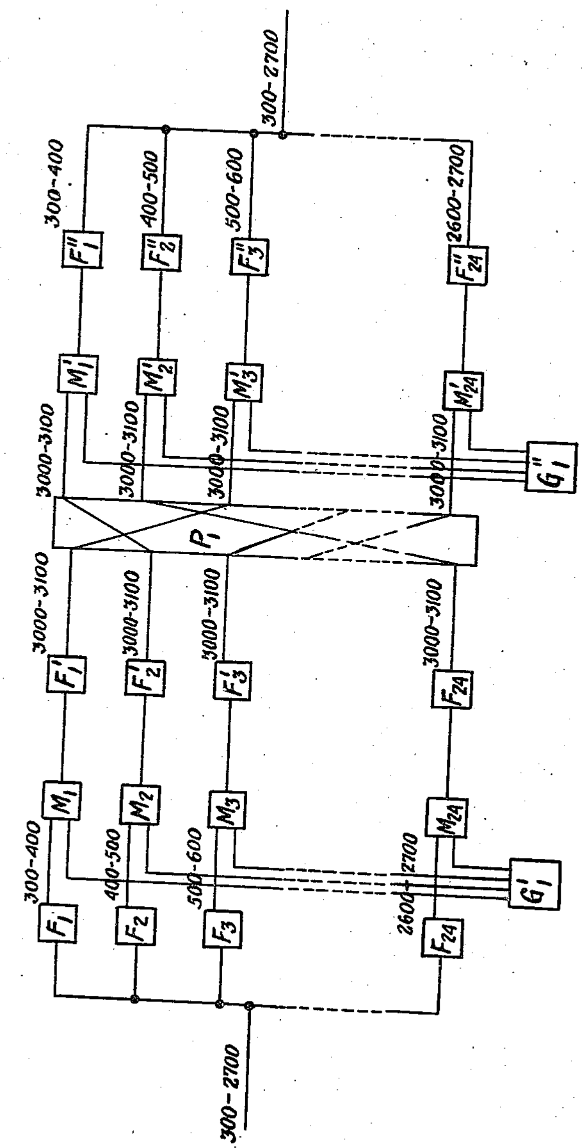
Nov. 26, 1946. G. GUANELLA 2,411,683

METHOD AND ARRANGEMENT FOR SCRAMBLING SPEECH SIGNALS

Filed June 15, 1944 3 Sheets-Sheet 1

Fig. 1



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3 Sheets-Sheet 2

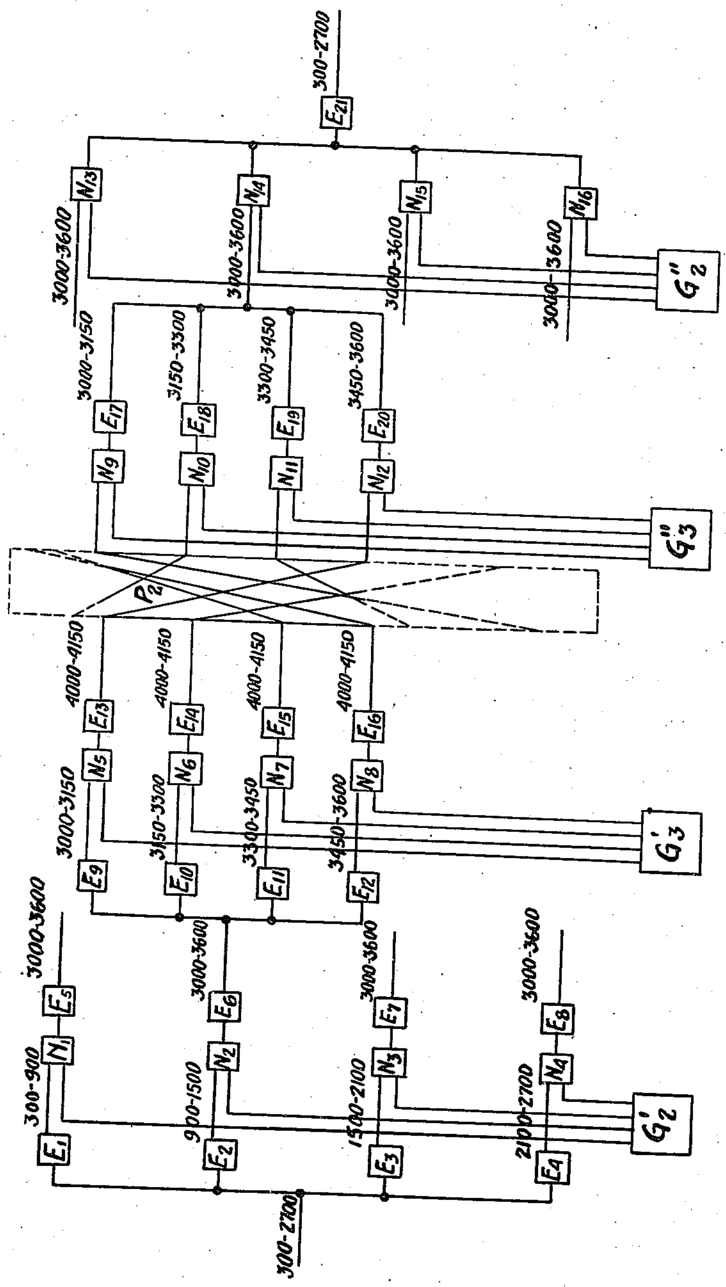

Fig. 2

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FIG. 3

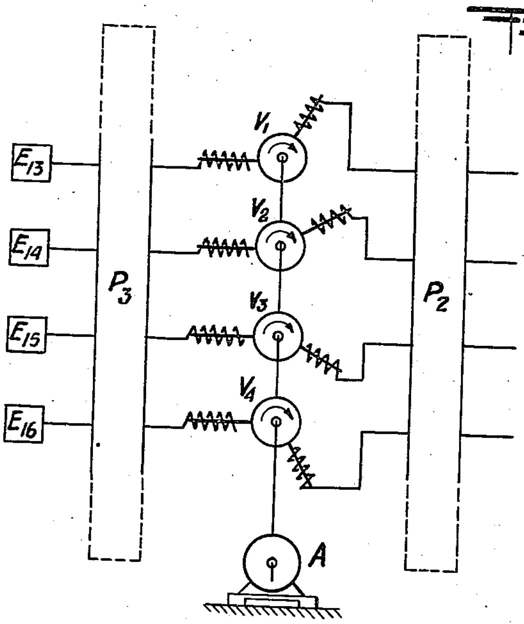
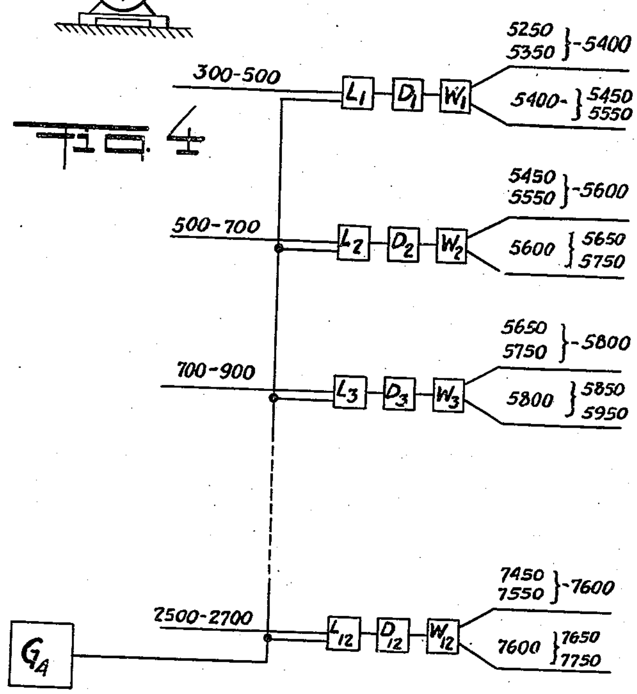


FIG. 4



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UNITED STATES PATENT OFFICE

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METHOD AND ARRANGEMENT FOR SCRAMBLING SPEECH SIGNALS

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1

The present invention relates to secrecy transmission of speech and like signals, more particularly to speech scrambling by subdividing a signal frequency band into a plurality of sub-bands which are mutually interchanged intermittently or in a continuously varying manner.

