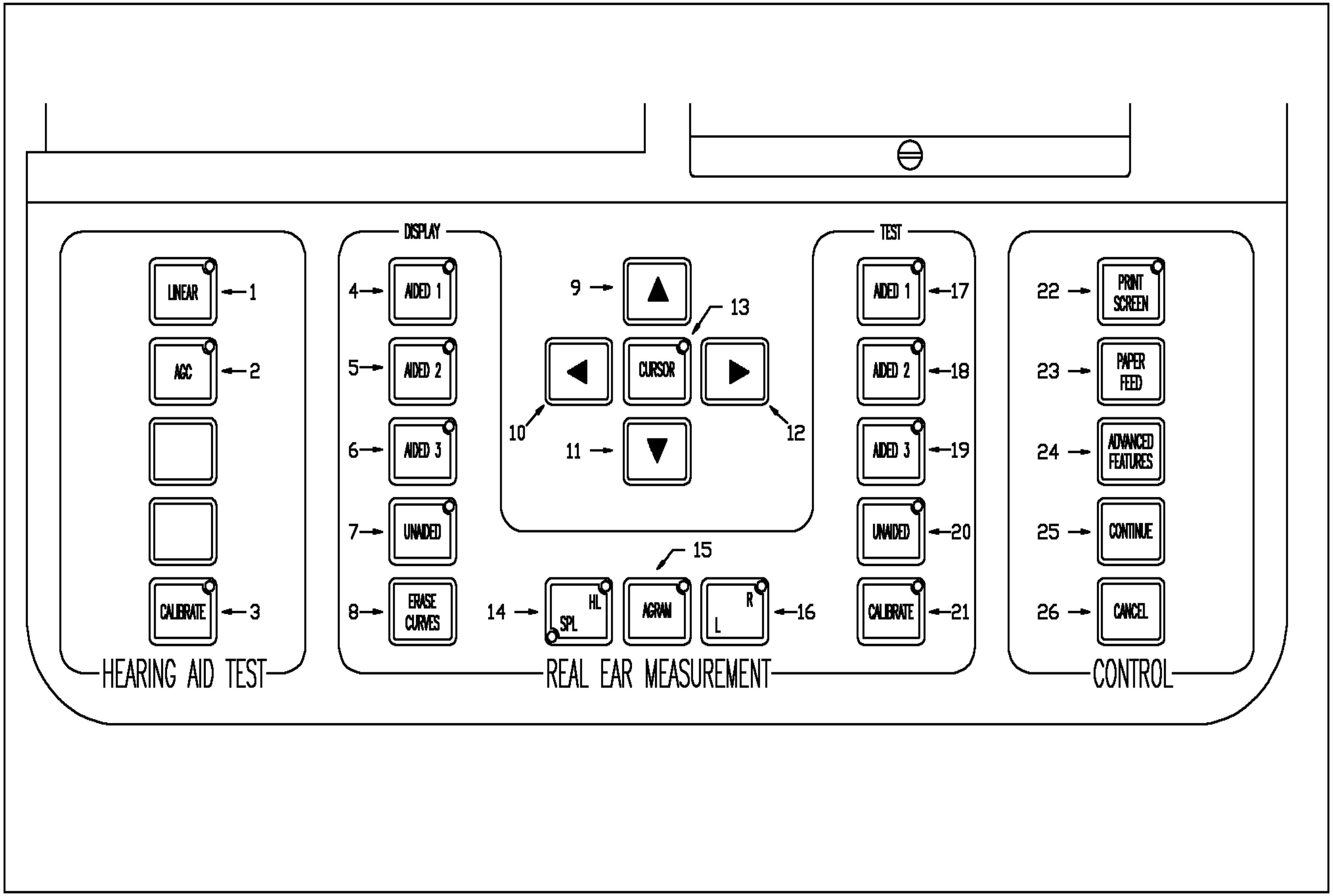
Electroacoustic Performance and Measurement

- Testing the electroacoustic performance of hearing instruments serves two general purposes:
- 1] Hearing Aid Testing (HAT): To verify that an instrument is functioning properly; that is, according to the manufacturer's specifications.
- 2] Real Ear Measurement (REM): To verify that an instrument is functioning appropriately; that is, according to the auditory needs of the wearer.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TEST
LINEAR
1
AGC
2
CALIBRATE
3
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AIDED 1
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AIDED 2
6
AIDED 3
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UNAIDED
8
ERASE CURVES
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CURSOR
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HL
SPL
AGRAM
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AIDED 1
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AIDED 2
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AIDED 3
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UNAIDED
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CALIBRATE
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PRINT SCREEN
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CONTINUE
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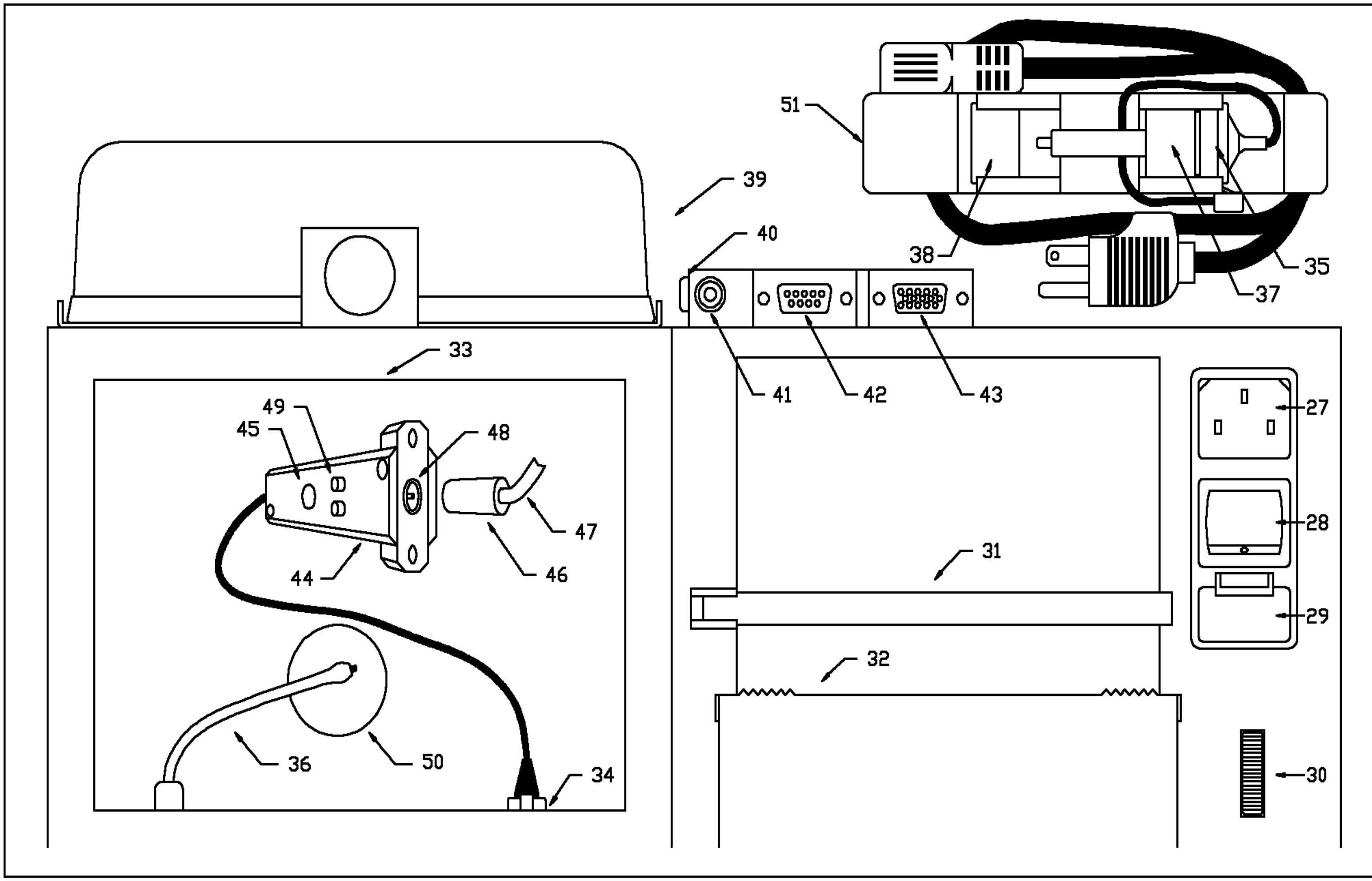
CANCEL
HEARING AID TEST
REAL EAR MEASUREMENT
CONTROL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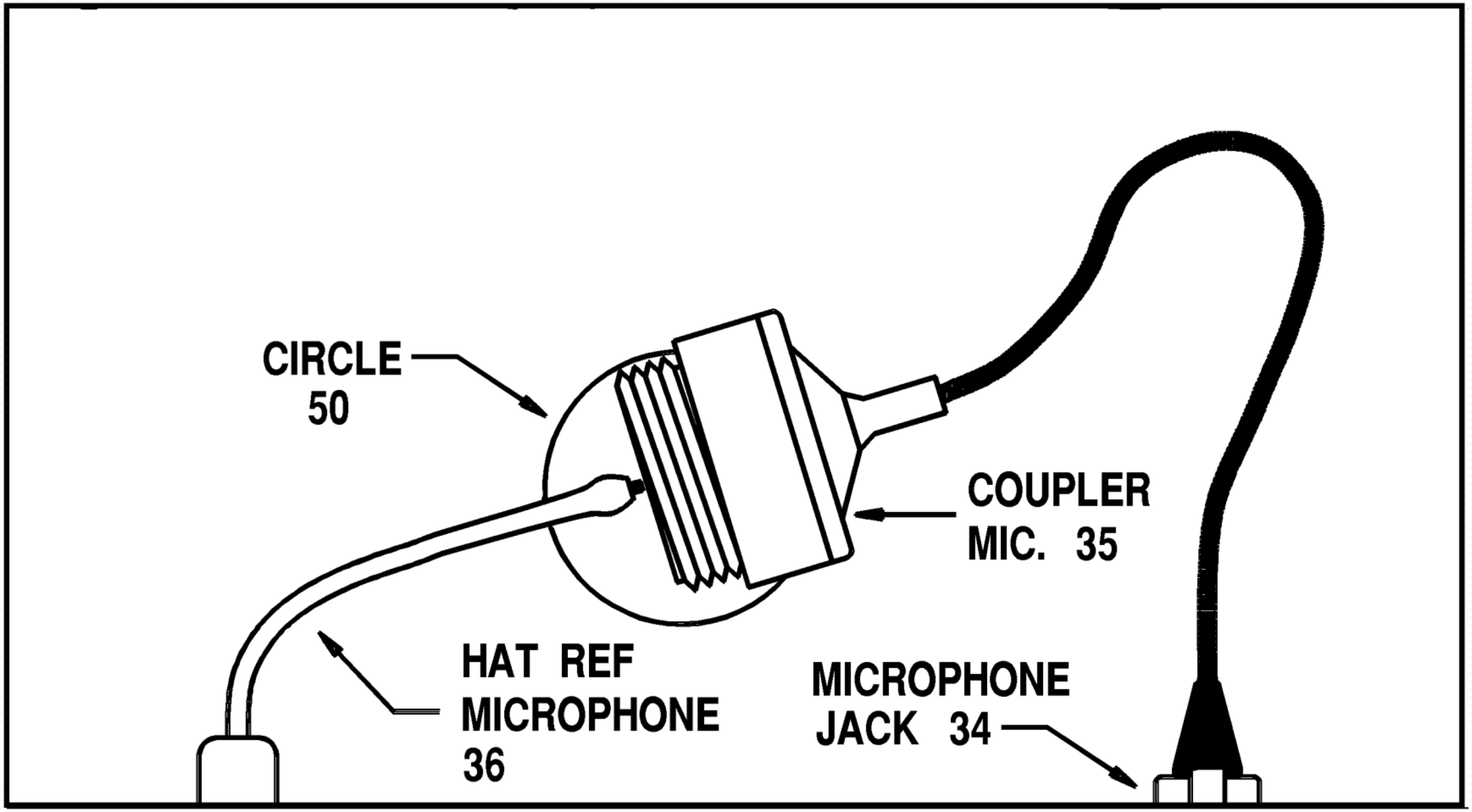
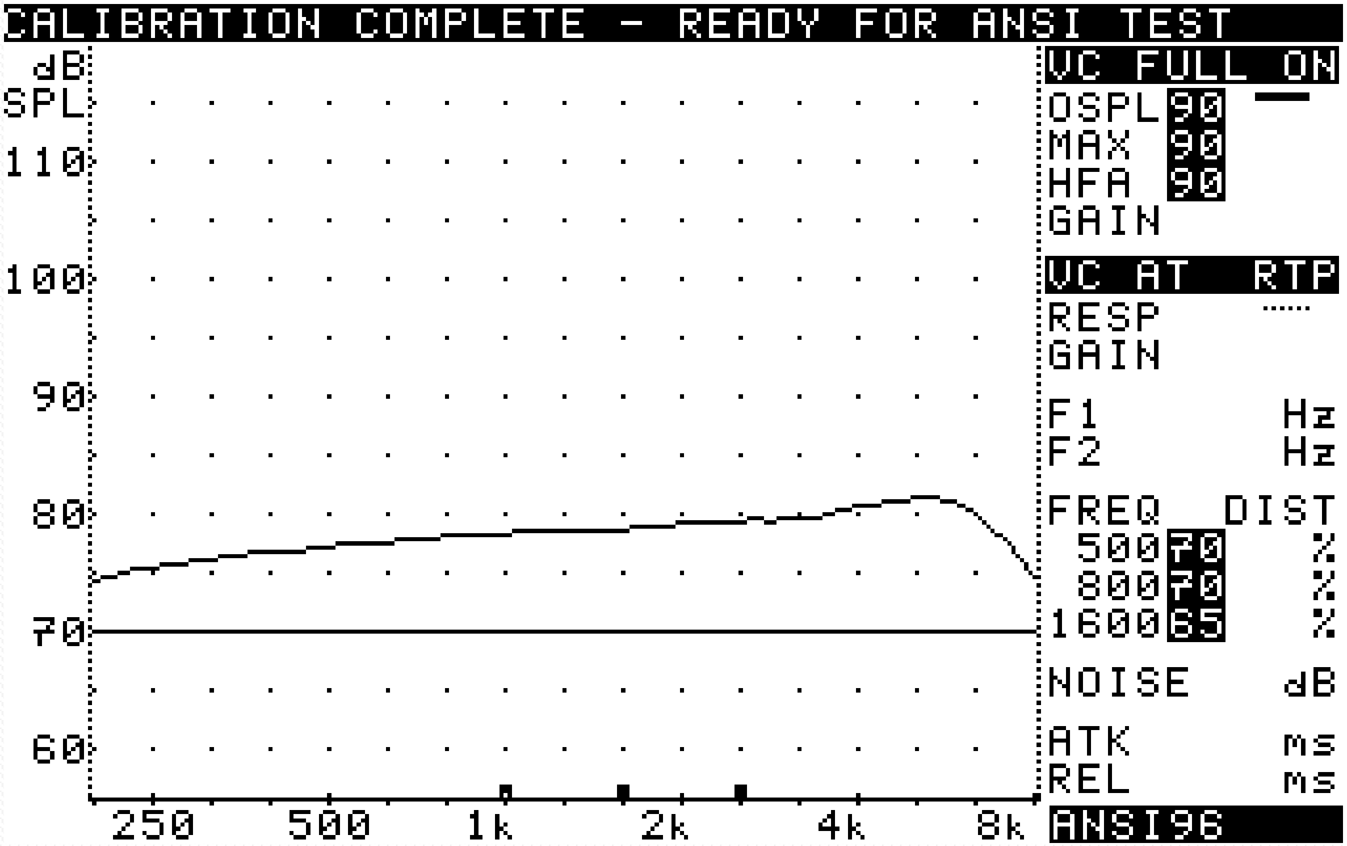
Hearing Aid Testing (HAT)

