July 16, 1946. L. Y. LACY 2,403,986

WAVE TRANSLATION

Filed May 8, 1944 2 Sheets-Sheet 1

FIG. 1

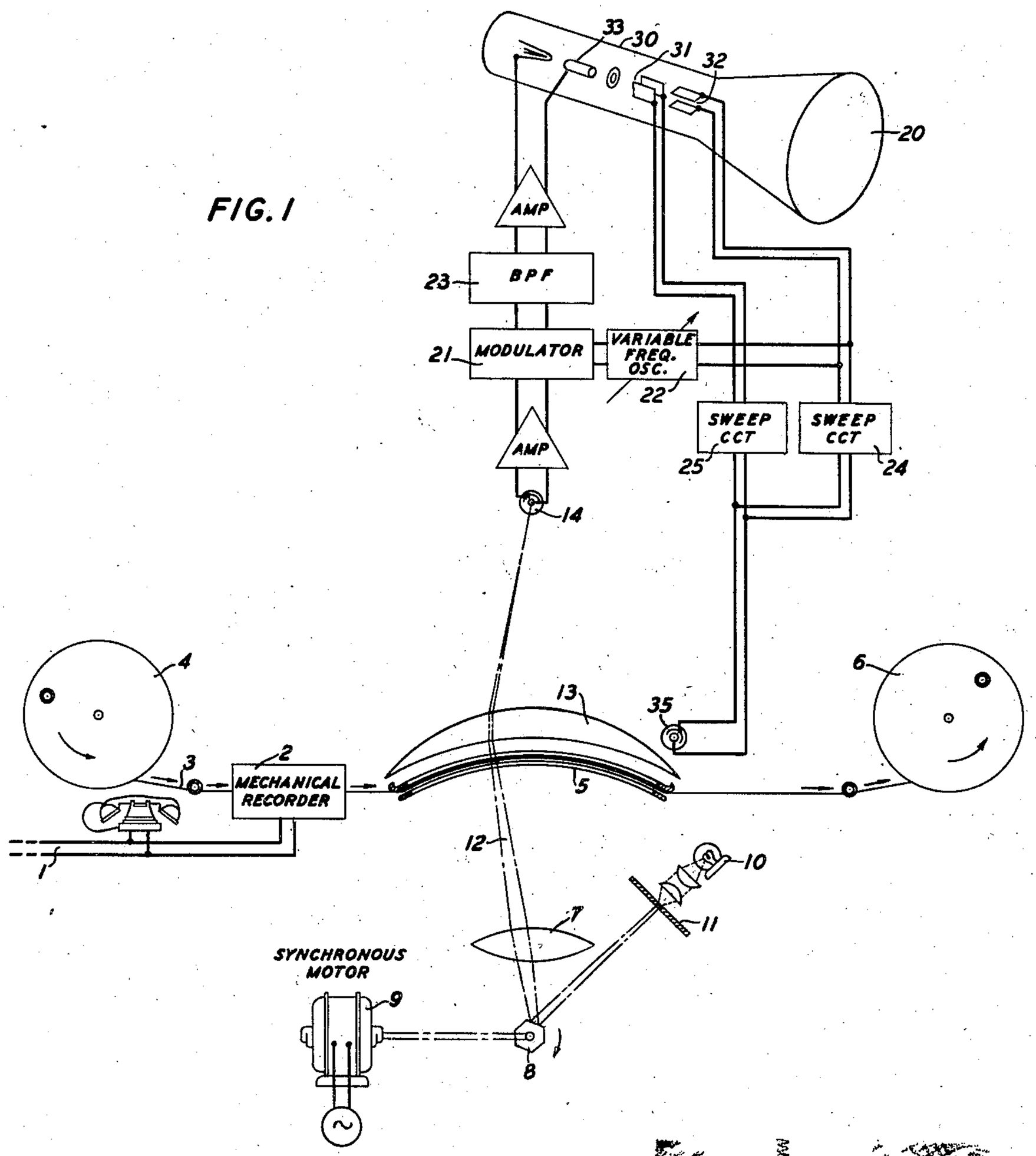

FIG. 3

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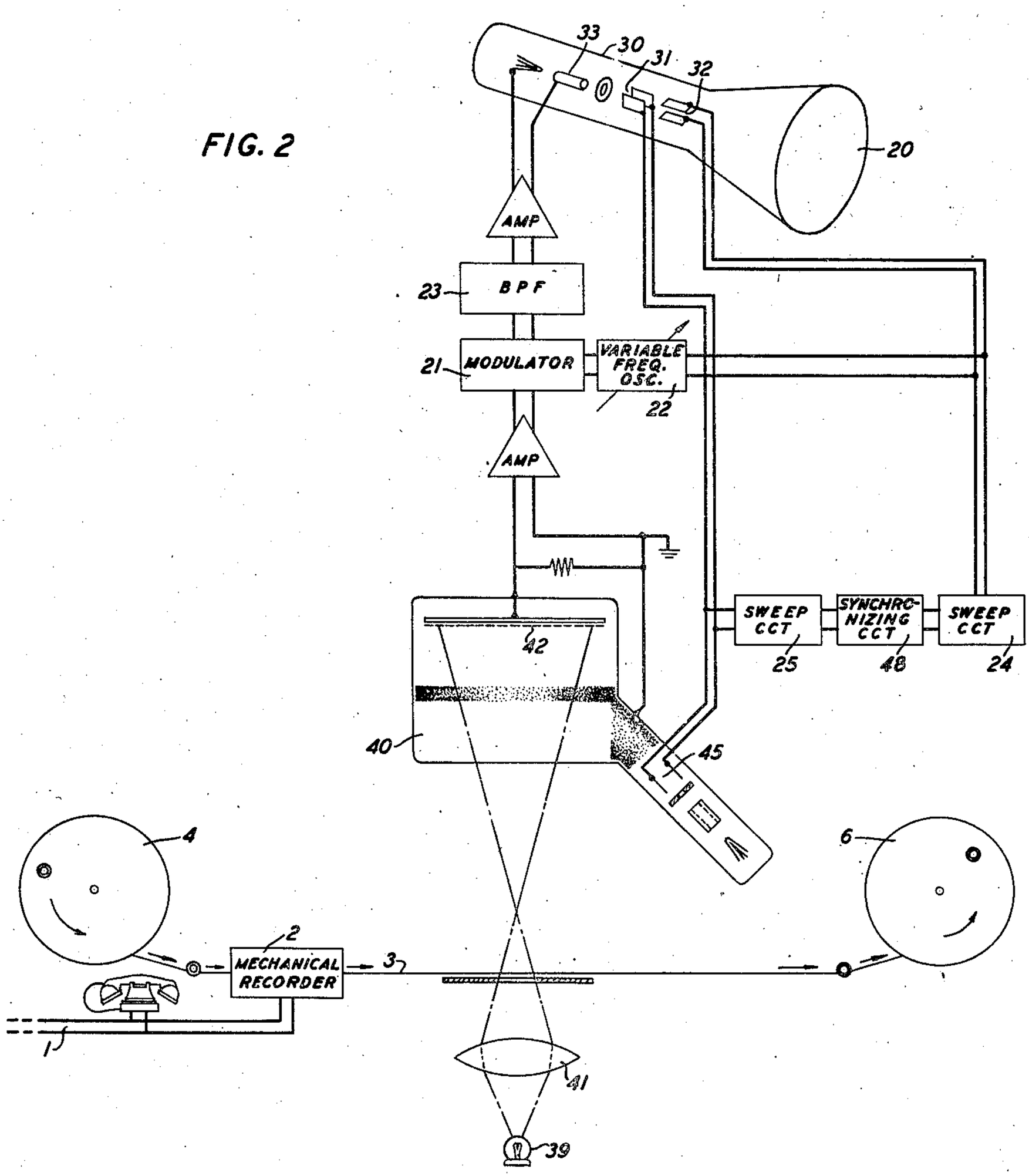
2 Sheets-Sheet 2

FIG. 2



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WAVE TRANSLATION

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19 Claims. (Cl. 179—1)

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This invention relates to the visual representation of complex waves and more particularly to the representation of speech waves and the like in a form such as to reveal directly the manner in which the spectrum or frequency composition of the waves varies with time.

