Voltage References

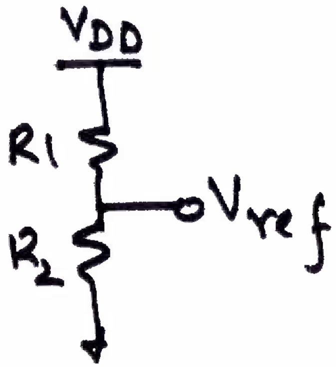
I. Voltage Divider Reference

ii MOS VOLTAGE Reference

iii All MOS Divider Reference

IV Band Gap Reference

1. Divider Reference with Resistors



$$V_{ref} = \frac{R_2}{R_1+R_2} V_{DD} = \frac{1}{1+\frac{R_1}{R_2}} V_{DD}$$

$$\therefore \frac{dV_{ref}}{dV_{DD}} = \frac{R_2}{R_1+R_2}$$

$$S_{V_{DD}}^{V_{ref}} = \frac{V_{DD}}{V_{ref}} \cdot \frac{\partial V_{ref}}{\partial V_{DD}} = \frac{R_1+R_2}{R_2} \cdot \frac{R_2}{R_1+R_2} = 1$$

We see $\dfrac{\partial V_{ref}}{V_{ref}} = \dfrac{\partial V_{DD}}{V_{DD}}$ [% change in V_{DD} directly reflect in % variation of V_{ref}]

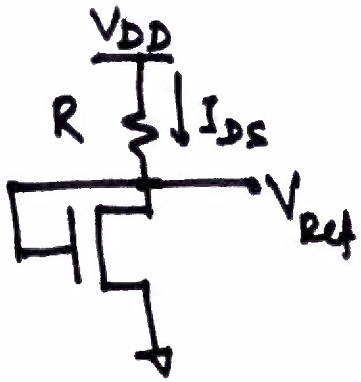
$$\therefore TC_f(V_{ref}) = \frac{1}{V_{ref}} \cdot \frac{\partial V_{ref}}{\partial T} = \frac{R_1}{R_2} \frac{V_{ref}}{V_{DD}} \left(\frac{1}{R_2} \frac{\partial R_2}{\partial T} - \frac{1}{R_1} \frac{\partial R_1}{\partial T} \right)$$

$$= \frac{R_1}{R_2} \frac{V_{ref}}{V_{DD}} \left[TC_f(R_2) - TC_f(R_1) \right]$$

CDEEP
IIT Bombay

EE 618 L____ / Slide____

Voltage Reference with MOSFET & Resistor



Clearly $V_{GS} = V_{Ref}$

& $I_{DS} = \dfrac{V_{DD} - V_{Ref}}{R}$

But $I_{DS} = \dfrac{\beta}{2}(V_{ov})^2$ for Transistor

$$\therefore \quad V_{DD} - V_{ref} = \frac{\beta}{2} R \left[V_{ref} - V_T \right]^2$$

Solving

$$V_{Ref} = V_T + \sqrt{\frac{2}{\beta R}\left(V_{DD} - V_{Ref}\right)}$$

If $V_{DD} \gg V_{Ref}$

Then $V_{Ref} = V_T + \sqrt{\dfrac{2}{\beta R}}\, V_{DD}^{1/2}$

Then $$S^{V_{ref}}_{V_{DD}} = \frac{V_{DD}}{V_{ref}} \cdot \frac{\partial V_{ref}}{\partial V_{DD}}$$

$$\cong \frac{1}{V_T \cdot \sqrt{\frac{2\beta R}{V_{DD}}} + 2}$$

Further

$$TC_f(V_{ref}) = \frac{1}{V_{Ref}} \cdot \frac{\partial V_{Ref}}{\partial T}$$

$$= \frac{1}{V_{Ref}} \left\{ \left[V_T\, TC_f(V_T) - \frac{1}{2} \sqrt{\frac{2}{W/L} \frac{V_{DD}}{R\,\beta'(T)}} \; * \right. \right.$$

$$\left. * \left[\frac{1}{R} \frac{\partial R}{\partial T} - \frac{1.5}{T} \right] \right\}$$

