

May 14, 1929.

L. ESPENSCHIED

1,713,039

PHONOGRAPH RECORDING AND REPRODUCING

Filed Nov. 15, 1919

3 Sheets-Sheet 1

Fig. 1

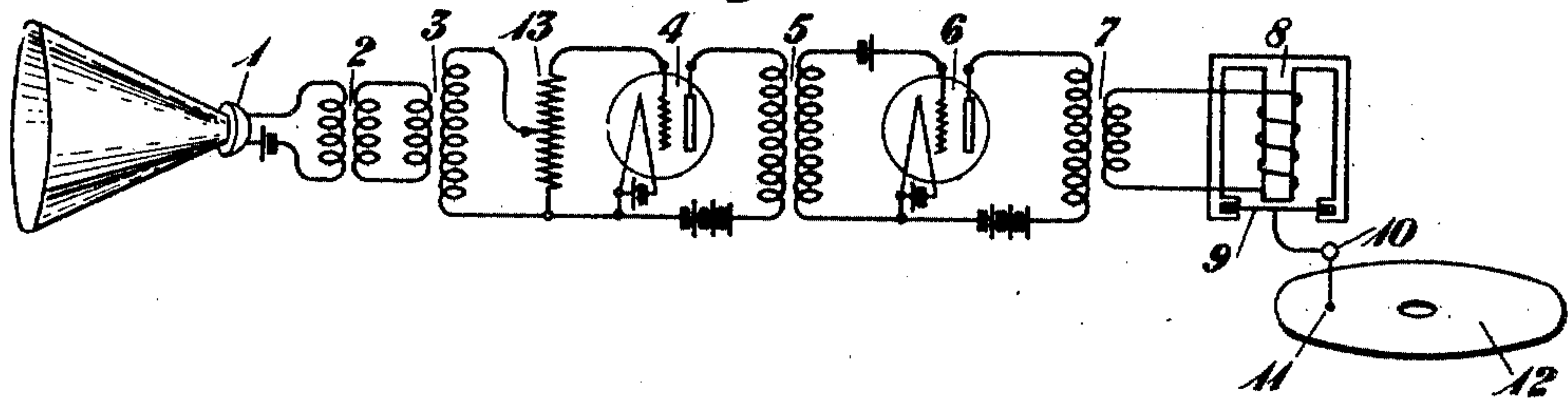


Fig. 2

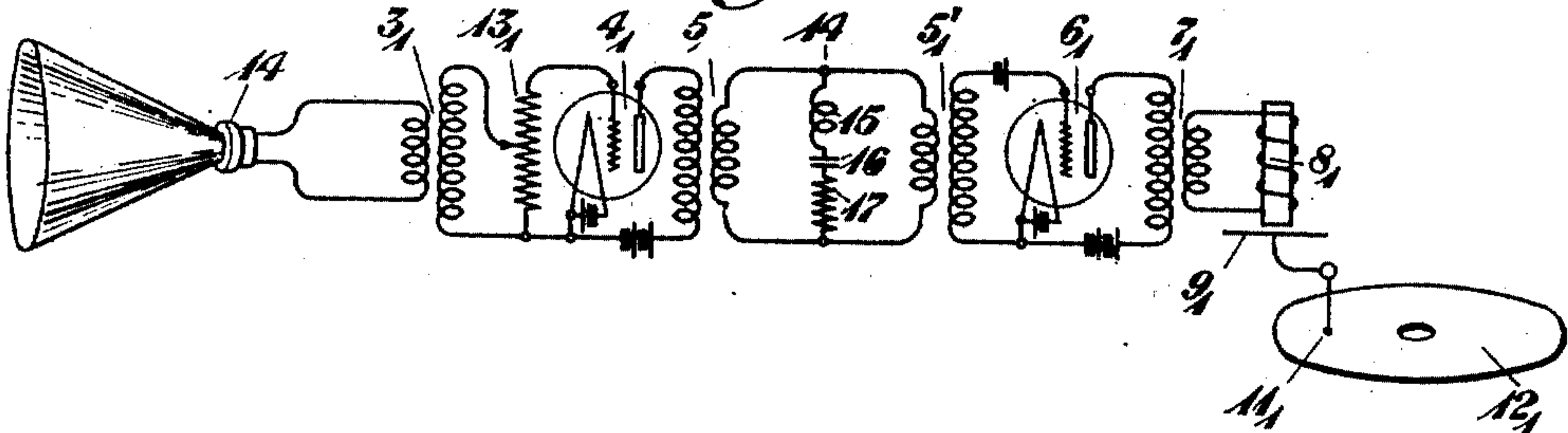
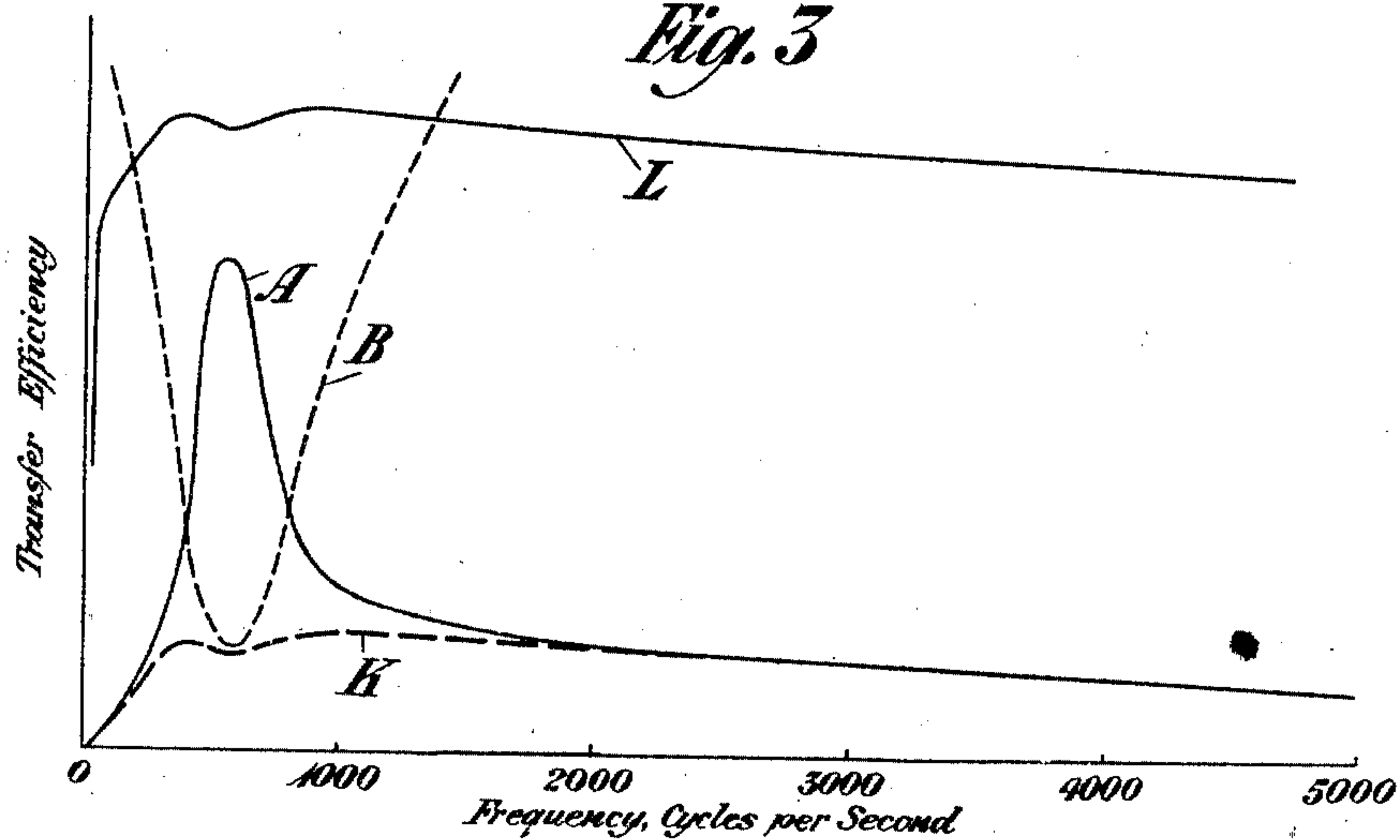


