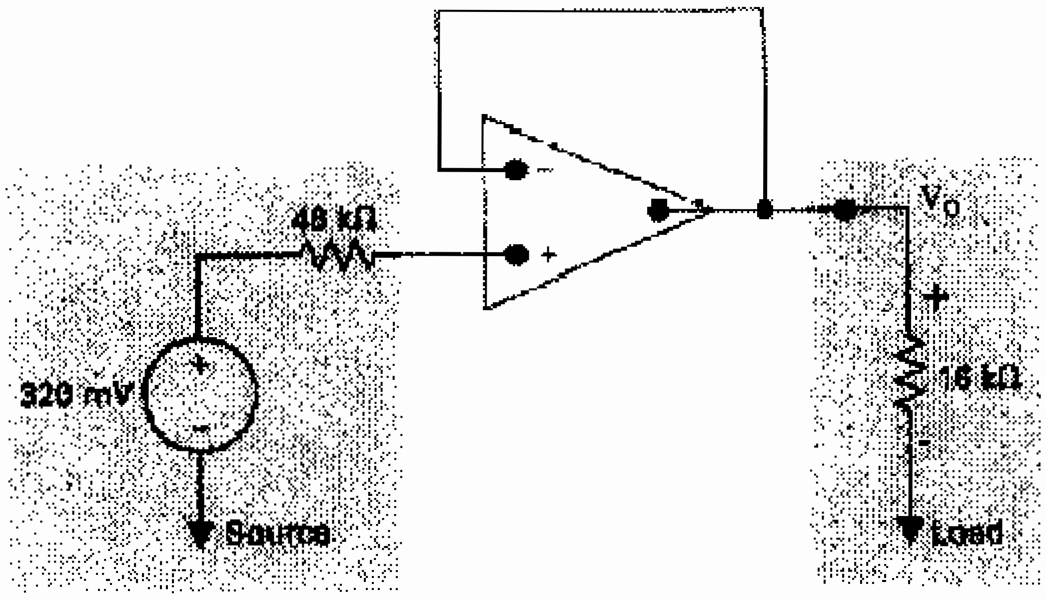
UNIVERSITY OF CALIFORNIA, BERKELEY
College of Engineering
Dept. of Electrical Engineering and Computer Sciences

EECS 40 **Fall 2003**

Homework #4 Solutions

Problem 1



Op amp is ideal operating in linear region:

$v_p = v_n$

$i_n = i_p = 0$

$P = v_{16k\Omega}{}^2/R$

$v_o = v_{16k\Omega}$

(a) KCL at +ve terminal:

$i_p = i_{48k\Omega} = 0$

$(320mV - v_p)/48k\Omega = 0$

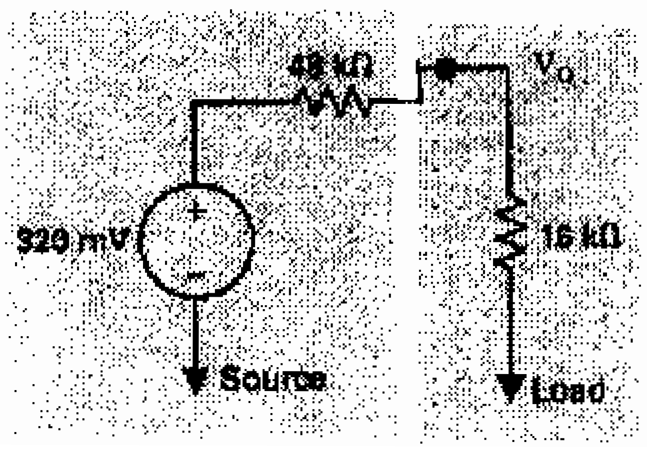
$v_p = 320mV$

$v_p = v_n = v_o$

$P = (320mV)^2/16k\Omega$

$P = 6.4\mu W$

(b)

