Jan. 13, 1931. H. C. HARRISON 1,788,519

MECHANICAL TRANSMISSION SYSTEM

Original Filed May 26, 1926 2 Sheets-Sheet 1

Fig. 1.

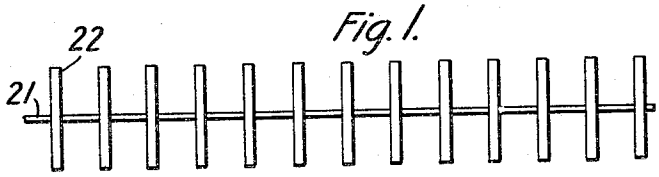


Fig. 2. Fig. 3. Fig. 4.

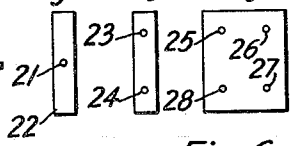


Fig. 5.

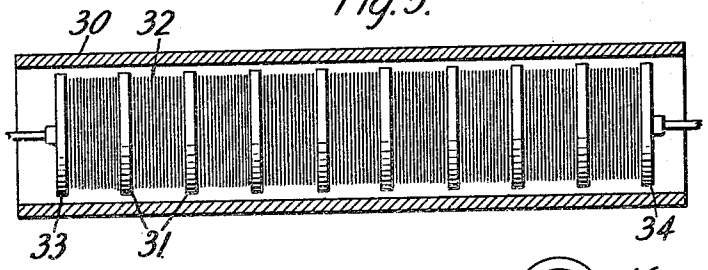


Fig. 6.

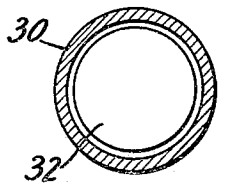


Fig. 9.

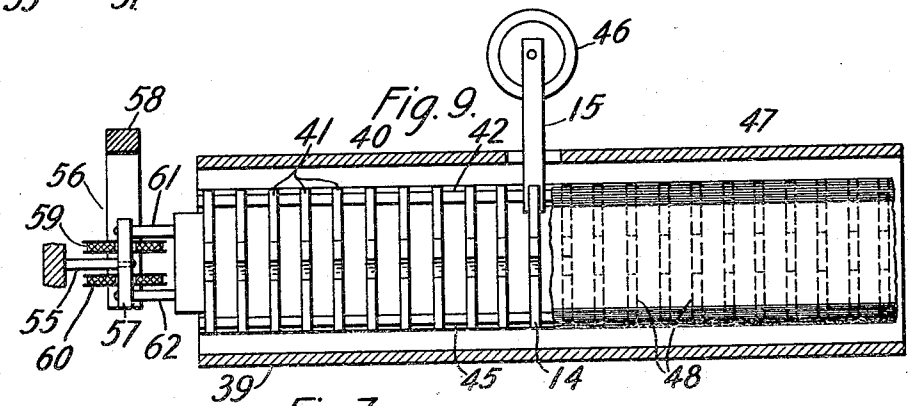


Fig. 7.

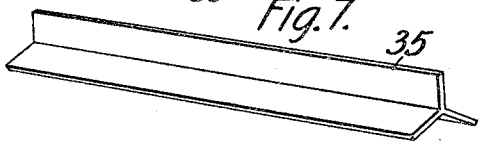


Fig. 11.

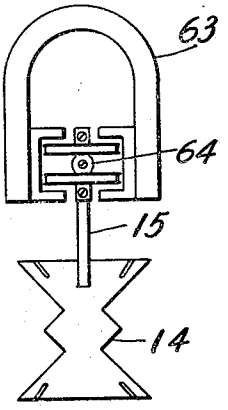


Fig. 10.

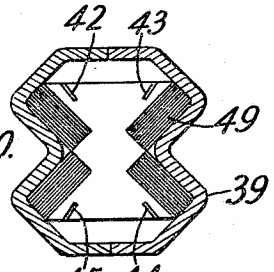
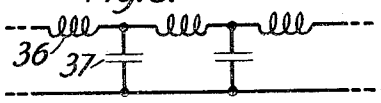


Fig. 8.



