THE UNIVERSITY *of* EDINBURGH

Analogue IC Design

Current Mirrors

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Contents

- Bias voltages/currents for a chip
- Current source
- Simple Current Mirror
- Wilson Current Mirror
- Cascode Current Mirror
- Current Ratioing

Current Source

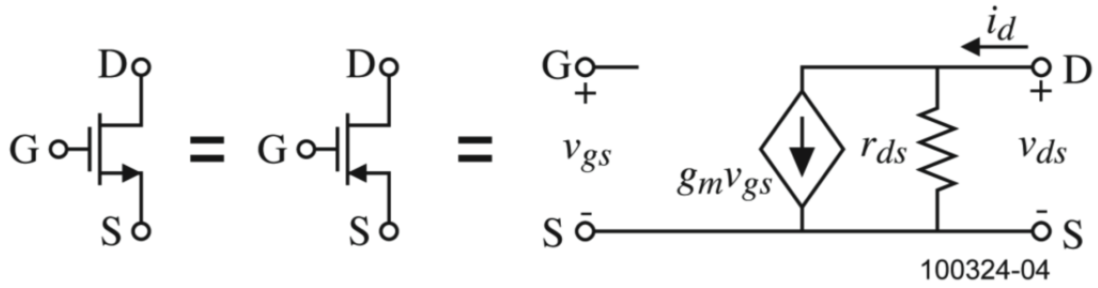
- Basic equations:

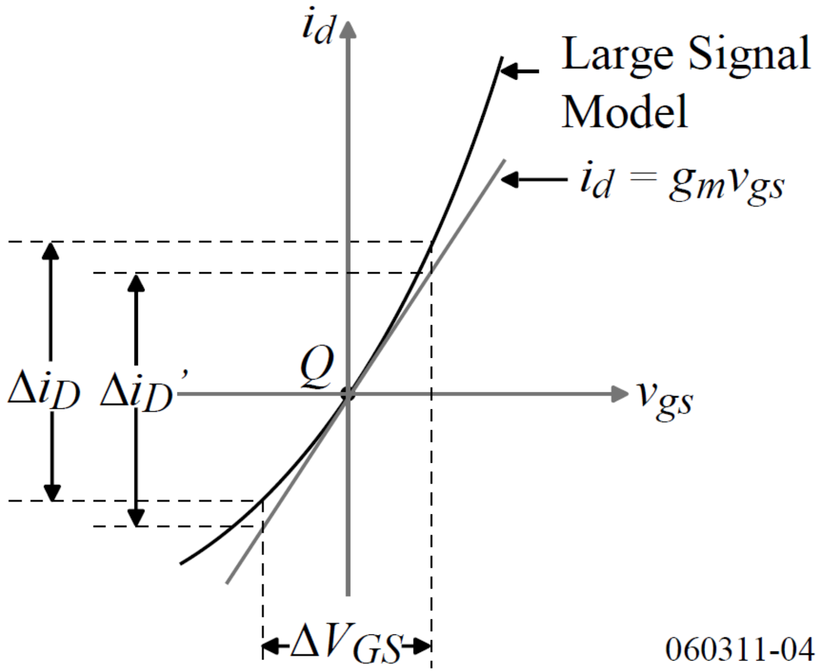
$$(v_{DS} \geq v_{GS} - V_T)$$

$$i_D = \frac{W\mu_O C_{ox}}{2L}(vGS - V_T)^2(1 + \lambda vDS)$$

Current Source

- Transconductance for small signal analysis





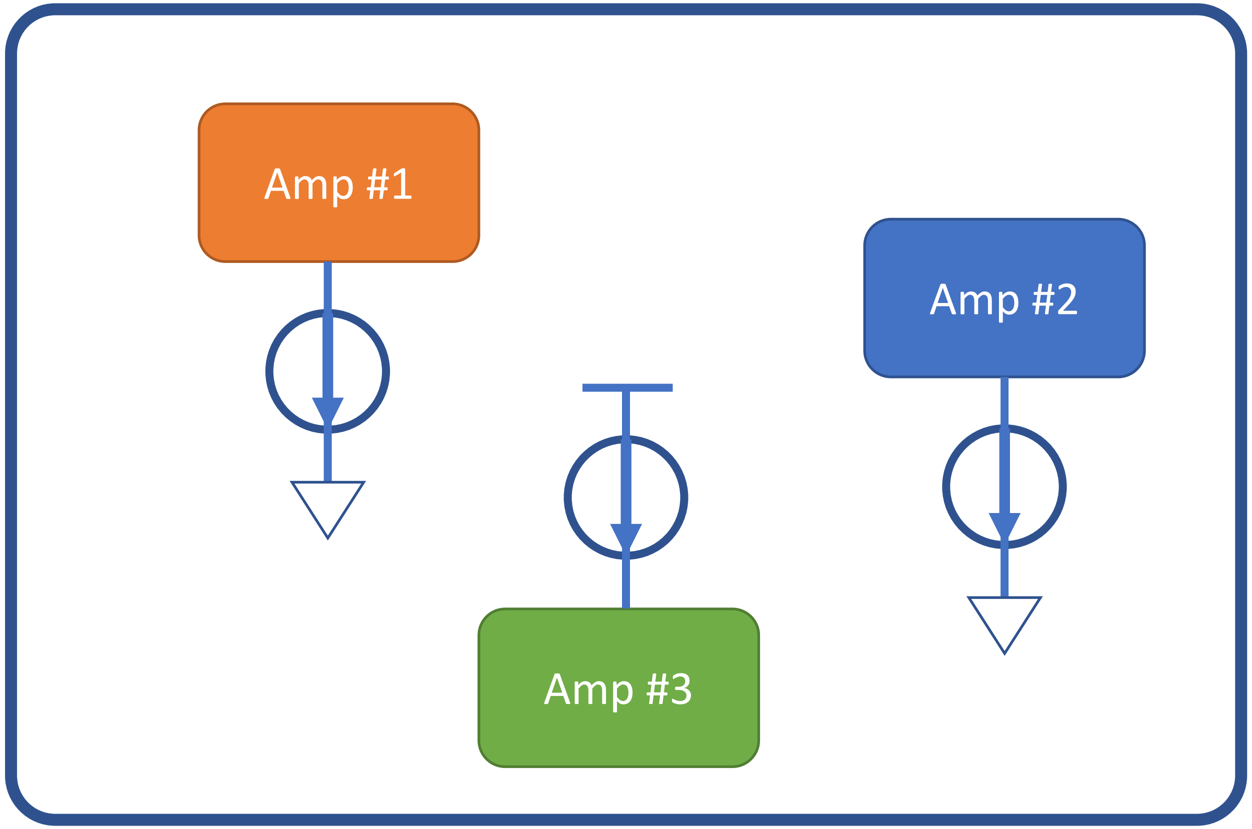
$$g_m = \frac{\partial i_D}{\partial v_{GS}} = \sqrt{2K'\frac{W}{L}i_D(1+\lambda v_{DS})}$$

Current Source

- Why do we need current mirrors?

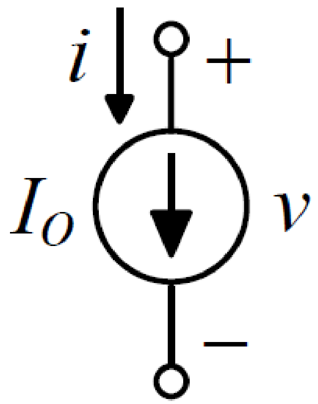
Current Source

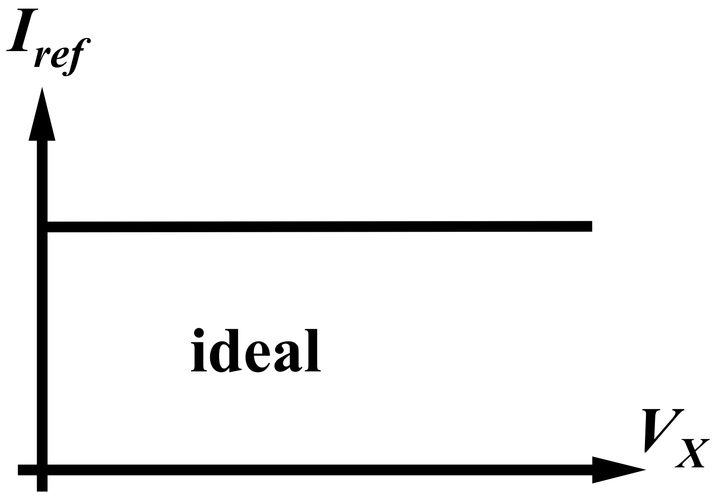
- Why do we need current sources?



Current Source

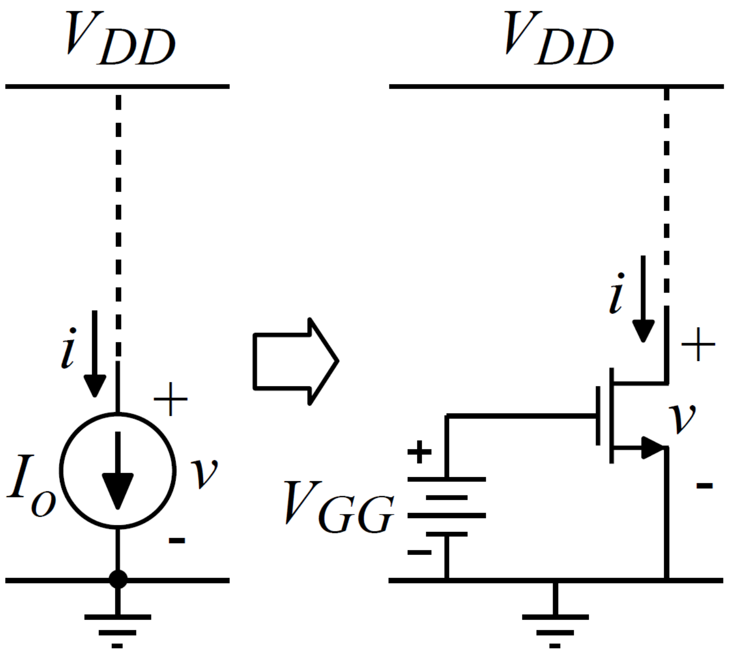
- An ideal current source
- Fixed current I_0
- I_{ref} is independent of V_x