Although a speech wave may be regarded as a single wave the instantaneous amplitude of which varies rapidly in complex manner, it is equally permissible to regard it in terms of a multiplex of frequency components, each component representing a different tone or frequency or narrow band of frequencies within the audible frequency range. To show graphically the varying composition of a speech wave, or other complex wave, it has been proposed heretofore to depict the wave in spectrographic form such that the dimensional coordinates of the graph represent frequency and time, respectively, and the brightness or darkness of each coordinate point in the visual representation indicates the mean intensity of a particular frequency component at a particular instant of time. It has been found that when speech waves are pictured in this form each syllable takes on the general appearance of a fingerprint and that the various "speech prints" or word patterns are quite distinctive.

One of the objects of the present invention is to provide improved methods and means for deriving from complex waves a substantially contemporaneous spectrographic representation thereof. Another object is to produce a spectrographic representation of speech waves and the like from a sound-on-film recording thereof. A further object is to improve the definition or detail of such representations. Still another object of the invention is to produce on the screen of an oscilloscope an uninterrupted progression of speech prints representative of contemporaneously received speech-bearing waves.

In embodiments of the invention that are to be described in detail hereinafter, a variable area or variable density recording of the complex waves is first made by a substantially instantaneous process and the recording is then translated by electrooptical means, a section at a time, into a spectrographic representation on the luminescent screen of a cathode ray oscilloscope. In accordance with a feature of the invention the recorded waves are reproduced in electrical form but with manifold enlargement of the frequency band occupied by the waves. The expanded band is then analyzed to derive respective measures of the varying mean intensity of the several components of the original waves. In

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accordance with a related feature, the waves represented in each section of the recording are reproduced, as aforesaid, repeatedly at a high cyclical rate, and during the successive reproductions successively different frequency components are selected and caused to register on the screen of the oscilloscope until all of the components have contributed to the formation of the luminous pattern. Another feature of these embodiments is that the recording may be continuously advanced so that the spectrographic pattern appears to flow continuously across the screen of the oscilloscope.

The nature of the present invention and its various features, objects and advantages will be more fully understood from a consideration of the following description of the embodiments illustrated in the accompanying drawings. In the latter, Figs. 1 and 2 illustrate diagrammatically two embodiments of the invention, which differ from each other principally in respect of the means employed for translating the recorded waves into electrical form; and Fig. 3 illustrates a word pattern.

Referring now to Fig. 1 there is shown schematically a system in accordance with the present invention that is adapted for the practice of what may be called visual telephony. More particularly, the system is one in which speech-bearing currents received over telephone subscriber's circuit 1 are caused to appear on the screen 20 of a cathode ray oscilloscope in spectrographic form so that the subscriber, if his hearing be impaired, may rely in whole or in part on the contemporaneous visual representation for an understanding of the received message.

The waves to be displayed are first recorded on film in one of the forms usually employed in the sound picture art, for example; that is, in the form of a variable density recording or a variable area recording. For the purposes of visual telephony it is required that the recording means be substantially instantaneous in its operation, and some type of mechanical recorder 2 is accordingly preferred. Recorder 2 may be, for example, a Millertape Recorder as manufactured and sold by the Miller Broadcasting System, Incorporated, which utilizes a film 3 that has an opaque backing and which operates under the control of the currents to be recorded to remove portions of the backing and form a variable area record. As shown in Fig. 1, the film 3 is fed to recorder 2 from a supply reel 4, and as it leaves the recorder it enters immediately a film guide

5 from which it is taken up on reel 6. In some applications of the invention, not involving visual telephony, it is immaterial whether the film recording be made contemporaneously, and in such case recorder 2 may be omitted and a previously formed film record may be employed.

