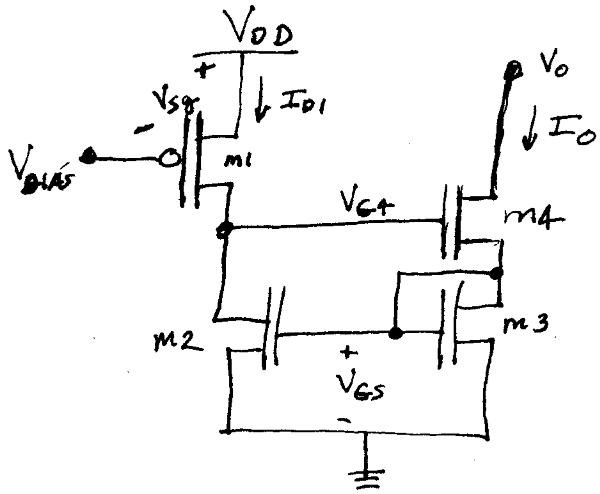
W3

Sec. 20.2

WILSON CURRENT MIRROR



Negative feedback to improve stability.

- Let I_{D1} be stable reference
- Assume $V_o \uparrow$
- $\Rightarrow I_o \uparrow$

  $\Rightarrow I_{d3} \uparrow$

  $\Rightarrow I_{d2} \uparrow$
- But I_{D1} fixed by V_{BIAS}

  $\Rightarrow I_{D2}$ discharges $G4 \Rightarrow V_{G4} \downarrow \Rightarrow I_o \downarrow$.

$$R_{out} \approx r_o + g_{m2} r_o^2/2$$

$$V_o(min) = V_{GS3} + V_{DS4,sat} = V_{GS3} + V_{GS4} - V_{THN}$$

$$\cong 1.2 + 0.37$$

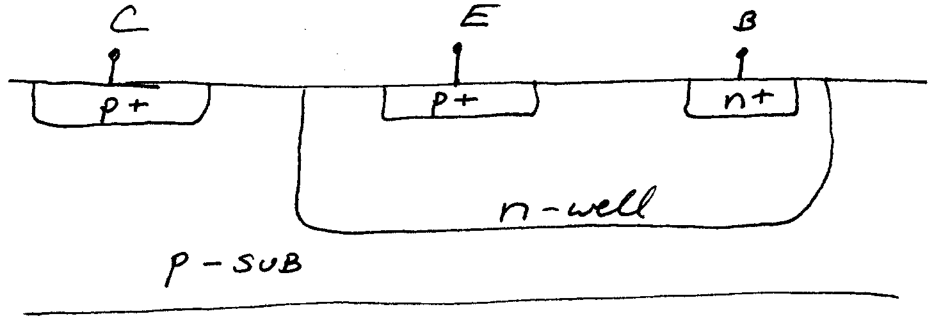
$$= 1.57 \quad \text{(cascode)}$$

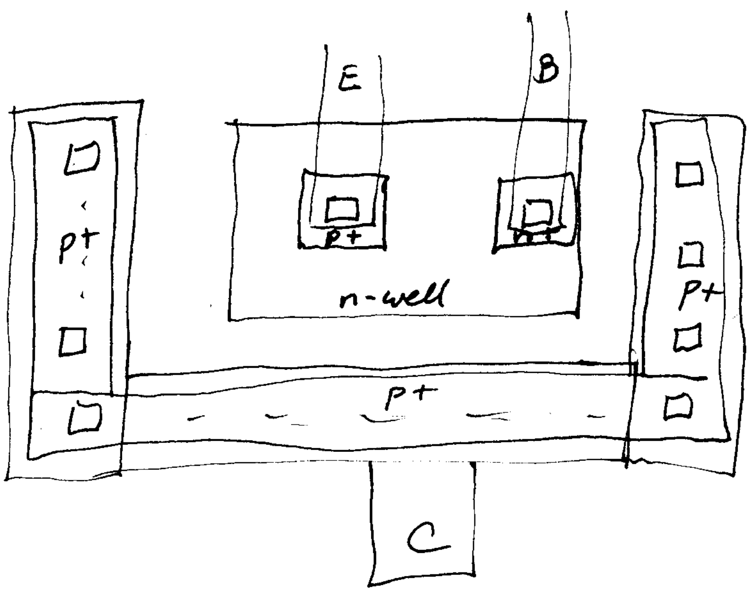
$$\boxed{\begin{aligned} I_o &= \frac{\beta_3}{2}(V_{GS3} - V_{TH})^2 \\ \sqrt{\frac{2I_o}{\beta_3}} + V_{TH3} &= V_{GS3} \end{aligned}}$$

