April 14, 1925. 1,533,311

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SECRET SIGNALING

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Fig. 1.

	a →	b →	c →
1)	b →	a →	c →
2)	b →	a ←	c →
3)	b ←	a →	c →

Fig. 2.

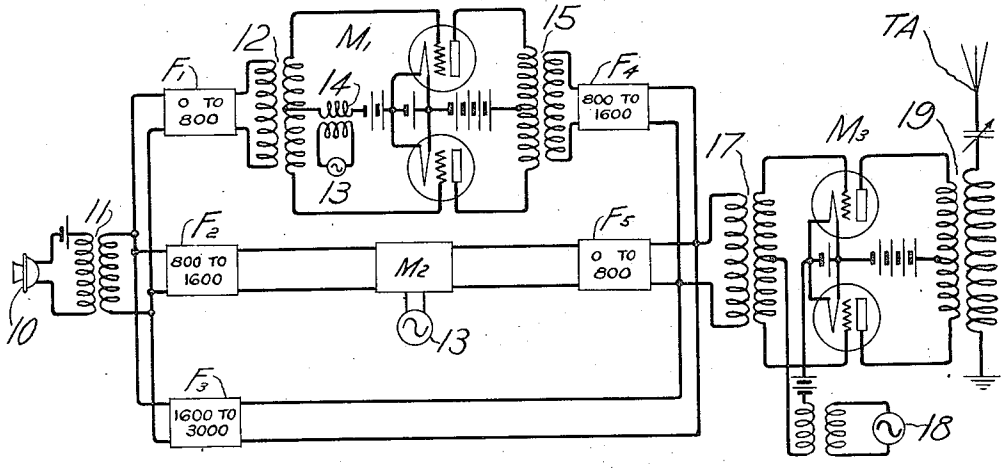
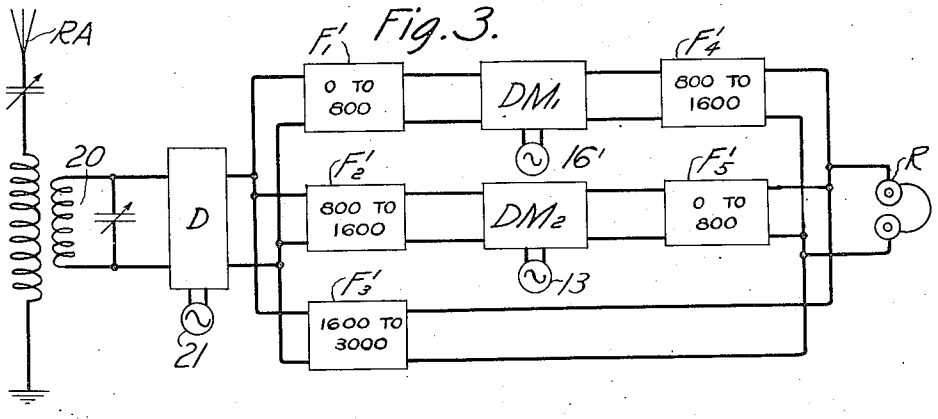


Fig. 3.



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UNITED STATES PATENT OFFICE.

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SECRET SIGNALING.

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To all whom it may concern:

Be it known that I, HARVEY FLETCHER, a citizen of the United States of America, residing at New York city, in the county of New York, State of New York, have invented certain new and useful Improvements in Secret Signaling, of which the following is a full, clear, concise, and exact description.

The present invention relates to wave transmission with secrecy.

The invention is applicable to the art of signaling and to the transmission of electrical waves for any purpose.

An object of the invention is to secure a high degree of secrecy in a signaling or other wave transmission system while at the same time maintaining the general efficiency of the system and the quality of the reproduced waves.

It has been proposed to divide the waves that are to be transmitted into sub-bands of frequency components and to render the waves difficult of recognition by transposing certain of the sub-bands of components prior to the transmission of the wave.

Such transposition may comprise interchanging two or more of the sub-bands as to the frequency positions normally occupied by the respective sub-bands, or it may comprise inversion of the frequency order of the components of one or more of the sub-bands either with or without an accompanying interchange being made between the frequency positions of the sub-bands. Still other transformations for the waves have been proposed.

From the standpoint of adaptability of a secrecy system to standard transmission circuits, it is desirable that the altered waves which are actually transmitted occupy the same absolute frequency range as the waves would occupy if left in their normal or unaltered condition. From the standpoint of secrecy, it is desirable that transformations made in the waves be such as will produce maximum confusion when an attempt is made to receive them on any ordinary and unauthorized receiver. From the standpoint of economy in transmitted power it is desirable that no noise components be added and that no components other than those derived from the waves themselves be sent.

