Oct. 30, 1956 F. VILBIG 2,769,031

APPARATUS AND METHOD FOR ANALYZING, COMPRESSING OR EXPANDING SPEECH AND OTHER SOUND RECORDINGS

Filed April 23, 1951 6 Sheets-Sheet 1

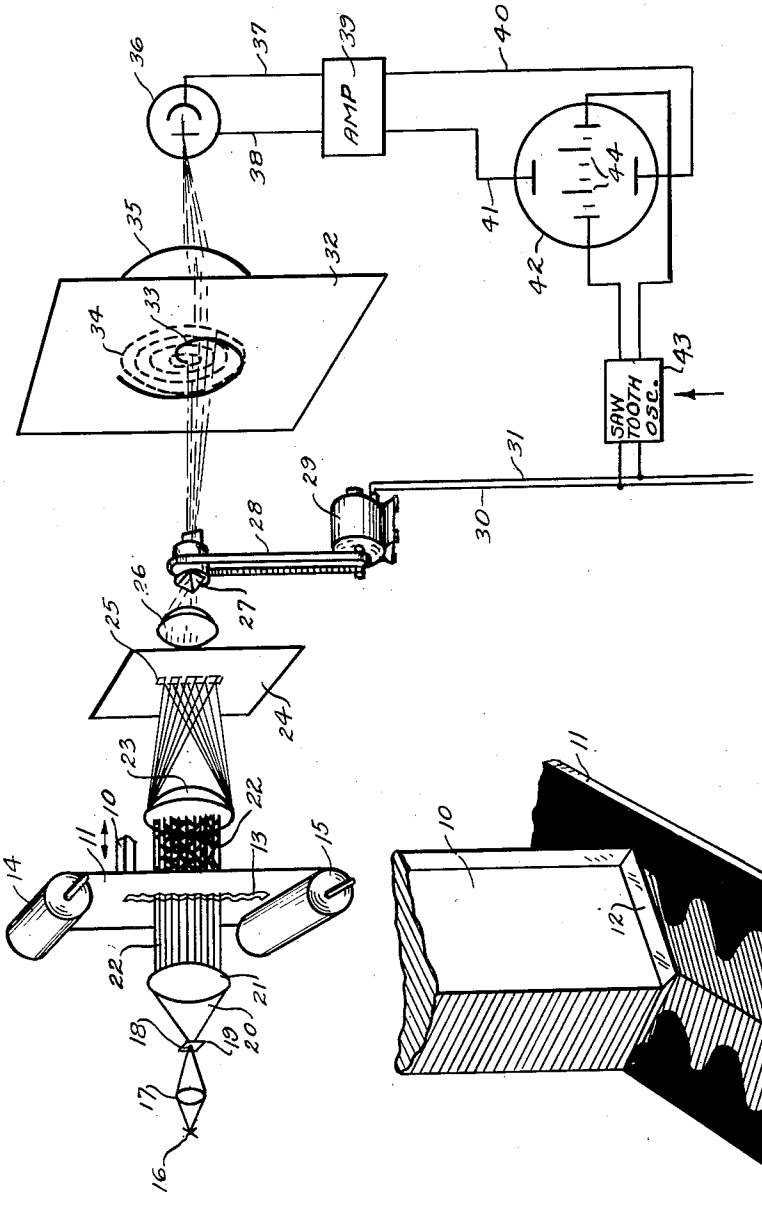


FIG. 2.

FIG. 1.