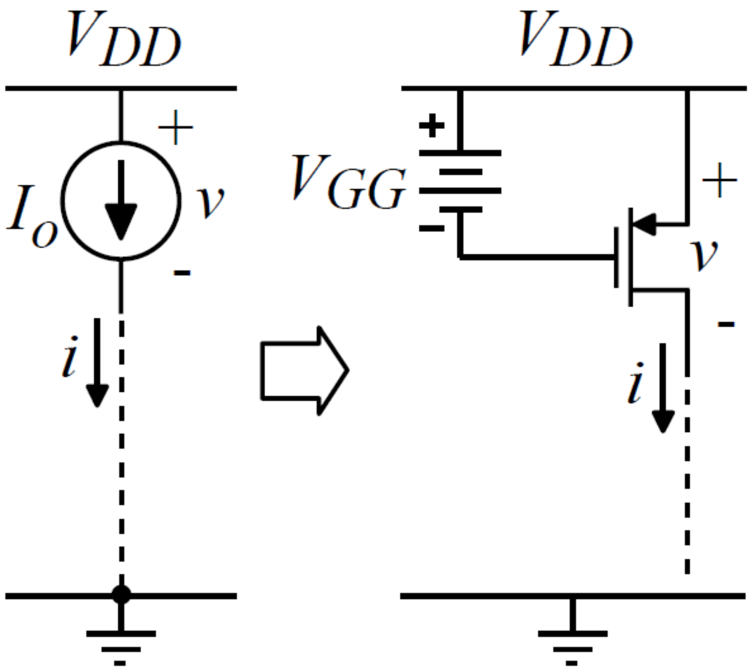


Current Source

- nFET and pFET as current source
- Both are called “current sources”!



Current Sink



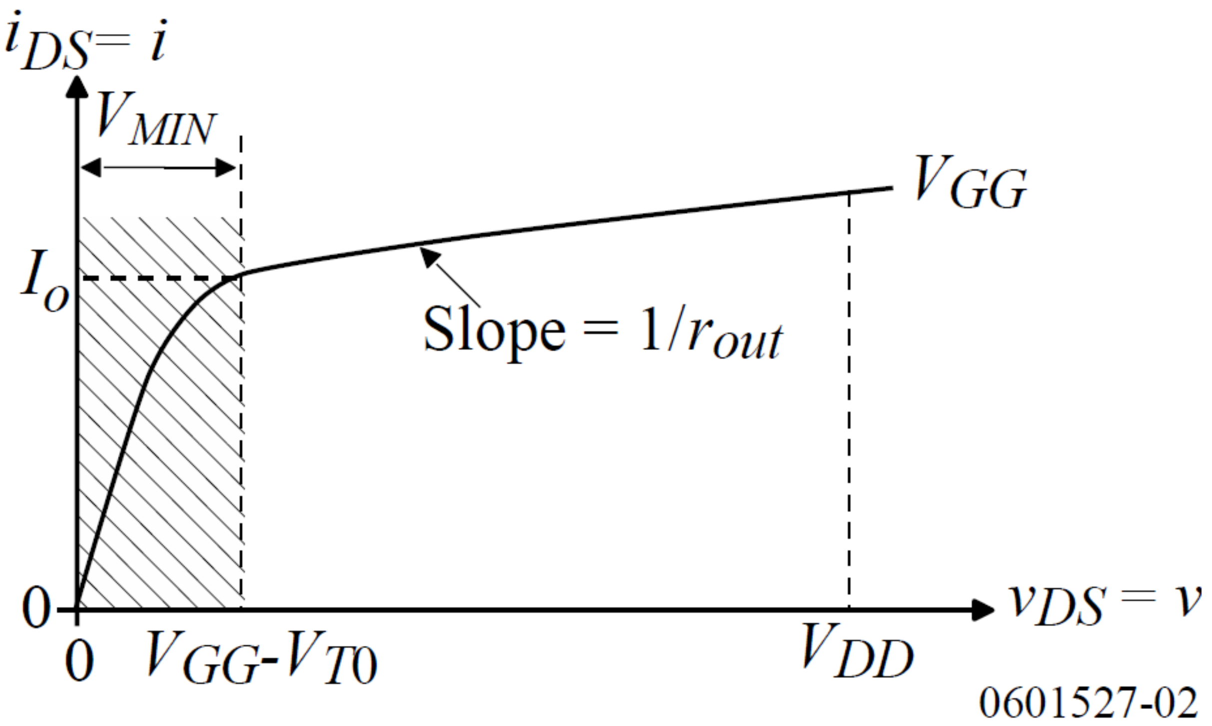
Current Source

Current Source

- nFET current source:

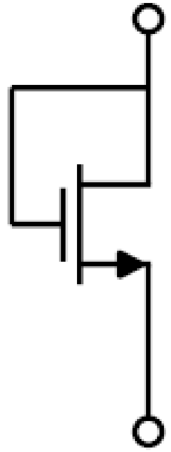
$$V_{MIN} = V_{DS}(\text{sat}) = V_{GS} - V_{T0}$$

$$r_{out} = \frac{1}{di_D/dv_{DS}} = \frac{1+\lambda V_{DS}}{\lambda I_D} \approx \frac{1}{\lambda I_D}$$



Current Source

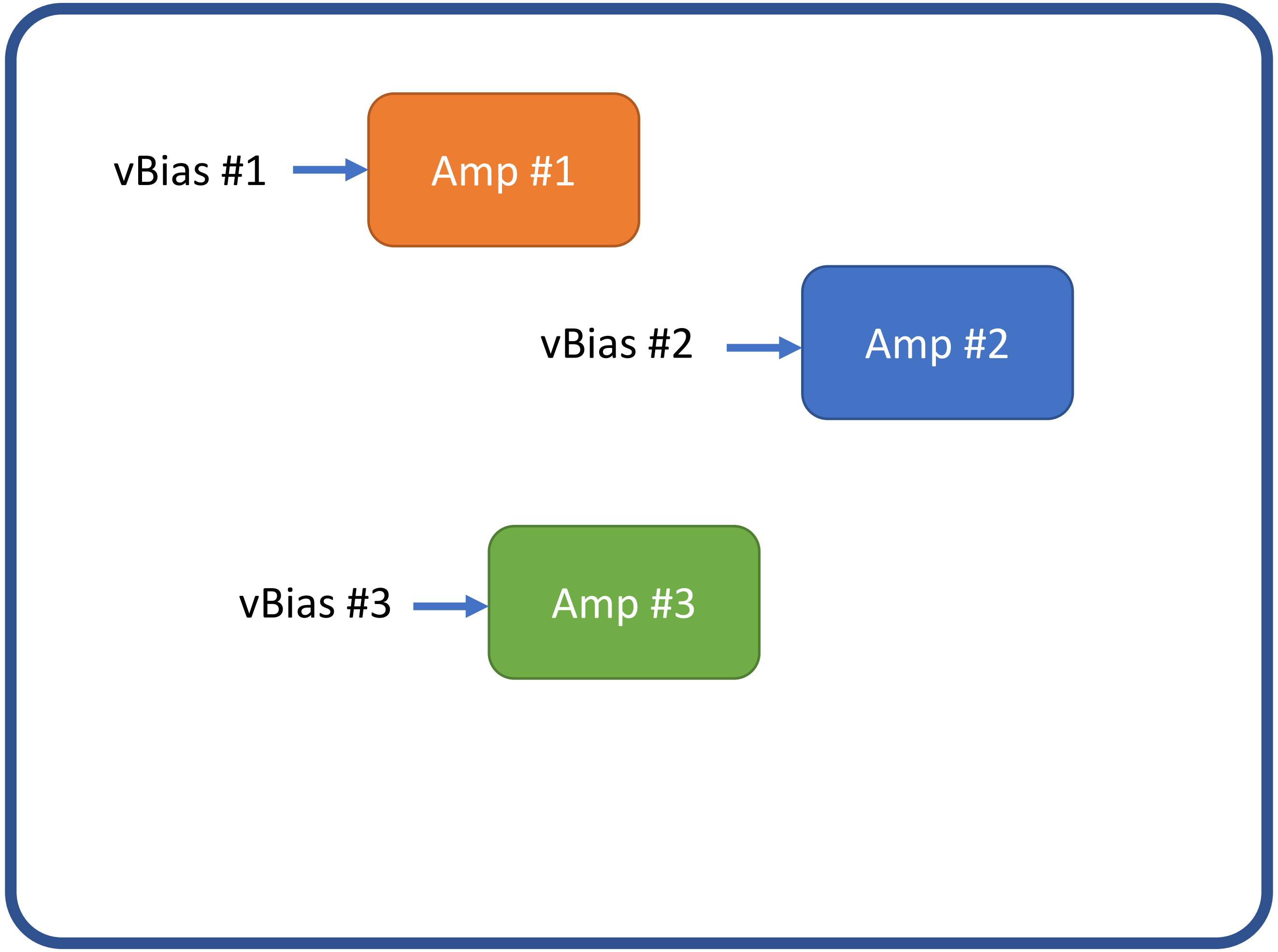
- Always in saturation



$$\text{AC resistance} = \frac{v_{ds}}{i_d} = \frac{1}{g_m + g_{ds}} \approx \frac{1}{g_m}$$