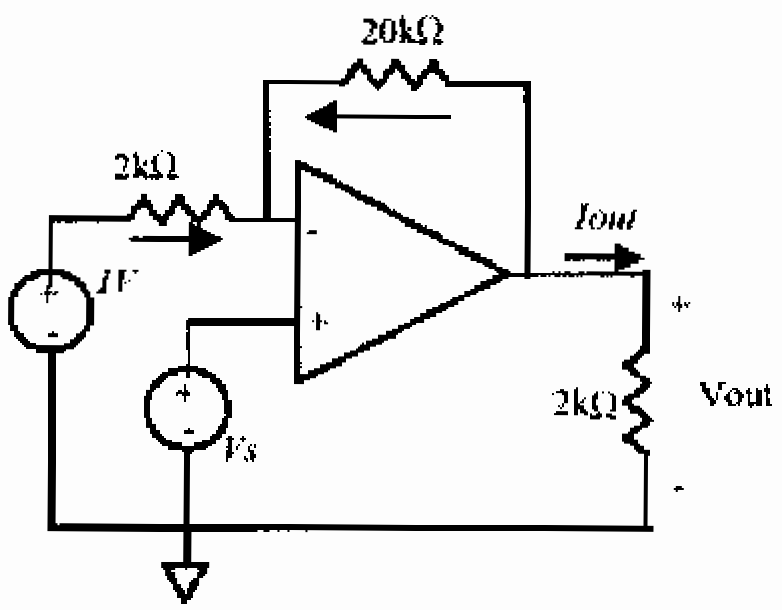


This is a simple voltage divider circuit; $v_o = (320mV \times 16k\Omega)/64k\Omega = 80mV$ which means that $P = (80mV)^2/16k\Omega = 0.40\mu W$

c) $6.4\mu W / 0.40\mu W = 16$

d) Yes. This is like the unity-gain voltage follower circuit; the weak voltage source at the input can drive a heavy load at the output (like the $16k\Omega$) with the op amp providing the power.

