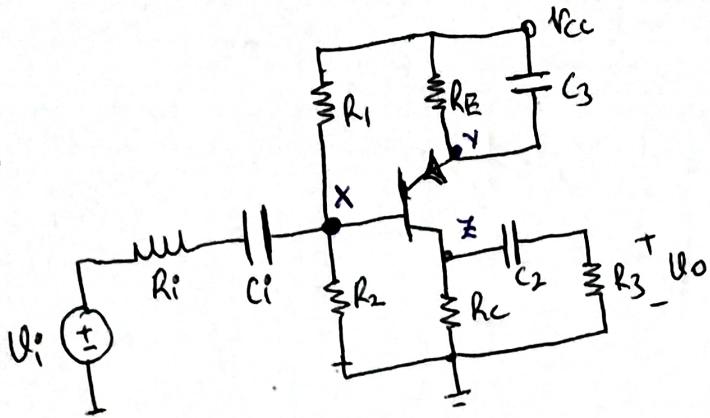


– EHB 335E – ANALOG ELECTRONICS – 11219 –



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1)



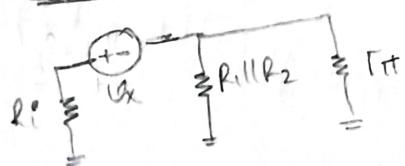
\$V_A \ll \infty\$

\$C_1, C_2\$: coupling caps.
\$C_3\$: bypass cap.

a) Each node introduces one pole

$U_{sig} = U_i = 0$;
We're treating \$C_1\$ and thinking others as short circuit because in the frequency of interest, impedances of coupling and bypass caps are small (cap values are large)

At node X



Since \$C_3\$ is shorted, \$R_E\$ is also shorted.
Let's call \$R_1 \parallel R_2 = R_B\$

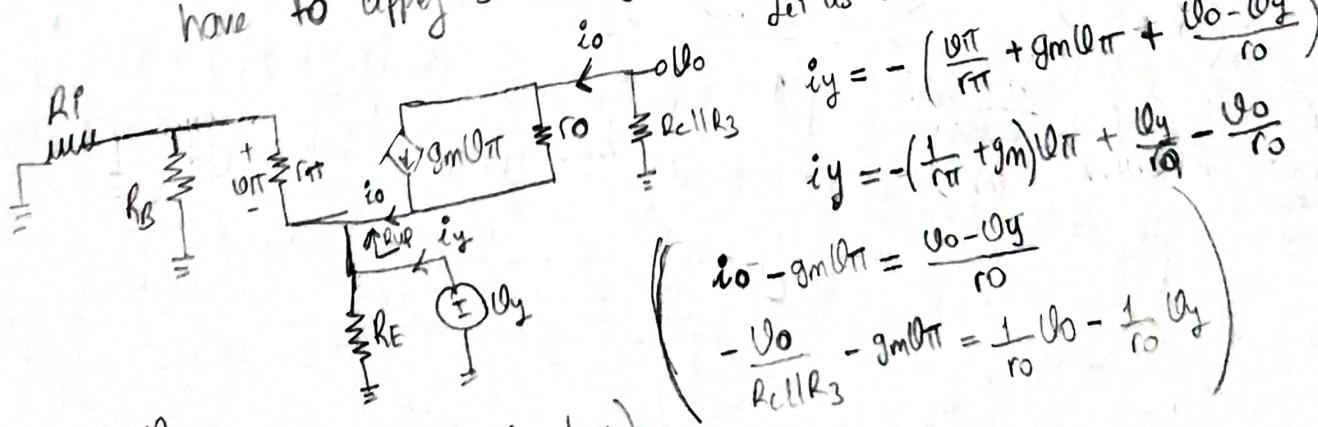
$$R_X = R_i + R_B \parallel R_T \Rightarrow Z_X = R_X C_1 \Rightarrow \omega_{p1} = \frac{1}{Z_X}$$

$$\omega_{p1} = \frac{1}{Z_X} = \frac{1}{R_X C_1}$$

$$f_3 = \frac{1}{2\pi C_1 (R_i + R_B \parallel R_T)}$$

At node Y

* Since \$V_A \ll \infty\$, we cannot simply determine \$R_Y\$ by dividing base resistances; we have to apply small-signal model



$$i_Y = -\left(\frac{U_T}{R_T} + g_m U_T + \frac{U_o - U_{oY}}{R_3}\right)$$

$$i_Y = -\left(\frac{1}{R_T} + g_m\right) U_T + \frac{U_o - U_{oY}}{R_3} - \frac{i_o}{R_3}$$

$$i_o - g_m U_T = \frac{U_o - U_{oY}}{R_3}$$

$$-\frac{U_o}{R_1 \parallel R_2} - g_m U_T = \frac{1}{R_3} U_o - \frac{1}{R_3} U_{oY}$$

$$U_T = -\frac{U_{oY}}{R_T + R_1 \parallel R_2} \cdot R_T \quad (\text{from the resistive divider})$$

