IEC TR 63079

Edition 1.0 2017-04

TECHNICAL REPORT

colour inside

Code of practice for hearing-loop systems (HLS)

IEC TR 63079:2017-04(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue
The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - www.iec.ch/searchpub
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

Electropedia - www.electropedia.org
The world's leading online dictionary of electronic and electrical terms containing 20 000 terms and definitions in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary
65 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

IEC TR 63079

Edition 1.0 2017-04

TECHNICAL REPORT

colour inside

Code of practice for hearing-loop systems (HLS)

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 17.140.50

ISBN 978-2-8322-4154-7

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

CODE OF PRACTICE FOR HEARING-LOOP SYSTEMS (HLS)

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a Technical Report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 63079, which is a Technical Report, has been prepared by IEC technical committee 29: Electroacoustics.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
29/917/DTR	29/923/RVC

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

The performance of induction-loop systems is specified in IEC 60118-4, whereas IEC TR 63079 gives recommendations and guidance for their design, planning, installation, testing, operation and maintenance. Provisions for components of a system are given in IEC 62489-1. Methods of calculation and measurement of the magnetic field, in the context of human exposure, are given in IEC 62489-2.

This document takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this document is expected to be able to justify any course of action that deviates from its recommendations.

CODE OF PRACTICE FOR HEARING-LOOP SYSTEMS (HLS)

1 Scope

This document, which is a Technical Report, gives recommendations for and guidance on the design, planning, installation, testing, operation and maintenance of a hearing-loop system (HLS) intended for communicating speech, music and/or other signals. It is mainly concerned with HLS for hearing enhancement, in which the signals are communicated to users of hearing aids equipped with magnetic pick-up coils.

This document does not apply to induction-loop systems which use a carrier frequency, nor to other systems for hearing enhancement purposes which do not use magnetic induction.

2 Normative references

There are no normative references in this document.

3 Terms, definitions, signs and symbols

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1 Terms and definitions

3.1.1
hearing-loop system
HLS
system including amplifier(s), microphones and/or other signal sources, in which magnetic fields are created by the flow of audio-frequency current in a conductor arranged in the form of one or more loops or a coil or solenoid

Note 1 to entry: The technical term for a hearing-loop system is "audio-frequency induction-lop system" (AFILS).

3.1.2
HLS for hearing enhancement
HLS in which the intended receivers are hearing aids or specially designed listening devices equipped with coils acting as magnetic antennas

3.1.3
direct-to-reverberant ratio
ratio, at a given point in the sound field, of the sound pressure due to the wanted sound source to the sound pressure due to reverberation

3.1.4
hearing aid
personal amplification system, worn entirely on the listener, which is designed to enable a person with impaired hearing to hear more easily

3.1.5
loop listener
listening device which is designed to give an audible output in response to signals transmitted by an HLS

3.1.6
HLS monitoring receiver
equipment designed to verify the performance of an HLS by audio and visual means

a) providing visible indication that it is powered and when the strength of the magnetic field produced by the loop falls within a specified range,
b) providing an audio-frequency output by which the sound quality of the HLS transmissions can be assessed, and
c) providing other, optional facilities (see Annex A)

3.1.7
magnetic field strength
magnitude of the magnetic field, at a stated point in space and in a stated direction, generated by the flow of alternating current in an HLS

3.1.8
listening plane
plane perpendicular to the axis of telecoils in hearing aids (see Annex B)

3.1.9
useful magnetic field volume
volume within which the system provides hearing-aid users with a signal of acceptable quality

[SOURCE: IEC 60118-4:2014, 3.2, modified — The brackets have been deleted from the definition, as well as the notes.]

3.1.10
system designer
technically competent person who takes responsibility for the technical specification, design and performance of the system

3.1.11
simple system
HLS that is neither large nor complex and does not require specialist skills in order to achieve a satisfactory result

3.1.12
counter system
ticket office system
small area HLS designed to assist communication between (usually) two persons, sometimes through a transparent screen

Note 1 to entry: For example at a ticket office or bank.

3.1.13
complex installation
HLS installation in which any of the following apply:

- HLS that has an approximate coverage area greater than 400 m^2;
- it is required to operate close to another HLS, which could lead to co-interference;
- it is required that a certain area is not covered by the HLS, in case it might interfere with sensitive electronic equipment, for example electric guitars or dynamic microphones;

- it is required that the system operates on a number of different listening planes;
- an unconventional layout of loop conductors is indicated;
- there is metal in the building's structure and this causes irregularity in the field strength when using a perimeter loop

Note 1 to entry: Such installations are likely to require specialized design knowledge in order to obtain a satisfactory result.

3.1.14
direction of the magnetic field
resultant direction of the magnetic field at a point in three dimensional space, arising from the phasor sum of components of the field derived by integration over all elements of the induction-loop

3.1.15
HLS reference plane
the plane to which the magnetic characteristics of the HLS are referred when stating specified values

Note 1 to entry The reference plane specification includes its inclination to the horizontal.

3.1.16
reference magnetic field strength level
0 dB reference for magnetic field strength levels, which is 400 mA/m

[SOURCE: IEC 60118-4:2014, 3.1, modified – The definition has been rephrased, and the note has been deleted.]

3.1.17
overspill
magnetic field of usable strength that is present outside the volume in which is it required

Note 1 to entry This magnetic field extends outside the useful magnetic field volume because a field of lower strength than the minimum specified in IEC 60118-4 can still interfere with other nearby HLS or be received with suitable equipment.

3.2 Signs and symbols

3.2.1 Symbol for an induction-loop

The symbol shown in Figure 1 should be used on circuit diagrams to indicate an HLS.

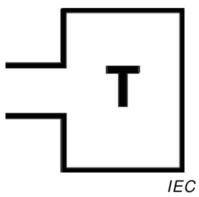
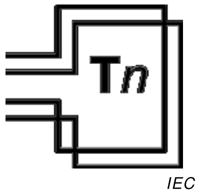


Figure 1 – Symbol for use on diagrams

3.2.2 Symbol for multiple loops

The symbol shown in Figure 2 should be used on circuit diagrams to indicate a complex or low-spill HLS.



NOTE *n* is the number or letter corresponding to the classification of loop. See Clause 11.

Figure 2 – Symbol for multiple loops for use on diagrams

3.2.3 Sign for display in premises where an HLS is installed and for HLS equipment identification

Signs for display should be produced on a durable material.

Areas where the reception of the HLS is satisfactory should be clearly indicated at visible positions by means of the sign shown in Figure 3, which is based on the one originally adopted by the World Federation of the Deaf. The sign should indicate T as shown. The background colour should be Pantone reference 661 or 662 (blue) and the printing should be in white.

NOTE Some organizations that support people with hearing loss do not approve HLS unless signs are displayed. Signs of other colours are found in use.

Normally the dimensions of the display signs should be a minimum of 100 mm × 100 mm; when used on equipment, they can be of any convenient size.

The sign should appear at a position visible in normal use on HLS equipment, on loop cable junction boxes and adjacent to the loop cable itself where it would be helpful to maintenance personnel or help to prevent accidental disturbance.

Figure 3 – Sign for display in premises to indicate that an HLS is installed and for HLS equipment identification

3.2.4 Identification of areas where reception of the HLS is not satisfactory

Areas where the reception of the HLS is not satisfactory should be clearly indicated on a plan of the space by means of the sign shown in Figure 4. The plan should be placed where it can be seen by both hearing-aid users and staff. This sign should also be placed visibly in the unsatisfactory area and/or on all seats in that area.

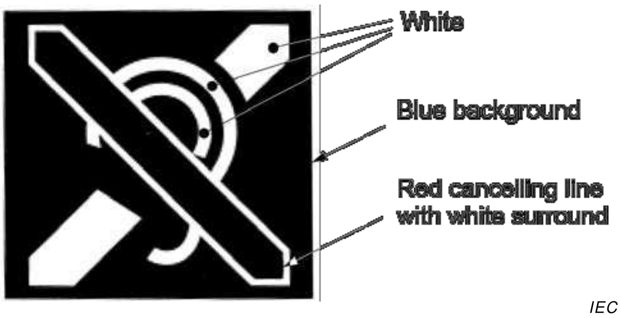


Figure 4 – Sign to show seating areas where HLS reception is not satisfactory

4 General

4.1 How to use this document

4.1.1 Persons addressed

This document is divided into clauses, with recommendations intended primarily for

- purchasers of HLS (Clauses 1 to 9, 20 and Annex B),
- designers of HLS and HLS equipment (Clauses 9 and 10, 20, Annex A, Annex C to Annex G),
- installers of HLS (Clauses 11 to 17, Annex A and Annex H),
- those responsible for commissioning, testing, operation and maintenance (Clauses 14 to 18, 20 and Annex H), and
- those responsible for day-to-day operations, ensuring that the facilities are accessible to as many people as is reasonably possible (Clauses 19 to 21, Annex A and Annex B).

4.1.2 Objectives

The recommendations of this document are intended to lead to the following.

a) Prospective purchasers clearly understand the functions and limitations of an HLS (see Annex B).
b) The design, installation and setting-up of the HLS allows compliance with the appropriate requirements for safety and electromagnetic compatibility and all relevant regulations relating to electrical installations.
c) Users wearing hearing aids equipped with a magnetic pick-up coil receive signals transmitted by the HLS that are intelligible and free from undue distortion and interference even when all non-HLS equipment normally used in the environment is in operation.
d) The reception of such signals is possible in any part of the space; where, by force of circumstance, the reception in some parts is limited, this is clearly defined and identified (see 3.2.4).
e) Visual indication is given to prospective users that an HLS is installed.
f) Means are provided for the building management to easily verify that an HLS is working satisfactorily (see Annex A).
g) The HLS can be satisfactorily operated and maintained by properly trained and competent personnel.
h) Where necessary, the HLS is arranged for minimum extraneous coverage. It should be understood, however, that even if an HLS is designed to limit extraneous coverage, it might be possible for a determined person outside the intended area of coverage to receive what might be confidential information.

Guidance is given on means to reduce possible effects of the magnetic field produced by the loop on other nearby equipment.

4.2 Specialist advice

Except for home systems sold as a complete kit, the engagement of a skilled system designer is advisable and is considered to be essential whenever large or complex installations are involved. Professional bodies can be approached for lists of such specialists.

4.3 Safety aspects

It is essential that an HLS, even if temporary, is installed in a safe manner and in accordance with safe work practices (see 10.7).

4.4 Conforming to existing performance documents

The performance document for HLS is IEC 60118-4, the requirements of which have been incorporated (where applicable) as recommendations in this document.

5 Technical advice

5.1 Complying with this document

Significant problems can arise with poorly designed or installed HLS. Purchasers should stipulate that the design and installation are to comply with this code of practice and that the system should conform to IEC 60118-4. Operation and maintenance procedures should also be in accordance with this code of practice.

NOTE For small self-install systems intended for home use, it is expected that the manufacturer has ensured that the basic requirements of this document will be met if the user follows the installation instructions carefully.

It is recommended that contracts include a specific variation clause under which parties agree to the terms of the contract and document any agreed variations.

5.2 Seeking technical advice

While many successful HLS have been installed to date, compliance with this document should greatly increase the probability that satisfactory results will be obtained. Its provisions, however, cannot be properly applied without adequate technical knowledge and experience, and each design presents individual challenges.

Wherever possible, technical advice should be sought during the early planning stages of an HLS. Such advice should cover

a) the suitability of an HLS for a particular venue and/or application (see Clauses 6 and 9),
b) factors that can adversely affect the performance of an HLS,
c) factors that can add to the cost of installing an HLS,
d) the need for, and scope of, an initial site assessment (see Clause 7),
e) details of the audio source(s) (see Clause 10), and
f) where microphones are to be used, their positioning to minimize extraneous noise and reverberation (see Clause 10).

In all cases, the responsibility for the correct performance of the system at the time of commissioning should lie with the system designer. It should be understood, however, that the system designer cannot be held responsible for the parts of the system outside their control.

Where the HLS is to be installed as part of other electrical works, it is especially important that all aspects of the design are clearly specified, especially regarding microphones, required coverage and overspill.

5.3 The nature of the advice

Advice sought will depend on the particular installation requirements for each HLS, but should generally be covered by the following categories:

a) advice from the designer/installer direct to the client on all aspects, from initial quotations for the task in the planning stages through to installation, commissioning and maintenance of the HLS;
b) advice from the designer to a technician who lacks experience with HLS installations but who has the task of installing the system (e.g. systems in new buildings where installation is to be carried out by electrical contractors; systems installed by in-house staff);
c) advice from an appropriate organization or professional body.

5.4 Professional (consultancy) advice

Professional advice from a specialist consultant should be sought when installations are to be undertaken in extra-large buildings, prestigious buildings and those posing special difficulties.

The advice of an independent consultant can also be sought in the event of a dispute between the purchaser and supplier or manufacturer. Such advice can often provide the most economical resolution of the dispute.

6 Purpose of the system

The most fundamental purpose is to help people to hear, not to meticulously obtain readings on meters; these are a method of achieving the desired result.

Before approaching a supplier, it is important to write down, in non-technical terms, what the users of the system require it to do and the environment it is to be used in. Care should be taken that this is as comprehensive as possible: anything left out at this stage can result in extra expenditure later.

Factors that should be considered include

a) the room(s) and three dimensional space(s) to be covered,
b) what sounds or audio signals are to be reproduced and where they will come from (all the sources and places),
c) whether the audio information needs to be confidential (e.g. a court),
d) known/likely interference from other equipment (e.g. power transformers, air-conditioning equipment, other HLS, and some fluorescent lighting),
e) building construction, such as structural steel work and metal in walls, floors and ceilings, particularly close to the looped area,
f) any metal construction within the space (e.g. tiered seating or metal suspended ceiling grids), and
g) architectural considerations or restrictions (e.g. listed building status).

7 Choosing the system supplier

7.1 General

Possible procedures for acquiring an HLS are recommended in 7.2, 7.3 and 7.4. The choice of procedure should depend on the size of the space to be covered and any special complications which might be involved. Advice can be obtained from organisations that care for people who are deaf or have hearing impairment.

7.2 Approaching a contractor

Particularly for a simple HLS, a contractor should be asked to conduct an initial site survey (see IEC 60118-4), design, supply and install suitable equipment and all cabling. Responsibility for choosing appropriate equipment (microphones, amplifier, monitoring device, etc.) and for installing and setting up the HLS correctly should rest with the contractor.

NOTE For a small HLS, the cost of a formal initial survey might not be justified, but many contractors will conduct an informal survey as a matter of course.

7.3 Approaching a manufacturer of HLS equipment

Some manufacturers of HLS equipment and their local representatives are willing to produce the site survey for the proposed installation, design a system and, perhaps, recommend a competent installation contractor. Manufacturers who are unable to provide this service themselves might offer contact with appropriate designers/installers who can undertake such projects.

Responsibility for choosing appropriate equipment (microphones, amplifier, etc.) and commissioning the system should rest with the selected manufacturer or designer/installer. The contractor should be responsible to the manufacturer for the correct installation of the HLS and commissioning (where this is also undertaken).

For some HLS, the installation contractor might call in a manufacturer to provide detailed technical advice on areas of uncertainty or particular difficulty. On these occasions the contractual obligations of the installation contractor and the manufacturer to the prospective purchaser should be clearly documented, preferably under a single contract.

7.4 Approaching a specialist consultant

When it is appropriate to engage a specialist consultant, this should be done at the earliest opportunity. The consultant should be responsible for the initial survey, design and commissioning of the HLS, choice of equipment and for helping to assess installers' proposals. Where necessary, the consultant should also liaise with architects and construction contractors on matters affecting the HLS. Names of consultants who specialize in this work can be obtained from professional associations.

NOTE Such a consultant might be independent or might be a competent person employed by a manufacturing or contracting organization.

8 Contractual provisions

8.1 Performance specification

The purchase contract should include an agreed performance specification, prepared by the system designer, to which the system is contractually required to conform at the commissioning stage. Where the choice of equipment to be used is not completely under the control of the system designer (for example, if some existing microphones are to be used), any reservation about the suitability of such equipment should be clearly explained to the purchaser in writing.

8.2 Verifying that the completed system delivers its intended performance

Tests of the completed installation to verify that the HLS performs satisfactorily should be specified in the contract and should cover

a) checks of the system using a meter designed to measure field strength in conformity with IEC 60118-4,

b) subjective tests using persons with normal hearing listening through suitable receiving units,

c) subjective tests by hearing aid users, with their hearing aids set to T, and

d) provision of either field-strength meters for use by trained staff or a fixed monitor receiver.

If the subjective tests are conducted correctly and do not provide confirmation of positive instrumentation checks, the system designer should be held responsible for identifying measures necessary to achieve satisfactory results. The contract should, therefore, include adequate provisions for properly defining the system designer's responsibility with regard to the preparation of any required remedial proposals and their implementation.

NOTE The emphasis is on satisfactory results, as determined by the users of the system, rather than achieving particular objective results from technical tests. See IEC 60118-4.

The system designer should advise on methods of eliminating interference by the HLS with other nearby electronic equipment, and modifications to the HLS should be agreed with the system designer; it is advisable for the contract to specify how the costs of such remedial work are to be apportioned.

It might be impossible to predict before the HLS is installed and tested the need for specific measures to eliminate interference by the HLS with other nearby electronic systems (e.g. multiple grounding, legacy equipment with inadequate immunity, unforeseen proximity of loop cabling to other cabling – see 10.9).

Remedial work should normally be carried out by the body having technical responsibility for the appropriate system (telephone systems, etc.).

The tests in Clause 14 are to determine the perceived sound quality of the system and its adequate freedom from noise, reverberation and distortion. They are not intended to demonstrate that the needs of any particular hearing-aid user are met.

8.3 Arbitration

It is recommended that provision is made in the contract for arbitration in the event that problems arise. Where possible, an arbitration body should be identified.

9 Classification of systems

Because of the diversity of use for HLS, the following classifications are intended to group similar applications, providing minimum performance characteristics for each group based on the intended use; for example, the permissible magnetic noise and overspill with adjacent counter loops can be considerably higher than that of a theatre system as the user is only in contact with the counter system for a small period of time.

HLS should be assessed by a competent person and assigned one of the following classifications for operation and performance.

a) Portable or hand held self-contained equipment. This equipment is designed for mobile/temporary use only to assist one-to-one communication. It is not intended to be used on counters or left permanently installed in a location. It should be understood that such systems have very limited performance, for example the coverage rarely exceeds 0,5 m from the equipment or its microphone.

b) Small volume systems, for use in counters, signage, intercom, emergency voice communication system. Coverage is required within a small defined volume (generally not more than 2 m × 2 m × 0,5 m), where the user is in a fixed position and use is transitory, for example counter systems for a ticket office, reception desk, help points or disabled refuges. For counter systems where confidentiality is important, the design of the HLS can be required to attenuate the magnetic field outside a designated space (usually the useful magnetic field volume) to a level at which speech cannot be understood. But it is not necessary for the magnetic attenuation to exceed the acoustic attenuation.

c) Perimeter loop systems, for coverage of a single volume where other HLS are not present in the vicinity and where security, overspill or overcoming significant metal losses is of no importance, for example church/stone building remote from other buildings containing HLS.

d) Mobile loop systems, for temporary use as a perimeter loop in a relatively small space, where other HLS are not present in the vicinity and where security, overspill or overcoming significant metal losses is of no importance, for example a system that provides a loop of 50 m perimeter.

e) Multi-loop systems, specifically designed to control the horizontal and vertical field components for HLS installed in close proximity and/or to overcome significant metal content, for example classrooms or cinemas with multiple HLS, an auditorium with a box office HLS in same building, reinforced concrete construction, or an office space with a raised steel computer floor. The techniques involved depend entirely on the individual application: from as simple as a figure-of-8 loop, to the use of separate arrays of loops in conjunction with a phase shifter or similar device. Consultation of a specialist in system design is essential to ensure that the correct solution is applied. Professional associations can be approached for lists of such specialists.

f) Loop systems designed for purposes other than assistive listening such as stage direction or observational counselling.

g) Body worn loops, such as neck loops and ear-hooks (also known as silhouettes).

h) Specialist loops which fall into none of the above categories, such as systems for lifts (elevators), which generally require detailed design work by a competent HLS specialist.

Table 1 gives the required features, performance and indications for different loop classes and covers the desired and minimum features of some classes; by their nature the other classes have specific requirements beyond the scope of this document.

Table 1 – Classes of loop system

<table>
<tr><th rowspan="2">Class</th><th>Allowable background noise</th><th>Field variation in the useful magnetic field volume</th><th rowspan="2">Loop separation[a]</th><th rowspan="2">Indications</th></tr>
<tr><th>dB (0 dB = 400 mA/m)</th><th>dB</th></tr>
<tr><td>Portable or hand held self-contained equipment</td><td rowspan="2">−32,
−22 for short time periods</td><td>12</td><td>2 m</td><td>Power</td></tr>
<tr><td>Small volume system</td><td>12</td><td>Width of loop × 2 e.g. 2 m for counters using 1 m wide loop</td><td rowspan="4">Power, loop current, input signal present or automatic gain control active</td></tr>
<tr><td>Perimeter loop systems</td><td rowspan="4">−32,
−22 for short time periods
(for critical listening systems, for example auditoria, as close as possible to −47)</td><td rowspan="3">6</td><td rowspan="2">Width of loop × 2 e.g. 10 m for 5 m wide loop</td></tr>
<tr><td>Mobile loop systems</td></tr>
<tr><td>Multi-loop systems</td><td>As specified by the designer</td></tr>
<tr><td>Body worn loop systems</td><td>Not applicable</td><td>Not applicable</td><td>Power</td></tr>
<tr><td>Specialist loops</td><td colspan="4">As specified by the designer</td></tr>
<tr><td colspan="5">[a] Separation between two adjacent loops in the plane of the loops to minimize the pick-up of signals from one loop by a hearing-aid user using the other loop. Where loops are installed in rooms one above the other, the situation is more complex and requires specialist knowledge to minimize interference.</td></tr>
</table>

10 Design

10.1 General

Many successful HLS designs have been produced but because of the proliferation of less-than-satisfactory design methods and general uncertainty, an in-depth treatment of verified design procedures is given here. Detailed derivations of the design formulas, and further information, are given in 10.4 and Annex C.

All values of alternating voltage, current and magnetic field strength are RMS values unless otherwise stated.

An HLS should be designed to provide the following.

a) A sufficiently (but not excessively) strong, and uniform (useful) component of magnetic field within the required working area, without producing an unacceptably extended coverage area which could cause interference with other systems or compromise confidentiality.
b) Usually, the plane of the loop is horizontal and only the vertical component of the magnetic field is effective. If some of the hearing aid users are lying down, such as in hospital, the loop plane should not be horizontal. A special loop system could alternatively be installed. In general, the component of the magnetic field parallel to the axis of the magnetic pick-up coil in the hearing aid is the effective component.
c) The magnetic field strength in item a) over the frequency range 100 Hz to 5 kHz (see IEC 60118-4) with acceptable uniformity and amount of non-linearity distortion.

   Normally, the system should be designed to have an overall frequency response (measured as magnetic field strength) which is –3 dB at 100 Hz and 5 kHz relative to the value at 1 kHz, and is as flat as practicable between these frequencies.

The factors relevant to item a) are the dimensions of the loop, the number of turns and the current flowing in it, and the perpendicular distance between the loop and the listening plane. Apart from the characteristics of the microphones or other signal sources and the amplifier(s), the major factor relevant to item b) is the effect of the impedance/frequency characteristic of the loop on the variation with frequency of the current flowing in it. This document considers several ways of achieving a sufficiently low variation with frequency.

10.2 Symbols

For the purposes of this document, the following symbols apply.

A length of the side of a square loop or of the shorter side of a rectangular loop, expressed in metres (m)

B length of the longer side of a rectangular loop, expressed in metres (m)

D length of the diagonal of a loop, expressed in metres (m)

d diameter of the loop conductor, expressed in metres (m)

f_c frequency of the upper limit of the loop pass band, expressed in hertz (Hz)

H RMS magnetic field strength, expressed in amperes per metre (A/m)

H_o RMS magnetic field strength at the centre of the loop and in its plane, expressed in amperes per metre (A/m)

H_{oz} perpendicular component of the RMS magnetic field strength at a point, distance z from the plane of the loop along the perpendicular through the centre of the loop, expressed in amperes per metre (A/m)

h height of the telecoil above or below the plane of the loop, expressed in metres (m)

NOTE The usual case where the plane of the loop is horizontal is assumed.

h_n height ratio, $2h/J(AB)$ for a rectangular loop

I RMS current in the loop conductor, expressed in amperes (A)

K direct to reverberant sound pressure level ratio, expressed in decibels (dB)

L inductance of the loop, expressed in henrys (H)

n number of turns in the loop

R resistance of the loop, expressed in ohms (Ω)

r_n resistance ratio ($R/\omega_c L$)

V RMS voltage between the ends of the loop conductor, expressed in volts (V)

Z impedance, expressed in ohms (Ω)

α temperature coefficient of the resistivity of copper (wire), 3,93 x 10^{-3} K^{-1}

γ aspect ratio = B/A

θ temperature, expressed in degrees Celsius (°C)

μ_0 magnetic permeability of space, expressed in microhenrys per metre (0,4 µH/m)

ρ_0 resistivity of copper (wire) at 0 °C, expressed in nano-ohm metres (16,5 nΩ·m)

ω_c angular frequency of the upper limit of the loop pass band, expressed in radians per second (rad/s)

10.3 Basic theory

10.3.1 Production of a magnetic field

Current flowing in a conductor in the form of a loop produces a magnetic field in the space inside and surrounding the loop. A pictorial representation of this field, in the form of "lines of force", is shown in Figure 5.

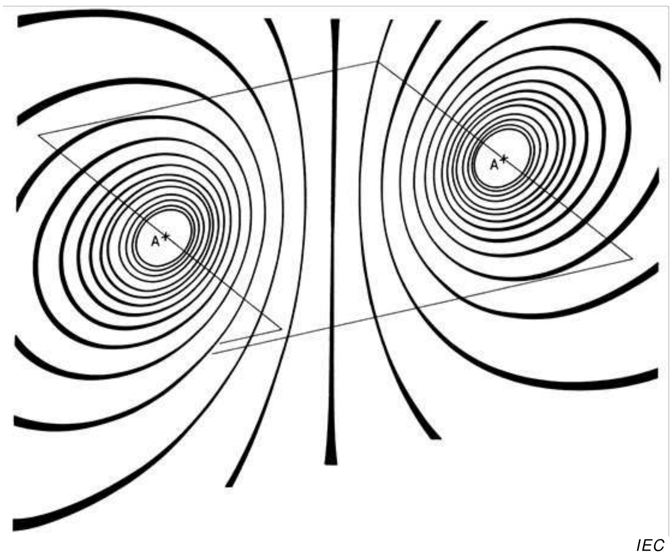


Figure 5 – Pictorial view of the magnetic field (lines of force) of a rectangular loop

The loop has an impedance which can be represented by a resistance and an inductance in series. For a single turn, rectangular loop, using a solid (not stranded) conductor, the following formulas apply.

The value of the current (in A) is given by:

$$I = \frac{\pi A B H_0}{2D} \tag{1}$$

The value of the resistance (in Ω) is given by:

$$R = \frac{8\rho_0(1+a\theta)(A+B)}{\pi d^2} \tag{2}$$

The value of the inductance (in H) is given by:

$$L = \left\{\frac{\mu_0(A+B)}{\pi}\right\} \ln\left\{\frac{A+B}{d}\right\} \tag{3}$$

These formulas are derived in Clauses C.1 to C.3. In most cases, an actual loop can be represented with sufficient accuracy by a plane rectangular loop of the same overall dimensions. Deviations from the plane (such as might be needed to negotiate doorways) increase the inductance by approximately half as much as would be expected from the increased length, but have full effect on the resistance. If the loop shape is approximately circular, or more complex (for example cruciform), the methods indicated by Dalsgaard [1][1], by Grover [2] and in C.1 to C.2 can be used to calculate the current required for a given field strength, resistance and inductance.

While the values calculated with Formulas (1) to (3) (or with the simplified versions, Formulas (7), (8) and (9)) are normally in close accordance with measured values, the resistance and inductance of both trial loops and installed loops should be measured. Unpredicted effects, such as those due to conducting and/or magnetic materials or caused by work hardening due to flexure of the loop conductor, might make the measured values significantly different from those calculated. The measurement might require the use of a bridge specially designed for measuring low values of inductance with high resistive losses. A measuring frequency of 5 kHz or even 10 kHz helps to avoid errors. It is essential that the *series* equivalent inductance and resistance are measured or calculated, not the *parallel* equivalent.

10.3.2 Directional pattern of the magnetic field

The magnetic field varies in both strength and direction within and outside the loop. At the centre of the loop, the field strength is at its lowest value within the loop, and is directed perpendicular to the plane of the loop.

