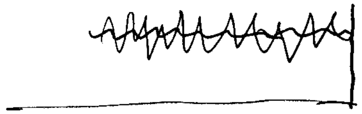
TOZER. EEE123 2nd half.

About EEE123 2nd half

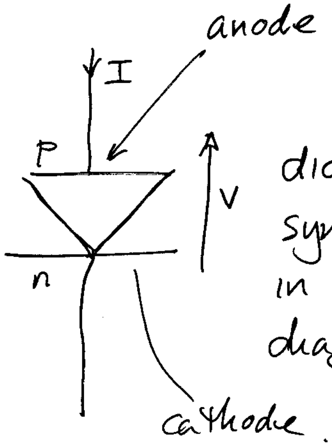
- start by talking about diodes
  - start by looking at diode behaviour
  - standard diodes modelling that behaviour.
  - some standard circuit shapes.
    - and the way they work.
- Introduce transistors — 3 legs
  - devices that control the flow of current through two of the legs on the basis of what's happening to the third leg.
  - applications throughout electronics → computing instrumentation, avionics control, bioelectronics .....
- Some applications — mainly in power and some very specialised applications

Most applications involving signals use transistors in an integrated circuit form. (op-amps, in this module).

My objective is to give you an insight into how ccts involving diodes, transistors and op-amps work.



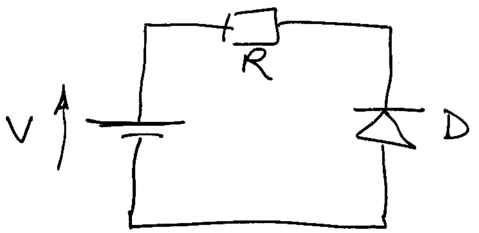
forward current flows from anode to cathode in direction of the arrowhead.



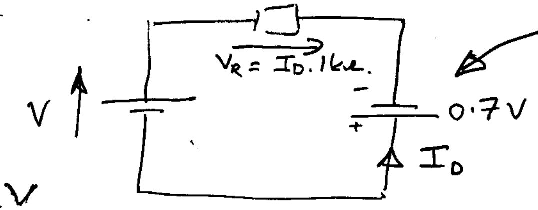
diode symbol used in circuit diagrams.

$$I = I_0\left(\exp\frac{eV}{\eta kT} - 1\right).$$

How to find out whether a diode is conducting.



1a assume diode is conducting
let $R = 1k\Omega$.



let V= 2V

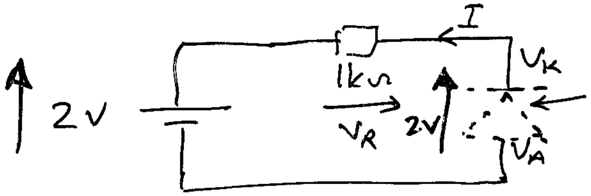
2a replace diode by a 0.7V source (+ end at anode end of diode).

3a
$$V + I_D\, 1k\Omega + 0.7 = 0$$
$$2 + I_D\, 10^3 + 0.7 = 0$$
$$I_D = \frac{-2.7}{10^3} = -2.7\ mA.$$

But I_D is indicated in a forward bias direction (allowed). The fact that I_D is -ve means that is actually trying to flow in the opposite direction to that indicated by I_D

— Physically not sensible
∴ assumption is wrong.

Diode is not conducting



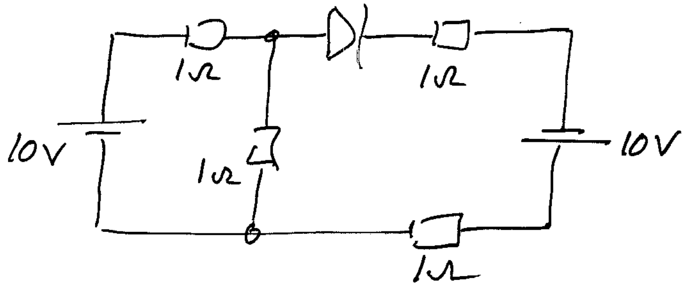
diode not conducting

$I = 0$, $V_R = 0$

voltage, V_{A-K}, across diode $= -2V$

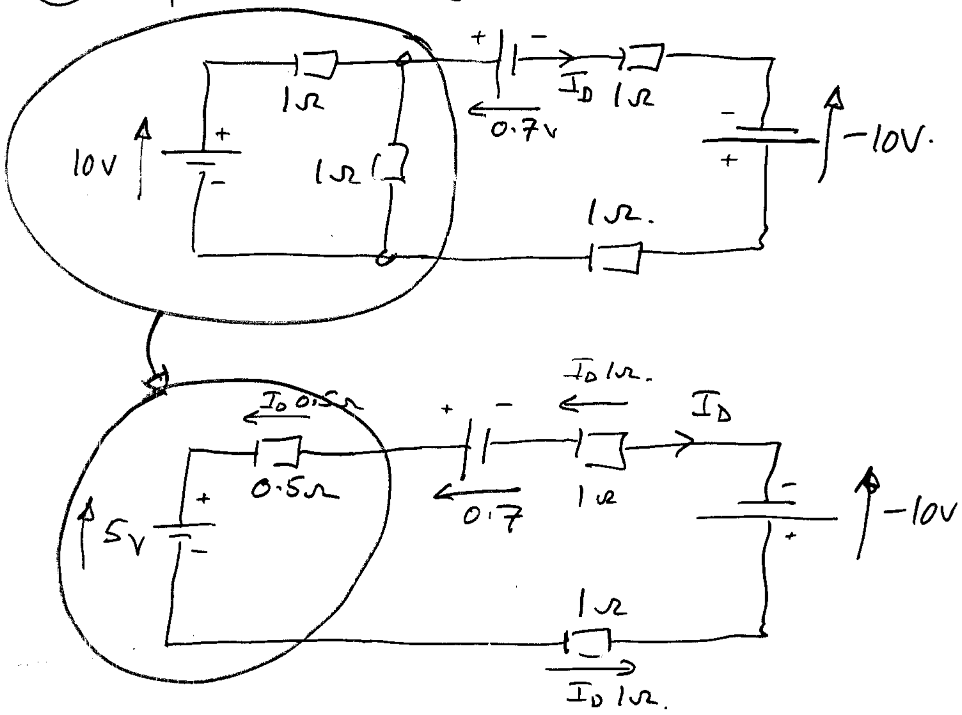
this is known as a reverse bias.

another example



(1a) assume diode is conducting

(2a) replace diode by a 0.7V source.



adding voltages around loop.

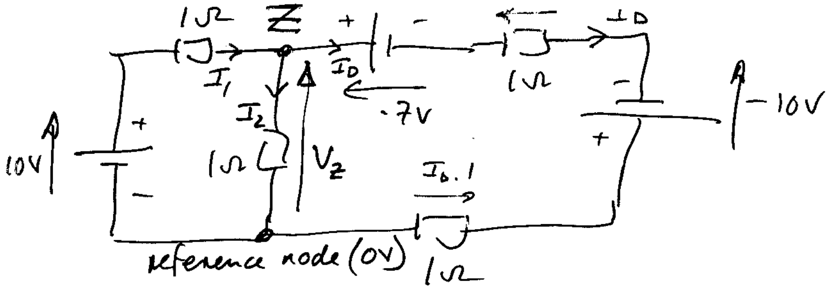
$$5 - I_D 0.5 - 0.7 - I_D + 10 - I_D = 0$$

$$15 - 0.7 = 2.5\, I_D$$

$$I_D = \frac{15-0.7}{2.5} = \frac{14.3}{2.5}.$$

This is positive, so diod is conducting and assumption was correct.

Without using a Thevenin transformation.



using nodal analysis
Sum currents at node Z

$$I_1 = I_2 + I_D.$$

$$\frac{10 - V_Z}{1\Omega} = \frac{V_Z - 0}{1\Omega} + \frac{V_Z - 0.7 - (-10) - 0}{1\Omega + 1\Omega}.$$

$$10 - V_Z = V_Z + \frac{V_Z}{2} - \frac{0.7}{2} + \frac{10}{2}$$

$$20 - 2V_Z = 2V_Z + V_Z + 9.3.$$

$$20 - 9.3 = 5V_Z$$

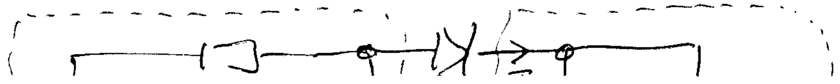
$$V_Z = \frac{10.7}{5}$$

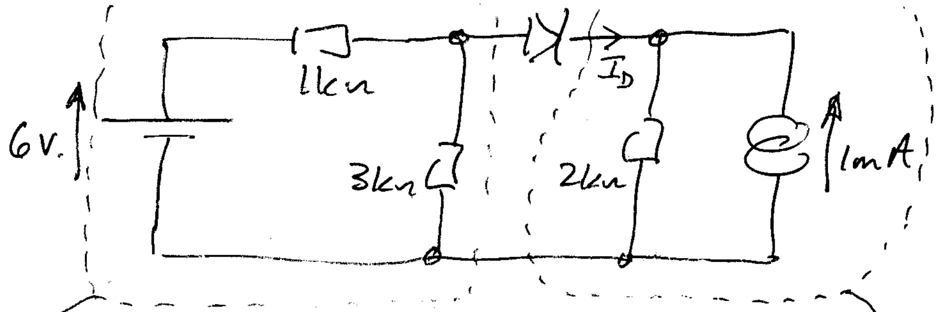
$$I_D = \frac{V_Z + 9.3}{2} = \frac{\frac{10.7}{5} + 9.3}{2}$$

$$= \frac{10.7 + 46.5}{10}$$

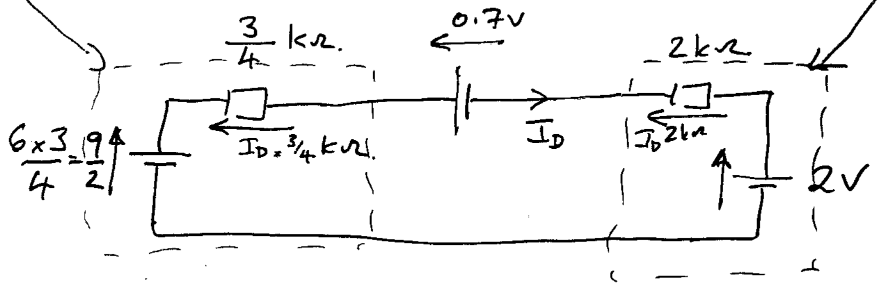
$$= \frac{57.2}{10} = 5.72$$

Another example.





