Lecture 1 : Emitter Follower

1. BJT Review
2. Emitter Follower Analysis
3. Emitter Follower Design

★ minerva.union.edu/bumat

- PreLab 1 due next Thu (Sep 19)
- HW1 due next Fri (Sep 20)

Textbook Reading: 6-3 Transistor currents

6-8 Reading data sheets

6-10 Variations in current gain

7-11 pnp transistors

9-6 Darlington

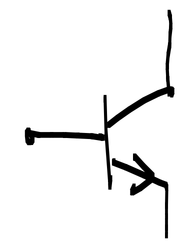
9-7 Zener Follower

Analysis vs. Design

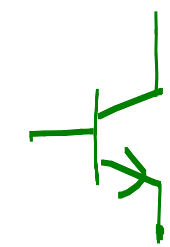
- ECE 248: Analyze circuits

★ ECE 363: Design circuits

Example Emitter Follower



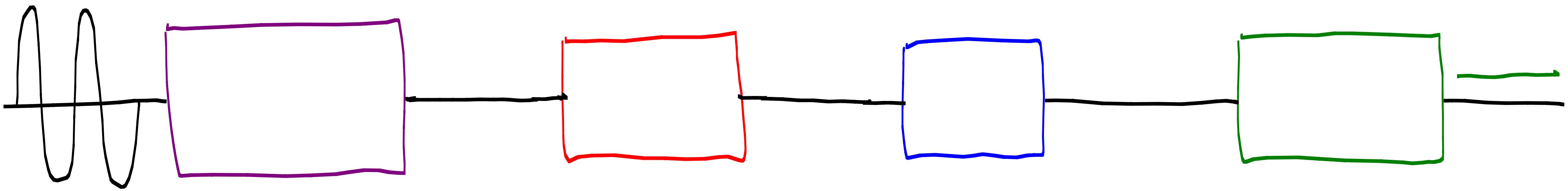
Example Audio Amplifier



1. Linear DC Supply

- Many electronic devices require a DC voltage.
- Wall outlet provides AC voltage
- Linear DC power supplies have the following:

Benchtop Supply

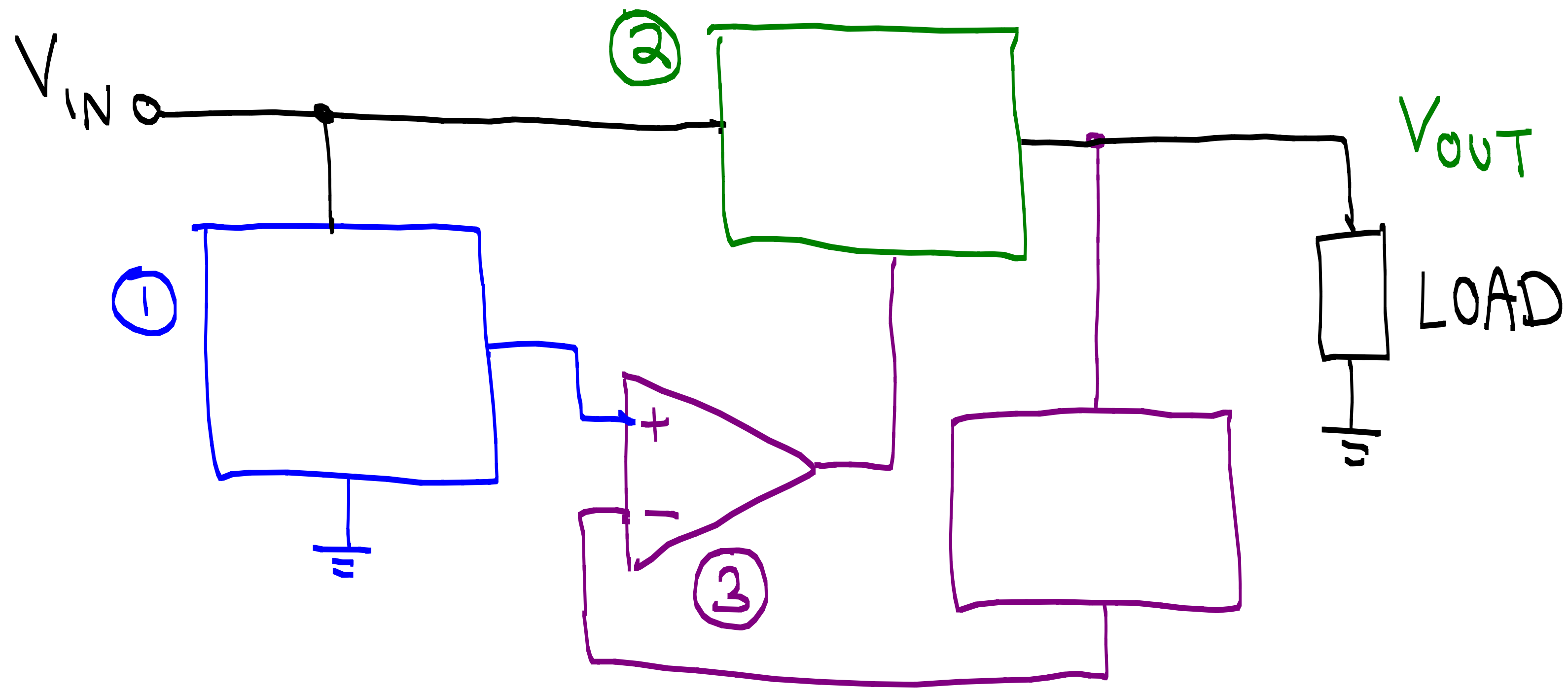


Q: How to make a voltage regulator?

① Voltage reference

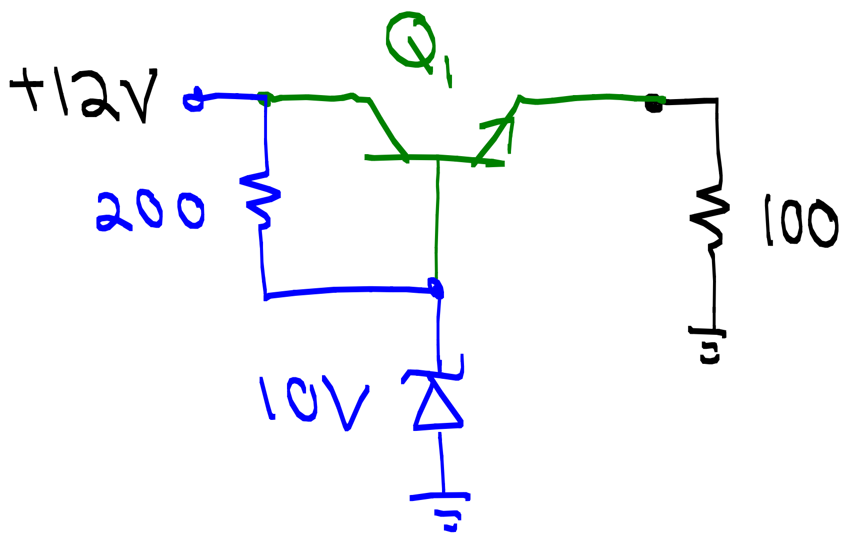
② Pass Transistor

③ Negative Feedback

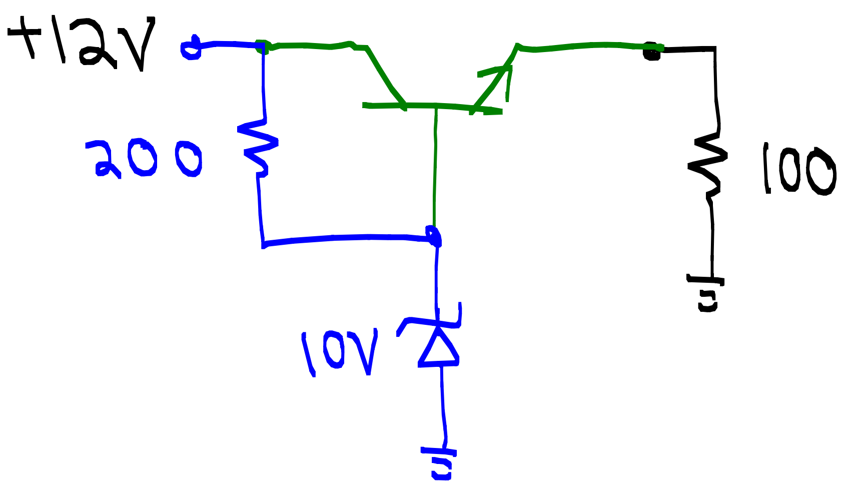


2. Emitter Follower Analysis

- Recall the zener follower from ECE248:



- "Quick" analysis (ECE 248 style):



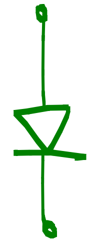
★ Problems with this circuit?

