EEE 103 → EEE students
EEE 121 → Aerospace students
EEE 141 → Physics / Comp Sci
EEE 151 → ACSE students.

About EEE103/121/141/151

- about application of active (non-linear) devices → the things that make electronics useful.
- diodes → only allow current to flow in one direction
  used in a wide variety of applications.
- transistors → basis of amplifying devices and of switches.
  - transistors as switches
  - transistors as amplifiers
- operational amplifiers – someone has done all the hard design work and produced a near perfect amplifier.

Books

Robert Spence Introductory Circuits
Wiley. 2008.

Horowitz + Hill The Art of Electronics
Cambridge

Smith R J. Circuits Devices + Systems.

Sedra + Smith "Microelectronic Circuits".
Oxford.

ACSE prob class PC-09

Course Material

- these are on the eee teaching resources web page

http://hercules.shef.ac.uk/eee/teach/resources/index.html

(1) open browser from within the U of S network

(2) find eee home page
shef.ac.uk/eee

(3) select "Information for Staff/Students"

(4) select "EEE Teaching Resources"

(5) select modules of interest.

Setting up a VPN connection described on

www.shef.ac.uk/cics/remote.

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

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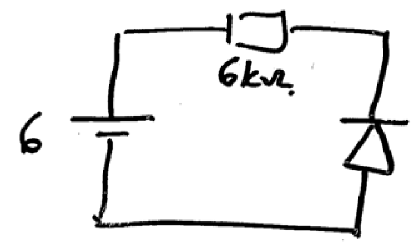
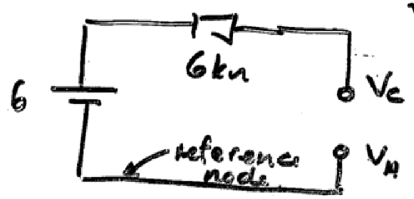


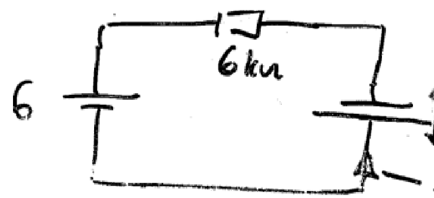


$V_A - V_C =$
$0 - 6 = -6$

using the "conduction for $V \geq 0.7$" model.

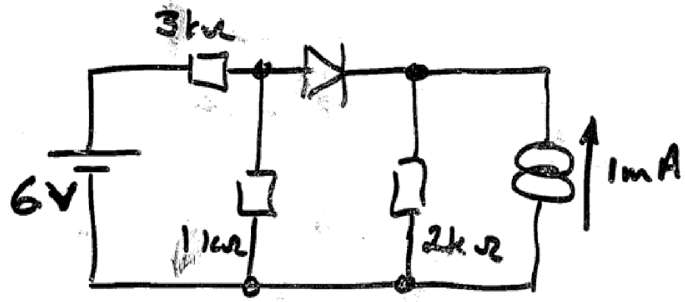
if $V_A - V_C > 0.7$ diode conducts
if $V_A - V_C < 0.7$ diode doesn't conduct — ie blocks.

Assume diode is conducting

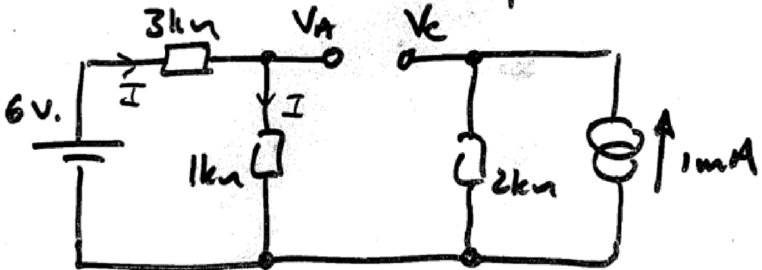


I must be in this direction if assumption is correct.

$$I = -\frac{6.7}{6k\Omega}.$$



Assume non-conducting



reference node.

$= I$

$$V_A = 6 \times \frac{1k\Omega}{1k\Omega + 3k\Omega}$$

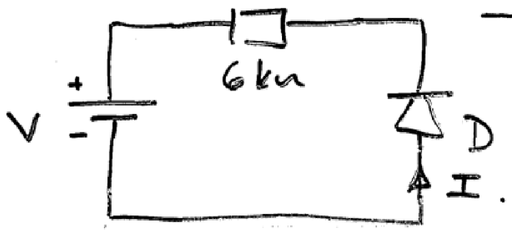
$$= 6 \times \frac{1}{4} = \frac{3}{2} = 1.5\,V.$$

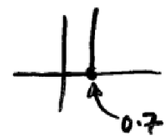
$$V_C = 1mA \times 2k\Omega = 2V$$

$$V_A - V_C = 1.5V - 2V$$
$$= -0.5V.$$

Try the same cct with 1kΩ + 3kΩ interchanged.

The other question that it is useful to know is "what is the boundary between conducting + non-conducting states"?

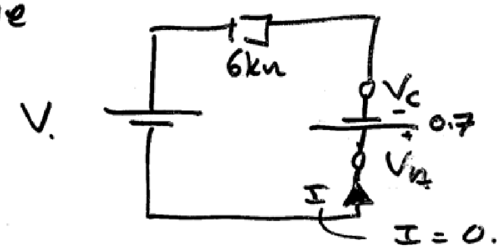




what value of V will put D on the point of conduction?

Diode is on the point of conduction when $V_A - V_C = 0.7$ (assuming 0.7v model) <u>AND</u> $I = 0$

ie

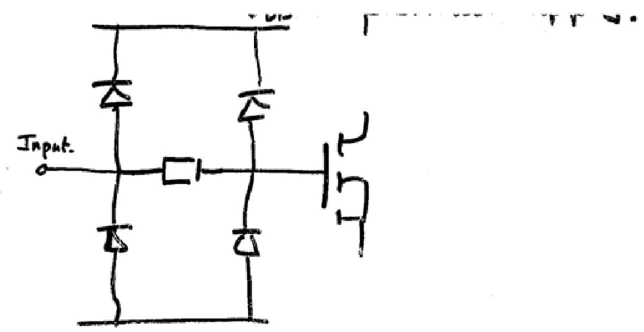


V must be −0.7v to get the diode terminal voltage, $V_A - V_C$ to 0.7 with 0A flowing through it.

if $V > -0.7$ diode will be non conducting

$V < -0.7$ diode will be conducting.