Procedure:

- A test box (ex audioscan) generates sounds of a required SPL at the hearing aid microphone.
- A test box includes a sound generator, an amplifier, a loudspeaker, measuring microphone and a control microphone.
- The control microphone or reference microphone is calibrated or leveled.
- Place the measuring microphone at the reference position in the sound chamber.
- Do not use a hearing aid or a coupler.
- Place the control microphone facing, and within 5±3 mm of, the measuring microphone.
- Close the chamber and calibrate.

Calibration




CALIBRATION COMPLETE - READY FOR ANSI TEST
dB SPL
110
100
90
80
70
60
250
500
1k
2k
4k
8k
VC FULL ON
OSPL90 90
MAX 90
HFA 90
GAIN
VC AT RTP
RESP
GAIN
F1 Hz
F2 Hz
FREQ DIST
500 70 %
800 70 %
1600 65 %
NOISE dB
ATK ms
REL ms
ANSI96

Hearing Aid Testing (HAT)

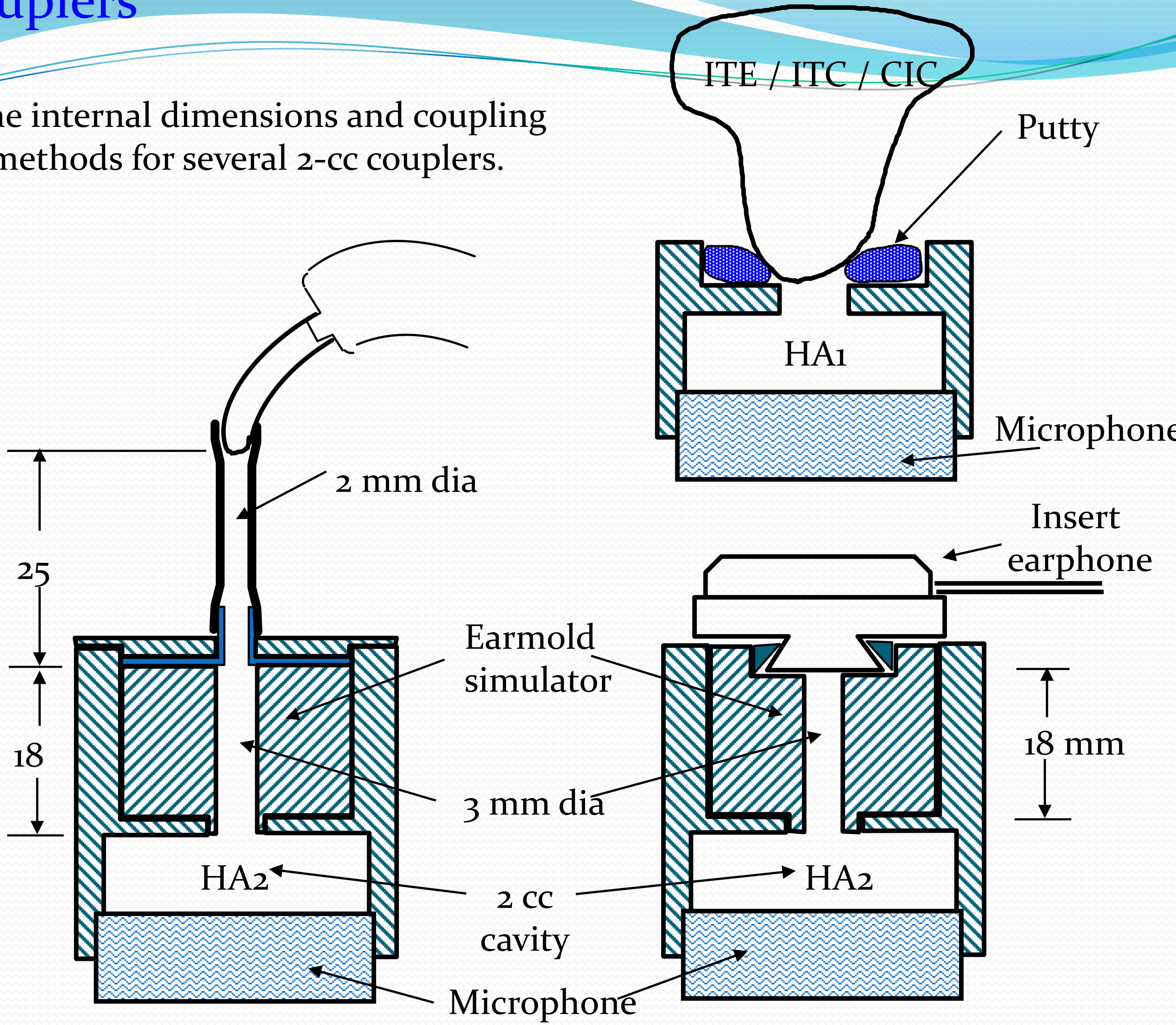
- The performance of hearing aids is most conveniently measured when the hearing aid is connected to a coupler.
- A coupler is a small cavity that connects the hearing aid sound outlet to a measurement microphone.

Hearing Aid Testing (HAT)

- The standard coupler has a volume of 2 cubic centimeters.
- This volume was chosen because it was an approximation of the volume of the adult ear canal past the earmold, i.e. the residual ear canal volume, when a hearing aid is worn.

2-cc couplers

The internal dimensions and coupling methods for several 2-cc couplers.



Source: Dillon (2001): *Hearing Aids*

Hearing Aid Testing (HAT)

- The hearing aid must be set to give the widest possible frequency response range, the maximum gain, and the maximum output.
- If it is not possible to achieve both the maximum output and the maximum gain, set the aid for the maximum output.
- An exception is an AGC instrument having compression controls. Set the controls as indicated by the manufacturer.
- If it is a directional hearing aid place it in omnidirectional mode. The hearing aid is then connected to a coupler.

Hearing Aid Testing (HAT)

HA1 coupler for in the ear hearing aids which are connected via putty, all vents must be sealed.

