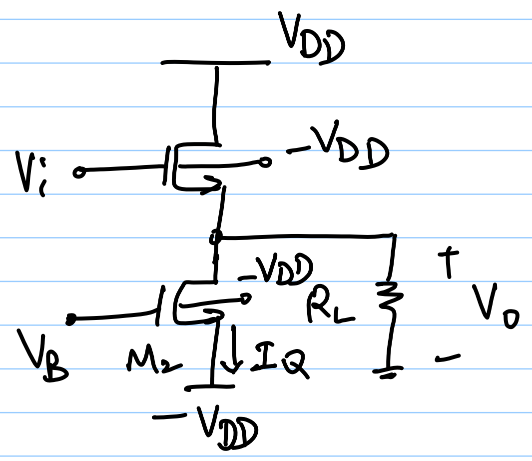
12-4-12

Lec 41

Source follower



$$V_i = V_o + V_{GS_1}$$

$$= V_o + V_{T_1} + V_{OV_1}$$

V_T = fn. of body effect

V_{OV_1} = fn. of current (not constant)

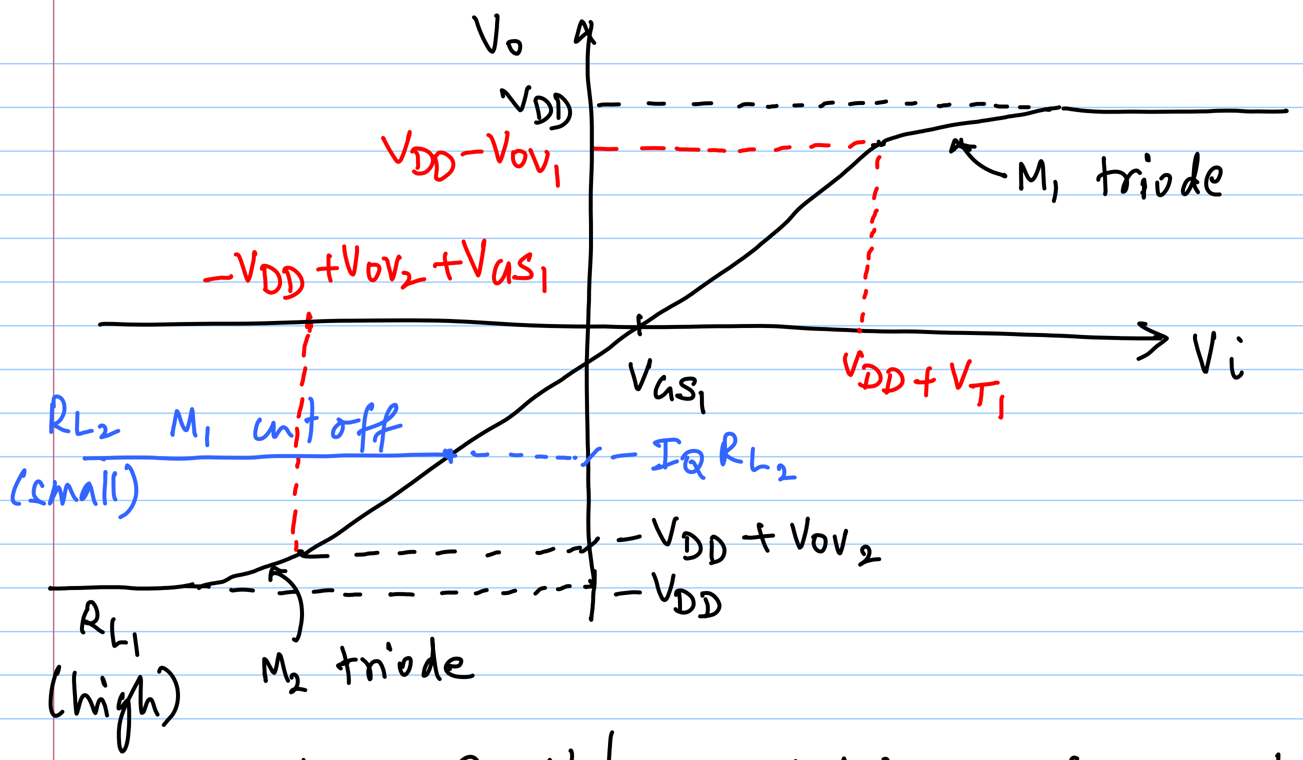
$$V_{SB} = V_o + V_{DD}$$

$$I_{D_1} = I_Q + V_o/R_L$$

$$\Rightarrow V_i = V_o + V_{T_0} + \gamma\left[\sqrt{2\phi_F + V_o + V_{DD}} - \sqrt{2\phi_F}\right] + \sqrt{\frac{2(I_Q + V_o/R_L)}{k'(W/L)_1}}$$

* M_1 & M_2 in active region
* $R_L >> r_{ds_1}, r_{ds_2}$

$$V_i\Big|_{V_o=0} = V_{GS_1} = V_{T_0} + \gamma\left[\sqrt{2\phi_F + V_{DD}} - \sqrt{2\phi_F}\right] + \sqrt{\frac{2I_Q}{k'(W/L)_1}}$$



slope @ $V_i\big|_{V_o=0}$ point = incremental gain

as $r_o \to \infty$

$$\frac{v_o}{v_i} = \frac{g_m R_L}{1+(g_m+g_{mbs})R_L}$$

as $R_L \to \infty$,

$$\frac{v_o}{v_i} = \frac{g_m}{g_m+g_{mbs}}$$

* gain $= f(g_{mbs}) = f(V_o+V_{DD})$

$\Rightarrow$ distortion

Distortion in source-follower

Use a Taylor series

$$V_i = V_I + v_i = \sum_{n=0}^{\infty} \frac{f^{(n)}(V_o = V_\Theta)(V_o - V_\Theta)^n}{n!}$$

