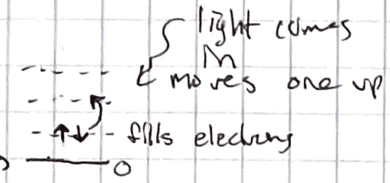
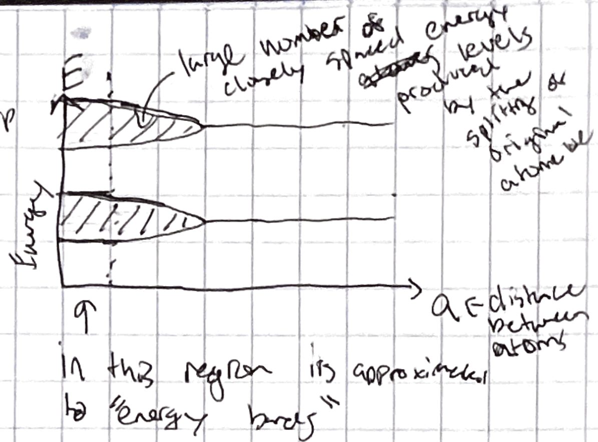
Diodes 1

[→atoms have discrete →energy levels] →



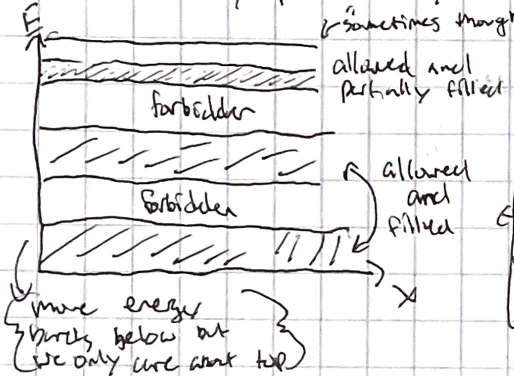


In this region its approximated to "energy bands"

[Now have multiple atoms as your potential] → "N" atoms

[the ///// region represents the large number of closely spaced energy levels produced by the splitting of energy levels ε when potential of N atoms is made]

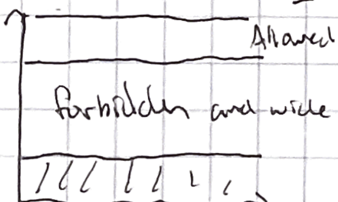
[Energy bands consist of a large number of closely spaced energy lvl's] ← [just as electrons in individual atoms cannot have energies between atomic energy levels, electrons in a solid, cant have energy between bands]



gives e^- room to move around

← [this last band being partially filled gives characteristic of conductor, also if the energy to move past forbidden band is small]

← [in order to produce a current e^- in the material must move & thus ↑E, thus moving to a higher energy level, lots of empty levels in top band]



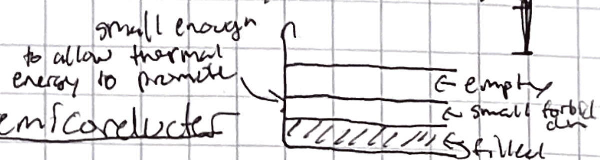
← [The gap is to wide to let electrons flow this is an insulator.]

[think about current as newtons cradel. dddb]

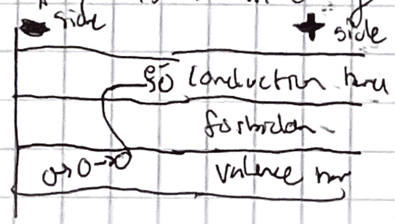
[the energy gained by e^- contributing to current is small, the voltage applied to produce the current accelerates e^- but before they gain much V they have collisions, that slow them down. As result varies energy 10^{-21} eV, this is comparable to spacing of bands (.1 eV). Thus there is no way e^- in an insulator can gain enough energy to cross forbidden band]

{thermal energy} is another important role in Energy contribution.

→[if T is big enough and gap is small enough, its possible for e^- to jump to the next allowed band. Once there it can be part of current band now there is a lot of open energy levels.]



→if it is small enough you have a semiconducter

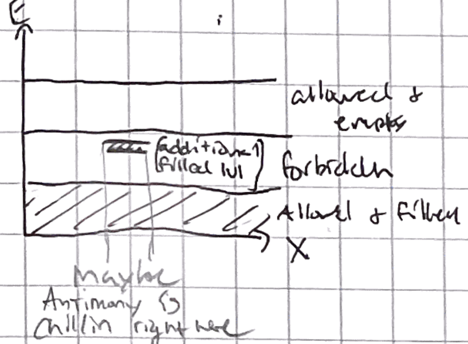


when an e^- jumps forbidden zone it leaves behind a + empty spot, in that band it gets filled by another e^-, but that leaves an empty + spot too! So normal current direction is OK.

Doping a semi conductor

[Pure germanium semiconductor] → $4e^-$ [outer shell of $4s^2 4p^2$] → $5e^-$ [if dope with Antimony which has $5s^2 5p^3$]

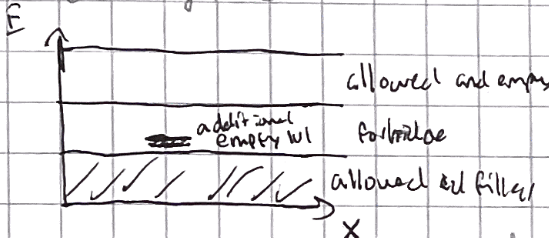
→ the semiconductor will then have a number of extra bound e^-
(*creates states near conductor band*)



[having the extra band by the empty band thus makes it easier for e^- to be promoted to conduction band than valence band. The charges that produce this current are e^-, it is called an n-typed semiconductor.]

$3e^-$ ← has vacancy at its highest lvl

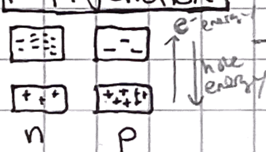
[If you dope w/ gallium ($4s^2 4p^1$), called accepter. effect of accepter is to add empty localized energy levels located just above valence.]



a few e^- do get promoted to conduction band, but most of current is done by holes. (unlike n-type)

Since these levels are localized, the promoted e^- can't move through material, so they don't contribute to current, the holes will get filled and move causing current, so positive hole motion is called p-type semiconducter

P-n junction



- P type has more holes
- n type has more e^-

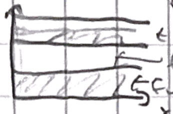
[when brought together the holes and e^- will spread out (diffuse evenly)]

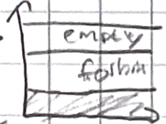
→ moving to full page...

100 x	3:53
95 x	4:03
90 x	4:13

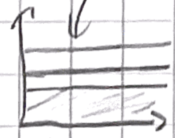
P-N Junctions

3

conductor: E — partially full / forbidden / full

e^- are free to move

insulator:


e^- can't move none there!

semiconductor:

e^- can freely move after jumping
← small gap which allows thermal energy to let it jump
→ leaves a hole in bottom that moves too.
↑ not very good conductor so dope it

* When hole and e^- "find eachother" e^- loses energy and drops back down.

p-type

empty energy level ← (close enough in energy e^- can jump to it (thermal E)) ← (creates positive holes)
small atom
↑ (makes + move around)

n-type

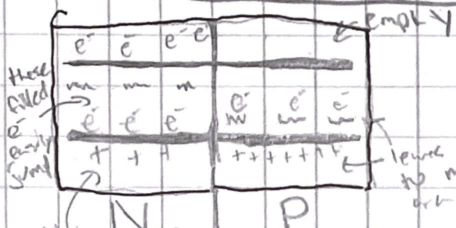
big atom
← (filled energy level) ← (these e^- can easily jump to that next open Energy level.)
↑ (makes e^- move around)

both of these enhance the "current" in different ways

Putting N and P together

* KEY: (empty levels in p-type) and (filled levels in n-type)

(→ N doped w/ Antimony — bigger than +, more e^- w/
P doped Gallium — smaller than Antimony, + less e^-)



(diffusion line)

(Here's what happens after connecting) → (what's really happening) idk why but e^- in N side move to P and fall down so P will have more negative charge → leaves N with less negative so it will then N have positive charge

N side becomes more positive → creates a difference in Electric Field which cause a force on q → $\vec{F} = q\vec{E}$
P side becomes more negative

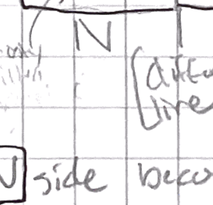
(not dont want to drop down or go over or later?)

