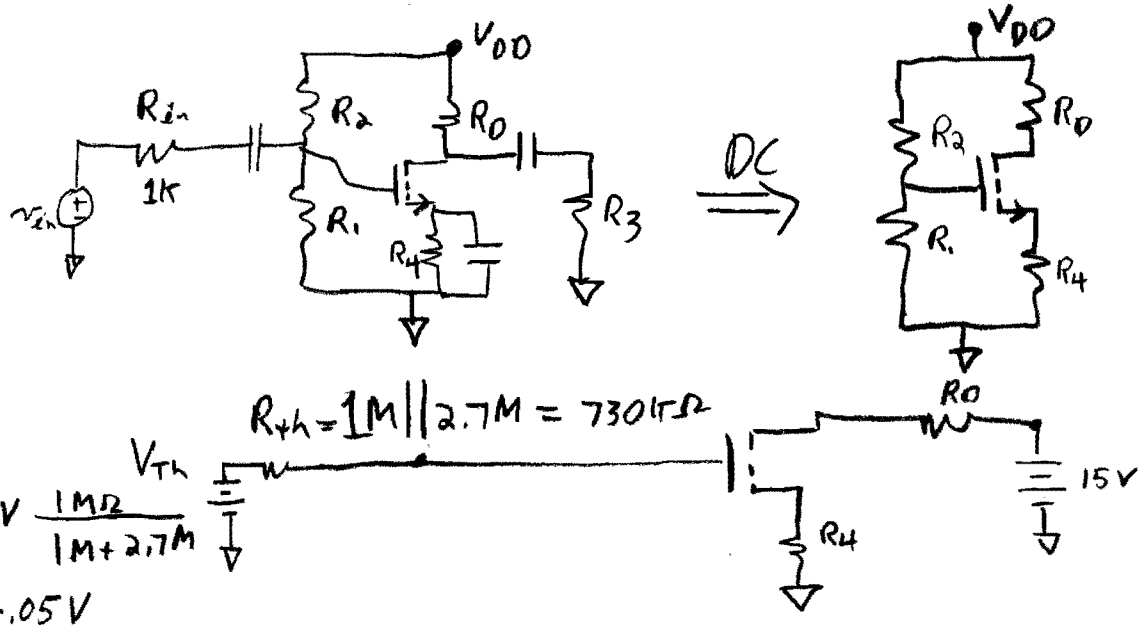
13.23



$V_{TH} = 15V \frac{1M\Omega}{1M + 2.7M}$

$= 4.05V$

Assume Saturation:

1) $I_D = \left(\frac{0.25 mA/V^2}{2}\right)(V_{GS} - 1)^2$

2) $V_{GS} = 4.05 - 27{,}000 I_D$

$I_D = (0.125\ mA/V^2)(3.05 - 27{,}000 I_D)^2$

$I_D = 82.2\ uA$

$V_{OS} = 15 - 82{,}000 I_D - 27{,}000 I_D = 6.04V$

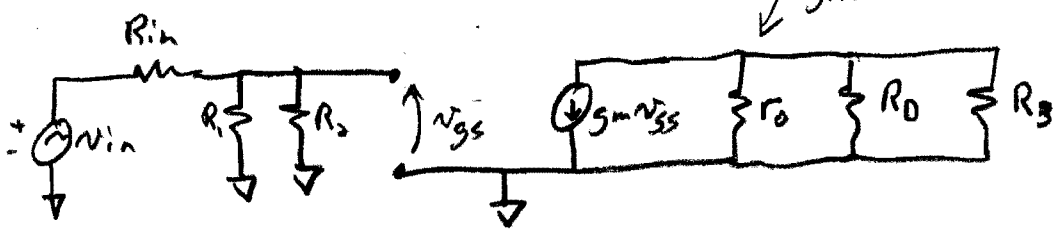
V_{GS}

$(1.93 - 1) < 6.04 \Rightarrow$ Saturation verified

V_{TN} V_{OS}

AC:

No $\lambda \Rightarrow \lambda = 0 \Rightarrow r_o = \infty$ given



$g_m = \frac{I_{DS}}{\left(\frac{V_{GS} - V_{TN}}{2}\right)}$

$g_m = \frac{(82.2e-6)(2)}{1.93 - 1}$

$g_m = (198e-6\ \frac{A}{V})$

$A_v = \left(\frac{R_1 \| R_2}{R_1 \| R_2 + R_{in}}\right)\left(-g_m (R_D \| R_3)\right)$

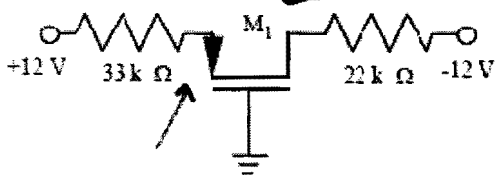
$A_v = (0.998)\left(-198.e-6\,(82k \| 470k)\right)$

$A_v = -13.8\ V/V$

13.31
PMOS Common-Gate Amplifier

Note only 1 current

Depletion mode PMOS) $V_{TP} > 0$



$$\therefore \quad I_D = \frac{12 + V_{GS}}{33000} = \frac{200x10^{-6}}{2}(V_{GS} - 1)^2$$

$V_{GS} = -0.84V \quad | \quad I_D = 338\ \mu A$

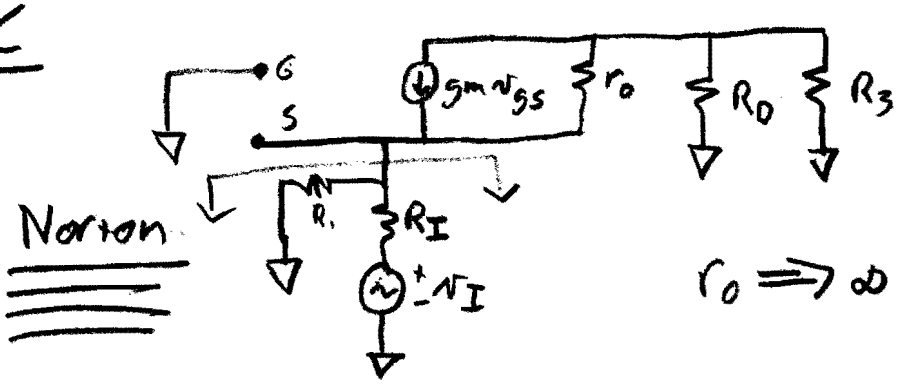
$V_{DS} = -(12 - 33000I_D - 22000I_D + 12)$

$V_{DS} = -5.41\ V \rightarrow 5.41 \geq \rightarrow 1.84$

$|V_{DS}| \geq |V_{GS} - V_{TP}| \geq 0 \Rightarrow$ saturation verified

Q-point : (338 μA, -5.41 V)

