Electronic Systems

Active Filters

Lecture 1

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The Course Grades

- **The Total Course grades 150 Marks**
- **Midterm (أعمال السنة) 30 Marks.**
- **Laboratory (عملي) 20 Marks**
- **Final Exam (الامتحان النهائي) 100 Marks**

جدول رقم (11)

خطة الدراسة للفرقة الثانية ـ قسم هندسة الالكترونيات والاتصالات

الفصل الدراسى الثانى

كود المقرر	اسم المقرر	عدد الساعات الأسبوعية				توزيع الدرجات			عدد ساعات الامتحان التحريرى	مجموع درجات المقرر	الساعات المعتمدة
		محاضرة	تطبيقات		مجموع	أعمال سنة	عملى وشفوى	تحريرى			
			تمرين	معمل							
إلك 2409	الأنظمة الإلكترونية	2	1	1	4	30	20	100	3	150	2

The Course Contents:

1- Wave Generators

2- Multivibrators

3-Voltage Regulators

4- **Active Filters**

References

- [1] Sedra and Smith, Microelectronic Circuits, Oxford University press, 8th edition, 2019,ISBN: 9780190853549.
- [2] Mike Tooley, Electronic Circuits, Fundamentals and Applications, Routledge, 5th edition, 2019, ISBN: 978-0367421984.
- [3] S. Franco: Design with operational Amplifiers and Analog Integrated Circuits.
- [4] L. Huelsman: Active and Passive Analog Filter Design
- [5] A. Budak:Passive and Active Network Analysis and Synthesis.

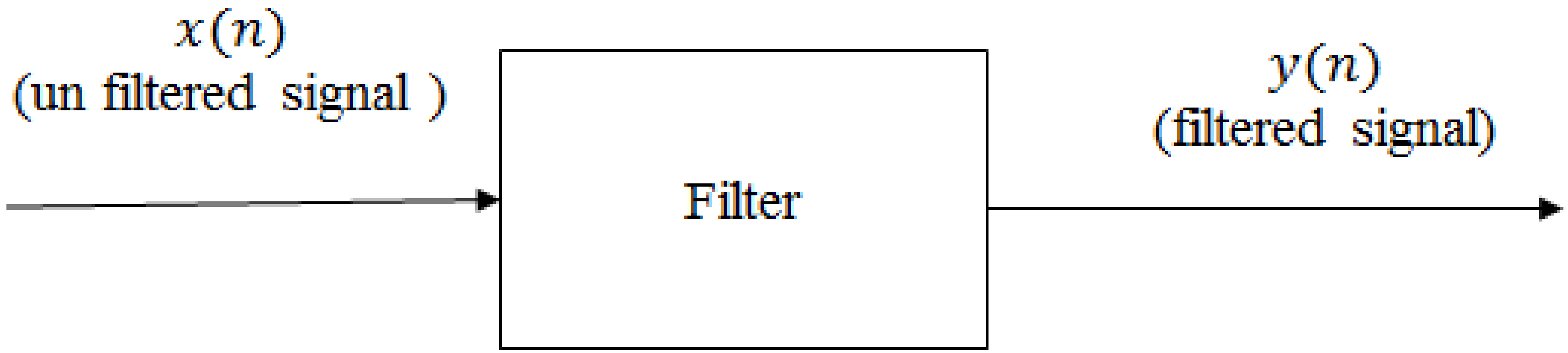
The Active Filters Contents:

1. Introduction to Filters.
2. Low Pass Filter.
3. High Pass Filter.
4. Band Pass Filter.
5. Butterworth Filter.
6. Chebyshev Filter.
7. Bessel Filter.
8. KHN Biquad filter.
9. Multiple Feedback Filters.
10. State Variable Filters.

Introduction to Filters

What Is a Filter?

- A filter is a circuit capable of passing (or amplifying) certain frequencies while attenuating other frequencies. Thus, a filter can extract important frequencies from signals that also contain undesirable or irrelevant frequencies.



What Is a Filter?

In the field of electronics, there are many practical applications for filters.

- **Radio Communications**: Filters enable radio receivers to only "see" the desired signal while rejecting all other signals (assuming that the other signals have different frequency content).
- **DC Power Supplies**: Filters are used to eliminate undesired high frequencies (i.e., noise) that are present on AC input lines. Additionally, filters are used on a power supply's output to reduce ripple.
- **Audio Electronics**: A crossover network is a network of filters used to channel low-frequency audio to woofers, mid-range frequencies to midrange speakers, and high-frequency sounds to tweeters.
- **Analog-to-Digital Conversion**: Filters are placed in front of an ADC input to minimize aliasing.