Since P is becoming more NEGATIVE it repels e^- from N → Since N is the source of e^- for P it reaches an equilibrium → where the build up of charge is enough to repel further e^- from going to P side (dropping down)

The resulting electric field requires energy to over come

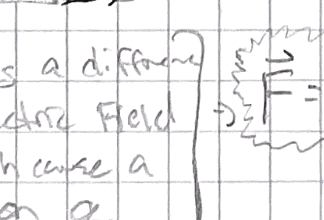
What does this do to Band Structure → in equilibrium, ΔE to an from N to P should just be enough to insure flow in N (f_1) = flow in P (f_2). (pg 75)

Originally $f_1 > f_2$ bec/ there are more e^- in N side than P side



ΔE "end state"

e^- went over here

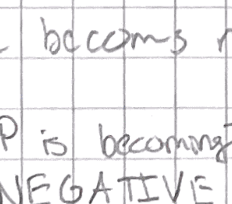


dropped down into holes

electrons leave (both started neutral)

excess

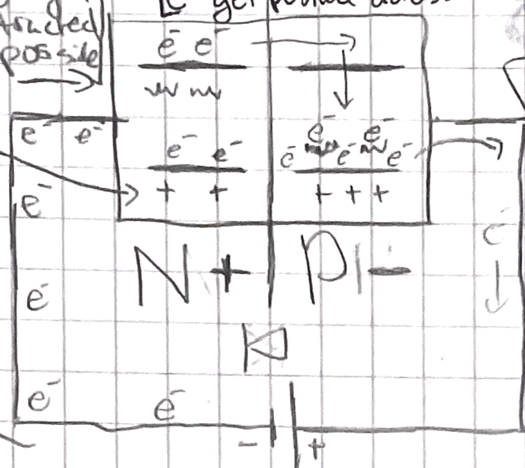
N + P −



Connecting to a voltage source

[e⁻ get attracted to pos side]

[e⁻ get pushed across this gap by the battery]



final side of diode

[Pushes this way]

[Positive side pulls the e⁻ this way]

[this lets electrons that crossed the diffusion gap drop down and get pulled which is current]

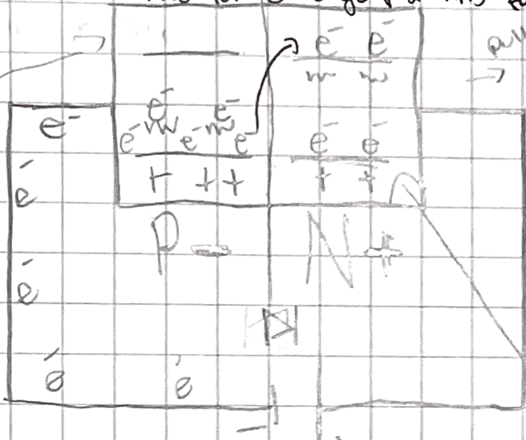
* when it takes energy to push across this is a Vdrop across
* behaves just like a wire

Flip the diode

* same as flipping source

hard for e⁻ to go past this forbidden zone so it just builds up

pulls elec's off



get pulled down build but up

* builds up more e⁻ on the left and takes e⁻ on right causing even HIGHER ΔE
  so it has very high impedance
* Can't flow bec/ e⁻ can't drop drop into holes and get pulled out this is full & can't drop

[* scaling this effect in the box creates a substrate like this]

[started out neutral but gave e⁻ to other side leaving positives & gaining negatives]

[normal "negative" flow self]

depletion region (no charges here!)

[normal positive self] → just at site it builds up

Reinforce idea

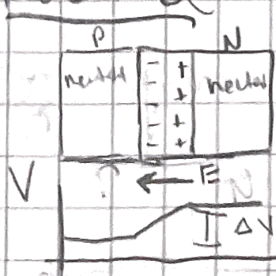
[• P has lots of "holes" in conduction band and places for e⁻ to drop in]

[• N has lots of e⁻ in conduction band]

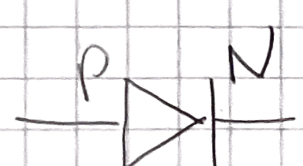
BOTH ARE NEUTRAL

[So when you connect two neutral things nothing happens except, The N conduction band e⁻ diffuse over (because they repel) BUT WHEN]

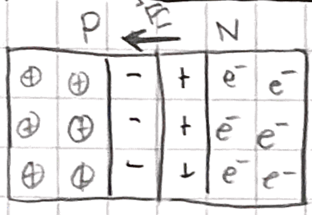
[THEY DO, They fall into holes of P. This creates a charge difference on each. This depletion zone will cause force on e⁻ from N]



[P is at a lower potential than N]



Flow of holes and e^- in PN junction (Another look)



Charged space slows down diffusion } [takes energy to push an e^- with $\vec{E}$] or [takes energy to push positive $\oplus$ against $\vec{E}$]

e^- are diffusing into P from N (or holes are diffusing from P to N) } [Charged particles moving] → current = [$I_{diffusion}$ (P to N) (direction of positive charge carrier)]

*$I_{diffusion}$ never equalizes due to e^- from N dropping down energy level in P

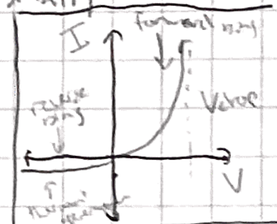
- $I_{diffusion}$ gets battled by $\vec{E}$

→ N will have some holes and P will have some e^-'s (very small)

these actually get accelerated by $\vec{E}$

$\boxed{I_{drift} \rightarrow \text{from N to P}}$ ← not electric field ≡

at equilibrium $\boxed{I_{diffusion} = I_{drift}}$ otherwise ΔE grows



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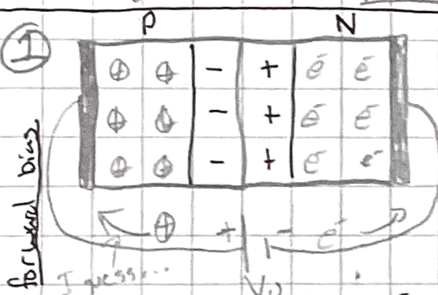
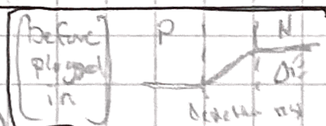
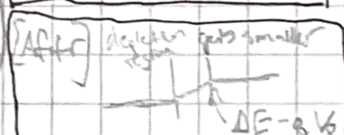
① Forward bias







[After being plugged in the battery pushes on e^- to diffuse more! decreasing depletion region]

I_{diff} goes ↑ so $I_{drift} \neq I_{diff}$ thus a current

when $qV_0 = \Delta E$, $I_{diffusion}$ skyrockets (no depletion zone stopping it)

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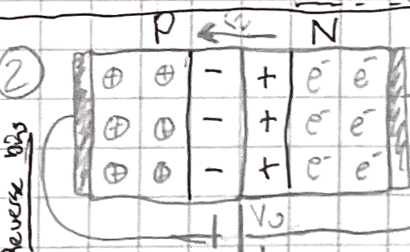
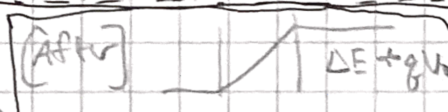
② Reverse bias





[Starts pulling on the e^- and $\oplus$ making depletion region bigger]

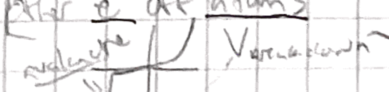
as V_0↑ $I_{diffusion} \rightarrow 0$

as V_0↑ I_{drift} doesn't change much (but! its winning beating I_{diff})

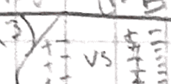
↳ (I_{drift} is due to minority charge carriers) 1000x smaller

I_{drift} is due to thermal generation of e^- in P getting swept by $\vec{E}$; P's depletion region [e^- zoom across to $\vec{E}$]

If you make V_0 high enough for reverse bias it widens $\vec{E}$ & makes e^- from P accelerate faster. If high enough it can cause a chain reaction creating TONS of e^- from knocking other e^- off atoms



Zener diode (heavily doped diode, more per cm^3)



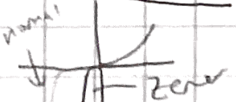
→ doping it a lot makes depletion region very narrow

↳ makes $\vec{E}$ super strong bec more ions per cm^3

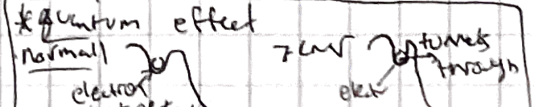
↳ a small depletion region is enough to reach equilibrium