Problem 2

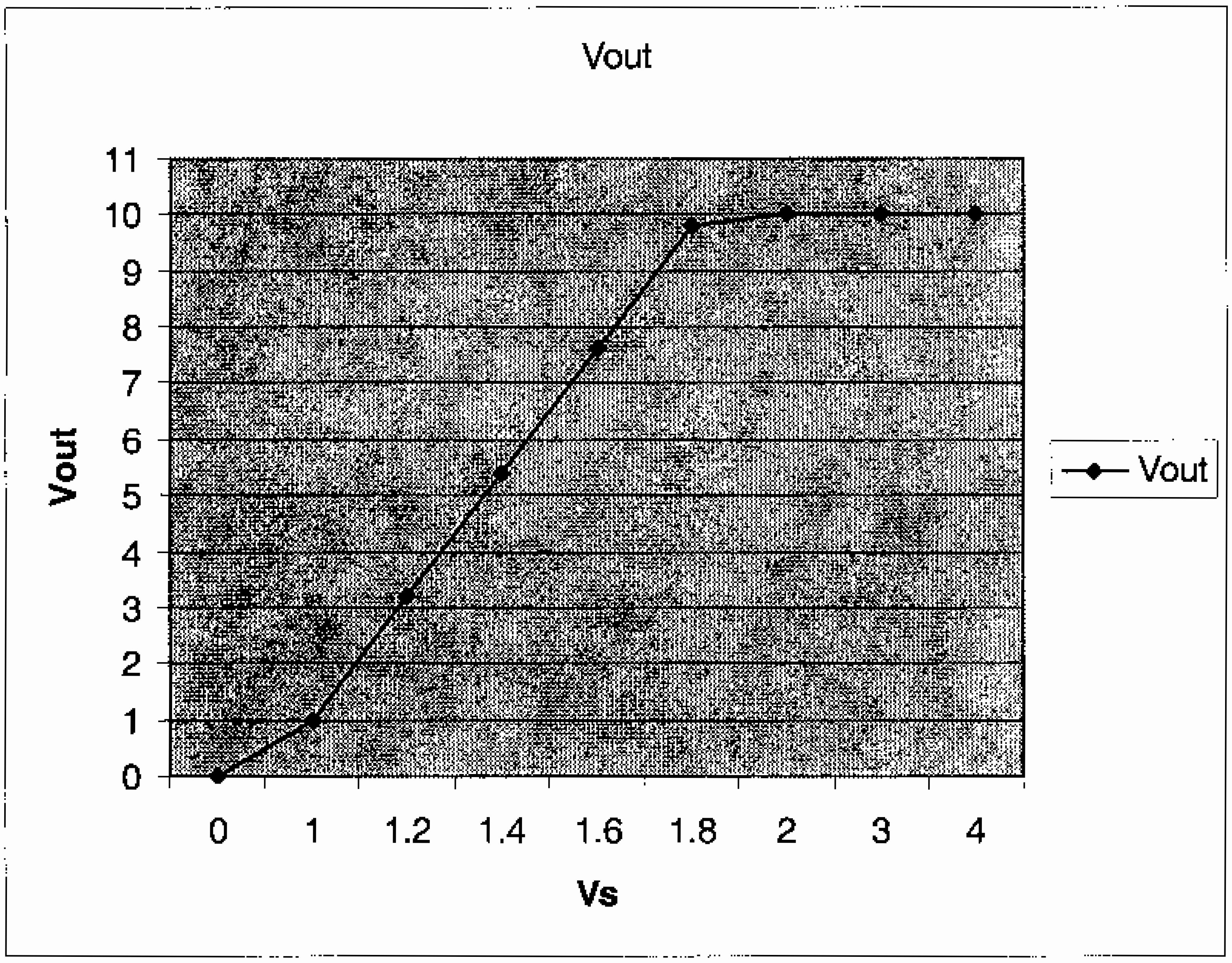


a) Op amp is ideal and operating in linear region
$v_s = v_p = v_n$; $i_n = i_p = 0$

KCL at –ve terminal:
$i_n = i_{2k\Omega} + i_{20k\Omega} = 0$
$(1 - v_n) / 2k\Omega + (v_{out} - v_n) / 20k\Omega = 0$
$(v_s - 1) / 2k\Omega = (v_{out} - v_s) / 20k\Omega$
$20v_s - 20 = 2v_{out} - 2v_s$
$v_o = 11v_s - 10.$

b)

Vs	Vout = 11Vs -10
0	0
1	1
1.2	3.2
1.4	5.4
1.6	7.6
1.8	9.8
2	10
3	10
4	10



Problem 3

Op amp is ideal and operates in linear region.
$v_n = v_p$; $i_n = i_p = 0$.
$R_a = 1k\Omega$
KCL at –ve terminal:
$i_{10k} + i_{Rf} = i_n = 0$
$0 - v_n/10k\Omega + (v_o - v_n)/R_f = 0$
$v_o = v_n(10k + R_f)/10k$
$\Rightarrow v_n = v_o 10k/(10k + R_f)$ [Note this is simple voltage division]

Let $z = 10k/(10k + R_f)$

Now use superposition to find contribution of each voltage source to v_p.
Note contribution by v_a to v_o is $4v_a$:
$\Rightarrow v_n = 4v_a \cdot z$
Contribution of v_a to v_p is given by:
$R_b||R_c \cdot v_a /(R_a + R_b||R_c)$ by voltage division
$\Rightarrow R_b||R_c /(R_a + R_b||R_c) = 4z$

Similarly, for v_b which contributes $2v_b$ to v_o:

Contribution of v_b to v_p is given by:
$R_a||R_c \cdot v_b / (R_b + R_a||R_c)$ by voltage division
$\Rightarrow R_a||R_c / (R_b + R_a||R_c) = 2z$

And, for v_c which contributes v_c to v_o:
Contribution of v_c to v_p is given by:
$R_a||R_b \cdot v_c / (R_c + R_a||R_b)$ by voltage division
$\Rightarrow R_a||R_b / (R_c + R_a||R_b) = z$

