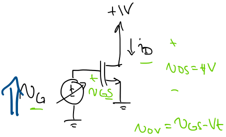
Exam 2 Review

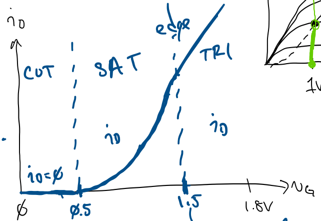
Wednesday, April 22, 2020 7:08 PM

$\boxed{5.27}$


+1V
i_D
+
$v_{DS} = 4V$
−
v_G
+
v_{GS}
$v_{ov} = v_{GS} - V_t$

$V_t = 0.5$

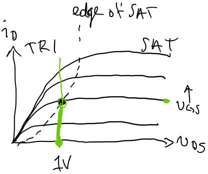
$k_n' \frac{W}{L} = 2 \frac{mA}{V^2}$



$v_{ov} = v_{GS} - V_t = 0.5 - 0.5 = 0$

$v_{ov} = v_{DS} \rightarrow v_{GS} - V_t = 1V$

$v_{GS} = 1.5V$



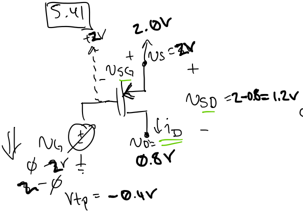
$$i_D = \begin{cases} 0 & ; \text{CUTOFF} \\ \frac{1}{2} k_n (v_{GS} - V_t)^2 & ; \text{SAT} \\ k_n \left[v_{GS} v_{DS} - \frac{1}{2} v_{DS}^2 \right] & ; \text{TRI} \end{cases}$$

Modes of Operation

CUTOFF	$v_{GS} < V_t$
TRIODE	$v_{GS} \geq V_t$; $v_{DS} < v_{ov}$
SAT	$v_{GS} \geq V_t$; $v_{DS} \geq v_{ov}$

(5.40)

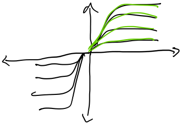
$\boxed{5.41}$


+2V
2.0V
+
$v_S = 2V$
v_{SG}
+
$v_{SD} = 2 - 0.8 = 1.2V$
−
i_D
$v_D = 0.8V$
v_G
0 2V
2 − 0
$V_{tp} = -0.4V$

$\boxed{\text{Modes}}$

$|v_{ov}| = v_{SG} - |V_{tp}|$

CUTOFF	$v_{SG} < \lvert V_{tp} \rvert$
SAT	$v_{SG} \geq \lvert V_{tp} \rvert$; $v_{SD} \geq \lvert v_{ov} \rvert$
TRI	$v_{SG} \geq \lvert V_{tp} \rvert$; $v_{SD} < \lvert v_{ov} \rvert$



$\boxed{v_G = 2V}$

$v_{SG} = v_S - v_G = 2 - 2 = 0V$

$v_{SG} = 0V < |V_{tp}| \Rightarrow$ CUTOFF

$v_{SG} = |V_{tp}|$

$v_S - v_G = 0.4V$

$2 - v_G = 0.4V \rightarrow \boxed{v_G = 1.6V} \Rightarrow$ NOT CUTOFF

$v_{SD} = 1.2V$

For $\boxed{v_{SD} \geq |V_{ov}|}$ in SAT

$v_G = 1.6V \rightarrow$ $|V_{ov}| = v_{SG} - |V_{tp}| = 0V$

$|V_{ov}| = (v_S - v_G) - |V_{tp}|$

$(2 - 1.6) - 0.4 = 0$

$1.2V \geq 0V \Rightarrow \boxed{SAT}$

Edge of SAT: $v_{SD} = (|V_{ov}|)$

$1.2V = v_{SG} - |V_{tp}|$

$1.2V = v_{SG} - 0.4V$

$v_{SG} = 1.6V$

$v_S - v_G = 1.6$

$2 - v_G = 1.6$

$\boxed{v_G = 0.4V} \rightarrow$ at Edge

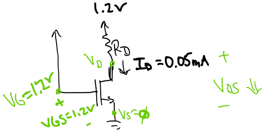
TRI $\Rightarrow$ $\boxed{v_G < 0.4V}$

CUTOFF : $1.6V < v_G \leq 2.0V$

SAT : $0.4V \leq v_G \leq 1.6V$

TRI : $0 \leq v_G < 0.4V$

D5.47


1.2V
RD
VD
ID = 0.05mA
+
VDS
−
VG=1.2V
+
VGS=1.2V
−
VS=0

$V_t = 0.4V \rightarrow$ $V_{ov} = V_{GS} - V_t = 1.2 - 0.4 = 0.8V$

Find RD at Edge of SAT

1) Edge of SAT

$V_{DS} = V_{ov} = 0.8V$

2) $\frac{1.2V - V_D}{R_D} = 0.05mA$

$\frac{1.2 - 0.8}{R_D} = 0.05mA$

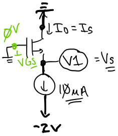
$\boxed{R_D = 8k\Omega}$

5.55

$k_n' \frac{W}{L} = 2\ mA/V^2$

$V_t = 0.5V$, $\lambda = 0 \rightarrow r_o = \infty$

(a)



