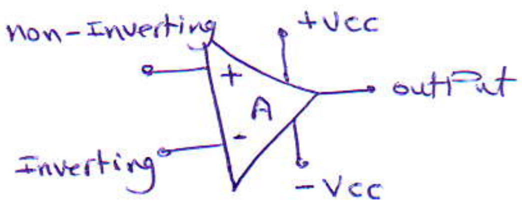
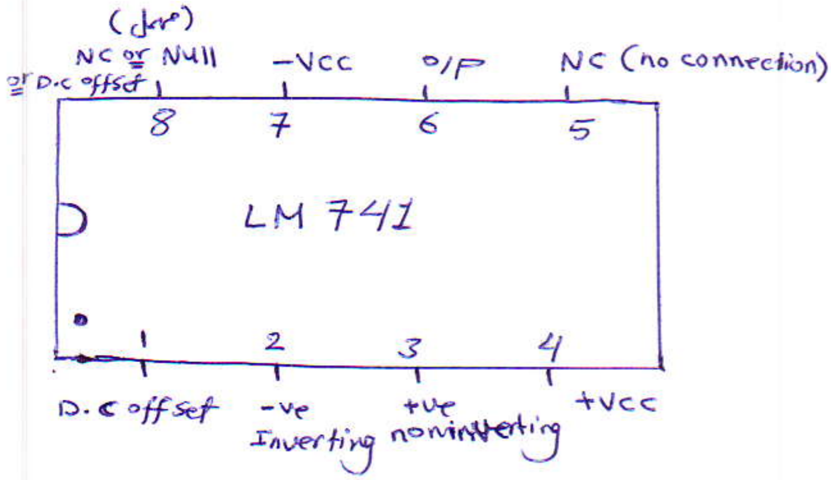
Opertional Amplifier:

It is an integrated Circuit (IC) cosisting of transistors, diodes, resistors, ... etc and Can be called (op-amp).





A: open loop gain

and we use negative F.B $\quad G = \dfrac{A}{1+\beta A}$ (Closed loop gain)

* OP-Amp Specification:

① High input impedance (Idealy $R_i = \infty$).

② Low output impedance ($R_o \simeq 70\,\Omega$ in 741 op-amp)

③ $A \simeq 1 * 10^5$ open loop gain (Idealy $A \simeq \infty$).

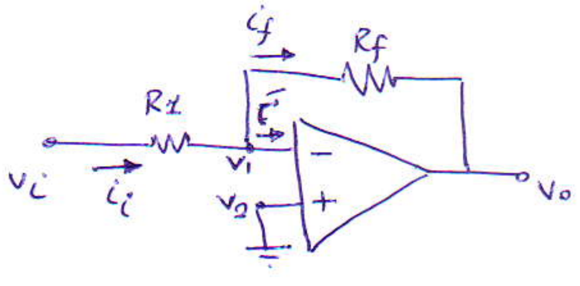
④ Better stability gain

⑤ Frequency response improvement

⑥ Reduce noise

Practical op-Amp circuits:

① Inverting Amplifier:



* عندما يكون الإدخال الى (−) والجزء الموجب الى الـ ground ونوع الـ F.B هو (Voltage − shunt)

$V_o = A(\underset{(+)}{V_2} - \underset{(-)}{V_1}) \Rightarrow V_2 - V_1 = \frac{V_o}{A}$ (A ideally $\simeq \infty$)

$\therefore V_2 - V_1 = \frac{V_o}{\infty} = 0 \Rightarrow V_2 = V_1$ (Virtual ground)

* بما ان V_2 مربوطة الى الارض والتوضيح اعلاه اثبت ان $V_2 = V_1$ وبالتالي فان V_1 كذلك يعتبر مربوط الى الارض وهذه الحالة تسمى الأرضي الوهمي (Virtual ground) بمعنى كأن نقطة V_1 مربوطة الى الأرضي وبالتالي فانها تساوي صفر

$\bar{i} \simeq 0$ because of $R_i \simeq \infty$

$\Rightarrow i_i = \frac{V_i - \cancel{V_1}^{\,0}}{R_1} = \frac{V_i}{R_1}$ ... ①

$\because V_o = \cancel{V_1}^{\,0} - i_f R_f$ and $\because i_i = i_f$ because of $\bar{i} = 0$

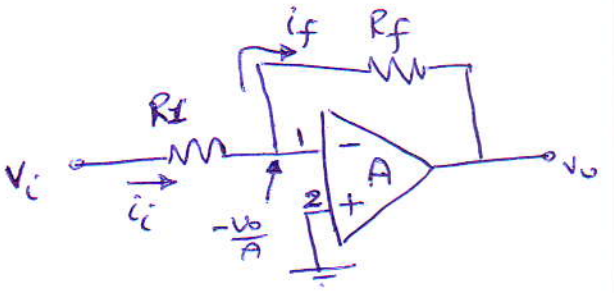
$= -i_i R_f$ .... ② Substitution ① in ② and we get:

$\Rightarrow V_o = \frac{-V_i}{R_1} * R_f \Rightarrow \boxed{\frac{V_o}{V_i} = -\frac{R_f}{R_1}}$ ① Phase shift 180° ② Closed loop gain

* [$100 < R_1, R_f < 100k\Omega$] في هذا التصميم يجب اختيار قيم المقاومات تتراوح بين القيم $100k\Omega$ و 100Ω لتجنب مرور تيار عالي ضمن الـ op-Amp عند القيم القليلة للمقاومات.

* بالإمكان التحكم بالكسب من خلال مقاومة الـ R_f و R_1 وبالإمكان جعل مقاومة الـ R_f متغيرة لغرض زيادة الكسب او تقليله.

* Effect of finit open loop gain :



* عندما نوضح علاقة الكسب ضمن الـ OP-Amp فان الكسب لا يكون (∞) وانما محدد ومنه الان نشتق تأثير الكسب المحدد على الـ close loop gain

for finite A :

$$V_o = A(\cancel{V_2}^{\,0} - V_1) \Rightarrow \boxed{V_1 = \frac{-V_o}{A}}$$

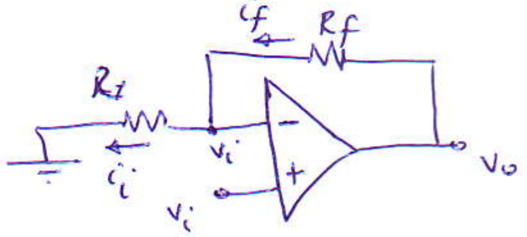
$$i_i = \frac{V_i - (-\frac{V_o}{A})}{R_1} = \frac{V_i + \frac{V_o}{A}}{R_1} \quad ; \text{ since } \boxed{i_i = i_f}$$

$$V_o = -\frac{V_o}{A} - i_f R_f \Rightarrow V_o = -\frac{V_o}{A} - \left(\frac{V_i + \frac{V_o}{A}}{R_1}\right) R_f$$

$$\Rightarrow \boxed{\frac{V_o}{V_i} = \frac{-R_f/R_1}{1 + [1 + (R_f/R_1)]/A}}$$

for $A \simeq \infty \Rightarrow \frac{V_o}{V_i} = -\frac{R_f}{R_1}$ and $V_1 = 0$ (Virtual ground).

