April 30, 1940. **W. DÄLLENBACH** 2,199,045

ELECTROMAGNETIC RESONATOR

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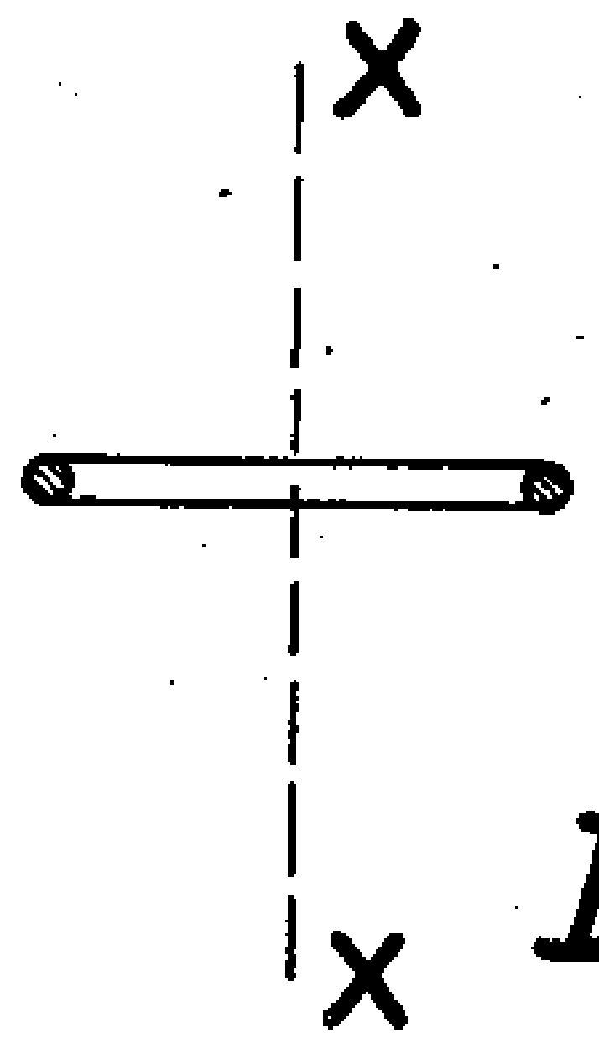

