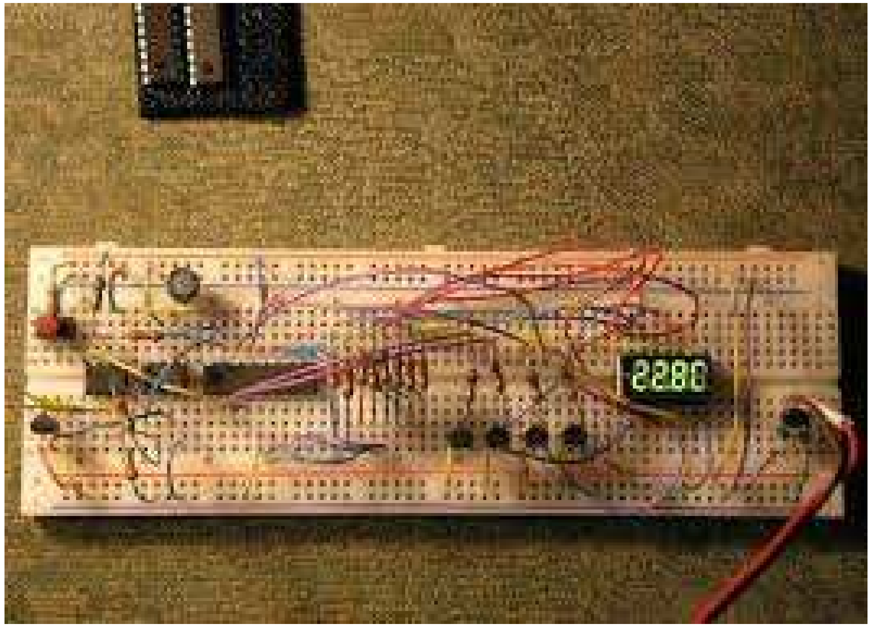
ENGG1000

Electrical Stream 2018

Lecture Week 4 – Power Sources and Regulators

Never Stand Still | Faculty of Engineering | School of Electrical Engineering and Telecommunications



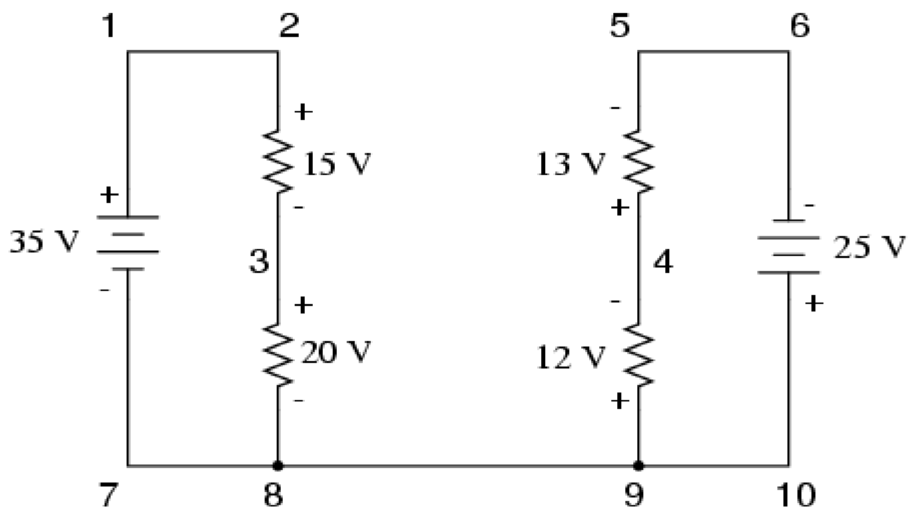
Advice from Students from Previous Years

- Start early and test as much as possible. When you find a flaw, fix it to the maximum extent possible. None of this "It probably won't be a problem.." stuff.
- The internet is a great source of info
- Learnt that organisation is very necessary in all activities
- It is always better to begin early rather than regret later
- Learnt to rely on and trust my team members
- Do not expect your design to work every time
- Use components that will actually work properly with each other
- Building this was fun :P
- Working as a team is vital
- COMMUNICATION..........something there wasn't enough of
- an initial plan would have been helpful
- Testing is paramount to success.....test that ***** as many times as you can!
- construction should start asap to allow sufficient testing
- be prepared to modify ur design during the construction stage, you are bound to run into small complications that you didn't foresee
- everyone needs to get involved, many hands make light work
- keep everything as simple as possible
- if things can go wrong, they usually happen at the worst time

Fundamental Laws - KVL

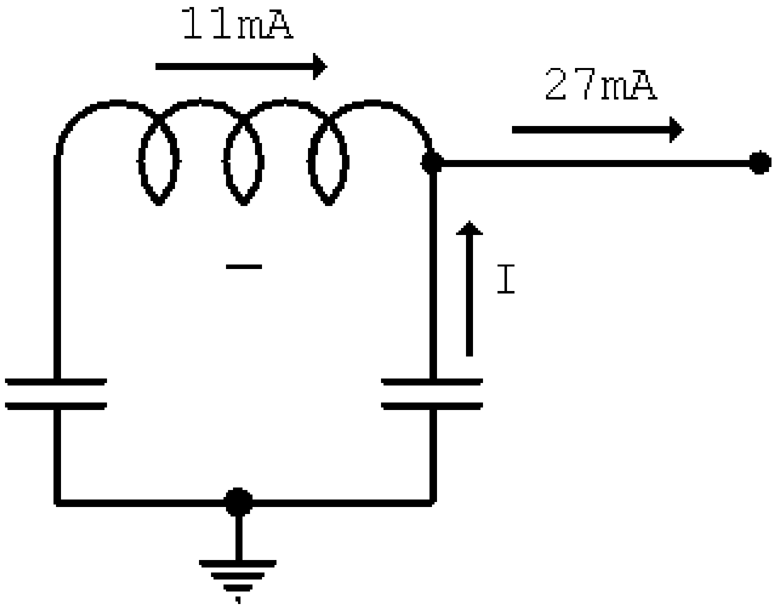
- Conservation of energy
- The sum of voltages around any closed loop in a circuit must be zero

$$V_1 + V_2 + V_3 + \ldots = 0$$



Fundamental Laws - KCL

- Conservation of Electrical charge
- The net current flowing into any junction is always equal to the net current flowing out

