

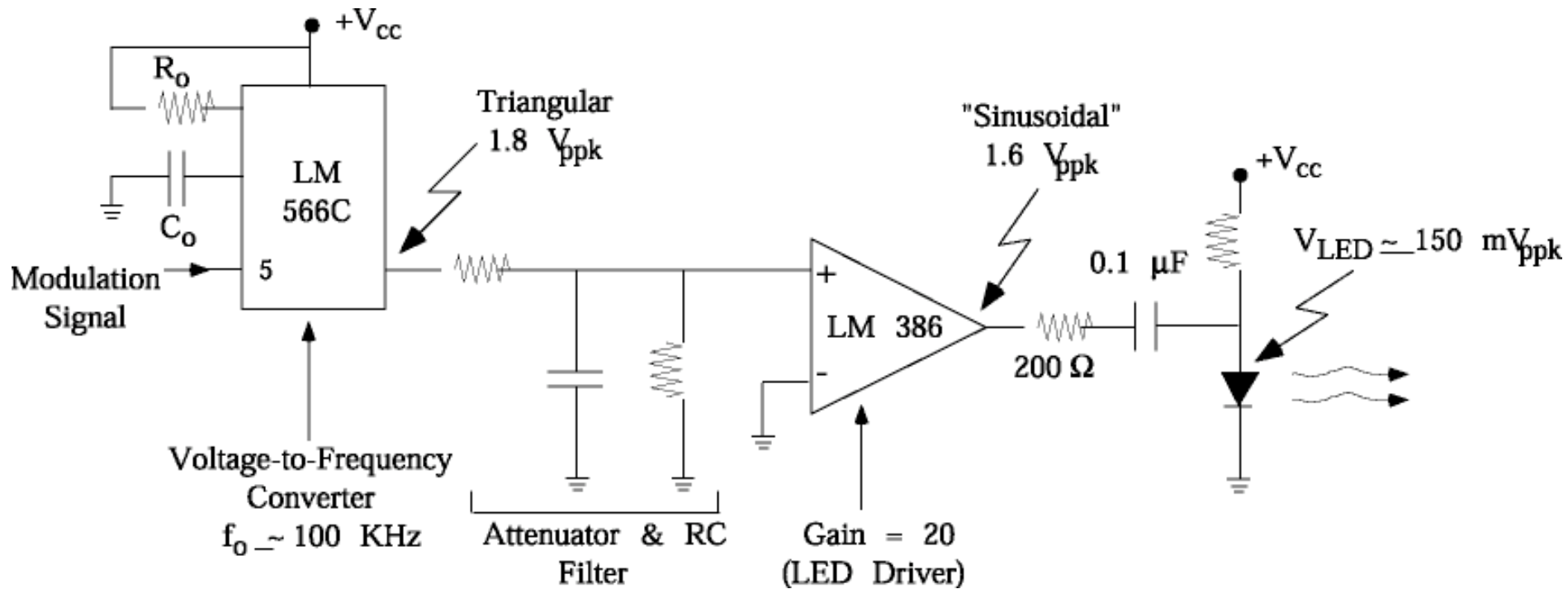
Trasmissione FM su canale ottico  
&  
altri argomenti su OpAmps

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*Corso di Metodi di Trattamento dei Segnali*

*A. A. 2015-2016*

# Trasmettitore con modulazione FM



# LM566C Voltage Controlled Oscillator

## General Description

The LM566CN is a general purpose voltage controlled oscillator which may be used to generate square and triangular waves, the frequency of which is a very linear function of a control voltage. The frequency is also a function of an external resistor and capacitor.

The LM566CN is specified for operation over the 0°C to +70°C temperature range.

## Features

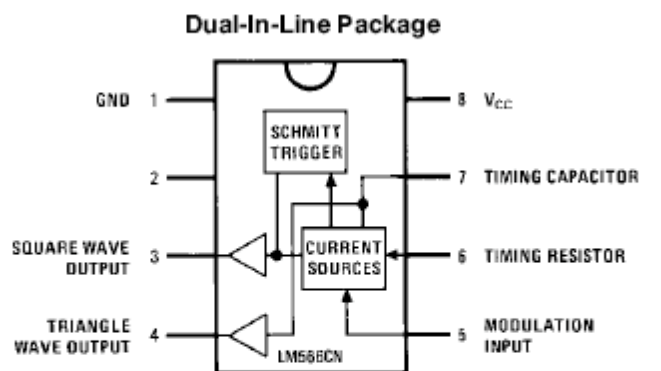
- Wide supply voltage range: 10V to 24V
- Very linear modulation characteristics

- High temperature stability
- Excellent supply voltage rejection
- 10 to 1 frequency range with fixed capacitor
- Frequency programmable by means of current, voltage, resistor or capacitor

## Applications

- FM modulation
- Signal generation
- Function generation
- Frequency shift keying
- Tone generation