Methods of scrambling speech signals are already known, wherein the signal frequency band is divided into several sub-bands which are mutually interchanged. In order to increase the degree of secrecy, the transposition of the frequency sub-bands may be varied periodically according to a prescribed schedule. It is also known to invert individual frequency bands before transmission.

The width of the frequency sub-bands usually amounts to from 500 to 700 cycles in methods of this type. Since the fundamental frequency of spoken vowels generally lies between 100 and 250 cycles, at least two components of the speech oscillation will occur in each of the bands, these components differing from each other by the amount equal to the fundamental frequency. By means of a simple frequency analysis of a single band, it is thus possible to determine the fundamental frequency of the transmitted speech, even though the sub-band in question may have been frequency-shifted. Important conclusions concerning the kind of speech transmitted can be deduced from the fundamental frequency, so that the degree of secrecy obtainable with this method is rather limited.

Other methods are known for improving the utilization of the transmission channel, wherein the message is divided into relatively narrow frequency bands and wherein in place of the bands themselves speech defining or pilot signals are transmitted characterizing the frequency position and the variation of the amplitude of each individual band. Messages transmitted according to this method are, however, indistinct and the characteristic tone of the transmitted speech is completely lost. Furthermore, the apparatus required for the realization of this method is rather complicated.

An object of the present invention is to avoid the above-mentioned disadvantages by the provision of a method of scrambling speech signals wherein the speech is converted into corresponding electrical oscillations and the frequency spectrum of these oscillations is divided into frequency sub-bands of which at least one is shifted or displaced, said sub-bands, according to the invention, being so designed as to have a frequency band width less than the mean fundamental frequency of the speech signals being transmitted.

2

The invention as to its objects and novel aspects will become more apparent from the following detailed description taken in reference to the accompanying drawings, and wherein:

Figure 1 is a block diagram illustrating a speech scrambling system constructed in accordance with the principles of the invention;

Figure 2 is a similar diagram showing an improved modified arrangement for carrying out the invention; and

Figures 3 and 4 are partial diagrams illustrating further improvements for embodiment in secrecy transmission systems described by the invention.

In the example illustrated in Figure 1, the speech or message to be scrambled is assumed to cover a frequency range of 300 to 2700 cycles. This range is divided by means of filters F_1, F_2 . . . F_{24} into sub-bands having frequency ranges of 300–400 cycles, 400–500 cycles . . . 2600–2700 cycles, respectively. In the modulators M_1, M_2 . . . M_{24}, which may be in the form of copper oxide modulators or of any other known type, the sub-bands are modulated with the auxiliary oscillations supplied by a first generator G_1', whereby the frequencies are shifted in such a manner that all sub-bands fall within the frequency range 3000–3100 cycles. The frequencies of this range are segregated from other undesirable oscillations by means of filters F_1', F_2' . . . F_{24}' all of which have the same passing range and which may therefore be of the same design and construction. The outputs of the filters F_1', F_2' . . . F_{24}' are applied to a permutating switch P_1 which, while constantly changing, passes the individual bands on to further modulators M_1', M_2' . . . M_{24}'. In the latter, the signals are subjected to a further modulation with the auxiliary frequencies of a further generator G_1'', these frequencies being so designed that each of the sub-bands is again shifted back into one of the original frequency ranges of 300–400 cycles, 400–500 cycles . . . 2600–2700 cycles. Thus, by the action of the permutating switch P_1, the reshifting occurs in such a manner that the frequency bands remain within the original signal frequency band, while undergoing a constant mutual change. Filters F_1'', F_2'' . . . F_{24}'' serve to suppress undesirable side bands and the carrier frequencies.

