

July 24, 1951

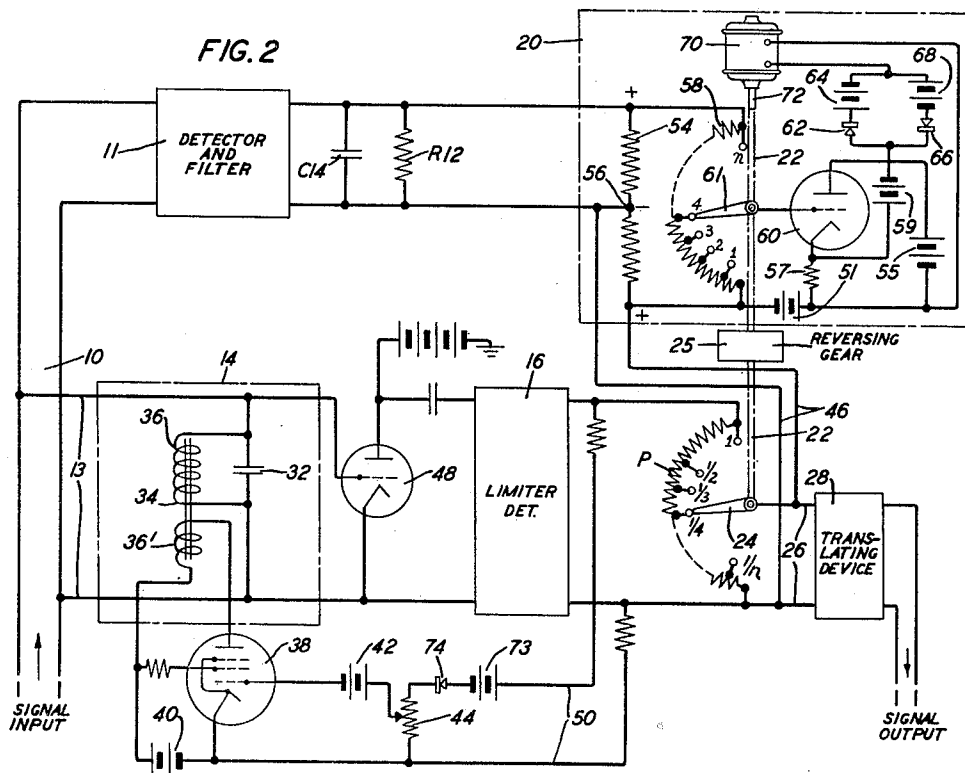
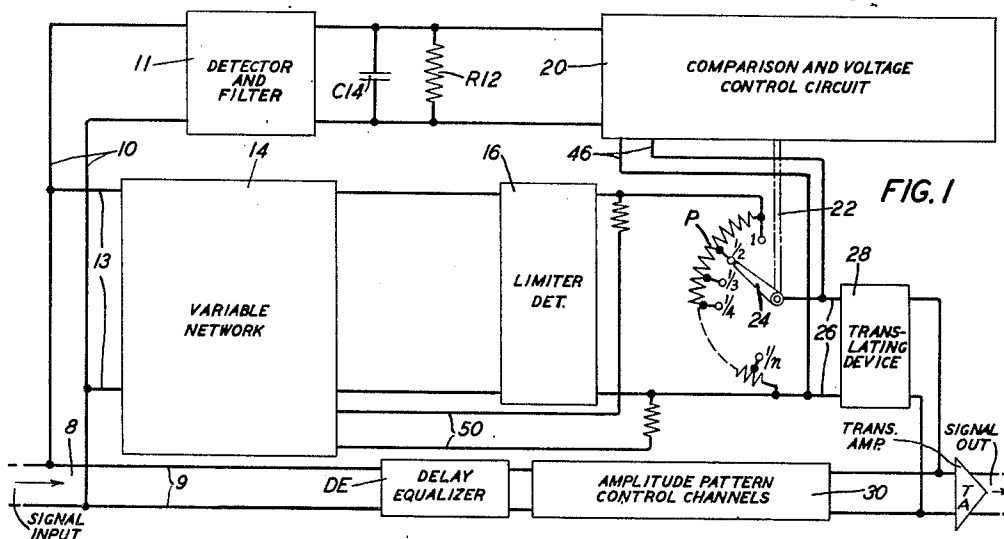
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2,562,109

