July 16, 1946. W. KOENIG, JR 2,403,983

REPRESENTATION OF COMPLEX WAVES

Filed April 3, 1945 2 Sheets-Sheet 1

FIG. 1

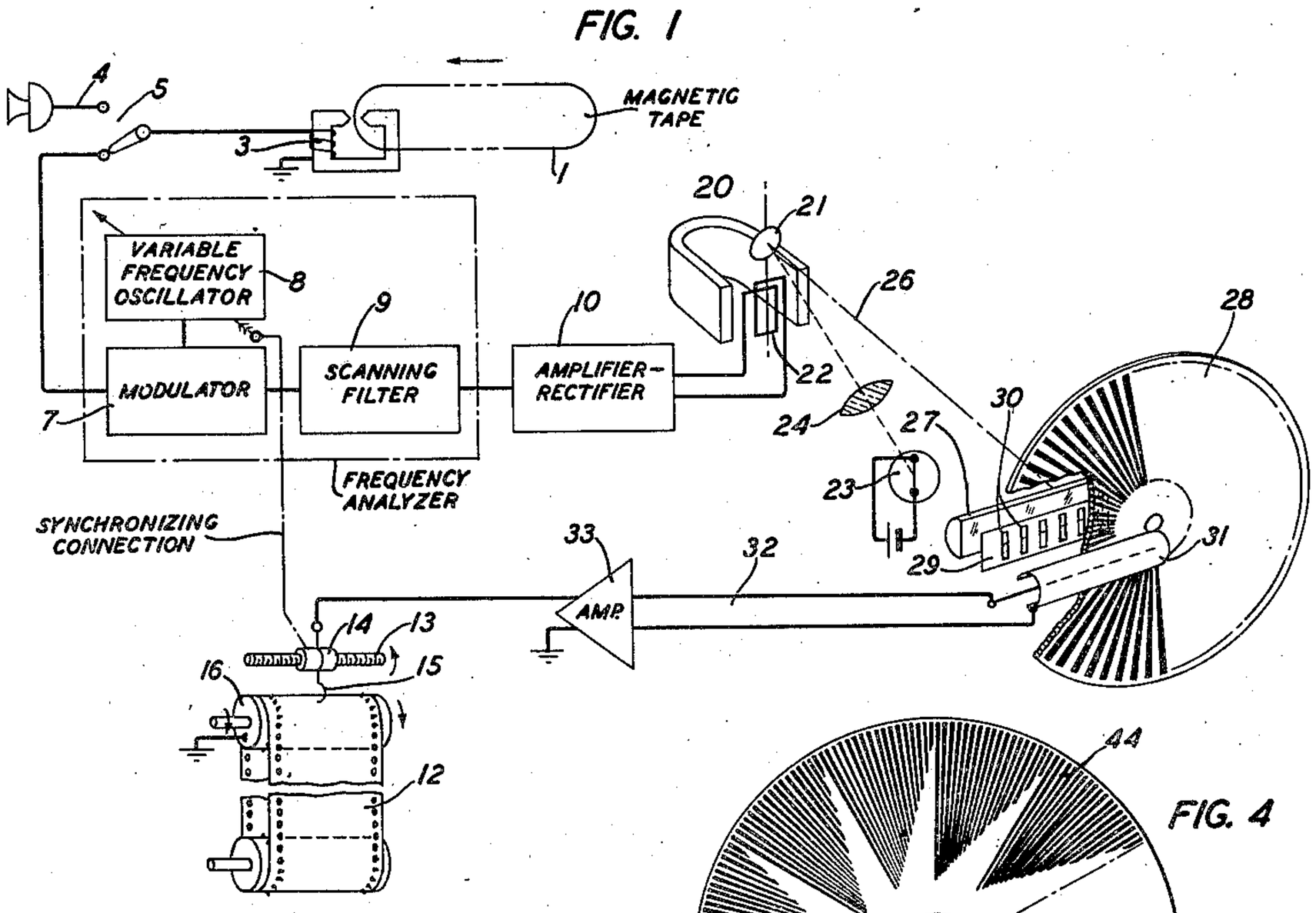

FIG. 2

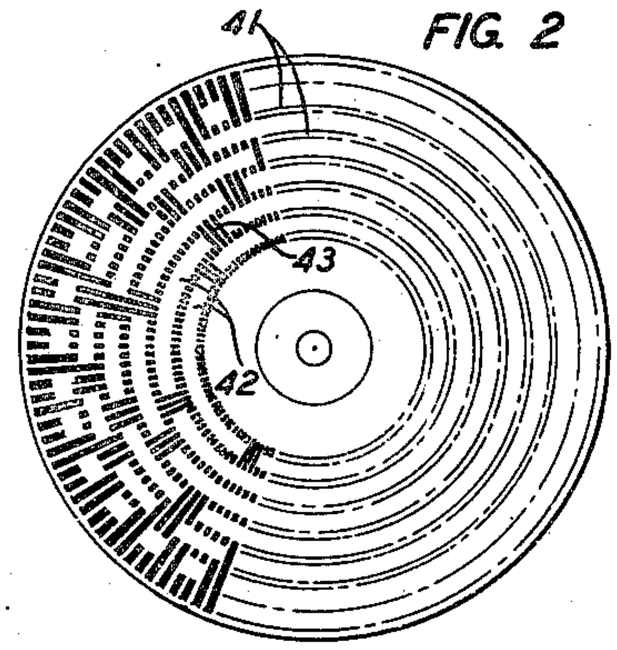

FIG. 3

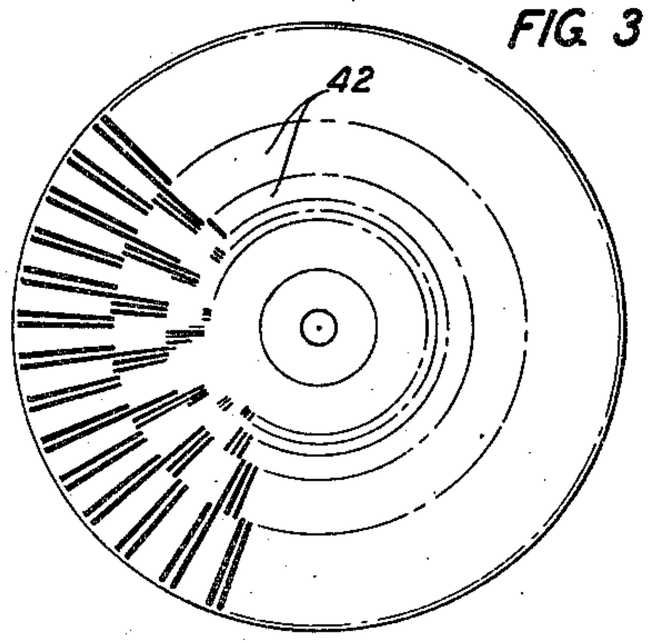

FIG. 4

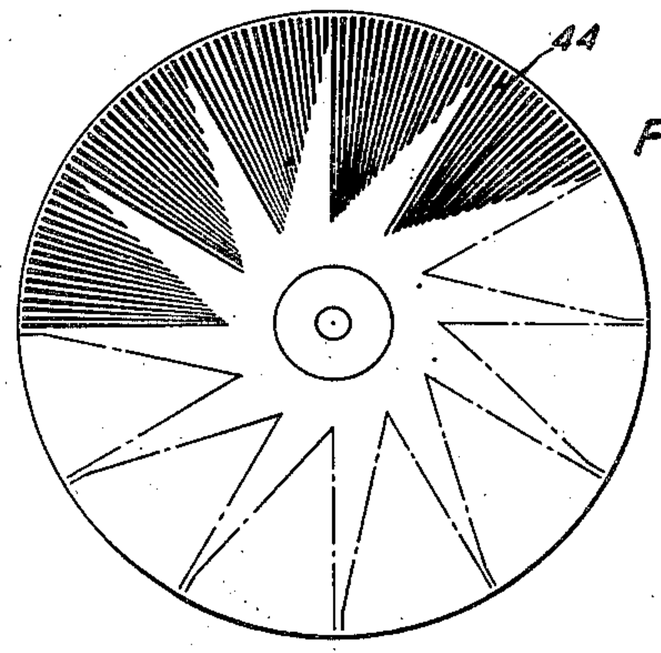

FIG. 5

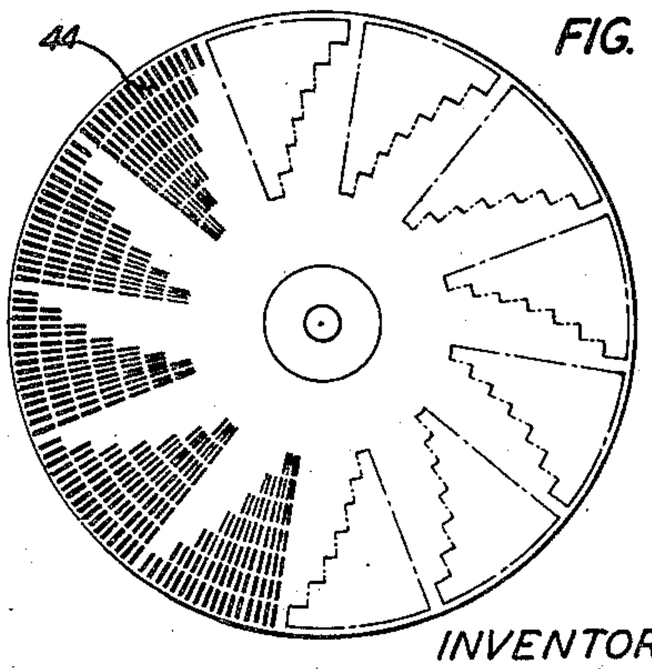

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FIG. 6

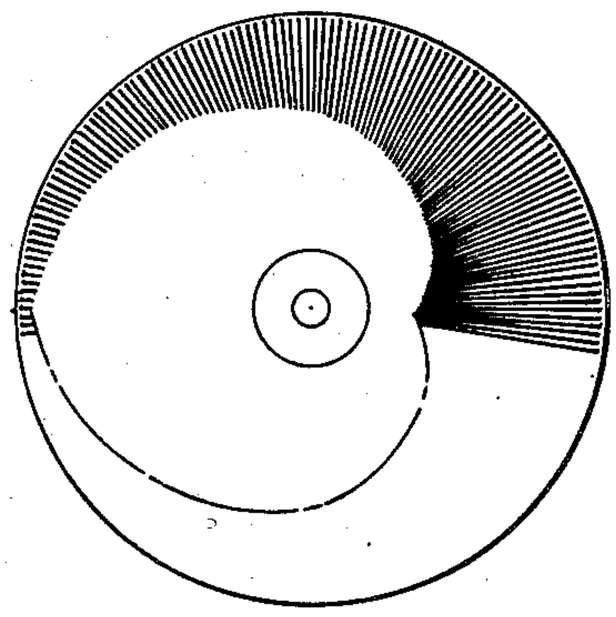

FIG. 7

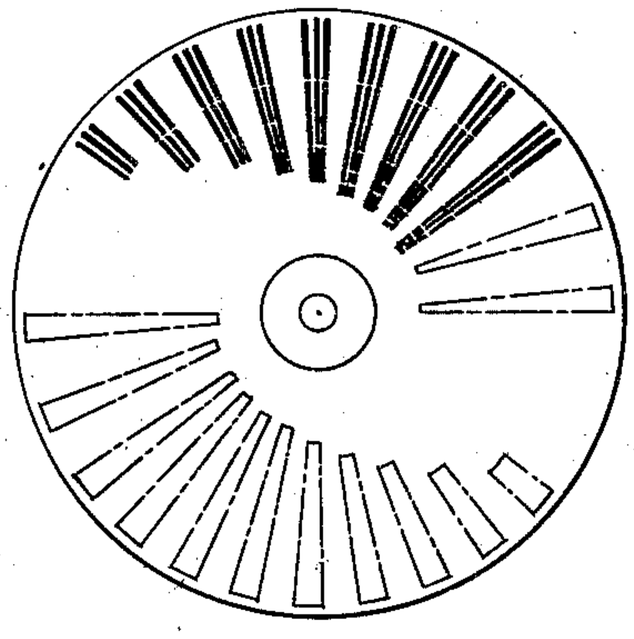

FIG. 8

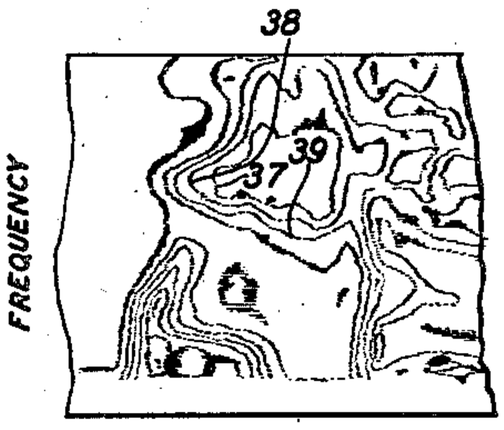

FIG. 9

FIG. 11

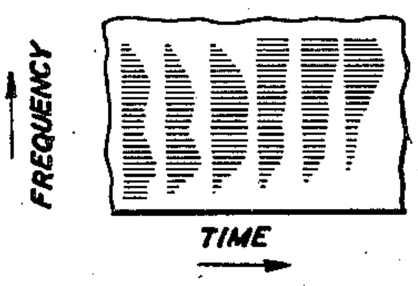

FIG. 10

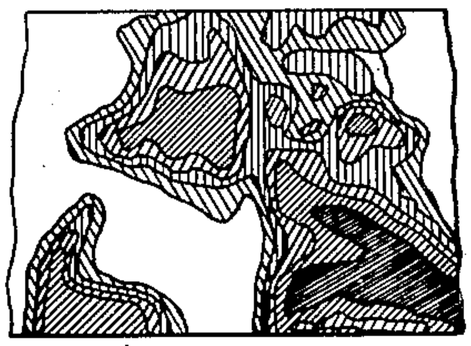

FIG. 12

FIG. 13

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Patented July 16, 1946 2,403,983

UNITED STATES PATENT OFFICE

2,403,983

REPRESENTATION OF COMPLEX WAVES

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Application April 3, 1945, Serial No. 586,308

10 Claims. (Cl. 179—1)

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This invention relates to the analysis of complex waves and more particularly to the production of complex-wave spectrograms.

It has been proposed heretofore to record complex waves, such as speech waves for typical example, in the form of a spectrogram or pattern the dimensions of which have the sense of coordinate axes representing frequency and time respectively. The character of the spectrogram is such that the effective intensity, or envelope amplitude, of the wave