Fig. 1ª

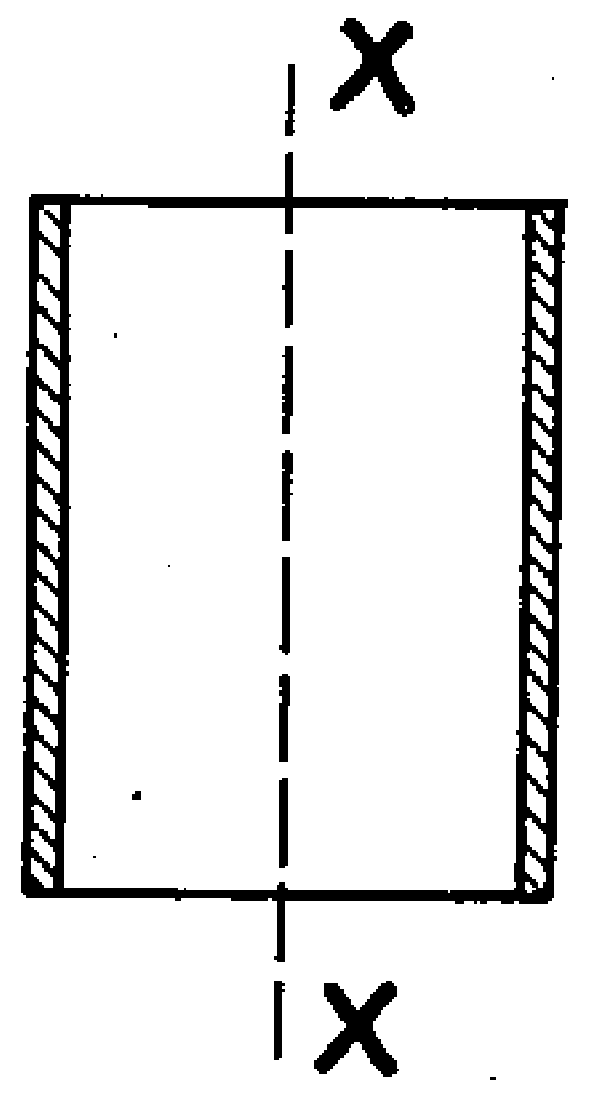

Fig. 2ª

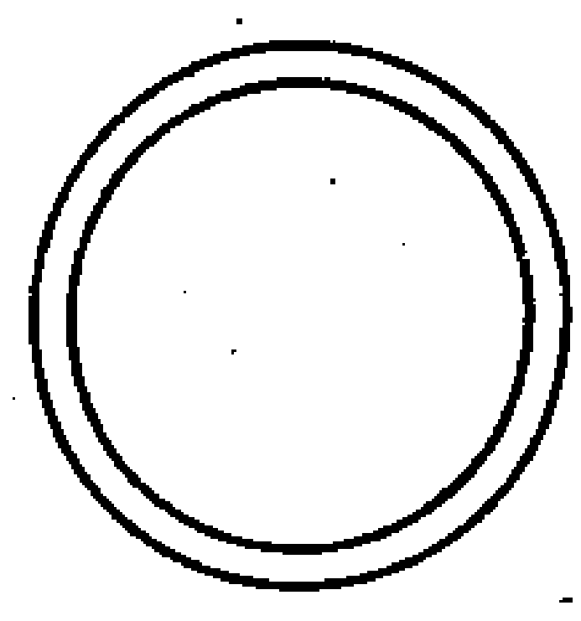

Fig. 1

