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Some Viewpoints on the Magnetic Field for the Test of Induction Pick-up Coils in Hearing Aids

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In this report the distribution of the magnetic field from circular and rectangular loops for testing the induction pick-up coil in hearing aids is described by calculations. The influence of magnetic materials in the vicinity of the loop is also discussed.

The induction pick-up coil in hearing aids is normally used in connection with telephone sets or with especially arranged magnetic loops. It is very important that the sensitivity of the induction pick-up coil is matched to that of the microphone.

It is desired that the frequency response should be the same for microphone as well as induction pick-up coil input.

It is obvious that there is a need for standardization how to test and describe the performance of the hearing aid with the use of the induction pick-up coil. Normally existing noise levels in the form of stray fields from different sources as well as the risk for saturation in the hearing aid has been described in earlier investigations[1].

The field strength must be adapted to the relevant inductive stray fields, and at the same time account must be taken of the requisite power output of the loop amplifier and the risk of overloading the hearing aid.

A simple device for the test of the induction pick-up coil is a loop with one single turn. The number of turns and the physical dimensions of the wiring is of minor interest, the volume in which a given field strength can be kept within given tolerances for its level and its direction being the important information.

The magnetic field from a circular loop

The magnetic field strength from a circular loop with the radius a - in air, under stationary conditions - can be calculated

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[1] Signal Matching in Inductive Transmission with Hearing Aids, H. Sjögren, S-E. Jalmell, Audiological Technique, May 1969

from Biot-Savart's law

$$\bar{B} = \frac{\mu_o I}{4\pi} \int \frac{d\bar{s} x \bar{r}}{r3}$$

or from

$$\bar{A} = \frac{\mu_o I}{4\pi} \oint \frac{d\bar{s}}{r} \quad \text{and } \bar{B} = \text{rot } \bar{A}$$

In cylindrical coordinates

$$B_\rho = \frac{\mu_o}{2\pi} I \frac{z}{\rho} \frac{1}{\left[(a+\rho)^2+z^2\right]^{1/2}} \left[-K(k) + \frac{a^2+\rho^2+z^2}{(a-\rho)^2+z^2} E(k)\right]$$

$$B_\phi = 0$$

$$B_z = \frac{\mu_o I}{2\pi} \frac{1}{\left[(a+\rho)^2+z^2\right]^{1/2}} \left[+K(k) + \frac{a^2-\rho^2-z^2}{(a-\rho)^2+z^2} E(k)\right]$$

where K and E are elliptical integrals of the first and the second order,

$$k^2 = \frac{4a\rho}{(a+\rho)^2+z^2}$$

In the plane of the loop and on the axis $B_\rho = 0$.

On the axis $B_z = \frac{\mu_o I a^2}{2(a^2+z^2)^{3/2}}$, which in the center of the loop gives

$$B_z = \frac{\mu_o I}{2a}$$

The magnetic field from a rectangular loop

A calculation made in the same manner as for the circular loop gives for a rectangular loop with the dimensions 2a and 2b, fig. 1,

$$B_x = \frac{\mu_o}{4\pi} I z \sum_{\alpha=1}^{4} \frac{(-1)^{\alpha+1}}{r_\alpha(r_\alpha+y_\alpha)}$$

$$B_y = \frac{\mu_o I z}{4\pi} \sum_{\alpha=1}^{4} \frac{(-1)^{\alpha+1}}{r_\alpha(r_\alpha+x_\alpha)}$$

$$B_z = \frac{\mu_o I}{4\pi} \sum_{\alpha=1}^{4} \frac{(-1)^{\alpha+1}(x_\alpha y_\alpha+z^2)}{r_\alpha\left[r_\alpha^2+x_\alpha y_\alpha+r_\alpha(x_\alpha+y_\alpha)\right]}$$

where
$$x_1 = x_4 = x + a$$
$$x_2 = x_3 = x - a$$
$$y_1 = y_2 = y + b$$
$$y_3 = y_4 = y - b$$
$$r_\alpha = \sqrt{x_\alpha^2+y_\alpha^2+z^2}$$

In the plane of the loop and on the axis $B_x = B_y = 0$.

