BJT Analysis:

1. DC (Active mode)
2. AC (hybrid π)
3. Thevenin - Resistance Reflection Rule
4. Saturation

(NPN) · $V_C < V_B$ (PNP) · $V_C > V_B$

Homework 9 due on April 20th

No Quiz Wed. (Quiz on April 18th)

Exam 3 on April 23rd

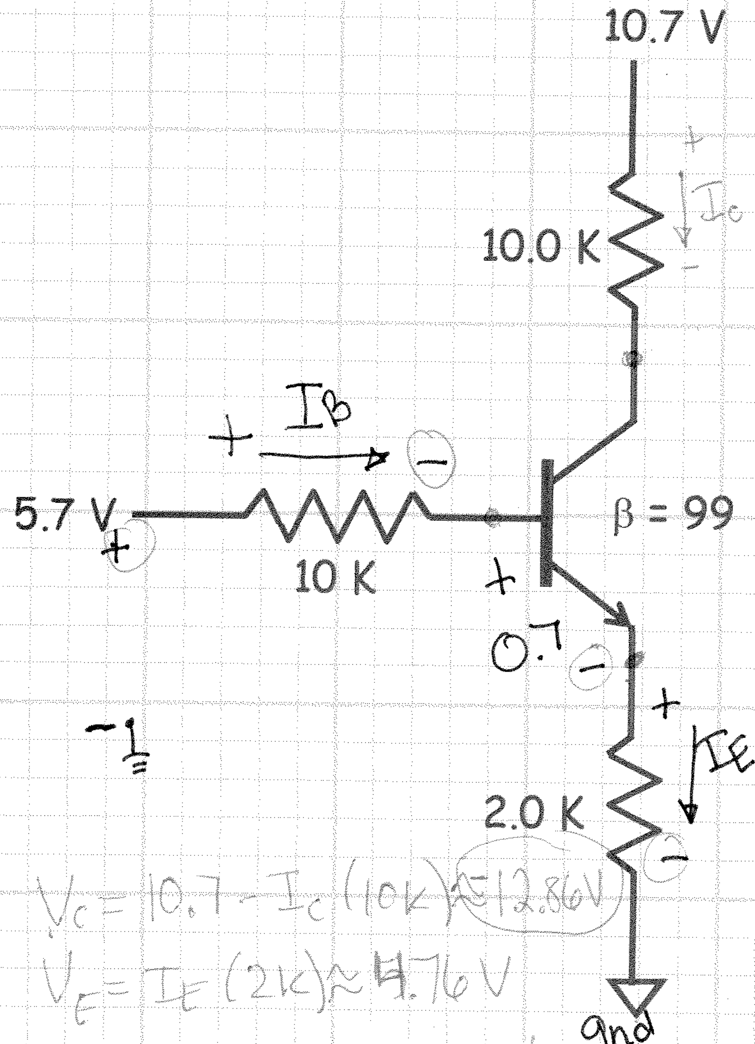
Final on April 27th

Exam 1	distributed 8am	collected 9am
" 2	" 9am	" 10am
" 3	" 10am	" 11am

You have to come during correct hour.

Example: A BJT Circuit in Saturation

Determine all **currents** for the BJT in the circuit below.



Hey! I remember this circuit, its just like a ***previous example****. The BJT is in* ***active*** *mode!*

Let's see if you are correct! ASSUME it is in active mode and ENFORCE $V_{CE} = 0.7$ V and $i_C = \beta\ i_B$.

$\beta = 99$

The B-E KVL is therefore:

$I_E = (\beta+1) I_B$

$$5.7 - 10\, i_B - 0.7 - 2\,(99+1)\, i_B = 0$$

Therefore $i_B = 23.8\ \mu A$

$I_E = (100)(23.8\mu) = 2.38m$

$I_C = \beta I_B = 99\,(23.8\mu) = 2.356m$

$V_C = 10.7 - I_C(10K) \approx -12.86V$

$V_E = I_E(2K) \approx 4.76\ V$

$V_B = 4.8 + 0.7 = 5.6V$

$V_C < V_B$ ∴ NOT ACTIVE

(power supply not big enough)