①

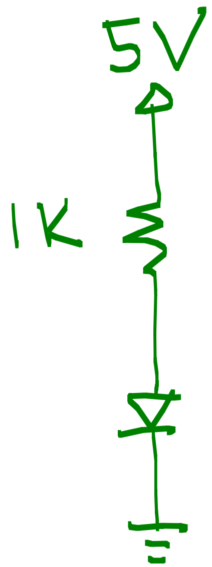
②

- Diode Review

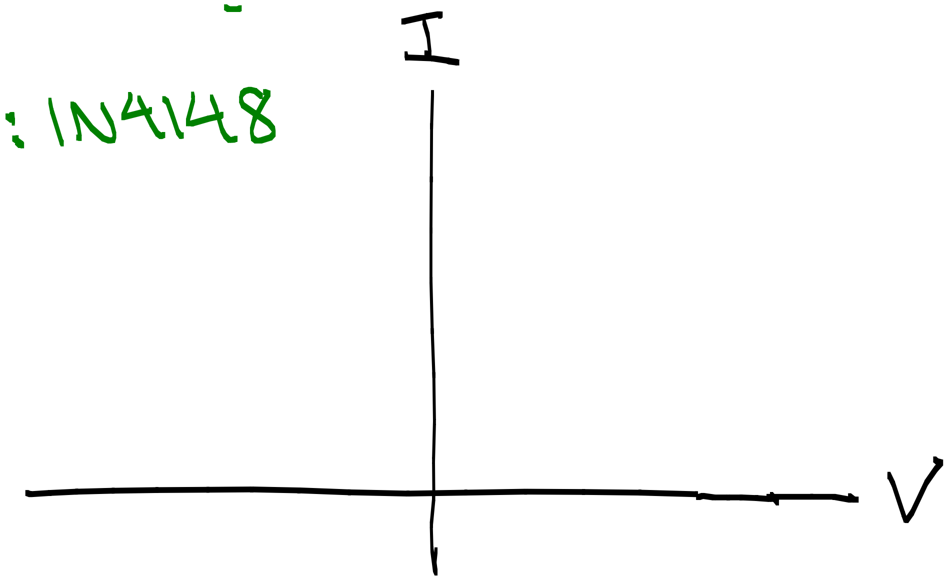
"Typical" Diode



Ex:

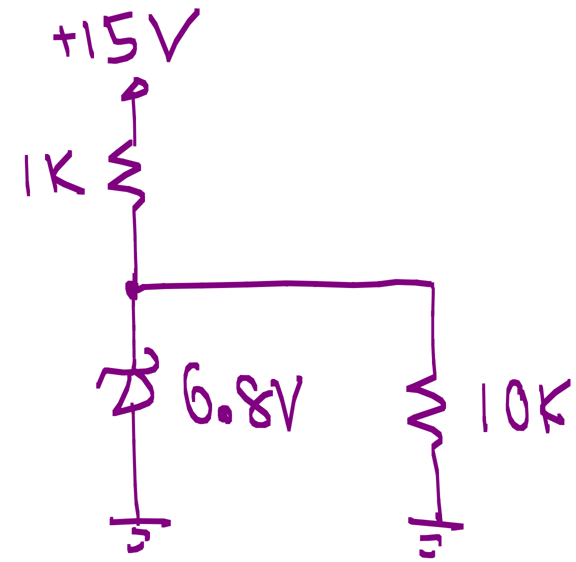


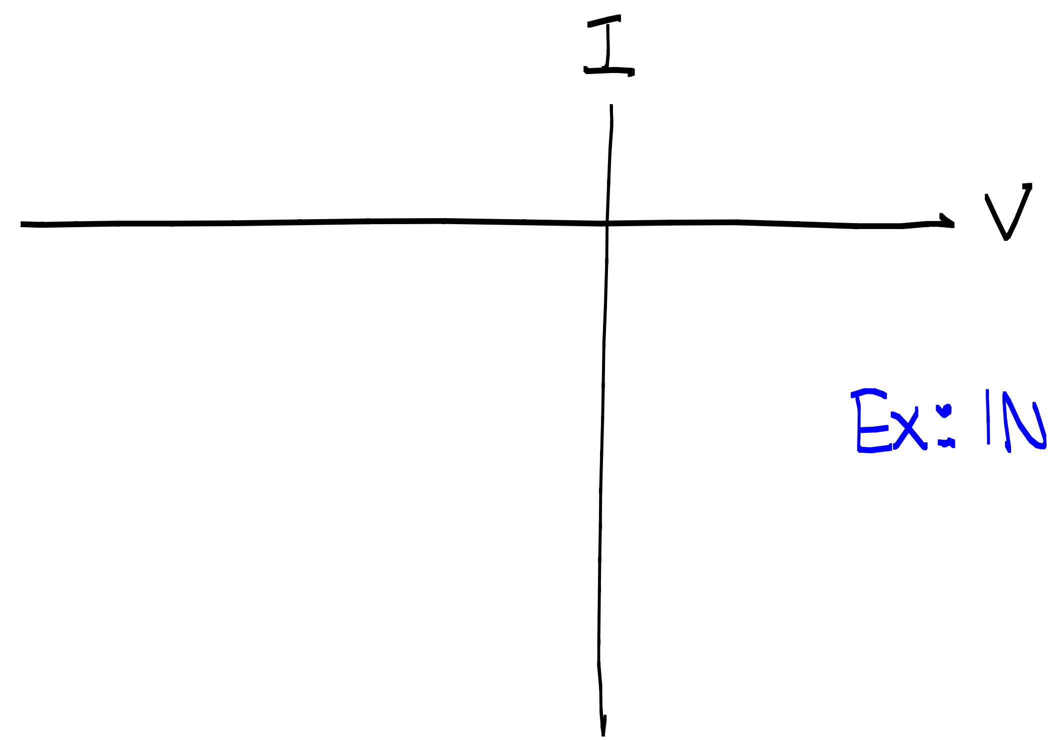
Ex: 1N4148



Zener Diode

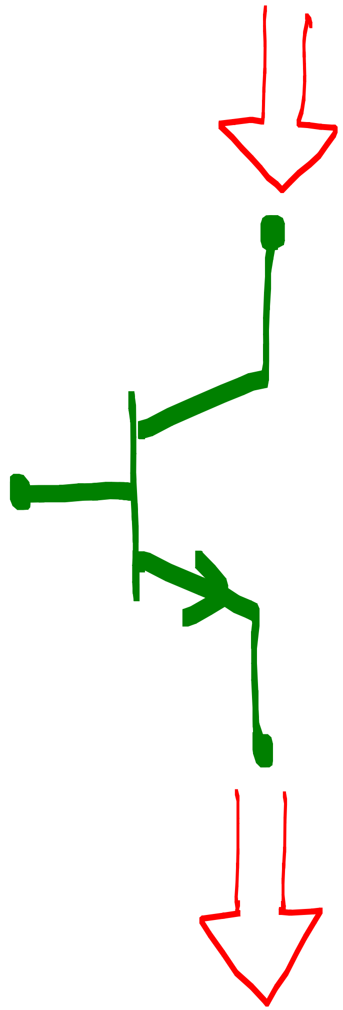
Ex:

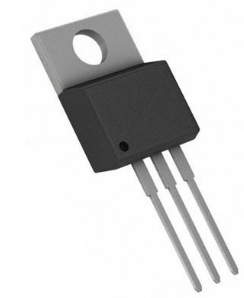




Ex: 1N4735A

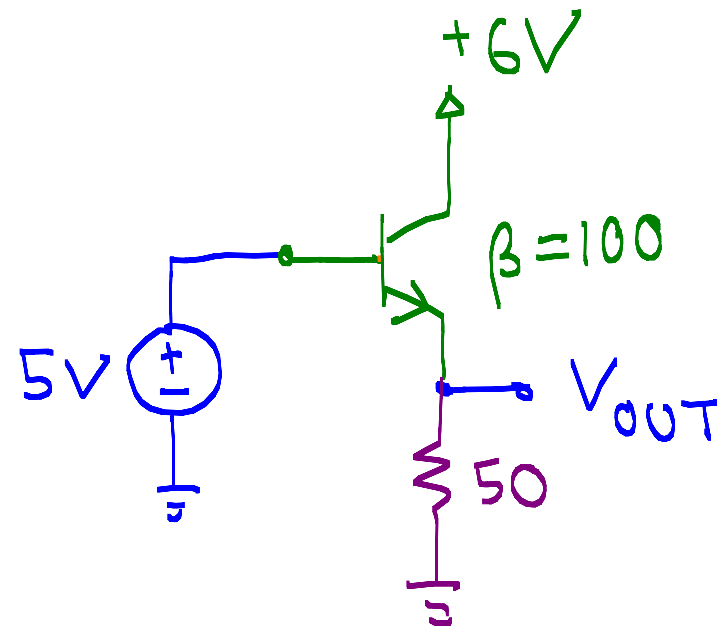
• Transistor Review (Active Mode)





Typical $\begin{cases} \beta = \\ I_c = \end{cases}$

Ex:



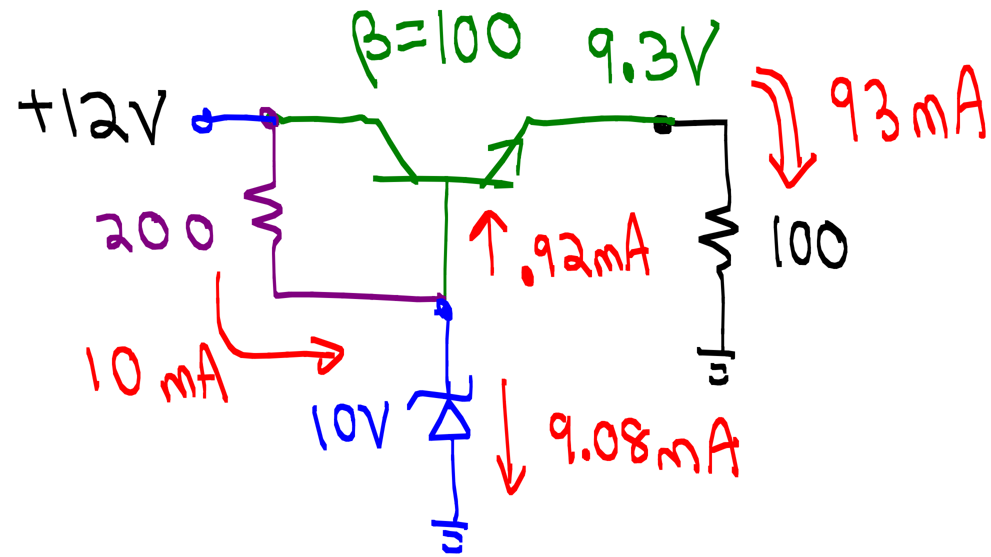
① V_{OUT}

② i_L

③ i_S

- Power Dissipation

Device failure is usually due to



☆ Rule of thumb:

Ex: 1/4 W resistor

P =

1/2 W Zener

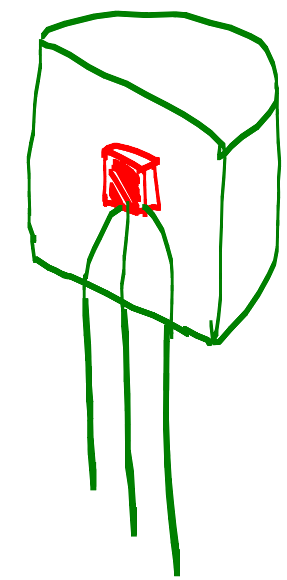
P =

0.6 W Transistor

P =

Q: What determines max power limit?

A: The temperature



① Power dissipation

② Heat travels

③ Heat escapes

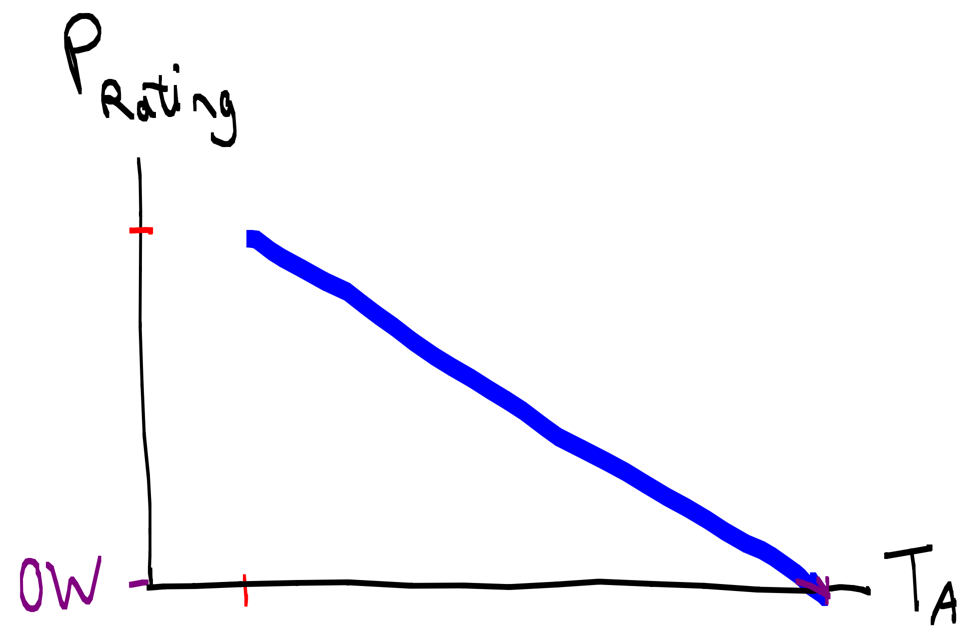
Thermal Characteristics $T_a = 25°C$ unless otherwise noted For 2N3904 transistor (1.8)

Symbol	Parameter	Max.			Units
		2N3904	*MMBT3904	**PZT3904	
P_D	Total Device Dissipation Derate above 25°C	625 5.0	350 2.8	1,000 8.0	mW mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction to Case	83.3			°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	200	357	125	°C/W

For BJT, max $T_J = 150°C$!