Now we have 3 equations

$$1) iy = -\left(\frac{1}{R_{\pi}} + gm\right)V_{\pi} + \frac{1}{R_0}V_y - \frac{1}{R_0}V_0$$

$$2) -\frac{V_0}{R_{\pi}||R_3} - gmV_{\pi} = \frac{1}{R_0}V_0 - \frac{1}{R_0}V_y$$

$$3) V_{\pi} = -\frac{R_{\pi}}{R_{\pi}+R_{\pi}||R_B}V_y$$

consider equation (2), and put V_{π} from (3) into (2)

$$\frac{1}{R_0}V_y - \left(\frac{1}{R_0} + \frac{1}{R_{\pi}||R_3}\right)V_0 - gm\left(-\frac{R_{\pi}}{R_{\pi}+R_{\pi}||R_B}\right)V_y = 0$$

$$\left(\frac{1}{R_0} + \frac{gmR_{\pi}}{R_{\pi}+R_{\pi}||R_B}\right)V_y = -\left(\frac{1}{R_0} + \frac{1}{R_{\pi}||R_3}\right)V_0$$

$$\Rightarrow V_0 = -\frac{\left(\frac{1}{R_0} + \frac{B}{R_{\pi}+R_{\pi}||R_B}\right)V_y}{\frac{1}{R_0} + \frac{1}{R_{\pi}||R_3}}$$

Now consider equation (1)

(put V_0 and V_{π} values obtained above)

$$iy = -\left(\frac{1}{R_{\pi}} + gm\right)V_{\pi} + \frac{1}{R_0}V_y - \frac{1}{R_0}V_0$$

$$iy = \left(\frac{1}{R_{\pi}} + gm\right)\left(\frac{R_{\pi}}{R_{\pi}+R_{\pi}||R_B}\right)V_y + \frac{1}{R_0}V_y - \frac{1}{R_0}\left[\left(\frac{1}{R_0} + \frac{B}{R_{\pi}+R_{\pi}||R_B}\right)(R_{\pi}||R_{\pi}||R_3)\right]V_y$$

$$1$$

$$\frac{V_y}{iy} = R_{up} = \frac{\frac{B+1}{R_{\pi}+R_{\pi}||R_B} + \frac{1}{R_0}}{1 - \left(\frac{1}{R_0} + \frac{B}{R_{\pi}+R_{\pi}||R_B}\right)(R_{\pi}||R_{\pi}||R_3)}$$

(we can see that $R_{up} = \frac{1}{gm} + \frac{R_{\pi}||R_3}{B+1}$ as $R_0 \rightarrow \infty$, which is satisfying)

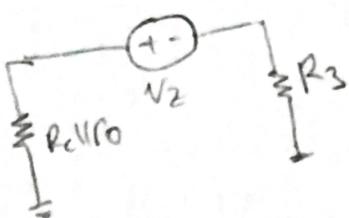
$$R_y = R_E || R_{up} \Rightarrow Z_y = R_y C_3 \Rightarrow W_{p1} = \frac{1}{Z_y}$$

$$W_{p1} = \frac{1}{R_y C_3} \Rightarrow \boxed{f_3 = \frac{1}{2\pi R_y C_3}}$$

At node Z

Since emitter is grounded due to C_3 .

Γ_0 becomes parallel to R_C



$$R_Z = R_3 + R_C \parallel R_O$$

$$\tau_Z = C_2 R_Z$$

$$f_2 = \frac{1}{2\pi\tau_Z R_2} = \frac{1}{2\pi R_2 C_2}$$

Since we're applying the short-circuit time constant method, 3-dB lower frequency is approximately

$$f_{L,3dB} \approx f_1 + f_2 + f_3$$

$$f_{L,3dB} \approx \frac{1}{2\pi R_1 C_1} + \frac{1}{2\pi R_2 C_2} + \frac{1}{2\pi R_3 C_3}$$

- b) At midband frequencies, all capacitors are shorted due to low impedance then the amplifier type becomes typical CE amplifier whose gain is