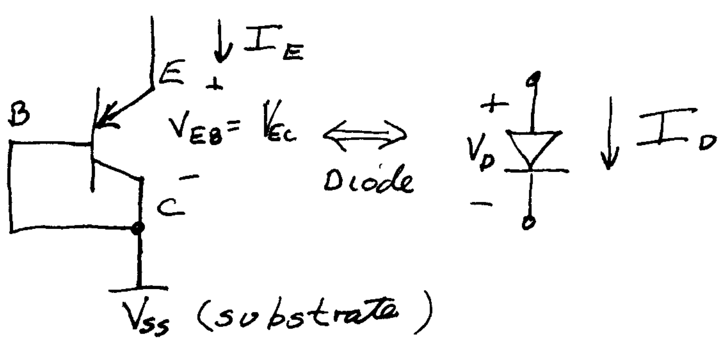
W4

(21.2.2) Diode Referenced Self Biasing.

USE parasitic PNP BJTs







Forward voltage reference, (V_{EB}) @ fixed I_E

$$I_D = I_S e^{V_d / n V_T} \qquad (V_T = kT/q) \quad \text{“} 26mV @ 300K$$

$I_S \propto$ Emitter area

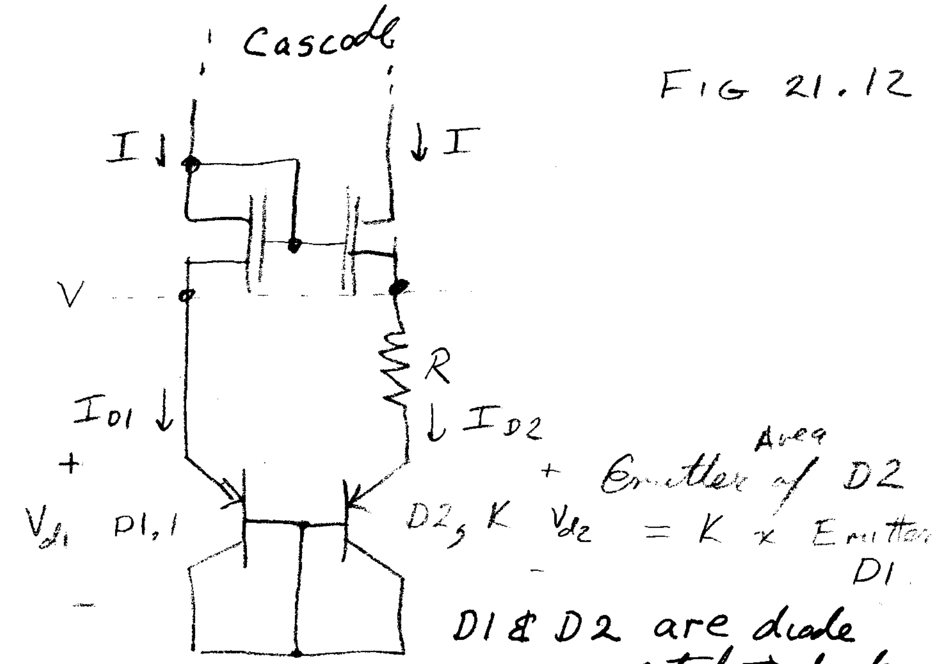
For given I_D, V_d is strongly T dependent.

W4

Thermal voltage ($V_T = \frac{kT}{q}$) referenced self biasing (21.2.3)

Cascode forcing same I thru both arms.

FIG 21.12



D1 & D2 are diode connected ⇒ diodes

$$V_{d1} = I_{d2} R + V_{d2}$$

$$I_{d1} = I_s e^{V_{d1}/nV_T} \Rightarrow V_{d1} = nV_T \ln\left(\frac{I_{d1}}{I_s}\right)$$

$$I_{d2} = K I_s e^{V_{d2}/nV_T} \Rightarrow V_{d2} = nV_T \ln\left(\frac{I_{d2}}{K I_s}\right)$$

$$nV_T \ln\left(\frac{I}{I_s}\right) = IR + nV_T \ln\left(\frac{I}{K I_s}\right)$$

$$\ln\left(\frac{I/I_s}{I/KI_s}\right) = \ln K = \frac{IR}{nV_T}$$

$$R = \frac{nV_T \ln K}{I}$$

$$I = \frac{n \ln K}{qR} k_B T =$$

Temp Coeff

$$TC_I = \frac{1}{I}\frac{dI}{dT} = \overset{3300\ \frac{ppm}{°C}}{\frac{1}{T}} - \underbrace{\overbrace{\frac{1}{R}\frac{\partial R}{\partial T}}^{2000\ \frac{ppm}{°C}}}_{>0} \simeq 1000 \frac{ppm}{°C}$$