In most hearing aids, the axis of the telecoil is approximately vertical when the user is standing (or sitting). The output voltage of the telecoil is therefore proportional to the vertical component of the magnetic field:

$$V = kH\cos\varphi$$

where

φ is the angle between the direction of the magnetic field and the axis of the telecoil;

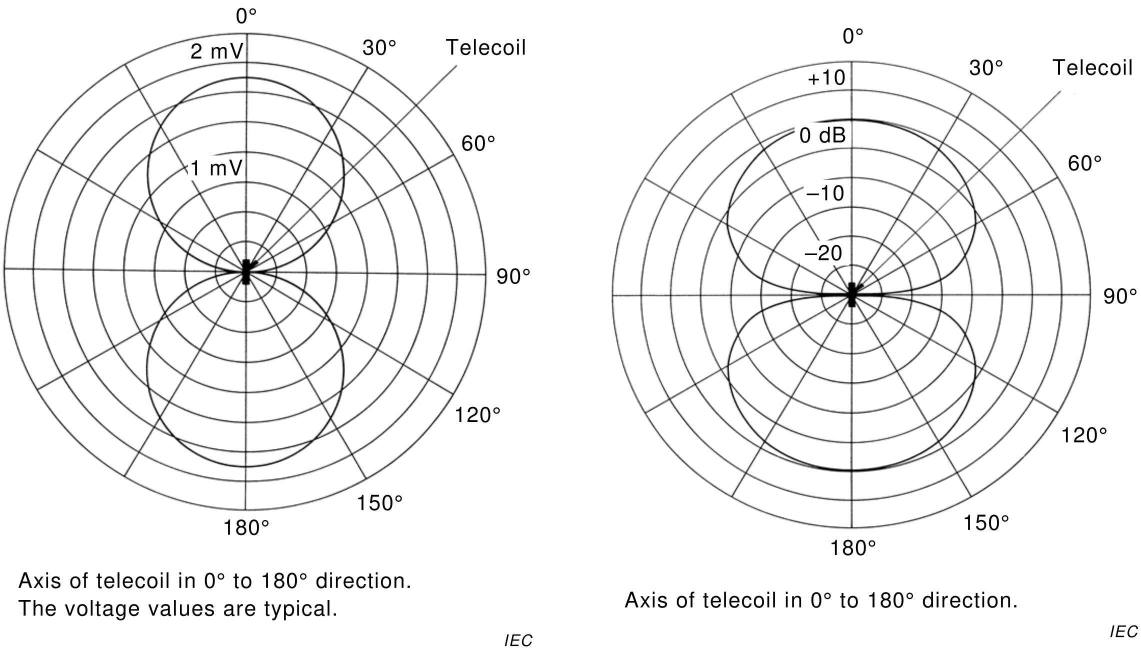
k is a constant.

The resulting directional response of the telecoil is shown in Figure 6. It should be noted that the response is reduced by only 3 dB at Î = 45° and by 6 dB at Î = 60°. If the axis of the telecoil is nearly perpendicular to the direction of the magnetic field, the response is greatly reduced. This occurs, for example, if the telecoil is nearly vertically above or below the conductor or a horizontal loop, where the direction of the magnetic field is horizontal. There is evidence that in some hearing aids the directionality of the response of the telecoil is greater

---

1 Numbers in square brackets refer to the Bibliography.

than predicted above, probably due to the presence of metal near the coil. It is therefore desirable that the plane of the loop should be horizontal, or nearly so, if the coverage area has a horizontal floor and the hearing aid users are standing or sitting.



Axis of telecoil in 0° to 180° direction.
The voltage values are typical.

a) Plotted on a linear amplitude axis

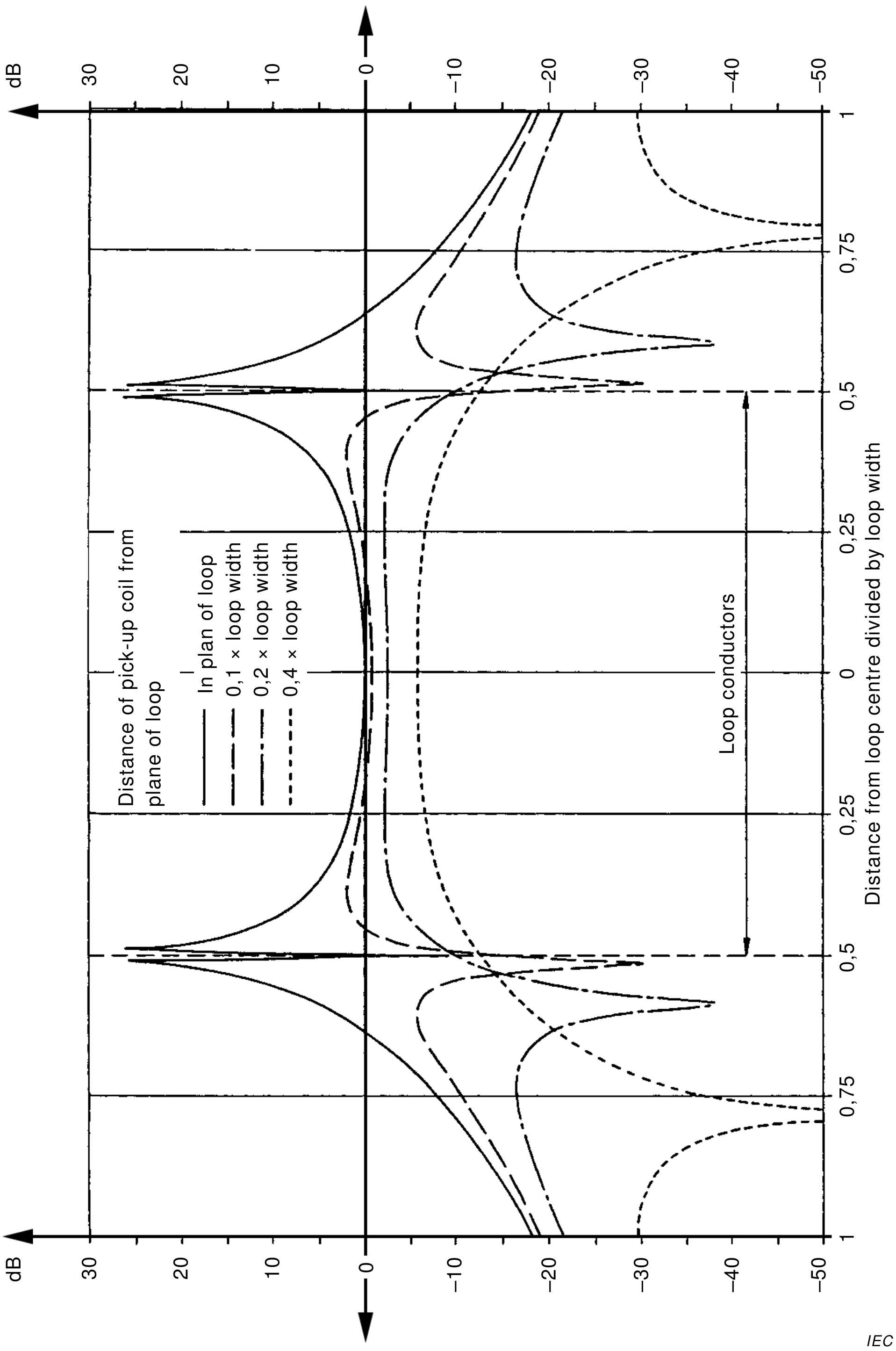
Axis of telecoil in 0° to 180° direction.

b) Plotted with amplitude in decibels (logarithmic axis)

Figure 6 – Directional response of a hearing aid telecoil

The average height of the telecoil above the floor can be taken as 1,4 m when the hearing aid users can be standing or sitting. For small loops (where the height affects the performance more significantly), and/or where the users can be in other attitudes (such as lying in hospital beds), a closer estimate of the actual average height is required. In the latter case, the plane of the loop (or, perhaps, of part of the loop) should clearly not be horizontal.

The variation of the magnetic field strength is quite large in the plane of the loop. In particular, the strength becomes very great close to the loop conductor, and this can cause disturbance to hearing aid users. A more uniform field strength, both in terms of the total field and of the perpendicular component, is obtained above or below the plane of the loop (see Figure 7).



NOTE The full line shows the perpendicular component and the dashed line shows the coplanar component of the field.

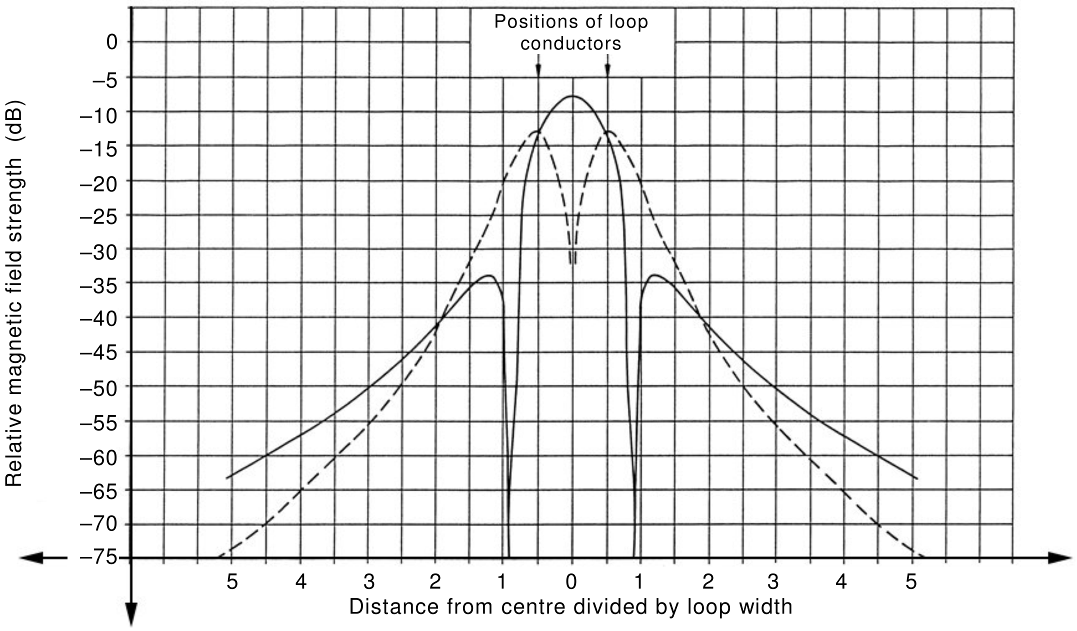
Figure 7 – Variation of the strength of the perpendicular component of the magnetic field across an axis of a rectangular loop, with listening height as parameter

Care should be taken to distinguish between the total field strength and its coplanar and perpendicular (normally horizontal and vertical) components, since their variations within and outside of the loop are quite different (see Figure 7, Figure 8 and Figure 9).

NOTE 1 In the plane of the loop, the direction of the magnetic field is perpendicular to the plane.

NOTE 2 In the areas A immediately surrounding each conductor, the lines of force continue to crowd together, representing a stronger field.

NOTE 3 At certain points, above and below each conductor, the direction of the magnetic field is parallel to the plane of the loop. Normally, at these points, a hearing aid produces no output. For normal listening heights, the points are outside the perimeter of the loop.

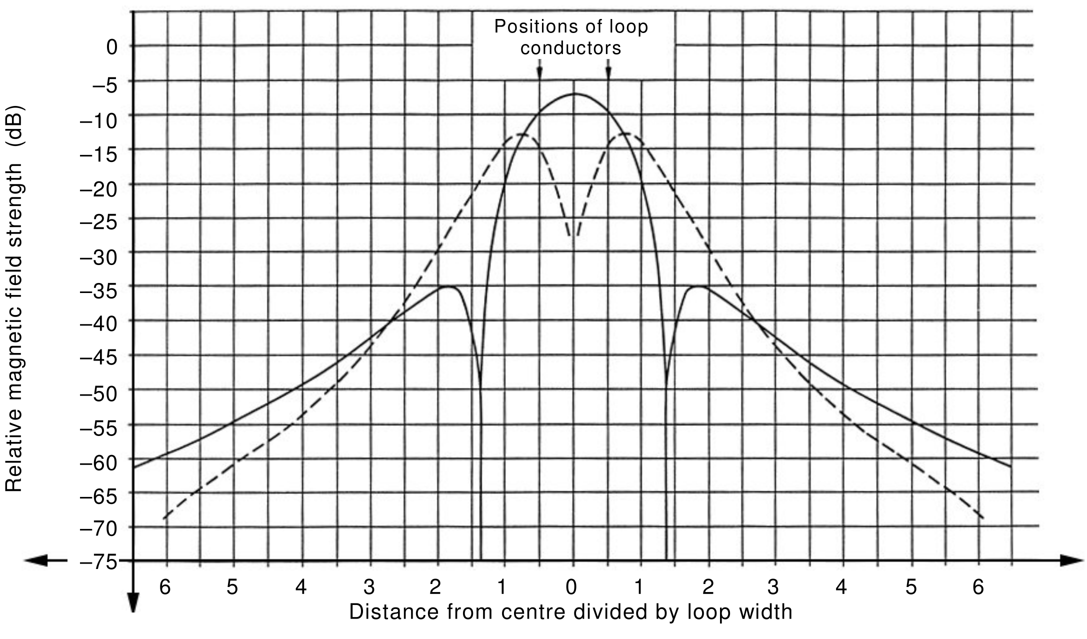


The direction of the coplanar component is along the median, and the field strengths are referred to the field strength at the centre of the loop and in its plane as 0 dB.

IEC

NOTE The full line shows the perpendicular component and the dashed line shows the coplanar component of the field.

Figure 8 – Variation across the median of a square loop of the perpendicular and coplanar components of the magnetic field at a height ratio h_n = 1



The direction of the coplanar component is along the diagonal, and the field strengths are referred to the field strength at the centre of loop in its plane as 0 dB.

IEC

Figure 9 – Variation across the diagonal of a square loop of the perpendicular and coplanar components of the magnetic field at a height ratio h_n = 1

10.3.3 Uniformity of the magnetic field strength

The problem of disturbance of hearing aid users due to the high field strength near the loop conductor could occur if the loop were at head-height (or chest-height, for body-worn aid users) for either seated or standing listeners, and where the listeners could approach the loop conductor closely. This should be avoided by installing the loop either at or below floor level or well above head-height, thus giving an even more uniform field than is achieved with the loop nearer the listening plane, but requiring more current in the loop for the same field strength at the listening position.

It can be shown (see Clause C.1) that a height ratio h_n (termed "relative listening height" by Dalsgaard) of 0,14 gives reasonable uniformity, for all likely values of aspect ratio of the loop, but the resulting distance from the plane of the loop to the listening plane might be too large to be practicable if the loop is large (for example 3,7 m for a square loop of 50 m side). In such a case, a suitable multiple loop layout can be used. This can reduce the actual listening height required, for a given degree of uniformity, to that required for each sub-loop considered separately.

The separation of the listening plane from the loop plane reduces the field strength at all points of the listening plane. At the centre of the projection of the loop on to the listening plane, i.e. at the loop reference point, the reduced field strength H_{0z}, for a square loop, is given by the following formula:

$$\frac{H_0}{H_{0z}} = \frac{\left(1+h_n^2\right)\sqrt{\left(2+h_n^2\right)}}{\sqrt{2}} \qquad (4)$$

The derivations of this formula and of the analogous expression for a rectangular loop of aspect ratio γ are given in Clause C.2, and values of H_0/H_{0z} with γ as parameter are given in Table C.1. The field strength due to a square loop falls off more slowly with distance than that of a rectangular loop. For height ratios up to 0,2 and aspect ratios up to 3,5, the reduction does not exceed 1 dB. It is practicable, in this case, to design on the basis of H_0 and to apply the appropriate correction during final adjustment, provided the amplifier has at least 1 dB of reserve.

However, for large values of h_n, the correction becomes large, and should be taken into account at an early stage in design. A large h_n usually occurs when the loop is small, as in household installations. For example, a 5 m square loop at floor level works with h_n between 0,4 and 0,6, for seated and standing listeners respectively, using head-worn aids, while for a loop at ceiling height, for example 2,4 m, the corresponding values are 0,56 and 0,36. These values imply that to achieve at the reference point the field strength calculated for the centre of the loop, an increase in loop current, calculated from Formula (4), of 15 % to 50 % is required. It should also be noted that, when a seated listener using a head-worn aid stands up, the field strength at the telecoil changes by about 1,8 dB for the floor-level loop and about 1,7 dB for the ceiling-level loop.

10.3.4 Reference points for magnetic field strength

Because the magnetic field strength varies from point to point, it is necessary to define at least one point where the system specification should be verified. It should be noted that there can be more than one listening plane, for example if the working area includes seating at different levels, but there can be only one HLS reference plane. It is also necessary to define the permissible variation of magnetic field strength within the working area. This variation should be kept to a minimum by a suitable choice of listening height, use of multiple loops, etc. However, in practice, limitations on the siting of the loop conductor, the presence of metal in the building and the possible need, in order to avoid overspill, to use multiple or other loop configurations which produce nulls in the useful component of the magnetic field often mean that variations of the order of approximately ±6 dB relative to the field strength at the reference point have to be accepted. In determining conformity to the specified value, nulls should be ignored, and their acceptability separately assessed. At present, this can be judged only subjectively.

In general, inadequate signal-to-noise ratio is even less acceptable than variations in field strength, so any necessary compromise should favour improvement in the former.

10.3.5 Relationship between the requirements of IEC 60118-4 and the characteristics of hearing aids and speech signals

For medical and other reasons, for example design constraints, the characteristics of hearing aids which are of interest for HLS design purposes exhibit quite wide variations. The most important of these characteristics are the "field-to-air sensitivity" which is the sound pressure level produced for a given magnetic field strength at a specified frequency, and the "field-to-air frequency response". Use of IEC 60118-4 is intended to make it unnecessary for the HLS designer to know these characteristics of hearing aids, by specifying that the magnetic field strength level 0 dB at a reference frequency of 1 kHz is 400 mA/m, and limits for its variation with frequency. However, there are indications that the designer should, in order to avoid over-simplification, be aware of the relevant characteristics of hearing aids in some depth.

The sound pressure level presented to the hearing aid user should clearly be the same, whether the signal is received by the microphone or the telecoil. However, the microphone signal varies in strength with the distance from the original source of sound, whereas the HLS signal strength is constant at a given point. It seems reasonable to adjust the field-to-air sensitivity of the hearing aid so that no great adjustment of the gain control of the aid (which normally affects the gain from both sources equally) is required when switching the aid from microphone (M) operation, where the gain control is usually set for normal conversation, to telecoil (T) operation. IEC 60118-4 implies that this is achieved if a field strength of 0,1 A/m produces the same output from the hearing aid as a sound pressure level of 70 dB (20 µPa).

The hearing aid user should also be presented with sound of the same spectral distribution (frequency response) whether the signal is received by the microphone or by the telecoil. The characteristics of the hearing aid amplifier and earphone are common to both modes of operation and can therefore be eliminated from consideration, except for the loading effect of the amplifier on the telecoil frequency response. It remains, therefore, to consider the frequency response characteristics of the microphone and telecoil. The frequency response of the hearing aid from microphone to earphone is known as the "air-to-air response". The characteristics of hearing aid microphones vary considerably, mainly for design reasons: all that can be said is that there is usually a falling response below 1 kHz, and one or more peaks in the 3 kHz range, before a steep fall at higher frequencies.

If the telecoil in the hearing aid had negligible losses and operated into a high-impedance load, it would produce an output voltage proportional to frequency, i.e. rising at 6 dB/octave. However, the field-to-air response can be made similar to the air-to-air response for most hearing aids if the magnetic field strength is within ±3 dB of the value at 1 kHz over the frequency range 100 Hz to 5 kHz, in accordance with IEC 60118-4.

In practice, it is usual to adjust the current in the loop, and hence the field strength, to be –3 dB at approximately 100 Hz and 5 kHz (reference 1 kHz), the latter, in some cases, being dictated by design constraints and/or electromagnetic compatibility (EMC) considerations. Further equalization of the overall frequency response might be desirable, for example to compensate for the low frequency response of the HLS microphone(s) (which can be rising or falling, depending on the distance of the sound source from the microphone) and/or for peaks in the high frequency response.

10.3.6 Impedance of the loop

The impedance of the loop can be accurately represented by a resistance and an inductance in series, the values being given by Formulas (2) and (3) respectively. Formula (2) includes a temperature-dependent term, because external sources of heat, such as central heating pipes, or the current flowing in the loop conductor, might raise its temperature, and therefore its resistance, significantly.

The current ratings of wires suitable for loop conductors should be determined from relevant IEC or national standards. See also Clause C.2. The value of current used to determine the required current rating should be the largest current that can flow continuously, taking fault conditions into account. If no special provisions are made, this is the current required to accommodate programme peaks, i.e. at least 12 dB above the long-term average value, because under fault conditions, for example an open-circuit microphone line, this current could flow continuously. However, this criterion demands the use of a much larger conductor than that required to carry the long-term average current, and this can result in a value of loop resistance which, for some design procedures, is undesirably low. It might be preferable to provide automatic current limiting, so that currents higher than the long-term average can flow only for periods in the order of tens of seconds. In this way, programme peaks are accommodated but serious overheating of the loop conductor is prevented.

The inductance is closely determined by the dimensions of the loop; very little change can be made by altering the conductor diameter. In fact, Formula (3) can be simplified (see Clause C.3) for nearly all practical cases of single turn loops to:

$$L = 3{,}2\ (A + B) \tag{5}$$

where L is expressed in microhenrys.

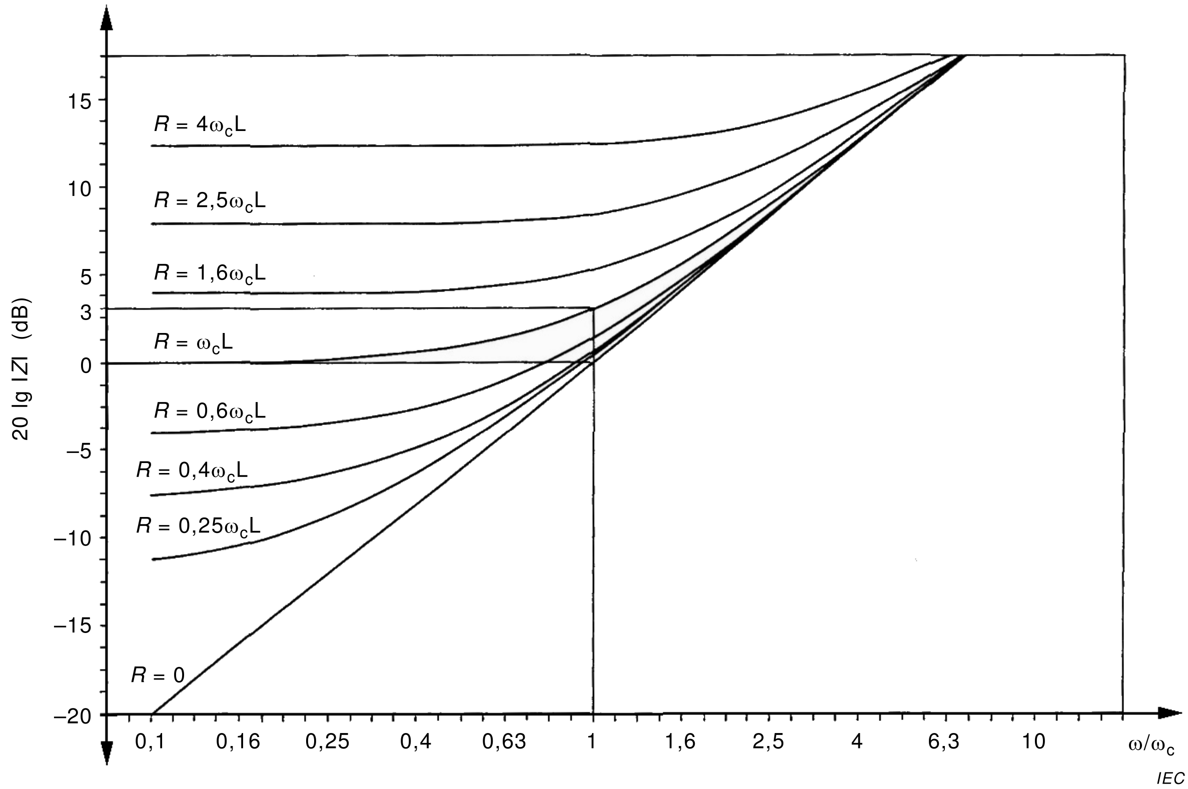
The current necessary to provide the required magnetic field strength and the impedance of the loop at the upper band-limit frequency (normally 5 kHz) determine the output capability required of the amplifier. It should be noted that the "rated output power" of the amplifier is not a very useful characteristic in this context. It is necessary for the amplifier, without producing an unacceptable amount of distortion, to be able to perform the following:

a) supply the required current;
b) produce enough voltage to drive $1/\sqrt{2}$ times that current through the impedance of the loop at an upper limit frequency which is lower than 5 kHz because the spectral levels of speech and music signals decline above about 1,6 kHz.

The analysis so far makes no assumptions about the value of the impedance of the loop at the upper limit frequency, relative to the value at lower frequencies. The value of the amplifier current is fixed by the size of the loop. The value of the voltage depends on the impedance, which in turn depends on the inductance and resistance. However, for practical purposes, the inductance is also fixed by the size of the loop; only the resistance is under the control of the designer, who can choose the diameter (and perhaps the material) of the loop conductor. Normally, it is kept low, so as to keep the required voltage as low as possible.

The impedance/frequency characteristics of loops with the same inductance but different values of resistance are shown in Figure 10, where the resistance values are normalized to the inductive reactance at the upper band limit frequency. It can be seen that decreasing the resistance from a normalized value of 1 to 0 reduces the value of the amplifier voltage by a factor of only $\sqrt{2}$.

NOTE A resistance or impedance is normalized to the inductive reactance at a given frequency by dividing the value of resistance or impedance by the value of the reactance at that frequency.



NOTE The impedance axis is graduated in decibels to simplify the use of the curves for determining current and voltage levels.

Figure 10 – Variation with frequency of the logarithm of the impedance of loops of constant inductance *L*, with the loop resistance *R* as parameter

10.3.7 Selection of the method of driving the loop

Although two techniques are known, termed "current drive" and "voltage drive", the common requirement is that the current in the loop conductor is independent of frequency within limits of ±3 dB, at least over the frequency range of 100 Hz to 5 kHz.

Unless a high level of technical knowledge and skill is available, a current-drive amplifier should be selected, specially made for HLS use, including signal-presence monitoring, automatic gain control and/or compression and/or limiting, and the manufacturer's instructions should be followed concerning the selection of a suitable conductor for the loop and other matters of design. A copy of the manufacturer's instructions should be examined before the commitment to purchase is made, since their quality and intelligibility varies considerably.

10.3.8 Current-driven loop

The use of an amplifier with a high output source impedance, i.e. a "current-drive amplifier", simplifies the selection of a suitable loop conductor. The amplifier "power" requirement is minimized by using a loop conductor sufficiently thick to make the resistance negligible compared with the inductive reactance at the upper band-limit frequency. In principle, the demands on the amplifier are further reduced if the conductor is made larger still, but the practical effect is usually negligible.

Under these conditions, it is necessary to determine only that the amplifier can supply the current (in amperes) calculated from Formula (1), i.e. $I = \pi ABH_0/2D$, and that it can supply enough voltage to drive $1/\sqrt{2}$ times that current through the impedance of the loop at the upper band limit frequency.

The value of V (in V) is given by:

$$V = \sqrt{2}\pi f_c L I$$

if the loop resistance is negligible.

The high output impedance of the current-drive amplifier is obtained by applying negative feedback proportional to the output current. In some cases, this is achieved in such a way that neither of the output terminals is connected to the common return (earth). In such a case, it is essential that the loop conductor is not allowed to come into electrical contact with earthed metalwork. Manufacturers using this technique should consider the effects which would occur in the amplifier if the mains supply was inadvertently connected to the loop conductor.

Since the high output impedance of the current-drive amplifier, or the defined output impedance of the intermediate-drive amplifier, is obtained by the use of a feedback technique, it can be shown that a minimum load resistance might be necessary in order to prevent the amplifier oscillating. It is possible to build this minimum value into the amplifier, so that the output terminals can even be short-circuited without risk of oscillation. This is not always done, however, and the manufacturer's specification should be consulted to determine whether a minimum value of load resistance is stated.

Since the impedance of even large single-turn loops is quite low (a loop of 100 m perimeter has an inductive reactance of 6,3 Ω at 5 kHz), the output source impedance of the amplifier does not need to be more than a few tens of ohms in order to achieve an adequate approximation to current drive. The provision of an unnecessarily high impedance can compromise stability.

It can be shown that the operation of an amplifier with a reactive load involves increased heat dissipation in the output devices. This effect is usually negligible if only speech (and music) signals, having a high peak-to-mean ratio, are involved and there is no clipping of the signals, but results in a heat dissipation of up to 2,5 times that occurring with a resistive load, if high level sinusoidal or other continuous tone signals are present.

10.3.9 Voltage-driven loop

A loop can be driven by a constant voltage if its resistance (including any added resistive component) is not less than the inductive reactance of the loop at 5 kHz. The amplifier requires no equalization (increase in frequency response at high frequencies).

For such a loop, using Formulas (2) and (5), and taking the copper conductor temperature as 20 °C (but see Clause C.2 for the effects of temperature rise), the following formula for R (in ohms) can be derived:

$$R = 1{,}42 \times 10^{-7} \frac{A+B}{\pi d^2} \tag{6}$$

For a current, and therefore a magnetic field strength, at a level of -3 dB at frequency f_c with respect to its low frequency value:

$2\pi f_c L = R$

and if f_c = 5 kHz, using Formulas (5) and (6), the cross-sectional area of the loop conductor is calculated as:

$\pi d^2/4$ = 0,281 mm^2

and

d = 0,60 mm

for a loop of any dimensions (see Clause C.2). In terms of 10.3.6, a voltage-driven loop has to have a normalized resistance of 1.

