

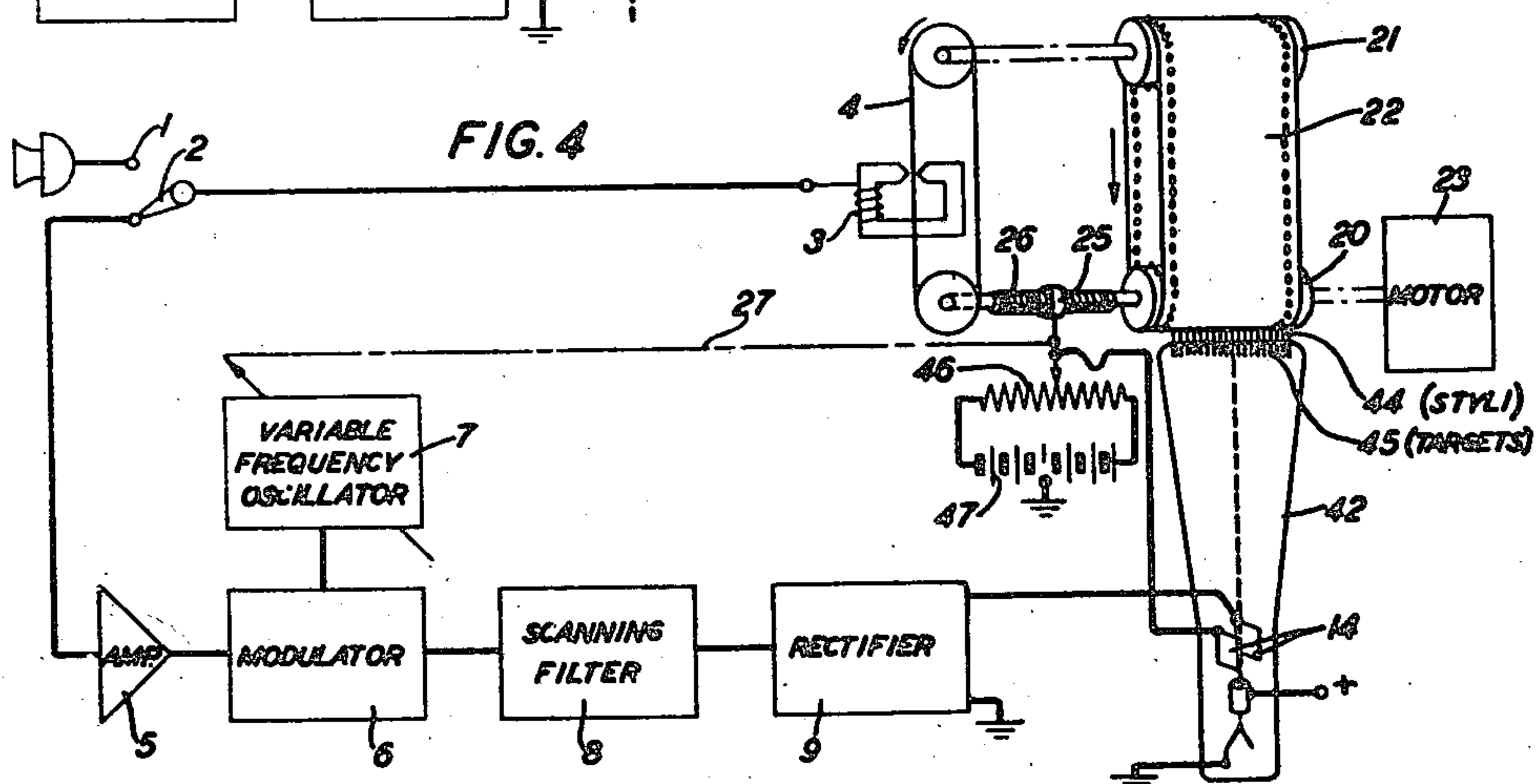
