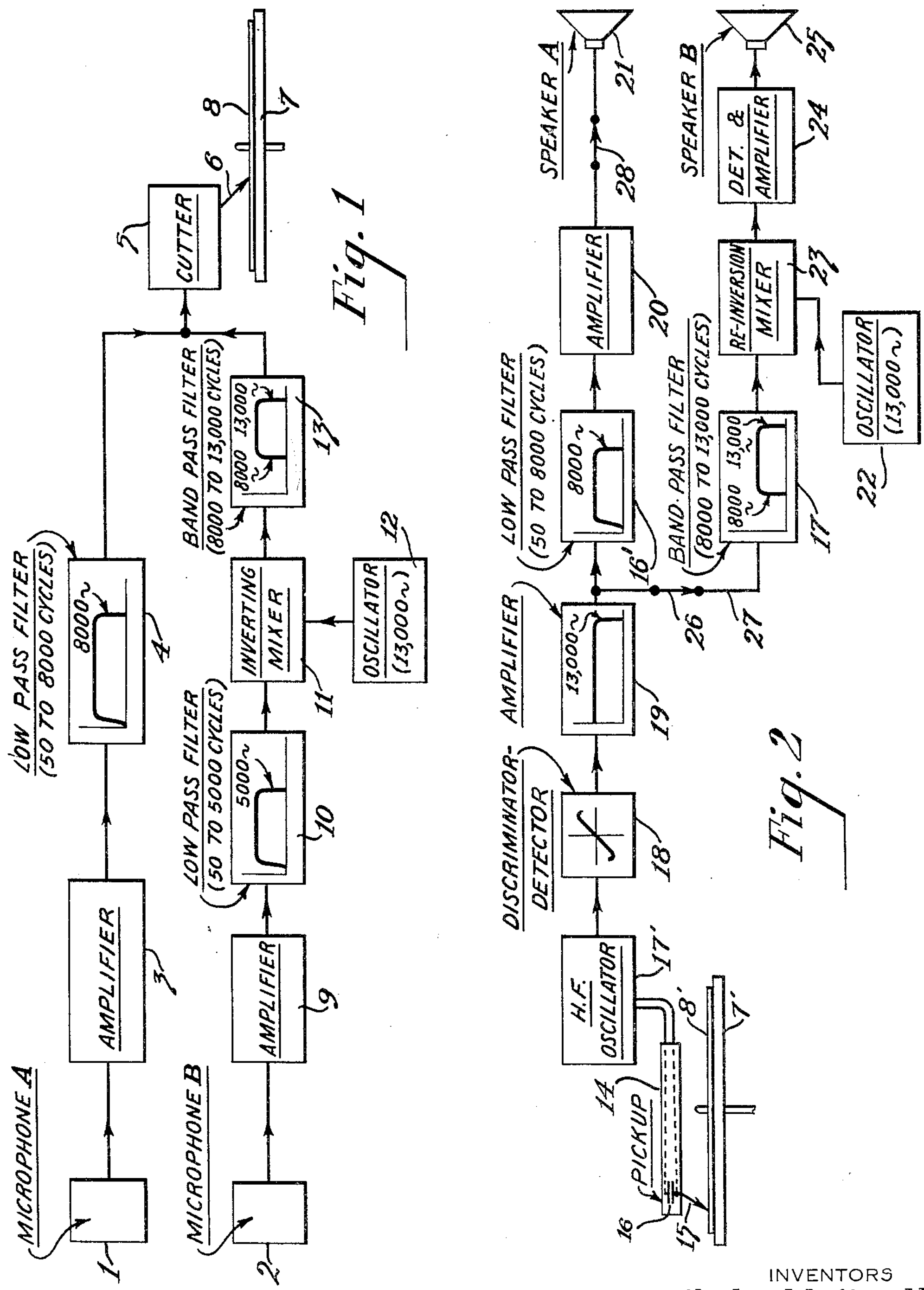
Jan. 2, 1951 C. M. SINNETT ET AL 2,536,664