NOTE It is usual to take 1 kHz as the reference frequency for HLS measurements and specifications. However, an unequalized HLS behaves as a first-order low-pass filter, and if the upper (–3 dB) band limit is 5 kHz, the response at 1 kHz is –0,17 dB relative to the value at a very low frequency. This discrepancy, or any similar discrepancy in the response of an equalized system, is usually negligible, but can cause confusion if the designer does not bear it in mind. If the upper band limit frequency is lower than 5 kHz, it can be necessary to take the resulting larger discrepancy into account.

The value of d calculated above is the diameter of conductor that produces a band limit frequency of 5 kHz; a thicker conductor produces a smaller bandwidth, and a thinner conductor allows a greater bandwidth. It should be noted that this result is independent of the size of the loop.

For a very small HLS, such as for a single living room or small committee room, a single turn loop might have an inconveniently low impedance unless a very thin and fragile conductor is used. It is possible to include a fixed resistance in series with the loop. Alternatively, a multi-turn loop can be used. The formulas for the characteristics of multi-turn loops are given in 10.3.6. Because, relative to a single turn loop, the inductance of an n-turn loop is increased approximately n^2 times, while the resistance is increased only n times, very thin (high resistance) conductors are necessary for multi-turn voltage-driven unequalized loops in order to keep the normalized resistance equal to 1 (see the Note to 10.3.6).

In the case of a very small multi-turn loop, such as a neck loop or a ticket office system (see Clause 9 and Annex B), the use of a series resistor, of adequate power dissipation, might be the optimum technique.

10.3.10 Voltage-driven loop with high-level equalization

If the loop dimensions are too large, or the chosen conductor is of too low resistance, for the loop to be voltage-driven without equalization, it is possible to provide this by connecting a network, consisting of a capacitor and a resistor in parallel, in series with the loop (see Figure 11). Careful design is necessary in order to achieve correct results. The technique could be of use if it is necessary or convenient to use an amplifier designed for "voltage line" (e.g. 100 V or 70 V) service, perhaps because other amplifiers of the same type are used for sound reinforcement in the same building, and in this case, a loop impedance higher than the optimum for other techniques is required. This is one of the cases where it can be advantageous to use a loop of more than one turn.

Another reason for considering this technique is that the equalization can be applied without making modifications to the amplifier or providing more than a minimum of supplementary equipment; the components can be incorporated in a terminal box where the amplifier output lead meets the loop conductor. Amplifiers for 25 V or 50 V line operation can be connected to loops of the appropriate impedance directly: those for 70 V or 100 V line operation can need a transformer unless the loop perimeter or the number of turns is large.

For a loop of n turns, the design formulas are converted as follows. The value of the current (in amperes) is given by:

$$I = \frac{\pi A B H_0}{2 n \mathrm{D}} \tag{7}$$

The value of the resistance (in ohms) is given by:

$$R = \frac{8n\rho_0\left(1+a\theta\right)\left(A+B\right)}{\pi d^2} \tag{8}$$

The value of the inductance (in microhenrys) is given by:

$$L = 3{,}2n^2\ (A + B) \tag{9}$$

Compared with a single turn, the value of the current needed is reduced n times, but the inductive reactance at the upper band limit is increased n^2 times, so the value of the amplifier voltage output needed is increased, by a factor that depends on the normalized resistance of the n-turn loop. For example, if the single turn has a normalized resistance of 1, an n-turn loop of the same conductor has a normalized resistance of $1/n$, and the normalized impedance at the upper band limit is $\sqrt{\left(1+1/n^2\right)}$, and is predominantly inductive. It can be seen that very little is to be gained, in terms of minimizing amplifier "power" (i.e. voltage requirement times the current requirement), by using more than three turns which give a normalized impedance of 1,054. The actual impedance continues to increase as n^2.

NOTE 1 Alternatively, since the n-turn loop requires only $1/n$ times the current for the single turn, the conductor cross-sectional area could be reduced in proportion. This results in an n-turn loop with a normalized resistance of 1, which could be voltage driven without equalization, but the conductor has to be very thin (e.g. a maximum area of 0,098 mm^2 for a three-turn loop). It is difficult to install such thin conductors without damage, and to protect them adequately so that they are not broken by movement of the building structure due to temperature and humidity changes. However, they can be used in neck loops.

NOTE 2 Because the equalizer network effectively presents the amplifier with a mainly resistive load, the use of this technique does not involve any extra heat dissipation in the amplifier, as is required in other cases.

If equalization is employed, it should be exploited to give the maximum practical advantage, in reducing the amplifier "power" requirement. It can be shown that the maximum possible reduction is by a factor of 2, which implies zero loop resistance.

It is shown in C.4.5 that, for a given shape of frequency characteristic and value of upper band limit frequency, there is a unique solution for the values of the components R_1, R_2 and C shown in Figure 10, in terms of the inductance L (in henrys), which itself is practically fixed by the loop dimensions. The design formulas, for a practicable case, giving a nearly flat frequency response, are as follows.

The value of R_1 (in ohms) is given by: $R_1 = \frac{2\pi f_c L}{2{,}652}$

The value of R_2 (in ohms) is given by: $R_2 = \frac{2\pi f_c L}{3{,}751}$

The value of C (in farads) is given by: $C = \frac{4{,}121}{4\pi^2 f_c^2 L}$

Thus, the normalized resistance of the loop is 1/3,751, i.e. 0,267, and the normalized impedance is 1,035, which is very close to the theoretical minimum. While R_1 and C are discrete components, R_2 is the resistance of the loop, and the conductor size should be chosen to achieve this value of resistance (while being of adequate current rating); a small discrete padding resistor can be necessary. It should be noted that the discrete resistors can dissipate considerable power, particularly under fault conditions giving a constant high loop current. If R_2 is too large, a padding inductor can be used, or a higher value of f_c accepted, so that the above formula for R_2 is satisfied.

The fact that a constant voltage applied to the input of the equalizer (see Figure 11) produces a nearly constant current in the loop at any frequency, falling by 3 dB at the upper band limit frequency, implies that the impedance at the equalizer input has the inverse characteristic. Since the impedance at low frequencies is ($R_1 + R_2$), a simple check of the correct design of the equalizer is to measure the equalizer input current at a range of frequencies, while applying a constant voltage V across the input terminals. The current should be substantially constant, at a value equal to $V/(R_1 + R_2)$ at low frequencies, falling to $\sqrt{2/2} = 0{,}71$ times the low frequency value at the upper band limit frequency f_c.

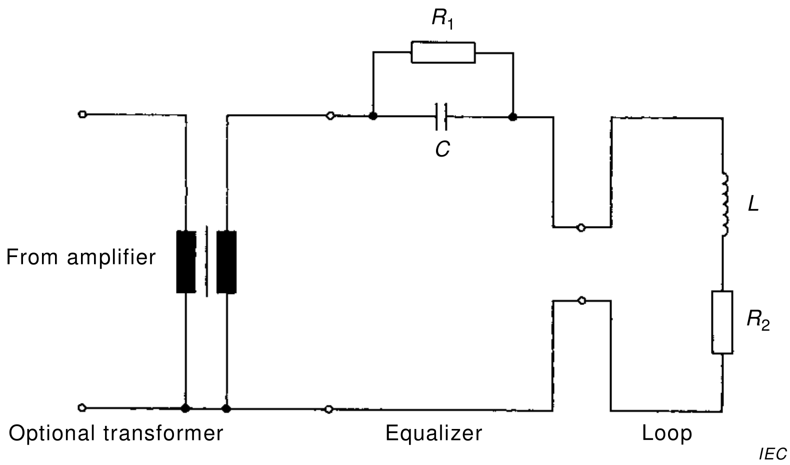


Figure 11 – Circuit diagram of a "high-level" equalizer (for insertion between the amplifier and the loop)

10.3.11 Voltage-driven loop with low-level equalization

It is theoretically possible to compensate for the frequency response produced by a loop of inadequate bandwidth by the inclusion of a passive equalizing network before the final amplifier. However, the use of this technique is not generally advisable because the final amplifier is then subject to the same increased heat dissipation requirements as for a current-drive amplifier, and it is not likely to have been designed with these in mind. Also, the equalizing network has to be designed specifically for the inductance and resistance of the loop being driven, and considerable technical skill is needed. It should be noted that the action of a treble-boost tone-control is most unlikely to produce correct equalization.

10.3.12 Use of transformers

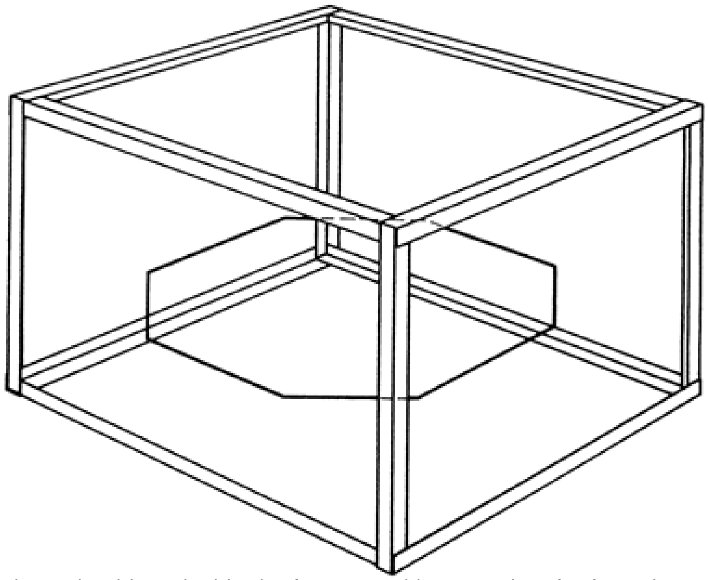
The design methods given in this document allow the connection of the loop to the amplifier, either directly or via a high-level equalizer, without the need for a transformer. This is because the use of transformers can pose difficult design problems, and the necessary transformer(s) are often not available as stock items and have to be made specially.

There are two cases where the use of a transformer can be the best practice. In the first case, the amplifier has to be sited several metres from the loop, and losses in the connecting cable would be excessive if it had to carry a large current. The design method described in 10.3.8 can then be used, resulting in a high-impedance loop carrying a low current. An alternative is to use the design method described in 10.3.10, making the loop resistance 4 Ω or 8 Ω, in conjunction with a "voltage line" amplifier, and to place the matching transformer, which can then be a standard type, close to the loop. The power required by the loop should be calculated as shown in 10.3.8 and an allowance of up to 2 dB made for the transformer losses.

The second case occurs where a very large loop is necessary, and the required current is larger than can be provided by any available amplifier. One technique which can be applicable is the use of multiple loops (see 10.3.17), but it is also possible to combine the output currents of several amplifiers by means of a transformer specially designed for this purpose. The advice of the manufacturer of the transformer should be followed in this case.

10.3.13 Effects of building construction

Metallic (or other electrically conducting) material used in the construction of the building, or in subsidiary structures such as the framework for tiered seating, can affect the performance of an HLS in two ways. The effect which is usually of lesser importance is the distortion of the magnetic field distribution caused by magnetic materials. Structural steelwork usually has an appreciable local distorting effect on the field distribution, and produces a less evident general reduction in field strength. If the steelwork forms closed magnetic circuits in a vertical plane, it can be better to position the loop inside these circuits rather than outside them (see Figure 12).



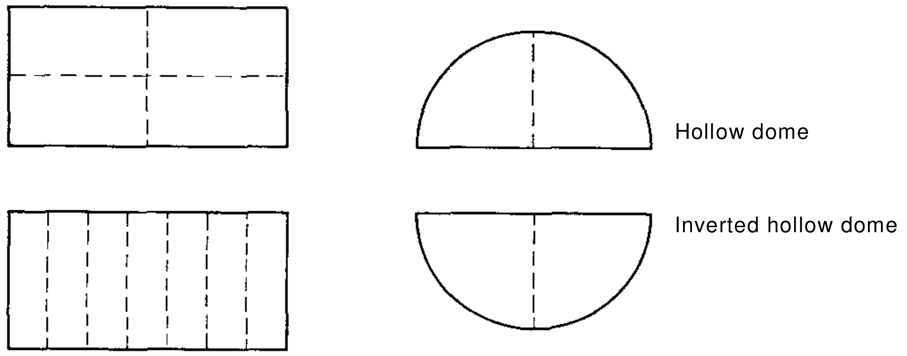
The loop should run inside the frames and be routed as far from them as possible. Note the shaped corners.

IEC

Figure 12 – Preferred loop layout in a steel-framed building

Extended steel frameworks, such as those used for false ceilings or tiered seating, produce gross distortion of the field distribution. To combat this as far as possible, the loop should be positioned as far below or above the framework as possible, the listeners being between the framework and the loop. The presence of steelwork can significantly increase the inductance of the loop, hence increasing the voltage requirement for the amplifier.

The effects of eddy currents in metal, even steel, structures are usually more significant than the magnetic effects. The general effect is a reduction in magnetic field strength, without the creation of areas of increased strength. This is increasingly a problem in new buildings, due to the use of expanded or perforated metal mesh in wall construction and to the use of aluminium foil-laminated insulation boards. Some improvement can be obtained by positioning the loop as far as practicable away from the structure concerned. In severe cases, it might be necessary to modify metal structures in order to break the main eddy current paths (see Figure 13). Eddy current loss tends to cause the overall frequency response of the HLS and hearing aid to be subject to a fall at 3 dB/octave with increasing frequency, superimposed on the other characteristics. Small metal objects and vertical metal panels, such as signboards, normally have very little effect on the magnetic field.



Dotted lines indicate insulated joints. It is not usually necessary to treat vertical panels (in the normal case where the plane of the loop is horizontal).

IEC

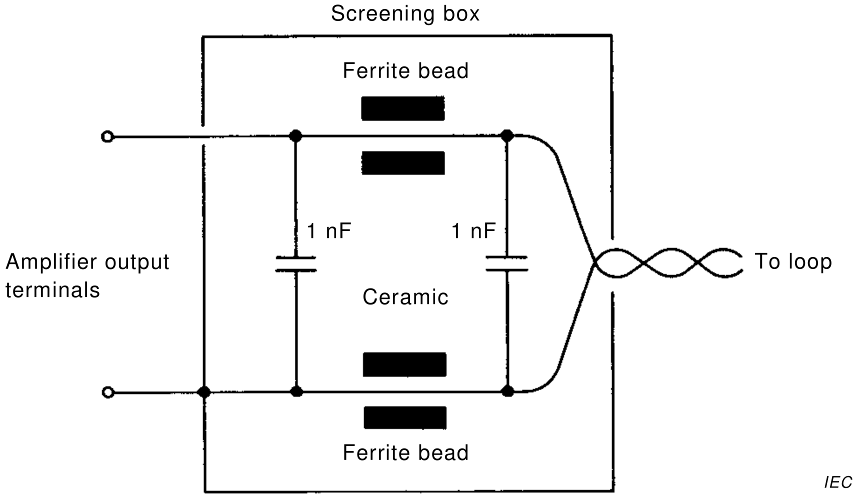
Figure 13 – Methods of breaking eddy current paths in metal structures

No theoretical design procedure has been found that takes account of the effects of metalwork on the magnetic field, but some heuristic procedures have proved useful. It is necessary to consider the results of measuring the current requirement and impedance characteristic of a trial loop, and the field distribution and frequency response achieved. Measures should then be taken in design and installation to overcome any problems disclosed.

10.3.14 Electromagnetic compatibility (EMC)

It should be noted that individual items of equipment used in the HLS are within the scope of the European Community (EC) requirements for EMC. It is also necessary to pay attention to the characteristics of the installation as a whole. Since this effectively consists, in part, of a large loop antenna connected to an amplifier, there is significant potential for both the emission and the reception of interfering signals.

It is very difficult to prevent radio signals of low radio frequency picked up by the loop, from reaching the amplifier, which should thus itself have adequate immunity from interference of this type. VHF signals can be filtered by means of ferrite beads and low-inductance capacitors (see Figure 14), but document suppressor inductors and, particularly, mains filter assemblies, have far too much inductance for connection in series with an HLS loop.



The box should be as close as possible to the amplifier output terminals. The voltage rating of the 1 nF capacitors should exceed the peak voltage expected from the amplifier output.

Figure 14 – Filter for attenuating VHF signals picked up by the loop

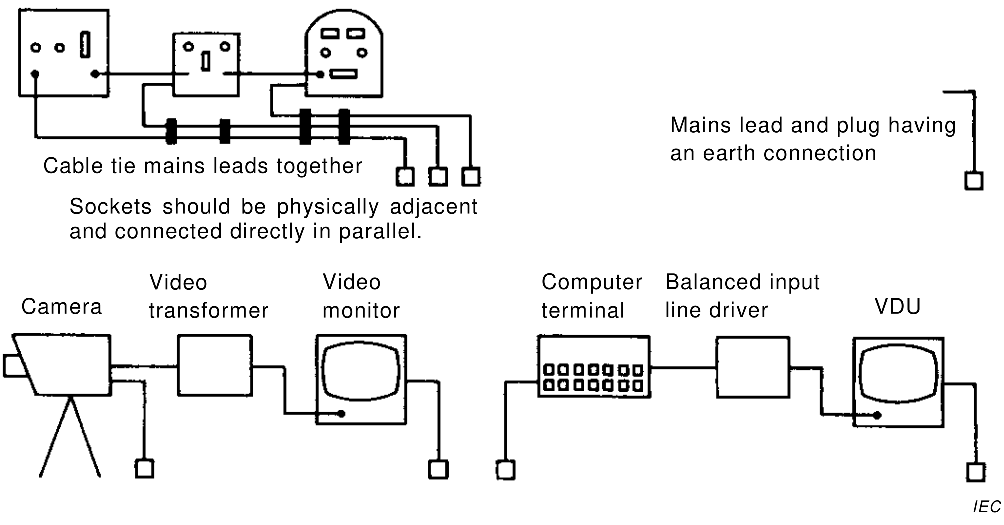
Interference due to external magnetic fields (usually from mains-powered electromagnetic equipment, such as transformers, motors and inductors in fluorescent lamp control gear) is often extremely difficult to reduce. Spatially separated line (or phase) and neutral mains conductors can also cause severe interference. This interference would be present even if there was no HLS installed. In some cases, shielding the source with high-permeability sheet can be effective and economically feasible. It should be noted that shielding materials which are much less costly than high permeability nickel-iron alloys are now available. If shielding is not usable, and the signal-to-noise ratio is unsatisfactory, even with a field strength of 400 mA/m, use of a modified or different system of communication, such as infra-red, should be considered, but it should be realized that these systems are not only more difficult to administer but are also less socially acceptable.

NOTE Some hearing aids can be susceptible to radio frequency interference.

Except for household systems, both the HLS itself and any sound reinforcement or reproduction system used in the same building should use balanced screened wiring for all low-level circuits. In some cases, it can be necessary to use high quality, correctly connected, screened star-quad cables. Electronic equipment should not be positioned inside the area of the loop, unless this is unavoidable.

In order to minimize the production of magnetic fields at frequencies above 5 kHz, due to harmonic distortion of the loop current, measures should be taken to prevent clipping of large-amplitude signals, not only at the output of the power amplifier, but elsewhere in the system. This can be achieved by means of automatic gain control (AGC) and "soft clipping" circuits (which usually work by applying non-linear negative feedback or voltage-controlled attenuation to excessive signal peaks), or by other techniques, such as dynamic bandwidth control. It should also be ensured that the high-frequency content of any tone signals is sufficiently low, and that the sending-end bandwidth of the system is no larger than necessary.

The magnetic field produced by the loop can affect other equipment and systems (such as telephones and video systems) by the direct induction of audio-frequency currents into conducting loops formed by the wiring of the target equipment or system. Such interference cannot normally be eliminated by modifying the HLS (except where re-routing of cables proves effective), but can be eliminated by suitably modifying the target equipment or system so as to break the loop(s). It is essential that electrical safety is not compromised in this event. Methods of breaking loops are shown in Figure 15.



NOTE The video transformer can be replaced by a balanced-input video distribution amplifier.

Figure 15 – Methods of "breaking" loops into which interference voltages could be induced by an HLS

10.3.15 Tone signals

Tone signals can be needed to show, in the absence of any other signal, that the HLS is working. They also can be needed as time signals, alarm signals, for communication with staff, or for testing purposes. It is essential that any tone signals used in the system do not include unnecessary high frequency signal components. All signals, particularly those digitally-generated, should be low-pass filtered so that the residual voltage above 5 kHz is at least 40 dB below the signal voltage. Appropriate levels for tone signals, referred to 0 dB = 0,4 A/m or other designed reference value, at the loop reference point(s), are as follows:

a) test tones: –12 dB;

b) administrative tones (time signals and staff messages): –18 dB;

c) emergency tones: 0 dB;

d) confidence tones: –18 dB.

The duty cycle (i.e. the ratio of "on" time to "off" time) should not exceed 1 to 4, in order to reduce heating effects in the amplifier due to operation with an inductive load.

10.3.16 Equalization, other than for compensating loop impedance characteristics

In a sound reinforcement system, equalization is provided to compensate for the frequency characteristics of microphones, loudspeakers and their interaction with the auditorium. In an HLS, only the loudspeakers are absent; the auditorium still affects the characteristics of the sound reaching the microphones. It is likely, therefore, that equalization to compensate for the microphone and auditorium characteristics can provide a useful improvement in sound clarity and intelligibility. The final adjustment of the equalization should involve a panel of hearing aid users.

10.3.17 Multiple loops

Many configurations of multiple loops have been reported in technical and scientific literature concerned with HLS. Some of these do not function as described by their authors, use techniques which are not optimum, are costly to install and/or have undisclosed disadvantages. Any complex loop layout should be constructed as a simple scale model, on which field strength and distribution measurements can be made.

Multiple loops should be used for the following four purposes:

a) to reduce the listening height required for a given degree of uniformity of the magnetic field;

b) to cover an area requiring, for a single loop, a larger loop current than one amplifier can provide;

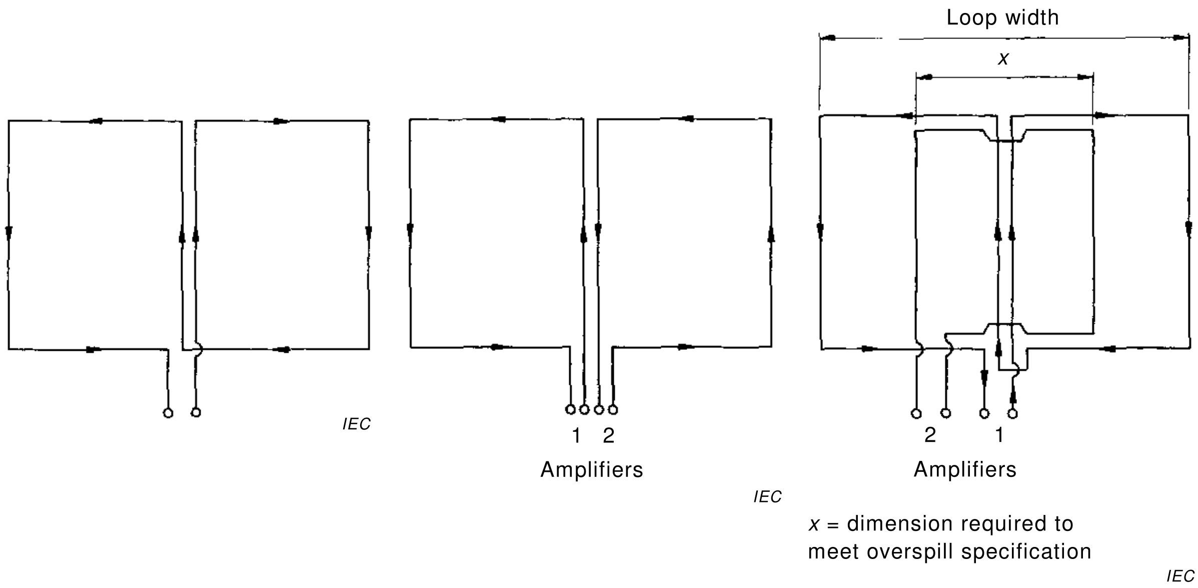
c) to minimize the magnetic field strength in regions outside the coverage area;

d) to improve coverage, when a single loop cannot provide even coverage due to the effects of steel in the building construction.

The layout shown in Figure 16 a), with currents in the adjacent conductors in the *same* direction, produces a field distribution similar to that for each loop separately, which achieves the object of item a). However, since the field distribution for each loop resembles that of a single loop, the field above or below the adjacent conductors is directed horizontally, so that a normal hearing aid produces no output in this zone. It is sometimes suggested that this is acceptable if the null region is located in a centre aisle, but this can cause hearing aid users not to hear emergency announcements.

NOTE 1 If the null region is very localized, as is often the case, this system can be used without difficulty.

The layout shown in Figure 16 b), with currents in adjacent conductors in *opposite* directions, produces a field distribution nearly identical to that of one large loop. This can be seen from the fact that the fields due to the opposing currents cancel, leaving only the fields due to the perimeter conductors. In this case, there are no nulls in the vertical component of the field within the loop, but the listening height has to be that calculated for the large loop. It is possible to combine the techniques of Figure 16 a) and Figure 16 b) if four sub-loops are used.



a) Layout for reducing the actual listening height required for a given degree of uniformity of field strength

b) Layout for covering an area larger than can be served with one amplifier

c) Layout for reducing the field strength outside the coverage area

Loops should never be connected in parallel, because the currents in the loops would be nearly impossible to predict.

Where conductors are shown close together, twin twisted or flat cable should be used. This does not necessarily apply to adjacent conductors of loops 1 and 2 in Figure 16 c).

In Figure 16 a), the adjacent conductors carry currents in the same direction so that their magnetic fields add together. The adjacent conductors in Figure 16 b) carry opposing currents. If these currents are of equal magnitude and phase, the fields generated by the conductors cancel.

The relative current directions in loops 1 and 2 in Figure 16 c) are unimportant, because the currents are 90° out of phase or have a time delay between them.

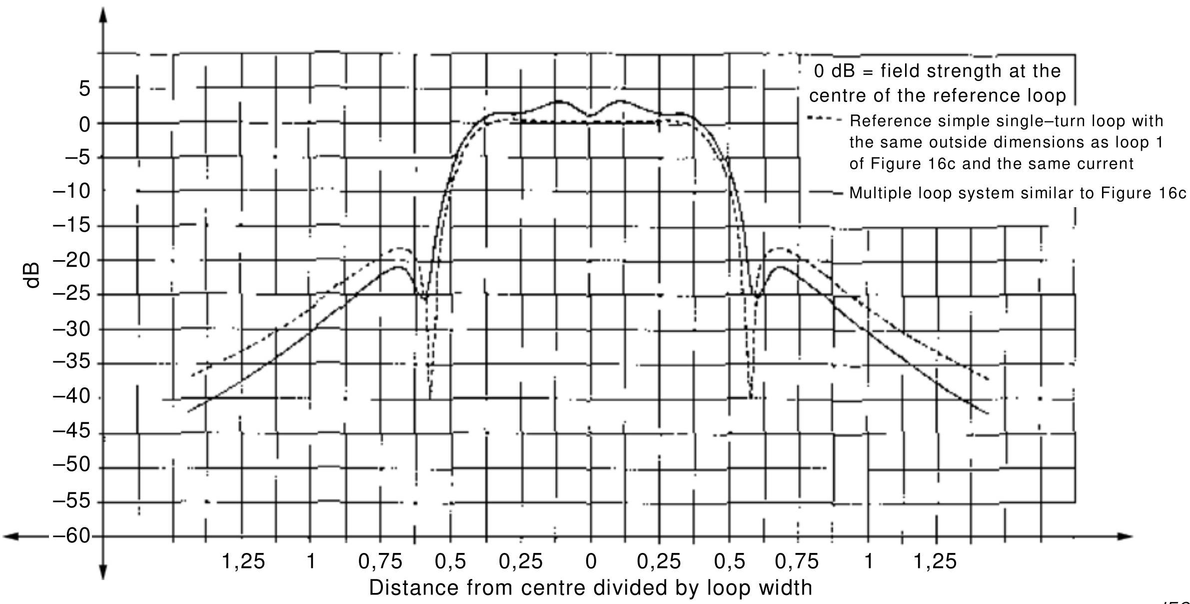
Figure 16 – Multiple loop layouts

While the number of possible loop configurations is clearly infinite, it is considered that in no case similar to the above should the adjacent conductors be separated, as this is liable to introduce unacceptable non-uniformity of the field distribution; twin flat or twisted cable should be used.