- $\vec{E}$ field is so strong it can tear e^- off the ions unlike impact like normal breakdown

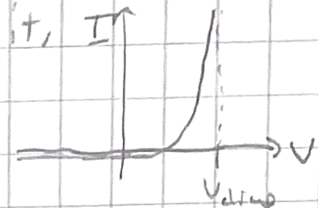
↳ $V_{breakdown}$ happens at much lower voltage



*quantum effect



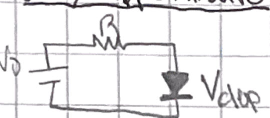
Diodes in Circuits
- an ideal diode has $Z=\infty$ when $V<0$ and $Z=0$ when $V>0$
- a real diode has a V_{drop} across it,



Shockley diode eq'n: $I = I_0\left[e^{\frac{eV}{k_BT}}-1\right]$

easy approximation: $\boxed{\text{if } V \gg V_{drop} \text{ or } V_{drop} \gg V}$ → if $V<V_{drop}$: $I=0$

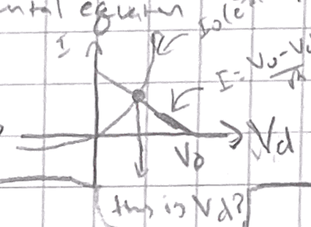
if $V \geq V_{drop}$: $\boxed{KVL}$ $V=V_{drop}-IR \Rightarrow I=\frac{V_0-V_{drop}}{R}$



solving for V_d CAN'T, transcendental equation

$\boxed{\text{If we use Shockley}}$ → $V_0 - IR - V_d = 0$ → $I = \boxed{\frac{V_0-V_d}{R} = I_0\left(e^{\frac{eV_d}{kT}}-1\right)}$

*solve w/ Newtons method or "load line"

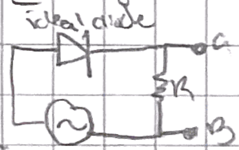


origin of V_{drop} w/ equations I don't understand

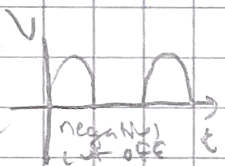
$I = Ce^{\frac{-\Delta E}{k_BT}}\left[e^{\frac{eV}{k_BT}}-1\right]$, when $\frac{eV}{k_BT} \gg 1$, $\frac{k_BT}{e}(\ln I - \ln C) = V - \frac{\Delta E}{e}$ ← energy of gap

($Ce^{\frac{-\Delta E}{k_BT}} = I_0$; C ← constant)

Making an AC adapter



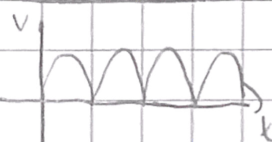
$V>0$ $Z=0$
$V<0$ $Z\to\infty$



(1) V

let's get the cut off part

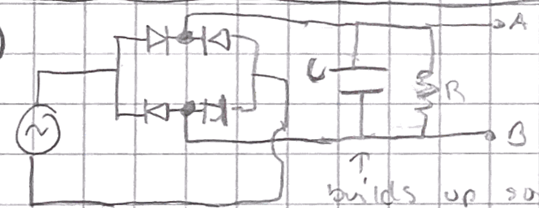
(2)



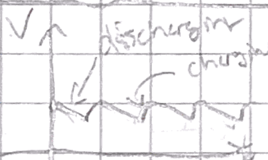
→ blocked
→ passed

to understand follow path from either side when

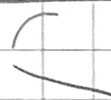
(3)



builds up some but when it switches it discharges



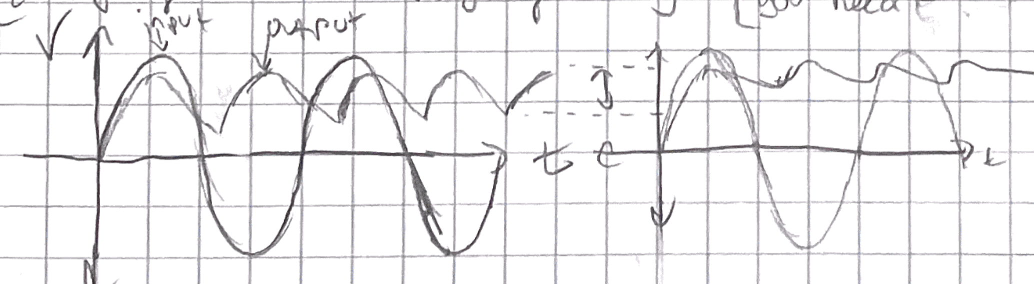
charges when
discharges when



→ this is one way to filter out the signals.

But what is actually happening?

$\boxed{\text{at certain times the capacitor is charging and discharging}}$ → $\boxed{\text{you don't want it to charge up quickly, to do this, you need}}$ →
- high capacitance ← scale up more charge
- ω be high?, so it acts like wire or doesn't conduct much
- low $f_c = \frac{1}{2\pi RC}$



← get this when you increase capacitor

Ripple factor of circuit?

form factor?

$$r = \frac{\text{Voltage (rms) of output signal}}{\text{average value of signal}} = \frac{V_{rms(AC)}}{V_{DC}} \begin{array}{l}\leftarrow \text{"AC part"} \\ \leftarrow \text{"direct current part"}\end{array}$$

[bec/ in rect circ we care about R_{Load}]

[getting equations]

$$P = \frac{1}{T}\int \frac{v(t)^2}{R} dt = \frac{V_{rms}^2}{R} \rightarrow V_{rms}^2 = \frac{1}{T}\int_0^T v^2(t)dt$$

$$V_{DC} = \frac{1}{T}\int_0^T v(t)dt$$

usually output voltage V_{out} or V_{Load}

of the load

$$* \text{you can say: } i_L(t) = \frac{V_L(t)}{R_L} \quad \text{and} \quad I_{DC} = \frac{V_{DC}}{R_L} \quad \text{and} \quad I_{rms} = \frac{V_{rms}}{R_L}$$

Lets think about ΔV drop of the capacitor thats causing these ripples

[for small ripples you can approximate I_{Load} to be constant] $\rightarrow$ [$Q = CV$, $I = C\frac{dV}{dt}$] $\rightarrow$ $\Delta V = \frac{I}{C}\Delta t$

- $\Delta t \approx \frac{1}{f}$ (half wave rectification)
- or
- $\Delta t \approx \frac{1}{2f}$ (full wave rectification)

[capacitor begins charging again in less than a half cycle]

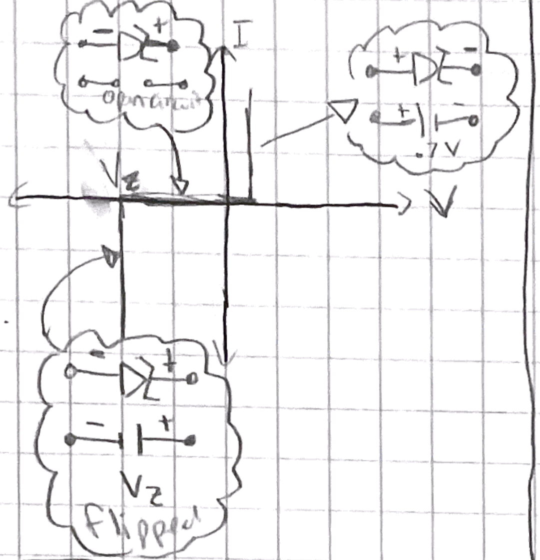
$$\boxed{\Delta V = \frac{I_{load}}{fC} \quad \text{or} \quad \Delta V = \frac{I_{load}}{2fC}}$$

[* Resistor causes capacitor to discharge "somewhat" between cycles (or half cycles for full wave rectification]

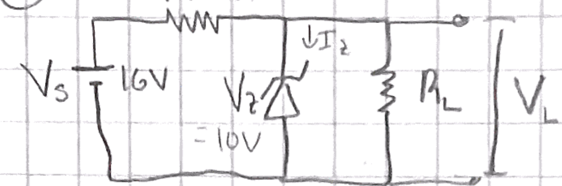
[assuming a linear approximation it is conservative in design]

* I think I_{load} is current across the resistor bec/ the resistor is what is making its $\frac{dV}{dt}$
↳ can't discharge anywhere else

Zener diode Practice Problems

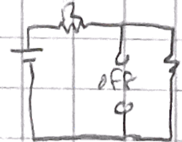


ex



$R_L = 1.2k\Omega$: find state of zener diode by seeing voltage

$V_L = V_Z = V_S \frac{R_L}{R_L + R} = 8.73V$ so zener is OFF



$V_R = V_S - V_L = 16 - 8.73 = 7.27V$

$I_Z = 0$, $P_Z = 0$

$R_L = 3k\Omega$:

$P_Z = I_Z V_Z$

$V_L = V_{Zen} = V_S \frac{R_L}{R_L + R} = 12V$ so zener on

$V_{zener} = V_L = 10V$ (zener regulates voltage)

$V_R = V_S - V_L = 16 - 10 = 6$

$I_R = \frac{V_R}{R} = 6mA$

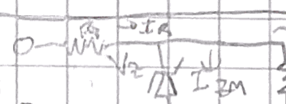
$I_L = \frac{V_L}{R_L} = \frac{10}{3k\Omega} = 3.33$

$I_Z = I_R - I_L = 6 - 3.33 = 2.67mA$

to find the minimum load resistance such that if $R_L > R_{Lmin}$, Zener is on and $R_L < R_{Lmin}$ Zener is off → $V_L = V_Z$, breakdown; $V_L = V_Z = V_S \frac{R_L}{R + R_L}$ → $\boxed{R_{Lmin} = R \frac{V_Z}{V_S - V_Z}}$

↳ also $I_{Lmax} = V_L / R_L = V_Z / R_{Lmin}$

Since zener diode regulates, there is a max resistance, (has an I_{mz} where it breaks down)



→ I_L; problem: KVL: $V_R = V_S - V_Z$, $I_R = \frac{V_R}{R}$

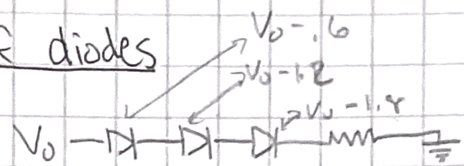
Once the diode is on: $I_Z = I_R - I_L$ (I_Z is limited to I_{Zm}) → $\boxed{I_{Zm} = I_R - I_{Lmin}}$

~~generally~~: $R_L = \frac{V_L}{I_L}$ ⇒ $\boxed{R_{Lmax} = \frac{V_Z}{I_{Lmin}} = \frac{V_Z}{I_R - I_{Zm}}}$

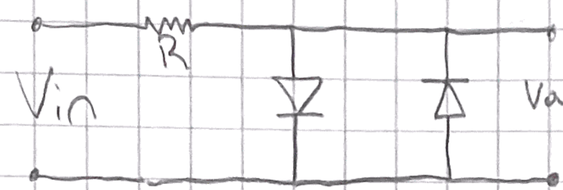
so zener is on when: $I_{Lmin} < I_L < I_{Lmax}$, $R_{Lmin} < R_L < R_{Lmax}$

Different uses of diodes

Voltage dropper



Limiter or Clipper ensures output voltage never exceeds a certain level
↳ uses the fact diodes have a V_{drop}



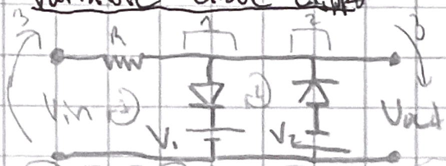
→ Vout only reads the drop across diode

$\boxed{SO}$ when $V_{in} \le V_{drop}$, $V_{out} = V_{in}$
when $V_{in} \ge V_{drop}$, $V_{out} = V_{drop}$

two diodes: $|V_{out}| \le V_{drop}$

1 diode: $V_{out} \le V_{drop}$ or $V_{out} \ge -V_{drop}$

Variable diode clipper * same thing as above but can change how much it clips



→ Vout reads only drop across diode AND battery

$\boxed{SO}$ when $V_{in} \le V_{drop} + V_b$, $V_{out} = V_{in} + V_b$
when $V_{in} \ge V_{drop} + V_b$, $V_{out} = V_{in} + V_b$

V_1, V_2 call V_b

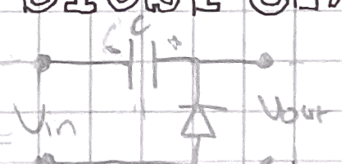
① $V_{out} = (V_{drop} + V_1)$
② $V_{out} = (V_{drop} + V_2)$

just follow current and drop like in Kirchoff

KVL: ① $V_{in} - IR - V_{drop} - V_1 = 0$
③ $V_{in} - IR - V_{out} = 0$
thus $V_{out} = V_{drop} + V_1$

DIODE CLAMP

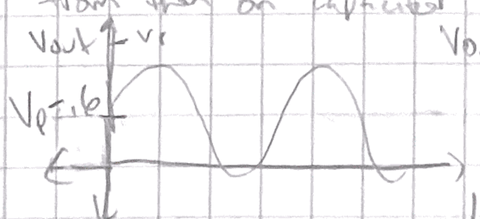
* used to shift an AC signal by a constant voltage



→ positive current this way gets blocked. Only this way is passed
→ if Vin is positive there's no voltage drop (blocked by diode)
→ if Vin is less than −.6 V the capacitor can charge up bec/ not all of the voltage is dropped across diode

$\boxed{SO}$ the capacitor can go to a voltage of $\boxed{V_C = V_p - .6}$ (V_p is peak voltage)
from then on capacitor has a constant voltage so $\boxed{V_{out} = V_{in} + V_C}$

$V_{out} = V_{in} + (V_p - .6)$



→ [in negative cycle it charges the capacitor and & the capacitor tries to discharge its blocked by diode]

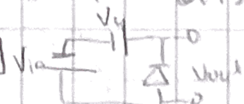
$V_C = V_p - .6$ ← [.6 is always taken off bec/ of diode]

[think of this as variable $0 \to V_p$]

[thus the capacitor charges to $V_p - .6$ and can't discharge]

[Now capacitor acts like a constant voltage source] →

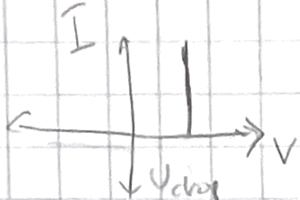
$\boxed{KVL}$

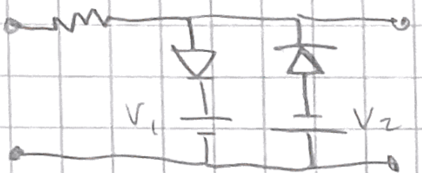


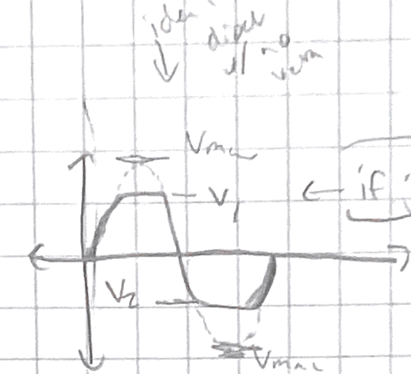
$V_{in} - V_{drop} - V_C = 0$
$V_{out} - V_{drop} = 0$

SO $\boxed{V_{in} = V_{out} + V_C}$

Clipper







← if just ∇ then its V_{drop} but it has to reach it first thus

$\begin{cases} \text{when } V_{in} < V_{drop} & V_{out} = V_{in} \\ \text{when } V_{in} \geq V_{drop} & V_{out} = V_{drop} \end{cases}$

TRANSISTORS

two types: npn and pnp, focusing on npn, pnp is same just polarities and current is reversed

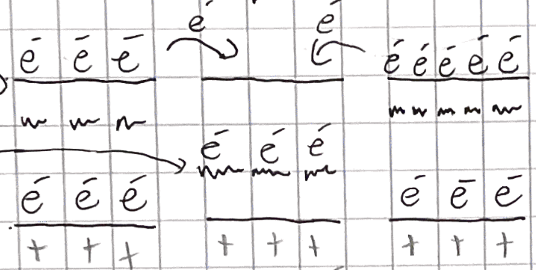
(N and P start off neutral)

npn junction

* "start state"

(filled spots where $\bar{e}$ hopped up)

vacancies created where the $\bar{e}$ hopped up



[electrons from N will fall down and create depletion layers]

* "end state" w/ batteries

↓ actually not really, this is to show how $\bar{e}$ fall down, just know in the end state a depletion layer is formed!

