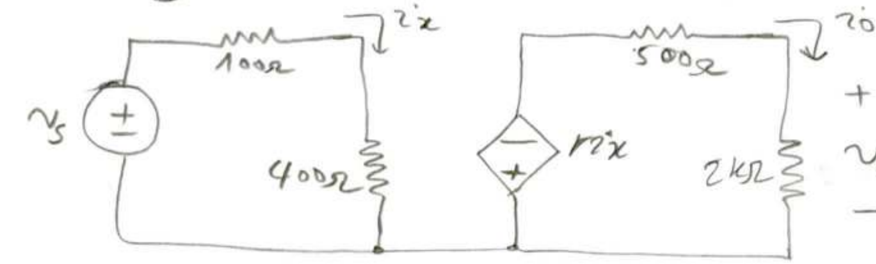
problem 4-1:

For the circuit shown in the following figure, we would like to find $\frac{v_o}{v_s}$ and $\frac{i_o}{i_x}$ where $r = 5\,k\Omega$.



First: for the portion of the circuit shown on the left hand side (LHS), and provided the two resistances are in series, we obtain:

$$i_x = \frac{v_s}{400+100} \Rightarrow \boxed{i_x = \frac{v_s}{500}} \quad (*)$$

Second: for the portion of the circuit shown on the right hand side (RHS), and provided the two resistances are in series, we obtain:

$$i_o = \frac{-r\,i_x}{2500} \Rightarrow \frac{i_o}{i_x} = \frac{-r}{2500}$$

which then recalling $r = 5000\Omega$, results the following:

$$\frac{i_o}{i_x} = -\frac{5000}{2500} \Rightarrow \boxed{\frac{i_o}{i_x} = -2} \quad (\star)$$

On the other hand, v_o can be also obtained by using voltage division technique which results the following:

$$v_o = -r\,i_x\left(\frac{2000}{2000+500}\right) \Rightarrow \boxed{v_o = -\frac{4r}{5}\,i_x}$$

which then by (*), we get:

$$v_o = -\frac{4r}{5}\left(\frac{v_s}{500}\right) \Rightarrow \boxed{v_o = -\frac{4r}{2500}\,v_s}$$

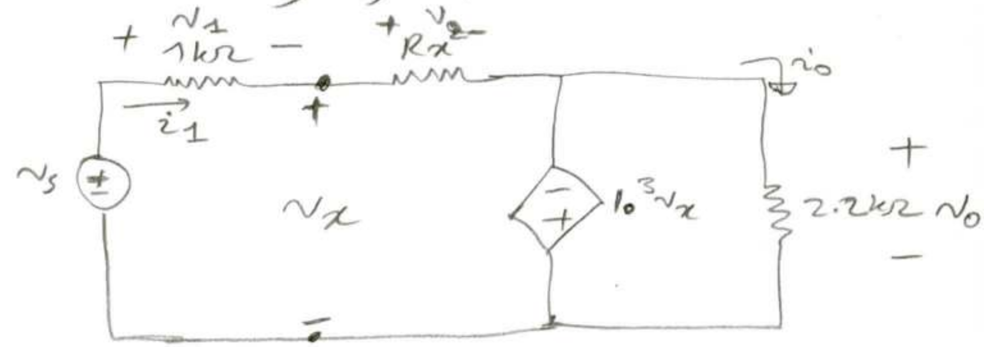
where then provided $r = 5000\,\Omega$, we get:

$$v_o = -\frac{4\times5\times10^3}{2.5\times10^3}\,v_s \Rightarrow v_o = -8\,V_s \Rightarrow \boxed{\frac{v_o}{v_s} = -8} \quad (\star\star)$$

Therefore, having obtained (★) and (★★), the solution to this problem is complete.

problem 4-8:

(a) Provided the circuit shown in the following figure, we would like to find $\frac{i_o}{v_s}$ in terms of R_x.



First: Referring to the circuit, we note that the value of the voltage drop, v_o, across 2.2kΩ resistance is $v_o = -10^3 v_x$, where then the current i_o passing through this resistance can be also characterized as follows:

$$i_o = \frac{v_o}{2.2\times10^3} = -\frac{10^3 v_x}{2.2\times10^3} \Rightarrow \boxed{i_o = -\frac{v_x}{2.2}} \quad (*)$$

Second: Referring to the figure, the voltage drop across R_x, i.e., v_2, can be obtained as follows:

$$v_2 = v_x + 10^3 v_x \Rightarrow \boxed{v_2 = 1001\, v_x} \quad (**)$$

Moreover, in a similar way, the voltage drop across 1kΩ resistance, i.e., v_1, can be obtained as follows:

$$\boxed{v_1 = v_s - v_x} \quad (***)$$

where then, accordingly, the current i_1 which passes through 1kΩ and R_x resistances can be developed in the following way:

$$i_1 = \frac{v_1}{1000} = \frac{v_2}{R_x} \xrightarrow[\text{and } (***)]{\text{by } (**)} \boxed{\frac{v_s - v_x}{1000} = \frac{1001 v_x}{R_x}} \quad (\star)$$

Therefore according to eqn ($\star$), we can find the following relationship b/w v_s and v_x: $\frac{v_s}{1000} = \frac{v_x}{1000} + \frac{1001}{R_x} v_x \Rightarrow v_s = 1000\left(\frac{1}{1000} + \frac{1001}{R_x}\right) v_x$

$$\Rightarrow v_s = \frac{R_x + 1001}{R_x} v_x \Rightarrow \boxed{\frac{v_x}{v_s} = \frac{R_x}{R_x + 1001000}} \; (**)$$