## Connection Diagram

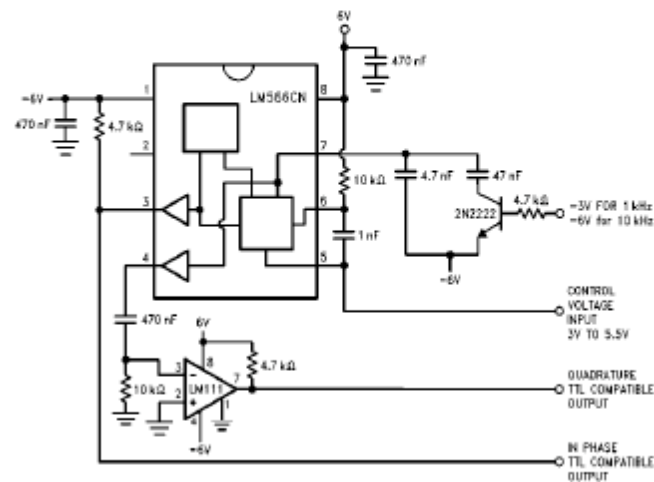


TL/H/7854-2

**Order Number LM566CN**  
**See NS Package Number N08E**

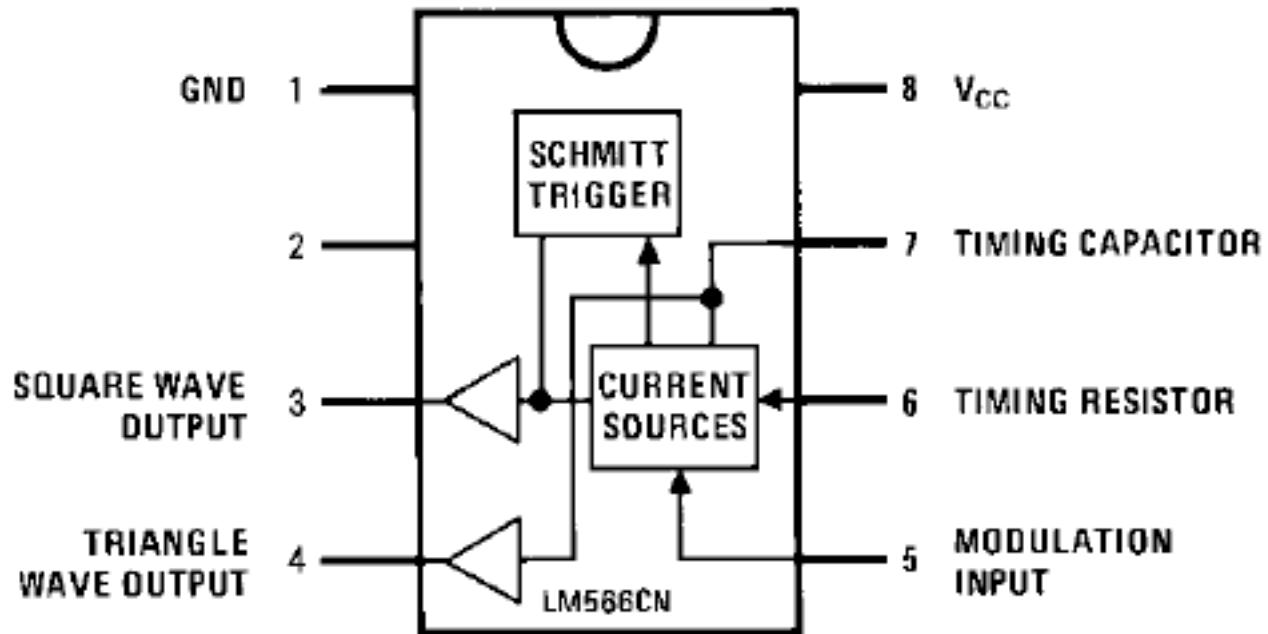
## Typical Application

**1 kHz and 10 kHz TTL Compatible  
 Voltage Controlled Oscillator**

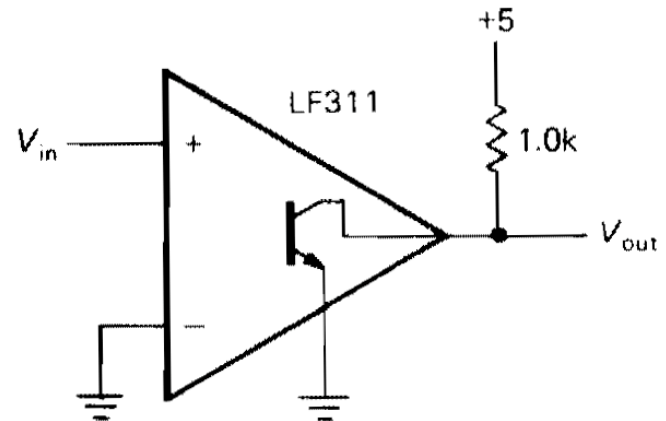
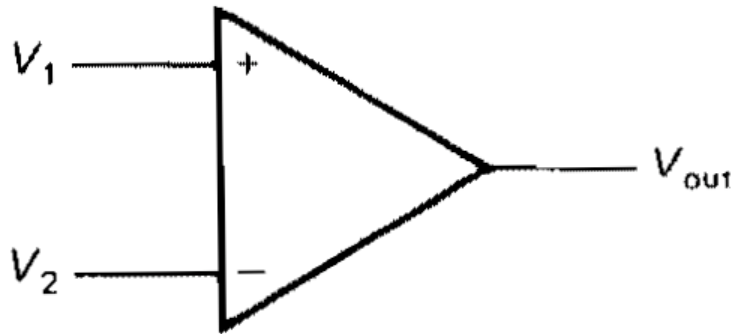


TL/H/7854-3

## Dual-In-Line Package

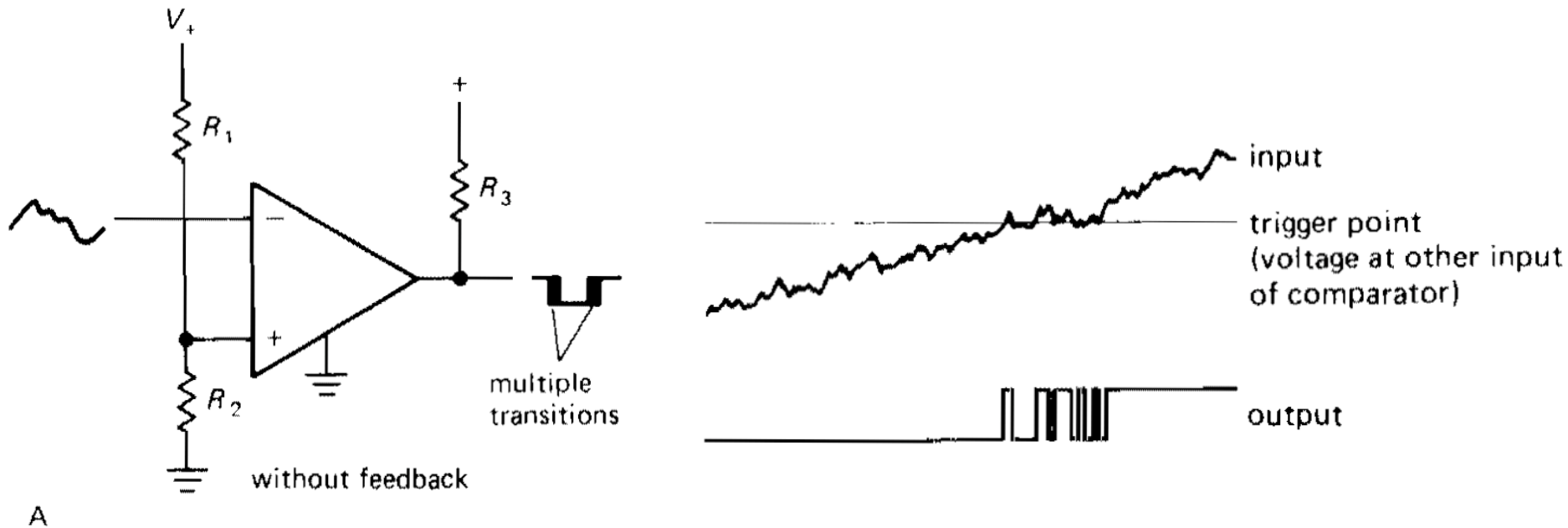


# Il trigger di Schmitt: 1. comparatori



L' esempio più semplice di comparatore: un amplificatore differenziale ad alto guadagno ( $V_{out}$  corrisponde alla tensione di saturazione =  $\pm V_{cc}$ )

## Il trigger di Schmitt: 2. comparatori



Comparatore con una rete di input che definisce il valore della tensione di soglia: in questo caso il rumore in prossimità della soglia rende instabile il passaggio dallo stato basso allo stato alto.

## Il trigger di Schmitt: 3. feedback

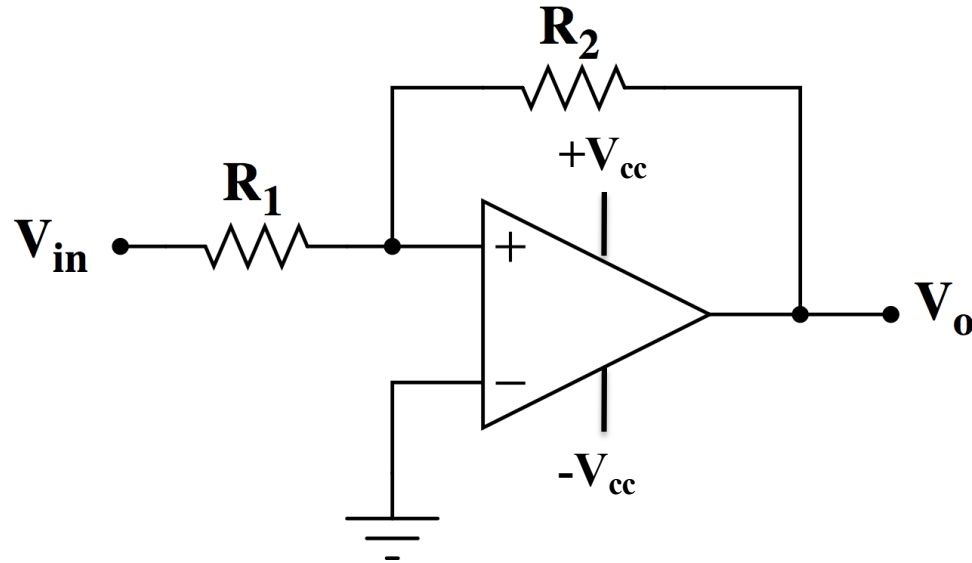
Il guadagno dell'amplificatore con feedback è dato genericamente da

$$G' = \frac{G}{1 - \alpha G} \rightarrow -\frac{1}{\alpha}$$

e quindi se  $G$  è molto alto, si trova – **sia nel caso di feedback negativo che di feedback positivo** – che il segnale all'ingresso dell'amplificatore diventa trascurabile

$$S_{in} + \alpha S_{out} \approx S_{in} + \alpha \left( -\frac{1}{\alpha} \right) S_{in} = 0$$

## Il trigger di Schmitt: 4. comparatori con feedback positivo



SE  $V_o = V_{cc}$  (stato alto)

