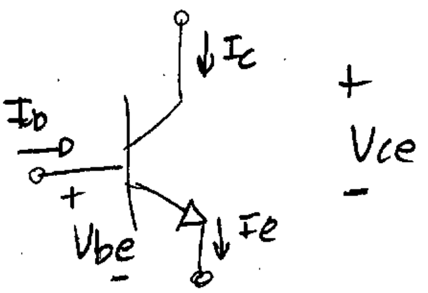
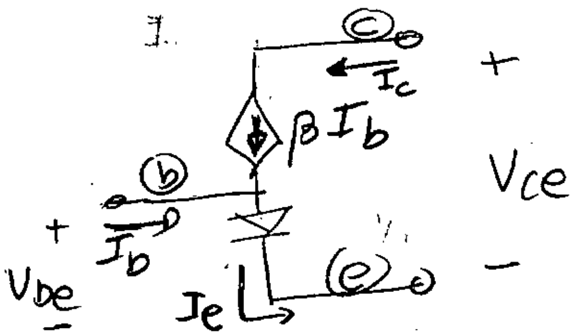
- BJT (Bipolar junction transistor)

NPN PNP

- Basic functional description (NPN)



- ACTIVE ZONE MODEL

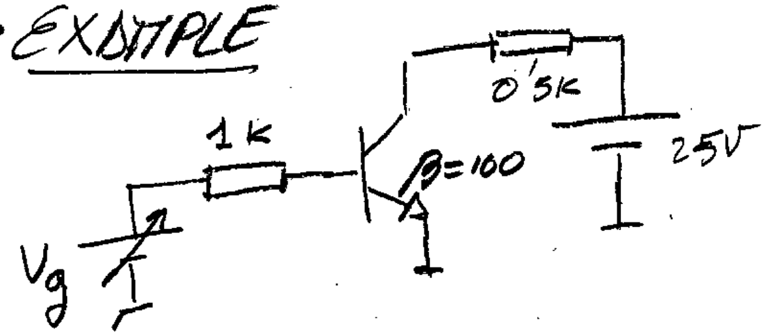


$V_{ce} > 0'2$ Volt
$I_b > 0$
} ACTIVE ZONE CONDITIONS

β = Current gain (10 ↔ 500)

$$I_c = \beta I_b$$
$$I_e = (\beta + 1) I_b$$

- EXAMPLE



- If the BJT operates in active zone

$$I_b = \frac{V_g - 0'7}{1} \Rightarrow I_c = 100\left(\frac{V_g - 0'7}{1}\right) \Rightarrow$$

$$V_{ce} = 25 - 0'5\, I_C$$

- If $V_g = 1\,V \Rightarrow I_b = 0'3\,mA \Rightarrow I_c = 30\,mA \Rightarrow$

  $V_{ce} = 25 - 0'5 \cdot 30 = 10$ Volt $\Rightarrow$ OK

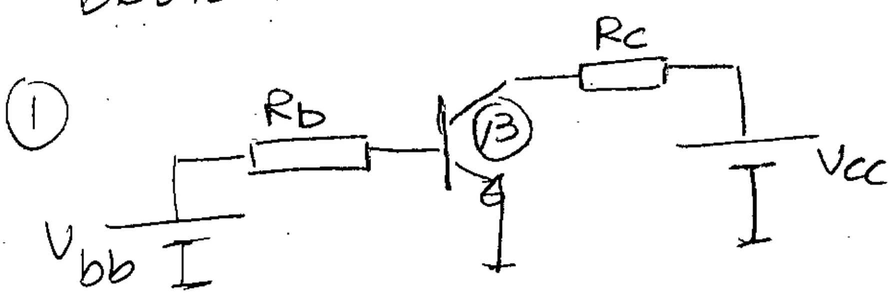
- If $V_g = 5\,V \Rightarrow I_b = 4'3\,mA \Rightarrow I_c = 430\,mA \Rightarrow$

  $V_{ce} = 25 - 0'5 \cdot 430 = -190$ Volt $\Rightarrow$ NOT IN ACTIVE ZONE

- If $V_g = 0'2$ Volt $\Rightarrow I_b = -0'5\,mA \Rightarrow$ NOT IN ACTIVE ZONE