(2) Non-Inverting Amplifier :



F.B Topology is voltage-series.

for infinite gain $(A \simeq \infty) \Rightarrow V_o = A(V_2 - V_1)$

$$\Rightarrow \cancel{\frac{V_o}{A}}^{\,0} = (V_2 - V_1) \quad \therefore V_2 = V_1 \quad \therefore V_2 = V_i \quad \therefore \boxed{V_1 = V_i}$$

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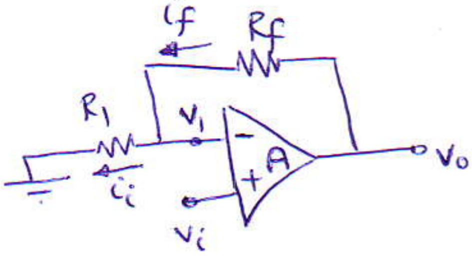
$i_i = \frac{v_i}{R_1}$ and $i_i = i_f$

$\because$ $V_o = V_f + V_i = i_f R_f + V_i$

$\Rightarrow V_o = \frac{V_i}{R_1} R_f + V_i \Rightarrow \boxed{\frac{V_o}{V_i} = 1 + \frac{R_f}{R_1}}$ ① zero phase shift ② closed loop gain

* Effect of finit open loop gain:



$V_o = A(V_2 - V_1)$

$\Rightarrow \frac{V_o}{A} = (V_i - V_1)$

$\Rightarrow \boxed{V_1 = V_i - \frac{V_o}{A}}$

$i_i = i_f = \frac{V_1}{R_1} = \boxed{\frac{V_i}{R_1} - \frac{V_o}{AR_1}}$

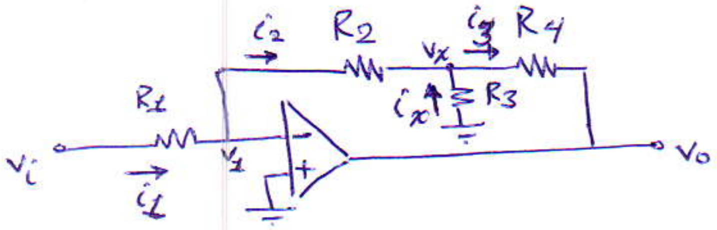
$V_o = V_{R_f} + V_1 = i_f R_f + V_1 = \left(\frac{V_i}{R_1} - \frac{V_o}{AR_1}\right) R_f + V_i - \frac{V_o}{A}$

$\Rightarrow V_o = \frac{V_i R_f}{R_1} - \frac{V_o R_f}{AR_1} + V_i - \frac{V_o}{A} \Rightarrow V_o\left(1 + \frac{R_f}{AR_1} + \frac{1}{A}\right) = V_i\left(1 + \frac{R_f}{R_1}\right)$

$\Rightarrow \boxed{\frac{V_o}{V_i} = \frac{1 + \frac{R_f}{R_1}}{1 + \left[\frac{1 + (R_f/R_1)}{A}\right]}}$ for $A \simeq \infty \Rightarrow \boxed{\frac{V_o}{V_i} = 1 + \frac{R_f}{R_1}}$

* نلاحظ من معادلة الكسب بأن قيمة الكسب تعتمد على قيمة المقاومات فقط.

Ex: For the circuit shown below; $\frac{V_o}{V_i} = -100$; $R_1 = 1M$, use this circuit to design the inverting amp. and do not use resistance greater than $1M\Omega$?



Solution:

$$i_1 = \frac{V_i - V_1^{\,0}}{R_1} = \boxed{\frac{V_i}{R_1}} \qquad \because i_1 = i_2 \quad \text{and} \quad i_x = \frac{0 - V_x}{R_3} = \boxed{\frac{-V_x}{R_3}}$$

$$V_x = V_1^{\,0} - i_2 R_2 = \boxed{-\frac{V_i}{R_1} R_2} \Rightarrow i_x = \boxed{+\frac{V_i}{R_1 R_3} \cdot R_2}$$

$$i_3 = i_2 + i_x = \boxed{\frac{V_i}{R_1} + \frac{V_i}{R_1 R_3} R_2} \qquad \because V_o = V_x - i_3 R_4$$

$$\Rightarrow V_o = -\frac{V_i}{R_1} R_2 - \left(\frac{V_i}{R_1} + \frac{V_i}{R_1 R_3} R_2\right) R_4$$

$$\Rightarrow \frac{V_o}{V_i} = -\frac{R_2}{R_1} - \frac{R_4}{R_1} - \frac{R_2 R_4}{R_1 R_3} \Rightarrow \boxed{\frac{V_o}{V_i} = \frac{-R_2}{R_1}\left[1 + \frac{R_4}{R_2} + \frac{R_4}{R_3}\right]}$$

$$\because \frac{V_o}{V_i} = -100 \quad \text{and } R_1 = 1M\Omega$$

① Assume $R_2 = 1M\Omega$ and $R_4 = 1M\Omega$

$$\Rightarrow -100 = -1\left[1 + \frac{1M}{1M} + \frac{1M}{R_3}\right] \qquad \therefore \boxed{R_3 = 10.2K\Omega}$$

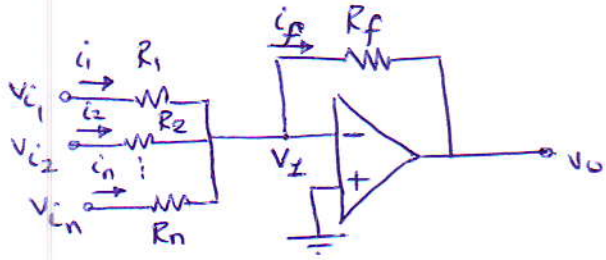
* Operational Amplifier Applications:

① Summing Amplifier:

Probably the most used of op-amp is the summing amplifier circuit and can be called "weighted summer"

$$i_1 = \frac{V_{i_1}}{R_1} \; ; \; i_2 = \frac{V_{i_2}}{R_2}$$

$$i_n = \frac{V_{i_n}}{R_n}$$



$$i_f = i_1 + i_2 + \cdots + i_n$$

$$= \frac{V_{i_1}}{R_1} + \frac{V_{i_2}}{R_2} + \cdots + \frac{V_{i_n}}{R_n}$$

$$V_o = V_I - i_f R_f = -\left(\frac{V_{i_1}}{R_1} + \frac{V_{i_2}}{R_2} + \cdots \frac{V_{i_n}}{R_n}\right) R_f$$ for three inputs

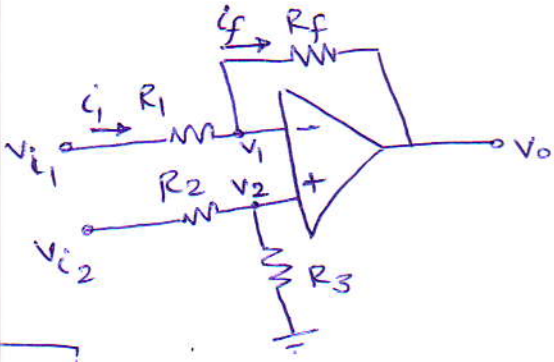
$$\Rightarrow V_o = -\left[\frac{V_{i_1}}{R_1} + \frac{V_{i_2}}{R_2} + \frac{V_{i_3}}{R_3}\right] R_f \quad \left[\text{Assume } V_{i_1} \neq V_{i_2} \neq V_{i_3} \neq V_i\right]$$