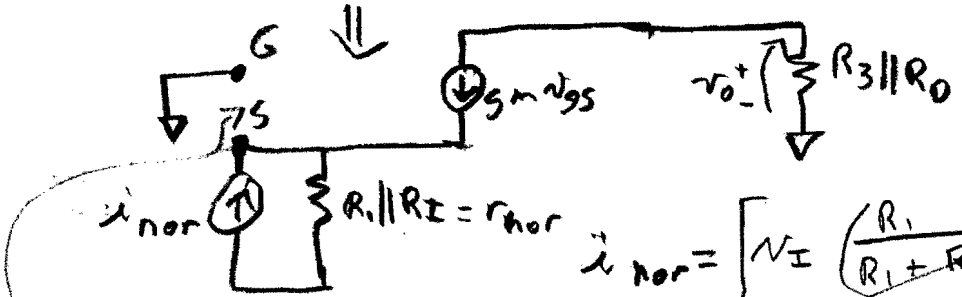
AC



$$g_m = \frac{2I_{DS}}{|V_{GS} - V_T|} = 367.4\ e\text{-}6\ A/V$$

Norton

$r_o \Rightarrow \infty$ since no λ given



$$i_{nor} = \left[v_I \left(\frac{R_1}{R_1 + R_I}\right)\right]\left(\frac{R_1 + R_I}{R_1 R_I}\right) = \left(v_{Th}/R_{Th}\right)$$

$$= \frac{v_I}{R_I}$$

1) $-v_{gs} = (i_{nor} + g_m v_{gs})\, r_{nor}$

$-v_{gs} = \left(\frac{v_i}{R_I} + g_m v_{gs}\right)(R_1 \| R_I)$

$-v_{gs} = \frac{v_i (R_1 R_I)}{R_I (R_1 + R_I)} + (g_m v_{gs})\left(\frac{R_1 R_I}{(R_1 + R_I)}\right)$

$-v_{gs}\left(1 + g_m R_1 \| R_I\right) = \frac{v_i}{R_I}\left(R_1 \| R_I\right)$

$\frac{v_{gs}}{v_i} = \frac{-R_1}{(R_1 + R_I)(1 + g_m R_1 \| R_I)}$

$= -0.834\ V/V$

2) $v_o = (-g_m v_{gs})(R_3 \| R_D)$

$\frac{v_o}{v_{gs}} = -g_m(R_3 \| R_D)$

$= -6.63$

$A = \frac{v_o}{v_{gs}} \frac{v_{gs}}{v_i} = (-0.834)(-6.6$

$A_v = 5.53\ V/V$

13.98

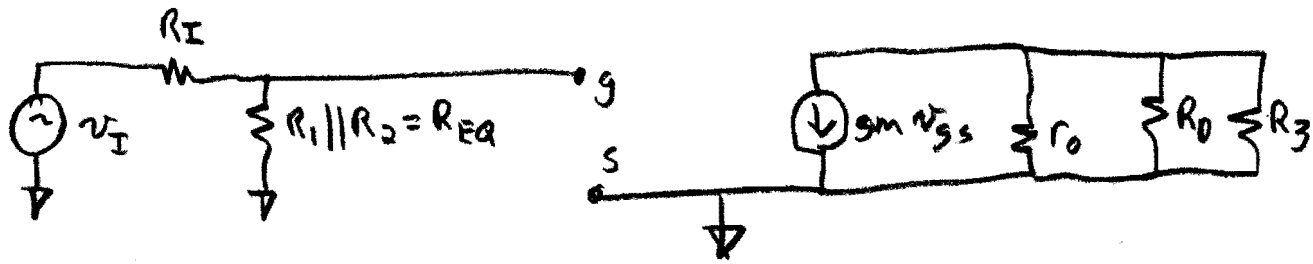
For the bias network : $V_{EQ} = 10V\dfrac{430k\Omega}{430k\Omega + 560k\Omega} = 4.343V \mid R_{EQ} = 430k\Omega \| 560k\Omega = 243k\Omega$

$I_D = \dfrac{5x10^{-4}}{2}(V_{GS} - 1)^2 \mid V_{GS} = 4.343 - 2x10^4 I_D \rightarrow V_{GS} = 1.72\ V \mid I_D = 131\ \mu A$

$V_{DS} = 10 - 63k\Omega(131\mu A) = 1.75V \geq V_{GS} - V_{TN}$ so active region assumption is ok.

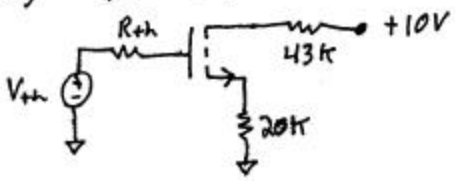
$g_m = \sqrt{2(5x10^{-4})(131\mu A)} = 362\mu S \mid r_o = \dfrac{\left(\dfrac{1}{0.0133} + 1.75\right)}{131\mu A} = 586k\Omega$

$A_v = -\left(\dfrac{243k\Omega}{243k\Omega + 1k\Omega}\right)(362\mu S)(586k\Omega \| 43k\Omega \| 100k\Omega) = -10.3$ V/V



3.) Jaeger 13.90 Plus, solve for the input and output resistances.

13.90) DC Solution



$V_{th} = 10 \dfrac{430}{560+430} = 4.343\ V$

$R_{th} = 430k \| 560k = 243\ k$

Assume Saturation:

$$(*)\quad i_{DS} = \frac{k_n}{2}\left(v_{GS} - V_{TN}\right)^2\left(1 + \lambda v_{DS}\right)$$

$k_n/2 = 0.5\ mA/V^2$, $V_{TN} = 1V$, $\lambda = 0.0133\ V^{-1}$

$V_{th} = v_{GS} + (20k)\, i_{DS}$

$10V = i_{DS}(20k + 43k) + v_{DS}$

$i_{DS} = (0.25e-3)\left(4.343 - 20k\, i_{DS} - 1\right)^2\left(1 + 0.0133\left[10 - i_{DS}(63k\right.\right.$

2 solutions:

$i_{DS} = 1.34\ mA$ X

$v_{GS} = -22.457$

$i_{DS} = 131\ \mu A$

$v_{GS} = 1.723\ V$

$v_{DS} = 1.747\ V$

$v_{GS} - V_{TN} = 0.723 < 1.747 = v_{DS}$

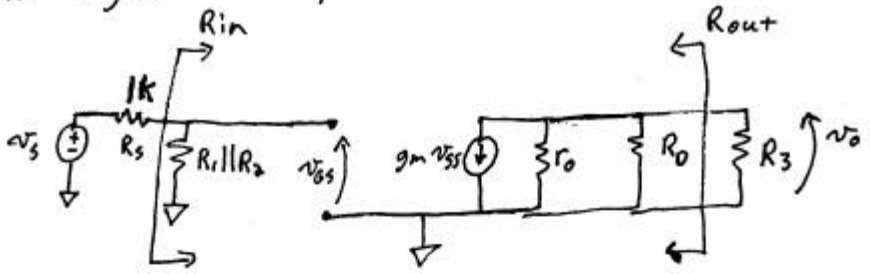
Is in saturation!

Small signal parameters!

$$g_m = \frac{131e-6}{\frac{V_{GS} - V_{TN}}{2}} = \frac{131e-6}{0.5(0.723)} = 0.000362\ A/V$$

$$r_o = \frac{\frac{1}{\lambda} + V_{DS}}{I_{DS}} = \frac{\frac{1}{0.0133} + 1.747}{131e-6} = 587k$$ very large

Small Signal Analysis



$$\frac{v_{gs}}{v_s} = \frac{R_1 \| R_2}{R_s + R_1 \| R_2} = 0.996 \ \text{V/V}$$

$$\frac{v_o}{v_{gs}} = -g_m (r_o \| R_D \| R_3)$$

$$= -0.000362 \ (28.6\,\text{k})$$

$$= -10.35 \ \text{V/V}$$

$$A_v = \frac{v_{gs}}{v_s} \frac{v_o}{v_{gs}} = -0.996\,(10.35)$$

$$\boxed{A_v = -10.31 \ \text{V/V}}$$

This is greater than the results from figure 13.33 in the text since $g_m = \frac{i_{DS}}{V_{GS}-V_T}$ increases with decreasing i_{DS} due to $V_{GS}-V_T$ falls faster than i_{DS} due to (*)

$$\boxed{R_{in} = R_1 \| R_2 = 243\ \text{k}\Omega}$$

$$\boxed{R_{out} = r_o \| R_D = 40\ \text{k}\Omega}$$

13.121

$0 = 10000 I_B + 0.7 + 66(1615) I_B - 5 \quad I_B = 36.9\ \mu A \quad | \quad I_C = 65 I_B = 2.40\ mA$

