May 17, 1927. 1,629,100

R. V. L. HARTLEY

TRANSMISSION SYSTEM

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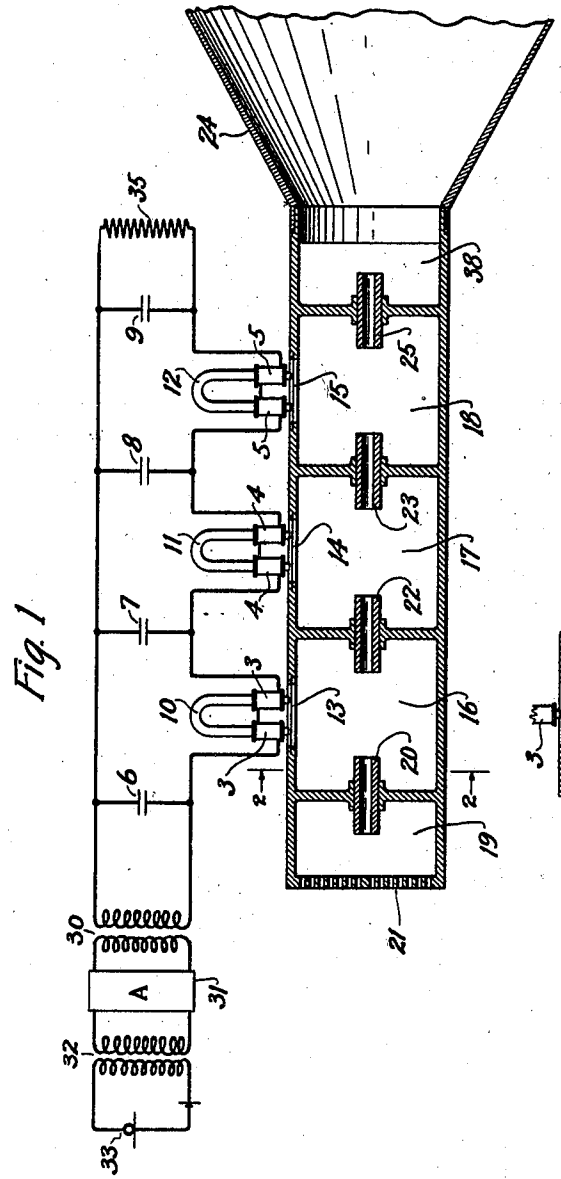


Fig. 1

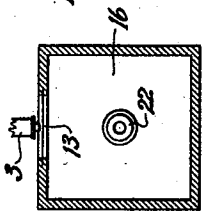


Fig. 2

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UNITED STATES PATENT OFFICE.

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TRANSMISSION SYSTEM.

Application filed December 21, 1923. Serial No. 681,926.

This invention relates to transmission systems, and more particularly, it relates to means for translating electric energy into mechanical energy or into energy of a different form and has for an object to increase the transmission efficiency of the translation.

As is well known in the art an electric line of a plurality of sections, each section comprising a series inductance and a shunt capacity may be made to give a substantially constant transmission over a wide range of frequencies such as the range of importance in speech or music. In order that the currents transmitted along such a line may be transferred into acoustic waves, it is proposed in accordance with one form of this invention to employ each of the series inductances of an electric line as the energizing winding for operating a vibrating member strictly in accordance with the electrical vibration. Each vibrating member may, for example, comprise a diaphragm forming a side wall for an air chamber of appreciable area. These air chambers are connected to each other or to the atmosphere by relatively short small diameter tubes so that said air chambers and said tubes may be adjusted to give an acoustic filter in which the masses of the air in the tubes and the elasticities of the air in the chambers cooperate to determine the transmission characteristics. If desired one end of the acoustic filter may be connected to the small end of a loud speaking horn so that the vibration of the air in the air chamber is produced by the concerted action of the diaphragms and will be suitably coupled and radiated to the outside air in the form of sound waves.

Referring to the drawing Fig. 1 represents an electric filter and an acoustic filter combined in accordance with the present invention and Fig. 2 is a cross sectional view of the acoustic filter of Fig. 1 taken in the plane marked "2, 2."

The electric wave filter illustrated in Fig. 1 comprises a plurality of series inductances 3, 4 and 5 coupled by shunt capacities 6, 7, 8 and 9 so as to form an electric wave filter of a plurality of sections, each section comprising a series inductance and a shunt capacity. Such a filter is of the well-known low pass type capable of transmitting with negligible attenuation a wide frequency range below a cut-off frequency while suppressing frequencies outside of said range. The values, the elements of such a low pass filter should have in order to produce this result is fully described in the U. S. patent to Campbell No. 1,227,113 of May 22, 1917, on electric wave filters.

