

Code of practice for

Audio-frequency induction-loop systems (AFILS)

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Electronic Equipment Standards Policy Committee (EEL/-) to Technical Committee EEL/32, upon which the following bodies were represented:

- Association of British Theatre Technicians
- Association of Electronics, Telecommunications and Business Equipment Industries (EEA)
- Audio Engineering Society
- British Broadcasting Corporation
- British Educational Equipment Association
- British Kinematograph Sound and Television Society
- British Radio and Electronic Equipment Manufacturers' Association
- British Telecommunications plc
- Consumer Policy Committee of BSI
- Consumers' Association
- Department of Health and Social Security
- Electronic Components Industry Federation
- Federation of British Audio
- Independent Television Association
- Institution of Electrical Engineers
- National Council for Educational Technology (NCET)
- Professional Lighting and Sound Association
- Radio Electrical and Television Retailers' Association
- Royal Institute of British Architects
- Royal National Institute for Deaf Persons
- Society of Cable Television Engineers
- Sound and Communication Industries Federation

The following body was also represented in the drafting of the standard through Panel EEL/32/-/1:

- British Association of the Hard of Hearing

This British Standard, having been prepared under the direction of the Electronic Equipment Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 15 August 1993

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The following BSI references relate to the work on this standard:
Committee reference EEL/32
Draft for comment 90/24169 DC

ISBN 0 580 22112 1

Amendments issued since publication

Amd. No.	Date	Comments

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Foreword

This British Standard has been prepared under the direction of the Electronic Equipment Standards Policy Committee.

This standard has been written as a code of practice at the express wish of industry and recommends good accepted practice for the accomplishment of the defined tasks and their sequence, as followed by competent practitioners. In particular it recommends the use of a magnetic field strength meter having peak programme meter (PPM) dynamic characteristics. This approach has been taken in the absence of any other wholly satisfactory and documented method for setting up and measuring the performance of an AFILS known to the Committee. Almost all meters (one exception is known) which have been commercially available previously, have had average or true r.m.s. rectifiers and meters with undefined dynamics, and in many cases the frequency response also has not been either appropriate or clearly specified. Assurances have been sought and received that at least one manufacturer intends to produce field strength meters conforming to the recommendations of this standard.

As a code of practice, this British Standard 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 conformity are not misleading.

The requirements for Electrical Installations published under BS 7671:1992 (formerly the IEE Wiring Regulations) are not statutory regulations, but conformity may satisfy the requirements of certain statutory regulations. It is therefore advisable to comply with BS 7671.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to vi, pages 1 to 88, an inside back cover and back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1.0 Introduction

1.0.1 How to use this code of practice

This standard is divided into sections intended primarily for:

- a) purchasers of AFILS (see particularly sections 1 and 2);
- b) designers of AFILS and AFILS equipment (see sections 3 and 5);
- c) installers of AFILS (see sections 4 and 5);
- d) users, both hard of hearing and those responsible for commissioning, testing, operation and maintenance (see section 5 to 7).

1.0.2 What is an audio-frequency induction-loop system (AFILS)?

An AFILS basically comprises a cable installed in the form of a loop usually around the perimeter of the room, hall, church, theatre, etc. in which the AFILS facility is to be provided. The cable is connected via an amplifier to one or more microphones or other source(s) of sound signals, such as a radio receiver, cassette recorder or disc player.

The amplifier produces an audio-frequency electric current in the induction loop cable, causing a magnetic field to be produced inside the loop. This magnetic field is a reproduction of the signal feeding the amplifier, and can be picked up by suitable receivers. This standard is mainly concerned with AFILS for assisted hearing, in which the receivers are hearing aids equipped with a telecoil and an M-T (or M-MT-T) switch. The standard also discusses other common situations where an AFILS may be used, such as information systems for museum tours.

In this standard, where the expression M-T is used, it also implies the expression M-MT-T and, except where stated, the symbol T also implies MT.

Hearing aids with the switch in the T position pick up the magnetic field and produce sound in the ear of the wearer. For hearing aids without an M-T switch and for other applications, a special receiver is required.

1.0.3 Advantages of AFILS (for assisted hearing)

Whilst a hearing aid worn by a person with impaired hearing can provide a useful improvement to the effectiveness of hearing local conversations, it is 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 a pair of headphones, the problems of reverberation and unwanted noise are, to a large extent, overcome, and the listener hears the sound more clearly.

Microphones may be coupled to hearing aids or headphones by means of wires, infra-red radiation, magnetic induction or radio transmission. AFILS make use of magnetic induction and can be used by anyone wearing a hearing aid fitted with a switch having a T (telecoil) position without the need for additional equipment. The wearer can be located anywhere in the area 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 AFILS does not require special receivers to be issued to and collected from the users. This saves equipment and the associated administrative costs.

AFILS are appropriate for installation in theatres, conference rooms, cinemas, churches, meeting halls, shopping areas, education establishments, etc. 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 and television programmes. Specialist installations using similar principles 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 AFILS 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 may prove to be relatively more expensive.

NOTE 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. To distinguish sound frequencies, which conventionally range from 20 Hz to 20 000 Hz, i.e. 20 kHz (where kHz is the abbreviation for kilohertz), they are called “audio frequencies”. For the purposes of this standard, the extremes of the audio frequency 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 five octaves above middle C).

1.0.4 Limitations

1.0.4.1 When using a hearing aid switched to the T position, only the AFILS can be heard. If there are likely to be long periods of silence on the system, hearing aid users might think that the system is not working. In these instances it may be necessary to give reassurance that the system is in operation by the use of a confidence signal (see **3.3.15**).

The benefits given by AFILS are lost if the system is not properly managed to ensure that it is available when required and adjusted to suit the circumstances. An AFILS cannot operate satisfactorily without adequate attention.

1.0.4.2 The operation of an AFILS can be affected by the following:

- a) the effect of metal in the building structure and within the coverage area;
- b) magnetic field overspill, for example from adjacent AFILS;
- c) magnetic noise interference.

The overall effects of these factors should be identified during the site assessment (see **3.2**).

1.0.5 Specialist advice

The engagement of a skilled System Designer is always advisable and is considered to be essential whenever large or complex installations are involved.

1.0.6 Safety aspects

It is essential that an AFILS, even if temporary, is installed in a safe manner and in accordance with accepted work practices.

1.0.7 Conforming to existing performance standards

A properly designed AFILS should conform to existing performance standards, the requirements of which have been incorporated (where applicable) as recommendations in this standard.

1.1 Scope

This British Standard gives recommendations for and guidance on the design, planning, installation, testing, operation and maintenance of AFILS intended for communicating speech, music and/or other signals. It is mainly concerned with AFILS for assisted hearing, in which the signals are communicated to users of hearing aids equipped with magnetic pick-up coils. However, most of the standard also applies to AFILS used for other purposes, and some additional information on these purposes is given in section **3**.

These recommendations are intended to assist achievement of the following results.

- a) The functions and limitations of an AFILS are clearly understood by prospective purchasers (see **2.4**).
- b) The design, installation and setting-up of the AFILS allows compliance with the appropriate requirements for safety and electromagnetic compatibility and all relevant regulations relating to electrical installations, together with Governmental requirements specific to AFILS.
- c) Users wearing hearing aids equipped with a magnetic pick-up coil will receive satisfactorily the signals transmitted by the AFILS, intelligible and free from undue distortion and interference even when all equipment normally used in the environment is functioning.
- d) The reception of such signals is possible in any part of the area, and where, by force of circumstance, the reception area is limited, this is clearly defined and identified (see **1.4.4**).

e) Visual indication is given to prospective users that an AFILS is installed.

f) Effective testing and monitoring are provided.

NOTE This should include the means for continuous visual and/or audible monitoring of the functioning of the AFILS.

g) The AFILS can be satisfactorily operated and maintained.

h) Where necessary, the AFILS is arranged for minimum extraneous coverage. It should be understood that however well an AFILS is designed, it will always be possible for a determined person outside the intended area of coverage to receive what may be confidential information.

