Operational Amplifiers

•Here we see two matched differential amps cascaded to form a basic OP-AMP.

•The differential pair cancel temperature drifts and common mode noise at the input.

•First built to perform math operations, analogue computers.

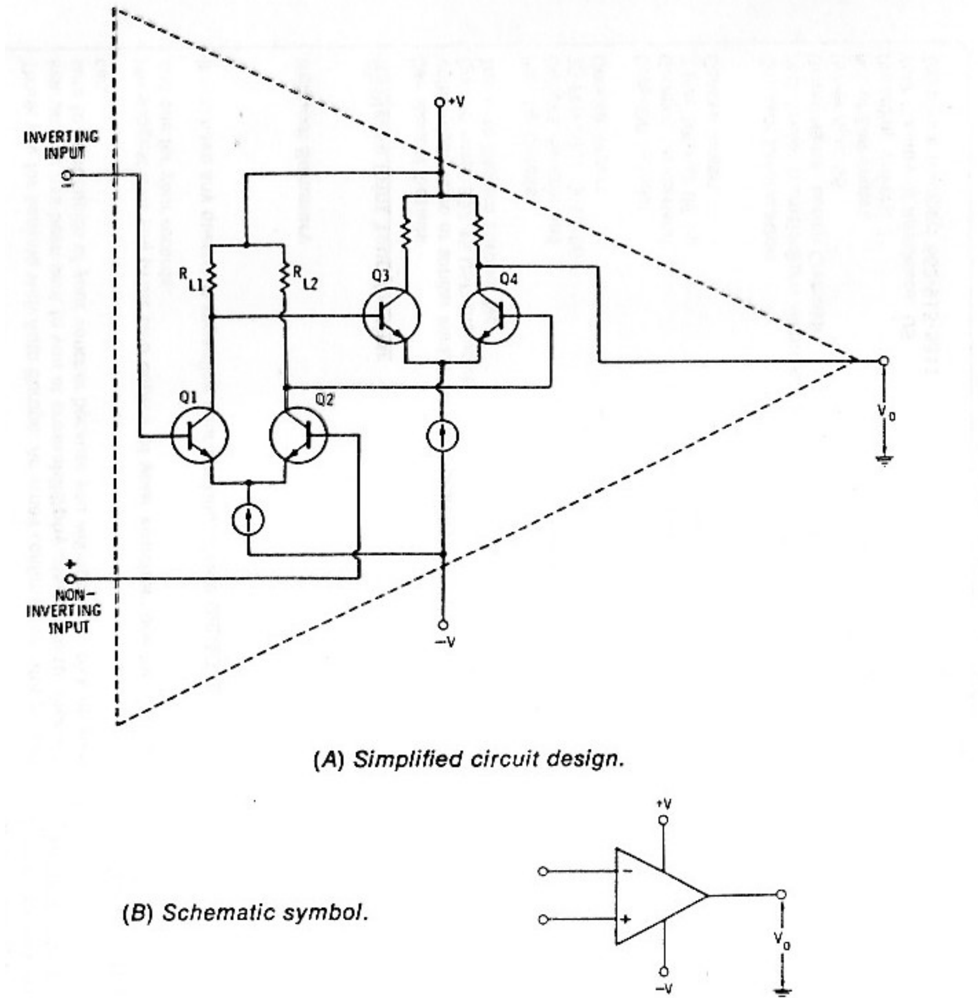
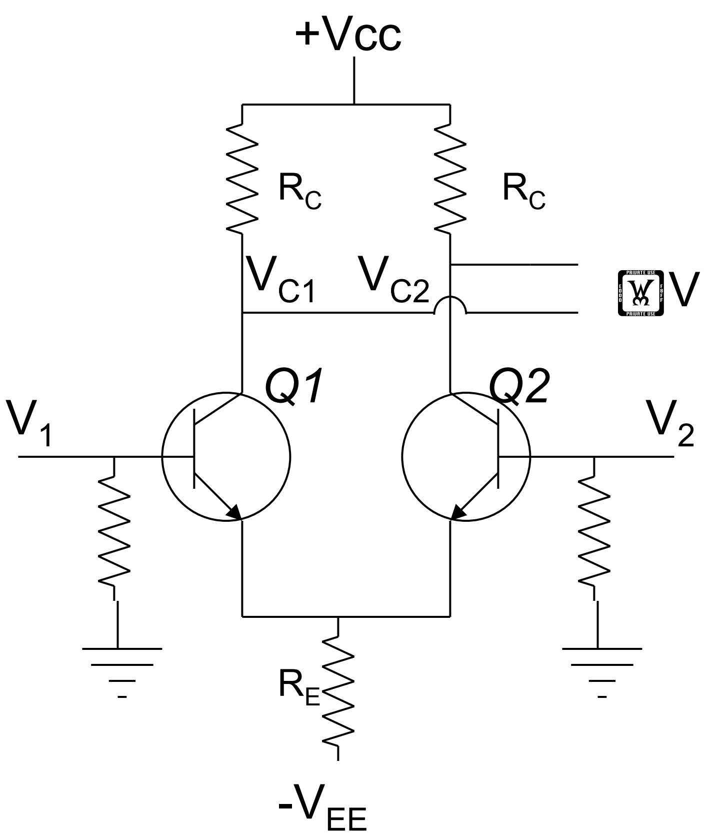
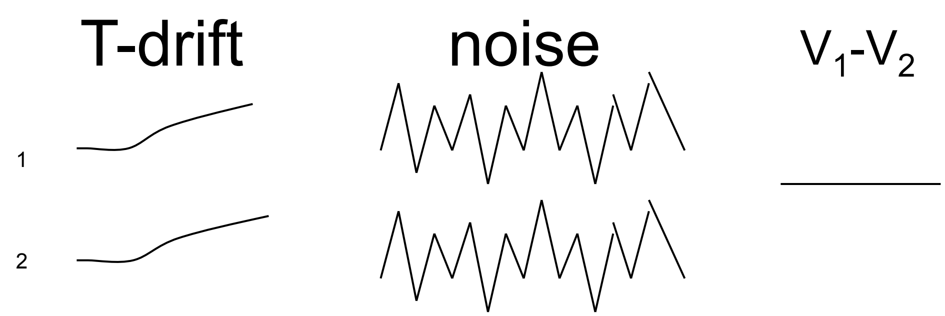


Fig. 5-8. Cascading differential amplifiers to build on op amp.

