NEW SYLLABUS

A TEXT BOOK OF

# ANALOG CIRCUIT DESIGN

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S. Y. B. Sc. ELECTRONIC SCIENCE • PAPER I - SEMESTER I

NIRALI PRAKASHAN

*A Book Of*

# ANALOG CIRCUIT DESIGN

**For S. Y. B. Sc. Electronic Science : Paper-I (EL 211) : Semester-I**
**As Per Pune University Revised Syllabus Effective from June 2014**


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# Preface ...

We are extremely happy to present the text book on **"Analog Circuit Design"** (EL 211) paper I for semester I which is written as per the syllabus of the University of Pune for S.Y.B.Sc Electronic Science to be implemented from June 2014. We have sincerely put our efforts to give complete information of the subject in a simplified manner. As prescribed in the syllabus, chapters are arranged in units in such a way that students can understand easily ensuring the flow of subject.

With the revised syllabus it is expected some objectives like, the student has to study the basic principles of the amplifiers and oscillators. He has to understand the working of various analog circuits and develop design skills. Finally students have to apply the knowledge of analog circuits in different applications. We have tried at our best level to explain all the basic circuits, their designing and applications in detail. In point of view of the examination and study, practice problems are included at the end of each unit. To understand the units more easily, some solved problems are given.

With continuing the flow of syllabus, in the first unit , transistor amplifiers are explained with classification, designing, types and their characteristics. The power amplifiers are discussed in the second unit where the basic information and comparison of different types of amplifiers is given. The techniques of feedback used to control performance of an amplifier are explained in unit three. We know that OP-AMP is one of the important and versatile amplifier and is used in various circuit designs and applications, and therefore in unit four it is explained with starting from the basic concepts, parameters of it and finally various applications of it. We hope as far as students' point of view, the course material is well sufficient for understanding the subject. We have jointly made every possible effort to make this book as good as it is.

We are thankful to Shri Dineshbhai Furia, Shri Jignesh Furia, Mrs. Manasi Pingle for carrying efforts like editing and proof reading, Mr. Santosh Bare, Mrs. Prachi Sawant and all staff of Nirali Prakashan for publishing the book in time.

Any suggestions for improvement of the book will be gratefully received.

**JUNE 2014** **AUTHORS**

**PUNE**

# Syllabus ...

**1. Transistor Amplifiers (12)**

General classification of amplifiers with respect to signal amplitude, frequency and configuration. Small signal amplifier : A.C.-D.C. analysis, frequency response, gain-bandwidth product. Design of single stage amplifier. Types of coupling (quantitative analysis) : RC coupled, transformer coupled and direct coupled. Multi-stage RC coupled CE amplifier : effect of coupling capacitor and bypass capacitor on frequency response (qualitative approach) and application area.

**2. Power Amplifiers (12)**

Concept : Difference between voltage and power amplifier, Comparison of small signal and large signal amplifiers with respect to : gain, efficiency and distortion. Classification of power amplifiers on the basis of conduction : class-A, class-B, class-AB, class-C. Class-A amplifier : resistive load/transformer coupled load, efficiency calculation. Concept of harmonic distortion. Class B amplifier : Push-pull amplifier concept, complimentary symmetry class-B push-pull amplifier, crossover distortion, class AB push-pull amplifier. Concept, use and types of heat sinks.

**3. Feedback Systems (12)**

Concept of negative and positive feedback and Barkhausen criterion. Types of feedback circuits : current shunt, current series, voltage shunt and voltage series, comparison and applications. Effect of negative feedback on gain, bandwidth, input and output impedance, stability of an amplifier. Positive feedback : oscillator circuits - Wein bridge , Phase Shift , Hartley , Colpitt's and Crystal. Design of oscillators for given feedback factor and frequency of oscillation.

**4. Differential Amplifiers and Applications of Operational Amplifier (12)**

Concept and working of differential amplifier. Configurations of differential amplifier: Single ended, double ended. Differential and Common mode gains, Use of constant current source and its effect on CMRR. Op-amp Applications : Integrator, Differentiator, Voltage to current converter, Current to voltage converter, Bridge amplifier, Instrumentation amplifiers with three op-amp, Precision rectifier, First order Butterworth active filters - Low pass and High pass filters and its design for cut-off frequency.