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Jan. 13, 1931. H. C. HARRISON 1,788,519

MECHANICAL TRANSMISSION SYSTEM

Original Filed May 26, 1926 2 Sheets-Sheet 2

Fig. 12.

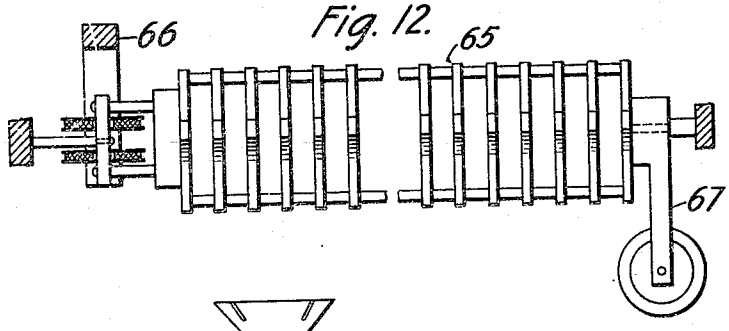


Fig. 13.

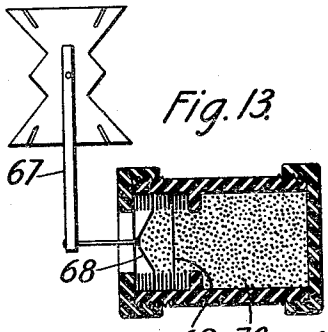


Fig. 15.

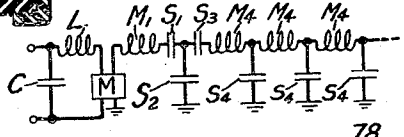


Fig. 14.

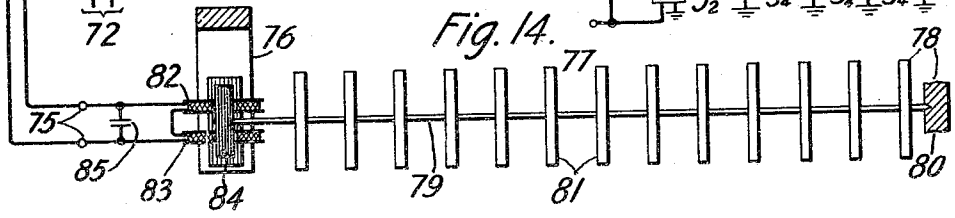
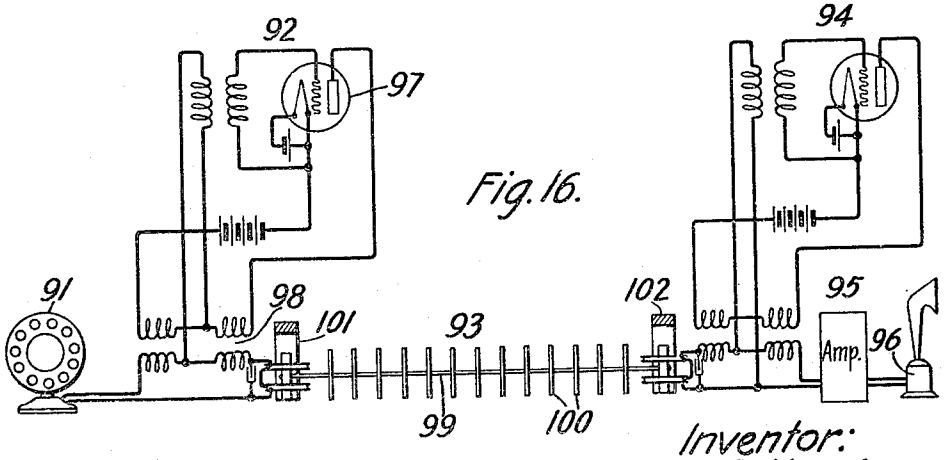


Fig. 16.