The invention comprises, among its features, provisions for securing each of the above-mentioned desirable results.

The various objects and features of the invention will more fully appear from the description now to be given of the embodiment illustrated in the accompanying drawing.

In this drawing, Fig. 1 shows in symbolic form the manner of division of the normal speech into sub-bands *a*, *b* and *c* and the manner of transposing the sub-bands prior to transmission according to the invention.

Figs. 2 and 3 show, in schematic form, a transmitting system and a receiving system, respectively, for carrying on secret signaling in accordance with the invention.

It has been found that the intelligibility of a sub-band of frequencies divided out of the speech band depends not only on the breadth of the sub-band but also upon the region of the speech band from which the sub-band is taken.

It is also found that the energy represented in any sub-band of speech of given frequency width differs markedly depending upon the region of the speech band from which it is taken. The degree of intelligibility of a sub-band does not as a rule correspond at all closely with the energy which it possesses, so that it is possible to divide normal speech into sub-bands of the same frequency width and same energy content but of widely different degrees of intelligibility, and, further, sub-bands of different frequency width and the same intelligibility may differ widely in energy content.

As might be expected from what has just been said relative to the effects of energy content and frequency position of sub-bands, it has been found that the amount of confusion that may be produced by a sub-band of noise currents of given frequency with and energy content differs widely according as the noise components are introduced into one region or another of the normal speech range. Since any selected sub-band of speech can be converted into noise or confusion components by making some transposition of the components, either by inverting their order within the sub-band or by shifting the frequency position of the sub-band, the total confusion produced from

so operating on a sub-band depends markedly upon the width of sub-band that is selected, the region of the normal speech band from which it is taken and the nature of the transposition made of it.

For a fuller discussion of the relations between band width, energy content and intelligibility of portions of the speech band, reference may be had to applicant's paper on "The Nature of Speech and its Interpretation," published in Journal of the Franklin Institute for June 1922, Vol. 193, No. 6.

In dividing the speech band into sub-bands for secret transmission in accordance with the invention, advantage is taken of the dependence of the degree of intelligibility upon the frequency width, the frequency position, and the energy content of the various sub-bands that may be derived from normal speech. Also, in making the required transformations in the transmitted waves in order to produce confusion, the invention takes advantage of the relation between the degree of confusion produced and the frequency width, energy content and position in the normal speech band of the confusion components.

Referring now to Fig. 1, the arrows *a*, *b* and *c* represent three sub-bands of normal speech. The sub-bands *a* and *b* are of equal frequency width and are each of less width than the band *c* which is indicated by an arrow of longer shaft. The sub-band *a* may comprise the frequencies 0 to 800 cycles, the sub-band *b* may extend from 800 to 1600 cycles and the sub-band *c* from 1600 to 3000 cycles. On this basis, the *a* sub-band has an intelligibility of about 16%, the *b* sub-band 27% and the *c* sub-band 25% while the voice energy represented by the *a* sub-band is about 72%, that of the *b* sub-band is 18% and that of the *c* sub-band is 6%. Each sub-band by itself is seen to be highly unintelligible since it enables only one sound in four, or one sound in six in the case of the *a* sub-band, to be understood. With this scheme of sub-division, it will be seen that the same sub-band width has greater intelligibility in the *b* position than in the *a* position and that the intelligibility in the sub-band *c* in spite of its greater frequency width is only of the same order as that of the sub-band *b*. It will also be seen that the sub-band *a* of the least intelligibility has the greatest energy content and that the smallest energy content is that of the sub-band *c* although this sub-band possesses the greatest frequency width.

Sub-bands *a* and b being of equal frequency width readily permit of being interchanged in their frequency position. The three possible transformations on this basis of sub-division are shown opposite the respective numbers in Fig. 1. The first combination is obtained by merely changing the frequency position of the sub-bands *a* and *b*. The second combination is obtained by shifting the sub-band *b* to the *a* position and by shifting the sub-band *a* to the *b* position and inverting its frequency order as is shown by the reversal of the arrow. The third combination is obtained by shifting the sub-band *a* to the *b* position and shifting the sub-band *b* to the *a* position and inverting its frequency order.

If an attempt is made to receive any of the combinations 1, 2 or 3 in an ordinary telephone receiver, the intelligibility will be practically nil. It is found that merely shifting a sub-band of the speech frequencies to a higher or lower frequency position without disturbing the frequency order within the sub-band renders the sub-band highly unintelligible. In each of the three combinations therefore, about 90% of the received sound energy comprises confusion or noise components so that the small intelligibility of the sub-band *c* is completely overwhelmed by these noise components.

