

Sept. 3, 1946.

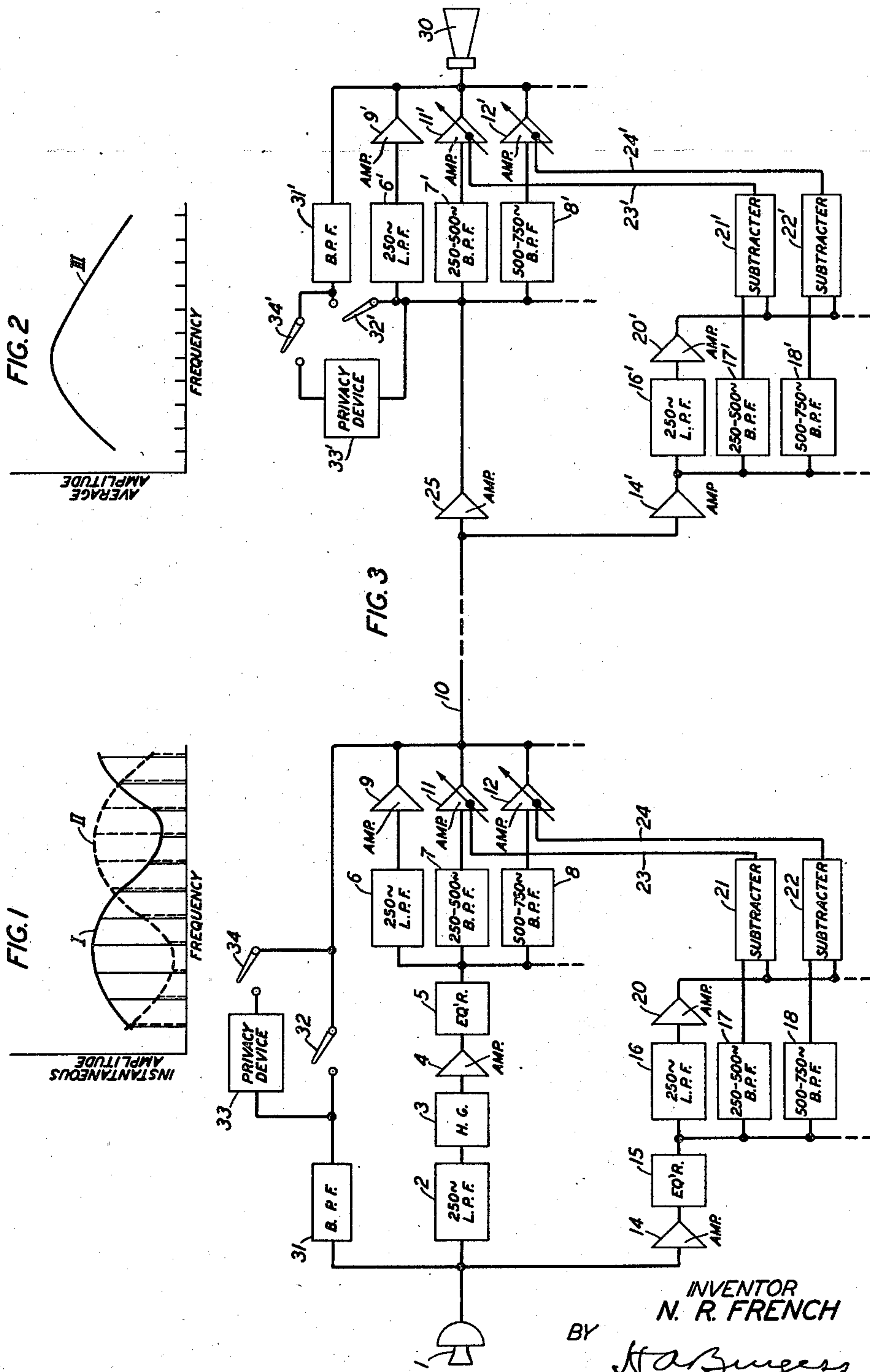
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2,406,825

PRIVACY SYSTEM FOR SPEECH TRANSMISSION

Filed March 18, 1943

2 Sheets-Sheet 1



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2,406,825

PRIVACY SYSTEM FOR SPEECH
TRANSMISSION

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Application March 18, 1943, Serial No. 479,571

11 Claims. (Cl. 179—1.5)

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The present invention relates to speech transmission, especially where privacy is desired.