BASIC CIRCUITS

①



BASE CIRCUIT $\frac{V_{bb} - 0'7}{R_b} = I_b$

COLECTOR CIRCUIT $V_{cc} - I_C R_C = V_{ce}$

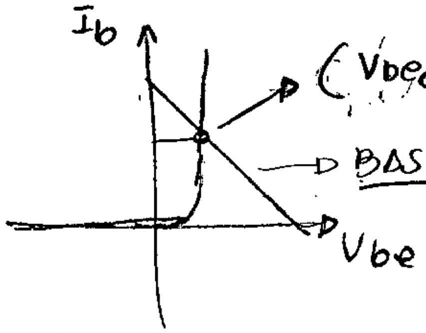
ACTIVE ZONE $I_C = \beta I_b$

$\Longrightarrow$ V_{ce_Q}, I_{b_Q}, I_{C_Q}

VALID RESULTS ONLY IF $V_{ce_Q} > 0'2$, $I_{b_Q} > 0$

Graphs

- BASE CIRCUIT

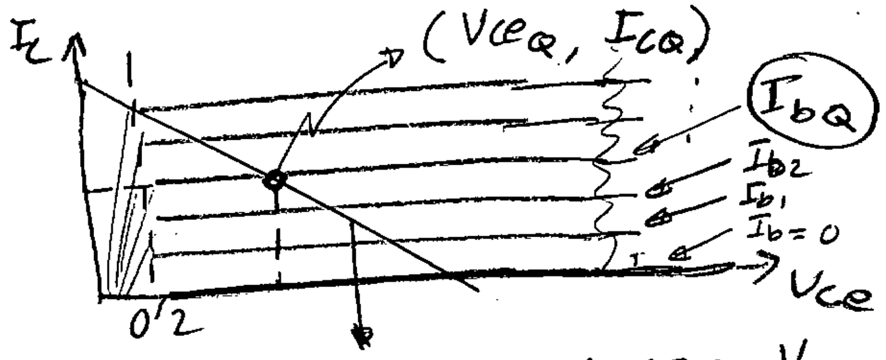


$(V_{be_Q}, I_{bQ}) \simeq (0'7, I_{bQ})$

BASE LOAD LINE $\quad V_{bb} - R_b I_b - V_{be} = 0$

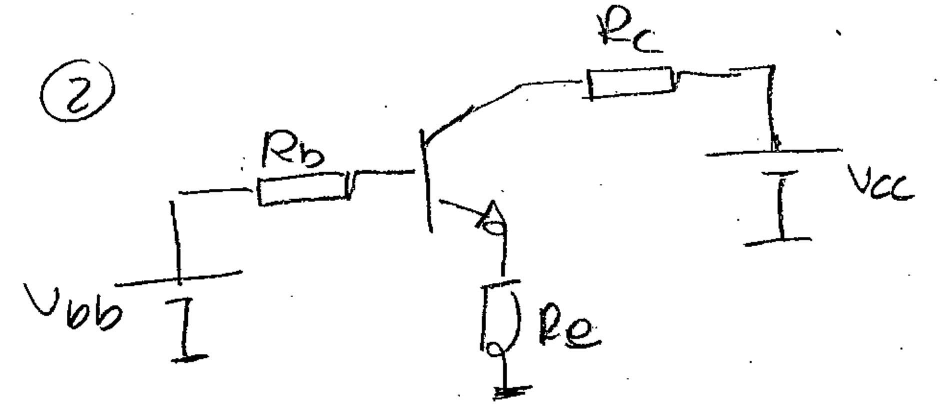
- COLECTOR CIRCUIT

(V_{ce_Q}, I_{C_Q})



COLECTOR LOAD LINE: $V_{cc} - I_C R_C - V_{ce} = 0$

(2)



BASE CIRCUIT : $V_{bb} - I_b R_B - V_{be} - I_e \cdot R_e = 0$

COLECTOR CIRCUIT: $V_{cc} - I_C R_C - V_{ce} - I_e \cdot R_e = 0$

ACTIVE : $V_{be} = 0'7$

$I_C = \beta I_b$

$I_e = (\beta + 1) I_b$

$\{ V_{ceQ}, I_{CQ}, I_{bQ}, I_{eQ}, V_{be} = 0'7 \}$ can be obtained

VALID RESULTS IF $V_{ceQ} > 0'2$ and $I_{bQ} > 0$

It can be obtained:

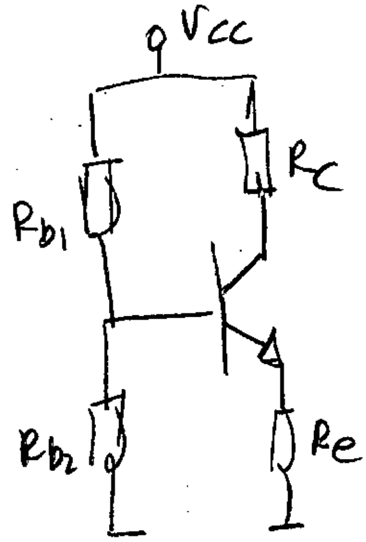
$$V_{bb} - (R_b + (\beta+1) R_e) I_b - V_{be} = 0$$

and

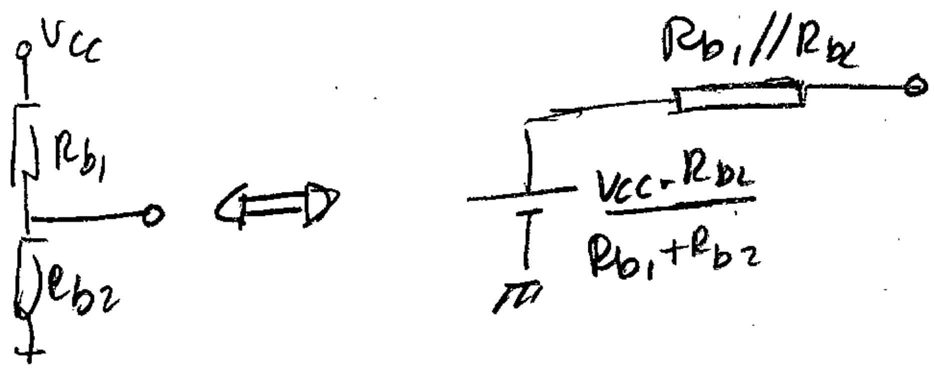
$$V_{cc} - \left(R_C + \left(\frac{\beta+1}{\beta}\right) R_e\right) I_e - V_{ce} = 0$$

The equations are similar than the ones of the first circuit (the slopes of the load lines are different)

(3)



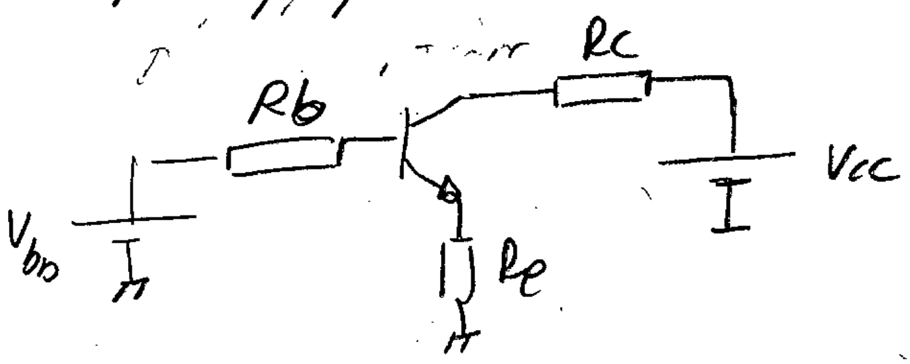
A Thevenin equivalent circuit can be used:



Then the same circuit as in (2) is obtained. but only one DC source is needed to determine Q point.

