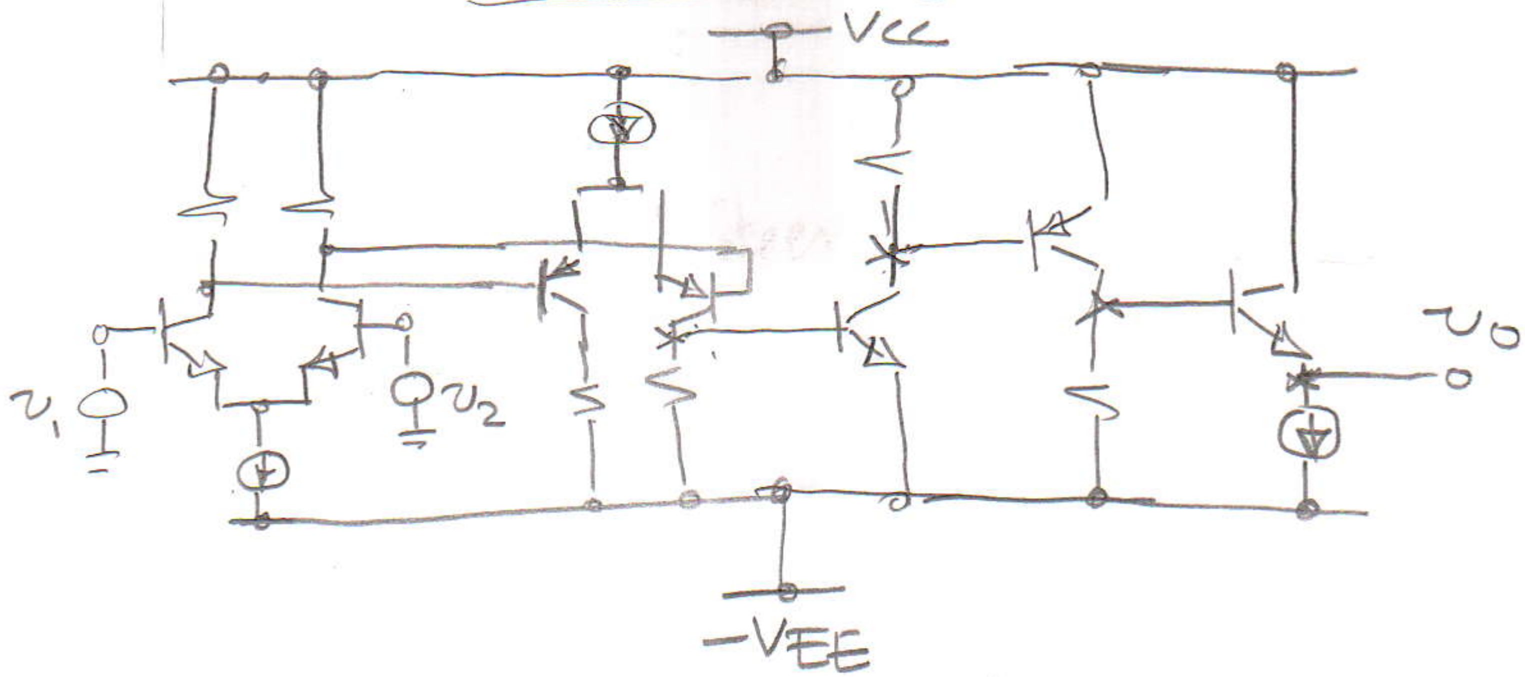
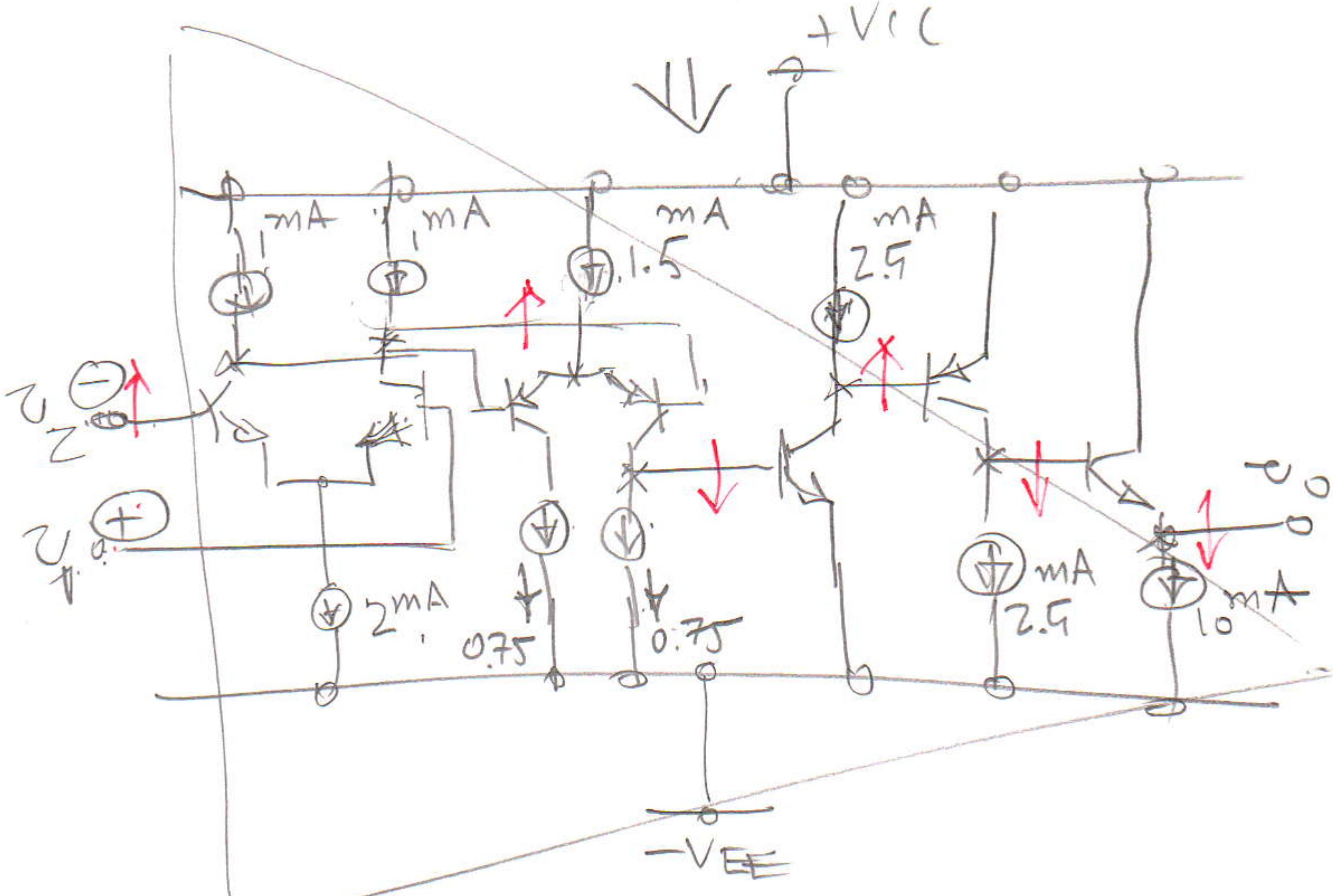