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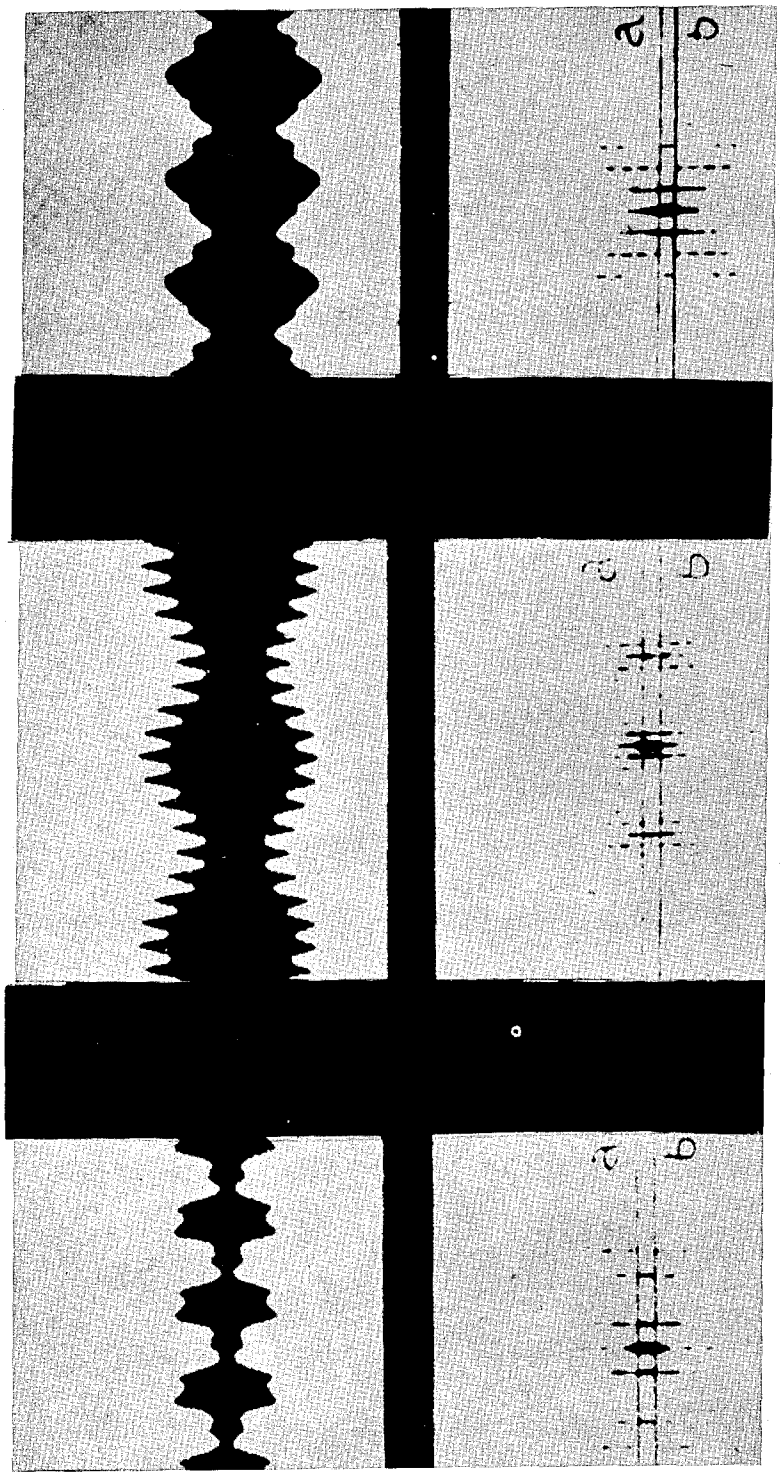