Q: *So what do we do **now** ?*

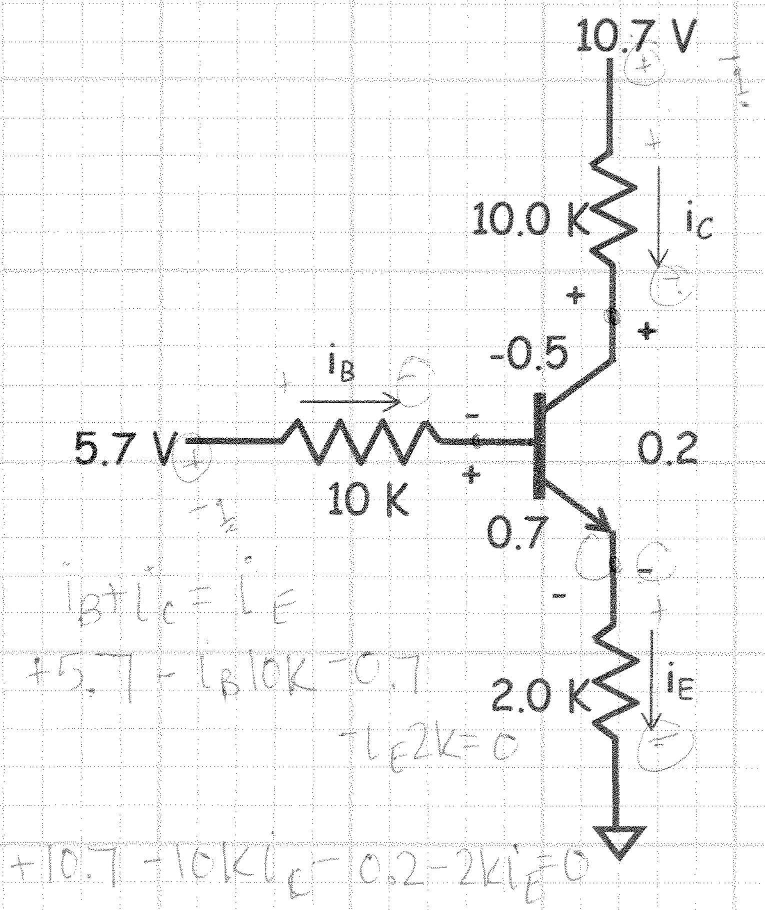
A: Go to **Step 5**; change the assumption and try it again!

Lets ASSUME instead that the BJT is in **saturation**. Thus, we ENFORCE the conditions:

OR $V_{CE}=0.3V$

$$V_{CE} = 0.2 \text{ V} \quad V_{BE} = 0.7 \text{ V} \quad V_{CB} = -0.5 \text{ V}$$

Now lets ANALYZE the circuit !



Note that we **cannot** directly determine the currents, as we **do not** know the base voltage, emitter voltage, or collector voltage.

But, we do know the **differences** in these voltages!

For example, we know that the collector voltage is 0.2 V **higher** than the emitter voltage, but we **do not** know what the collector or emitter voltages are!

Q: *So, how the heck do we ANALYZE this circuit !?*

A: Often, circuits with BJTs in **saturation** are somewhat more **difficult** to ANALYZE than circuits with **active** BJTs. There are often **many approaches**, but all result from a logical, systematic application of **Kirchoff's Laws**!

ANALYSIS EXAMPLE 1 – Start with **KCL**

We **know** that $i_B + i_C = i_E$ (KCL)

But, what **are** i_B, i_C, and i_E ??

Well, from **Ohm's Law**:

$$i_B = \frac{5.7 - V_B}{10} \qquad i_C = \frac{10.7 - V_C}{10} \qquad i_E = \frac{V_E - 0}{10}$$

Therefore, combining with KCL:

$$\frac{5.7 - V_B}{10} + \frac{10.7 - V_C}{10} = \frac{V_E}{10}$$

Look what we have, **1 equation** and **3 unknowns**.

➡ We need 2 more **independent** equations involving V_B, V_C, and V_E!