STEREOPHONIC SOUND SYSTEM FOR RECORDINGS

Filed Sept. 10, 1945 4 Sheets-Sheet 1



INVENTORS
Chester M. Sinnett
& Herbert Belar
BY H.S. Grover
ATTORNEY

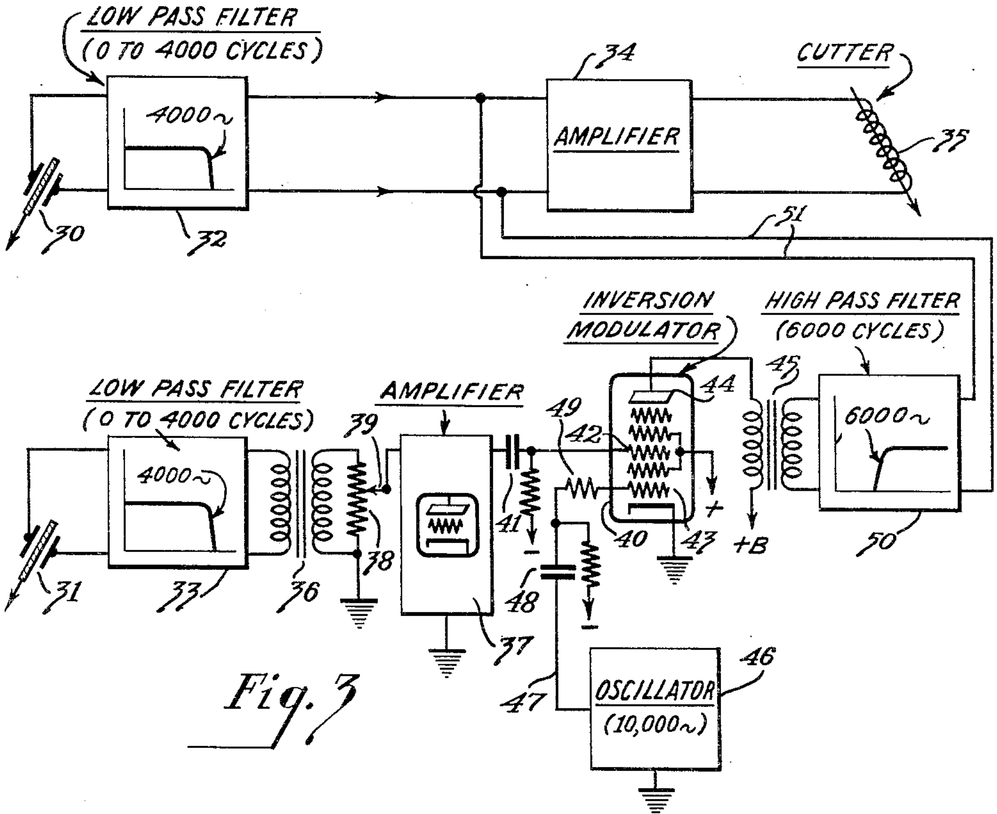


Fig. 3

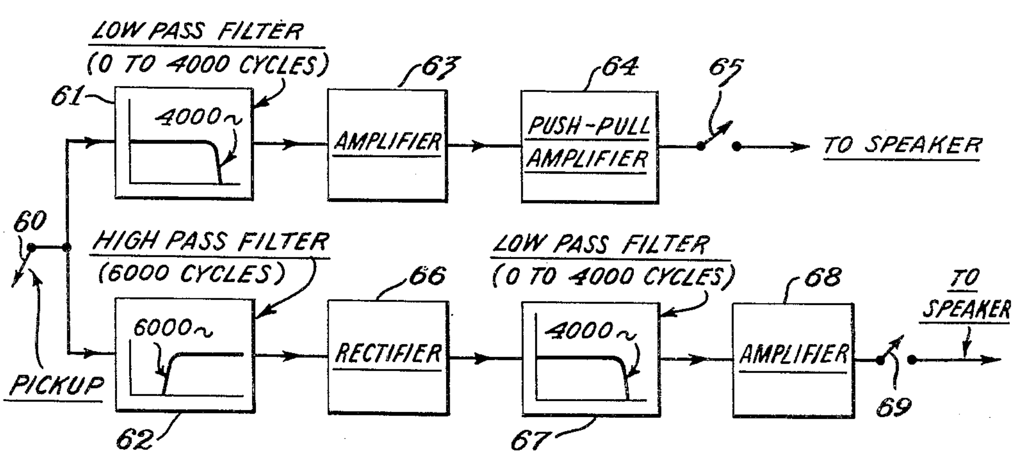


Fig. 4

INVENTORS
Chester M. Sinnett
& Herbert Belar
BY H. S. Grover
ATTORNEY

STEREOPHONIC SOUND SYSTEM FOR RECORDINGS

Filed Sept. 10, 1945

4 Sheets-Sheet 3

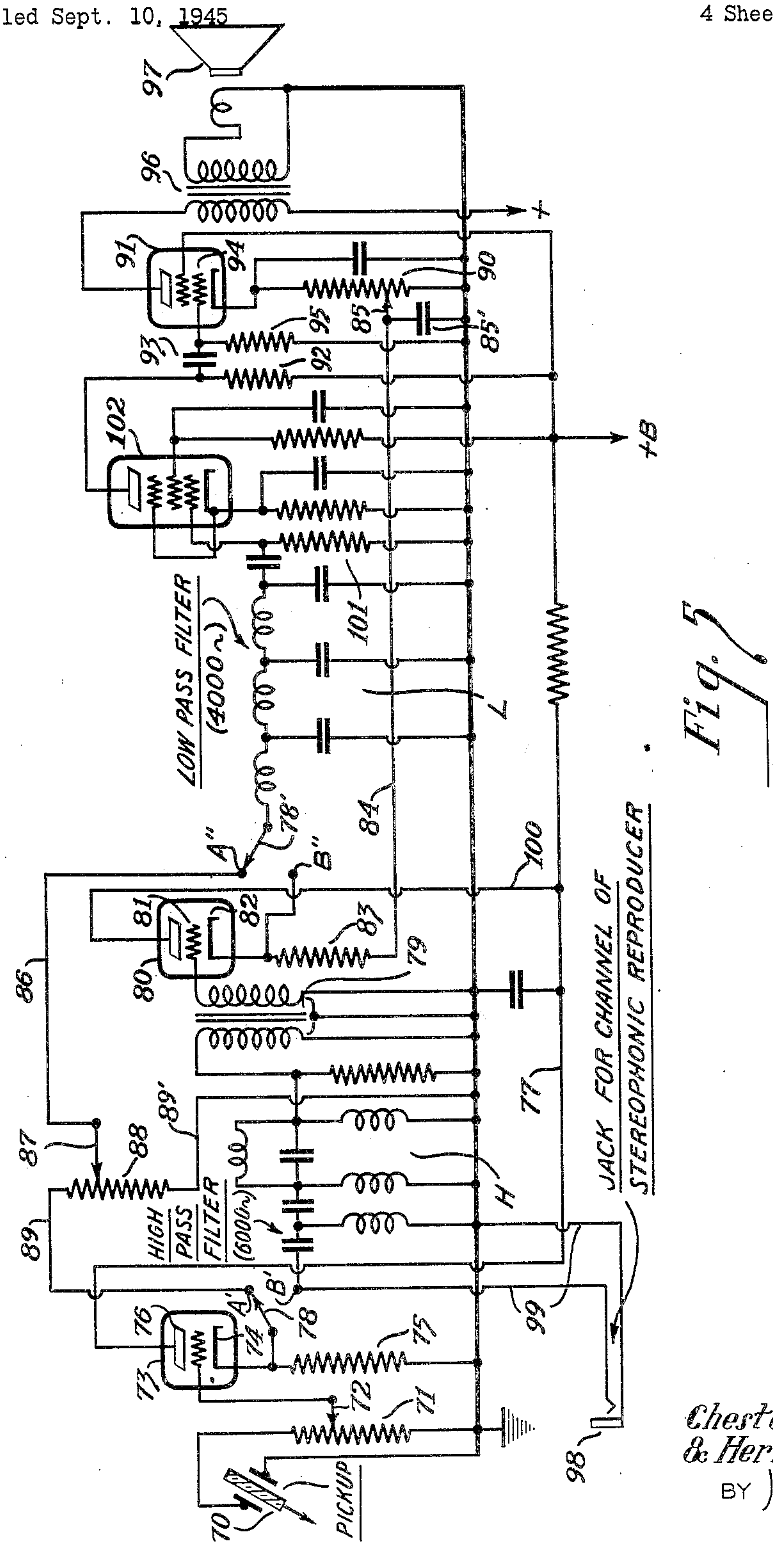


Fig. 5

INVENTORS
Chester M. Sinnett
& Herbert Belar
BY H. S. Grover
ATTORNEY

Jan. 2, 1951 C. M. SINNETT ET AL 2,536,664

STEREOPHONIC SOUND SYSTEM FOR RECORDINGS

Filed Sept. 10, 1945 4 Sheets-Sheet 4

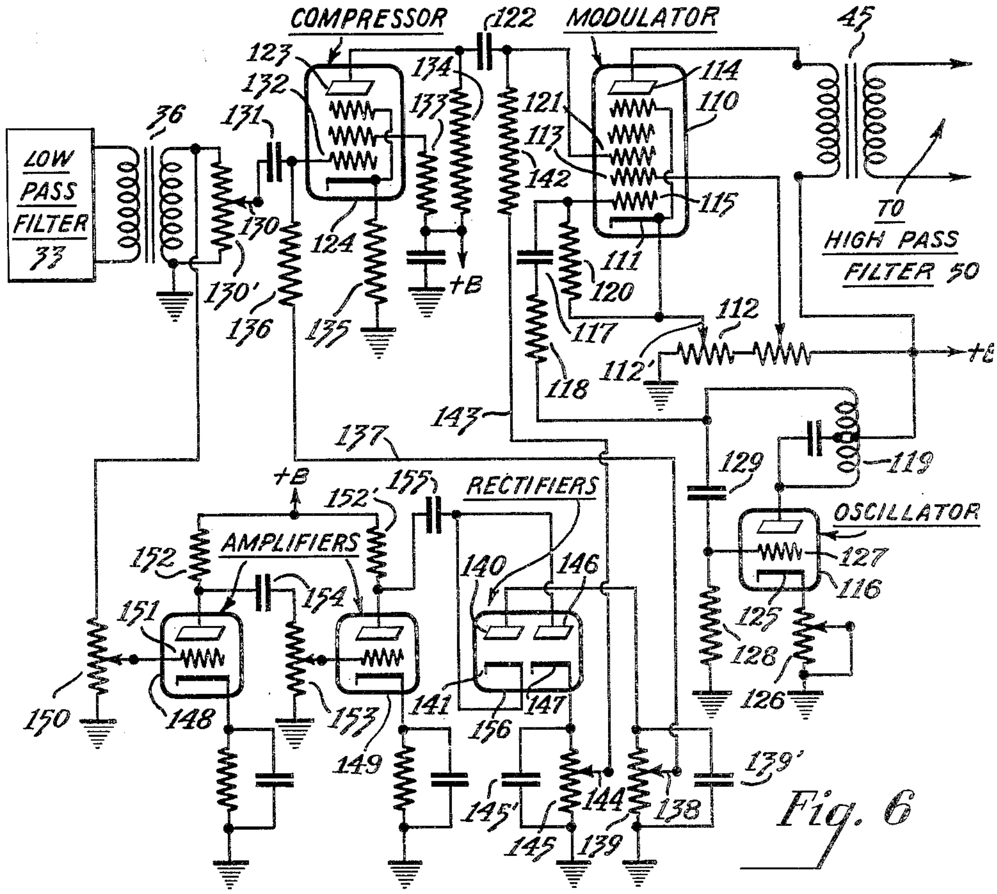


Fig. 6

Fig. 7a

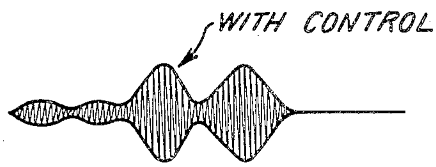
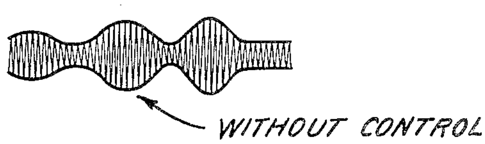


Fig. 7b



INVENTORS
Chester M. Sinnett
& Herbert Belar
BY H. S. Grover
ATTORNEY

Patented Jan. 2, 1951 2,536,664

UNITED STATES PATENT OFFICE

2,536,664

STEREOPHONIC SOUND SYSTEM FOR RECORDINGS

Chester M. Sinnett, Westmont, and Herbert Belar, Palmyra, N. J., assignors to Radio Corporation of America, a corporation of Delaware

Application September 10, 1945, Serial No. 615,440

20 Claims. (Cl. 179—100.4)

Our present invention relates generally to stereophonic sound systems, and more particularly to improved methods of, and means for, providing stereophonic effects.

Binaural hearing includes the faculty of locating a source of sound by means of the difference in the sound reaching each ear. It is customary to think of a binaural reproducing channel, then, as one in which sound from a source is fed to each ear separately. This is usually done with two microphones, two amplifiers and separate earphones for each ear. With such a system by greater spacing of the microphones, the binaural effect of locating a source can be increased, as used for example in sound ranging. It is, also, possible to mount the microphones in an artificial head, and obtain results as though the source was walking around the auditor. These effects are well known, and have many other interesting properties. Some of these are that if two persons are speaking in one room it is possible to concentrate on either one, whereas it would be quite difficult to do this with a single microphone channel. Also, it may be possible with use of two microphones to understand speech in a room so reverberant that with a single microphone speech would be unintelligible.

By stereophonic reproduction is usually meant a reproducing system which appeals to the binaural sense of the listener by reproducing sound picked up by separate microphones with separate speakers in separate locations. This includes such setups as have been publicly demonstrated in which sound, due to various instruments of an orchestra, are reproduced in various locations of a stage. The listener by his binaural sense can then locate instruments, such as violins on the left and cellos on the right, etc.

Stereophonic reproduction offers interesting possibilities for enhancing the reproduction of music in the home by either radio or phonograph. In a home application this improvement is only in part due to the different apparent sources of various types of sound. A great part of the enhancement may be due to each channel acting as a delayed channel for the other, if the two microphones are in the same room and can pick up some sound from all instruments. This latter effect is not so well known, although it can be explained from known observations.

When a listener is in the same room in which a group of instruments are being played, he will, if the room is at all suited for music reproduction, hear but a small portion of the total sound direct. Probably 90% of the energy will reach

him after being reflected from the walls, etc. This reflected sound will reach him later, and from a different direction than the direct sound. Apparently the listener is not satisfied if it is not so, because experience has taught him that there is a definite optimum reverberation time for each room and an optimum size room for each type of musical presentation. Due to the binaural sense there is a considerable difference between sound arriving at different times from different directions and sound of the same total amplitude arriving from one source. This can be proved by placing a microphone in a very reverberant room and listening to a person speaking. As stated above, the reverberation may make it difficult to understand speech, whereas no such difficulty had been encountered when the listener himself was in the same room.

