Dec. 3, 1929. E. H. SMYTHE ET AL 1,738,327

VIBRATION DEVICE

Filed March 30, 1927 2 Sheets-Sheet 1

Fig. 1.

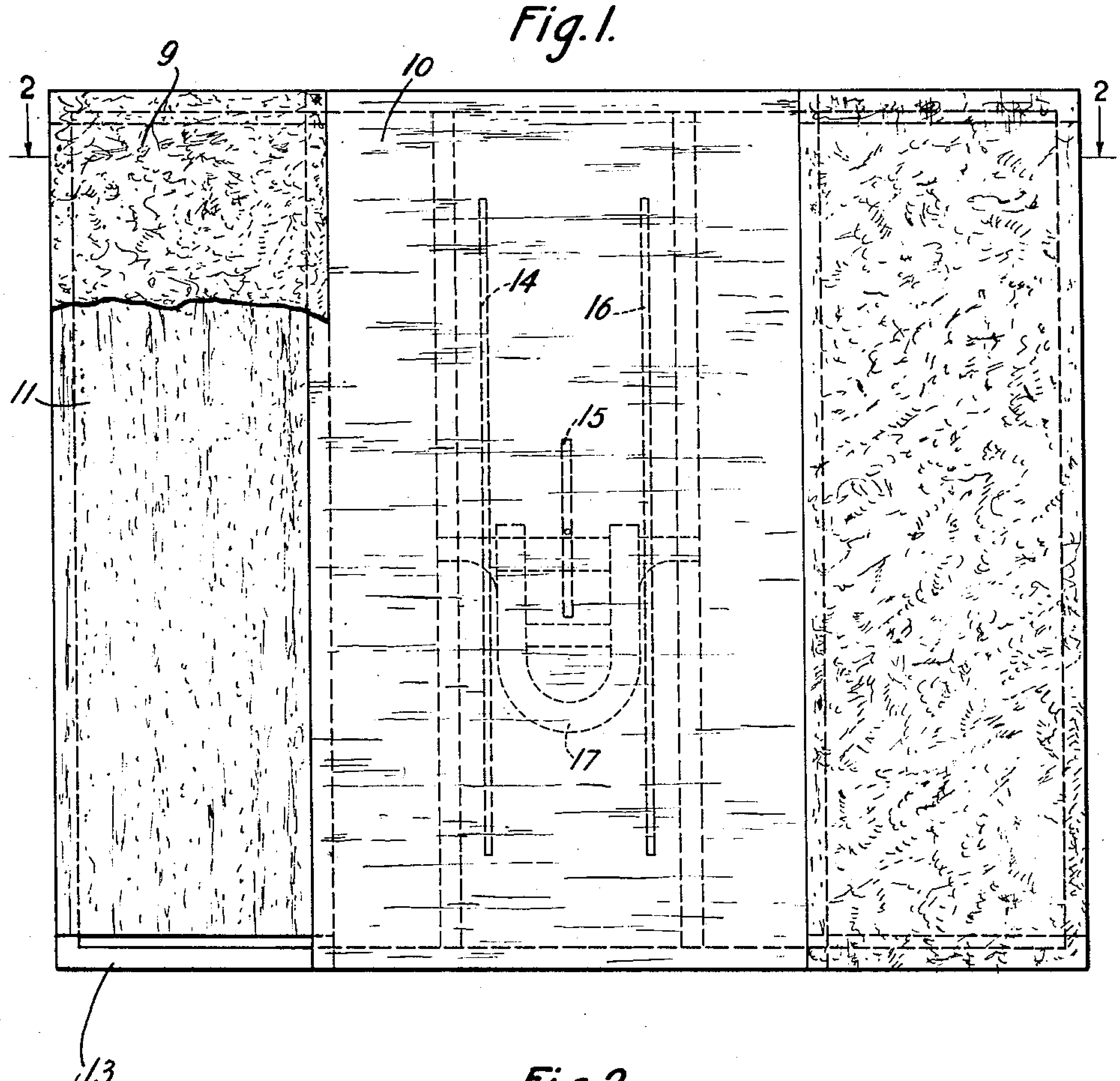
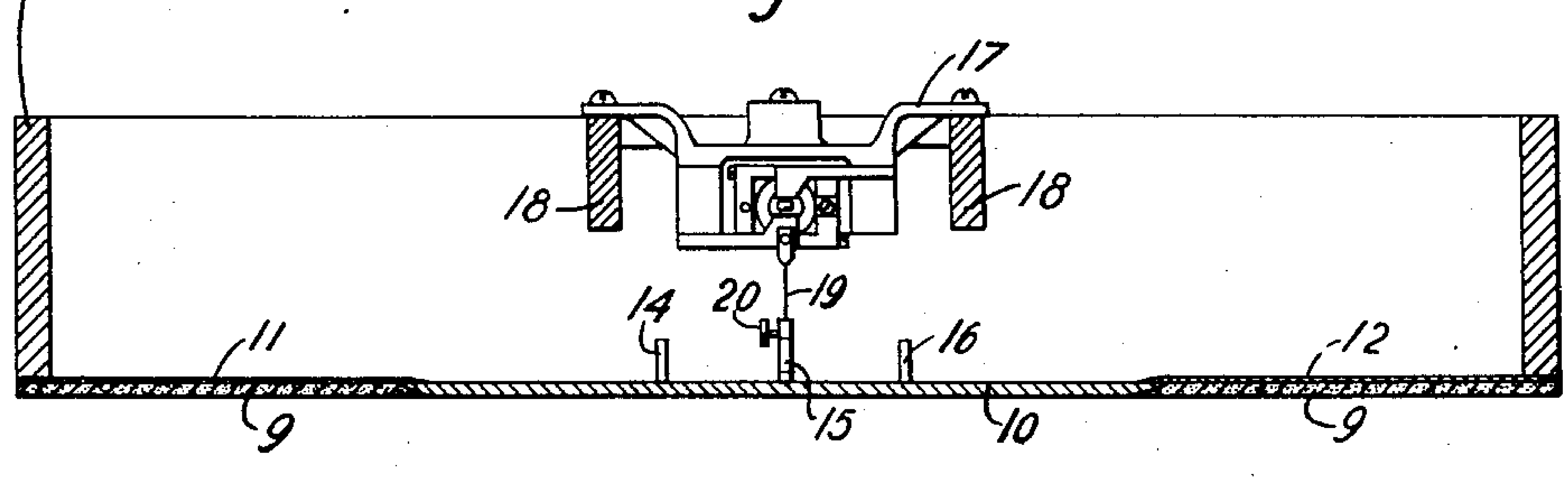