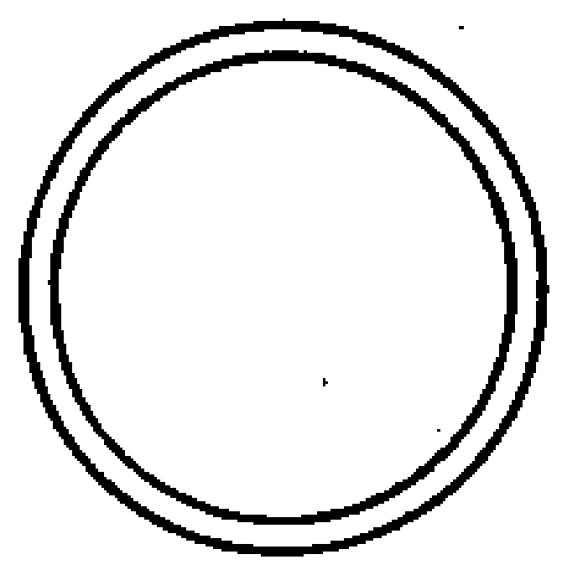

Fig. 2

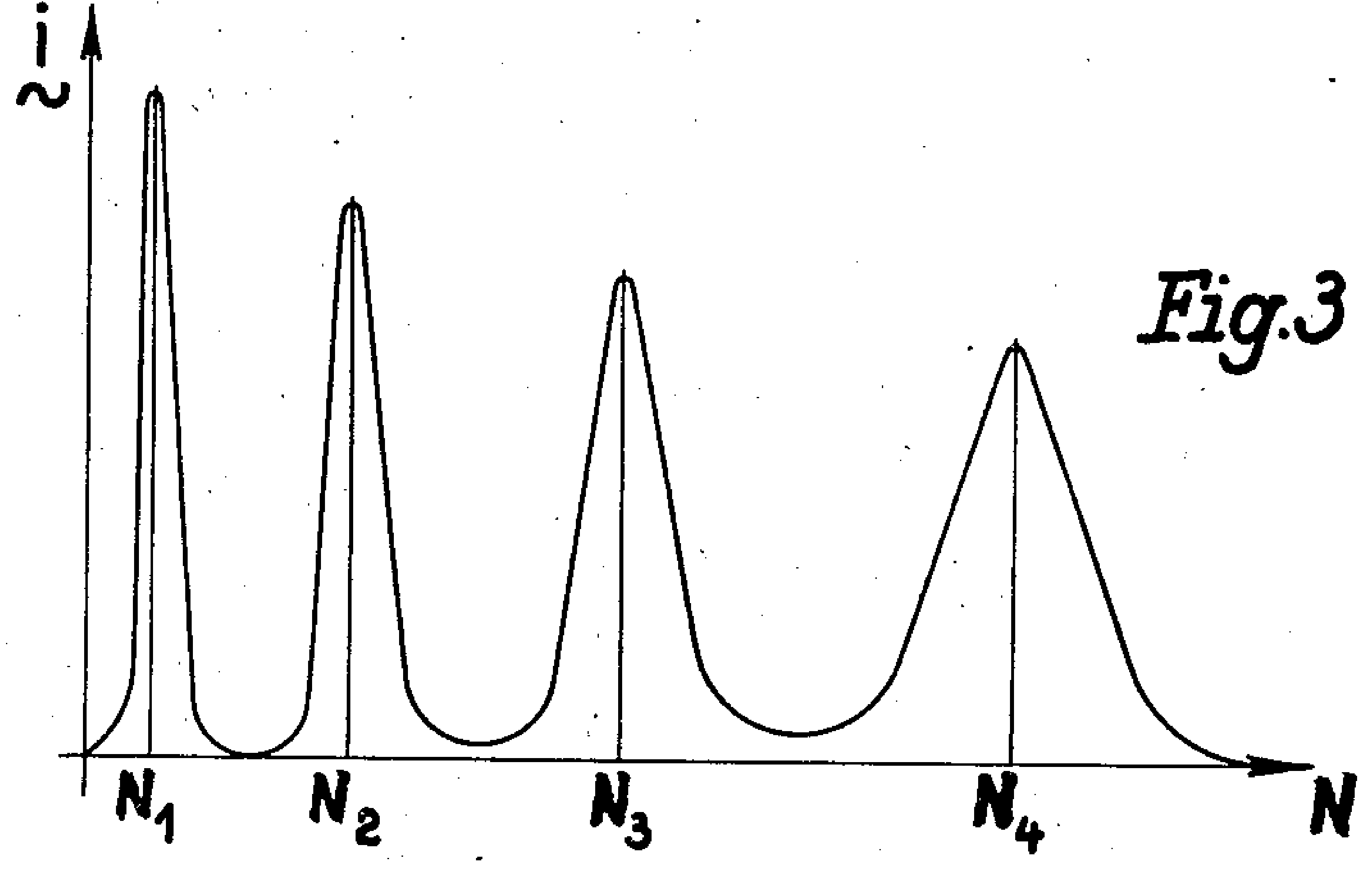

Fig. 3

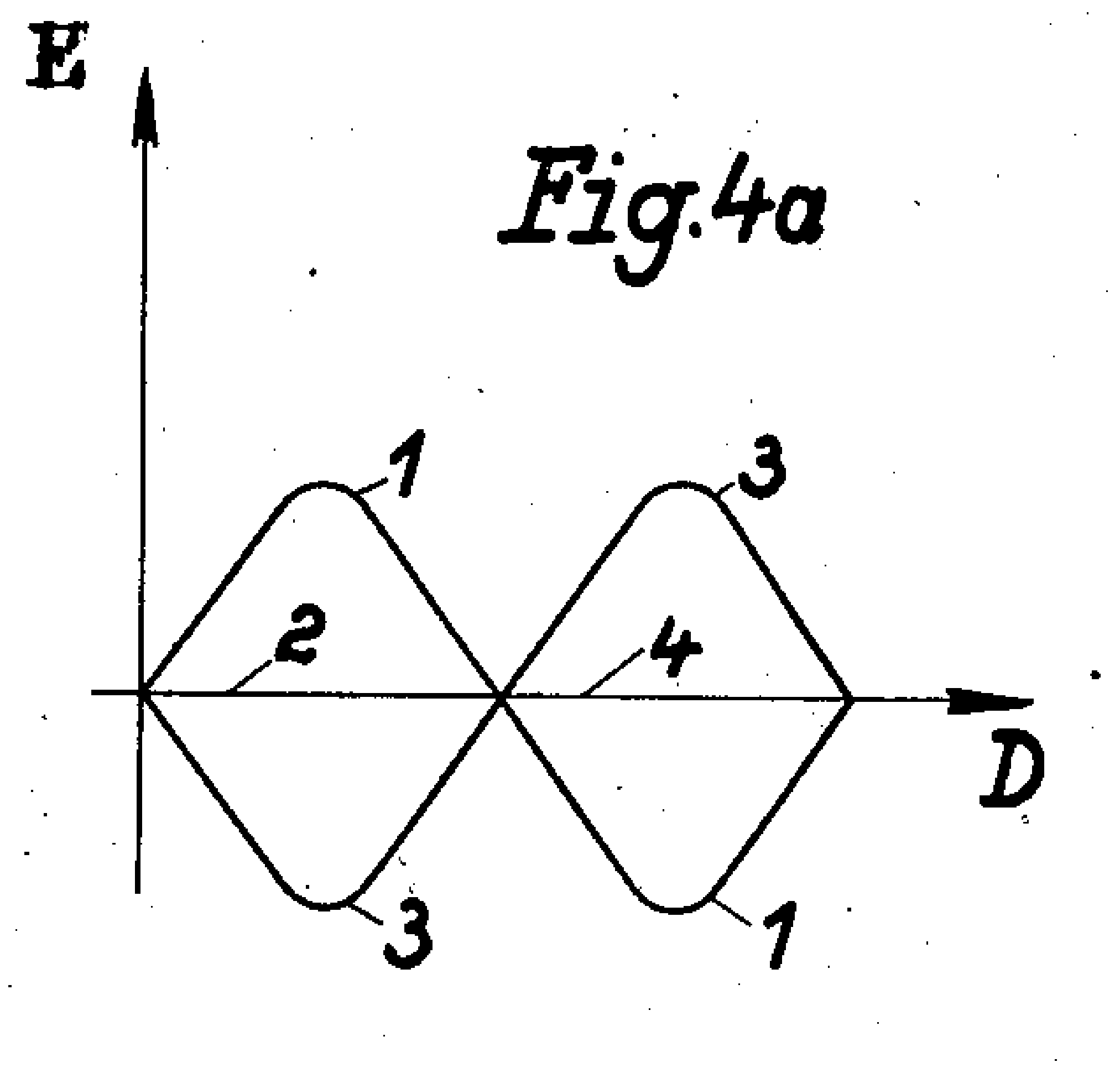