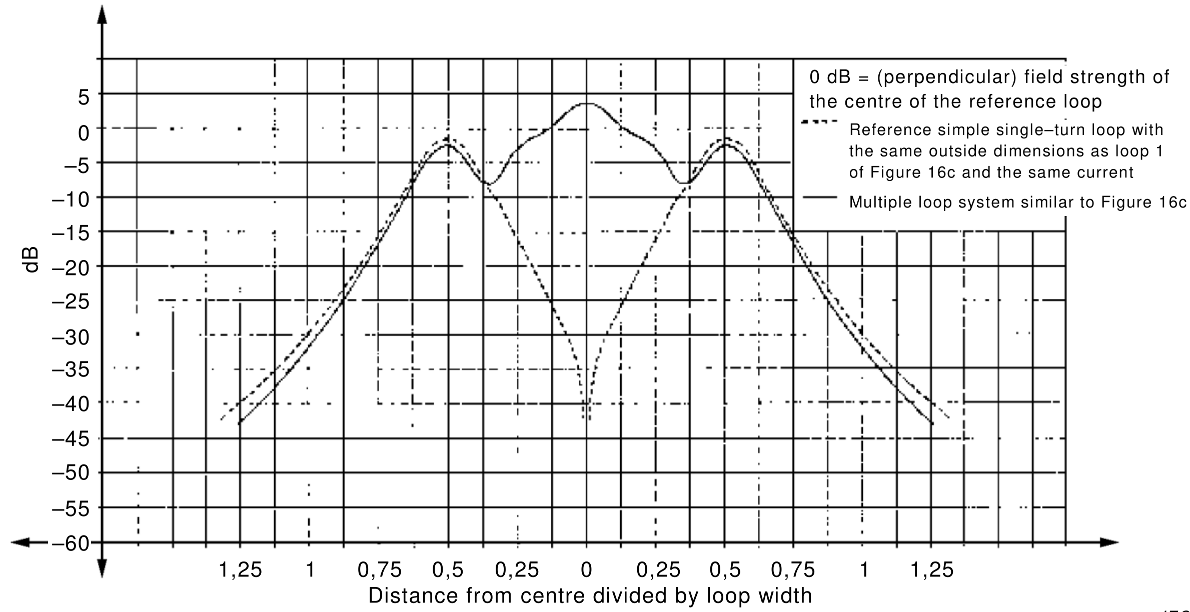
The reduction of the field strength outside the coverage area has been the subject of much study; some proposed solutions require complex loop layouts. A reasonably practicable method is to use groups of loops fed with currents having a 90° phase difference [see Figure 16 c)]. Two amplifiers and a wide-band audio 90° phase-shift network are needed. The principle is explained, with practical results by Olofsson [3]. Design information on suitable wide-band 90° phase-shift networks is given by Williams [4]. It should be noted that according to Olofsson [3], the word "uncorrelated" is mostly used to mean "in quadrature" or "with a 90° phase difference", and that some of the examples of less than satisfactory designs are particularly bad examples.

An illustration of what can be achieved with this technique is given in Figure 17. It should be noted that the horizontal component of the magnetic field is not reduced as much as is the vertical field. This can cause disturbing effects as listeners (including hearing aid users outside the coverage area) change attitude. Within the loop working area, the horizontal field is uniform enough to be usable, if required. An alternative technique mentioned by Olofsson [3] is to use an electronic delay instead of a 90° wide-band phase-shift network. A delay of 10 ms is reported as satisfactory, in spite of producing a comb-filtered frequency response characteristic, with a null at every multiple of 100 Hz. The audible effect of this comb filtering is very small on speech signals.

NOTE 2 The phase difference between the fields due to adjacent loops (90° if a wide-band phase-shift network is used, or proportional to frequency if a time-delay is used) produces a rotating magnetic field in the vertical plane (see [4]). If the vertical and horizontal components of the magnetic field are of approximately equal strength, the directional response of the telecoil (see Figure 5) is partially nullified, and communication can take place irrespective of the body attitude of the hearing aid user, but can vary according to the direction the user is facing.



a) Perpendicular to the plane of the system



b) Parallel to the plane of the system

Figure 17 – Variation across an axis of the system, at a height ratio of 0,32, of the component of the field strength, for a loop system similar to that shown in Figure 16 c), compared with the corresponding variations for a conventional single loop

10.3.18 Protection of loop conductors

Insulated and sheathed cable or cable conforming to recognized international documents might in many cases need no further protection, if sited out of reach. In other cases, and particularly if unsheathed equipment wire is used, protection by means of rigid plastics tubing, or equivalent, should be provided. It has been shown that non-magnetic metal sheathing or tubing (for example in the form of mineral insulated copper sheathed (MICS) cable), as can be needed in extreme environments or to minimize the risk of spread of fire, has very little effect on the magnetic field, provided that the sheathing does not form a complete circuit around the perimeter of the loop. The cable should be of the plastics sheathed type, earthed at one point only, and suitably identified so that it is not used as an earth continuity conductor when mains supply wiring is subsequently modified.

10.3.19 Automatic gain control (AGC), compression, limiting, noise gating and voice control

10.3.19.1 Explanation of techniques

It is necessary to distinguish carefully between these rather similar techniques, because incorrect application can have serious consequences.

AGC is a technique which automatically controls the gain of an amplifier so that the output voltage remains practically constant even though the input voltage varies (above a certain threshold value). To be effective, the system should have a fast attack time, of the order of 100 ms, with a peak detector. The release time should be much longer, of the order of several seconds.

Compression is a technique which changes the gain of an amplifier (above a certain threshold input voltage) from a constant value to a value proportional to a fractional power (e.g. the square root) of the input voltage. The attack time can be short enough to follow the signal waveform approximately (e.g. 50 µs), while the release time is normally much longer, up to a few seconds.

Limiting is a fast-acting technique, in which the peaks of the output voltage are removed. This can result in much distortion, and the production of radiated interference, but there are techniques which produce only reasonably acceptable amounts of distortion (e.g. "soft clipping") and which are not likely to cause interference.

Noise gating is a technique which considerably reduces the amplifier gain (perhaps slowly) when the input signal falls below a threshold level for several seconds.

Voice control is a technique which holds the amplifier gain at a low value until a signal exceeding a threshold level is received, when the gain is rapidly increased to a pre-set value. The technique is also often described as "automatic microphone mixing" or "automatic microphone control".

10.3.19.2 AGC

AGC is useful in microphone amplifiers to compensate for quiet or distant talkers, while compression or limiting can be used to reduce the peak-to-mean ratio of programme signals so as to reduce amplifier demands. This should not be carried too far; a peak-to-mean ratio of about 9 dB should be preserved, in order to prevent speech sounding too strident.

10.3.19.3 Noise gating

Noise gating is useful if acoustic noise is relayed by the HLS at a level which is annoying in the absence of wanted signals. Voice control is useful in that it enables some systems to operate satisfactorily without the need for an operator to switch microphones on and off.

10.3.20 Signal-to-noise ratio

An HLS that produces the correct magnetic field strength and the correct frequency response can still be unsatisfactory if the signal-to-noise ratio is inadequate. Noise in the absence of signal can be annoying if too loud, and noise in the presence of wanted signals reduces intelligibility. It is known that, to reflect accurately the results of subjective tests with persons of normal hearing, these two effects should be measured with different meters and frequency weightings. Noise alone should be measured with a true RMS meter and A-weighting, while the disturbing effect of noise in the presence of a wanted signal should be measured by means of a quasi-peak meter and psophometric weighting. In the absence of reports of subjective tests with hearing-impaired persons, the above methods should be used. For most types of noise, the psophometric method gives less favourable values, by a margin of 6 dB to 14 dB or even more, depending on the spectrum of the noise signal.

Noise in an HLS comes from the following three sources:

a) electrical noise, generated in microphone amplifiers, etc.;
b) acoustic noise, picked up by the HLS microphone(s);
c) magnetic noise (interference), mostly from mains-powered electromagnetic equipment, such as transformers, motors and inductors in fluorescent lighting control gear.

Electrical noise should not be a problem with well-designed equipment, but care should be taken not to operate amplifiers at unnecessarily low signal levels, as this can significantly reduce the signal-to-noise ratio. Careful adjustment of gain distribution in the system might be necessary to prevent overload (clipping), while maintaining a high signal-to-electrical noise ratio.

Acoustic noise should be reduced to a practicable minimum, bearing in mind that the noise should be assessed by measuring and listening to the signal picked up by the microphones, as this can be more affected by air-conditioning noise, for example, than by the sound in the body of the auditorium. An HLS cannot provide the degree of discrimination against unwanted sound that normal binaural hearing does. If necessary, noise gating can be used in the amplifier to reduce noise in the absence of wanted signals.

Magnetic noise normally occurs as a mains power frequency (normally 50 Hz or 60 Hz) signal with strong harmonic components, especially at odd multiples of the fundamental frequency. Such a signal can produce very different results when measured with a true RMS meter and A-weighting, compared with those obtained with a quasi-peak meter and psophometric weighting. The shape of the overall frequency response of the HLS and hearing aid tends to emphasize the harmonics, and the psophometric measurement gives more realistic results under these conditions. Noise gating cannot reduce magnetic noise, which would be picked up directly by the hearing aid even if the HLS were not present.

Research by Zurek and Delhorne [5] has suggested that in the absence of reverberation, normal, mildly and moderately sensorineurally-impaired subjects behave similarly with respect to consonant reception (which mostly determines intelligibility) when presented with signals of equal audibility (i.e. at the same level with respect to the individual's (shifted) threshold). In the context of HLS, the audibility should be secured by the action of the hearing aid in presenting an appropriate sound pressure level to the ear. The signal-to-noise ratio which is then acceptable is, according to [6], similar for mildly and moderately sensorineurally-impaired subjects as for normal subjects, and for the latter a signal-to-noise ratio (psophometric) of at least 26 dB, referred to the signal level measured with a peak programme meter (PPM), is generally considered acceptable. This ratio normally corresponds to a signal-to-A-weighted noise ratio (the signal level being measured on a PPM) of between 30 dB and 40 dB, depending on the noise spectrum.

Harris and Swenson [6] indicate that the combined effects of reverberation and noise are complex, and can depend on the individual talker and listener, independent of conventional measures of the listener's hearing status. In general, moderate to severe hearing loss results in great sensitivity to reverberation in the presence of noise, and in cases of severe loss, reverberation by itself is very destructive of intelligibility. It is therefore essential to minimize the reverberation content of the signal applied to the loop.

10.3.21 HLS for purposes other than assisted hearing

HLS are increasingly being used for communication with persons of normal hearing, for example for private signalling to staff and for commentaries at exhibitions. For speech-only communication, there is no reason to extend the frequency response of the system above 5 kHz (compare, for example, the public telephone system bandwidth of 3,4 kHz, and that of AM radio of less than 4,5 kHz). In some cases, however, realistic music reproduction is required, which demands equalization in the receiver. An extended overall bandwidth can then be obtained without extending the bandwidth at the sending end (i.e. still allowing the magnetic field strength to fall by 3 dB at 5 kHz), by relaxing the equalization above 5 kHz. This reduces the signal-to-magnetic noise ratio at very high frequencies, which is rarely a problem, whereas extending the bandwidth at the sending end can cause increased EMC problems.

10.4 System components

10.4.1 Final amplifiers

NOTE 1 The term "final amplifier" is used in preference to "power amplifier" because the function of the amplifier is not primarily to deliver power to the load.

NOTE 2 The term "integrated amplifier" is used to mean a combination of a final amplifier and a preamplifier or mixer in the same enclosure.

Distortion should not be a problem with modern amplifiers of good design, provided clipping does not occur. In the working range, the total harmonic distortion should not exceed 1 % under any conditions, or 5 % if AGC or "soft clipping" is used.

NOTE 3 See also Annex E.

In connection with the need to provide sufficient voltage and current to the loop, it is important that built-in protection circuits in the amplifier do not malfunction, so reducing the maximum voltage and/or current available to meet the requirements of highly reactive loads associated with loops of low normalized resistance. A method of determining this is given in IEC 60268-3 (see also Baxandall [7]).

To reduce the risk of hum problems due to earth loops, the connection of the safety earth conductor to the metalwork of a safety class I amplifier should not be shared with any other connection, least of all a high-current return connection for the power supply. Any switching, or removable links, intended to separate "technical" and "safety" earths, should not compromise safety.

Except for household systems, inputs for microphones should preferably be balanced, and should preferably employ magnetically-screened transformers, although properly designed electronically balanced circuits are also satisfactory. Signal indicators should be provided for input signals, and for the output current. Preferably, the output current indicator should show whether the current is within the necessary range, either by means of a meter or bar-graph display with scale marks set on commissioning, or by means of, for example, three illuminated indicators with different, pre-set sensitivities. An indicator light should also be provided to show that mains power is "on". Provision should be made for monitoring the signal current in the loop using headphones and/or a loudspeaker.

10.4.2 Preamplifiers and mixers

Inputs for microphones should preferably be balanced, and should preferably employ magnetically-screened transformers, although properly designed electronically balanced input circuits are also satisfactory. Phantom power should be provided for capacitor microphones that require it. The use of user-variable tone controls on individual channels should be minimized; equalizer controls should be set and locked on commissioning. Where a graphic or parametric equalizer is provided, either built-in or as a separate unit, the controls should also be set and locked. The same applies to controls for gain (except where an operator controls the system), AGC and limiting. Signal level indication should be provided to give assurance of correct operation of AGC. Signal level metering should have PPM characteristics; it is usually not necessary to use true RMS metering.

If any but the simplest system is required to work for more than approximately 24 h with no operator present, voice control and or noise gating, together with AGC are recommended.

Connectors for low-level circuits should preferably be of the noble metal plated type.

10.4.3 Signal sources

10.4.3.1 General

The prime technical objectives of an HLS are the improvement in the signal to noise ratio and direct-to-reverberant ratio, in order to improve the intelligibility for the hearing aid user. As such, the choice of the audio source and the choice and positioning of microphones are of paramount importance.

10.4.3.2 Connection to television sets

Some television sets have the circuits in electrical contact with the mains supply. Unless the receiver has external connections for loudspeakers or line-level audio output, it is essential that no attempt is made to connect an HLS to it electrically without first consulting the manufacturer, as the safety certification of the receiver would be violated and a fatal accident could result. HLS kits which use a microphone, or other non-contact means of obtaining the audio signal can be used, in accordance with the manufacturer's instructions, without safety hazard.

10.4.3.3 Interconnection with sound reinforcement systems

Where the room configuration is constant, it can be satisfactory to derive the signal for the HLS from a sound reinforcement system. If so, it should be derived from a low-level output on the mixer or amplifier of the sound reinforcement system. If the loop amplifier is remote from the sound reinforcement amplifier, it can be necessary to include a balanced line driver near the sound reinforcement amplifier and use a balanced interconnecting cable. Level adjustment should be independent of that of the sound system, and the HLS signal should not be subject to the sound system equalization for the room characteristic. It should be made difficult to switch off inadvertently, or to fade down the feed to the HLS. Makeshift methods, such as placing a microphone in front of a loudspeaker, should not be used in a permanent installation.

10.4.3.4 Interconnection with voice alarm systems

Where the HLS is used as a supplementary alarm device to reproduce messages or signals from a voice alarm system, provision should be made to silence or override all other input signal inputs for the duration of the voice alarm message. Some HLS amplifiers have this feature built-in while others require additional equipment for this purpose. A voice alarm system should provide both an audio signal connection and a control connection (usually a switched DC voltage) to the HLS.

The HLS should also provide an indication to the voice alarm system that the amplifier is working correctly and that current is flowing in the loop. This is usually provided by volts-free contacts that open when a fault is detected.

10.4.3.5 Use and siting of microphones

For the best possible intelligibility, the microphone should be as close to the talker’s mouth as possible, for example by use of a headset microphone which can be a wireless microphone.

Where the talker position is predictable, the microphone should be securely fixed and maintained in position.

Especially where the room configuration changes, it can be necessary to provide one or more microphones, and a mixer or mixing amplifier, for the HLS alone. Such microphones should be chosen and sited with a view to obtaining as much direct sound from the original sources as possible, and a uniform loudness balance if there are several sources. Directional microphones normally give better results than omnidirectional types; highly directional microphones require considerable skill and experience in order to achieve consistent loudness, unless the signal levels are continuously monitored and adjusted.

Microphones should be located so as to have a clear "view" of the source they are intended to cover, and should be located away from air conditioning grilles, fans, strong air currents or other potential sources of acoustic noise pick-up, for example fluorescent or theatre lighting, and video projectors.

In order to avoid introducing audibly delayed signals, the difference in path lengths between any source and the two nearest microphones should not exceed 5 m for music or 8 m for speech. Adjacent microphones should not in general be closer together than three times the distance between the microphone and the source of sound.

Microphones, except wireless microphones, requiring internal batteries should not be used, because of the inconvenience of replacing them and the impairment of reliability of the system consequent on failure to replace them before their end of life. Microphones vary greatly in their susceptibility to picking up the magnetic field of the loop. Particularly for dynamic microphones having a non-metallic case, a test for magnetic pick-up should be carried out unless the manufacturer provides adequate assurance of immunity.

If there is no fixed position for a talker in the space, it is advisable to consider wireless microphones or multiple microphones and suitable audio processing such as manual switching, noise gates or automatic mixers to minimize noise. Where questions or comments from an audience are to be relayed via the HLS, specially positioned stand microphones or hand-held microphones managed by staff should be used. It is usually necessary to provide a separate pre-amplification channel for each of these microphones, and for an operator to control the channel gains when the microphones are in use.

If separate microphones are required for the HLS, suitable microphone sites and appropriate types of microphone should be chosen, as far as possible, during the initial assessment, in liaison with the occupier of the building, architect, etc. Alternative sites can require evaluation with the trial loop and an induction-loop monitor receiver.

It is essential that the signal delivered to hearing aid users is as free from reverberation and noise (as well as other forms of degradation) as possible. This is because the single-channel nature of the HLS prevents the listener using the mechanisms of the ear-brain system to distinguish wanted sounds from unwanted. Microphones should, therefore, be positioned as close to the original source(s) of sound as possible, and the output signal of each microphone should be checked by listening for absence of reverberation and noise (short of being completely anechoic) at an early stage, so that any unsatisfactory performance can be corrected. The use of appropriate equalization on an individual microphone channel can considerably help to reduce unwanted room effects and low frequency acoustic noise transmission.

10.4.3.6 Microphone accessories

HLS microphones should be mounted to minimise vibration, impact or similar disturbance (either accidental or deliberate), because hearing aid users can be significantly disturbed by floor noise and noise generated by kicks and handling. Microphones are very susceptible to accidental damage and vandalism, so they should be secured against unauthorized access, especially when the HLS is left unattended.

HLS microphones, except wireless microphones, should not normally be provided with a switch accessible to the microphone user, because of the likelihood of incorrect operation. An exception can be made if only properly trained persons use the microphones, and the switch is not built into or mounted directly on the microphone.

10.4.3.7 Use of several microphones

In general, the fewer the number of microphones in operation at any one time the better the clarity and intelligibility of the wanted signal becomes. Microphones which are not directly picking-up the wanted signal should be switched off. Microphone amplifiers which include voice switching or noise gating are extremely useful when more than one or two microphones are needed and a trained operator is not consistently available.

For systems according to Clause 9 a), the microphone is usually contained within the device. For systems according to Clause 9 b), microphones are used for counter systems, with particular attention to counters where the server and customer are separated by glass and the need for the hearing aid user to hear a proportion of their own voice to help regulate their speech; for help points and signage, the audio source is usually taken directly from the loudspeaker or public address/voice alarm system (see 10.4.3.3).

Where several microphones are used in a space or the talkers move to set locations within a space (such as places of worship), the use of several open microphones increases the background noise, thus lowering the intelligibility of the system.

For theatres, cinemas and places of worship, it is advisable to consider an audience-response microphone for ambience between events and to reassure users the HLS is in operation. This ambient input can be passed through an overridable channel to prevent the performance system audio being picked up by this ambient input and thus reducing the intelligibility.

In small to medium-sized meeting rooms, a boundary-layer microphone located centrally on the meeting table or on the ceiling immediately above it can prove more effective than four or five simultaneously operating cardioid table microphones. However, the maximum distance over which such a device operates effectively is likely to be approximately 3 m only. To improve the direct-to-reverberant sound-pressure level ratio at larger distances than this, the use of a greater number of local microphones should be considered, with the absolute minimum number of microphones being in operation at any given time.

10.4.3.8 Distance between the microphone and the source of sound

It is essential that the signal delivered to hearing aid users is as free from reverberation and noise (as well as other forms of degradation) as possible.

Microphones should be positioned as close to the original source(s) of sound as possible, and the output signal of each microphone should be checked by listening for sufficiently low levels of reverberation and noise at an early stage, so that any unsatisfactory performance can be corrected.

Although it is not possible to give numerical design procedures for determining the maximum permissible distance between an HLS microphone and the wanted source of sound, two primary factors should be jointly taken into account, i.e. general noise and room reverberation.

For talker-to-microphone distances larger than 3 m, use of a number of local microphones should be considered to improve the direct-to-reverberant sound-pressure level ratio, with the absolute minimum number of microphones being in operation at any given time.

Adjacent microphones should not in general be closer together than three times the distance between the source of sound and the closest microphone.

NOTE 1 The further a microphone is located away from the sound source, the weaker the wanted signal becomes. This effectively reduces the signal-to-noise ratio and also reduces the direct-to-reverberant sound pressure level ratio.

The effects of reverberation, however, are additive to noise, and tend to reduce the distance still further. For effective speech intelligibility, a direct-to-reverberant ratio greater than 0 dB is necessary for otologically-normal listeners. For hearing impaired listeners, a direct-to-reverberant sound pressure level ratio of at least +6 dB is usually necessary but this is highly dependent upon a number of factors including size, shape, volume and reverberation time of the room, and the characteristics of any reflecting surfaces.

NOTE 2 For example in an auditorium with a volume of 3 000 m^3 and a reverberation time of 1,5 s, the maximum acceptable distance with two cardioid microphones operating might be as little as 4 m to 5 m.

The directional characteristics (somewhat idealized) of some common types of microphone are shown in Figures 18 to 24. The hypercardioid characteristic gives the maximum rejection of reverberant sound of all simple microphones, while the supercardioid characteristic gives the maximum ratio of front to random energy efficiency. The directional characteristics of highly-directional or shotgun interference-tube rifle microphones vary considerably with frequency (see Figures 22 to 24), and they might therefore pick up considerable low-frequency reverberation: this can be reduced by the careful use of equalization.

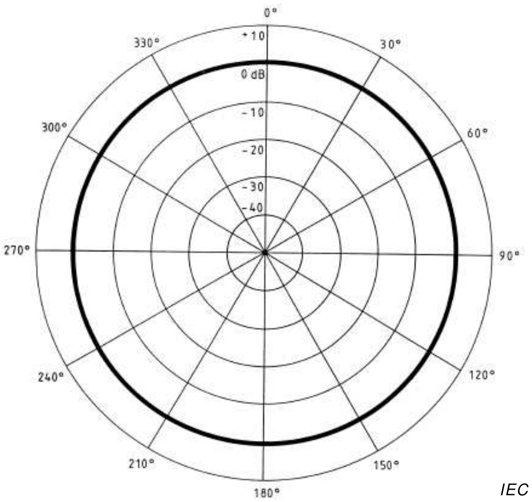


Figure 18 – Horizontal directional response of an omni-directional microphone with its axis vertical: decibel scale

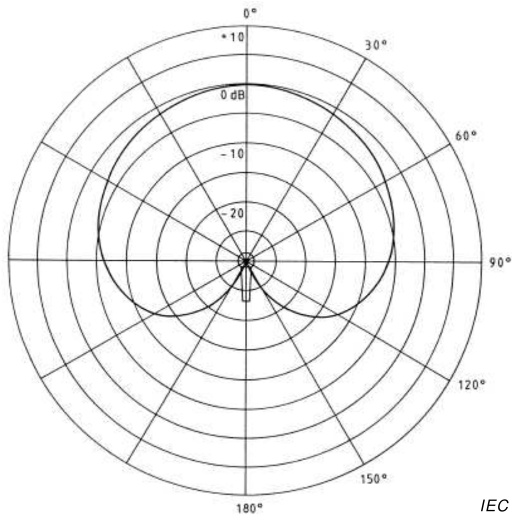
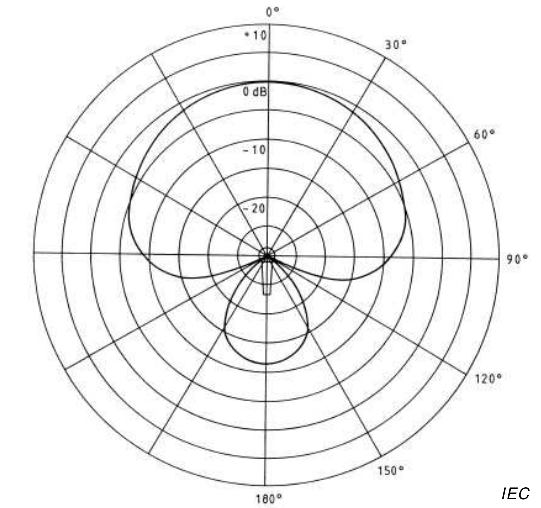
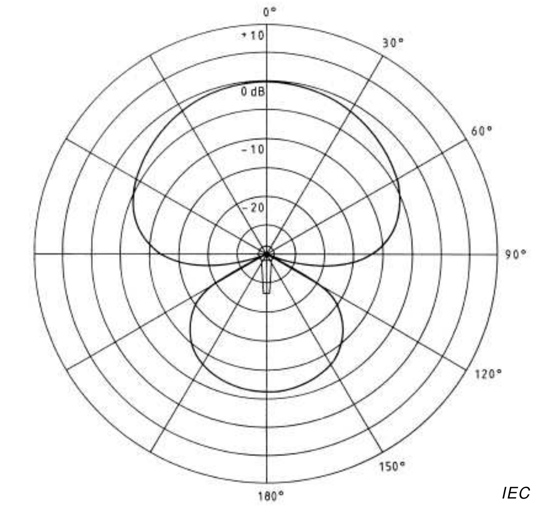


Figure 19 – Directional response of a cardioid microphone: decibel scale



NOTE Some microphones of this type have an approximately cardioid response (see Figure 18) at low frequencies.

Figure 20 – Directional response of a supercardioid microphone: decibel scale



NOTE Some microphones of this type have an approximately cardioid response (see Figure 18) at low frequencies.

Figure 21 – Directional response of a hypercardioid microphone: decibel scale

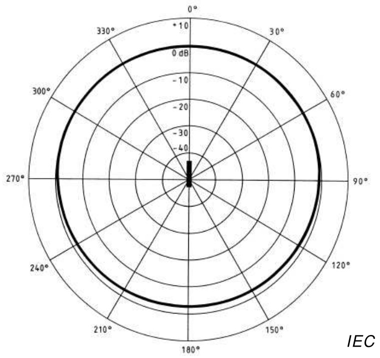


Figure 22 – Directional response of a highly directional shotgun (rifle) microphone where f = 250 Hz and barrel length is 275 mm

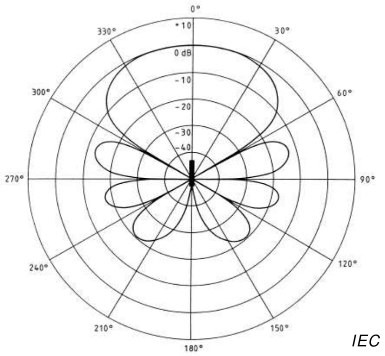


Figure 23 – Directional response of the same microphone where f = 2,5 kHz

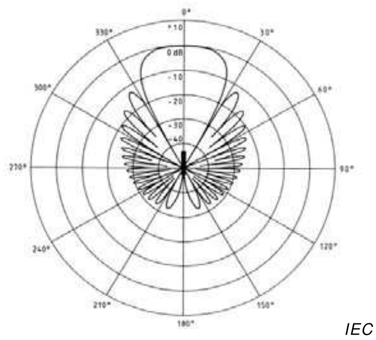


Figure 24 – Directional response of the same microphone where f = 10 kHz

A type of microphone which has low sensitivity to reverberant sound is the boundary-layer (pressure-zone) microphone, in which the microphone capsule is mounted very close to a plane reflecting surface, supplied as part of the microphone. These microphones are designed to be placed in contact with a large flat surface, and owe their reduced sensitivity to reverberation to the confinement (by the large flat surface) of the directional response in three dimensions to half-space, instead of the full-space which applies to other types of microphone. The basic directional characteristic of the microphone capsule can be omni-directional, in which case the three-dimensional directional characteristic is a hemisphere, or a cardioid, giving a three-dimensional pattern in the form of a half-cardioid of revolution.

Figure 25 shows the relative distances from the source of sound at which different types of microphone can be operated, for a given direct-to-reverberant sound pressure level ratio. It is important to minimize the actual distance in all cases, but with a minimum distance of approximately 300 mm, below which breath noise, coloration and large variations in signal level with small changes in distance can lead to degradation of intelligibility. Further information is given in Annex G.

NOTE 3 Figures 27 to 30 show typical examples of good and bad microphone positioning.

