Sept. 17, 1935. A. C. KELLER 2,014,528

SOUND RECORDING AND REPRODUCING SYSTEM

Filed May 6, 1932

FIG. 1

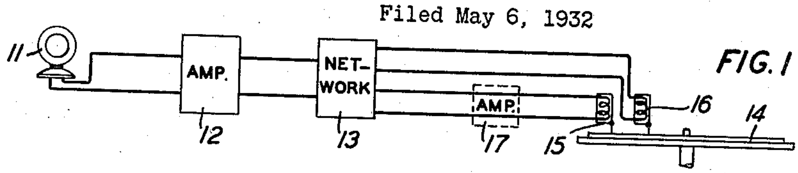


FIG. 2

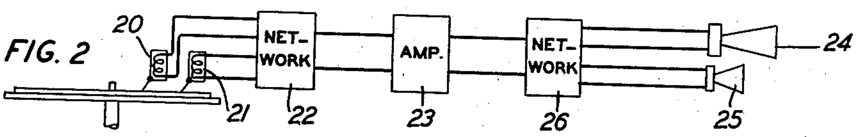


FIG. 3

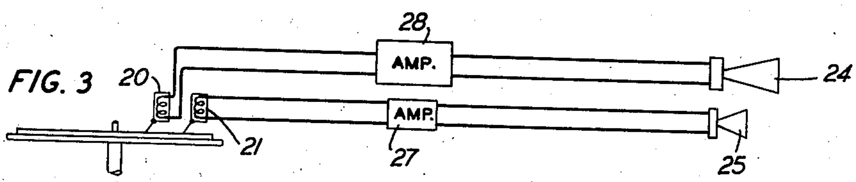


FIG. 4

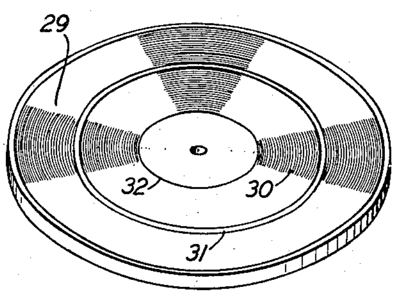


FIG. 6

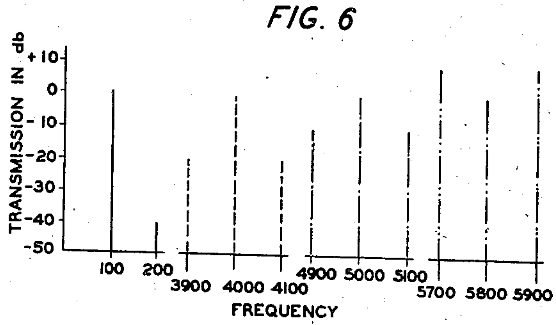


FIG. 5

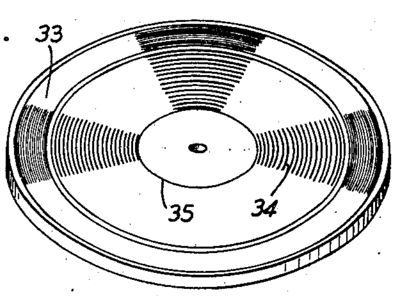
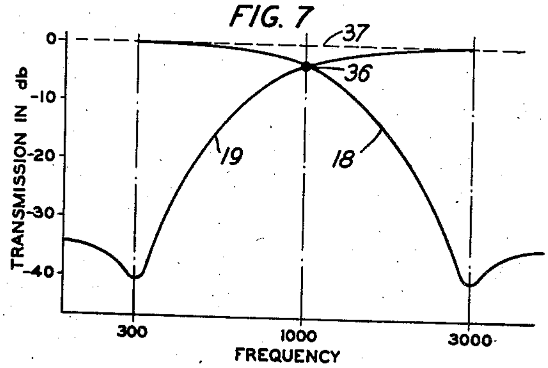


FIG. 7



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SOUND RECORDING AND REPRODUCING SYSTEM

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Application May 6, 1932, Serial No. 609,564

5 Claims. (Cl. 274—42)

This invention relates to sound recording and reproducing systems and more particularly to those employing mechanical recording devices, such as the groove cutting type in which the work performed by the device varies considerably with the amplitude of the sound being recorded.

The object of the invention is to improve the quality of reproduction obtainable from records made in such recording devices.

In cutting phonograph records and particularly those of the hill and dale type, there are various factors tending to cause variations in the relative velocity of the recording material with respect to the cutting face of the recording stylus. Such variations are typically non-linear and therefore introduce into the record harmonics of the impressed frequency and also cross-modulation terms when more than one frequency is present.