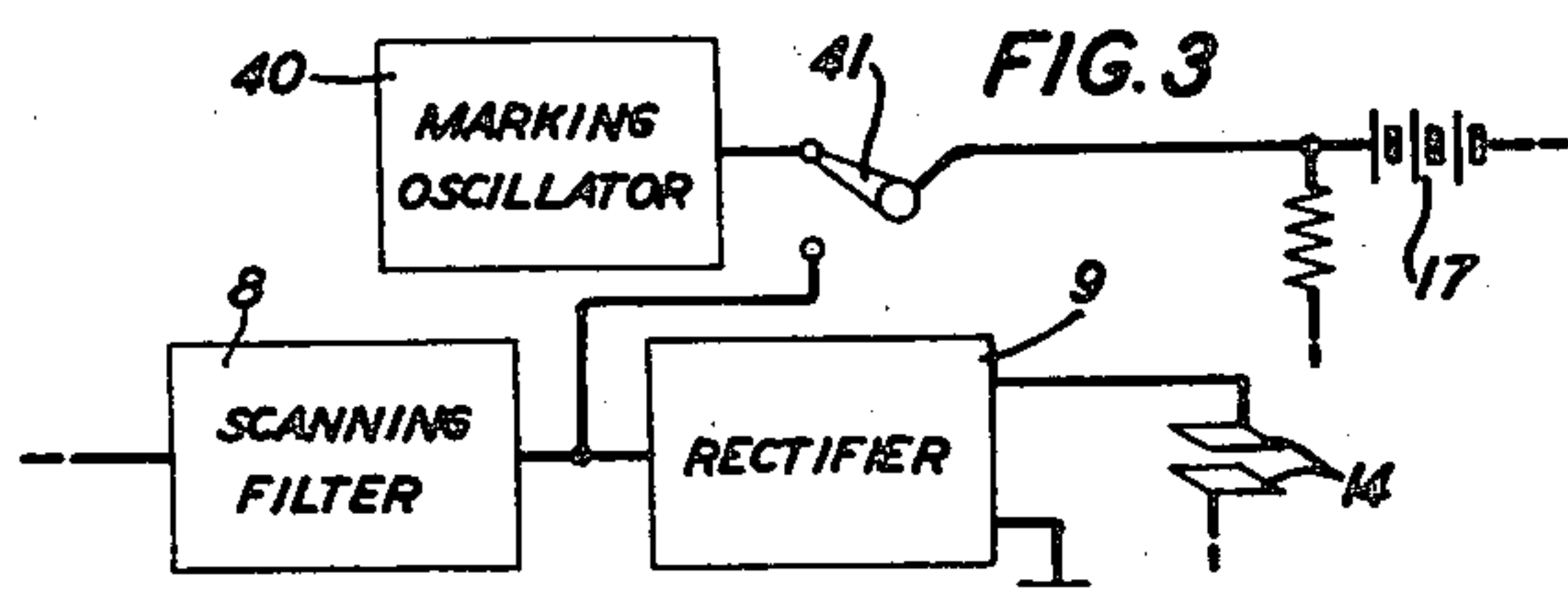
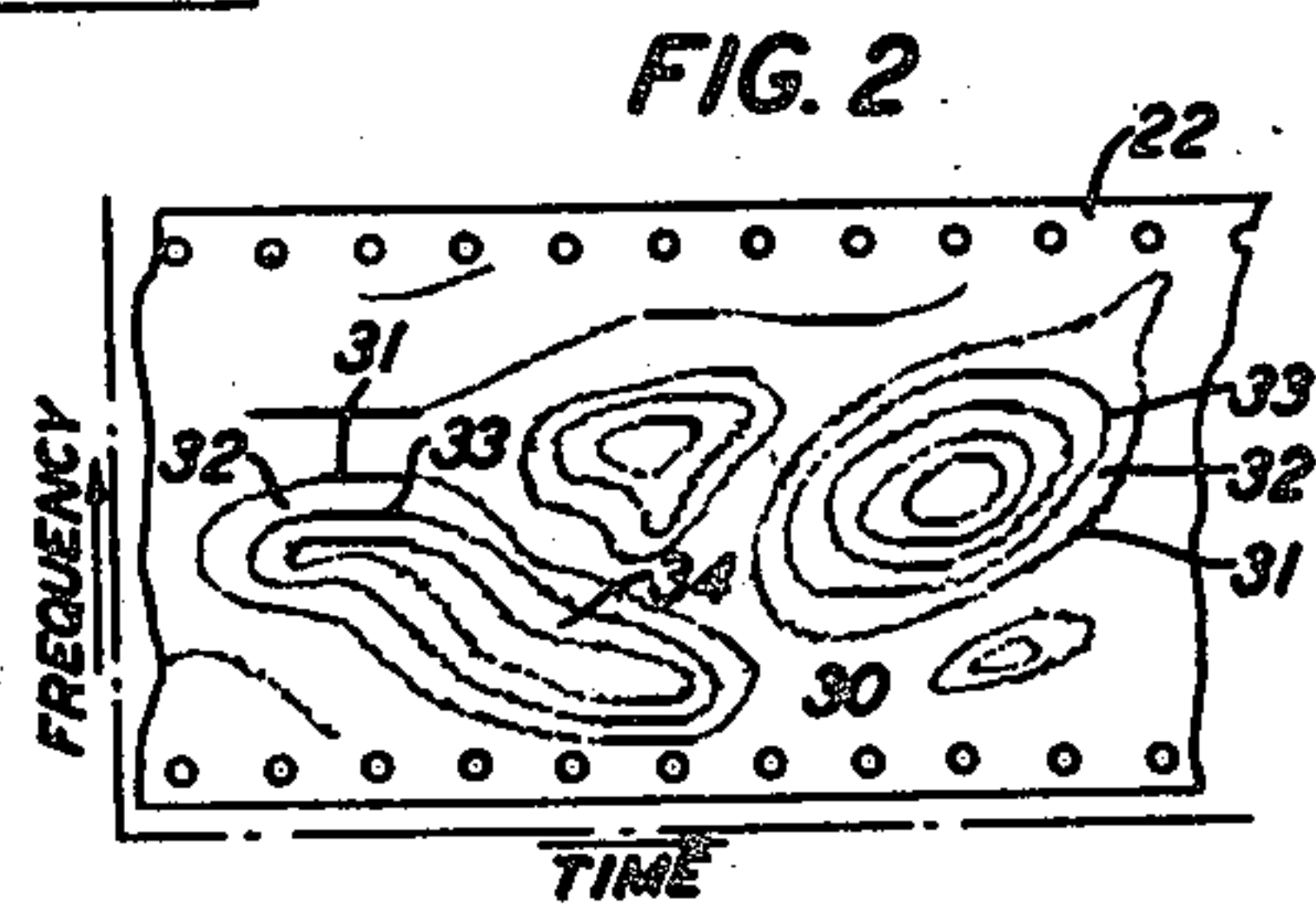