0V
$I_D = I_S$
V_{GS}
V1
$= V_S$
10μA
-2V

$\ast$ SAT: $I_D = \frac{1}{2} k_n' \frac{W}{L} \underbrace{(V_{GS} - V_{tn})}_{V_{OV}}^2 = 10 \mu A$

Is it CUTOFF? $V_{GS} \overset{?}{\geq} V_{tn}$ → not sure... but

$I_D > 0 \Rightarrow$ NOT CUTOFF

$V_{OV} = 0.1V$

$V_{OV} = V_{GS} - 0.5V$ → $V_{GS} = 0.6V$

$V_{GS} = \overset{0}{\cancel{V_G}} - V_S = 0.6V$

$\boxed{V_S = -0.6V}$ $\boxed{= V_1}$

Check: $V_{DS} \overset{?}{\geq} V_{OV}$

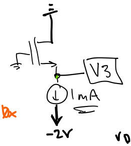
$V_D - V_S \geq$

$0 - -0.6$

$0.6 \geq 0.1V$

☑ SAT

(c)



comment: same as (a) but I_S is 100x ∴ expect V_{OV} 10x and larger V_{GS} so lower $V_S = V_3$

Assume SAT

$I_D = 1mA = \frac{1}{2} k_n' \frac{W}{L} V_{OV}^2$

$V_{OV} = 1V$ (note: 10x of (a))

$V_{GS} = V_{OV} + V_{tn} = 1.5V$

$\overset{0}{\cancel{V_G}} - V_S = 1.5V$

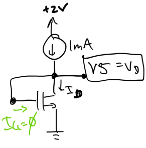
$\boxed{V_S = -1.5V = V_3}$ (lower than (a))

$V_{DS} \overset{?}{\geq} V_{OV}$

$V_{DS} = 0 - -1.5 = 1.5 \geq 1V$

☑ SAT

(e)



+2V
1mA
$V_S = V_D$
I_D
$I_G = 0$

$V_G = V_D$ and $I_G = 0$

$V_{GS} = V_{DS}$ so $I_D = 1mA$

what mode?

→ Is there current flowing? → NOT CUTOFF

$I_D = 1mA$, b/c $I_G = 0$

SAT: $V_{DS} \overset{?}{\geq} V_{GS} - V_{tn}$

equal in this circuit $V_{GS} \overset{?}{\geq} V_{GS} - V_{tn}$

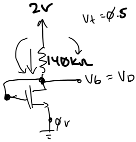
☑ SAT

$I_D = \frac{1}{2} k_n' \frac{W}{L} V_{OV}^2$ → $V_{OV} = 1V$

$V_{GS} = 1.5V$ → also V_{DS}

$\boxed{V_{DS} = 1.5V = V_5}$

(f)


2V
140kΩ
V_G = V_D
0V

$V_t = 0.5$

$V_G = V_D$

$\boxed{V_{GS} = V_{DS}}$

$V_{DS} \overset{?}{\geq} V_{GS} - V_{th}$

$V_{GS} \geq V_{GS} - V_{tn}$ ☑ SAT

$I_D = \frac{1}{2} k_n' \frac{W}{L} V_{ov}^2$

$I_D = \frac{1}{2} k_n V_{ov}^2$

$V_{ov} = V_{GS} - V_t$

$= V_{DS} - V_t = (2 - I_D \cdot 140k) - V_t$

$I_D = \frac{1}{2} k_n \left[2 - I_D \cdot 140k\Omega - V_t\right]^2$

$I_D = \begin{cases} 10\mu A \\ \underline{11.5}\ \mu A \end{cases}$ → Which is physical solution?

$I_D = 11.25\mu A$ → $V_D = 2 - $ ~~$11.5e^{-6} \cdot 140e^3 = 0.39V$~~

$V_G = 0.39V$ → ~~$V_{GS} = 0.39V$~~ $< 0.5V$

→ This implies CUTOFF so I_D cannot be 11.5 mA > 0!