***Q:* *Two more* independent equations !? It looks to me as if we have written all that we can about the circuit using Kirchoff's Laws.**

A: True! There are no more **independent** circuit equations that we can write using KVL or KCL ! But, recall the hint sheet:

*"Make sure you are using **all** available information".*

There is more **information** available to us – the ENFORCED conditions!

$$V_{CE} = V_C - V_E = 0.2 \quad \Rightarrow \quad V_C = V_E + 0.2$$

$$V_{BE} = V_B - V_E = 0.7 \quad \Rightarrow \quad V_B = V_E + 0.7$$

Two more **independent** equations! Combining with the earlier equation:

$$\frac{5.7 - (0.7 + V_E)}{10} + \frac{10.7 - (0.2 + V_E)}{10} = \frac{V_E}{10}$$

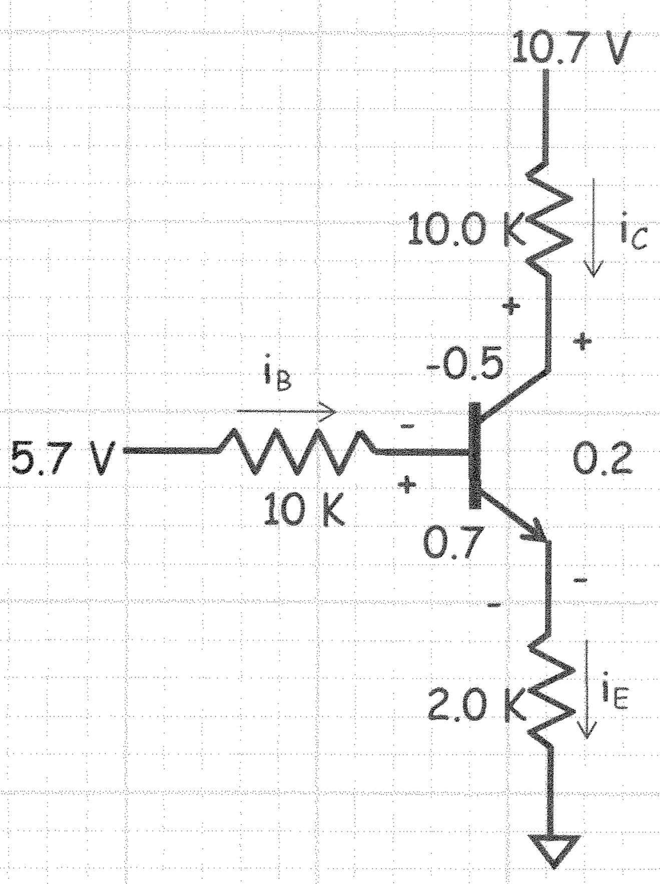
One equation and **one** unknown ! Solving, we get V_E **=2.2 V**.

Inserting this answer into the above equations, we get:

$$V_B = 2.9 \text{ V} \qquad V_C = 2.4 \text{ V}$$ $V_C < V_B \therefore$ SAT

$$i_C = 0.83 \text{ mA} \qquad i_B = 0.28 \text{ mA} \qquad i_E = 1.11 \text{ mA}$$

ANALYSIS EXAMPLE 2 - Start with **KVL**



We can write the KVL equation for any **two** circuit legs:

B-E KVL:

$$5.7 - 10\, i_B - 0.7 - 2\, i_E = 0.0$$

C-E KVL:

$$10.7 - 10\, i_C - 0.2 - 2\, i_E = 0.0$$

Note the ENFORCED conditions are **included** in these KVL equations.

Simplifying, we get these **2** equations with **3** unknowns:

$$5.0 = 10\, i_B + 2\, i_E$$

$$10.5 = 10\, i_C + 2\, i_E$$

We need **one more** independent equation involving i_B, i_C, and i_E.

Try KCL ! $i_B + i_C = i_E$

Inserting the KCL equation into the 2 KVL equations, we get:

$$5.0 = 12\, i_B + 2\, i_C$$

$$10.5 = 2\, i_B + 12\, i_C$$

Solving, we get the **same answers** as in analysis example 1.

> **Lesson:** There are **multiple** strategies for analyzing these circuits; use the ones that you feel most **comfortable** with !

However you ANALYZE the circuit, you **must** in the end also CHECK your results.