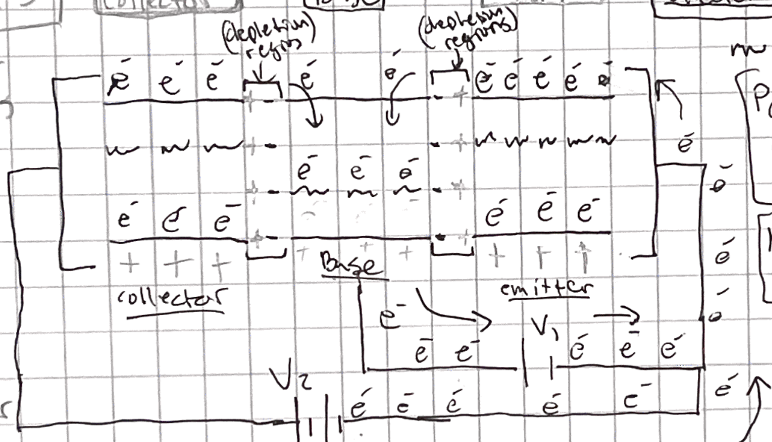
emitter-base depletion small

collector-base depletion large

ʍ = doped added states

[P doping adds holes to crystal, for $\bar{e}$ to move between bonds]

[N doping adds $\bar{e}$ move free in conducting layer]



Emitter → Base

- forward biased
- use V_1 to push across ΔE
- V_1 pulls $\bar{e}$ from base and emitter $\bar{e}$ fall down into base

collector → Base

- reverse bias
- creates larger depletion region
  - ↳ pulls $\bar{e}$ from N and supplies $\bar{e}$ to P (N is +, P is −)

collector to emitter

- complete loop
- emitter to collector for $\bar{e}$ (flipped for current)

electrons from the emitter

2 fates

(base $\bar{e}$ flow)

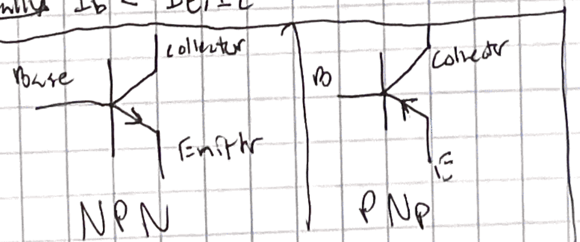
1) combines w/ hole in P type

2) they go pass P and into → collector

to encourage this, P is lightly doped (less recombination), also the collector is lightly doped while emitter has high dope, this causes more emitter $\bar{e}$ to disperse and can pass over that tiny P region.

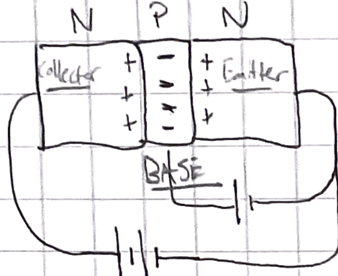
in total; $I_{emitter} = I_{collector} + I_{base}$

typically $I_b \ll I_e, I_c$

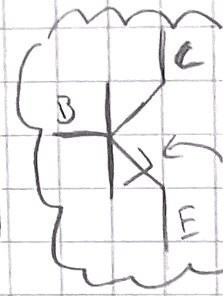


↳ base current controls the $\bar{e}$ from emitter to collector

Transistors



$$\begin{cases} I_e = I_c + I_b \\ I_b << I_e, I_c \end{cases}$$



e^- go from emitter to collecter so current is opposite

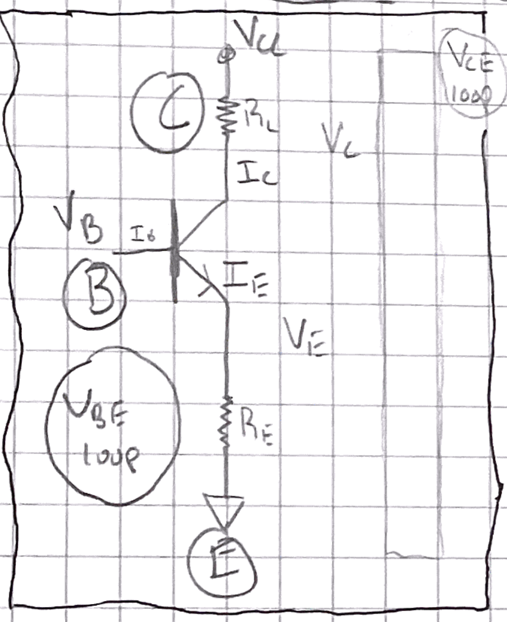
$I_c = \alpha I_e$, "α" fraction of emitter current that makes it to the collecter

$I_b = (1-\alpha) I_e$, $(1-\alpha)$ means the rest of emitter current is base

*α is typically close to 1

also: $I_e = I_c + I_b$ plug in, $I_e = \alpha I_e + I_b \rightarrow I_b = (1-\alpha) I_e$

another look is: $\beta \equiv \frac{I_c}{I_b} = \frac{\alpha}{1-\alpha}$



BE loop: $V_B - V_{BE} - I_E R_E = 0$ $I_E = I_c + I_B$

CE loop: $V_{cc} - I_c R_L - V_{CE} - I_E R_E$

Transistor Khan

↑ for silicon this is when depletion region vanishes

+5V with just 5V no flow because of depletion region

w/ .7V on P it forward biases that region, meaning it shrinks the depletion region allowing charge carriers to flow.

→ Most go from bottom N to top N while very few go to .7V terminal

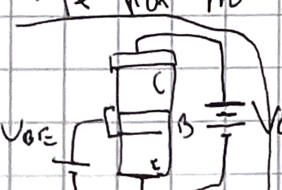
→ if 1 e^- goes to base and 99 e^- go to top and if you want 2 e^- to go to base 198 e^- go to top. Origin of "β" and shows amplification!

- In order to act like an ~~emit~~ amplifier the P region has to be forward biased

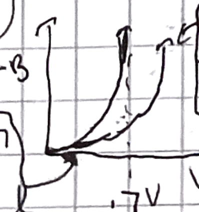
emitter - base → forward bias ← the voltage touches P which is + and V_b is +

collecter - base → reverse bias ← V_{cc} is touching N which is − and V_{cc} is +

→ if not emitter base no current from emitter, if not collecter - base causes flow, but there's also emitter flow, messy

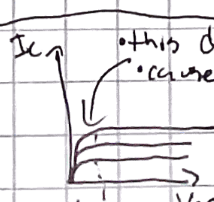


→ If you make V_{CE} bigger its reverse biasing P which increase depletion region on the top part which make the bottom e^- get swept away more easily, less chance of recombination for V_{BE}



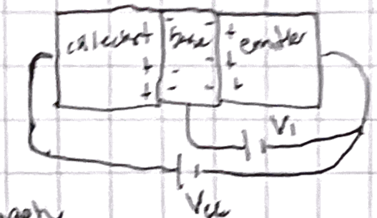
notice if V_{BE} is small, <.7 $I_b \approx 0$ then

increased V_{CE} you get + less I_B at .7V

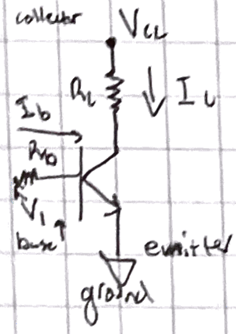


- this decrease in current is when $V_{CE} > V_B$
- causes a forward bias on collecter - base
- destroys depletion and diffusion happens
- emitter base is same so its harder for them to move

Book rough notes



DC switching control of current



- V_{cc} is name of constant power supply
- V_1 is control voltage (controls flow of current through R_c)

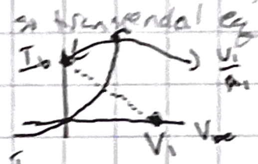
V_{be} voltage from base to emitter

base-emitter loop: $V_1 - I_b R_b - V_{be} = 0$ $\quad V_{be} = V_b - V_e$ } not used but for clarification

$$\boxed{I_b = \frac{V_1 - V_{be}}{R_b}}$$ ← approx like diode drop

*I_b is a complicated function of V_{be}, so transcendental eq

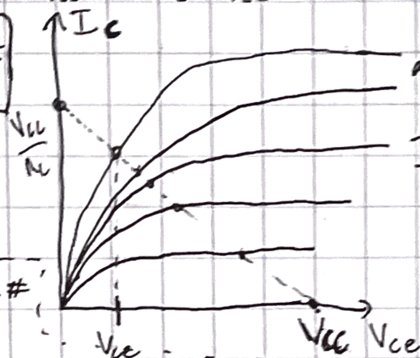
→ often will say $V_{be} = .6V$ for approx [or load line]



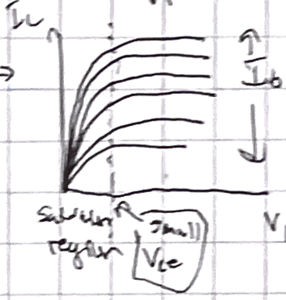
collector-emitter loop: $V_{cc} - I_c R_c - V_{ce} = 0$

$$\boxed{I_c = \frac{V_{cc} - V_{ce}}{R_c}}$$

But what line do we use?
depends on I_b, thus solution



[looks more like] →



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switching V_1 between 0 and big #

- $\boxed{V_1 = 0}$ from load line in base-emitter loop, $\boxed{I_b = 0}$
  ↳ from that $I_b = 0$ and in collector emitter loop, $\boxed{I_c = 0}$ and then → from load line $\boxed{V_{ce} = V_{cc}}$

  * to not hit saturation have low I_b and high V_{cc}/R_c

- if $\boxed{V_1 = \text{big number}}$ then $\boxed{I_b \text{ will also be large}}$, thus load line hits in saturation region w/ $\boxed{I_c \text{ high}}$ and where it connects shows a $\boxed{V_{ce} = \text{small}}$

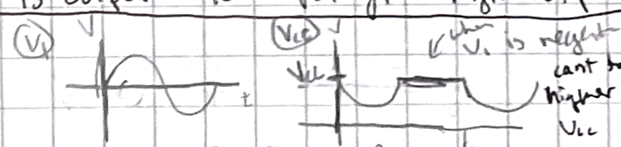
recap   look back at NPN transistor, MAKES SENSE!