Therefore, recalling eqn (*), we get:

$$i_o = -\frac{v_x}{2.2} \xRightarrow{\text{By}(**)} i_o = -\frac{1}{2.2}\left(\frac{R_x}{R_x + 1001000}\right) v_s$$

$$\Rightarrow \boxed{\frac{i_o}{v_s} = \frac{-R_x}{2.2R_x + 2202200}} \; (+)$$

(b) Provided (+), obtained in the previous part of the problem, we shall find R_x such that $\frac{i_o}{v_s} = -0.227$ in the following way:

$$\frac{-R_x}{2.2R_x + 2202200} = -0.227 \Rightarrow R_x = 0.5 R_x + 5\times10^5$$

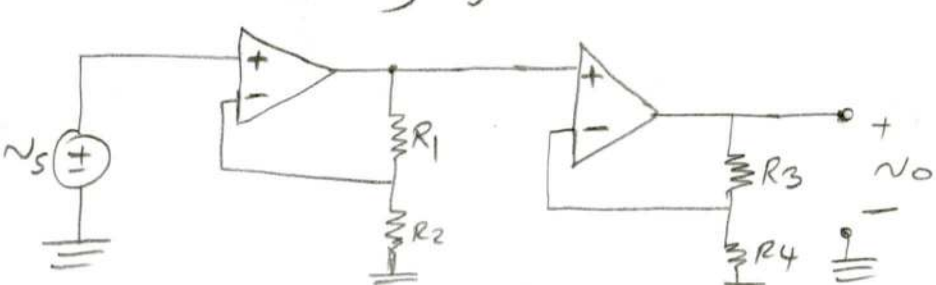
$$\Rightarrow \boxed{R_x = 1000 \, k\Omega}$$

prob 4-24:

According to the problem statement, we would like to design OPAMP Circuit using standard 1% tolerance resistors maintaining selected values of voltage gains. In order to proceed, we shall categorize the voltage gains into positive and negative values and treat them in the following two points, where K stands for the voltage gain.

→ Positive-valued voltage gains:

(*) $K = 200$: for this case, we have designed a circuit using two noninverting OPAMP circuits as shown in the following figure:



therefore, recalling noninverting OPAmp gain and provided these 2 circuits are connected in series, the overall gain of this circuit would be obtained as follows:

$$K_{tot} = \left(\frac{R_1 + R_2}{R_2} \right) \times \left(\frac{R_3 + R_4}{R_4} \right)$$

where, on the other hand, we would like to maintain $K = 200$, therefore, we need to choose the resistances R_1, R_2, R_3 and R_4 such that the following holds:

$$\frac{R_1 + R_2}{R_2} \times \frac{R_3 + R_4}{R_4} = 200$$

Hence, w/o loss of generality, we can consider the following:

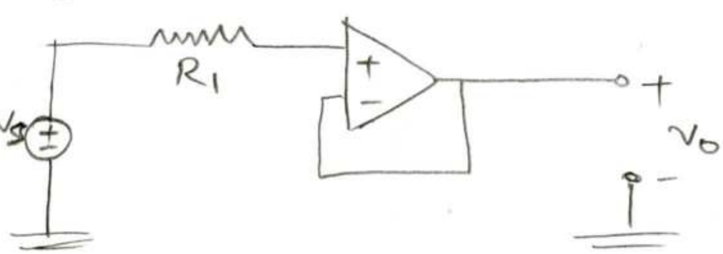
$$\begin{cases} \dfrac{R_1 + R_2}{R_2} = 10 \Rightarrow \underline{R_1 = 9R_2} \quad (*) \\ \dfrac{R_3 + R_4}{R_4} = 20 \Rightarrow \underline{R_3 = 19R_4} \quad (**) \end{cases}$$

Provided (*) and (**) and recalling standard values for 10% resistance, we have considered the following values for these resistances:

$\underline{R_2 = 10\Omega}$ $\underline{R_1 = 90\,\Omega = 9 \times 10\Omega \text{ (9 resistances of } 10\Omega \text{ in series)}}$

$\underline{R_4 = 10\Omega}$ $\underline{R_3 = 190\Omega = 19 \times 10\Omega \text{ (19 resistances of } 10\Omega \text{ in series)}}$

(*) $K = 1$: For this case, we have selected the buffer circuit, as shown in the following figure:

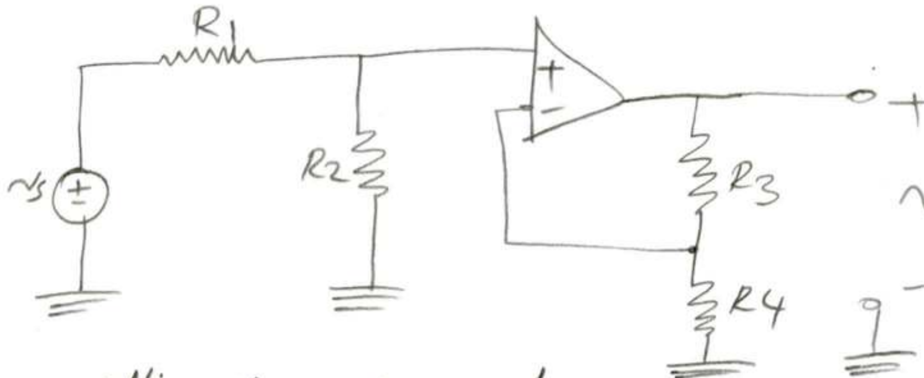


where recalling buffer gain, the following holds:

$$\frac{v_o}{v_s} = 1$$

which satisfies the design requirement. Resistance R_1 can be chosen to be $R_1 = 10\,\Omega$ which is one of the 10% standard resistances.