$V_{CE} - 5 - 1000 I_C - 1615 I_E - (-5) - 3.66\ V \qquad \text{Q-point}: (2.40\ mA,\ 3.66\ V)$

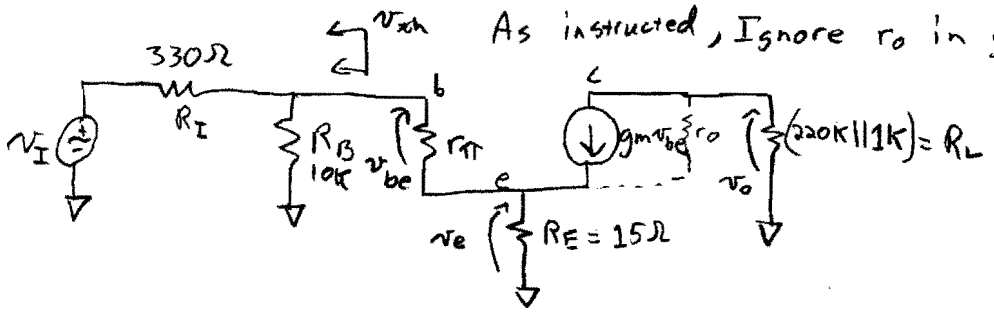
$g_m = \frac{(2.40mA)}{0.0259} = 96.0mS \quad | \quad r_\pi = \frac{65}{96.0mS} = 677\ \Omega \quad | \quad r_o = \frac{50V + 3.66V}{2.40mA} = 22.4\ k\Omega$

$R_{in} = R_B \| r_\pi (1 + g_m R_E) = 10k\Omega \| 677\Omega [1 + 0.096(15)] = 1.42\ k\Omega$

$A_v = -\left(\frac{1.42k\Omega}{0.33k\Omega + 1.42k\Omega}\right) \frac{96.0mS}{1 + 0.096(15)} (1k\Omega \| 220k\Omega) = -31.8$

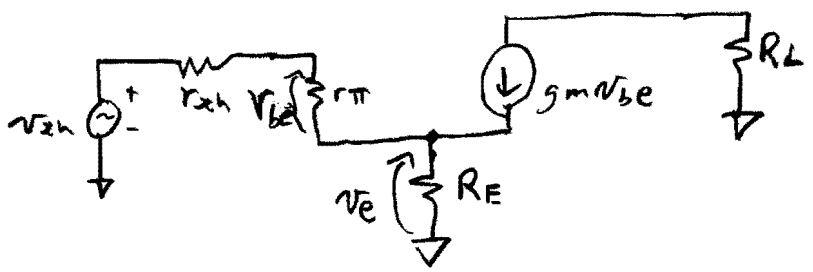
$R_{out} = 1k\Omega \| 22.4k\Omega [1 + 0.096(15)] = 982\ \Omega$

As instructed, Ignore r_o in gain calculation.



1) $v_{th} = v_I \left(\frac{R_B}{R_I + R_B}\right) \Rightarrow \frac{v_{th}}{v_I} = (0.968)$

$r_{th} = R_I \| R_B = 319.45$



2) $v_{th} = v_e + v_{be} + i_b r_{th}$

$= \left[(i_b + g_m v_{be}) R_e\right] + v_{be} + i_b r_{th}$

$= \left(\frac{v_{be}}{r_\pi} + g_m v_{be}\right) R_e + v_{be} + \frac{v_{be}}{r_\pi} r_{th}$

$v_{th} = v_{be} \left[\left(\frac{1}{r_\pi} + g_m\right) R_e + 1 + \left(\frac{r_{th}}{r_\pi}\right)\right]$

$\frac{v_{be}}{v_{th}} = \frac{1}{\left(g_m + \frac{1}{r_\pi}\right) R_e + \frac{r_{th}}{r_\pi} + 1} = \frac{1}{2.93} = 0.34\ V/V$

3) $v_o = (-g_m v_{be}) R_L$

$$\frac{v_o}{v_{be}} = -(0.096)(995)$$

$$= -95.56 \text{ V/V}$$

$$A_v = \left(\frac{v_o}{v_{be}}\right)^{③} \left(\frac{v_{be}}{v_{sh}}\right)^{②} \left(\frac{v_{sh}}{v_I}\right)^{①}$$

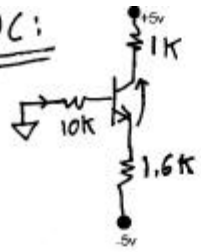
$$= (-95.56)(0.34)(0.968)$$

$$\boxed{A_v = -31.45 \text{ V/V}}$$

This problem is the same problem without the 15 ohm resistor. Understand what an emitter resistor does to the gain. It also shows more detail on the DC solution and calculates input and output resistances.

4.) Jaeger 13.119 Plus, solve for the input and output resistances.

13.119) DC:



$-5V + I_E\,1.6K + V_{BE} + I_B\,10K = 0$ (0.7V)

$I_E = (\beta+1)I_B$, $\beta = 65$

$-5V + 66\,I_B 1.6K + 0.7 + I_B\,10K = 0$

$I_B = 37.2\ \mu A$

$I_C = 2.418\ mA$

$I_E = 2.455\ mA$

$g_m = \frac{I_C}{V_{th}} = \frac{2.418mA}{0.0259} = 0.09336$

$r_\pi = \frac{\beta V_{th}}{I_C} = \frac{65(0.0259)}{2.418mA} = 696\ \Omega$

$r_o = \frac{V_A + V_{CE}}{I_C} = \frac{50V + 6.34V}{2.418e\text{-}3} = 23.3\ K\Omega$

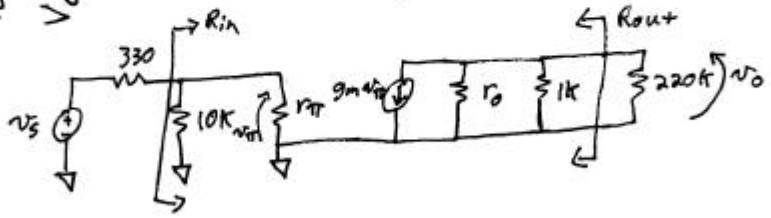
Check Bias Mode

$V_{CE} + I_E(1.6K) + (1K)I_C + (-5) - (+5) = 0$

$V_{CE} = 10 - (2.45e\text{-}3)(1.6K) - (2.42e\text{-}3)1K$

$V_{CE} = 3.66\ V$ $\quad V_{BE} = 0.7$ $\quad V_{CB} = 2.96\ V$

$\Rightarrow$ for ward Active



$\frac{v_\pi}{v_s} = \frac{r_\pi \| 10K}{330 + r_\pi \| 10K} = 0.664\ V/V$

$\frac{v_o}{v_\pi} = -g_m(r_o \| 1K \| 220K) = -89.13\ V/V$

$A_v = 0.664(-89.13) = -59.2\ V/V$

$R_{in} = 10K \| 696 = 651\ \Omega$

$R_{out} = r_o \| 1K = 959\ \Omega$

5.) a.) Use ideal opamps to design a filter (show work) that has 2 zeros at DC, and poles at 100 Hz, 10KHz, and 500 kHz and to have a bandpass gain of 1000 v/v. b.) Simulate this filter in PSPICE using ideal voltage controlled voltage amplifiers (setting gain to ~1e9). Plot the 20xLOG(Voltage Gain) verses Log(frequency) up to 10 MHz. c.) Simulate this filter in PSPICE using the u741 Operational amplifier model. Plot the 20xLOG(Voltage Gain) verses Log(frequency) up to 10 MHz. d.) Explain the differences between your results in b and c.