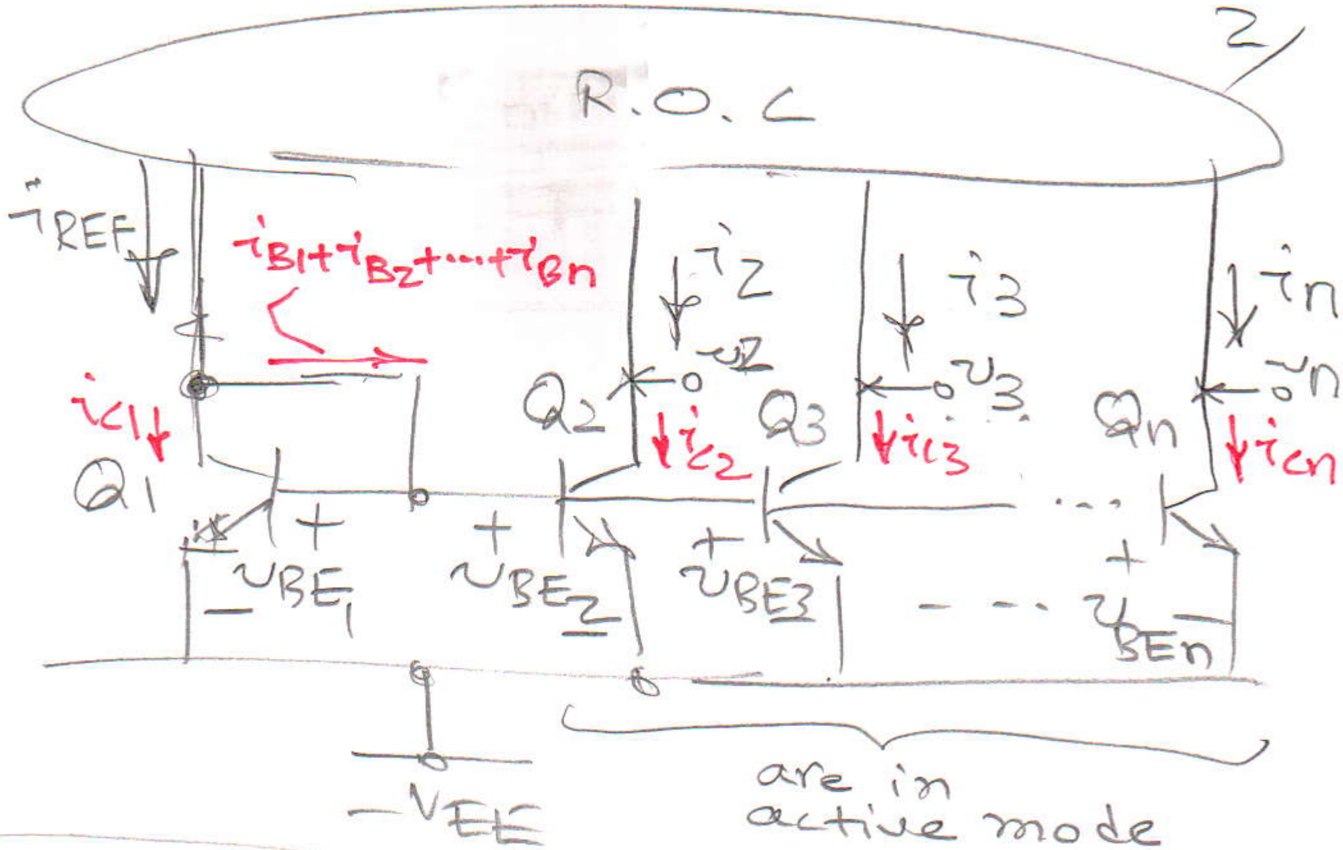
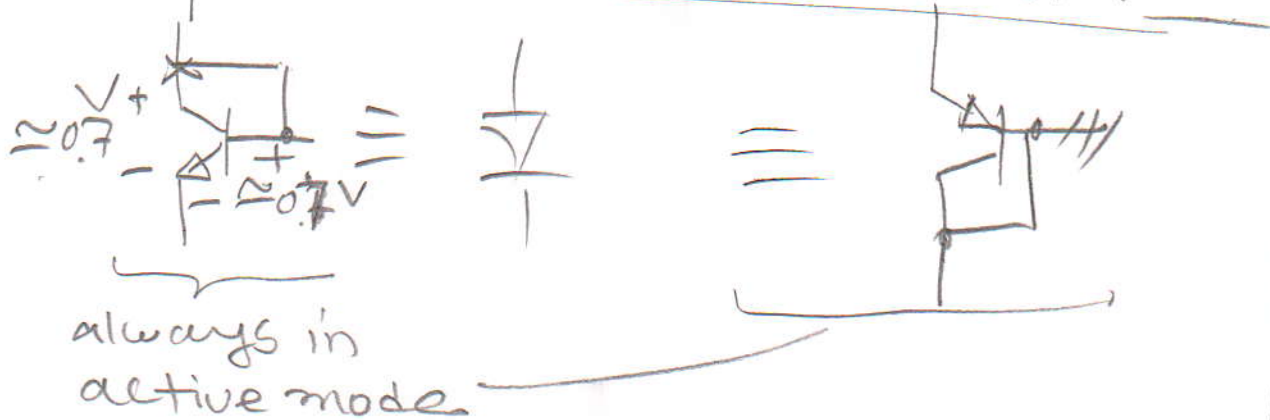
Current-Steering Circuits