An object of the invention is to analyze and reconstruct speech waves in a form suitable for transmission to secure privacy or other special effects.

A feature of the invention comprises a novel treatment of the vowel or voiced sounds for purposes of transmission.

In accordance with the invention the voiced sounds are analyzed into their fundamental and harmonic frequency components and the relative amplitudes of these components are changed in a manner that can be reversed at a receiving point, the change made in the waves prior to transmission being of such character as to render the transmitted waves unintelligible.

Analysis of the vowel or voiced sounds shows that they consist of a fundamental which is varying in amplitude and frequency from moment to moment and a large number of overtones in harmonic relationship to the fundamental. The different voiced sounds are characterized by different relationships between the amplitudes of the various harmonics. This relationship is not constant, however, with time for a particular voiced sound, but is continuously changing during the existence of the sound, particularly during the building up and dying down portions of the sound.

The basis of the privacy method of the invention is a radical and variable alteration of the relative amplitudes of the various components throughout the speech frequency range. In some respects, the method can be regarded as equivalent to the insertion of a frequency distortion network, the response characteristics of which are, however, not constant with time but are made to vary radically from moment to moment during the progress of each speech sound.

The nature and objects of the invention will be more fully understood from the following detailed description read in connection with the accompanying drawings in which:

Figs. 1 and 2 are graphs to be referred to in the description;

Fig. 3 is a block schematic diagram of a complete one-way telephone system showing how the invention may be applied in practice; and

Figs. 4 and 5 are schematic circuit diagrams of transforming or distorting circuits which may be used at points shown in block diagram in Fig. 3.

The general method employed in accordance with the invention will be outlined with special reference to Figs. 1 and 2. Let it be supposed

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that during the production of a voiced sound attention is focussed on a short interval of the sound comprising one complete period of the fundamental frequency. Analysis of the sound during this short period would show that in addition to the fundamental there are harmonic components scattered over the frequency range. In Fig. 1 the curve I may be taken as representing the envelope of the frequency distribution of the amplitudes of the fundamental and its harmonics during the particular one cycle period of the fundamental. During this period the sound is analyzed in accordance with the invention and reformed with altered relations, such as shown by the envelope curve II, between the various harmonics and fundamental. If the sound during the succeeding intervals is also analyzed it will be found that the fundamental may have changed somewhat in frequency and that the envelope of the amplitudes of fundamental and harmonics are changed from that of the preceeding period represented by curve I. The sound in these intervals is also analyzed and reformed, in accordance with the invention. This process of analyzing and reforming the sound with altered relations between the components is not confined to any one or a few of the short time intervals but is carried out as a continuous process from the beginning of each speech sound to its end. As a consequence the radical and constantly varying distortion resulting from changing envelopes typified by curve I to envelopes typified by curve II prevents the speech sound from being recognized until it has been properly operated upon to restore it to the original condition.

The operation illustrated by these two curves may be stated as follows: If at any particular instant a particular component of the signal exceeds the fundamental in amplitude by x db the amplitude of this component in the coded speech is to be x db lower than that of the fundamental.