First CHECK to see that **all** currents are **positive**:

$i_C = 0.83 \text{ mA} > 0$ ✓ $i_B = 0.28 \text{ mA} > 0$ ✓ $i_E = 1.11 \text{ mA} > 0$ ✓

Also CHECK **collector current**:

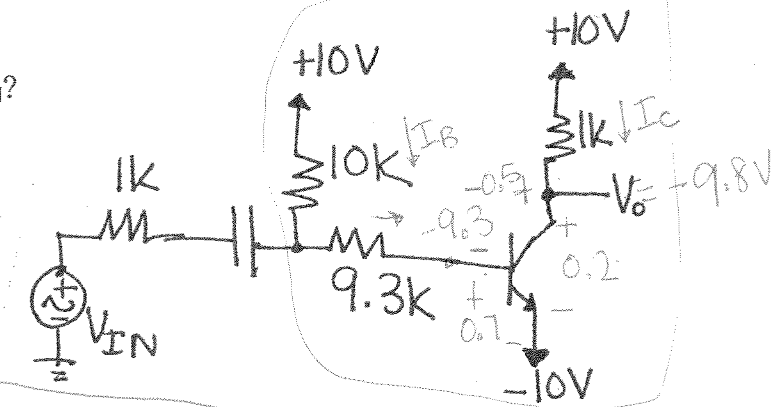
$$i_C = 0.83 \text{ mA} < \beta\, i_B = 27.7 \text{ mA} \checkmark$$

Our solution is **correct** !!!

Problem 5 – (10 points) (+10)

$|V_{BE}|=0.7$, $\beta=100$, $V_T=25mV$, ignore r_o, and r_x, $v_{sig}=\{2+0.1\sin(\omega t)\}$ Volts. Assume that the capacitor acts as an open for DC operation and short for AC operation. Assume saturation for the transistor. Use the attached datasheet.

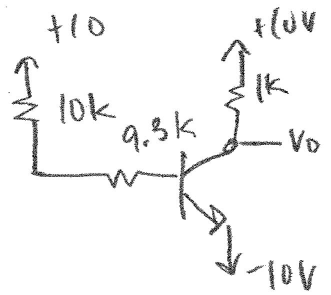
What is β_{forced}?



$I_C = \beta_{forced} \cdot I_B$

$V_{CESAT} = .2V$ when $I_B = 1mA$

DC:



$V_E = -10V$

$V_B = -10 + .7 = -9.3V$

$I_B = \frac{10 + 9.3}{19.3k} = \frac{19.3}{19.3k} = 1mA$

$V_{CE} = .2$

$V_C - V_E = .2V$

$V_C = .2 + V_E = .2 - 10 = -9.8V$

$V_C < V_B$

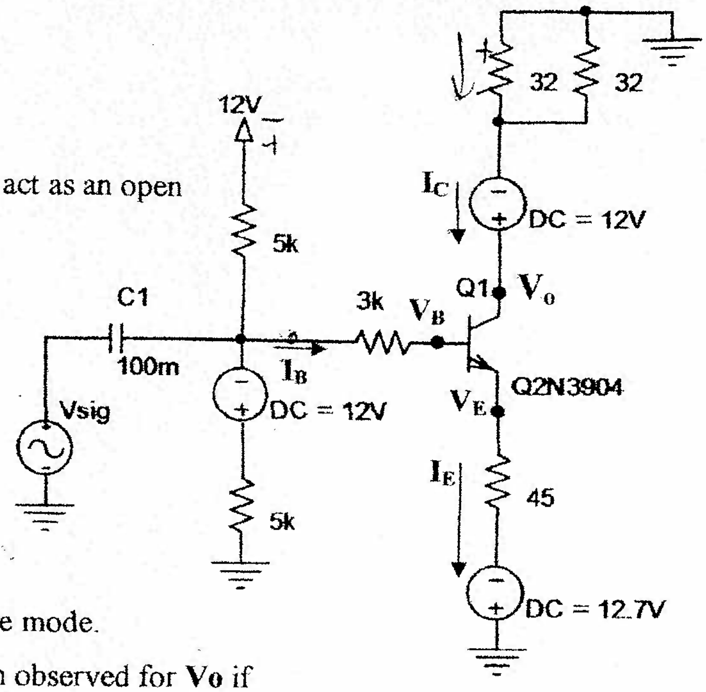
In SAT: $\beta_{forced} \ll (\beta = 100)$