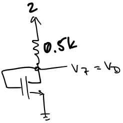
$\boxed{I_D = 10\mu A}$ → $V_G = V_D = 2 - 10\mu A \cdot 140k\Omega = 0.6V$

$\boxed{V_G =}\boxed{V_G = 0.6}$ → $V_G = 0.6V \geq 0.5V$

→ NOT CUTOFF

∴ consistent.

(g)



SAT:

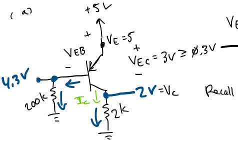
$I_D = \frac{1}{2} k_n \left[2 - I_D \cdot 0.5k\Omega - V_t\right]^2$

$I_D = \begin{cases} 1mA \\ \cancel{3.645mA} \end{cases}$ → not physical, results in CUTOFF

$V_D = 2 - 1mA \cdot 0.5k\Omega = \boxed{1.5V}\boxed{= V_z}$

$\boxed{6.29}$

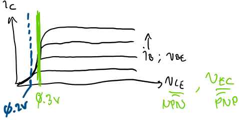
(a)


+5V
+
V_EB
−
V_E = 5
+
V_EC = 3V ≥ 0.3V
−
4.3V
200k
I_c
2k
2V = V_c

$V_{EB} = V_E - V_B = 5 - 4.3V = 0.7V$

→ ☑ ACTIVE

Recall NPN: ACTIVE mode for $V_{CE} \geq 0.3V$ edge of SAT



ACTIVE

$I_C = \beta I_B$

$I_C = \alpha I_E$ $\quad \alpha = \frac{\beta}{\beta+1}$

$I_B = (1-\alpha) I_E$

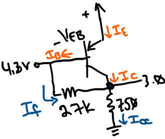
$I_B = \frac{I_E}{\beta+1}$

$I_C = \frac{2V - 0V}{2k} = 1mA$, $I_B = \frac{4.3V - 0V}{200k} = 0.0215mA$

$\beta = \frac{I_C}{I_B} = \frac{1mA}{0.0215\ mA} = 46.5$

$\boxed{\beta = 46.5}$

(b)


+5
+
I_E
$-V_{EB}$
I_B
4.3V
I_C
3.0V
I_f
27k
750
I_{cc}

$V_{EB} = 0.7$

$V_{EC} = 5 - 3 = 2 \geq 0.3 \Rightarrow$ ~~0~~ ACTIVE

→ The trick in this problem is addressing the coupling of B and c through 27K.

$I_f = (4.3 - 3.0)/27k = 48\mu A$

$I_{cc} = (3.0 - 0)/750 = 4mA$

$\Rightarrow$ KCL @ collector:

$I_c + I_f = I_{cc}$ → note: $I_f = I_c + I_B$ also

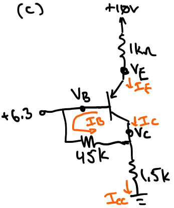
$I_c = I_{cc} - I_f = 3.952 \text{ mA}$

→ Since I_B cannot flow anwhee except the 27K resistor,

$I_B = I_f = 48\mu A$

$$\beta = \frac{I_c}{I_B} = \frac{3.952 mA}{48\mu A} = 82.33 \qquad \boxed{\beta = 82.33}$$

(c)


+10V
1kΩ
V_E
I_E
V_B
+6.3
I_B
I_C
V_C
45k
1.5k
I_{cc}

→ Now we do not know V_E but if we assune ACT mode:

$V_{EB} = 0.7V$

$V_E = V_B + V_{EB} = 7.0V$

$$I_E = \frac{10 - 7}{1k} = 3mA$$

$I_c = \alpha I_E$

$V_c = I_{cc} \cdot 1.5k = I_E \cdot 1.5k = 4.5V$

$$I_B = \frac{6.3 - 4.5}{45k} = 40 \mu A$$

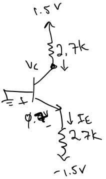
$I_c = I_E - I_B = 3mA - 40 \mu A$
$= 2.96 \text{ mA}$

$$\beta = \frac{I_c}{I_B} = \frac{2.96 mA}{40\mu A} = 74$$

$\boxed{\beta = 74}$

$\boxed{6.35}$ (a) $\beta = 50$, $|V_{BE}| = 0.7$

$V_{EB} = 0.7$


1.5V
2.7k
V_C
0.7V
I_E
2.7k
-1.5V

$\boxed{V_B = 0}$

$V_E \Rightarrow$ $V_{BE} = V_B - V_E$

$0.7V = 0V - V_E$

$\boxed{V_E = -0.7V}$

$V_c = 1.5 - I_c \cdot 2.7k\Omega$

$\boxed{V_c = 0.81V}$

$$I_E = \frac{V_E - (-1.5V)}{2.7k\Omega} = \boxed{0.296 mA = I_E}$$

If ACT:

$$I_C = \alpha I_E = \frac{\beta}{\beta + 1} I_E = \frac{50}{51} \cdot 0.296 mA$$