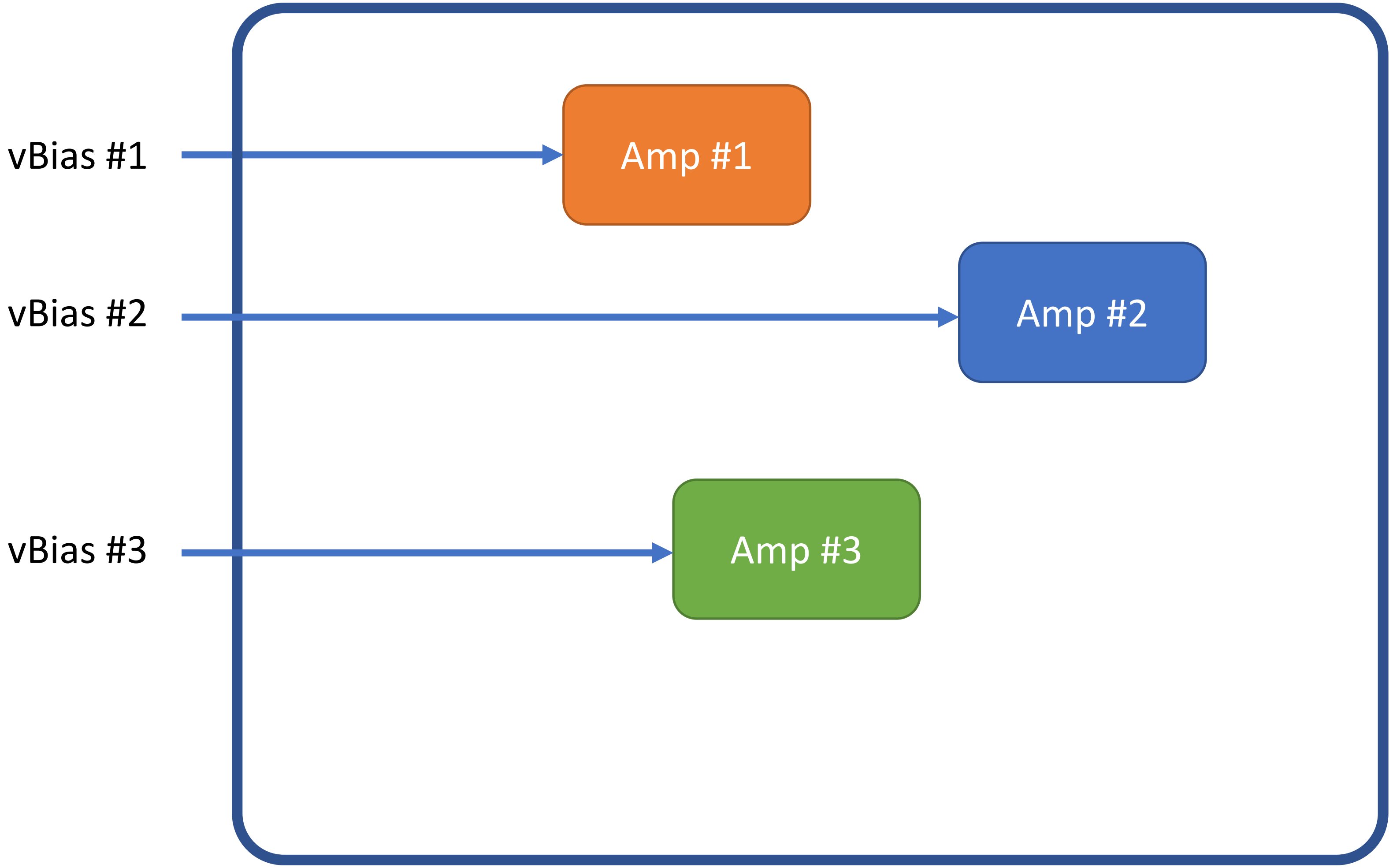
Current Source

- There are multiple current sources on a chip
- Each nFET current source needs a gate voltage
- How do we generate these voltages?



Current Source

- External Supplies
- How many of them?



Current Source

- Internal generation of bias voltages
- Resistor dividers
- The problem with resistor dividers

Intro to Current Mirrors

- If we want a current-copying device it should have:
  - very high output impedance
  - very low input impedance
    (to accept incoming current)
- The advantage of current mirrors additives and subtractive
- Accuracy and trimming

Simple Current Mirror

- nFET current mirror:

$$\frac{i_O}{i_I} = \left(\frac{L_1 W_2}{W_1 L_2}\right)\left(\frac{V_{GS}\text{-}V_{T2}}{V_{GS}\text{-}V_{T1}}\right)^2\left[\frac{1+\lambda v_{DS2}}{1+\lambda v_{DS1}}\left(\frac{K_2'}{K_1'}\right)\right]$$

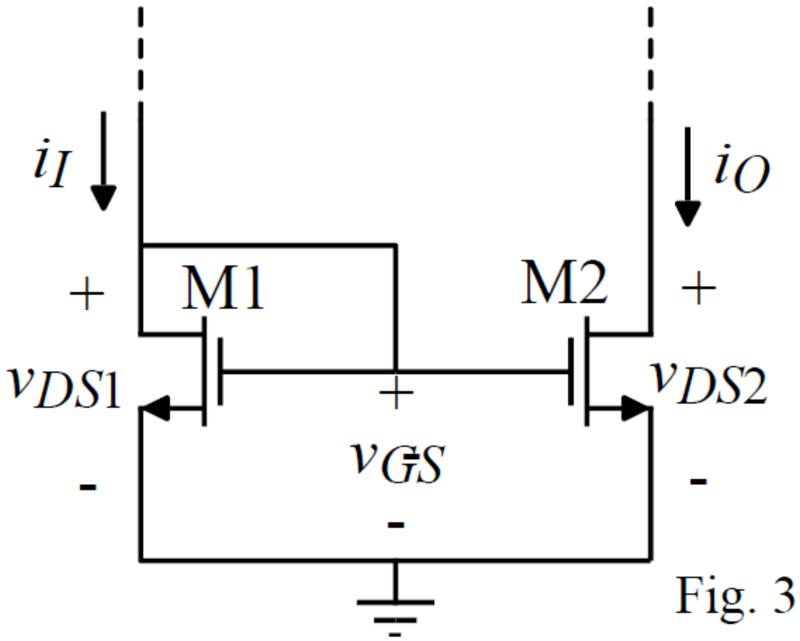


Fig. 300

$$\frac{i_{out}}{i_{in}} = \left(\frac{L_1 W_2}{L_2 W_1}\right)\left(\frac{1+\lambda v_{DS2}}{1+\lambda v_{DS1}}\right)$$

Simple Current Mirror

- nFET current mirror:

$$R_{out} = \frac{1}{\lambda I_D}$$

$$R_{in} \approx \frac{1}{g_m}$$

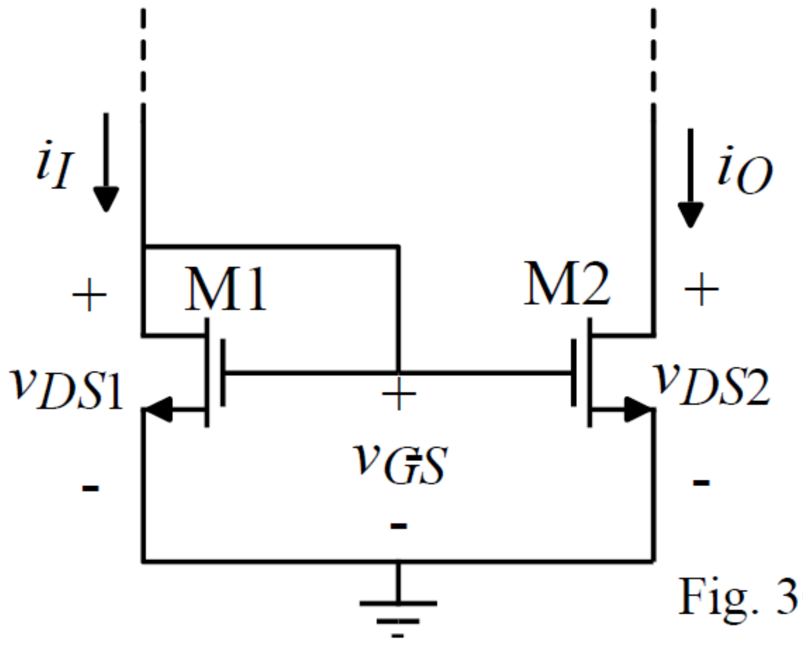


Fig. 300-02

Simple Current Mirror

- Assume: Vgs = Vt + Von

$$V_{MIN}(\text{in}) = V_T + V_{ON}$$

$$V_{MIN}(\text{out}) = V_{ON}$$

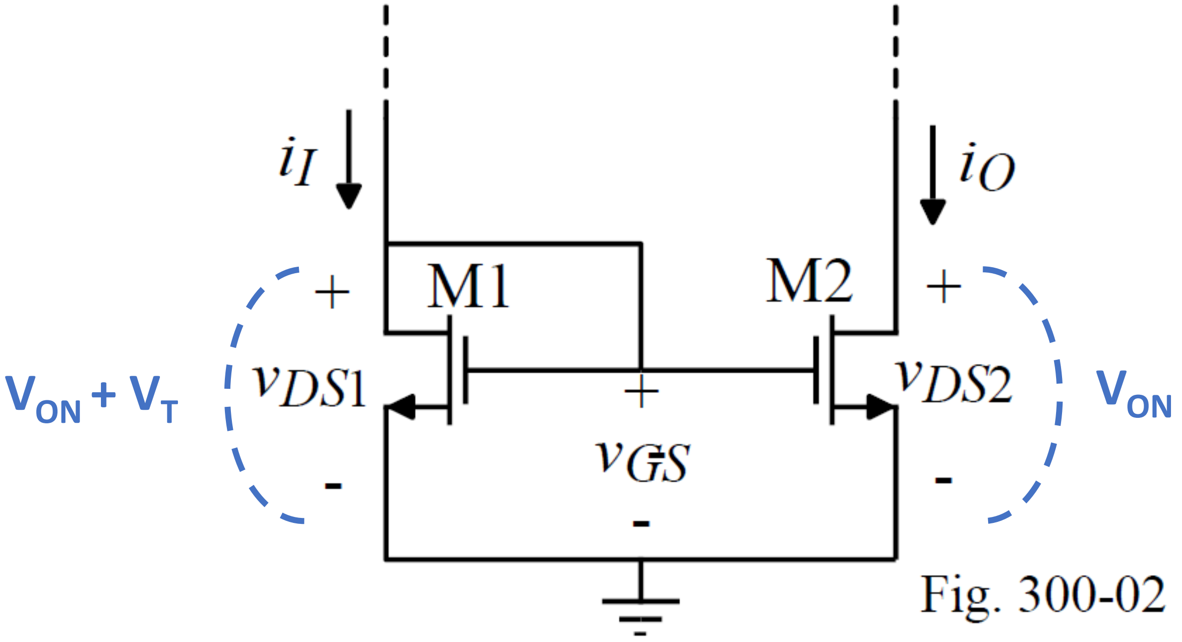
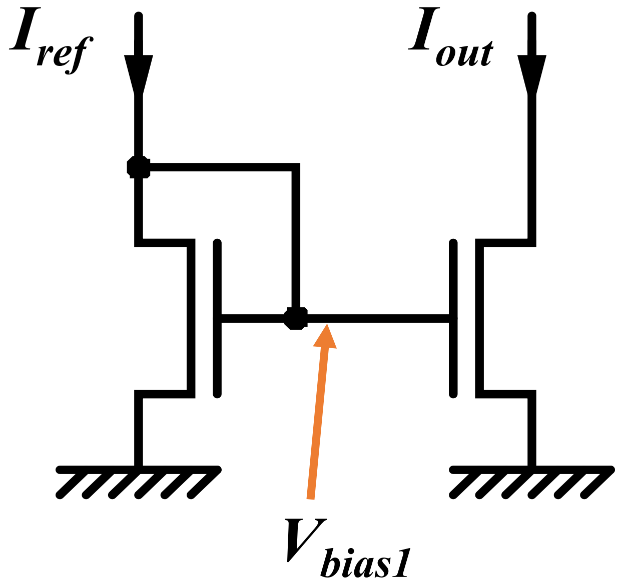