Practically, it probably would not be advisable to carry out the operation in exactly this manner since the average speech spectrum has a pronounced frequency characteristic of the type shown by curve III of Fig. 2. While the relation between any component and the fundamental may at any particular instant depart considerably from the relation shown in this figure, yet at the higher frequencies the amplitudes will for the most part be considerably lower than that of the fundamental. Following the above rule, these high frequencies would, therefore, nearly always

have to be transmitted at levels very much higher than that of the other components. For this reason, it will be desirable to carry out the operation according to the following rule: If at any particular instant the amplitude of a particular component of the signal exceeds the fundamental by x db more than the average difference in levels between the speech in these two frequency regions, the component in the coded speech is to be lowered by $2x$ db.

Referring to Fig. 3, means are shown for carrying out the operation in accordance with the last stated rule. Speech spoken into the microphone 1 is applied in part to the low-pass filter 2 which has a sufficiently low-cut-off to isolate the fundamental component. This is applied to the harmonic generator 3, followed by amplifier 4, for causing the generation of a series of harmonics covering the speech range. These are passed through equalizer 5 and applied to an analyzer consisting of filters 6, 7, 8, etc., filter 6 being for the fundamental and filters 7, 8, etc., for selecting one or more of the individual harmonic components. There are as many filters 7, 8, etc., as are required to select all of the harmonic components that it is desired to transmit. The fundamental component passed through the filter 6 is amplified at 9 and sent to line 10 for transmission. The other components passed by the analyzer filters 7, 8, etc., are individually amplified at 11, 12, etc., by variable gain amplifiers, the gains of which are individually controlled in a manner to be described.

The speech waves from microphone 1 are also applied to an amplifier 14, equalizer 15 and an analyzer consisting of filters 16, 17, 18, etc. Filter 16 selects the fundamental component which is amplified at 20 and impressed upon each of the subtractors 21, 22, etc. The various harmonic components are individually selected by the filters 17, 18, etc., and also impressed upon the subtractors 21, 22, etc.

The subtractors, to be described in detail presently, serve to compare the instantaneous amplitude of individual harmonic components against the instantaneous amplitude of the speech fundamental and to produce a difference voltage in the leads 23, 24, etc., for purposes of controlling the gains of the amplifiers 11, 12, etc. For example, if the harmonic component selected by filter 17 is at one instant of higher amplitude than the fundamental the subtractor 21 will produce a voltage in lead 23 such as to reduce the gain of amplifier 11 (or insert a loss) to cause the corresponding harmonic component passed by filter 7 to be sent to line 10 with a reduced amplitude in accordance with the foregoing stated rules. Conversely, if the harmonic component passed through filter 18 is of lower amplitude than the fundamental at the same instant, the subtractor 22 produces a voltage in lead 24 of the right value to adjust the gain of amplifier 12 to increase the amplitude of the harmonic component sent from filter 8 to line 10.

If the operation is to be in accordance with the second rule above stated, the equalizer 5 has a characteristic of such shape as to make the frequency amplitude distribution in its output correspond with curve III of Fig. 2. The equalizer characteristic is determined by the difference between the spectrum of the output of harmonic generator 3 and curve III of Fig. 2. The equalizer 15 has a loss characteristic like that of curve III so that currents of both low and high frequencies are transmitted with less loss than waves

in the middle part of the speech range. In other words, if waves having a frequency amplitude distribution in accordance with curve III were applied to the equalizer 15 the spectrum of the output waves would be flat.

In the operation of the transmitting circuits of Fig. 3, then, there are produced in the apparatus 2, 3, 4, 5 fundamental and harmonic frequency components having a distribution over the speech range in accordance with curve III. This would be the shape of the spectrum transmitted into the line 10 if there were no control voltages impressed on leads 23, 24, etc. The speech wave after distortion, in the manner described, by equalizer 15 is analyzed by the filters 16, 17, 18, etc., and if any given component has an amplitude x db greater or smaller than the fundamental component the corresponding subtractor 21, 22, etc., applies such a voltage to the corresponding amplifier 11, 12, etc., as to decrease or increase, respectively, the component selected by the corresponding analyzer filter 7, 8, etc., by an amount $2x$ db.