First approach using Thevenin to Norton or vice versa transformation and a Thevenin simplification ...



$$\frac{9}{2} - I_D\,750\Omega - 0.7V - I_D\,2000 - 2V = 0$$

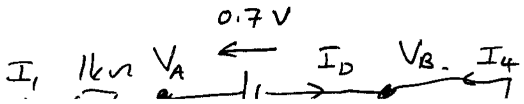
$$= 2750\, I_D$$

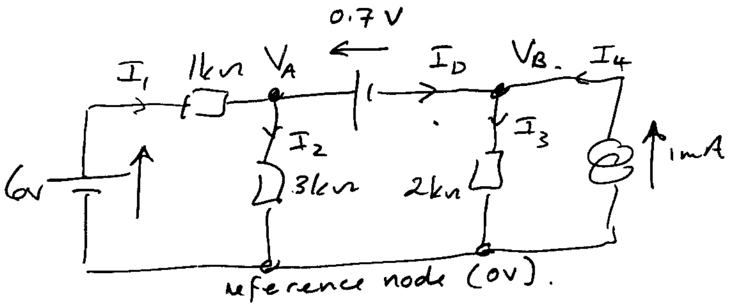
$$\frac{9-1.4-4}{2} = \frac{3.6}{2} = 1.8 = 2750\, I_D$$

$$I_D = \frac{1.8}{2750}\ A.$$

I_D is +ve so diode conducts.

2nd approach using a nodal analysis...





Sum currents at node A

$$I_1 = I_2 + I_D.$$

$$\frac{6 - V_A}{1k\Omega} = \frac{V_A - 0}{3k\Omega} + I_D.$$

Sum currents at node B.

$$I_D + I_4 = I_3$$

$$I_D + 1mA = \frac{V_B}{2k\Omega}.$$

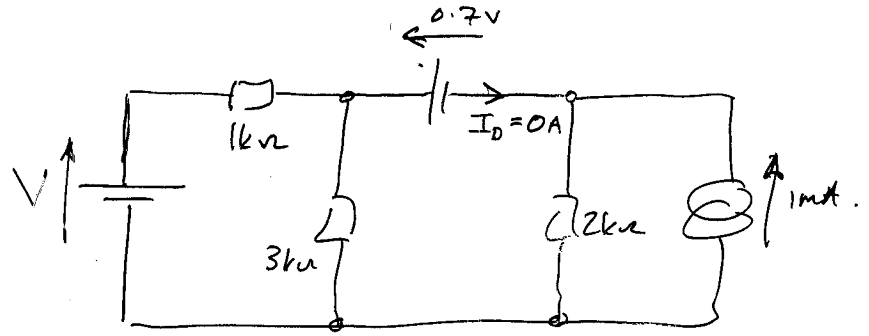
but $V_A = V_B + 0.7$

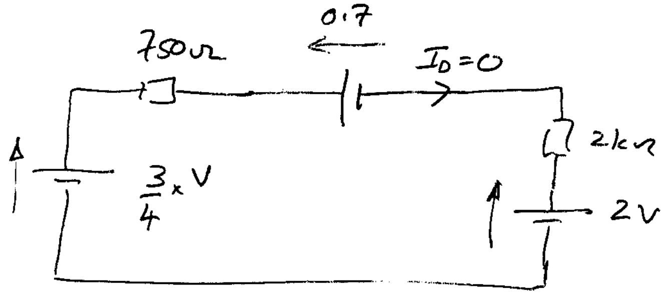
so the node B current sum becomes

$$I_D + 1mA = \frac{V_A - 0.7}{2k\Omega}.$$

Next step is to tidy up the equations then eliminate either V_A or I_D — eliminating V_A would be most sensible here.

Next problem is to identify the point at which a varying source takes the diode to the point of conduction.

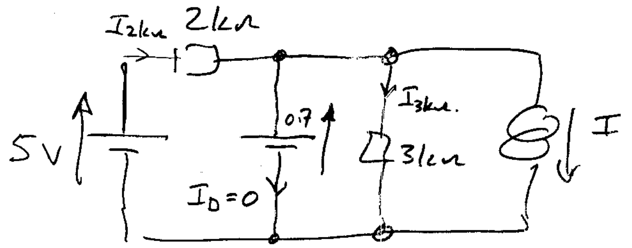




$$\frac{3}{4}V - 0.7 - 2 = 0$$

or $\frac{3}{4}V = 2.7$

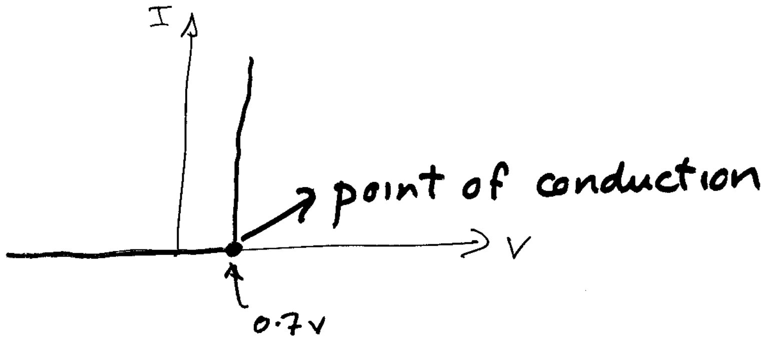
$$V = \frac{4 \times 2.7}{3} = 3.6\ V.$$



$$I_{3k\Omega} = \frac{0.7}{3k\Omega}$$

$$I_{2k\Omega} = \frac{5 - 0.7V}{2k\Omega} = \frac{4.3V}{2k\Omega}.$$

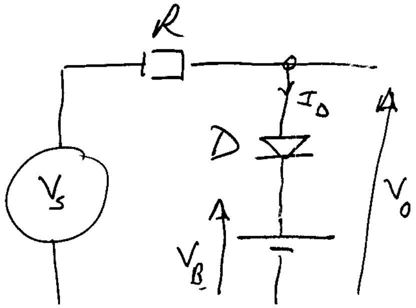
$$I_{2k\Omega} = \underset{(I_D)}{0} + I_{3k\Omega} + I.$$



Clipping Circuits

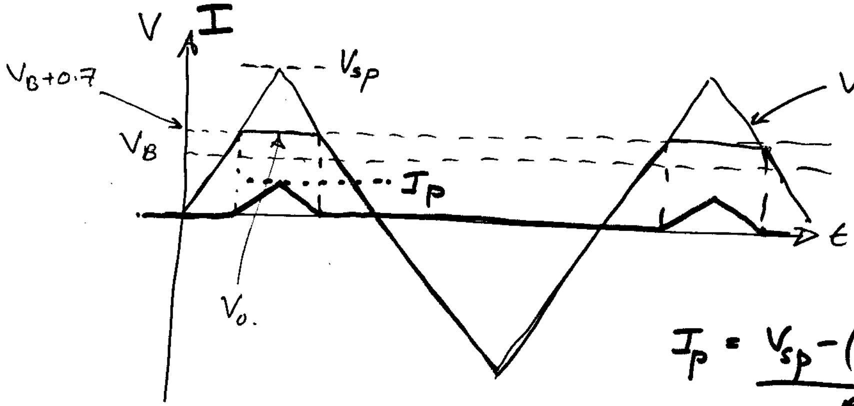
- chop off the top or bottom or both top and bottom of a signal to keep it within specified voltage bounds.

basic circuit..