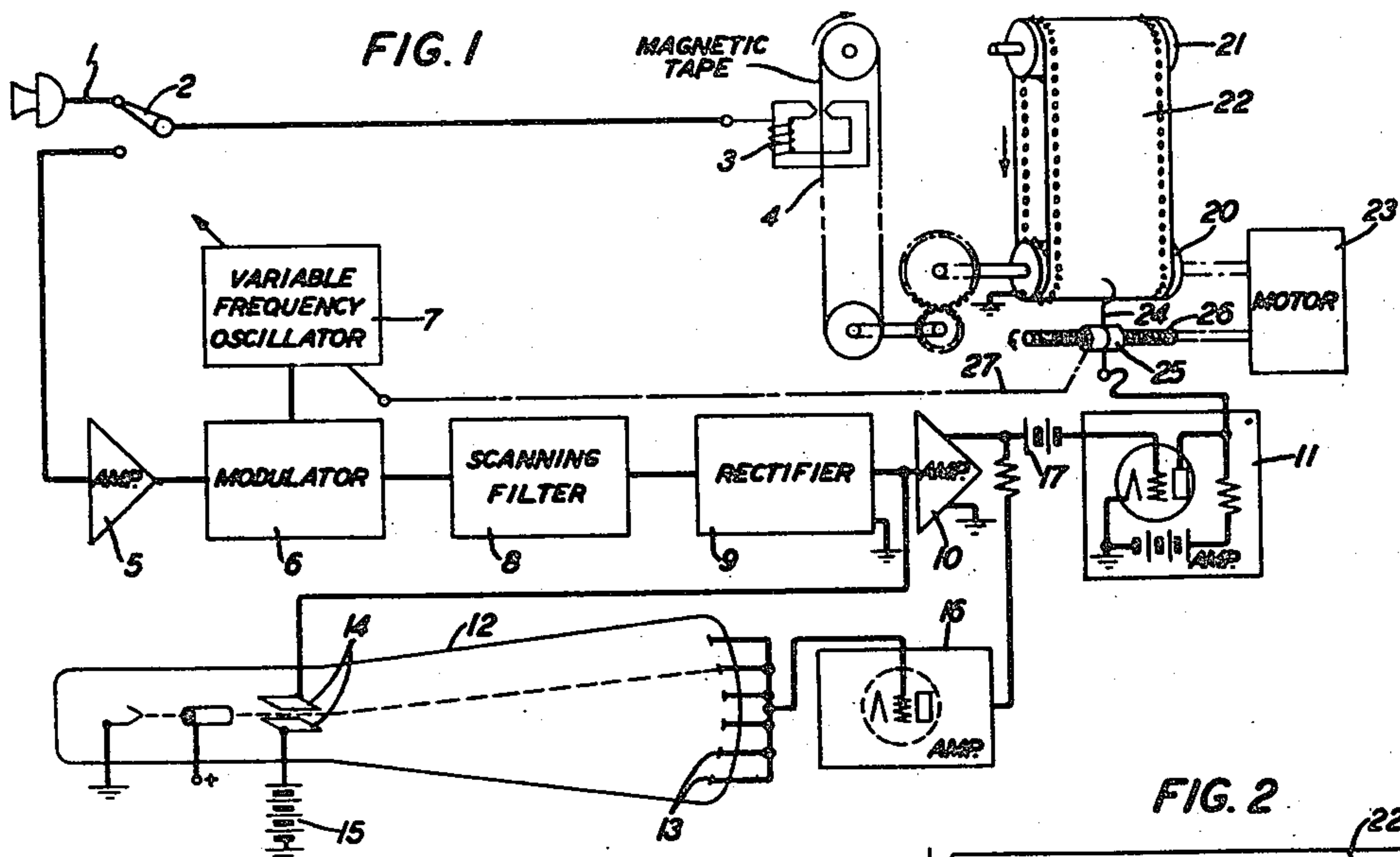
Aug. 5, 1947.

