End Semester Project Report on

ACTIVE WIDE BAND REJECT FILTER

Submitted for the partial fulfillment of the subject

Analog Circuits Workshop
(EET1707)

Project Presented By:-

SAI SUBHAM ROUT

B. Tech. 1st Semester

DEPT. OF ELECTRONICS & COMMUNICATION ENGINEERING
Institute of Technical Education and Research

SIKSHA 'O' ANUSANDHAN
DEEMED TO BE UNIVERSITY

Bhubaneswar, Odisha, India.
(2025)

Abstract

An Active Wide Band Reject Filter is an electronic circuit designed to suppress a specific range of frequencies (called the stop band) while allowing frequencies outside this range (both lower and higher) to pass with minimal attenuation. This filter is constructed using three main components: a Low Pass Filter (LPF), a High Pass Filter (HPF), and a Summing Amplifier. The Low Pass Filter is responsible for allowing low frequencies below the stop band to pass while attenuating higher frequencies, whereas the High Pass Filter permits high frequencies above the stop band to pass and blocks lower frequencies. These filters are implemented using operational amplifiers, resistors, and capacitors, which enable precise tuning of the cutoff frequencies that define the edges of the stop band. The outputs of the Low Pass Filter and High Pass Filter are then fed into a summing amplifier, which combines the two signals, resulting in an output that excludes the stop band frequencies while preserving the frequencies outside it. Active components, such as op-amps, ensure that the filter maintains signal strength, minimizes distortion, and provides greater accuracy and flexibility in tuning compared to passive filters. This configuration is widely used in applications such as audio processing, communication systems, and noise suppression, where selective rejection of frequency ranges is essential.

Key Words: Active Wide Band Reject Filter, Low Pass Filter (LPF), High Pass Filter (HPF), Summing Amplifier

Contents

Chapter 01: Introduction

1.1. Introduction

Introduction to Active Wide Band Reject Filter

An Active Wide Band Reject Filter, also known as a Band Stop Filter, is an indispensable component in modern electronics and signal processing. Its primary purpose is to block or attenuate a specific range of frequencies, called the stop band, while allowing all other frequencies outside this range to pass through. This makes it a critical tool for eliminating noise or interference in systems where signal clarity and integrity are paramount. By selectively filtering out unwanted frequencies, the filter ensures clean and reliable transmission of signals, which is essential in many electronic and communication applications.

This type of filter is designed with active components, such as operational amplifiers (op-amps), in addition to passive components like resistors and capacitors. The incorporation of op-amps significantly enhances the performance of the filter by providing signal amplification, better stability, and more precise control over the filter's frequency response. Active filters offer several advantages over passive filters, such as the ability to achieve higher gain, operate at lower power levels, and eliminate the need for bulky inductors, making them more compact and efficient for modern applications.

A key factor in the operation of an Active Wide Band Reject Filter is its transient response, which refers to the temporary, short-lived fluctuations that occur when the input signal changes abruptly or the circuit switches states. Transients are especially relevant in filters, as they can cause distortion, introduce noise, or affect the system's stability. Controlling transients is crucial to maintaining the filter's effectiveness, ensuring smooth transitions and consistent performance

Active Wide Band Reject Filters are widely used in communication systems, audio processing, and instrumentation. In communication systems, they suppress specific interference frequencies, ensuring clear signal transmission. In audio processing, they remove unwanted noises like hums or whistles, improving sound quality. In instrumentation, they filter out noise that could affect measurement accuracy, making them vital for scientific and industrial applications requiring precision.

This project involves using both active and passive components to construct the filter. Op-amps serve as the core active components, providing the necessary gain and control over the filtering process. Resistors and capacitors are used to define the filter's frequency response and determine the stop band. By carefully selecting and configuring these components, the filter is designed to effectively block the unwanted frequency band while ensuring high signal integrity and precise control. This combination of active and passive components makes the Active Wide Band Reject Filter a highly efficient and versatile tool for modern electronics.

1.2. Background

Filters are vital components in electronic and signal processing systems. Their purpose is to modify signals by either amplifying or attenuating specific frequency ranges.

For example, in communication systems, filters are used to remove noise or interference, ensuring that the transmitted signal is clear and undistorted.

Filters are broadly categorized into:

1. Low-pass filters: Allow frequencies below a certain threshold to pass while attenuating higher frequencies.

2. High-pass filters: Allow frequencies above a certain threshold to pass while attenuating lower frequencies.

3. Band-pass filters: Allow a specific range of frequencies to pass while attenuating others.

4. Band-reject filters: Attenuate a specific range of frequencies while allowing others to

A wide band reject filter is a type of band-reject filter that suppresses a broader range of frequencies compared to a narrow-band notch filter.

Its primary application is eliminating unwanted frequency components over a wide range, which is often required in noise removal, signal conditioning, and communication systems.

The Evolution of Filters

Early filters were purely passive and relied on inductors and capacitors for their operation. However, they were limited by their bulky size, cost, and inefficiency at low frequencies.

The development of operational amplifiers in the mid-20th century led to the rise of active filters, which eliminated the need for inductors and offered more flexibility in circuit design.

Today, active filters are preferred in applications that demand compact, high-performance designs. The Active Wide Band Reject Filter is a modern implementation that leverages these advancements.

Significance of Active Wide Band Reject Filters

1. Versatility: They can be used in a variety of applications, including telecommunications, audio processing, and instrumentation.

2. Efficiency: Active filters provide precise frequency rejection, making them ideal for applications where unwanted frequencies must be removed without affecting the desired signals.

3. Compactness: By eliminating inductors, active filters can be implemented on smaller circuit boards, which is crucial for modern, miniaturized devices.

4. Cost-Effectiveness: They are cheaper and easier to manufacture compared to passive filters requiring large inductors.

Achieving high performance across a wide frequency range can be complex due to component tolerances and stability issues in operational amplifiers.

Factors like bandwidth, quality factor (), and gain must be carefully optimized to ensure the filter performs as desired.

1.3. Project Objectives

Key Objectives:

To design and implement an active wide band reject filter using operational amplifiers, resistors, and capacitors.

Ensure that the filter effectively suppresses a specified range of frequencies while allowing others to pass.

To analyse the filter's performance characteristics, such as frequency response, bandwidth, and attenuation.

Evaluate the filter's efficiency in rejecting unwanted signals while maintaining stability and precision.

To explore potential applications of the filter in real-world scenarios, such as:

Removing unwanted noise from audio signals.

Eliminating interference in communication systems.

Filtering out specific noise in biomedical applications.

1.4. Scope

The scope defines the boundaries and limitations of the project, as well as its broader applications. It helps to clarify what the project will cover and what it will not.Inclusions:

1. Filter Design:

Focus on designing a wide band reject filter using active components such as operational amplifiers.

Target a frequency range of X Hz to Y Hz (define based on your project requirements).

2. Circuit Simulation:

Use software tools to model and simulate the filter's behavior under various conditions.

3. Practical Implementation:

Build a physical prototype of the filter circuit to verify its real-world performance.

4. Performance Metrics:

Analyze critical performance metrics, including attenuation, bandwidth, and frequency stability.

5. Applications:

Highlight applications in fields like audio processing, communication systems, and signal conditioning.

Exclusions:

High-Frequency Applications:

The project will focus on low- to mid-frequency ranges and will not cover high-frequency RF applications due to operational amplifier limitations.

Complex Architectures:

The filter design will avoid overly complex architectures to maintain simplicity and cost-effectiveness.

The scope defines the boundaries and limitations of the project, as well as its broader applications. It helps to clarify what the project will cover and what it will not.

1.5. Project Management

According to the PMBOK Guide (Project Management Body of Knowledge), a project management life cycle consists of 5 distinct phases including initiation, planning, execution, review, and closure that combine to turn a project idea into a working product.