$V_S \rightarrow$ a time varying signal

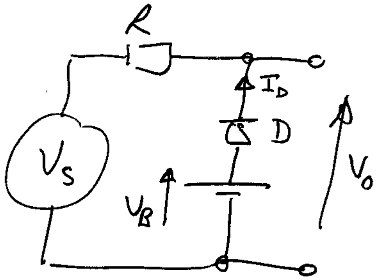
$V_B \rightarrow$ a fixed bias voltage.



$$I_p = \frac{V_{sp} - (V_B + 0.7)}{R}.$$

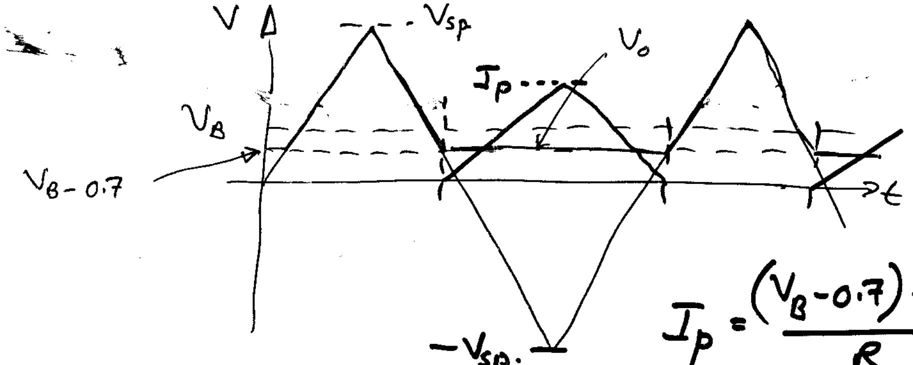
- current flows only when the clipping action is active.

If the cct was changed to



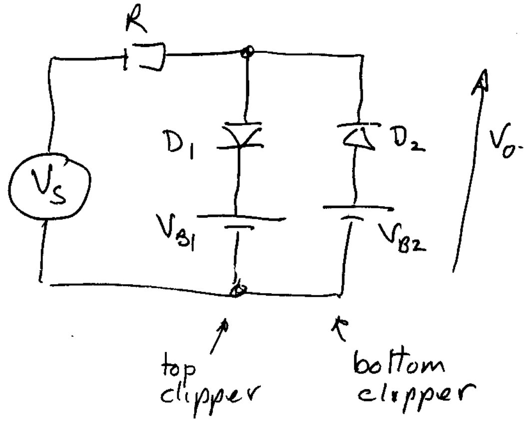
At point of conduction

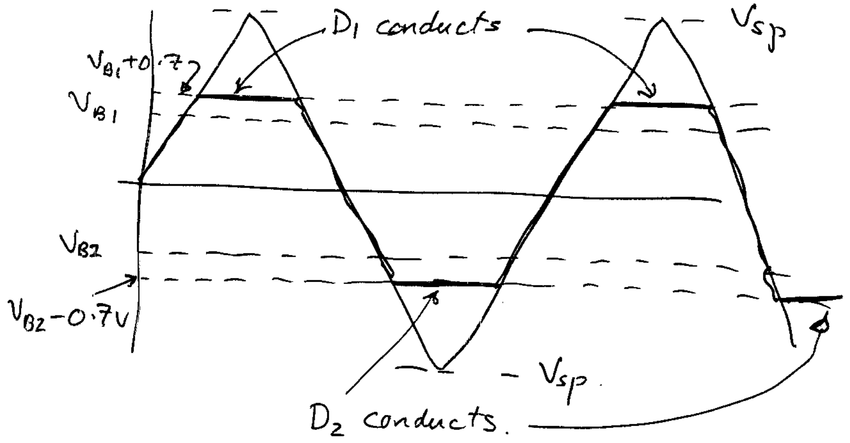
$V_o = (V_B - 0.7)$ V.



$$I_p = \frac{(V_B - 0.7) - (-V_{sp})}{R}$$

top and bottom clipping





top + bottom protection is commonly used to protect the inputs of sensitive IC circuits

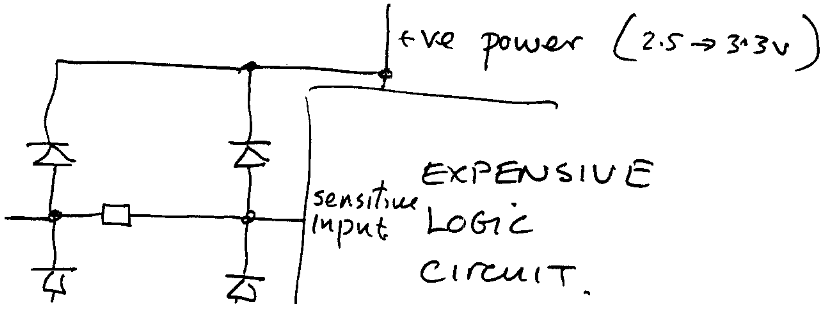
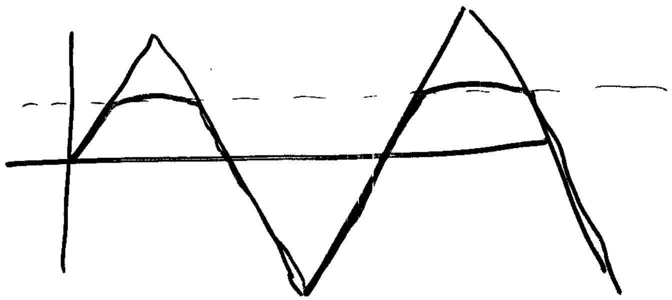
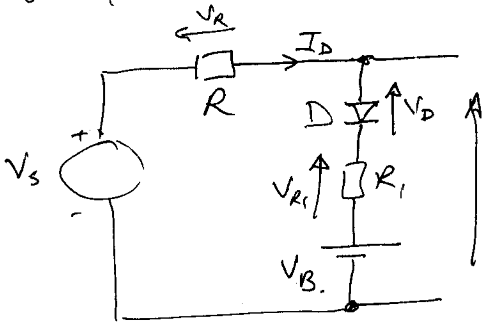


figure 2 in sheet . . .



Soft Clipping ....

Soft clipping allows V_o to change slightly after the onset of diode conduction

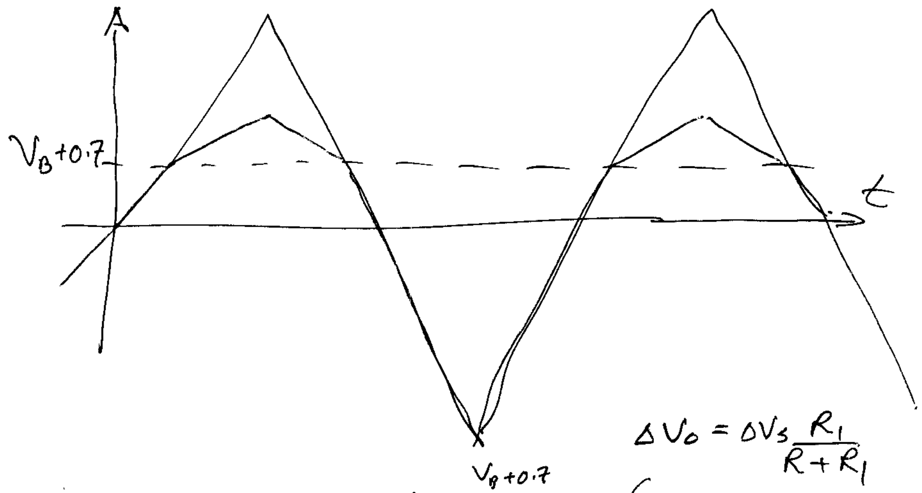


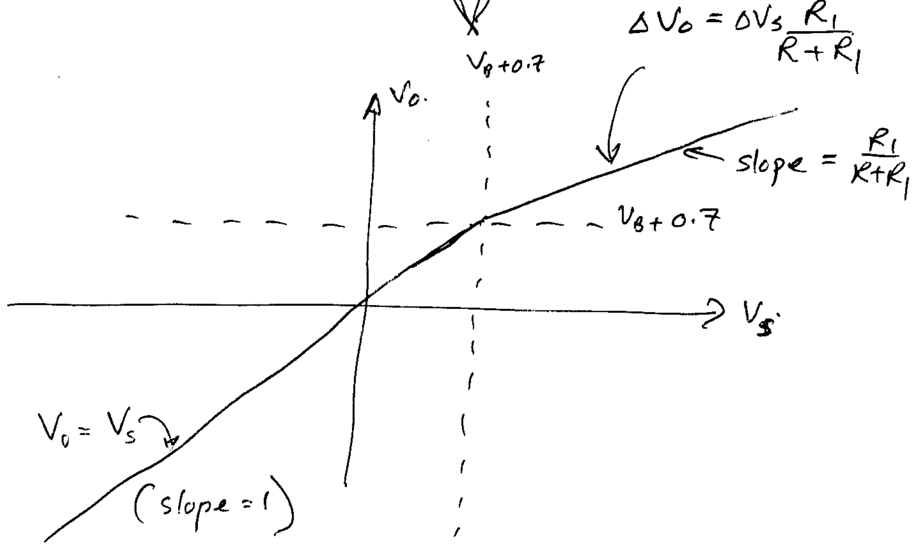
point of conduction will be when $V_s = V_B + 0.7$ ⟶ this will give $V_D = 0.7$ and $I_D = 0$.

If v_s changes to $V_s + \Delta V$ from $V_s = V_B + 0.7$

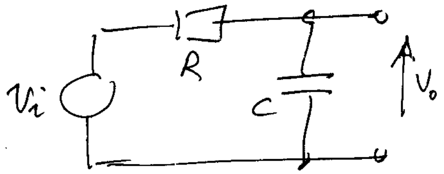
$$\Delta I_D = \frac{\Delta V}{R+R_1}$$

$$\text{so } \Delta V_R = \Delta V \cdot \frac{R}{R+R_1} \qquad \Delta V_{R_1} = \Delta V \cdot \frac{R_1}{R+R_1}$$

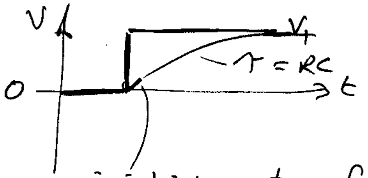




Review of R-C circuit behaviour.