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Patented Jan. 13, 1931 1,788,519

UNITED STATES PATENT OFFICE

HENRY C. HARRISON, OF PORT WASHINGTON, NEW YORK, ASSIGNOR TO WESTERN ELECTRIC COMPANY, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

MECHANICAL TRANSMISSION SYSTEM

Application filed May 26, 1926, Serial No. 111,706. Renewed June 11, 1928.

This invention relates to systems for the transmission of the mechanical vibratory energy and is a continuation in part of patent application Serial No. 603,005, filed November 24, 1922.

One object of this invention is to obtain a required phase shift or time delay by means of a mechanical transmission system.

Another object of this invention is to improve the coupling between electrical and mechanical systems.

Another object of this invention is to efficiently couple a mechanical system to an electrical system, at the same time properly terminating the mechanical system in a desired impedance.

As explained in U. S. Patent 1,678,116, issued July 24, 1928, which is a continuation in part of the patent application referred to above, the characteristics of wave motion are analogous in mechanical and electrical systems so that the fundamental mechanical and electrical equations are identical except for the symbols employed. The corresponding quantities in the two systems are:

Mechanical systems	Electrical systems
Force	Electromotive force
Displacement	Charge
Velocity of vibration	Current
Mass	Inductance
Stiffness or elasticity	Reciprocal of capacity
Friction	Resistance

The transmission characteristic of any system for the propagation of wave energy is measured in terms of the propagation constant P. In an electrical system the propagation constant per unit length of a uniform line, or per section of a line of recurrent structure is defined as the natural logarithm of the vector ratio of the steady state currents at two points separated by a unit length in a uniform line of infinite length or at two successive corresponding points in a line of recurrent structure of infinite length, that is,

$$P=\log_e\frac{I_1}{I_2}$$

where I_1 is the input current and I_2 the output current. This definition and expression also hold true for mechanical systems where I_1 and I_2 represent the mechanical currents (velocities of vibration).

The propagation constant is composed of two components ($P=A+jB$). The real part A is called the attenuation constant and the imaginary part B is called the phase constant or wave length constant. Since B is the phase or wave length constant, i. e., the retardation angle in radians, the velocity (V) of the propagation of a wave of angular velocity (ω) is

$$V=\frac{\omega}{B}$$

or the time of transmission or retardation (t) per unit length or per section is

$$t=\frac{B}{\omega}$$

A feature of this invention is a mechanical system for obtaining a phase shift or time delay analogous to the electrical systems used for the same purpose. Mechanical lines either of the continuously loaded or lumped loaded types are particularly adapted for this purpose, since the delay is a direct function of the mass of the line and, by means of the loading, a large delay may be obtained with a short length of line. Mechanical networks of recurrent structure, for example wave filters analogous to the electrical wave filters disclosed and claimed in U. S. Patent No. 1,227,113 granted to G. A. Campbell May 22, 1917, are also well suited for this purpose.

Another feature of this invention is a mechanical network for properly terminating a mechanical line or filter. This is a desirable arrangement since in order to prevent reflection losses, it is necessary that a transmission network be terminated in an impedance equal to the impedance of the network, and, as disclosed and claimed in U. S. Patent No. 1,493,600 granted to G. A. Campbell May 13, 1924, it is particularly expedient that a filter composed of a finite number of recurrent sections be terminated in an impedance equal to that of an infinite series of such sections, in

order to obtain a proper operation of the filter.

In accordance with another feature of this invention a mechanical system is closely coupled to an electrical system so that the mechanical system is terminated in an impedance equal to the impedance of the electrical system in such a way as to give the desired terminating impedance. Broadly the same design principles set forth and the same features described and claimed in my copending patent application, Serial No. 678,935, filed December 6, 1923, in connection with an electromagnetic receiver for operating a sound radiating system, are made use of in the construction of a receiver for terminating and coupling to an electrical system a mechanical line or filter, in accordance with this feature of the invention.