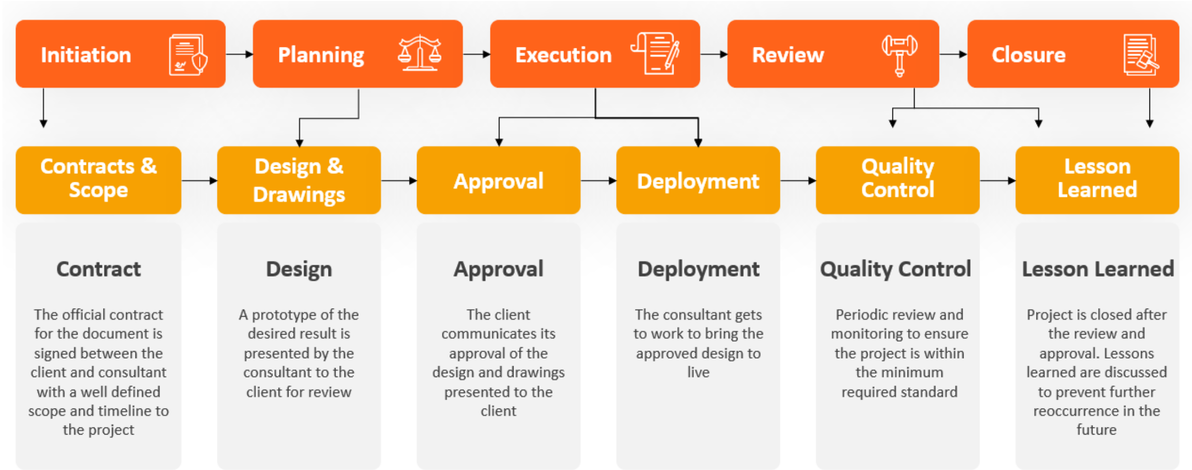


Figure 1. Model of phases in project management.

The project initiation phase is the first stage of turning an abstract idea into a meaningful goal. In this stage, we need to develop a business case and define the project on a broad level.

The project planning stage requires complete diligence as it lays out the project's roadmap.

The project execution stage is where the project team does the actual work. The job of a project manager is to establish efficient workflows and carefully monitor the progress of the team.

In the project management process, the third and fourth phases are not sequential in nature. The project monitoring and controlling phase run simultaneously with project execution.

The project closure stage indicates the end of the project after the final delivery.

1.6. Overview and Benefits

The Active Wide Band Reject Filter project aims to design and implement an electronic filter capable of suppressing a wide range of unwanted frequencies while allowing others to pass. The project involves:

1. Understanding the theoretical aspects of active filters, including their characteristics and advantages over passive filters.

2. Designing the filter circuit using operational amplifiers, resistors, and capacitors.

3. Simulating the circuit to analyse its frequency response and verify its performance.

4. Building a physical prototype and testing its performance against theoretical and simulated results.

This project combines theoretical knowledge with practical implementation, providing a hands-on approach to circuit design, simulation, and analysis.

Benefits

1. Efficient Noise Removal:
   The filter is effective in suppressing a wide range of unwanted frequencies, making it ideal for noise reduction in communication systems, audio processing, and biomedical applications.

2. Compact Design:
   By using active components, the design is compact and eliminates the need for bulky inductors, which are commonly used in passive filters.

3. Signal Amplification:
   Unlike passive filters, this active filter can amplify the signal while filtering, ensuring no signal loss during processing.

4. Improved Performance:
   Provides precise control over filter parameters such as cutoff frequency, bandwidth, and attenuation, resulting in better performance in specific applications.

5. Real-World Applications:
   The filter can be used in various industries, such as:

   Communication Systems: Eliminating interference in transmitted signals.

   Audio Processing: Removing background noise without distorting the main audio.

   Medical Devices: Filtering out noise from sensitive biomedical signals like ECG or EEG.

6. Learning Opportunity:
   Offers a practical learning experience in electronics, involving circuit design, simulation, and troubleshooting.
   Enhances understanding of operational amplifiers, filter theory, and signal processing concepts.
7. Cost-Effective Solution
   Active filters provide a more economical and efficient alternative compared to traditional passive filters for many applications.

1.7. Organization of the Report

The report is organized into the following chapters. Each chapter is unique on its own and is described with the necessary theory to comprehend it.

Chapter 2 deals with a background survey and review, Chapter 3 has the description of the theoretical aspects that have been acquired to commence the project work.

Chapter 02: Theoretical Aspects

2.1. Background Theory and Modeling

The Active Wide Band Reject Filter is a powerful and versatile electronic circuit that plays a critical role in modern signal processing systems. Its primary function is to attenuate or reject a specific range of frequencies (the stop band) while allowing frequencies outside this range (the pass band) to pass with minimal distortion. This filter is essential in applications such as noise cancellation, interference rejection in communication systems, and audio signal processing. By integrating low pass filters (LPF), high pass filters (HPF), and an active summing amplifier, it provides precise filtering with minimal signal loss, making it a superior alternative to passive filters.

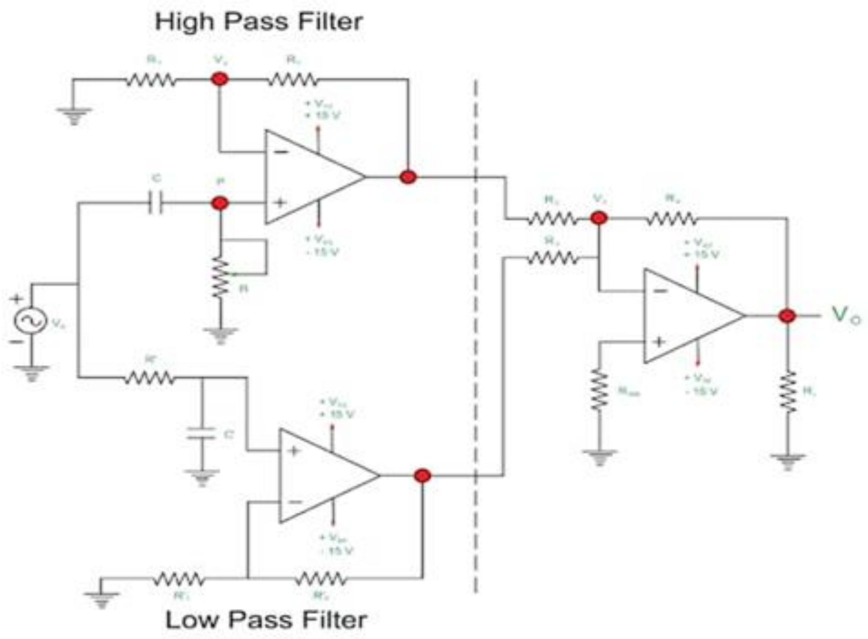


Fig. 2.1: Wide Band Reject Filter

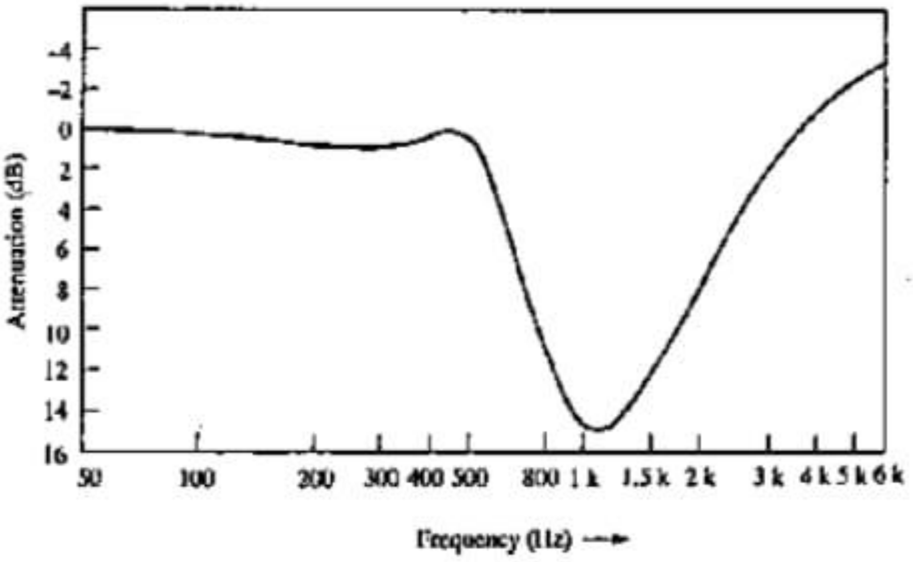


Fig.2.2: Frequency Response of active wide band reject filter

Principles of Operation:

At the heart of wide band reject filters lies their incredible ability to target and eliminate a wide range of frequencies. Picture it as a vigilant bouncer at an exclusive club, only letting in the VIPs while keeping the troublemakers out.