SIGNAL WAVE ANALYZER FOR DERIVING PITCH INFORMATION

Filed April 30, 1948

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 3

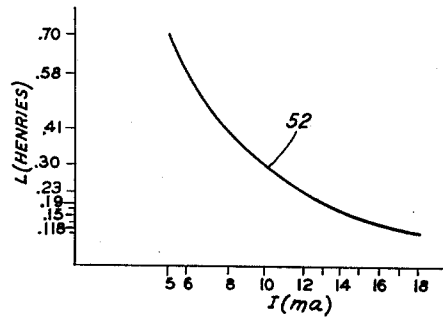


FIG. 4

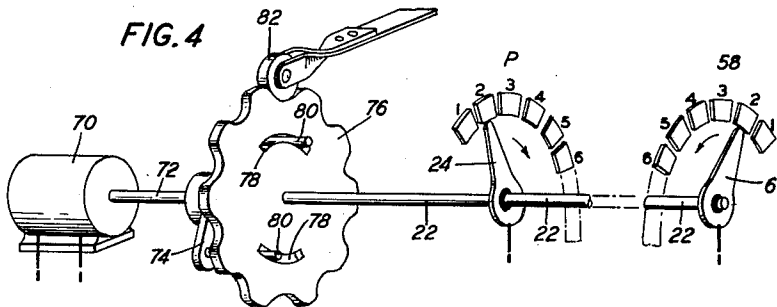
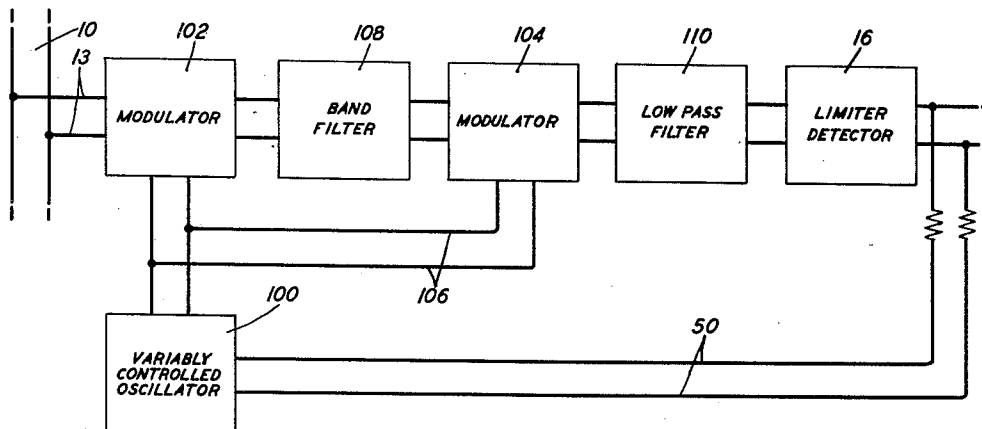


FIG. 5



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8 Claims. (Cl. 175-183)

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The present invention relates to signal wave transmission systems and in particular to such systems wherein a complex wave is analyzed to determine its fundamental characteristics. The invention is concerned with the securing of information relative to these fundamental characteristics, for transmission in place of the signal wave itself. Although the invention is particularly applicable to the transmission of speech signaling waves, it is not limited to such waves and particularly is this true as to some of its more important aspects and features.

In the particular embodiments described herein the invention is shown as being incorporated in a vocoder type of transmission system, a system of transmission and reception of speech as disclosed in H. W. Dudley United States Patent 2,151,091, March 21, 1939. The invention is in the nature of an improvement on certain aspects of such a system.

In the vocoder type of transmission system, speech waves are analyzed by subdivision of the wave into two portions, from each of which fundamental characteristics of the wave are derived. In one such type of system, such as the above-mentioned Dudley system, the speech wave is analyzed by subdivision of its frequency band into narrow bands and by integration of the energy in each band, giving a number of slowly varying speech defining currents in separate paths, each current requiring for its transmission a band of about 25 cycles per second. Additionally, one portion of the original speech wave is subjected to a heterodyning process from which there is secured a low frequency, slowly-varying current that is representative of the fundamental frequency of the original speech wave. This current, which may be called the fundamental frequency pattern, or pitch, control current, is transmitted along with the other slowly-varying speech-defining currents to the receiving point. For purposes of discussion, these other slowly varying currents may be classified as the amplitude pattern control currents. At the receiving point, speech is synthesized under control of these low frequency speech-defining currents by controlling sources of energy which have a frequency distribution covering the essential speech range. This energy is subdivided in frequency into narrow bands and the energy in each band is passed through a circuit whose admittance is made a function of the corresponding low frequency speech-defining current. Simultaneously, the frequency of one of these energy sources is controlled by the fre-

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quency pattern control current. The outputs of all of these circuits are combined to constitute the synthesized signal. For a more complete understanding of this particular type of vocoder transmission system, reference should be had to the Dudley patent above cited.

Although the invention is being described in connection with this particular type of vocoder system, it should be understood that it is not so limited, as it may be employed with equal facility in the so-called resonance type of vocoder system such as described in H. W. Dudley United States Patent 2,243,527, May 27, 1941.

In its general application, the invention is concerned with the analysis of complex waves, of periodic or quasi-periodic character, to determine the frequency of the fundamental wave component. In the specific embodiment to be described herein, the invention is incorporated in the frequency pattern control branch of a vocoder system such as was previously described.

In the previously referred to vocoder transmission system, in which the frequency pattern control current is derived by a heterodyning process, it occasionally happens that the heterodyning components temporarily assume such relative amplitude and phase relations that the derived frequency, which corresponds to the fundamental component, is momentarily of very small magnitude. At such times the heterodyning process may give rise to a relatively large component which is derived from heterodyning non-adjacent components, such as to produce a frequency corresponding to the second harmonic of the fundamental component. Under such circumstances the derived frequency pattern control current rapidly changes from a frequency corresponding to the fundamental frequency to one corresponding to the second harmonic of this frequency. This corresponds to a pitch change of one octave in the reproduced signal and to this extent is erroneous. Although the foregoing situation is relatively infrequent and of but momentary duration, it is not desirable and it is accordingly an object of this invention to enable the derivation of this frequency pattern control current without being subject to this effect.

