# REPORT ON THE COUPLING OF TELEPHONES AND HEARING AIDS

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# REPORT ON THE COUPLING OF TELEPHONES AND HEARING AIDS



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# SUMMARY

The Department of Communications is establishing an ad-hoc technical committee which will recommend measures to ensure that hearing-impaired persons have adequate access to telephone services in Canada. The ad-hoc committee will include representatives from major telephone companies, manufacturers of telephone equipment and hearing aids, consumer associations, provincial governments and associations representing hearing-impaired persons. This report was commissioned by the Department of Communications to provide background information for such a multi-disciplinary task force. It is expected that the report will help to establish a common reference ground so that the committee's recommendations may be prepared in the shortest practicable time.

For the purpose of this report, hearing impairments are classified into three categories that were identified in earlier Canadian studies, plus a residual or fourth category for hearing impairments that cannot be so classified. Excluded from consideration is a very severe or total loss of hearing such that communication is possible only though the use of visual aids. Statistics on the incidence of hearing impairments are presented from studies conducted in Canada, Australia, the U.S. and Sweden. The methods permitting the use of telephones by hearing impaired are discussed, including direct coupling to the telephone receiver. A comparison is made of the advantages and disadvantages of each method.

The basic components of the telephone set are described, consisting of the transmitter, receiver and bridging network or hybrid coil, and their performance is discussed in terms of sensitivity, loudness, frequency response, distortion, linearity and maximum output. Objective performance characteristics for the telephone have been derived from subjective tests and 100 years of operating experience with the telephone system. Particular emphasis is placed on the telephone receiver, which provides the acoustic or magnetic output necessary for coupling with hearing aids. Electro-magnetic recievers are still the best performers and cheapest to manufacture, accounting for their universal use. Non-magnetic technologies are under development, however, and these may prove to be advantageous in the future.

An overview of hearing aid design and performance is presented, similar to that for the telephone set. Hearing aids are available for in-the-ear, behind-the-ear, eyeglass and "body" applications, which determine the physical layout of the basic hearing aid components: microphone, amplifier, receiver and battery. Performance can be related to frequency response, acoustic gain, dynamic range and other factors, but according to experts in the field, there is little real understanding of what should be done to provide maximum benefit for the user. A major reason given for this is the lack of clinical studies involving the proper skills in electro-acoustics and audiology, the appropriate test equipment, and sufficient number of subject. Hearing aid technology is described, such as the miniaturization and improved performance made possible by the integrated circuit, and the future benefits that digital techniques might bring.

National and international standards activities are discussed in relation to telephone sets, hearing aids and telephone/hearing aid coupling. The Canadian Standards Association (CSA) is becoming active in telephone performance standards, and the International Electrotechnical Commission (IEC) has issued a number of standards related to test methods for hearing aids, but not hearing aid performance. A consideration of all possible methods of coupling hearing aids to telephones is now underway in IEC/WG 17 and CCITT/SG XII; contributions to this work from Canada, Japan, France and the U.S. are summarized. Reference is also made to a standard proposed by the Electronic Industries Association for the magnetic field strength of telephone receivers, which is being reviewed by CSA. It is doubtfull whether some telephones complying with this standard would provide for the adequate magnetic coupling of hearing aids.

There are no known studies concerning the coupling of hearing aids to telephones that were performed in Canada prior to 1976. Since that time, various work has been sponsored by Bell Canada as outlined in the report, including the development of special test equipment such as the audiometer telephone interface and the experimental hearing aid. Almost 100 types of hearing aids have been evaluated, as well as other commerically available equipment such as acoustic couplers. The performance of magnetically-coupled hearing aids was found to vary considerably because of the location and type of hearing aid telecoil. There was also a wide variation in the magnetic and acoustic sensitivity of hearing aids indicating that some hearing aids with telecoils are more suitable for magnetic coupling to telephones than others.

The report concludes that there is no single coupling method which can be satisfactory for all hearing aid users, and that direct coupling to the ear with an amplifier handset should be retained since it is effective for a significant number of hearing-impaired users. The performance characteristics for hearing aids are not standardized nor uniformily reported, and they are seldom verified before the hearing aid is fitted to the user. Further work is necessary in order to characterize the performance of both telephone and hearing aid when they are coupled together, and to develop methods for the selection and fitting of hearing aids that will optimize their use with the telephone as well as for face-to-face applications. These technical obstacles and others must be overcome before the telephone access of hearing-impaired persons can be considered adequate. Certain recommendations are made toward this goal.

## 1. INTRODUCTION

Telecommunication has become as important to modern society as electric light, radio or television. An apparatus used to communicate by voice -a telephone- is an intrinsic piece of equipment to be found in almost every home in most of the industrialized countries. Yet, statistics for industrialized countries do not differ, ten per cent of the population is qualified as hearing impaired and about two per cent are hearing aid users. The above two facts; that is the increasing popularity of the telephone as an everyday communication tool and the need for hearing aids; are raising a growing concern to ensure that the telephone network is really accessible to everybody.

The ability of a hearing impaired person to communicate via the telephone network is not as good as one would expect. When hearing aids come into the picture, the ability to communicate over the telephone network appears less than satisfactory. Until recently, the question "can a telephone be made compatible with a hearing aid?" sounded as a threat to the communication industry. Even today, the question "can a hearing aid be made compatible with a telephone?" is not welcomed by the hearing aid industry. The hostility from both can only be explained by the lack of knowledge and understanding of what the technical; and therefore economic; consequences of the possible solutions could be. The non-technical parties involved (hearing aid users and their associations, audiologists, etc.) are more practical in their approach to solving the problem aiming their fire at those who can afford the cost of doing research, namely the healthier telecommunication industries or government agencies. There are missing components in this puzzle, namely adequate technical and scientific background and communication between interested parties. Better understanding of the technical problems involved can lead to a rational analysis of the available alternatives and to decisions as to which alternatives are practical as short or long term solutions.

This report aims to provide some background information on the technology and standards related to the coupling of hearing aids and telephones also to give a general description of the hardware involved, future technology trends, and a general light on available standards. The aim of this report is to help a multidiscipinary group of experts to broaden their understanding and to hopefully provide a focus on the specific issues to be addressed.

## 2. BACKGROUND

The coupling of telephones and hearing aids is an issue with a long history. A chronological analysis to determine what was first, the magnetic public address loop systems or the telephone magnetic pick-up or was the telephone designed first to generate a magnetic or acoustic signal etc., would contribute very little in the search for a solution. A historical review of events, included in Appendix "A", can show only that much effort is being spent by experts in various parts of the world and in various disciplines, to contribute to knowledge of the problem, which is an improvement, but results are not necessarily yet adequate to mandate a solution. This is the basis upon which work toward short and long term solutions might be founded.

Also, reviewing this history of the search for better access to the telephone network by hearing aid users, one can see that in different countries the same problem exists, although the triggering mechanism was different. In the U.S.A. and later in the Bell serviced part of Canada, the question was emphasised by the introduction of a new receiver which did not give a magnetic output as high as its predecessor. The void created by the inadequate magnetic field has to be filled. However, restoration and permanence of the magnetic field is not necessarily the long term solution to a problem which is more that of a social need, which has matured to the point where a better technological solution needs to be implemented.

This could be compared to the problem of the use of the telephone network for data transmission, which also arose as a need resulting from changes within the modern technological society. Maybe, from its beginning, data transmission has a higher potential for economic benefit than had providing access to the telephone network for hearing aid users, who are the minority of telephone subscribers.

All components of the basic telephone set have undergone significant changes over the years. However, telephones built to utilize modern technologies are still designed for "compatibility" with a handset design almost unchanged since about 1920. History often repeats: it is being said that A.G. Bell, while working on hearing aids, invented the telephone; perhaps research on the telephone-and-hearing-aid compatibility will lead to changes in telephone design, resulting in an overall betterment of service. With the introduction of digital techniques, the possibility of higher quality transmission will probably lead to a better design of the handset. Many of the advances in hearing aid designs have been based on research done in the telecommunication industries for telecommunication purposes. It is possible that the need to make the hearing aid work with the telephone in a different scenario than fundamental face-to-face conversation, will lead to a better overall design of the hearing aid.

A technical rather than emotional or historical approach will be taken in this report. Some basic definitions and concepts in hardware design will be included. This seems to be necessary, because most concerned experts are not involved simultaneously in multidisciplinary research and development work on telecommunication and hearing conservation.

As has been said, the coupling of hearing aids and telephones is an old problem. A question to be asked is: "Why with all the research and development and legislative effort and taking into account the extraordinary speed of recent technological evolution, has a solution not been forthcoming?"

There are thousands of pages of technical discourse and testimony from which summaries could already be made pointing in the direction of a sensible decision once and for all. This report will not be limited to a brief summary of general conclusions from interested and still opposing groups but will also try to indicate major gaps in knowledge and understanding which need to be filled before a "universal solution" can be determined. The problem can be communicated very simply: The two electro-acoustic apparatus need to be interfaced with each other. There are several interested parties, each of which seems to have a different opinion of how this can be best achieved.

According to telephone manufacturers, their apparatus is well defined and well engineered. All essential characteristics are included in the basic apparatus, and so universal introduction of some spurious parameters serving a minority, and paid for by all subscribers will result in an unreasonable cost of the telephone set. Three questions will be discussed in this report. 1) How well is the hardware defined? 2) How do "spurious" parameters contribute to the cost of current hardware? 3) How can introduction of new requirements impact the progress of technology?

Hearing aid manufacturers are almost passive in their search for better compatibility, since, in their opinion, the latest technological advances are implemented in new designs characterized by highly improved hearing aid performance. Questions discussed in the report will encompass technology and performance level of current designs and how future technology advances can impact hearing aids.

Audiologists are operating in a world of non-technical subjective values collected with technical evaluation tools, resulting in equations between sensations and physical quantities. The equations are only as correct and good as the accuracy of their parameters. These latter depend on sound materials used, precision and calibration of sound sources, etc. The limited data gathered by an audiologist is made available to the fitter-audiologist, and the fitter-distributor, so the best match can be made between patient and prostheses. Questions to be considered with respect to this group are those regarding accuracy and choice of audiometric tools, and the possibility of balancing the equation: hearing impairement plus hearing compensation equals normal hearing. In fact, this equation can never achieve perfect balance, since a hearing prosthesis can no more fully restore hearing capability than can an artificial limb replace healthy arm or leg functions.

## 3. HEARING DISABILITY

### 3.1 Hearing Impairment Categories

According to the I.S.O. (International Standards Organisation), "normal hearing" subjects used in sound related experiments shall not have evidence of illness and shall be between 18 - 20 years old. The hearing mechanism may have deteriorated with age or as a result of illness, sound over exposure or accident. There is no legal definition of hearing impairment or deafness.

In the absence of legal definitions supported with scientific quantification procedures, it is very difficult to deal with classifications or statistics. There are many people with hearing loss such that the use of a hearing aid would improve their impaired ability to communicate, however, because of cosmetic or social barriers they are rejecting the use of auxiliary devices. There are cases of hearing aid users with misjudged or misfitted amplification characteristics. Another group are very severely hearing impaired. Hearing aids are helping them only in a small percentage of situations, mostly when additional visual aids or lip-reading is added.

For the purpose of this report, hearing disability will be divided into three (3) major categories:

- -Mild Hearing Loss: People who have decreased ability to communicate but do not yet use a hearing aid.
- -Hard of Hearing: People who can communicate only with the help of additional amplifying devices such as hearing aids, but do not need visual aids (including lip-reading, signing etc.)
- -Deaf People: People who cannot communicate by speech only even with the help of amplifying devices.

## 3.2 Hard-of-Hearing Categories

"Sensorineural" hearing loss results from damage to the nerve centres in the inner ear, the nerve pathways to the brain, or perhaps that portion of the brain that receives and interprets audio signals. It is characterized by the inability to hear sound in specific frequency regions or in a whole audible frequency range, which may lead to difficulty in understanding sounds appearing in normal speech. This inability can be detected as, for instance, a shift of hearing threshold. It is also accompanied by change of dynamics in speech perception, etc. Sensorineural hearing loss is the most common condition in which a hearing aid may have to be fitted. Hearing impairement is difficult to categorize because of the large number of parameters and characteristics for the various impairements. For the purpose of this report, hard-of-hearing will be divided into four groups using as criteria the amplification needed (insertion gain approximately equal to hearing threshold loss) and the type of frequency response to alleviate the impairement. The first three of the porposed categories were distinguished in Canadian studies which will be discussed later. The following are hard-of-hearing (hearing aid user) categories:(see also fig.20)

1 - Moderate precipitous impaired have mild threshold loss (between 0 and 25 dB) at low frequencies from 250Hz to about 1kHz with a precipitous drop of hearing loss at 2kHz to above 4kHz with a slope usually not less than 25dB/octave.

2 - Moderate Gradual Impaired have threshold loss between 10 - 40 dB at 250Hz with a gradual slope of 10 -20dB/octave to about 4kHz.

3 - <u>Severely Impaired</u> have threshold loss between 40 and 85dB in the frequency range up to 4kHz with no threshold differences higher than 15dB between any two frequency octaves within that range.

4 - <u>Other Impaired</u> have threshold loss, usually selective, which cannot be categorized in 1, 2 or 3.

The above classifications of hearing impairements could be further developed by distinguishing perceptive (sensori-neural), conductive, or mixed hearing loss. Within these groups further classification, taking into account mechanism and/or symptoms, can define applicability and selection of the required corrective action. Only very detailed study of the particular hearing aid performance can help a qualified specialist to make a decision as to which of the dozens of types of hearing aids can help the one of a kind patient's need.

## 3.3 Some Statistics

Available statistics on how many people admit to having hearing problems and how many hearing aid users experience difficulties in coupling their hearing aids with telephones are not very reliable. It is very difficult to find common denominators because of the lack of clear-cut definitions and poor descriptions on methodology for data collection. It can, however, be approximated that in most western countries 10 per cent of the total population suffers from defficiencies in communicating by speech. About 2 per cent of the total population are hearing impaired (using hearing aids).

A Canadian survey made in 1976 produced additional information:

- 51% of users of hearing aids use the telephone unaided.
- 21% of users of hearing aids use acoustic coupling with the telephone.
- 14% of users of hearing aids use magnetic coupling with the telephone.
- 60% of those who use the hearing aid with the telephone either do not have or do not use a "telecoil".
- Less than one tenth of one per cent of the subscribers in the operating area serviced by Bell Canada in which the surveys were conducted use a "telecoil" with the telephone, even though an adequate magnetic field is available.

Another survey, the "Pan-Canadian Survey of the Communication Needs of Hearing-Impaired Youths and Adults", sponsored by the Department of Communications, gives detailed statistics. These statistics are complex and given in Appendix "B". A large percentage of the people questioned had problems when using a telephone but the most common method of obtaining satisfying use of the telephone was the use of an amplified handset.

Mr. Dingell from the U.S. Committee on Energy and Commerce proposed in his report to the House of Representatives "that 10.8 million citizens have sufficiently impaired hearing to require the use of a hearing aid. Four hundred thousand are totally deaf, while twice that number cannot understand any speech that is not amplified to a level that is medically dangerous". This statement is complemented with data per age as illustrated below:

| AGE | DEAF SINCE CHILDHOOD | SIGNIFICANT BILATERAL LOSS | HEARING IMPAIRED | TOTAL POPULATION |
|---|---|---|---|---|
| Less than 5 ..... | 6,000 | 43,000 | 70,000 | 16,344,000 |
| 5 to 14 ........ | 67,000 | 298,000 | 665,000 | 34,933,000 |
| 15 to 24 ....... | 72,000 | 365,000 | 1,159,000 | 42,474,000 |
| 25 to 44 ....... | 75,000 | 850,000 | 2,837,000 | 62,707,000 |
| 45 to 64 ...... | 100,000 | 1,993,000 | 4,479,000 | 44,497,000 |
| over 65 ....... | 158,000 | 4,437,000 | 7,020,000 | 25,544,000 |
| | 478,000 | 7,986,000 | 16,230,000 | 226,499,000 |

In Australia, a study on telephone transmission quality included questions of hearing quality. 3,148 subjects were questioned representing all age groups. Three questions were asked:

| | | | |
|---|---|---|---|
| A | Rather Hard-of Hearing | 32 | 1% of total |
| B | Slightly Hard-of Hearing | 269 | 8.5% of total |
| C | No Hearing Difficulty | 2847 | |
| | | 3148 | |

Additional questions were asked of groups A and B, as follows:

"Do you normally use a Hearing Aid?"

| | | |
|---|---|---|
| YES | 41 | 13.0% |
| NO | 260 | 86.4% |

If the answer was yes, the question "Are you using your hearing aid for this telephone call?"

| | | |
|---|---|---|
| YES - Magnetic Coupling | 0 | |
| YES - Acoustic Coupling | 27 | 66% |
| NO - | 14 | 34% |

In Sweden, the number of persons in each "hearing aid" category has been calculated for a population of 8.5 million people and the results are illustrated in the table below.

| CLASS | AHL* | PROBLEMS WITH TELEPHONE COMMUNICATION | PERCENTAGE OF POPULATION | NUMBER IN SWEDEN |
|---|---|---|---|---|
| A | 23dB | None | | |
| B | 24-34dB | Not appreciable | 4.1% | 350,000 |
| C | 35-54dB | Can hear satisfactorily at normal speech levels | 2.4% | 200,000 |
| D | 55-89dB | Have difficulties at normal levels without additional aid | 0.8% | 70,000 |
| E | 90dB | Cannot use telephone with any acoustical aid | 0.2% | 17,000 |

*AHL is an average hearing loss at 500Hz and 2kHz on the better ear.

In Holland it was estimated that hearing aids are seldom asked for unless the hearing loss is higher than 40dB, even if hearing aids are free of cost. This estimate is consistent with data in Denmark and Sweden stating that not more than 2% of the population have a hearing aid, which corresponds to an AHL of more than 40dB.

# 4. USE OF THE TELEPHONE BY THE HEARING DISABLED

## 4.1 Mild Hearing Loss

In most cases people with mild hearing loss can communicate by telephone better than in face-to-face conversation. Usually the impairement is not equal in both ears and the balance of binaural listening is affected. The intrinsic amplification of the telephone used with the better ear (Figure 2) improves comprehension (refer to section 5.3.4). Decreased ability of the other ear usually helps to better discriminate against background noise. Further improvement comes when the transmitter is muffed (eg. covering the transmitter with hand) since background noise through the sidetone path is attenuated. A step to improving telephone communication affected by mild hearing loss is the use of amplification in the receive path (amplified handset). People with a mild hearing loss are using "the same" telephone as normal people ie. objective characteristics defined in telephone standards and specifications are applicable to this usage. (Telephone performance and standards will be discussed in a later section.)

## 4.2 Deaf People

Special aids can be added to the telephone to enable the deaf person to communicate via the telephone network. These devices, such as the TTY, Visual Ear, etc, will not be discussed in this report. However, it should be noted that severely impaired hearing aid users supplementing speech perception with visual aids, lip-reading etc., should probably be helped with the same devices as deaf people.

## 4.3 Hard-of-Hearing (Hearing Aid Users)

### 4.3.1 General:

The hard-of-hearing whose impaired capability to communicate by speech can be improved with the use of adequately tailored sound amplification are dependant on the use of hearing aids to carry on their normal every day activities. Only head-located hearing aids can potentially be coupled to a telephone handset without upsetting the transmit characteristics. (Classification of hearing aids is given in section: Hearing Aids (#6).)

Two outputs can be made available from the telephone (see Figure 1), an acoustic sound pressure signal developed by the telephone receiver and a magnetic field alternating in concert with the speech signal. These two quantities can be routed to a hearing aid/ear either directly or via an interfacing device such as auxiliary acoustic tube, acousto-acoustic amplifier, acousto-magnetic coupler, magneto-acoustic amplifier etc. The signal perceived by a hearing aid (picked up by a microphone or telecoil) and/or via the ear mold, nominally occluding or obstructing the ear canal.

A constant amplitude electrical signal containing all frequency components of the speech spectrum arriving via the network to a telephone set will give a "normal output" with a spectrum as shown in FIGURE 2 and FIGURE 16 only when the receiver is acoustically loaded with a real or an artificial ear. This would nominally be correct if a sealed coupling exists between the receiver cap and the pinna. Therefore, when a hearing aid is removed and telephone used directly coupled to the ear, its characteristics would correspond to those specified by known standards, but not when the receiver is coupled "loosely" to the input of a hearing aid.

### 4.3.2 Acoustic Coupling

Acoustic signals generated by the telephone receiver in the ear which has the ear canal occluded with an ear mold and the housing of the hearing aid located behind the pinna will be different from what is described in specifications for normal telephones. FIGURE 3 shows the routing of the acoustic signal from a telephone receiver when behind-the-ear or eye-glass hearing aids are used. The physical volume of the ear canal and concha would be decreased by the volume of the ear mold. As a result, the acoustic pressure developed in the concha would raise as a function of the frequency (refer to point 2'). This pressure would be transmitted to the other side of the ear mold toward the eardrum with the attenuation depending on the type of ear mold (point 2"). There is no comprehensive study quantifying ear mold attenuation. Some qualifying information is shown in FIGURE 4. The presence of the hearing aid body would make it impossible to achieve a good seal between the receiver and pinna. This "leaking" sound pressure would be picked up by the hearing aid microphone and transmitted to the ear via the hearing aid. The characteristic of the sound pressure generated by receiver and then activating the hearing aid microphone is not well defined. It would vary depending on the position of the receiver with respect to the pinna/hearing aid configuration. Some indication of the change of the sound pressure level depending on the receiver's position is given in FIGURE 5. Some better control of the sound pressure level arriving at the hearing aid was expected to be achieved by the use of an acoustic tube bringing the pick up point within the ear/receiver cup/concha volume (FIGURE 6). The results achieved with this interface were not satisfactory. Another scenario in which acoustic pressure presented to the hearing aid is better controlled is when an in-the-ear hearing aid is coupled to the telephone (FIGURE 7). This configuration should be easier to define. However, its application is limited since even with small amplification there are serious stability problems, and in-the-ear hearing aids are often not sufficiently in the ear to allow a good seal to be achieved between receiver cap and pinna.

In all of the above situations, the caharacteristics of the telephone output as well as the microphone and ear mold acoustic performance characteristics need to be difined since existing specifications for both telephone and hearing aid are not dealing with either of these scenarios.

Similar characterization of the telephone set performance would be required for amplified handsets or additional interfacing devices generating acoustic signals, such as acousto-acoustic amplifier or magneto-acoustic amplifier. The operation of the magneto-acoustic amplifier is presented graphically in FIGURE 8. There is very little difference between the latter configuration and the coupling through the acoustic leakage when a hearing aid is used. The only complication is that adequate magnetic field has to be generated by the telephone receiver. Magneto-acoustic amplifiers are relatively inexpensive and readily available in places such as Radio Shack, etc, but their quality is generally poor.

### 4.3.3 Magnetic Coupling

Considerable effort has been spent recently to characterize the magnetic field generated by the telephone receiver. Much less information is available on hearing aid telecoil characteristics. Because of the importance of the above characteristics a separate section will address this issue. In this section we will discuss only the routing of the signal.

The magnetic field generated by the telephone receiver can be available to the hearing aid user simultaneously with an acoustic output. When the magnetic field from the receiver is weak, it can be generated by an auxiliary magnetic coil built into the handset ("flux coil"). There will be no difference to the user between these two hardware arrangements providing performance is the same. This coupling method is shown schematically in FIGURE C-9 & C-10. The acoustic signal generated by the receiver is transmitted to the eardrum via the ear mold in a similar manner to that discussed with acoustic coupling. The hearing aid input is switched to the telecoil position (ie. in most cases the microphone input is not active) and senses the alternating magnetic field present in the vicinity of the receiver. If the magnetic field is not generated by the handset or is not strong enough to work with the hearing aid, an auxiliary device called an acousto-magnetic coupler can convert the acoustic signal into a harmonized magnetic field. The main difference between magnetic coupling with an acousto-magnetic coupler and direct coupling to the handset is that in the latter case two signals are present while with a coupler the acoustic signal is attenuated (FIGURE 11). It was shown in recent studies that the magnetic signal alone is giving much less comprehension than when both are present. This fact confirms that an acoustic signal transmitted through the ear mold, even when this nominally occludes the ear canal, is needed in the communications process. Parallel studies showed that the background noise discrimination is not as great as was expected by switching the hearing aid input from the microphone to the telecoil. A significant portion of the background noise is transmitted via the sidetone path.

### 4.3.4 Summary

The comparative summary of various modes of coupling is presented in FIGURE 12. Disadvantages, limitations, inconveniences, etc., are not quantified since in most cases it would be premature to do so due to the lack of adequate criteria or test methods.

Disadvantages such as frequency response dependance on receiver/microphone position or loss of low frequency content are decreasing communication ability in almost all situations when using the telephone and hearing aid. Compensations for these losses will only be possible when the main problem, namely lack of adequate hardware specifications, is overcome. Acoustic feedback resulting in howling (whistling) is a serious limitation of the hearing aid design but new technologies are promising practical solutions. Inconvenience of gain adjustment of the hearing aid seems to be inevitable until uniformity of hearing aid design is achieved.

More information qualifying some of the listed problems will be given in a review of research studies carried out in Canada.

## 5. TELEPHONE

### 5.1 Basic Components

A telephone is an apparatus allowing a user to transmit a voice message to another user and to receive a voice message from the latter via the telephone network. Therefore, basic components of the telephone set are microphone, called transmitter and earphone, called receiver (FIGURE 13). They are both connected to a single pair of wires (telephone line) via a bridging network called a telephone hybrid routes the voice message to the line and prevents the transmit signal from going to the receiver. Also, the hybrid routes the signal from the line to the receiver and prevents the received signal from going to the microphone. The attenuation between transmitter an receiver (transhybrid loss) is not infinity and a portion of the signal from the microphone goes to the receiver and to the user's ear (sidetone).

The main electro-acoustic (transmission) parameters of the telephone are transmit, receive and sidetone. Transmit is a parameter which tells how sound pressure generated while speaking is converted into an electrical signal; receive is a parameter which tells how electrical signals arriving at the telephone terminals (tip and ring) are converted into acoustic pressure in the ear and sidetone is a parameter which tells how different is the acoustic pressure arriving at the ear of the person while speaking into the microphone. The above electro-acoustic (transmission) parameters of the telephone set are characterised basically by sensitivity, loudness, frequency response, distortion, linearily and maximum or saturated output. These parameters will be discussed later.

The magnetic field generated by the telephone receiver can be available to a hearing aid user simultaneously with an acoustic output. When the magnetic field from the receiver is weak, it can be generated by an auxiliary magnetic coil built into the handset ("flux coil"). There will be no difference to the user between these two hardware arrangements providing performance is the same. This coupling method is shown schematically in FIGURE C-9 & C-10. The acoustic signal generated by the receiver is transmitted to the eardrum via the ear mold in a similar manner to that discussed with acoustic coupling. The hearing aid input is switched to the telecoil position (ie. in most cases the microphone input is not active) and senses the alternating magnetic field present in the vicinity of the receiver. If a magnetic field is not generated by the handset or it is not strong enough to work with the hearing aid, an auxiliary device called an acousto-magnetic coupler can convert the acoustic signal into a harmonized magnetic field. The main difference between magnetic coupling with an acousto-magnetic coupler and direct coupling to the handset is that in the latter case two (2) signals are present while with a coupler the acoustic signal is attenuated (FIGURE 11). It was shown in recent studies that the magnetic signal alone is giving much less comprehension than when both are present. This fact confirms that an acoustic signal transmitted through the ear mold, even when this nominally occludes the ear canal, is significant to the communications process. Parallel studies showed that the background noise discrimination is not as great as was expected by switching from the hearing aid input microphone to a telecoil mode since a significant portion of the background noise is transmitted via the sidetone path.

In a classical telephone the transmitter and receiver are located in a handset. The receiver part of the handset is coupled to the ear and the plastic geometry determines the position of the transmit performance of the set. Some of the new telephones are not restricted to a handset. Microphones can be mounted in the telephone housing or remotely connected via R.F. or infrared link. A receiver is substituted by a loudspeaker built into the telephone housing or remotely located. In most modern handsfree loudspeaking telephones, the trans-hybrid loss is not sufficient to prevent oscillation. Stability is achieved with an automatic switching (voice switching) from transmit to receive function.

### 5.2 Other Telephone Components

To complete a description of the most commonly used telephone set, three additional functions; connecting, signaling and alerting; will be briefly described.

These elements of the telephone serve to establish the connection necessary to allow a conversation to take place. The serve to allow special signals to be sent to and received from the servicing network equipment. They are:

#### Connecting

The switch-hook which serves to switch the telephone from its inactive state "on-hook" when it is conditioned to receive incoming call alerting signals, to its active state "off-hook" when it is conditioned to allow signals to be sent to the central office to establish a call to a desired correspondent, receive tone signals to indicate the progress of the call and, assuming success in reaching the other telephone, to allow a comprehensive conversation to take place using the primary elements (microphone, earphone, hybrid).

Signaling

Dialing devices exist in two common forms; The older more common is a rotary dial which modulates the terminating condition presented to the serving network equipment. The more recent and increasingly common is an electronic push-button dial. There are two types of push-button dialer: pulse equivalent to rotary and "touch-tone" dialing which produces up to twelve combinations of tones form electronic circuitry (DTMF).

Alerting

The device most commonly used is an electro-mechanical ringer, which responds to a low frequency alternating current transmitted from the central office to indicate an incoming call attempt. An alternative device, which is becoming more common, is a tone alerter which generates an acoustic signal by electronic means.

All telephone elements, except the alerting device, are powered from a battery located in the telephone company network equipment which feeds direct current over the "local loop". The alerting device is powered by a "ringer supply" also located in the telephone company network equipment which is connected to feed low frequency (typically 20 to 60 hertz) alternating current when appropriate.

The above described elements are to be found in the telephones the world over and are functionally the same. Other terminating devices exist such as multi-button sets, automatic dialers, handsfree units, etc. They all transmit and receive similar signals to and from the line, though in some cases their features require additional power to that provided from the telephone network equipment. This additional power is usually provided from the local electrical supply and may or may not be protected against supply failure.

Only the three primary elements are of concern when considering the use of the telephone by the hearing disabled, but further mention will be made of the alerting device as it is often used to trigger an auxiliary device such as a light or fan when a person's hearing is not good enough to hear the normal alerting signal. The older electro-mechanical ringer often produces an alternating magnetic field which can be detected outside of the telephone set housing and used to trigger the auxiliary device. This will rarely be the case with the newer and increasingly used tone alerters. Auxiliary devices which are triggered by the relatively high level acoustic signal, which is always produced, will thus likely be preferrable.

## 5.3 TELEPHONE PERFORMANCE

### 5.3.1 General

From the compatibility with hearing aids point of view, the handset operation of the telephone will be discussed. In handsfree mode of operation the hearing aid is expected to react in the same way as in face-to-face communication. Some special devices were available in the past to interface with the telephone by using the magnetic output of earlier transformer type hybrid networks. Modern telephones have an electronic hybrid and a magnetic field is not present.

Since only performance with respect to basic transmission parameters is important to the compatibility with hearing aid issue, the performance needed to establish connection to make use of these features will not be discussed, i.e. connecting, signaling and alerting.

Early telephone sets had performance limited by the poor quality of transducers and lack of adequate amplification. The resonant character of the frequency response was a result of the high transduction efficiency needed and the technological inability to construct transducers with constant high sensitivity over the whole speech frequency range.

Performance of the modern telephone set is highly improved and well determined world wide by various standards such as CCITT P- series, IEE, EIA, complemented with local requirements issued by national regulatory bodies and telephone administrations.

Transmission performance has been established as a result of trade-offs between requirements determined by almost one hundred years "field trial" feedback on telephone network capability. The ability of telephone users to communicate efficiently over the telephone network determined by various subjective studies are translated into sets of objective parameters. Objective characteristics of telephones are physical quantities measureable in well defined (often idealized) conditions. Standards include those parameters which are judged to best describe the quality of the telephone set. Performance standards allow exchange of specifications and verification of product quality. Inter-laboratory test results is also a prime concern. This is why test methods and parameter definitions do not indicate directly the real performance. Changes of hardware configuration or scenario in which hardware is used would ask for new parameters to be defined or the objective test methods to be modified. Some of the most important objective parameters will be reviewed.

The primary elements of the telephone - the transmitter, receiver and network- have undergone evolutionary changes as the technology has developed. These evolutionary changes are continuing and will continue to take place into the future. The changes are motivated by two factors. The first is to take advantage of technological progress to improve the performance of the telephone itself and of the overall telephone system of which it forms a part and the second is to take advantage of technological changes to achieve the same or improved performance at lower cost.

The performance of the primary elements is not only a function of the elements in isolation but is also affected by the acoustical and electrical environment in which they function. The transmitter performance is affected by the housing in which it is mounted, its location relative to the mouth of the telephone user and often by the "local loop" and network equipment to which the telephone is connected . Similarly the receiver performance is affected by the housing in which it is mounted, its location relative to the ear of the telephone user, the individual ear characteristics and the network equipment to which it is connected. The sidetone performance is mostly affected by the "local loop" to which it is connected and by transmitter and receiver characteristics. The variations in performance of the telephone set is often a design parameter. For example, a transmitter output signal level high enough to overcome the attenuation of the longest loop used to make connection to the serving network equipment would be far too high on the shortest loop used. The hybrid network is often designed to compensate, in part, for these differences by reducing the transmitted level to short loops. The sidetone effect is often made lower when the set is connected to a long loop which encourages the user to speak more loudly, and vice-versa for the short loop. The sidetone is also adjusted to ensure that any extraneous signals picked up by the transmitter are not so loud as to affect the ability to hear a received signal.

The mounting of the transmitter and receiver units into a common handset was probably used for convenience as early as 1878. It however came into common use in the late 1920's and was largely motivated by the requirement to ensure, as far as possible, that the transmitter was held in a particular position relative to the mouth of the user. This ensures a much more constant level of acoustic input into the transmitter. It also ensures a preferred position for the type of transmitter which has been commonly used until recently in virtually all sets, that is the carbon transmitter. This type of transmitter is still widely used but is being replaced in modern sets by the electret, which requires amplification to be available, now possible with electronic circuitry.

