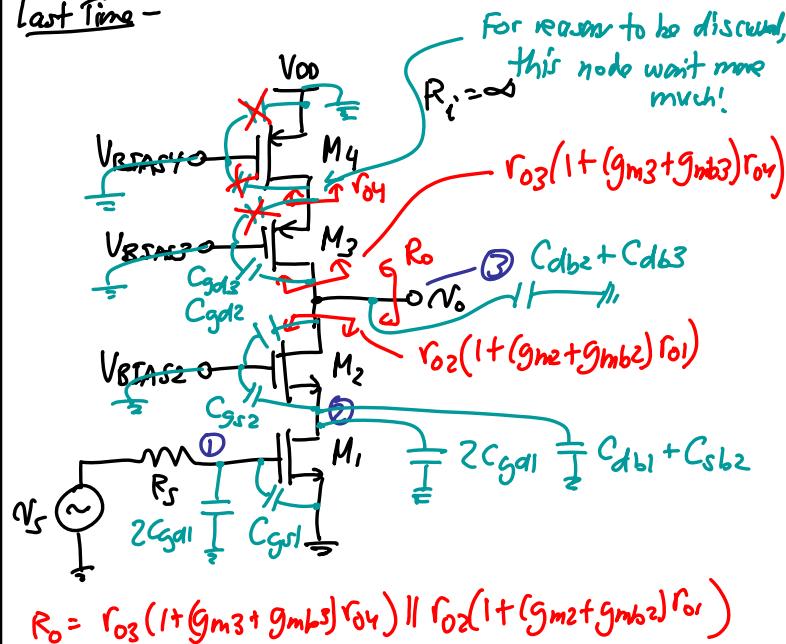


Lecture 10: Current Sources

Today:

- Current Source V_{BIAS} Generators
- Problem 4 moved to HW#4: replace the HW#4 problem 4 with the HW#3 problem 4 (i.e., no need to do Razavi problem 5.2)

Last Time -

$$A_N = \frac{V_O}{V_S} = \frac{N_3}{N_1} \cdot \frac{N_2}{N_1} \cdot \frac{N_1}{N_2} \approx 1$$

$$= (1) \left(-g_m1 \left(\frac{1}{g_m2 + g_m1} \right) (g_m2 + g_m1) R_o \right) = -g_m1 R_o = A_{NR}$$

Get dominant pole: (use OCTC analysis)

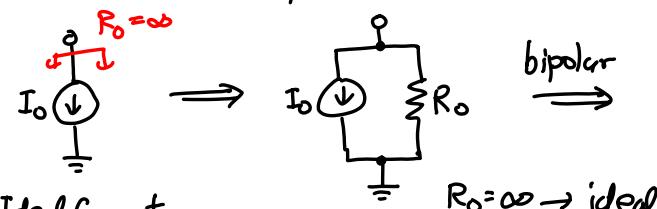
$$T_D = (2C_{gd1} + C_{gr1}) R_S$$

$$T_2 = (2C_{gd1} + C_{gr2} + C_{db1} + C_{sb2}) \left(\frac{1}{g_m2 + g_m1} \right)$$

... and so on...

Transistor Current Sources

How can a transistor implement a current source?

Ideal Current SourceActual Current SourceBipolar Xistor Current SourceForward-Active Sourcelarge.

$$I_o = I_c = I_s \exp \left(\frac{V_{BIAS}}{V_T} \right) \left(1 + \frac{V_{CE}}{V_A} \right)$$

$$R_o = r_o$$

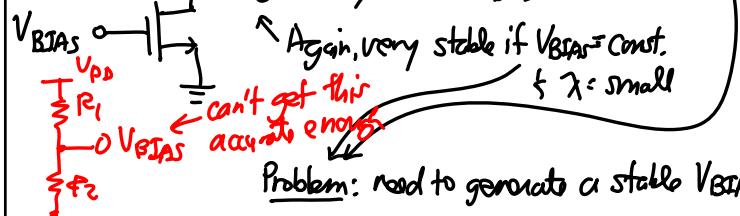
Very stable if $V_{BIAS} = \text{const.}$
 $\downarrow V_A = \text{large}$

Note that V_{BIAS} must be very accurate due to exponential
 \downarrow to several sig. figs.

$$\hookrightarrow \text{e.g., } V_{BIAS} = 0.68745V$$

Saturated MOS Xistor Current Source

$$R_o = r_o \rightarrow I_o = I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{BIAS} - V_t)^2 (1 + \lambda V_{DS})$$



Lecture 10: Current Sources

We now focus on methods for generating V_{BSA} .

