Early History of Single-Sideband Transmission*

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Summary—**This paper briefly reviews wire and radio art at the time of the invention of the single-sideband method of transmission. Recognition of sidebands, realization that either sideband contains the entire information and that the carrier wave conveys none, and the experimental discovery of homodyne reception, all preceded the invention.**

The method was first employed commercially in carrier telephone systems.

Narrow resonance characteristics and limited transmitting power necessitated elimination of one sideband and carrier in the first transoceanic radio telephone system.

Successful application to hf radio systems and superior performance under fading conditions resulted in general adoption of single sideband for long-haul services.

THE SINGLE-SIDEBAND METHOD of transmission was conceived in the mind of John R. Carson in 1915 through pure analysis resulting from his mathematical studies related to modulation of a continuous-wave carrier by means of thermionic vacuum tubes.[1] Almost simultaneously, H. D. Arnold realized the possibility in connection with tests of the Arlington experimental radio telephone transmitter of that year. Like situations preceding some other great contributions to telephone communication, in this instance the high frequency wire and radio art was ripe for the invention.[2]

The first step was the recognition of sidebands *per se*. Until well after Carson's invention, there seems to have been no general, clear-cut recognition outside the Bell System, that modulation of a carrier by voice waves results in side frequencies above and below the carrier. LeBlanc, in describing his multiplex system,[3] speaks of the modified high-frequency wave and calls for a channel spacing "high compared with the pitch of the sound waves." This might be construed as implying that a transmission band is involved but LeBlanc makes no comments in this direction. Fleming[4] treats the modulated carrier as a wave of constant frequency but varying amplitude. Stone[5] as late as 1912 says, "There is, in fact, in the transmission of a given message, (by carrier) but a single frequency of current involved."

The combining of two waves in a nonlinear element to produce sum and difference waves was an old phenomenon in acoustical physics. There appears to have been a certain carryover of that knowledge to the case of electric-wave modulation by both Campbell and Colpitts whereby sidebands were tacitly assumed to exist although admittedly not very concretely visualized. The band spectrum of voice waves was well known. Campbell's electric wave filter[6] had been invented. It is clear from correspondence that by 1913 Bell System engineers were assuming that speech, in being translated upward in frequency by modulation on a carrier, would still constitute a band of frequencies.

In the summer of 1914 a young physicist who was working on radio, in familiarizing himself with the subject, worked out a simple trigonometric analysis of an amplitude-modulated wave in his notebook. It showed three distinct components, the carrier and the upper and lower waves set off therefrom by the modulating frequency. The youthful analyst was Carl R. Englund; his notebook was dated August 19, 1914. Others may have done the same but this is the earliest known record. Nothing seems to have come directly from it. Those who knew apparently did not grasp the entire significance.

In October, 1914, R. A. Heising set up and tested a vacuum tube transmitting and receiving terminal, over an artificial line in the laboratory, which simulated two carrier telephone channels. This was the first putting together of an all-vacuum tube, high-frequency telephone system. It used separation coupled tuned circuits for frequency. Heising's report, dated December 18, 1914, recognized sidebands and mentioned the filter for realizing a "flat-topped transmission band."

The full blown appreciation came in mid-1915 during the radio-telephone experiments conducted at the U. S. Navy Radio Station at Arlington, Va. H. D. Arnold suggested that the antenna at Arlington be tuned to one side of the carrier frequency in order to pass one-sideband well, even though the other was attenuated. Here was recognition that one sideband contained all the signal elements necessary to reproduce the original speech. During this same period, John R. Carson independently set about analyzing vacuum-tube modulation, found the discrete components and recognized that one sideband and the carrier need not be transmitted. Kendall[7] had just discovered that injection of a carrier at the receiver greatly enhanced detection. Carson knew of these homodyne experiments and, since they demonstrated the feasibility of reintroducing the carrier at the receiving end, they may have promoted his idea of eliminating the carrier at the transmitter. At any rate, Carson in addition to suppressing one sideband, did propose suppression of the carrier as well: a step beyond Arnold's

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[1] J. R. Carson, U. S. Patents 1,449,382, 1,343,306, and 1,343,307.

[2] E. H. Colpitts and O. B. Blackwell, "Carrier current telephony and telegraphy," *AIEE Trans.*, vol. 40, pp. 205–300; February, 1921.

[3] M. LeBlanc, U. S. Patent 857,079; 1907.

[4] J. A. Fleming, "Electric Wave Telegraphy and Telephony," Longmans, Green and Co., London, Eng., 2nd ed., 1910.

[5] J. S. Stone, "The practical aspects of the propagation of high-frequency electric waves among wires," *J. Franklin Inst.*, vol. 174, p. 353; October, 1912.

