PROCEEDINGS OF THE IEEE

Scanning the Issue

Time and Frequency

Nearly two decades have passed since the first special issue of the PROCEEDINGS on Time and Frequency (May, 1972). In reviewing the contents of that earlier issue, we saw no reason to change appreciably the format for this issue. The scope therefore ranges from work in the laboratory to large scale international collaboration. Let's take a quick tour, now, of this issue.

In Section I, "Time and Frequency: An Overview," the first of three papers (Quinn) gives insight into timekeeping at the international level, while the second paper (Sullivan and Levine) broadly reviews the scientific and technical environment in today's timing community. The third paper (McCarthy) reminds us that the business of timekeeping has not passed entirely from the hands of astronomers to physicists—from telescopes to atomic clocks. Together these three papers cover the broad spectrum of activities mentioned previously, and they also provide a foundation for the more technical papers that follow.

The next three sections are concerned with the nuts and bolts of timekeeping: the clocks and frequency standards themselves, the analysis of the signals generated by these devices, and the distribution of these signals. The first section in this group, Section II, "Generation of Time and Frequency," contains four papers which provide us, first, with historical perspective (Ramsey), second, with a down-to-earth guide to the operation and varieties of frequency standards (Lewis), and, finally, with two papers bringing us up to date on the latest concepts for new frequency standards.

At the turn of the century, the heart of a clock, the device that determined its ticking rate, a frequency standard, was based on what we might call macrotechnology—swinging pendulums and oscillating balance wheels. As our understanding of the microworld improved, it became clear that the natural oscillations of atomic particles promised orders of magnitude improvement in our ability to keep time. That promise was fulfilled with the development of atomic frequency standards in the 1950's. This microtechnology continues today. However, recent work (Itano) shows that clocks based on ions trapped in electromagnetic fields portend, as did the first atomic clocks, orders of magnitude improvement. A companion paper (Rolston and Phillips) reviews the prospects for another kind of standard based on what is called the "atomic fountain." Atomic fountain frequency standards have better signal-to-noise ratios than ion standards, but suffer from larger systematic effects.

The next section in this nuts and bolts triad, Section III, "The Statistical Characterization of Frequency Standards," contains two papers which show why conventional statistical methods have not worked when applied to characterizing frequency standards. The first paper (Rutman and Walls) outlines the two main approaches to characterizing frequency standards: the so-called "time domain" and "frequency domain" approaches. The paper concludes with a detailed discussion of the time domain approach. Historically, the time domain approach blossomed first because it required relatively simple calculations, based on easily made measurements, to statistically characterize a frequency standard. The second paper (Percival) focuses on the frequency domain approach which provides a complete characterization of frequency in a mode which may be more intuitively appealing in systems engineering. Some of this frequency domain characterization may be computationally laborious, but advances in computer technology eliminate this disadvantage.

The last section in this group, Section IV, "Advanced Techniques for Time Coordination and Dissemination," contains four papers. The first three of these papers describe approaches that depend on artificial earth satellites for their implementation, while the last paper describes promising optical techniques depending on both satellites and optical fibers.

Now, as in the past, improvements in time coordination and dissemination are intimately related to advances in navigation systems. Twenty years ago the Loran-C navigation system was the backbone of international time coordination. Today it is the Global Positioning System (GPS), a satellite based navigation system providing position fixes to meters in minutes.

But communication satellites also play an important role. The first paper in this section (Sen Gupta, Hanjura, and Mathur) describes an operational satellite time broadcast service—essentially the traditional time broadcast with a virtual transmitter high above the earth. The second paper (Kirchner) describes a satellite based time comparison technique which routinely supports time comparisons to nanoseconds over intercontinental distances. This technique

U.S. Government Work Not Protected by U.S. Copyright

will likely replace GPS for international timekeeping in the next few years.

The third paper (Lewandowski and Thomas) describes GPS for time coordination. When GPS first became available, it provided a quantum leap in time coordination with little or no effort on the part of the user. But, as usually happens, workers realized that with more sophisticated analysis techniques even greater accuracy could be wrung from GPS. This paper describes the level of time coordination these more sophisticated techniques have effected.

The fourth and last paper in Section IV (Leschiutta) describes what will probably be the technology for the best time coordination techniques of the future—optical signals traveling though space and through fibers. Limited work has been done to date in this area but, as the paper shows, the work that has been done shows that optical techniques have great promise.

Section V is titled "Emerging Needs for Accurate Time and Frequency." The first paper (Wilson) describes the need for accurate time coordination in the generation and distribution of electric power. This subject has become especially important as we now, almost daily, more fully realize how important it is to effectively use our energy resources. As the paper points out, we can not only increase the efficiency of our present electric power systems with a liberal dose of time and frequency technology, but also that the same technology is an important ingredient in new electric power systems.

The last paper in this section (Kartaschoff) describes the need for accurate time in communication systems. Time and frequency technology has always played a major part in telecommunications. When the first broadcasts came on the air, frequency standards were needed to keep radio stations on their assigned frequencies. Later, sophisticated analog frequency modulation schemes required cheap and reliable frequency standards for their implementation. Today the world is moving from analog to digital forms of communications. Here, as this paper shows, the demands on time and frequency technology are greater than ever.