Here's how they work:

Frequency Range Selection: The filter is meticulously designed to pinpoint a broad range of frequencies that need to be eliminated. By setting the lower and upper cutoff frequencies, we can define the boundaries of the stop band.

Attenuation Mechanism: Within this stop band, unwanted frequencies are significantly attenuated, meaning their amplitude is reduced, and they are effectively "rejected." It's like turning down the volume on the noise so that only the sweet melody of the desired signal remains.

Pass Bands: Frequencies outside the stop band are allowed to pass through with minimal attenuation, ensuring that the quality and integrity of the essential signal components are preserved.

Applications:

Wide band reject filters are everywhere, making our lives better in countless ways:

Communications: Imagine a world with clear, uninterrupted communication. These filters remove broad spectrum interference and unwanted signals, ensuring that your calls and data transfers are smooth and noise-free.

Audio Engineering: In the realm of audio, these filters work like magic to eliminate a wide range of hums and noise. Whether you're recording a podcast or enjoying your favorite music, wide band reject filters ensure you get the best sound quality.

Medical Devices: In the medical field, precision is key. These filters help in cleaning up biomedical signals, removing noise and artifacts, so that accurate measurements can be taken from instruments like ECG machines.

Radar and Sonar: For those in radar and sonar technology, wide band reject filters are indispensable. They reject clutter and unwanted echoes over a wide frequency range, enhancing the detection and tracking of target signals.

Design and Implementation:

Creating a wide band reject filter involves a detailed process that brings together various components and design strategies to achieve the desired performance. Here's a more in-depth look at the design and implementation, highlighting the roles of LPFs, HPFs, and summing amplifiers:

Filter Topology:

Choosing the right filter topology is crucial for designing an effective wide band reject filter. The topology determines the arrangement and interaction of components to achieve the desired frequency response. Common topologies include Butterworth, Chebyshev, Elliptic, and Bessel filters.

Component Selection:

Low Pass Filter (LPF): An LPF allows frequencies below a certain cutoff frequency to pass through while attenuating higher frequencies. In the context of a wide band reject filter, LPFs can be used to control the lower bound of the stop band, ensuring that frequencies below this threshold are preserved.

High Pass Filter (HPF): An HPF does the opposite, allowing frequencies above a certain cutoff frequency to pass through while attenuating lower frequencies. HPFs can be utilized to control the upper bound of the stop band, ensuring that frequencies above this threshold are maintained.

By combining LPFs and HPFs, we can create a band-stop effect where a wide range of intermediate frequencies is attenuated while preserving the frequencies outside this range.

Summing Amplifier:

A summing amplifier is a circuit configuration that combines multiple input signals into a single output. In the design of a wide band reject filter, a summing amplifier can be used to add the outputs of the LPF and HPF stages, effectively creating the desired attenuation band.

Here’s how the design comes together:

LPF Stage: The LPF is designed with a specific cutoff frequency to define the lower bound of the stop band. This stage ensures that frequencies below this threshold are unaffected.

HPF Stage: The HPF is designed with a specific cutoff frequency to define the upper bound of the stop band. This stage ensures that frequencies above this threshold are unaffected.

Summing Amplifier: The outputs of the LPF and HPF stages are fed into a summing amplifier. This configuration combines the preserved low and high frequencies while attenuating the intermediate frequencies, thus achieving the wide band reject effect.

Performance Metrics:

Evaluating the performance of the wide band reject filter involves several key metrics:

Attenuation Depth: The amount of attenuation provided within the stop band.

Transition Band Sharpness: The steepness of the roll-off between the pass band and stop band.

Phase Response: The phase characteristics of the filter and its impact on the signal integrity.

By carefully selecting and configuring the LPF, HPF, and summing amplifier, we can design a wide band reject filter that meets the specific requirements of the application.

2.2. Project Layout

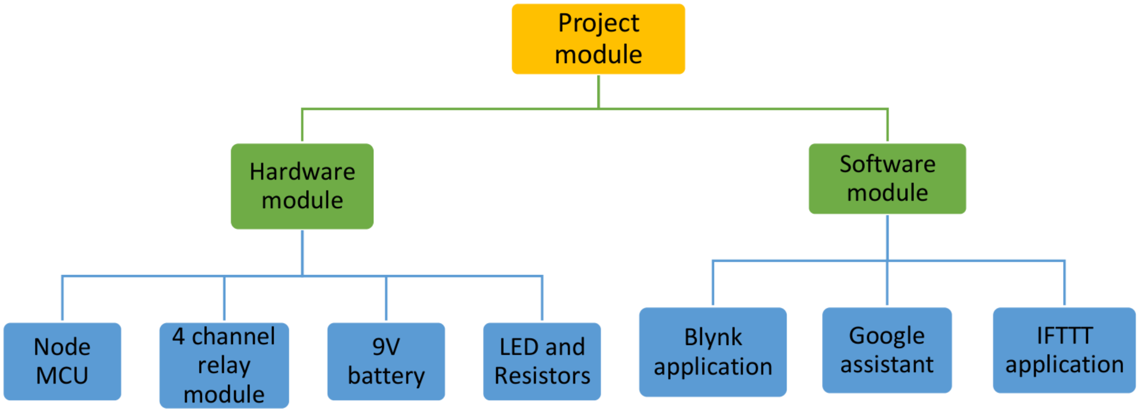


Figure 2.3: Layout of project module

2.2.1. Brief Description

The Active Wide Band Reject Filter is a highly efficient and versatile electronic circuit designed to suppress a specific range of unwanted frequencies while allowing all other frequencies to pass through with minimal distortion. This filter is essential in applications where selective frequency elimination is required, such as noise reduction, interference rejection, and signal processing in audio and communication systems. It achieves this unique functionality by combining the properties of a Low Pass Filter (LPF) and a High Pass Filter (HPF), enhanced by the precision of an active summing amplifier.

The LPF ensures that low frequencies below a specific cutoff point pass through, while the HPF allows higher frequencies above another cutoff point to pass. By carefully designing the cutoff frequencies of these filters, a rejection band—or "notch"—is created, effectively eliminating frequencies within this range while preserving the integrity of the remaining signal. The summing amplifier plays a critical role by combining the outputs of the LPF and HPF, amplifying the desired signals while ensuring precise attenuation of the rejected band.

What sets the Active Wide Band Reject Filter apart from passive alternatives is its active design, which utilizes operational amplifiers (op-amps) to achieve superior performance. These active components not only provide greater precision in filtering but also allow signal amplification, ensuring there is no loss of strength in the output signal. This makes the filter especially suitable for high-performance applications, where accuracy and reliability are critical.

Moreover, the filter's design is highly adaptable, allowing for easy adjustments to the cutoff frequencies to cater to various applications. From removing background noise in audio systems to eliminating unwanted harmonics in power circuits and mitigating interference in wireless communication, the Active Wide Band Reject Filter is a key solution in modern electronics. Its combination of flexibility, efficiency, and precision makes it an indispensable tool for engineers and professionals seeking optimal signal processing in their systems.