· Q DEPENDENCY ON β

1. β is not known for a single BJT (statistical distribution on manufacturing)
2. $\{V_{CEQ}, I_{CQ}\}$ must be determined without any dependency on β.
3. This performance is achieved using R_e.



$$\left.\begin{array}{l} V_{bb} - I_b R_b - 0'7 - (\beta+1) R_e I_b = 0 \\ V_{cc} - \beta I_b - V_{ce} - (\beta+1) I_b R_e = 0 \end{array}\right\} \Rightarrow$$

$$I_{b_Q} = \frac{V_{bb} - 0'7}{(\beta+1)R_e + R_b}$$

$$I_{C_Q} = \beta \frac{(V_{bb} - 0'7)}{(\beta+1)R_e + R_b}$$

$$V_{ce_Q} = V_{cc} - (\beta R_c + (\beta+1) R_e) \frac{(V_{bb} - 0'7)}{(\beta+1)R_e + R_b}$$

If:

① β is large enough ($\beta > 20$)

② $(\beta+1) R_e >> R_b$

$$I_{CQ} \simeq \frac{V_{bb} - 0'7}{R_e}$$

$$V_{CEQ} \cong V_{CC} - (\beta R_C + (\beta+1) R_e) \frac{V_{bb} - 0'7}{(\beta+1) R_e} \simeq$$

$$\cong V_{CC} - \left(\frac{R_C + R_e}{R_e} \right) \cdot (V_{bb} - 0'7) =$$

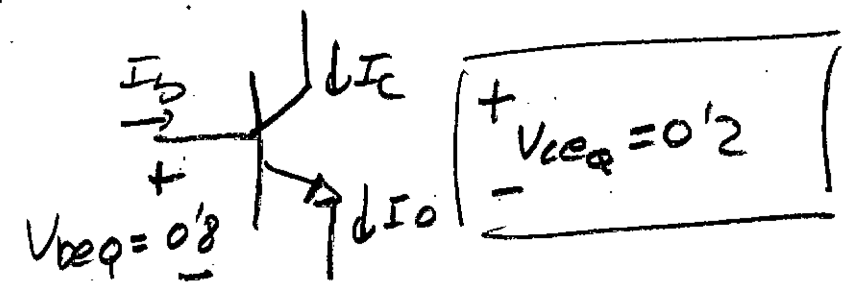
$\frac{\beta}{\beta+1} \simeq 1$

$$V_{CEQ} = V_{CC} - \left(1 + \frac{R_C}{R_e}\right)(V_{bb} - 0'7)$$

I_{CQ}, V_{CEQ} have no dependency on β

• BJT SATURATION ZONE

If I_{CQ} is large enough, V_{ce} falls to zero (in fact falls to $V_{ceQ} = 0'2$)



- V_{beQ} is greater than in active zone
- $I_{CQ} \neq \beta \cdot I_{bQ}$

The BJT is like a switch in its <u>ON STATE</u>

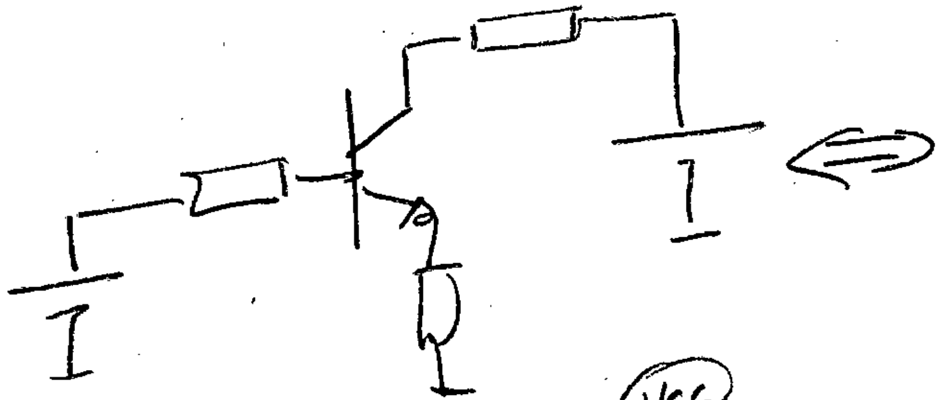
(I_c is flowing and $V_{ce} \simeq 0$)

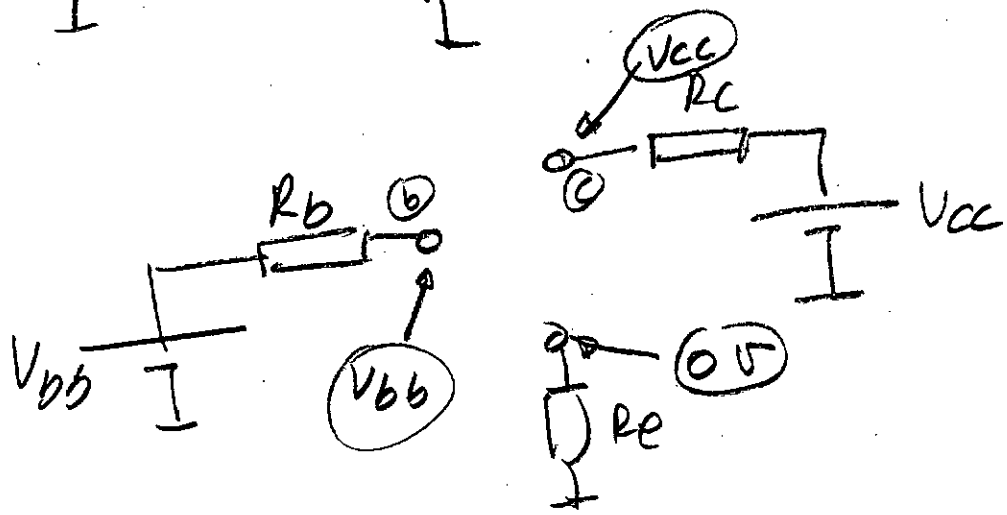
- This zone is used in logic (digital) circuits
- A BJT comes to the saturation zone if ($R_c + R_e$) is large, and if I_b is also large

BJT CUT OFF ZONE

$$\left.\begin{array}{l} I_b = 0 \\ V_{ce} > 0 \end{array}\right\} \Rightarrow I_c = 0 \,,\; I_e = 0$$