Diode-Connected transistor



$$i_{C_1} = I_{S_1} e^{v_{BE1}/V_T}$$

$$i_{C2} = I_{S2} e^{v_{BE2}/V_T}$$

$$\vdots$$

$$i_{Cn} = I_{Sn} e^{v_{BEn}/V_T}$$

$$v_{BE_1} = v_{BE_2} = \cdots = v_{BE_n}$$

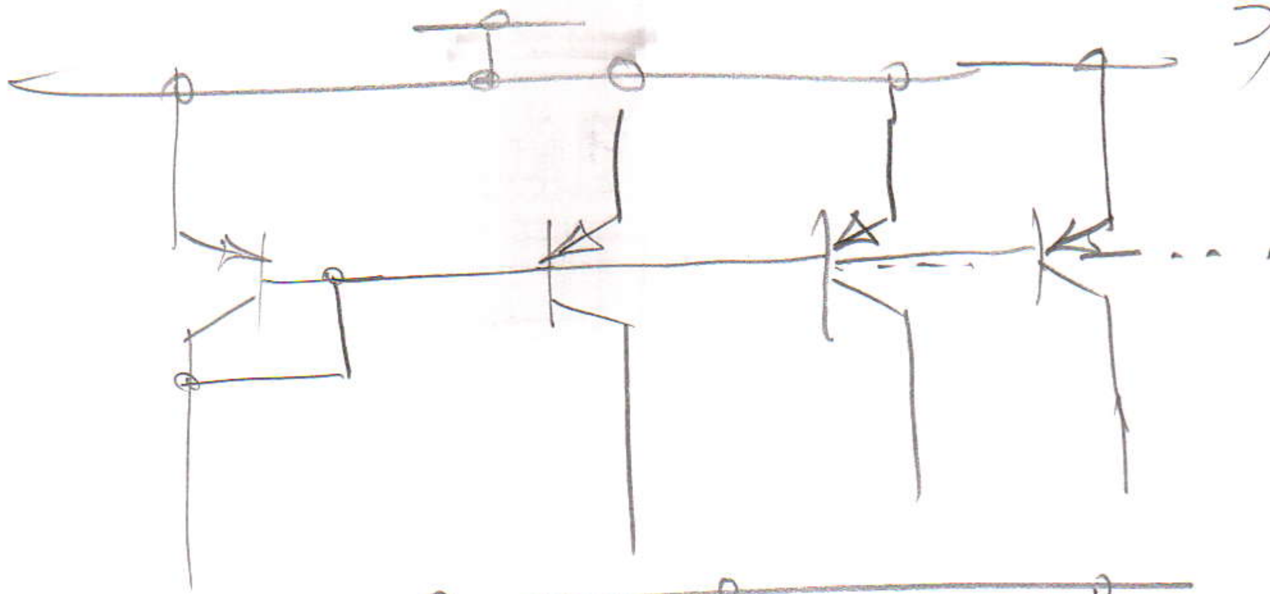
$$\frac{i_2}{i_{REF}} \simeq \frac{I_{S2}}{I_{S1}} \quad \text{for } \beta \gg$$

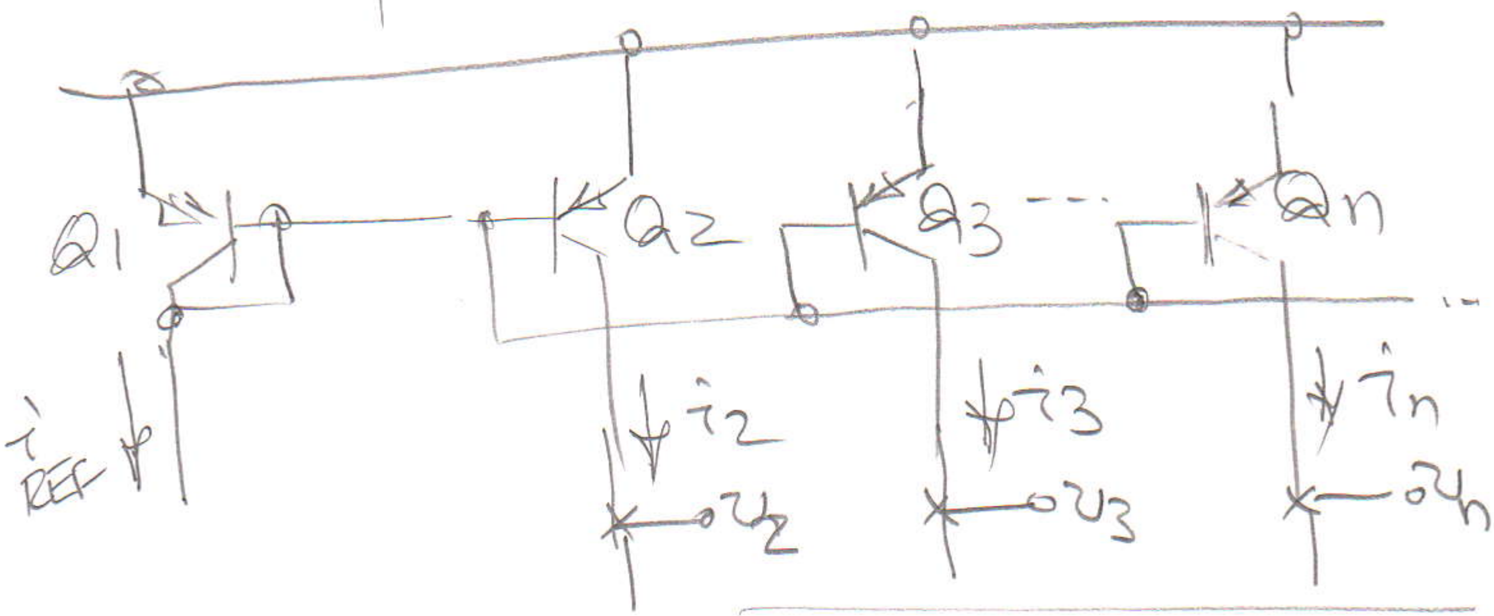
$$\frac{i_3}{i_{REF}} \simeq \frac{I_{S3}}{I_{S1}}$$