Fig. 2.



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2 Sheets-Sheet 2

Fig. 3.

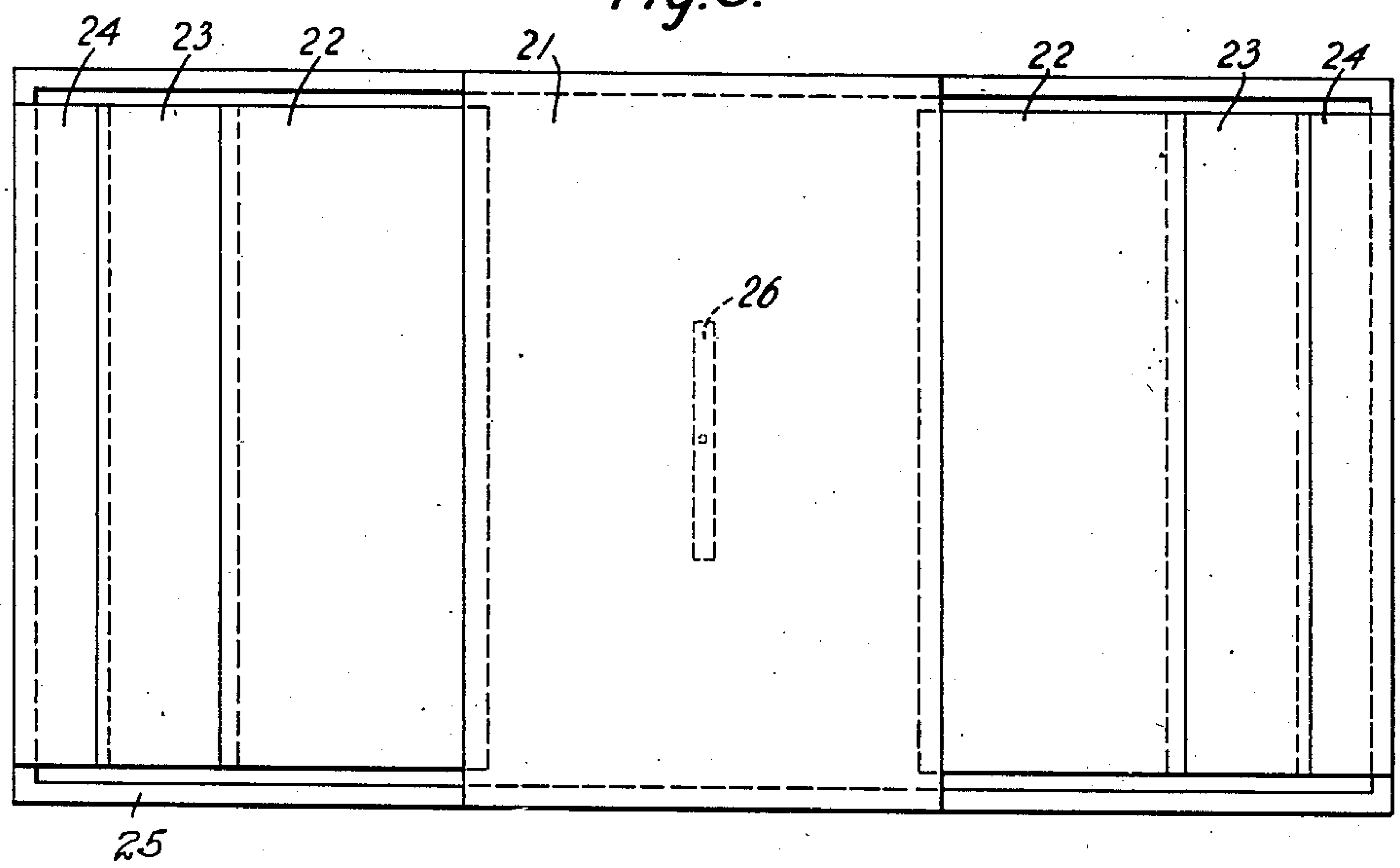


Fig. 5.