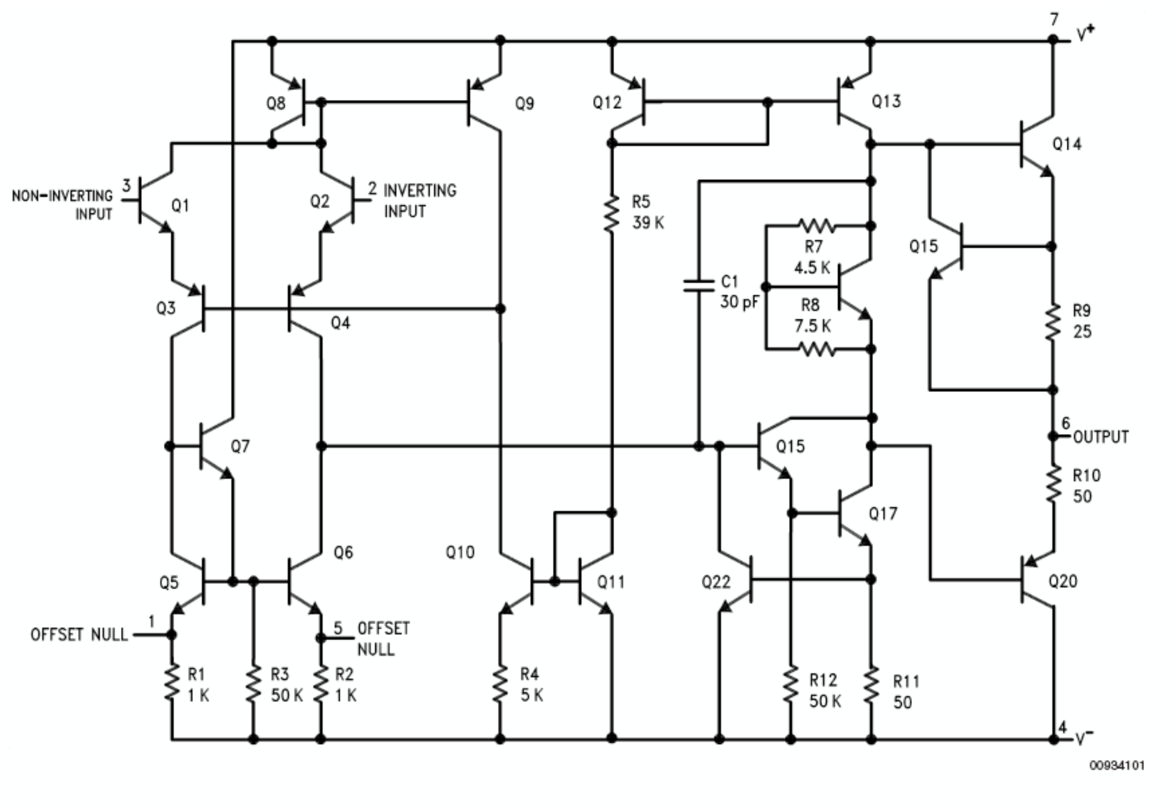
Differential Amplifiers



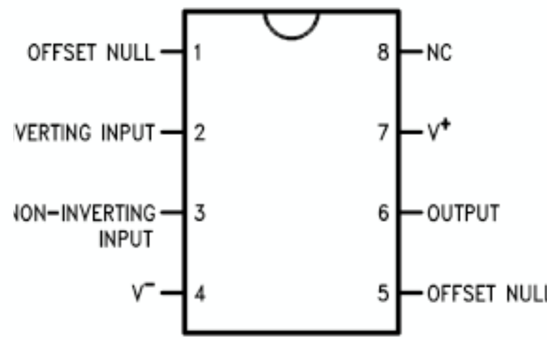
- $V_{OUT} = A_V (V_1 - V_2)$
- +Vcc and $-V_{EE}$ bias the inputs and output to 0 volts.
- Common mode noise refers to same sign pickup on V_1 and V_2.
- The differential pair cancels common-mode signals in transistors Q_1 and Q_2 eg, temperature drifts, noise,etc.

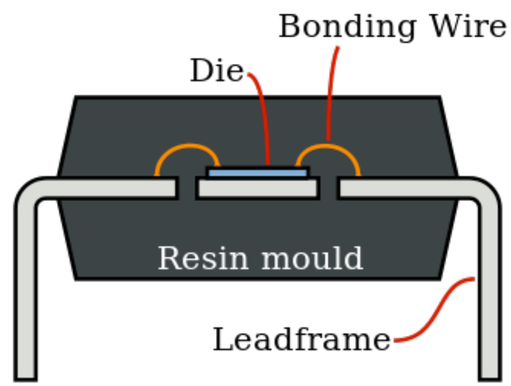


LM741

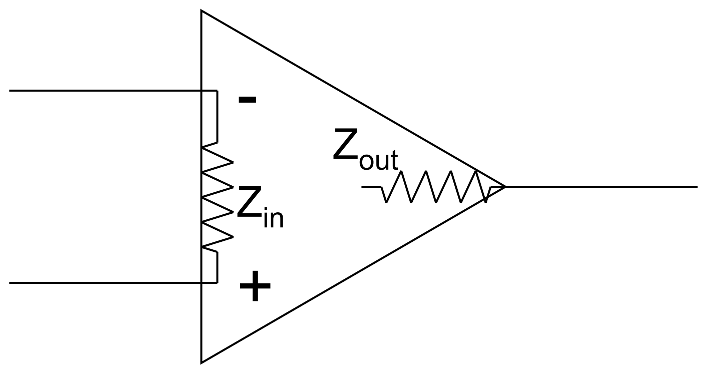


Dual-In-Line or S.O. Package



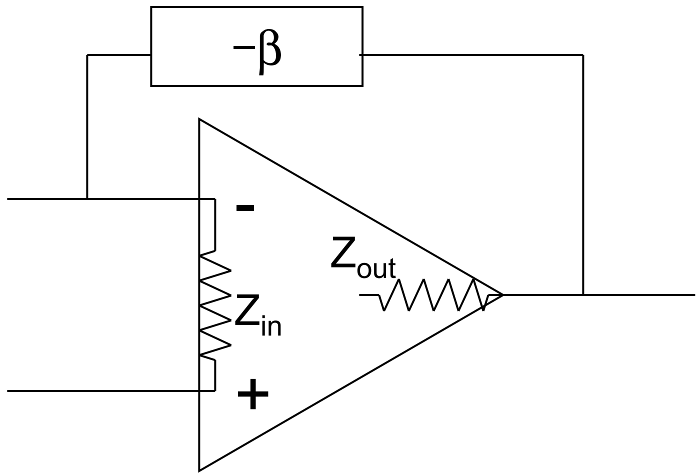


Ideal Op Amp



- Very high or Infinite **open loop gain**. A_V~100K
- Very high or Infinite input impedance ~100MΩ.
- Very low or zero output impedance. ~1Ω
- Zero DC output voltage when inputs grounded.

Negative Feedback



- High gain amplifiers can become unstable in **open loop** configuration.
- A portion of the output β can be feed back to the input to correct this situation.
- For Av>>1 the **closed loop gain**

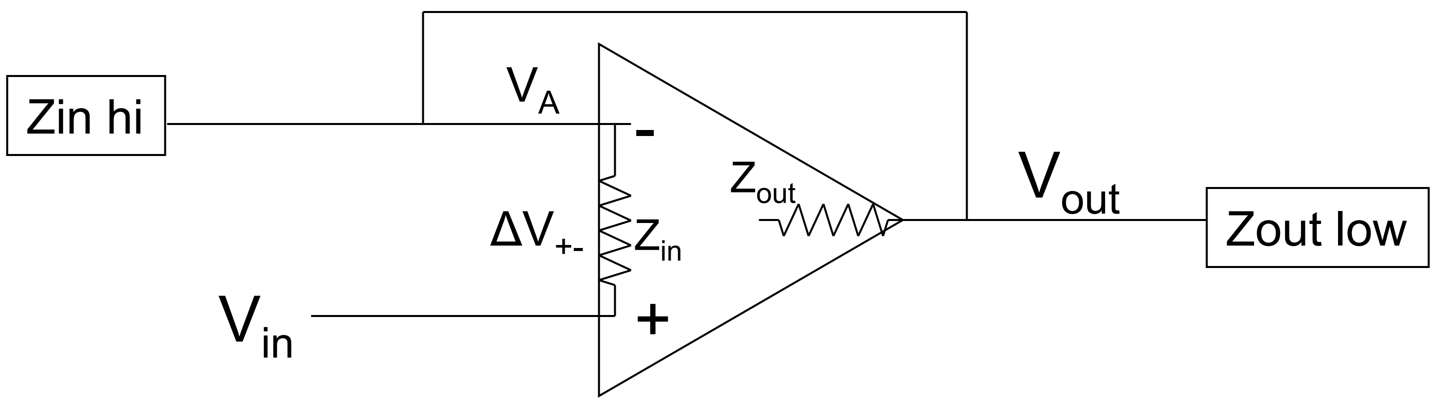
$$A_v^{\beta} = 1/\beta$$

is only a function of the feedback loop and β easily fixed.

