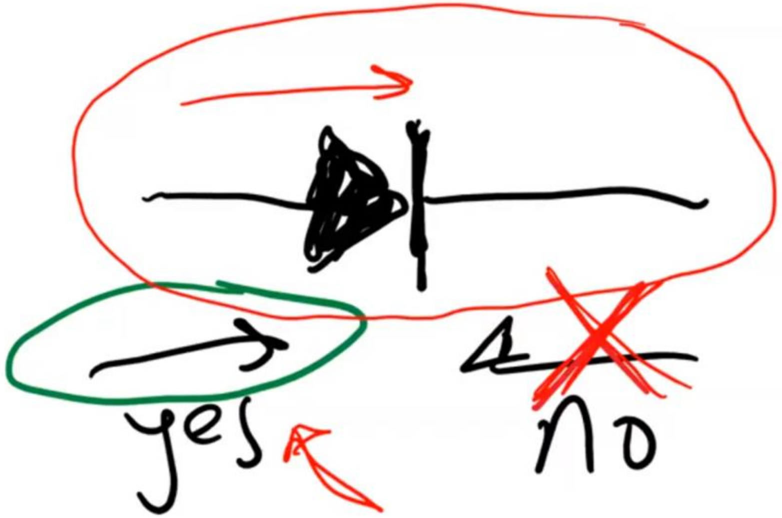
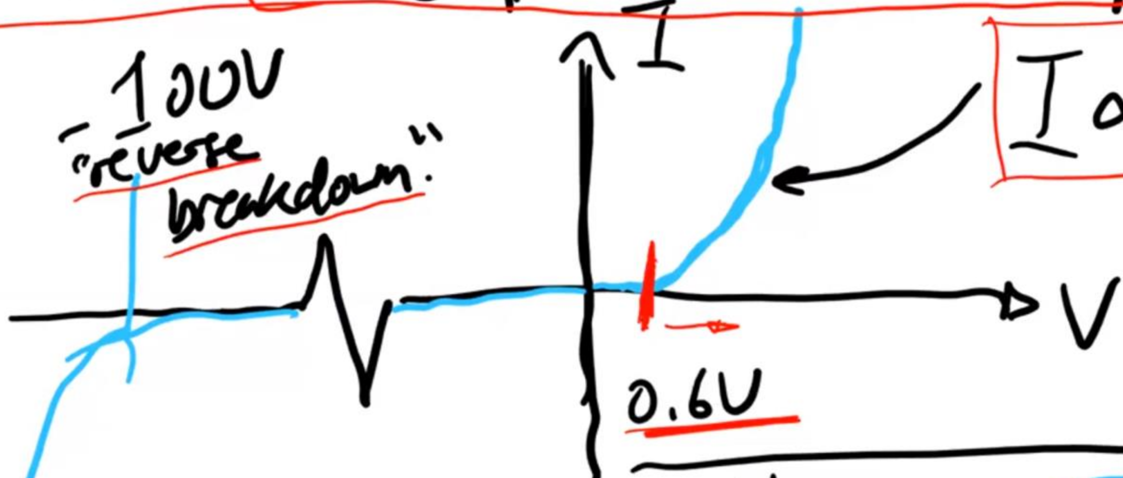
Active circuit elements: the transistor (`**trans**fer resis**tor**’)

And some useful circuits with transistors

A quick interlude on diodes...



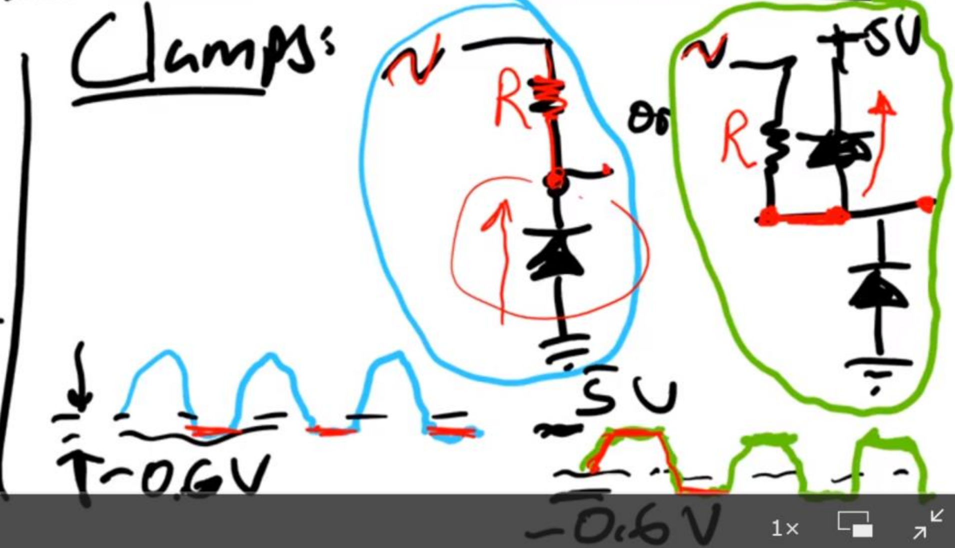
- Note: 0.6V "diode drop":



