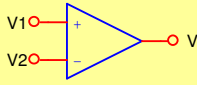
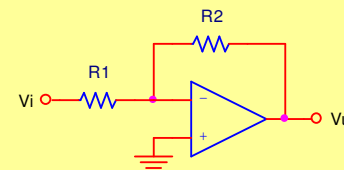


**Operazionale ideale**  
Caratteristiche

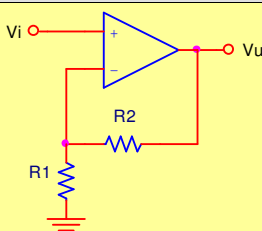
	$A_v = \frac{V_u}{V_1 - V_2} \rightarrow \infty$	Produce desensibilizzazione totale in presenza di reazione negativa
	$R_i \rightarrow \infty$	Non assorbe corrente dai morsetti di ingresso
	$R_u \rightarrow 0$	Si comporta come un generatore ideale di tensione
	$CMRR \rightarrow \infty$	È un amplificatore differenziale con ingressi perfettamente bilanciati

**Circuiti lineari**

Amplificatore invertente

	$\frac{V_u}{V_i} = -\frac{R_2}{R_1}$	$R_i = R_1$
---	--------------------------------------	-------------

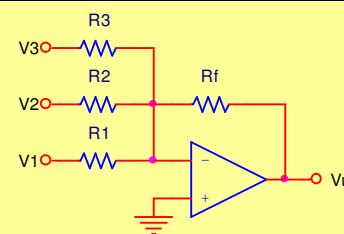
Amplificatore non invertente

	$\frac{V_u}{V_i} = 1 + \frac{R_2}{R_1}$	$R_i \rightarrow \infty$
---	---	--------------------------

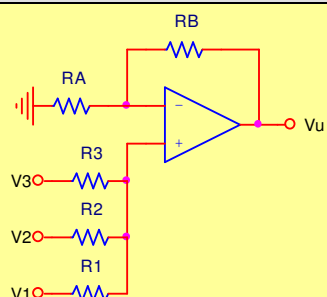
Stadio separatore, inseguitore di tensione

	$\frac{V_u}{V_i} = 1$	$R_i \rightarrow \infty$
--	-----------------------	--------------------------

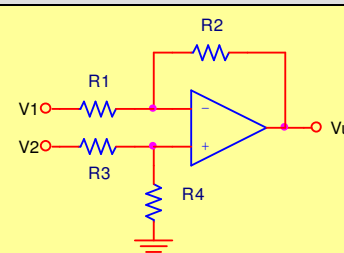
Amplificatore sommatore invertente

	$V_u = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)$ $V_u = -\frac{R_f}{R}(V_1 + V_2 + V_3) \Rightarrow se R_1 = R_2 = R_3 = R$ $V_u = -(V_1 + V_2 + V_3) \Rightarrow se R_1 = R_2 = R_3 = R_f = R$
---	---

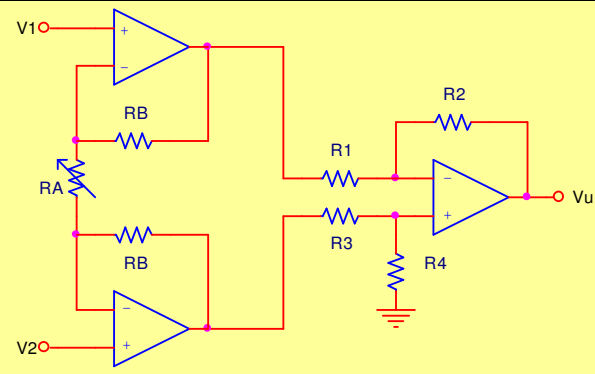
Amplificatore sommatore non invertente

	$V_u = \left(1 + \frac{R_B}{R_A}\right) \left(\frac{\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}\right)$ $V_u = \left(1 + \frac{R_B}{R_A}\right) \frac{(V_1 + V_2 + V_3)}{3} \Rightarrow se R_1 = R_2 = R_3 = R$
---	--

Amplificatore differenziale

	$V_u = \frac{R_2}{R_1}(V_2 - V_1) \Rightarrow se \frac{R_2}{R_1} = \frac{R_4}{R_3}$
---	---