$$A_v = \frac{Vout}{Vin} \Rightarrow \frac{Vout}{Vin - \beta Vin} = \frac{\left(Vout/Vin\right)}{1 - \beta\left(Vout/Vin\right)} = \frac{A_v^{\beta}}{1 - \beta A_v^{\beta}}$$

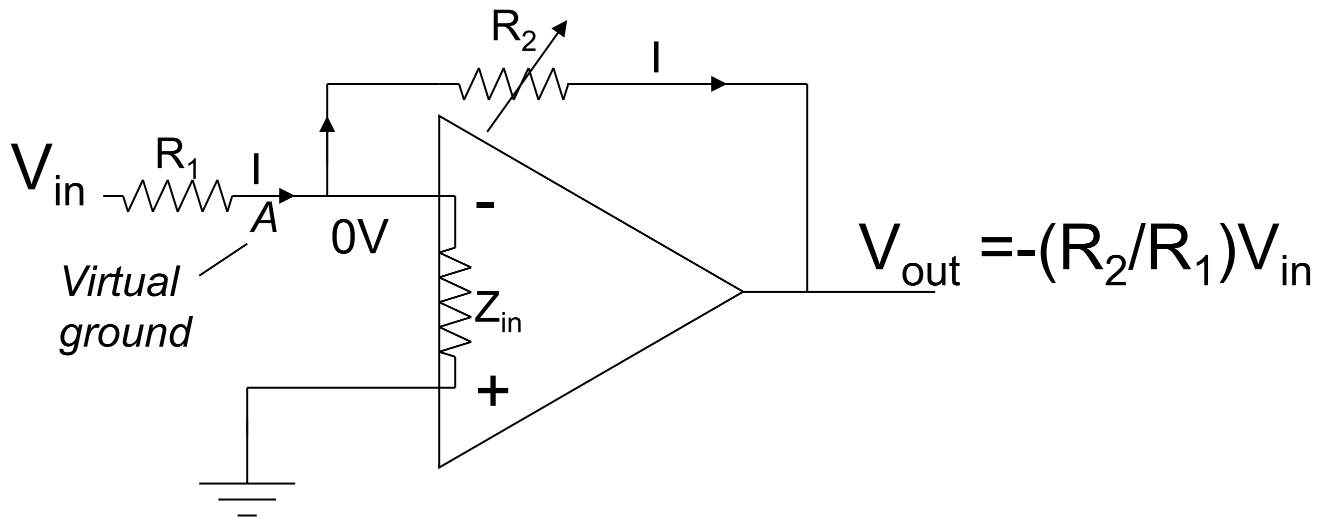
$$A_v^{\beta} = \frac{A_v}{1 + \beta A_v} \quad \Rightarrow \quad A_v^{\beta} \simeq \frac{1}{\beta} \qquad when \;\; A_v >> 1$$

Voltage Follower



1. ΔV_{+-} =0 no current flows no voltage drop!
2. $V_{in}=V_A=V_{out}$
3. Voltage Follower is used as an impedance matching device from a hi to low impedance devise. It also acts as a current booster or buffer amp.

Inverting Amp

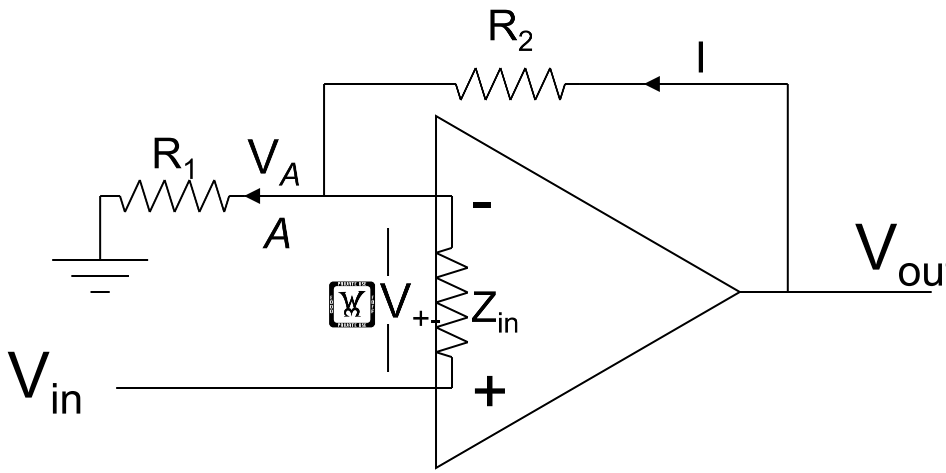


1. $V_+ = V_- = 0$ (since no current flows thru Zin)
2. $V_{in} - I\,R_1 = 0$
3. $0 - I\,R_2 = V_{out}$

4. A_V^{β} = Vout / Vin = -R2/R1 (combining 2 and 3)
5. $Z_{in} = R_1$ (point-*A* at virtual ground).

   R_1 should be fixed and not too small!