Fig. 300-02

(for M2 to be in saturation -> min requirement is vds=vgs-Vt)

Simple Current Mirror

- Both transistors must be in saturation
- M1 and I_{ref} make V_{GS2} constant
- M2 saturated and V_{GS2} constant, so $I_{DS2} = I_{out}$ must also be constant
- *But* V_{DS2} is highly variable so I_{DS2} is *not* constant (because of the λ term)

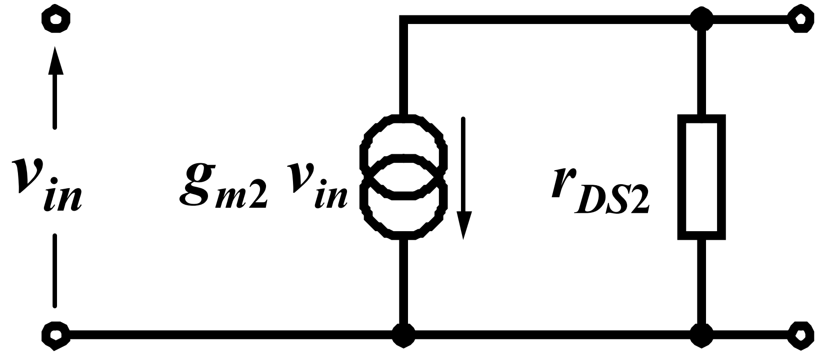


Simple Current Mirror

- We have $I_{DS2} = (\beta/2)\,(V_{bias1} - V_T)^2\,(1 + \lambda V_{DS})$
- Therefore $dI_{DS2}/dV_{DS2} = (\beta/2)\,(V_{bias1} - V_T)^2\,(\lambda)$
  $= \lambda\, I_{out}/(1+\lambda\, V_{DS}) \approx \lambda\, I_{out}$
- Therefore $R_{out} = 1/\lambda\, I_{out}$
- This tends to give an output impedance of about 1MΩ which is not high enough for most purposes
- The output impedance of a single MOSFET, used in saturation, as a current-sink, is too low

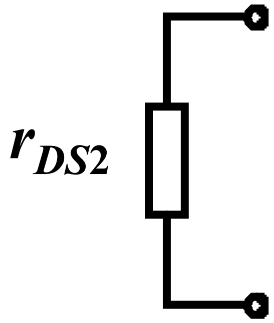
Simple Current Mirror

- The model for the simple current mirror is as shown top right



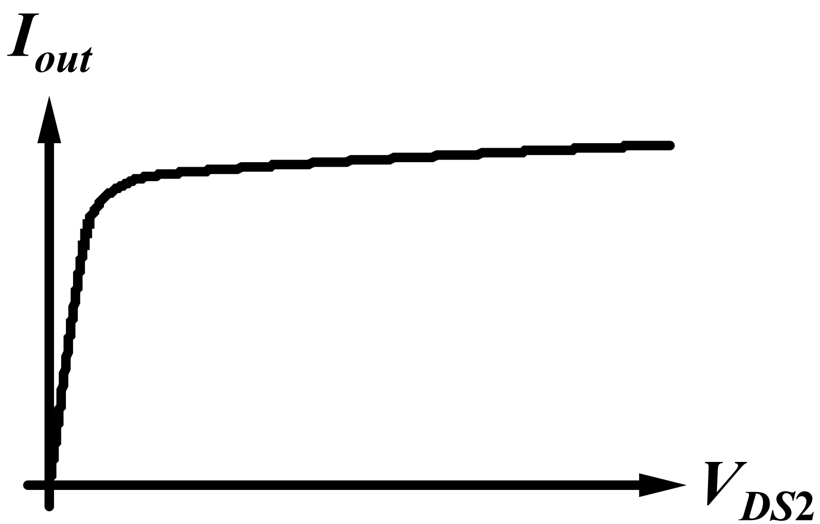
- But V_{in} is constant so v_{in} is zero

- Therefore the model becomes that shown bottom right, where $r_{DS2} \approx 1/\lambda I_{DD}$



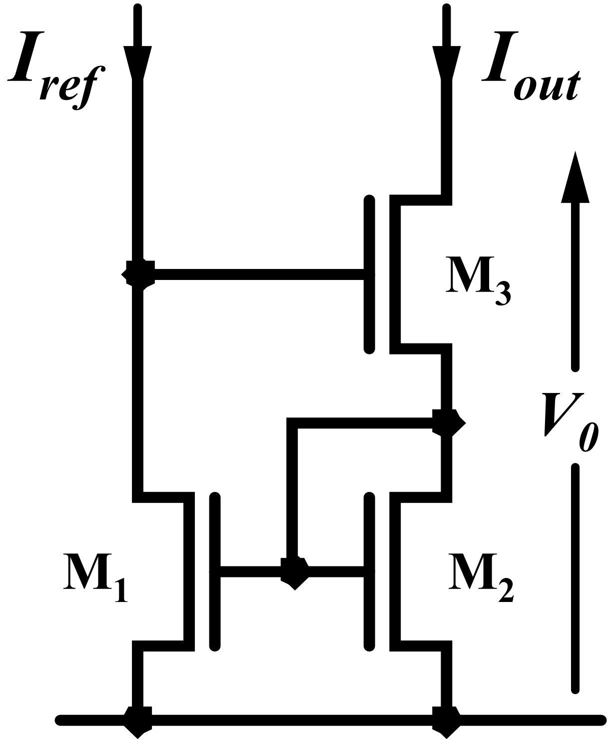
Simple Current Mirror

- Note how I_{out} increases with V_{DS2}
- This not desirable and a sign that R_{out} is too low
- Must increase R_{out}



Wilson Current Mirror

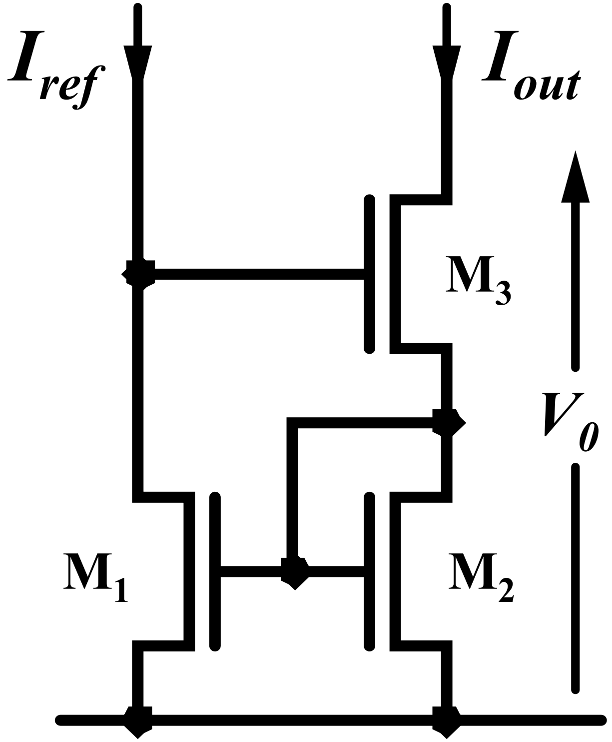
- Negative feedback $\rightarrow$ opposes change



Wilson Current Mirror

- Follow chain of events if I_{out} rises (falls)

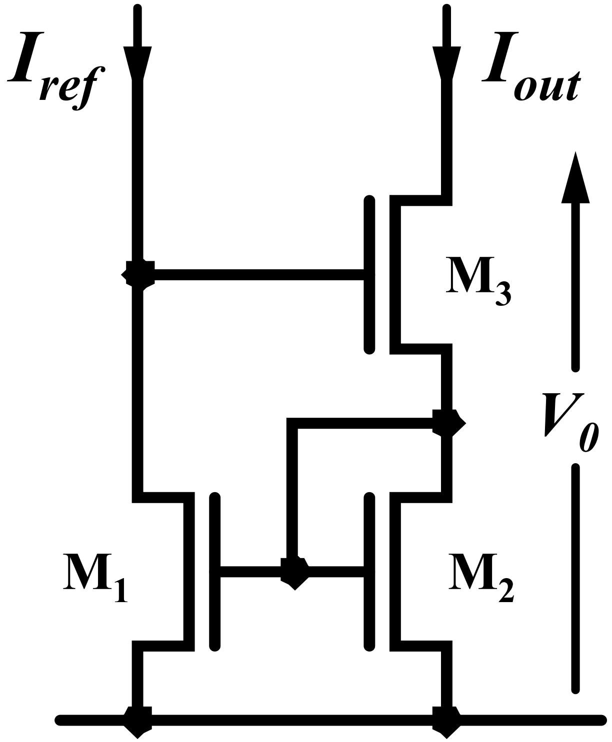
- V_{DS2} **rises (falls) sharply**
- V_{GS1} **rises (falls) sharply**
- I_{ref} **cannot rise (fall)**
- V_{DS1} **falls (rises) sharply** ***(saturation equation)***
- V_{GS3} **falls (rises) sharply**
- I_{out} **falls (rises)**



