

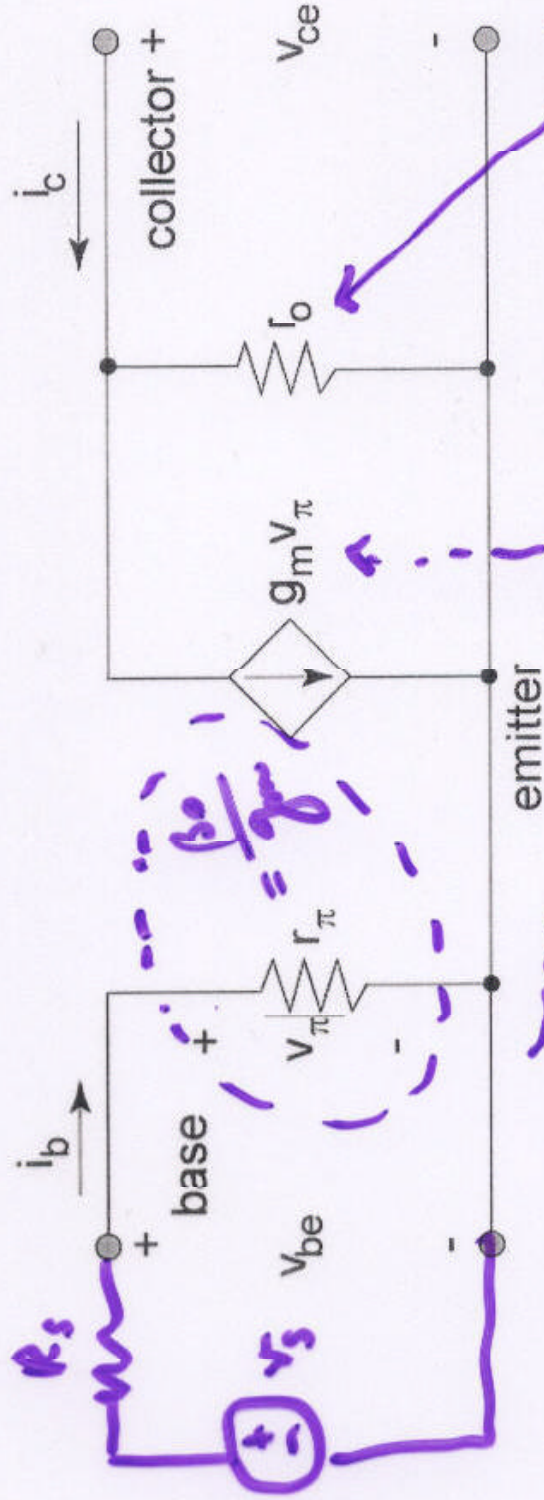
Lecture 22

- Last time:
 - Small-signal model of the npn bipolar transistor

FINISH HYBRID- π
(B.J.T.)

-
- Today: Start Chapter 8!
 - Introduction to amplifiers: a common-source MOS single-stage amplifier

BJT Small-Signal Model



$\frac{V_A}{I_C} \dots$
 100's of $k\Omega$.
 Huge!
 $\frac{I_C}{V_{th}}$
 $\sim 25k\Omega$
 MODERATE
 INPUT RESISTANCE



BJT Capacitances

REVERSE - BIASED JUNCTION.

Base-charging capacitance C_b : due to minority carrier charge storage (mostly electrons in the base)

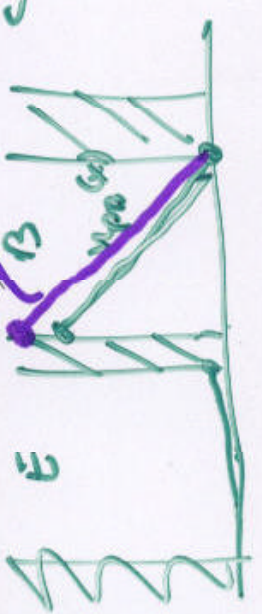
$$C_b = g_m \tau_F$$

$\Delta V_{BE} \Rightarrow$
 Δ electrons in base

TRANSIT TIME τ_F

$\lesssim 1$ ps.