Note: Sample lowpass filter circuits are available on the web page illustrating how to model the op amps.

Since each basic high pass filter has a zero at DC and a pole, and each basic low pass filter has only one pole, we need 2 high pass stages and one low pass stage. Noting as was done in the notes that we can use a bandpass configuration to combine the low and high pass functions around one op-amp, we can perform this operation with only 2 op-amps.

Generally, to preserve the "pass-band gain" at the desired 1000 v/v (or 60 dB), we need to have our lowest and highest "break frequencies" (the frequencies where the slope of the Bode Plot changes) in our first stage. Otherwise, the first stage will be reducing the gain in frequency ranges where the second stage is trying to amplify the signal.

Thus, the circuit on the next page is our solution. This circuit's transfer function is:

$$\frac{Vout}{Vin} = \left(\frac{R_2C_1s}{1+R_1C_1s}\right)\left(\frac{1}{1+R_2C_2s}\right)\left(\frac{R_4C_3s}{1+R_3C_3s}\right)$$

where the first term is the high pass filter of the first op-amp (E1, or U1), the second term is the low pass filter of the first op-amp (E1, or U1), and the last term is the high pass filter of the second op-amp (E2, or U2).

This function implements the zeros at DC due to the s^2 term in the numerator. I will choose to give (free choice) 20 dB of gain (10 V/V) in the first stage, and 40 dB of gain (100 V/V) in the second stage for a total gain of 60 dB (1000 V/V). This sets the ratio of resistors as:

$$\frac{R_2}{R_1} = 10 \qquad and \qquad \frac{R_4}{R_3} = 100$$

due to the desired "pass-band gain" constraints .

Now we can set our frequencies:

$$f_{pole@100\,Hz} = \frac{1}{2p\ R_1C_1}$$

$$f_{pole@500\,kHz} = \frac{1}{2p\ R_2C_2} = \frac{1}{20p\ R_1C_2}$$

$$f_{pole@10kHz} = \frac{1}{2p\ R_3C_3}$$

Beyond these limitations (and practical limits of resistor and capacitor choices), we are free to choose parameters at will. The values below satisfy all of these constraints:
R1=1K, R2=10K, R3=10K, R4=1Meg, C1=1.59uF, C2=31.9pF, and C3=1.59nF

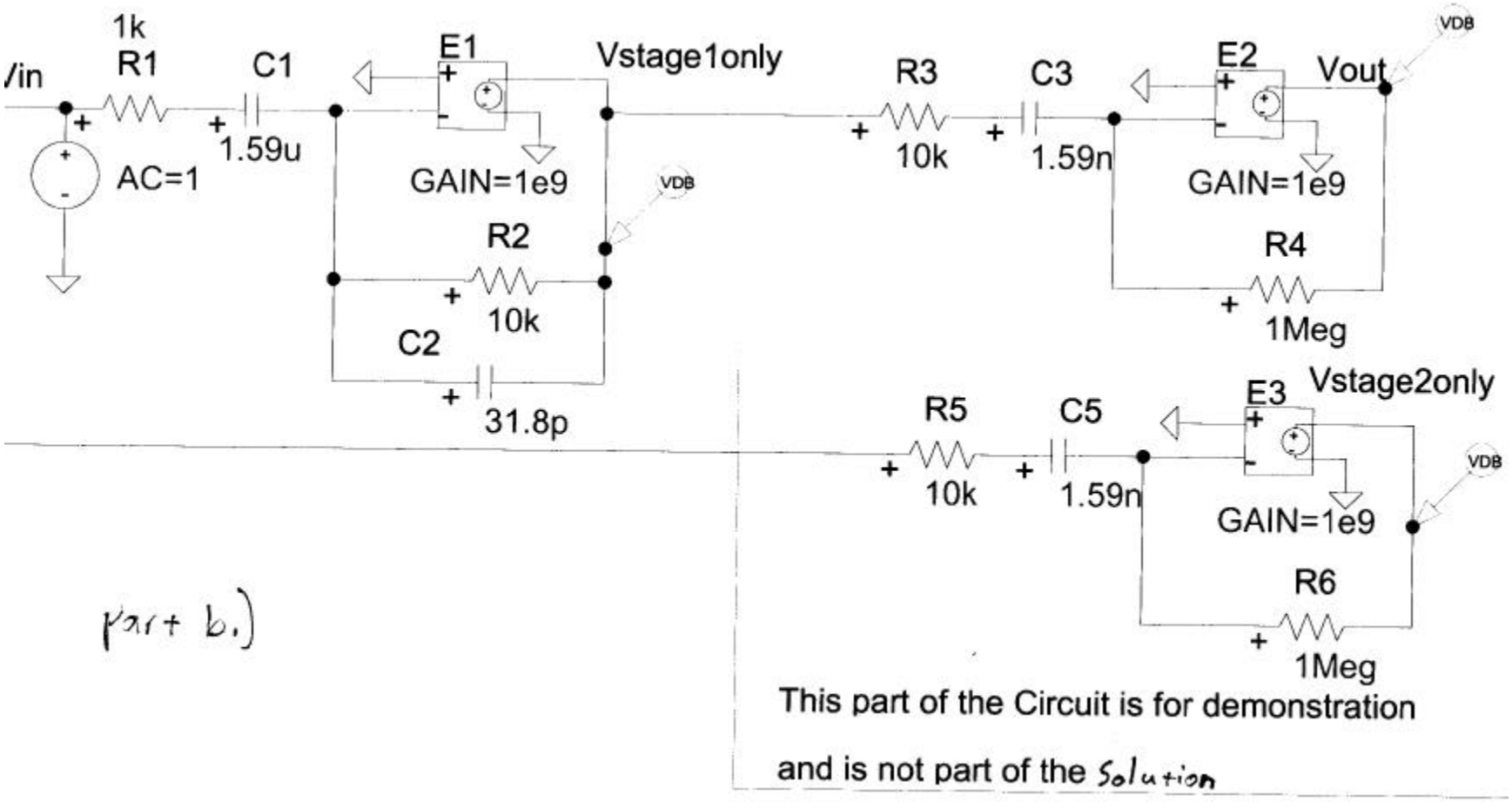
b.) The Bode Plot of the gain simulation from PSPICE of each stage (stage 1 is for E1, or U1 and stage 2 is for E2, or U2) is shown on the page following the circuit diagram. Note that the slope of the Bode Plot starts out at +40 dB per decade due to the existence of 2 zeros at DC. After the first pole at 100 Hz (set by stage 1), the slope reduces to +20 dB/decade. After the second pole at 10

kHz (set by stage 2) the slope is zero. After the last pole at 500 kHz (set by stage 1), the slope is –20 dB/decade. Also note that stage 2 implements the high pass function while stage 1 implements the bandpass function. The pass-band gain is correct at 60 dB (or 1000 V/V).