### 5.3.2 Frequency Responses

Over the years, advances in the acoustics design of the transmitter and the associated housing has produced a smooth frequency response ranging from about 300Hz to 3400Hz. Above and below these frequencies the response falls sharply. From 300Hz to 2000Hz the response is flat with an increase at about 3000Hz of about 10dB (FIGURE 14). The increase at about 3000Hz is designed to off-set the increased attenuation at these frequencies of the local distribution facilities (local loops), and to compensate for diffraction around the head.

It is to be noted that the compensation for the local loop loss can be distributed between transmit and receive characteristics. The approach of "distributed compensation" was proposed by some European administrations but in most countries (including Canada) the whole compensation is "built into" the transmit characteristics.

The telephone receiver construction will be discussed in a separate section. The frequency response of the receiver used in today's telephones is nominally flat within the frequency range 300Hz - 3.4k Hz. Acoustical response of a typical receiver used in North America is shown in FIGURE 15. A by-product (also called spurious parameter) of electro-acoustic transduction of many receivers is an alternating magnetic field. Because of a special importance of this parameter in coupling with the hearing aid question a separate section will be devoted to it later in the report.

The reduction below 300Hz is deliberate and designed to reduce, at lower frequencies, interference from power supply systems and above 3000Hz to reduce interference due to network signaling and other devices. The band-width transmitted is also reduced to that required for intelligible speech which allows for more efficient use of the broad-band long-haul inter-city and inter-continental transmission facilities.

The sidetone was the first "spurious" parameter of a telephone terminal. It was there because of the inability to fully separate transmit and receiver in all telephone line conditions. The role of the sidetone in the effectiveness of the telephone communication is not yet fully understood. The advantages of having sidetone are qualified as a feedback helping to influence talker level as a function of temporary network performance, feeling about telephone being "alive", etc. Disadvantages of sidetone are psycho-acoustic effects when listening to ones own voice with levels and delays different from those resulting from bone conduction and head defraction, increased "dose" of background noise transmitted to the ear, etc. Current technologies necessitated elimination of sidetone in handsfree telephones based on "voice switching" techniques. A typical sidetone response is shown in FIGURE 16.

5.3.3 Noise; Distortion

It was established by many subjective studies that in the presence of randomly distributed noise with fluctuating amplitude, the limitation of the frequency range of transmitted signal to some 300-3500Hz will not result in decreased intelligibility but would improve it. However, further limitation of the frequency band will significantly decrease intelligibility. These characteristics apply virtually universally to the world's telephone facilities.

The limited frequency range with which the telephone operates makes the telephone user not only better able to tolerate the noise present in the system and picked up from the environment but also to better tolerate non-linear distortion. As a general rule, arrived at from subjective experiments, the more extended a frequency range the more disturbing a non-linear distortion would be. This is why typical second harmonic distortion of a carbon microphone, which can be as high as 25%, is not perceived as strongly as 5-10% distortion of a high quality communication system. To the contrary, the second harmonic in the telephone system, was found to add pleasant "coloration" to the speech signal. However, it was also found that the third harmonic (up to 8% in case of a typical carbon microphone) can be annoying and decreases intelligibility.

### 5.3.4 Loudness

One of the most important parameters of the transmits signal is loudness. There are many studies giving information varying by 10 dB or more on average loudness levels of speech. For the purpose of this report, typical values are presented to facilitate understanding of the speech transmission mechanism when using telephones and hearing aids. Typical speech level at a short distance of about 2 cm from a speaker's lips is about 90 dB. This average speech level will correspond to about 70dB SPL (Sound Pressure Level).speech level at the listener's ear position at a distance of about 1m. There is no information if this relation between speech levels includes or does not include transfer function from free field to ear (difraction, reflection from shoulders, etc.). However, because of level variations it can be assumed at this stage of discussion that 70dB is the speech level in free field and a similar speech level would be picked up by the hearing aid microphone. A person with normal hearing will detect this speech with two ears. Binaural listening will give the same sensation as monaural when the sound level pressure is 6dB lower. Listening via a hearing aid in most cases can be considered as monaural and adequate higher amplification is needed. The 70 dB average speech level at the pinna would correspond to a much higher level, say 75-80 dB, in the ear canal in the vicinity of the eardrum. A telephone handset is generating sound pressure directly into the ear canal. This is why a preferred listening level over the telephone is much higher than in face-to-face communication. According to studies conducted in North America a preferred listening level when using the handset is about 85 dB SPL.

Sound pressure levels developed within the ear volume for optimum speech loudness in telephone conversation is about 15-20 dB higher than the sound pressure level developed at the nominal position of the opening of the hearing aid microphone in face-to face communication. This difference is equivalent to an acoustic gain of the same value provided by a hearing aid (insertion gain). Amplifiers built into a handset can provide and additional 20 dB of gain. It means that a telephone set, if equipped with an additional amplifier, can give acoustic gain equivalent to a hearing aid insertion gain of up to 40 dB!! Depending on the acoustic output impedence of the receiver used (see section "telephone receiver") the sound pressure can further increase when "sealed coupling" is changed into "loose coupling" or if an ear mold is present. Characteristics of hearing aids will be discussed in a later section.

The above described intrinsic gain of the telephone can explain why (see section "Research in Canada") in many instances an amplified handset outperforms a hearing aid if used instead and also why the use of acoustic coupling can easily lead to overloading of the hearing aid, decreasing communication ability.

Loudness levels given above are obviously some average values and are subject to variations not only with talker's speech level but also will depend on local telephone line conditions. "Loop loss" is another major contributor to variations in received signal loudness and contributes to the problems experienced by all telephone users. Some new telephone sets are protected against loop variations with compensating characteristics similar to automatic gain control in hearing aids but reacting on changes in current available to the telephone set..

### 5.3.5 Maximum Output

The transmit signal sent to a telephone line is limited so that the network cannot be overloaded if the talker is too loud. Also the maximum receive signal is controlled. Extraneous electrical signals or lightning could reach the receiver and generate sound pressure levels high enough to damage the hearing mechanism. For this reason high electrical signals are cut off by a varistor mounted on the receiver and limiting maximum sound pressure level (typically at about 120 dB SPL). Some new telephones have protective devices built into their electronic circuit and eliminate signals above 110-115dBSPL.

## 5.4 TELEPHONE RECEIVER

### 5.4.1 Current Design

Almost one hundred per cent of transducers used as telephone receivers today are electro-magnetic devices. They are of either the electro-magnetic or magneto-electric type. The electro-magnetic receiver has a stationary coil through which a current alternating with the voice flows. The alternating current modulates the magnetic flux in a magnetic circuit composed of a permanent magnet, pole pieces and armature which is attracted to or pushed away from the pole pieces. The permanent magnet "polarizes" the transducer so that the flux is linearly dependent on the current flowing through the coil. The armature can be attached to or be a part of a diaphragm. The vibrating diaphragm moves the air surrounding it and generates a sound pressure. Characteristics of current to sound pressure transduction are dependent on electro-magnetic and mechanical parameters of the transducer as well as on the acoustic impedances behind and in front of the diaphragm (the latter impedance includes the acoustic load presented to a diaphragm, eg. ear impedance). Typical constructions of electro-mechanical receivers are shown in FIGURE 18: ring armature such as U-1 types FIGURE 18a, balanced armature receiver FIGURE 18b, center armature receiver FIGURE 18c. The magneto-electric receiver (called also "Dynamic" or "Moving coil") works on a principle that if alternating current flows through a coil located in a constant magnetic field perpendicular to a current direction, the coil will be pushed by magneto-electric force proportional to this current. A Dynamic receiver is shown schematically in FIGURE 18d.

Electroacoustic characteristics of a telephone receiver were defined so that interchangability of receivers could be maintained across at least all telephones within one operating company. This approach was valid in the past when one type of handset design was used eg. North American "Industry Standard" G-type handset. The interchangeability of receivers was important in electro-mechanical telephones because transducers (transmitter and receiver) were much less reliable than any other telephone component.

### 5.4.2 Acoustic and Magnetic Receiver Output

This classical but still valid concept of the design limited the possibility to decrease physical dimensions of receivers and therefore it was not necessary to restrain the size of electro-magnetic driving mechanism. Every electro-magnetic or magneto-electric receiver is generating a magnetic field alternating with current flowing through its coil. This magnetic field is proportional to current but also depends on the geometry of the coil, its location within a receiver, and the magnetic shielding of the coil.

The concept of interchangability leads to physical, electrical and acoustic "compatibility" of today's receiver design. Electrical output signal from the electro-mechanical telephone set is limited by the "amplification" capability of a carbon microphone. In the local loop configuration additional amplification is not normally available.

A low power electrical signal, further attenuated by loop impedance and telephone hybrid network is activating the telephone receiver. A few microwatts of electrical power are available to generate sound pressure sufficient for effective speech communication (as a comparison the electrical power available to hi-fi earphones is thousands to millions of times greater than that available to the telephone receiver). This is why in an electro-mechanical telephone with a carbon microphone, the efficiency of electro-acoustic transduction has to be very high.

A supra-aural concept of the receiver is limiting possible variations of the size of the diaphragm, which has to move air in the concha/ear canal volume to generate the required sound pressure level.

The large size of the coil was typical in the older designs. Some of them had the coil located at the very back and the alternating magnetic field in front of the handset was not very strong. A transducer with a very large coil located just below the front grid was the U-1 type center armature electro-magnetic receiver which was designed and introduced in the late 1940's. This receiver was replaced in 1970 with a variable reluctance receiver (LB in the U.S.), balanced armature receiver (BAR in Canada) or a dynamic type (ie. Belgium). In Canada and in the U.S. an additional external coil was added to generate an alternating magnetic field. This additional coil (called "flux coil") is designed to generate a magnetic field having the same performance characteristics as the U-1 receiver.

The magnetic field around the handset is characterized with :

-Magnetic field strength H in A/m or dB relative to 1A/m

-field geometry ie. spacial distribution and direction of field lines

-frequency response

-sensitivity defined as relationship between magnetic field generated by the coil and acoustics pressure generated by the receiver.

-linearity determining changes in magnetic output when acoustic pressure changes.

The detailed characterization of the U-1 and Balanced Armature Receiver with flux coil is given in Appendix "C".

Major characteristics of magnetic and acoustic output of the above receivers can be compared as follows:

-"loudness" (i.e. output weighted over telephone frequency range) of the speech signal will decrease when the receiver is moved away from pinna for both magnetic and acoustic output.

- frequency response of the magnetic output remains unchanged with receiver's movements around the ear.

-frequency response of the acoustic output changes as soon as sealed contact of the receiver's cup with pinna is disturbed, displacement of the handset away from coaxial position with respect to concha will affect frequency response for low frequencies (decrease of output) and, for the same type of receivers, for mid-frequency range (increase of output).

-acoustics background noise would interfere with acoustic output; it will be transmitted to the ear directly (acoustic "leak") and via the handset sidetone path.

- acoustic background noise would interfere with magnetic output via handset sidetone path only.

- magnetic background noise would have practically no effect on the acoustic output.

-magnetic background noise will interfere with magnetic output.

### 5.4.3 Technology Evolution and Trends

The telephone receivers used over the years have been virtually universally based on electro-magnetic technology. Earlier designs used diaphragms of magnetic material which were heavy and restricted as to the shape and thickness by the properties of the material. This early diaphragm has a double role as a sound generator and an armature. Considerable advances have been made in the understanding and formulation of magnetic materials so that low magnetic field strengths of equal values can be produced by physically much smaller magnets. The cost of these magnets, both from a raw material and a manufacturing point of view, is much lower. They have made possible more efficient receivers with a separated diaphragm and armature having a much preferred response at lower cost.

In the earlier designs, to achieve the necessary efficiencies, use was made of resonance. The unit was tuned so that it naturally tended to oscillate at what was considered a preferred frequency in the voice range. While this achieved the necessary loudness, it also gave the unit a response which peaked about a particular frequency which reduced the quality of the reproduced signal. The newer materials meant that it was no longer necessary to rely on the resonance effect and beginning in the 1930's receivers were designed to have a much flatter response. About 1950, the Bell Laboratories introduced its well known ring armature receiver, the unit receiver type U-1, which took the application of these techniques to a high level. By pure coincidence this design, while achieving an excellent electro-acoustic response, also produced a significant magnetic signal which could be detected outside the receiver enclosure. This magnetic field was not a required parameter and is nowhere mentioned in the design literature.

The receivers of this era had a smooth, essentially flat frequency response from about 300Hz to about 3000Hz, with the response decreasing sharply above and below these frequencies.

The desirable frequency response characteristics of the transmitters and receivers to produce good transmission in conjunction with the telephone network were then largely decided. The earlier approaches at the turn of the century to improve performance by subjective experiments or trial and error techniques had been replaced with the advent of the new technologies which made sophisticated measuring instruments available and by the theoretical approach which allowed ideas to be implemented and tested in the laboratories using both objective and subjective techniques to determine what compromise produced the best service to the telephone user. These advances have progressed to the point where it became possible for most people to talk to one another satisfactorily between virtually any two points in the world by using the telephone.

In the 1960's, it seems almost spontaneously, the world's telephone set manufacturers became interested in producting more efficient lower cost telephone sets. The increased competition as the telecommunications market became a world market was probably a big factor. Bell Laboratories designed the L-type rocking armature receiver, Bell-Northern Research produced the balanced armature receiver, other manufacturers produced similar designs. All were motivated by the primary aim of reducing cost while maintaining high performance. This was done by using less magnetic material in a small, efficient magnetic circuit. This made the decreased size of the driving mechanism possible including the coil which reduced the external magnetic field. It was at this point the telecommunications industry appeared to become generally aware that some hearing aid users were making use of the magnetic field produced by the earlier designs to couple hearing aids to the telephone.

While the Bell System, including Bell Canada, and some other companies in North America, has used the ring-type armature receiver with the external magnetic field from 1950 it is not at all clear what the situation was in the rest of the world. Most other areas of North America and Canada used receivers which did not produce a strong enough magnetic field and indications are that elsewhere in the world, whereas older receivers may have produced a significant magnetic field, newer ones in manufacture from the 1940's onwards did not do so.

As a consequence of the use of the magnetic field by the hearing disabled and the pressure to maintain it available, at least until a preferrable alternative is found, most manufacturers are either making a standard receiver which produces an equivalent magnetic field to that produced by the U-type or make a version of their standard receiver available which does so. So far as is known, none of these receivers produce the magnetic field as a by-product of the basic design. All are believed to add an additional coil designed and provided uniquely for the purpose. This is not always easy to do cheaply. The power consumed by the receiver and coil is almost twice as great and the power input from the line remains constant. It can only be done by improving design efficiency. Where it is done by adding a coil to an existing design it is often at the expense of the acoustic power ouput or causes reduction of the yield of units meeting repuirements as the process fails to maintain the tighter tolerances, etc., necessary.

If the optimum parameter of the magnetic output required from the handset could be defined with respect to some standard input performance of hearing aids then it will probably be possible to design telephones producing such ouput with no cost penalty using different, from what is available today, electro-magnetic receivers. The concept of impedance matching and efficiency/amplification trade-offs will have to be revised. However, there is a belief within the telecommunication industry that replacement of electro-magnetic technology with receivers based on the principle of changes in electrostatic field (ie. electric transducers such as piezoelectric, electret piezo-film, etc) would further improve manufacturability, cost and performance, but this will make provision of a magnetic field more difficult and expensive.

Electric receivers are not popular today because of either poor performance over the required frequency spectrum or they require much higher voltage than is available in today's telephones. Also their cost is not yet lower than that of the conventional electro-magnetic receivers.

Recently there were significant changes in piezo electric material technology and low cost, high reliability transducers became popular as alerting devices (smoke alarm and electronic toy industries increased market requirements and stimulated new research and manufacturing). This is why the electro-mechanical telephone ringer is today becoming a thing of the past. The powerful capability of electronic telephones to provide features distracted telephone designers and manufacturers from research on better electro-acoustic input and output transducers. However, another similar to the piezo-beepers spinoff can lead to the design of a new receiver. A change in telephone hybrid design philosophy can lead to the design of telephones with "voltage" output available to receivers but not power to drive additional coils.

Also significant industry trends which could conceivably affect today's concepts of the use of the telephone by the hearing disabled is the introduction of digital technology. Rather than transmit an electrical signal that is an analogue of the acoustical voice signal over the telephone transmission facilities the signal is encoded into numeric data which carries the information. This has significant advantages which are more and more being used in a transmission network to transmit numeric data for both more sophisticated signaling purposes and to carry data for communication between machines and computers. So far this technology has been largely confined to the telecommunications (both voice and data) switching machines and to the long haul inter-city and inter-continental transmission facilities. However, it can only be a matter of time before it permeates further business terminal equipment and then residential terminals. At this time the aim will dobtless be to convert directly from the digital electrical signal to an acoustic sound pressure. Bell Laboratories have already produced and experimental electrostatic receiver that does just that. Magnetic fields will then no longer be as easily or as cheaply added on. It is not however thought that this stage will be achieved in the near future. Similarly complicated scenarios can be expected when the signal at the output of the optical fibre can be directly converted into acoustic sound pressure. Experiments described by the Bell Laboratories on a fibreoptics tone ringer are not yet convincing but strongly stimulate the designer's imagination.

Today, electro-magnetic receivers are still the best performers and the cheapest to manufacture. There is probably still time available to resolve the potential problems of working hearing aids with telephones satisfactorily before the era of electric or digital transducers arrives.

# 6 HEARING AIDS

## 6.1 Basic Components

The hearing aid is an electro-acoustic device detecting sound from the environment, amplifying this sound and finally delivering this amplified sound to the ear. A block diagram of the Hearing Aid is shown in Figure 19.

Conventional aids are classified in power categories for instance: very strong 65dB or more, strong 56-64dB, moderate 46-55dB, mild 31-45dB and very mild less than 30dB. There is no agreement on correctness of classification by gain (power). Frequency characteristics consideration leads to another classification such as wide band, high frequency hearing aids, etc. There are four common hearing aids available on the market when classified by their construction. The smallest and most inconspicuous is worn (completely) in the ear (in-the-ear type). It provides limited amplification and is best suited to people who have only a mild hearing impairement. The largest and most powerful aid is worn on the body with only the receiver extending to the ear ("body" type). This type of aid, is generally used in cases of extreme hearing loss and often by children needing robust reliable devices. The largest percentage of hearing aids in use are light weight hearing aids worn on the side of the head. There are two types available today; one is the "behind-the-ear" aid (the familiar half moon shaped instrument), and the other is an "eyeglass" aid. In both of these models the earphone (receiver) is located in the hearing aid body and sound is directed to the ear canal with tubing terminated with an ear mold.

The hearing aid consists of four basic sections; the microphone, amplifier, receiver and battery. Each of these section has to be selected or designed to interact with each of the other sections for optimal performance of the hearing aid.

The input transducer (microphone) converts acoustic sound pressure into an electrical signal. The microphone is important in determining several performance characteristics of the hearing aid. Among these are frequency response, signal to noise ratio, acoustic sensitivity threshold, linearity, dynamic range, directionality, etc. Before the 1970's the magnetic and crystal microphones were the standards of the industry. The incorporation of the electret condenser microphone has resulted in the development of hearing aids of smaller size, with better performance and reliability than was previously possible.

The electret microphone offers a much broader frequency range than the magnetic or piezo-electric type. The size and weight of the moving system in an electret microphone (light diaphragm only) allows designers to achieve better dynamic range (signal to noise and signal to vibration ratios.)

Besides the microphone, there are several alternative inputs by which the signal can be provided to a hearing aid amplifier: a telecoil, infrared detectors, RF receivers or a direct electrical input. A telecoil was introduced as a solution to overcome high background noise in schools, concert halls, churches, etc. where the sound source was far away from the hearing aid microphone. This was especially important with early, poor quality microphones where a distorted electrical signal was already strongly masked with noise generated by hearing aid vibrations and friction of clothing etc., against hearing aid housing. Permanently installed magnetic loops in conjunction with the telecoil permitted extension of both the frequency spectrum and dynamic range of hearing aids. Electro-magnetic interferance, portability and cost were major factors limiting the popularity of magnetic loop systems. The two first drawbacks are often being overcome by the use of special wireless hearing aids working with infrared or radio transmitters. However, complexity of a wireless input stage makes hearing aids working on these principles bulky and expensive.

The popularity of the telecoil as a marketable feature and the limited availability of permanent magnetic loops stimulated other applications of the telecoil such as the use with small magnetic sources (coils for television and radio or telephones and recently with portable room loops or neck loops. Different characteristics of various magnetic sources lead to a variety of telecoils having different sensitivity, frequency characteristics or orientation (see section Research in Canada).

Miniaturization of electromechanical components and improved quality of materials made it possible to provide externally direct electrical input to hearing aid amplifiers which can be connected by wire with an ouput of any audio device such as radio, recorder, television set, etc.

This variety of input devices permits the achievement of a high quality conversion of sound into electrical signal which was not possible until the introduction of quality electret microphones. On the other hand, the choice of input transducers adaptable to specific usage is often creating serious compatibility problems.

The hearing aid with telecoil and/or electrical input would always have a microphone built in. A switch (often called the "T" switch) permits choice of the input depending on what mode of operation is judged by user to be the best in given circumstances. The basic input device, a microphone, is not built into the wireless hearing aid. Therefore, a wireless hearing aid's use is limited to special applications only.

The amplifier boosts the level of electrical output of the microphone or alternative input stage. The amplifier must provide high gain, low noise, and good electrical dynamic range. In the early 70's the advent of the integrated circuit profoundly affected the hearing aid. The integrated circuits used in hearing aids provide amplification and permits the addition of other functions required of the amplifiers: frequency corrections, automatic gain control, etc. while still providing long battery life. The amplified electrical signal is delivered to an output transducer.

The output transducer (receiver) converts the electrical output of the amplifier to acoustic sound pressure. The receiver is the most critical component of the hearing aid design. In most designs, the receiver is determining the final output, overall acoustic gain, frequency response and dynamic range of the hearing aid. All hearing aid receivers manufactured today are of the magnetic type. The receiver is terminated with an ear mold occluding the ear canal or simply maintaining the terminating receiver tube in its proper position. The ear mold is not only the most uncomfortable part of the hearing aid, but also it can degrade the quality of the hearing aid and its performance. An alternative to a receiver as an output transducer is a bone vibrator transmitting sound directly to a mastoid.

Some wireless hearing aids will have the output transducer substituted with a magnetic loop placed around a neck. This means, the "personal" hearing aid such as a behind-the-ear type does not have to be removed, but can be used in its telecoil position to pick up signal produced by the neck loop. In spite of the inconvenience of using two devices, this hardware configuration is gaining increasing application because of its efficiency.

The power source of the hearing aid is the battery. The battery mandates that there is a constant need to open and close the hearing aid compartment in order to change batteries, thus allowing dirt and moisture into the instrument, increasing the chance of mechanical problems. Rechargable batteries have limited capacity and are used mostly in large hearing aids. However, they make it possible to design a sealed hearing aid. Voltage available from the battery is related to its physical size and is often limiting linear amplification capability of the hearing aid.

## 6.2 Hearing Aid Performance

Hearing aid performance can be related to three prime parameters: frequency response, acoustic gain, and the saturated output. Other important performance parameters are: dynamic range, distortion and signal to noise ratio. A more comprehensive list of parameters includes over 30 factors. Discussion in this section is limited to some basic considerations in addition to what was already said in paragraph 6.1.

The frequency range of normal hearing is about 20 to 20,000Hz. However, most hearing aids have a narrower comprehensive frequency response within 200Hz to 5000Hz range. This frequency range is sufficient to make speech sound intelligible, but should not be limited to less than 300Hz - 3kHz. Often hearing aids have narrower frequency response, however the sound is not only transmitted by the hearing aid but also by bones, other ear, etc.

The acoustic gain is the amount by which the soudness of the sound produced by the hearing aid earphone exceeds the loudness of the sound picked up by the hearing aid microphone. The user generally sets the gain of his instrument to achieve the most comfortable listening level of conversational speech. In order to prevent pain and damage to the ear, aids have a limit to the loudness they can produce. This limit is called the "saturation output" and is an important factor in determining the so called "power" of a hearing aid. The saturation output is generally set below threshold of pain which is approximately 130dB.SPL. The maximum output of the hearing aid is limited by battery voltage which determines the clipping level of the amplifier. A higher acoustic output can be produced when receiver transduction efficiency is high. This is often achieved at the expense of the frequency response shape. As a result, many hearing aids using a small battery and miniature receiver have a narrow frequency response and sharp resonances.

The dynamic range of the normal ear is higher than 100dB. Typically the hearing aid has a narrow dynamic range of 30dB to 40dB, yet 70 to 80dB is obtainable with present technology. Two parameters affect the dynamic range: distortion and signal to noise ratio. Distortion is the unwanted sound that is created from the original input signal generally as the harmonics of the fundamental frequency or intermodulation product of multiple input frequencies. Signal to noise ratio is the difference in dB between the maximum power output and the inherent electrical noise generated in the hearing aid. An improvement in recent designs of the hearing aid is the introduction of directional microphones. The second microphone port permits the partial cancellation of unwanted background noise, however it can adversely affect the basic hearing aid frequency response.

The overall performance of hearing aids is largely related to the characteristics of the transducers, but also depends on the supply voltage available from small (typically 1.3V) batteries. This is why very often the high acoustic gain required depends on a quality of the receiver. A simultaneous requirement of high "power" output and frequency response flatness is difficult to achieve and most of the so called strong hearing aids have a limited frequency range and an irregular frequency response. The over-emphasised importance of a hearing aid gain (high gain aids are often believed to be better than medium or low power aids) is in most cases of small aids and the expense of an inappropriate, limited frequency range. Such a potential mis-fit of the hearing aid's performance means an increased danger of oscillations and impossibility to achieve a comfortable listening level of conventional speech, being judged as the most important criterion against which a hearing aid user should set up gain of his device. In relation with a comfortable listening level, the maximum acoustic output or saturation output of a hearing aid can be considered as a vital parameter in determining hearing aid performance. Several electro-acoustic parameters (eg. harmonic distortion) are often used as criteria for quality with normal hearing people. However, with people having sensouri-neural or mixed hearing loss this normal performance standard may not apply. For this reason performance capabilities of hearing aids are difficult to evaluate.

## 6.3 Industry State-of-the-Art and Technology Trends

The hearing aid industry is probably one of the most difficult to analyze. It belongs to the world of consumer electronics and yet is so far away from calculator, digital watch or walkman radio success. Slow technology progress and elevated prices are being explained by manufacturers and dealers by the small size of the market and fragmented nature of the industry.

In 1975 the scientists from the Royal National Institute for the Deaf in London, England, concluded their study on hearing aid performance: "Hearing aids are used by millions of people throughout the world, yet we do not have a basic understanding of what should be done to give a person optimum benefit. The study of hearing aids requires a knowledge of electro-acoustics and audiology, together with a combination of acoustical testing facilities with clinical assessment and adequate availability of subjects. The above combination is perhaps one of the main reasons for the lack of knowledge.

However, if detailed studies are made on hearing aid users and effort is concentrated on measuring the hearing impaired person's ability to make use of his residual hearing rather than the hearing aid itself, some progress may be made into what still remains largely an unresolved problem. Many people obtain benefit from hearing aids, but there remains a very significant proportion who do not, and perhaps we could do even better for those who do benefit".

The suggestion about the significance of the use of residual hearing in conjunction with a hearing aid is especially relevant to the special usage of the hearing aid such as in the coupling to the telephone.

Scott D. Holden, President of HC Electronics in his article "The Hearing Aid: An Engineer's Perspective" expresses his concern about the insufficient engineering knowledge: "Most hearing aid manufacturers subscribe to the standards set forth by the Hearing Aid Industry Conference, Inc. (HAIC). Although these procedures help standarize performance measurements for the industry, they do not necessarily reflect all of what may now be desirable as design criteria, nor do they tell the whole story concerning the acoustic performance of the hearing aid." and then he states that: "Theoretically the hearing aid should be designed to best meet the acoustic needs of the hearing handicapped. Cosmetic design should be secondary. Unfortunately this is not always the case."

It is indeed a fact that a giant step forward on the side of cosmetics and comfort resulting from miniaturization of hearing aids was at the same time a set-back in performance improvement because of the power supply (battery) and receiver technology limitations.

In recent articles (late 70's) from the hearing aid industry and components manufacturers one can find many statements about improved performance and reliability of hearing aids and yet criticism from hearing aid users, audiologists and hearing aid specialists is very strong. Most complaints are about poor performance with respect to noise and stability / oscillations as well as high repair cost (users) or reliability/durability (audiologists, hearing aid specialists). G.D. Zink reports in 1979 about his literature search and laboratory study: "Evidence in the literature states that minimally 50% of the hearing aids...are malfunctioning...A cross-sectional sample of 14 manufacturer's hearing aid submissions (a total of 166 new aids) were comprehensively studied by the British Columbia Research and Development Laboratory, Victoria. Sixty-five percent of the hearing aids failed the primary and secondary criteria during the initial evaluation period."

The above quotation shows very clearly that better implementation of current technology could significantly improve the quality and performance of hearing aids. The three major obstacles of today are: engineering resources available to hearing aid manufacturers are weak and scattered; criteria for hearing aid designs are driven by marketing rather than users/audiologists/specialists's feedback (lack of comprehensive standardized specifications); current methods used to quantify hearing loss and specify required hearing aids are not always adequate. The above obstacles have technical and administrative aspects and both should be dealt with simultaneously. Research and development effort should be accompanied with better communication between interested parties and some improved legislative actions (standards and their enforcement).

Developments in digital techniques are promising many undreamable features in all areas of electronics. It is to be expected that physical dimensions and price will be soon on a level acceptable for applications in hearing aids. The two most promising applications of digital techniques are adaptive filtering and multi-band compression.

Adaptive filtering would help to solve the stability problem and the reduction of background noise. Parallel research on improving ear molds is required. Multi-band compression in hearing aids could permit to adapt amplification to requirements needed to normalize the hearing threshold and to normalize the subject equal loudness contour corresponding to the preferred listening level for speech. This technique together with the development of small three volt batteries would greatly improve the adaptation of hearing aids to particular needs with respect to acoustic gain and shape of the frequency response. A caution is needed in making the above promises. Already today many "analog" hearing aids have several adjustments for frequency response contour and for automatic gain control. This already available control could allow a more precise fitting of the hearing aid if hearing aid testing techniques and fitting procedures were more compatible with existing needs.

# 7. STANDARDS

## 7.1 General

Three technical standard areas are of interest from compatibility of hearing aids and telephones point of view: 1) Telephone transmission performance, 2) Hearing aid performance, 3) Telephone and hearing aid interface parameters. The performance in order to be properly described should be accompanied with a standard test method and described in a standard format.

Various international standards organizations are preparing recommendations elaborated by experts in respective technical areas. These recommendations are expected to be followed by industry (on a voluntary basis) to facilitate exchange of specifications in case of international trade, usage of common facilities (eg. transport, communica - tion),etc.

Peculiarity of local requirements or design practices are reflected in national standards (voluntary requirements) or individual industry standards.

Appropriate government authorities can legislate voluntary standards as mandatory (or mandate especially developed standards) and advise on a lawful way of enforcing such standards.

## 7.2 Standards Activities for Telephone Sets

In the past, all telephone sets and other terminal equipment were provided by the telecommunication carriers, who had their own comprehensive specifications governing the network harm, performance and quality of the equipment (e.g. Bell Canada DS 8610 and Bell System PUB 48005). This situation has changed in North America with the advent of terminal attachment, which permits the user to purchase or lease his terminal equipment from any supplier once the equipment has been type approved. Type approval is obtained by testing a sample of the equipment against a technical specification, which is intended to guard against network harm. Certain kinds of network harm involve equipment performance, so that no clear distinction can be made between the two. Thus, the terminal attachment specifications include performance requirements for the telephone set, but none of these apply to transmitter/receiver characteristics, magnetic fields or similar matters of significance to the end user including a hearing impaired user.

The industry has recognized a need for terminal equipment standards which go beyond network harm. In Canada, this work has been undertaken by a newly formed telecommunications committee of the Canadian Standards Association (CSA); mention is made later of its activities concerning the magnetic field for telephone receivers. The U.S. Electronic Industries Association (EIA) is also active in the telecommunications area (e.g. RS-470). The standards published by these two agencies are developed by a consensus process involving all interested parties and are voluntary within the industry

## 7.3 Standards Activities on Hearing Aids

### 7.3.1 IEC Publications relating to Hearing Aids

Most of the IEC documents related to hearing aids were prepared by experts in Working Group 6 in Technical Committee 29. The list of documents follows.

The current task of this Working Group is considered to be completed and the Working Group was disbanded at the last Plenary Meeting of the TC 29 in Paris, July, 1983. The remaining task being an interfacing of hearing aids with telephones is assigned to the working group W.G. 17 formed recently.

IEC Publication II8-0: "Measurement of Electro-Acoustical Characteristics". This standard defines the measurement of physical performance characteristics of air-conduction hearing aids based on a free field technique and measured with an ear simulator.

IEC Publication II8-I: "Hearing aids with induction pick-up coil input", describes a method of determining the physical performance of hearing aids using an induction pick-up coil within an audio-frequency magnetic field.

IEC Publication II8-2: "Hearing aids with automatic gain control circuits", applies to hearing aids of any type with automatic gain control (AGC) circuits.

IEC Publication II8-3: "Hearing aid equipment not entirely worn by the listener", describes a method of determining the overall electro-acoustic performance of hearing aid equipment used in the rehabilitation of persons having impaired hearing.

IEC Publication II8-4: "Magnetic field strength in audio-frequency induction loops for hearing aid purposes", applies to audio-frequency induction loop systems producing an alternating magnetic field and intended to provide an input signal for hearing aids operating with an induction pick-up coil.

IEC Publication II8-5: "Nipples for insert earphones", applies to insert earphones which can be fitted to an ear mold inserted into the ear canal.

IEC Publication II8-6: "Standard for the characteristics of electrical inputs to personal hearing aids (in preparation)", specifies the characteristics of an electrical intput to a personal hearing aid in order to ensure compatibility with external electrical or electro-acoustic signal sources.

IEC Publication II8-7: "Measurement of performance characteristics of hearing aids for quality inspection for delivery purposes", defines the measurement of performance characteristics of air-conduction hearing aids of a particular model for the purpose of comparing measured properties with those specified by the manufacturer.

IEC Publication II8-8: "Measurement of hearing aids under simulated in-situ working conditions (report in preparation)", describes test methods which simulate the acoustical effects of a median adult wearer on the performance of a hearing aid.