$I \propto e^{V-0.6V}$

Devices: **Rectifier:**

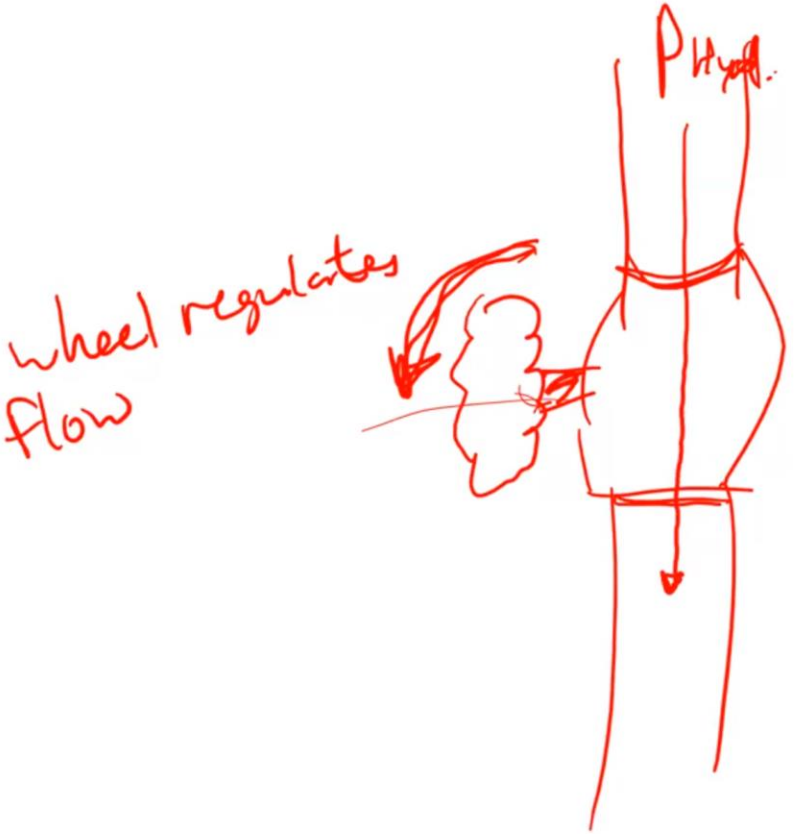
Clamps:



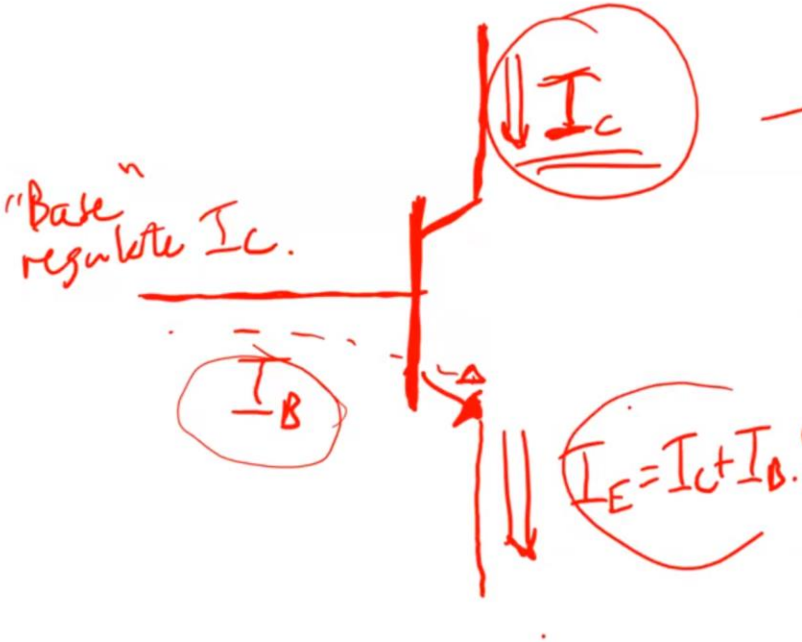
Onward with transistors: We'll work with BJTs (bipolar junction transistors)