component or components appearing in any particular frequency band at any particular time is indicated in the pattern at the coordinate position respective to the particular frequency band and time. The amplitude may be indicated, for example, by the density or blackness of the pattern at the respective coordinate position, as disclosed in my copending application Serial No. 568 880, filed December 19, 1944.

One of the objects of the present invention is to produce complex-wave spectrograms of certain novel types disclosed herein. Another object is to provide simplified and improved equipment for producing spectrograms of types known heretofore, including spectrograms of the contour type disclosed in the copending application of R. K. Potter, Serial No. 569,557, filed December 23, 1944.

A further object is to facilitate accurate determination of the envelope amplitude indicated in a complex-wave spectrogram.

Principal features of the invention lie in means provided for translating the variations in envelope amplitude detected in any particular frequency band into variations in recording current.

In accordance with embodiments of the invention hereinafter to be described in detail, a beam of light is deflected across a multiply-apertured screen or mask more or less in proportion to the varying envelope amplitude of a selected component, and the light intermittently transmitted through the apertures is utilized to control the application of marking current to a recording stylus.

The nature of the invention and its various features, objects and advantages will appear more fully on consideration of the embodiments illustrated in the accompanying drawings and the following description thereof.

In the drawings:

Fig. 1 illustrates an analyzing and recording system in accordance with the present invention;

Figs. 2 to 7 illustrate rotatable screens that are utilized, in modifications of the Fig. 1 system, in the place of a stationary screen and light modulating disc shown in Fig. 1;

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Figs. 8 to 12 illustrate various types of spectrogram produced in accordance with the invention; and

Fig. 13 illustrates an optional auxiliary for certain of the modified systems.

Referring more particularly now to the system illustrated in Fig. 1, there is included a magnetic recorder-reproducer shown diagrammatically as comprising an endless magnetic tape 1 which is passed continuously at a suitable constant speed between the pole-pieces of an electromagnet comprising a coil 3. The complex waves of which a pattern is to be formed may be speech bearing waves, for example, received from a microphone circuit 4 which can be connected at will to coil 3 by means of a switch 5. With the latter in its upper operating position the incoming waves are recorded on the magnetic tape 1. The switch is then opened and the recorded waves are thereupon reproduced electrically or played back, repeatedly, once for each complete revolution, or cycle of movement, of tape 1.

With switch 5 in its lower position as shown, the waves so reproduced are passed to a frequency analyzer or scanner of the heterodyne type comprising a modulator 7, which is supplied with beating oscillations from an oscillator 8, and a band-pass or scanning filter 9 which is connected to receive the wave output from modulator 7. Modulator 7 effectively translates the applied band of speech bearing waves to a higher position in the frequency range depending on the frequency of the beating oscillations, and the latter frequency is varied continuously from one limiting value to another such that the translated band progressively shifts in frequency position. The total shift of the band is comparable with its width. Scanning filter 9 has a relatively narrow pass band the mean frequency of which is such that as the translated band wave shifts in frequency, filter 9 selects progressively different component frequency bands therefrom. In effect, the pass band of filter 9 moves gradually across the frequency range occupied by the speech bearing waves and admits the wave components appearing in the different bands. The waves selected by filter 9 are passed to an amplifier-rectifier 10, the constants of which are so chosen that the unidirectional output voltage is more or less proportional to the envelope amplitude or effective intensity of the selected waves. This voltage may be taken also as an approximate measure of the power content of the selected wave band.

