SINGLE-SIDEBAND RECEIVERS

by

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OVER THE PAST twenty-five years, the growth of radio communication by use of single-sideband techniques has been "slow but sure." As early as 1922, Hartley[1] discussed the "Relations of Carrier and Sidebands in Radio Transmission." But, the separation of the sidebands from the carrier wave and from each other . . . and their separate use for radio communication was not seriously undertaken until a decade later. In 1933, Reeves[2] reported on "The Single-Sideband System applied to Short Wave Telephone Links." Two years later in the Proceedings of the Institute of Radio Engineers, Polkinghorn and Schlaack[3] described "A single-Sideband Short Wave System for Transatlantic Telephony." The study of single-sideband techniques became quite widespread in the ensuing years.

RETARDING FACTORS REMOVED

Widespread adoption of single-sideband communication systems was retarded for some years by the size and complexity of the equipment and the requirement of extreme frequency stability. Techniques are presently available, however, for securing adequate frequency stability. At the same time electromechanical filters, new phasing systems, transistors, and modular assemblies are reducing the size and complexity of the circuits and equipment. Currently, then, the retarding factors have been largely removed.

One purpose of this paper is to describe a modern system of frequency generation, stabilization, and control of such accuracy that it is unnecessary to transmit any carrier at all for demodulation or synchronization purposes. Another purpose is to describe a receiver design which has been successfully used over a wide range of high frequencies for long-distance reception of single-sideband transmissions.*

REASONS FOR CONSIDERING SSB

Single-sideband communication systems were first adopted to relieve an over-crowded radio spectrum resulting from the rapid growth of radio communications for commercial, military, and amateur uses. It was recognized that the bandwidth of radio frequencies required for communication by a single-sideband system was only half as great as that needed for the conventional double-sideband transmissions. At the same time, studies of the fading of amplitude modulated radio signals over long distances revealed that the fading was frequency selective. The carrier was found to fade intermittently, compared with one or the other of the two sidebands. Further, the sidebands would fade with respect to one another.

On radio waves, modulated to 100% by audio-frequency signals, the selective fading of the carrier with respect to the sidebands produced over-modulation. This resulted in the existence of distortion in the audio signals recovered from the transmitted wave by demodulation at the receiver.

Distortion of the phase relationships of carrier and sidebands due to multipath transmission is fully as serious as direct relative amplitude changes. Both of these troubles are avoided by use of single-sideband communication except for a possible slight amount of selective fading within the one sideband itself.

ADVANTAGES OF SSB

Of course, the inherent advantages of narrower bandwidth and relative freedom from selective fading still exist in single-sideband communication today. Now, others are also recognized.

A third advantage is that an interfering signal near the desired frequency is less troublesome than that of conventional AM transmissions. With a suppressed carrier SSB transmission, no carrier is present at the receiver to heterodyne with the interfering signal. A fourth advantage (compared with AM) is the marked decrease in power needed from primary sources at the transmitter for a given radiated power. This power gain has been indicated by various writers to be in the order of 12 to 15 db, depending upon the transmission conditions.

The single-sideband system decribed here incorporates all of these design features.

SSB FREQUENCY STANDARD

A special feature of this SSB system is that it uses separate master frequency standards at both transmitting and receiving stations of such accuracy that frequencies equal to those

* Also see RCA ENGINEER, Vol. 1, No. 6; Design of Single-Sideband Radio Communication Equipment by N. L. Barlow.