Fig. 3

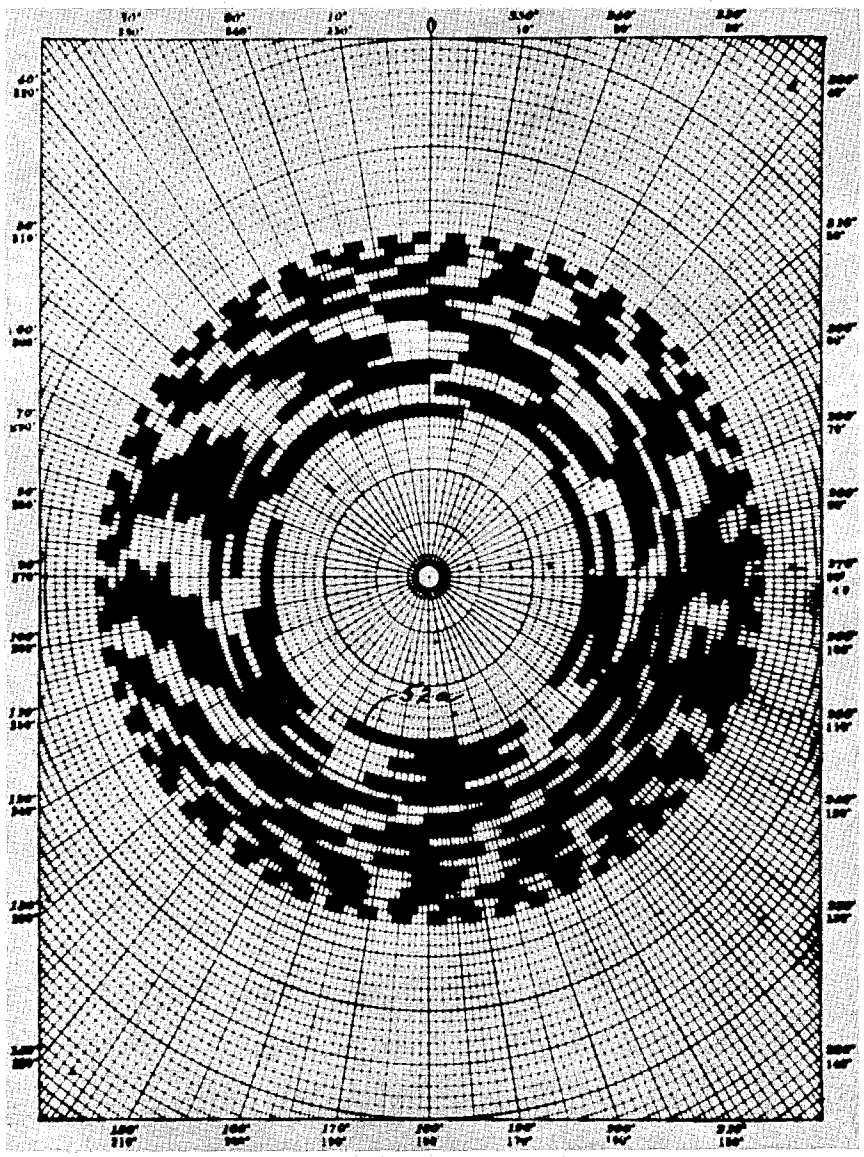
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APPARATUS AND METHOD FOR ANALYZING, COMPRESSING OR EXPANDING SPEECH AND OTHER SOUND RECORDINGS

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FIG 4

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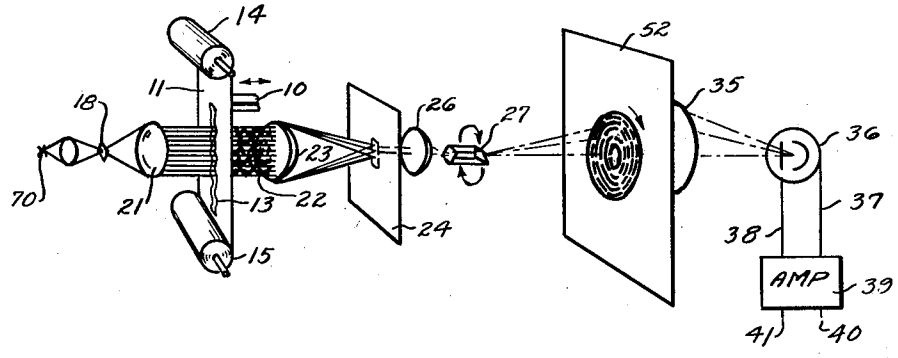
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Fig. 5.



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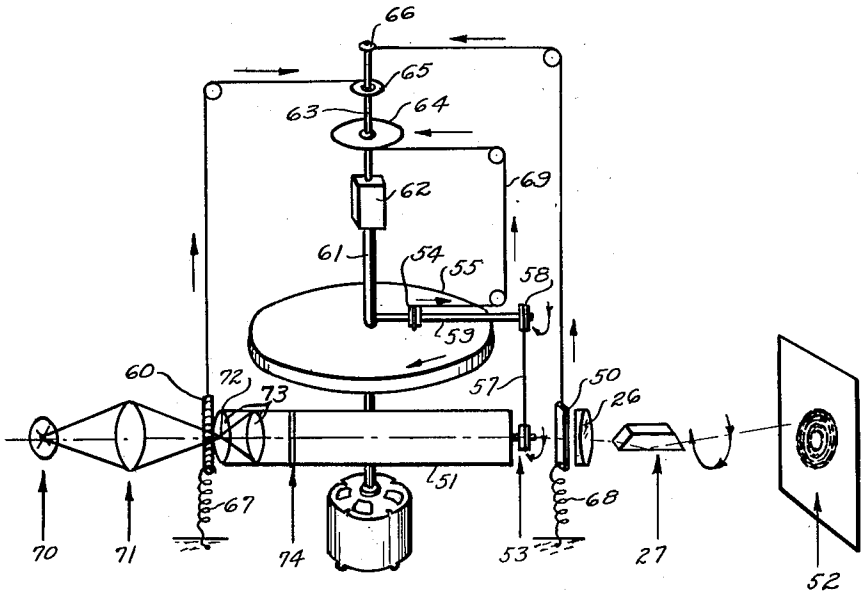
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Fig. 6