The pattern recorder is illustrated diagrammatically in Fig. 1 as comprising an endless mov-

ing belt 12 of sensitized paper and a rotating threaded shaft 13 on which rides a traveling nut 14 that carries the recording stylus 15 across the strip of paper. The latter may be dry facsimile paper, preferably one with a titanium oxide coating and carbon backing, such as the "Teledeltos Grade H" facsimile paper developed by the Western Union Telegraph Company. Belt 12 is driven at constant speed in synchronism with tape 1 by means of a motor or the like (not shown) connected to belt drum 16. Stylus 15, which may be a stainless steel wire 10 mils in diameter for specific example, bears lightly against the recording surface of the facsimile paper and in the course of production of a spectrogram it is driven slowly across the paper, that is, longitudinally of the drum 16. Whenever and so long as electric current of sufficient intensity is supplied to stylus 15, the current passes through the stylus and the facsimile paper to drum 16, which has a grounded conductive surface, and by virtue of the current passing through the point of contact of stylus 15 a mark is made on the paper.

The progressive change in the operating frequency of oscillator 8 is electrically or mechanically geared with the progressive change in the position of stylus 15 so that as the stylus moves once across the facsimile paper, the oscillator frequency progresses from its one limiting value to the other. This operation is completed only after many revolutions of the belt 12 or in other words only after many reproductions of the recorded waves. In one instance in practice, for example, in which a 3500-cycle band of speech waves was to be recorded the parts were so arranged that the complex waves were reproduced 200 times while stylus 15 moved once across the facsimile paper. Disregarding the slight change in the frequency of oscillator 8 that takes place during each reproduction of the speech waves and the corresponding slight change in the frequency band selected by filter 9, it will be understood that during each reproduction of the recorded waves the filter 9 selects a definite predetermined frequency band while the stylus 15 traverses a respectively corresponding path substantially longitudinally of the facsimile paper, i. e., lengthwise of the belt. The mechanism for supplying current to stylus 15, which will be described presently, is such that along each path on the paper the stylus leaves a trace that is interrupted in a variable manner depending on the varying envelope amplitude of the respectively corresponding band of waves selected by filter 9.

The Fig. 1 system includes also a mirror galvanometer 20 comprising a mirror 21 and a driving coil 22 both mounted for limited rotary movement about a vertical axis. Coil 22 is connected to the output terminals of amplifier-rectifier 10, and the mirror 21 is therefore deflected from its rest position more or less in proportion to the envelope amplitude of the wave components that are selected by filter 9 at any time. Light from the vertical filament of an incandescent lamp 23 is directed through an optical system symbolized by lens 24 to mirror 21 from which the light is reflected in a beam 26 that varies in horizontal direction according to the varying deflection of mirror 21. Disposed horizontally across the path traversed by beam 26 is a semicylindrical lens 27 which extends radially along the face of a rotary screen 28. Interposed between lens 27 and screen 28 is a stationary screen 29 in the form of an elongated mask that has a multiplicity of transverse slits 30 spaced apart at different distances from the axis of rotation of screen 28. The latter is disposed in the focal line of lens 27 and it serves to chop or interrupt intermittently any light that passes through the openings 30 to an elongated photoelectric cell 31. Screen 28 may comprise a multiplicity of transparent and opaque sectoral portions disposed in alternation, in which case it is disposed between screen 29 and photoelectric cell 31 as shown, although alternatively it may comprise alternate light reflecting and light absorbing portions, the photoelectric cell 31 in such case being so disposed as to receive the interrupted reflected light. In either case the varying light emanating from the screen 28 and reaching the photoelectric cell 31 gives rise to electric currents of corresponding varying intensity in the photoelectric cell circuit 32. The currents are intensified by an amplifier 33 and then transmitted to the stylus 15.