$$\vdots$$

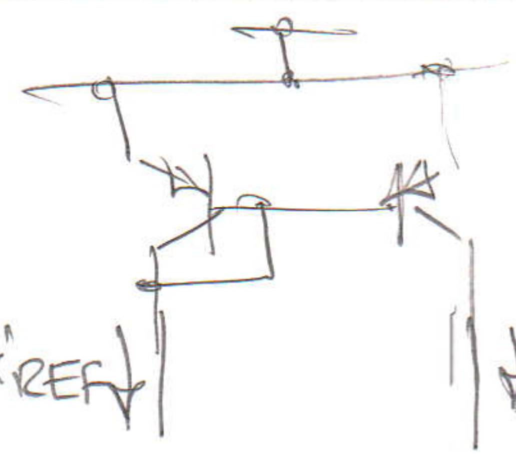
$$\frac{i_n}{i_{REF}} \simeq \frac{I_{Sn}}{I_{S1}}$$

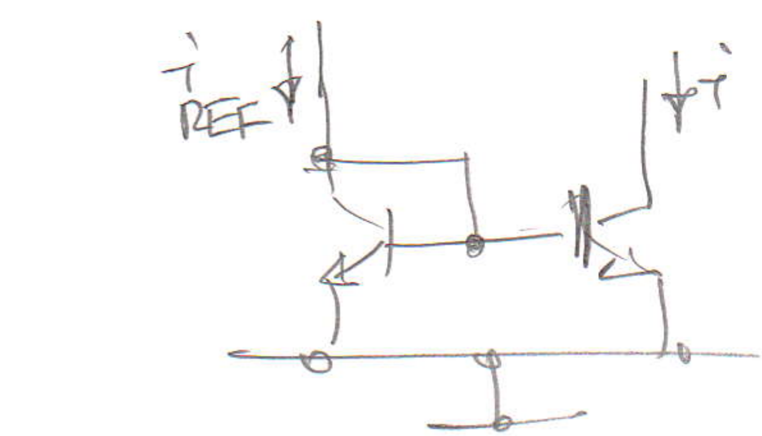
$I_S \propto$ cross-sectional area of the corresponding B-E junction





Special Case



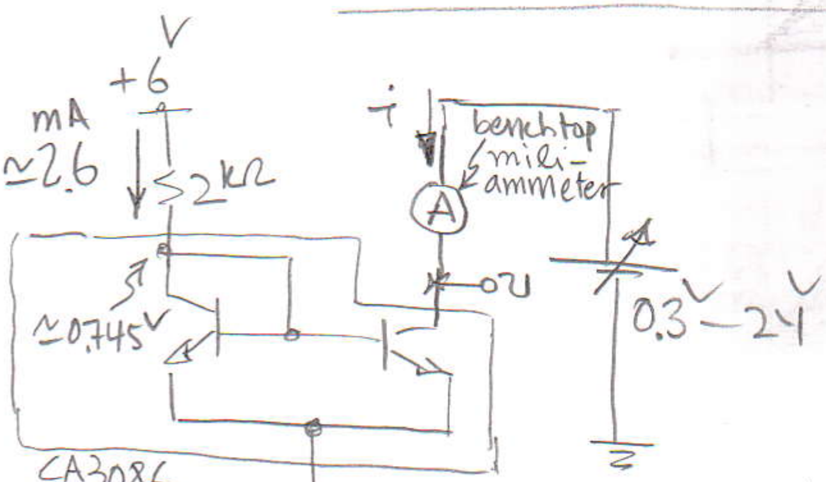


Called
"Current mirror"

