Criteria for DPOAE [1]

by

Michael J.M. Raffin, Ph.D.[2,3]

Candace R. Blank, M.A., CCC-A [2]

&

Andrew J. Hotaling, M.D.[3]

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1 *Short Course taught at the Annual Convention of the American Academy of Audiology Dallas, TX 30 April 1995*

2 *Department of Audiology, Loyola University Medical Center, Maywood, IL*

3 *Department of Otolaryngology, Head & Neck Surgery, Loyola University Medical Center, Maywood, IL*

Our past experiences (Hotaling, Blank, Park, Matz, Yost and Raffin, 1994[1]; Hotaling, Blank, Park, Yost, Matz and Raffin, 1994[2]) have shown characteristic instrument distortions which could be mistaken for emissions. In the present report, we review our findings and also present some data on newly marketed instruments and upgrades of existing instruments. Specifically, since our previous report, the Virtual Instrument Company has released a new version of software, and also has made available thicker tubing. For the measurements obtained with this instrument as reported in the present investigation, new earphones were used which had not been used previously in the clinic, and the instrument was calibrated immediately prior to any measurement. We will also present data related to the performance of the Biologic OAE Instrument.

For the present investigation, the Virtual Model 300 was assessed using version 1.06 for the software, and the thick transducer tubing attached to apparent clones of the Etymotic, ER-3A earphones.

The Biologic instrument was evaluated using the TEOAE as well as the DPOAE options. Typical instrument settings were 50 sweeps per set and 2048 token, a clock rate of 50 kHz and the $2F_1 - F_2$ distortion product. The F_2/F_1 ratio was 1.20, and presentation levels for the two primaries were equal at 75-dB SPL. Measurements were obtained at 8 points per octave.

Figure 1 shows a DPOAE-Gram based on data obtained in a 3.0-cc capacity syringe adjusted for an effective volume of 1.0 cc, using the Virtual, Model 330 system. A signal-to-noise ratio of 19.7 dB is observed at F_2 = 8.8 kHz. A resonant peak of about 12.9-dB SPL (17.3 dB greater than the noise floor) is observed at $F_2 \approx$ 980 Hz. In the 2100 Hz to 2700 Hz region the peak distortion amplitude is -6-

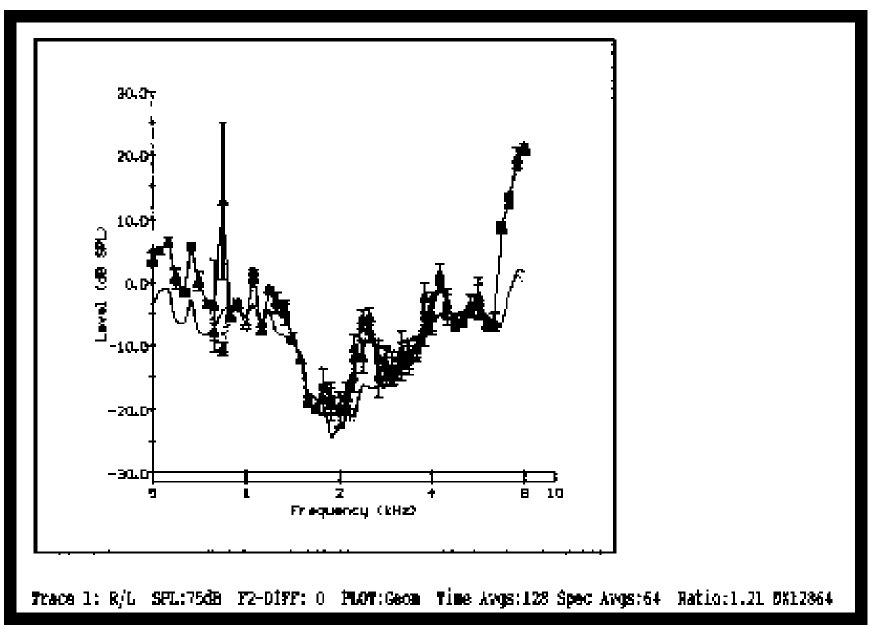

Figure 1 **DPOAE-Gram obtained with Virtual, Model 300, Version 1.06, hard-walled tubes, in a 3-cc capacity syringe adjusted to 1 cc.**

dB SPL and is 10.1 dB greater than the noise floor.