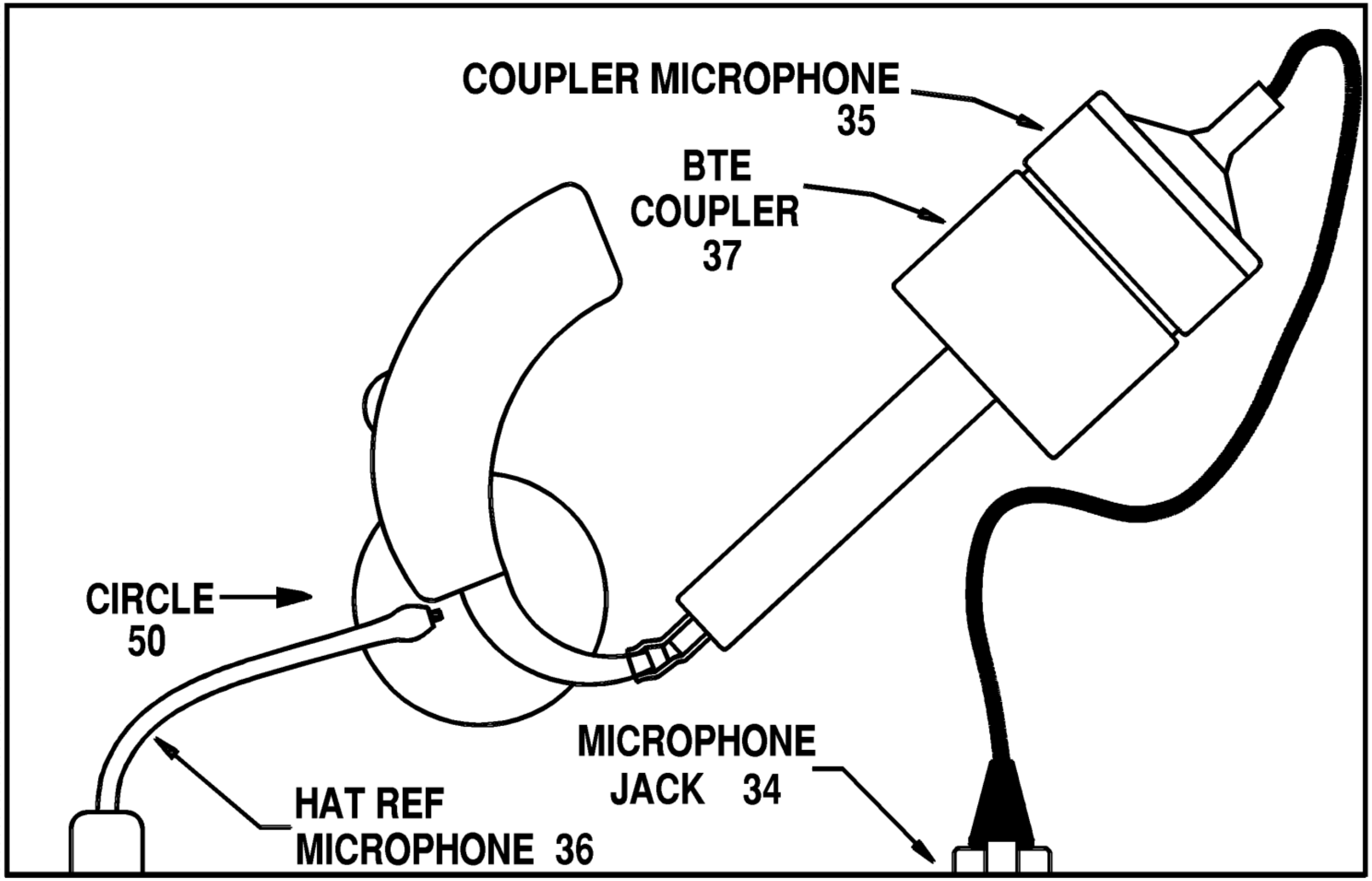
HA2 coupler for BTE and body worn, it has a tube to connect to the BTE.

Then the coupler is connected to the measuring microphone.

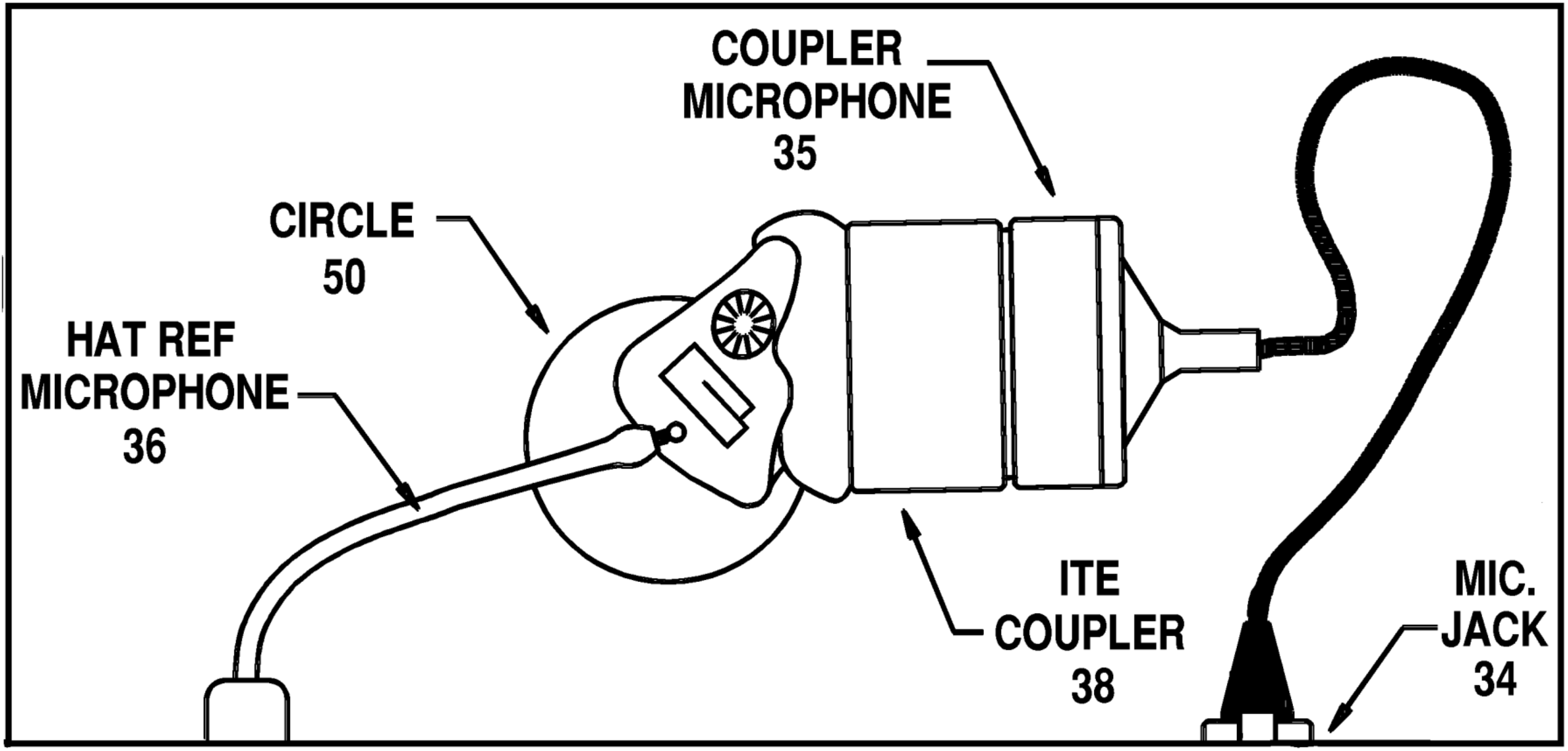
The measuring microphone measures the output from the hearing aid.

Next the control microphone is placed next to the hearing aid microphone. The control microphone monitors the SPL reaching the hearing aid from the loudspeaker.

Hearing Aid Testing HA2 Coupler



Hearing Aid Testing HA1 Coupler



- Choose either Linear or AGC Hearing aid:

- **LINEAR HEARING AID:**

A true linear hearing aid is a hearing aid whose gain and frequency response remain the same, regardless of the input signal.

- **AUTOMATIC GAIN CONTROL (AGC) HEARING AID**

An AGC hearing aid is an instrument whose gain is controlled automatically as a function of the level of the signal being amplified. This automatic control of gain is usually designed to reduce the range of output levels as compared to the range of input levels. Such AGC action is called “compression.”

Compression

- Two forms of compression:
- **Input compression** (dynamic-range compression)—

The extent of gain reduction is determined by the level of the input to the hearing aid. This form of compression is used to match the dynamic range of a hearing aid to the reduced auditory dynamic range found in the recruiting ear.

- **Output compression** (output-limiting compression)—

The extent of gain reduction is determined by the level of the output of the hearing aid. This form of compression is used to limit the maximum output of a hearing aid while avoiding saturation distortion.

Input-output diagram

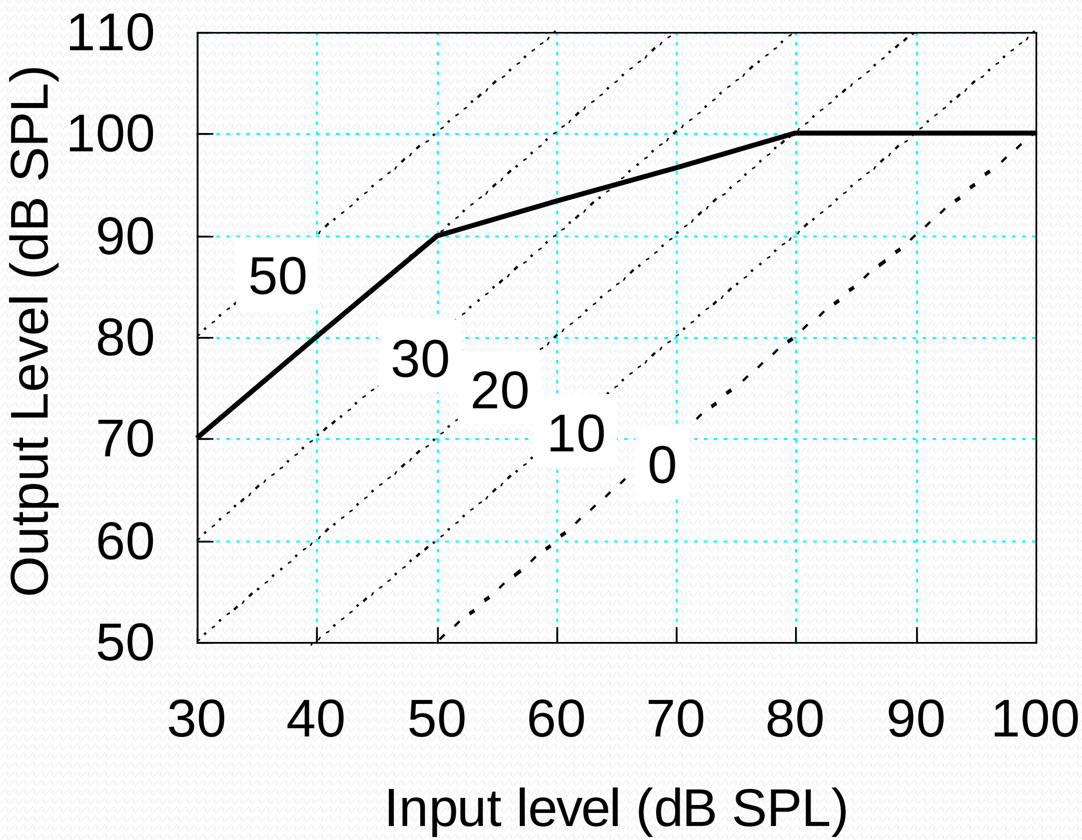


Figure 4.7 Input-output diagram of a compression hearing aid at 2 kHz (bold line) and lines of constant gain (dotted lines).

Source: Dillon (2001): *Hearing Aids*

HAT


TEST COMPLETE
dB SPL
110
100
90
80
70
60
250
500
1k
2k
4k
8k
VC FULL ON
OSPL 90
MAX 90 116
HFA 90 114
GAIN 50 54
VC AT RTP
RESP 50
GAIN 60 38
F1 < 200Hz
F2 6000 Hz
FREQ DIST
500 70 1%
800 70 1%
1600 65 1%
NOISE 33 dB
ATK 144 ms
REL 393 ms
ANSI96 AGC

Definitions of terms:

- ACOUSTIC GAIN —Acoustic gain (also called, simply, gain) is the difference, in dB, between the output level and the input level.

- FREQUENCY RESPONSE—In general, a frequency response is a set of output levels, generated as a function of frequency, for a fixed input level.

- FULL-ON POSITION—Full-on means the gain control of the hearing aid is at its maximum position.

- GAIN CONTROL —Gain control is the technically correct term for what is commonly called “volume control.”

Definitions of terms:

- HARMONIC—A harmonic is an integral multiple of a given frequency. For example, the first harmonic of a frequency is the frequency itself; the second harmonic of a frequency is twice the frequency; the third harmonic is three times the frequency; etc.

- HARMONIC DISTORTION —An instrument exhibits harmonic distortion when the instrument produces harmonics in the output signal that are not present in the input signal.

- HIGH-FREQUENCY AVERAGE (HFA) —The HFA is the average of the decibel values at 1000, 1600, and 2500 Hz.