$\boxed{I_c = 0.290 mA}$

Check ACT

$V_{CE} \overset{?}{\geq} V_{CE,SAT} = 0.3V$

$$I_B = \frac{I_c}{\beta} = \frac{0.296 mA}{50} = \boxed{5.92\mu A = I_B}$$

$V_C - V_E \geq 0.3$

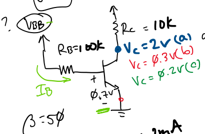
$0.717 - (-.7) \overset{?}{\geq} 0.3V$

$1.4V \geq 0.3V$ ☑ ACT

$V_c = 1.5 - I_c \cdot 2.7k = 0.717V$

skip (b) - (d)

$\boxed{6.48}$



? VBB
Vcc = 5V
Rc = 10K
RB=100k
Vc=2V (a)
Vc = 0.3V (b)
Vc = 0.2V (c)
IB
+
0.7V
-

$\beta = 50$

(a) ACT w/ $V_c = 2V$

assume $\begin{cases} V_{BE} = 0.7V \\ I_c = \beta I_B \end{cases}$

Table 6.3

$I_c = \frac{5-2}{10k} = 0.3mA$

$I_B = \frac{I_C}{\beta} = 0.006mA$

$V_{BB} = V_{BE} + I_B R_B$

$0.7 + \underline{\underline{I_B}} \cdot 100k$

$I_c \rightarrow I_B = \frac{I_c}{\beta}$

$\boxed{V_{BB} = 1.3V}$

(b) Operating at edge of SAT

ACT

$V_{BE} = 0.7V$

$I_c = \beta I_B$

$V_{CE} = V_{CE,SAT} = 0.3V$

$I_c = \frac{V_{cc} - V_c}{R_c} = \frac{5-0.3}{10k} = 0.47mA$

$I_B = \frac{I_c}{\beta} = 0.0094mA$

$V_{BB} = V_{BE} + I_B R_B$

$\boxed{V_{BB} = 1.64V}$

(c) Deep SAT w/ $\beta_{forced} = \frac{I_c}{I_B} = 10$

From Table 6.3 → assume $\begin{cases} V_{BE} = 0.7V \\ V_{CE} = 0.2V \end{cases}$

check: $\beta_{forced} \equiv \frac{I_c}{I_B} \overset{?}{<} \beta$

$I_c = \frac{V_{cc} - V_c}{R_c} = \frac{5-0.2}{10k} = 480\mu A$

$I_B = \frac{I_c}{\beta_{forced}} = \frac{480\mu A}{10} = 48\mu A$

$V_{BB} = V_{BE} + I_B R_B = 0.7V + 48\mu A \cdot 100k = \boxed{5.5V}$

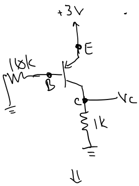
Summary

VBB	IB	Ic	β, βforced
1.3V	6μA	0.3mA	50
1.64	9.4μA	0.47mA	50
5.5	48μA ⇑	0.48mA ~	10 ⇓

In SAT I_B increases rapidly with little to no change in I_C. Their ratio, β_{forced}, drops from β rapidly.

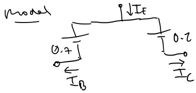
$\boxed{6.50}$ $\beta = 50$

- Show SAT mode → β



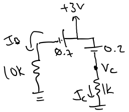
+3V
E
10k
B
C
Vc
1k
⇓

model



IE
0.7
0.2
IB
Ic

Check: $\beta_{forced} = \frac{I_c}{I_B} < \beta$


+3V
I_B
0.7
0.2
10k
V_C
I_C
1k

$I_C = \frac{3-0.2}{1k} = 2.8mA$

$I_B = \frac{3-0.7}{10k} = 0.23mA$

$\beta_{forced} = \frac{2.8mA}{0.21mA} = 12.2 < 50$

☑ SAT

$\boxed{\beta_{forced} = 12.2}$

$V_C = 0 + I_C R = (2.8mA)\,1k\Omega = 2.8V$

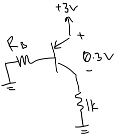
$\boxed{V_C = 2.8V}$

→ also could find from Vcc

$V_C = V_{CC} - V_{EC,sat} = 3 - 0.2 = 2.8V$

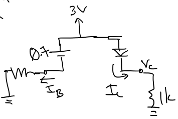
- Change R_B fore edge of SAT

At edge of SAT, $V_{EC} = 0.3V$



Use ACT model

⇒


3V
0.7
I_B
I_c
V_c
1k

At edge of SAT,

$V_{EC} = 0.3V$ so

$V_C = 3 - 0.3 = 2.7V$

$\therefore I_C = \frac{V_C}{1k} = 2.7mA$

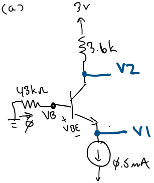
At edge of SAT we are still in ACT so $I_C = \beta I_B$.

