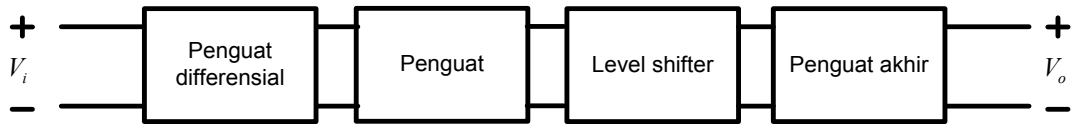
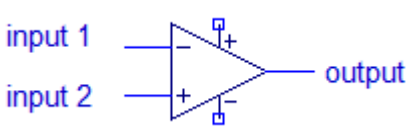
BAB XII OPERATIONAL AMPLIFIER (OP – AMP)

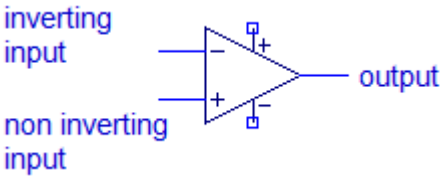
11.1 *Operational Amplifier (Op-Amp)*

Op-Amp dinamakan juga dengan penguat differensial dengan impedansi input tinggi dan output impedansi rendah. Op-Amp banyak digunakan untuk pengubah tegangan (amplituda dan polaritas), osilator, filter dan rangkaian instrumentasi.

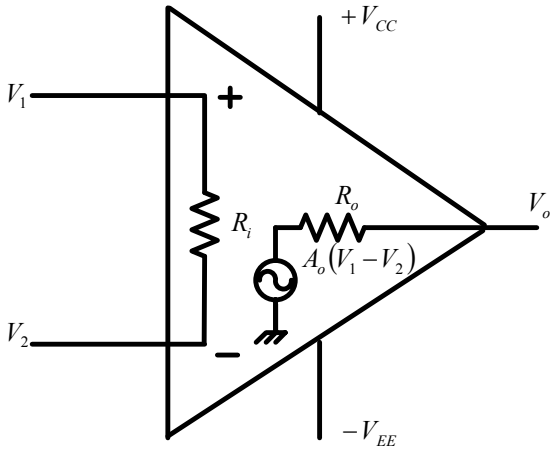


Gambar 11.1 Diagram blok Op-Amp





Simbol Op-Amp



Gambar 11.4 Simbol Op-Amp

Umumnya Op-Amp bekerja dengan *dual supply* ($+V_{CC}$ dan $-V_{EE}$) atau *single supply* ($+V_{CC}$ - ground).

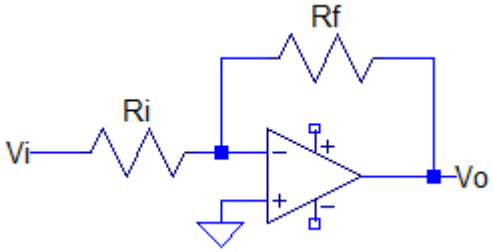
$R_i = \infty$, $R_o = 0$, dan $A = \infty$ (penguatan loop terbuka).

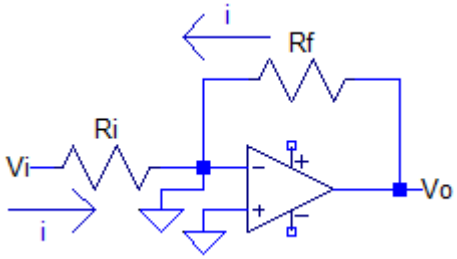
Penguatan yang besarmembuat Op-Amp menjadi tidak stabil dan pengauatannya menjadi tidak terukur → diperlukan *feedbak* negatif.

