Purdue University Department of Physics

Physics 53600
Electronics Techniques for Research

Now in PowerPoint!

Spring 2020 Semester

Prof. Matthew Jones

Midterm Exam – February 25

1. Resistor divider as a non-ideal voltage source
2. Initial value problem – transient response
3. AC circuit analysis/filter circuit
4. Transmission line question

If you are interested, Dawith Lim will give a review session at 4:30 pm on Friday, probably in the lab (Phys 349?)

Bipolar Junction Transistors

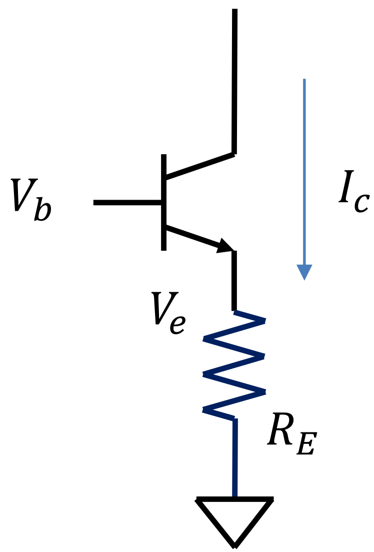
- Simplified design rules:
  1. Assume $V_{be} \approx 0.7\ V$
  2. NPN: $V_e = V_b - V_{be},$ PNP: $V_e = V_b + V_{be}$
  3. Collector current: $I_c = I_e$
- Example:
  - Design a current 10 mA current source
  - A typical problem with electronics design is that this is not enough information to constrain the design.

Bipolar Junction Transistors

- Additional constraints:
  - Let's use an NPN transistor
  - What is the voltage source?
  - What is the maximum acceptable collector voltage?
    - $V_b < V_c$ to reverse bias an NPN transistor.
    - $V_b > V_c$ to reverse bias an PNP transistor.
  - What is a convenient way to generate the required base voltage?

Bipolar Junction Transistors

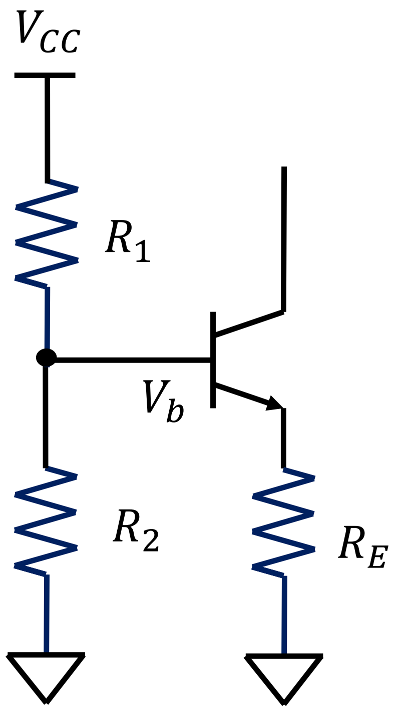
- Assume, in this example, that $V_{CC} = 5\text{ V}$.
- Furthermore, assume that $V_c > 2.5\text{ V}$.
  - This constrains the base voltage: $V_b \approx 2.4\text{ V}$.
  - If $V_{be} = 0.7\text{ V}$, then $V_e = V_b - V_{be} = 1.7\text{ V}$.



$$R_E = \frac{V_e}{I_e} = \frac{1.7\text{ V}}{10\text{ mA}} = 170\ \Omega$$

Bipolar Junction Transistors

- A convenient way to generate the base voltage is with a voltage divider:



$$V_b = V_{CC}\frac{R_2}{R_1 + R_2}$$

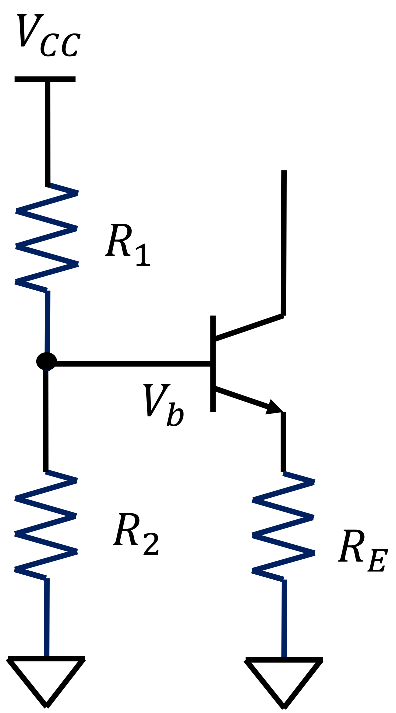
But this is not enough information to constrain R_1 and R_2.

The impedance of the voltage source should be small compared with the input impedance of the base.

$$R_b \sim \beta R_E \approx 17\ \mathrm{k\Omega}$$

Bipolar Junction Transistors

- Suppose we want the impedance of the voltage source to be about $R_{th} = 10\ \text{k}\Omega$.



$$V_b = V_{CC}\frac{R_2}{R_1 + R_2}$$

$$R_{th} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1}$$

$$R_1 = \frac{V_{CC}}{V_b}\ R_{th} = \left(\frac{5\ V}{2.4\ V}\right)(10\ \text{k}\Omega)$$

