E151 Lecture 4 – Diodes in Circuits

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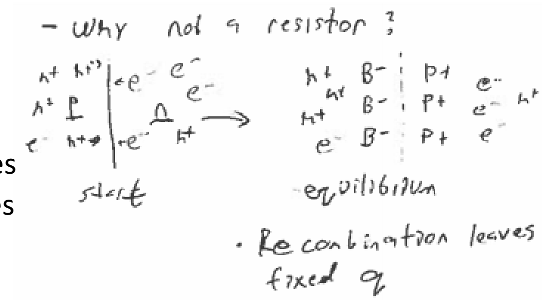
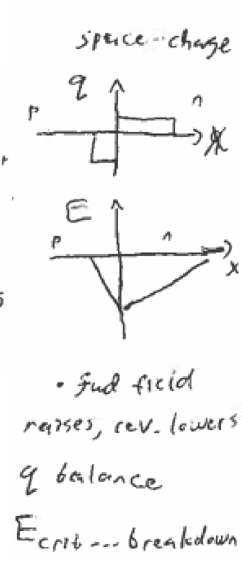
Disclaimer

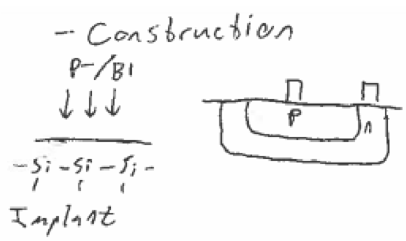
These are note for Prof. Spencer to give the lecture, they were not intended as a reference for students. Students asked for them anyway, so I'm putting them up as a courtesy. Remember that they are not intended as a substitute for lecture.

Diodes – 1st Nonlinear Element

- What are diodes
  - PN Junctions
  - One way current valves
  - Exponential I-V devices







Also,

- Field points right to left
- minority drift cancels majority diffusion
- Net charge imbalance makes P+

Diodes – why are they exponential?

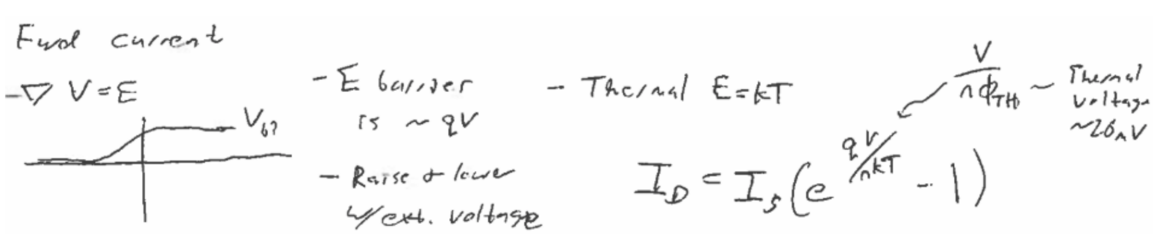
- 3 descriptions: Nonlinear element, 1 way current valve, exponential
- Why exponential & 1 way?
- What's breakdown?

- what is I-V?

Reverse current - minority pushed across depl.

↳ push hard → e⁻/h⁺ pair, avalanche

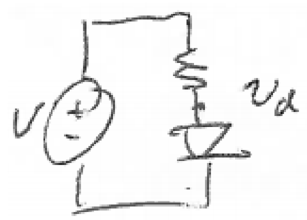
↳ Fixed current ∴ limited by # carriers



Probability of transit (let Vbi=0) – carrier limited drift

Can’t solve them gracefully

- Let’s make the easiest circuit: series resistor-diode ← transcendental
- Can’t even do easiest circuit! How to solve?
  - Graphically
  - Approximate
  - Linearize
  - Computers ← Don’t got straight here because we want design insight

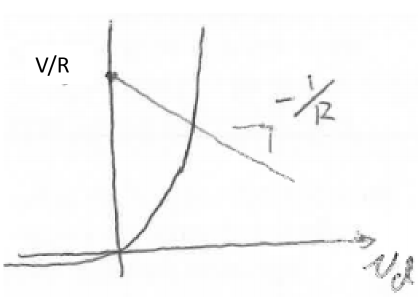


$$\frac{V - v_d}{R} = I_s\left(e^{v_d/n\phi_{th}} - 1\right)$$

$$V = v_d + R I_s\left(e^{v_d/n\phi_{th}} - 1\right)$$

Graphically

- One point – “Operating point” or “Bias point” – where both eqn true
- This is called load line analysis
- Good for qualitative understanding, esp. with resistive loads



