

Oct. 21, 1947.

W. KOENIG, JR

2,429,229

ANALYSIS AND REPRESENTATION OF COMPLEX WAVES

Filed April 4, 1945

3 Sheets-Sheet 1

FIG. 1

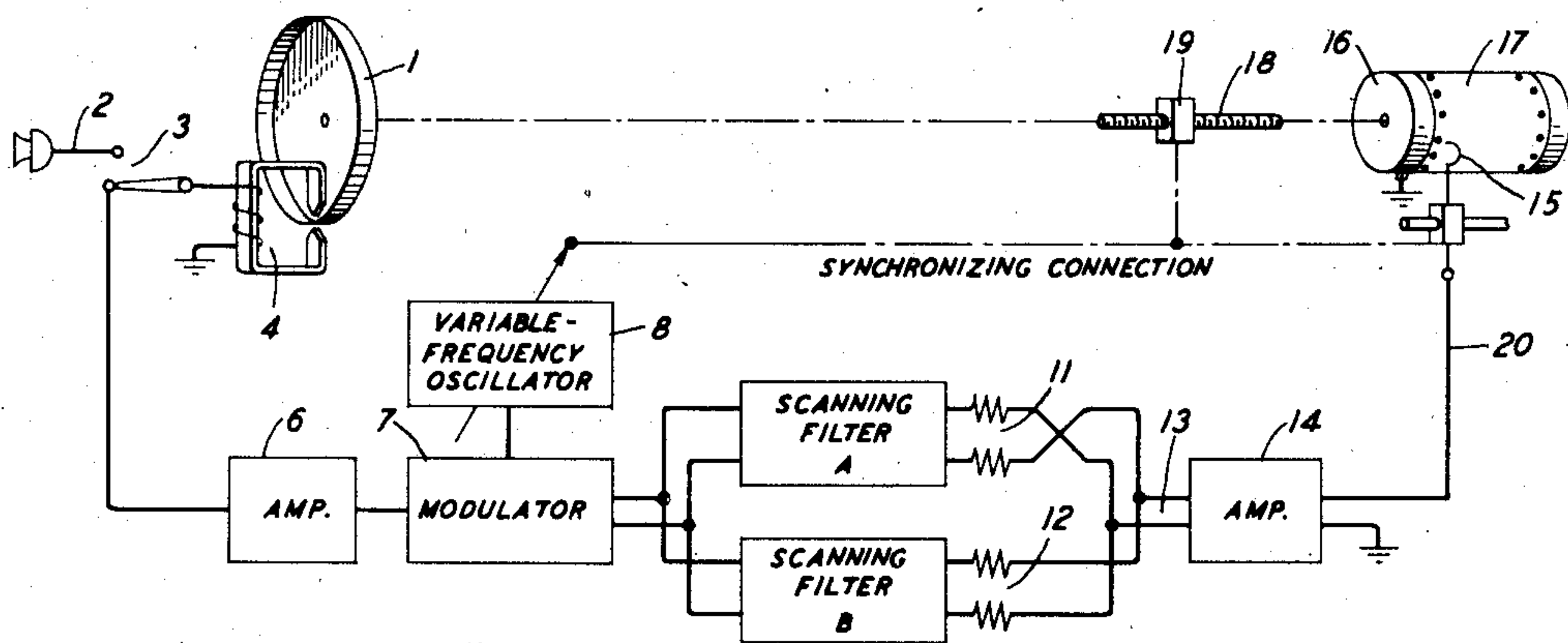


FIG. 5

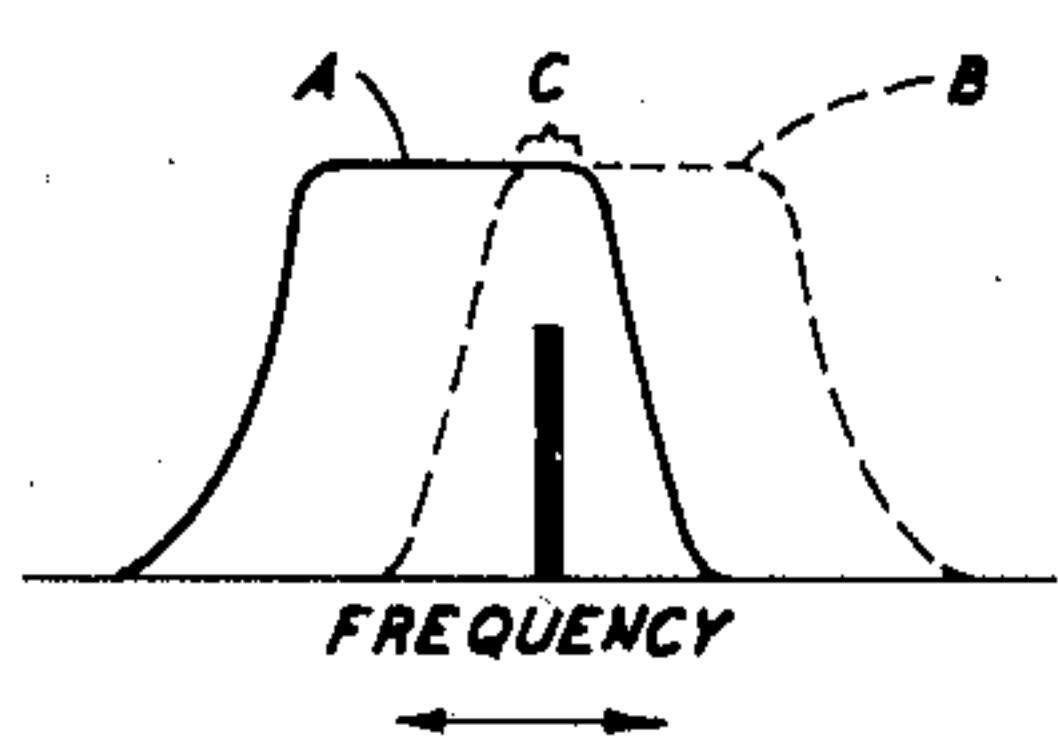