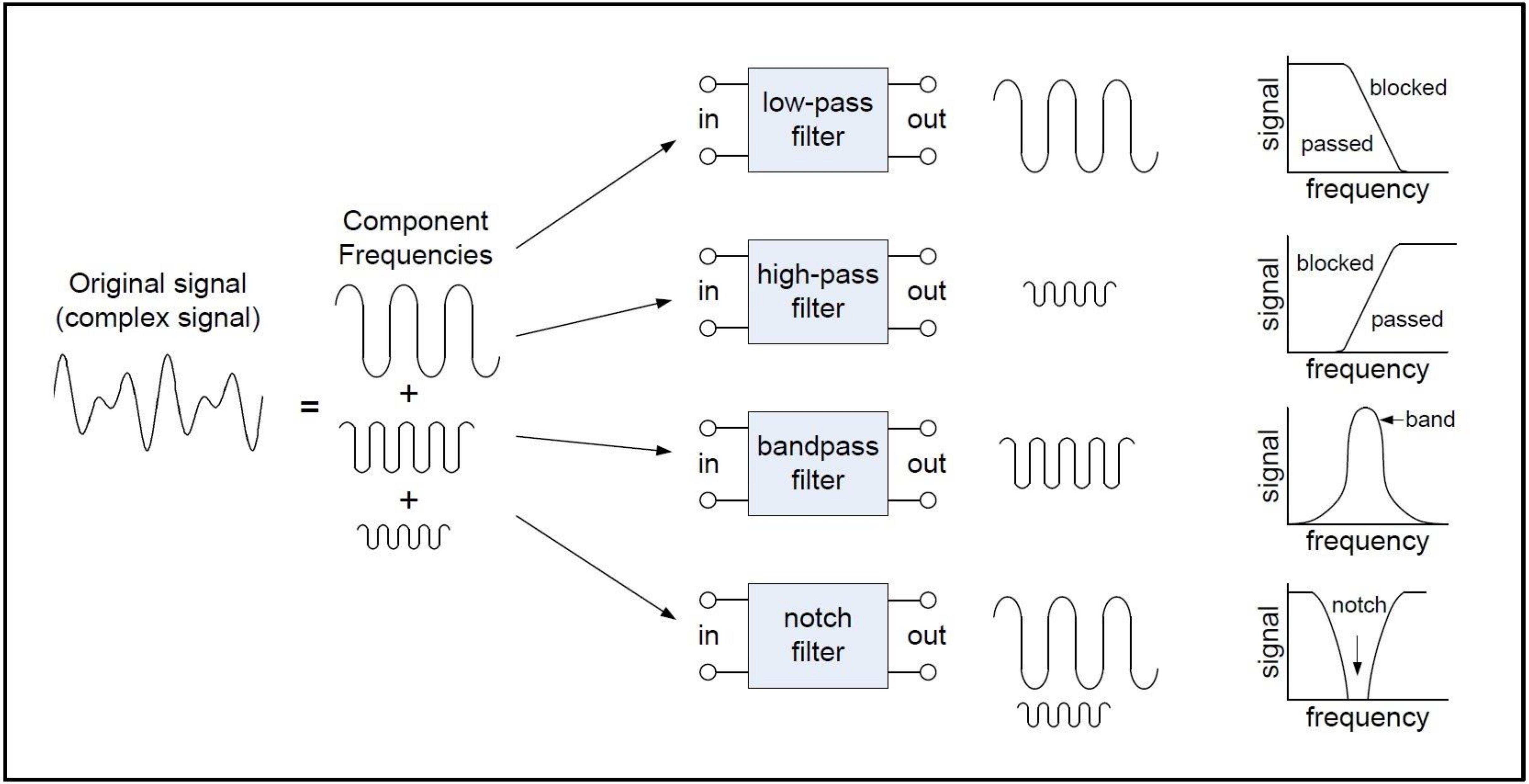
Types of Filters

- The four primary types of filters include:

1. The Low-pass filter.
2. The High-pass filter.
3. The Band-pass filter.
4. The Notch filter (band-reject or band-stop filter).

