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Analysis of the TEL-PHONE Telecoil Simulator Program

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Abstract

The TEL-PHONE Telecoil Simulator Program was invented as a solution to the problem of customizing programmable telecoils (T-coils) in a standardized and convenient manner. The objective of this project was to evaluate the suitability of the device for clinical use. A preliminary review of the TEL-PHONE protocol revealed that the protocol was in need of refinement. Following a preliminary examination of the TEL-PHONE device, a detailed evaluation of acoustic and electromagnetic output was conducted. The output was analyzed using information gleaned from Electronic Industries Association Recommended Standard RS-504 (EIA RS-504) Magnetic Field Intensity Criteria for Telephone Compatibility with Hearing Aids and American National Standards Institute (ANSI) S3.22-1996 Specification of Hearing Aid Characteristics. This analysis indicated that the controls on the device were not reliable and the output did not approximate that of a standard telephone.

1. Introduction

Testing, evaluating, and adjusting telecoil (T-coil) parameters requires additional time and effort beyond that of the traditional hearing aid fitting in order to determine the best settings for each patient. Low satisfaction with T-coils among amplification consumers and the lack of an appropriate and/or convenient method for assessing the T-coil fit may have been the impetus for constructing the TEL-PHONE telecoil simulator program, an invention created with the intention of standardizing assessment and customization of digitally programmable T-coils. The purpose of this study is to evaluate the ability of the device to fulfill those goals. If the TEL-PHONE is successful, the ability of persons with hearing impairment using T-coils to communicate via telephone may be substantially improved, impacting the social and professional aspects of their lives. The need for such improvement becomes more obvious when one reviews the literature regarding T-coil satisfaction and the methods available for assessment and adjustment of T-coils.

While the inclusion of T-coils in hearing aids is increasingly more common (Gilmore, 1994), satisfaction with T-coil performance is low (Compton, 1994; Hall & Zakry, 1999; Van Vliet, 2001). Insufficient power and inadequate frequency response are common complaints among T-coil users (Grimes & Mueller, 1991a). Low T-coil output necessitates manipulation of the volume control by the hearing aid user. For many this is inconvenient and/or difficult due to poor manual dexterity (Hall & Zakry, 1999). Problems with reduced T-coil sensitivity are compounded by variation in the strength of electromagnetic output of telephone receivers of different manufacturers and models (Hall & Zakry, 1999). Ideally, a T-coil would be calibrated using a device and signal similar to a standard telephone. As T-coil orientation in the hearing aid affects the position at which the telephone must be held by the hearing aid wearer to provide the strongest signal possible, simulation of this condition during calibration is imperative. The signal of interest must resemble the output of a standard telephone as closely as possible in order to program T-coils validly.

As there exists no commonly implemented standardized protocol for testing and evaluating programmable T-coils and hearing aid wearers report dissatisfaction with telephone communication, a need exists for improvement in the T-coil services provided by audiologists.

1.1 Current methods of T-coil assessment

Although not widely used, there are three methods available for the assessment of T-coil fitting: 2-cc coupler measures, real-ear probe-microphone measures, and behavioral assessment (Grimes & Mueller, 1991). For the purpose of measuring the simulated telephone sensitivity (STS), the 2-cc coupler method per American National Standards Institute (ANSI) Specification of Hearing Aid Characteristics (S3.22 – 1996) is appropriate. With gain control at reference-test position and the hearing instrument in T-coil mode, a magnetic field stimulus (with a root mean square magnetic field strength of 31.6 mA/m as required by ANSI standard S3.22, 1996) is produced by a telephone magnetic field simulator (TMFS) and applied to the aid in the hearing aid test box. The reference-test position is achieved with a 60 dB SPL input and adjustment of the volume control until the output is 17 dB below the high frequency average (HFA) SSPL 90 or the special purposes average SSPL90, whichever is applicable to hearing instrument. A frequency response curve is produced in the 200 to 5 kHz band. The T-coil response at 1000, 1600, and 2500 Hz is averaged to obtain the high frequency average of the sound pressure level for an inductive telephone simulator (HFA-SPLITS). The STS is calculated by subtracting the reference test gain plus 60 from the HFA-SPLITS value (Teder, 2003).

Real-ear probe microphone measures provide excellent verification of the sound pressure level in the patient's ear canal during T-coil use. One method of performing this measure requires a personal FM system or an assistive listening device. To execute this measure, the assistive listening device microphone must be placed at the aid (in situ) containing the T-coil. The acoustic signal emitted from the real ear receiver is transduced into electromagnetic energy through the neck-loop or silhouette receiver of the assistive listening device or the boot of the personal FM. This signal is received by the T-coil, and the acoustic output of the hearing aid is measured through a probe microphone in the canal of the aided ear. This method is not practical for most hearing aid users as only a small percentage use personal FM systems or assistive listening devices. Another method suggested by Grimes and Mueller (1991a) requires transmission of speech-spectrum shaped noise from one telephone source to a telephone receiver in contact with the patient's hearing aid while in T-coil mode during real-ear measurement. This appears to be the most appropriate method, yet most clinicians do not have the proper instrumentation for this procedure.

According to an informal survey conducted at the American Academy of Audiology in Philadelphia, 2002, the majority of audiologists use informal, behavioral assessment when evaluating T-coils (Yanz & Pehringer, 2003). In fact, not a single audiologist surveyed used formal speech recognition measures for T-coil performance evaluations. Typically, an informal evaluation requires the patient to use the office telephone to call a recording of the weather or speak with the office receptionist. The verbal stimulus is not standardized and the electromagnetic output of the telephone is not quantified. Clinicians must rely on subjective reports from patients. It is possible that this method is used because it allows the clinician to combine assessment of the T-coil response via the patient's response while training the patient to use the T-coil, thereby saving time. However, the reliability and validity of this method are questionable.

An attempt was made by an audiologist to make T-coil assessment and customization standardized and convenient. The TEL-PHONE telecoil simulator program, developed by James Pehringer, Au.D., in 2001, was designed to provide clinicians with a behavioral yet reliable means of customizing the T-coil program.

1.2 The TEL-PHONE Telecoil Simulator Program

The TEL-PHONE is a battery (two alkaline AA) operated, hand-held device made of plastic. The size (8" by 2.5" by 2.5") and shape is similar to a standard telephone handset. The handset, made in China, is a product of the

Record-A-Phone Corp called the Record a Call Model HR100. The device features a built-in analog tape deck suited for micro-cassettes and controls standard on most tape decks: stop/eject, play, record, fast forward, rewind, and pause buttons. Volume control and speed control wheels can be used to manipulate the output. There is a standard play/long play (SP/LP) switch, which changes the speed of the playback. A female jack connection terminal on the device appears in the same location as that of a standard telephone receiver handset.

According to the inventor, several modifications were made to the original device. The female jack connection terminal was altered, shielding was added as well as a transducer, and an output capacitor was added to change the high frequency response. Specific information regarding the method of these modifications or reasons for them was not offered. The inventor states that the electro-magnetic output meets the ANSI S3.22-1996 standard for testing T-coils. The testing protocol, designed by Fred Cobb, Ph.D. and James Peringer, Au.D., is detailed in a pamphlet titled Telecoil Evaluation and Training Manual. The pamphlet includes information about T-coils (see Appendix A), an illustrated guide of the some of the components and controls of the TEL-PHONE (see Appendix A), guidelines for set-up and testing (see Appendix B), a table of telecoil troubleshooting options, (see Appendix B), two lists of twenty-five single syllable words and one list of twenty-five two syllable words with spaces for scores underneath (see Appendix C), and a table for “Perceptual Evaluations” with three categories followed by likert scale ratings from one (worst) to five (best) (see Appendix C).

