20EC105
Linear Integrated Circuit Applications

Program Core

(Common to: B.Tech ECE & also its splns. AIML & IOT)

by

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20EC105 LIC Course Objectives (COs)

1. Illustrate and analyze the basic principles and important characteristics of Linear ICs.
2. Design and develop solutions using Integrated Circuits for specific applications.
3. Elucidate and design the interfacing applications through ICs that promote health and well-being.

Linear Integrated Circuit Applications (LICAs)

Semester	Hours/Week			C	Marks		
	L	T	P/D		CIE	SEE	Total
III	2	-	2	3	60	40	100
Pre-requisite	20ES103 Analog Circuit Analysis						
Note	1. Vide the R22 Course structure is L:T:P/D:C :: 2 : 0 : 2 : 3 2. R22 Lab Integrated Course Academic regulations apply						

UNIT I: Introduction to ICs (05 Hrs.)

- Integrated circuits - basics, types, block diagram, Features & Characteristics: DC and AC Characteristics, Modes of operation. Illustrative Example Overview of ICs (OPAMP IC, Timer IC, Regulator ICs, ADCs, DACs)

LIC: Syllabus & Course Brief (continued)

UNIT II: Linear Applications of Op-Amp. (06 Hrs.)

- Introduction, Inverting and Non-Inverting OPAMPs, Adder, Subtractor, Integrator, Differentiator, Instrumentation amplifier, Voltage follower, V-I/ I-V Converters. Filters First Order and Second Order Active Low Pass Filters; An overview of Band Pass, Band Reject, All Pass Filters.

UNIT III:Non-Linear Applications of Op-Amp (04 Hrs.)

- S/H Circuits, Comparators, Schmitt triggers, Waveform generators, Precision Rectifiers, Clippers and Clampers

LIC: Syllabus & Course Brief (continued)

UNIT IV: Special Purpose ICs (05 Hrs.)

- 555 timer: Functional diagram, Multi vibrators- Astable and Mono stable operations, Illustrative applications; Voltage Regulator ICs – Basics, 78xx/79xx series ICs, 723 General purpose regulator.

UNIT V:D-A and A-D Converters (05 Hrs.)

- DAC – basics, Weighted Resistor type, R-2R Ladder type;
- ADCs- basics, Parallel Comparator Type, Successive Approximation Register Type; ADC and DAC specifications and applications

LIC Practical -Experiments List:

1. OPAMP Inverting Amplifier
2. OPAMP Non-Inverting Amplifier
3. OPAMP Adder
4. OPAMP Subtractor
5. OPAMP Integrator,
6. OPAMP Differentiator,
7. OPAMP Voltage follower,
8. OPAMP Comparators,
9. OPAMP Schmitt triggers,
10. OPAMP Precision Rectifiers (Half wave/ Full Wave)
11. IC 555/ OPAMP Astable Multivibrator
12. IC 555/ OPAMP Monostable Multivibrator
13. IC 78xx/79xx series or IC 723 Voltage Regulator

Linear Integrated Circuits: Learning Resources

TEXT BOOKS

1. D.Roy Choudhry, Shail Jain, Linear Integrated Circuits, New Age International Pvt. Ltd., 2021, Sixth Edition ISBN 978-8122472127.
2. Sergio Franco, -Design with Operational Amplifiers and Analog Integrated Circuits, 4th Edition, Tata Mc Graw-Hill, 2016

REFERENCE BOOKS

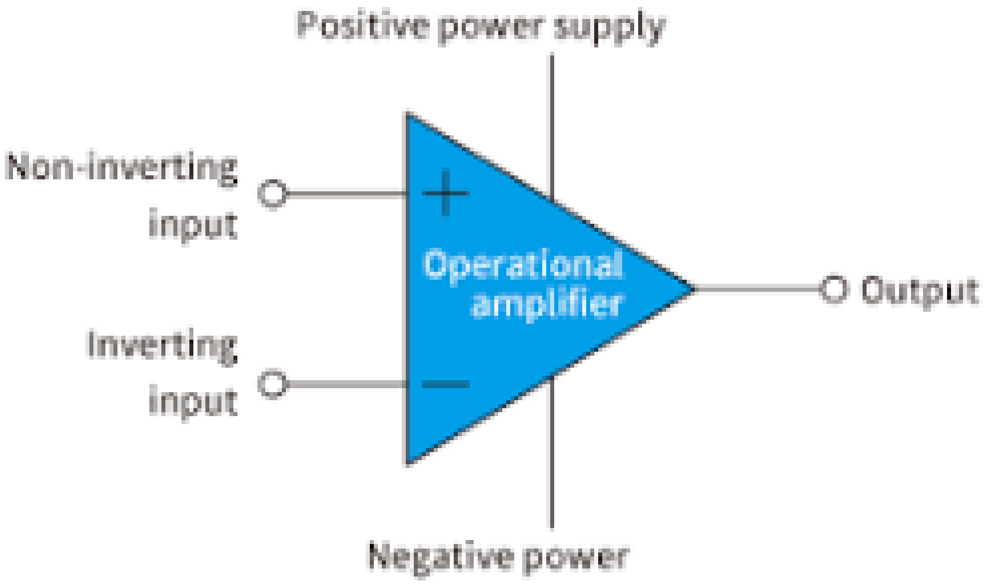
1. A. Ramakant A. Gayakwad, -Operational Amplifiers and Linear IC, 4th Edition, Prentice Hall / Pearson Education, 2015
2. B. S.Salivahanan & V.S. Kanchana Bhaskaran, -Linear Integrated Circuits, TMH,3rd Edition, 2018

Useful Links

1. https://nptel.ac.in/courses/108/108/108108111/
2. https://nptel.ac.in/courses/117/107/117107094/
3. https://onlinecourses.nptel.ac.in/noc20_ee13/preview

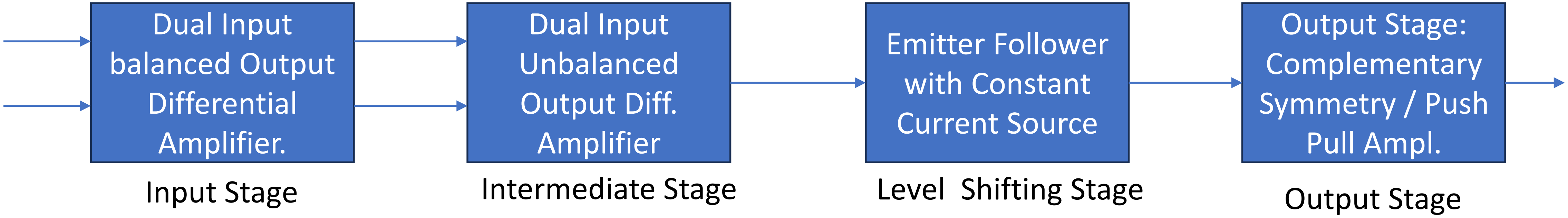
Module II: Introduction to OPAMPs

- basic role is to amplify and output the voltag difference between the two input pins
- Often, with only a handful of external components, Op-amps can be used
  - as a linear device for ideal DC amplification
  - in signal conditioning/processing, filtering or other mathematical operations (add, subtract, integration and differentiation) since 1960sµA-741. (Fairchild Semiconductor -1965 First widely used General purpose OPAMP: µA-709)



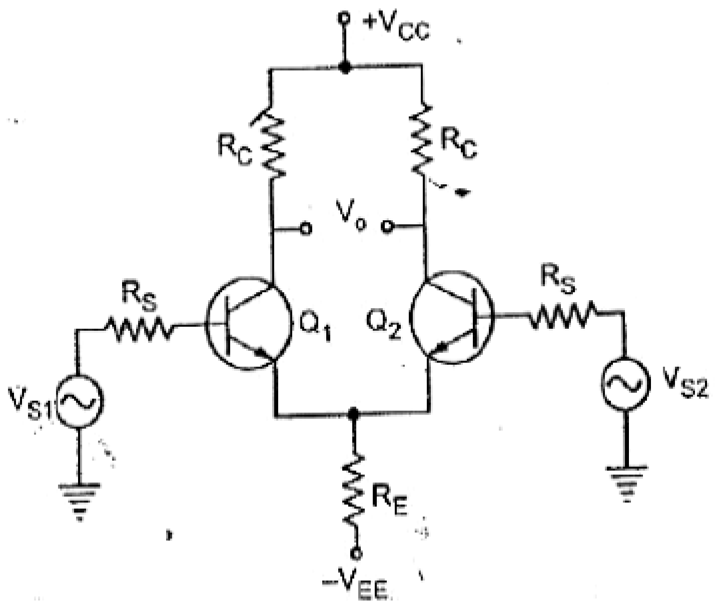
- **Ideal** OPAMP features: Infinite input impedance, Infinite bandwidth, Infinite Differential gain, Zero output impedance, Zero power consumption, zero Common Mode Gain, Zero Offset Voltage, Zero Bias Current
- **Virtual short/ground Concept** in OPAMPs: OPAMP force the differential voltage across the inputs to zero as both inputs are held either at a ground/short.