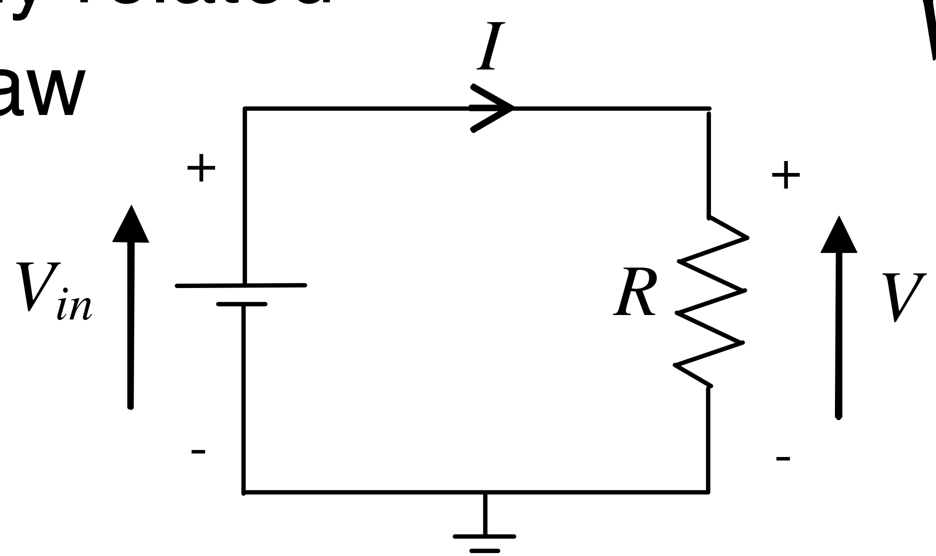


$$I_1 + I_2 + I_3 + \ldots = 0$$

Voltage, Current and Resistance

- The simplest is for current and voltage to be linearly related
- Ohm's Law

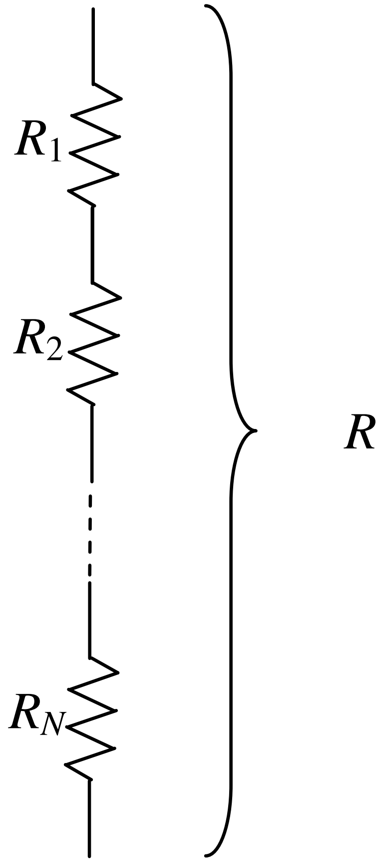
$$V = IR$$



  - Current *I* is the flow of positive charge through the circuit in Amps (A)

Resistive Circuits

- Resistors connected in series **increase** the total equivalent resistance

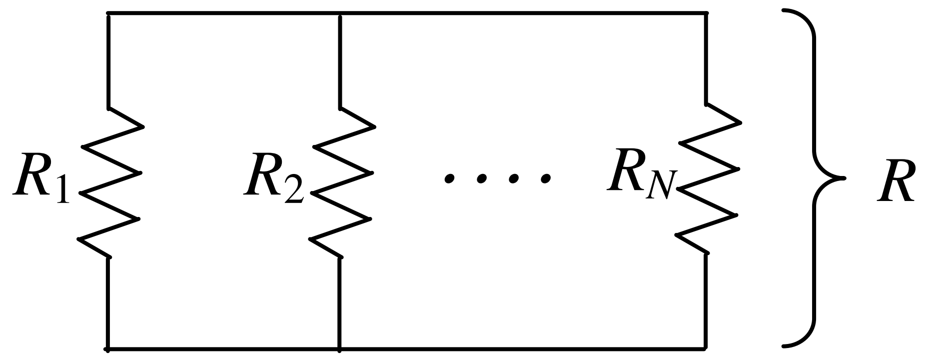


$$R = R_1 + R_2 + \ldots + R_N$$

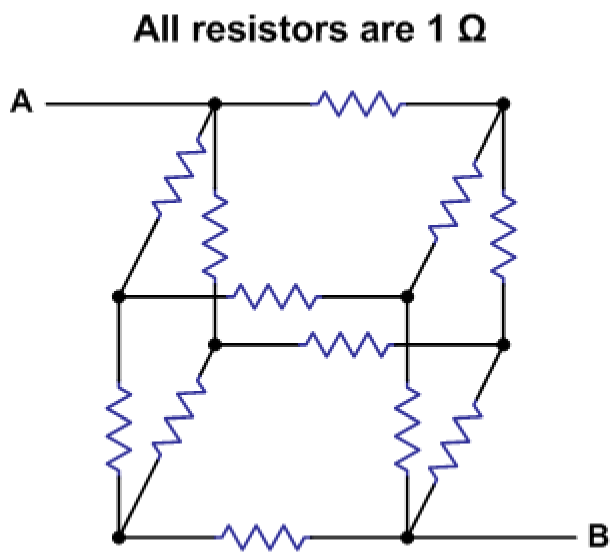
Resistive Circuits

- Resistors connected in parallel **decrease** the total equivalent resistance

$$R = R_1 \,//\, R_2 \,//\, \ldots // \, R_N = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_N}}$$



A Problem



What is the resistance between A and B?

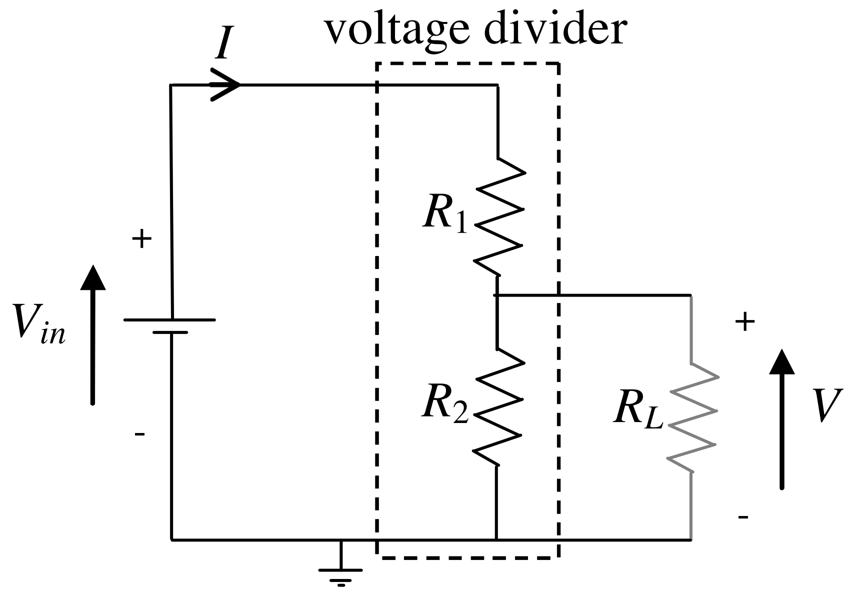
The Voltage Divider

- Assume there is no R_L ($R_L = \infty$)

$$V = IR_2 \quad \text{and} \quad I = \frac{V_{in}}{R_1 + R_2}$$

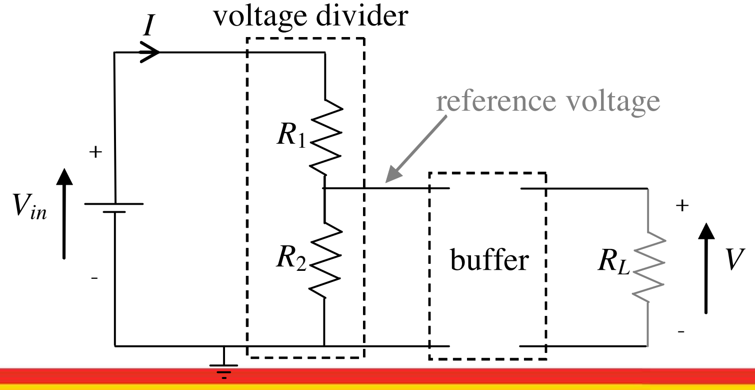
so

$$V = \frac{R_2}{R_1 + R_2} V_{in}$$



The Voltage Divider

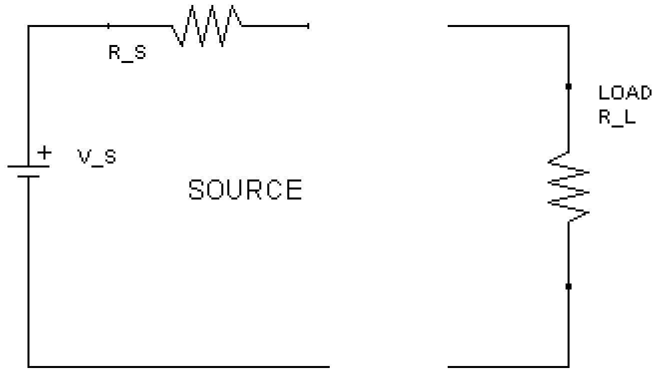
- Can use this circuit to step down voltages by a constant factor $\frac{R_2}{R_1 + R_2}$
- Take care: in practice $R_L \neq \infty$ $\quad V = \frac{R_2 // R_L}{R_1 + R_2 // R_L} V_{in}$
  - Small $R_L \Rightarrow$ affects the voltage division
  - Large $R_L \Rightarrow$ most power dissipated in divider
- Voltage divider good as reference voltage



Voltage Sources

- Real voltage sources have internal resistance
- When a load is connected, the supplied voltage is really

$$V_O = \frac{R_L}{R_S + R_L} V_S$$



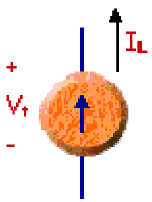
- The ideal is $R_L >> R_S$
- Important to realise this when you drive one circuit by another – may not always be possible!