Then $I_Q R = V_{Tn} + \sqrt{\dfrac{2 I_Q}{\beta_n'(W/L)_1}}$

$$\therefore \; (I_Q R - V_{Tn})^2 = \frac{2 I_Q}{\beta_n'(W/L)_1}$$

or $$I_Q^2 R^2 + V_{Tn}^2 - 2 I_Q R V_{Tn} - \frac{2 I_Q}{\beta_n'(W/L)_1} = 0$$

One solution is

$$\therefore \; I_Q = \frac{V_{Tn}}{R} + \frac{1}{\beta_1 R^2} + \frac{1}{R}\sqrt{\frac{2V_{Tn}}{\beta_1 R} + \frac{1}{\beta_1^2 R^2}} = I_1 = I_2$$

and other solution is

$$I_Q = 0 \quad \text{giving} \quad I_1 = I_2$$

This is trivial solution, but can occure in reality.

Since M3 & M4 are chosen to be Identicle (Same β and V_T), with the mirror connected combination $\therefore I_1 = I_2$, where I_1 flows from V_{DD} to V_{SS} (0V) through M5 and M1 and I_2 flows similarly from M4 – M2 and through R.

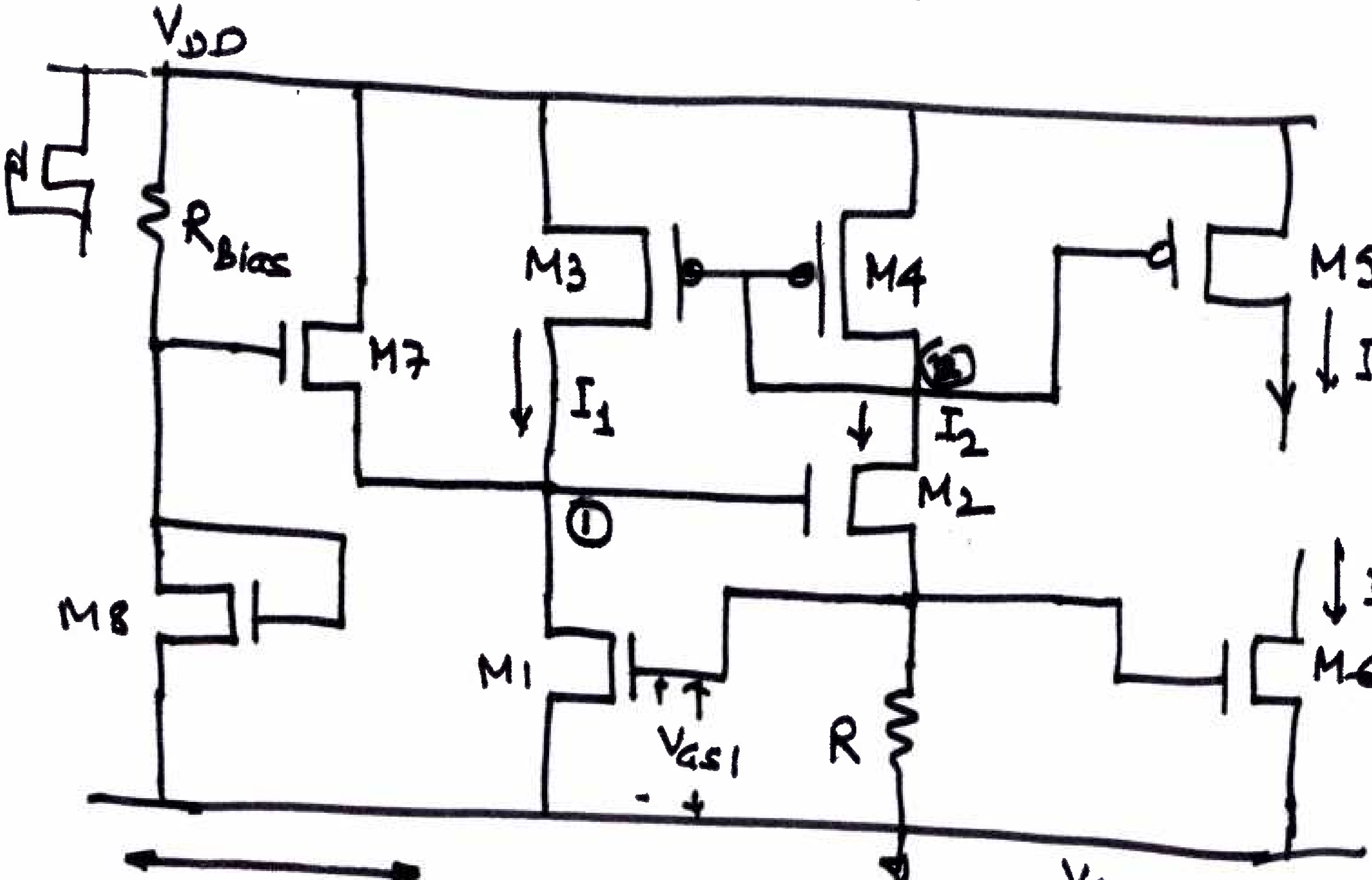
Clearly $V_{GS1} = I_2 \cdot R$ or $= I_1 R$