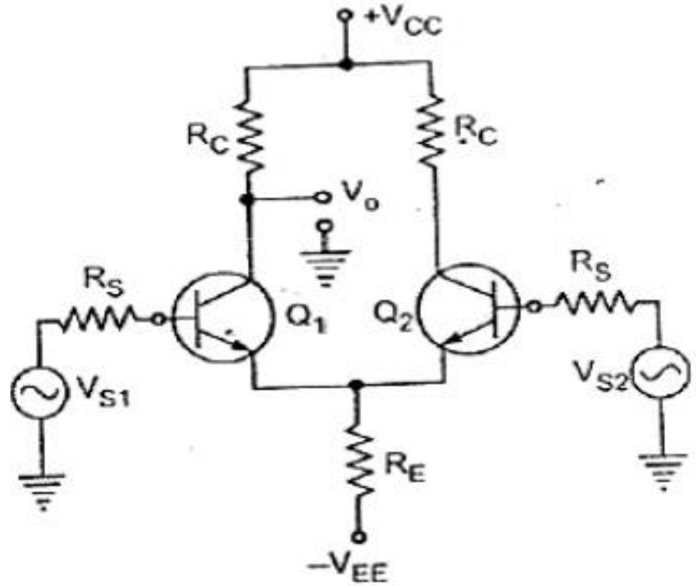
IC Op-Amp Block Diagram

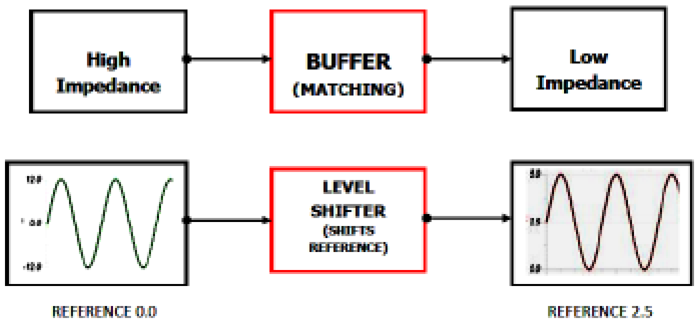


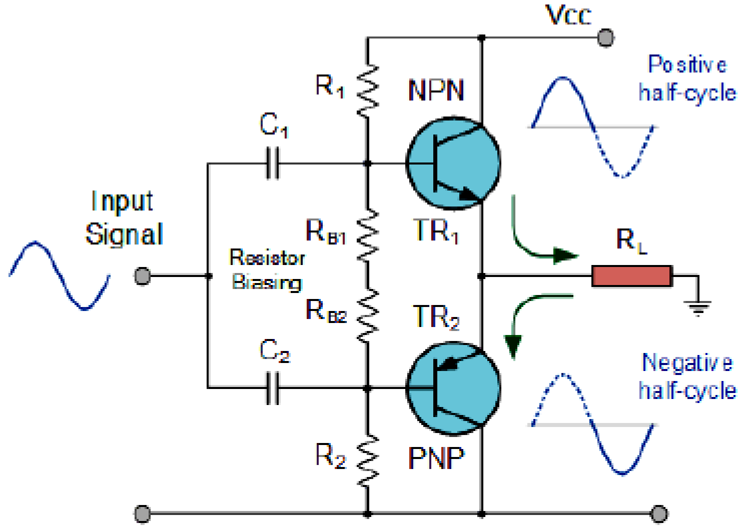
- Input Stage: offers high impedance to the input terminals
- Intermediate Stage: Offers high differential gain
- Level Shifting Stage: consists of a buffer and level shifter circuits;
  - Buffer matches an input circuit of impedance low (or high) with an output load of high (or low) thus, load does not drain more current thus causing shift of operating point. T
  - he level shifter enhances the input reference level 0.0 is shifted to 2.5 in output signal.
- Output Stage is push-pull complementary symmetry amplifier, thus separately amplifies positive and negative cycle

IC Op Amp's each Block Internal Circuit Diagram









Freq. response & feedback Concepts - A review

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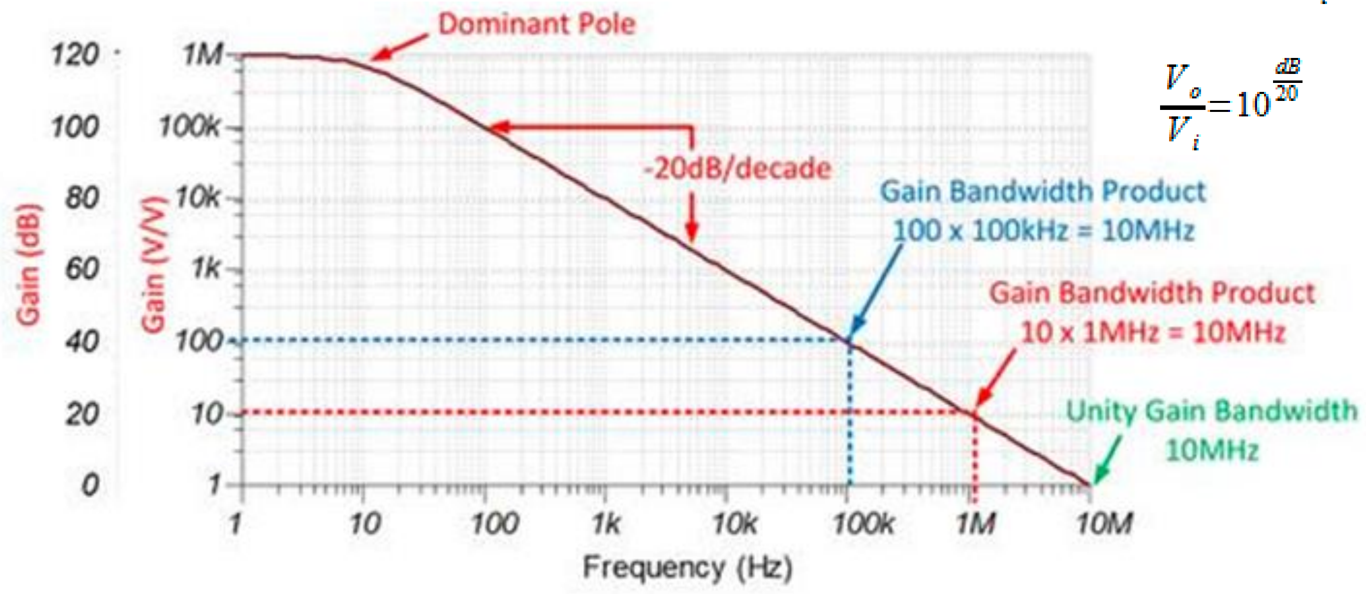
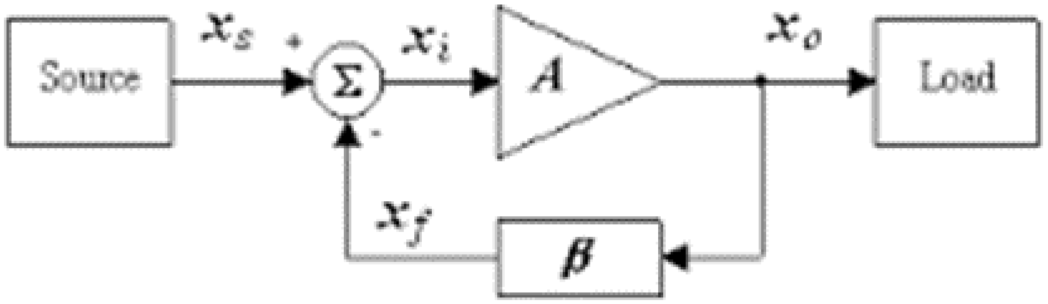
$$dB = 20\log\left(\frac{V_o}{V_i}\right)$$

$$\frac{V_o}{V_i} = 10^{\frac{dB}{20}}$$

- Note that Op-amps are generally used employing feedback.
- Unlike open-loop gain (A or Ao), the closed-loop gain (Af) is dependent on the external circuitry because of the feedback
- Also it is learnt that, feedback implies that the output of a system is fed back into as input(s) and there are two types of feedback: positive (regenerative) and negative (degenerative). Recall the below diagram & concept w.r.t. Feedback theory
  - if A, the open loop gain, is infinity/ or very large compared to β.
  - Thus the closed loop gain mostly depends on the component values of the feedback block contributing to β .





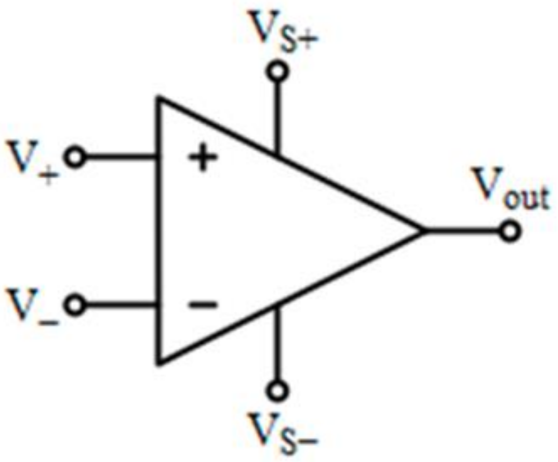
$$Closed\ loop\ gain, A_f = \frac{A}{1+A\beta} \cong \frac{1}{\beta}$$

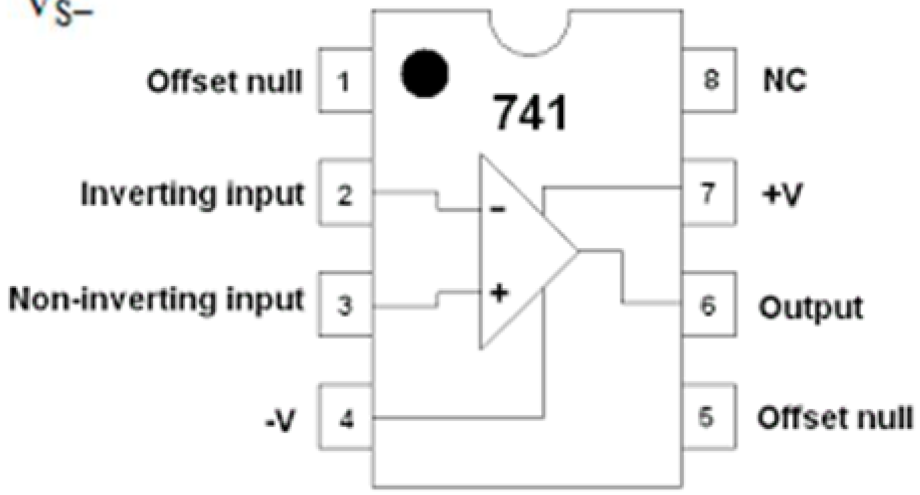
Negative feedback concepts – A review

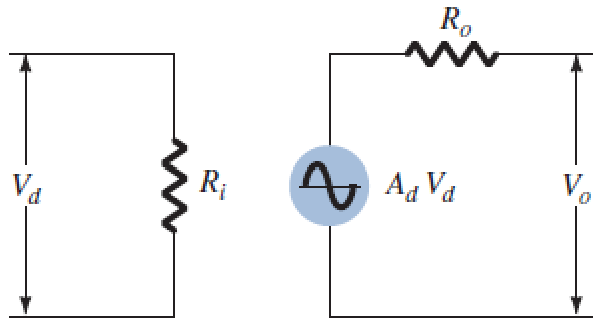
- Desensitize the gain - the value of the gain becomes less sensitive to variations in the values of the circuit component, such as temperature effects on transistors.
- Reduces non-linear distortion - the output is proportional to the input.
- Reduces the effect of noise - reduces the amount of unwanted electrical interference on the output. This interference could be external or from the circuit components themselves.
- Controls the input and output resistances - with an appropriate feedback configuration the input and output resistances can be controlled.
- Extend the bandwidth of the amplifier. Usually Gain-Bandwidth Product is constant; So, bandwidth can be extended (to a certain degree) but at the cost of the gain. Gain Bandwidth Product is constant and it describes the op amp gain behavior with respect to frequency