Element 5 is an arcuate film guide that has an elongated aperture or that is otherwise adapted to allow a beam of light from a rotating mirror 8 to pass through the recording on the film. Mirror 8, which is rotated at high speed by a synchronous motor 9, is shown diagrammatically in the form of a hexagonal prism although in practice it may take any of the more elaborate forms known in the art for sweeping a beam of light repeatedly in the same direction through a predetermined angle. The beam is formed by light source 10 and optical slit 11, and it is so directed against the rotating mirror 8 that the reflected beam 12, passing through lens 7, sweeps repeatedly from left to right across the aperture in film guide 5. The optical system is such that the beam, at the point where it passes through the film 3, is substantially as wide as the recording on the film and quite narrow in the other cross-sectional direction. As the light beam 12 leaves the film 3 it enters a condensing lens 13 which, regardless of the angular position of the beam, directs it upon photoelectric cell 14. It will be understood then that each time the beam 12 sweeps from left to right it is modulated by the recording on the portion of film within the guide 5, and that the recorded speech waves on this portion of the film are converted into corresponding electrical waves by the photoelectric cell 14.

The character of the electrical waves produced by photoelectric cell 14 depends in part on the rate at which light beam 12 scans the recording. For present purposes this rate is made many times faster than the rate at which the recording is produced by recorder 2, or in other words, the period of the cyclical movement of the light beam is many times smaller than the time interval represented by the exposed portion of the recording. For specific example, the portion of the recording that is being scanned by the light beam may represent a one-second portion of the received speech signals, and the light beam may traverse this portion six thousand times per second. To simplify the exposition the relatively slow movement of the film 3 through the guide 5 may be disregarded or it may be assumed that the film is stationary in the guide, as it would be if it were desired to produce on screen 20 a still picture of some portion of the recording. In such case it will be understood that the one-second recording is translated into electrical wave form six thousand times a second. Because of this abnormal rate of reproduction, each frequency represented in the recorded wave is multiplied by a factor of 6000. Thus, if it be further assumed, for specific example, that the recorded waves represent a frequency band 3000 cycles wide extending from 500 cycles per second to 3500 cycles per second, the resulting electrical waves in photoelectric cell 14 occupy a frequency band of 18 megacycles ranging from 3 to 21 megacycles per second. Likewise, each narrow band represented in the recorded waves is expanded by a factor of 6000.

The electrical waves derived from photoelectric cell 14 are amplified and applied to a modulator 21 which receives also beating oscillations from a variable frequency oscillator 22. The output of the modulator or at least one of the 18-megacycle

side-bands produced thereby is applied to a filter 23 that has a relatively narrow pass-band, and the oscillator frequency is so varied that the desired side-band is repeatedly swept across the pass frequency of the filter 23. Virtually, the filter 23 passes repeatedly across the side-band and during each traverse selectively passes successively different frequency components thereof. This frequency scanning operation is repeated cyclically and at a cyclical rate that is a low submultiple of the cyclical rate of movement of the light beam 12. More particularly, the period of the frequency scanning is made substantially equal to or less than the period of persistence of vision; it may be one-fifteenth second, for example. The required cyclical variation in the frequency of the beating oscillator 22 may be effected in usual manner by subjecting a frequency controlling element thereof to the control of a saw-tooth voltage wave. The latter is generated by a sweep circuit 24 which may be, for example, a multivibrator the frequency of which, for the case assumed, is 15 cycles a second.