(*) $K = 0.5$: for this case, we have designed a circuit similar to Ex. 4-13 and as drawn in the following figure:



for which, recalling the analysis of Ex. 4-13, the following gain holds:

$$K_{tot} = \frac{R_2}{R_1 + R_2} \times \frac{R_3 + R_4}{R_4}$$

where we would like to ensure $K_{tot} = 0.5$, therefore the following needs to hold:

$$\frac{R_2}{R_1 + R_2} \times \frac{R_3 + R_4}{R_4} = 0.5$$

Then, in order to ensure the above and provided resistances are positive-valued quantities, we have considered:

$$\begin{cases} \dfrac{R_2}{R_1 + R_2} = 0.25 \Rightarrow \underline{R_1 = 3R_2} \\ \dfrac{R_3 + R_4}{R_4} = 2 \Rightarrow \underline{R_3 = R_4} \end{cases}$$

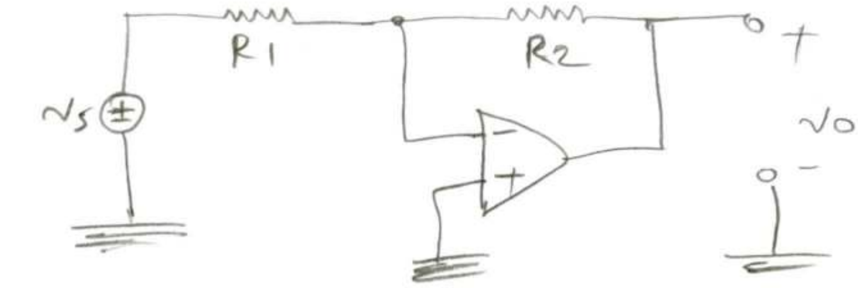
therefore, referring to the standard resistance values of 10% tolerance, we can pick:

$$\underline{R_2 = 10\,\Omega,\ R_1 = 30\,\Omega = 3 \times 10\,\Omega}\ \text{(3 resistances of } 10\,\Omega \text{ in series)}$$

$$\underline{R_3 = 10\,\Omega,\ R_4 = 10\,\Omega}$$

→ Negative-valued voltage gains:

(*) $K = -100$: for this case, we have designed an inverting op Amp circuit as shown in the following figure:



where recalling inverting opamp gain, the following holds:

$$K_{tot} = -\frac{R_2}{R_1}$$

we also would like to ensure $K_{tot} = -100$, therefore we obtain:

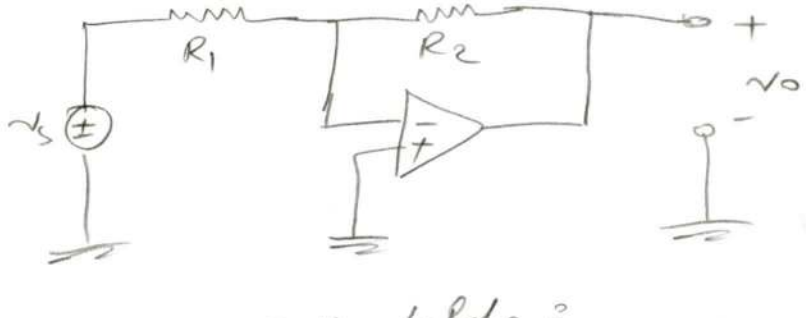
$$\frac{-R_2}{R_1} = -100 \Rightarrow \boxed{\frac{R_2}{R_1} = 100}$$

In order to satisfy the above, we have chosen:

$$\begin{cases} R_2 = 10 \times 150\,\Omega = 10\,(68+82)\,\Omega = \text{10 series of } 68\,\Omega \text{ and } 82\,\Omega \text{ resistances} \\ R_1 = 15\,\Omega \end{cases}$$

we also note that 15, 68, and 82 Ω resistances are amongst the standard 10% values of resistances.

(*) $K = -0.5$: for this case, we again consider an inverting opamp circuit as shown in the following figure:



for which the following gain holds:

$$K_{tot} = -\frac{R_2}{R_1}$$

where we would like to ensure $K_{tot} = -0.5$, therefore:

$$-0.5 = -\frac{R_2}{R_1} \Rightarrow \boxed{\frac{R_2}{R_1} = 0.5}$$

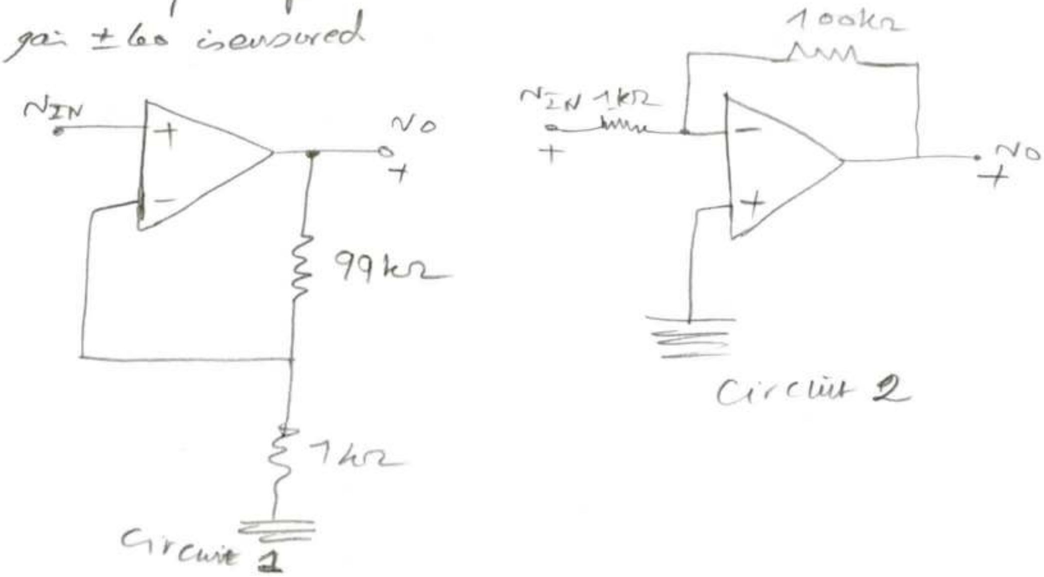
in order to satisfy the latter eq'n, we have considered the following values for resistances:

$$\begin{cases} R_2 = 10\Omega \\ R_1 = 20\Omega = 2\times 10\Omega \equiv 2 \text{ resistances of } 10\Omega \text{ in series} \end{cases}$$

