# Analogue electronic circuits and systems

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This book is an undergraduate textbook for students of electrical and electronic engineering. It is written at an intermediate level, with second year students particularly in mind, and discusses analogue circuits used in various fields, including the interfacing of microcomputer systems. Basic electronics has been omitted so that appropriate emphasis can be given to the design of the most popular and useful circuits. Indeed, the contents of Chapters 3, 5, 7 and 8 are not covered together by any other single textbook available on the market.

The author begins with a summary of the knowledge which is prerequisite to a full study of the book. The second chapter then discusses the operation of several basic circuits which are commonly used in most integrated circuit chips. Other sections included in this chapter will acquaint the reader with different types of power amplifier circuit. The three important areas on which the book places greatest emphasis are operational amplifier circuits and their applications, data acquisition circuitry, and computer aided analysis and design. Oscillators, phase-locked loops and different types of modulation are also discussed, and particularly helpful detail is given to the important topics of phase-locked loops and analogue filter circuits. Each chapter contains a significant number of worked examples, and several carefully chosen problems at various levels of difficulty are also included to help the reader gain a better understanding of the topics under discussion.

Each topic has thus been carefully selected, and the author concentrates on the practical details and applications of the material he covers. Both students and practising engineers alike will therefore find this book extremely useful and informative.

**Electronics texts for engineers and scientists**

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# Analogue electronic circuits and systems

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# Preface

This book is intended particularly as a text for undergraduate students of electrical and electronic engineering at the intermediate level of a degree course. Some material may, however, be appropriate to the final year. Each topic has been deliberately selected and emphasis has been given to operational amplifier circuits and their applications, data acquisition circuitry and computer aided analysis and design. Other useful topics which have been covered in some detail are analogue filter circuits and phase-locked loops. A list of the prerequisite knowledge for this text is given in the first chapter.

This book is most appropriate for students because (i) a specific subject area, analogue circuits for more advanced students has been highlighted and (ii) particular attention has been given to a descriptive treatment of practical details and applications, e.g. CAD rather than theoretical analysis, because these areas are often neglected and are essential for practising engineers. Therefore it is hoped that students and engineers alike will find this text useful and informative, but less analytical than many other books presently available, and thus be able to cover a wider range of topics within a given period of time. Several carefully chosen problems set at various levels of difficulty are included at the end of each section to help readers gain a better understanding of the topics under discussion.

I would like to thank my parents and my immediate colleagues both academic and industrial for their encouragement and advice in the preparation of the manuscript. Thanks are also due to the staff of Cambridge University Press for their support through the many stages of production. I am also grateful to my research assistant Paul Ling and student Fatih Anayi for checking the problems.

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# 1

# Introduction

In recent years there has been rapid progress in electronic circuit design and the main reason for this is the advance in digital techniques. This volume differs from the texts which are available on the market nowadays in two respects. Firstly it covers only analogue electronic circuits and systems; secondly basic electronics is omitted so that appropriate emphasis can be given to the design of the most popular and useful analogue electronic circuits. The following are prerequisites for studying this text:

(a) P-N junction diodes: principles of operation both in the forward and reverse mode, characteristic equation, resistance and junction capacitance, Zener diodes.

(b) Junction transistors: principle of operation, common-emitter (CE), common-collector (CC) and common-base (CB) configurations, static characteristics, definition of active, cut-off and saturation regions, the concept of load lines and the need for biasing, the transistor as an amplifier.

(c) Amplifiers: voltage and current gains ($A_v$ and $A_i$), input and output resistance ($R_{in}$ and $R_{out}$), frequency response concept, the use of the $h$-parameter model of the transistor for circuit analysis, midband frequencies of the CE, CC and CB configurations and calculation of $A_v$, $A_i$, $R_{in}$ and $R_{out}$ for each case.

(d) Field effect transistor: principle of operation, static characteristics, load lines, biasing circuits, use as an amplifier.

(e) Positive and negative feedback and their advantages and disadvantages.

(f) Operational amplifiers: ideal amplifier, analysis of inverting, noninverting, differential, buffer and summer amplifiers, use of operational amplifiers as integrators and differentiators.

A list of books which comprehensively cover the above topics is given at the end of this volume. Standard symbols are used throughout the text and a glossary is included as one of the appendices.

In the second chapter the operation of several basic circuits which are commonly used in most integrated circuit chips is described. A section is also devoted to the analysis of multistage amplifiers and the ways of choosing the right configuration of transistor amplifiers for a particular stage. These are included in the text in order to acquaint the reader with the operational amplifier integrated circuit which is the building block of most analogue circuits. The principle of operation of tuned amplifiers is briefly explained in the penultimate section. In the last section, different types of power amplifiers are studied. Various types of heat sinks and their use in power circuits are also discussed in this section.

Chapter 3 deals with operational amplifiers in great detail, but at a level higher than the introductory one which is [one of the] required knowledge, as mentioned earlier. The circuits are analysed and designed assuming operational amplifiers to be ideal, but in practice they are not so. In this book, therefore, the chapter starts with the imperfections in operational amplifiers, their effects on various operational amplifier circuits and the ways in which readers can minimise these effects. Several widely used linear and nonlinear circuits using operational amplifiers are discussed in the remaining sections of this chapter. One of the major applications of operational amplifiers is in active filters and therefore readers will find both resistor–capacitor and switched-capacitor type active filters, which are discussed in this chapter with design examples, rather useful. Principles of design of waveform and function generators and also analogue computation using operational amplifiers are comprehensively studied in the next section.

