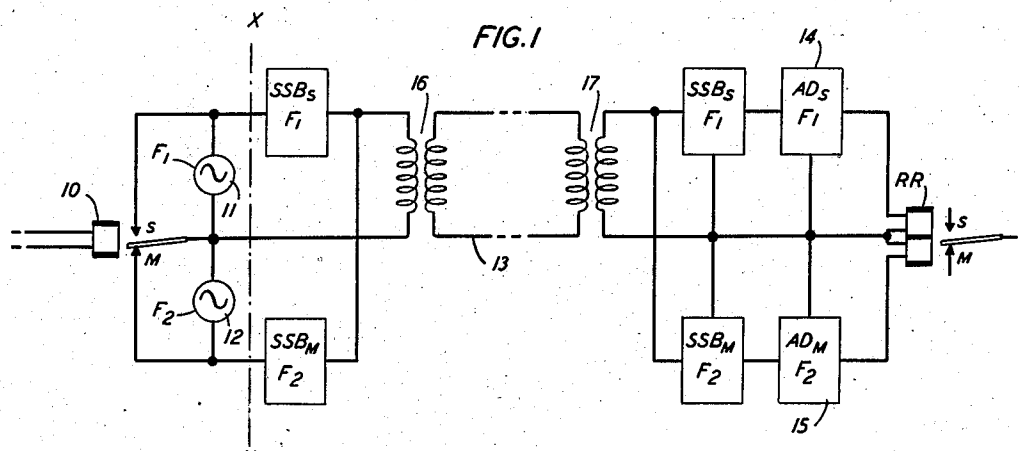
Oct. 9, 1945. H. NYQUIST 2,386,566

TELEGRAPH SIGNALING SYSTEM

Filed March 4, 1943

FIG. 1



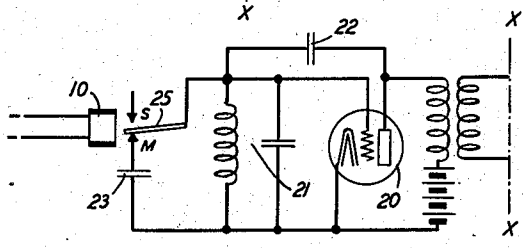
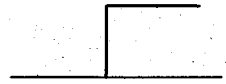


FIG. 4

FIG. 2A



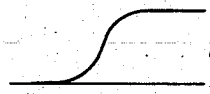


FIG. 2B

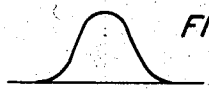


FIG. 2C

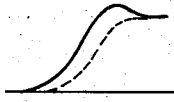


FIG. 2D

FIG. 3A

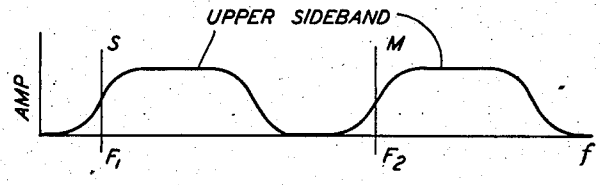
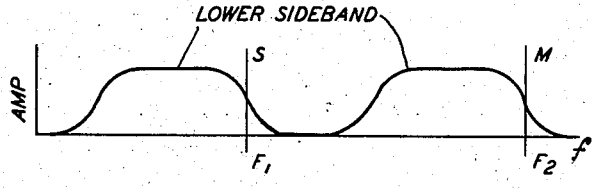


FIG. 3B



INVENTOR
H. NYQUIST
BY H. A. Burgess
ATTORNEY

Patented Oct. 9, 1945 2,386,566

UNITED STATES PATENT OFFICE

2,386,566

TELEGRAPH SIGNALING SYSTEM

Harry Nyquist, Millburn, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application March 4, 1943, Serial No. 477,986

8 Claims. (Cl. 178—66)

This invention relates to carrier current telegraph systems, and more particularly to two-tone carrier telegraph systems operated on a single side-band basis such that a certain distortion effect in each signal tends to nullify a corresponding distortion effect in the other signal.