$\boxed{V_1 = 0,\ I_b = 0,\ I_c = 0,\ V_{ce} = V_{cc}}$ or $\boxed{V_1 = \text{big},\ I_b = \text{big},\ I_c = \text{big},\ V_{ce} = \text{small}}$

- On off controll of current (I_c) (through R_c) by controlling V_1 (switch)
- also if V_{cc} is output, low input gives high output etc.. idk... voltage inverter?

amplifiers

qualitative look!



* Only matches if it stays in linear active region *

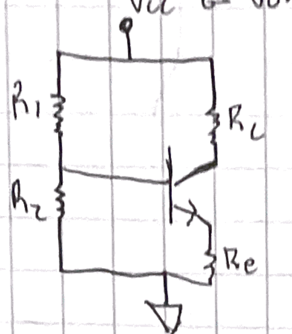
$V_1 = 0$ $\quad V_{ce} = V_{cc}$ (1)	almost an amplified signal
$V_1 = +$ $\quad V_{ce} =$ decrease (2) ↳ $I_b = \uparrow$ (follow load line path)	→ add a offset and it is ← [cant handle negative signals] → idk I dont get it
when V_1 is negative then it gets clipped bcz it acts like a diode. $I_b = 0$ when $V_1 = -$	

amplifier

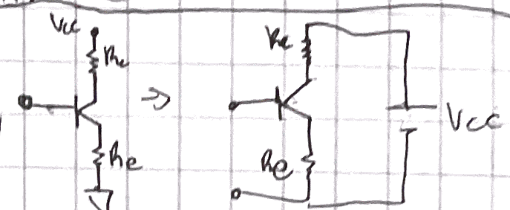
universal DC bias circuit

→ devise a circuit that keeps the transistor operating in the linear active region → sets the constant DC operating conditions (Later add AC to produce Amplifier)

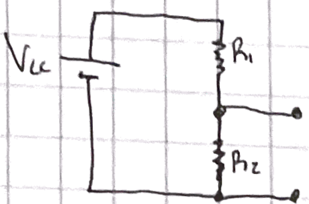
V_{cc} ← voltage source

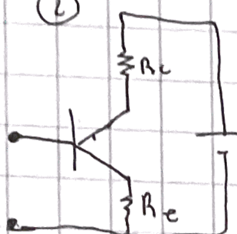


- R_1 and R_2 form a voltage divider
- R_e and R_c complete the circuit
- other bias circuits can be derived from this one



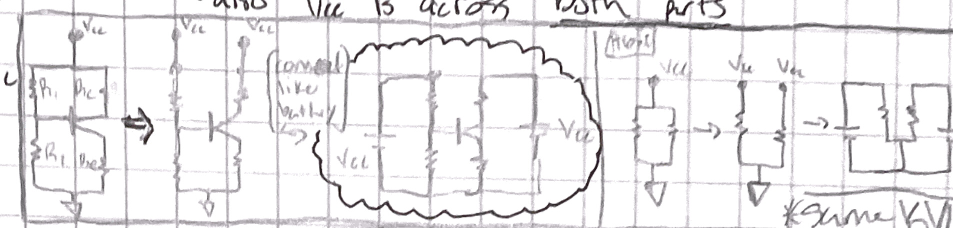
from this thing you can make

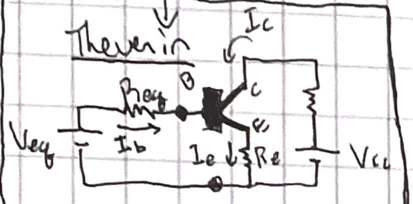
① 

② 

this is accurate, well

• also V_{cc} is across both parts





where:

$$V_{eq} = V_{cc}\left(\frac{R_2}{R_1+R_2}\right), \quad R_{eq} = \frac{R_1 R_2}{R_1+R_2}$$

KVL $V_{eq} - I_b R_{eq} - V_{BE} - I_e R_e = 0$

(voltage drop entire transistor) (voltage drop across diode)

$V_{cc} - I_c R_c - V_{ce} - I_e R_e = 0$

Using these equations along with $I_e = I_c + I_b$, $I_c = \beta I_b$ to get * I_e, I_b, V_{ce} *, operating point

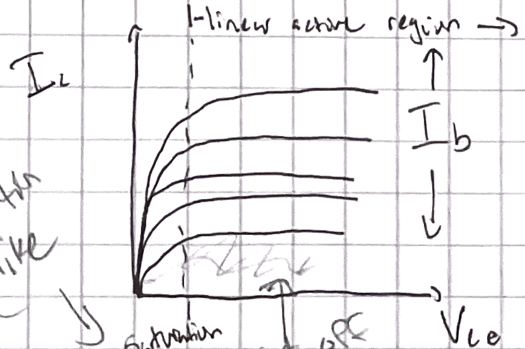
$\boxed{1}$ $I_b = \dfrac{V_{eq} - V_{be}}{R_{eq} + (\beta+1)R_e}$ $\xrightarrow{\text{plugging in } V_{eq},\ R_{eq}}$ $\boxed{I_b\left[\dfrac{R_1R_2}{R_1+R_2} + (\beta+1)R_e\right] = \left(\dfrac{R_2}{R_1+R_2}\right)V_{cc} - V_{be}}$

$\boxed{2}$ $V_{ce} = V_{cc} - I_c\left(R_c + \dfrac{\beta+1}{\beta}R_e\right)$ $\xrightarrow{\text{rearrange}}$ $\boxed{R_c + \left(\dfrac{\beta+1}{\beta}\right)R_e = \dfrac{V_{cc} - V_{ce}}{I_c}}$

operating point is the DC voltage or current at a specific terminal of an active device with no input signal applied

Side note: if input (V_b) varies from 0-1V you could configure transistor to multiply by 5 so it (V_{CE}) goes from 0-5V, If you want to do 1000 but your supply (V_{cc}) is only 5 then it will only go between 0 and 5V

The above circuit keeps transistor in linear active region, its DC mode.



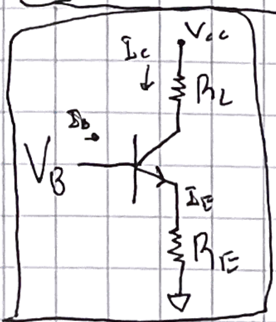
Biasing is the process of providing DC voltage which helps in the functioning of the circuit, A transistor is biased in order to make the emitter-base junction forward biased and the collector-base junction reverse biased, so it remains in linear active region (to work as an amplifier)

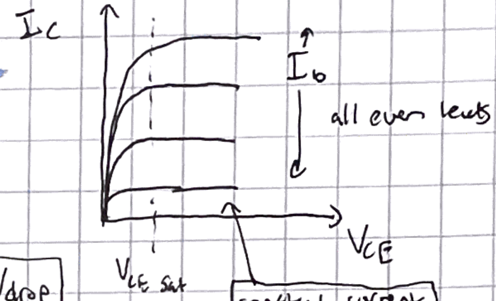
(by connecting to a V_{cc} you can

→ V_{cc} drops all to E, low base current

Transistor example problems

5





BE loop $V_B = V_{BE} + I_E R_E$

* if transistor is conducting then $\boxed{V_{BE} = V_{drop}}$

$\hookrightarrow V_B = V_{drop} + I_E R_E$

$\frac{\beta}{\beta+1} \approx 1$ if $\beta \gg 1$

$I_C = \beta I_B$ ($\leftarrow$ only true for linear active region) ← think discrete levels) then $I_C = \frac{\beta}{1+\beta} I_E \approx I_E$

then $\boxed{I_C \approx I_E = \frac{V_B - V_{drop}}{R_E}}$ * I_C is controlled by V_B, doesnt depend on load (R_L) *
(current source bec/ its constant and doesnt change)