The receiving end of the system shown at the right of Fig. 3 may be identical with the transmitting end except for the omission of certain elements including the elements 2, 3, 4, 5, and 15. The corresponding elements in the receiving side are designated by the same reference characters as those in the transmitting side but primed. It is thought that the construction of the receiving circuits will be sufficiently understood by describing their operation.

The received distorted waves are passed in parallel through the amplifiers 25 and 14'. The waves in the output of amplifier 25 are applied to the analyzer circuit to select and amplify the fundamental component at 6' and 9' and to select the various harmonic components at 7', 8', etc., and apply them to individual amplifiers 11', 12', etc. The outputs of amplifiers 7', 8', 9', etc., are applied to the receiving circuit shown as terminating in a telephone receiver or loud-speaker 30. Amplifier 9' is a constant gain amplifier, while the amplifiers 11', 12', etc., are variable gain amplifiers (or may be variable loss circuits).

The waves in the output of amplifier 14' are applied to the analyzer consisting of a filter 16', 17', etc., for selecting the various harmonic components. As in the case of Fig. 1, these components are compared in the subtractors 21', 22', etc., against the fundamental and difference voltages are set up in the leads 23', 24', etc., for adjusting the gains of the amplifiers 11', 12', etc. The polarities of these voltages or the sense of the change made in the gains of the amplifiers 11', 12', etc., are the reverse of those employed at the transmitter so as to restore the waves to recognizable form in the receiver 30. For example, if a harmonic component in subtractor 21' is x db greater in amplitude than the fundamental at a particular instant, the gain of amplifier 11' is so changed as to reduce by $2x$ db the amplitude of the corresponding harmonic component applied to the receiver 30 and vice versa. In this way each individual distorted sound component such as might be represented at a given instant by the ordinates designed by curve II, Fig. 1, is restored to approximately its original assumed form shown by curve I.

The apparatus described thus far in Fig. 3 suffices only for the transmission of the voiced sounds, these being the sounds which are made up of the vocal cord frequency as a fundamental

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and harmonics thereof. Experience shows that a considerable degree of intelligibility is carried by the voiced sounds alone since the ear apparently supplies the missing consonants to some extent from the somewhat different effect which each particular consonant has in modifying the character of the voiced sounds with which they are associated. For some purposes, therefore, the apparatus thus far described in Fig. 3 may suffice. However, if it is desired to increase the intelligibility somewhat a narrow band of frequencies in the consonant range may be supplied directly to the line 10 from the transmitter 1 through band-pass filter 31 by closure of switch 32, corresponding elements 31' and 32' being provided at the receiver. Use of the filters 31, 31' to transmit such a band would reduce the degree of secrecy if the band were directly transmitted through switches 32, 32'. As an alternative, therefore, a suitable privacy device 33 can be inserted by closing switch 34, with switch 32 open, of course. Similar parts 33' and 34' are shown at the receiver. The privacy device 33 may be of any suitable or known type for masking or disguising the intelligibility of the transmitted band such as a frequency inverter or other scrambler. An example of such a device, by way of illustration, is found in U. S. patent to B. W. Kendall, No. 1,571,010, dated January 26, 1926.

Referring to Fig. 4, one type of subtractor and gain or loss control applicable to the system as shown in Fig. 3 is illustrated in detail. In this case variable loss devices are used instead of the variable gain amplifiers 11, 12 of Fig. 3. These loss devices comprise varistor bridges 43, 44, etc., connected individually in the output circuits from the analyzer filters 7, 8, etc. The filter 6 leads through constant gain amplifier 9 to the outgoing line 10 as before. The analyzer filters 7, 8, etc., are connected to the outgoing line 10 through individual loss devices 43, 44, etc., and fixed gain amplifiers 52, 53, etc.

The subtractor 21 shown in detail in Fig. 4 is in two parts, 21a and 21b. Part 21a comprises a transformer 54 with a center tapped secondary and a pair of similar varistors 48, 49 connected across the winding with a mid-branch comprising a resistor 45 shunted by resistor 46 and varistor 47 in series. The various varistors may be, for example, copper oxide.

