Aug. 8, 1961 F. DE JAGER ET AL 2,995,707

FREQUENCY DETECTOR

Filed Sept. 29, 1958 2 Sheets-Sheet 1

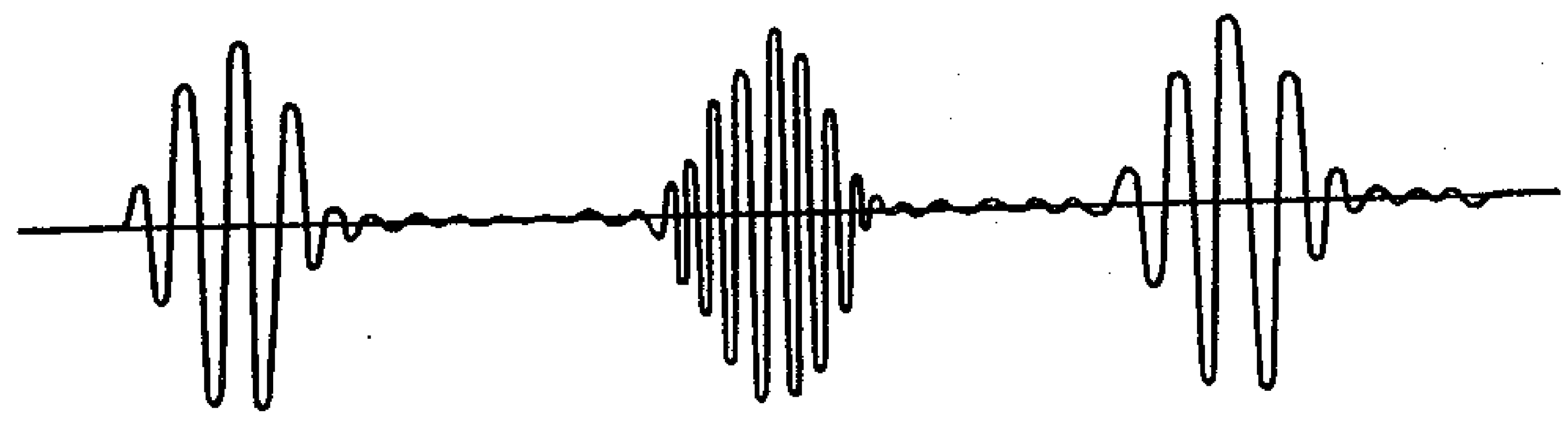

FIG.1a