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

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

1.2 References

1.2.1 Normative references

This standard incorporates, by reference, provisions from specific editions of other publications. These normative references are cited at the appropriate points in the text and the publications are listed on page 88. Subsequent amendments to, or revisions of, any of these publications apply to this standard only when incorporated in it by updating or revision.

1.2.2 Informative references

This standard refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on page 88, but reference should be made to the latest editions.

1.3 Definitions

For the purposes of this standard, the following definitions apply.

NOTE Certain technical definitions are also contained in 3.3.3.

1.3.1

audio-frequency induction-loop system (AFILS)

a system in which magnetic fields intended to be received by suitable receivers are created by the flow of audio-frequency current in a conductor arranged in the form of a loop. The system also includes the amplifier(s), microphones and other signal sources used by the AFILS

1.3.2

AFILS for assisted hearing

an AFILS in which the receivers are hearing aids or specially designed receivers equipped with magnetic antennas (usually pick-up coils)

1.3.3

hearing aid

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

NOTE Many hearing aids incorporate a receiving coil which enables direct reception of magnetic fields generated by an AFILS. The coil (telecoil, T) is selected by moving a switch to a position marked with a T or MT. In the latter position, the hearing aid receives from both its microphone (M) and the AFILS.

1.3.4

induction-loop receiver

a listening device which is designed to give an audible output in response to signals transmitted by an AFILS

1.3.5

induction-loop monitor receiver

equipment designed to verify the performance of an AFILS by:

- a) providing an indication when the strength of the magnetic field (see the note to 1.3.9) produced by the loop falls within a specified range; and

- b) providing an audio-frequency output by which the sound quality of the AFILS transmissions may be assessed.

NOTE Other facilities may be included (see 7.1).

1.3.6 magnetic field strength

the strength of the resultant field, at a stated point in space, generated by the flow of alternating current in an AFILS

1.3.7 listening plane

the plane which lies at the median level of the ears of users of the AFILS

NOTE It may be necessary to identify more than one listening plane if auditorium seating is on several widely separated levels in the vertical direction.

1.3.8 coverage area

that portion of the listening plane over which the magnetic field strength does not deviate from the specified value by more than a stated amount. (See the note to 1.3.9)

1.3.9 working area

that portion of the listening plane over which the signal-to-noise ratio exceeds a stated value

NOTE 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 (see 3.3.17). The component of the magnetic field parallel to the axis of the magnetic pick-up coil in the hearing aid is the effective component.

1.3.10 system designer

a technically competent person who takes responsibility for the technical specification, design and functioning of the systems

1.3.11 control point

the location of the normal operating controls of the AFILS

1.3.12 ticket office (counter) system

a local AFILS designed to assist communication through a transparent screen, normally between two persons engaged in a transaction, for example at a ticket office, bank, or a social security office

1.3.13 large or complex installation

an AFILS which has an approximate coverage area greater than 50 m² or consists of two or more AFILS operating in close proximity

1.4 Signs and symbols

1.4.1 General

Except for the symbol given in 1.4.2, it is recommended that all signs for display should be produced on poly(vinyl chloride) (PVC) with a laminated surface or on a more durable material if deemed necessary.

1.4.2 Circuit symbol for an induction-loop

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

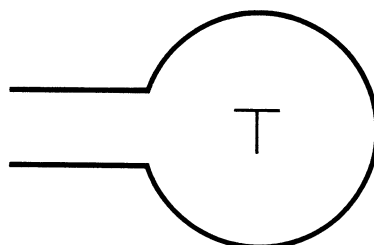


Figure 1 — Symbol for use on AFILS circuit diagrams

1.4.3 Sign for display in premises where an AFILS is installed and for AFILS equipment identification

The sign shown in Figure 2, which is based on the one adopted by the World Federation of the Deaf, should be used. The sign should indicate T as shown. The background colour should be 542 ruby conforming to BS 381C:1988 (approximate Munsell reference 7.5RP 3/10) or similar to Pantone reference 242 C and the printing should be in white.

NOTE Signs of other colours are to be found in use.

Normally the dimensions of the signs should be a minimum of 100 mm × 100 mm, but for equipment it may be of any convenient size.

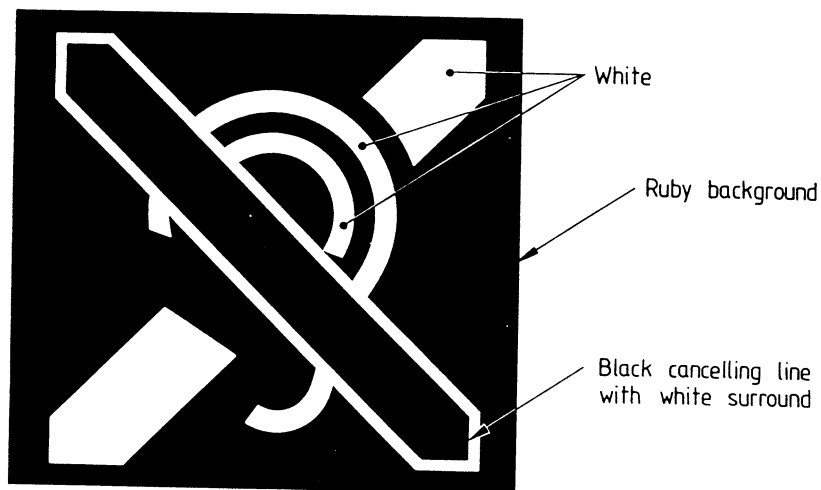


Figure 2 — Sign for display in premises to indicate that an AFILS is installed and for AFILS equipment identification

The sign should appear at a position visible in normal use on AFILS 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.

1.4.4 Identification of seating areas where reception of the AFILS is not satisfactory

Areas where the reception of the AFILS is not satisfactory should be clearly indicated on a plan of the auditorium by means of the sign shown in Figure 3. 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 the seats in that area.



NOTE This sign is based on Figure 2.

Figure 3 — Sign to show seating areas where AFILS reception is not satisfactory

Section 2. Guidance on purchasing an AFILS or placing a contract for its installation, or obtaining independent assessment of the performance of an installation

2.1 Technical advice

2.1.1 Conformity to this standard

Before the publication of this standard, optimum design and installation procedures for loop systems have not been widely known. Prospective purchasers should, therefore, stipulate that the design and installation are to conform to this standard. Operation and maintenance procedures should also be in accordance with its recommendations.

2.1.2 Seeking technical advice

While many successful AFILS have already been installed, conformity to this standard will greatly increase the probability that satisfactory results will be obtained. However, its provisions cannot be properly applied without adequate technical knowledge and experience, and each design presents individual problems. Wherever possible, therefore, technical advice should be sought during the early planning stages of an AFILS. Such advice should cover:

- a) the suitability of an AFILS for a particular venue and/or application (see 1.0.3);
- b) factors that may adversely affect the performance of an AFILS;
- c) factors that may add to the cost of installing an AFILS;
- d) the need for, and scope of, a site assessment (see 3.2).

In all cases, the responsibility for the correct performance of the system at the time of commissioning should lie with the System Designer (see 1.3.10).

2.1.3 The nature of the advice

Advice sought will depend on the particular installation requirements for each AFILS, 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 AFILS;
- b) advice from the designer to a technically competent engineer who lacks experience with AFILS 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).

2.1.4 Sources of technical advice

Technical advice should be sought only from the following:

- a) bona fide System Designers/installers (see also 2.1.5);
- b) AFILS equipment manufacturers;
- c) appropriate professional organizations.

2.1.5 Independent professional (consultancy) advice

Independent 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 may also be necessary 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.