FIG. 2

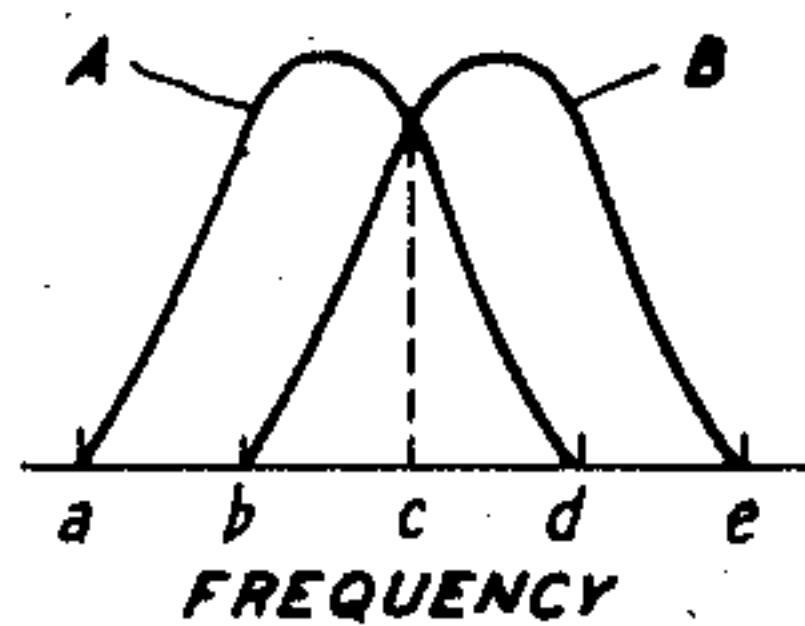


FIG. 3

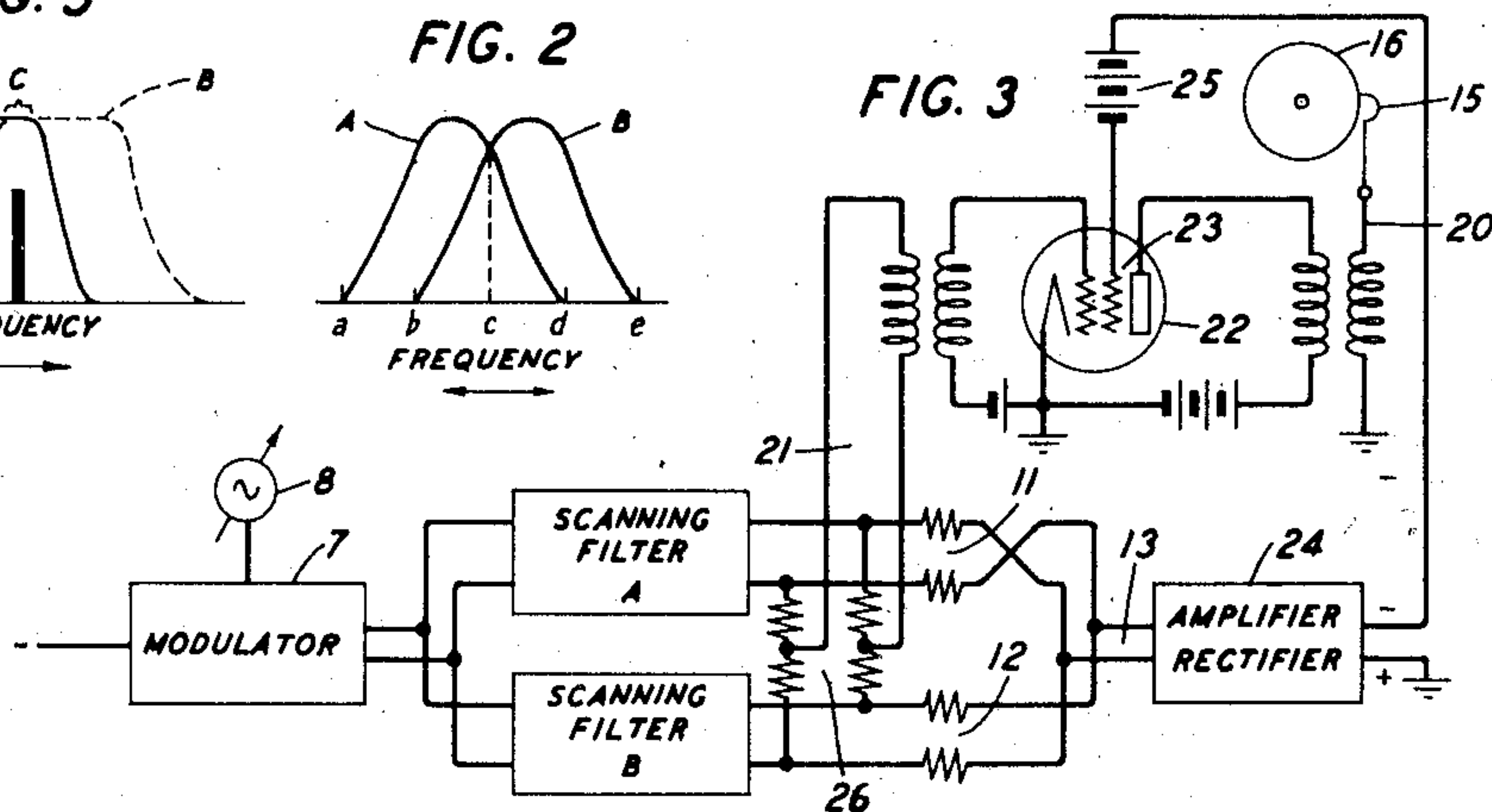
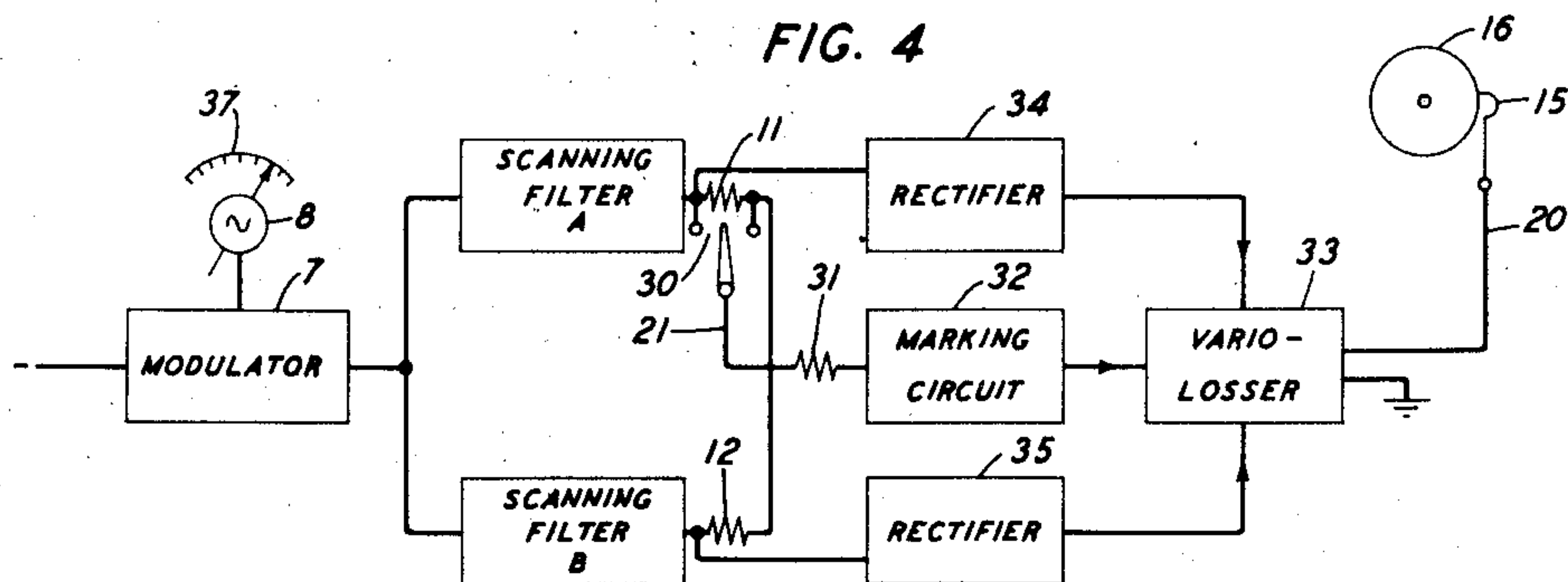


FIG. 4



INVENTOR
W. KOENIG, JR.
BY
N. D. Ewing
ATTORNEY

Oct. 21, 1947.