$$\underset{\text{signal}}{v_o} = \underset{\text{total}}{V_o} - \underset{\text{DC}}{V_\Theta}$$

$$\Rightarrow \quad V_i = V_I + v_i = \sum_{n=0}^{\infty} b_n (v_o)^n$$

$$b_n = f^{(n)}(V_o = V_\Theta)/n!$$

Assume $R_L \to \infty$ for simplicity

$$V_i = f(V_o)$$

$$= V_o + V_{T_0} + \gamma\left[\sqrt{V_o + V_{DD} + 2\phi_F} - \sqrt{2\phi_F}\right] + V_{ov_1}$$

$$f'(V_o) = 1 + \frac{\gamma}{2}(V_o + V_{DD} + 2\phi_F)^{-1/2}$$

$$f''(V_o) = -\frac{\gamma}{4}(V_o + V_{DD} + 2\phi_F)^{-3/2}$$

$$f'''(V_o) = \frac{3\gamma}{8}(V_o + V_{DD} + 2\phi_F)^{-5/2}$$

$$b_o = f(V_o = V_\Theta) = V_\Theta + V_{T_0} + \gamma\left[\sqrt{V_\Theta + V_{DD} + 2\phi_F} - \sqrt{2\phi_F}\right]$$

$$+ V_{OV_1}$$

$$b_1 = f'(v_0 = V_\theta) = 1 + \frac{\gamma}{2}(\overbrace{V_\theta + V_{DD} + 2\phi_F}^{X})^{-1/2}$$

$$b_2 = \frac{f''(v_0 = V_\theta)}{2} = -\frac{\gamma}{8}(X)^{-3/2}$$

$$b_3 = \frac{f'''(v_0 = V_\theta)}{3!} = \frac{\gamma}{16}(X)^{-5/2}$$

$b_0 = V_I =$ DC input voltage

$$\Rightarrow v_i = \sum_{n=1}^{\infty} b_n (v_0)^n = b_1 v_0 + b_2 v_0^2 + b_3 v_3^3 + \ldots$$