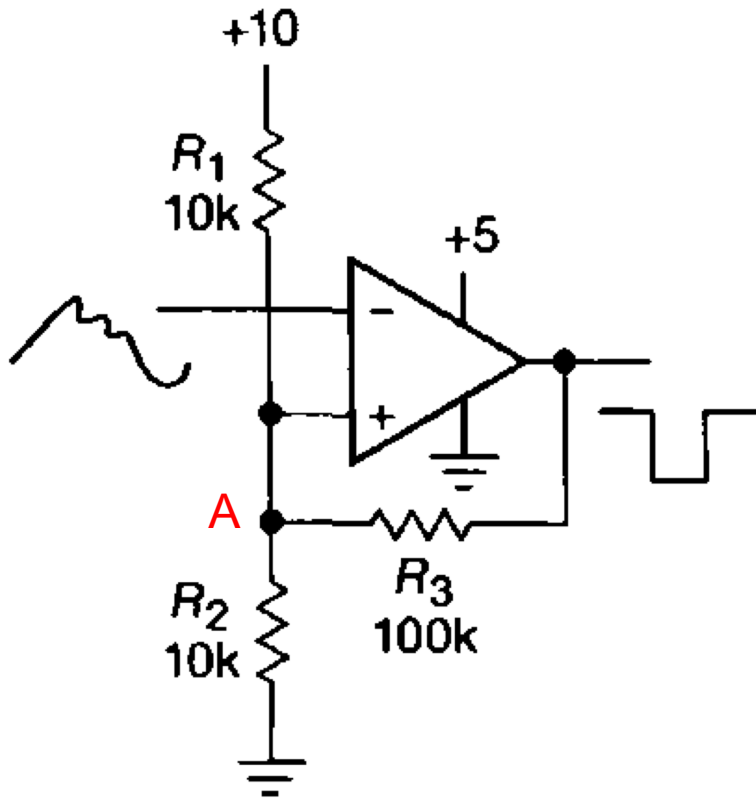
$$\frac{V_{in}}{R_1} + \frac{V_{cc}}{R_2} = 0 \quad \Rightarrow \quad V_{in} = -\frac{R_1}{R_2} V_{cc}$$

SE  $V_o = -V_{cc}$  (stato basso)

$$\frac{V_{in}}{R_1} - \frac{V_{cc}}{R_2} = 0 \quad \Rightarrow \quad V_{in} = \frac{R_1}{R_2} V_{cc}$$



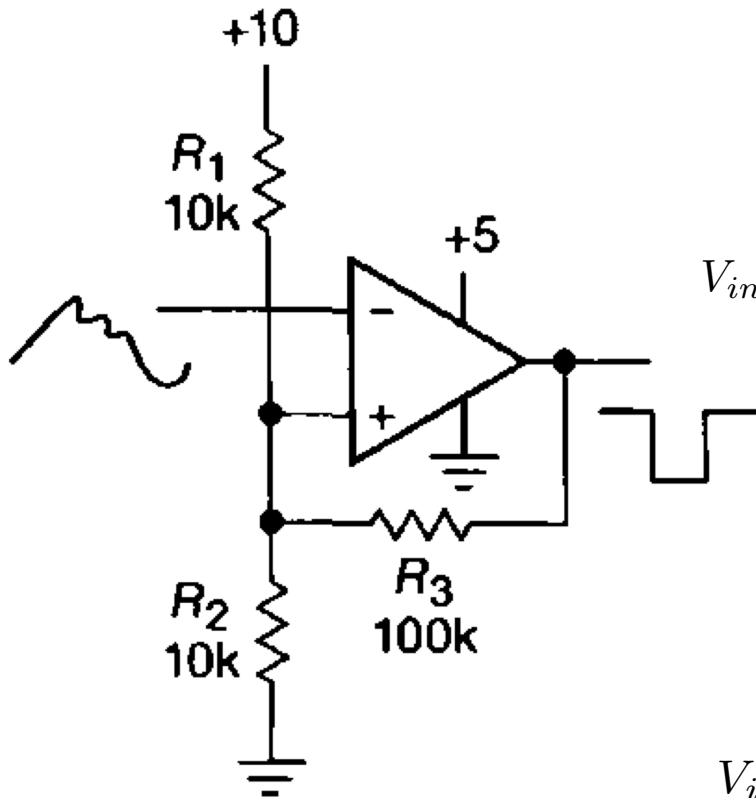
## Il trigger di Schmitt: 5. comparatori con feedback positivo



Se l'output dell'Op-Amp è basso (0 V)  
allora la tensione in A è  $\approx 4.76$  V

Se l'output dell'Op-Amp è alto (5 V)  
allora la tensione in A è  $\approx 5$  V

# Il trigger di Schmitt: 5. comparatori con feedback positivo



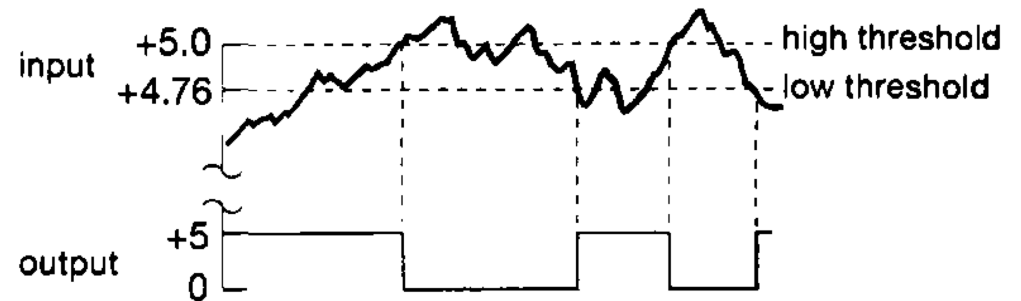
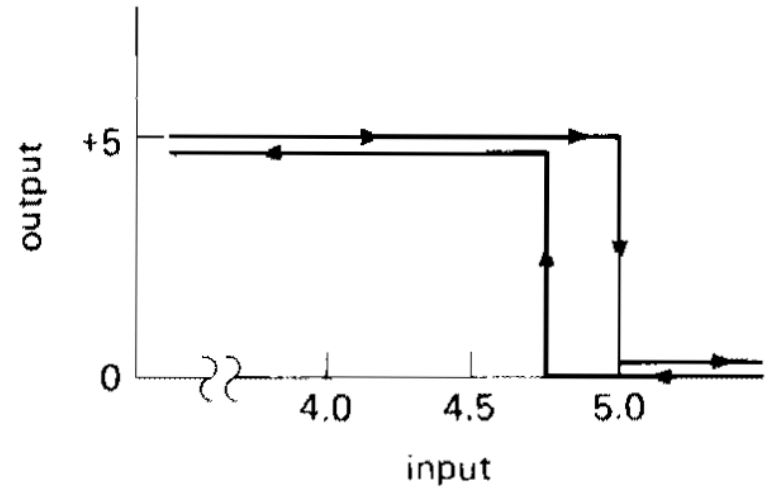
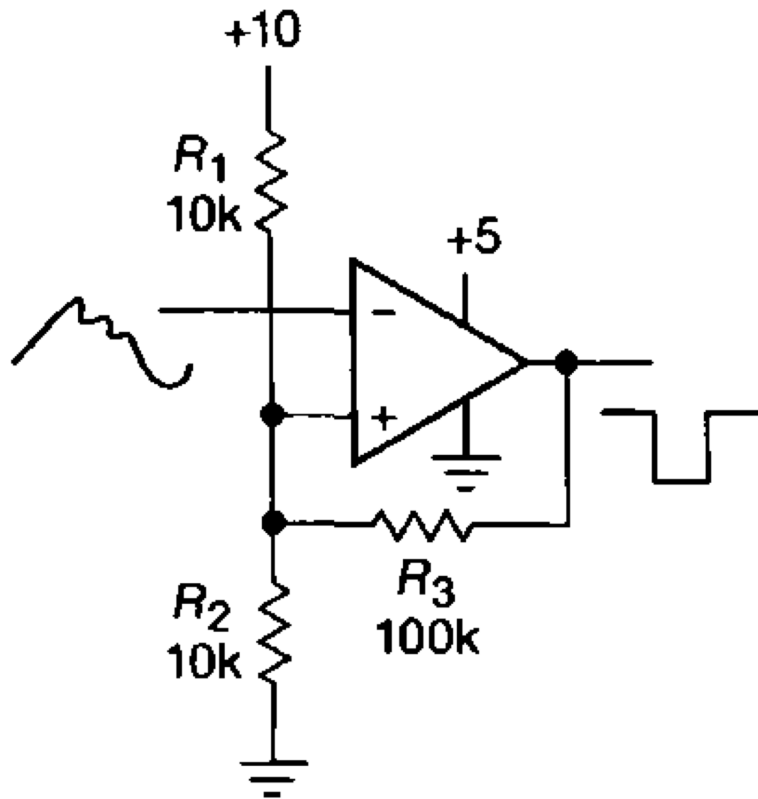
$$\text{SE } V_o = 5V \quad \frac{V_{in} - 10V}{R_1} + \frac{V_{in} - 5V}{R_3} + \frac{V_{in}}{R_2} = 0$$

$$V_{in} \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) = \left( \frac{10V}{R_1} + \frac{5V}{R_3} \right) \Rightarrow V_{in} = 5V$$

$$\text{SE } V_o = 0V \quad \frac{V_{in} - 10V}{R_1} + \frac{V_{in}}{R_3} + \frac{V_{in}}{R_2} = 0$$

$$V_{in} \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) = \left( \frac{10V}{R_1} \right) \Rightarrow V_{in} = 4.762V$$