2.2 Choosing the system supplier

2.2.1 General

Possible procedures for acquiring an AFILS are given in 2.2.2 to 2.2.4. The choice of procedure should depend on the size of the area to be covered, the funds available and any special complications which may be involved.

2.2.2 Approaching a contractor

Particularly for small and uncomplicated AFILS, a contractor can be asked to supply and install suitable equipment and all cabling. Names of contractors who specialize in this work can be obtained from business directories and trade associations. Responsibility for choosing appropriate equipment (microphones, amplifier, etc.) and for installing and setting up the AFILS correctly, should rest with the contractor. For a small AFILS, the cost of a formal initial survey may not be justified, but many contractors will conduct an informal survey as a matter of course.

2.2.3 Approaching a manufacturer of AFILS or AFILS equipment

Some manufacturers of AFILS or AFILS equipment 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 may offer contact with appropriate designers/installers who can undertake such projects. Names of manufacturers can be obtained from business directories and trade associations. 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 AFILS and commissioning (where this is also undertaken).

For some AFILS, the installation contractor may 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.

2.2.4 Approaching a specialist consultant

For large or complex AFILS, when it is appropriate to engage a specialist consultant, he should be responsible for the initial survey, design and commissioning of the AFILS, choice of equipment and for recommending an installation contractor. In a new building, the consultant should also liaise with architects, main and subsidiary construction contractors on matters affecting the AFILS. Names of consultants who specialize in this work can be obtained from business directories and trade associations (see Annex A). Such a consultant may be independent or may be a competent person employed by a manufacturing or contracting organization.

2.3 Contractual provisions

2.3.1 Compliance with this standard

The word “should” used in this standard should be taken as being sufficient to require the System Designer to provide a good reason why any variation to the stated requirement is proposed. 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.

2.3.2 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. A guide to the preparation of a specification is given in Annex B. 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 he may have about the suitability of such equipment should be clearly explained to the purchaser in writing.

2.3.3 Verification of the performance of the completed system

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

- a) instrumentation checks;
- b) subjective tests using persons with normal hearing;
- c) subjective tests using hearing aid users.

When the subjective tests do not provide confirmation of the 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 refining the System Designer's responsibility for the preparation of remedial proposals and their implementation.

NOTE The need for elimination of interference by the AFILS with other nearby electronic systems (see 3.2 f) and 3.3.14) may be impossible to predict before the AFILS is installed and tested. It is reasonable to expect the System Designer to advise on methods of eliminating this interference for the AFILS and the affected system (see 3.3.14). Remedial work should, however, be carried out by the body having technical responsibility for the appropriate system. Modifications to the AFILS 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.

2.3.4 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.

2.4 Limitations of an AFILS

2.4.1 Magnetic noise interference

Magnetic fields radiated from mains 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 can be at a much higher intensity and in this case can 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. Examples of sources of magnetic interference are fluorescent and other types of discharge lamps, electronic lamp dimming systems and electricity meters (see 3.3.13).

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 the 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.

2.4.2 Magnetic field overspill

In general an AFILS can potentially interfere with any other communication system using a magnetic induction link in any part of its chain of communication. For example, an AFILS installed in a theatre auditorium is likely to interfere with a ticket office system installed at the box office. Since the magnetic field produced by an induction loop is not confined to the area within the loop, overspill signals can often 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. 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 may also hear overspill signals from the other. Care should be taken to ensure that confidential information is not fed into the AFILS as it may be possible to hear this information with a suitable receiver some distance outside the loop. Special designs of loop should be considered, which can help to reduce the overspill field (see 3.3.17).

2.4.3 Effect of metal in the building structure and within the coverage area

The performance of the AFILS can be seriously degraded if there is metal (which may be concealed) in the building. Local impairment of performance can also occur near large metal objects within the coverage area. These effects are difficult to predict and a specific preliminary investigation should be considered as part of the design procedure.

Section 3. Recommended procedures for planning and designing an AFILS

3.1 Planning and project management

The planning function should involve the solution of any immediate problems disclosed by the site assessment (see 3.2), and scheduling and monitoring progress of the project in the following phases:

- a) collection of data for cost estimation and quotation or tendering;
- b) design;
- c) installation, including scheduling delivery of equipment to site;
- d) commissioning;
- e) information for the managerial staff of the owners of the system;
- f) training for system operators.

These activities should be carried out for projects of any size, otherwise progress may not be under control. If the activities are complex and time consuming, the appointment of a specific, qualified person as project manager should be considered.

The information and training phases are affected in scope and importance by the permanence or otherwise of the room configuration. If the position of sound sources, audience, objects affecting magnetic fields, microphones, or other loop equipment is subject to change, in-house staff should ensure that the AFILS works satisfactorily in the new configuration and that other equipment nearby is not adversely affected.

3.2 Site assessment

The satisfactory completion of the design and installation of an AFILS is frequently a demanding task, whose critical aspects vary from case to case. To achieve a good result, it is essential that the preparations for design and installation are very thorough, so the site should be examined at the earliest reasonable time, to collect data and investigate any potential problems.

The site assessment should take account of the following:

- a) the use(s) of the premises;
- b) the location and dimensions of the required working area(s);
- c) whether the room configuration is permanent or subject to change (see 3.1);
- d) the construction of the building, especially whether structural or reinforcing steelwork is present, or whether there is expanded or perforated metal in the wall lining;
- e) the presence or planned introduction of any equipment which might produce magnetic interference, for example lifts, stage lighting equipment, electric underfloor heating, fluorescent lighting (see note 1), electronic dimming equipment (see also 2.4.1). It may be possible for the AFILS loop and equipment to be sited so that any interference from these sources can be tolerated, but generally measures have to be taken to suppress the interference at source.

Measurements should be made of the level of background magnetic field with all potential sources of interference in operation. These measurements should be made at a sufficient number of points over the whole coverage area;

NOTE 1 Fluorescent lighting equipment varies greatly in the amount of magnetic interference generated, depending on the design and, in some cases, the location of the control gear.

- f) the presence or planned introduction of any equipment which might be subject to magnetic interference from the AFILS, for example telephone, audiovisual systems, computer terminals;

NOTE 2 In many cases, such interference cannot be eliminated by modifying a correctly-designed AFILS, but can be eliminated by modifying the system suffering interference (see 3.3.13).

NOTE 3 Liaison with the bodies having technical responsibility for other systems should be established at an early stage.

- g) if the mains supply is of the TT or TNC-S (PME) type (see BS 7671:1992), attention is drawn to the possibility of interfering magnetic fields at mains frequency, caused by earth currents;
- h) what equipment is likely to be needed for the AFILS, so that its location, storage (for non-fixed items), security, cost, etc. can be taken into account at an early stage in the project. The precise specifications of the equipment should be determined during the design stage;
- i) in the case of a new building, the need to establish an early liaison with the architects and main contractors, so that foreseeable problems may be resolved. A trial loop (see below) should be installed at an early stage, even if magnetic interference cannot be finally assessed, due to potentially interfering equipment not being present or operational;

j) whether the level of magnetic interference at the proposed control point (if within the intended working area) would permit monitoring of the loop at this point, bearing in mind that a hearing aid user might be employed as an operator;

NOTE 4 The inclusion of the control point in close proximity to the loop may cause magnetic interference with the AFILS amplifier or other audio equipment sited near to the control point. In this case, or if the control point is outside the working area, or if the level of magnetic interference at the control point is excessive, an alternative means of communicating with a hard-of-hearing operator may need to be provided (for example wired or infra-red (IR) cordless headphones).

k) possible and inadmissible routes for loop and microphone wiring.

Care should be taken to obtain reliable information on these points from the appropriate authorities, for example, the architect, builder, management of the premises.

In all but the simplest cases, it is strongly recommended that a trial loop should be installed. The current required to produce a known magnetic field strength, the limits of the coverage area and the variation of field strength with frequency for a constant current in the loop should be measured.

