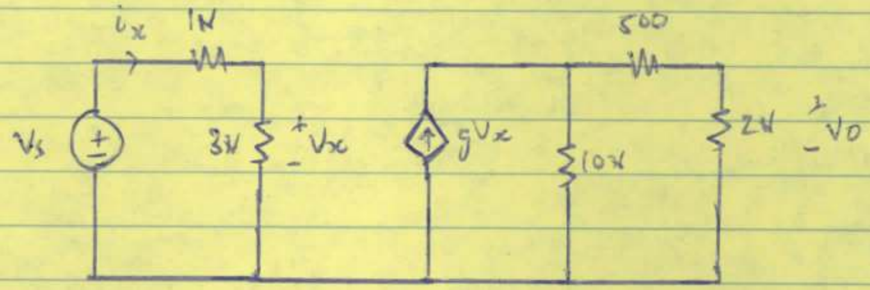
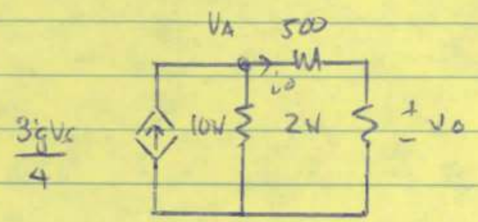
4.3



$$i_x = \frac{V_s}{4K}, \quad V_x = i_x \cdot 3K = \frac{3V_s}{4},$$

Now we can rewrite the circuit as follows,



We can compute V_A,

$$V_A = \frac{3gV_s}{4} \cdot 10K \| 2.5K = \frac{3g}{4} V_s \cdot 2000$$

$$V_A = \frac{6000}{4} g V_s$$

$$V_o = \frac{V_A}{2500} \cdot 2000$$

$$V_o = V_s \frac{6000}{4(2500)} \cdot 2000g \Rightarrow \frac{V_o}{V_s} = 1200g = \underline{\underline{3.6}}$$ ⇐ This is the voltage gain.

Now, we want an expression for the current gain $\frac{i_o}{i_x}$

$$i_o = \frac{V_A}{2500} = 0.6g V_s$$

$$i_x = \frac{V_s}{4k}$$

$$\frac{i_o}{i_x} = \frac{0.6g \cancel{V_s}}{\cancel{V_s}} \cdot 4k = 0.6g\, 4k = \underline{7.2}$$

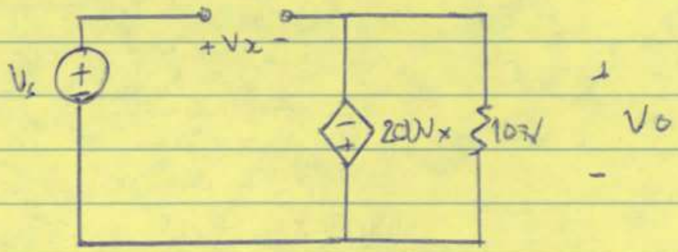
Power supplied by the input voltage source

$$\begin{aligned} P_{input} &= V_s \cdot i_x \\ &= V_s \cdot \frac{V_s}{4k} = \frac{V_s^2}{4k} = \frac{10^2}{4k} = \underline{\underline{0.025\,W}} \end{aligned}$$

$$\begin{aligned} P_{output} &= i_o^2 \cdot 2k \\ &= (0.6g\, V_s)^2\, 2k \\ &= \underline{0.648\,W} \end{aligned}$$

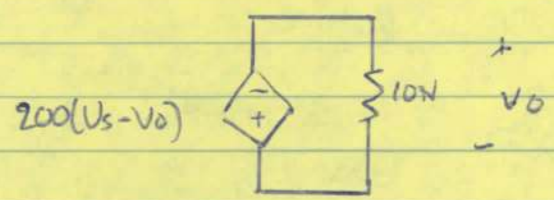
4.6

Find the voltage gain.



