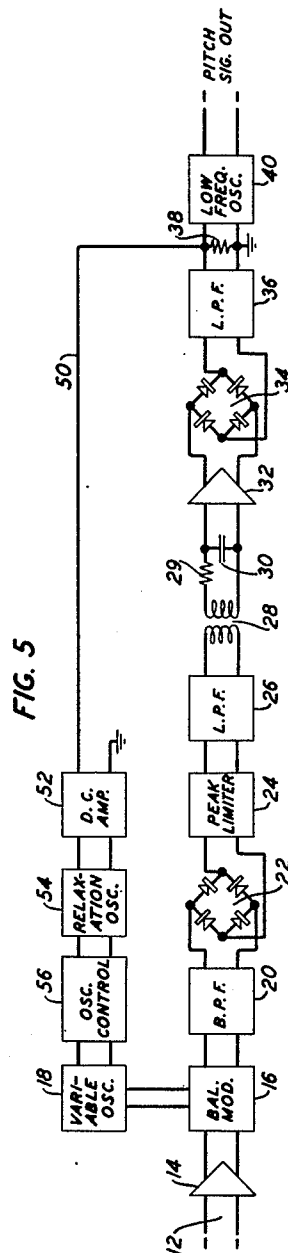
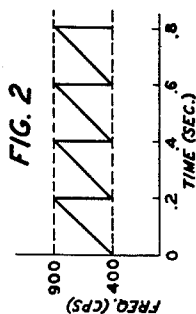
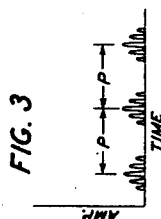
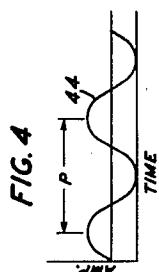
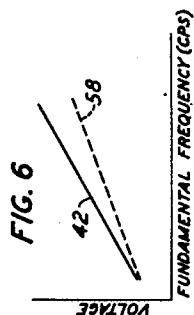
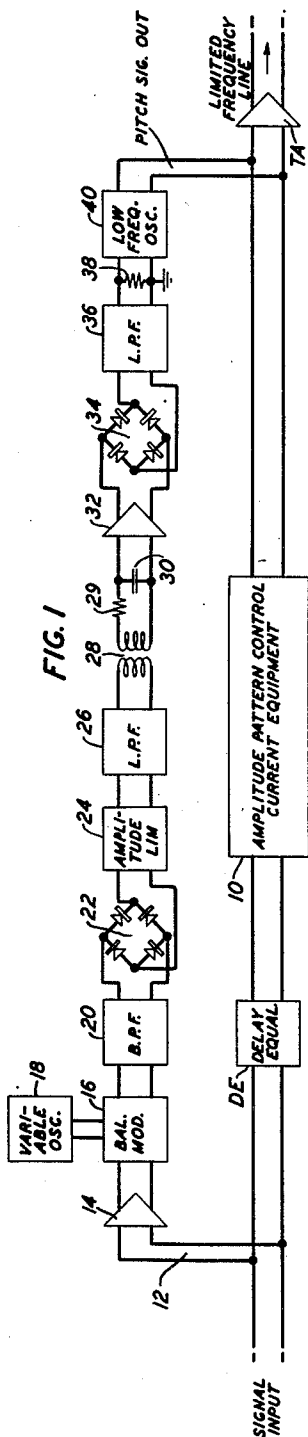


July 24, 1951

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ANALYZING SYSTEM FOR DETERMINING THE FUNDAMENTAL
FREQUENCY OF A COMPLEX WAVE
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ANALYZING SYSTEM FOR DETERMINING
THE FUNDAMENTAL FREQUENCY OF A
COMPLEX WAVEDoren Mitchell, Martinsville, N. J., assignor to
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9 Claims. (Cl. 175-183)

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This invention relates to wave translation and signaling systems, and in its more specific aspects is concerned with the analysis of complex signal waves.

The invention has as one of its objects the determination of the frequency of the fundamental component of complex waves such as, for example, speech, or other signal waves.

A further object of the invention is to effect this determination regardless of the presence or absence of the fundamental component of the wave.

It is also an object of the invention to improve systems for reducing the frequency range required for the transmission of signals, such as facilitating the transmission of a message over a transmission medium not adapted to accommodate the band width of the message in its original state.