2.2.2. Block Diagram of the Proposed System

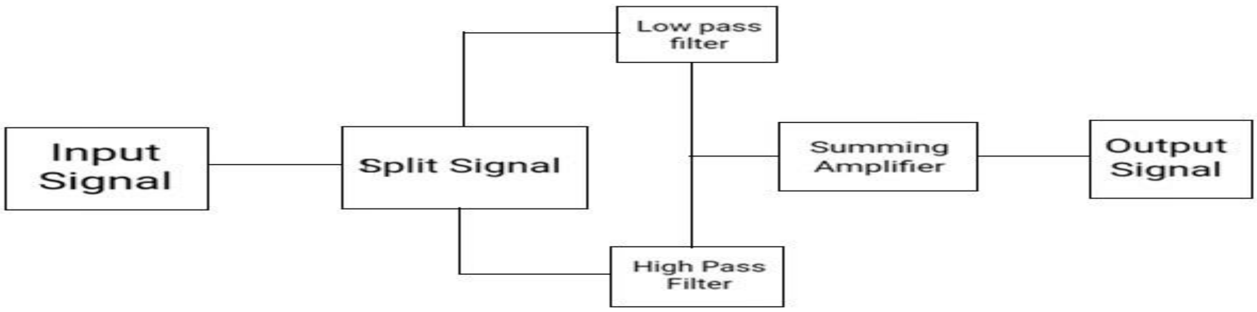


Fig.2.4: Block Diagram Of Active Wide Band Reject Filter.

2.2.3. Working of the system

Working System of an Active Wide Band Reject Filter

An active wide band reject filter is designed to effectively attenuate a broad range of undesirable frequencies while allowing the desired frequencies to pass through. This type of filter leverages both passive and active components to achieve the desired filtering characteristics. Here's a detailed breakdown of how it works:

1. Input Signal (Vin):

The process begins with the input signal VIN entering the filter system. This signal typically contains a mix of desired and unwanted frequencies. The objective is to filter out the unwanted frequencies within a specific broad range.

2. Low Pass Filter (LPF) Stage:

The input signal is first directed to a Low Pass Filter (LPF). The LPF is designed to allow frequencies below a certain cutoff frequency to pass through while attenuating higher frequencies. This stage defines the lower boundary of the frequency range that will be rejected.

Operation: The LPF typically consists of resistors and capacitors, which create a frequency-dependent impedance. Frequencies below the cutoff experience low impedance and pass through, while higher frequencies experience high impedance and are attenuated.

Output of LPF: The result is a signal that contains frequencies primarily below the cutoff frequency, with higher frequencies significantly attenuated.

3. High Pass Filter (HPF) Stage:

Simultaneously, the same input signal is also directed to a High Pass Filter (HPF). The HPF is designed to allow frequencies above a certain cutoff frequency to pass through while attenuating lower frequencies. This stage defines the upper boundary of the frequency range that will be rejected.

Operation: The HPF also uses resistors and capacitors, but in a configuration that allows high frequencies to pass while attenuating low frequencies. Capacitors block low-frequency signals, while high-frequency signals pass through.

Output of HPF: The result is a signal that contains frequencies primarily above the cutoff frequency, with lower frequencies significantly attenuated.

4. Summing Amplifier (Adder):

The outputs of both the LPF and HPF stages are then fed into a summing amplifier. The summing amplifier is an active component, usually implemented using an operational amplifier (op-amp). It combines the two filtered signals to achieve the desired wide band reject effect.

Operation of the Summing Amplifier: The summing amplifier takes the outputs from the LPF and HPF, which contain only the low and high frequencies, respectively. By adding these two signals together, the summing amplifier reconstructs the original signal but without the frequencies that fall within the rejected band.

Advantages: The use of an active component like an op-amp in the summing amplifier ensures that the combined signal is amplified to a suitable level, maintaining the overall signal strength.

5. Output Signal (Vout):

The final output signal $VOUT$ from the summing amplifier is a clean signal with the broad range of unwanted frequencies effectively attenuated. The frequencies outside the defined stop band are preserved, ensuring the integrity of the desired signal components.

6.Result: The output signal is free from the broad range of unwanted frequencies, providing a clearer and more accurate signal. This is particularly important in applications where signal quality and precision are critical.

Chapter 03: Hardware and Software Requirements

3.1. Operational Amplifier

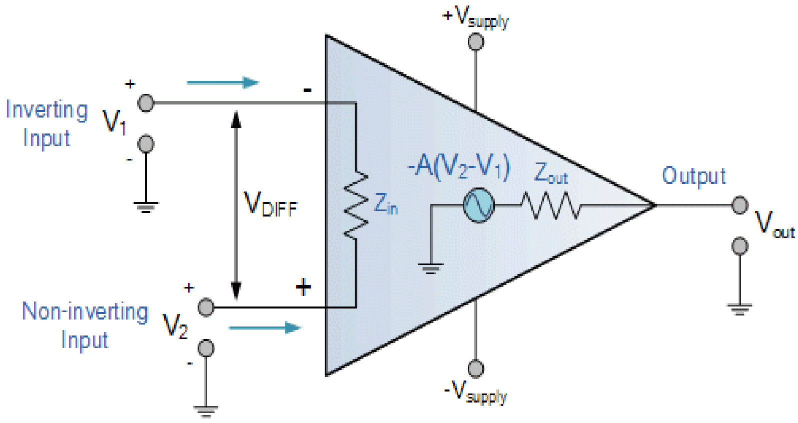


Fig .3.1: Equivalent Op-amp.

Operational Amplifiers, or **Op-amps** as they are more commonly called, are one of the basic building blocks of Analogue Electronic Circuits.

Operational Amplifiers are linear devices that have all the properties required for nearly ideal DC amplification and are therefore used extensively in signal conditioning, filtering or to perform mathematical operations such as add, subtract, integration and differentiation.

An **Operational Amplifier**, or op-amp for short, is fundamentally a voltage amplifying device designed to be used with external feedback components such as resistors and capacitors between its output and input terminals. These feedback components determine the resulting function or "operation" of the amplifier and by virtue of the different feedback configurations whether resistive, capacitive or both, the amplifier can perform a variety of different operations, giving rise to its name of "Operational Amplifier".

An **Operational Amplifiers** is a three-terminal device that consists of two high-impedance inputs. One of the inputs is called the **Inverting Input**, marked with a negative or "minus" sign, (–). The other input is called the **Non-inverting Input**, marked with a positive or "plus" sign (+).

A third terminal represents the operational amplifiers output port which can both sink and source either a voltage or a current. In a linear operational amplifier, the output signal is the amplification factor, known as the amplifier gain (A) multiplied by the value of the input signal, and depending on the nature of these input and output signals, there can be four different classifications of operational amplifier gain.

- Voltage – Voltage "in" and Voltage "out"
- Current – Current "in" and Current "out"
- Transconductance – Voltage "in" and Current "out"
- Trans-resistance – Current "in" and Voltage "out"

The output voltage signal from an Operational Amplifier is the difference between the signals being applied to its two individual inputs. In other words, an op-amps output signal is the difference between the two input signals as the input stage of an Operational Amplifier is in fact a differential amplifier as shown below.

3.1.1. Differential Amplifier

The circuit below shows a generalized form of a differential amplifier with two inputs marked V1 and V2. The two identical transistors TR1 and TR2 are both biased at the same operating point with their emitters connected together and returned to the common rail, - Vee by way of resistor Re.

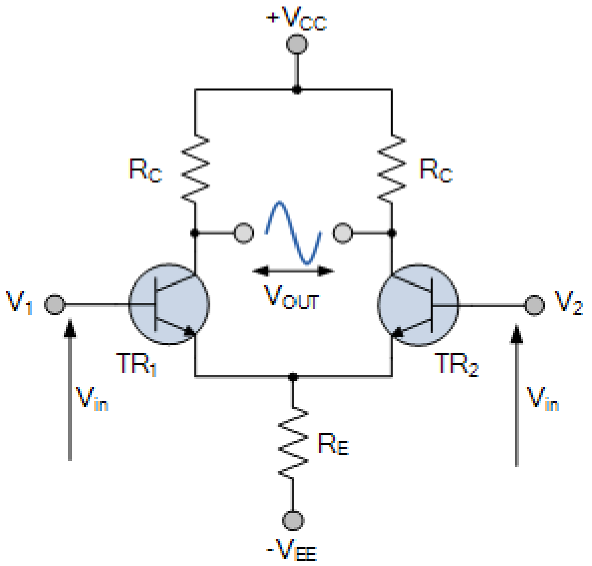


Fig.3.2: Equivalent Differential Amplifier

The circuit operates from a dual supply +Vcc and -Vee which ensures a constant supply. The voltage that appears at the output, Vout of the amplifier, is the difference between the two input signals as the two base inputs are in *anti-phase* with each other.