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| 3. | Feedback Systems | 3.1 – 3.42 |
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Unit **1**...

# Transistor Amplifiers

## *Learning Objectives ...*

- To know the general classification of amplifiers with respect to signal amplitude, frequency and configuration.
- To study the small signal amplifier and load lines i.e. ac and dc load line.
- To study the concept of Bode plot and Nyquist criteria.
- To know design steps of single stage amplifier.
- To study the effect of coupling capacitor and bypass capacitor or frequency response.

## 1.1 Introduction

- **Analog circuit and system design today is more essential than ever before. With the growth of digital systems, wireless communications, complex industrial and automotive systems, designers are challenged to develop sophisticated analog solutions.** An **analog** or **analogue signal** is any continuous signal for which the time varying feature (variable) of the signal is a representation of some other time varying quantity, i.e., analogous to another time varying signal. For example, in an analog audio signal, the instantaneous voltage of the signal varies continuously with the pressure of the sound waves. It differs from a digital signal, in which a continuous quantity is represented by a discrete function which can only take on one of a finite number of values.
- The term analog signal usually refers to electrical signals; however, mechanical, pneumatic, hydraulic and other systems may also convey analog signals. An analog signal uses some property of the medium to convey the signal's information. Any information may be conveyed by an analog signal; often such a signal is a measured response to changes in physical phenomena, such as sound, light, temperature, position or pressure. In an electrical signal, the voltage, current or frequency of the signal may be varied to represent the information.
- In the first year B.Sc. course, we have learned about passive components, circuit elements, semiconductor devices and basic circuits using diodes and transistor. An amplifier is a circuit used to increase the amplitude and strength of a signal. We have considered the amplifier as a "black box" that has two input terminals for the signal to be amplified, two output terminals for the connection of load and a means of supplying power to the amplifier as shown in the Fig. 1.1 below.

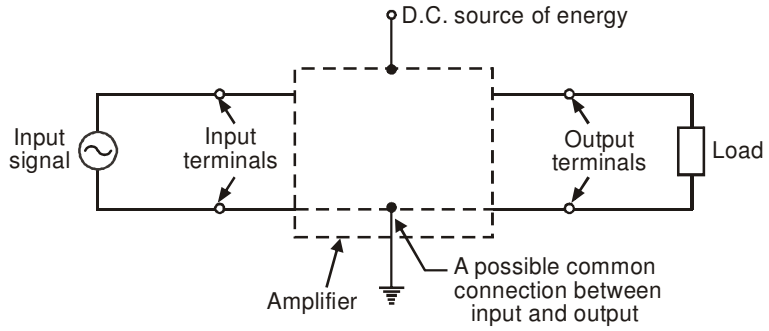


**Fig. 1.1 : Black box representation of an amplifier**

- The input is a low level alternating signal obtained from a taperecorder head, transducer output like thermocouple, piezocrystal, pressure gauge or output of microphone etc. The output load may be a loudspeaker in an audio amplifier, a motor in a servo amplifier, a relay in an instrumentation system etc.
- In all these events, the output of an amplifier is an enlarged version of the input. To do this, all amplifiers need an active element and a source of energy. This source of energy is generally a d.c. battery or d.c. power supply derived from a.c. mains.
- An increase in the amplitude of an electrical signal may be achieved using passive components also, like a transformer or an L-C circuit working at resonance can be used to amplify voltage or current levels. However, as far as the power level of a signal is concerned which is to be increased, an active device such as transistor, FET must be used. This is due to the power amplification that occurs when we use active devices which are biased.
- The load power and the input signal power are maintained by the power supply with the help of an active device.
- In other words, the capability of an active device like transistor where a small input signal controls the variation in a larger output i.e. load current or load voltage. Here we have to remember the amplification factor $\beta$ for a transistor. Thus, an amplifier must be provided d.c. power and the input signal.
- The signal is varying electrical quantity which is too small in its present form to be usable. For example, microphone output which cannot drive loudspeaker directly, unless it is amplified. The amplifier provides a function called as *gain*. The output signal is greater than input because of gain of amplifier, which is designed by the user.
- Fig. 1.2 below shows the amplifier which provides gain to increase power and amplification of the input signal.
- Transistor provides the power gain that is needed for most electronic application circuits. They can also provide voltage gain and current gain with proper designing of circuit.
- Now, according to different applications like audio amplifier, public address system, tape recorder, instrumentation system, process control system, servo motor controls,

communication systems like radio, TV, satellite communication, mobile phone, weather monitoring systems etc. the requirement of amplification is different.

