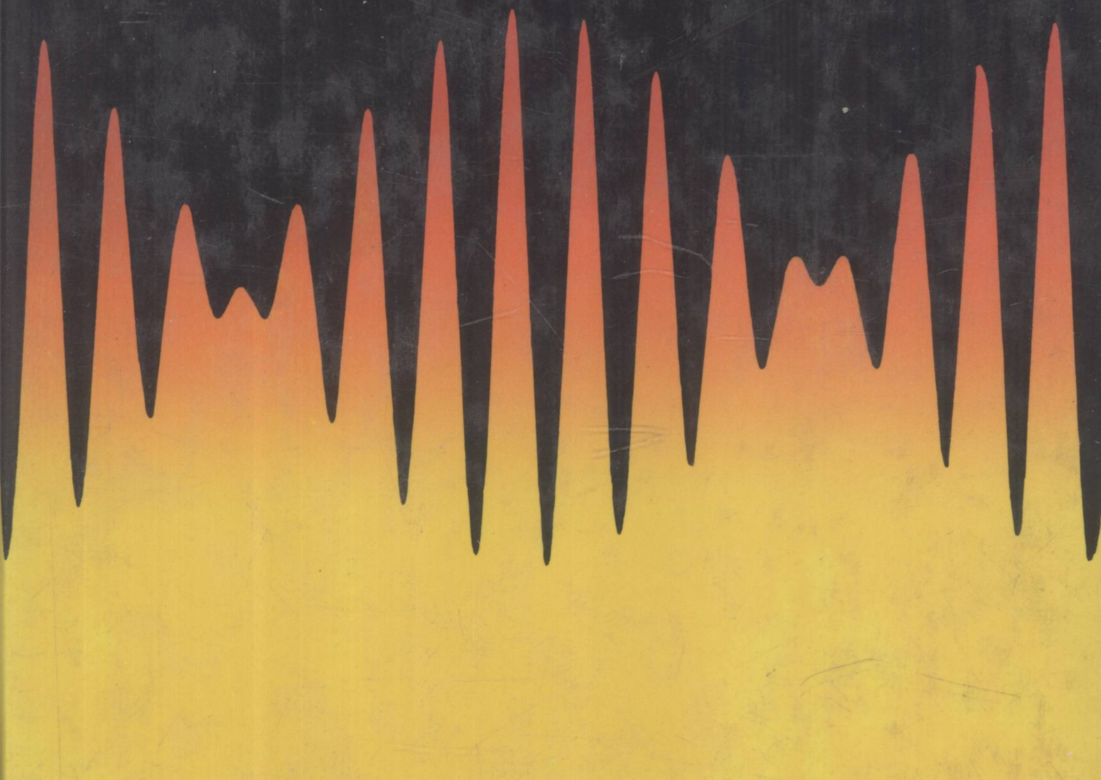
SINGLE-SIDEBAND SYSTEMS & CIRCUITS

Edited by William E. Sabin & Edgar O. Schoenike



Single-Sideband Systems and Circuits

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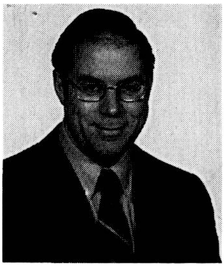

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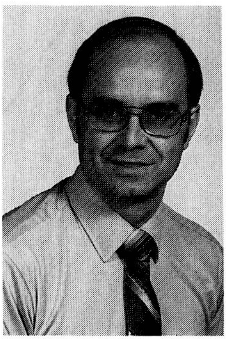
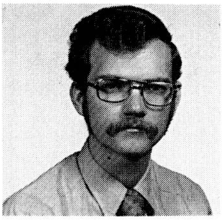
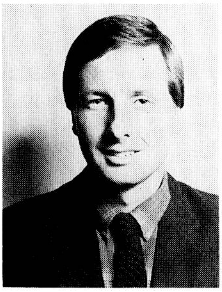


Rodrick K. Blocksome MSEE, Kansas State University, 1973. Manager of HF Power Amplifier Group, Rockwell-Collins Defense Communications, since 1981; Air Force officer, 1969–1972, communications system design. Designs HF power amplifiers and systems integration. An expert on PA protection and spurious emission reduction. Holds one U.S. patent.