$I_C = \frac{10 + 9.8}{1k} = 19.8mA$

$\frac{I_C}{I_B} = \beta_{Forced} = \frac{19.8m}{1m}$ = **$\beta_{forced} = 19.8$** $< \beta$

Problem 1 – **(35 points)**

Use: **ignore r_o, $|V_{BE}|=0.7$, $\beta=99$**
$V_{sig} = 3+0.005\sin(20t)$
For DC analysis, assume that the capacitors act as an open



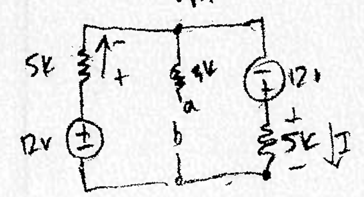
(a) Solve for the DC currents:
 a. I_B
 b. I_E
 c. I_C

(b) Solve for the DC voltages:
 a. V_B
 b. V_E
 c. V_o

(c) Prove that the transistor is operating in active mode.

(d) Sketch the **TOTAL** instantaneous waveform observed for **Vo** if the AC amplification is $V_o/V_{sig}=3V/V$.

Exam 3 Solution

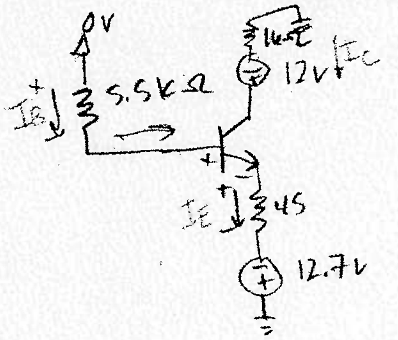


$5kI - 12 + 5kI - 12 = 0$

$I = \frac{24}{10k} = 2.4mA$

$V_{th} = 5k(2.4m) - 12 = 0V$

$R_{TH} = 5k \| 5k + 3k = 5.5k\Omega$



$I_C = \beta I_B = \alpha I_E$

$I_E = I_\beta(\beta + 1$

$0 - 5.5k I_B - 0.7 - 45 I_E + 12.7 = 0$

$12V = I_B(5.5k + 45(99+1))$

(a)

$I_B = 1.2mA$

$I_E = 120mA$

$I_C = 118.8mA$

$V_B = 0 - 5.5k I_B = -6.6; \quad V_E = 0 - 12.7 + 45(120m) \approx -7.3$

$V_C = 0 - 16 I_C + 12 \approx 10.1V$

(b)

$V_B = -6.6V$

$V_E = -7.3V$

$V_C = 10.1V$

$V_{o\,total} = V_{o\,DC} + V_{o\,AC}$

$= 10.1V + 3.5m\sin(20t)$

(c)