Fig. 4a

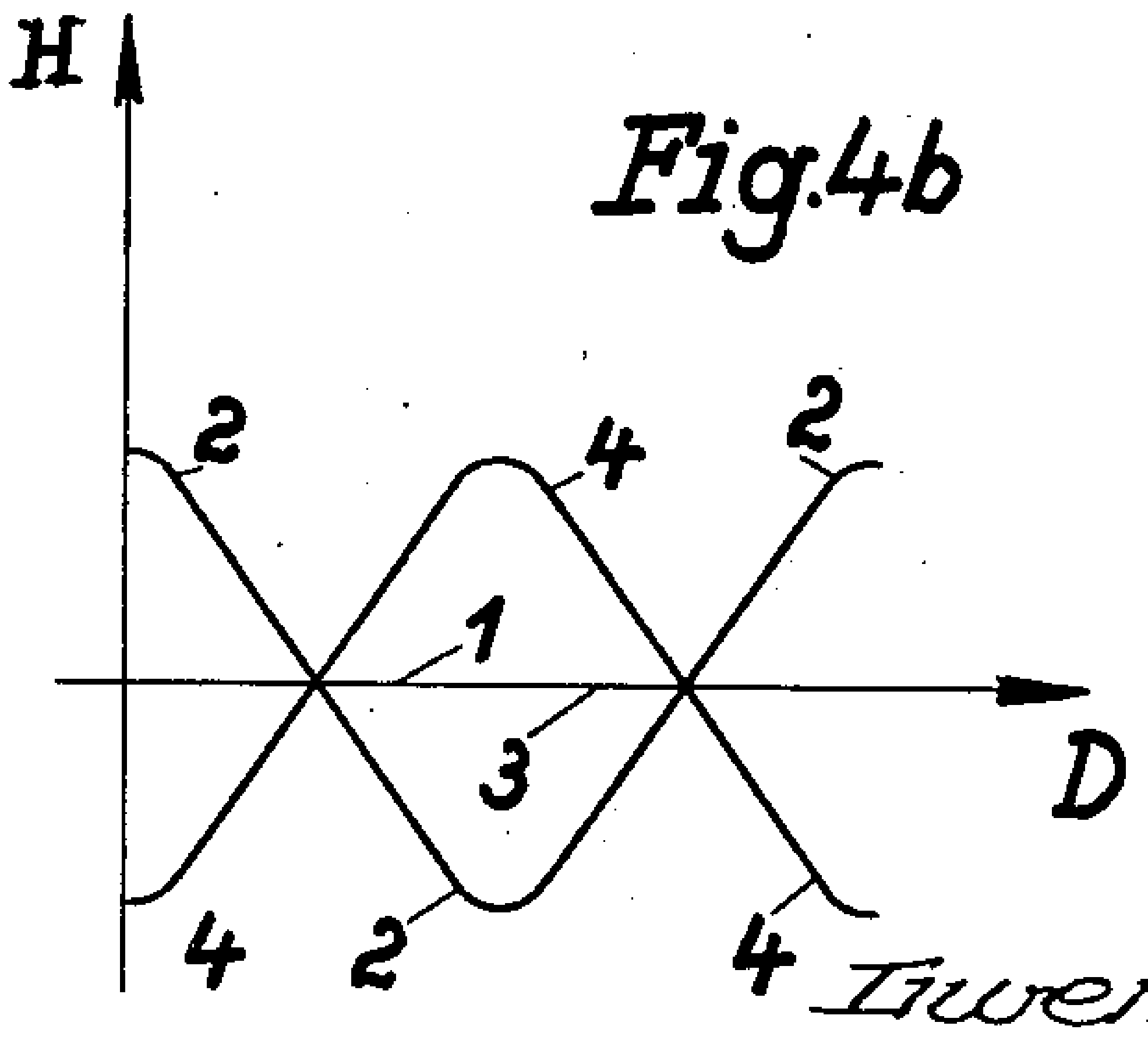

Fig. 4b

Inventor
Walter Dallenbach
By
Atty.