The part 21b may be entirely similar to the part 21a. The circuit 23 shown in this case as a two-conductor circuit leads from conjugate points on varistor bridge 43 through a biasing battery 52, resistor 51 and through an adjustable portion of resistance 50 in subtractor 21b and of resistance 45 in subtractor 21a.

With this circuit configuration and with proper adjustment of the biasing battery 52 and the various resistors and varistors, the current through resistor 45 may be made to vary in accordance with the logarithm of the alternating current voltage across the primary winding of the repeating coil 54 and the current through resistance 50 similarly may be made to vary in accordance with the logarithm of the alternating current voltage occurring in the output of filter 17. The resistances 45 and 50 are connected in the circuit 23 in opposition so that if the two impressed voltages corresponding to the fundamental and harmonic components are equal no current flows in circuit 23 and no change is made in the loss of the device 43. If, however, the current in resistance 50 exceeds the current in resistance 45 the transmission loss introduced by the

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varistor device 43 in the connecting filter 7 and amplifier 52 is increased, while if the current in resistor 50 is less than the current in resistor 45, the loss variation is in the opposite direction.

In order to compare the amplitude of the fundamental with the amplitude of the next harmonic component, namely that selected by filter 18, the fundamental is applied to a further subtractor 22 comprising circuits 22a and 22b operating in the same manner as circuits 21a and 21b. Varistor loss device 44 connected between filter 8 and amplifier 53 has its loss controlled over circuit 24 which is connected to subtractor 22 in similar manner to the case of circuit 23 and subtractor 21.

Fig. 5 illustrates in detail a subtractor circuit arranged to control the gain of amplifier 11 in accordance with the block schematic of Fig. 3. In this case the two parts of the subtractor 21 are shown as comprising circuits 21a and 21b as in Fig. 4, while the circuit 23 has its terminals connected between the cathode and control grid of amplifier 11. Bias control battery and potentiometer 56 are for the purpose of setting the initial or normal bias to the proper value to provide a normal reference gain. This gain is either unchanged, increased or decreased according as the harmonic component passed through filter 17 has the same amplitude as the fundamental or a smaller or larger amplitude respectively. That is, current through resistor 45 varies as the logarithm of the impressed fundamental voltage and decreases the negative grid bias, while the current through resistor 50 varies as the logarithm of the impressed harmonic voltage and increases the negative grid bias. Input and output terminals 60 and 61 are provided for the amplifier 11 for connecting it between filter 7 and line 10. Similar subtractors and amplifiers would, of course, be provided for the other harmonic channels of the transmitting circuit. The amplifier tube 11 may advantageously be a variable mu tube in order to provide a sufficiently wide range of gain variation.

The invention is not limited to the specific circuit arrangements that have been disclosed nor to stated values or other details and the disclosure is to be taken as illustrative rather than limiting. The scope of the invention is defined in the claims, which follow.

What is claimed is:

1. The method of transmission of the voiced sounds of speech comprising comparing the amplitude of the voice fundamental with the amplitude of each of a series of harmonics of the voice fundamental to derive a series of differential values, generating a series of harmonics of the voice fundamental, controlling the relative amplitude of each latter harmonic frequency wave with respect to the strength of the voice fundamental in accordance with a respective differential value derived from comparison of the corresponding voice harmonic and voice fundamental and transmitting said generated and controlled harmonics and voice fundamental.

2. In speech transmission, means to analyze speech sounds into their fundamental and harmonic frequency components, means to compare the amplitude of each harmonic frequency component with the amplitude of the fundamental component to determine their relative strengths from instant to instant, means to generate a series of harmonics of the fundamental frequency component, and means to construct a wave for

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transmission from the speech fundamental component and said generated harmonics comprising means to determine the strength of each such harmonic in accordance with the difference in strength between the fundamental and harmonic components resulting from such analysis.

