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Single Sideband Systems & Circuits

SECOND EDITION

William E. Sabin and
Edgar O. Schoenike,
Editors

Single Sideband Systems and Circuits

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Preface to the Second Edition

Since the publication of the first edition, several important advances in SSB technology have occurred:

1. The technology of link establishment has become a major topic in HF SSB communications. A new chapter is dedicated to that subject.
2. The use of digital signal processing has advanced. Integrated circuits and design algorithms have made great strides.
3. The use of MOSFETs in power amplifier design has become widespread.
4. The use of the personal computer for the design and simulation of circuits and for systems analysis has become a fact of life for design engineers.
5. There is an increasing interest in the use of pilot carrier SSB in various applications. The widespread manufacture of special integrated circuits and design methods for personal communication systems, such as cellular telephones, has implications for low-cost SSB equipment.
6. Recent equipment designs such as the Spectrum 2000 are excellent examples of the union of the SSB radio with the personal computer.
7. Recent receiver design methods, such as direct conversion, are becoming more useful as digital processing becomes more cost-effective and more efficient.
8. The embedding of digital circuitry and sensitive analog receiver circuits in the same framework has created new philosophies regarding electromagnetic compatibility.

This second edition provides coverage of all these topics in sufficient detail to enable the design engineer and the advanced amateur experimenter to get started in these various subjects. Many other subjects in the various chapters have been expanded and modernized.

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Preface to the First Edition

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 a 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 trade-offs are discussed. However, only amplitude modulation SSB is discussed. Angle-modulated single sideband is beyond the scope of this 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.

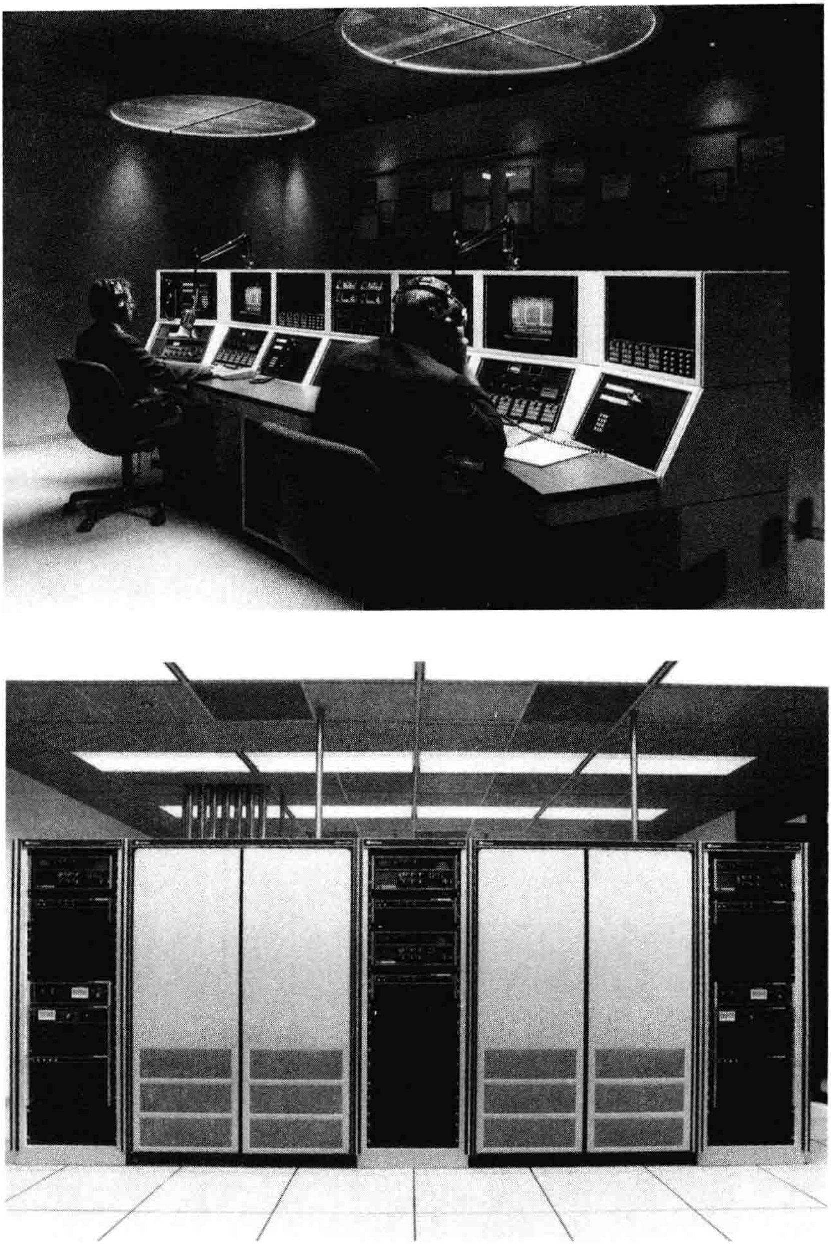
We also owe a special debt to the many secretaries who contributed their spare time to the word processor typing chores.