It is well known that in the construction of speech signal waves, the resonant cavities of the mouth and nasal passages impart a slowly varying modulatory effect upon the fundamental frequency as generated by the vocal cords. In the above-described vocoder transmission system, the frequency pattern control current is concerned only with the fundamental frequency of

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the signal wave, and slightly undesirable effects may be experienced where this control current is influenced by this shifting modulatory effect. The present invention also has as an object, therefore, the production of this frequency pattern control current in such a manner that this modulatory effect is minimized and a control current is produced which is closely representative of the true fundamental frequency of the original signal wave.

It is a feature of the present invention that the actual presence or absence of the fundamental component in the signal wave is of no consequence because the essential information is derived from a single harmonic component of this fundamental component.

It is also a feature of the invention that as this single harmonic component assumes varying positions in the frequency spectrum, tracking means are brought into play which select it to the exclusion of the other varying components.

Other desirable aspects of the invention and the manner in which the foregoing objects are realized, will be apparent from the following detailed description of one embodiment of the invention, when considered in connection with the drawings, in which:

Fig. 1 is a block schematic diagram of an embodiment of the invention as incorporated in the frequency pattern control branch of the transmitting apparatus of a vocoder transmission system;

Fig. 2 is a schematic diagram of the pitch deriving arrangement of Fig. 1;

Fig. 3 is an explanatory diagram referred to in the description;

Fig. 4 illustrates a mechanical arrangement that is suitable for use in the voltage control portion of the system shown in Fig. 2; and

Fig. 5 illustrates in block schematic form an alternative arrangement that may be used in place of the variable network arrangement of Fig. 2.

In the lower part of Fig. 1 the block 30 indicates all of the amplitude pattern control channel equipment shown in Fig. 2 of H. W. Dudley Patent 2,151,091, March 21, 1939, as being included between the delay equalizer DE and the transmitting amplifier TA. Signal waves, which for the purpose of this explanation are assumed to be a complex wave, for example speech waves, are received at the left side of Fig. 1 over connecting line 8 where they are divided into two portions from one of which, over conductors 9, the amplitude pattern control currents are derived in the equipment 30 as described in the Dudley Patent No. 2,151,091. The second portion of the signal wave is directed over conductors 10 and 13 to the frequency pattern control branch to be now described. This branch comprises two parallel circuits, in the upper one of which the detector 11 operates as an approximate pitch-determining device. This unit may assume any suitable form for deriving an indication that is approximately equivalent to the frequency of the fundamental component of the complex wave. In accordance with the invention, this derived indication need not be an accurate representation of the fundamental frequency, and it may be subject to occasional breaks or shifts to the second harmonic, such as have been described. For purposes of this explanation, it may be assumed that the detector 11 includes the heterodyning detector arrangement that is described in detail in the Dudley Patent 2,151,091.

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In such an arrangement, the speech wave may be passed through a band-pass filter to eliminate its upper component frequencies. The lower component frequencies may be detected in any suitable non-linear rectifying device, from which a fair amount of the fundamental component may be derived, if the applied wave contained sufficient vowel energy. This output may be passed through an equalizer circuit, the attenuation of which increases with frequency, such that the lower frequencies, corresponding to the fundamental component, are relatively enhanced. A frequency counter, or frequency modulation detector, when actuated by this enhanced lower frequency, will produce a unidirectional fluctuating voltage in which the amplitude is related to the frequency of the fundamental component of the signal wave, and in which the fluctuations correspond to frequency changes in this fundamental component. This fluctuating voltage appears across the load, comprising resistor R12 and capacitor C14, in such manner that, for example, the upper end of the resistance is positive with respect to the lower end. The shunting capacitor C14 imparts a time constant to this load circuit such that it sluggishly follows any momentary breaks to the second harmonic. This slowly fluctuating unidirectional voltage is then applied to the input of the comparison and voltage control circuit 20, where it is compared with a similar voltage that is derived in the lower parallel branch.

Concurrently with the detection process in detector 11, the signal wave is supplied to the input of variable network 14 over conductors 13. This network selects or segregates one harmonically related component of the signal wave, and effectively excludes the adjacent harmonics, or attenuates them to a degree whereby they are relatively small with respect to the selected component. The selected or segregated component is passed to the limiter detector 16 wherein it is detected in any suitable frequency selective circuit, such that the derived product is a unidirectional voltage, the amplitude of which instantly varies with changes in the frequency of the segregated component at substantially the same linear rate-of-change with frequency as does the sluggish unidirectional pitch-defining voltage across resistor R12. This derived output voltage serves two purposes, one of which is to influence, over path 50, the tuning of the variable network 14 such that this network centers on the appropriate harmonic wave component. Two methods by which this may be accomplished will be explained in connection with the discussions of Fig. 2 and Fig. 5. The derived voltage also appears across the linear potentiometer P, the resistive element of which is tapped at appropriate points corresponding to unity, one-half, one-third, one-fourth and so forth to

$$\frac{1}{n}$$

parts. As the unidirectional voltage appearing across this linear resistive element varies linearly with frequency, it is apparent that these tapped points provide voltage magnitudes which correspond with subharmonic frequencies of any applied wave. Potentiometer wiper arm 24 is controlled in its step setting by the comparison and voltage control circuit 20 acting through the mechanical linkage 22. The voltage selected by the wiper arm 24, that is, the voltage appearing be-