W. KOENIG, JR

2,429,229

ANALYSIS AND REPRESENTATION OF COMPLEX WAVES

Filed April 4, 1945

3 Sheets-Sheet 2

FIG. 6

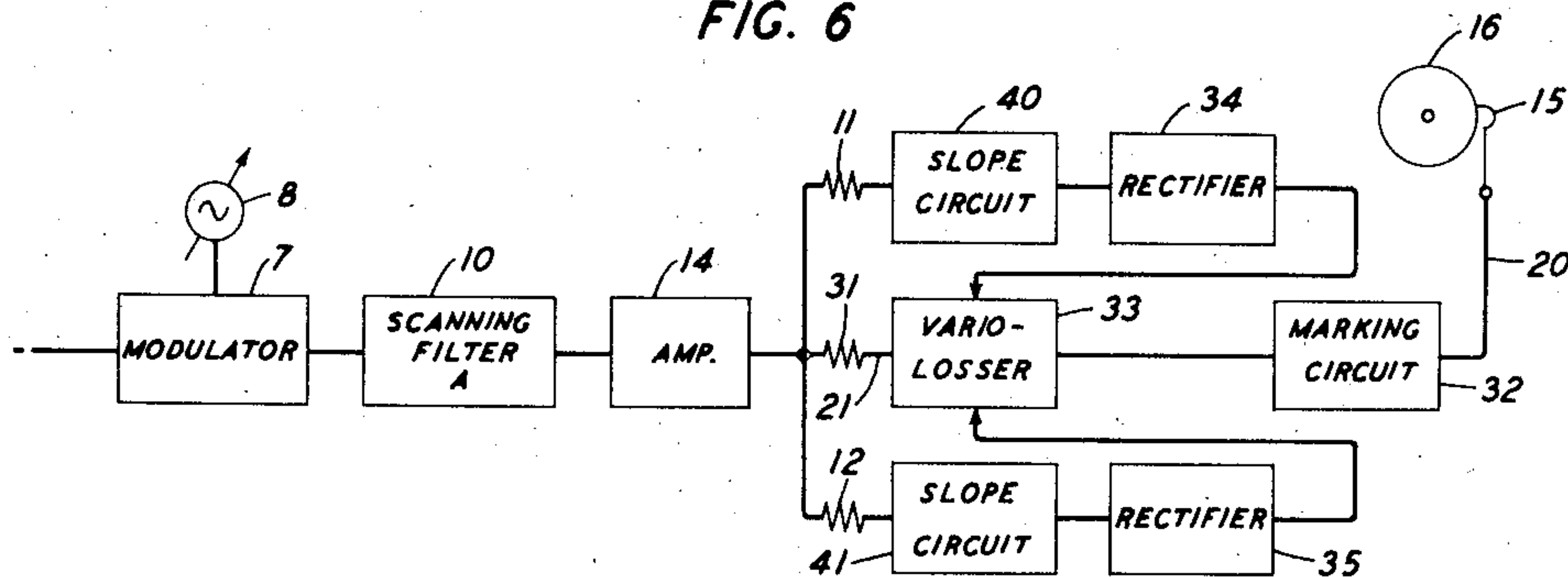


FIG. 7

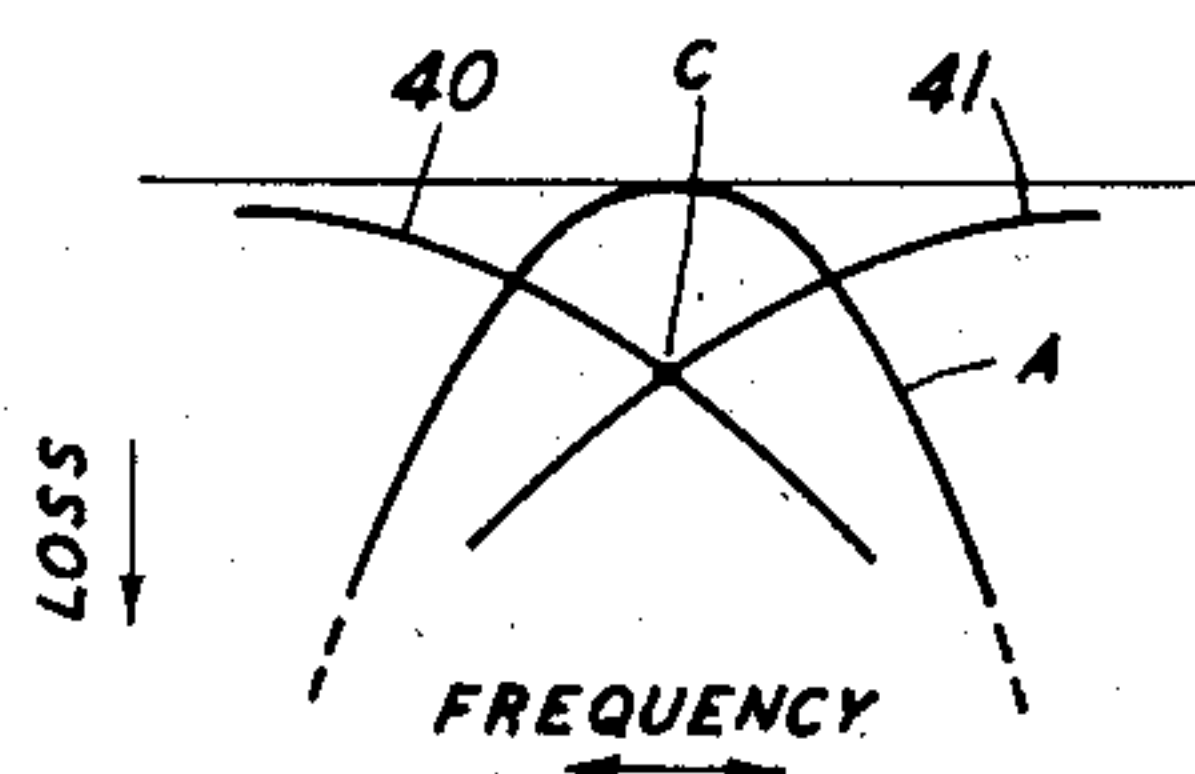


FIG. 8

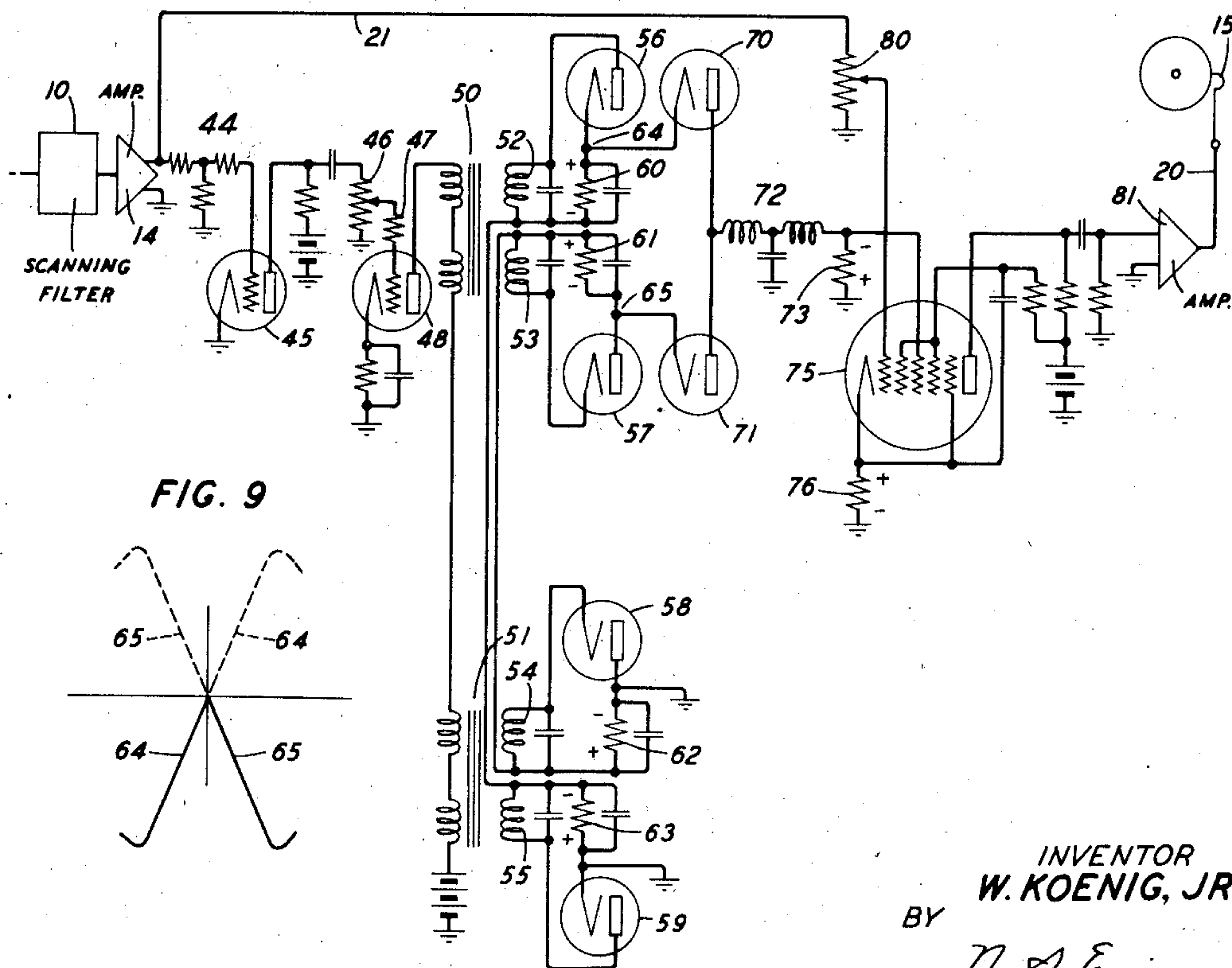
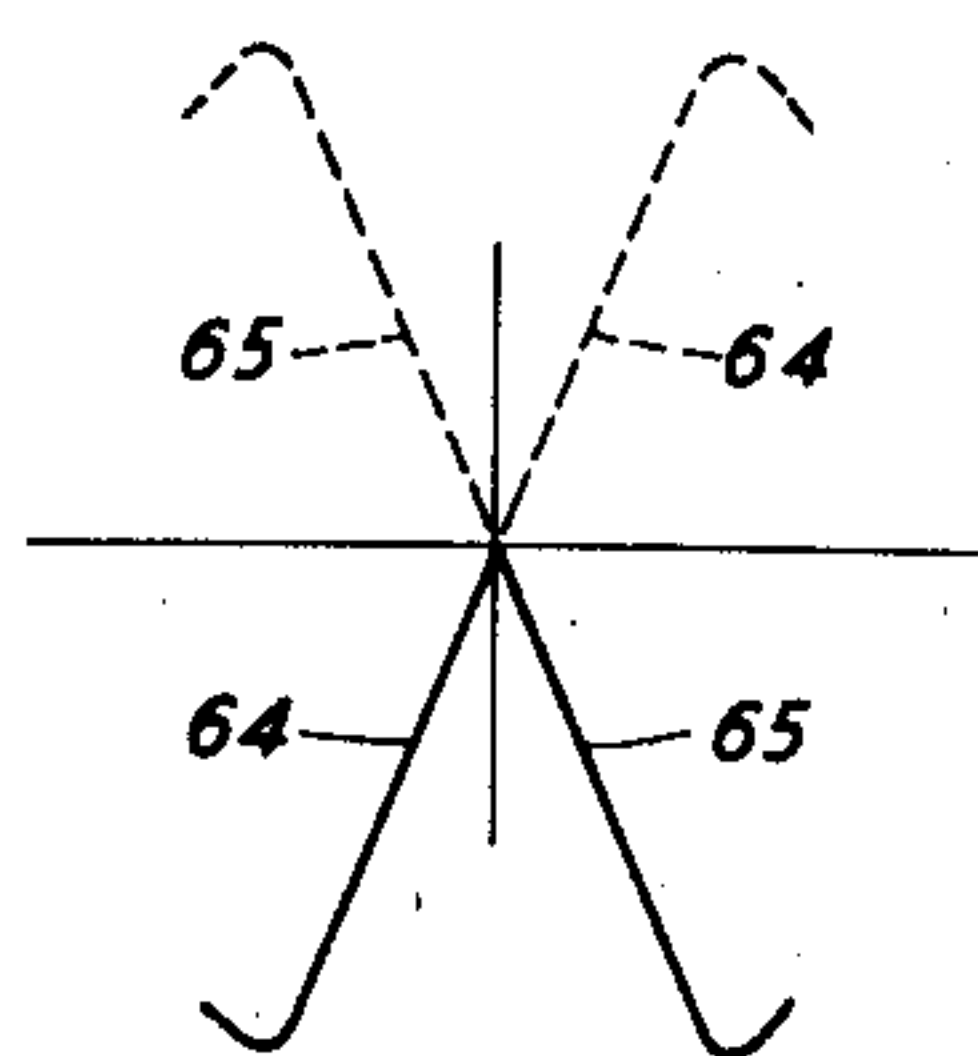