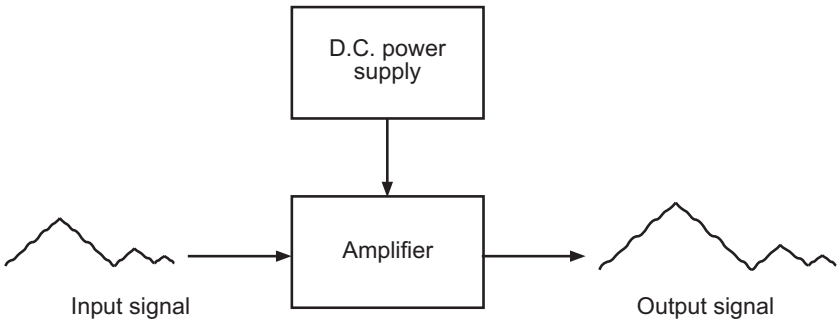


**Fig. 1.2 : Amplifier provides gain**

- Hence, to choose proper amplifier circuit, we have to study the classification of amplifier, types of amplifier, characteristics of different amplifiers, how to design an amplifier ? and other devices used with some additional characteristics to an amplifier like FET amplifier etc. When only one transistor with associated circuitary is used for amplifying a small signal, the circuit is known as *single stage transistor amplifier*.
- In the applications, single stage amplifier may be sufficient or multistage amplification achieved by using two or more stages of amplifier will be required. In the latter case, what are the effects of coupling two stages, frequency response of amplifier circuit, gain, impedance that should be known to us. In this chapter, we will discuss all these issues in detail.
- The need to study the amplifiers and power amplifiers with their characteristics like gain, input impedance, output impedance, frequency range of operation, effect of coupling and efficiency can be understood if we consider a simple example of lens from optics.
- Generally, a lens is used to magnify the images. But a single lens and cascaded lens systems are used in different applications having different characteristics like size, power, type, focal length etc. A watchmaker uses lens only to magnify the small parts inside the watch infront of him, whereas the spects used by different persons are designed as per their eye and spect combination.
- In a microscope, combination of lenses is used to magnify micro objects, whereas in binocular there is cascading of two lenses to get required magnification of objects which are at larger distance from the viewer. For a large telescope, there are several combinations of lenses to get proper image of object which is at very large distance away from the viewer. On the other hand, we have cinema projector or overhead projector where small image is to be projected, the lens required is different.
- In the similar way, if we know characteristics, design, classification, types of an amplifier, we can understand working of electronic systems listed above.

## 1.2 General Classification of Amplifiers

- The amplifiers may be classified in the various different ways by referring to different properties or construction of amplifier. This classification is summarized in Fig. 1.3 below.