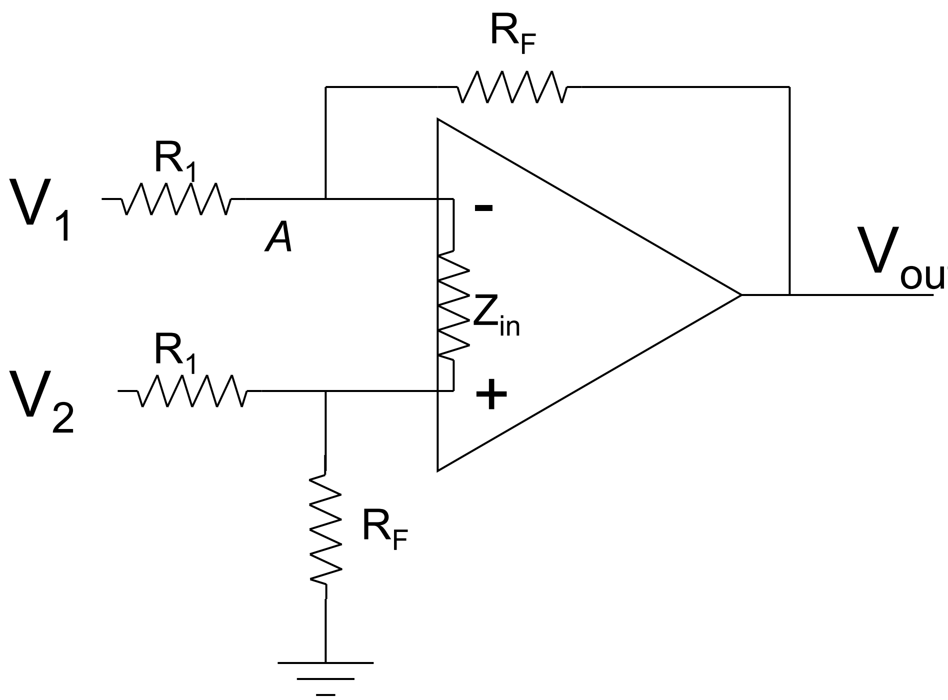
Non-Inverting Amp



$V_{out} = V_{in}\,(1+R_2/R_1)$

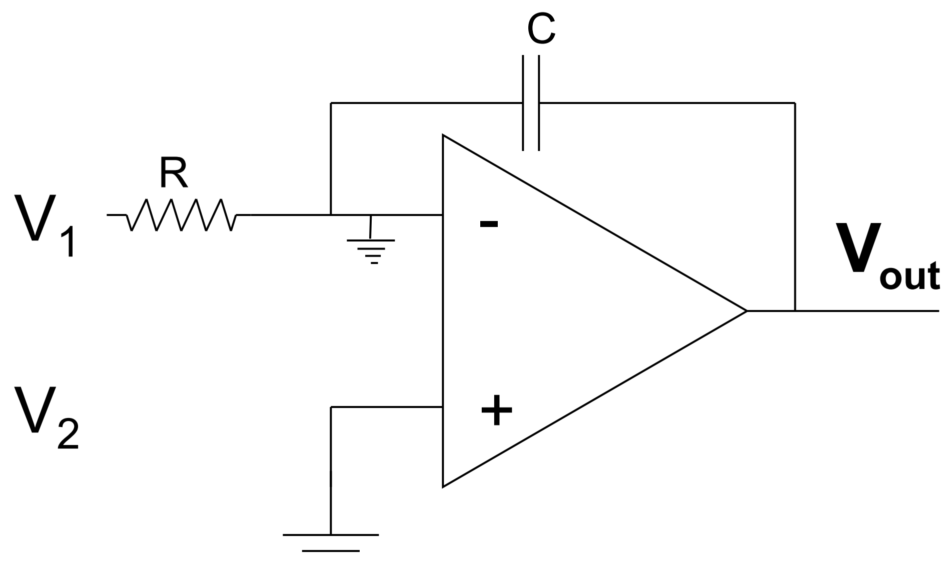
1. $V_A = V_{in}$ (No current flows thru Z_{in} so $\Delta V_{+-} = 0$)
2. $V_{out} - I\,R_2 = V_A = V_{in}$
3. $V_{in} - I\,R_1 = 0$
4. $V_{out} = V_{in}\,(1+R_2/R_1)$ combining 1,2
5. Input impedance = $Z_{in} + R1 \sim Z_{in}$