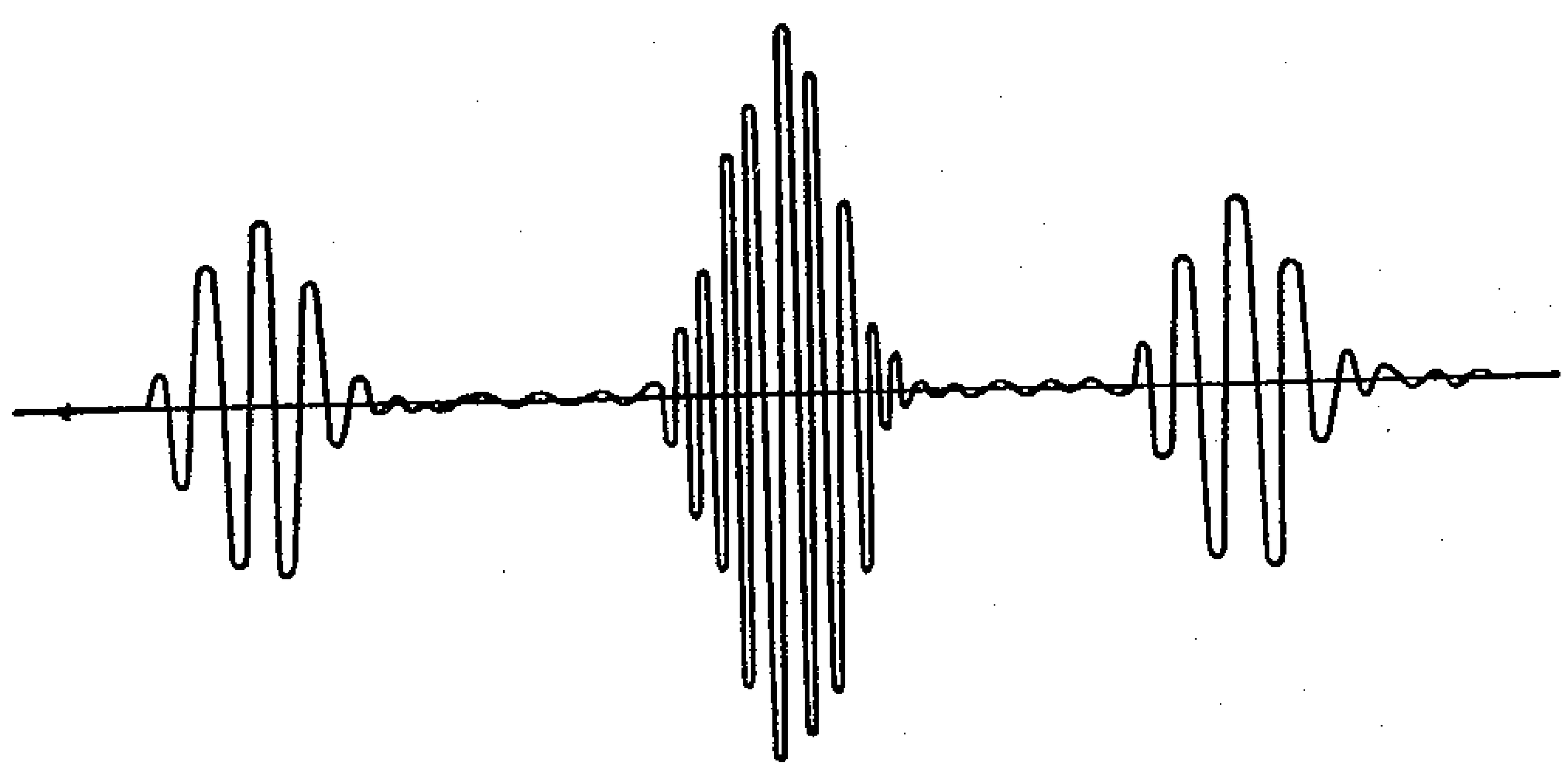

FIG.1b

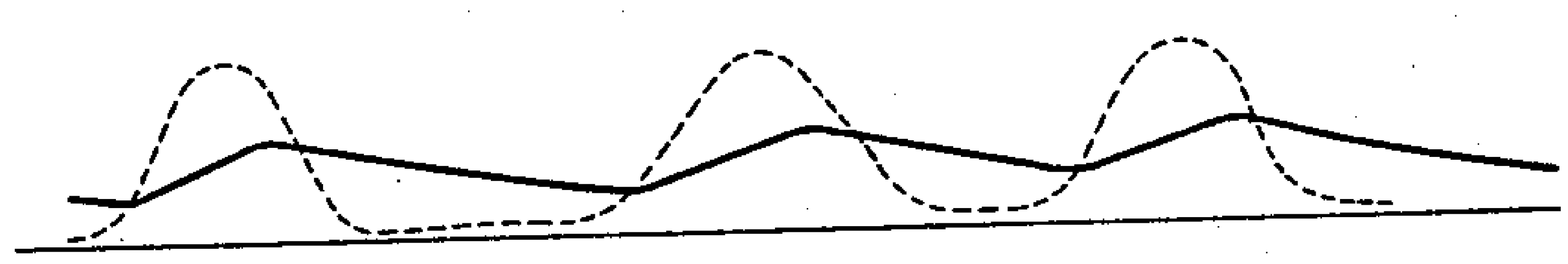

FIG.1c

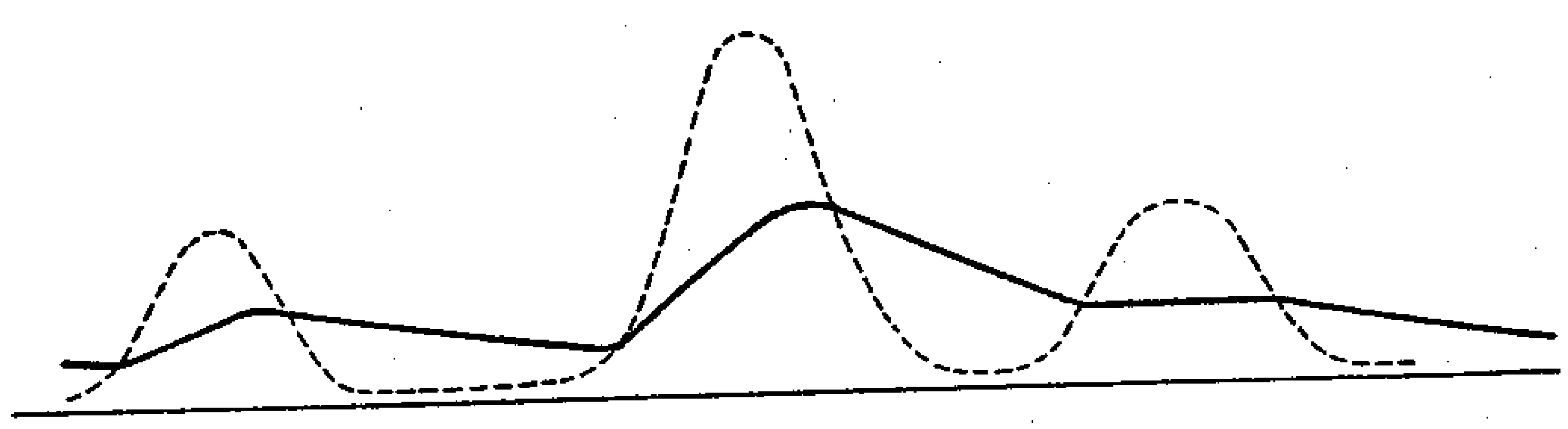

FIG.1d

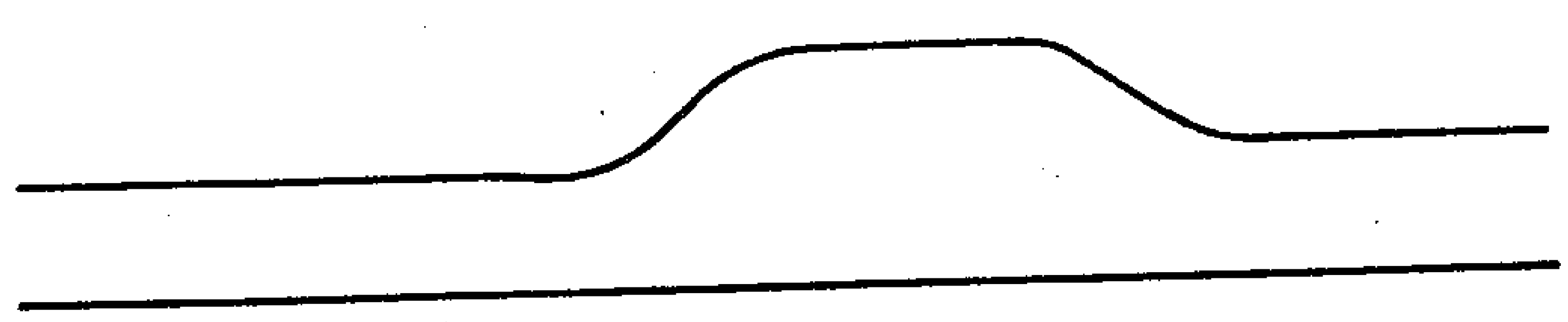