Warren B. Bruene BSEE, Iowa State University, 1938. Staff Engineer, Electrospace Co., since 1984; Senior Engineer with Rockwell-Collins, 1939–1984. Registered P.E., Texas; Fellow of the IEEE, 1961 "for Advancing SSB Radio Communication"; IEEE Section Chairman, 1962; Rockwell DaVinci Medal, 1982, for engineering excellence; Engineer of the Year, Texas Professional Engineers Society, 1975; listed in *Who's Who in Engineering* and *Leaders in Electronics;* awarded 22 U.S. patents.



David H. Church BSEE, Iowa State University, 1974. Project Design Engineer, HF Products Dept., Rockwell-Collins Defense Communications; joined Rockwell-Collins in 1974. Registered P.E., Iowa. Involved with design, development, and support of HF receivers, exciters, and receiver/exciters.



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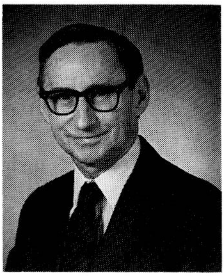
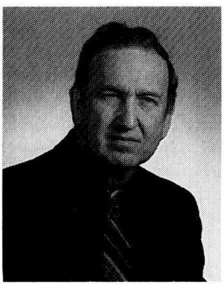


Robert L. Craiglow BSEE, Ohio State University, 1947. Systems analyst and consultant in the area of radio communications techniques since 1947. Widely experienced and recognized in the design and analysis of data communications, modulation, signal processing, and speech processing; awarded 11 U.S. patents. Previous experience in oscillator and vocoder design; has performed pioneering work in digital signal processing analysis and design.



Sylvan L. Dawson BSEE, Kansas State University, 1954; MSEE, Kansas State University, 1960. Project Engineer in the HF Engineering Dept., Rockwell-Collins Defense Communications; joined Collins Radio Co. in 1956; Radio Officer, U.S. Army, 1954–1956. Has been in charge of design of HF preselectors, receivers, and transceivers; awarded four U.S. patents.

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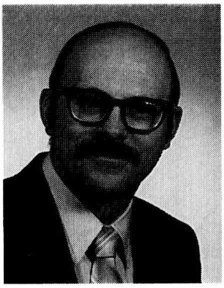
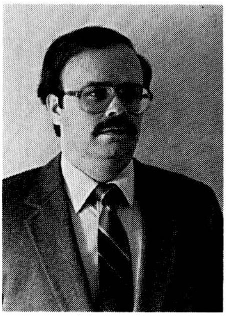
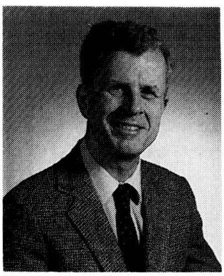


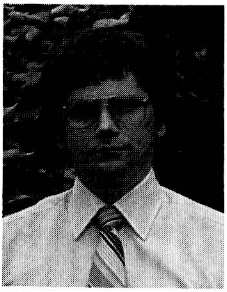
Marvin E. Frerking BSEE, University of Missouri, 1958; MSEE, University of Iowa, 1964. Group Manager, Advanced Technology Dept., Rockwell-Collins Defense Communications. Supervises the application of new technology to the design of communications equipment; author of *Crystal Oscillator Design and Temperature Compensation,* 1978, and co-author of *Precision Frequency Control,* 1985; member of Frequency Control Symposium Program Committee for 8 years; member of four honorary technical societies; awarded 12 U.S. patents.



Richard A. Groshong BSEE, University of Minnesota, 1976. Design Engineer, Advanced Technology Dept., Rockwell-Collins Defense Communications, since 1977. Involved in the design of HF SSB receivers and exciters and digital signal processing for a variety of applications in digital radio equipment.