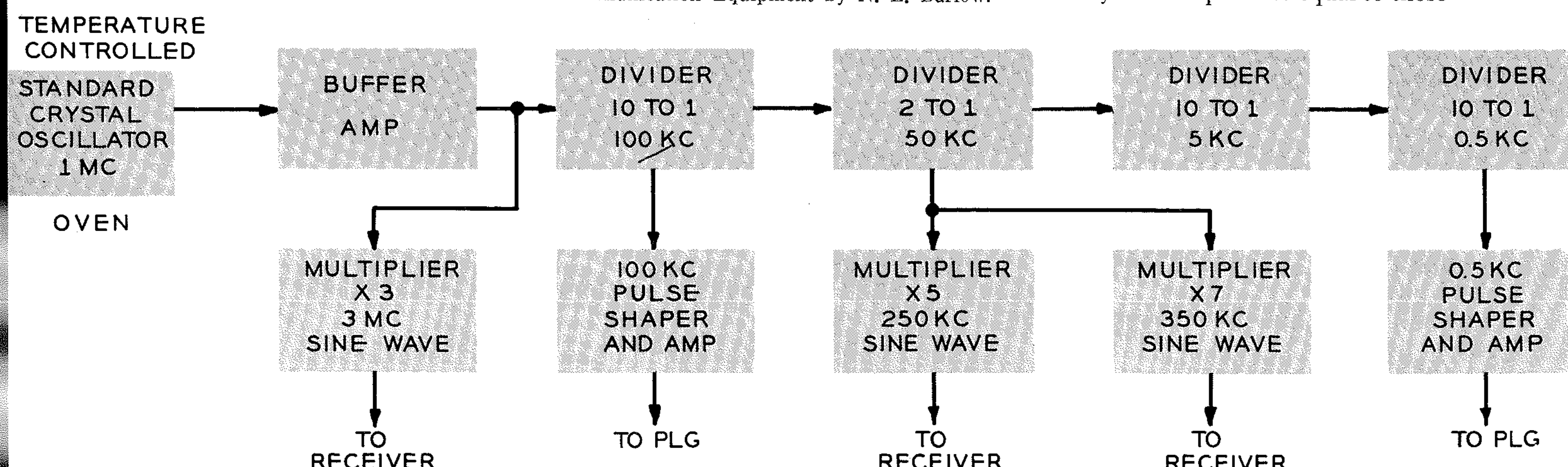


Fig. 1—Block diagram of the RCA-developed Frequency Standard for the Single Sideband system.

Fig. 2—Block diagram of the Pulse Locked Generator (PLG) which supplies accurate phase-locked frequencies.

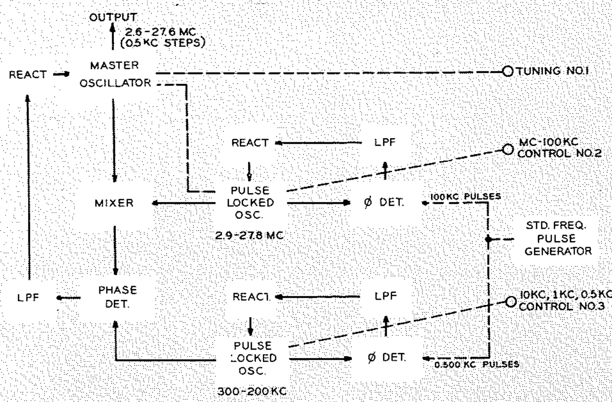


Fig. 3—Panel view of the Pulse Locked Generator.

at the transmitter can be generated locally at the receiver, without necessity of synchronizing signals from the transmitter. The frequency standard at both stations is a 1-megacycle, highly-stabilized crystal oscillator, "oven-controlled." Each standard is accompanied by the necessary number of frequency dividers, multipliers, and pulse shapers to produce the required standard radio frequencies as well as pulsed output signals. Signals are precisely spaced pulses, of 100-kc and 0.5-kc repetition rates, used to "lock" the frequencies of the Pulse Locked Generator. The "standard" frequencies are the 3-mc and 350-kc standard injection frequencies and the 250-kc local carrier fed to the SSB demodulators.

A block diagram of the Frequency Standard developed by RCA is shown in Fig. 1.

The basic unit of this frequency standard is a 1-mc crystal controlled Colpitts oscillator. The quartz crystal is supported on a shock and vibration-free, octal-base mounting enclosed in an evacuated glass envelope. Firmly clamped in its socket and mounted in an oven of accurately controlled temperature, this crystal controls the oscillating circuit, the pulse-locked generator, and the whole receiving system . . . *within one part in ten million,* under all conditions of shock and vibration.

The 1-mc output voltage of the frequency standard is passed through a buffer amplifier to a multiplying circuit and then a dividing circuit. The multiplier gives a standard reference 3-mc voltage which is fed to one of the mixers in the receiver. In the "divider" circuit, the standard frequency is accurately divided by 10, resulting in a 100-kc standard reference frequency. This is then fed to a 100-kc pulse shaper and amplifier. Sharp pulses from the latter are fed to the pulse-locked generator used with the receiver.

The output of the 10-to-1 "divider" circuit is further divided and multiplied so that 350-kc and 250-kc sinusoidal voltages are produced. These are fed to the receiver for conversion and demodulation. In a separate circuit, the 2-to-1 "divider" output is further divided, resulting in a 500 cycle signal, still accurately referenced to the 1-mc frequency standard. This passes through a pulse shaping circuit and thence to the pulse-locked frequency generator. It is now a train of pulses with a repetition rate of exactly 500 pulses-per-second.