Definitions of terms:

- INPUT-OUTPUT (I/O) CHARACTERISTIC —An input-output characteristic is a set of output levels, generated as a function of input level, for a fixed input frequency (or frequency band). I/O testing is done only on AGC instruments.

- INPUT SOUND PRESSURE LEVEL —The input sound pressure level (also called input level) is the SPL at the inlet of the hearing aid microphone.

- OUTPUT SOUND PRESSURE LEVEL—The output sound pressure level (also called output level) is the SPL measured by the coupler microphone.

- OUTPUT SOUND PRESSURE LEVEL FOR 90 dB INPUT SPL (OSPL90) —the OSPL90 is the output level of a hearing aid when the input level is 90 dB SPL and the gain control is full-on.

- REFERENCE TEST SETTING (RTS) —The reference-test setting is the position of the gain control necessary to yield the reference-test gain.

- REFERENCE TEST GAIN - The reference-test gain is the gain of the hearing aid when the gain control is set so that a 60 dB SPL input signal yields an HFA value that is 17 dB below the HFA OSPL90 value.

- Exceptions: If the actual HFA output level for the full-on position is already lower than 17 dB below the OSPL90 level, then the full-on gain is considered the reference-test gain (As in some AGC).

- The average level of normal, conversational speech in quiet is 65 dB SPL. Typically, speech levels vary over time by +12 dB and –18 dB relative to the average level.

- Therefore, the typical maximum level of conversational speech in quiet is 77 dB SPL. For testing hearing aids under simulated normal-use conditions, ANSI prescribes a gain setting such that the range of amplified speech levels would fall at or below the hearing-aid saturation level.

- Because the typical maximum speech (input) level is 77 dB SPL, the reference-test gain is the hearing aid saturation level (HFA OSPL90 level) minus 77 dB.

- To set the gain control to the reference-test position, you must first determine a target HFA output level.

- The input level used to set the gain control to the reference-test position is 60 dB SPL (50 for AGC).

- In general, the output level is the input level plus the gain. Therefore, the target HFA output level would be 60 dB SPL plus the reference-test gain. This level is also equal to the HFA OSPL90 level minus 17 dB.

HAT

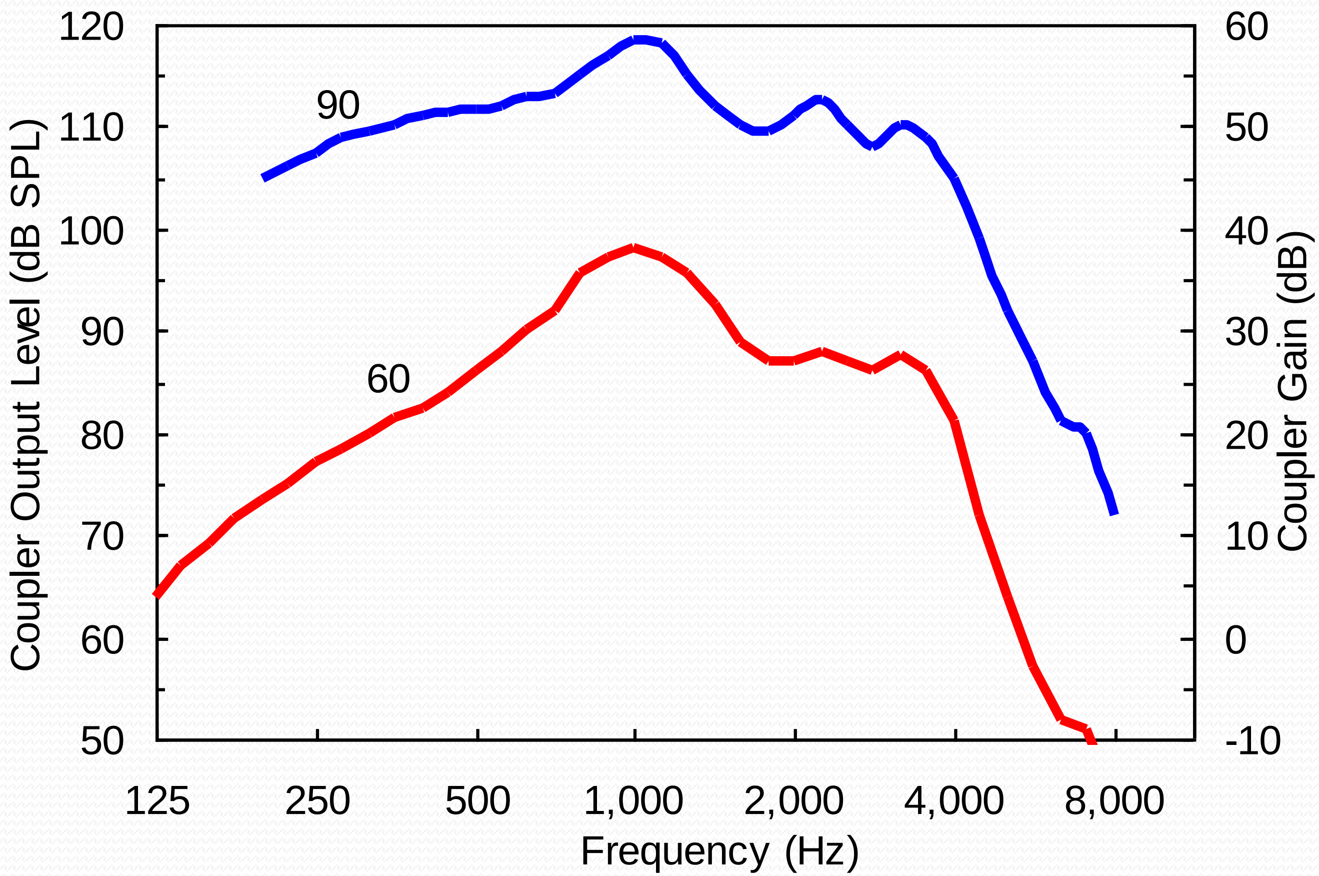
- Test boxes use two different types of measurement signals.

- The traditional signal is a pure tone that automatically sweeps fq over the desired fq range, 125 Hz to 8000 Hz and a broadband signal.

- The measurements most commonly performed on hearing aids are the gain frequency response and OSPL90- frequency response.

- HFA gain & Internal Noise is also measured

Gain-frequency response



Gain-frequency response (measured with a 60 dB SPL input level) and OSPL90-frequency response of a BTE measured in a 2-cc coupler with a swept pure tone. The 60 dB curve can be read against either axis; the OSPL90 curve must be read against the left hand axis.

Source: Dillon (2001): *Hearing Aids*

HAT


TEST COMPLETE
dB SPL
110
100
90
80
70
60
250
500
1k
2k
4k
8k
VC FULL ON
OSPL 90
MAX 90 116
HFA 90 114
GAIN 50 54
VC AT RTP
RESP 50
GAIN 60 38
F1 < 200 Hz
F2 6000 Hz
FREQ DIST
500 70 1%
800 70 1%
1600 65 1%
NOISE 33 dB
ATK 144 ms
REL 393 ms
ANSI96 AGC

Tolerances:

- **The maximum OSPL90** reading has to be no more than 3 dB higher than the manufacturer's specification.
- **The HFA OSPL90** has to be within ±4 dB of the manufacturer's specification.
- **HFA Full on gain** has to be within ±5 dB of the manufacturer's specification.
- **The frequency response curve:** The low-band portion of the frequency response curve (<2 kHz) must fall within ±4 dB of the specified curve.

  The high-band portion of the frequency response curve (>2 kHz) must fall within ±6 dB of the specified curve.

Tolerances:

- **Total harmonic distortion (%THD):** The measured %THD values have to be less than or equal to the published values plus 3%.

- **EQUIVALENT INPUT NOISE:** The EIN level has to be less than or equal to the highest value specified by the manufacturer plus 3 dB.

Real-Ear Measurements

- If you want to know how a specific hearing aid is performing on a specific patient, you need to do real-ear measurements.

- What are Real-Ear Measurements?
- Allows one to measure:
- 1. Ear canal resonance (no HA) (REUR)
- 2. Aided responses (HA in, and ON) (REAG)
- 3. Occlusion effect (HA in, and OFF) (REOR)

REM Acronyms

If the term ends in a 'G' it refers to Gain, it is a difference measure (e.g., REUG). That is, the input level used to generate the response has been subtracted from the absolute output level across frequencies.

If the term ends in an 'R‘ which refers to Response, it is an absolute measure of output in SPL (e.g., REUR). That is, there is no consideration given to the input level used to generate the response.

R or G

	Frequency (Hz)								
	250	500	750	1000	1500	2000	3000	4000	6000
REU**R**	51	53	53	57	58	60	68	64	58
- Input	50	50	50	50	50	50	50	50	50
REU**G**	1	3	3	7	8	10	18	14	8

Why do Real-Ear Measurements?

- Is the HA output what you think it is?
- Evaluate performance of advanced hearing aid features, such as noise reduction technology.

- Is the patient's subjective report consistent with the HA output?

- REM characterize the performance of a HA as worn as opposed to in a 2cc coupler

- 2cc coupler has greater volume and impedance relative to the real ear.

- 2cc coupler under-predicts the output of a HA in the ear.

REM

- Where a fitting rationale contains an acoustic target, each hearing aid should be verified by REM.

- Tolerances to the prescription rationale +/- 5 dB at frequencies of 250, 500, 1000 and 2000 Hz

- +/- 8 dB at 30000 and 4000 Hz

Probe Tube Calibration

- Most real-ear measurement systems require you to calibrate the probe tube prior to conducting REM.
- Probe tube calibration accounts for the acoustic effects the probe tube introduces as sound travels through it to the probe microphone during actual use conditions.

Probe Tube Calibration

- In effect, calibration removes the acoustic effects the probe tube and microphone introduce during real-ear measurement, thereby making the probe tube and the microphone 'acoustically invisible.'

- As the probe tube calibration values will be applied to all probe microphone readings via a mathematical correction, careful and accurate probe tube calibration is particularly important.

Probe Tube Calibration

- Hold the headset .5m from the loudspeaker
- Microphone and probe should be facing the loudspeaker
- Your hand should not be placed between the microphone and loudspeaker
- Run calibration

Prepare Patient

- The patient should be instructed to sit as still as possible during recording, in particular to maintain the same head position.
- They should also be informed that they may interrupt the test at any time in the case of discomfort
- Otoscopic Examination must always precede REM. Examine the ear canal for obstruction.