In our opinion, the large distortion products observed in the neighborhood of 8 kHz in Figure 1, warranted some more detailed investigation. The Fast-Fourrier transform of the DPOAE-Gram focussing on the data based on a geometric-mean frequency of 8 kHz, is shown in Figure 2. The peak distortion at F_{dp} = 5745 Hz is 21.5-dB SPL, while the noise is at 1.8-dB SPL. No significant aberration is observed that would indicate instrument malfunction.

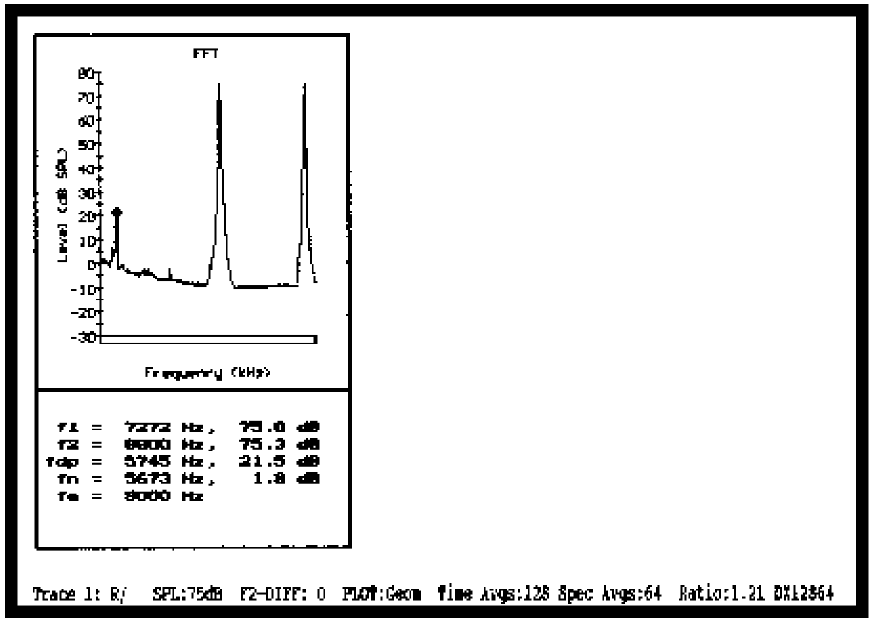

Figure 2 **Fast-Fourrier Transformed detail of data shown in Figure 1.**

Additional details of the DPOAE-Gram shown in Figure 1 were generated by examining the Input-Output function at 500 Hz (shown in Figure 3) and at 8 kHz (shown in Figure 4). At 500 Hz, an essentially monotonic function is observed with approximately unity gain from input levels of 60-dB SPL (where the distortion amplitude exceeds the noise floor) to the maximum 75-dB SPL.

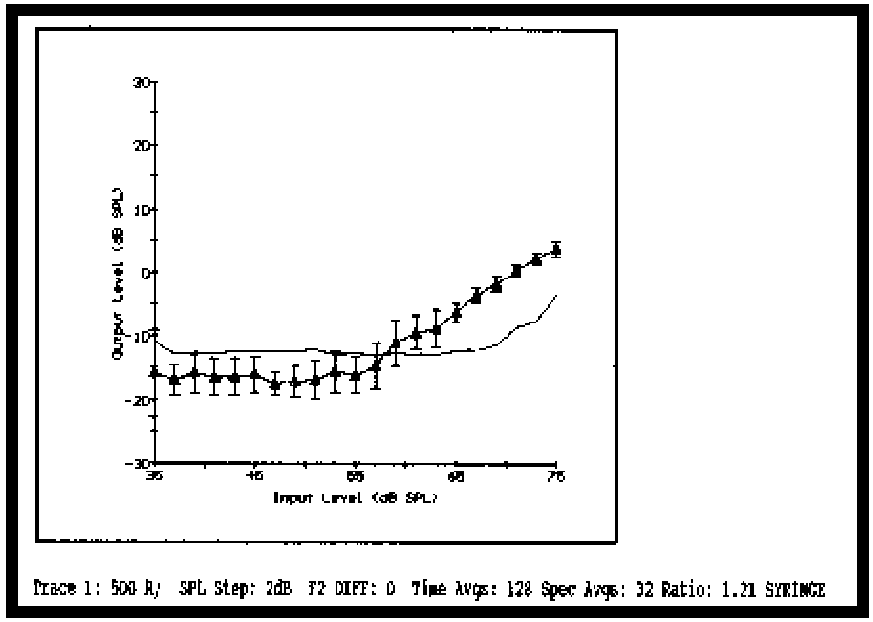

Figure 3 **Input/Output function in 3.0-cc capacity syringe adjusted to a volume of 1.0 cc, at 500 Hz [see Figure 1].**