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 Division of Rockwell Corporation. It is dedicated to them and to all the employees, past and present, of the Collins Division of the Rockwell Corporation on the occasion of the fiftieth anniversary of the founding of the Collins Radio Company.



A

B

Figure I.1 The Rockwell HF SSB Comm Central station in Cedar Rapids, Iowa. (A) The operating console with Collins 651S SSB receivers and Rockwell computers, attended by two operators, 24 hours a day. (B) The SSB transmitter/receiver rack consists of four 10-kW and three 1-kW units. A remote-controlled, unattended station in Newport Beach, California, is accessed by a dedicated telephone line. Automatic link establishment (ALE) computer programs are used extensively. A 20-acre antenna farm contains 13 HF antennas.*(David G. Berner)*

Contents

Chapter

1

Overview of Single Sideband

William E. Sabin

1.1 The Radio Link

The principal task that 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) that 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 that are in close proximity (collocated). Also involved here is the creation of false signals (intermodulation or IM) due to nonlinearities within the collocated 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 that may be repeated several times by a good operator.

One of the principal system design approaches used is to select a method of modulation that 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 (75 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 narrowband 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. Single sideband 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 versus 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-lock 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 that 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 that help to reduce bandwidth with no appreciable loss of intelligibility have been undergoing 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 link establishment or ALE). The extensive application of microprocessor technology has produced highly programmable, remotely controllable radios that combine with recently perfected techniques to produce orders of magnitude of improvement in HF link reliability. Link quality analysis (LQA) quickly determines the ability of the selected channel to support message transfer.

In very recent years the revolution in digital signal processing technologies has been applied to SSB receivers and transmitters to produce levels of performance and flexibility (programmability) that are setting new standards in radio design. Also, developments in high-power, solid-state transistors and circuit design have revolutionized linear power amplifier (LPA) design. The development of ultralinear power amplifiers using feedforward techniques promises to reduce transmitter distortion products by two or three orders of magnitude. Improvements in high-power, fast-tuning vacuum tube amplifiers are described in this book. Advanced measurement techniques for high-performance receivers and transmitters have been developed. The design of antenna couplers used in SSB transmitters has been elevated to a high level of sophistication. To complete the discussion, recent developments in intermediate frequency (IF) filters and tunable bandpass filters for SSB equipment are covered.

1.2 Overview of SSB Equipment

The transmitter

Figure 1.1C shows a block diagram for a complete SSB transmitter that uses the filter method of generating the desired wave. A baseband signal $f(t)$ has a spectrum $F(\omega)$ which is shown in Figure 1.1A. For the purpose of this discussion, it is often preferred, but not essential, to use the concept of a *two-sided* spectrum shown in Figure 1.1B, where the physical signal is decomposed mathematically into two coherent, complex conjugate segments, one of which is at a fictitious "negative frequency."