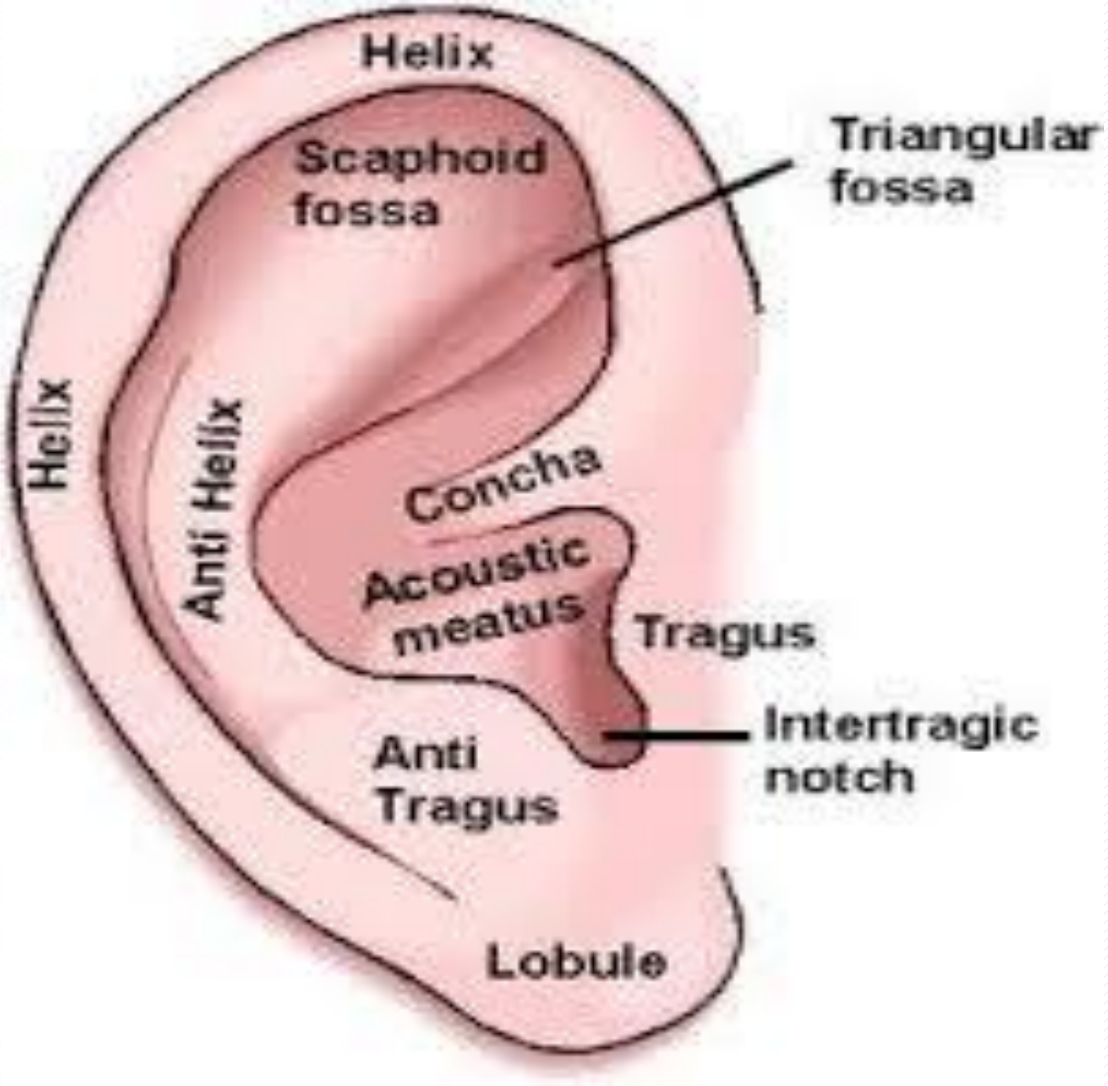
Prepare Patient

- The patient should be seated so that the ear under test is:
- At a distance of 0.5 m from the loudspeaker,
- level with centre of loudspeaker itself
- placing the patient directly in front of and facing the speaker (0 degrees azimuth)

Insertion of probe tube

Always use a new probe tube for each patient

- As the typical length of the adult ear canal is 25 mm and the typical distance from the ear canal opening to the intertragal notch is 10 mm,
- Using an insertion depth of 28 mm past the tragus should result in placement within 5 mm of the eardrum for the average adult
- Mark the probe tube the appropriate distance (e.g. 28 mm) from its open end
- Insert the probe tube into the ear canal until the mark approaches the intertragal notch


Helix
Scaphoid fossa
Triangular fossa
Helix
Anti Helix
Concha
Acoustic meatus
Tragus
Intertragic notch
Anti Tragus
Lobule

Insertion of probe tube

- The probe tube should be placed within 5mm of the eardrum.

- The guidelines regarding how far to insert the probe tube can vary depending on the age and gender of the patient.

- This length should be modified for shorter or longer-than-average earcanals [children's ear canals are typically between 20mm and 25mm in length (0.8 to 1 inch)

- Adult males ear canals are approximately 30mm in length and females 28 mm.

To perform a REM:

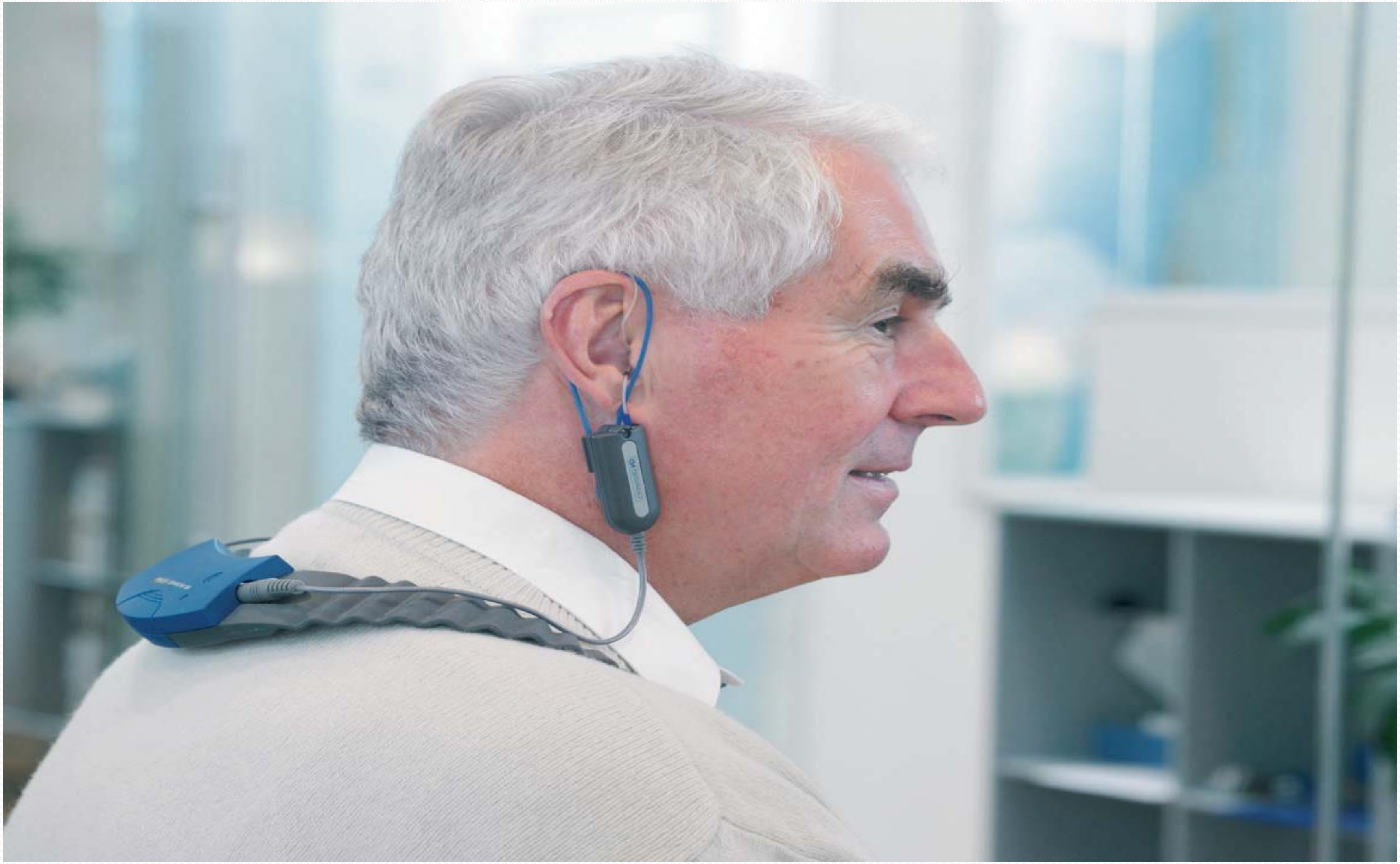
- Adjust the length of the blue probe module cord on the client’s ear until the probe module is snug against the head directly below the client’s earlobe (cheek level).

- The reference microphone should face outwards. Establishing a consistent position for the reference microphone can be facilitated by running the cable from the RM probe module across the front of the client and clipping it to the clothing on the side opposite the test ear.

To perform a REM:

- A small amount of "otoferm" (or similar lubricant) can be applied to the probe tube to help it remain along the bottom of the ear canal during insertion.

- Otoferm will also help to reduce friction between the probe tube and earmold, and to assist in providing a good acoustic seal.



Measurments:

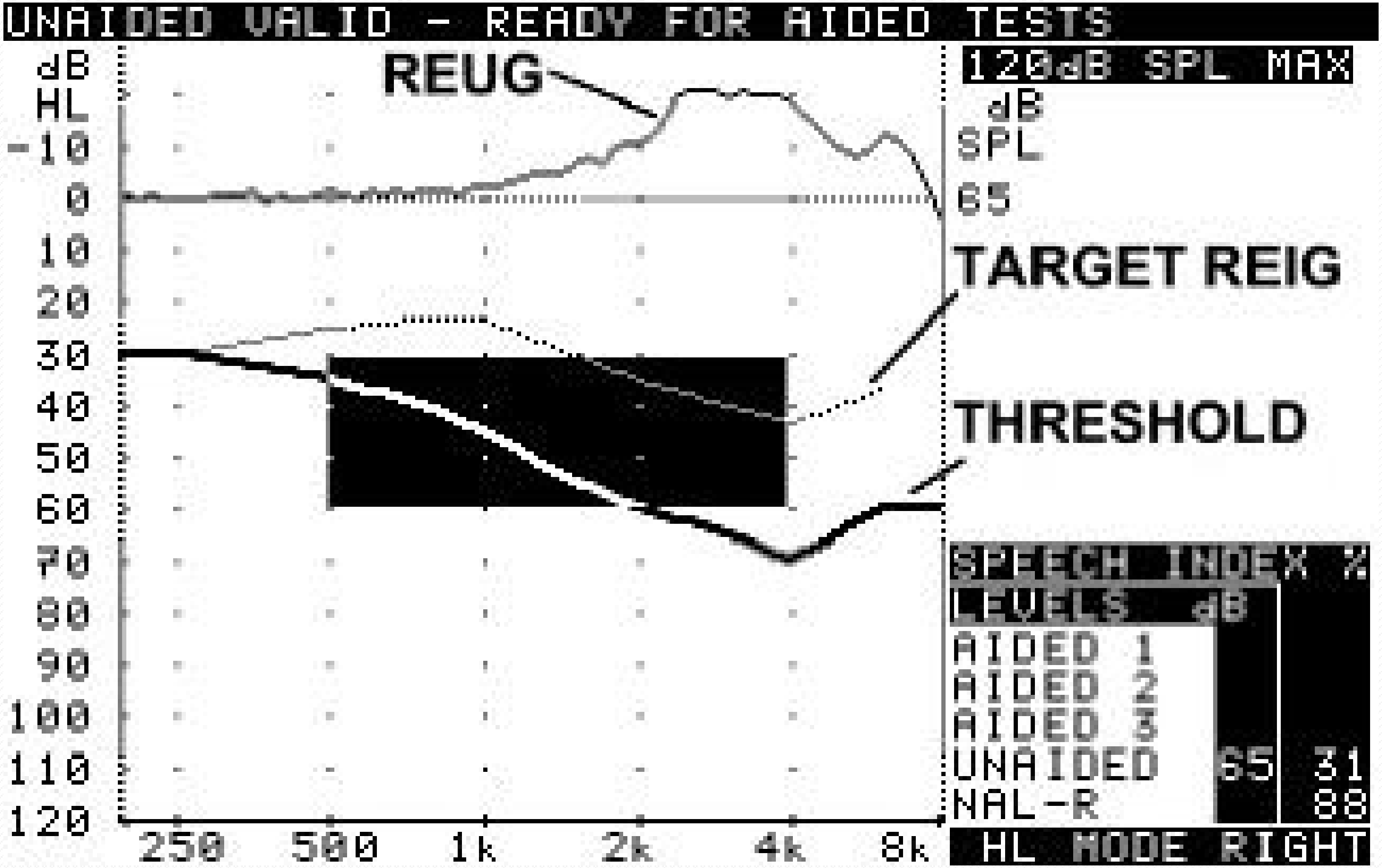
1. REUR/REUG

- Real-Ear UNAIDED Response/Gain

- The level, in dB SPL, as a function of frequency, measured in an open (unaided) ear canal.