[6] G. A. Campbell, U. S. Patent 1,227,113 and 1,227,114; 1917.

[7] B. W. Kendall, U. S. Patent 1,330,471.

proposal. After several patent interferences Carson was granted in U. S. Patent 1,449,382, filed in 1915, claims both to suppression of one sideband and to suppression of the carrier with or without suppression of one sideband. (See Fig. 1.)

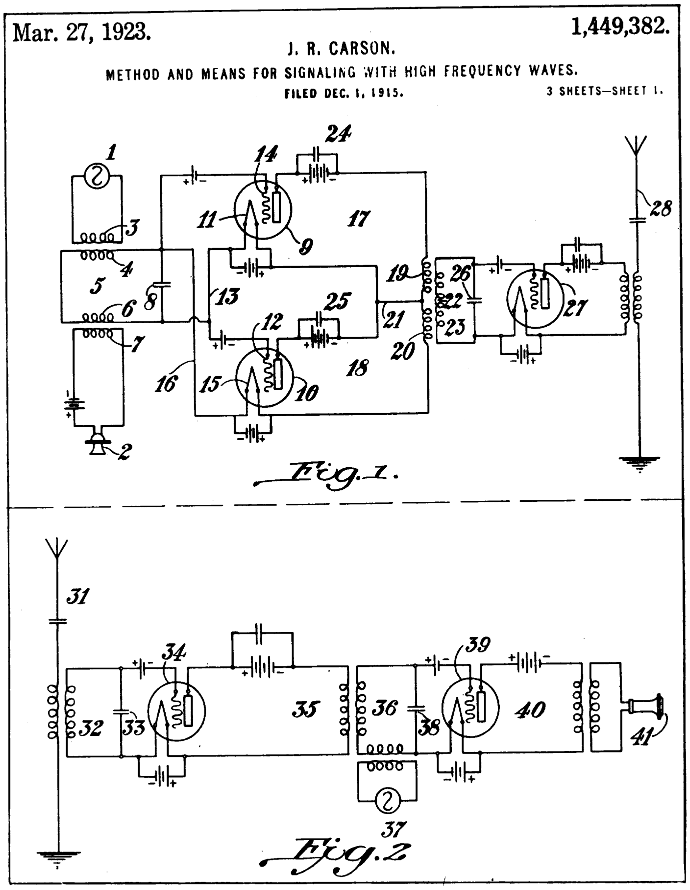

Fig. 1—Figs. 1 and 2 of J. R. Carson's patent.

It was from the modulation side of the laboratory work of 1913–1915 that the reality of sidebands and the possibility of single-sideband transmission were established. For more than a decade thereafter the physical reality of sidebands continued to be argued vigorously in some quarters; it was alleged that sidebands were merely a mathematical fiction. The establishment of the first transoceanic radio telephone system which employed single-sideband suppressed carrier transmission, provided an effective answer to radiomen.

Advantage was taken of single-sideband transmission in developing the first commercial wire carrier telephone system—Western Electric Company Type A—placed in service in 1918.[8] Thus the first application of single-sideband transmission was for high-frequency wire telephony. Both time division and frequency division multiplex schemes had been invented much earlier. Single-sideband permitted obtaining twice as many channels in the very limited frequency spectrum then usable for wire transmission. Since 1918 single-sideband transmission has been of unique value in carrier-telephone development; it is standard for many systems throughout the world. The first published mention concerning single-sideband applications to radio seems to have been made by Espenschied[9] late in 1922.

The invention of the copper-to-glass seal by Housekeeper brought rapid development of water-cooled thermionic vacuum tubes following World War I. This opened the possibility of early realization of the Bell System's long quest for a transoceanic telephone service. During 1922 a powerful experimental single-sideband transmitter, operating at a midband frequency of 57 kc, was set up by their research engineers at Rocky Point, Long Island.[10] (See Figs. 2 and 3, on the next page.) A receiving station was established at New South Gate, near London, England. Reliable one-way speech transmission was publicly demonstrated over this system in January, 1923. Thereafter the British Post Office worked hand-in-hand in establishing the first New York-London circuit which was opened for service in January, 1927. The limited transmitting power capacity and the narrow-resonance bands of efficient antennas at the low frequencies employed in this system, made imperative the adoption of single-sideband suppressed carrier methods. However, the frequencies were about three times higher than those used in existing carrier telephone systems. Hence, both the sideband generators[11] and the power amplifiers[12] involved pioneer development.