Example of application of diodes

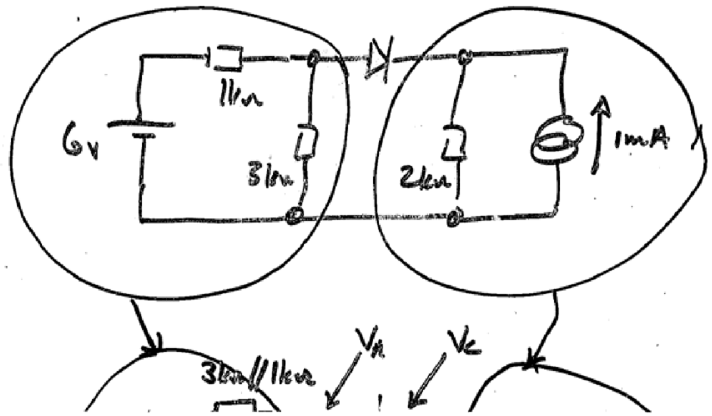


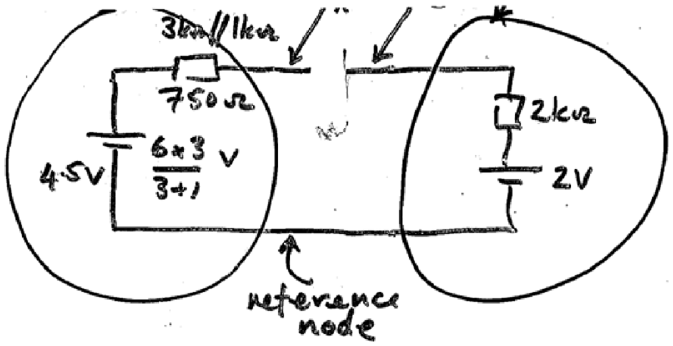
V_{SS} ← negative supply

If input voltage > $V_{DD} + 0.7$, diodes with cathodes connected to V_{DD} will conduct + <u>limit</u> input voltage.

If input voltage < $V_{SS} - 0.7$, similar behaviour occurs.

Challenge was





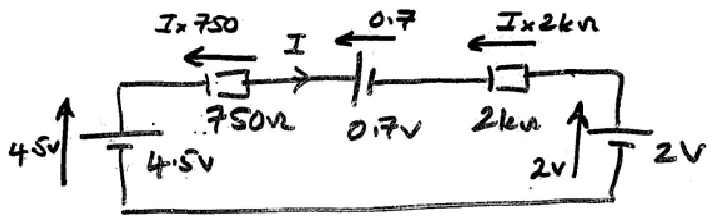
assume diode doesn't conduct

$V_A = 4.5V$ (since no current flows through 750 Ω)

$V_C = 2V$ (since no current flows through 2kΩ)

$V_A - V_C = 4.5V - 2V = 2.5V$

So diode will be conducting
— replace diode in cct by a voltage source equal to its forward voltage drop (0.7V)



$$4.5 = I.750 + 0.7 + I.2k\Omega + 2$$

$$1.8 = I.2750$$

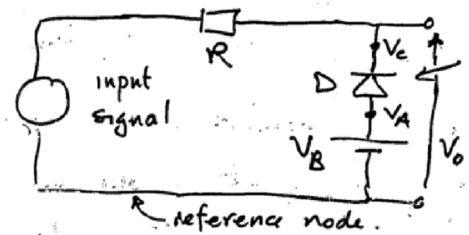
$$\text{or } I = \frac{1.8}{2750} \text{ A}$$

$$\text{or } = \frac{1.8}{2.75} \text{ mA}$$

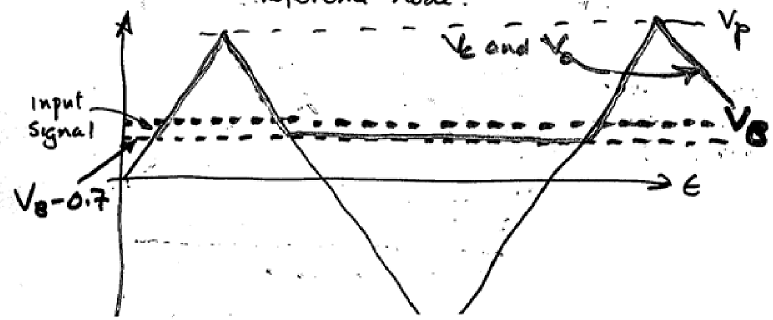
Back to diodes as limiters ....

Diodes as waveform shapers....

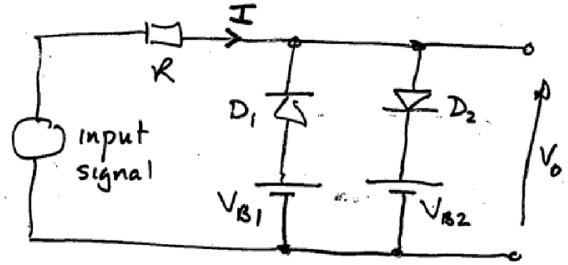
Limiting is the same as "clipping" — a form of waveform shaping.



assume diode conducts if $V_A - V_C \geq 0.7$

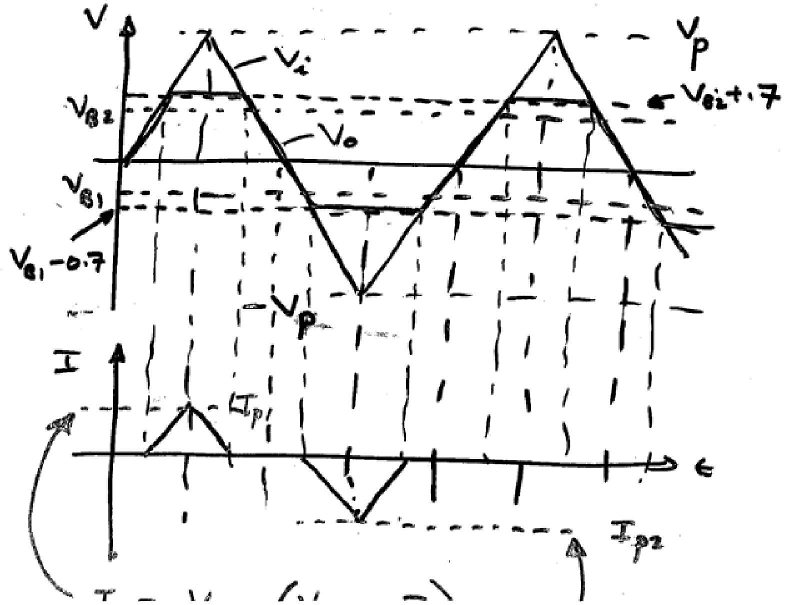


Can clip positive + negative extremes simultaneously . . . .