It is known that substantially all of the intelligence contained in certain types of complex signal waves may be transmitted while using only a fraction of the frequency space occupied by the wave in its original state. This is particularly true of speech signal waves; and signaling systems employing this principle have been proposed. One such system, as disclosed in United States Patent 2,151,091, March 21, 1939, to H. W. Dudley, analyzes the original signal wave in terms of its fixed and variable parameters, to secure information concerning both its frequency and its amplitude patterns. As there explained, the human vocal system is considered to be composed of both fixed and variable parts, which differentiation may be applied to characterize the types of signal they produce. So considered, the fixed features correspond to the oscillatory sound produced with the various parts of the vocal system in their average or normal condition which includes an average vocal cord tension for the voice sound. The variable features correspond to the changing, or modulating of the system by varying the different vocal system parts from their average condition. In accordance with this system, substantially all of the intelligence of a speech signal can be transmitted between two points by transmitting only information concerning the variable parameters, since the fixed parameters are equally known at those points.

Speech signals vary more or less continuously, and relatively slowly, between two distinct types. In one type, there is a fundamental frequency component of relatively low frequency, its upper harmonic frequency components extending to

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several thousands of cycles. The frequency of this fundamental component is the rate at which the human vocal cords vibrate, and in general, although it can be held constant by sustaining a continuous sound, it continuously increases or decreases as the inflection of the voice rises or falls. This type of signal has been characterized as the voiced sound and includes the vowel and near-vowel sounds. In it the energy is distributed in discrete subgroups, or bands, within the frequency spectrum of the signal. These subgroups, or bands, are separated by a frequency interval that is numerically equal to the frequency of the fundamental component of the signal, and the energy content of the subgroups generally decreases as their frequency is increased. In the second type of signal, there is a continuous and generally random distribution of the energy through the frequency spectrum, as distinguished from discrete subbands in integral harmonic relation. This second type of signal has been characterized as the unvoiced sound and may be considered to be the limiting case of the first pattern type as its fundamental frequency approaches zero cycles per second. In addition, although the energy is distributed throughout the frequency spectrum of the signal, the unvoiced sound often contains the major portion of its energy in the middle or upper half of its frequency range. In distinguishing between these two types of signal patterns, advantage may be taken of the fact that in the voiced sound there is a relatively high power level, while in the unvoiced sound the power level is usually much lower. In the so-called vocoder type of transmission system, such as is disclosed in the above-mentioned Dudley patent, this difference in power level of the signals is utilized to distinguish between the voiced and the unvoiced sound. In addition, the relatively high power level of the voiced sound permits the production of a frequency pattern signal to denote the instantaneous frequency of the fundamental component of the original speech signal. This frequency pattern signal, sometimes designated as the pitch control signal, is transmitted along with the amplitude control pattern signal to the receiving point to control the synthesizing apparatus of this system. For a more complete description of the operation of this type of system, reference may be had to the above-mentioned Dudley patent.

It has been suggested that this frequency pattern, or pitch control signal, be derived by beating, or heterodyning, adjacent frequency com-

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ponents of the speech signal to produce a difference frequency that is equivalent to the instantaneous frequency of the signal's fundamental component. Such a system is capable of satisfactory operation where the fundamental component of the signal is actually present in the analyzed sound, or if not present, where the adjacent harmonic components are of sufficient relative magnitude and constancy of phase relation to permit a satisfactory heterodyning procedure. It is often desirable to transmit the original speech signal a considerable distance from its originating point before analyzing the signal to determine its frequency and amplitude pattern. In such cases, it may frequently happen that the frequencies in the range of about 80 to about 250 cycles per second are considerably reduced by virtue of the attenuation characteristic of the transmitting medium, or they may be subjected to considerable relative phase shift before their analysis. Under such circumstances the derivation of the frequency pattern signal may present considerable difficulty, since the fundamental and possibly the lower ones of its harmonic components have been effectively eliminated, and the relative phase and amplitude relations between the remaining adjacent harmonic components may be shifting. In this latter case, it occasionally happens that the adjacent harmonic components momentarily assume a relative amplitude such that the heterodyning process derives a difference frequency between non-adjacent harmonic components. In such a case, the derived frequency pattern signal indicates a shift of one or more octaves in the fundamental component, whereas in fact no change has actually occurred. In view of the foregoing, it appears desirable to determine the frequency of the fundamental component of such a signal wave by a method and means that are not dependent upon the presence in the signal wave of the fundamental component, and which are not affected by this occasional shifting of the phase and amplitude relations between the various adjacent wave components.