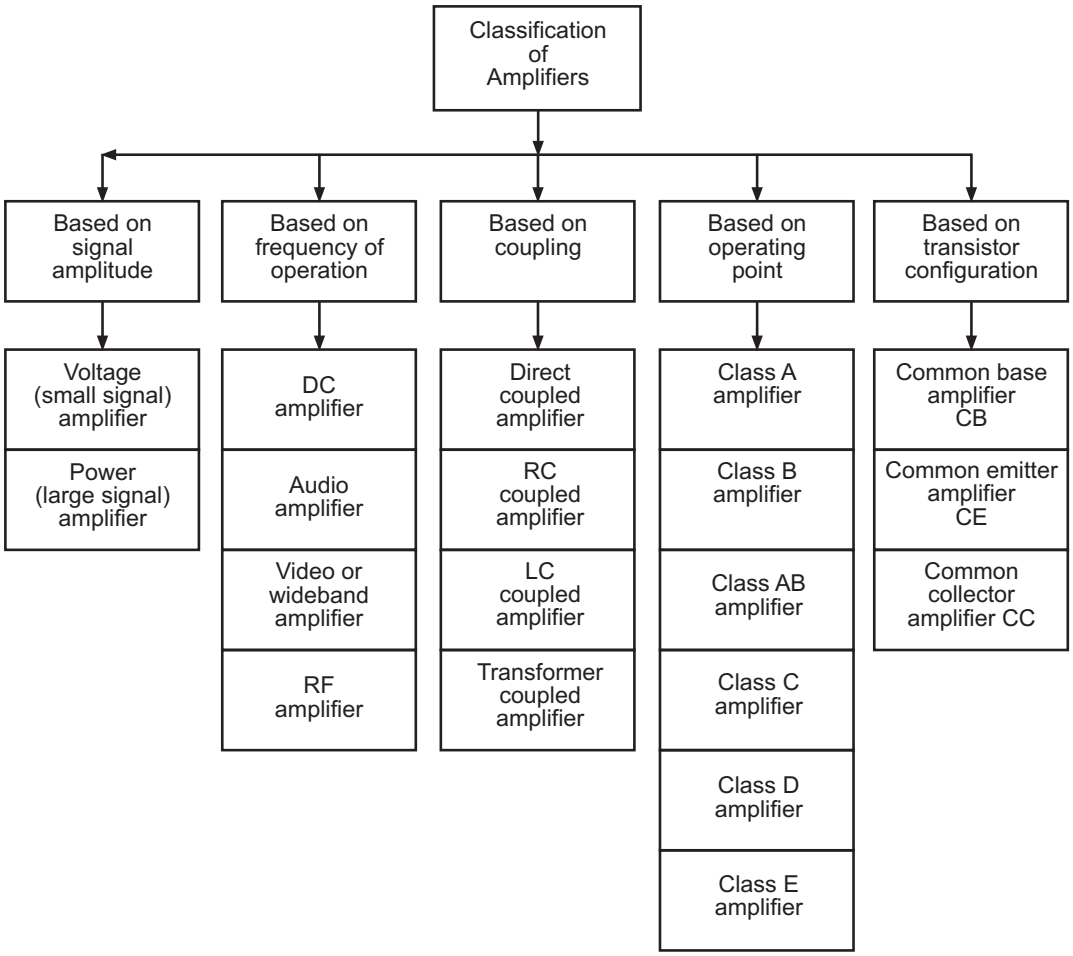


**Fig. 1.3 : Classification of amplifier**

### 1.2.1 Classification Based on Signal Amplitude

- According to signal amplitude for amplification purpose, the amplifiers are classified as voltage amplifier or small signal amplifier and power amplifier or large signal amplifier.
- When the amplifier circuit is basically used to increase the amplitude of a small signal with least distortion of the signal waveform, it is called as **voltage amplifier**. These circuits operate at low power level. On the other hand, when the amplifier circuit is used to provide a desired amount of signal power, it is called as **power amplifier**. These amplifiers are designed to give desirable power characteristics and voltage gain has less importance.

- The input signals required to drive power amplifier are sufficiently large in amplitude, hence they are also known as large signal amplifiers. In general, voltage amplifiers are used as preamplifiers and power amplifiers as output driver stage amplifiers in any electronic systems like audio amplifier, tape recorder or instrumentation system.

### 1.2.2 Classification Based on Frequency of Operation (M-16)

- The frequency response of an amplifier is very important, since in the applications the signals in particular frequency range must be amplified with constant gain. The operating frequency range of components like transistor, capacitor and types of resistors used in the circuit, also the coupling configuration of the amplifier cause the frequency range of operation limitation on the working of an amplifier.
- By using signal generator and CRO, the amplifier circuits are tested for the frequency response and then used in the applications for particular bandwidth of frequency with proper amplification. The classification according to frequency of operation, range of frequency and applications are summarized in the Table 1.1 below.