The telecoil testing procedure requires the clinician to instruct the patient to determine the best position of the handset relative to the hearing instrument for loudness and clarity, which is the recorded by the clinician. An abbreviated word recognition test (sample of ten to fifteen words recommended) is administered via recorded word lists (source of word lists unspecified) on mini-cassette played through the device. Specifics regarding how to score the small sample are not provided and as a result, a clinician must judge the patient's performance subjectively. The clinician is then instructed to make necessary changes to T-coil settings to maximize performance but the instructional booklet does not include specific instructions regarding how to achieve maximum performance. However, in the troubleshooting section (see Appendix B), a column titled "Symptom" describes potential problems regarding clarity, loudness, and quality adjacent to a column titled "Action" which prescribes programming adjustments for resolving each problem. The next portion of T-coil testing requires assessment of subjective perceptual evaluations of tonal quality, loudness, and clarity but again includes no guidelines for performing this assessment. It appears that the table for "Perceptual Evaluations" (see Appendix C) with three categories (tonal quality, loudness, and clarity) followed by likert scale ratings from one (worst) to five (best) is intended for this purpose, but again specific instructions are not provided.

The next section "Speech Recognition in Noise" (see Appendix C) instructs the clinician to perform the word recognition in the presence of background noise such as that from a fan, radio, or pre-recorded noise source and to record the test results, but level of noise presentation, scoring, orientation of the speech and noise, and course of action are not described. The final section is for “Telephone Feedback” (see Appendix B). The clinician is directed to find the best position for loudness and clarity using the “acoustic microphone interface”. Adjustments are to be made, again unspecified, for maximum loudness and clarity prior to feedback.

1.3 Relevant Industry Standards

As the inventor intended the TEL-PHONE to function as a means to assess and customize T-coils with an output like that of a telephone (an electro-acoustic and electromagnetic speech signal), the output of the device was analyzed and compared to that of a standard telephone. Literature searches were performed to obtain standards for acoustic and electromagnetic output of telephones. Remarkable was the lack of any obtainable standards dictating the acoustic output of telephones in the United States. Information regarding the electromagnetic output requirements was found in the Electronic Industries Association Recommended Standard RS-504 (EIA RS-504) Magnetic Field Intensity Criteria for Telephone Compatibility with Hearing Aids. The standard was developed as a result of the Telecommunications Act of 1982, which addressed the need for access to telephone communication by persons with disabilities, and was adopted by the Federal Communications Commission (FCC), the entity with regulatory authority over telephones.

The Hearing Aid Compatibility Act of 1988 (Public Law 100-394) requires manufacturers that produce telephones to use internal components which emit a standardized electromagnetic field to enable hearing aid wearers to take advantage of inductive coupling. The EIA RS-504 serves as formal documentation of the legal requirements for magnetic field intensity emission from standard telephone receivers for hearing aid compatibility. The document describes the manner in which the field must be measured and sets forth minimum field intensity strengths and frequency response characteristics. No maximum intensities are stated. Test conditions for telephone receiver electromagnetic measures are as follows: the handset, attached to its telephone set, is driven by an appropriate circuit with a -10 dBV input at 1 kHz. A probe coil with a DC resistance of 900 Ohms, 140 mH inductance, and -60.5 dBV/ (A/m) sensitivity must be used to measure the electromagnetic field. The axial field is measured perpendicular to the face of the receiver, with the center of the coil less than or equal to 10 mm away from the face plate and less than or equal to 10 mm away from the center of the hole array in the handset. The radial field intensity is measured parallel to the face of the receiver with the center of the coil less than or equal to 10 mm away from the face plate and less than or equal to 10 mm away from the center of the hole array. Minimum electromagnetic field strengths are – 22 dB re 1 A/m (or 79 mA/m) for axial measures and – 27 dB re 1 A/m (or 45 mA/m) for radial measures. Frequency response requirements are made in the axial field with the same 1 kHz stimulus and are dependent on the strength of the measured field. Frequency response requirements are less stringent for telephones emitting a stronger response. Figure 4A and Figure 4B from the EIA RS-504 document the frequency response requirements (Appendices D and E respectively) and imply some maximum intensity limits relative to the strength of the 1 kHz region.

While the FCC regulates telephones, hearing aids are regulated by the Food and Drug Administration. The American National Standards Institute (ANSI) S3.22-1996 Specification of Hearing Aid Characteristics does not address T-coil compatibility with telephones but serves as a measure of T-coil function for quality assurance. Devices suitable for hearing aid testing administration (a hearing aid test box) in T-coil mode perform a frequency sweep from 200 to 5000 Hz with a field strength of 31.6 mA/m (-30 dB re 1 mA/m) at each frequency in the axial plane via the TMFS. This magnetic field strength approximates that produced by telephones deemed hearing aid compatible (HAC) as dictated by the HAC Act (Public Law 100-394) (Kozma-Spytek, 2003). This magnetic field strength ideally produces the same output from a hearing aid as an acoustic stimulus received by the microphone of 60 dB SPL (Kozma-Spytek, 2003). The results of the t-coil sensitivity test reveal the STS, or the acoustic output from the simulated telephone relative to the output of the hearing aid with a 60 dB SPL acoustic input. The STS dictates whether or not the hearing aid wearer will need to adjust the volume control while alternating between the microphone and t-coil modes. If there is no difference and STS = 0, the volume control will not need to be adjusted. A negative value implies a relatively weaker T-coil response that would necessitate volume control adjustment; a positive number implies a relatively stronger T-coil response. While no standards dictate minimum or maximum STS in the U.S., Australia, Great Britain, and Sweden require the acoustic output from the simulated telephone and the microphone response to a 60 dB input to be within 5 dB (Teder, A.B, 2003).

In this study, the acoustic and electromagnetic analyses of the TEL-PHONE were performed using information from the EIA RS-504 and ANSI S3.22-1996. As the device is not a telephone or a device intended to test the quality of T-coils, neither standard could be applied directly to the analysis. However, both reference 1 kHz stimuli. Therefore, the stimulus chosen to evaluate the TEL-PHONE was 1 kHz.

2.0 Preliminary Analysis of the TEL-PHONE

An informal inspection of the device was made initially, performed by simply playing a taped wordlist provided by the inventor through the TEL-PHONE. The words were distorted: the playback speed was slow. The SP/LP switch was manipulated and the tape was played in both positions: in the original position (LP) the words were distorted by inadequate speed, in the SP position the words were distorted by excessive speed. It was noted that the speed wheel moved freely and smoothly: no detents were evident that may prevent the wheel from moving without intention by the user. The variability in output created by these speed controls may render the customization of T-coils invalid if the stimulus is unlike that of standard speech. Adjustment of the speed controls to playback word lists at the proper rate was necessary. Also noted was the lack of detents on the volume control wheel. A subjective judgment was made that the output of the device was more intense than that of typical telephones. The volume control wheel needed adjusting to simulate the intensity output of a standard telephone.

