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C. D. LINDRIDGE

METHOD AND APPARATUS FOR RECORDING AND REPRODUCING SOUND

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Fig.2

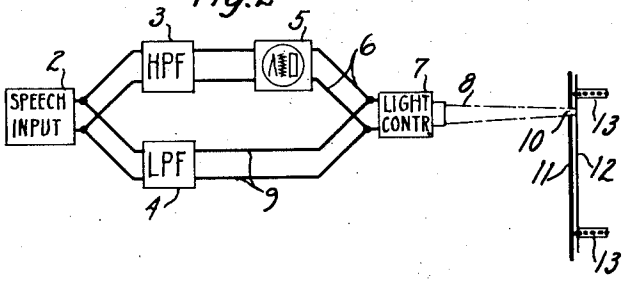

Fig.1

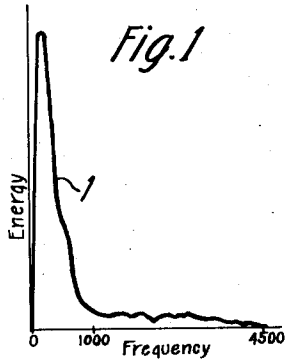

Fig.3

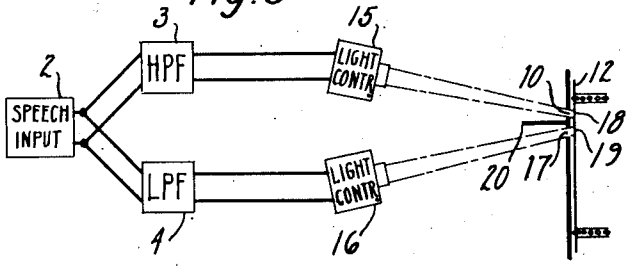

Fig.4

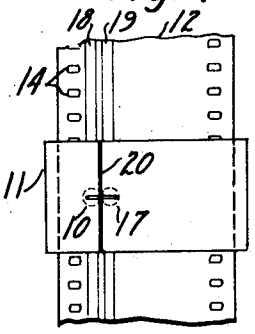

Fig.5

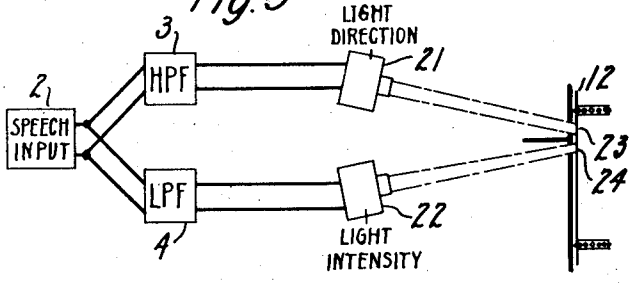

Fig.6

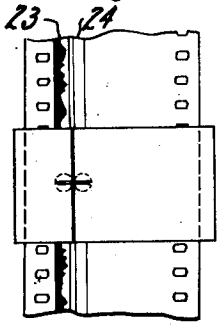

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Fig. 7

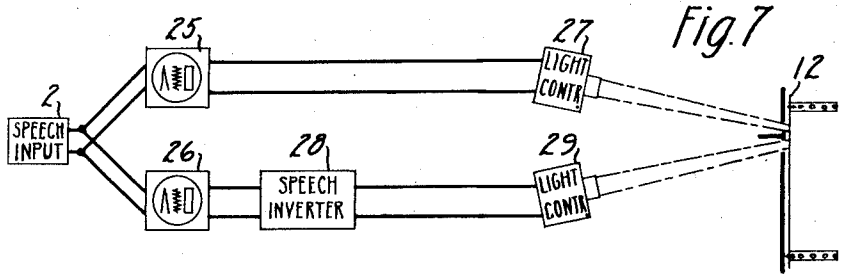

Fig. 8

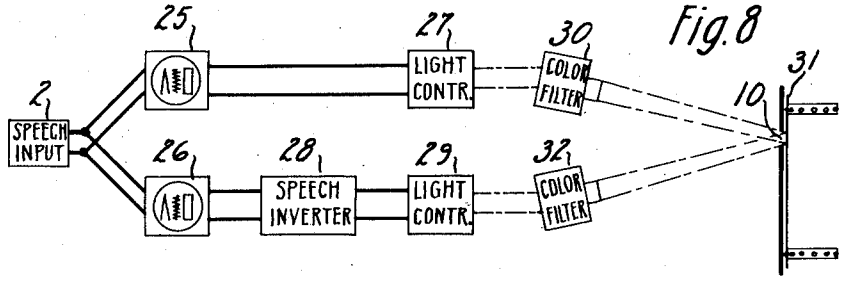

Fig. 9

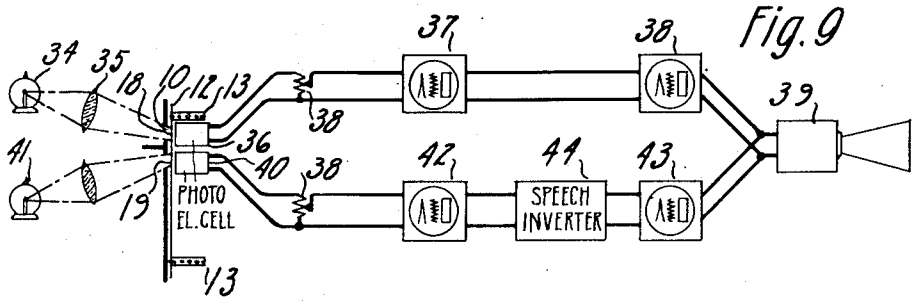

Fig. 10

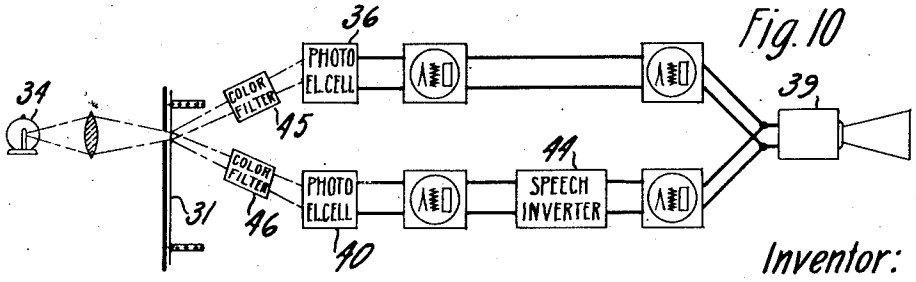

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Fig. 11

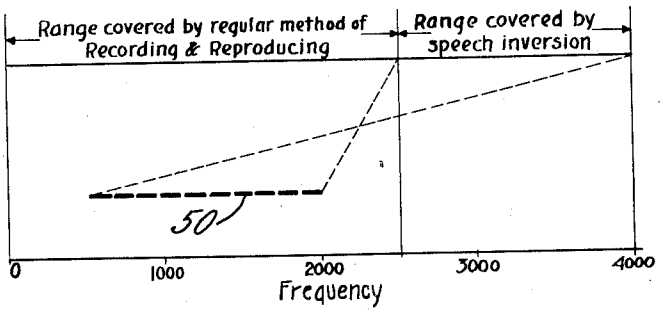


Fig. 12

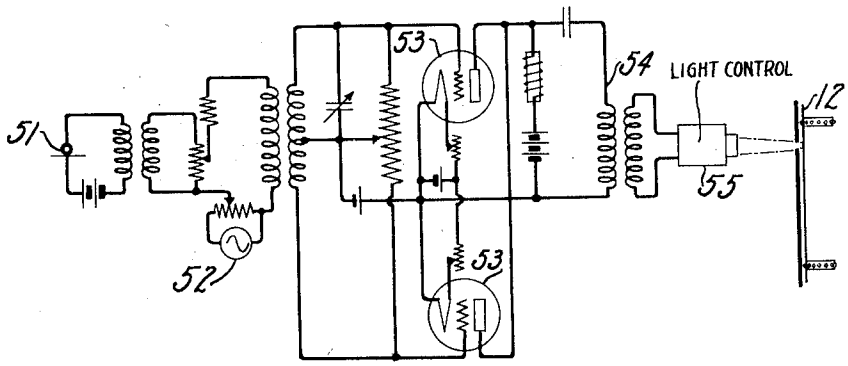
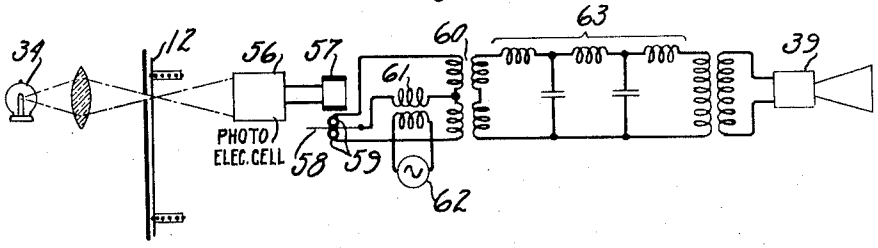


Fig. 13



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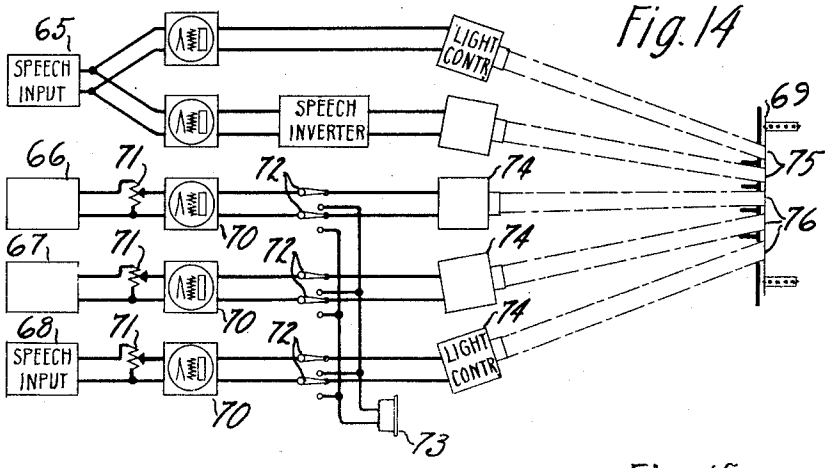

Fig. 14

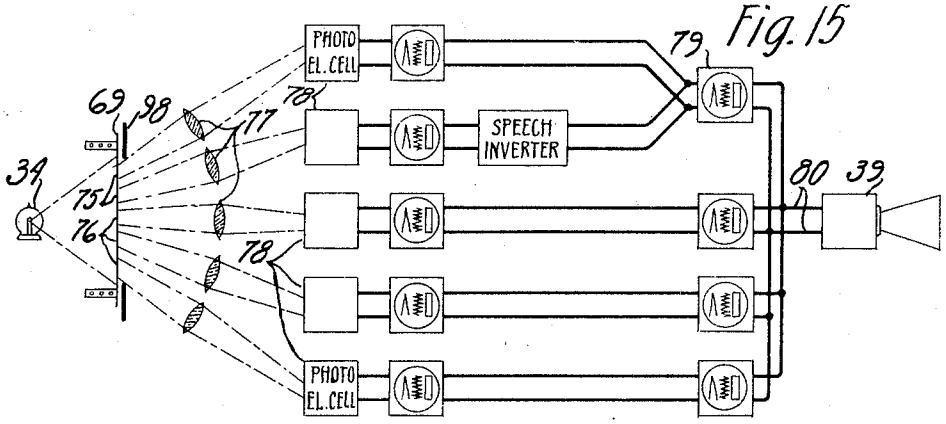

Fig. 15

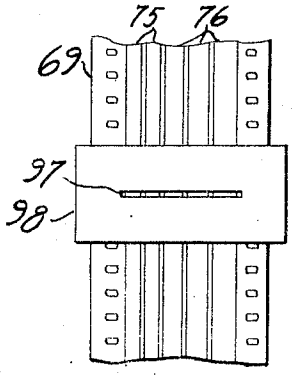

Fig. 16.

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METHOD AND APPARATUS FOR RECORDING AND REPRODUCING SOUND

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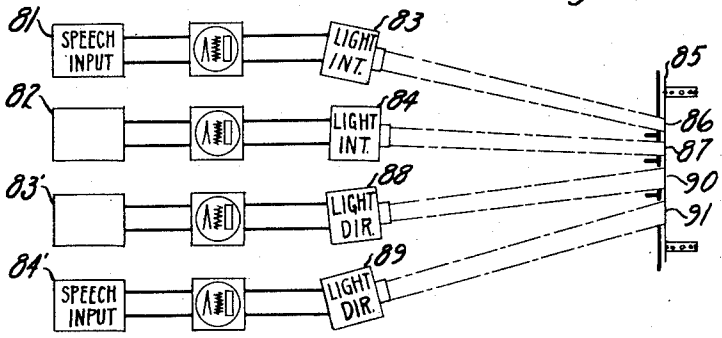
Fig. 17



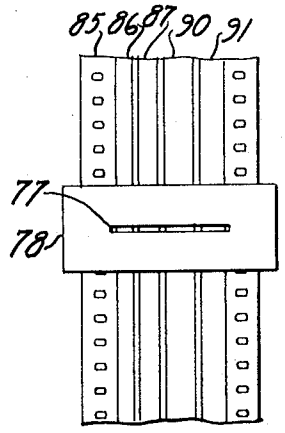
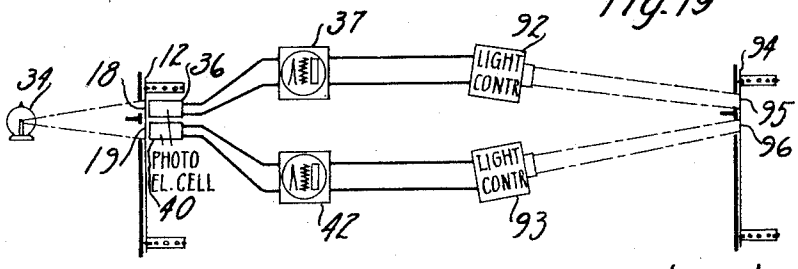


Fig. 18

Fig. 19



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UNITED STATES PATENT OFFICE.

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METHOD AND APPARATUS FOR RECORDING AND REPRODUCING SOUND.

Application filed June 20, 1924. Serial No. 721,360.

This invention relates to the art of transmitting, recording and reproducing speech, music and other sounds or waves, and particularly to photographically recording sound on a film and reproducing sound therefrom.

It has been found that when speech is recorded on a moving picture film by exposing the film to light, the intensity of which is varied in accordance with the speech, and is thereafter reproduced, the speech reproduced from the record is often distorted. The record on the film consists of a series of relatively opaque areas separated by relatively transparent areas. The sounds of low frequency produce relatively long areas upon which are superposed comparatively short areas corresponding to the high frequency sounds. The contrast between successive transparent and opaque areas corresponding to the high frequency sounds, in general, is reduced by the masking or obliterating effect of the background formed by the record of the low frequency waves, the contrast being especially poor in the opaque areas of the low frequency record. The reproduced high frequency sounds consequently have a smaller amplitude than they should relatively to the low frequency sounds, and the reproduced speech is distorted.

