ELECTRONIC MEASUREMENT SYSTEMS

Anton F.P. van Putten

Electronic Measurement Systems

Anton F. P. van Putten
University of Technology, Eindhoven

PRENTICE HALL
New York London Toronto Sydney Tokyo

First published 1988 by
Prentice Hall International (UK) Ltd,
66 Wood Lane End, Hemel Hempstead,
Hertfordshire, HP2 4RG
A division of
Simon & Schuster International Group

Printed and bound in Great Britain at
The University Press, Cambridge

Library of Congress Cataloging-in-Publication Data

Putten, Anton F.P. van, 1939–
Electronic measurement systems.

Bibliography: p.
1. Electronic measurements. I. Title.
TK7878.P87 1988 681'.2 87-29251
ISBN 0-13-251893-7

1 2 3 4 5 92 91 90 89 88

ISBN 0-13-251893-7
ISBN 0-13-251885-6 PBK

Electronic Measurement Systems

To *Ria*
Michel
Maurice
Antoinette
Pascal

with love

Only knowledge in harmony is progress

AFPVP

PREFACE

Electronic measurement systems have become complicated machines able to perform complex tasks in a large variety of environments. Moreover, such systems are found in every area of science and technology.

The large impact of digital electronics has changed the world of electronic measurement systems dramatically, both inside and outside the system. Multipurpose, multifunctional measurement systems which are capable of performing tasks that were impossible ten years ago are common place now. Another important aspect of these systems is society's increasing dependence on them; the reliability of systems has become of vital importance.

Measuring systems are realizations of technical concepts able to gather, handle, modify, store, retrieve and present information. The design of a measurement system not only requires a great deal of knowledge about components and their possibilities: aspects related to the underlying philosophy of a system and its specific architecture are increasingly important. For example, a large shift to digital control and microprocessor-driven measurement systems has taken place in a large variety of applications.

The design of a measurement system is a complicated process and often the designer of a system is highly specialized in a few areas, but in practice, the designer is confronted with numerous questions concerning the (technical) specifications, for instance:

1 What degree of accuracy is required of the system?
2 What are the environmental conditions, e.g., temperature range, shock, vibration and electromagnetic interference?
3 What is the required reliability or the expected mean time between failures?
4 Which type of transducer is needed for the physical quantity to be measured and what possibilities are available?
5 Which type of architecture should be applied?
6 What is the required sensitivity of the measurand?
7 What about noise behavior?
8 What is the required common-mode rejection ratio?
9 Which kind of ergonomic layout is best?

This book covers a large number of topics encountered in the design, application and verification of electronic measurement systems. The system is considered to be composed of three parts: the *input* stage, the *modifier* stage and the *output* stage. Each stage can be treated separately.

In the first four chapters a general picture is presented of measurement architectures, structures, the tools used to describe systems and implementation of components. Further system specifications are discussed in detail and illustrated with many examples. The remaining chapters discuss topics of major importance to the proper functioning of a system.

Not all subjects could be covered in the same detail here, mainly due to limitations of space. As will be recognized, attention is devoted to subjects that are usually not found together in one book. Often it is these aspects that ultimately determine if a system can operate within its stated specifications.

For several years, the material on which this textbook is based has been used for graduate and undergraduate students in electrical and electronic engineering with a basic knowledge of electronics, but of course some topics discussed have a much broader application than to electronics systems alone. For the sake of completeness, and to make an introduction more easy, some topics which may be assumed to be well known are also discussed here.

The contents of the chapters may be summarized as follows:

Chapter 1 is devoted to basic ideas of measurement systems, such as what information is and why it is preferred to handle information electronically.

Chapter 2 considers measurement architectures and structures. This includes functional structures, signal, spatial and automated structures.

Chapter 3 is devoted to the available tools, such as the Bode plot, the polar plot and the pole-zero plot and the relationships between them. Further implementations of frequently applied functions are presented. These implementations cover analog functions, analog-to-digital and digital-to-analog conversion and some miscellaneous functions. Under this last heading a new integrated bridge is discussed.

Chapter 4 is devoted to general and more specific technical system specifications. All the usually met technical specifications are presented with their meanings and consequences. This includes a discussion of the common-mode behavior, linear amplification and the implications of feedback. Error definitions, classifications and calculations are also presented. After some error causes are introduced, some frequently applied improving measures are reviewed. The chapter concludes with a discussion of a microprocessor-based measuring system.

Chapter 5 provides a comprehensive introduction to reliability concepts, including the basic concepts and calculation techniques used in this area. Markov techniques are included as the most generally applied and powerful techniques for calculating reliability.

Chapter 6 is devoted to transducers or sensors and actuators for energy conversions to and from the electrical energy domain. Basic ideas, concepts and definitions are discussed in detail and a general review of most known energy conversion mechanisms is presented. The possibility of silicon and compatible technologies for the manufacture of transducers is also discussed.

Chapter 7 discusses aspects of offset and drift in basic electronic active components. The influence of temperature on bipolar transistors, FETs and differential input stages is treated in detail. Offset and drift are treated separately.

Chapter 8 is devoted to the problems concerning guarding and shielding systems from electromagnetic noise. With the increasing trend to handling all kinds of information electronically, the environment is charged with an ever-increasing electromagnetic pollution. Moreover, electronic measurement systems are highly sensitive to electromagnetic interference and effective precautions should be taken to avoid these influences. All kinds of preventative remedies are discussed in detail. The influence on the common-mode rejection ratio of sources of interference is also discussed.