**Table 1.1 : Classification by Frequency of Operation**

| Classification | Range of frequency operation | Application area |
|---|---|---|
| DC amplifier | DC level i.e. 0 Hz to 10 Hz | Instrumentation systems |
| Audio amplifier | 20 Hz to 20 kHz | Audio circuits like radio, tape recorders, public address systems etc. |
| Radio frequency<br>RF amplifier | 300 kHz to 30 MHz | Used as tuned circuits and known as tuned amplifiers. |
| Video amplifier or wide band amplifiers | Wide frequency range from few Hz to several MHz | Communication devices for audio as well as video signal amplification. |

- Thus, one has to select proper amplifier in the range of frequency of operation for particular application.

### 1.2.3 Classification Based on Coupling

- When a single stage amplifier is not sufficient to provide large gain, cascaded stages of amplifiers are used. These cascaded stages multiply the gain at individual levels and provide high gain. To cascade the amplifiers in order to get high gain the coupling from one stage to other is necessary; where the output of first stage drives the input of next stage. This coupling can be done directly, by using capacitor, by LC combination or transformer, hence amplifiers are also classified based on types of coupling used.
- There are certain advantages and disadvantages of the coupling types depending on the characteristics of an amplifier. Hence, one has to choose proper coupling type in

particular cascaded stage amplifier application. The types of coupling and classification of amplifiers with their advantages and disadvantages are listed in Table 1.2 below.

**Table 1.2**

| Classification based on coupling | Component used for coupling | Advantages | Disadvantages |
|---|---|---|---|
| Direct coupled amplifier | Direct connection from one stage to next | • Efficient at low frequency upto 10 Hz.<br>• Where capacitor coupling is not useful since it blocks dc i.e. signals at lower frequency. | • Overall gain of the amplifier system may be decreased than expected.<br>• Drift in the output is more. |
| RC coupled amplifier | Resistor and capacitor combination | • Efficient at frequency above 10 Hz.<br>• Stabilizes the operating point. | • Bandwidth of amplifier changes due to RC filter action.<br>• Not useful at low frequency operations. |
| LC coupled amplifier | Inductor and capacitor combination | • Useful in RF amplifier.<br>• Impedance matching between two stages can be done.<br>• Small power dissipation at output delivery. | • Proper inductor is to be designed with LC resonance frequency. |
| Transformer coupling | Small transformer | • Useful in audio frequency range.<br>• Impedance matching between two stages can be done. | • Bulky and expensive method.<br>• Introduces frequency distortion at output. |

### 1.2.4 Classification Based on Operating Point **(M-16)**

- Amplifiers are also classified according to the Quiescent point position for their operation. The input and output signal magnitude with a fixed position of Quiescent point classifies the amplifiers in four classes as class A, class B, class AB and class C amplifiers.
- To understand this type of classification, we have to refer output characteristic I-V curves of common emitter amplifier as shown in the Fig. 1.4 below.

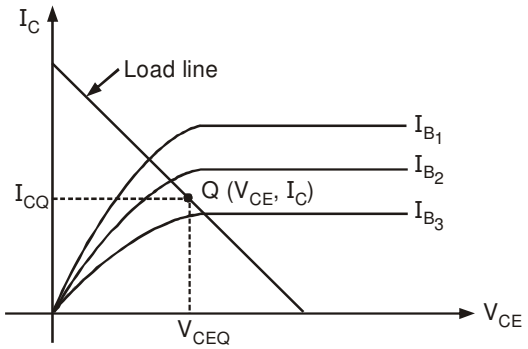


**Fig. 1.4 : Output characteristics of CE amplifier**

- We see that on the load line, the zero signal values of collector current $I_C$ and collector to emitter voltage $V_{CE}$ indicate the operating point or Quiescent point. When the a.c. input is given to amplifier, the base current $I_B$ changes around the operating point Q causing corresponding change in $I_C$ and $V_{CE}$.
- This change will depend on the amplitude of input a.c. signal and Q point. Thus, we can classify the amplifiers according to the position of Q point and input, output waveforms of amplifier circuit.

We shall see in detail this classification as described below.

**Classification of Amplifiers :**

**(i) Class A amplifier :** In class A amplifier, current flows through the active device for the whole of the input signal's period. Therefore in class A amplifier, we have to choose the position of the operating point Q at the centre of load line; where the magnitude of the input signal and output current flows for all the time. This is shown in the Fig. 1.5 below.