Difference Amp



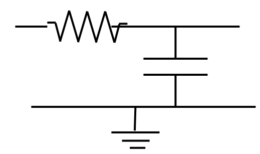
$V_{out}=(V_2-V_1)\ R_F\ /R_1$

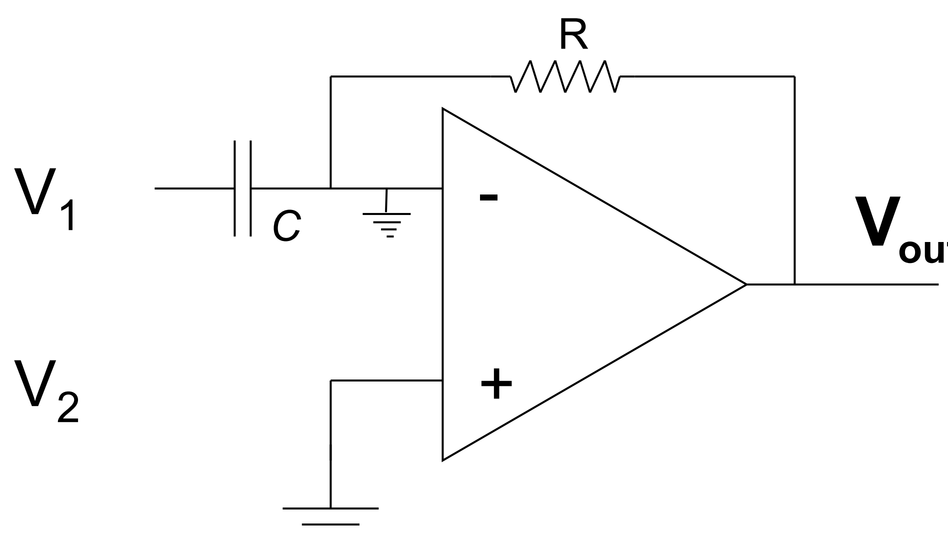
Integrator/Differentiator



integrator

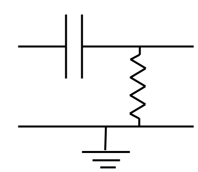
$$V_{out} = -1/RC \int V_{in} dt$$



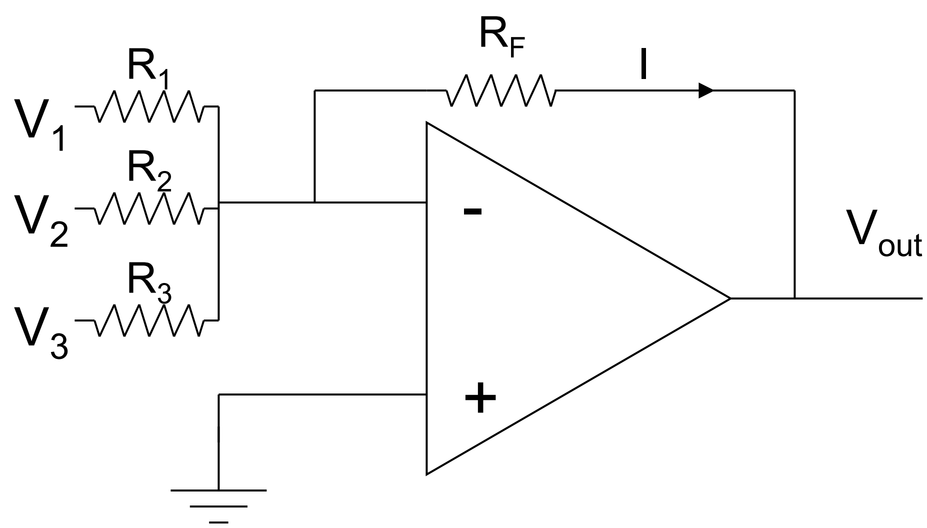


differentiator

$$V_{out} = -RC \, {}^{d}\!/_{dt} \, V_{in}$$



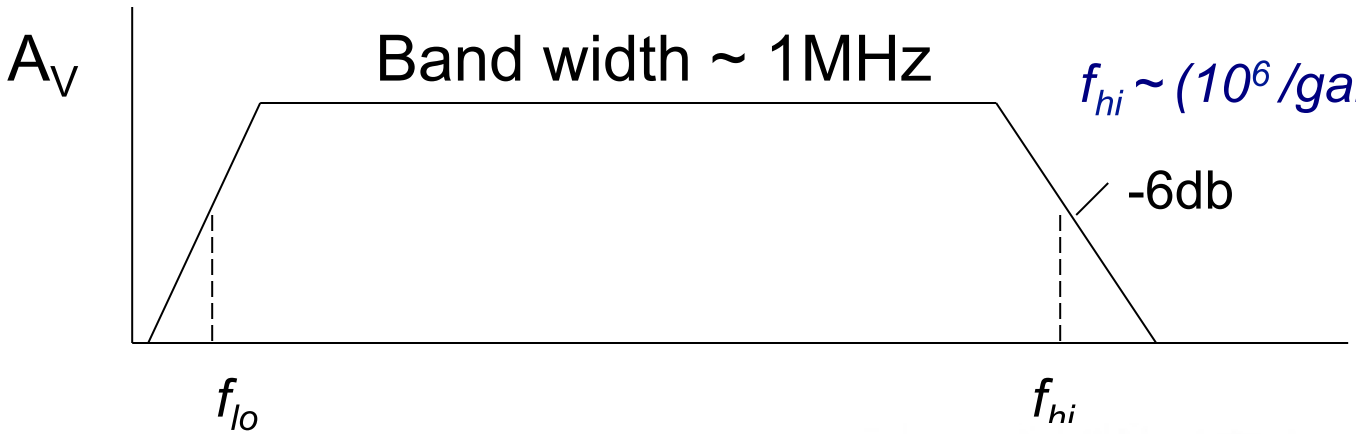
Voltage Summer



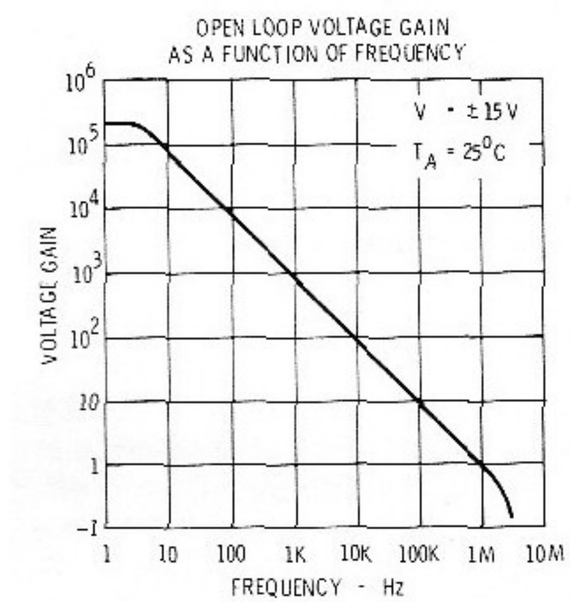
$V_{out} = -(V_1/R_1+V_2/R_{2+}V_3/R_3)R_F$

•Inputs V_1,V_2,V_3 are summed with gain factor R_i/R_F I=1,2,3.

Frequency Response



$f_{hi} \sim (10^6/gain)$ Hz

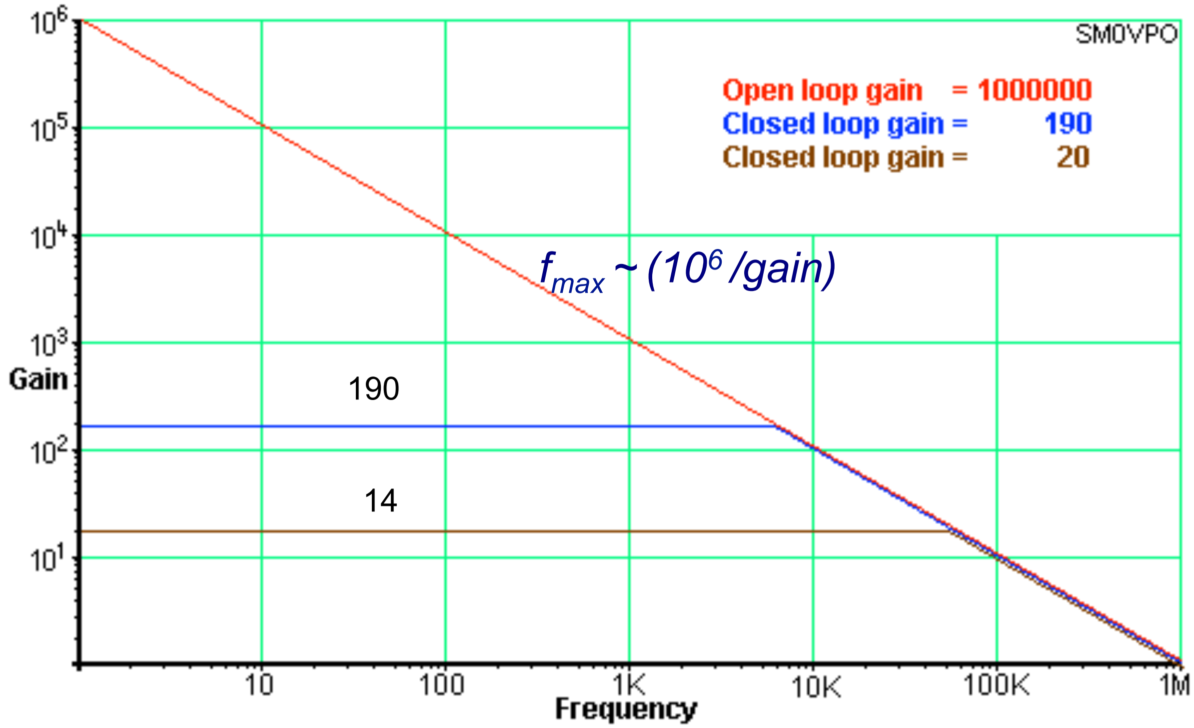


We build an amplifier with gain of 1000, what will f_{hi} be?

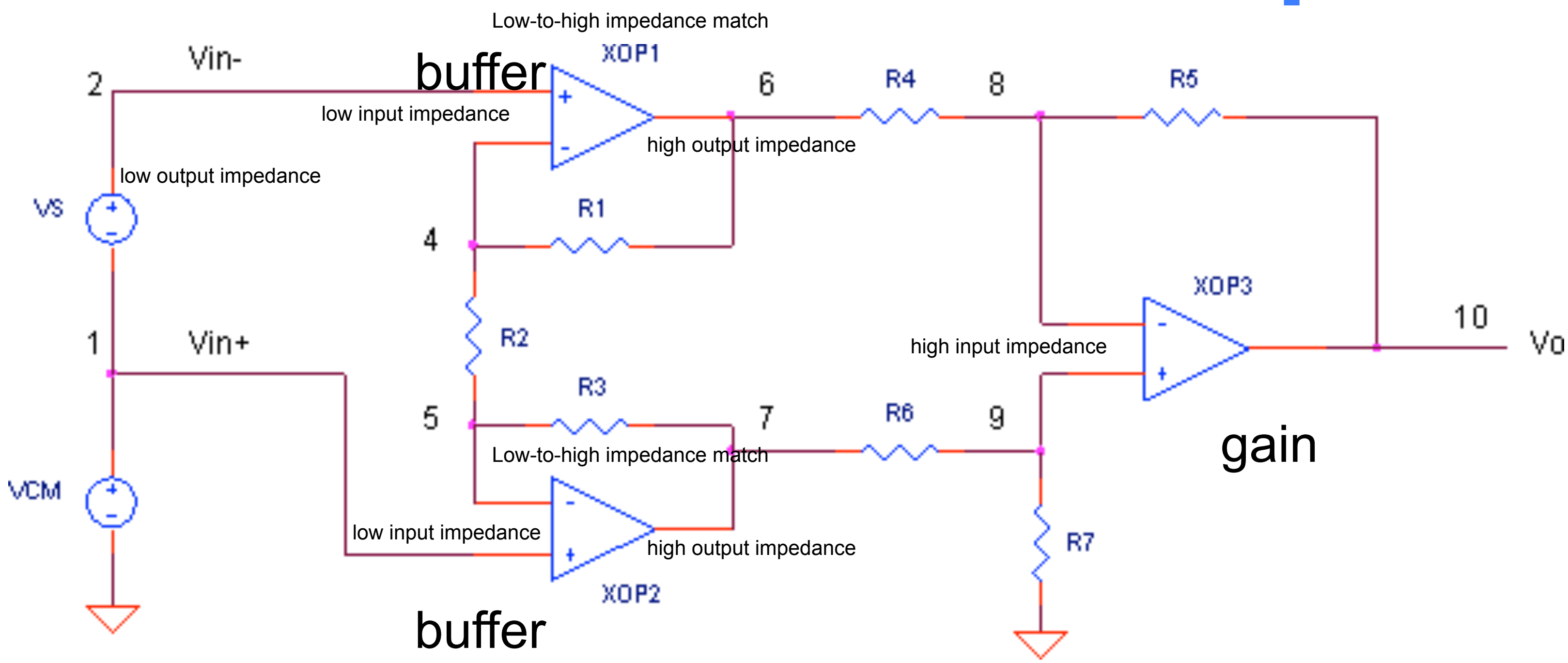
Ans.- Based on the graph:
$f_{hi} \sim (10^6/gain)$ --> $f_{hi} \sim 1$ kHz