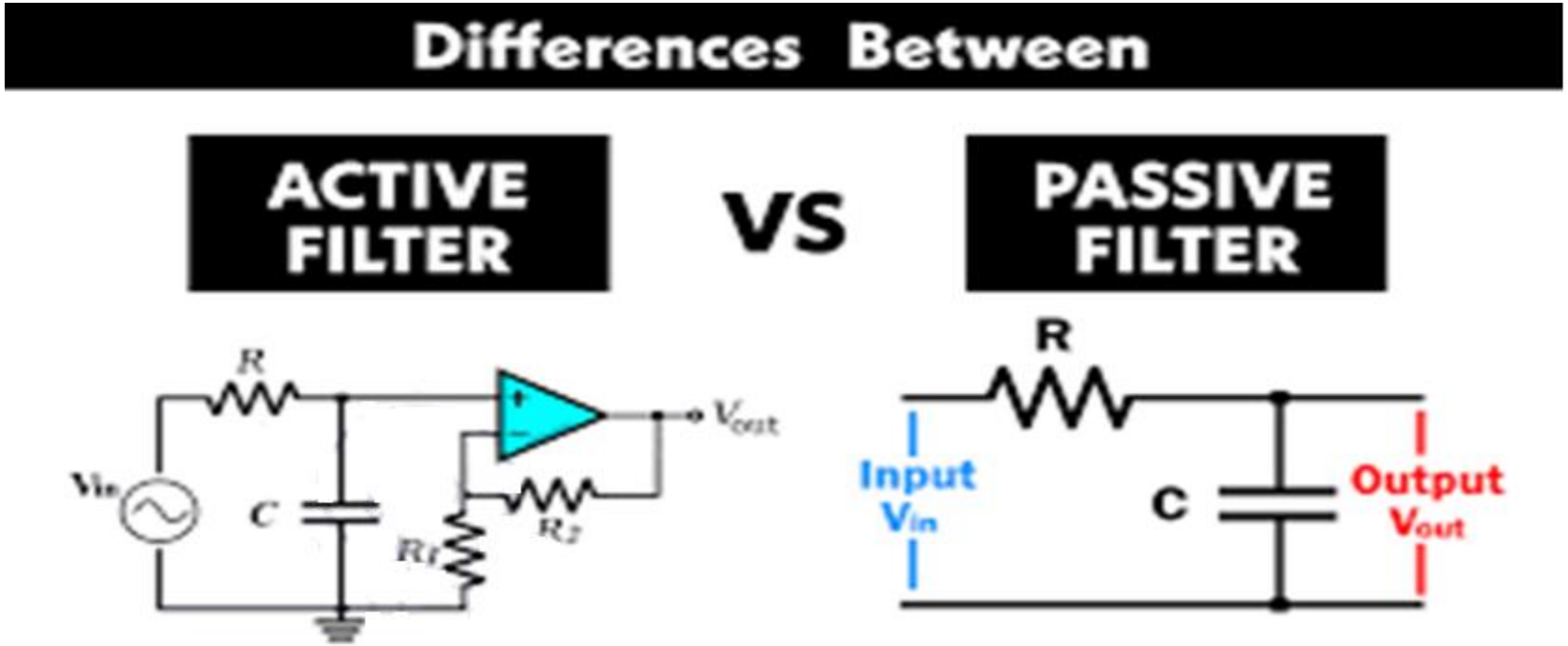
- The terms "low" and "high" do not refer to any absolute values of frequency, but rather they are relative values with respect to the cutoff frequency.

Types of Filters



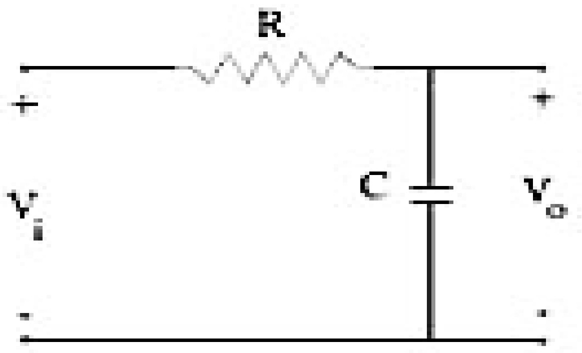
Passive and Active Filters

- Filters can be placed in one of two categories: *passive* or *active*.
- Passive filters include only passive components—resistors, capacitors, and inductors. In contrast, active filters use active components, such as op-amps, in addition to resistors and capacitors, but not inductors.

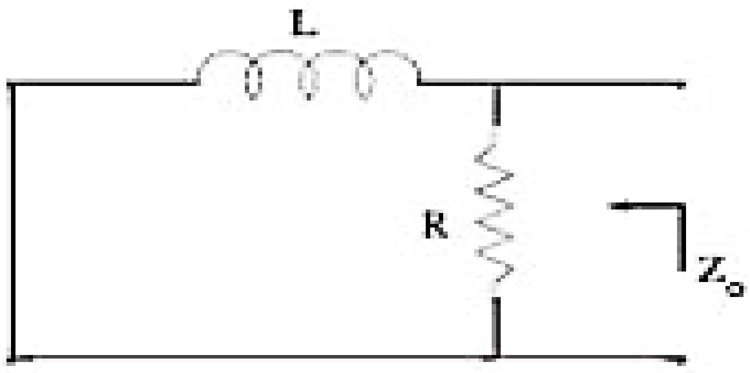


Passive Filters

- Passive filters are most responsive to a frequency range from roughly 100 Hz to 300 MHz. The limitation on the lower end is a result of the fact that at low frequencies the inductance or capacitance would have to be quite large. The upper-frequency limit is due to the effect of parasitic capacitances and inductances. Careful design practices can extend the use of passive circuits well into the gigahertz range.