Voltage Sources

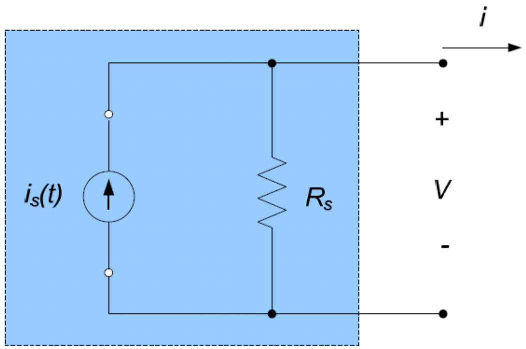
- Practical Solutions for Buffers:
  - Zener Diodes
  - Transistors
  - Operational Amplifiers
- Aim of a ‘Buffer’:
  - From the view of the Load, make the source impedance $\rightarrow 0$
  - Source provides same voltage, regardless of how much current is drawn
  - From the view of the Source, make the load impedance very large

Current Sources

- By analogy, can also construct current sources
  - Will use transistors and op-amps (later)
- An ideal current source can supply the same current, regardless of the load that is attached



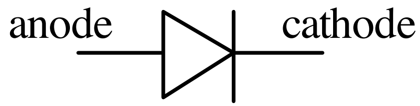
- Non-ideal current source offers some level of shunt(parallel) resistance

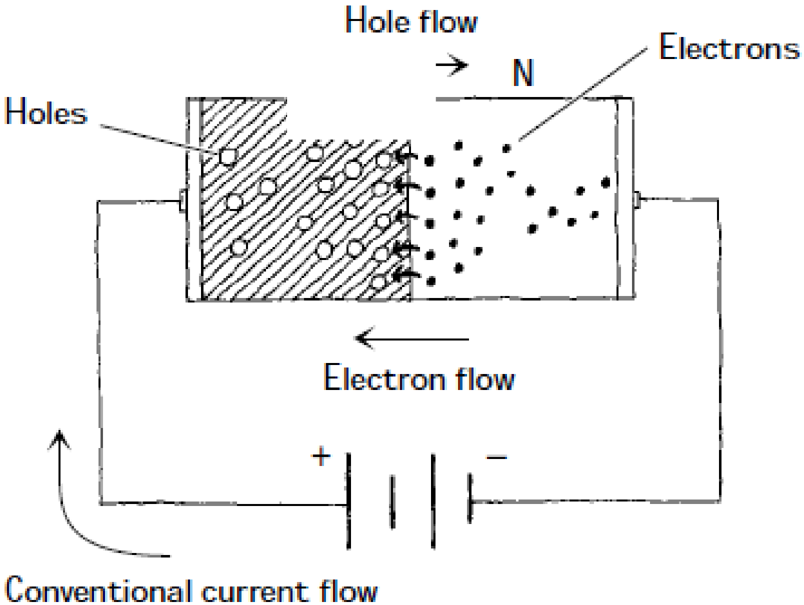


Diodes

- $V_D < V_{on}$
  - Diode is reverse-biased
    - i.e. “off” or acts as an open circuit
- $V_D > V_{on}$
  - Diode is forward-biased
    - i.e. “on” or acts as a short circuit
- Summary: a diode conducts current in one direction
  - Good for protecting sensitive components
- Caveat: $V_{on} \approx 0.6$ to 0.7V

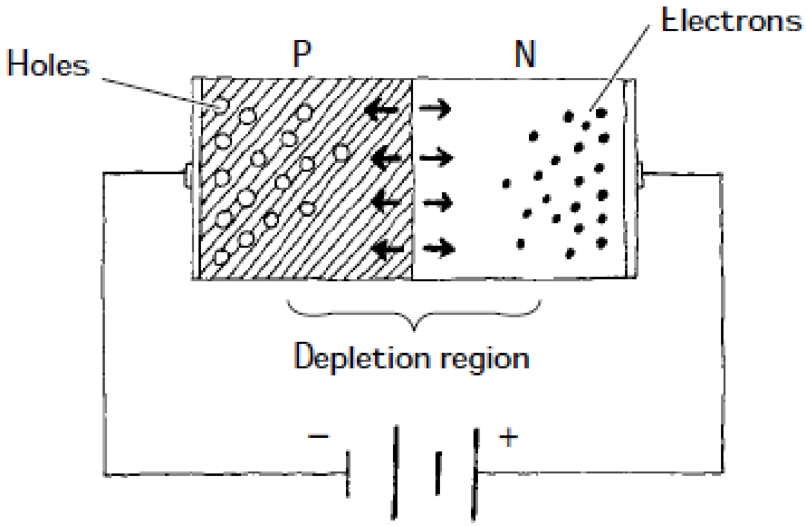
How?





- Forward biased
  - conductor

N: has ‘spare’ electrons
P: has ‘missing’ electrons



- Reverse biased
  - insulator

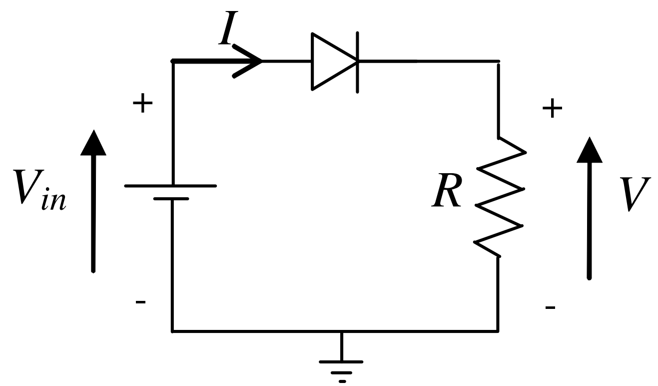
Diode properties can be *electrically* controlled

source: Scherz, 2000

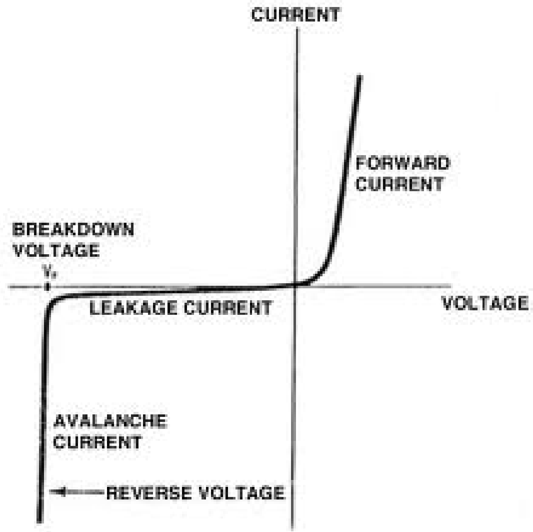
Analysis of Diode Circuits

- Split into two cases:
- $V_{in} < V_{on}$
  - No current flows through diode $\Rightarrow$ $V = 0$
- $V_{in} > V_{on}$
  - Diode has voltage $V_D = V_{on}$, so $V = V_{in} - V_{on}$