In the operation of the Fig. 1 system the beam 26 sweeps back and forth along the screen 29, following the variations in envelope amplitude of the wave components selected by the frequency analyzer. The several slits 30 are respective to different discrete values of envelope amplitude, for beam 26 is incident on a given slit only when and so long as the envelope amplitude has a predetermined particular value. The light momentarily passing through a particular slit 30 tends to produce in circuit 32 a unidirectional current pulse of corresponding duration. The screen 28, however, is rotated at a speed such that the light reaching photoelectric cell 31 is interrupted repeatedly at a high rate such as 10,000 times per second for example. The result is that the current supplied to stylus 15 is alternating in character, which is substantially more effective in marking the facsimile paper than a unidirectional current. While the frequency analyzer selects the waves in a particular component frequency band, therefore, the stylus 15 traverses the corresponding longitudinal path on facsimile paper 12 and produces a mark whenever the envelope amplitude of the selected wave passes through one of the predetermined values.

Fig. 8 illustrates the type of spectrogram that is produced by the Fig. 1 system, assuming that the width of the slits 30 is small in comparison with the distance between them. The marks made in the course of successive reproductions align themselves, it will be observed, to form contour lines such as 37, 38, 39, in Fig. 8. Each contour line is identified with a particular value of envelope amplitude. The envelope amplitude pertaining to any particular frequency band and time may be determined by noting what contour line, if any, passes through the corresponding coordinate point on the spectrogram, or by interpolating with reference to the adjacent contour lines. One will observe in Fig. 8 several regions where the beam 26 repeatedly dwelt on a particular slit 30 long enough to produce horizontal lines of appreciable length. In such regions the contour line takes on the appearance of a band.

The width, number and spacing of the slits 30 can be adjusted to provide a variety of different effects. If the width of the slits 30 is made equal to the spacing between them, for specific example, all of the contour lines will appear as bands or, in other words, successive contour zones in the spectrogram will appear alternately light and shaded, respectively. If the spacing between slits is small compared with the width of the slits the resulting spectrogram comprises light contour lines on a

dark or shaded background. Again, the slits 30 may be spaced approximately equal distances apart so that the contour lines represent equal amplitude steps, or they may be differently spaced to provide logarithmic amplitude steps.

In lieu of the screens 28 and 29 a single rotary screen may be employed that combines the light-chopping function of screen 28 and the amplitude discriminating function of screen 29. In such a screen the transparent portions may be confined to concentric annular bands spaced from the axis of rotation as the slits 30 in Fig. 1 are spaced therefrom. This will become more evident on consideration of Fig. 2.

In accordance with a further modification of the Fig. 1 system, the screens 28 and 29 are replaced by a single rotary screen of the kind illustrated in Fig. 2. The shaded areas in Fig. 2 represent transparent portions of the screen. These portions define, in part, a multiplicity of narrow concentric light-chopping bands 41. The several bands 41 are identified with respectively corresponding different values of envelope amplitude and beam deflection, and their presence results in the formation of corresponding contour lines in the spectrogram substantially as illustrated in Fig. 8. The intervening annular zones 42, which are identified with respectively corresponding different ranges of envelope amplitude values and of beam deflection, are opaque except for occasional sets of closely spaced, radial transparent portions 43. The several sets of transparent portions 43 are uniformly spaced around each zone 42, but their angular separation decreases progressively from a maximum in the innermost or low-amplitude zone. Whenever and so long as the light beam 26 impinges on one of the zones 42, it gives rise in circuit 32 to a succession of current pulses, each of an alternating character adapted for effective marking of the facsimile paper, and the time interval between pulses depends on the radius of the particular zone. The marks produced by the stylus 15 in any given longitudinal path are spaced in proportion to the time separation of the current pulses, and they are substantially uniform in size. Thus each range of envelope amplitude is identified with a particular zone 42, with a particular manner of modulation of the marking circuit, viz., a particular spacing of the current pulses, and with a particular spacing of the dot-like marks that are produced by the current pulses.

The spectrogram produced with the aid of the screen shown in Fig. 2 may take on the general appearance of a half tone, but with superposed contour lines. The value of envelope amplitude represented by any particular contour line can be established readily by observing what ranges of envelope amplitude are recorded on either side of it, that is, by measuring on each side the distance, parallel with the time axis, between successive dots. The outermost zone of the rotary screen may provide for continuous chopping of the light beam, as shown in Fig. 2, in which case the marks appearing in the maximum amplitude regions of the spectrogram are longitudinally continuous.