Frequency Response(2)

With a voltage gain of 190, an amplifier will have that gain up to the frequency response of about 5.3 KHz below. Not very good for Hi-Fi reproduction! But if we were to reduce the voltage gain to just 20 then the frequency response would extend to 50 KHz. If we needed an amplifier to have a gain of 190 then we would be far better off to have two cascaded amplifier; each with a voltage gain of just 14. The total gain would then be a little over 190 and the frequency response would be flat to over 70KHz.



Instrumentation Amp



An unwanted common mode noise signal V_{CM} appears on inputs 1 and 2 with a weak transducer signal V_S .

The V_{CM} is cancelled by the Difference Amp resulting in a noise-free V_S signal.

$$\mathbf{Vout = A_v(Vs_+ - Vs_-) + A_{CMRR}(Vcm_+ + Vcm_-)}$$

INSRUMENATION AMPLIFIER

Instrumentation amplifiers are actually made up of 2 parts: a buffered amplifier XOP1, XOP2 and a basic differential amplifier XOP3. The differential amplifier part is often essential when measuring sensors. Why? A sensor produces a signal between its terminals. However, for some applications, neither terminal may be connected to the same ground potential as your measuring circuit. The terminals may be biased at a high potential or riding on a noise voltage. The differential amplifier rescues the signal by directly measuring the difference between the sensor’s terminals.

The buffered amplifier XOP1 and XOP2 not only provides gain, but provides impedance matching from a low Impedance transducer to the high impedance Differentiral amplifier stage XOP3.

SIGNAL GAIN

The instrumentation amp offers two useful functions: amplify the difference between inputs and reject the signal that’s common to the inputs. The latter is called Common Mode Rejection (CMR). The signal gain is accomplished by XOP1 and XOP2 while XOP3 typically forms a differential gain of 1. You can calculate the overall gain by

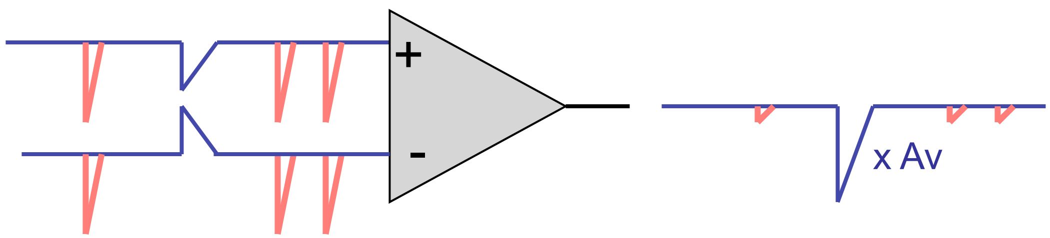
$$\frac{Vo}{Vs} = \left(1 + 2\frac{R1}{R2}\right)\frac{R5}{R4}$$

where R1=R3 and R5/R4 = R7/R6.   http://www.ecircuitcenter.com/Circuits/instamp1/instamp1.htm

CMRR

- The common mode rejection ratio (cmrr) reflects the ability of the op-amp to reject noise common to both inputs.
- cmrr = A_v / A_{cmrr} = Ndb

Vout = $A_v(V_+ - V_-) + A_{CMRR}(V_+ + V_-)$



*Consider an amplifier with cmrr=80db and Av=180 gain. If a differential signal of **+2mV,-2mV** is applied along with an unwanted common mode signal of **10mV**, what is the amplitude of each at the output*

Vdiff = 180 (4mV) = 720mV

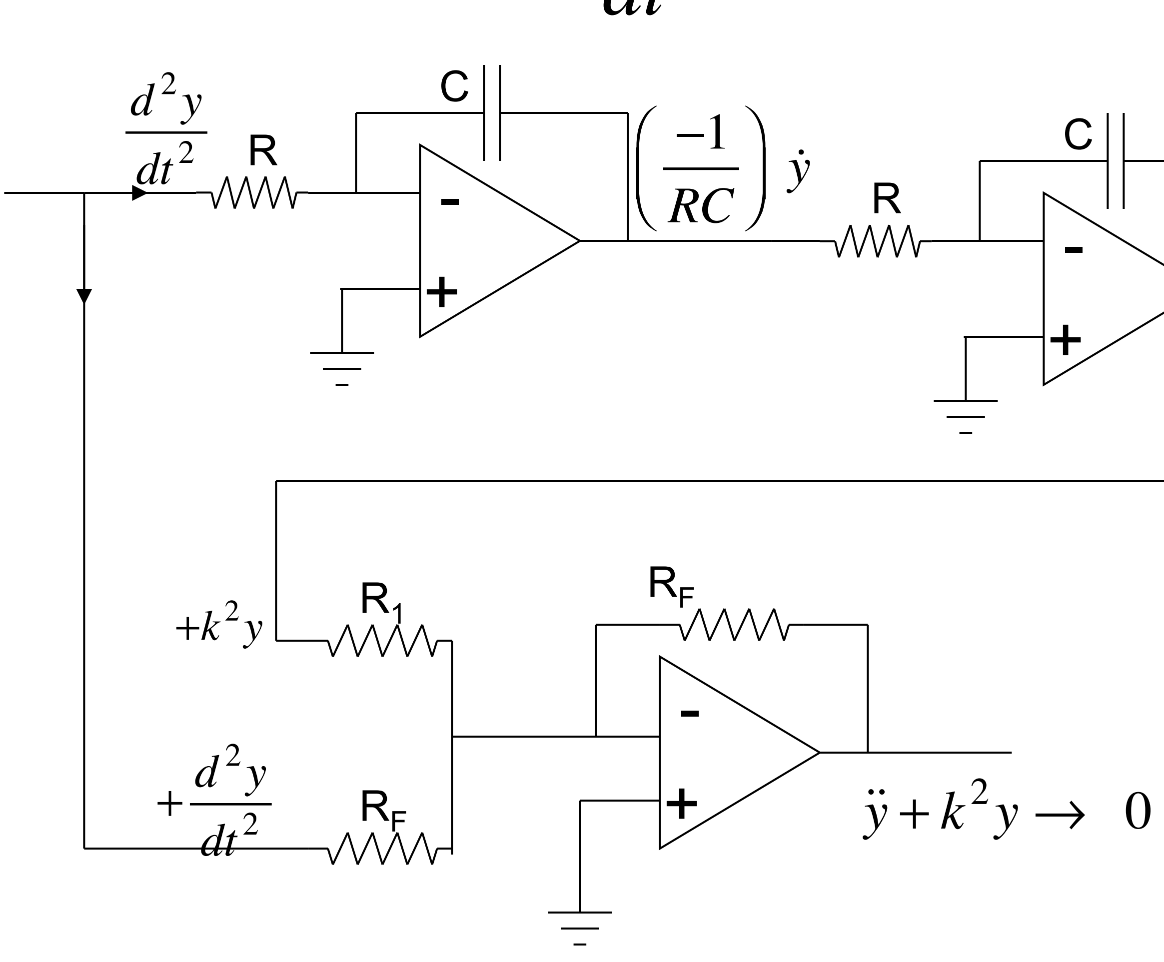
A_{CMRR} = Common mode gain =Av/80db = 180/10^4 = 0.018