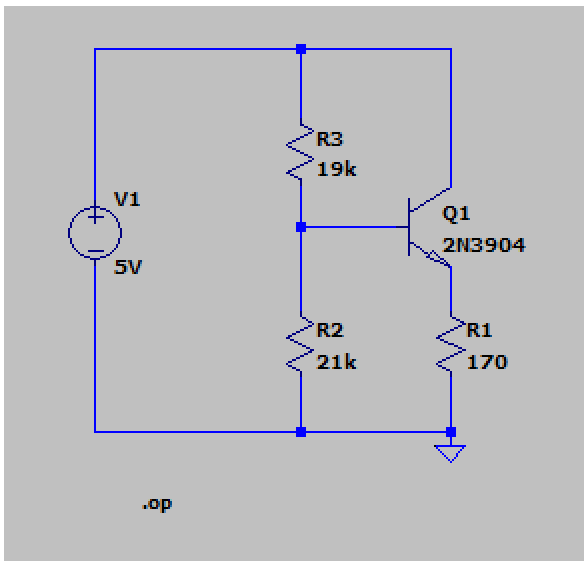
$$= 21\ \text{k}\Omega$$

$$R_2 = R_1\frac{V_b}{V_{CC} - V_b} = (21\ k\Omega)\left(\frac{2.4\ V}{2.6\ V}\right)$$

$$= 19\ \text{k}\Omega$$

Bipolar Junction Transistors

- These estimates provide a good starting point for simulating the circuit:



--- Operating Point ---

V(n001):	5	voltage
V(n002):	2.31434	voltage
V(n003):	1.59986	voltage
Ic(Q1):	0.00937979	device_current
Ib(Q1):	3.11436e-005	device_current
Ie(Q1):	-0.00941094	device_current
I(R3):	0.00014135	device_current
I(R2):	0.000110207	device_current
I(R1):	0.00941094	device_current
I(V1):	-0.00952115	device_current

This is close… maybe raise the base voltage a little bit by increasing R2.

$$R_2 = 24\ \mathrm{k\Omega} \text{ gives } I_c = 10.075\ \mathrm{mA}.$$

Temperature Dependence

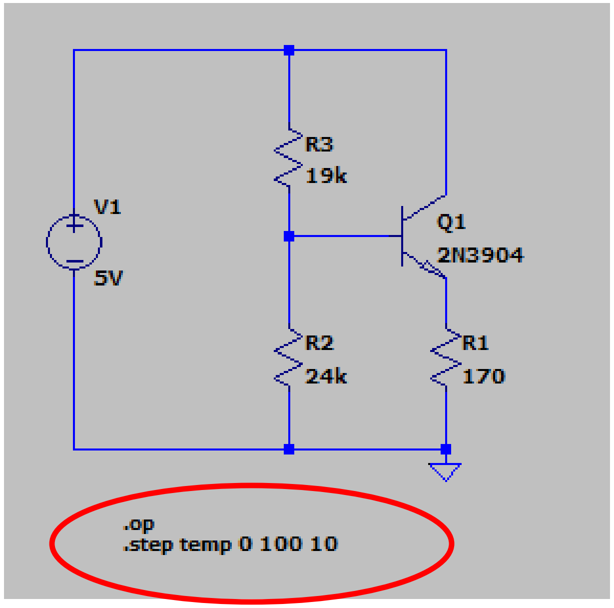
- Recall that the potential across the PN junction is temperature dependent:

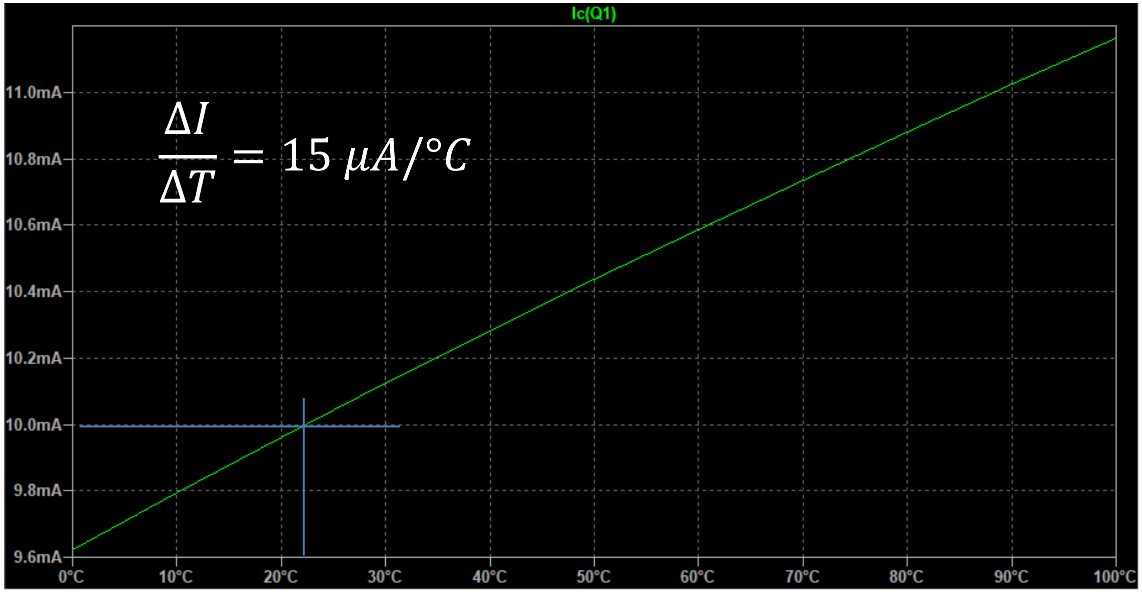
$$I = I_0\left(e^{eV/kT} - 1\right)$$

$$V_{be} = \frac{kT}{e}\log\left(\frac{I}{I_0}\right)$$

- The current source should vary linearly with temperature.