But how do we get this degree of precision using a transfer function?

Solution:

Replica Biasing (a simple & effective approach)

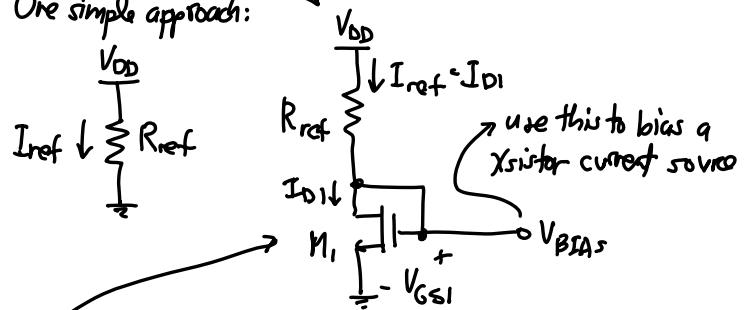
① Generate the desired current.

② Push the current through a Xsistor and allow it to reach a stable bias pt.

③ Use this stable bias pt. as V_{BSA}

→ this can be very precise!

One simple approach:



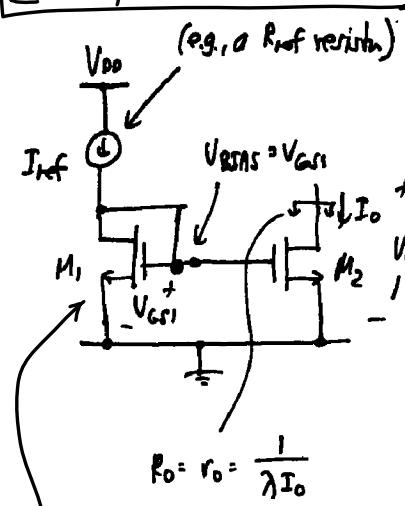
A diode-connected Xsistor is always in saturation and will basically bias itself to support the needed current!

$$I_{ref} = I_{D1} = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L} \right) (V_{GS1} - V_t)^2 (1 + \lambda V_{DS1})$$

V_{BSA}

Now, can distribute this V_{BSA} to the gates of many MOS transistors current sources!

Ex. Simple MOS Current Source



$$R_o = r_o = \frac{1}{\lambda I_o}$$

In general,

$V_{DS1} \neq V_{DS2}$, but if λ is small, then little difference in I_{D1} & I_{D2}

$$I_{D1} = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L} \right)_1 (V_{BSA} - V_t)^2 (1 + \lambda V_{DS1})$$

$$I_{D2} = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L} \right)_2 (V_{BSA} - V_t)^2 (1 + \lambda V_{DS2})$$

① Case: matched M_1 & $M_2 \Rightarrow I_o = I_{ref}$

② Case: M_1 & M_2 scaled wrt to each other

$$\Rightarrow I_o = I_{ref} \frac{(W/L)_2}{(W/L)_1}$$

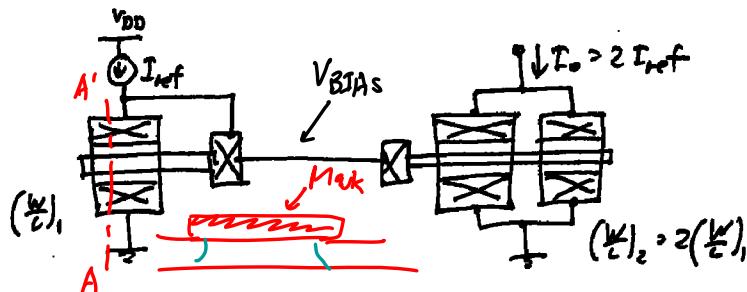
⇒ use $L_1 = L_2$ for both accuracy, then:

$$\frac{I_o}{I_{ref}} = \frac{W_2}{W_1}$$

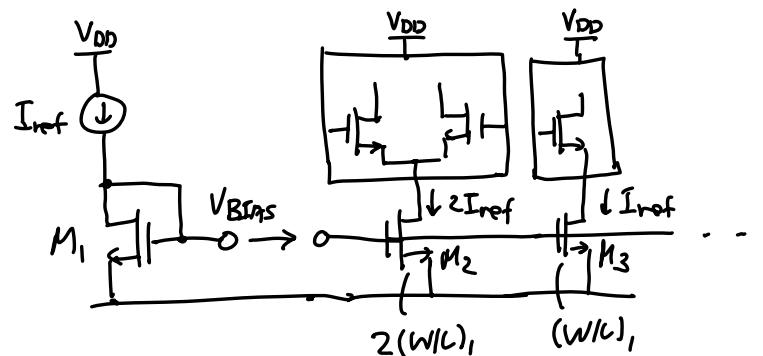
Note: For better accuracy, should use multiple copies of one device when scaling currents → reduces edge effects!

Lecture 10: Current Sources

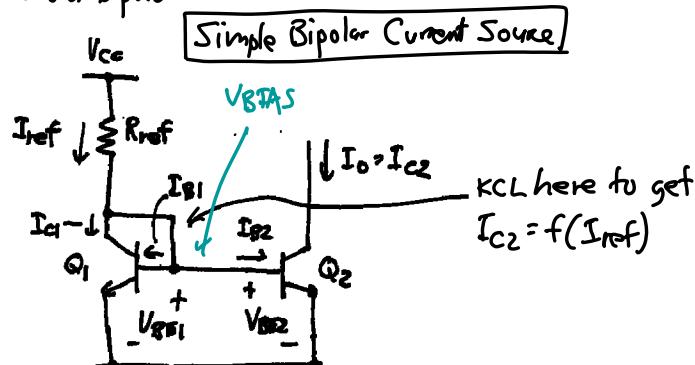
Ex: Layout for a Doubling Current Source



A single V_{BIAS} generator can now serve numerous current sources:



How about bipolar?



$$I_o = I_{c2} \quad KCL \text{ here to get } I_{c2} = f(I_{ref})$$

Assume $Q_1 + Q_2$ are matched.

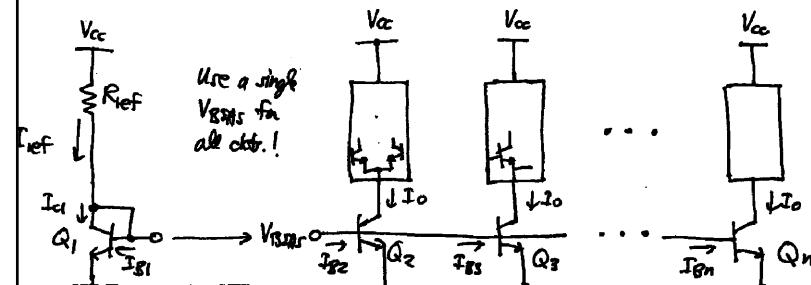
$$V_{BE1} = V_{BE2} \rightarrow I_{c1} = I_{c2} = I_o \quad (\text{neglecting } V_A)$$

$$\text{KCL: } I_{ref} = I_{c1} + I_{B1} + I_{B2} = I_{c1} \left(1 + \frac{2}{\beta}\right)$$

$$\therefore I_{c1} = I_{c2} = I_o = \frac{I_{ref}}{1 + \frac{2}{\beta}} \rightarrow I_o \approx I_{ref}$$

$$\text{and } I_{ref} = \frac{V_{cc} - V_{BE(0)} - V_A}{R_{ref}} \quad R_o = r_{o2} \quad \text{can say } \epsilon_m \sim \frac{2}{\beta}$$