Distances in metres

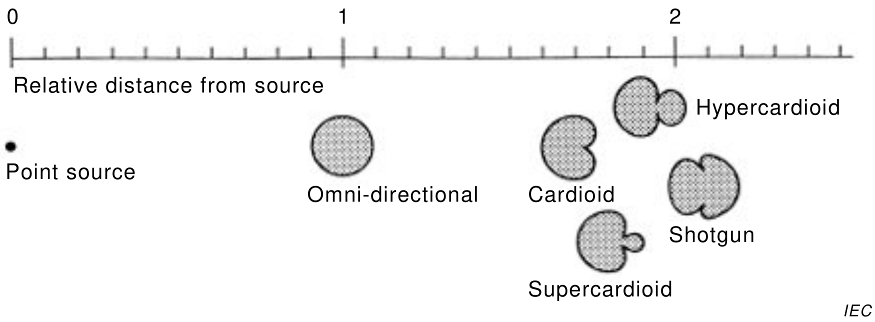
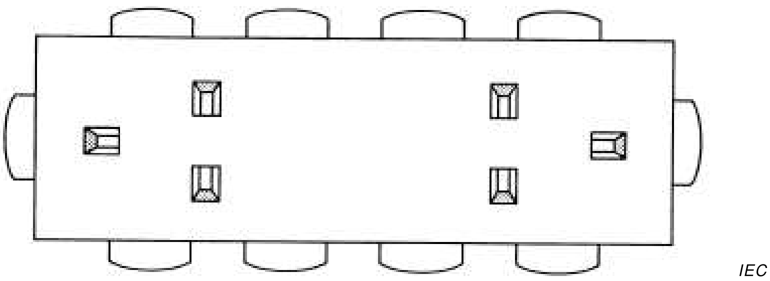


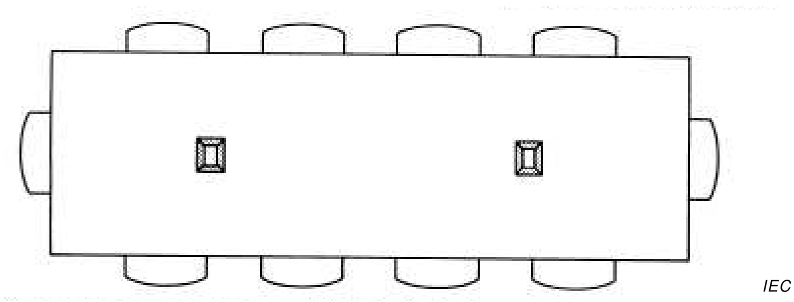
Figure 25 – Relative operating distances of directional microphones for equal direct-to-reverberant signal ratios

Table 2 – Relative operating distances of directional microphones for equal direct-to-reverberant signal ratios

Type of microphone	Distance relative to that of an omni-directional microphone	Approximate angle between the directions at which the response is −3 dB relative to the axial response
Omni-directional	1,0 ×	360°
Cardioid	1,7 ×	130°
Supercardioid	1,9 ×	115°
Hypercardioid	2,0 ×	105°
Shotgun	Depends on the frequency and design of the microphone	Depends on the frequency and design of the microphone



a) Microphones positioned in accordance with the 3-to-1 rule, using cardioid microphones



b) Alternate placement using two omnidirectional microphones

Figure 26 – Two methods of positioning microphones on a conference table

Dimensions in millimetres

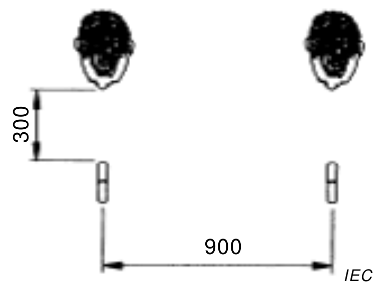


Figure 27 – The 3-to-1 ratio for microphone positioning (normal)

Dimensions in millimetres

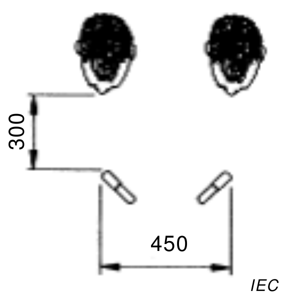


Figure 28 – A reduced 3-to-1 ratio using angled microphones

Dimensions in millimetres

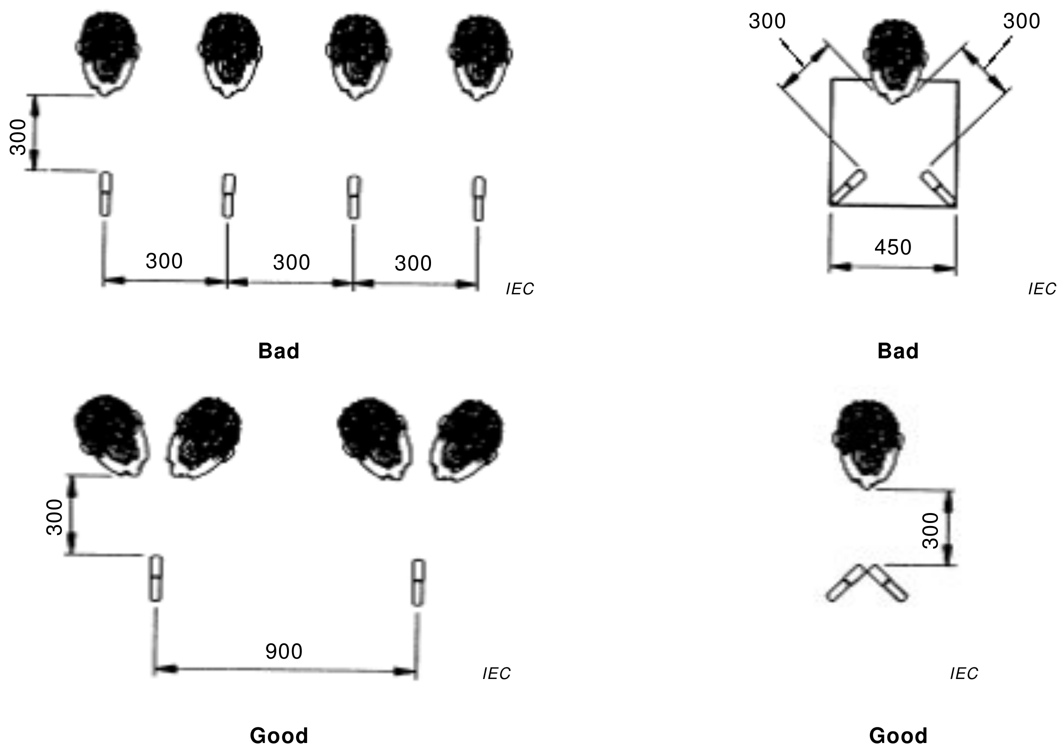


Figure 29 – Illustrations of good and bad microphone placements

The sound wave reflected from a desk top can interfere with the direct sound (as shown in Figure 30) which should be taken into consideration. This effect can cause considerable unevenness in the frequency response above 1 kHz, which can be minimized by positioning the microphone at least 150 mm above the surface. It can be helpful to cover the part of the desk top around the microphone with a layer of soft material.

Dimensions in millimetres

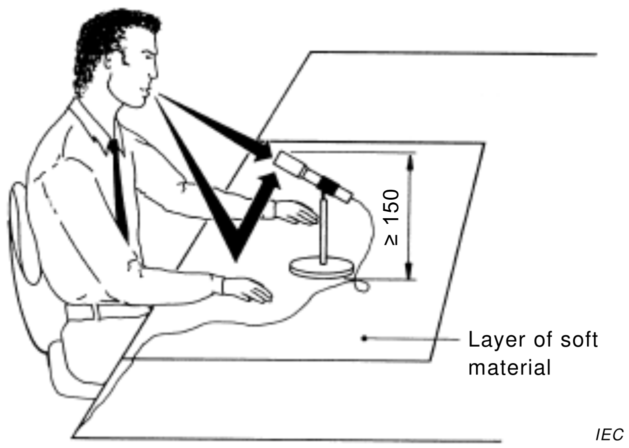


Figure 30 – Optimization of the height of the microphone above the table

10.5 Objective measurement of intelligibility

Several methods currently exist of objectively measuring speech intelligibility, one of which is the speech transmission index (STI) (as described in IEC 60268-16). The STI method can be used to measure the potential intelligibility of an HLS, by using a calibrated telecoil receiver instead of a measuring microphone. For hard-of-hearing users, an STI value of at least 0,65 is normally the minimum acceptable level. The STI technique takes into account both reverberation and noise, but not perceptual effects associated with hearing loss; relevant research is on-going. The technique presupposes that the HLS meets the frequency response criterion of a maximum variation of ±3 dB over the range 100 Hz to 5 kHz.

The recommended procedure is to use the STIPA method (described in IEC 60268-16) with acoustic input.

10.6 Safety and reliability considerations

In the design and installation of an HLS, emphasis should be placed on the safety and reliability of the system. It is essential that the completed HLS should not create a safety hazard to either those working in or those using the building in which the system has been installed. Electronic equipment used in HLS should conform to IEC 62368-1. For exposure to electromagnetic fields, see IEC 62489-2.

A portable or mobile HLS (see Clause 9), which is likely to be handled frequently, usually requires the use of cables which are particularly flexible and resistant to conductor damage due to bending.

10.7 Designing for monitoring and maintenance

The system designer should specify the number and type of induction-loop monitor receiver(s) (see Annex A) to be supplied with the system, together with the siting of any fixed receiver(s).

The system designer should also ensure that the system is designed so that maintenance requirements are minimized and are as simple as possible. It can be false economy, for example, to specify inexpensive microphone cables and connectors, if they prove to require frequent repair.

Adequate maintenance information should be supplied to the purchaser of the system.

10.8 External factors

10.8.1 Magnetic noise interference

Magnetic fields radiated from electric transport vehicles and systems, mains power cables and overhead and underground power lines or cables and equipment can be picked up in most buildings on a hearing aid switched for use with a loop system (T position). Where the field is at a low level of intensity, it is not normally troublesome. However, under certain circumstances the field strength can be sufficiently high to interfere with the signal picked up from the induction-loop, causing annoyance to the listener and in some cases making it impossible to use the loop system. Serious magnetic interference can be caused by the separation of live and neutral conductors (or of phase conductors) of mains circuits, which is particularly found in old buildings where numerous changes have been made to electrical installations. Magnetic interference is also a problem in newer buildings where loop circuits have been installed in rooms with suspended ceilings and the fluorescent lighting circuits have an interlinked neutral instead of each lighting circuit having an individual neutral. Such wiring is not in accordance with power installation requirements based on IEC 60364 (all parts). Other examples of sources of magnetic interference are fluorescent and other types of discharge lamps, electronic lamp dimming systems and faulty mains power wiring.

For the limits on magnetic noise level, see IEC 60118-4.

NOTE It can be impossible to test or to predict the magnetic interference in new buildings until these are completed and the electrical installation is in use.

10.8.2 Effect of metal in the building

The performance of the HLS can be seriously degraded if there is metal (which might be concealed) in the building. Local degradation of the performance can also occur near large metal objects or constructions within the coverage area. For new builds, the building designers should provide detailed drawings and information regarding structural metal and sheet metal in the vicinity of all HLS.

While the degradations are difficult to predict, the customer should be made aware of their likely or potential impact. Site measurements of the effect of metal in the building structure on magnetic fields should be considered as part of the design procedure, and any detrimental effects reported to the customer.

10.9 Magnetic field overspill

Since the magnetic field produced by an induction-loop is not entirely confined to the area within the loop, signals can be picked up on a suitably equipped hearing aid or receiver outside the room or the building in which the loop is installed, or even in an adjacent public road or area. Care should be taken to ensure that confidential information is not fed into the HLS as it can be possible to hear this information with a suitable receiver some distance outside the loop.

This "overspill" can cause difficulties when two or more loop systems in close proximity to each other are in operation simultaneously, as listeners to one of the loops might also hear overspill signals from the other. For example, an HLS installed in a theatre auditorium might interfere with the intelligibility of an HLS installed at the box office (interference in the other direction is much less likely).

HLS can be designed to greatly reduce the field strength outside the space where the system is intended to be used. It is not practicable to recommend limits on overspill field strength as the acceptable strength depends on many site-specific factors. The requirements for overspill should be specified contractually in each case in which it is necessary.

10.10 The role of the system designer in commissioning

If the system designer supervises the commissioning, he should work from a check-list, which provides a written record of the procedure followed. If the commissioning is undertaken by someone else, the system designer should provide a recommended commissioning procedure for the benefit of the installer and purchaser of the HLS. This should detail the steps in the procedure so that the commissioning procedure can be systematically and correctly carried out. Specific points should be highlighted where care is necessary or difficulty might be experienced. The document should also give the full performance specification, with reference to this document, to which the system is expected to conform and details of the verification tests which should be carried out.

11 Responsibility of the installer

The work associated with installation of the HLS equipment in a building might be undertaken by the same organization that designed the system or by a different organization. For example, the designer and installer might be a single, specialist HLS contractor. Alternatively, the purchaser might be responsible for the design of the HLS (which might be undertaken by consultants acting on behalf of the purchaser), and the design might then be communicated, by means of a specification and/or drawings, to a specialist HLS contractor or to an electrical installation contractor, which would, in either case, then be responsible for installation.

Various contractual arrangements are possible but it is important that one organization is responsible for compliance with this document and that this responsibility is agreed prior to the start of the installation contract.

It is not, in general, the responsibility of the installer to check or verify whether the design of the system complies in full with these recommendations, unless the installer is also the designer. The responsibility of the installer is to install the system in accordance with the requirements of the design specification and to follow good practice in the installation work. However, in practice, compliance with a number of the recommendations impacts on both design and installation, and might, therefore, be delegated by the designer to the installer, provided the responsibility for compliance is clear in any specification or contract, that the installer is competent to address the issues and that the responsibility is accepted by the installer. For example, the designer can delegate decisions regarding cable routes to the installer, by simple reference in the design to comply with Clause 11.

At the design stage, the designer might have inadequate information to enable compliance with all the recommendations. For example, drawings on which the design is based might not show sufficient information about structural features or final fittings of the building to enable the design to conform to IEC 60118-4 in respect of field strength and bandwidth. Accordingly, it is often necessary for compliance with certain recommendations, or verification of compliance, to rest with an installer.

Even though identification of design shortcomings is not generally the responsibility of an installer, good practice dictates that, if the installer is aware of such shortcomings, particularly those arising from features of the building that might not have been known to the designer, they ought to be drawn to the attention of the designer, user or purchaser.

HLS can be used for multipurpose venues, and controls can be provided for reassigning or reconfiguring the equipment. Care is needed to ensure that access to these controls does not unnecessarily include access to critical controls such as loop drive.

The responsibilities associated with the installation of the system should be clearly defined, agreed and documented prior to the commencement of work.

In particular, the following points should be considered.

a) All cables should be carefully laid and secured in order to avoid the possibility of tripping. The installation of mains wiring and protective devices used in HLS should conform to the applicable regulations for mains power installations.
b) The loop conductor(s), microphone and other signal cables should be regarded as Category 2 circuits as defined in the applicable regulations for mains power installations and should be segregated from mains and other cables in Category 1 circuits in accordance with the applicable regulations for mains power installations.
c) Loop cables should be clearly identified with the HLS symbol for the benefit of painters and other trades people, particularly in order that the purpose of the cables cannot be mistaken.
d) Loop equipment should be located where it is easily accessible to authorized personnel, and it should not be positioned so that access to it might be awkward or dangerous.
e) A detailed wiring diagram for the system should be placed on or close to the loop equipment to ensure that it can be correctly reconnected, should it need to be moved.

The installer should ensure that

- adequate space is provided around the equipment for access,
- the structure can accept the weight of the equipment, and
- adequate cooling/ventilation is provided to keep the equipment within its rated temperature range.

The installation of microphones should be in accordance with the recommendations of Clause 11.

All metallic parts of the installation, including conduit, trunking, ducting, cabling and enclosures, should be separated from any metalwork forming part of a lightning protection system.

NOTE Further guidance is given in IEC 62305 (all parts).

The installer should provide as-fitted drawings which include, at least

a) the positions of all HLS equipment,
b) the positions of all loop cables including the type, sizes and actual routes of cables,
c) the position(s) of microphone(s), and
d) the positions of all equipment that might require routine attention or adjustment.

The cable routes shown should comprise a reasonable representation of the route followed to enable a competent person to locate the cable in the event of a fault or need for modification or extension of the system; a simple schematic showing the sequence in which devices are wired is unlikely to satisfy this recommendation, other than in small, simple systems.

In the case of extensions or alterations, existing as-fitted drawings should be updated.

On completion of the installation work, the installer should issue a certificate in accordance with the model given in Annex H, signed by a competent person.

The installer of the mains supply can be required by local documents or regulations to issue an electrical installation certificate in the specified form.

A designer might accept responsibility for variations from any of the above recommendations and communicate this in the form of specific written requirements (e.g. within a specification). In this case, the installer should record the relevant variations within the installation certificate issued by the installer.

12 Installation practices and workmanship

The nature and quality of the installation work needs to be such as to maintain the integrity of the HLS and minimize the duration and extent of disablement of the system during maintenance or modifications. Penetration of construction (e.g. for the passage of cables, conduit, trunking or tray) has to be made good to prevent the free passage of fire or smoke, regardless of whether the construction has a recognized degree of fire resistance.

Cables that are directly fixed to surfaces should be neatly run and securely fixed at suitable intervals, in accordance with the recommendations of the cable manufacturer. Cables should not rely only on suspended ceilings for their support. The installer should ensure that all wiring and cable types conform to the design documentation.

Cables should be installed without external joints wherever practicable. All terminations and other connectors should be such as to minimize the probability of early failure. Other than in the case of joints at or within system components such as amplifiers and microphones, terminals and connectors used to joint cables should be constructed of materials that will withstand a similar environment and be of similar durability to that of the cable. All joints, other than those within system components, should be enclosed within junction boxes, labelled with the HLS symbol to avoid confusion with other services. Copper foil tape is often used under carpets and vinyl flooring; this can be identified using printed tape identifying it as an HLS loop cable.

Arrangements for earthing should be in accordance with the recommendations of the manufacturer. The loop cable should *not* be earthed unless the amplifier manufacturer explicitly states that it should, or can, be earthed. Otherwise, serious damage to the amplifier is very likely to result.

Where a cable passes through an external wall, it should be contained in a smooth-bore sleeve of metal or other non-hygroscopic material sealed into the wall. This sleeve should slope downwards towards the outside and should be plugged with a suitable non-hardening waterproof compound to prevent the entry of rain, dust and vermin. Where a cable passes through an internal wall, a small clearance hole should be provided. If additional mechanical protection is necessary, a smooth-bore sleeve should be sealed into the wall. Care should be taken to ensure that the ends of any sleeves are free from sharp edges which might damage cables during installation. When a cable, other than a floor-level loop cable, passes through a floor, the recommendations above should be applied. The sleeve should extend as far above floor level as is required to provide adequate protection of the cable, but never less than 300 mm.

Where cables, conduits, trunking or trays pass through floors, walls, partitions or ceilings, the surrounding hole should be as small as reasonably practicable and made good with fire stopping materials that ensure that the fire resistance of the construction is not materially reduced. Spaces through which fire or smoke could spread should not be left around the cable, conduit, trunking or tray.

If cables or conduits are installed in channels, ducts, trunking or shafts that pass through floors, walls, partitions or ceilings, barriers with the appropriate level of fire resistance should be provided within the channels, etc., to prevent the spread of fire unless, in the case of ducts and shafts, the construction of the duct or shaft affords equivalent fire resistance to the structure penetrated; in the latter case fire stopping need only be provided where cables pass into, or out of, the duct or shaft.

13 Inspection and testing of wiring

On completion of wiring, or sections of wiring, the installer should carry out tests to ensure the integrity of cable insulation and adequacy of earthing. Usually, the tests on cables are carried out with equipment disconnected and prior to completion of the entire system. Further tests need, therefore, to be carried out on completion of the system and these tests form part of the commissioning process.

These tests should be completed while the loop wire is accessible and before any floor coverings etc. are fitted. For complex loops, especially multi-loop systems, it is strongly recommended to test the system with amplifiers equivalent to the equipment planned for the system. The tests should include field strength and frequency response over the design area. Signal-to-noise measurements should also be completed if the electrical installation has been completed.

All installed cables with a manufacturer’s voltage rating suitable for mains use should be subject to insulation testing at 500 V DC. Prior to this test, cables should be disconnected from all equipment that could be damaged by the test.

Insulation resistance, measured in the above test, between conductors, between each conductor and earth, and between each conductor and any screen, should be at least 2 MΩ.

Continuity of all circuits should be tested.

Earth continuity and, for mains supply circuits, earth fault loop impedance, should be tested to ensure compliance with applicable regulations.

The following should be tested on completion of the installation work, after connection of all loops, unless there is specific agreement that they will form part of the commissioning process:

- if possible, the impedance of each loop circuit at 1 kHz in class A3 and A4 systems; if not possible, the DC resistance of each loop circuit should be measured and recorded;
- correct polarity of circuits where this is required in class A4 systems;
- any other tests specified by the manufacturer of the system.

The results of all tests should be recorded and made available to the organization responsible for commissioning the system.

14 Commissioning

The process of commissioning involves thorough testing of the installed HLS to ensure that it operates correctly in accordance with the recommendations of this document and with the specification. At completion of commissioning, it also needs to be confirmed that all relevant documentation has been handed over to the user. The organization responsible for commissioning the system might, or might not, be the same organization that designed and/or installed the system, but the responsibility for commissioning needs to be clearly defined prior to the start of the installation work.

It is not, in general, the responsibility of the commissioning engineer to verify compliance of the design, or of the installation work. The responsibility of the commissioning engineer is to verify that the system operates correctly in the manner designed and that the installation workmanship is generally of an adequate standard. However, in practice, it might be difficult to ensure that the system complies in full with all recommendations until the time of commissioning. For example, commissioning might represent the first (and only) opportunity to ensure that structural features of the building, of which the designer might have been unaware, do not compromise the effectiveness of the system as it was originally designed.

The system (if not of class A1) should be commissioned by a competent person, who has access to the requirements of the designer (i.e. the system specification) and any other relevant documentation or drawings.

NOTE The performance of systems of type A1 is fixed by design and commissioning is not appropriate.

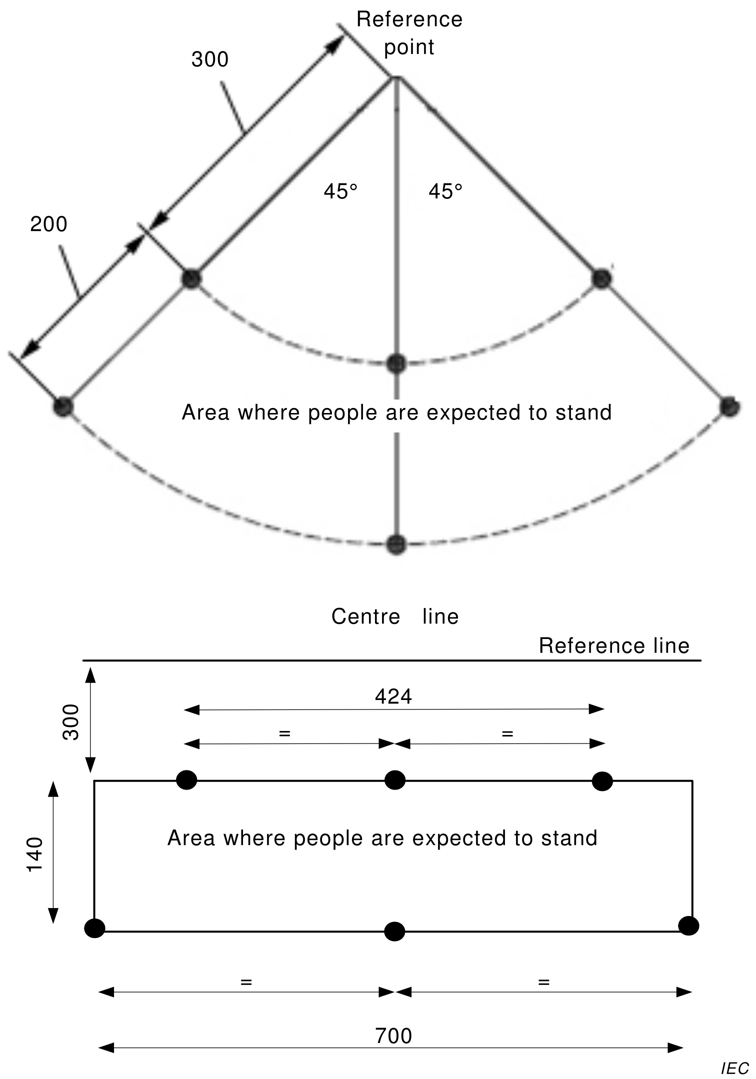
Any person responsible for commissioning an HLS in accordance with the recommendations of this document should possess a thorough knowledge and understanding of the applicable documents, IEC 60118-4 and IEC 62489-1.

At commissioning, the entire system should be inspected and tested to ensure that it operates satisfactorily and that, in particular:

a) magnetic field strengths, frequency responses and signal-to-noise ratios conform to the requirements of IEC 60118-4. Testing of class A2 systems should be performed at the points specified in Figure 31, at heights above the floor of 1,2 m and 1,7 m. In accordance with Annex A of IEC 60118-4:2014, the measured field strength levels should be within ±4,5 dB when 400 mA/m is achieved at one point at least. At a height of 1,45 m, the field strength level can be greater than +4,5 dB ref. 400 mA/m (but should not exceed +8 dB ref. 400 mA/m), as this can overload some hearing aids;
b) an acceptable level of intelligibility is achieved throughout the useful magnetic field volume;
c) no changes to the building since the time of the agreed design have compromised the conformity of the system to this document (e.g. by erection of new partitioning or metal structures that affect the effectiveness of the HLS);
d) mains power supplies are inspected as far as reasonably practicable to ensure compliance with relevant regulations;
e) all relevant documentation has been provided to the user or purchaser;
f) on completion of commissioning, a certificate signed by a competent person in accordance with the model given in Annex H has been issued.

All results obtained during the commissioning process should be clearly recorded.

Dimensions in millimetres



The upper figure is appropriate for magnetic field sources of small dimensions; the lower figure is more suitable where a larger vertical loop is used.

The reference point or line, and the centre line, establish the geometry of the drawings. Because of the diversity of mounting arrangements for the source of magnetic field and the range of physical dimensions, it is not possible to relate the measuring points to its position. The area where people are expected to stand should be determined first and the position of the reference point or line determined from it.

It is recommended to indicate on the floor the area where people are expected to stand.

NOTE The source of the magnetic field is not necessarily positioned where the "reference point" or "reference line" is defined – these are just used as references to determine where the user is likely to be positioned, and hence where the field strength needs to be controlled. The source itself is typically further away from the user than the reference point or line is, in order to achieve an acceptably low gradient of field strength levels, but the actual distance is likely to be limited by the physical characteristics of the installation.

Figure 31 – Measuring field strength of type 2 HLS – Plan views

15 Documentation

On completion of the system, adequate records and other documentation have to be provided to the user or purchaser (the user and purchaser might, or might not, be the same organization). The responsibility for provision of the documentation might rest with more than one organization and needs to be defined before an order for the system is placed. On completion of commissioning, it needs to be ensured that, either the documentation has been provided to the relevant parties, or that any absent documentation is identified for appropriate action (see Clause 14 above).

Particular importance needs to be attached to the preparation and accuracy of "as fitted" drawings and operation and maintenance manuals. The manuals need to be adequately specific to the system. Without these drawings and manuals, maintenance or future modification of the system might be difficult.

The following documentation should be provided to the purchaser or user of the system:

a) certificates for design, installation and commissioning of the system;
b) an adequate operation and maintenance manual for the system; this should provide information, specific to the system in question, regarding the following:
   1) a list of equipment provided and its configuration (e.g. schematic diagram);
   2) use and operation of the system;
   3) service and maintenance of the system;
   4) the importance of ensuring that changes to the building, such as relocation of partitions, and new metal structures do not affect the document of coverage in the space;
c) "as fitted" drawings indicating at least the following:
   5) the positions of all HLS equipment;
   6) the positions of all microphones;
   7) the type, sizes and actual routes of cables;
d) a log book for recording tests and checks performed on the system, maintenance of the system and changes to the system;
e) a record of any agreed variations from the original design specification;
f) records as are specified in Clauses 15 to 17.

The contract for design, supply, installation and commissioning of the system needs to define the type of documentation which is to be provided by each organization involved.

The cable routes shown need to comprise a reasonable representation of the route followed, such as to enable a competent person to locate the cable in the event of a fault or need for modification or extension of the system; a simple schematic showing the sequence in which loops are wired is unlikely to satisfy this recommendation, other than in small, simple systems.

In some complex buildings, a cabling schedule cross-referencing the drawings can be necessary in order to help explain the cable routes.

In the case of extensions or alterations, existing "as fitted" drawings have to be updated.

16 Certification

On, or as soon as practicable after, completion of each of the following processes, a certificate should be issued by the organization responsible for the process, certifying compliance with IEC 60118-4 and the recommendations of this document in respect of the process or, if variations exist, clearly identifying these variations:

a) design;
b) installation;

c) commissioning.

Model certificates of design, installation, commissioning, acceptance and verification are contained in Annex H.

The certificate issued for any of these processes can vary in format from that shown in Annex H but, as a minimum, the information and statements of conformity within the model certificates should be provided.

These processes might be undertaken by one organization, or might be carried out by independent organizations, whichever arrangement applies, and three separate certificates ultimately need to be issued. It needs to be possible for an organization to issue a certificate for the process for which they are responsible, regardless of whether a certificate has been issued for either of the other processes.

It is essential that the person(s) who sign(s) these certificates is competent to verify whether the recommendations of this document in respect of the process to which the certificate refers have, or have not, been satisfied. The purchaser or user might, subsequently, rely on the certificate as, for example, evidence of compliance with legislation. Liability could arise on the part of any organization that issues a certificate without due care in ensuring its validity.

Where modifications are carried out to a system, the purchaser should require that the organization responsible for the work issues a new commissioning certificate.

If a system is modified or a new system is installed, it might also be necessary to check for overspill effects to and from any other HLS in proximity.

