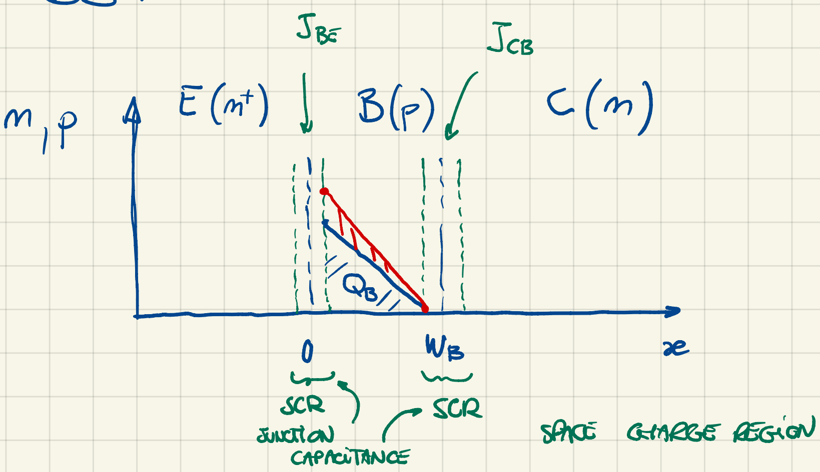
11/10/2022

CHARGE STORAGE EFFECTS IN BJTs AND MOSFETs

- CHARGE STORAGE EFFECTS ARE INTRISIC TO BOTH BJTs AND MOSFETS
- THESE EFFECTS ARE THE ORIGIN OF ω_H

◊ BJT



IN THE FORWARD ACTIVE REGION:

J_{BE} IS DIRECTLY BIASED

J_{CB} IS INVERSELY BIASED

WE HAVE MINORITY CARRIER ACCUMULATION IN THE BASE REGION

THE CHARGE STORED IN THE BASE IS APPROXIMATELY GIVEN BY

$$Q_B = i_C \cdot \tau_F \qquad \tau_F \in [1 - 100\,\text{ps}]$$

τ_F : AVERAGE LIFETIME OF A MINORITY CHARGE (e^- IN THIS CASE) INSIDE THE BASE REGION ⟶ TECHNOLOGICAL CONSTANT

$$i_C \cong I_S \cdot \exp\left(\frac{v_{BE}}{V_T}\right)$$

WE CAN LINEARIZE THE FUNCTION $Q_B = f(v_{BE})$ AROUND THE DEVICE OP.

BIAS POINT CURRENT

$$C_{diff} \triangleq \left.\frac{\partial Q_B(v_{BE})}{\partial v_{BE}}\right|_{v_{BE}=V_{BE}} = \tau_F \cdot \frac{I_C}{V_T} = \tau_F \cdot g_m$$

C_{diff} IS THE MAIN COMPONENT OF THE CAPACITANCE (SMALL SIGNAL) THAT WE CAN MEASURE AT THE B-E PORT, THAT IS CALLED

$$C_\pi = C_{diff} + C_{J_{BE}} \cong C_{diff}$$

NEGLIGIBLE DUE TO J_{BE} BEING FORWARD BIASED

WE ALSO HAVE A SECOND CHARGE STORAGE MECHANISM, DUE TO SPACE CHARGE REGIONS.
THIS EFFECT IS MORE RELEVANT FOR THE CB JUNCTION THAT IS REVERSE-BIASED.

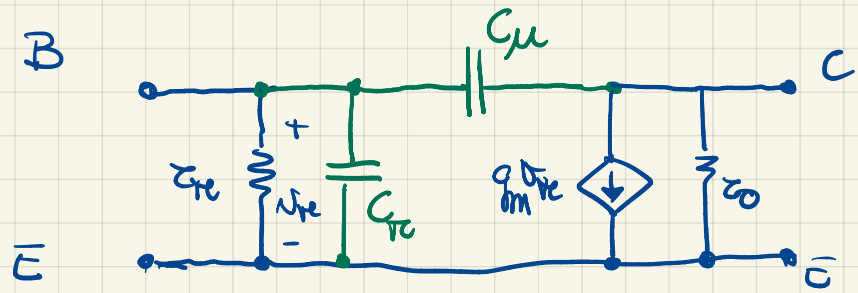
CAPACITANCE WHEN $V_{CB} = \emptyset$

$$C_{CB} \triangleq C_\mu = \frac{C_{CB\emptyset}}{\sqrt{1 + \frac{V_{CB}}{\Phi_{\emptyset CB}}}}$$