In two-tone carrier current telegraph systems it is the practice to apply the output of each of two different carrier current sources to a transmission line for individual spacing and marking signals by means of a key or equivalent mechanism such that the time duration of the individual currents on the line corresponds relatively closely to the keying action. As is well known, the process of connecting the individual carrier current sources to the line and disconnecting them therefrom gives rise to a band of currents whose frequencies are higher than the frequencies of the individual carrier currents, and a band of currents whose frequencies are lower than the frequencies of the individual carrier currents. These two bands constitute, for the individual marking and spacing signals, the upper and lower side-bands as modulation components. In so far as transmitting intelligence is concerned, one side-band is substantially the equivalent of the other side-band. Hence, signal intelligence may be obtained by transmitting one side-band and suppressing the other side-band for each of the spacing and marking signals. This reduces the width of the frequency band required for the transmission of signal intelligence. In single side-band transmission, however, a relatively strong quadrature component in the filtered wave tends to introduce bias at the receiving end. Such bias can be compensated by the use of additional apparatus which is expensive from the standpoints of both initial cost and maintenance. The present invention is concerned with two-tone carrier current telegraph systems operated on a single side-band basis without involving the use of such additional apparatus to control the biasing effects caused by the quadrature components.

In my Patent No. 1,748,186, granted February 25, 1930, it is disclosed that when a filter is used to pass one side-band only, the output wave of the filter comprises two components, (*a*) an in-phase component, and (*b*) a quadrature component. For the present purpose, the in-phase component is one whose zeros coincide with the zeros of the steady state carrier current, that is, is in-phase with the latter current; and the quadrature component is one whose zeros are a quarter period out-of-phase with the zeros of the steady state carrier current. Further discussion of single side-band transmission is contained in my article entitled "Certain topics in telegraph transmission theory" appearing in the transactions of the American Institute of Electrical Engineers, volume 47, April 1928, at page 617, and in an article entitled "Effect of the quadrature component in single side-band transmission" by H. Nyquist and K. W. Pfleger appearing in the Bell System Technical Journal, volume 19, January 1940, at page 63. In these discussions, it is noted that the quadrature component is present when the amplitude of the in-phase component is changing, and tends to have substantially its maximum value when the amplitude of the in-phase component is changing most rapidly. When the in-phase component attains a steady state condition, the value of the quadrature component falls substantially to zero. The quadrature component tends to change the shape of the received current so that, in the case of single side-band transmission, it tends to cause bias at the receiving end of the transmission line.

It is the object of my invention to provide a telegraph system in which carrier currents of two different frequencies are used to transmit spacing and marking signals on a single side-band basis such that the bias due to the quadrature component in each signal tends to nullify the bias due to the quadrature component in the other signal.

In a specific embodiment, the present invention comprises a transmission line, means at the sending end to apply carrier currents of different frequencies to the line in response to corresponding spacing and marking signals, means at the receiving end of the line to detect the received carrier currents on a differential basis for reproducing the marking and spacing signals. As the application of the different carrier currents to the sending end of the line and their disconnection therefrom involves the generation of upper and lower side-bands of the individual carrier currents, a filter proportioned with an amplitude versus frequency characteristic to pass one carrier current and one side-band for identifying the respective spacing and marking signals is interposed in each of the marking and spacing branches at both the transmitting and receiving ends of the line. The output of each filter includes a quadrature component which tends to bias the individual marking and spacing signals. In the differential detection, the bias due to the quadrature component in each signal substantially nullifies the bias due to the quadrature component in the other signal.

A feature of the invention relates to the nullification of the effects of the quadrature compo-

nent in the individual spacing and marking signals without aid of complicated and expensive apparatus. A further feature involves the reduction of the width of the useful frequency range. Another feature concerns the economy of frequency range while at the same time retaining certain advantages of two-tone systems, one of which is that the discrete carrier currents are substantially insensitive to fluctuations in line loss. This is so far the reason that the receiving relay is operated differentially from space-to-mark and mark-to-space so that any variation in the magnitude of each signal also occurs in like manner in the magnitude of the other signal.

The invention will be readily understood from the following description taken together with the accompanying drawing in which:

Fig. 1 is a two-tone telegraph circuit adapted for single side-band transmission;

Figs. 2A through 2D are curves illustrating certain action in Fig. 1;

Figs. 3A and 3B are curves showing various modifications of Fig. 1, and

Fig. 4 is a circuit of an alternate transmitter which may be substituted in Fig. 1.