Base-emitter depletion capacitance: $C_{jE} = 1.4 C_{jE0}$ small



Total B-E capacitance: $C_\pi = C_{jE} + C_b$

$\uparrow V_E$: \parallel capacitors

$$C_{be} = C_\mu = \frac{C_{jAO} \cdot A_{BC}}{\sqrt{1 - V_{BC}/\phi_{bc}}}$$

Complete Small-Signal Model

IMPORTANT!!

base

import RE
cap/o. \leftarrow
C_π C_μ

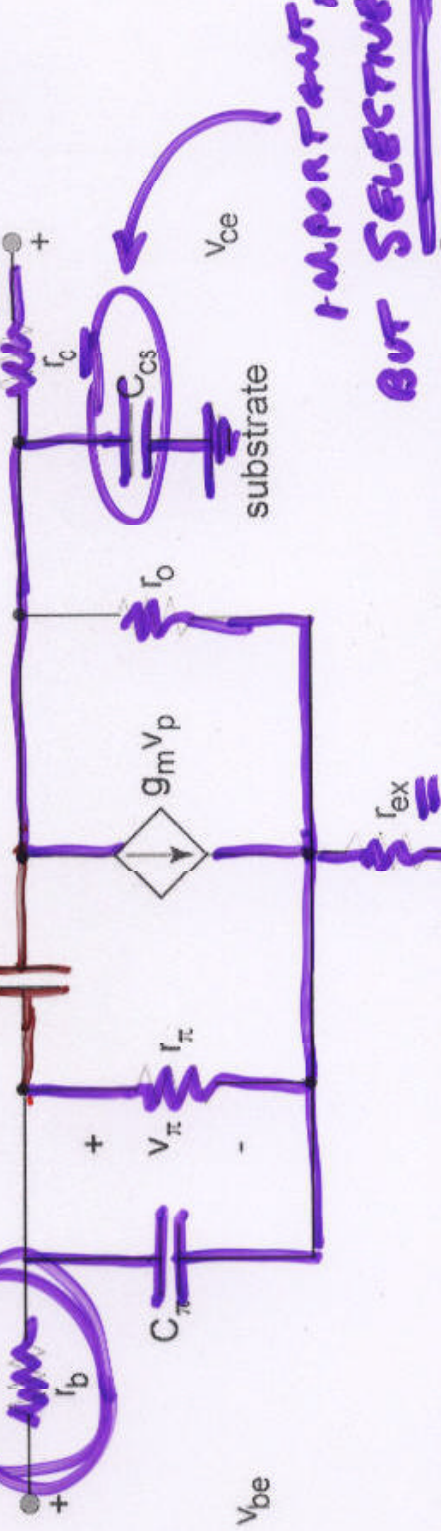
collector

roofs

IMPORTANT, BUT SELECTIVELY INCLUDED BECAUSE OF CALC. DIFFICULTIES.



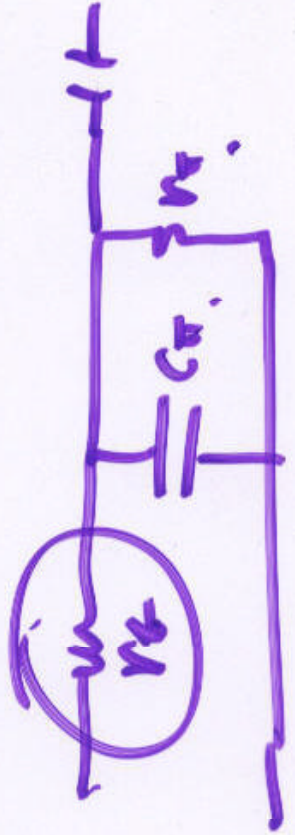
emitter



collector

IMPORTANT, BUT SELECTIVELY INCLUDED BECAUSE OF CALC. DIFFICULTIES.

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$$V_{OUT}(t)_{TOTAL} = V_{OUT} + v_{out}(t)$$