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Fig.5

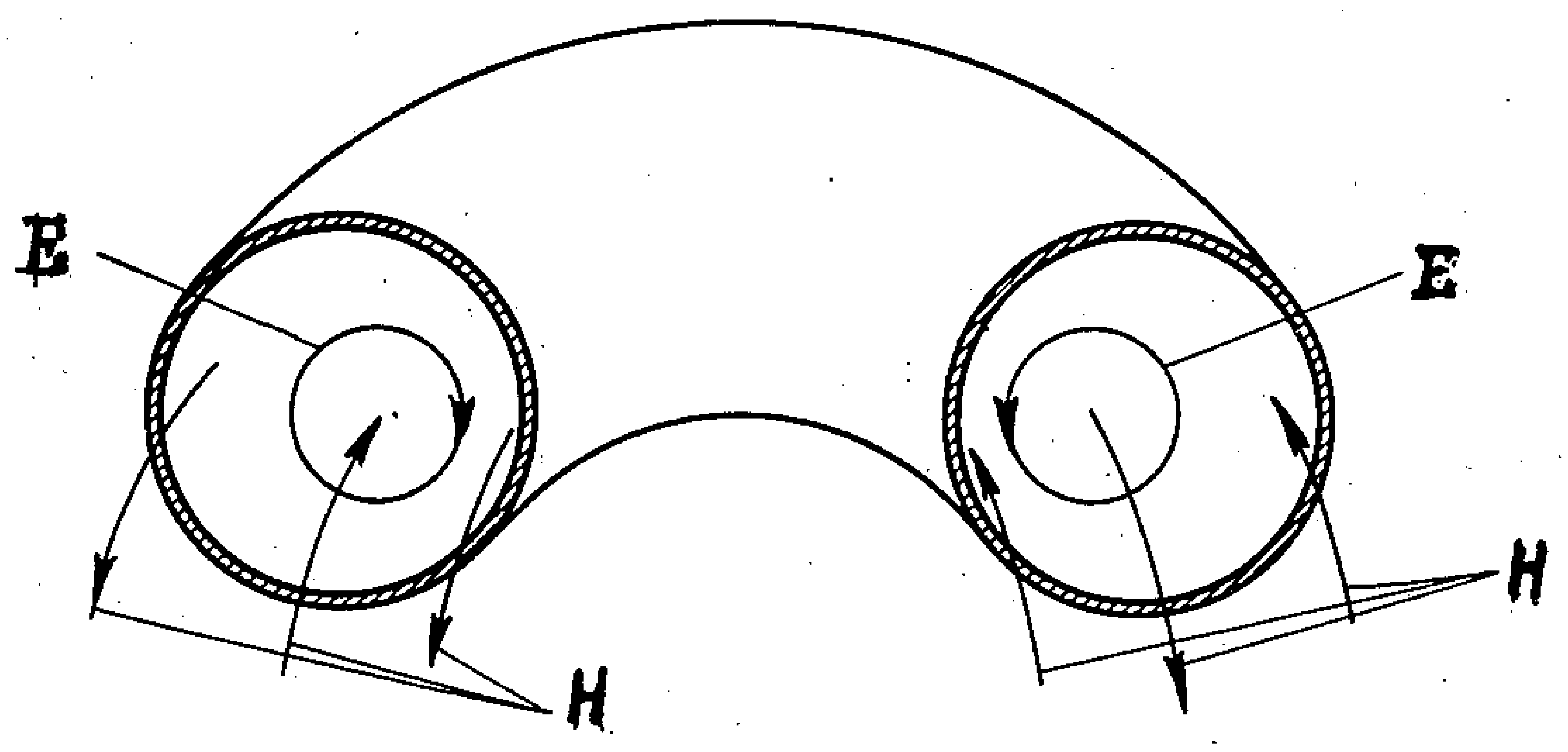
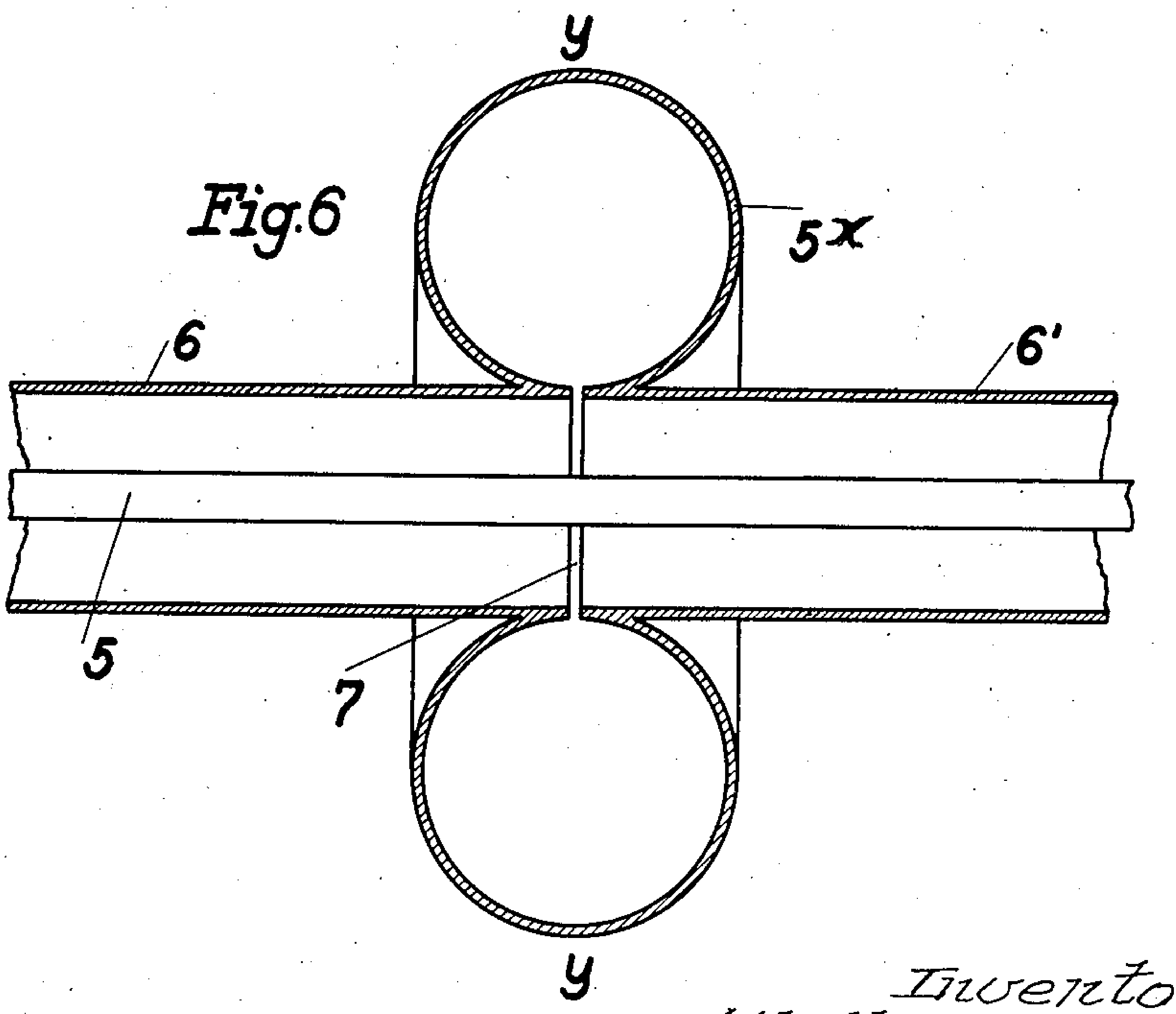