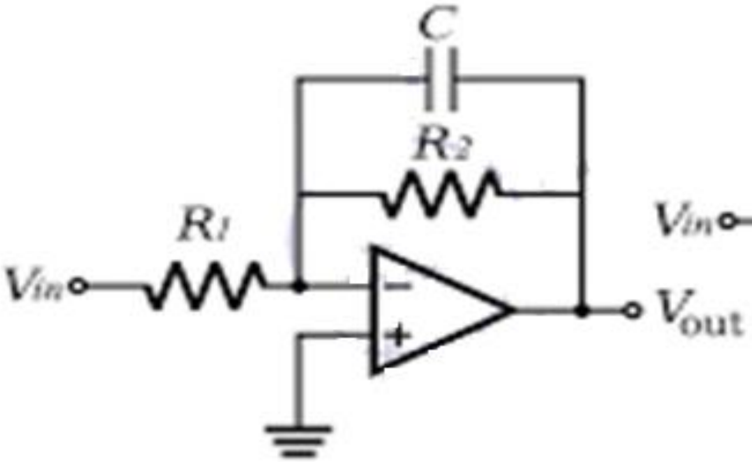
RC Low Pass Filter



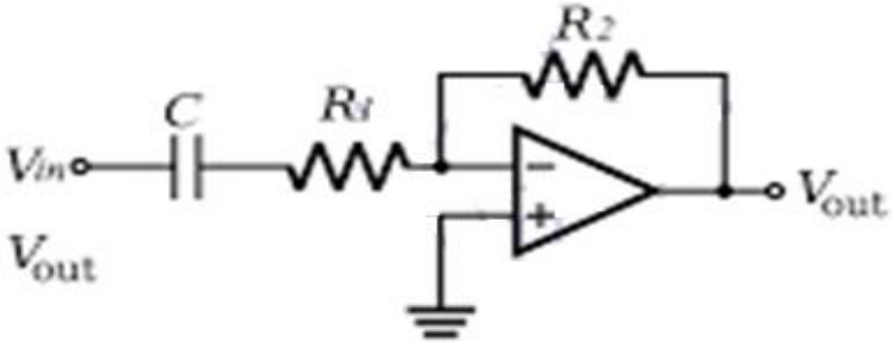
RL Low Pass Filter

Active Filters

- Active filters are capable of dealing with very low frequencies (approaching 0 Hz), and they can provide voltage gain (passive filters cannot). Active filters can be used to design high-order filters without the use of inductors; this is important because inductors are problematic in the context of integrated-circuit manufacturing techniques. However, active filters are less suitable for very-high-frequency applications because of amplifier bandwidth limitations. Radio-frequency circuits must often utilize passive filters.



Active Low Pass Filter



Active High Pass Filter

Passive and Active Filters

The Advantages of Each Filter Type:

PASSIVE	ACTIVE
• no power supply required • can handle large currents and high voltages • very reliable • least number of components for given filter • noise arises from resistances only • no bandwidth limitation	• no inductors • easier to design • high Zin, low Zout for minimal loading • can produce high gains • generally easier to tune • small in size and weight

Passive and Active Filters

The Disadvantages of Each Filter Type:

PASSIVE	ACTIVE
• inductors large for lower frequencies • some inductors (non-toroidal) may require shielding • limited standard sizes, often requiring variable inductors and therefore tuning • low tolerance inductors (1-2%) very expensive • must be designed with consideration to input and output loading • generally not amenable to miniaturization • no power gain possible • no voltage gain	• power supply required • susceptible to intermodulation, oscillations • susceptible to parasitics from DC output offset voltage and input bias currents • op amp gain bandwidth constrained • op amp slew rate constrained • can require many components