3. The method of constructing a distorted speech wave for transmission with privacy comprising extracting the vocal cord frequency from the speech wave and generating a series of harmonic frequency components thereof having arbitrary amplitudes and individually controlling the amplitude of the harmonic frequency components in accordance with the relative strengths of the fundamental and harmonic frequency components of the speech message wave from instant to instant, but in inverse sense.

4. In a speech transmission system, means to extract the voice fundamental frequency and to generate a series of harmonics based on it and covering a substantial part of the speech transmission range, an analyzer for speech waves for deriving the fundamental and harmonic frequency components thereof, means to compare the strength of each derived harmonic against the derived fundamental component to determine their relative differences from moment to moment, means to control the strength of the respective generated harmonic in accordance with the respective determined difference from moment to moment but in inverse sense, and means to transmit said generated harmonic waves of controlled strength.

5. In a speech transmission system, means to extract from speech waves the voice fundamental component, means to build up a coded speech wave therefrom comprising means for generating a series of harmonics thereof extending over the speech transmission band, means to analyze speech into its fundamental and harmonic components continuously, means to determine relative strengths of harmonic to fundamental components, and means controlled by the last means to cause a given harmonic component in the coded wave to exceed by a given amount the extracted fundamental component whenever the corresponding harmonic component obtained by analyzing the speech wave has a definite lower amplitude than the fundamental component derived by analysis of the speech wave and to be less than such extracted fundamental by a given amount whenever the corresponding harmonic component obtained by analysis of the speech wave exceeds the fundamental component of the analyzed speech wave by a definite amount.

6. A system in accordance with claim 5, in which said controlled means causes each harmonic in the coded wave to be less or greater in amplitude than the fundamental component of the coded wave by x db whenever the respective harmonic components of the analyzed wave are greater or less in amplitude, respectively, than the fundamental component of the analyzed wave by x db.

7. In a speech privacy system, means at a

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transmitting point to derive from input speech waves the vocal cord frequency and to transmit a wave varying in frequency and amplitude in accordance therewith, means to analyze the input speech waves to determine how the instantaneous amplitudes vary with reference to the voice fundamental, means to transmit with the transmitted wave of vocal cord frequency a succession of harmonics thereof, means to distort the transmitted harmonics under control of said analyzing means to render transmission private, means at a receiving point to receive the transmitted wave of vocal cord frequency and harmonics thereof, means to analyze the received wave, and means controlled by said latter analyzing means to introduce a counter distortion into the received harmonics to render the resultant waves understandable.

8. In speech privacy transmission, means at a transmitting point to extract from input speech waves the vocal cord wave component and to transmit the same to a distant receiving point, means to use the frequency and amplitude variations of said component from instant to instant as a reference wave from which to construct a distorted speech wave for transmission and from which to reconstruct an intelligible speech wave at the receiving point, said last means comprising in part an analyzer at each point and harmonic control means controlled by the respective analyzers.

9. In speech transmission, means to extract the vocal cord frequency from speech message waves and transmit the same, means to distort the harmonic components of the speech wave before transmission comprising means for continuously changing their amplitudes by definite amounts relative to the vocal cord component to make the transmission private, and means at a receiving point to restore the waves to recognizable form comprising means to effect opposite changes in the harmonic amplitudes relative to the vocal cord component.

10. In a speech transmission system, means to derive from the speech message waves components representative of the voiced sounds, a privacy channel for transmitting indications of said components in disguised form, means to derive from the speech message waves other components representative of unvoiced sounds and a privacy channel for transmitting indications of said latter components in disguised form, said two privacy channels operating on the respective components transmitted through them to disguise the respective components in different ways.

11. A system according to claim 4 including means to select from the speech waves a band of high frequency components representative of unvoiced sounds, privacy means for disguising said selectde band of waves to obscure their intelligibility and means to transmit said waves so disguised along with said generated harmonic waves of controlled strength.

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