Fundamental and Applications of Operational Amplifiers

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Abstract:

"Fundamental and Applications of Operational Amplifiers" explores the complex world of operational amplifiers or op-amps and looks at the theoretical foundations as well as real-world uses for these crucial electrical components. Written as an all-inclusive reference for electronics novices and experts alike, this book provides a complete overview of op-amps, encompassing their basic principles, sophisticated ideas, and wide range of applications in many fields.

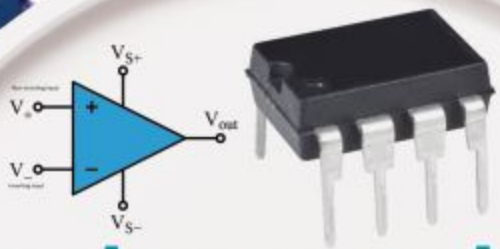
The book begins by providing a solid foundation in the basic principles of operational amplifiers, elucidating topics such as ideal op-amps characteristics, input-output configurations and basic circuit analysis techniques. Through clear explanations and illustrative examples, readers gain a deep understanding of op-amp behaviour and operation.

Building upon this foundation, the book progresses to explore more advanced topics, including frequency response, stability analysis and noise considerations. By delving into these intricacies, readers are equipped with the knowledge to design and analyzed op-amp circuit with precision and efficiency.

Moreover, "Fundamental and Applications of Operational Amplifiers" goes beyond theoretical discussions to present a plethora of real-world applications. From signal conditioning and instrumentation amplifiers to active filters and oscillators, the book showcases how op-amps are utilized in diverse electronic circuits across industries.

Whether you are a student, hobbyist, or seasoned engineer, "Fundamental and Applications of Operational Amplifiers" serves as an invaluable resource for mastering the principles and applications of these ubiquitous electronic components. With its comprehensive coverage, practical insights and illustrative examples, this book empowers readers to harness the full potential of operational amplifiers in their electronic designs and projects.

Keywords: Applications of Operational Amplifiers, solid foundation,electronic circuits



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PREFACE

Welcome to "Fundamentals and Applications of Operational Amplifiers." This book aims to serve as a comprehensive guide to understanding the theory, principles, and practical applications of operational amplifiers (op-amps). Whether you are a student delving into the world of electronics, an engineer seeking a refresher, or a hobbyist eager to explore new projects, this book is designed to provide you with the knowledge and tools necessary to master the fundamentals and harness the potential of these ubiquitous devices.

Operational amplifiers are fundamental building blocks in modern electronics, playing a crucial role in a wide range of applications, from simple signal conditioning circuits to complex control systems. Their versatility, high gain, and differential input make them indispensable in various fields, including audio processing, instrumentation, telecommunications, and control engineering.

In this book, we begin by laying a solid foundation, starting with the basic principles of operation, characteristics, and idealized behavior of op-amps. We then progress to explore more advanced topics such as frequency response, feedback configurations, stability analysis, and noise considerations. Through clear explanations, illustrative examples, and practical insights, we aim to demystify complex concepts and empower readers to analyze and design op-amp circuits with confidence.

One of the distinguishing features of this book is its emphasis on real-world applications. We provide numerous examples and case studies that demonstrate how op-amps are used in practical scenarios, from designing active filters and amplifiers to implementing signal processing algorithms and control systems. Additionally, we discuss the latest advancements in op-amp technology, including low-power designs, rail-to-rail operation and integrated solutions for emerging applications.

Whether you're a novice or an experienced practitioner, we hope that this book will serve as a valuable resource in your journey to mastering the theory and applications of operational amplifiers. We encourage you to engage with the material actively, work through the exercises, and explore the suggested projects to deepen your understanding and enhance your skills.

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We would like to express our gratitude to all those who have contributed to this book, whether directly or indirectly. Special thanks to our colleagues, students, and reviewers for their valuable feedback and insights. We also extend our appreciation to the pioneers and researchers whose work has paved the way for the advancements in op-amp technology.