Vcmrr = 0.018 (20 mV) = 0.36 mV

*Vout = Vdiff + Vcmrr = 720mV + **0.36mV***

Analogue Computation

$$\frac{dy^2}{dt^2} + k^2 y = 0$$



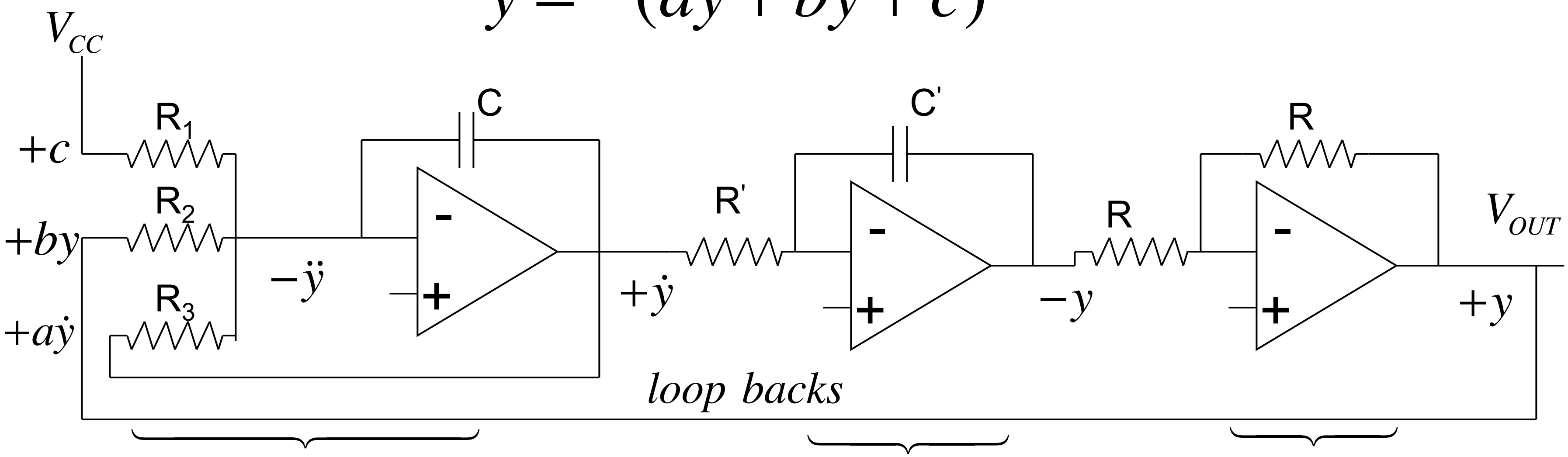
$RC = 1$

$R_F / R_1 = k^2$

Analogue Computation

$$\ddot{y} + a\dot{y} + by + c = 0$$

$$\ddot{y} = -(a\dot{y} + by + c)$$



$Summing\ Integrator$

$a = 1/R_3C$

$b = 1/R_2C$

$c = 1/R_1C$

$Integrator$

$1 = 1/R'C$

$Inverter$

$1 = R/R$

Amp Distortion

1.8.1 Amplitude Distortion Basics

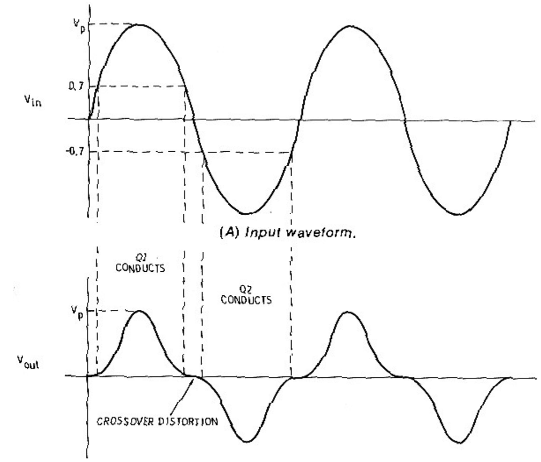
Amplitude distortion occurs in the transistor and is the result of operating the transistor over the *nonlinear portion* of the characteristics curve (Fig. 1-6). The usual remedy is to use a bias that places the operating point well within the linear portion, preferably at the *center of the linear portion.* In addition, the amplitude of the input signal must be small enough so that the positive and negative half-cycles do not drive the transistor beyond the linear portion. Generally, a low input signal and proper operating point (at the center of the linear portion) mean that gain must be sacrificed. To sum up, an overdriven amplifier (used to get maximum gain) almost always results in some amplitude distortion. A low-distortion amplifier generally requires at least two stages to get the same gain as an overdriven amplifier.

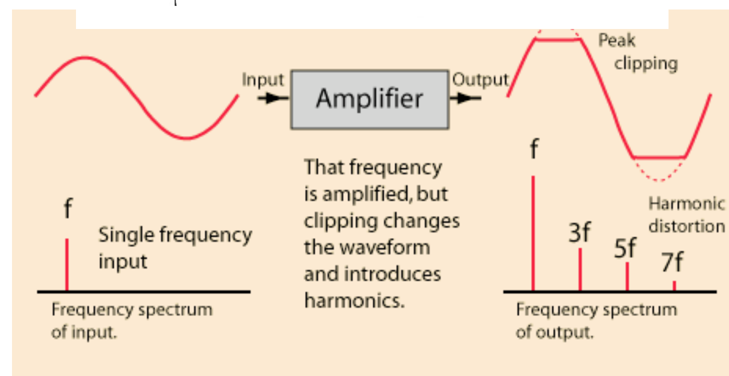
1.8.2 Frequency Distortion Basics

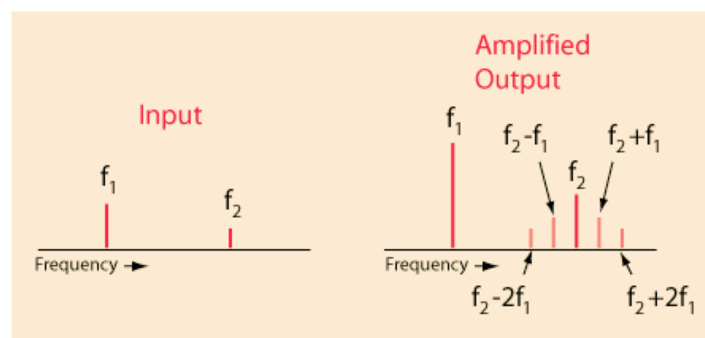
Frequency distortion occurs because the input signal rarely, if ever, is at a single frequency. Instead, the input signal usually contains components of several frequencies, making the signal waveform somewhat complex. The amplifier circuit is composed of resistors, capacitors (unless direct coupled), and possibly inductances (coils/transformers). Capacitors and inductances have reactance. Because reactance is a function of frequency, the different signal frequencies produce different reactances and attenuate the signal by different amounts. This produces distortion of the signal waveform from the original.