    and $$I = \frac{V}{R} = \frac{V_{in} - V_{on}}{R}$$



Real Diodes



- True I-V relationship:
- The forward current does

Increase slightly as the

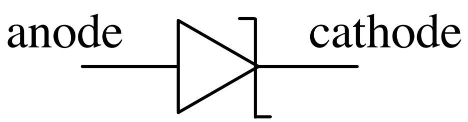
voltage increases

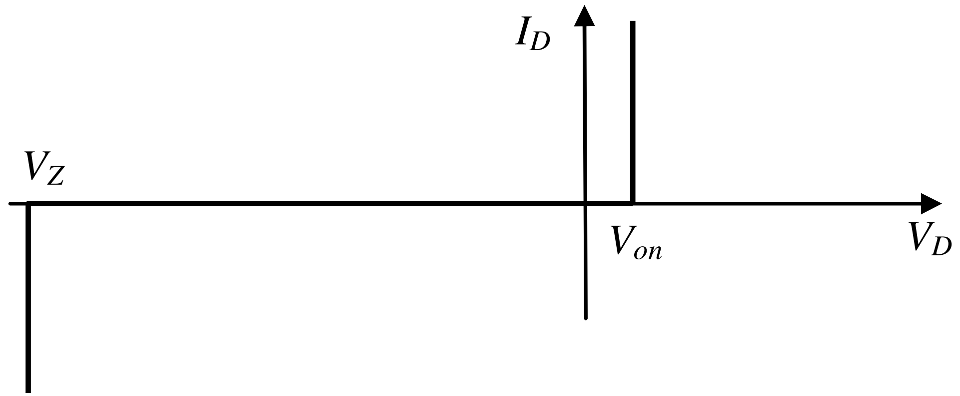
- There is a reverse leakage current
  - Due to the thermal creation of electron-hole pairs
- As previously stated, it can break down if the reverse voltage is very large
  - A normal diode will not recover

Source: http://openwetware.org/wiki/20.309:DiodePrimer

Zener Diodes

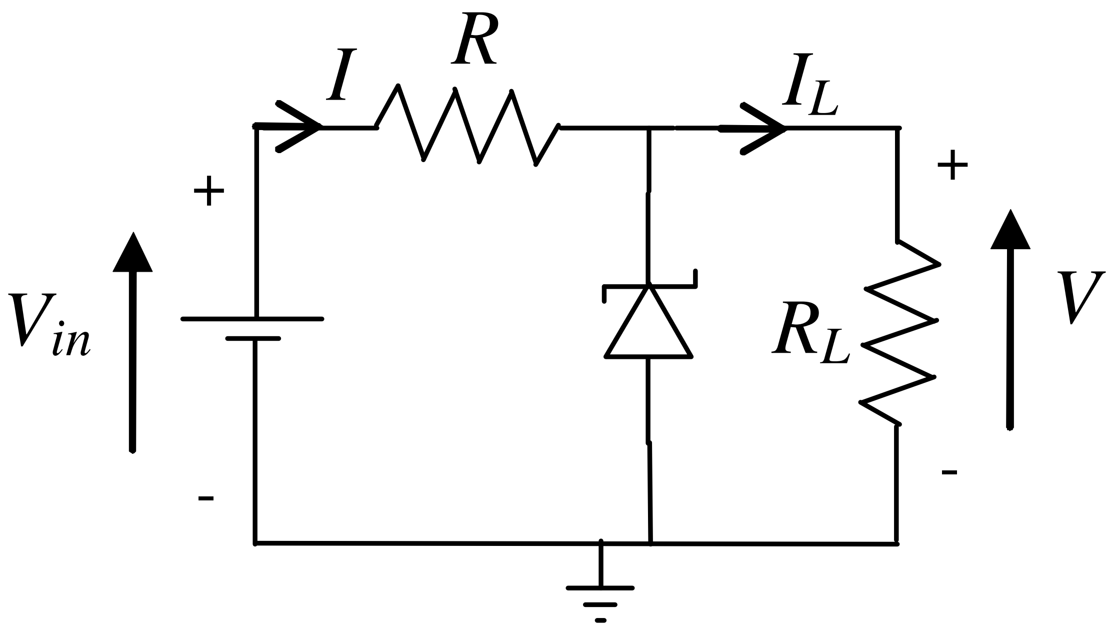
- Zener diodes are similar to diodes, but have another property known as reverse breakdown
  - Seen from current-voltage relationship





Zener Applications

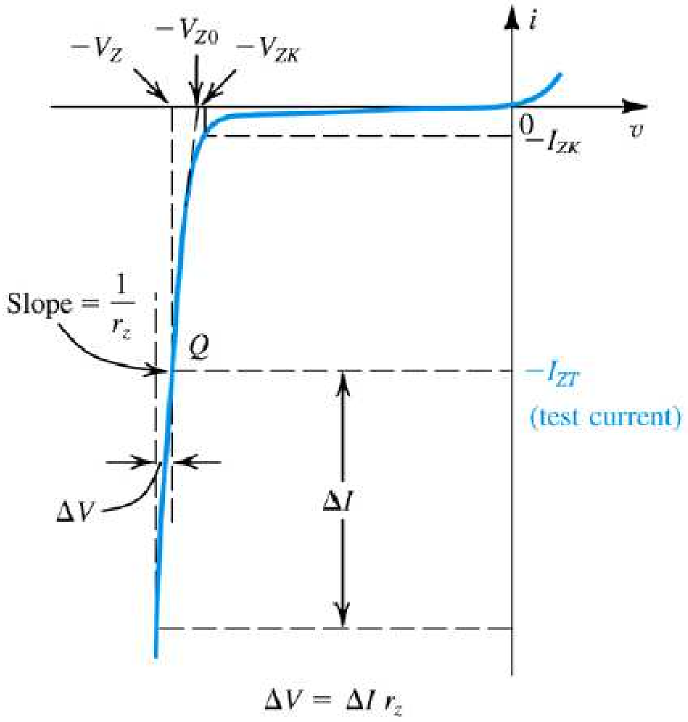
- Used in voltage regulation
  - e.g. if $V_{in} = 6\text{V}$, $V_Z = 5\text{V}$ then the circuit below steps the input voltage down to $V = V_Z$

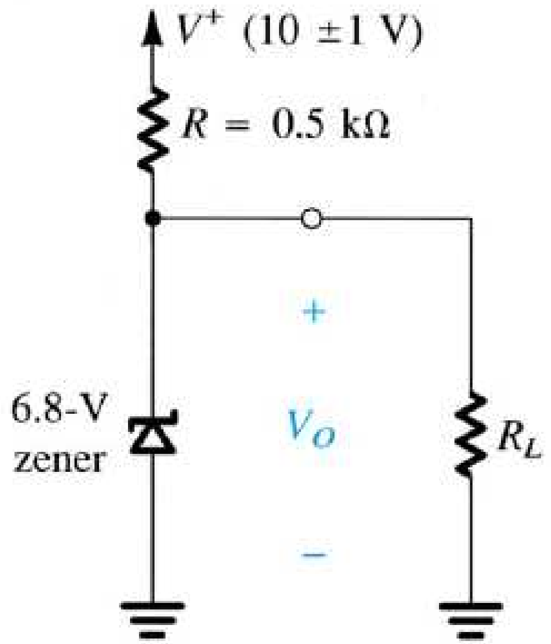


Better still for voltage regulation: Regulator integrated circuits like the LM7805 or the LM317

Zener Diode Regulation

- Handles changes in load supply





Which power supply?

