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BY A. P. C.

K. MENGES
DEVICE FOR DIRECTED TRANSMISSION OR
RECEPTION OF WAVE ENERGY
Filed March 6, 1941

Serial No.
382,084

5 Sheets-Sheet 1

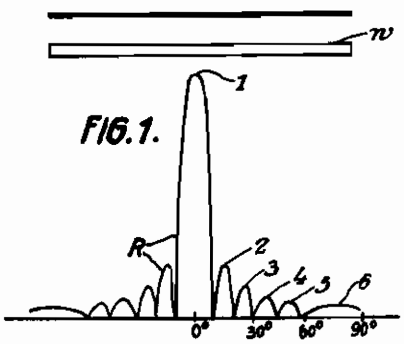

FIG. 1.

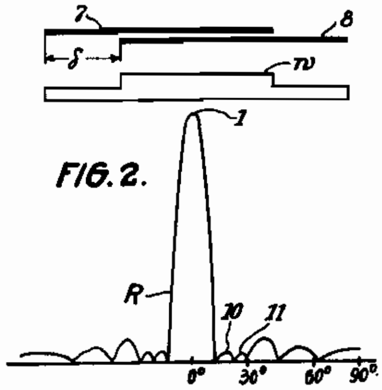

FIG. 2.

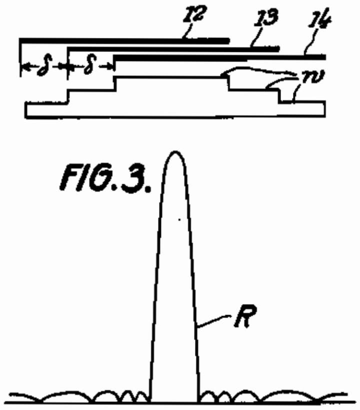

FIG. 3.

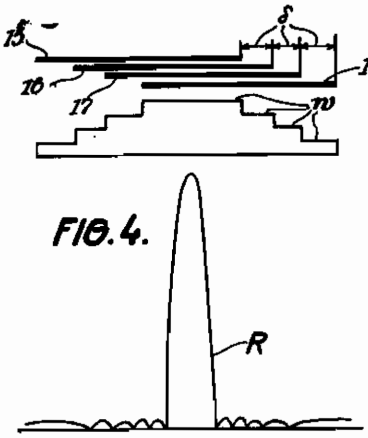

FIG. 4.

FIG. 5.

FIG. 6.

FIG. 7.

FIG. 8.

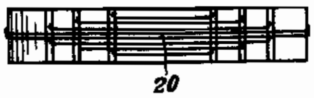

FIG. 9.

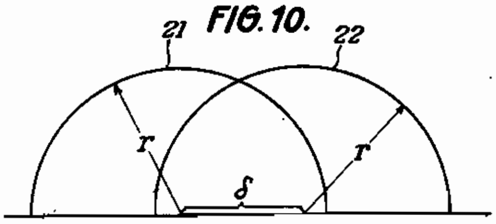

FIG. 10.

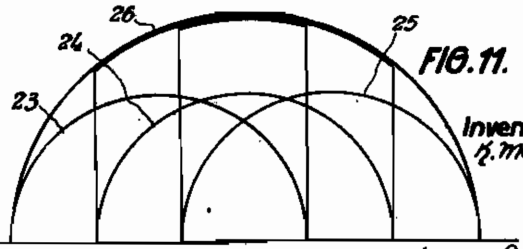

FIG. 11.

Inventor
K. Menges

By: Glascock Downing & Seebold
Attorneys.

