Oct. 14, 1930. W. P. MASON 1,778,035

HARMONIC NOISE SUPPRESSION DEVICE

Filed June 28, 1929 2 Sheets-Sheet 1

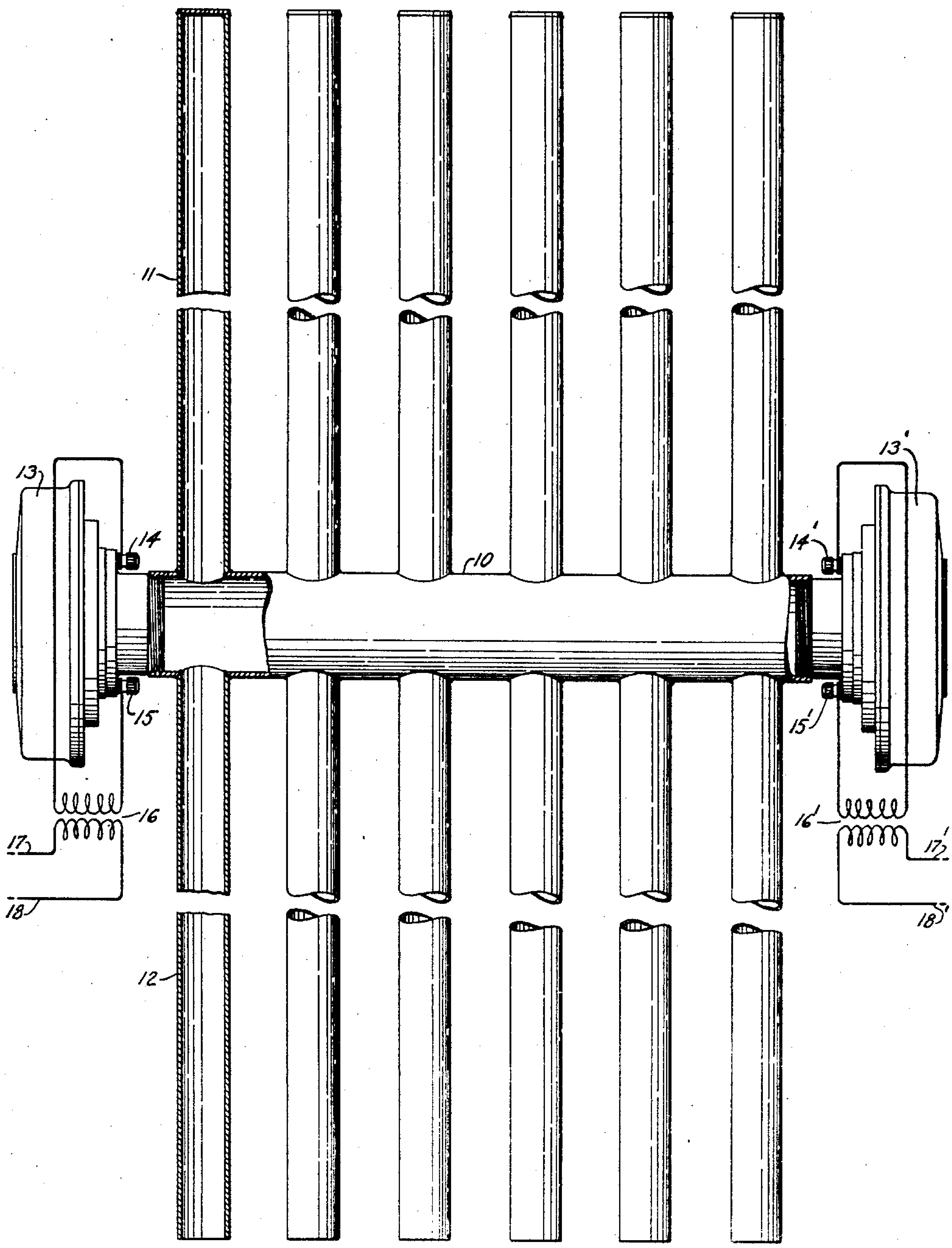

Fig. 1.