R. K. POTTER

2,425,003

ANALYSIS AND REPRESENTATION OF COMPLEX WAVES

Filed Dec. 23, 1944



INVENTOR
R. K. POTTER
BY
N. A. Ewing
ATTORNEY

UNITED STATES PATENT OFFICE

2,425,003

ANALYSIS AND REPRESENTATION OF
COMPLEX WAVES

Ralph K. Potter, Morristown, N. J., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application December 23, 1944, Serial No. 569,557

9 Claims. (Cl. 179—1)

1

This invention relates to the spectrographic representation of complex waves and more especially to the visual representation of waves of variable complexity such as music and speech waves.

In my copending application Serial No. 438,878, filed April 14, 1942, Patent No. 2,403,997, July 16, 1946, there are disclosed method and means for producing a visual record 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, so that each elemental area in the pattern is identified with a particular frequency band and a particular time interval. The shade or density of the pattern varies from one elemental area to another to depict for each such area the relative wave power that is found in the component frequency band identified with that area during the time interval identified with that area.

One of the objects of the present invention is to provide a spectrographic representation in which variations in the power content of the various frequency bands are represented, otherwise than by continuous gradation in shade or density or the like, in a form allowing readier and more accurate quantitative determination of the power content indicated in the pattern.

In accordance with a feature of the present invention a spectrographic representation of complex waves is constituted of a multiplicity of distinctly marked zones respective to different ranges of power content whereby the power content pertaining to any particular frequency band and time can be determined directly by noting what particular zone embraces the corresponding elemental area in the representation. In accordance with a further feature the aforesaid zones are distinctly marked by means of contour lines at their respective boundaries.

In accordance with another feature of the invention the complex waves to be visually represented are subjected to frequency analysis while on the surface on which the visual representation is to appear a dot or other mark is made, in the proper coordinate position, whenever the varying power content found by the analyzing means passes through any of a multiplicity of predetermined discrete values. The marks so made align themselves to form contour lines, each representing a particular power content and each defining a boundary of one of the aforementioned zones.

In accordance with another feature of the invention a spectrographic representation of complex waves is formed of a multiplicity of lines each identified with a particular component fre-

2

quency band and each having irregularities therein to indicate quantitatively the variations in power content of the corresponding frequency band.

The nature of the present invention and its various features, objects and advantages will appear more fully from a consideration of the embodiments illustrated in the accompanying drawings. In the drawings:

Fig. 1 illustrates a system for recording spectrographic representations of the multizone type;

Fig. 2 illustrates the character of the representations formed by the system of Fig. 1;

Fig. 3 illustrates an alternative detail of the Fig. 2 system;

Fig. 4 illustrates another recording system in accordance with the invention; and

Fig. 5 illustrates the type of record formed thereby.