# Il trigger di Schmitt: 5. comparatori con feedback positivo

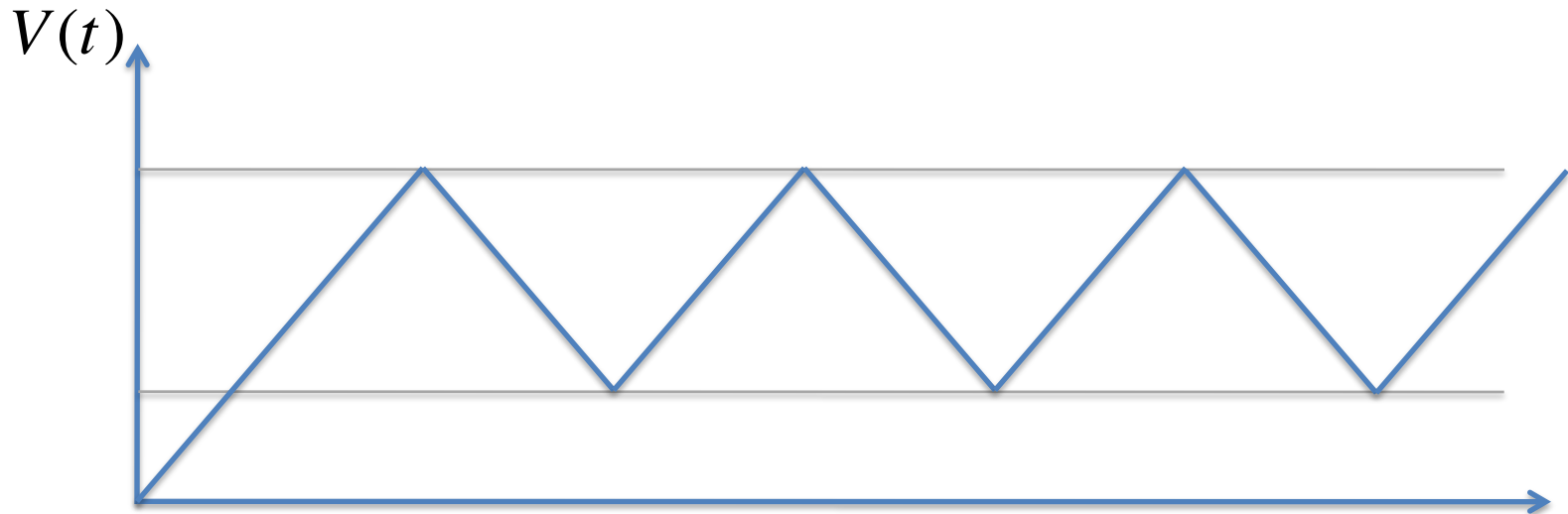


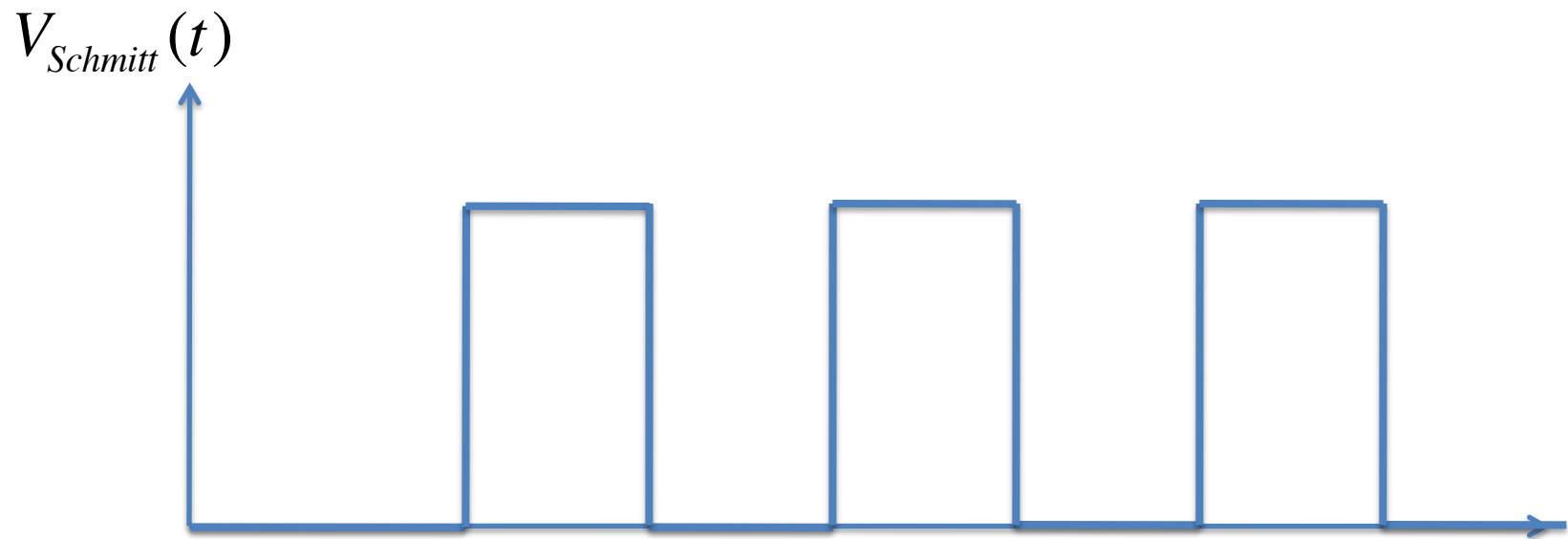
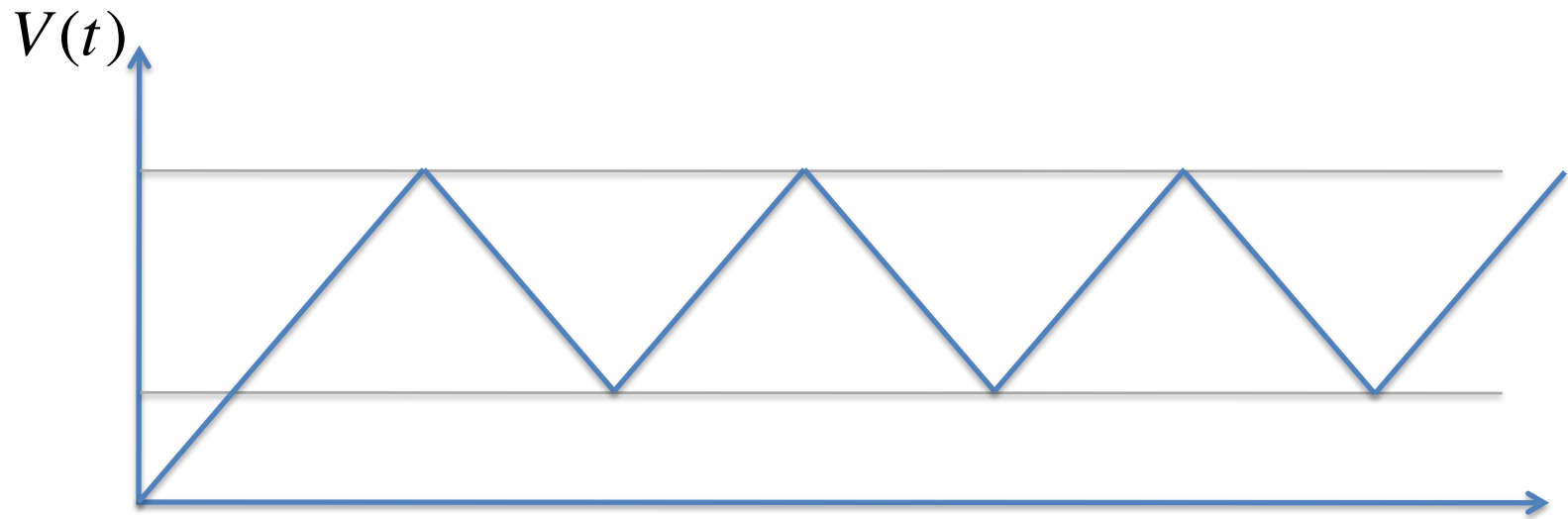
## Sorgenti di corrente e condensatori

$$\frac{dQ}{dt} = \frac{1}{C} \frac{dV}{dt} = I_0 \quad \Rightarrow \quad \frac{dV}{dt} = I_0 C \quad \Rightarrow \quad V(t) = V_0 + I_0 C \cdot t$$