- Normal variations in length and diameter of EAC change center frequency and level of resonant peak.

- Use a 65dB SPL broad band stimulus


UNAIDED VALID - READY FOR AIDED TESTS
120dB SPL MAX
dB HL
REUG
dB SPL
65
TARGET REIG
THRESHOLD
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
250
500
1k
2k
4k
8k
SPEECH INDEX %
LEVELS dB
AIDED 1
AIDED 2
AIDED 3
UNAIDED 65 31
NAL-R 88
HL MODE RIGHT

2. REAR/REAG

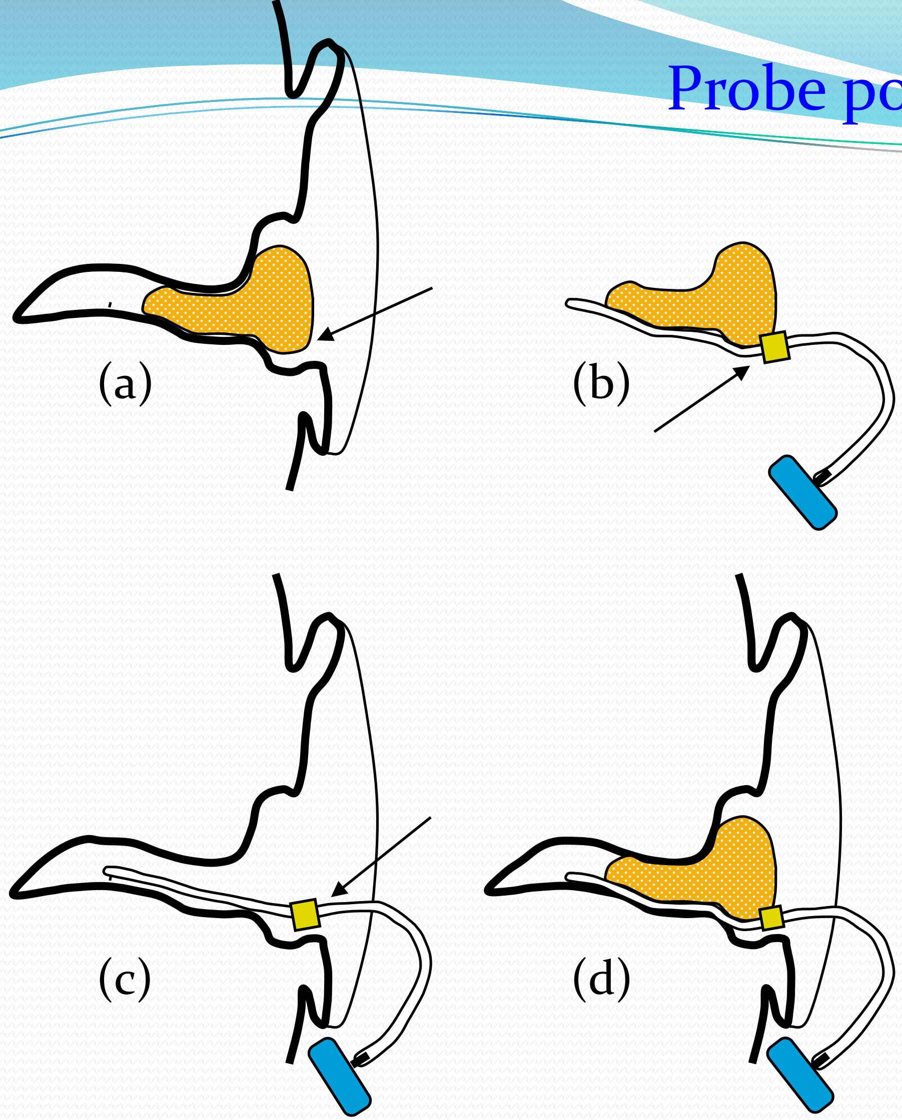
- Real-Ear AIDED Response/Gain
- The level, in dB SPL, as a function of frequency, measured in the ear canal with the hearing in place, and turned on.

- 1. Fit the hearing aid (or custom earmold with aid attached) into the client's ear while holding the REM probe tube so that its position in the ear canal is not disturbed. Turn the hearing aid on and set the volume control wheel to the desired test position.

- 2. Ensure that the client is as close as possible to the position that was used for the REUR measurement.

- 3. The tube must extend 5 mm past the end of the mold or aid, to avoid the transition region near the sound outlet.

Probe position for insertion gain



Probe positioning for measuring insertion gain: (a) noting a landmark on the ear; (b) marking the probe; (c) measuring the unaided response; (d) measuring the aided response.

Source: Dillon (2001): *Hearing Aids*

REAR

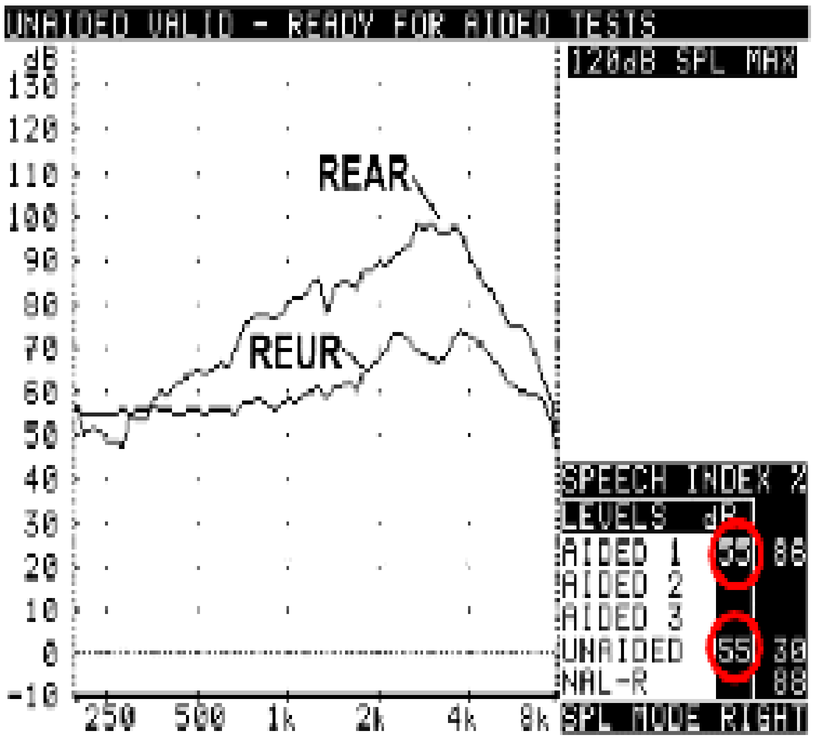


Figure 4. Example of a real-ear aided response (REAR) on the Audioscan RM500, obtained with an input of 55 dB SPL. Also shown is the previously measured real-ear unaided response (REUR).

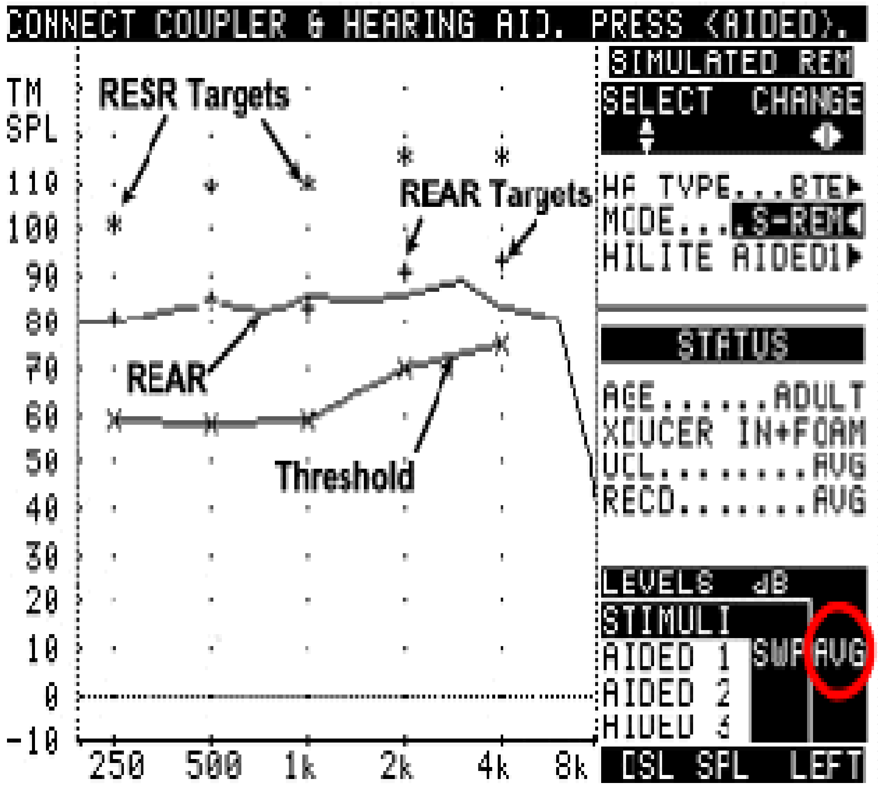


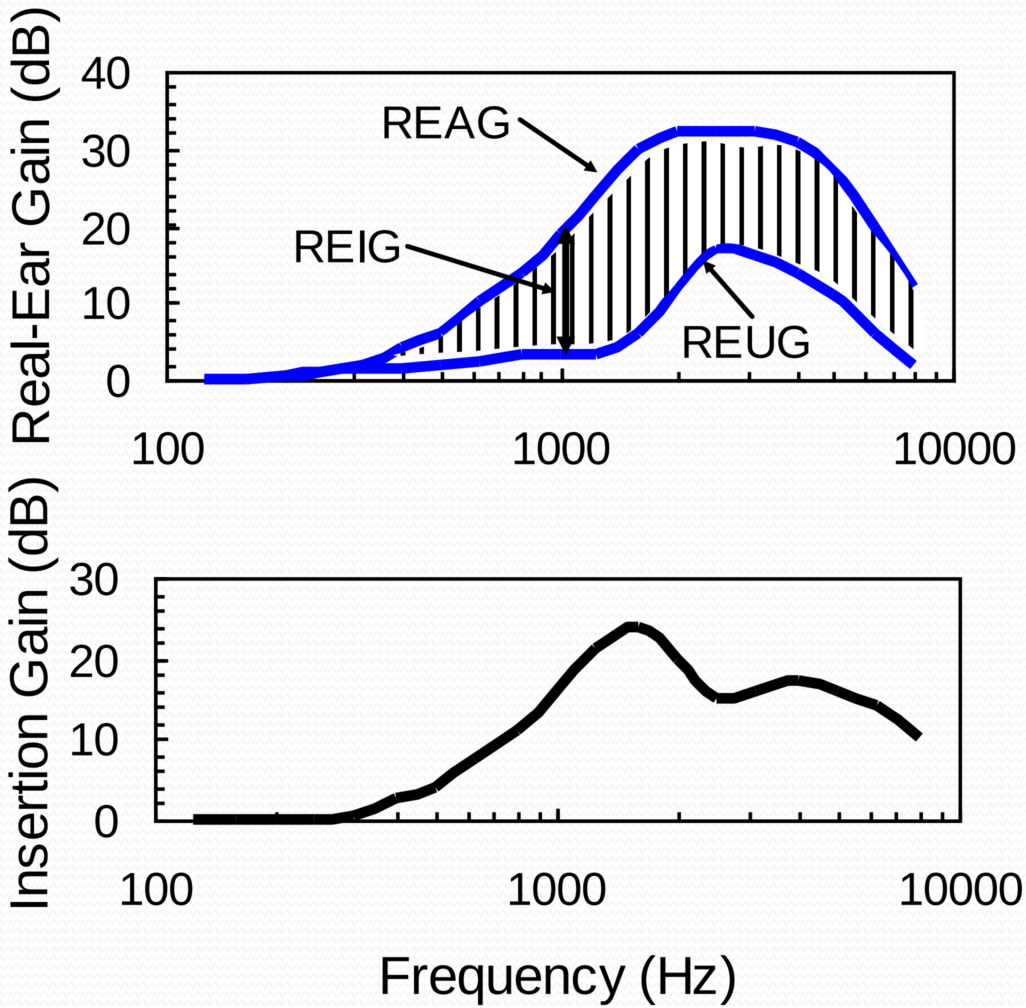
Figure 5. Example of a real-ear aided response (REAR) on the Audioscan RM500 in Speechmap/DSL, obtained with an average speech input.