IEC Publication II8-9: "Measurements of characteristics of hearing aids with bone vibrator outputs (in preparation)", specifies methods of measurement of the characteristics of hearing aids using bone vibrator outputs.

IEC Publication II8-II: "Symbols and other markings on hearing aids and related equipment", is applicable to symbols and other markings on hearing aids and related equipment for the purpose of identifying control settings and giving information regarding technical functions and characteristics.

Other Related IEC Publications:

IEC Publications 90: "Dimensions of plugs for hearing aids".

IEC Publication 126: "IEC reference coupler for the measurement of hearing aids using earphones coupled to the ear by means of ear inserts".

IEC Publication 303: "IEC provisional reference coupler for the calibration of earphones used in audiometry".

IEC Publication 318: "An IEC artificial ear, of the wide band type, for the calibration of earphones used in audiometry".

IEC Publication 373: "An IEC mechanical coupler for the calibration of bone vibrators having a specified contract area and being applied with a specific static forc." (in revision)

IEC Publication 711: "Occluded-ear simulator for the measurement of earphones coupled to the ear by ear inserts.

### 7.3.2 National Standards

Most of the industrialized countries have their national standards related to hearing aids. In many cases, the national standards are derived from IEC recommendations, complemented with some performance requirements and enforced by local government authorities.

In the United States an equivalent of the IEC II8 series was prepared by the American National Standards Institute and was newly revised as ANSI Standard S-3.22-1982

In Canada there was a standard prepared by CGSB based on first the IEC publication II8 (1959) later modified to comply with former ANSI Standard and withdrawn in the early 1970's. Since then, there is no federally recognized national standard hearing aids in Canada.

Some Canadian provinces including Saskatchewan, Manitoba, British Columbia and Québec are establishing testing and acceptance programs for hearing aids. Even though Canada is participating in IEC standards preparation, provincially procedures are based in part on ANSI requirements and partially on old SGSB standards and they are not utilizing the latest revisions of IEC recommendations. It is to be noted that IEC and ANSI documents relate to the methods of measurements test equipment and its physical parameters and not to hearing aid performance (with some exceptions on marking dimensions. At the present time there is an effort being made to propose a set of uniform specifications which could be based on the latest international proposals, and take into account specific Canadian requirements. Probably including some performance recommendations.

## 7.4 Standards Related to the Coupling of Hearing Aids to Telephones

In so far as specification of requirements for telecommunications equipment for use by hearing impaired persons is concerned there has been relatively little activity. There are significant gaps in the knowledge related to various modes of coupling of hearing aids and telephones which the standard activity toward the apparently easiest to determine mode of coupling, namely magnetic. The specification of a magnetic field to be produced by the receiver of telephone handsets has been the subject of activity in the U.S.A. and Canada and internationally. A magnetic field strength based on the magnetic field fortuitously produced by North American telephone sets and used by hearing aid designers, has recently been recommended by the E.I.A., after work done in association with the Hearing Industries Association, which represents many hearing aid manufacturers. The recommendation of a compatible magnetic field strength and associated measurement method is high on the agenda of the new CSA Telecommunications Committee. The latest issue of the proposed EIA recommendation suggests the handset (receiver) will be tested in a telephone set with a feed bridge arranged to give long loop current but with no loop simulation and an open circuit feed signal - 10dBv. This does not in any way represent working conditions and it is different from typical test conditions for the telephone set. As a result, measured performance could be misleading to the hearing aid manufacturers and other interested parties even though it may be acceptable for comparison purposes and production quality testing of telephone sets in the telecommunications insustry. It is not clear why the test method proposed by EIA deviates from the draft proposal prepared by IEEE , the document on which it was originally based. Furthermore the tolerances to be allowed for the complete system suggests that the magnetic field strengths may be lower than 10 mA/meter for a typical average voice transmission level. The latter value of the magnetic field is much lower than any value proposed by international experts or generated by the U-1 receiver or flux coils. C.C.I.T.T. and I.E.C. are working "in concertation" to recommend a compatible magnetic field strength and associated method of measurement to be recommended for coupling telephone receivers to hearing aids and possibly other proximity devices for disabled persons. A question to investigate all possible methods of coupling hearing aids to telephones is currently before IEC/WG 17 and CCITT/SGXII.

Unfortunately the field strength recommended by the E.I.A. as well as that currently being distributed for comment within C.C.I.T.T. appears to be in conflict with the magnetic field strength previously recommended in I.E.C. for the coupling of public address system, magnetic loops to hearing aids.

Public address system magnetic loops are commonly provided in Scandinavia in theatres, cinemas, churches, meeting halls, etc. but are rare outside some classroom applications in North America. In Scandinavia hearing aids are required by law to have a pick-up coil for use with these public address magnetic loop systems.

The C.C.I.T.T. commitment has been broadened by the intervention of Canadian representatives to consider the alternative coupling methods.

It is hoped similar activities of Canadian representatives in I.E.C. will lead to the broadening of activities which will lead to recommendations to hearing aid manufacturers relative to coupling hearing aids to telephones as well as public address loop systems and to other forms of coupling other than magnetic. The specification of a magnetic field to be produced by a telephone receiver under test conditions will not produce sufficient information to the hearing aid manufacturers to allow them to optimise the operation of their hearing aids with telephones under normal operating conditions.

A significant increase of interest in the problem related to the coupling of hearing aids and telephones was demonstrated by the submission of four contributions from Canada, Japan, USA and France. Simultaneously to the CCITT/SGNI and to the IEC/WG17. The submitted contributions are summarized below.

The contribution from France: "Characteristics of the magnetic field produced by telephone earphones and hearing aid systems." described the performance of seven systems studied in France; two regular telephone sets, two earphones designed to radiate a magnetic field, two handsets amplifying the signal received and one acousto-acoustic coupler. The test method chosen to measure magnetic output is compatible with the method formerly proposed by the CCITT Special Raporteur. Results indicate that the magnetic field generated by the standard receiver used in France is very weak. Some other units, especially those with a built-in amplifier, are generating too high a magnetic output. Another concern is related to the small area in which magnetic coupling can be effective. In conclusion, the suggestion is made that probably two different standards will be developed: one for the regular "telephone used by any subscriber" and a different standard describing special telephones for hearing aid users.

Delayed Contribution from Canada: "Coupling of Hearing Aids to Telephone Receivers" presents some of the results of an ongoing research program aimed to improve the use of the telephone by the hearing impaired. It discusses the effect of coupling signals on comprehension, characteristics of hearing aid pick-up coils and comprehension of levels when using different coupling modes. Conclusions proposed in this contribution reveals degree of difficulty to be expected in an attempt to standardize magnetic output of a telephone. The need for compatibility between various related standards is stressed.

Delayed Contribution from AT&T, U.S.A. : "Draft Standard Proposed by the Joint Committee of North American Telephone Set and Hearing Aid Manufacturers for the Inductive Coupling of Hearing Aids to Telephones", describes a tentative agreement on magnetic field intensity criteria for telephone set compatibility with hearing aids reached at a meeting on May 10, 1983, by members of the above joint committee. The minimum magnetic field strength permitted by the proposed criteria is in the order of 14dB lower than the nominal level proposed in the preliminary reply to the Question 23/XII. A document attached to the AT&T contribution (annex I) is intended to be adopted by EIA as their standard (PN-1652). Even though proposed test methods and values are questionable, presented material gave a new light in discussion on the Nordic proposal.

Delayed Contribution from NTT, Japan,: "Magnetic Coupling of Hearing Aids to Telephone", examined the feasibility of the coupling with a leakage magnetic field from standard telephone receivers used in Japan. The measurement results of receivers used in Model 600 and Model 601 telephones are given. The contribution conclusion is that the above standard telephones are not adequate for magnetic coupling with hearing aids and that special telephones should be designed for that purpose.

Two temporary Documents No. 25 and 41 were submitted by the CCITT Special Raporteur. TD25 is a modified version of the Nordic contributionin Study Period 1977-1980. The only difference is the input signal being an acoustic pressure from the receiver rather than electrical signal to tip-ring terminals. The latter input is now adopted by the EIA. Temporary Document No. 41 is a Special Raporteur's Report on question 23/XII. It suggests that the recommendation should be put forward "in order to improve performance instead of manifesting earlier technical solutions that are less than optimal". This opinion was challenged at the Ad-Hoc group meeting. In North America, where an approximately 6dB lower field than the nominal proposed is provided, most hearing aid user's seem to be satisfied. As a result of the Ad-Hoc group meeting a compromise proposal was prepared to be submitted for comments to telephone administrations. The Special Raporteur, in his conclusion to the TD41 suggested that "the scope may be amended to say that the recommendation is concerned with the coupling of hearing aids having a magnetic pick-up that complies with the IEC Publication 118-4". This statement is very important since it focuses on enforcement of recommendations for hearing aids.

Experts involved in the study on Question 23/XII are divided into two groups. One is supporting design practices leading to implementations accepted as satisfactory by hearing aid users. The second group, concerned with the lack of acceptable implementation in their countries, supports "ideal" magnetic performance of the receiver. This performance is derived from similar but not analogue scenarios and will not necessarily lead to better user acceptance. On the contrary, variation of the signals in the telephone line can overload hearing aids and decrease comprehension, and the frequency response of the signal presented with both magnetic and acoustic coupling is not well understood.

Introduction of a standard for magnetic field around the telephone receiver seems to be needed at this point in time. Recommendation of values compatible with design practices and accepted by hearing aid users will be less dangerous than introduction of values not verified by use of controlled experiment.

# 8. RESEARCH IN CANADA

## 8.1 General

There are no known studies done by the telecommunications industry in Canada concerning the coupling of hearing aids to telephones before 1976. After 1976, Bell Canada and its associate company Northern Telecom, learned that some hearing disabled used the magnetic field accidentally produced by the then standard receiver to couple their hearing aids to the telephone. Bell Canada then began negotiations with representatives of the hearing disabled community in Ontario and Québec and undertook a programme of investigation committed to: "research to ensure services received by the hearing disabled would not deteriorate but improve, also that a portable acousto-magnetic coupler would be made available at a nominal cost, and that payphones and phones at locations frequently used by the hearing disabled would have an equivalent flux coil, which would also be made available on request at no cost."

Since 1976 the problem has been studied by Bell-Northern Research, and a research program, sponsored by Bell Canada, is proceeding at Pennsylvania State University and Aprel Industrial Acoustics Limited. Surveys have been conducted to assess the situation in Canada. Considerable laboratory work has been done on coupling, and an acousto-magnetic coupler has been produced. Work was conducted in conjunction with teaching hospitals, medical centers, and representatives of the hard-of-hearing. It is recognized that the work is not yet complete. However, significant contributions have already been made to North American and international standards.

The outputs from the telephone and the inputs to the hearing aid that are available or practical with present technology are: acoustic, magnetic and electric. Various combinations of these coupling alternatives have been analyzed or identified as needing further research effort with consideration of the following factors:

- -ambient acoustics noise interference
- -frequency response considerations (response variations, filtering, etc.)
- -gain considerations
- -input signal cancellation effects (acoustic or magnetic shadows)
- -non-linear distortion
- -acoustic feedback (Larson effect)
- -electro-magnetic interference
- -universal applicability
- -privacy
- -human factor aspects (switch operations, gain adjustments, interfaces, etc.)
- -economics (special telephones, special coupling devices, etc)

## 8.2 Hardware for Experimentation

### 8.2.1 Special Test Tools

#### 8.2.1.1 Audiometer Telephone Interface

Considerations of the advantages and disadvantages, limitations and inconveniences imposed by most of the factors involved in coupling of telephones with hearing aids can best be assessed by objective studies and subjective evaluation, with participation of real subjects. In the case of face-to-face communications, a tool to assess hearing ability is an audiometer terminated with loudspeaker or earphones. If a telephone is used at the output of an audiometer, the evaluation of the hearing ability in this mode of communication can also be done by using common audiometric techniques.

The Audiometer-Telephone Interface (A.T.I.) allows a standard audiometer to be connected to a standard telephone set in order to make a testing and evaluation of the various coupling methods possible. The Audiometer-Telephone Interface was designed and built to provide an additional tool for audiologists to facilitate selection of the best mode of coupling of a hearing aid to a telephone, selection of the best hearing aid for a given telephone set or the best telephone set for a given hearing aid. Also the ATI is intended to be used in standard procedures for assessing telephone communication skils amongst the hearing impaired and may help in aural rehabilitation, as well as in the design of hearing aids and telephone sets. In another scenario, the audiologist can help hearing impaired persons to obtain optimum performance from their hearing aids, when these are used in conjunction with the telephone.

Besides its application in subjective testing the ATI can be used for objective testing of coupling devices or magnetic flux coils. The latest advanced ATI-Mark IV was built by APREL Industrial Acoustics Limited and is being used by Penn State University in current subjective studies (eg see section 8.3).

The latest prototype consists of two major blocks, the Central Office Simulator (C.O.Simulator), providing power to a telephone set being examined, and the Typical Connection Simulator (T.C.Simulator), reproducing average characteristics of the network and the other subscriber's station set (FIGURE 21).

8.2.1.2 Experimental Hearing Aid

The study, sponsored by Bell Canada, "Acoustic Coupling of Hearing Aids and Telephones: Does Frequency Response Matter?", was designed to investigate the relationship between the frequency response of signals transmitted via acoustical coupling of hearing aids and telephones and the performance of subjects tested using the ATI.

An error analysis study on this report carried out by APREL Industrial Acoustics Ltd. concluded that although the experiment was well designed and the recording procedures were properly carried out, the characteristics of the filters and the methods of calibration introduced significant measurement errors.

Major areas where errors can occur were identified as follows:

1) The TH 39 earphone as used with the ATI is mounted supra-aurally on an artificial ear during calibration. A hearing aid generates sound in the occluded portion of the ear canal. Thus, a corrective filter to account for the transfer function between the concha and the eardrum should be used.

2) An important conclusion reached in previous studies is that subjective loudness is a factor linked to intelligibility scores. The filtering technique used in the study introduced large loudness errors. When the filters were used in conjuction with the ATI and a telephone, the actual variation between the flat and high pass characteristics was 6dB.

3) In other parts of the experiments, subjects were allowed to use their own hearing aids. Thus, the researchers were unable to account for the variations in frequency response due to fit and the variations in performance from model to model.

The Experimental Hearing Aid (EHA) was designed to eliminate errors caused by variations in filter characteristic, variations in fit and the calibration of the hearing aid receiver. The EHA consists of two major components; a hearing aid case containing a receiver and microphone modified to produce a known, linear frequency characteristic, and a control amplifier. One of the limitations of the conventional hearing aid amplifier is that the low battery voltage available reduces the dynamic range possible and can cause an unacceptable increase in distortion. In addition, the low audio power delivered by a hearing aid amplifier makes it necessary to increase the overall subjective loudness by taking advantage of mechanical resonances in the transducer. Consequently, a conventional transducer modified to produce an acoustically linear response will not produce adequate subjective loudness, or conversely a conventional transducer designed to produce adequate subjective loudness will not produce an acoustically linear response. The EHA overcomes this problem by providing the modified receiver with a signal from an amplifier employing a 19 volt supply instead of the normal 1.4 volt mercury cell. Thus the experimenter is guaranteed a linear, wide dynamic range and low distortion signal at the ear drum.

The amplifier is intended for use with all subjects and is therefore provided with suitable compensation for the three types of hearing loss: via the Hearing Loss Category Switch:

I Moderate (precipitous): thresholds between 0 and 25 dB HL from 250 to 1000Hz with a precipitous drop in HL at 2000 to 4000Hz (slope greater than or equal to 25 dB/octave.)

II Moderate (gradual): thresholds between 10 and 40 dB JL at 250 Hz with gradual slope (10-20 dB/octave) to 4000Hz.

III Severe: thresholds between 40 and 85 dB from 500 to 4000 Hz with no threshold differences greater than 15 dB HL between any two octave frequencies over that range.

Low frequency compensation is provided via two multi-position switches arranged so that their effects are additive. Up to +35 dB of compensation is available. An important feature of the circuit is that the subjective loudness level is not affected by the low frequency compensation selected.

An accurate four position attenuator allows the experimenter to adjust the overall gain in the system so that the experiments can be conducted at known, preselected acoustic power levels. The EHA also includes a microphone telecoil switch to allow direct comparison between the two modes of operation. A black diagram of the Experimental Hearing Aid is shown in Figure 22. The Hearing loss compensation characteristics are shown in Figure 20 and the low frequency compensation in figure 23.

8.2.1.3 Miscellaneous Devices

An electro-magnetic telecoil locator was built in APREL to allow the localization of the telecoil without opening the housing. The "source element" in the device is a flat core telecoil. The locator works on a similar principle to a transformer. When the source element and the telecoil in the hearing aid are aligned, the ouput ofthe hearing aid is maximum. The source element can be displaced in x-y-z directions and rotated. When the maximum output is found, the location of the telecoil can be read on the locator's scales. The preliminary measurements using the telecoil electro-magnetic locator have not yet been entirely successful. The geometry of the source element and the magnitude of the input signal have to be further optimized.

8.2.2 Tested Hardware

Most of the experiments were conducted with the "industry standard" handset G type. Handsets, receivers and coupling devices were evaluated objectively before they were introduced into the subjective studies. In most cases the same devices were verified, after tests, for possible changes during experiments.

Handsets used in the experiments were the standard G-3 type and the G-6 amplified one, both manufactured by Northern Telecom. Receivers used in experiments were : U-type, Balanced Armature Receiver, BAR with flux coil all manufactured by Northern Telecom, and a dynamic receiver R-53 manufactured by APREL Industrial Acoustics Limited.

In addition to handsets and receivers, two acousto-magnetic couplers were studied. The acousto-magnetic coupler manufactured by Northern Telecom and 100A type coupler manufactured by Western Electric were also evaluated. The latter one was used only in early experiments and discarded later because it performed the same function as Northern Telecom version but had several deficiencies.

Included in experiments were various hearing aids actually worn by subjects as well as almost 100 types of hearing aids evaluated objectively to establish some performance parameters. In addition to the evaluation of the hardward directly involved in the research program other aids for the hard of hearing available on the market were also evaluated. The list of commercial aids available includes the Radio Shack magneto-acoustic coupler, Phonic Ear acoustic coupler, warmex hand held "hearing aid", various ringers, etc.

## 8.3 Some Research Results

### 8.3.1 Evaluation of Hearing Aid's Magnetic Circuit Parameters

The objective evaluation included physical examination of hearing aids, physical examination of the telecoil as well as comparison of acoustic and magnetic sensitivity and frequency response of hearing aids. The preliminary results led to the selection of eight types of hearing aids to be used in the subjective study.

Two groups of hearing aids were used in the objective evaluation. The first group included 43 types (164 units) used in previous experiments. Most of these hearing aids were modified externally (additional tubing etc.). However, they were adequate for the purpose of physical examination of telecoil characteristics telecoil location and physical distribution of other components.

The second group included 30 hearing aids borrowed from the Canadian Hearing Society. Those hearing aids were examined for both physical properties and electro-acoustic performance.

Both groups included behind-the-ear, eye glass and body types of hearing aids. "In-the-ear type" of hearing aid was not included in this part of the project.

Most of the hearing aids are built with a provision to be opened for repair. It was then possible to carry on the examination without damaging the housing. The physical examination consisted of:

- hearing aid features.
- internal lay-out of components with emphasis on telecoil positioning.
- identification of major components such as microphone receiver, telecoil, electronic circuit and interfaces, switches, etc.
- geometrical characterisation of the telecoil.

An example of the examination results is shown in Figure 24. The hearing aids with ultrasonically welded housing (6 types) were not opened.

The electromagnetic telecoil locator built in APREL to allow the localization of the telecoil without opening the housing, previously described in paragraph 8.2.1.3 was used to identify the characteristics of the telecoils in these aids.

Acoustic input to acoustic output transfer function was measured and compared with magnetic input to acoustic output transfer function for the same hearing aid.

Acoustic transfer function was measured using the standard test method for insertion gain characteristics (IEC-118). Magnetic transfer function was measured using the standard magnetic loop as signal source (IEC 118-1).

Since the main objective of this study was to assess the probability of efficient use with the telephone by examining the type, location and orientation of the telecoils and the relative performance of the hearing aid with acoustic and magnetic inputs, the detailed analysis concentrated on 58 types of behind-the-ear hearing aids. All of them are manufactured in North America and Europe and available on the Canadian market.

The study showed that among those hearing aids which have a telecoil, there is a variety of telecoil types, locations, and orientations. Three typical locations of hearing aids telecoil are shown in Figure 25.

Figure 26 shows the distribution of the 58 telecoils orientation of the hearing aids with telecoils normally in the vertical plane.

The hearing aid telecoil output is not only dependent on the angle of the telecoil to the vertical axis referred to in Figure 26. It depends also upon the orientation of the telecoil to the telephone receiver's magnetic field as shown in figure 27. IEC Standard 118-4 discusses the magnetic field strength in audio-frequency induction loops. When using a hearing aid telecoil to pick up this magnetic field, telecoils oriented vertically will provide maximum output. However, when coupling a telephone receiver magnetic field, the output of the telecoil is dependent on the angle of the coil relative to the receiver magnetic field. Appendix "C" describes the magnetic field for a typical North American receiver with a circular magnetic coil.

The specific angle for testing which appears in proposed CCITT or EIA draft recommendations assumes a particular telecoil location not necessarily corresponding to a typical telephone receiver/hearing aid configuration.

Subjective experiments, not yet complete, are currently being done to evaluate the effect on the transmitted and received signals and on the required manipulation of the handset caused by this diversity of telecoil types, locations, orientations, etc.

The analysis of the test results in this study indicated that

- there is no uniformity in the choice of telecoil location in different models of hearing aids;

-in the majority of models the telecoil location is not constrained by packaging limitations;

-there are hearing aids with a telecoil located adjacent to the earphone cartridge without obvious feedback problem;

-it is hard to understand the design intent for the choice and location of telecoils; and probably results from different applications for which a particular telecoil is designated.

-only some models of hearing aids have the same sensitivity and frequency response for magnetic and acoustic inputs; (see figure 28)

-there are models of hearing aids with magnetic sensitivity much higher than acoustic (see fig.29) and vice-versa (see fig.30);

-not all models of hearing aids have the circuitry to compensate for differences in magnetic and acoustic transfer functions. (see fig.31)

8.3.2 Telephone Coupling in the Presence of Noise

A comparative evaluation of four telephone coupling methods for the hearing impaired in the presence of competing background noise.

The methods that hearing impaired persons employ to use the telephone were:

1) Amplifier handset (G-6)
2) Magnetic coupling (U-1 receiver and hearing aid on "T" switch)
3) Acoustic coupling (B.A.R. receiver and hearing aid on "M" switch)
4) Tube microphone adaptation (A2-3" extension of the hearing aid microphone port onto the cheek of user)

Two levels of competing background noise were used, 76dB (A) and 86dB (A). Three groups of subjects (N - 100 each) were tested at six different sites. There were two groups of hearing impaired subjects (moderate and severely impaired) and one control group of normally hearing individuals equated to the experimental groups by age and sex.

The task was a test of speech intelligibility in noise (SPIN) and the data were expressed in terms of percentage correct scores. Results showed that the overall best coupling mode was the telephone only used with the amplifier handset. Next best was the magnetic coupling mode. Acoustic and tube microphone modes were significantly poorer. A non-significant small group of moderately impaired subjects actually performed better on the tube microphone than the other modes. (NOTE: The values of background noise used in this early experiment were abnormally high t- evaluate what was considered to be a limiting case)

### 8.3.3 Normal Hearing Impaired Listener's Behavior in Background Noise

The purpose of this research was to evaluate several listening strategies to improve telephone communication ability in a noisy background for normal and hearing impaired (sensorineural loss) subjects. Telephone listening ability of normal hearing subjects decreased as the level of background White noise (WN) or Multitalker Noise(MTN) was increased from 65 to 75 to 85dB SPL. MTN significantly decreased telephone listening, moreso than WN. However, telephone listening ability was significantly increased in a MTN or WN background at 75 or 85dB SPL when the transmitter was occluded (blocked) by the palm of the subject's hand and/or by electronically disengaging the transmitter. Telephone listening was also assessed in hearing impaired subjects in a background noise environment. When hearing impaired as well as normal hearing subjects listened to speech transduced through a telephone handset, set to simulate an amplifier handset (output - 106dB SPL), in MTN background of 75dB SPL, telephone communication did not significantly improve when the transmitter was disengaged to eliminate sidetone effects.

The findings of this research were interpreted to indicate that normal hearing listeners could significantly improve telephone listening ability in high noise backgrounds by occluding the transmitter to eliminate sidetone masking effects. This could also be accomplished by electronically disengaging the transmitter and or using an amplifier handset. Using an amplifier handset, telephone listening ability for hearing impaired subjects in a background noise (MTN at 75dB SPL) was not significantly increased by electronically disengaging the transmitter to eliminate sidetone feedback effects.

### 8.3.4 Effect on Comprehension of Modified Frequency Response with Equal Loudness in Acoustic Coupling

The above experimentation using the EHA is complete and now being analyzed. Preliminary conclusions are that - Group 1 comprehension is signigicantly improved but group 2 and 3, while not adversely affected are not significantly improved by additions to the low frequency content. (see section 3.2 for definitions)

An interesting fact which appears as a side-benefit of this experimentation is that:

Subjects who are able to work acoustically without problems of acoustic feedback (instability whistling) and those unable to do so can be distinctly divided.

The Bell Canada programme of research with Penn State University and APREL Industrial Acoustics is continuing.

## 9. CONCLUSIONS

This report provides a summary of the information available from literature and research projects on the coupling of hearing aids and telephones. Certain conclusions may be noted, especially for their relevance to the Canadian scene.

A. In relation to telephone sets:

- Telephone sets provided by the carriers are defined by internal standards which guarantee satisfactory transmission performance for most users by prescribing objective (measurable) parameters derived from subjective tests.
- The new interconnect enviornment could degrade the transmission quality of telephone sets for hearing-impaired and other users in the absence of mandatory performance standards.
- There is not sufficient characterization of the performance of the telephone when it is used by the hearing impaired, especially those using hearing aids.
- The critical element for telephone/hearing iad compatibility is the telephone receiver, which is now universally of electro-magnetic design. However, non-magnetic technologies are under development which promise improved performance of the receiver and its adaptibility to digital transmission, a potential benefit for all telephone users.

B. In relation to hearing aids:

- The characteristics of hearing aids used in configurations for which they were designed (free space, face-to-face communication, magnetic PA loops, etc.) are not standardized nor uniformily reported, and they are seldom verified before the hearing aid is fitted to the user. The test methods for hearing aids (but not performance criteria) have been developed by the IEC.

-There is not sufficient information available on the characteristics of hearing aids using a signal from small magnetic sources and from proximity acoustics sources (e.g. telephone).

C. In relation to telephone/hearing aid coupling and direct coupling to the ear:

-There is no single coupling method which can be universally satisfactory for all hearing aid users.

-Acoustic output of the telephone receiver is the only characteristic which is universally available for coupling, and its importance will increase if the digital/acoustic transducer is introduced. Acoustic coupling, however, requires a new approach to hardware design and the fitting procedures for hearing aids.

-Magnetic coupling combined with the use of the residual hearing (magnetic plus acoustic i.e., receiver plus flux coil) is satisfactory to some percentage of hearing aid users.

-Magnetic coupling alone even with elevated magnetic output has deficiencies demonstrated by scientific research and the low popularity of the acousto-magnetic coupler.

-Electrical direct coupling has strong technical merits especially in an interconnect environment, but physical compatibility of cables and adaptors is an obstacle.

-Direct coupling to the ear with an amplifier handset is effective for a significant number of hearing-impaired users, and it should therefore be retained.

## 10. RECOMMENDATIONS

There are several gaps in scientific and engineering knowledge which should be filled before telephone/hearing aid coupling can be improved. The following recommendations are intended to address this problem:

- Encourage further research work towards identifying the relative advantages and disadvantages of the various potential methods of coupling hearing aids to telephone receivers. Representatives of the hearing aid industry should be encouraged to participate in this work.
- Encourage research and development to apply the latest technologies to hearing aid design, and to characterize those parameters of the hearing aid which determine its effectiveness for both free field and telephone use.
- Encourage the selection and fitting of hearing aids to optimize their use with the telephone as well as for face-to-face "free field" operation.
- Encourage the development of standards for the basic operating requirements of hearing aids. As an interim measure, manufacturers could be encouraged to specify the performance of their hearing aids in terms of internationally-accepted criteria and test methods.

-Encourage work to identify the operating environment of hearing aids, e.g., magnetic noise. If desireable, recommend magnetic noise emission standards for all electro-magnetic equipment.

-Encourage the characterization of those parameters of the telephone set necessary to determine its effectiveness when used by the hearing impaired, especially those using hearing aids.

-Encourage development of telephone performance standards to maintain transmission quality in the interconnect environment.

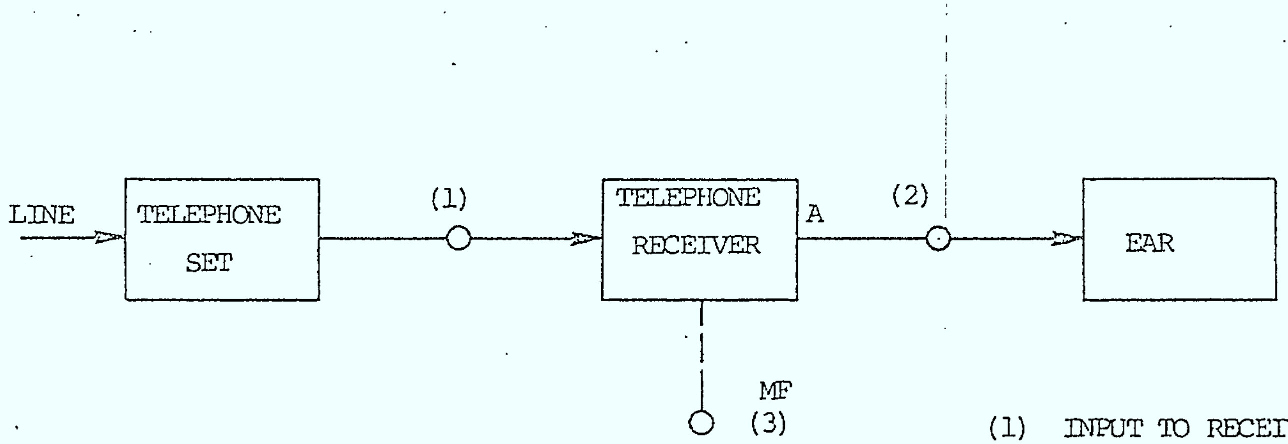
# LIST OF FIGURES

TELEPHONE COUPLING FOR HEARING IMPAIRED

| TELE-PHONE OUTPUT / COUPLING MODE | ACOUSTIC (MICROPHONE) | MAGNETIC (TELECOIL) | DIRECT COUPLING TO THE EAR (NO H.A.) |
|---|---|---|---|
| ACOUSTIC | ACOUSTIC LEAK<br>ACOUSTIC TUBE<br>IN-THE-EAR AID | ACOUSTIC-MAGNETIC COUPLER | HANDSET AMPLIFIER |
| MAGNETIC | MAGNETIC-ACOUSTIC AMPLIFIER | MAGNETIC LEAK (STRAY FIELD)<br>INDUCTIVE COIL | MAGNETIC-ACOUSTIC AMPLIFIER |

FIGURE 1.