$\therefore I_B = \frac{I_C}{\beta} = \frac{2.7mA}{50} = 54\mu A$

Since $V_B = 3V - V_{EB} = 3 - 0.7 = 2.3V$, $R_B = \frac{V_B}{I_B} = \frac{2.3V}{54\mu A} = 42.6k\Omega$ $\boxed{R_B = 42.6k\Omega}$

$\boxed{6.61}$

(a)


3V
3.6k
V2
43kΩ
VB
0
+
VBE
-
V1
0.5mA

β is high →

ACT

$I_C = \beta I_B$ → β high: $I_B = 0$

$I_C = \alpha I_E = \frac{\beta}{\beta+1} I_E$ → $I_C = I_E$

$I_E = 0.5mA$

$I_C = I_E = 0.5mA$

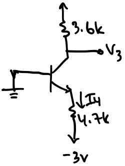
$V_2 = V_C = 3 - I_C \cdot 3.6k\Omega = 3 - 0.5m \cdot 3.6k$

$\boxed{V_2 = 1.2V}$

$V_1 = V_E = V_B - V_{BE} = 0 - \overset{0}{\cancel{I_B}} \cdot 43k\Omega - V_{BE}$

$\boxed{V_1 = -0.7V}$

(b) +3V


3.6k
V_3
I_4
4.7k
-3V

$I_B \approx 0$ b/c $\beta \to \infty$

$I_4 = I_E = I_C$

$V_3 = 3 - I_4 \, 3.6k = 1.24\,V$

$I_4 = \dfrac{(0 - 0.7) - (-3)}{4.7k} = 489\,\mu A$

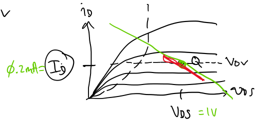
$\boxed{V_3 = 1.24\,V}$

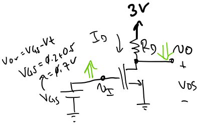
$\boxed{I_4 = 489\,\mu A}$

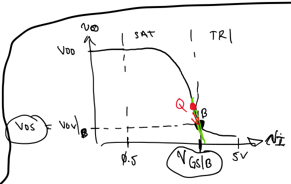
$\boxed{7.3}$ Q: $V_{ov} = 0.2V$, $V_{DS} = 1V$

Q $\boxed{V_{DS}, I_D}$

$V_t = 0.5V$, $k_n = 10\,mA/V^2$


i_D
$0.2mA = I_D$
Q
V_{ov}
v_{DS}
$V_{DS} = 1V$


$V_{ov} = V_{GS} - V_t$
$V_{GS} = 0.2 + 0.5 = 0.7V$
3V
I_D
R_D
v_O
+
V_{DS}
-
v_I
V_{GS}


v_O
SAT
TRI
V_{DD}
Q
B
$V_{DS} = V_{ov}|_B$
0.5
$V_{GS}|_B$
5V
v_I

$I_{DQ} = \frac{1}{2} k_n V_{ov}^2 = 0.2mA$

$R_D = \dfrac{3 - V_{DS}}{I_{DQ}} = \dfrac{3-1}{0.2mA} = 10\,k\Omega$

$V_{DS} = V_{DD} - i_D R_D = V_{ov}|_B = V_{GS}|_B - V_t$

See (7.6) in text.

$V_{GS}|_B = V_{ov} + V_t$

$= V_t + \dfrac{\sqrt{2 k_n R_D V_{DD} + 1} - 1}{k_n R_D}$

$V_{GS}|_B = 0.735V$

$V_{DS}|_B = V_{ov} = V_{GS}|_B - V_t = 0.735 - 0.5 = 0.235V$

Large signal gain: L.S. S.S.

$A_v = -k_n V_{ov} R_D \approx (-g_m R_D)$

$A_v = -10 \frac{mA}{V^2} \cdot 0.2 \cdot 10k\Omega = -20 \frac{V}{V}$

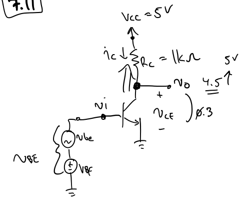
Max allowed neg. signal @ output?

$V_{DS}|_Q = 1V$
$V_{DS\,min} = 0.235$ } $-0.765V$

Peak input voltage?