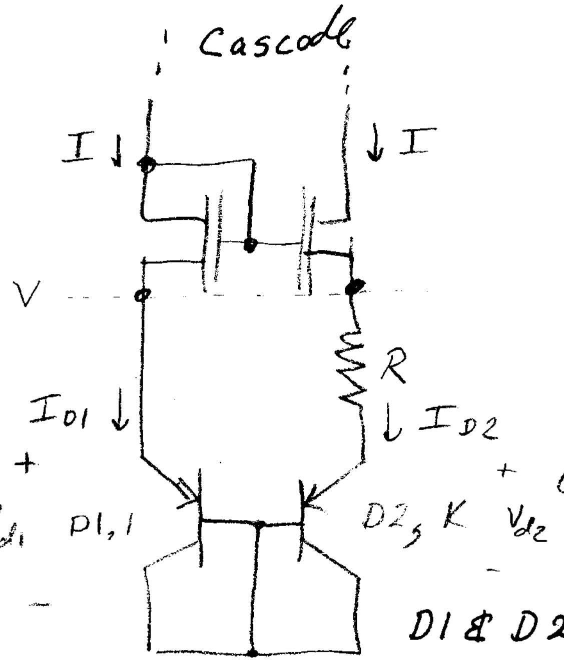
cancellation

W4

Thermal voltage $\left(V_T = \frac{kT}{q}\right)$ referenced self biasing (21.2.3)

Cascode forcing same I thru both arms.

FIG 21.12



Area
Emitter of D2 = K × Emitter D1

D1 & D2 are diode connected ⇒ diodes

$$V_{d1} = I_{d2} \cdot R + V_{d2}$$

$$I_{d1} = I_s e^{V_{d1}/nV_T} \implies V_{d1} = nV_T \ln\left(\frac{I_{d1}}{I_s}\right)$$

$$I_{d2} = K I_s e^{V_{d2}/nV_T} \implies V_{d2} = nV_T \ln\left(\frac{I_{d2}}{K I_s}\right)$$

$$nV_T \ln\left(\frac{I}{I_s}\right) = IR + nV_T \ln\left(\frac{I}{KI_s}\right)$$

$$\ln\left(\frac{I/I_s}{I/KI_s}\right) = \ln K = \frac{IR}{nV_T}$$

$$R = \frac{nV_T \ln K}{I}$$

$$I = \frac{n \ln K}{qR} k_B T =$$

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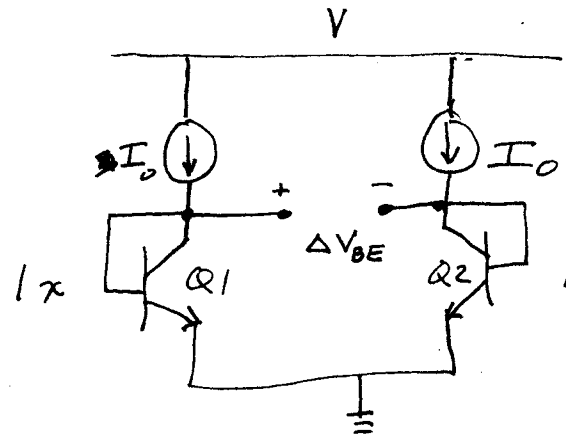
$$TC_I = \frac{1}{I}\frac{dI}{dT} = \overset{3300 \frac{ppm}{°C}}{\frac{1}{T}} - \overbrace{\underbrace{\frac{1}{R}\frac{\partial R}{\partial T}}_{>0}}^{2000 \frac{ppm}{°C}} \simeq 1000 \frac{ppm}{°C}$$

cancellation

Underlying Principle of thermal voltag (V_T) ref.



Different Current densities.

$$\Delta V_{BE} = V_{BE1} - V_{BE2}$$

$$= V_T \ln\left(\frac{I_o}{I_{S1}}\right) - V_T \ln\left(\frac{I_o}{K I_{S1}}\right)$$

$$\Delta V_{BE} = V_T \ln K = \frac{k_B T}{q} \ln(K)$$

$\Delta V_{BE} \propto T$ & independent of I

(21.3) BANDGAP V REFERENCE

Combine + TC of thermal Voltage (V_T) w/
− TC of diode forward V. (V_d).