DIRECT TELEPHONE COUPLING




(1) INPUT TO RECEIVER

(2) OUTPUT SOUND PRESSURE

(3) NO STRAY MAGNETIC FIELD

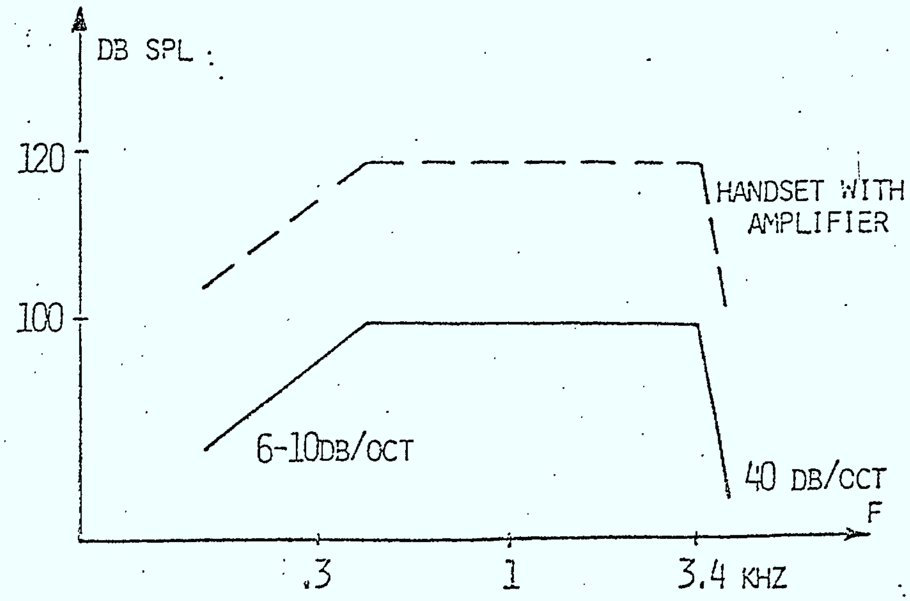
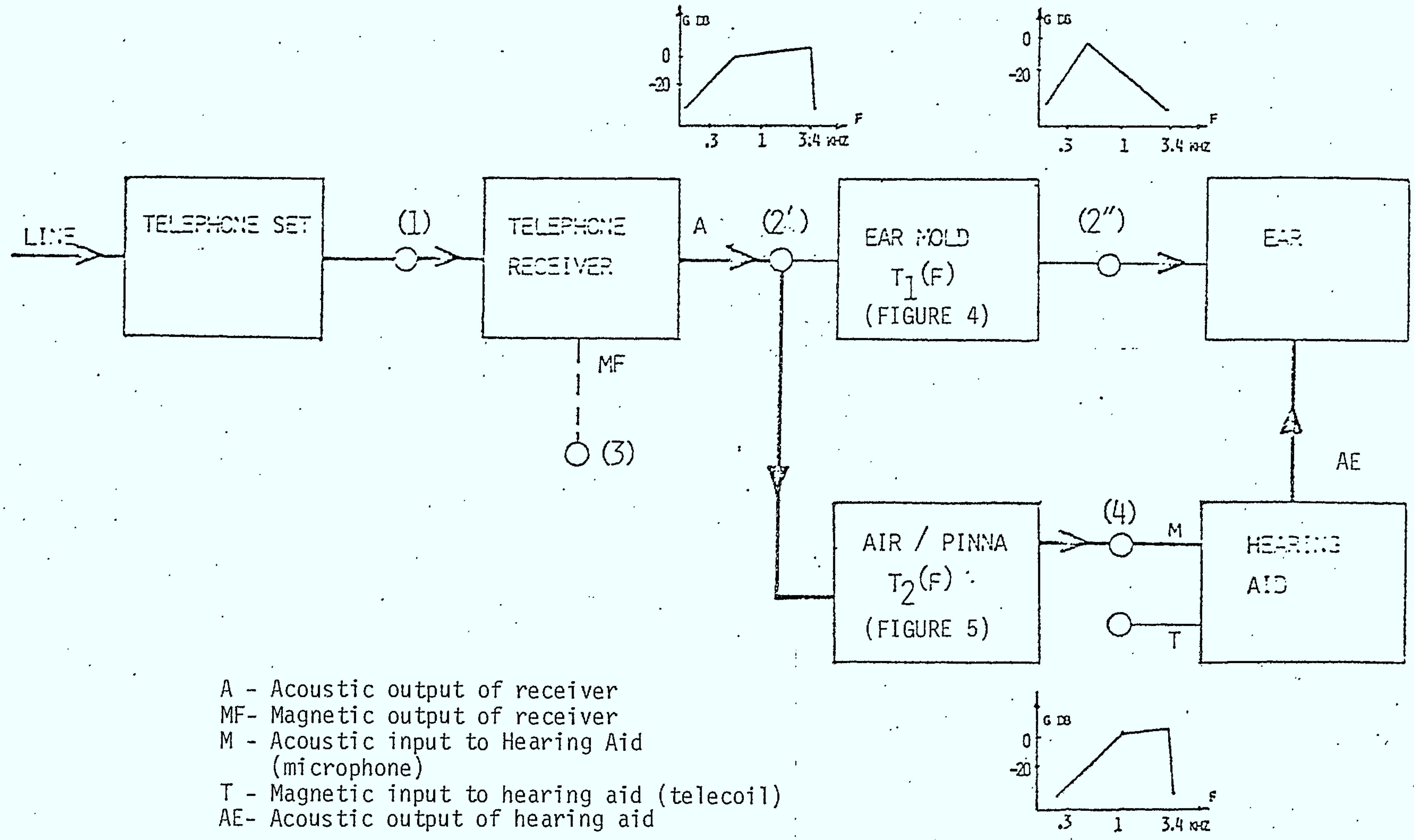



FIGURE 2

ACOUSTIC (LEAKAGE) COUPLING




A - Acoustic output of receiver
MF- Magnetic output of receiver
M - Acoustic input to Hearing Aid (microphone)
T - Magnetic input to hearing aid (telecoil)
AE- Acoustic output of hearing aid

FIGURE 3

# TRANSFER FUNCTIONS $T_1$ AND $T_2$

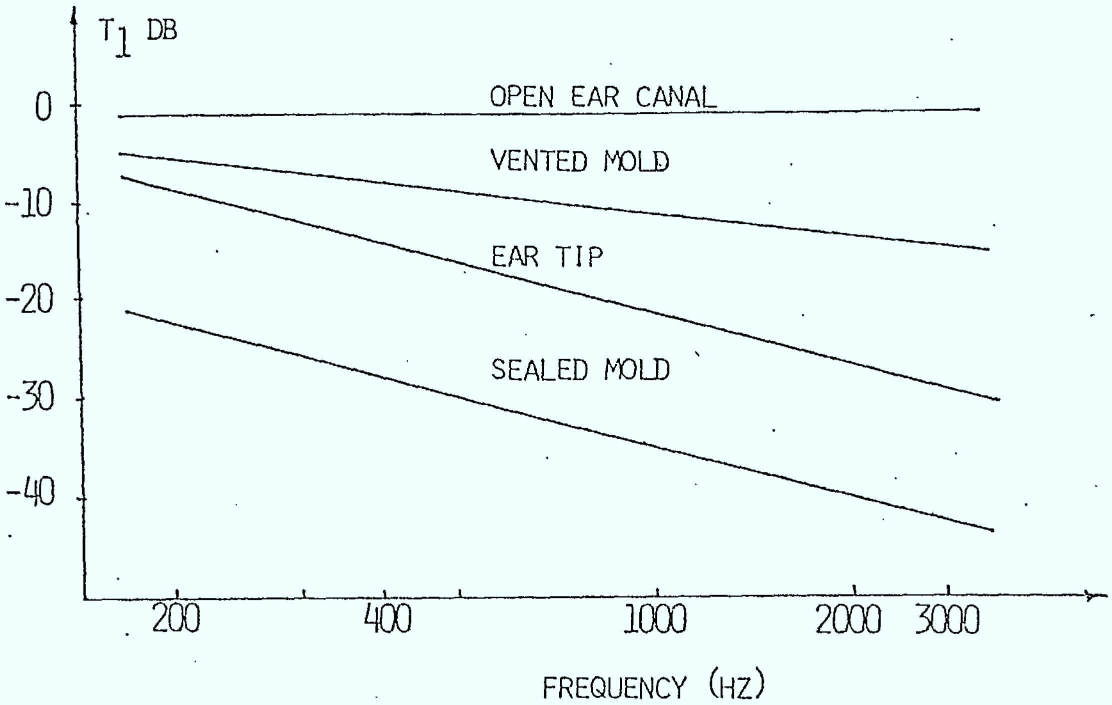



FIGURE 4

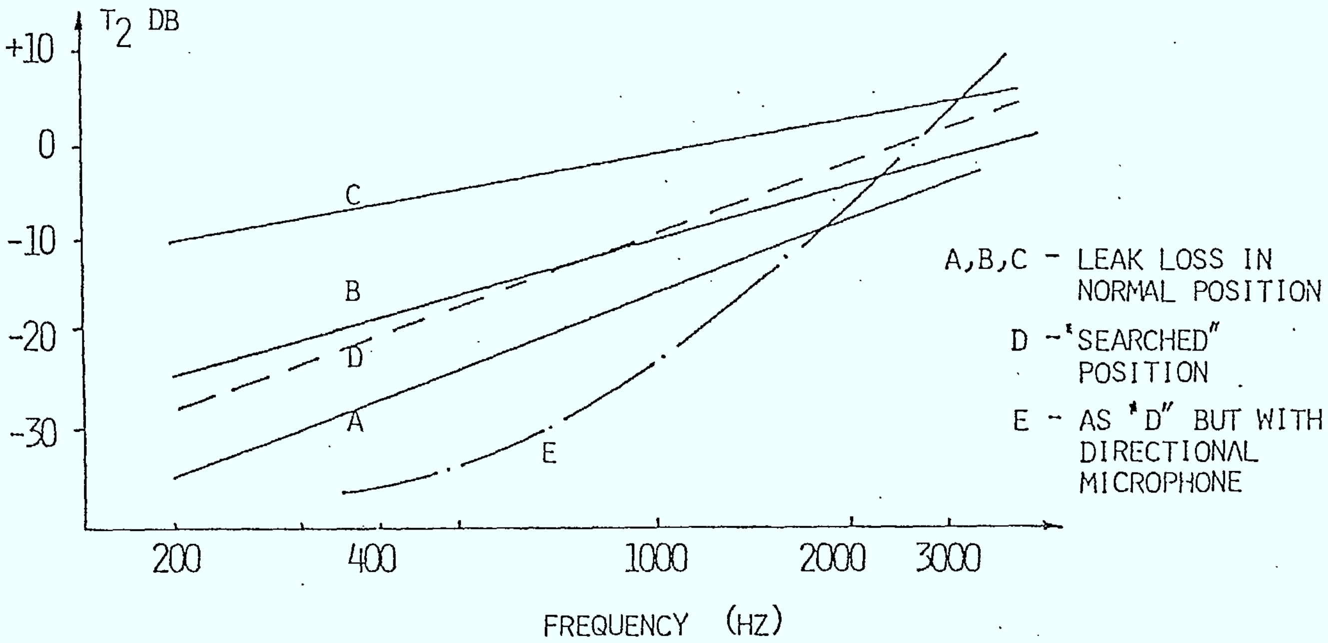



FIGURE 5

ACOUSTIC COUPLING (TUBE)

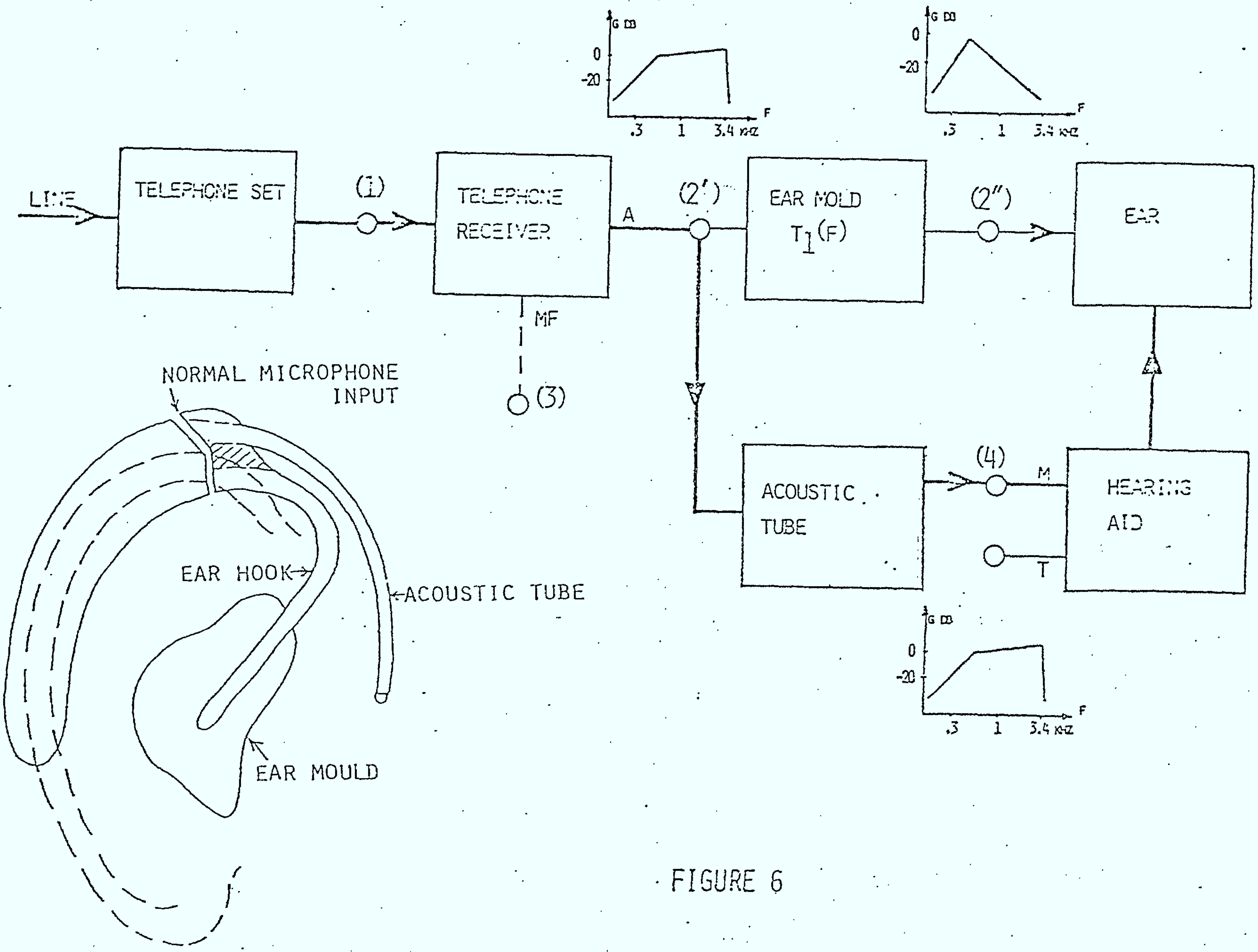



FIGURE 6

IN-THE-EAR HEARING AID

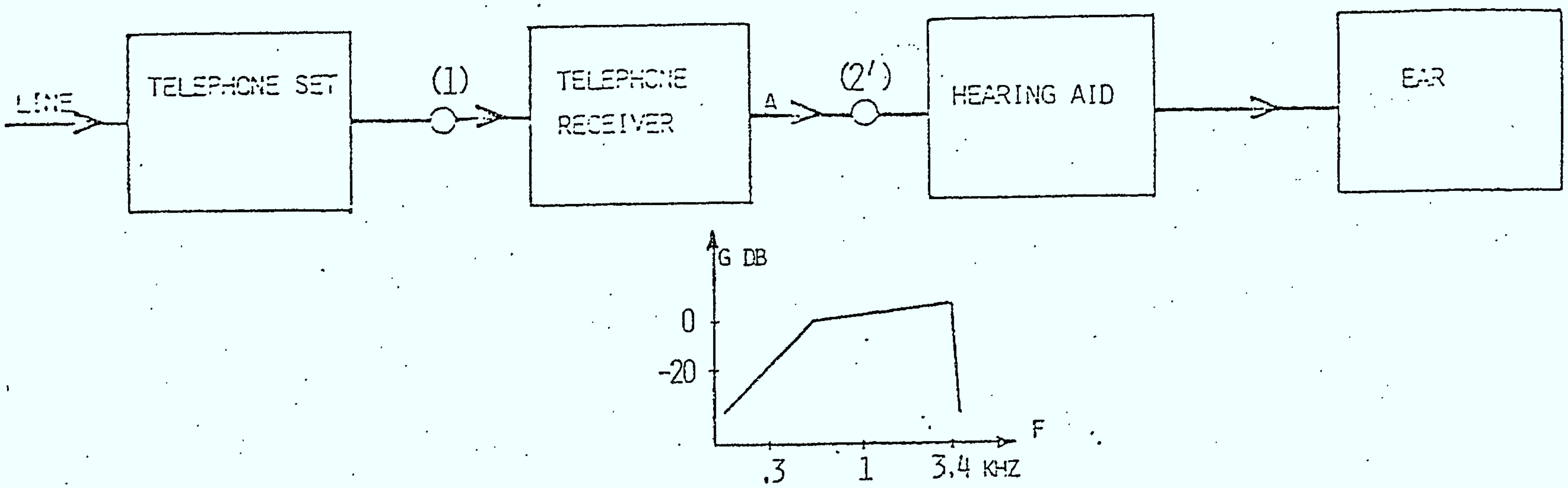
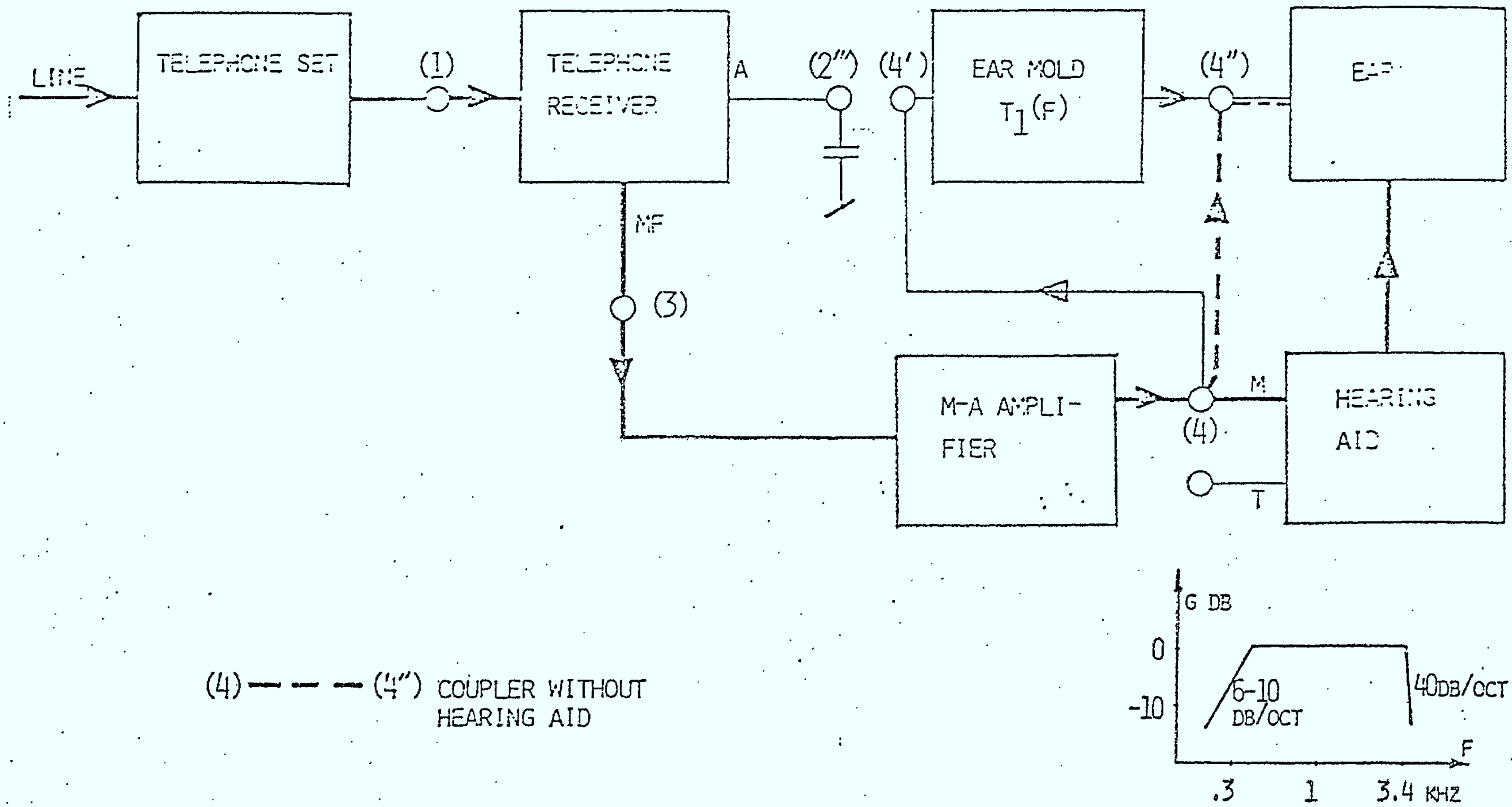



FIGURE 7

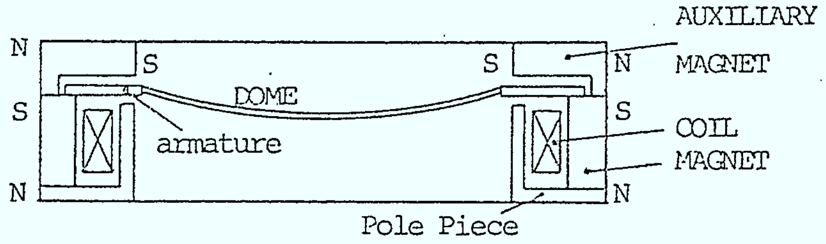
MAGNETIC-ACOUSTIC AMPLIFIER

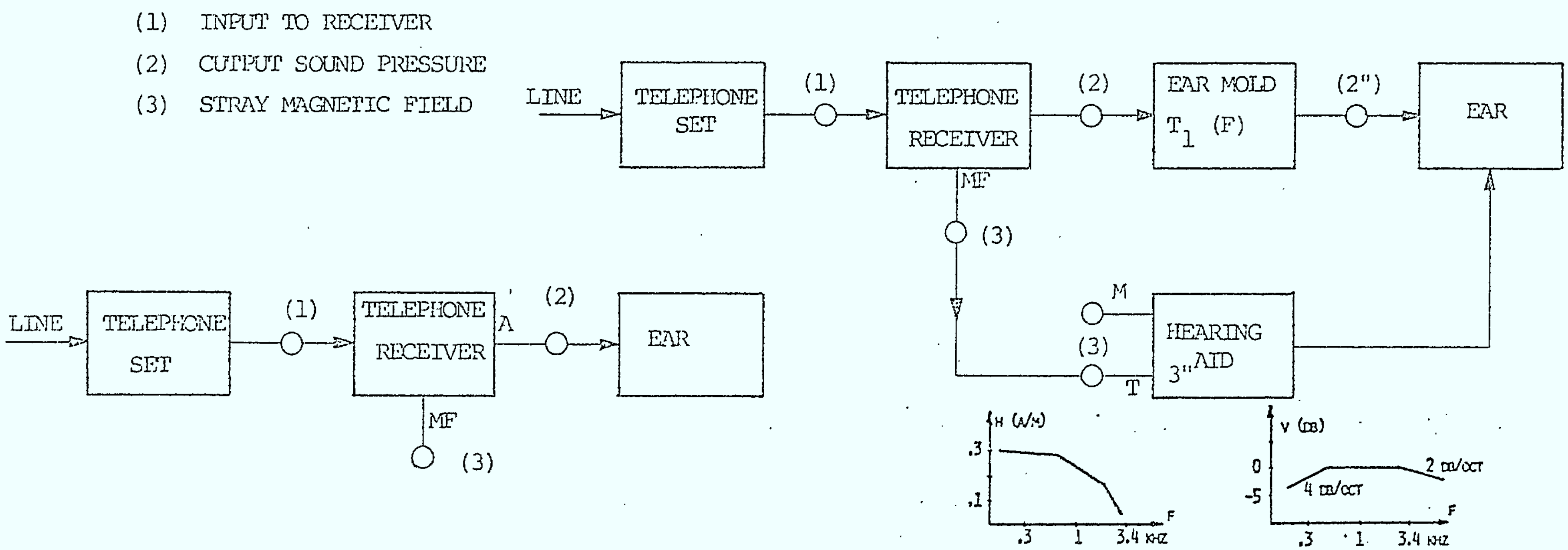



(4) — — — (4") COUPLER WITHOUT HEARING AID

FIGURE 8

RECEIVER ELECTROMAGNETIC "ring armature"



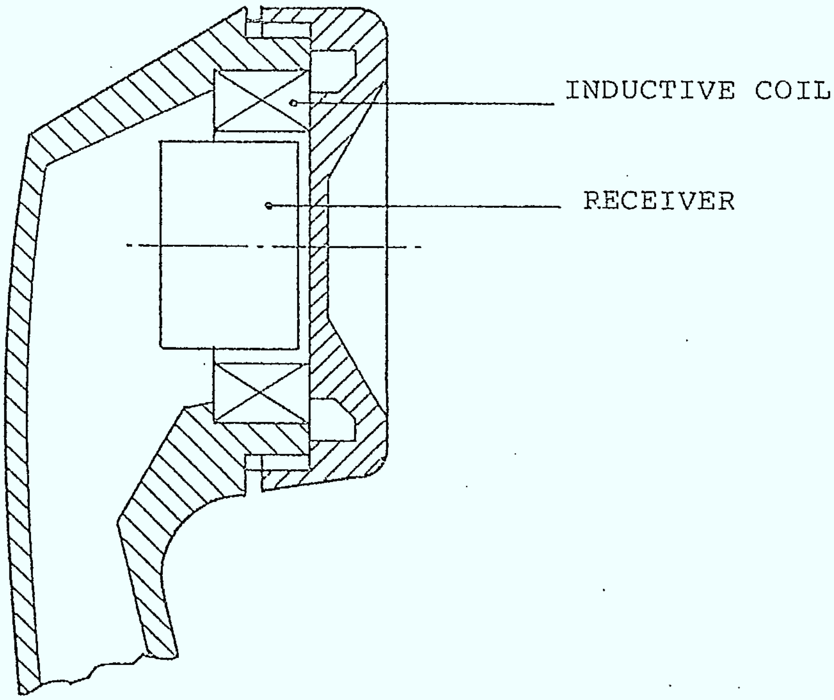



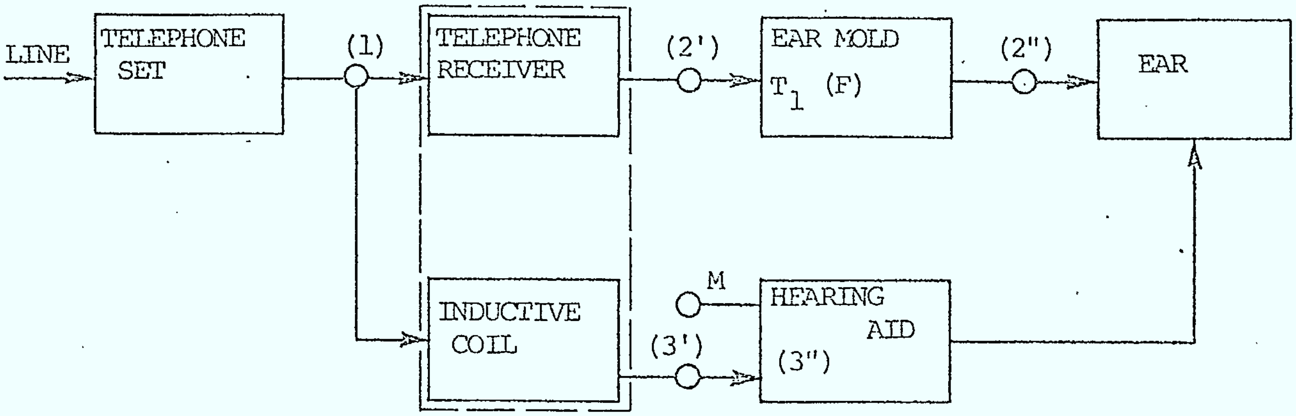

STANDARD TELEPHONE COUPLING

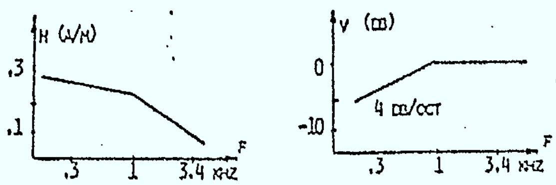
MAGNETIC COUPLING-RECEIVER's STRAY RADIATION

FIGURE 9

MAGNETIC COUPLING - INDUCTIVE COIL




(3″) - TELECOIL OUTPUT

ACOUSTIC OUTPUT (2′) IS LOWER BY ONE TO TWO DB.

FIGURE 10

ACOUSTIC-MAGNETIC COUPLER

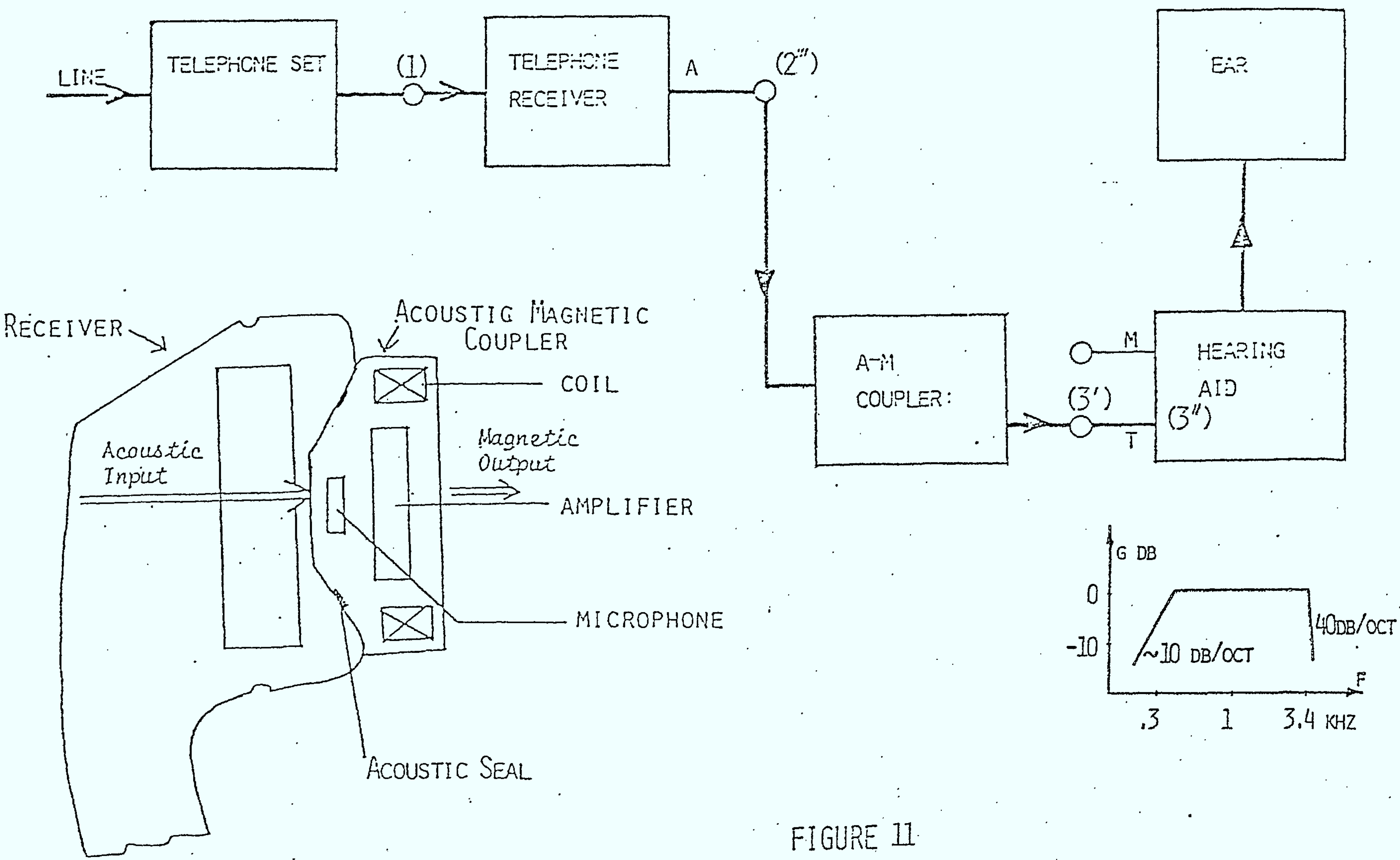



FIGURE 11

COMPARATIVE SUMMARY

| | COMMENTS \ MODE OF COUPLING | ACOUSTIC LEAK | ACOUSTIC TUBE | IN-THE-EAR AID | M-A AMPLIFIER (+H.A.) | A-M COUPLER | MAGNETIC LEAK | INDUCTIVE COIL | HANDSET AMPLIFIER | M-A AMPLIFIER (NO H.A.) | NOTES |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DISADVANTAGE | LOSS OF LOW FREQUENCIES | – | | | – | | | | | | |
| | FREQUENCY RESPONSE DEPENDENT ON REC. OR MIC. POSITION | – | * | * | – | | | | | | * MARGINAL |
| | SIGNAL CANCELLATION IF DIRECTIONAL MIC. | – | | | – | | | | | | |
| | UNSPECIFIED TEL. OUTPUT | | | | – | | – | | | | |
| LIMITATION | LIMITED GAIN | | | | | | | | – | – | |
| | FEEDBACK (WHISTLING) | – | | – | | | | | | | |
| | DISTORTION | | | | | | | | – | | |
| INCONVENIENCE | SWITCH MODE T↔M | | | | – | – | – | – | | | |
| | GAIN ADJUSTMENT WHEN T↔M | | | | – | – | – | – | | | |
| | EXTRA DEVICE TO CARRY | | * | | – | – | | | | – | *IF NOT PERMANENT |
| | BATTERY REPLACEMENT | | | | – | – | | | | – | |
| | SPECIAL PHONES | | | | | | | – | – | | NOT IN HOTELS |
| ADVANTAGE | ONE MODE FOR ALL SITUATIONS | + | + | + | | | | | | | |
| | AMBIENT NOISE REDUCED | | +* | | + | + | + | + | | + | * MARGINAL |
| | FREQUENCY RESPONSE INDEPENDENT OF REC. POSITION | | | | | + | + | + | | | |
| | NO H.A. REQUIRED | | | | | | | | + | + | |