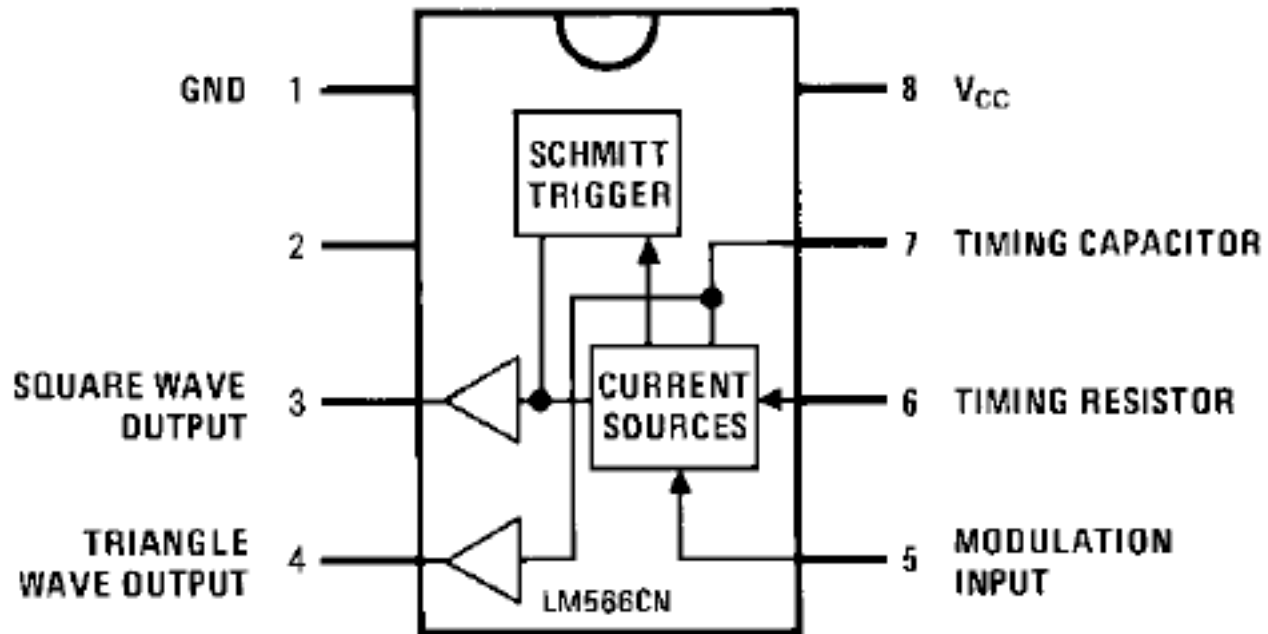
Qui supponiamo che l'uscita del trigger di Schmitt faccia cambiare la polarità della corrente quando vengono attraversate le soglie

**Se  $I_0$  dipende da  $V_{in}$  allora la frequenza dell'onda triangolare è funzione di  $V_{in}$   
Questo si può fare con un transistor**