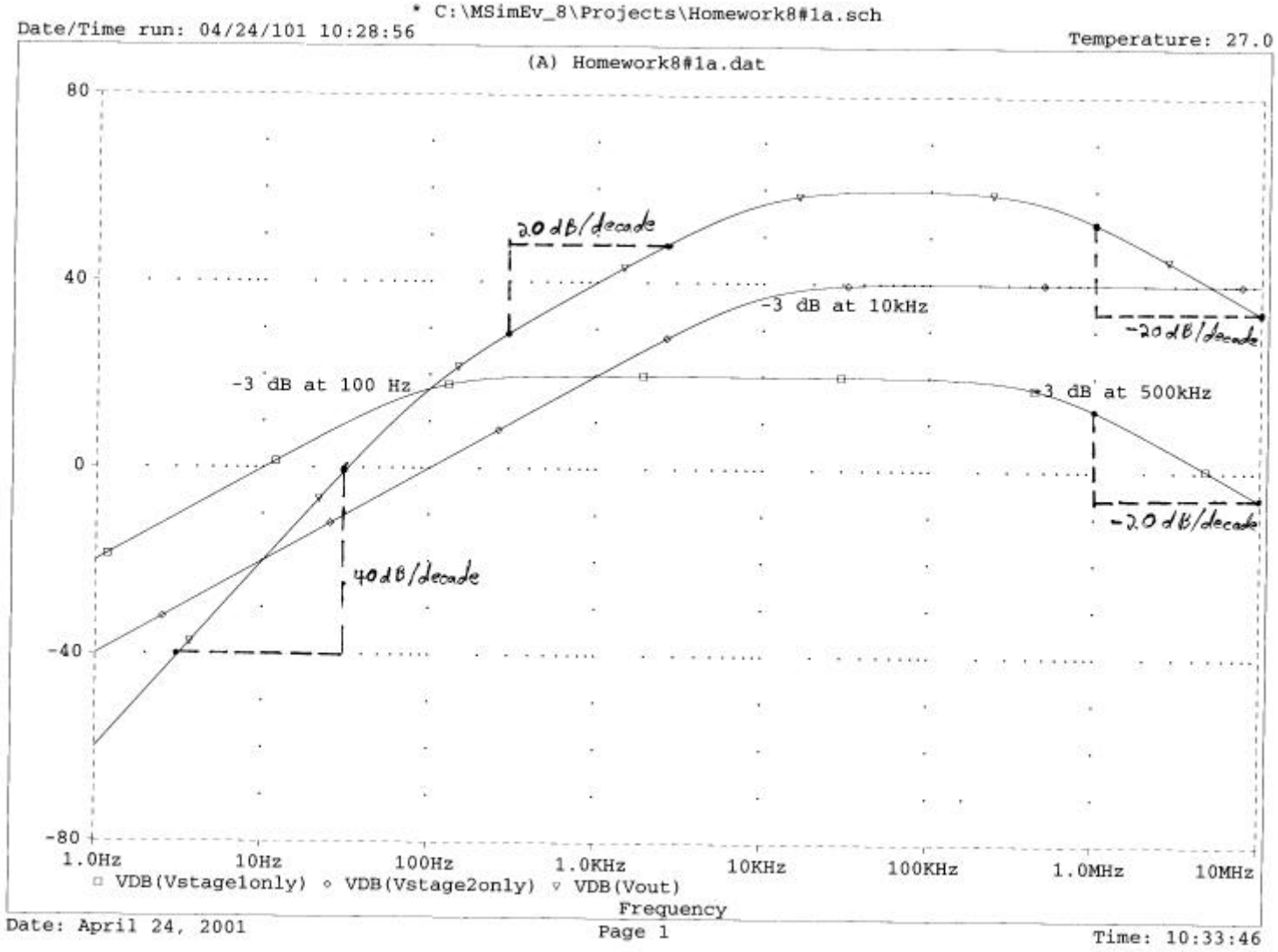
c.) The circuit using the ua741 op-amp is shown on a following page. Note that the model for the ua741 op-amp does require us to include the power supply voltage sources. Otherwise everything is identical to the previous circuit from parts a and b. The Bode Plot for this circuit is shown on a following page. The lower frequency response (~<10kHz) behaves identically to that of the ideal case. However, the frequency response at high frequencies is severely degraded resulting in gain that falls off faster than the expected –20 dB/decade.

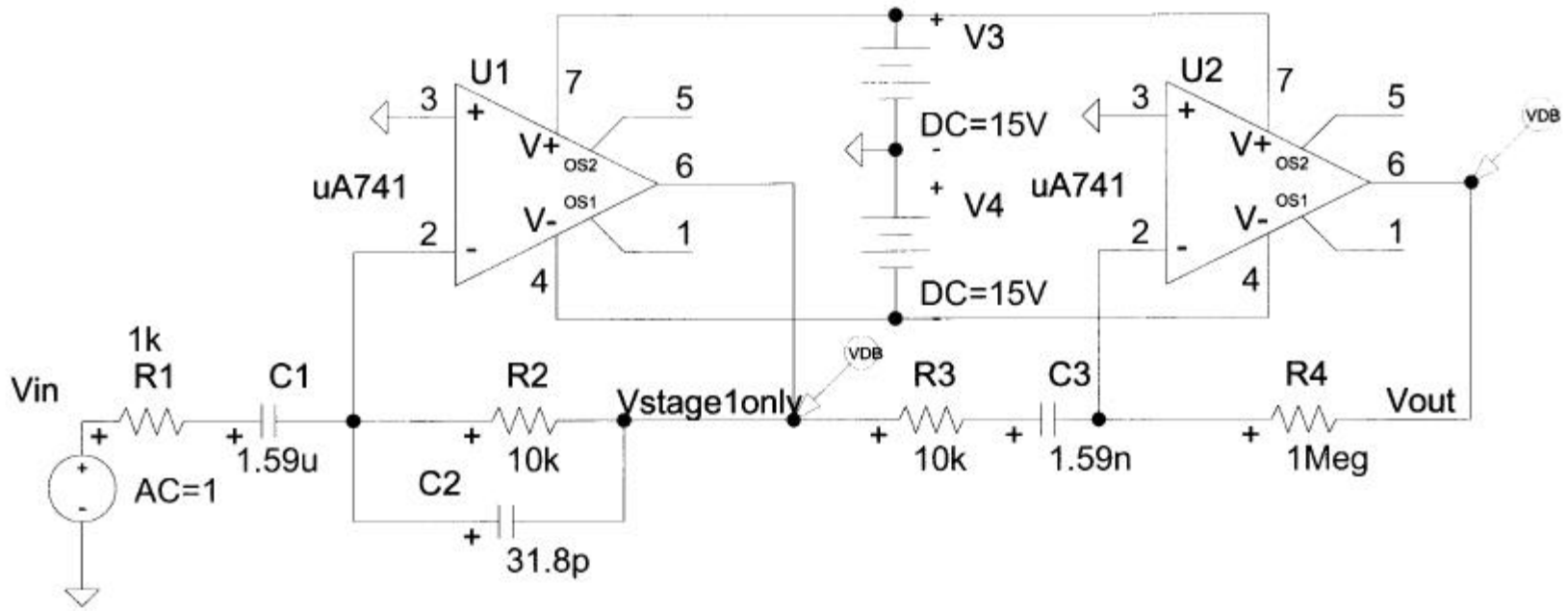
d.) The rapid decrease in the high frequency gain results from the finite "Gain-Bandwidth" of the ua741.