Fig. 3



INVENTOR.
L. Espenschied
BY *L. Espenschied*
ATTORNEY

May 14, 1929.

L. ESPENSCHIED

1,713,039

PHONOGRAPH RECORDING AND REPRODUCING

Filed Nov. 15, 1919

3 Sheets-Sheet 2

Fig. 4

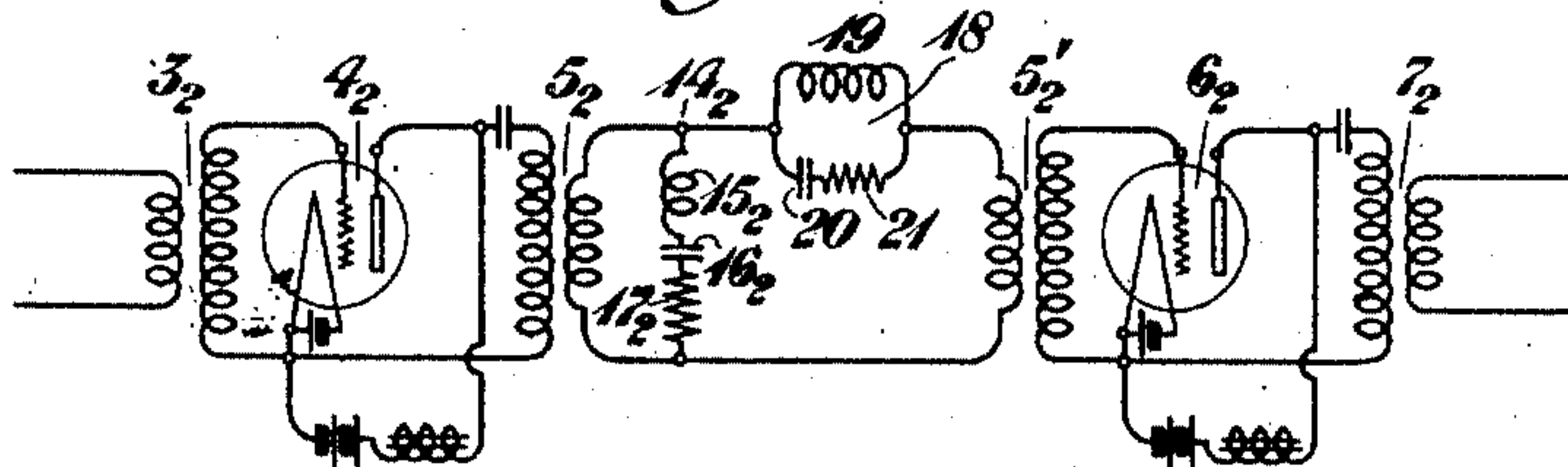


Fig. 5

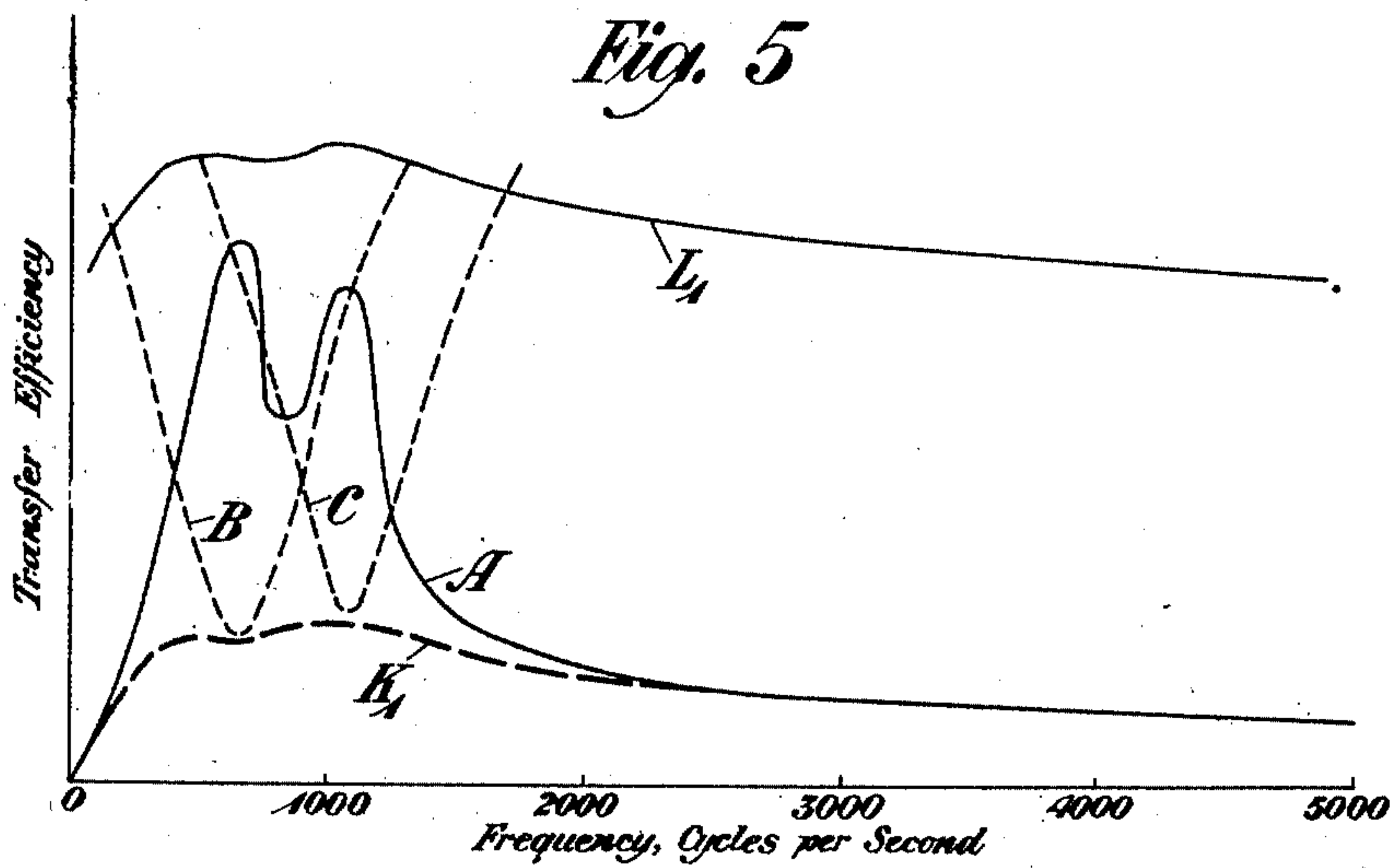
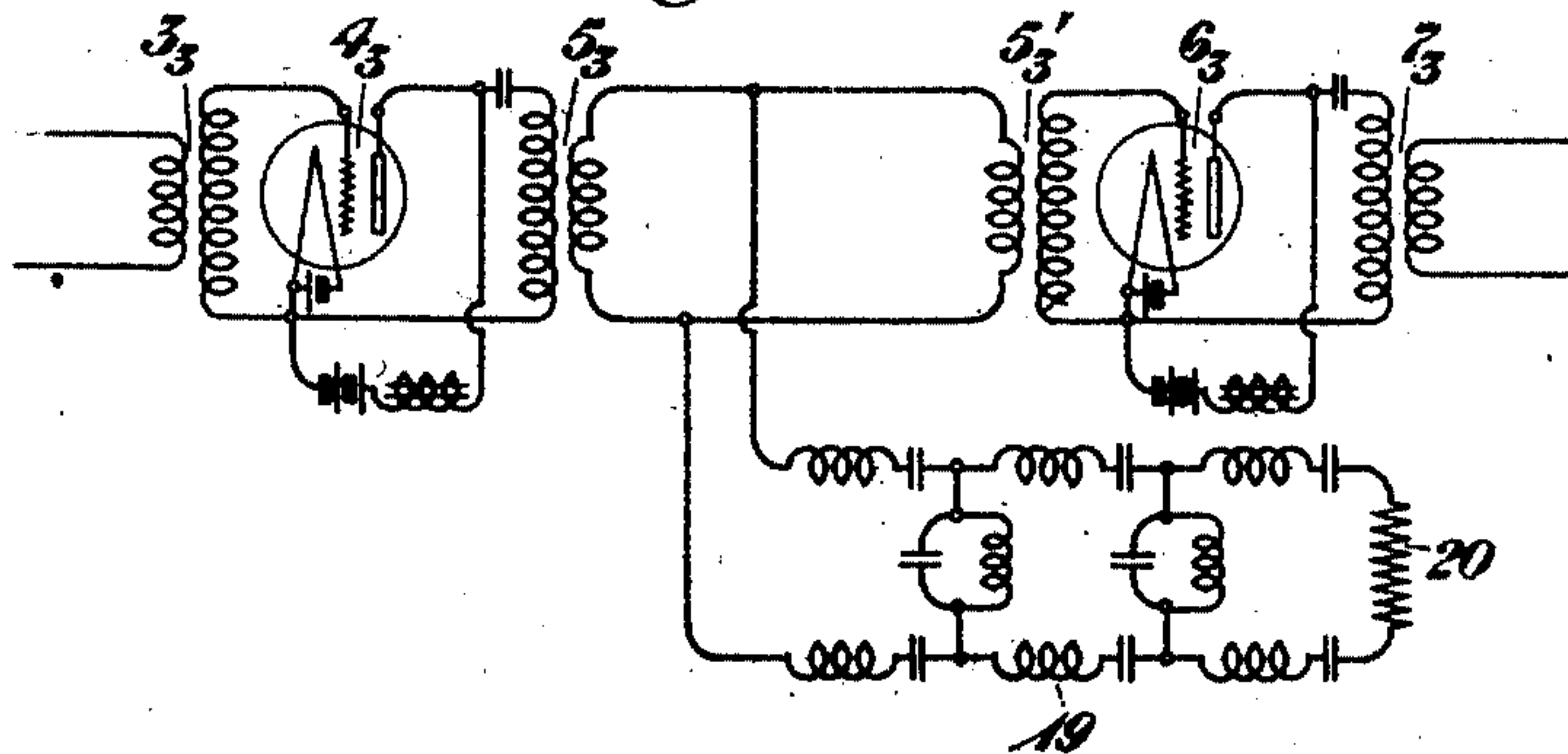


Fig. 6



INVENTOR.
L. Espenschied
BY *L. Espenschied*
ATTORNEY

May 14, 1929.