These and other objects and features of the invention can be more readily understood by reference to the following detailed description in connection with the drawings in which:

Fig. 1 is a side view of one embodiment of the invention for transmitting torsional motion;

Fig. 2 is an end view of the system of Fig. 1;

Figs. 3 and 4 are end views of modifications of the system of Figs. 1 and 2;

Fig. 5 shows a form of the invention for transmitting longitudinal vibrations;

Fig. 6 is a sectional view of the system of Fig. 5;

Fig. 7 shows a uniform line constructed in accordance with this invention;

Fig. 8 shows diagrammatically an electrical low-pass filter;

Figs. 9 and 10 show another form of this invention in combination with coupling and terminating arrangements;

Fig. 11 shows a modification of the form of the invention shown in Fig. 9;

Figs. 12 and 13 show a form of this invention similar to that shown in Figs. 9 and 10, except that the line is terminated by means of a properly designed carbon button;

Fig. 14 shows a form of this invention embodied in a system for obtaining a delay in the transmission of electrical currents;

Fig. 15 shows an electrical circuit analogous to the coupling means employed in the system of Fig. 14; and

Fig. 16 shows a form of this invention embodied in a system for producing artificial reverberation.

Figs. 1 and 2 show a mechanical system, comprising a rod 21 uniformly distributed along which are a plurality of equal weights 22. When such a system is employed for transmitting torsional vibratory energy, it is analogous to a lumped loaded line in which the rod 21 represents a uniform line loaded at regular points by means of the weights 22. If the dissipation in the line is kept negligible, such a system may be designed to uniformly transmit a wide band of frequencies with little or no attenuation and a definite time delay.

Fig. 3 shows an end view of a mechanical system similar to that of Figs. 1 and 2, except that two rods 23 and 24 are employed instead of a single rod. Similarly, Fig. 4 shows an end view of a system employing four rods 25, 26, 27 and 28.

Figs. 5 and 6 show a system for transmitting longitudinal vibrations by means of a plunger action. There is shown a casing 30 containing a plurality of spaced weights 31 separated from each other by a plurality of thin sheets 32 of material such as aluminum foil or paper. Plungers 33 and 34 serve to close the ends of the casing 30 so that the movement of the plunger 33, for example, will be transmitted through the air cushioning between the foil sheets and the spaced weights 31 to the plunger 34 at the opposite end. The spaced weights constitute the mass of the mechanical line and the air between the thin air cushioned sheets of foil, together with the spring contacts of the sheets, presents an elastic reaction to motion so that the system is the mechanical equivalent of an electrical system comprising series masses and shunt elasticities. The weights 31 may be considered as representing loading coils and the elasticity between the air cushioned foil sheets which lie between the weights as corresponding to the shunt capacities. The system may be designed to have a definite time delay in the same way as the systems described above.

If the sheets fit tightly into the casing, so as to substantially prevent the escape of air, there is very little dissipation of energy and the mechanical line is the equivalent of an electrical line composed solely of inductances and capacities.

In some cases where a time delay is required, it may be more desirable to employ a uniform line rather than one of lumped elements. Fig. 7 shows one device 35, which may be used for this purpose. This device comprises three strips of metallic material integral with each other and placed at an angle of 120° with respect to one another. This bar, when subjected, for example, to a twisting motion, may be employed in the transmission of vibratory energy from one end to the other. The arrangement of the strips permits the device to be subjected to a torsional movement only, and reduces to a considerable degree the danger of having the device bend due to force exerted at right angles to its axis. Such a bar will give uniform delay for all frequencies if the dissipation is negligible or if it is so designed that the leakage G (effective shunt dissipation)

is proportioned with respect to the series resistance R in the following manner:

$$\frac{R}{G}=MS$$

Under these conditions the delay per unit length is:

$$t=\sqrt{\frac{M}{S}}$$

where M and S represent respectively the mass and elasticity per unit length.