$$\frac{V_{out}}{V_{in}} = -g_m (R_C \parallel R_3 \parallel R_O)$$

and since the signal is attenuated due to source resistance R_i

$$V_{th} = \frac{R_1 \parallel R_2}{R_1 \parallel R_2 + R_i} \cdot V_i$$

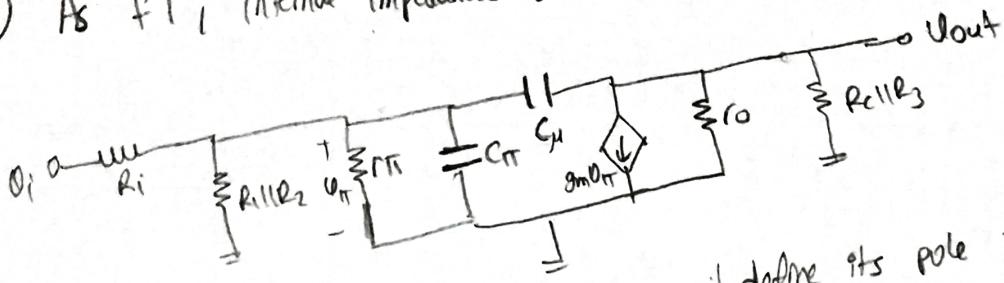
$$\frac{V_{out}}{V_{th}} = \frac{r_i}{r_i + R_{th}} \cdot \left[-g_m (R_C \parallel R_3 \parallel R_O) \right]$$

$$R_{th} = R_1 \parallel R_2 \parallel R_O$$

$$A_v = \frac{V_{out}}{V_{th}} \cdot \frac{V_{th}}{V_i}$$

$$A_v = \frac{V_{out}}{V_{in}} = - \frac{R_1 \parallel R_2}{R_1 \parallel R_2 + R_i} \cdot \frac{g_m r_i (R_C \parallel R_3 \parallel R_O)}{r_i + R_1 \parallel R_2 \parallel R_O}$$

c) As $f \uparrow$, internal impedances becomes effective in gain expression.



Since C_{μ} is an intact capacitor, we can't define its pole just looking the resistance it sees. By Miller theorem we can separate C_{μ} into two ground touching capacitors.

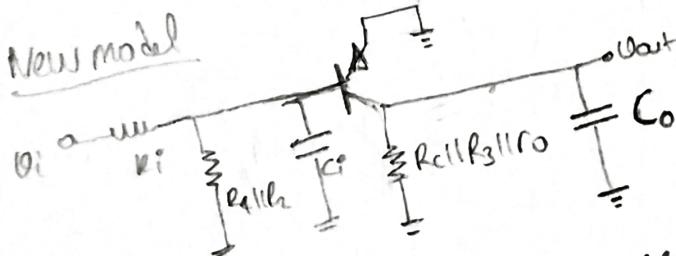
$$A_v = -g_m(R_{cll}R_3||R_0)$$

$$C_{UB} = C_{\mu}(1 - \underbrace{\frac{-g_m(R_{cll}R_3||R_0))}{A_v}}_{Av}) = C_{\mu}(1 + g_m(R_{cll}R_3||R_0))$$

$$C_{UC} = C_{\mu}(1 - \frac{1}{A_v}) = C_{\mu}\left(1 - \frac{1}{-g_m(R_{cll}R_3||R_0)}\right) = C_{\mu}\left(1 + \frac{1}{g_m(R_{cll}R_3||R_0)}\right)$$

& C_{π} and C_{UB} are in shunt, we can see them as one capacitor

$$C_i = C_{\pi} + C_{UB} \quad ; \quad C_o = C_{UC} + C_{CS} \xrightarrow{\text{These are also in shunt}}$$

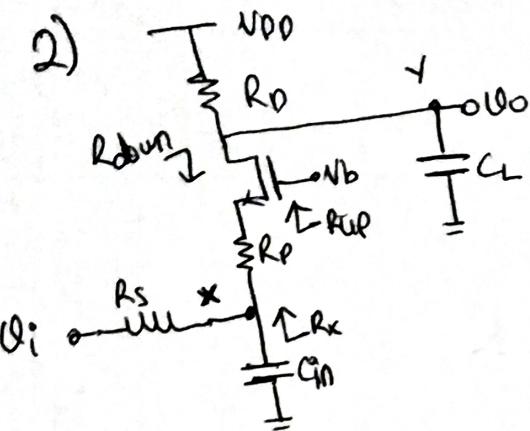


$$R_i = R_i \parallel R_1 \parallel R_2 \parallel R_{\pi} ; \quad Z_i = R_i C_i \Rightarrow f_1 = \frac{1}{2\pi R_i C_i}$$

$$\Rightarrow f_1 = \frac{1}{2\pi (R_i \parallel R_1 \parallel R_2 \parallel R_{\pi}) (C_{\pi} + C_{\mu}(1 + g_m(R_{cll}R_3||R_0)))}$$