Assume $R_1 = R_2 = R_3 = R_f$ and we get

$$\boxed{V_o = -\left(V_{i_1} + V_{i_2} + V_{i_3}\right)}$$

* نلاحظ من الدائره اعلاه بان قيم الإدخالات تم جمعها وبالتالي يمكن استخدام هذه الدائره لجمع قيمة اي فولتية مع اخرى او جمع عدة قيم مع بعضها ، وكذلك يمكن استخدامها لزيادة اي قيمة من الفولتيات الداخله حسب اهميتها وذلك من خلال التحكم بقيمة مقاومة (R_1 او R_2 او R_3) مع قيمة الـ R_f

(2) Subtraction Amplifier:



$V_1 = V_2$ (Virtual ground)

$$V_2 = V_{i_2}\left(\frac{R_3}{R_3+R_2}\right) = V_1$$

$$i_1 = \frac{V_{i_1} - V_1}{R_1} = \boxed{\frac{V_{i_1}}{R_1} - \frac{V_{i_2} R_3}{R_1(R_3+R_2)}}$$

$$\because i_1 = i_f \implies V_o = V_1 - i_f R_f$$

$$\implies V_o = V_{i_2}\left(\frac{R_3}{R_3+R_2}\right) - \left(\frac{V_{i_1}}{R_1} - \frac{V_{i_2} R_3}{R_1(R_3+R_2)}\right) R_f$$

$$\implies V_o = V_{i_2}\left(\frac{R_3}{R_3+R_2} + \frac{R_3 R_f}{R_1(R_3+R_2)}\right) - \left(\frac{V_{i_1} R_f}{R_1}\right)$$

Assume $R_f = R_1$

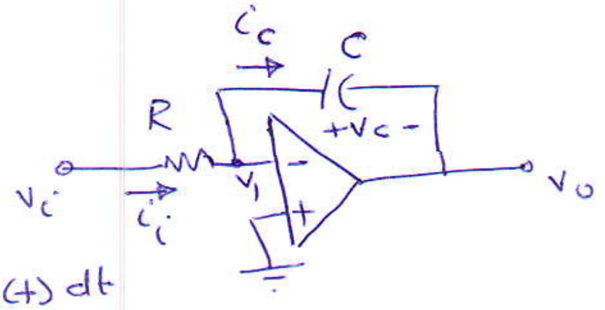
$$\implies V_o = V_{i_2}\left(\frac{R_3}{R_3+R_2} + \frac{R_3}{R_3+R_2}\right) - V_{i_1} = V_{i_2}\left(\frac{2R_3}{R_3+R_2}\right) - V_{i_1}$$

Assume $R_3 = R_2$

$$\therefore \boxed{V_o = V_{i_2} - V_{i_1}}$$

* بالامكان استخدام هذه الدائرة لطرح اي فولتية من اخرى.
* بالامكان ايجاد حل هذه الدائرة بطريقة التراكب superposition

③ Integrator Amplifier:



$$V_{C(t)} = V_{C(intial)} + \frac{1}{C}\int_0^t i_c(t)\,dt$$

$$i_i = \frac{V_i - V_1^{\,0}}{R} = \frac{V_i}{R} \quad \Rightarrow \quad \boxed{i_i = i_c}$$

$$\therefore \; V_o = \cancel{V_1} - V_{c(t)} \Rightarrow V_o = -V_{c\,(intial)} - \frac{1}{C}\int_0^t i_i(t)\,dt$$

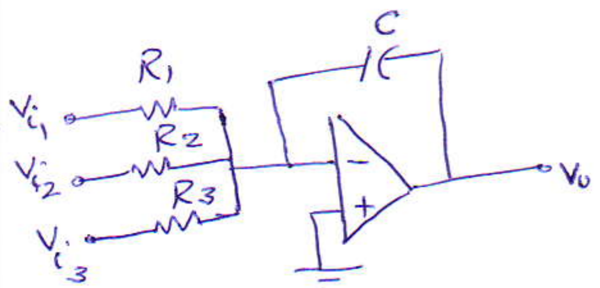
$$\therefore \; \boxed{V_o = -V_{c\,(intial)} - \frac{1}{RC}\int_0^t V_i\,dt}$$

* $V_{c\,(intial)}$: هي عبارة عن الفولتية المخزونة سابقاً في المتسعة جراء عملية الشحن اما اذا كانت المتسعة غير مشحونة فان هذه القيمة تساوي صفر

* بالامكان الملاحظة بان هذه الدائرة تقوم بعملية تكامل للفولتية الداخلة مع فرق طور (180°) وكذلك ضرب بـ factor هو $\frac{1}{RC}$. وكلما كانت قيمة RC قليلة كلما زمن الشحن اسرع.

* Summing Integrator circuit:

$$V_o = -\left[\frac{1}{R_1C}\int_0^t V_{i_1}(t)\,dt + \frac{1}{R_2C}\int_0^t V_{i_2}(t)\,dt + \frac{1}{R_3C}\int_0^t V_{i_3}(t)\,dt\right]$$



* Evaluating Frequency Response of the Amp.:

To evaluate the freq. response of an amp. one has to analyze the amp. circuit model taking into account all reactive component.

1- $Z = R$ —ΛΛΛ—

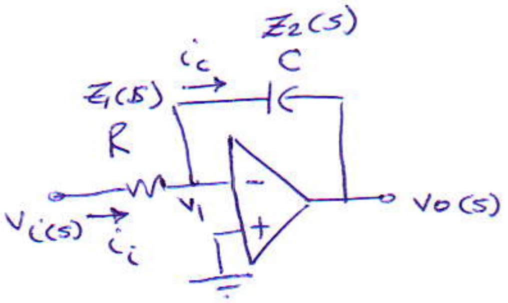
2- $Z = \frac{1}{JWC}$ —|(—

3- $Z = JWL$ —mmm—

by using complex freq. variable ($Jw = s$)

$\Rightarrow Z = \frac{1}{JWC} = \frac{1}{SC}$ and $Z = JWL = SL$

* Analysis Integrator circuit using complex freq.:



$x_C = \frac{1}{SC}$

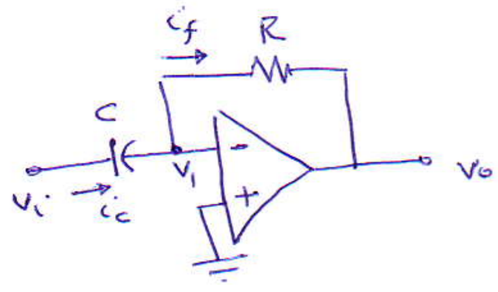
$i_i = \frac{V_i(s)}{R} = i_c$

$\Rightarrow V_{o(s)} = \cancel{V_1}^{\,0} - V_{c(s)} = -i_c Z_2(s)$

$\Rightarrow \mathcal{L}^{-1} V_o(s) = \mathcal{L}^{-1} - \frac{V_i(s)}{RCS}$ Take laplace Inverse for two sides