PULSE-LOCKED GENERATOR

The pulse-locked generator supplies phase-locked frequencies held accurately to their required values. The pulses, with 100-kc and 500-cycle repetition rates, are the ones used for phase-and frequency locking of the pulse-locked generator (PLG) of Fig. 2.

The term "generator" means the production of signals of more than one frequency. The RCA pulse-locked generator contains three oscillators, as follows. Two are "locked" (or phase and frequency stabilized) by phase comparison of their output signals with the 100-kc and 500-cycle pulses obtained directly from the master Frequency Standard. Each is a conventional L-C oscillator, one with a 2.9-to-27.8 mc frequency range, and the other a 300-to-200 kc range. The output of each oscillator, the 100-kc pulses, and the 500-cycle standard-frequency pulses are fed to their appropriate phase detectors.

Now, if the phase of either oscillator output is different at arrival than it was when an earlier pulse arrived, the associated phase detector develops an output-error voltage. This voltage is of such polarity that, when applied to an oscillator-reactance tube or voltage-sensitive capacitive diode, transient changes are initiated in frequency and phase of the oscillator voltage, restoring the oscillator outputs to their proper values.

The third oscillator of the pulse-locked generator produces an output voltage that is mixed with incoming signals. A 2400-kc i-f mixer output signal results for all frequencies in the upper three bands of the receiver . . . and for the two lower bands an intermediate frequency of 600 kc is produced.

In each frequency-control loop of the pulse-locked generator, the d-c error voltage is passed through a low-pass filter to eliminate any spurious signal or hum voltage. This frequency-

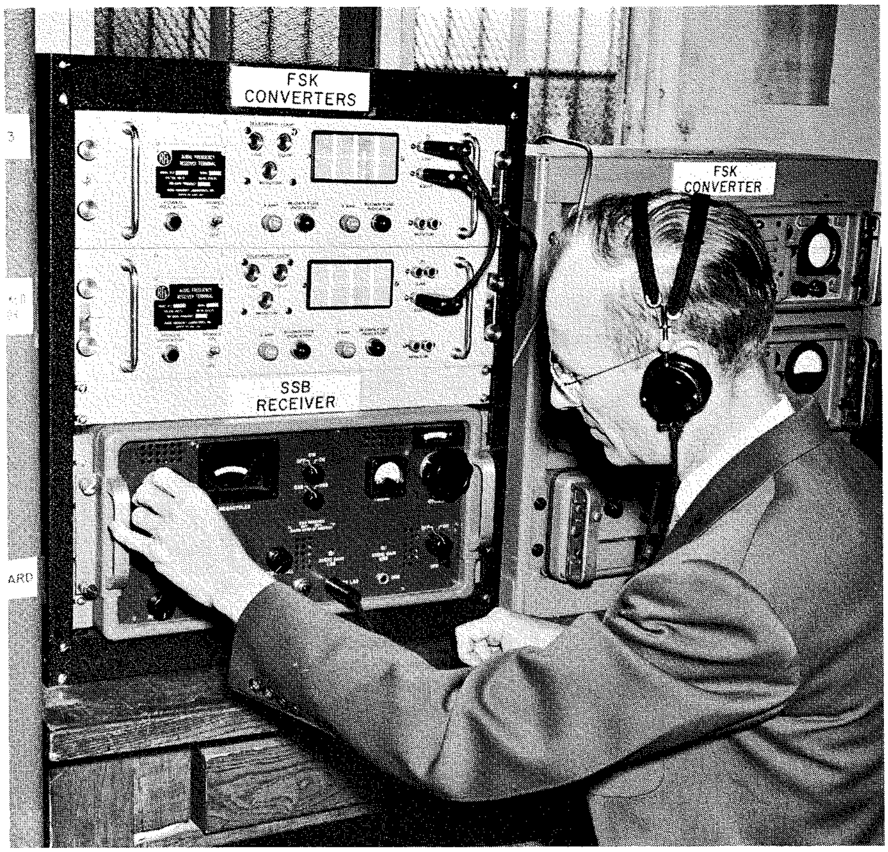


Fig. 4—The author tuning the SSB receiver.

control system has been tested under all standard prescribed conditions of shock and vibration. In no case have deviations of the system exceeded the prescribed goal of one part in ten million—or 3 cycles at 30 megacycles.

Fig. 3 is a photo of the Pulse-Locked Generator showing cabinet and front panel controls.