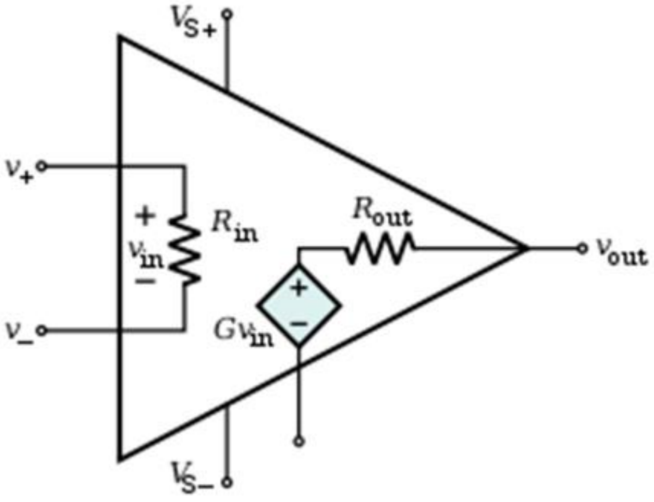
Symbol, Pin Configuration, Equivalent Circuit

- The terminal voltage is the voltage at a terminal measured with respect to ground

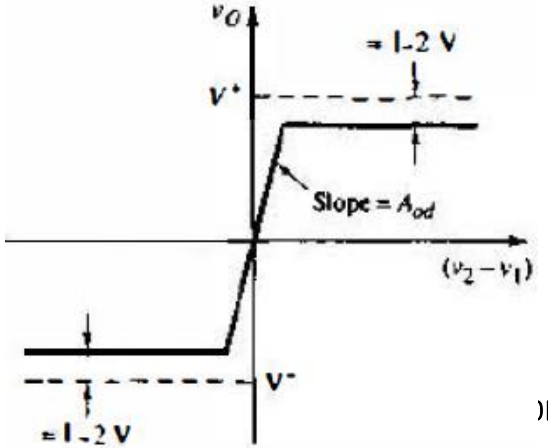








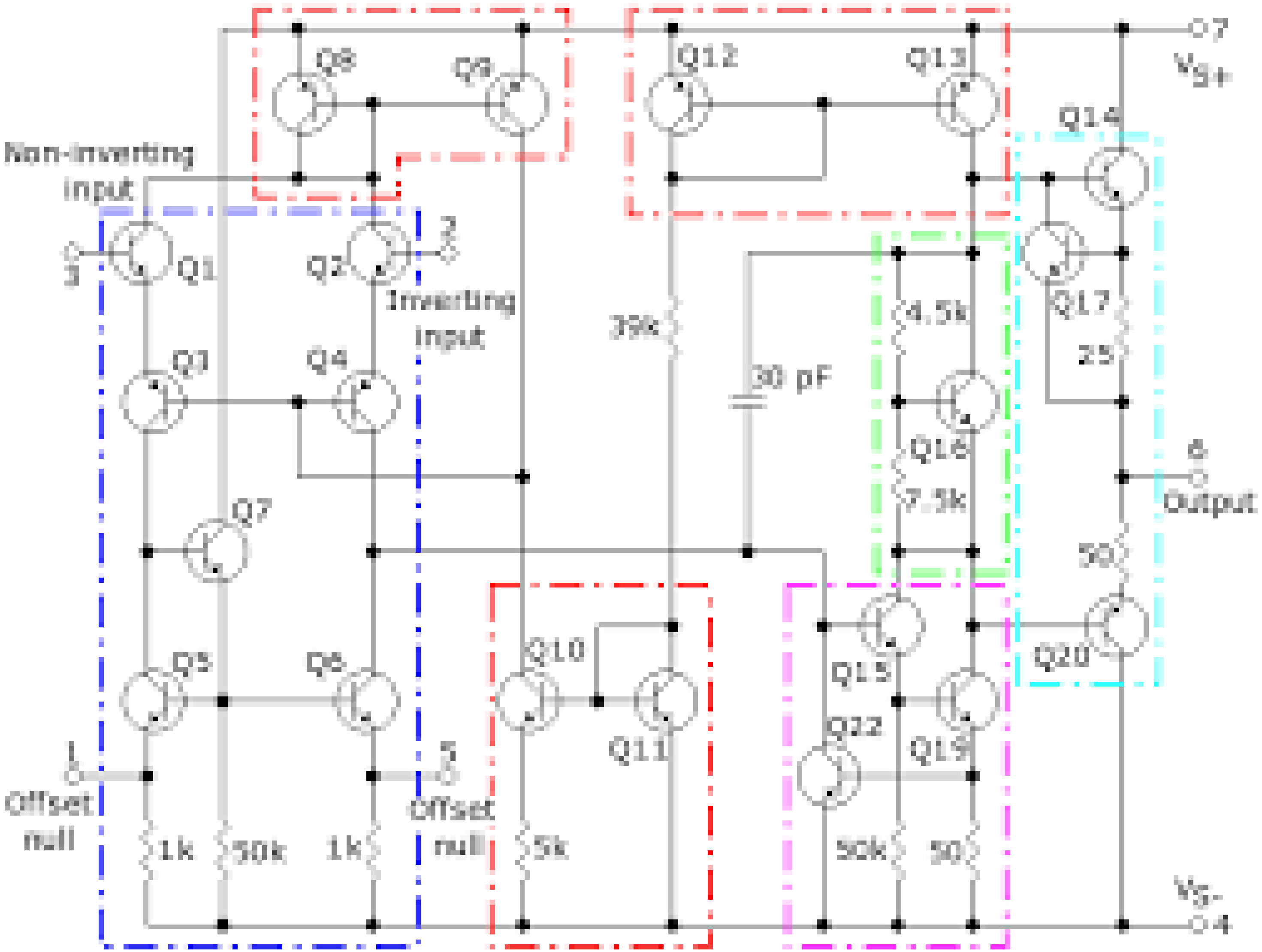
Equivalent Circuits (real OPAMP)



- V_+ : non-inverting input
- V_- : inverting input
- V_{out} : output
- V_{S+} : positive power supply
- V_{S-} : negative power supply

OPAMP: Internal Circuit Diagram

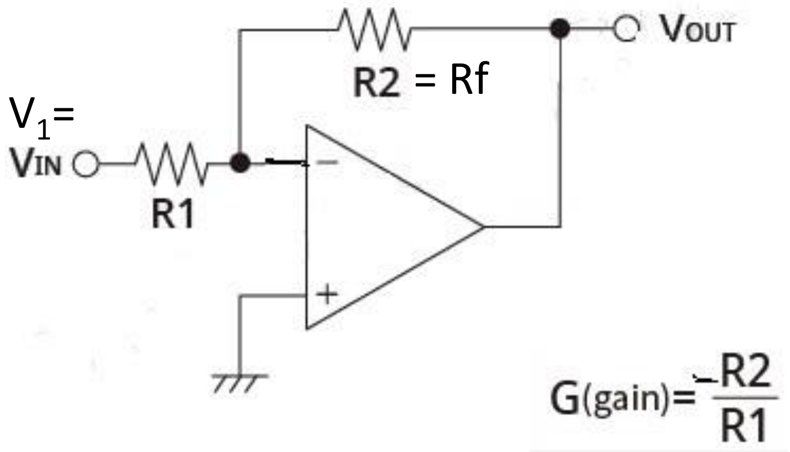
- For detailed description refer to additional info. [Doc1](Doc1).
- 20 to 30 transistors, Approx.

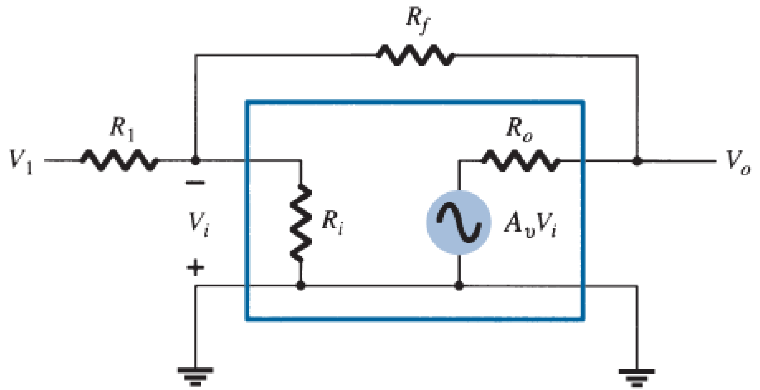


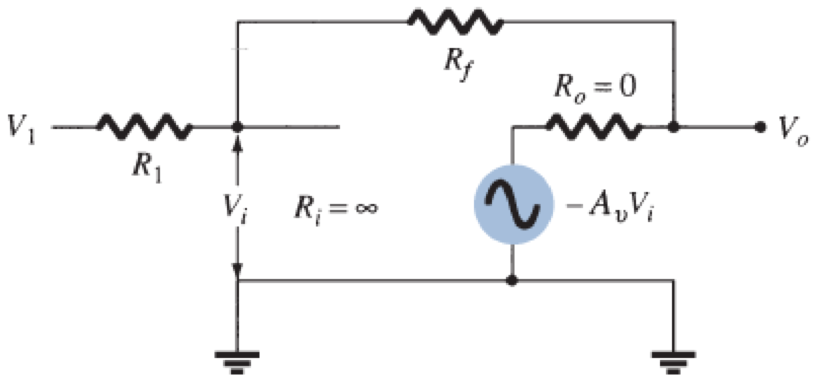
Ideal Versus Real OPAMP

Ideal op-amps	**Real op-amps**
• Infinite input impedance (zero input current)	⇒ Very high but finite input impedance
• Zero output impedance	⇒ On the order of several tens of ohms
• Infinite input dynamic range (common-mode input voltage range, CMV_{IN})	⇒ Constrained by power supply and GND
• Infinite open-loop voltage gain (G_V)	⇒ On the order of 10^4 to 10^5
• Infinite frequency bandwidth (cut-off frequency, f_T)	⇒ Several hundreds of kHz to several tens of MHz
• Zero input offset voltage (V_{IO})	⇒ Several millivolts
• Infinite common-mode rejection ratio (CMRR)	⇒ High but finite CMRR (roughly 80 dB)
• Zero internal noise (equivalent input noise voltage, V_{NI})	⇒ V_{NI} = several $nV/\sqrt{Hz}$ to several tens of $nV/\sqrt{Hz}$ (thermal noise region)

