Nov. 26, 1946. W. P. MASON 2,411,551

RADIATING SYSTEM

Filed Aug. 19, 1941

FIG. 1

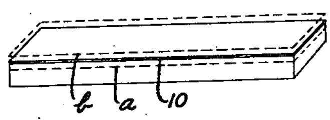


FIG. 2

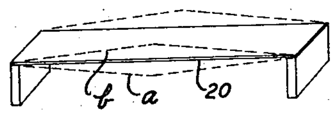


FIG. 1A

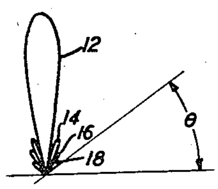


FIG. 2A

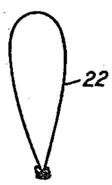


FIG. 3

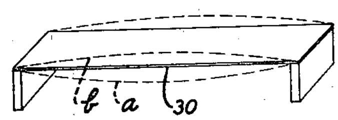


FIG. 4

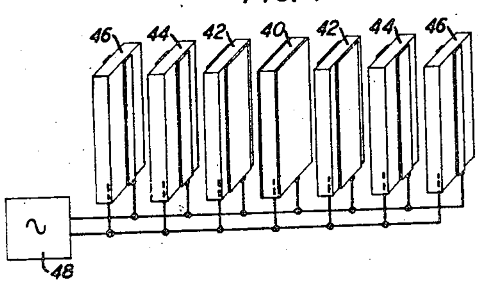


FIG. 5

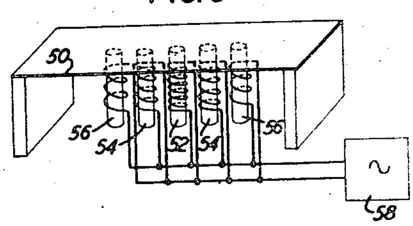
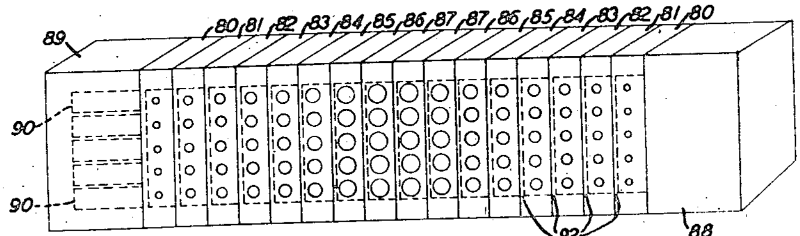


FIG. 6



INVENTOR
W. P. MASON
BY H. O. Wright
ATTORNEY

Patented Nov. 26, 1946

UNITED STATES PATENT OFI

2,411,551

RADIATING SYSTEM

Warren P. Mason, West Orange, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application August 19, 1941, Serial No. 407,457

4 Claims. (Cl. 177—386)

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This invention relates to improved directional compressional wave radiating systems of the multielement type. More particularly it relates to radiating systems in which the energy is distributed non-uniformly over the elements of the radiating system to reduce the relative strength of secondary radiation lobes with respect to the main radiation lobe.

A principal object of the invention is therefore to produce directional radiating systems having relatively small secondary radiation lobes.

Another object of the invention is to reduce secondary lobe radiation from multicrystal radiating systems.

A further object is to reduce secondary lobe radiation from multiunit magnetostrictive radiating systems.

Other and further objects will become apparent during the course of the following description and in the appended claims.

The systems of the invention will be more readily understood from the following description of illustrative embodiments taken in conjunction with the accompanying drawing in which:

Fig. 1 illustrates a radiating element of substantial surface area uniformly driven;

Fig. 1*a* indicates the directive radiating pattern of the surface of Fig. 1;

Fig. 2 illustrates a radiating element of substantial surface area driven with straight line variation of intensity from zero intensity at the ends to maximum intensity at the center;

Fig. 2*a* indicates the directive radiating pattern of the surface of Fig. 2;

Fig. 3 illustrates a radiating element of substantial surface area driven with sinusoidal variation of intensity from zero intensity at the ends to maximum intensity at the center;

Fig. 4 shows a radiating system comprising a plurality of piezoelectric crystals aligned to form a multielement radiating surface, the driving electrode areas of said crystals varying from very narrow areas for the outermost crystals to substantially complete coverage of the central crystal;

Fig. 5 shows a radiating diaphragm of substantial surface area driven by a plurality of magnetostrictive vibrators, the driving intensity varying from small intensity at the outermost vibrators to maximum intensity at the center vibrator; and

Fig. 6 shows a sound radiator of the multisection wave filter type with energy radiation provided from each section of the structure.

In more detail in Fig. 1 a member or diaphragm **10** is assumed to be driven from position *a* to position *b* with uniform amplitude at all points thereof. This may be accomplished, for example, by the well known electromagnetic type of driving mechanism employed in the so-called dynamic

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type of loudspeaker such as, f disclosed in United States Pat sued May 7, 1929, to A. I. Abra driving mechanism is not show it would unnecessarily compli Such mechanisms are well know are not involved in systems of will become apparent presently.