By designing the structures of Figs. 1, 3, 4 and 5 so that the mass of the sections of line between the weights is negligible compared to the mass of the weights, they may be made to approximate a low-pass filter analogous to the electrical filter shown in Fig. 8. Such a filter is composed of a plurality of similar sections, each comprising series inductance 36 and shunt capacity 37 equivalent, respectively, to the mass M of the weights 22 and the reciprocal of the elasticity S of the interconnecting sections of the bar 21 of Fig. 1, for example. Within the transmission range, the phase shift constant per section of a wave filter is,

$$B=2\sin^{-1}\frac{1}{2}\sqrt{\frac{-Z_1}{Z_2}}$$

where Z_1 and Z_2 represent respectively series and shunt impedance. For the low-pass filter of Fig. 1 this is,

$$B=2\sin^{-1}\frac{\omega}{2}\sqrt{\frac{M}{S}}$$

for all frequencies below the cut-off,

$$f_c=\frac{1}{\pi}\sqrt{\frac{S}{M}}$$

For a filter of n sections this gives a total phase shift

$$B_T=2n\ \sin^{-1}\frac{\omega}{2}\sqrt{\frac{M}{S}}$$

or a total time delay

$$T=\frac{2n}{\omega}\sin^{-1}\frac{\omega}{2}\sqrt{\frac{M}{S}}$$

Such a system is particularly suitable for use as a delay network since, below the cut-off, the attenuation is negligible and the impedance is substantially equal to the constant value,

$$Z=\sqrt{MS}.$$

As set forth in detail in Patent 1,493,600, referred to above, it is desirable that, in order to obtain efficient operation, a wave filter be terminated in an impedance equal to the impedance of an infinite number of sections similar to those comprising the filter. One method of obtaining such a termination is shown in the device of Figs. 9 and 10.

The form of a mechanical filter 40 disclosed in these figures comprises a plurality of lumped masses 41 connected by four strips 42, 43, 44 and 45 of elastic material and mounted in a casing 39. These four strips as shown in Fig. 10 are placed in four corners of a rectangle and are so regularly and angularly spaced that their projections pass through the centers of the masses 41. Each of the weights 41, as shown in Fig. 10, is of an irregular shape to allow them to be readily mounted in the casing 39 while permitting the strips 42, 43, 44 and 45 to be subjected to a twisting vibratory motion. The filter is pivotally supported at one end by means of a pivot member 55 to enable it to be freely twisted in accordance with the mechanical vibratory energy of the armature of a loosely coupled magnetic receiver 56. The armature 57 of this receiver is mounted in the field of a permanent magnet 58 and surrounded by two receiver coils 59 and 60, which may be connected to an electric circuit to receive signals or other alternating current waves therefrom, and to produce corresponding mechanical vibrations of the armature. The armature 57 is coupled by means of two members 61 and 62 to the end section of the filter 40 to impress vibrations thereon. The resulting vibrations in the filter are transmitted therethrough, producing resulting vibratory motion of the end mass 14 which is transmitted through the coupling member 15 to the carbon button 46, so as to vary the pressure exerted on the carbon granules therein to produce a varied resistance and a resulting vibratory current in a circuit connected to the electrodes thereof. A mechanical resistance 47 is added to the structure for increasing to a desired amount the terminating resistance of the line 40. This resistance is formed by extending the spring strips 42, 43, 44 and 45 of the filter 40 a desired amount and mounting thereon a plurality of weights 48 to form a mechanical line. A plurality of thin sheets 49 of material such as metal foil are packed between the weights 48 and the casing 39. These sheets of damping material are provided for dissipating the energy transmitted to the portions of the spring strips extending beyond the mass 14 where the carbon button is coupled to the mechanical filter and it is obvious that the amount of packing employed in the particular case will depend upon how rapidly it is desired to dissipate this energy.

Fig. 11 shows a detail of a modification of the device in which a loosely coupled magnetic receiver 63 is substituted for the carbon button 46, the armature 64 being attached to the coupling strip 15.