L. ESPENSCHIED

1,713,039

PHONOGRAPH RECORDING AND REPRODUCING

Filed Nov. 15, 1919

3 Sheets-Sheet 3

Fig. 7

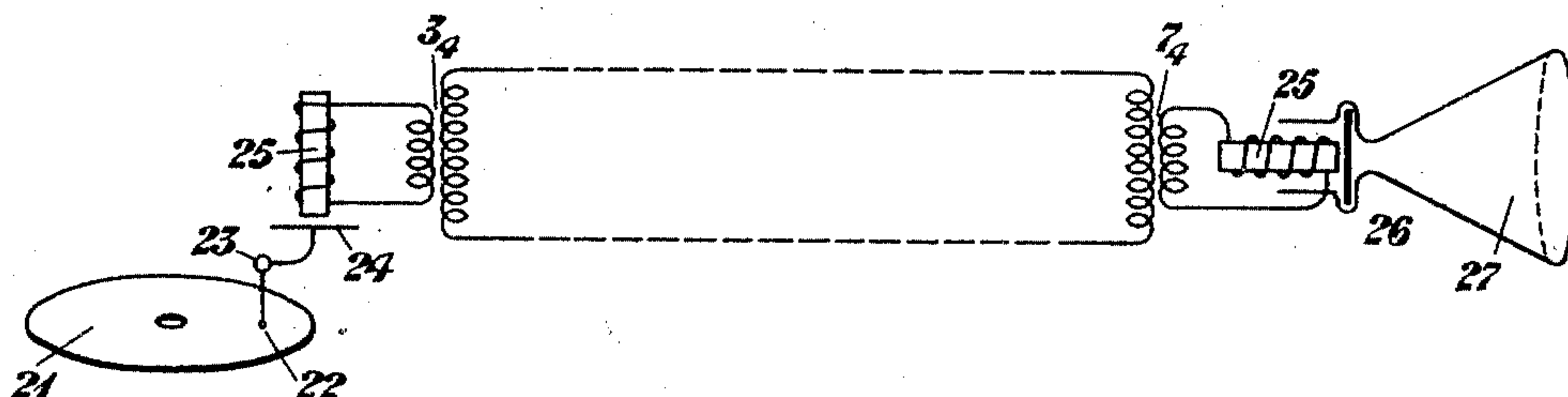
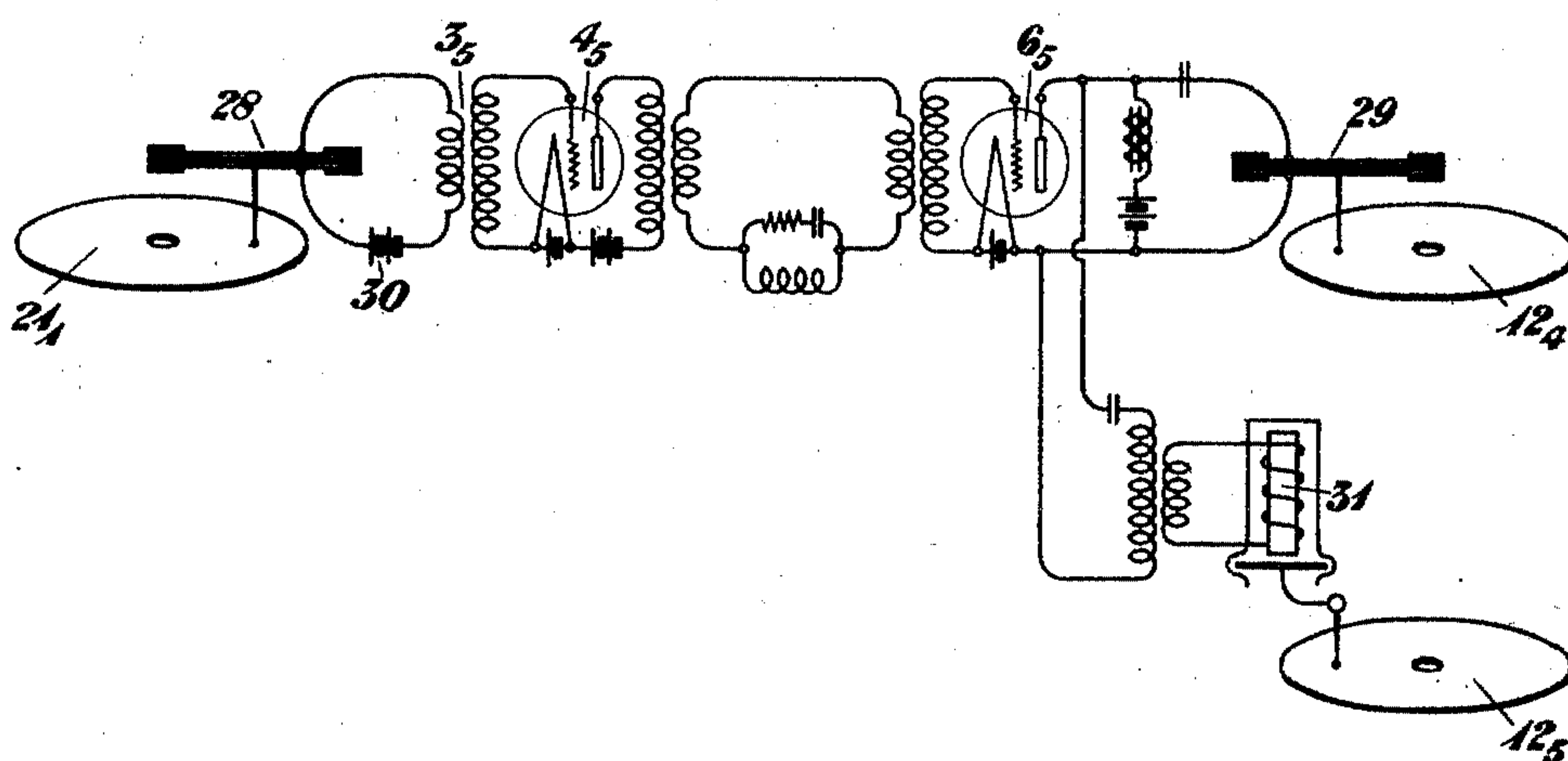