For radiating surfaces of the by member **10** of Fig. 1, characte particle velocity over the surf well known that the directional will be substantially as indicate acterized by a main lobe **12** of directivity and secondary lobes small but not negligible streng appreciably in angular directivi lobe.

For directive systems in whic directive indications are desire of radiators of the type illustrat been found to be objectionable s is sometimes misled by minor lo tains false directive indication

It is well known in the art member such as **10** of Fig. 1 uni have a pattern of the type descri nection with Fig. 1*a* and represe tion.

$$\frac{P_{(\theta)}}{P_N}=\frac{\sin\left(\frac{\omega L}{2v}\cos\right.}{\frac{\omega L}{2v}\cos\theta}$$

where L is the length or width is 2π times the frequency, v i propagation in the medium, θ i ured between the direction of t length of the radiator as showr the pressure at the angle θ, an sure normal to the radiator. Th that if most of the radiation within $\pm 1°$ from the normal, tl be about 57 wave-lengths across plications would be inconvenie

Also, secondary lobes will exi

$$\left(\frac{\omega L}{2v}\cos\theta\right)=\frac{3\pi}{2},$$

etc., whose values compared to

$$\frac{2}{3\pi}=13.5\text{ db.};\ \frac{2}{5\pi}=17.9\text{ db.};\ \frac{2}{7\pi}$$

The first lobe is only 13.5 de pared to the main one and ma tioned, introduce some difficu readings.

A method for reducing sec respect to the main one is discu 2,225,312, issued December 17, thereof, column 1, line 75 to

As applied to the radiator of Fig. 1, this method requires the particle velocity at the edge of the radiator to be much less than that at the center. A distribution investigated, by way of example, was one in which the particle velocity was zero at the edges and increased linearly to the center as indicated for the diaphragm 20 of Fig. 2, dotted lines a and b indicating the mode of vibration of diaphragm 20. For this distribution the radiation pattern is illustrated by curve 22 of Fig. 2a and is given by the equation

$$\frac{P_{(\theta)}}{P_{(N)}}=\left[\frac{\sin\left(\frac{\omega L}{4v}\cos\theta\right)}{\frac{\omega L}{4v}\cos\theta}\right] \quad (3)$$

For this distribution the first minimum comes at twice the angle as for the uniform distribution of Fig. 1, but the secondary lobes are down compared to the fundamental by the values

$$\left(\frac{2}{3\pi}\right)^2=27.0\text{ db.};\ \left(\frac{2}{5\pi}\right)^2=35.8\text{ db.};\ \left(\frac{2}{7\pi}\right)^2=41.6\text{ db., etc.} \quad (4)$$

To get the same sharpness requires a radiator with twice the length, but all the radiation maxima are down twice as far in decibels as for the uniform radiator.

A radiator in which the secondary maxima are not down quite as far, but which requires only a 50 per cent larger radiator to get the same sharpness is shown in Fig. 3. For this radiator the particle velocity of diaphragm 30 is substantially zero on the two ends and has a sine wave distribution of particle velocity between dotted lines a and b indicating the mode of vibration of diaphragm 30. A sine wave distribution of energy as applied to a multitube directive acoustic receiver is discussed and analyzed in my above-mentioned Patent 2,225,312 on pages 2 and 3 thereof; page 2, column 2, line 48 to page 3, column 1, line 10. In the device of the patent the areas of the respective tubes, or their orifices, are varied substantially in accordance with a sinusoidal law of variation. In this particular instance the row of tubes is wound about itself to form a compact assembly so that the tubes may be more readily associated with a conventional type of receiver-microphone and to facilitate the pointing of the assembly. For the type of radiator illustrated by Fig. 3 and the arrangement of my patent just mentioned the distribution pattern is given by the equation

$$\frac{P_{(\theta)}}{P_{(N)}}=\frac{\cos\left(\frac{\omega L}{2v}\cos\theta\right)}{1-\left(\frac{\omega L}{\pi v}\cos\theta\right)^2} \quad (5)$$

The first minimum comes when

$$\left(\frac{\omega L}{2v}\cos\theta\right)=\frac{3\pi}{2} \quad (6)$$

which is 50 per cent larger than that of Fig. 1, but the secondary lobes have the values with respect to the primary lobe of

$$\frac{1}{15}=23.5\text{ db.};\ \frac{1}{35}=30.8\text{ db.};\ \frac{1}{63}=36\text{ db.} \quad (7)$$

This decreases the first secondary lobe with respect to the primary by 10 decibels at the expense of widening the radiator only 50 per cent to retain the same sharpness of the primary lobe.

Figs. 4 and 5 show two methods of realizing particle velocity distributions of the above and

similar types for piezoelectric tive radiating systems, respect tric radiator frequently used c or an "array" of substantially salt crystals connected in pa physically to present, substant radiating surface as represen 42, 44 and 46 of Fig. 4.