$\underbrace{I_{S1} = I_{S2}}_{\text{matched pair}}$

$\Rightarrow \boxed{i = i_{REF}}$

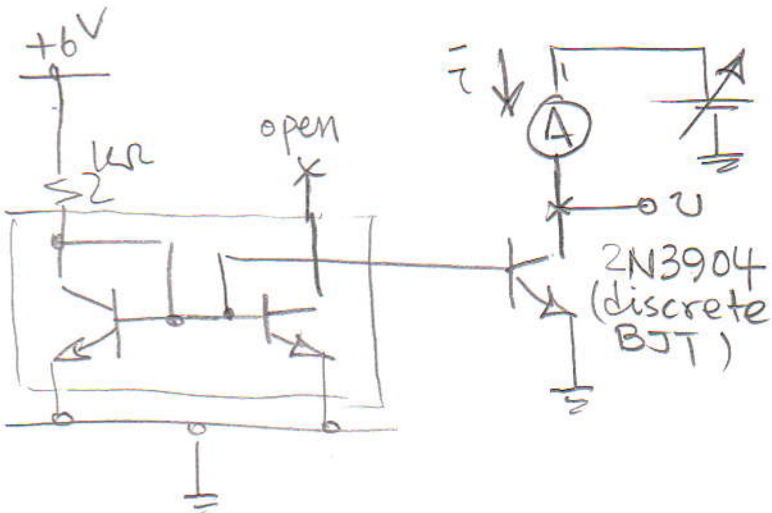
Documentation of an Experiment



CA3086 Matched transistor Pair

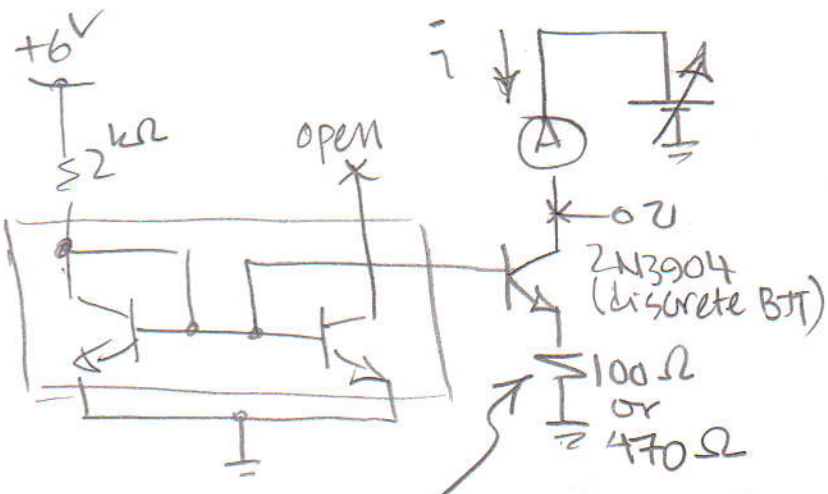
"This is a current mirror"

v	i
0.3V	2.46 mA
0.75V	2.56 mA
4.0V	2.72 mA
8.0V	2.90 mA
15.0V	3.27 mA
24.0V	4.15 mA
	$\Delta i/\Delta v$ $\simeq 71\mu A/V$



v	i
0.3V	14.7 mA
0.75V	19.6 mA
4.0V	Starts at about 30mA

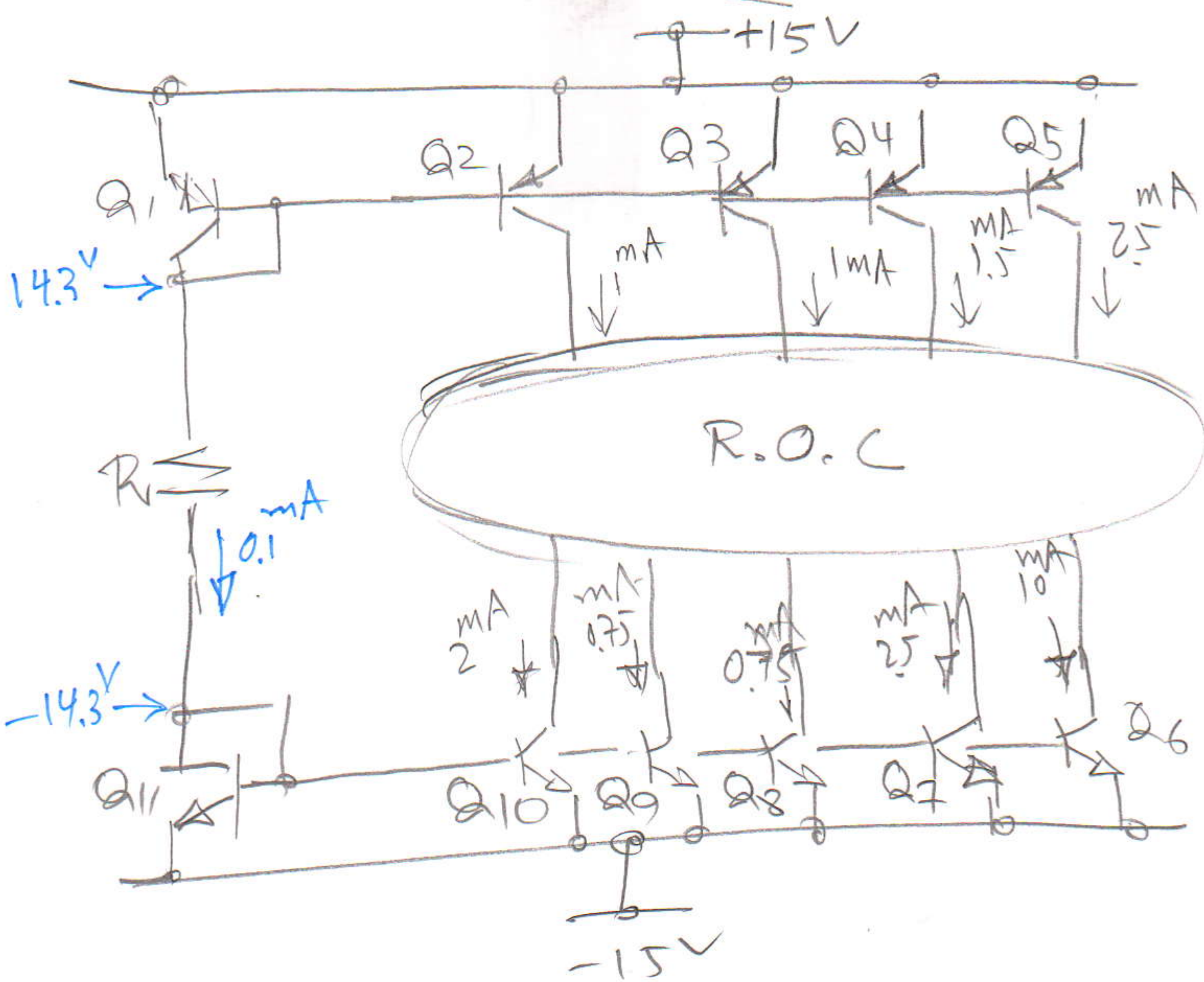
At $v=4.0V$, i starts at 30mA but quickly rises on its own since the transistor heats up, thus, further increasing the current. A thermal runaway is taking place that can eventually burn the BJT



emitter degeneration
1 – brings the current down
2 – makes the current less sensitive to v (i.e., increases R_o).