$\tau = RC$



$V_i = 0$

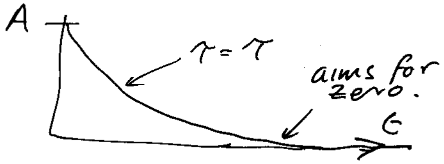
initial rate of change of voltage

$$\frac{dV}{dt} = \frac{i}{C} = \frac{V_1 - 0}{CR} = \frac{V_1}{RC} = \frac{V_1}{\tau}$$

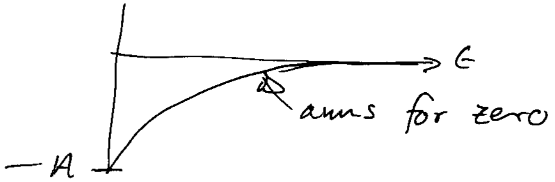
$$V_o(t) = V_1\left(1 - e^{-t/\tau}\right).$$

— must be a combination of $e^{-t/\tau}$ and constants.

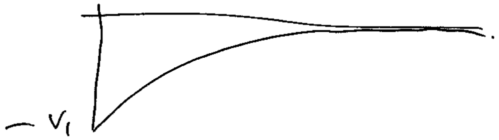
$Ae^{-t/\tau} \longrightarrow$



The shape for the cct above is a $-e^{-t/\tau}$ shape



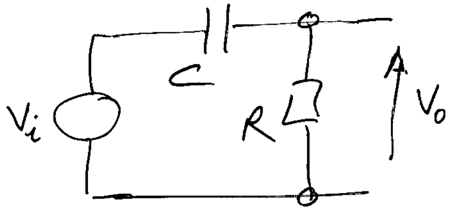
$A = V_1$ for the cct above.

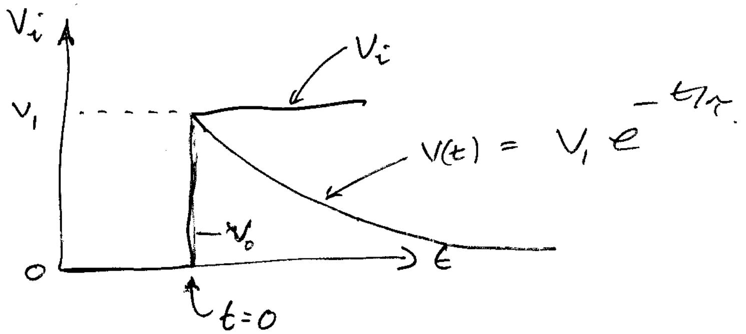


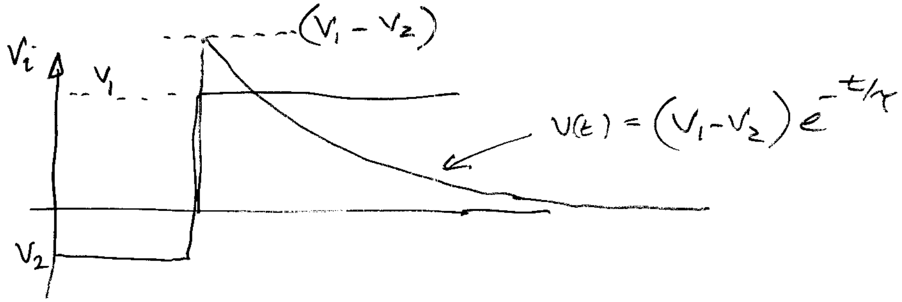
Need to add V_1 to this shape to get the response of the circuit above.

$$-V_1 e^{-t/\tau} + V_1$$

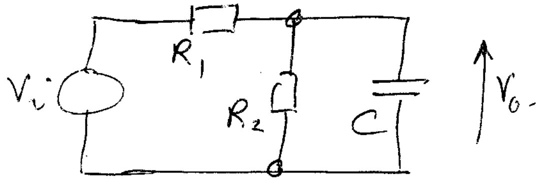
Another R-C circuit ...

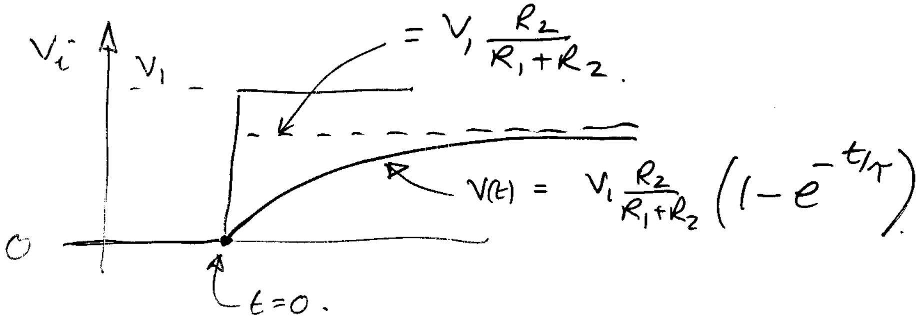






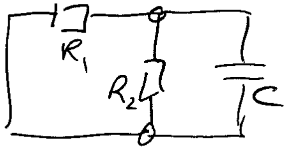
What if there is more than one resistor?





To find τ, replace all sources by their Thevenin internal impedance....

V_i replaced by 0Ω



looking at the cct from C's point of view, R_1 + R_2 are in parallel with each other.

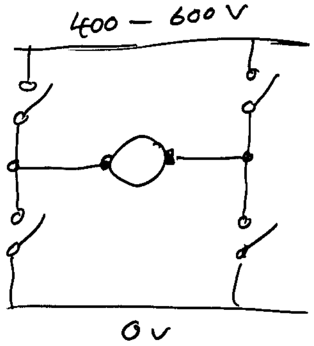
so $\tau = C(R_1 \| R_2)$

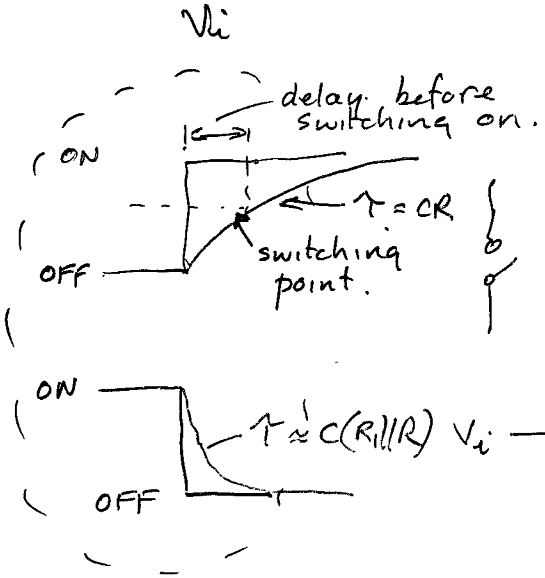
here, C sees a resistance

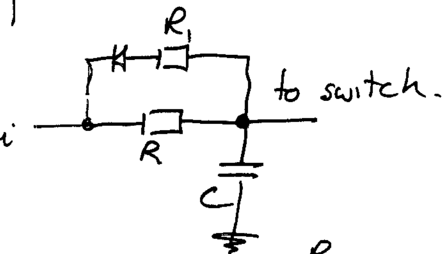
$R_2 + (R_1 \| R_3)$.

So $\tau = C\left[R_2 + (R_1 \| R_3)\right]$.

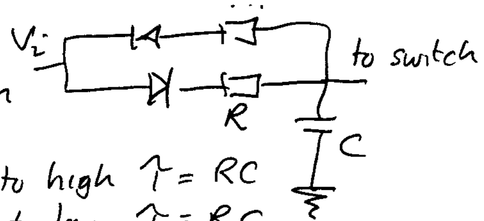
Most circuits involving diodes also involve capacitors.







alternative form

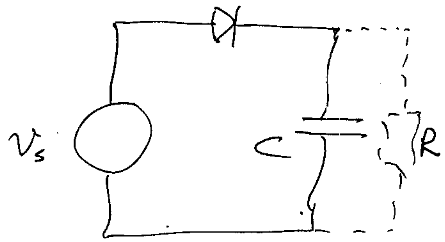


for low to high $\tau = RC$
for high to low $\tau = R_1 C$

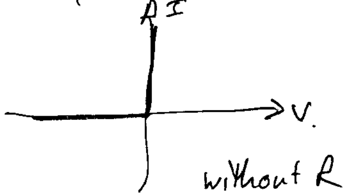
Peak detectors

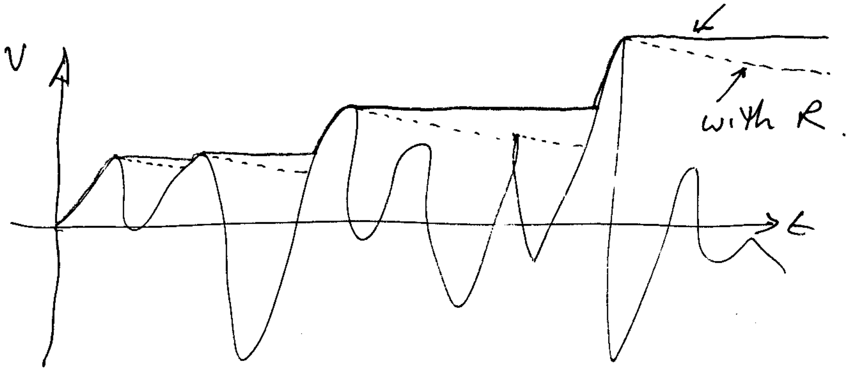
– use capacitors as charge stores

basic cct is



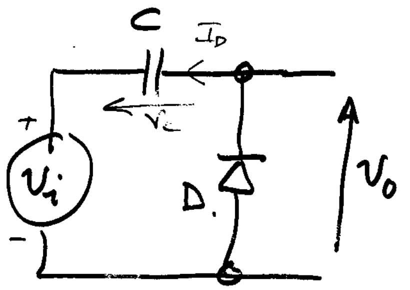
(using the model)