Fig.6



Inventor
Walter Dallenbach

by
Atty.

Patented Apr. 30, 1940 **2,199,045**

UNITED STATES PATENT OFFICE

2,199,045

ELECTROMAGNETIC RESONATOR

Walter Dällenbach, Berlin-Charlottenburg, Germany, assignor to Julius Pintsch Kommanditgesellschaft, Berlin, Germany

Application January 29, 1937, Serial No. 123,077
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8 Claims. (Cl. 178—44)

This invention relates to an electromagnetic resonator.

It is known to obtain an electromagnetic resonator by connecting the plates of a condenser of C capacity to the ends of a coil of the self-induction L. The period of oscillation of such a resonator follows from the relation

$$T=2\pi.\sqrt{L.C}$$

For short waves, preferably decimeter and centimeter waves, electromagnetic resonators are further known which consists of open or closed circuits with capacity and self-induction uniformly distributed over the conductors.

It has been found, however, that there is still another type of electromagnetic resonator which, compared with the known kinds, affords certain advantages and is particularly well suited for short waves, especially decimeter and centimeter waves.

The invention proposes to provide an electromagnetic resonator, wherein an essential part of the electric field co-determining natural frequency consists of an electric eddy field, especially one with closed electric eddy lines.

The invention is illustrated in the accompanying drawings, in which:

Figure 1 shows in plan one simple form of resonator of the present invention, Figure 1*a* is a section of the same.

Figure 2 shows in vertical section another simple form of the resonator of the invention, Figure 2*a* is a plan of the same.

Figure 3 is a diagrammatic view representing indications relative to the magnitude of the current amplitudes of a resonator of the present invention dependent upon the frequency N.

Figure 4*a* and Figure 4*b* illustrate diagrammatically the intensity course of the electric and magnetic field in the field space of the resonators shown in Figures 1 and 2, Figures 4*a* and 4*b* being at right angles to each other.

Figure 5 is a perspective view of a portion of another form of resonator.

Figure 6 is a section through the resonator of which Figure 5 indicates a part.

The invention will be explained by first referring to Figs. 1 to 4*b*.

Figure 1 shows in plan and elevation a metal ring and Fig. 2, a metal cylinder. Assumed that the metal ring or cylinder is cut open at one point and the cut surfaces are fed with alternating current, a magnetic dipole having the magnetic axis X—X will be produced. If the dimensions of the ring are small relative to the wavelength of the oscillation used in excitation, the entire area of the ring will be permeated by an alternating magnetic field which on the whole inner surface of the ring has the same sign. In case of higher frequencies, there will be perceptible merely a non-uniform distribution of current on the conductor by the skin effect, the current flowing chiefly on the surface of the ring or cylinder facing the axis. At further increase of the frequency of the alternating current one will be surprised at reaching a sphere where the current amplitudes on the ring attain a maximum and the ring discloses therefore resonance properties. If this maximum, as indicated in Fig. 3, is attained at a frequency N_1, further frequency multiplication will yield additional maxima N_2, N_3, N_4 . . . , which apparently are harmonic frequencies with respect to the fundamental frequency N_1. This behavior is all the more surprising as this resonant circuit does not show at first a capacity required for bringing about resonance. The resonance phenomena appear also if the wire circuit or cylinder is fully closed and, for instance, inductively coupled with the exciting field or excited by a free electromagnetic wave.

Closer examination has shown that in the resonator concerned the electric field co-determining natural frequency consists to an essential degree of an electric eddy field, the field lines of which extend substantially vertically to the magnetic field lines and coaxially preferably within the wire circuit or cylinder. This eddy field is therefore of decisive importance for the appearance of resonance. Detailed investigation has disclosed the fact that a periodic change of the energy of this electric eddy field and the magnetic field energy is effected, similarly to the known electromagnetic resonators, in which the electric field lines are open and terminate at electric charges on the conductors used for forming the resonators. The new resonator has therefore nothing to do with the known phenomenon of oscillation of closed circuits, where potential nodes and loops appear on the conductor and the electric field lines extend from one part of the conductor to another one.