In the position of the permutating switch shown in the drawings, the frequency sub-band having a range of 300–400 cycles is moved to the range of 500–600 cycles in the scrambled signal, the original frequency sub-band having a range of 400–500 cycles is now located within the range of 300–400 cycles in the scrambled signal band and the original signal sub-band of 2600–2700 cycles now occurs as a new frequency band of 400–500 cycles. In the next position of the permutating switch P_1, the displacement of the original sub-bands to new positions in the scrambled signal will be different, and so on during the operating cycle of the switch. It is advantageous to use for the second modulation the same auxiliary frequencies as for the first modulation, whereby the scrambling device will require only a single generator.

Generally, in order to increase the difficulty of deciphering a message, it is advantageous to invert individual frequency bands, while other bands remain unchanged. For this purpose, the auxiliary frequencies of generator G_1' may be so designed that the lower side band of the modulation product of individual bands falls within the passing range of the filters F'. The partial inversion may also be effected during the second modulation in the modulators M'. The permutating switch P_1 may operate at a high rate, such as within periods of .5 second.

Since even in a low male voice the fundamental frequency generally lies above 100 cycles, each sub-band contains at the most one component of the signal oscillation, so that it is impossible to determine the fundamental frequency from one of the sub-bands having widths of 100 cycles.

The damping of an electrical filter is a maximum at the extreme ends of the filter passing range and decreases again as the distance from the passing range increases. A band-pass filter therefor may pass frequencies far removed from the desired passing range. For this reason it is advisable to effect the sub-division of the signal band in two stages, as shown in the modified arrangement according to Figure 2. In the latter, the total frequency band covering the range 300–2700 cycles is at first divided into four bands, viz., 300–900 cycles, 900–1500 cycles, 1500–2100 cycles, and 2100–2700 cycles, and each of these bands is subsequently again divided into four further sub-bands. Such a double division is shown in Figure 2 for the band 900–1500 cycles. For this purpose, this band is first shifted to the range 3000–3600 cycles and then divided into the frequency sub-bands 3000–3150 cycles, 3150–3300 cycles, 3300–3450 cycles, and 3450–3600 cycles. Before these bands are mutually transposed, they are all shifted into the same frequency range of 4000–4150 cycles by means of the auxiliary oscillations supplied by generator G_3', modulators N_{5-8} and filters E_{13-16}. A corresponding analogous conversion is carried out for the frequency bands segregated by filters E_1, E_3 and E_4. Each intermediate sub-band finally produces four frequency sub-bands, which lie within the range 4000–4150 cycles. These 16 sub-bands are mutually interchanged in a desired manner by means of the permutator switch P_2 and subsequently re-shifted in such a manner that they fall within the original range of 300–2700 cycles so that there is no overlapping of the bands. The manner in which the bands are shifted back is easily seen from the drawings. Four groups of sub-bands 3000–3150 cycles, 3150–3300 cycles, 3300–3450 cycles, and 3450–3600 cycles, respectively, are formed from which the four intermediate bands 3000–3600 are obtained, these latter being finally shifted back into the range of 300–2700 cycles.

As in the case of the example illustrated in Figure 1, with a frequency-substitution scrambling method according to this modified method, the individual signal channels also lie to a great extent in the same frequency range, so that again many elements of the scrambling device may be of the same design and construction, whereby to considerably simplify the design of the apparatus. The same auxiliary frequencies are produced by generators G_2' and G_2'' so that they may be replaced by a single generator. The same applies to generators G_3' and G_3''.