Think of it like a valve:

valve



npn - transistor

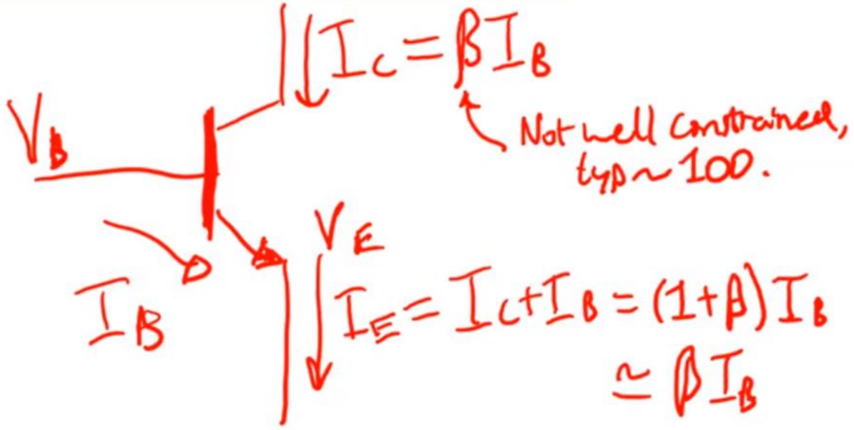


- A little bit of base current I_B ⇒ a lot of collector current.

Some ground rules and two views of the transistor:

A relatively simple view: current amplifier

Current flows on transistor:



$I_C = \beta I_B$

Not well constrained, typ β ~ 100.

$I_E = I_C + I_B = (1+\beta) I_B \simeq \beta I_B$

A simpler view: just assume β (aka h_{FE}) is at work

$$V_{BE} = 0.6\ V$$

"Diode drop"

$$I_C \approx I_E$$

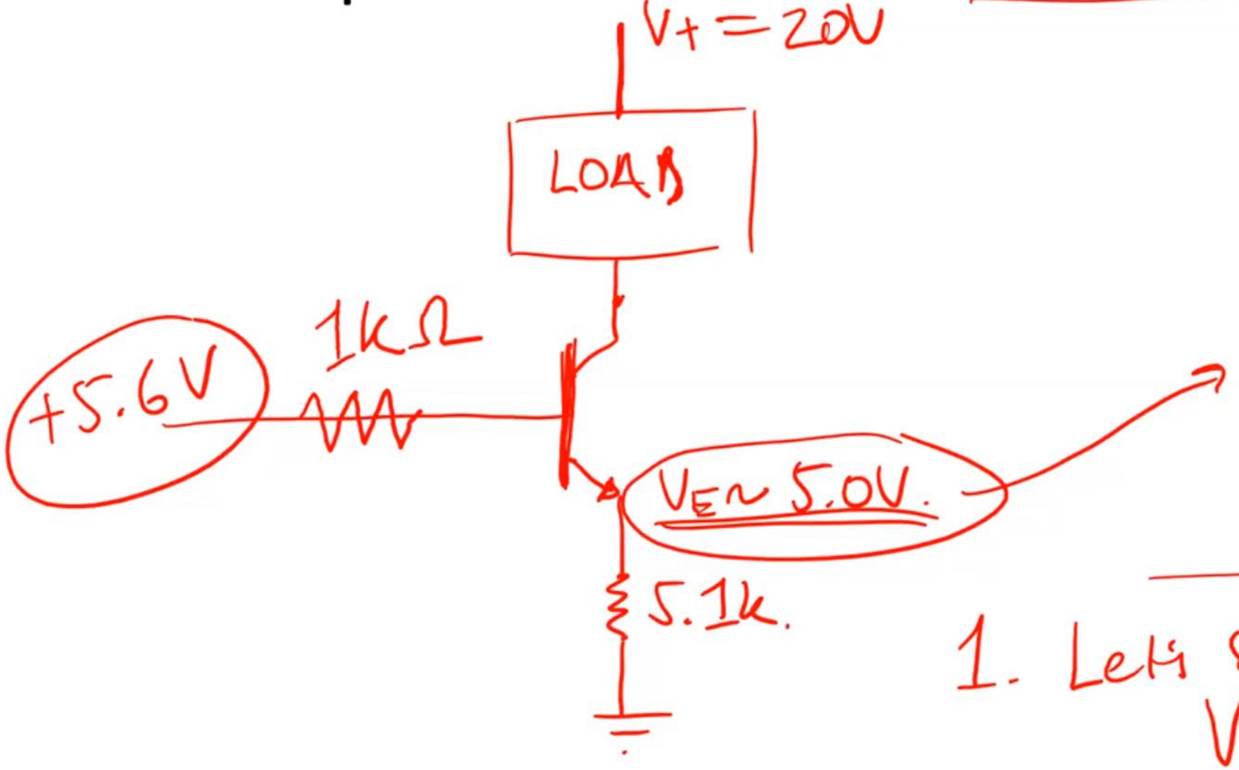
$I_B \ll I_E.$

$$^*\beta = I_C/I_B$$

Ground rules:

1. $V_C > V_E$ by at least ~ 0.1 V
2. $V_B - V_E \approx 0.6\ V$

Understanding transistor behavior through example circuits: *a current source*



$V_E = 5V$, by Ohm: $5 = I_E \cdot 5.1k$.