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FIG. 2

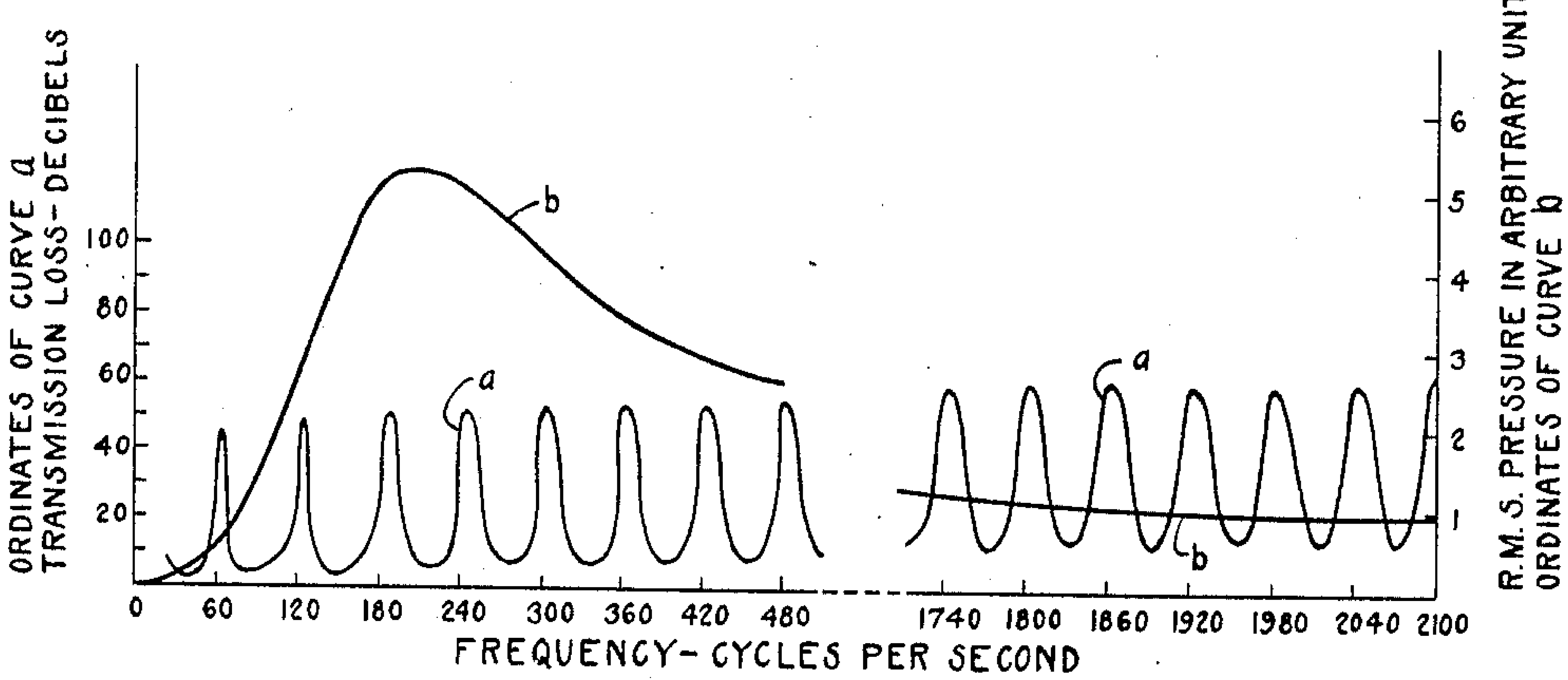
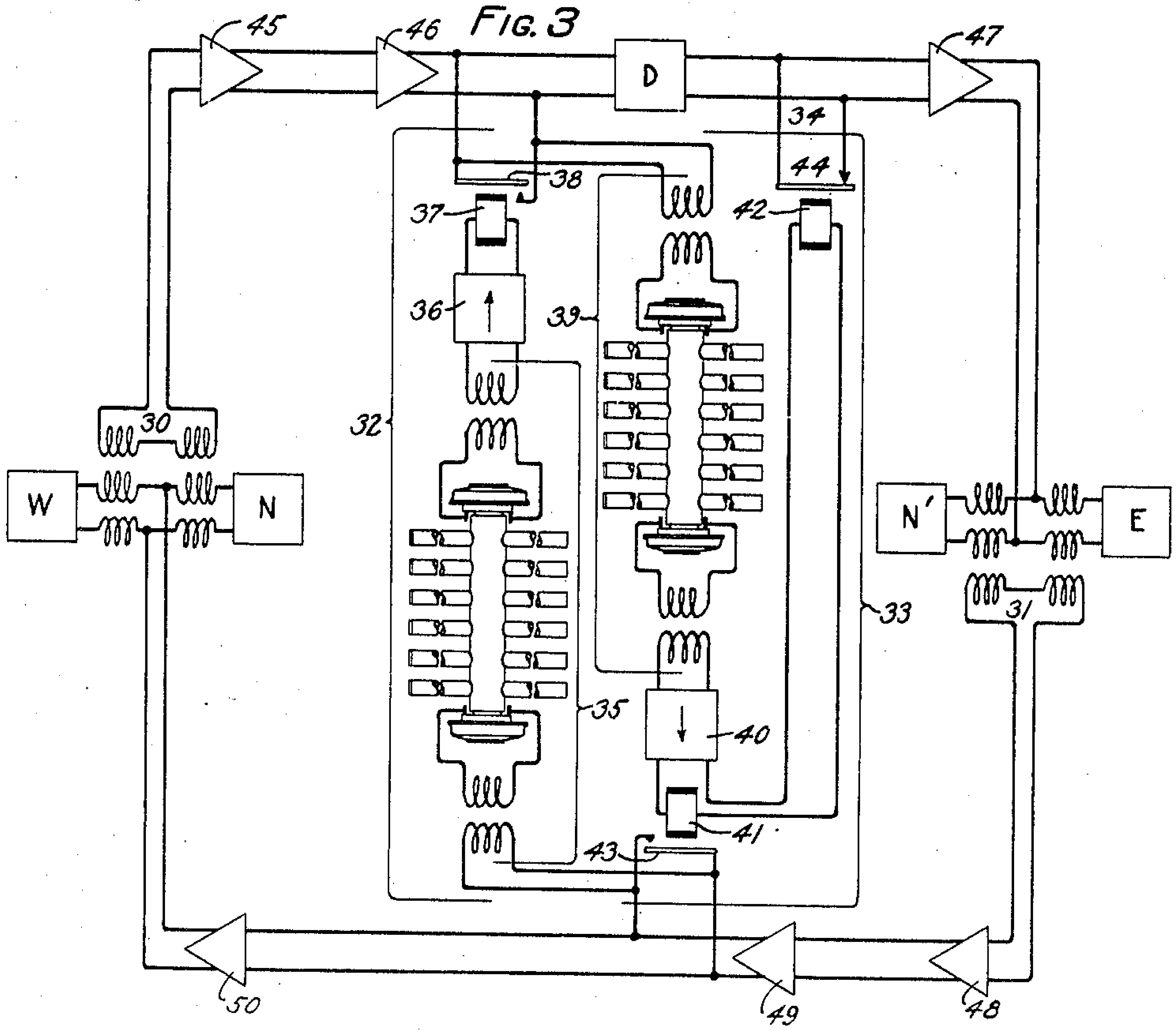