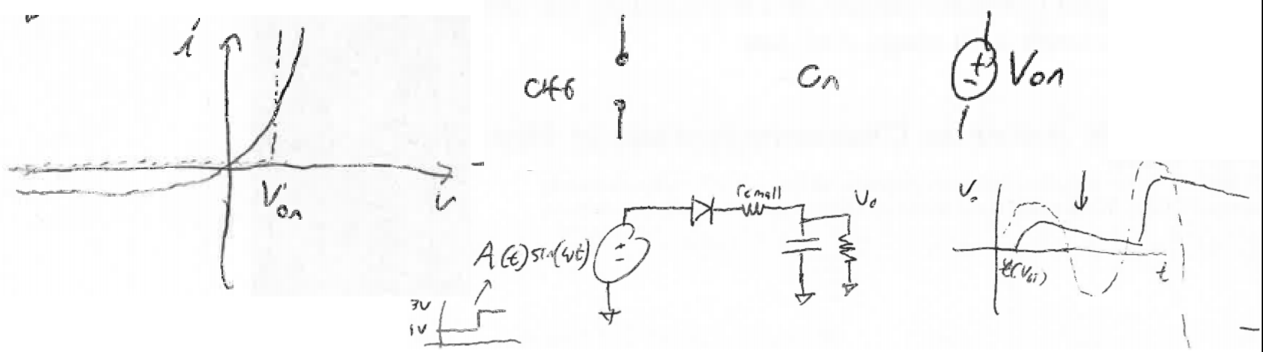
$$i = I_s\left(e^{v_d/n\phi_{th}} - 1\right) \text{ and } i = \frac{V - v_d}{R}$$

— V_{on} = 0.7 for Si, 1.7V for red, 2.3 V for green, 3.1V for blue

Increasing V across rainbow

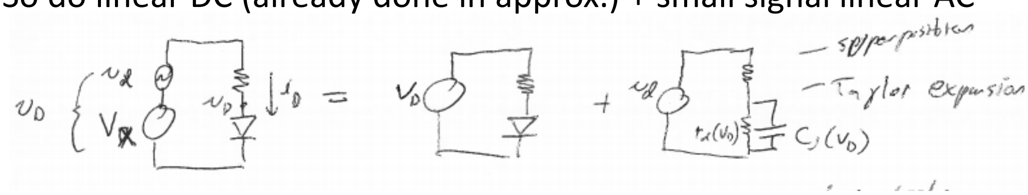
Approximate

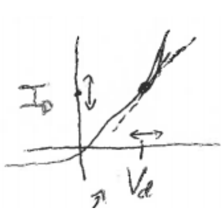
- Exponential can be approximated by L shape: “inf current @ V_ON”
- (Only really works @ one current level, grain of salt)
- Switch-voltage source or switch–resistor model



Linearize → Small signal modeling

- Time varying nonlinear hard in general: Is*exp(qV/nkT*sin(w*t) …)
- So do linear DC (already done in approx.) + small signal linear AC





$$f(x) \text{ near } a \simeq f(a) + \frac{df}{dx}\Big|_a \cdot (x-a) + \frac{d^2f}{dx^2}\Big|_a \frac{(x-a)^2}{2} \dots$$

$$i_d(v_D) \text{ near } V_D \simeq i_d(V_D) + \frac{di_D}{dv_D}\Big|_{V_D} \cdot v_d + \dots$$

Differential Resistance

$$\frac{di_D}{dv_D} = \frac{d}{dv_D} I_s\left(e^{v_D/n\phi_{th}} - 1\right) = \frac{1}{n\phi_{th}} I_s e^{v_D/n\phi_{TH}} \approx \frac{I_D}{n\phi_{th}}$$

- Define this as 1/rd ← differential resistance: rd = n*phi_th/I_D
- Eq. circuit is a resistor – voltage wiggle → linear I wiggle
- Notation: i_D (total signal) = I_D (large signal + i_d (small signal
- Need to shut off voltage sources b/c differential – "wiggles go to die"

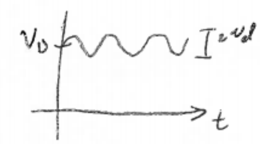
If time:

example

$$I_D = \frac{V_R - V_{on}}{R}$$

$$V_D = V_{on}$$

$$v_d = \frac{n\phi_{th}/I_D}{R + n\phi_{th}/I_D} v_x$$



Computers

- Newton's method / iteration – TI-83+, Matlab, etc.
- Brute force – calculate every vd value and pick one that matches KCL
- Circuit simulator
  - LTSpice demo
  - Components and models
  - Simulator directives
  - "You may consider this like a calculator in this class, use it throughout"
  - AC vs. DC (or .OP) vs. TRAN