Two Input-Output functions were obtained at 8 kHz and are shown superimposed in Figure 4. This function is marked by unusual nonlinear characteristics, not unlike what we have described previously. This function rises sharply to a peak output (with an input level of 61-dB SPL), decreases to a trough and then increases monotonically. This non-monotonic input-output function also has been observed in humans and we have previously discussed this pattern [See Figures 17 and 18 from the paper presented to the American Auditory Society by Hotaling *et alii*, 1994].

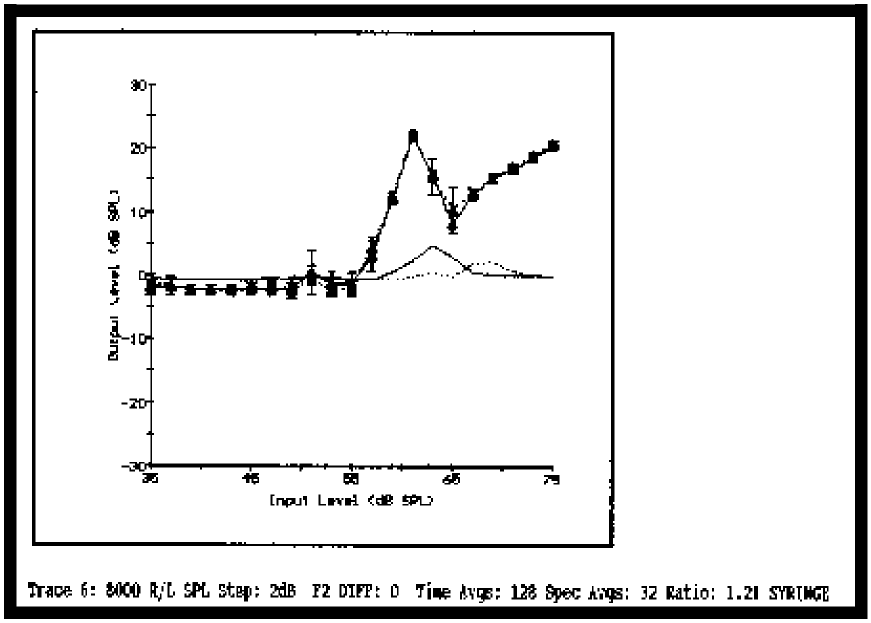

Figure 4 **Input/Output function at 8 kHz, for distortions measured in a 3.0-cc capacity syringe adjusted to a volume of 1.0 cc [see Figure 1].**

Figure 5 illustrates a DPOAE-Gram obtained in a rubber ear. This particular DPOAE-Gram is characterized by large distortion peaks at the two extremes of the frequency range sampled, with signal-to-noise ratios exceeding 30 dB at the geometric-mean frequency of 500 Hz and exceeding 20 dB at the geometric-mean frequency of 8 kHz. When the probe assembly is removed and then re-inserted into the rubber ear, identical results may not be obtained.