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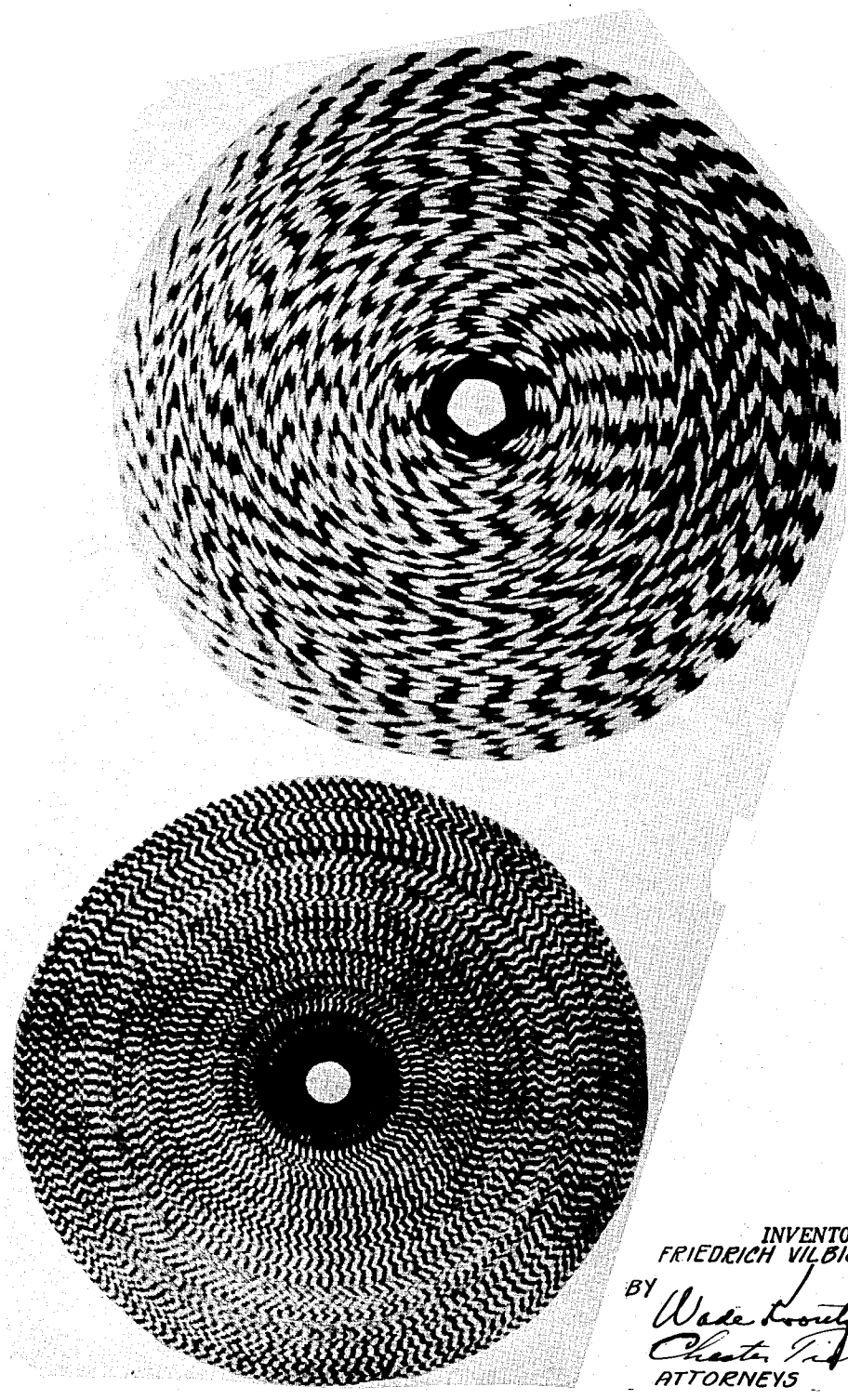


Fig. 7.