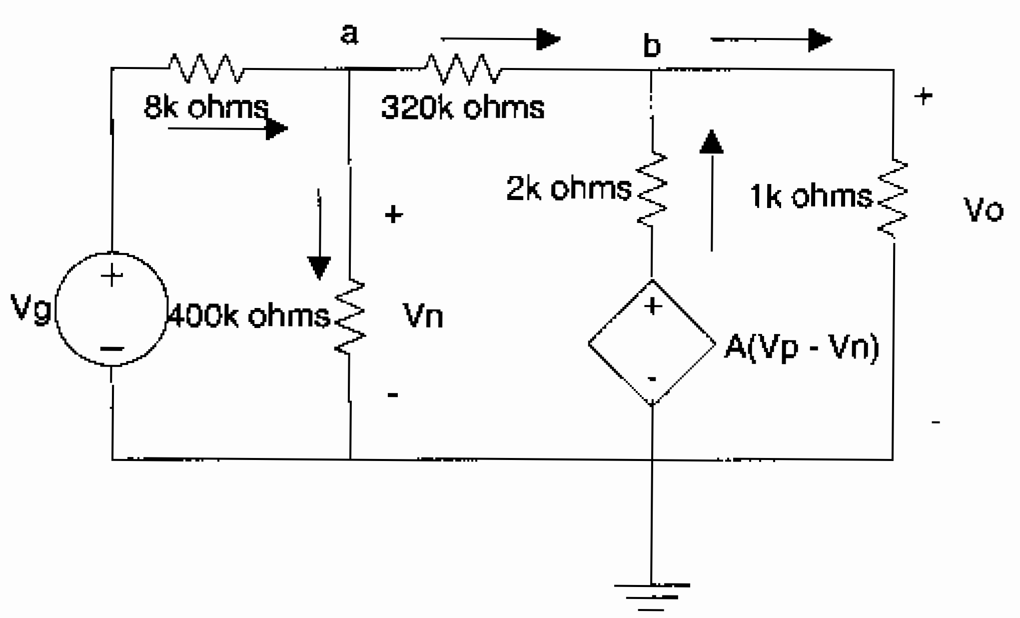
Then using the above equations we can solve for R_b and R_c:
$\Rightarrow R_b||R_c / (R_a + R_b||R_c) = 4 \cdot R_a||R_b / (R_c + R_a||R_b)$
$\Rightarrow R_b \cdot R_c / (R_aR_b + R_aR_c + R_bR_c) = 4\, R_a \cdot R_b / (R_aR_b + R_aR_c + R_bR_c) \cdot$
$\Rightarrow R_c = 4R_a$
$\Rightarrow \mathbf{R_c = 4k\Omega}$

$R_a||R_c / (R_b + R_a||R_c) = 2 \cdot R_a||R_b / (R_c + R_a||R_b)$
$\Rightarrow R_a \cdot R_c / (R_aR_b + R_aR_c + R_bR_c) = 2\, R_a \cdot R_b / (R_aR_b + R_aR_c + R_bR_c) \cdot$
$\Rightarrow R_c = 2R_b$
$\Rightarrow \mathbf{R_b = 2k\Omega}$

Then $z = 10k/(10k + R_f) = R_a||R_b / (R_c + R_a||R_b) = 1k||2k/(4k + 1k||2k) = 1/7$
$\Rightarrow \mathbf{R_f = 60k\Omega}$

Problem 4

a) Redraw the circuit as follows:



Note: Vp = 0; Vn = Va; Vb = Vo
KCL at node a:
Va/400k + (Va – Vb)/320k = (Vg – Va)/8k
⇒ Va + 1.25Va – 1.25Vb = 50Vg – 50Va
⇒ Vg = 1.045Va – 0.025Vb

KCL at node b:
$(Va - Vb)/320k + (A(-Vn) - Vb)/2k = Vb/1k$
$\Rightarrow (1 - 160A)Va - 161Vb = 320Vb$
$\Rightarrow Va = 481Vb/(1-160A)$

$Vg = 1.045[481Vb/(1-160A)] - 0.025Vb$
$Vg = -0.0250062Vo$
$Vo/Vg = -39.99$
$Vo/Vg \approx -40$

Another solution is to use equation 5.49 in the textbook to determine Vo:
$Vo/Vg = -A + (Ro/Rf) / (Rs/Rf)(1 + A + Ro/Ri + Ro/RL)+(1 +Ro/RL)(1+Rs/Ri) + Ro/Rf$
Substituting the values for all the variables, we get:
$Vo/Vg = -500\,000 + (2k/320k) / (8k/320k)(1 + 500\,000 + 2k/400k + 2k/1k)+(1 +2k/1k)(1+8k/400k) + 2k/320k$
$Vo/Vg = -39.99$
$Vo/Vg \approx -40$

b) Ideal op amp in linear region; $Vn = Vp$; $In=Ip=0$; we can directly apply the result for an inverting amplifier as derived in class:
$Vo = -Rf \times Vs/Rs$
$Rf = 320k\Omega$, $Rs = 8k\Omega$, $Vs = Vg$

$Vo/Vg = -320/8 = -40$