3.3 Design

3.3.1 General

Many successful AFILS 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 equations, and further information, are given in Figure 5 to Figure 16 and in Annex C with Figure C.1 to Figure C.5.

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

An AFILS 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;

NOTE 1 The useful component of magnetic field is normally the vertical component, but see the note to 1.3.9.

NOTE 2 The value of field strength recommended in this standard ($0.56 \text{ A} \cdot \text{m}^{-1} \pm 3 \text{ dB}$, measured on programme signals with a meter conforming to Annex D, which has been found to correspond (see 3.3.5) to a long-term average field strength on speech signals of $0.1 \text{ A} \cdot \text{m}^{-1} \pm 3 \text{ dB}$, as specified in BS 6083-4:1981) is chosen to be high enough to produce an acceptable signal-to-noise ratio in as many locations as possible, without being so high as to risk overloading hearing aids.

b) the magnetic field strength in item a) over the frequency range 100 Hz to 5 kHz (see BS 6083-4:1981) with acceptable uniformity and amount of non-linearity distortion.

NOTE 3 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. The standard considers several ways of achieving a sufficiently low variation with frequency.

3.3.2 Symbols

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

A	length of the side of a square loop or of the shorter side of a rectangular loop (in m)
B	length of the longer side of a rectangular loop (in m)
D	length of the diagonal of a loop (in m)
d	diameter of the loop conductor (in m)
f_c	frequency of the upper limit of the loop pass band (in Hz)
H	r.m.s. magnetic field strength (in $\text{A} \cdot \text{m}^{-1}$)
H_0	r.m.s. magnetic field strength at the centre of the loop and in its plane (in $\text{A} \cdot \text{m}^{-1}$)

H_{oz}	perpendicular component of the r.m.s. magnetic field strength at a point, distance z from the plane of the loop along the perpendicular through the centre of the loop (in $A \cdot m^{-1}$)
h	height of the telecoil above or below the plane of the loop (m) NOTE The usual case where the plane of the loop is horizontal is assumed.
h_n	height ratio, $2h/\sqrt{AB}$ for a rectangular loop
I	r.m.s. current in the loop conductor (in A)
K	direct to reverberant sound pressure level ratio (in dB)
L	inductance of the loop (in H)
n	number of turns in the loop
R	resistance of the loop (in Ω)
r_n	resistance ratio ($R/\omega_c L$)
V	r.m.s. voltage between the ends of the loop conductor (in V)
Z	impedance (in Ω)
α	temperature coefficient of the resistivity of copper (wire) (0 °C to 100 °C average), $3.93 \times 10^{-3} K^{-1}$
γ	aspect ratio = B/A
θ	temperature (in °C)
μ_0	magnetic permeability of space, i.e. $0.4\pi \mu H \cdot m^{-1}$
ρ_0	resistivity of copper (wire) at 0 °C, i.e. $16.5 n\Omega \cdot m$
ω_c	angular frequency of the upper limit of the loop pass band, i.e. $2\pi f_c$ rad/s

3.3.3 Design definitions

3.3.3.1 direction of magnetic field

The 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. (See the note to 1.3.9.)

3.3.3.2 AFILS reference plane

The plane to which the magnetic characteristics of the AFILS are referred when stating specified values.

NOTE The reference plane specification should include its inclination to the horizontal.

3.3.3.3 AFILS reference point

The point on the reference plane to which the magnetic characteristics of the AFILS are referred when stating specified values.

3.3.3.4 reference value of the magnetic field strength

The value of magnetic field strength specified by the System Designer for reference purposes.

NOTE 1 The reference value should be approximately equal to the long-term average value for speech signals and be within the ± 3 dB tolerance permitted in BS 6083-4:1981 for the average value of magnetic field strength in the specified magnetic field area (see 3.3.5).

NOTE 2 The level of the field strength due to speech signals, measured with a field strength meter having peak programme meter (PPM) characteristics (see Annex D), is approximately 15 dB above the reference level if the system does not use compression and the amplifier is not overdriven.

NOTE 3 If the reference level is chosen as $0.1 A \cdot m^{-1}$, then the level measured using a PPM is $0.56 A \cdot m^{-1}$, on speech signals under the conditions of note 2 (see 3.3.1).

3.3.4 Basic theory

3.3.4.1 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 4. 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 equations apply.

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

$$I = \frac{\pi ABH_0}{2D} \quad (1)$$

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

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

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

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

These equations are derived in 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 may 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 Dalsgaard¹⁾ [1], by Grover²⁾ [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 equations (1) to (3) (or with the simplified versions, equations (7), (8) and (9) [see 3.3.9]) 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 (see 3.3.13) or caused by work hardening due to flexure of the loop conductor, may make the measured values significantly different from those calculated. The measurement may 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.

3.3.4.2 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 field and the axis of the telecoil;

k is a constant.

The resulting directional response of the telecoil is shown in Figure 5. It should be noted that the response is reduced by only 3 dB at $\varphi = 45^\circ$ and by 6 dB at $\varphi = 60^\circ$. If the axis of the telecoil is nearly perpendicular to the direction of the 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 field is horizontal. There is evidence that in some hearing aids the directionality of the response of the telecoil is greater 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.

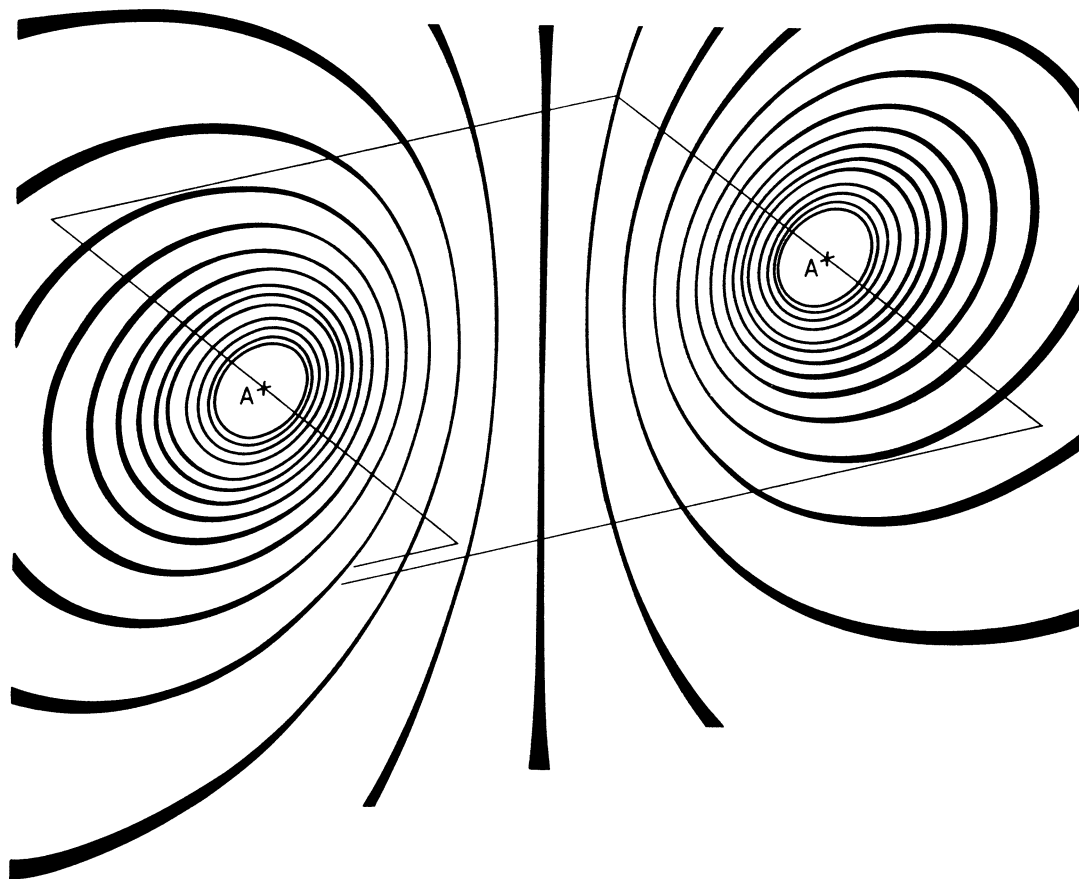
¹⁾ DALSGAARD, S.C. *Field distribution inside rectangular induction loops*. Odense: State Hearing Centres, Research Laboratory for Technical Audiology, University Hospital, 1973.