The optimum "build up" and reverberation time for various rooms, music and speech has been determined and this knowledge can be employed in stereophonic sound reproduction. Of particular interest is the finding of Benecke (Analen der Physik, August, 1930) that the build-up time for all rooms should be 0.06 second, and that the ratio of reverberant to direct sound should be as large as possible for any given size room without exceeding the optimum buildup time. Fulfillment of these two requirements results in an optimum reverberation time varying as the cube root of the volume, if the process is all in air. But with an electrical reproducing system one is not bound to the cube root law, but may follow the fundamental requirements as formulated by Benecke.

When a single microphone is used with an orchestra, similar defects are noted. A microphone in the same location that would be selected for good, direct listening position will pick up more "room" than is considered desirable. To overcome this the microphone is placed closer to the orchestra than it otherwise would be. Now, if a means is used to reproduce the reverberant "room" sound and the direct sound separately, then the impression upon the listener can be more realistic. The effect has been pleasing to most people witnessing such demonstrations. Part of this effect can be simulated with a single record and two reproducing channels.

One of the important objects of our present invention is to provide a method of obtaining binaural, stereophonic or artificial reverberation effects in phonograph reproduction by recording the outputs of two independent audio frequency channels on one record portion, and, preferably by a single pickup, reproducing the duplex recording through independent channels feeding separate, spaced reproducers.

Another important object of our invention is to provide a system of recording the outputs of a pair of transducers, upon which may be applied similar or dissimilar recordable material; the system employing a first channel designed to pass without frequency change the energy from one transducer to a recording unit, a second channel passing the energy from the second transducer to the same unit with signal frequency inversion, and a recording unit providing a common record groove representative of the outputs of both channels.

Another important object of our invention is to provide a novel method of reproducing a record of the type wherein different signals are recorded in common grooves as a composite signal whose components cover a wide frequency range.

Another important object of our invention is to record the outputs of a modulated carrier channel and a separate standard audio channel on a single record, preferably in such manner as to provide a single record portion representative of both such outputs.

Another important object of our invention is to provide a method of, and means for, reproducing a record provided with a portion, e. g., a record groove or a film sound track, representative of relatively lower and higher frequency bands in the audio frequency range, including deriving from said portion audio frequency currents over the frequency range of both of said bands, separating the audio frequency currents into the respective bands of audio frequencies, inverting the higher frequency band to a band of lower audio frequencies commensurate with the said other frequency band, and separately reproducing the resultant bands of audio frequencies.

Still another object of our invention is to provide a method of, and means for, recording a modulated carrier signal, wherein the carrier amplitude is varied at the modulator in accordance with the modulating signal, and concurrently the modulating signal is compressed prior to application to the modulator.

Still other objects of our invention are to improve generally the operation of stereophonic sound systems, and more particularly to provide sound record reproducer system of a highly efficient and economical construction.

Other objects and advantages of the invention will best be understood by reference to the following description, taken in connection with the drawings, in which we have indicated diagrammatically several circuit organizations whereby our invention may be carried into effect.

In the drawings:

Fig. 1 schematically shows a recording system in accordance with our invention;

Fig. 2 schematically illustrates a record reproducing system for records of the type produced in the system of Fig. 1;

Fig. 3 shows in partial schematic a modified form of recording system;

Fig. 4 schematically represents a modified form of record reproducing system;

Fig. 5 is a circuit diagram of a further modification of a record reproducing system;

Fig. 6 is a circuit diagram of a signal-responsive carrier control system adapted for use in connection with the modulator of Fig. 3;

Fig. 7*a* shows the effect on the wave form of the signal-responsive control; and

Fig. 7*b* is an illustrative modulated carrier wave form at the modulator output circuit produced in the absence of the signal-response control.