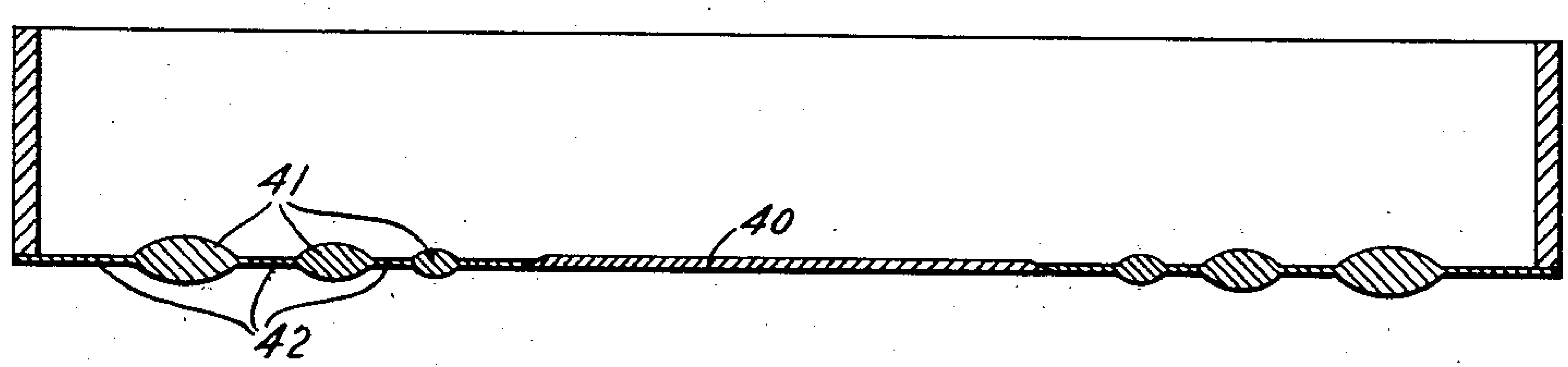
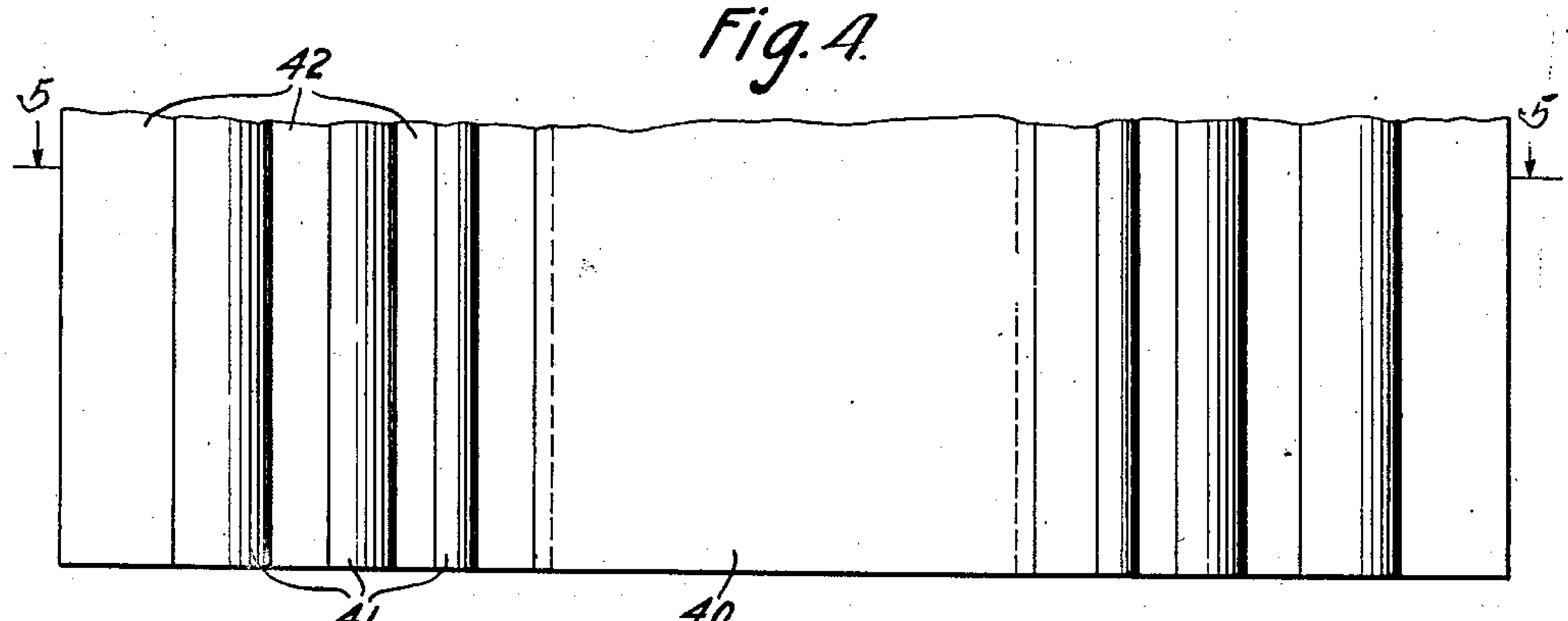


Fig. 4.



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UNITED STATES PATENT OFFICE

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VIBRATION DEVICE

Application filed March 30, 1927. Serial No. 179,453.

This invention relates to vibration devices and particularly to such devices for radiating sound waves.

An object of the invention is to simulate the transmission characteristics of a long vibration transmitting path by means of a relatively short path.