The secrecy of the system is considerably improved if the frequency sub-bands are not merely mutually shifted as regards frequency but are furthermore retarded in time by different amounts, i. e., by adjusting the recurrent elements of the sub-bands to a combined frequency-substitution and time-delay scrambling. A practical example of such a delay device for this purpose is shown diagrammatically in Figure 3. This delay device may be arranged between the filters E_{13}–E_{16} and the permutator P_2 of Figure 2. The frequency sub-bands of 4000–4150 cycles are passed from the filters E_{13}—E_{16} at first to a further permutating switch P_3 through which they reach the delay devices $V_1 \ldots V_4$, subjected to a continuous change, whereby the sub-bands are retarded by different time periods.

In Figure 3, four of the delay devices associated with the 16 signal sub-channels are indicated at $V_1 \ldots V_4$. After passing through the delay devices, the signals reach the permutator P_2 and are then, as in the case of Figure 2, subjected to a further frequency-substitution scrambling. In the example shown, the time-delay device V is in the form of a steel tape moving at constant speed and on which the message is recorded by means of a recording magnet, this message being picked up again from the tape after a certain time delay by means of a pick-up head. The storage or transit time of the various devices differ from each other in accordance with the different positions of the pick-up heads. The drums for the tapes of the various devices are driven by a common motor A. The temporal signal elements of the sub-bands lying between two changes of the permutator P_3 are thus retarded by different amounts of time, so that for instance two signal elements in the scrambled message which originally belonged to the same sub-band can now have a reverse sequence as regards time when compared with the original message.

In order to insure secrecy, it is not always necessary to subject the sub-bands to a frequency shift. It is often sufficient to retard only some of the frequency sub-bands without any mutual frequency shift. One method of secret signalling consists of subdividing the message to be scrambled into frequency sub-bands of which at least some are subjected to different time delays by means of retarding devices. When listening to such scrambled messages they are entirely unintelligible to an unauthorized receiver. In order to decipher them it is necessary for the corresponding sub-bands to be shifted back again in time.

To increase the secrecy, the frequency bands may be given different widths. If they have the same width, it is possible by means of the position of the fundamental and harmonic waves of a certain oscillation process within the individual frequency sub-bands to determine by mathematical means how the sub-bands must be originally arranged. Deciphering is still further complicated if the frequency band width is made variable.

A method of producing frequency bands of continuously variable width will be explained with reference to Figure 4. In the latter, the message is divided into sub-bands each having a 200-cycle width and which wall within the frequency ranges 300–500 cycles, 500–700 cycles . . . 2500–2700 cycles indicated in the drawings. These sub-bands are modulated by means of modulators L_{1-12} with a variable auxiliary oscillation supplied by a generator G_4, the frequency of this oscillation varying continuously and periodically such as between 4950 and 5050 cycles in the example illustrated.

In the modulators L_{1-12}, the frequency bands are thus shifted by amounts which vary continuously. The rhythmically shifted frequency bands are applied to electrical switches or cut-off filters W_{1-12} which are so constructed that they divide the bands which are shifted by the instantaneous auxiliary oscillation of 5000 cycles exactly in the middle. Thus, for instance, referring to the first band of 300–500 cycles, this is shifted in modulator L_1 in such a manner that it varies within the range 5250–5550 cycles. The lower side band is suppressed by filter D_1. The electrical switch W_1 is at 5400 cycles. Accordingly, therefore, after the switch two bands of variable width will occur. The lower limit of one band varies between 5250 and 5350 cycles, while its upper limit varies between 5450 and 5550 cycles. These values are shown in Figure 4. For the other bands the corresponding limits are also indicated in the figure.

Instead of using the method illustrated in Figure 4, frequency bands of variable width may also be obtained by employing filters having a variable passing range. In this case, it is not necessary to modulate with a variable auxiliary oscillation.

It is conceivable that the scrambled message might be deciphered by observing the speech power rhythm obtained from the power rhythm of the individual frequency bands. In order to eliminate this possibility, it is advisable to alter the variation of the amplitude of the original signal frequency band or at least of individual sub-bands of frequency by means of a tme-dependent damping. In many cases the alterations also consist in diminishing the fluctuations of the amplitude of the electrical oscillations. Furthermore it is often an advantage to adjust the average amplitude of the individual sub-bands so as to suit each other.