The course of intensity of the electric and magnetic field in the field space of the resonators shown in Figs. 1 and 2 is represented by the curves of Figs. 4*a* and 4*b*. The curves of Fig. 4*a* show the course of intensity of the electric field extending in the plan and those of Fig. 4*b* that of the magnetic field shown in elevation and extending beyond the diameter of the annular conductors. The time moment **1** is characterized by the fact that the total energy of the resonator is accumulated within the annular conductors in the form of an electric eddy field. As these whirls are concentric with the annular conductors and at the surface of the conductors the limiting condition must be met that no tangential component field exists there, the intensity of the electric field at both ends of the diameter will be zero. A second zero point is in the center where the field changes direction. The electric eddy field discloses therefore the wavy course indicated by the curve **1** in Fig. 4*a*. The current on the conductor at this moment is zero. As Fig. 4*b* indicates, the energy of the magnetic field is therefore also zero.

The time moment later to the extent of T/4 shows a considerably different condition. The energy of the electric eddy field is zero, and in Fig. 4*a* the curve **2** coincides with the axis of abscissae. The magnetic field has its maximum, and the course of intensity of the magnetic field is shown by the curve **2** of Fig. 4*b*. This curve indicates that the magnetic field has on the surface of the conductor a maximum which towards the center decreases to zero and at the center itself discloses a minimum. This distribution of intensity positively results from the fact that inside and outside the vanishing electric eddy field magnetic whirling fields of opposite signs develop. Magnetic flux in one direction has the same magnitude as that in the other direction, due to the freedom from sources of the electromagnetic field. The integral of the magnetic flux must therefore disappear.

The magnetic field shows therefore not a homogeneous course within the conductors, but two magnetic fields of opposite direction are concentrically disposed within each other.

In the time moment later to the extent of T/4 a condition has arisen represented by the curves **3**. The total energy is accumulated again in the form of an electric eddy field the direction of which is, however, opposed to that of the eddy field at the time moment **1**. The magnetic field is zero again. The time moment later to the extent of T/4 is represented by the curves **4**. The intensity of the electric eddy field is therefore zero again and that of the magnetic whirling field a maximum, the fields having the opposite direction to that at the former time moment. At the excitation of the harmonic oscillation similar phenomena showing a correspondingly larger number of nodes and loops of the electric and magnetic fields arise.

The resonator shown in Figs. 1 and 2 further suffers from the drawback that it discloses, besides this electromagnetic eddy field, a radiation field which imparts to it a certain amount of damping. To attain a resonator with very little self-damping the invention proposes to construct such an electromagnetic resonator in the form of a hollow space surrounded on all sides by well conducting walls. Such a cavity formed as hollow torus is shown for instance in section in Fig. 5.

If the inner space of this hollow body is subjected to natural oscillation in the manner described, an alternating electromagnetic field will be produced that is free from radiation. As indicated in the drawing by the arrows E and H, the fields are totally closed, the field for the time moments **1** and **3** being an electric eddy field extending in hoselike fashion within the hollow torus, whilst the fields for the time moments **2** and **4** are concentric alternating magnetic fields surrounding the torus like rings. The only damping losses disclosed by this resonator are due to the only finite conductivity of the inner surface of the hollow body. If the resonator is to be made quite undamped, a hollow body having a highly conducting inner surface provided for instance with a copper or silver coating may preferably be employed, the coating receiving preferably a high polish. Self-damping may further be reduced by cooling the hollow body to a low temperature.

The toruslike hollow space may further oscillate in such manner that the current paths extend vertically to those hitherto observed. The resonator produced will then be similar to the one shown in Fig. 5, except that the electric and magnetic lines of force exchange their rôles.

Instead of this toruslike hollow space other hollow spaces may be used of course, such as a cavity formed by two toruslike bodies arranged within one another and insulated relative to each other. Furthermore, a hollow cylinder, a hollow sphere, or the space between two cylinders or spheres arranged within one another may for example be excited to natural oscillation in similar manner. The same applies to all hollow bodies which can be obtained by continuous deformation of the forms mentioned. For example, an ellipsoid is equivalent to a sphere and can be excited to natural oscillation in similar manner as a hollow sphere.

Moreover, the relations between the wavelength produced of the resonator and the dimensions of the hollow bodies limiting the resonator can be calculated, though in difficult cases only by means of simplified assumptions. For a cylinder, the zero places of Bessel's cylinder functions of the null and first order furnish the desired relation. If the E lines extend in the direction of the cylinder axis and the H lines in planes disposed vertically to the axis, the equation

$$J_0\left(\frac{\pi . d}{\lambda}\right)=0\rightarrow\frac{\pi . d}{\lambda}=2.40;\ 5.52\ .\ .\ .$$

prevails, wherein J_0 is Bessel's cylinder function of zero order; d, the diameter of the cylinder; and λ, the wavelength produced. If E and H are exchanged, Bessel's cylinder function of the first order yields for

$$J_1\left(\frac{\pi . d}{\lambda}\right)=0$$

the relation

$$\frac{\pi . d}{\lambda}=3.83,\ 7.02\ .\ .\ .$$

If the hollow sphere is excited to produce oscillations of such type that the closed E lines extend relative to one another in sectional planes, the equation

$$tg\frac{\pi . D}{\lambda}=\frac{\pi D}{\lambda};\ \frac{\pi D}{\lambda}=4.49;\ 7{,}725$$

prevails, wherein D is the diameter of the sphere.