FIG.1e

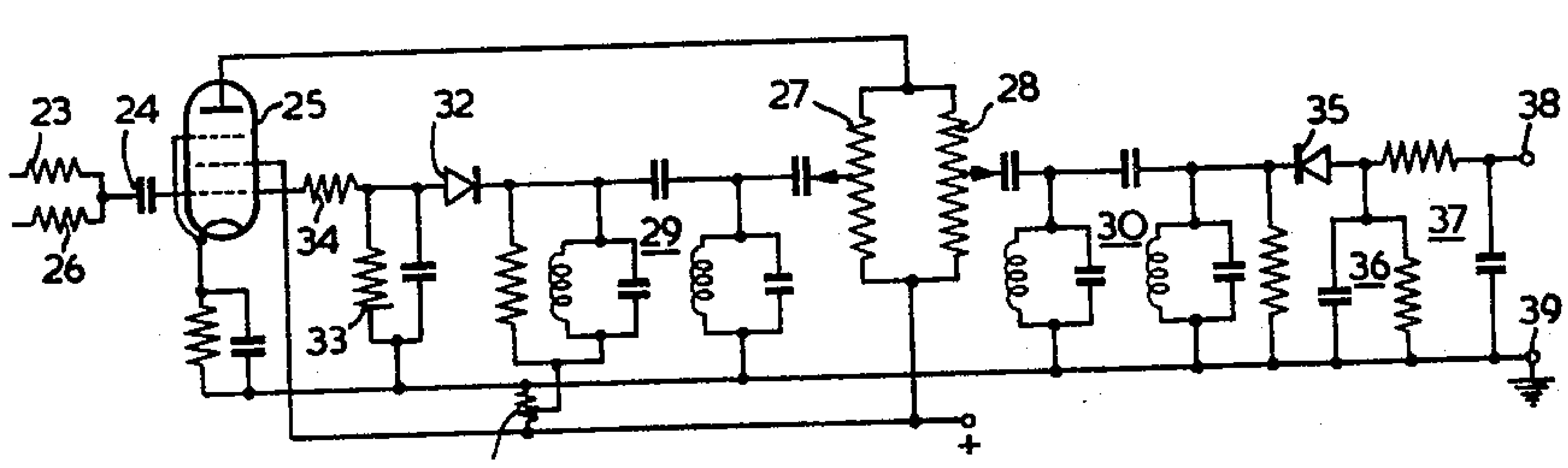

FIG.4

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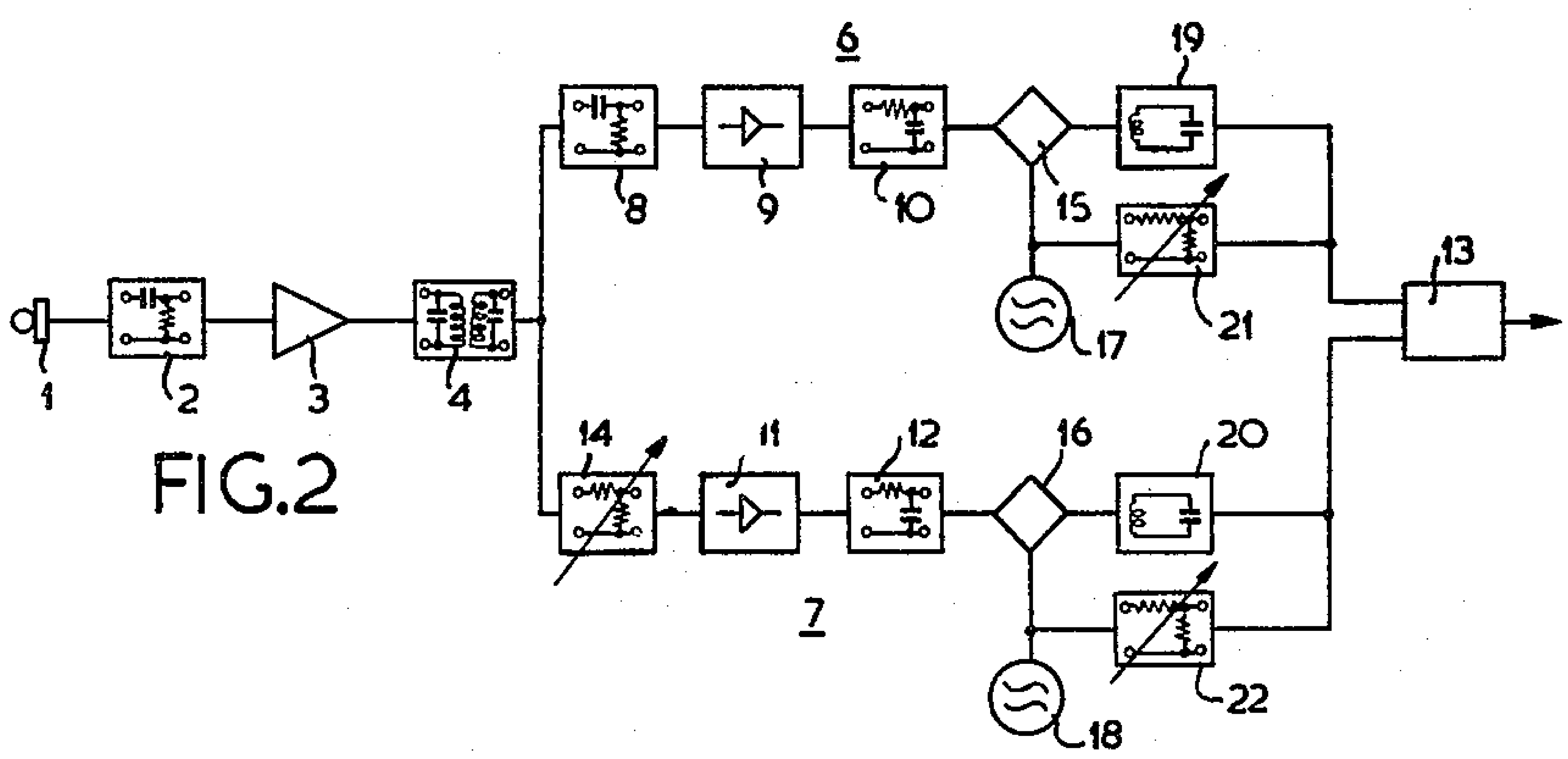