So as the forward bias of transistor, TR1 is increased, the forward bias of transistor TR2 is reduced and vice versa. Then if the two transistors are perfectly matched, the current flowing through the common emitter resistor, Re will remain constant.

Like the input signal, the output signal is also balanced and since the collector voltages either swing in opposite directions (anti-phase) or in the same direction (in-phase) the output voltage signal, taken from between the two collectors is, assuming a perfectly balanced circuit the zero difference between the two collector voltages.

This is known as the *Common Mode of Operation* with the **common mode gain** of the amplifier being the output gain when the input is zero.

Operational Amplifiers also have one output (although there are ones with an additional differential output) of low impedance that is referenced to a common ground terminal and it should ignore any common mode signals that is, if an identical signal is applied to both the inverting and non-inverting inputs there should no change to the output.

However, in real amplifiers, there is always some variation, and the ratio of the change to the output voltage with regards to the change in the common mode input voltage is called the **Common Mode Rejection Ratio** or **CMRR** for short.

Operational Amplifiers on their own have a very high open loop DC gain and by applying some form of **Negative Feedback** we can produce an operational amplifier circuit that has a very precise gain characteristic that is dependent only on the feedback used. Note that the term "open loop" means that there are no feedback components used around the amplifier so the feedback path or loop is open.

An operational amplifier only responds to the difference between the voltages on its two input terminals, known commonly as the "*Differential Input Voltage*" and not to their common potential. Then if the same voltage potential is applied to both terminals the resultant output will be zero. An Operational Amplifiers gain is commonly known as the **Open Loop Differential Gain** and is given the symbol (A_o).

3.1.2. Equivalent Circuit of an Ideal Operational Amplifier

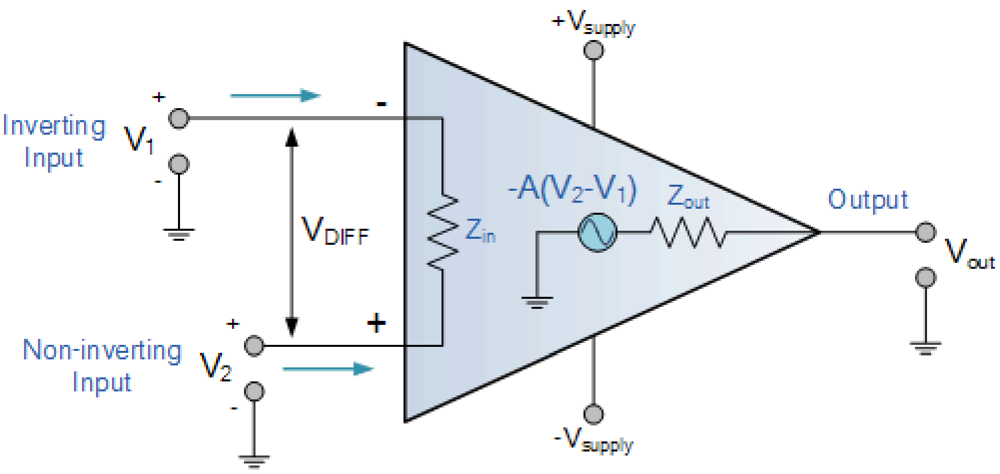


Fig.3.3:Equivalent Op-Amp

3.1.3. Op-amp Parameter and Idealized Characteristic

Open Loop Gain, (Avo)

Infinite – The main function of an operational amplifier is to amplify the input signal, and the more open loop gain it has the better. Open-loop gain is the gain of the op-amp without positive or negative feedback and for such an amplifier the gain will be infinite but typical real values range from about 20,000 to 200,000.

Input impedance, (ZIN)

Infinite – Input impedance is the ratio of input voltage to input current and is assumed to be infinite to prevent any current flowing from the source supply into the amplifiers input circuitry (IIN = 0). Real op-amps have input leakage currents from a few pico-amps to a few milli-amps.

Output impedance, (ZOUT)

Zero – The output impedance of the ideal operational amplifier is assumed to be zero acting as a perfect internal voltage source with no internal resistance so that it can supply as much current as necessary to the load. This internal resistance is effectively in series with the load thereby reducing the output voltage available to the load. Real op-amps have output impedances in the 100-20kΩ range.

Bandwidth, (BW)

Infinite – An ideal operational amplifier has an infinite frequency response and can amplify any frequency signal from DC to the highest AC frequencies, so it is therefore assumed to have an infinite bandwidth. With real op-amps, the bandwidth is limited by the Gain-Bandwidth product (GB), which is equal to the frequency where the amplifiers gain becomes unity.

Offset Voltage, (V_{IO})

Zero – The amplifiers output will be zero when the voltage difference between the inverting and the non-inverting inputs is zero, the same or when both inputs are grounded. Real op-amps have some output offset voltage.

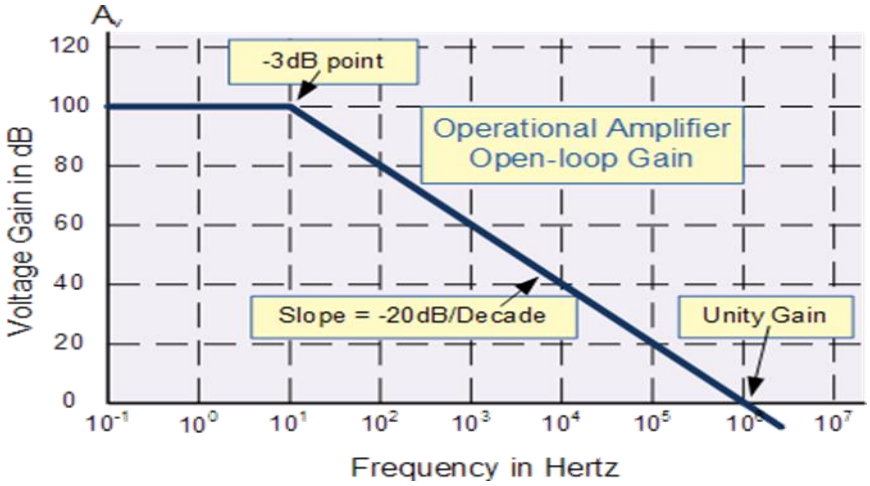
From these "idealized" characteristics above, we can see that the input resistance is infinite, so **no current flows into either input terminal** (the "current rule") and that the **differential input offset voltage is zero** (the "voltage rule"). It is important to remember these two properties as they will help us understand the workings of the **Operational Amplifier** with regard to the analysis and design of op-amp circuits.

However, real **Operational Amplifiers** such as the commonly available **uA741**, for example, do not have infinite gain or bandwidth but have a typical "Open Loop Gain" which is defined as the amplifiers output amplification without any external feedback signals connected to it and for a typical operational amplifier is about 100dB at DC (zero Hz). This output gain decreases linearly with frequency down to "Unity Gain" or 1, at about 1MHz and this is shown in the following open-loop gain response curve.

3.2. Open-loop Frequency Response Curve

From this frequency response curve, we can see that the product of the gain against frequency is constant at any point along the curve. Also, the unity gain (0dB) frequency also determines the gain of the amplifier at any point along the curve. This constant is generally known as the **Gain Bandwidth Product** or **GBP**. Therefore:

GBP = Gain x Bandwidth = A x BW



For example, from the graph above the gain of the amplifier at 100kHz is given as 20dB or 10, then the gain bandwidth product is calculated as:

GBP = A x BW = 10 x 100,000Hz = 1,000,000.

Similarly, the operational amplifiers gain at 1kHz = 60dB or 1000, therefore the GBP is given as:

GBP = A x BW = 1,000 x 1,000Hz = 1,000,000.