Another object is to radiate sound with substantially uniform efficiency over a wide frequency range.

In accordance with the present invention, there is provided a vibration device comprising a plurality of vibratile sections having different propagation constants, respectively, and having their impedances substantially matched so as to reduce reflection of vibrations from the joined portions. Vibratory energy is preferably applied to the device at a section in which the velocity of wave propagation is greatest and the device is preferably supported at a section in which the velocity of propagation is least.

In accordance with an embodiment of the invention herein shown and described for the purpose of illustration, diaphragm sections having different propagation constants and substantially matched impedances are obtained by employing in the different sections, materials of different mass and stiffness, respectively, per unit length in the direction of propagation of vibration. The width of the diaphragm and the flexural stiffness for lengths of equal masses are maintained substantially constant throughout the whole length of the diaphragm.

This invention may be readily understood by referring to the following detailed description and the accompanying drawings in which:

Fig. 1 is a front elevation, partly in section, of a sound radiator constructed in accordance with the present invention;

Fig. 2 is a sectional view taken along the line 2—2 of Fig. 1;

Figs. 3 and 4 show modifications of the sound radiator of Fig. 1; and

Fig. 5 is a sectional view taken along the line 5—5 of Fig. 4.

In all of the sound radiators shown in the drawing, it is desired to simulate a long vibration transmission path in the horizontal direction as viewed in the figures.

Referring particularly to Figs. 1 and 2, the diaphragm of a sound radiator comprises a central section 10 of balsa or other light wood, the grain of which runs in a horizontal direction, and which is joined to sections 11 and 12 of relatively heavy wood, such as mahogany, the grain of which runs vertically. These sections are bevelled at their joined edges and are glued or otherwise secured to the frame 13 along the unjoined edges which extend in the direction of the grain. Felt or other material 9 possessing negligible stiffness is secured to the end sections of the diaphragm in order to give added mass without stiffness and at the same time it may serve as a damping agent to decrease the amplitude of resonance peaks due to vibrational waves reflected from the edge of the diaphragm or to other causes. The ribs 14, 15 and 16 are provided for stiffening in a transverse direction the central section 10 of the diaphragm so that at lower frequencies the driving force is essentially applied over the full width of the diaphragm. A driving means such as the electromagnetic receiver 17, is secured to the upright members 18 of the frame and is connected to the rib 15 by means of the rod 19 which is secured to the rib by means of the thumb set screw 20.

While the theory of wave propagation in a diaphragm constructed in accordance with this invention is not definitely established, and while the invention is independent of the theory of operation, it is believed that the following is a correct explanation of the principles which account for the improved results obtained with this sound radiator. In this type of sound radiator it is desired primarily to radiate sound energy laterally from the diaphragm, and the propagation of wave energy longitudinally through the diaphragm is desired only to the extent necessary to permit the lateral movement of a sufficient area of the diaphragm to make possible the lateral radiation of a desired amount of sound energy. The longitudinal propagation out toward the support is something which not only is ordinarily not usefully employed, but which also is capable of producing undesirable effects, and for this reason may advantageously be dissipated as completely as possible to prevent its reaction upon the wave movements in the active portion of the diaphragm.

In the diaphragm of this invention, the active radiating portion is made sufficiently large to radiate a desired amount of energy into the air and is provided with a marginal terminal section for attenuating the wave energy propagated in the diaphragm beyond the active radiating portion so that no large amount of reflected wave energy is returned from the marginal terminal section and support to the active radiating portion of the diaphragm. To meet this requirement for the marginal terminal section, the elastic restoring force or stiffness per unit length in the direction of wave propagation should be low and the mass per unit length in this direction should be high as compared with the corresponding constants for the active radiating portion. A marginal portion having such constants has a relatively low wave propagation velocity, and a relatively high value of wave energy attenuation. In order to avoid wave reflection from the joined area of the active radiating portion and the marginal terminating portion of the diaphragm, the mass and stiffness constants in these portions are made such that their impedances are matched at their joined portions. This is accomplished by making the stiffness for lengths of equal mass in the direction of wave propagation the same for the marginal and the radiating portions of the diaphragm.