K. MENGES
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FIG. 13.

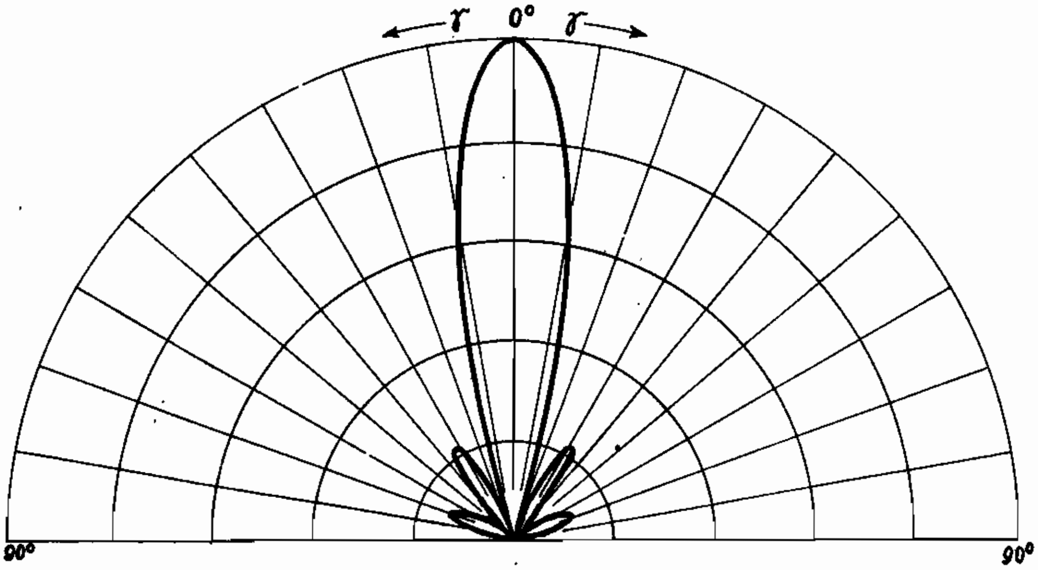
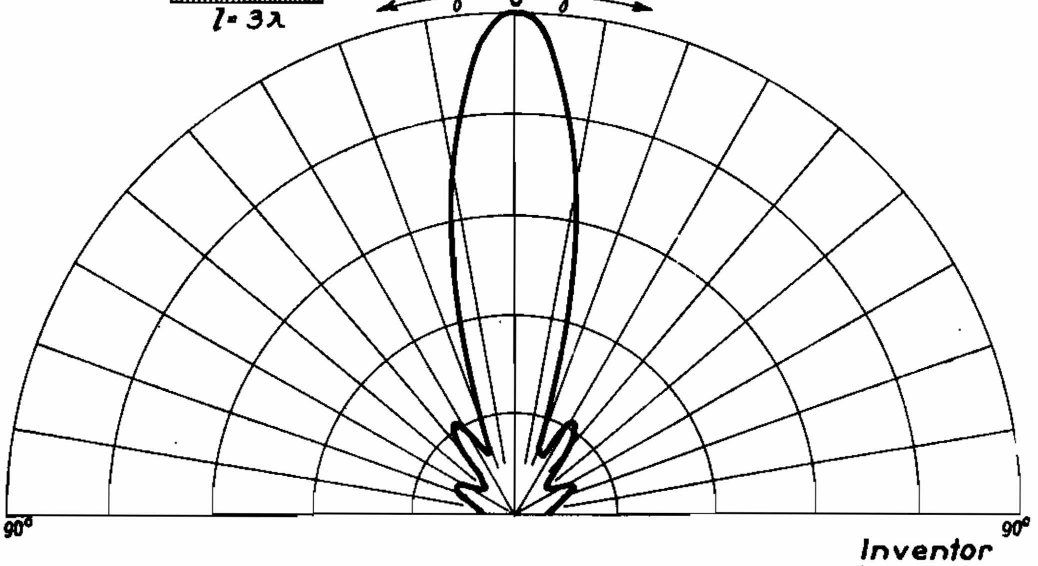


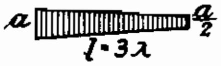
FIG. 12.

FIG. 15.



Inventor
K. Menges

FIG. 14.



By
Glascock Downing & Seebold
Attorneys.

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FIG. 17.