For the purposes advanced by the inventor of this device, the electro-acoustic output of the TEL-PHONE should simulate that of the standard telephone. To standardize output of the device for an experimental protocol, the SP/LP switch and speed wheel were set to approximate the true period of a pure tone and the volume control wheel was set to approximate the electroacoustic output of a standard telephone. First, speed and volume controls were adjusted. Second, frequency response measures were performed to observe the response characteristics of the device. Table 1 lists the instruments used for these procedures.

Table 1. Instrumentation

Instrument	Manufacturer	Model	Last Calibration
Sound Level Meter	Larson-Davis	System 824	09/21/01
Oscilloscope	Tektronix	TDS 210	
Cassette Recorder	Sony	BM-530	
Sound Level Meter	Bruel & Kjaer	Type 2235	12/04/01
Hearing Aid Test Box	Frye Electronics, Inc.	Fonix 6500-CX	
Cassette Recorder	Sony	V-O-R Microcassette-corder M-530V	
Octave Filter Set	Bruel & Kjaer	Type 1624	12/04/01

2.1 Adjustment of speed controls

To standardize the speed of stimuli played through the device, a 1 kHz tone was generated via computer using SoundForge®, v.4.5, signal processing software. The tone was played through Harmon/Kardon speakers, measured at 94 dB SPL with the Larson-Davis System 824 sound level meter on the dB flat setting. The Larson-Davis sound level meter was connected directly to the oscilloscope. The period of the pure tone as displayed by the oscilloscope was noted. The same tone was recorded on a micro-cassette using the TEL-PHONE device. The tone was then played through the TEL-PHONE device and received by the Larson-Davis sound level meter (dB flat) coupled to the oscilloscope. The standard play/long play (SP/LP) switch was set to SP and the speed control wheel was adjusted while the tone played through the devices in order to find the setting that matched the period of the 1 kHz tone (0.001 seconds). The speed control wheel was then secured with tape in that position.

2.2 Adjustment of volume control

For the purpose of simulating the electro-acoustic output of the standard telephone, the output of four standard office telephones was measured as no official documentation of standard telephone acoustic output was available. As engineering standards and ANSI standards utilize a 1 kHz stimulus to evaluate telephone electromagnetic fields and T-coil function, a 1 kHz tone was chosen as well as a saw-tooth wave with a 200 Hz fundamental frequency, (a broadband, or BB, similar to speech and available on our software programs). The selected stimuli were generated via computer SoundForge® and played through Harmon/Kardon speakers with an output of 75 dBA as measured by the Bruel & Kjaer sound level meter. For measuring the stimuli, the following settings were used: A-weighting, random sound incidence, 40-110 dB range, slow time weighting, and maximum display. The microphone was placed within 2 mm of the speaker. The level of 75 dBA was selected as it is similar to the upper levels of conversational speech. Informal measurements of speech close to the lips of speakers revealed similar dBA levels, simulating the levels received by the telephone microphone during telephone communication. The following scenario was repeated four times: the Au.D. candidate placed a call from the telephone to be measured to the telephone adjacent to the computer producing the stimulus. A USF professor held the receiver of the transmitting telephone within 2 mm of the speakers emitting the tone while the USF student measured the output of the receiving telephone with the B&K SLM with the above mentioned settings and also with the dB flat setting (all others remained the same). The microphone of the B&K was held within 2 mm of the telephone receiver. All volume controls on telephones were set at nominal volume position. The output level was noted. Table 2 lists the make and model of the telephones and the output level of each as measured in the manner described.

Table 2. Telephone Descriptions and Output Levels for 1 kHz and BB signals

Telephone Make and Model	1 kHz (dB SPL)		Broad-band (dB SPL)	
	A-weighting	Linear	A-weighting	Linear
AT&T 8102M	67.2	71.5	63.8	70.7
AT&T 8102	68.9	71.5	65.6	70.9
AT&T 8110	66.2	72.3	61.1	70.4
AT&T 8102	66.8	70.4	63.1	70.6
Average	**67.28**	**71.43**	**63.4**	**70.7**

The average output of the telephones for all stimuli was calculated (see Table 2). These levels, in addition to EIA RS-504 and ANSI S3.22-1996 standards, served as guideline levels for setting the volume control on the TEL-PHONE device.

To ascertain the appropriate volume control setting, two 1000 Hz tones were generated using the SoundForge® program. The level of the digital signals generated was described as -50 and -40 dB (RMS). On this occasion, the tones were recorded on micro-cassette using a Sony BM-530 micro-dictator via direct line input with the computer in order to obtain a clean recording. It was noted that when these tones were played back using the Sony BM-530, the volume control wheel could be adjusted such that the tones were inaudible to the AuD candidate. The micro-cassette was then placed in the TEL-PHONE and played back: it was noted that volume control wheel adjustments could not reduce the level of the sound to the point where the tones were inaudible. A subjective judgment was made: adjustments of the volume control wheel of the TEL-PHONE did not produce as broad of a range of sound level as that of the Sony BM-530. The micro-cassette was played through the TEL-PHONE device while the level of the output was measured using the B& K SLM (with previously mentioned settings, dBA). The microphone of the SLM was placed with 2 mm of the receiver of the device. The volume control wheel was adjusted while measurement was taking place. The lowest sound pressure level achievable was 81.3 dBA with the volume control wheel set at minimum output.

To further explore the capability of the volume control wheel a broadband noise was recorded on micro-cassette using the Sony BM-530. The noise was generated on computer using the SoundForge® program. The micro-cassette was inserted in both the Sony BM-530 initially and then the TEL-PHONE device. Two measurements were taken while the tape was played through each device with the volume control wheels set to maximum output and minimum output. SLM settings were as previously mentioned, dB flat. Table 3 illustrates the outcome.

Table 3. Minimum and Maximum Output of the Sony BM-530 and the TEL-PHONE

Device	Minimum Output (dB SPL)	Maximum Output (dB SPL)
Sony VOR	59.2	118.5
TEL-PHONE	91.8	109.5

Note. Values obtained using broad band noise stimuli recorded on micro-cassette.

A subsequent attempt was made to record a 1 kHz tone that would be of sufficiently low intensity for playback through the TEL-PHONE. Three 1 kHz tones were produced using a Roland 24-bit Digital Studio Workstation VS 890 and the CoolEdit 2000 Program. The master output on the workstation was set at -36 dB. The dB levels of the digital signals generated by the CoolEdit program were described as follows: -40 (-43 RMS), -50 (-53 RMS), -55 (-58 RMS). These tones were recorded on micro-cassette using the Sony BM-530 micro-dictator via direct line input with the computer in order to obtain a clean recording. The micro-cassette was placed in the TEL-PHONE and played back. The tones were measured with the B & K SLM using the same settings previously mentioned (dBA). The microphone of the SLM was placed approximately 2 mm of the receiver of the TEL-PHONE during measurement. The ambient room noise in the sound-treated booth was measured at 19 dBA. The dBA value of the tones was measured as 75, 65, and 60, respectively with the volume control wheel of the TEL-PHONE set a minimum output.