Amplificatore differenziale per strumentazione ( $R_i \rightarrow \infty$  e guadagno regolabile con  $R_A$ )

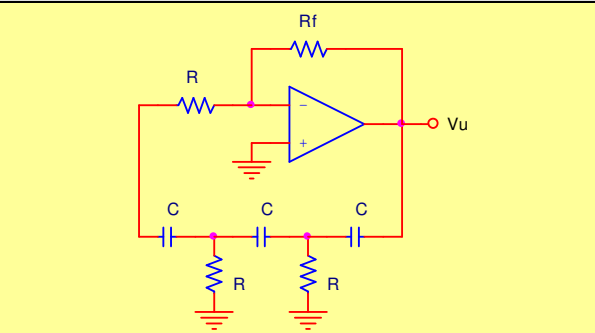


$$V_u = \frac{R_2}{R_1} \left(1 + \frac{2R_B}{R_A}\right) (V_2 - V_1) \Rightarrow \text{se } \frac{R_2}{R_1} = \frac{R_4}{R_3}$$

**Oscillatori**

**Oscillatori sinusoidali**

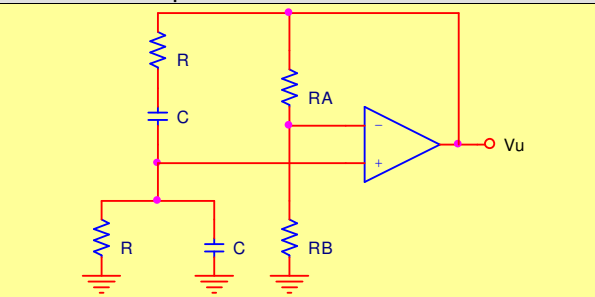
Oscillatore a sfasamento



$$\omega_0 = \frac{1}{\sqrt{6}RC}$$

$$\frac{R_f}{R} \geq 29$$

Oscillatore a ponte di wien

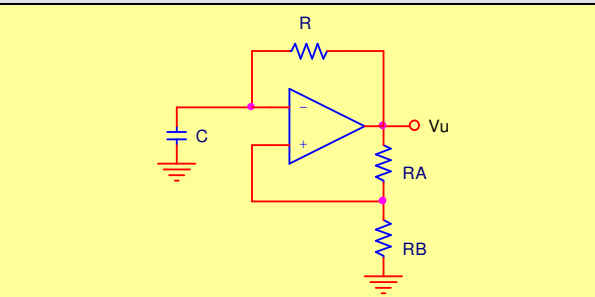


$$\omega_0 = \frac{1}{RC}$$

$$\frac{R_A}{R_B} \geq 2$$

**Oscillatori di rilassamento (multivibratori, timer)**

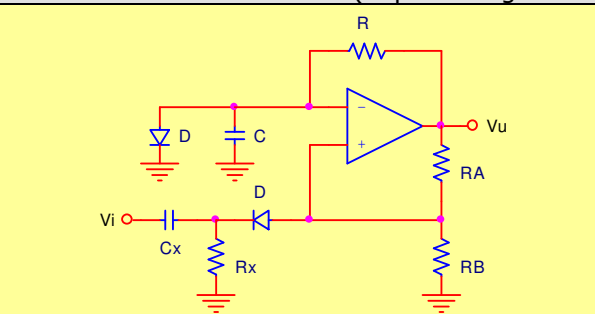
Multivibratore astabile



$$T = 2RC \ln \frac{1+\beta}{1-\beta}$$

$$\beta = \frac{R_B}{R_A + R_B}$$

Multivibratore monostabile (impulso negativo comandato sul fronte di discesa)