- Bench-top
  - Use if system “mains powered”
- Batteries
  - Portable system
  - Alkaline, NiMH, Li-Ion?
  - In-circuit charger?
- Linear Regulators
  - Easy to design
  - Available for fixed and variable voltages
- Switch-mode
  - Much better efficiency than linear regulators
  - Harder to design
  - Some ICs available

Voltage Regulators

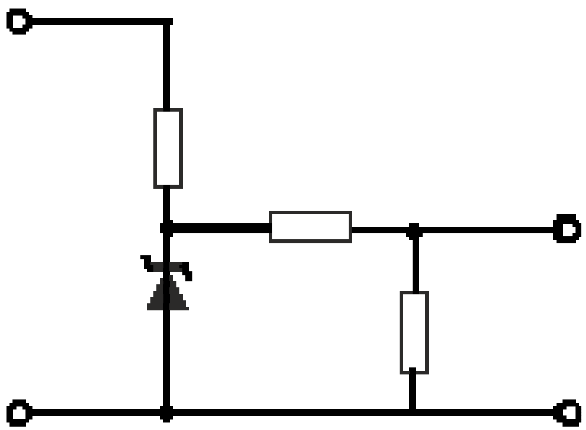
- Aim
  - Maintain a stable output voltage, given variations in output load and fluctuations in the input voltage
- Regulated Supply - Contain a reference voltage
  - Zener diode?
  - Output voltage compared to reference voltage
  - Feedback then used
- Two main types
  - Linear Voltage Regulators
  - Switch-mode Voltage Regulators

Voltage Reference

Typically use Zener diodes

These are quite noisy

- avalanche noise
- use capacitors to remove high-frequency noise



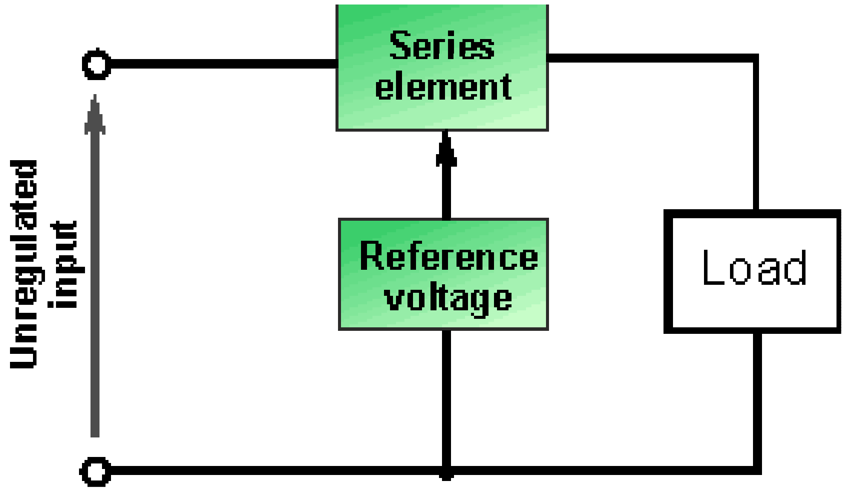
- Tantalum capacitor in series with the output removes noise spikes

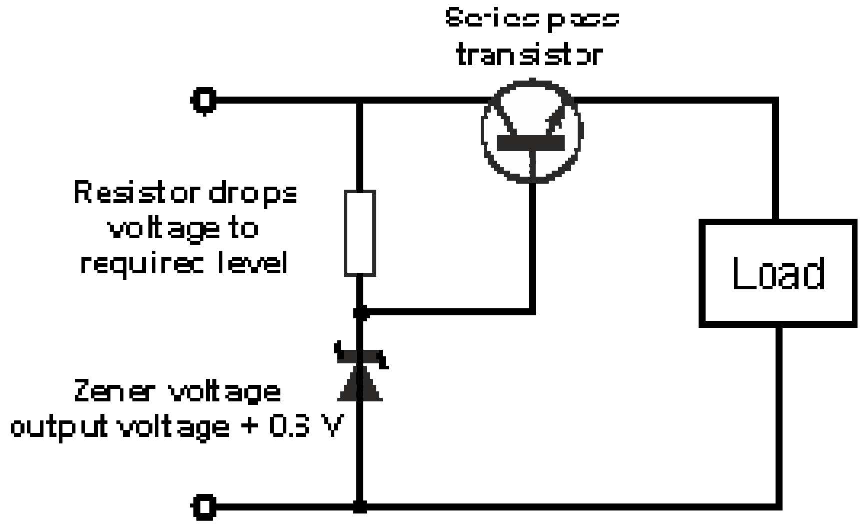
Linear Voltage Regulator

Series Topology

Design Considerations

- Consider max and
  min load currents
- Zener will require a
  certain current
  to remain RBD
- Max power that
  Zener can
  dissipate

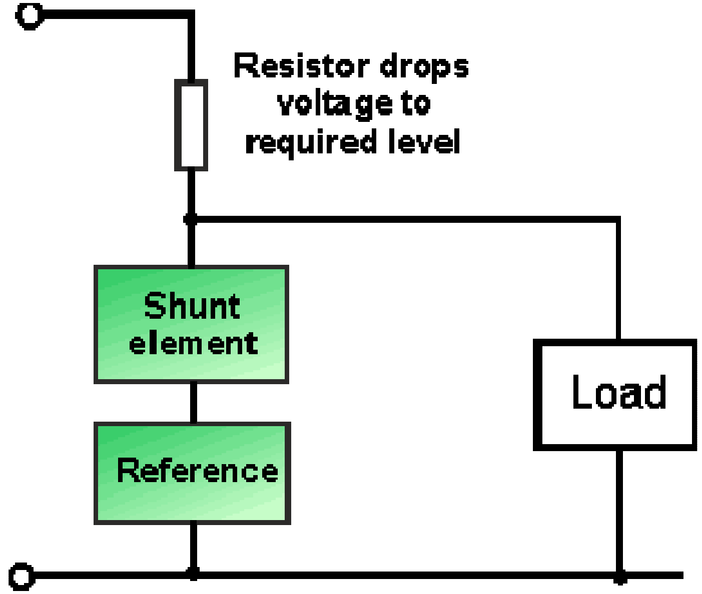




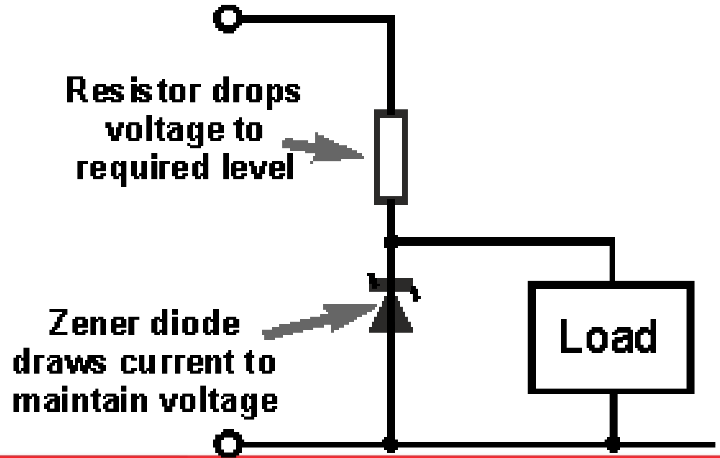
Linear Voltage Regulator

Shunt Topology

- Maximum current is drawn from the source regardless of load
- Hence, inefficient



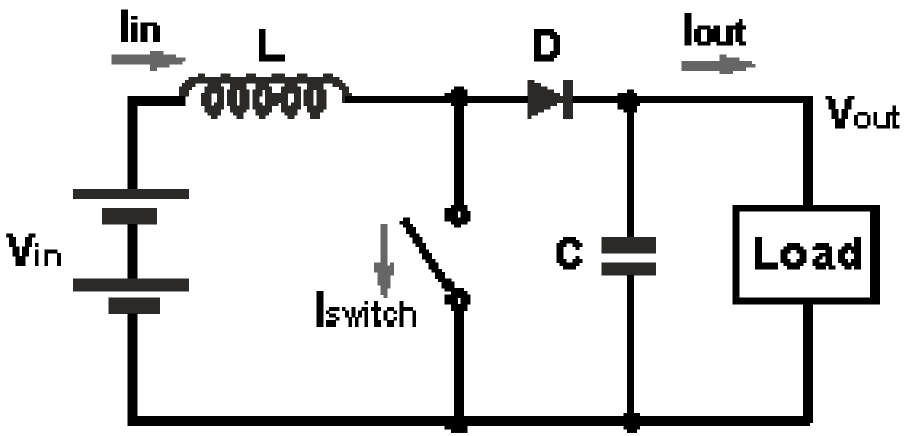
- Simplest Shunt Linear Voltage Regulator