Wilson Current Mirror

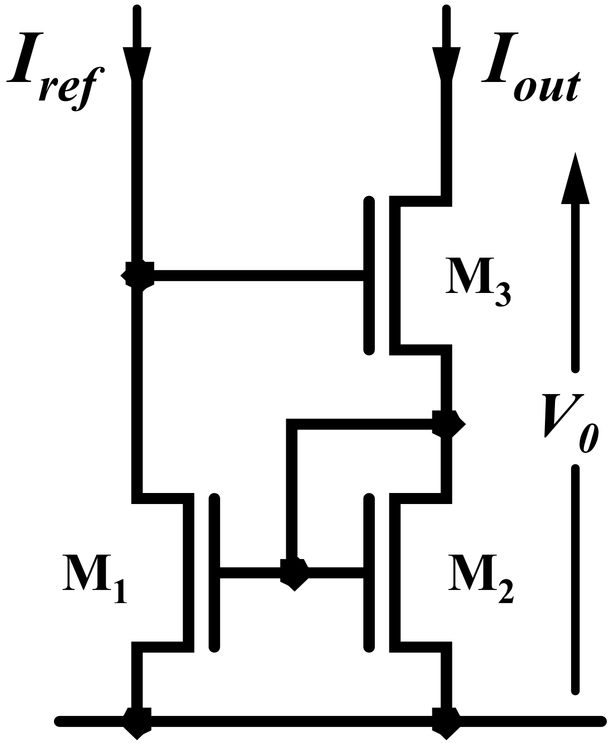
- Current gain same as simple current mirror

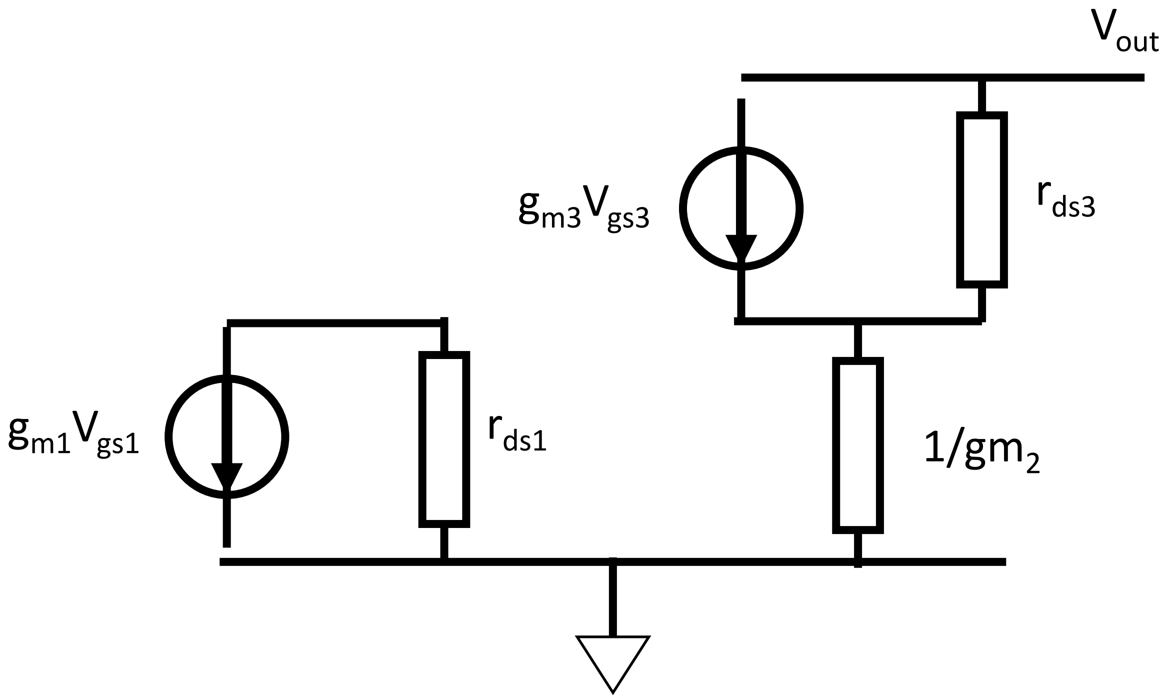
$$\frac{i_{out}}{i_{in}} = \left(\frac{L_1 W_2}{L_2 W_1}\right)\left(\frac{1+\lambda v_{DS2}}{1+\lambda v_{DS1}}\right)$$



Wilson Current Mirror

- How to find out Ro?