The first overseas system was followed in the next few years by so-called short-wave systems operating in the range now designated as high frequency (3–30 mc). Until about 1936 all the short-wave systems transmitted double sideband and carrier because the art in this frequency range did not permit practical single-sideband operation. However, the Bell System and British Post Office transmitters and possibly others were designed with low-level signal generators and power amplifiers so that the generators could be replaced by single-sideband generators when available.

In the late 1920's the Bell Telephone Laboratories constructed a special receiver with which to investigate the characteristics of shortwave single-sideband reception. This receiver occupied seven bays and used crystal filters. It was capable of receiving double-sideband transmissions and separating the sidebands and the carrier for experimental purposes. Provision was made for isolating, reconditioning, and re-inserting the transmitted carrier. Locally generated carrier and automatic frequency control were also provided, so that

[8] B. W. Kendall, "Carrier-current telephone systems," *Bell Labs. Rec.*, vol. 1, pp. 154–159; December, 1925.

[9] L. Espenschied, "Applications to radio of wire transmission engineering," PROC. IRE, vol. 10, pp. 344–368, October, 1922; and *Bell Sys. Tech. J.*, vol. 1, pp. 117–141; November, 1922.

[10] H. D. Arnold and L. Espenschied, "Transatlantic radio telephony," *J. AIEE*, vol. 42, August, 1923; and *Bell Sys. Tech. J.*, vol. 2, pp. 116–144; October, 1923.

[11] R. A. Heising, "Production of single-sideband for transatlantic radio telephony," PROC. IRE, vol. 13, pp. 291–312; June, 1925.

[12] A. A. Oswald and J. C. Schelling, "Power amplifiers in transatlantic radio telephony, PROC. IRE, vol. 13, pp. 313–361; June, 1925.

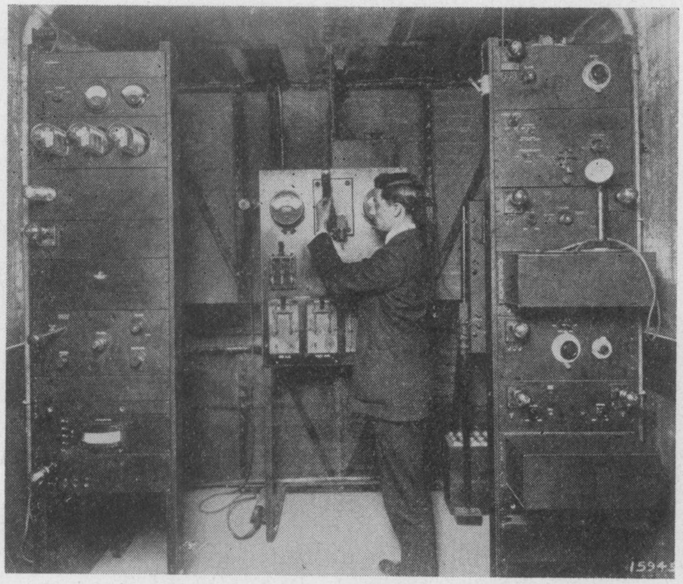

Fig. 2—Single sideband-generator installed at Rocky Point for 1922 Transatlantic experiments.

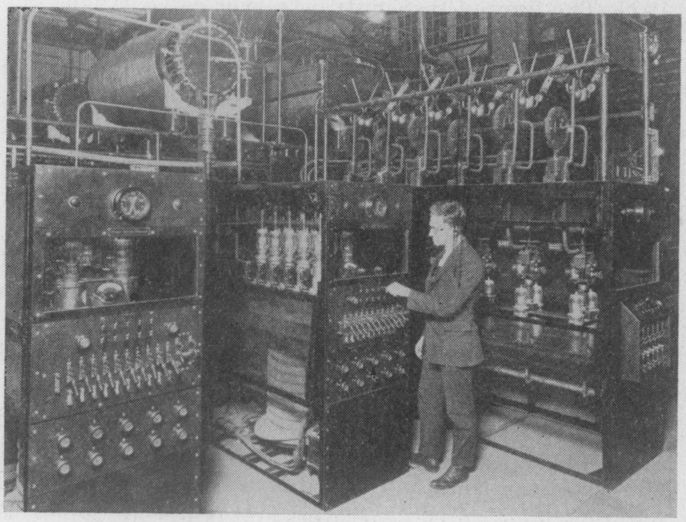

Fig. 3—Main rectifier (right) and two banks (left) of the power amplifier last stage as installed for single-sideband radio telephone experiments in 1922.

it was possible to simulate almost any kind of reception. The observations made with this equipment brought decisions to develop shortwave single-sideband transmitting and receiving units for a transoceanic trial.[13,14] Upon completion, the transmitter was taken to England and with the cooperation of the British Post Office, set up in the station at Rugby. There followed extensive tests which confirmed that the theoretical advantages could be achieved in practice, in the presence of multiple path transmission. This trial equipment was placed in commercial operation; in 1936 designs for production were initiated.[15–18] During the next decade about 50 single-sideband circuits were established in all parts of the world using units of these designs; the applications increased thereafter.