Figs. 12 and 13 show a mechanical line 65 driven by a loosely coupled magnetic receiver 66 and similar to that of Fig. 9, excepting that the terminating impedance is

obtained by use of a deep chamber carbon button of the type disclosed and claimed in U. S. Patent 1,648,120, issued November 8, 1927. This button is attached to the end section of the line remote from the receiver by means of an arm 67, as shown in Fig. 13, and comprises a front electrode 68 and a back electrode 69. The back electrode 69 should be of flexible material, for example, a wire mesh or gold plated cloth, to allow the vibrations to be transmitted to the deep chamber 70 beyond the electrode 69. It has been found that the best quality of reproduction of mechanical vibrations transmitted to the front electrode 68 from the mechanical line takes place when only a thin layer of carbon is located between the electrodes. Preferably the distance between the electrodes 68 and 69 should not be greater than 40 mils. The cross sectional area and depth of the deep carbon chamber 70 should be so designed as to give the button a mechanical impedance equal to the mechanical impedance of the line 65 as measured at the end of the lever arm 67.

Fig. 14 shows a mechanical system terminated in a closely coupled magnetic receiver in such a manner that the impedance of the mechanical line is matched to the impedance of the electrical circuits. This arrangement has been shown in connection with a delay circuit of the type disclosed and claimed in U. S. Patent 1,607,687, issued November 23, 1926. This system comprises two line sections 71 and 72 between which it is desired to obtain a definite time delay. Currents coming in from the section 71, for example, are impressed upon the hybrid coil 73, half going to the balancing network 74 and half to the delay circuit 75. The network 74 is designed to have an impedance to match the impedance of the delay circuit 75 so that no current is impressed on the line section 72. The portion of the current flowing into the circuit 75 is transformed, by the electromagnetic receiver 76, into mechanical vibrations which are impressed upon the mechanical delay circuit 77, transmitted therethrough to the remote end 78 where they are reflected back to the input, retransformed into electrical current by the receiver 76 and impressed back upon the hybrid coil 73 where they divide between the lines 71 and 72. By means of this arrangement a required delay is obtained with a line of half the length that would be otherwise required.

The mechanical delay circuit 77 of this embodiment of the invention is of the type shown in Fig. 1, comprising a rod 79, along which are distributed a plurality of weights 81. One end of the line is connected to the armature of the electromagnetic receiver 76 and the other end is supported by a bearing 80. The receiver 76 is of the closely coupled type, for example, as described and claimed in U. S. Patent 1,709,571, issued April 16, 1929, to which reference is made for a more detailed description. A receiver of this type may be designed to match the impedance of the electrical and mechanical systems to prevent reflection loss and to properly terminate the mechanical system. Connected in shunt to the windings 82 and 83 of the receiver is a condenser 85 provided to properly terminate the coupling system, as described and claimed in my copending application Serial No. 678,935, filed December 6, 1923.

The equivalent electrical circuit of the mechanical system and coupling arrangement is shown in Fig. 15, where L and C represent respectively the inductance of the windings 82 and 83 and the capacity of the condenser 85, and the rectangle M, the coupling metween the mechanical and electrical circuits. In the portion of the diagram representing the mechanical system, the series mass M_1 represents the mass of the armature 84; the series elasticity S_1, the negative elasticity of the magnetic field of the air-gap; the shunt elasticity S_2, the elasticity of the shaft connecting the armature and the line; the series elasticity S_3, the elasticity of the armature retaining spring (not shown); and the masses M_4 and elasticities S_4, the masses of the weights 81 and elasticities of the connecting sections of the rod 79, respectively. The elements of such a system may be designed to uniformly transmit a wide band of frequencies, at the same time giving impedance matching at the terminals of both the electrical and mechanical systems. For further details of the design of such a system reference is made to the above mentioned applications and to U. S. Patent 1,681,554, issued August 21, 1928.