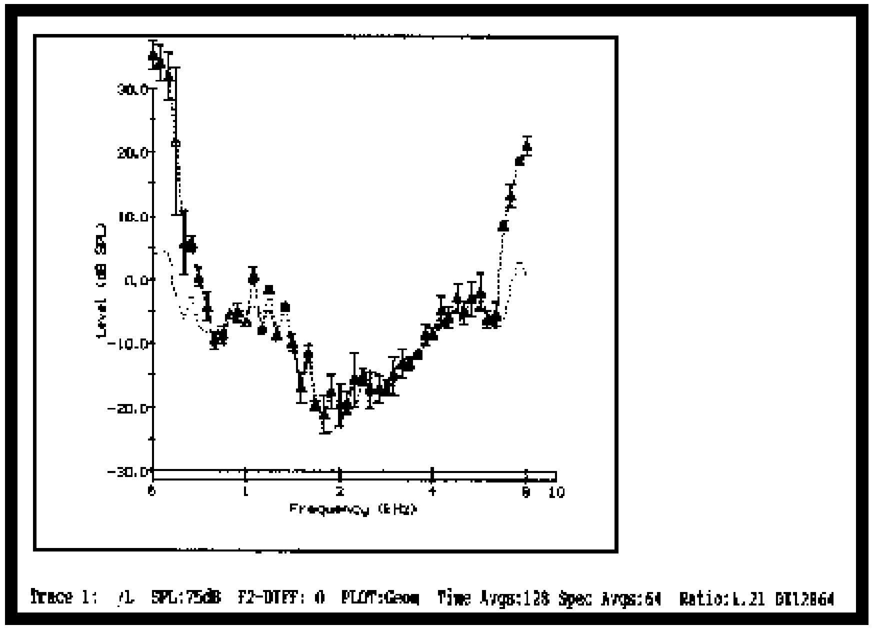

Figure 5 **DPOAE-Gram measured in a rubber ear.**

Figure 6 illustrates this attempted replication of the results observed in Figure 5. The major peak distortion previously observed at 500 Hz, is no longer evident, although the peak distortion observed at 8 kHz is larger in this replication (the signal-to-noise ratio now exceeds 25 dB, although the noise floor has not changed appreciably remaining at about -2-dB SPL). Moreover, there is, in this replication, a new region of distortion products previously not evident from Figure 5. Between 4 and 6 kHz, there is a region of distortion which consistently exceeds 0-dB SPL, and is more than 15 dB "above" the noise floor, reaching a peak value of 20-dB SPL! A Fast-Fourrier detail of this DPOAE-Gram in this frequency region is shown in Figure 7.

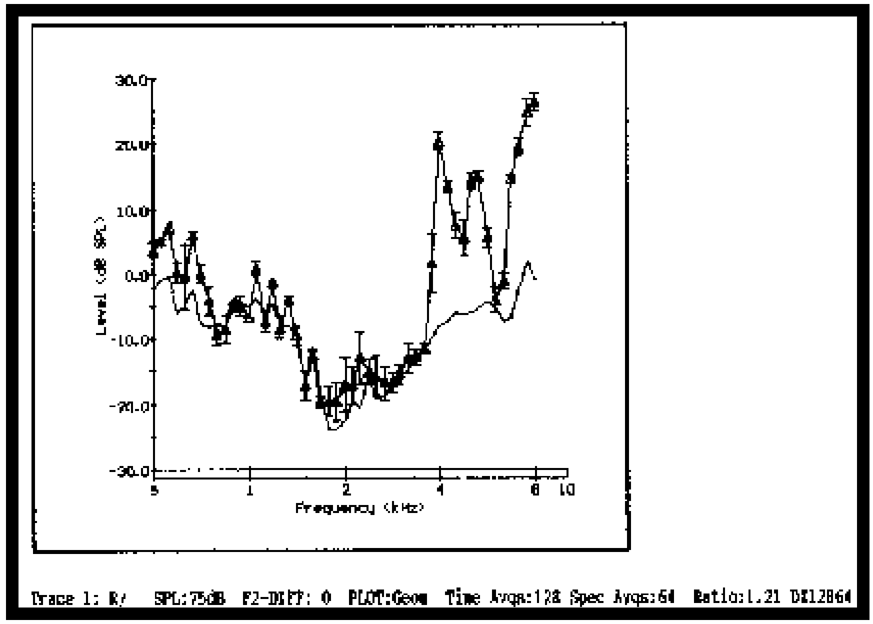

Figure 6 **DPOAE-Gram obtained in a rubber ear, showing a resonance in the 4 to 6 kHz region [see also Figure 5].**

Figure 7 illustrates details of distortion products shown in Figure 6. For a geometric-mean frequency of 4 kHz, the peak distortion value is 20.4 dB SPL, with a noise floor at
-7.8-dB SPL producing a signal-to-noise ratio for this distortion product of 28.2 dB! The Fast-Fourrier transform failed to indicate significant instrument malfunction.