The last section in this special issue, Section VI, "The Scientific Needs for Accurate Time," contains five papers. The first (Winkler) is concerned with a subject that was almost exclusively of academic interest a few years ago: relativity theory. This paper gives the reader an introduction to the concepts of both special and general relativity—particularly as they apply to time coordination. This introduction creates a framework for the papers that follow and furnishes the reader the necessary background to appreciate the need for the concepts and formulas of relativity theory in today's emerging electronic systems—especially systems operating over large expanses of space.

The next paper (Vessot) describes several scientific experiments requiring highly stable oscillators. It is clear from this paper that technology has advanced to the point where concepts of relativity theory can be tested in a number of ways.

The third paper (Taylor) in Section VI is concerned with one of the most intriguing astronomical discoveries of this century: pulsars. A particular class of pulsar—the millisecond pulsar—spins at rates of thousands of radians per second, emitting radio signals that are comparable in stability to the "ticks" from the best atomic clocks. This paper describes the role pulsars might play in time and frequency technology. It is perhaps ironic that we are once again looking to the sky for our timekeepers.

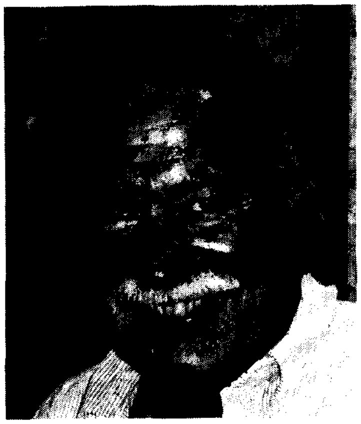
The next to last paper in this special issue (MacDoran and Born) discusses the development of space geodetic systems—important tools in our attempt to understand the evolution of the atmosphere and oceans—particularly as they pertain to the problem of global warming. Here we see time and frequency technology as a strong supporting player throughout.

Our last paper (Petley) shows that because time and frequency are the most accurately measured physical quantities, it is desirable to tie other physical quantities to time and frequency measurements. Here you will find a review of the progress that has been made in this direction along with speculation on possibilities for the future.

Of course, as with any discipline embracing a broad variety of subjects, it is not possible to cover in a limited number of pages every subject that might be of interest to every reader. And that certainly is true here. Nevertheless we hope that the casual reader will gain from these pages a notion of the role that time and frequency plays in almost every facet of science and technology and that those of you who wish to pursue the subject in more detail will find here enough background and references to allow you to dig as deeply as necessary.

As a final note, we have included in this issue, at the request of the National Communications System, a revised Federal Standard concerned with the interoperability of telecommunications systems of the U.S. Government. It establishes how the Federal Government should utilize, for telecommunications facilities and systems, time and frequency information based upon Coordinated Universal Time.

James Jespersen and *D.W. Hanson*, Guest Editors
National Institute of Standards and Technology
U.S. Department of Commerce
325 Broadway
Boulder, CO 80303-3328



James Jesperen *(Fellow, IEEE) is physicist on the staff of the Time and Frequency Division of the National Institute of Standards and Technology. In 1956 he joined the Radio Propagation Physics Division of the National Bureau of Standards where he worked in the areas of radio astronomy, ionospheric research, and radio propagation. From 1962 to 1963 he was a Visiting Scientist at the Radio Research Laboratory, Slough, England, where he was engaged in theoretical investigations of the propagation of very-low-frequency radio waves. During 1971 he was a Department of Commerce Fellow where he worked on telecommunications policy issues. In May, 1972 he was Guest Editor of a special issue of the PROCEEDINGS OF THE IEEE devoted to time and frequency. Since that time he has been involved in a number of projects including closed captioning for the hearing impaired, participation in several national and international organizations concerned with time generation and coordination, acted as a consultant to the International Telecommunications Union, and both led and participated in the development of satellite time dissemination systems.*

Mr. Jespersen is the author or coauthor of over 90 scientific papers and has coauthored six books. He is a member of Sigma Xi and Sigma Pi Sigma and received the Exceptional Service Medal from the Department of Commerce.

D. Wayne Hanson *(Fellow, IEEE) received the B.S.E.E. degree from the University of Colorado, Boulder, in 1959 and the M.S.E.E. degree from Stanford University, Calfornia in 1961.*

From 1959 to 1961 he worked on MASER's and parametric devices at Lockheed Missile and Space Company. He joined Ford Aerospace in 1961 and worked on satellite tracking and communications systems. Between 1963 and 1979, while with the National Bureau of Standards, he worked in radio propagation, radiometry, noise, millimeter waves, and time and frequency metrology. From 1979 to 1981 he was with the National Telecommunications and Information Administration and directed projects concerned with satellite communications and with supporting the Department of Commerce's role as coexecutive agent with the Department of Defense in fulfilling Presidential Directive 24. Since 1981 he has been with the Time and Frequency Services Group of the National Institute of Standards and Technology where his work has focused on the development of satellite based time transfer systems. He became the group's chief in 1984.

Mr. Hanson is a member of Eta Kappa Nu and Tau Beta Pi. He is a Registered Professional Engineer in the State of Colorado. He received the M. Barry Carlton Award of the IEEE, the Industrial Research Magazine's IR-100 Award, and the Exceptional Service Medal from the Department of Commerce.