Finally, we dedicate this book to the curious minds, the passionate learners, and the innovators who continue to push the boundaries of what is possible with operational amplifiers. May this book inspire you to explore new ideas, tackle new challenges, and make meaningful contributions to the world of electronics.

Thank you for joining us on this journey.

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1

INTRODUCTION OF OPERATIONAL AMPLIFIER

1.1 INTRODUCTION

An operational amplifier, often abbreviated as op-amp, is a type of analog electronic component that is widely used in electronic circuits. This book is a fundamental book that uses basic knowledge in electronics especially in op-amp. However, the reference and revision of the theoretical basis was carried out using the books at [1-6]. It is a high-gain, voltage-amplifying device with two input terminals (inverting and non-inverting) and one output terminal. The symbol for an operational amplifier is usually depicted as a triangle, with the inputs marked as "+" and "-", and the output at the apex of the triangle.

Operational amplifiers are used in a wide range of electronic applications, including audio amplifiers, signal conditioning, filters, oscillators, voltage regulators, and many more. They are a fundamental building block in analog electronics and are often employed in conjunction with other components to perform various tasks within electronic circuits. Op-amps are available in integrated circuit (IC) form, making them easy to use in various applications. Op-amps are linear integrated circuits (ICs). Linear integrated circuits are devices consisting of many transistors, diodes, resistors, and capacitors fabricated in a single tiny chip of semi conductive material and packaged in a single case to form a functional circuit.

Figure 1.1 shows a block diagram of an op-amp. A typical op-amp is made up of 3 types of amplifier circuit: a differential amplifier (input stage), a voltage amplifier and a push-pull amplifier (output stage). Op-amps are mostly direct coupled devices connected in cascaded form; hence there will be a slight delay between the input and output signals.

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2

LINEAR OP-AMP CIRCUITS

2.1 INTRODUCTION

A linear op-amp circuit provide the output of a linear op-amp circuit has the same shape as the input signal. Linear op-amp circuits include inverting amplifiers, non-inverting amplifiers, differential amplifiers, instrumentation amplifiers, etc.

2.2 INVERTING AMPLIFIER

For inverting amplifier, the input signal V_i is applied to the negative terminal as shown in Figure 2.1.

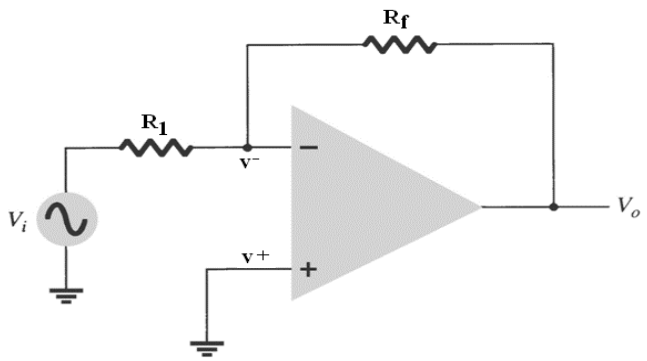

Figure 2.1: Inverting Amplifier

Analysis is done using the ideal model of the op-amp and Superposition Theorem: In Superpostion theorem;

Superposition Theorem Steps:

Step 1: Turn Off Independent Sources Except One:
First, consider only one independent voltage source and turn off all others. In an inverting amplifier, this means only consider either the input voltage (Vin) or the feedback voltage (Vout).

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NON-LINEAR OP-AMP APPLICATIONS

Non-linear operational amplifier (op-amp) applications involve utilizing the inherent non-linear characteristics of op-amps to perform specific functions or achieve desired behaviour.

3.1 COMPARATOR

A comparator is a specific application of an operational amplifier (op-amp) that compares two voltage inputs and produces a digital output indicating which input is greater op-amps can be configured as voltage comparators to compare two input voltages. The output is typically in a high or low state, depending on the relative magnitudes of the input voltages. This is widely used in applications like zero-crossing detectors and window comparators.

The threshold level is determined by applying Vth or reference voltage (Vref) to one of the inputs. Op-amp will then compare the input signal with the reference voltage. The output of the op-amp will be either positive or negative saturation value (± Vout(max) = ± Vsat).