Ada 2 aturan penting dalam melakukan analisis rangkaian Op-Amp :

1. Perbedaan tegangan V_+ dan V_- adalah nol
2. Arus input Op-Amp adalah nol.

11.4.1 *Inverting Amplifier*



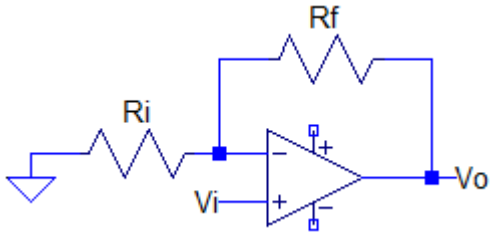


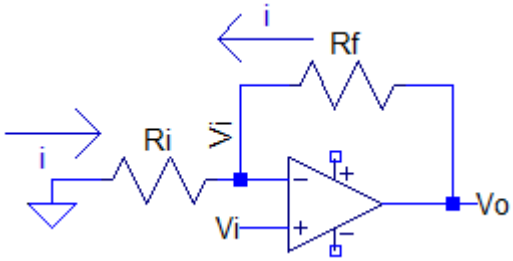
$$i = -i$$

$$\frac{V_i - 0}{Ri} = -\frac{V_o - 0}{R_f}$$

$$\frac{V_o}{Vi} = -\frac{R_f}{R_i}$$

11.4.2 *Non Inverting Amplifier*





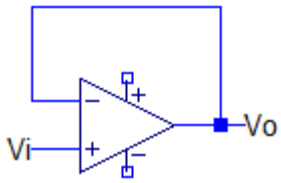
$$i = -i$$

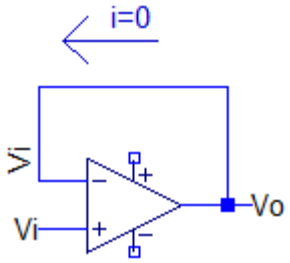
$$\frac{0 - V_i}{R_i} = -\frac{V_o - V_i}{R_f}$$