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tween this arm and the lower end of the resistive element, is applied over path 46 as a second input to the comparison and voltage control circuit 20, wherein it is compared in amplitude with the approximate pitch voltage appearing across load resistor R12. A suitable reversible motivating force in the comparison circuit 20 actuates the mechanical linkage 22 and moves the wiper arm 24 to select from potentiometer P a voltage that matches the voltage appearing across the load resistor R12. To prevent momentary breaks or shifts to the second harmonic, or other similar disturbing effects, from appearing in the final frequency pattern control current, suitable arrangements may be made to move wiper arm 24 in integral steps, such that no movement is made until the voltage difference between the compared voltages exceeds about one-half the voltage difference between adjacent steps on potentiometer P. In this manner, the voltage appearing between the wiper arm 24 and the lower end of the potentiometer P is equal to the voltage appearing across the load resistor R12 which in turn is a voltage corresponding to the fundamental frequency of the signal wave. However, because of the sluggish character of the upper pitch determining branch, and also because voltage step changes in the derived voltage in the lower branch are restricted to large increments, corresponding to changes in the selection of the harmonic component, the frequency pattern control voltage in circuit 26 is exceedingly stable. Also, because this voltage rapidly follows frequency variations, it is representative of the instantaneous frequency of the fundamental component. This voltage is then applied to any suitable translating device 28, which may take the form of a conventional frequency modulator. The output of the translation device 28 may then be combined with the output of the various amplitude pattern control channels 30 for transmission to the receiving point over any suitable transmission medium, such as a limited frequency line, or a radio channel.

One particular, though not exclusive, embodiment of the invention, by which the above-described operational steps may be performed, is indicated in Fig. 2. As previously stated, the detector 11 in combination with the load resistor R12 and capacitor C14 forms a sluggish pitch-detection circuit. In the lower branch of the circuit, the variable network 14 comprises a parallel resonant circuit shunted across the input conductors or line 13, which circuit comprises the capacitor 32 and winding 36 of inductor 34. Inductor 34 may be any suitable reactor, the effective inductance of which is variably controllable by an outside force. One such suitable inductor comprises a metallic-core coil having two windings 36, 36' on the same core, one winding 36 being the operating winding and the second winding 36' being the control winding. Curve 52, Fig. 3, indicates the characteristics of such a coil, from which it may be seen that the effective inductance of winding 36 varies in inverse relation to the square of the current flowing in the control winding 36'. Since the resonant frequency of such a parallel-connected circuit varies in accordance with the relation

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

and since the effective inductance of the operat-

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ing winding 36 varies in accordance with the relation

$$L = \frac{1}{f^2}$$

it is evident that the frequency of resonance of the variable network 14 varies linearly with the magnitude of the control current through the winding 36'. In a variable network 14 utilizing an inductor 34, having the characteristic shown in Fig. 3, the foregoing relation may be utilized to render the system self-tracking by feeding back over feedback path 50 a portion of the output voltage from the limiter detector 16. It will be recalled that the amplitude of the output voltage from detector 16 varies linearly with the frequency of the applied wave. Consequently, if a suitable portion of this output voltage is fed back to the control winding 36' of inductor 34, the latter's effective inductance will change in such manner that the network resonates at the frequency of the wave component that most closely approximates its existing resonant frequency, and it will attempt to remain in resonance as this component changes its frequency. As an example, assume the condition where there is present in the applied signal wave a prominent fourth harmonic of the 80-cycle fundamental, and at this time the parallel resonant circuit has a resonant frequency of 300 cycles. Since the 320-cycle fourth harmonic component most closely approximates the instantaneous resonant frequency of the network, this component will assume a greater relative magnitude than its adjacently related components, and will be passed through the isolating amplifier 48 to the limiter detector 16, where it produces its characteristic voltage amplitude across the potentiometer P. A portion of this output voltage will be fed back to amplifier 38 over path 50, for use in resetting the resonant frequency of the selective network 14 at 320 cycles per second. In similar fashion the resonant frequency of network 14 will be reset at an appropriately different frequency when the signal wave again changes its pitch, or frequency.