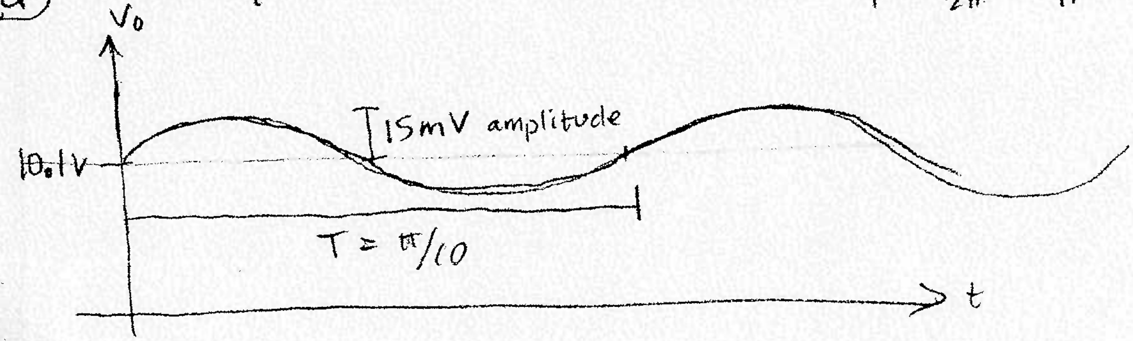
Active if $V_C \geq V_B > V_E$

$10.1 \geq -6.6 > -7.3$ ∴ Active

(d) $V_{o\,total} = [10.1 + 15m\sin(20t)]\ V$

$\omega = 20$

$f = \frac{20}{2\pi} = \frac{10}{\pi} \quad T = \frac{1}{f} = \frac{\pi}{10}$



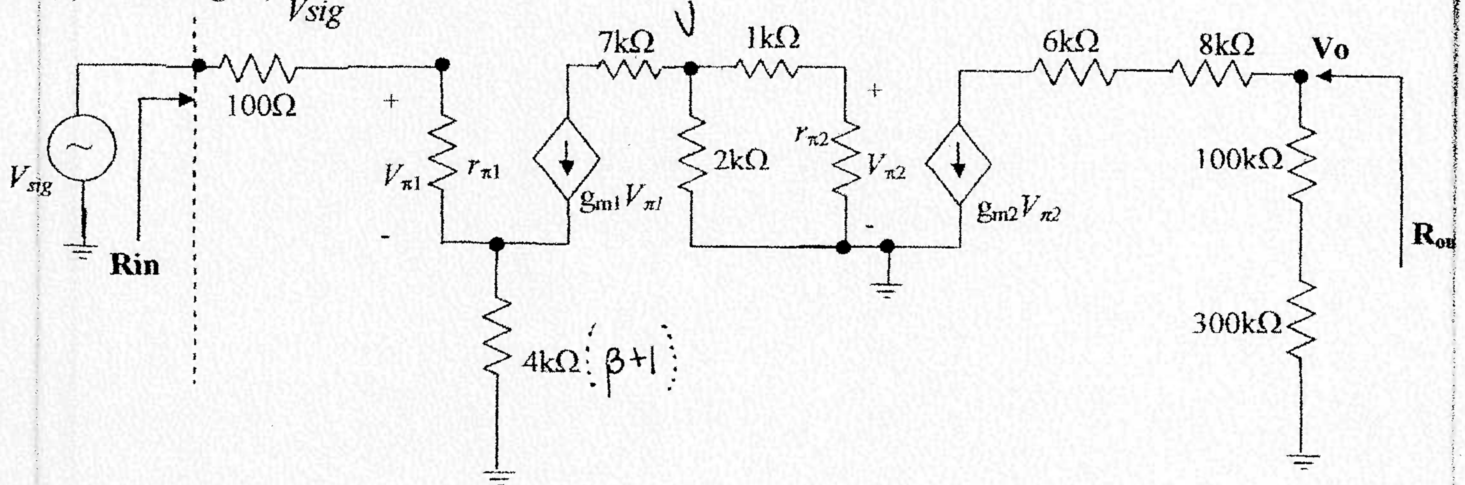
Problem 2 – **(40 points)**

Use: **ignore r_o, $|V_{BE}|=0.7$, $\beta=100$**
$V_I = 7+0.004\sin(500t)$

$r_{\pi 1}=4,000$ $g_{m2}=100mA/V$, and $I_{B2}=25\mu A$ (DC value) $r_{\pi 2} = \frac{\beta}{g_{m2}} = 1k\Omega$

$g_{m1} = \frac{\beta}{r_{\pi 1}} = 25m$

For the following hybrid-π equivalent circuit below, find the following values:
(a) R_{in} (input resistance –ignore only the input source, Vsig and include all resistors at the base)
(b) R_{out} (output resistance-include **all** resistors at the collector{no load is connected}) *Hint: A floating resistor does not have a pathway to ground.*
(c) midband gain, $\frac{Vo}{Vsig}$