$$V_i = \frac{R_i}{R_i + R_f} V_o$$

$$\frac{V_o}{V_i} = \frac{R_i + R_f}{R_i} = 1 + \frac{R_f}{R_i}$$

11.4.3 *Unity Follower/ Buffer*

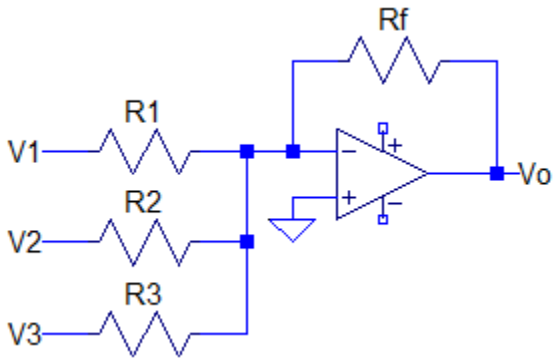




$$V_o = V_i$$

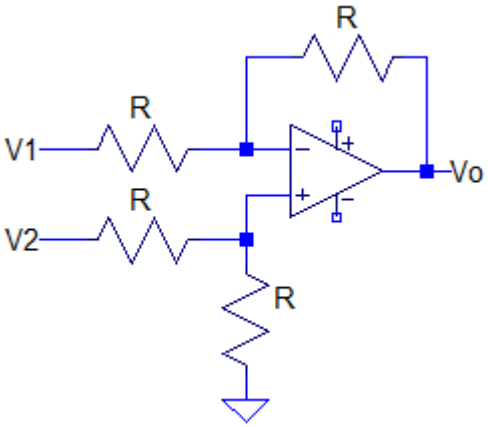
$$\frac{V_o}{V_i} = 1$$

11.4.4 *Adder Amplifier*

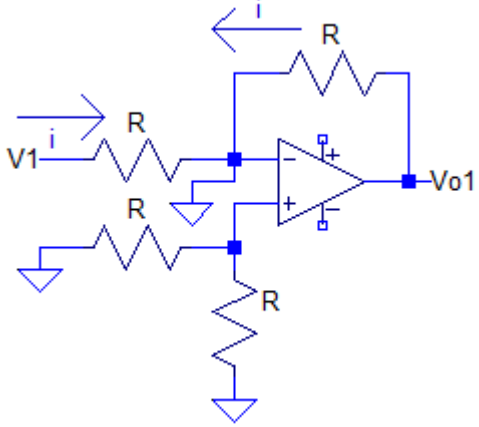


$$V_o = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)$$

11.4.5 *Substractor Amplifier*

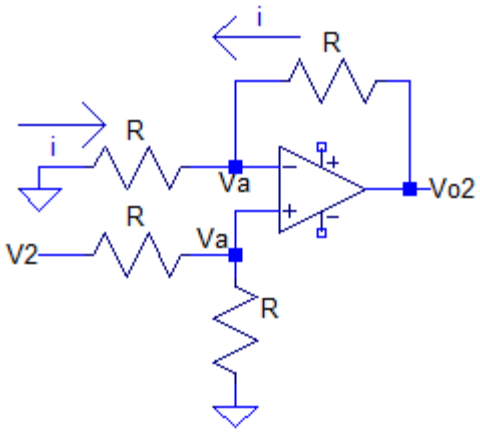


Teorema Superposisi :



$$i = -i$$

$$\frac{V_i - 0}{R} = -\frac{V_{o1} - 0}{R} \Rightarrow V_{o1} = -V_1$$



$$i = -i$$

$$\frac{0 - V_a}{R} = -\frac{V_{o2} - V_a}{R} \Rightarrow V_a = \frac{V_{o2}}{2}$$

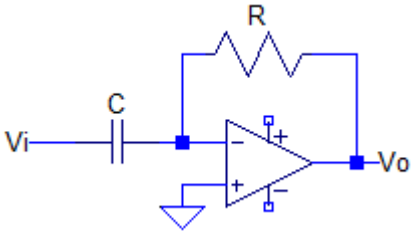
$$\frac{V_2 - V_a}{R} = \frac{V_a - 0}{R}$$

$$\frac{V_2 - V_{o2}/2}{R} = \frac{V_{o2}/2}{R} \Rightarrow V_{o2} = V_2$$

$$V_o = V_2 - V_1$$

11.4.6 *Differentiator Amplifier*

Contoh praktis sinyal input segitiga maka sinyal outputnya segiempat.



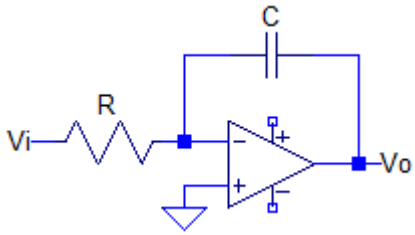
$$i = -i$$

$$C\frac{dV_1}{dt} = -\frac{V_o}{R}$$

$$V_o = -RC\frac{dV_1}{dt}$$

Termasuk jenis filter HPF.

11.4.7 *Integrator Amplifier*



$$i = -i$$

$$\frac{V_1}{R} = -C\frac{dV_o}{dt}$$

$$V_o = -\frac{1}{RC}\int V_1 dt$$

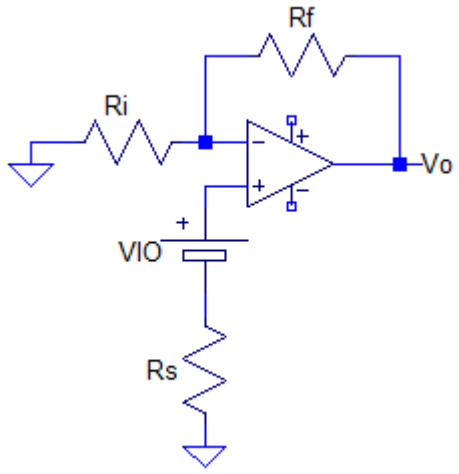
Termasuk jenis filter LPF.

11.5 Spesifikasi Op-Amp

11.5.1 Parameter DC Offset

Sementara output Op-Amp 0 V saat input 0 V, dalam operasi aktualnya terdapat tegangn output offset. Contoh jika kedua input dihubungkan ke 0 V lalu diukur tegangan outputnya sebesar 26 mV (merupakan tegangan yang tidak diiinginkan yang dibangkitkan rangkaian bukan oleh sinyal input).