$\Rightarrow I_E = \frac{5}{5.1k} \sim \underline{1mA}$

$\Rightarrow I_C \cong I_E$.

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1. Let's say R_L is v. small: $R_L = 1k$:
   $V_C \cong 19V(?)$ $V_C > V_E$, Okay.

2. R_L gets large: 100k. $\Rightarrow V_+ = V_C \simeq 1mA \cdot 100k \simeq 100V$ (!)
   $\Rightarrow V_C \cancel{>} V_E \Rightarrow$ transistor behavior changes.
   effect is I_C is reduced.

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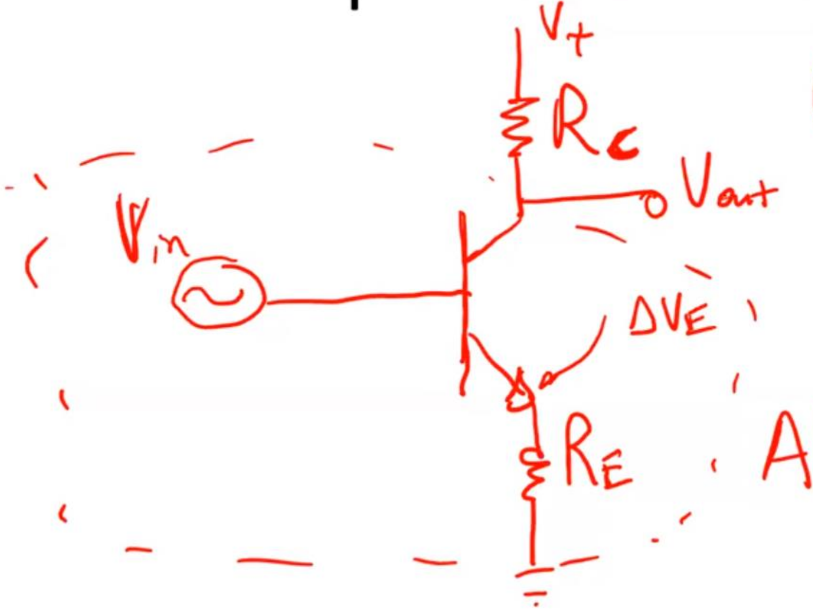
1×

Understanding transistor behavior through example circuits: *an emitter amplifier*

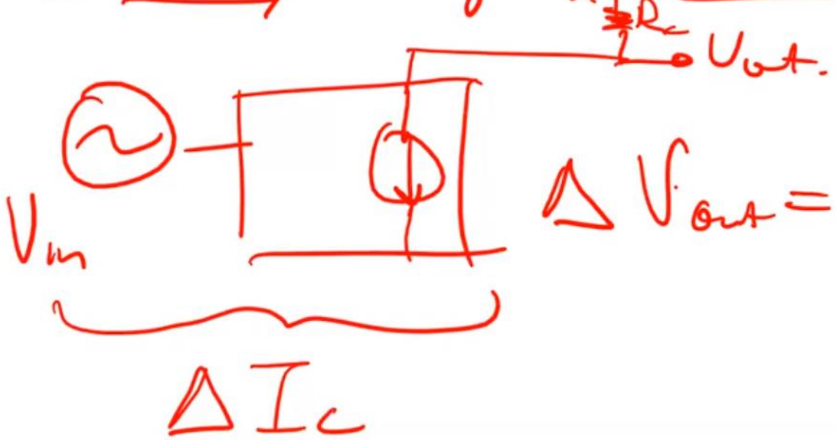


① Let $|V_{in}| = \Delta V_B$. ② $\Rightarrow \Delta V_B \rightarrow \Delta V_E$

$\Delta V_E \Rightarrow \Delta I_E \Rightarrow \Delta I_C$.

③ If R_E is <u>small</u>, we get a <u>large</u> ΔI_C.