3.0 Frequency response measures

EIA RS-504 guidelines describe the required response of the voltage induced in the probe coil within the 300 to 3300 Hz region during axial measurements (utilizing the -10 dBV 1 kHz input) of the magnetic field. Interestingly, precise decibel values are not stated: two graphs included in the standard describe output requirements in terms of probe coil voltage relative to the strength of the 1 kHz response. Figure 4A “Induced Voltage Frequency Response for Receivers With an Axial Field That Exceeds -19 dB” describes less stringent requirements than that of Figure 4B, which is utilized for fields that equal or exceed -22 dB yet are less than -19 dB.

As proper instrumentation was unavailable to perform frequency response measures via electromagnetic field, the output was analyzed acoustically. The output of the device was measured using the Frye Fonix 6500-CX as a spectrum analyzer, however, the device was too large to enable closure of the hearing aid test (HAT) box. Therefore, the ambient noise levels in partially open HAT box were established to ensure that measurements made with an open HAT box were appropriate. ANSI Specifications for Testing Hearing Aids with a Broad-Band Noise Signal (S3.42-1992) require the overall dB SPL level of ambient noise to be less than 40 dB SPL between 200 and 5000 Hz and less than 50 dB SPL between 100 and 5000 Hz. The signal to noise ratio must also be greater than 10 dB in each analysis band. To establish ambient noise levels in the open HAT box, the TEL-PHONE was placed in the same position in which frequency response measures were made (with the lid ajar) and the Fonix was run in spectrum mode with no output from the TEL-PHONE. Figure 1 details the levels obtained.

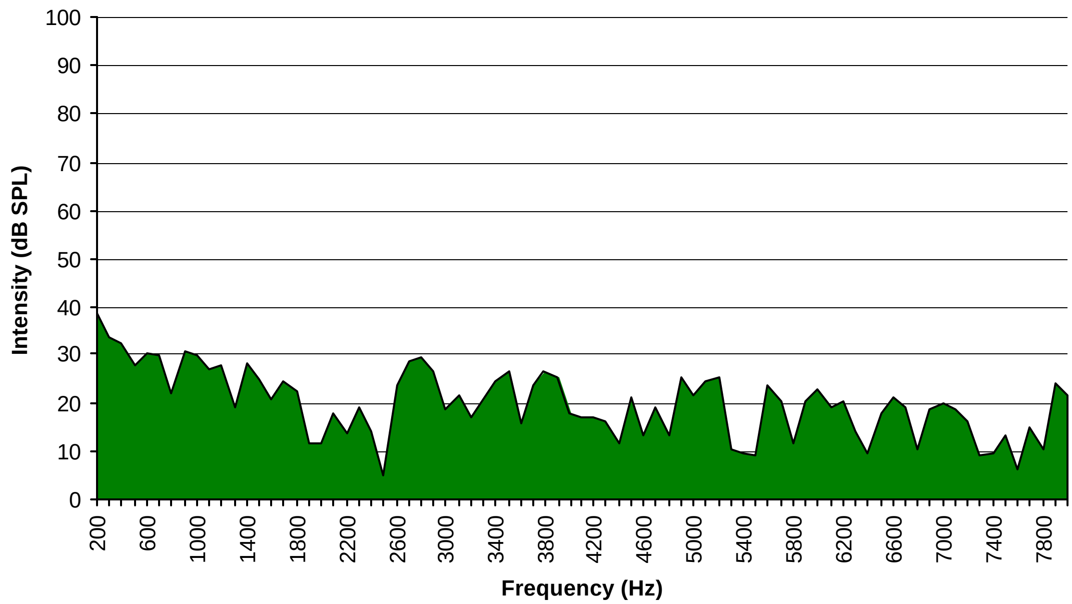

Figure 1. Hearing aid test box ambient noise levels.

Data indicate that ANSI S3.42-1992 requirements regarding ambient noise between 200 and 5000 Hz in a test environment were not met. Ambient noise in the 200 to 5 kHz band was 43.8 dB SPL. The overall ambient noise level between 200 and 8 kHz as calculated was 44.2 dB SPL. The most significant omission in the data is an intensity level at 100 Hz as the Fonix does not measure at that frequency, excluding calculation of the ambient noise levels between 100 and 5000 Hz. Although requirements for ambient noise level in the 200 to 5 kHz band were not met the analysis of the frequency response of the device proceeded.

After ambient levels were established, the output of the device was measured using the Frye Fonix 6500-CX as a spectrum analyzer. The cassette with the previously recorded 60, 65 and 75 dBA SPL 1000 Hz tone recording was inserted and played through the TEL-PHONE device. The Fonix microphone was placed within 2mm of the receiver of the TEL-PHONE and the output was measured as the taped pure tones were played. The Fonix was in spectrum mode. The volume control of the TEL-PHONE was at the lowest setting. The SP/LP switch and speed wheel was set as previously described.

Figures 2, 3, and 4 describe the spectrum level with a 60, 65 and 75 dBA 1 kHz output from the TEL-PHONE device in the HAT box and compare the output to the ambient noise levels. Three days prior to these measures, recalibration of the speed of playback was performed with the Larson-Davis and the oscilloscope.

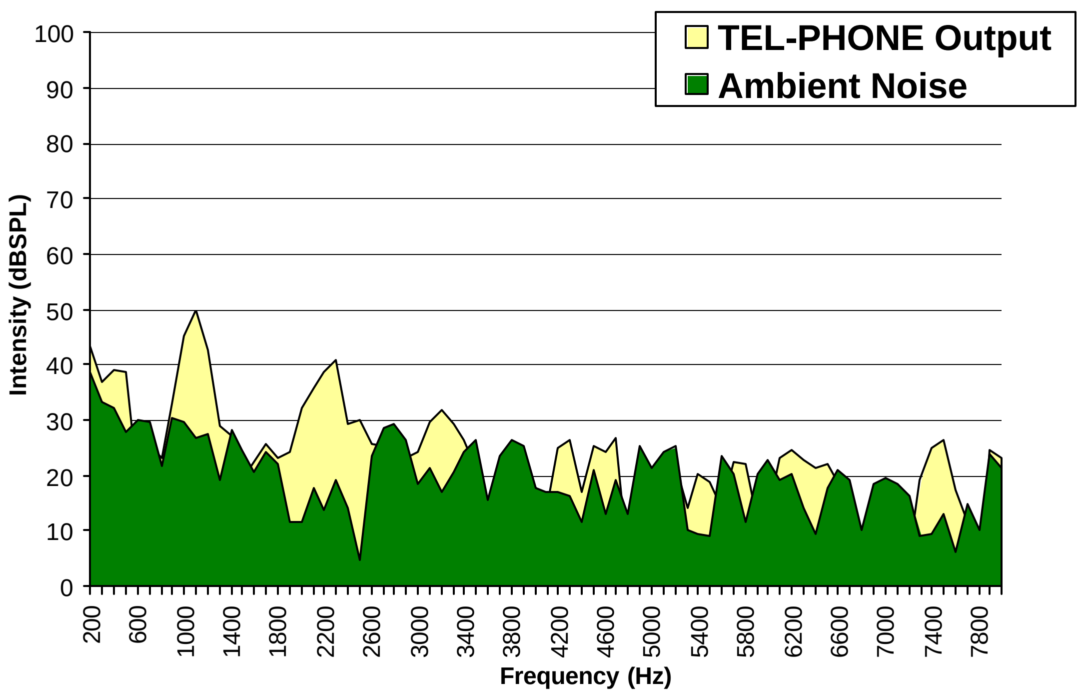

Figure 2. Hearing aid test box ambient noise level spectrum and 60 dBA 1 kHz TEL-PHONE output spectrum.