It is a feature of the invention that it may be practiced through the use of a relatively simple and inexpensive arrangement for scanning a portion of the signal wave to determine the frequency interval between observed harmonically related wave components in such a manner that the final result is not affected by relative phase and amplitude displacements of the components.

It is also a feature of the invention that the derivation of the pitch control signal is not dependent upon the high energy level of the low frequency signal component, and, consequently, the presence or absence of the lower ones of the harmonic components is not a necessary precedent for the successful practice of the invention.

It is a further feature of the invention that the distinction between voiced and unvoiced signals does not depend upon a difference in the power level of the original signal.

Other objects and features of the invention will be apparent from the following description of a preferred embodiment, when considered in conjunction with the drawings, in which:

Fig. 1 is a block schematic diagram of an embodiment of the invention when arranged for operation in a frequency compression signal transmission system;

Figs. 2, 3 and 4 are explanatory graphs to which references are made in the description of the operation of the arrangement of Fig. 1;

Fig. 5 is a schematic diagram of a second em-

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bodiment of the invention such as might be employed in a frequency compression signal transmission system; and

Fig. 6 is an explanatory diagram indicating one difference in the operating characteristics of the Fig. 1 and Fig. 5 embodiments of the invention.

Fig. 1 shows an embodiment of the invention as being incorporated in a frequency compression type of signal analyzing and synthesizing system such as was disclosed in the above-mentioned United States Patent 2,151,091, March 21, 1939, to H. W. Dudley. In this figure, the delay equalizer DE and the amplitude pattern control equipment 10 function to derive indications of the amplitude of the signal energy in a number of predetermined subbands of the original signal wave. For a complete description of the operation and structure of this branch of the circuit, reference may be made to the above-mentioned Dudley patent. The determination of the frequency, or pitch, of the fundamental component of the signal wave is made in the upper branch circuit which comprises amplifier 14 connected to the signal source over path 12. Variable oscillator 18 supplies modulating energy to the balanced modulator 16, and band-pass filter 20 selectively attenuates a portion of the modulator output before its rectification in rectifier 22. Limiter 24 removes amplitude variations from the output of rectifier 22 before the higher frequency components therein are attenuated in the low-pass filter 26, and before the direct current component is removed by transformer 28. The frequency selective network comprising resistor 29 and capacitor 30 is followed by an amplifier 32 and rectifier 34. Low-pass filter 36 eliminates substantially all alternating current components before an output voltage is produced across the load resistor 38. Low frequency oscillator 40 may have its frequency of oscillation determined by the magnitude of this output voltage such that the pitch control, or frequency pattern, signal is in a convenient form for transmission purposes.

In its operation, the signal analyzing arrangement of Fig. 1 receives signal waves, which, for example, may be speech signals of the voiced type, from the signal input at the left of the drawing. These signals are simultaneously applied through the delay equalizer DE to the amplitude pattern control equipment 10, and over connecting path 12 to the input of amplifier 14 in the pitch determining branch. Amplifier 14 serves to isolate this branch from the remainder of the system and insures that the signal will be of a suitable level before its application to one input circuit of the balanced modulator 16. Oscillator 18 provides a linearly changing frequency supply to the second input circuit of modulator 16. As indicated in Fig. 2, for example, the frequency of oscillator 18 may be caused to vary in a saw-tooth fashion between frequencies of 400 and 900 cycles per second during each two-tenths second interval. If desired, these frequencies, or the time interval, or both may be changed to satisfy varying operating conditions. The combination, in modulator 16, of the input signal wave, comprising wave components f_1, f_2, f_3 , etc. in integral harmonic relation to a fundamental component f_0 , which may or may not be present, and the linearly changing modulating frequency from oscillator 18, produces linearly changing sum and difference frequency output patterns of modulation in which the energy is grouped in discrete subbands having the same frequency separation interval as did components f_1, f_2 , etc. of the orig-