Fig. 8



INVENTOR.
L. Espenschied
BY *Loyd Espenschied*
ATTORNEY

UNITED STATES PATENT OFFICE.

LLOYD ESPENSCHIED, OF QUEENS VILLAGE, NEW YORK, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

PHONOGRAPH RECORDING AND REPRODUCING.

Application filed November 15, 1919. Serial No. 338,211.

The invention relates to phonographic devices and provides methods and means for improving the recording and the reproducing of sound waves.

5 The broad object of the invention is to improve the clarity and fidelity of sound reproduction. More specifically the objects of the invention are to reduce the scratching sound so common to phonographs, to improve the quality of the reproduced sound by correcting the distortion of the recording and reproducing instruments, and to provide means for increasing as desired the volume of the reproduced sound. Further objects and detailed features of the invention will be evident from the following description taken in conjunction with the accompanying figures.

20 A comprehensive understanding of the invention will be facilitated by first considering briefly the causes of the imperfect operation of phonographic devices. In this discussion of the principles involved and in the descriptive matter, the ordinary mechanically recording phonograph will be referred to, but it will be understood that the broad features characterizing the present invention apply equally well to all types of phonographs, such as those employing magnetism or light as the recording agent.

30 The disagreeable scratching sound of ordinary phonographs arises from extraneous variations or irregularities in the wave as represented in the recording medium, caused in the case of the ordinary mechanical type of record by physical imperfections and irregularities in the surface of the record, and by the presence of dust particles, etc. on the record surface. These irregularities cause the reproducing needle in tracing the surface of the wave to be thrown off from its true course in an irregular manner and to give rise to diaphragm movements representing noise.

45 Another limitation of the ordinary phonograph resides in its characteristic of not reproducing with equal efficiency all of the frequencies which constitute the frequency spectrum of sound. The ordinary phonograph, in fact, reproduces at maximum efficiency only a small part of the total frequency range involved and transmits inefficiently the greater part of the frequency

range necessary for good quality in the reproduction of music or speech. This inequality in the efficiency of reproduction of the broad band of frequencies involved in sound waves is hereinafter referred to as distortion. It is this effect which causes the monotonous "twang" so characteristic of the ordinary phonograph. The distortion is caused very largely by the inertia of and by resonance effects in the various translating devices employed. The ordinary diaphragm, for instance, which is used in the recorder and also in the reproducer or phonograph proper, has a natural period or several natural periods of vibration and therefore responds much more readily to some component frequencies present in the original sound than to others. Resonance effects also occur in the acoustic chambers of horns, such as those employed in directing the original sound to the recording diaphragm and in distributing the vibrations of the phonograph diaphragm throughout a room. These resonance effects are frequently so pronounced and selective in their action as to substantially suppress frequency components of the original sound other than those in the region of the natural periods.

In accordance with the present invention the difficulty first enumerated above, that of scratching, is ameliorated by amplifying the original sound wave energy and using the enhanced energy in obtaining a greater ratio between the amplitude of the desired record waves and of the undesired deviations in the true wave caused by the record irregularities. The second difficulty mentioned, that of distortion, is corrected by introducing compensating distortions which when added to the previously existing distortions gives a resultant substantially distortionless. These compensating distortions are illustrated as introduced electrically, but it will be understood, may be also introduced otherwise, as mechanically. The distortions, being due to the enhanced efficiency of reproduction at frequencies corresponding to the resonant periods of the instrument, are offset by similar resonance effects so inserted in the system as to produce a maximum loss in efficiency instead of gain in efficiency at the resonant periods.

Thereby the two resonance effects or sets of resonance effects are made to offset each other. Such an arrangement, of course, lowers the over-all efficiency of the system, but this is not a serious objection, since the amplitude of the currents representing the original sounds may be increased to any desired extent by distortionless amplification. The method of carrying out these operations and likewise the means therefor are more fully explained in the following disclosure taken in conjunction with the figures forming a part of this specification.

Figure 1 illustrates an arrangement for increasing the amplitude of the waves available for recording upon the master record and has for its object minimizing scratching and interference effects. Figure 2 illustrates an arrangement for introducing into the phonographic process an anti-distortion in accordance with the method of improving the quality of reproduction as outlined broadly above. Figure 3 presents curves illustrating the variation in the efficiency with which the different frequencies constituting sound are reproduced in the ordinary phonograph, together with curves illustrating the characteristics of the anti-distorting means and illustrating also the resultant characteristic after amplification. Figure 4 illustrates the case of providing a plurality of anti-distorting means and shows a variation in the specific anti-distorting means employed. Figure 5 presents curves similar to those of Figure 3, but for the case where correction for a plurality of resonant periods is involved. Figure 6 illustrates a further development of means for correcting for a plurality of natural periods causing distortion.

The above figures illustrate the application of the anti-distorting means in the process of making the original record. Figure 7 illustrates the application of the same means in the process of reproducing the record in the ordinary phonograph, as distinguished from the process of making the original record. Figure 8 shows the invention applied to the reproducing or multiplying of phonograph records.