Referring now to the accompanying drawings, wherein like reference characters in the different figures denote similar circuit elements, the system of Fig. 1 comprises a pair of sources 1 and 2 of alternating currents to be recorded. By way of specific illustration it is assumed that the currents are in the audio frequency range of zero to 15,000 cycles per second. It is, also, assumed that the sources are transducers, such as microphones. Of course, the transducers 1 and 2 could also be electric phonograph pickup devices, detectors of radio broadcast receivers, or any other devices capable of supplying audio frequency currents. Moreover, the audio current outputs of the sources 1 and 2 could be of the same wave forms, or they can be of different forms. That is to say, the microphones A and B may be spaced in a predetermined manner and subjected to a common source of sound to be recorded. On the other hand, they could be isolated from each other and subjected to respectively different sound waves.

In order to simplify the explanation of our invention, and also to show the manner in which our method simplifies stereophonic sound reproduction, it is assumed that a common sound source actuates the respective diaphragms of microphones A and B. These microphones may be of any suitable and known construction. The audio frequency currents produced at the output terminals of microphone A are amplified, as at amplifier 3, and then applied to a suitable low pass filter 4. The latter may be of known construction in the audio filter art, and preferably passes a band of frequencies from 50 up to 8000 cycles per second. We prefer a relatively sharp cut-off at 8000 cycles per second, although our invention is in no way restricted to the specific band of frequencies. The filtered output is then applied to a suitable record cutting device 5 of known construction whose cutting stylus 6 is schematically represented. The turntable 7 and a suitable record blank 8 are schematically represented, since those skilled in the art of producing records are fully acquainted with the manner of constructing these devices. Moreover, by well known means, the record could be made on film instead of on record blank 8.

In accordance with one aspect of our present invention, we cause the stylus 6, or other recording means, to be actuated in response to the output of microphone B as well as to the output of microphone A. This we accomplish in the following manner. The audio frequency current output of microphone B, after suitable amplification at amplifier 9, is applied to a low pass filter 10 which passes a band of audio frequencies of substantially less width than that passed by filter 4. The specific band passed by filter 10 is 50 to 5000 cycles per second, the cut-off being relatively sharp at 5000 cycles per second. The filtered current output of filter 10 is applied to an inverting mixer, or modulator, 11. The mixer may be of any suitable construction, and functions to convert the 50 to 5000 cycle band of audio frequencies to an inverted band of audio frequencies extending from 8000 cycles per second up to approximately 13,000 cycles per second. This is accomplished by feeding the mixer 11 with constant amplitude-constant frequency oscillations of 13,000 cycles (kc.) per second from oscillator 12 and by modulation of the 13,000 cycle carrier frequency by the 50 to 5000 cycle band.

The oscillator 12 may be of any well-known and suitable construction. Those skilled in the art of radio communication are fully acquainted with the mode of operation of an inversion mixer. Briefly, the output currents at the mixer 11 consist of lower side band frequency components resulting from the difference between the oscillation frequency (13,000 cycles per second) and each frequency component of the 50 to 5000 cycle band at the output of filter 10. A given audio frequency is mixed with the 13 kc. carrier, and sidebands are produced. One of these side bands, the lower one, decreases in frequency as the audio frequency increases. For example, a 1000 cycle audio tone mixed with the 13,000 cycle carrier will produce a 12,000 cycle sideband in addition to a 14,000 cycle sideband, which can be rejected by a suitable filter. Similarly, a 2000 cycle tone produces an 11,000 cycle lower sideband, and a 5000 cycle tone results in an 8000 cycle lower sideband. Hence, there is provided a form of inversion in which an increasing audio frequency produces a decreasing sideband frequency.

The mixer output current is applied to a band pass filter 13, passing only a 8000 to 13,000 cycle per second band of audio frequencies, so as positively to prevent the passage of frequency components less than 8000 cycles per second, or more than 13,000 cycles per second. Such lower and higher components may well exist at the mixer output terminals by virtue of the mixing process per se. The filtered output energy of filter 13 is fed to the cutter 5. Hence, the cutter 5 has applied thereto duplexed audio channels representative of common sounds, but composed of adjacent audio frequency bands whose components are inversely related. That is to say, the low frequency sounds of channel B exist at the cutter input terminals as components of the inverter lower sideband frequencies. The high frequency sounds of channel B exist as low frequency components of the said inverted band. The stylus 6 cuts, or deforms, the record material in response to the composite 50 to 13,000 cycle band. In other words, the record 8 is provided with a single groove, or impression, representative of the aforesaid duplexed audio channels. It is to be understood that the record may be cut to have vertical or lateral grooves, and that the particular technique of record cutting is no part of our invention. It is only required that there be employed a cutter adapted to respond faithfully over the entire band of frequencies presented to it. If the input to the cutter is kept at a reasonable level no cross-modulation between the channels will be encountered.

In Fig. 2 we have shown, as another aspect of our invention, a system for reproducing a record 8′ which is to be understood as being a copy of the master record 8. The turntable 7′ is driven in any suitable manner, and is provided with a device for converting the groove variations into corresponding audio frequency currents. As is well known, a tone arm 14 is provided with a pickup head which employs a needle or stylus 15 to ride or scan the record grooves. The current output of the pickup device, preferably of the piezo-electric type although any other known and suitable type may be used, is applied to a pair of filters 16′ and 17. Filter 16′ is a low pass filter constructed to pass a band of from 50 to 8000 cycles per second, while filter 17 is a band pass filter designed to pass an 8000 to 13,000 cycle band. In the practice of the invention with a disc record 8′, it may be preferable to employ a frequency modulation arrangement to provide the wide range of audio frequencies from the record grooves. Such a frequency modulation arrangement is disclosed and claimed in application Serial No. 459,375, filed September 23, 1942, now Patent No. 2,481,886, granted September 13, 1949, by C. M. Sinnett. When using such an arrangement the pickup head is preferably provided with a ribbon type of capacity pickup device of the type disclosed and claimed in application Serial No. 414,305, filed October 9, 1941, by C. M. Sinnett, now Patent No. 2,376,456 granted May 22, 1945. The numeral 15 designates a schematic representation of such a capacity pickup device. The capacity pickup is, as disclosed in the aforesaid Sinnett application, connected across the resonant tank circuit of a high frequency oscillator 17′ of suitable construction. The condenser 16 has one of its electrodes mobile and responsive to displacements of the needle 15. In this way displacements of needle 15 are converted into corresponding changes of the capacitance of condenser 16. These capacitance variations, in turn, produce corresponding frequency variations of the oscillator 17′. The oscillator 17′ may produce oscillations of the order of 30 megacycles (mc.) per second, although the latter frequency value is merely illustrative.

The resulting frequency modulated oscillations, whose frequency variations are in accordance with amplitude variations of the modulating signal, are applied to discriminator-detector 18 whose typical frequency response characteristic is depicted. The network for the discriminator-detector is well known, and functions to derive from the frequency modulated oscillations corresponding amplitude modulated currents which are detected to provide the audio frequency currents. The latter, of course, are those representative of the grooves or impressions of record 8′. However, as stated previously, the capacity pickup device 16 and network 17′ and 18 may be omitted, and any other suitable transducer may be employed at the tone arm head directly to translate displacements of needle 15 into corresponding audio frequency signals.