FIG. 3



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HARMONIC-NOISE-SUPPRESSION DEVICE

Application filed June 28, 1929. Serial No. 374,535.

This invention relates to wave transmission, and more particularly to means for separating sustained noises from speech in a telephone line.

An object of the invention is to obtain improved selectivity in the separation of interfering noise currents from speech waves in telephone systems.

Another object is to improve the operation of voice operated relays in speech transmission systems.

In telephone systems subject to interference arising from power conductors the interference currents have frequencies which in general occur in a fairly well defined harmonic order. These harmonically related currents produce sustained noises in telephone receivers which cause difficulty in interpreting speech and in addition, they impair the operation of voice-operated relays in systems where devices of this sort are used. Since the interfering noise currents occur in harmonic order, and in general have their frequencies distributed throughout the speech range, any means for effecting their suppression must necessarily be very sharply selective in order that the loss of speech energy in the suppressing device may not be excessive. In accordance with the present invention noise current suppression is effected by means of an acoustic wave filter so designed as to have narrow attenuation peaks at the harmonically related frequencies of the interfering noises, and to have substantially free transmission elsewhere in the voice frequency range.

Power line currents may vary in frequency from time to time by a small amount, generally being held constant within one-half of one per cent. Consequently, the possible deviation of the frequency of any harmonic component is proportional to the frequency of that component, and a satisfactory filter for the suppression of noise currents due to power line interference should therefore have attenuating bands wider at high frequencies than at low frequencies. If a filter be used whose bands are uniform in width, then, if the deviations of higher frequency harmonics are adequately covered, the low frequency attenuation bands will be unnecessarily wide, and will remove more of the speech waves than is desirable. A feature of this invention is that the attenuation bands are graded in width in proportion to the frequency in such a manner as to effectually suppress all harmonics of the interfering current regardless of the ordinary variations of the frequency.