Referring to Fig. 1, a sender **10** is actuated in accordance with signal waves of direct current corresponding to the signal elements which are to be transmitted. The sender **10** controls alternately the outputs of sources **11** and **12** of carrier current of frequencies F_1 and F_2, respectively, such that discrete groups of spacing and marking carrier currents including the upper and lower side-bands associated with each thereof are produced. A single side-band filter F_1 is interposed in the transmitting branch of the spacing current F_1 for passing the carrier current F_1 and either the upper or the lower side-band for identifying the spacing signal. A single side-band filter F_2 is interposed in the transmitting branch of the marking current F_2 for passing the carrier current F_2 and either the upper or the lower side-band for identifying the marking signal. At the receiving end, the transmitted carrier currents and side-bands corresponding substantially to the transmitted spacing and marking signals are passed through further filters F_1 and F_2, and amplifier-detectors **14** and **15** embodied in the receiving branches of the spacing and marking currents F_1 and F_2, respectively. The outputs of the amplifier-detectors **14** and **15** actuate a differential receiving relay RR for controlling a sounder, a circuit associated with a printer, or equivalent apparatus, to reproduce the succession of spacing and marking signals originating at the transmitting end. Line transformers **16** and **17** may be used to connect the sending and receiving terminals to the transmission line.

Fig. 2A represents the envelope of a single reversal such as would be obtained in the circuit of Fig. 1 at the input of each of the transmitting and receiving filters F_1 and F_2. Results of certain action by the individual filters F_1 and F_2 may be represented by individual components illustrated by the curves of Figs. 2B, 2C and 2D. In Fig. 2B the envelope represents the in-phase component of the current received at one of the amplifier-detectors **14** and **15**, and such component is assumed to be distortionless in the sense in which this term is used herein. In Fig. 2C the envelope represents qualitatively the accompanying envelope of the quadrature component which, as pointed out above, has the property of being present only when a change is occurring, reducing to zero when the transmitted current has been held constant for some time. In the absence of homodyne reception, of which one type is disclosed in my patent, supra, the envelope of the received current is obtained by combining the curves of Figs. 2B and 2C by root-means-square addition, the result of which is shown in Fig. 2D. Since the addition of two components in quadrature to each other always gives a resultant which is greater than either component, the presence of the quadrature component results in a bias indicated by the solid line in Fig. 2D in which figure the broken line is a reproduction of the curve in Fig. 2B.

As the individual spacing and marking branches at both the transmitting and receiving ends of the line **13** embody one single side-band filter F_1, each of the spacing and marking signals transmitted and received on the line **13** possesses approximately the distortion indicated by the envelope in Fig. 2D. With the system of Fig. 1, using two-tone single side-band transmission, it is clear that the distortion in the spacing signals due to the presence of the quadrature component therein tends to cancel the distortion in the marking signals due to the presence of the quadrature component therein, and vice versa. This is so for the reason that the current in the spacing winding of the receiving relay RR tends to release the armature substantially at the same value at which the current in the marking winding tends to actuate the armature, and vice versa.

Further distortion of the envelope of Fig. 2D due to unequal attenuation of the amplitudes of the transmitted currents at a certain frequencies and the phase delay thereof is obviated by proportioning the amplitude versus frequency characteristics of the individual filters F_1 and F_2 such that the cut-off is sloping and such that the individual carrier frequencies F_1 and F_2 lie at or near the mid-points of the sloping cut-offs as disclosed in my patent, supra. In the system of Fig. 1, it is desirable that the individual spacing and marking carrier frequencies F_1 and F_2 be located at corresponding edges of the characteristics of both single side-band filters F_1 and F_2 as shown in Figs. 3A and 3B. Referring to Fig. 3A, the single side-band filters F_1 and F_2 pass substantially the upper side-bands of frequencies only of the respective spacing and marking signals, and the individual frequencies of the spacing and marking carrier currents F_1 and F_2 lie at or near the mid-points of the sloping cut-offs at the lower edges of both characteristics. In Fig. 3B, the single side-band filters F_1 and F_2 pass substantially the individual lower side-bands of frequencies only but now the individual frequencies of the spacing and marking carrier currents F_1 and F_2 lie at or near the mid-points of the sloping cut-offs at the upper edges of both characteristics.

Fig. 4 shows an alternate transmitting apparatus which may be substituted in Fig. 1 for the circuit portion shown to the left of the line X—X in the latter figure. Referring to Fig. 4, an oscillator comprises an electron tube **20**, a parallel tuned circuit **21** applied across the input thereof, and a capacitor **22** applied across the control electrode and anode of the tube **20**. This oscillator is provided with a further capacitor **23** interposed in its frequency controlling circuit and arranged to be cut in and out of the latter circuit

by the sender 10. The capacitance of the capacitor 23 is fixed at such value as to give the desired frequency change in the oscillator. Hence this oscillator generates substantially, for example, the frequency F_1 when the armature 25 is on the spacing contact S (to disconnect the capacitor 23 from the oscillator), and the frequency F_2 when the armature 25 is on the marking contact M (to connect the capacitor to the oscillator). In other respects the combination of Figs. 1 and 4 operates in the manner described previously for the operation of Fig. 1 alone.