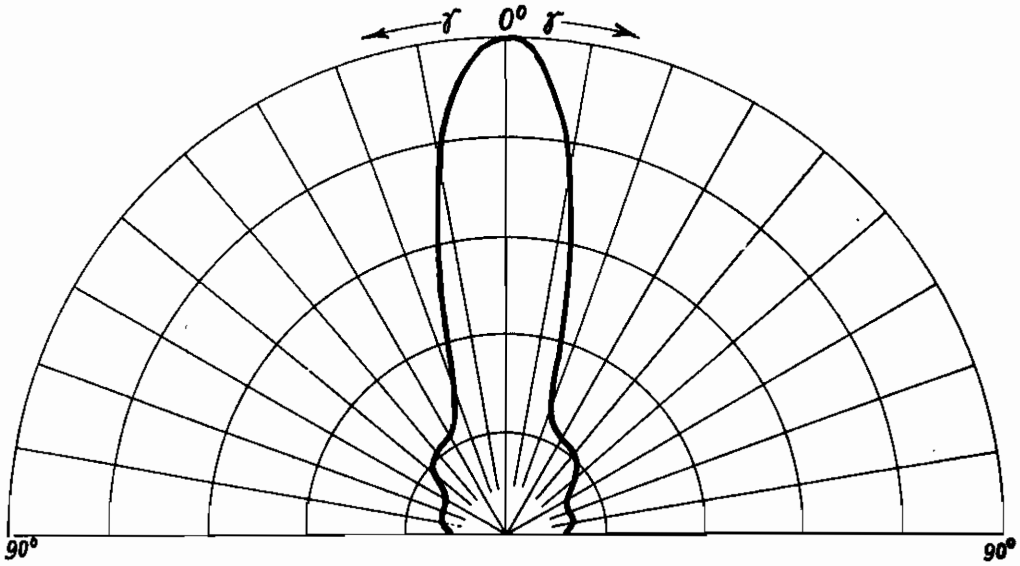

FIG. 16.

Inventor
K. Menges

By:
Glascock Downing & Seebold
Attorneys.

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FIG. 18.

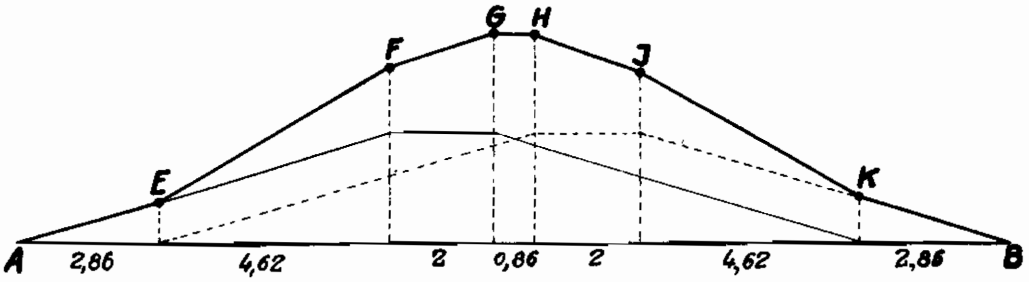
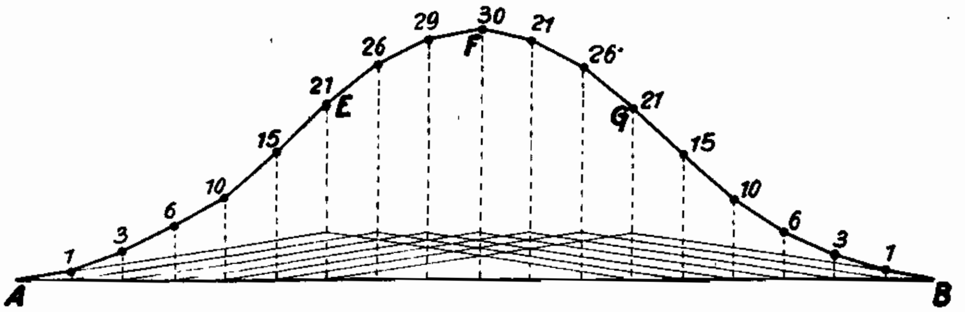


FIG. 19.



Inventor
K. Menges
By: Glascock Downing & Seebold
Attorneys

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K. MENGES

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FIG. 20.

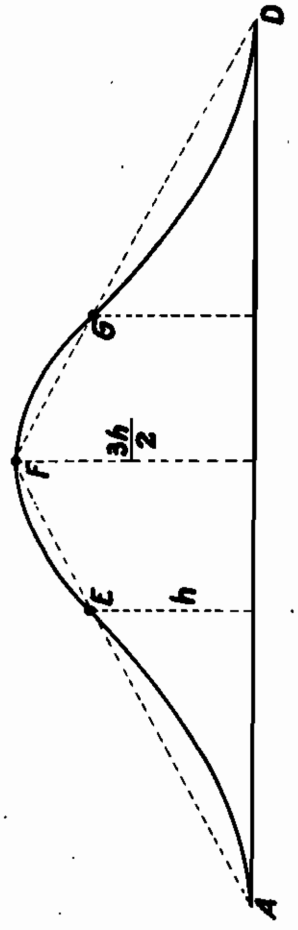
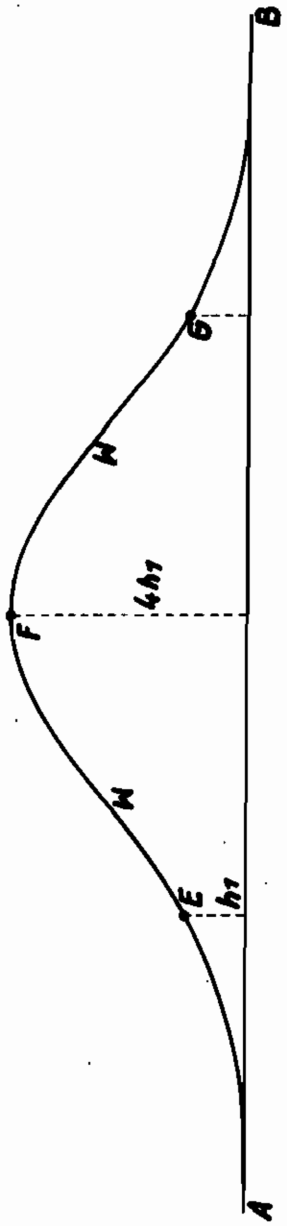


FIG. 21.