Derating Curve

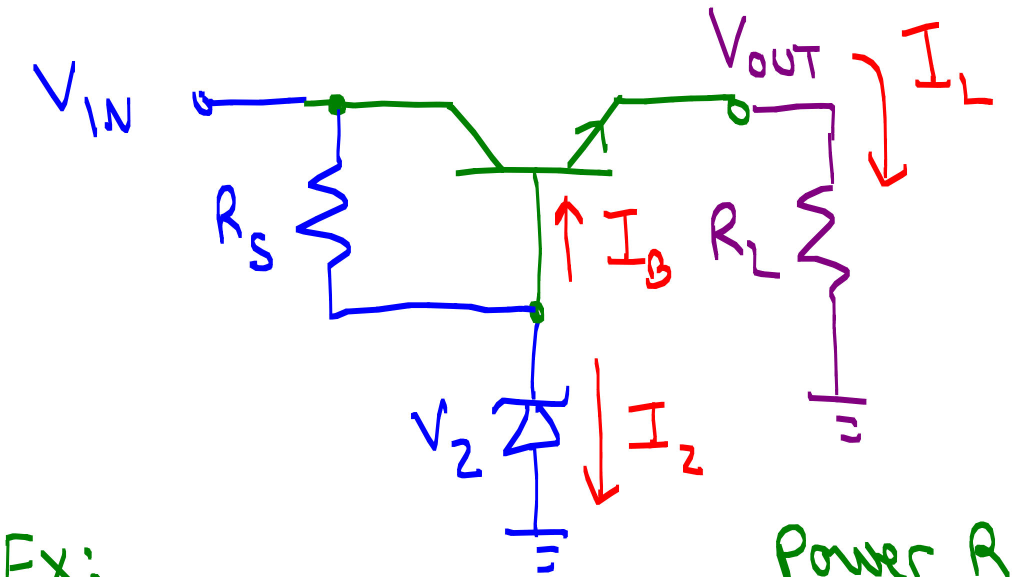
$(T_A = 25°C)$ $P_{Rating} =$



$(T_A = 75°C)$ $P_{Rating} =$

3. Emitter Follower Design

Q: How to choose components?



Ex:

Transistor	Max I_C	Power Rating: No heat sink $T_A = 25°C$	Power Rating: With Heat sink $T_C = 25°C$
2N3904	200 mA	625 mW	
2N4401	600 mA	625 mW	1.5W
TIP31	3 A	2 W	40 W

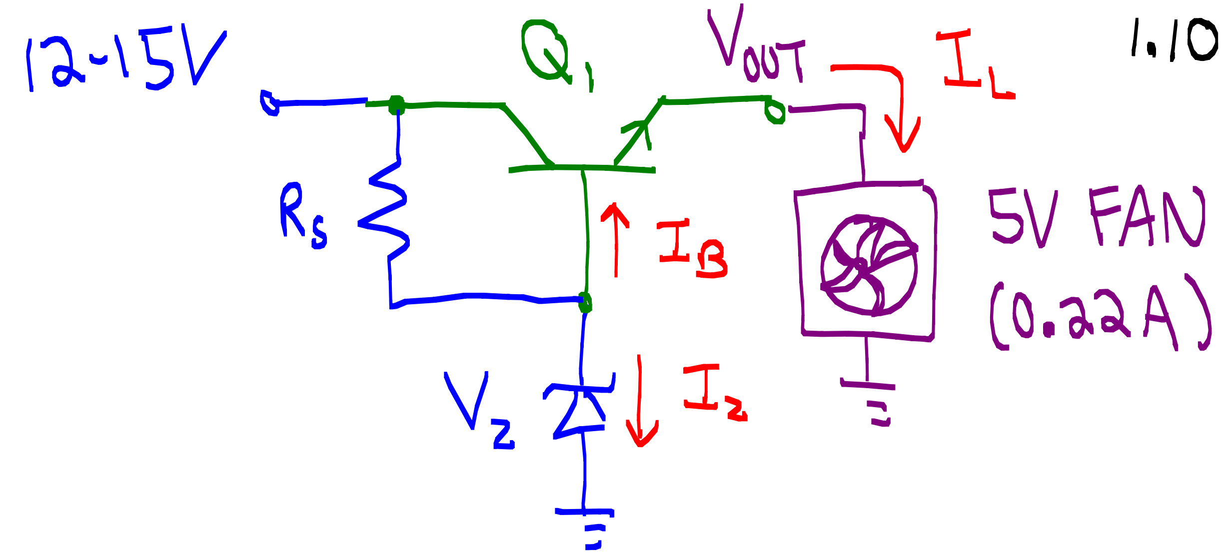
☆ Know your load:

☆ Proper Transistor:

☆ Zener:

2N3904 2N4401 TIP31

- Design example



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- Q1 ?

- RS ?

- If designing for "typical" Q, properties:

$\Rightarrow R_s <$

Power rating?

Zener?

- If designing for "worst case" Q, properties:

$\Rightarrow R_s <$

Zener?

Appendix #1

(A1.1)

- In reality, β depends on I_c!