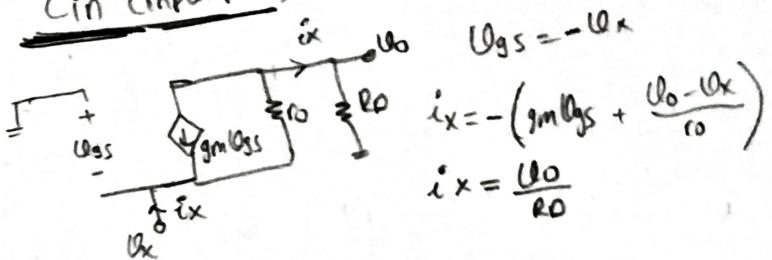
$$R_o = R_{cll}R_3||R_0 ; \quad Z_o = R_o C_o \Rightarrow f_2 = \frac{1}{2\pi R_o C_o}$$

$$\Rightarrow f_2 = \frac{1}{2\pi (R_{cll}R_3||R_0) (C_{CS} + C_{\mu}\left(1 + \frac{1}{g_m(R_{cll}R_3||R_0)}\right))}$$



In order to determine pole frequencies, we need the resistances seen by capacitors

C_{in} (input pole)



$$\frac{V_{in}}{R_D} = gmV_X - \frac{1}{R_D} V_{in} + \frac{1}{R_D} V_X \Rightarrow V_{in} = \frac{gmR_D + 1}{R_D + R_P} V_X$$

$$V_{in} \left(\frac{1}{R_D} + \frac{1}{R_P} \right) = \left(gm + \frac{1}{R_D} \right) V_X$$

$$\Rightarrow i_x = \frac{1}{R_D} V_{in} = \frac{1}{R_D} \left(\frac{gmR_D + 1}{R_D + R_P} \right) V_X \Rightarrow \frac{V_X}{i_x} = \frac{R_D + R_P}{gmR_D + 1} \approx \frac{R_D + R_P}{gmR_D}$$

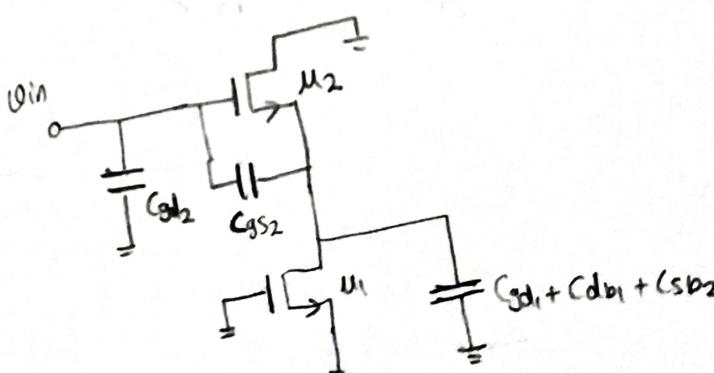
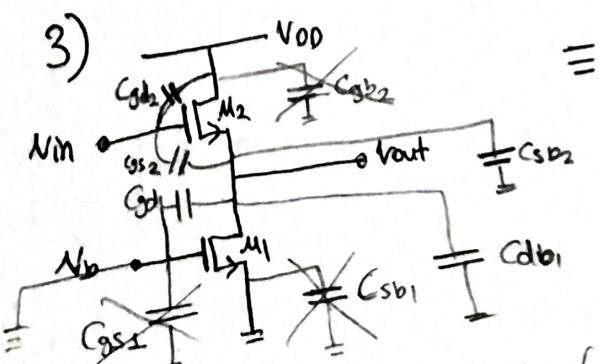
$$\Rightarrow R_X = R_S \parallel \left(R_P + \frac{R_D + R_P}{gmR_D} \right) \Rightarrow f_1 = \frac{1}{2\pi C_{in} \left(R_S \parallel \left(R_P + \frac{R_D + R_P}{gmR_D} \right) \right)}$$

C_L (output pole)

$$R_{down} = R_D + (R_P + R_S) + gmR_D(R_P + R_S) \approx gmR_D(R_P + R_S)$$

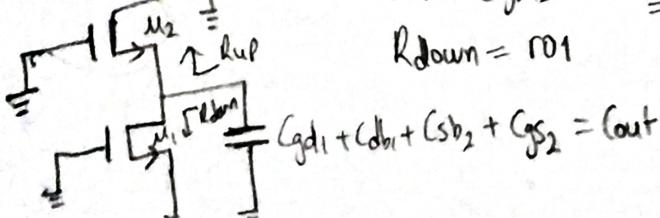
$$R_Y = R_{down} \parallel R_D = [gmR_D(R_P + R_S)] \parallel R_D$$

$$f_2 = \frac{1}{2\pi C_L [gmR_D(R_P + R_S) \parallel R_D]}$$



For open-time constant method ($V_{SRG} = 0$), then $C_{gd} = 0$, $C_{gs2} \parallel (C_{gd1} + C_{db1} + C_{sb2})$

$$R_{out} = \left(\frac{1}{gm_2} \parallel R_D \right) \Rightarrow R_{out} = R_D \parallel R_2 \parallel \frac{1}{gm_2}$$