Chapter 9 presents a discussion of noise calculations. It is not necessary to have a detailed knowledge of the physics of noise for this, and it suffices to use only the specifications of the manufacturer. The theoretical discussion is left to the following chapter.

Chapter 10 treats the physics of noise in three important noise mechanisms and the noise behavior of the active components to be met in electronics today, such as the bipolar transistor and the field-effect transistor.

Finally, **Chapter 11** is devoted to human engineering or ergonomics. Some interesting aspects concerning man–machine relations are presented, in particular the ergonomics of the visual and auditory organs for the presentation of information.

Almost every chapter can be read independently from the others; hence a flexible presentation of subjects can be realized. The consequence of this approach is that some details are repeated in different contexts, but this can only improve understanding. Besides this, every chapter is provided with examples and exercise material.

It will be clear that writing a book is a tremendous task and cannot be realized without the help of others. I therefore would like to thank all the persons who have given advice directly and indirectly in the preparation of this book.

Special thanks are due to the following persons: Jim Sherwin of National Semiconductor Corp. for his permission to use material about noise calculations. I am also indebted to A. W. Wijkman, P. J. van den Akker and K. E. Kuijk from Philips Corp. for their permission to use relevant material concerning shielding and guarding. I also want to thank Paul A. M. Maas of Delft University Press; Paul P. L. Regtien and Prof. Simon Middelhoek, both of Delft University of Technology, for providing material about transducers and related topics. Special thanks are due to Dr Mark Browne of University of Manchester Institute of Science and Technology for his careful reading of the manuscript and his valuable advice.

Last but not least, I express my gratitude for the everlasting patience of my wife Ria and the influence of my sons Michel and Maurice on this book.

A. F. P. van Putten
Eindhoven
1988

CONTENTS

One

INTRODUCTION TO ELECTRONIC MEASUREMENT SYSTEMS

Ever since human beings began to think, we have exchanged information and have given measures to quantities in an attempt to understand our surroundings. We appear to have a basic curiosity about and a need to investigate our environment. We recognize this with our senses, but our natural capacities are limited, so we have developed tools to help us fulfill our measurement needs.

In a continual process towards perfection, we are still refining our tools to improve our understanding of all kinds of mechanisms. Often models are shaped which describe more or less accurately the real world. This requires collecting information about the environment, a system or a process. Knowledge is related to information and, with collected information concerning a system or a process, we can increase our knowledge. This is a continuous story of interaction: model-making and performing measurements and vice versa.

1.1 INFORMATION

The word 'information' is interpreted as a type of arrangement or regularity which can be recognized in the environment, for instance, the letters on a page show a certain regularity and the message involved is recognized by the sequence in which the letters have been printed.

Information content is implemented in the order in which the letters appear on the paper, and a limited quantity of information is conveyed. If the same letters appear at random, however, all information is lost and interpretation is no longer possible. The amount of information has become zero. This example explains why it is said that information always involves a certain amount of regularity. Put in a reverse way, every regularity contains a quantity of information. Here order and disorder or information and chaos are each other's opposites.

This interrelationship, between information and chaos, was first shown by Shannon, who connected the idea of information to entropy. In accordance with the second law of thermodynamics, entropy increases in a closed system towards a maximum which corresponds with the minimum amount of energy in that system. Hence, entropy is defined as a measure of chaos.

Information can be quantified, which is what information theory is about. In this discipline, even the smallest amount of information is defined. Information can be represented in different forms, but it is always bound to a certain type of energy carrier or mass.

Five different types of energy carriers can be distinguished: radiation, electrical or magnetic energy, heat, chemical energy and mechanical energy.

Today everyone is familiar with the fact that information can be measured, handled, stored, retrieved and represented, depending on its application and requirements demanded of it. Besides this, information can be converted from one energy form into another by so-called transducers.

Our world is a very complex one with a tremendous amount of information available, coming from all kinds of processes and physical mechanisms, often so complex that it is not possible to understand all collected information directly. A good example of such a process is the climate, which is very complex indeed. If statements have to be made about the weather, a lot of data are collected concerning temperature, pressure, humidity, wind velocities and directions at different heights and so on. Finally, we make a weather forecast, which always involves a certain amount of uncertainty. This uncertainty is a basic characteristic of every statement which is based on data collected by measurement techniques. The reason for this may be that the process is too complicated, or the way the data are collected is imperfect, or the amount of data collected is insufficient.

In the above example, this uncertainty is quite obvious, but errors are inherent in every measurement technique. The result is that we create an image of part of the world with a limited amount of information. However, despite this implicit imperfection, measurement remains the heart of science and technology and without it no progress can be made.

The first thing to do when performing measurements is to characterize the type of process needed to investigate and determine the physical parameter(s) which are to be measured. This means criteria must be formulated for every measurement concerning type, response time, accuracy, etc. After characterizing the process, decisions can be made concerning which type of measurement will be applied, and then collection of data can begin. After the collection of the data we have to analyze, synthesize and evaluate the measurements. Finally an interpretation and check of the results must follow.

Collecting data corresponds with receiving information about the system or process. As more information is received, uncertainty concerning the system is decreased.

Two different kinds of information have to be distinguished. Firstly, in the process under consideration, the type of information must be recognized. This concerns the characteristics of the process. It is a qualitative description of the information involved and describes what sort of energy is present. This is called the *structural* information of the process. Secondly, the magnitude or intensity of the relevant characteristics must be discovered, for instance, scaling factors concerning