→ To obtain "typical" value, use graph of β vs I_c in datasheet

TIP31

STEP 1 Estimate I_c

STEP 2 Use plot to find β

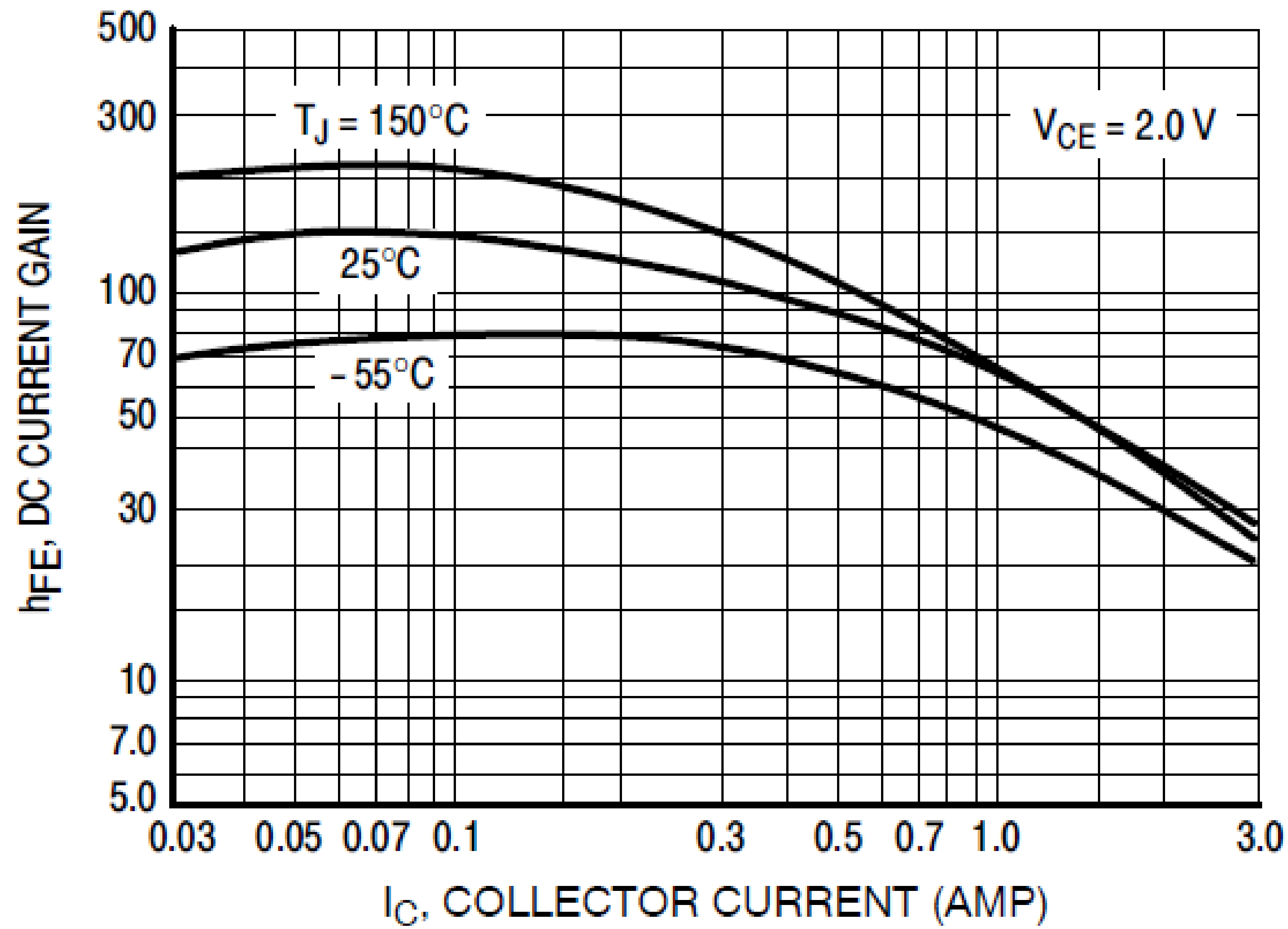


Figure 9. DC Current Gain

- Any device parameter has "typical" and "worst case" values! (A1.2)

use the table of "On Characteristics" ←

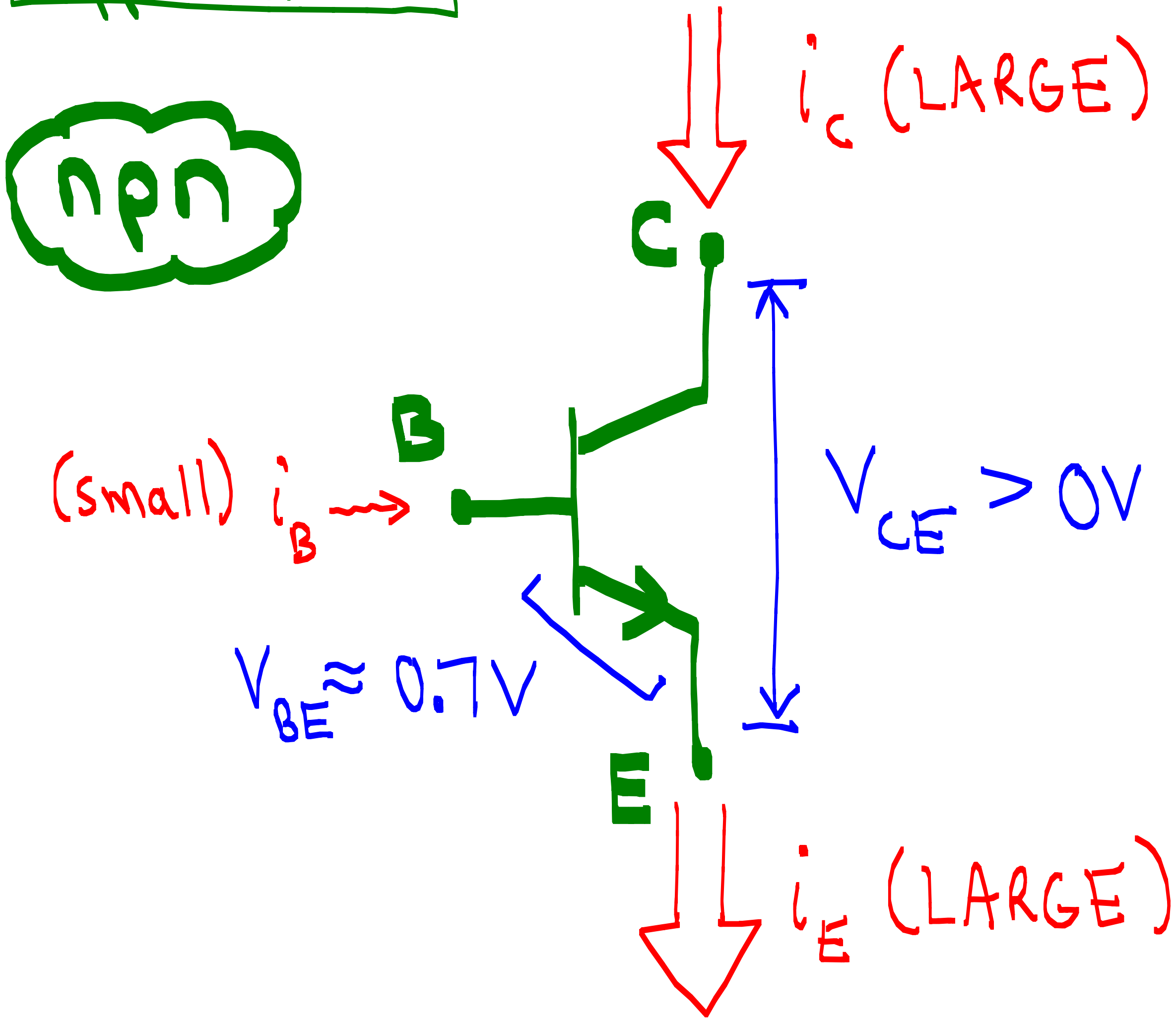
TIP31

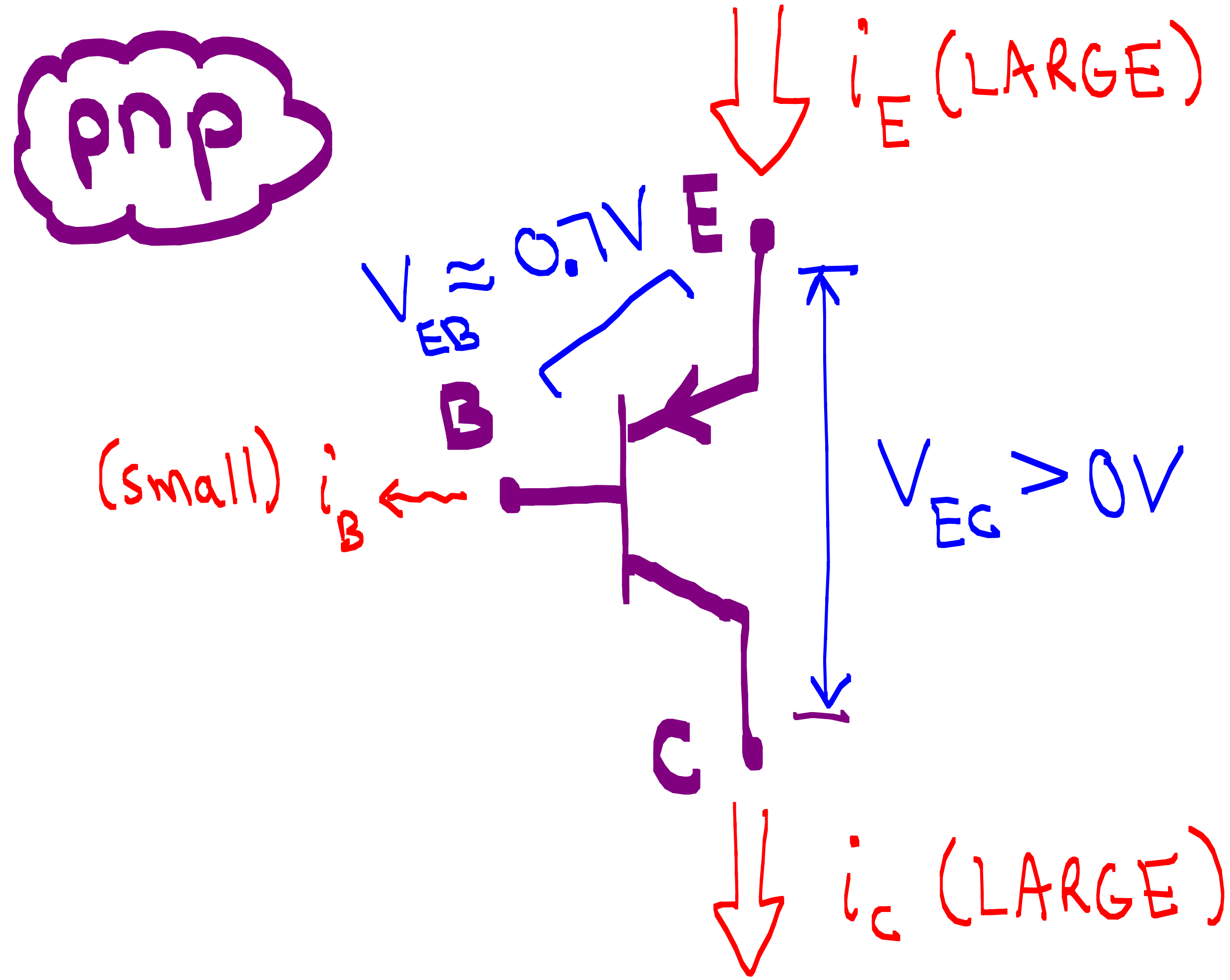
ON CHARACTERISTICS (Note 2)