FIG. 9



INVENTOR
W. KOENIG, JR.
BY
N. D. Ewing
ATTORNEY

Oct. 21, 1947.

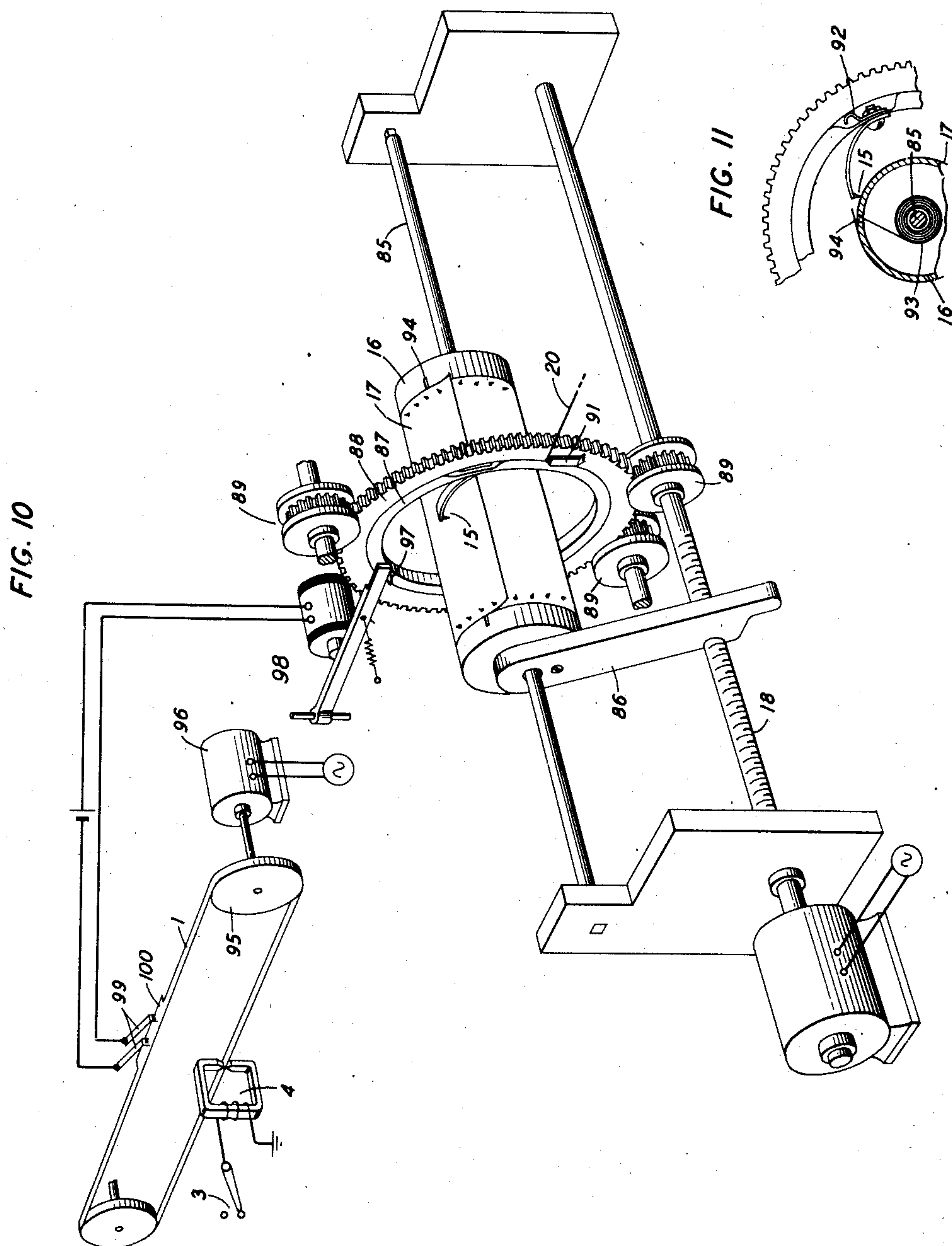
W. KOENIG, JR

2,429,229

ANALYSIS AND REPRESENTATION OF COMPLEX WAVES

Filed April 4, 1945

3 Sheets-Sheet 3



INVENTOR
W. KOENIG, JR.
BY *N. S. Ewing*
ATTORNEY

UNITED STATES PATENT OFFICE

2,429,229

ANALYSIS AND REPRESENTATION OF
COMPLEX WAVESWalter Koenig, Jr., Clifton, N. J., assignor to Bell
Telephone Laboratories, Incorporated, New
York, N. Y., a corporation of New York

Application April 4, 1945, Serial No. 586,601

11 Claims. (Cl. 179—1)

1

This invention relates to frequency-selective wave transmission systems and more particularly to the analysis and visual representation of complex waves.

One of the objects of the invention is to improve the effective frequency resolution of systems for the production of complex-wave spectrograms such as disclosed in my copending applications Serial No. 568,880, filed December 19, 1944, and Serial No. 586,308, filed April 3, 1945, which issued on July 16, 1946, as U. S. Patents No. 2,403,982 and No. 2,403,983, respectively.

A further object is to circumvent a limitation heretofore inherent in the use of frequency selective wave transducers, viz., that an indefinite increase in the frequency selectivity of the transducer is incompatible with faithful transmission of the variations in effective intensity, or envelope amplitude, of the selected waves. A related object is to achieve in a system having a given frequency-selective wave transmission characteristic, and corresponding capacity for transmitting the envelope variations of selected waves, a frequency-discriminating capacity that is substantially greater than that afforded by the selectivity of its transmission characteristic.

In accordance with a feature of the invention, a frequency analyzer is provided with a pair of conjointly operative frequency-selective wave transmission elements that have overlapping transmission-frequency characteristics, and transmission of the selected waves beyond said elements is governed according to the relation between the wave outputs of the two elements.