Temperature Dependence

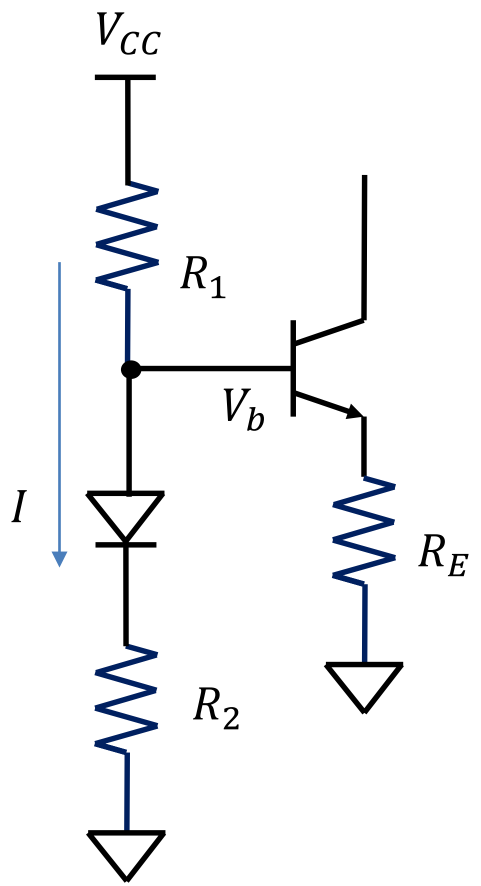




- Sometimes this is perfect: it provides an ideal way to measure temperature.
- This is usually not ideal... the current depends linearly on temperature.
- Thermal runaway: more current dissipates more power and heats up the junction even more...

Temperature Compensation

- What if we added another PN junction in the voltage divider?