In accordance with one embodiment of this invention it is desired to remove a considerable portion from the ends of a rectangular diaphragm and substitute therefor a portion of shorter length without altering certain characteristics of the original diaphragm such as its fundamental resonance frequency and the wave propagation distance between the point of drive and the point of support. By substituting a section the mass per unit length of which is high compared with that of the removed portion and/or the stiffness per unit length of which is relatively low, it is possible to obtain a diaphragm such that the time required for a wave to travel from the driven portion to the ends of the diaphragm is the same for the new diaphragm as for the original one having relatively longer dimensions. The impedance offered to vibrations transmitted along a diaphragm is a function of its mass and stiffness. Consequently it is possible to approximately match the impedance between the dissimilar portions of a diaphragm, and thus prevent reflection of vibrations at their joined portions, by making the stiffness the same for lengths of equal masses.

A specific method of computing the requirements of a rectangular diaphragm in accordance with this invention is described as follows. This method is based upon static rather than dynamic considerations but also probably holds for the latter with reasonable accuracy.

Assume a rectangular diaphragm of length $2l_0+L$, of thickness t_0 and width W, in which the restoring force is flexural stiffness, and in which we are interested primarily in the propagation of waves in the direction of the length. It is desired to substitute for a length l_0 at each end of this diaphragm a new portion of length l_1, thickness t_1, and the same width W as before such that the mass and flexural stiffness measured in the direction of the length for any portion $\frac{l_1}{n}$ is the same for the new material as for $\frac{l_0}{n}$ of the old, where n may be given any value.

The mass M, for any element of the original diaphragm is $Kl_0t_0D_0$ where K is a constant depending upon the length of the element chosen and the value of W, and D_0 is the density. The mass for the corresponding element of the new material is $Kl_1t_1D_1$, where D_1 is its density. Therefore we have for matched impedances where l_1 and l_0 are any lengths:

$$Kl_1t_1D_1=Kl_0t_0D_0$$

or

$$l_1t_1=l_0t_0\frac{D_0}{D_1} \quad (1)$$

Likewise if we equate the flexural stiffness of these elements, we have

$$\frac{Ct_1^3E_1}{l_1^3}=\frac{Ct_0^3E_0}{l_0^3}$$

where C is a constant depending on the width of the material and E_1 and E_0 are values of Young's modulus of elasticity for the materials. Or

$$t_1=l_1\frac{t_0}{l_0}\left(\frac{E_0}{E_1}\right)^{\frac{1}{3}} \quad (2)$$

Combining (1) and (2) gives

$$\frac{l_1}{l_0}=\left(\frac{E_1}{E_0}\right)^{\frac{1}{6}}\left(\frac{D_0}{D_1}\right)^{\frac{1}{2}} \quad (3)$$

and

$$\frac{t_1}{t_0}=\left(\frac{E_0}{E_1}\right)^{\frac{1}{6}}\left(\frac{D_0}{D_1}\right)^{\frac{1}{2}} \quad (4)$$

Suppose the middle portion of the diaphragm is made of balsa wood and is .47 cm. thick (t_0), the grain of the balsa wood running lengthwise of the diaphragm, and the two ends are made of mahogany with the grain running crosswise. Measurements give us the following table of values:

$D_0=.104$
$E_0=2.3\times10^{10}$
$D_1=.55$
$E_1=.9\times10^{10}$

Substituting these values in (3) and (4) gives

$$l_1 = .36\ l_0 \quad (5)$$

and

$$t_1 = .50\ t_0 \quad (6)$$

Suppose we wish to simulate a balsa wood diaphragm 20″×60″×3/16″ (.47 cm.). The middle portion of the diaphragm of length $L = 12''$ will be left made of balsa wood and mahogany substituted for the two ends $l_0 = 24$. From (5) and (6) above we have $l_1 = 8.7''$ and $t_1 = 3/32''$. Therefore the new diaphragm will have a total length of $2l_1 + L = 29.5''$ and the thickness of the mahogany ends will be only 3/32″.