In the specific embodiment of the invention illustrated in Fig. 1 the waves to be recorded in visual form are first recorded in electrically reproducible form and then repeatedly played back into a frequency analyzer from which are derived effects that control the formation of the visual record. It will be assumed for sake of concreteness that the waves to be represented are speech bearing waves.

In Fig. 1 the speech bearing waves are derived from a microphone circuit 1 and applied through a switch 2 to the recording coil 3 of a magnetic recorder. The latter includes an endless magnetic tape 4 which is driven continuously at a constant speed and upon which the speech bearing waves are magnetically recorded. After the waves have been so recorded switch 2 is thrown to its alternate position whereupon the recorded waves are repeatedly played back or electrically reproduced over and over again into a frequency analyzer comprising elements 5 to 8, inclusive.

The reproduced waves are transmitted through a wave amplifier 5, which may introduce a certain amount of frequency weighting or equalization if desired, to a frequency translator or modulator 6 that is supplied with beating oscillations from an oscillator 7. The position in the frequency range that is occupied by the translated band of speech bearing waves appearing in the output circuit of modulator 6 depends on the operating frequency of oscillator 7; and the latter frequency is changed progressively from one limiting value to another such that the translated band of waves sweeps across the pass band of a scanning filter 8. The change in the frequency of the

beating oscillations is so gradual that it is completed only after the magnetically recorded waves have been reproduced many times, 200 times, for example, in one instance in practice. Disregarding the slight change in oscillator frequency that may occur during any one reproduction if the change is continuous rather than intermittent, it may be said that the scanning filter 8 selectively passes a different component frequency band on each reproduction of the recorded waves.

The band width of the scanning filter 8 is small compared with the frequency range occupied by the speech bearing waves and it may be assigned any of rather widely different values depending on the resolution desired. For high frequency resolution the band width may be 20 or 45 cycles, for specific example, or if lower frequency resolution or higher time resolution be desired the band width may be 300 cycles, for example. In any case the frequency bands selected in the course of successive reproductions may overlap each other to a considerable extent; that is, a wave component of a given frequency may be accepted by the scanning filter during several successive reproductions. In the interest of simplicity it may be assumed henceforward that the filter 8 has a narrow pass band capable of resolving the various harmonics of the fundamental voice frequency.

The wave output of filter 8 has a frequency approximating the mean frequency of the filter pass band, which may be 12,000 cycles for specific example, and its effective intensity, i. e., its power content or envelope amplitude, varies in the course of each reproduction in accordance with the variations in the effective intensity of the speech wave component appearing in a respectively corresponding frequency band. It is this varying intensity that is to be shown in the visual record.

The visual recording elements include a pair of cylindrical metal drums 20, 21 which carry a belt of electrosensitive facsimile paper 22. The belt 22 and the endless magnetic tape 4 are driven in synchronism with each other, and any suitable means may be provided for this purpose. For example, a common motor 23 may be provided as illustrated, or individual motors with an electromechanical interlock to insure that tape 4 and belt 22 start each revolution simultaneously. Facsimile paper 22 may be of a type comprising a titanium oxide recording surface and a carbon backing, such as the "Teledeltos grade H" facsimile paper developed by the Western Union Telegraph Company. The marking element is a stylus 24 which presses lightly against the face of the facsimile paper 22. Marking current supplied to stylus 24 passes through the facsimile paper to the grounded metal drum 20, and the electrothermal effect of the marking current causes the paper to darken at the point of contact. The means provided for supplying and varying the marking current will be described presently. The stylus 24, which may be a wire having a diameter of ten mils, for specific example, is driven progressively across the belt 22 in step with the change in the frequency of beating oscillator 7 so that each position of the stylus crosswise of the belt 22 is identified with a particular frequency band selected by the frequency analyzer. It may be attached to a traveling nut 25 that rides on a rotating threaded shaft 26 driven by motor 23. The linkage 27 signifies that the frequency adjustment of oscillator 7 is elec-

trically or mechanically geared with the position of stylus 24.

In view of the foregoing description of Fig. 1, it will be understood that in the course of each reproduction the frequency analyzer selects a particular frequency band while the stylus 24 traverses a particular longitudinal, or circumferential, path on paper 22, the position of the path crosswise of the paper being preassigned to the particular selected frequency band. At the same time the wave output of filter 9 varies in strength in accordance with the varying power content of the selected band.