The kinescope or cathode-ray tube 30 is of a standard form comprising a pair of ray deflecting plates 31 for controlling displacement of the spot horizontally across the luminescent screen 20 and a pair of ray deflecting plates 32 for controlling displacement of the spot vertically across the screen. It includes also an electrode 33 for controlling the intensity of the ray and therefore also the brightness of the luminous spot produced on the screen 20, and it may include various auxiliary electrodes, not shown. For simplicity, the usual electrode biasing circuits are omitted from the drawings.

Deflecting plates 31 are connected to a sweep circuit 25 which is a multivibrator or the like producing a saw-tooth voltage wave. The period of sweep circuit 25 is made exactly the same as the period of scanning beam 12, or in other words, for the example assumed, the operating frequency of sweep circuit 25 is 6000 cycles per second. To synchronize the two, a photoelectric cell 35 is provided at one extremity of the swing of light beam 12 so that a synchronizing electrical pulse is applied to the sweep circuit 25 just before the beginning, or just after the end, of each swing of the beam 12. The relations are such that as the light beam 12 swings from left to right sweep circuit 25 causes the luminous spot to move from left to right across screen 20. Sweep circuit 24, which may be synchronized or stabilized in its operation by connection to photoelectric cell 35 or otherwise, is connected to deflecting plates 32 to control the vertical position of the spot. Under the conditions assumed the luminous spot moves horizontally across the screen 20 six thousand times per second while moving relatively gradually in the vertical direction from, say, bottom to top of the viewing area fifteen times a second.

Filter 23 is connected through an amplifier and also a rectifier, if desired, to control electrode 33 so that the brightness of the luminous spot at any instant is dependent on the mean intensity, or wave power content, of the waves passed by the filter 23 at that instant. It is preferred that the elements be so biased, by means not shown, that the luminous spot is barely extinguished when the wave power output of filter 23 is substantially zero, so that the spot appears only when waves are being passed by the filter 23 and with a brightness that is more or less proportional to the filter output.

The Fig. 1 system operates in the following

manner: At the beginning of a cycle of operation the luminous spot appears at, say, the lower left-hand corner of a rectangular area on the screen 20. While light beam 12 swings from left to right the luminous spot moves from left to right across the screen in synchronism. At the same time filter 23 selectively passes waves substantially corresponding to the lowest component frequency band in the recorded speech waves, so that the brightness of the horizontal line traced by the spot varies along its length in accordance with the time variation in the intensity or power content of the 500-cycle component of the recorded waves scanned by the light beam 12. On the next swing of beam 12 the next higher component is passed by the filter 23 and the variations in its intensity are recorded as another luminous line that lies just above the line first produced on the screen and that varies in brightness along its length to represent the variations in the intensity of the selected frequency component. This process is repeated until after four hundred repetitions, completed in one-fifteenth second, the entire 3500-cycle speech frequency band has been scanned and the viewing area on screen 20 has been traversed once. Inasmuch as the action described takes place fifteen times a second the visual representation appears to remain continuously on the screen.

Fig. 3 represents a portion of a speech print or word pattern as it might appear on the screen 20. The vertical coordinate dimension of the representation is a substantially continuous frequency coordinate, for each point along it is respective to a particular frequency component. Similarly, the horizontal coordinate dimension may be scaled to represent time.

If the film 3 moves gradually through the guide 5, the speech prints on screen 20 appear to move off the screen to the left and to flow in continuously from the right. As the speed of movement of the film is increased to the rate at which the recording is produced by recorder 2, the rectangular area becomes somewhat trapezoidal but not so much so as to interfere with ready identification of the speech prints.

The definition of the visual representation on screen 20 is dependent in large part on the width of the band passed by filter 23, and in general the narrower the band width the greater the frequency definition. It is important to note in this connection that by virtue of the frequency expansion introduced by the electrooptical scanning system the filter 23 effectively isolates or derives from the recorded wave a frequency band that is six thousand times as narrow as the filter band width. If, for example then, the band width of filter 23 is 52,500 cycles, the selectivity is in effect the same as that of a filter having a band width of 8.75 cycles operating directly on the audio-frequency wave. These figures are such that the effective filter band width is equal to the width of the scanned frequency range, 3500 cycles, divided by the number of scanning cycles required to cover that range, i. e., 400.