In operation, the values of the elements of network 14 may be selected such that the network has a predetermined frequency of resonance, or resting frequency, when no signal is applied to its input terminal. For this purpose, the anode-cathode current of amplifier 38 may be suitably adjusted, by bias source 42, to cause the resonating element 36 of inductor 34 to assume the correct inductive value. For purposes of this example, assume this resting frequency to be 300 cycles per second. For this condition, bias source 73 is proportioned such that its potential is equal to the fed-back portion of the voltage derived by detector 16 from a 300-cycle wave, and exceeds this portion of a voltage that is derived from a wave component of lower frequency. Rectifier 74 is poled such that no current from source 73 flows through potentiometer 44. Therefore, as long as the frequency of the applied wave component does not exceed 300 cycles per second, the effective value of inductor 34 will remain fixed at a value which corresponds to a resonant frequency of 300 cycles per second. When the frequency of the applied wave component exceeds 300 cycles, for example, 320 cycles per second, the potential of the voltage that is fed back over path 50 will exceed the potential of source 73, and current will flow through rectifier 74 and potentiometer 44. This action will decrease the con-

trol grid bias on amplifier 38, and increase the anode current flowing in control winding 36'. If the characteristics of amplifier 38 are suitably related to the potential of source 73, and to the adjustment of potentiometer 44, the increased anode current will cause inductor 34 to assume the correct value corresponding to a new resonant frequency of 320 cycles per second. Thus, when the network 14 has selected a harmonic wave component, it will change its frequency of resonance to continue the delivery of this same component, with maximum efficiency of coupling, to the input of detector 16, even though the frequency of the component changes as the pitch of the signal wave is varied. Although in this described example, the network 14 has been described as having a resting frequency of about 300 cycles per second, and as being controlled by signal wave component of a frequency above 300 cycles, this arrangement is not mandatory. If desirable, the resting frequency of network 14 may be adjusted to any other value that is suitable to the operating conditions under which it will be used, and appropriate arrangements may be used for controlling the resonant frequency of the network either above or below that resting frequency. Although a discussion of its arrangement will be deferred until later, it may be noted that the arrangement shown in Fig. 5 may be used as an alternative arrangement for the selective network 14 as here shown. In yet another respect it may be seen that the described arrangement is merely exemplary. In the foregoing example, the inductive characteristic of the inductor 34 varies, as shown in Fig. 3, in inverse relation to the square of the current as fed back from the output of the limiter detector 16. It is evident that this relation, though desirable, is not a necessary one, since by properly proportioning the control grid bias source 42 and its connected resistor 44, and including in the feedback path 50 a suitable non-linear device such as, for example, a thermistor or a rectifying crystal, the inductive characteristic of the inductor 34 may be caused to assume any suitable relation with respect to the voltage output from detector 16.

Although the assumed 320-cycle fourth harmonic component of the signal wave produces across the potentiometer P a unidirectional voltage the amplitude of which is representative of 320 cycles, it is evident that this voltage may not be used directly for frequency pattern control purposes, since it is not known which harmonic of the fundamental component has been chosen. This determination may be made by comparing this voltage with the approximate pitch-defining voltage generated across the load resistor R12. The output of detector 16 is fed over connecting circuit 46 to the lower one-half of resistor 54 in the input circuit of the comparison unit 20. This voltage is so poled that it causes the lower half of resistor 54 to assume a positive polarity with respect to its mid-point 56. The approximate pitch voltage derived across load resistor R12 is also supplied to input resistor 54 in such manner that it causes the upper end of the upper one-half of this resistor to be of positive polarity with respect to the same mid-point 56. This differential connection delivers to the potentiometer 58 a voltage that is equal to the difference in amplitudes of the approximate and instantaneous voltages, and the polarity of which changes as one or the other of the compared voltages assumes the greater magnitude. It will be recalled that

the magnitudes of the applied voltages vary as the frequency of the input wave varies, being greater for waves of higher frequencies. For this reason, the voltage difference across resistor 54 will be considerably greater for higher frequency wave components than it will be for the lower frequency components, although the percentage of discrepancy may be the same in the two cases. In order to provide the comparison and voltage control circuit with approximately uniform sensitivity throughout its operating range, the voltage applied to the input of amplifier 60 should be proportional to the degree of magnitude unbalance between the compared voltages, irrespective of their actual frequencies. It will be recalled that the resistive element of potentiometer P was tapped at appropriate points corresponding to fractional parts of the entire voltage appearing across that element. In similar fashion the resistive element of potentiometer 58 may be provided with voltage taps so located that the voltages appearing between the lower end of that element and any two taps are in integral relation. Wiper arm 61 rests on step 1 of potentiometer 58 when wiper arm 24 rests on step 1 of potentiometer P. Motor 70 actuates shaft 72, mechanical linkage 22 and reversing gear 25 to move the wiper arms 24 and 61 in opposite directions such that, as arm 24 is moved downward to lower voltage positions arm 61 moves upward to select greater portions of the total voltage across potentiometer 58.