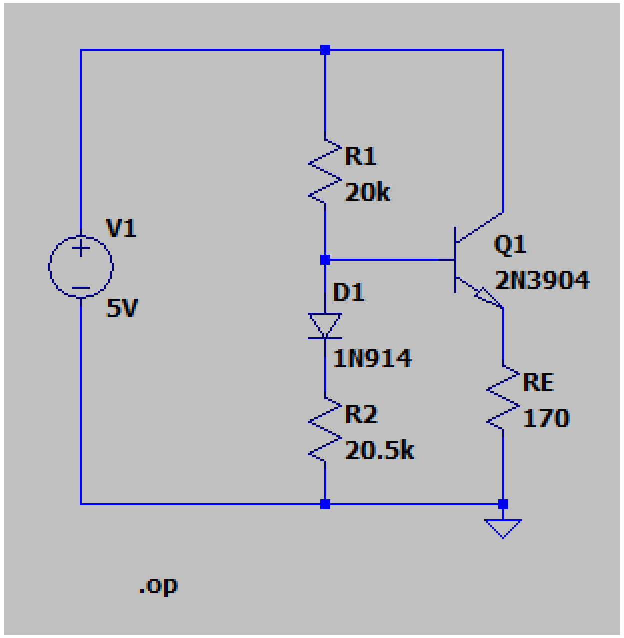
- Now the base voltage is

$$V_b = I\,R_2 + V_D$$

$$I = \frac{V_{CC} - V_D}{R_1 + R_2}$$

$$V_b = \frac{V_{CC}R_2 + R_1 V_D}{R_1 + R_2}$$

Temperature Compensation

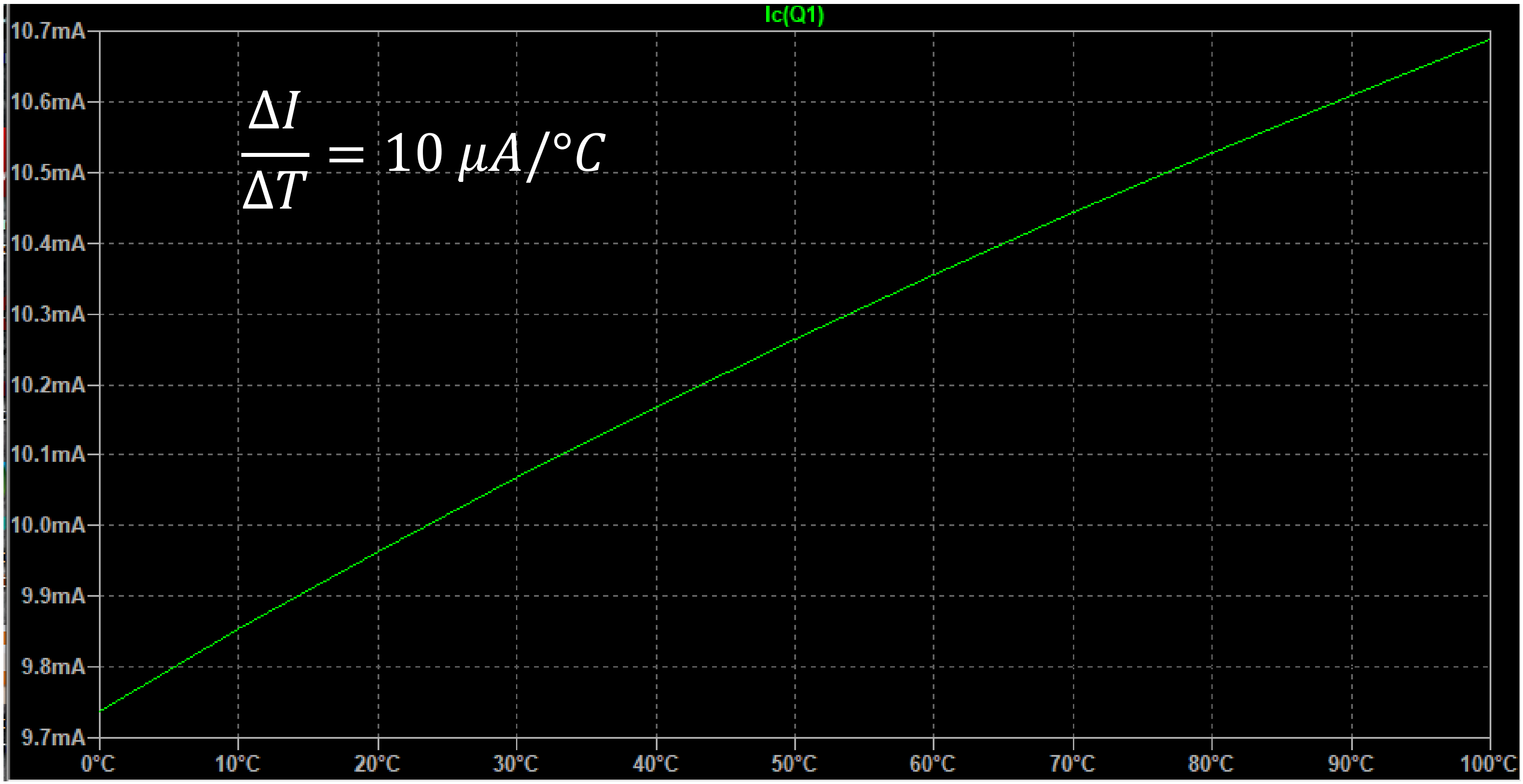


--- Operating Point ---

V(n001):	5	voltage
V(n002):	2.42848	voltage
V(n003):	1.71207	voltage
V(n004):	1.95074	voltage
Ic(Q1):	0.0100376	device_current
Ib(Q1):	3.34179e-005	device_current
Ie(Q1):	-0.010071	device_current
I(D1):	9.5158e-005	device_current
I(R1):	0.000128576	device_current
I(R2):	9.5158e-005	device_current
I(Re):	0.010071	device_current
I(V1):	-0.0101661	device_current

- R_1 and R_2 are adjusted to achieve 10 mA
- This results in only partial temperature compensation: $V_b \propto \frac{R_1 V_D}{R_1 + R_2}$

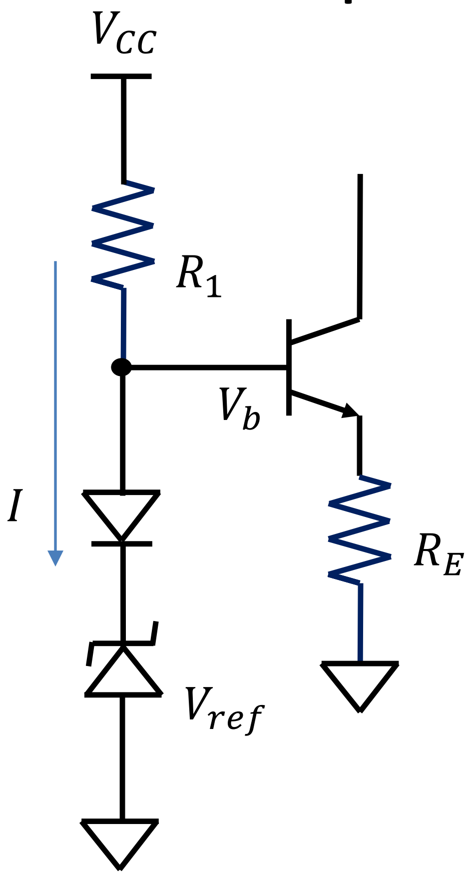
Temperature Dependence



The base voltage still depends on the current through the resistor divider.

Temperature Dependence

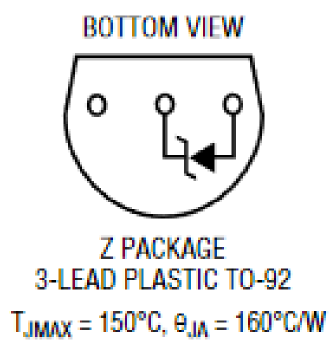
- A voltage reference can provide a voltage that is independent of the current

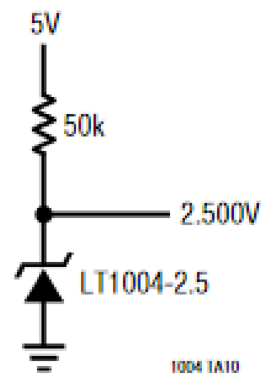


- They typically have a high output impedance
- Example:

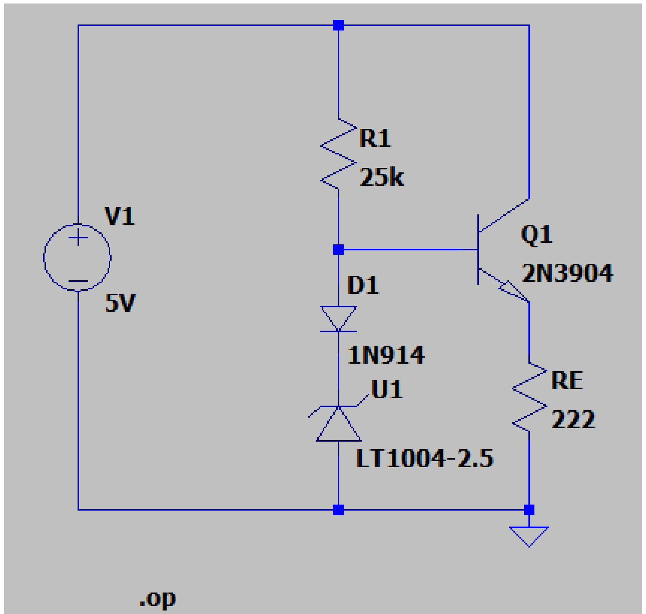
LT1004

Micropower Voltage Reference





Temperature Compensation



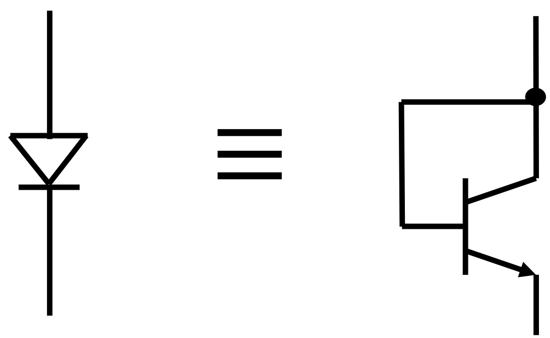
--- Operating Point ---

V(n001):	5	voltage
V(n002):	2.94711	voltage
V(n003):	2.23062	voltage
V(n004):	2.49994	voltage
Ic(Q1):	0.0100143	device_current
Ib(Q1):	3.35122e-005	device_current
Ie(Q1):	-0.0100478	device_current
I(D1):	4.86034e-005	device_current
I(R1):	8.21156e-005	device_current
I(Re):	0.0100478	device_current
I(V1):	-0.0100964	device_current
Ix(u1:1):	4.86034e-005	subckt_current
Ix(u1:2):	-4.86034e-005	subckt_current

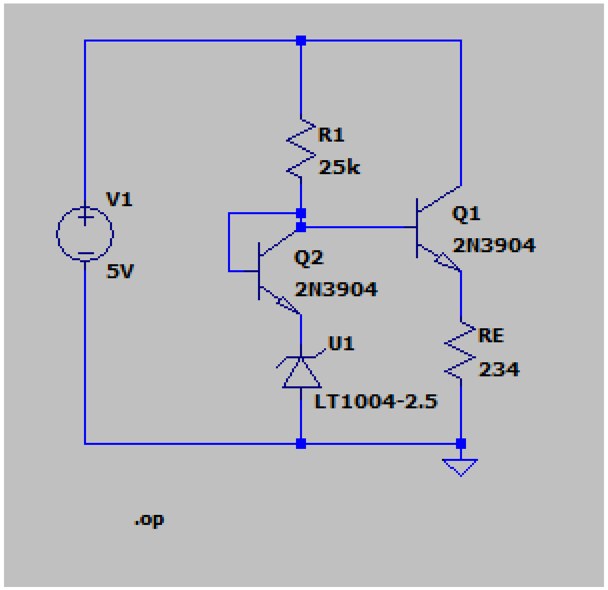
$$\frac{\Delta I}{\Delta T} = 3\ \mu A/°C$$

Temperature Compensation

- Better temperature compensation can be achieved by using exactly the same type of PN junction in the voltage reference circuit



Temperature Compensation

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--- Operating Point ---

V(n001):      5              voltage
V(n002):      3.07384        voltage
V(n003):      2.35724        voltage
V(n004):      2.49994        voltage
Ic(Q2):       4.32593e-005   device_current
Ib(Q2):       1.44214e-007   device_current
Ie(Q2):       -4.34035e-005  device_current
Ic(Q1):       0.01004        device_current
Ib(Q1):       3.3643e-005    device_current
Ie(Q1):       -0.0100737     device_current
I(R1):        7.70465e-005   device_current
I(Re):        0.0100737      device_current
I(V1):        -0.0101171     device_current
Ix(u1:1):     4.34035e-005   subckt_current
Ix(u1:2):     -4.34035e-005  subckt_current
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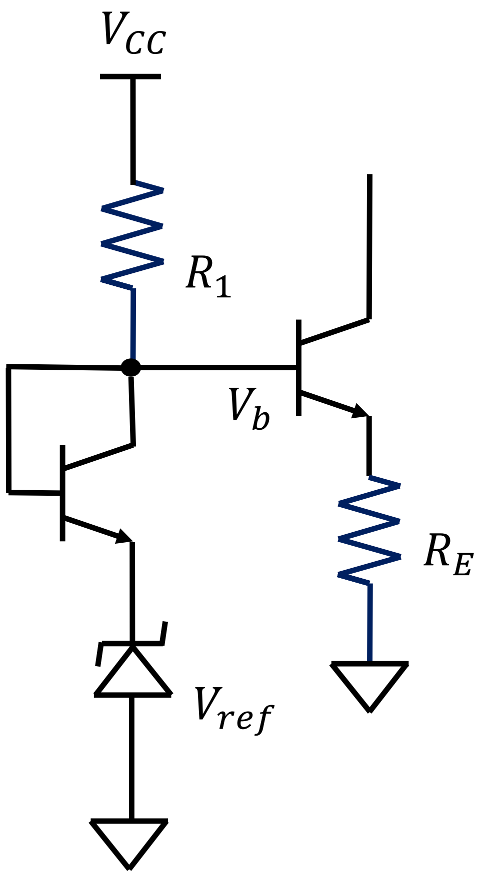
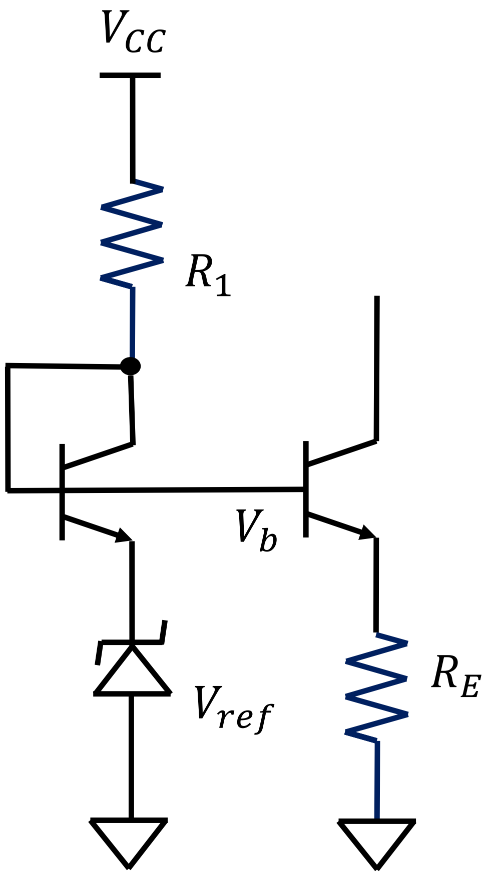
$$\frac{\Delta I}{\Delta T} = 0.68\ \mu A/°C$$