FIGURE 12

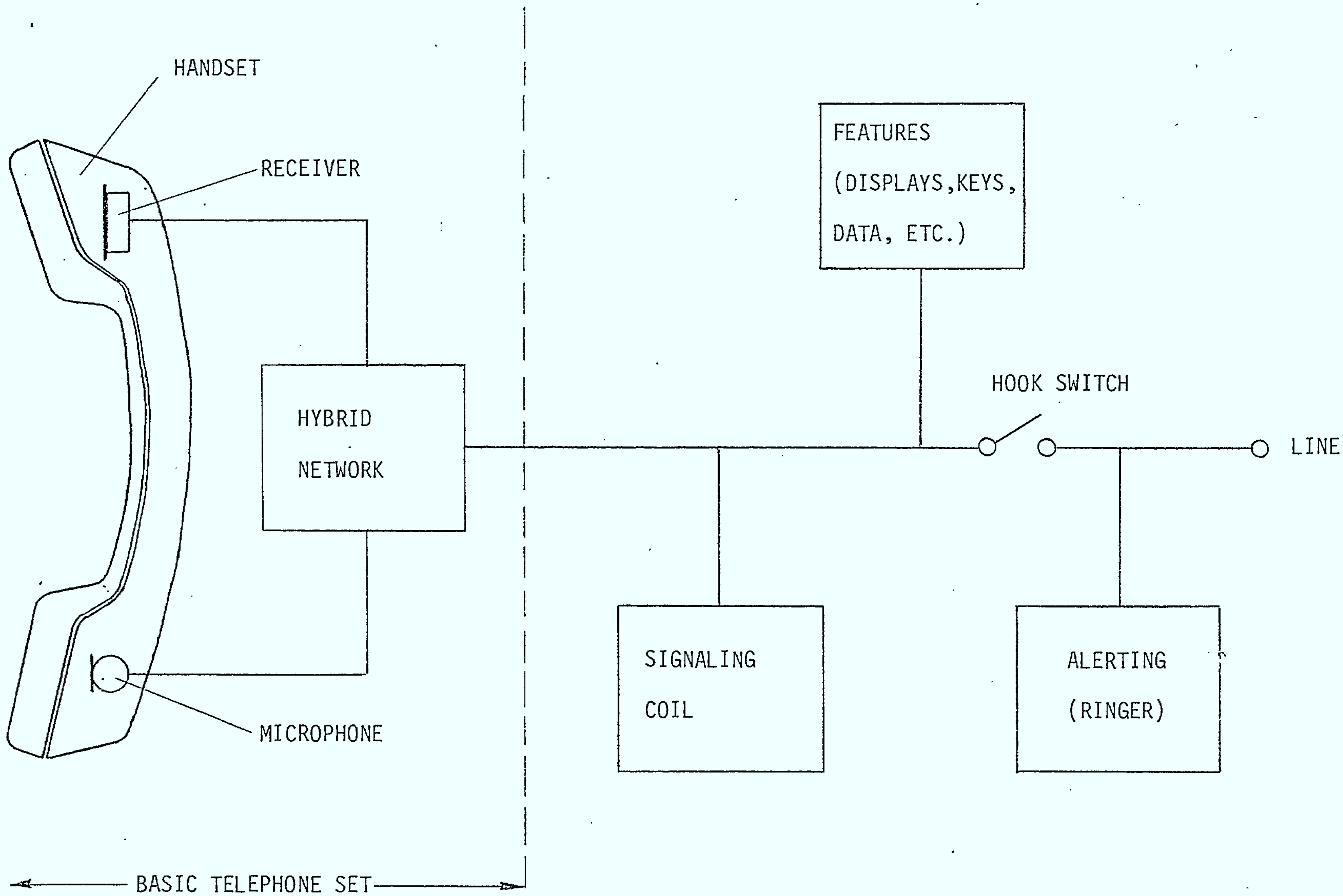



FIGURE 13: BLOCK DIAGRAM OF A TELEPHONE TERMINAL

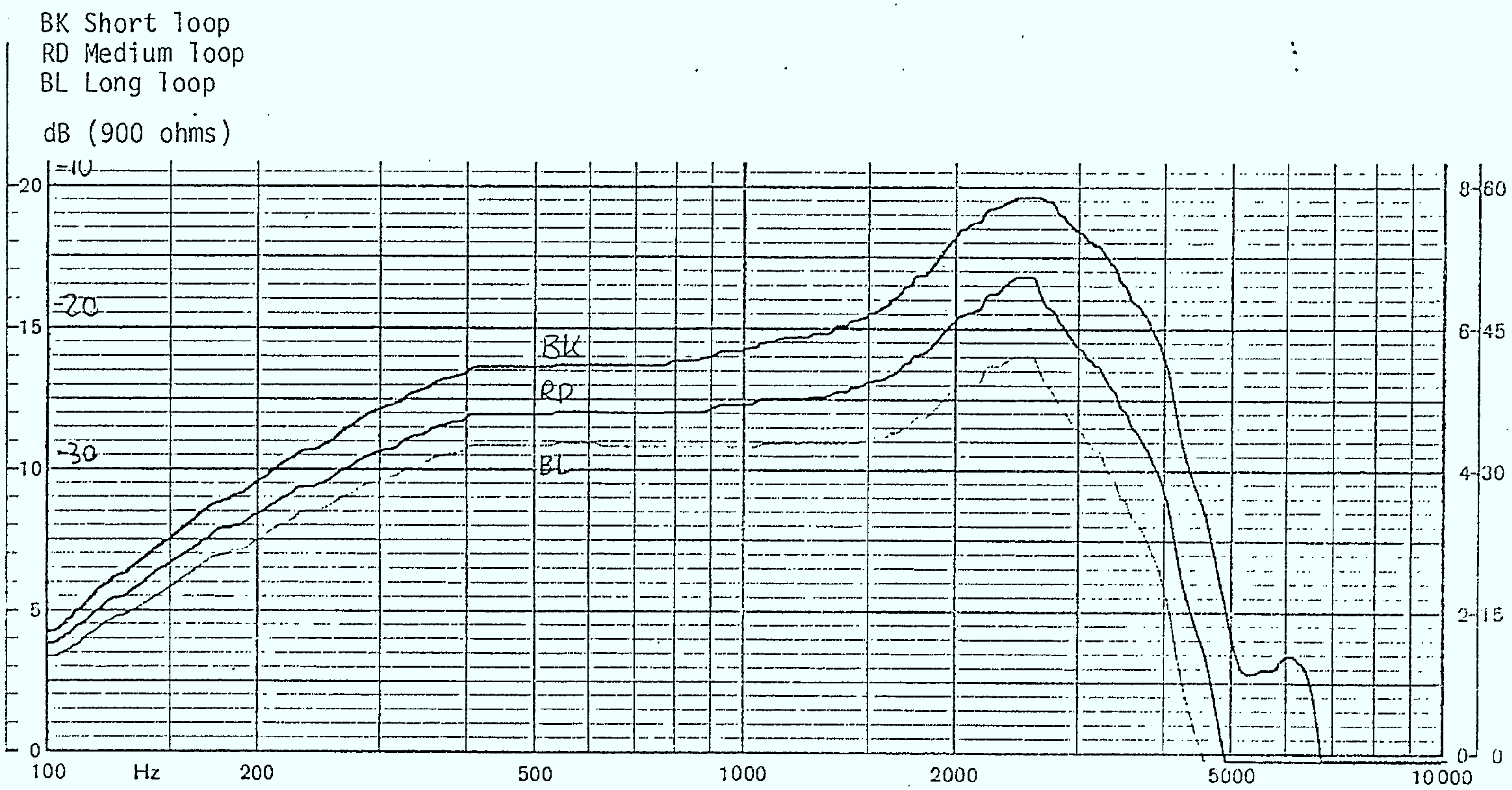



FIGURE 14

TRANSMIT FREQUENCY RESPONSE

BK Short loop
RD Meduim loop
BL Long loop

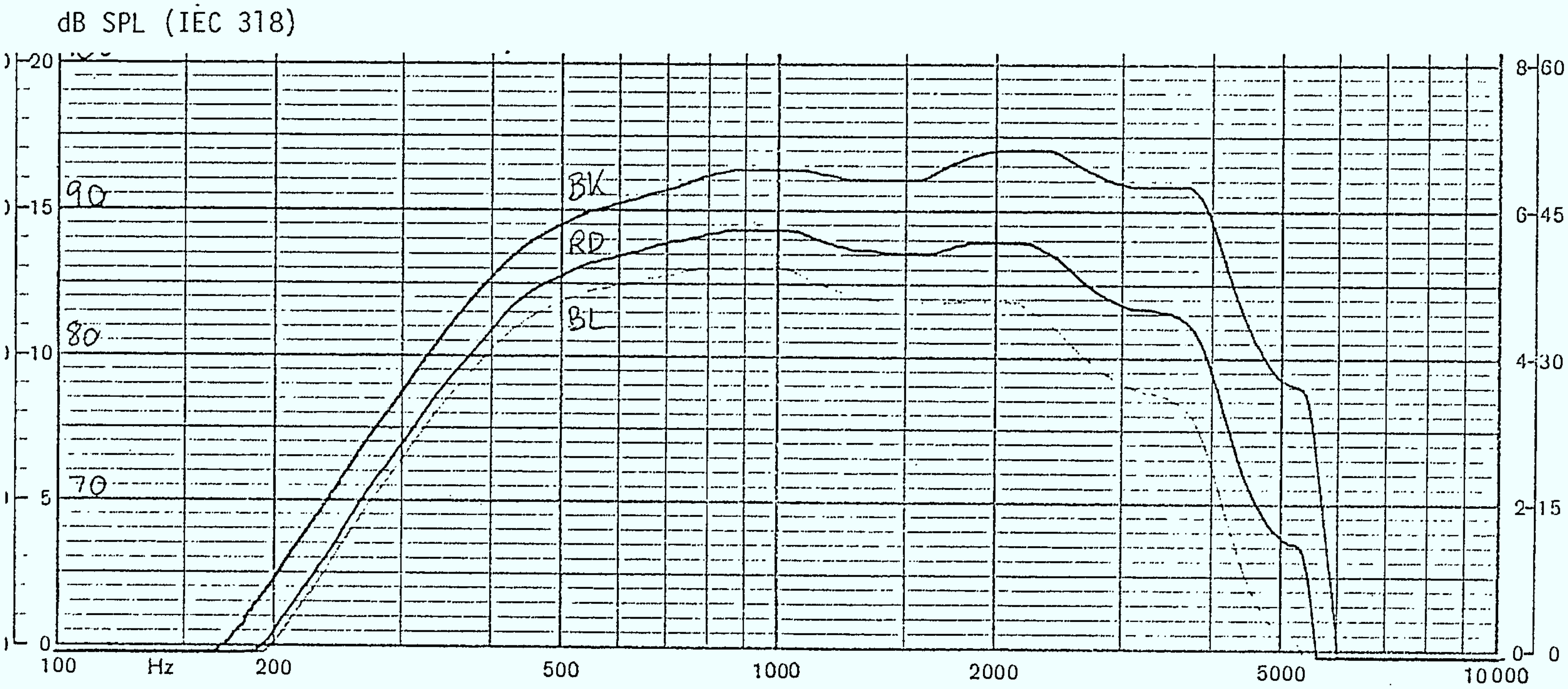



FIGURE 15

RECEIVE FREQUENCY RESPONSE

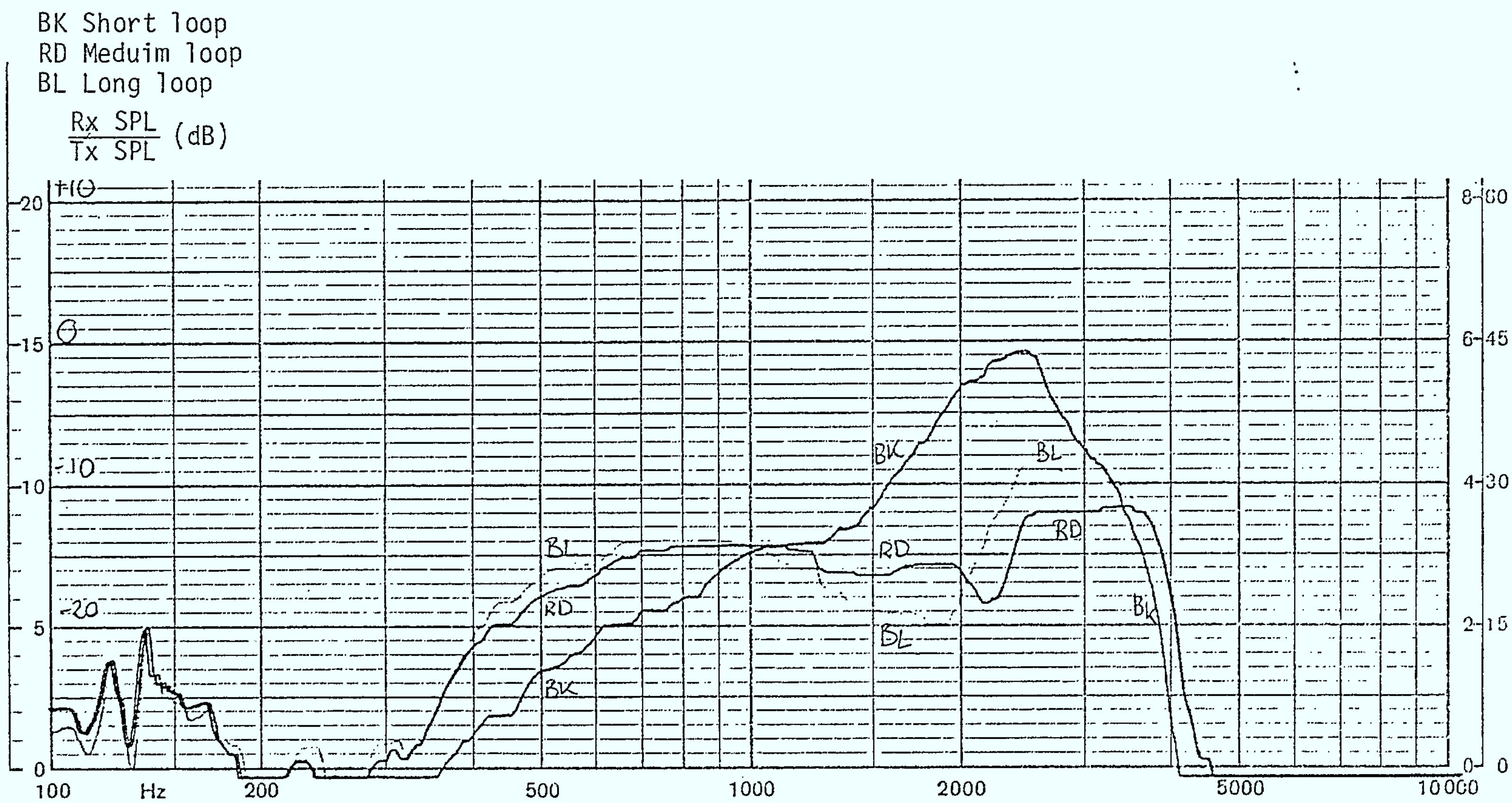



FIGURE 16

SIDETONE FREQUENCY RESPONSE

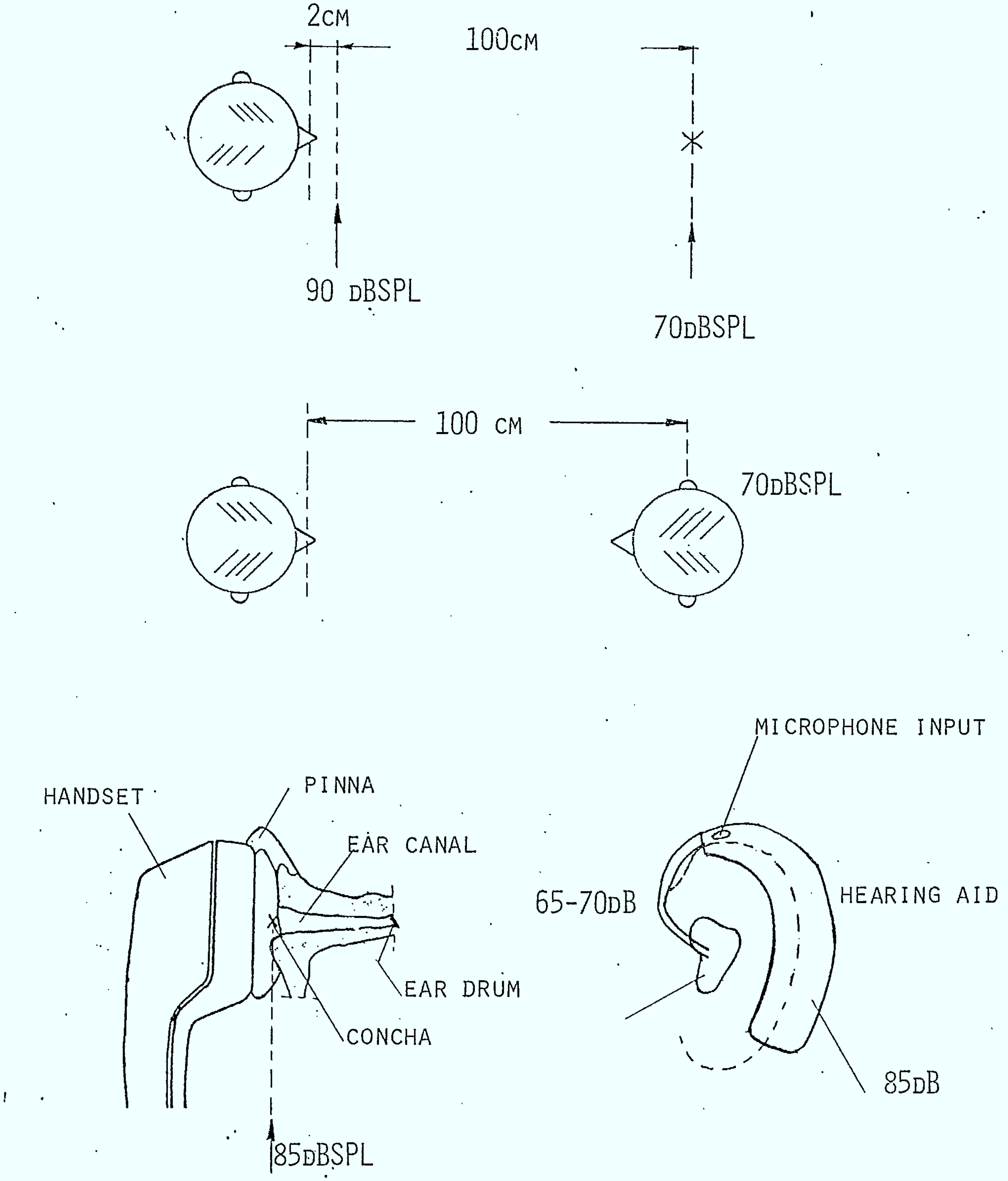
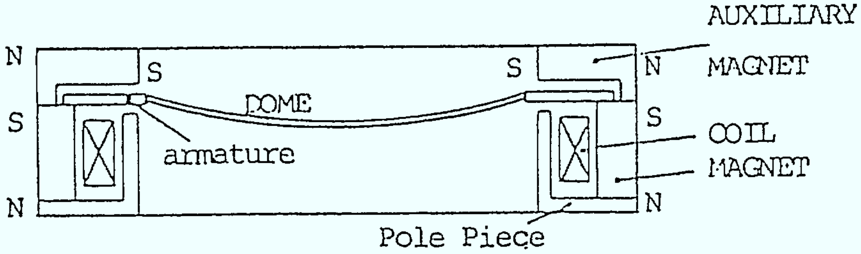



FIGURE 17

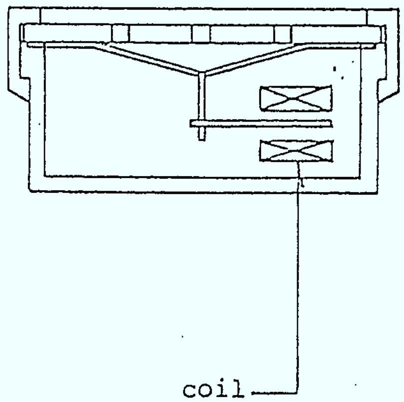
LOUDNESS CONSIDERATIONS

RECEIVER "A" ELECTROMAGNETIC "ring armature"



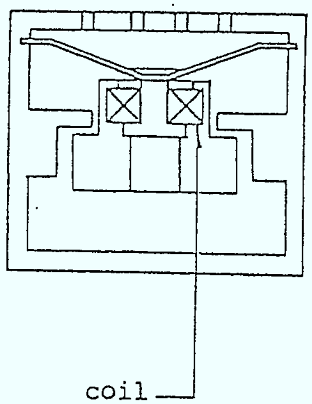

RECEIVER "B"

electromagnetic "Balance Armature"




RECEIVER "C"

electromagnetic "center armature"




RECEIVER "D"

Magnetoelectric "dynamic"

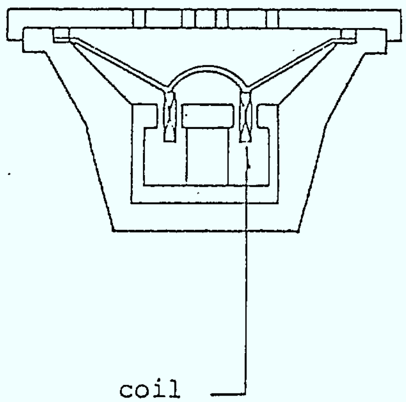
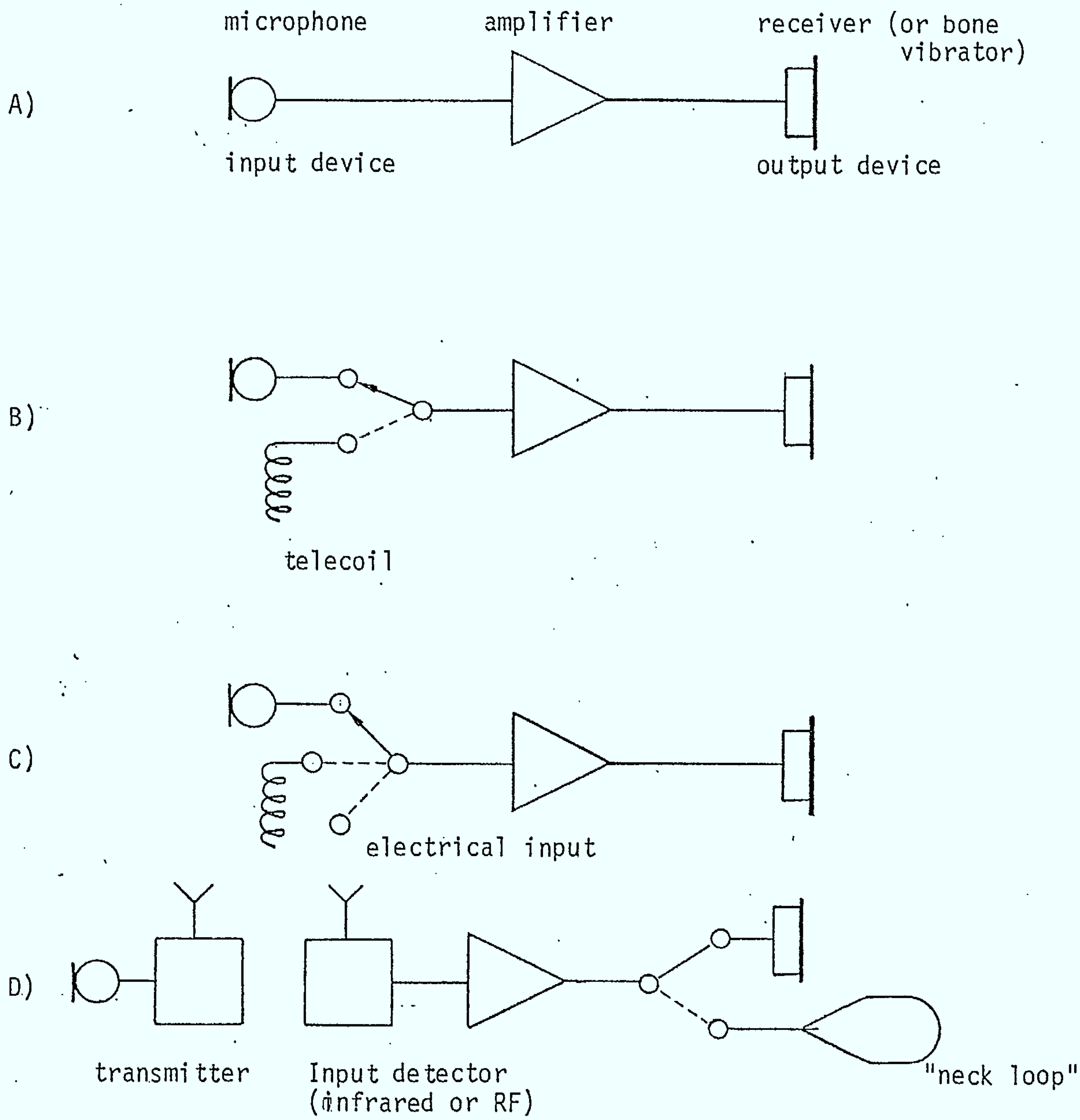



FIGURE 18: MAGNETIC RECEIVERS




BLOCK DIAGRAM OF HEARING AID

A) basic hearing aid
B) hearing aid with a telecoil
C) hearing aid with a telecoil and a direct electrical input
D) wireless hearing aid

FIGURE 19

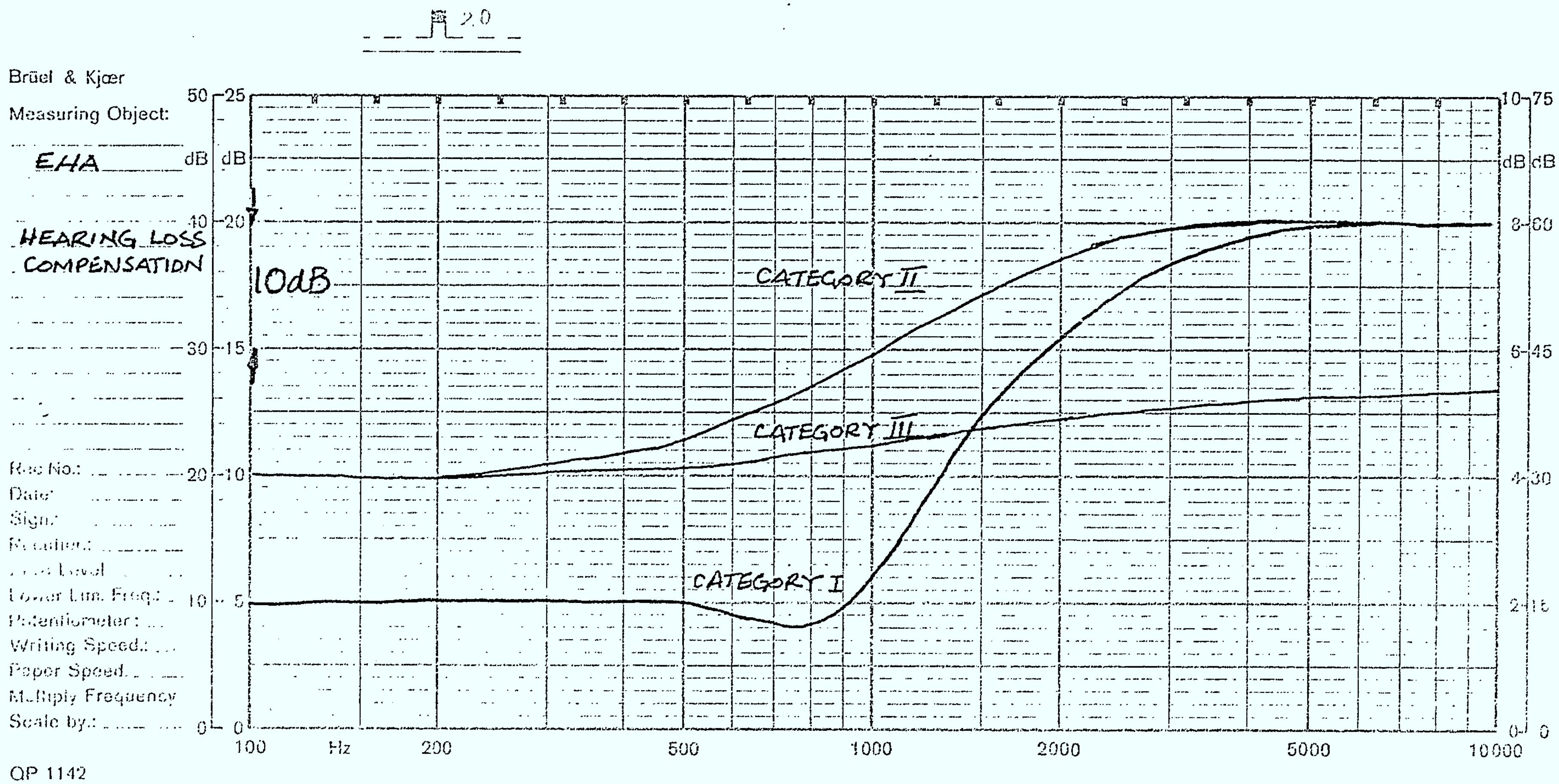

Brüel & Kjær
Measuring Object:
EHA
HEARING LOSS COMPENSATION
10dB
CATEGORY II
CATEGORY III
CATEGORY I
dB
dB
50
40
30
20
10
0
25
20
15
10
5
0
10
8
6
4
2
0
75
60
45
30
15
0
100
Hz
200
500
1000
2000
5000
10000
QP 1142

FIGURE 20

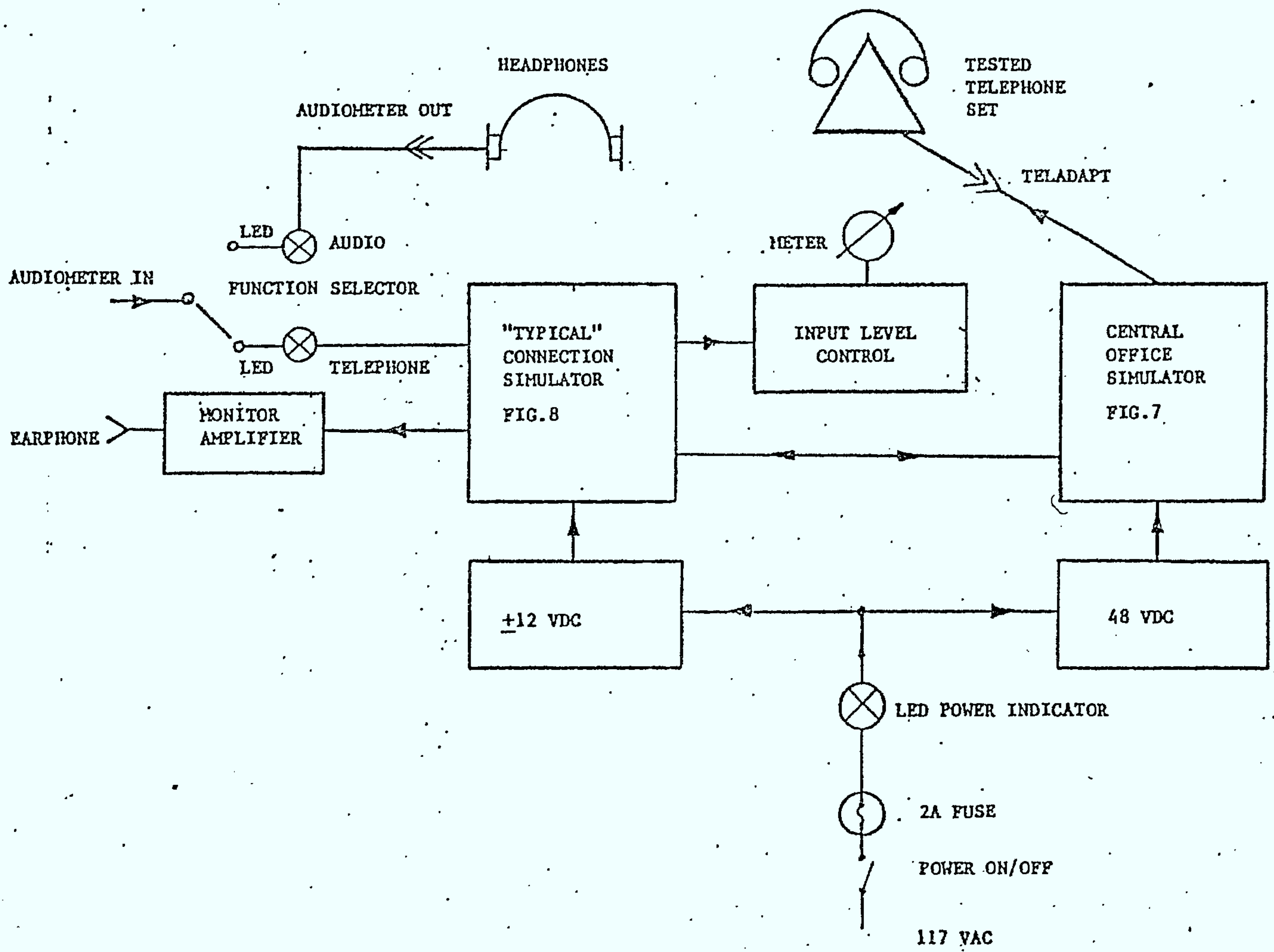



FIGURE 21: BLOCK DIAGRAM OF THE ATI-MARK IV

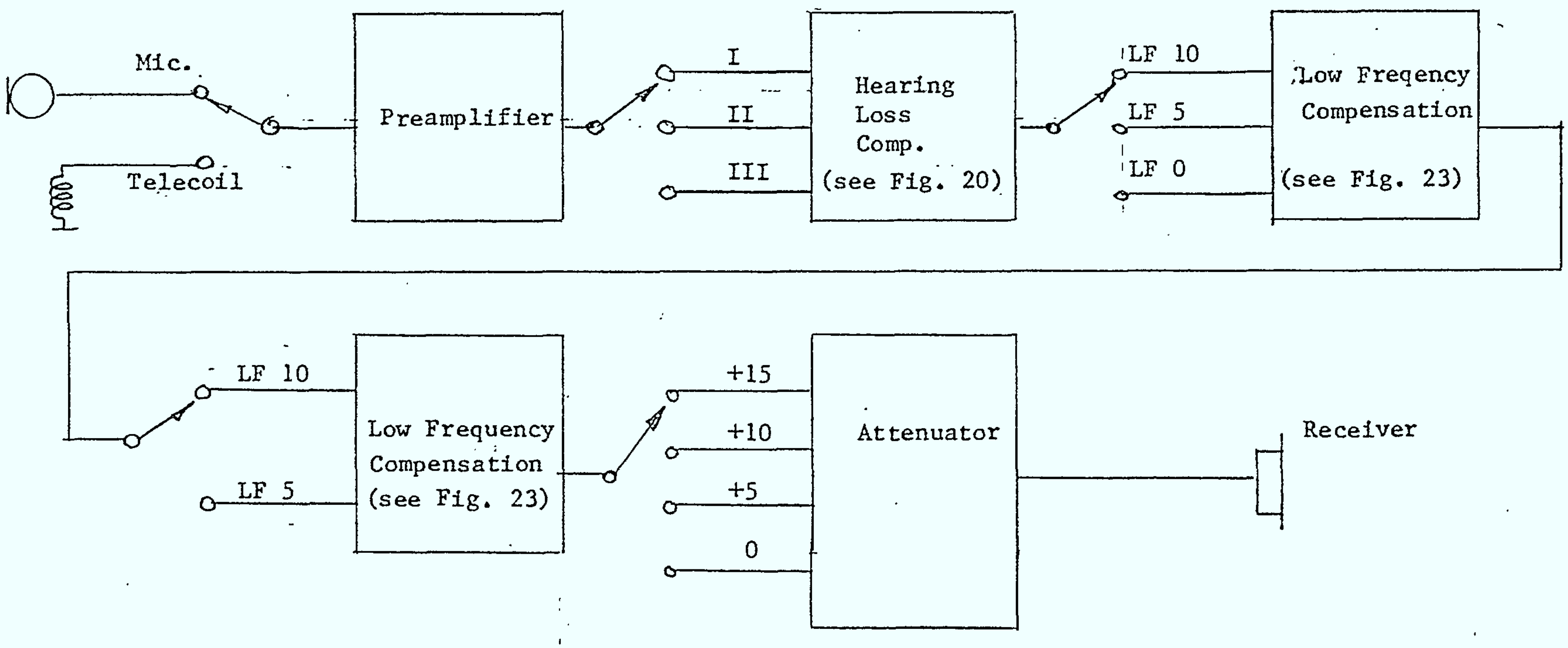



Fig. 22 Experimental Hearing Aid

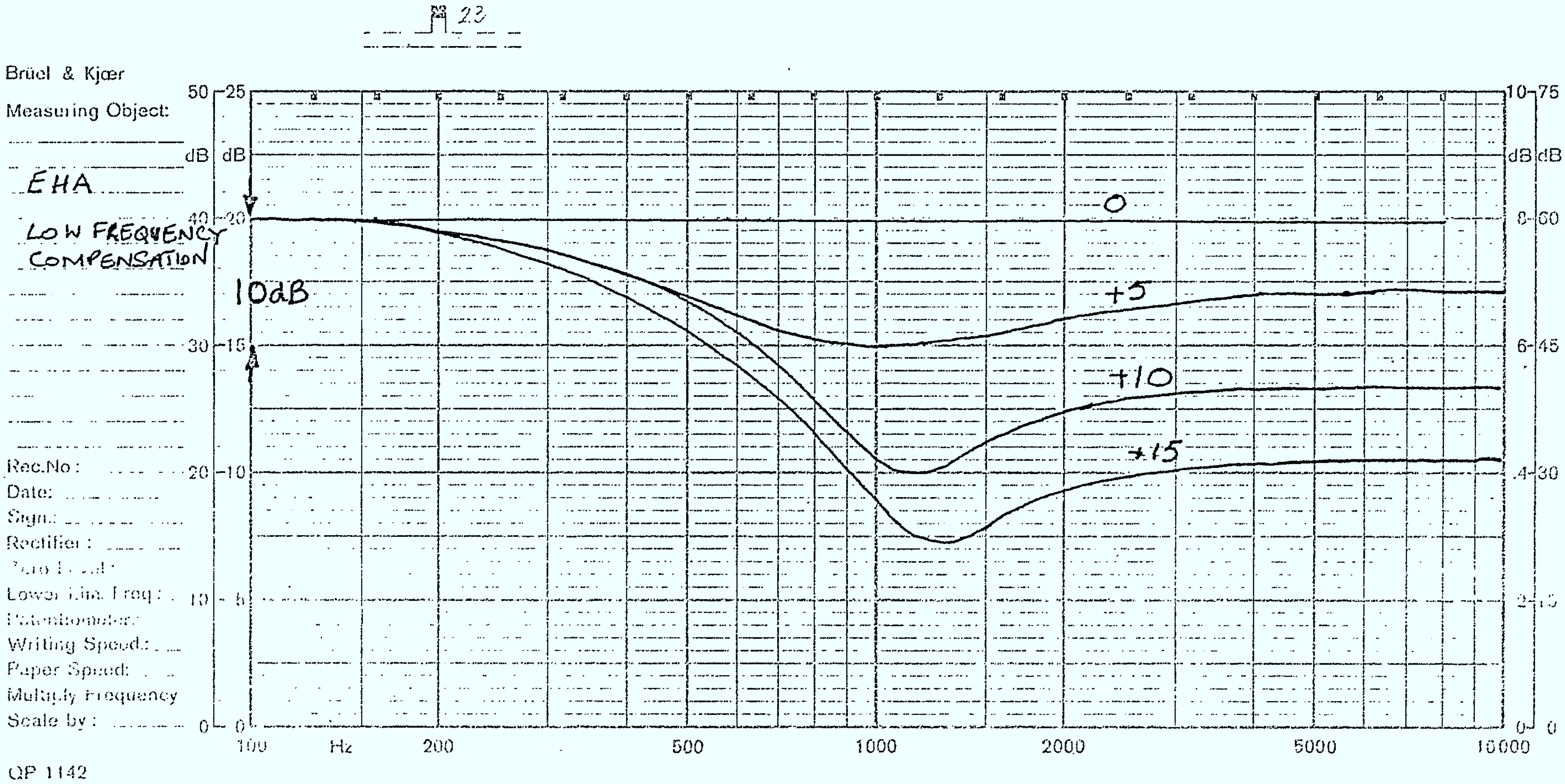

Brüel & Kjær
Measuring Object:
EHA
LOW FREQUENCY COMPENSATION
10dB
0
+5
+10
+15
Rec.No.:
Date:
Sign.:
Rectifier:
Lower Lim. Freq.:
Writing Speed:
Paper Speed:
Multiply Frequency
Scale by:
dB
100
Hz
200
500
1000
2000
5000
10000
QP 1142

FIGURE 23

# HEARING AIDS SURVEY: PHYSICAL

MANUFACTURER SIEMENS TYPE 26E-HT-CPC S/N 292011, 292019

CONTROLS: M/T YES ON/OFF YES AGC IN NO AGC OUT NO LFR N/A HFR N/A
VOL. YES OTHERS [illegible]

MICROPHONE: MFG. KNOWLES ELECTR. TYPE [illegible] 7H516

RECEIVER: MFG. KNOWLES EL. TYPE [illegible]

TELECOIL: MFG. not identified TYPE CORE-METAL

INTERFACE TELE/MIC YES

ELECTRONICS CONTINUOUS PEAK CLIPPING, PUSH-PULL (?)