FIG.2

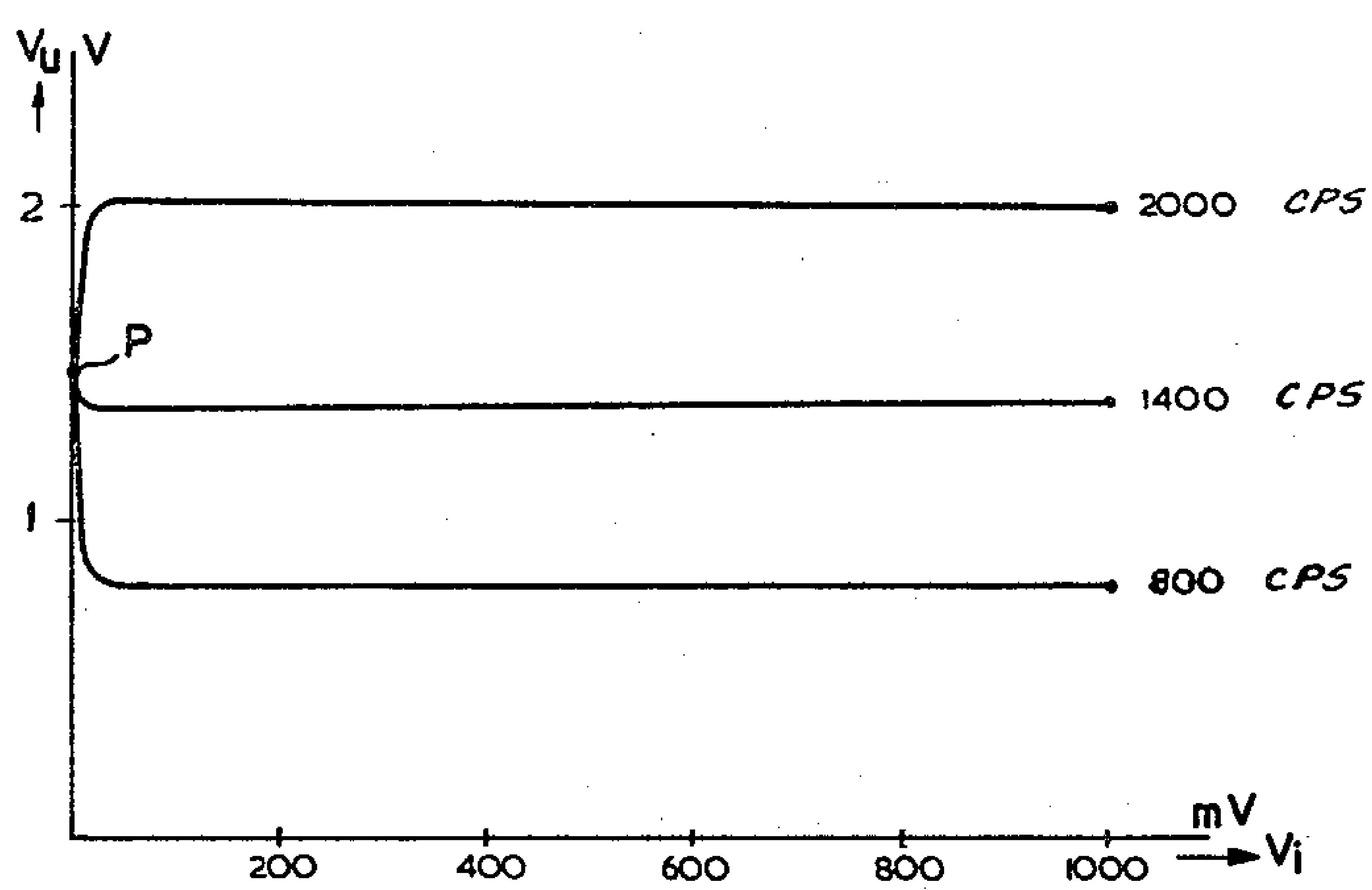

FIG.3

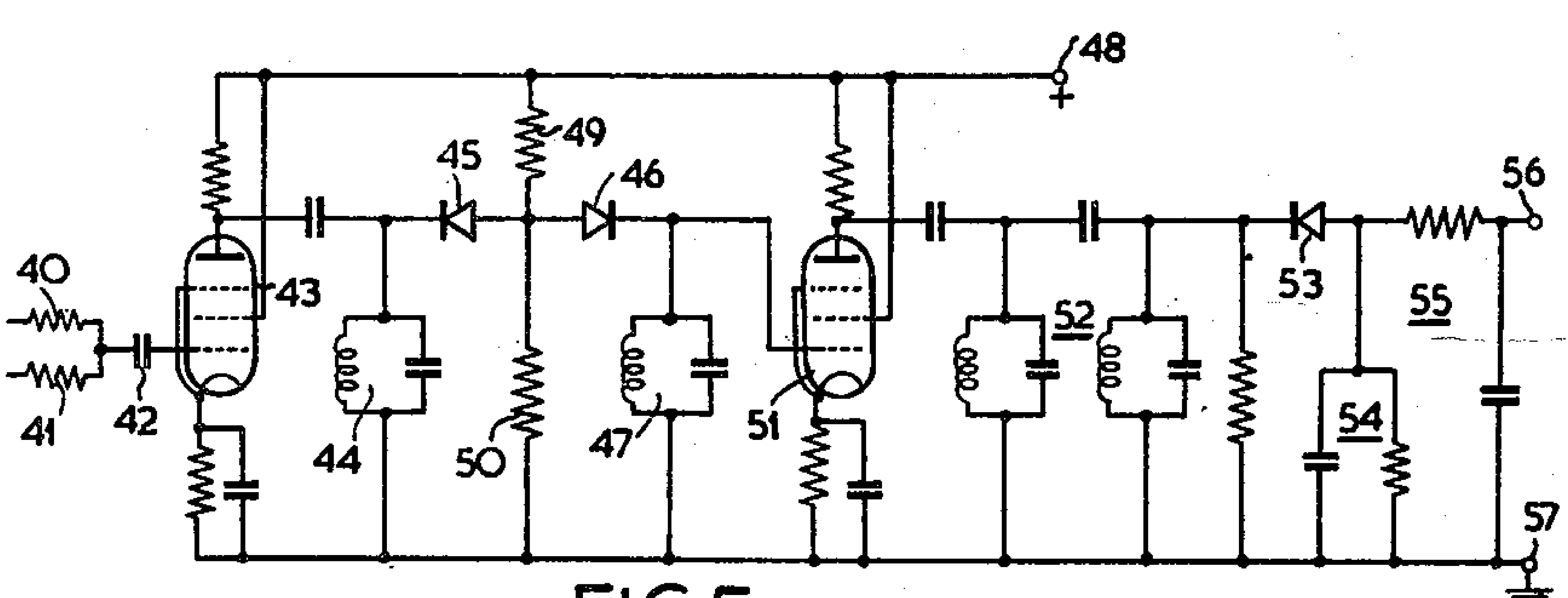

FIG.5

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FREQUENCY DETECTOR

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This invention relates to a frequency detector for detecting the variation of a characteristic speech frequency lying within a speech sub-band, the speech sub-band selected by means of a filter being supplied to the input of the frequency detector. For various uses, for example speech synthesis or speech analysis, it is of importance to know these characteristic speech frequencies, the so-called formant frequencies, which are determined by the resonant frequencies of the resonant cavities in the oral and nasal cavities and in the pharynx, and the so-called fundamental frequency, which is determined by the vibration frequency of the vocal cords.

During a speech signal the shape of these resonant cavities is gradually changed by muscular movements and at the same time they are excited by a plusatory air current in accordance with the fundamental frequency lying in the frequency band of from about 80 c./s. to 300 c./s., so that during a speech signal a number of oscillations of various frequencies are produced which are pulse-amplitude modulated. The speech-components associated with the various formant frequencies are located in different frequency sub-bands determined by formant ranges, the first three subbands, for example, being situated in the frequency bands of about from 300 c./s. to 800 c./s. 800 c./s. to 2000 c./s., 2000 c./s. to 3400 c./s. This is illustrated in FIG. 1*a* which is a time diagram showing the variation of the oscillations associated with three letter sounds in the formant range from 800 c./s. to 2000 c./s.