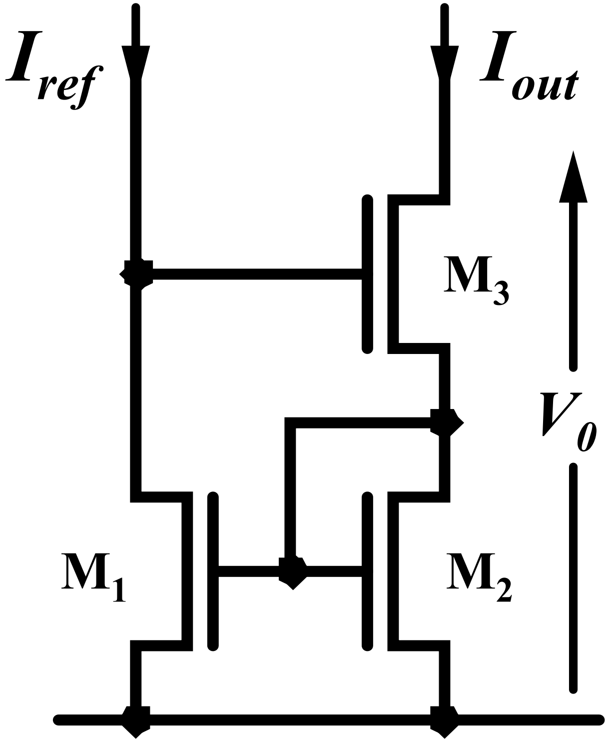




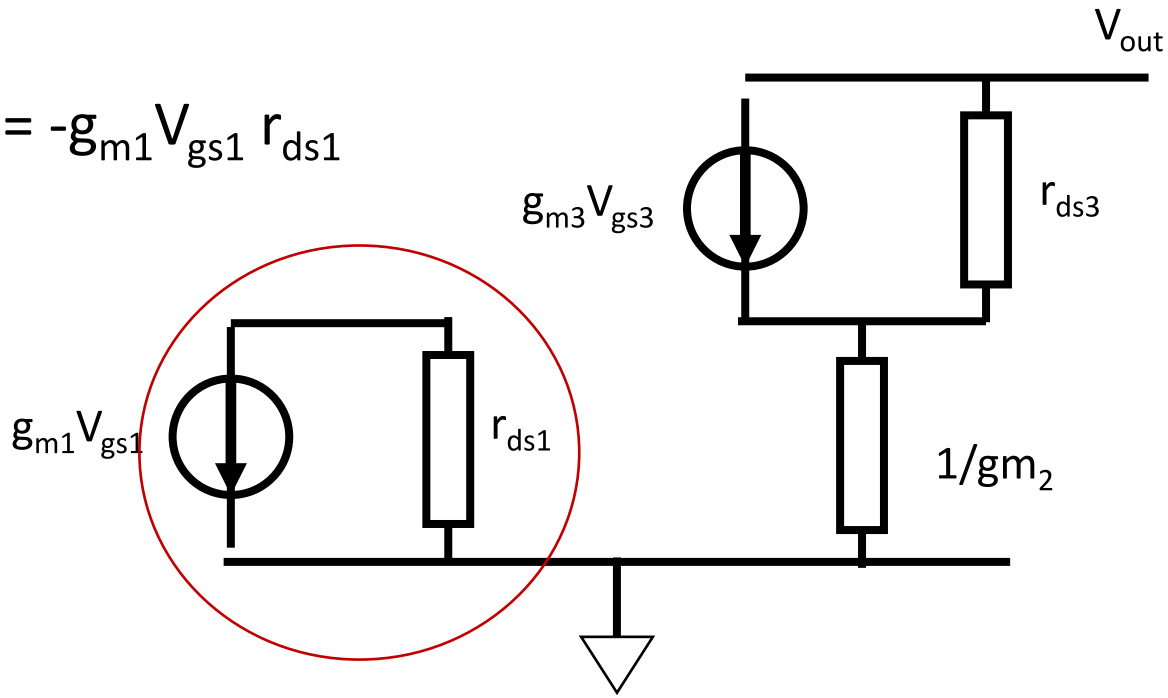
Wilson Current Mirror

$$V_{ds1} = V_{gs3} + V_{gs1}$$

$$V_{gs1} = V_{gs2}$$



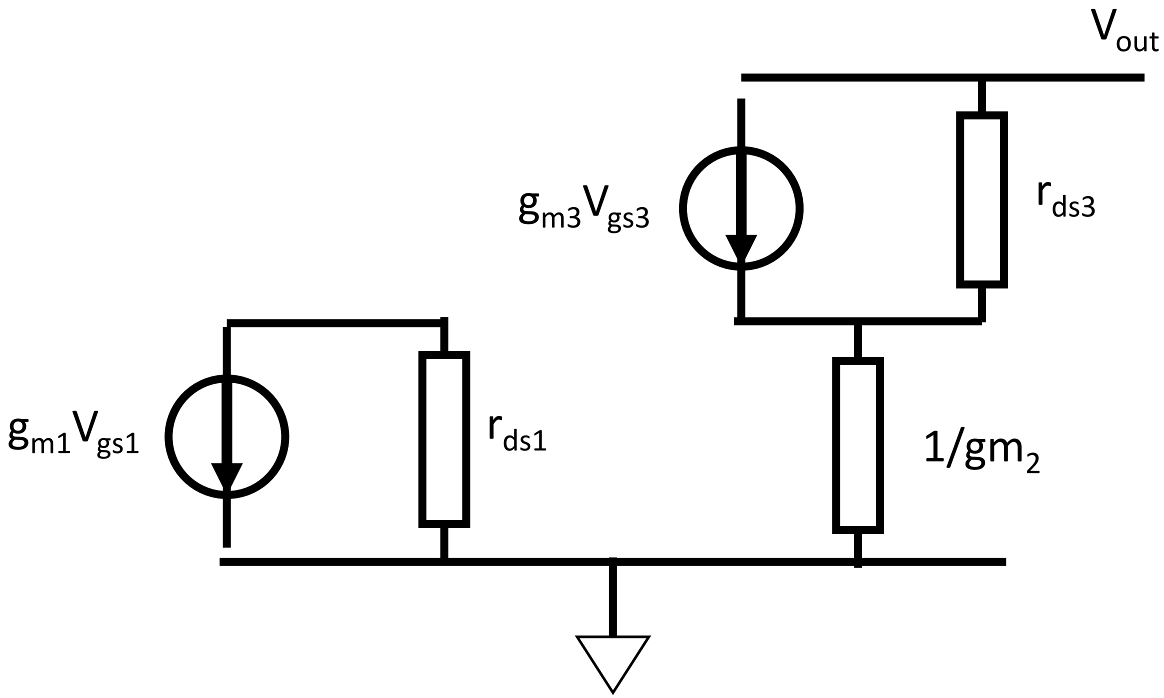
$$V_{ds1} = -g_{m1}V_{gs1}\, r_{ds1}$$



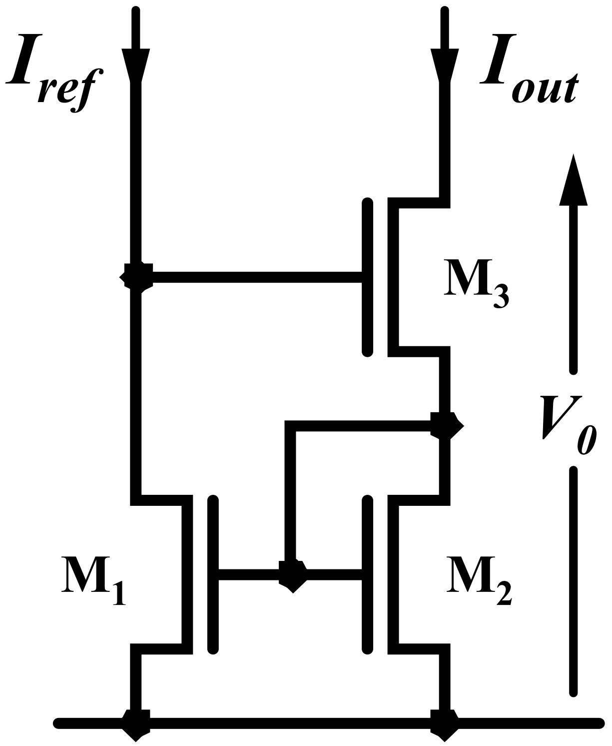
Wilson Current Mirror

$$r_{out} \approx \frac{g_{m3}g_{m1}}{g_{m2}} r_{ds1} r_{ds3}$$

$$\boxed{r_{out} \approx g_m r_{ds}^2}$$



Wilson Current Mirror



+

V_{ON}

-

+

$V_{ON} + V_T$

-

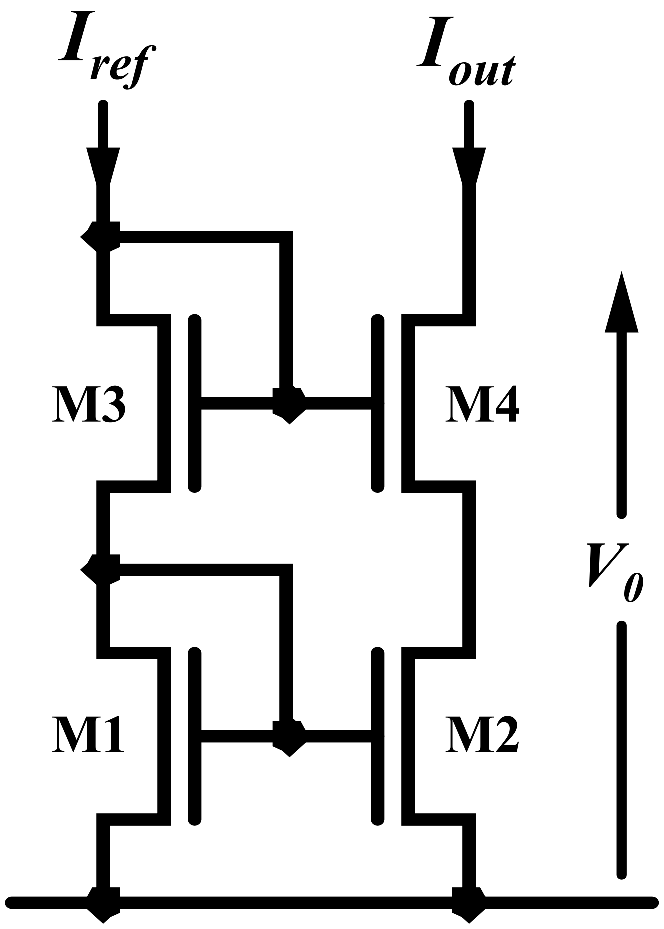
$$V_{out}\,(min) = 2V_{ON} + V_T$$

Cascode Current Mirror

- *The current gain:*

$$\frac{i_{out}}{i_{in}} = \left(\frac{L_1 W_2}{L_2 W_1}\right)\left(\frac{1+\lambda v_{DS2}}{1+\lambda v_{DS1}}\right)$$

Can we do anything about this?