Inverting OPAMP







$$V_{i_1} = \frac{R_f}{R_1 + R_f} V_1$$ (w/o $-A_V V_i$)

$$V_{i_2} = \frac{R_1}{R_1 + R_f}(-A_v V_i)$$ (w/o v_1)

$$V_i = V_{i_1} + V_{i_2} = \frac{R_f}{R_1 + R_f} V_1 + \frac{R_1}{R_1 + R_f}(-A_v V_i)$$

$$V_i = \frac{R_f}{R_f + (1 + A_v)R_1} V_1$$

If $A_v \gg 1$ and $A_v R_1 \gg R_f$, as is usually true, then

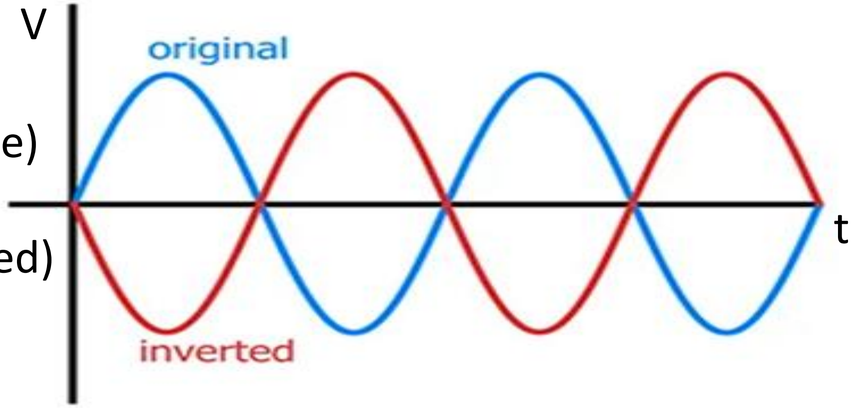
$$V_i = \frac{R_f}{A_v R_1} V_1$$

Solving for V_o/V_i, we get

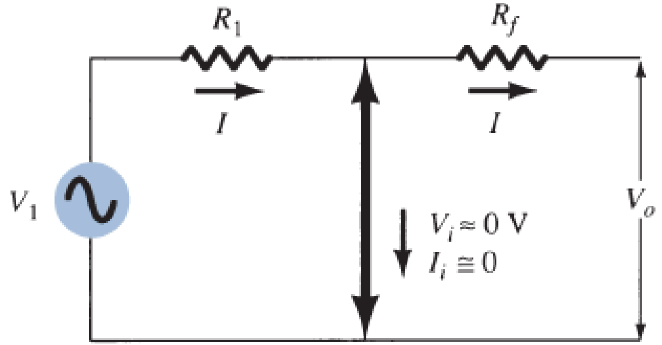
$$\frac{V_o}{V_i} = \frac{-A_v V_i}{V_i} = \frac{-A_v}{V_i}\frac{R_f V_1}{A_v R_1} = -\frac{R_f}{R_1}\frac{V_1}{V_i}$$

$$\boxed{\frac{V_o}{V_1} = -\frac{R_f}{R_1}}$$

If R1=R2,
Input (blue)
&
Output (red)



Virtual Ground Concept



- If Vo = -10 V & Av = 20,000, the input voltage is

$$V_i = \frac{-V_o}{A_v} = \frac{10\text{ V}}{20{,}000} = 0.5\text{ mV}$$

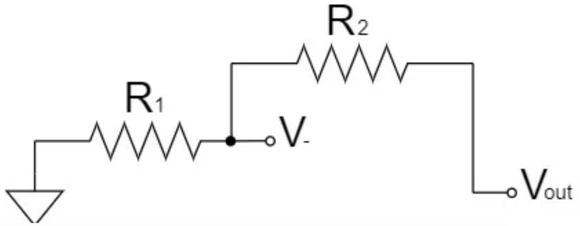
- If the circuit has an overall gain (Vo > V1) of, say, 1, the value of V1 is 10 V
- Compared to all other input and output voltages, the value of V_i is then small and may be considered 0 V
- Note that although *Vi* 0 V, it is not exactly 0 V. (The output voltage is a few volts due to the very small input *Vi* times a very large gain *Av*.) The fact that V_i 0 V leads to the concept that at the amplifier input there exists a virtual short-circuit or virtual ground.
- The concept of a virtual short implies that although the voltage is nearly 0V, there is no current through the amplifier input to ground

