AEC 12.2 9/2/22

f_T : Unity-gain frequency/Bandwidth of MOSFET

- → Transistion frequency
- → Definition: f_T is the frequency at which the short circuit current gain of MOSFET becomes unity (0dB)
- → f_T is figure of merit for high frequency operation of MOSFET

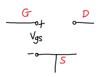
Q. Is current gain possible in MOSFET ?

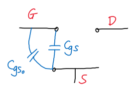
→ Yes, since now at extremely high frequencies, input impedance of MOSFET is not infinite

→ It is finite due to the presence of parasitic capacitances C_{gs} and C_{gs_0}

Thus, at high-frequencies, current gain of MOSFET is defined

So far, we have considered zero gate current for a MOSFET, because of very high resistance between gate and source terminals





$$X_C = \frac{1}{s(C_{gs}+C_{gs_0})} \qquad X_c = \frac{1}{sC}$$

$s \to j\omega$

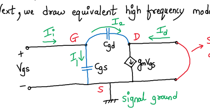
$$X_{in} = \frac{1}{j\omega(C_{gs}+C_{gs_0})}$$

At high ω value → X_{in} is finite

✳ f_T derivation for MOSFET :

① The unity-gain frequency or bandwidth is a figure of merit for the MOSFET

② Next, we draw equivalent high frequency model for MOSFET



$$\boxed{A_i = \frac{I_d}{I_i}}$$

③ Since the input impedance is no longer infinite at high frequency, we can define the short-circuit current gain

④ KCL at node G, gives

$$I_i = I_1 + I_2$$

i.e $$I_i = \frac{V_{gs}}{1/sC_{gs}} + \frac{V_{gs}}{1/sC_{gd}} = V_{gs}(sC_{gs}+sC_{gd})$$

i.e $$I_i = V_{gs}(C_{gs}+C_{gd})s \quad \text{— (1.1)}$$

⑤ KCL at node D, gives

$$I_2 + I_d = g_m V_{gs}$$

i.e $$\frac{V_{gs}}{1/sC_{gd}} + I_d = g_m V_{gs}$$

i.e $$V_{gs}(g_m - sC_{gd}) = I_d \quad \text{— (1.2)}$$

⑥ Short-circuit current gain A_i is

$$A_i = \frac{I_d}{I_i}$$

i.e $$A_i = \frac{\cancel{V_{gs}}(g_m - sC_{gd})}{s\cancel{V_{gs}}(C_{gs}+C_{gd})} = \frac{g_m - sC_{gd}}{s(C_{gs}+C_{gd})}$$

⑦ For physical frequencies, $s = j\omega$

$$A_i = \frac{g_m - j\omega C_{gd}}{j\omega(C_{gs}+C_{gd})} \quad \text{— (1.3)}$$

Recalling that C_{gd} is small at the frequencies of interest

Typical values → $g_m = \frac{1mA}{V}$, $C_{gd} = 10fF$

$f = 1GHz$

$\omega C_{gd} = 2\pi f C_{gd} \approx 0.0628 \times 10^{-3}$

i.e $g_m \gg \omega C_{gd}$ → $g_m - \omega C_{gd} \approx g_m$

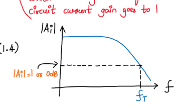
⑧ $$|A_i| \approx \frac{g_m}{j2\pi f(C_{gs}+C_{gd})}$$

⑨ At $f = f_T$, we have $|A_i| = 1$

(f_T is defined as the frequency at which the magnitude of the short circuit current gain goes to 1)

i.e $$1 \approx \frac{g_m}{2\pi f_T(C_{gs}+C_{gd})}$$

i.e $$\boxed{f_T \approx \frac{g_m}{2\pi(C_{gs}+C_{gd})}} \quad \text{— (1.4)}$$



⑩ Observation :-

ⓐ f_T is a parameter of the transistor, usually given in the datasheet.

ⓑ f_T is independent of the circuit

ⓒ $f_T \propto g_m$; $f_T \propto \frac{1}{C_{gs}+C_{gd}}$

ⓓ C_{gs} and C_{gd} Limits the bandwidth

ⓔ Typical values, $f_T = 100MHz$ (For older technology, 5μm CMOS process)

$f_T = 5-10GHz$ (For high-speed circuits, 0.13μm CMOS process)

Numerical :

Consider an n-channel MOSFET with parameters $k_n = 0.2\frac{mA}{V^2}$, $V_{tn} = 1V$, $\lambda = 0$, $C_{gd} = 0.02pf$, $C_{gs} = 0.25pf$. Assume the transistor is biased at $I_D = 0.4mA$

Calculate the unity-gain bandwidth of the MOSFET

Solution:

$$g_m = 2k_n(V_{GS} - V_{tn})$$

$$g_m = 2\sqrt{\underbrace{I_D}_{0.4m}\,\underbrace{k_n}_{0.2m}} = 0.5657\frac{mA}{V}$$

$$f_T = \frac{\overset{0.56m}{g_m}}{2\pi(\underbrace{C_{gd}}_{0.02p}+\underbrace{C_{gs}}_{0.25pf})}$$

$$\boxed{f_T = 333.46 MHz}$$

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