PRECISION FREQUENCY CONTROL

Volume 2

Oscillators and Standards

Edited by
Eduard A. Gerber
Arthur Ballato

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Preface

The editors take pleasure in presenting this two-volume work on precision frequency control. The title encompasses the spectrum of frequency-determining and frequency-selective devices, subject to the constraint imposed by the adjective. A simple circuit consisting of an inductance and a capacitance can function as a frequency-controlling element. Its precision, however, is completely insufficient for modern electronic equipment. Different physical phenomena must be utilized to meet today's requirements. The discussion and explication of these phenomena and their applications are the main purposes of these books.

The aims are twofold: first, to offer a concise compendium of the state of the art to researchers and specialists engaged in a rapidly expanding and complex field of technology. It will enable them to work efficiently in their fields and to develop devices that meet the requirements of the equipment and systems engineer.

A second purpose of the books is to furnish information concerning properties and capabilities of frequency-control devices to users of these devices, such as equipment and systems designers. The volumes will also be very useful for technical managers who will be able to find, in a single publication, a description of the world of precision frequency control, written by experts, and an entree to the full literature of the field.

The idea of these books originated several years ago when the editors recognized that the literature in the field of frequency control was increasing at an explosive rate and that it would be extremely difficult, particularly for a novice in this field, to attain without guidance an essential level of knowledge in a reasonable time. Another incentive for compiling this text is the fact that there is no single book available on the world market that treats all precision frequency-control devices and allows the reader to weigh the advantages or disadvantages of the various technical approaches against one another.

The number of experimental observations and theoretical investigations in the field of precision frequency control has increased steadily over the past 60 years and has led, particularly during the past few years, to a deluge of original publications that is becoming more and more difficult to absorb in its totality, even for the trained specialist. In view of this, our aim is not to attempt to offer a textbook on the subject, but rather to provide a tutorial and coherent treatment of the more recent developments in the field, supported by an extensive literature reference list covering approximately the past fifteen years. The individual chapters are written by experts in their respective specialities. The editors feel that the fundamentals of this field, starting with the seminal works of the Curies, Voigt, Cady, Townes, Ramsey, and others, are very well represented in older textbooks and in many voluminous review papers and handbook articles whose titles the reader will find in the bibliography.

The material of the work is presented in two volumes, ''Acoustic Resonators and Filters'' (Volume 1) and ''Oscillators and Standards'' (Volume 2). The reader will find in the introduction to the bibliography, included in both volumes, some suggestions on how to use the chapter bibliographies to best advantage. The 16 chapters of the text can be read independently of one another. Their topics have been chosen to maximize the readability of the book, with lengths governed jointly by the number of publications pertinent to each chapter and by the importance the editors attach to each topic, although obviously it is impossible to discuss in the text all of the more than 5000 publications referenced. The selection of specific areas discussed is to a certain extent subjective, but we feel that they give a good indication of the overall progress in our field.

The reader will find glossaries of letter symbols—whenever necessary—at the beginning of each chapter and, in certain instances, introducing a section. These characters, as well as graphic symbols used in the book, correspond as much as possible to those specified in the following IEEE Standards:

IEEE 260	1978	Letter Symbols for Units of Measurement
IEEE 280	1968	Letter Symbols for Quantities Used in Electrical Science and Electrical Engineering
IEEE 315	1975	Graphic Symbols for Electrical and Electronics Diagrams
IEEE 176	1978	Piezoelectricity
IEEE 177	1966	Definitions and Methods of Measurement for Piezoelectric Vibrators

Copies of these standards may be obtained from The Institute of Electrical and Electronics Engineers, 345 East 47th Street, New York, New York 10017.

The editors wish to express their sincere thanks to the authors of the various chapters for their cooperation and enjoyable collaboration, the editorial and production staffs of Academic Press for their patience and support, Mrs. Carolyn

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Introduction

The history of precision frequency control provides a good example of how technological maturity follows upon the prior accomplishment of scientific groundwork. The foundations of modern frequency control began with discovery of the piezoelectric effect by the brothers Curie in 1880, which found theoretical treatment in Voigt's classic book (1910). Founded on these accomplishments, the development of devices using the piezoelectric effect started during World War I and has proceeded since at an accelerating rate. Quartz crystals used for frequency control developed from rather simple, unevacuated, pressure-mounted units of the 1920s and 1930s to the present highly sophisticated plated units operating in ultrahigh vacua with temperature-compensating or temperature-controlling arrangements. Influences of the environment, such as mounting structure, pressure, and acceleration, have been greatly reduced by using doubly rotated crystal plates. Similarly, great progress has been made in the development of frequency-control devices based on atomic or molecular processes since Essen built and described the first cesium-beam frequency standard in 1957. They have progressed from the original 8-ft giant to the currently commercially available equipment of modest size and weight.

It is no accident that the flowering of our field has coincided with the advent of the space age. No stretch of the imagination is required to see the demands placed on oscillator stability by rocket and satellite environments; and in few applications is the need for precision so severe. Concurrently, similar requirements were imposed in the fields of communication and guidance systems, both commercial and military. For instance, systems for frequency- and time-division multiplex communication, satellite-assisted positioning, as well as remote surveillance and collision avoidance, would be impossible without precision frequency-control and timing devices.

In the dozen years from the launching of the first artificial satellite about the earth to the first manned lunar landing, the frequency-control field and its correlate areas of selection, signal processing, timing, and time distribution experienced an enormous period of development and growth. The advances made during this time turned out, in retrospect, to be only a prelude to the developments of the next decade. The interval following the first Apollo landing initiated what might justly be called the golden age of frequency control. The editors made no predictions as to the extent and duration of this exciting period—certainly it is continuing; but one may well question if we shall soon see a decade in which the development of both accuracy and precision will experience such favorable conditions as have been met within the area of frequency control.

The attribute ''precision'' in the title restricts the contents of this work to those devices whose Q value and frequency stability far exceed that of an ordinary LC circuit. Consequently, the reader will not find ceramic resonators and filters discussed. Material on polycrystalline and similar devices is included only if it bears on the behavior of high-Q devices (e.g., the theory of vibration of anisotropic bodies). On the other hand, superconductive LC devices with their high Q are properly included. One other remark regarding selection of material is pertinent: The main application of bulk-wave monocrystalline devices is to frequency control, whereas surface-acoustic-wave devices are being used in many other fields. We therefore discuss the fundamental properties of bulk-wave devices and their materials to a fuller extent. As far as surface-wave monocrystalline devices are concerned, only those aspects of material and resonator properties considered pertinent to precision frequency control are covered.

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