In the plane of the loop B_z can be written

$$B_z = \frac{\mu_0 I}{4\pi} \Sigma \frac{(-1)^{\alpha+1} r_\alpha}{x_\alpha y_\alpha}$$

On the axis of a quadratic loop

$$B_z = \frac{\mu_0 I 2a^2}{\pi\sqrt{2a^2+z^2}(z^2+a^2)}$$

and in the center of the loop

$$B_z = \frac{\mu_0 I \sqrt{2}}{\pi a}$$

Tolerances

The field strength and the direction of the magnetic field should be kept within given tolerances in a volume of sufficient size for hearing aids. This volume could be described as a cube or as a sphere. For the field the tolerances 5% for the level and 10° for the direction could be regarded as reasonable.

The field distribution for a quadratic loop has been calculated over computer.

The absolute value of B_z on the axis and B_z as a function of x and y for z = 0 and z = 0.2a is shown in fig. 2. The first quadrant may be rotated around the z-axis to get the other quadrants. B_z increases when moving from the center with z constant and decreases with increasing absolute value of z. The tendencies work against each other at points not lying in the plane of the loop making a better result than at corresponding points in the plane. According to the results in fig. 2, a sphere with a radius of 0.2a is a better test space than any easily used cube.

The angle between the field and the z-direction is presented in fig. 3. The angle increases with z, but is well within the tolerance of 10° for analyzed points.

In the suggested test sphere the absolute value of B will always be within the tolerances.

Thus for a quadratic loop a sphere with the radius 0.2a is a suitable test space. Similar calculations for a circular loop will be presented in a later report.

Influence by metallic objects

The distribution of the magnetic field can be seriously changed by metallic objects in the vicinity of the loop. Such an influence has been theoretically calculated for two special conditions, a sphere and a cylinder of infinite length in a homogeneous field.

A sphere with the radius a in a homogeneous field, B_o, gives a superimposed field that can be described in spherical coordinates

$$\Delta B_r = \frac{2(\mu-1)a^3 \cos\upsilon}{(\mu+2)r^3} B_o$$

$$\Delta B_\upsilon = \frac{(\mu-1)a^3 \sin\upsilon}{(\mu+2)r^3} B_o$$

$$\Delta B_\phi = 0$$

For a cylinder of infinite length and the radius a

$$\Delta B_r = \frac{\mu-1}{1+\mu} \frac{a^2}{r^2} \cos\phi \, B_o$$

$$\Delta B_\phi = \frac{\mu-1}{1+\mu} \frac{a^2}{r^2} \sin\phi \, B_o$$

$$\Delta B_z = 0$$

For μ:s very much near 1, the influence is negligible. When μ is increased, however, and approaching an infinite value, the 5% tolerance limit of the field strength will be reached at 5.4a and 4.5a from the sphere and the cylinder center respectively.

Objects made of magnetic materials should not be allowed within the loop.

Reinforced concrete can influence the field distribution as being a magnetic material in the vicinity of the loop as well as through transformer effects with shortcircuited turns. Measurements have been made with a quadratic loop over a grid made of steel. The quadratic loop was placed parallel to the grid with a distance between the loop and the grid of 1.5a. The magnetic field strength level in the center of the loop was reduced by 0.1 dB. With the same distance reduced to 0.3a, the level decreased by 0.2 dB. With the loop perpendicular to the grid surface and the nearest side of the loop at a distance of 0.6a and 0.3a, the field strength level was reduced 0.1 dB and 0.2 dB respectively. To be quite safe for an influence of reinforcements, the distance between the loop and any surface of the test room should be at least 2a.