Further incite into this problem: Since the gain begins to role off somewhere around ~100 kHz for stage 1 which has a gain of 10, we can estimate the gain-bandwidth product to be (10 v/v)(100kHz)=1,00,000 Hz. We can check this calculation by using the unity gain (follower) circuit shown on a following page. The Bode Plot for this circuit is also shown. From this figure we clearly see that the gain drops by –3dB at ~1MHz confirming our calculation. This concept of gain effecting frequency response is also shown in the last Bode Plot for this problem for 3 standard non-inverting amplifiers with gains of 101, 1001 and 10,001 V/V. Note the lower frequency response for the higher gain circuit. All of these gain responses converge to the open loop frequency response for the ua741 (not shown).

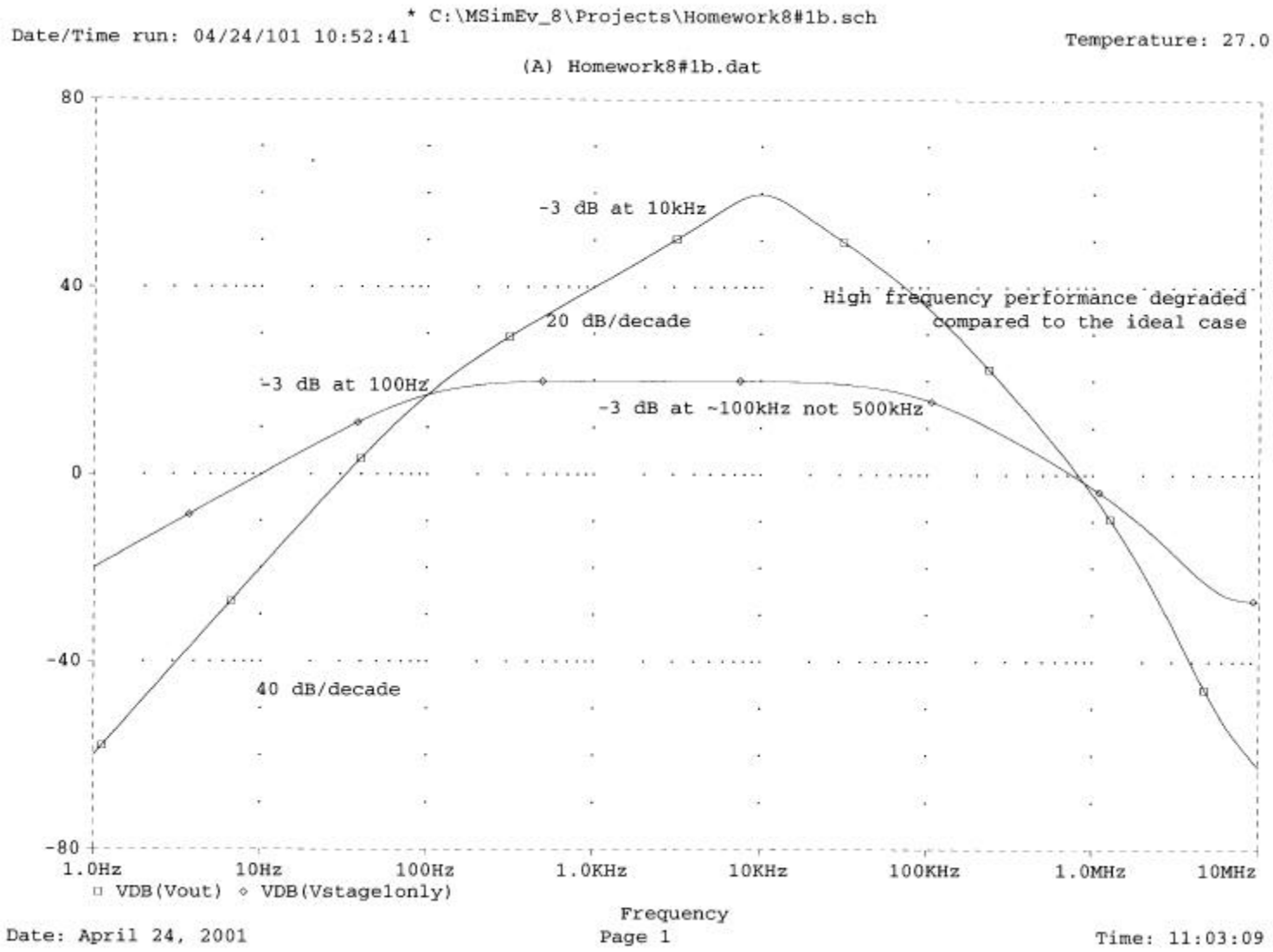

1k
R1
C1
E1
Vstage1only
R3
C3
E2
Vout
VDB
/in
AC=1
1.59u
GAIN=1e9
10k
1.59n
GAIN=1e9
R2
R4
10k
1Meg
C2
31.8p
R5
C5
E3
Vstage2only
10k
1.59n
GAIN=1e9
R6
1Meg
This part of the Circuit is for demonstration
and is not part of the Solution

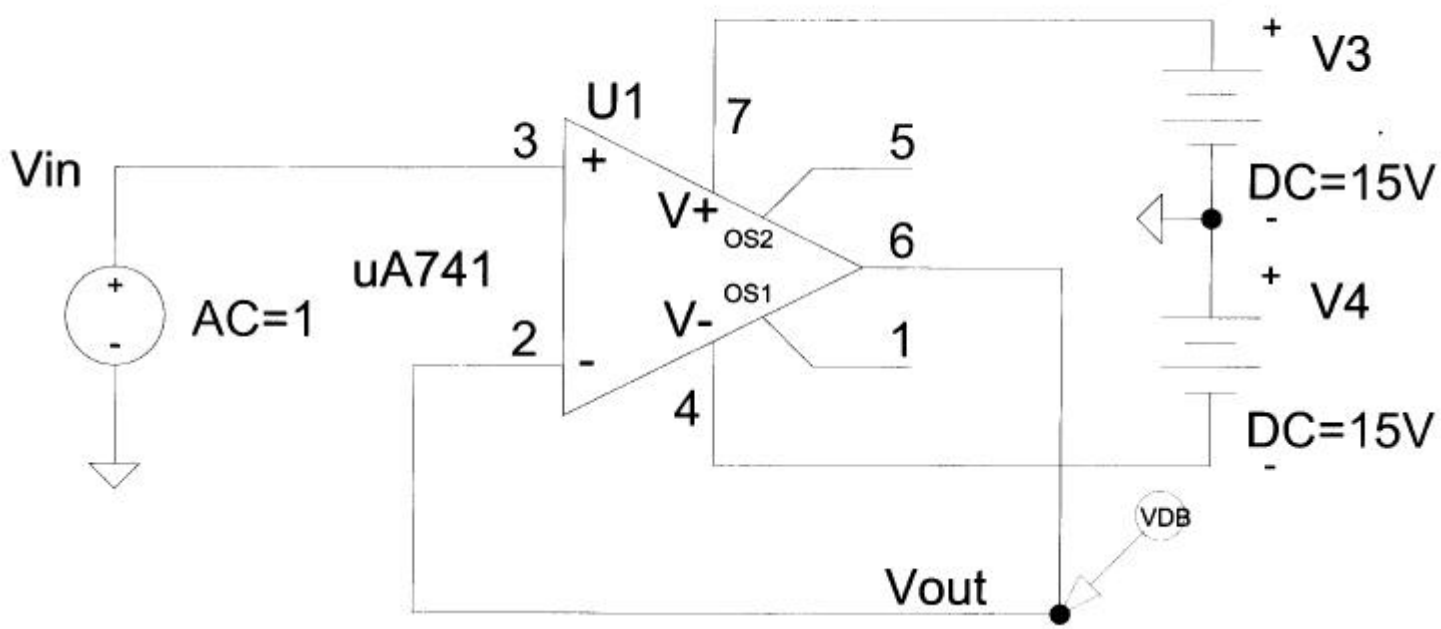
part b.)