When a conventional frequency detector is used for obtaining, from the pulsatorily varying oscillations shown in FIG. 1*a*, information about the formant frequency lying within this formant range, the frequency variation being obtained in the usual manner by determining the average number of passages through zero of the produced oscillations, it has been found that considerable practical difficulties occur.

It is found especially that during the small amplitude values which occur in the pulsatory oscillations, the output voltage of the frequency detector is adversely affected in a high degree and this phenomenon is due to the fact that at these instants the variation of the oscillations produced has an uneven nature while the noise and interference voltages which occur at these instants exert a comparatively great influence. In addition, in the output voltage of the frequency detector abrupt amplitude variations occur owing to the fact that the frequency detector invariably adjusts itself to the frequency component having the largest amplitude similarly to what takes place when a number of frequency-modulated oscillations of different strengths are received simultaneously.

It is an object of the present invention to provide a frequency detector of the kind described in the preamble in which the said difficulties are obviated by simple means.

According to the invention, the selected speech sub-band is supplied on the one hand to a network connected in a first chanel which differentiates signal frequencies and is succeeded by a rectifier with an associated low-pass filter, and on the other hand to a rectifier with an associated low-pass filter which are connected in a second channel, the frequency detector also containing a ratio meter which is controlled by the output voltages of the two channels and is used for determining the ratio of the

output voltage of the first channel to the output voltage of the second channel, the output voltage of the frequency detector being taken from the output circuit of the ratio meter.