1.8.3 Phase Distortion Basics

When a signal flows through a capacitance or inductance, the signal is shifted in phase. The degree of this shift is a function of frequency. Because several frequencies are present simultaneously, several phase shifts occur, producing phase distortion. As in the case of frequency distortion, amplifier phase distortion can be minimized by proper design.







Phase-shift oscillator

From Wikipedia, the free encyclopedia

A **phase-shift oscillator** is a simple sine wave electronic oscillator. It contains an inverting amplifier, and a feedback filter consisting of an RC network which 'shifts' the phase by 180 degrees at the oscillation frequency.

The filter must be designed so that at frequencies above and below the oscillation frequency the signal is shifted by either more or less than 180 degrees. This results in constructive superposition for signals at the oscillation frequencies, and destructive superposition for all other frequencies.

The most common way of achieving this kind of filter is using three cascaded resistor-capacitor filters, which produce no phase shift at one end of the frequency scale, and a phase shift of 270 degrees at the other end. At the oscillation frequency each filter produces a phase shift of 60 degrees and the whole filter circuit produces a phase shift of 180 degrees.

Op-Amp implementation

[edit]

One of the simplest implementations for this type of oscillator uses an operational amplifier (op-amp), three capacitors and four resistors, as shown in the diagram.

The mathematics for calculating the oscillation frequency and oscillation criterion for this circuit are surprisingly complex, due to each R-C stage loading the previous ones. The calculations are greatly simplified by setting all the resistors (except the negative feedback resistor) and all the capacitors to the same values. In the diagram, if R1 = R2 = R3 = *R*, and C1 = C2 = C3 = *C*, then:

$$f_{Oscillation} = \frac{1}{2\pi RC\sqrt{6}}$$

and the oscillation criterion is:

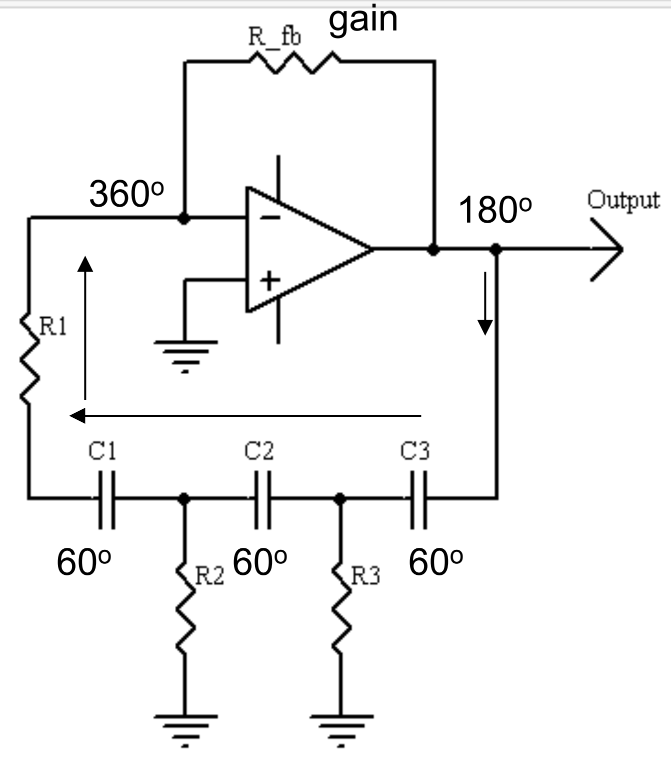
$$R_{feedback} = 29 \cdot R$$

1)High gain for +feedback cancellation

2) 180º+60º+60º+60º=360º

- Music Tremolo

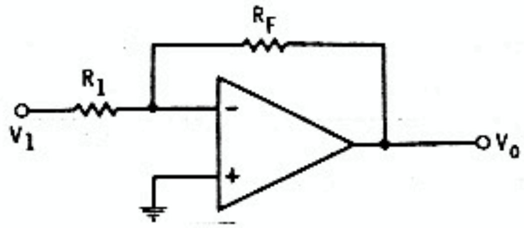
- Flasher



A simple example of a phase-shift oscillator

Without the simplification of all the resistors and capacitors having the same value, the calculations become more complex:

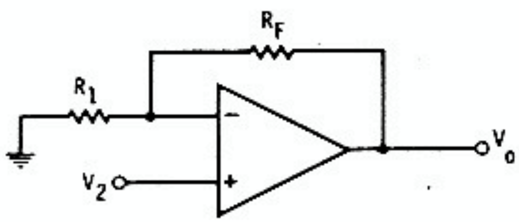
Summary



$A_v = -\frac{R_F}{R_1}$

$Z_{in} = R_1$

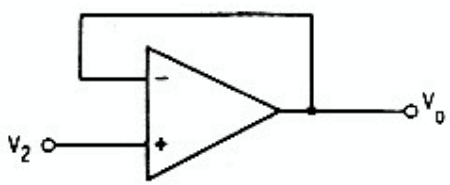
(A) Inverting amp.



$A_v = \frac{R_F + R_1}{R_1}$

Z_{in} VERY HIGH

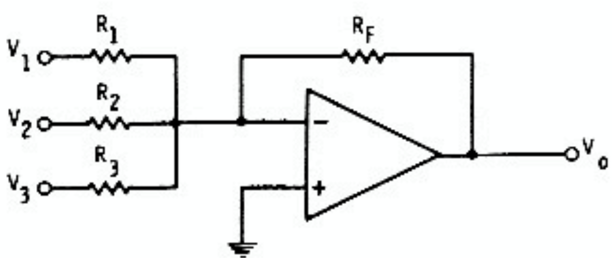
(B) Noninverting amp.



$A_v = 1$

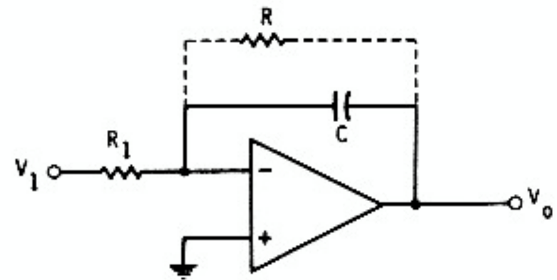
Z_{in} VERY HIGH

(C) Voltage follower.



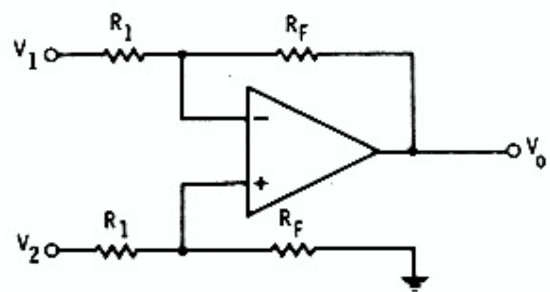
$V_o = -R_F\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$

(D) Summer.



$V_o = -\frac{1}{R_1 C}\int V_1\,dt$

(E) Integrator.



$V_o = \frac{R_F}{R_1}(V_2 - V_1)$

(F) Differential-input amp.