Switch-mode Regulator

- Buck or Boost
- Here is a Boost-mode Regulator

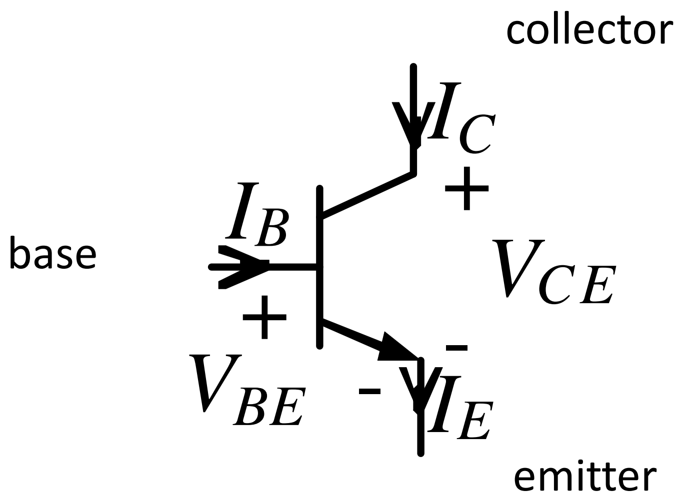
$$V_{out} > V_{in}$$

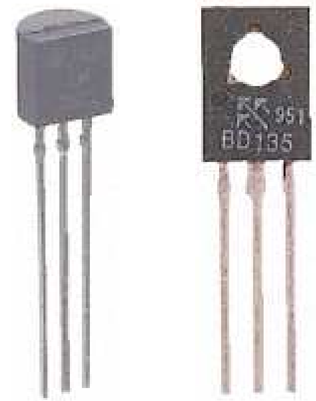


– Efficiencies of up to 90% are common

The Bipolar Junction Transistor (BJT)

- Nonlinear device with three terminals:



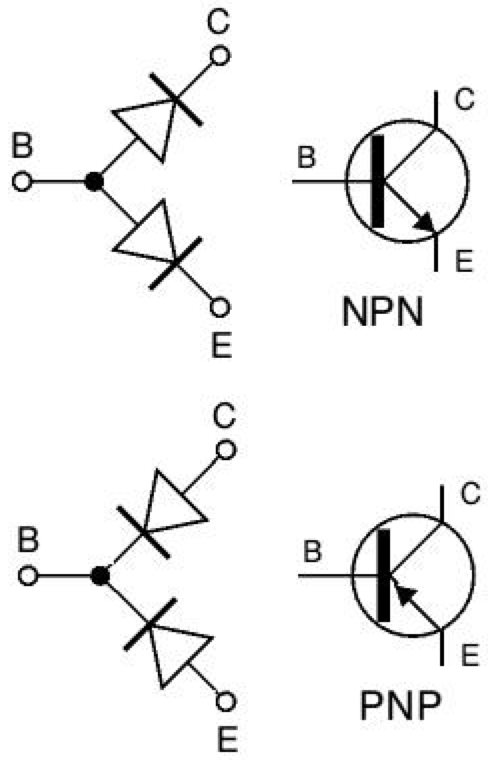


- Has several operating modes
  - $V_{BE} > 0.7$V, $V_{CE} > 0.3$ V $\Rightarrow$ forward active mode

source: http://australia.rs-online.com

Transistor as Two Diodes

- Two types – NPN and PNP
- Effectively a diode as C-B and B-E (two back to back PN junctions)
- PNP transistor has the N and P regions reversed
- Work the same way, but all polarities are the opposite for a PNP (versus an NPN)



source: http://www.mobileelectronics.com.au/forums/index.php?/topic/58571-blown-jay-car-amp-help/page__st__15

Transistor – Forward Active Mode

Most circuits aim to bias the transistor so it is in forward-active mode -> straight-forward to analyse

- VC > VE, and BE junction forward-biased (CE junction reverse-biased)
- When conducting, VB – VE ≈ 0.6-0.8V (forward-bias voltage)
- If the above is true, the current CE will be proportional to the BE current…

Transistor Current Gain

- In forward active mode

$$I_C = \beta I_B$$

  - β (or H_{FE} or h_{FE}) is the current gain
    - Typically large, e.g. 50 to 200
  - A small input current (I_B) can be used to control a large output current (I_C or I_E)
  - Also

$$I_E = I_B + I_C = (\beta + 1) I_B = \frac{(\beta + 1)}{\beta} I_C$$

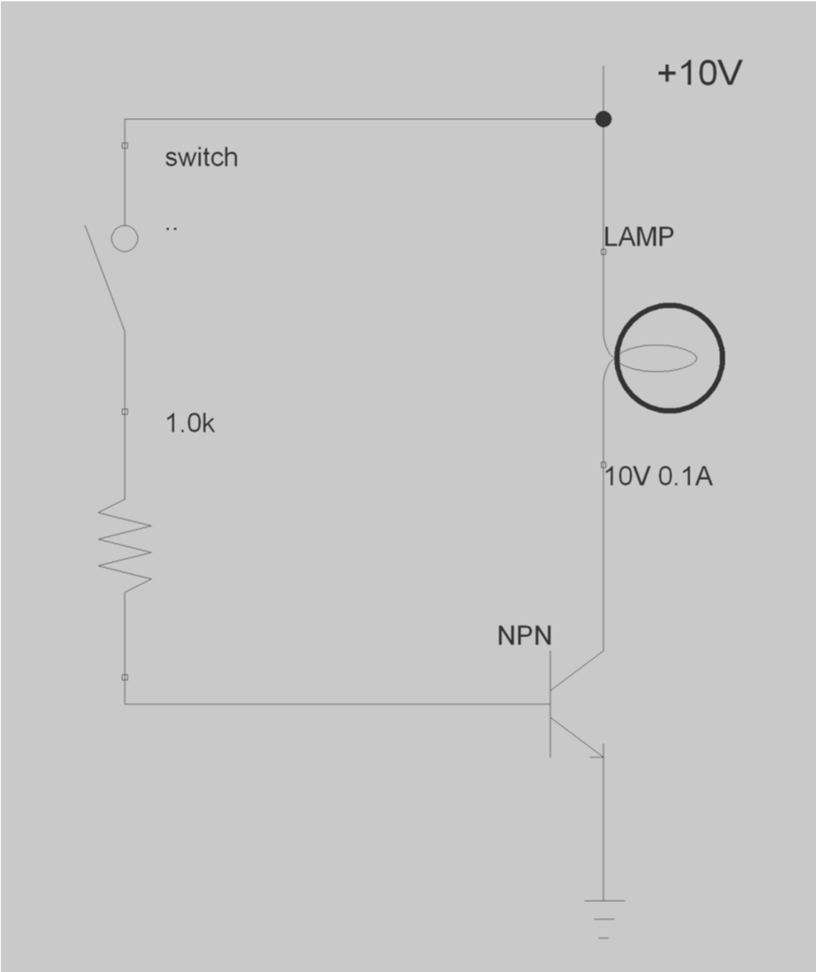
    - Most current is going from collector → emitter