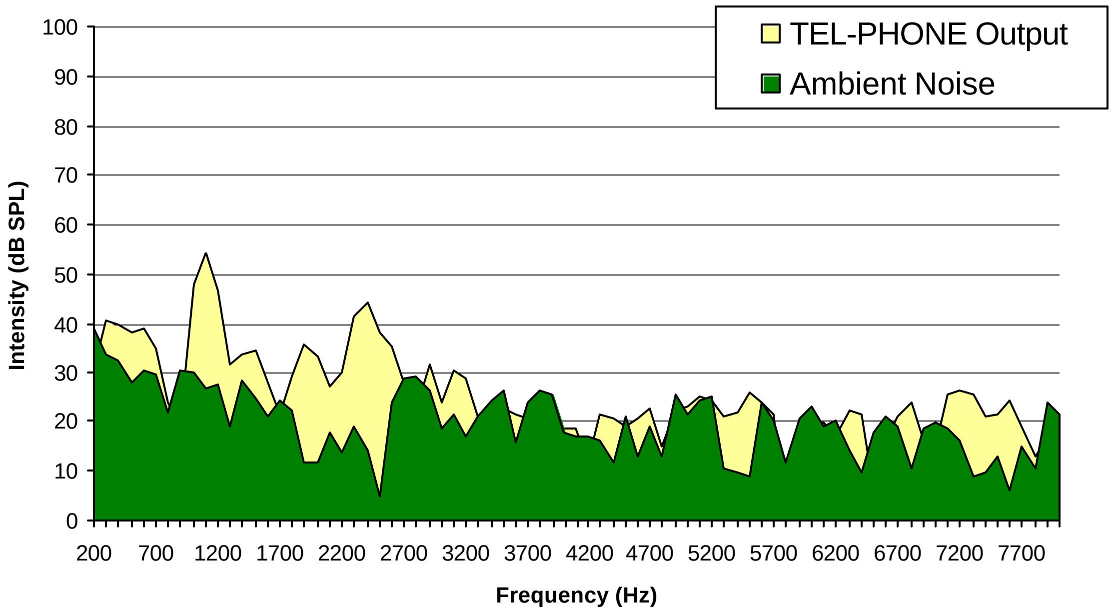

Figure 3. Hearing aid test box ambient noise level spectrum and 65 dBA 1 kHz TEL-PHONE output spectrum.

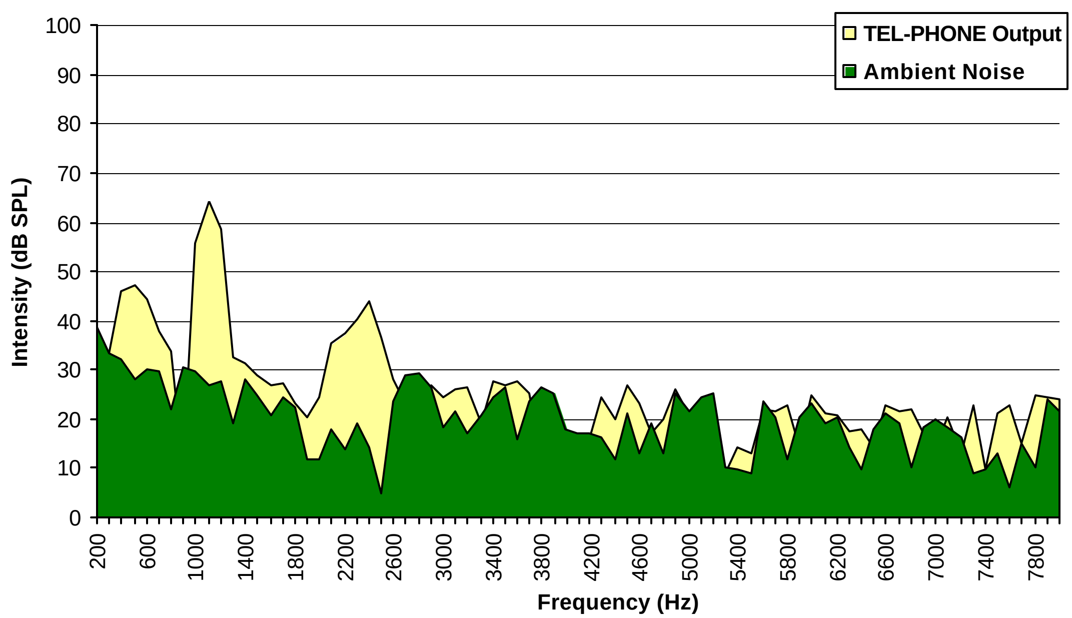

Figure 4. Hearing aid test box ambient noise level spectrum and 75 dBA 1 kHz TEL-PHONE output spectrum.

The signal to noise ratio requirements were met for the signal of interest in this evaluation: the ambient noise level at 1 kHz (29.7 dB SPL) was more than 10 dB lower than the 60, 65, and 75 dBA tones (45, 47.9, and 55.8 dB SPL respectively). The values obtained by the procedure reveal that the maximum output of the TEL-PHONE device occurred at 1100 Hz consistently. This was unexpected as the speed of playback was re-calibrated three days prior to this measure, using these same tones. TEL-PHONE output was also high in the 500 and 2 kHz areas (also frequency areas meeting the signal to noise ratio requirements). While comparison of these results to the EIA standard may not be valid, the effort does enable us to observe the frequency response of the device.

4.0 Electromagnetic measurements

Measurement of the electromagnetic field emitted from the device was performed to determine if this device was appropriate for its intended use. In particular, the goal was to determine whether the axial and radial electromagnetic fields of the TEL-PHONE device were comparable to those found in standard telephones. In order to make this assessment, the measured fields were compared to 1) the minimum field strengths specified by the EIA RS-504 standard for a -10 dBV input, which the standard states are approximately 15 dB above the average level encountered in the field, and 2) the axial field strength of a device called a “Telephone Magnetic Field Simulator” which is said to produce a field strength of similar strength to that produced by a HAC telephone receiver in real use, according to the ANSI standard for measurement of hearing aid performance (S3.22-1996).

Paris Wiley, Ph.D. an associate chairman of electrical engineering at the University of South Florida guided the effort to evaluate the magnetic field of the device. The procedures described in EIA RS-504 were used as guidelines for measurement of the electromagnetic field as replicating the procedures described in the standard precisely is not possible with this device. A Tibbetts MM-45 probe coil was purchased for this purpose as its inductance properties are calibrated to meet the probe coil requirements set forth in the standard. The coil was connected to a lock-in amplifier (constructed by Dr. Wiley) tuned to 1 kHz with a gain of 1000 and a bandwidth of 20 Hz. The output of the lock-in amplifier was displayed on an oscilloscope, which enabled readings of the strength of the electromagnetic field sensed by the probe coil. The purpose of the lock-in amplifier was to amplify the output of the probe coil to a level that could be measured reliably by the oscilloscope. The operation of the measurement circuit was verified by measuring a magnetic field of known strength (the field induced by a 1 kHz AC current of 7 mA in a coil with 8 turns and radius 2.85 cm) and confirming that the appropriate value (1 mA/m, i.e. nI/2R by Biot-Savart's Law) was obtained. This procedure confirmed that the measurement circuit operated properly at 1 kHz.