Non-Inverting OPAMPs

$$V_+ = V_{in}$$

$$V_- = V_+ = V_{in} \cdots (1)$$

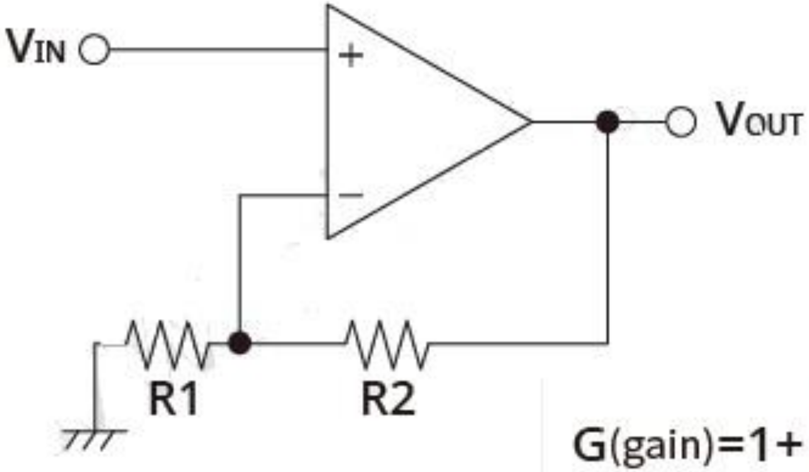
high input impedance and
no current V_



$$V_- = \frac{R_1}{R_1 + R_2} V_{out} \cdots (2)$$

$$V_{in} = \frac{R_1}{R_1 + R_2} V_{out}$$

$$V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_{in}$$

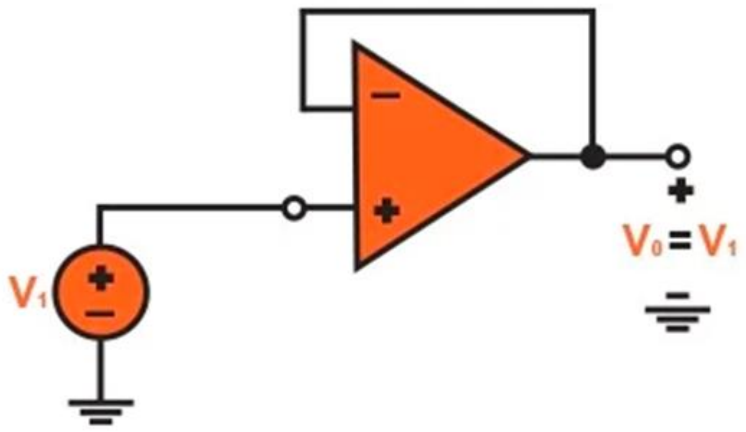


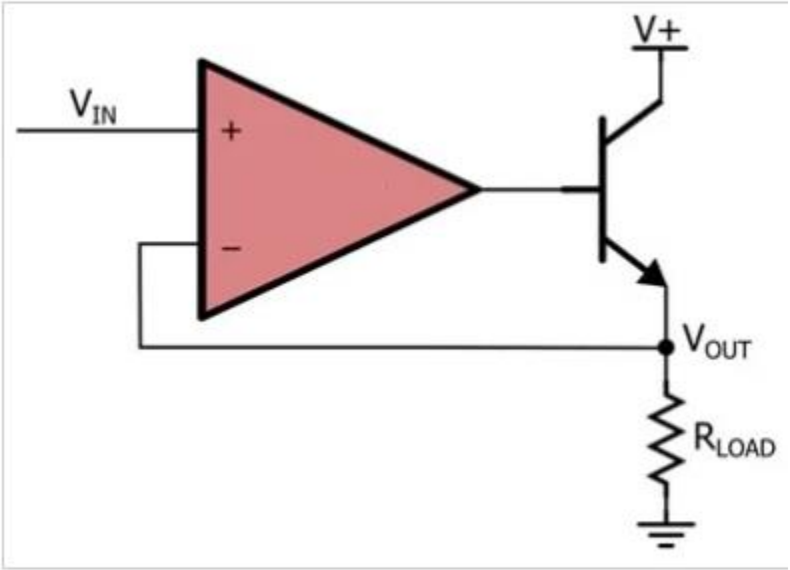
$$G(\text{gain}) = 1 + \frac{R2}{R1}$$

$$\frac{v_0}{v_1} = 1 + \frac{R_1}{R_2}$$

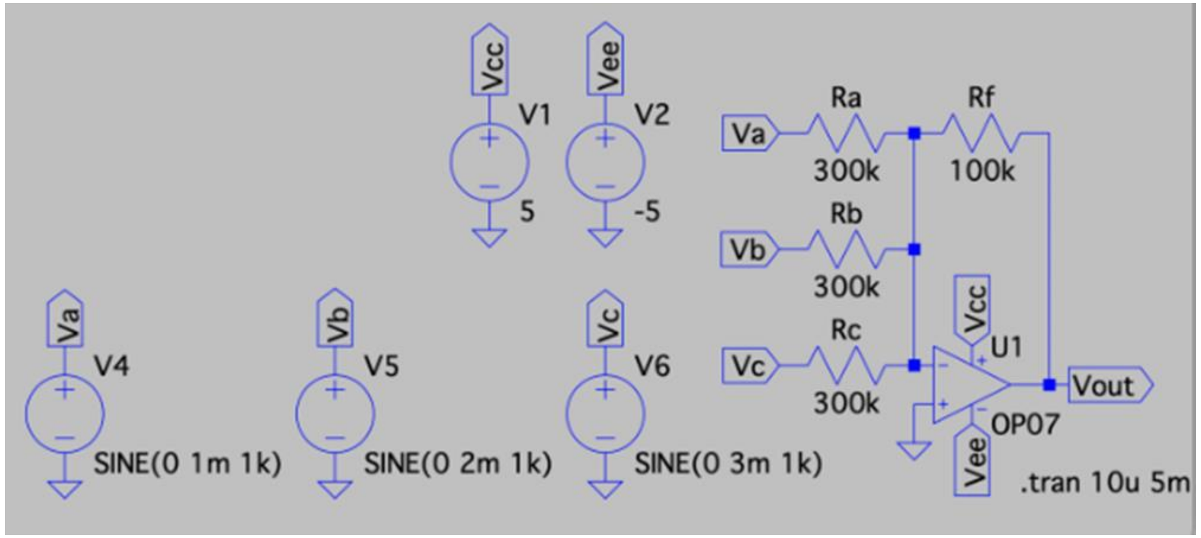
Voltage follower

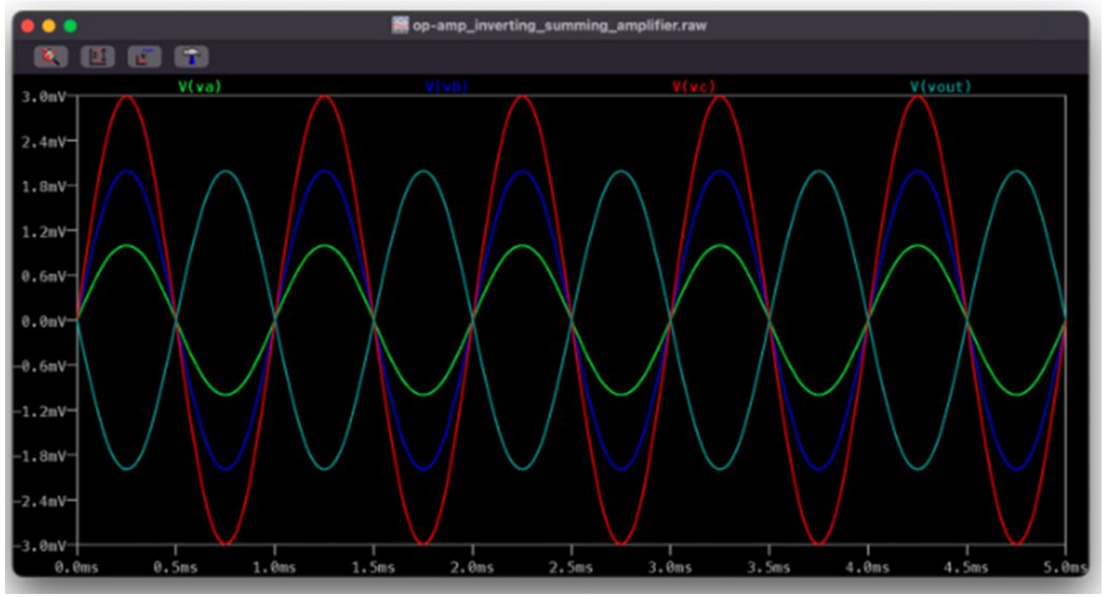
- Effective voltage transfer requires a source circuit with low output impedance and a load circuit with high input impedance
- A voltage follower has low output impedance and extremely high input impedance
- Note:
  1. voltage followers are more susceptible to oscillation than circuits with higher gain
  2. choose an op-amp that is described as “unity-gain stable.”
- The voltage follower’s low output impedance makes it a good circuit for driving current into a low-impedance load, but it’s important to remember that most op-amps are not designed to deliver large output currents
- high-current unity-gain driver can be created by incorporating an external transistor





Adder



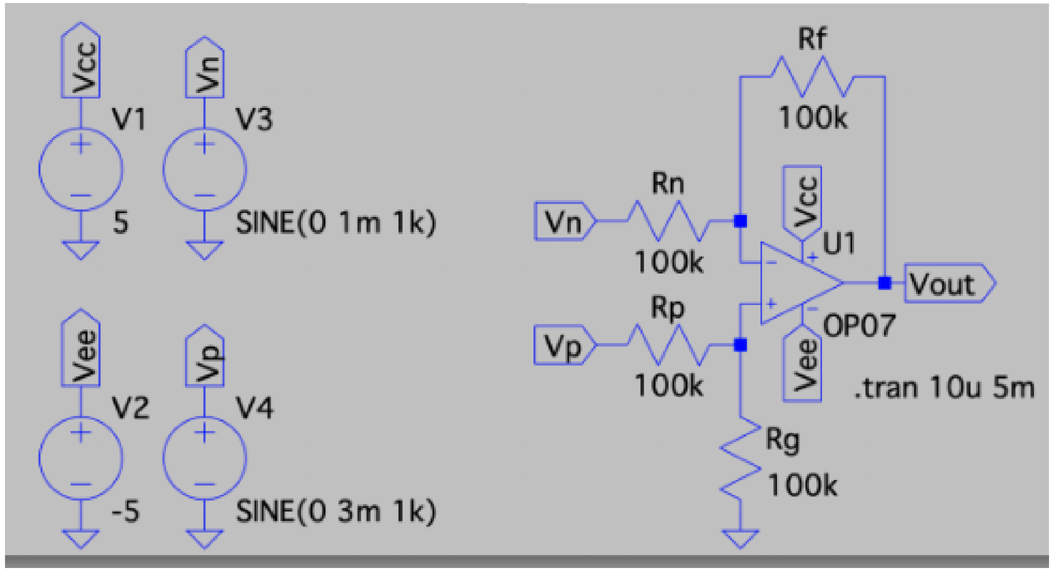


$$V_{out} = -R_f\left(\frac{V_a}{R_a} + \frac{V_b}{R_b} + \ldots + \frac{V_n}{R_n}\right)$$

- where R_f represents the feedback resistor and R_a, R_b, …, and R_n represent the input resistors for the V_a, V_b, …, and V_n inputs respectively

Subtractor $V_{out} = (1 + \frac{R_f}{R_n})(\frac{R_g}{R_p+R_g})V_p - \frac{R_f}{R_n}V_n$

- where R_f represents the feedback resistor, R_g represents the grounded resistor, and R_p and R_n represent the input resistors for the V_p and V_n inputs respectively