To achieve a V_{ref} with 0 TC.

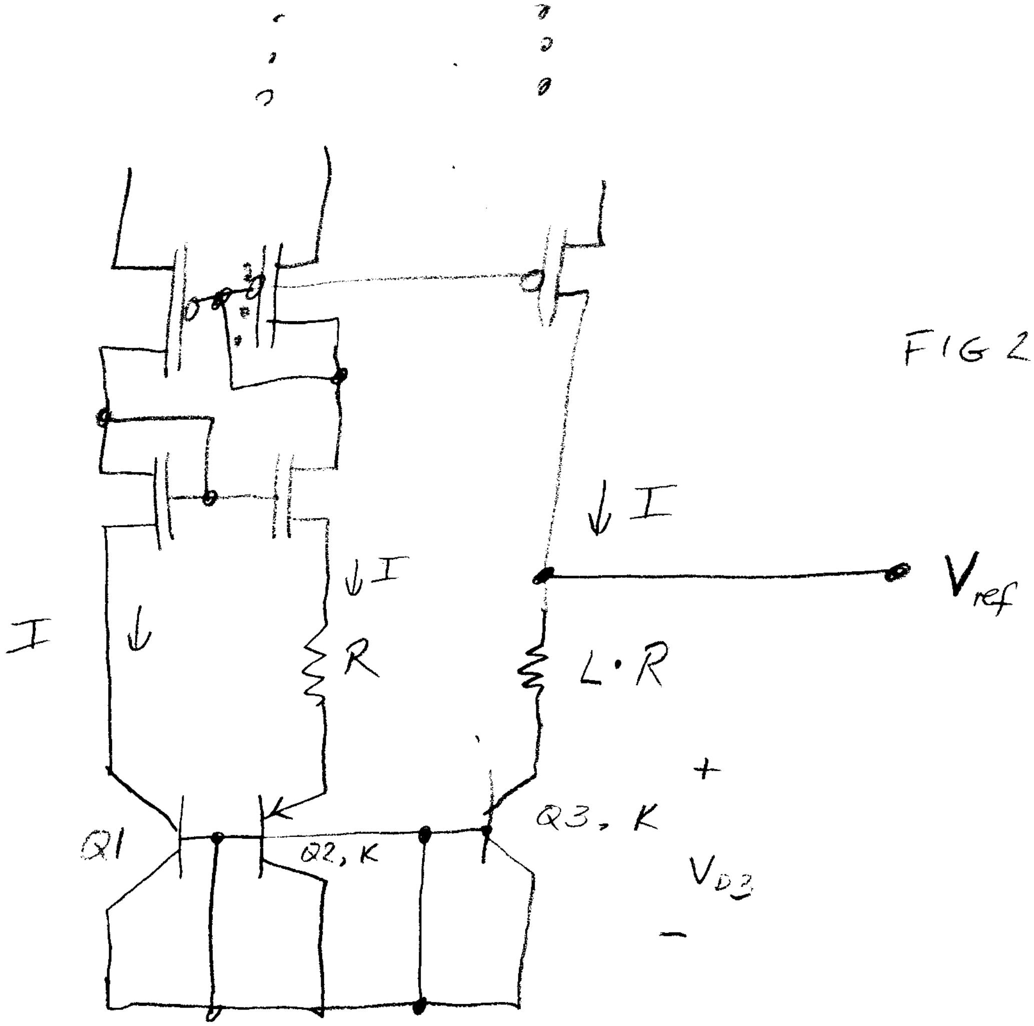


FIG 21.14

$$I = \frac{nV_T \ln K}{R}$$

$$V_{ref} = I\,L\,R + V_{D3}$$

$$V_{ref} = \underbrace{nV_T}_{\text{Thermal V}} (\ln K)\, L + \underbrace{V_{D3}}_{\text{Diode forward V}}$$

$$\frac{\partial V_{ref}}{\partial T} = n\,L \ln K \underbrace{\frac{\partial V_T}{\partial T}}_{0.085\frac{mV}{^oC}} + \underbrace{\frac{\partial V_{D3}}{\partial T}}_{-2mV/^oC} = 0$$

