Let's revisit last few AC ckt.

\[ V_{DC} = \frac{R_2}{R_1 + R_2} \cdot V \]

- Thevenin from cap to find 1st test

\[ V_{AC} = V \]

- \( Z \) set by pole \& zero

\[ Z = (R_1 + R_2)C \]

- Standard form for

\[ X \] for \( fn \) (easy to get

DC gain or "back solve"

- AC response also has \( V_{AC} \& V_{DC} \)

- Pole zero sep related
to gain

- Frequency indept.

- Nominal works \& DC input!

- But output is DC floating

susceptible to all sorts of
perturbation (scope probe?)
Oscilloscope Probes

At DC, \( \frac{V_o}{V_p} = \frac{1}{10} \), so called 10x probe
Scope needs to multiply by 10 internally
At AC, gain is still \( \frac{V_o}{V_p} \)
Can get flat response from DC to AC
See much less cap @ input \( V_c \) in this design, so probe won't disturb circuit.

* Feel free to talk to me about mystery box once you've taken a crack at it.

Diodes

- Up until now we've been working on "good at circuits" or "good at dynamics" learning goals
- Diodes are our 1st non-linear element
- Start of "large signals" (which secretly means DC) analysis
- This lecture is about convincing you that diodes come from real physics
  by most isn't testable, won't be quizzed, editing by semiconductors are pretty mysterious, ask questions!
- Do a bit of handy modeling @ end of lecture
What are diodes?

- Exponential I-V devices
- One way current gates
- pn junctions \(\rightarrow\) differently doped pieces of semiconductor

How do we calculate current in semiconductors?

To figure out how many \(e^-\) are moving between energy states.

- Fermi Level is the energy \(e^-\) would occupy @ absolute zero
- "Chemical potential" of electrons
- Energy required to add one \(e^-\)
Let's consider some materials

- **E**

- Can easily find new states to move
  - "Conductor"
  - Bottom band full (valence band) top band (conduction band) far away
  - "Insulator"
  - Upper band full but conduction band close
  - "Semiconductor"

- **Doping**
  - Adds or takes away free e^-
  - Si - Si - Si
  -
  - Si - P - Si
  -
  - Si - Si - Si

- **E** = midvalence levels

- **E** ~ acceptor levels

- **E** ~ donor levels

- **E** = change in # of e^-

- Obvious affects **E**

- Lower e^-, easy to add

- More e^- hard to add

- **E** = not conducting yet, but only takes a little

- **Temperature**
  - Adds little energy to system
  - e^- have "probability" of being in different spots

- **DOS**
  - DOS ~ P(e^-) gives
  - Probabilities of e^- in a state

- **# of free e^- to move**

- Suggests # e^- exponential in temperature
Lec 3: Diodes

- pn Junctions

Recall that $E_F$ is a chemical potential, represents equilibrium

Apply a voltage

Tricks: I'm showing a simple model

Voltage is "like" potential, shifts bands

Inward, biaxial = voltage or dev. moves p and down

Rev. biaxial moves p up

Quasi Fermi levels for e- or holes

From this we have

$$I_d = I_s (e^{-\frac{qV}{kT}} - 1)$$

$V_{TH}$ = thermal voltage

$\sim 26mV @ RT$

$e^{-\frac{qV}{kT}}$ is exponential in voltage or temp

$-1$ is drift current in rev. bias
Let's look at the silicon picture again to make this concrete.

- Depletion or space-charge region
- $E$ field points $+$ to $-$, cancels diffusion pressure $+$ minority carrier
- Recombination leaves behind fixed charge
- Charge must balance the extra carriers from the fixed charge
- Depletion mostly on lightly doped side
- $Q = N_A \cdot A \cdot W_h$
- $N_A$ atoms $\approx 10^{29}$, intrinsic holes $\approx 10^{10}$, typical $p$-type $\approx 10^{18}$
- Degenerate $10^{10}/cm^3$
- Depletion width interesting, comes from diffusion
- $-V \cdot \dot{E} = q \frac{dE}{dt}$
- Integrate $q$ to get $E$
- High peak field in depletion region
- Points one way

- $E = \frac{C_0}{V} - PV = -\frac{dV}{dt}$ for $V$
- Integrate again to get $V$
- Built-in voltage same as energy barrier

Width changes $V$ with applied voltage $-$ more diffusion pressure

$E$ field $\propto V$ (weak field), $\propto V^{1/2}$ (strong field)

implies

$\frac{dQ}{dV} \propto C_0$ for linear

$C_0 = \frac{Q}{V}$ for non-linear
Dealing with exponentials in calculations is hard. Why do we do it? Quick understanding. But we can make a quick approximate model.

\[ V_{on} \approx V_{drop} \]

- Note: both models passive, solar cells, LEDs

- \( V_{drop} \) is switch + V src.

- \( V_{on} = 0.7 \) for Si, 1.7V for red, 2.3V for green, 3.1V for blue.

- Set current in diode:

- Why need R? Blowup down.

- Solve by assuming diode static.

- Common case: envelope detector

- Height follows envelope

- First charge + slow discharge

- Rectifies DC to AC!