In accordance with another feature of the invention a frequency-selective wave transmission element is supplemented by a wave responsive element that has a substantially greater frequency-discriminatory capacity, and the transmission of waves selected by the first element is regulated by the second element according to the proximity of the selected waves to a predetermined frequency.

In accordance with a further feature, a wave transmission system is provided with two frequency-discriminatory elements at least one of which is adapted to selectively transmit applied waves lying within a predetermined frequency range, and the two elements are so associated that an applied wave having a frequency within said range is freely transmitted through the system, or substantially modified in intensity, or suppressed, according to the proximity of the wave frequency to a predetermined frequency within the said range.

Other features of the invention are more especially concerned with the analysis of speech waves or the like and with the formation of spectrograms as will presently appear.

The nature of the present invention and its

2

various features, objects and advantages will appear more fully from a consideration of the embodiments illustrated in the accompanying drawings and now to be described.

In the drawings:

Fig. 1 illustrates a system in accordance with the invention for recording sound spectrograms;

Figs. 3, 4, 6 and 8 illustrate modified systems in accordance with the invention;

Figs. 10 and 11 illustrate a modified component of the several illustrated systems; and

Figs. 2, 5, 7 and 9 are curve diagrams qualitatively illustrating certain details of design in accordance with the invention.

Referring more particularly now to Fig. 1, there is illustrated a sound spectrograph or system for analyzing and visually representing complex waves, which except for the inclusion of an auxiliary scanning filter, is or may be essentially the same as systems disclosed in my copending application Serial No. 568,980 and in that of R. K. Potter, Serial No. 569,557, filed December 23, 1944. The specific embodiment shown in Fig. 1 comprises a magnetic recorder-reproducer of the type having an endless, continuously driven magnetic tape 1. The complex waves, which it may be supposed are received over a microphone circuit 2, are first recorded on the tape 1, and for this purpose a switch 3 is operated to connect circuit 2 to recording coil 4. The latter serves also as a pick-up coil by means of which the recorded waves are reproduced or played back in the form of electrical waves repeatedly, once for each cycle of movement of the endless tape 1. The reproduced waves are applied through switch 3 and an amplifier 6 to a frequency scanner or analyzer of the heterodyne type comprising a modulator 7 which is supplied with beating oscillations from an oscillator 8 the frequency of which is varied progressively from one limiting value to another in the course of production of a spectrogram. There is little or substantially no change in oscillator frequency during any one reproduction of the recorded waves and many reproductions, two hundred for specific example, are completed while the oscillator frequency progresses from the one limiting value to the other. The latter values are so fixed that the translated band of complex waves appearing at the output terminals of modulator 7 progresses, from substantially its one extremity to the other, across the relatively narrow pass-band of a scanning filter A.

During successive reproductions of the recorded waves filter A selectively transmits the wave component or components that appear in successively different parts of the wave band, and a given component may be selectively transmitted throughout each of several reproductions if the band width of filter A is large enough in relation to the incremental change in oscillator frequency

that takes place from one reproduction to the next. If the complex waves are speech bearing waves, for specific example, the incremental frequency change may be 10 or 15 cycles per second and filter A may advantageously have a pass-band that is about 45 cycles wide. This band width is sufficiently restricted to resolve the harmonically related frequency components that are present in certain speech sounds; that is, it insures that only one such component is transmitted through the filter at any time. Furthermore, it is wide enough that the filter responds substantially as well as the human ear to rapid changes in the envelope amplitude of the selected components. Any frequency selective wave transmission device, it should be noted, accurately preserves the envelope variations of transmitted waves only if its band width is at least equal to a critical value dependent on the maximum rate at which the envelope amplitude varies.

The wave output of filter A is transmitted through a resistance pad 11, a circuit 13 and wave amplifier 14 in succession to the conducting stylus 15 of a recorder. The recorder is shown diagrammatically in Fig. 1 as comprising a drum 16 that has a conductive cylindrical surface about which is wrapped a strip of dry facsimile paper 17. The latter may be of a well-known type having a carbon backing and a recording surface of titanium oxide. Drum 16 is rotated in synchronism with the magnetic tape 1 and so also is a threaded shaft 18 which carries a traveling nut 19 that drives stylus 15 progressively across the strip of facsimile paper, that is, longitudinally of drum 16. The movement of nut 19 also controls the progressive change in the frequency of oscillator 3. During each rotation of drum 16, and therefore also during each reproduction of the recorded waves, stylus 15 follows a different, substantially longitudinal path across the face of the facsimile paper 17 and leaves a trace that varies in darkness or density more or less in conformity with the variations in the effective intensity of marking current delivered to it from amplifier 14. Disregarding any slight change in oscillator frequency in the course of a given reproduction, the several longitudinal paths are substantially respective to different, although overlapping, 45-cycle frequency bands, and they are substantially contiguous.

The auxiliary scanning filter B that is provided in the Fig. 1 system is connected on its input side to the output terminals of modulator 7, like filter A, and on its output side it is connected through a resistance pad 12 to circuit 13. The connections are such, however, that with respect to any component transmitted through both of the filters simultaneously the wave output of the one combines in phase opposition with that of the other in circuit 13. The transmission characteristic of filter B is or may be the same as that of filter A except for a slight displacement in frequency. Fig. 2 illustrates diagrammatically a suitable relation between the two transmission-frequency characteristics, assuming a displacement of about 15 cycles, or a third of the band width of either filter.

A given frequency component delivered to the two filters may assume, during successive reproductions, the successive relative frequency positions indicated at *a* to *e* in Fig. 2. During the first and last of these reproductions the particular component, appearing at positions *a* and *e*, respectively, lies substantially outside both of the transmission bands and therefore it leaves no

trace on the facsimile paper. During the second reproduction the same component appears at position *b*, and it is accordingly transmitted through filter A only, somewhat attenuated, and a trace is left in one of the paths on the facsimile paper. During the fourth reproduction, likewise, the component, appearing at position *d*, is transmitted through filter B only, and recorded. If the component appears at any position between *b* and *d*, however, it is transmitted through both of the filters and it passes through circuit 13 with substantially reduced intensity by virtue of the phase opposing relation of the two filter connections. Thus if the component appears at position *c*, the two filter outputs will be of substantially equal intensity as well as in phase opposition and the marking current will accordingly be nil. The net result is that each component, repeatedly selected, produces a dark band on the facsimile paper with a white line or unmarked portion extending along the center thereof. Once the system is calibrated the position of this fine line may be taken as an accurate indication of the frequency of the particular component. The variations in darkness of the portions adjoining the central line indicate the variations in the envelope amplitude of the component.

Fig. 3 illustrates a modification of the Fig. 1 system in which the two filters A and B are connected to the circuit 13 in phase opposing relation in the manner previously described. Circuit 13 in this case leads to an amplifier-rectifier 24 which delivers a unidirectional output voltage that is approximately proportional to the effective intensity of any currents supplied to it. The output circuits of the two filters are connected also, through an H-type resistance pad 26, to a circuit 21 in phase aiding relation. Currents appearing in circuit 21 are impressed on an amplifier comprising a variable-gain amplifier tube 22, and, under certain conditions to be described, the impressed currents are amplified and delivered to stylus 15 of the recorder. The transmission equivalent, or gain, of amplifier tube 22 is widely variable under the control of the output voltage of amplifier-rectifier 24 which is applied as a biasing or control voltage to grid electrode 23, supplementing the constant biasing voltage derived from a battery 25. The control voltage is applied with such polarity that an increase in voltage reduces the amplifier gain.

The biasing voltage provided by battery 25 in Fig. 3 is of a critical value such that currents supplied from circuit 21 are effectively amplified if the output voltage of device 24 is substantially zero, and such that transmission of currents through the amplifier is substantially blocked in the presence of a substantial control voltage. In other words, the amplifier tube 22 has two substantially different operating conditions depending on whether or not substantially any currents appear in circuit 13, the one condition allowing transmission of marking current to the stylus 15 and the other condition preventing such transmission.