What is claimed is:

1. In a two-tone single side-band telegraph system, the method of transmitting marking and spacing signals which consists in modifying a carrier current of one frequency to produce frequency components including the one carrier current frequency and upper and lower side-band frequencies for representing a marking signal, modifying a carrier current of a different frequency to produce frequency components including the different carrier current frequency and upper and lower side-band frequencies for representing a spacing signal, filtering said one and different carrier currents and said upper and lower side-bands associated therewith for selecting each of the carrier currents and one side-band associated therewith for identifying the respective signals, said one side-bands lying to the one side of the respective carrier frequencies, transmitting the selected carrier currents and one side-bands, filtering the received carrier currents and one side-bands in a similar manner whereby a quadrature component causes bias in the respective signals, and detecting and receiving differentially the second filtered carrier currents and one side-bands such that the bias due to the quadrature component of each signal substantially nullifies the bias due to the quadrature component of the other signal.

2. In a carrier telegraph system employing marking and spacing signals, a transmission line, means at the transmitting end of said line to modify each of two carrier currents of different frequencies with one of said signals for producing different carrier current impulses having as frequency components the individual carrier current frequencies and upper and lower side-bands of frequencies of each thereof, a filter for each of the different signal impulses at both the transmitting and receiving ends of said line for passing current impulses whose frequencies comprise one carrier current frequency and but one of the two side-bands of frequencies associated therewith whereby marking to spacing and spacing to marking bias due to the quadrature components in the respective filtered signal current impulses is produced, and means at the receiving terminal to detect and receive differentially the filtered individual signal current impulses such that the bias due to the quadrature component of each filtered signal current impulse substantially cancels the bias due to the quadrature component of the other filtered signal current impulse.

3. In a two-tone single side-band carrier telegraph system, means at the transmitting end to produce two discrete carrier currents of different frequencies, means to modify one of said carrier currents with a marking signal to form components whose frequencies include said one carrier current frequency and upper and certain lower side-bands of frequencies, means to modify the other of said carrier currents with a spacing signal to produce components whose frequencies include said other carrier current frequency and upper and further lower side-bands of frequencies, a filter individual to each of said signals at both the transmitting and receiving ends to pass components whose frequencies correspond to one carrier current frequency and but one of the two side-bands of frequencies associated therewith whereby marking to spacing and spacing to marking bias due to the quadrature component individual to each of the filtered signal currents is produced, said filters being provided with amplitude versus frequency characteristics having sloping cut-offs such that the frequencies of the individual carrier currents lie at or near the mid-points of said cut-offs at corresponding edges of said characteristics, and means at the receiving end to detect and receive differentially the filtered signal currents such that the bias due to the quadrature component in the filtered currents of each signal tends to nullify the bias due to the quadrature component in the filtered currents of the other signal.

4. The two-tone single side-band telegraph system according to claim 3 in which said filters for both the marking and spacing signals are provided with amplitude versus frequency characteristics to pass the lower side-band of frequencies associated with each of the modified carrier currents.

5. The two-tone single side-band telegraph system according to claim 3 in which said filters for both the marking and spacing signals are provided with amplitude versus frequency characteristics to pass the upper side-band of frequencies associated with each of the modified carrier currents.

6. The two-tone single side-band telegraph system according to claim 3 in which said filters for both the marking and spacing signals are provided with amplitude versus frequency characteristics having sloping cut-offs to pass the upper side-band of frequencies of each of the modified carrier currents, and in which the frequencies of the individual carrier currents lie at or near the mid-points of the cut-offs at the lower edges of the respective characteristics.

7. The two-tone single side-band telegraph system according to claim 3 in which said filters for both the marking and spacing signals are provided with amplitude versus frequency characteristics having sloping cut-offs to pass the lower side-band of frequencies of each of the modified carrier currents, and in which the frequencies of the individual carrier currents lie at or near the mid-points of the cut-offs at the upper edges of the respective characteristics.

8. In a two-tone single side-band telegraph system, the method of transmitting marking and spacing signals which comprises modifying a carrier wave of one frequency to produce frequency components including the one carrier wave frequency and upper and lower side-band frequencies for identifying a marking signal, modifying a carrier wave of a different frequency to produce frequency components including the different carrier wave frequency and upper and lower side-band frequencies for identifying a spacing signal, filtering the individual carrier waves and associated side-bands to pass each carrier wave and only one of said side-bands associated therewith, and transmitting the filtered carrier waves and one side-bands.

HARRY NYQUIST.