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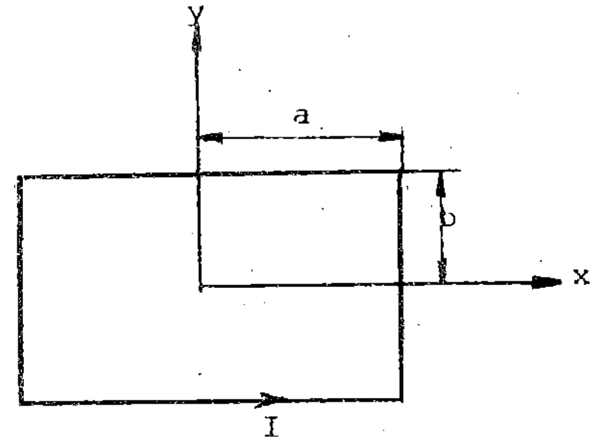
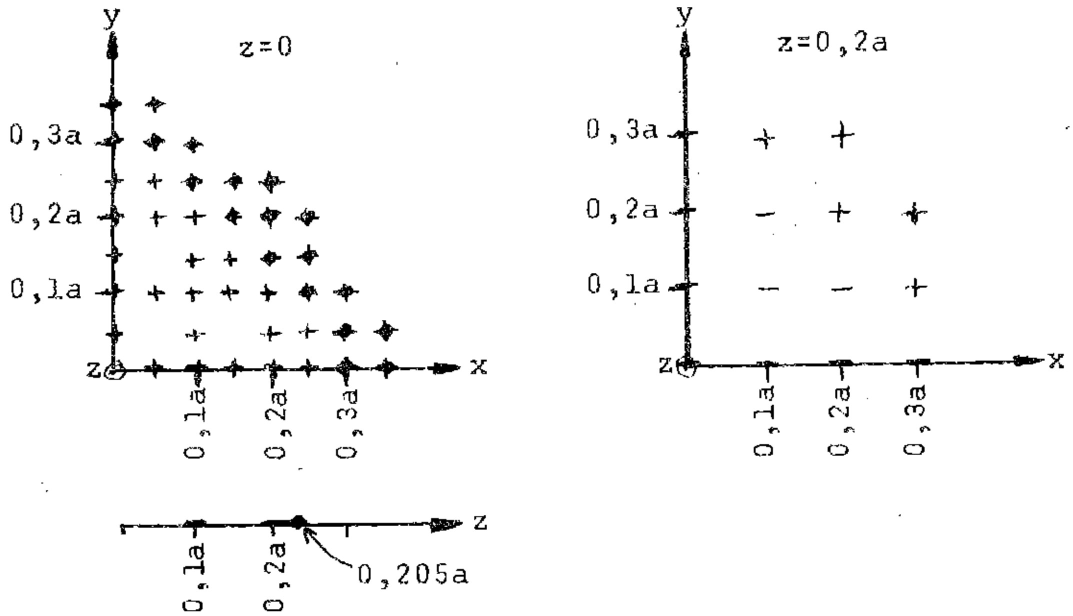


Fig. 1. The rectangular test loop.



✦ $|B_z| > 1{,}05\ B_{z_o}$ outside the tolerance

+ $B_{z_o} < |B_z| \leq 1{,}05\ B_{z_o}$

– $0{,}95\ B_{z_o} \leq |B_z| < B_{z_o}$

● $0{,}95\ B_{z_o} < |B_z|$ outside the tolerance

Fig. 2. The distribution of the absolute value of B_z, $|B_z|$.