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inal signal wave. In the normal voiced speech signal, this frequency separation may vary from about 80 to about 250 cycles per second, for the more important voiced speech signals. The filter 20 may be of the band-pass type having a suitable pass-band such as, for example, 50 cycles centered at about 950 cycles per second. However constituted, the width of the filter pass-band should be less than the minimum frequency separation between energy subbands, which for normal speech signals should be about 80 cycles per second. Filter 20 rejects one of the modulation products which, in this assumed example, would be the difference frequency, and selects from the changing sum product a band of frequencies about 50 cycles in width. As the frequency output from oscillator 18 is changing from, for example 400 to 900 cycles per second at the rate of 2500 cycles per second, the modulation product will also be changing at that rate, and subbands of energy will be selected from this changing modulation product by filter 20 in a scanning manner. Since these subbands of energy are located f_0 cycles per second apart, the filter 20 will select bursts, or pulses, of energy from this modulation product at the rate of

$$\frac{2500}{f_0}$$

times a second, where f_0 is the frequency of the fundamental components of the original speech wave. These energy subbands, each of which has a frequency of about 950 cycles per second, are detected, or rectified, in bridge type rectifier 22 to produce a pulsating unidirectional voltage, as indicated in Fig. 3. As there indicated, the time interval, or period, between pulsation peaks is equivalent to

$$\frac{f_0}{2500}$$

and varies directly as the frequency of the fundamental component f_0 varies. Amplitude limiter 24 removes any amplitude differences from these pulsations, and low-pass filter 26 rejects all wave components in excess of a suitable maximum frequency such as, for example, 500 cycles per second. Passage through transformer 28 removes the direct current component from this rectified output, and results in a purified wave 44 of approximate sine character, as indicated in Fig. 4. This wave 44 is variable in frequency and has the same period P between its adjacent points of maximum amplitude, at any instant, as did voltage pulsations from the bridge rectifier 22. Assuming that the original speech signal wave had a range of fundamental frequency from 80 to about 250 cycles per second, this purified wave 44 after passage through transformer 28 varies in inverse relation from about 31 cycles to 10 cycles per second. Resistor 29 and capacitor 30 form a frequency-sensitive network having an inverse frequency-attenuation characteristic such that the higher frequencies of the purified wave 44 are attenuated to a greater extent than are the lower frequency components of this wave. Amplifier 32 restores the level of the selectively attenuated derived wave before the second bridge rectifier 34 and low-pass filter 36 convert it into a slowly varying unidirectional voltage appearing across the load resistor 38. Low-pass filter 36 may have an upper frequency limit of about 10 cycles per second, and removes substantially all of the alternating current components from the rectified signal. This provides a band width

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capable of passing changes of inflection in the original signal, which changes occur at syllabic rates not usually in excess of eight times per second. As indicated by curve 42 of Fig. 6, the amplitude of this output voltage is inversely related to the frequency of the purified low frequency wave 44, obtained at the secondary terminals of transformer 28, and is directly proportional to the frequency of the fundamental component of the original input voiced signal wave. This slowly varying output voltage may be used to control the frequency of oscillator 40 to derive therefrom a constant amplitude, variable low frequency signal, say, for example, 10 to 60 cycles per second, suitable for transmission over the limited frequency line along with the currents derived from the amplitude pattern control equipment 10.

From the foregoing description it will be apparent that a pitch determining arrangement in accordance with this invention is insensitive to the unvoiced type of speech signal. It will be recalled that the unvoiced signal wave has its energy content randomly distributed throughout the spectrum of the signal, with any concentration of energy generally occurring in the middle or upper half of the spectrum. When such a wave is modulated by the variable frequency modulating energy from oscillator 18, the modulation product retains this random energy distribution, which distribution provides a very small, if any, separating interval between energy subbands. This condition may be said to approximate the limiting condition of zero cycles per second for the fundamental of a voice signal wave. When such a modulated output wave is scanned by the scanning band-pass filter 20, and is rectified in rectifier 22, there results either a constant value of unidirectional voltage output, or an output of unidirectional voltage in which there is such a small separating interval between the maximum amplitudes that it appears to have a very high frequency alternating current component. In either event, the combined action of the low-pass filter 26 and transformer 28, acting to eliminate all components above 500 cycles per second and all direct current components, reduces this rectified output to a negligible factor, and renders the circuit effectively insensitive to unvoiced signal waves.