$v_{gs} = \dfrac{0.765}{|A_v|} = \dfrac{.765}{20} = \boxed{38\,mV}$

7.11



$V_{CC} = 5V$
i_C
$R_C = 1k\Omega$
5V
v_O
4.5
+
v_{CE}
0.3
−
v_i
v_{be}
V_{BE}
v_{BE}

① $A_v = -g_m R_C = -\left(\frac{I_C}{V_T}\right) R_C \Uparrow$

② $\underline{\underline{V_{CE}}} = V_{CC} - I_C R_C$

$\Delta v_O^+ = \underline{\underline{V_{CC}}} - V_{CE} \longrightarrow$ NPN BJT cannot cause current to flow up to Vcc so $V_C < V_{CC}$

$\Delta v_O^- = V_{CE} - 0.3V$

↓

must remain in ACT/SAT

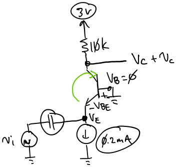
I_C	V_{CE}	A_v	ΔV_O^+	ΔV_O^-
0.5	4.5	$\underline{\underline{-20}}$	0.5	$\underline{\underline{4.2}}$
1				
2.5	2.5	−100	2.5	2.2
4				
4.5	0.5	−180	4.5	0.2

⇒ compromise of $\underline{\underline{A_v}}$ and $\underline{\underline{\Delta v_O}}$

7.48

β is high

Find V_C, r_e, $\frac{v_c}{v_i}$



3V
10k
$V_C + v_c$
$V_B = 0$
+
−V_{BE}
V_E
v_i
0.2mA

L.S. Since $\underline{I_E = 0.2\,mA}$, not in CUTOFF

Find V_C, check ACT

$V_C = 3V - I_C\, 10k\Omega$

↓

$I_C = \alpha I_E \approx I_E$

$V_C = 3 - 0.25mA \cdot 10k\Omega = 0.5$

$\boxed{V_C = 0.5V}$

$V_{CE} = V_C - V_E$, $V_E = 0 - V_{BE} = -0.7V$

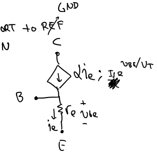
$V_{CE} = 0.5 - -0.7 = 1.2 \overset{?}{\geq} 0.3V$ ☑ ACT

Small signal parameters, defined w.r.t. large signal Q:

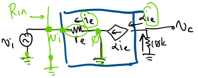
$r_e = \frac{\alpha}{g_m} = \frac{V_T}{I_E} = \alpha \frac{V_T}{I_C} = \frac{25mV}{0.25mA} = \boxed{100\,\Omega = r_e}$

Small signal gain, $\frac{v_c}{v_i}$:

- null L.S. sources
  - V → 0 → SHORT to ~~REF~~ GND
  - I → 0 → OPEN
- short capacitors
- insert SS model (T-model)



C
αi_e; $I_S e^{v_{BE}/V_T}$
B
r_e
+
v_{be}
−
i_e
E



Rin
i_e
αi_e
v_c
v_i
v_i
r_e
0
αi_e
10k

$\frac{v_c}{v_i}$

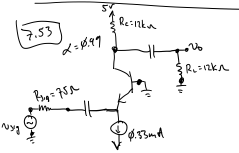
$v_c = -\alpha i_e 10k \Rightarrow v_c = -\alpha\left(-\frac{v_i}{r_e}\right) 10k$

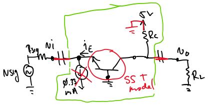
$i_e = \frac{0 - v_i}{r_e}$

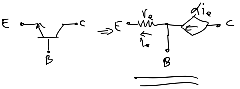
$A_v = \frac{v_c}{v_i} = \frac{\alpha 10k}{r_e}\Big|_{\alpha=1} = \frac{10k\Omega}{100\Omega} = 100\frac{V}{V}$

$\boxed{7.53}$

Find $\frac{v_o}{v_{sig}}$, R_{in}


5V
$R_C = 12k\Omega$
$\alpha = 0.99$
v_o
$R_L = 12k\Omega$
$R_{sig} = 75\Omega$
v_{sig}
0.33mA


5V
R_C
R_{sig}
v_i
i_E
v_o
R_L
v_{sig}
0.33 mA
SS T model


E
C
B
⇒
E
r_e
αi_e
C
i_e
B

① LS Anal.

