Commercial Single Sideband Radiotelephone Systems

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THE KEEN INTEREST that has been shown recently both in professional and amateur circles in the single-sideband method of radio transmission has focused attention on the early developments in this field including the choice of means for generating and receiving the signals. The present interest no doubt stems from the splendid service which these systems gave during the war and from the reports of the numerous men who became acquainted with them, coupled with a better appreciation, since the 1947 International Radio Conference in Atlantic City, of the possibilities of single sideband in increasing the potential number of channels which can be crowded into the spectrum.

New Developments

Considerable impetus to the widespread use of single-sideband systems can reasonably be expected to result from the development of such complete low-power, single-sideband radiotelephone systems as the *LE* system. This apparatus was specially designed by Bell Telephone Laboratories for point-to-point medium-distance applications.

Carson's Pioneering Work

The single-sideband method of transmission was born in the mind of John R. Carson by pure analysis as a result of his mathematical investigations of the operation of vacuum tubes.[1] Almost simultaneously H. D. Arnold discovered the possibility in connection with tests of the Arlington transmitter in 1915. For a considerable period thereafter the physical reality of sidebands was vigorously argued by some engineers.

Experiments of Thirty Years Ago

The single-sideband method of transmission has been standard in Bell System carrier telephone equipment for nearly three decades.[2] The first published mention of the use of single sideband for radiotelephony, however, seems to have been made by Espenschied in 1922.[3] About 1922 an experimental single-sideband radio system was set up with a transmitter operating at about 60 kc located at Rocky Point, Long Island,[4] and publicly demonstrated on Jan. 5, 1923. This system was put into commercial service between New York and London in 1927 and is still in operation, being, as far as is known, the first single-sideband radio system to be used commercially. The large size of the antenna structure required for efficient radiation at such a low frequency made it difficult to obtain a broad

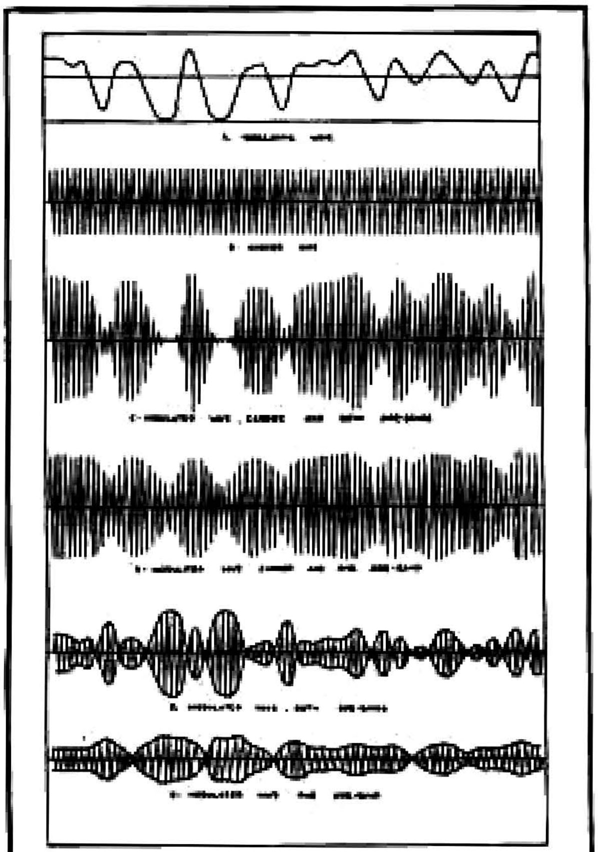
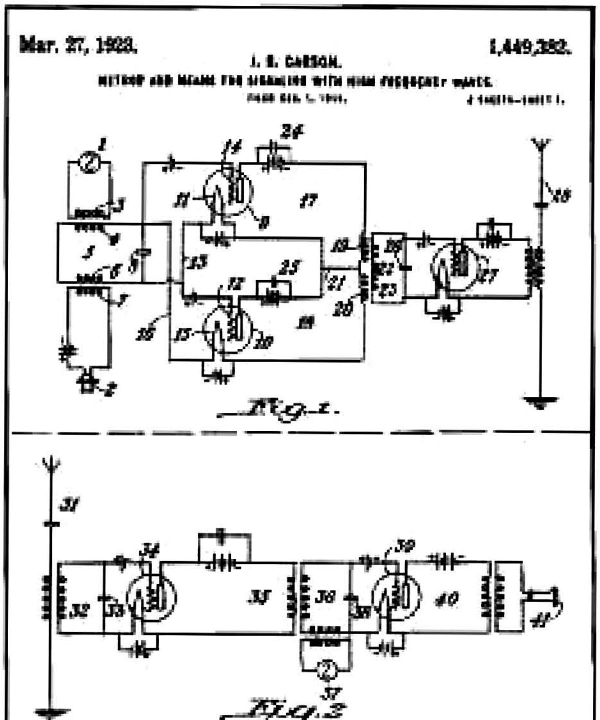