Inventor

K. Menges

By: Glascock Downing & Seebold

Attorneys.

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ALIEN PROPERTY CUSTODIAN

DEVICE FOR DIRECTED TRANSMISSION OR RECEPTION OF WAVE ENERGY

Karl Menges, Bremen, Germany; vested in the Alien Property Custodian

Application filed March 6, 1941

The invention relates to a device for directed transmission or reception of wave energy, particularly for transmitting and receiving sound waves. For this purpose, there are used oscillation bodies whose transmitting or receiving surface is sufficiently large in comparison with the wave lengths used. The action of these bodies depends on the directing characteristic showing the course of the received or transmitted amplitude in dependence of the direction. According to the receiving body and the range of frequencies chosen, the directing characteristics will show, apart from the principal maximum, more or less intense side maxima which may increase to the magnitude of the principal maximum. This will often cause great difficulties in sounding, especially the clearness is impaired by the side maxima and may even be lost if the side maxima reach the magnitude of the principal maximum.

Furthermore, if there are several oscillations of different intensities and arriving from different directions, it will easily occur that the principal maximum of the weak oscillations is hidden by the side maxima of the intense oscillations or it will be impossible to distinguish it.

It is known to depress the side maxima in a group of transmitters by the reduction of the absolute amounts of the currents in the single transmitters from the centre towards the ends of the base. In this case, however, the distance of the single transmitters was made greater than one half of the wave length. This is connected with the disadvantage that the dimensions will often be undesirably large, or that it will not be possible, with given spatial conditions, to obtain the necessary receiving or transmitting energy. Moreover, it is known to adjust the amplification of the individual received currents in a rectilinear group of receivers acting upon a common indicator so as to be so different that the degree of amplification will increase from the ends towards the centre of the base. But this method is only applicable in cases where the base is composed of single oscillators with separate electric current conductors, as only in such cases a differing adjustment of the degree of amplification along the base may be obtained.

Another disadvantage of the known devices or methods serving to depress the side maxima consists in the fact that they were only applicable to groups of single oscillators and that no instructions were given as to how the most favourable graduation of the oscillation amplitudes might be obtained or according to what rule this graduation should be effected.

In contradistinction to these known devices, the nature of the present invention consists in the fact that the base is charged continuously or quasi-continuously, and that the unequal amplitudes of the individual elements of the length of the base are produced by unequal conversions of the waves, arriving with equal amplitudes at all elements of the length of the base, into electric oscillations, or by unequal conversions of the electric energizing currents, arriving with equal amplitudes at all elements of the length of the base, into radiating oscillation energy. The most favourable graduation of the effectiveness of the base is obtained by forming the graduation according to a numerical proportion, which is found when several continuous bases are shifted with respect to each other by such an amount that the factor introduced in the directing characteristic by this shifting will be zero at the place where, without this factor, there would be a maximum in the directing characteristic.

The different intensities in the conversion of the energy along the base may be obtained in various manners. For example, in magneto-stricture oscillators for sound production, these different intensities are obtained by using, at different parts of the base, metal plates of different thickness for the construction of the oscillator or by providing different numbers of turns in the winding of the oscillator. The desired distribution of the sensitivity may also be effected by unequally distributing the material of the oscillator along the base. This method may likewise be applied to piezo-electric oscillators. In the case of magneto-stricture oscillators, the unequal distribution may be obtained by gaps or by inserting intermediate layers between the individual lamellas.

As has been found by calculations and experiments with continuous transmitting or receiving surfaces, a considerable improvement of the directing characteristic may be obtained by subdividing the base into a few sections only, in which the intensity of the conversion of energy remains uniform, whereas it varies in steps from one section to another. However, it is necessary to correctly dimension the lengths of the sections and the proportion of the intensity with which they partake in the conversion of energy. Therefore, the correct graduation represents an important part of the invention. A subdivision into three sections, viz. two end portions, each equal to about one quarter of the total length of the base, and a middle portion, equal to half the length of the base, will already be sufficient to make the most disturbing first side maximum vanish completely, if the two end sections of the base are operating with half the efficiency of the central section.

