Electronic Circuits and Instrumentation Systems

JACK J. STUDER

ELECTRONIC CIRCUITS AND INSTRUMENTATION SYSTEMS

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Preface

Systems of electronic instrumentation play a dominant role in modern research, and great ingenuity is sometimes needed to adapt them to particular requirements. Engineers and scientists must be able to gage the capabilities as well as the limitations of such systems. This presupposes a knowledge of the underlying principles not only of electronics but also of circuits and systems.

Information on these topics is available in separate texts. It is rather difficult, however, to coordinate the interplay of the various disciplines.

This book is a novel attempt to introduce an integrated treatment of circuits and electronics in a general approach to systems concepts by which the theory of electronic instrumentation is developed. It is not intended to show how a particular type of electronic instrument is operated nor what to choose for a particular application. The choice of material was made by analyzing complex modern systems to determine the concepts of signal processing most often used. The presentation of the material emphasizes signal transfer properties.

The text is grouped into three main parts: *electric circuits*, treated first, are viewed as signal transfer devices with emphasis on frequency response. We then deal with basic *electronics* in which modern electron devices—vacuum tubes, semiconductors, and gas tubes—are analyzed by graphic and equivalent circuit methods. *Systems of electronic instrumentation* are studied with a view to general systems concepts.

Special care has been taken to bring out the facts in the clearest possible manner. A large number of illustrations and extensive use of graphic methods help to promote understanding, although mathematical treatment is by no means neglected.

This book is intended for a one-semester course on the college level for students in engineering and the physical sciences. Knowledge of college physics and calculus is required. The material is also of special interest to practicing engineers and scientists who use complex systems of electronic instrumentation.

Some of the book's examples on instrumentation systems have been adapted from the most recent sources available. They show to good advantage the ingenuity employed in modern systems.

Subdivisions of the text material will facilitate the instructor's choice of topics for lecture presentation or for reading assignments. Certain sections can be omitted if he so wishes; for instance, those on quantitative analysis in Chapter 9. However, he can expand the material by discussing other examples of modern instrumentation systems which might be of particular interest to his students.

Problems appear at the end of the text to help the student to deepen his understanding of the subject, and a bibliography lists books for supplementary reading if the student feels the need for it. This list contains only a few titles: it would be impossible to mention them all.

The material in this book has been used successfully in a new electrical engineering service course. It was evolved to meet the requirements of science and engineering students (those not majoring in electrical engineering) who have to use systems of electronic instrumentation. The experience with this course gained during several semesters has helped in the selection of the most suitable methods of presentation.

The material presented in Part I, Circuits, and in Part II, Electronics, is, however, also well suited to a modern unified introductory course in electrical engineering for all students in engineering (including those majoring in electrical engineering) and for students of the physical sciences. A desirable method of presentation would be to have the instructor alternate his lectures between "Circuits" (Part I) and "Electronics" (Part II). The broad scope of the book combined with this procedure would stimulate the students' interest and avoid the monotony of many of the usual "one-sided" approaches. Topics selected by the instructor from "Electronic Instrumentation Systems" (Part III) to suit his students could then culminate the one-semester course. This would not only make the students aware of important systems concepts, but it would put what they learned into proper perspective by analyzing sophisticated applications in electronic instrumentation systems.

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Berkeley, California
January 1963

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PART ONE

Circuits

1

Electrical Devices and Systems

1-1 Electrical Devices

Electrical engineering has developed a large variety of devices for different applications. Some of these devices, such as the electronic amplifier and transformer, are purely electrical. Others, which are energy converters and are called *transducers*, operate on electrical and nonelectrical energy. Examples are the microphone, which converts acoustical into electrical energy, the thermocouple, which converts caloric into electrical energy, and the electric motor, which converts electrical into mechanical energy. The expression "electrical device" is used here in a broad sense.

1-2 Electrical Systems

Frequently a combination of different electrical devices is used for a given purpose to form an electrical *system*.

A broad distinction can be made between electrical systems, as shown in Fig. 1-1. The dominant idea for their operation is either *power transfer* or *signal transfer*.