$\therefore \mathcal{L}^{-1} V_o(s) = \frac{-1}{RC} \mathcal{L}^{-1} \frac{V_i(s)}{s}$ $\Rightarrow$ $\boxed{V_o = -\frac{1}{RC} \int_0^t v_i(t)\, dt}$

(4) Differentiator Amplifier:



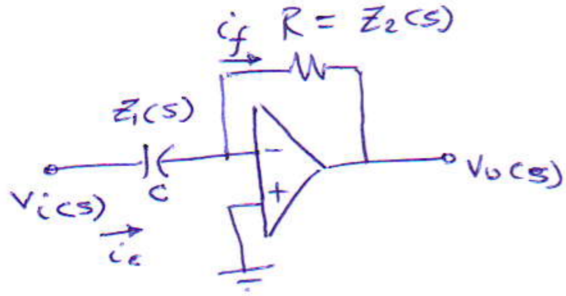
$$i_c = C\frac{dV_i}{dt} = i_f$$

$$V_o = V_1 - V_{R_f} = -i_f R$$

$$\Rightarrow \boxed{V_o = -RC\frac{dV_i}{dt}}$$

* اذن هنه الدائره تقوم باشتقاق الفولتية الداخلة بالاضافة الى فرق طور 180° وبالتالي اذا كان الإدخال مثلا sinx فان مشتقة الـsinx هي cosx ولكن الإخراج سيكون هو cosx- بسبب فرق الطور 180° نتيجة الـInverting بالاضافة الى قيمة الـAmplitude للموجة الداخلة فانه تعتمد بالاساس على قيمة الـ Rc.

* Analysis Differentiator circuit using complex freq.:



$$\frac{V_o(s)}{V_i(s)} = \frac{-Z_2(s)}{Z_1(s)}$$

$$Z_2(s) = R \quad \text{and} \quad Z_2(s) = \frac{1}{sC}$$

$$\Rightarrow V_o(s) = -RCs\,V_i(s)$$

بأخذ للطرفين laplace Inverse

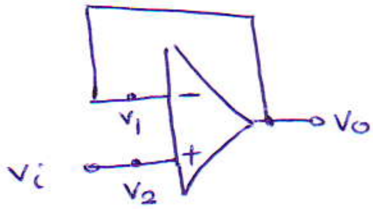
$$\Rightarrow \mathcal{L}^{-1} V_o(s) = -RC\,\mathcal{L}^{-1} s\,V_i(s)$$

$$\therefore \boxed{V_o = -RC\frac{dV_i}{dt}}$$

⑤ Unity Follower:

A unity follower circuit Provides a gain of unity (1) with no Polarity or Phase reversal.

$$\boxed{V_o = V_i}$$



To Prove that we begin from the gain equation:

$$\frac{V_o}{V_i} = 1 + \frac{R_f}{R_1} \to 0 \implies \boxed{V_o = V_i}$$

$$\boxed{R_{inf} = R_{in}(1+A)} \quad \text{and} \quad \boxed{r_{of} = \frac{r_o}{1+A}} \quad D = 1+\beta A \quad \text{but } \beta = 1 \text{ (unity Resistance)}$$

* هذه الطريقة تمكننا من جعل مقاومة الإدخال عالية جداً ومقاومة الإخراج قليلة جداً.

$$V_o = A(\underset{(+)}{V_2} - \underset{(-)}{V_1})$$

$\because V_2 = V_i$ and $V_1 = V_o$

$$\implies V_o = A(V_i - V_o) \implies V_o = AV_i - AV_o$$

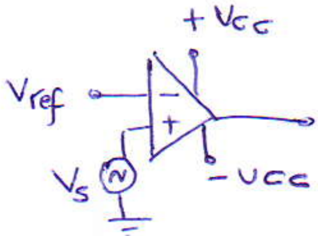
$$\implies V_o(1+A) = AV_i \implies \frac{V_o}{V_i} = \frac{A}{1+A} \simeq 1 \quad \therefore \boxed{V_o = V_i}$$

⑥ comparator:

* Noninverting comparator:

If $V_s > V_{ref} \implies V_o = +V_{cc}$

If $V_s < V_{ref} \implies V_o = -V_{cc}$



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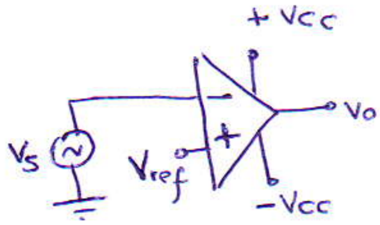
* Inverting comparator:

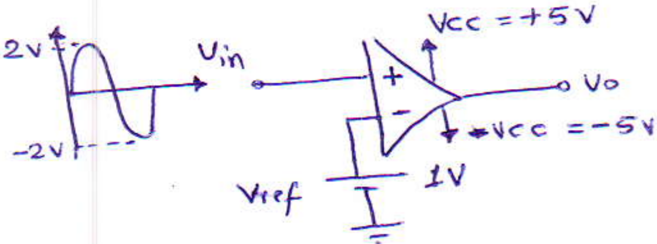
If $V_s > V_{ref} \Rightarrow V_o = -V_{cc}$

If $V_s < V_{ref} \Rightarrow V_o = +V_{cc}$

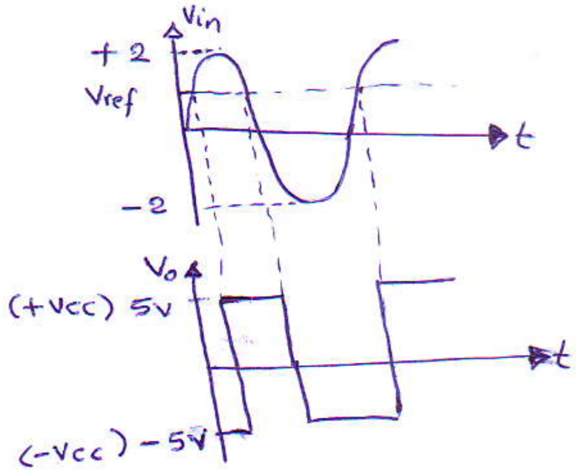


* اذا تم ربط Vref على الارضي فان هذه الدائرة تقوم بكشف Vs عندما تتقاطع مع الصفر فولت وتسمى عندها Zero crossing Detector (ZCD) ويكون الإخراج عبارة عن موجة مربعة.

Ex: For the circuit shown below; if the input voltage is a sinusoidal wave, find the output waveform.

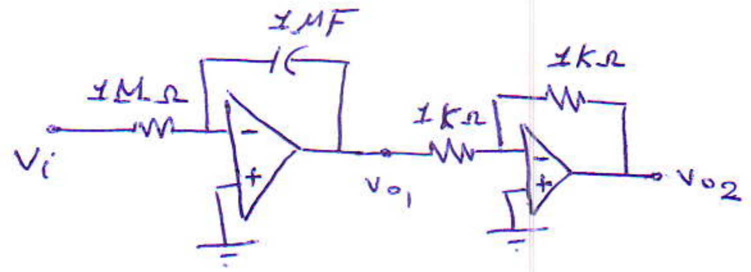


Solution:



H.w: If $V_{ref} = 0$ for the circuit above; find V_o waveform.