$R_{in} = 100 + r_{\pi 1} + (4k)(\beta+1)$

$R_{in} = 100 + (4k) + (4k)(101)$

$\boxed{R_{in} = 408.1 k\Omega}$

$R_{OUT} = 100k + 300k$

$\boxed{R_{OUT} = 400k}$

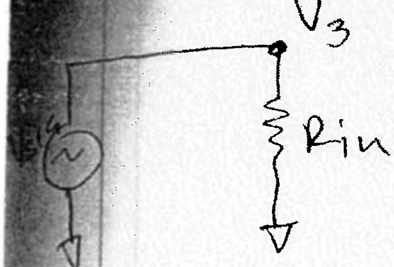
$r_{\pi 1} = 4k\Omega$

$g_{m1} = \frac{100}{4k} = 25m$

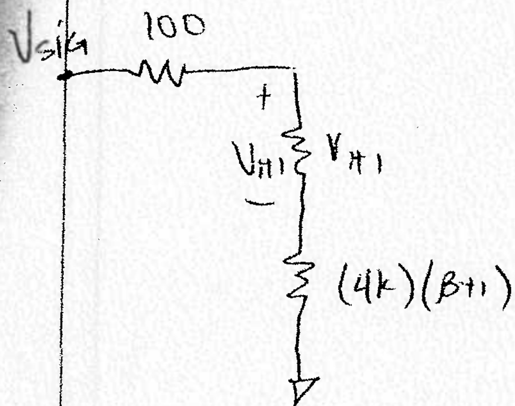
$r_{\pi 2} = 1k\Omega$

$g_{m2} = 100m$

Vs'

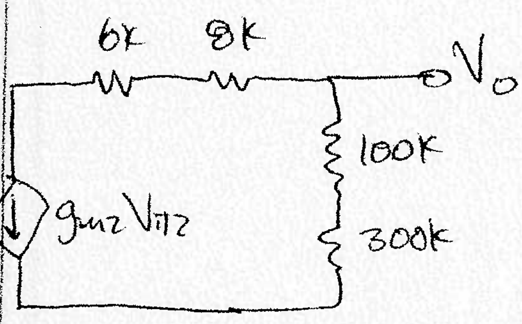


$$V_3 = V_{sig}$$



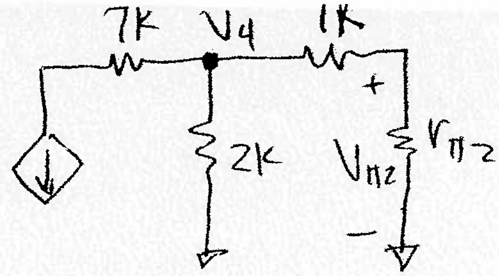
$$V_{\pi 1} = V_{sig} \frac{r_{\pi 1}}{R_{in}}$$

$$\frac{V_{\pi 1}}{V_{sig}} = \frac{r_{\pi 1}}{R_{in}}$$



$$V_o = -g_{m2} V_{\pi 2} (400K)$$

$$\frac{V_o}{V_{\pi 2}} = -g_{m2} (400K)$$



$$V_{\pi 2} = -g_{m1} V_{\pi 1} \frac{2K}{2K + 1K + r_{\pi 2}} \cdot r_{\pi 2}$$

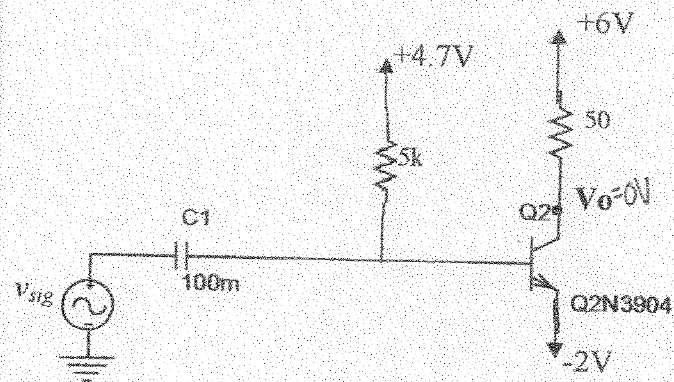
$$\frac{V_{\pi 2}}{V_{\pi 1}} = \frac{-g_{m1} (2K) r_{\pi 2}}{3K + r_{\pi 2}}$$

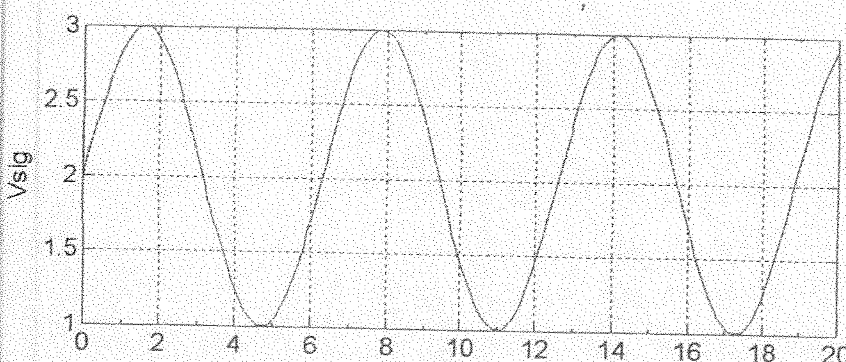
$$\frac{V_o}{V_{sig}} = \frac{r_{\pi 1}}{R_{in}} \cdot \frac{-g_{m1}(2K) r_{\pi 2}}{3K + r_{\pi 2}} \cdot \frac{-g_{m2}(400K)}{1}$$

