March 13, 1928. 1,662,247

W. HAHNEMANN ET AL

METHOD AND ARRANGEMENT OF DIRECTIONAL WAVE RECEPTION AND EMISSION

Filed Sept. 26, 1925 3 Sheets-Sheet 1

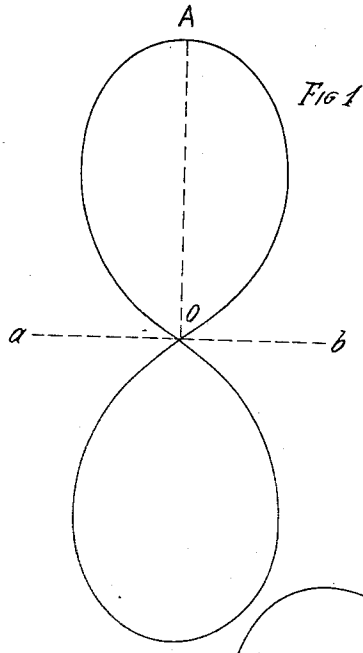


Fig 1

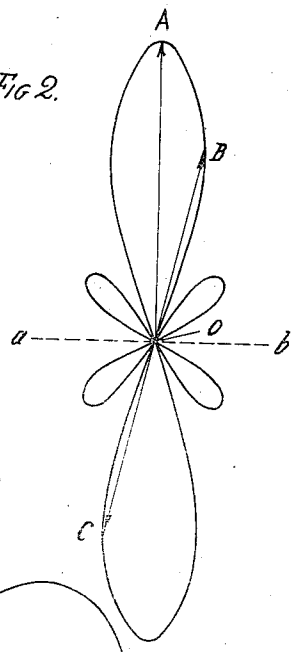


Fig 2.

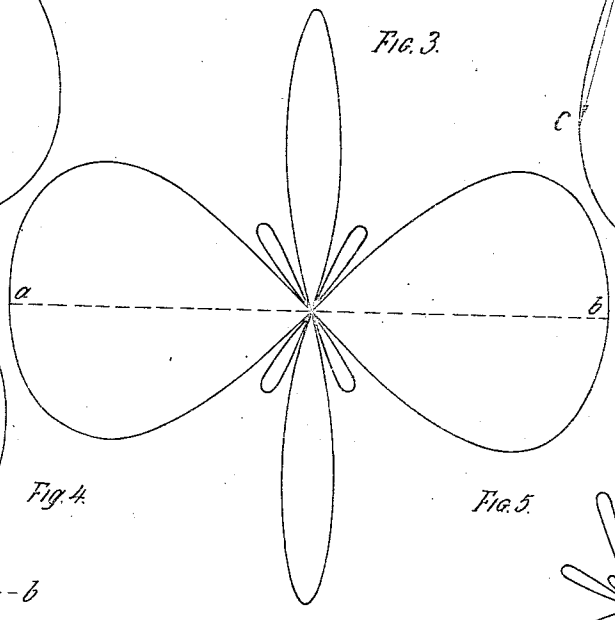


Fig. 3.

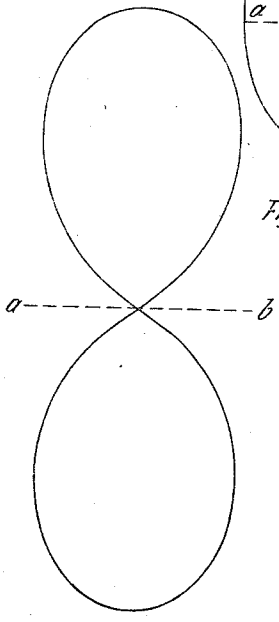


Fig. 4.

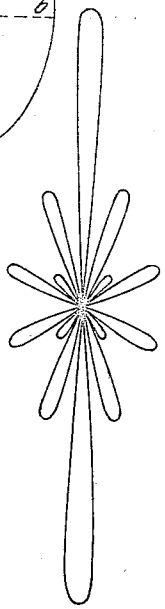


Fig. 5.