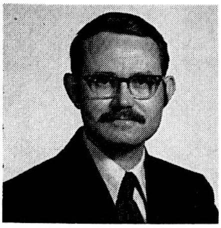


David B. Hallock MSEE, Worcester Polytechnic Institute, 1954. Technical Staff Member, Advanced Technology Dept., Rockwell-Collins Defense Communications, since 1954. Responsible for analysis and design of receivers over the frequency range 2 to 400 MHz; received Rockwell DaVinci Medal, 1984, for engineering excellence; awarded four U.S. patents. Has served as a consultant on a large number of difficult company projects.

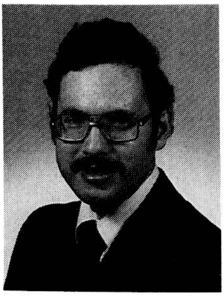


Stephen J. Harmening Attended University of Iowa and Iowa State University, 1965–1982. Designer of microprocessor and digital control software and hardware for digitally controlled radio equipment since 1965.

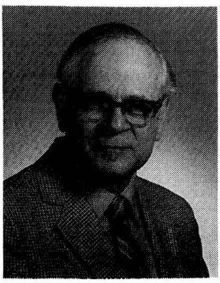
James V. Harmon BSEE, University of Missouri at Rolla, 1966. Program Manager for SELSCAN equipment at Rockwell-Collins Defense Communications. Awarded three U.S. patents.



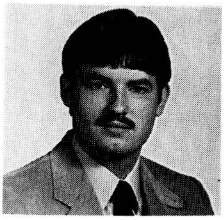
Bill D. Hart BSEE, Iowa State University, 1972; MSEE, Iowa State University, 1982. Design Engineer in the Advanced Technology Dept., Rockwell-Collins Defense Communications, since 1972, participating in equipment design. Registered P.E., Iowa; holds commercial and amateur FCC licenses; member IEEE.



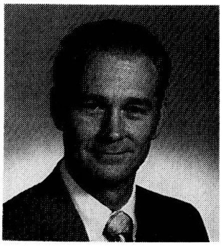
Wayne A. Kalinsky BSEE, Iowa State University, 1966. Design Engineer and project leader in power supply technology in the HF Equipment Design Dept., Rockwell-Collins Defense Communications, 1966–1971 and since 1973. Awarded two U.S. patents.



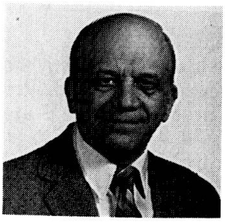
Donald E. Phillips MA, University of Wisconsin, 1949. Synthesizer Design Engineer in the Advanced Technology and Engineering Dept., Rockwell-Collins Defense Communications, since 1973. Awarded five U.S. patents. Has developed numerous contributions in the areas of direct digital synthesis (DDS), phase discriminators, and computer-aided analysis.



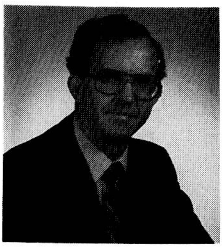
Edward G. Silagi BSEE, University of Illinois, 1978. Technical Staff Member in the HF Product Design Dept., Rockwell-Collins Defense Communications, since 1980. Responsible for the design of solid-state linear amplifiers; awarded three U.S. patents. Highly experienced in the design of ultralow distortion power amplifiers.



Glenn R. Snider BSEE, Michigan Technological University, 1966. Design Engineer in the HF Antenna Coupler Group, HF Product Dept., Rockwell-Collins Defense Communications, since 1966. Concerned with antenna coupler design, network theory, and control system theory, and design. Awarded two U.S. patents.

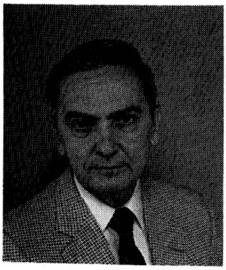


Joseph A. Vanous BSEE, University of Iowa, 1949. Joined the Collins Radio Research and Development Division in 1949. Technical Staff Member in the HF Products Design Dept., Rockwell-Collins Defense Communications; U.S. Army, 1943–1946. Participated in the design and development of early SSB radio equipment. Awarded four U.S. patents.