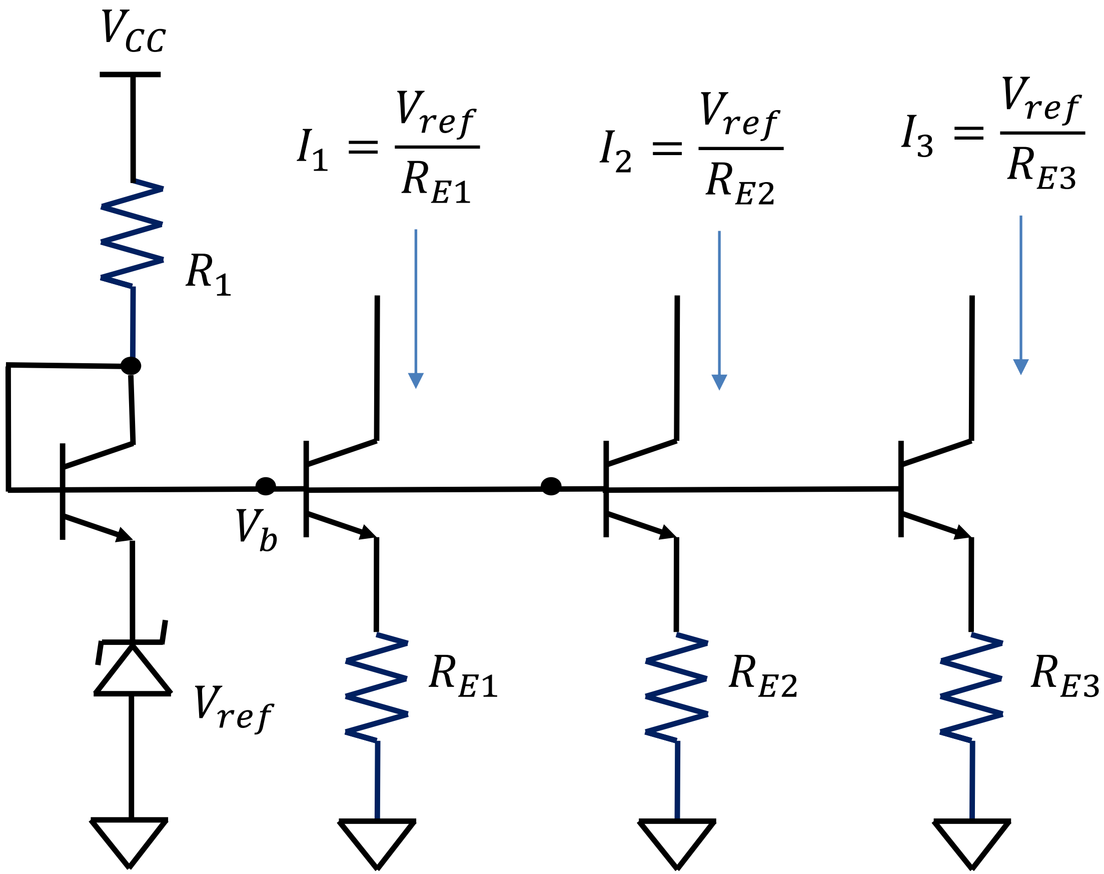
Current Mirror



This is frequently also drawn this way, particularly in IC designs…



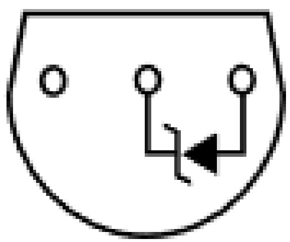
Current Mirror



Current Mirror

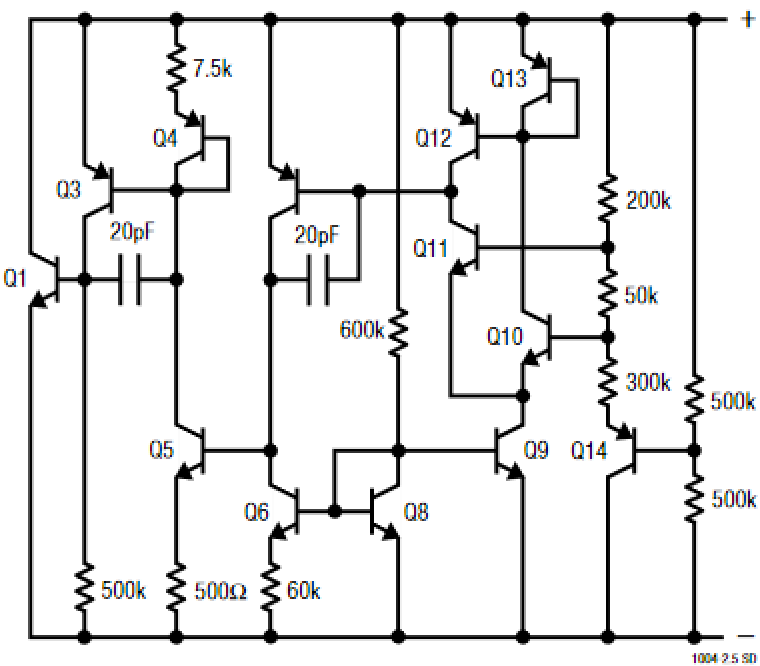
- Now you can recognize the purpose of some of the transistors in complicated circuits:

BOTTOM VIEW



Z PACKAGE
3-LEAD PLASTIC TO-92
$T_{JMAX} = 150°C$, $\theta_{JA} = 160°C/W$

LT1004-2.5



Current Mirror

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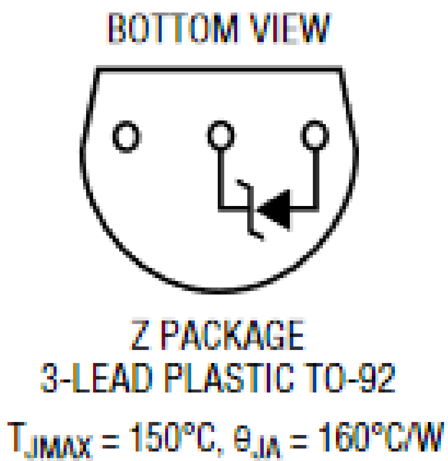
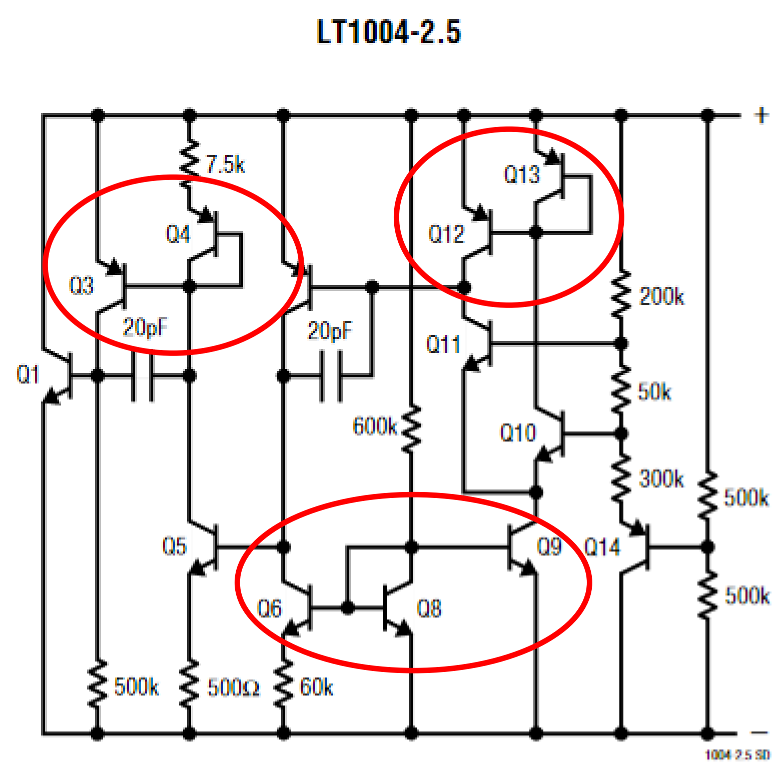




Current Mirror

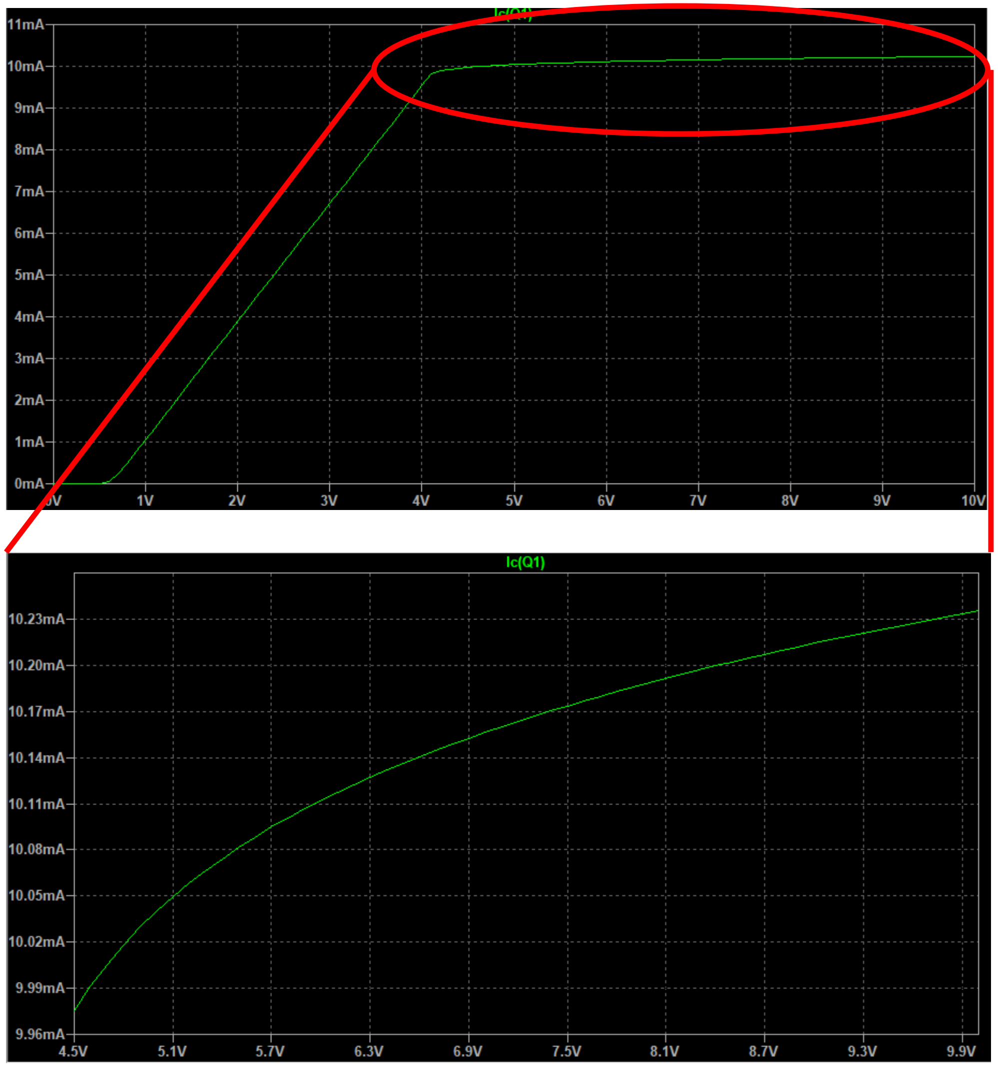
- Transistors have maximum current ratings:

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector – Emitter Voltage	V_{CEO}	40	Vdc
Collector – Base Voltage	V_{CBO}	60	Vdc
Emitter – Base Voltage	V_{EBO}	6.0	Vdc
Collector Current – Continuous	I_C	200	mAdc
Total Device Dissipation @ $T_A = 25°C$ Derate above 25°C	P_D	 625 5.0	 mW mW/°C
Total Device Dissipation @ $T_C = 25°C$ Derate above 25°C	P_D	 1.5 12	 W mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−55 to +150	°C

- This may not matter much for discrete components, but it can be limiting in integrated circuits.

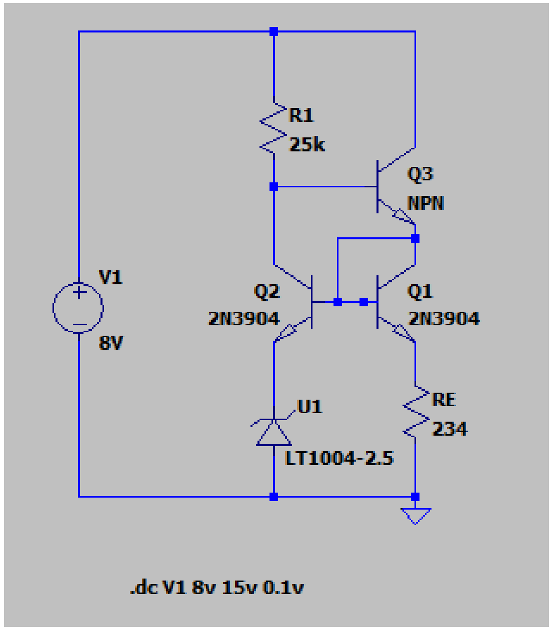
Output Characteristics

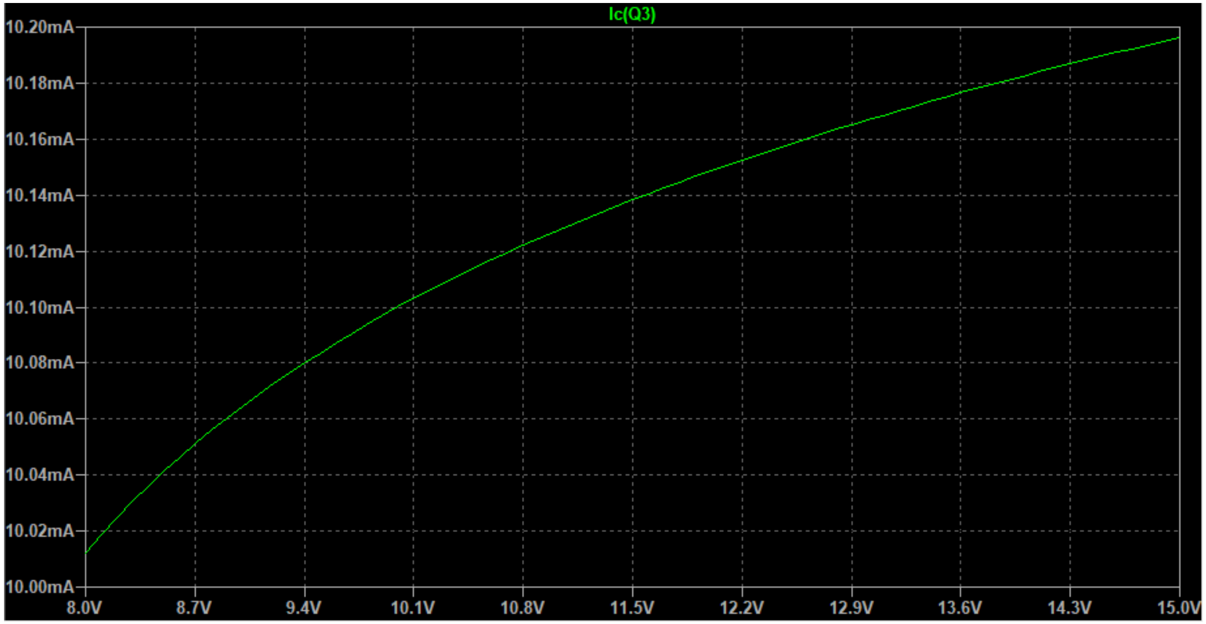


This is still not a perfect current source. The output impedance is about 20 kΩ.

Sensitivity to the exact power supply voltage could be a problem.

Wilson Current Mirror





Now the output impedance is 35 kΩ but the collector of Q3 is at a higher potential with respect to ground.