v	i $(R=100\Omega)$	i $(R=470\Omega)$
0.3V	0.931 mA	0.273 mA
0.75V	0.934 mA	0.275 mA
4.0V	0.943 mA	0.277 mA
8.0V	0.961 mA	0.279 mA
15.0V	0.994 mA	0.285 mA
24.0V	1.039 mA	0.289 mA
	$\Delta i/\Delta v$ $\simeq 4.6\mu A/V$	$\Delta i/\Delta v$ $\simeq 0.67\mu A/V$

Combine



① Find R to make $i_{REF} = 0.1\ mA$

② Determine the junction area ratios...

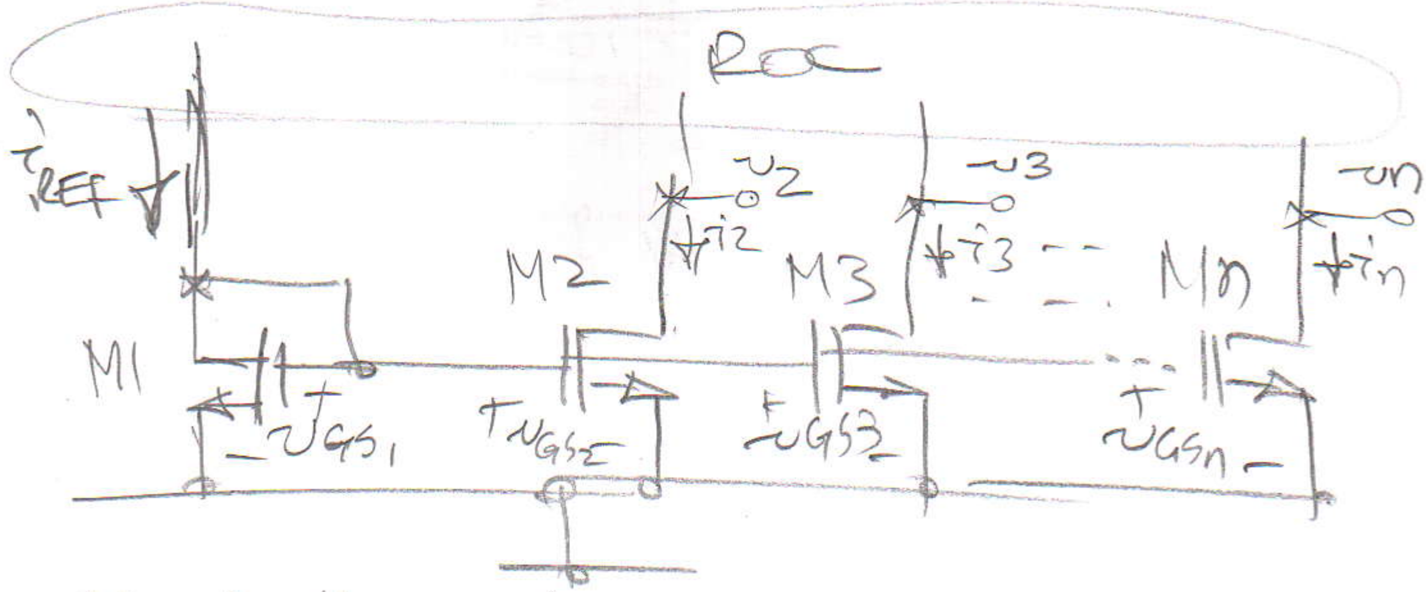
Solution

$$R = \frac{14.3-(-14.3)}{0.1} = 286\ k\Omega$$

$$\frac{I_{S2}}{I_{S1}} = \frac{EBJA2}{EBJA1} = \frac{1}{0.1} = 10\ ;\quad \frac{I_{S3}}{I_{S1}} = 10;\quad \frac{I_{S4}}{I_{S1}} = 15;\quad \frac{I_{S5}}{I_{S1}} = 25$$

$$\frac{I_{S10}}{I_{S11}} = \frac{EBJA10}{EBJA11} = \frac{2}{0.1} = 20\ ;\quad \frac{I_{S9}}{I_{S11}} = 7.5\ ;\quad \ldots$$

MOS Versions



M2 ... Mn in the saturation mode

$$i_{REF} = \frac{1}{2}k_1(v_{GS_1}-V_t)^2 = \frac{1}{2}k'\left(\frac{W}{L}\right)_1(v_{GS_1}-V_t)^2$$

$$i_2 = \frac{1}{2}k_2(v_{GS_2}-V_t)^2 = \frac{1}{2}k'\left(\frac{W}{L}\right)_2(v_{GS_2}-V_t)^2$$

$$\vdots$$

$$i_n = \frac{1}{2}k_n(v_{GS_n}-V_t)^2 = \frac{1}{2}k'\left(\frac{W}{L}\right)_n(v_{GS_n}-V_t)^2$$

$$v_{GS1} = v_{GS2} = \cdots = v_{GSn}$$

Technology the same: $k'_1 = k'_2 = \cdots = k'_n \triangleq k$

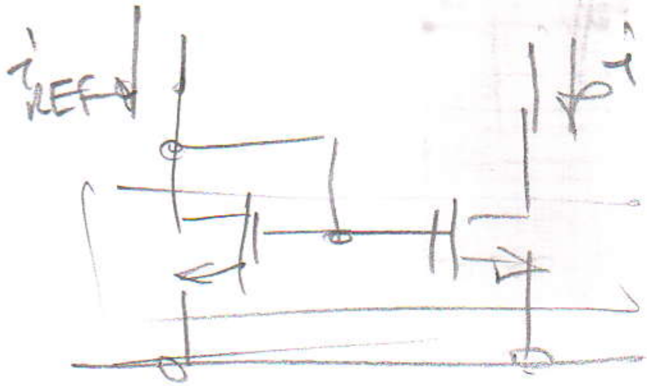
$$V_{t_1} = V_{t2} = \cdots = V_{tn} \triangleq V_t$$