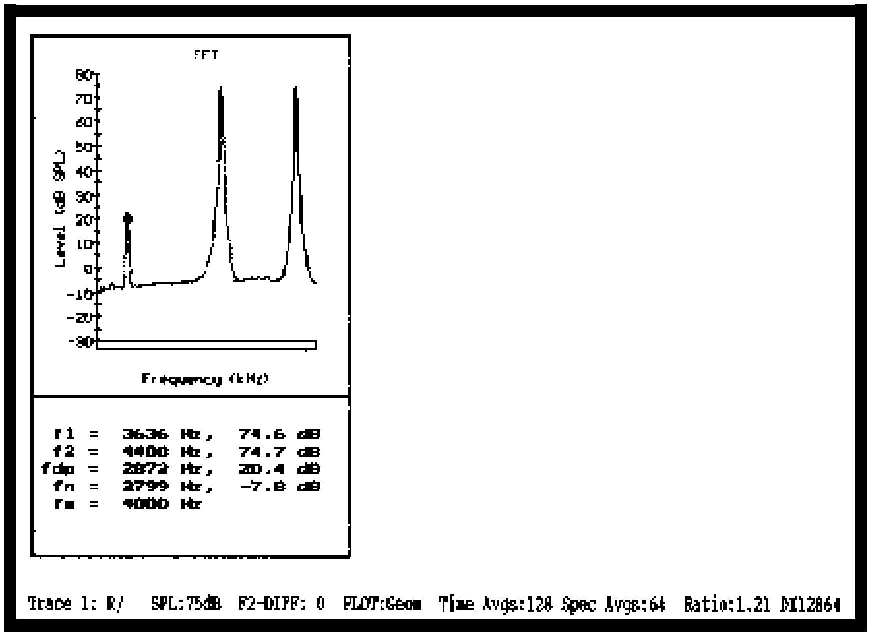

Figure 7 **Fast-Fourrier transformation detail of data shown in Figure 6.**

Figure 8 illustrates DPOAE-Grams obtained in a 3.0-cc capacity syringe adjusted to a volume of 2.0 cc for two stimulus signal levels (75-dB SPL and 55-dB SPL). Neither the noise levels nor the distortion levels show a linear relationship as a function of stimulus levels. That is, while the stimulus levels were reduced by 20 dB, this did not result in a reduction in the noise level by 20 dB across frequencies, nor in a reduction of 20 dB in the distortion products across frequencies. Near 4500 Hz, the distortion product amplitude decreased by only about 7 dB, but the noise floor decreased by over 15 dB. At a geometric-mean frequency of about 1000 Hz, both the distortion amplitude and the noise level decreased by about 20 dB. At a geometric-mean frequency of about 2000 Hz, the noise floor decreased by about 5 dB while the distortion amplitude decreased by about 15 dB. The instrument noise floor observed with this device may be, in part, a function of the signal intensity or amplifier setting. Instrument distortion products also vary with signal levels, although that relationship is not predictable across frequencies.

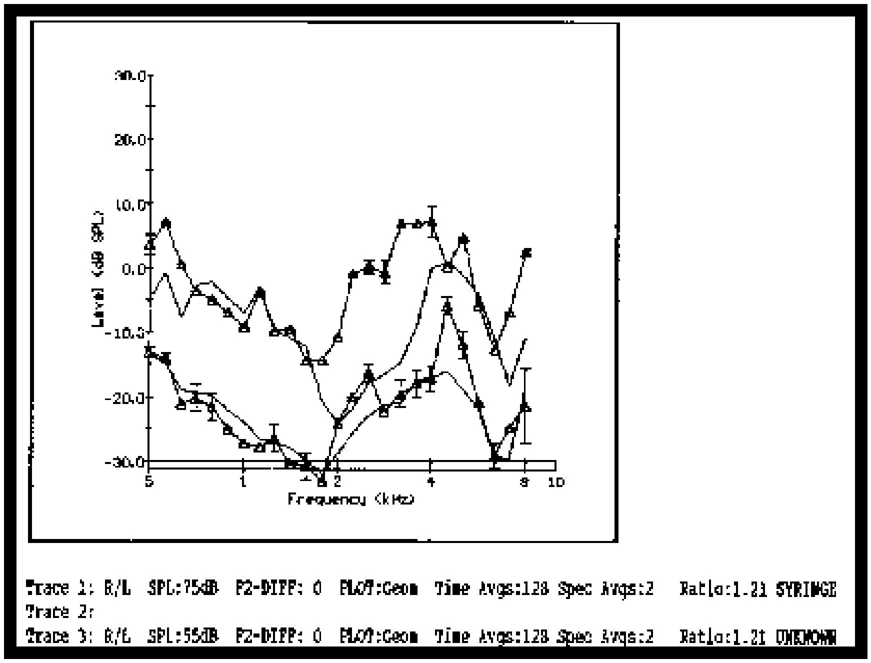

Figure 8 **DPOAE-Grams obtained in a 3.0-cc capacity syringe adjusted to a volume of 2.0 cc for two primary frequency levels (55-dB SPL [lower tracing] and 75-dB SPL [upper tracing]).**

