Basic Electronic Instrument Handbook

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Preface

This is a book about electronic instruments. In it we have described and discussed the equipment and devices themselves: what they do, how they do it, how to select the best one for your use, and how to get the most out of the instruments in actual use. The information available here ranges from very basic to highly sophisticated, and from the general nature of types of instruments to the specific definition of an individual device.

Although the act of measurement itself is the result of using instruments, this is not a "measurements" book. There are so many types of measurements possible with the instruments described that to include them all would be impossible and any attempt would be confusing. As a result, specific measurements are discussed only as examples of applications of the instruments. It is felt that with a clear understanding of the instruments themselves and how they work together, the reader is in the best position to define his own solution to a measurement problem.

The title, therefore, states exactly what the book contains: handbook information on basic electronic instruments.

The fundamental nature of commercial electronic instrumentation has not changed significantly since its beginning. The process by which an electronic quantity is detected and measured is still essentially the same, but the equipment used has undergone great changes in accuracy, ease of operation, reliability, and range of capabilities. To understand this, it must be kept in mind that there are only certain physical properties that can be detected electronically. All other phenomena must be changed into analogous electrical units before they can be measured. After the physical property is represented as an electronic quantity, it must proceed through the same series of processing steps used from the beginning of the art of electronic measurement that allow it finally to be presented to the human senses for interpretation, or to another machine, such as a computer, for further processing. These steps are all basic to the measurement process and will continue to be in the foreseeable future.

In the first half of the book (Chapters 1 to 19) we discuss the general steps, in both measurement and signal generation, as they apply to all instruments in these categories. We also review the problems in guaranteeing accuracy, the problems associated with the use of any electronic device, and the general problems involved in putting instruments into systems. These chapters approach the instrument usage situation from the common denominators associated with each class of electronic device, signal measurement, or signal generation.

In the second half of the book (Chapters 20 to 40) individual instruments are described in detail and their unique applications and usage are considered. This is to give the reader all the specific information he needs about a particular device so that he will have an intuitive feeling for the instrument as well as a theoretical understanding of its operation. He should feel comfortable with the tools he is using.

This book should give those who use electronic instruments, for any reason, a source of better understanding of what they are using, and provide a ready reference to refresh the backgrounds of professional engineers and scientists.

The early encouragement of Ralph Lee, Jack Melchoir, Bill Abbott, and Bob Brunner is gratefully acknowledged. I also thank the international team of typists who made this book possible: Virginia DeBoer in Colorado, Sally Wells and Carol Board in California, and Linda Ng in Singapore.

Clyde F. Coombs, Jr.

Section One

Introduction to Instrumentation

The most important aspect of the information one receives from a measuring device is the confidence the user has in the accuracy of that information. As the ability to measure electrical quantities has been refined over the years the need to ensure a greater and greater degree of accuracy has increased. Or, to express it another way, the limits of uncertainty have had to be narrowed and those limits themselves have had to be defined more precisely.

To provide a common source of information on the relationship of the absolute magnitude of a measurable quantity to that actually measured by a particular device, the governments of most countries maintain a set of "standards." These standards are used for comparison with the local "quantity," which defines the amount of uncertainty involved in the measurement. In the United States this service is provided by the National Bureau of Standards. The need for this service and how it operates for each electrical unit are described in this section.

There are some statistical aspects of understanding the degree of uncertainty involved in a measurement, and these are discussed in this section. Also considered are the differences between "precision" and "accuracy" as well as the types and sources of error involved in electrical measurements.

A basic understanding of the use of standards and the sources and risks of error in electrical measurement is therefore fundamental to the confidence one has in the information his equipment is providing.

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Chapter 1

Measurement and the Growth of Knowledge

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The advancement of science and technology is matched by a parallel progress in the art of measurement. It can, in fact, be said that the quickest way to assess the state of a nation's science and technology is to examine the measurements that are being made and the way in which the data accumulated by measurements are utilized.

The reasons for this are simple. As science and technology move ahead, phenomena and relations are discovered that make new types of measurements desirable. Concurrently, advances in science and technology provide means of making new kinds of measurements that add to understanding. This in turn leads to discoveries that make still more measurements both possible and desirable.

It is thus axiomatic that sophisticated science and technology are associated with sophisticated measurements, while simple-minded science is associated with only elementary measuring techniques.

As the art of measurement has advanced, the technology of making measurements has increasingly relied on electrical and electronic methods. This comes about for two reasons. First, once information is transformed into electrical form, it can be readily processed in ways that will meet the needs of a great variety of individual situations. Second, most phenomena, such as temperature, speed, distance, light, sound, and pressure, can be readily transformed into electrical indications for processing and interpretation.

The result has been that during the last 30 years, there has developed a remarkable world of instruments based on electronics, which both supports and feeds on the ever-advancing frontiers of knowledge, and concurrently makes it possible to carry on the old tasks more easily and with greater accuracy.

Modern electronic instruments are typically direct-reading, making it unnecessary to resort to calibration curves. Increasingly, their outputs are available in digital form, which eliminates the necessity of even reading the indication of a needle or the scale of a cathode-ray tube. Moreover, data in digital form can be processed through a computer that can instantly perform necessary ancillary calculations; this eliminates possibilities of error and saves time of high-priced personnel. Through the use of recorders and cathode-ray oscilloscopes, it is now even possible to draw the final results in the form of plotted curves, thereby further speeding up the entire process of gathering and analyzing data.

A third of a century ago, most electronic measurements were made with instruments which the experimenter had constructed with his own hands. More often than not these early instruments were not only inconvenient but also useless unless operated by highly skilled personnel, preferably the men who had built them. This situation has now changed completely. Today one can usually buy a much better instrument than he can build, and one does not have to possess expert knowledge about a particular instrument in order to keep it in adjustment and functioning properly.

At the same time, even with the marvelous array of professionally made instruments that are listed in catalogs today, the user must provide an input of his own in order to take full advantage of the opportunities available to him. He must know what the instruments he uses, or is considering purchasing, will and will not measure; types of difficulties that can arise in making measurements under special or unusual conditions; possibilities and limitations; and the errors that can be introduced by distortions in waveform, by noise, by stray electric currents, etc. Today's user of instruments must also consider the characteristics of what he wishes to measure, and then relate these characteristics to the properties, possibilities, and limitations of the measuring instrument he plans to use.

It is the purpose of this book to help a worker in some field of science and technology match his needs with those of the world of instruments, in situations in which he is a nonexpert "consumer" of the fruits of instrumentation technology.