Reversing motor 70 provides the actuating force for positioning the wiper arms 24 and 61 and is controlled in the following manner. Wiper arm 24, some or all of the resistance elements of potentiometer 58, and grid bias source 51 are included in series connection in the control grid-cathode circuit of the vacuum tube amplifier 60. This amplifier may take the form of a triode, the anode-cathode circuit of which includes the anode potential source 55, and the voltage generating cathode resistor 57. Potential source 59, the parallel-connected bias rectifiers 62, 66 and reversing motor 70 may all be serially connected, and may also be in parallel connection with the voltage generating resistor 57. For the condition where no extraneous signal voltage is applied to the control grid of the tube 60, the voltage generated across resistor 57 should be approximately in the center of the operating range of the amplifier 60. This condition will permit the generated voltage to be increased or decreased in accordance with the voltage supplied to the control grid element, and may be realized by suitably proportioning the grid bias source 51. For this same no-signal condition, the potential of source 59 may be selected to be just equal to this generated voltage. When the positive terminal of source 59 is connected to the cathode end of resistor 57, there will be no voltage difference existing across the serially-connected motor 70 and the rectifier elements 62, 66. As the voltages which are being compared across the input resistor 54 assume various magnitudes, the difference voltage across the resistor 54 appears across the potentiometer 58, with the polarity sense of this voltage changing as one or the other of the compared voltages assumes the greater magnitude. This difference voltage aids or opposes the bias source 51 to increase or decrease the effective control grid bias of the triode, and thereby increase or decrease the voltage generated across cathode resistor 57. Since the potential of the equalizing source 59 is unchanged, these voltage

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variations across resistor 57 actuate the motor 70 to rotate in a direction depending upon whether the voltage is increased or decreased.

It was previously stated that, to minimize undesired momentary changes in the output pitch control current, it was desirable that changes in the setting of the wiper arm 24 be delayed until the difference in the approximate and instantaneous voltages compared in the comparison circuit 20 exceeds about one-half of the voltage difference between adjacent steps on potentiometer P. The oppositely-poled bias rectifiers 62, 66 provide one means that may be employed to secure this result. It will be recalled that reversing motor 70 is actuated when voltage changes across the cathode resistor 57 cause voltage differences to appear across the serially-connected motor 70 and parallel rectifiers 62, 66. Rectifiers 62 and 66 are in parallel connection in conjugate branches, and are so poled that current flows in opposite directions in the two branches. Considering one branch, the magnitude and the polarity of bias source 64 may be so chosen that current flows through rectifier element 62 and motor 70 only when a positive potential difference in excess of about one-half of the voltage difference between adjacent steps on potentiometer P exists between the negative terminal of equalizing source 59 and the lower end of voltage generating resistor 57. In similar fashion, the magnitude and polarity connection of bias source 68 may be so chosen that current flows in the opposite direction through the motor 70 and the other branch rectifier 66 only when a potential difference of about the same magnitude exists in the opposite direction. As motor 70 rotates its attached shaft 72, mechanical linkage 22 and reversing gear 25 are actuated to move potentiometer arms 24 and 61 in the previously described manner, to effectuate equality in the compared voltages, and also to provide a substantially uniform signal input to amplifier 60.

One mechanical arrangement for actuating these potentiometer wiper arms in the desired integral step relation is schematically indicated in Fig. 4 in which the motor 70 actuates its connected shaft 72 to which is rigidly connected the U-shaped yoke 74 having pins 80 at its extremities. The pins 80 are loosely coupled to the notched or scalloped disc 76, protruding through the apertures 78. The dimensions of apertures 78 and the scallops in the periphery of the disc 76 are so proportioned that the disc is driven in discrete steps by rotation of the shaft 72. A positive drive of the disc 76 is secured by the action of the ball or follower 82 dropping into the detent position provided by the scalloped edge of the disc 76 as the disc is driven through the loose coupling provided by the pins 80 and the apertures 78. Movement of the disc 76 actuates the connecting link 22 in such manner that wiper arms 24 and 61 are driven in integral steps from one to another of the adjacent taps on potentiometers P and 58.

In the previously assumed example, the applied signal wave of 80-cycle fundamental frequency, was impressed upon the detector 11 to cause a corresponding unidirectional voltage amplitude across the load resistor R12. Its fourth harmonic component was selected by the variable network 14, to produce across the output potentiometer P a unidirectional voltage the amplitude of which characterized this frequency. The amplitude of this latter voltage will be substantially four times

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as great as the voltage amplitude across the load resistor R12. Comparison of these voltages across the comparison and voltage control input resistor 54 results in rotation of the reversible motor 70 in such direction that the mechanical linkage 22 actuates the potentiometer wiper arm 24 to assume a position on the one-fourth step of potentiometer P. In this position the voltage between the potentiometer wiper arm 24 and the lower end of potentiometer P is numerically equal to the voltage existing across resistor R12, and is representative of a fundamental frequency of 80 cycles per second, which frequency corresponds to the frequency of the fundamental component of the signal wave. This selected voltage is supplied over connecting circuit 26 to the translation device 28 for conversion into any suitable form for further use at the analyzing position, or for transmission to the distant receiving point. As previously stated, translation device 28 may take any desired form, such as an oscillator the frequency of which is controlled by the magnitude of the applied voltage.

Although the variable network 14 comprising the variable inductor 34, the inductance of which is controlled by a biasing current in the winding 36', will usually provide a most satisfactory arrangement for selecting and following a single harmonic component of the signal wave, it is possible that an alternative arrangement may be desired. Such an arrangement is schematically illustrated in Fig. 5, in which is shown an arrangement for shifting the frequency position of the desired harmonic component, relative to a fixed frequency band filter 108, instead of tracking the desired component as it moves in the frequency spectrum. In this arrangement, a variable carrier frequency C is obtained from a suitable source, such as a variably controlled oscillator 100, the frequency of oscillation of which is determined by the fed-back portion of the output voltage from limiter detector 16.