²⁾ GROVER, F.W. *Inductance calculations*. New York: Instrument Society of America, 1973.

The average height of the telecoil above the floor may be taken as 1.2 m when the hearing aid users may be standing or sitting. For small loops (where the height affects the performance more significantly), and/or where the users may 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 may 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 6).

NOTE 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 the outside the loop are quite different (see Figure 7 and Figure 8).



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

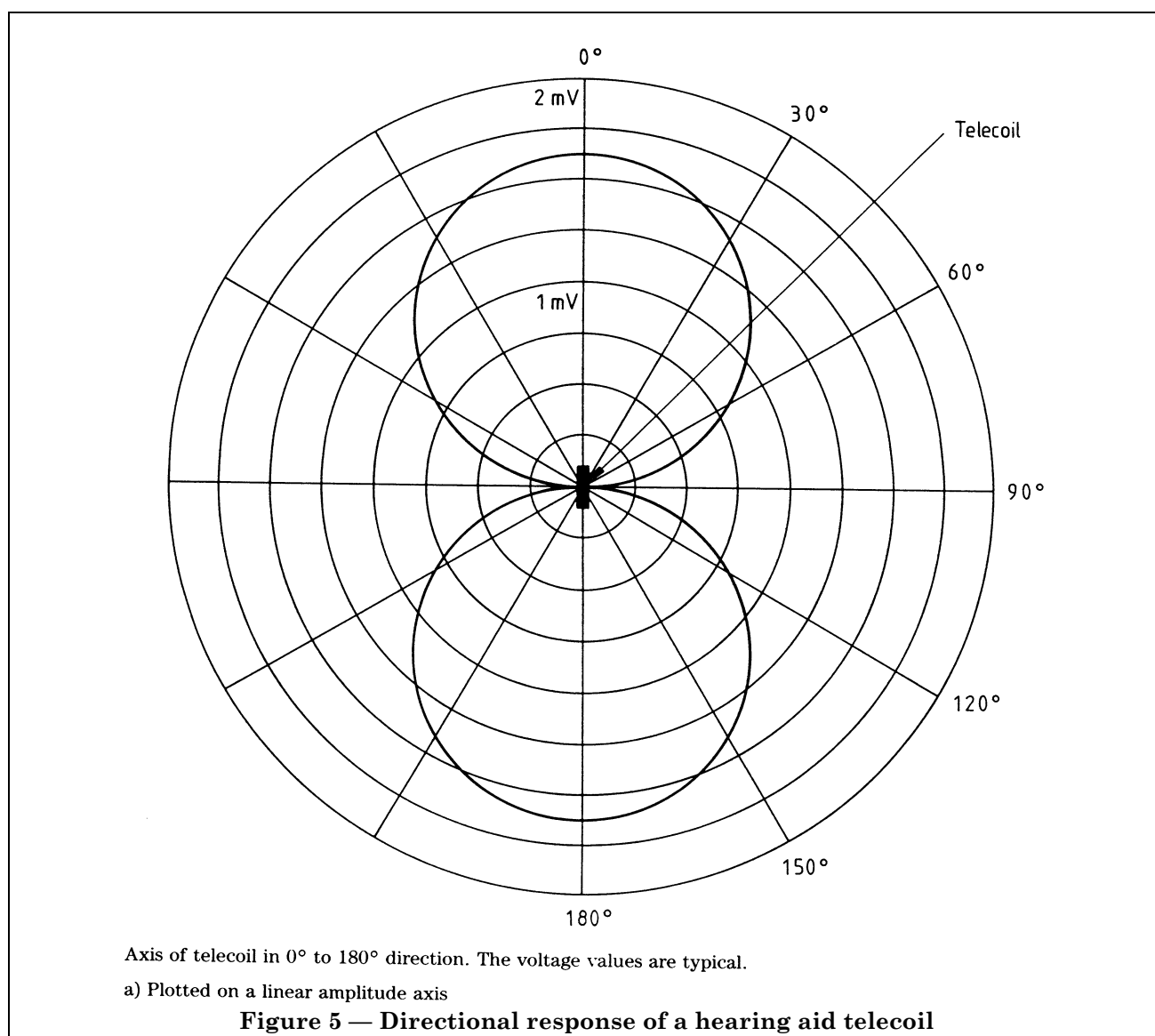
NOTE 2 In the areas A immediately surrounding each conductor, the lines of force continue to crowd together, representing a stronger field.

NOTE 3 At certain points, above and below each conductor, the direction of the 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.

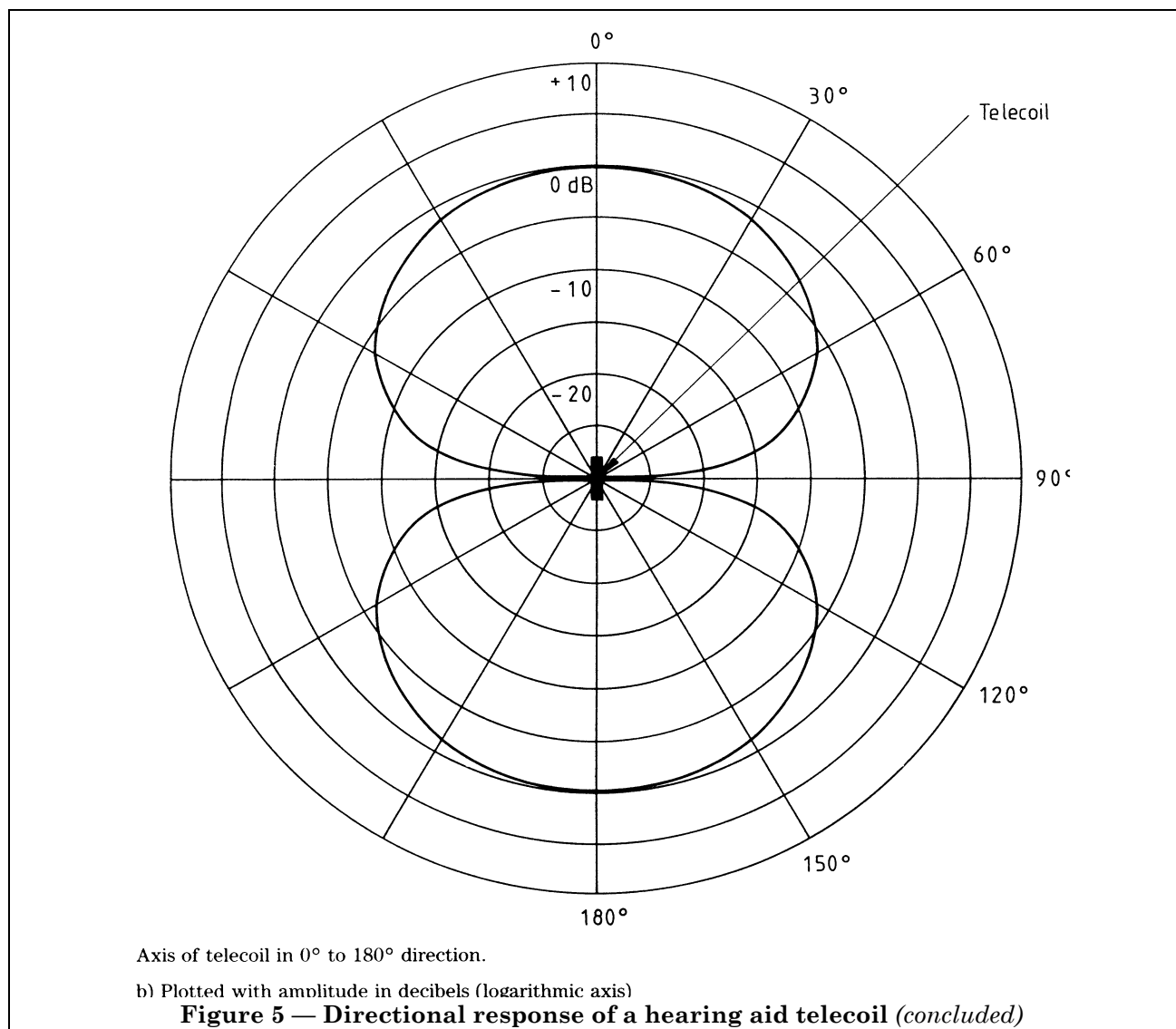
Figure 4 — Pictorial view of the magnetic field (lines of force) in a plane through one axis of a rectangular loop