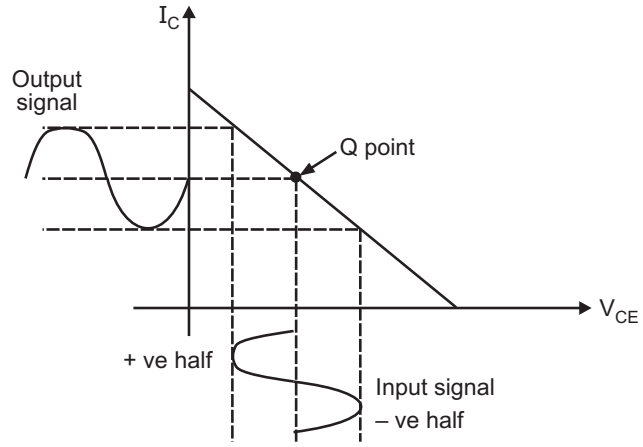


**Fig. 1.5 : Class A amplifier**

Here we see that class A amplifier must operate over a linear region of the I-V characteristic curve.

**(ii) Class B amplifier :** In class B amplifier, current flows through the active device for nearly one half cycle of the input signal. Hence, the operating point for this type of operation is situated at an extreme end of the I-V characteristic curve. When the input signal is absent, there is no current through the device. When a.c. input signal is applied, current flows during the positive half cycle of the signal only as shown in the Fig. 1.6. Here we see that, the collector current can vary from its minimum value to maximum value on the I-V characteristic curve, causing more output power, than class A amplifier.

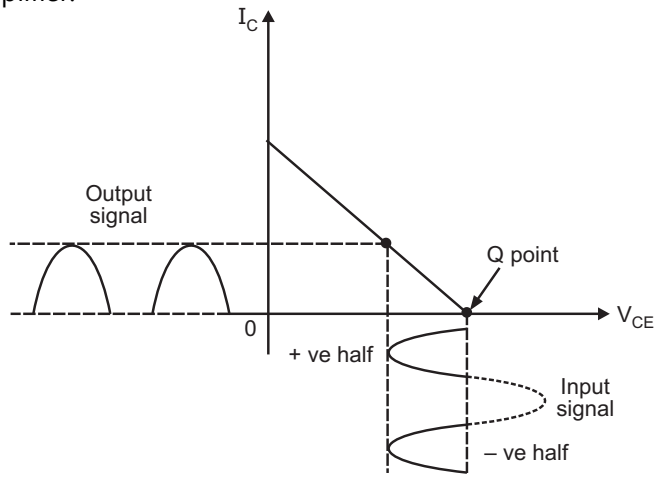


**Fig. 1.6 : Class B amplifier**

**(iii) Class AB amplifier :** Class AB amplifier operates between the two extreme conditions laid down by class A and class B amplifiers. In this type, the current through the active device flows for more than half the input signal period, but never for the complete period. i.e. the operation is between class A and class B. It is used for the desired output power and for faithful amplification of the input signal. The operating point in this type of operation is near to cut-off point as shown in the Fig. 1.7, where we see that the output current flows for more than 180$^o$, but less than 360$^o$.

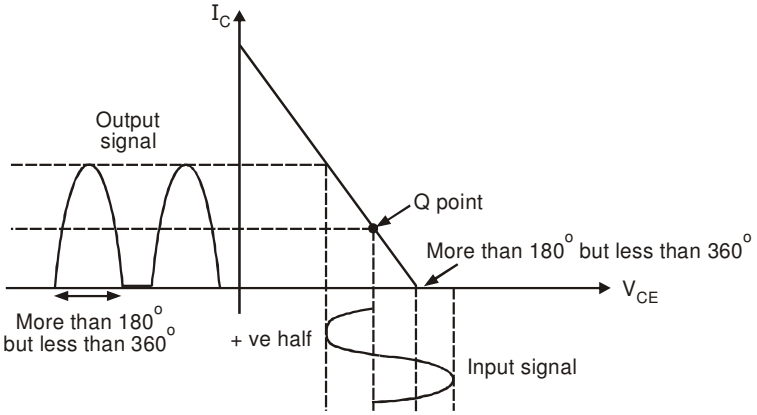


**Fig. 1.7 : Class AB amplifier**

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