Q1 Given $R_E, R_L, V_{CE\,sat}$, whats the maximum current this source can provide. ($I_C \approx I_E$) * remember $V_{CE} \geq V_{CE\,sat}$ *

$V_{CC} = V_{CE} + I_C R_L + I_E R_E \rightarrow V_{CE} = V_{CC} - I_C(R_L + R_E) \geq V_{CE\,sat}$

then $\boxed{I_C \leq \frac{V_{CC} - V_{CE\,sat}}{R_L + R_E}}$

Q2 Find R_E so a $I_C = 0.5A$ flows through the load, $V_B = 3.2V$
(assuming transistor action condition)

$I_C = .5A \rightarrow I_C \approx I_E \longrightarrow I_E = \frac{V_E}{R_E} = \frac{V_B - V_{drop}}{R_E}$

$\boxed{R_E = \frac{V_B - V_{drop}}{I_E} = 5.2\,\Omega}$

Q3 What is the maximum value of the load resistor with $I_C = 0.5$, $V_{cc} = 15V$
* or how big can you make R_L so it stays in linear active region *

$V_{CC} = I_C R_L + I_E R_E + V_{CE} \rightarrow V_{CE} = V_{CC} - I_C R_L - I_E R_E \geq V_{CE\,sat}$ ← $= .2V$

$R_L \leq \frac{V_{CC} - I_E R_E - V_{CE\,sat}}{I_C}$, ($R_E$ is from above), [if past saturation $I_C \approx I_E$] $= 24.4\,\Omega$

as R_L gets bigger it takes up a larger fraction of V_{CC} meaning V_{CE} gets lower pushing it into saturation

Q4 If $R_L = 10\,\Omega$ what value of V_B will put transistor into saturation?

as V_B gets bigger, I_B goes up causing a larger proportion to drop across R_E, which makes V_{CE} less

• in linear active region $V_{CE} > V_{CE\,sat}$
• at saturation $V_{CE} = V_{CE\,sat}$

$I_E \approx I_L$

actually look at load line on other sheet

$V_{CC} = I_C R_L + I_E R_E + V_{CE} \approx I_E(R_L + R_E) + V_{CE}$

$\rightarrow \hookrightarrow I_E \approx \frac{V_{CC} - V_{CE}}{R_L + R_E}$

$V_B = V_{drop} + I_E R_E \approx \frac{V_{CC} - V_{CE}}{R_L + R_E} R_E + V_{drop}$

plug in $V_{CE\,sat}$ you can rearrange to assure $\leq$ is right

$\boxed{V_B \leq \frac{V_{CC} - V_{CE\,sat}}{R_L + R_E} R_E + V_{drop}} \approx 5.7V$

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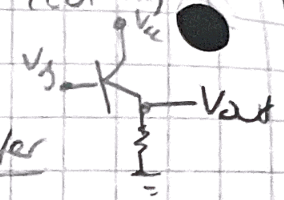
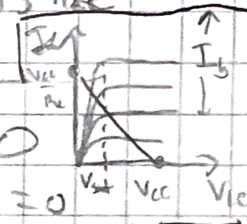
Tips tricks overview

(open circuit)

- if V_{in} or $V_B < (V_{BE} = V_{drop})$ then there is no flow (cut off)

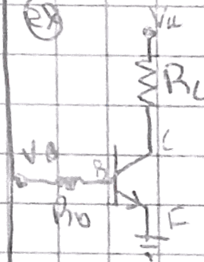


- $V_{CE} > V_{CE_{sat}}$ to be in linear active region
  - ↳ commonly use: $V_{cc} = V_{CE} + V_{out}$, V_{out} is voltage across emitter
  - ↳ you then can use $I_C = \beta I_B \rightarrow I_C \approx I_E$ vs $I_E = \frac{\beta+1}{\beta} I_C$
    - β is big
- if $V_{CE} < V_{CE_{sat}}$ you are in saturation $V_{CE_{sat}}$ is small so its like (acts like wire) ($I_C = I_E$)
  - ↳ $V_{CE} = 0$



~ impedance seen by V_B is $Z_B = \frac{V_B}{I_B}$
↳ if in linear active

ex



- $V_B = 0$ then $I_b = 0$ which means $I_c = 0$ then $V_{CE} = V_{cc}$ (cut off)
- $V_B =$ big, $I_b =$ big (only if R_b is chosen correctly) then $I_c = bR_?$ and $V_{CE} =$ small (saturation)

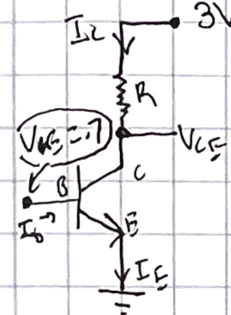
Amplifiers

npn emitter follower can't sink current | pnp follower can't source current

Intro

7

cut off state: (OFF STATE)



① if $V_{BE} < .7V$ (P region isnt biased enough so no flow) (max voltage ever)

$I_b \simeq I_c = 0$ * no voltage drop across R ($V_{CE} = V_{cc} = 3$)

② $V_{BE} \simeq .7V$ lets say $I_b = 10\mu A$ (input current), $\beta = 100$, $R = 1k\Omega$

- $I_c = \beta I_b = 1mA$ and $I_c R = 1V$
  - so $3V - 1V = V_{CE} = 2V$ (output) *AMPLIFYER*

Output across $V_{CE} = 2V$, $1mA$

input $= 10\mu A$, I think V_{BE} is increasing so I_b increases

→ $I_b = 30\mu A$ → $\boxed{I_c = 3mA}$ so $I_c R = 3V$ so $\boxed{V_{CE} = 0}$

* max current cant go past 3V drop *

[$0 < I_B < 30\mu A$ → $I_c = \beta I_B$ and $0 < V_{CE} < 3V$]

LINEAR ACTIVE REGION

[$I_B > 30\mu A$ → $I_c = 3mA$ (maximum) $V_{CE} = 0$ min]

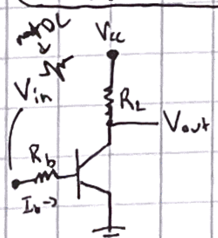
Saturation State (ON STATE)

* Saturation its fully conducting
  - acts like wire

* cut off not conducting
  - acts like open circuit

Transistor as a voltage Amplifier

we want: $V_{out} = 10 V_{in}$ but its also amplifying if $\Delta V_{out} = 10 V_{in}$, which means a DC offset can amplify



$\Delta V_{out} = 10 \Delta V_{in}$ * assume in active state * $I_c = \beta I_b$

* V_{in} is not DC current so I_c and I_b change in time → $\Delta I_c = \beta \Delta I_b$

→ $[V_{cc} - V_{out} = I_c R_L] \Delta$ (take Δ derivative) → , $V_{cc} = 0$ → $\boxed{-\Delta V_{out} = R_L \Delta I_c}$

$[V_{in} - \underset{\text{constant}}{V_{BE}} = I_B R_b] \Delta$ → $\boxed{\Delta V_{in} = \Delta I_B R_b}$

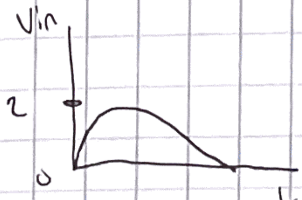
minus sign just flips magnitude

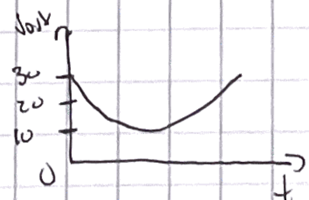
increase V_{in}, $I_b = \uparrow$ then $I_c = \uparrow$ (more drop across R_L) then $V_{out} = \downarrow$

then: $\boxed{\dfrac{\Delta V_{out}}{\Delta V_{in}} = -\dfrac{R_L}{R_b}\dfrac{\Delta I_c}{\Delta I_b} = -\dfrac{R_L}{R_b}\beta}$