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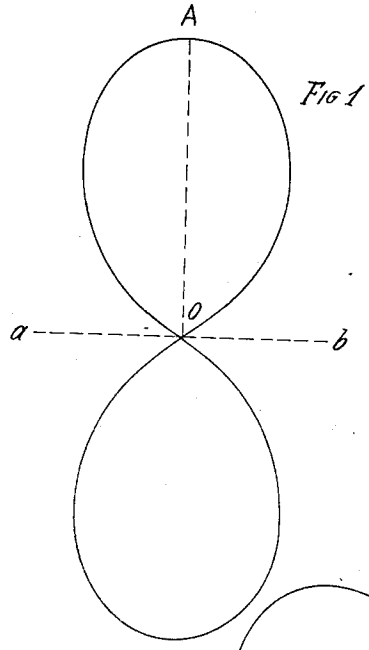


Fig 1

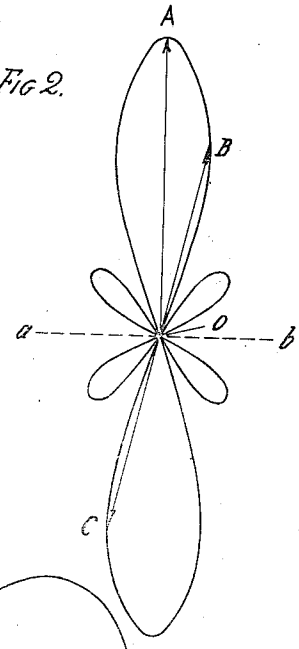


Fig 2.

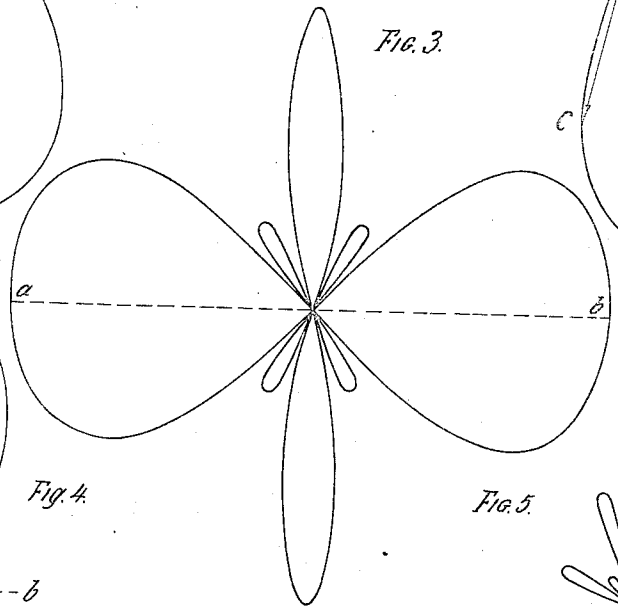


Fig. 3.

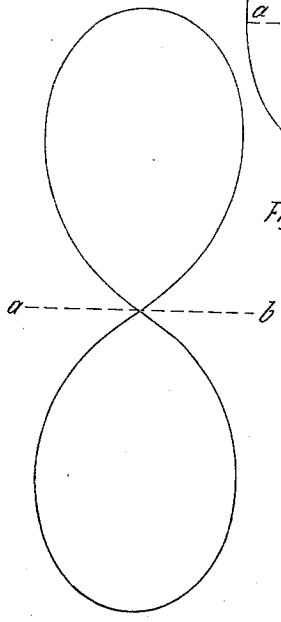


Fig. 4.

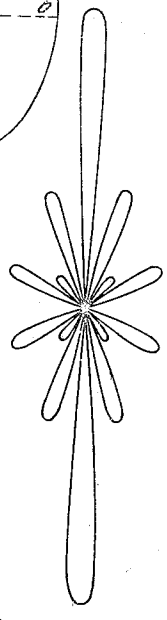


Fig. 5.