Figure 2

Carrier modulated by speech waves; at bottom, single-sideband pattern. (*Taken from the paper on carrier by Colpitts and Blackwell, A.I.E.E.; 1921.*)

Figure 1

Portion of one of John R. Carson's original patents showing application of the combination of balanced modulation for suppressing the carrier, and output filter for stripping off one sideband.



Single Sideband Systems, Which Have Had an Unusually Interesting Developmental History Since 1915, When the Method Was Used in a Transmitter at Arlington by H. D. Arnold, Now Being Applied To Solve Many Current Transmission Problems. One Procedure, Designed for Point-To-Point Work in the 3.4 to 25 and 2.7 to 14 mc Bands, Provides 200 Watts Peak Envelope Power, With Ranges of 200 to 2500 Miles.

enough band for a good telephone channel and the use of single sideband made the problem much simpler by permitting the required band to be halved. Efficient operation of the system was imperative since a power of 150 kw or more was involved.

The early Bell System work on high frequencies (it was short waves in those days) wash done in the 1920's on double sideband but it was not long before the theoretical advantages of single sideband resulted in experiments with the same arrangement of suppressed carrier and hand-synchronized receiver which has recently been taken up by the amateurs. This work was done by Raymond A. Heising, who, in 1915, worked on the Arlington transmitter, the forerunner of all modern radiotelephony, and who invented the constant current system of modulation now so widely used.

The hand adjustment of the heterodyne frequency was not very practical however, and a few years elapsed before active work on the commercialization of single-sideband radiotelephony was taken up in earnest. In those years, the high-frequency double-sideband circuits were put in operation to many parts of the world and ship-to-shore telephony became a permanent commercial service.

In the late 1920's an unusual receiver was constructed at the Bell Laboratories with which to investigate the characteristics of single-sideband reception. This receiver occupied seven bays and used the first crystal filters to go in equipment of this kind. It was capable of receiving double-sideband transmissions and separating the sidebands and carrier for experimental purposes. Reconditioned and local carrier and automatic frequency control were provided so that it was possible to simulate almost any kind of reception. The results obtained with this receiver were in accordance with expectations and consequently designs for a single-sideband transmitter and a receiver for a transoceanic trial were initiated. Upon the completion of the transmitter it was taken to England and, in cooperation with the British Post Office, set up in their transoceanic transmitting station at Rugby. There followed extensive tests which confirmed that the theoretical advantages could be achieved in practice.[5, 6]

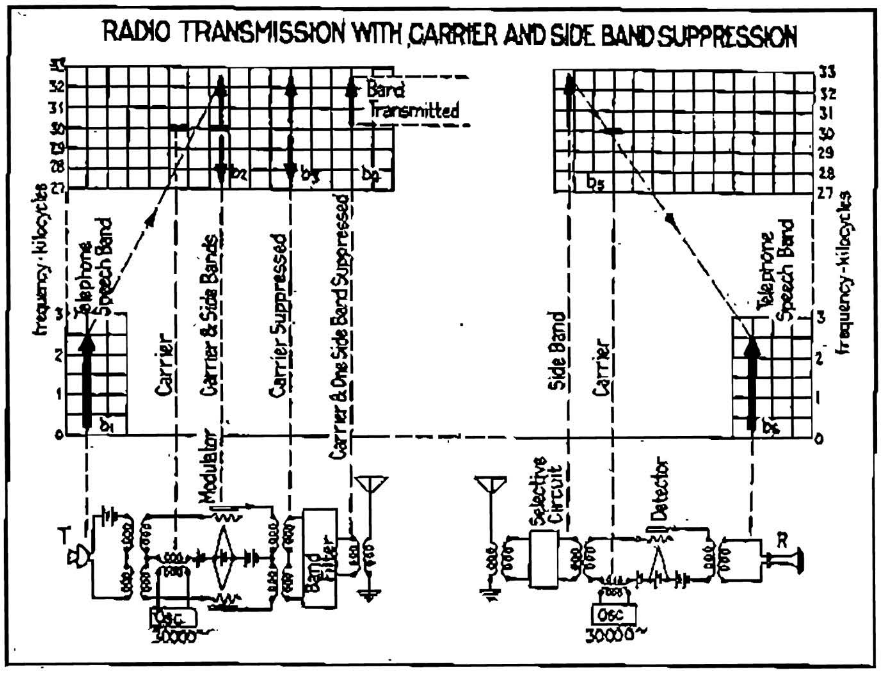
Comparisons with double-sideband transmissions were made on a basis of signal-to-noise ratio, articulation, and judgment tests. The articulation tests consisted of transmitting meaningless syllables and determining the errors in interpretation by a number of observers. After making corrections for differences in bandwidth, the signal-to-noise improvement checked the theoretical 9 db very closely. The number of articulation errors obtained also showed that the field strength of a double-sideband signal had to be 8 or 9 db stronger than a single-sideband signal in order to get equivalent results. Finally, judgment, or so-called circuit merit, tests gave approximately the same results.