■

problem 4-25:

(a) for the two op-amp circuits shown below, we would like to show that either gain ± 100 is ensured



(Circuit 1): let first $R_1 = 99k\Omega$, $R_2 = 1k\Omega$, then we note that this circuit is indeed the non-inverting opamp circuit for which the following holds:

$$K_1 = \frac{R_1 + R_2}{R_2}$$

therefore, for circuit 1 and provided $R_1 = 99k\Omega$, $R_2 = 1k\Omega$ the following holds:

$$k_1 = \frac{99k + 1k}{1k} \Rightarrow \boxed{k_1 = 100} \ (*)$$

(Circuit 2): let first $R_1 = 1k\Omega$ and $R_2 = 100k\Omega$, then we note that this circuit is indeed the inverting opamp circuit for which the following holds:

$$K_2 = -\frac{R_2}{R_1}$$

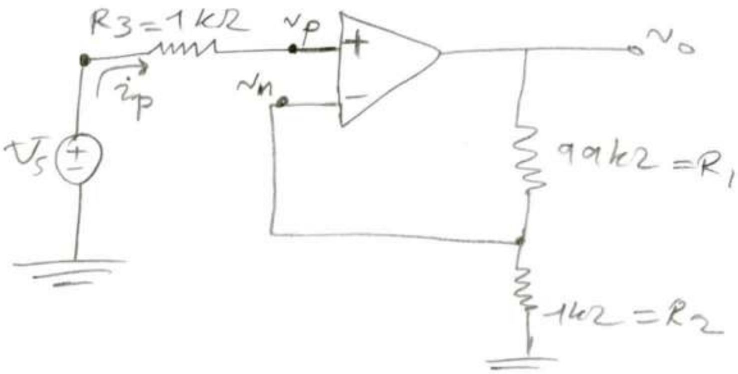
therefore, for circuit 2 and provided $R_1 = 1k\Omega$ and $R_2 = 100k\Omega$ the following holds:

$$k_2 = -\frac{100k}{1k} \Rightarrow \boxed{k_2 = -100} \ (**)$$

Having derived eq'ns (*) and (**), the claim is shown to be true. That's to say these circuits produce gain of either ± 100.

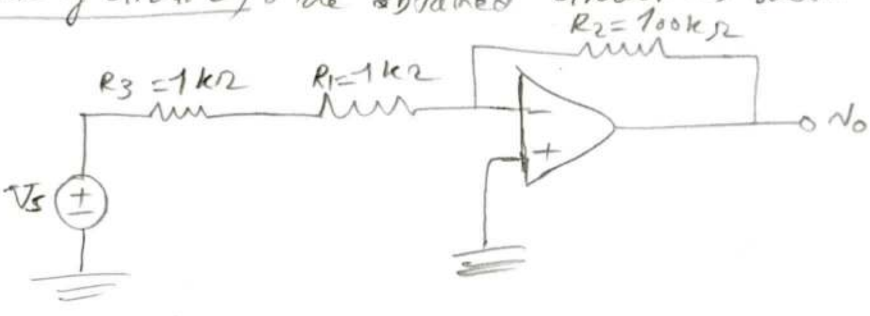
(b) Recalling Circuits 1 and 2 as discussed in the previous part of the problem, we consider in this part of the problem the connection of the circuits w/ a practical voltage source of V_s connected in series w/ 1 kΩ resistor. This is discussed below.

(Connection of Circuit 1): The obtained circuit is shown below:



We first note that provided it is an ideal op amp, therefore, $i_p = 0\,A$, therefore, referring to the circuit, there would be no voltage drop across $R_3 = 1\,k\Omega$ resistance, i.e., $v_p = v_s$. Having noted this fact, it is sufficient to recall what stated in the first part of this problem to conclude $\boxed{K_1 = 100}$. (★)

(Connection of circuit 2): The obtained circuit is shown below:



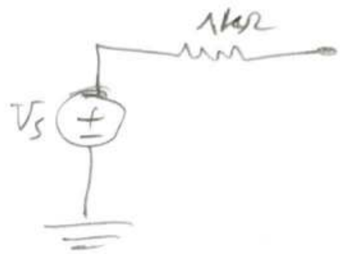
In this case, R_1 and R_3 can be treated as 2 resistances connected in series with the equivalent resistance of $R_1 + R_3 = 2\,k\Omega$. Therefore, the new gain for this inverting op amp is:

$$K_2 = -\frac{R_2}{R_1 + R_3} = -\frac{100k}{2k} \Rightarrow \boxed{K_2 = -50} \quad (★★)$$