Active Filters

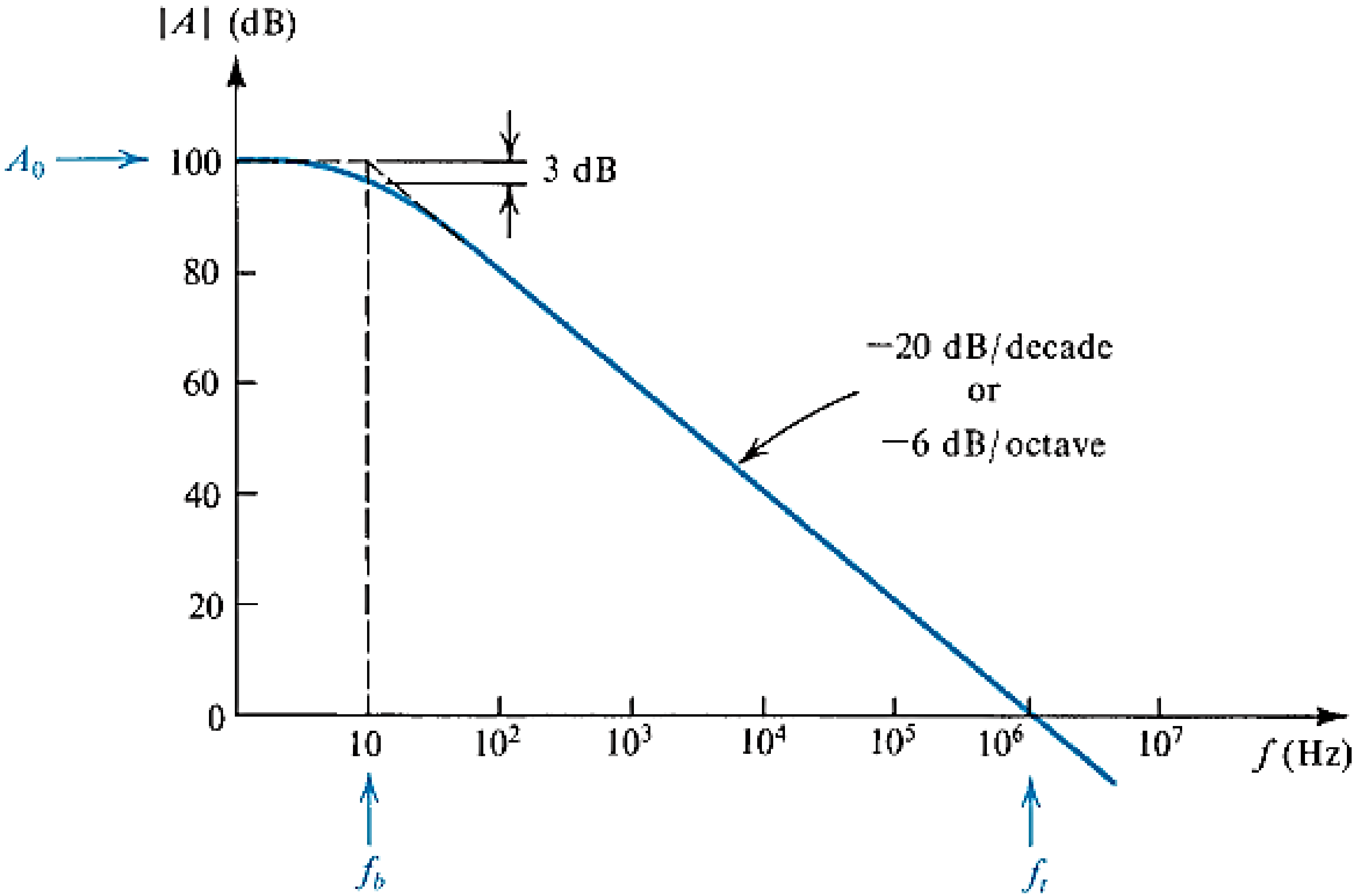
Effect of Finite Open-Loop Gain and Bandwidth on Circuit Performance

- The differential open-loop gain A of an op amp is not infinite; rather, it is finite and decreases with frequency.

- Note that although the gain is quite high at dc and low frequencies, it starts to fall off at a rather low frequency (10 Hz in our example).

- The uniform –20-dB/decade gain roll off shown is typical of internally compensated op amps. These are units that have a network (usually a single capacitor) included within the same IC chip whose function is to cause the op-amp gain to have the Single-Time-Constant (STC) low-pass response shown.

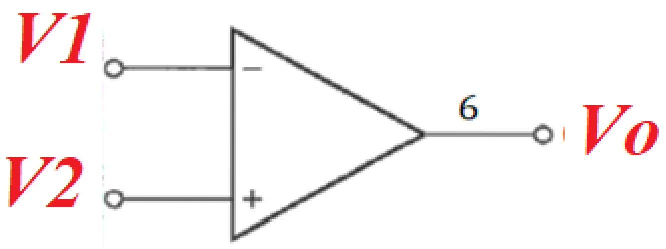
Effect of Finite Open-Loop Gain and Bandwidth on Circuit Performance



- **This process of modifying the open-loop gain is termed frequency compensation, and its purpose is to ensure that op-amp circuits will be stable (as opposed to oscillatory).**