An obvious cause of such variations would be fluctuations in the speed of the turntable due to the load changes incident to the varying depths of cut. These fluctuations can be kept negligibly small by providing a driving motor of adequate power and a turntable having considerable inertia and hence these fluctuations need not be particularly considered here. In effect, however, similar fluctuations are produced by deflections in the recorder structure, the recorder stylus, the recording material and in the reproducer structure and stylus.

The stylus arm and other linkage members of the recorder are necessarily of finite stiffness and therefore take a deflection along the record groove which is a function of the depth of cut. Due to other design factors, to be explained, the recorder stylus must taper to a tip which is very thin in the direction of the groove and therefore subject to a varying deflection when cutting the groove. The recording material itself being necessarily somewhat resilient is temporarily, slightly deformed by the stress of the cutting operation and since the magnitude of deflection will vary with the groove depth, it produces a distortion in the contour of the groove which is equivalent to the introduction of extraneous frequency components. The same effect may be present to some extent in the pressings, particularly when weak materials, such as cellulose acetate are used. The reproducer structure also tends to take a deflection along the groove due to the force of friction between the stylus and the groove and since the pressure between them changes with the groove depth, the deflection will vary and introduce further undesired components. Although the reproducer stylus may be inherently somewhat stiffer than the tip of the recorded stylus, it also may cause more or less distortion of this type.

While even a single frequency is distorted by the addition of harmonics and any two frequencies produce cross-modulation currents in addition to their own harmonics as already pointed out, it is found that these components are, for the most part, small as compared to the components producing them, except when one of the frequencies is in the lower part of the range where the amplitudes are relatively large. In some cases of this kind the higher extraneous frequencies so introduced may be even greater in amplitude than adjacent impressed frequencies thereby very noticeably impairing the quality of reproduction in the upper part of the range.

This form of distortion is substantially eliminated, according to this invention, by separating the frequencies to be recorded into two or more component bands which are recorded separately and separately reproduced and retranslated into sound through one or more loudspeakers as desired. In this way the low frequency components which require high amplitudes in the record are prevented from modulating the high frequency and the latter may, if desired, be recorded at greater than normal amplitude to increase their margin over the noise. In the case of orchestral music, for example, a very decided improvement is obtained by recording in two bands with the dividing frequency at about one thousand cycles as will be more fully explained.

The recording system, according to the invention, includes suitable means for separating the frequencies recorded into the desired component bands and means for amplifying the high frequency components more than the low frequencies when the high frequencies are to be recorded above normal amplitude. The reproducing system may then be provided with amplifiers of the usual capacity for the low frequencies and a smaller amplifier for the higher frequencies to restore the proper relation between the components as reproduced. The several component bands may be recorded on separate record blanks or on a single blank. When a single blank is used, the bands may be cut on opposite sides of the blank or in concentric bands on one side, the high frequencies preferably being on the outer portion and the lower frequencies on the inner portion of the disc. In the latter case the record may have normal or greater than normal playing time without increasing its diameter since the low frequencies can be successfully recorded on the central normally unused portion of the disc. The high frequencies occupy the normal recording band and may be recorded considerably above their proper relative amplitudes with consequent reduction in surface noise. Alternatively the high frequency may be recorded at normal amplitude, but with greatly reduced groove spacing, so that only a portion of the usual recording space is required for these frequencies. The space saved in this matter may be apportioned between the component bands to increase materially the maximum playing time of the record.

These and other features of the invention will be more clearly understood from the following detailed specification and the drawing in which Fig. 1 is the schematic of one type of recording system according to the invention.

Figs. 2 and 3 are schematics of reproducing systems for a record made by the system of Fig. 1.

Figs. 4 and 5 are records according to the invention showing the grooves of the several component bands.

Fig. 6 is a diagram illustrating the relative magnitude of the impressed and extraneous frequencies; and

Fig. 7 is the transmission characteristic of a suitable network for dividing the frequency band into the required component parts.

Fig. 6 illustrates a possible situation showing the relative magnitude of harmonic frequencies and the cross-modulation current for three separate cases when using a recorder of a well known type and recording each note at the maximum level permissible for satisfactory reproduction with an ordinary stylus needle that is, at such a level that the minimum radius of curvature of the groove undulations is .0022 inch which is the radius of the stylus tip. As already pointed out, a note recorded either alone or in combination with other notes produces a series of harmonic frequencies, but these are negligibly small for high frequencies and of relatively small magnitude even for low frequencies as shown by the two hundred-cycle component introduced by the one hundred-cycle note. When, however, a one hundred-cycle note and a four thousand-cycle note are recorded together, they produce cross-modulation terms, the most prominent of which are the thirty-nine hundred and forty-one hundred-cycle frequencies which in magnitude are only twenty decibels below the value of the impressed frequencies producing them. The combination of one hundred and five thousand cycles produces most prominently forty-nine hundred and fifty-one hundred-cycle terms of a magnitude only ten decibels below the impressed frequencies and when fifty-eight hundred cycles which is near the resonant frequency in the direction of the groove of the particular recorder used, is recorded with a one hundred-cycle note, the resulting fifty-seven hundred and fifty-nine hundred-cycle components for example are ten decibels above the level of the impressed frequencies. These results are typical of the interaction of the low and high frequencies and give an indication of the magnitude of the distortion which may occur in the cutting of a record in the usual manner. This effect seems to account, to a large extent at least, for the apparent lack of "detail" in records of complex subjects such as orchestral selections whereas very good "detail" is obtained in parts of the same record where a single instrument stands out. Moreover, it is found that distortion of this type due to one or more of the causes explained above is, to a large extent, responsible for the increase in distortion at high frequencies, for as shown by Fig. 6, this effect increases rapidly as the resonant frequency of the recorder is approached.