The mechanism for translating the varying wave output of filter 8 into variations in marking current includes a special cathode-ray tube 12 comprising conventional means for producing the cathode ray and a row of spaced conductive targets 13 to which the ray may be selectively deflected by voltages applied to ray deflecting plates 14. A rectifying device 9 connected to the output circuit of scanning filter 8 is designed to produce a unidirectional voltage that fluctuates according to the envelope amplitude or effective intensity of the waves delivered by the scanning filter. This unidirectional voltage is applied to the deflecting plates 14 and it is supplemented by a battery 15 which provides an opposing fixed biasing voltage sufficient to deflect the cathode ray to a point just beyond one end of the row of targets 13 when the output voltage of rectifier 9 is zero.

The electrical output of rectifier 9 is applied also through an amplifier 10 to an amplifier 11 that is normally inoperative, or blocked, but which is rendered operative, or unblocked, under the control of the cathode-ray tube 12. The targets 13 of the latter are connected in multiple to the input circuit of direct-current amplifier 16 which delivers an unblocking voltage to amplifier 11 whenever and so long as the cathode ray impinges on one or another of the targets 13. In its operative, or unblocked, condition amplifier 11 amplifies the effects derived from rectifier 9 and transmits them to stylus 24 as a marking current. Although any suitable means may be employed to block and unblock amplifier 11, it may be normally blocked, as illustrated, by a negative grid biasing battery 17 of sufficient voltage, and unblocked by applying an opposing biasing voltage derived from the output of amplifier 16.

It is to be noted that marking current is supplied to stylus 24 only as the voltage supplied by rectifier 9 passes through one or another of a multiplicity of discrete finite values such that the cathode ray impinges on one or another of the targets 13, and therefore also only as the power content of the selected frequency band passes through corresponding predetermined values. Thus, each mark that is made signifies a certain wave power level. What different levels of power content are to be so marked, depends on the spacing of the targets 13, and the spacing may be made uniform or non-uniform (logarithmic, for example) as desired. Although only six targets have been indicated in the drawing, it is contemplated that many more may be actually employed, depending on the use to which the visual record is to be put or the number and size of the amplitude steps that are to be recognized and indicated in the pattern. If the width of each target 13 is made small in comparison with the intertarget spacing, the marks made on the facsimile paper will for the most part be in the

5

form of dots although each mark has a certain longitudinal extent that depends on the length of time the cathode ray remains on one of the targets. Occasional targets, every fifth one, for example, may be made wider than the others so that every fifth contour line will be made up of definitely elongated marks and appear as a band.

Fig. 2 illustrates the character of the speech pattern produced by the Fig. 1 system. The vertical, or transverse, dimension of the pattern has the sense of a frequency axis, as previously explained. Both the frequency and time axes are indicated in Fig. 2. The marks pertaining to a given amplitude level align themselves to form contour lines, such as 31 and 33, marking the boundary of zonal areas, such as 32 and 34. Contour lines 31 represent the first amplitude level, 33 the second, etc. As to any elemental area falling in the background area 30, it may be said that at the frequency and time indicated by its coordinate position the power content was below the first critical value. As to any other elemental area, the power content at the frequency and time pertaining thereto is indicated, accurately, by the contour line which may happen to pass through the area or, approximately, by the zone in which it lies. In the latter case a substantially accurate evaluation of power content may be reached by interpolation: for example, if the area lies midway between two contour lines and the gradient indicated by the neighboring contour lines is substantially linear, the indicated power content would be midway between the values represented by the two contour lines.

Fig. 3 illustrates a modification of a part of the Fig. 1 system in accordance with which alternating marking current is employed. The latter may be derived from a local marking oscillator 40 or alternatively, by operating a switch 41, from scanning filter 8. The marking oscillations are in either case applied directly to the input circuit of amplifier 10, and their transmission to stylus 24 is controlled by the intermittent unblocking of amplifier 11 as previously described. The fluctuating voltage appearing in the output circuit of rectifier 9 is applied only to the deflecting plates 14 and not to amplifier 10.

In accordance with a further modification of Figs. 1 and 3, amplifier 11 is normally operative so that marking current is normally supplied to stylus 24, and it is intermittently blocked under the control of the cathode-ray tube 12. This modification, which entails a reversal of the polarity of the grid biasing voltage derived from amplifier 16, produces a pattern in which the contour lines appear as light lines on a dark background.