The BJT behaves like a switch in its <u>OFF STATE</u>, that is





This is:

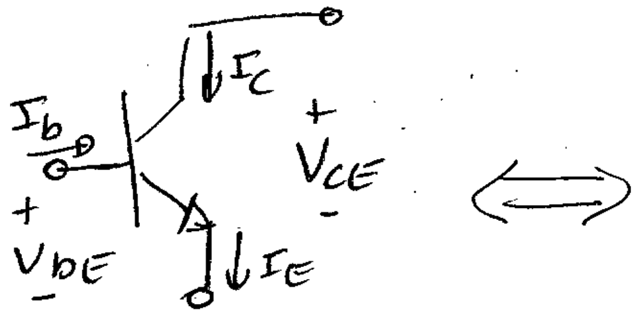
$V_{be} = V_{bb}$

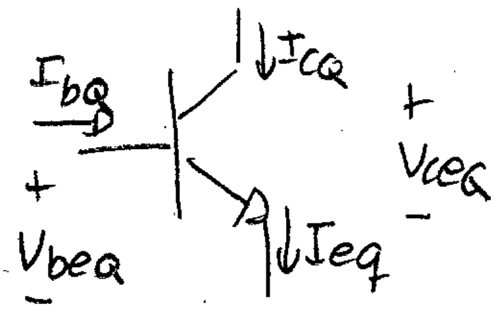
$V_{ce} = V_{cc}$

$I_c = I_e = I_b = 0$

A BJT comes to the OFF STATE if $V_{bb} < 0.7$

BJT
Small signal model





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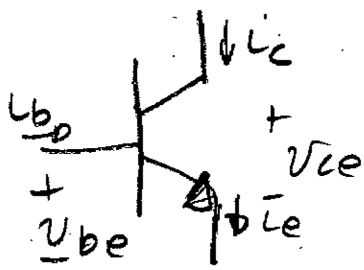


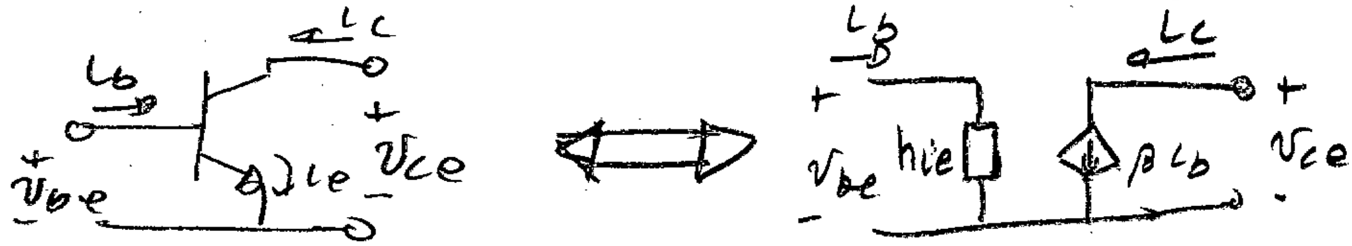
Q MODEL

Small signal model

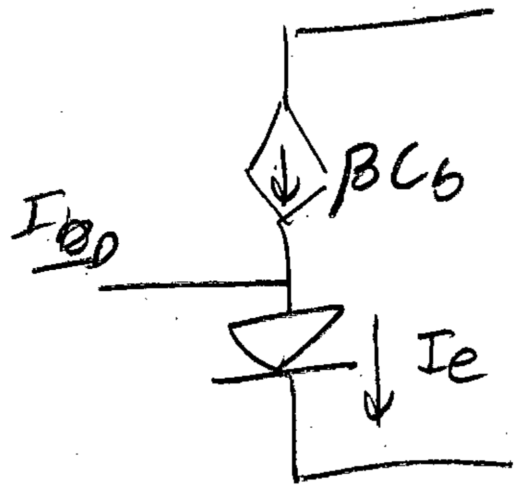
(lower case means Δ, that is $i_b \hat{=} \Delta I_b$ ....)

The small signal model is based on Taylor's series of $\{I_b, I_c, I_e, V_{ce}, V_{be} \ldots\}$

It can be shown:



• hie calculus



$$I_e = I_b + \beta I_b = (\beta+1) I_b = I_s \left(e^{\frac{V_{be}}{V_T}} - 1 \right)$$

$$\Downarrow$$

$$I_b = \frac{1}{\beta+1} \cdot I_s \left(e^{\frac{V_{be}}{V_T}} - 1 \right) \Rightarrow$$

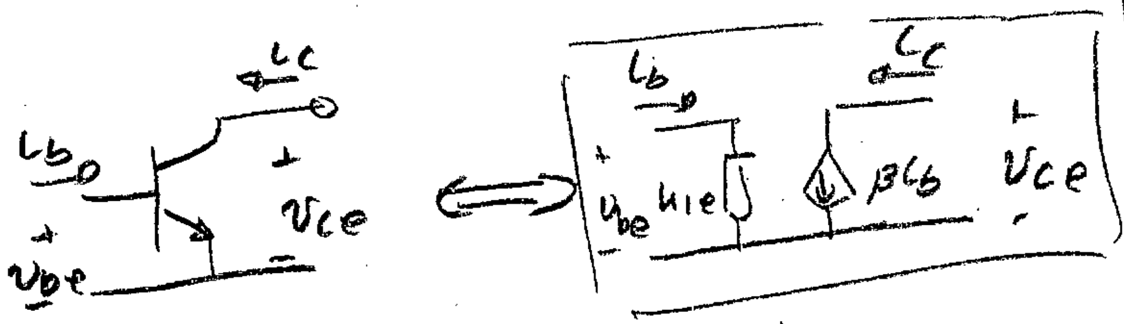
↑ TAYLOR'S SERIES

$$i_b = \left. \frac{\partial I_b}{\partial V_{be}} \right|_Q \cdot v_{be} \Rightarrow$$

$$i_b = \left(\frac{1}{\beta+1} \cdot \frac{1}{V_T} \cdot I_s e^{\frac{V_{be}|_Q}{V_T}} \right) \cdot v_{be} \Rightarrow$$