1. Tegangan Input Offset (V_{IO})



$$V_o = AV_i = A\left(V_{IO} - \frac{R_i}{R_i + R_f}V_o\right)$$

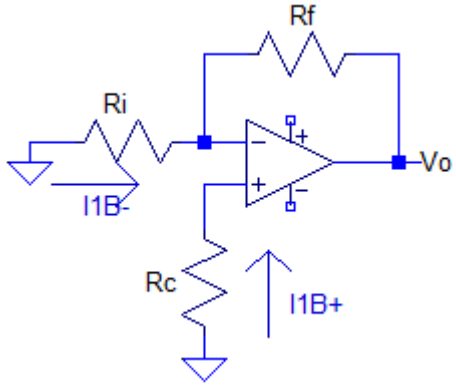
$$V_o = \frac{AV_{IO}}{1 + \frac{AR_i}{R_i + R_f}} \approx \frac{1}{\frac{R_i}{R_i + R_f}}V_{IO}$$

$$V_o \approx \left(1 + \frac{R_f}{R_i}\right)V_{IO}$$

$$V_{o(offset)} = \left(1 + \frac{R_f}{R_i}\right)V_{IO}$$

2. Arus Input Offset (I_{IO})

Tegangan output disebabkan perbedaan dalam arus DC bias pada kedua input.



$$V_o^{+} = I_{1B}^{+} R_C\left(1 + \frac{R_f}{R_i}\right)$$

$$V_o^{-} = I_{1B}^{-} R_C\left(-\frac{R_f}{R_i}\right)$$

$$V_{o(offset)} = V_o^{+} + V_o^{-}$$

$$V_{o(offset)} = I_{1B}^{+} R_C\left(1 + \frac{R_f}{R_i}\right) + I_{1B}^{-} R_C\left(-\frac{R_f}{R_i}\right)$$

11.5.2 Parameter Frekuensi

Op-Amp didesain untuk penguatan tinggi dengan *bandwidth* lebar. Operasi ini memiliki kecenderungan tidak stabil (*unstable*/osilasi) yang disebabkan umpan balik positif. Untuk menjadi operasi stabil, Op-Amp dibangun dengan rangkaian kompensasi. Penguatan ini bersifat mereduksi → *Roll off*.

$$f_1 = \beta_1 = A_{VD} f_c$$

11.5.3 Slew Rate

Rata-rata maksimum penguatan output yang dapat berubah dalam $V/\mu s$.

$$SR = \frac{\Delta V_o}{\Delta t}$$

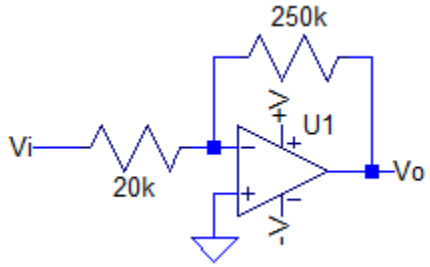
11.5.4 Frekuensi Sinyal Maksimum

Frekuensi maksimum dimana dapat diperoleh sinyal sinusoidal yang ukurannya sama dengan daerah tegangan keluaran (ayunan keluaran maksimum tanpa cacat).

$$f_M = \frac{SR}{2\pi V_{omaks}}$$

Latihan soal :

1. Tentukan tegangan outputnya, jika $V_i = 1{,}5\ Volt$

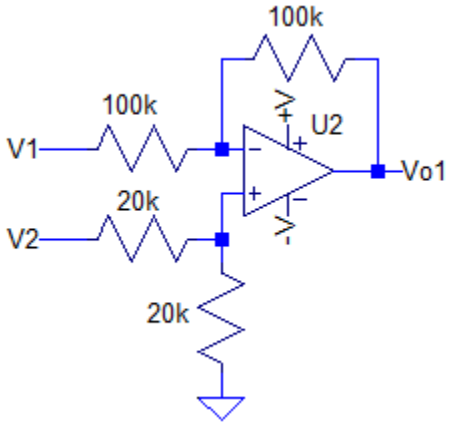


Jawaban :

$$A_V = -\frac{V_o}{V_i} = -\frac{250k}{20k}$$

$$V_o = -\frac{250k}{20k} V_i = -18{,}75V$$

2. Tentukan tegangan output



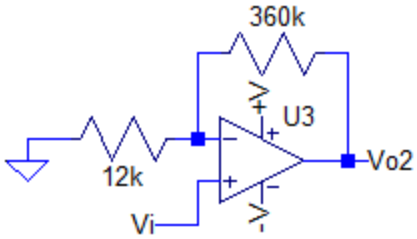
Jawaban :

