Real-Ear Measures in Evaluation of Frequency Response and Volume Control Characteristics of Telephone Amplifiers

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Abstract
The spectral frequency response, frequency response range, and volume control linearity of five telephone amplifiers were examined using real-ear measures. All measurements were performed in KEMAR's (Knowles Electronics Manikin for Acoustic Research) ear canal using a composite speech-shaped waveform as the stimulus. Spectral frequency response and response range of each device was obtained at four volume control settings and compared to those of a standard telephone receiver. Only two of the amplifiers replicate the spectral frequency response of the standard receiver and show an increase in the amount of gain provided with increasing volume control rotation. The remaining three amplifiers show a more restricted spectral frequency response and response range when compared to those of the standard receiver. The volume control characteristics of the amplifiers were somewhat more uniform. Overall results indicate that the spectral frequency response and response range of telephone amplifiers can be objectively evaluated using real-ear measures, and these measures are essential in determining the usefulness of certain telephone amplifying devices.

Key Words: Real-ear measures, telephone amplifiers

Selection and fitting of a hearing aid follows specified standards of clinical practice, however, the same does not apply to the selection and fitting of a telephone amplifier. Selection of a telephone amplifier may occur with or without professional guidance. It may be based on personal preference, anticipated need or lifestyle considerations (Bergman, 1983). An additional consideration may be telephone amplifier-hearing aid electroacoustic compatibility (Beaulac et al, 1989). While frequency and gain characteristics are likely to be verified using probe microphone measures in the hearing aid selection/evaluation process (Skinner, 1988), there are no known reports of telephone amplifier frequency and gain characteristics being measured at any time in their evaluation. It is uncommon for telephone amplifier manufacturers to provide electroacoustic performance data for their devices, therefore it is important for audiologists to obtain and apply this information in selection and fitting decisions. This should increase the efficiency and objectivity of the selection process while potentially optimizing user benefit.

A variety of approaches to measuring the electroacoustic properties of assistive listening devices, including telephone amplifiers, have been reported. Functional gain and word recognition measures have gradually been supplemented or replaced by probe microphone measures (Hawkins, 1984). Clinical studies have incorporated the use of hearing aid processed audiotaped signals (Hodgson and Sung, 1972; Tannahill, 1983); the Knowles Electronics Manikin for Auditory Research (KEMAR) (Hawkins and Van Tasell, 1982); and a 2 cm³ coupler (Calvert et al, 1965; Matkin and Olsen, 1970; Van Tasell and Landin, 1980; Hawkins and Shum, 1985) in an attempt to define assistive listening device characteristics. Of all procedures, only probe microphone measures provide an objective and immediate visual display of the intensity by frequency characteristics of
the auditory signal the user receives. Only probe microphone data can be compared directly with audiometric data to serve as a guide in device selection.

The purpose of this study was to implement probe microphone measures in the examination of electroacoustic characteristics of selected, commonly available telephone amplifiers. A related purpose was to demonstrate the importance and ease of incorporating probe microphone measures in the clinical selection of telephone amplifiers. Specifically, this study investigated physical and spectral frequency response shape, frequency response range, and linearity of volume control setting in selected telephone amplifiers.

MATERIALS AND METHOD

Three portable amplifiers (AT&T strap-on model (AT&T), Radio Shack receiver-amplifier handset model #43-269 (RS-269), and Radio Shack Duofone Snap-in amplifier model #43-237 (RS-237)) and two telephones with internally hardwired amplifiers (Walker Clarity Amplifier Phone model # W-1000 (W-1000) and Williams Sound Teletalker model #Tel 004 (Tel-004)) were selected for use in this study. A standard, Western Electric (WE), G-type telephone receiver handset served to provide baseline data.

Measures were made using a Fonix 6500 Real-Ear Analyzer System and a Knowles Electronics Manikin for Acoustic Research (KEMAR) placed in an Industrial Acoustics Corporation (IAC) sound-isolation booth. A speech-shaped composite waveform consisting of 80 simultaneously presented pure tones spaced at 100-Hz intervals between the frequencies of 100 and 8000 Hz served as the test signal. A Fast Fourier Transformation (FFT) analysis provided data at each 100-Hz frequency point beyond the fundamental at 100 Hz, resulting in 79 measured frequencies for each curve. The smoothing function of the real-ear analyzer was set at log to smooth the set of curves according to an algorithm that averaged the measured data from a group of 3, 5, or 7 adjacent frequencies to obtain the curve point plotted at the central frequency in each group. The number of frequencies per group increased with frequency level. This smoothing algorithm had the same effect on the composite signal as that of warbling a pure-tone signal (Revit, 1991).