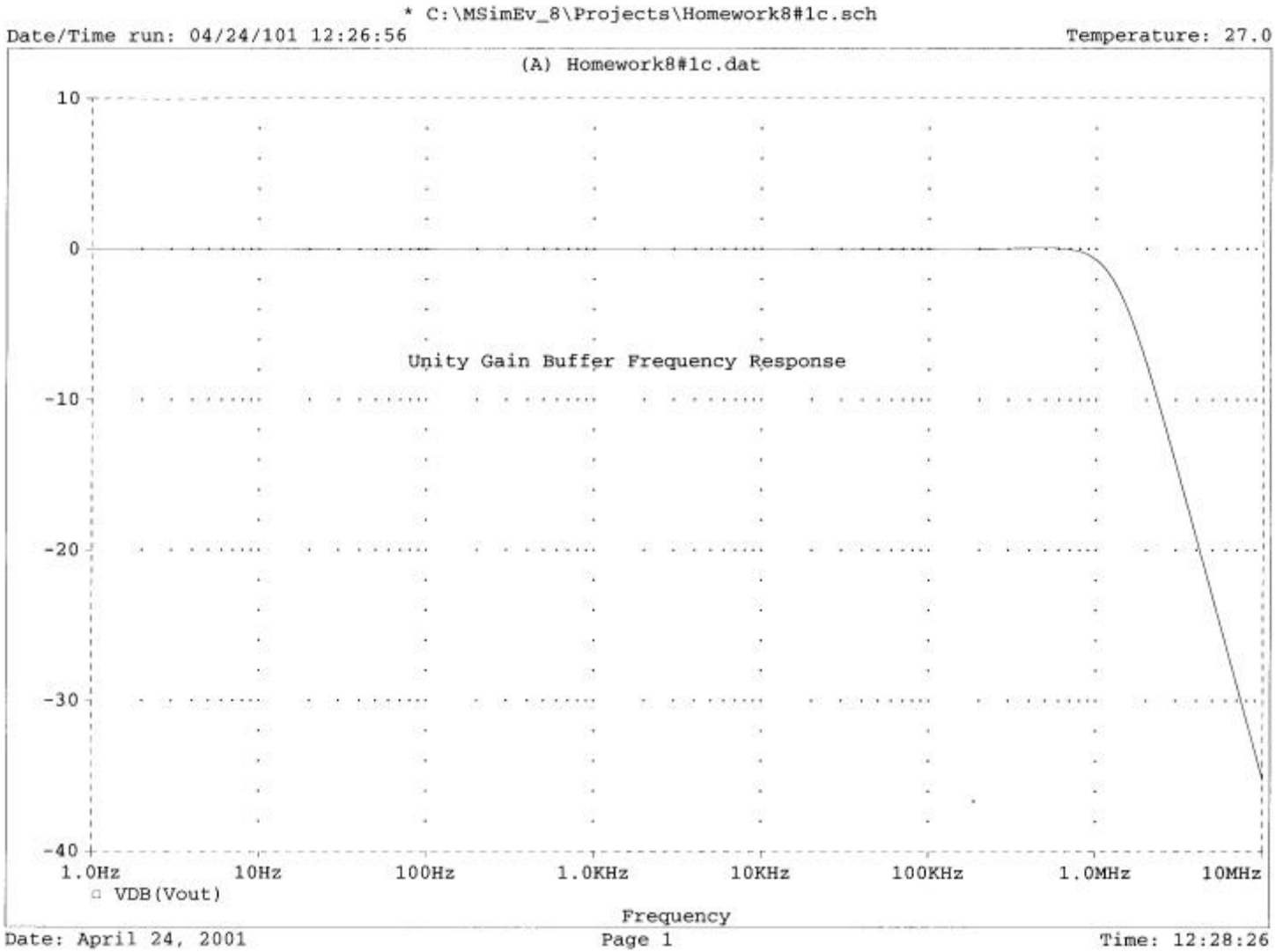

* C:\MSimEv_8\Projects\Homework8#1a.sch
Date/Time run: 04/24/101 10:28:56
Temperature: 27.0
(A) Homework8#1a.dat
80
40
0
-40
-80
20dB/decade
-3 dB at 10kHz
-20dB/decade
-3 dB at 100 Hz
-3 dB at 500kHz
-20dB/decade
40dB/decade
1.0Hz
10Hz
100Hz
1.0KHz
10KHz
100KHz
1.0MHz
10MHz
VDB(Vstage1only) VDB(Vstage2only) VDB(Vout)
Frequency
Date: April 24, 2001
Page 1
Time: 10:33:46