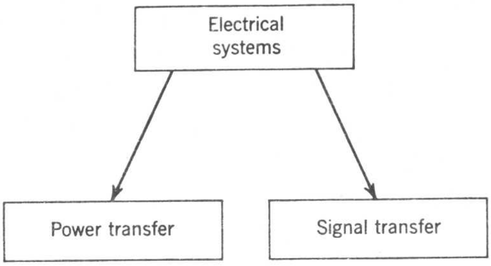

Fig. 1-1. Classification of electrical systems according to their use.

1-3 Power Transfer

Let us assume that we are using an electric room heater, which converts electrical into caloric energy. The heater consumes electric power, the average value* of which is P_0. This power may be, for instance, 2 kw (kilowatts), and it must be supplied by a *power source*, which is frequently quite remote from the installation. Between power source and heater other devices are connected, such as power transformers and high- and low-voltage transmission lines (Fig. 1-2*a*).

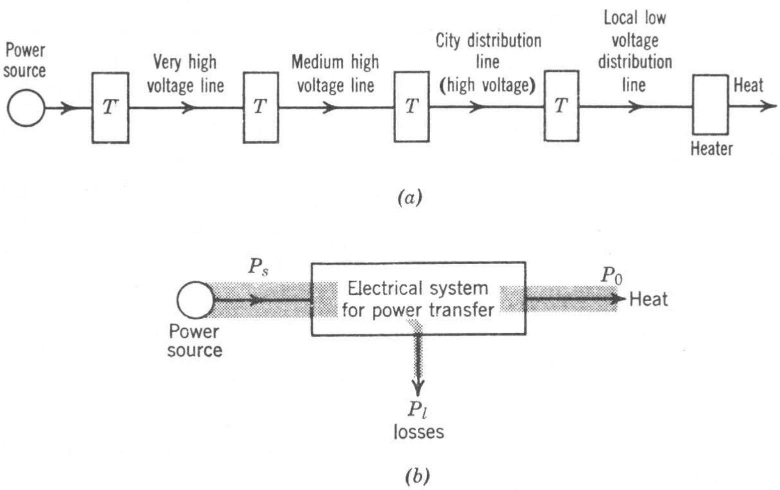

Fig. 1-2. Electrical system for power transfer: (a) typical setup of system, (b) power-flow diagram. T signifies transformer.

* The letter P denotes average power. See Chapter 2, Section 2-6.

The combination of these devices is an electrical *system for power transfer*. Its distinctive feature is that *power* flows from the source to the heater through every device of the system.

The average power P_s, which the source has to supply, is not equal to the average power P_0 consumed by the heater; P_s must be larger than P_0. The reason for this is that because all the devices are not ideal there are power *losses*. We call the sum of these electrical losses P_l. The average power P_s then becomes

$$P_s = P_0 + P_l \tag{1-1}$$

For an economical power transfer system the value P_l must be small compared with P_0. We speak of the efficiency of the power transfer by relating P_0 to P_s as

$$\eta = \frac{P_0}{P_s} \times 100 \tag{1-2}$$

which is the expression for percent efficiency. The aim is toward maximum efficiency, as close to 100% as possible.

Because the dominant feature of this system is power transfer, Fig. 1-2*b* is a *power flow diagram*, which illustrates the formula expressed by (1-1).

1-4 Signal Transfer

Systems and devices for signal transfer are characterized by all-important signal flow. We consider as an example a broadcasting system (Fig. 1-3). We have as the source of the signal a voice or some musical instruments at the studio, where the microphone converts the signal from acoustical to electrical. At the output end of the system a loudspeaker serves the listener, and the electrical signal is reconverted to acoustical. The purpose of this system is to recreate for the listener the voice or music from the broadcasting studio. The dominant idea is clearly that of *signal transfer*.

Between the source and the listener is a link through the air over which the signal must be transmitted by electromagnetic radiation from the broadcasting station to the listener's location. This requires a means of generating and radiating the electromagnetic energy and of incorporating the signal in it. A radio-frequency transmitter and antenna are used. A certain amount of average power P_B is needed at the broadcasting station for the transmission of the electromagnetic radiation so that as many listeners as possible can be reached. Where

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