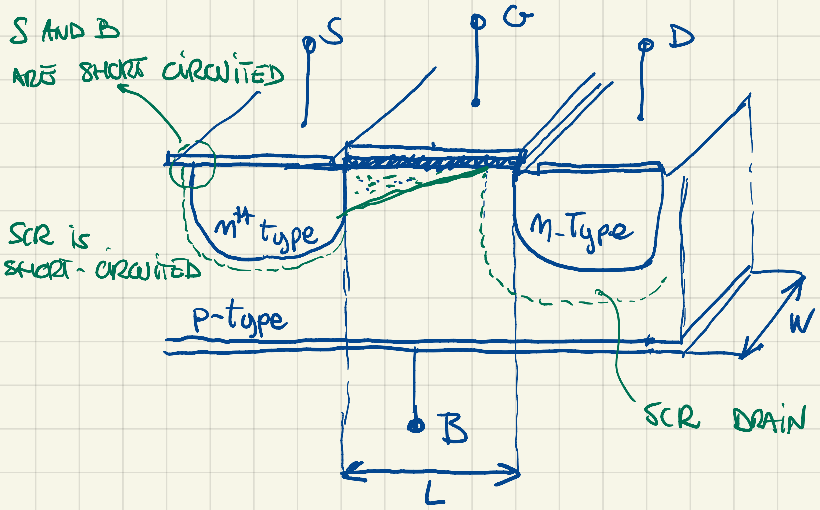
$\Phi_{\emptyset CB} \cong 0.75\ V$

AS A RULE OF THUMB $C_\mu \ll C_\pi$

IN CONCLUSION: THE HIGH FREQUENCY MODEL OF THE BJT (SMALL SIGNAL MODEL) IS THE FOLLOWING:



◊ MOSFET

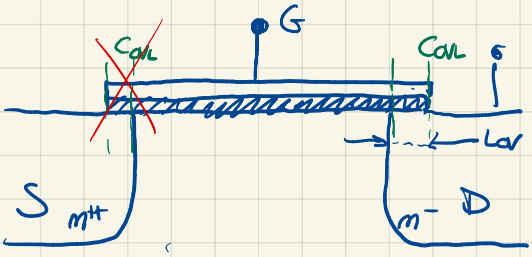


IN THE LINEAR OPERATING REGION (SATURATION) THE DEVICE IS STORING CHARGE AT 3 DIFFERENT LOCATIONS

#1 GATE CHARGE STORAGE $f(V_{GS})$

$$C_{GS} = \frac{2}{3} C_{ox} W L \quad \text{WHERE} \quad C_{ox} = \varepsilon_{SiO_2} / t_{ox} \quad [F/cm^2]$$

#2 OVERLAP CHARGE STORAGE



C_{OVL} AT THE SOURCE IS PLACED IN PARALLEL TO C_{GS} WHICH IS TYPICALLY MUCH LARGER ⟹ WE NORMALLY NEGLECT THIS COMPONENT

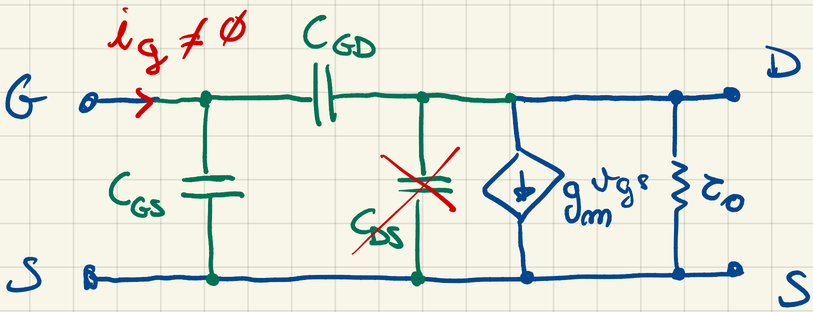
$$C_{GD} = \underbrace{C_{OVL}}_{[F/cm^2]} \cdot W \cdot L_{OV} \qquad L_{OV} \in [0.05 \div 0.1\, L]$$