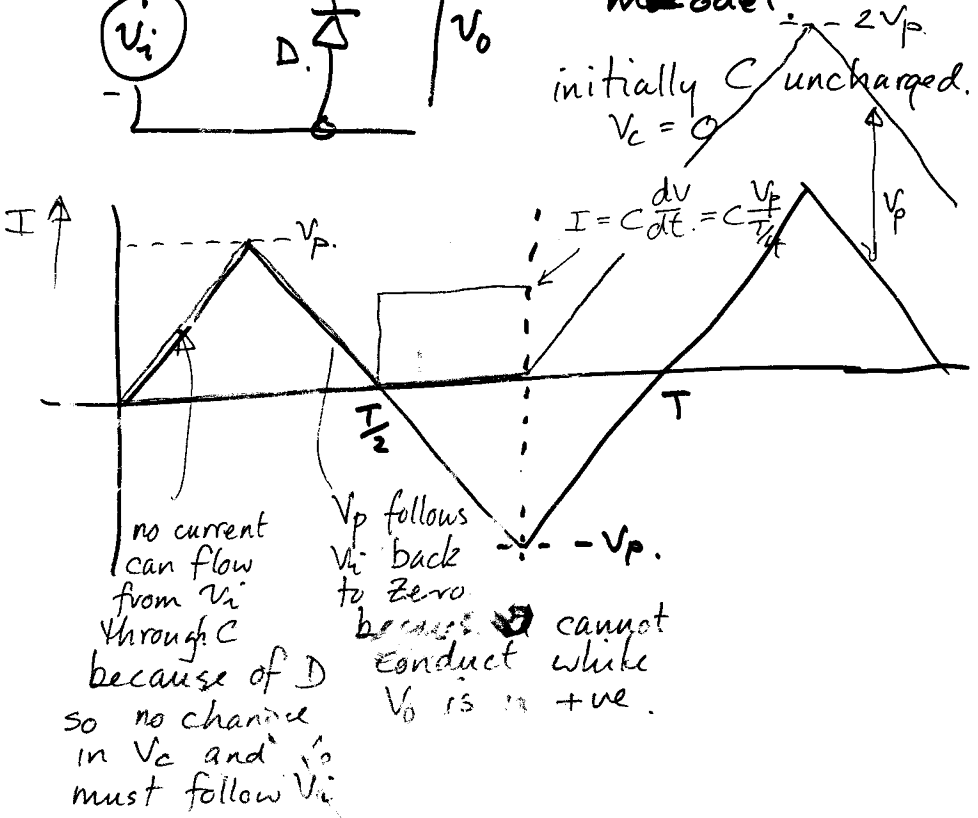


R is added to the peak detector to allow the circuit to respond to slowly varying peak values over specified time

Diode Clamps



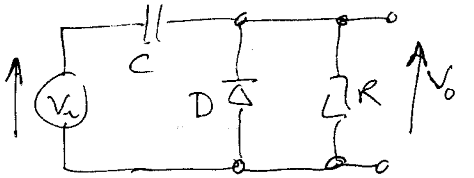
use the 0V diode model



In order to enable the circuit to respond to slow variations in pk-pk signal voltage, some way of leaking charge from the capacitor is necessary.

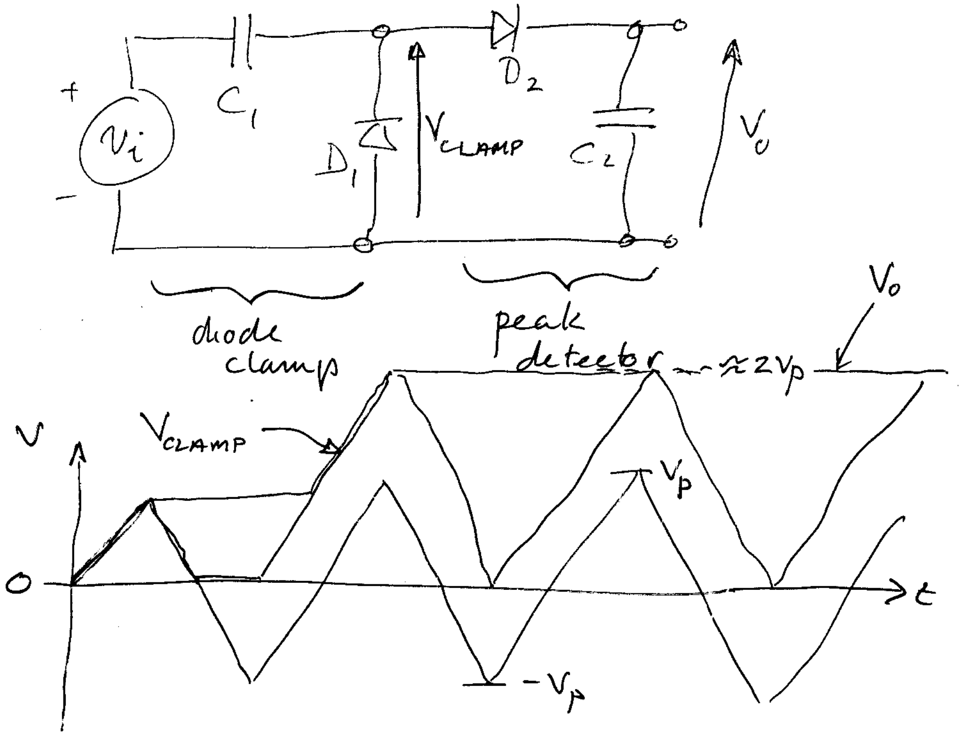
– Usually achieved by a resistor in parallel with the diode.

ie

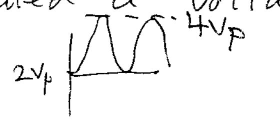


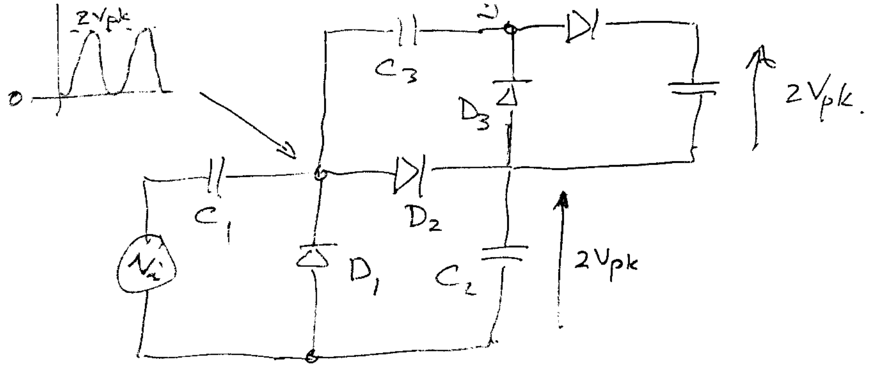
Peak to Peak Detector

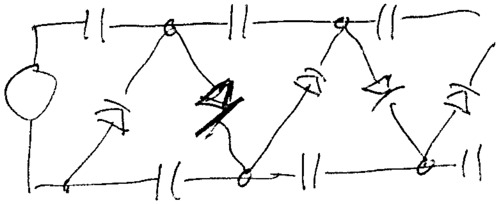
– combination of diode clamp circuit and a peak detector.