17 Acceptance

On completion of the system, arrangements need to be made for formal handover of the system to the purchaser or user, and formal acceptance of the system by the purchaser (or representative of the purchaser).

Before accepting the handover of the system, the purchaser or a representative needs to ensure that they are satisfied with the installed system, and that the user has an adequate understanding of the operation of the system. In the case of small, simple systems, or systems installed in the premises of small organizations with little relevant in-house expertise, acceptance might involve little more than a brief inspection of the system by the user, demonstration of its operation by the commissioning engineer, and handover of the relevant documents to the user. In large, complex systems, it is likely that the purchaser would wish to witness relevant tests, as part of a formal and structured acceptance procedure.

As evidence of acceptance, an acceptance certificate needs to be signed by the purchaser.

Acceptance procedures should be carried out in accordance with the agreed purchase specification, including any tests that are to be witnessed and details of the witnessing procedure.

Before accepting a system, the purchaser (or appropriate representative of the purchaser) should ensure, at least, that

a) all installation work appears to be satisfactory,
b) the system is capable of meeting the field strength, frequency response and requirements of IEC 60118-4,
c) the system is capable of giving intelligible broadcasts,
d) the following documents have been provided to the purchaser or user:

- “as fitted” drawings;
- operating and maintenance instructions;
- certificates of design, installation and commissioning;
- a log book to record the periodic testing of the system;

e) sufficient representatives of the user have been adequately trained in the operation of the system,

f) the nominated responsible person has been advised of their responsibilities and how these might be discharged,

g) all relevant tests, defined in the purchase specification, have been witnessed, and

h) as evidence of acceptance, the purchaser (or appropriate representative of the purchaser) should sign an acceptance certificate.

18 Verification

The purchaser or user might decide that there is a need for verification of compliance of the installed system with this document as a result of one or more of the following:

a) the division of work elements between different organizations;

b) the evolution of the building design during construction;

c) the lack of detailed information at the time of design.

The verifying organization might be one of those involved in the design, supply, installation or commissioning processes (e.g. the system supplier or the designer) or an independent third party, such as an organization supporting the hard-of-hearing that has the necessary expertise.

In the event that the verification process identifies areas of non-compliance, the purchaser or user might require a further verification of the affected areas after correction.

Where a purchaser or user considers that it would be beneficial, for example if there is significant potential for the installed system to deviate from the recommendations of this document, verification of compliance with this document should be arranged.

Any person responsible for verification should be competent in the design of HLS in accordance with this document and familiar with the relevant installation practices.

The scope and extent of the verification process should be agreed between the purchaser or user and the organization responsible for verification.

On completion, a verification certificate should be issued (a model certificate is given in Annex H). The verification certificate should also contain information on the scope and extent of the verification carried out or identify where this information is available.

19 Owner responsibilities

19.1 Signage

To alert potential users to the presence of a working HLS, clear signage should be clearly visible at least at the entrance to an equipped room or venue and inside where a user will see it. See 3.2.

In places where the performance of the HLS is not satisfactory, a sign indicating this should be displayed, for example on the rear of seats in front of a row of seats where magnetic interference is unacceptable. See 3.2.

19.2 User feedback

Management of a building fitted with HLS should establish a process by which users experiencing problems with the HLS can quickly and efficiently communicate their concerns to staff and have their problems resolved.

This can take the form of a specified contact person with authority and knowledge to investigate each complaint and to take appropriate actions.

Positive feedback from users should also be sought to provide assurance to management that the HLS investment is worthwhile and as a source of valuable marketing material.

19.3 Staff training

All existing staff should receive HLS awareness training on first installation of an HLS, and every new member of staff should receive such training as part of their induction.

HLS awareness training should include the existence of the HLS, how a hearing instrument user benefits from an HLS, the places where HLS coverage is (and is not) acceptable, the established process of managing complaints from users, and the names and contact details of the person with authority and knowledge to investigate each complaint and to take appropriate actions.

20 Operation and maintenance

20.1 General

The continued advertising of an HLS which is inoperative might constitute misrepresentation, so any failure which cannot be rectified promptly should be notified to the management without delay and to potential users by a notice adjacent to the HLS sign(s) (see Figure 3).

NOTE Notification that an HLS is actually in operation can be given by an illuminated HLS sign.

20.2 Routine testing

Experience normally shows that the electronic equipment is significantly more reliable than the system mechanical components, for example loop wires, microphones, connectors, connecting leads and switches and, although some modern HLS incorporate a high degree of automatic operation, it is still necessary for the responsible person to ensure that the system operates correctly and any faults are acted upon.

It is therefore important that regular tests are carried out to ensure that there has not been any major failure of the HLS.

In large or complex systems, it can be impractical to carry out all the required tests on one occasion and it can be necessary for tests to be carried out to a defined programme over a fixed period.

On a weekly basis, the responsible person should ensure the satisfactory operation of the HLS by use of a test signal and either a fixed loop monitor receiver (see Annex A) or a portable field strength meter. It is essential to supplement this with a listening test using real speech into the microphone(s) to ensure that the microphone(s) are working correctly and amplifier control settings have not been inappropriately changed.

These routine tests and any user complaints should be recorded in the system log book.

20.3 Inspection and servicing

It is essential that the system is subject to periodic inspection and servicing so that faults are identified, preventive measures can be taken to ensure the continued reliability of the system, and that the user is made aware of any changes to the building that affect the performance afforded by the system.

Periodic inspection and servicing needs to be carried out by a competent person with specialist knowledge of HLS, adequate access to spares and sufficient information regarding the system. The procedure below applies to fixed systems but should be applied as far as possible to portable and mobile systems; inspection and test of these might need to be more frequent if much remedial action is required after a year.

At intervals, initially not exceeding 12 months, but longer if experience indicates acceptability, the following inspection and test of the system should be carried out.

a) The system log book should be examined. It should be ensured that any faults recorded have received appropriate attention.
b) A visual inspection should be made to check whether structural or occupancy changes have affected the compliance of the system with the recommendations of this document for field coverage and overspill. Particular care should be taken to verify whether
   - any new or relocated partitions have been erected affecting the volume to be covered,
   - any changes to the use or occupancy of an area makes the existing HLS design unsuitable, for example increase in magnetic or acoustic ambient noise, and
   - any building alterations or extensions require the installation of additional HLS equipment.
c) Any structural or occupancy changes that have been found as a result of the inspection have been reported to the responsible person so that appropriate design and implementation of corrective works can be commissioned.
d) All controls and visual indicators at control and indicating equipment should be checked for correct operation.
e) All further checks and tests recommended by the manufacturer of the HLS equipment and other components of the system should be carried out.
f) The following physical checks should be made:
   - ensure that the amplifier ventilation holes are clear and no unauthorized articles are stacked on it;
   - check mains leads, microphone leads and loop wiring (where accessible) for fraying, damage, or incorrect location which could affect safety;
   - for temporary or modified systems, clean any connectors that appear to be tarnished, before they are inserted;
   - clean dust and grime from the system equipment;
   - check and remake as necessary all leads that are heavily used (or abused) to improve reliability; it should be noted that leads with moulded plugs can fail with little or no warning, as their internal condition cannot be accurately assessed.
g) The field strength should be checked to see that it meets the design minimum within the useful magnetic field volume.
h) The frequency response of the HLS should be checked to see that it meets the minimum design requirement.
i) The signal-to-noise ratio when all the electrical equipment normally used in the environment should be checked to ensure that it is functioning.
j) The organization commissioned for the corrective works should be competent in HLS design. Following modification, the system should be re-commissioned to the extent

needed, all documentation should be brought up to date to reflect the new status and a modification certificate should be issued.

Following the work carried out above, any outstanding defects should be reported to the responsible person and the system log book should be completed.

On successful completion of any remedial works, an inspection and servicing certificate should be issued (see Annex H).

20.4 Non-routine attention

The arrangements in 20.2 and 20.3 are intended to maintain the system in operation under normal circumstances. However, from time to time, the HLS is likely to require non-routine attention, including special maintenance. Non-routine maintenance includes

a) a special inspection of an existing HLS when a new organization takes over maintenance of the system,
b) repair of faults or damage,
c) modification to take account of extensions, alterations or changes in occupancy, and
d) inspection and test of the system following a user complaint.

20.5 Special inspection on appointment of a new maintenance organization

The following should be undertaken on appointment of a new maintenance organization.

a) For an existing system, a special inspection should be carried out and records should be studied in order to produce a plan for effective maintenance of the system.
b) Areas of non-compliance with this document should be documented and identified to the responsible person and, although the degree of a non-compliance is subjective, the following non-compliances should be regarded as requiring resolution:
   - areas of non-coverage;
   - areas of unacceptable field strength;
   - areas where overspill is an issue for security or intelligibility;
   - where inappropriate solutions are used, for example a portable unit permanently placed on a counter, when a counter loop should be installed;
   - requirements for electrical safety are not satisfied.
c) If no log book suitable for enabling compliance with the recommendations exists, a suitable log book should be provided by the maintenance organization.

20.6 Arrangements for repair of faults or damage

The following should be undertaken if a fault or damage to the system is detected.

a) Where maintenance is carried out by a third party, there should be an agreement for call out to deal with any fault or damage that occurs to the system, and this agreement should be such that a technician of the maintenance organization can normally attend the premises in an acceptable period after a call from the user.
b) The name and telephone number of any third party responsible for maintenance of the system should be prominently displayed, and the records and documentation should be kept updated.
c) The user should record all faults or damage in the system log book, and should arrange for repair to be carried out as soon as possible.

20.7 Modifications to the system

Modifications to the system can arise for a number of reasons. Examples include extension of the system to cover areas of the building previously uncovered or newly constructed.

Since modification of a system effectively involves an element of re-design, responsibility for modification of a system needs to rest with a person who has relevant design competence.

Responsibility for modification of an HLS should rest, ultimately, with a person who is competent in the principles of HLS design, is conversant with this document and conversant with the installed system, including access to the "as fitted" drawings;

NOTE 1 This person might, for example, be the original designer, or a competent representative of the user or maintenance organization.

On completion of the modifications, all "as fitted" drawings and other relevant system records should be updated as appropriate.

On commissioning of the work and completion of the tests, a modification certificate should be issued, confirming that the work has been carried out in accordance with the recommendations of this document, or identifying any variations (see Annex H for a model modification certificate).

Where responsibility for the compliance, or otherwise, of the modified system rests with any person other than the organization carrying out the modification, that person should sign the appropriate section of the modification certificate and ensure it is made available with the system documentation.

21 User responsibilities

21.1 Responsible person

A single, named responsible person should be appointed to supervise all matters pertaining to the HLS. The responsible person should be given sufficient authority to carry out the duties described in Article 21 and should normally be the keeper of the documentation of the system.

The responsible person should perform the following.

a) Ensure that the HLS is checked at least once a week, or before each use if the HLS is used less frequently than once a week, to confirm that there are no faults on the system.
b) Ensure that arrangements are in place for testing and maintenance of the system.
c) Ensure that the system logbook is kept up to date and is available for inspection by any authorized person.
d) Ensure that authorized operators of the HLS are instructed in the proper use of the system. Particular care should be taken to ensure that operators are able to interpret fault indications and that they are adequately familiar with the appropriate controls and the circumstances in which they should, and should not, be used.
e) Ensure that the persons responsible for routine testing are trained in the use of the portable field strength meter or fixed loop monitor, whichever is applicable.
f) Establish a liaison between those responsible for changes in, or maintenance of, the building fabric (including redecoration) to ensure that the work does not unnecessarily compromise the performance of the system or create system faults. If structural or occupancy changes occur or are planned, the responsible person should ensure that any necessary changes to the HLS are considered at an early stage.
g) Ensure that operating instructions and "as fitted" drawings are updated when changes have been made to the system.
h) Ensure that the spare parts agreed between the user and the organization responsible for the maintenance of the system are held within the premises.

21.2 Logbook

The following information should be recorded in the logbook:

a) the name of the responsible person;
b) details of the maintenance organization;
c) brief details of maintenance arrangements;
d) dates, times and types of all tests;
e) dates, times and types of all faults and defects;
f) dates and types of all maintenance (e.g. maintenance visit or non-routine attention).

It is important to ensure that the log book is updated to reflect any changes of responsible person, maintenance organization, or maintenance arrangements.

Annex A
(informative)

HLS monitoring receivers

A.1 General

A fixed monitor receiver (se IEC 62489-1) should be sited so that non-technical staff and members of the public can easily verify whether the HLS is working. In auditoriums, care should be taken that the audible and/or visible output is not distracting and the monitor output can also be relayed to the sound system control point. Portable monitor receivers should be used for checking the performance of the system in all parts of the coverage area, on a routine basis and after any changes have been made to the system or the building, or potential sources of interference have been introduced.

A.2 Recommendations for fixed receivers

Fixed receivers should conform to the following recommendations.

a) The receiver should provide an audio output to a loudspeaker. A lockable pre-set gain control, which cannot reduce the audio output to zero, should be provided. A "press-to-listen" switch can be provided, which should be labelled as such. An alternative output can be provided for headphones, at which the open-circuit output voltage should not exceed 5 V under any circumstances, and the output source impedance should be 120 Ω ± 10 %. If a headphone output is fitted, suitable headphones, of a type that attenuates external noise, should be supplied with the receiver. The loudspeaker should give an output sound pressure level (SPL) exceeding 80 dB at 300 mm with the gain control at maximum and a field strength at 1 kHz of −12 dB (400 mA/m). The loudspeaker amplifier should not overload under these conditions.

b) The receiver should provide an illuminated signal that it is in operation and another to show that it is receiving an adequate magnetic field strength.

c) If a signal output is provided for remote monitoring, the output should be balanced and should have a rated voltage of 0,775 V, corresponding to −8 dB (400 mA/m) (i.e. 0,16 A/m) on the meter, and a source impedance of approximately 75 Ω.

d) An alarm output, if required, to indicate failure of reception, should be in the form of an isolated, normally closed, relay contact rated at 24 V DC, 1 A. The threshold of detection for the alarm circuit should be chosen so that it reliably detects a real fault in spite of any magnetic interference that might be present, without false triggering, due, for example, to pauses in the original signal.

e) A pause in the speech of several seconds should not cause the alarm to trigger. If the loop system and the receiver are normally switched on some time before an event, there might be no significant signal to the microphone, so that the alarm operates. In this case, the alarm should not initiate any automatic response.

f) The direction of maximum response of the magnetic pick-up device should be marked on the equipment enclosure.

NOTE The receiver can be made sensitive enough to operate on overspill field strengths. Optionally, a means for rotating the pick-up device to align with the magnetic field direction can be provided.

A.3 Recommendations for portable receivers

Portable receivers should conform to the following recommendations.

a) The recommendations of Clause A.2 for fixed receivers should be followed, except that there is no need for a provision for a loudspeaker, and an output for headphones is essential. If the open-circuit output voltage is limited to less than 5 V (for example if a 1,5 V battery is used), the output source resistance can be reduced in proportion from 120 Ω.

b) A battery condition check or "battery low" indication should be provided.

Annex B
(informative)

What is a hearing-loop system (HLS) and how does it work?

B.1 General

An HLS is a method of improving communication with hearing-aid users using magnetic fields. A basic HLS comprises a cable in the form of a loop, often laid around the perimeter of the room, hall, church, theatre, etc. in which the HLS facility is to be provided. Other types of HLS include portable systems and systems for counters and help points. The loop cable is connected via an amplifier to one or more microphones or other source(s) of sound signals, such as a radio receiver or CD player. The amplifier produces an audio-frequency electric current in the loop cable, causing a magnetic field to be produced in the vicinity of the loop. This magnetic field is a reproduction of the signal feeding the amplifier, and can be picked up by suitable hearing aids and receivers.

This document is principally concerned with HLS for hearing enhancement, for which receivers are normally hearing aids equipped with a telecoil (the use of which is conventionally designated as "set to T"). The majority of hearing aids incorporate this feature, but it might not be activated at the time the hearing aid is dispensed. Hearing aids set to T pick up the magnetic field and produce sound in the ear of the wearer. For hearing aids without this feature, a special loop listener is required.

NOTE 1 In newer hearing aids, the T input can be assigned to a user-selectable program that can be selected by (typically) operating a small push-button on the hearing aid. It is important to note that it can be difficult to determine externally if such a hearing aid is fitted with a coil, and if it has been assigned to a program.

The expression MT is conventionally used to indicate a situation in which both magnetic and acoustic signals are being picked up simultaneously by the hearing aid or receiver. This combined setting might be preferred by the user in certain situations – for instance, in order to be able to hear alerting or emergency sounds or alarms.

As most hearing aid users are standing or sitting, and most hearing aids have vertical or near-vertical telecoils, only the vertical component of the magnetic field of an area-coverage loop system is useful everywhere within the useful magnetic field volume and the listening plane is horizontal. However, in the outer regions of some loop systems, or if the user is lying down, the horizontal component of the magnetic field can be useful. The listening plane for seated listeners is conventionally taken as 1,2 m above floor level and that for standing listeners as 1,7 m above floor level. Where a single plane height is required for design purposes, it should be taken as being 1.45 m above floor level, and the resultant design checked for heights of 1,2 m and 1,7 m.

NOTE 2 Sound consists of vibrations, usually in air. The number of vibrations per second is related to the pitch (high or low) of the sound, and is called the "frequency", which is measured in hertz (Hz). 1 Hz is equal to one vibration per second. Frequencies within the range from 20 Hz to 20 000 Hz (20 kHz) conventionally cover the range of human hearing. For the purposes of this document, the extremes of this range are of lesser importance, and attention is concentrated on a restricted range, from 100 Hz (a little more than one octave below middle C) to 5 kHz (approximately four octaves above middle C).

B.2 Benefits of HLS (for hearing enhancement)

While hearing aid(s) worn by a person with impaired hearing can provide a useful improvement to the effectiveness of hearing local conversations, they are not so effective when listening to speech or music at a distance. This is because the microphone of the hearing aid picks up the wanted speech or music together with the general noise and reverberation of the room and the unwanted speech of other conversations.

General noise and unwanted conversations present less of a problem for people with normal hearing, as they are better able to focus on to the wanted sound. If a suitable microphone is placed near the source of wanted sound, and coupled by some means to a hearing aid or other suitable listening device, the problems of reverberation and unwanted noise are, to a large extent, overcome, and the listener hears the sound more clearly.

While the coupling between remote microphones and hearing aids (or other listening devices) can be achieved by means of wires, infra-red radiation or radio transmission, magnetic induction provides a simple means by which users of hearing aids with a T (telecoil) function can receive the transmissions without the need for additional equipment. The wearer can be located anywhere covered by the induction-loop and can move around, stand up, or sit down as necessary. There is no inconvenience of a trailing wire and use can be made of the user's own hearing aid which is correctly matched to the hearing deficiency. An HLS does not require special receivers to be issued to and collected from the users. This saves equipment and the associated administrative costs.

HLS are appropriate for installation where information needs to be imparted, for example in theatres, conference rooms, cinemas, places of worship, meeting halls, shopping areas, and education establishments, and also for passenger handling buildings associated with rail, sea and air transport. Smaller scale installations in household premises and residential homes can increase enjoyment of radio, television programmes and personal computers. HLS can also prove to be valuable for interview areas, ticket booths and service counters (ticket office systems). All of these facilities can enable people with impaired hearing to participate more fully in the relevant proceedings.

The majority of HLS can be successfully designed and installed at reasonable cost. Advice on likely costs can be obtained from caring organizations or from appropriate trade associations. As a general rule, small systems in simple buildings can give good results with a simple approach to design and maintenance. Large installations and those in complicated buildings do, however, require considerable care and can prove to be relatively more costly.

B.3 Limitations of HLS

When using a hearing aid set to T, and there can be long periods without any signal being sent to the system, hearing aid users might think that the system is not working. In these instances, it can be desirable to give reassurance that the system is in operation by the use of a "confidence signal", a tone-burst or "pip" that repeats very ten seconds or so. Care is required that such a feature does not become annoying.

The benefits given by HLS are lost if the system is not properly managed and maintained to ensure that it is available when required and adjusted to suit the circumstances.

Failure of an HLS might not be evident to the owners or managers of the installation unless monitoring is provided (see Annex A).

The operation of an HLS can be affected by

a) the effect of metal in the building structure and within the coverage area,

b) magnetic field overspill from adjacent HLS, and

c) magnetic noise interference.

The overall effects of these factors should be identified during the site assessment.

Annex C
(informative)

Explanations of the basis of the design formulas

C.1 Magnetic field strength

C.1.1 Magnetic field strength produced by an element of conductor

By Ampère's rule (also attributed to Laplace, and to Biot and Savart), the magnetizing force δH at a point P, distance d from a conductor element δx in conductor XL carrying a current I is given by the following formula:

$$\delta H = I(\delta x)\cos\left(\frac{\phi}{4\pi d^2}\right)$$

where

ϕ is the angle between the line joining the point to the element and the perpendicular from the point to the line containing the element (see Figure C.1).

If a is the length of the perpendicular PX, then:

$$\cos\phi = \frac{a}{d}$$

and:

$$\delta\phi = (\delta x)\cos\left(\frac{\phi}{d}\right)$$

so that:

$$(\delta x)\cos\left(\frac{\phi}{d^2}\right) = \frac{\delta\phi}{\mathrm{d}} = \frac{(\delta\phi)\cos\phi}{a}$$

and:

$$\delta H = \frac{I(\delta\phi)\cos\phi}{4\pi a}$$

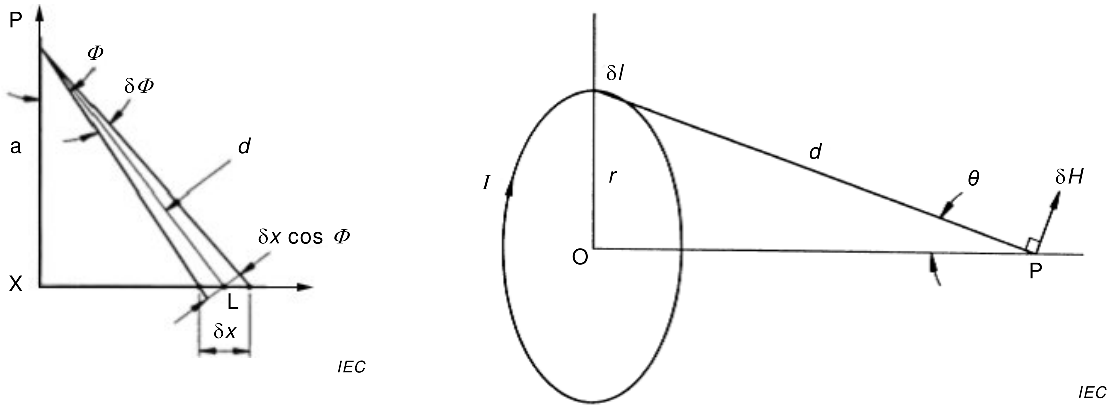
C.1.2 Field strength produced by a circular loop at a point on its axis

Consider a conductor in the form of a circular loop of radius r and centre C, carrying a current I [see Figure C.1)]. The field strength H at the point P on the axis of the loop is given by the following formula:

$$H = \sum(\delta H)\sin\theta$$

along the axis, and by symmetry, the components perpendicular to the axis sum to zero. Thus:

$$H = \sum \frac{I(\delta l)\sin\theta}{4\pi d^2}$$



a) Produced by an element of conductor XL

b) Produced by a circular loop

Figure C.1 – Generation of magnetic fields

Now, $\sin\theta = r/d$, so that:

$$H = \frac{Ir^2}{2d^3}$$
$$= \frac{Ir^2}{2(r^2+h^2)^{3/2}}$$

If h = 0, r = d, so that the field strength H_0 at the centre of a circular loop is given by:

$$H_0 = \frac{I}{2r}$$

The ratio of the field strength at the centre to that at any point on the axis is given by:

$$\frac{H_0}{H} = \frac{\left(r^2+h^2\right)^{3/2}}{r^3}$$

Expressed in terms of the height ratio h_n, which for a circular loop is equal to h/r, this becomes:

$$\frac{H_0}{H} = \left(1+h_n^{\,2}\right)^{3/2}$$

Values of this function for values of h_n from 0 to 12 are given in Table C.1, for comparison with the corresponding values for square and rectangular loops.

Table C.1 – Factor by which the loop current has to be increased, compared with that required for a given magnetic field strength at the centre of a square loop, to obtain the same field strength for a rectangular loop at a point at height ratio of h_n above or below the centre of the loop

Height ratio, h_n	Rectangular loop												Circular loop
	Values of aspect ratio γ												
	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5	5,0	5,5	6,0	6,5	
0,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
0,100	1,013	1,015	1,019	1,024	1,029	1,034	1,039	1,044	1,049	1,054	1,059	1,064	1,015
0,200	1,050	1,059	1,076	1,095	1,115	1,135	1,155	1,176	1,196	1,216	1,236	1,256	1,061
0,300	1,114	1,134	1,171	1,213	1,258	1,303	1,348	1,394	1,439	1,484	1,530	1,575	1,138
0,400	1,206	1,239	1,304	1,378	1,456	1,536	1,616	1,696	1,777	1,857	1,938	2,018	1,249
0,500	1,326	1,377	1,475	1,589	1,709	1,832	1,956	2,081	2,206	2,332	2,457	2,583	1,398
0,600	1,477	1,548	1,685	1,846	2,017	2,191	2,369	2,547	2,726	2,906	3,086	3,266	1,586
0,700	1,663	1,755	1,937	2,150	2,378	2,613	2,851	3,092	3,334	3,577	3,821	4,065	1,819
0,800	1,884	2,001	2,231	2,503	2,795	3,097	3,404	3,715	4,029	4,344	4,660	4,977	2,100
0,900	2,145	2,288	2,570	2,906	3,268	3,644	4,028	4,417	4,810	5,205	5,603	6,001	2,435
1,000	2,449	2,619	2,958	3,363	3,801	4,256	4,724	5,198	5,678	6,162	6,648	7,136	2,828
1,100	2,800	2,999	3,398	3,876	4,395	4,937	5,494	6,060	6,634	7,213	7,796	8,383	3,285
1,200	3,200	3,431	3,893	4,450	5,055	5,688	6,341	7,006	7,681	8,362	9,050	9,741	3,811
1,300	3,654	3,918	4,448	5,088	5,784	6,515	7,269	8,039	8,821	9,612	10,410	11,214	4,412
1,400	4,165	4,465	5,067	5,794	6,587	7,421	8,282	9,163	10,058	10,965	11,881	12,804	5,093
1,500	4,738	5,075	5,754	6,574	7,469	8,412	9,386	10,383	11,398	12,426	13,466	14,515	5,859
1,600	5,375	5,753	6,513	7,431	8,435	9,491	10,584	11,703	12,844	14,000	15,170	16,351	6,717
1,700	6,083	6,504	7,349	8,371	9,488	10,665	11,882	13,130	14,402	15,692	16,999	18,318	7,672
1,800	6,863	7,330	8,267	9,399	10,636	11,938	13,286	14,668	16,077	17,508	18,957	20,421	8,731
1,900	7,721	8,237	9,271	10,519	11,882	13,317	14,802	16,325	17,877	19,454	21,051	22,666	9,898
2,000	8,660	9,228	10,366	11,737	13,233	14,806	16,435	18,104	19,807	21,536	23,288	25,060	11,180

C.2 Magnetic field strength at the centre of a rectangular loop

Consider a conductor, in the form of a rectangular loop WXYZ, sides A and B, with centre O, carrying a current (see Figure C.2).

The field at O due to element δx (see C.1.1) is given by:

$$\delta H = I \cos\psi \left(\frac{\delta \psi}{2\pi B} \right)$$

since OE = $B/2$. Therefore, the field at O due to conductor WX is given by:

$$H_{\mathrm{wx}} = \frac{I}{2\pi B} \int_{-\Phi}^{\Phi} \cos\psi \, \mathrm{d}\,\psi$$

where

$$\Phi = \arctan\left(\frac{\mathrm{WE}}{\mathrm{OE}} \right) = \arctan\left(\frac{A}{B} \right)$$

Thus:

$$H_{WX} = \left(\frac{I}{\pi B}\right)\left(\frac{A}{\sqrt{\left(A^2 + B^2\right)}}\right)$$

Similarly, the field at O due to CD is given by the same formula, and that due to BC or DA is given by:

$$H_{XY} = H_{ZW} = \left(\frac{I}{\pi B}\right)\left[\frac{B}{\sqrt{\left(A^2 + B^2\right)}}\right]$$

and all these fields are in the same direction, so the total field strength at O is given by:

$$H_0 = \left(\frac{2I}{\pi}\right)\left[\frac{A}{B\sqrt{\left(A^2 + B^2\right)}} + \frac{B}{A\sqrt{\left(A^2 + B^2\right)}}\right]$$
$$= \frac{2I\sqrt{\left(A^2 + B^2\right)}}{\pi AB}$$

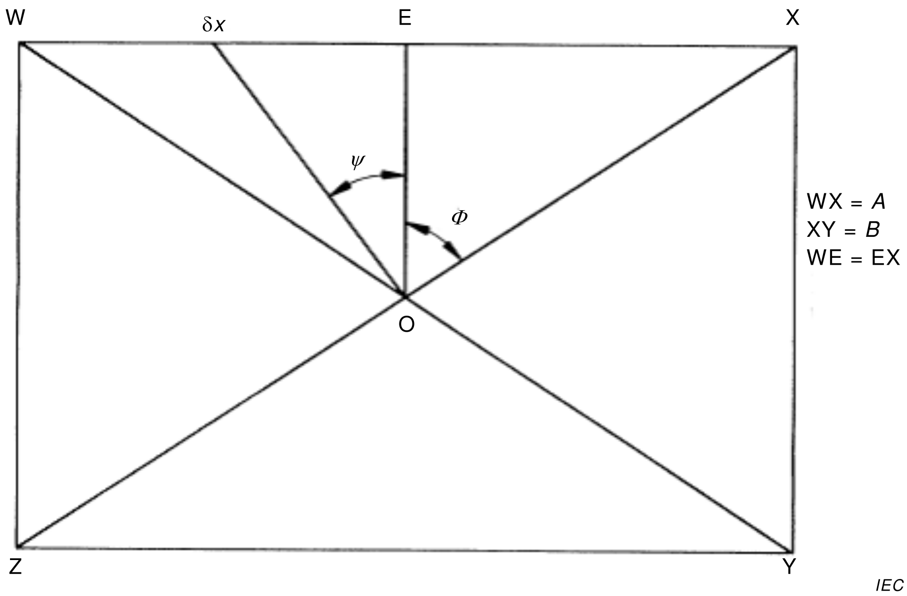


Figure C.2 – Diagram for calculating magnetic field strength at the centre of a rectangular loop

C.3 Magnetic field strength at an arbitrary point

To calculate the magnetic field strength at an arbitrary point due to a current in a rectangular loop, leading to the current required for a given field strength at the centre of the loop and the variation of field strength with distance from the plane of the loop, consider Figure C.3 in which XQY is a conductor having a right-angle bend at Q.