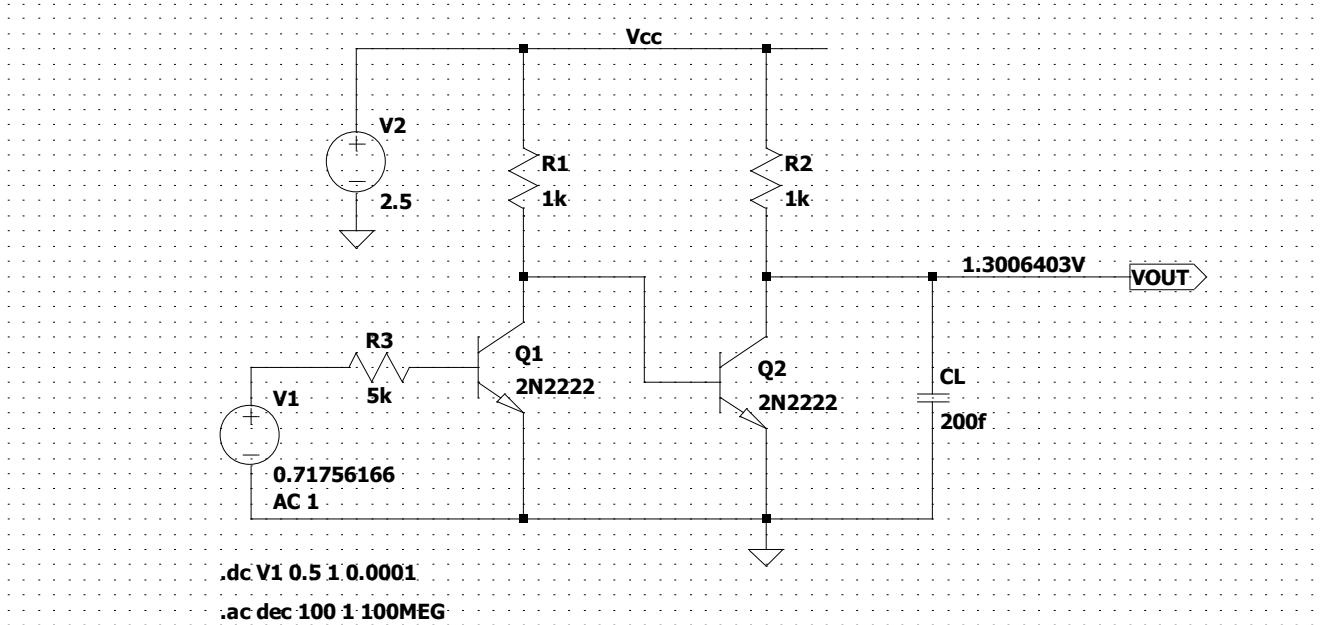


$$f_1 = \frac{1}{2\pi (R_D \parallel R_2 \parallel \frac{1}{gm_2}) (C_{gd1} + C_{db1} + C_{sb2} + C_{gs2})}$$

↳ only one pole, because all capacitors are tied to the same node.