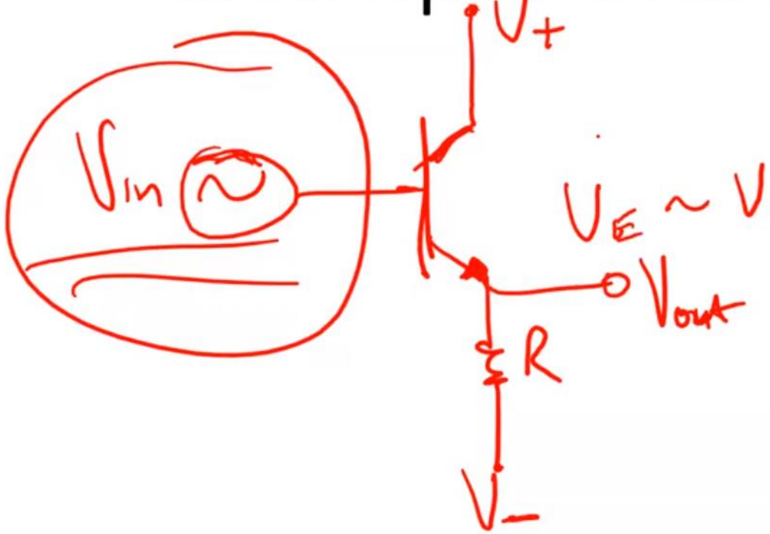
Alternatively,



$\Delta V_{out} = \Delta I_C R_C$.

* Note: gain of emitter amp comes from $R_C > R_E$.

Understanding transistor behavior through example circuits: *a follower*

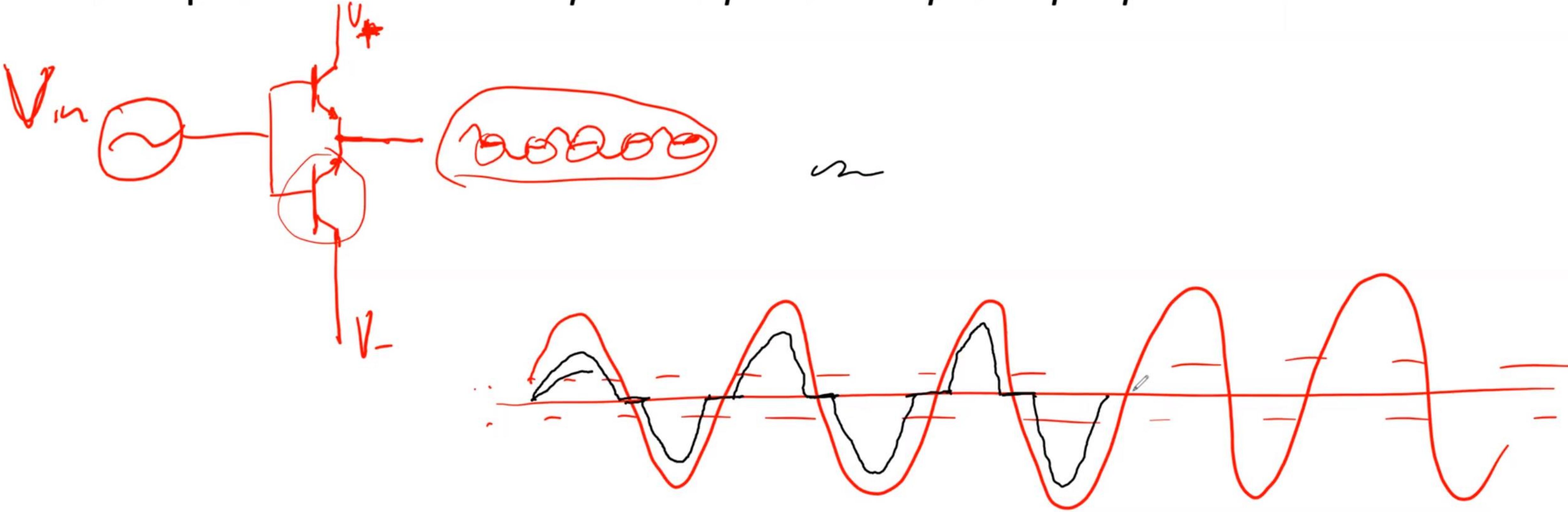


$V_E \sim V_{in}$ $(= V_{in} - 0.6)$.

Why would we do this?