The problem of disturbance of hearing aid users due to the high field strength near the loop conductor could also 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.

3.3.4.3 It can be shown (see [1]³⁾ and C.1) that a height ratio h_n (termed relative listening height by Dalsgaard) of 0.15 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 may be too large to be practicable if the loop is large (for example 3.75 m for a square loop of 50 m side). In such a case, a suitable multiple loop layout (see 3.3.17) may be used. This can reduce the actual listening height required, for a given degree of uniformity, to that required for each subloop considered separately.



³⁾ DALSGAARD, S.C. *Field distribution inside rectangular induction loops*. Odense, Denmark: State Hearing Centres, Research Laboratory for Technical Audiology, University Hospital, 1973.



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 equation:

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

The derivations of this equation and of the analogous expression for a rectangular loop of aspect ratio γ are given in C.1.3 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 equation (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.

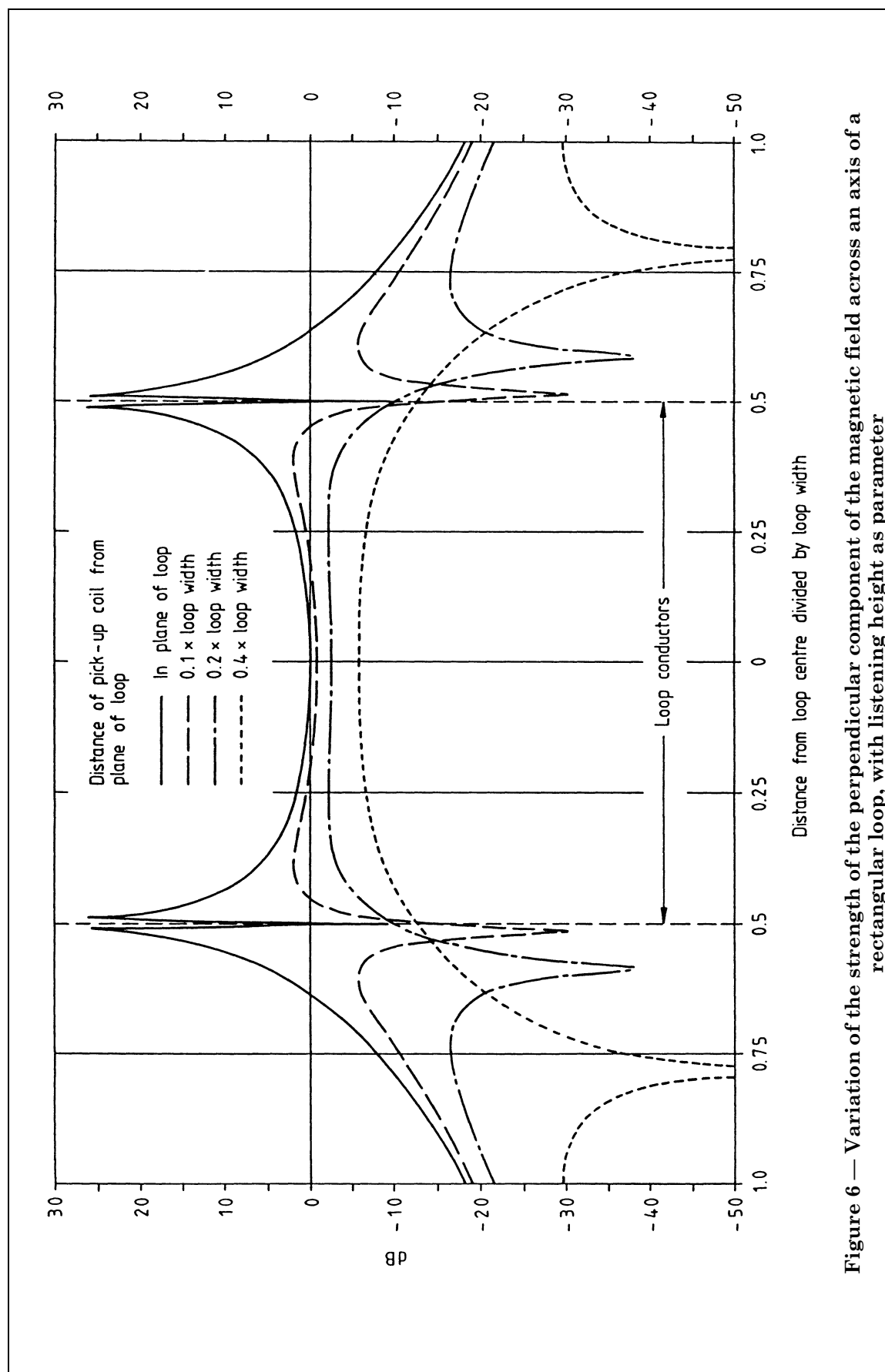
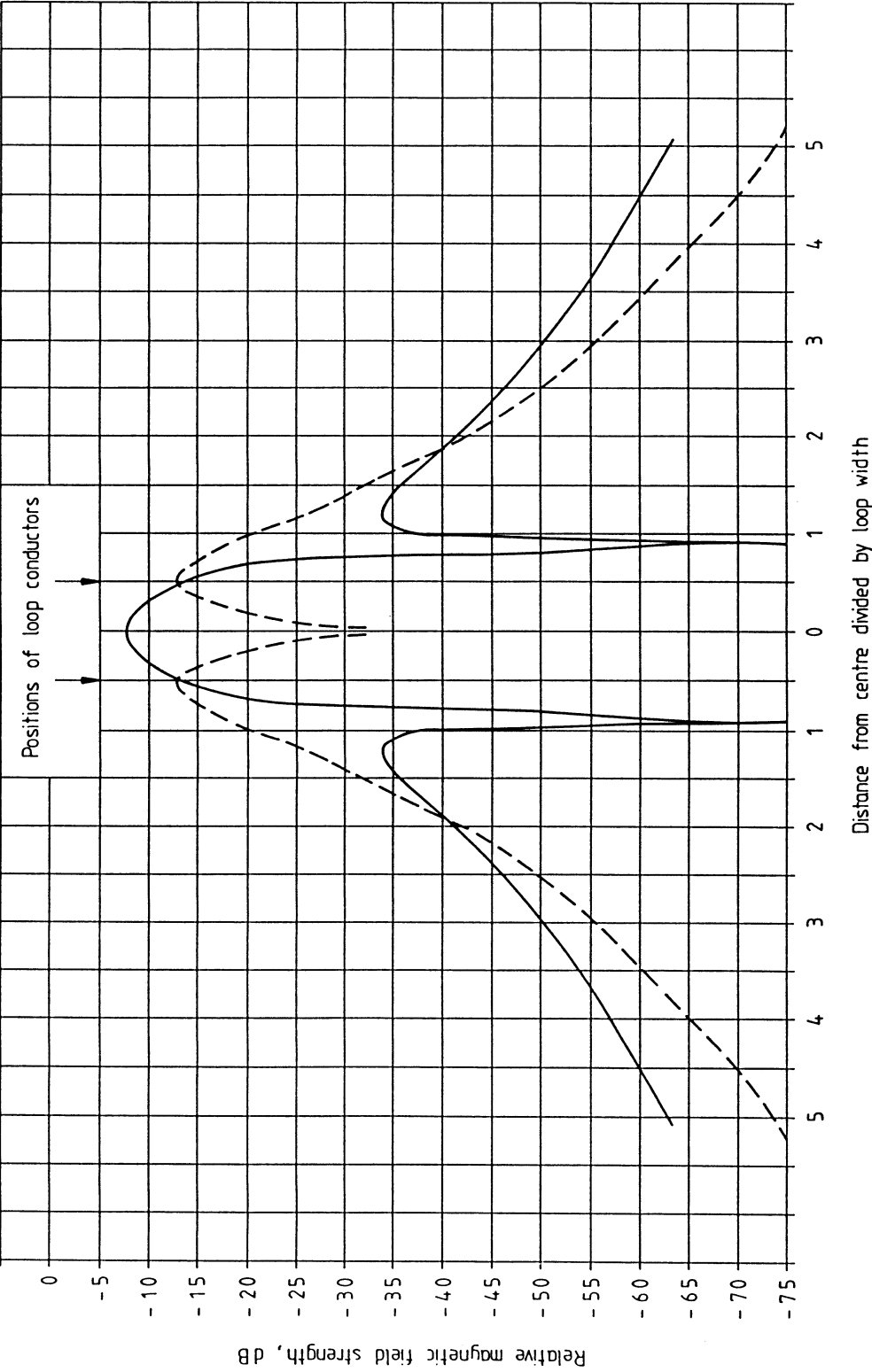