An amplifier 19, having a frequency response substantially flat up to 13,000 cycles, may be employed to amplify the audio frequency currents prior to separation of the adjacent bands by filters 16 and 17. It will be obvious that the low pass filter 16′ separates from the output of amplifier 19 the band of audio frequencies corresponding to the audio frequency currents produced at the output terminals of low pass filter 4 of Fig. 1. This band of audio frequencies extending up to 8000 cycles per second is further amplified by an amplifier 20. The amplified output of amplifier 20 is then applied to any suitable reproducer, such as a loud speaker 21. The speaker 21 is designated "speaker A" to denote that it corresponds to microphone A.

The band pass filter 17 is designated to have a relatively sharp cut-off at 8000 cycles per second and 13,000 cycles per second. Accordingly, the audio frequency currents at the output terminals of filter 17 correspond to the audio currents produced at the output terminals of the filter 13 of Fig. 1. Since the latter currents are inverted relative to the audio frequency currents produced at the output terminals of filter 10, there is employed in the system of Fig. 2 a means for reinverting the signals back to a band of 50 to 5000 cycles per second. This is accomplished by using a source 22 of oscillations of a frequency of 13,000 cycles per second. Here, again, the oscillations produced by oscillator 22 are of constant amplitude and constant frequency, and are fed to reinversion mixer 23.

The mixer 23 has applied to it the audio frequency currents at the output terminals of filter 17. At the mixer 23, which may be of any known and suitable construction, the reinversion process takes place. The mixer 23, as a matter of fact, may be of the same construction as the mixer 11 of Fig. 1, and functions to provide difference and sum frequency components of the audio frequency components and the fixed-frequency oscillations from source 22. That is, lower and upper side bands are produced. In other words, the low frequency component of 8000 cycles per second beating with the 13,000 cycle oscillation would produce a difference frequency component of 5000 cycles per second, while the high frequency component of 13,000 cycles per second would beat with the 13,000 cycle oscillations to provide zero cycle component. It will be evident, therefore, that at the output terminals of the re-inversion mixer 23 there is provided side bands whose components are audio frequency currents which correspond to the audio currents existing at the output terminals of low pass filter 10 of Fig. 1. This band of 50 to 5000 cycle components is subjected to detection and amplification at 24. The amplified band of audio energy is then reproduced by a suitable speaker 25. Here the reproducer 25 is designated "speaker B" to represent that it corresponds to the microphone B.

It will now be appreciated that the speakers A and B respectively reproduce the sounds which were applied to microphones A and B. Accordingly, there is provided a means for preserving and re-creating the spacial effect which existed originally by virtue of the spacing of microphones A and B. It is only necessary to place the speakers A and B in a relative relation analogous to that which existed between the microphones. The listener will have the sensation of stereophonic sound reproduction. The fact that one of the speakers reproduces up to 8000 cycles per second, whereas the other reproducer reproduces up to 5000 cycles per second will not substantially affect the resultant effect on the listener. Stereophonic reproduction is provided in the case of the system of Fig. 2, because we have provided here a reproducing system which appeals to the binaural sense of the listener by reproducing sound picked up by separate microphones A and B with separate speakers A and B in separate locations. In effect, the speakers A and B act as if one of them reproduced the direct sound (that is, the sound reaching the ears of the listener directly), while the other reproduces the reverberant sound. Due to the binaural sense of a listener there is a considerable difference between sound arriving at different times from different directions and sound of the same total amplitude arriving from one source. By means of the recording and reproducing systems of Figs. 1 and 2 there is provided a method of simulating stereophonic effects with a single record and duplex reproducing channels.

It is to be understood, however, that the present method is not restricted to simulating stereophonic effects. Besides stereophonic reproduction and artificial reverberation effects, the method can be employed to provide the equivalent of four-sided records instead of the usual two-sided record. This is readily seen when it is realized that it is only necessary to use microphones 1 and 2 for separate sound selections, such as different musical selections, and recording as shown in Fig. 1 on one face of record 8. Subsequently, the record 8 is reversed and upon its opposite face there would be recorded a pair of different musical selections separately and concurrently, applied to microphones 1 and 2. Such a recording would be readily reproduced as four successive musical selections in the system of Fig. 2 by providing switch 26 in the connection 27 to the input terminals of filter 17. In other words, the musical selection applied to microphone 1 on each face of the record would be reproduced by speaker 21, the switch 26 being open in that case. Closure of switch 26, but opening a switch as for example 28 located anywhere in the line feeding speaker 21, will provide reproduction of the musical selection applied to microphone 2.

It will, also, be seen that additional music records, such as orchestra accompaniments and solo parts, can be recorded through the separate A and B channels. Then, in the system of Fig. 2 one can selectively switch from solo to accompaniment, or with switches 26 and 28 both closed the accompaniment could be had with the solo reproductions. Again, it would be possible to record two versions of the same selection on each face of a record. In that case a suitable adjustment of switch 26 and switch 28 will provide a means for comparing the separate versions of each selection.

As stated previously, it is not essential to employ microphones as the source of audio frequency currents in the recording systems. In Fig. 3 we have shown a modified system for recording duplex channel-single groove records from separate piezo-electric pickup devices 30 and 31. These pickup devices may be of any suitable known construction, and are assumed to be reproducing similar or different records (not shown). The audio frequency current outputs of the respective pickup devices are applied to respective low pass filters 32, 33. Each filter is designed, by way of example, to cut off at 4000 cycles per second. The output of filter 32 is amplified by amplifier 34, and the amplified currents are then fed to the energizing coil of the cutter 35. The latter is schematically represented, and may be of any suitable construction.

The filtered output of filter 33 is subjected to the inversion step described in Fig. 1. Thus, the audio transformer 36 couples the output of filter 33 to the amplifier 37. The potentiometer 38, shunted across the secondary winding of transformer 36, has its slider 39 connected to the signal control grid of amplifier 37 whereby there is provided a control over the amplitude of signal fed to inversion modulator 40. The amplified audio output of amplifier 37 is applied through coupling condenser 41 to the signal input grid 42 of pentagrid tube 40.

The tube 40, which may be for example of the 6SA7 type, has its cathode grounded, while its oscillation control electrode 43 and its signal input electrode 42 are provided with suitable negative biases from any suitable direct current source. The plate 44 of tube 40 is connected to the +B terminal of the direct current supply source through the primary winding of audio transformer 45. The source of oscillations is designated by the numeral 46, and it is to be understood that the source of oscillations produce oscillations of constant amplitude and fixed frequency of 10,000 cycles per second. These oscillations are applied over lead 47, blocking condenser 48 and resistor 49 to the grid 43 of tube 40. It will be recognized that the modulation or mixing process taking place in tube 40 is the so called "electron coupled" type. There is produced in the plate circuit of tube 40 the sum or difference components of the input frequencies and the 10,000 cycle oscillation frequency. Since it is desired to utilize solely the difference frequency components i. e., the lower side band components in the frequency range of 6,000 to 10,000 cycles per second, the secondary of transformer 45 feeds into the input terminals of a high pass filter 50 constructed to pass only frequency components above 6000 cycles per second. Although the carrier frequencies and the upper carrier frequencies and the upper side bands are also passed by the filter, as shown, they are above the audio frequency range and are therefore not objectionable in the recording. Inertia of the cutter itself will also act in the same manner as a low pass filter cutting off frequencies above the range of about 10,000 cycles per second.

Modulator tube 40 accordingly functions as an inversion device in the same manner described in connection with the inverting mixer 11 of Fig. 1. It is to be clearly understood that the inversion modulator 40 may be employed as the inverting mixer 11 of Fig. 1 due allowance being made for the differences in the signal frequencies supplied to the respective grids 42 and 43. The amplified output of filter 50 is applied to the cutter device 35 by connections 51 to the input terminals of amplifier 34. It will, therefore, be appreciated that in general the recording system shown in Fig. 3 is similar to that shown in Fig. 1. However, the specific nature of the input transducers are different; the specific frequency bands of the low pass filters are the same in the case of Fig. 3 whereas in Fig. 1 they are different; and a specific inversion modulator is shown in Fig. 3.