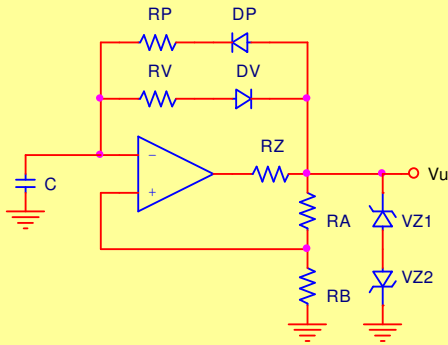


$$T_0 = RC \ln \frac{1}{1-\beta}$$

$$\beta = \frac{R_B}{R_A + R_B}$$

$$R_x C_x \ll T_0$$

Multivibratore astabile con uscita compresa tra +VZ1 e -VZ2 e duty cycle ≠ 50%



$$T_p = R_p C \ln \frac{1+\beta}{1-\beta}$$

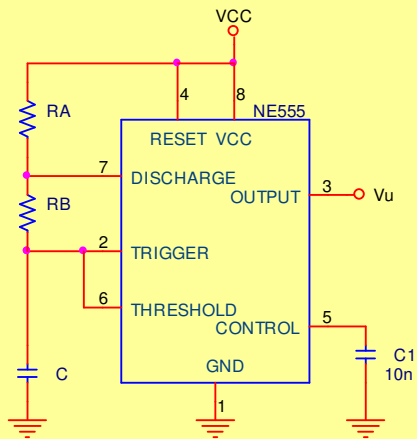
$$T_v = R_v C \ln \frac{1+\beta}{1-\beta}$$

$$duty\ cycle = \frac{T_p}{T_p + T_v} \cdot 100$$

$$\beta = \frac{R_B}{R_A + R_B}$$

$$R_Z = \frac{V_{CC} - V_Z}{I_Z}$$

Multivibratore astabile con NE 555

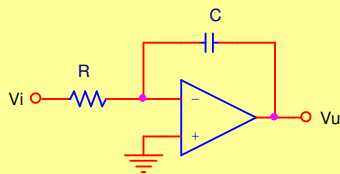


$$T = (R_A + 2R_B)C \ln 2$$

$$duty\ cycle = \frac{R_B}{R_A + 2R_B}$$

**Applicazioni matematiche**

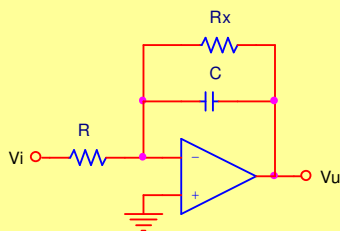
Amplificatore integratore ideale



$$V_u = -\frac{1}{RC} \int_{-\infty}^t V_i dt$$

*Vi cost.* →  $V_u = -\frac{1}{RC} V_i t$   
*in regime sinusoidale*  
 $V_u = -\frac{1}{j\omega RC} V_i$

Amplificatore integratore reale

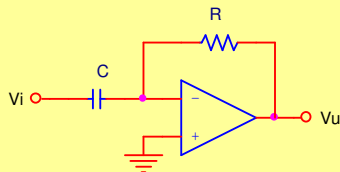


$\omega = 0$  →  $\frac{V_u}{V_i} = -\frac{R_x}{R}$

*Vi cost.* →  $V_u = -\frac{1}{RC} V_i t (1 - \frac{t}{2R_x C})$

con  $\frac{t}{2R_x C} = \text{errore di non linearità}$

Amplificatore derivatore ideale

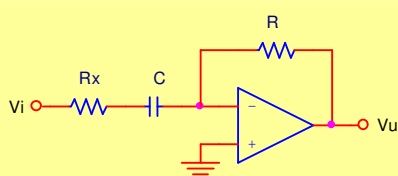


$$V_u = -RC \frac{dV_i}{dt}$$

*in regime sinusoidale*

$$V_u = -j\omega RC V_i$$

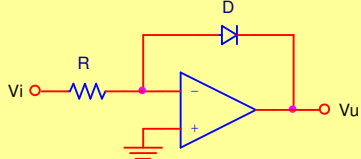
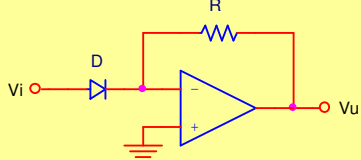
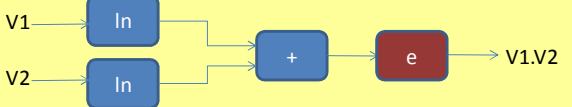
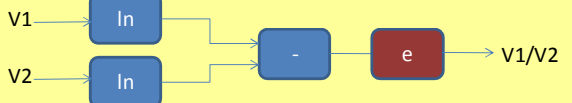
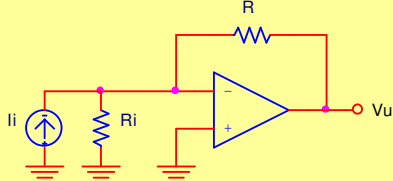
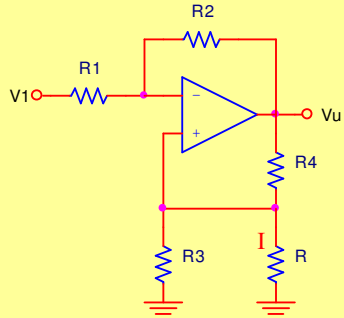
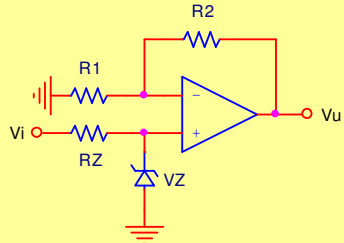
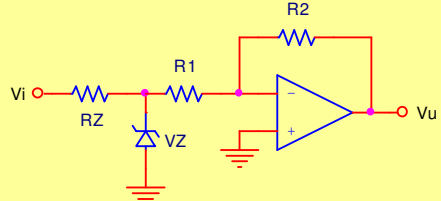
Amplificatore integratore reale