By Ampère's rule, the magnetic field vector perpendicular to plane PXQ, due to current *I* in an element of conductor δy is given by:

$$\delta H_{\mathrm{XQ}} = \frac{I\delta y\cos\varphi}{4\pi s^2}$$

where

$$\cos\varphi = \frac{\mathrm{PX}}{\mathrm{PL}} = \frac{m}{s}\text{; and}$$

$$\delta y = \frac{s\delta\varphi}{\cos\varphi}$$

Thus:

$$\delta H_{\mathrm{XQ}} = \frac{I\delta\varphi}{4\pi s} = \frac{I\delta\varphi\cos\varphi}{4\pi m}$$

so that the field due to all the conductor parallel to the y-axis, i.e. XQ (see Figure C.3), is given by:

$$H_{\mathrm{XQ}} = \frac{I}{4\pi m}\int_0^{\Phi}\cos\varphi\,\mathrm{d}\varphi$$

where

$$\cos\Phi = \left(\frac{x^2+z^2}{x^2+y^2+z^2}\right)^{1/2}$$

Hence:

$$H_{\mathrm{XQ}} = \frac{I}{4\pi m}(\sin\Phi - \sin 0) = \frac{I}{4\pi m}\sin\Phi$$

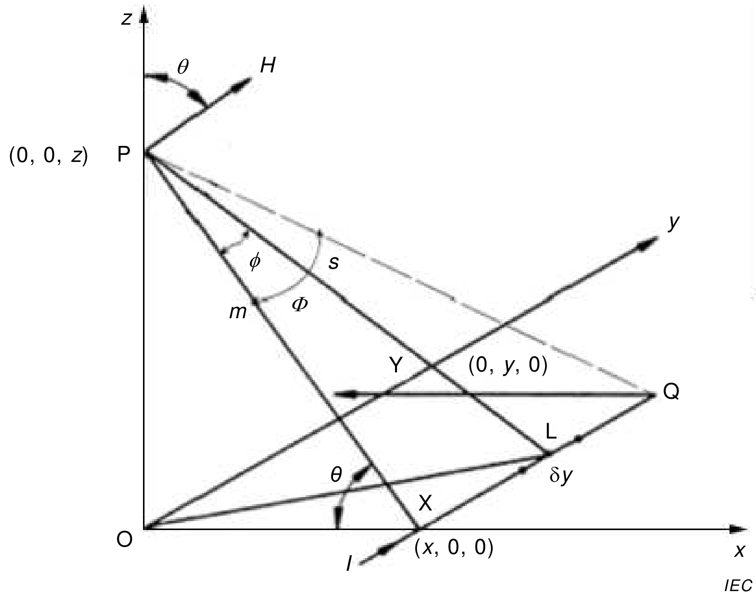


Figure C.3 – Diagram for calculating magnetic field strength at an arbitrary point

From Figure C.4:

$$\sin\Phi = \frac{y}{\sqrt{\left(x^2 + y^2 + z^2\right)}}$$

so that:

$$H_{XQ} = \frac{I}{4\pi m}\left[\frac{y}{\sqrt{\left(x^2 + y^2 + z^2\right)}}\right] = \frac{Iy}{4\pi\sqrt{\left(x^2 + z^2\right)}\sqrt{\left(x^2 + y^2 + z^2\right)}}$$

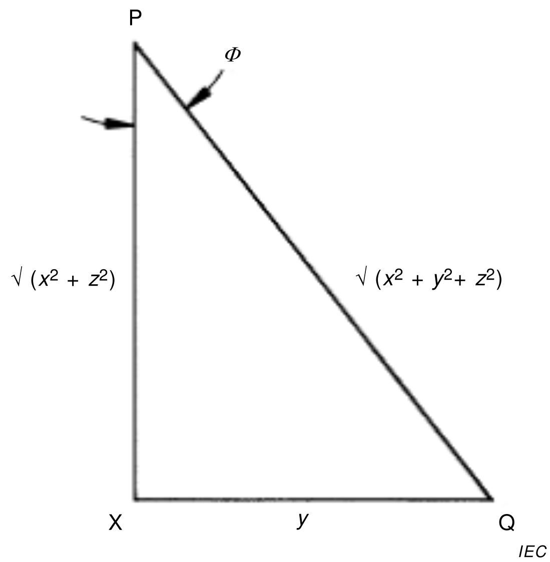


Figure C.4 – Diagram for calculating cos*Φ* and sin*Φ*

The component in the *z*-direction, H_{XQz}, due to the conductor parallel to the *y*-axis (see Figure C.3) is given by:

$$H_{XQz} = H_{XQ}\cos\theta = \frac{Ixy}{4\pi\left(x^2+z^2\right)\sqrt{\left(x^2+y^2+z^2\right)}}$$

A similar expression gives the component due to the conductor parallel to the x-axis, so that the total field strength in the z-direction H_{XQYz} is given by:

$$H_{XQYz} = \frac{Ixy}{4\pi\sqrt{\left((x^2+y^2+z^2\right)}}\left(\frac{1}{x^2+y^2}+\frac{1}{y^2+z^2}\right)$$

which agrees with Formula (1) given in [2].

Similarly, the horizontal component in the x-direction, which is due to the conductor parallel to the y-axis, is given by:

$$H_{QYx} = H_{QY}\cos\theta = \frac{Iyz}{4\pi\left(x^2+z^2\right)\sqrt{\left(x^2+y^2+z^2\right)}}$$

which agrees with formula (2) given in [2], and there is an analogous expression for the horizontal component in the y-direction.

These expressions become indeterminate at the interesting point (0, 0, 0), so, using the method given in [2] but using the notation given in this document, a rectangular loop is built up with sides $A = 2p$, $B = 2q$, as shown in Figure C.5, and the new variables $x_1 = (p - x)$, $x_2 = (p + x)$, $y_1 = (q - y)$ and $y_2 = (q + y)$ are defined. The field strength in the z-direction at a point (x, y, z) for a current I in the loop is then given by the formula:

$$H_z(x,y,z) = \frac{I}{4\pi}\sum_{i=1}^{2}\sum_{j=1}^{2}\frac{x_i y_j}{\sqrt{\left(x_i^2+y_j^2+z^2\right)}}\left(\frac{1}{x_i^2+z^2}+\frac{1}{y_j^2+z^2}\right)$$

At the point (0, 0, 0), the centre of the loop, this becomes:

$$H_0 = \frac{I}{\pi}\left[\frac{\sqrt{\left(p^2+q^2\right)}}{pq}\right]$$

as derived directly in Clause C.2, so that:

$$H_0 = \frac{2ID}{\pi AB}$$

Hence,

$$I = \frac{\pi ABH_0}{2D}$$

Also, the field strength at a point $(0, 0, z)$, which represents a point vertically above or below the centre of a horizontal loop, is given by:

$$H_{0z} = \frac{I}{\pi}\left[\frac{pq}{\sqrt{\left(p^2+q^2+z^2\right)}}\right]\left(\frac{1}{p^2+z^2}+\frac{1}{q^2+z^2}\right)$$

For a square loop, $p = q = r$. Put $z = h$. Then:

$$H_{0z} = \frac{I}{\pi}\left[\frac{r^2}{\sqrt{\left(2r^2+h^2\right)}}\right]\left(\frac{2}{r^2+h^2}\right)$$

Hence,

$$\frac{H_0}{H_{0z}} = \frac{\left(1+h^2\right)\sqrt{\left(2r^2+h^2\right)}}{\sqrt{2}(r^3)}$$

and, if $h_n = h/r$, the height ratio:

$$\frac{H_0}{H_{0z}} = \frac{\left(1+h_n^2\right)\sqrt{\left(2+h_n^2\right)}}{\sqrt{2}}$$

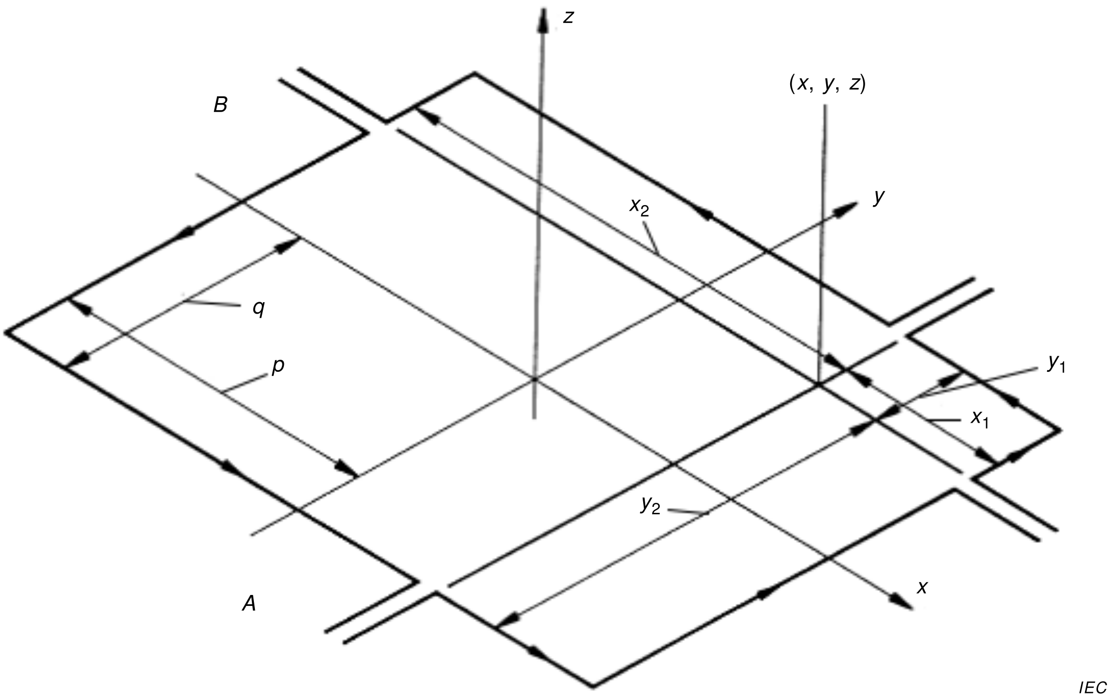


Figure C.5 – Diagram for calculating magnetic field strength at point (*x*, *y*, *z*)

In the general case of a rectangular loop, aspect ratio $\gamma = q/p$, substituting γ and $h_n = h/\sqrt{(pq)}$ in the formula for H_{0z} above gives:

$$\frac{H_0}{H_{0z}} = \frac{\sqrt{\left[\left(1+\gamma^2\right)\left(\gamma^2+\gamma h_n^2+1\right)\right]}\left(\gamma+h_n^2\right)\left(1+\gamma h_n^2\right)}{\left(\gamma^2+2\gamma h_n^2+1\right)}$$

This formula connects the field strength at height ratio h_n with the field strength at the centre of a rectangular loop of aspect ratio γ. The field strength decreases more slowly with perpendicular distance from the plane of a square loop than from that of a loop of any other aspect ratio.

C.4 Loop conductor sizes and resistances

C.4.1 General

In order to develop the design formulas, it is necessary to derive the resistance of the loop conductor in terms of its material (assumed to be copper), its area of cross section and its length, from first principles. This derivation is given in C.4.2 and the same method can also be used to determine the resistance of a loop using a type of conductor for which there is no applicable product, such as a ribbon cable for use under carpeting.

Where the loop conductor conforms to IEC 60228, Class 1 or Class 5, then Table C.2 and Table C.3 can be used for quick reference.

C.4.2 Resistance of the loop conductor and relation between conductor size and cut-off frequency for a voltage-driven loop

The average resistivity of copper, as used in wire, at 0 °C is ρ_0 = 16,5 nΩ·m, and the temperature coefficient of resistance is a = 3,93 × 10^{-3} K^{-1} at room temperature. The loop conductor is heated by the current flowing through it, so it is above room temperature. External sources of heat such as central heating pipes can also raise the temperature of the conductor to a greater extent than the heating due to the current. The temperature rise of a copper conductor is slightly larger than proportional to the square of the current, because the temperature coefficient of resistance is positive. The temperature limit for widely-used PVC (or similar) insulated conductor in a cable operating at its rated current is 70 °C. For a conductor whose rated current is sufficient to produce a magnetic field strength of 400 mA/m, the long-term average current (producing a field strength of approximately 100 mA/m) is therefore sufficient to produce a temperature rise of about 2 K above an assumed 20 °C ambient temperature, which is negligible in this case. The resistivity at θ = 20 °C is given by:

$$\rho_{20} = \rho_0 (1 + a\theta) = 17.8 \mathrm{n}\Omega \cdot \mathrm{m}$$

Both the resistivity and the temperature coefficient of resistance of manufactured conductors can differ slightly from these values (see Table C.2 and Table C.3). The resistance in ohms of a rectangular loop, sides A and B, of copper wire with diameter d is given by:

$$R = \frac{8\rho_{20}(A+B)}{\pi d^2} = \frac{1.42 \times 10^{-7}(A+B)}{\pi d^2}$$

For a voltage-driven loop at the cut-off frequency f_c (at which the current falls by 3 dB referred to its low-frequency value), the loop resistance and inductive reactance are equal. That is:

$$2\pi f_c \times 4 \times 10^{-6}(A+B) = \frac{1.42 \times 10^{-7}(A+B)}{\pi d^2}$$

Table C.2 – Class 5 flexible annealed copper conductors for standard single-core and multi-core cables

Nominal cross section mm²	Number/diameter of conductors mm⁻¹	Effective diameter mm	Maximum resistance at 20 °C mΩ·m⁻¹	Current rating A
0,22	7/0,2	0,53	92,0	1,4
0,40	13/0,2	0,71	48,0	1,8
0,50	16/0,2	0,80	39,0	3
0,75	24/0,2	0,98	26,0	6
1,00	32/0,2	1,10	19,5	10
1,25	40/0,2	1,26	15,6	13

NOTE Effective diameter values are calculated.

Hence, the cross-sectional area (in m^2) is given by:

$$\frac{\pi d^2}{4} = \frac{1.42 \times 10^{-7}}{32\pi f_c \times 10^{-6}} = \frac{1.42 \times 10^{-3}}{f_c}$$

It should be noted that the terms (A + B) cancel, so that the result does not depend on the loop dimensions.

C.4.3 Quick reference tables (derived from IEC 60228)

The values of resistance given in Table C.2 and Table C.3 are the maximum values permitted (or extrapolated from those) in IEC 60228. Values calculated by the method given in C.4.2, and actual measured values, are usually lower.

Table C.3 – Class 1 solid annealed copper conductors for single-core and multi-core cables

Nominal cross section mm²	Effective diameter mm	Maximum resistance at 20 °C mΩ·m⁻¹	Current rating A
0,50	0,80	36,0	—
0,75	0,98	24,5	—
1,00	1,10	18,1	11,0
1,50	1,38	12,1	14,5
2,50	1,80	7,41	19,5
4,00	2,26	4,61	26,0

NOTE 1 Effective diameter values are calculated.

C.4.4 Inductance of two parallel wires, leading to the inductance of a rectangular loop

This analysis uses the method given in [4]. Consider two parallel wires, P and Q, radius a and separation D, with $D >> a$, carrying a current I in opposite directions. For the wire P, the magnetic field strength at radius r, H_r is given by:

$$H_r = \frac{I}{2\pi r}$$

and the flux density at radius r, B_r is given by:

$$B_r = \frac{\mu I}{2\pi r}$$

Consider a cylindrical shell, radius r and thickness δr. The total flux in 1 m length of shell, ϕ is given by:

$$\phi = B_r \delta r = \frac{\mu I}{2\pi r}\left(\frac{\delta r}{r}\right)$$

This flux links with wire P alone.

Linkage with conductor P due to flux in an element, Φ_{Pe} is given by:

$$\Phi_{Pe} = \frac{\mu I}{2\pi}\left(\frac{\delta r}{r}\right)$$

Thus, total linkages with P due to current in P, Φ_{PP} is given by:

$$\Phi_{PP} = \frac{\mu I}{2\pi}\int_a^R \frac{dr}{r} = \frac{\mu I}{2\pi}\ln\left(\frac{R}{a}\right)$$

where R is a very large radius.

Similarly, total linkages with Q due to current in P, Φ_{QP} is given by:

$$\Phi_{QP} = \frac{\mu I}{2\pi}\int_D^R \frac{dr}{r} = \frac{\mu I}{2\pi}\ln\left(\frac{R}{D}\right)$$

total linkages with Q due to current in Q, Φ_{QQ} is given by:

$$\Phi_{QQ} = \frac{\mu I}{2\pi}\ln\left(\frac{R}{a}\right)$$

total linkages with P due to current in Q, Φ_{PQ} is given by:

$$\Phi_{PQ} = \frac{\mu I}{2\pi}\ln\left(\frac{R}{D}\right)$$

Thus, total linkages with P, Φ_P is given by:

$$\Phi_{PQ} = \frac{\mu I}{2\pi}\left[\ln\left(\frac{R}{a}\right) - \ln\left(\frac{R}{D}\right)\right] = \frac{\mu I}{2\pi}\ln\left(\frac{D}{a}\right)$$

and the total linkages with Q are also equal to this. Therefore, the total inductance of the two wires (i.e. the linkages for unit current), per metre of length, L is given by:

$$L = \frac{\mu}{\pi}\ln\left(\frac{D}{a}\right) = \frac{\mu}{\pi}\ln\left(\frac{2D}{d}\right)$$

where the wire diameter $d = 2a$. At low frequencies, there is flux inside the conductor which produces an additional inductance of $\mu/4\pi$ in henrys per metre, but in most of the cases considered here, this is negligible. It would not be negligible if ferromagnetic wire were used.

For two pairs of wires, forming a rectangular loop of sides A and B, the inductance L_e is therefore, by superposition:

$$L_e = \frac{\mu}{\pi}\left[B\ln\left(\frac{2A}{d}\right) + A\ln\left(\frac{2B}{d}\right)\right]$$

This formula is difficult to handle. The side of a square loop of equal perimeter to the rectangular loop would be $(A + B)/2$, and the inductance L_a of this would be:

$$L_a = \frac{\mu}{\pi}(A+B)\ln\left(\frac{A+B}{d}\right)$$

It is found by calculation that, for aspect ratios (B/A) between 1 and 12 (and therefore between 0,083 and 12, since A and B can be interchanged), the ratio of L_a/L_e does not exceed 1,2 for values of A/d from 2 000 to 128 000, which more than covers the likely practical range. Table C.4 gives values for this ratio.

The practical range of A/d can be considered to extend from the case of a loop of smaller side 3 m (used in a household system, for instance) to a loop of the maximum practicable size of about 40 m side. If the conductor diameters were (in conflict with the design methods presented here) 1,4 mm and 0,6 mm respectively, then A/d varies from 2 143 to 66 666,7, and for square loops of these dimensions:

$$8{,}0 \le \ln\left(\frac{2A}{d}\right) \le 12{,}0$$

Setting $\ln\left(\frac{A+B}{d}\right) = 10$:

$$L = \frac{10\mu}{\pi}(A+B)$$

Normally, $\mu = \mu_0 = 4\pi \times 10^{-7}$ H/m, so that:

$$L = 4 \times 10^{-6}(A+B)$$

where L is measured in henrys; or

$$L = 4(A+B)$$

where L is measured in microhenrys.

NOTE A more extensive treatment of the calculation of inductance can be found in [2].

Table C.4 – Ratio of approximate to exact inductance

A/d	L_a/L_e											
	Values of γ											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2 000 000	1,000	1,020	1,049	1,075	1,097	1,117	1,134	1,149	1,163	1,176	1,187	1,198
4 000 000	1,000	1,019	1,045	1,069	1,090	1,108	1,124	1,138	1,151	1,163	1,173	1,183
8 000 000	1,000	1,018	1,042	1,064	1,083	1,100	1,115	1,128	1,140	1,151	1,161	1,170
16 000 000	1,000	1,016	1,039	1,060	1,078	1,094	1,108	1,120	1,131	1,141	1,151	1,159
32 000 000	1,000	1,015	1,037	1,056	1,073	1,088	1,101	1,113	1,123	1,133	1,141	1,149
64 000 000	1,000	1,015	1,035	1,053	1,069	1,083	1,095	1,106	1,116	1,125	1,133	1,141
128 000 000	1,000	1,014	1,033	1,050	1,065	1,078	1,090	1,100	1,110	1,118	1,126	1,133

C.4.5 Variation of the impedance of a loop of fixed dimensions with conductor resistance

Values of $L_{|z|}$ are given in Table C.5.

Table C.5 – Values of $L_{|z|}$

ωL	$L_{|z|}$											
	Values of r_n											
	0,100	**0,158**	**0,251**	**0,398**	**0,631**	**1,000**	**1,585**	**2,512**	**3,981**	**6,310**	**10,000**	**15,849**
0,100	–16,990	–14,545	–11,361	–7,734	–3,982	0,043	4,017	8,007	12,003	16,001	20,000	24,000
0,158	–14,545	–12,990	–10,545	–7,361	–3,734	0,108	4,043	8,017	12,007	16,003	20,001	24,000
0,251	–11,361	–10,545	–8,990	–6,545	–3,361	0,266	4,108	8,043	12,017	16,007	20,003	24,001
0,398	–7,734	–7,361	–6,545	–4,990	–2,545	0,639	4,266	8,108	12,043	16,017	20,007	24,003
0,631	–3,892	–3,734	–3,361	–2,545	–0,990	1,455	4,639	8,266	12,108	16,043	20,017	24,007
1,000	0,043	0,108	0,266	0,639	1,455	3,010	5,455	8,639	12,266	16,108	20,043	24,017
1,585	4,017	4,043	4,108	4,266	4,639	5,455	7,010	9,455	12,639	16,266	20,108	24,043
2,512	8,007	8,017	8,043	8,108	8,266	8,639	9,455	11,010	13,455	16,639	20,266	24,108
3,981	12,003	12,007	12,017	12,043	12,108	12,266	12,639	13,455	15,010	17,455	20,639	24,266
6,310	16,001	16,003	16,007	16,017	16,043	16,108	16,266	16,639	17,455	19,010	21,455	24,639
10,000	20,000	20,001	20,003	20,007	20,017	20,043	20,108	20,266	20,639	21,455	23,010	25,455

C.4.6 High-level equalizer

Referring to Figure C.6:

$$\frac{I}{V} = \left[(R_2 + sL) + \frac{R_1}{sC(R_1 + 1/sC)} \right]^{-1}$$

Let $CR_1 = \tau_1$ and $L/R_2 = \tau_2$, then:

$$\frac{I}{V} = \frac{(1 + s\tau_1)}{R_2(1 + s\tau_1)(1 + s\tau_2) + R_1}$$

Let $R_1 = aR_2$ and $\tau_2 = \beta\tau_1$, then:

$$\frac{IR_2}{V}=\frac{(1+s\tau_1)}{(1+a)+s(1+\beta)\tau_1+s^2\beta\tau_1^2}$$

Let $\gamma = 1/(1 + a)$ and $\tau = \sqrt{(\beta\gamma)}\,\tau_1$, then:

$$\frac{IR_2}{V}=\frac{\gamma\left(1+s\tau/\sqrt{\beta\gamma}\right)}{1+s\tau\gamma(1+\beta)/\sqrt{\beta\gamma}+s^2\tau^2}$$

It is possible to obtain a maximally flat response using this network, but it is not possible to find usable analytical expressions for the circuit values in terms of the upper −3 dB frequency ω_c, and it is important to be able to do this in practice. A practicable solution, giving a small peak in the response at approximately $0{,}4\omega_c$ (not exceeding 0,82 dB), is to force the squares of the moduli of numerator and denominator, after substituting $s = j\omega$, into the forms $1 + \tau^2$ and $1 + \tau^4$ respectively. Hence $\sqrt{(\beta\gamma)} = 1$ and $\gamma(1 + \beta)/\sqrt{(\beta\gamma)} = \sqrt{2}$, i.e. $\beta = 1 + \sqrt{2}$, $\gamma = \sqrt{2} - 1$ and $a = \sqrt{2}$. Also $\tau_1 = \tau/\sqrt{(\beta\gamma)} = \tau$.

At the upper −3 dB band-limit frequency ω_c:

$$\frac{\left(1+\omega_c^2\tau^2\right)}{\left(1+\omega_c^4\tau^4\right)}=\frac{1}{\sqrt{2}}$$

Therefore:

$$\omega_c^2\tau^2=1+\sqrt{2\sqrt{2-1}}$$

so that:

$$\tau=\tau_1=\frac{\sqrt{1+\sqrt{2\sqrt{2}-1}}}{\omega_c}=\frac{1.534}{\omega_c}$$

and:

$$\tau_2=(1+\sqrt{2})\tau_1=\frac{3.703}{\omega_c}$$

Thus:

$$R_2=\frac{\omega_c L}{3.703}$$

$$R_1=aR_2=\sqrt{2}R_2$$

and:

$$C=\frac{\tau_1}{R_1}=\frac{4.015}{\omega_c^2 L}$$

An example of the frequency response achieved with a loop inductance of 100 μH is shown in Figure C.7.

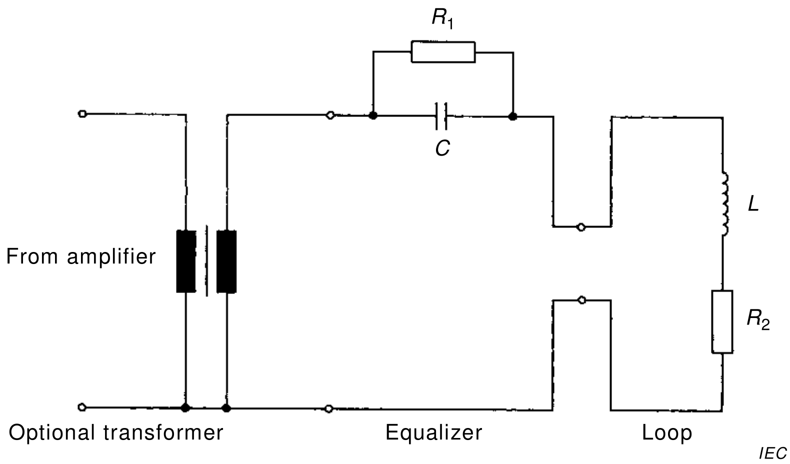


Figure C.6 – Circuit diagram of a "high-level" or Poperwell equalizer (for insertion between the amplifier and the loop)

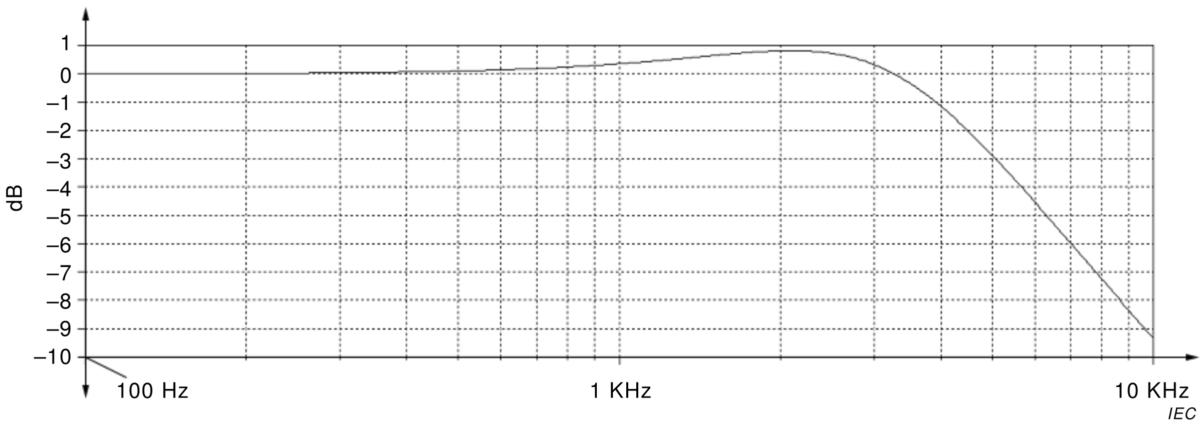


Figure C.7 – Frequency response obtained with a high-level equalizer

Annex D
(informative)

Explanation of the specification and measurement of magnetic field strength of induction-loop systems

IEC 60118-4:1981 (now withdrawn) specified a "long-term" average field strength of 0,1 A/m RMS, without defining "long term". This figure represented an arbitrary but convenient value based on data relating to sensitivities of typical hearing aids and of commonly encountered background magnetic noise levels. Measurements of field strength at 1 kHz can be performed with a sinusoidal signal and an ordinary audio-frequency voltmeter. However, such a measurement does not verify that the required field strength is produced by the speech signals, because the microphone gain control setting(s) can be too low or too high. It is essential to measure the field strength produced by actual speech signals.