Under some operating conditions it may be found that the low frequency end of the derived purified wave 44, obtained after the higher frequency components and the direct current components have been removed from the output of rectifier 22, is sufficiently low to impart undesired voltage fluctuations to the voltage output of filter 36 and as derived across the load resistor 38. In Fig. 5 there is shown an embodiment of the invention which provides means for accommodating the full frequency range of the input signal, and also provides increased frequency at the low frequency end of the purified low frequency wave. This arrangement provides increased margin between the lowest frequency of the derived wave 44, and the cut-off frequency of filter 36 by increasing the scanning rate of filter 20 as the frequency of the fundamental component of the original signal wave increases. The previously described arrangement of Fig. 1 is modified by inclusion of the direct coupled amplifier 52, connected over path 50 to the upper end of load resistor 38; and the relaxation oscillator 54 which produces saw-tooth shaped output voltage waves at a frequency controlled by the voltage output from amplifier 52. This os-

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illator 54 may be any conventional type of relaxation oscillator for the production of a saw-tooth shaped output wave that is suitable for application to the oscillator control circuit 56, which may be a reactance tube. Control circuit 56 regulates the frequency changing rate of oscillator 18 in such a manner that the number of its frequency excursions, between the upper and lower frequency limits, varies as the pitch of the incoming signal increases.

In its method of operation, this Fig. 5 embodiment closely follows the previously described procedure of the Fig. 1 embodiment. Increased margin between the lowest frequency of the derived purified wave and the upper cut-off of low-pass filter 36 is secured by tapping the output voltage appearing across load resistor 38 at the upper end of the resistor. This voltage may be supplied over path 50 to the direct-coupled amplifier 52, the amplified output of which controls the operating frequency of relaxation oscillator 54. Oscillator 54 produces saw-tooth shaped output voltage waves, at a frequency that may be in direct proportion to the magnitude of the amplified voltage from amplifier 52. When impressed upon the oscillator control 56, the saw-tooth wave operates to cause the variable oscillator 18 to progressively change its frequency from its lower to upper frequency limit. Therefore, during any particular time interval, the number of frequency excursions by oscillator 18 will be determined by the amplitude of the output voltage appearing across resistor 38. Increasing the number of frequency excursions of oscillator 18 effectively increases the number of cycles per second that are scanned by band-pass filter 20, and changes the separation between energy subbands as seen by this filter from the previously described relation

$$\frac{2500}{f_0}$$

to a new relation of

$$\frac{X}{f_0}$$

where X is a variable quantity in excess of 2500 by some arbitrary quantity, the exact value of which depends upon the frequency of the fundamental component of the applied signal wave. In this manner, the energy subbands, as seen by the scanning filter 20, change from a separation interval equal to

$$\frac{2500}{f_0}$$

for the lowest frequency fundamental component of say 80 cycles to a variable separation interval of

$$\frac{X}{f_0}$$

as the higher fundamental components increase in frequency. In this manner there is produced at the secondary terminals of transformer 28, a derived purified wave the frequency of which is related to the instantaneous value of the fundamental wave component, but in which the minimum frequencies are of a higher value than in the previously described embodiment. As indicated by curve 58 of Fig. 6, the output voltage appearing across load resistor 38 has lower amplitudes at values corresponding to the higher fundamental frequencies of the applied

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signal wave. Curves 42 and 58 (Fig. 6) indicate the comparative effect upon the output voltage of increasing the scanning rate in direct relation to the frequency of the fundamental component of the voiced input signal.

As in the case of the embodiment of Fig. 1, the amplitude of the output voltage at resistor 38 is directly related to the frequency of the fundamental component of the original signal wave. As previously described, this voltage may be used to control the frequency of low frequency oscillator 40, to produce a pitch-defining signal having suitable characteristics for transmission through or over the available medium as indicated in the above-mentioned Dudley patent.

Although the invention has been described in embodiments that were especially adapted for association with the so-called vocoder type of signal analyzing and synthesizing system, it should be appreciated that its utility is not limited to this type of system. Rather, it has general utility wherever a periodic or quasi-periodic complex wave is to be analyzed to determine the frequency of its fundamental component, regardless of whether the fundamental component and its lower harmonically related component are actually present in the analyzed wave.

What is claimed is:

1. A system for producing an indication of the frequency of the missing fundamental component of a complex signal wave which includes a plurality of harmonic components in integral relation to said fundamental component, which comprises selective means for repetitively selecting from a portion of said wave each discrete harmonic component in said portion during a known interval, unidirectional conducting and translating means for deriving from said selected components a series of unidirectional voltage impulses, means for deriving from said impulses a smoothly varying alternating voltage, and means for converting said derived alternating voltage into a unidirectional voltage, the amplitude of which is proportional to the frequency of said missing fundamental component.