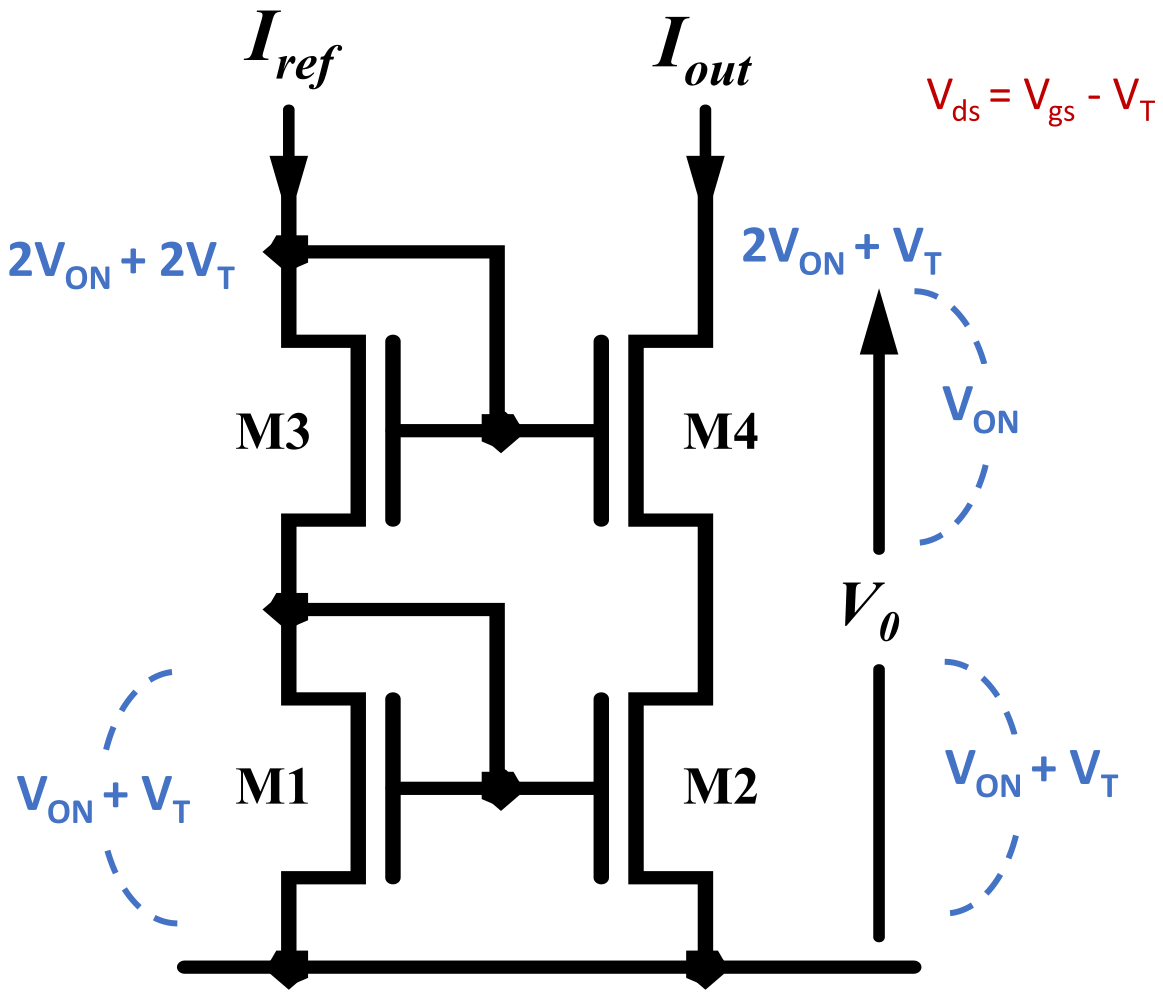


Cascode Current Mirror

- *The minimum output voltage:*

$$V_{out}\,(min) = 2V_{ON} + V_T$$

$$V_{DS1} = V_{DS2}$$



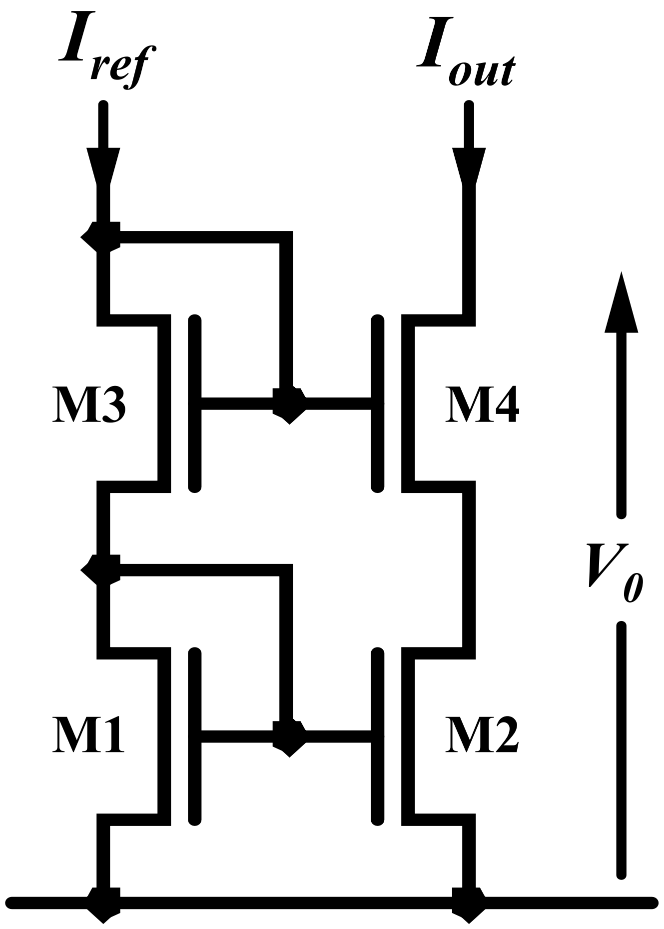
Cascode Current Mirror

- *The current gain:*

$v_{DS1} = v_{DS2}$

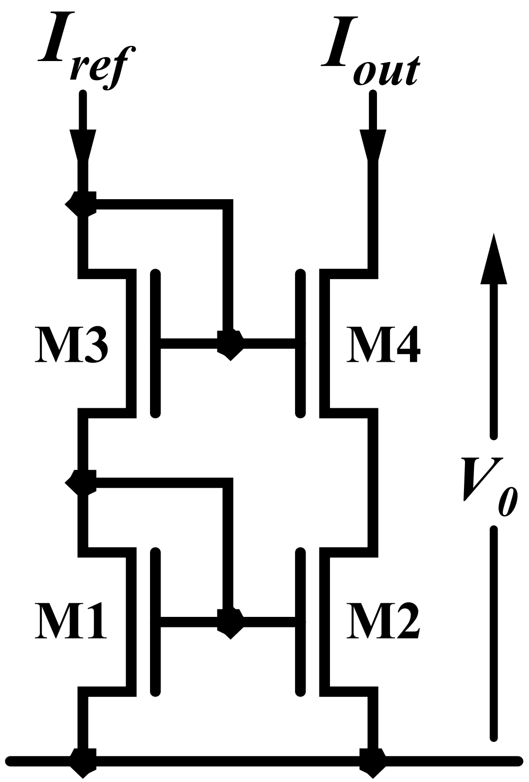
$$\frac{i_{out}}{i_{in}} = \left(\frac{L_1 W_2}{L_2 W_1}\right)\left(\frac{1+\lambda v_{DS2}}{1+\lambda v_{DS1}}\right)$$

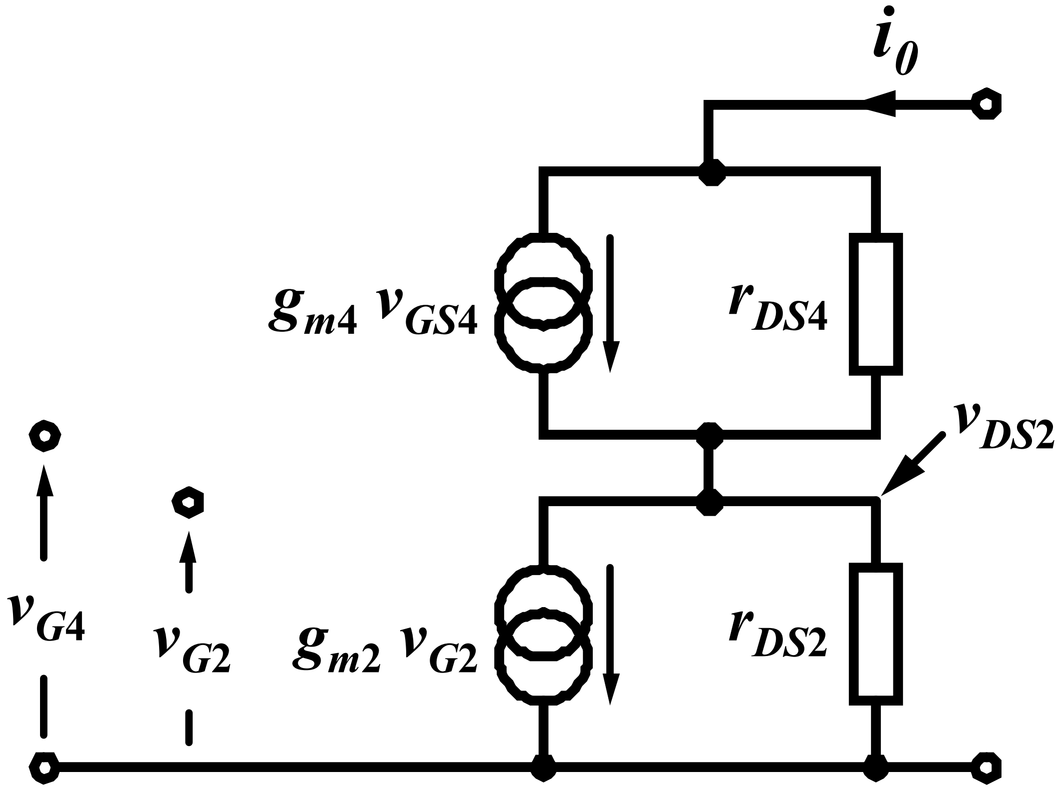
$$\Rightarrow \quad \frac{i_{out}}{i_{in}} = \left(\frac{L_1 W_2}{L_2 W_1}\right)$$



Cascode Current Mirror

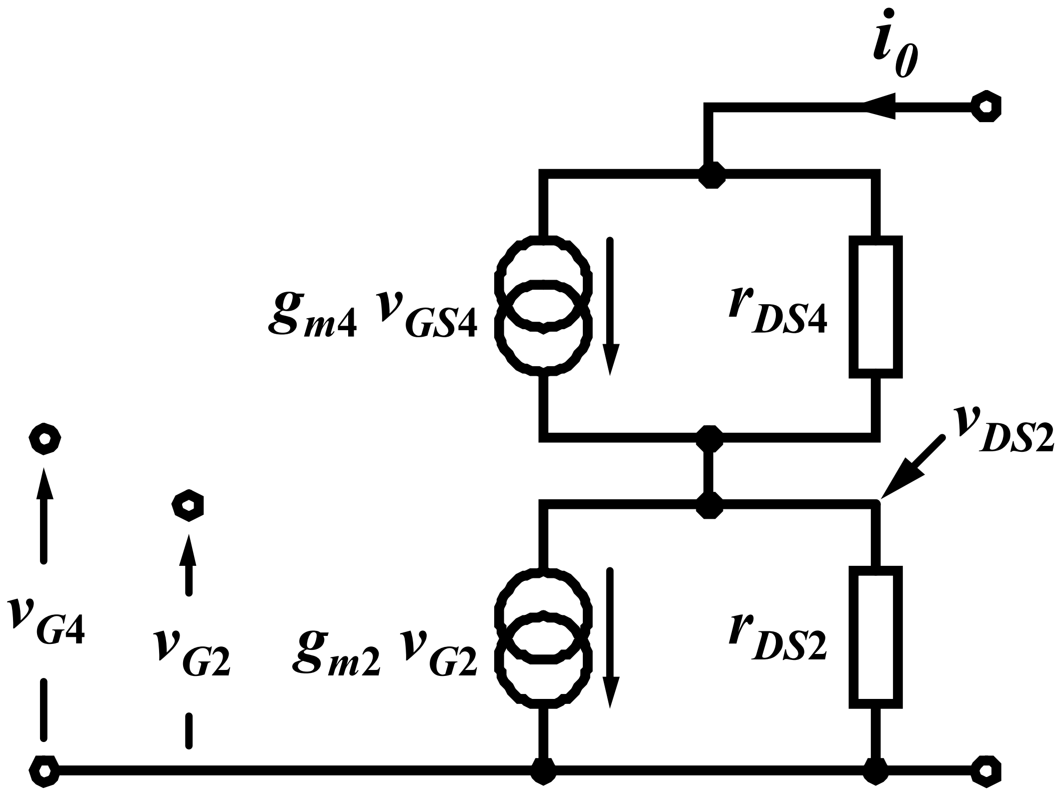
- *The output resistance:*





Cascode Current Mirror

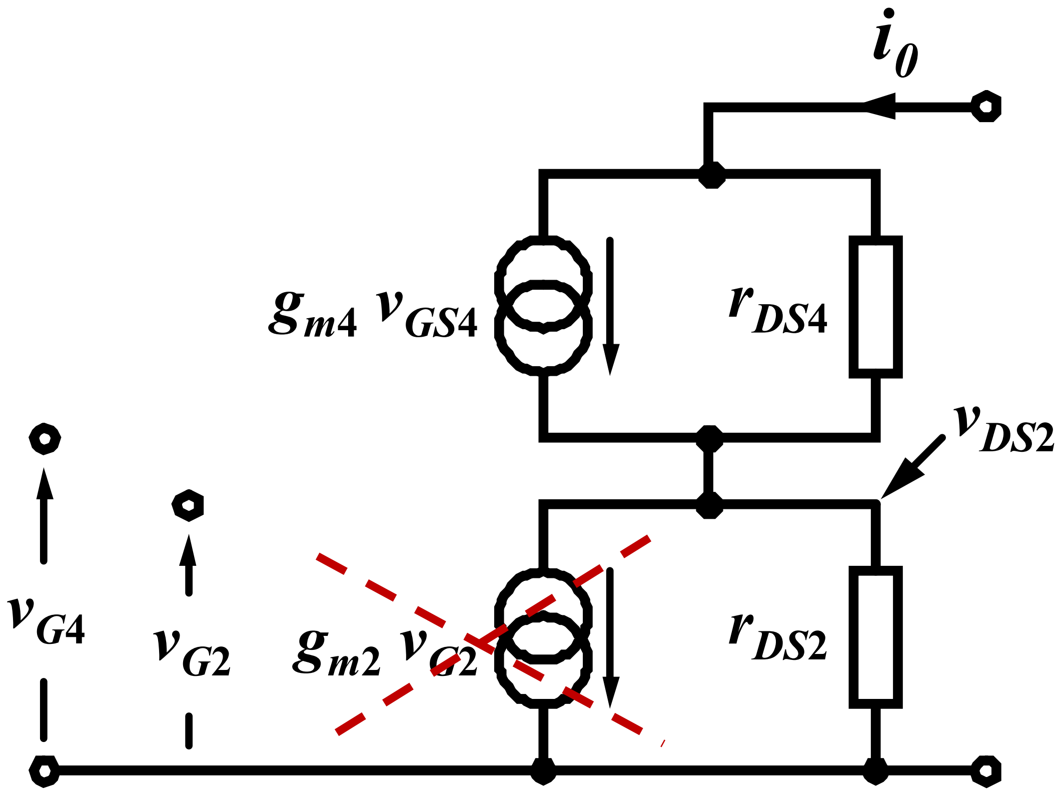
- $R_{out} = V_{out} / i_{out}$
- For small signal analysis:
- $i_{in} = 0$
- $v_{G2} = v_{G4} = 0$
- $v_{GS2} = 0$