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METHOD AND ARRANGEMENT OF DIRECTIONAL WAVE RECEPTION AND EMISSION

Filed Sept. 26, 1925 3 Sheets-Sheet 3

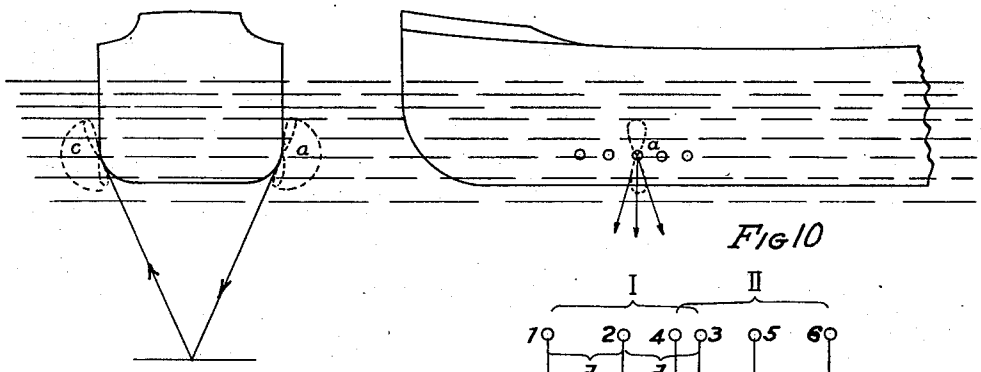


FIG 10

FIG 9

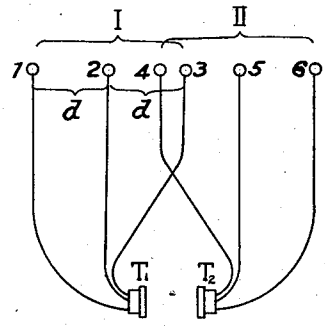


FIG 11 a

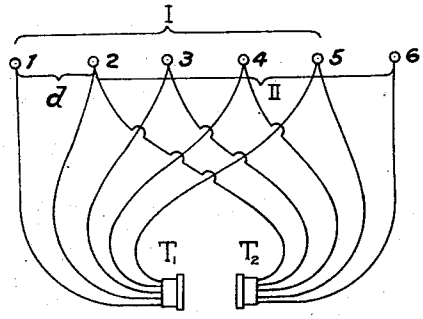


FIG 11 b

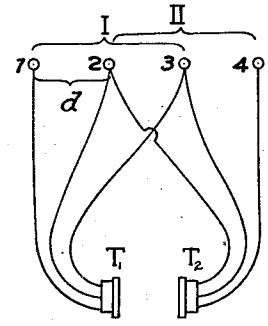


FIG 11 c

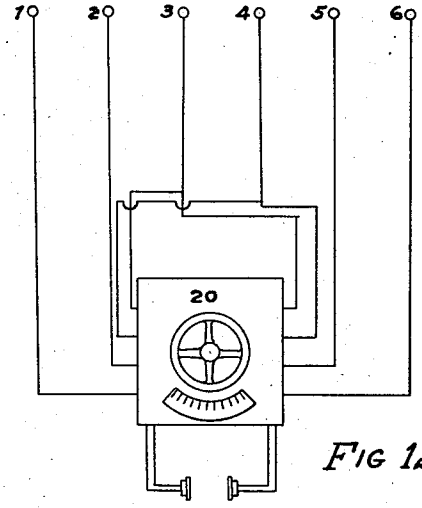


FIG 12

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Patented Mar. 13, 1928. 1,662,247

UNITED STATES PATENT OFFICE.

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METHOD AND ARRANGEMENT OF DIRECTIONAL WAVE RECEPTION AND EMISSION.

Application filed September 26, 1925, Serial No. 58,943, and in Germany October 6, 1924.

The present invention deals particularly with the method of arrangement of receivers and senders for directive and binaural listening, and directive sending, respectively.

In the prior art, the use of a plurality of receivers and senders is well known for directive sending and also for binaural reception. However in none of the previous uses of a plurality of receivers has it been attempted to obtain the most effective spacing for the purpose desired.