2. Apparatus for producing an indication of the frequency of the fundamental component of a complex signal wave which includes a plurality of harmonic components in integral relation to said fundamental component, which comprises a source of oscillations the frequency of which is repetitively varied between designated limits at a known rate, means for combining said signal wave with said variable frequency oscillations to produce at least one sideband product, the frequency of which repetitively linearly varies between designated limits in a known interval, selective means for segregating from a portion of said sideband each discrete harmonic component in said portion during said interval, unidirectional conducting and translating means for converting said segregated components into a series of unidirectional voltage impulses, amplitude limiting and frequency sensitive means for converting said impulses to an alternating voltage the frequency of which is indicative of the number of harmonic components that were segregated in a corresponding interval, and unidirectional conducting means for deriving from said variable frequency alternating voltage a unidirectional voltage the magnitude of which is indicative of the frequency of the fundamental component of said wave.

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3. The method of producing an indication of the frequency of the fundamental component of a complex signal wave comprising a plurality of wave components in integral harmonic frequency relation to said fundamental component, which comprises repetitively scanning a portion of said wave to repetitively segregate each harmonically related wave component, detecting said harmonically related wave components, producing a unidirectional voltage the magnitude of which is proportional to the intervals between adjacent successively detected components, and varying the rate at which said wave is scanned in accordance with the changes in said interval of separation.

4. Apparatus for producing an indication of the frequency of the fundamental component of a complex signal wave having a plurality of wave components in integral harmonic relation to said fundamental component, which comprises a source of signal waves, a source of oscillations the frequency of which repetitively varies between designated frequency limits at a substantially linear rate during a time interval, modulatory means for combining said signal wave with said varying frequency oscillations to produce sideband products of modulation, means for selecting from a predetermined portion of said modulation products each harmonically related wave component within said portion during said time interval, means responsive to the number of said wave components that were selected during a given interval for producing a unidirectional voltage the magnitude of which is indicative of the frequency of the fundamental component of said signal wave, and means responsive to the amplitude of said frequency indicating voltage for controlling the rate at which said oscillatory source changes in frequency.

5. Apparatus for producing an indication of the frequency of the fundamental component of a complex signal wave having a plurality of wave components in integral harmonic relation to said fundamental component, which comprises a source of signal waves, a source of repetitively varying oscillations, modulatory means for combining said signal waves and said oscillations, selective means for segregating a portion of said combined waves, unidirectional conducting means for detecting said wave components in said selected portion, means for converting said detected wave components into a relatively low frequency alternating wave in which the frequency of alternation is related to the rate at which said wave components were detected, frequency responsive means for attenuating said alternating wave in accordance with its frequency of alternation, and unidirectional conducting means for converting said alternating wave into a unidirectional output voltage the amplitude of which is indicative of the frequency of the fundamental component of said signal wave.

6. Apparatus in accordance with claim 5 in-

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cluding means responsive to said unidirectional output voltage for changing the rate of variation of said source of repetitively varying oscillations in accordance with the magnitude of said output voltage.

7. The method of producing an indication of the frequency of the fundamental component of a complex wave including a plurality of wave components in integral harmonic relation to said fundamental component, which method comprises the steps of (1) segregating each harmonic wave component in a predetermined frequency portion of said wave once during each of successive time intervals, (2) producing from said segregated components a train of voltage impulses, each of said impulses corresponding in time to the segregation of one of said components, and (3) producing from said train of impulses a fluctuating unidirectional voltage the magnitude of which is at any instant indicative of the interval between successive ones of said impulses and of the frequency of said fundamental component.

8. In a system for producing an indication of the frequency of the fundamental component of a complex signal wave including a plurality of wave components in integral harmonic relation to said component, the combination which includes a frequency selector, frequency translating means for impressing on said selector the heterodyned product of said complex wave and a wave whose frequency is linearly varied between predetermined minimum and maximum values during recurring intervals of known duration, means for detecting the wave components that are segregated by said frequency selector, means for converting said detected components to an alternating voltage the frequency of which is proportional to the number of wave components that are segregated by said selector in a unit interval, and frequency demodulating means for converting said alternating voltage into a unidirectional voltage the magnitude of which is indicative of the frequency of said fundamental component.

9. The combination described in claim 8, including means responsive to said derived unidirectional voltage for varying the interval during which said heterodyned wave is changed between its minimum and maximum frequency values in accordance with changes in the magnitude of said voltage.

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