Referring to Figure 1, 1 represents a telephone transmitter provided with an enlarged mouth-piece to facilitate the collection and concentration of sound waves upon the diaphragm. The transmitter is connected through the usual battery and the battery-supply transformer 2 to the input transformer 3 of a vacuum tube amplifier indicated as of two stages of amplification and including the input transformer 3, the audion amplifier bulbs 4 and 6 related by the transformer 5 and the terminating output coil 7. These amplifiers are provided with their usual battery supply circuits and being of a well-known audion or vacuum

tube type, need not be described in detail. The output transformer 7 is connected with an electromagnetic device 8 which is similar electrically to the ordinary telephone receiver. Its diaphragm 9 is attached to an arm which is pivoted at 10, the outer end of which carries a record scribing needle 11.

This general arrangement constitutes a means for amplifying substantially without distortion the energy available for making the impression on the original or master record 12. Sound waves falling upon the telephone transmitter 1 are converted into electric current waves of corresponding frequency, the currents are amplified, the amount of which may be adjusted by the potentiometer 13, and are impressed upon the device 8 for conversion into energy of mechanical vibration in diaphragm 9. The scribing needle 11 undergoes undulations corresponding in frequency to the original sound waves which undulations are cut or otherwise impressed upon the record 12. The enhanced energy thus obtained is used for overcoming extraneous record noises in either of two ways as follows: (a) by causing the scribing needle 11 to undergo undulations larger in amplitude than otherwise possible without the amplifying means, and to thereby cut in the master record waves of correspondingly larger amplitude. In this manner the ratio of the amplitude of the desired wave undulations of the record to the amplitude of the undesired variations in such undulations caused by record irregularity, dust, etc. is made so large that the extraneous noises are lost in comparison with the desired sound, when the record is reproduced in the phonograph. The other method of using the enhanced energy (b) is that of using the increased force of the excursions of the needle 11 to inscribe the record wave upon the record with no greater amplitude than normal but with much greater precision of wave shape and clearness of cut than heretofore possible. The record is preferably made of a harder and more homogeneous material than is the usual wax master record, and one which therefore is less subject to irregularities or variations in its texture or structure. When such record of harder material is employed the amplitude of the engraved waves may, to advantage, be made smaller than that which is ordinarily used. In order to obtain the same or even a greater volume of sound when the record is "played" on the reproducing machine, a stiff and more tightly pressing needle should be employed. Owing to the stronger biasing force of such a needle it will be caused to vibrate with greater power and thus to produce an enhanced sound output, which is greater for the desired sounds than for the undesired noises, because of the improvement initially

effected in the quality of the record. Furthermore, it is obvious that the enhanced energy obtained by amplification offers the further advantage of permitting a wide degree of selection in the materials employed in a master record and in the manner of taking and of working such record. For example, a number of master records may be simultaneously inscribed. By thus amplifying the sound waves before or in the recording process, as distinguished from amplifying in the reproducer or phonograph proper, and incorporating in the record the effect of the increased energy by either producing record undulations of greater amplitude or by employing the increased force in executing recordgraphs of cleaner cut and greater perfection of wave shape, the improvement is propagated into all of the record output and is realized in the reproducing phonographs without the addition thereto of supplementary apparatus.

Figure 2 illustrates the inclusion in an amplifying system of the type of Figure 1, of distortion-correcting means. In this case the device 14 for converting the sound waves into electric current waves is indicated as a telephone receiver, the actuation of the diaphragm of which causes a current to flow in the windings and in turn to input transformer 3₁. This current is amplified in the vacuum tube 4₁, is passed through output transformer 5₁ and into a circuit across which is connected a shunt 14, consisting of three elements in series, inductance 15, condenser 16, and resistance 17. The current is then transferred by transformer 5₁ to amplifier 6₁ and actuates the recording mechanism as described above. The shunt circuit is in effect a tuned circuit bridged across the transmission path and designed to introduce in the path a large loss in transmission efficiency at a frequency corresponding to the predominant natural period of the phonograph system, preferably including in the system the recording as well as the reproducing devices. The frequency at which the maximum loss in efficiency of the anti-distortion network occurs and the frequency range over which it extends and also the absolute magnitude of the loss in efficiency are all designed to correspond in inverse manner to the similar characteristics of the phonograph system itself. The frequency at which this loss occurs is determined by the formula

$$N = \frac{1}{2\pi} \sqrt{\frac{1}{CL} - \left(\frac{R}{2L}\right)^2}$$

where L is the inductance of the coil 15, C is the capacity of the condenser 16 and R is the resistance of the shunt indicated as localized in 17. The width of the band over which the transmission loss occurs, corresponding inversely to the sharpness of tun-

ing, is controlled by the resistance 17. That is, the damping factor

$$\alpha = \frac{R}{2L}$$

is preferably adjusted to correspond to that of the distorting device the effect of which it is desired to offset. When the distortion correcting device is arranged to counteract the distortion of the entire phonograph system, i. e., both the recording and reproducing phonographs, as above noted, the record thus made will have the sound waves recorded thereon in a distorted manner, this distortion being such as to correct for the distortion which will be encountered when the said record is played on a reproducing phonograph. The sound waves on the record and the record itself, may, therefore, be appropriately termed "predistorted" to designate that the distortion therein is not inherent or undesired but of predetermined character, being designed to compensate entirely or partially for the distortion which will be entailed in the reproducing process.