try sketching V_o for triangular input with $V_{B1} < V_{B2}$

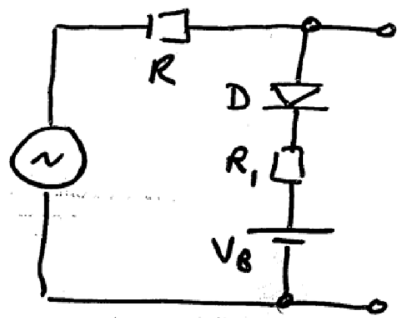
what might go wrong if $V_{B1} > V_{B2}$

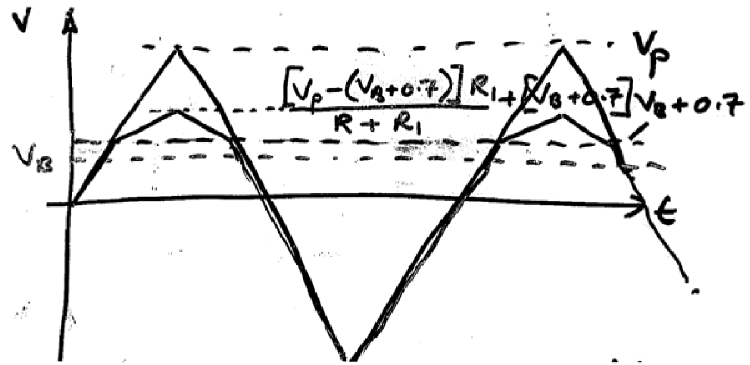


$$I_{p1} = \frac{V_p - (V_{B2}+0.7)}{R}$$

$$\frac{-V_p - (V_{B1}-0.7)}{R} = I_{p2}$$

Soft limiting.





Changes of V_i are operated on by a potential divider behaviour

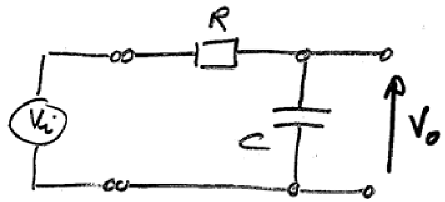
$$\Delta V_o = \Delta V_i \times \frac{R_1}{R + R_1}$$

where ΔV = change of voltage.

— cct can be extended to include many diodes + many resistors giving many changes of gain over input signal range.

— Used to convert triangular waves into sine waves in cheap function generator applications.

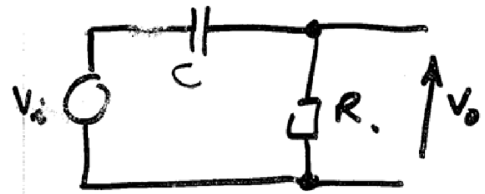
Review of R-C ccts. from a transient point of view.

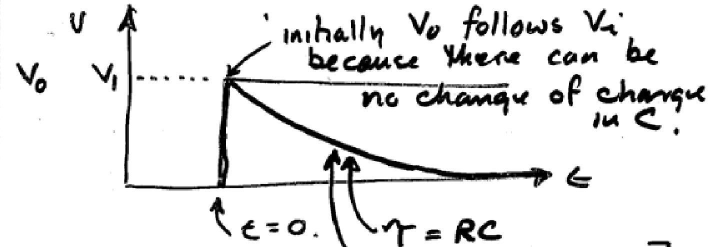


$$V(t) = V_1(-e^{-t/\tau}) + V_1$$
$$= V_1(1 - e^{-t/\tau})$$

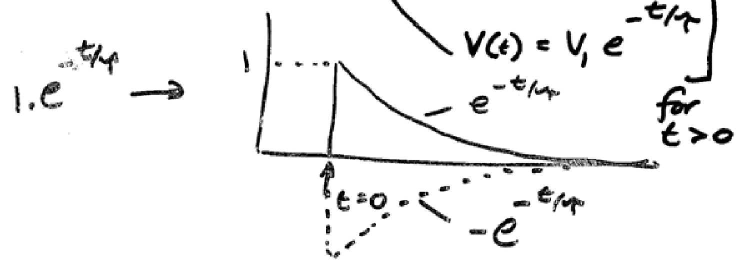
$\tau = CR$

How would V_o change if C + R were interchanged?

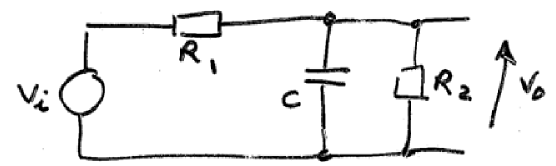


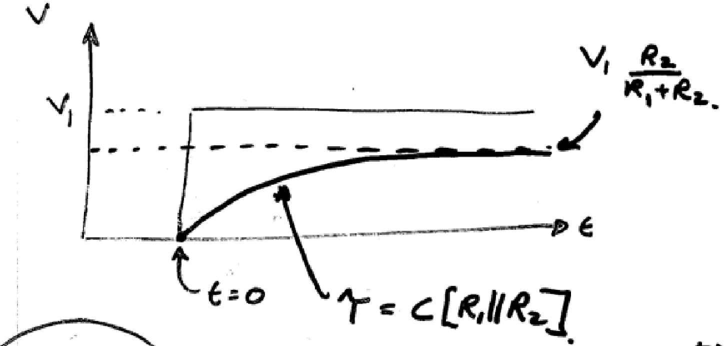


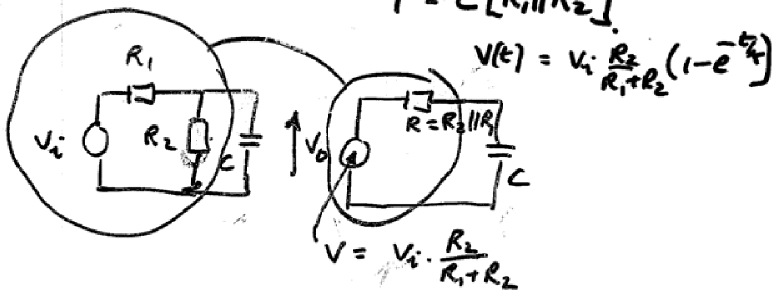
$\left[V(t) = V_1 e^{-t/\tau}\right.$ for $t > 0$