4TH QUESTION // SOLVED BY USING LTSPICE SIMULATION PROGRAM

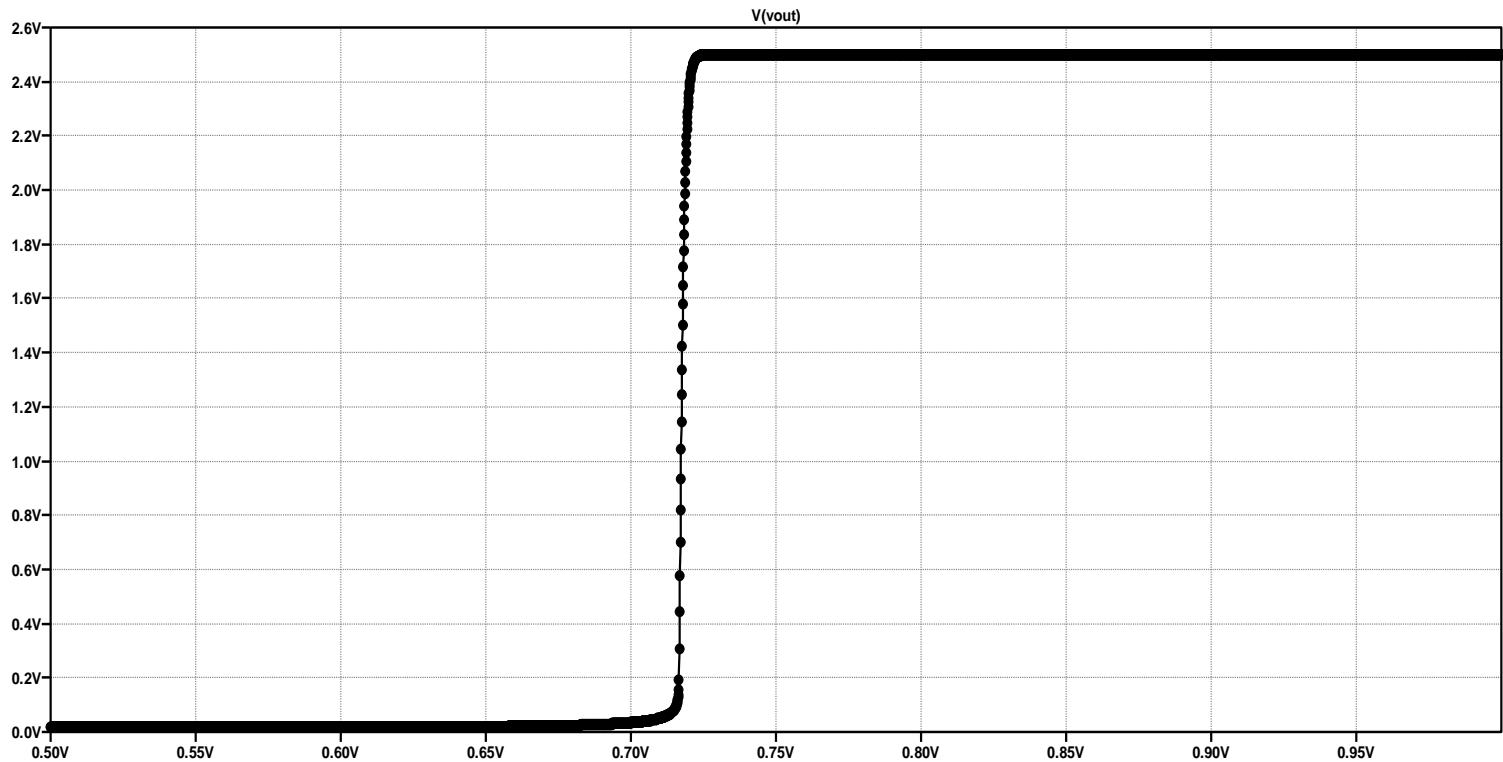
a) First of all, the circuit is drawn as shown:



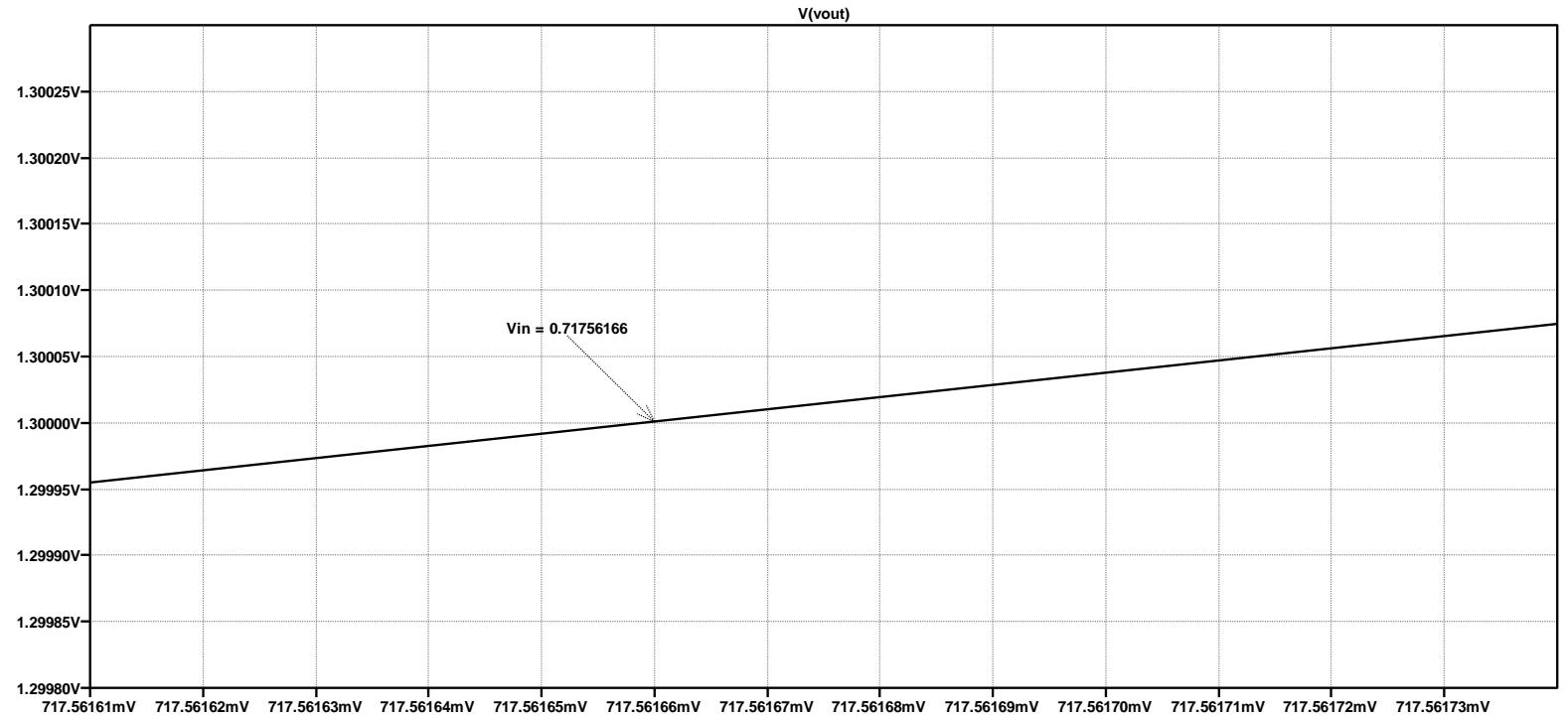
We need an input voltage that creates 1.3V at the output. Therefore, we need to sweep a specified predetermined range of V1(input voltage) to see which one succeed that.