Note that $V_x = V_s - V_o$,

So we can redraw the circuit,



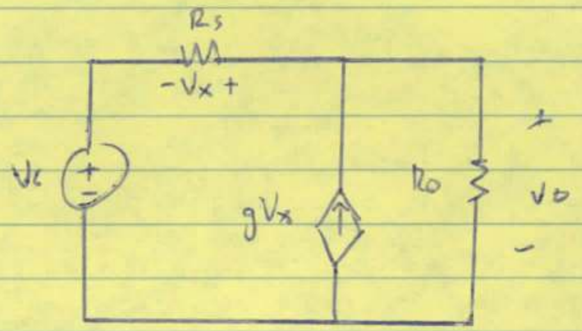
$$V_o = -200(V_s - V_o)$$

$$V_o = 200V_o - 200V_s$$

$$200V_s = 199V_o$$

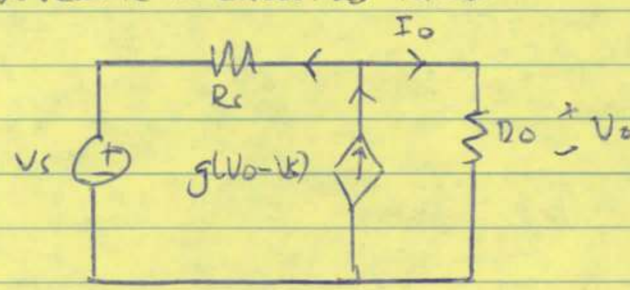
$$\frac{V_o}{V_s} = \frac{200}{199}$$

4.10



$V_x = V_o - V_s$,

So we can rewrite the circuit as follows



Find an expression for I_o,

$$I_o + \frac{V_o - V_s}{R_s} = g(V_o - V_s)$$

$$I_o = g(V_o - V_s) - \frac{(V_o - V_s)}{R_s} = V_o\left[g - \frac{1}{R_s}\right] + V_s\left[\frac{1}{R_s} - g\right] = I_o$$

$$V_o = R_o I_o = R_o\left[V_o\left[g - \frac{1}{R_s}\right] + V_s\left[\frac{1}{R_s} - g\right]\right]$$

$$V_o = V_o R_o\left[g - \frac{1}{R_s}\right] + V_s R_o\left[\frac{1}{R_s} - g\right]$$

$$V_s R_o\left[g - \frac{1}{R_s}\right] = V_o R_o\left[g - \frac{1}{R_s} - \frac{1}{R_o}\right],$$

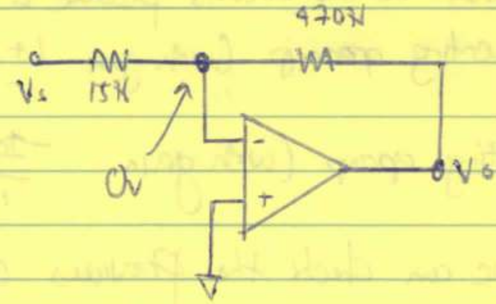
$$V_s\left[\frac{gR_s-1}{R_s}\right] = V_o\left[\frac{gR_sR_o - R_o - R_s}{R_sR_o}\right]$$

$$V_s[gR_s-1] = V_o\left[\frac{gR_sR_o - R_o - R_s}{R_o}\right]$$

$$\Rightarrow \quad \frac{V_o}{V_s} = \frac{(gR_s-1)R_o}{gR_sR_o-R_o-R_s}$$

4.26

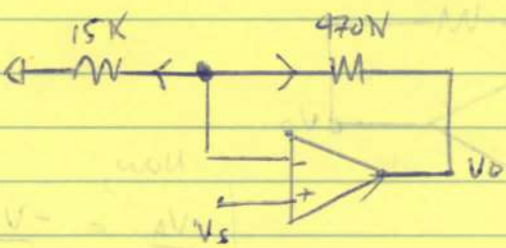
Find the voltage gain of the two following circuits



- The (-) terminal is zero volts because $V_+ - V_- = 0$, and because we know that no current flows into the negative terminal, we must have that:

$$\frac{V_s}{15K} = \frac{-V_o}{470K} \Rightarrow \frac{V_o}{V_s} = -\frac{470K}{15K}$$

(This is an inverting amplifier)



Here $V_- = V_s$, so we have

$$\frac{V_s}{15K} = -\left(\frac{V_s - V_o}{470K}\right), \Rightarrow \frac{V_o}{470K} = +\frac{V_s}{470K} + \frac{V_s}{15K}$$

$$\frac{V_o}{470K} = V_s\left(+\frac{1}{470K} + \frac{1}{15K}\right)$$

$$\frac{V_o}{V_s} = 1 + \frac{470K}{15K}$$

(non inverting amp)

4-28

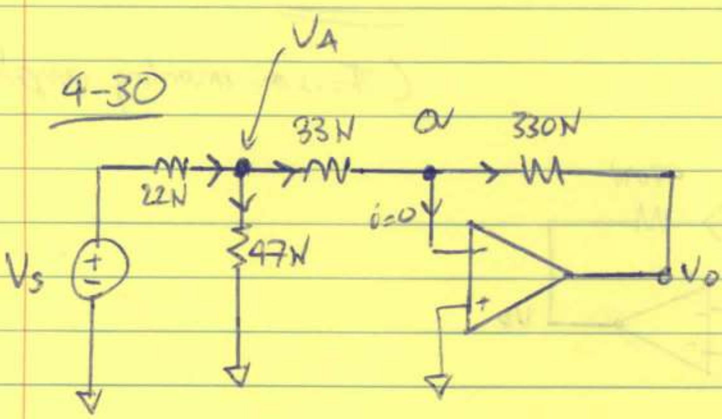
(a) We can verify straight away that the two circuits produce a gain of ± 100. The top circuit is a non-inverting opamp (with gain $1 + \frac{99k}{1k}$), and the bottom circuit is an inverting opamp (with gain $-\frac{100k}{1k}$).