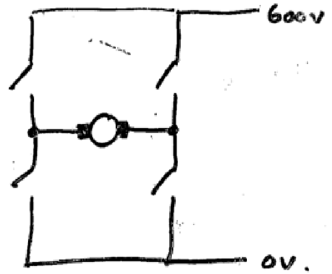


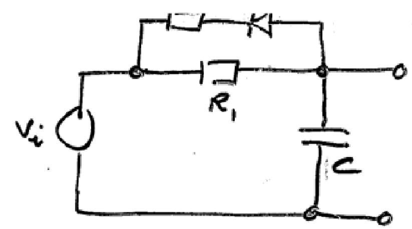
Sometimes the cct might be a bit more complicated ...

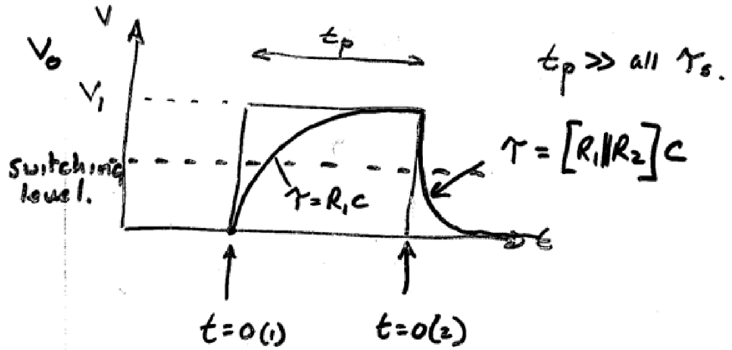








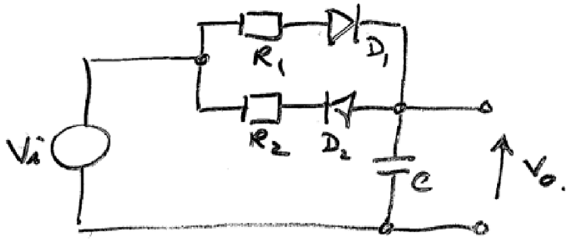




$t_p \gg$ all τs.

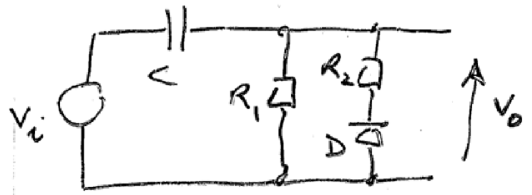
$$\left[\, \cancel{R_1 \| [R_2 C]} = \cancel{\frac{R_1 (R_2/j\omega C)}{R_1 + R_2 + 1/j\omega C}} \quad [R_1 \| R_2] C \,\right]$$

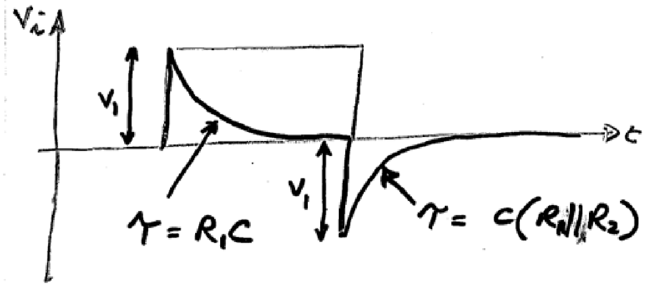
another cct that will achieve the same objective



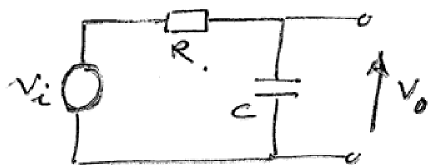
$R_1 D_1$ would conduct on rising pulse edges; $R_2 D_2$ would conduct on falling pulse edges

Can have time constant control on

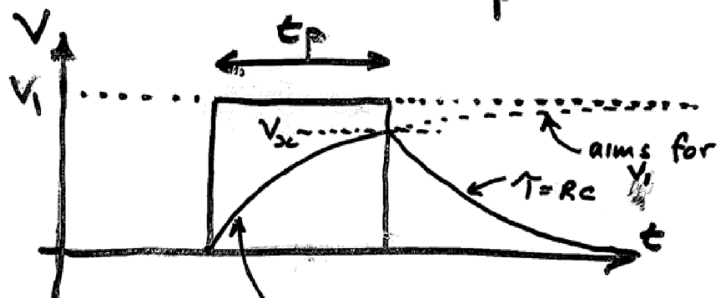




What happens if $t_p \approx \tau$



$t_p \sim \tau$

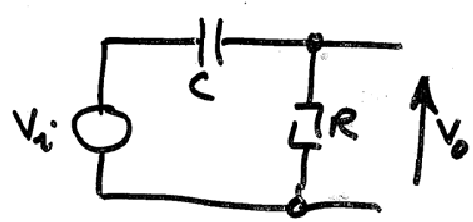


$V(t) = V_1(1 - e^{-t/RC})$

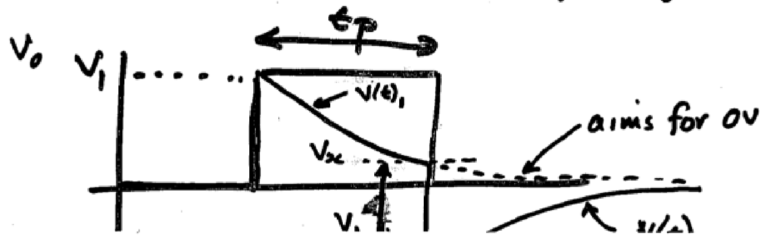
V_x = value of $V(t)$ at $t = t_p$.