So long as a component of the reproduced complex waves is transmitted by either of the filters A and B in Fig. 3, there will be substantial current in the circuit 13 unless the selected component has approximately the relative frequency position indicated at *c* in Fig. 2. In the latter event the biasing voltage supplied by amplifier-rectifier 24 is substantially nil and amplifier tube 22 is in condition to transmit marking current to

5

the stylus 15. If the marking current is so transmitted, the variations in envelope amplitude of the selected component are recorded along one of the longitudinal paths on the facsimile paper. In the course of several reproductions the envelope variations may be recorded either along a single path or along a plurality of them depending on the relation between the incremental change in the frequency of oscillator 8 and the degree of overlap of the two filter characteristics, and dependent also on the sensitivity of the system to a departure of the selected component from the indicated frequency position *c*. When the selected component substantially departs from the position *c*, the amplifier tube 22 is rendered inoperative, hence the trace is confined to the particular path or paths just mentioned. The position of the trace that is made indicates the frequency of the particular component more accurately and directly than would the relatively wide multiple-line trace that would otherwise be formed, and a truer picture of the actual composition of the complex waves is thereby obtained. When the particular component falls outside of both of the filter bands, amplifier tube 22 is operative, but inasmuch as no current then reaches circuit 21 the facsimile paper, of course, remains unmarked.

In the operation of the Fig. 3 system it is presupposed that the composition of the reproduced waves is such that when a particular component appears at about position *c*, any wave energy elsewhere within the selected band will be insufficient to effect cut-off of amplifier tube 22. Vowel sounds are of such composition and also certain voiced consonants.

The systems described with reference to Figs. 1 to 3 involve a comparison of the instantaneous amplitudes, or relative phases, of the wave components transmitted through the respective filters, and they may entail careful design of the filters to obtain the required phase characteristics. This condition is avoided and other advantages are secured in the embodiments of the invention that are illustrated in Figs. 4 and 6.

Referring to the modification shown diagrammatically in Fig. 4, modulator 7 is connected to the input terminals of the two scanning filters A and B as in preceding examples and the output circuits of the two filters are connected together in phase-aiding relation through respective similar resistance pads 11 and 12. Current may be supplied to a circuit 21 either substantially exclusively from filter A or from both filters by means of a switch 30 through which circuit 21 can be connected to either the input end or the output end of resistance pad 11. Circuit 21 is connected through a resistance pad 31 to a marking circuit 32 in which the current received from one or both of the filters, varying in envelope amplitude, is or may be translated into a current of different frequency or into one that is otherwise modulated in correlation with the varying envelope amplitude. The marking current delivered from circuit 32 in any case is conveyed to a vario-losser 33, the output circuit of which is connected through marking circuit 20 to stylus 15. The transmission equivalent of vario-losser 33 is controlled differentially by the respective unidirectional voltages delivered by detectors or rectifiers 34 and 35. Rectifier 34 is connected to receive input current substantially exclusively from scanning filter A and rectifier 35 is similarly connected to scanning filter B. For an understanding of the present invention it will suffice to as-

6

sume that any current received in circuit 21 is transmitted through marking circuit 20 without any substantial modification excepting for that introduced by vario-losser 33.

The operation of the Fig. 4 system will be explained on the assumption first that the filters A and B have transmission characteristics of the kind illustrated in Fig. 2, and second that switch 30 is closed to its right-hand contact so that the two filters are coupled substantially equally to circuit 21. It may be further assumed that vario-losser 33 is a device that has one or the other of two operating conditions depending on whether or not the respective control voltages delivered by rectifiers 34 and 35 are substantially equal. More particularly, when the control voltage from rectifier 34 is substantially equal to the opposing control voltage from rectifier 35, vario-losser 33 assumes a cut-off or transmission blocking condition, and when the two control voltages are not substantially equal, the vario-losser freely transmits the marking current supplied to it.

It will be evident that when a component of the translated complex waves delivered by modulator 7 falls within the frequency range embraced by the pair of scanning filters A and B the vario-losser 33 will allow transmission of marking current to the stylus only if the component occupies substantially the frequency position *c* indicated in Fig. 2. Only in this circumstance will the component supplied to rectifier 34 have substantially the same strength as that supplied to rectifier 35. In any other relative position of the selected component the two control voltages applied to the vario-losser 33 will be substantially unequal and transmission of marking current will therefore be blocked.

It may be noted at this point that upon closing switch 30 to its left-hand contact neither of the control circuits is affected, but marking current is then derived from only filter A rather than from both of the filters. Filter B then functions only as a part of the frequency-discriminatory control means operating on vario-losser 33 and it may be designed to meet only the requirements of this function.

Reviewing the design and operation of the Fig. 4 system, it will be understood that the frequency selective scanning means, i. e., filter A for example, is assigned a transmission band width that is at least narrow enough to resolve the discretely different principal components of the reproduced complex waves such as the harmonically related components of voiced sounds, and yet wide enough to transmit faithfully the variations in envelope amplitude of the selected component. The operating frequency of oscillator 8, or the position of stylus 15 crosswise of the facsimile paper when a given component is transmitted through the scanning means affords some indication of the frequency of the reproduced component. It is only an approximate indication, however, in the absence of an indication as to the particular position the component occupies within the pass-band of the selective means.

The aforementioned frequency-discriminatory control means affords the desired indication of the relative position of the component, for it is responsive only when the component occupies a predetermined position *c* within the filter band and it is substantially only in this circumstance that marking current is delivered to the stylus. The position of the mark or trace left by the stylus and also the frequency of the beating oscillator when the trace is made indicates the fre-

quency of the component with an accuracy that need be limited only by the sensitivity or frequency-discriminatory capacity of the control means.

The latter capacity should be so correlated with the incremental change in the beating frequency that occurs from one reproduction to the next as to insure that each component is selected and recorded during at least one reproduction. If the incremental change in beating frequency takes place progressively in the course of each reproduction, it will be appreciated that a given component may be recorded partly in one longitudinal path and partly in a contiguous path. The incremental frequency change of the beating oscillations should be not greater than the small frequency interval around position *c* over which the control circuit is responsive else there may be intervals along the spectrogram in which a given component, although present in the reproduced waves, is not recorded. In some applications of the invention it may be preferred to determine the frequency of any given component by measuring or observing the beating frequency at the moment vario-losser 33 is actuated, and oscillator 8 may be provided with a frequency indicating scale 37 for this purpose.

It will be understood on reference to Fig. 2 that the control means involves the intersection of oppositely sloping response-frequency characteristics. The particular point of intersection and the difference in slopes at that point influence the sensitivity of the control means and may be varied to suit the requirements of the particular case in practice. The filters A and B may have flat-topped transmission-frequency characteristics such as are obtainable with multisection band-pass filters. These characteristics may overlap only slightly so that the point of intersection falls on the sharply sloping sides of the transmission characteristics, or they may overlap to a greater extent such that they have a small flat-topped portion in common, as illustrated in Fig. 5. The limited frequency interval represented by the common portion corresponds to the critical frequency position *c* in Fig. 2. Fig. 5 illustrates perhaps more clearly than Fig. 2 the fact that the control means comprises frequency-discriminatory means defining a frequency interval that is much smaller than the band width of the scanning filter, much as if the frequency selective transmission function and the control function were effected independently by separate filters of different band widths.

Certain speech sounds do not have the discretely different components considered above but partake more of the nature of resistance noise in that the speech wave power is distributed more or less continuously over the frequency range or over separated parts thereof. At a given time some of these wave components may appear in the overlapping frequency region, others in the non-overlapping portion of characteristic A, and still others in the non-overlapping portion of characteristic B. The first-mentioned components will be recorded in the desired manner if the effective intensities of the other sets of components are equal to each other. Fortunately for present purposes this substantial equality generally obtains, for although the wave power in one part of the speech frequency range may differ widely from that in another, the variation in wave power over the frequency band *a—d* or *a—e* is generally insubstantial. Vario-losser 33 is accordingly maintained in its operative or

transmitting condition and enables the selected components to be recorded.

If it be desired to have each frequency component recorded not as a single fine line but as a heavier bar or band consisting of a plurality of laterally contiguous traces, vario-losser 33 may be so adjusted or designed, as in the manner described with reference to Fig. 3, that its transmission equivalent varies continuously or progressively with progressive change in the resultant of the two opposing control voltages supplied to it. A given component, selected throughout each of several successive reproductions, will then be recorded along several corresponding different paths, but the average density or blackness of the trace will vary markedly from one path to another in proportion to the deviation of the component from the frequency position *c*. When the selected component lies near the extremities of the transmission frequency band, but within the band, the loss introduced by device 33 is so high that no trace at all is made. The edges of the dark band produced on facsimile paper 17 are accordingly sharply marked and the spaces between the dark bands pertaining to successive harmonic components are clearly defined and unmarked. From one point of view, one of the filters precedes the other in its relative movement across the frequency range occupied by the reproduced waves and substantially prevents recording of any given component until the latter is well within the transmission band of the other filter. Likewise as the component leaves the transmission band of the latter filter, the other filter, operating through the control circuit, reduces the strength of the marking current at a faster rate than would otherwise be the case.