It is also possible to render harmless the zero points and the side maxima by an unsymmetrical distribution of the amplitude of oscillation over the length of the base, so as to decrease from the centre of the base towards one end only, but to increase towards the other end. Though, in this manner, the amplitude of oscillation will not be reduced in any transmitting or receiving direction, it will be possible to depress to any desired extent pronounced zero points and side maxima at any intensity of the principal maximum.

Several constructional examples of the subject of the invention are illustrated diagrammatically in the accompanying drawing, in which:

Fig. 1 shows a continuously charged base with a uniform effectiveness over the entire length of the base, as well as its directing characteristic in cartesian coordinates;

Figs. 2 to 4 each show a base with unequal effectivenesses over its length, as well as a diagram of the effectiveness, and the respective directing characteristic;

Figs. 5 to 9 show two magneto-structure oscillators in front and side views according to the directing characteristic of Fig. 4, the windings of the oscillator being merely indicated in Figs. 7 and 9;

Figs. 10 and 11 are diagrammatical illustrations of two or three combined semicircular bases;

Figs. 12 and 13 show the base and the directing characteristic as in Fig. 1, the directing characteristic being, however, shown in polar coordinates;

Figs. 14 to 17 show two unsymmetrical bases and the respective directing characteristics in polar coordinates; and

Figs. 18 to 21 show further constructional examples of the base.

The directing characteristic R of an oscillator according to Fig. 1, representing the course of the received or transmitted amplitudes in dependence of the direction, is obtained with a continuously charged base, the entire length of which has a uniform effectiveness w of the sound conversion of, for example, 41 cm. length at 22 kHz or 6.6 cm. wave length in water. As will be seen from the drawing, there are on both sides of the principal maximum **1** several side maxima **2**, **3**, **4**, **5**, **6**, whose amplitudes decrease with increasing distance of the direction from that of the principal maximum. The first side maximum **2** still amounts to about 22% of the principal maximum.

The directing characteristic of the oscillator according to Fig. 1 may be represented by the equation

$$R=\frac{\sin\left(\frac{\pi d}{\lambda}\sin\gamma\right)}{\frac{\pi d}{\lambda}\sin\gamma}$$

where d is the length of the straight base, λ the wave length employed, and γ the deviation of the direction from the direction of the principal maximum $(\gamma=0)$.

Imagining two continuous bases **7**, **8**, each of d cm. length, as diagrammatically illustrated in Fig. 2, combined into one base by longitudinal shifting them with respect to each other by the amount of δ, the directing characteristic of this arrangement will be

$$R=\frac{\sin\left(\frac{\pi d}{\lambda}\sin\gamma\right)}{\frac{\pi d}{\lambda}\sin\gamma}\cdot\cos\left(\frac{\pi\delta}{\lambda}\sin\gamma\right)$$

If, to abridge,

$$\frac{\pi d}{\lambda}\sin\gamma=\phi$$

then

$$R=\frac{\sin\phi}{\phi}\cdot\cos\frac{\delta}{d}\phi$$

The factor

$$\frac{\sin\phi}{\phi}$$

has its zero positions at $\varphi=\pi, 2\pi, 3\pi \ldots$, its first side maximum at $\varphi_1=4.494$ (somewhat before $3\pi/2$), amounting to 0.22, and the further maxima closely before $5\pi/2$, $7\pi/2$, . . . with decreasing amounts. If δ is chosen so that

$$\frac{\delta}{d}\phi_1=\frac{\pi}{2}$$

that is, if

$$\delta=\frac{\pi\cdot d}{2\cdot 4.494}=0.35d$$

then

$$\cos\frac{\delta\phi_1}{d}=0$$

and therefore $R=0$, that is, the first side maximum of

$$\frac{\sin\phi}{\phi}$$

is divided into two considerably smaller ones **10**, **11** amounting to 0.04. Similarly it is with the fourth, seventh, . . . maximum, whereas the two maxima, always being between, will be weakened but little.