Open-Loop Op-Amp:

The open-Loop gain A_{ol} or $A\ (S)$ can be expressed as:



$$A(S) = \frac{A_o}{1+\frac{S}{W_b}}$$

where:

A_o is the maximum gain,

Wb is the Band-Width (B.W) rad/Sec

Wb = $2\pi f_b$

$$\boxed{v_o = A_{ol}\,(v_2 - v_1)}$$

A_{ol} = A(S) is The open-loop gain

(Very high)

S = jw = j2πf

$$A(jw) = \frac{A_o}{1+j\frac{w}{W_b}}$$

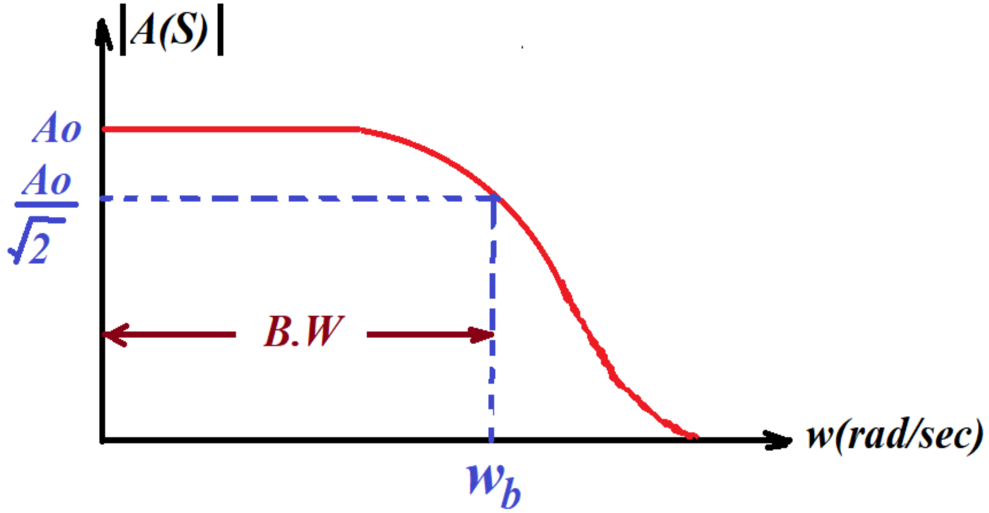
Magnitude of the open loop gain is:

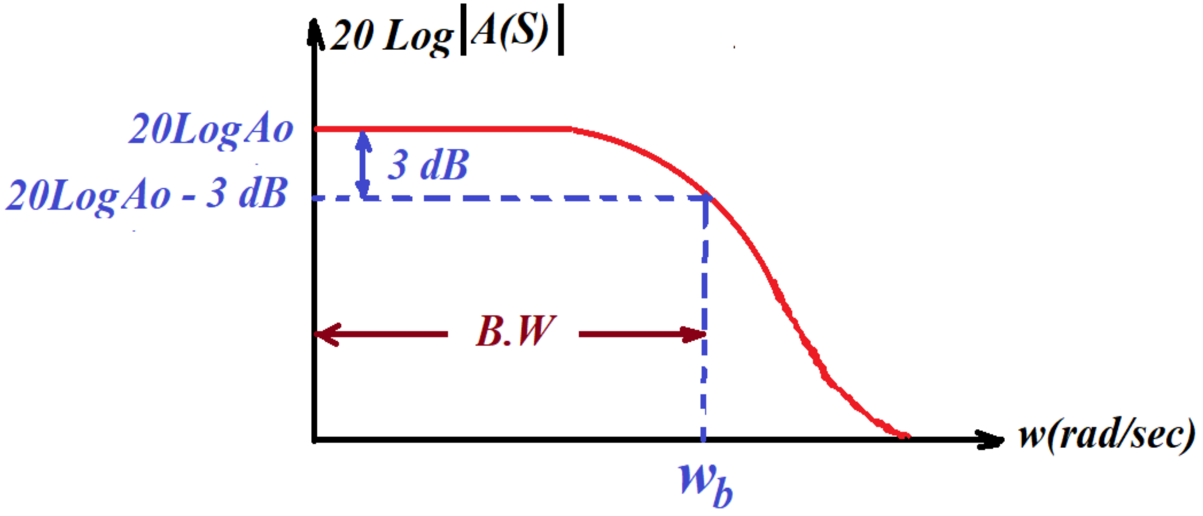
$$|A(jw)| = \frac{A_o}{\sqrt{1+(\frac{w}{W_b})^2}}$$

Frequency Response of Open-Loop Op-Amp

Open-Loop Gain-Band Width Product (GBP)