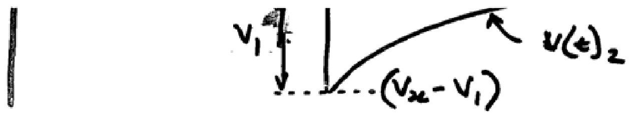
falling $V(t)$ is $V(t) = V_x e^{-t/RC}$

Think about..



what will V_o look like for V_i =





where $t_p \approx \tau$.

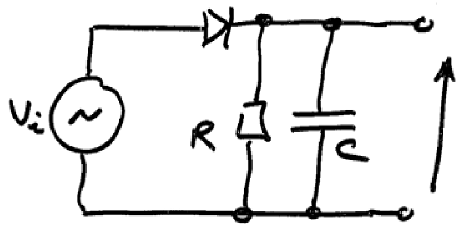
$$V(t)_1 = V_1 e^{-t/\tau} \qquad (\tau = RC)$$

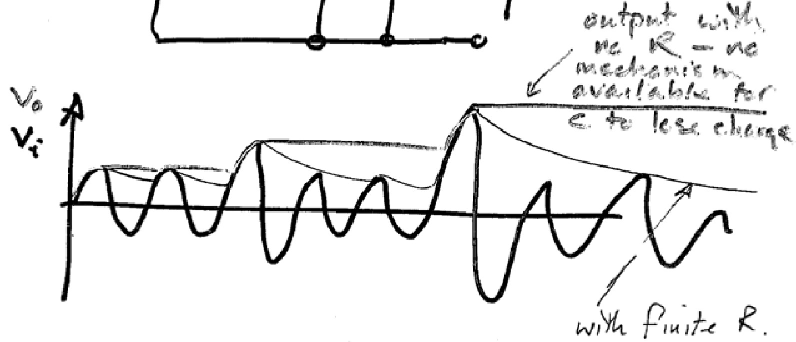
$$\text{so } V_x = V_1 e^{-t_p/\tau}$$

$$V(t)_2 = (V_x - V_1) e^{-t/\tau}$$

Detectors and Clamps.

Peak detector

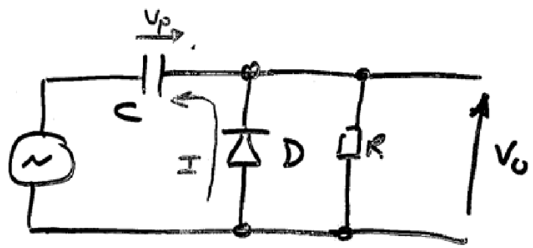


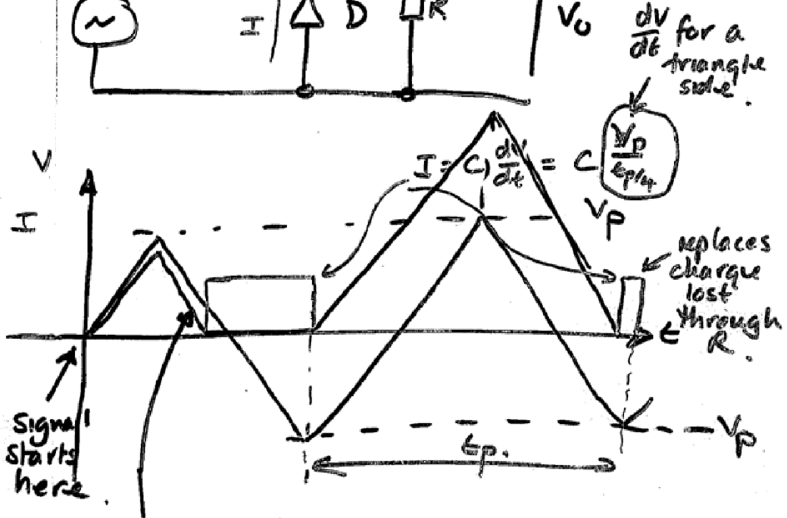


Clamps.

Purpose of a clamp is to anchor, or clamp some part of a waveform — either positive peak or negative peak — to a defined potential — often ~~to~~ zero.

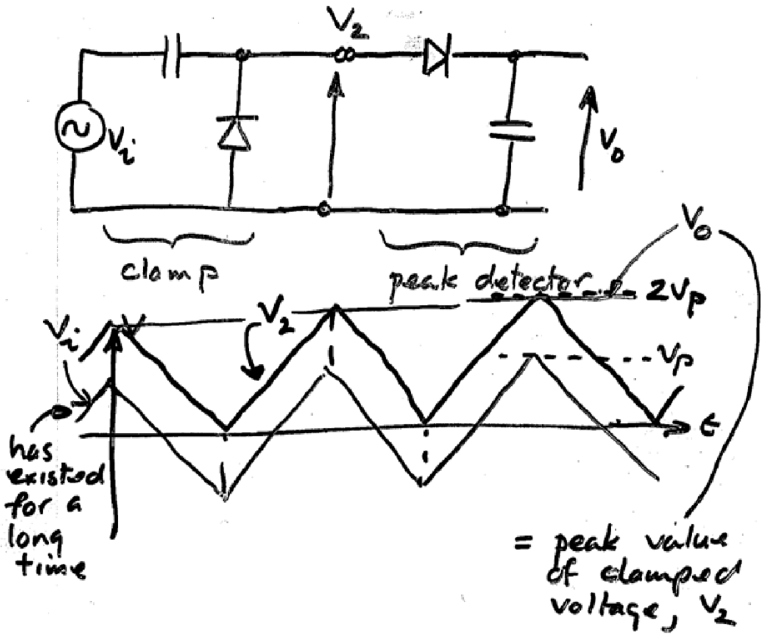
Basic clamp circuit



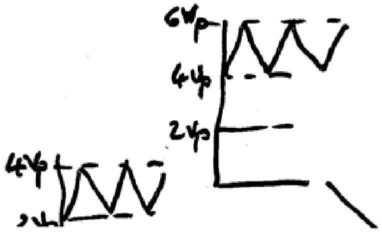


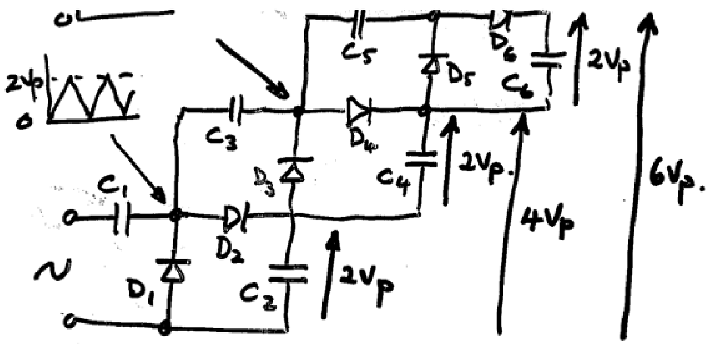
Vo will follow Vi because D will not conduct ... but over the half cycle, some charge will leak through than V_i