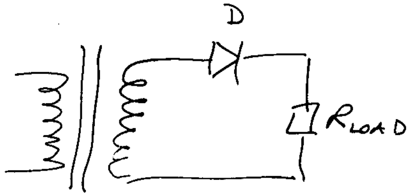
A cascade of peak to peak detectors is called a voltage multiplier



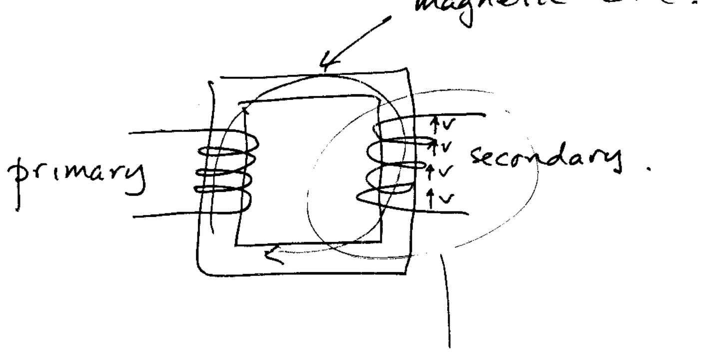


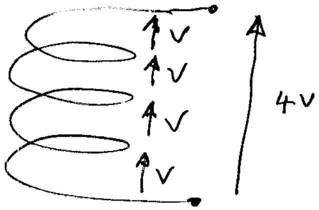


Power Supplies

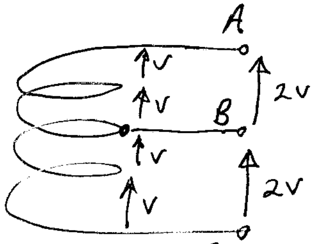


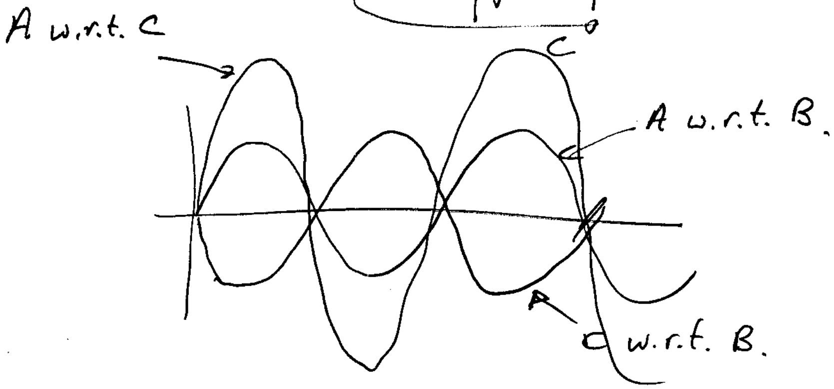
review of transformers



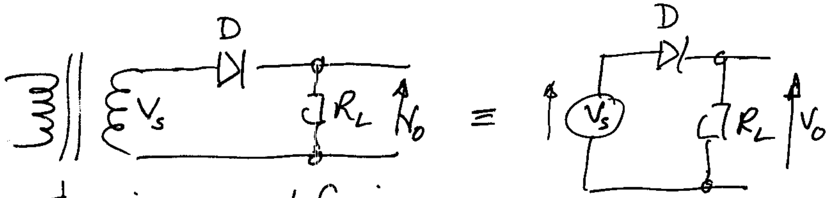


centre tapped winding



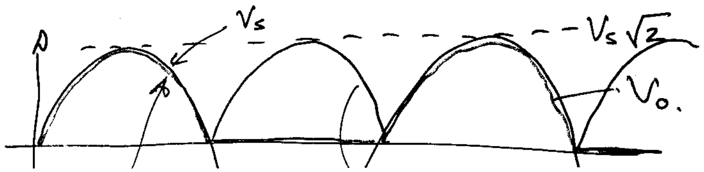


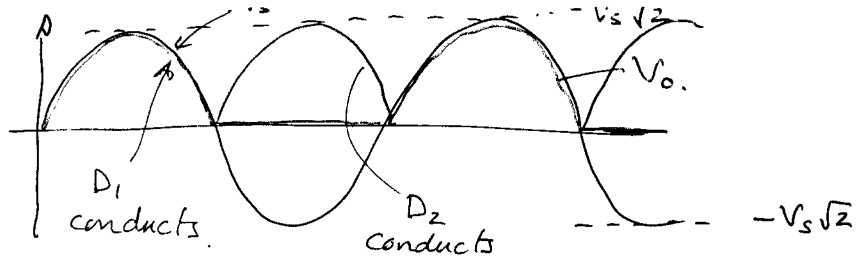
Back to power supplies



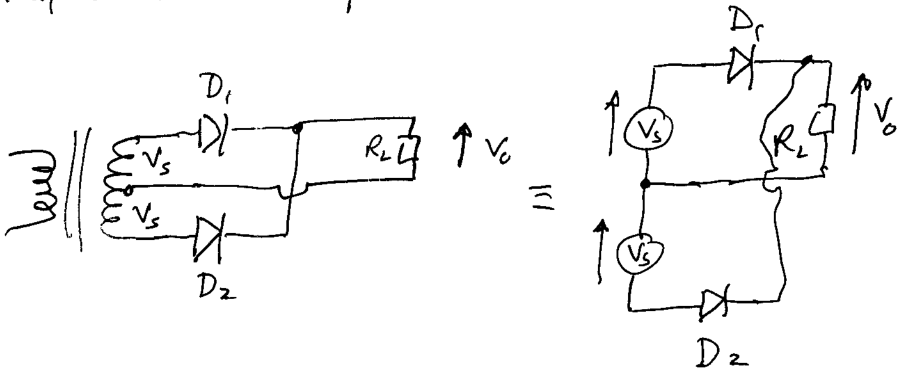
This is a rectifier circuit

V_s = rms voltage measure.



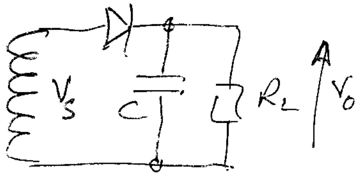


using a centre tap



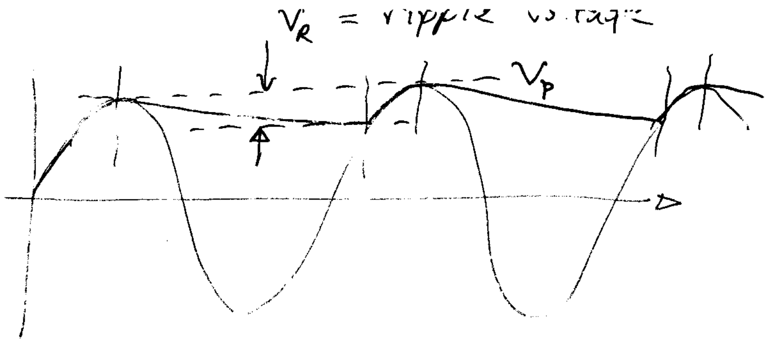
— need an energy store to store energy at the peaks and give it up to fill the gaps.

— can use capacitor (or inductor).



C → acts as energy store.

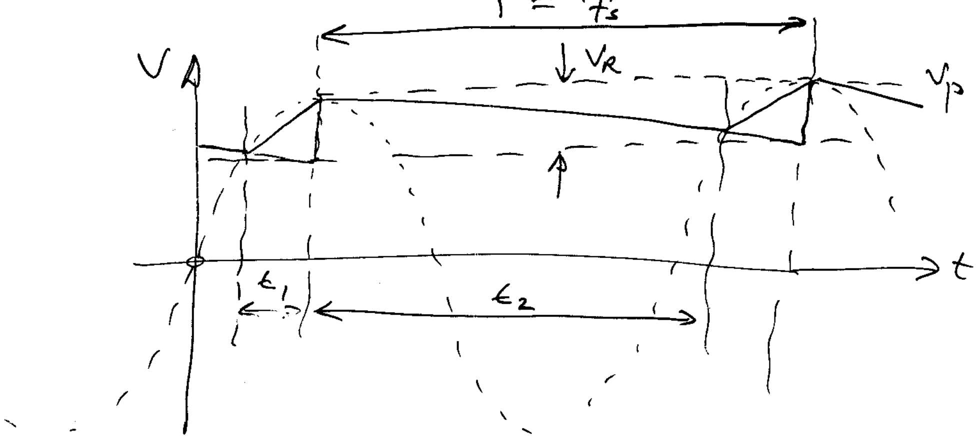
V_R = ripple voltage



ripple voltage is usually small compared to V_p

It is usual to assume that the capacitor discharges linearly – ie
$\frac{dV_c}{dt}$ = const during discharge.
→ implies constant I_c during discharge

A model for the capacitive energy store ....



C charges during t_1
C discharges through load during t_2

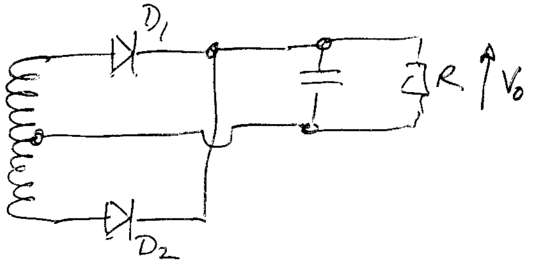
$$\boxed{I_L = C\frac{dV}{dt} = C\frac{V_R}{T}}$$ basic relationship

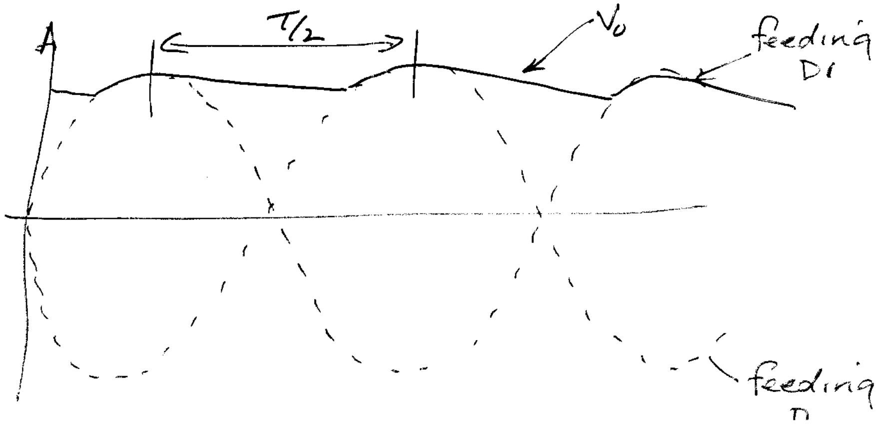
In the cct above $I_L = \frac{V_o}{R_L}$
biggest I_L occurs for biggest V_o
← ie when $V_o = V_p = V_s\sqrt{2}$

$\therefore$ biggest $I_L = \frac{V_s\sqrt{2}}{R_L}$

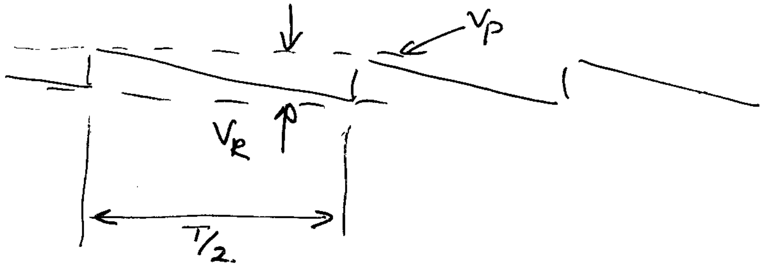
$$\therefore \frac{V_s\sqrt{2}}{R_L} = C\frac{V_R}{T} = C\frac{V_R}{1/f_s}$$

Complications ....