THE SINGLE-SIDEBAND RECEIVER

Several factors were involved in reaching a decision on the type of receiver to design and the types of communication service to be provided. With the limited time set aside for the project, it was decided not to attempt to design and build a packaged receiver as a final, fully developed model. However, a goal was adopted that the receiver must be capable of straightforward progression into a fully developed model, capable of meeting all military requirements such as vibration, shock, and extremes of temperature and relative humidity.

It was believed that for use by the Armed Services the receiver should be capable of single-sideband or twin-sideband operation with either partially- or fully-suppressed carrier, as well as possible use with conventional amplitude-modulated signals, i. e., double-sideband operation with full carrier, or continuous wave operation. The receiver should have low distortion in multiple-tone operation, good sensitivity, and freedom from cross-talk when operating in the vicinity of powerful transmitters. For some tactical uses, a SSB receiver for military communications would need only to operate on one sideband with completely suppressed carrier, and would be used primarily for speech communication. However, it was considered advisable to design the receiver to cover the greater variety of services mentioned above.

The final receiver (see Fig. 5) is capable of receiving single-sideband transmissions with or without carrier suppression, twin-channel single-sideband transmissions, conventional amplitude modulated signals, frequency-shift-keyed signals, tone-modulated continuous wave, or interrupted continuous wave signals.

The r-f amplifier has two tuned circuits ahead of the first tube, followed by two tuned stages using pentode tubes. As shown in the block diagram, the amplified r-f signal proceeds from the amplifier to the first mixer stage. Here, the correct frequency is injected from the pulse-locked generator when it is tuned to the precise frequency which, when mixed with the chosen incoming r-f signal, produces the correct i-f signal. The dials of the pulse-locked generator are calibrated to read the exact frequency of the desired incoming signal instead of the difference between it and the intermediate frequency to be produced in the mixer. In the r-f section of the receiver, any one of five sets of r-f coils may be chosen by the bandswitch on the front panel. The h-f range of 2-to-30 megacycles is thus divided into five bands: these are 2-to-4, 4-to-8, 8-to-14, 14-to-22, and 22-to-30 mc.

Single- or double-sideband reception may be selected from the front-panel function switch. In the case of double-sideband operation, this switch disconnects the upper sideband amplifier and passes the double-sideband signal through the same audio amplifier used for the lower sideband in SSB operation.

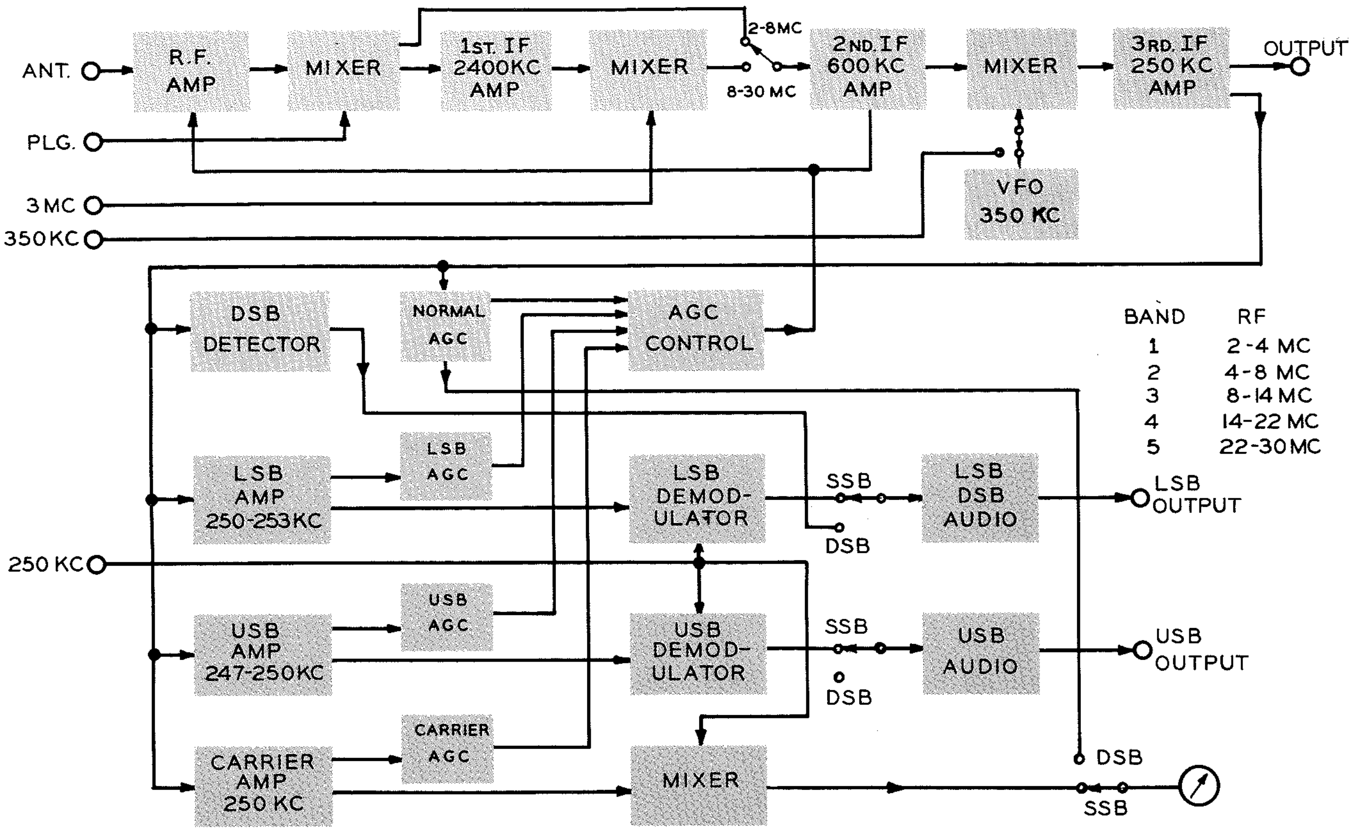
With the function switch in the SSB position, either sideband can be used for voice. Or, voice can be used in the upper sideband channel while multiple tone operation (with as many as sixteen frequency-shift-keyed (FSK) channels) is occurring in the lower sideband channel. Continuous wave (CW) signals can also be processed in the lower sideband branch.