Transistor – Limitations

Practical limitations of forward-active mode

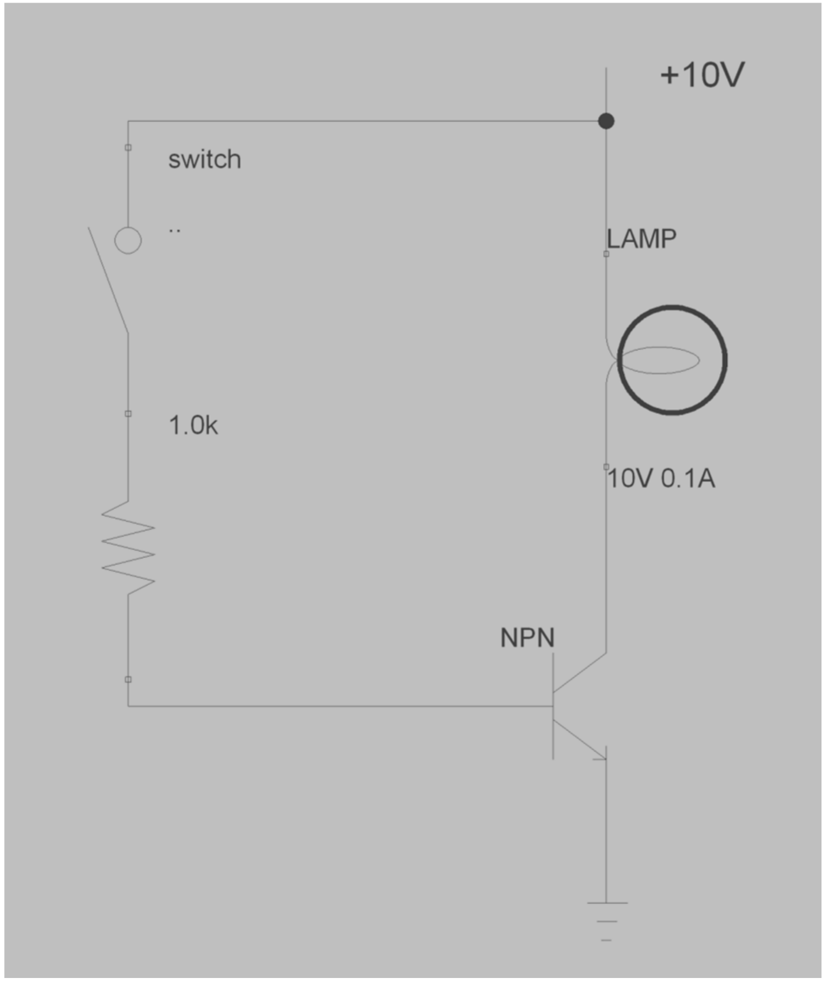
- A transistor has maximum values of I_C, I_E, and V_CE that it can handle
- The power dissipation is limited (I_C*V_CE)
- The properties depend heavily on temperature
- The current gain, β, varies substantially within models -> don't build circuits that depend on this parameter
- Always limit the base current (since is a forward-biased diode BE)

Transistor Switch



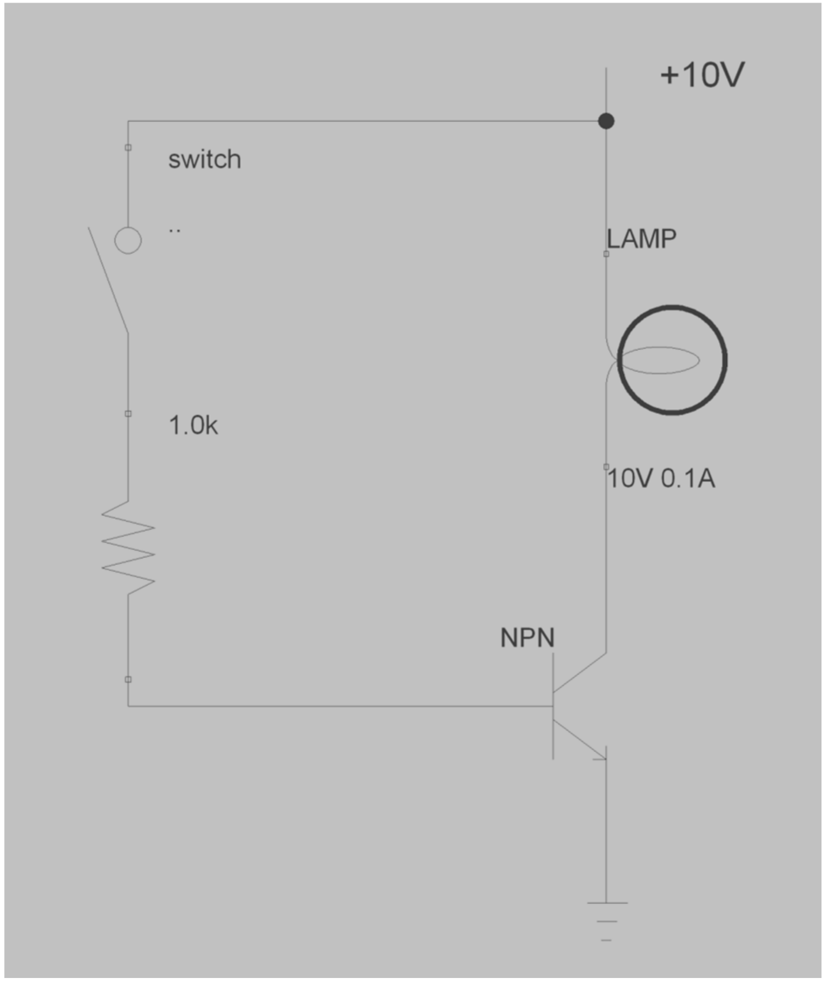
- When switch is open, I_B = 0, so I_CE = 0 -> lamp is off
- When switch is closed, how do we analyse this circuit?
- Assume the transistor is in forward-active mode
  - BE junction is conducting

Transistor Switch



- V_BE = 0.6V
- I_B = 9.4mA
- If say, β = 100, then I_C = 940mA!
- But then V_C < 0 -> so transistor is not operating in the forward-active region
- Transistor here saturates

Transistor Saturation

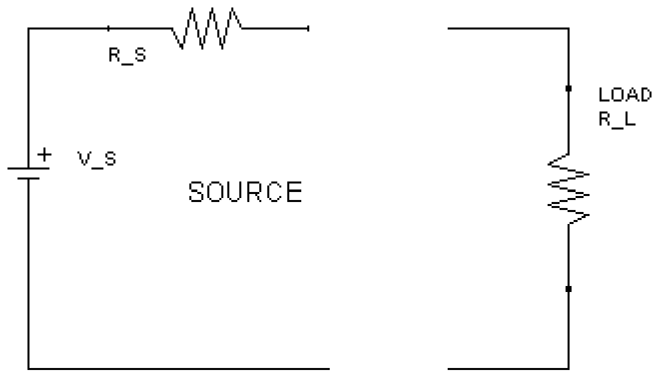


- Here, V_CE is forced as close to zero as it can go
  - Typical saturation voltages 0.05-0.2V
- Approx. 10V across the lamp, so I_C = 100mA
- Note here – a small current (9.4mA) controls a large current (100mA)

Voltage Sources

- Real voltage sources have internal resistance
- When a load is connected, the supplied voltage is really

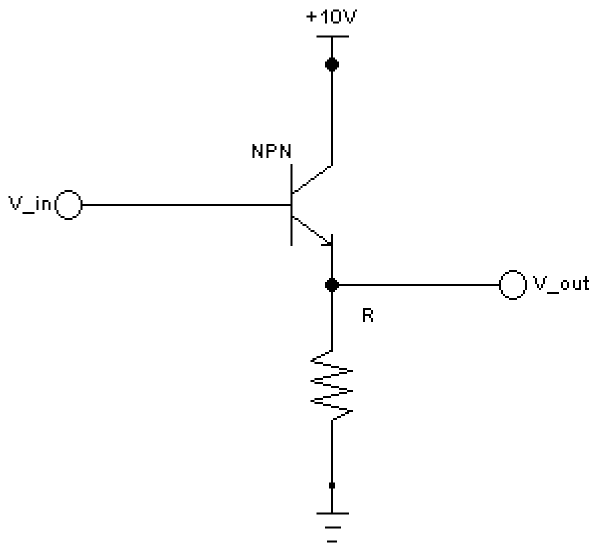
$$V_O = \frac{R_L}{R_S + R_L} V_S$$



- The ideal is $R_L >> R_S$
- Important to realise this when you drive one circuit by another – may not always be possible!