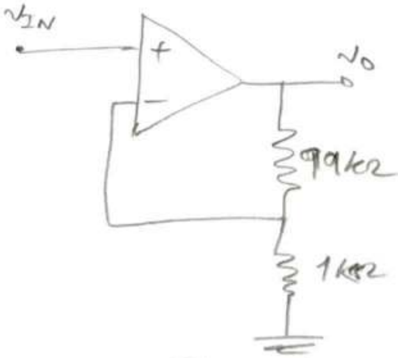
Having derived eq'ns (★) and (★★), we now conclude that for the case of connected circuits, the original claim holds true only for circuit 1, thus not circuit 2.

problem 4_26:

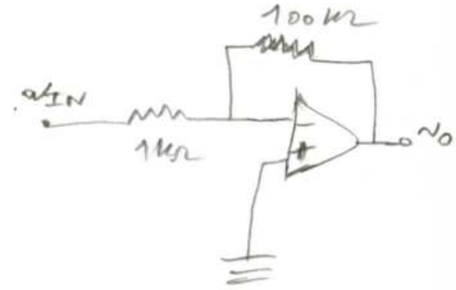
According to the problem statement, we would like to ensure the overall gain of $\frac{v_o}{v_s} = -10^4$ by properly connecting "Source", "Circuit 1", and "Circuit 2" which are shown below:



Source



Circuit 1

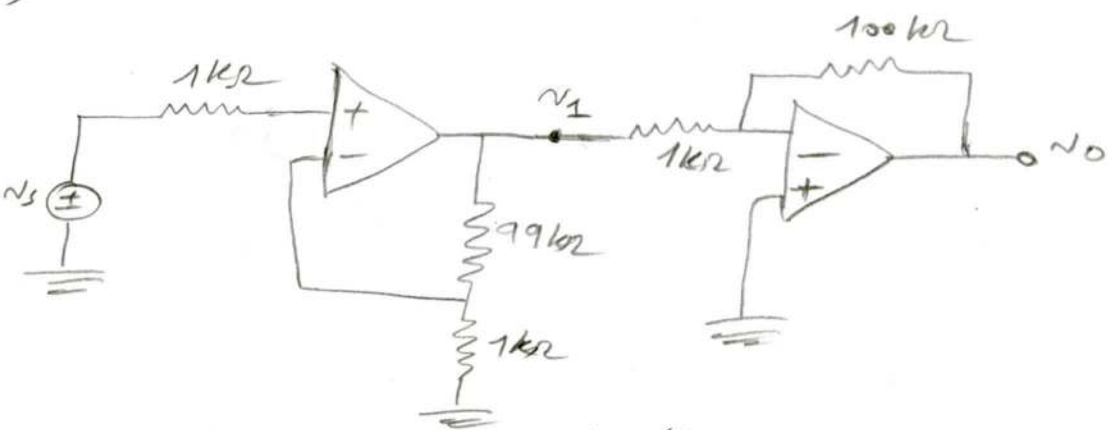


Circuit 2

we note that 2 possibilities may be considered, i.e., [possibility #1: Source - Circuit 1 - Circuit 2] and [possibility #2: Source - Circuit 2 - Circuit 1]. In what follows we shall study these 2 possibilities addressing whether gain of $\frac{v_o}{v_s} = -10^4$ can be ensured.

(possibility #1: Source - Circuit 1 - Circuit 2):

The following circuit will be obtained:



First, we recall what we explained in problem 4_25:

$$K_1 = \frac{v_1}{v_s} = 100 \quad , \quad K_2 = \frac{v_o}{v_1} = -100$$

therefore, the overall gain is obtained as follows:

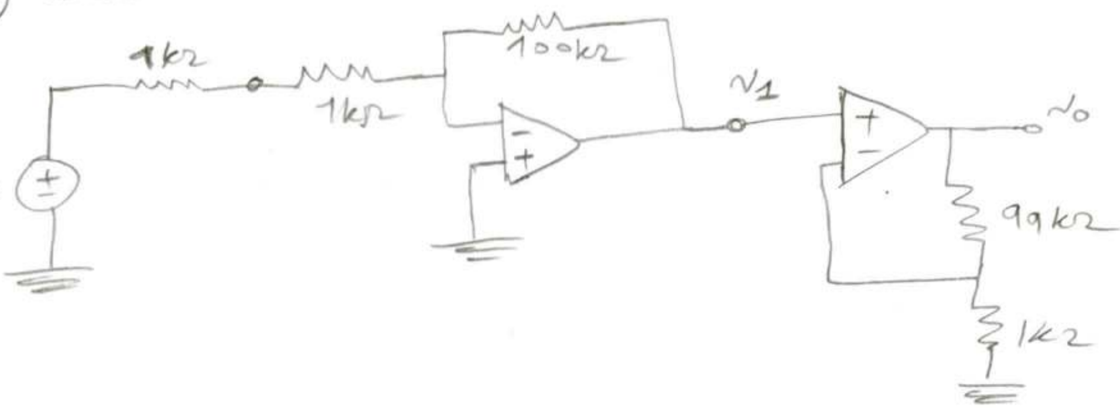
$$K_{tot} = \frac{v_o}{v_s} = \frac{v_o}{v_1} \times \frac{v_1}{v_s} = K_2 \times K_1 = (-100) \times (100)$$

$$\Rightarrow \boxed{K_{tot} = -10^4} \quad (*)$$

Let us now study possibility #2.