GBP (Open-Loop) = A_o W_b



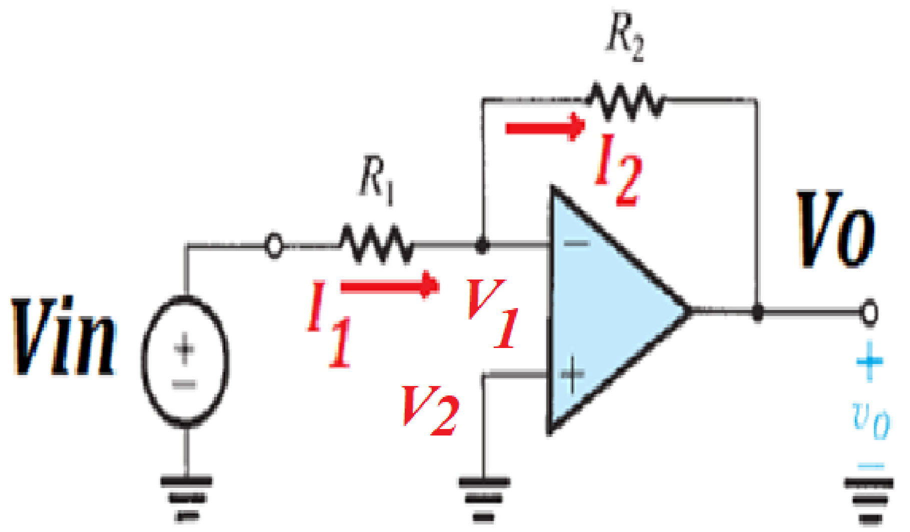


Effect of Finite Open-Loop Gain and Bandwidth on Circuit Performance

1. Inverting Amplifier (Finite-Gain): Closed Loop

- $Vo = A(S)\,(V_2 - V_1)$

- $V_2 = 0 \qquad V_1 = \dfrac{Vin.R2}{R1+R2} + \dfrac{Vo.R1}{R1+R2}$



- Then, $Vo = A(S)\,[0 - (\dfrac{Vin.R2}{R1+R2} + \dfrac{Vo.R1}{R1+R2})]$

  $Vo(R1+R2) = A(S)\,[-Vin.R2 - Vo.R1]$

  $Vo\,[(R1+R2) + A(S)\,R1] = -A(S)\,R2\,Vin$

- The Closed Loop Gain is

$$G = \frac{Vo}{Vin} = \frac{-A(S)\,R2}{[(R1+R2) + A(S)\,R1]} = \frac{-A(S)\,(R2/R1)}{(1+\frac{R2}{R1})+A(S)} = \frac{-(R2/R1)}{\frac{(1+\frac{R2}{R1})}{A(S)}+1} = \frac{-(R2/R1)}{\frac{1+\frac{R2}{R1}}{(\frac{A_o}{1+\frac{S}{W_b}})}+1}$$

1. Inverting Amplifier (Finite-Gain): Closed Loop

$$G = \frac{Vo}{Vin} = \frac{-A(S)\,R2}{[(R1 + R2) + A(S)\,R1]} = \frac{-A(S)\,(R2/R1)}{(1+\frac{R2}{R1}) + A(S)} = \frac{-(R2/R1)}{\frac{(1+\frac{R2}{R1})}{A(S)} + 1} = \frac{-(R2/R1)}{\frac{1+\frac{R2}{R1}}{\left(\frac{Ao}{1+\frac{S}{W_b}}\right)} + 1}$$

$$G = \frac{-(R2/R1)}{\frac{\left(1+\frac{R2}{R1}\right)\left(1+\frac{S}{W_b}\right)}{Ao} + 1} = \frac{-(R2/R1)}{\frac{\left(1+\frac{R2}{R1}\right)}{Ao} + \frac{\left(1+\frac{R2}{R1}\right)\left(\frac{S}{W_b}\right)}{Ao} + 1} \approx \frac{-(R2/R1)}{\frac{\left(1+\frac{R2}{R1}\right)\left(\frac{S}{W_b}\right)}{Ao} + 1} \approx \frac{-(R2/R1)}{1 + \frac{S}{\frac{A_o W_b}{\left(1+\frac{R2}{R1}\right)}}} = \frac{Am}{1+\frac{S}{Wc}}$$

Then, The Closed Loop maximum gain $Am = -\frac{R2}{R1}$

And The Closed Loop Band-width $Wc = \frac{A_o W_b}{\left(1+\frac{R2}{R1}\right)}$