The operation of the arrangement of Figure 2 in correcting distortion is illustrated in curve form in Figure 3. These curves show the variation in the efficiency of reproduction, or the transmission efficiency of the phonographic system, with change in frequency. Frequency is plotted as abscissas and efficiency of reproduction as ordinates. By efficiency of reproduction is here meant the ratio of the energy output to the energy input of the phonograph system including both the recording and reproducing steps. Curve A illustrates the manner in which the efficiency of reproduction rises to a relatively high value at some frequency corresponding to a resonant period in one or more of the devices involved, and then rapidly falls off and maintains a relatively low value up through the higher frequencies. The curve indicates a predominant period at about 500 cycles. This means that the 500 cycle component of the music or speech involved will be over-emphasized in the reproduced sound and will thereby distort the reproduced sound as compared with the original sound. Such distorting effect is often much larger than that indicated by the curve A. Curve B represents the performance of the shunt network 14 of Figure 2. As indicated by the curve, it transmits very inefficiently at the resonant frequency of say 500 cycles, and progressively more efficiently at frequencies divergent therefrom. The resultant overall characteristic obtained by the combination of the anti-distorting characteristic B with the natural distorting characteristic A of the system is indicated by curve K. The peak corresponding to the resonant point of the original system has been taken out by the

correction network, and the various frequencies throughout the broad range are now transmitted quite uniformly. The efficiency of reproduction has however been greatly
 5 reduced and would be so low as to seriously reduce the volume of sound obtainable from the phonograph. This otherwise serious limitation is overcome by amplification of the resultant current by means of the vacuum
 10 tubes of Figure 2. These amplifiers are in themselves substantially distortionless so that the currents of all frequencies are amplified alike and the line K is shifted bodily upward to line L which indicates the res-
 15 toration of the efficiency of reproduction. The volume or efficiency of reproduction may be increased to any desired value above or below that obtainable without the distortion-correcting feature, by merely control-
 20 ling the amplification effected by the vacuum tube circuits in some such manner as is indicated by the potentiometer 13₁.

A further development of the single network 14 of Figure 2, is indicated by Figure
 25 4 which illustrates the use of a plurality of distortion-correcting networks. The network 14 of Figure 2 is connected in shunt across the circuit. It is possible to introduce a similarly functioning network suitably de-
 30 signed for inclusion serially in the circuit, as indicated at 18 in Figure 4. This series network comprises the inductance 19 connected in series with the circuit, said in-
 35 ductance being shunted by capacity 20 and resistance 21 mutually in series. This is the so-called anti-resonant network, and is the electrical equivalent in the circuit of the
 40 shunt resonant circuit 14 of Figure 2, which is here reproduced as 14₂. These two distortion-correcting networks may be both de-
 45 signed for the same resonant frequency or may be designed for different frequencies corresponding to a plurality of natural periods in the phonograph system. Like-
 50 wise further networks may be added to the circuit corresponding to additional periods of resonance in the phonograph system and these networks may be distributed as be-
 55 tween the series and shunt type in any desired manner.

Figure 5 illustrates in curve form the operation of the circuit arrangement of Figure
 4 in compensating for the distortion effect of two natural periods in the same manner as
 55 do the curves of Figure 3 illustrate the arrangement of Figure 2 in the case of one such resonant period. The curve A, representing the reproduction efficiency of the
 60 phonograph system, has in it two humps or points of maximum efficiency corresponding to two natural periods somewhere in the phonograph system, one perhaps in the re-
 65 cording mechanism, and one in the reproducing device or phonograph proper. These resonance effects are compensated by individ-

ual anti-distorting networks, the network 14₂, for instance, introducing an efficiency loss in the system corresponding to curve B and compensating for one of said resonance effects, and network 18 compensating for the
 70 other of said resonance effects as indicated by curve C.

The summation of these effects results in a much more uniform frequency-efficiency curve, as indicated by curve K₁, correspond-
 75 ing to curve K of Figure 3. The amplification of the vacuum tubes raises the over-all volume of reproduction to any desired value as indicated by curve L₁.

Figure 6 illustrates a further development
 80 of distortion-correcting means. Where distortion is caused by a considerable number of devices not necessarily coincident as to their natural periods, but all occurring in
 85 some limited range of frequencies, it may be desirable to compensate for them as a group. This is accomplished in Figure 6 by the network 19 and the element 20 which
 90 together insert in the system a transmission loss throughout a band or range of frequencies corresponding to the band in which the resonance effects occur. Network 19 is a
 95 selective circuit of the so-called G. A. Campbell band filter type, now well known in electric communication engineering. It ex-
 100 cludes all frequencies lying without a certain band of frequencies and transmits freely the frequencies lying within said band. The currents within this frequency band are
 105 transmitted to element 20 which may be merely a resistance as illustrated and which is designed in conjunction with filter 19 to give the transmission loss necessary for off-
 110 setting the abnormal efficiencies of reproduction which would be caused by the predominant periods of the phonograph devices. It is preferable to insert the anti-distortion
 115 networks in between amplifiers rather than directly with the distorting device under correction, such as a diaphragm-actuated re-
 120 corder, in order to prevent reactions between such devices and complications of the natural periods involved. It is, however, permissible for the major purposes of the invention to connect the distortion-correcting elements
 125 between the amplifier taken as a whole and either the air-electric or the electric-record translating devices.

In the adaptation described above the distortion correcting means and the amplify-
 120 ing means are shown applied in the recording process of making the master record. They may, of course, be as well applied in the process of reproducing the original
 125 sounds; that is, in the reproducing phonograph itself. This condition is illustrated in Figure 7 where 21 indicates the record being played, 22 the reproducing needle, 24,
 130 25 the pivoted diaphragm and telephone receiver device corresponding to 9 and 8 Fig-

ure 1, for example, but used here on the input instead of the output side of the amplifying and distortion correcting stage. Transformer 3₄ corresponds to input trans-
 5 former 3 of Figure 1 or 3₁ of Figure 2, etc., and output transformer 7₄ to the corresponding output transformer of the other figures. In between these input and output trans-
 10 formers any of the means for amplifying and correcting distortion previously described in connection with Figures 1, 2, 4 and 6 may be employed. In this instance the current from the output transformer 7₄
 15 actuates an electromagnetic reproducing device 25 similar to a telephone receiver which in turn actuates the diaphragm 26 and transmits the reproduced sounds out through the horn 27.