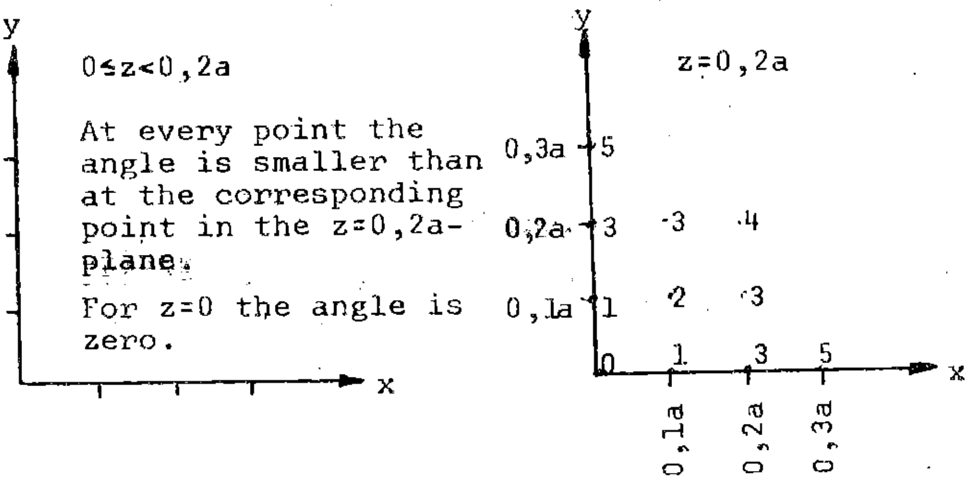


Fig. 3. Angle in degrees between the field and the z direction.

Addendum to the report
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by Ann-Cathrine Lindblad

With the radius a, in air, under stationary conditions B_z has been calculated using cylindrical coordinates.

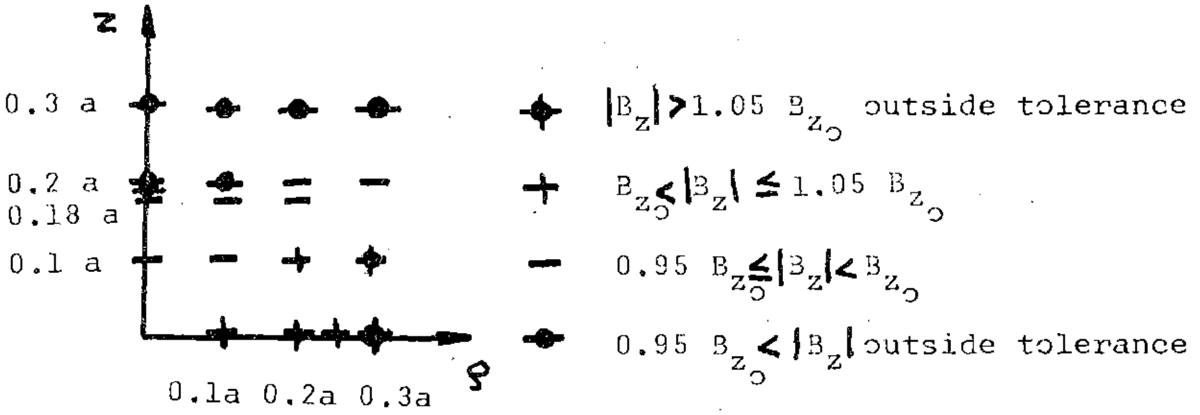

Fig. 4 The distribution of the absolute value of B_z, $|B_z|$, for a circular loop with the radius a.

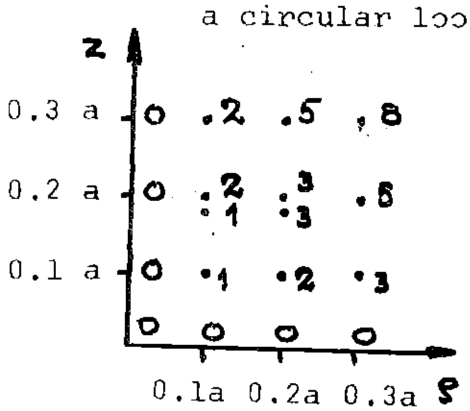

Fig. 5 Angle in degrees between the field and the z direction for a circular loop with the radius a.

Thus the test space can be described by a sfere with the radius 0.20 a or as a cylinder with the radius 0.18 a and the length 2 x 0.25 a.