Fig. 2 illustrates an embodiment of the invention that differs from the one illustrated in Fig. 1 principally in the means provided for electro-optically reproducing the recorded waves. In Fig. 2 there is provided an iconoscope 40, shown diagrammatically in plan view, and an optical system, symbolized by light source 39 and lens 41, for projecting on the screen or mosaic 42 of the iconoscope an image of, say, a one-second portion of the recording on film 3. If the recording is of

the variable density type the image on the mosaic also will be of variable density, and the amount of light impressed on any part of the mosaic will be correlated with the intensity that the recorded waves had at some particular instant. Iconoscope 40 may comprise the usual means for producing a cathode ray and a pair of deflecting plates 45 for sweeping the ray across screen 42 along the wave image appearing thereon. Sweep circuit 25, which corresponds to element 25 of Fig. 1, is connected to deflecting plates 45 and thereby causes the cathode ray to traverse mosaic 42, say from left to right, repeatedly at a high cyclical rate which as in the previous example may be six thousand times a second. As a result of the electronic scanning of the wave image, corresponding electrical waves appear in the wave output circuit of the iconoscope 40. These waves are exactly the same as those derived from the photoelectric cell 14 in Fig. 1. They are applied through an amplifier to modulator 21 and scanned by the frequency scanning element including filter 23, and applied to oscilloscope 30 in exactly the same manner. Sweep circuits 24 and 25 are connected to cathode-ray tube 30 and to beating oscillator 22, respectively, in the manner described with reference to Fig. 1. Any suitable means 48 may be provided for synchronizing the operation of the two sweep circuits.

If the recording on film 3 in Fig. 2 is of the variable area type the optical system should allow for diffusion of the image in the vertical direction or be otherwise arranged to yield a variable density image. Both variable density and variable area types of recording may be accommodated, however, if the cathode ray be spread out in the vertical direction so that in its traverse across mosaic 42 it covers a band of fixed width that is at least equal to the maximum width of the variable area image.

Although the invention has been described with reference to specific embodiments thereof it will be understood that these embodiments are illustrative and that the invention may take other forms within the spirit and scope of the appended claims.

What is claimed is:

1. A system for translating recorded sound waves into a visual representation, comprising means for repeatedly reproducing the recorded waves in the form of electrical waves at a periodic rate such that the frequency band occupied by said electrical waves is many times as wide as that occupied by said sound waves, frequency selective means cyclically operative over the said frequency band for selectively transmitting in succession the various component frequency bands represented in said electrical waves, said periodic rate being many times the cyclical rate of operation of said selective means, and means for visually representing the effects transmitted by said selective means.

2. In combination, a recording of speech waves, means for translating the recorded speech waves into electrical waves comprising means for repeatedly scanning a section of the recording at a high periodic rate of repetition such that the frequency range occupied by said electrical waves is many times greater than the frequency range occupied by said speech waves, frequency selective means for deriving from said electrical waves an effect that varies in accordance with the variations in the intensity of a selected frequency component, means for substantially continuously changing the frequency component that is se-

lected, from one extremity of the frequency range to the other repeatedly in timed relation to the said repeated scanning, a utilization means, and means for supplying the said derived effects to said utilization means.

3. In combination, a recording of complex waves, reproducing means for repeatedly playing back the recorded waves in electrical form at a rate of reproduction that is many times the normal rate of reproduction, frequency analyzer means for selecting substantially different frequency components from the reproduced waves substantially throughout respectively corresponding different reproductions, and utilization means connected to receive the successively selected components.