The **Voltage Gain** (Av) of the operational amplifier can be found using the following formula:

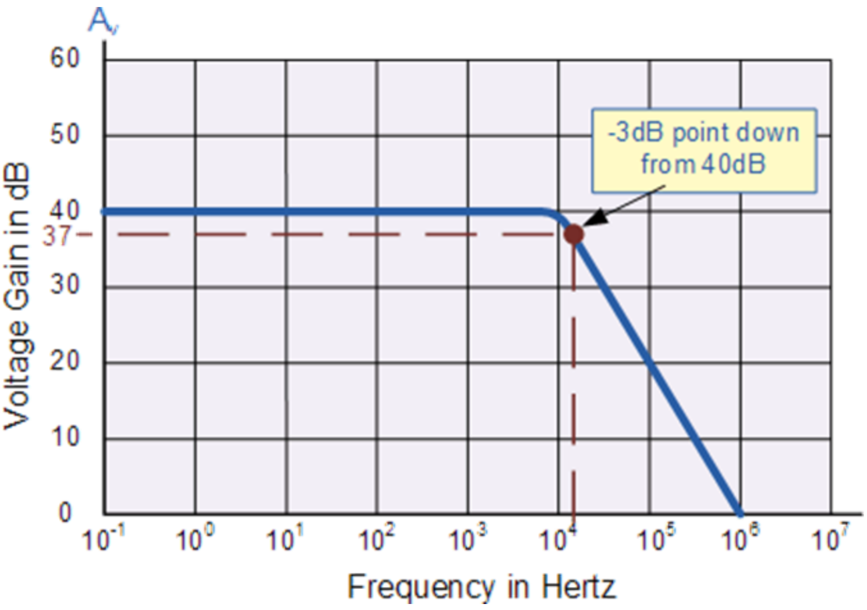
$$\text{Voltage Gain, (A)} = \frac{V_{out}}{V_{in}}$$

and in **Decibels** or (dB) is given as:

$$20\log(A) \text{ or } 20\log\frac{V_{out}}{V_{in}} \textit{ in dB}$$

3.3. An Operational Amplifiers Bandwidth

The operational amplifier bandwidth is the frequency range over which the voltage gain of the amplifier is above **70.7%** or **-3dB** (where 0dB is the maximum) of its maximum output value as shown below.



Here we have used the 40dB line as an example. The -3dB or 70.7% of Vmax down point from the frequency response curve is given as **37dB**. Taking a line across until it intersects with the main GBP curve gives us a frequency point just above the 10kHz line at about 12 to 15kHz. We can now calculate this more accurately as we already know the GBP of the amplifier, in this particular case 1MHz.

3.4. Ideal characters of an Op-Amp:

Open Loop gain

Open loop gain is the gain of the Op Amp without positive or negative feedback. An ideal OP Amp should have an infinite open loop gain but typically it ranges between 20,000 and 2, 00000.

Input impedance

It is the ratio of the input voltage to the input current. It should be infinite without any leakage of current from the supply to the inputs. But there will be a few Pico ampere current leakages in most Op-Amps.

Output impedance

The ideal Op Amp should have zero output impedance without any internal resistance. So that it can supply full current to the load connected to the output.

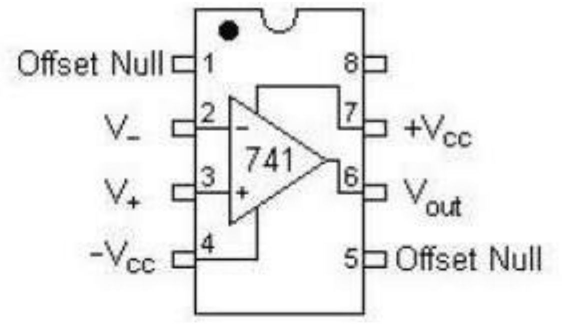
Band-width

The ideal Op Amp should have an infinite frequency response so that it can amplify any frequency from DC signals to the highest AC frequencies. But most Op Amps have limited bandwidth.

Offset

The output of the Op Amp should be zero when the voltage difference between the inputs is zero. But in most Op Amps, the output will not be zero when off but there will be a minute voltage from it.

3.5. OPAMP Pin Configuration:



In a typical Op-Amp there will be 8 pins.

These are

Pin1 – Offset Null

Pin2 – Inverting input INV

Pin3 – Non-inverting input Non-INV

Pin4 – Ground- Negative supply

Pin5 – Offset Null

Pin6 – Output

Pin7 – Positive supply

Pin8 – Strobe

Chapter 04: Project Development & Testing Aspects

4.1. Design Statement:

Design a wide band reject filter having f_H =400Hz and fL=2kHz with gain of 2 for each case. From frequency response curve find out lower cutoff frequency fL , higher cut off frequency fH , band reject width BRW, centre frequency fc and Quality factor Q.

Circuit Diagram:

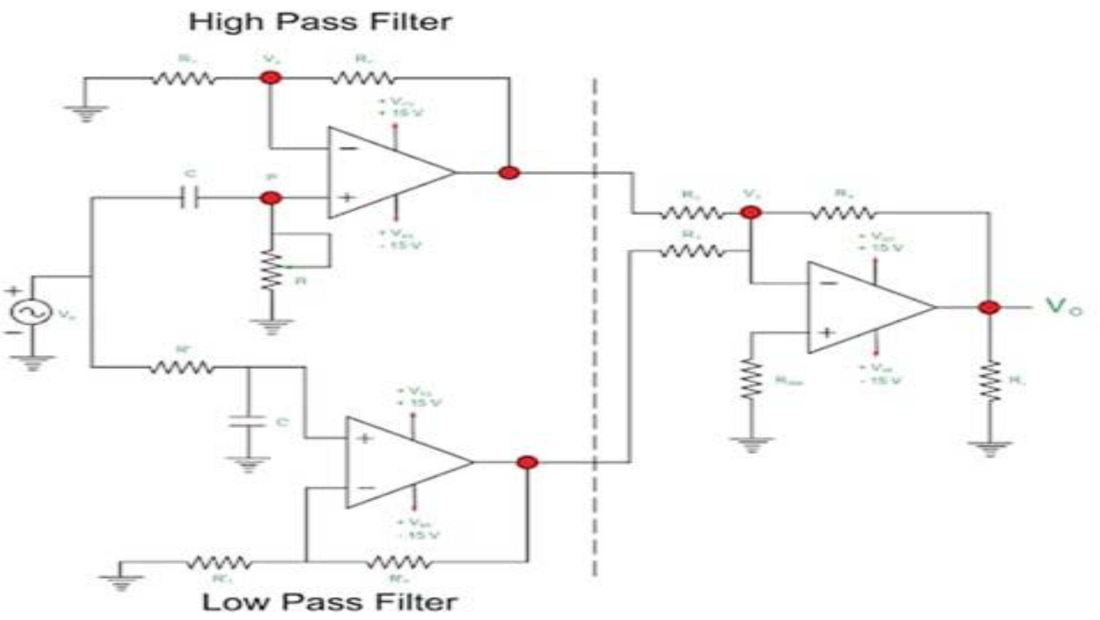


Fig.4.1: Wide Band Reject Filter

4.2. Design Procedure

Step-1:

Calculate Q factor

If Quality factor Q<10 then the filter is wide band reject filter on the other hand Quality factor Q>10 then the filter is narrow band reject filter.

Data Given:

Lower cut off frequency fL=400Hz

Higher cut off frequency fH=2kHz

Centre Frequecy(fC)= (√fHfL) = (400x2000)^1/2 =894.42Hz

Band Rejection Width BRW= fH- fL=2000-400=1600Hz

Quality Factor Q=(fc/BW)=894.42/1600=0.559

Though the quality factor Q=0.559, so it is a wide band reject filter.