In Fig. 4 we have shown a modified system for reproducing a duplex channel-single groove record produced by either of the system of Figs. 1 and 3. It will be noted that the essential difference between the reproducing system of Fig. 4 and that shown in Fig. 2 is the fact that the system of Fig. 4 does not utilize an oscillator and a re-inversion mixer. Instead, there is utilized a simple rectifier. Referring to Fig. 4, which is in block diagram form since the various networks are well known to those skilled in the art, the individual channel record will, as explained in connection with Fig. 2, be associated with a pickup device schematically represented at 60. As previously explained the pickup device 60 may be of any suitable construction, it being preferable to utilize one which is adapted advantageously to transduce signals having frequencies up to at least 10,000 cycles per second. The audio frequency electrical signals produced by pickup device 60 are fed to a low pass filter 61 and a separate high pass filter 62. The low pass filter is designed to have a sharp cut-off at 4000 cycles per second, while the high pass filter has a sharp cut-off at 6000 cycles per second and passes the frequency components above 6000 cycles per second. The output energy of low pass filter 61 is amplified by amplifier 63, and is subjected to further push-pull amplification 64, if desired. A switch 65 may be inserted between the output terminals of amplifier 64 and the subsequent speaker.

The output energy of high pass filter 62 is applied to a rectifier 66. The rectifier may be, for example, a simple diode, or it may be of the specific type to be described in connection with Fig. 5. The overall wave presented to rectifier or detector 66 may be treated as an amplitude modulated 10 kc. carrier wave. The amplitude modulations are detected, that is, separated from the carriers by rectifier 66 to reproduce the desired audio component without requiring a separate inverter. Thus, a 9000 cycle per second signal generated at pickup 60 from a recording of an inverted signal of 1000 (10,000—1000) cycles per second, is detected as a 1000 cycle per second side band of the 10 kc. carrier. Similarly a 6000 cycle signal picked up from a recording of an inverted 4000 cycle signal is detected as a 4000 cycle signal. Filter 67 blocks passage of the carrier after detection.

As indicated, the filter 50 and 62 may have an extended high frequency response and pass both the low and the high side-bands of the modulated oscillations. The amplifier 68 may be used to amplify the output energy of filter 67, and a switch 69 may be inserted in the output connections between amplifier 68 and the subsequent loud-speaker. It will be understood that the recording and reproducing systems of Figs. 3 and 4 may be utilized for precisely the same functions as described in connection with the systems of Figs. 1 and 2. Switches 65 and 69 in Fig. 4 may be employed in the manner described in connection with respective switches 28 and 28 of Fig. 2.

In Fig. 5 there is shown the circuit diagram of a reproducing system which may be employed for reproducing records made with the system of Fig. 3. In general, the reproducing system of Fig. 5 utilizes a single pickup device and a single loud-speaker. Switching means are provided for selectively permitting reproduction of either of the recorded audio channels. Reference to the system of Fig. 3 shows that one of the channels, or band, of audio frequencies covers a range from zero to 4000 cycles per second, while the other channel covers a band of from 6000 to 10,000 cycles per second. As disclosed in the system of Fig. 4, the first step in reproducing the double channel-single groove record is to separate the two bands by proper filtering.

Hence, in the system of Fig. 5 the pickup 70, which is of the piezo-electric type, has its output electrodes connected to the opposite ends of the potentiometer resistor 71. The slider 72 is connected to the control grid of an amplifier tube 73, and the cathode 74 of the tube is connected to the grounded side of potentiometer resistor 71 by a load resistor 75. The plate 76 of tube 73 is connected by lead 77 to the +B terminal of any suitable direct current source. It is to be clearly understood that tube 73 may be of any suitable type. For example, the electrodes of tube 73 may be included in the same tube envelope with the electrodes of the following amplifier tube 80. In that case a twin triode tube of the 6F8 type may be employed.

The resistor 75 functions as the output load of amplifier 73, and the voltage across resistor 75 may be applied to either of two channels by virtue of a switch whose adjustable element 78 is connected to the cathode end of resistor 75. The contacts A′ and B′ designate the respective input terminals of the low audio frequency and high audio frequency channels of the recording. The contact B′ is connected to the ungrounded end of the primary winding of transformer 79 through a plurality of series-connected condensers, and the winding is shunted by a plurality of coils. The reference character H generally designates that these series condensers and shunt coils cooperate to provide a high pass filter having a relatively sharp cut-off at 6000 cycles.

It will be noted that the last of the series condensers is shunted by a coil, and that the filter has an appropriate terminating resistance. The condensers of the filter elements are chosen to provide the desired high pass filter characteristic. The secondary winding of transformer 79 has its ungrounded end connected to the control grid 81 of amplifier tube 80. It will, therefore, be appreciated that when switch element 78 is adjusted into contact with the terminal B′, there will be transmitted to the input grid 81 solely the band of frequency components between 6000 and 10,000 cycles per second.

The cathode 82 of amplifier tube 80 is connected through a load resistor 83, lead 84 and slider 85 to a desired point on the cathode resistor 90 of the output amplifier tube 91. The cathode end of load resistor 83 is connected to the contact point B′′ of a second switch whose adjustable element is denoted by numeral 78′. The contact point A′′ associated with switch element 78′ is connected by lead 86 to the slider 87 of potentiometer resistor 88. The upper end of resistor 88 is connected by lead 89 to contact point A′, while the lead 89′ connects the lower end of resistor 88 to ground. It is to be understood that when the switch element 78 contacts point A′, then switch element 78′ is in contact with contact A′′, and switch elements 78 and 78′ will be adjusted concurrently to contact points B′ and B′′.

It will be further appreciated that amplifier tube 80 is also of the cathode follower type, as is the case with tube 73, since the plate of tube 80 is connected by lead 100 to the +B terminal. The audio frequency voltage is developed across the cathode resistor 83. The switch element 78′ is connected to the ungrounded input terminal of a low pass filter L composed of a plurality of series-connected coils and shunt condensers having a suitable terminating resistance 101. It will be understood that the low pass filter L has a relatively sharp cut-off point at 4000 cycles per second, and that its constants are chosen to provide the desired low pass filter characteristic. When the switch elements 78 and 78′ respectively connect with contacts A′ and A′′, then there will be developed at the output terminals of low pass filter L the band of audio frequencies between zero and 4000 cycles per second, as shown at the output terminals of network 61 of the system of Fig. 4. The potentiometer 87, 88 may be adjusted to provide the proper intensity of input signal to the input terminals of the low pass filter.

On the other hand, when the switch elements 78 and 78′ are selectively connected to their respective contact points B′ and B′′, then there will be developed at the output terminals of the low pass filter L the band of audio frequencies as indicated at the output terminals of network 67 in the system of Fig. 4. In other words, tube 80 functions as the rectifier 66 of Fig. 4. It is to be understood that the pickup device 70 should be capable of developing faithfully the audio frequency components up to 10,000 cycles per second. The output of the pickup device in that case is fed to the control grid of a triode which is cathode coupled to the switching device. When the switching device is in position A′, as pointed out before, the triode 73 feeds directly into the input terminals of the low pass filter L, provided switch element 78′ is at position A′′. In this case no components of 6000 to 10,000 cycle band will be present at the output terminals of filter L. In other words, the modulated carrier channel will not be applied to the input electrodes of the amplifier tube 102. However, when the switch elements 78 and 78′ are in the respective contact positions B′ and B′′ the voltage across output resistor 75 is fed to the high pass filter H, which, in turn, feeds through transformer 79 to the input electrodes 81 and 82 of triode 80.