REIG

- Subtract the REUR from the REAR across frequencies or subtract the REUG from the REAG across frequencies

- Adjust hearing instrument characteristics so that the REAG and thus the subsequent calculation of REIG provides the best match to the target REIG values across frequencies

REIG = REAG - REUG



Source: Dillon (2001): *Hearing Aids*

Real ear unaided and aided gains (top half). The difference between these curves is the insertion gain, shown as the shaded region in the top half and as the curve in the lower half.

REIG

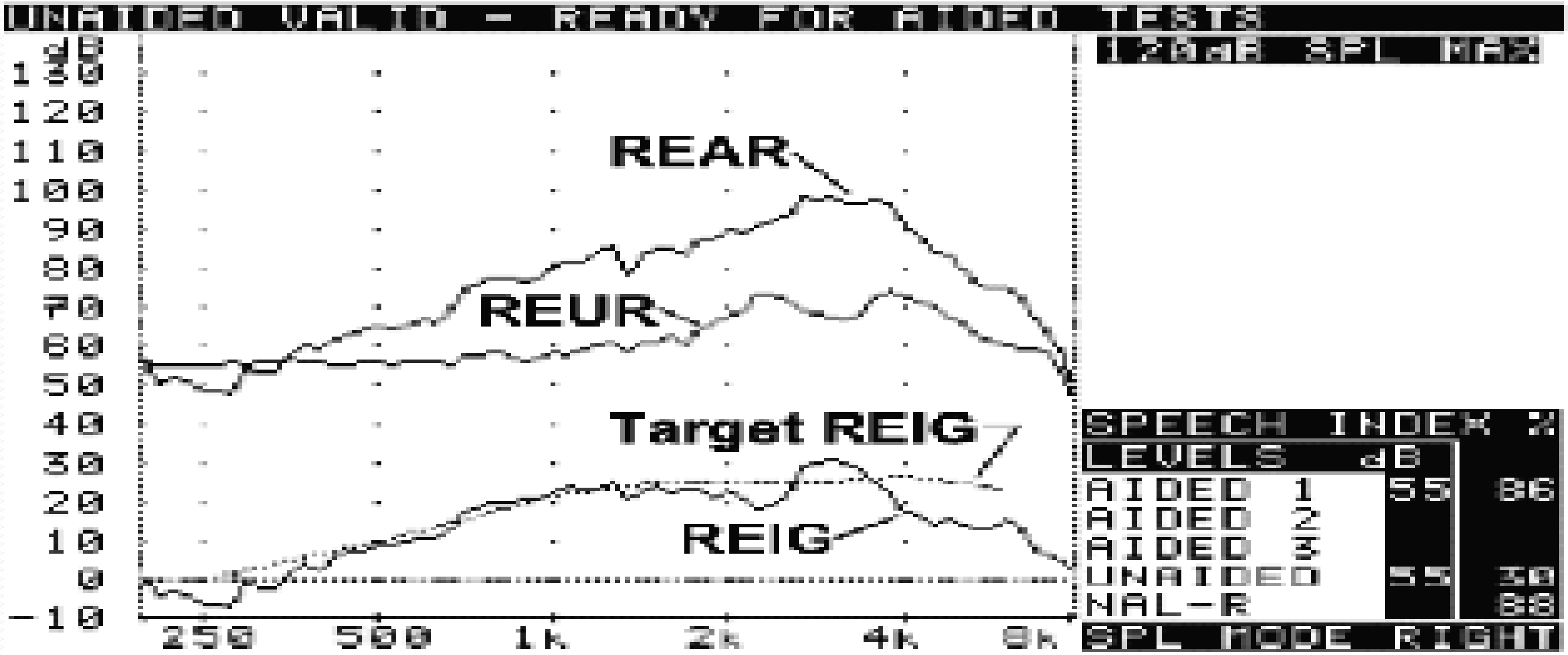


Figure 6. Example of the calculation of real-ear insertion gain (REIG) on the Audioscan RM500. Also shown is the target REIG and the previously measured real-ear unaided response (REUR) and real-ear aided response (REAR).

Occlusion Effect

- Occlusion effects are characterized by descriptions of people with low frequency thresholds less than 40 dB HL

- They complain that, when their ear canal is occluded by an earmold, their voice sounds like it is hollow, boomy, echoic, or coming from inside a tunnel.

- It is caused by bone-conducted sound vibrations reverberating off the object filling the ear canal

Occlusion Effect

- When talking or chewing, these vibrations normally escape through an open ear canal; most people are unaware of their existence.

- When the ear canal is blocked, the vibrations are reflected back toward the eardrum.

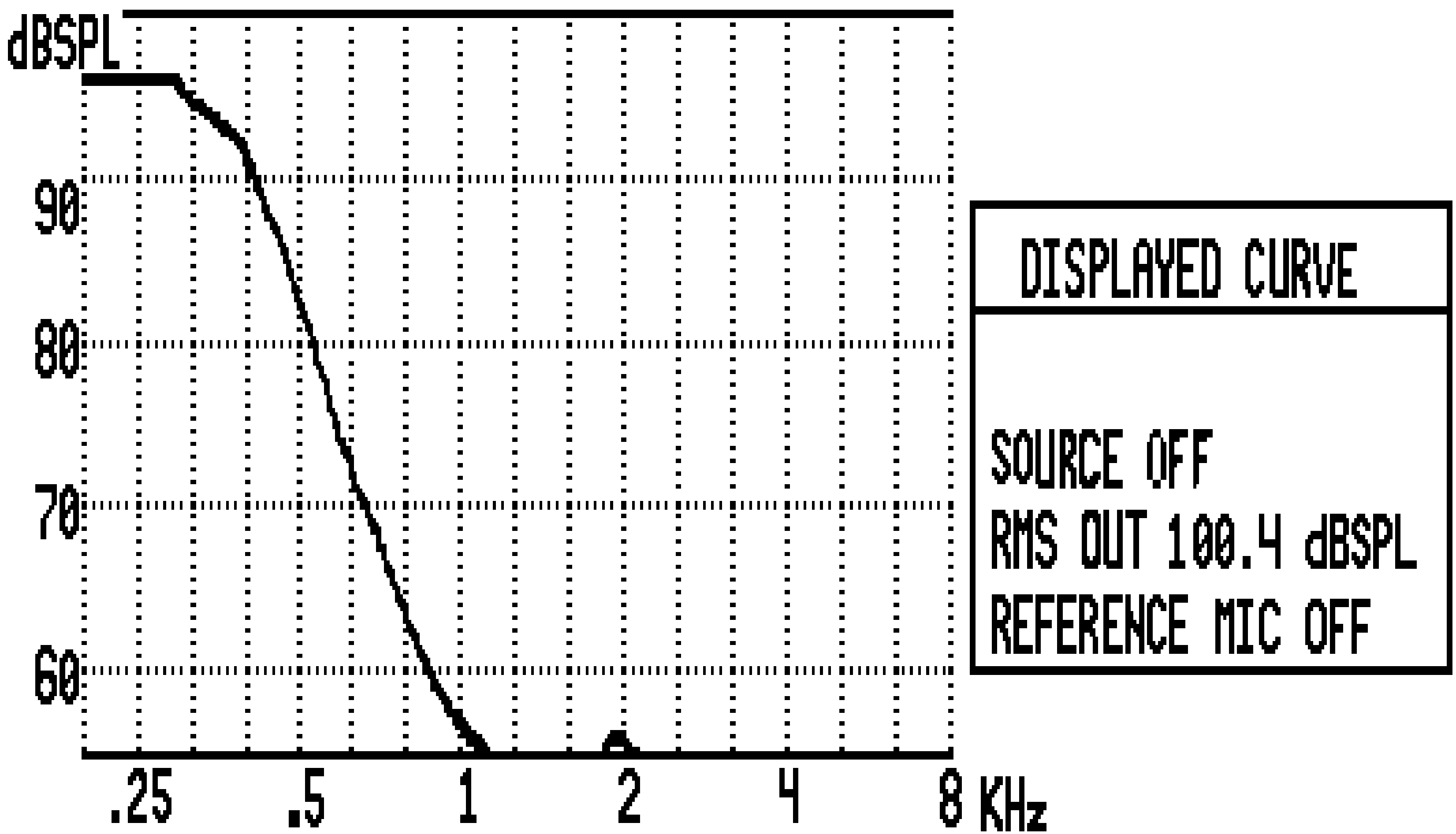
- Compared to a completely open ear canal, the occlusion effect can boost low frequency (usually below 500 Hz) sound pressure in the ear canal by 20 dB or more

Why measure REOR

- The primary purpose of the REOR measurement is to determine venting characteristics.
- Specifically, it is reported that this measurement will allow the audiologist to determine whether the vent is performing as expected by allowing certain frequencies to pass through it.

REOR

- The REOR can be measured by placing a probe microphone in the ear canal with their hearing aid in the ear canal but turned off.
- Record using 65 dB SPL broad band stimulus
- A reduction of the peak around 2000-3000 Hz is expected
- It is the natural resonance of the ear canal


dBSPL
90
80
70
60
.25
.5
1
2
4
8 KHz
DISPLAYED CURVE
SOURCE OFF
RMS OUT 100.4 dBSPL
REFERENCE MIC OFF

RECD

- **RECD (Real-Ear-to-Coupler Difference)**

- **What is it?**
- **Formal Definition:** Difference in decibels, as a function of frequency, between the SPL at a specified measurement point in the ear canal and the SPL in a 2cc coupler, for a specified input signal.

RECD

- **Informal Definition:** Difference in dB across frequencies, between the SPL measured in the real-ear and in a 2cc coupler, produced by a transducer generating the same input signal.

- Given the differences in volume and impedance between the ear and the coupler, RECD values are generally greater than or equal to 0 dB (i.e., greater output in ear than coupler for same input signal level).

RECD

- As can be expected, RECD values can vary substantially across age groups (with children typically having larger RECDs than adults) and even within age groups (Feigin et al., 1989).

- A negative RECD value may indicate an inadequate seal of the transducer to the ear (e.g., foam ear tip), a larger than average ear, or a perforated eardrum.

Why should you do it?

- The RECD allows you to accurately convert assessment information collected with insert phones from dB HL to dB SPL (Scollie et al., 1998b) by, in effect, adjusting the 2cc coupler calibration values used with insert phones.
- This is helpful when using hearing instrument fitting methods that use the SPL-O-GRAM format (e.g., DSL).
- RECD values can also be used to convert real-ear targets to 2cc coupler targets to assist with selection of hearing instruments via manufacturers' specification sheets.

- Arguably the most useful application of the RECD is in the prediction of real-ear output when measuring hearing instruments in the 2cc coupler.

- Given that the RECD allows us to know the difference between output in the real-ear and the 2cc coupler, real-ear hearing aid output (e.g., REAR, RESR) can be accurately predicted to within approximately 2 dB (Seewald et al, 1999).

How is it done?