As will be seen in the following discussion, the advantages obtained in the proper spacing is applicable to many useful purposes. According to the present method it is possible to arrange upon the mast or funnel of a vessel, vertically, a plurality of high powered diaphragm whistles or air oscillators in such a manner that the passengers walking about the deck or, in fact, anywhere upon the vessel will not be troubled by the sound when the whistles are in operation. But for reflections it is possible that their operation may not be heard.

Likewise for directive transmission under water it is possible to arrange a system for sound senders so that a receiver placed very near the senders will not be affected by the operation of the sender. This method is especially useful in depth sounding, in that the receiver and sender may be placed close together, as is always desirable, and yet be in a position where the sounds of the senders do not reach the receiver.

A further usefulness of the present system is the prevention of ambiguity in binaural direction determination where the source which is being detected is a sustained note or one which is not greatly damped, so that a balance will be obtained from two successive vibrations of the note as well as the same vibration.

A further purpose of the present invention is that a minimum binaural base length may be obtained by allowing some of the receivers to serve both for the left and right ear compensation.

While it is evident that there are many other useful purposes to which the present invention may be applied, only a few above have been stated, the rest being disclosed from further discussion and description in the specification and also from the drawing in which

Figure 1 shows the intensity curve of a base of two receivers in a distance of ½ wave length from one another.

Figure 2 represents the intensity curve of three receivers each at the specified distance.

Figure 3 represents the intensity curve of three receivers each at a distance of a wave length of the sound.

Figure 4 shows the intensity curve for the case if $n=3$ and

$$d=\frac{n-2}{n}\lambda.$$

Figure 5 represents the intensity curve of the five receivers at proper distances.

Figure 6 shows the application of Figure 5 for directing the sound within a zone.

Figure 7 shows the combination of vertical and horizontal receivers.

Figures 8*a*, *b* and *c* show how various directive and uniform distributional effects may be obtained.

Figure 9 shows the application to screening receivers or senders.

Figure 10 is a side view of Figure 9.

Figures 11*a*, *b* and *c* show the application of the principle to binaural listening in which a shortened base is also obtained.

Figure 12 shows the application to compensation.

The applicants have discovered that if similar sound emitting devices operating at the same phase with respect to each other are spaced in a straight line at a distance equal to the wave length of the sound emitted multiplied by the expression

$$\frac{n-1}{n}$$

where n is the number of emitters, then there will be no sound heard along the line of the emitters or senders. The applicants have further discovered that the greater the number of senders or receivers, since one is really the reverse operation of the other, in such a line the more directive the sending or reception becomes, especially in the direction perpendicular to the axis of the senders or receivers. The applicants have further

discovered that in the case of the before mentioned condition being fulfilled, the greatest possible portion of the energy emitted from the group of senders or received by the group of receivers is chiefly concentrated in the plane perpendicular to the base line and that auxiliary maxima, if any, are smaller in any event than the maximum above referred to. That this is true may be derived from the following calculations and from the figures, especially from Figs. 1–5 and their discussion.

It may be shown that the sum of the sound vectors may be expressed by the following equation

$$(1)\quad I=\frac{I\sin n\Theta}{\sin\Theta}$$

$$(2)\quad \text{where}\ \Theta=\frac{\pi x}{\lambda}$$

where x is the linear phase difference between successive receivers due to the direction of the wave front and compensation between receivers (here receivers and senders are used interchangeably) and where λ is the wave length of the sound. The expression (1) has a maximum when $\Theta=0$, another when $\Theta=\pi$ or any whole multiple of π. In order to prevent a double maximum from occurring, it is necessary therefore to make $\Theta<\pi$. A minimum will occur when $n\Theta=K\pi$ where $K<n$, where K is any whole number. If K were equal to n or greater then Θ would not be less than π. Assume $K=n-1$ which will give the greatest range of Θ without allowing two maxima then

$$(3)\quad n\Theta=(n-1)\pi$$

and substituting value of Θ as given in (2)

$$(4)\quad \frac{nx}{\lambda}=n-1 \text{ whence}$$

$$(5)\quad x=\left(\frac{n-1}{n}\right)\lambda$$

or that the linear phase difference between successive receivers due to direction of the wave front and compensation should be

$$\frac{n-1}{n}.$$

In evaluating x it must be remembered that it has two component effects and may be written

$$(6)\quad x=d\,(\sin\phi\omega+\sin\phi_c)$$

where d=the spacing between receivers.