Step- 2:

Calculate Ri, Rf, R and C of low pass filter

Lower cut off frequency fH = 400Hz and Pass band gain Av1=Over gain Av/2=4/2=2

Av=1+(Rf/Ri)

Assume, R12=10kΩ, so R1=10kΩ

R12= (1/2π fLC1)

Assume,

C=0.01x10^-6F,So R=39.8 kΩ

Step-3:

Calculate Ri,Rf,R and C of high pass filter

However cut off frequency fL = 2KHz and Pass band gain Av1=Over gain Av/2=4/2=2

Av=1+(Rf/Ri)

Assume, R12=10kΩ, so R1=10kΩ

R12= (1/2π fLC1)

Assume,

C=0.01x10^-6F,So R=7.96kΩ

Step-4:

Calculate R2,R3 and R4 of Summing amplifier

Assume the gain of summing amplifier = 1

Therefore ,

R2= R3=R4 = 10kΩ

Finally the value of

ROM = R2||R3||R4=3.3 kΩ

4.3. Circuit Diagram:

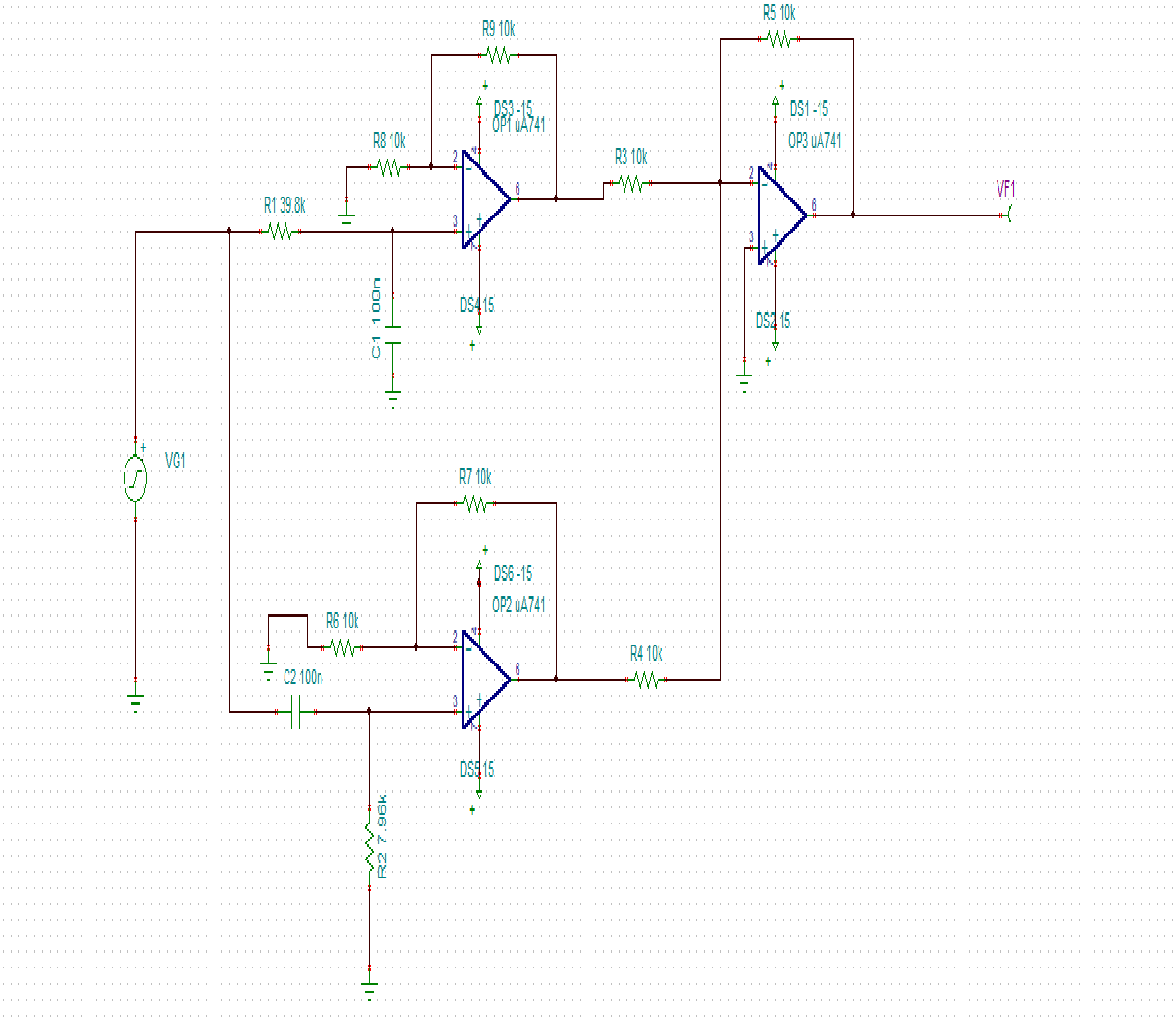


Fig.4.2: Active Wide Band Reject Filter

4.4. Test Results:

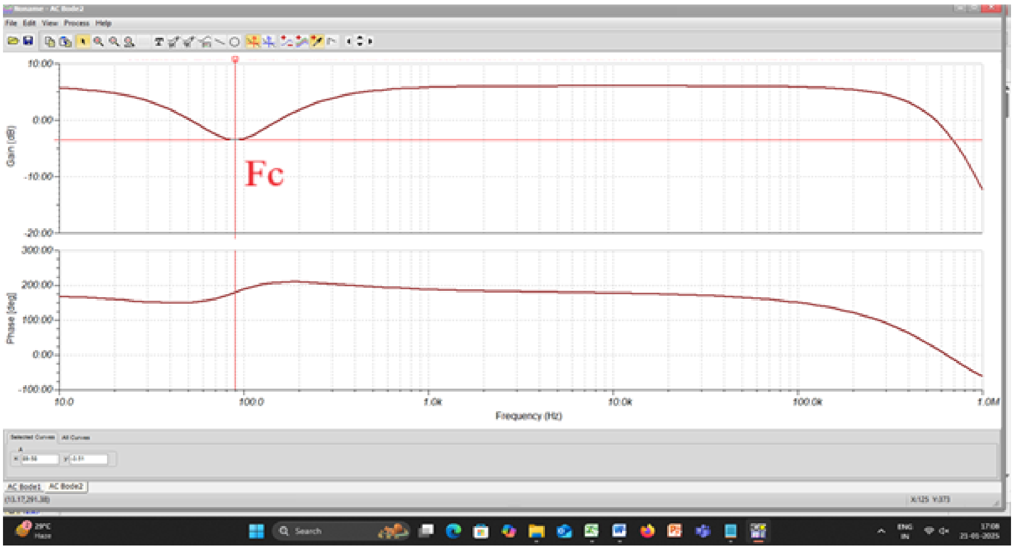


Fig 4.3: Frequency Response Of Active Wide Band Reject Filter

4.5. Interpretation Of Test Results:

This graph represents the Bode plot for an Active Wide Band Reject Filter . A Wide Band Reject Filter is designed to attenuate frequencies within a specific range while allowing frequencies outside this range to pass.

Components of the Bode Plot:

1. Gain Plot (Top Graph):

The Y-axis represents gain in decibels (dB), and the X-axis represents frequency (Hz) on a logarithmic scale.

At low frequencies, the gain is high (close to 0 dB).

In the mid-frequency range (around the center frequency), the gain decreases significantly, indicating rejection of these frequencies.

At high frequencies, the gain returns to its original high value.

This behavior shows the band-reject characteristic where the filter blocks a specific band of frequencies.

2. Phase Plot (Bottom Graph):

The Y-axis represents phase shift in degrees, and the X-axis represents frequency (Hz).

At low and high frequencies, the phase is relatively constant.

In the transition regions around the rejected band, the phase shifts occur.

The phase curve typically shows a transition that corresponds to the center frequency where rejection occurs.

Key Observations:

Notch Frequency (Center Frequency):

The center frequency of the rejection band is where the gain dips significantly. This is the main characteristic of the filter.

Passbands:

Frequencies lower and higher than the rejected band (outside the attenuation range) are passed with minimal attenuation.

Chapter 05: Conclusion & Future Scope

5.1. Conclusion:

The active wide band reject filter is a fundamental circuit designed to attenuate a broad range of unwanted frequencies while allowing frequencies outside this range to pass with minimal attenuation. Its versatility makes it a critical component in various applications, such as communication systems, audio signal processing, and electromagnetic interference suppression.