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United States Patent Office 2,769,031 Patented Oct. 30, 1956

2,769,031

APPARATUS AND METHOD FOR ANALYZING, COMPRESSING OR EXPANDING SPEECH AND OTHER SOUND RECORDINGS

Friedrich Vilbig, Cambridge, Mass.

Application April 23, 1951, Serial No. 222,517

3 Claims. (Cl. 179—1)

(Granted under Title 35, U. S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government for governmental purposes without payment to me of any royalty thereon.

It is known from the work of J. F. Schouten (Philips Technische Rundschau, vol. 10, pgs. 310–317 and October 1939 pgs. 302–303, also vol. 3, pg. 310, 1938) that a tone film strip produced by the Philips-Miller method, when illuminated from a point source of light, diffracts the light after the manner of a Rowland grating. The present inventor makes use of this effect for the purpose of producing an apparatus for speech compression and expansion and for speech analysis. In speech band compression or expansion, all of the frequencies of the band are divided or multiplied in a certain ratio without changing the time dimension. Other recorded sounds may be treated similarly.

There are numerous practical uses for a sound analysis apparatus capable of compressing or expanding speech or other sound. If a sound frequency can be divided, say into quarters, so that a frequency can be obtained which is one-fourth the frequency of the original sound, this lower frequency can be transmitted by radio or by a loud speaker and when so transmitted it can be understood through much heavier interference than the original sound. By this process, it is also possible to understand the transmission of a friendly radio station despite enemy efforts to jam it. The apparatus and method to be described herein will also be useful in visually analyzing the voices of singers to make their defects apparent to them and also to analyze and then improve the acoustic qualities of musical instruments and loud speakers.

It is the object therefore of this invention to provide a method and apparatus which will be useful in attaining the goals which have above been discussed.

Referring to the accompanying drawings:

Fig. 1 is a more or less diagrammatic representation of a knife which is cutting a sound track through the emulsion coating of a sound film according to the Philips-Miller method. The means for vibrating the knife according to the modulations of the sound waves is not shown because it is well known.

Fig. 2 shows schematically an apparatus for producing an oscillographic representation or analysis of a film sound track made according to the Philips-Miller method.

Fig. 3 is a photographic reproduction of a sound track, above, and below the diffraction pattern thereof produced by the apparatus shown in Fig. 2.

Fig. 4 is a plan view of a hand-drawn disc suitable for frequency multiplication and division.

Fig. 5 is a diagrammatic representation of an apparatus employing the disc shown in Fig. 4 for the purpose of frequency multiplication and division, for example to reduce the frequency of the sound track which has been recorded upon a sound film.

Fig. 6 is a diagrammatic representation of an apparatus

for making a pattern disc which is useful in the frequency multiplication and division of sound.

Fig. 7 is a plan view of an improved disc produced by the apparatus shown in Fig. 6. It has the same purpose of the disc shown in Fig. 4.

Referring again to Fig. 1, 10 is a triangular knife which is held by means not shown, in light contact with a sound film 11. The knife 10 is provided with a chisel edge 12 which is quite sharp and which when vibrated by a modulating means (not shown) is able to remove the blackened emulsion of the sound film into a track 13 of varying area in accordance with the sound pressure variation of the sound being recorded. The steps described comprise the Philips-Miller method and are the steps referred to whenever the term Philips-Miller method is used in the specification and the claims. It is a characteristic of this Philips-Miller method of sound recording that the track obtained is bounded on each side by a wave which is more or less sinusoidal according to the number and order of higher harmonics in the original sound. Each sinusoidal wave opposes its neighbor. It is also true that each cut varies in thickness from its neighbors thereby giving a prismatic effect.