The next three chapters describe oscillators, phase-locked loops and different types of modulation respectively. Principles of design and operation of oscillators using transistors, operational amplifiers and quartz crystals have been presented. The most common uses of phase-locked loops in the field of communications and also in the field of control of motor speed are discussed to a limited extent, with a full treatment of the theory of phase-locked loops which will help readers to understand and design similar circuits.

In Chapter 7, under the heading of data acquisition and distribution systems, analogue-to-digital and digital-to-analogue conversion techniques are discussed in great detail. Sample-and-hold circuits, multiplexers and demultiplexers are also studied in great depth. Analysis of errors in individual circuits and also in complete systems are discussed. In the age of computerised measurement in research and in most aspects of control systems this chapter is a significant part of the text.

The last chapter deals with computer aided analysis and design of electronic circuits. It describes various computer aided design models giving special attention to the Ebers–Moll model of a transistor. Models for bipolar junction and field effect transistors and also integrated circuits are described. Techniques of a.c. small signal, d.c. and transient analysis of circuits are discussed with the help of examples. Several commercially available computer programs are also discussed. Two widely used software packages are described with the aid of circuits and their analyses in order to make students familiar with the procedure for drawing and analysing various active and passive circuits.

To summarize it can be said that this volume on analogue electronic circuits and systems has been written mainly keeping in mind the requirements of undergraduate students at the intermediate level. Practising engineers interested in various aspects of analogue electronic circuit design will also find this text informative.

# 2

# Transistor circuit techniques and amplifiers

## Objectives

At the end of the study of this chapter a student should be:

1. familiar with the operation of the differential amplifier, its voltage gain, common-mode gain and common-mode rejection ratio
2. familiar with constant current sources and current mirror circuits
3. capable of explaining the principle of Darlington connections
4. able to design level shifting circuits
5. familiar with multistage amplifiers and able to calculate their input and output impedances and overall current and voltage gains
6. able to design class A, class B and tuned amplifiers
7. familiar with different types of heat sinks and able to choose the right heat sink for a particular circuit

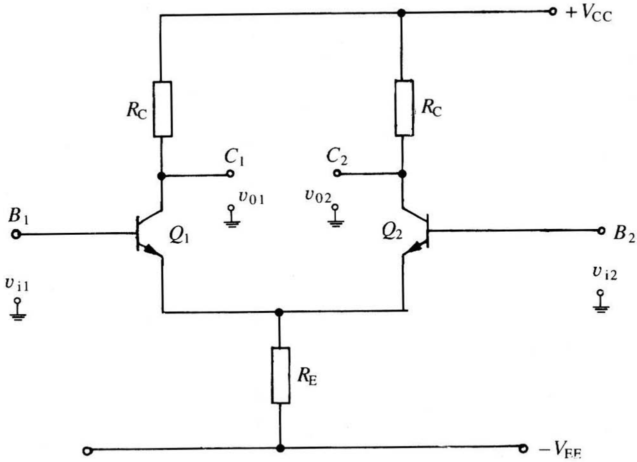
## 2.1 Linear integrated circuits

Complete multistage amplifiers and other linear devices can be constructed on a single chip of silicon occupying a very small volume by using modern techniques for the fabrication of integrated circuits. In the case of monolithic integrated circuits, all components may be manufactured on the chip by a diffusion process. A diffusion isolating technique is used to separate the various components from each other electrically. The design techniques used for the construction of these integrated circuits are basically the same as those used to build circuits employing discrete components, although, in many cases some modification in techniques is needed.

The operational amplifier is the most common type of integrated circuit (small scale integration) which is widely used with different forms of external circuitry to build summers, subtractors, integrators, filters, etc. Audio amplifiers, timers, modulators and frequency dividers are only a few among many other types of integrated circuits.

In this section, the operation of several basic circuits which are commonly used in integrated circuits are described.

Fig. 2.1. Basic differential amplifier.




## 2.1.1 Differential amplifiers

One of the basic circuits used in operational amplifiers is the differential amplifier. This forms the basis of practically all operational amplifiers. Also known as the long tailed pair, one of its advantages is that its gain tends to be very stable if any variations in supply voltage or ambient temperature occurs.

The basic form of the differential amplifier is shown in Fig. 2.1. It consists of two identical bipolar transistors coupled at their emitters. The collector resistors, connected between the positive voltage supply rail and the collectors of the transistors, are of the same value, $R_c$. Two input signals are applied to the bases of the two transistors $Q_1$ and $Q_2$ with respect to ground and the output is usually obtained from either of the two collectors, again with respect to ground.

### Differential voltage gain

The differential voltage gain, $A_d$ is the ratio of the output voltage to the difference between the input voltages applied to terminals $B_1$ and $B_2$. If the output voltage is obtained from either of the two collectors with respect to ground, then the ratio gives the single-ended differential voltage gain $A_{d(s)}$. If the output voltage is the difference between the two collector voltages then the ratio yields the double-ended differential voltage gain $A_{d(d)}$.

In order to find the single-ended differential voltage gain $A_{d(s)}$ of the circuit let us apply a very small voltage $v_d$ between the two bases $B_1$ and $B_2$. Since the circuit is fundamentally symmetrical and the total emitter current