- **Coupler Measure:**

- 1. Attach the transducer used to generate the signal to the speaker jack if necessary.
- 2. Attach the 2cc coupler (i.e., HA-2 coupler) to the coupler microphone.
- 3. Couple the transducer to the coupler.
- 4. Introduce the signal.
- 5. Store the coupler measurement (most equipment will store this coupler response automatically).

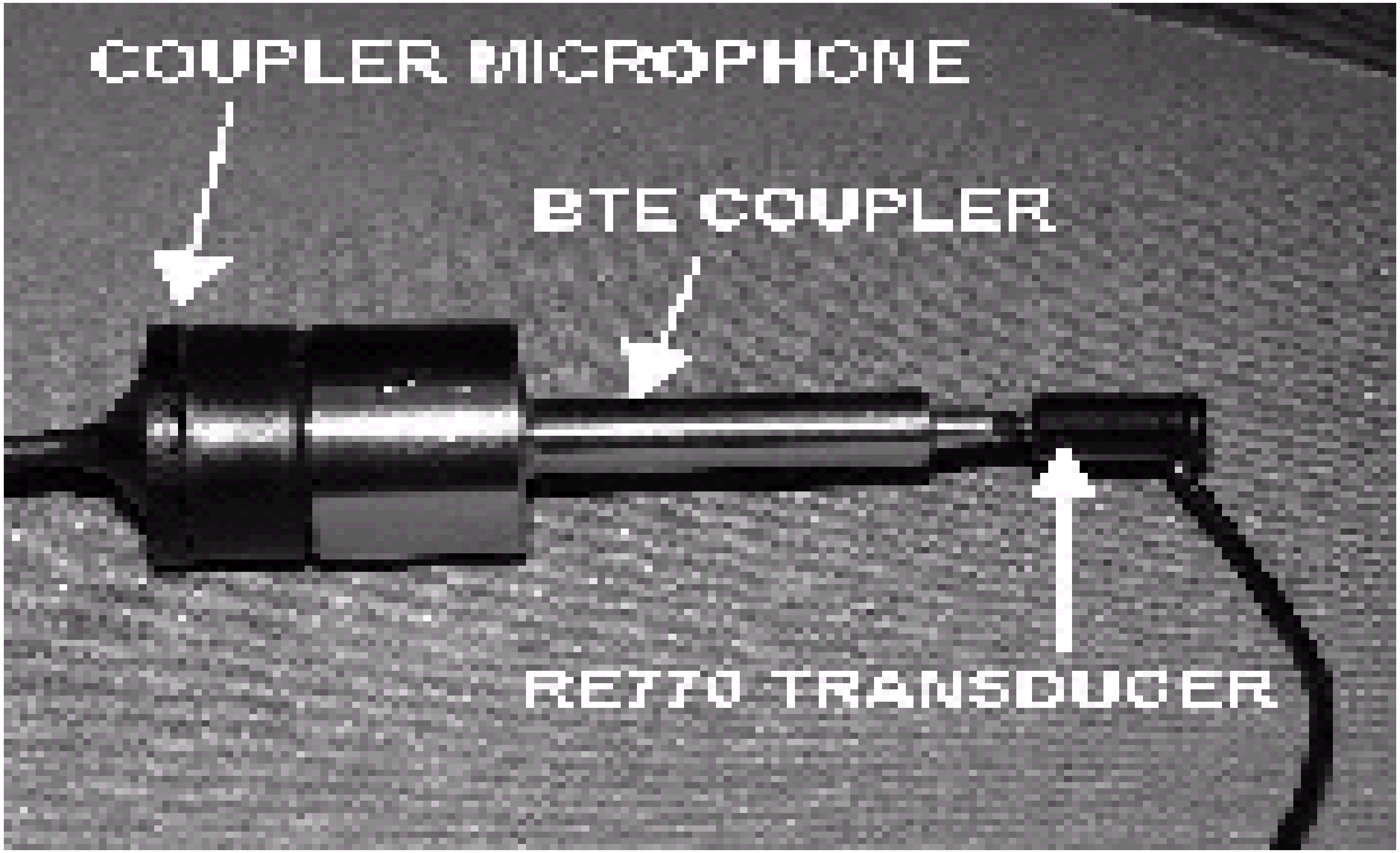
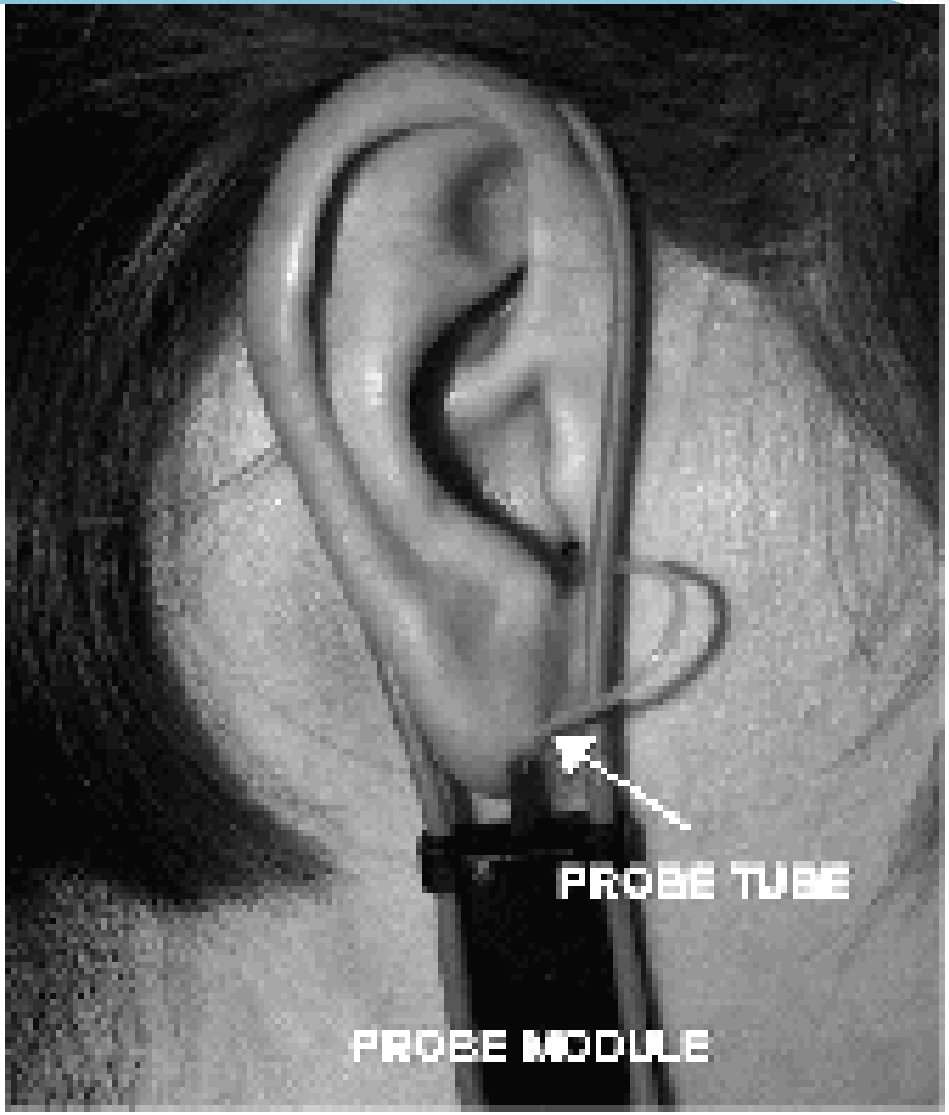


Figure 8. Setup for the coupler portion of the real-ear-to-coupler difference (RECD) measurement on the Audioscan RM500.

Real-Ear Measure:

- 1. Conduct otoscopic examination.
- 2. Place probe tube in the ear canal, with end of the tube at appropriate distance from the intertragal notch (i.e., within 5 mm of the eardrum).
- 3. Couple transducer to the standard foam ear tip (or earmold tubing).
- 4. Insert foam ear tip (or custom earmold) into the ear, being careful not to move the inserted probe tube.
- 5. Introduce the same signal as used with the coupler measurement.
- 6. Store the real-ear measurement.
- 7. Subtract the stored coupler response from the real-ear measurement to produce the RECD. (Most equipment will calculate the real-ear-to-coupler difference for you).


PROBE TUBE
PROBE MODULE

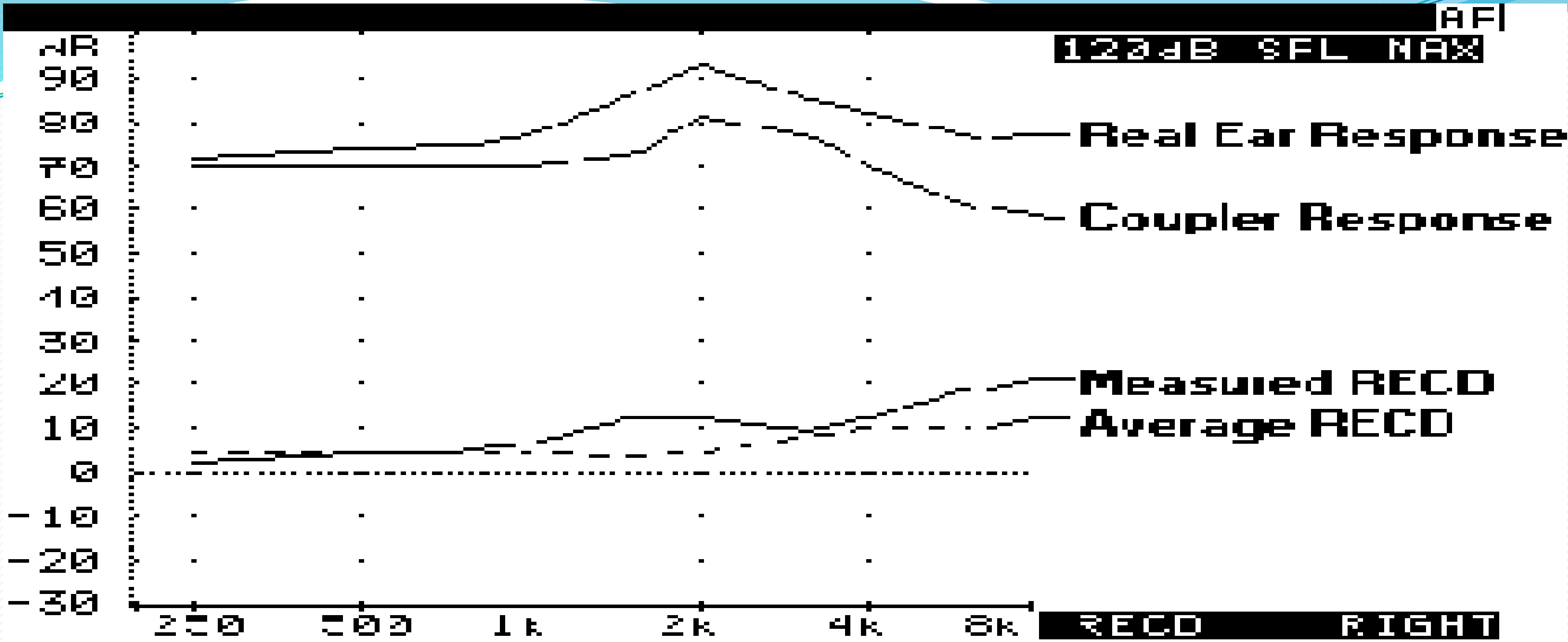


Figure 10. Example of the real-ear-to-coupler difference (RECD) measurement screen on the Audioscan RM500. The two curves at the upper portion of the screen represent the real-ear response and the coupler response, both measured using the same input signal. The two curves at the lower portion of the screen represent the measured RECD (difference between real-ear and coupler response curves) and the age-appropriate RECD (dotted line) for comparison purposes.