Ex: For the circuit shown below; determine the output voltage when V_i equal to: (a) 10 mV (b) 100mV (c) $\sin wt$



Solution:

(a) $V_{o1} = -\frac{1}{RC}\int_0^t V_i(t)\,dt$ $\qquad RC = 1M * 1\mu = 1$

$= -\frac{1}{1}\int_0^t 0.01\,dt = -0.01t$

$V_{o2} = \frac{-R_f}{R_1} V_{o1} = -\frac{1k\Omega}{1k\Omega} * -0.01t = \boxed{0.01t}$

(b) $V_{o1} = \frac{-1}{1}\int_0^t 0.1\,dt = -0.1t$

$V_{o2} = -1 * -0.1t = \boxed{0.1t}$

(c) $V_{o1} = \frac{-1}{1}\int_0^t \sin wt\,dt = \frac{-1}{w}[-\cos wt] = \frac{\cos wt}{w}$

$V_{o2} = (-1)\left(\frac{\cos wt}{w}\right) = \boxed{\frac{-\cos wt}{w}}$

Ex: Design an op-amp circuit to produce $V_o = -(V_1 + 5V_2)$ with max output voltage is 10V and the feedback current is 1mA?

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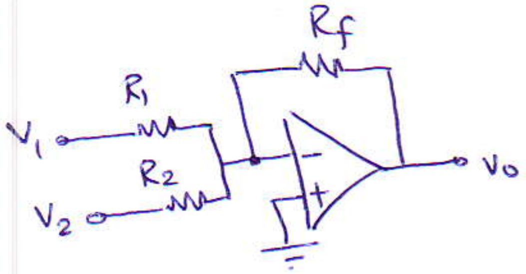
Solution:

$V_o = -(V_1 + 5V_2)$

* من الملاحظ من معادلة الإخراج انها عبارة عن عملية جمع للإدخاليين (V_2 , V_1) اذن الدائرة المستخدمة هي الـ Summing

$V_o = 10V \ , \ I_f = 1mA$

$R_f = \frac{V_o}{I_f} = \frac{10V}{1mA} = \boxed{10k\Omega}$



$V_o = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} \right)$ ← معادلة الـ summing

$\Rightarrow V_o = -10k \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} \right)$ بالمقارنة مع المعادلة المعطاة في السؤال

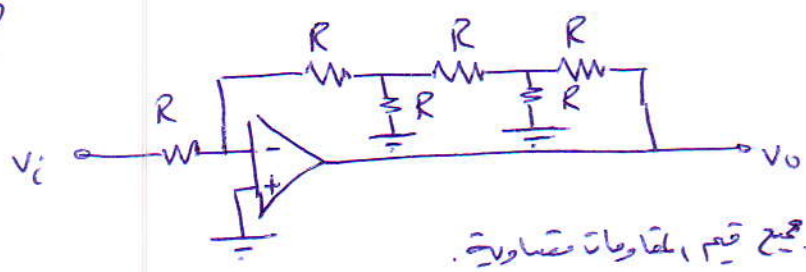
$V_o = -(V_1 + 5V_2)$

* من المقارنة يمكن الاستنتاج ان

$R_f = R_1$ و $\frac{R_f}{5} = R_2$

$\Rightarrow R_1 = R_f = 10k\Omega$ and $R_2 = \frac{R_f}{2} = \frac{10k\Omega}{5} = 2k\Omega$

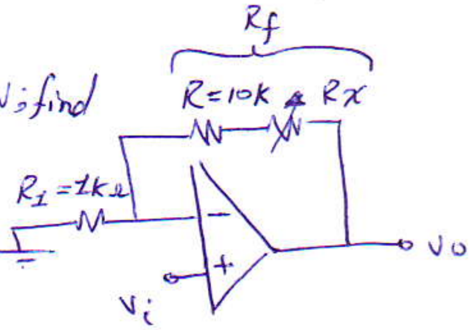
H.w: Find $\frac{V_o}{V_i} = ?$



* جميع قيم المقاومات متساوية.

Ans: $\frac{V_o}{V_i} = -8$

Ex: For the circuit shown below; find



① The value of Rx range to give a gain ranging from (11-26)

② Name the F.B Topology and find the value of β for both values of Rx.

Solution:

① $\frac{V_o}{V_i} = 1 + (R_f/R_1) \Rightarrow 11 = 1 + \frac{R_f}{1K} \Rightarrow \frac{R_f}{1K} = 10$

$\therefore R_f = 10K\Omega \quad \because R_f = R + R_x$ and $R = 10K\Omega$

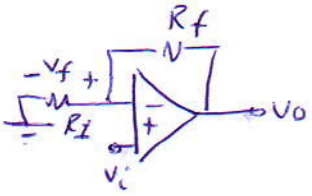
$\Rightarrow 10K = R + R_x \Rightarrow 10K = 10K + R_x \quad \therefore \boxed{R_x = 0\,\Omega}$

for $\frac{V_o}{V_i} = 26 \Rightarrow 26 = 1 + \frac{R_f}{1K} \Rightarrow R_f = 25K\Omega$

$\Rightarrow R + R_x = 25K \Rightarrow R_x = 25 - R = 25 - 10 = \boxed{15K\Omega}$

$\therefore R_x$ range from $(0 \longrightarrow 15K\Omega)$

② F.B Topology is voltage-series. and $\beta = \frac{V_f}{V_o}$

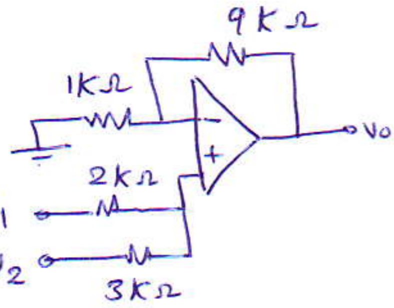


$\beta = \frac{R_1}{R_1 + R_f} = \frac{R_1}{R_1 + R + R_x} \quad (\because R_f = R + R_x)$

A- $R = 0\,\Omega \Rightarrow \beta = \frac{1K}{1K + 0 + 10K} = \boxed{\frac{1}{11}}$

B- $R = 15K\Omega \Rightarrow \beta = \frac{1K}{1K + 15K + 10K} = \boxed{\frac{1}{26}}$

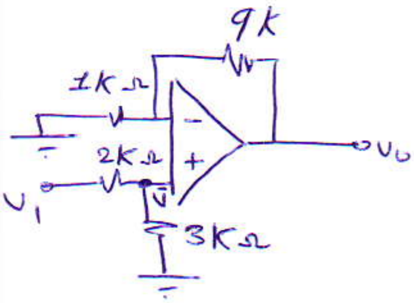
Ex: Find closed loop gain $G = \frac{v_o}{v_i}$? For the circuit shown below.



Solution:

By using superposition.

① Take the effect of v_1.