$$V_{SUP} = 2.5V$$

$$V_{OUT} = 2V$$

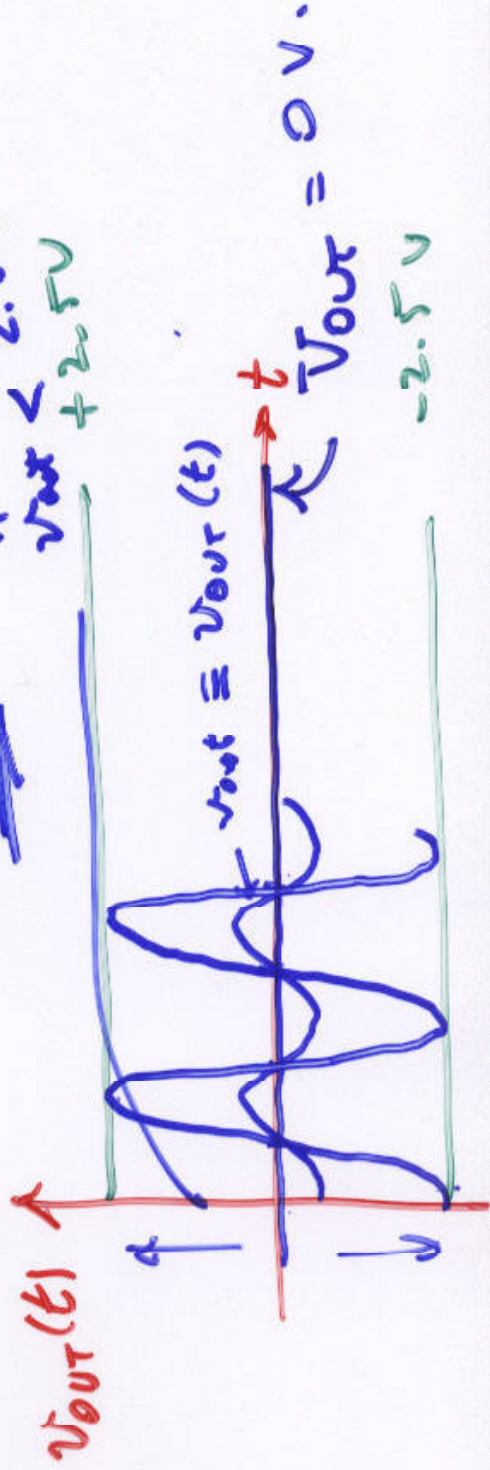


$$V_{OUT} = -2V$$

$$V_{OUT}(t) = v_{out}(t)$$

$$< 0.5V$$

$$V_{OUT} < 2.5V + 2.5V$$

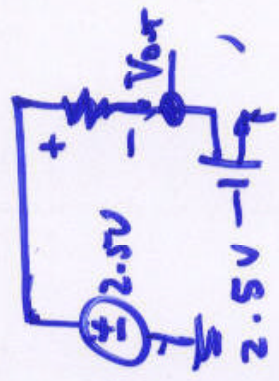


WE DO THIS!

Selecting the Output Bias Point

V_{BIAS} is selected so that V_{OUT} is centered between $+V_{SUP}$ and $-V_{SUP}$ (why?)

$V_{OUT} = 0\text{ V}$... **NOT** $V_{OUT} = 0\text{ V!}$

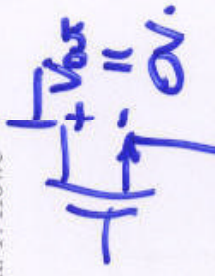


Constraint on the DC drain current:

Other's $I_{RD} = (V_{SUP} - V_{OUT}) / R_D = V_{SUP} / R_D + I_D$

2.5V 0V ~~$I_{D,SAT}$~~ $I_D = I_{D0}$

$I_{RD} = I_D = I_{D,SAT}$... verify that MOSFET is saturated after finding V_{BIAS}



Finding the Input Bias Voltage

Hand calculation: neglect "fudge factor" in $I_{D,SAT}$.

$$I_{D,SAT} = (W/2L)\mu_n C_{ox} (V_{GS} - V_{Tn})^2 (1 + \lambda V_{DS})$$

Typical numbers: $W = 40 \mu\text{m}$, $L = 2 \mu\text{m}$, $R_D = 25 \text{ k}\Omega$
 $\mu_n C_{ox} = 100 \mu\text{A/V}^2$, $V_{Tn} = 1 \text{ V}$,
 $V_{SUP} = 2.5 \text{ V}$

$$I_{RD} = \frac{V_{SUP}}{R_D} = I_{D,SAT} = 10 \cdot 100 \cdot (V_{GS} - 1)^2$$

Dept. of EES
 25kΩ

$$100 \mu\text{A} = 1000 \mu\text{A} (V_{GS} - 1)^2$$

$$\sqrt{0.1} = V_{GS} - 1 \dots V_{GS} = 1.3 \text{ V}$$

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CHAPTER 8.