(possibility # 2: Source – Circuit 2 – Circuit 1):

The following circuit will be obtained:



Firstly we recall what we explained in problem 4-25, in particular, in part (b) for (connection of circuit 2):

$$k_1 = \frac{v_1}{v_s} = -50 \quad , \quad k_2 = \frac{v_o}{v_1} = 100$$

therefore, the overall gain is obtained is obtained as follows:

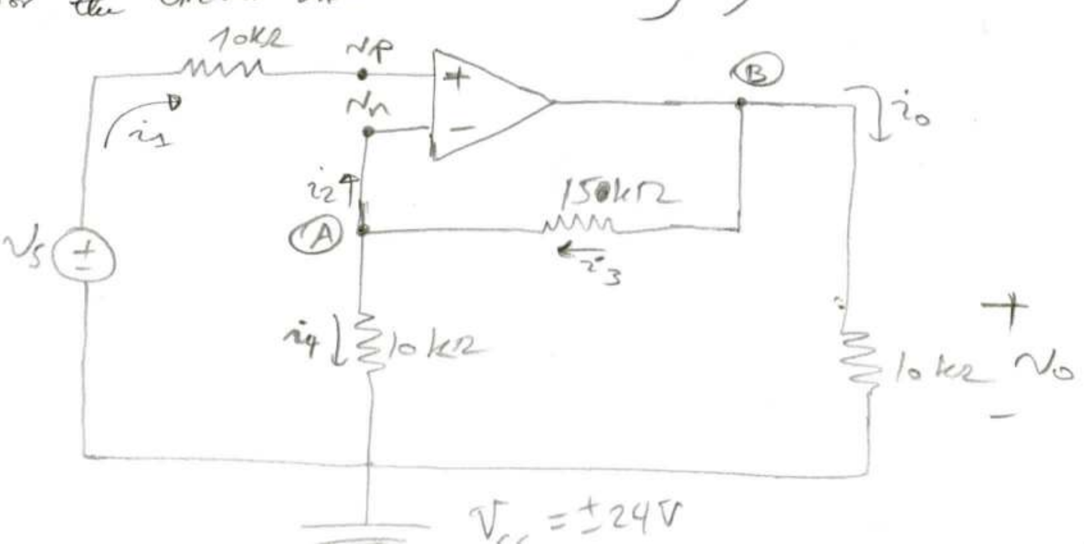
$$k_{tot} = \frac{v_o}{v_s} = \frac{v_o}{v_1} \times \frac{v_1}{v_s} = K_2 \times k_1 = (+100) \times (-50)$$

$$\Rightarrow \boxed{k_{tot} = -5000} \quad (**)$$

Hence, having derived (*) and (**), and provided the desired gain is -10^4, therefore, we conclude that (possibility # 1: source – circuit 1 – circuit 2) has to be considered.

problem 4-30:

(a) For the circuit shown in the following figure:



we would like to find v_o in terms of v_s. In order to proceed, we shall first note that provided we are considering an ideal opamp, then $i_1 = i_2 = 0$, based on which we can derive the following:

$i_1 = 0 \Rightarrow$ no voltage drop across $10k\Omega$ resistance connected to the positive terminal $\Rightarrow v_p = v_s$

provided we are considering an ideal op-amp $\Rightarrow v_n = v_p$

$i_2 = 0 \Rightarrow v_A = v_n$

$\Rightarrow \boxed{v_A = v_s}$ (*)

Given eq'n (*), we can find the current, i_4: $i_4 = \frac{v_A - 0}{10k} \overset{(*)}{\Rightarrow} \boxed{i_4 = \frac{v_s}{10} mA}$ (**)

Then KCL at node (A), provided $i_2 = 0 \Rightarrow i_3 = i_4 \overset{(**)}{\Rightarrow} \boxed{i_3 = \frac{v_s}{10} mA}$ (***)

We note that, on the other hand, i_3 can be obtained by developing voltage drop across $150k\Omega$ resistance $\Rightarrow \boxed{i_3 = \frac{v_B - v_A}{150} mA}$ (****)

By (***), (****) and recalling (*), we get:

$$\frac{v_B - v_s}{150} = \frac{v_s}{10} \Rightarrow v_B - v_s = 15 v_s \Rightarrow \boxed{v_B = 16 v_s} \ (\star)$$

Also referring to the circuit, we note $v_o = v_B - 0 \overset{(\star)}{\Rightarrow} \boxed{v_o = 16 v_s}$ ($\star\star$)

(b) In here, we would like to find i_o for $v_s = 1$ v and $v_s = 3$V. In order to proceed, we recall eq'n ($\star\star$), where according to the circuit results in the following:

$$\boxed{i_o = \frac{v_o}{10k}}$$

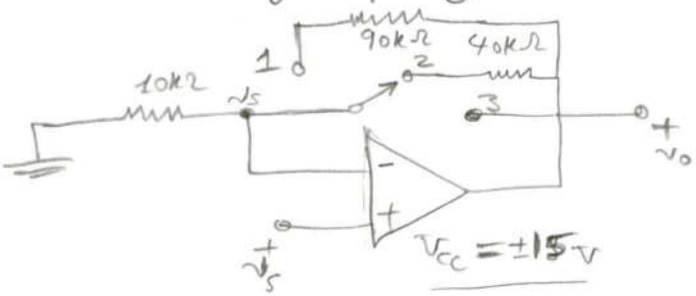
Therefore,

$v_s = 1\text{v} \overset{(\star\star)}{\Rightarrow} v_o = 16 \times 1 = 16\text{V} \Rightarrow i_o = \frac{16}{10k} \Rightarrow \boxed{i_o = 1.6 mA}$

$v_s = 3\text{V} \overset{(\star\star)}{\Rightarrow} v_o = 16 \times 3 = 48\text{V}$, therefore opamp is saturated in this case, i.e., $v_o = V_{cc} = 24\text{V} \Rightarrow i_o = \frac{24}{10k} \Rightarrow \boxed{i_o = 2.4 mA}$

proble 4-32:

According to the problem statement, we would like to assess the circuit shown in the following figure, in terms of amplifying an input voltage of 2V, w/ gains of 1, 5, and 10.