In practice, the base, diagrammatically illustrated in Fig. 2, may be formed in various manners. In the first place, it is possible, as shown in Fig. 2, to connect two continuous bases with a uniform effectiveness over the entire length d, the centres being shifted with respect to each other by the amount of δ. But with the same result, a uniform base of the length of $(d+\delta)$ and a likewise uniform base of the length of $(d-\delta)$ may be arranged and connected with equal centres. Moreover, it is possible, instead of combining two separate bases with uniform effectivenesses, to form the base at once as a unit with a correspondingly variable effectiveness of the sound conversion over its length. The variable effectiveness of the sound conversion may not only be effected by a graded widening of the base, but also by other means, for example in magneto-stricture oscillators, by using correspondingly thinner metal plates in the centre than at the ends, thus distributing the losses over the base in the unequal manner provided by the invention. It is also possible to let the turns increase towards the centre of the base in the effective proportion, or to unequally distribute the effective oscillating material over the base, for example by providing gaps or ineffective intermediate layers at the places where the extent of the sound conversion is to be reduced. A variation of the cross section over the length of the base with uniform width may be obtained by composing the oscillator of lamellas of different or variable areas arranged so as to leave openings, or to provide interruptions at the edge.

If only two steps are provided, as in Fig. 2, it is of course also possible to effectively suppress any other side maximum if the amount of δ is chosen accordingly. In order to be able to simultaneously suppress several side maxima, it is necessary to provide more than two steps in the graduation of the effectiveness.

Three steps 12, 13, 14, as shown in Fig. 3, will give a directing characteristic of

$$R=\frac{\sin\phi}{\phi}\cdot\frac{\sin 3\frac{\delta}{d}\phi}{3\sin\left(\frac{\delta\phi}{d}\right)}$$

By making $\delta=0.23d$ (about $\frac{2}{9}d$), the three first side maxima will be pressed down from

$$\frac{\sin\phi}{\phi}$$

to the amount of 0.04, as will be seen from the directing characteristic in Fig. 3, whereas the fourth side maximum will retain its amount of 0.08.

Finally, Fig. 4 shows the diagram of a base with four steps 15, 16, 17, 18, which is obtained by combining two bases, strengthened in the centres according to Fig. 2, with a distance of

$$\delta=\frac{d}{5}$$

between the centres. In a further repetition of the method, the new distance between the centres would have to be made $d/7$, resulting in a directing characteristic of

$$R=\frac{\sin\phi}{\phi}\cdot\cos 0.35\,\phi.\cos\frac{1}{5}\phi.\cos\frac{1}{7}\phi$$

By progressively arranging additional steps in the graduation of the effectiveness, the side maxima remaining in each case may be further divided and weakened. The increase in the graduation of the effectiveness from the ends towards the centre of the base will then approach a continual curve. The steps required in the graduation for suppressing the side maxima may also be ascertained by a different mathematical or experimental method, for example by arranging two or more bases of different lengths or also of different effectivenesses so as to have equal centres and by choosing the numerical proportions so that the first or any others of the disturbing side maxima will be suppressed.

Thus, for example, as illustrated in Fig. 18, there may be combined two bases with trapezoidal distribution of the amplitudes, the length proportions of the base lines and the distance between the trapezoids being determined so that the distribution of the amplitudes given by the edge line A, E, F, G, H, I, K, B will lead to the most effective weakening of the side maxima.

It is also possible, as shown in Fig. 19, that bases with triangular distribution of amplitudes, shifted with respect to each other, with equal distances between the centres, are superposed so as to form one total base, whose distribution of amplitudes is determined by the line A, E, F, G, D. An increase in the number of triangles with simultaneously decreasing distances between the centres will lead to the continual distribution of amplitudes according to the line A, E, F, G, D of Fig. 20, which is composed of three parabolic curves (parabolas of the second degree). By applying to this form the same method as for the triangles, a distribution of amplitudes A, E, W, F, W, G, D, as shown in Fig. 21, is obtained which is composed of parabolas of the third degree.

By successively proceeding in this manner, which may be continued as desired, the side maxima will decrease in geometrical progression and may be depressed below any amount. In the distribution of amplitudes according to Fig. 21, the greatest of the remaining side maxima only amounts to ½% of the principal maximum.

For practical use, the first form of construction (Fig. 2), in which the ends of the base operate over one quarter of the total length, with half the effectiveness of the centre, will give rather good results, and the graduation in four steps will already result in a characteristic practically free from side maxima. Owing to the smaller difference in the effectiveness, these arrangements are particularly easy to realize in technical construction.

Figs. 5 to 7 show a magneto-stricture oscillator with graduation in the width in order to obtain a directing characteristic according to Fig. 4.

A particularly simple method of grading the effectiveness of the sound conversion in the manner prescribed by the invention consists in covering the effective transmitting or receiving surface of the normally constructed oscillating body, for example, with crepe rubber and thereby preventing it from converting the sound.