Cascode Current Mirror

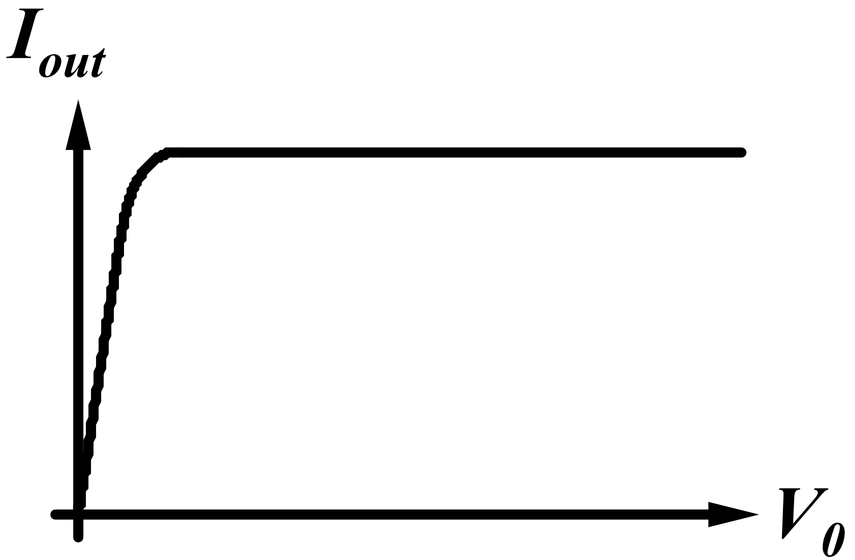
$$R_{out} = r_{o2} + r_{o4} + g_{m4} r_{o2} r_{o4}$$

$$\boxed{R_{out} \approx g_m r_o^2}$$



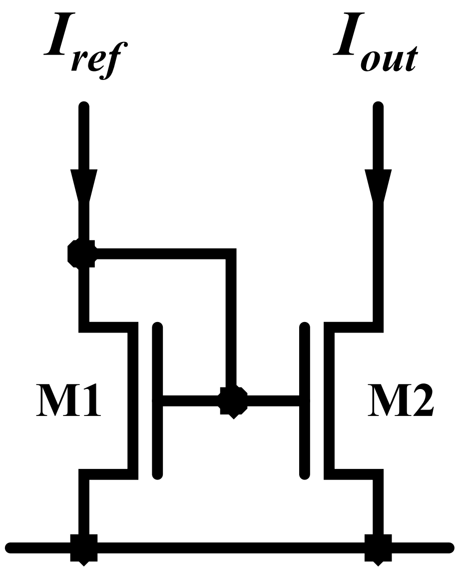
Cascode Current Mirror

- Now I_{out} is very close to constant while V_0 varies
- As expected, R_{out} for this circuit is very high.
- If an even half decent current source/mirror is required this is the type to choose



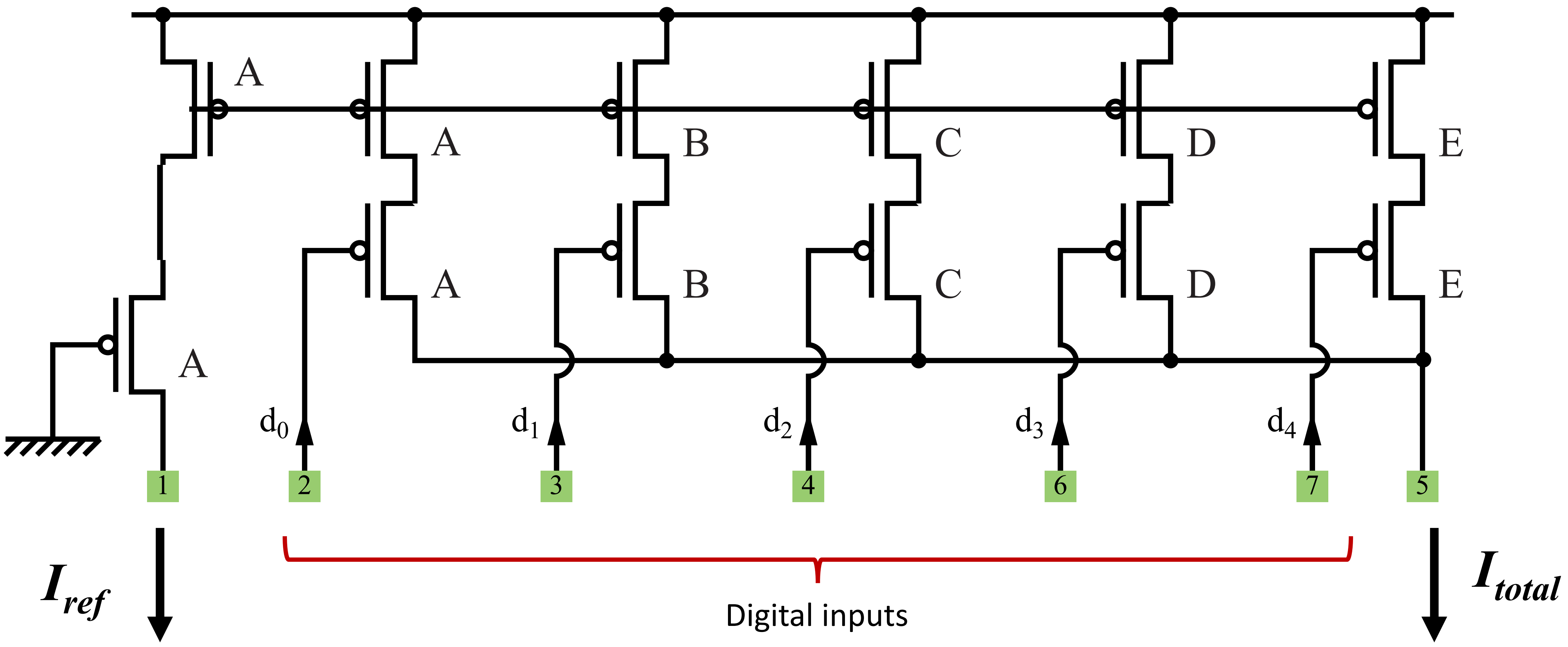
Current Mirror – considerations

- If we make *W/L* for M2 "*n*" times bigger than *W/L* for M1, $I_{out} = nI_{ref}$
- In this manner we can ratio currents
- This is *very* common practice, but it must be done with *care*!



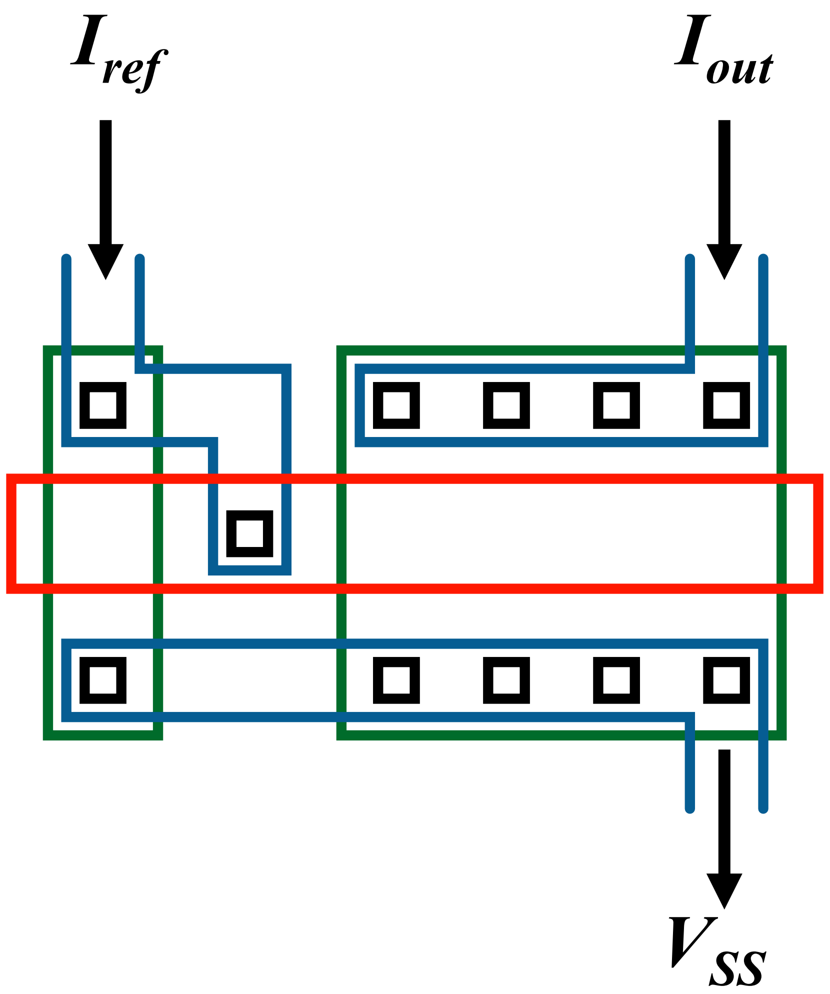
Current Mirror – considerations

- Current Digital-to-Analogue(DAC)example:



Current Mirror – considerations

- Here M1:M2 = 1:4
- This is *not* a good layout
- Takes no account of
  - edge effects
  - ΔW effects
  - ΔV_t effects



Current Mirror – considerations

- This is a better layout
- Matches one transistor with four identical transistors in parallel
- Takes account of edge effects and ΔW effects
- Still no account of ΔV_t effects