$I_E = 0.33mA$

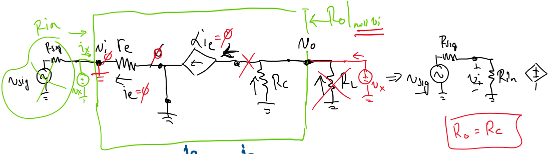
$I_C = \alpha I_E = 0.99 \cdot 0.33mA = 0.327\,mA$

$V_C = 5 - 0.327mA \cdot 12k\Omega = 1.079V$

$V_{CE} = 1.079V - (0 - 0.7) = 0.379V \overset{?}{\geq} 0.3V$ ☑ ACT

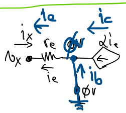
② SS parameter : $r_e = \frac{V_T}{I_E} = \frac{25mV}{0.33mA} = 75\Omega$

③ Solve SS circuit


R_{in}
R_{sig}
i_x
v_i
r_e
$\alpha i_e = 0$
$i_e = 0$
v_o
R_C
R_L
v_x
$R_o|_{null\ v_i}$
v_{sig}
⇒
R_{sig}
v_i
R_{in}

$\boxed{R_o = R_C}$

$R_{in} \equiv \frac{v_x}{i_x}$


i_e
i_c
i_x
r_e
0V
αi_e
v_x
i_e
i_b
0V

$i_x = \frac{v_x - 0}{r_e}$

$R_{in} \equiv \frac{v_x}{i_x} = \frac{v_x}{\frac{v_x}{r_e}} = r_e$

$G_v \equiv \frac{v_o}{v_{sig}}$

$v_o = -\alpha i_e (R_C // R_L)$

$i_e = \frac{0 - v_i}{r_e} = \frac{-v_i}{r_e}$

$v_o = -\alpha\left(-\frac{v_i}{r_e}\right)(R_C//R_L) = v_i\left[\frac{\alpha}{r_e} R_C//R_L\right]$

$A_v \equiv \frac{v_o}{v_i} = \frac{\alpha}{r_e}(R_C//R_L) = \frac{\alpha}{\frac{\alpha}{g_m}} R_C//R_L = g_m(R_C//R_L)$

$r_e = \frac{\alpha}{g_m}$

$\boxed{A_v = 79.2\frac{V}{V}}$

$G_v \equiv \frac{v_o}{v_{sig}} = \frac{v_o}{v_i}\cdot\frac{v_i}{v_{sig}} = A_v \cdot \boxed{\frac{v_i}{v_{sig}}} = A_v\left(\frac{R_{in}}{R_{in}+R_{sig}}\right) = g_m(R_C//R_L)\cdot\left(\frac{r_e}{r_e+R_{sig}}\right)$

$v_i = v_{sig}\left(\frac{R_{in}}{R_{in}+R_{sig}}\right)$

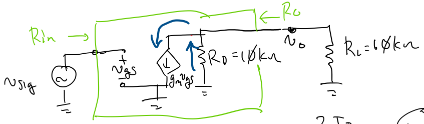
$G_v = \frac{\alpha}{r_e+R_{sig}} R_C//R_L$ $\boxed{= 39.6\frac{V}{V}}$

$\boxed{7.65}$

$\mu_n C_{ox} = 400 \frac{\mu A}{V^2}$, $\frac{W}{L} = 10$

$I_D = 0.5\,mA$

Find R_{in}, A_{vo}, R_o, G_v with $R_L = 10 k\Omega$



Rin →
← Ro
v_{sig}
$+ v_{gs}$
$g_m v_{gs}$
$R_D = 10 k\Omega$
v_o
$R_L = 10 k\Omega$

$\boxed{R_{in} = \infty\,\Omega}$

$\boxed{R_o = R_D = 10 k\Omega}$

$$g_m = \frac{2 I_D}{V_{ov}} = \cancel{\left(\mu_n C_{ox} \frac{W}{L}\right)} V_{ov} = \sqrt{2 \mu_n C_{ox} \frac{W}{L} I_D}$$

$$I_D = 500\,\mu A = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} V_{ov}^2$$

$$V_{ov} = 0.5\,V$$

$$g_m = \frac{2 I_D}{V_{ov}} = 2 \frac{mA}{V}$$

$$A_{vo} \equiv \frac{v_o}{v_i}\Big|_{R_L = \infty} \qquad v_o\Big|_{R_L=\infty} = -g_m \underset{\hookrightarrow v_{sig}}{v_{gs}} R_D = -g_m R_D v_{sig}$$

$$\boxed{A_{vo} = -g_m R_D} = -2 \frac{mA}{V} \cdot 10 k\Omega = \boxed{-20 \frac{V}{V} = A_{vo}}$$

$G_v = A_v$ b/c $R_{sig} = 0$ (or $R_{in} = \infty$)

$$A_v \equiv \frac{v_o}{v_i}$$

$$G_v = \frac{v_o}{v_{sig}} = \frac{v_o}{v_i} \cdot \cancel{\frac{v_i}{v_{sig}}} = A_v$$

$$v_o = -g_m v_{gs} (R_D // R_L)$$

$$\frac{v_o}{v_{sig}} = \boxed{-g_m R_D // R_L = G_v}$$

$$\boxed{-10 \frac{V}{V}}$$

Peak signal voltage for a 0.5 Vpk output voltage?