		min	max	
DC Current Gain (I_C = 1.0 Adc, V_{CE} = 4.0 Vdc) (I_C = 3.0 Adc, V_{CE} = 4.0 Vdc)	h_{FE}	25 10	– 50	–
Collector–Emitter Saturation Voltage (I_C = 3.0 Adc, I_B = 375 mAdc)	$V_{CE(sat)}$	–	1.2	Vdc
Base–Emitter On Voltage (I_C = 3.0 Adc, V_{CE} = 4.0 Vdc)	$V_{BE(on)}$	–	1.8	Vdc

- Table only has β_{min} for $I_c = 1A$.
  → But we need $I_c \sim 220$ mA.

Appendix #2





Always true!

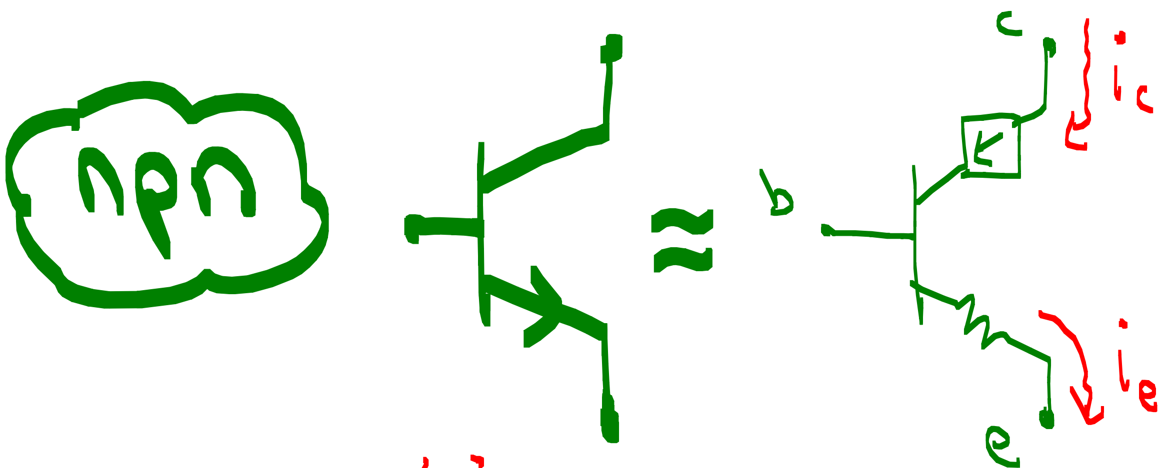
$$i_B + i_C = i_E$$

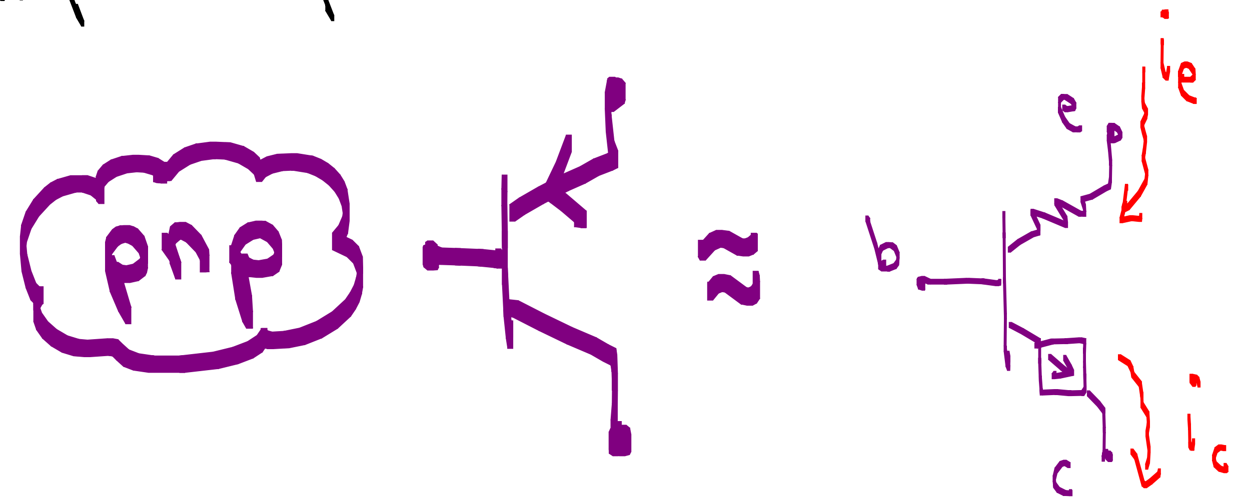
Only true for Active Mode

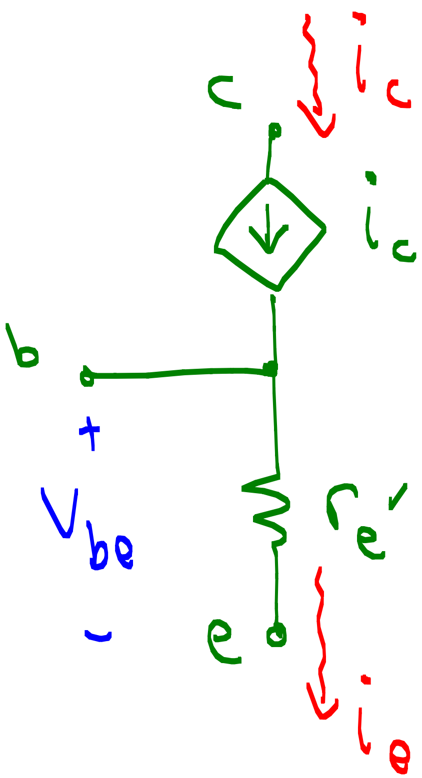
$$i_C = \beta i_B = \alpha i_E \text{ AND } i_E = (\beta + 1) i_B$$

★ For both npn + pnp ⟹ $i_B + i_C = i_E$

- **T-model** ← useful for understanding amplifier gain and input/output impedance