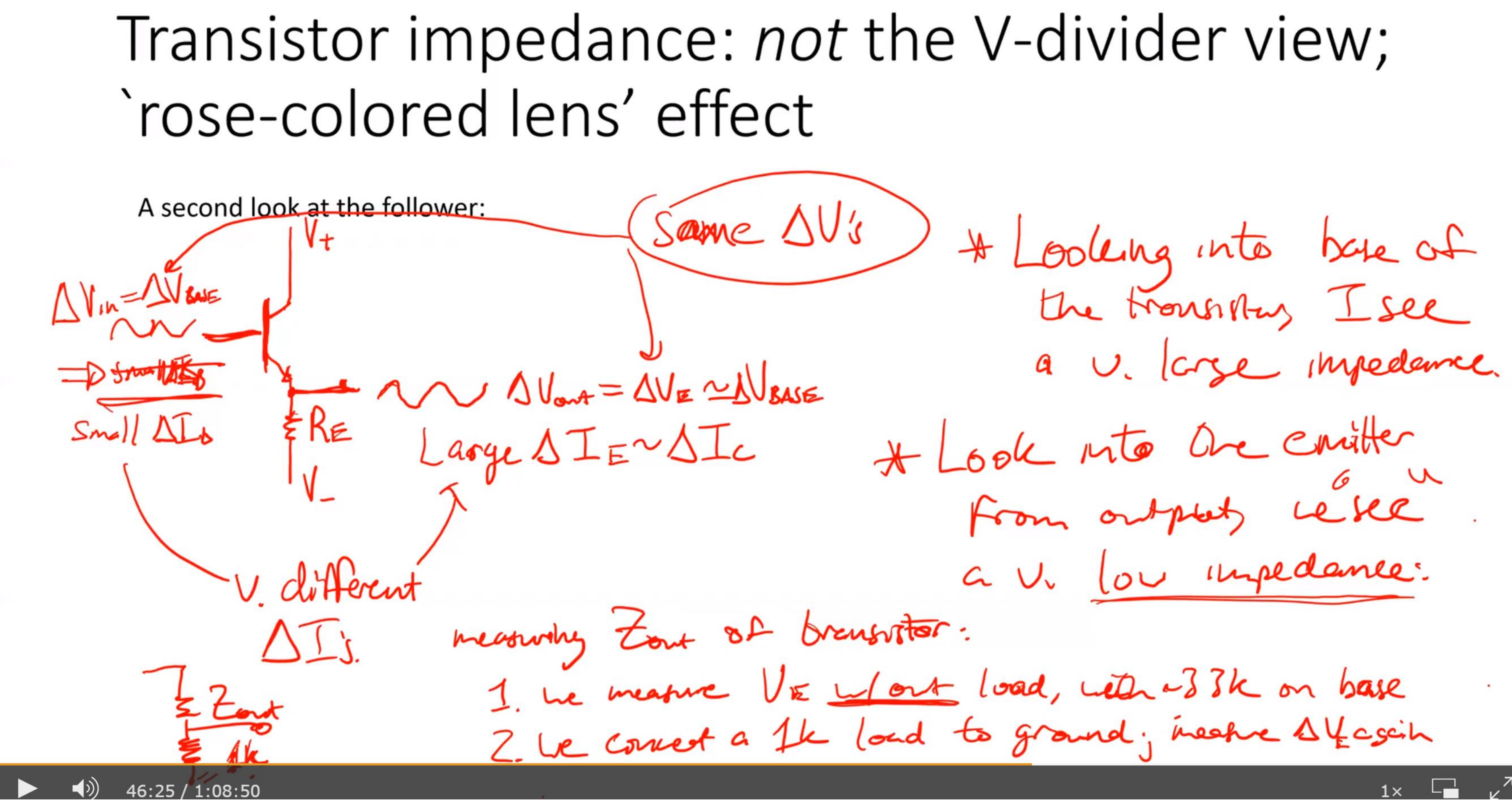
- Incredible behavior of the transistor in changing impedances

Understanding transistor behavior through example circuits: *a push-pull – npn - pnp device*



β is a poorly constrained parameter, around 100 but varies by 50-100%!!!

β – **do *not* use it as a design parameter**



Transistor impedance: *not* the V-divider view; `rose-colored lens' effect

A second look at the follower:

Same ΔV's

$\Delta V_{in} = \Delta V_{BASE}$

⇒ ~~small ΔI~~

Small ΔI_b

$\Delta V_{out} = \Delta V_E \simeq \Delta V_{BASE}$

Large $\Delta I_E \sim \Delta I_c$

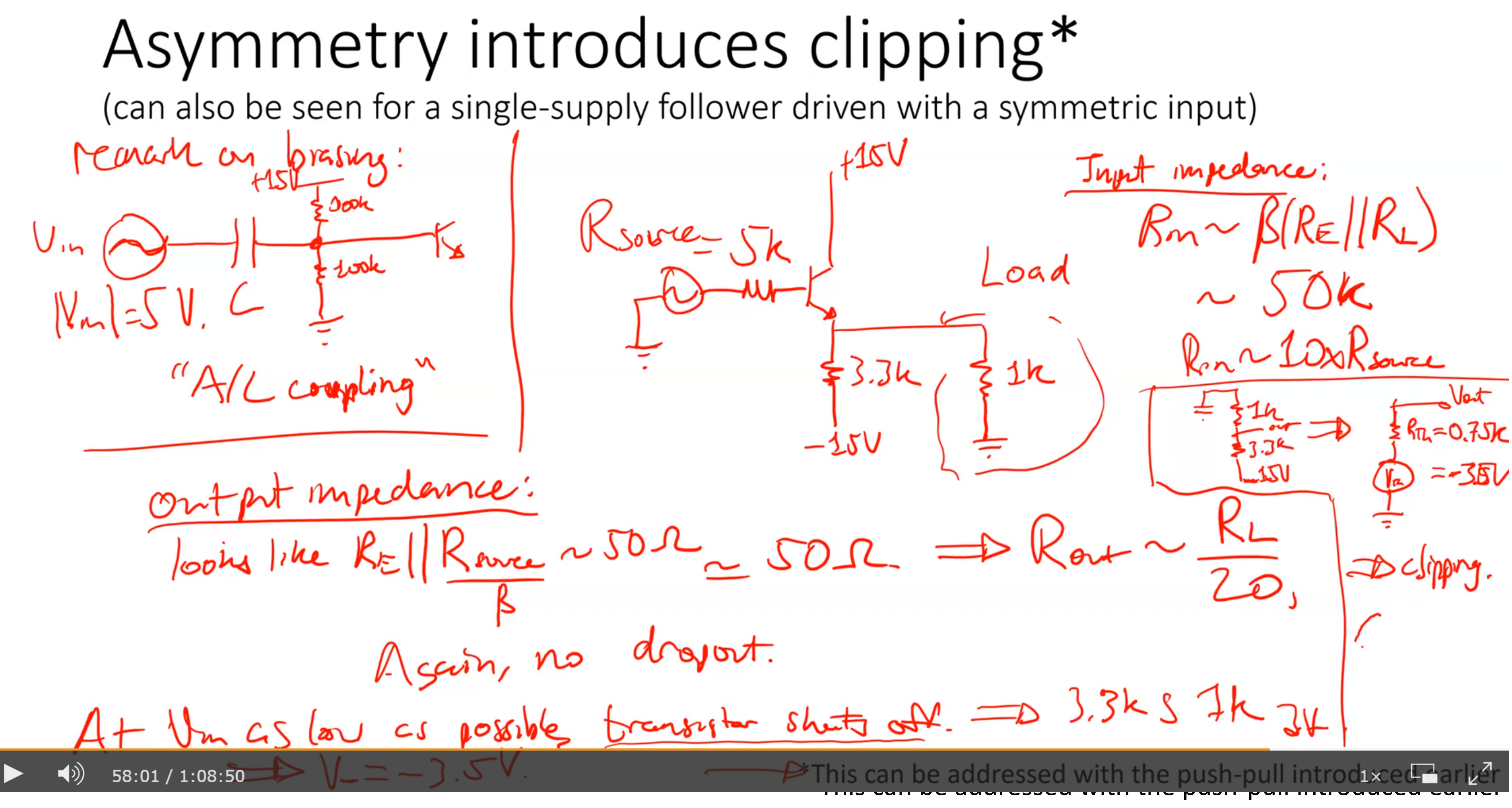
V. different ΔI's.

* Looking into base of the transistor I see a v. large impedance.

* Look into the emitter from output, we "see" a v. <u>low impedance</u>:

measuring Z_{out} of transistor:

1. we measure V_E w/out load, with ~33k on base
2. We connect a 1k load to ground; measure ΔV_E again



Asymmetry introduces clipping*

(can also be seen for a single-supply follower driven with a symmetric input)

remark on biasing:

$|V_{in}| = 5V,\ C$

"A/C coupling"

Input impedance:

$R_{in} \sim \beta(R_E \| R_L)$

$\sim 50k$

$R_{in} \sim 10 \times R_{source}$

$\Rightarrow$ $= -3.5V$

Output impedance:

looks like $R_E \| \frac{R_{source}}{\beta} \sim 50\Omega \simeq 50\Omega \Rightarrow R_{out} \sim \frac{R_L}{20}$,

$\Rightarrow$ clipping.

Again, no dropout.