In order that the invention may readily be carried out, it will now be described more fully, with reference to the accompanying diagrammatic drawings, in which:

FIG. 1 shows a number of wave forms illustrating the frequency detector in accordance with the invention,

FIG. 2 is a block-schematic diagram of the frequency detector in accordance with the invention,

FIG. 3 is a frequency-voltage diagram illustrating the operation of the frequency detector in accordance with the invention,

FIG. 4 shows in detail the circuit arrangement of an embodiment of a ratio meter for use in a frequency detector in accordance with the invention, while

FIG. 5 shows a preferred embodiment of such a ratio meter.

In the frequency detector in accordance with the invention showin in FIG. 2, which is adapted to the detection of the frequency variation of the formant frequency in the formant range from 800 c./s. to 2000 c./s., the speech signals are derived from a microphone **1** and subsequently, after amplitude equalization in a differentiating network **2**, amplified in a low-frequency amplifier, **3**. By means of a band-pass filter **4** connected to the output circuit of the low-frequency amplifier **3** the oscillations $U(t)$ situated in the formant range from 800 c./s. to 2000 c./s. are selected, which oscillations may have the variation shown in FIG. 1*a*.

In order to detect the frequency variation of the formant frequency lying in the formant range between 800 c./s. and 2000 c./s., the oscillations $U(t)$ selected by the band-pass filter **4** are supplied to a frequency detector **5** which is provided with two channels **6** and **7** connected in parallel to the band-pass filter **4**. In the channel **6** the signal $U(t)$ is differentiated in a differentiating network **8**, which may comprise a series capacitance and a parallel resistance and has a time constant of about 10^{-5} seconds, so that a signal $S(t)$ is produced the amplitude of which is proportional to the amplitude of the original signal $U(t)$ multiplied by the instantaneous frequency ω. The variation of the differentiated signal $S(t)$ is illustrated in FIG. 1*b*.

In the channel **6** the differentiated signal $S(t)$ is supplied to a rectifier **9** with an associated low-pass filter **10**, which may comprise a series-resistance and a parallel-capacitance, while in the channel **7** the original signal $U(t)$ is likewise supplied to a rectifier **11** with an associated low-pass filter **12**, this rectifier circuit **11, 12** being designed similarly to the rectifier circuit **9, 10**. The cut-off frequencies of the low-pass filters **10, 12** are chosen so that during the intervals between the letter sounds an output voltage is also produced at the output of the low-pass filters **10** and **12**, these cut-off frequencies being situated, for example, between 10 c./s. and 50 c./s. and being about 30 c./s. in the embodiment shown. In FIGURES 1*c* and 1*d* the broken lines show the envelopes of the oscillations of FIGURES 1*a* and 1*b*, the voltages which are produced at the output circuits of the low-pass filters **10** and **12** being indicated by the solid curves.

In order to obtain a voltage which varies with the frequency variation of the formant frequency, the output voltages of the low-pass filters **10** and **12** control a ratio meter **13** the desired variation of the formant frequency, which is illustrated in FIG. 1*e*, being achieved by determining the ratio between the output voltages of channels **6** and **7**. Initially the ratio of the output voltages of the channels **6** and **7** is adjusted to a suitable value by means of an adjustable attenuator **14** connected in the channel **7** so as to precede the rectifier **11**.

In the frequency detector described there are produced by rectification in the rectifiers **9** and **11** and by the subsequent smoothing in the low-pass filters **10** and **12** at the output circuits of these low pass filters **10** and **12** voltages which are equal to the smoothed values of the voltages set up at the outputs of the rectifiers **9** and **11**. If the amplitude of the input voltage of the rectifier **11** is $a(t)$ at a certain instant, the input voltage of the rectifier **9** is proportional to the product of the amplitude $a(t)$ and of the instantaneous frequency, as has been mentioned hereinbefore, so that in mathematical form the output voltages of the low-pass filters **12** and **10** can be represented by the values of the time integrals:

$$\int a dt \ldots \qquad \text{(I)}$$

$$\int a\omega dt \ldots \qquad \text{(II)}$$

taken over a period of time which is determined by the time constants of the low-pass filters **10** and **12**.

Thus, at the output circuit of the ratio meter **13** an output voltage is produced which is proportional to the quotient of the time integrals (II) and (I):

$$\frac{\int a\omega dt}{\int a dt} \ldots \qquad \text{(III)}$$

the time integral in the numerator of the quotient (III) showing that in order to determine the formant frequency there is attached to the frequency ω occurring at a certain instant a value which is determined by the instantaneous amplitude $a(t)$ of the signal. Thus the output voltage of the frequency detector is determined substantially by the frequencies of the oscillations during the maximum amplitude values of the letter sounds the frequencies of which are found to correspond exactly to the formant frequencies, while the small amplitude values have only a slight influence on the output voltage of the frequency detector.

It has been found experimentally that the output voltage of the frequency detector exactly follows the formant frequency while interfering secondary effects owing to the special character of the speech oscillations are materially reduced.

The ratio between the output direct voltages of the low-pass filters **10** and **12** in the channels **6** and **7** can be determined by supplying each of these direct voltages to an amplifier having a logarithmic amplification characteristic, the output voltages of these amplifiers being compared in a differential network so that at the output of this network a voltage is produced which is proportional to the logarithm of the output voltage of the low-pass filter **10** less the logarithm of the output voltage of the low-pass filter **12**. Thus, at the output of the differential network a voltage is produced which is proportional to the logarithm of the ratio between the output voltages of the low-pass filters **10** and **12**, the required ratio being obtained by supplying the output voltage of the differential network to an amplifier having an exponential amplification characteristic.