Again, a single V_{BIAS} generator can serve many current sources throughout the IC chip:



$$I_{ref} = I_{c1} + I_{B1} + I_{B2} + \dots + I_{Bn}$$

$$[\text{Identical resistors}] \Rightarrow I_{ref} = I_{c1} \left(1 + \frac{n}{\beta}\right)$$

$$\Rightarrow I_o = I_{c1} = \frac{I_{ref}}{\left(1 + \frac{n}{\beta}\right)}$$

Problem:

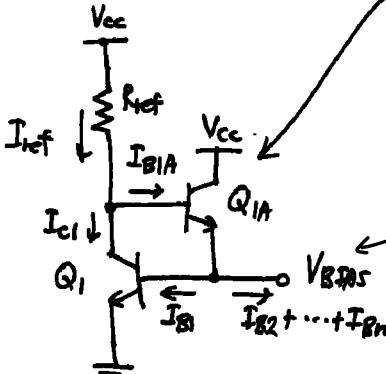
$\epsilon_m \sim \frac{n}{\beta}$ increases as n increases
(I_o deviates from I_{ref} , and the deviation depends on n)

This was not the case for MOS!

How can we reduce the error?

Lecture 10: Current Sources

To reduce the error term, use a

Buffered V_{BE} -Generator


Add a buffer Xistor to attenuate base currents from Xistor current sources.

This can now drive the base currents of many bipolar transistors current sources (i.e., active loads).

$$I_{ref} = I_{cl} + I_{B1A}$$

$$I_{B1A} = \frac{I_{cl} + I_{B2} + \dots + I_{Bn}}{\beta + 1} = \frac{n I_{cl}}{\beta(\beta + 1)}$$

[Assuming identical Xistors]

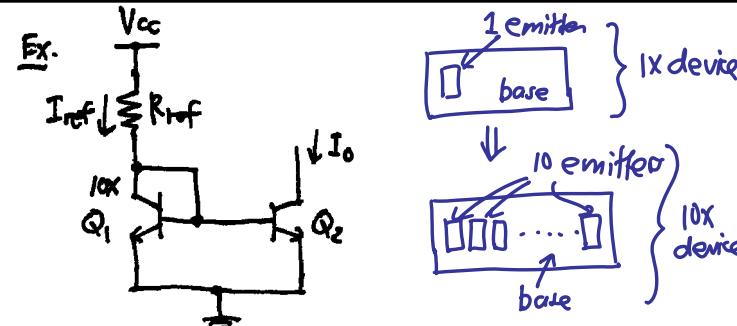
$$I_{ref} = I_{cl} \left(1 + \frac{n}{\beta(\beta + 1)} \right)$$

$$\rightarrow I_o = I_{cl} = \frac{I_{ref}}{1 + \frac{n}{\beta(\beta + 1)}} \approx I_{ref} \left(1 - \frac{n}{\beta^2} \right)$$

Note: Now,

$$I_{ref} = \frac{V_{cc} - 2V_{BE(on)}}{R_{ref}}$$

Problem: For power savings reasons, oftentimes very small bias currents are needed, on the order of $5\mu A$. This might force too large an R_{ref} in the above bipolar V_{BE} generator.



i.e., larger emitter area: \rightarrow Layout like this to get more accurate ratio.
If Q_1 is $10X$ larger than Q_2 .

$$\therefore I_{cl} = 10 I_{cl} \rightarrow I_o \approx I_{ref}/10$$

$$\therefore I_o = \frac{(V_{cc} - V_{BE(on)})}{10 R_{ref}} \rightarrow R_{ref} = \frac{V_{cc} - V_{BE(on)}}{10 I_o}$$

\curvearrowleft That helps to lower R_{ref} , but is it enough?