Let first the resistance on the f/b line of the op-amp be $R k\Omega$, then the gain provided by this op-amp circuit can be derived as follows:

$$\frac{v_s}{10k} = \frac{v_o - v_s}{Rk} \Rightarrow \frac{R}{10} v_s = v_o - v_s \Rightarrow v_o = \left(\frac{R}{10} + 1\right) v_s$$

$$\Rightarrow \boxed{k = \frac{v_o}{v_s} = \frac{R}{10} + 1} \quad (*)$$

This is provided for an ideal opamp the voltage of the positive and negative terminals are equal and that there is zero current on the negative terminal.

Hence, by (*) and for three values of resistances associated to three positions of the switch, we obtain the following values for the gain:

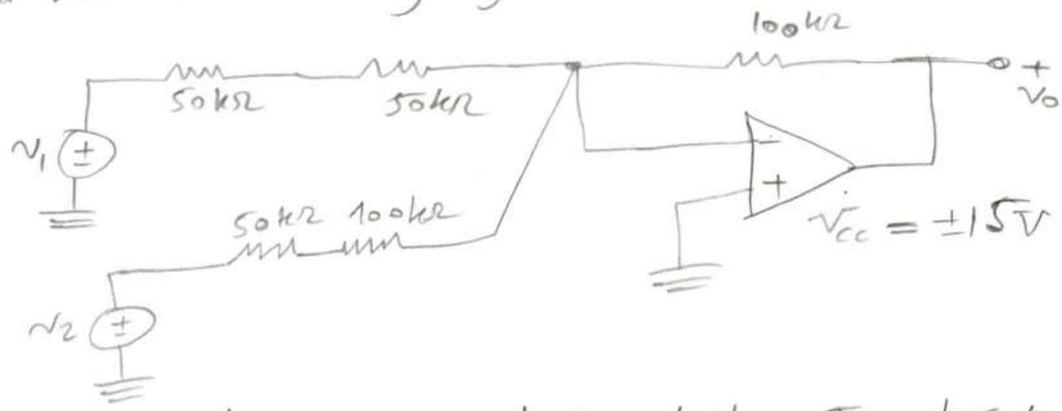
$$\begin{cases} R_1 = 90 k\Omega \Rightarrow \underline{k_1 = 10} \\ R_2 = 40 k\Omega \Rightarrow \underline{k_2 = 5} \\ R_3 = 0 k\Omega \Rightarrow \underline{k_3 = 1} \end{cases}$$

Therefore, it seems that the three required gains have been fulfilled. However, the design is not correct b/c for $k_1 = 10$ saturation occurs, i.e., $v_o = k_1 v_s = 10 \times 2 = 20 V$ which exceeds the saturation voltage of $V_{cc} = 15V$.

One way to fix the aforementioned issue of the design is to consider an opamp with higher value of V_{cc}. E.g., $V_{cc} = \pm 24 V$ works well for this design provided $v_o = 20V \leq 24V$.

Problem 4_34:

(a) For the circuit shown in the following figure:



we would like to find v_o in terms of v_1 and v_2. In order to proceed, we first note that the considered circuit is an inverting summing amplifier, for which we can derive the following.

$$\left.\begin{array}{l} \text{let } R_F = 100k\Omega \\ R_1 = 50k\Omega + 50k\Omega = 100k\Omega \\ R_2 = 50k\Omega + 100k\Omega = 150k\Omega \end{array}\right\} \Rightarrow v_o = k_1 v_1 + k_2 v_2 = \left(-\frac{R_F}{R_1}\right) v_1 + \left(-\frac{R_F}{R_2}\right) v_2$$

$$\Rightarrow v_o = \left(-\frac{100k}{100k}\right) v_1 + \left(-\frac{100k}{150k}\right) v_2 \Rightarrow \boxed{v_o = -v_1 - \frac{2}{3} v_2} \quad (*)$$

(b) Having derived (*), we would like to see that w/ $v_1 = 1V$, for which values of v_2, we do not see saturation in op-amp. In order to proceed, we recall that $V_{cc} = \pm 15V$ for this opamp therefore, saturation does not occur if $-15 \leq v_o \leq 15$, hence by (*) and $v_1 = 1v$, we get:

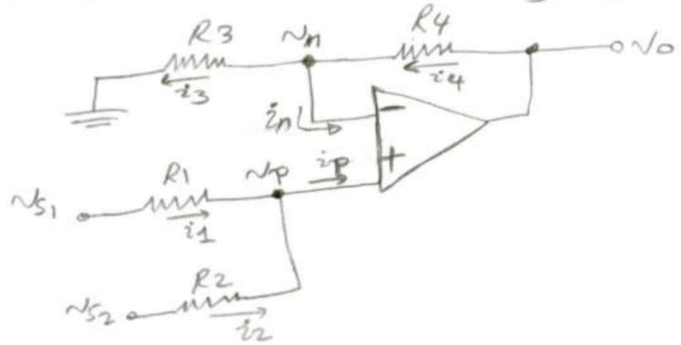
$$v_o = -1 - \frac{2}{3} v_2 \Rightarrow -15 \leq -1 - \frac{2}{3} v_2 \leq 15 \Rightarrow -14 \leq -\frac{2}{3} v_2 \leq 16$$

$$\Rightarrow \left\{\begin{array}{l} \frac{2}{3} v_2 \geq -16 \Rightarrow \underline{v_2 \geq -24v} \\ \frac{2}{3} v_2 \leq 14 \Rightarrow \underline{v_2 \leq 21v} \end{array}\right\} \Rightarrow \boxed{-24v \leq v_2 \leq 21v} \quad (**)$$

Therefore, for the range of v_2 described in (**), saturation in opamp would not occur.

problem 4-38:

For the circuit shown in the following figure:



we would like to find v_o in terms of v_{s1} and v_{s2}. In order to proceed, we shall first note that provided it is an ideal opamp, then $v_n = v_p$, and $i_n = i_p = 0$. The next computation would be as follows:

$$\left.\begin{array}{l} \text{kcl at } p: \; i_1 + i_2 = i_p = 0 \\ \text{voltage drop across } R_1: \; i_1 = \dfrac{v_{s1} - v_p}{R_1} \\ \text{voltage drop across } R_2: \; i_2 = \dfrac{v_{s2} - v_p}{R_2} \end{array}\right\} \Rightarrow \frac{v_{s1} - v_p}{R_1} + \frac{v_{s2} - v_p}{R_2} = 0$$

$$\Rightarrow v_p \left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{v_{s1}}{R_1} + \frac{v_{s2}}{R_2} \Rightarrow \boxed{v_p = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} \left(\frac{v_{s1}}{R_1} + \frac{v_{s2}}{R_2}\right)} \; (*)$$

$$\left.\begin{array}{l} \text{kcl at } n: \; i_4 = i_n + i_3 \xrightarrow{i_n = 0} i_4 = i_3 \\ \text{voltage drop across } R_3: \; i_3 = \dfrac{v_n - 0}{R_3} \\ \text{voltage drop across } R_4: \; i_4 = \dfrac{v_o - v_n}{R_4} \end{array}\right\} \Rightarrow \frac{v_o - v_n}{R_4} = \frac{v_n}{R_3}$$

$$\Rightarrow \boxed{v_o = v_n \left(1 + \frac{R_4}{R_3}\right)} \; (**)$$

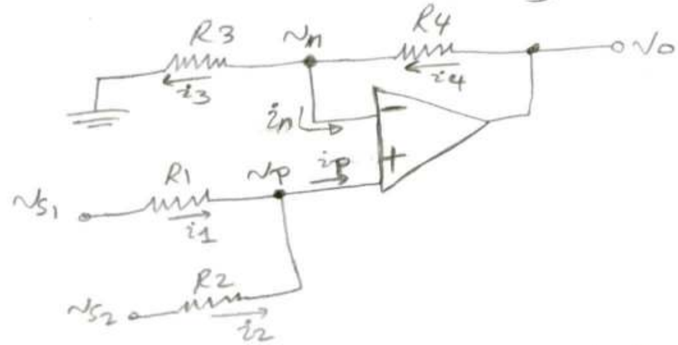
By (*), (**) and that $v_n = v_p$, we get:

$$v_o = \left(\frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} \left(\frac{v_{s1}}{R_1} + \frac{v_{s2}}{R_2}\right)\right)\left(1 + \frac{R_4}{R_3}\right) = \frac{R_1 R_2}{R_1 + R_2} \left(\frac{v_{s1}}{R_1} + \frac{v_{s2}}{R_2}\right)\left(\frac{R_3 + R_4}{R_3}\right)$$

$$\Rightarrow \boxed{v_o = \frac{R_1 R_2}{R_3} \left(\frac{R_3 + R_4}{R_1 + R_2}\right)\left(\frac{v_{s1}}{R_1} + \frac{v_{s2}}{R_2}\right)}$$

problem 4-38:

For the circuit shown in the following figure:



we would like to find v_o in terms of v_{s_1} and v_{s_2}. In order to proceed, we shall first note that provided it is an ideal op-amp, then $v_n = v_p$, and $i_n = i_p = 0$. The next computation would be as follows:

$$\left.\begin{array}{l} \text{KCL at } p: \; i_1 + i_2 = i_p = 0 \\ \text{voltage drop across } R_1: \; i_1 = \dfrac{v_{s_1} - v_p}{R_1} \\ \text{voltage drop across } R_2: \; i_2 = \dfrac{v_{s_2} - v_p}{R_2} \end{array}\right\} \Rightarrow \frac{v_{s_1} - v_p}{R_1} + \frac{v_{s_2} - v_p}{R_2} = 0$$

$$\Rightarrow v_p\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{v_{s_1}}{R_1} + \frac{v_{s_2}}{R_2} \Rightarrow \boxed{v_p = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}\left(\frac{v_{s_1}}{R_1} + \frac{v_{s_2}}{R_2}\right)} \quad (*)$$

$$\left.\begin{array}{l} \text{KCL at } n: \; i_4 = i_n + i_3 \xrightarrow{i_n = 0} i_4 = i_3 \\ \text{voltage drop across } R_3: \; i_3 = \dfrac{v_n - 0}{R_3} \\ \text{voltage drop across } R_4: \; i_4 = \dfrac{v_o - v_n}{R_4} \end{array}\right\} \Rightarrow \frac{v_o - v_n}{R_4} = \frac{v_n}{R_3}$$

$$\Rightarrow \boxed{v_o = v_n\left(1 + \frac{R_4}{R_3}\right)} \quad (**)$$

By (*), (**) and that $v_n = v_p$, we get:

$$v_o = \left(\frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}\left(\frac{v_{s_1}}{R_1} + \frac{v_{s_2}}{R_2}\right)\right)\left(1 + \frac{R_4}{R_3}\right) = \frac{R_1 R_2}{R_1 + R_2}\left(\frac{v_{s_1}}{R_1} + \frac{v_{s_2}}{R_2}\right)\left(\frac{R_3 + R_4}{R_4}\right)$$

$$\Rightarrow \boxed{v_o = \frac{R_1 R_2}{R_4}\left(\frac{R_3 + R_4}{R_1 + R_2}\right)\left(\frac{v_{s_1}}{R_1} + \frac{v_{s_2}}{R_2}\right)}$$