In the above the devices employed in
 20 translating between the sound waves and the electric waves of the circuit are of the electro-magnetic type. These devices may be of the well-known electrostatic type, as shown in Figure 8. This figure illustrates the fur-
 25 ther feature that the general distortion-correcting-amplifying system may be applied in the reproduction or duplication of phonograph records. The electrostatic translating devices 28 and 29 are condensers
 30 consisting of two plates or sets of plates one of which is stationary and the other of which is capable of displacement. The displaceable member is attached to the phono-
 35 graph needle. In the case of the transmitting condenser 28, the rotation of the record causes the needle and attached plate or plates to vibrate and to thereby vary the capacity of the condenser and in turn the potential impressed thereon by the polar-
 40 izing battery 30. These potential variations cause corresponding current variations in the input coil 3₅. These variations are amplified and their distortion corrected as before, and are impressed upon and cause
 45 mechanical vibration of the output condenser-translator 29. These vibrations are copied upon the second record in any well known manner.

Figure 8 illustrates also the possibility of
 50 transferring the matter recorded on one record, such as a master record 21, simultaneously to a plurality of other records 12₄ and 12₅. This is made possible by the increased energy resulting from the amplifi-
 55 cation of amplifiers 4₅ and 6₅. The translating devices 29 and 31 for the respective new records are connected together and to the output circuit of the last amplifier 6₅. Obviously by increasing the amplification of
 60 the system the number of the new records which can be thus simultaneously produced may be increased indefinitely.

In respect to the distortion-correcting feature of this invention, it will be under-
 65 stood that although the means illustrated

are electric circuit networks it is the intention to cover such means broadly as applied to phonographs, irrespective of whether they are electrical, mechanical or acoustical in their operation.

While the invention has been broadly set forth in the initial outline, the disclosures of it have been necessarily limited to specific embodiments. It therefore will be under-
 70 stood that many variations from these arrangements and amplifications of them are possible without departing from the spirit of the invention.

What I claim is:—

1. The method of reducing extraneous
 80 noises in phonographic reproduction which consists in amplifying the original sound waves, then impressing the amplified waves upon a record and finally reproducing the record upon a phonograph of reduced sensi-
 85 tivity.

2. The method of reducing extraneous sounds in phonographic reproduction which consists in amplifying the sound wave en-
 90 ergy, then impressing the amplified sound wave energy upon a record, producing thereon undulations of enlarged amplitude and finally of operating from such a record a phonograph reduced in sensitivity by an amount corresponding to the amplification
 95 of the record.

3. The method of reducing extraneous sounds in the reproduction of sound which consists in amplifying the sound wave en-
 100 ergy before recording, impressing the amplified sound wave energy upon a record of material having compressive or shearing strength large as compared with wax and finally of actuating by such record or copy thereof a relatively tightly-pressing needle
 105 member of a phonograph.

4. In a recording system, an electric circuit comprising means for converting sound waves into electrical waves, an electromag-
 110 netic recording device, a vacuum tube amplifier for augmenting said electric waves before recordation, said circuit having the characteristic of passing different frequen-
 115 cies unequally, compensating means for equalizing the transmission of the circuit over a wide range of frequencies, and means in said circuit for governing the amplitude of current applied to the recorder so as to permit of the control of the amplitude of
 120 the recorded wave independently of variations in loudness of the original waves.

5. A phonograph record having the undulation thereon distorted substantially opposite to the distortion entailed when the record is played on a reproducing phono-
 125 graph, so that the emitted sound energy is free from said distortion.

6. The method of obtaining faithful reproduction of sound, which consists in sub-
 130 jecting the sound energy prior to its recor-

dation to distortion substantially opposite to that of the reproducing device so as to compensate for the distortion of the said device.

5 7. The method herein described which consists in modifying the undulations of the sound waves before they are recorded substantially in accordance with the distortion entailed in the reproducing process, so as
10 to neutralize for the distortion entailed in the said process.

8. The method herein described which consists in excluding from the record the distortion inherent in the recording process
15 and introducing into the record distortion tending to neutralize the distortion entailed in the reproducing process.

9. The method of obtaining improved reproduction of sound which consists in constructing the reproducing phonographs to
20 have distortion of predetermined character, making records with distortion of opposite character, and operating said records in said phonographs so that said distortions tend
25 to cancel each other.

10. In combination, a reproducing phonograph arranged to distort the sound reproduced thereby, and a record therefor having sound recorded thereon in distorted manner,
30 the distortion of said phonograph and record being such as to tend to compensate for each other.

11. In combination, means for forming a record of sound, means associated therewith
35 for diminishing the amplitude of recordation of such components of the sound waves as are augmented relatively to the other components during the reproduction of the record, and means associated with said first-
40 mentioned means for amplifying the amplitude of recordation of all of said components of said sound as to offset the loss caused by said second-mentioned means in the volume of the sound when reproduced
45 from the record.

12. The method of correcting distortion in phonographs which consists in moulding the records with a predistortion the opposite of that caused by the phonograph itself.

50 13. The process of making phonograph

records which consists in moulding in the record a predistortion which compensates for the distortion in the phonograph itself.

14. The method of recording and reproducing sound waves, which consists; first, 55 in accurately determining the acoustic transmission properties of the reproducing machine; second, in similarly accurately fixing the transmission properties of the recording system in a manner such as to compensate 60 for distortion effects in the reproducing machine; third, in producing by said recording system a predistorted record; and fourth, in playing the record so formed, or copy thereof, upon said reproducing machine. 65

15. A phonograph system comprising a recording machine including an electrical circuit, a reproducing machine for playing records originated by the recording machine, and means in said electrical circuit for 70 causing a distortion which is greater than is necessary for neutralizing any distortion which may exist in said recording machine, the distorting means being of such character that the distortion caused thereby in 75 excess of the distortion naturally existing in the recording machine will tend to offset the distortion entailed in the reproducing machine.

16. The method of recording sound vibrations which consists in distorting the vibrations to be recorded inversely to the predetermined distortive effects of a given reproducing system and recording the modified vibrations. 85

17. The method of recording sound vibrations which consists in converting sound vibrations into electrical vibrations, attenuating vibrations of such frequencies as are overemphasized by the elements of the recording system, further attenuating vibrations of such frequencies as are overemphasized by the elements of any given reproducing system and recording the modified vibrations. 95

In testimony whereof, I have signed my name to this specification this 12th day of November, 1919.

LLOYD ESPENSCHIED.