Referring to Fig. 2, 14 is a roll upon which a sound film 11 made according to the Philips-Miller method is wound. This film is being wound from the roll 14 onto the other roll 15 by power means, not shown, if desired. The Philips-Miller track may be made by the knife 10 shown in this apparatus from fresh film wound on the roll 14 so that the analysis of the track 13 will take place almost immediately after it is recorded. 16 is a brilliant point light source, the ray formations from which are sent through a small condensing lens 17 and thence through a small hole 18 in a screen 19 at the focus of the lens 17. The light rays 20 are next directed onto a larger plano-convex lens 21 which directs the rays 20 in parallel bundles 22 through the track 13 which produces a diffracted bundel of rays 22. This bundle is then received in a plano-convex lens 23, so that the optical spectrum produced by the diffracting action of the sound track is focused upon a screen 24 in which there is a vertical slit 25. From the work of Schouten it is known that this spectrum will take the form of one of those in Fig. 3, in which each of the frequencies present in the sound track will be displayed on either side of a center line as vertical lines of light, their spacing from center being proportional to frequency and their intensity in proportion to their amplitude. There will also be a variation in height due to the variable height of the sound track used as a diffraction grid. By means of the vertical slit 25 it is possible to eliminate the variable height portions extending beyond the edges of the slit. By positioning the slit so that one end is at the center line, it will pass only one-half of the double spectrum, while the other half is arrested by the screen 24. It is immaterial which half of the spectrum is transmitted through the slit. The image in the slit is then thrown in enlarged form by the action of lens 26 and prism 27 onto screen 32. A rotating prism 27 is interposed between lens 26 and screen 32, causing the spectral lines thrown upon the screen to rotate in circular paths about the center, the innermost circles corresponding to the lower frequencies and the outermost to the higher frequencies. The prism 27 may be rotated at a regulatable speed by a belt 28 or other driving mechanism which is actuated by electric motor 29. The motor 29 is supplied with current from leads 30 and 31.

Screen 32 is provided with a spiral slot 33 which originates at the center of the rotating beams of light thrown on the screen. It will be seen that the innermost or lowest frequency spectral lines will cross the spiral near its origin and the highest frequency lines will cross the spiral near its end. If the prism is rotated in a clockwise man-

ner the spectral lines of the low frequencies will cross the spiral first and the high frequencies last. The screen 32 does not ordinarily rotate but for some applications, which will later be discussed, rotating means may be provided. Behind the screen 32 there is a plano-convex lens 35 mounted with its plane side in close up toward the screen. Its diameter is at least equal to that of the spiral slot 33. Whenever a spectral line crosses the spiral the light from the spiral will be focused by lens 35 onto the sensitive area of photocell 36 and converted by it into voltage pulses which are transmitted by leads 37 and 38 to an amplifier 39, the output of which is taken through leads 40 and 41 to the vertical deflecting electrodes of a kinescope 42. The horizontal deflecting electrodes are fed with a saw tooth wave by oscillator 43, which is synchronized with the motor 29 which drives the prism. The frequency in cycles per second of the saw tooth wave is therefore the same as the number of revolutions per second of the rotating prism. Each saw tooth is originated by means, not shown, at the instant the spectral lines are in a position opposite the origin of the spiral slot, so that the electron beam of the kinescope will sweep across its face in synchronism with the rotation of the spectral lines about their centers. The horizontal position of the cathode ray at any instant will then be in proportion to the angular position of the spectral lines at that instant.

When a spectral line crosses the spiral the cathode ray will be deflected vertically by the voltage pulse forming a vertical pip 44. The horizontal position of the pip will depend on its frequency, the lower frequency pips being formed on the left side of the screen if the sweep goes from left to right. This is because the low frequency spectral lines will cross the spiral first. The amplitude of the vertical pips will be in proportion to the amplitude of the frequency component which it represents, since the brighter spectral lines will cause the photocell to deliver larger pulses to the vertical deflecting plates. For convenient use as an analyzer the face of the kinescope may be calibrated horizontally in terms of frequency and vertically in terms of amplitude.

Discussing the operation of the apparatus shown in Fig. 2, it is to be noted that the sound film may be used immediately after being scraped with the knife edge 12 with a delay time of less than $\frac{1}{20}$ second. If a photographic film is moved across the slot 25, the continuous sound spectrum of the first film can be written upon the second one. But only the position of the single frequencies and only ineffectively, the amplitudes can be indicated by the greater or lesser blackness of the lines. If it is desired to produce immedately a picture of the frequencies present and their amplitudes, a lens 26 must be placed behind the slot. This lens gives an amplified picture on the screen of the spectral lines passing through the small slot 25. If the rotating prism 27 is employed behind the lens, the spectral points are projected on the screen 32 in circular paths. The circles having a small radius correspond to the low frequencies and those of large radius to the higher frequencies. The spectral slot 33 is a true Archimedean spiral. The light can pass the slot 33 if the light point circle cuts the spiral. At this moment the light which passes the spiral slot will be condensed by the condenser lens 35 onto the photo-cathode of the photocell 36 to produce the photo current impulse. The impulse is applied to the vertical deflection plates of the cathode ray tube or kinescope 42 after amplification. A linear saw tooth voltage is applied to the horizontal plates. The saw tooth voltage wave is synchronized with the synchronous motor which drives the prism. Consequently it is possible to calibrate the horizontal deflection in frequencies and the vertical deflection gives corresponding amplitudes.