Each of the inductances 3, 4 and 5 is divided into two sections and mounted on the ends of the magnet members 10, 11 and 12. In close proximity to the ends of these magnets are mounted the metallic diaphragms 13, 14 and 15, respectively. These diaphgrams 13 to 15 constitute portions of the side walls enclosing the air chambers 16, 17 and 18 of an acoustic filter. Air chamber 16 is coupled to the adjacent air chamber 19 and to the outer air by the short tube 20 of small diameter which leads through the side wall of air chamber 16 to air chamber 19, air chamber 19 being coupled to the outer air by an apertured member 21 which will be described later. Air chambers 16 and 17 are connected by the short tube 22. Air chambers 17 and 18 are connected by the short tube 23 and air chamber 18 is connected to the small end of a loud speaking horn 24 by a tube 25. The tubes 20, 22, 23 and 25 are suitably mounted to project through the side wall separating adjacent chambers. The side walls connecting adjacent chambers are preferably rigid so that the sole means for causing sound waves in one chamber to produce sound waves in an adjacent air chamber is by means of the coupling tube.

The acoustic line just described is of a plurality of sections and comprises air chambers connected to each other or to the atmosphere by relatively short small diameter tubes so that the acoustic line in effect is a bounded region of fluid forming a tube or channel capable of transmitting sound waves in the direction of the channel only. The impedance of any section of such an acoustic line depends upon the inertance or mass per unit area of the fluid of the line and the capacitance or stiffness per unit area of the fluid. Since the impedance of fluid in a relatively short small diameter tube is proportional to the rate of change of the applied force and has the effect of inertia, it may be considered as an i: ertance. On the other hand, the application of force to a fluid contained in a chamber, results in a

compression and expansion of the fluids so that the impedance of such a member is in the nature of a capacitance. The arrangement of the capacities and the inertances is similar to that of the inductances and capacities of an electric wave filter of a plurality of sections, each section comprising a series inductance and a shunt capacity so that the acoustic filter may be designed to pass with negligible attenuation a wide range of frequencies of sound waves, while substantially suppressing frequencies outside said range.

The analogy existing between the properties of an acoustic filter having inertances and capacitances and those of an electric wave filter having inductances and capacities is set forth in some detail by G. W. Stewart in the March 1921 issue of the Physical Review at page 321 and in the December 1922 issue of the Physical Review at page 528. It is shown in these articles that the impedance of an acoustic filter to the transmission of sound waves depends upon the inertances and capacitances, each arranged in a manner equivalent to the arrangement of the inductances and capacities of an electric wave filter. The formulæ for acoustic and electric filters are analogous.

According to the disclosure in the U. S. patent to G. A. Campbell No. 1,227,113 of May 22, 1917, the design formula for the type of electric filter shown in Fig. 1 is as follows:

$$LC = 4\left(\frac{1}{2\pi f_c}\right)^2,$$

where L is the series inductance, C the shunt capacity, and f_c the cut-off frequency.

Referring back now to the acoustic filter disclosed in Fig. 1, if the volume of each chamber 16 to 18 is represented by V and the density of the fluid contained therein by ρ and if a represents the velocity of sound in air and k_1 the direct measure of ease of flow through each of the tubes 20, 22, 23 and 25, then the quantity $\frac{\rho}{k_1}$ designates the mass or inertia of the vibratory air in the short tube in Fig. 1 per unit current and the quantity $\frac{V}{a^2\rho}$ is proportional to the capacity of the resonator. By analogy to the formula of an electric wave filter it follows that the following formulæ determine the range of frequencies of sound waves transmitted by the acoustic filter disclosed in Fig. 1,

$$\frac{V}{a^2 k_1} = 4\left(\frac{1}{2\pi f_c}\right)^2.$$

The acoustic filter is preferably terminated at either end with a half section termination. This may be done by making each of the chambers 19 and 38 of one half the volume of a chamber for a full section.

As described above the end chamber 19 is closed by a perforated plate 21. The openings in this plate should be uniformly distributed and should be of such a number and size that the impedance presented to the air passing through the openings is substantially equal to the surge impedance of the acoustic filter. The impedance of the horn 24 should also be equal to the surge impedance of the acoustic filter.

The electric filter of Fig. 1 by an output transformer 30 is coupled to the output of a suitable amplifier 31 which, in turn, is connected by an input transformer 32 to a telephone transmitter 33. The electric wave filter is, therefore, connected to receive amplified speech or music frequencies from the transmitter 33, and the alternating current windings 3, 4 and 5 will produce the vibration of the diaphragms 13, 14 and 15 in accordance with the electrical vibrations and the vibratory energy set up thereby in the air chambers 16, 17 and 18 will be accumulatively impressed upon the small end of horn 24 and radiated to the outside air as sound waves corresponding to the character of the electric currents impressed upon the alternating current windings 3, 4 and 5 by transmitter 33.

The velocity of electrical wave transmission through the electric filter should preferably be made the same as the velocity of transmission of the sound waves through the acoustic channel by suitably adjusting the values of the inductance and capacity of the electric filter and the inertance and capacitance of the acoustic filter. If these values, are adjusted according to the above formulæ to give the same cut-off frequency for both the acoustic and electrical filters, it will be found that the velocity of transmission in the two filters will be the same. The same velocity of transmission in the two filters insures that the waves arriving at the end of the acoustic filter from each of the diaphragms will be in phase and will therefore give an additive effect.