The real-ear analyzer's reference microphone was disabled and the sound field was left unleveled since sound was routed through devices other than the real-ear analyzer system's loudspeaker. The real-ear analyzer was set to display the data values for the last curve in dB SPL. The probe microphone was placed in KEMAR's left ear canal at a point 20 mm from the ear canal entrance and secured with surgical tape. Frequency response readings for each device were observed on the real-ear analyzer monitor and recorded for later analysis.

Measurement of WE, RS 269, and AT&T

A Hal-Hen telephone handset demonstrator unit, a commercially available device that is designed to couple a telephone receiver with an audiotape player for purposes of demonstrating the effect of portable telephone amplifiers, served as a relay unit to direct the speech-shaped composite waveforms from the real-ear analyzer system to the standard receiver and portable amplifiers. The relay unit was used to couple the WE receiver, RS 269, and AT&T amplifiers to the sound source of the real-ear analyzer system.

The sound source of the Fonix system was connected to the relay unit at the quik-probe jack. The relay unit was then connected to the WE handset and the RS 269 amplifier, in turn. The AT&T amplifier was measured by coupling it to the WE receiver. Using this procedure, an input composite signal generated by the system was directed to the telephone receiver handset/portable amplifier as illustrated in Figure 1.

A signal of 55 dB SPL was selected to simulate the level of everyday telephone conversation. The telephone receiver was handheld in place over KEMAR's left pinna to simulate in-use telephone receiver placement. Frequency response data were obtained by activating the real-ear analyzer system's sound source and allowing the frequency response reading of the receiver to stabilize on the system's monitor.

Measurement of W-1000, Tel-004, and RS 237

A modified measurement set-up was used with the RS 237, W-1000, and Tel-004 amplifiers. These amplifiers, unlike the AT&T and the RS 269 amplifiers, altered the telephone signal as it was input to the telephone unit (RS 237) or as it was transduced through the internal wiring of the telephone unit (W-1000 and Tel-004). To measure these devices, the composite signal generated by the real-ear analyzer system was
recorded on an endless audio cassette tape and measured by a sound level meter to input at 55 dB SPL into the receiver of a stimulus-sending telephone located in a sound-isolated room adjacent to the room with the stimulus-receiving telephone, amplifiers, and monitoring equipment (Fig. 2).

The stimulus receiving telephone handset was handheld in place over KEMAR's left pinna. A transmission line between sending and receiving telephone units was opened by placing a call from one room to the other via the Illinois Bell Telephone network. Once again, the frequency response of these devices was measured with the sound source of the analyzer turned off and with the probe microphone tube placed 20 mm into KEMAR's left ear canal.

Data Management

The above procedures were used to obtain frequency response measures at 25, 50, 75 percent; and full-on (100%) volume control rotation to determine the linearity of each device's volume control. All measurements of frequency response range and volume control linearity were repeated once to observe test-retest variability. Frequency response test-retest variability was found to be less than 3 dB across test frequencies.

The spectral frequency response of each telephone amplifier set at different volume control settings was observed and recorded for comparison with data from the standard receiver (WE). Frequency response range and
volume control linearity was measured for each amplifier at octave and half-octave frequencies. In order to conservatively define the frequency response range for each amplifier, ANSI standard S3.22-1987 for hearing aid measurement was modified by using a -10 dB re: high frequency average intercept instead of the proposed -20 dB. This modified standard provided a means for measuring the frequency response range of telephone amplifiers when no national standard currently exists. This modified procedure is believed to maintain the standard's validity as a bandwidth measure.

The high frequency average was determined by averaging the output levels at 1000, 1600, and 2500 Hz at each volume control setting for each amplifier. The intersection of a horizontal line drawn at a 10 dB down point from the high frequency average on the frequency response curve defined the limits of the frequency response range. This procedure provided a systematic method for recording measurements and making comparisons across amplifiers.