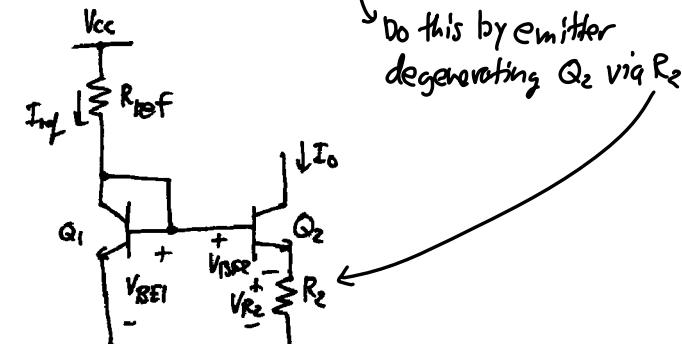
Ex. $I_o = 5\mu A$, $V_{cc} = 30V$

$$R_{ref} \approx \frac{30}{5\mu A} = 600k\Omega \leftarrow \text{That's way too big!}$$

(Yes, there's only one of them on the chip, but this takes up too much space!)

The Low Current Solution: Widlar Current Source

\Rightarrow scale $I_{cl} = I_o$ by reducing V_{BE2} (relative to V_{BE1}):



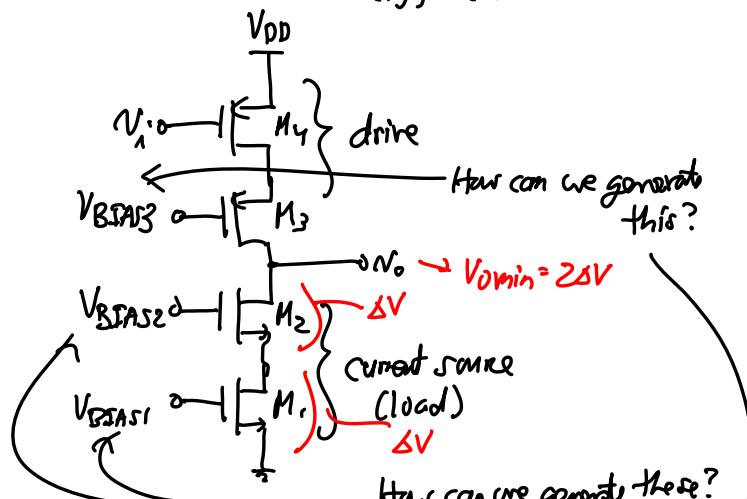
\curvearrowleft Do this by emitter degenerating Q_2 via R_2

Lecture 10: Current Sources

Thus, the minimum V_0 (that still keeps a good M_s current source): $V_{0\min} = V_{D,\text{sat}} = V_{0V} - \Delta V$

$$\therefore \text{the output swing is: } V_{\text{swing,pp}} = V_D - V_{D-\text{sat}} / V_{D-\text{sat}} = V_D - 2AV$$

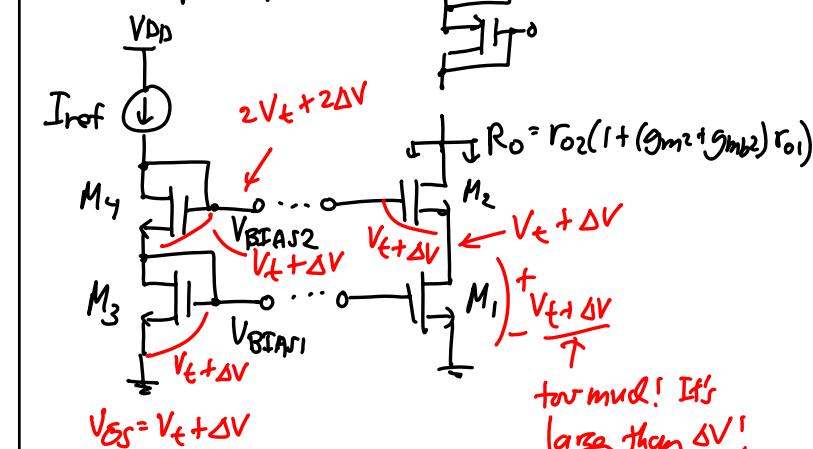
What about using a better current source?
e.g., a cascode:



So that we get
maximum hadron!

MDS Cadence Current Source

→ the simple way:



too much! It's
large than SV!