The distribution of energy in the frequency spectrum of ordinary speech is such that a very large proportion of the energy lies in the low frequency range or fundamental frequencies, the high frequency sounds, or harmonics, being relatively weak and producing only a feeble record in comparison to the low frequency sounds. The high frequency record is accordingly very susceptible to the masking effect of the low frequency record.

According to another well known method, speech waves are recorded on a moving picture film as variations in the width of a record of constant transparency or opacity. This method, as practised, has the disadvantage of requiring large space for the record on the film. The average amplitude of the high frequency waves in speech is so much smaller than that of the low frequency waves that when the high frequency waves produce a record of smallest practicable width, the low frequency waves spread over an undesirable width of the film. The accuracy of reproduction of the low frequency sounds is not improved in proportion to the space occupied by the record and an appreciable portion of the space utilized by the low frequency waves may be considered uneconomical, especially when the rounds are recorded on a moving picture film where as large a space as possible should be reserved for pictures.

In addition to the above described difficulties and objections, it is found that various parts of the apparatus usually employed for recording and reproducing sound is incapable of operating as efficiently at high frequency as at low frequency, the result being that the reproduced high frequency sounds are disproportionately weaker than the reproduced low frequency sounds, thus causing objectionable distortion of speech.

Objects of the present invention are: To overcome the above difficulties; to efficiently record and reproduce speech, music and other sounds or waves having components relatively remote from each other in the frequency scale, so that the reproduced waves closely conform to the original waves; to conveniently control the relative amplitudes of the wave components; to more effiectively utilize the space occupied by the record on a photograph film, such as a moving picture film; to automatically produce a secondary record for a primary record and to readjust different portions of the record; to efficiently transmit sound by means of light rays; and generally to provide simple and reliable methods and apparatus of the kind referred to.

In accordance with one aspect of the present invention, speech, music and other sounds or waves are recorded on a photographic film, or other element, by separately transmitting over different paths components of the waves within different freqeuncy ranges. The components are recorded and photo-electrically reproduced separately or together and transmitted to responsive apparatus, for example a telephone receiver. During these operations the quality of the reproduced waves may be controlled as desired by changing the relative amplitudes, frequencies or other characteristics of the waves in the different ranges.

According to another feature of the in-

vention, waves to be recorded are transmitted to a modulator wherein they modulate a carrier wave and undergo a frequency change. Unmodulated components of modulating and carrier wave frequency are suppressed, and modulated components are recorded on a photographic film or other element. Upon reproduction the modulated waves are demodulated. When speech or similar sounds are to be recorded on a narrow section of film, waves in only the lower portion of the frequency spectrum of the modulated waves, or waves principally of inverted frequency, are recorded in such a manner that they can be satisfactorily reproduced. The record of the modulated waves may be supplemented by a separate record of the lower frequency component waves.

When different wave components are separately recorded on a film the space allotted for the record of the high frequency components may be of the same width as, but is preferably of greater width than that of the low frequency components. When relatively high and low frequencies are to be recorded, a record of the low frequencies may be made on the film as variations in the transparency of a strip of uniform width and a record of the high frequencies may be made as variations in the width of a strip of uniform transparency or opacity. By making separate records in different colors and utilizing color selection in reproducing the waves, the records may be superposed on each other without causing interference of the waves.

Secondary or master records are automatically made by reproducing waves from one or more primary records and recording the reproduced waves on the secondary record after adjustment of their relative intensities. The reproducing and recording operations are similar to those employed when the waves are first recorded and then reproduced.

These and other features and objects of the present invention will be understood more clearly in connection with the following detailed description in view of the accompanying drawings, in which:

Fig. 1 is a graph showing the distribution of energy in the frequency spectrum of ordinary speech.

Figs. 2, 3, 5, 7, 8, 12, 14 and 17 are diagrams of different modifications of apparatus for recording waves on a moving film.

Figs. 4, 6, 16 and 18 are fragmental side views of films bearing records produced in the apparatus of Figs. 3, 5, 14 and 17 respectively.

Figs. 9, 10, 13 and 15 are diagrams of different modifications of apparatus for reproducing waves from a film.

Fig. 11 is a graph showing the relation of inverted speech frequencies to the uninverted frequencies.

Fig. 19 is a diagram of apparatus for producing a secondary record from a primary record.

Referring to Fig. 1, the curve 1 was obtained from a study of the energy distribution of sound in normal speech. The abscissæ of the curve represent wave frequencies in speech and the ordinates represent the energies of the respective waves. It will be seen that there are two fairly clearly defined frequency ranges in curve 1. The lower range embraces all the fundamental frequencies of normal speech and the upper range embraces all the frequencies necessary for clear reproduction of speech. It will also be noted that a very large proportion of the total energy lies in the lower frequency range, below 1000 cycles, the waves in the higher frequency range being relatively weak.

In Fig. 2 the apparatus is arranged to make use of the relationship shown in Fig. 1 between the energy and frequency of waves to be recorded. Electrical waves from the speech input 2 are separated into a high frequency range and a low frequency range by means of a high pass filter 3 and a low pass filter 4, respectively, of any well known suitable type. The filter 3 efficiently transmits waves having a frequency in excess of about 1000 cycles per second and prevents the transmission of appreciable current of lower frequency, while the filter 4 efficiently transmits waves having a frequency below 1000 cycles per second and prevents the transmission of appreciable current of higher frequency. If desired filters 3 and 4 may be designed to separate frequencies above and below some critical frequency other than 1000 cycles. The waves of high frequency are transmitted to the amplifier 5 conventionally shown as being of the space current type but which may be of any well known type capable of amplifying waves without substantial distortion. The output circuit 6 of the amplifier is connected to the light control element 7 of any well known construction capable of transmitting a beam of light 8, the rays of which either vary in intensity or in direction in accordance with the electric potentials impressed upon the element.

The output circuit 9 of filter 4 is connected in parallel with the amplifier output circuit 6. High frequency waves from circuit 6 and low frequency waves from circuit 9 are thus transmitted together to the light control element 7 to produce light variations corresponding to the impressed waves. The light variations are transmitted through a narrow slit 10 Figs. 2 and 4 in an opaque screen 11 in front of the moving picture film, or film of other type 12, which is longitudinally moved transversely to the beam of light 8 by rotating spur gears 13 meshing with perforations 14 in the film or similar

means. The speech input 2 in Fig. 2, and in any of the figures, may be a source of electric waves corresponding to speech, music and other sounds or waves having components relatively remote from each other in the frequency scale.

In operating the apparatus shown in Fig. 2, high frequency waves from the source 2 are transmitted separately from the low frequency waves, the high frequency waves being transmitted through filter 3 and amplified by amplifier 5 and transmitted in amplified form to the light control element 7. The low frequency waves are transmitted through filter 4 and circuit 9 to element 7 without amplification. The amplified high frequency waves and the unamplified low frequency waves together produce variations in the light rays 8 corresponding to the waves from source 2 and produce a photographic record on film 12.

When the light variations consist of variations in the intensity of a beam of light of constant width, the record produced consists of a series of variations in the transparency of the film corresponding to the intensity variations of the light. When the light variations consist of variations in the direction of a beam of light of constant intensity, variable portions of the beam are screened from the film by screen 11, and the record consists of a band of uniform transparency or opacity, varying in width in accordance with the variations of light direction.