Figure 9 shows distortion products obtained in a 1.0-cc capacity syringe adjusted to 0.5 cc with a recently released instrument (Biologic). The frequency spectrum of the signal, shown in the top center panel, exhibits resonance peaks and at least one major anti-resonance (near 3 kHz). In the DPOAE-Gram, the low-frequency region (less than 1500 Hz) shows the largest distortion products, though their amplitudes remain less than 0-dB SPL, and the signal-to-noise ratio in that frequency range is on the order of 30 to 40 dB. The region near 2 kHz appears to remain free of artifact. Other distortion areas (between 3 and 4 kHz, and near 8 kHz) appear to coincide with anti-resonances, and their magnitude remains well below 0-dB SPL, across the 10 replications.

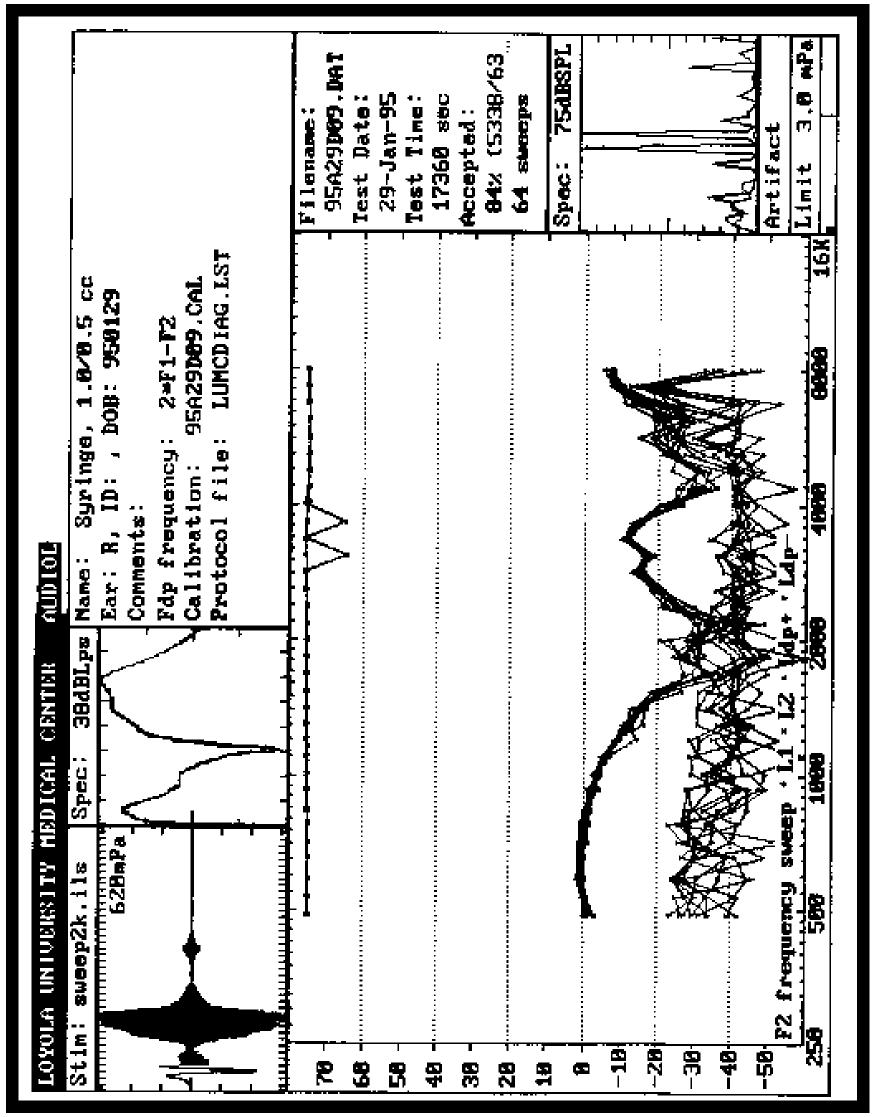

Figure 9 **DPOAE-Grams obtained in a 1.0-cc capacity syringe adjusted to an effective volume of 0.5 cc.**