Choose L & K:

$$n\,L\ln K = \frac{2}{0.085} = 23.5$$

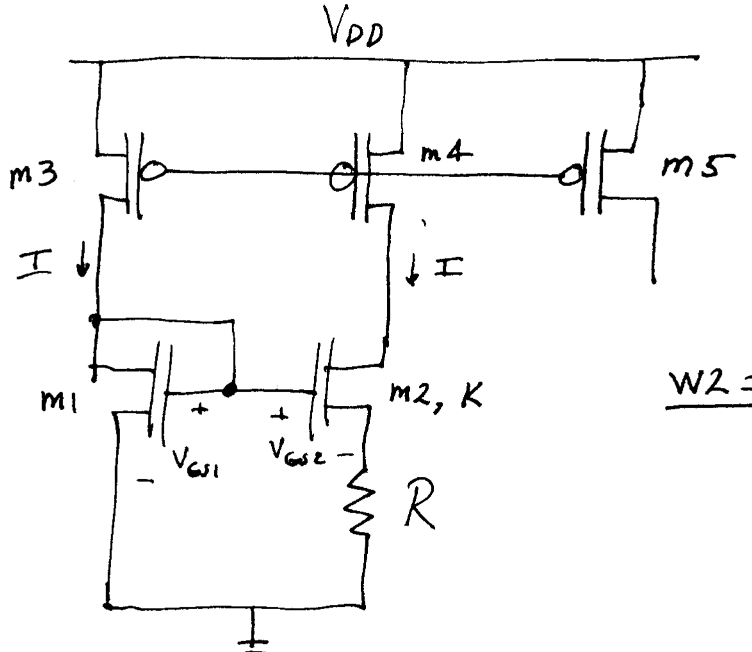
$n=1$, $K=8$, $L=11.3$ for $TC=0$

$V_{G2} \sim 0 \Rightarrow$ m5 turns on & pulls V_{G2} up to $2V_{GS}$.

When $V_{G2} = 2V_{GS}$ (pt A) (Desired op. PT.), $V_{GS5} = 0$ & m5 shuts off.

21.4 BETA MULTIPLIER REFERENCED SELF BIASING

FIG 21.16



W2 = K·W1

$L_1 = L_2$ & $W_2 = K\,W_1 \Rightarrow \beta_2 = K\beta_1$

$$V_{GS1} = V_{GS2} + IR$$

$$V_{GS1} = \sqrt{\frac{2I}{\beta_1}} + V_{THN}$$

$$V_{GS2} = \sqrt{\frac{2I}{K\beta_1}} + V_{THN}$$

$$\sqrt{\frac{2I}{\beta}} = \sqrt{\frac{2I}{K\beta}} + IR$$

$$\sqrt{\frac{2I}{\beta}}\left(1 - \frac{1}{\sqrt{K}}\right) = IR$$

$$\frac{2I}{\beta}\left(1 - \frac{1}{\sqrt{K}}\right)^2 = I^2R^2$$

$(I \neq 0)$

$$I = \frac{2}{R^2 \beta}\left(1 - \frac{1}{\sqrt{K}}\right)^2 \qquad (K > 1)$$

Needs start up circuitry Fig. 21.17.

$$TC_I = \frac{1}{I}\frac{\partial I}{\partial T} = \frac{1}{I}\left(\frac{\partial I}{\partial R}\frac{\partial R}{\partial T} + \frac{\partial I}{\partial \beta}\frac{\partial \beta}{\partial T}\right)$$

$$= \frac{R^2 \beta}{\cancel{2}} \cancel{\left(1-\frac{1}{\sqrt{K}}\right)} \left(\frac{-2}{R^3 \beta}\frac{\partial R}{\partial T} + \frac{-1}{R^2 \beta^2}\frac{\partial \beta}{\partial T}\right)$$

$$= \left(\underbrace{-\frac{2}{R}\frac{\partial R}{\partial T}}_{-4000 \frac{ppm}{°C}} - \underbrace{\frac{1}{\beta}\frac{\partial \beta}{\partial T}}_{+\frac{1.5}{T}}\right)$$

$$= \begin{cases} 0 \ @ \ T = 375\,K \\ 1000 \frac{ppm}{°C} \ @ \ 300\,K \end{cases}$$