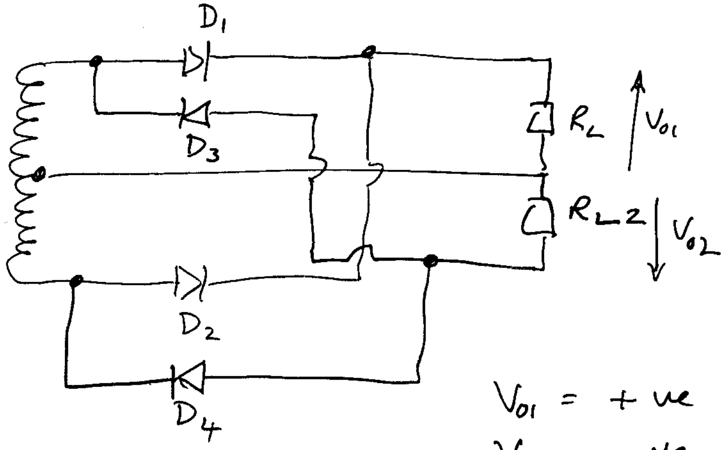
model would be.



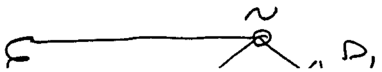
$$I_L = C\frac{dV}{dt} = C\frac{V_R}{T/2} = C\frac{V_R}{1/2f_s}$$

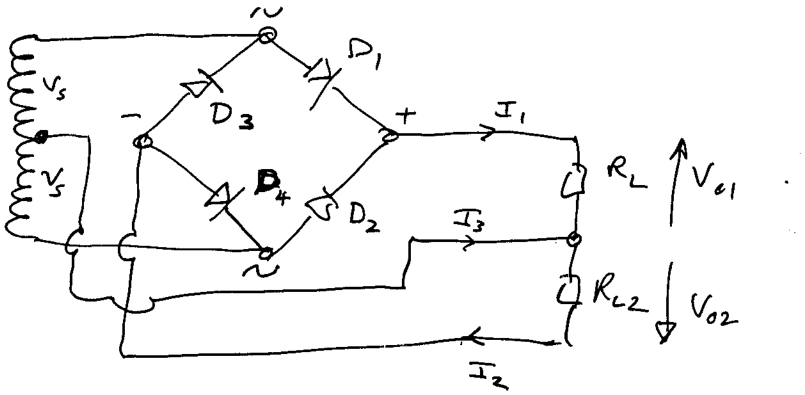
notice that the frequency of the ripple is twice the input frequency for a full wave rectifier.

Full wave rectifier cct shapes

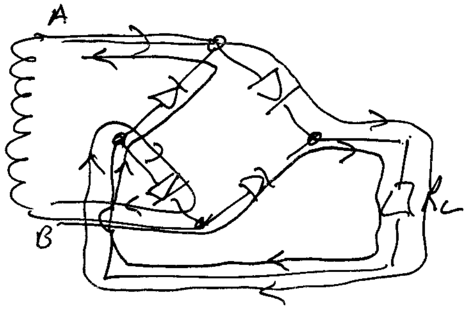


$V_{o1} = +ve$
$V_{o2} = -ve$.





if V_s is the same in each half winding and if Ds are identical and R_Ls are identical $I_1 = I_2$ and $I_3 = 0$.



A +ve w.r.t. B
B +ve w.r.t. A

For most equipment dc + ripple from simple capacitor smoothing cct is not good enough.

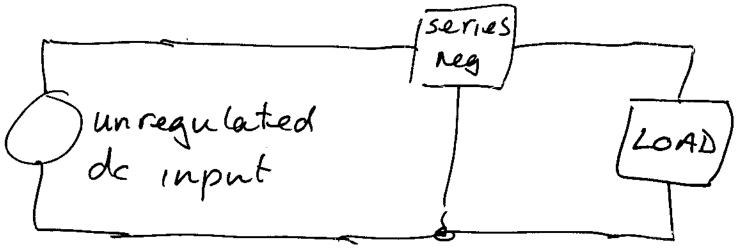
- voltage needs to be "conditioned"
  - stabilisation and
  - regulation.

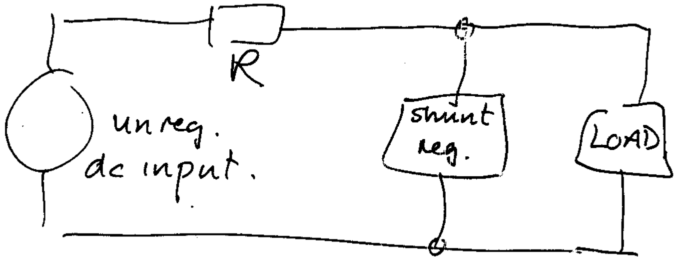
stabilisation stabilises output

input voltage

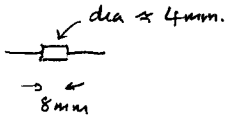
regulation stabilises output voltage against changes of load.

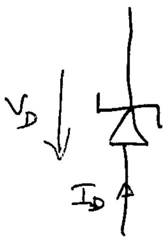
— both reg. + stab. achieved by using a regulator circuit

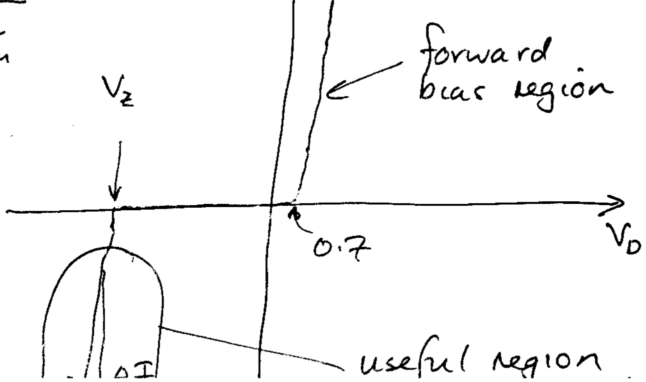


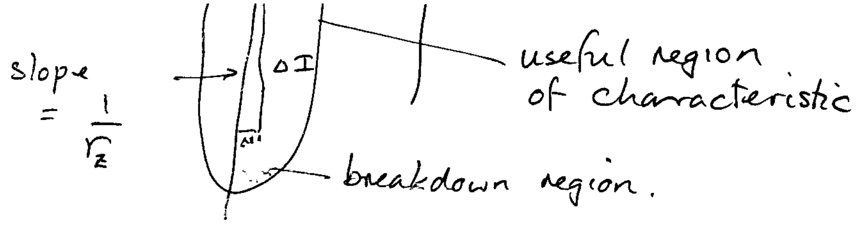


Zener diodes

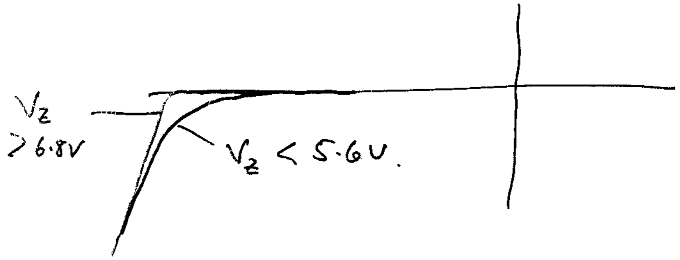






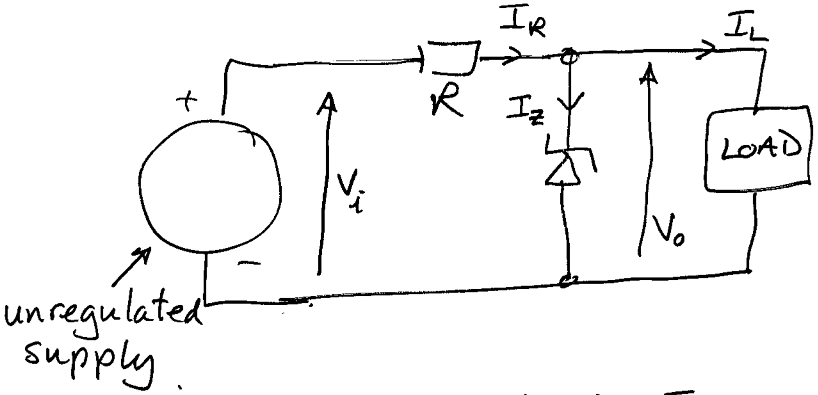


r_Z = Zener slope resistance.