An MOS Amplifier

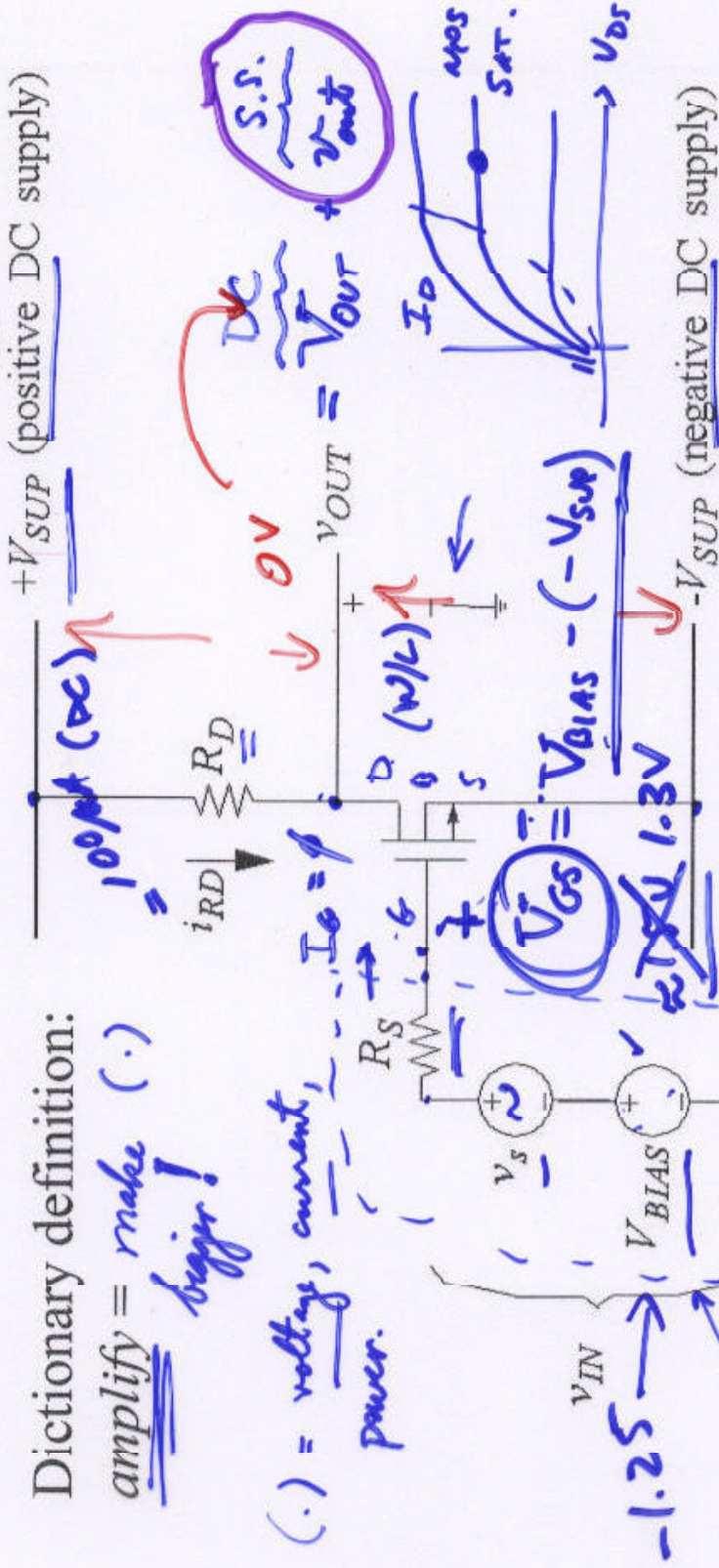
+ 2.5V

+V_{SUP} (positive DC supply)

Dictionary definition:

amplify = make (·) bigger!

(·) = voltage, current, power.



V_{TH} = 1V = -2.5V.

VOLTS $(-V_{SUP})$ DISCONNECTED v_s SETTING (V_{OUT} , V_{BIAS})

$V_{GS} = V_{BIAS} - V_{DS}$

$V_{BIAS} = 1.3 - 2.5$

Applying the Small-Signal Voltage

→ HARD way.