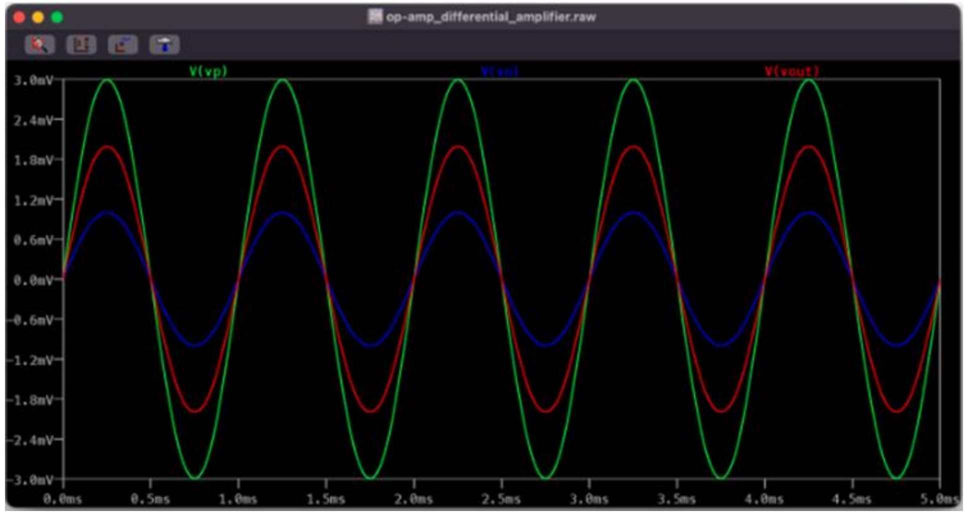
When $R_p = R_n$ and $R_f = R_g$,

$$V_{out} = \frac{R_f}{R_p}(V_p - V_n)$$

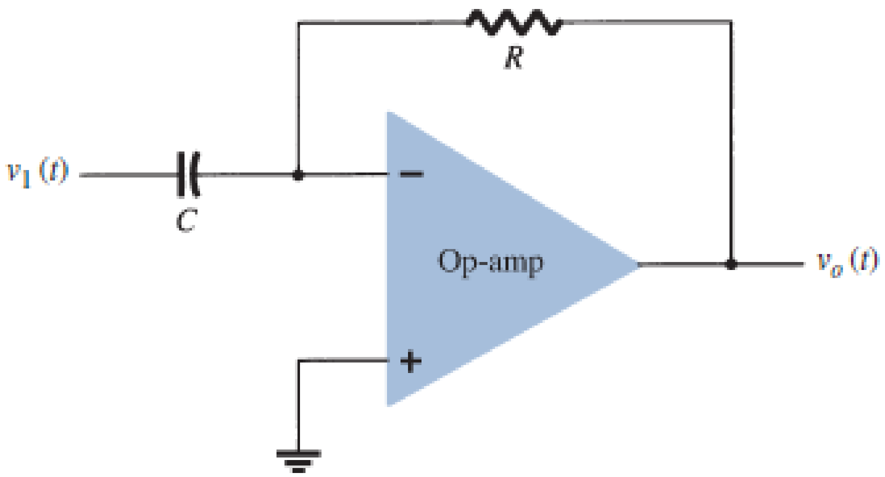
When all resistors are equal,

$$V_{out} = (1 + \frac{R_f}{R_n})(\frac{R_g}{R_p+R_g})V_p - \frac{R_f}{R_n}V_n$$

$$V_{out} = V_p - V_n$$

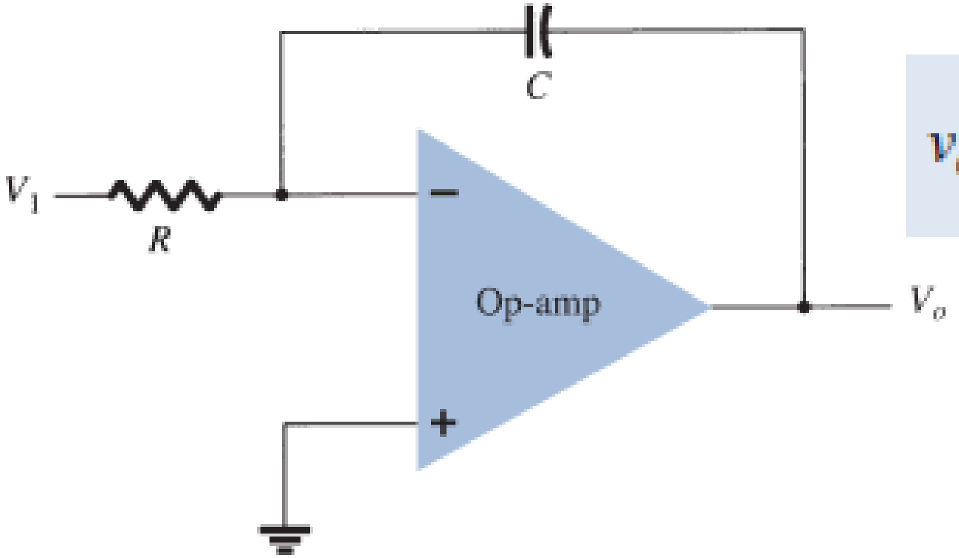


Differentiator



$$v_o(t) = -RC\frac{dv_1(t)}{dt}$$

Integrator



$$v_o(t) = -\frac{1}{RC}\int v_1(t)\,dt$$

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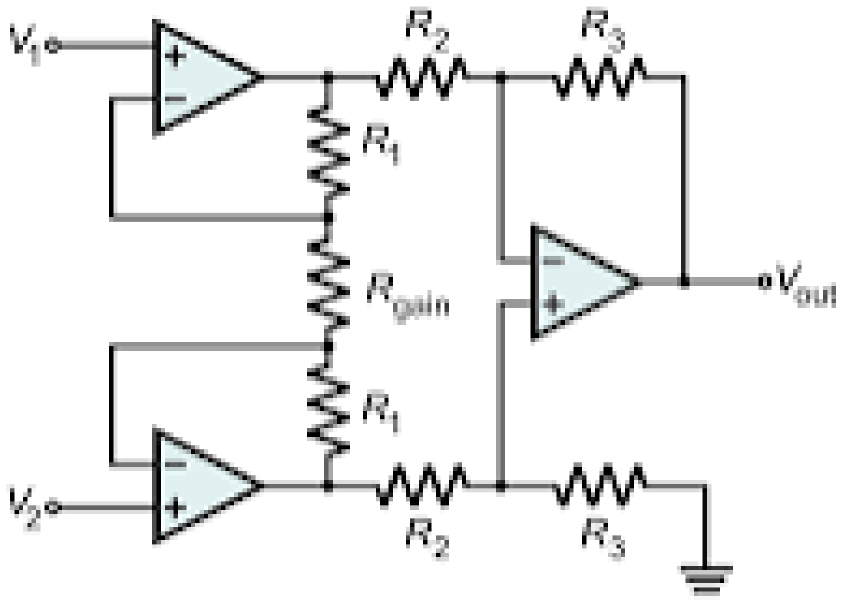
Instrumentation Amplifier (practical circuit)



Practical Instrumentation Amplifier:
A 3-OPAMP Configuration

- The final output Vout is the amplified difference of the input signals applied to the input terminals of OPAMP3
- $V_{out} = (R_3/R_2)(V_{o1}-V_{o2})$
- $V_{out} = (R_3/R_2) \{(2R_1+R_{gain})/R_{gain}\} (V1-V2)$

Requires to have

- -High gain accuracy (since inputs have very low signal energy)
- -Gain adjustable using a single control
- -High input impedance and low output impedance (to prevent load)
- -High CMRR (since transducer output contain common mode signals.
- High slew rate (to handle sharp rise times and provide maximum undistorted output swing)

V to I Converters

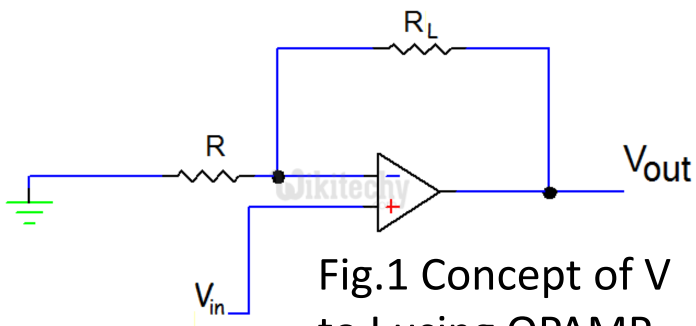


Fig.1 Concept of V to I using OPAMP

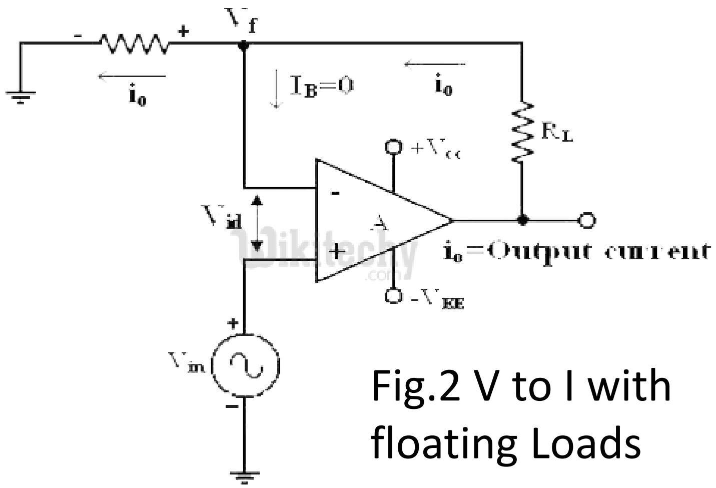


Fig.2 V to I with floating Loads

- Fig.1: Voltage to current converter produce a current which is directly proportional to the applied voltage and the resistance used in the circuit. It should be noted that all the resistances used in the circuit are equal to R
- Fig.2: a current – series negative feedback amplifier; the feedback voltage across R1 (applied Non-inverting terminal) depends on the output current i0 and is in series with the input difference voltage Vid; Voltage $V_{id}=V_f$ and $I_B=0$, Vi = $R_L i_0$ Where io=V_i/R_L; If RL is a precision resistor, the output current ($i_0 = V_{in}/R_1$) will be precisely fixed.
- Fig.3:

Analysis & Applications of V to I converters

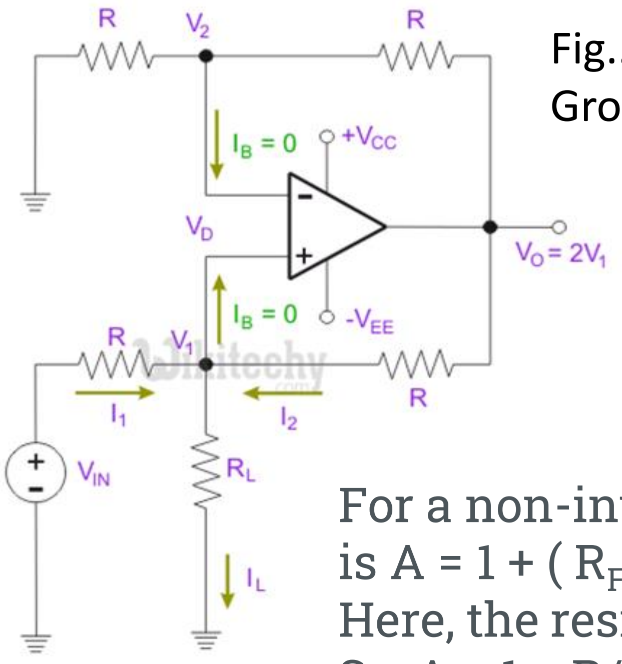


Fig..3 V to I With Grounded Loads

$$I_1 + I_2 = I_L$$

$$\frac{V_{IN} - V_1}{R} + \frac{V_0 - V_1}{R} = I_L$$

$$V_{IN} + V_0 - 2V_1 = I_L R$$

$$V_1 = \frac{V_{IN} + V_0 - I_L}{2}$$

For a non-inverting amplifier, gain is A = 1 + (R_F / R_1)
Here, the resistor, $R_F = R = R_1$.
So. A = 1 + R/R = 2

$$V_0 = 2V_1 = V_{IN} + V_0 - I_L R$$

$$0 = V_{IN} - I_L R$$

$$\therefore V_{IN} = I_L R$$

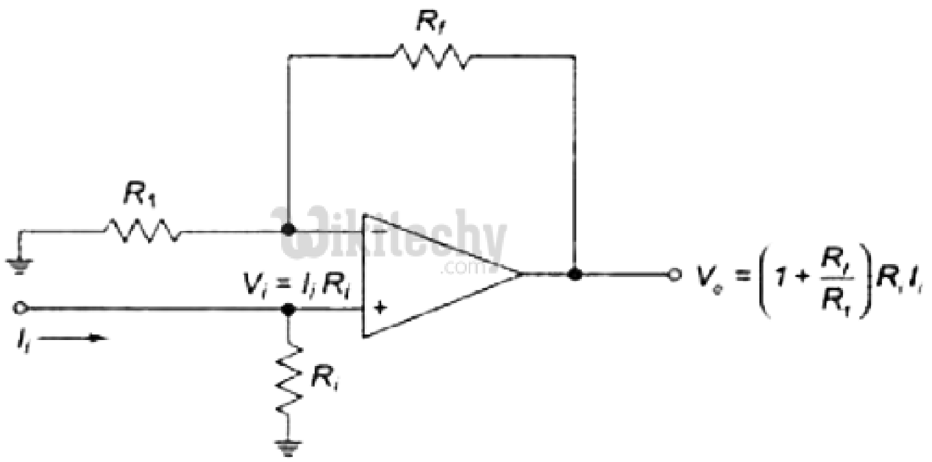
$$I_L = \frac{V_{IN}}{R}$$

Thus, the current I_L is related to the voltage, V_{IN} and the resistor, R

Applications:
(V to I with floating load)

- Low voltage ac and dc voltmeters
- Diode match finders
- LED and Zener diode testers

I to V Converters



- produces a voltage proportional to the given current
- Open – loop gain A of the op-amp is very large. Input impedance of the op amp is very high.

- Sensitivity: $V_0 = -R_F I_{in}$; so, gain of this converter is equal to $-R_F$. Magnitude of the Gain is called the sensitivity; it decides change in output volt ΔV0 for a given change in the input current ΔIin; keeping RF variable, it is possible to vary the sensitivity as per the requirements
- Applications: Digital to analog Converter (DAC); Sensing current through Photodetector such as photocell, photodiodes and photovoltaic cells; Photoconductive devices to detect the light or incident energy

Active Filters – Comparison with Passive Filters

- Filter is a circuit passes a particular frequency or a set of frequencies and attenuates certain other/set of frequencies

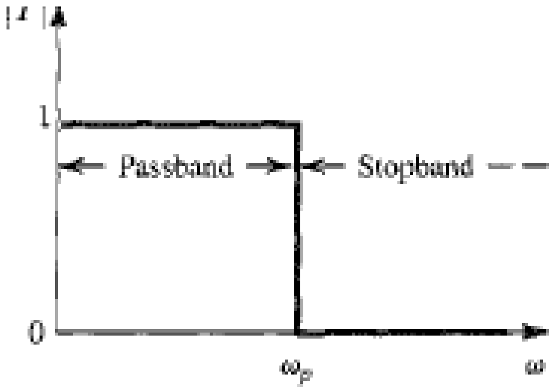
#	Active Filters (OPAMP Based)	Passive Filters
1	Require an external power source to operate	Do not require an external power source to operate
2	Filter's performance maintain irrespective of the changes in connected load	Output changes with Load connected.
3	Can apply additional gain to the signal	Cannot apply additional gain to the signal; instead they attenuate the signal
4	are built using active components such as Amplifiers and passive components	are built using passive components: Resistors, Capacitors and Inductors
5	Costs high	Costs low
6	More complex circuitry	Less complex or relatively far simpler circuitry
7	Less weight	Due to Inductors could be bulkier
8	Quality Factor High	Relatively the Quality Factor is very low
9	More Sensitive	Comparatively less sensitive