$\phi\omega$=the angle of the wave front with the line of receivers

ϕ_c=the additional angle of retardation due to compensation. Where there is no compensation connected in the receivers or senders $\phi_c=0$ and maximum value that that x can obtain under these circumstances is d. When there is compensation added, the maximum value of $x=2d$ so that under these circumstances the spacing of the receivers is just half as great or

$$(\text{without compensation})=\left(\frac{n-1}{n}\right)\lambda$$

$$(\text{with compensation})=\left(\frac{n-1}{2n}\right)\lambda$$

Figure 1 shows a section in the plane including the line of two receivers or senders at a distance of

$$\frac{n-1}{n}\lambda$$

i. e. in this case of

$$\frac{\lambda}{2}$$

from one another. The directional effect is in this case rather faint. No auxiliary maxima exist. The polar vector OA shows the intensity perpendicular to the line of receivers. This case is well known and described only for elucidation purposes. The directional effect is too small for practical use.

Figure 2 shows a section in the plane including the line of three receivers or senders each at a distance of

$$\left(\frac{n-1}{n}\right).$$

The polar vector OA represents the intensity in the direction perpendicular to the line of receivers, the vectors OB and OC in their respective directions. If the spacing had been a wave length the effect would not be very directive, there existing under these conditions four maxima of about equal intensity covering a broad angle as shown in Figure 3.

Figure 4 shows the intensity curve of five receivers spaced

$$\left(\frac{n-1}{n}\right)$$

distance apart. It will be seen from the curve that the intensity of the large maximum is greater than those of next in order. In fact, since in Figure 4 the vectors are simply the current vectors, the intensities vary as their squares, in which case it is apparent that all but the maximum loop are negligible.

Figure 5 shows the intensity curve for the case $n=3$ and

$$d=\frac{n-2}{n}\lambda=\frac{1}{3}\lambda.$$

The sharp directional effect is highly diminished and the curve is similar to that of Figure 1.

It is understood already from the different curves that optimum form of the energy

distribution perpendicular to the line of receivers is obtained only in the case

$$d=\frac{n-1}{n}\lambda.$$

In Figure 6 is shown the application of such a definitely spaced set of units to directional sending. The senders 1, 2, 3, 4 and 5, which may be of the oscillator type, may be arranged vertically upon the mast of a vessel and operated simultaneously. In this manner the maximum sound loop will be within the angular opening shown in the figure, which in the case of five senders is about 29°, and the intense sound vibration which otherwise is felt all over the vessel will be confined to a zone outside of that used by the passengers.

Figure 7 illustrates the grouping for obtaining a combination of directive effects. By using the proper combination of receivers directive effects can be obtained as shown in Figure 8^a, 8^b and 8^c.

Figures 9 and 10 show the application by which directive effect and screening may be obtained in cases where one set of apparatus are desired to be shielded or unaffected by the operation of another. In this case the receivers or senders *a* and *b* respectively may be arranged horizontally along the vessel in such a manner that the maximum loop is directive in the angle shown. Such being the case not only will most of the energy be directed towards the bottom but the second system *b*, when considering *a* the first system, will be outside the cone of great intensity so that no sound from *a* will reach *b*. This is advantageous in depth sounding since the greatest amount of energy possible will be directed towards the bottom while at the same time the receiving system may be shielded. If both *a* and *b* are directive, one receiving and the other sending, then the receiver *b* can be made directive for reception from the bottom in which case it will be very insensitive to the effect of the direct sound since sound received from the direction of the sender will arrive along the line of zero sensitivity. This is shown diagrammatically in Figure 9. By placing the receiver on one side of the vessel and the sender upon the other the additional screening from the vessel may be obtained.