Unlike narrowband filters, the wide band reject filter eliminates an extensive frequency range, making it particularly useful for rejecting noise or interference that spans a significant bandwidth. By utilizing active components like operational amplifiers, this filter achieves improved performance, including higher input impedance, adjustable gain, and greater flexibility in design. The filter's behavior is primarily determined by the values of resistors and capacitors, which control the center frequency and the bandwidth of the rejected range.

A well-implemented wide band reject filter demonstrates efficient attenuation, stability, and adaptability to different requirements. Its active design allows for compact implementation and potential signal amplification alongside filtering, setting it apart from passive alternatives.

5.2. Limitations:

Active wide band reject filters, while useful, come with several limitations:

Complexity and Cost: Active filters typically require multiple components, including operational amplifiers, resistors, and capacitors. This increases the complexity of the circuit design and can drive up costs, especially for high-performance applications.

Power Consumption: Active filters need a power supply for the operational amplifiers or other active components. This can be a significant disadvantage in battery-powered or portable devices where power efficiency is crucial.

Frequency Limitations: Active filters are generally limited in their frequency range by the bandwidth and speed of the operational amplifiers. This can restrict their use in high-frequency applications, where passive filters might be more suitable.

Temperature Sensitivity: The performance of active filters can be affected by temperature variations, leading to drift in the filter characteristics. This can be problematic in environments where temperature stability cannot be maintained.

Non-Ideal Components: Real-world components, such as resistors and capacitors, have tolerances and imperfections that can affect the precision of the filter. This can lead to deviations from the expected filter performance.

Signal Distortion: At high signal levels, active filters can introduce distortion due to the nonlinear behavior of the active components, particularly the operational amplifiers. This can degrade the quality of the filtered signal.

Despite these limitations, active wide band reject filters remain valuable tools in many applications due to their versatility and ease of tuning.

5.3. Further Enhancement and Future Scope:

Further Enhancement:

Better Materials: Using high-quality components like precise resistors and capacitors can make filters more stable and reliable, even in different temperatures.

Smaller Size: Miniaturizing the filter is crucial for portable devices. By making components smaller, filters can fit into gadgets like smartphones and smartwatches without losing functionality.

Hybrid Systems: Combining analog filters with digital signal processing (DSP) can enhance performance. Analog filters offer real-time processing, while DSP provides flexible and accurate filtering.

Adaptive Filters: Filters that automatically adjust to changing signals can be more effective. For example, in communication systems, adaptive filters can maintain optimal performance as signals vary.

Improved Cooling: Better cooling methods, such as using heat sinks or advanced materials, help keep filters within safe temperature ranges, ensuring consistent performance and longer component life.

Low-Noise Design: Reducing noise from active components improves signal quality. Using low-noise parts and optimizing the circuit layout can minimize interference, crucial for high-fidelity audio and sensitive communication systems.

Future Scope:

1. 5G and Advanced Communication:

As 5G and future communication systems operate on crowded frequency bands, wide band reject filters will help eliminate interference from unwanted signals, ensuring clearer and faster data transmission.

2. Medical Devices:

In biomedical applications, like ECG and EEG machines or wearable health devices, these filters can remove noise (e.g., power line interference) for accurate signal detection and processing.

3. IoT and Smart Devices:

With the rise of IoT devices, which often operate in shared frequency environments, these filters will be crucial to suppress interference, making devices more reliable and efficient.

4. Aerospace and Space Technology:

Space and aerospace systems require high precision in communication. Wide band reject filters will help eliminate broad noise ranges to ensure accurate and stable signals in harsh environments.

5. Quantum Computing:

Quantum systems are highly sensitive to noise. These filters can ensure precise signal processing by removing broad-frequency noise that could disrupt operations.

6. Energy-Efficient and Compact Devices:

As electronics become smaller and more power-efficient, there is a demand for compact and eco-friendly filters. Future filters will focus on low power consumption and miniaturization for portable and sustainable devices

References

[1] B.WILLIAMS &FROD. J. TAYLOR, “ ELECTRONIC FILTER DESIGN”, MC.GRAW HILL PUBLICATION FOURTH EDITION, 2007.

[2] STEFANIEWIDOMSKI , “ FILTER HANDBOOK”,HEINEMANNNEWNES PUBLICATION, 2013.

[3] FLOYD & BUCHLA, “FUNDAMENTALS OF ANALOG CIRCUIT”, PEARSON PUBLICATION, SECOND EDITION,2002

Appendix 01

A01.1. Data Sheet I

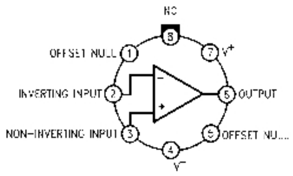
PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
Input offset voltage		$R_S \leq 10\ k\Omega$	$T_A = 25°C$		1	5	mV
			$T_{AMIN} \leq T_A \leq T_{AMAX}$			6	mV
Input offset voltage adjustment range		$T_A = 25°C$, $V_S = \pm 20\ V$			±15		mV
Input offset current		$T_A = 25°C$			20	200	nA
		$T_{AMIN} \leq T_A \leq T_{AMAX}$			85	500	
Input bias current		$T_A = 25°C$			80	500	nA
		$T_{AMIN} \leq T_A \leq T_{AMAX}$				1.5	µA
Input resistance		$T_A = 25°C$, $V_S = \pm 20\ V$		0.3	2		MΩ
Input voltage range		$T_{AMIN} \leq T_A \leq T_{AMAX}$		±12	±13		V
Large signal voltage gain		$V_S = \pm 15\ V$, $V_O = \pm 10\ V$, $R_L \geq 2\ k\Omega$	$T_A = 25°C$	50	200		V/mV
			$T_{AMIN} \leq T_A \leq T_{AMAX}$	25			
Output voltage swing		$V_S = \pm 15\ V$	$R_L \geq 10\ k\Omega$	±12	±14		V
			$R_L \geq 2\ k\Omega$	±10	±13		
Output short circuit current		$T_A = 25°C$			25		mA
Common-mode rejection ratio		$R_S \leq 10\ \Omega$, $V_{CM} = \pm 12\ V$, $T_{AMIN} \leq T_A \leq T_{AMAX}$		80	95		dB
Supply voltage rejection ratio		$V_S = \pm 20\ V$ to $V_S = \pm 5\ V$, $R_S \leq 10\ \Omega$, $T_{AMIN} \leq T_A \leq T_{AMAX}$		86	96		dB
Transient response	Rise time	$T_A = 25°C$, unity gain			0.3		µs
	Overshoot				5%		
Slew rate		$T_A = 25°C$, unity gain			0.5		V/µs
Supply current		$T_A = 25°C$			1.7	2.8	mA
Power consumption		$V_S = \pm 15\ V$	$T_A = 25°C$		50	85	mW
			$T_A = T_{AMIN}$		60	100	
			$T_A = T_{AMAX}$		45	75	

(1) Unless otherwise specified, these specifications apply for $V_S = \pm 15\ V$, $-55°C \leq T_A \leq +125°C$ (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to $0°C \leq T_A \leq +70°C$.

Fig : A [Specification table of an op-amp (LM147)]

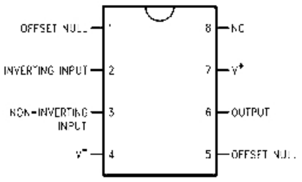
A01.2. Data Sheet II

LMC Package
8-Pin TO-99
Top View



LM741H is available per JM38510/10101

NAB Package
8-Pin CDIP or PDIP
Top View



Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
INVERTING INPUT	2	I	Inverting signal input
NC	8	N/A	No Connect, should be left floating
NONINVERTING INPUT	3	I	Noninverting signal input
OFFSET NULL	1, 5	I	Offset null pin used to eliminate the offset voltage and balance the input voltages.
OFFSET NULL			
OUTPUT	6	O	Amplified signal output
V+	7	I	Positive supply voltage
V–	4	I	Negative supply voltage

Fig : B [Pin Function table of an op-amp (LM147)]