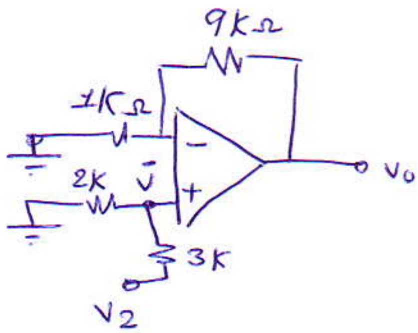


$$\bar{v} = v_1 * \frac{3k}{3k+2k} = \boxed{\frac{3V_1}{5}}$$

$$V_{o1} = \left(1 + \frac{9k}{1k}\right)\bar{v} = (10)\frac{3V_1}{5}$$

$$\Rightarrow V_{o1} = \frac{30 V_1}{5} = \boxed{6V_1}$$

② Take the effect of V_2.



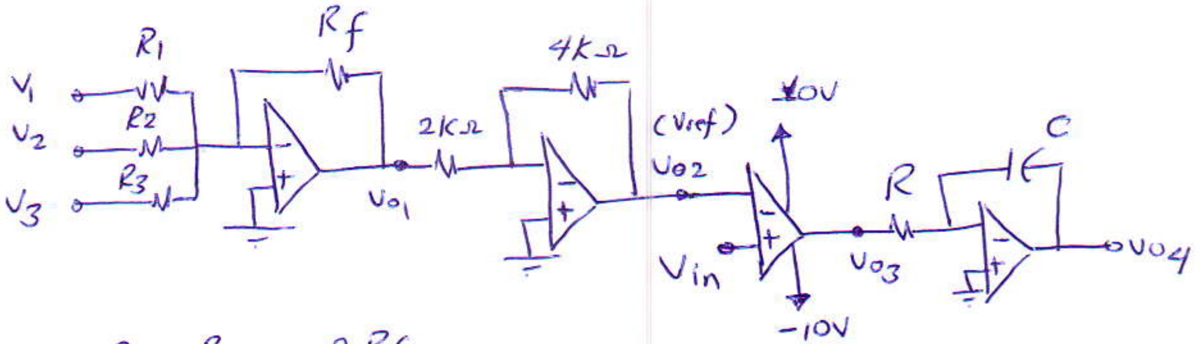
$$\bar{v} = V_2 \left(\frac{2k}{2k+3k}\right) = \boxed{\frac{2V_2}{5}}$$

$$V_{o2} = \left(1 + \frac{9k}{1k}\right)\bar{v}$$

$$\Rightarrow V_{o2} = (10)\frac{2V_2}{5} = \boxed{4V_2}$$

$$\therefore V_{o\,total} = V_{o1} + V_{o2} = \boxed{6V_1 + 4V_2}$$

Ex: For the circuit shown below; find V_{o1}, V_{o2}, V_{o3} and V_{o4}



$R_1 = R_2 = R_3 = 0.2 R_f$

$V_1 = V_2 = V_3 = 0.2\,V$

Solution:

$$V_{o1} = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)$$

$$= -\left(\frac{R_f}{0.2R_f}V_1 + \frac{R_f}{0.2R_f}V_2 + \frac{R_f}{0.2R_f}V_3\right) = -(1+1+1) = \boxed{-3V}$$

$$V_{o2} = -\frac{R_f}{R_1}V_{o1} = -\frac{4k}{2k}(-3) = \boxed{6V}$$

V_{o3} : comparator

If $V_{in} > 6V \Rightarrow V_{o3} = +10V$

or $V_{in} \leq 6V \Rightarrow V_{o3} = -10V$

$$V_{o4} = -\frac{1}{RC}\int_0^t V_{o3}(t)\,dt \rightarrow -\frac{1}{RC}\int_0^t (10)\,dt = \frac{-10t}{RC}$$

or

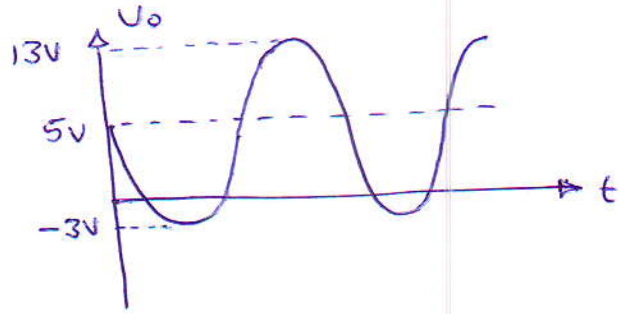
$$\rightarrow -\frac{1}{RC}\int_0^t (-10)\,dt = \frac{10t}{RC}$$

H.W1: Design an OP-Amp circuit that Produce an output given by $v_o = -(4V_1 + V_2 + 0.1V_3)$

If $v_1 = 2\sin\omega t$; $V_2 = 5V$ and $V_3 = -100V$

sketch the output voltage waveform?

Ans:



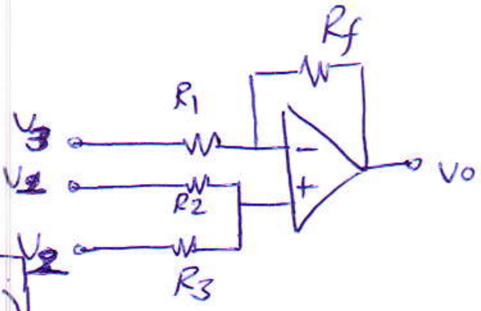
H.W2: For the Integrator OP-Amp the input voltage is $0.5\cos 100t$, find the value of Capacitor required to give Peak o/p voltage is $-5V$.

Ans: $C = 1\mu F$, if you Assume $R = 1K\Omega$

H.W3: For the circuit shown below; find V_o?

$R_1 = 1K\Omega$, $R_2 = 2K\Omega$

$R_3 = 3K\Omega$, $R_f = 9K\Omega$



Ans: $V_o = (6V_1 + 4V_2$ [illegible] $9V_3)$

Operational Amplifier Specifications:

1- Gain Bandwidth (F_T):

2- Slew Rate (SR):

3- Common Mode Rejection Ratio (CMRR):

~ . ~ . ~ .

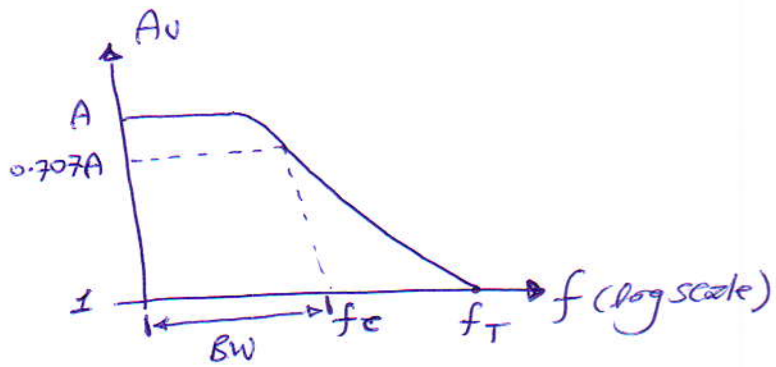
① Gain Bandwidth (f_T):

ملاحظة: f_T تمثل اعلى قيمة تردد يعمل عندها الـ (مكبر العمليات) عندما يكون قيمة الكسب هي واحد او صفر dB وكما موضح في الشكل

$$\boxed{f_T = A f_c}$$

$$\boxed{f_c = BW}$$

A: open loop gain.