$$V_i = \frac{20k}{20k + 20k} V_1 = \frac{1}{2} V_1$$

$$\frac{V_2 - \frac{1}{2}V_1}{100k} = \frac{\frac{1}{2}V_1 + V_o}{100k}$$

$$V_{o1} = V_2 - \frac{1}{2}V_1 - \frac{1}{2}V_1 = V_2 - V_1$$

3. Tentukan tegangan output, jika $V_i = -0{,}3\ Volt$

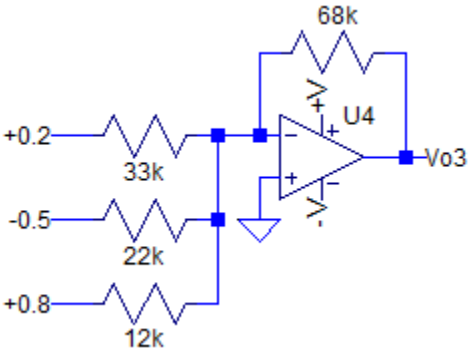


Jawaban :

$$A_V = \frac{V_{o2}}{V_i} = 1 + \frac{360k}{12k}$$

$$V_{o2} = \left(1 + \frac{360k}{12k}\right) V_i = -9{,}3V$$

4. Tentukan tegangan output

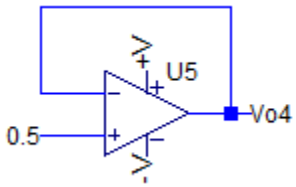


Jawaban :

$$V_{o3} = -\left(\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3\right)$$

$$V_{o3} = -\left(\frac{68k}{33k} 0{,}2 - \frac{68k}{22k} 0{,}5 + \frac{68k}{12k} 0{,}8\right) = -3{,}392V$$

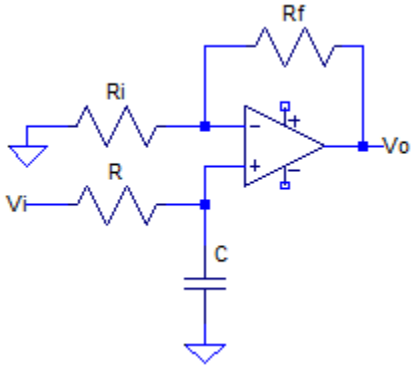
5. Tentukan V_o!



Jawaban:

$V_{o4} = 0{,}5\ V$

6. Tentukan V_o!



Jawaban:

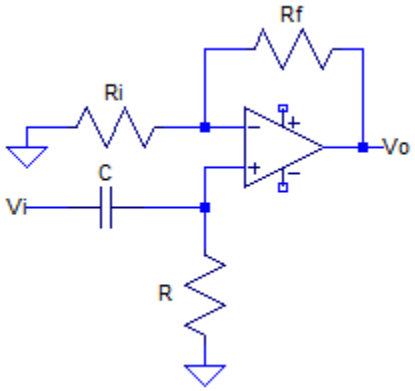
$$V_a = \frac{\frac{1}{sC}}{\frac{1}{sC}+R} V_i = \frac{1}{1+sCR} V_i \Rightarrow\Rightarrow \frac{V_a}{V_i} = \frac{1}{1+sCR}$$

$$\frac{V_o}{V_a} = 1 + \frac{R_f}{R_i}$$

$$\frac{V_o}{V_i} = \frac{V_o}{V_a}\frac{V_a}{V_i} = \left(1+\frac{R_f}{R_i}\right)\left(\frac{1}{1+sCR}\right)$$

$$f_{OH} = \frac{1}{2\pi CR}$$

7. Tentukan V_o!



Jawaban:

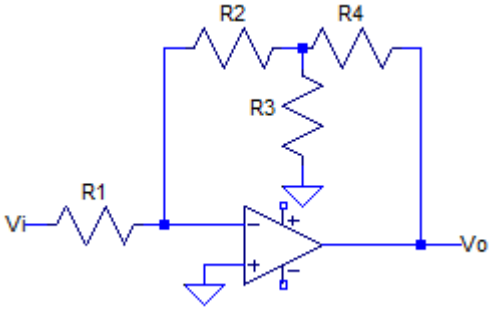
$$V_a = \frac{R}{R+\frac{1}{sC}} V_i = \frac{sCR}{1+sCR} V_i \Rightarrow\Rightarrow \frac{V_a}{V_i} = \frac{sCR}{1+sCR}$$

$$\frac{V_o}{V_a} = 1 + \frac{R_f}{R_i}$$

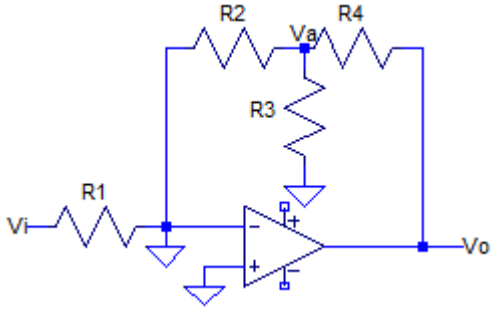
$$\frac{V_o}{V_i} = \frac{V_o}{V_a}\frac{V_a}{V_i} = \left(1+\frac{R_f}{R_i}\right)\left(\frac{sCR}{1+sCR}\right)$$

$$f_{OH} = \frac{1}{2\pi CR}$$

8. Tentukan V_o!



Jawaban:



Node Va:

$$\frac{V_a - V_o}{R_4} + \frac{V_a - 0}{R_2} + \frac{V_a - 0}{R_3} = 0$$

$$\frac{V_o}{R_4} = \frac{V_a}{R_3} + \frac{V_a}{R_2} + \frac{V_a}{R_4}$$

$$V_o = R_4\left(\frac{1}{R_3} + \frac{1}{R_2} + \frac{1}{R_4}\right)V_a$$

$$\frac{V_o}{V_a} = R_4\left(\frac{1}{R_3} + \frac{1}{R_2} + \frac{1}{R_4}\right)$$

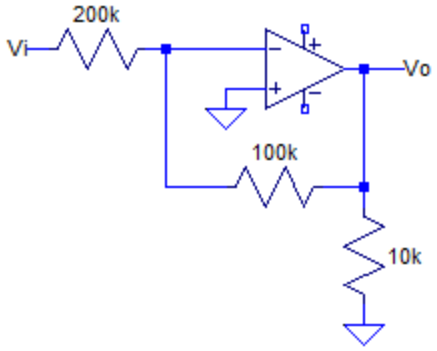
Node ground:

$$\frac{0 - V_i}{R_1} + \frac{0 - V_a}{R_2} = 0$$

$$\frac{V_a}{V_i} = -\frac{R_2}{R_1}$$

$$\frac{V_o}{V_i} = \frac{V_o}{V_a}\frac{V_a}{V_i} = -\frac{R_2 R_4}{R_1}\left(\frac{1}{R_3} + \frac{1}{R_2} + \frac{1}{R_4}\right)$$

9. Tentukan V_o!

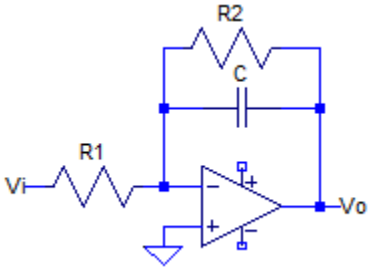


Jawaban:

$$\frac{0-V_o}{100k}+\frac{0-V_i}{200k}=0$$

$$\frac{V_o}{V_i}=-\frac{100k}{200k}=-0{,}5$$

10. Tentukan V_o!



Jawaban:

$$\frac{V_o}{V_i}=-\frac{Z_p}{R_1}$$

$$Z_p=\frac{1}{\frac{1}{Z_p}}=\frac{1}{\frac{1}{R_2}+sC}=\frac{R_2}{1+sCR_2}$$

$$\frac{V_o}{V_i}=-\frac{\frac{R_2}{1+sCR_2}}{R_1}=-\frac{R_2}{R_1}\frac{1}{1+sCR_2}$$

$$f_{OH}=\frac{1}{2\pi CR_2}$$