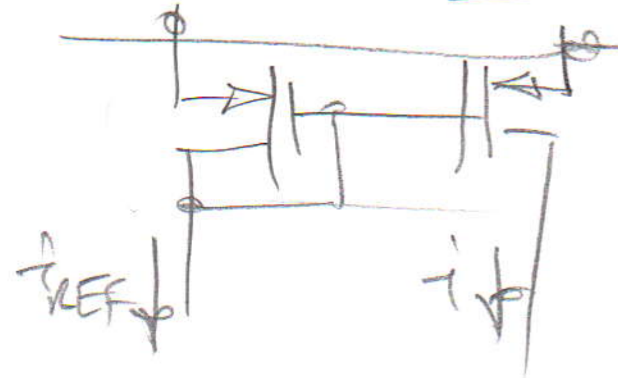
$$\frac{i_2}{i_{REF}} = \frac{\left(\frac{W}{L}\right)_2}{\left(\frac{W}{L}\right)_1}$$

$$\frac{i_3}{i_{REF}} = \frac{(W/L)_3}{(W/L)_1}$$

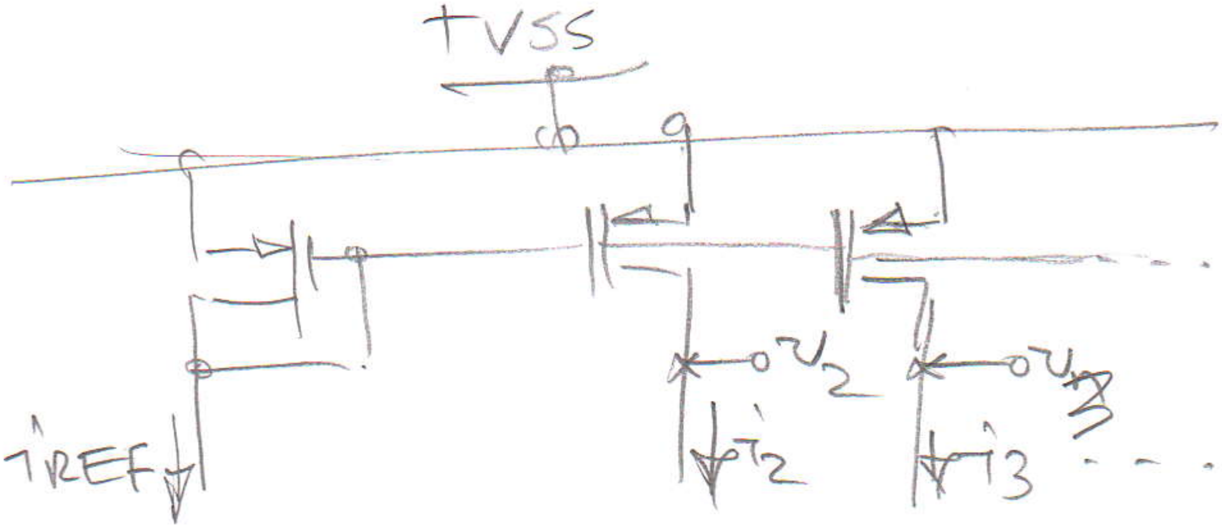
$$\vdots$$

Current Mirror





$$\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 \Rightarrow \boxed{i = i_{REF}}$$