The filter in its preferred form is an acoustic device comprising a main sound wave conducting tube having connected thereto at regular intervals, side branches consisting of tubes of uniform length. The side branches are made long enough to resonate at the lowest of the harmonically related interfering frequencies, thereby causing all of the interfering tones to be strongly suppressed. The sharp selective characteristic of the device, and the graduation of the attenuating band widths are obtained by using a plurality of side branches and spacing them at short intervals along the main conducting tube as hereinafter described. The filter is incorporated into a telephone system by means of acoustical-electrical transducers, for example a pair of telephone receivers or by a transmitter at one end and a receiver at the other if one-way communication only is required.

The invention can be understood from the following detailed description and reference to the drawings, in which

Fig. 1 illustrates an acoustic harmonic suppression filter system in accordance with the invention;

Fig. 2 shows a transmission characteristic of a system like that shown in Fig. 1 in relation to the energy distribution characteristic of speech;

Fig. 3 shows an adaptation of the invention in voice operated relay circuits of a telephone repeater.

Referring to Fig. 1, the system comprises a main sound channel, constituted by a pipe 10, to which at equal intervals are connected a plurality of similar pairs of branch pipes such as 11 and 12. Each pair comprises a closed-ended pipe 11 and an open-ended pipe 12 of the same length. The main sound pipe is coupled at each end to telephone receivers 13 and 13′ which are provided with binding posts 14, 15 and 14′, 15′ whereby the device may be connected into an electrical line. This connection is made through impedance matching transformers 16 and 16′ the primary windings of which are connected to the receiver terminals, and the secondary windings to the transmission line wires 17, 18, and 17′, 18′. The operation is as follows: The receiver 13 converts electrical waves from the line 17—18 into sound waves which are propagated through the sound conduit 10 to the receiver 13′, where they are reconverted into electrical waves and delivered to the line 17′, 18′. The sound waves in passing through the sound conduit are modified by the action of the side branches. Each pair of side branches acts as a unit, resonating at a series of harmonically related frequencies corresponding to the frequencies of the interfering currents, thereby causing waves of these frequencies to be strongly attenuated. The attenuation due to each of the pairs of side branches is cumulative and by the use of a sufficient number of pairs the attenuation may be made as great as may be desired.

The propagation constant per section, designated P, of an acoustic conduit having side branches is expressed by the following formula which assumes no dissipation of waves in the conduits due to viscosity:

$$\mathrm{Cosh}\, P=\left[\cos\frac{2\omega L}{c}+\frac{Z_s}{2Z_2}\frac{S_2}{S_1}j\sin\frac{2\omega L}{c}\right] \quad (1)$$

where 2L is the length of the main channel between the junction points of side branches;
S_1 is the cross-sectional area of the main channel;
S_2 is the cross-sectional area of each of the side branches;
Z_s denotes the characteristic impedance of a channel one sq. cm. in cross-section, about 41 c. g. s. units;
Z_2 denotes the acoustic impedance of a side branch pair per unit of the cross-sectional area S_2;
c is the velocity of sound;
j is the imaginary operator $=\sqrt{-1}$; and
ω is equal to 2π times the frequency.

The acoustic impedance of a sound path is here defined as the ratio of the excess pressure intensity to the volumetric flow per second over the cross-section of the path at a given point. The characteristic acoustic impedance of a sound path of one square centimeter area, denoted by Z_s above, is sometimes referred to as the specific characteristic impedance of a medium. The characteristic impedance of a path of any given area is equal to Z_s divided by the area. For the filter illustrated in Fig. 1, impedance Z_2 of each pair of side branches is expressed by the following formula, which neglects wave dissipation:

$$Z_2=\frac{Z_s}{2}j\tan\frac{2\omega l}{c}, \quad (2)$$

where l is the length of each of the side branch tubes.