Another consideration is to assume that the added portion of the diaphragm is loaded with a uniform mass "m" per cm.² which does not contribute toward the stiffness. We then have

$$l_1 t_1 D_1 + l_1 m = l_0 t_0 D_0 \quad (7)$$

Equation (2) still holds. Combining (2) and (7) gives

$$\frac{l_1}{l_0} = \sqrt{\frac{m^2 + 4at_0D_0D_1 - m}{2aD_1}} \quad (8)$$

and

$$\frac{t_1}{t_0} = \frac{l_1}{l_0}\left(\frac{E_0}{E_1}\right)^{\frac{1}{3}} \quad (9)$$

where

$$a = t_0\left(\frac{E_0}{E_1}\right)^{\frac{1}{3}}$$

Suppose again we wish to simulate a balsa wood diaphragm 20″×60″×3/16″ and replace $l_0 = 24$ by mahogany grain running crosswise, letting $m = .22$. This gives us

$$l_1 = .17\ \ l_0 \quad (10)$$
$$t_1 = .233\ t_0 \quad (11)$$

The total length of the new diaphragm then is 20.1″ and thickness of the mahogany end will be .044″.

Fig. 3 shows a modification of the diaphragm of Fig. 1, comprising a central section 21 of light stiff material and the sections 22, 23 and 24 between the central section and the two ends of the supporting frame 25. Section 22 has a greater mass and lower stiffness per unit length than section 21; section 23 has a greater mass and lower stiffness per unit length than section 22, etc. The stiffness for lengths of equal masses, however, is the same for all of the sections. The means for driving the diaphragm is secured to the rib 26 attached to the central section of the diaphragm which has the greatest ratio of stiffness to mass.

In the embodiments of the invention heretofore considered, the distribution of mass and stiffness was uniform in each section of the diaphragm. The transmission characteristics of such a diaphragm may be approximated by employing short sections of lumped mass and lumped compliance, by compliance being meant the reciprocal of stiffness. As shown in Figs. 4 and 5 the central or driven portion 40 of the diaphragm is preferably made of light, stiff material, and the end sections are composed of the lumped masses 41 and the lumped compliances 42 which may be formed in a diaphragm of uniform material throughout. As previously pointed out the stiffness for lengths having equal mass should be substantially the same for all portions of the diaphragm. If desired the masses 41 may be progressively increased from the edge of the central portion 21 out to its supported portion and at the same time the compliances progressively increased, or, in other words, the stiffnesses progressively decreased so as to maintain the characteristic impedance of the loaded sections substantially constant while tapering the propagation constants of the sections.

Although the diaphragms shown in the drawing and described above are all rectangular in shape, it is apparent that the invention is also applicable to diaphragms of other shapes, such as a circular diaphragm having a central driven portion of light stiff material and an annular portion joined thereto of relatively heavy, flexible material. The invention, moreover, is not limited to plane diaphragms but may be applied to other diaphragms. Another application of the invention is to diaphragms in which the restoring force is mainly tensional, instead of flexural such as in the case of the diaphragm heretofore described.

What is claimed is:

1. A vibration device, in which the mass increases and the stiffness simultaneously decreases at a point on a line extending in the direction of propagation of vibration in said device.

2. A vibration device, in which one portion has greater mass and lower stiffness per unit length in the direction of propagation of vibration than another portion the characteristic impedances of said portions being substantially equal.

3. A vibration device in which one portion has greater mass and lower stiffness per unit length in the direction of propagation of vibration than another portion, the stiffness of lengths having equal mass being substantially equal.

4. A vibration device comprising a vibratile means, supporting means therefor, and means for actuating said vibratile means at a position remote from said supporting means, the mass of said vibratile means increasing and its stiffness decreasing from its driven portion to its supported portion.

5. A vibration device comprising a plurality of vibratile sections joined together, and

having different mass and stiffness respectively per unit length in a given direction, said sections being so arranged that the mass per unit length in said direction in said vibration device increases while the stiffness simultaneously decreases.

6. A vibration device comprising a plurality of joined vibratile sections having different propagation constants, respectively, and having their characteristic impedances substantially matched.