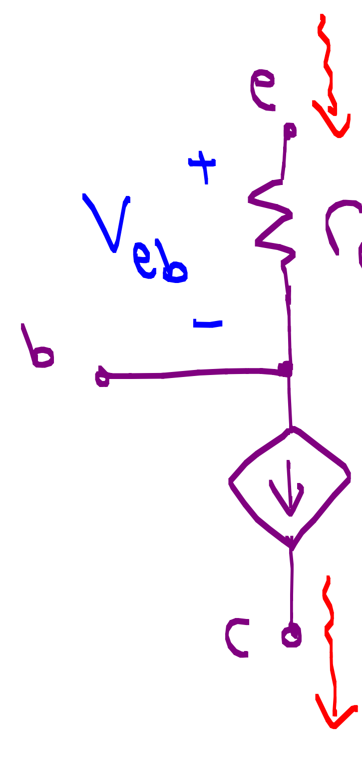






$$i_c = \alpha i_e = \alpha \frac{V_{be}}{r_e'}$$

$$r_e' = \frac{.026V}{I_{EQ}}$$



$$r_e' = \frac{.026V}{I_{EQ}}$$

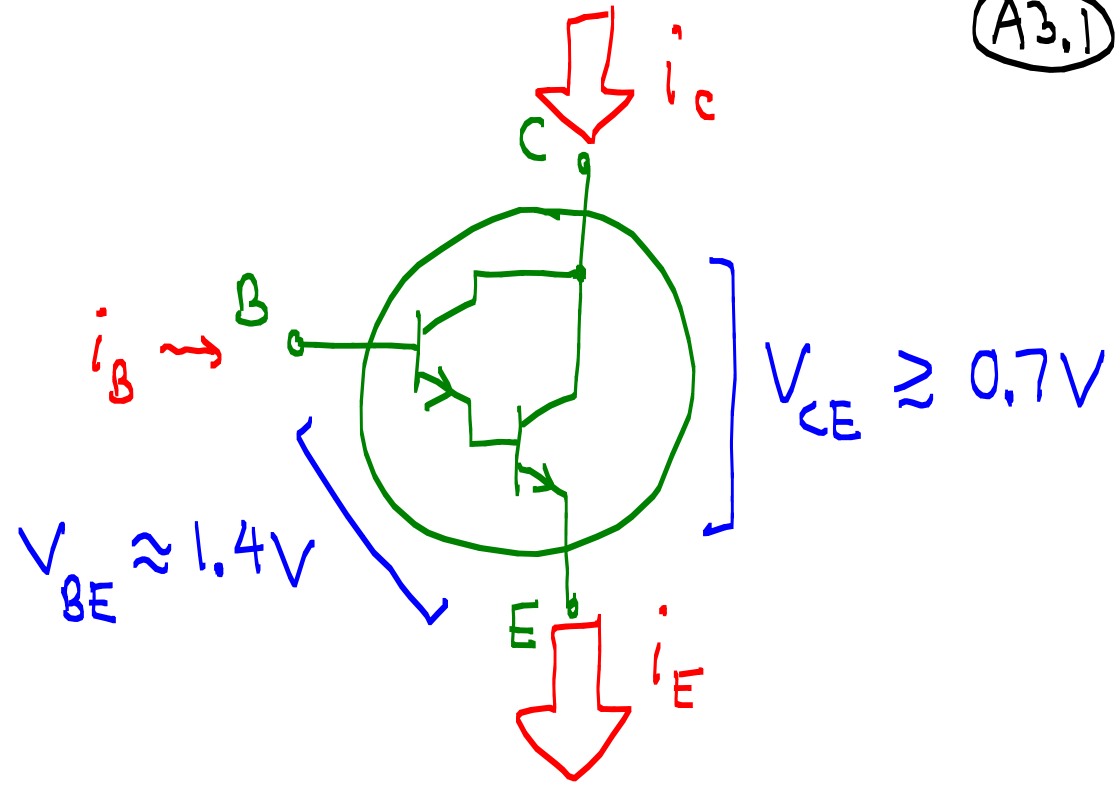
$$i_c = \alpha i_e = \alpha \frac{V_{eb}}{r_e'}$$

Appendix #3

- Extra high current gain is possible with a Darlington! ($\beta > 1000$)

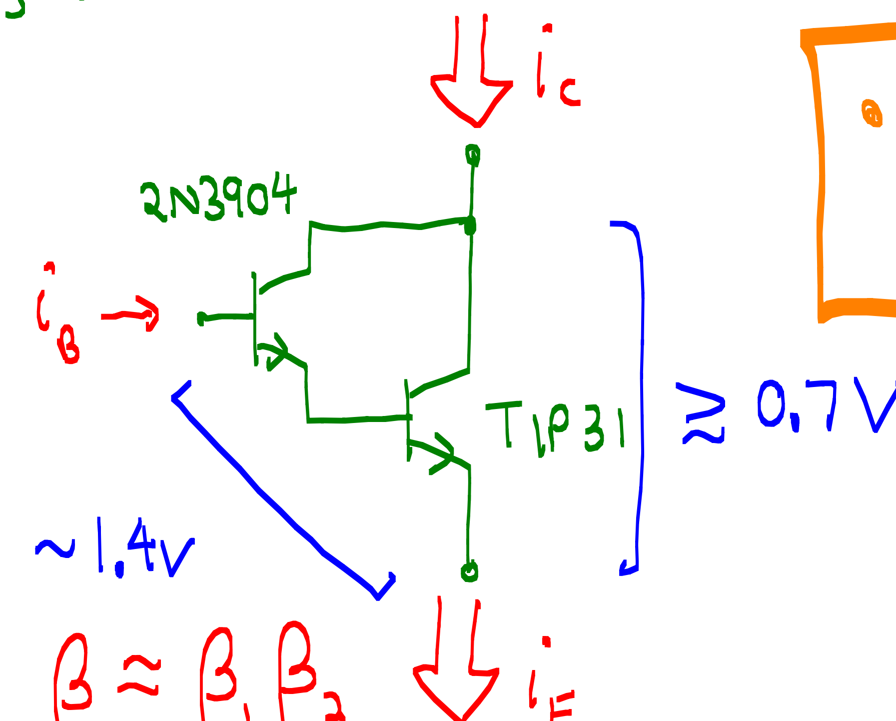
(a) Darlington Transistor

→ single device containing both transistors (e.g. KSP14, TIP120)



(b) Darlington Pair

→ two separate transistors connected to each other (e.g. 2N3904 + TIP31)