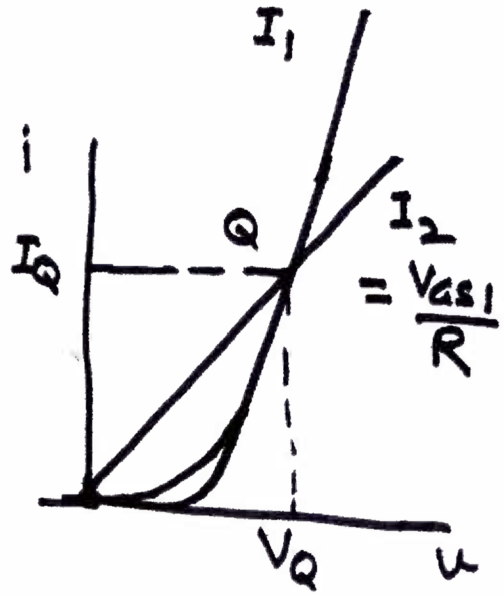
But $V_{GS1} = V_{Tn} + \sqrt{\dfrac{2 I_1}{\beta_n' (W/L)_1}}$

$$\therefore \quad I_2 R = I_1 R = V_{Tn} + \sqrt{\frac{2 I_1}{\beta_n' (W/L)_1}}$$

We define $I_1 = I_2 = I_Q$

A Better V_T reference is possible using Bootstrap Technique.





Start-up circuit

Bootstrap Circuit for V_T reference.

In case of $I_1 = I_2 = I_Q = 0$, we see that we need a Start-up circuit.

Transistor M7 is 'ON' when initially Node (1) is at '0' V. Thus M7 provides current to M1. This increases V_{GS1} of M1, which in turn increases I_2 ($\frac{V_{GS1}}{R}$). By feedback (& Mirror) action Node (1) voltage starts increasing ($V_{GS1}+V_{GS2}$) and at one time V_{GS} for M7 goes below V_{T7}, thereby shutting off M7. Here the Q point of Reference reaches second stable point. Further Starting Circuit then stops participating.