Equation (1) refers to a symmetrical T-section of the filter including a side branch pair and a portion of length L of the main conduit on each side. Preferably the whole filter should consist of a plurality of these symmetrical sections and length of conduit between the end side branches and the receiver diaphragms should therefore also be equal to L. It is not always physically possible to construct the device in this way, but the effect of varying the lengths of the end connections is not serious when the filter comprises several sections. By substituting in equation (1) the value of Z_2 expressed in equation (2), equation (1) becomes

$$\cosh P=\left[\cos\frac{2\omega L}{c}+\frac{S_2\sin\frac{2\omega L}{c}}{S_1\tan\frac{2\omega l}{c}}\right] \quad (3)$$

An inspection of equation (3) shows that there is theoretically infinite attenuation at frequencies for which $\tan\frac{2\omega l}{c}$ is zero, which occurs when $\frac{2\omega l}{c}$ is equal to π or a multiple thereof; hence the frequencies of maximum attenuation are harmonically related.

When cosh P lies between the limits +1 and −1, there is no attenuation of waves in the filter; and these limits determine the edges or cut-offs of bands of free transmission. The lower cut-offs of the transmission bands occur when cosh P = +1 and from equation (3) are found to lie at frequencies for which

$$\frac{S_2}{S_1}\cot\frac{2\omega l}{c}=\tan\frac{\omega L}{c}. \quad (4)$$

The upper cut-offs of the transmission bands occur when cosh P = −1 and are found to exist at frequencies for which

$$\frac{S_2}{S_1}\cot\frac{2\omega l}{c}=-\cot\frac{\omega L}{c}. \quad (5)$$

The transmitting and the attenuating bands alternate with each other throughout the frequency scale, and in general, the theoretical widths of the attenuation bands are somewhere near the widths of the transmitting bands; but it has been discovered that for practical purposes the effective widths of the attenuating bands are much less than their theoretical widths at the lower frequencies. At very low frequencies the upper cut-off frequencies of the transmitting bands are very close to the frequencies of maximum attenuation, while the lower cut-offs are further removed from the attenuation peaks. The result is that over a considerable portion of an attenuating band between a lower cut-off and an attenuation peak, there is very little attenuation so that waves are relatively freely transmitted through the filter. At higher frequencies, however, as $\cos\frac{2\omega L}{c}$ approaches zero, the upper cut-off frequencies move further away from the attenuation peaks and the lower cut-offs move closer to the peaks, the result being that the effective widths of the attenuation regions increase. When $\cos \frac{2\omega L}{c}$ is equal to zero, the cut-offs are spaced equidistant from the attenuation peak and the effective attenuating band width is widest. As the frequency further increases, it is found that the effective attenuating band width becomes narrower again; but in practice this narrowing of the attenuation bands at high frequency is usually unimportant since the filter can be proportioned so that the narrow attenuation bands at high frequencies occur above the frequencies of importance.

Some control can also be exercised over the band widths by means of the ratio $\frac{S_2}{S_1}$, the larger this ratio, the wider being the attenuating bands.

It should be noted that the invention is not limited to the use of side branches which exist in pairs. The operation would be the same if the side branches were single, open-ended tubes of length $2l$; for it can be shown that the impedance of the parallel combination of an open-ended and a closed-ended tube, each of length l, is equal to the impedance of an open-ended tube of length $2l$.

To design a filter to suppress harmonically related frequencies the widest effective attenuation bands should be situated at the highest frequency of importance, which in speech transmission lines is generally about 2000–2500 c. p. s., and in voice-operated relay circuits is generally about the same, being dependent on the energy of the power line harmonics. Since the widest effective attenuation band occurs when $\cos \frac{2\omega L}{c} = 0$, the length, 2L, of the main conduit between side branches is determined from the relation

$$\frac{2\omega L}{c} = \frac{\pi}{2}, \quad (6)$$

the value of ω being chosen to correspond to this highest frequency of importance. The length l of the side branches is determined from the relation

$$\frac{2\omega l}{c} = \pi, \quad (7)$$

which is the condition for $\tan \frac{2\omega l}{c}$ being equal to zero, ω here being chosen to correspond to the fundamental frequency of the power line noise, usually 60 c. p. s.

The length 2L of the sections of the main conduit, being inversely proportioned to the frequency for which the attenuation band width is a maximum, becomes very small when this frequency is placed high in the speech range. On the other hand, since the branch paths must have resonance at the lowest frequency of the interfering waves, their lengths are relatively large.

The cross-sectional area, S_1 of the main pipe may be any convenient size and should be chosen to fit the telephone receivers. The side branch cross-section S_2, can conveniently be made equal to S_1, although as explained above, the attenuation band widths can be increased or decreased by increasing or decreasing S_2.