In order to reduce reflection losses it generally will be preferable to terminate the end of the electric filter opposite the transmitter 37 with an impedance or resistance 35 of an impedance equal to the surge impedance of the filter as seen from its terminals; and it will also be preferable to have the impedance looking from the electric filter towards the amplifier 31 equal to the surge impedance of the electric filter.

The particular arrangement disclosed for producing an operative relationship between the alternating current windings 3, 4 and 5, the diaphragms and the magnets is shown for illustrative purposes only, since various types of electromagnetic structures known in the art may be employed for causing the efficient vibration of the armatures or dia-

phragms 13 to 15 in accordance with the electric currents in the energizing windings.

It is also to be understood that various other modifications of this invention may be made without departing in anywise from the spirit of this invention as defined in the appended claims.

The invention claimed is:

1. In combination, an acoustic filter of a plurality of sections, each section comprising an enclosed air chamber, an electric filter comprising a line of a plurality of sections, each section comprising an impedance in shunt with the line and an impedance in series with the line, one of said impedances in each of said sections comprising an inductance, and means for causing the electrical currents flowing through each of said inductances to produce vibratory energy in one of said air chambers.

2. In combination, an acoustic filter of a plurality of sections, each section comprising an inertance and a capacitance, said capacitance in each section comprising an air chamber, an electric filter comprising a line of a plurality of sections, each section comprising a shunt impedance and a series inductance, and means for coupling each of said inductances to a capacitance of said acoustic filter to cause the alternating currents present in each of said inductances to produce corresponding sound waves in one of said air chambers.

3. In combination, an acoustic filter designed to pass a wide band of wave frequencies with negligible attenuation comprising an air chamber, a short tubular member leading from said air chamber, a loud speaking horn coupled to said filter and arranged to transmit to the open air sound waves passing through said tubular member, an electric filter designed to transmit substantially the same band of wave frequencies as said acoustic filter comprising an inductance, and means for causing alternating currents from said inductance to produce sound waves in said air chamber.

4. In combination, an acoustic filter comprising a series of inertances, a capacitance in shunt to each of said inertances, each of said capacitances comprising an air chamber, an electric line comprising a plurality of inductances, means for causing alternating currents in each of said inductances to produce sound waves in one of said air chambers, and means for insuring that the waves produced in each of said air chambers on arriving at one end of said acoustic filter act accumulatively.

5. In combination, an acoustic filter comprising a series of relatively narrow tubular members, chambers of relatively large area connecting succeeding tubular members, an electric line of a plurality of sections, each section comprising a shunt capacity and a series inductance, and means for causing alternating currents in each of said inductances to produce corresponding sound waves in one of said air chambers.

6. In combination, an acoustic filter comprising a series of air chambers, a relatively narrow tubular member for connecting adjacent chambers, each of a plurality of said chambers comprising an enclosed wall having a flexible portion, an electric line of a plurality of sections, each section comprising a shunt impedance and a series impedance, one of said impedances of each section comprising an inductance, and means for causing alternating currents present in each of said inductances to produce the mechanical vibration of the flexible portion of one of said side walls.

7. In combination, an acoustic filter comprising a series of relatively narrow tubular members, air chambers of relatively large area connecting succeeding tubular members, a diaphragm forming a portion of one side wall of each of said chambers, an electric line of a plurality of sections, each section comprising a shunt capacity and a series inductance, and means for causing alternating currents in each of said inductances to produce the mechanical vibration of one of said diaphragms.

8. In combination, an acoustic filter comprising a series of relatively narrow tubular members, chambers of relatively large area connecting succeeding tubular members, said chambers and said tubular members being arranged to provide a filter of negligible attenuation for a wide range of frequencies of importance in speech, an electric filter comprising a line of a plurality of sections, each section comprising a series inductance and a shunt capacity, said inductances and capacities having values adjusted to cause said filter to transmit with negligible attenuation electric currents of a wide range of frequencies of importance in speech, and means for causing alternating currents present in each of said inductances to produce sound waves in each of said chambers.

9. In combination, an acoustic filter comprising a series of relatively narrow tubular members and chambers of relatively large area connecting succeeding tubular members, said tubular members and chambers being arranged and adjusted to produce an acoustic filter having a substantially constant transmission characteristic for a wide range of frequencies of importance in speech, a diaphragm forming a portion of the enclosure of each of said chambers, an electric filter comprising a line of a plurality of sections, each section comprising a series inductance and a shunt capacity, said inductances and capacities having such values that said electric filter transmits with a substantially constant transmission char-

acteristic alternating currents of a wide range of frequencies of importance in speech, and means for causing alternating currents present in each of said inductances to produce the mechanical vibration of one of said diaphragms.

10. In combination, an electric filter of a plurality of sections, each section comprising a series inductance and a shunt capacity, an acoustic filter of a plurality of sections, each section comprising a series of relatively narrow tubular members, an air chamber of relatively large area connecting succeeding tubular members, means for causing alternating currents in each of said inductances to produce vibratory energy in one of said chambers, and means for terminating each end of each of said filters in an impedance substantially equal to the surge impedance of the filter.

In witness whereof, I hereunto subscribe my name this 14th day of December A. D., 1923.

RALPH V. L. HARTLEY.