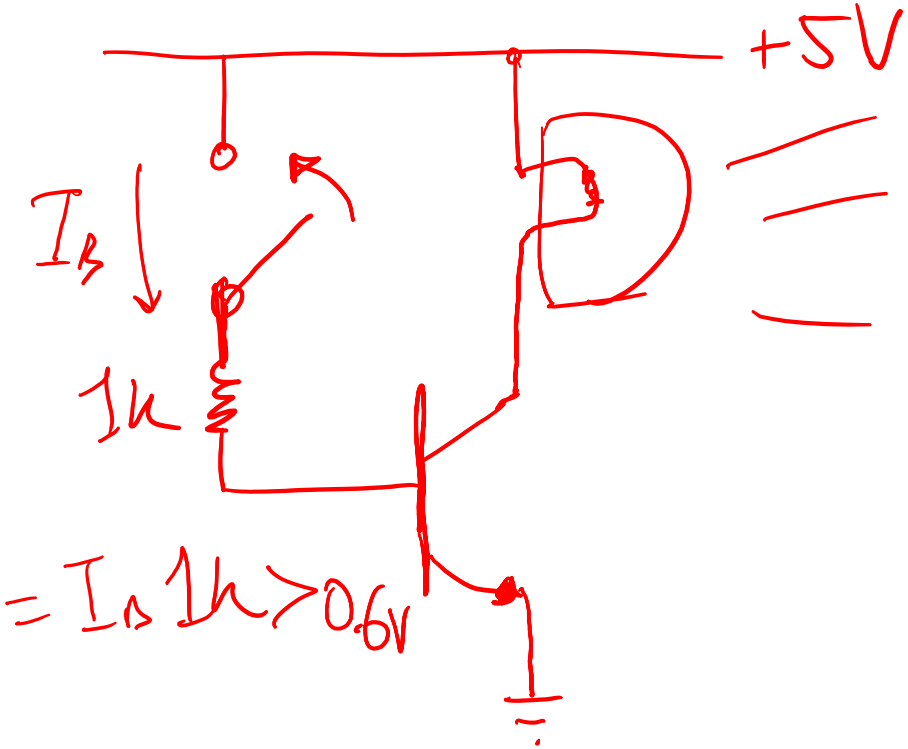
At V_{in} as low as possible transistor shuts off. $\Rightarrow$ 3.3k & 1k $\Rightarrow$ $V_- = -3.5V$.

$\longrightarrow$ *This can be addressed with the push-pull introduced earlier

This can be addressed with the push-pull introduced earlier

* Read ch. 2 of AoE. up through § 2.2.7.

An anomalous transistor circuit: the switch



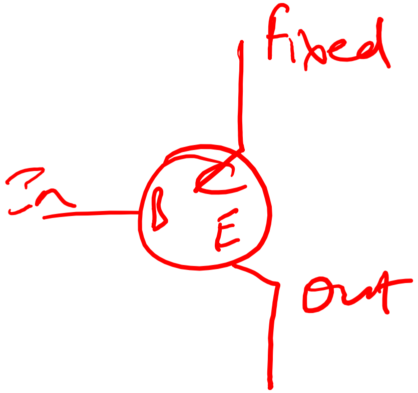
$V = I_B \, 1k > 0.6V$

- Transistor is in one of two states:
  1. totally on → current passes through lamp, light emits.
  2. Totally off: → No current through lamp, no light.

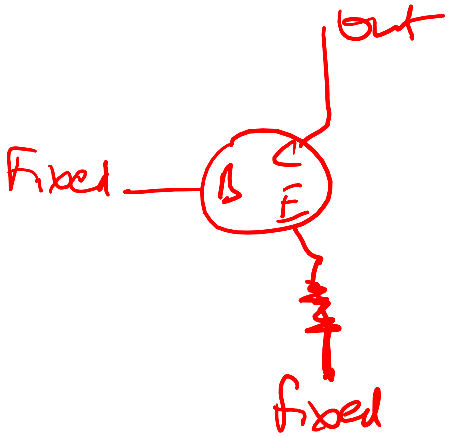
$I_C \neq \beta I_B$; V_{CE} is low reducing power consumed by transistor.

A summary of our transistor circuits:

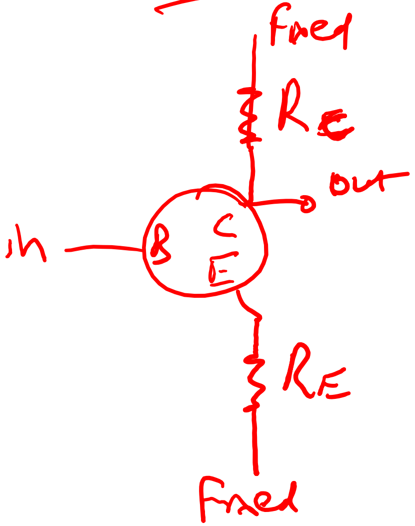
Follower



Current source



Amplifier



Switch