Instead of directly determining the ratio between the direct voltages shown in FIGURES 1*c* and 1*d* by the solid curves, it has been found advantageous to convert the output direct voltages of the low-pass filters **10** and **12** into alternating voltages having frequencies f_1 and f_2 which correspond to the direct voltages in amplitude.

For this purpose in the embodiment described the output direct voltages of the low-pass filters **10** and **12** in the channels **6** and **7** control amplitude modulators **15** and **16**, which may be push-pull modulators, with associated output filters **19** and **20** and carrier-wave oscillators **17** and **18** the frequencies f_1 and f_2 of which are 32 kc./s. and 48 kc./s., respectively. The ratio meter to be employed will be described more fully hereinafter with reference to FIGURES 4 and 5.

It can be ensured in a simple manner that even in the absence of a speech signal the ratio meter **13** provides a mean output voltage by only providing that in this event the carrier-wave oscillations f_1 and f_2 of the oscillators **17** and **18** are set up at the input of the ratio meter **13** in a suitable strength ratio. For this purpose in the present embodiment the output circuits of the carrier-wave oscillators **17** and **18** are connected, through adjustable attenuators **21** and **22**, to the outputs of the output filters **19** and **20**, respectively, provision being made by suitable adjustment of the attenuators **21** and **22** that in the absence of a speech signal the ratio meter **33** supplies an output voltage which corresponds to a frequency situated in about the middle portion of the formant range concerned. Such an adjustment also provides the advantage that when a speech signal occurs after a speech interval, the frequency detector rapidly adjusts itself to the desired value.

Obviously the adjustment of the ratio between the carrier frequencies f_1 and f_2 in the absence of a speech signal can also be ensured in a different manner, for example, by a slight modification in the push-pull of the push-pull modulators **15**, **16** used.

FIG. 3 shows a voltage diagram of the frequency detector shown in block-schematic form in FIG. 2, the output voltage V_u of the frequency detector being plotted as a function of the input voltage V_i at various frequencies of the input voltage.

In the absence of an input voltage there is produced at the output of the frequency detector owing to the adjustment of the attenuators **21**, **22** an output voltage P which, in the embodiment concerned, corresponds to a frequency of about 1400 c./s.

If there is supplied to the input of the frequency detector an oscillation of constant frequency f, the amplitude of which is gradually increased, starting from the adjusted point P the output voltage associated with this frequency f will be reached even at a very low input voltage while it remains substantially constant at a further increase of the input voltage. Thus, the curves shown represent the variation of the output voltage V_u of the frequency detector as a function of the input voltage V_i at frequencies of 800 c./s., 1400 c./s. and 2000 c./s., respectively.

In the frequency detector described it is remarkable that the output voltage V_u of the frequency detector is substantially independent of the amplitude of the input voltage while furthermore, as will be seen from the figure, this input voltage varies in a substantially linear relationship with the frequency within the comparatively wide frequency band (800 c./s.–2000 c./s.) of this formant range.

Tests have also shown that when an intermittent alternating voltage is supplied to the input, the output voltage of the frequency detector is substantially independent of the ratio between duration and spacing of these wave trains (duty cycle).

FIG. 4 shows in detail the circuit arrangement of a ratio meter for use with the frequency detector shown in FIG. 2.

In this ratio meter the alternating voltage f_1 which is derived from the channel **6** and the amplitude of which is determined by the rectified differentiated input signal of the frequency detector, is supplied, through a resistor **23** and a grid capacitor **24**, to the control grid of a pentode **25**, there being also applied to this control grid through a resistor **26** the alternating voltage f_2 which is derived from the channel **7** and the amplitude of which is determined by the rectified input signal.

For ratio measurements the anode circuit of the pentode **25** contains two parallel-connected resistors **27**, **28**, there being connected to a tapping on the resistor **27** a selecting filter **29** tuned to the frequency f_2 and to a tapping on the resistor **28** a selecting filter **30** tuned to the frequency f_1. The oscillation at frequency f_2 derived from the filter 29 is rectified by a rectifier 32 to which a bias voltage is applied which is supplied by a potentiometer 31 connected between the positive voltage terminal and earth, the negative direct voltage obtained being supplied, through a resistor 34, to the control grid of the pentode 25 for slope control. Owing to this slope control the amplitude of the oscillations at frequency f_2 taken from the output of the pentode 25 will be kept substantially at a constant level so that the slope of the pentode 25 varies in substantially inverse proportion to the amplitude of the oscillator f_2 supplied to the input of the pentode 25.

The oscillation at frequency f_1 selected by the filter 30 is rectified in a rectifier circuit comprising a rectifier 35 and an output impedance 36 and subsequently is supplied, through a low-pass filter 37, to output terminals 38, 39, the direct voltage taken from the terminals 38, 39 being the output voltage of the ratio meter. The use of the slope control ensures that the oscillations at frequency f_1 are amplified in the pentode 25 in inverse proportion to the amplitude of the oscillation f_2 supplied to the input of the pentode 25, so that the voltage taken from the terminals 38, 39 is proportional to the amplitude ratio between the output voltages of channels 6 and 7.

Similarly to the ratio meter shown in FIG. 4, in the embodiment shown in FIG. 5 the output voltages of the channels 6 and 7 are supplied through series-resistors 40 and 41 and a grid capacitor 42 to the control grid of a pentode 43, the amplitude ratio being determined, however, by amplitude limitation instead of by slope control.

For this purpose, there is connected to the output circuit of the pentode 43 provided with a resonant circuit 44 which passes the oscillations f_1 and f_2 an amplitude limiter comprising two rectifiers 45, 46 connected with asymmetric conductivity with respect to each other, there being connected to the output circuit of the limiting arrangement a resonant circuit 47 which passes the oscillations f_2 and f_1, while the junction of the rectifiers 45, 46 is connected to the junction of a potentiometer 49, 50 which is connected between the positive voltage terminal 48 of the voltage supply source and earth and supplied a current in the pass direction of the rectifiers 45, 46.