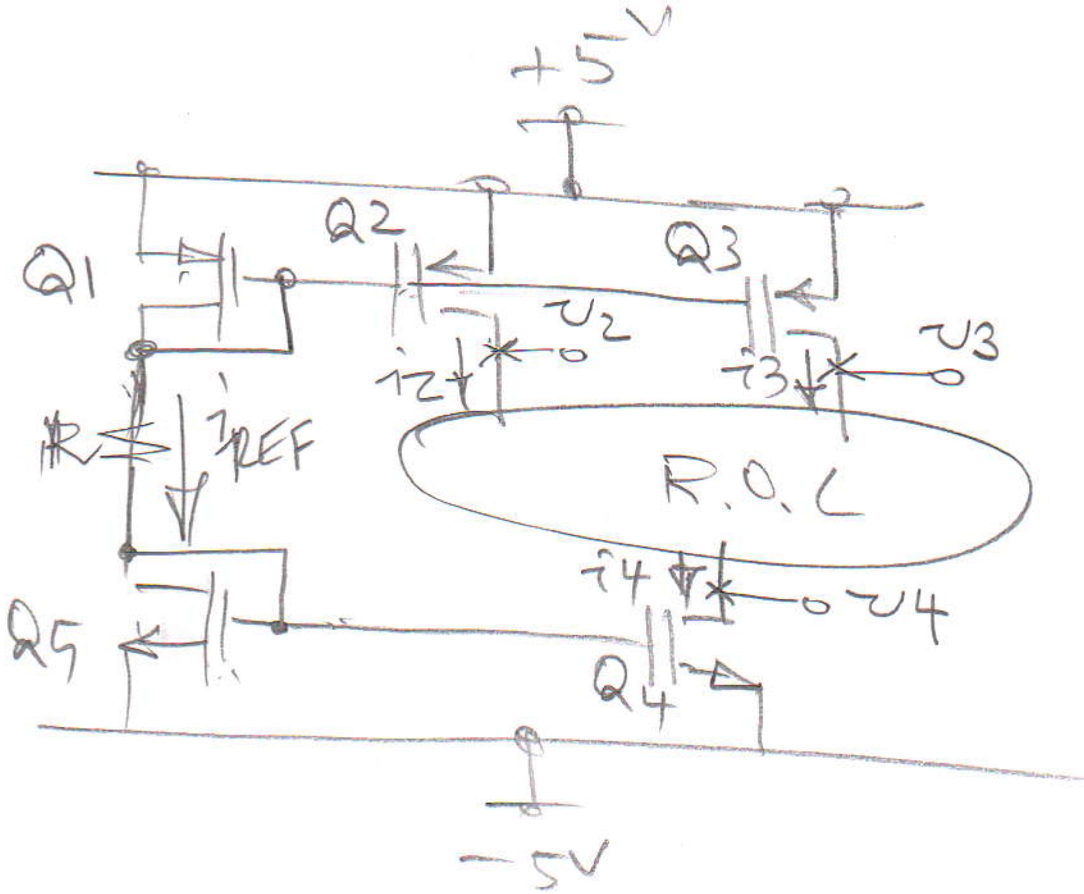


$k_n' = 2k_p' = 2.0\ mA/V^2$

$\left(\frac{W}{L}\right)_1 = 4\left(\frac{W}{L}\right)_2 = 2\left(\frac{W}{L}\right)_3 = 2\left(\frac{W}{L}\right)_4 = 2.5\left(\frac{W}{L}\right)_5 = 50$

$V_{tn} = 0.8^V$

$V_{tp} = -1.0^V$



① Find R for $i_{REF} = 1^{mA}$

② calculate everything else!

$i_{REF} = 1.0^{mA}$

$i_1 = \frac{1}{2} k_1 V_{ov_1}^2$

$\Rightarrow i_1 = \frac{1}{2} \times k_p' \left(\frac{W}{L}\right)_1 V_{ov_1}^2$

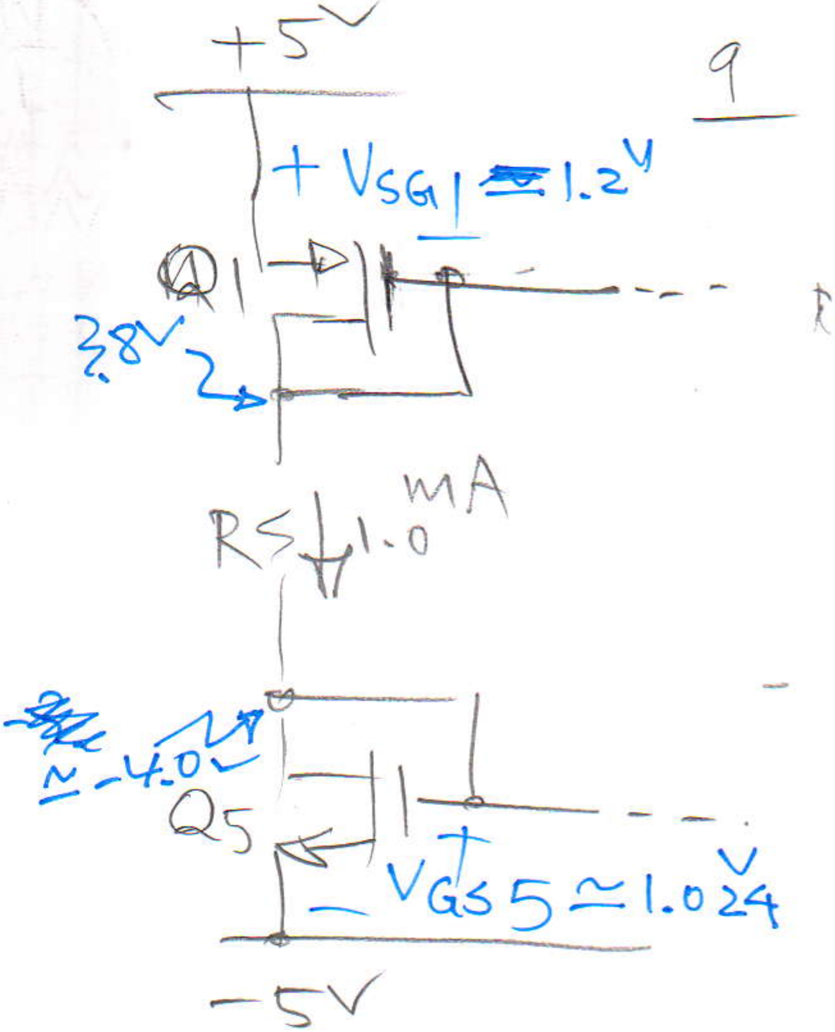
$\Rightarrow 1.0 = \frac{1}{2} \times 1.0 \times 50 \times V_{ov_1}^2$

$\Rightarrow V_{ov_1} = 0.2^V$

$V_{SG_1} = V_{ov_1} + |V_{tp}|$

$= 0.2 + |-1.0|$

$= \underline{1.2V}$



$i_5 = \frac{1}{2} k_5 V_{ov_5}^2$

$1.0 = \frac{1}{2} \times 2 \times \left(\frac{50}{2.5}\right) V_{ov_5}^2$

$\Rightarrow V_{ov_5} = 0.224^V$

$V_{GS_5} = V_{ov_5} + V_{tn}$

$= 0.224 + 0.8 = 1.024^V$

$R = \frac{3.8 - (-4.0)}{1.0} = \underline{7.8 k\Omega}$

$i_2 = 0.25mA$; $i_3 = 0.5mA$; $i_4 = 0.125^{mA}$