The effect last described may be used to advantage also in the formation of wide-band spectrograms, that is, in recording systems in which two or more adjacent harmonic components are concurrently operative in the marking circuit. The filters A and B in Fig. 4 may each have a pass-band 300 cycles wide, for specific example, to achieve this mode of operation. In the wide-band spectrogram, the individual harmonics are not distinguishable in the spectrogram, but the relatively broad resonance regions defined by the vocal cavities are displayed. The control function provided in accordance with the present invention enables the boundaries of the resonance regions as pictured in the spectrogram to be sharply defined and readily distinguished from the intervening regions, the latter remaining substantially unmarked.

Fig. 6 illustrates diagrammatically a modification of the systems described with reference to Figs. 4 and 5, in which a single scanning filter A, or 10, is employed and in which the frequency-discriminatory function performed by filters A and B jointly in Fig. 4 is accomplished by means of a pair of slope circuits 40 and 41. Excepting for the elements that control the operation of vario-losser 33, the system is much the same as the Fig. 4 system with switch 30 of the latter so positioned that current is received in circuit 21 substantially exclusively from the one scanning filter A. Thus in Fig. 6 the scanning filter A is followed by an amplifier 14, resistance pad 31, circuit 21, vario-losser 33, marking circuit 32, circuit 20 and stylus 15. Vario-losser 33 and marking circuit 32 have been interchanged to illustrate the fact that the vario-losser may operate either on the currents as received from the

scanning filter or upon a translated form thereof, such as a current comprising variably spaced pulses, that may be produced by the marking circuit 32. In view of the close relation to Fig. 4 it is only the control circuits of the Fig. 6 system that require attention.

Slope circuit 40 in Fig. 6 is connected through resistance pad 11 to receive the selected components from the output circuit of amplifier 14, and slope circuit 41 is similarly connected to amplifier 14 through resistance pad 12. The output currents of the two slope circuits are delivered to the respective rectifiers 34 and 35 which provide the two opposing control voltages that operate on vario-losser 33. Slope circuit 40 has a transmission-frequency characteristic that slopes sharply across the pass-band of scanning filter 10 as illustrated diagrammatically in Fig. 7. The transmission characteristic of slope circuit 41 is the same excepting that it slopes in the opposite sense and intersects that of 40 at a point well within and preferably at substantially the center of the pass-band of filter 10. Otherwise stated, the two slope circuits introduce substantially the same loss at the mid-band frequency of filter 10, and the loss introduced by each varies sharply and oppositely to that of the other upon a progressive change in frequency in either direction from the mid-band frequency. Similar remarks are applicable to Figs. 2 and 4, excepting for the difference in the relative position of the point of intersection c.

The operation of the Fig. 6 system is substantially the same as that of the Fig. 4 system and it is thought to require little or no additional explanation. When a component selected by the scanning filter 10 appears at substantially the relative frequency position c, the currents delivered to the rectifiers 34 35 are attenuated substantially equally and the two control voltages are accordingly substantially equal. The transmission equivalent of vario-losser 33 is thereby reduced to a minimum and the selected component passes freely to stylus 15. In any other circumstance the control voltages are unequal and the vario-losser blocks or relatively attenuates the currents applied to it.

The slope circuits 40 and 41 may be of the type commonly employed in frequency modulation systems and sometimes referred to as frequency discriminators. Circuit details appropriate for these and other elements of the systems herein described are shown schematically in Fig. 8.

In the system shown schematically in Fig. 8, the output circuit of amplifier 14 is connected through a resistance pad 44 to an amplifier 45, the output circuit of which is shunted by a potential divider 46. The contactor of the latter is connected through a large amplitude-limiting resistance 47 to the grid of an amplifier tube 48. Connected in series relation in the output circuit of amplifier 48 are the primary windings of a pair of transformers 50 and 51 each of which has a pair of condenser-tuned secondary windings. The secondary windings 52 and 53 of transformer 50 are tuned to a frequency f_1 that lies above the pass-band of scanning filter 10, and the secondary windings 54 and 55 of transformer 51 are tuned to a frequency f_2 that lies about the same distance below the filter band. For specific example, if the filter 10 has a pass-band that is 45 cycles wide and that has a mean frequency f of 11.9 kilocycles, the frequency f_1 may be 12.05 kilocycles and frequency f_2 , 11.75 kilocycles. Each of the secondary windings 52 to 55

is connected in series with a respective thermionic diode 56 to 59 and a respective condenser-shunted output resistor 60 and 63. Resistors 60 to 63 are connected in series relation with each other between the grounded cathode of diode 59 and the cathode terminal 64 of diode 56. Resistors 61 and 62 are similarly connected in series relation between the grounded anode of diode 58 and the anode terminal 65 of diode 57. The voltages appearing across resistors 60 and 63, respectively, are in mutually opposing relation and so also are the voltages appearing across resistors 61 and 62, as indicated in Fig. 8. The cathodes of a pair of thermionic diodes 70 and 71 are connected respectively to terminals 64 and 65, and the anodes thereof are connected together to the ungrounded input terminal of a low-pass filter 72. The output circuit of filter 72 is shunted by a grounded resistor 73.

It will be evident to those skilled in the art that if amplifier 48 were to deliver current of a constant intensity and of a frequency varying progressively from f_2 to f_1 , the potential of terminal 64 would vary sharply from a large negative value to a large positive value, as indicated qualitatively by the curve marked 64 in Fig. 9. Similarly, the potential of terminal 65 would vary from a large positive value to a large negative value as illustrated at 65 in Fig. 9. The two curves intersect at a point that represents zero potential at the selected frequency position c, viz., the mean frequency f of scanning filter 10. The voltage appearing across resistor 73 varies with frequency in the manner represented by the solid-line curves in Fig. 9, for each of the diodes 70 and 71 is so poled as to block the flow of current when its associated terminal 64 or 65 has a positive potential.

In view of the foregoing it will be understood that whenever a frequency component selected by filter 10 appears at the critical frequency position c, the voltage across resistor 73 is substantially nil, and that the voltage increases sharply with any substantial departure of the component from the position c. The filter 72 eliminates ripple currents accompanying the direct current outputs of the discriminators.

The resultant control voltage appearing across resistor 73 is utilized in Fig. 8 to control the operating condition, or gain, of an amplifier comprising a pentagrid mixer tube 75 which may be specifically of the type 6L7. The ungrounded negative terminal of resistor 73 is connected to one of the control grids of tube 75 to provide a negative biasing voltage component that supplements a steady negative biasing component developed by the flow of anode current through cathode circuit resistor 76. The other control grid of tube 75 is connected to the contactor of a potential divider 80, the resistance element of which is shunted directly across the output circuit of amplifier 14 by means of circuit 21.

The operation of the Fig. 8 system is substantially the same as that described with reference to Figs. 4 and 6. Tube 75 has relatively high gain when the control voltage is substantially zero. Hence, whenever a component selected by filter 10 occupies the predetermined critical frequency position c, the component is transmitted through circuit 21, amplified in tube 75, further amplified in an amplifier 81, if desired, and applied to the marking circuit 20 that leads to stylus 15. If the selected component occupies any other relative position, the resultant voltage ap-

11

pearing across resistor 73 will cause tube 75 to be biased to cut-off and thereby prevent application of marking current to the stylus.

The intensity level of the marking current delivered to stylus 15, or the average density of the trace left on the facsimile paper, may be adjusted by means of potential divider 80. Potential divider 43 affects the sensitivity of the control circuit; and it may be adjusted to so reduce the sensitivity, for example, that a given component will be recorded throughout two or more successive reproductions.