By using the command: `.dc v1 0.5 1 0.0001`

We get a graph as shown:



From this graph we need the vertical line that intersect the 1.3V horizontal line, which can be seen by zooming the considered area:

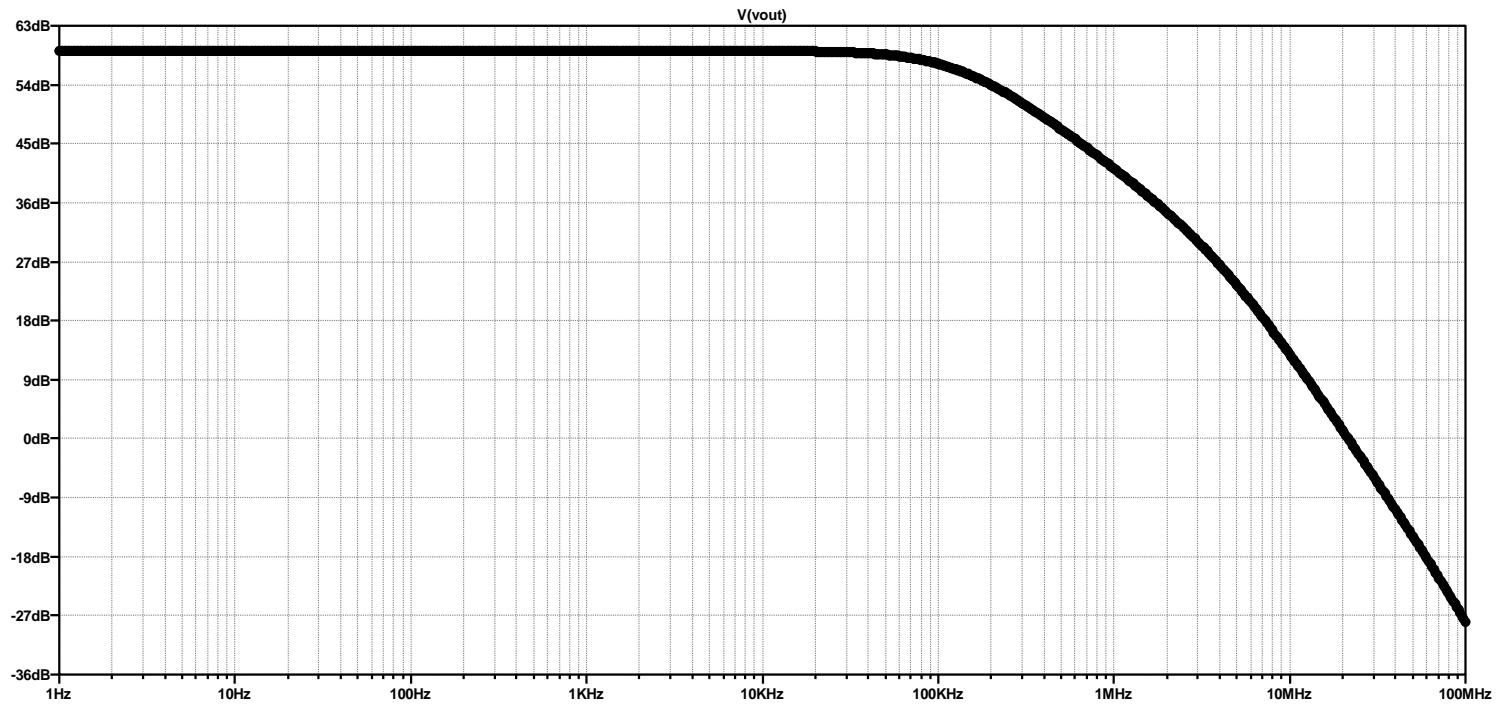


We can clearly see that $V_{in} = 0.71756166V$ corresponds to $V_{out} = 1.3V$.