The sound pressure levels of the previously recorded 1 kHz tones were deemed appropriate for conducting electromagnetic measures for several reasons. Based on the ANSI S3.22 logic that the electromagnetic field of a telephone should produce a similar output from the hearing aid as a 60 dB SPL acoustic input, the 60 dBA tone was utilized. The discrepancy between 60 dB linear and 60 dBA was noted: the A-weighting attenuates frequencies below 1 kHz. A 65 dBA tone was also utilized because the 65 dBA closely approximates the 1 kHz dBA levels measured from the telephones surveyed for the purpose of this study (the average output of which was 67.28 dBA). It was hoped that the level of the 75 dBA tone would approximate the stimulus used in the EIA standard, -10 dBV, as that stimulus is expected to produce an electromagnetic output 15 dB greater than that produced during standard use of a hearing aid compatible telephone. Axial and radial measurements were made for the 60, 65 and 75 dBA 1 kHz tones played through the built in tape deck of the TEL-PHONE device. The probe coil arrangement was secured in a vice and the TEL-PHONE was positioned on a stable surface such that measurements could be made in accordance with EIA RS-504 requirements. The axial field was measured perpendicular to the face of the receiver, with the center of the coil at a 10 mm distance from the face plate and a 0 mm displacement from the center axis of the hole array in the handset. The radial field intensity was measured parallel to the face of the receiver with the center of the coil at a 10 mm distance from the face plate and a 0 mm displacement from the center axis of the hole array. The speed of the TEL-PHONE playback was recalibrated two days prior to these measures. Table 4 details the outcome of the measures.

Table 4. Axial and Radial Field Strengths of the TEL-PHONE per 1 kHz dBA Output.

1 kHz Intensity dBA	Axial Strength mA/m Maximum (Minimum)	Radial Strength mA/m Maximum (Minimum)
60	77 (21)	31 (21)
65	112 (32)	51 (23)
75	362 (198)	126 (73)
EIA RS-504 (minimum)	(79)	(45)
ANSI S3.22-1996	31.6	No value available

Immediately notable during measurements was the instability of field strength at each intensity level. Large disparities between maximum and minimum field strengths were noted. This indicated instability in the speed of playback. As the lock-in amplifier was tuned to 1 kHz, deviation from that frequency would attenuate the detectable response.

EIA RS-504 requires the strength of the axial field to be at least 79 mA/m and the radial field to be at least 45 mA/m under the specified test conditions. The standard clearly states that these intensities will in fact be approximately 15 dB greater than those fields emitted by standard hearing aid compatibility during real use. Kozma-Spytek (2003) stated that the ANSI 1996 logic for utilizing the axial field strength of 31.6 mA/m is because this intensity approximates the field intensity emitted by standard hearing aid compatible telephones in use. This intensity also closely approximates a similar output from the hearing aid as a 60 dB SPL acoustic input, the intensity commonly cited as the level of conversational speech at a distance of 3 feet. As most programmable and digital hearing aids are customized for the reception of conversational speech in the regular listening program, receiving an equal intensity input during telephone conversation would eliminate the need to adjust the volume control wheel to increase or decrease intensity.

While the output of the TEL-PHONE meets the minimum requirements for electromagnetic field strength set forth by the EIA standard for the 65 dBA and 75 dBA tones, one must keep in mind that these levels exceed those actually emitted by a standard hearing aid compatible telephone during standard use. Although there are no maximum field requirements, it may be reasonable to assume this is due to lack of that problem. The field strengths emitted at 65 and 75 dBA acoustic output appear excessive when considering ANSI 1996 field strength rationalizations. If the output of the standard telephone is indeed in 31.6 mA/m in the axial field, which according to ANSI standards is matched by a 60 dB SPL acoustic input (Kozma-Spytek, 2003), the output of the TEL-PHONE at 60 dBA in the axial plane, 77 mA/m, is significantly stronger. A desirable STS is defined by a maximal value of +/- 5 dB (at least in other countries). This may not be achievable if we program T-coil programs using such a strong stimulus. The hearing aid wearer may find the reception from standard hearing aid compatible telephones to be too weak for communication.

5.0 Conclusion

The device had several problems that were revealed by these analyses. Speed and volume controls offered no mechanism by which the user could establish a desirable output with confidence. Excessive acoustic output (relative to other devices) may imply that the volume control wheel has a limited dynamic range. An alternative explanation for the excessive output may also be the presence of a strong amplifier.

The large fluctuations in electromagnetic field during measurements may be caused by variation in the speed of playback. While EIA RS-504 and ANSI 1996 do not make reference to this issue, it is reasonable to assume that extreme variations in field strength are undesirable. This could cause distortion in the speech signal received by the T-coil user, perhaps making speech unintelligible.

While it appears that the field strength is too strong for the purposes intended by the inventor, the methods used to evaluate the electromagnetic output of the device were modifications of those used for standard telephones. The frequency response measures may be the least valid effort in this analysis as standards require the evaluation to be performed via electromagnetic output. As the proper instrumentation was not available, measures were performed acoustically. The procedure allowed observation of the response of the device; however, comparison to EIA RS-504 requirements is not fair. It may not be judicious to compare values derived from such methods to those applicable to standard telephones tested in the manner prescribed by EIA RS-504. However, the device must be evaluated in some manner prior to use with human subjects. After reviewing the available literature on measurement of electromagnetic fields and T-coil performance assessment, the methods used were deemed most appropriate.

While the protocol for using the TEL-PHONE was not a major focus of this analysis, instructions were considerably vague and/or completely lacking for some procedures. It would be necessary to construct a very concise, detailed protocol to make this endeavor worthwhile to audiologists. Prior to completion of this project, the inventor recognized some of the weaknesses of the device. Per the inventor, a more sophisticated, digital version of this device is being designed. The intentions of the inventor were on target: a device that performs like a telephone would be ideal for customizing T-coils.

An electromagnetic field of sufficient but not excessive strength emanating from a telephone-like device with a speech signal would allow for in-situ customization while simultaneously educating the patient about the T-coil program of the hearing aid. The output of the device should be properly calibrated, and perhaps should be constructed in a manner that allows evaluation. A digital sound source would provide a higher fidelity signal than an analog instrument. To greatly improve the chances of success with an appropriate device, a specific, concise protocol with prescribed courses of action to solve T-coil problems should be included. As there is a need for further refinement of hearing aid function in T-coil mode, advances in this area are welcome.

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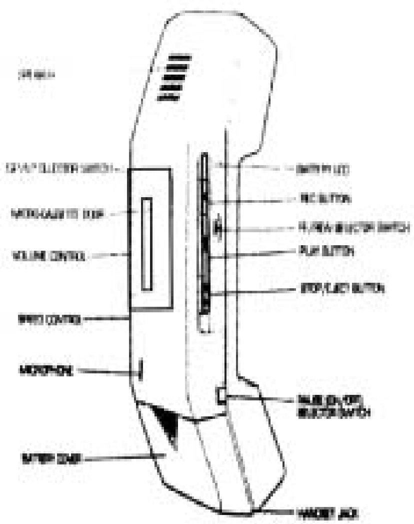
Appendix A.