COMMENTS: Gain 44; Output 122 500-[illegible] Hz
# 097336 - CAN. HEARING SOC

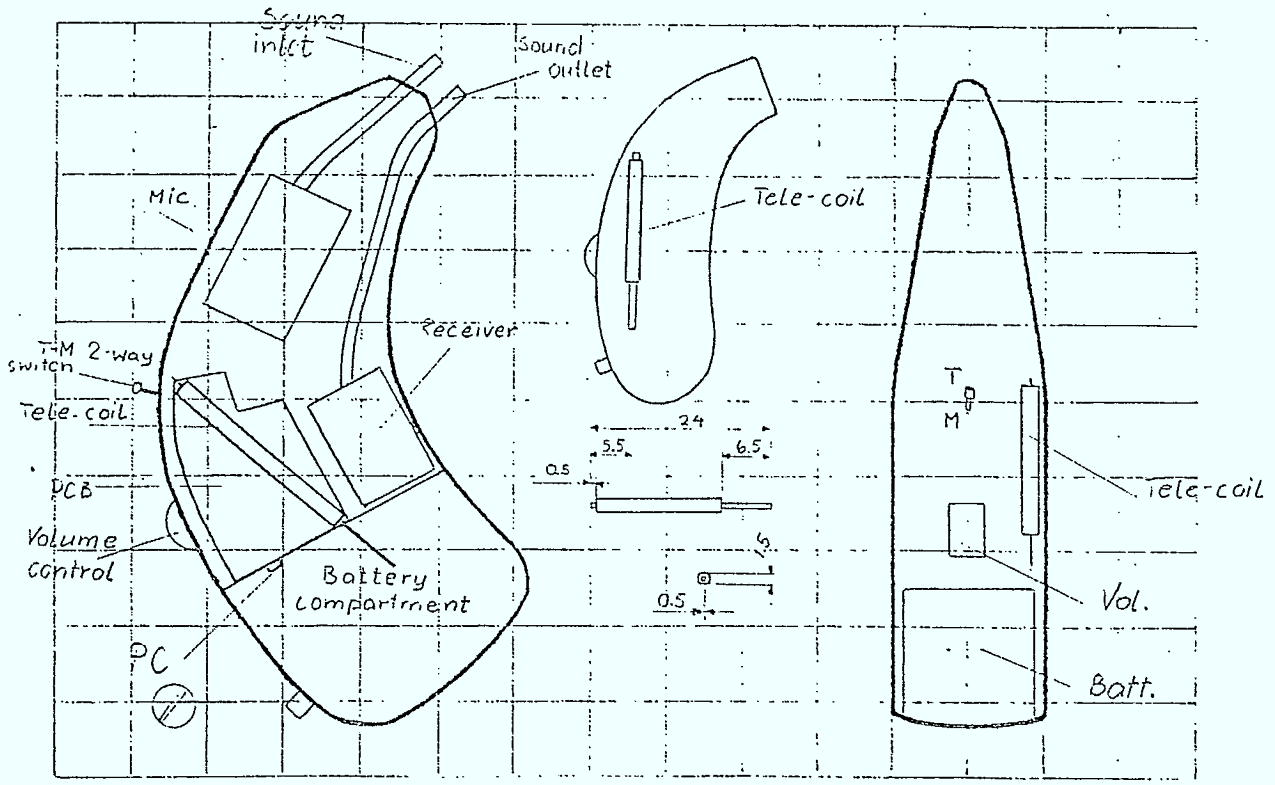



FIGURE 24: SAMPLE FROM HEARING AID PHYSICAL SURVEY

TELECOIL LOCATION IN
THE HEARING AID

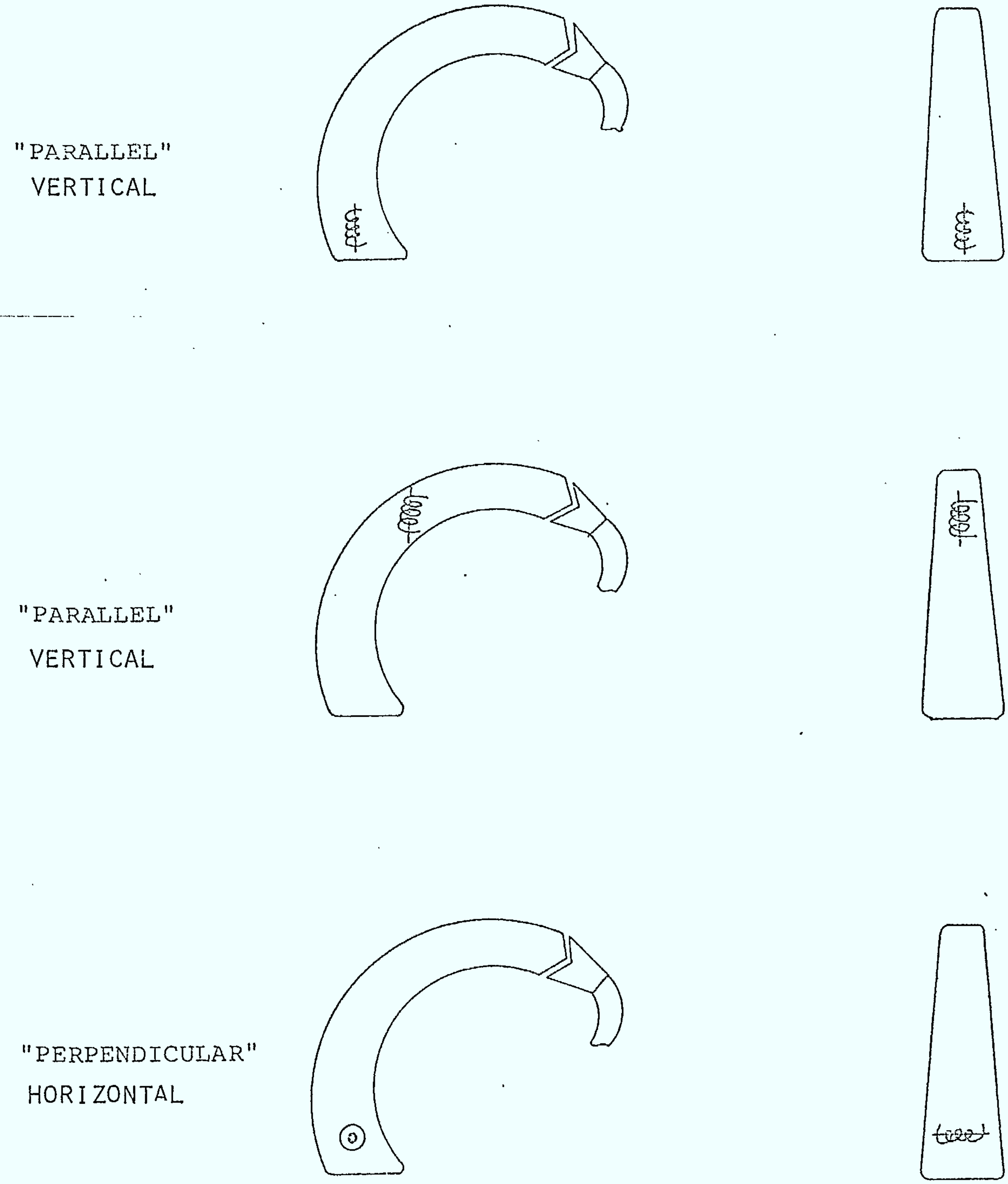
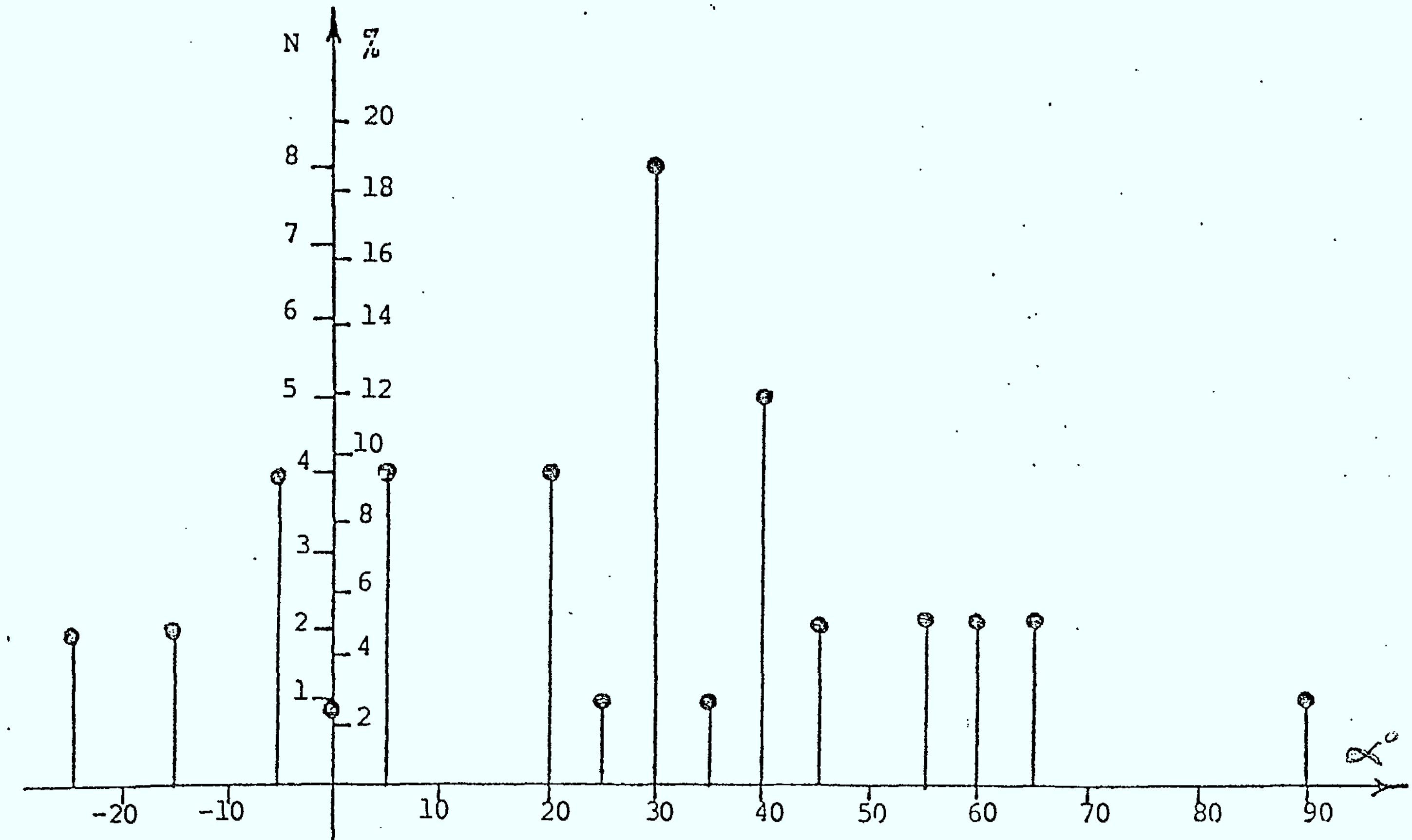
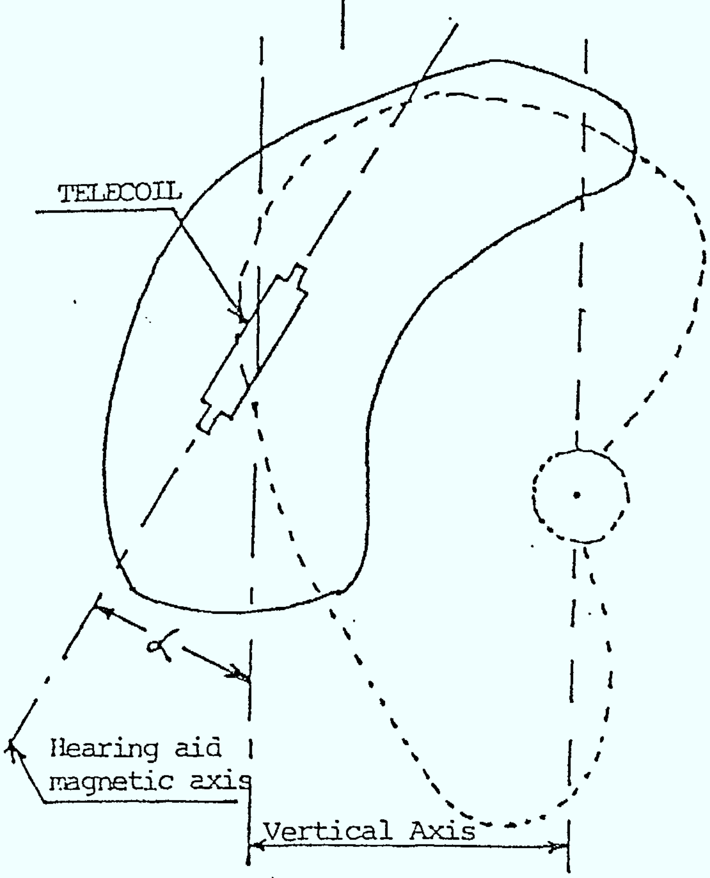



FIGURE 25





Angle of telecoil to vertical axis (α°)
BTE equipment with telecoils normally in the vertical plane.





TYPES TESTED

BEHIND THE EAR (BTE)

| | |
|---|---|
| NO TELECOIL | 9 |
| Telecoil in the horizontal plane | 4 |
| Telecoil in the vertical plane | 41 |
| SKEWED TELECOIL | 4 |

FIGURE 26: ORIENTATION OF PICK UP COILS

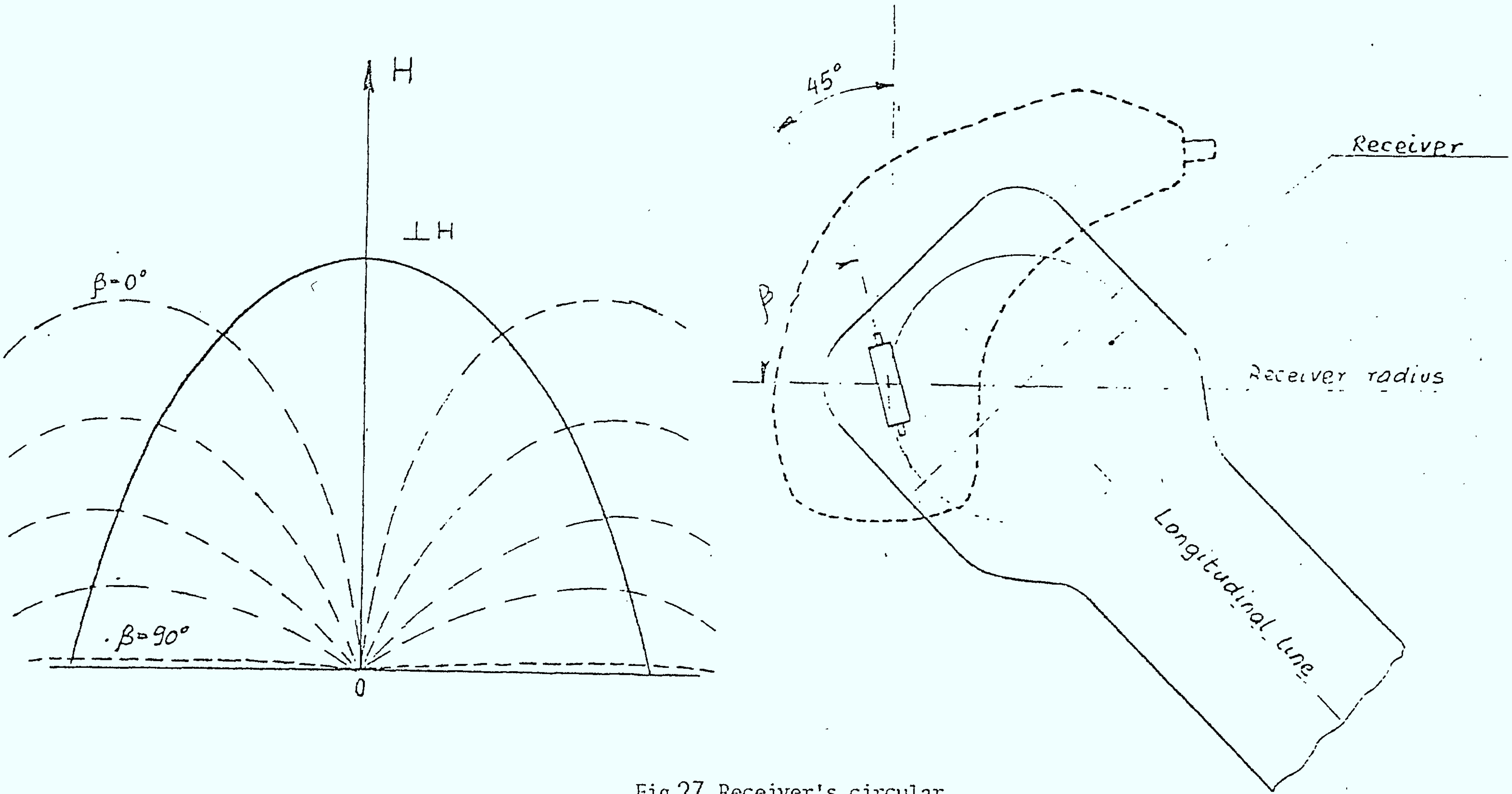



Fig.27 Receiver's circular
coil field distribution

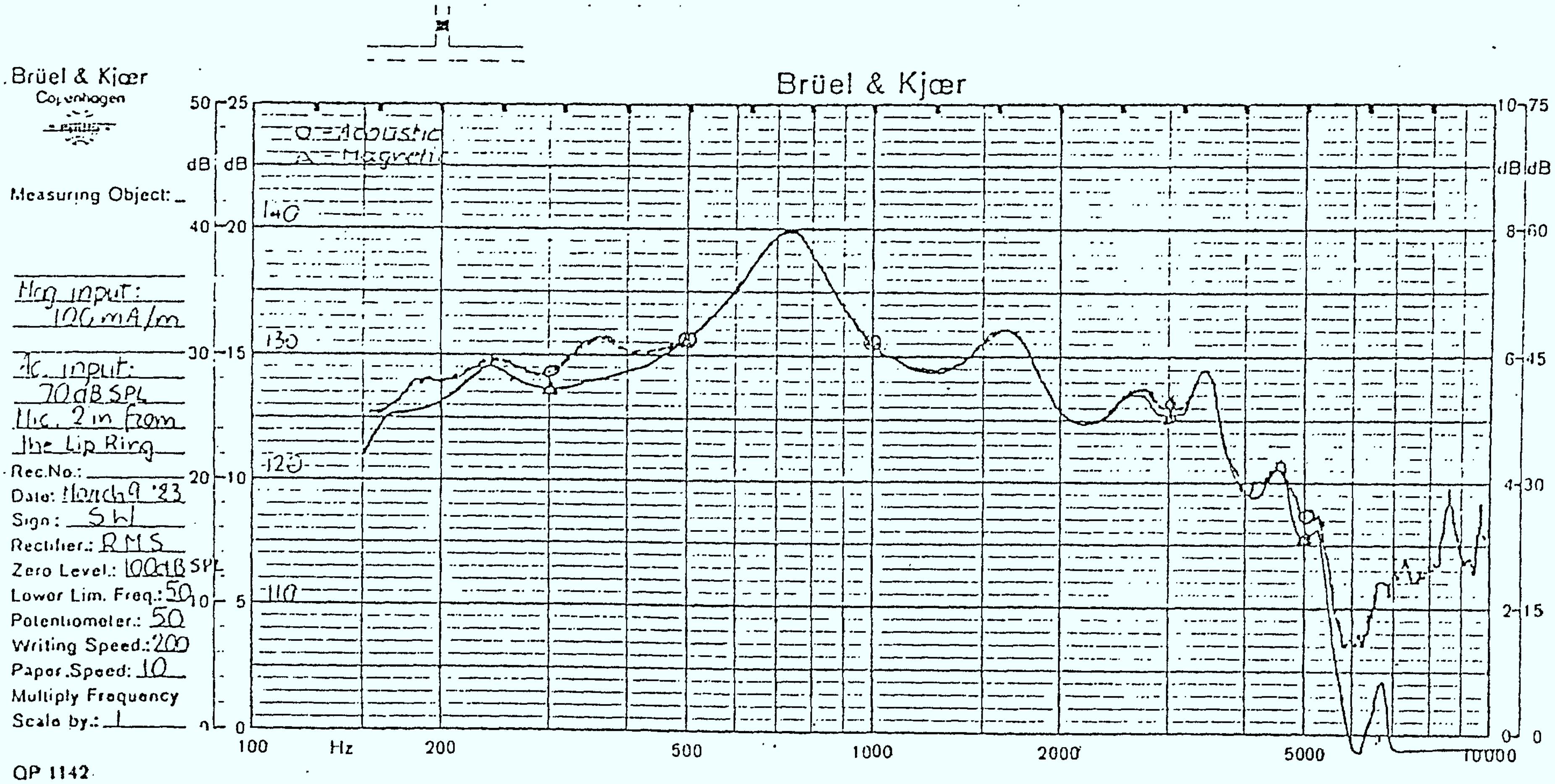



FIG 28 Hearing aid with equal performance - with magnetic and acoustic inputs.

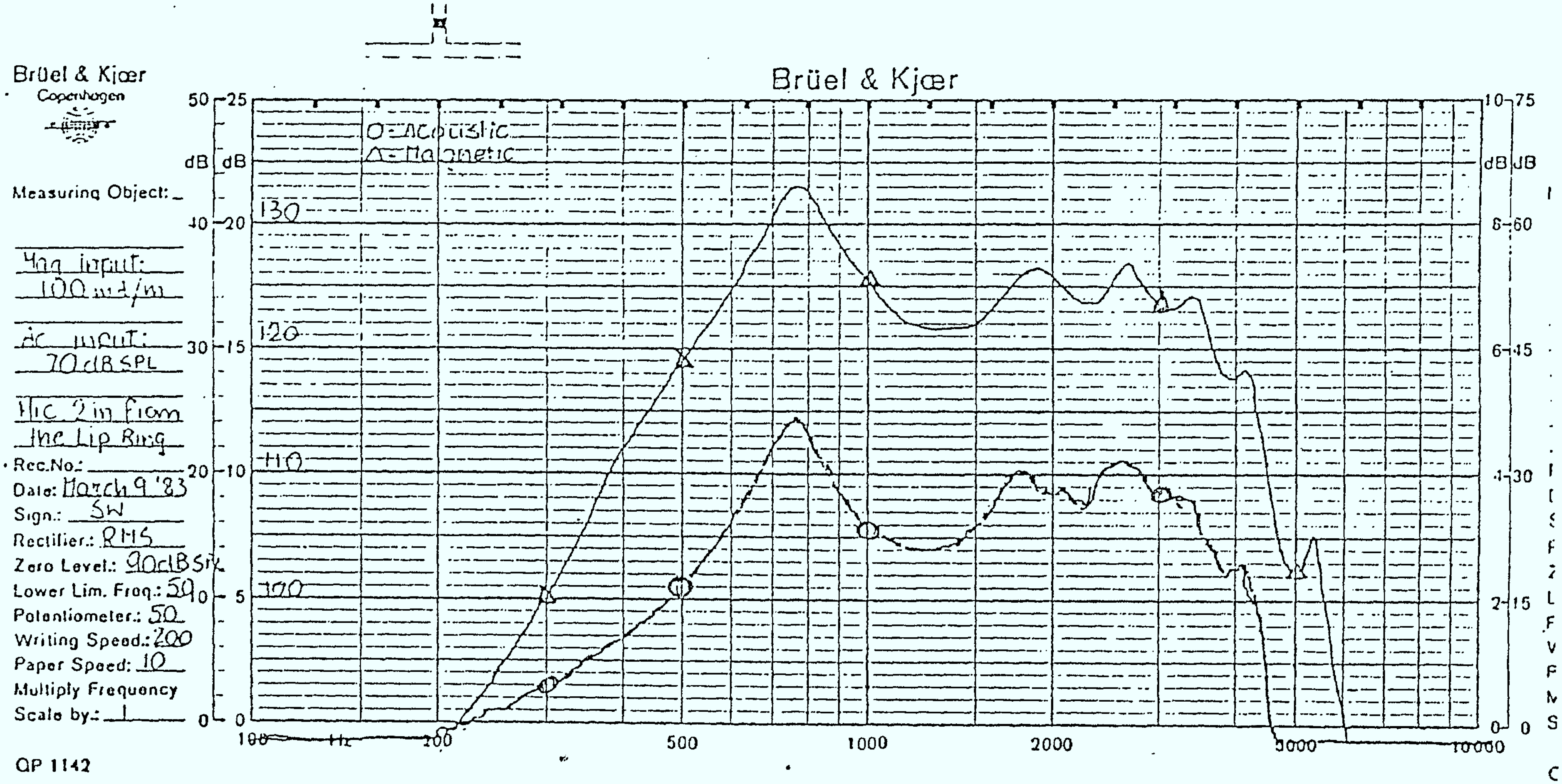



FIG 29 .Hearing aid with higher gain with magnetic input than with acoustic input.

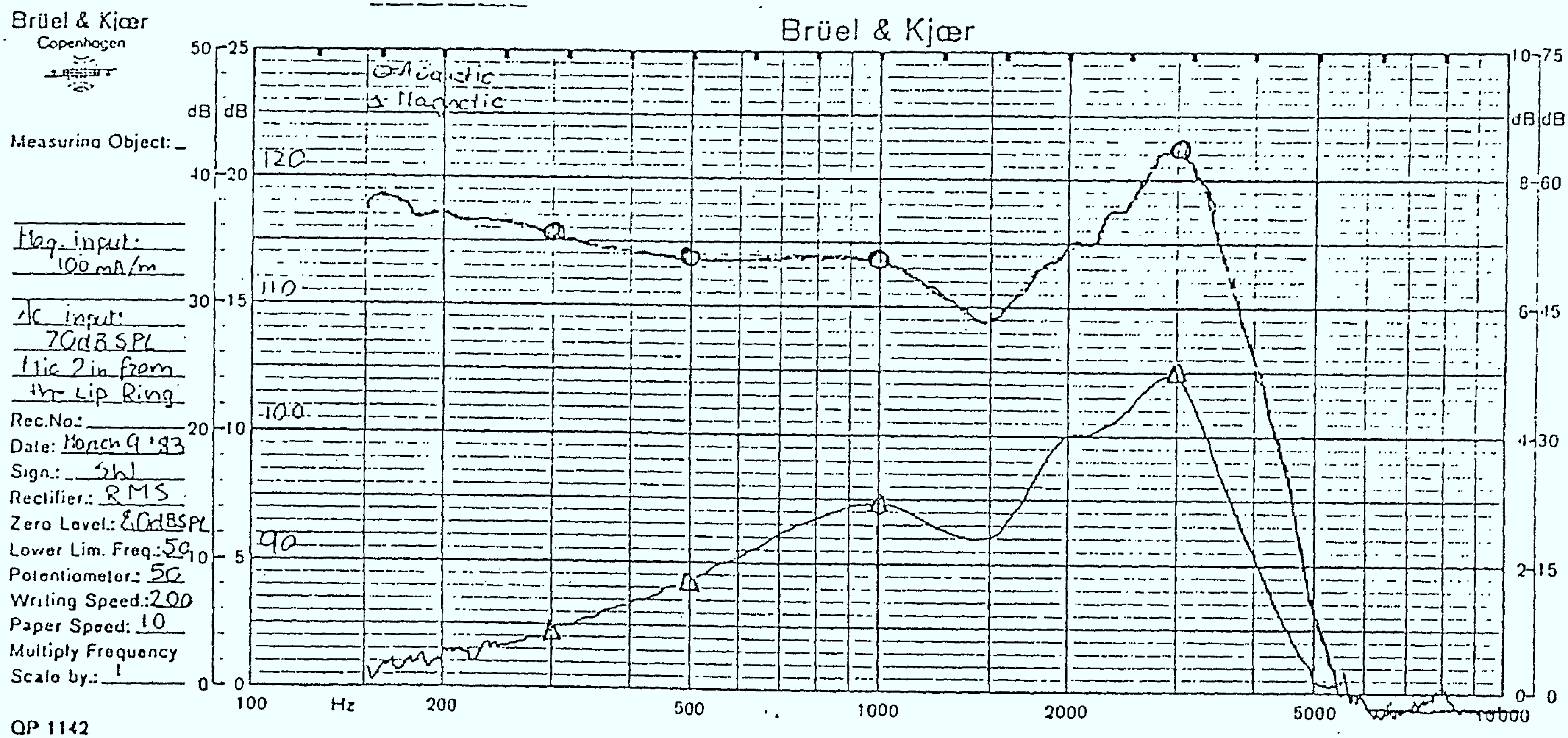



FIG 30. Hearing aid with higher gain with acoustic input than with magnetic input.