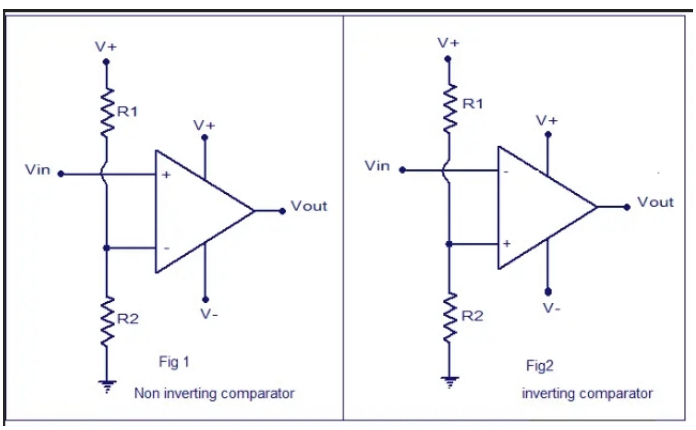

Figure 3.1: Inverting and Non-Inverting Comparator

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ACTIVE FILTERS

4.1 ACTIVE FILTERS

Active filters are electronic circuits that use active components like operational amplifiers (op-amps) along with passive components like resistors, capacitors, and inductors to filter signals. They offer several advantages over passive filters, including higher gain, better selectivity, and the ability to amplify signals. Active filters can be classified into several types based on their frequency response and filter characteristic. Passive filters use only passive components: R, C and L but does not provide voltage amplification. Active filters consist of a combination of resistor, capacitor and op-amp provides voltage amplification and signal isolation or buffering. Adding capacitors to Op-Amp circuits provide controllable cutoff frequencies. Practical limit to active filter is frequency higher than 100 kHz. Common types of filters are:

- Low-pass: pass low frequencies and reject high frequencies
- High-pass: pass high frequencies and reject low frequencies
- Band-pass: pass some range of frequencies, reject other frequencies outside that band
- Band-reject / Band-stop: reject a range of frequencies and pass all other frequencies (e.g., a special case is a notch filter)

Active filters offer the following advantages over passive filters:

- **Gain**: Active filters can provide gain, which is not possible with passive filters alone.
- **Accuracy**: Active filters have better accuracy and predictable characteristics compared to passive filters, especially at higher frequencies.
- **Tunability**: Active filters can be easily tuned or adjusted by varying component values or using variable resistors or capacitors.
- **Impedance Matching**: Active filters can provide impedance matching between the input and output circuits, which is beneficial in interfacing between different stages of a system.

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POWER AMPLIFIER

5.1 POWER AMPLIFIER CLASSIFICATIONS

In general, the purpose of an amplifier is to take an input signal and make it stronger (or in more technically correct terms, increase its *amplitude*). A power amplifier is an electronic device designed to increase the magnitude of a signal to a level suitable for driving the load, such as speakers, motors, or antennas. It takes a low-power input signal and delivers a higher power output signal without significantly distorting the waveform. Power amplifiers are crucial components in audio systems, RF transmitters, motor control circuits, and many other applications where high-power signals are required.

Basic of a power amplifier:

a. **Input Stage**: The input stage of a power amplifier typically consists of a pre-amplifier or driver stage. This stage amplifies the weak input signal to a level suitable for the power amplification stage. It may also provide impedance matching between the signal source and the power amplifier circuit.

b. **Power Amplification Stage**: The power amplification stage is where the bulk of signal amplification occurs. It utilizes one or more active devices, such as bipolar junction transistors (BJTs), metal-oxide-semiconductor field-effect transistors (MOSFETs), or vacuum tubes (valves), to amplify the signal power. This stage is responsible for delivering the required output power to the load.

c. **Output Stage**: The output stage of the power amplifier is connected to the load, such as speakers or antennas. It provides the necessary current and voltage to drive the load while maintaining the amplified signal's fidelity. Output stages are often designed to have low output impedance to ensure efficient power transfer to the load.