For the analysis of this, we can check the previous question

(b) The gain will still hold in the case of the non inverting amplifier because the source is connected to the positive terminal, therefore no current flows through the 1k resistance, so $V_+ = V_s$.

In the case of the inverting opamp, the gain changes to $\frac{V_o}{V_s} = \frac{-100}{2}$

4-30



(1) Assign current directions
(2) Nodal analysis at V_A,

$$\frac{V_s - V_A}{22k} = \frac{V_A}{47k} + \frac{V_A}{33k}$$

$$\frac{V_s}{22k} = V_A\left(\frac{1}{47k} + \frac{1}{33k} + \frac{1}{22k}\right)$$

$$\frac{V_s}{V_A} = 22k\left(\frac{1}{47k} + \frac{1}{33k} + \frac{1}{22k}\right)$$

Now,

$$\frac{V_A}{33k} = \frac{-V_o}{330k}$$

$$V_A = -0.1V_o$$

sub into the first expression

$$\frac{V_s}{-0.1V_o} = 22k\left(\frac{1}{47k} + \frac{1}{33k} + \frac{1}{22k}\right)$$

$$\frac{V_o}{V_s} = \frac{-10}{22k\left(\frac{1}{47k} + \frac{1}{33k} + \frac{1}{22k}\right)}$$

$$= -4.6844$$

Now we want to determine the input voltage range to prevent saturation.

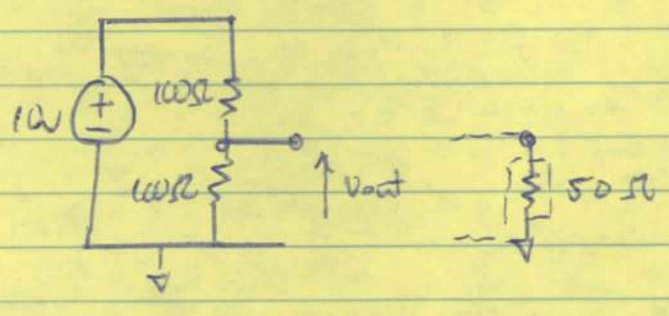
$$\frac{+15}{V_s} = -4.6844$$

$$\frac{-15}{V_s} = -4.6844$$

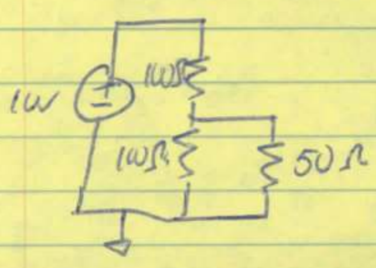
Which shows us that $V_s \in \left[\frac{-15}{4.6844}, \frac{+15}{4.6844}\right]$

4.35 We can illustrate this with an example.

Let us say we have a cellphone which can be modeled with a 50Ω resistor. To charge our cellphone, we need to supply it 5 volts. One way we may think to do this is with a voltage divider.

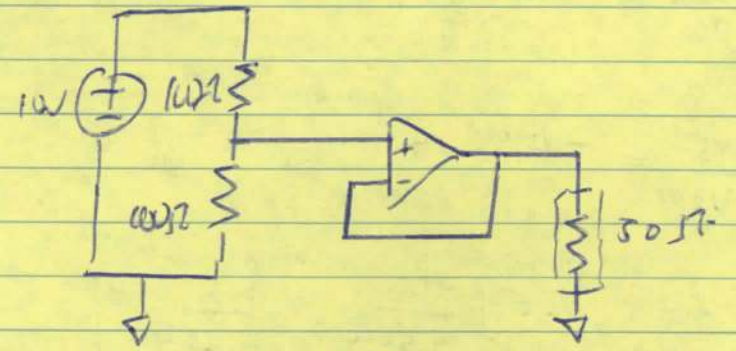


We see that using this circuit we can produce a 5V output. But what happens when we connect the cellphone?



The cellphone resistance is in parallel with the bottom resistance of the voltage divider, so it does not get 5V.