TEL-PHONE Telephone Telecoil Simulator



CASSETTE TAPE PROGRAM

SP/LP SWITCH-Changes the speed of playback. (leave in SP position)
VOLUME CONTROL-Preset volume setting to meet ANSI standard
SPEED CONTROL-Varies the rate of playback speed . (Leave at Off)
BATTERY COVER-Slide back to access batteries. (Two AA size)
BATTERY LED-Glows when batteries are good.
REC BUTTON-Press to record a blank tape.
FF/REW-Press in the direction to fast forward or rewind tape.
PLAY-Press to play tape for test.
STOP/EJECT-Press to stop tape, press further to eject tape.
PAUSE-Turn ON to temporarily stop tape. OFF to resume playback.

FITTING HEARING AIDS WITH TELECOILS

WHAT IS A TELECOIL?

The name telecoil is a shortened word to represent telephone and coil the two components necessary to induce sound energy from the telephone loudspeaker into a coil of wire within a hearing aid. In the past, many telephones emitted electromagnetic fields from the small loudspeakers in the handsets (due to an inefficient design). It was found that placing a small coil of wire near the electromagnetic field of the telephone handset would induce the sound signal into the coil of wire which then could be connected to the amplifier of a hearing aid.

WHAT AFFECTS THE PERFORMANCE OF A TELECOIL?

The efficiency and overall performance of a telecoil in a hearing aid is directly related to its size and orientation relative to the source of the electro-magnetic source. As the size of the telecoil decreases the overall area is reduced to intercept the electro-magnetic waves emanating from the source (the telephone hand-set).

The other aspect of telecoil performance is the orientation within the hearing aid. Since the maximal pick up strength is located at the perpendicular ends of the coil's central axis, the coil must be positioned appropriately within the hearing aid for best performance. This goal is compromised by the desire for miniaturizing hearing aids and competing with the placement of other components within the hearing aid such as the battery and microphone for optimum position.

For instance, the telephone handset is usually held parallel to the ear
requiring the telecoil to be oriented laterally or side-to-side within the hearing aid for maximum pickup from the phone.

Appendix B.

TEL-PHONE SET-UP

1) Install batteries and program tape into handset
2) Rewind program tape to beginning of test
   (Volume control is preset at the calibrated level)
   Tape Speed= .SP Pause=OFF SPEED WHEEL=OFF

TELECOIL TESTING

WORD RECOGNITION

1) Press play to begin test. Ask user to hold and position the TEL-PHONE handset in varying positions to determine the best place for loudness and clarity. (Take precaution not to position the telecoil training system too close to the computer or monitor where large amounts of electro-magnetic waves may be present.)
2) Record angle and elevation of handset for optimal testing position.
3) Ask user to begin repeating the speech words as they hear them through the telecoil of the hearing aid. Obtain a sample of 10-15 words.
4) Make necessary changes to telecoil settings to maximize performance (I.e. best speech-understanding score)
5) Assess subjective perceptual evaluations of Tonal quality, Loudness, and clarity

SPEECH RECOGNITION IN NOISE

Rewind tape to beginning. Press play button to begin test. Generate background noise with radio, fan, or pre-recorded noise sources throughout the test. Record test results for 10-15 words.

TELEPHONE FEEDBACK

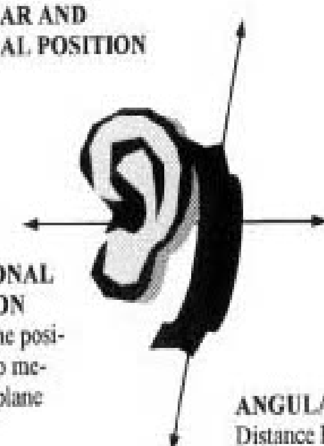
Position the telephone handset for maximum loudness and clarity when using the acoustic microphone interface. Make adjustments to telecoil performance for maximum loudness and clarity before feedback using the acoustic telephone coupling.

NOTE 2.) Remember, that Telecoil performance is dependent upon the sensitivity and orientation of the telecoil ***and*** the amount and quality of electro-magnetic field strength generated from the source or telephone.

PROGRAMMABLE TELECOIL TROUBLESHOOTING

SYMPTOM	ACTION
Humming or buzzing interference	Reduce low frequency gain Decrease 500 Hertz channel
Lack of clarity	Reduce or eliminate compression Choose a linear response
Staticy or scratchy sound quality	Reduce high frequency gain Decrease 4000 & 6000 Hz channels
Low volume	Increase overall gain across frequencies. Increase 500 Hz.
Feedback	Reposition phone to reduce pressure on the ear that could break seal