The rotary screen illustrated in Fig. 3 is substantially the same as that shown in Fig. 2, excepting for omission of the light chopping rings 41 and inequality of the width of the several zones 42. The latter are graded logarithmically from minimum width in the innermost zone to maximum width in the outermost zone. There being five of the zones 42, the spectrogram exhibits five distinctly different inter-dot spacings, and five different logarithmically related ranges of envelope amplitude are indicated in the spectrogram. The general appearance of the spectrogram is illustrated in Fig. 9, which pictures a fragment of a speech spectrogram. The band width of the scanning filter 9 employed in obtaining this spectrogram was approximately 300 cycles, or wide enough to suppress detail of the harmonic structure. The marks may be caused to so align themselves as to form shading lines of various slopes. Thus, by maintaining the period of rotation of the screen in accurate harmonic relation to the period of movement of belt 12, all of these shading lines may be made vertical. By maintaining a fixed inharmonic relation, however, the shading line may be made to slope differently for each different contour zone in the spectrogram. This is illustrated diagrammatically in Fig. 10. The amplitude range pertaining to any given zone, it is evident, can be identified by the inclination of the shading lines, and by the spacing of the shading lines. The rate of rotation of the screen may be allowed to vary slightly if it be desired to prevent the formation of such shading lines.

Figs. 4 and 5 illustrate rotary screens of a type such that the length of the mark made by stylus 15 is sensibly dependent on the amount of deflection of beam 26 and therefore also on the envelope amplitude. Each of these screens may be regarded as being divided into an integral number of equal sectors in each of which the light-chopping striations 44 extend from the leading edge of the sector arcuately toward the trailing edge to an extent that increases progressively with progressive increase in distance from the axis of rotation. In Fig. 4 the progressive increase in arcuate extent is substantially continuous whereas in Fig. 5 it takes place in several distinct steps. Wherever the beam of light 26 strikes it will be transmitted through the screen, modulated at the chopping frequency, at regularly recurring times, beginning each time as the leading edge of a sector passes through the beam and continuing for a period that depends on the position of the beam. The marks produced by stylus 15 are made likewise at regularly recurring intervals and their lengths are correspondingly variable, being least for low values of envelope amplitude and progressively greater for higher values thereof. The character and appearance of the spectrogram depends on how fast the screen is rotated and on the constancy of its speed in relation to that of belt 12. If an exact harmonic speed relation is maintained one obtains a spectrogram of the kind represented in Fig. 11, in which the marks pertaining to successive time intervals are aligned in corresponding successive frames. If the speed relation is allowed to vary, the alignment of the left-hand extremities of the marks shown in Fig. 11 will not be maintained. The length of each line, however, will remain a measure of the envelope amplitude pertaining to the particular frequency band and time indicated by its coordinate position. Depending on the relation of the various factors noted above, Fig. 11 may be taken as an unmagnified representation of the spectrogram or as a greatly magnified representation. In the latter case the spectrogram, held at normal viewing distance, would appear as a half tone picture.

The rotary screen illustrated in Fig. 6 is closely related to that described with reference to Fig.

4. The light-chopping striations extend radially inward from the periphery and vary in length continuously at logarithmic rate in both circumferential directions from a minimum length at the left to a maximum length at the diametrically opposite point. The central opaque section of the screen is roughly heart-shaped. The spectrogram obtained by using the Fig. 6 screen is similar to that illustrated in Fig. 11 except that the horizontal lines in each frame along the time axis are symmetrical about a vertical axis.

Each horizontal line in a spectrogram of the type described with reference to Fig. 11, it will be understood, is produced by a continuous series of light-chopping striations of corresponding arcuate extent. By breaking the continuous series into several spaced sets of striations, each horizontal line in the spectrogram can be made to appear as a dotted line, the number of dots to be counted in any line being a measure of the envelope amplitude. Fig. 12 illustrates such a spectrogram and Fig. 7 shows an appropriate type of screen.

In certain analytical work it may be desired to have in addition to the spectrogram a record of the average power or envelope amplitude, or of the total energy, associated with each of the bands selected by the analyzer. If the spectrograph is so designed that the power content or envelope amplitude is represented by a proportional number of dots the desired record can be had by recording the total number of marking current pulses that appear during each reproduction of the recorded waves. For this purpose the current pulses may be applied to a counting circuit or to a storing circuit in which each pulse contributes to an electrical charge that is accumulated on a condenser. Then immediately after the end of each reproduction and before the beginning of the next the accumulated charge is caused to operate the amplitude recording apparatus. Such an auxiliary to the spectrograph is illustrated diagrammatically in Fig. 13, which shows a pulse accumulator **45** connected to photoelectric cell circuit **32**, and a switch **46** which may be operated manually or automatically at the proper time to apply the accumulated charge to deflecting coil **24**. A mark is thereby made at the end of each line in the spectrogram, and the character of the mark varies according to the total number of dots in the line.