The original equipment was put into commercial operation and in '36 redesigns were started for commercial production.[7, 8, 9, 10] In the following decade over 50 single-sideband circuits were set up in all parts of the world using this equipment.

During World War II the single-sideband equipment did particularly valuable service in connecting continental United States with the armed forces all over the globe. Multichannel teletype using two-tone operation with frequency diversity (4 tones total) was used in most cases with speech channels for special purposes.

The first commercial single-sideband equipment provided only a single speech channel, but it was soon determined that two channels could be obtained almost as easily as one by using two low-power modulators to place one channel on one side of the carrier and another on the other side of the carrier. Somewhat better performance was obtained by spreading one channel from the carrier so that modulation products generated by one channel would put less noise or crosstalk into the other. During the war years and shortly thereafter the need for more radiotelephone circuits caused

Figure 3
Early illustration of single-sideband transmission applied to radio, showing derivation of single band, and at receiver the reintroduction of the carrier.[3]



both channels to be spread from the carrier and a third divided the two sidebands; thus permitting three separate simultaneous conversations over the same equipment.

The 9-db transmission advantage of single sideband as compared with double sideband is explained entirely on the basis of amplitudes. It is assumed that the same *rf* power amplifier is used and the peak driving voltage is the same. This results in approximately the same distortion. Since the carrier represents half the peak amplitude of a fully modulated double-sideband transmission, reducing this to a negligible value permits doubling the amplitude of the sideband, an improvement of 6 db. The other 3 db comes from the reduction in noise at the receiver by reducing the received band to one-half, permitted by the elimination of one sideband at the transmitter.

In the commercial operation of single-sideband circuits the carrier is normally transmitted 26 db below the envelope peak amplitude. This permits the automatic tuning of the receiver, so that the receiver may remain in service hour after hour with little or no attention from the receiving-station operator, who may have a dozen or more receivers under his care. The reduced carrier is separated from the sidebands by a crystal filter which is only about 40 cycles wide. This filter reduces the noise to a point where automatic frequency control and automatic volume control can be obtained at as low signal strengths as the speech circuit remains commercial.

The *afc* device of the W. E. receiver* is frequency operated, i.e., it is operated by a beat note between the carrier at the final intermediate frequency and a local crystal oscillator. This beat frequency drives a motor connected to the beating oscillator frequency adjustment, either forward or backward, depending upon whether the carrier is too high or too low in frequency, until frequency of the beat note is reduced to zero. This system has the advantages that it is accurate, not sensitive to amplitude, and the absence of a carrier for a short period need not cause the oscillator frequency to move in one direction or the other.

Commercial single-sideband receivers are generally arranged so that either a carrier from a local oscillator or the transmitted carrier may be used for the final demodulation. Using the transmitted carrier has the advantage of insuring the proper frequency relationship between carrier and sideband, but requires an effective rapid-acting volume control or limiter to insure a constant amplitude of carrier. Using a local carrier insures an adequate amplitude at all times but requires a good *afc* system. Receivers can be built in which no difference can be detected between the two methods of demodulation.

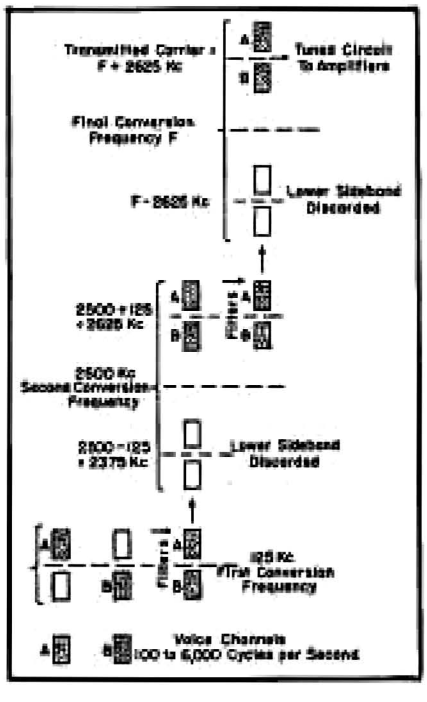
A single-sideband signal is generated by modulating a carrier with a sideband to produce a double-sideband signal and then either shaving off one sideband by a sharp filter or balancing out one sideband in a double modulator arrangement in which the carrier and sideband to one modulator are both shifted by 90°.