Frequency division and multiplication

The same arrangement can be used for frequency band division and multiplication if instead of the spirally slotted screen, a transparent modulation or pattern disc 52, which is shown in Fig. 4, is employed. This disc 52 is made of a sheet of transparent material on which is drawn a series of concentric circles 52*a*, each circle consisting of alternate clear and darkened areas as in Fig. 4. The rate of alternation increases regularly toward the periphery. The coordinate background of Fig. 4 illustrates the relationship. If light from a spectral line corresponding to a frequency component present in the sound track falls on a given circle, the light passing through the disc will be modulated as it passes over the alternate light and dark areas of its circular path. This arrangement is illustrated in Fig. 5. The rate of modulation will be dependent on the R. P. S. of the prism and on the number of sets of alternate dark and transparent areas in the circular path. For example, a sound frequency of 300 cycles can be made to produce a spectral light point which rotates in a small circle.

Now if this circular path falls on a circle having 10 sets of alternate dark and light areas and if the prism rotates at 6 R. P. S., then a frequency 60 C. P. S. will be produced in the output of the photocell 36. If the R. P. S. is changed to 60, then a frequency of 600 C. P. S. will be produced. Because the pattern or modulation disc can be changed in any manner, it is also possible to produce any division or multiplication ratio thereof. For example, it is possible to diminish the low frequency by factor of 3 and slowly to increase the compression. This is advantageous because of the transient time of speech.

It has been mentioned that it is possible to divide a speech frequency by a factor, for example 3. The output of amplifier 39 (Fig. 5) could then be transmitted by radio or wire and would be less subject to interference because the noise is proportional to the band width in transmission and by sending a reduced band width, a corresponding amount of noise can be filtered off. Such a reduced frequency, after transmission and reception could be sent through the apparatus shown in Fig. 5, in which the rotation of the prism 27 for example is speeded up 300% or alternatively, if the prism stands still, the disc 52 is rotated three times faster than the prism originally rotated. The original frequency of the speech would be thereby restored.

The pattern disc shown in Fig. 4 is not entirely satisfactory because the abrupt changes in the black and white areas will produce square wave impulses containing many harmonics. Sinusoidal light modulation is more desirable and is preferred. A light modulation disc similar to those shown in Fig. 7 can be produced by using the apparatus shown in Fig. 6. Referring to Fig. 6, 50 is an opaque movable plate having a very fine hole through it. If this hole (not shown) is illuminated through a tube 51 with a parallel beam of monochromatic light, the beam will make circles on a disc (photographic plate) 52 when the prism 27 is rotated. If the plate 50 with the hole is moved slowly in a radical direction, a spiral appears on the photographic plate. If the ascendency on the spiral line is very slow so that spiral lines touch each other, the photographic plate will be uniformly black (following development). For production of the light pattern, the light which illuminates the hole must be modulated sinusoidally with slowly increasing frequency. This may be done with a polarized light and a rotating analyzer 53. For the production of the slowly increasing light modulation frequency, a small friction wheel 54 is provided and moved across a constantly rotating disc 55 which is driven by an electric motor 56. One revolution of the disc 55 will be necessary for the purpose of preparing one sinusoidally modulated spiral turn on the pattern disc 52. The rotating analyzer 53 is driven by means of a belt 57 by the small wheel 58 which is connected to the wheel 54 equal diameter by means of a shaft 59. Since the exposure time of the light falling upon the disc 52 decreases with the radius, the light intensity must be regulated by means of a slowly moving absorption glass 60. Both the

plate 50 and the adsorbing glass 60 are driven from the shaft 61 of the electric motor 56. The shaft 61 enters a gear box 62 containing a reduction gear (not shown) which imparts to an extension shaft 63 a slower number of R. P. M. than the speed of the shaft 61. Mounted on the shaft 63 are pulleys 64, 65 and 66 each at a higher level than the preceding. The glass 60 is driven from the pulley 65 and is attached to a fixed base by a spring 67. The plate 50 is driven from the pulley 66 and is attached to a fixed base by a spring 68. The small wheel 54 is moved outwardly from the center of the disc 55 by a cord 69 which is wound over the pulley 64 and tightly attached thereto.