The Fig. 8 system, like other systems in accordance with the invention and described herein, has a certain degree of frequency selectivity as measured by the accuracy with which the current delivered to the load varies in conformity with variation in the effective intensity of applied waves, but at the same time the system appears to have also a substantially greater degree of frequency selectivity as measured by the effect that a change in the frequency of the applied waves has on the load current. From a somewhat different point of view it may be observed that the band width of the frequency selective wave transmission means interposed between wave source and load, viz., filter 10 in Fig. 3, affords the system the required capacity to resolve components of different frequency that may be simultaneously applied and affords it also the required capacity to translate variations in effective intensity of a resolved or selected component. Once a particular component is resolved, or selected, the greater sensitivity or frequency discriminatory capacity of the control means enhances the sensitivity of the system to variations in the frequency of that component. It will be understood too that the control means is so related to the rest of the system that it is not required to preserve the variations in effective intensity, and its relatively high frequency selectivity imposes no corresponding restriction on the responsiveness of the system to rapid changes in effective intensity of the selected components.

Figs. 10 and 11 illustrate details of an improved recorder that may be incorporated in any of the systems herein disclosed. In this arrangement drum 16 does not rotate but is caused to move longitudinally, on the shaft 85 on which it is mounted, whenever the arm 86 that is attached to one end of the drum is adjusted to engage the rotating threaded shaft 12. Stylus 15 is attached to a light-weight ring 87 that is mounted within and frictionally held by a ring gear 88. The latter is supported concentrically of drum 16 by means of pinions 89 one of which is keyed to and driven by shaft 12. Marking circuit 20 is electrically connected to stylus 15 by means of a brush 91 that rides on one face of gear 88 and a brush 92, shown in Fig. 11, that is electrically connected to the stylus and that bears on the inner face of gear 88.

The rotation of gear 88 and the simultaneous gradual longitudinal movement of drum 16 produce the same relative movement between the stylus 15 and facsimile paper 17 that has been described hereinbefore. One advantage of this arrangement is that the spectrogram can be closely examined while it is being formed. Hence, if the portions first recorded are unsatisfactory for any reason, this may be seen immediately and the fault can be corrected promptly.

In accordance with another feature illustrated in Fig. 10, the facsimile paper 17 is supplied in the form of a roll 93 adapted to be inserted into drum 16 through a removable end thereof. The roll 93 rides on shaft 95, as shown in Fig. 11, and

12

one end of the strip is brought out through a longitudinal slit 94 in the face of drum 16 and wrapped about the drum in the manner shown.

Another feature embodied in Fig. 10 is calculated to maintain the proper relation between the movement of stylus 15 and the movement of magnetic tape 1. In practice the latter may comprise a long belt linking a system of pulleys, one of the pulleys 95 being driven by a constant speed motor 96 or the like. Each reproduction of the recorded waves should begin the instant the stylus 15 passes through a predetermined starting position, but slippage of the tape 1 with reference to the driving pulley 95 tends to cause the beginning of successive reproductions to be variably and increasingly delayed. To compensate for this effect, Fig. 10 includes means for stopping rotation of the stylus-carrying ring 87, after each reproduction, just long enough for the magnetic tape to catch up with it. For this purpose ring 87 is provided with a stop pin 97 which is arranged to be engaged by the spring-biased armature of a relay 98 whenever the latter is actuated. Suitable means are provided for operating relay 98 at a predetermined point in the cycle of movement of tape 1 just before pin 97 reaches the relay armature, and for energizing it at another predetermined point in the cycle just after pin 97 has reached the relay armature.

As shown in Fig. 10, the energizing circuit of relay 98 includes a pair of brushes 99 through which the circuit is closed whenever and so long as both brushes make contact with a short conductive strip 100 that is connected to and laterally offset from the tape 1. It will be understood that each time the relay circuit is broken, the relay armature disengages pin 97, ring gear 88 resumes its frictional drive of ring 87, and stylus 15 resumes its circumferential movement relative to facsimile paper 17.

Although the present invention has been described largely with reference to several specific embodiments it will be understood that the latter are in some respects only illustrative of the invention and 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 of the kind described comprising means for repeatedly reproducing recorded complex waves in the form of electrical waves, frequency translating means for progressively changing the frequency position occupied by said reproduced waves, means for selecting during different reproductions the wave components appearing in corresponding different parts of the wave frequency range, said selecting means comprising a pair of frequency selective wave transmission elements that have mutually overlapping frequency-transmission characteristics, means for applying the translated waves to said elements concurrently, means for combining the wave outputs of said selective elements in phase opposition, and stylus recording means responsive to the said combined wave output.

2. A system in accordance with claim 1 including means for carrying said stylus means to traverse a multiplicity of different collateral paths on a record surface, in succession, throughout respectively corresponding different reproductions of the recorded waves.

3. In combination, a frequency selective device having a band-pass wave transmission characteristic, utilization means, wave translating means responsive to waves transmitted through

said device for conveying to said utilization means effects that vary in substantial conformity with variations in the effective intensity of said transmitted waves, control means selectively responsive to waves transmitted through said device having a predetermined frequency substantially removed from the limiting frequency of said band, and means actuated by said control means for governing the operativeness of said translating means.

4. In combination, an electric wave translating circuit including a frequency selective means having a limited transmission-frequency band, a utilization means, means connecting said selective means to said utilization means for conveying electrical effects that vary in predetermined relation to variations in the effective intensity of waves transmitted through said selective means, frequency discriminatory means differently responsive according as the transmitted waves have a frequency within or without a predetermined part of said band, and means controlled by the response of said frequency discriminatory means for changing the transmission equivalent of said connecting means.

5. In combination, a wave translating path comprising wave input means adapted to selectively transmit applied waves of any frequency lying within a predetermined limited frequency range, a load responsive to currents of varying intensity derived from said input means, and transmission modifying means interposed between said input means and said load; and means responsive to applied waves having a frequency within a predetermined fractional part of said frequency range, and operative on said transmission modifying means, for altering the transmission equivalent of said path.

6. In combination with wave receiving means, means adapted to selectively transmit waves lying within a predetermined frequency band, means for applying the received waves to said transmitting means including means for shifting the frequency position occupied by the applied waves relatively to and progressively across the said frequency band, utilization means, translating means for conveying to said utilization means effects that vary in substantial conformity with and in response to variations in the effective intensity of waves selectively transmitted by said transmitting means, and frequency discriminating means operative on said translating means for substantially suppressing said effects whenever the selectively transmitted waves lie outside a predetermined part of said frequency band.

7. In combination with a source of electrical waves having a multiplicity of different frequency components that vary in effective intensity, a utilization means, frequency selective wave transmission means connected to said source, a transmission-level controller connecting said frequency selective means and said utilization means, said frequency selective means having a transmission band narrow enough to resolve said frequency components yet wide enough to substantially preserve the variations in effective intensity of any components selectively transmitted thereby to said utilization means, means for substantially enhancing the effective frequency resolution of said frequency selective means without substantially impairing the said variations in effective intensity, said last-mentioned means comprising

frequency discriminatory means responsive differently to a component transmitted through said frequency selective means according to the proximity of said component to a particular frequency interval within the said transmission band of the frequency selective means, said frequency discriminatory means being operative on said transmission level controller to adjust the transmission level.

8. In combination, electric wave filter means having a predetermined transmission band, means for applying to said filter means a varying electric wave the frequency of which shifts progressively across said transmission band, utilization means connected to said filter means and responsive to variations in the effective intensity of the wave transmitted through said filter means, means normally maintaining said utilization means substantially non-responsive to said transmitted wave, and frequency discriminatory means controlled by said transmitted wave for rendering said utilization means substantially responsive whenever the frequency of said transmitted wave comes within a predetermined part of said transmission band.

9. In combination, frequency analyzer means adapted to selectively transmit waves lying within a predetermined frequency band, means for applying complex waves to said analyzer means including means for progressively shifting the frequency position of the applied waves relative to and across said predetermined frequency band, means for recording individually the variations in effective intensity of each of a multiplicity of different frequency components transmitted successively by said analyzer means during the said progressive shifting of frequency position, said recording means being responsive to the said successively transmitted components, and means for maintaining said recording means substantially non-responsive to a transmitted component except when said component occupies a predetermined frequency position within said band.

10. A combination in accordance with claim 9 comprising means for storing said complex waves, and means for reproducing the stored waves repeatedly for application to said analyzer means.

11. A wave analyzer comprising wave input means for receiving waves to be analyzed, filter means for selecting from the received waves any wave components lying within a predetermined band, said filter means including means whereby said predetermined frequency band is adjustable in frequency position, a utilization means responsive to wave components selected by said filter means, and means for substantially altering the responsiveness of said utilization means in response to the appearance of a selected component at a predetermined frequency position in said band.

WALTER KOENIG, JR.

REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
2,096,082	Beatty	Oct. 19, 1937
2,005,425	Kwartin	June 16, 1935