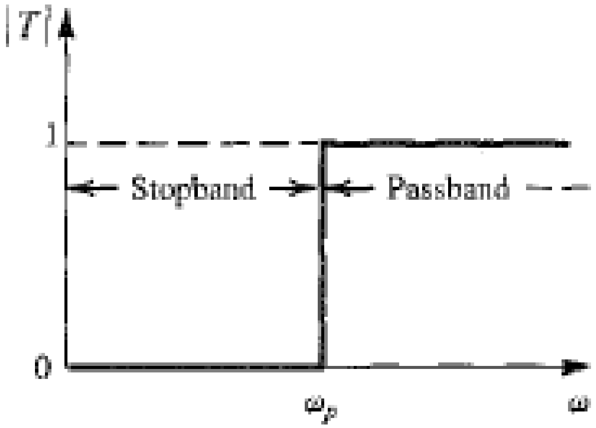
An Overview of Filters

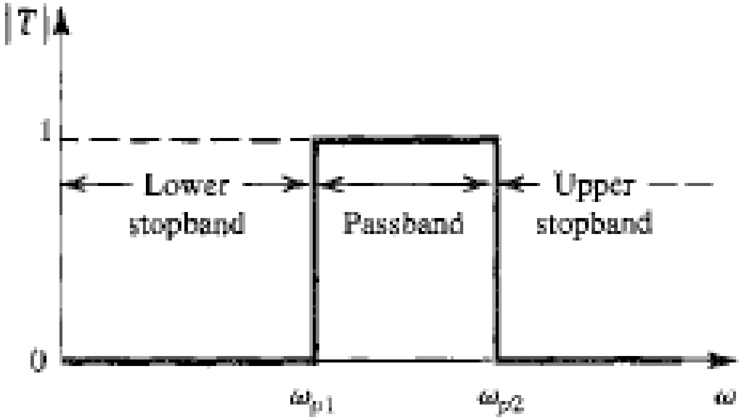
- Low Pass
- High Pass
- Band Pass
- Band Reject

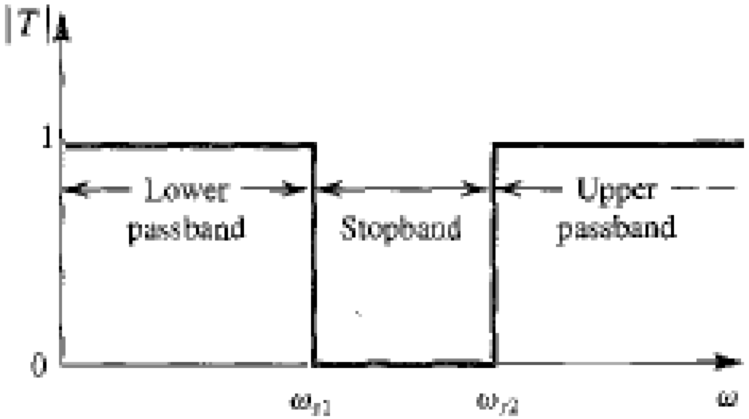
$$T(s) = \frac{a_M s^M + a_{M-1} s^{M-1} + \cdots + a_0}{s^N + b_{N-1} s^{N-1} + \cdots + b_0}$$

$$T(s) = \frac{a_M (s - z_1)(s - z_2) \cdots (s - z_M)}{(s - p_1)(s - p_2) \cdots (s - p_N)}$$

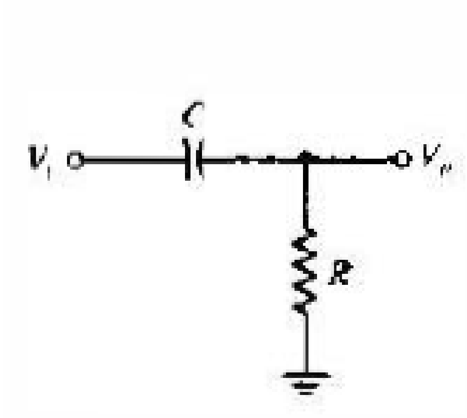


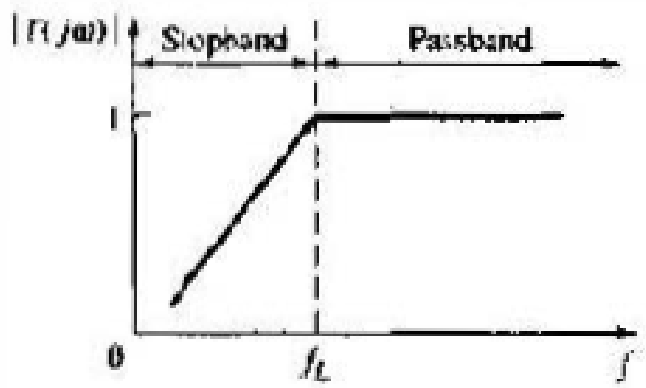




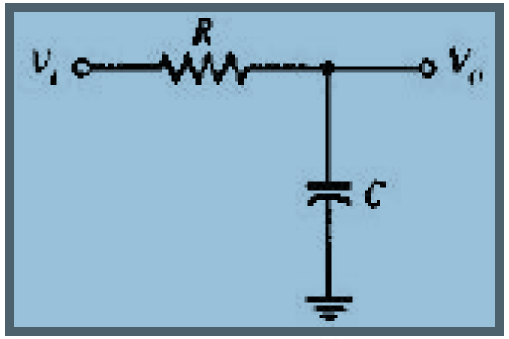


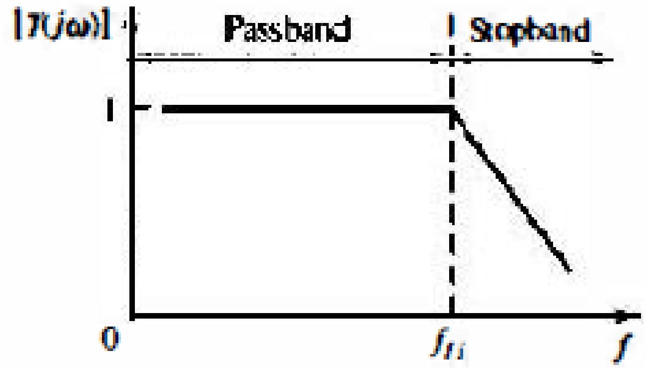
First Order Filters





$$T(s) = \frac{V_o(s)}{V_i(s)} = \frac{R}{R + \frac{1}{sC}} = \frac{sRC}{1 + sRC}$$

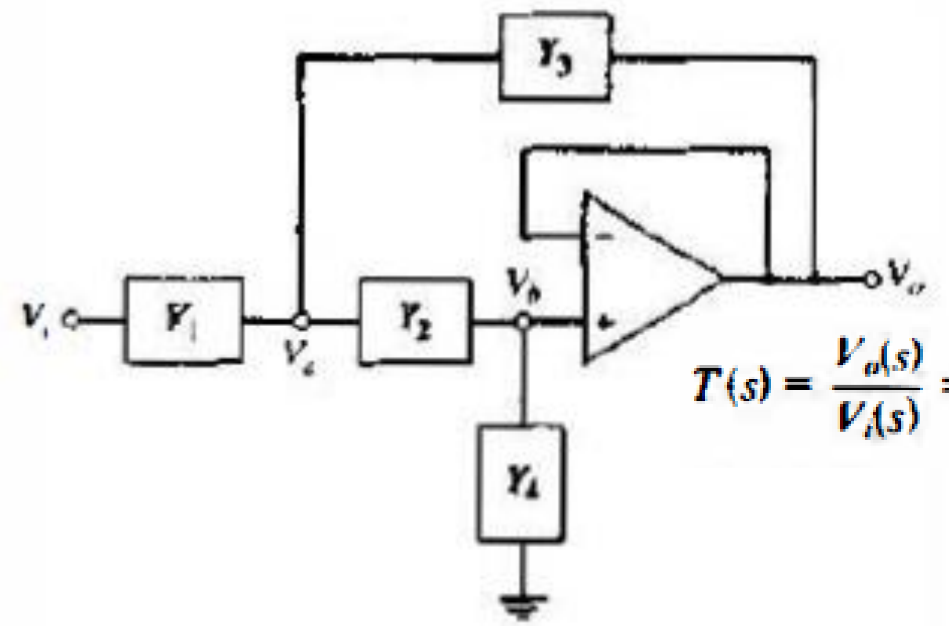




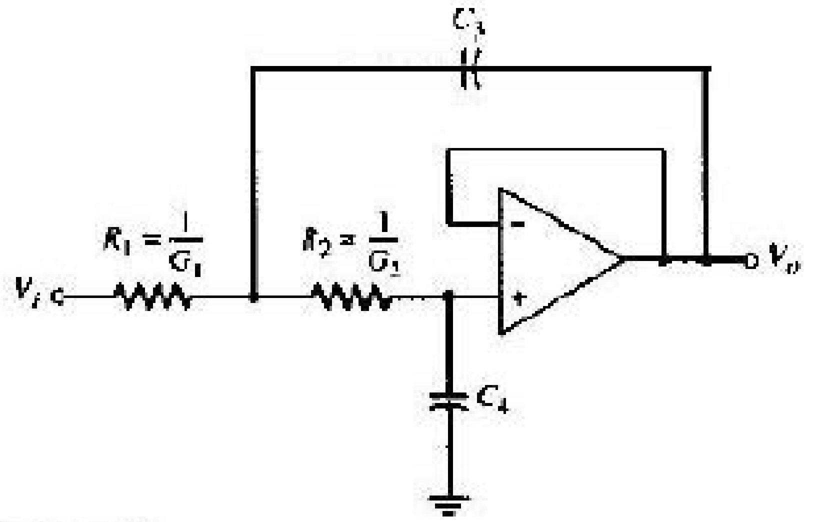
$$T(s) = \frac{V_o(s)}{V_i(s)} = \frac{\frac{1}{sC}}{\frac{1}{sC} + R} = \frac{1}{1 + sRC}$$