$$i_b = \frac{1}{V_T} \cdot I_b|_Q \, v_{be} \Rightarrow \boxed{\frac{v_{be}}{i_b} = h_{ie} = \frac{V_T}{I_b|_Q}}$$

hence



$$h_{ie} = \frac{V_T}{I_b|_Q}$$

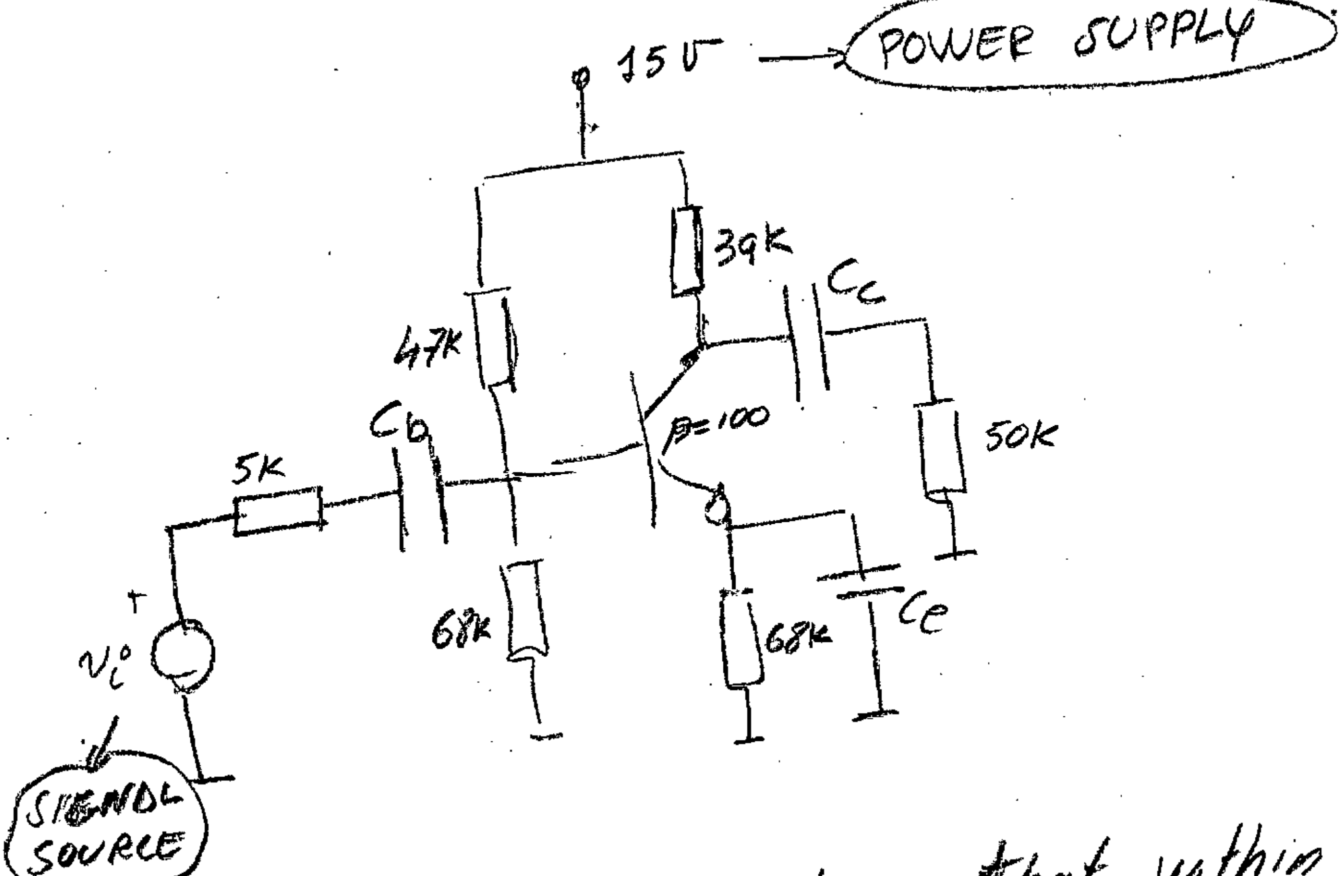
For instance

$I_b|_Q = 20\mu A \Rightarrow h_{ie} = 1'25K$

$I_b|_Q = 0'1mA \Rightarrow h_{ie} = 250\Omega$

AMPLIFIERS (BJT BASED)