It will be understood that the embodiments herein disclosed are in some respects only illustrative of preferred forms and that the invention is susceptible of embodiment in various other forms within the spirit and scope of the appended claims.

What is claimed is:

1. In a system for producing on a record surface a visual representation of complex waves in the form of a pattern the dimensions of which have the sense of a frequency axis and a time axis, respectively, frequency analyzer means operative on the complex waves for deriving from each of a multiplicity of component frequency bands thereof an electrical effect individual to said band that varies in accordance with the varying effective intensity of the wave components therein, means for producing a beam of light, a screen having a multiplicity of aperture means respective to different values of said varying electrical effect, means controlled by said effects in succession for directing said beam of light to said aperture means selectively according

to the varying value of each said effect, and means responsive to the light received successively by said aperture means for marking the variation in effective intensity appearing in each of said bands on said record surface in the coordinate position respective to each.

2. A system of the kind described comprising means for repeatedly reproducing a complex wave, frequency analyzer means for selecting during each successive reproduction the wave components appearing in a respective different component frequency band, a rotating screen, means for directing a beam of light to said screen, means for displacing said beam relative to and across said screen under the control of the selected components to different positions respective to each different effective intensity of the selected components, a photoelectric device exposed to the light incident on and emanating from said screen, means for modulating the light emanating from any of a multiplicity of annular regions concentric with the rotational axis of said screen comprising screen portions of dissimilar optical character disposed in alternation around each said annular region, the several said annular regions and the said portions thereof being of such size and spacing that the modulation of said light is distinctively different for different displacements of said beam, and stylus means for marking on a record surface along successively different collateral paths during respective different reproductions of the said complex waves, said stylus means being responsive to electrical currents produced by the exposure of said photoelectric device to said modulated light.

3. A system in accordance with claim 2 including means, comprising said screen, for modulating said light in substantially the same manner throughout each of different ranges of displacement of said beam, the manner of modulation differing distinctly from any one of said ranges to another.

4. A system in accordance with claim 2 including modulating means, comprising said screen, for impressing on the said emanating light a series of spaced pulsations, the duration and spacing of the pulsations being different for different ranges of displacement of said beam.

5. A system of the kind described comprising means for repeatedly reproducing a complex wave, frequency analyzer means for selecting during each successive reproduction the wave components appearing in a respective different component frequency band, a rotating screen, means for directing a beam of light to said screen, means for displacing said beam relative to and across said screen under the control of the selected components to different positions respective to each different effective intensity of the selected components, a photoelectric device exposed to the light incident on and emanating from said screen, means comprising said screen for varying the intensity of the emanating light in pulses of alternating character the time separation of which changes progressively with progressive change in the extent of displacement of said beam, and stylus means for marking on a record surface along successively different collateral paths during respective different reproductions of the said complex wave, said stylus means being responsive to electrical current produced by the exposure of said photoelectric device to said modulated light.

6. A system in accordance with claim 5 in

which the said time separation progresses substantially in discrete steps.

7. A system in accordance with claim 5 in which the said time separation progresses substantially continuously.

8. A system of the kind described comprising means for storing complex waves, means for repeatedly reproducing the stored waves, frequency selective means for deriving from the reproduced waves an effect that varies during each successive reproduction in accordance with the variation in effective intensity of the wave content of a different component frequency band, current-responsive stylus marking means movable relative to and across a sensitized surface along a multiplicity of collateral paths in succession, each of said paths being respective to a different component frequency band and each being followed by said marking means while the said effect is being derived from the said respective frequency band, means for producing

a beam of light that is displaced variably in conformity with the variations in said derived effect, photoelectric means positioned to receive the said beam, a screen interposed in the path of said beam, said screen having apertures spaced apart to pass said beam selectively in dependence on the extent of displacement thereof, and means for applying the currents produced by said photoelectric means to control the response of said current-responsive marking means.

9. A system in accordance with claim 8 in which said screen is stationary.

10. A system in accordance with claim 8 in which said screen comprises a rotatable element having a multiplicity of spaced apertures in each of a multiplicity of rings concentric with the axis of rotation, said system including means for rotating said element at a speed such that the light incident on each ring is modulated at audio frequency.

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