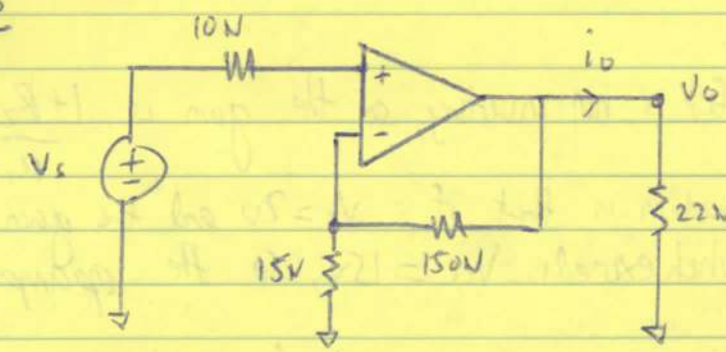
We can generate the required 5V to the cellphone with the following modification



Now, the cellphone will get the necessary 5V. The reason this circuit works is because the input resistance of the voltage follower is infinite, so the cellphone resistance no longer loads the voltage divider which is happened in the original circuit.

4.36

4.36



Using the voltage divider rule, we have

(a)

$$\frac{V_o}{15N + 150N} \cdot 15N = V_s \qquad \Rightarrow \frac{V_o}{V_s} = \frac{15N + 150N}{15N} = \underline{\underline{11}}$$

(b) If $V_s = 1V$, $V_o = 11V$, $i_o = \frac{V_o}{22N} = \underline{\frac{11}{22N}, \text{ amps}}$

If $V_s = 3V$, $V_o = 24V$ (BECAUSE THE OPAMP WILL SATURATE AT 24V], $i_o = \frac{V_o}{22N} = \underline{\frac{24}{22N} \text{ amps}}$

(Incorrect if $i_o = \frac{33}{22N}$ amps)

4-38

We see the amplifier is non inverting, so the gain is $1+\frac{R_2}{R_1}$.

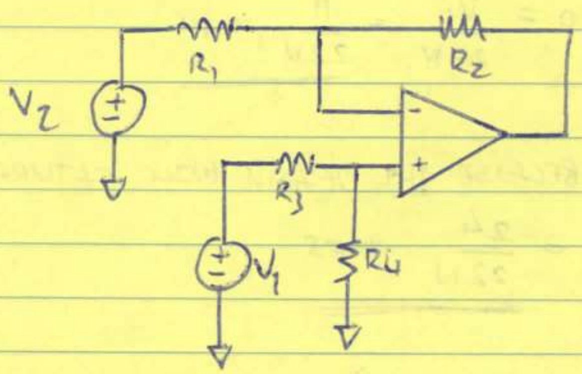
However, the problem is that if $V_s = 2V$ and the gain is 10, then $V_o = 20V$ which exceeds $V_{cc} = 15V$, so the opamp will saturate.

To overcome this problem, we need to either increase Vcc or reduce the gain

4.39

$$V_o = 2V_1 - 4V_2$$

(a) Use a standard subtractor circuit:



So, we get the following gain,

$$V_o = -\frac{R_2}{R_1}V_2 + \left[\frac{R_4}{R_3+R_4}\right]\left[\frac{R_1+R_2}{R_1}\right]v_1$$

so, lets set

$R_2 = 4000$

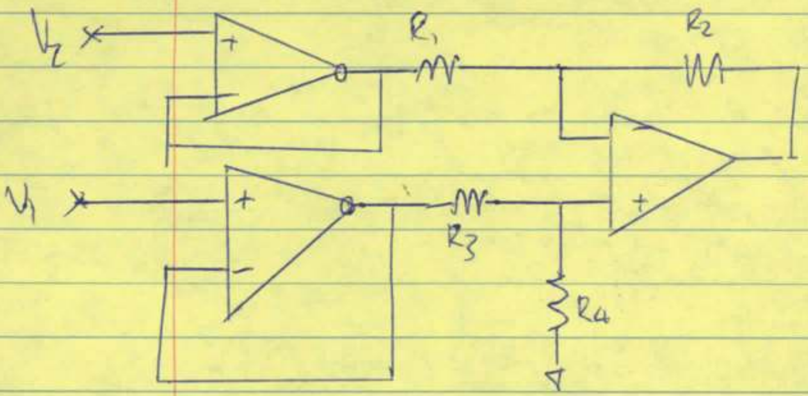
$R_1 = 1000$, so we need $\frac{R_4}{R_3+R_4} \cdot \frac{5000}{1000} = 2$

$$\Rightarrow \frac{5R_4}{R_3+R_4} = 2,$$

If we set $R_4 = 1000$, $\Rightarrow \frac{5000}{R_3+1000} = 2 \Rightarrow 5000 = 2R_3 + 2000$

$R_3 = 1500$

One easy solution to ensure a high resistance input is to add two voltage followers to the circuit as follows:



Where R_1, R_2, R_3, R_4 have the same values as before

Other solutions are possible.