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TIMER

6.1 555 TIMER

The 555 timer was first introduced in 1971 by Signetics Corporation and it was called "The IC Time Machine". The 555 timer comes in 2 packages, either the round metal-can called the 'T' package and the more familiar 8-pin DIP 'V' package. It has eight connections (called pins) to its plastic case, arranged as four on one side and four on the other, as shown in the pin-out diagram of Figure 6.1.

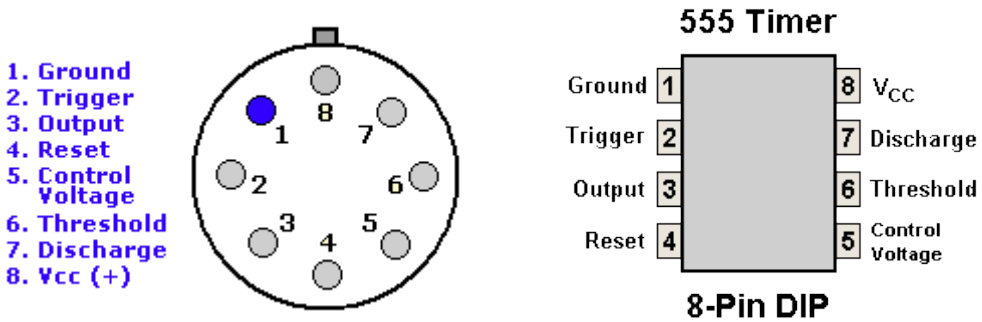

Figure 6.1: 555 Timer

A part from the standard 555 timer, there are also timer version available for low current applications or use in extreme temperatures. Generally, the 555 timer is used in applications such as: precision timing, pulse generation, sequential timing, time delay generation, and pulse width modulation. The basic circuit is either a one-shot (monostable) or an astable. Additional components may have to be connected to the 555 timer to interface the device to external circuits or devices.

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OSCILLATOR

7.1 OSCILLATOR

An oscillator is a circuit which produces a continuous, repeated, alternating waveform without any input. Oscillators basically convert unidirectional current flow from a DC source into an alternating waveform which is of the desired frequency, as decided by its circuit components. Oscillator is also known as a **sinusoidal waveform generator**. For the square-wave generator, it is known as *multivibrator*. Four conditions are absolutely required to begin and sustain the operation of an oscillator; *a power source*, *a device or components that determine the frequency of oscillation, amplification* and *positive feedback*.

7.2 HOW OSCILLATORS WORK

A mechanical or electrical device that operates on the oscillation principle, a periodic fluctuation between two objects based on changes in energy is called an oscillator. Numerous gadgets, including computers, clocks, watches, radios, and metal detectors, employ oscillators.

Typically, an oscillator's operating frequency is set by a quartz crystal. Such a crystal vibrates at a frequency determined by its thickness and the way it was cut from the original mineral rock when a direct current is applied to it. To calculate the frequency, some oscillators use combinations of resistors, capacitors, and/or inductors. However, oscillators using quartz crystals have the highest stability (constancy of frequency).

7.3 TYPES OF WAVEFORM GENERATOR

In general, oscillators fall into two main categories: relaxation oscillators and feedback oscillators. The operation of feedback oscillators, which produce sinusoidal waves broadly, is based on the idea of positive feedback.

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BIOGRAPHY

Hasliza Hassan is a lecturer in the Department of Electrical Engineering Technology, Faculty of Engineering Technology, UTHM. She obtained her Bachelor's Degree in Microelectronics Engineering from Universiti Malaysia Perlis (UniMAP) and went on to pursue her Master's degree at Universiti Kebangsaan Malaysia (UKM) in Microelectronic Engineering. Then pursued her Doctor of Philosophy (PhD) at UTM in Electrical Engineering. She is committed to contribute to the development of engineering knowledge She is committed to contribute to the development of electronic engineering and strengthen the microelectronics industry through research and teaching. Apart from excellence in engineering, Hasliza Hassan is a passionate author in sharing life experiences and thoughts through various forms of media, including creative writing. He believes that personal experience and diversity of interests can form a unique and valuable perspective of life.

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