At the receiving end, the energy rhythm of the message must again follow its original course. This may be accomplished by a synchronous alteration of corresponding damping elements both in the transmitter and receiver or by directly controlling the change of the amplitude by means of pilot signals transmitted together wih the message.

The energy rhythm may also be scrambled and thus unauthorized deciphering made more difficult by retarding the signal frequency band by constantly varying amounts of time before dividing it into the sub-bands. By this means, the message is divided into individual elements subject to a mutual time shift.

To decipher or unscramble a message, it is necessary to eliminate in the reverse sequence the changes to which the message has been subjected. For shifting back the frequency bands generally, the same filters and auxiliary frequencies may be used as for scrambling. Care must, of course, be taken that the devices such as the corresponding permutators and retarding devices operate in exact synchronism.

I claim:

1. A method of scrambling signals which comprises dividing a signal frequency band into a plurality of sub-bands each having a band width less than the mean fundamental frequency of the signal to be scrambled, and subjecting said sub-bands to a continuously changing scrambling process.

2. A method of scrambling speech signals which comprises dividing the signal band into a plurality of sub-bands each having a band width less than the mean fundamental frequency of the signal to be scrambled, and subjecting said sub-bands to a frequency-substitution scrambling process.

3. A method of scrambling speech signals which comprises dividing the signal band into a plurality of sub-bands each having a band width less than the mean fundamental frequency of the signal to be scrambled, and subjecting recurrent elements of said sub-bands to a time-delay scrambling process.

4. A method of scrambling speech signals, which comprises dividing the signal band into a plurality of sub-bands having unequal band widths each being less than the fundamental frequency of the signal to be scrambled, and subjecting recurrent elements of said sub-bands to a time-delay scrambling process.

5. A method of scrambling speech signals which comprises dividing the signal band into a plurality of sub-bands each having a band width less than the mean fundamental frequency of the signal to be scrambled, and subjecting the elements of recurrent groups of sub-bands to a frequency-substitution scrambling.

6. A method of scrambling speech signals which comprises dividing the signal band into a plurality of sub-bands each having a band width less than the mean fundamental frequency of the signal to be scrambled, and subjecting the elements of recurrent groups of sub-bands each to a different periodically recurrent frequency-substitution scrambling.

7. A method of scrambling speech signals which comprises dividing a signal frequency band into a plurality of intermediate sub-bands, dividing each of said intermediate sub-bands into secondary sub-bands each having a band width less than the mean fundamental frequency of the signal to be scrambled, and subjecting said secondary sub-bands to a scrambling process.

8. A method of scrambling speech signals which comprises dividing a signal frequency band into a plurality of intermediate sub-bands, dividing each of said intermediate sub-bands into secondary sub-bands each having a band width less than the mean fundamental frequency of the signal to be scrambled, and subjecting said secondary sub-bands to a frequency-substitution scrambling.

9. A method of scrambling speech signals which comprises dividing a signal frequency band into a plurality of intermediate sub-bands, dividing each of said intermediate sub-bands into secondary sub-bands each having a band width less than the mean fundamental frequency of the signal to be scrambled, and subjecting the elements of recurrent groups of signal elements of the intermediate sub-bands to a continuously changing frequency-substitution scrambling.

10. A method of scrambling speech signals which comprises dividing a signal frequency band

into a plurality of intermediate sub-bands, dividing each of said intermediate sub-bands into secondary sub-bands each having a band width less than the mean fundamental frequency of the signal to be scrambled, and subjecting the elements of recurrent groups of signal elements of the intermediate sub-bands each to a different periodically recurrent frequency-substitution scrambling.