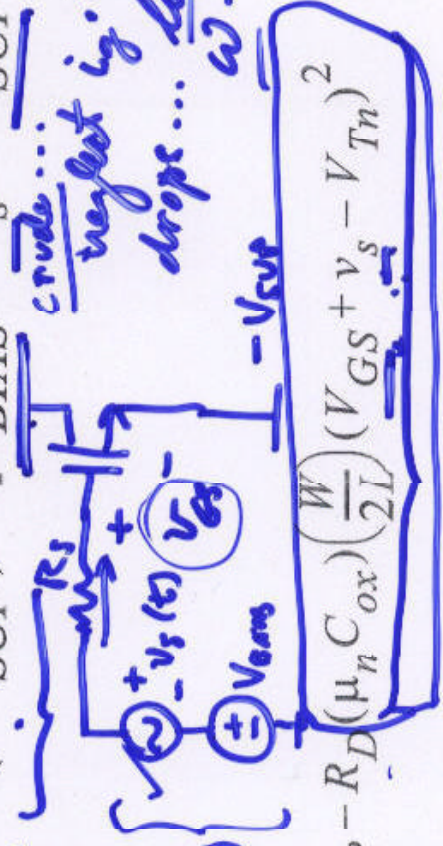
Approach 1. Just use v_{IN} in the equation for the total drain current i_D and find v_{OUT}

$$v_{IN}(t) = V_{BIAS} + v_s(t)$$

$$v_{IN} = V_{BIAS} + v_s \quad V_{GS} = v_{IN} - (-V_{SUP}) = [V_{BIAS} + v_s + V_{SUP}]$$

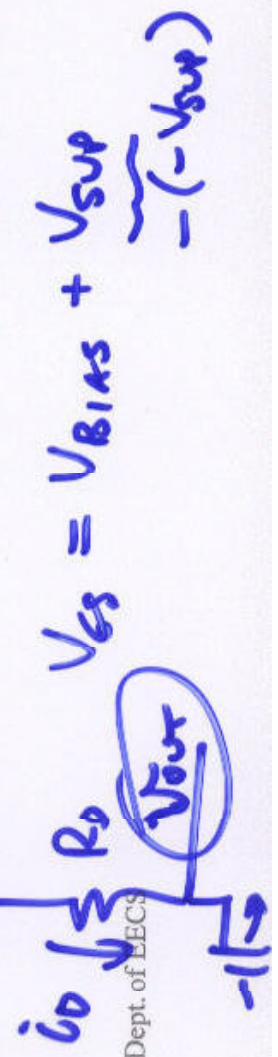
$$v_s(t) = \hat{v}_s \cos(\omega t)$$

crude... neglect $i_g \cdot R_s$ drops... low ω .



Result:

$$v_{OUT} = \frac{V_{SUP} - R_D i_D}{2.5V} \approx V_{SUP} - R_D \left(\frac{W}{2L} \right) (\underbrace{V_{GS} + v_s - V_{Th}}_{-V_{SUP}})^2$$



L.T. Hove

$$(V_{GS} + v_s - V_{Tn})^2 = (V_{GS} - V_{Tn})^2 (1 + \frac{v_s}{V_{GS} - V_{Tn}})^2$$

Solving for the Output Voltage v_{OUT}

(PULL OUT TERM WITH v_s .)

$$I_D = \frac{W}{2L} (\mu_n C_{ox}) \left(1 + \frac{v_s}{V_{GS} - V_{Tn}} \right)^2$$

$$v_{OUT} = V_{SUP} - R_{DD} I_D \left(1 + \frac{v_s}{V_{GS} - V_{Tn}} \right)^2$$

$V_{SUP} = 2.5V$

$v_s = 0 \dots DC$

$$v_{OUT} = 0V = V_{OUT}$$

$$(1.3 - 1) = 0.3V$$

$$v_{OUT}(t) = 2.5 - 2.5 \left(1 + \frac{v_s}{0.3} \right)^2$$

Small-Signal Case

Linearize the output voltage for the s.s. case

Expand $(1 + x)^2 = 1 + 2x + x^2 \dots$ last term can be dropped when $x \ll 1$ $v_s \ll V_{GS} - V_{Tn} = 0.3V$ Assume

$$\left(1 + \left(\frac{v_s}{V_{GS} - V_{Tn}} \right)^2 \right)^2 = 1 + \frac{2v_s}{V_{GS} - V_{Tn}} + \left(\frac{v_s}{V_{GS} - V_{Tn}} \right)^2$$