To find distortion, we want

$$v_0 = \sum_{n=1}^{\infty} a_n (v_i)^n = a_1 v_i + a_2 v_i^2 + \ldots$$

$$\Rightarrow v_i = b_1(a_1 v_i + a_2 v_i^2 + \ldots)$$

$$+ b_2(a_2 v_i + a_2 v_i^2 + \ldots) + \ldots$$

Match coefficients on both sides

$$1 = b_1 a_1$$

$$0 = b_1 a_2 + b_2 a_1^2$$

$$0 = b_1 a_3 + 2 b_2 a_1 a_2 + b_3 a_1^3$$

$$\Rightarrow \quad a_1 = 1/b_1 \qquad a_2 = -\frac{b_2}{b_1^3} \qquad \Bigg| \qquad a_3 = \frac{2b_2^2}{b_1^5} - \frac{b_3}{b_1^4}$$

$$\therefore \quad a_1 = \frac{1}{1+\frac{\gamma}{2}(x)^{-1/2}}$$

$$a_2 = \frac{\frac{\gamma}{8}(x)^{-3/2}}{\left[1+\frac{\gamma}{2}(x)^{-1/2}\right]^3}$$

$$a_3 = -\frac{\frac{\gamma}{16}(x)^{-5/2}}{\left[1+\frac{\gamma}{2}(x)^{-1/2}\right]^5}$$

can be used to calculate distortion of MOS source follower stage

* Amplifier non-linearity specified by <u>Harmonic Distortion</u> (HD)

let $v_i = \hat{v}_i \sin \omega t$

$$v_o = a_1 \hat{v}_i \sin \omega t + a_2 \hat{v}_i^2 \sin^2 \omega t + a_3 \hat{v}_i^3 \sin^3 \omega t + \ldots$$

$$= a_1 \hat{v}_i \sin \omega t + \frac{a_2 \hat{v}_i^2}{2}(1-\cos 2\omega t) + \frac{a_3 \hat{v}_i^3}{4}(3\sin\omega t - \sin 3\omega t) + \ldots$$

* o/p contains freq. components @ $\omega, \underbrace{2\omega, 3\omega \ldots}_{\text{distortion products}}$

$$HD_2 = \frac{\text{amplitude of } 2\omega \text{ component}}{\text{'' '' } \omega \text{ ''}}$$

$$HD_2 \simeq \frac{a_2 \hat{v}_i^2}{2} \cdot \frac{1}{a_1 \hat{v}_i} = \frac{1}{2} \frac{a_2}{a_1} \hat{v}_i$$

→ HD_2 varies <u>linearly</u> with $\hat{v}_i$

$$HD_2 \simeq \frac{\frac{\gamma}{16} (x)^{-3/2} \cdot \hat{v}_i}{\left[1 + \frac{\gamma}{2} (x)^{-1/2}\right]^2}$$

If $\gamma << 2\sqrt{V_\theta + V_{DD} + 2\phi_F}$,

$$HD_2 \simeq \frac{\gamma}{16} \left(V_\theta + V_{DD} + 2\phi_F\right)^{-3/2} \hat{v}_i$$

* $HD_2 \downarrow$ if $V_\theta \uparrow$ (DC level @ output ↑)

→ ∵ distortion produced from body effect

* $HD_2 \propto \gamma$

$$HD_3 = \frac{\hat{v}_o(3\omega)}{\hat{v}_o(\omega)}$$

$$= \frac{a_3 \hat{v}_i^3}{4} \cdot \frac{1}{a_1 \hat{v}_i} = \frac{1}{4} \cdot \frac{a_3}{a_1} \cdot \hat{v}_i^2$$

* $HD_3 \uparrow$ as $\hat{v}_i^2$

$$HD_3 \simeq \frac{-\frac{\gamma}{64}(x)^{-5/2} \hat{v}_i^2}{\left[1 + \frac{\gamma}{2}(x)^{-1/2}\right]^4}$$

Class-B push-pull stage