Figures 11*a*, *b* and *c* show the application to binaural listening. Here the spacing should be equal to

$$\frac{(n-1)}{2n}$$

if compensation is introduced. If no compensation is introduced but the base merely rotated, the spacing need only be

$$\frac{(n-1)}{n}$$

in order to avoid an ambiguity by a double image. Figures 11*a*, *b* and *c* show the additional feature of using the central receivers for both the right and left base.

In Figure 11^a two receivers 3 and 4 are shown close together, 3 serving for the left base T_1 and 4 serving for the right base T_2. This is equivalent to having one reeciver serve in common for the right and left. Similarly there is no objection to having the bases overlap or to have a common center region serve for both the right and left base as shown in Figures 11*b* and 11*c*. In each of these cases the left base is connected to telephone T_1 and the right to T_2.

In order to produce a binaural image it is necessary of course to have the end receivers connected only to one ear, as shown in 11^b where 1 is connected only to T_1 and 6 to T_2.

Where compensation is to be introduced, as shown in Figure 12 where receivers 1, 2, 3 and 4 are connected to the left side of the compensator 20 and receivers 3, 4, 5 and 6 are connected to the right side of the compensator, it is necessary to space the receivers one half the distance apart they would otherwise be spaced. The spacing in this case is

$$\frac{n-1}{2n}$$

in order to avoid ambiguity of double images. This results from the fact that by compensation the apparent spacing between receivers can be doubled, since the amount of compensation to bring about a balance for any direction (the direction along the axis requiring the most compensation) requires a compensation equivalent to the spacing between the receivers or that the artificial spacing plus the natural spacing, equaling twice the natural spacing, requires the receivers to be placed just half the ordinary distance in order to avoid a double maximum.

Having now described our our invention we claim:—

1. A method of preventing objectionable vibrations in undesired regions in operation of sound transmitters which comprises spacing *n* said transmitters in a straight line perpendicular to the plane in which it is desired to prevent said vibration operating said transmitters at a definite frequency such that the spacing of said *n* transmitters satisfies the relation

$$\frac{n-1}{n}$$

times the wave length.

2. A method of reducing the base length in binaural reception which consists in spacing receiving units at proper distances from each other, using as the left base a plurality of units commencing from the left end of the base, using as the right base an equal number of units commencing from the right

base, said number of units being greater than half the whole number of units.

3. A system for propagating wave energy of a known wave length substantially in a plane and for receiving similarly propagated wave energy, substantially free from disturbance of energy propagated in other manner, comprising three or more operating units, n in number, spaced in a straight line perpendicular to the plane in which the wave is being propagated, and at a distance equal to

$$\frac{n-1}{n}$$

times the wave length of the transmitted or received energy.

4. In a system for receiving wave energy propagated in a plane substantially free from disturbance of energy propagated in other manners, three or more receiving units, n, in number, compensating means for retarding the wave energy received by the various receiving units, said receiving units being spaced in a straight line perpendicular to the plane in which the wave is being propagated, and at a distance such that the actual distance plus the equivalent distance of compensation is equal to

$$\frac{n-1}{n}$$

times the wave length.

5. In a system for the directive reception of sound waves comprising a plurality of receiving units spaced in a straight line the spacing between units being

$$\frac{n-1}{2n}$$

times the wave length of the sound to be received, compensating means associated with each of said units for retarding proportionally the sound received on said units respectively, said retardation in effect changing the orientation of said straight line.

6. In a system for the directive sending of sound waves comprising a plurality of sending units spaced in a straight line, the spacing between units being

$$\frac{n-1}{2n}$$

times the wave length of the sound to be sent, compensating means associated with each of said units respectively, said compensation in effect changing the orientation of said straight line.

In testimony whereof we affix our signatures.

WALTER HAHNEMANN.
HEINRICH HECHT,
BERNHARD NIELSEN.