$-\dfrac{R_L}{R_b}\beta$ } → Voltage gain

ex



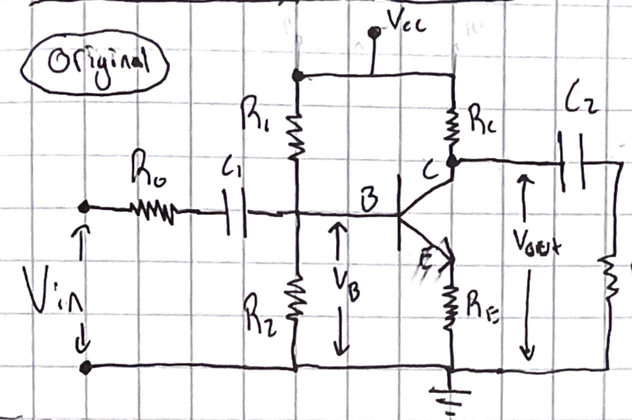


Common ~~Collector~~ Emitter

a

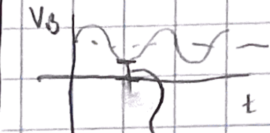
* To analyze this common ~~collector~~ emitter we will be doing the method of combining AC part and DC part. *

Original



- R_0 is like input impedance of ~~source~~
- Capacitors are useful for seperating AC part and DC part, (only lets AC to load)
  ↳ When analyzing DC part the impedance of capacitor goes infinite $Z_C = \frac{1}{j\omega C} \to \omega = 0 \quad Z_C \to \infty$

- R_1 and R_2 decide the voltage "V_B". If most of the voltage drops across R_1, V_B will be small and might not have enough voltage to go across V_{BE} = Vdrop

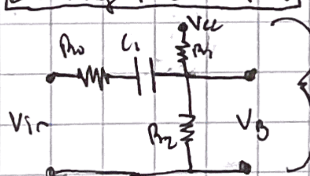


this has to be > Vdrop or cutoff

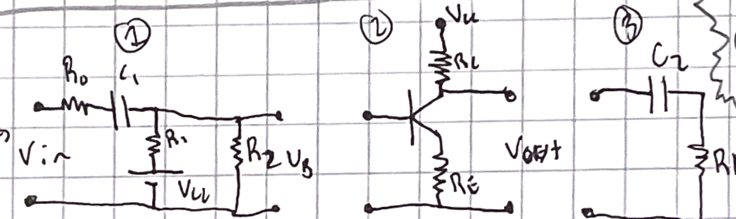
SCRAP?

- R_C controls drop across transistor as whole
- R_E controls the drop across $V_B = V_{drop} + I_E R_E$ loop

Breaking into 3 parts



equal to →



$\phi = \tan^{-1}\left(\frac{R_1+R_2}{\omega C_1(R_0(R_1+R_2)+R_1R_2)}\right)$

AC PART

Complex Ohm's Law

- interested in voltage thats changing so V_{cc} is 0 thats part of DC part (time derivative = 0)

→ Voltage divider: $\hat{V}_B = \frac{(R_1 \| R_2)\hat{V}_{in}}{R_0 + R_1 \| R_2 + Z_{C_1}} \to \hat{V}_B = \frac{(R_1 \| R_2)V_0 e^{j(\omega t+\phi)}}{\sqrt{(R_0+R_1\|R_2)^2 + \left(\frac{1}{\omega C_1}\right)^2}}$ • take the part for cos

$$\boxed{V_B = \frac{V_0(R_1R_2)\cos(\omega t+\phi)}{\sqrt{(R_0(R_1+R_2)+R_1R_2)^2+\left(\frac{R_1+R_2}{\omega C_1}\right)^2}}}$$

now for (2)

Even though I messed up it shows that all other DC parts are 0 too

(2) $V_{cc} = 0$ again, using universal DC bias equations and setting $V_{cc} = 0$:

- $I_b\left(\frac{R_1R_2}{R_1+R_2}+(\beta+1)R_E\right) = -V_{BE}$ and • $R_C + \left(\frac{\beta+1}{\beta}\right)R_E = \frac{-V_{CE}}{I_C}$

$\boxed{I_C = \beta I_b}$ amplifyer...

KVL

- $V_B - V_{BE} - I_E R_E = 0$
- $V_{out} = V_{CE} + I_E R_E$

$$\boxed{V_{out} = V_{CE} + V_B - V_{BE}}$$

* solve above eq's for V_{CE} *

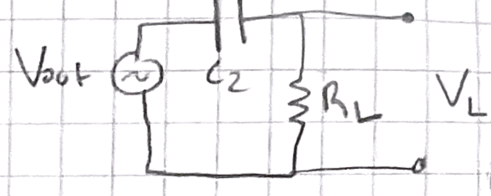
$$V_{CE} = \cancel{V_{BE}}^{\,0}\left(\frac{R_1R_2 + R_E(\beta+1)(R_1+R_2)}{(R_1+R_2)(\beta R_C+(\beta+1)R_E)}\right)$$

plug into this and pull out V_{BE}

! $\boxed{V_{BE} = 0\text{, under AC condition}}$!

$$V_B = \boxed{V_{out} = \frac{R_1R_2V_0\cos(\omega t+\phi)}{\sqrt{(R_0(R_1+R_2)+R_1R_2)^2+\left(\frac{R_1+R_2}{\omega C_1}\right)^2}} + \cancel{V_{BE}\left(\frac{R_1R_2+R_E(\beta+1)(R_1+R_2)}{(R_1+R_2)(\beta R_C+(\beta+1)R_E)}+1\right)}}$$

$\boxed{\text{AC Part gets to the load}}$ → So now we have something like



$$\cancel{V_B = V_{out} = \frac{(R_1+R_2)V_p\cos(\omega t+\phi)}{\sqrt{(R_0+R_1+R_2)^2+\left(\frac{1}{\omega C_1}\right)^2}}}$$

$$V_B = V_{out} = \frac{R_1 R_2 V_p \cos(\omega t+\phi)}{\sqrt{(R_0(R_1+R_2)+R_1R_2)^2+\left(\frac{R_1+R_2}{\omega C_1}\right)^2}}, \quad \phi = \tan^{-1}\left(\frac{R_1+R_2}{\omega C_1(R_0(R_1+R_2)+R_1R_2)}\right)$$

$$\hat{V}_L = \hat{V}_B \frac{R_L}{R_L+Z_{C_2}} = \overbrace{\frac{R_L R_1 R_2 V_p}{\sqrt{(R_0(R_1+R_2)+R_1R_2)^2+\left(\frac{R_1+R_2}{\omega C_1}\right)^2}}}^{A} \cdot \frac{e^{j(\omega t+\phi)}}{R_L - \frac{j}{\omega C_2}}$$

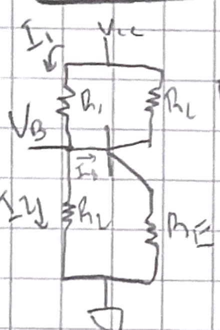
$$\boxed{V_L = A \cdot \frac{\cos(\omega t+\phi+\phi_2)}{\sqrt{(R_L)^2+\left(\frac{1}{\omega C_2}\right)^2}}, \quad \phi_2 = \tan^{-1}\left(\frac{1}{\omega C_2 R_L}\right)}$$ (no DC part)

$\boxed{\text{DC part}}$

*capacitors have $Z = \infty$ so it breaks it off

if R_1 and $R_2 << (\beta+1)R_E$ $\quad V_B = V_{cc}\frac{R_2}{R_1+R_2}$

Equations



$$\boxed{\begin{aligned} V_B &= V_{drop} + I_E R_E \\ V_{cc} &= I_L R_L + V_{CE} + I_E R_E \\ I_L &= \beta I_B \\ I_E &= I_L + I_B \\ V_{cc} &= I_1 R_1 + V_B \\ V_B &= I_2 R_2 \\ I_1 &= I_2 + I_B \end{aligned}}$$

$$\boxed{V_B = \frac{V_{drop}(R_1+R_2) + (1+\beta)R_E R_2 V_{cc}}{R_1R_2 + (1+\beta)(R_1+R_2)R_E}}$$

$$I_B = \frac{V_{cc}R_2 - V_{drop}(R_1+R_2)}{R_1R_2 + (1+\beta)(R_1+R_2)R_E}$$

$$\boxed{V_B = \hat{V}_B + V_{DC(B)} = \frac{R_1R_2 V_p\cos(\omega t+\phi)}{\sqrt{(R_0(R_1+R_2)+R_1R_2)^2+\left(\frac{R_1+R_2}{\omega C_1}\right)^2}} + \frac{V_{drop}(R_1+R_2)+(1+\beta)R_E R_2 V_{cc}}{R_1R_2+(1+\beta)(R_1+R_2)R_E}}$$