$\beta \approx \beta_1 \beta_2$

- For Darlington "quick" analysis,

$V_{BE} = 1.4V$

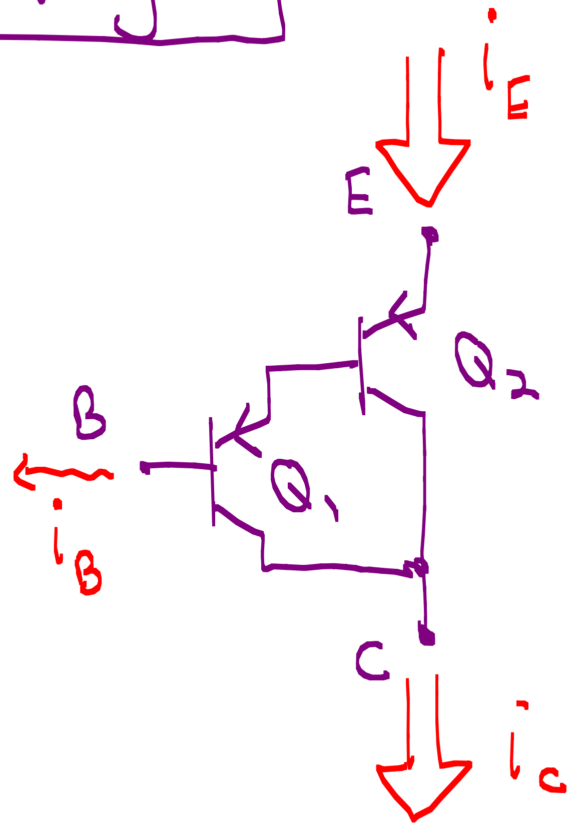
$\beta = 10{,}000$

$V_{CE(sat)} = 0.7V$

pnp Darlington

Method 1

Two pnp's

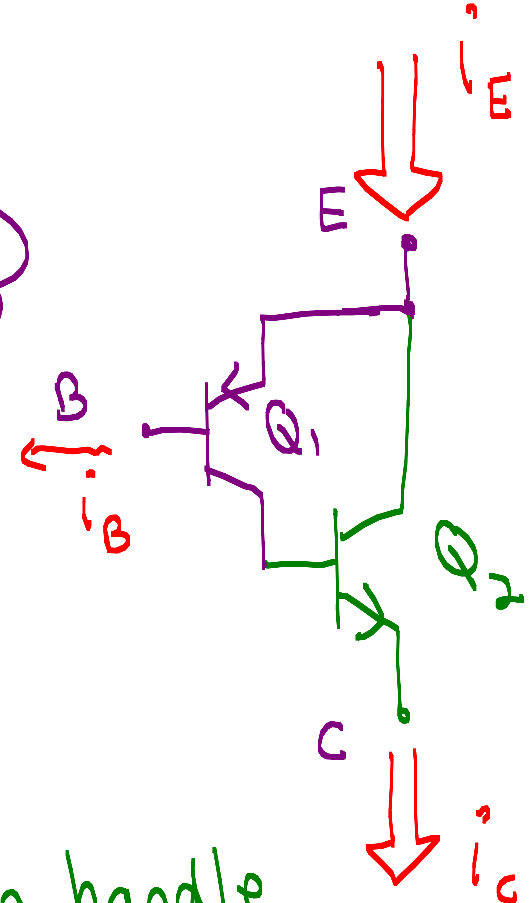


Method 2

Q_1 = pnp

Q_2 = npn

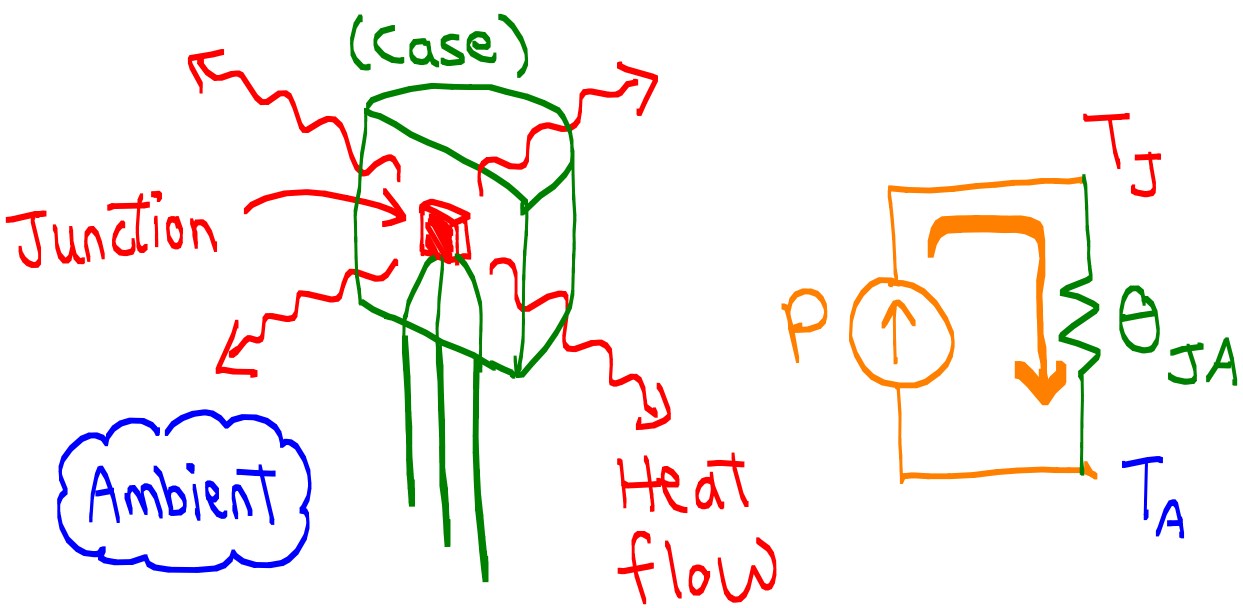
npn can handle higher currents than pnp



Called "Complementary" or "Sziklai" Pair

Appendix #4 Heat sink formulas

• NO heat sink



$$T_J = T_A + P \times \theta_{JA}$$

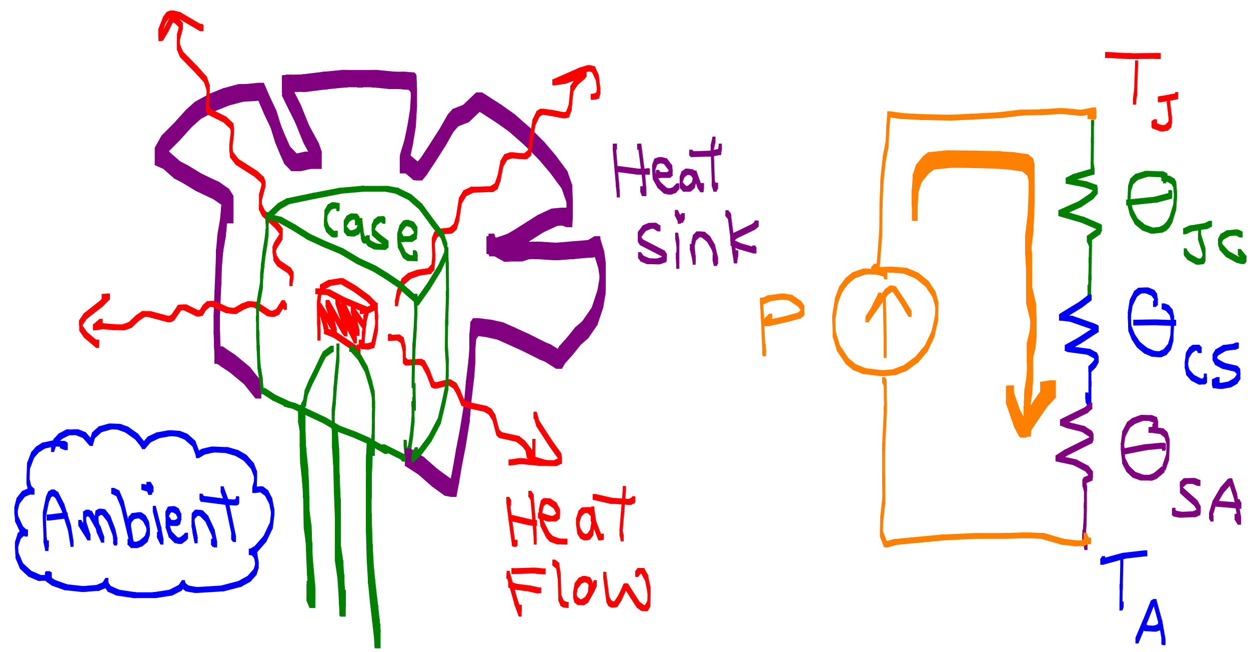
Junction to Ambient

$$= T_A + P \times [\theta_{JC} + \theta_{CA}]$$

Junction to case

Case to Ambient

• WITH heat sink



"new" θ_{JA}

$$T_J = T_A + P \times [\theta_{JC} + \theta_{CS} + \theta_{SA}]$$

Junction to case

Case to Sink

Sink to Ambient