In one common form the ro all be mounted on a common b for example, could be placed crystals of Fig. 4 and have the crystals cemented to it, the crystals forming a radiating s able area. An alternate com would be to support all the cry employ radiation from both to of the crystals. The crystals a trically in parallel across the lator 48.

To reduce the secondary lob suggested above, we can use arrangements of crystals bu width of the electrodes, or plat trodes are employed, so that the crystals 46 on the ends trodes, or plating areas, wher in the center has its sides com the electrodes, and intermedi electrodes of intermediate wid creasing with proximity to the viding that the plating, or elec same length as the crystals vary in width only, the force e dividual crystal will be propor ing or electrode area and the di portional to the force since al similar. Hence, if the area of linearly from the two ends of center, the radiation pattern be obtained, whereas if the area or plating, is distributed accord curve with the maximum at the zero on the end crystals, the dis tion 5 will be obtained. In th plating areas should vary as ta of the tubes of the acoustic de mentioned Patent 2,225,312 beg column 2, line 47 as above poi present application being the electric vibrators and α being

$$\frac{\pi}{n+1}$$

An alternative arrangement, tenuator for each crystal, or ea at a particular distance from array, would be to use crystals trodes but to limit, by interposi suitable amounts, the energy to tals to obtain an appropriat energy among them.

Fig. 5 shows one way of obtai particle velocity distribution strictive drive. For this cas diaphragm 50 clamped on the a number of magnetostrictive Since the edges are clamped t and the shape assumed by th vibrating will be nearly that giving the radiation pattern sho The central magnetostrictive course driven most strongly and 56 progressively less strong all energy distribution preferab tially sinusoidal, from a maximum at the center to minima at the ends. The desired non-uniform distribution of energy may be effected by proportioning the windings of the magnetostrictive members as indicated in Fig. 5 or alternatively by employing attenuators as suggested above for crystal arrays. The magneto-strictive members are connected electrically in parallel across the output of an oscillator 58.

In Fig. 6 a sound radiator in the form of a multi-section wave filter having sixteen sections 80, 81, 82, 83, 84, 85, 86 and 87 (two sections on opposite sides of the center of the structure being assigned the same number) is shown. At the left end of the structure a plurality of piezoelectric crystals 90 enclosed in a housing member 89, are employed to energize the structure and at the right end a member 88 of absorbing material is provided to absorb such energy as may reach the right end of the filter.

Each of the sections comprises a cup-like member of square cross-section, the cup bottoms 92 serving as diaphragms, coupling adjacent cavities. Each section is provided with several holes from which a small portion of the total energy passing through the filter is radiated. The hole sizes are adjusted so that maximum energy is radiated from the central sections 87 and decreasing amounts of energy from sections 86, 85, 84, 83, 82, 81 and 80, respectively, in accordance with their respective distances from the center. Because of attenuation and loss of energy by radiation the sections on the right half of the structure will have somewhat larger holes in order to radiate the same energy as corresponding sections of the left half of the structure. Again, the distribution of radiated energy may vary from maximum at the central elements to minima at each end in accordance with a straight line, sinusoidal, geometrical progression or other law of variation depending upon the particular performance desired.

The structure of Fig. 6, though of different form and proportions, is of the same general type as that illustrated by Figs. 15, 16 and 17 of, and described in, my copending application, Serial No. 381,236, filed March 1, 1941, entitled "Pipe antennas and prisms."

Obviously, an array of magnetostrictive vibrat-

ing members similar to the crystal array of Fig. 4 could be employed without a diaphragm, or, conversely, a plurality of crystals could be employed in place of the magnetostrictive vibrators of Fig. 5 to drive the diaphragm 50, sinusoidally, and numerous other arrangements within the spirit and scope of the invention can readily be devised by those skilled in the art. No attempt to exhaustively cover such arrangements has here been made. The scope of the invention is defined in the appended claims.

What is claimed is:

1. A piezoelectric radiator comprising a plurality of substantially identical piezoelectric crystals arranged in line, corresponding radiating ends of the crystals lying in a common plane, a pair of electrodes on each crystal, the electrodes extending in every case the full length of the crystals, the width of the electrodes on the end crystals of the line being small with respect to the width of the crystals, the width of electrodes for intermediate crystals being progressively greater as the center of the line is approached, the central crystal or crystals having electrodes of greatest width whereby minor lobe radiation from said array of crystals is substantially reduced.

2. In a directive radiating system a plurality of substantially identical piezoelectric crystals aligned in parallel relation with particular radiating ends of each in a common plane, the electrode plating on each crystal extending the full length of the crystal, the width of the plating varying from a small fraction of the width of the crystal for the outermost crystals to substantially the full width of the crystal for the centrally positioned crystal, the variation in plating area following a substantially sinusoidal law of variation.

3. The radiator of claim 1 the electrode area varying from the central to the end crystals substantially in accordance with a straight line law of variation.

4. The radiator of claim 1 the electrode area varying from the central to the end crystals substantially in accordance with a power series law of variation.

WARREN P. MASON.