Volume control linearity was defined as the degree to which the gain (in dB) is a linear function of volume control rotation. A modified version of the ANSI S3.33-1971 standard for hearing aids was used to determine the linearity of each volume control. According to the standard, linearity is measured as the difference in output and input sound pressure level in relation to the gain control setting. In the present study, this difference was calculated at 2000 Hz rather than at the 1000 Hz as stated in the standard, to accommodate measurement of the peak of a tulip-shaped component of the frequency response curve that appeared to be characteristic of telephone amplifiers.

RESULTS

Spectral Frequency Response and Frequency Response Range

As expected, real-ear frequency response data for the portable telephone amplifiers are influenced by the electroacoustic characteristics of their host receiver. A conventional telephone receiver operates on a bandwidth of approximately 800 to 4000 Hz (Erber, 1985). Its spectral frequency response is characterized by a sharply rising output from about 800 to 1200 Hz, followed by a slowly rising pattern to about 2000 Hz, and then a precipitous drop after 4000 Hz, thus resembling a tulip peak (Erber, 1985). In this study, the WE standard receiver showed the characteristic tulip peak in its spectral frequency response and was found to provide a frequency response range extending from 900 Hz to 3900 Hz. The characteristic tulip peak was evidenced in the frequency response configuration obtained for all amplifiers, portable and hardwired.

The spectral frequency responses obtained from the AT&T and the RS 269 amplifiers were smooth and at 25 percent volume control rotation were within 8 and 10 dB of the response of the standard receiver (WE), respectively. With increasing volume control rotation the spectral frequency response of these devices maintained its general shape but increased in the amount of gain provided. The spectral frequency responses...
Characteristics of Telephone Amplifiers/Fikret-Pasa and Garstecki

Frequency Response of W-1000 Amplified-Telephone at Four Volume Settings

Figure 5  Frequency response of Walker Clarity Amplifier Telephone at four volume settings, as compared to that of standard receiver handset (WE).

The frequency response range and total response width for each amplifier calculated according to the modified ANSI S3.22-1987 standard are listed in Table 1. Overall, telephone amplifier frequency response ranges were comparable to the range demonstrated by the unamplified receiver (WE). While two amplifiers (RS 237 and Tel-004) were found to have

Table 1  Frequency Response Limits and Ranges of Telephone Amplifiers at Four Volume Control Settings

<table>
<thead>
<tr>
<th>Telephone Equipment</th>
<th>VC Rotation (%)</th>
<th>Low</th>
<th>High</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Receiver</td>
<td>NA</td>
<td>900</td>
<td>3900</td>
<td>3000</td>
</tr>
<tr>
<td>Radio Shack</td>
<td></td>
<td>1000</td>
<td>4000</td>
<td>3000</td>
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<tr>
<td>Amplifier-Rece iver</td>
<td>25</td>
<td>950</td>
<td>4500</td>
<td>3500</td>
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<tr>
<td></td>
<td>50</td>
<td>900</td>
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<td>3600</td>
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<tr>
<td></td>
<td>75</td>
<td>850</td>
<td>4500</td>
<td>3650</td>
</tr>
<tr>
<td>AT&amp;T Strap-on Amplifier</td>
<td>25</td>
<td>900</td>
<td>3700</td>
<td>2800</td>
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<tr>
<td></td>
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<td>3800</td>
<td>3100</td>
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<td></td>
<td>100</td>
<td>1000</td>
<td>3400</td>
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<tr>
<td>Williams Sound Teletalker Amplifier</td>
<td>25</td>
<td>1100</td>
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<td>800</td>
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</table>

CNA = Could not assess.

Figure 6  Frequency response of Teletalker Amplifier Telephone at four volume settings, as compared to that of standard receiver handset (WE).

Figure 7  Frequency response of RS 237 Snap-in Amplifier at four volume settings, as compared to that of standard receiver handset (WE).

d of the RS 237, Tel-004, and W-1000 amplifiers showed more peaks and valleys than the frequency response of the standard receiver (WE), AT&T, and RS 269 amplifiers. W-1000 and RS 237 amplifiers showed a more restricted frequency response spectrum at all volume control settings than the standard receiver. The frequency response spectra of the Tel-004 at 25 and 50 percent volume control rotations also were more restricted than that of the standard receiver, while at 75 percent and full-on (100%) they were very similar to that of the standard receiver. Spectral frequency responses for each amplifier are shown in Figures 3 to 7.
open frequency ranges at selected volume control settings, these findings were regarded as artifactual since they were not evidenced at neighboring settings. Except for the open lower frequency limit at the 75 percent volume control rotation for the Tel-004, open frequency limits can be generally surmised from the remaining family of results for any given amplifier. That is, the higher frequency limit for the Tel-004 at 25 percent volume control rotation is likely to be in the neighborhood of 4000 Hz and for the RS 237 it is likely to be approximately 3700 Hz.