As indicated by dot and dash lines in Fig. 5, the oscillator itself may then be of uniform width and may assume the characteristic of an oscillator with a graduation in four steps, for example, by sticking on pieces of crepe rubber in the shape of the pieces 19. Such a method may also be easily carried out afterwards in ready installations. If, in this case, the covered portions of the oscillator, owing to coupling, should still be partly engaged in converting the sound, this may be prevented by correspondingly enlarging the pieces 19.

Figs. 8 and 9 show a magneto-stricture oscillator, in which the steps in the graduation of the effectiveness are produced by the type of the winding 20, in varying the number of turns in the individual sections.

The invention may also be applied to not rectilinear bases, although the suppression of the side maxima will then generally not be obtained equally well in all directions, if the curvature should entirely or partly coincide with the sounding plane or with the plane of the directing characteristic.

In particular, there may be combined a number of continuously or quasi-continuously charged circular lines in the same plane, in which case the distance between the centres may be chosen so that, for plane E, which is perpendicular to the circular surfaces, the directing characteristic will be nearly free from the side maxima. In the case of two circles 21, 22 with the radius r and the distance δ between the centres (Fig. 10), the directing characteristic in the plane E will be

$$R=J_0(\phi).\cos\left(\frac{\delta}{2r}\phi\right)$$

where J_0 is the Bessel function, and where, to abridge,

$$\frac{2\pi r}{\lambda}\sin\gamma=\phi$$

$J_0(\varphi)$ will reach its first side maximum amounting to 0.4 of the principal maximum at $\varphi_1=3.83$. This side maximum is divided by the factor

$$\cos\left(\frac{\delta}{2r}\phi\right)$$

into two maxima amounting to about 0.1, when making

$$\frac{\delta}{2r}\phi_1=\frac{\pi}{2}\text{ or }\delta=0.82r.$$

The second side maximum amounting to 0.3 at $\varphi=7$ will be but slightly weakened. In order to suppress this also, two pairs of circles with a distance between the centres amounting to

$$\delta=\frac{\pi\cdot 2r}{\pi\cdot 2.7}=0.45r$$

may be combined, the directing characteristic being

$$R=J_0(\phi).\cos(0.41\phi).\cos(0.225\phi)$$

It is also possible to at once combine three equal circles **23**, **24**, **25** (Fig. 11) having the distance δ between the centres, in which case there will result for the plane E a directing characteristic of

$$R=J_0\left(\frac{2\pi}{\lambda}\sin\gamma\right)\cdot\frac{\sin\left(\frac{3\pi\delta}{2}\sin\gamma\right)}{3\sin\left(\frac{\pi\delta}{\lambda}\sin\gamma\right)}=J_0(\phi)\frac{\sin\left(\frac{3\delta}{2r}\phi\right)}{3\sin\left(\frac{\delta}{2r}\phi\right)}$$

If

$$\frac{3\delta}{2r}\cdot 3.83=\pi\text{ or }\delta=\frac{\pi\cdot 2r}{3\cdot 3.83}=0.55r$$

then

$$R(\phi_1)=0$$

and generally

$$R=J_0(\phi)\frac{\sin 0.82\phi}{3\sin 0.27\phi}$$

Thereby the sound side maximum is pressed down from 0.3 to about 0.05.

The resulting characteristics are quite similar to those illustrated in Figs. 1 to 4 for straight bases.

The same effects are obtained if semicircles are substituted for the circles and if the characteristic is taken in the plane E (Fig. 10). In this case, those group listening installations are approached, in which the receivers are arranged in semicircular arcs on the ship's wall. Therefore, the side maxima are overcome by arranging, for example, three arcs, instead of one, with a distance between the centres amounting to 0.55r according to the above calculation, or, which is easier in technical construction, by using one arc **26** graded in such a manner that, in the horizontal projection, the same distribution of the effectiveness will be obtained as in the case of several arcs. The arcs being, in practice, about semicircular and lying approximately in a plane inclined at, for example less than 60° with respect to the horizontal plane of observation, it will be possible to approximately obtain the calculated effect for the ideal case.

The directing characteristic illustrated in Fig. 13 is based upon an oscillator according to Fig. 12, whose transmitting or receiving surface is shaped like an rectangle having a length of $l=3\lambda$, where λ indicates the employed wave length of the sound or of any other wave energy to be transmitted. The directing characteristic shows one principal maximum, every two side maxima having a pronounced zero point between them. It is mathematically represented by the equation

$$R=f(\phi)=\frac{\sin\phi}{\phi}$$

where

$$\phi=\frac{\pi.l}{\lambda}\cdot\sin\gamma$$

and γ is the angular deviation from the principal maximum.