Triode 80 has a bias applied to grid 81 such that with no signal applied thereto the anode or plate of the tube draws very little space current. In other words, an initial negative bias is applied to signal grid 81 of triode 80 such that in the no-signal state a very small amount of plate current flows and the triode 80 functions as a biased detector. The output voltage developed across resistor 83, being rectified, is cathode coupled into the input terminals of the low pass filter L which does not transmit the carrier. The cathode coupling of the first two tubes is chosen to provide a low impedance output, and this allows the use of a filter employing air-core reactances or coils. It will be noted that resistor 83 is arranged in series with a portion of the cathode load 90 of tube 91. The slider 85 is adjusted to a point on resistor 90 such that the desired negative bias will be applied to grid 81 to bias tube 80 as a detector. The slider 85 is bypassed to ground for audio frequencies by condenser 85′.

The amplifiers 102 and 91 may be of any suitable construction, as for example types 6J7 and 6L6 respectively. The screen and plate electrodes of each of these tubes are connected to the +B terminal of the system. Resistor 92 in the plate circuit of tube 102 functions as the output load of the amplifier 102. The plate end of resistor 92 is connected through coupling condenser 93 to the input grid 94 of tube 91. The input grid 94 is returned to the grounded end of cathode resistor 90 by resistor 95. The output transformer 96 couples the plate circuit of tube 91 to the reproducer 97.

It will now be seen that the duplex channel record may have its separate selections reproduced by selective adjustment of switch elements 78 and 78′. The single pickup device 70 will feed the entire zero to 10,000 cycle band to amplifier 73, but the adjustments of switch elements 78 and 78′ will determine which one of the two channels will be reproduced at reproducer 97. An outlet jack 98 has its leads 99 connected to the input terminals of high pass filter H. This jack may be used for stereophonic reproduction by connecting it with a system including a low pass filter (cut-off at 4000 cycles), subsequent amplifiers and a final sound reproducer. This would provide stereophonic sound reproduction when the switches 78 and 78′ are in position B′ and B′′ respectively, as explained in connection with Fig. 2.

To avoid the necessity for using special record cutters which can tolerate the extended application of the entire output of oscillations having frequencies as high as 10,000 cycles per second the amplitude of the injected oscillations (the carrier) may be varied in accordance with the signal intensity thereby enabling the use of the normal present-day cutters.

Fig. 6 shows such an exemplification of a circuit that can be substituted for the circuit portion between transformers 36 and 45 of Fig. 3. The modulator tube 110, which may be of the 6SA7 type for example, has its cathode 111 connected to a suitable positive potential point on direct current voltage supply resistor combination 112. The screen 113 and plate 114 are respectively connected to successively higher positive potential points on the resistor combination. The inner grid 115 is coupled to the plate circuit of oscillator tube 116 by blocking condenser 117, resistor 118 and tank coil 119, while resistor 120 returns grid 115 to the cathode 111. The signal grid 121 is coupled through condenser 122 to the plate 123 of a tube 124, of the 6SK7 type, for example, which functions as a gain compressor and is so designated. The oscillator tube 116 may be of any suitable construction, and generates constant amplitude-constant frequency oscillations of 10,000 cycles per second.

The cathode 125 of the tube 116 is connected to ground by bias resistor 126, while the grid 127 is returned to ground through resistor 128. The plate coil 119 is coupled to grid 127 by condenser 129, and the center tap on coil 119 is connected to the +B terminal.

The signals passing low pass filter 33 (from zero to 4000 cycles per second) are applied through transformer 36, potentiometer slider 130 and coupling condenser 131 to the signal grid 132 of compressor tube 124. The potentiometer resistor 130′ shunts the secondary winding of transformer 36. The screen and plate of tube 124 are connected through respective resistors 133 and 134 to the +B terminal of the direct current supply source. The audio voltage developed across resistor 134 and covering a band of from zero to 4000 cycles per second, is applied to signal grid 121. The signal grid 132 is returned to the grounded end of cathode resistor 135 over a path including resistor 136, lead 137, slider 138 and resistor 139. The latter resistor is the output load of diode rectifier 140, 141. The signal grid 121 of modulator 110 is returned to the grounded end of cathode 111 over a path comprising resistor 142, lead 143, slider 144 and resistor 145. The latter resistor is the output load of diode rectifier 146, 147. Each of load resistors 139 and 145 is shunted by respective audio frequency bypass condensers 139′ and 145′.

The signals applied to grid 121 and oscillations applied to grid 115 are mixed by virtue of electronic coupling in tube 110. There is produced in the plate circuit of tube 110 the sum and difference components of the signal frequencies and oscillator frequency. The transformer 45 applies these components to high pass filter 50. The inversion of the 0–4000 cycle band to a 6000–10,000 cycle band is accomplished in this manner.

To carry out the control function, a predetermined magnitude of input signal at transformer 36 is amplified by cascaded amplifier tubes 148 and 149. Potentiometer 150, connected across the secondary of transformer 36, controls the intensity of signal applied to the grid 151. Triodes 148 and 149 may be, for example, of the 6J5 type, and the plates thereof are connected through like resistors 152 and 152′ to the +B terminal. The signal grid of tube 149 may be adjustably coupled to coupling resistor 153 whose upper end is connected by blocking condenser 154 to the plate end of resistor 152.

The amplified audio voltage across resistor 152′ is applied by coupling condenser 155 to the rectifiers 140, 141 and 146, 147. The rectifiers may be separate tubes, or may have the electrodes thereof located in a common tube envelope 156, as in the case of a 6H6 type tube. The cathode 141 is connected to the output terminal of condenser 155, while anode 140 is connected to the ungrounded end of load resistor 139. Accordingly, there is applied to signal grid 132 a rectified voltage which becomes increasingly negative in polarity as the signal amplitude at transformer 36 increases. The anode 146 of the second diode is connected to condenser 155, while its cathode 147 is connected to the upper end of load resistor 145. The signal grid 121 will, therefore, have applied thereto a rectified voltage which becomes increasingly positive in polarity as the signal amplitude at transformer 36 increases.

The signal grid 121 is given a normal negative bias (adjustment of slider 112′) such that only a small amount of 10,000 cycle oscillatory voltage may be developed at plate 114. In other words, the normal negative bias on grid 121 causes the space charge in front of grid 115 to increase thereby to reduce the effect of the 10,000 cycle carrier on the electron stream flowing to plate 114. When the signal amplitude at transformer 36 is low the rectified voltage across resistor 145 is small and the positive bias applied to grid 121 by this resistor is also small. When the signal strength at transformer 36 increases, the bias of grid 121 becomes more positive. Hence, the bias of grid 121 will vary to permit signals of higher intensity to increase the effect of the oscillator on the electron stream of tube 110.

The average bias of grid 121 is thus varied in direct dependence on the input signal amplitude. There is always provided sufficient carrier at the modulator to permit modulation. The purely pictorial wave forms of Figs. 7*a* and 7*b* show the effect of control of the average bias of control grid 121. Fig. 7*a* shows the wave form of modulated carrier output of modulator 110 when control is applied, whereas Fig. 7*b* shows the same wave form in the absence of control. It will be noted that in Fig. 7*b* low intensity modulations are carried by large carrier amplitudes, whereas in Fig. 7*a* the carrier amplitude shows a pronounced drop with low intensity modulation.