4. In combination, a record bearing a recording of complex waves, means repeatedly reproducing in electrical form the waves recorded in at least a portion of said record, said reproducing means operating substantially continuously and at an abnormally high rate of reproduction such that the reproduced waves occupy a frequency range that is many times wider than that occupied by said complex waves, frequency analyzer means for deriving from each of a multiplicity of component frequency bands of said reproduced waves an effect that varies in substantial conformity with the varying mean intensity of the wave components appearing in each said band, utilization means, means for applying said derived effects in succession to said utilization means, and means for progressively changing the said portion of the record from which the waves are reproduced.

5. In combination, a record bearing a recording of complex sound waves, means for translating the recorded waves into electrical waves comprising reproducing means for scanning a section of said record repeatedly at a high periodic rate of repetition such that the frequency range occupied by said electrical waves is many times wider than that occupied by said sound waves, utilization means, frequency selective means for transmitting successively different frequency components of said electrical waves to said utilization means substantially throughout respectively corresponding different reproductions, and record advancing means for gradually changing the section of record that is being scanned.

6. A system for translating recorded sound waves into a visual representation comprising means for reproducing the recorded waves in the form of electrical waves repeatedly and substantially continuously at a periodic rate of repetition, frequency selective means for periodically scanning the frequency range occupied by said electrical waves and selecting progressively different frequency components of said electrical waves, said periodic rate of repetition being many times greater than the periodic rate of scanning, and means responsive to the frequency components selected by said selective means for displaying the variations in the mean intensity of the several components separately and substantially simultaneously.

7. In combination, a recording of complex waves, reproducing means for repeatedly playing back the waves recorded in a portion of said recording that is presented to said reproducing means, means operative on said reproduced waves for selecting a multiplicity of different frequency components therefrom substantially throughout respectively corresponding different reproductions, oscilloscopic means synchronized with said

reproducing means and responsive to the selected components for displaying the variation in intensity of the several selected components along individually corresponding collateral lines, said reproducing means being operated at an abnormally high rate of reproduction such that said variations appear to be displayed substantially uninterruptedly, and means for presenting progressively different portions of said recording to said reproducing means.

8. In combination, a recording of complex waves, reproducing means for repeatedly reproducing in electrical form the waves recorded in a portion of said recording, frequency analyzer means for selecting different frequency components from the reproduced waves substantially throughout respectively corresponding different reproductions in each of successive sets of reproductions, said reproducing means being operated at a rate such that each said set of reproductions is completed in a fraction of a second, a cathode ray tube having a luminescent screen, means for deflecting the cathode ray across said screen repeatedly in synchronism with the repeated reproduction of said waves, means for deflecting said cathode ray in another direction across said screen repeatedly in synchronism with the repetition of said sets of reproductions, means varying the intensity of said cathode ray in conformity with variations in the intensity of the component being selected, and means for continuously changing the portion of said recording that is being reproduced.

9. In combination, a recording of complex waves, means for electrically reproducing the recorded waves over and over again, frequency analyzer means for selecting the different frequency components of the reproduced waves during respectively corresponding different reproductions in each of a repeated series of reproductions, oscilloscopic means responsive to the different selected components for separately displaying the variations in intensity thereof, and means operating said reproducing means at a rate high enough that said variations appear to be continuously displayed.

10. A system for visually representing complex waves comprising a record that bears a recording of said complex waves, means for translating the recorded waves into varying electrical waves comprising reproducer means for repeatedly traversing progressively different sections of said recording at a rate of traverse many times greater than the rate for normal reproduction of said complex waves, frequency selective means operative on said electrical waves for selecting the wave components appearing in the several component frequency bands thereof, a luminescent screen, successive positions in one coordinate direction across said screen being respective to different selected frequency bands and successive positions in another coordinate direction across said screen being respective to successive different elemental portions of the section of said recording that is being traversed, means for selectively exciting said screen to luminescence at the various coordinate positions thereon including means for controlling the excitation at each said coordinate position according to the effective intensity of the selected wave components derived from the respectively corresponding elemental portion and frequency band.