#3 D-S JUNCTION CHARGE STORAGE

$$C_{DS} = \frac{C_{DS0}}{\sqrt{1 + \frac{V_{DS}}{\phi_{0DS}}}}$$

AS A RULE OF THUMB $\quad C_{GS} \gg C_{GD} > C_{DS}$

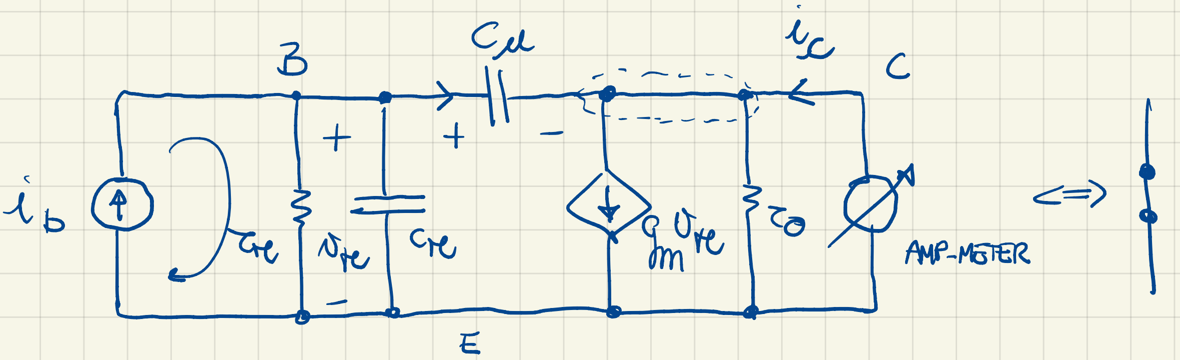
WE CAN NOW DRAW THE SMALL SIGNAL HF MODEL OF THE MOSFET



THE MODEL HAS REDUNDANT CAPS (THEY FORM A LOOP!). WE SIMPLIFY IT BY NEGLECTING C_{DS}. (THE SMALLEST ONE).

EXAMPLE: LET'S CALCULATE THE SHORT CIRCUIT CURRENT GAIN OF A BJT AS A FUNCTION OF FREQUENCY

$$\beta_0(s) = \left. \frac{I_C(s)}{I_B(s)} \right|_{V_{CE}=0}$$



WE ARE CONSIDERING A SPECIFIC OP $\longrightarrow$ $r_\pi, C_\pi, C_\mu, g_m, r_o$ ARE KNOWN

WE NEED TO FIND $i_c = f(i_b) \Longrightarrow \beta_0(s)$

(1) KCL AT COLLECTOR NODE $\quad i_{C\mu} + i_c = g_m v_\pi$

(2) CAPACITOR C_μ EQUATION $\quad i_{C\mu} = sC_\mu (v_\pi - 0) = sC_\mu v_\pi$

(3) KVL AT BASE $\quad v_\pi = i_b \cdot \dfrac{r_\pi}{1 + s r_\pi (C_\pi + C_\mu)}$

USING (3) AND (2) INTO (1) WE FIND

DC VALUE OF $\beta_0(s)$

$\beta_0 = g_m r_\pi$

$$i_b s C_\mu \cdot \frac{r_\pi}{1 + s r_\pi (C_\pi + C_\mu)} + i_c - g_m i_b \frac{r_\pi}{1 + s r_\pi (C_\pi + C_\mu)} = 0$$

$$- i_b \frac{-s r_\pi C_\mu + \beta_0}{1 + s r_\pi (C_\pi + C_\mu)} + i_c = 0$$

RHP ZERO !

$$\beta_0(s) \triangleq \frac{I_C(s)}{I_B(s)} = \beta_0 \frac{1 - s \frac{C_\mu}{g_m}}{1 + s r_\pi (C_\pi + C_\mu)}$$

$$\left.\begin{aligned} \omega_{z\beta} &= \frac{g_m}{C_\mu} \\ \omega_{p\beta} &= \frac{1}{r_\pi (C_\pi + C_\mu)} \end{aligned}\right\} \quad \frac{\omega_{z\beta}}{\omega_{p\beta}} = \frac{g_m}{C_\mu} \cdot r_\pi (C_\pi + C_\mu) = \beta_0 \Big(1 + \overset{>10}{\frac{C_\pi}{C_\mu}}\Big) \propto 10^3$$

$\beta_0 \in [10^2 \div 10^3]$