7. A vibration device comprising a plurality of joined vibratile sections having different propagation constants, respectively, the characteristic impedance looking into any one of said sections from its junction with another section being such that negligible reflection occurs at said junction.

8. A vibration device comprising a plurality of vibratile sections joined together, the propagation constants of at least two of said sections being unequal, and the characteristic impedance looking into one of said sections from its junction with the other section being substantially equal to the characteristic impedance looking into the other of said sections from said junction, whereby reflection at said junction is minimized.

9. A vibration device comprising a plurality of joined vibratile sections having different propagation constants, respectively, and having their characteristic impedances substantially matched, and means for applying energy to at least one of said sections.

10. A vibration device comprising a plurality of vibratile sections joined together, the propagation constants of at least two of said sections being unequal and the characteristic impedance looking into one of said sections from junction with another being substantially equal to the characteristic impedance looking into the other of said sections from said junction, and means for applying energy to a section in which the rate of propagation of vibration is highest.

11. A vibration device comprising a plurality of joined vibratile sections having different propagation constants, respectively, the stiffness for lengths having equal masses being substantially equal throughout said vibration device.

12. A sound radiator comprising a driven portion of light material having high stiffness in the direction of propagation of vibration therein and another portion joined to said driven portion having a higher density and a smaller stiffness in said direction of propagation, the stiffness for lengths of equal masses being substantially the same for each of said portions.

13. A sound radiator comprising a plurality of joined vibratile sections, actuating means for applying energy to a section of said device and means for supporting another section thereof, the lengths of said sections for equal masses decreasing progressively from said actuating means to said supporting means and the stiffness per lengths of equal mass being substantially constant throughout said vibration transmitting device.

14. A sound radiator comprising a substantially plane diaphragm and actuating means therefor, said diaphragm comprising a plurality of joined sections having different mass and different stiffness, respectively, per unit length in the direction of wave propagation in the diaphragm, the stiffness for lengths of equal mass in said direction of wave propagation being substantially constant throughout the diaphragm.

15. A sound radiator comprising a substantially plane diaphragm, supporting means for a peripheral portion of the diaphragm, and means for actuating a portion of the diaphragm remote from the supported peripheral portion, said diaphragm comprising a central section of light, stiff material and a peripheral section of relatively heavy, flexible material, the stiffness for lengths of equal mass in the direction of wave propagation in the diaphragm being substantially the same for both of said sections.

16. A sound radiator comprising a central section of light wood joined to two relatively short end sections of relatively denser wood, the grain of said central section running lengthwise therein, and the grain in said end sections running perpendicular to the grain in said central section, means for driving said device near the mid-portion of said central section, ribs for increasing the stiffness of said central portion across the grain, means for supporting said end sections along the direction of the grain, and a material attached to a portion of each of said end sections for increasing the weight without appreciably increasing the stiffness thereof.

17. A sound radiator comprising a relatively large area driven portion having distributed mass and compliance, and a relatively small area peripheral portion having concentrated mass and compliance.

18. A sound radiator comprising a relatively large area driven portion having distributed mass and compliance and a relatively small area marginal portion having concentrated mass and compliance of such values that the characteristic impedance of said marginal portion is substantially equal to the characteristic impedance of said driven portion.

19. A sound radiator comprising a driven portion, having distributed mass and compliance, a support, and a supporting marginal portion interposed between said driven portion and said support, said driven portion and said marginal portion having substantially equal characteristic impedances, the propagation constant of said marginal

portion being tapered from said driven portion to the support of said vibration device.

20. A sound radiator comprising a diaphragm, certain portions of which vary in density and have different propagation constants from other portions thereof, all of said portions having their characteristic impedances substantially matched.

21. A sound radiator comprising a diaphragm, consisting of portions having different constants for the propagation of sound, the elasticity of said diaphragm between said portions decreasing from the point of drive outwardly.

In witness whereof, we hereunto subscribe our names this 22 day of March A. D., 1927.

EDWIN H. SMYTHE.
CLARENCE E. LANE.