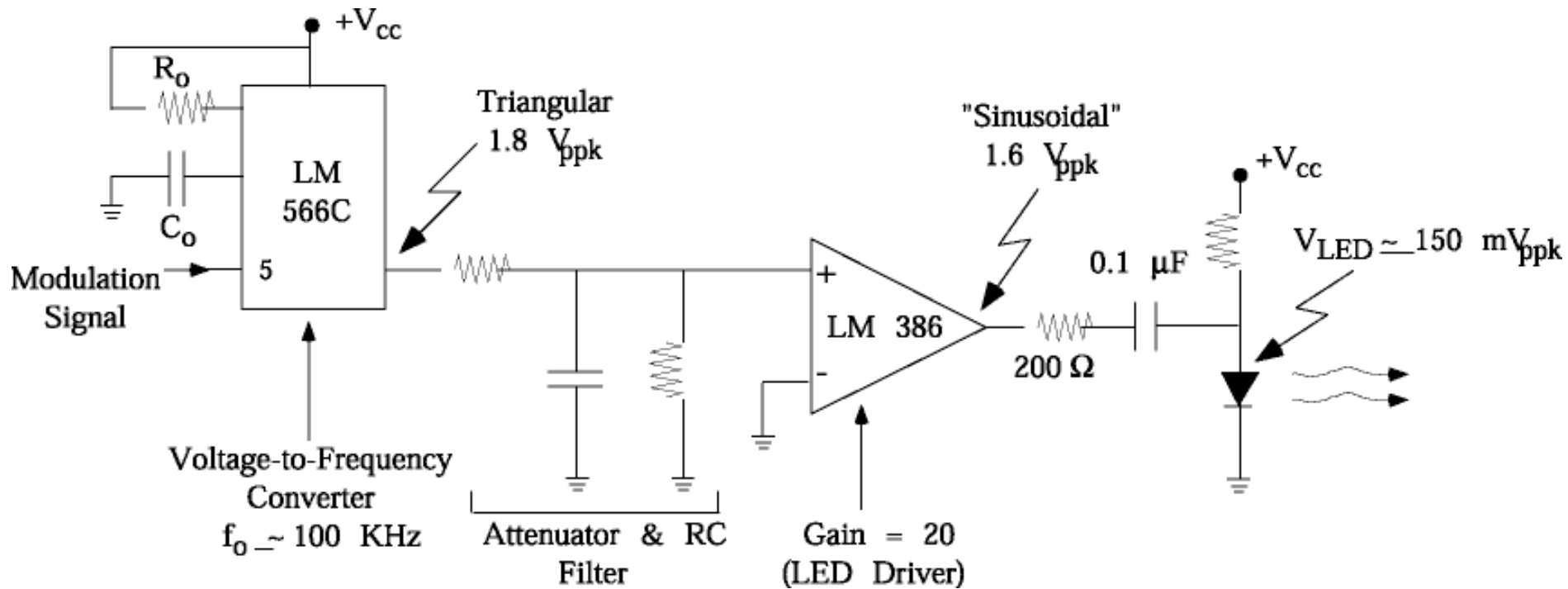




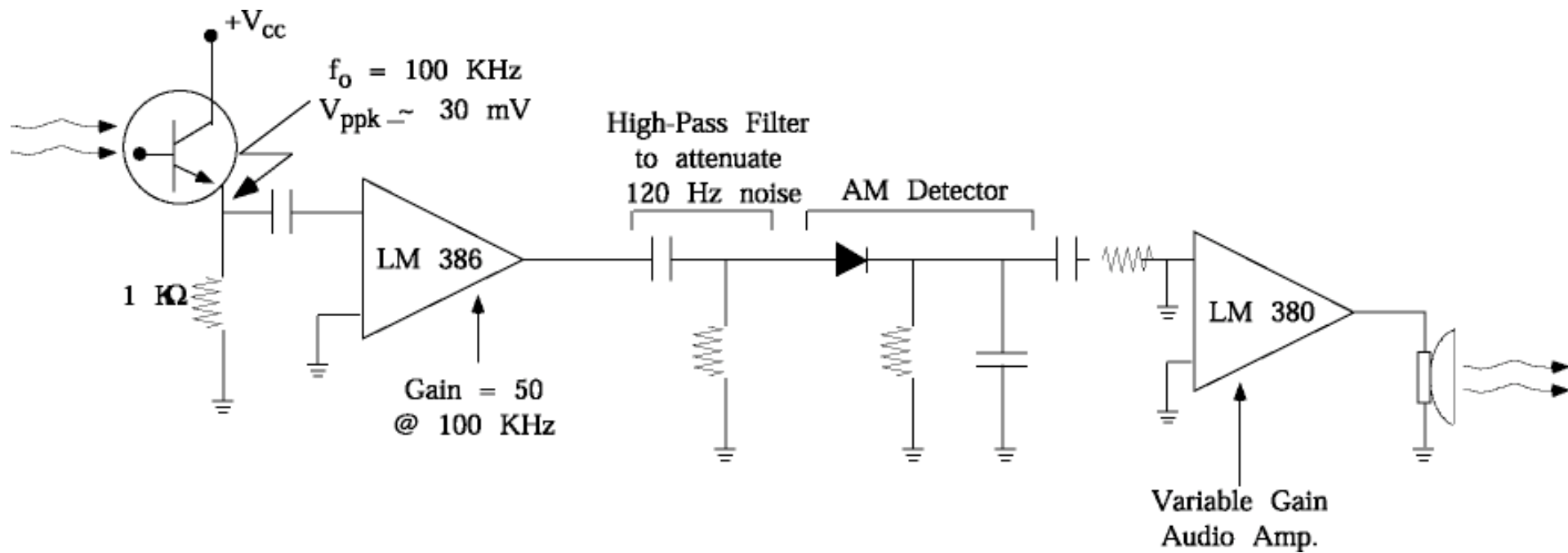
## Dual-In-Line Package



# Trasmettitore con modulazione FM

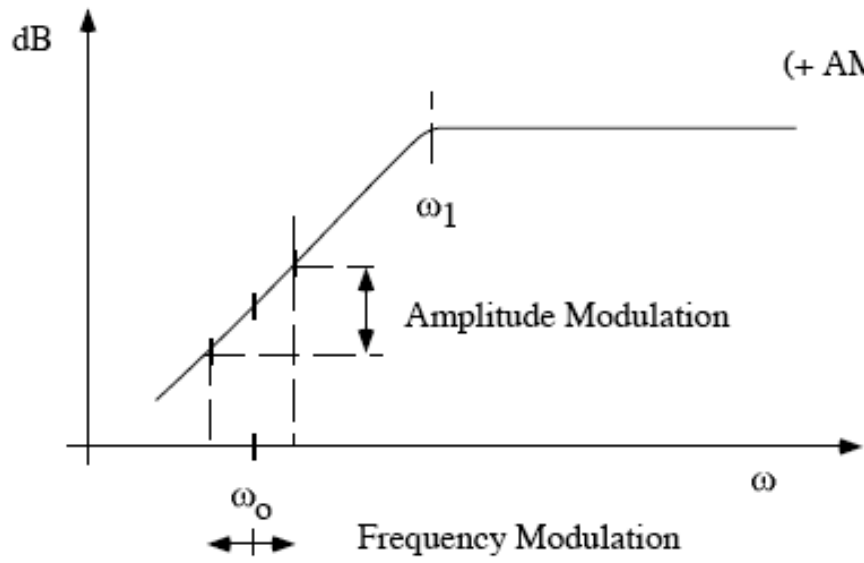
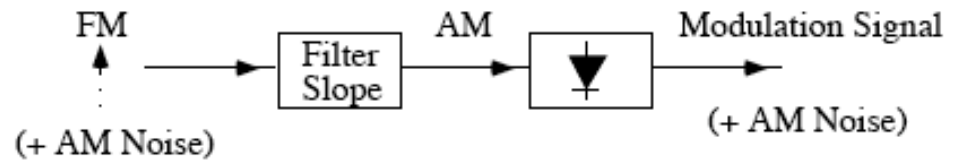
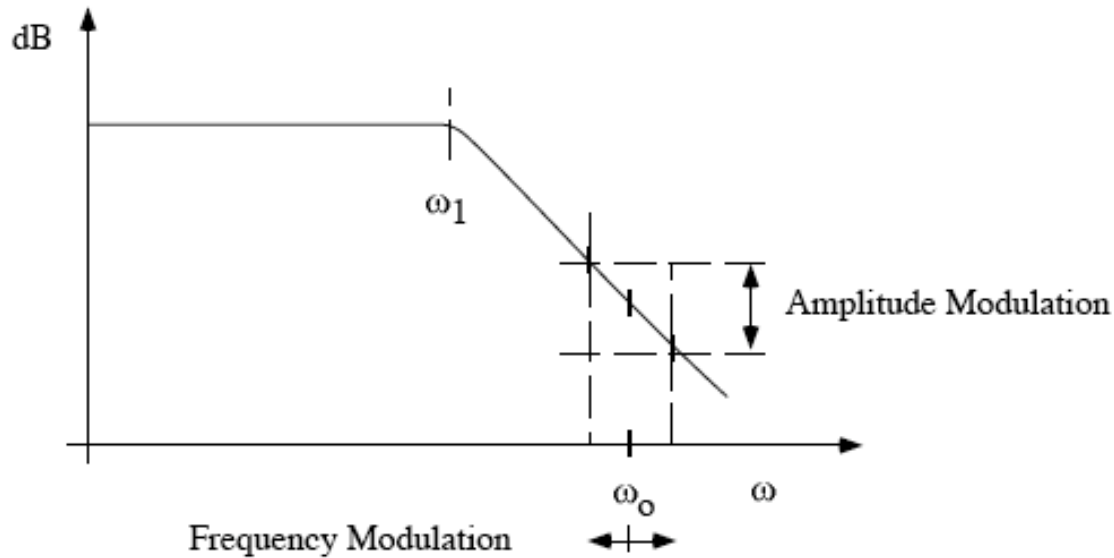


# Ricevitore con demodulazione FM



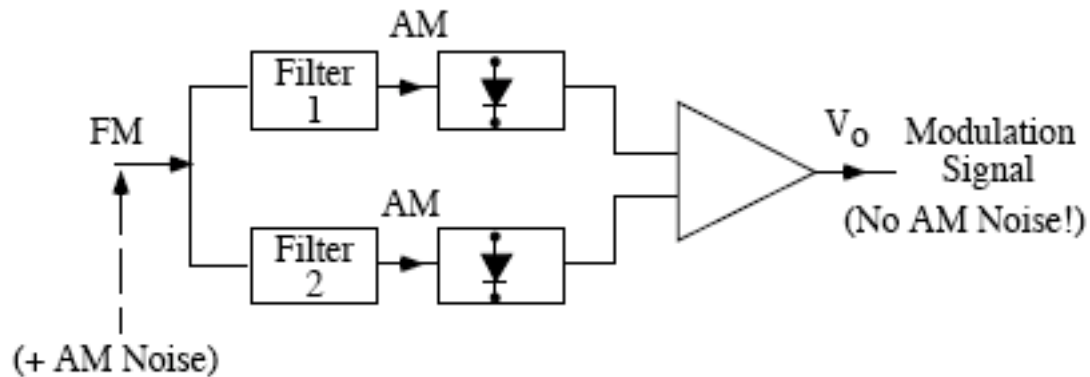
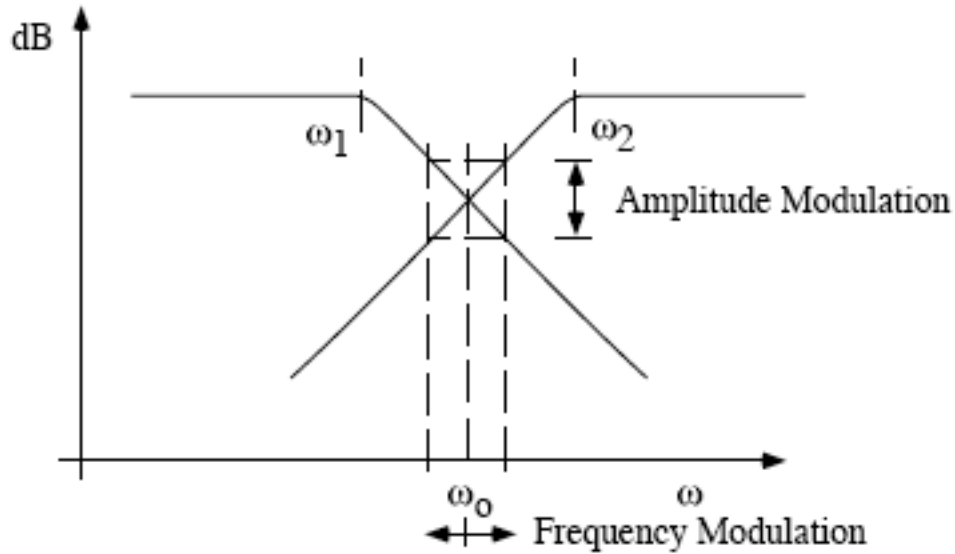