If an attempt is made to break the secrecy of these combinations by using a heterodyne oscillator, the frequency of which may be varied throughout the range of the received frequencies the best than can be accomplished will be the restoration of one of the sub-bands to its normal position in the speech range but this restored sub-band will have superposed upon it a large number of confusion or noise components. For example, let it be supposed that a heterodyne oscillator is adjusted to receive the sub-band *a* of the first combination by having its frequency set at 800 cycles. If the sub-bands of combination 1 are used to modulate a carrier wave the heterodyne oscillator would, of course, have its frequency made equal to the corresponding component in the side band, that is,—the component produced from the 800-cycle component in the modulating wave. The effect of this will be not only to reproduce the sub-band *a* in its normal position in the speech range but also to superpose the sub-band *b* upon the sub-band *a* and to displace the sub-band *c* downward from its normal position by 800 cycles. Both the sub-band *b* and the sub-band *c* therefore appear as noise currents. Further, the sub-band *b* cannot be separated from the sub-band *a* by filtering since they occupy the same frequency range.

If the heterodyne oscillator be set to receive the sub-band *b* of combination 1 properly, both the sub-bands *a* and *c* are displaced upward in the frequency scale 800 cycles from their combination position and will, therefore, appear as noise currents. On account of the greater energy content of the sub-band *a* the noise produced by it will be much greater than the volume of the restored sub-band *b*.

Similarly, with combinations 2 and 3, if the heterodyne oscillator be set to receive any sub-bands properly, the other sub-bands will be automatically converted into noise currents and will therefore overlap the restored sub-band or will be so shifted in the frequency scale that their respective energies as noise will practically completely mask the restored sub-band.

It has been assumed above that the scheme of transposition of the transmitted wave is known to the unauthorized observer and that he is able to locate the frequency of the heterodyne oscillator exactly at the desired point in the various frequency combinations. In practice, however, these conditions would rarely, if ever, exist and the chances of obtaining even as good intelligibility as is assumed above would be very small, first, because there will always be other distortions which are not considered in the above discussion, and secondly, because the probability of accurate tuning with an intelligibility so low is very small.

Reference will now be made to Figs. 2 and 3 which illustrate one form of carrying out the invention. In Fig. 2 the speech currents derived from the circuit of the microphone 10 are transmitted through the repeating coil 11 to the three filters F_1, F_2 and F_3 which serve to divide the speech currents into three sub-bands *a*, *b* and *c* as indicated in Fig. 1. The filter F_1 is designed to transmit selectively the components 0 to 800 cycles and to effectively suppress components of all other frequencies. Similarly, the filter F_2 transmits only the components of 800 to 1600 cycles and the filter F_3 transmits only components of 1600 to 3000 cycles as well as the other filters employed in the system. Each of these filters may be of the type disclosed in U. S. patent to Campbell No. 1,227,113, May 22, 1917.

The output of the filter F_1 is passed through a repeating coil 12 and is applied differentially to the grids of the two tubes of the balanced modulator M_1. A source of waves 13 is applied from the grids of these tubes in parallel through the transformer 14. The resulting modulation components are transmitted through the output transformer 15 to the outgoing filter F_4. The filter F_4 is designed to have a transmission range of 800 to 1600 cycles and to suppress the transmission through it of components of all other frequencies. The frequency of the sourse 13 depends upon the particular frequency transformation that is to be produced in the sub-band *a*. If this sub-band is to be shifted as in combination 1 of Fig. 1 so that it occupies the sub-band *b* position, source 13 will have a frequency of 800 cycles. The modulation components will comprise an upper and a lower side band, the upper side band extending from 800 cycles to 1600 cycles. This side band will be selectively transmitted by the filter F_4 while the other side band will be completely suppressed. Since the transmission ranges of the filters F_1 and F_4 do not overlap there will be no direct transmission through the modulating system of any of the *a* sub-band frequencies unchanged.

The modulator circuit M_1 is of the general type disclosed in U. S. patent to Carson No. 1,343,306, June 15, 1920.

The output of the filter F_2 is impressed on a second balanced modulator M_2 which may be of the same type as the modulator M_1 but which, for simplicity, in the drawing, is merely indicated by a rectangle. This modulator is supplied from a source 16, with a wave, the frequency of which depends upon the particular transformation that is to be made in the outgoing wave. If the *b* sub-band is to be shifted to the *a* sub-band position as in combination 1 of Fig. 1, the scurce 16 will have a frequency of 800 cycles. As a result of the action of the modulator circuit M_2, side bands will be produced, one of which is represented by the difference in frequency between the applied *b* sub-band and the frequency of the source 16, that is,—each component of the *b* sub-band will be displaced downward in frequency by 800 cycles so that the resulting side band will occupy the frequency range, 0 to 800 cycles. This side band will be selectively transmitted through the filter F_5 to the exclusion of components of all other frequencies.