If R is created from Polysilicon Layer (n^+),

then $TC_f(R) = \frac{1}{R}\frac{dR}{dT} \cong -2000$ ppm/°C

The β-Multiplier circuit thus show

$$TC_f(I_o) = -2 \times 2000 + \frac{1.5}{T\,(°K)}$$

$$= +1000 \text{ ppm/°C} \quad \text{at } T = 300°K$$

We can use this circuit as Voltage Reference V_{REF} equal to V_{GS1}

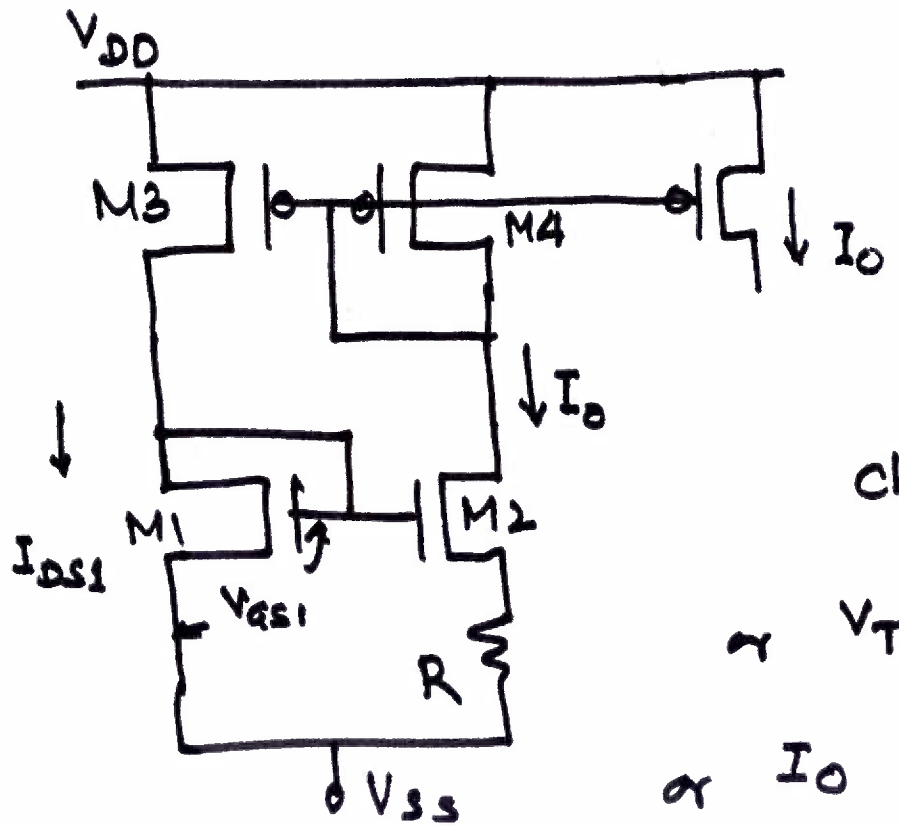
$$V_{REF} = V_{GS1} = \frac{2}{\beta_1 R}\left(1 - \frac{1}{\sqrt{K}}\right) + V_{TN}$$

$$\frac{\partial V_{REF}}{\partial T} = \frac{\partial V_{TN}}{\partial T} + \frac{2}{\beta_1 R}\left(1 - \frac{1}{\sqrt{K}}\right)\left[\frac{1}{R}\frac{dR}{dT} + \frac{1}{\beta_1}\frac{\partial \beta_1}{\partial T}\right]$$

CDEEP
IIT Bombay

β - Multiplier V_{REF}.

This scheme is also called Self-Biasing Scheme
This also uses 'Starting Circuit' for operation to begina.



$I_{DS1} = I_0$

Here width of M2, W_2 is chosen K times of width W_1 of M1

or $\beta_2 = K\,\beta_1$

Clearly $V_{GS1} = V_{GS2} + I_0 R$

or $$V_{Tn} + \sqrt{\frac{2I_0}{\beta_1}} = V_{Tn} + \sqrt{\frac{2I_0}{K\beta_1}} + I_0 R$$

or $$I_0 \doteq \frac{2}{R^2 \beta_1}\left(1 - \frac{1}{\sqrt{K}}\right)^2$$

We can find value of K, for $\frac{dV_{REF}}{dT} = 0$

Thus choice of K can give $TC_f(V_{REF}) = 0$

Corresponding

$$V_{REF} = V_{Tn} + \frac{2}{R\beta_1}\left[1 - \frac{1}{\sqrt{K}}\right]$$