peak to peak detector



Voltage multipliers





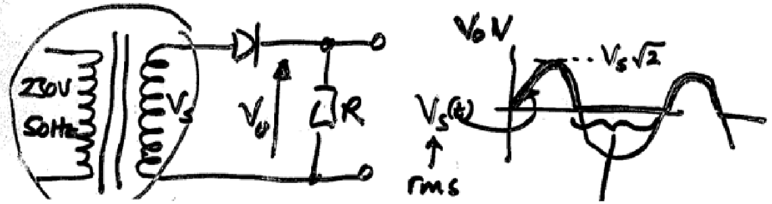
V_p = peak value of input V.

Rectifiers

— peak detectors designed to deal with larger currents.

— two types of rectifier
- full wave → makes use of whole input cycle
- half wave → makes use of +ve half cycle or −ve half cycle ONLY.

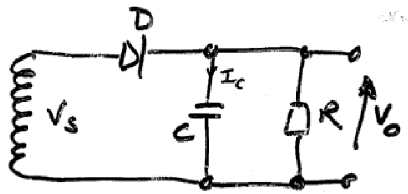
Half wave

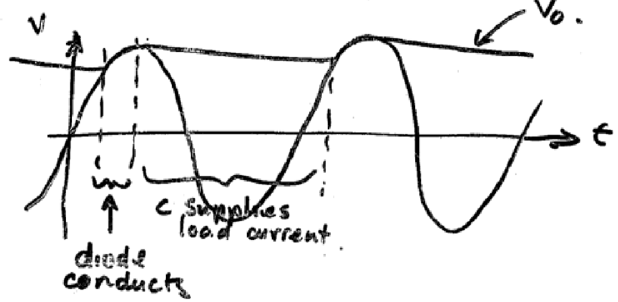


This is perfect for this module.

... need an energy store that can be charged when diode conducts and supply the load with energy when diode doesn't conduct.

For low voltage + 50Hz, C is usually used ...



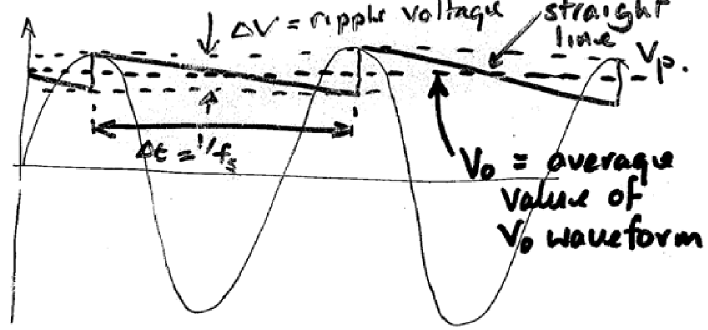


designing a circuit like this makes extensive use of approximations.

— MUST WRITE DOWN APPROXIMATIONS USED.

— Assume capacitor discharges linearly
— implies that I_L = constant.

— Assume that discharge occurs for whole interval between half cycle peaks



f_s = supply frequency.

Since $I_c = C\frac{dV_c}{dt}$ if this is const its easy to make an equation linking ΔV, Δt, I_c + C

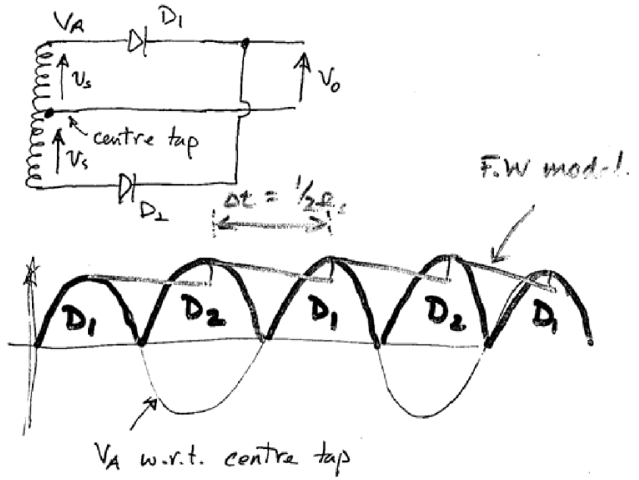
$I_c = C\frac{\Delta V}{\Delta t}$

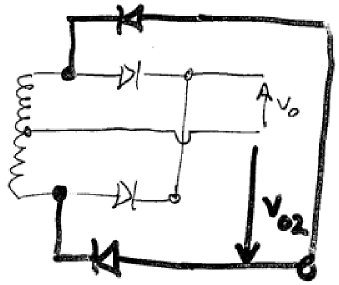
assume this is constant at its peak value which is $\frac{V_p}{R}$

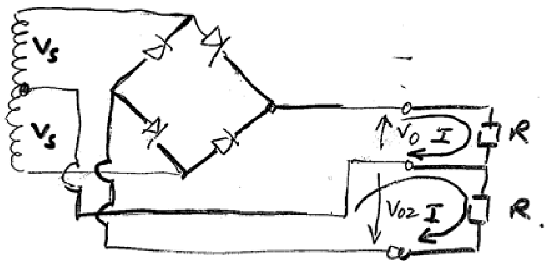
putting this all together

$$\frac{V_p}{R_L} = C\,\frac{V_R}{1/f_s} = C\,f_s V_R$$

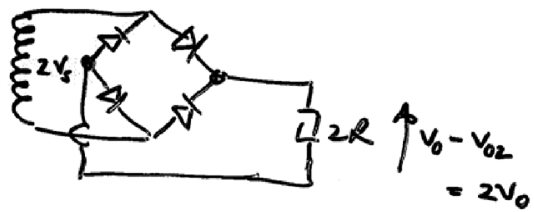
Full wave rectifier ccts







Since $V_{o2} = -V_o$, and same R is on both outputs – current I will flow as shown. Total current in centre tap arm of the cct $= 0$
Sum of two I_s, identical but opposite in direction