As the carrier effect is varied in response to signal amplitude variation, the modulator output is no longer proportional to the original audio modulating voltage. To overcome this defect, the signal grid of compressor tube 124 is provided with the signal-responsive bias developed at resistor 139. The control in this instance is in a polarity sense such as to decrease the gain of tube 124 as the signal amplitude increases and the modulator output increases. Hence, the increase in modulation amplitude of the modulator tube due to "expansion" is reduced or offset by "compression" in the tube 124. However, the effect of compression at tube 124 is merely to reduce the effective signal intensity at grid 121 as the effect of the carrier voltage at the modulator tube increases.

Summing up the action of the control system of Fig. 6, the effect of a bias change on grid 121 is to vary the ratio of audio to carrier, rather than to vary the oscillator output. We have found that without the system of Fig. 6, the noise level of the reproduced signals is too high at low levels of modulation. With the control system a high modulation level is maintained at all times.

While we have indicated and described several systems for carrying our invention into effect, it will be apparent to one skilled in the art that our invention is by no means limited to the particular organizations shown and described, but that many modifications may be made without departing from the scope of our invention.

What we claim is:

1. In a stereophonic sound reproducing system, a spaced pair of transducers for providing separate sets of signals corresponding to the sound waves reaching them, recording device, a low pass filter connected to one of the transducers and to said recording device and passing a predetermined band of audio frequencies, a filter connected to the second transducer and adapted to pass a similar band of audio frequencies, inverting means for inverting the frequencies of the second band, and means for feeding the inverted band of audio frequencies to said cutter device.

2. A sound reproducing system comprising in combination, a recording device having an extended frequency response range, a first transfer network connected to said recording device, input elements connected to said first transfer network for providing a first set of signals, a band pass filter connected in said first transfer network for passing a first predetermined band of frequencies, a second transfer network connected to said recording device, input elements connected to said second transfer network for providing a second set of signals, and inverting means connected in said second transfer network for inverting the frequencies of the second set of signals whereby the inverted frequencies occupy a second limited band of frequencies within said response range but distinct from said first predetermined band.

3. A sound reproducing system as defined by claim 2, in which the second transfer network also includes a band pass filter circuit, one of said band pass circuits being a high pass filter adapted to transmit solely the band of higher frequencies in said response range and the other band pass circuit being a low pass filter adapted to transmit solely the band of lower audio frequencies in said response range.

4. A sound reproducing system as defined by claim 2, in which the inverting means includes a mixer circuit connected in said second transfer network and an oscillator circuit connected to said mixer circuit.

5. A sound reproducing system as defined by claim 4, in which a band pass filter is connected between said mixer and said recording device in said second channel for selecting signals within said second limited band of frequencies from the output of said mixer.

6. A sound reproducing system comprising in combination, a recording device having an extended frequency response range, a first transfer network connected to said recording device, input elements connected to said network for providing a first set of audio frequency signals, a band pass filter connected in said network for passing only a first band of frequencies within said response range, a second transfer network connected to said recording device, input elements for providing a second set of audio frequency signals connected to said second transfer circuit, a mixer circuit connected in said second transfer circuit, an oscillator circuit connected to said mixer, and a band pass filter circuit connected in said second transfer network to the output of said mixer to select a band of inverted frequency signals corresponding to said second set of signals and within said response range.

7. A sound reproducing system as defined in claim 6, in which the first transfer network includes a band pass filter passing a band of signal frequencies within said response range but distinct from the inverted frequency signal band.

8. A sound reproducing system as defined in claim 7 in which the filter in said first transfer network has a high pass band characteristic, and the filter in said second transfer network has a low pass band characteristic.

9. A sound reproducing system as defined in claim 8 in which a third band pass filter is connected in said second transfer network succeeding said mixer circuit having a pass band including the frequency of oscillations in said oscillator circuit.

10. A system as defined in claim 7 in which means is provided for automatically controlling and reducing the oscillator circuit output level at low modulation levels thereby relieving sustained high intensity high frequency operation of said input elements.

11. A sound reproducing system as defined in claim 6 including means for varying the average amplitude of signals in said second transfer network in accordance with signal amplitude at said mixer circuit.

12. In a stereophonic sound reproducing system, a spaced pair of reproducers for reproducing separate sets of signals corresponding to sound waves, a record device, a means for picking up signals recorded on said device within an extended frequency response range, a band pass filter connected between said means and one of said reproducers for passing a band of signals within said range, a second filter connected between said means and the second of said reproducers for passing a different band of signals within said range, and inverting means connected to one of said filters for inverting the frequencies of the signals within the band of the said filter.

13. A sound system for reproducing records of different sets of signals recorded within an extended frequency response range on a single recording comprising in combination, record transducing means having a frequency response range corresponding to said extended range, a signal transfer network connected to said transducing means, a signal reproducing means connected to said transfer network for reproducing signals in one of said sets, a band pass circuit connected in said network, frequency inverting means connected in said network, and a selective filter circuit connected in said network for passing to said reproducing means signals in only one of said sets.

14. A sound system as defined in claim 13 in which a second signal transfer network is provided including a band pass circuit connected with the transducing means for directly passing to the reproducing means signals in the second of said sets.

15. A sound reproducing apparatus for records having recorded an extended frequency range of signals including separate bands devoted to individual signal sets, record transducing means having a frequency response over said extended

frequency range, signal reproducing means, a signal transfer network including a band pass circuit connected between said transducing means and said reproducing means, said band pass circuit for passing a band of signals corresponding to one of said individual signal sets, rectifying means connected in said transfer network, and a band pass filter connected between said rectifying means and said reproducing means, a second transfer network including a second band pass circuit connected between said transducing means and said reproducing means, said second band pass circuit for passing a band of signals corresponding to a second of said separate band of signals.

16. Apparatus as defined in claim 15 having a second transfer network including a second band pass circuit connected between said transducing means and said reproducing means, said second band pass circuit for passing a band of signals corresponding to a second of said separate bands of signals.

17. Apparatus as defined in claim 15 wherein said last mentioned band pass filter has a sharp high frequency cut off characteristic.

18. Apparatus as defined in claim 15 having means for selectively connecting to said reproducing means either said first or said second transfer network.

19. A stereophonic sound reproducing system comprising in combination, a plurality of spaced signal reproducers for independently reproducing separate sets of stereophonically related signals, a record transducing means having a frequency response of an extended frequency range, a signal transfer network connected between said transducing means and one of said reproducers, a first band pass circuit connected in said network, a rectifying means connected in said network, and a second transfer network including a second band pass circuit connected between said transducing means and a second of said reproducers for directly supplying a different stereophonic signal set.

20. A system as defined in claim 18 in which the first band pass circuit has a low pass characteristic and a low frequency cut off, said rectifying means is connected to said low band pass circuit, a third high pass band circuit is connected between said rectifier and said reproducer to pass substantially only demodulated signals, and said second band pass circuit has a high pass characteristic and a high frequency cut off.

CHESTER M. SINNETT.
HERBERT BELAR.

REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
1,675,894	Lindridge	July 3, 1928
1,685,357	Griggs	Sept. 25, 1928
1,707,260	Fetter	Apr. 2, 1929
1,797,317	Brand et al.	Mar. 24, 1931
1,799,795	Horton	Apr. 7, 1931
1,855,149	Jones	Apr. 19, 1932
1,910,254	Keller	May 23, 1933
2,114,019	Friebus	Apr. 12, 1938
2,258,662	Snow	Oct. 14, 1941
2,261,628	Lovell	Nov. 4, 1941
2,292,014	Roberts	Aug. 4, 1942
2,343,471	Nixon	Mar. 7, 1944