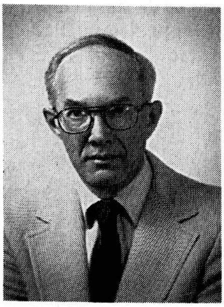


William R. Weaverling BS in Physics (with distinction), Indiana University, 1963. Synthesizer and RF Design Engineer with the Advanced Technology Dept., Rockwell-Collins Defense Communications, since 1965. Involved in low noise, fast tuning synthesizer design and research for HF, VHF, and UHF equipment.

About the Editors



William E. Sabin is a Design Engineer in the Advanced Technology Department, Collins Division, Rockwell International, Cedar Rapids, Iowa, where he has been working since 1964. He received the MSEE degree from the University of Iowa and is widely experienced in HF receiver and exciter design, synthesizer design, power supplies, spread spectrum techniques, and digital design.



Edgar O. Schoenike is Senior Technical Staff Member in the Advanced Technology Department at Rockwell and holds five U.S. patents. He received the MSEE degree from Iowa State University, and has completed all course work for the Ph.D. (EE) degree. He was a coauthor of SINGLE SIDEBAND PRINCIPLES AND CIRCUITS, McGraw-Hill, 1964.

Preface

It was 23 years ago that McGraw-Hill published *Single Sideband Principles and Circuits,* by E. W. Pappenfus, W. B. Bruene, and E. O. Schoenike. Since then many changes have occurred in the components, circuits, and systems analysis used in SSB technology. In 1964 transistors were just beginning to become dominant in low-power amplifiers and oscillators, while vacuum tubes still reigned supreme for medium- and high-power amplifiers. Integrated circuits were just beginning to be used in SSB equipment, and microprocessors were unknown. The development of these new electronic components has led to new circuits, greater flexibility in design, and more sophisticated equipment control.

One aim of this book is to incorporate an explanation of the developments that have taken place in the design of SSB equipment while retaining explanations of those techniques which have withstood the test of time. Thus, solid-state power amplifiers and power supplies are discussed in detail, but advances in high-power vacuum tube amplifiers are not overlooked. Similarly, balanced diode mixers and modulators, instead of being superseded, are used today perhaps more widely than ever before, and so are also fully covered.

This book was written at the level of the practicing engineer, although it will be appreciated by the engineering student and advanced amateur as well. Most explanations are intended to be practical in nature, but the theoretical basis of SSB is treated in some detail, design principles are not overlooked, and, when relevant, performance tradeoffs are discussed. However, only amplitude modulation SSB is discussed. Angle-modulated single sideband is beyond the scope of the book.

Special emphasis is placed on the system analysis and system design of the SSB communications link. The cost and complexity of modern communications equipment and systems are such that accurate estimates of performance, prior to commitment of resources, are essential.

Greater sophistication in design has led to specialization, and it is therefore appropriate that a large number of experts in specialized areas should contribute to this book. It is almost impossible for one person to completely master all of the disciplines involved; therefore the editors have gathered together some of the leading equipment designers and analysts from the Collins Division of the Rockwell Corporation to contribute chapters in their fields of specialization.

Besides the chapter authors, the editors give special thanks to our engineering colleagues for their ideas and contributions to this book, and to Rockwell International for its permission to publish.

We also owe a special debt to the many secretaries who contributed their spare time to the word processor typing chores.

In chapters where multiple authors appear, names are listed in alphabetical order.

One final note: Recognizing as we do the important and growing role of women in the sciences, every effort has been made to use gender-neutral language in the writing of this book. In the single instance of "specsmanship," however, no generally recognized gender-neutral equivalent exists; thus the term should be taken in a purely generic sense, intended to apply to both women and men.