This carrier energy is combined with the complex signal wave in modulator 102, which may be of any suitable type known in the art, to produce the usual sideband products of modulation. Band filter 108 may have a pass band the center of which is located symmetrically about a frequency that is equal to the carrier frequency C plus the resting frequency as assumed for the first described tracking arrangement. In order to confine the selection of this filter to one harmonic component, its pass band width should be slightly less than the lowest fundamental frequency to be detected, which in this example is assumed to be 80 cycles. Assume for example that filter 108 passes the upper sideband modulation component $(C+nf)$, which is numerically equal to the frequency of the output from oscillator 100 plus the n th harmonic component of fundamental f . This selected sideband product is modulated a second time in modulator 104, which may be a duplicate of modulator 102, where it is combined with the same oscillator frequency C, to produce a lower sideband modulation product nf . Low pass filter 110 has its cut-off frequency so arranged that it acts to select only the desired component nf , which is then detected in the limiter detector 16 in the previously described manner. A portion of the output voltage from detector 16 is fed back over feedback path 50 to control the selection process. In this embodiment, oscillator 100, which may have any suitable frequency, when no voltage is fed back over feedback path 50, will be shifted up-

ward in frequency as the magnitude of the feedback voltage is increased, until the modulation product ($C+nf$), produced in modulator 102, most closely approximates the center of the pass band of filter 108, and the voltage output from detector 16 attains its maximum value. This output voltage from detector 16 may be compared in comparison circuit 20 (Fig. 2), with the voltage derived by detector 11 (Fig. 2) in the previously described manner.

Although in the foregoing description, the invention has been described with particular emphasis upon its incorporation in a vocoder type of transmission system, wherein speech signals are analyzed for transmission with reduced frequency range and are synthesized at a receiving point, it should be realized that in scope it is not limited to this arrangement. It will be evident that the invention has many applications in the field of wave analysis, where it may be desired to obtain an accurate indication of the frequency of the fundamental component of the wave without being subjected to the effects of various momentary transient conditions within the complex wave, which conditions are not caused by frequency changes of the fundamental component. Other desirable aspects of the invention will appear to those skilled in the art, and suggest embodiments thereof, which do not depart from the spirit and scope of this invention.

What is claimed is:

1. A system for producing an indication of the frequency of the fundamental component of a complex wave comprising a plurality of wave components in integral harmonic frequency relation, which comprises means for producing from said wave components an electrical quantity representative of the frequency interval separating adjacent ones of said components, means for selecting from said wave a single one of said harmonically related components, means for producing from said selected component a second electrical quantity representative of the instantaneous frequency of said component, means for comparing the magnitudes of said first-mentioned quantity and said last-mentioned quantity, and means responsive to the difference in the magnitudes of said compared quantities for dividing from said last-mentioned selected harmonic quantity a third electrical quantity the magnitude of which is indicative of the frequency of the fundamental component of said complex wave.

2. In a system for producing an indication of the frequency of the fundamental component of a complex wave comprising a plurality of wave components in integral harmonic frequency relation, means for producing from said wave electrical quantity approximately representative of the frequency separation of adjacent ones of said wave components, variable means for selecting from said wave a single one of said wave components, means for producing from said selected component a second electrical quantity the instantaneous magnitude of which is indicative of the instantaneous frequency of the selected component, means responsive to changes in the magnitude of said second quantity for controlling the selective characteristic of said variable selecting means whereby said means is progressively rendered more selective at the frequency of said selected component, means for comparing the magnitudes of said first-mentioned and second-mentioned electrical quantities, and means responsive to the difference in magnitude of said compared quantities for determining the inte-

gral harmonic relation of the wave component which was selected and for dividing from said second indication a quantity the magnitude of which is indicative of the frequency of the fundamental component of said complex wave.

3. In a system for determining the frequency of the fundamental component of a complex signal wave comprising a plurality of wave components in integral harmonic frequency relation, means for separating the signal wave into first and second portions, means for producing from said first portion a first electrical quantity approximately representative of the frequency difference between adjacently located harmonic wave components, the magnitude of said quantity varying linearly with variations in said frequency difference, variable means for selecting from said second portion a single wave component, means for producing from said selected component a second electrical quantity the magnitude of which varies with changes in the frequency of said selected wave component at the same linear rate as said first quantity, means responsive to said second quantity for controlling said variable selecting means whereby its frequency of maximum response varies linearly as the magnitude of said second quantity is varied, variable means for selecting a fractional part of said second quantity, means for comparing the magnitudes of said first quantity and the selected portion of said second quantity, and means responsive to the difference between said compared magnitudes for controlling said fractional selection means whereby said means selects from said second quantity a portion thereof the magnitude of which is substantially equal to said first quantity and which is directly proportional to the frequency of the fundamental component of said complex signal wave.