This $f(t)$ is multiplied in a balanced mixer by the local oscillator (LO) wave cos $(2\pi f_0 t)$. The spectrum at the mixer output, Figure 1.1D, is therefore the convolution of $F(\omega)$, the spectrum of $f(t)$, and the spectrum of the LO, shown at Figure 1.1E. Observe that although the balanced mixer output contains very little carrier, the phase noise impurities in the LO are transferred to the output signal in the form of amplitude sidebands, as shown. These often tend to establish the maximum in-band signal-to-noise (S/N) ratio of the desired transmitter signal.

The narrowband filter passes accurately one of the sidebands and sharply attenuates the other sideband, the carrier frequency, high and low speech frequencies, wideband LO noise and other noise, and spurious emissions from the low-level stages of the transmitter. Therefore this filter is a critical item in the design. Alternative approaches that attempt to eliminate this filter are considered in Chapter 2.

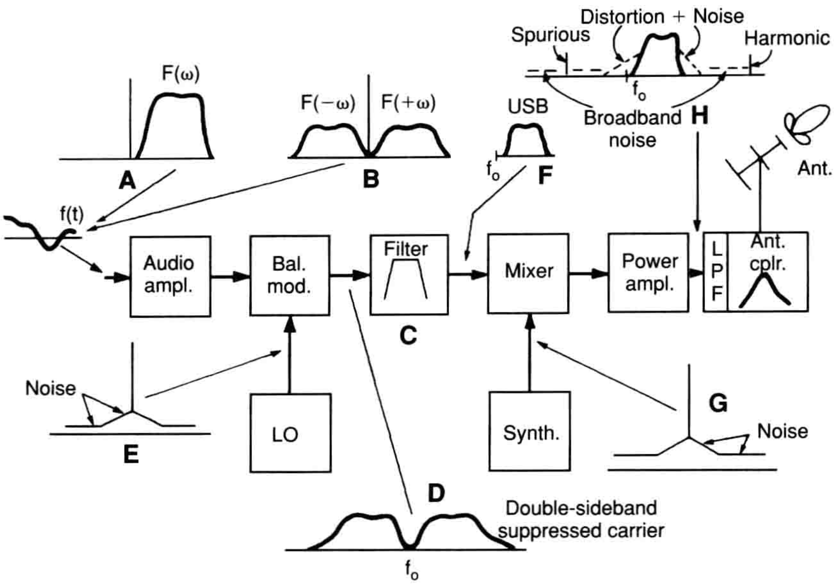


Figure 1.1 Block diagram of an SSB transmitter. Parts (A) and (B) show the baseband signal as one-sided or two-sided spectra; (D) is the double-sideband suppressed-carrier signal; (F) is the filtered SSB signal which is amplified, contaminated, and filtered as it moves to the antenna; (H) is the output of the PA; (E) and (G) show the contaminated local oscillator signals.

Following the filter, amplification, frequency translation, speech processing (to increase the average power), and power amplification occur. During these processes, LO contamination, amplifier noise, out-of-band and in-band distortion products, and discrete spurious frequencies and harmonics are added to the desired signal. These spurious emissions either degrade the desired signal or are a source of interference to other users, especially those who are collocated or on closely adjacent or certain other frequencies. At the output of the transmitter, the impedance of the antenna is transformed to the desired power amplifier (PA) load impedance, and band filtering is also performed. Adjacent transmitters must be electrically isolated from each other to prevent interactions between their outputs. The antenna tries to focus the energy on the desired destination.

The design challenge for the transmitter can thus be defined: to provide accurately the required power output with levels of fidelity, frequency stability, and undesired emissions that are acceptable to the user, and to provide as much communications effectiveness as possible. The desired usage may require that a carrier signal be wholly or partially inserted if needed.

Other aspects of the design are weight and size restrictions, temperature rise, reliability, and duty cycle. Furthermore, the equipment may