The following example illustrates the design of a harmonic suppression system which was actually built to suppress the noise in a voice-operated relay circuit, due to a 60 c. p. s. power line. The telephone receivers to be used are of a standard type and are adapted to be coupled to an acoustical device whose diameter at the neck is .7″, which consequently must be diameter of the main sound pipe. The highest harmonic of importance in this case is taken to be 2100 c. p. s. so the widest attenuation band is to be placed at this frequency. In formula (6), then ω is taken as 2π times 2100, and since the velocity of sound, c is 13,600″ per second, the distance 2L between junctions is found to be 1.61 inches. Since the side branches must resonate waves of 60 c. p. s. and their harmonics, the value of ω in formula (7) is taken as 2π times 60, and the value of l is found to be 56.67″. For convenience the cross-section S_2 of the side branches is taken equal to S_1. It is found that six sections of this filter are sufficient to adequately suppress the power line harmonics. The total length of a six section filter is $1.61 \times 6 = 9.66''$ from which it is seen that the time of propagation through the filter is very small. The time of delay, designated T, is expressed by

$$T = \frac{2Ln}{c} \quad (8)$$

where n is the number of sections, and in the example considered has the value .00072 sec.

Fig. 2 shows the relation between the attenuation of the filter and the power in the voice. Curve a represents the overall attenuation of the filter system, including the receiver, of the above example. The attenuation is plotted along the axis of ordinates, the unit of attenuation being the decibel, which is a logarithmic measure of the ratio of the wave power. A treatment of the decibel is given by W. H. Martin in an article in the Journal of the American Institute of Electrical Engineers, March 1929, page 223. It is seen that the bands of great attenuation are very narrow at low frequencies, while at higher frequencies they are wider. Due to the fact that there is some dissipation of wave energy from viscosity in the pipes, the attenuation is never zero. The increased attenuation noted at the upper end of the frequency spectrum is the result of dissipation.

Curve *b* illustrates a typical distribution of the energy in the voice and is plotted on the same frequency scale as curve *a*. The ordinates are plotted in arbitrary units of the root-mean-square value of the wave pressure, which is the effective pressure for determining the wave energy. It is seen that most of the voice energy exists in waves of comparatively low frequency, and since the bands of great attenuation of the filter are very narrow at these frequencies, most of the voice energy is transmitted with comparative freedom. At the higher frequencies, around 2000 c. p. s., where the attenuation bands are widest, and less of the voice is transmitted, there is not much energy in the voice anyway. But, since the attenuation bands are wider at the upper frequencies, they are adapted to cover the harmonic noise frequency variation, which is greater at high than at low frequency. Although the attenuation band widths decrease again at frequencies above that for which $\cos \frac{2\omega L}{c}=0$, which in this case is 2100 c. p. s., the amplitude of power line harmonics are generally so small at these higher frequencies as to cause no trouble.

Fig. 3 illustrates a two-way telephone repeater equipped with echo-suppressor circuits in which harmonic suppression filters of this invention are utilized. The application of echo-suppressors in telephone repeaters is well known and a treatment of the subject is given by Clark and Mathes in the Journal of the American Institute of Electrical Engineers, June 1925, pages 618–626. The repeater illustrated is a well known type comprising two speech transmission paths joined at the ends by hybrid coils 30 and 31. The telephone lines which are connected by the repeater are represented by squares W and E. The squares designated N and N′ represent balancing networks. The upper path, which transmits in one direction only, from left to right, comprises three speech amplifiers 45, 46 and 47 and a delay network D. The lower path comprises amplifiers 48, 49 and 50 and transmits in the opposite direction. The echo suppressor circuit comprises two parallel circuits 32 and 33 bridged across the two sides of the four-wire circuit, and a circuit 34 which normally shortcircuits the upper voice transmission path. Consider for the moment circuit 32. A harmonic filter syster 35, similar to that in Fig. 1, is connected at one end across the lower transmission line of the repeater circuit. The other end of the filter is connected to the input of an amplifier-detector 36 which operates a relay 37. The operation of the relay closes contact 38 thus shortcircuiting the upper transmission path. Circuit 33 is similar to circuit 32 except that its filter system, designated 39, is connected to the upper transmission path instead of the lower. The filter system is connected in tandem with an amplifier-detector 40 whose output is in series with two relays 41 and 42. The operation of these relays closes contact 43 which shortcircuits the lower transmission path and opens contact 44 which removes the short circuit across the upper path.