The light which is used in the tube 51 is derived from a monochromatic point source 70 and is condensed by a condensing lens 71, the focal point of which is located at a distance beyond the far side of the absorbing glass 60. By means of lens 73 the light is caused to pass through the polarizing disc 74 and thence through a rotating analyzer 53 thereby modulating the light sinusoidally. Then there will appear on the pattern plate 52 the sinusoidally modulated pattern or disc shown in Fig. 7.

From the foregoing description, it is evident that a new method of radio communication has been described in which a transcription is first prepared of the radio message which is to be sent. This transcription is made a reduced frequency which is considerably lower than the frequency which would ordinarily be transmitted. The frequency should be at least ⅓ lower, but is preferably ½ or even ¾ lower than would be customarily transmitted and also lower by a like proportion to the interference which the radio transmission is likely to encounter. That is to say, that if an enemy jamming transmitter is operating on a frequency of 1,000 C. P. S., the message to be transmitted should first be prepared by transcription to a frequency of from 666 C. P. S. to 250 C. P. S. The message is then transmitted without altering the total length of time that it would have taken to transmit the message before the frequency was reduced. The reduced frequency message is then received, recorded and its frequency multiplied by the same factor as was used in reducing its frequency before transmission, or as near thereto as feasible. The apparatus necessary to make the reduction and multiplication of frequency is not necessarily the apparatus which has been disclosed. Other apparatus, operating upon different principles, for example the principle of heterodyning, acoustic or electrical, can be employed so long as the total time base remains unaltered. This process of transmitting intelligence by radio is specifically claimed in my divisional application filed June 22, 1953, bearing the Serial Number 363,422.

The invention claimed is:

1. Means for analyzing sound waves recorded on a film as a variable area sound track comprising means for illuminating the film with a point source of light to form a line spectrum of light representing component sound frequencies of the illuminated zone of the sound track, means for forming a rotating optical image of the line spectrum, means having a spiral slot for line scanning the rotating spectral image, a photocell for receiving the light transmitted through the scanning means and producing an electrical pulse output representative of the frequency components of the area of the sound track being illuminated.

2. An apparatus for the visible analysis of speech recorded upon tone film in strip form, by vibrating a chisel-edged knife in contact with blackened sound film to remove blackened emulsion therefrom when the knife is being vibrated by a modulating means to produce a tone track bounded on its sides by wavy lines, which includes a source of light, means for arranging light from said source in parallel bundles of rays, means for transilluminating said film and the tone track thereon with the bundle of parallel light rays, a lens for receiving and condensing the diffracted light which has passed the tone track, a first screen having a slit arranged at the focal point of said lens to pass the light from only one side of said tone track, lens means for amplifying the image which passes said first screen, a prism positioned to receive the light passed by the amplifying lens means, a variable speed electric motor for rotating said prism whereby to convert the prism received light into a succession of circles, at least two conductors supplying said motor with electric current, a second screen in which there is an Archimedean spiral slot positioned to intercept the concentric circles of light produced by rotation of the prism, a condensing lens positioned behind the second screen to receive the light passed through said slot, a photocell positioned at the focus of said last-mentioned condensing lens to generate electrical pulses from the light pulses received, an electrical amplifier for said electrical pulses, a kinescope of the cathode ray tube type having a pair of electrostatic plates to receive said impulses and a second pair of electrostatic plates at right angles thereto, a sawtooth wave-generating oscillator energized from the conductors supplying the electric motor, said sawtooth wave being applied to said second pair of electrostatic plates, whereby said pulses will be rendered visible in a form similar to spectroscopic presentation.

3. Means for altering the frequency of a succession of sounds recorded on film as a variable area sound track comprising means for illuminating an area of the film with a point source of light to form a line light spectrum representing the component sound frequencies of the illuminated zone of the sound track, means for rotating an image of the line spectrum at a constant predetermined speed, a filter adapted to pass light from said rotating spectrum image, said filter having concentric filter bands, each band having alternate transparent and opaque sectors such as to pulse the light received from the rotating spectrum image by a desired factor and photoelectric means for converting the light pulses into electrical pulses of the desired altered frequency.

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