The amplification of the high frequency waves by amplifier 5 is adjusted to any desired value such that the high frequency waves are recorded with the proper intensity in relation to the low frequency waves. Preferably the amplification is adjusted to such a value that the high frequency waves may be reproduced from the record with the same amplitude in relation to the reproduced low frequency waves as that existing between the high frequency and the low frequency waves transmitted from source 2. After the film has been exposed to the light variations, the record is photographically developed, so that it becomes permanent and ready for reproduction.

In Fig. 3, the source 2 transmits waves selectively through filters 3 and 4. The high frequency waves transmitted through filter 3 operate light control element 15, while the low frequency waves transmitted from filter 4 operate the light control element 16 so that separate beams of light, corresponding respectively to the high frequency waves and the low frequency waves, are transmitted to the film 12 through slits 10 and 17 respectively, producing the records 18 and 19 parallel to each other on film 12. The dotted lines, encircling slits 10 and 17, Fig. 4 represent the edges of the areas illuminated by light from elements 15 and 16, Fig. 3. The partition 20 screens from record 19 the light intended for record 18 and vice versa. By separately transmitting light variations corresponding respectively to the high frequency waves and the low frequency waves a better and more sharply contrasted record of the high frequency waves is obtained than when the high frequency and low frequency waves are recorded together as in Fig. 2, and the obliterating effect of the low frequency record on the high frequency record is avoided. Records 18 and 19 are preferably disposed as shown adjacent the margin of film 12 so that the center space on the film may be utilized for moving pictures synchronized with the recorded sounds, for example, speech or music. Filters 3 and 4 in Fig. 3 are of the same design as those in Fig. 2.

In Fig. 5, the light control element 21 produces variations in the direction of the beam of light in accordance with the high frequency waves transmitted from sources 2 through the high pass filter 3, while the light control element 22 produces variations in the intensity of light corresponding to low frequency waves from the source 2 transmitted through low pass filter 4. The light variations from elements 21 and 22 are separately recorded on the film 12, and are preferably so adjusted that the high frequency record 23 is of greater width than the low frequency record 24, as shown in Fig. 6. By allotting a larger space for the high frequency record, the high frequency waves may be more accurately reproduced than if restricted to as small an area as the low frequency record. By recording the low frequency waves as variations in the transparency of the film it is possible to restrict the width of the low frequency waves to such a narrow strip on the film that the total width of the two records is less than that of the single record produced by the apparatus of Fig. 2. At the same time the quality of the reproduced waves is higher than that obtainable when the waves are recorded by the apparatus of Fig. 2.

In Fig. 7, waves from the source 2 are transmitted to amplifiers 25 and 26. Amplified waves from the output circuit of amplifier 25 are transmitted to the light control element 27, which in turn produces variations of light in accordance with the waves from source 2, these variations being recorded on film 12. Owing to limitations in the wave transmission characteristics of photoelectric cell used in reproduction when subjected to light variations from a narrow section of film, only those waves having frequencies lying below approximately 2500 cycles are efficiently reproduced from the film. Element 27, together with the associ-

ated apparatus may be looked upon as a frequency selective element which permits only those frequencies lying below, say approximately 2500 cycles, to be recorded on the film so that the frequencies may be effectively reproduced.

In order to reproduce a record corresponding to waves having a frequency in excess of 2500 cycles, amplified waves from the output circuit of amplier 26 are transmitted to the speech inverter 28, wherein the frequency spectrum of the waves from source 2 is inverted, as by a modulating operation with the elimination of unmodulated components of carrier wave and modulating wave frequency. When speech is to be recorded, the carrier wave frequency is preferably of the order of 4500 cycles, that is, of the order of the highest speech frequencies. A specific form of inverter circuit is disclosed in connection with Fig. 12. The inverted or modulated waves from inverter 28 are transmitted to light control element 29 which produces light variations corresponding to the waves from source 2 but having frequencies arranged in reverse order from that in which they occur in the output circuit of source 2. These light variations are recorded beside the record of light variations from element 27. Element 29, together with the associated apparatus is similar to element 27 in functioning as a frequency selective element which permits only those frequencies below, say approximately 2500 cycles, to be effectively recorded. However, since the waves of inverted frequency, below 2500 cycles, corresponds to original frequencies above 2000 cycles, it will be seen that the resulting record of the inverted waves is really a record of original waves in the high frequency range above 2000 cycles, the record of the uninverted waves together with the record of the original uninverted waves constituting a complete record of the waves from source 2.

Fig. 8 shows the source 2, amplifiers 25 and 26, speech inverter 28, and light control elements 27 and 29, as in Fig. 7. Light rays from element 27 are transmitted through the color filter 30, which selectively transmits light of one color to the exclusion of light of other colors, the transmitted light being recorded on the film 31. Light from element 29 is transmitted through the color filter 32, which selectively transmits light of a different color from that of filter 30 to the exclusion of other colors, the transmitted light being directed through the same slit 10 as the light transmitted through filter 30. Film 31 is designed to produce colored records corresponding respectively to the colors of the light transmitted to the film. This may be any of the well-known types of films sensitive to colored records, such as for example, that described on page 268 of Behind the motion picture screen by A. C. Lescarboura, Scientific American Publishing Company. For example, if blue light be transmitted from element 30 and yellow light be transmitted from element 32, film 31 is designed to respond selectively to these colors and produce corresponding records in blue and yellow colors superposed on each other. By superposing the separate records considerable space is saved on the film, the space between the records 18 and 19, Fig. 4, being saved as well as that occupied by one of these records 18 and 19. This method of recording separate colored records superposed on each other is obviously applicable to the methods described in connection with Figs. 3 and 5.

Fig. 9 shows apparatus for reproducing waves from one or more records 18 and 19 on film 12. When the record is produced by the method described in connection with Fig. 2, only a single strip, or record 18, of exposed area on the film, is utilized in the reproduction of waves from the record. Film 12 is longitudinally moved by rotating spur gears 13, as in Fig. 2, the record 18, which for the present may be assumed to have been produced by the apparatus shown in Fig. 2, is illuminated on one side by light from the incandescent electric lamp, or other source of light 34. Lens 35 concentrates the light on the film through a slit 10, corresponding to that in Fig. 2, registering with record 18. As the film moves transversely to the light from source 34, light is variably transmitted to photo-electric cell 36, these variations in light corresponding to variations in the transparency of the record 18.

Photo-electric cell 36, which may be of any well known suitable design capable of producing electric waves in accordance with variations of the light impressed on the cell, transmits the waves to amplifier 37, the amplification of the reproduced waves being adjusted by means of potentiometer 38, or other suitable gain control apparatus. Amplified waves from the output of amplifier 37 may be still further amplified to any desired extent by other amplifiers such as amplifier 38, the output of which is connected to the wave responsive device 39, of any suitable form, conventionally represented in the drawing as a loud speaking telephone receiver. Considering Fig. 2 in connection with upper path of Fig. 9, it will be noted that the relative amplitudes of waves in the high frequency range and the low frequency range may be adjusted relatively to each other by controlling the amplification in amplifier 5, so that the distortion of waves in the course of transmission from source 2 to device 39 is substantially compensated, and the sound reproduced by device 39 conforms closely to the sound or other energy giving rise to the waves from source 2.