11. A method of scrambling speech signals, which comprises dividing a signal into a plurality of frequency sub-bands each having a band width less than the mean fundamental frequency of the signal to be scrambled, subjecting the elements of recurrent groups of sub-bands to a frequency-substitution scrambling, and simultaneously subjecting the elements of recurrent groups of said sub-bands to a time delay scrambling.

12. A method of scrambling speech signals which comprises dividing a signal into a plurality of frequency sub-bands each having a band width less than the mean fundamental frequency of the signal to be scrambled, and subjecting the elements of recurrent groups of sub-bands to a periodically recurrent time-delay scrambling.

13. A method of scrambling speech signals which comprises dividing a signal frequency band into a plurality of intermediate sub-bands, dividing each of the intermediate sub-bands into secondary sub-bands each having a band width less than the mean fundamental frequency of the signal to be scrambled, subjecting the elements of recurrent groups of the secondary sub-bands each to a different periodically recurrent frequency-substitution scrambling, and simultaneously subjecting the elements of recurrent groups of sub-bands to a periodically recurrent time-delay scrambling.

14. A method of scrambling speech signals which comprises dividing a signal frequency band into a plurality of frequency sub-bands, and subjecting said sub-bands to a continuous frequency-substitution scrambling by varying the relative width of said sub-bands while maintaining the sum thereof equal to the band width of the signal being scrambled, said sub-bands having a width less than the mean fundamental frequency of the signal to be scrambled throughout the scrambling period.

15. In a system of scrambling signals, means to divide a signal frequency band into a plurality of frequency sub-bands each having a band width less than the mean fundamental frequency of the signal being scrambled, and means for subjecting said sub-bands to a continuous scrambling process.

16. In a system of scrambling speech signals, means to divide a signal into a plurality of frequency sub-bands each having a band width less than the mean fundamental frequency of the signal being scrambled, and means for subjecting said sub-bands to a continuous frequency-substitution scrambling.

17. In a system of scrambling speech signals, means to divide a signal into a plurality of frequency sub-bands each having a band width less than the mean fundamental frequency of the signal being scrambled, and means for subjecting said sub-bands to a continuous time-delay scrambling.

18. In a system of scrambling speech signals, means to divide a signal into a plurality of frequency sub-bands each having a band width less than the mean fundamental frequency of the signal being scrambled, and means for subjecting said sub-bands to a combined simultaneous and continuous frequency-substitution and time-delay scrambling.

19. In a system for scrambling speech signals, means to divide a signal frequency band into a plurality of intermediate sub-bands, further means to divide each of said intermediate sub-bands into secondary sub-bands, and means for subjecting said secondary sub-bands to a continuous scrambling process.

20. In a system for scrambling speech signals, means to divide a signal frequency band into a plurality of intermediate sub-bands, further means to divide each of said intermediate sub-bands into secondary sub-bands each having a band width less than the mean fundamental frequency of the signal being scrambled, and means for subjecting said secondary sub-bands to a continuous scrambling process.

21. In a system for scrambling speech signals, means to divide a signal frequency band into a plurality of intermediate sub-bands, further means to divide each of said intermediate sub-bands into secondary sub-bands each having a band width less than the mean fundamental frequency of the signal being scrambled, and means for subjecting said secondary sub-bands to a continuous frequency-substitution scrambling.

22. In a system for scrambling speech signals, means to divide a signal frequency band into a plurality of intermediate sub-bands, further means to divide each of said intermediate sub-bands into secondary sub-bands each having a band width less than the mean fundamental frequency of the signal being scrambled, and means for subjecting the elements of recurrent groups of said intermediate sub-bands to a continuous time-delay scrambling.

23. In a system for scrambling speech signals, means to divide a signal frequency band into a plurality of intermediate sub-bands, further means to divide each of said intermediate sub-bands into secondary sub-bands each having a band width less than the mean fundamental frequency of the signal being scrambled, and means for subjecting the elements of recurrent groups of said secondary sub-bands to a combined simultaneous and continuous frequency-substitution and time-delay scrambling.

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