Single stage inverter amplifier

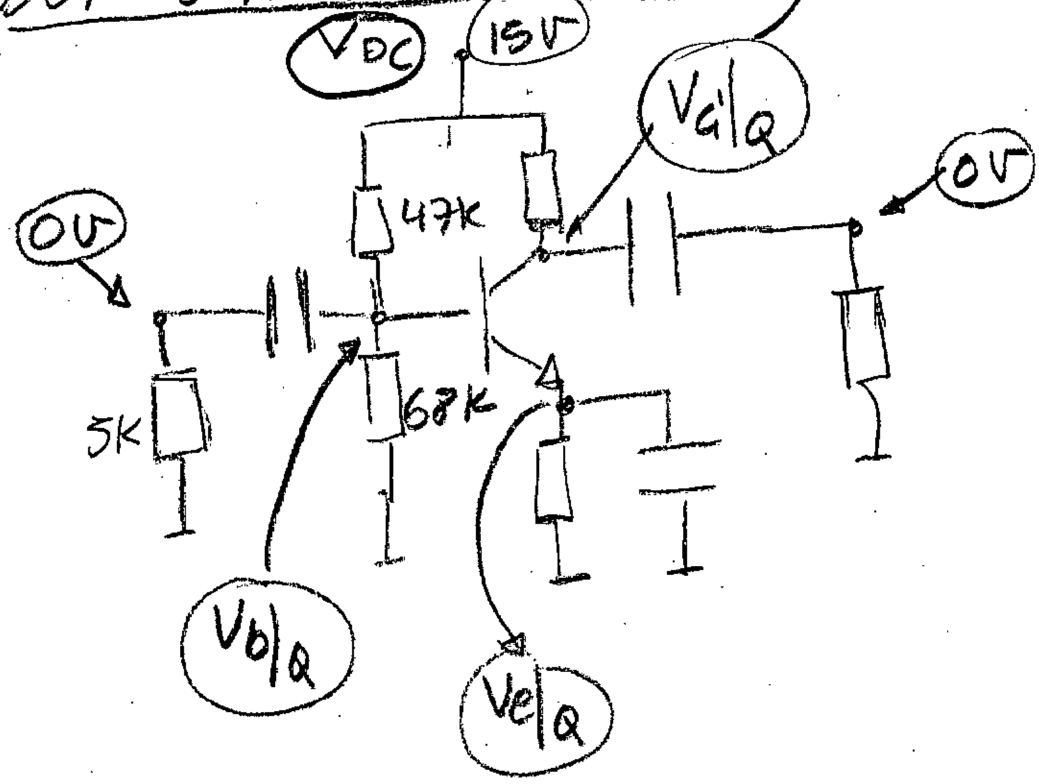


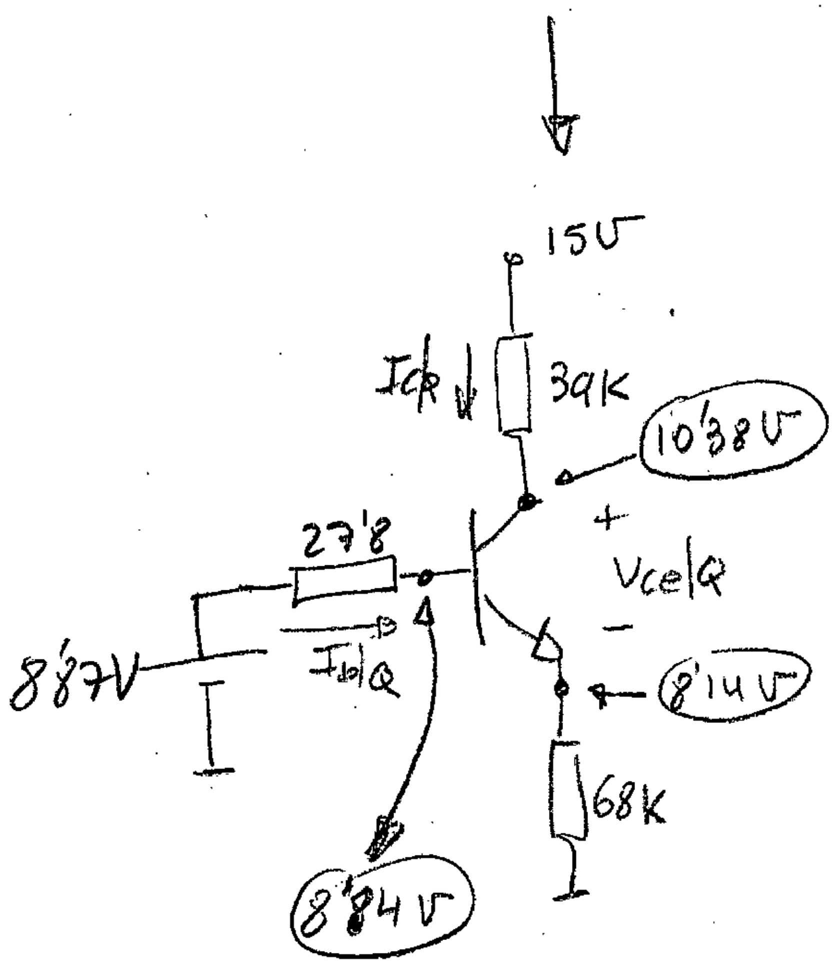
- C_b, C_e, C_c are large enough, so that within the frequency range of interest

$5K + [C_b] \simeq 5K$
$68K \,//\, [C_e] \simeq 0$
$50K + [C_c] \simeq 50K$

That is, the capacitor impedance $Z_C = \frac{-j}{\omega C}$ is very small within the frequency range of interest

- DC analysis - Q point: $v_i = 0$ (BJT is in ACTIVE ZONE)





Base thevenin equiv.

$R_b = 47K // 68K = 27'8K$

$V_{th} = \frac{15}{68+47} \cdot 68 = 8'87V$

• BASE LOOP

① $8'87 - I_b|_Q \cdot 27'8 - 0'7 - 101 \cdot 68 \cdot I_b|_Q = 0$

• COLLECTOR LOOP

② $15 - 100\, I_b|_Q \cdot 39 - V_{ce}|_Q - 101 \cdot I_b|_Q \cdot 68 = 0$

From ① $I_b|_Q = 1'185 \mu A \Rightarrow \begin{cases} I_{CQ} = 0'1185 \text{ mA} \\ I_{eQ} = 0'1197 \text{ mA} \end{cases}$

From ② $V_{ce}|_Q = 2'24$ Volt

Also $V_e|_Q = 0'1197 \cdot 68 = 8'14$ Volt

$V_c|_Q = 8'14 + 2'24 = 10'38$ Volt

(It can be seen also: $V_{CQ} = 15 - I_{CQ} \cdot 39 =$
$= 15 - 0'1185 \cdot 39 = 10'38$ Volt)

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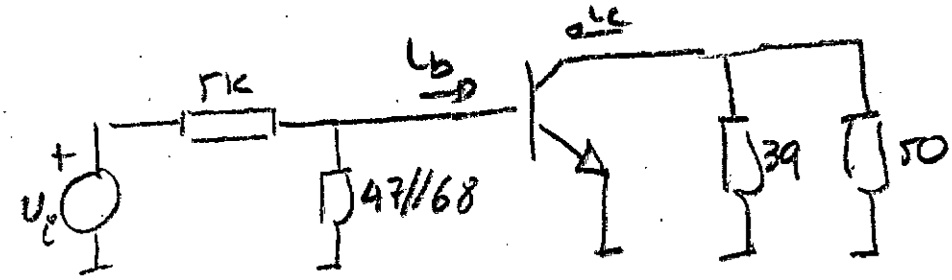
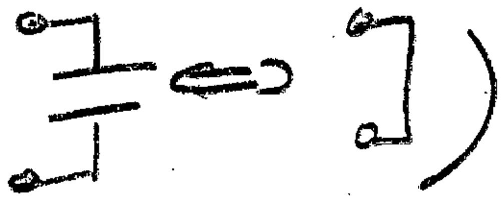
Small signal analysis