The embodiment of the invention that is illustrated in Fig. 4 is similar in many respects to the Fig. 1 system and corresponding elements have been assigned the same reference characters. As in the Fig. 1 system, the speech bearing waves that are to be visually recorded are first recorded on a magnetic tape 4 and repeatedly placed back into the frequency analyzer while the visual record is formed on the belt of facsimile paper 22. Where the Fig. 1 system employs a single movable stylus 24 the Fig. 4 system employs a multiplicity of fixed styli 44 associated with a multiplicity of spaced targets 45 at the end of a special cathode-ray tube 42.

The targets 45 are closely spaced and in considerable number. For example, there may be 100 of them per inch or a total of 200 for a belt

6

of facsimile paper that is about two inches wide. The number of targets, however, depends on the degree of frequency resolution desired, as will presently appear, and a greater or lesser number may be employed as desired. Each of the targets 45 is connected to a respective external stylus 44 that bears on the facsimile paper 22. The construction of cathode-ray tube 42 may conform with the disclosure and teaching of the United States patent to E. Bruce, No. 2,301,199, issued November 10, 1942.

The control voltage applied to deflecting plates 14 of the cathode-ray tube 42 is derived in part from a potential divider 46 that is connected across a battery 47, and in part from rectifier 9. The movable contactor of potential divider 46 is driven by the traveling nut 25 which controls also the operating frequency of beating oscillator 7. The voltage derived from potential divider 46 and supplied to deflecting plates 14 tends to drive the cathode ray from one end of the row of targets 45 to the other while the frequency of oscillator 7 progresses from its one limiting value to the other. Each target 45 is therefore identified with a particular beating frequency and with a particular frequency band. The change, from one reproduction to the next, in the voltage supplied by potential divider 46 may be a stepped voltage change just sufficient to deflect the cathode ray to the next adjacent target or, more advantageously, to a target several spaces removed, depending on the ratio of the number of targets 45 to the total number of reproductions of the recorded waves. In either case the excitation of successively different targets 45, and of their connected styli 44, on successive reproductions of the wave tends to produce on the facsimile paper 22 a multiplicity of longitudinal or circumferential lines on the facsimile paper, the position of each such line crosswise of the paper identifying it with a particular part of the frequency range.

The deflecting voltage concurrently supplied by rectifier 9, however, introduces local irregularities in the visual record which serve as a measure of the varying amplitude of the several wave components. While one such line is being traced during a particular reproduction of the waves, for example, the power content of the band then selected may increase from zero to a certain maximum value and then return to zero. In such case the cathode ray is deflected to targets progressively farther removed from the target on which it impinged initially, i. e., the target identified with the selected band, and it then returns to the initial target, the rate of departure and return conforming with the rate of increase and decrease of the wave power content. This deflection of the cathode ray is traced on the facsimile paper 22 by the styli which the ray successively excites. The parts of the system are so designed that the maximum deflection produced by the output voltage of rectifier 9 is small compared with the length of the row of targets 45.

Fig. 5 illustrates the nature of the visual record produced by the Fig. 4 system. Each line is identified with a particular part of the frequency range, as previously explained, and its departure crosswise of the record, i. e., vertically in Fig. 5, from the position it occupies when the wave power content of its respective frequency band is zero, is a measure of the power content. So long as the cathode ray remains on a particular target, i. e., so long as the power content of a selected band remains constant, the line formed on the record surface is a continuous longitudi-

nal line. As the ray is deflected the line becomes discontinuous and comprises a multiplicity of laterally displaced discrete marks or dots each having a longitudinal extent depending on the length of time the cathode ray impinges on the associated target.

It may be necessary or desirable in some cases, where patterns such as illustrated in Figs. 2 and 5 are to be used for quantitative measurement of power content, to take into account the frequency-transmission characteristic of the recording system. Frequency equalization or weighting may be introduced into the system at a point either preceding or following the magnetic recorder in circuit sequence, for example, with the result that those frequency components which are relatively attenuated thereby will appear in the pattern to have a lower relative intensity than is actually the case. This may be corrected by adding the amount of relative attenuation to the intensity indicated in the pattern. In other cases it will suffice to accept the indicated intensity, understanding that it refers to the reproduced waves as they appear at the input terminals of the frequency translator. For the determination of absolute, rather than relative power content, the system may be calibrated by use of multifrequency waves of variable, measurable intensity.

Although the present invention has been described largely in terms of the several embodiments set forth herein, it will be evident to those skilled in the art that the invention may be embodied in various other forms within the spirit and scope of the appended claims.