$$\beta = \mu_n C_{ox} \frac{W}{L}$$

$$\mu = \mu(T_0)\left(\frac{T}{T_0}\right)^{-1.5}$$

$$\beta = \beta_0 \left(\frac{T}{T_0}\right)^{-1.5}$$

(21.4-1) <u>β Multiplier Voltage Ref</u>

$$V_{ref} = V_{GS1} = V_{GS2} + IR$$

$$= \underbrace{\sqrt{\frac{2I}{K\beta_1}} + V_{THN}}_{V_{GS2}} + \underbrace{\frac{2}{R\beta_1}\left(1 - \frac{1}{\sqrt{K}}\right)^2}_{IR}$$

$$= \frac{2}{R\beta_1 \sqrt{K}}\left(1 - \frac{1}{\sqrt{K}}\right) + V_{THN} + \frac{2}{R\beta_1}\left(1 - \frac{1}{\sqrt{K}}\right)^2$$

$$\left(\cancel{\frac{1}{\sqrt{K}}} - \cancel{\frac{1}{K}}\right)$$

$$1 - \cancel{2}\frac{1}{\sqrt{K}} + \cancel{\frac{1}{K}}$$

$$= \frac{2}{R\beta_1}\left(1 - \frac{1}{\sqrt{K}}\right) + V_{THN}$$

$$\frac{dV_{ref}}{dT} = \underbrace{\frac{dV_{THN}}{dT}}_{-2.4\,\frac{mV}{^\circ C}} - \frac{2}{R\beta_1}\left(1-\frac{1}{\sqrt{K}}\right)\left[\underbrace{\frac{1}{R}\frac{\partial R}{\partial T}}_{2000\,\frac{ppm}{^\circ C}} + \underbrace{\frac{1}{\beta}\frac{\partial \beta}{\partial T}}_{-\frac{1.5}{T}}\right]$$

$$\left.\frac{dV_{ref}}{dT}\right|_{300K} = 0 \quad \text{when} \quad \frac{2}{R\beta_1}\left(1-\frac{1}{\sqrt{K}}\right) = \frac{-0.0024}{[0.002 - 0.005]}$$

Let $K=4$:

$$= 0.8$$

$$R = \frac{1}{(0.8)\beta_1} \qquad V_{ref} = \frac{0.8\beta_1}{\beta_1}\, 2\left(\tfrac{1}{2}\right) + V_{THN}$$

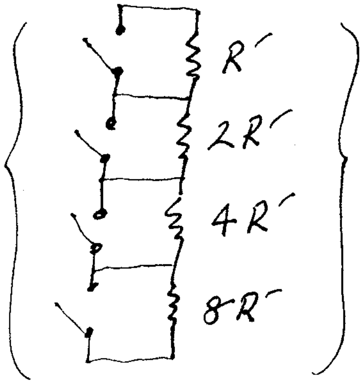
$$\boxed{V_{ref} = V_{GS1} = 0.8 + V_{THN}} = 1.63V$$

Notes:

- Errors in Vref
  - process variations (ΔV_{THN}, ΔR, $\Delta \beta$)
  - $\vec{\nabla} T$
  - Body Effect
- Less precise than BJT bandgap Vref
- Laser trimming of R. CN20 Table A.? N-well $R_\square$ 2000 - 3000 $\frac{\Omega}{\square}$
- Fuses

Fusible Al links

Opened by I pulse



2^n values of R_{TOT} for n Rs.

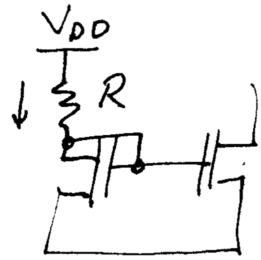
LOW I SOURCE (Subthreshold)

- Want $I = 100\,nA$.

Simple I Mirror

Choose $V_{GS} = 1V$

$V_{DD} = 2V$



$$I = \frac{1V}{R} = 1e\text{-}7\,A$$

$R = 10\,M\Omega$ (not available)

- Use β multiplier in subthreshold (Widlar)

$$I \approx I_{DO} \frac{W}{L} e^{(V_{GS} - V_{THN})/nV_T}$$ (Same form as diode equation)

SEE FIG 21.16

$$V_{GS1} = nV_T \ln\left[\frac{I\,L}{I_{DO}\,W}\right] + V_{THN}$$

$$V_{GS2} = nV_T \ln\left[\frac{I\,L}{K I_{DO}\,W}\right] + V_{THN}$$

$$V_{GS1} = V_{GS2} + IR$$

$$nV_T \ln(K) = IR$$

$$I = \frac{nV_T}{R} \ln(K)$$ Thermal Voltage referenced

~~Use this to create a~~

$n = 1$
$K = 2$
$V_T = 0.026\ V$

$R = 180\,k\Omega$