Fig. 15 shows the directing characteristic of an unsymmetrical oscillator arrangement, in a first form of construction shown in Fig. 14. The transmitting surface is constructed so that its width from one end to the other decreases from the amount of a to the amount of $a/2$. As will be seen by comparing this with the directing characteristic of the uniform oscillator arrangement according to Fig. 1, the side maxima have the same magnitude and position as in the case of an equally long base with uniform amplitude or with uniform width of the oscillator surface. But the minima are the flatter and the nearer to the side maxima, the more the width of the oscillator surface decreases from one end to the other.

If the width of the oscillator surface decreases to zero, as illustrated in Fig. 16, then the minima will combine, as in Fig. 17, with the side maxima to form terrace points. Therefore, it is possible to more or less remove the zero points and still to reach any required sounding accuracy by a corresponding length of the base. In the limit case, there are no side maxima and no zero points or minima at all. The directing characteristic decreases monotonically from the principal maximum with any sounding accuracy.

The directing characteristics according to Figs. 15 and 17 are mathematically represented by the equations

$$R=\sqrt{f(\phi)^2+\left(\frac{1}{3}f^1(\phi)\right)^2}$$

or

$$R=\sqrt{f(\phi)^2+f^1(\phi)^2}$$

Of course, the invention is not restricted to the examples illustrated, various modifications and other forms of construction being possible. Especially there may be used piezo-electric instead of magneto-stricture oscillators or simple electromagnetic oscillators. The numerical values given for the grading of the base also need not be accurately adhered to, although they will afford the most effective suppression of the side maxima. The steps in the graduation may more or less continually merge into one another.

While the above mathematical calculation assumes a base with a continuous transmitting or receiving surface, the practical results may also be obtained with a quasi-continuous base, viz. with a base composed of single oscillators in a sufficient number and of an adequate density with respect to the wave length employed. In this case, the group will advantageously be constructed so that the most favourable grading calculated for the continuous charging of the base may be carried out as approximately as possible. In the simplest case, viz. in the arrangement with two steps, there will be provided according to the invention 8, 12, 16, etc. oscillators. In the arrangement with three steps, it is preferably to provide at least 13 oscillators.

The advantages of the invention are not only obtained when using one single frequency, but also for all frequencies at the same time, which is important in acoustical sounding, as long as the quasi-continuous charging exists with respect to all wave lengths employed. The invention is of special importance when using objective indicating methods, because in this case the side maxima will be more disturbing than when listening with the ear.

The invention may not only be applied to the transmission of acoustical energy, but also to other kinds of wave energy, for example to directed electromagnetic or optical radiation. For example in optics, instead of employing the usual slots with sharp edges, the brightness may be graded from the centre of the slot towards the edge so as to suppress the secondary spectra.

In the case of bases having a pronounced directing effect in different planes, the grading may be similarly effected in different directions, for example in case of a base with a circular surface in all directions from the periphery towards the centre.

The grading of continuous or quasi-continuous bases according to the invention may also be obtained, if the electric system of the base consists of electric circuits, separate for each section and closed in themselves, provided with a resistance and with adjustable taps. Preferably, the resistances and the taps will be constructed so as to form a unit with the base, that is, they will be accommodated in the housing of the base and will be connected in the common electric circuit. In applying the invention to a group, the grading may also be obtained by regulating the electric current supply of the single oscillators.

In order to prevent the individual sections of a continuously charged base from being influenced to an undesired extent by coupling, there may be produced a mutual uncoupling of the steps by means of separating joints or the like. In the case of laminated magneto-stricture oscillators, an uncoupling may be obtained by arranging the lamellas so as to cross the longitudinal direction of the base.

There may also be provided an arrangement for selectively switching in the grading, especially if switching is required in any case, in order to pass from a smaller to a larger base. In group listening installations, the grading may be variable with the sounding angle, in order to obtain an equally or approximately equally good suppression of the side maxima in every sounding direction.

Furthermore, the unsymmetrical distribution along the base may be effected in various manners. Thus, the unequal distribution of the amplitudes may be produced by switching means (resistances, amplifiers, and the like). The group or arrangement of oscillators may have the shape of a uniformly charged surface, whose width decreases from one end to the other end of the arrangement.

The shape of the effective transmitting or receiving surface may be obtained by means of screens.

It is also not necessary to let the amplitudes decrease over the length of the base according to a linear function. Just as well the decrease may follow any other rule. The invention may also be applied to oscillator arrangements with quasi-continuous charging.

KARL MENGES.