b-) Now, for $V_{in} = 0.71756166V$, let's see the frequency response and the 3-dB bandwidth

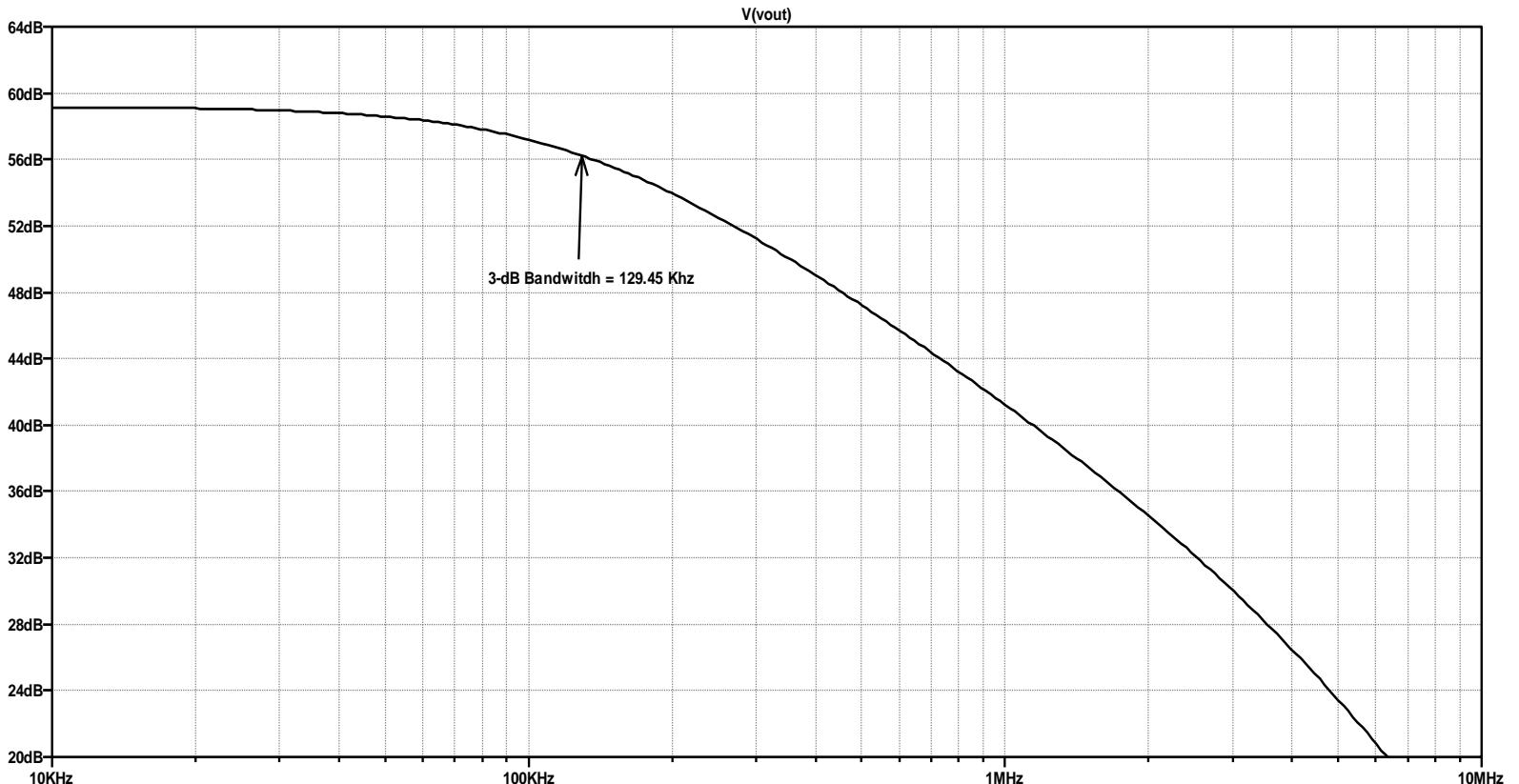
Frequency response is obtained by the command: `.ac dec 100 1 100MEG` which occupies a range from 1 Hz to 100Mhz.

And the graph is shown as:



To see both midband gain and the 3-dB bandwidth, we should zoom this a bit in to the area that we think the gain is attenuated by 3dB.

The zoomed in graph as shown:



When we plot the frequency response for $V_{in} = 0.71756166V$ and $V_{ac} = 1V$, we get a midband gain of around $A_v = 59.4$ dB and the 3-dB bandwidth corresponds to the frequency at which the gain is around $A_v' = 56.4$ dB. Then the frequency that corresponds to this gain is

$$\text{Midband gain } A_v \approx 59.4 \text{ dB}$$

$$f_{3-dB} \approx 129.45 \text{ Hz}$$