# Demodulazione per mezzo di uno slope detector



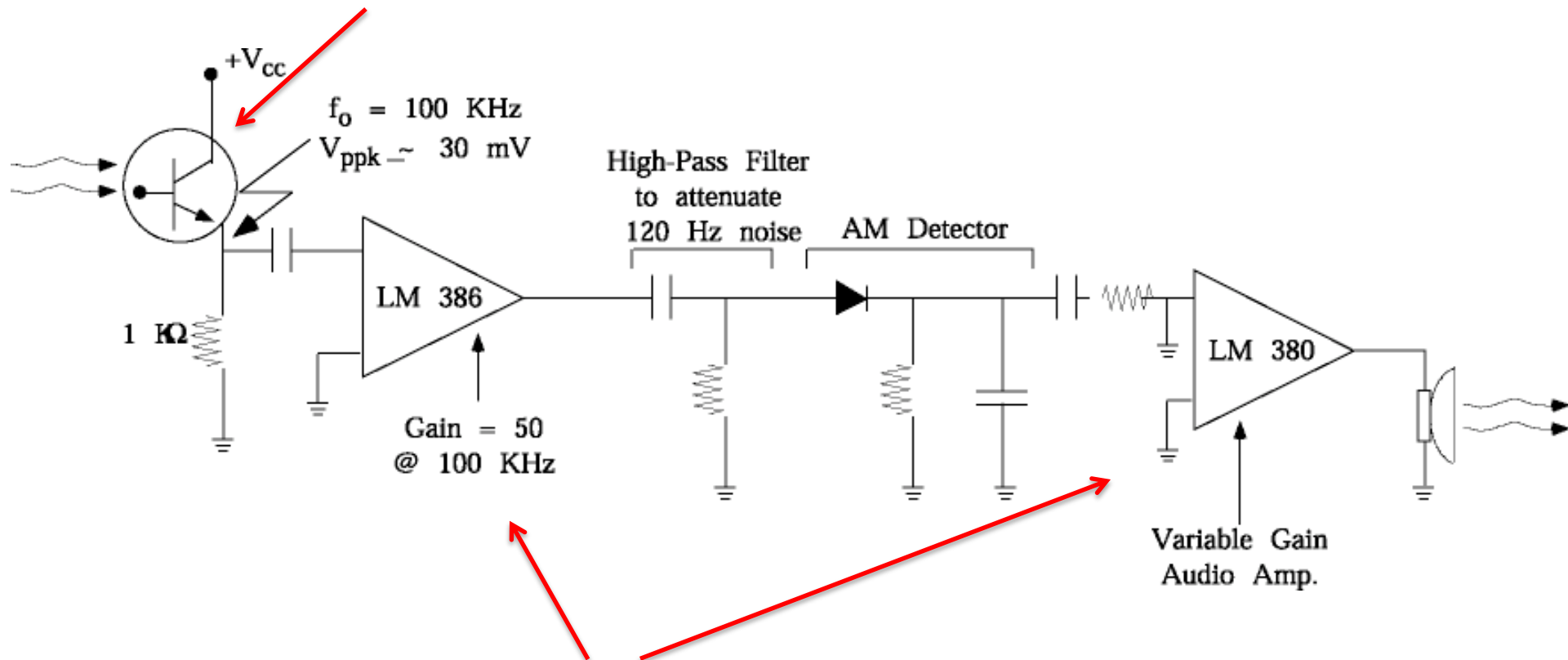
# Matched slope detector

(migliore linearità, rimozione del rumore AM)



# Ricevitore con demodulazione FM

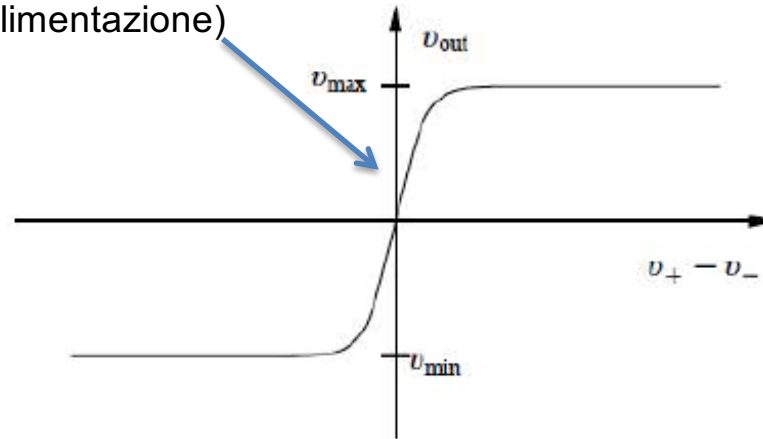
il fototransistor fa  
anche da slope detector



Questi amplificatori non sono essenziali nello schema di demodulazione, servono solo a dare potenza al segnale

# Analisi statica del funzionamento degli OP-Amps

il guadagno dell'OP-AMP è dato dalla pendenza di questa curva. Il guadagno si annulla quando l'OP-AMP va in saturazione (la tensione di uscita raggiunge la tensione di alimentazione)



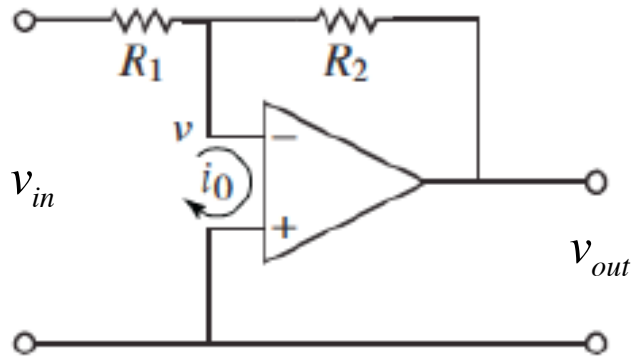
**Figure 3.8:** Input/output characteristics of an operational amplifier. The differential input is given by  $v_+ - v_-$ . The output voltage is a linear function of the input in a small range around 0, with saturation at  $v_{\min}$  and  $v_{\max}$ . In the linear regime the op amp has high gain.

$$\text{sat}(x; a, b) = \begin{cases} a & x < a \\ x & a \leq x \leq b \\ b & x > b \end{cases}$$

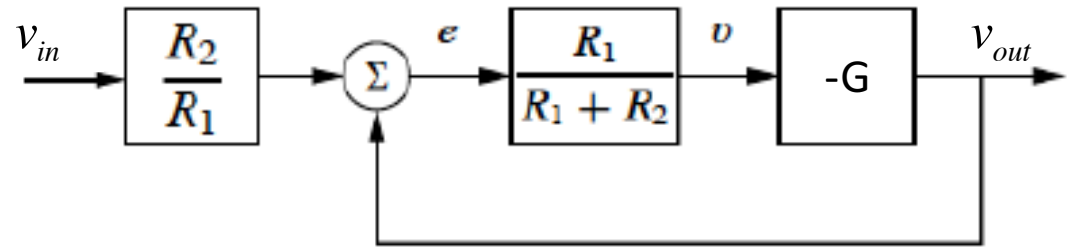


approssimazione spline della caratteristica di ingresso-uscita dell'OpAmp

# analisi con guadagno infinito



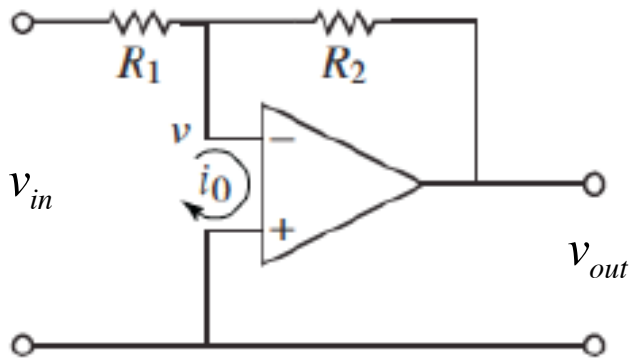
(a) Amplifier circuit



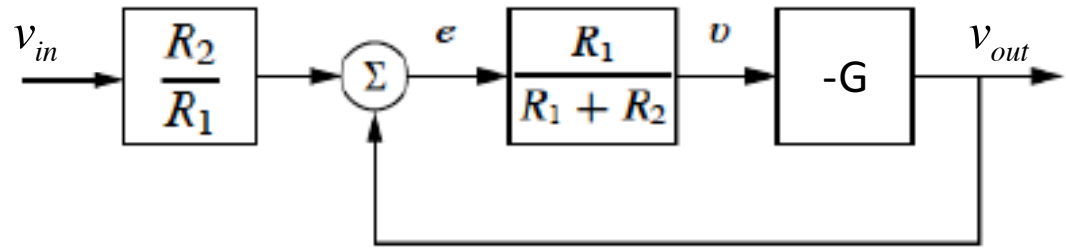
(b) Block diagram

$$v \approx 0; \quad I_1 = \frac{v_{in}}{R_1}; \quad I_2 = \frac{v_{out}}{R_2}; \quad I_1 + I_2 \approx 0 \quad \Rightarrow \quad v_{out} = -\frac{R_2}{R_1} v_{in}$$