When reproducing waves recorded by apparatus shown in Fig. 3 wherein two records are arranged side by side on the film, the separate records 18 and 19 may be reproduced by separate photo-electric cells or by a single cell. When separate cells are used, high frequency waves are reproduced from record 18 as already described, while low frequency waves are reproduced from record 19 by photo-electric cell 40 in a manner similar to that described in connection with cell 36, the source of light 41 transmitting light through record 19 to produce variations in the excitation of cell 40 in accordance with the variations of transparency in the record. Waves from cell 40 are transmitted through amplifiers 42 and 43. The speech inverter 44 is omitted when reproducing waves recorded by the apparatus of Fig. 3. Amplified waves from devices 38 and 43 are transmitted together to the receiver 39, which reproduces the waves in the form of sound corresponding to the original sound from source 2, Fig. 3.

By means of the gain control apparatus 38, the relative amplitudes of waves in the high frequency and low frequency ranges, respectively, are adjusted to compensate for distortion produced in the apparatus between source 2 and receiver 39. If desired, cell 40 and its connections to receiver 39 may be omitted, cell 36 being so disposed as to respond to variations of the light transmitted through both records 18 and 19, thus affording a simpler form of reproducing apparatus. If desired, one of the sources 34 or 41 may be omitted and light from the other source directed through both records 18 and 19, as shown in Fig. 19.

Waves recorded by the apparatus shown in Fig. 5 may be reproduced by the apparatus of Fig. 9, in the manner just described in connection with Fig. 3. It will be noted that record 23 consists of an exposed strip of constant transparency or opacity and of varying width, whereas record 24 consists of a strip of constant width and of varying transparency. The beam of light transmitted through record 23 accordingly varies in width rather than in intensity but produces a similar excitation of photo-electric cell 36 as that produced by the light of varying intensity transmitted through record 24. Owing to the greater width of record 23 and to the method by which the waves are recorded, the reproduced high frequency waves are of better quality than if recorded by the method used in producing record 24. At the same time the method used in producing record 24 saves space on the film without detriment to the quality of the reproduced low frequency waves.

When the record is produced by the apparatus shown in Fig. 7, the waves may be reproduced by the apparatus shown in Fig. 9, the records 18 and 19 corresponding respectively to the record of the unmodulated waves and the record of the inverted or modulated waves. Record 18 is reproduced in the manner already described, the reproduced waves being transmitted to receiver 39. Inverted or modulated waves reproduced from record 19, are transmitted from cell 40 to amplifier 42 and speech inverter 44, which may be of any suitable type, such for example, as speech inverter 28, Fig. 7. Inverter 44 inverts or demodulates the inverted or modulated waves and restores them to the original frequencies of the waves from source 2 to which they correspond. The demodulated waves are amplified by amplifier 43 and transmitted to receiver 39 where they supplement the action of waves from amplifier 38. Inasmuch as the entire range of wave frequencies from source 2, Fig. 7, are recorded and reproduced in Fig. 9, at relatively low frequencies as compared to the highest frequencies of the original waves to be recorded and of the final reproduced waves, the waves transmitted to receiver 39 are comparatively free from distortion such as would be encountered if the waves in the high frequency range were transmitted without frequency change and without inversion. Other features of the method of and apparatus for recording and reproducing waves by modulation are described in connection with Figs. 11 and 12.

Fig. 10 shows reproducing apparatus for use in conjunction with the recording apparatus of Fig. 8. Source 34 transmits light through the superposed colored records on film 31. Color filter 45 selectively transmits one color to the exclusion of other colors, and, in the example cited, where blue and yellow records are superposed, transmits only blue light which excites photo-electric cell 36 corresponding to cell 36, Fig. 9. Color filter 46 selectively transmits colored light from the other record, exclusive of all other colors, and, in the example cited, transmits yellow light to photo-electric cell 40, corresponding to cell 40, Fig. 9. Waves from cells 36 and 40 are transmitted to receiver 39 in the manner described in connection with Fig. 9, the inverter 44 inverting or demodulating the waves from cell 40 before transmission to receiver 39. Except for recording and reproducing the records by color selection, the operation of Fig. 8 in connection with Fig. 10 is similar to that of Fig. 7 in connection with Fig. 9. The principles of recording and reproducing in colors, as described, may be applied to Figs. 3 and 5 in connection with Fig. 10, similarly to the manner in which they have been applied to Figs. 7 and 9.

Fig. 11 shows diagrammatically the frequency relationship between the original waves from source 2, and the inverted waves

of most importance, produced by inversion of the frequency spectrum of the original waves. The abscissæ indicate frequencies. The range extending from substantially zero to 2500 cycles is readily recordable and reproducible by well known methods. The range from 2500 cycles to 4000 cycles, is important in determining the clearness of articulation of speech and the quality of music, but is of too high frequency to be suitably recorded and reproduced by ordinary methods. By modulating a carrier wave of 4500 cycles in accordance with speech waves, the waves of inverted frequency corresponding to the range extending from 2500 cycles to 4000 cycles, are reduced in frequency, and at the same time the frequency spectrum of the original waves from 2500 to 4000 cycles is inverted, so that a wave having an original frequency of 2500 cycles becomes a wave of 2000 cycles upon inversion, and an original wave of 4000 cycles frequency becomes a wave of 500 cycles frequency. The heavy dashed horizontal line 50 represents the extent and location of the inverted waves in the frequency scale. The oblique dashed lines extend from components before inversion to the corresponding components after inversion, showing graphically the inverted relationship.

Fig. 12 shows a well known arrangement for inverting or modulating sound waves, the modulating apparatus being of the type disclosed in detail in U. S. Patent to R. V. Hartley 1,419,562 of June 13, 1922. The telephone transmitter 51 produces electric waves corresponding to the sound impressed thereon. These waves, together with carrier waves from the local source 52, preferably of 4500 cycles when speech is to be recorded, are transmitted to the balanced modulating tubes 53. As described in the patent cited, tubes 53 are so associated, that only waves of modulated frequency appear in output circuit 54, the unmodulated waves of modulating frequency from source 51 and of carrier frequency from source 52, being suppressed without transmission through circuit 54. Modulated waves from circuit 54 are transmitted to the light control element 55 of similar construction to that of light control element 7, Fig. 2, which transmits light variations to film 12 whereon a corresponding record is produced. Owing to the transmission characteristics of the recording and reproducing apparatus, the lower frequencies are more satisfactorily recorded on film 12 than the higher frequencies. However, by inversion before recording and reinversion upon reproduction the higher frequencies are satisfactorily reproduced. The record on the film may be affected by the low frequencies in the upper side band of the modulated waves. The presence on the record of the low frequencies in the upper side band is not objectionable, since demodulation of the upper side band produces the same frequencies as demodulation of the lower side band.

It is obvious that the modulating or inverting apparatus of Fig. 12 may be utilized in place of the speech inverter shown in any of the preceding Figs. 7, 8, 9 and 10.

Fig. 13 shows apparatus for reproducing speech, or sounds corresponding to those actuating transmitter 51 and recorded on record 12, Fig. 12. Light from source 34 is concentrated on the film and transmitted therethrough to photoelectric cell 56, from which waves are transmitted to the coil 57 which magnetically vibrates the elastically restorable conducting member 58 between the microphonic contacts 59. Contacts 59 are connected respectively to opposite ends of the primary winding of transformer 60, the mid-point of which is connected through transformer winding 61 to member 58. The local source of carrier waves 62, of the same frequency as waves from source 52, is coupled to winding 61. Coil 57 together with elements 57 and 62, inclusive, constitute a balanced demodulator of well known form in which, waves impressed on coil 57 are demodulated, the demodulated waves being transmitted to the secondary winding of transformer 60. Filter 63 of well known construction is designed to suppress the transmission of waves from source 62 and to efficiently transmit demodulated waves of other frequencies corresponding to waves from source 51. Demodulated waves are transmitted to receiver 39, which produces sound corresponding to that acting on transmitter 51, Fig. 12.