* من الشكل اعلاه نلاحظ امور عدة ① ان قيمة f_T تكون عندما يكون الكسب (A) (open loop) يساوي واحد

② تردد القطع الاعلى (f_c) (high cutoff freq.) يمثل قيمة الحزمة الترددية (B-W) لان الـ (op.Amp) لا يوجد فيه تردد قطع واطيء لعدم وجود متسعات داخلية مربوطة مثل (coupling او by pass).

③ عندما يربط مكبر العمليات مع مقاومات الـ (R_f, R_I) فان قيمة الكسب التي تؤخذ بعين الاعتبار هي الـ closed loop gain

② **Slew Rate:** It's a parameter represents a maximum rate at which amplifier output can change in volts per microsecond ($V/\mu s$)

$$SR = \frac{\Delta V_o}{\Delta t} \; V/\mu s \quad \text{with } t \text{ in } \mu s.$$

* (SR) : تمثل معدل تغير فولتية الإخراج بالنسبة للزمن بالمايكرو second حيث اذا كان معدل التغير مثلا 2V/µs فان قيمة تغير فولتية الاخراج يجب ان لاتزيد عن هذه القيمة وبالتالي يتم اقتطاعها او تشويهها. ولذلك كلما زادت قيمة الـ(SR) كان افضل لان قيمة الفولتية عليه ان تتغير بسرعة من دون تشوية

Ex: For an Op-Amp having a slew Rate = $2V/\mu s$, what is the maximum closed loop voltage gain that can be used when the input signal varies by 0.5V in $10\mu s$?

Solution:

$$V_o = G * V_i \Rightarrow \frac{\Delta V_o}{\Delta t} = G * \frac{\Delta V_i}{\Delta t}$$

$$\Rightarrow \frac{2V}{\mu s} = G * \frac{0.5}{10\,\mu s} \Rightarrow \boxed{G = 40}$$

Ex: For a 741 Operational Amplifier the open loop gain is typically $2*10^5$ and the unity gain frequency is 1.5MHz; determine the -3dB corner frequency?

Solution:

$$\underset{\text{(unity gain)}}{f_T} = A f_c \Rightarrow \underset{\text{(corner freq)}}{f_c} = \frac{1.5*10^6}{2*10^5} \cong \boxed{8Hz}$$

Maximum Signal Frequency:

* يمثل اعلى تردد ممكن ان يعمل فيه مكبر العمليات من غير ان تتشوه موجة الإخراج.

$V_o = V_{om} \sin \omega t$

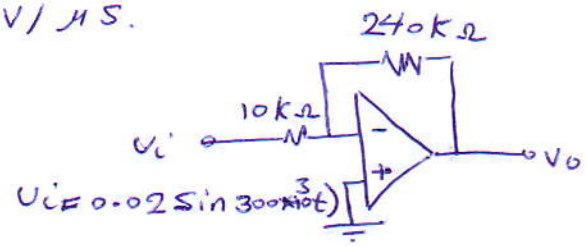
$= V_{om} \sin(2\pi f t)$

Signal maximum rate of change $= 2\pi f V_{om}$ (V/s)

$2\pi f V_{om} \leq SR \implies \omega V_{om} \leq SR$

$\therefore \boxed{f \leq \frac{SR}{2\pi V_{om}}}$ Hz or $\boxed{\omega \leq \frac{SR}{V_{om}}}$ rad/s

Ex: For the circuit shown below; determine the maximum freq. that may be used without distortion in the o/p signal. op-amp slew rate is 0.5 V/μS.



Solution:

$G = \left| \frac{-240k}{10k} \right| = 24$

$V_{om} = G \cdot V_{im} = 24 \cdot 0.02 = \boxed{0.48V}$

* وضعت علامة المطلق (Absolute) لاننا بصدد ايجاد زمن وتردد ولا يوجد تردد او زمن بالسالب.

$f \leq \frac{SR}{2\pi V_{om}} \implies f \leq \frac{0.5 \text{ V}/\mu s}{2\pi \cdot 0.48} = \boxed{0.165 \text{ MHz}}$

(3) Common Mode Rejection Ratio (CMRR):

* يمثل العامل الذي يحدد قيمة الكسب الذي يضرب في رفض قيمة الضوضاء (niose) وكذلك اعلى قيمة للكسب يمكن ان نحصل عليه عمليا من المكبر. حيث يتم احتساب قيمة الـ CMRR من خلال قياسات يتم اجرائها على الـ op-Amp

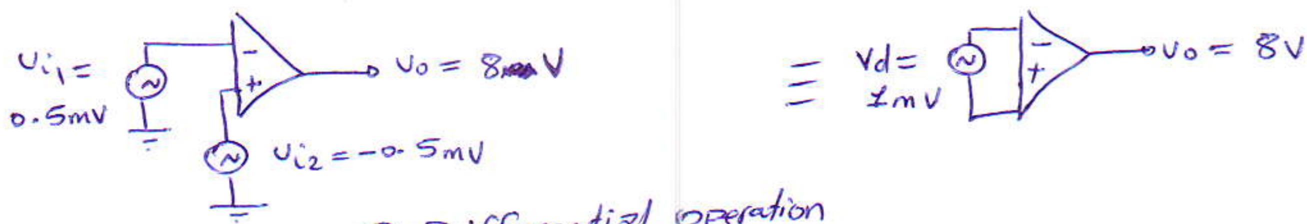
$$CMRR = \frac{A_d}{A_c}$$

$$CMRR\,(\log) = 20 \log_{10} \frac{A_d}{A_c}$$

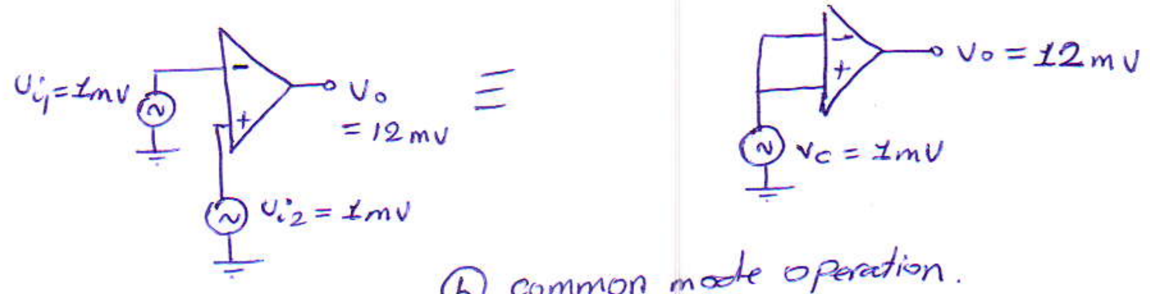
$$V_d = V_{i_1} - V_{i_2} \qquad V_c = \frac{1}{2}(V_{i_1} + V_{i_2})$$

$$V_o = A_d V_d + A_c V_c$$

Ex: Calculate the CMRR for the circuit measurements below?



(a) Differential operation



(b) common mode operation.