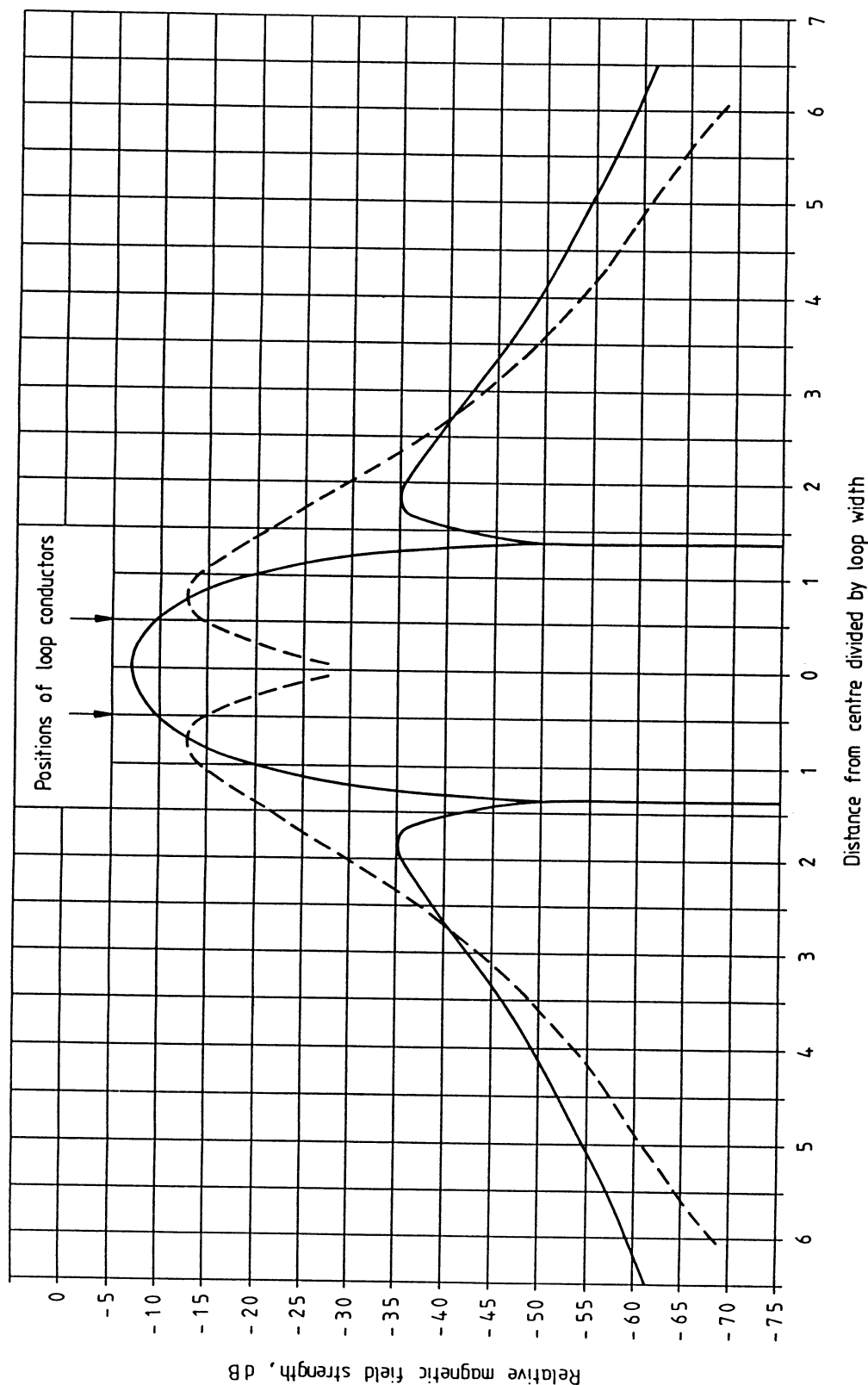
Figure 6 — Variation of the strength of the perpendicular component of the magnetic field across an axis of a rectangular loop, with listening height as parameter



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.