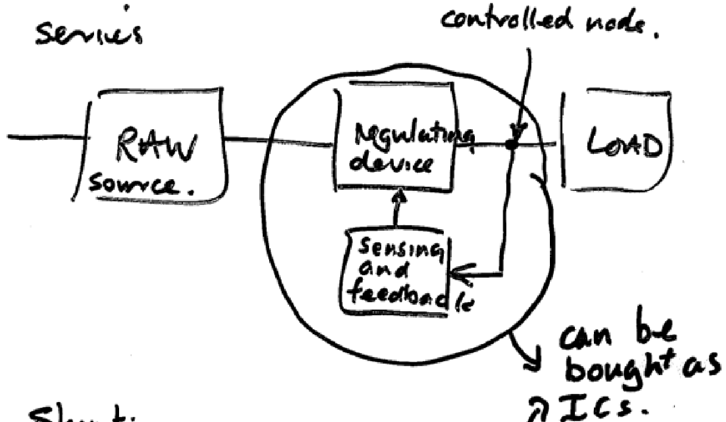


Ouput from a capacitor (or inductor) smoothed rectifier cct is not good enough for most modern equipment — good quality dc needs a regulator to be used.

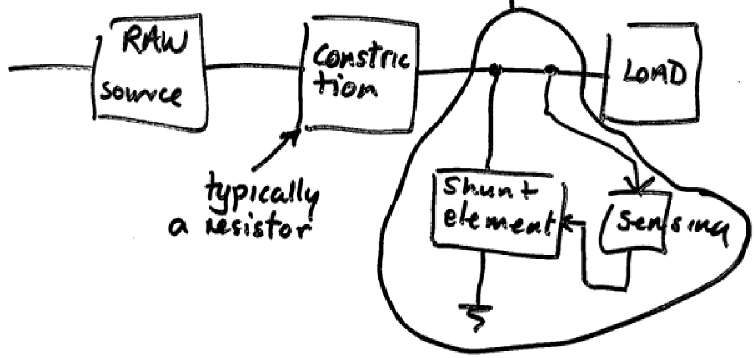
Regulators regulate the flow of current in order to maintain a constant potential at a node in a circuit

two types — series regulator
— shunt regulator.

Series



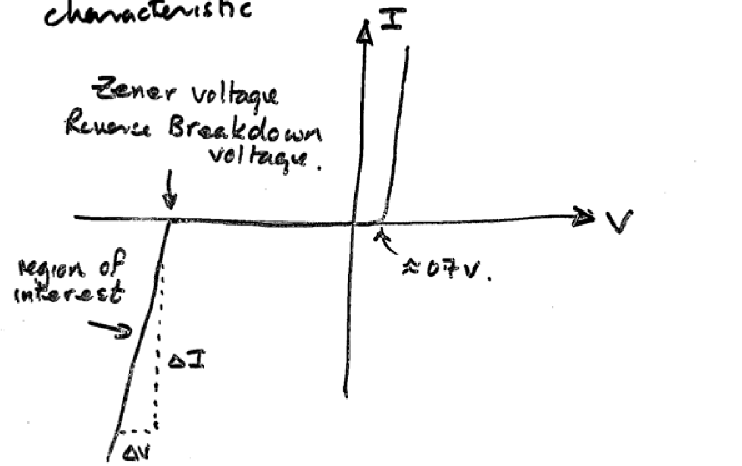
Shunt.



Zener Diode

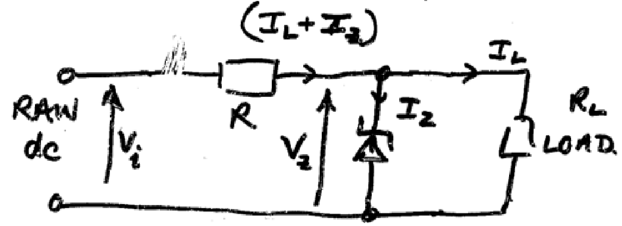
— p-n junction designed to breakdown in a reverse direction at a well defined voltage.

characteristic



$\frac{\Delta V}{\Delta I} = r_z =$ Zener slope resistance

Typical Zener diode regulator cct



For proper operation

$I_Z > I_{Zmin}$ at all times

— in some cases I_{Zmin} can be taken as zero

$(I_L + I_Z) = I_L + I_Z$

— conditions that threaten $I_Z > I_{Zmin}$ are as V_i gets smaller and as I_L gets bigger

$\rightarrow$ minimum V_i and maximum I_L must be known design inputs.

Need to find maximum value of R that can be used for a particular set of circumstances.

$I_{Zmin} + I_{Lmax}$ must be current that flows through R at minimum V_i

same as V_Z

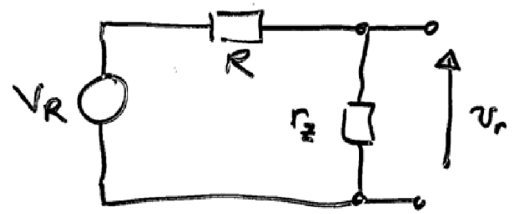
$V_{imin} - V_o$

ie $\frac{V_{imin} - V_o}{R} = I_{Zmin} + I_{Lmax}$.

$\rightarrow V_{imin}, I_{Zmin}, I_{Lmax} \rightarrow$ specified

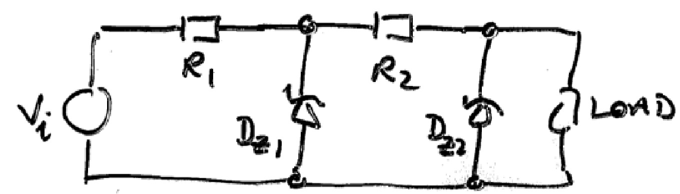
What happens to the ripple ??

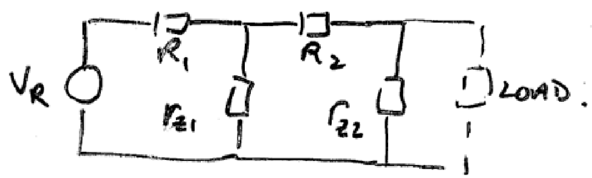
— described by a small signal model.