Each time the voltage at the anode circuit of the pentode 43 exceeds the voltage at the junction of the rectifiers 45, 46, the rectifier 45 is cut off, while a constant current flows through the resistor 49 of the potentiometer 49, 50, which is made comparatively large, and through the rectifier 46 to the output impedance 47, while conversely, when the output voltage of the pentode 43 is lower than the voltage at the junction of the rectifiers 45, 46, the rectifier 45 is conductive and the rectifier 46 is cut off so that no current flows to the output impedance 47. The limiter is proportioned so as to provide complete limitation already at signals of small amplitude.

In the arrangement described the output voltage of the limiter circuit is supplied for amplification to a pentode 51, the oscillation f_1 being selected by means of a selecting filter 52 connected in the output circuit of the pentode 51 and providing the output voltage of the frequency detector after rectification in a rectifier stage comprising a rectifier 53 and an output impedance 54 and subsequent smoothing in a low-pass filter 55. The output voltage of the frequency detector is taken from output terminals 56, 57.

If in the circuit arrangement described care is taken to ensure that the amplitude of the oscillation f_1 taken from the channel 6 is smaller than the amplitude of the oscillation f_2 supplied by the channel 7, there are produced at the output circuit of the limiter arrangement current pulses having a repetition frequency f_2 the duration of which varies in accordance with the amplitude of the oscillation at the frequency f_1. The value of these variations in duration is determined by the amplitude ratio between the oscillations f_1 and f_2 so that after selection of the oscillation f_1 in the filter 52 and subsequent rectification in the rectifier stage 53, 54 and smoothing in the low-pass filter 55 there is set up at the output terminals 56, 57 a direct voltage which varies in accordance with the amplitude ratio between the oscillations f_1 and f_2 supplied to the input of the pentode 43. In order to achieve a linear relationship between the direct voltage taken from the output terminals 56, 57 and the amplitude ratio between the oscillations f_1 and f_2 at the input of the pentode 43, the amplitude of the oscillation f_1 is made smaller than the amplitude of the oscillation f_2 by a factor of, for example, 4 to 5. It should be remarked here that in the output circuit of the limiter instead of the oscillation at frequency f_1 use can also be made of the image frequency of f_1 with respect to f_2, which consequently has a frequency of $2f_2-f_1$.

The ratio meters described hereinbefore can obviously be replaced by other ratio meters. For example, the output voltages of the low-pass filters in the channels 6 and 7 may be converted into alternating voltages of equal frequencies, the output alternating voltage of the channel 6 being subsequently shifted 90° in phase and added to the alternating voltage of the channel 7. Thus the phase of the sum voltage obtained varies in accordance with the amplitude ratio between the output voltage of channel 6 and the output voltage of channel 7 so that the desired ratio is obtained by phase measurement.

As has been mentioned hereinbefore, the frequency detector described can also be used for the detection of the variation of the fundamental frequency, for which purpose a suitable speech sub-band containing the fundamental frequency is supplied to the input of the frequency detector. This speech sub-band can be selected directly from the speech signal or it can be obtained by means of amplitude detection of preferably at least one higher formant range.

What is claimed is:

1. A frequency detector for the detection of the variation of a characteristic speech frequency situated within a speech sub-band comprising first and second channels having input and output terminals, means applying signals of said sub-band to the input terminals of said first and second channels, said first channel comprising in the order named serially connected differentiating means, first rectifier means, first low-pass filter means, and modulator means, said second channel comprising in the order named serially connected second rectifier means, second low-pass filter means, and second modulator means, ratio meter means connected to said output terminals to provide an output signal that is a function of the ratio of the output voltages of said first and second channels, and oscillator means connected to said first and second modulator means.

2. The frequency detector of claim 1, comprising means for adjusting the outputs of said first and second modulator means so that an output signal from said ratio meter means occurs in the absence of said signals of said sub-band.

3. A frequency detector comprising a source of input signals, first and second channels having input and output terminals, means applying said signals to said input terminals, said first channel comprising in the order named serially connected differentiating means, rectifier means, low-pass filter means, and first modulator means, said second channel comprising in the order named serially connected rectifier means, low-pass filter means, and second modulator means, first and second oscillator means having different frequency oscillations connected respectively to said first and second modulator means whereby said oscillations are modulated by the signals in their respective channels, and ratio meter means connected to said output terminals to provide an output signal that is a function of the ratio of the output voltages of said first and second channels.

4. The frequency detector of claim 3, in which said ratio meter means comprises an amplifier device having

an input electrode and an output electrode, said output terminals being connected to said input electrode, a first output filter tuned to the frequency of one of said oscillator means, rectifier means connected between said input electrode and said first output filter, and a second output filter tuned to the frequency of the other of said oscillator means and being connected between said output electrode and an output circuit.

5. The frequency detector of claim 3, in which said ratio meter means comprises limiter means having an input circuit connected to said output terminals and an output circuit connected to frequency selective filter means tuned to the frequency of one of said oscillator means, the amplitude of the output voltage of the one channel comprising said one oscillator means being less than the output voltage of the other channel.

6. The frequency detector of claim 5, in which said limiter comprises a pair of rectifiers connected with asymmetric conductivity with respect to each other between said input and output circuits, the junction of said pair of rectifiers being connected, by way of resistor means, to a source of voltage which supplies current to said pair of rectifiers in the pass direction.

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