One advantage of the resonator according to the invention is its very slight self-damping, so that it is still better suited than the known resonators for a great variety of purposes and preferably for exciting, producing, amplifying or receiving electromagnetic oscillations.

A further advantage is that the dimensions of the resonator remain large or comparable to the wavelength. For example, the diameter of the cylinder or torus surface is approximately equal to λ, even at excitation in the fundamental oscillation. For this reason, such resonators can be used for producing transmitters, receivers or amplifiers for extremely short waves, which still have relatively large dimensions, and the resonator according to the invention is thus particularly adapted for waves whose length amounts to only a few centimeters.

An example of applying the toruslike resonator is shown in section 5ˣ in Fig. 6. The toruslike hollow body is cut open at the point where its diameter is smallest. The cut edges are each connected with the portion 6, 6′ of the outer of a concentric energy conductor 5, 6 or 5, 6′, so that the inner space of the torus communicates via the gap 7 with the hollow space of the energy line. If on the latter a stationary wave is produced, so that a current loop develops just at the gap, the resonator, provided its natural frequency coincides with the frequency of excitation, will be excited to high amplitudes while oscillating in the manner described in detail above. Instead of being cut up at its smallest diameter, the resonator can of course be cut up also at another point or at several points vertically to the current path.

The energy line 5, 6 can serve for coupling an excitation space discharge device or a loading resistance, for instance of an aerial, with the resonator. The characteristic impedance thereof can be chosen in a manner favoring excitation or loading and may be particularly small relative to that of the resonator, whereby a relative loose coupling of the resonator to the excitation or loading is effected. For coupling at the gap of a hollow member limiting the resonator, conductor leads can be connected which form approximately a short circuit condenser for the resonator. A potential node and a current bulge of the oscillation always form at the transition point. That is to say, the resonator can be provided with a gap from which energy may pass and with which there can be connected any kind of a conductor, which has such great reciprocal capacity as to form approximately a short circuit condenser. The effect of this resembles that which results from Lecher wires which are bridged over by means of condensers because, when two Lecher wires are short circuited, a potential node and a current bulge of the oscillation always occurs at this point.

I claim:

1. A frequency-determining electromagnetic resonator tuned to a desired wave in at least two dimensions and including a member constituting a hollow torus.

2. A resonator as defined in claim 1 wherein the hollow member is provided with a slot and wherein an electrical conductor lead is connected to the member at an edge of the slot in such manner that the energy flux in the lead is perpendicular to the slot.

3. A resonator as defined in claim 1 wherein the hollow member is provided with an annular slot extending therearound to form a gap and a tubular electrical conductor lead is connected to the member at each edge of the gap.

4. An electromagnetic resonator consisting of a metallic hollow member in the form of an annular torus providing a hollow space defined by conducting walls, means for producing an electric field therefor, an essential part of said field codetermining natural frequency consisting of an electric eddy field with closed electric eddy lines, the hollow space serving as a resonator and being excited in a fundamental or harmonic oscillation.

5. An electromagnetic resonator consisting of a metallic hollow member in the form of an annular torus wherein the closed eddy lines extend in meridianal planes and the corresponding magnetic whirl lines in normal planes and providing a hollow space defined by conducting walls, means for producing an electric field therefor, an essential part of said field codetermining natural frequency consisting of an electric eddy field with closed electric eddy lines, the hollow space serving as a resonator and being excited in a fundamental or harmonic oscillation.

6. A resonator as defined in claim 1 wherein the hollow member is provided with an annular slot extending therearound to form a gap and alined tubular conductor leads are connected to respective edges of the gap at right angles to the plane of the locus of the center of the circle whose revolution forms the torus.

7. A resonator as defined in claim 1 wherein the hollow member is provided with an annular slot extending therearound to form a gap and alined tubular conductor leads are connected to respective edges of the gap at right angles to the plane of the locus of the center of the circle whose revolution forms the torus, said gap being formed at the smallest diameter of the member.

8. An electromagnetic resonator consisting of a metallic hollow member providing a hollow space defined by conducting walls, means for producing an electric field therefor, an essential part of said field codetermining natural frequency consisting of an electric eddy field with closed eddy lines, the hollow space serving as a resonator and being excited in a fundamental or harmonic oscillation, the hollow member being formed as a hollow torus divided throughout its area of inner diameter to provide a gap, the edges of the gap connecting with the parts of the outer of a concentric energy line.

WALTER DÄLLENBACH.