The basic idea of the balancing scheme was invented by R. V. L. Hartley** in 1928.[11] To this R. K. Potter** added the idea of obtaining separate speech channels on the two sides of the carrier[20] and E. I. Green** suggested the use for separating the two sidebands at the receiver.[18] Recently several companies have either used these methods or indicated their intention of doing so. The system is well suited for certain purposes. The suppression of the unwanted sideband depends upon phase and amplitude balances and may not be adequate for all purposes.

The telephone transmitters and receivers have used crystal filters for the purpose of eliminating the undesired sideband and interfering signals to a high degree. Crystal filters permit obtaining the desired selectivity at frequencies as high as 100 to 125 kc or more. With crystal filters operating at these frequencies only one intermediate modulation is required, generally operating around 2,800 kc. Crystal filters have the same advantage when used in single-sideband receivers. Even at 100 kc the filters may give 80 or 90 db attenuation at the end of the first 1,000 cycles outside the transmitted band.

Figure 4.

Application of single-sideband to short-wave transoceanic radiotelephony, showing the manner of deriving two independent speech channels, each occupying one of the sideband positions with respect to the high-frequency suppressed carrier. (From *A Twin-Channel Single-Sideband Radio Transmitter* by K. L. King, Bell Laboratories Record; March 1941).



The Bell System was not alone in recognizing the merits of single-sideband radiotelephony. The British Post Office worked hand-in-hand in establishing the North Atlantic circuits. Among those who made important contributions, A. H. Reeves of International Standard Electric did some major pioneer work.[14]. The Dutch were pioneer workers in the field and established a circuit between Holland and the Dutch East Indies at an early date.[20] The Japanese and Germans also constructed equipments.

At the present time a large proportion of the overseas telephone services operating from the United States use single-sideband equipment and the number of circuits is increasing yearly. With the production of simpler and cheaper equipment, it is expected that many of the services still using double-sideband transmission will be converted to single-sideband.

Typical of the modern trend to simpler, less expensive equipment is the *LE* system previously mentioned. This system was specifically designed to make available the important advantages of single-sideband techniques in an economical form for use in point-to-point radiotelephone services. It provides complete radio transmitting and receiving facilities, including the new *synchro-switched* speech privacy equipment which is built directly into the circuits of the radio units.

In addition to the transmitter and receiver, a versatile manually-operated telephone-control terminal is available as a part of the *LE* system. This control terminal includes all necessary control apparatus for connecting the transmitter and receiver to a conventional telephone system. Where a semi-automatic control terminal is desired to relieve the operator of constant monitoring during calls, a suitable control terminal may be substituted.

The *LE* system transmitter delivers 200 watts peak-envelop power and is ideally suited to the following applications:

(*1*) Satellite feeder circuits from remote points to higher pow-

* Model D-99941.
** Bell Labs.