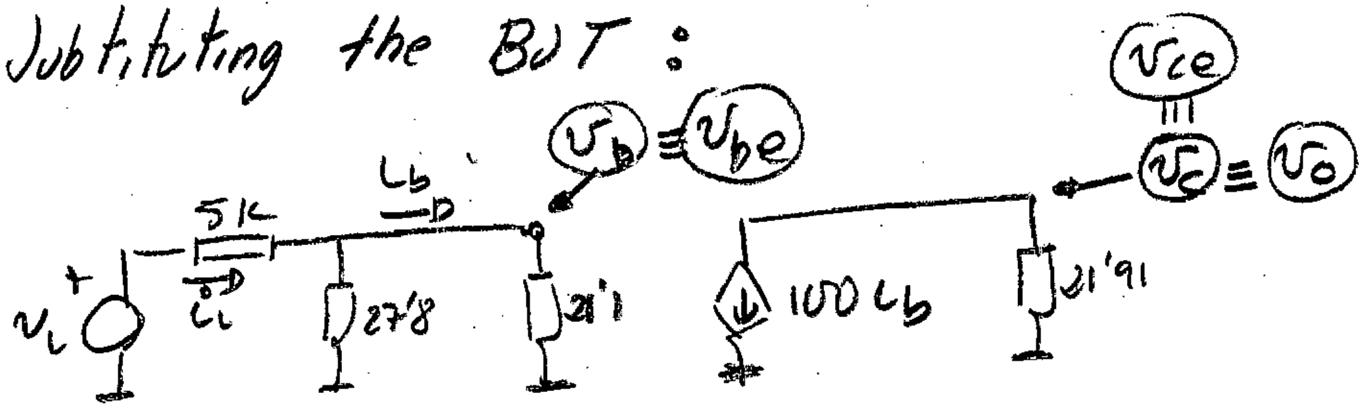
- V_{DC} (power supply) $\equiv 0$



(It has been assumed that $\omega \uparrow\uparrow$ and


)

Substituting the BJT:



$$h_{ie} = \frac{V_T}{I_b|_Q} = \frac{0'025}{0'001185} = 21'1K$$

The analysis can be performed:

$$i_b = \underbrace{\frac{v_i}{5+(27'8//21'1)}}_{i_i} \cdot \underbrace{\frac{27'8}{27'8+21'1}}_{\text{CURRENT DIVIDER}} = v_i \cdot 0'063345$$

$v_o = -100\, i_b \cdot 21'91 =$

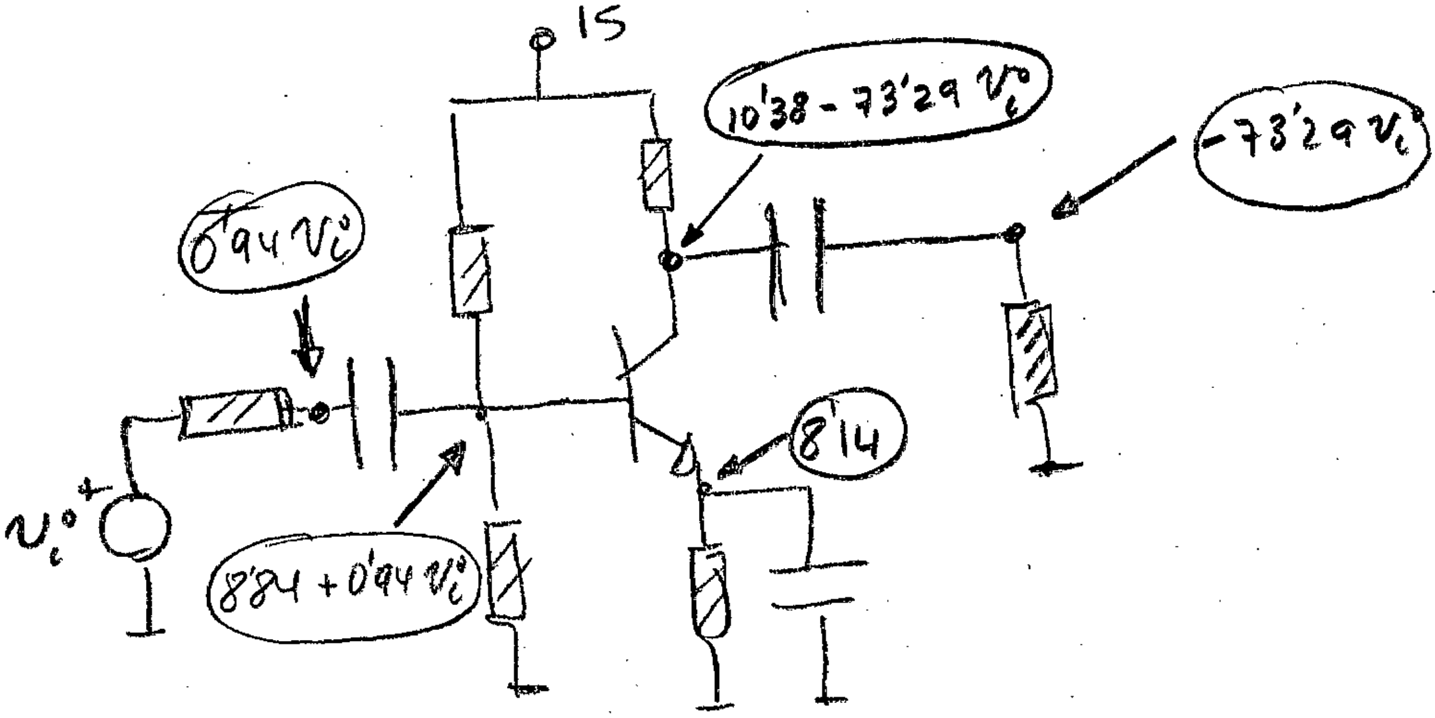
$= -100 \cdot v_i\, 0'03345 \cdot 21'91 \Rightarrow$