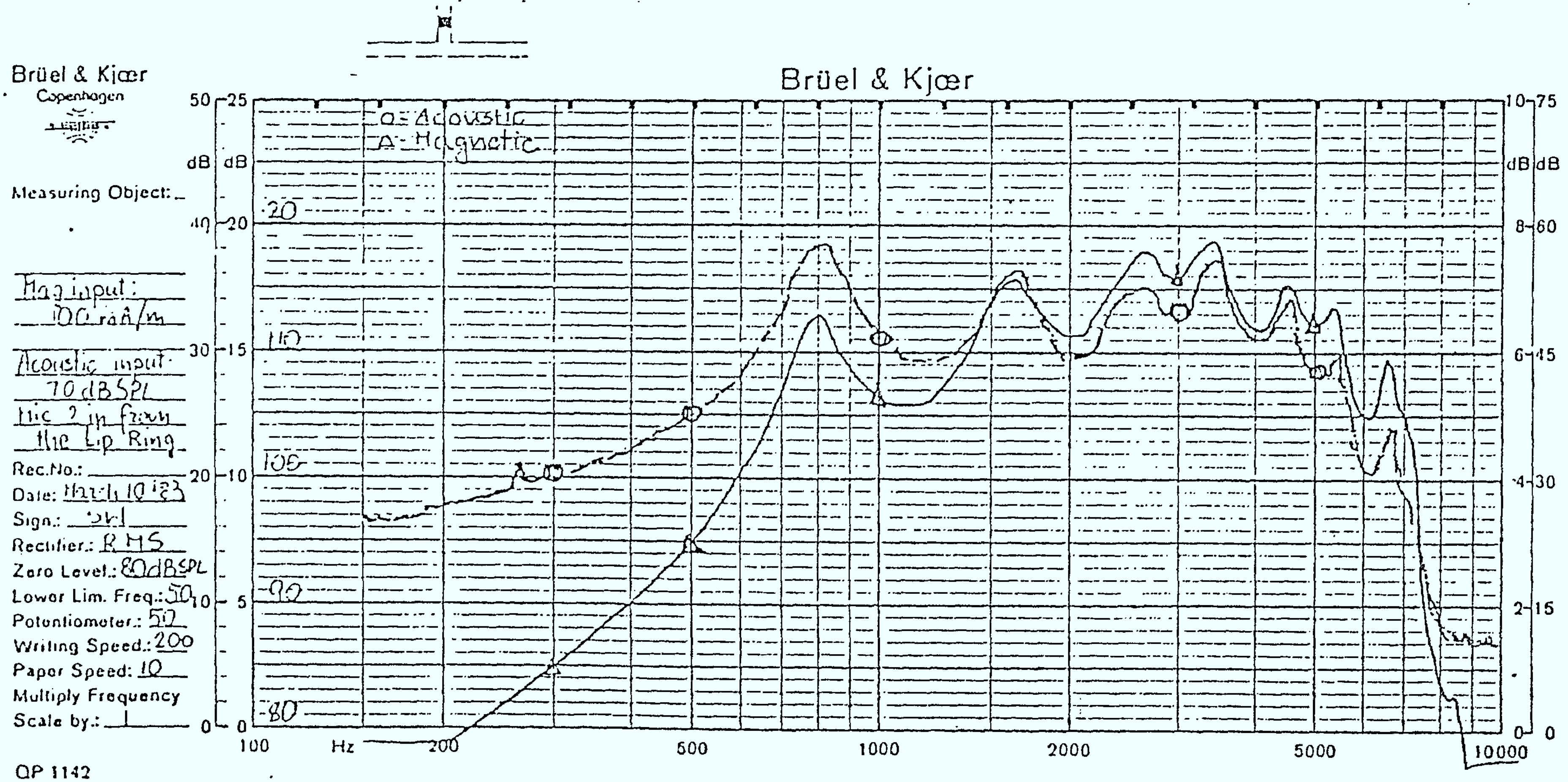



FIG 31 Hearing aid with cross over of gain.

# A P P E N D I X " A "

## HISTORICAL EVENTS

A) INTERNATIONAL (CCITT/IEC)

| | | |
|---|---|---|
| 1- | Establishment of I.E.C. technical Committee 29/working group 6 to recommend standards for hearing aids | Mid 70's |
| 2- | Agreement by CCITT/Study group XII to a proposal of IEC/TC29/WG6 that they work "in concertation" on problem of recommending standard for coupling hearing aids to telephones | Sept.'78 |
| 3- | Nordic proposal to establish standards and methods of measurement for magnetic coupling | Feb'79 |
| 4- | Nordic proposal questioned by Canada at meeting of I.E.C.T.C.29 Stockholm Canadian support to study hearing aid-telephone | May '79 |
| 5- | Canadian proposal to gather more information at I.E.C. meeting | May '79 |
| 6- | Canadian submission to CCITT, SG XII proposing study of all alternative methods of coupling | June '79 |
| 7- | Distribution of a questionnaire prepared by Canadian representatives to all IEC National Committees to determine status quo-results very confusing | Jan.'80 |
| 8- | Canadian proposal to CCITT SG XII approved for submission to Plenary Session Nov '80 | Mar '80 |
| 9- | IEC/TC 29/WG6 declines responsibility to prepare standards on telephone (hearing aid) coupling | Mar '80 |
| 10- | Proposal to study all alternative methods of coupling approved at CCITT Plenary meeting | Nov '80 |
| 11- | IEC 11-4 standard on magnetic field required from loop systems introduced | mid 1981 |
| 12- | Proposal for recommended standards for electrical input connection to hearing aids to CCITT by Netherlands | July 1981 |

A) INTERNATIONAL (cont.)

| | | |
|---|---|---|
| 13- | Establishment of new IEC working group entitled "Measuring Methods related to magnetic coupling of hearing aid to tèlephone sets" TC 29/WG17 Berlin . | March 1982 |
| 14- | Proposal for a recommended field strength and associated method of measurement agreed and forwarded for sidtribution for comments by CCITT/Study group XII | May 1983 |
| 15- | TC29/WG6 - standards for hearing aids disbanded- Paris. | August 1983 |
| 16- | TC29/WG17 Meeting. First steps taken to establish methods of measurement for protable coupling devices and agreement this group would work on wider issues of coupling once initial task completed | August 1983 |

B) U.S.A.

| | | |
|---|---|---|
| 1- | Senate Committee on ageing | 1973 |
| 2- | Meeting between E.I.A. and Hearing Aid representatives | May '78 |
| 3- | F.C.C. Docket CC-78-50 opened to receiver submissions concerning telecommunications for the hearing impaired. | May 1978 |
| 4- | Long bill HR 5022 becomes HR 375 - Hearing | 1980-81 |
| 5- | E.I.A. establishes AD HOC group "to coordinate industry action in matters of hearing aid/telephone compatibility" | October 1980 |
| 6- | First meeting of E.I.A. and HIA reps to work jointly on recommended standard for magnetic field | July 1981 |
| 7- | U.S. government bill requiring compatibility of telephones with hearing aids | Early 1983 |
| 8- | E.I.A. recommended standard for magnetic field circulate for comments to members (result of joint EIA/HIA activity) | July 1983 |

C) CANDA (Bell Canada Operating Territory)

| | | |
|---|---|---|
| 1. | Balanced Armature Receiver (BAR) development by Bell Northern Research (BNR) | 1970-75 |
| 2. | Field trial of BAR by Bell Canada | Feb-Sept 1974 |
| 3. | Evaluation of possible harm to hearing disabled by the introduction into service of BAR. | Mar 74 - May 75 |
| 4. | Meeting with Canadian Hearing Society to discuss the nature and mangnitude of potential harm of BAR. | June 1974 |
| 5. | Meeting with Quebec Consulting Council to discuss the nature and magnitude of potential harm of BAR. | Sept 1975 |
| 6. | Formation of Steering Committee in Ontario to work with Bell Canada/BNR to prevent harm to hearing disabled by the introduction of BAR. | August 1975 |
| 7. | Intervention of Steering Committee in Bell Canada Rate Case in an attempt to indluence Bell Canada to retain the magnetic field in all sets. | October 1975 |
| 8. | Conduct of first survey to determine the profile of the hearing disabled telephone user. | Jan - Mar 1976 |
| 9. | Conduct of second survey to measure the event of hearing aid ownership in Canada and to obtain owner profiles in demographic terms and in terms of telephone behavior. | May - June 1976 |
| 10. | Agreement of Steering Committee on policy to be followed by Bell Canada when introducing the BAR into service. | |
| 11. | Introduction of BAR and portable acousto-magnetic coupler into service and start of BNR program of research into the use of the telephone by the hearing disabled. | January 1977 |
| 12. | BNR lab tesitng of alternative methods of acoustical coupling of the hearing aid to telephone receivers. | Aug 76 - June 77 |

13. Filed trial of "Tube-microphone" by BNR modification to heraing aids intended to achieve efficient acoustical coupling of aids to telephones. Results inconclusive. — Sept - Dec 1977

14. Conference between Bell Canada/BNR and three independent consultants to discuss future fromat of BNR research program — February 1979

15. Development of Audiometer/Telephone Interface (ATI-MARK IV) to allow subjective evaluation using existing audiometric proceudres of telephone sets, hearing aids and alternative ways the hearing disabled make use of the telephone. — Apr 79 - May 80

16. Clinical test program to evaluate subjectively methods used by hearing disabled when using the telephone. — Jun 80 - Dec 80

17. Research into potentials of adaptive cancellation to reduce feedback and noise in acoustic coupling — April 1979

18. Letter from Steering Committee to CRTC expressing dissatisfaction with status of Bell Canada program. — December 1979

19. Agreement by Bell Canada to restore an equivalent magnetic field into all newly purchased telephone sets — February 1980

20. Establishment by Bell Canada Telecommunication Centers for the Handicapped (special need centers) in Toronto and Montreal to serve Bell Canada customers — April 1980

21. Letter from the Steering Committee to CRTC expressing concern that as a result of the ruling permitting interconnection of customer owned telephone sets the number of telephone sets without a "compatible" magnetic field would increase — July 1980

22. Establishment of standards Steering Committee on Telecommunications to be responsible for CSA technical Committee to develop and support standards for telecommunications. — March 1983

The Bell Canada program of research and development aimed at improving the opportunities of the hearing disabled to communicate via the telephone network has done considerable work which is continuing.

# A P P E N D I X " B "

Some Statistics on the use of the
Telephone by the hearing impaired
From the report on:
"a Pan-Canadian Survey of the Communication
Needs of Hearing Impaired Youths and
Adults" 1979

## 8. RESULTS: HARD OF HEARING CASES

### 8.1. Telecommunications

Of the 201 hard of hearing cases interviewed, 168 (84%) had hearing aids, and the remainder did not (33 cases; 16%). In any sample of hard of hearing individuals it would be fairly normal to find a proportion of this magnitude not wearing hearing aids. There could be a variety of causes for this including sore or mis-shapened ears, acquired deafness too marked to make the use of a hearing aid of any value, or loss of hearing so slight as to make it unnecessary. Only 11 cases (6%) said that they could hear very well without their hearing aids; 88 cases (44%) said that they could get by without them, and 75 cases (37%) said that they could not manage well without their hearing aids. Twenty-six cases (13%) said that they could not hear at all without amplification. The same kind of distribution was given in response to questions about the ability to follow a normal voice when not wearing aids. However, 64 cases (42%) said that they could hear well enough to follow a normal conversation if people spoke fairly loudly. When asked about their ability to hear radio and television, without aids, 114 cases (57%) said that the volume had to be turned very high to permit good comprehension.

All but six of the cases in the sample (3%) had telephones in their homes. This small minority were, in all cases, very markedly hearing-impaired and half of them lived alone. One hundred and six cases (53%) had one phone where they lived, and 60 (30%) had two phones. Twenty-six cases (13%) had what seemed like extraordinarily large numbers of phones in their homes, in some cases five or six. These may have been people who were extremely affluent and lived in very big houses or, if they lived in more modest dwellings, felt the need for a telephone in virtually every room because of their hearing difficulties. Although 53 cases (27%) were familiar with amplifying devices being built into hearing aid receivers, the majority of the sample were aware of very few other devices (20 cases). This is clearly shown in Table 18. These figures are almost unbelieveably low, and apply from coast to coast. They may explain to some extent why so many individuals had several phones in their homes. Possibly they did not know that one loud bell could be heard by most hard of hearing people in an average sized home.

These data reflect badly on those responsible for fitting aids to the hard of hearing and on those who sell them, on the assumption that counselling, with regard to telephone modifications, is either not given to patients or is not given adequately. The evidence throws a very heavy shadow over telephone companies who, although all of them have at least some special features for hearing-impaired people, have not succeeded in having them utilized by the vast majority of the cases in this hard of hearing sample. When it became clear to the project team that interviewers were finding large numbers of people who were in total, or partial, ignorance of what their local telephone companies could do to lessen the effects of their hearing losses, a series of telephone calls was made to head and branch offices of companies in several provinces. It proved extremely difficult to find even one person in most of the offices called, who could provide information and services, or any aspects of them such as pricing and installation procedures. One project staff member was spoken to in terms verging on hostility, about the ethics of giving out this type of information. Although some of the inquiries were eventually answered satisfactorily, they were a very small minority. If the kind of "interrogation" described was afforded to well-informed individuals making realistic inquiries about equipment that is supposed to be publicly available, it is not surprising that the customer who is hard of hearing and groping for information can receive neither answers nor devices to assist him or her in the use of the telephone. One hundred and thirty-five people, out of the total hard of hearing sample of 201 (67%), heard about the most commonly known form of telephone adaptation (an amplifier built into a hand set) in a vareity of ways. The most common, as represented by 54 people (27%) were advised of its existence by friends or relatives. Only 21 cases (10%) heard about it by calling the telephone company, but no consistent record was kept by the interviewers of the number of calls required before information was given and the equipment was installed. Twenty-three individuals (11%) heard about it from their hospital or hearing clinic. Other sources of information were said to be advertisements, associations for the hearing-impaired, and hearing aid dealers. In the case of other kinds of devices to be used with the telephone friends and relatives were, again, the most common source of information.

TABLE 18

Preference for Telephone Accessories

Hard of Hearing Cases

| Equipment | Number | Percentage |
|---|---|---|
| Impaired Hearing Hand Sets | 53 | 26 |
| Audible Signals | 20 | 10 |
| Visible Signals | 14 | 7 |
| Acoustic Coupling | 8 | 4 |
| Clip-on Amplifier | 6 | 3 |
| Bone Conduction Receiver | 1 | 1 |
| Radio Shack Amplifier | 3 | 2 |
| No Response/No Awareness | 96 | 47 |
| TOTAL | 201 | 100 |

When the interviewers described the items of equipment that could be obtained from telephone companies, the respondents were clearly interested, and often discussed obtaining devices that were available. One hundred and twenty-three cases (61%) felt that the hearing-impaired hand set, or similar equipment, would be useful to them. Seventy-four cases (37%) were interested in having a loudly ringing bell. Sixty-two people (30%) expressed a desire to have a flashing light attached to their phones and 59 individuals (29%) said that some form of acoustic coupling would be useful to them.

One hundred and twenty-seven cases (63%) in the sample said that they had difficulties in using the telephone all or some of the time. The nature of these difficulties is set out in Table 19. As a result of difficulties like the ones shown in the table, 84 cases (42%) had to ask other people to make telephone calls for them all the time, or more frequently, sometimes. On average, the group interviewed used the telephone about 20 times per week but others, usually those with lesser hearing losses and in professional positions, said that they used it up to 150 or even 300 times. One hundred and twenty-one cases (60%) said that they used the telephone as often as they wished. Thirty-six cases (18%) said that they did not use the telephone as often as they would like to or were not sure about this issue.

TABLE 19

Specified Difficulties in Using the Telephone

Hard of Hearing Cases

| Problem | Number | Percentage |
|---|---|---|
| Can't Hear it Ringing | 10 | 5 |
| Can't Tell if it is Ringing | 1 | 1 |
| Can't Understand People | 17 | 9 |
| Trouble Distinguishing Voices | 5 | 3 |
| Can't Tell Males From Females | 1 | 1 |
| Trouble With Some People | 20 | 10 |
| Some People Mumble | 12 | 6 |
| Some Talk Too Softly | 11 | 6 |
| Others, Not Specified | 13 | 7 |
| No Response | 2 | 1 |
| Not Applicable | 109 | 55 |
| TOTAL | 201 | 104 |

When asked to rank, in order of importance, the purposes for which good telephone access was required, calling family members was the most frequently mentioned (76 responses; 38%). These and other responses are listed in Table 20.

TABLE 20
Persons to be Called Most Frequently
Hard of Hearing Cases

| Purpose | Number | Percentage |
|---|---|---|
| Family | 76 | 38 |
| Friends | 34 | 17 |
| Work Contacts | 50 | 25 |
| Shopping | 7 | 4 |
| Emergencies | 23 | 11 |
| Other | 5 | 3 |
| No Response | 6 | 3 |
| TOTAL | 201 | 101 |

When asked if they had any problems in dealing with their local telephone company, 153 cases (76%) said that they did not. This is an interesting figure, and remarkably high in view of the fact that the companies appeared relatively uncaring with regard to this hard of hearing group. Perhaps this high number of negative responses can partly be explained by many of these respondents being in the same situation as another 16 subjects (8%) who said that they had never dealt with theirs. Twenty-two cases (11%) did report having some difficulties, and the highest single proportion (8 cases; 4%) related to obtaining information on special devices for the hearing-impaired. Two individuals (1%) referred to installation difficulties; two to operators apparently not understanding the special needs of the hard of hearing and two to confusions over billing.

### 8.2. Hearing Aids

Among the hard of hearing cases interviewed, 132 (66%) wore one hearing aid and 29 people (14%) wore two. Many of those who needed to have two aids were also those who had fairly marked losses of hearing. Almost every make of hearing aid available in Canada was represented among the hard of hearing sample seen. The single most commonly found brand was Siemens whose aids were worn by nine cases (5%). The next most common were Philips (8 cases; 4%), Zenith (6 cases; 3%), Unitron and Widex (all being worn by three people; 2%), followed by Oticon, Fidelity and Beltone, each being used by two people (1%). There was some evidence that certain brands were favoured in some parts of the country more than in others. This probably related to local availability and servicing. For instance, the Siemens aids are distributed in Vancouver to all parts of Canada and frequently have to be returned there for major servicing. This was almost certainly the reason why the Siemens aids listed were worn by residents of British Columbia, exclusively.

This was a sample of people who appeared to be relatively experienced hearing aid users and the length of time that they had been using hearing aids is shown in Table 21. One would, therefore, expect they should be fairly well accustomed to the difficulties of living with a hearing aid and adjusting to a prosthetic device. One hundred and thirteen of the cases (56%) said that they always wore their hearing aids and another 49 cases (24%) said that they did so most of the time or sometimes. The number of people who wore their aids when using the telephone was smaller. Fifty-seven cases (28%) said that they always used them, and 34 cases (17%) said they usually, or sometimes, utilized them. Among the reasons given by those who did not use their aids for telephone conversations were technical problems, hearing as well on the phone without the aid as with it, and adequate hearing being available in the ear not amplified.

TABLE 21

Length of Time Aid Has Been Worn

Hard of Hearing Cases

| Duration | Number | Percentage |
|---|---|---|
| <1 Year | 21 | 10 |
| 1-4 Years | 31 | 15 |
| 5-9 Years | 34 | 17 |
| >9 Years | 81 | 40 |
| No Response | 1 | 1 |
| Not Applicable | 33 | 16 |
| TOTAL | 201 | 99 |

When the sample was asked if they had a telephone (T) switch on their hearing aids, there were 115 (57%) affirmative answers and 38 negatives (19%). Thirteen people in the sample used the T-switch on their hearing aid to watch television. This is quite a high proportion (7%) when one notes that a considerable amount of wiring is needed in a room in which a television "transmitting" to a hearing aid is located. Thirty-two cases (16%) said that they used the T-switch all the time when using the telephone, and 12 cases (7%) said that they used it sometimes. This total of 22% of cases is also relatively high when it is recognized that magnetic coupling of telephones, though widely available, is not widely publicized and is rarely available, automatically, in private homesor places of work. In this sample, 30 of the 32 cases referred to, do have telephones with magnetic spill-over and 26 find that it also exists in most public telephones of which they make use.

### 8.3. Safety Devices

Sixty-seven of the 201 hard of hearing cases interviewed (33%) had heard of a doorbell or buzzer being made louder for use by the hearing-impaired. Forty-eight cases (24%) were aware of smoke detectors that could be adapted. Seventy-eight cases (39%) were aware of alarm clocks that could flash or be attached to vibrating mechanisms in a pillow or bed. Eighty-nine cases (44%) were aware of the existence of very loud telephone bells and 67 people (33%) knew about bright lights attached to telephones. In comparison with the responses given by the deaf sample to similar questions these figures are low. It must be remembered, however, that this group had, in general, much better hearing and presumably had far less need of these items of equipment. Generally, the sample expressed confidence in the value of these devices for alerting purposes. One hundred and sixty-one cases (80%) felt that it was appropriate to make adapted doorbells and buzzers available. One hundred and sixty-two cases (81%) looked with particular favour on smoke detectors; 155 (77%) did so on adapted alarm clocks, 150 (75%) on loud telephone bells and 146 (73%) on bright phone lights. When asked to rank the signals in order of usefulness, most first places were assigned to smoke detectors followed by doorbells or buzzers, phone bells, phone lights, and adapted alarm clocks.

The sensory stimuli of various signals were ranked as follows in order of their potential value as alerting mechanisms for the hearing-impaired: loud noises, flashing lights, vibration, strong smells and mild electric shocks. In making these ratings, the hard of hearing group gave loud noises by far the highest ranking. It was put into first place by 71 individuals (35%). When making these judgements this group was clearly thinking in terms of hard of hearing individuals rather than the total spectrum of the hearing-impaired, many of whom felt that they would not necessarily be able to perceive loud noises. The group was unable to suggest any other form of signalling that would help hearing-impaired people to be more aware of dangerous situations, and the fairly realistic number of 126 cases in the total sample of 201 (63%) felt that they had enough alerting and safety devices for their particular needs. When pressed to say what other safety or alarm devices they might need, 26 cases (13%) said that smoke detectors might be useful to them, and 16 cases said that they could probably make more use of further adaptations to doorbells. Opinions were divided evenly three ways when the group was asked the question "Do you Feel that Specially Adapted Safety Devices are Readily Available?". Sixty-seven cases (33%) said "Yes"; 61 people (30%) said "No" and 70 (35%) were not sure. Like the deaf sample, the great majority of the hearing-impaired people interviewed said that they obtain the safety devices they have, either commercially in Canada or from agencies for the hearing-impaired also within the country.

# A P P E N D I X "C"

## MAGNETIC PERFORMANCE OF THE U-1 AND BALANCED ARMATURE RECEIVER

## 1. Introduction

The Balance Armature Receiver is manufactured in two versions marked as QUUIB and QUUIC. The QUUIC receiver is a Balanced Armature Receiver (QUUIB) surrounded by a coil wound on a plastic bobbin. Electrically, the coil is connected in series with the receiver terminals. Such a device produces an acoustic pressure (BAR itself) in the ear cavity and a magnetically alternating field (coil's product) around the unit. The magnetic field's parameters are supposed to be the same as those of the U-1 receiver.

This Appendix describes:

-characterization of the magnetic field distribution around the unit.

-comparative evaluation of the frequency response of the QUUIC vs U-1.

-Magnetic strength and sensitivity at the point where hearing aid will.

## 2. Probe Coil (Sensor)

### 2.1. Physical Description

The probe coil is a sensing device which generates an electric voltage. This voltage is proportional to the magnitude and frequency of the alternating magnetic field at the point where the coil is located. The physical dimensions of the probe coil should be those of an average telecoil in hearing aids. (ie. length 9-14 mm, diameter 1.5-2 mm)

## 2.2. Probe Coil Calibration

The search coil shall be calibrated according to the recommendation IEC-118-1. The calibration point shall be the geometrical center of a one-turn magnetic loop (FIGURE C-1). The search coil center coincides with the loop center and the search coil main axis is perpendicular to the loop surface.

The sensitivity of the probe coil is defined as the ratio of the output coltage at the sensor terminals to the strength of the magnetic field generated by the loop.

$$S = \frac{V}{H} \quad [V.A^{-1}m]$$

or expressed in decibels

$$S = 20 \log \frac{S}{So} \quad [dB\ (H)]$$

where

$$So = 1\ V\ A^{-1}m$$

the magnetic filed strength produced by the magnetic field source (loop) is computed from the geometry of the source.

a) magnetic field strength in the center of a square loop with a side of "a" meters and carrying a current of "i" amperes is given by

$$H = \frac{2\sqrt{2}}{\pi} \times \frac{i}{a} \quad [A / m]$$

b) In the center of a circular loop with a diameter of "d" meters carrying current of "i" ampers. The magnetic field strength is given by

$$H = \frac{i}{d} \quad A/m$$

2.3. Frequency Characteristic of the Probe Coil

The IEC magnetic loop carries a current determined by a series resistance R (FIGURE C-1). This current has a constant magnitude throughout the frequency range 100Hz - 5000Hz. The magnitude of the magnetic field produced by this loop is constant as a function of frequency. The frequency response of the probe coil in this set up has a rising slope of 6dB/oct. The output of the probe coil as function of frequency is shown in FIGURE C-2.

## 3. Magnetic Field's Geometrical Distribution

### 3.1. General

The distribution of the alternating stray magnetic field around the U-1 receiver and around the QUUIC receiver was analyzed with the method and set up for geometrical distribution of the magnetic field is a device for precise positioning the probe coil This device allows the probe coil to travel in three directions (two horizontal and one vertical) and to change the angle of the probe coil from 0° (vertical position) through 90° (horizontal position) to 360°.

In both cases of the U-1 and the QUUIC an alternating magnetic field is generated by the circular coil with a square cross section. The general shape of this field (at a distance greater than the ear cup thickness) is toriodial (FIGURE C-4). The vector of the magnetic field strength (H) can be broken into two vectors: perpendicular to the transducer's surface (Hp) and radial-parallel (Hr). These two vectors give information about the field magnitude and the firection (Hp;Hr) correspond to the practical positioning of the Hearing Aids's telecoil versus the telephone receiver.

3.2. Magnetic Field - Perpendicular Component (Hp)

The perpendicular component of the magetic field generated by the receiver was measured in the plane passing though the receiver's main axis. The probe coil displacement from the receiver's main axis was in steps of 5mm and covered a distance of 70mm (-35mm, 35mm). The measurements were taken at distances of 3mm, 12mm and 18mm - the distance being measured between the receiver's pane and the end of the probe coil. The results of the measurements for the U-1 recei er are sho n in FIGURE C-5 The comparison of the U-1 vs. QUUIC shows that for all practical purposes the perpendicular component Hp generated by either receiver is the same.

3.3. Magnetic Field - Radial - Parallel Component (Hr)

The radial-parallel component of the magetic field was measured at the same test points as the perpendicular component. The probe coil was situated the same as for the measurements in paragraph 3.2. and turned 90° around its center. The acutal distance from the receiver's plane to the probe coil center was respectively: 3mm + 1/2$\ell$ = 7.5mm; 12mm + 1/2 $\ell$ = 16.5mm; 18mm + 1/2 $\ell$ = 22.5mm. (1$\ell$=length of the probe coil used in the set up)

The characteristics of Hr as a function of distance are shown in FIGURE C-6 (U-1, various distances from the receiver surface) and are practically the same for the QUUIC receiver.

The magnitude of the parallel component will decrease if the telecoil (or probe coil) is not displaced along the receiver's radius. The characteristics demonstrating this effect are shown in FIGURE C-7

3.4. Field Linearity; Test Point

The magnitude of the alternating magnetic field decreases with the distance from the receiver's surface (FIGURE C-8). For a given distance of the probe coil (or Tèlecoil in the Hearing Aid) from the receiver the magnitude of the magnetic field is almost constant (± 3dBO around the receiver's center ( d = 40mm).

In most of over-the-ear hearing aids a telecoil is mounted in such a way that its position with respect to the "normally" applied telephone receiver is either perpendicular or radial. This is why the measurements of the compinents Hp and Hr are important information. Form the anthreopometric data the distance between the center of the telecoil and the center of the concha is about 15 mm for an average ear. The center of the concha coincides with the telephone receiver axis (again, if properly applied). For the above reason it is practical to test magnetic field at a distance of 15mm from the main axis of the receiver (FIGURE C-9).

The end of the probe coil is a practical reference for measurements of the perpendicular component: easy access with a simple spacer However, in most of new descriptions of test method the counter of the probe coil is proposed as the reference because there is no agreement on the length of the probe coil. In the case of the Hr measurements, the reference is the center of the probe coil or its axis.

4. <u>Magnetic Field Frequency Characteristics</u>

The magnitude of the magnetic alternating field generated by the U-1 and QUUIC receivers was measured as a function of frequency at various distances of the probe coil in front, sides and back of the handset. It was found that there was no change of the shape of the frequency response when the coil was displaced. The magnetic field generated around the receiver as a function of the SPL generated by the receiver in the artificial ear was measured and the measurements show good linearity for all considered frequencies.

The comparison of the magnetic frequency reponse of the U-1 and QUUIC receivers is shown in FIGURE C-10. For comparison the frequency response of the magnetic loop is added to this figure. It is to be noted that the frequency response is presented as voltage on probe coil terminals vs frequency. To convert this into magnetic field vs frequency the slope of 6dB/oct has to be added.

5. Magnetic Field Strength - Magnitude at 1 kHz

The magnitude of the magnetic field generated at 1kHz by the QUUIC receiver at the test point ie 15mm from the receiver's main aixis and 16.5mm form the receiver's plane should be the same as that generated by the U-1 unit: perpendicular component $H_p$ -14 $3dB_H$

radial-parallel component $H_r$ -19 $3db_H$

The direct result of the field measurement of a voltage developed, by this field, across a probe coil's terminals. From this measurement the strength of the magnetic field is

$$H = V_{sc} - S$$

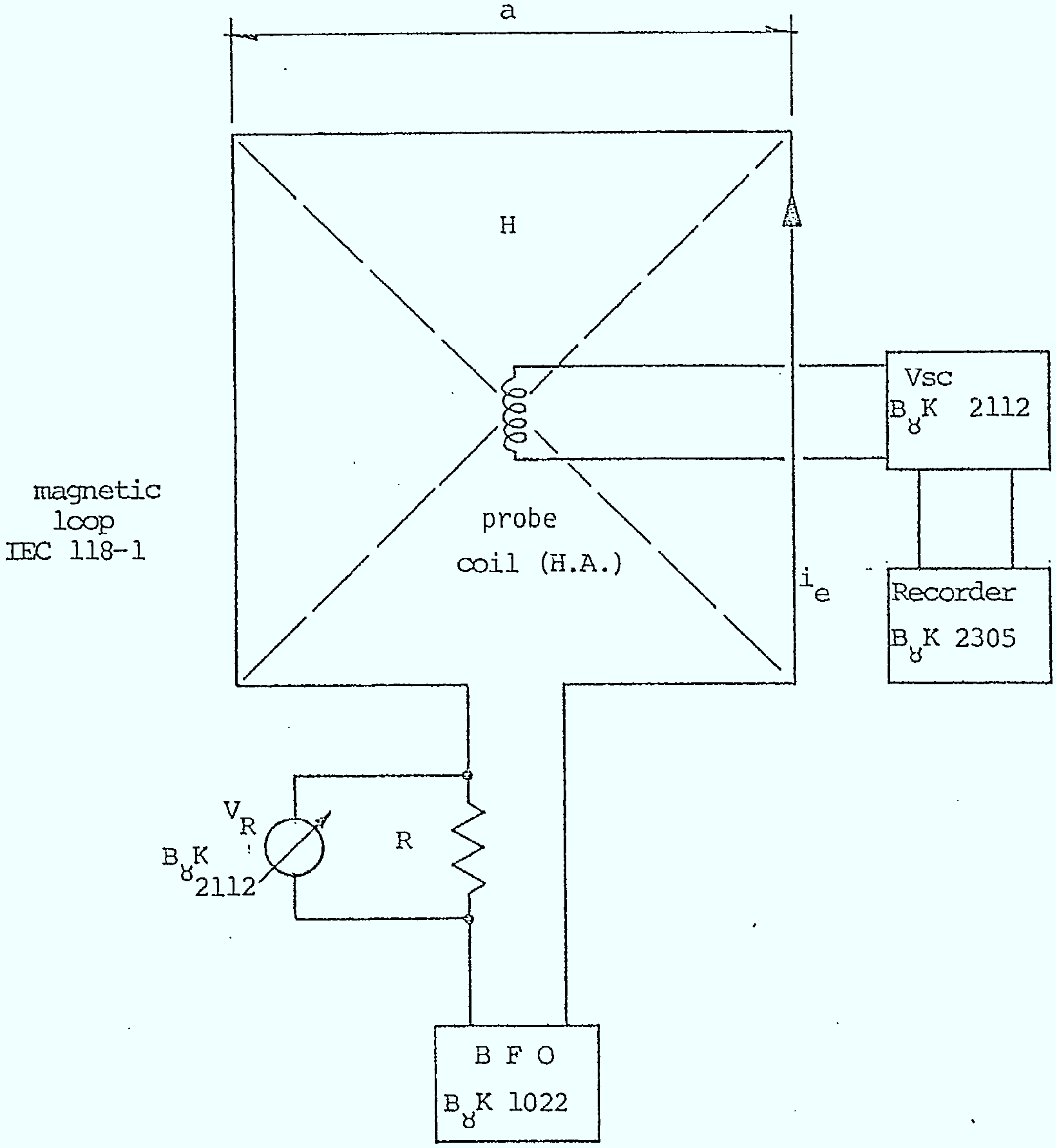
Where

S - Probe coil sensitivity in dB (H) (related to 1 $V\text{-}A^{-1}m$)

$V_{sc}$ - voltage across probe coil open terminals in $dB_v$ (related to 1V)

H - Magnetic field strength in $dB_H$ related to 1A/m

TELECOIL CALIBRATION (IEC 118-1)