11. In combination with a recording of complex waves, a cathode ray tube, means for deflecting the cathode ray repeatedly in a first direction of

deflection at a first cyclical rate of repetition, means for simultaneously deflecting the cathode ray repeatedly in another direction of deflection at a second cyclical rate of repetition that is many times said first rate, means for reproducing the recorded waves repeatedly in synchronism with the repeated deflection in said other direction, a modulator, means for applying the reproduced waves to said modulator, means for concurrently applying beating oscillations to said modulator, and means for progressively changing the frequency of the beating oscillations from one limiting value to another repeatedly in synchronism with the repeated deflection in said first direction.

12. A system for translating a recording of complex waves into a spectrographic visual representation comprising means for repeatedly reproducing the recorded waves in the form of electrical waves, frequency selective means for deriving from the reproduced waves a measure of the intensity of a selected frequency component, means for continually changing the component that is selected in timed relation to the repetitions of the reproduction, a visual indicator comprising a luminescent screen and means for producing a luminous mark of controllable position and brightness on said screen, means for varying the brightness of said mark under the control of the said derived measure, means for repeatedly moving said mark in one direction across said screen in timed relation with each reproduction of the waves, and means for moving said mark simultaneously in another direction across said screen.

13. A system in accordance with claim 12 in which the rate at which said recorded waves are reproduced is many times the rate at which said waves were recorded whereby the mean frequency of the reproduced waves and the frequency range occupied thereby are substantially increased.

14. A system in accordance with claim 12 in which said visual indicator comprises a cathode-ray tube.

15. In combination, a sound-on-film recording of speech waves or the like, an iconoscope comprising a photosensitive mosaic, means for projecting on said mosaic an image of at least a portion of said recording, and means for repeatedly reproducing the waves represented in said image in the form of electrical waves, said reproducing means comprising means for cyclically electronically scanning said mosaic.

16. In combination, a film bearing a recording of complex waves, an iconoscope comprising a mosaic of photosensitive elements, means for projecting on said mosaic an image of at least a portion of said recording, means for repeatedly reproducing the waves represented in said image in the form of electrical waves comprising means for electronically scanning said elements, frequency analyzer means for selecting different frequency components from said electrical waves substantially throughout respectively corresponding different reproductions, and utilization means responsive to the successively selected components.

17. In combination, a film bearing a recording of complex waves, an iconoscope comprising a mosaic of photosensitive elements, means for projecting on said mosaic an image of at least a portion of said recording, means for repeatedly reproducing the waves represented in said image in the form of electrical waves comprising means for electronically scanning said elements, frequency analyzer means for selecting different frequency components from said electrical waves substantially throughout respectively corresponding different reproductions, a display device having a luminescent screen, and means responsive to each selected frequency component for displaying the time variation in its mean intensity along one of a multiplicity of substantially collateral lines on said screen, each of said lines being substantially individual to a corresponding different frequency component.

18. A combination in accordance with claim 17 including means for progressively changing the said portion of said recording, said reproducing means operating at a rate of reproduction so high that a given frequency component is selected not less than about fifteen times a second.

19. In combination, a film bearing a recording of complex waves, wave reproducing means including means for optically scanning at least a portion of said recording repeatedly at a periodic rate, frequency analyzer means for individually selecting the several frequency components of the reproduced waves, a cathode ray tube, means for varying the cathode ray under the control of successively different selected frequency components, means for deflecting the cathode ray repeatedly in a first direction in timed relation with the repeated scanning of the recording, a photoelectric device positioned to be actuated by said optical scanning means at a predetermined point in the scanning period, a synchronizing circuit connection between said photoelectric device and said deflecting means, and means for concurrently deflecting the cathode ray repeatedly in a second direction.

LESTER Y. LACY.