A narrow band carrier amplifier is used primarily to supply a noise and modulation free carrier source of voltage for automatic gain control (AGC) when a partially suppressed carrier is transmitted.

CONVENIENT FRONT-PANEL CONTROLS

The completed communications receiver (see Fig. 4) was designed for companion control and operation with the Frequency Standard and Pulse-Locked Generator. The front-panel is arranged to provide maximum convenience for this type of operation. The function switches, allowing a choice in the class of reception, are in the center of the front panel. The wave bandswitch is seen at the center

Fig. 5—Block diagram of the SSB receiver.



left and the r-f tuning control and frequency dial on the upper left portion of the panel. Various degrees of carrier suppression can be compensated for by use of the front-panel carrier level control.

Selection of reception of upper-sideband transmissions, lower-sideband, or conventional AM are provided by jacks on the front panel. The tuning meter at the left of the VFO tuning knob indicates when a given radio transmission, not an exact multiple of 0.5 kc, is correctly tuned by the VFO.

GENERAL OBSERVATIONS

The following conclusions concerning the new receiver seem to be in order:

1. The mechanical design of the equipment uses the subassembly type of construction with modular construction for the tubes and associated components. The layout can very easily be adapted to printed wiring which would appear to be desirable in the final model design.

2. In the model built, miniature tubes were used in nearly all stages of the receiver. In a final model it would be possible and desirable to use transistors in much of the circuitry. Germanium diodes are used in the present model in the ring demodulators in order to obtain low distortion output in multiple tone operation.

3. Distortion in the audio amplifiers is minimized by the use of negative feed-back obtained by omitting bypass condensers for the cathode resistors.

4. Temperature control and voltage regulation of the plate and screen supply voltages are both used to obtain the desired stability in the operation of the variable frequency oscillator (VFO) when used.

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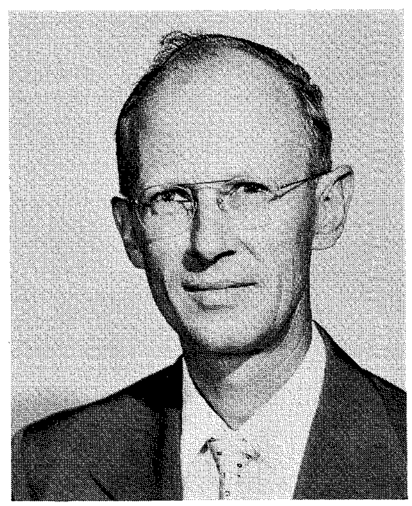

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Mr. Comfort joined RCA in 1940 and has been active in the Receiver Development Group since 1945, where he participated in the design and development of various communication equipments for the Armed Services. He was responsible for the design of the AN/SRR-16, a single sideband receiver for the U. S. Navy, and was recently promoted to his present position of Engineering Leader.