Since no shift is to be made in the frequencies of the sub-band *c*, no modulator is required, but the filter F_3 has its output connected in common with the outputs of filters F_4 and F_5 to the common repeating coil 17.

If desired the sub-bands from the filters F_3, F_4 and F_5 could be transmitted directly over a telephone line or other circuit to the distant receiving station. These sub-bands would in such case appear merely as unintelligible noise in any ordinary receiver which might be associated with the line since they represent a normal speech wave transformed in accordance with combination 1 of Fig. 1, the effect of which has been discussed above.

The particular type of transmission circuit that has been chosen for illustration, however, is a radio transmission system, so that the transformed speech wave is used in the system illustrated to modulate a radio frequency wave which may be derived from any suitable oscillator 18. The radio waves are applied in parallel to the grids of the modulator M_3 and the secret speech waves are applied differentially to the modulator grids. As a result, the unmodulated carrier component from source 18 is suppressed and only the two side bands of the secret speech based on the radio wave are produced.

These side bands are impressed on the transmitting antenna TA by means of the transformer 19. The antenna TA may be tuned to transmit selectively one of the two side bands to the exclusion of the other. Or, in case the radio frequency is too high to permit of discrimination between the side bands by simply tuning the antenna, the type of transmitter disclosed in the patent to Osborne, No. 1,361,488, December 7, 1920, may be employed to obtain a single side band for transmission.

If combination 2 of Fig. 1 is desired, the source 13 is made to have a frequency of 1600 cycles in which case the modulator M_1 produces an upper side band extending from 1600 to 2400 cycles and a lower side band extending from 800 to 1600 cycles. Due to the characteristics of the filter F_4 only the lower side band is transmitted. Since this side band represents the difference in frequency between the applied waves the frequency order within this side band is the reverse of that of the applied *a* sub-band. To obtain the necessary shift of the sub-band *b* for combination 2, the source 16 is made to have a frequency of 800 cycles as in the case of combination 1.

To obtain combination 3 of Fig. 1, the source 13 is made to have a frequency of 800 cycles as in the case of combination 1 and the source 16 is made to have a frequency of 1600 cycles. In this case an upper side band extending from 2400 to 3400 cycles is obtained and a lower side band extending from 0 to 800 cycles is obtained. Only the latter of these two side bands is transmitted through the filter F_5 to the outgoing circuit.

The wave transmitted from the station of Fig. 2 is received on the receiving antenna RA which may be tuned to the frequency of the waves to be received. The waves picked up by the antenna RA are transmitted into the tuned circuit 20 from which they are impressed on the detector D the input of which is also supplied with a wave of the radio or carrier frequency from source 21. As a result of the interaction in the detecting circuit of the received side band with the locally supplied carrier wave, a band of frequency components is produced of the same character as those used to modulate the carrier at the transmitting station. These components are divided into sub-bands by the filters F_1', F_2' and F_3' which may be duplicates respectively of the filters F_1, F_2 and F_3 of Fig. 2.

The sub-band selectively passed by the filter F_1' represents the transposed sub-band *b* and is impressed on the input of the demodulator DM_1 which may be of the same type as the modulator circuit M_1 of Fig. 2. This demodulator is supplied with waves from the source 16′ of the same frequency as the source 16 of Fig. 2. As a result of the action of the demodulator circuit DM_1, two side bands are produced, the upper of which extends from 800 to 1600 cycles and represents the restored sub-band *b*. This sub-band is selectively passed by the filter F_5' to the exclusion of components of all other frequencies. The sub-band from the filter F_2' represents the transposed sub-band *a* and is impressed on the demodulator DM_2 which may be of the same type as the demodulator DM_1 and which is supplied with a wave from source 13′ of the same frequency as source 13 of Fig. 2. The resulting lower side band occupies the frequency range 0 to 800 cycles and is selectively passed by the filter F_4' to the exclusion of components of all other frequencies.

The remaining sub-band representing the unchanged sub-band *c* is transmitted directly through the filter F_3', which may be a duplicate of the filter F_3, and is impressed in common with the waves from the filters F_4' and F_5' upon the receiver R. The waves so impressed on the receiver represent the restored sub-bands originally derived from the speech currents transmitted from the repeating coil 11 of Fig. 2 and represents therefore, the speech which was to be transmitted.