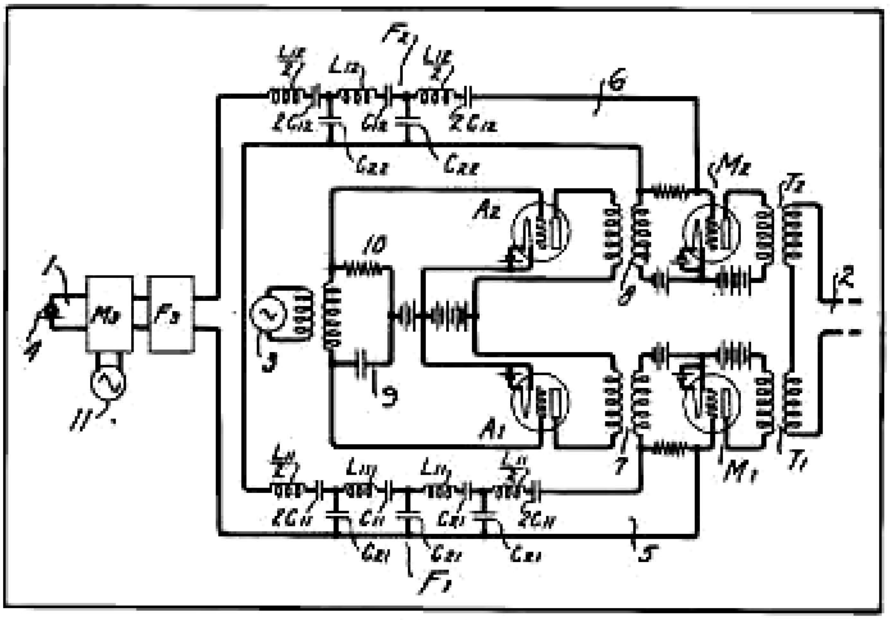


Figure 5

Circuit diagram illustrating another method of deriving single-sideband, which was invented by R. V. L. Hartley in 1928. This method uses a double modulator arrangement and balances out one sideband instead of eliminating it by filter. This method was later further developed by R. K. Potter and E. I. Green. (*Figure from Hartley patent No. 1,666,206.*)

ered transoceanic radiotelephone stations,

(2) Radio circuit extension of telephone land lines, and

(3) Intercity or point-to-point radiotelephone circuits.

The ranges which can be covered by the *LE* System depend, as with all *hf* radio systems, on a number of factors which affect the signal-to-noise ratio. Atmosphere static varies with frequency, geographical location, season, and time of day. The radio fields received in sky-wave transmission depend upon power, antenna characteristics, frequency, distance, geographical region, direction of path, and ionosphere conditions.

Representative figures for the *LE* service ranges, with suitable antennas and appropriate frequencies, are estimated to be: In the tropics, night ranges up to 200-600 miles, day ranges up to 700-2,000 miles; in temperate latitudes, night ranges up to 400-1,000 miles, day ranges up to 1,000-2,500 miles.

The transmitter and receiver of the system can be furnished for operation in either the frequency range from 3.4 to 25 mc or from 2.7 to 14 mc.

The transmitter and receiver are designed to permit the selection of any one of ten crystal-controlled preselected frequencies.

In making a change from one to another frequency, the operator is guided by a *control-position indicator* which provides information for setting all controls for any of the ten preselected frequencies. The indicator is located at eye level on the front panel of both transmitter and receiver. When rotated to the chosen frequency, the necessary control settings pertaining only to that frequency are shown on a dial. A change in operating frequency is then accomplished by use of selector switches and tuning controls readily accessible on the front panel of each cabinet. The time required to make a frequency change is about three minutes.

The *rf* emission consists of (*a*) two pilot frequencies which are spaced 3,625 cycles apart, and (*b*) signal frequencies radiated between these two pilot frequencies in a band 3,000 cycles wide. The signal frequencies correspond to voice frequencies in the band 250-3,250 cycles.

The system provides an electronic privacy equipment of the *synchro-switched* type which will prevent a casual listener from eavesdropping. It is obtained by alternately transmitting one or the other of the two pilot frequencies in inverted relation to the signal, and is directly incorporated in the circuits of the transmitter and receiver. This switching feature can be turned off for testing purposes or to permit transmission of a normal or inverted sideband.

Special attention has been given to providing unusually complete testing and metering facilities, which have been built directly into both the transmitter and receiver, providing observation of operating conditions in the vacuum tube circuits. An alarm circuit is also provided in the receiver to indicate loss of signal, and relay contacts are available to permit extension of this alarm to remote positions.

The receiver is a triple detection receiver having a crystal-controlled first beating oscillator and automatic frequency control acting on the second beating oscillator. The first *if* operates at about 2,800 kc, and the second *if* at about 100 kc. A crystal filter at the second *if* is used to obtain high selectivity and high fidelity in the band. Both *avc* and *afc* operate from both pilots, thus taking advantage of the frequency diversity to obtain improved performance. The alternate transmission of the pilots is used to synchronize the privacy switching.

The control terminal has been specifically designed to achieve the full transmission capabilities of the radiotelephone links, in addition to the effective handling of telephone traffic. The adjustment of received volume which, until the new model*** has been the most difficult of manual adjustments, is now effected by mechanical coupling to the other controls so that it does not require any attention. Built-in transmission testing equipment essential to maintaining the terminal at peak efficiency is provided.

For maximum transmission results, the highly directional rhombic-type antenna can be used for longer transmission paths. Other types of antennas possessing desirable transmission and directional characteristics may be used over shorter circuits.

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References

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[15]N. Koomans, *Single-Sideband Telephony Applied to the Radio Link between the Netherlands and the Netherlands East Indies*, Proc. IRE; Feb. 1938.