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

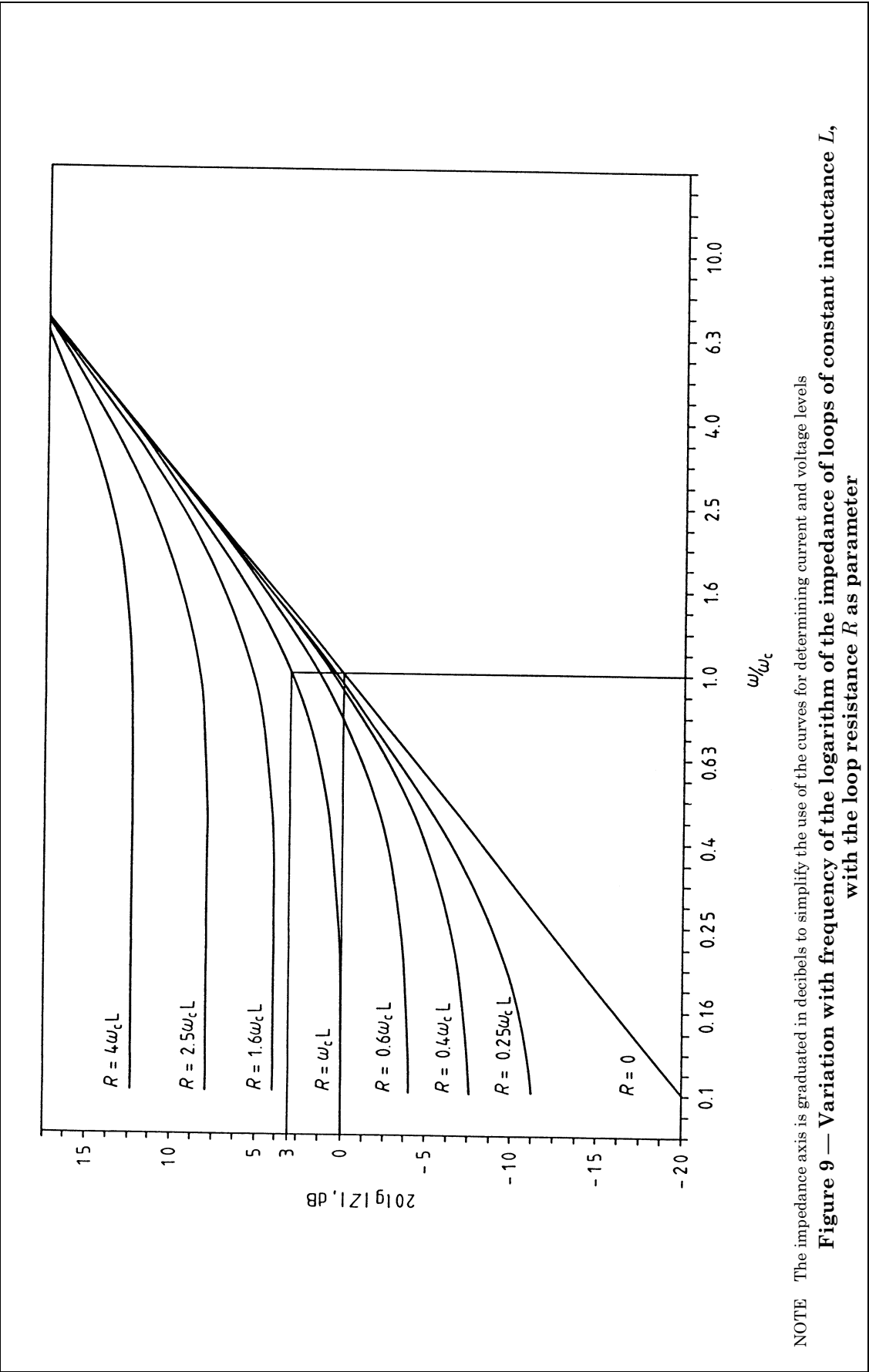
Figure 7 — Variation across the median of a square loop of the perpendicular and coplanar components of the magnetic field at a height ratio $h_n = 1$



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

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

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



3.3.4.4 Because the magnetic field strength varies from point to point, it is necessary to define the point where the system specification should be verified, and this is achieved using the terms defined in **1.3.7** and **3.3.3.2** to **3.3.3.4**. It should be noted that there may be more than one listening plane (**1.3.7**), for example if the working area includes seating at different levels, but there can be only one AFILS reference plane (**3.3.3.2**). 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.

3.3.5 Relationship between the requirements of BS 6083-4:1981 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 AFILS 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 BS 6083-4:1981 is intended to make it unnecessary for the AFILS designer to know these characteristics of hearing aids, by specifying a value for the magnetic field strength at a reference frequency 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 AFILS 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. BS 6083-4:1981 implies that this is achieved if the long-term average value of the r.m.s. loop current is such as to produce a field strength of $0.1 \text{ A} \cdot \text{m}^{-1} \pm 3 \text{ dB}$ (see **3.3.1**) within the “specified magnetic field area” (see note). However, recent results indicate that a field strength approximately 3 dB lower than the nominal value gives a closer approximation to equal output levels for some aids. For National Health Service hearing aids, the output sound pressure level measured at $10 \text{ mA} \cdot \text{m}^{-1}$ is required to be $95 \text{ dB} \pm 5 \text{ dB}$ (20 μPa), with the air-to-air gain set at 40 dB, so that the input sound pressure level equivalent to a field strength of $0.1 \text{ A} \cdot \text{m}^{-1}$ (see **3.3.1**) is $75 \text{ dB} \pm 5 \text{ dB}$ (20 μPa). Since the sound pressure level at the ear in conversation in a group, in the presence of background noise, may be taken as about 70 dB (20 μPa), there appears to be some justification for the 3 dB lower field strength mentioned above. For the convenience of hearing aid users, therefore, it may be permissible to take advantage of the downward tolerance. However, if there is any doubt about the achievement of adequate signal-to-noise ratio, or if the sound pressure level in the area is significantly greater than 75 dB (20 μPa), the upward tolerance should be exploited, if possible.

NOTE 1 The specified magnetic field area is defined in BS 6083-4:1981. It is not necessarily the same as the coverage area or the working area.

The note to 4.1 of BS 6083-4:1981 also indicates that the achievement of a long-term average magnetic field strength of $0.1 \text{ A} \cdot \text{m}^{-1}$ without distortion due to amplifier overload, requires the achievement of a field strength of $0.4 \text{ A} \cdot \text{m}^{-1}$ (r.m.s.), averaged over 0.125 s, to accommodate the amplitude fluctuations of speech signals. (In fact, there is a practical difficulty in determining the “long-term average” of speech signals, because the measured value continues to fall as the averaging time is increased.) However, the achievement of $0.4 \text{ A} \cdot \text{m}^{-1}$, averaged over 0.125 s, is possible with an inadequate amplifier that is, in fact, sufficiently overloaded under this condition for the resulting distortion to reduce intelligibility. The statistical properties of speech signals are such that amplitudes very much larger than the long-term average can occur, but very infrequently. To reduce the possibility of overload to an acceptable minimum, an r.m.s. field strength of $0.56 \text{ A} \cdot \text{m}^{-1}$ (+ 15 dB referred to $0.1 \text{ A} \cdot \text{m}^{-1}$) (see 3.3.1) is required, albeit only for periods of typically tens of milliseconds. This means that for every ampere required to produce a field of $0.1 \text{ A} \cdot \text{m}^{-1}$ at the mid-point of the listening plane, the amplifier should be capable of producing an “undistorted” output of at least 5.6 A. The preferred method of measuring speech signals in analogue electrical form is by means of a peak programme meter (PPM) (see BS 6840-10:1991 and Annex D). It should be clearly understood that the requirement for a r.m.s. field strength of $0.56 \text{ A} \cdot \text{m}^{-1}$, measured with a field-strength meter having PPM characteristics, is entirely consistent with the informative $0.4 \text{ A} \cdot \text{m}^{-1}$ given in the note to 4.1 of BS 6083-4:1981 and does not imply a requirement for either a more powerful or a less powerful amplifier, provided that the system is adequately free from clipping distortion on actual speech signals.

NOTE 2 See also Annex E.

NOTE 3 Although the above explanation refers to speech signals, the results are normally applicable also to music signals. Compression may be applied in order to ensure that overload distortion cannot rise to unacceptable levels, even under unusual conditions.

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. In practice, with some designs of coil, eddy-current losses may reduce the rise in output with frequency, to become approximately proportional to the square root of frequency, i.e. rising at 3 dB/octave. In addition, resistive loading is usually applied, so that the response ceases to rise above approximately 1.5 kHz. The effective value of resistive load, and hence the turnover frequency, may vary with the setting of the hearing aid gain control. Capacitive loading can also be applied. The overall effect of all these influences is that 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 $\pm 3 \text{ dB}$ of the value at 1 kHz over the frequency range 100 Hz to 5 kHz, in accordance with BS 6083-4:1981. 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 (see 3.3.14). Further equalization of the overall frequency response may be desirable, e.g. to compensate for the low frequency response of the AFILS microphone(s) (which may be rising or falling, depending on the distance of the sound source from the microphone) and/or for peaks in the high frequency response. This is considered in 3.3.15.

3.3.6 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 equations (2) and (3) respectively (see 3.3.4.1). Equation (2) includes a temperature-dependent term, because external sources of heat, such as central heating pipes, or the current flowing in the loop conductor, may raise its temperature, and therefore its resistance, significantly (see 3.3.8). The current ratings of wires suitable for loop conductors should be determined from BS 6500, BS 6004 or other relevant British Standards. See also C.2.