Fig. 14 shows recording apparatus particularly adapted for high quality work, and intended especially for use in recording music and sounds of different origin and kind. The sounds may consist of vocal, or instrumental sounds, or music, with a piano, orchestra, or other accompaniment. The plurality of sources 65, 66, 67 and 68, each adapted to pick up music from an individual singer, or instrument, or group of sound sources of similar kind, are arranged to produce separate records on the film 69. When vocal or instrumental music is to be recorded with an accompaniment, source 65 may be made responsive to the principal music, vocal or instrumental, without the accompaniment, and sources 66, 57, etc., being made responsive respectively to the different classes of sounds in the accompaniment. When an orchestral or concert selection is to be recorded, sound sources of similar character may be grouped and arranged to produce waves in a single wave source 65 or 66, and so on. Source 65 is connected to apparatus, such as shown connected to source 2 in Fig. 7, and produces a record corresponding to waves of unmodulated frequency in

the lower frequency range of the original waves, and a separate record of inverted waves corresponding to original waves in the higher frequency range. Source 65, together with its connected apparatus, is therefore particularly adapted for recording vocal music or sounds, or instrumental sounds of corresponding range.

Sources 65, 66, 67 and 68 are similar to each other and non-microphonic in character so as not to pick up sounds at a distance and each being connecting to apparatus for producing a separate record on film 69. Each of these sources is connected to an amplifier 70, the amplification of which is adjusted by means of a potentiometer 71, individual to the amplifier. Before recording is begun the two pole switches 72 are thrown to the lower position connecting the amplifiers to the telephone receiver 73, by means of which the relative intensities of waves from the different sources may be observed, and proper adjustment of potentiometers 71 made, so that the waves from the separate sources will be recorded with the proper relative intensities, or, in other words, so that waves may be reproduced from the record in a well balanced relationship. Switches 72 are then placed in their upper positions establishing connection between amplifiers 70 and light control elements 74, which transmit light producing separate records on film 69.

The width of the separate records is preferably adjusted, for reasons already given, so that the waves of higher frequency are recorded as a wider strip than the records of waves of lower frequency; for example in the case of film 69, Figs. 14 and 16, it is assumed that sources 66, 67 and 68 respond to waves of relatively higher frequency. Records 75 corresponding to waves from source 65 are records of low frequency waves, it being recalled that the high frequency waves from source 65 are reduced in frequency by inversion and recorded in inverted form as waves of low frequency. Records 76, corresponding to waves of relatively higher frequency from sources 66, 67 and 68, are wider than records 75.

Fig. 15 shows apparatus for reproducing waves from film 69, the film being shown in more detail in Fig. 16. In reproducing the waves from record 69, light from source 34 is transmited through the film and the long slit 97 in the opaque screen 98. Lenses 77 are positioned so that light from a single record is focused exclusively on a corresponding photo-electric cell 78, thus selectively concentrating the light from any given record on a corresponding photo-electric cell and excluding the light from any other record. The upper two photo-electric cells are connected to apparatus corresponding to that shown connected to cells 36 and 40, Fig. 9, with the exception that a common amplifier 79 is substituted for separate amplifiers 38 and 43, Fig. 9. The lower three cells 78, Fig. 15, are connected to apparatus similar to the uppermost cell 78, Fig. 15, the waves from all of the cells being transmitted after amplification to a common input circuit 80 for receiver 39. The operation of the individual circuits connected to photo-electric cells 78 is similar to that already described in connection with Fig. 9.

One advantage of recording and reproducing sounds by the apparatus of Figs. 14 and 15, results from the separate recording of different kinds of sounds, particularly the recording of the low frequencies separately from the high frequencies whereby the resulting record is free from the obliterating effect of the low frequencies on the high frequencies. Another advantage is that larger light variations are obtainable than is possible when using a single light varying element for a wide range of frequencies, a further advantage being that a well balanced record can be easily made. Potentiometers 71 afford convenient means for adjusting the loudness of the sounds from any particular source without requiring moving of the sound transmitter. By providing in the output circuit of cells 78, Fig. 15, potentiometers such as potentiometers 38 shown in Fig. 9, the intensity of sounds in the different frequency ranges and from the different sources may be adjusted after record 69 is made, to obtain the desired combined sound from receiver 39. If desired, a single photo-electric cell may be subjected to the light from the records of the unmodulated waves, the output of the cell being connected to receiver 39, as shown in the circuit connected to the uppermost photo-electric cell 78, Fig. 15, thus providing a simpler form of reproducing apparatus.

The cost of recording sound by the multiple record method, while apparently large, may, in many instances, be justified, or actually prove to be less than that involved in producing a single record from a single light control element, for the reason that when a single record is made to represent a large number of sounds, and the record is found to be defective due to lack of balance between the different components of sound, it is necessary to bring the artists and operators to the studio a second time in order that the record may be remade. A multiple record made in accordance with the principles of the present invention avoids this difficulty in that the proper relationship between the wave components of the sound may be readjusted upon reproduction.

Fig. 17 shows a plurality of wave sources 81, 82, 83 and 84, arranged similarly to sources 65, 66, etc., Fig. 14, each wave source being responsive to a different sound source. In order to obtain very high quality of re-

production of the original sounds, waves from sources 81, 82, etc., after suitable amplification, are recorded by different methods according to the frequencies of the waves to be recorded, each method being chosen in view of its particular effectiveness for recording the particular range of frequencies concerned. The method of operation is similar to that described in connection with Figs. 5 and 6.

In the specific arrangement shown, sources 81 and 82 are assumed to transmit waves of relatively low frequency. These waves are efficiently recorded by light control elements 83 and 84 respectively, which transmit to film 85, narrow beams of light of constant width, the intensities of which vary in accordance with the waves from the associated wave sources. The resulting records 86 and 87 are comparatively narrow. It is assumed that sources 83′ and 84′ transmit waves having higher frequency components than those from sources 81 and 82. In order to obtain an efficient record of the high frequency waves, so that they may be reproduced with proper intensity in relation to waves reproduced from records 86 and 87, the light control elements 88 and 89, connected respectively to sources 83′ and 84′, are of the type in which the direction of the beam of light varies in accordance with the waves impressed thereon. Records 90 and 91 produced by light variations from elements 88 and 89, therefore, consist of exposed strips of constant transparency or opacity, the widths of the strips varying respectively in accordance with waves from the associated sources 83′ and 84′.

Fig. 18 shows the film 85, bearing the narrow records 86 and 87, consisting of exposed strips of varying transparency, and the exposed strips 90 and 91 of varying width. The opaque screen 78, having a slit 77 registering with all of the exposed strips, functions similarly to the corresponding parts in Fig. 16. Reproduction of waves from records 86, 87, 90 and 91 is accomplished by apparatus of the kind described in connection with Fig. 15.

Fig. 19 shows apparatus arranged to automatically produce a secondary or master record from a primary or preliminary record, or, in other words, to transfer one or more records from one film to another. The source of light 34 illuminates the film 12, transmitting light through the film and exciting the photo-electric cells 36 and 40 in the manner described in connection with Fig. 9. Instead of connecting the output circuit of amplifiers 37 and 42 to a single responsive element 39, as shown in Fig. 9, separate light control elements 92 and 93 are connected respectively to these amplifiers to respond to the impressed waves and transmit light variations to film 94 and produce separate records 95 and 96 thereon, corresponding to records 18 and 19 on film 12. By varying the amplification of amplifier 37 with respect to that of amplifier 42, as described in connection with Fig. 9, waves in the two different ranges represented by records 18 and 19 may be readjusted with respect to each other so that a better balance is obtained in records 95 and 96. In adjusting the amplification of amplifiers 37 and 42, use may be made of the method disclosed in connection with receivers 73, and switching arrangements 72, Fig. 14, to permit of intercomparison between the waves in the separate circuits. After proper adjustment of the amplification, film 12 may be run off with film 94, whereby a revised record on film 94 is automatically produced.