A system for eliminating this type of distortion in recording, as shown in Fig. 1, comprises a pick-up microphone 11, connected to the input circuit of an amplifier 12, the output of which is conducted to a suitable filter network 13 for dividing the frequency components into two or more bands which are separately recorded in accordance with any one of the schemes already mentioned as for example on the record blank 14 by recorders 15 and 16. If the high frequencies are to be recorded in over-amplified relation with respect to the low frequencies, the additional gain required may be furnished by a second amplifier 17.

The choice of the dividing frequency depends on a number of considerations, one of the most important being the nature of the sound to be recorded. For orchestral music, for example, the energy in the high frequency portion of the range is a maximum around three thousand cycles and since it is desirable to avoid cross-modulation in this part of the range, this means that the dividing point should be below three thousand cycles. The largest amplitudes in the record groove for a constant velocity recording system of the usual type occur below three hundred cycles so that the dividing point should be above this frequency to avoid large amplitudes with resulting large cross-modulation terms in the high frequency band. The amplitudes of the frequencies above one thousand cycles is relatively small as compared with the amplitudes of frequencies below three hundred cycles so that under the various conditions encountered good results may be obtained, according to the invention, by choosing the dividing frequencies anywhere in a range extending from perhaps five hundred to two thousand cycles. When multiple unit loudspeakers are used to avoid the cross-modulation incident to the use of a single speaker, the characteristics of the loudspeakers may be a determining factor within this range. For example, when using a dynamic speaker for the low frequencies and a small horn type speaker for the high frequencies, it may be desirable to split the band as low as five hundred cycles.

For purposes of illustration, the dividing frequency will be assumed as one thousand cycles which is approximately the geometric mean of the limiting frequencies of the portion of the band within which the band should be split. The division may be accomplished in various ways known in the art, for example, one very simple arrangement consists merely of an inductance and a condenser connected in series across the output of the amplifier 12 with the high frequency recorder connected across the inductance and the low frequency recorder connected across the condenser. Since the impedance of the inductance varies directly with frequency and the impedance of the condenser varies inversely with frequency, the proper choice of constants effects a division of the band of frequencies between the two recorders. In order to avoid excessive loss in the neighborhood of the dividing point, the transmission characteristics of the impedance and condenser must overlap to a considerable degree and hence the separation of the band can not be as complete as may be desired in some high quality systems. For this reason a more desirable arrangement is a combination of multisection low and high pass filters having transmission characteristics 18 and 19 as shown in Fig. 7. With this arrangement, each filter may be designed to have a sharp cut-off near the dividing frequency and maximum attenuation in the region of the frequencies of highest energy content in each of the subbands thereby effectively separating the frequencies most likely to produce excessive cross-modulation.

The curves 18 and 19 are drawn to show the transmission in decibels for various frequencies with respect to some arbitrarily chosen zero recording level. It will be seen that one thousand cycles, the dividing frequency in this case, each filter introduces about 3 db. loss and hence one-half the energy at this frequency is recorded in each of the subbands but the two components when reproduced together give a volume level equal to the recording level. Beyond the common point 36 each filter cuts off sharply so that frequencies much removed from one thousand cycles are recorded practically entirely in one of the subbands. The slight attenuation from zero level for frequencies in the immediate neighborhood on either side of one thousand cycles is practically compensated by the small components of these frequencies recorded in the other band in each case so that the resulting over-all reproduction characteristic is practically flat as shown by the dotted curve 37. The curves 18 and 19 have maximum attenuation at three hundred and three thousand cycles in the regions of maximum energy so that the subbands are very effectively separated and prevented from reaching one another.