Fig. 16 shows a circuit in which both ends of the mechanical delay system are coupled to electrical circuits by means of closely coupled electromagnetic receivers. This embodiment is shown in a type of artificial reverberation producing circuit disclosed and claimed in U. S. Patent 1,647,242, issued November 1, 1927. Here a transmitter 91 is connected to a two way-one element type repeater circuit 92, which is in turn connected through a mechanical delay circuit 93 to a second two way-one element type repeater circuit 94 and thence through an amplifier 95 to a reproducer 96. As explained in detail in the application referred to above, part of the current going from the transmitter 91 is transmitted directly to the delay circuit 93, but the larger part divides between the input and output circuits of the vacuum amplifier 97. The energy which flows into the output circuit is lost, but the wave flowing into the input circuit is amplified and the amplified current passes to the output coil 98 where it divides between the circuit of

transmitter 91 and the delay circuit 93, half going to each, if the impedances of 91 and 93 are balanced, which must be substantially the case in order to avoid singing. The energy of that half which passes into the transmitter circuit is dissipated while the wave flowing into the delay circuit goes to the repeater 94 where it is amplified and the amplified current transmitted to the output coil where it divides between the reproducer circuit and the delay circuit. The wave which flows back into the delay circuit is amplified by the repeater 92 and half the amplified current is dissipated in the transmitter circuit while the other half passes into the delay circuit and is amplified by repeater 94, half of the amplified current passing back into the delay circuit to repeat the cycle while the other half flows into the reproducer circuit. This last current lags behind the original current and is of similar amplitude due to the phase shift of the delay circuit, and so appears as a first reflection. Part of the current which flows back into the line is also finally impressed upon the reproducer after having been repeated and reduced by division in the hybrid coils. Thus we have a series of currents in the reproducer 96, each one lagging behind the preceding one by a definite time and decreasing in amplitude in a logarithmic ratio until the last is inappreciable.

The delay system 93 consists of a rod 99, along which are mounted weights 100, and the ends of which are connected to the armatures of two closely coupled electromagnetic receivers 101 and 102 similar to the receiver 76 shown in Fig. 14. The windings of these receivers are connected to the line sides of the hybrid coils of the repeaters 92 and 94 respectively. The receivers may be designed in the manner explained in connection with the receiver 76 of Fig. 14 so as to properly terminate the mechanical line at each end.

It is understood that this invention is not limited to the particular embodiment shown, but may be variously modified without departing from the spirit of the invention as defined in the appended claims.

What is claimed is:

1. In combination, a system for the transmission of mechanical vibratory energy, comprising a plurality of sections each having mass and elasticity effectively in series and shunt relation to the line of propagation of mechanical wave energy, an electric circuit, and a closely coupled electromagnetic receiver for coupling said mechanical system to said electric circuit, the mechanical, electrical and magnetic characteristics of said receiver being so proportioned with respect to one another and to the constants of the mechanical system and the electric circuit that said mechanical system is terminated in an impedance substantially equal to the impedance of an infinite number of similar sections for frequencies to be transmitted.

2. In combination, a mechanical transmission line having mass and elasticity effectively in series and shunt relation to the line of propagation of wave energy and so proportioned with respect to one another as to give said line a substantially constant impedance for a wide range of frequencies to be transmitted, means associated with said line at one end for impressing vibrations thereon, and means associated with said line at the other end for terminating said line, said means comprising a mechanical line of a plurality of sections each comprising mass and elasticity so arranged and proportioned as to give said means an impedance substantially equal to the impedance of said first line for the frequencies to be transmitted thereby.

3. A combination according to claim 2, in which the terminating means includes damping means for dissipating substantially all the energy transmitted thereto.

4. In combination a mechanical transmission line comprising a plurality of sections, each having mass and elasticity effectively in series and shunt relation to the line of propagation of mechanical wave energy and so proportioned with respect to one another as to give said line a substantially constant transmission characteristic for a wide range of frequencies to be transmitted, means associated with one end of said line for impressing vibrations thereon, means associated with said line at another point for receiving wave energy therefrom, and a terminating mechanical line associated with the other end of said line, said terminating line comprising a plurality of sections each having mass and elastic elements effectively in series and shunt relation to the line of propagation of mechanical wave energy, and so proportioned with respect to one another as to give said terminating line a mechanical impedance substantially equal to the impedance of a line of an infinite number of sections like those comprising said first line.

5. A combination according to claim 4, in which said terminating line includes damping means associated with each of said sections for dissipating substantially all the energy impressed on said line.

In witness whereof, I hereunto subscribe my name this 22d day of May A. D. 1926.

HENRY C. HARRISON.