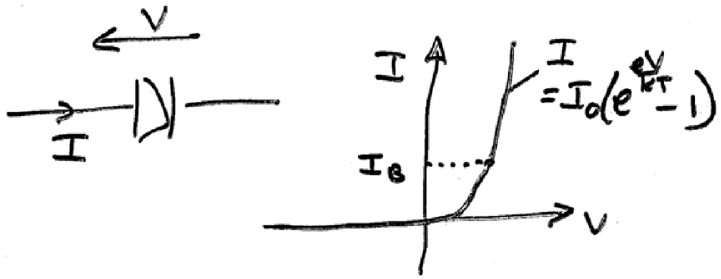
v_r = output ripple = $V_R \cdot \frac{r_Z}{R + r_Z}$

Can extend zener regulators





Other small signal diode application....



slope at I_B

is $\frac{dI}{dV} = I_o e^{\frac{eV}{kT}} \cdot \frac{e}{kT}$

$= \frac{eI_o}{kT} \cdot e^{\frac{eV}{kT}}$

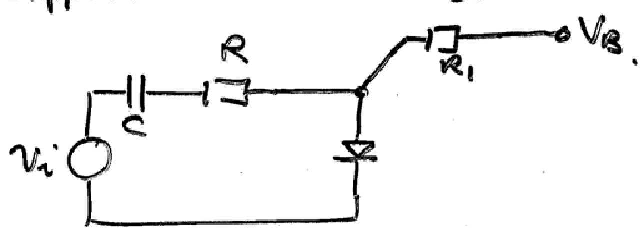
$I = I_o\left(e^{\frac{eV}{kT}} - 1\right) \approx I_o e^{\frac{eV}{kT}}$ for forward bias.

forward bias.

$\therefore \frac{dI}{dV} \approx \frac{e}{kT} \cdot I$

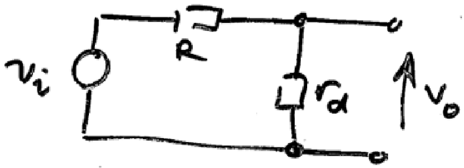
$\frac{dI}{dV} = \frac{1}{r_d}$

Suppose I have a cct



Let $R_1 \gg R$

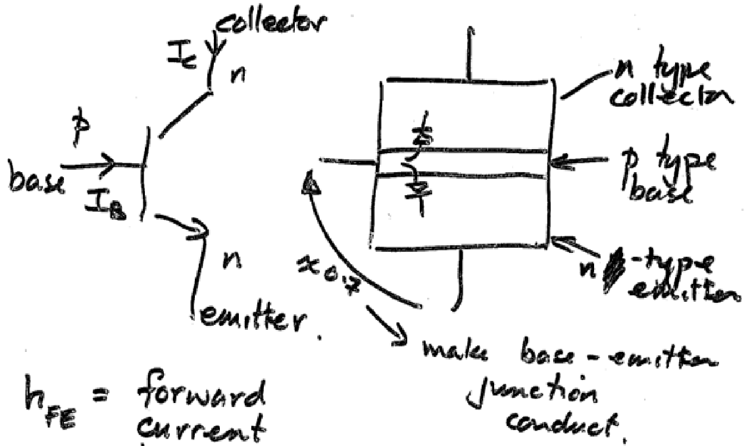
Let X_C be $\ll R$ at all frequencies of interest.



$r_d = \frac{kT}{eI_D}$

$I_B = \frac{V_B - 0.7}{R_1}$

Bipolar Transistors

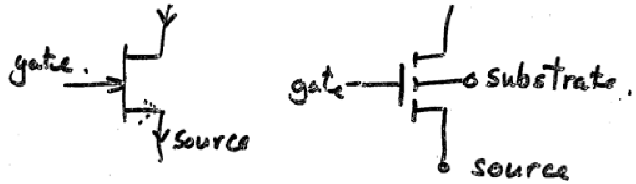


h_{FE} = forward current transfer ratio.

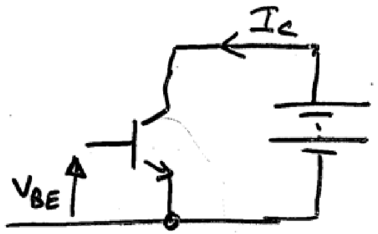
— d.c. ratio.

FET.

—both work by constricting channels.



JFET



I_C is controlled by V_{BE}

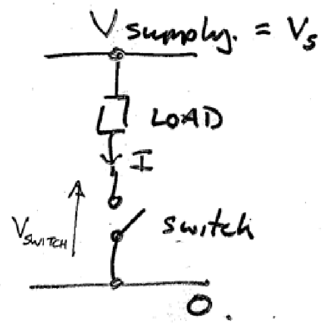
Transistors as Switches.

—A bit about switches

Switch open, ideally
$I = 0$

Switch closed, ideally
$I = \frac{V_S}{R_{LOAD}}$.

$[V_{SWITCH} = 0]$

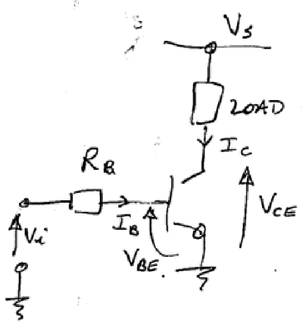


Electronic switches

— Off state $I \approx 0$ → in reality there is a leakage current.
- but can usually be ignored.

— On state $V_{SWITCH} \rightarrow$ small.
tends to be constant in BJTs but increases with on-state current in FETs.

BJT switches



need to supply a big enough I_B to ensure that on-state I_c can be supported.

— relationship between I_c + I_B is given by manufactures as $h_{FE} = \frac{I_c}{I_B}$

If $I_{CON} = \frac{V_s}{R_{LOAD}}$ I_B must be at least $\frac{I_{CON}}{h_{FE}} = \frac{V_s}{h_{FE} R_{LOAD}} = I_B$.

and $I_B = \frac{V_{i(ON)} - V_{BE(ON)}}{R_B}$

To work out power loss in "on" state

power loss $= I_{CON} \times \underbrace{V_{CE(ON)}}_{\text{(Sometimes called } V_{CE(SAT)})}$

may or may not be calculated using $V_{CE(ON)}$