When amplifier 17 is not used in making a record, the record may be reproduced by a system such as that shown in Fig. 2. The reproducers 20, 21 cooperating with the low and high frequency grooves respectively are connected to the network 22 which is similar to network 13, but in this case serves to reunite the frequencies into a single band and at the same time prevent one reproducer from reacting on the other. The single band is amplified by amplifier 23 having suitable receiver means in its output circuit. A single receiver may be used but better results are obtained by providing separate receivers 24, 25 and a band splitting network 26 which may be similar to network 13 or to the simpler type discussed above. The use of separate receivers eliminates the cross-modulation distortion which would occur in a single receiver and also results in better reproduction since each receiver may be particularly adapted to reproduce the frequencies in the portion of the band in which it operates. A multiple unit receiver combination of this general type is more fully described in an application of L. G. Bostwick, Serial No. 395,802, filed September 28, 1929, now Patent No. 1,907,-723, granted May 9, 1933.

Alternatively, the record may be reproduced by a system of the type shown in Fig. 3 in which separate circuits are provided throughout for each of the reproducers 20 and 21 and no networks are required. This system is well adapted to reproducing records in which the high frequencies are recorded in over-amplified relation to the low frequencies since only a small amplifier 27 is required to deliver the high frequencies to the horn type receivers 25 at proper volume level and amplifier 28 for the low frequencies, need be of only moderate capacity since it does not carry the full frequency range.

Reference is made to Patent Re. 18,228 to Maxfield, October 20, 1931 for a full explanation of the factors affecting the playing time of phonograph records.

Fig. 4 shows a record in which the high frequencies are in the outer band 29 in the part of the record ordinarily used and in which the low frequencies are contained entirely within the normally blank portion 30. For good reproduction from a twelve inch disc turning at a speed of 33⅓ R. P. M. the inner groove 31 must be approximately four inches from the center of the record to provide the minimum linear velocity of about fourteen inches per second in accordance with usual practice. This limitation is due to the fact that the radius of curvature of the undulations representing a given frequency decreases as the center is approached but for satisfactory reproduction can not be less than the tip radius of the reproducer stylus. This curvature limitation first affects the higher frequencies which are inherently of smaller radius of curvature, but as there are no high frequencies in the band 30, this band may extend much farther toward the center without impairing the quality of the record. Even when the dividing frequency is as high as one thousand cycles, the minimum velocity of the groove 32 may be much less than when higher frequencies are present, hence the band 30 may be confined entirely to the normally unused portion of the disc and still have the same playing time as band 31.

The record illustrated in Fig. 5 shows a high frequency band 33 recorded in closely spaced grooves with the low frequencies in the band 34 in which the grooved spacing is somewhat larger, whereby an increase in playing time is obtained in addition to the elimination of cross-modulation as compared to a standard record, without loss of volume level or impairment of quality due to curvature difficulties. Since the high frequencies require only small amplitude variations in the record as compared with the low frequencies, the groove spacings for the band 33 may be 300 lines per inch for example as compared with the normal spacing of 100 lines per inch for the band 34. If, as before, the minimum linear velocity of the inner grove 35 is to be not materially less than seven inches per second, band 34 may be about three inches wide and band 33 about one inch wide to give equal playing times. Since band 34 is three inches wide and band 30 of Fig. 4 is two inches wide, the record of Fig. 5 provides a gain of fifty per cent in playing time.

While the invention has been described with reference to particular recording and reproducing circuits and record constants, it will be understood that this is for purposes of illustration only and that many modifications may be made within the scope of the invention. The principles of the invention are applicable primarily to hill and dale type systems but the records may be of any size or groove spacing or combination of groove spacings. The low frequency band, moreover, may not be entirely confined to the normally unused portion of the disc as for instance in the case of very large records, or records in which these frequencies are recorded at greater than normal groove spacings to permit large amplitudes in the groove undulations.

What is claimed is:

1. A disc phonograph record of sounds having a wide range of component frequencies with the

high frequency components of each sound recorded adjacent the periphery of the disc and the low frequency components of each sound recorded on the inner, normally unused portion of the disc.

2. A disc phonograph record of a selection, all of the higher frequencies of which are recorded in the space on the record between a groove having a radius which is substantially the minimum consistent with good recording and the periphery of the record, and all of the lower frequencies of which are recorded within the space enclosed by said groove.

3. A disc phonograph record of a selection, all of the higher frequencies of which are recorded in over-amplified relation to the low frequencies on the outer portion of the disc and all of the low frequencies of which are recorded on the inner portion of the disc.

4. A disc phonograph record of a selection, all of the higher frequencies of which are recorded in closely spaced grooves on the outer portion of the disc and all of the lower frequencies of which are recorded in more widely spaced grooves on the inner portion of the disc.

5. A long playing disc record of the important frequencies within the range of speech and music having two concentric bands of grooves, the inner band comprising normally spaced grooves containing only the low frequencies of relatively high energy content and extending outwardly from an inner groove of substantially the minimum radius at which the highest frequency in said band may be successfully reproduced and the outer band comprising closely spaced grooves containing only high frequencies of relatively low energy content.

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