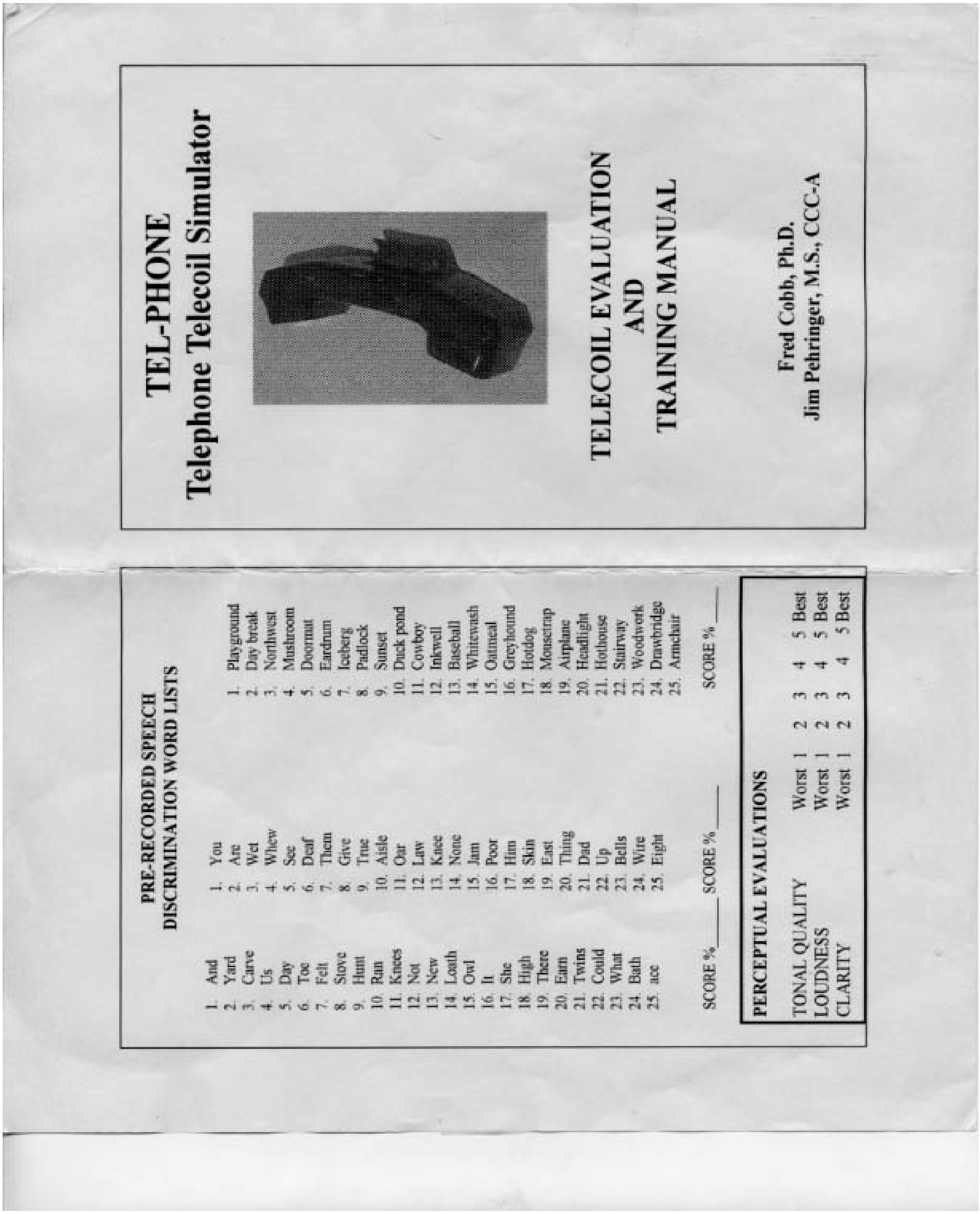
ANGULAR AND ELEVATIONAL POSITION



ELEVATIONAL POSITION
Angle of phone position relative to median midline plane

ANGULAR POSITION
Distance held away from head pivoting phone at top of ear

Appendix C.



PRE-RECORDED SPEECH DISCRIMINATION WORD LISTS

1. And	1. You	1. Playground
2. Yard	2. Are	2. Day break
3. Carve	3. Wet	3. Northwest
4. Us	4. Whew	4. Mushroom
5. Day	5. See	5. Doormat
6. Toe	6. Deaf	6. Eardrum
7. Felt	7. Them	7. Iceberg
8. Stove	8. Give	8. Padlock
9. Hunt	9. True	9. Sunset
10. Ran	10. Aisle	10. Duck pond
11. Knees	11. Oar	11. Cowboy
12. Not	12. Law	12. Inkwell
13. New	13. Knee	13. Baseball
14. Loath	14. None	14. Whitewash
15. Owl	15. Jam	15. Oatmeal
16. It	16. Poor	16. Greyhound
17. She	17. Him	17. Hotdog
18. High	18. Skin	18. Mousetrap
19. There	19. East	19. Airplane
20. Earn	20. Thing	20. Headlight
21. Twins	21. Dad	21. Hothouse
22. Could	22. Up	22. Stairway
23. What	23. Bells	23. Woodwork
24. Bath	24. Wire	24. Drawbridge
25. ace	25. Eight	25. Armchair
SCORE %_____	SCORE %_____	SCORE %_____

PERCEPTUAL EVALUATIONS

TONAL QUALITY	Worst 1	2	3	4	5 Best
LOUDNESS	Worst 1	2	3	4	5 Best
CLARITY	Worst 1	2	3	4	5 Best

TEL-PHONE
Telephone Telecoil Simulator

TELECOIL EVALUATION
AND
TRAINING MANUAL

Fred Cobb, Ph.D.
Jim Pehringer, M.S., CCC-A

Appendix D.

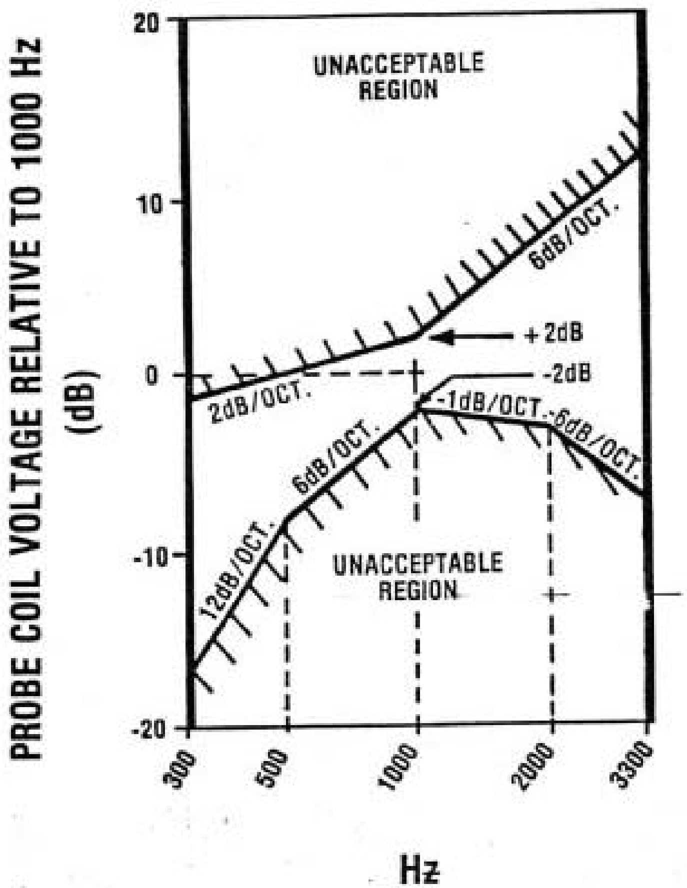


FIG 4A INDUCED VOLTAGE FREQUENCY RESPONSE
FOR RECEIVERS WITH AN AXIAL FIELD THAT EXCEEDS -19 dB

Appendix E.

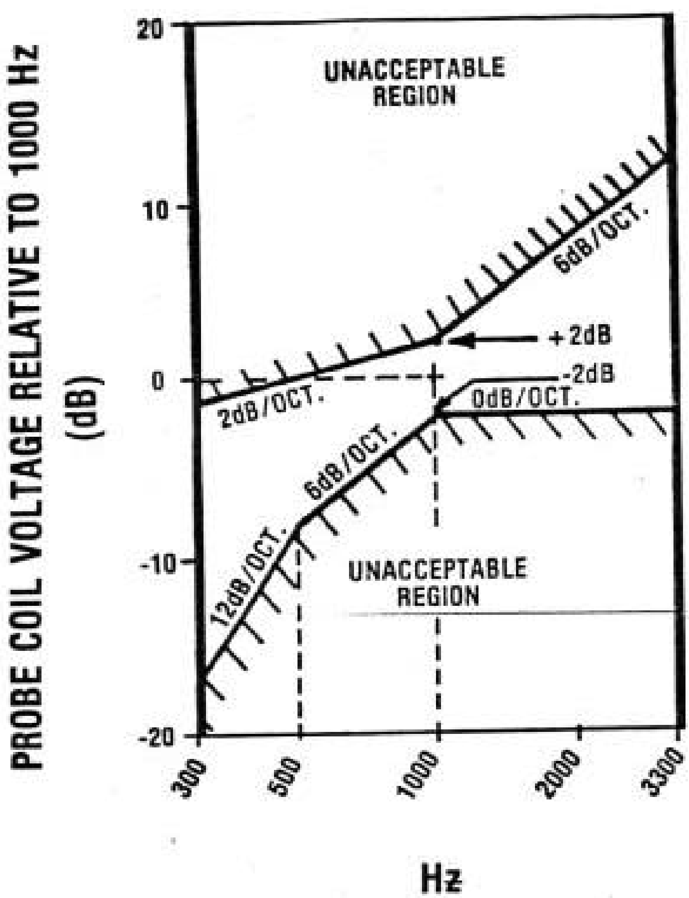


FIG 4B INDUCED VOLTAGE FREQUENCY RESPONSE
FOR RECEIVERS WITH AN AXIAL FIELD THAT EXCEEDS -22 dB