4. A system for determining the pitch of a speech signal wave comprising a plurality of wave components in integral harmonic frequency relation to a missing fundamental component, which comprises means for producing from said signal wave a first fluctuating unidirectional voltage the amplitude of which is linearly related to the frequency separation of said wave components, means for retarding fluctuations in said derived voltage, variable selective means for segregating from said signal wave a single wave component the integral harmonic position of which is unknown, means for producing from said selected component a second unidirectional voltage the magnitude of which varies in instantaneous linear relation with the frequency of said selected component and at the same rate-of-change as said first voltage, means for controlling the frequency selective property of said variable selective network in accordance with variations in the magnitude of said second unidirectional voltage, means for differentially comparing the amplitudes of said first and second unidirectional voltages, and means responsive to the difference in the magnitudes of said compared unidirectional voltages and to the polarity sense of said difference voltage for variably controlling the selection of a portion of said second unidirectional voltage, the magnitude of said selected portion being substantially equal to that of said first indication and indicative of the frequency of said missing fundamental component.

5. A system for determining the frequency of a fundamental component of a complex signal wave including a plurality of wave components, which comprises, a signal wave input circuit,

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unilaterally conducting and rectifying means connected to the input circuit for producing from said signal wave a unidirectional fluctuating voltage the magnitude of which varies at a known rate with respect to changes in the frequency of said signal wave, an output circuit for said means, a load resistor connected across the output of said means, a capacitor in shunt connection to said load resistor for retarding rapid fluctuations in said derived unidirectional voltage, a variable selective network connected to said input circuit and comprising a parallel resonant combination in which the effective value of the inductance element of said combination is variably controlled by an external source whereby a single wave component is selected from said complex signal wave, a frequency sensitive unidirectional conducting means connected to the output of said network for producing from said selected component a second unidirectional voltage, the instantaneous value of which is related to the instantaneous frequency of said selected wave component in such manner that the ratio of magnitude-to-frequency is substantially the same as in the case of said first-mentioned produced voltage, means for feeding back a portion of said unidirectional voltage to said parallel resonant combination whereby the value of said inductance element is controlled in accordance with the magnitude of said second unidirectional voltage, means for differentially comparing the magnitudes of said first and said second derived unidirectional voltages, and means responsive to the difference between said voltages for controllably selecting from said second derived voltage a portion thereof the magnitude of which is indicative of the frequency of said fundamental signal wave component.

6. The method of obtaining an indication of the instantaneous frequency of the fundamental component of a complex signal wave including a plurality of wave components in integral harmonic frequency relation to said fundamental component which comprises, producing from said wave an electrical quantity the magnitude of which varies at a fixed rate with changes in the frequency separation of adjacently disposed wave components, segregating from said wave a single one of said wave components, producing from said wave component a second electrical quantity the magnitude of which varies at the same fixed rate with changes in the frequency of said component, comparing the magnitudes of said electrical quantities, and dividing from said second electrical quantity a fractional part thereof which fraction is equal in value to the reciprocal of the integral relation between the magnitudes of said compared quantities.

7. The method of deriving an indication of the instantaneous frequency of the fundamental component of a complex signal wave which wave includes a plurality of wave components in integral harmonic frequency relation to a fundamental component, said method comprising analyzing said wave to derive an electrical quantity representative of the approximate frequency interval between adjacently disposed wave components, the magnitude of said derived quantity

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being linearly variable with changes in the separation of said components, simultaneously selecting from said wave a single one of said wave components, the integral harmonic relation of which to said fundamental component is unknown, converting said selected wave component into a second electrical quantity which is indicative of the instantaneous frequency of said component and the magnitude of which varies linearly and directly with changes in the frequency of said component, comparing said first and second derived quantities to determine the integral relationship between the magnitudes of said quantities, and selecting from said second derived quantity a fractional portion thereof, the magnitude of which is numerically equal to the reciprocal of the integral relationship between said compared quantities, said selected portion being at all times indicative of the separation between adjacently disposed components of said signal wave of the frequency of the fundamental component of said wave.

8. In a system for deriving an indication of the pitch of a speech signal wave which comprises a plurality of wave components in integral harmonic frequency relation to a fundamental component, the combination of unilaterally conducting means for deriving from said signal wave a first unidirectional voltage the amplitude of which is linearly and directly related to the frequency interval between said harmonically related components, variable frequency-sensitive means for segregating from said signal wave a single wave component the integral harmonic position of which is unknown, a second unilaterally conducting means for deriving from said selected wave component a second unidirectional voltage, the instantaneous magnitude of which is indicative of the instantaneous frequency of said selected component and in which the magnitude varies linearly and directly as the frequency of said selected component changes, means for controlling the frequency selective characteristic of said variable frequency-sensitive means in accordance with the magnitude of said second unidirectional voltage, means for comparing the amplitudes of said first and second derived unidirectional voltages, and means responsive to the difference in the magnitudes of said compared voltages for selecting from said second unidirectional voltage a fractional portion thereof, the magnitude of which is the reciprocal of the integral relation of the magnitude of said second voltage to that of said first voltage, said selected portion being approximately equal to the magnitude of said first voltage and being representative of the instantaneous frequency of the fundamental component of said signal wave.

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