

# Preface

FOR centuries only mathematicians were interested in the problems of the approximation of real numbers, such as  $\pi$ , with rational fractions. However, with the advent of the modern age, practical applications were born. At the end of the seventeenth century, Huygens introduced continued fractions as a tool for the design of gear boxes, the real *mechanical synthesizers*, in his planetarium. During the Industrial Revolution, the problem became a concern for mechanical engineers who now confronted the practical restrictions posed by their hardware.

A new era began when electronic systems applied basic mathematical operations (addition, subtraction, multiplication, and division) to frequencies. After earlier simple frequency multipliers, mixers, and dividers, real *frequency synthesizers* were designed. In recent years, the perfection of these devices with the help of digital integrated circuits has resulted in fresh investigation of the problem of the approximations of real numbers.

For nearly two centuries, mechanical synthesizers—which change the angular velocity of the driving engine into the desired speed of the working shaft, that is gear boxes—were designed with the assistance of simple continued fractions. Because of practical limitations, the desired approximation was often too large. However, with experience engineers learned that many other suitable approximations were possible and they compiled tables. This approach was not possible with electronic frequency synthesizers. Reinvestigation of the problem with the assistance of computers resulted in finding an exact solution for both gear boxes and frequency synthesizers. Another incentive for modern direct digital frequency synthesizers\* was the rapid technological progress made in the field of integrated circuits.

After arranging the material for this book, dedicated exclusively to DDFS, we finally decided to present a collection of reprinted papers with a few specially written articles. Our purposes were twofold: to provide a useful textbook for students seeking essential background theory; and to help practicing engineers obtain a better understanding of actual devices, without the prerequisite of a specialist's knowledge of the theory. In addition, we wanted to provide a collection of often cited papers.

Based on these considerations, we have divided the monograph into eleven parts.

Part I is an introduction into the problem.

Part II is dedicated to the theory and design of single-frequency DDFS and the new general approximation theorem useful for mechanical and electronic synthesizers.

Part III acquaints the reader with the principle and the state of the art of wide-range DDFS.

\*Please note that the acronym for *direct digital frequency synthesizers* is either DDFS or DDS; both are used in this book and in the literature.

Parts IV and V collect papers dealing with the problems of spurious signals in DDFS, with Part V devoted to the possibilities of reducing these troublesome phenomena.

Since the range of the output frequencies of DDFS is limited (at present below 1 GHz), the extension of their advantages (such as the tuning speed, very small frequency steps, small weight, and low power consumption), to higher frequencies is possible. However, application of direct multiplications or mixing is practical in a limited number of cases only, but the assistance of *phase-lock loops* (PLLs) provides simple and elegant solutions. The basics of the PLL theory and combinations with DDFS are discussed in Part VI.

In some applications the knowledge of DDFS output phase noise may be needed. Therefore, after a general introduction into the problem, Part VII summarizes some practical, hard-to-find published results.

Digital-to-analog converters (DAC) on the one hand form one of the most important building blocks of DDFS and on the other hand limit speed resolution and spectral purity. For these reasons, Part VIII discusses their construction and properties at some length.

Parts IX and X briefly review the present state of the art, with several new ideas in designed DDFS.

The monograph concludes with Part XI which contains two specially written papers by the editor. Included is an explanation of a theory of quasiperiodic omission of pulses with a mathematical background. In addition, the editor provides several computer programs useful for theoretical investigations of DDFS properties.

We apologize to the many authors of valuable papers and articles which we had to leave out of the collection because of inevitable space limitations. To provide at least a partial remedy, we mentioned some of them in the introductions to the individual parts and in the references.

Finally, the editor would like to thank the IEEE Press for publishing this volume, as well as the IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society for its support of this enterprise.

My thanks are also extended to the Institute of Radio Engineering and Electronics of the Academy of Sciences of the Czech Republic for its generous support of the present work.

The editor would like to express his gratitude to the unknown reviewers for their efforts, particularly to those who read all the specially written parts with such great attention and suggested many useful improvements.

Since this work also contains much new matter, we hope that it will be a useful textbook.

Věnceslav F. Kroupa  
Prague, September 1998