It is not possible to ensure a long term average of 0,1 A/m, unless the amplification system possesses sufficient headroom to accommodate short term bursts of louder speech. The document indicated in a note that 12 dB headroom is sufficient for this purpose, i.e. a short-term maximum field strength of 0,4 A/m RMS is needed.

It was recognized that a definitive headroom requirement could not be stated simply. In particular, it would not be possible to specify exactly both long-term and short-term values, without an exact definition of the signal being handled. Such a definition would, however, be in conflict with the generality required in a document intended for work with a wide range of speech (and music) signals. As a result, reference to the issue of headroom was restricted to a note in the document. However, this is inconsistent with the need to ensure that the amplifier is not driven into non-linearity during short periods of louder speech. It also led to the misunderstanding that a maximum field strength of 0,1 A/m was adequate, when measured with the specified meter (see Annex E).

IEC 60118-4:2014 is therefore based on a reference value of field strength of 400 mA/m, corresponding to the loudest speech signals.

IEC 60118-4:1981 assumed that the short-term magnetic field strength would be measured by means of a sound level meter whose microphone had been replaced by a magnetic pick-up coil. (For measurements at a fixed frequency, it is not necessary to compensate for the rising frequency response of such an arrangement). This meter has an RMS detector and an integration time of 125 ms.

Because of the practical need to check for undistorted output on the more extreme bursts of speech, it is considered by some experts that a peak programme meter (PPM, as specified in IEC 60268-10) is more suited to the task of measuring the magnetic field strength (or loop current) of HLS when delivering real programme material. Such an instrument is also simpler than one incorporating an RMS detector. IEC 60118-4:2014 therefore allows the use of either the RMS/125 ms meter or the PPM.

Because the integration time of a PPM is very short (i.e. it is a peak programme meter), it might, with some speech signals, register higher levels on short bursts of speech than an RMS meter having an integration time of 125 ms, even though both meters read the same on a sinusoidal signal.

Almost all HLS amplifiers incorporate automatic gain control (AGC), to maintain loop current levels despite fluctuations in the sound level presented to the microphone(s). However, different techniques are in use, and these differences can affect the closeness of the relationship between the readings of the RMS/125 ms meter and the PPM. These differences rarely exceed 3 dB, which is normally just perceptible as a change in "loudness". Nevertheless, 3 dB would be important if IEC 60118-4 did not include a provision to adjust the magnetic field strength as a result of the opinions of the users of the system on whether the reproduction is of an appropriate loudness.

NOTE The HLS system designer and operator have no control over the settings of the volume controls of the hearing-aids, which, in some cases, might not be under the control of anyone except the hearing-aid dispenser.

As a result of the above considerations, it is advisable to follow the instructions of the manufacturer of the amplifier as to the type of field strength meter to be used and the field strength to be obtained. The final goal, however, is to satisfy the users of the system, not to achieve any particular numerical results. But this cannot be taken as a licence to ignore the measured results entirely.

Annex E
(normative)

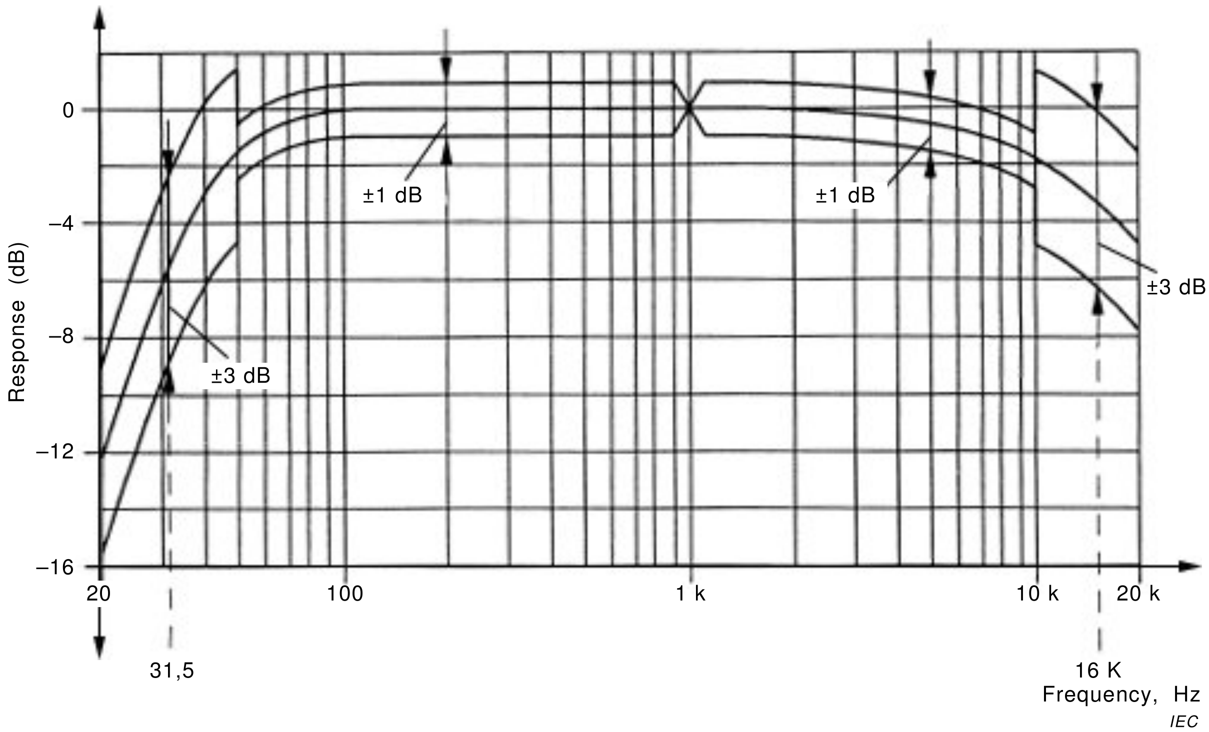
Specification of the PPM-based field strength meter

E.1 General

The meter should provide a measurement of magnetic field strength, accurate within 1 dB at 1 kHz, using an electronic display having PPM characteristics, i.e. an attack time-constant of 6,33 ms if the electronic display has negligible latency and a return time of 2,3 s for 20 dB fall (corresponding to a discharge time-constant of 1 s). The display should be scaled in decibels, with +6 dB as the highest scale value, and should have a range of at least 56 dB. 0 dB should correspond to an RMS magnetic field strength of 0,4 A/m, measured with a continuous sinusoidal signal.

A switch should be provided to select two frequency response characteristics. The switch positions should be labelled "A-weighted" and "EQ" (equalized). In the "A-weighted" position, the frequency response measured at each electrical output for a constant magnetic field strength should conform to the requirements for A-weighting for Class II sound level meters specified in IEC 61672-1. In the "EQ" position, the response should fall within the mask shown in Figure E.1.

It is necessary to provide both an "A-weighted" frequency response, approximating to that of the human ear to low-level sounds, as well as an "EQ" response for frequency response measurements and other technical tests on the system. The latter response gives meaningless results in the presence of high but tolerable levels of mains-related magnetic interference.



NOTE 1 The performance is normally checked at the frequencies where the tolerance are shown.

NOTE 2 The reference 0 dB is the actual response at 1 kHz irrespective of where this falls within the 1 dB tolerance given in Clause E.1.

Figure E.1 – "EQ" or "wideband" frequency response: target curve and tolerances on response

E.2 Checking magnetic field strength meters

In common with all measuring instruments, a field strength meter used in checking or commissioning an HLS should be tested (calibrated) at intervals, to ensure that it is indicating correctly and that any errors do not exceed the permitted values.

The meter can be tested by subjecting the probe to a known value of magnetic field strength at the relevant frequencies.

A convenient method of producing a determinate value of magnetic field strength is a short circular coil. The magnetic field strength (in A/m) at the centre of a short circular coil is given by:

$$H = \frac{nI}{d}$$

where

n is the number of turns of wire of the coil;

I is the current in the coil in amperes (A);

d is the diameter of the coil in metres (m)

The values of n, I and d can have any convenient values, but d should not be so small that minor deviations of the position of the probe from the centre of the coil have a significant effect. A deviation of one-twentieth of a diameter (50 mm for a 1 m diameter coil) produces an increase in magnetic field strength of about 3,5 %. To avoid problems with inaccurate centring of the probe, a coil diameter of 560 mm is convenient (as stated in IEC 60118-0). The 400 mA/m RMS reference strength therefore requires 0,224 ampere-turns.

NOTE A more complex but smaller apparatus, which can also produce a uniform magnetic field within a volume suitable for the present purpose is described in IEC 60118-4.

A coil comprising a single turn carrying 224 mA is suitable. This current can conveniently be provided by an audio-frequency oscillator feeding an audio amplifier. The current can be measured using the "AC current" range of an analogue or digital multimeter. This instrument should have been calibrated recently to assure its accuracy at the relevant frequencies.

The coil should be wound on a suitably sized former, for example a 560 mm diameter disc of plywood having a shallow groove around its edge to locate the wire and a central hole (say 100 mm diameter) to accept the probe. Four radial lines on the surface of the disc assist in correct location of the probe.

Ferromagnetic and conductive parts should be avoided, though a terminal block to terminate the winding is acceptable. The wires from the amplifier to the coil should be a twisted pair.

The oscillator, amplifier and current meter should be at least 2 m away from the coil, so as not to affect the magnetic field produced. Similarly, the space around the coil should be free from ferromagnetic and conductive material.

The probe should be placed at the centre of the coil, using the radial lines as a guide. The probe should be orthogonal to the plane of the coil and in its plane.

Annex F
(informative)

Magnetic field direction near the loop conductor

Figure F.1 shows the patterns of the vertical and horizontal components of the magnetic field of a horizontal loop, and *vice versa* for a vertical loop (such as used in a small loop system). The loop is square and the distance of the listening point from the loop plane is 0,14 times the loop width.

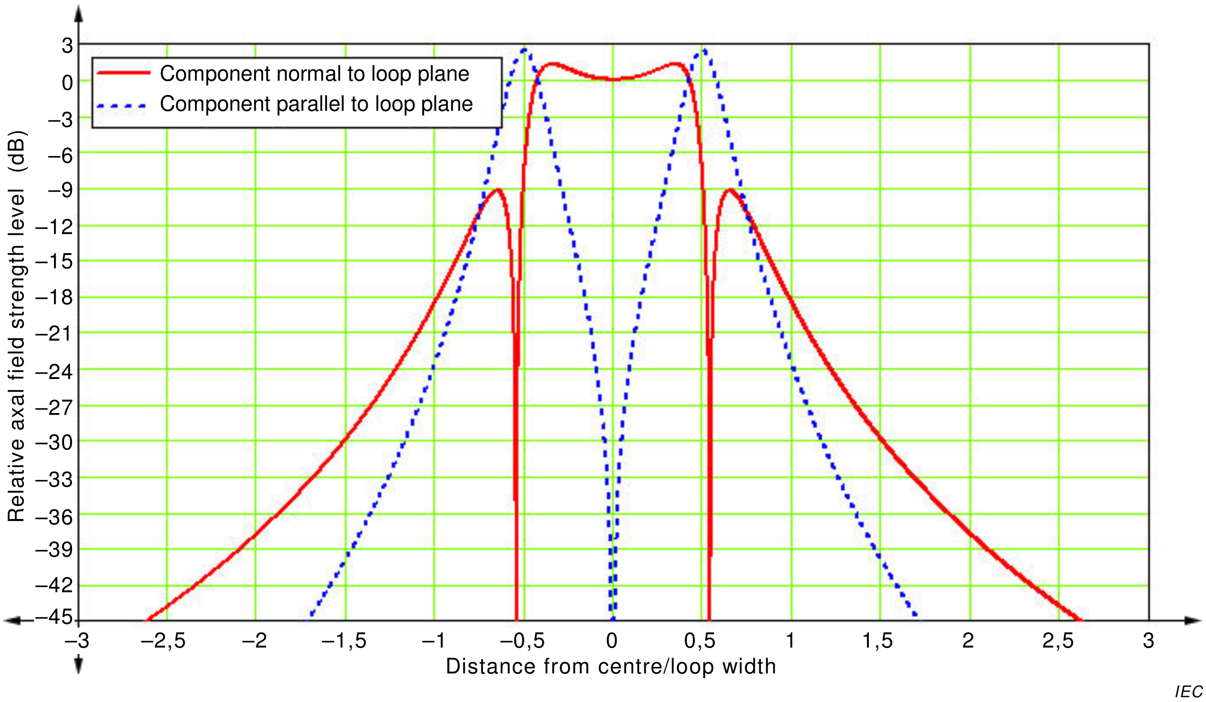


Figure F.1 – Magnetic field patterns

For a horizontal loop, it can be seen that over most of the area of the loop, the vertical component is much stronger than the horizontal. The angle of the magnetic field direction to the vertical is given by:

$$\theta = \arctan(10^{L/20})$$

where L is the level difference between the horizontal and vertical components. For example, if L is −9 dB, θ = 19,5° and the level difference L' in decibels between the vertical component and the resultant vector is:

$$L' = 20\lg(\cos\theta)$$

which, in the present case, is −0,5 dB.

However, at distances from the centre of the loop of approximately 0,4 to 0,6 times the loop width, the horizontal component of the magnetic field is comparable with, or much stronger than, the vertical component. In this region, the attitude of the hearing-aid user's head can cause the field direction to be perpendicular to the axis of the telecoil, or nearly so, resulting in a significant loss of signal strength.

This effect is illustrated in Figure F.2 and Figure F.3.

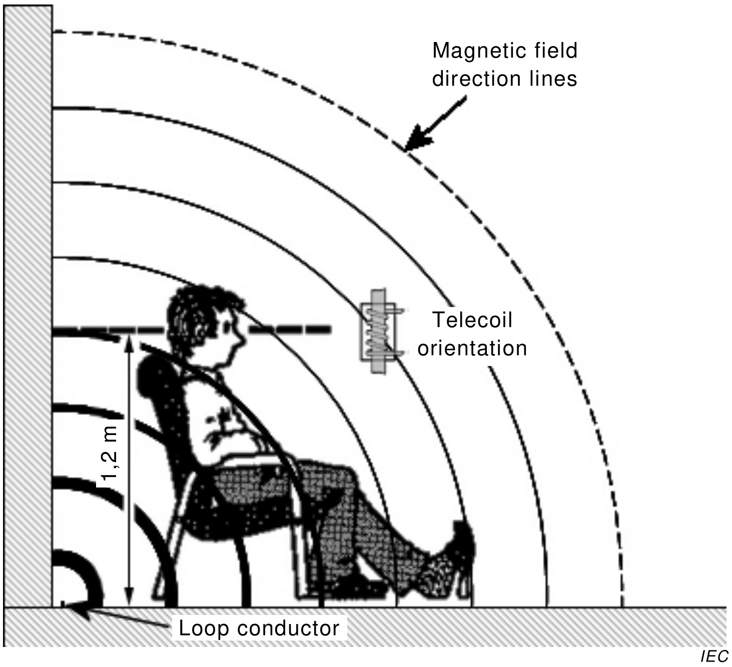


Figure F.2 – Magnetic field directions for a floor-level loop

This effect can be eliminated by using a two-loop array with two amplifiers and a wide-band quadrature circuit.

For a vertical loop, as used in some small loop systems, the above considerations are reversed. Because the listener is normally much further away from the loop in proportion to its dimensions than is the case for a large loop, the shape of the field patterns is somewhat different and there are two regions, centred approximately on the top and bottom loop conductors, where the field vector is substantially vertical. Clearly, a large region, centred on the centre of the loop, is outside the useful magnetic field volume.

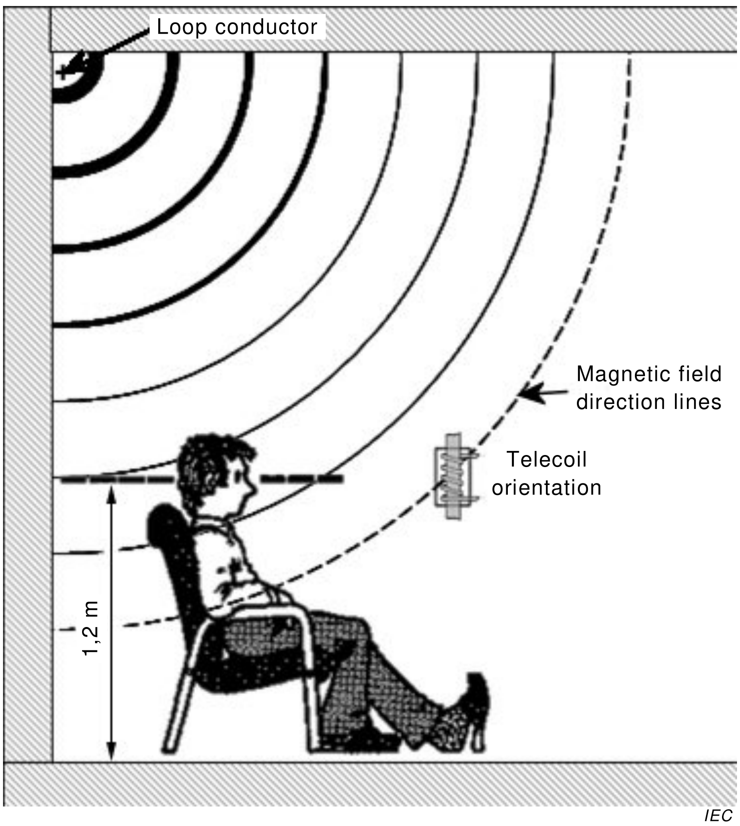


Figure F.3 – Magnetic field directions for a ceiling-level loop

Annex G
(informative)

Direct-to-reverberant sound pressure ratio

The direct-to-reverberant sound pressure level ratio K can be calculated from the following formula, if only a single microphone is used:

$$K = 10\lg\left[\frac{QV}{314\,D^2(RT)}\right]$$

where

Q is the directivity index of the microphone;

V is the volume of the room (in m^3);

D is the distance between sound source and the microphone (in m);

RT is the reverberation time of the room (in s).

If more than one microphone is used, the subject becomes significantly more complicated and specialist advice should be sought. The ratio K decreases by a factor of 3 dB each time the number of active microphones in operation is doubled. For example, using two microphones instead of one reduces the direct-to-reverberant sound pressure level ratio by approximately 3 dB.

Since the formula for K includes the directivity index Q of the microphone, the directional characteristic of the microphone affects the distance from the source of sound at which a given direct-to-reverberant sound pressure level ratio is achieved.

NOTE 1 The above formula assumes a diffuse, statistical sound field to exist and does not take into account the effects of local reflections, or non-exponential sound decay within the room. However, the formula can be used to obtain an initial estimate of the likely maximum usable microphone distances.

NOTE 2 Except for large auditoriums and places of worship, RT for most medium to large rooms is likely to be between 1 s and 2 s. Small rooms generally have a shorter RT, for example around 0,5 s for well furnished (domestic) rooms and up to around 1 s to 1,2 s for lecture theatres and similar sized rooms.

Primary school classrooms should have an RT value of 0,6 s or less, 0,8 s for secondary school classrooms and open plan areas/seminar rooms and 0,8 s to 1,2 s for assembly halls. Lecture theatres should have RT values less than 1,0 s and less than 0,8 s for small rooms (<50 people).

Annex H
(informative)

Model certificates

H.1 Design certificate

Certificate of design of the HLS at:

Address:

Postcode:

I/we being the competent person(s) responsible (as indicated by my/our signatures below) for the design of the HLS, particulars of which are set below, CERTIFY that the said design for which I/we have been responsible complies to the best of my/our knowledge and belief with applicable regulations for electrical installations except for the variations, if any, stated in this certificate.

Name (in block letters): Position:

Signature: Date:

For and on behalf of:

Address:

Postcode:

Variations from applicable regulations for electrical installations:

Extent of system covered by the certificate:

Installation and commissioning

It is strongly recommended that installation and commissioning be undertaken in accordance with the recommendations of this document.

Verification

Verification that the system complies with IEC 60118-4 should be carried out, on completion.

Yes ☐ No ☐ To be decided by the purchaser ☐

Maintenance

It is strongly recommended that, after completion, the system is maintained in accordance with this document.

User responsibilities

The user should appoint a responsible person to supervise all matters pertaining to the HLS.

H.2 Installation certificate

Certificate of installation of the HLS at:

Address:

Postcode:

I/we being the competent person(s) responsible (as indicated by my/our signatures below) for the installation of the HLS, particulars of which are set below, CERTIFY that the said installation for which I/we have been responsible complies to the best of my/our knowledge and belief with the recommendations of this document except for the variations, if any, stated in this certificate.

Name (in block letters): Position:

Signature: Date:

For and on behalf of:

Address:

Postcode:

The extent of liability of the signatory is limited to the system described below.

Extent of system covered by the certificate:

Specification against which the system was installed:

Variations from the specification and/or this document:

Wiring has been tested in accordance with applicable regulations for electrical installations. Test results have been recorded and provided to:

Unless supplied by others, the “as fitted” drawings have been supplied to the person responsible for commissioning the system.

H.3 Commissioning certificate

Certificate of commissioning for the HLS at:

Address:

Postcode:

I/we being the competent person(s) responsible (as indicated by my/our signatures below) for the commissioning of the HLS, particulars of which are set below, CERTIFY that the said installation for which I/we have been responsible complies to the best of my/our knowledge and belief with the recommendations of this document except for the variations, if any, stated in this certificate.

Name (in block letters): Position:

Signature: Date:

For and on behalf of:

Address:

Postcode:

The extent of liability of the signatory is limited to the system described below.

Extent of system covered by the certificate:

Variations from the recommendations of this document

☐ All equipment operates correctly.

☐ Installation work is, as far as can be reasonably ascertained, of an acceptable document.

☐ The entire system has been inspected and tested in accordance with the recommendations of this document.

☐ The system performs as required by the specification prepared by:

a copy of which I/we have given.

☐ The documentation described in this document has been provided to the user.

The following work should be completed before/after (delete as applicable) the system becomes operational:

H.4 Acceptance certificate

Certificate of acceptance for the HLS at:

Address:

Postcode:

I/we being the competent person(s) responsible (as indicated by my/our signatures below) for the acceptance of the HLS, particulars of which are set below, ACCEPT the system on behalf of:

Name (in block letters): Position:

Signature: Date:

For and on behalf of:

Address:

Postcode:

The extent of liability of the signatory is limited to the system described below.

Extent of system covered by the certificate:

☐ All installation work appears to be satisfactory.

☐ The system is capable of giving an audible and intelligible signal.

The following documents have been provided to the purchaser or user:

☐ "As fitted" drawings.

☐ Operating and maintenance instructions.

☐ Certificate of design, installation and commissioning.

☐ A log book.

☐ Sufficient representatives of the user have been properly instructed in the use of the system

☐ All relevant tests, defined in the purchasing specification, have been witnessed. (Delete if not applicable.)

The following work is required before the system can be accepted:

H.5 Verification certificate (optional)

Certificate of verification for the HLS at:

Address:

Postcode:

I/we being the competent person(s) responsible (as indicated by my/our signatures below) for the verification of the HLS, particulars of which are set below, CERTIFY that the verification work for which I/we have been responsible complies to the best of my/our knowledge and belief with the recommendations of this document.

Name (in block letters): Position:

Signature: Date:

For and on behalf of:

Address:

Postcode:

The extent of liability of the signatory is limited to the system described below.

Extent of system covered by the certificate:

Scope and extent of the verification work:

☐ In my/our opinion, that as far as can reasonably be ascertained from the scope of work described above, the system complies with, and has been commissioned in accordance with, the recommendations of this document, other than in respect of variations already identified in the certificates of design, installation or commissioning.

The following non-compliances with the recommendations of this document have been identified (other than those recorded as variations in the certificates of design, installation or commissioning):

H.6 Inspection and servicing certificate

Certificate of servicing for the HLS at:

Address:

Postcode:

I/we being the competent person(s) responsible (as indicated by my/our signatures below) for the servicing of the HLS, particulars of which are set below, CERTIFY that the said installation for which I/we have been responsible complies to the best of my/our knowledge and belief with the recommendations of this document except for the variations, if any, stated in this certificate.

Name (in block letters): Position:

Signature: Date:

For and on behalf of:

Address:

Postcode:

The extent of liability of the signatory is limited to the system described below.

Extent of system covered by the certificate:

Variations from the recommendations of this document

☐ Relevant details of the work carried out and faults identified have been entered in the system log book.

H.7 Modification certificate

Certificate of modification for the HLS at:

Address:

Postcode:

I/we being the competent person(s) responsible (as indicated by my/our signatures below) for the modification of the HLS, particulars of which are set below, CERTIFY that the said installation for which I/we have been responsible complies to the best of my/our knowledge and belief with the recommendations of this document except for the variations, if any, stated in this certificate.

Name (in block letters): Position:

Signature: Date:

For and on behalf of:

Address:

Postcode:

The extent of liability of the signatory is limited to the system described below.

Extent of system covered by the certificate:

Variations from the recommendations of this document

☐ Following the modifications, the system has been tested in accordance with the recommendations of this document.

☐ Following the modifications, "as fitted" drawings and other system records have been updated as appropriate.

I/we the undersigned confirm that the modifications have introduced no additional variations from the recommendations of this document other than those recorded above:

Signed:

Capacity:

(e.g. maintenance organization, system designer, consultant or user representative)

Bibliography

[1] DALSGAARD, S.C. *Field distribution inside rectangular induction loops.* Odense: State Hearing Centres, Research Laboratory for Technical Audiology, University Hospital, 1973

[2] F. W. Grover, *Inductance Calculations, New York,* Dover Publications, 2009

[3] OLOFSSON, A. *Improvement of induction-loop field characteristics using multiple-loop systems with uncorrelated currents* Report TA-110 Dept. of Technical Audiology, Karolinska Intitutet, Stockholm January 1984

[4] WILLIAMS, A. B. *Electronic Filter Design Handbook.* New York: McGraw Hill. 1981

[5] ZUREK, P.M. and DELHORNE, L. M. Consonant, reception in noise by listeners with mild and moderate sensorineural hearing impairment. J. Acoust. Soc. Am. November, Vol. 82, No. 5, 1987 p. 1548-1559

[6] HARRIS, R.W. and SWENSON, D. W. Effects of reverberation and noise on speech recognition by adults with various amounts of sensorineural hearing impairment. *Audiology.* 1990, Vol. 29, p. 314-321

[7] BAXANDALL, P. J. A technique for displaying the current and voltage output capability of amplifiers and relating this to the demands of loudspeakers. *Journ, Aud. Eng. Soc.* 1988 Jan/Feb, Vol. 36 No. 1/2 p. 3-17. New York: 1988

[8] IEC 60118-4:2014, *Electroacoustics - Hearing aids – Part 4: Induction-loop systems for hearing aid purposes – System performance requirements*

[9] IEC 62489-1, *Electroacoustics – Audio-frequency induction-loop systems for assisted hearing – Part 1: Methods of measuring and specifying the performance of system components*

[10] IEC 62489-2, *Electroacoustics – Audio-frequency induction-loop systems for assisted hearing – Part 2: Methods of calculating and measuring the low-frequency magnetic field emissions from the loop for assessing conformity with guidelines on limits for human exposure*

[11] IEC 60268-3, *Sound system equipment – Part 3: Amplifiers*

[12] IEC 62368-1, *Audio/video, information and communication technology equipment – Part 1: Safety requirements*

[13] IEC 60364 (all parts), *Low-voltage electrical installations*

[14] IEC 62305 (all parts), *Protection against lightning*

[15] IEC 61672-1, *Electroacoustics – Sound level meters – Part 1: Specifications*

[16] IEC 60118-0, *Electroacoustics – Hearing aids – Part 0: Measurement of the performance characteristics of hearing aids*

[17] IEC 60228, *Conductors of insulated cables*

[18] IEC 60268-10, *Sound system equipment – Part 10: Peak programme level meters*

[19] IEC 60268-16, *Sound system equipment – Part 16: Objective rating of speech intelligibility by speech transmission index*

[20] IEC 60118-4:1981, *Methods of measurement of electro-acoustical characteristics of hearing aids – Part 4: Magnetic field strength in audio-frequency induction loops for hearing aid purposes*[2]

[21] IEC 60268-10, *Sound system equipment - Part 10: Peak programme level meters*

____

2 This document has been withdrawn, but for the purposes of this document it is given as a reference.

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

3, rue de Varembé
PO Box 131
CH-1211 Geneva 20
Switzerland

Tel: + 41 22 919 02 11
Fax: + 41 22 919 03 00
info@iec.ch
www.iec.ch