1. Inverting Amplifier (Finite-Gain): Closed Loop

where

Am = The closed loop maximum gain

Ao =The Open Loop maximum gain

Wc = The Closed Loop Band Width

Wb = The Open Loop Band Width

$Am = -\frac{R2}{R1}$ and **Wc =** $\frac{AoW_b}{(1+\frac{R2}{R1})}$

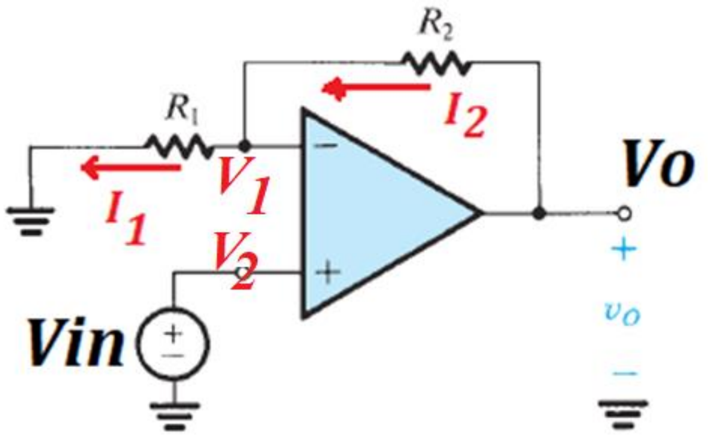
Closed Loop Gain-Band width product:

GBP(Closed-Loop) = Am Wc = $(\frac{R2}{R1})\ (\frac{AoW_b}{(1+\frac{R2}{R1})}) = AoW_b$ **= GBP(Open-Loop)**

Since $\frac{R2}{R1} >> 1$

2. Non-Inverting Amplifier (Finite-Gain): Closed Loop

- $Vo = A(S)\,(V_2 - V_1)$



- $V_2 = Vin \qquad V_1 = \dfrac{Vo.R1}{R1+R2}$

- Then, $Vo = A(S)\,[Vin - \dfrac{Vo.R1}{R1+R2}]$

  $Vo = A(S)\,Vin - A(S)\,\dfrac{Vo.R1}{R1+R2}$

  $Vo\,[\,1 + A(S)\,\dfrac{R1}{R1+R2}] = A(S)\,Vin$

- The Closed Loop Gain is

$$G = \frac{Vo}{Vin} = \frac{A(S)}{[\,1 + A(S)\,\frac{R1}{R1+R2}]} = \frac{1}{\frac{1}{A(S)} + \frac{R1}{R1+R2}} = \frac{1}{\frac{1}{A(S)} + \frac{1}{1+\frac{R2}{R1}}} = \frac{1+\frac{R2}{R1}}{\frac{1+\frac{R2}{R1}}{A(S)} + 1}$$

2. Non-Inverting Amplifier (Finite-Gain): Closed Loop

$$A(S) = \frac{A_o}{1 + \frac{S}{W_b}}$$

The closed loop gain $G = \dfrac{1+\frac{R2}{R1}}{\frac{1+\frac{R2}{R1}}{A(S)} + 1} = \dfrac{1+\frac{R2}{R1}}{\frac{1+\frac{R2}{R1}}{\frac{A_o}{1+\frac{S}{W_b}}} + 1} = \dfrac{1+\frac{R2}{R1}}{\frac{(1+\frac{S}{W_b})(1+\frac{R2}{R1})}{Ao} + 1} =$

$$\frac{1+\frac{R2}{R1}}{\frac{(1+\frac{R2}{R1})}{Ao} + \frac{\frac{S}{W_b}(1+\frac{R2}{R1})}{Ao} + 1} \approx \frac{1+\frac{R2}{R1}}{\frac{S\,(1+\frac{R2}{R1})}{AoW_b} + 1} \approx \frac{1+\frac{R2}{R1}}{1+\frac{\frac{S}{AoW_b}}{(1+\frac{R2}{R1})}}$$

$$G = \frac{1+\frac{R2}{R1}}{1+\frac{\frac{S}{AoW_b}}{(1+\frac{R2}{R1})}} = \frac{Am}{1+\frac{S}{Wc}}$$

2. Non-Inverting Amplifier (Finite-Gain): Closed Loop

Where

Am **= The closed loop maximum gain**

Ao **=The Open Loop maximum gain**

Wc = The Closed Loop Band Width

Wb = The Open Loop Band Width

$$Am = 1 + \frac{R2}{R1} \qquad \text{and} \qquad Wc = \frac{AoW_b}{(1+\frac{R2}{R1})}$$

Closed Loop Gain-Band width product:

GBP(Closed-Loop) = Am Wc = $\left(1 + \frac{R2}{R1}\right)\left(\frac{AoW_b}{(1+\frac{R2}{R1})}\right) = AoW_b$ **= GBP(Open-Loop)**