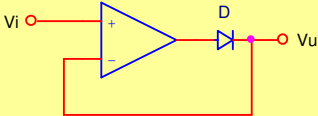
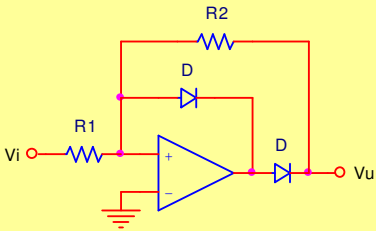
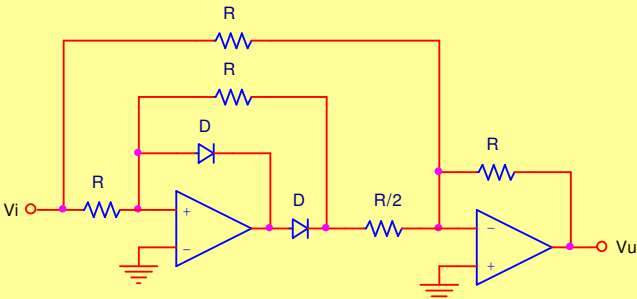
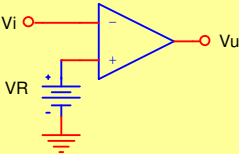
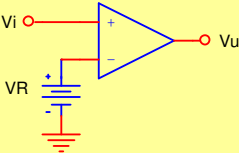
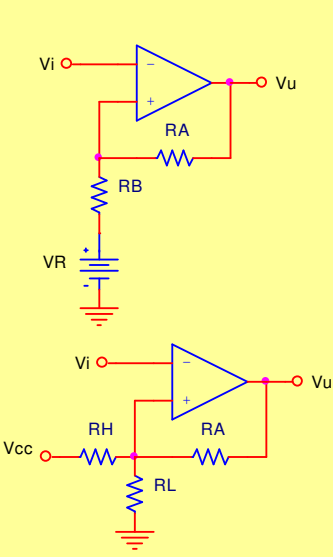


$\omega = \infty$  →  $\frac{V_u}{V_i} = -\frac{R}{R_x}$

*Vi rampa* →  $V_u = -\frac{R}{R_x} V_i (1 - e^{-\frac{t}{R_x C}})$

Amplificatore logaritmico

	$V_u = -V_T \ln\left(\frac{V_i}{RI_o}\right)$ <p><math>I_o</math>=corrente inversa, <math>V_T</math>=tensione termica</p>
<b>Amplificatore antilogaritmico</b>	
	$V_u = -RI_o e^{\frac{V_i}{V_T}}$ <p><math>I_o</math>=corrente inversa, <math>V_T</math>=tensione termica</p>
<b>Prodotto di tensioni</b>	
	$\ln(V1) + \ln(V2) = \ln(V1.V2)$
<b>Rapporto di tensioni</b>	
	$\ln(V1) - \ln(V2) = \ln(V1/V2)$
<b>Applicazioni varie</b>	
<b>Convertitore corrente-tensione</b>	
	$V_u = -R.I_i$
<b>Convertitore tensione-corrente</b>	
	$\text{se } \frac{R_4}{R_3} = \frac{R_2}{R_1}$ $I = -\frac{V_i}{R_3}$
<b>Tensione di riferimento positiva</b>	
	$V_u = V_Z \left(1 + \frac{R_2}{R_1}\right)$
<b>Tensione di riferimento negativa</b>	
	$V_u = -\frac{R_2}{R_1} V_Z$
<b>Diodo senza soglia</b>	