WILLIAM E. SABIN
EDGAR O. SCHOENIKE

This book is the result of a difficult and comprehensive team effort by many members of the Engineering Staff of the Collins Divisions of Rockwell International. It is dedicated to them and to all the employees, past and present, of the Collins Divisions of the Rockwell International Corporation on the occasion of the fiftieth anniversary of the founding of the Collins Radio Company.

Contents

Chapter

1

Overview of Single Sideband

William E. Sabin

1.1 The Radio Link

The principal task which confronts a radio communications link between two or many mutually distant points is to provide, within the framework of a limited available transmitter power, reliable, high-quality communication. Very often, real-time voice contact is desired. Opposing this goal are the inimical characteristics of the radio frequency (RF) spectrum. Among these are noise from the ionosphere and the galaxy, artificially produced electrical noise, severe variations in the received signal strength (fading) which are observed over time spans from milliseconds to hours or days, propagation disturbances, interference from other users of the spectrum, and multiple arrivals of the signal along different paths. Interference caused to other users is aggravated by technical limitations in transmitter spectral purity and directional antenna design. Interference experienced from other users is increased by deficiencies in receiver design and receiving antennas. One especially difficult mode of interference is between transmitters and receivers which are in close proximity (colocated). Also involved here is the creation of false signals (intermodulation or IM) due to nonlinearities within the colocated environment.

The approach to reliable communication used by radio engineers is to obtain from a given amount of available transmitter power the maximum amount of intelligibility of a speech signal or the minimum error rate of a digital signal (at the distant receiver) under the conditions described above. Two important constraints in this design are the conservation of bandwidth and time. That is, the spectrum in use very often requires a small ratio of RF bandwidth to baseband message bandwidth in order to accommodate a large number of users. Also, the time used to transmit a message is very often required to be nearly the same as the duration of the original message; in this situation the amounts of redundancy and encoding available must be small. An equivalent statement is that the ideal communication channel, in the sense described by Shannon [1], is, in most near-real-time situations, not approached. In practice, voice or digital messages usually contain inherently high levels of redundancy or predictability, except for key elements which may be repeated several times by a good operator.

One of the principal system design approaches used is to select a method of modulation which is optimal within the environment and the constraints described above. For real-time speech communication, from 10 kHz to 250 Mhz, and in recent times up to as high as 10 GHz, the use of single-sideband (SSB) suppressed-carrier (or quite often reduced-carrier) modulation has provided a very satisfactory answer. A long period (65 years) of analytical and experimental investigation has proven the efficacy of this method, especially in the high-frequency (HF) band, which is a difficult arena.

A further consideration in situations where the volume and weight of the transmitter are critical is that SSB is competitive with narrow band frequency modulation (FM), in terms of communications effectiveness for a given weight and size. The results of recent studies will be considered in later sections. SSB also is a decisive improvement, in nearly all respects, over high-level double-sideband amplitude modulation (AM).

One of the costs involved in SSB, as compared with AM, is the additional complexity of the receiver vs. the conventional low-cost AM broadcast receiver. Various responses to this will be considered in this book. In the transmitter, the need for large amounts of linear amplification of the RF signal is a technical and economic burden.

The development of phase-locked loop (PLL) techniques has opened up many uses of reduced-carrier SSB, where the reduced pilot carrier provides frequency-locked and phase-locked reception and serves other functions. The improvements in frequency synthesizer design and low-cost, portable frequency standards have made SSB practical at much higher frequencies than were possible a few years ago.

A further enhancement of SSB has been the development of speech processors which utilize the peak power capabilities of the transmitter more effectively by compressing the dynamic range of human speech, thereby increasing the average power. The Lincompex system and other companders have the ability to restore the original dynamic range at the receiver, providing a telephone-grade signal. Vocoder and other techniques which help to reduce bandwidth with no appreciable loss of intelligibility have been undergoing a continuous development.

In long-distance HF (2- to 30-MHz) communication, a major problem is to locate a favorable frequency very quickly and automatically tune to it (automatic connectivity). The extensive application of microprocessor technology has produced highly programmable, remotely controllable radios