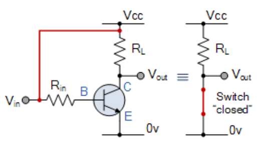
http://www.electronics-tutorials.ws/transistor/tran_4.html

Cut-off



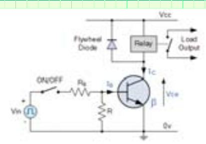
- The input and Base are grounded (0v)
- Base-Emitter voltage $V_{BE} < 0.7v$
- Base-Emitter junction is reverse biased
- Base-Collector junction is reverse biased
- Transistor is "fully-OFF" (Cut-off region)
- No Collector current flows ($I_C = 0$)
- $V_{OUT} = V_{CE} = V_{CC} = "1"$
- Transistor operates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

Saturation



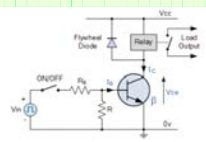
- The input and Base are connected to V_{CC}
- Base-Emitter voltage $V_{BE} > 0.7v$
- Base-Emitter junction is forward biased
- Base-Collector junction is forward biased
- Transistor is "fully-ON" (saturation region)
- Max Collector current flows ($I_C = Vcc/R_L$)
- $V_{CE} = 0$ (ideal saturation)
-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

NPN Transistor Relay Driver



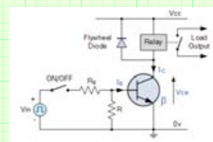
- Transistor operates as a switch the transistor needs to be turned either fully "OFF" (cut-off) or fully "ON" (saturated).
- An ideal transistor switch would have infinite circuit resistance between the Collector and Emitter when turned "fully-OFF" resulting in zero current flowing through it and zero resistance between the Collector and Emitter when turned "fully-ON", resulting in maximum current flow.

NPN Transistor Relay Driver



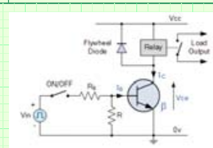
- In practice when the transistor is turned "OFF", small leakage currents flow through the transistor and when fully "ON" the device has a low resistance value causing a small saturation voltage (VCE) across it. Even though the transistor is not a perfect switch, in both the cut-off and saturation regions the power dissipated by the transistor is at its minimum.

NPN Transistor Relay Driver



- In order for the Base current to flow, the Base input terminal must be made more positive than the Emitter by increasing it above the 0.7 volts needed for a silicon device. By varying this Base-Emitter voltage VBE, the Base current is also altered and which in turn controls the amount of Collector current flowing through the transistor as previously discussed.

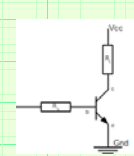
NPN Transistor Relay Driver



- When maximum Collector current flows the transistor is said to be Saturated. The value of the Base resistor determines how much input voltage is required and corresponding Base current to switch the transistor fully “ON”.

Calculations

- A simple configuration for an NPN transistor switch circuit.
  - R_L (load) - lamp or relay or some other device that needs a larger current than the input is able to drive directly.
  - R_b (Base Resistor) - used to prevent damage at the base of the transistor. This needs to be large enough to prevent damage to the transistor, but should still allow sufficient current to ensure the transistor switches on.



http://www.penguintutor.com/electronics/transistor-switch

Calculations (cont)

- First we calculate the appropriate load current:

$$I_C = \frac{V_{cc} - V_{ce}}{R_L}$$

- Where
  - I_c – Collector current
  - V_{cc} - supply voltage
  - V_{ce} - voltage drop across the transistor (Collector to Emitter) from the data sheet
  - R_L - load resistance

Check the datasheet to ensure the transistor can handle the current required for the load!

Calculations (cont)

- Calculate the minimum base current

$$I_b = \frac{I_c}{\beta}$$

Where
- β or h_{FE} - gain
- I_b - base current
- I_c – Collector current

Calculations (cont)

- Calculate R_b

$$R_b = \frac{V_{in} - V_{be}}{I_b * 10}$$

- Where:
  - R_b – Base resistor
  - V_{in} – voltage in (at base)
  - V_{be} – voltage drop Base to Emitter (from data sheet)
  - I_b – Base Current (from previous calculation)
  - 10 – Fudge factor
- As a **rule of thumb**, we use a fudge factor of 10 to ensure we go into full saturation (If I_b*10 exceeds the maximum base current then a value below the maximum base current should be used instead)

Example #1

- Given
  - β = 200
  - I_c = 4mA
  - I_b = 20uA
  - V_{be} = 0.7V
- Find the value of the Base resistor (R_b) required to switch the load fully "ON" when the input terminal voltage exceeds 2.5v.

$$R_b = \frac{V_{in} - V_{be}}{I_b * 10} = \frac{2.5V - 0.7V}{20uA * 10} = 9K$$

- (note, the biggest resistor you can use is 90K (taking out the 10x fudge factor)

Example #2

- Given
  - β = 200
  - I_c = 200mA
  - V_{be} = 0.7V
  - V_{in} = 5V

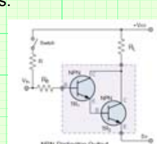
$$I_b = \frac{I_c}{\beta} = \frac{200mA}{200} = 1mA$$

$$R_b = \frac{V_{in} - V_{be}}{I_b * 10} = \frac{5.0V - 0.7V}{1mA * 10} = 43K$$

Darlington Pair

- Sometimes the DC current gain of the bipolar transistor is too low to directly switch the load current or voltage.
- In these cases multiple switching transistors are used.
  - one small input transistor is used to switch "ON" or "OFF" a much larger current handling output transistor.
  - To maximise the signal gain, the two transistors are connected in a "**Darlington Pair"** configuration were the amplification factor is the product of the two individual transistors.

$$\beta_{TOTAL} = \beta_1 \times \beta_2$$



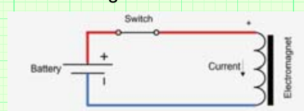
Physics

- Lenz's Law - An induced electromotive force (emf) always gives rise to a current whose magnetic field opposes the original change in magnetic flux.*
- The opposite is also true, EMF opposes a change in the applied current.

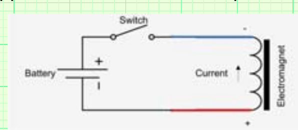
https://simple.wikipedia.org/wiki/Lenz's_law

Back EMF

- Consider the following:



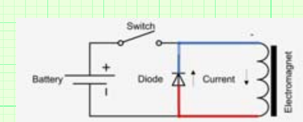
- What happens when the switch is opened?



http://forum.arduino.cc/index.php?topic=308022.0

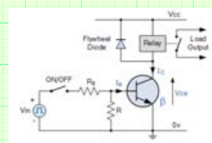
Back EMF (cont)

- There is no path for the current (and if the switch was a Transistor, or other silicon device) it would be damaged.
- So we add a diode:



Back EMF Diode

- Flyback Diodes are common when using transistor circuits to turn on/off inductive devices (motors, relays, etc).
- They are also called:
  - Snubber Diodes
  - Back EMF Diodes
  - Flyback Diodes
  - Flywheel Diode



Summary

- Transistor switches can be used to switch and control lamps, relays or even motors.
- When using the bipolar transistor as a switch they must be either "fully-OFF" or "fully-ON".
- Transistors that are fully "ON" are said to be in their Saturation region.
- Transistors that are fully "OFF" are said to be in their Cut-off region.
- When using the transistor as a switch, a small Base current controls a much larger Collector load current.
- When using transistors to switch inductive loads such as relays and solenoids, a "Flywheel Diode" is used.