Manufacturers will specify a minimum reverse current needed to keep out of the "knee" region.

Applying a Zener diode....



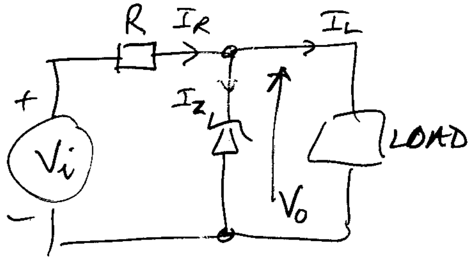
I_Z must be $> I_{Z\,min}$ at all times.

$[I_L = \text{const}]$

Worst case for V_i is when ... lowest — this gives lowest I_R hence lowest I_Z

[V_i = const] Worst case will be when I_L is at its largest value, I_{LMAX}

The real worst case is when V_i is at its lowest value and I_L is at its biggest value.



Condition is

$$I_{Z\,min} \leq I_{RMIN} - I_{Lmax}.$$

$$I_{RMIN} = \frac{V_{iMIN} - V_o}{R}$$

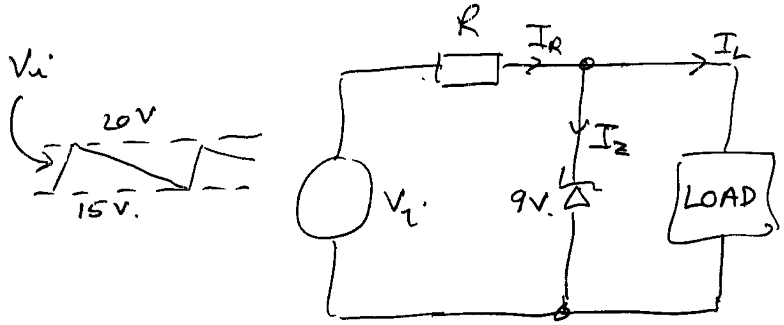
I_{RMIN} must provide I_{LMAX} and I_{ZMIN}

$$I_{LMAX} + I_{ZMIN} = \frac{V_{iMIN} - V_o}{R}$$

so value of R needed is $\dfrac{V_{i\,min} - V_o}{I_{L\,max} + I_{Z\,min}}$.

This is the largest value of R that can be used if zener diode is to work properly. — ie maintain a constant V_o

A quick example.



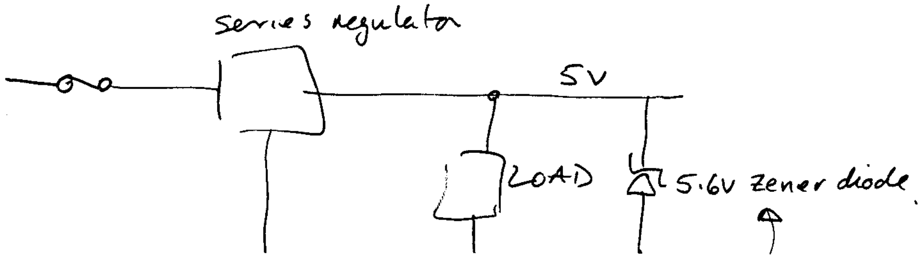
I_L can vary between 5mA + 20mA.

$I_{Z\,min}$ = 2mA.

$$R \leq \frac{V_{i\,min} - V_o}{I_{Lmax} + I_{Z\,min}} = \frac{15 - 9}{20\,mA + 2\,mA}$$

$$= \frac{6}{22\,mA} = \frac{3}{11\,mA}.$$

$$\approx 270\,\Omega.$$



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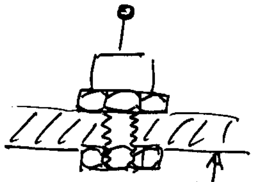
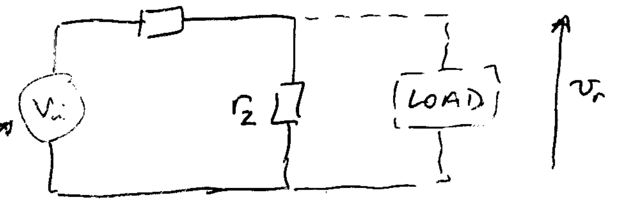


used in series regulator circuits to prevent excessive voltage across the load in the event of regulator failure.

Ripple behaviour ...



neglecting the load ...

$$v_r = v_{ir} \frac{r_z}{R + r_z}$$

r_z typically 5Ω is! for a 400mW zener diode.

$$v_r = 5 \times \frac{5}{270+5} = \frac{25}{275} = \frac{1}{11}$$

$$= \underline{\underline{0.09\ V}}$$

Transistors

— invented in 1949.

— controllable vacuum tube invented in ~ 1918.

modern transistors are nearly all made of Silicon (Si)

$$\text{Transconductance} = \frac{\Delta I_c}{\Delta V_{BE}} \text{ for BJTs}$$

$$\text{or} = \frac{\Delta I_D}{\Delta V_{GS}} \text{ for FETs.}$$

I_D

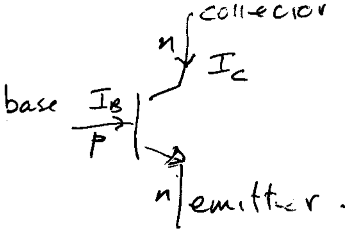
V_{GS1}

V_{GS2}

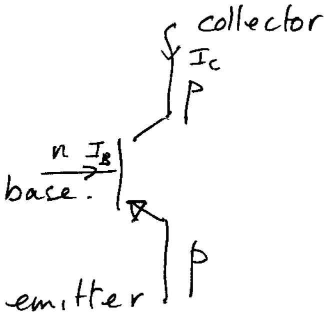
V_{GS3}

V_{DS}.

n collector



V_{DS}.



h_{FE} = static current gain

$= \frac{I_c}{I_B}$.

[h_{fe} = dynamic current gain

$= \frac{\Delta I_c}{\Delta I_B}$]

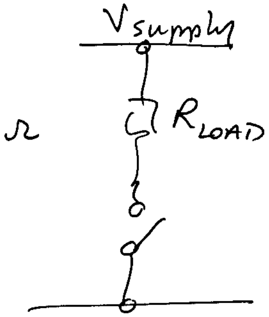
Switches.

— interest here is power management applications.

Ideal Switch

closed or "on" resistance $= 0\,\Omega$

→ power dissipation in the switch $= 0$ W



open or "off" state resistance → $\infty\,\Omega$

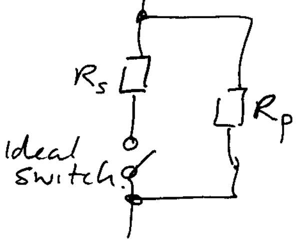
— no power dissipated in the load or the switch.

— mechanical switches come close to this ideal --- but speed is limited.

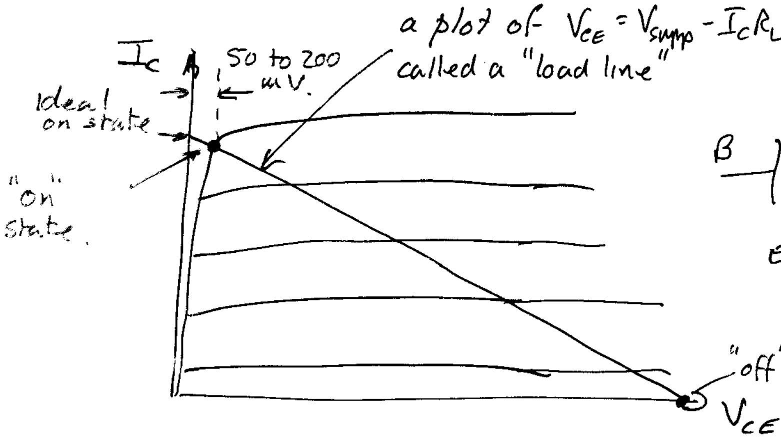
— electronic switches can operate at rates in excess of a MHz. (10^6 Hz)

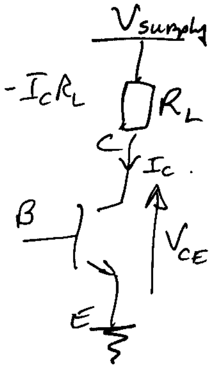
— attractive for many applications because switching at high frequencies leads to lighter, smaller volume and more efficient power management systems.

a model of an electronic switch



Bipolar Transistor Switches





$$V_{CE} = V_{supply} - I_c R_L$$

As a switch there are two important positions — "off" state and the "on" state.

The switch control must get the switch from one of these states to the other as quickly as possible

IT MUST NEVER LEAVE THE SWI IN BETWEEN STATES.

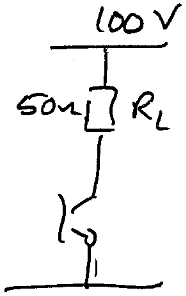
Transistor ZTX653 $I_{c\,max} = 2A$

$V_{CE\,max} = 100V.$

$P_{D\,max} = 2W.$

switch controls

$\frac{100^2}{50}\,W = \frac{\cancel{10,000}^{\,200}}{\cancel{50}_{\,1}}\,W.$



If the switch is switch half on so the $I_c = 1A$ + $V_{CE} = 50V.$

$\longrightarrow P_{DISS} = 50 \times 1 = 50W.$