$$\boxed{v_o = -73'29\, v_i}$$

That is, $V_o = V_o|_Q + v_o \Longleftrightarrow$

$$\boxed{V_o = 10'38 - 73'29\, v_i}$$

V_o is an amplified (73'29), inverted (-) "version" of v_i



$(v_b = i_b \cdot 28'1 = 0'94\, v_i)$

Dynamic range of v_i

Some considerations are needed

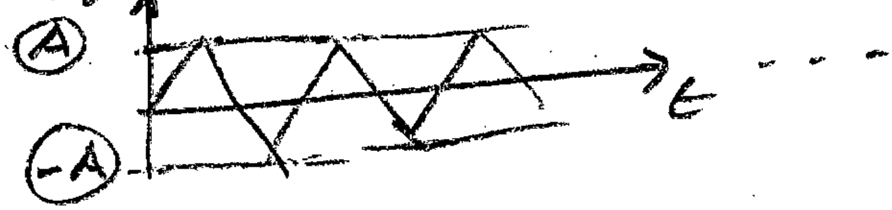
① This is an AC coupled amplifier.

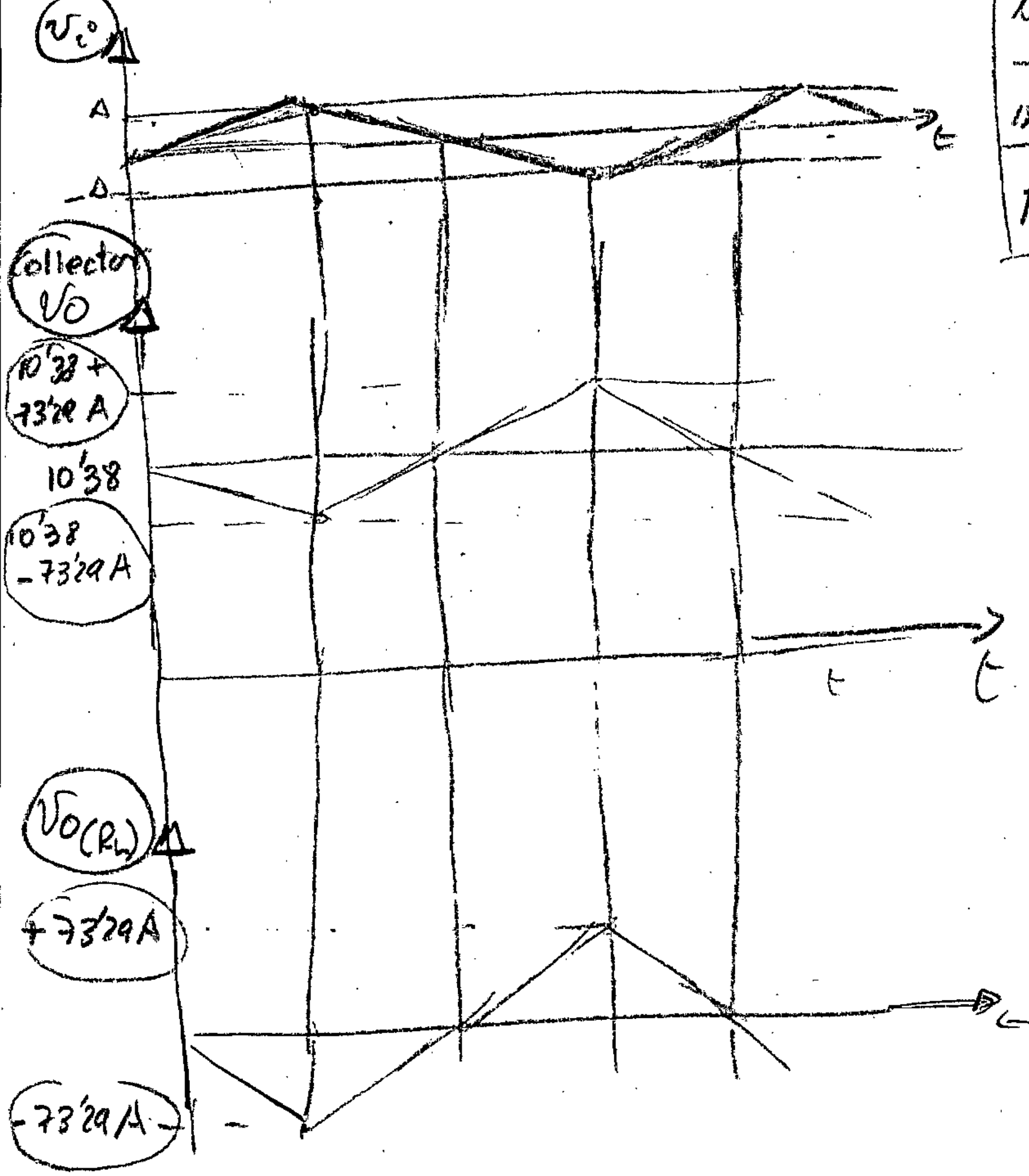
V_o (either in the collector or in the load resistor) are 'non sensitive' on DC – v_i voltage.

That is, V_o is the same for $v_i(t)$ or for $(v_i(t) + \bar{V})$.

· The base capacitor blocks DC

② If the $v_i(t)$ signal source is symmetric (equal maximum and minimum values):





$$V_O(\text{collector})\Big|_{max} = 10'38 + 73'29\,A = 15$$

MAXIMUM Vo value

$$V_O(\text{collector})\Big|_{min} = 10'38 - 73'29\,A = 8'14 + 0'2$$

$V_{ce}|_{SAT}$

MINIMUM Vo value

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$$A = \frac{15 - 10'38}{73'29} = 63'03 mV$$

OR

$$A = \frac{10'38 - 8'16}{73'29} = 30'29 mV$$

The $A = 30'29 mV$ is the dynamic range of V_i.
"Non distorsion" is obtained.