Of all, the frequency response range of the RS 269 and AT&T amplifiers at 25 percent volume control rotation is very close to the frequency response range of the standard receiver. The lower frequency limits of both amplifiers, at all four volume control settings, were within ± 100 Hz of the lower frequency limit of the standard receiver. The higher frequency limit of the RS 269 amplifier was up to 600 Hz higher and the higher frequency limit of the AT&T amplifier was as much as 400 Hz lower than that of the standard receiver across volume control settings. The lower frequency limit of the W-1000 was 200 Hz lower to 100 Hz higher than that of the standard receiver while its higher frequency limit was up to 600 Hz higher and its higher frequency limit was within 100 Hz of the lower and higher frequency limits of the WE unamplified receiver, respectively, across different volume settings. Across the volume range, the lower frequency limit of the RS 327 was within 100 Hz of that of the standard receiver, while its higher frequency limit was up to 200 Hz lower than that of the standard receiver.

**Volume Control Linearity**

Volume control linearity was defined as the degree to which the gain, in dB steps, is a linear function of volume control rotation, as discussed above. Figure 8 shows change in gain as a function of the volume control rotation for each amplifier. In this figure, slopes of the lines rather than the absolute values are of interest.

The slope of the line signifying change in gain of the RS 269 amplifier was uniform across the four check points, indicating that gain changed linearly with change in volume control rotation. For the AT&T and Tel-004 amplifiers, the slope of the lines was the steepest between the two middle check points, suggesting that the amount of gain increase was greater between the 50 and 75 percent than between the 25 and 50 percent or the 75 and 100 percent volume control rotation settings. The amount of gain change versus volume control function for the RS 237 was similar to that of the AT&T and Tel-004, however the RS 237 amplifier showed no change in gain between the 75 and 100 percent volume control rotation setting. The W-1000 amplifier showed the greatest increase in gain between the 25 and 50 percent volume control settings, with increasingly smaller gain changes for the preceding settings.

**DISCUSSION**

Probe microphone measures provide an immediate and objective visual display of the amount and configuration of the auditory signal received by the user of the telephone amplifier. Probe microphone measurement data can be directly compared with audiometric data as a guide in device selection and fitting. The influence of an amplifying device's response properties on user benefit is as important to know in selection of telephone amplifiers as it is in selection of hearing aids. Since electroacoustic performance data are not routinely provided by device manufacturers, real-ear measures may be more important in the selection and fitting of telephone amplifiers than in the selection and fitting of hearing aids that typically incorporate electroacoustic performance data provided by the manufacturer.

Utilization of modified ANSI standards in determination of response bandwidth and volume control linearity ensures systematic com-
comparison of these specific characteristics across selected amplifiers, while tailoring the specific standard to the characteristics of telephone amplifiers. A modified ANSI S3.22-1987 standard for determining response bandwidth appropriately assesses the frequency response range of the telephone amplifiers and open ranges are observed only in isolated instances. Similarly, a modified ANSI S3.33-1971 standard adequately demonstrates volume control linearity characteristics of telephone amplifiers. While the above standards appropriately demonstrate the specified characteristics of selected telephone amplifiers, standards specific to telephone amplifiers are needed to ensure universally systematic evaluation and comparison.

An input signal of 55 dB SPL was utilized to simulate the level of everyday telephone conversation. Although some may argue that this level is an underestimation of typical input into a telephone mouthpiece, because the purpose of this study was to evaluate spectral characteristics and not the gain of telephone amplifiers, an input level of 55 dB SPL is believed to be valid to adequately represent typical frequency response range and volume control characteristics. In addition, two different methods of stimulus input (on-line versus taped) were required for the evaluation of the devices. The RS 269 and AT&T amplifiers were evaluated using on-line input, while the Tel-004, W-1000, and RS 237 amplifiers were evaluated with taped stimuli. The differences in the spectral frequency responses of the devices could be due in part, to different evaluation methods.