Emitter Follower

- A simple transistor buffer circuit to connect between circuits to overcome the voltage-divider problem



- For input voltage

  0.6V < V_in < 10V

- Transistor in the forward-active region

$$V_{out} = V_{in} - 0.6\mathrm{V}$$

- So, what's the point?

Emitter Follower

- The point is that the output impedance is significantly reduced -> $R_L >> R_S$
  - If you are going to connect something to the output, this external circuit sees a reduced source resistance
- Equivalently, the input impedance is significantly increased
  - If you think of V_out as the load, and you driving this with a circuit -> that external supply circuit sees a much larger R_L

Emitter Follower

- Input resistance is $R_{in} = \dfrac{\Delta V_B}{\Delta I_B}$
- Output resistance is $R_{out} = \dfrac{\Delta V_E}{\Delta I_E}$

Analysis:

- Since $\Delta V_B = \Delta V_E$ and $R = \dfrac{\Delta V_E}{\Delta I_E}$
- For the transistor in the forward-active region:

$$\Delta I_E = (\beta + 1)\Delta I_B$$

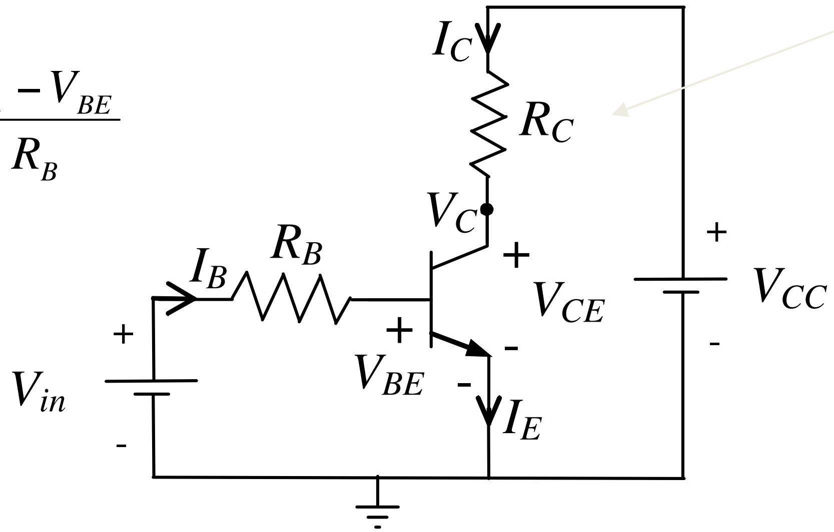
- Therefore, $R_{in} = (\beta + 1)R_{out}$
- If we though the resistance seen by a load connected at V_out, when driven by a source of R_s at V_in

$$R_{out} = \frac{1}{(\beta + 1)}R_s$$

Transistor circuit analysis

- Common-emitter configuration

$$I_C = \beta I_B = \beta \frac{V_{in} - V_{BE}}{R_B}$$



in many applications, R_C is the load

directly controlled by I_B

constant

device constants

$$V_C = V_{CC} - R_C I_C = V_{CC} - \beta R_C \frac{V_{in} - V_{BE}}{R_B}$$

output

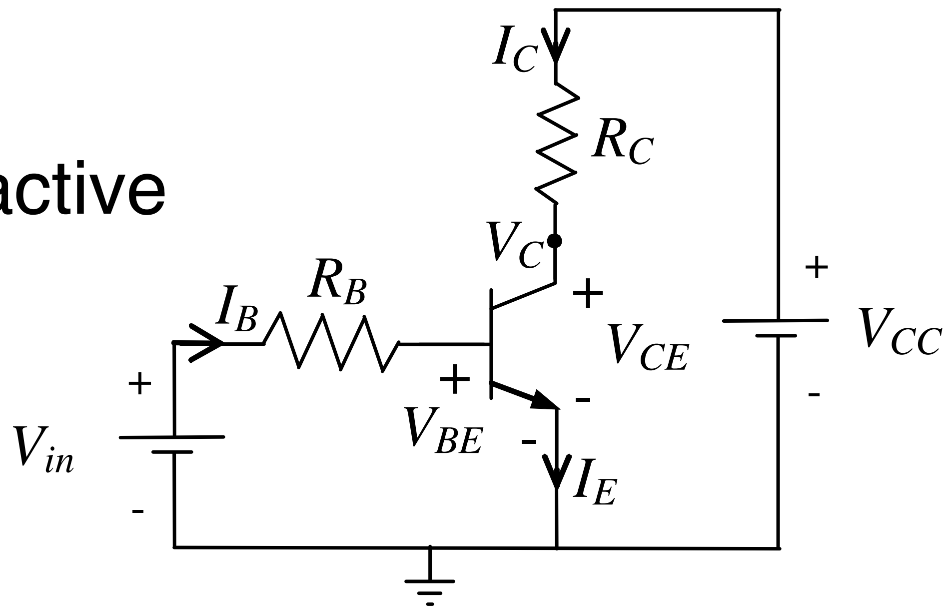
constant, determined by design

Transistors as switches

- Common-emitter configuration

  V_{in} large -> saturation
  - $\Rightarrow I_B$ large
  - $\Rightarrow I_C$ large
  - $\Rightarrow R_C I_C$ large
  - $\Rightarrow V_C$ small

  V_{in} small -> forward-active
  - $\Rightarrow I_B$ small
  - $\Rightarrow I_C$ small
  - $\Rightarrow R_C I_C$ small
  - $\Rightarrow V_C$ large

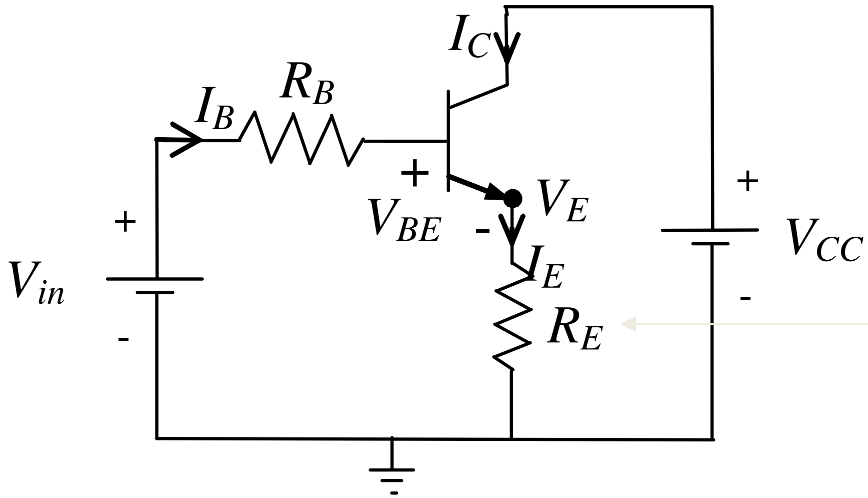


Transistors as switches

- If V_{in} is large and R_C is chosen large enough, then the output $V_C \approx 0$
  - "high" input → "low" output
- If V_{in} is so small that $V_{in} \leq V_{BE}$, then the output $V_C = V_{CC}$
  - "low" input → "high" output
    - Note: if $V_{in} < V_{BE}$, actually the transistor is no longer in the forward active mode, and no current flows

Transistor circuit analysis

- Common-collector configuration



in some applications, R_E is the load

directly controlled by V_{in} — constant — design — device constant

$$V_E = V_{in} - V_{R_B} - V_{BE}$$

$$I_E = \frac{V_{in} - V_{BE}}{\frac{R_B}{\beta + 1} + R_E}$$

Announcements

- Labs Open
  - Every Monday 2-6pm and Thursday 2-6pm
  - EE labs EEG14 and EE214
- Lab Exercises
  - Lab 1 this week – introduction
  - Labs 2, 3 & 4 available next week
  - Any one of them for 10%
  - Attend as convenient
- Lab Equipment
  - Breadboard would be ideal