Square loop $$H = \frac{2\sqrt{2}}{\pi}\,\frac{i}{a} \quad (A\ m^{-1})$$

FIGURE C-1

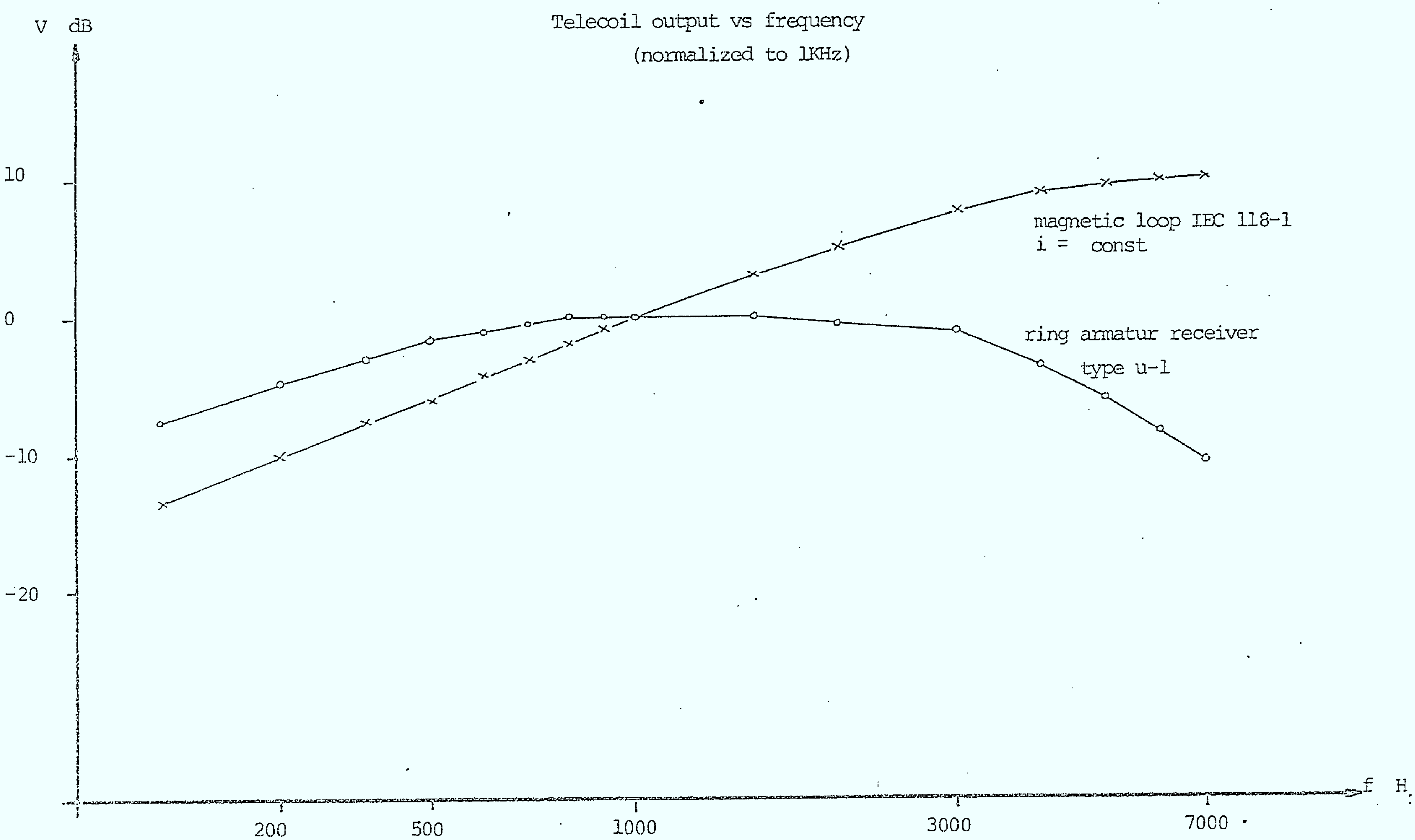

V dB
Telecoil output vs frequency
(normalized to 1KHz)
10
0
-10
-20
magnetic loop IEC 118-1
i = const
ring armatur receiver
type u-1
200
500
1000
3000
7000
f H

FIGURE C-2

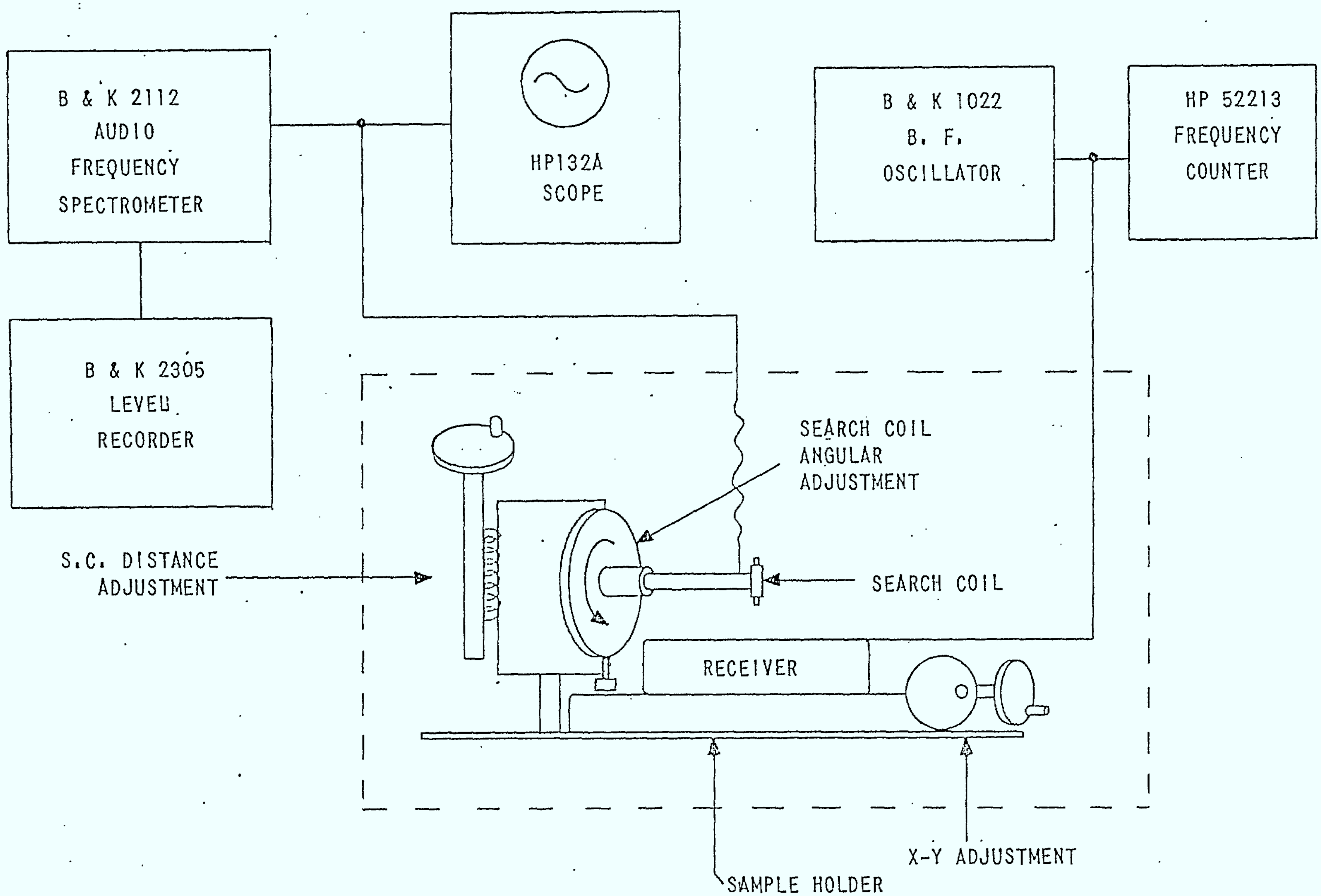



FIGURE C-3: TEST SET-UP
FOR MAGNETIC FIELD DISTRIBUTION MEASUREMENTS

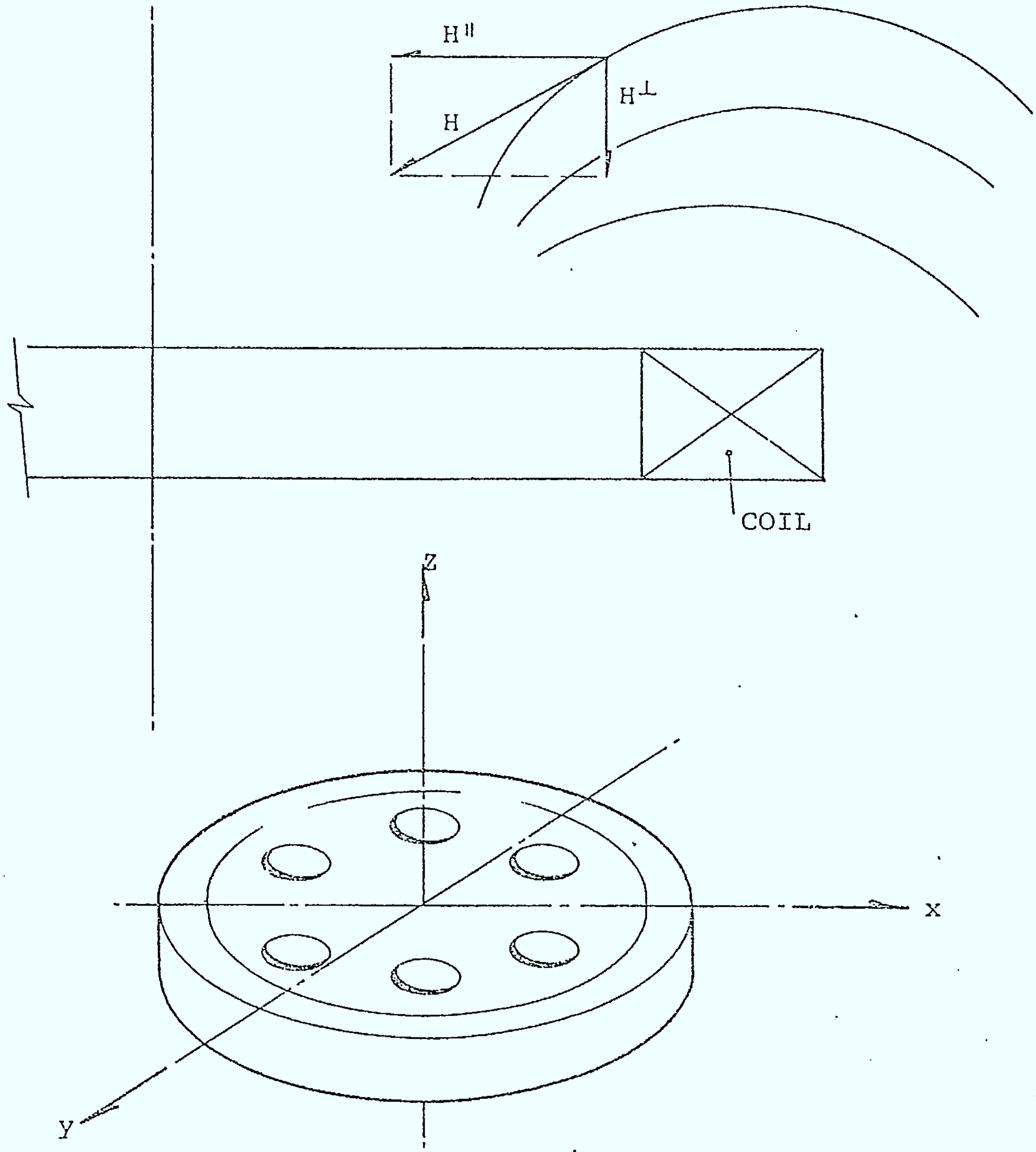



FIGURE C-4

RECEIVER

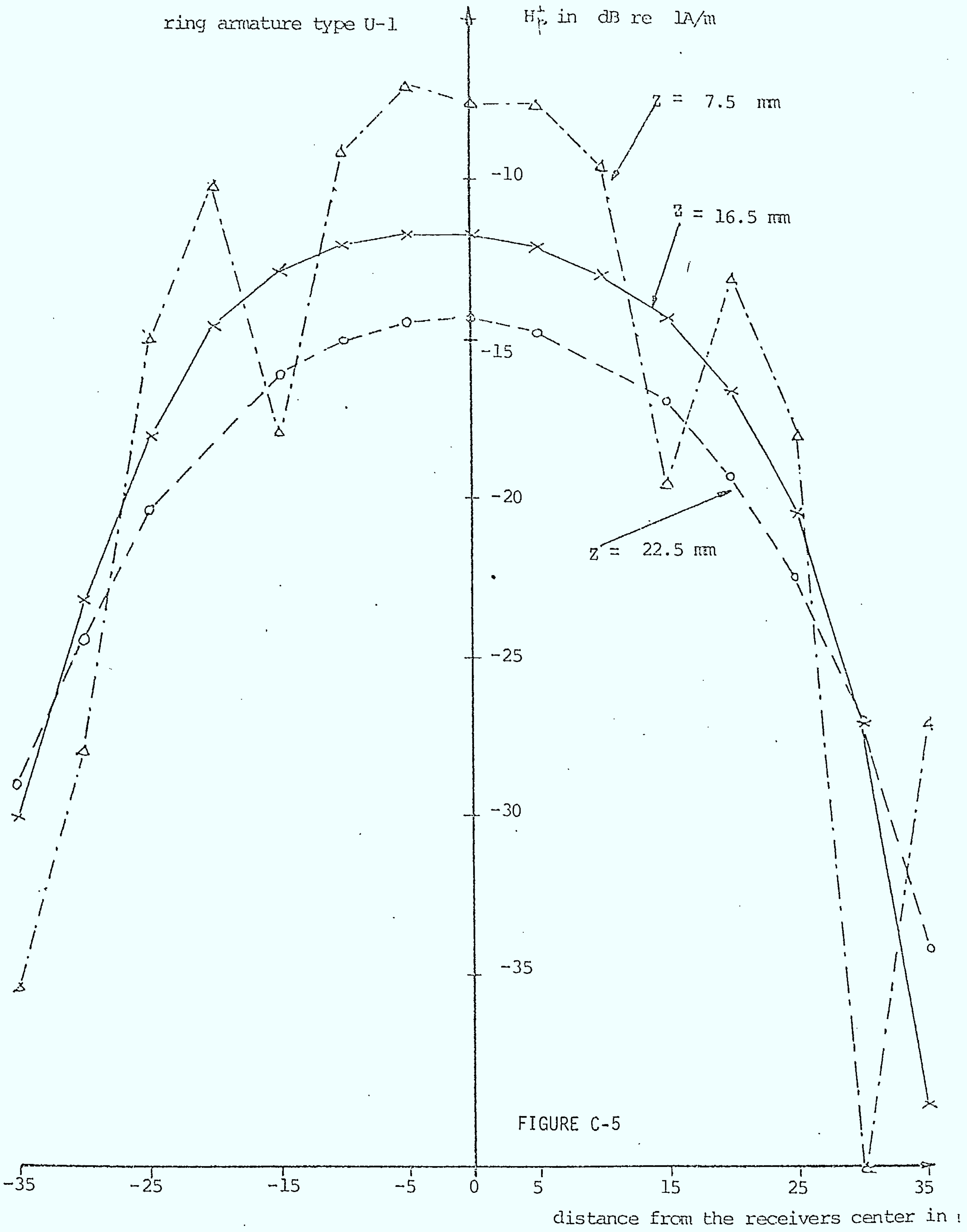
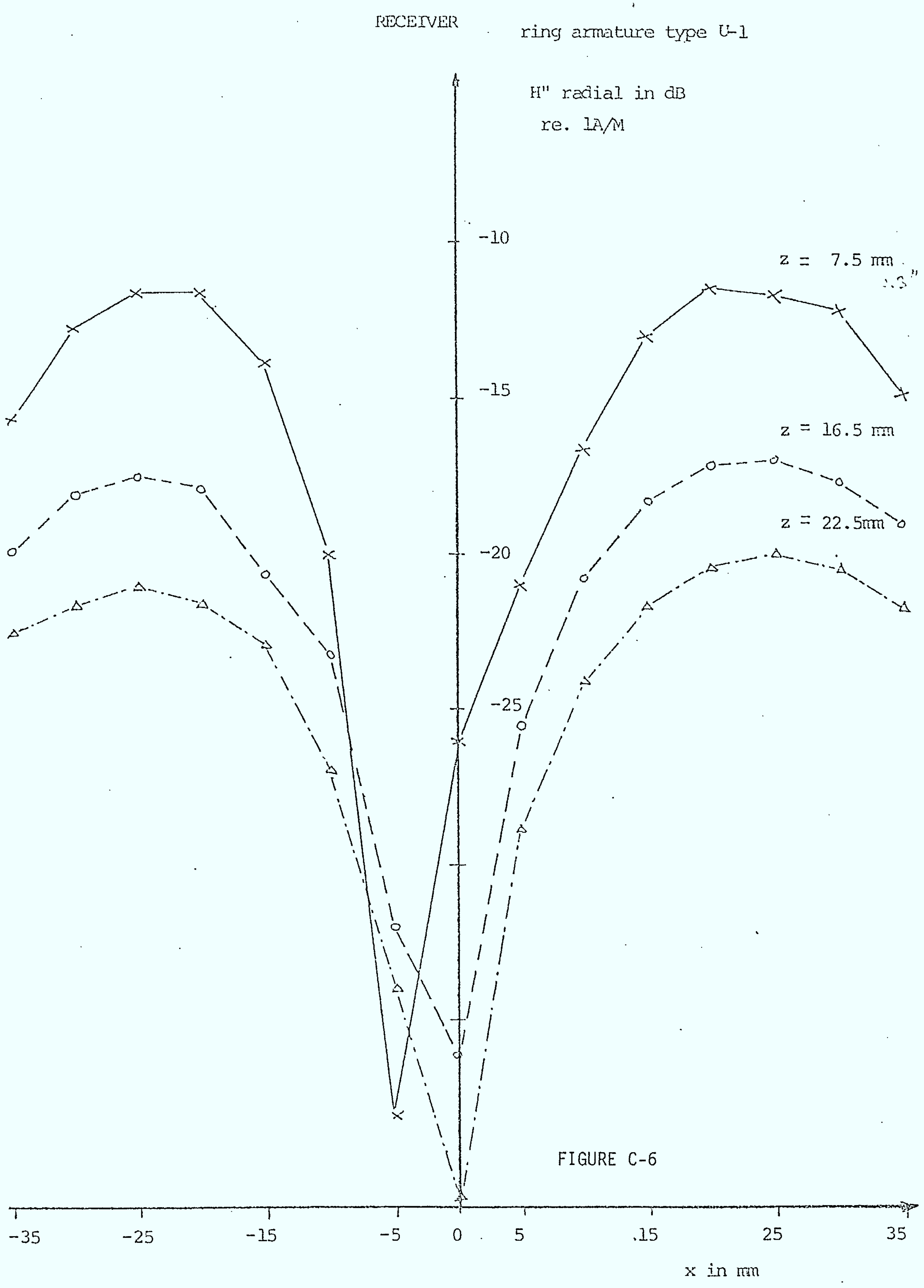
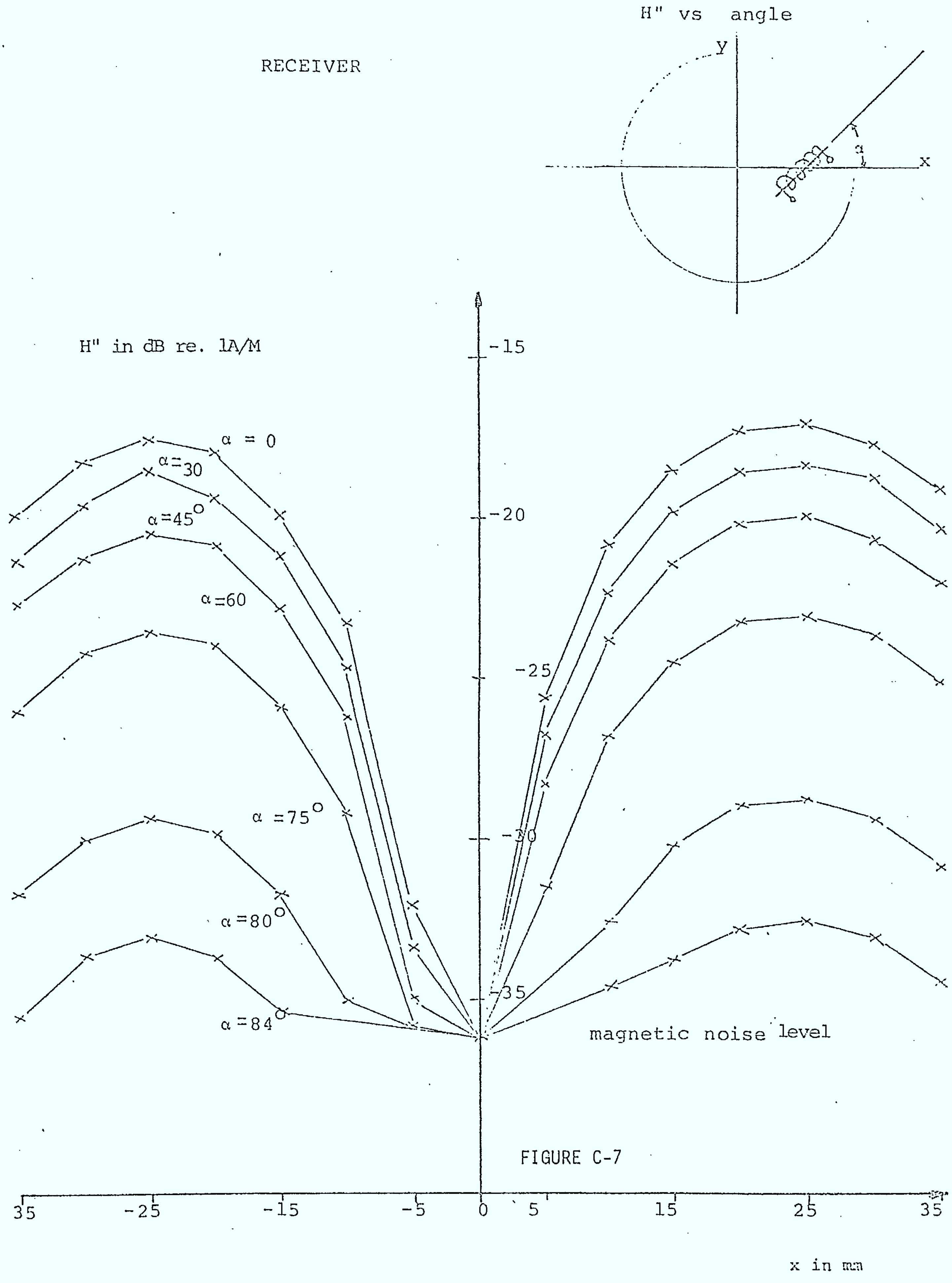



FIGURE C-5



RECEIVER
ring armature type U-1
H" radial in dB
re. 1A/M
-10
-15
-20
-25
z = 7.5 mm
z = 16.5 mm
z = 22.5mm
-35
-25
-15
-5
0
5
15
25
35
x in mm


FIGURE C-6



RECEIVER
H" vs angle
y
x
α
H" in dB re. 1A/M
-15
-20
-25
-30
-35
α = 0
α=30
α=45°
α=60
α =75°
α=80°
α=84°
magnetic noise level
35
-25
-15
-5
0
5
15
25
35
x in mm


FIGURE C-7

RECEIVER

Ring armature type u-l  Linearity of the magnetic field

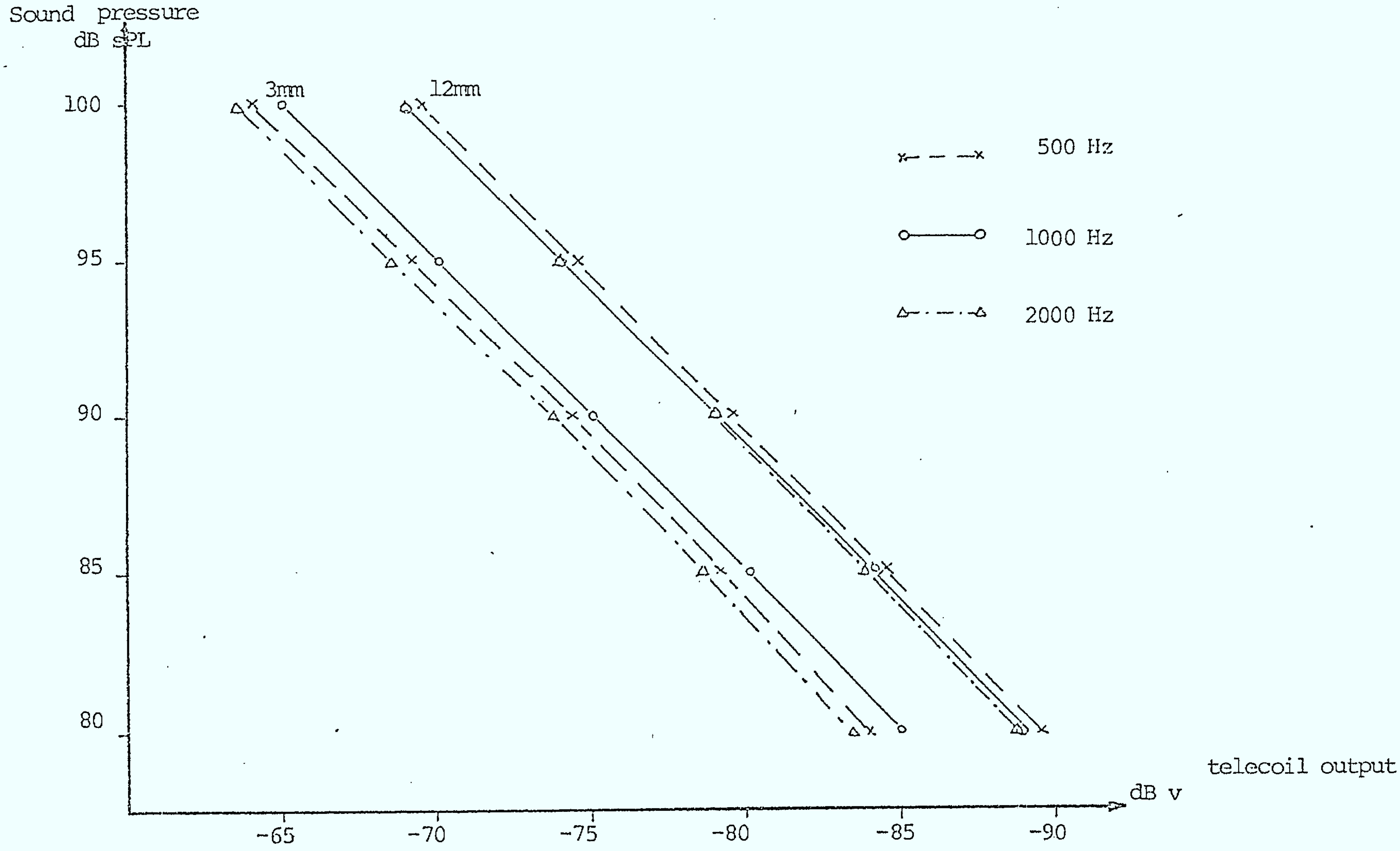



FIGURE C-8

TEST POINT

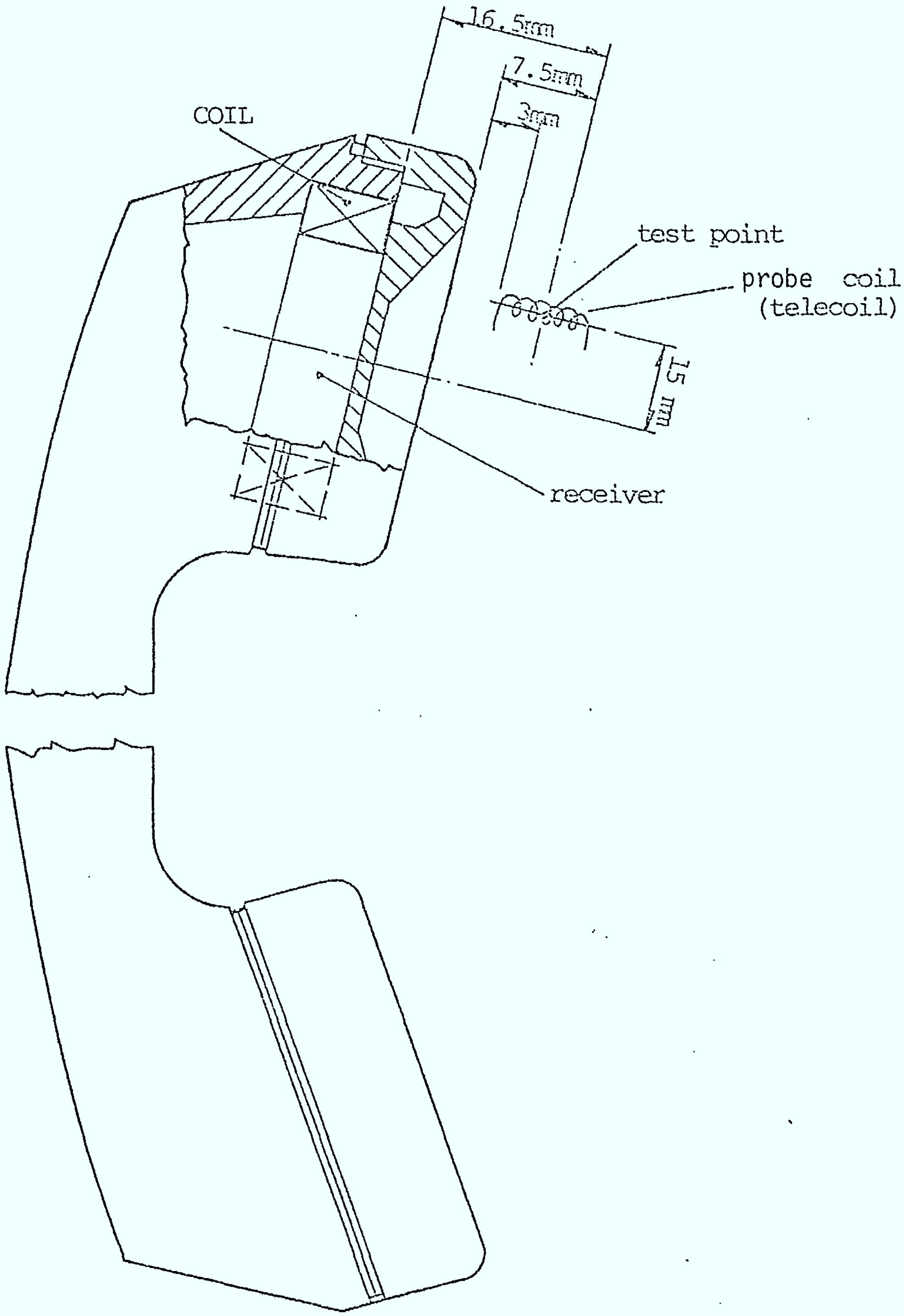
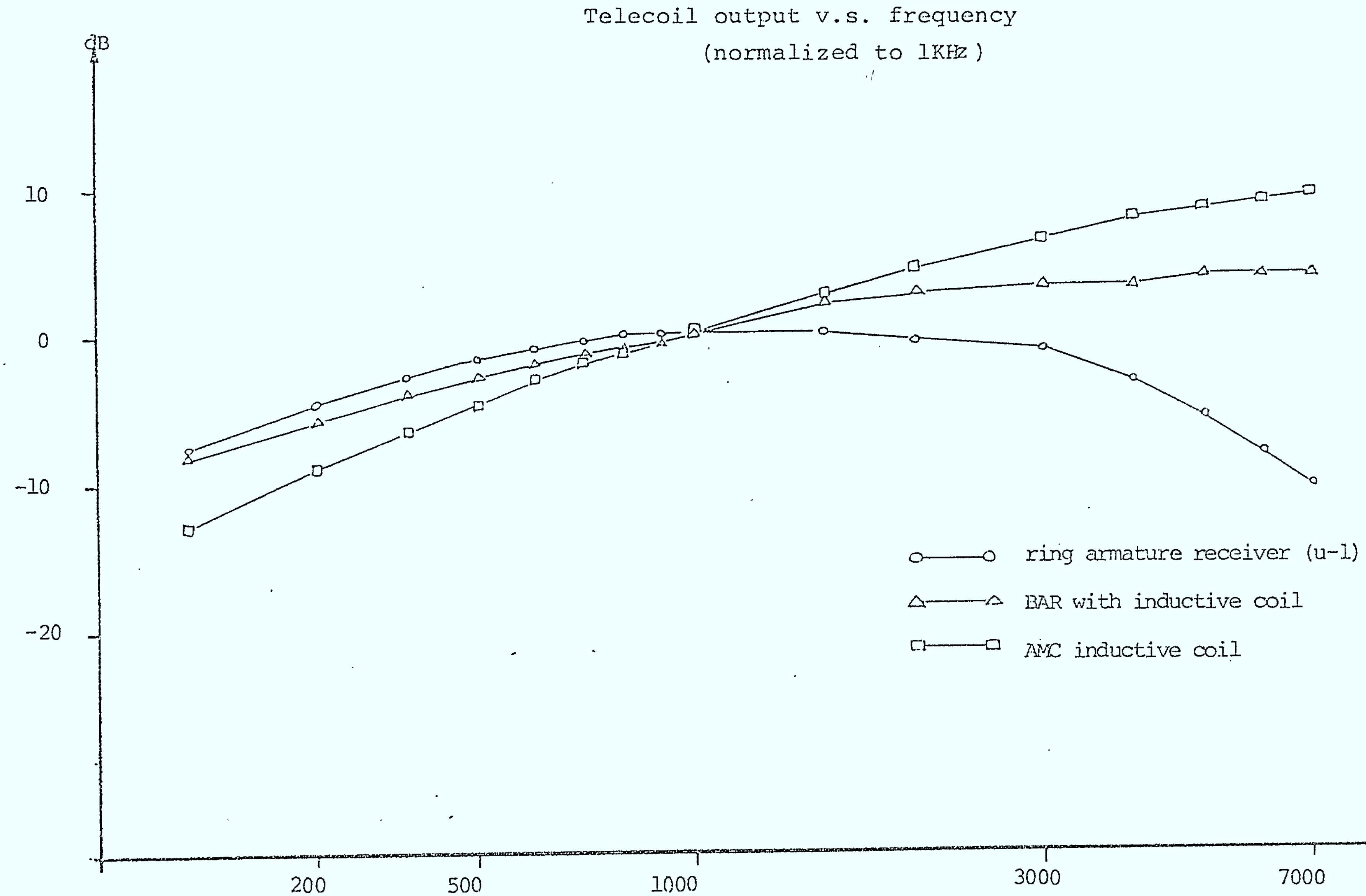



FIGURE C-9



Telecoil output v.s. frequency
(normalized to 1KHz )
dB
10
0
-10
-20
f Hz
200
500
1000
3000
7000
ring armature receiver (u-1)
BAR with inductive coil
AMC inductive coil


FIGURE C-10