While it is preferable, for the sake of economy in transmitting energy and in the frequency range employed where transmission takes place by modulating a carrier or radio wave to suppress the carrier and to transmit only one side band this is not essential to the invention.

It will be understood from what is stated above that any type of transmission, either carrier or radio transmission or direct transmission over a line at speech frequencies may be employed.

While it has been assumed above that speech is sub-divided into only three sub-bands, two of which are of the same frequency width, it is within the invention to employ more than two sub-bands of the same frequency and to interchange them prior to transmission together with one or more sub-bands which are unchanged.

What is claimed is:

1. The method of secretly transmitting speech waves comprising dividing the waves into sub-bands of frequencies, the sub-bands differing among themselves as to the breadth of included frequencies, interchanging certain of said sub-bands with others while keeping the total range of the resultant wave within the same frequency limits as the speech waves, and transmitting said resultant waves to a distance.

2. The method of secret transmission of speech comprising dividing the normal speech components into sub-bands including a plurality of sub-bands of the same fre-

quency width and a sub-band comprising the higher frequency region of normal speech and having a greater width than any of the other sub-bands, transposing certain of the sub-bands of equal width among themselves, and transmitting the resulting sub-bands together.

3. The method of secret transmission of speech comprising dividing the speech waves, by filtering, into sub-bands of frequency components, of different frequency width, in such manner that the frequency region of normal speech having the greater voice energy is subdivided into sub-bands of less frequency width than the region having smaller voice energy, interchanging the frequency position of certain of said sub-bands with others while keeping the resultant waves within practically the same extreme frequency limits as the original speech waves, and transmitting the resultant waves.

4. The method of secret transmission of speech which comprises dividing normal speech waves into a sub-band of frequency components possessing small voice energy and low intelligibility, and into other sub-bands possessing low intelligibility but greater voice energy than the first-mentioned sub-band, transposing only the sub-bands of larger energy content among themselves to reduce the intelligibility of the resultant waves below that of any sub-band by itself, and transmitting the wave so transposed.

5. The method of secret transmission of speech comprising transmitting certain of the frequency components of normal speech in their normal frequency relations, selecting sub-bands of other frequency components from normal speech and interchanging the frequency positions of the sub-bands to produce unintelligible confusion components occupying as a whole the same frequency positions as before their transposition, and transmitting the interchanged components along with the unchanged components.

6. The method of secret telephony comprising dividing normal speech waves into sub-bands of frequency components, each sub-band by itself possessing small intelligibility, said sub-bands differing among themselves in energy content and in frequency width, producing noise currents from certain of the sub-bands of components of the larger energy content and transmitting the resulting noise currents along with the unchanged components whereby the intelligibility of the wave components as a whole is practically nil, the transmitted wave occupying substantially the same frequency limits as the original speech.

7. In a telephone system an incoming circuit, an outgoing circuit, a source of speech waves in said incoming circuit, means including filters for dividing the speech waves into sub-bands of frequency components, means between said circuits for transmitting certain frequency components from said source directly to the outgoing circuit substantially unchanged in frequency, means for interchanging the frequency positions of certain sub-bands of components from said source while keeping them as a whole within substantially the same frequency limits, and transmitting the changed components to said outgoing circuit.

8. In a secret telephone system means to divide normal speech waves into sub-bands of frequency components, said sub-bands differing among themselves as to energy content and each by itself possessing small intelligibility, means to transmit substantially unchanged a sub-band of relatively small energy content and means to interchange the frequency positions of sub-bands of relatively large energy content and to transmit the interchanged sub-bands along with the unchanged sub-band.

9. In a secret telephone system, means to modulate a high frequency carrier wave in accordance with the unchanged and interchanged sub-bands produced by the means defined in claim 8, means for suppressing one of the side-bands of the resulting modulated wave and means for transmitting the remaining side-band.

10. The method of receiving and rendering intelligible the waves transmitted by the method defined in claim 1 comprising dividing the received waves into respective sub-bands composing the wave that is transmitted, and interchanging in reverse manner the sub-bands that result from interchanging sub-bands of normal speech, to restore the speech.

11. A receiving system for receiving and rendering intelligible the waves transmitted by a system as claimed in claim 7, comprising filters for dividing the received waves into sub-bands of frequency components, a receiver, means to transmit the components from one of said filters directly to said receiver, and means for restoring to normal frequency position the sub-bands from others of said filters and for impressing the restored sub-bands on said receiver.

In witness whereof, I hereunto subscribe my name this 12 day of December A. D., 1923.

HARVEY FLETCHER.