# analisi con guadagno finito



(a) Amplifier circuit

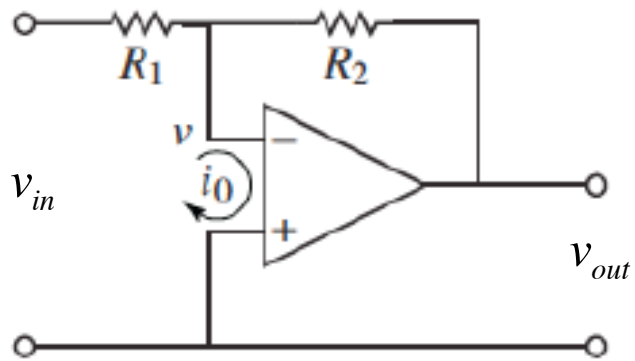


(b) Block diagram

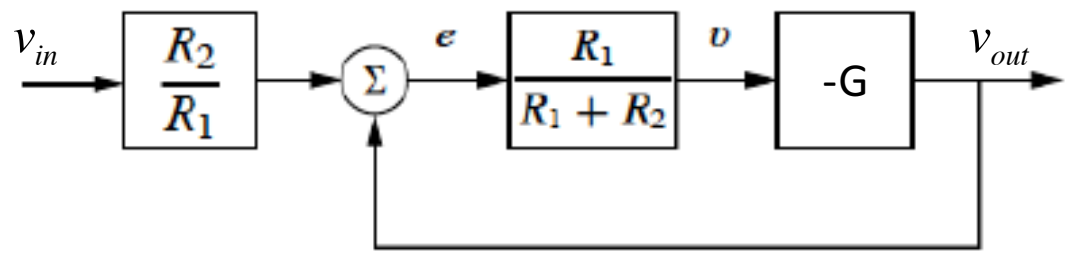
$$I_1 = \frac{v_{in} - v}{R_1}; \quad I_2 = \frac{v_{out} - v}{R_2}; \quad I_1 + I_2 \approx 0; \quad v_{out} = -Gv$$

$$\Rightarrow \frac{v_{in}}{R_1} + \frac{v_{out}}{R_2} = \frac{R_1 + R_2}{R_1 R_2} v \quad \Rightarrow \quad v = \frac{R_1}{R_1 + R_2} \left( \frac{R_2}{R_1} v_{in} + v_{out} \right)$$

# analisi con guadagno finito (cont.)



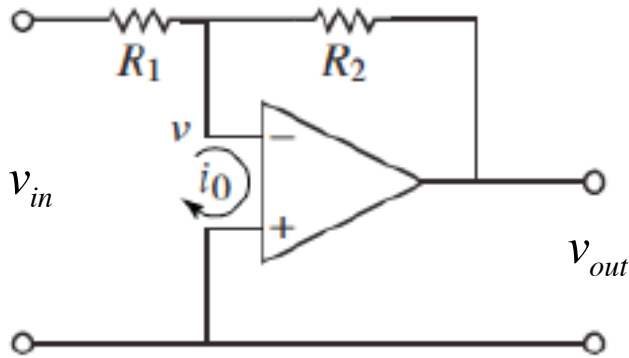
(a) Amplifier circuit



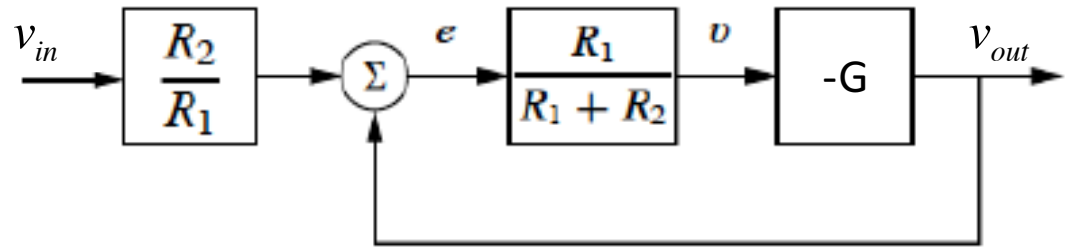
(b) Block diagram

$$v_{out} = -\frac{R_2}{R_1} \left( \frac{R_1 G}{R_1 G + R_1 + R_2} \right) v_{in}$$

# dinamica degli op-amp



(a) Amplifier circuit



(b) Block diagram

Espansione in serie

$$v_{out}(t + \Delta t) \approx v_{out}(t) + \frac{dv_{out}}{dt} \Delta t$$

$$= \alpha v_{out}(t) - \beta v(t)$$

Tempo di propagazione attraverso l'OpAmp

Descrizione del feedback



$$\frac{dv_{out}}{dt} = -\frac{1-\alpha}{\Delta t} v_{out}(t) - \frac{\beta}{\Delta t} v(t)$$

$$= -\frac{1}{\tau} v_{out}(t) - bv(t)$$

$$= -Bv_{out}(t) - bv(t)$$



$$\begin{aligned}
\frac{dv_{out}}{dt} &= -\frac{1-\alpha}{\Delta t} v_{out}(t) - \frac{\beta}{\Delta t} v(t) \\
&= -\frac{1}{\tau} v_{out}(t) - bv(t) \\
&= -Bv_{out}(t) - bv(t)
\end{aligned}$$

nel caso statico  $v_{out} = -b\tau v = -\frac{b}{B} v = -Gv$

$B$  è l'inverso di un tempo caratteristico e corrisponde quindi ad una frequenza caratteristica e inoltre  $b = BG = \text{gain-bandwidth product (GBP)}$

Inoltre, da

$$\frac{dv_{out}}{dt} = -Bv_{out}(t) - bv(t) = -Bv_{out}(t) - BGv(t)$$

si trova anche

$$\begin{aligned} v(t) &= -\frac{1}{G} \left( v_{out}(t) + \tau \frac{dv_{out}}{dt} \right) \\ &= -\frac{\tau}{G} \left( Bv_{out}(t) + \frac{dv_{out}}{dt} \right) = -\frac{1}{BG} e^{-Bt} \frac{d}{dt} \left( e^{Bt} v_{out}(t) \right) \end{aligned}$$

e quindi

$$v_{out}(t) = -BGe^{-Bt} \int_0^t e^{Bt'} v(t') dt' = -BG \int_0^t e^{-B(t-t')} v(t') dt'$$

Rianalisi dell'amplificatore invertente con il modello dinamico appena trovato

$$I_1 = \frac{v_{in} - v}{R_1}; \quad I_2 = \frac{v_{out} - v}{R_2}; \quad I_1 + I_2 \approx 0;$$

$$v(t) = -\frac{1}{BG} \left( Bv_{out}(t) + \frac{dv_{out}}{dt} \right)$$

$$\Rightarrow \frac{v_{in}}{R_1} + \frac{v_{out}}{R_2} = \frac{R_1 + R_2}{R_1 R_2} v = -\frac{1}{BG} \left( \frac{R_1 + R_2}{R_1 R_2} \right) \left( Bv_{out}(t) + \frac{dv_{out}}{dt} \right)$$

$$\Rightarrow v_{in} = -\left[ \frac{R_1}{R_2} + \frac{R_1 + R_2}{GR_2} \right] v_{out} - \frac{R_1 + R_2}{BGR_2} \frac{dv_{out}}{dt}$$

Ponendo

$$\gamma\delta = \frac{R_1}{R_2} + \frac{R_1 + R_2}{GR_2}; \quad \delta = \frac{R_1 + R_2}{BGR_2}$$

si trova

$$v_{in} = -\gamma\delta v_{out} - \delta \frac{dv_{out}}{dt} = -\delta \left( \gamma v_{out} + \frac{dv_{out}}{dt} \right) = -\delta e^{-\gamma t} \frac{d}{dt} \left( e^{\gamma t} v_{out} \right)$$

e quindi

$$v_{out}(t) = v_{out}(0) - \frac{1}{\delta} \int_0^t e^{-\gamma(t-t')} v_{in}(t') dt'$$

quindi il circuito si comporta come un filtro RC passa basso con costante di tempo

$$\frac{1}{\gamma} = \frac{R_1 + R_2}{B(GR_1 + R_1 + R_2)}$$