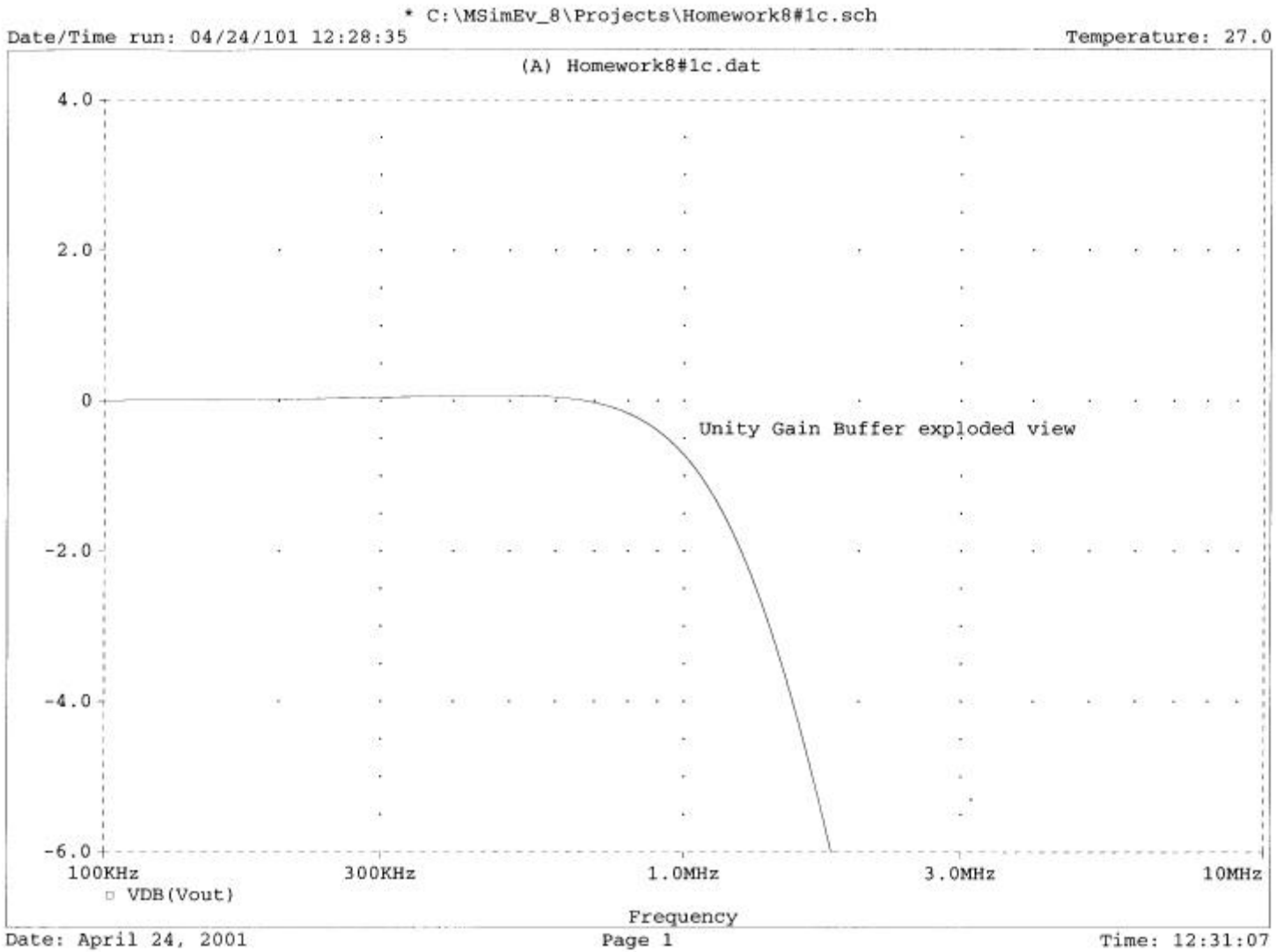

V3
DC=15V
V4
DC=15V
U1
U2
uA741
uA741
V+
V-
OS1
OS2
VDB
VDB
Vin
1k
R1
C1
1.59u
AC=1
C2
31.8p
R2
10k
Vstage1only
R3
10k
C3
1.59n
R4
1Meg
Vout

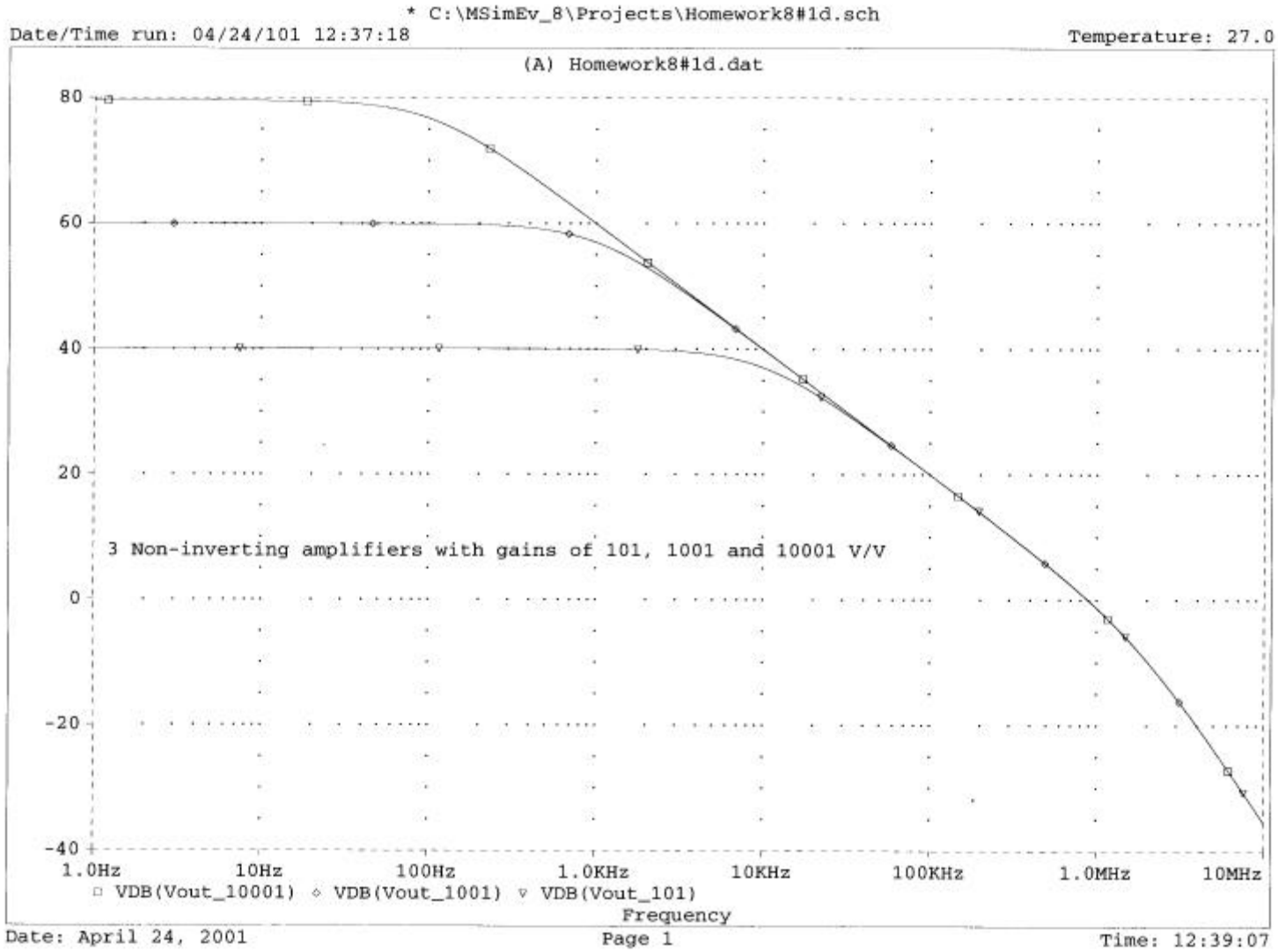
part c.)


* C:\MSimEv_8\Projects\Homework8#1b.sch
Date/Time run: 04/24/101 10:52:41
Temperature: 27.0
(A) Homework8#1b.dat
80
40
0
-40
-80
-3 dB at 10kHz
20 dB/decade
High frequency performance degraded
compared to the ideal case
-3 dB at 100Hz
-3 dB at ~100kHz not 500kHz
40 dB/decade
1.0Hz
10Hz
100Hz
1.0KHz
10KHz
100KHz
1.0MHz
10MHz
VDB(Vout) VDB(Vstageonly)
Frequency
Date: April 24, 2001
Page 1
Time: 11:03:09


Vin
AC=1
U1
uA741
3
2
7
5
6
1
4
V+
V-
OS2
OS1
+
V3
DC=15V
V4
DC=15V
VDB
Vout


* C:\MSimEv_8\Projects\Homework8#1c.sch
Date/Time run: 04/24/101 12:26:56
Temperature: 27.0
(A) Homework8#1c.dat
Unity Gain Buffer Frequency Response
10
0
-10
-20
-30
-40
1.0Hz
10Hz
100Hz
1.0KHz
10KHz
100KHz
1.0MHz
10MHz
VDB(Vout)
Frequency
Date: April 24, 2001
Page 1
Time: 12:28:26


* C:\MSimEv_8\Projects\Homework8#1c.sch
Date/Time run: 04/24/101 12:28:35
Temperature: 27.0
(A) Homework8#1c.dat
4.0
2.0
0
-2.0
-4.0
-6.0
Unity Gain Buffer exploded view
100KHz
300KHz
1.0MHz
3.0MHz
10MHz
VDB(Vout)
Frequency
Date: April 24, 2001
Page 1
Time: 12:31:07


* C:\MSimEv_8\Projects\Homework8#1d.sch
Date/Time run: 04/24/101 12:37:18
Temperature: 27.0
(A) Homework8#1d.dat
80
60
40
20
0
-20
-40
3 Non-inverting amplifiers with gains of 101, 1001 and 10001 V/V
1.0Hz
10Hz
100Hz
1.0KHz
10KHz
100KHz
1.0MHz
10MHz
VDB(Vout_10001)
VDB(Vout_1001)
VDB(Vout_101)
Frequency
Date: April 24, 2001
Page 1
Time: 12:39:07