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Solution :

$$V_o = A_d V_d \Rightarrow A_d = \frac{V_o}{V_d} = \frac{8}{1m} = \boxed{8000}$$

$$V_o = A_c V_c \Rightarrow A_c = \frac{V_o}{V_c} = \frac{12\,mV}{1\,mV} = \boxed{12}$$

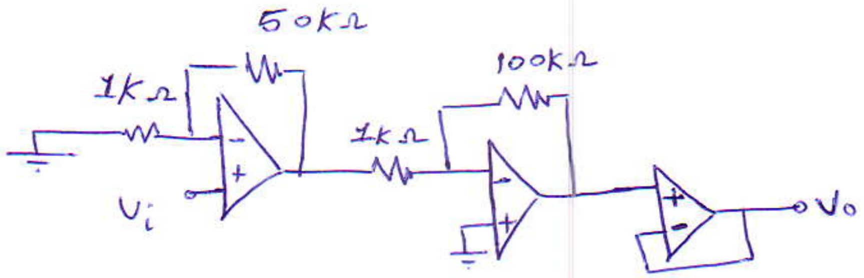
$$\Rightarrow CMRR = \frac{A_d}{A_c} = \frac{8000}{12} = \boxed{666.67}$$

$$\therefore CMRR = 20\log\frac{8000}{12} = \boxed{56.48}\,dB$$

~ . ~ . ~ .

Ex: For the circuit shown below; calculate:

① R_{if} ② R_{of} ③ Total gain ④ The maximum input voltage without distortion (clipping) in the o/p voltage ⑤ How can make the o/p impedance equal to 50Ω ⑥ Band width.



Note: $V_{CC} = 9V$; $V_{EE} = -9V$; $A = 10^5$; $R_i = 1M\Omega$, $R_o = 70\Omega$

and $f_T = 1MHz$.

Solution:

① The first stage F.B Topology is voltage-series

$\Rightarrow R_{if} = R_i(1+\beta A) = R_i * D_1$

and the last stage is an unity gain voltage follower (voltage-series)

$\Rightarrow R_{of} = R_o/(1+\beta A) = \frac{R_o}{D_3}$

$G_1 = 1 + \frac{R_f}{R_1} = 1 + \frac{50k}{1k} = \boxed{51}$

$G_2 = \frac{-R_f}{R_1} = \frac{-100k}{1k} = \boxed{-100}$

$G_3 = \boxed{1}$ (Voltage follower).

$\because G = \frac{A}{1+\beta A} = \frac{A}{D} \Rightarrow D_1 = \frac{A}{G_1} = \frac{10^5}{51} = \boxed{1960}$

$\therefore D_3 = \frac{A}{G_3} = \frac{10^5}{1} = \boxed{10^5}$

$\therefore R_{if} = R_i(D_1) = 1M(1960) = \boxed{1.96\ G\Omega}$

②

$\therefore R_{of} = \frac{R_o}{D_3} = \frac{70}{10^5} = \boxed{0.7\ m\Omega} \simeq 0\ \Omega$

③ $G_T = G_1 \cdot G_2 \cdot G_3 = (51)(-100)(1) = \boxed{-5100}$

④ $V_{i(P-P)}$ (without distortion) $= \frac{V_{CC} + V_{EE} - 2}{G_T} = \frac{9+9-2}{-5100} = \boxed{-3.14\ mV}$

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⑤ To make the o/p impedance equal to 50Ω; we must connect 50Ω in series with voltage follower at last stage.

⑥ to calculate the Bandwidth

$f_T = G f_c \quad \therefore \boxed{f_c = B.W} = f_H$

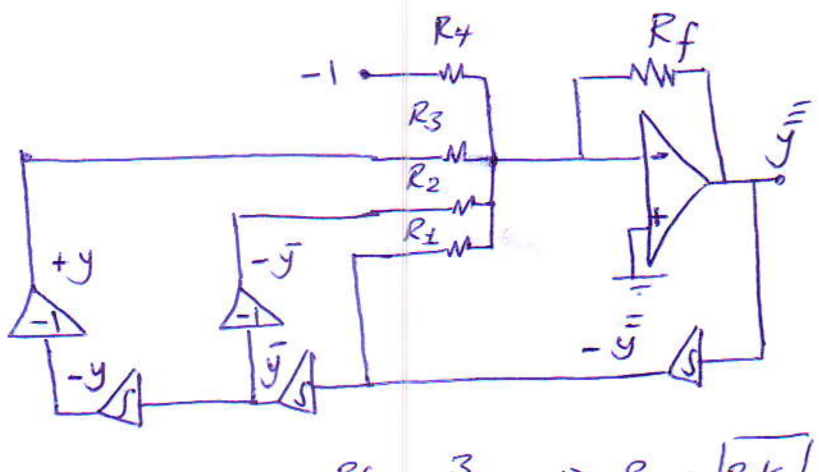
$\Rightarrow f_T = G * B.W = G * f_H \Rightarrow f_{H1} = \frac{f_T}{G_1} = \frac{10^6}{51} = \boxed{19.6\ KHz}$

$f_{H2} = \frac{10^6}{100} = \boxed{10\ KHz} \quad f_{H3} = \frac{10^6}{1} = \boxed{1\ MHz}$

$\boxed{f_{H\,dominant} = 10\ KHz = B.W}$

Ex: Design an analog circuit to simulate the following equation? $2\dddot{y} - 3\ddot{y} - 4\dot{y} + 5y = 6$

Solution: $\dddot{y} = \frac{3}{2}\ddot{y} + 2\dot{y} - \frac{5}{2}y + 6$



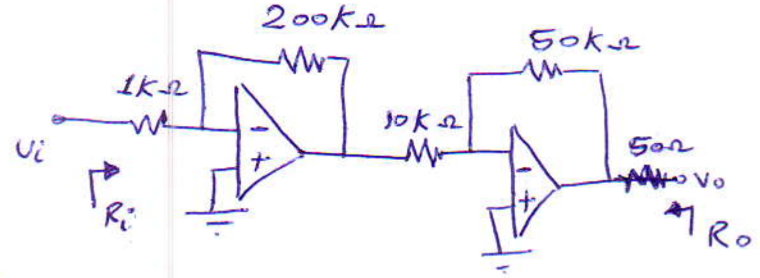
let: $Rf = 3K\Omega \Rightarrow \frac{Rf}{R_1} = \frac{3}{2} \Rightarrow R_1 = \boxed{2K}$ $\quad \boxed{R_4 = 1K\Omega}$

$\frac{Rf}{R2} = 2 \Rightarrow R_2 = \boxed{1.5K}$ $\quad \boxed{R_3 = 1.2K}$

H.W1 For the circuit shown below, gain total (G_T) = 60dB ; $A=10^5$

$BW = 5KHz$; $f_T = 1MHz$; $R_i = 1M$ and $R_o = 70\Omega$; find

① R_{of} ② R_{if}



Ans: $R_{of} \simeq 50\Omega$

$R_{if} \simeq 0.666\,k\Omega$

H.W2 Determine the output voltage of an op-amp for i/p voltages of $V_{i_1} = 150\mu V$ and $V_{i_2} = 140\mu V$. The amplifier has a differential gain of $A_d = 4000$ and CMRR is:

① 100 ② 10^5

Ans: ① $V_o = 45.8mV$ ② $V_o = 40mV$

H.W3 Show that $v_o(t) = -\left[\frac{R_2}{R_1} V_i(t) + \left(CR_2 + \frac{L}{R_1}\right)\frac{dV_i(t)}{dt} + LC\frac{d^2 V_i(t)}{dt^2}\right]$

For the circuit shown below?