Spectral Frequency Response and Frequency Response Range

Results from the present investigation reveal that telephone amplifiers differ in frequency response spectra and range as well as volume control characteristics, signifying the importance of incorporating probe microphone measurements in telephone amplifier selection and evaluation. Of all the amplifiers evaluated, the RS 269 demonstrates a frequency response range greater than that of the standard, unamplified receiver (WE). The frequency response spectra of the RS 269 amplifier, at 25 percent volume control setting, is similar to that of the standard receiver. Overall frequency response spectra increased with increasing volume control rotation. Additionally, gain changed linearly with change in volume control rotation. If one can assume that most telephone amplifiers are likely to be used at 50 to 75 percent volume control rotation, then the RS 269 amplifier would seem to provide the greatest benefit of all amplifiers studied. It has the widest frequency response range and the highest upper frequency response limit which is likely to increase a user's potential for high frequency speech signal detection (within the upper limits of the host receiver) over other tested amplifiers. The AT&T amplifier demonstrates a frequency response range close to that shown by the standard receiver and RS 269 amplifier, however, the higher frequency limit of the AT&T amplifier is consistently lower than that obtained from either the RS 269 amplifier or the standard receiver by as much as 400 Hz. Similar to the RS 269 amplifier, the frequency response spectra of the AT&T amplifier follows the general contour demonstrated by the standard receiver, and it increases with increased volume control rotation.

The frequency response range of the Tel-004, W-1000, and RS 237 amplifiers remains in the vicinity of the range of the standard receiver. What is more important, however, is that their frequency response spectra either minimally matches the standard receiver, as in the case of the Tel-004 amplifier, or fails to reach the frequency response spectra of the standard receiver, as in the case of the W-1000 and the RS 237 amplifiers, even at the highest volume control settings. The restricted frequency response spectra demonstrated by these amplifiers at all volume control settings reveals that, in reality, these devices actually attenuate rather than amplify telephone transmitted auditory signals. The difference in output and the restricted frequency response spectra could easily have a detrimental effect on a hearing-impaired individual's speech-understanding ability.

Volume Control Linearity

In regard to their volume control characteristics, portable and hardwired amplifiers do not differ significantly from each other. The RS 269 demonstrates a linear volume control while AT&T, RS 237, and Tel-004 amplifiers reveal smaller increases in gain with increased volume control rotation. A change in the amount of gain as a function of volume control rotation evident in four of the five amplifiers suggests a change in frequency response with volume control setting. This characteristic is used beneficially in most high fidelity amplifiers and in
some advanced hearing aids to compensate for changes in equal loudness contours with level. It is also useful in hearing aids and devices such as telephone amplifiers to reduce feedback at high gain settings.

**CLINICAL IMPLICATIONS**

Information describing frequency spectra and range as well as volume control characteristics of telephone amplifiers is essential in their fitting and optimal use. Results of the present investigation reveal that telephone transmitted sound is attenuated rather than amplified at all volume control settings in two of the amplifiers and at 25 and 50 percent volume control settings for one amplifier, actually worsening the potential for successful telephone communication when compared to telephone transmission with a standard receiver. Alternatively, of the devices evaluated with the on-line input method, the RS 269 would seem to be the amplifier of choice if there is need for high frequency amplification due to its higher upper frequency limit at all volume control settings. The AT&T amplifier may be more appropriate when amplification is needed in the middle frequencies. Of those devices evaluated by means of taped input stimuli, the Tel-004 amplifier provides a relatively broader frequency response range when compared to the W-1000 and RS 237 amplifiers.

Audiologists are advised to select telephone amplifiers only after obtaining real-ear response measurements and after considering these measurements along with the audiometric data of the potential user. Real-ear response measurement data also may be important to consider in educating hearing-impaired individuals in how to use such devices most effectively.

Telephone devices can be measured objectively using real-ear techniques and such measurement is called for on the basis of variability across devices and within devices at various volume control rotation settings. It is therefore recommended that because of immediacy, objectivity and ability to be directly compared with audiometric data, probe microphone measures be applied in routine selection of telephone amplifiers. Incorporation of these measures in selection and fitting of telephone amplifiers may help ensure that a hearing-impaired individual's sensory capability is maximized in telephone communication.

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**REFERENCES**