	$V_i > 0 \rightarrow V_u = V_i$
<b>Raddrizzatore di precisione ad una semionda</b>	
	$V_i > 0 \rightarrow V_u = V_i$ $V_i < 0 \rightarrow V_u = -\frac{R_2}{R_1} V_i$
<b>Raddrizzatore di precisione a doppia semionda</b>	
	$V_i > 0 \rightarrow V_u = -V_i$ $V_i < 0 \rightarrow V_u = +V_i$
<b>Applicazioni non lineari</b>	
<b>Comparatore invertente</b>	
	$V_i > V_R \rightarrow V_u = -V_{CC}$ $V_i < V_R \rightarrow V_u = +V_{CC}$
<b>Comparatore non invertente</b>	
	$V_i > V_R \rightarrow V_u = +V_{CC}$ $V_i < V_R \rightarrow V_u = -V_{CC}$
<b>Comparatore invertente con isteresi (trigger di Schmitt)</b>	
	$V_A = V_R \left( \frac{R_A}{R_A + R_B} \right) + V_{CC} \left( \frac{R_B}{R_A + R_B} \right) \rightarrow \text{tensione di soglia superiore}$ $V_B = V_R \left( \frac{R_A}{R_A + R_B} \right) - V_{CC} \left( \frac{R_B}{R_A + R_B} \right) \rightarrow \text{tensione di soglia inferiore}$ $V_H = V_A - V_B = 2V_{CC} \left( \frac{R_B}{R_A + R_B} \right) \rightarrow \text{tensione di isteresi}$ <ul style="list-style-type: none"> <li>- Se la tensione di ingresso è crescente la commutazione si ha in corrispondenza della tensione di soglia superiore;</li> <li>- Se la tensione di ingresso è decrescente la commutazione si ha in corrispondenza della tensione di soglia inferiore.</li> </ul> <p>Per ottenere <math>V_R</math> da <math>V_{CC}</math>:</p> $V_R = V_{CC} \left( \frac{R_L}{R_L + R_H} \right)$ $R_B = \frac{R_L \cdot R_H}{R_L + R_H}$
<b>Comparatore a finestra</b>	

$V_i > V_A \rightarrow V_u = +V_{Z1}$   
 $V_i < V_B \rightarrow V_u = +V_{Z1}$   
 $V_A < V_i < V_B \rightarrow V_u = -V_{Z2}$

**Filtri attivi**

Passa basso 1° ordine

$$A(s) = \frac{A_0}{\frac{s}{\omega_0} + 1}$$

$$\omega_0 = \frac{1}{RC}$$

$$A_0 = 1 + \frac{R_A}{R_B}$$

Passa basso 2° ordine a reazione positiva semplice dia Sallen Key (VCVS)

$$A(s) = \frac{A_0}{\frac{s^2}{\omega_0^2} + 2\xi \frac{s}{\omega_0} + 1} = \frac{A_0}{\frac{s^2}{\omega_0^2} + (3 - A_0) \frac{s}{\omega_0} + 1}$$

Approssimazione di Butterworth

$$|A(j\omega)| = \frac{|A_0|}{\sqrt{1 + \left(\frac{\omega}{\omega_0}\right)^{2n}}}$$

N	Polinomi di Butterworth
1	$s+1$
2	$s^2+1.414s+1$
3	$(s+1)(s^2+s+1)$
4	$(s^2+0.765s+1)(s^2+1.84s+1)$
5	$(s+1)(s^2+0.618s+1)(s^2+.618s+1)$
6	$(s^2+0.518s+1)(s^2+1.414s+1)(s^2+1.932s+1)$
7	$(s+1)(s^2+0.455s+1)(s^2+1.247s+1)(s^2+1.802s+1)$

Ordine **n** del filtro Butterworth con frequenza di taglio **fo** in grado di fornire per una frequenza **fx** una attenuazione relativa pari ad **X dB**

$$n = \frac{\log(10^{\frac{|X|}{20}} - 1)}{2 \log \frac{f_o}{f_x}}$$