Briefly, the operation is as follows: When there is no talking or other disturbance, contacts 38 and 43 are open and contact 44 is closed. When talking commences on line W, the voice currents travel along the upper transmission path and a small portion of the energy, entering circuit 33, operates relays 41 and 42, thus applying a short circuit across the lower transmission path and removing the short circuit across the upper path. There is then a direct path for transmission to line E; but echoes cannot return along the lower path because of the short circuit there. The purpose of the delay network D in the upper path is to hold up the passage of the voice currents until relay 42 has had time to operate. When the talking from line W ceases, the relays return to normal. Then when line E commences talking, the voice currents travel through the lower path and part of the energy, entering circuit 32, causes relay 37 to operate thus putting a short circuit across the input to circuit 33 which might otherwise be set into operation by the echoes.

If the filters were not present the relays might be operated by noise in the system, particularly power line noise. Since the currents before entering the relays are made to pass through filters, most of the power line energy is prevented from reaching the relays.

While the invention is probably most applicable in voice operated relay circuits there may arise conditions would make desirable the use of the filter directly in the telephone line. Such a condition would be the case where power line disturbances are so severe as to impair the intelligibility of speech reception. A filter connected into the telephone line would suppress the noise and although it would also remove a portion of the speech, it has been found that the amount removed is not sufficient to impair the intelligibility to any great extent.

What is claimed is:

1. The combination with a telephone line subject to speech currents and relatively sustained interfering currents, of an acoustical wave filter for selectively suppressing the interfering currents, said filter comprising a main sound conduit and a plurality of side branch tubes connected to said main conduit at regular intervals, said side branch tubes having a uniform length of such a value that they resonate a series of harmonically related frequencies corresponding to the frequen-

cies of the sustained interfering waves, and the length of the portion of said main channel between side branches being small in comparison to the length of the side branches.

2. In a voice operated relay circuit, acoustic means for separating relatively sustained noise waves from speech waves, said means comprising a main wave conducting acoustical channel subject to both speech waves and sustained noise waves, there being connected to said main wave conducting channel at regular intervals, acoustical side branch tubes having such a length as to be resonant at a series of harmonically related sustained noise waves present in the system, and the lengths of the portions of said main channel between the junction points of side branches being not greater than about one-quarter of the wave length of the highest noise frequency of importance, whereby said means is characterized by attenuation bands which are narrow at low frequency and progressively increase in width up to said highest voice frequency of importance.

3. In combination, a voice transmission line, an acoustic filter and two acoustical-electrical translating devices, said filter comprising a main sound conduit having a plurality of side branch tubes connected thereto at regular intervals, said side branches having a uniform length of such a value that they resonate a series of harmonically related frequencies corresponding to the frequencies of the sustained interfering waves, said main conduit being inserted between two portions of said transmission line and connected thereto by means of one of said translating devices at each end, the length of said main conduit between the junction points of side branches being small whereby the attenuation bands, which include the frequencies resonated by said side branches, are narrow at low frequency and progressively increase in width up to a high frequency.

4. A filter system for suppressing noise currents in a speech transmission line, said system comprising an acoustic filter and two telephone receivers, one at each end of said filter, for connecting said filter into said transmission line, said filter comprising a main sound channel subject to both speech waves and sustained noise waves, and side branches connected to said main sound conduit at regular intervals, said side branches being tubes resonant at a series of harmonically related sustained noise waves present in the system, the lengths of the portions of said main channel between the junction points of side branches being small and the ratio of the cross-section of the side branches to the cross-section of the main channel being small whereby said system is characterized by narrow effective attenuation bands which include the frequencies at which said side branches are resonant, and the bands progressively increase in width up to a high frequency.

5. In a voice operated relay circuit, acoustic means for suppressing relatively sustained noise currents, said means comprising a main sound conduit subject to both speech waves and sustained noise waves, and side branches connected thereto, said side branches comprising acoustical tubes of uniform length connected to the main conduit at regular intervals in pairs, one of each pair being closed and the other open at the outer end, the lengths of the side branch tubes being such that they resonate a series of harmonically related sustained noise waves present in the system and the length of said main wave conducting channel between the junction points of side branches being equal to one-quarter the wave length of the highest noise harmonic to be effectively attenuated, whereby said means is characterized by attenuation bands which are narrow at low frequency and progressively increase in width at higher frequencies to a maximum at the highest noise harmonic to be attenuated.

In witness whereof, I hereunto subscribe my name this 27th day of June, 1929.

WARREN P. MASON.