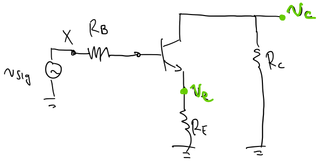
$$\hat{v}_{sig} = \frac{0.5\,Vpk}{gain} \rightarrow \text{Use } A_v \text{ or } G_v \text{ or } A_{vo}?$$

$$\hat{v}_{sig} = \frac{\hat{v}_{opk}}{G_v} = \frac{0.5}{-10} = \boxed{-50\,mVpk}$$

$\boxed{7.88}$ Neglect Early Effect → $r_o = \infty$
($V_A = \infty$)

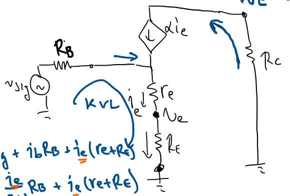
$$r_o = \frac{V_A}{I_D} = \frac{1}{\lambda I_D} \rightarrow I_D'$$

⇒ Find $\frac{v_c}{v_{sig}}, \frac{v_e}{v_{sig}}$


X
R_B
v_{sig}
v_c
R_c
v_e
R_E

Approach: write v_c vs. i_e and v_{sig} vs. i_e directly, then divide

$v_c = -\alpha i_e R_c$


αi_e
R_B
v_{sig}
KVL
i_e
r_e
v_e
R_E
R_c

$0 = -v_{sig} + i_b R_B + i_e(r_e + R_E)$

$v_{sig} = \frac{i_e}{\beta+1} R_B + i_e(r_e+R_E)$

prefer α relationship b/c v_c vs. α

$\frac{i_e}{\beta+1} = (1-\alpha) i_e$

CE w/ R_E

$$\boxed{\frac{v_c}{v_{sig}}} = \frac{-\alpha i_e R_c}{i_e(r_e+R_E) + (1-\alpha) i_e R_B}$$

$v_{sig} = i_e(r_e+R_E) + i_b R_B$ ↳ relate to i_e

$v_c = -\alpha i_e R_c$

$v_{sig} = i_e(r_e+R_E) + (1-\alpha) i_e R_B$

$$\boxed{\frac{v_c}{v_{sig}} = \frac{-\alpha R_c}{(r_e+R_E) + (1-\alpha) R_B}}$$

$\boxed{\frac{v_e}{v_{sig}}}$ have $v_{sig} = f(i_e)$, so find $v_e = f(i_e)$

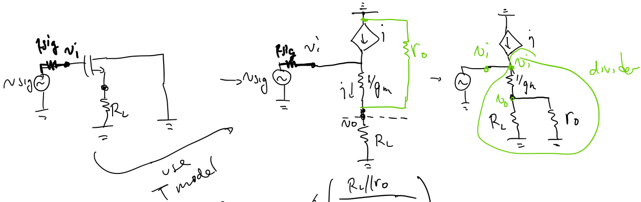
emitter follower

$v_e = i_e R_E$

$$\frac{v_e}{v_{sig}} = \frac{i_e R_E}{i_e(r_e+R_E) + (1-\alpha) i_e R_B} = \boxed{\frac{R_E}{r_e + R_E + (1-\alpha) R_B}}$$

$\boxed{7.90}$ Show that source follower w/ r_o is:

$$G_v \equiv \frac{v_o}{v_{sig}} = \frac{(R_L \| r_o)}{(R_L \| r_o) + 1/g_m}$$


R_{sig}
v_i
v_{sig}
R_L
use T model
R_{sig}
v_i
v_{sig}
i
r_o
$1/g_m$
v_o
R_L
v_i
i
$1/g_m$
v_o
R_L
r_o
divider

divider: $v_o = \cancel{v_i} \left(\frac{R_L \| r_o}{R_L \| r_o + 1/g_m}\right)$

$v_{sig} = v_i$ b/c $R_{in} = \infty$

$$\boxed{G_v \equiv \frac{v_o}{v_{sig}} = \frac{R_L \| r_o}{R_L \| r_o + 1/g_m}}$$

$G_v \big|_{R_L=\infty} = 0.98 = \frac{r_o}{r_o + 1/g_m}$ ⇒ $\boxed{\begin{array}{l} r_o = 25\text{ k}\Omega \\ g_m = 1.96\ \frac{\text{mA}}{\text{V}} \end{array}}$

$G_v \big|_{R_L=500} = 0.49 = \frac{500 \| r_o}{500 \| r_o + 1/g_m}$