- First Order Active LPF

Second Order Filters



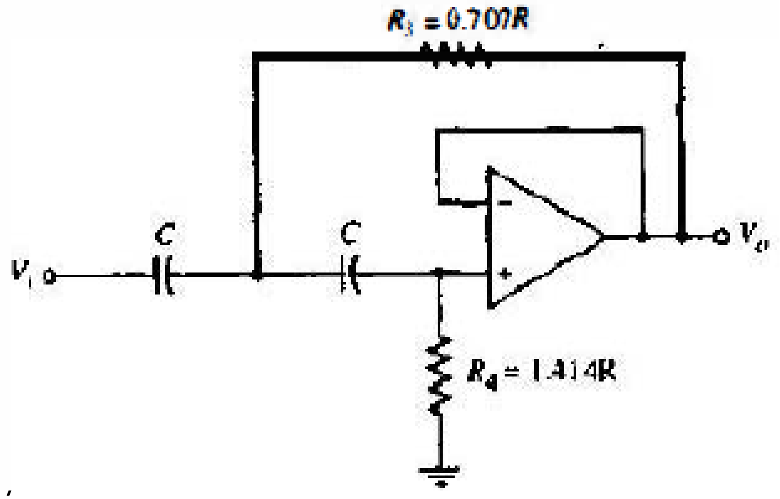
LPF



$$T(s) = \frac{V_o(s)}{V_i(s)} = \frac{Y_1 Y_2}{Y_1 Y_2 + Y_4(Y_1 + Y_2 + Y_3)}$$

- A General Two pole Active Filter.
- To obtain a low-pass filter, both Y1 and Y2 must be conductance

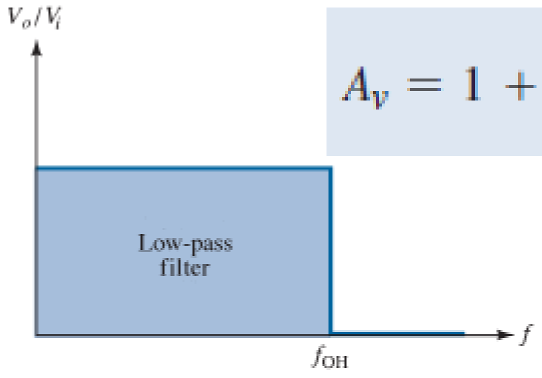
HPF



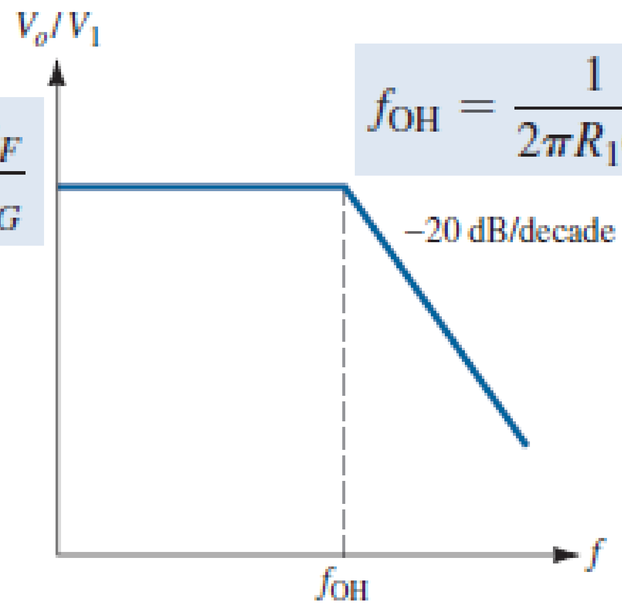
Second Order Filters

- The circuit voltage gain and the cutoff frequency are the same for the second-order circuit as for the first-order filter circuit, except that the filter response drops at a faster rate for a second order filter circuit
- A Btterworth filter is a maximally flat magnltade filter. The transfer function is designed such that
  - the magnitude of the transfer function is as flat as possible within the passband of the filter.
  - This objective is achieved by taking the derivatives of the transfer function with respect to frequency and
  - setting as many as possible equal to zero at the center of the passband, which is at zero frequency for the low-pass filter

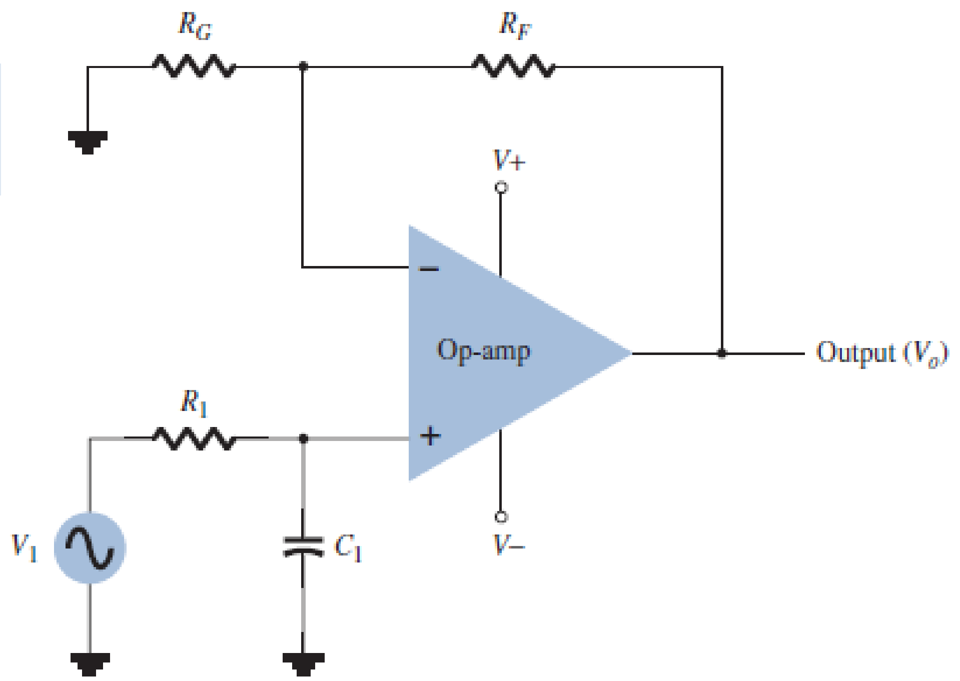
First Order Active Low pass Filter



$$A_v = 1 + \frac{R_F}{R_G}$$

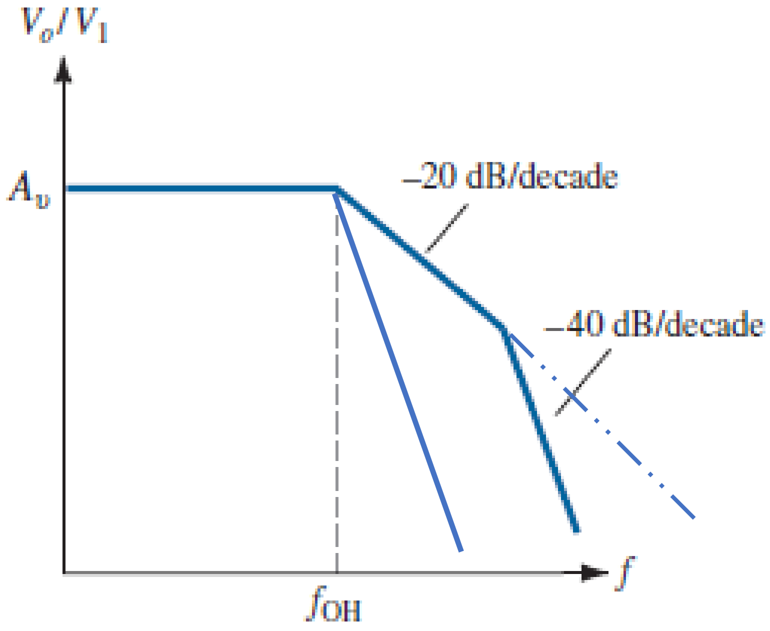


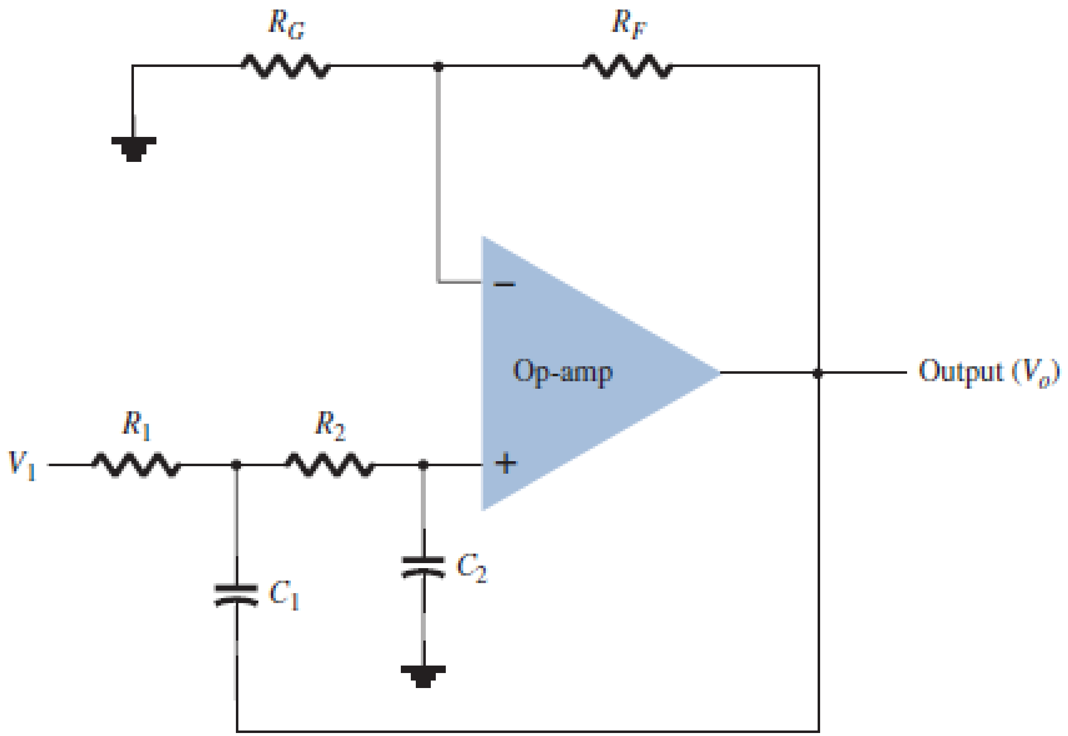
$$f_{OH} = \frac{1}{2\pi R_1 C_1}$$



- Calculate the cutoff frequency of a first-order low-pass filter for R1 = 1.2 kV and C1 = 0.02 mF.
- Ans. 6.63 KHz.

Second Order Active Low Pass Filter





- The circuit voltage gain and the cutoff frequency are the same for the second-order circuit as for the first-order filter circuit, except that the filter response drops at a faster rate for a second order filter circuit

Overview: Band Pass, Band Reject, All Pass Filters