What is claimed is:

1. A system for translating complex waves into a visual representation comprising frequency analyzer means operative on said waves for deriving from each component frequency band an effect individual thereto that varies in value in accordance with the variations in the power content of the respectively corresponding band, means controlled by the said varying derived effect for distinguishing a multiplicity of predetermined ranges of the value of said effect, marking stylus means for systematically following a multiplicity of collateral paths across a surface on which the representation is to appear, each of said paths being individual to a corresponding component frequency band, and means responsive to said controlled means and operative on said stylus means for depicting in each said path the transition, from one of said ranges to another, of the value of the effect derived from the frequency band corresponding to each said path.

2. A system for translating complex waves into a visual representation comprising frequency analyzer means operative on said waves for deriving from each component frequency band an effect that varies in value in accordance with the variations in the power content of the respectively corresponding band, means responsive during the transition of the value of said varying derived effect from one to another of a multiplicity of predetermined ranges of value, stylus means for systematically following a multiplicity of collateral paths across a surface on which the representation is to appear, each of said paths being individual to a corresponding different frequency band, said stylus means having a marking condition and a non-marking condition, and means controlled by said responsive means for altering the said condition of said stylus means during each said transition.

3. A combination in accordance with claim 2 in

which said last-mentioned means maintains said stylus means in its non-marking condition except during said transitions.

4. A combination in accordance with claim 1 in which said control means comprises a row of spaced targets, means for producing a substantially inertialess beam adapted to be deflected along said row of targets and means for varying the deflection of said beam in accordance with the value of said derived effect, and means actuated whenever said beam strikes a target.

5. A system for the production of a visual representation of complex waves in the form of a pattern the dimensions of which have the sense of a time axis and a frequency axis, respectively, comprising a record surface on which the representation is to appear, stylus means movable relative to and across said surface along a multiplicity of collateral paths in succession, means for storing the complex waves, means for repeatedly reproducing the stored waves, means for deriving from the reproduced waves an effect that varies in value, in the course of each reproduction, as the wave power varies in a respectively corresponding frequency band, means sensitive to a change in the value of said variable effect from any one to another of a multiplicity of predetermined ranges of said value, and means controlled by said last-mentioned means for distinctively varying the marking effect of said stylus means upon each such change.

6. A system for the production of a visual representation of complex waves in the form of a pattern the dimensions of which have the sense of a time axis and a frequency axis, respectively, comprising a record surface on which the representation is to appear, means for marking on said surface, said marking means including stylus means for following each of a multiplicity of collateral paths extending across said surface, means operative on said complex waves for deriving from each of a multiplicity of component frequency bands an effect, individual to each said band, that varies in value according to the variations in the wave power content of the individually corresponding band, and means operative on said stylus means for producing a mark in any of said paths whenever the value of the effect individually corresponding to that path passes through any of a plurality of predetermined discretely different values, said last-mentioned means comprising an array of spaced target means and a substantially inertialess contact means variably displaced across said array under the control of the varying value of the said derived effects.

7. A combination in accordance with claim 6 in which said operative means includes a cathode-ray tube having an array of spaced conductive targets.

8. In combination with a source of complex waves, means for storing the said waves in reproducible form, means for repeatedly reproducing the stored waves, means for selecting successively different frequency bands from said reproduced waves during corresponding successive reproductions of the said waves, a record surface, marking stylus means, means for moving said stylus means relative to and across said record surface repeatedly in synchronism with the repeated reproduction of said waves, means operative on said stylus means for marking on said record surface during each reproduction the changes in power content of the selected band, said last-mentioned means including a cathode-ray tube having a multi-

9

plicity of targets to which the cathode ray may be selectively deflected, and means for variably deflecting said cathode ray under the control of the varying wave power appearing in the selected frequency band.

9. A system for translating complex waves into a visual representation comprising frequency analyzer means for resolving the said waves into their various frequency components, means for repeatedly applying the said complex waves to said analyzer means, a record surface on which the representation is to be formed, a multiplicity of marking styli spaced apart across said record surface, means for moving said record surface past said styli repeatedly in synchronism with the repeated application of the waves to said analyzer means, a cathode-ray tube having a

10

5 multiplicity of targets each connected to an individual stylus, means for variably deflecting the cathode ray across said targets in accordance with the varying intensity of the frequency component selected by said analyzer, and means for simultaneously deflecting said cathode ray to an extent dependent on the frequency of the component selected by said analyzer means.

RALPH K. POTTER.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,005,425	Kwartin	June 18, 1935