It is to be understood that film 12, as originally recorded, is ordinarily in the form of a negative, while film 94 is also a negative. The film distributed to exhibitors, such as motion picture exhibitors, for use in speech, music or sound reproducing projecting machines at motion picture theaters, or elsewhere, would ordinarily be positive films made as prints from the negative films. Film 94 is used as a master record from which any number of positive records may be printed for distribution. The transfer apparatus, shown in Fig. 19, makes it possible to conveniently revise a record or a plurality of records obtained from a concert, or the rendering of a musical selection, particularly where, under the circumstances, it is either impossible or objectionable to repeat the original recording process. The method disclosed permits of balancing the volume of an accompaniment to a solo, or of one part of the orchestra to the remainder, and so on.

While specific methods and arrangements utilized in the transmission, recording and reproduction of sounds and other waves have been described, it is to be understood that these specific forms are susceptible to various other obvious groupings, associations and uses than those specifically mentioned. Novel features of the invention are set forth in the appended claims.

What is claimed is:

1. In apparatus for recording and reproducing waves corresponding to sound, means for transmitting waves corresponding to sound within a given frequency range and for separately transmitting waves corresponding to sound within another frequency range, means for recording the transmitted waves, and means for reproducing from the resulting record waves corresponding to the original sound.

2. In apparatus for recording and reproducing waves, a source of waves corresponding to sound, means for transmitting from said source waves corresponding to sound above a given frequency, separate means for

transmitting from said source waves corresponding to sound below said frequency, means for recording said transmitted waves, and means for reproducing from the resulting record waves corresponding to the original sound.

3. In apparatus for recording and reproducing waves corresponding to sound having components remote from each other in the frequency scale, record receiving means, means for producing thereon a record of waves corresponding to said components, said record producing means including means for controlling the recording of waves corresponding to said components of high frequency separately from waves corresponding to said components of low frequency, and means for reproducing from the resulting record waves corresponding to said components.

4. The method of recording and reproducing waves corresponding to sound, which comprises transmitting waves corresponding to components of sound having a frequency above a given value, separately transmitting waves corresponding to sound components having a frequency below said value, recording said transmitted waves, and reproducing said waves from the resulting record.

5. The method of recording and reproducing waves corresponding to speech, which comprises controlling the transmission of said waves corresponding to speech frequencies of the order of one thousand cycles per second or higher, separately controlling the transmission of said waves corresponding to lower speech frequencies, recording the waves thus transmitted, and reproducing from the resulting record waves corresponding to said speech.

6. The method of recording a wave band within which waves in a given frequency range have relatively small energy as compared with waves outside said range, which comprises transmitting and amplifying the waves within said range, separately transmitting the waves outside said range, and recording the amplified waves and the waves outside said range.

7. The method of recording waves corresponding to speech, which comprises transmitting said waves corresponding to the components of speech having a frequency above a given value, separately transmitting said waves corresponding to components of speech having a frequency below said value, amplifying said waves corresponding to said higher frequency components, and recording the amplified waves and the transmitted waves corresponding to said low frequency components.

8. In sound recording apparatus, means for producing electric waves varying in accordance with the sound, a plurality of transmission circuits connected thereto, means in one of said circuits for selectively transmitting waves within a given frequency range, means in another of said circuits for selectively transmitting waves within another frequency range, unitary means for receiving a record of said waves, and means for recording thereon the waves transmitted by said circuits.

9. In apparatus for recording waves corresponding to sound, means for receiving a record of said waves, and means for separately recording thereon said waves corresponding respectively to sound components within a given frequency range and to components outside said range.

10. In apparatus for recording waves corresponding to sound, means for transmitting a wave corresponding to a sound of high frequency and for separately transmitting a wave corresponding to a sound of low frequency, means for receiving a record of said waves, and means for separately recording thereon the transmitted waves corresponding respectively to the high frequency sound and the low frequency sound.

11. In sound recording apparatus, means for producing electric waves varying in accordance with the sound, a plurality of transmission circuits connected thereto, means in one of said circuits for selectively transmitting waves within a given frequency range, means in another of said circuits for selectively transmitting waves within another frequency range, unitary means for receiving a record of said waves, and means for separately recording thereon the waves transmitted respectively by said separate circuits.

12. In wave transmitting apparatus, a source of waves of different frequencies, and means connected to said source for variably transmitting light in accordance with said waves, said light transmitting means including means for separately controlling the light variations corresponding respectively to the high frequency waves and the low frequency waves.

13. In apparatus for recording waves corresponding to sound, means for transmitting said waves, means connected to said transmitting means for variably transmitting light in accordance with said waves, said light transmitting means including means for separately controlling the light variations corresponding respectively to the high frequency sounds and the low frequency sounds, and means for receiving a record of said light variations.

14. In apparatus for recording waves corresponding to sound, means for transmitting said waves, means connected to said transmitting means for variably transmitting light in accordance with said waves, said light transmitting means including means for separately controlling the light varia-

tions corresponding respectively to the high frequency sounds and the low frequency sounds, and a photographic film having a portion exposed to said light variations and arranged for longitudinal movement transversely to the incident light rays.

15. The method of recording waves corresponding to sound, which comprises variably transmitting light in accordance with said waves, separately controlling said light variations corresponding respectively to sounds of high frequency and to sounds of low frequency, and photographically recording said light variations.

16. The method of recording waves corresponding to sound, which comprises variably transmitting light in accordance with said waves, separately and differently controlling said light variations corresponding respectively to sounds of high frequency and to sounds of low frequency, and photographically recording said light variations.

17. The method of recording on a strip of photographic film light variations corresponding to sound waves, which comprises progressively recording along a path on the strip variations of light corresponding to sounds of low frequency, and progressively recording along one side of the path variations of light corresponding to sounds of high frequency.

18. A sound record comprising a photographic film having a plurality of records, each of different color, corresponding respectively to sounds of different frequency.

19. A sound record comprising a photographic film having a plurality of records superposed on each other, each of different color, corresponding respectively to sounds of different frequency.

20. In apparatus for recording and reproducing waves of different frequencies, means for transmitting said waves, means for receiving a record of said waves, means for producing on said record receiving means a record of said waves of low frequency, means for reducing the frequency of said waves of high frequency, means for producing on said record receiving means a record of said waves of reduced frequency, and means for producing from the resulting record waves corresponding to said original waves.

21. In apparatus for recording waves of different frequencies, means for transmitting said waves, means for receiving a record corresponding to said waves, means for producing thereon a record of said waves of low frequency, means for reducing the frequency of said waves of high frequency, and means for producing on said record receiving means a record of said waves of reduced frequency.

22. In apparatus for producing a record of waves of different frequencies, means for transmitting said waves, means for receiving a record of said waves, means for producing on said record receiving means a record of said waves of low frequency, means for inverting and lowering the spectrum of said waves of high frequency, and means for producing on said record receiving means a record of the inverted components.

23. The method of recording and reproducing sound, which comprises producing waves corresponding to the sound, modulating a carrier wave in accordance with said waves, producing a photographic record of the modulated components in the resulting waves, simultaneously producing a photographic record of the unmodulated first mentioned waves, separating reproducing waves corresponding to said records, demodulating the resulting carrier waves, combining the demodulated waves with the reproduced unmodulated waves, and producing sound in accordance with the combined waves.