During World War II single-sideband systems did valuable service in providing connections between continental United States and the armed forces in various parts of the globe. Many of these were multichannel teletypewriter systems using telephone circuits with speech channels used only for special purposes. The telegraph signal was two-tone (mark and space) with frequency diversity (4 tones per telegraph channel). After the war improved single-sideband equipments were developed in the Bell Telephone Laboratories and by several other companies in the United States and abroad. Today the single-sideband method is rather generally recognized as standard for long-haul point-to-point transmissions and is being seriously considered for other purposes such as communication with aircraft.[19] Recently the Federal Communications Commission has proposed rules requiring single sideband for all point-to-point radio telephone transmission below 30 megacycles.

The first short-wave single-sideband equipment provided only a single speech channel on one side of the carrier, but it was quickly determined that a common power amplifier could be made sufficiently linear to permit adding a second channel on the opposite side of the carrier. At first, better performance was secured by spreading one channel from the carrier so that unwanted distortion products generated in the power amplifier by one channel would fall in the space between active bands and thus not create noise in the other channel. The urgent need for more telephone channels during the war years resulted in spreading both normal speech bands away from the carrier. A third circuit was then secured by splitting a speech channel and fitting the parts into the narrow-frequency space available adjacent to and on both sides of the carrier.

A single-sideband signal is generated by one of two basic methods: 1) modulating a carrier with a baseband signal and then suppressing all but one sideband with filters; or 2) balancing out the carrier and one sideband by an arrangement of double modulators in which the carrier and modulating signal applied to one modulator are shifted 90° with respect to those applied to the other modulator. The filtering method easily provides greater

[13] F. A. Polkinghorn and N. F. Schlaack, "A single-sideband short-wave system for transatlantic telephony," Proc. IRE, vol. 23, pp. 701–718, July, 1935; and *Bell Sys. Tech. J.*, vol. 14, pp. 489–507; July, 1935.

[14] G. Rodwin, "Single-sideband short-wave receiver," *Bell Labs. Rec.*, vol. 14, pp. 405–410; August, 1936.

[15] A. A. Roetken, "A single-sideband receiver for short-wave telephone service," Proc. IRE, vol. 26, pp. 1455–1465; December, 1938.

[16] A. A. Oswald, "A short-wave single-sideband radio telephone system," Proc. IRE, vol. 26, pp. 1431–1454; December, 1938.

[17] J. C. Gabriel, "Single-sideband short-wave receiver," *Bell Labs. Rec.*, November, 1939.

[18] K. L. King, "A twin-channel single-sideband radio transmitter," *Bell Labs Rec.*, vol. 19, pp. 202–205; March, 1941.

[19] Radio Technical Commission for Aeronautics, Rep. of Special Comm. 65, Paper 11-54/DO-53; January 25, 1954.

suppression and operating stability. The basic idea of the balancing scheme was invented by Hartley.[20] A scheme for transmitting independent intelligence on the two sides of the carrier is shown in a patent issued to Potter.[21] Green[22] suggested use of balancing methods for separating the two sidebands at the receiver. Balancing has been used in some short-haul carrier telephone systems where high suppression is not essential. In recent years balancing methods have received considerable attention in a number of laboratories as the search proceeds for economical ways to make various new single-sideband applications.

Once the feasibility of single-sideband transmission had been demonstrated, the Bell System was not alone in appreciating its advantages. The British Post Office supported a continuous program of development to establish improved systems. The Dutch, pioneer workers in the field, developed equipment and established multiplex circuits between the Netherlands and the Netherlands East Indies.[23] Reeves[24] of International Standard Electric Corporation did some major pioneer work. This paper makes no attempt to cover the expanded activity in the single-sideband field since World War II.

Acknowledgment

In closing the author wishes to acknowledge the valuable assistance given by L. Espenschied and F. A. Polkinghorn in making available material gathered in some of their historical studies.

[20] R. V. L. Hartley, U. S. Patent 1,666,206.

[21] R. K. Potter, U. S. Patent 1,773,116.

[22] E. I. Green, U. S. Patent 2,020,409.

[23] N. Koomans, "Single-sideband telephony applied to the radio link between the Netherlands and the Netherlands East Indies," Proc. IRE, vol. 26, pp. 182–206; February, 1938.

[24] A. H. Reeves, "The single-sideband system applied to short-wave telephone links," *J. IEE*, vol. 73, pp. 245–278; September, 1933.

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