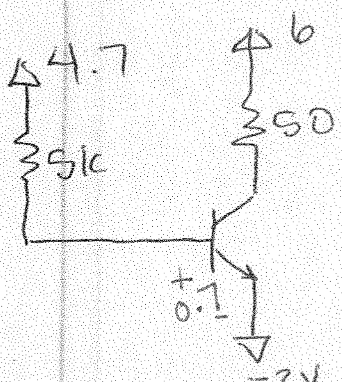
$$\boxed{\frac{V_o}{V_{sig}} = 4901 \frac{V}{V}}$$

Problem 5 – (5 points)

$|V_{BE}|=0.7$, $\beta=100$, ignore r_o, v_{sig} is shown in the graph below. Assume that the capacitor acts as an open for DC operation and short for AC operation. Does this circuit operate as a **linear** AC amplifier? If so, what is the gain, $\frac{Vo}{Vsig}$, of the following circuit? If not, explain why.







$V_E = -2V$

$V_B = -1.3V$

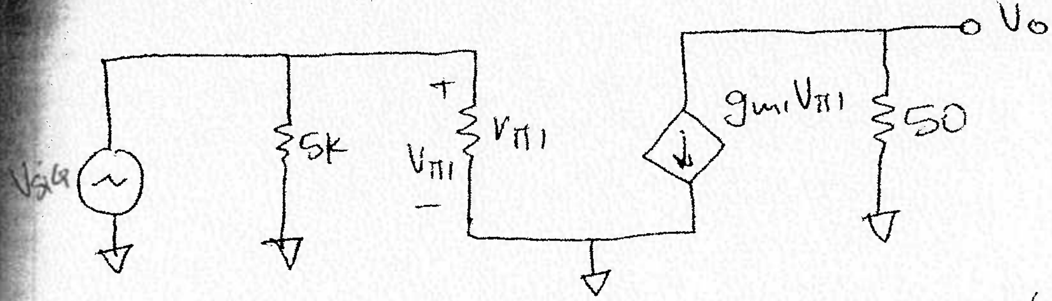
$V_C = 0$

$V_C \geq V_B > V_E \rightarrow$ ACTIVE

$I_E = 121.2mA$

$I_B = (4.7-(-1.3))/5k = 1.2m$

$I_C = 120mA$



$V_{\pi 1} = V_{sig}$

$\frac{V_{\pi 1}}{V_{sig}} \approx 1$

$V_o = -g_{m1}V_{\pi 1}(50)$

$\frac{V_o}{V_{\pi 1}} = -g_{m1}(50)$

$\frac{V_o}{V_{sig}} = -g_{m1}(50)$

$r_{\pi 1} = \frac{V_t}{I_B} = \frac{25m}{1.2m}$

$r_{\pi 1} = 20.83\,\Omega$

$g_m = \frac{100}{r_{\pi 1}}$

$g_{m1} = 4.8$

$\frac{V_o}{V_{sig}} = -(4.8)(50)$

$\boxed{\frac{V_o}{V_{sig}} = -240\,\frac{V}{V}}$

with $V_{sig} = \underset{(DC)}{2} + \underset{(AC)}{\sin(\omega t)}$ then

$V_o = -240(\sin(\omega t))$

$V_{o\,total} = 0 - 240\sin(\omega t)$

The maximum voltage supplied is 6V so there is no way to have an output greater than that. Therefore, the output will clip.

Not linear

ECE 2280 Midterm #3

Name____________________

Scores:

Prob 1 ____________ of a possible 35p

Prob 2 ____________ of a possible 40p

Prob 3 ____________ of a possible 15p

Prob 4 ____________ of a possible 5pt

Prob 5 ____________ of a possible 5p

Total ____________ of a possible 100