24. In sound reproducing apparatus, a plurality of sound records, separate means for simultaneously producing waves corresponding respectively to portions of said separate records, means connected to one of said wave producing means for inverting the frequency spectrum of the waves produced thereby, and means common to said inverting means and to said other wave producing means for producing a sound corresponding to the resulting waves.

25. In sound reproducing apparatus, a film having a plurality of complementary records thereon, each of different color, means for illuminating said film with light of said colors, separate means, each for selectively transmitting a different one of said colors from said film, separate means associated with each said selective means for producing waves corresponding to variations in the light transmitted by said selective means when said film is longitudinally moved transversely to the light, and means controlled by the resulting waves for producing sound corresponding to said complementary records.

26. A method of recording and reproducing waves corresponding to sound on a recording means which efficiently records only waves below a certain frequency, which comprises producing a record on said means corresponding to said waves, inverting said waves to bring those above said limiting frequency into the region below said limit, separately recording said inverting waves and reproducing the original sound from the resulting records by producing waves corresponding to said directly recorded waves and to said inverted waves, reinverting said last mentioned waves and producing sound corresponding to said first waves and to said reinverted waves.

27. A method of recording and reproduc-

ing sound on a medium, which efficiently records only waves below a certain frequency range which comprises producing electrical waves corresponding to said sound, transmitting said electrical waves to a recording means and recording said waves on said medium, separately transmitting said waves to a modulator, modulating said waves therein with a carrier wave to produce a modulated wave, free from unmodulated components, in which the waves outside said range are brought within the range, producing on said medium a record corresponding to said modulated wave and reproducing the original sound from the resulting record by producing electrical waves corresponding to directly recorded waves and to said modulated waves, demodulating said last waves and producing sound corresponding to said first waves and to said demodulated waves.

28. In an apparatus for recording sound on a recording medium only efficiently sensitive to frequencies within a certain range, means for directly recording on said medium frequencies within said range, means for changing the frequency spectrum of said sound to bring the frequencies outside said range within said range, and separate means for recording said changed spectrum.

29. An apparatus for recording waves of different frequencies on a recording medium only efficiently sensitive to frequencies below a certain limit, means for producing on said medium a record of said waves below said limit, a modulator for modulating said waves with a carrier wave of a frequency in the neighborhood of said limiting frequency to produce modulated waves free from unmodulated components and means for producing on said medium a record of said modulated waves.

In witness whereof, I hereunto subscribe my name this 19th day of June A. D., 1924.

CHARLES D. LINDRIDGE.

DISCLAIMER

1,675,894.—*Charles D. Lindridge*, Montclair, N. J. METHOD AND APPARATUS FOR RECORDING AND REPRODUCING SOUND. Patent dated July 3, 1928. Disclaimer filed March 4, 1931, by the assignee, *American Telephone and Telegraph Company.*

Hereby enters this disclaimer to the said claims of said Letters Patent which are in the following words to wit:

"1. In apparatus for recording and reproducing waves corresponding to sound, means for transmitting waves corresponding to sound within a given frequency range and for separately transmitting waves corresponding to sound within another frequency range, means for recording the transmitted waves, and means for reproducing from the resulting record waves corresponding to the original sound.

"2. In apparatus for recording and reproducing waves, a source of waves corresponding to sound, means for transmitting from said source waves corresponding to sound above a given frequency, separate means for transmitting from said source waves corresponding to sound below said frequency, means for recording said transmitted waves, and means for reproducing from the resulting record waves corresponding to the original sound.

"3. In apparatus for recording and reproducing waves corresponding to sound having components remote from each other in the frequency scale, record receiving means, means for producing thereon a record of waves corresponding to said components, said record producing means including means for controlling the recording of waves corresponding to said components of high frequency separately from waves corresponding to said components of low frequency, and means for reproducing from the resulting record waves corresponding to said components.

"4. The method of recording and reproducing waves corresponding to sound, which comprises transmitting waves corresponding to components of sound having a frequency above a given value, separately transmitting waves corresponding to sound components having a frequency below said value, recording said transmitted waves, and reproducing said waves from the resulting record.

"5. The method of recording and reproducing waves corresponding to speech, which comprises controlling the transmission of said waves corresponding to speech frequencies of the order of one thousand cycles per second or higher, separately controlling the transmission of said waves corresponding to lower speech frequencies, recording the waves thus transmitted, and reproducing from the resulting record waves corresponding to said speech.

"6. The method of recording a wave band within which waves in a given frequency range have relatively small energy as compared with waves outside said range, which comprises transmitting and amplifying the waves within said range, separately transmitting the waves outside said range, and recording the amplified waves and the waves outside said range.

"7. The method of recording waves corresponding to speech, which comprises transmitting said waves corresponding to the components of speech having a frequency above a given value, separately transmitting said waves corresponding to components of speech having a frequency below said value, amplifying said waves corresponding to said higher frequency components, and recording the amplified waves and the transmitted waves corresponding to said low frequency components.

"8. In sound recording apparatus, means for producing electric waves varying in accordance with the sound, a plurality of transmission circuits connected thereto, means in one of said circuits for selectively transmitting waves within a given frequency range, means in another of said circuits for selectively transmitting waves within another frequency range, unitary means for receiving a record of said waves, and means for recording thereon the waves transmitted by said circuits.

"9. In apparatus for recording waves corresponding to sound, means for receiving a record of said waves, and means for separately recording thereon said waves corresponding respectively to sound components within a given frequency range and to components outside said range.

"10. In apparatus for recording waves corresponding to sound, means for transmitting a wave corresponding to a sound of high frequency and for separately transmitting a wave corresponding to a sound of low frequency, means for receiving a record of said waves, and means for separately recording thereon the transmitted waves corresponding respectively to the high frequency sound and the low frequency sound.

"11. In sound recording apparatus, means for producing electric waves varying in accordance with the sound, a plurality of transmission circuits connected thereto, means in one of said circuits for selectively transmitting waves within a given frequency range, means in another of said circuits for selectively transmitting waves

within another frequency range, unitary means for receiving a record of said waves, and means for separately recording thereon the waves transmitted respectively by said separate circuits.

"12. In wave transmitting apparatus, a source of waves of different frequencies, and means connected to said source for variably transmitting light in accordance with said waves, said light transmitting means including means for separately controlling the light variations corresponding respectively to the high frequency waves and the low frequency waves.

"13. In apparatus for recording waves corresponding to sound, means for transmitting said waves, means connected to said transmitting means for variably transmitting light in accordance with said waves, said light transmitting means including means for separately controlling the light variations corresponding respectively to the high frequency sounds and the low frequency sounds, and means for receiving a record of said light variations.

"14. In apparatus for recording waves corresponding to sound, means for transmitting said waves, means connected to said transmitting means for variably transmitting light in accordance with said waves, said light transmitting means including means for separately controlling the light variations corresponding respectively to the high frequency sounds and the low frequency sounds, and a photographic film having a portion exposed to said light variations and arranged for longitudinal movement transversely to the incident light rays.

"15. The method of recording waves corresponding to sound, which comprises variably transmitting light in accordance with said waves, separately controlling said light variations corresponding respectively to sounds of high frequency and to sounds of low frequency, and photographically recording said light variations."

"17. The method of recording on a strip of photographic film light variations corresponding to sound waves, which comprises progressively recording along a path on the strip variations of light corresponding to sounds of low frequency, and progressively recording along one side of the path variations of light corresponding to sounds of high frequency."

[*Official Gazette March 24, 1931.*]