Figure 10 illustrates measurement findings for 10 replications of a DPOAE-Gram obtained in a 3.0-cc capacity syringe adjusted to a 0.5-cc volume. While the volume for this cavity is identical to that used for Figure 9, the aspect ratio of the cavity is different (the diameter of the present cavity being larger, and the length therefore shorter). The major anti-resonance appears to have shifted to a slightly lower frequency (approaching 2 kHz rather than 3 kHz), and is now incomplete. The DPOAE-Gram shows that, except at low frequencies, the noise floor is quite low (near -40-dB SPL). There does not appear to be any artifact in the 2-kHz region. However, at lower frequencies, while the distortion product amplitude is at or below 0-dB SPL, the signal-to-noise ratio typically exceeds 20 dB. Beyond 2000 Hz, there is a peak distortion near 4000 Hz, and also near 8000 Hz. The pattern across 10 trials is highly replicable.

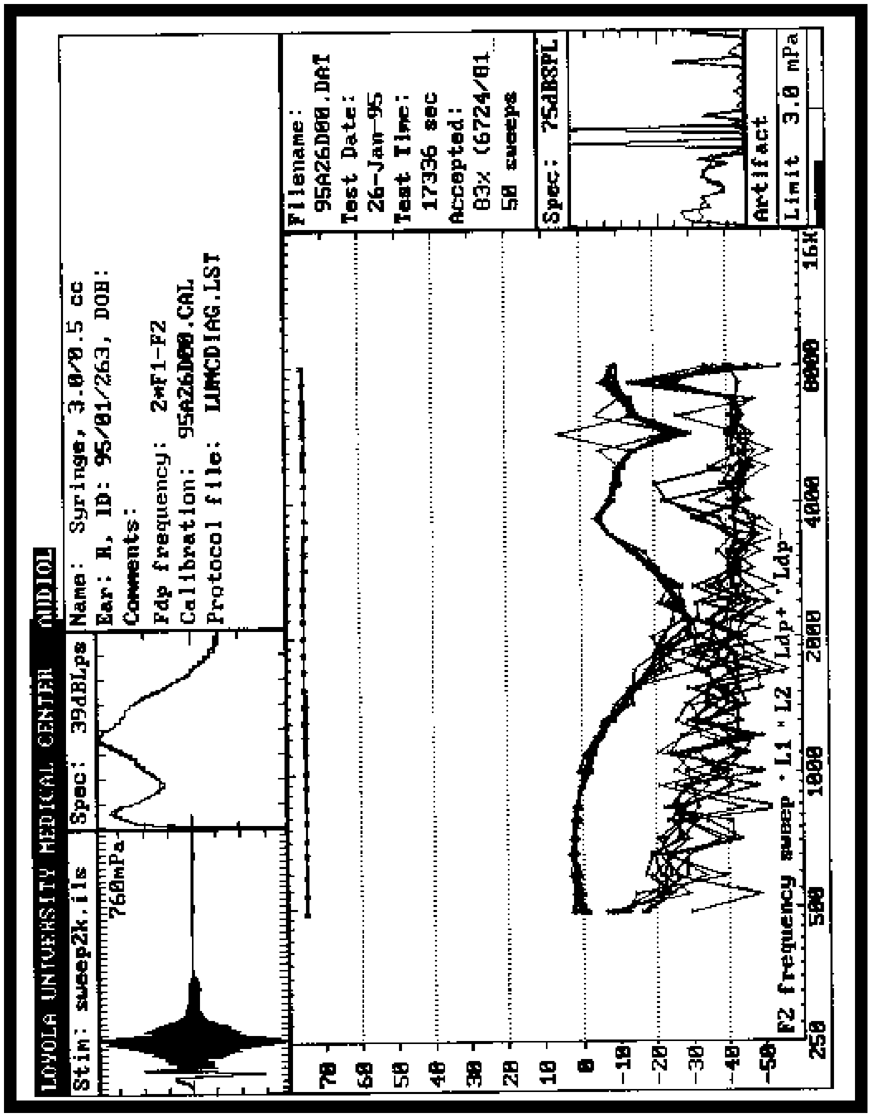

Figure 10 **DPOAE-Gram obtained in a 3.0-cc capacity syringe adjusted to a volume of 0.5 cc**.

Figure 11 shows 10 replications of an input-output function for F_2 = 708 Hz measured in a 3.0-cc capacity syringe adjusted to a volume of 0.9 cc. A monotonic function is indicated with about unity gain, and no evidence of saturation.

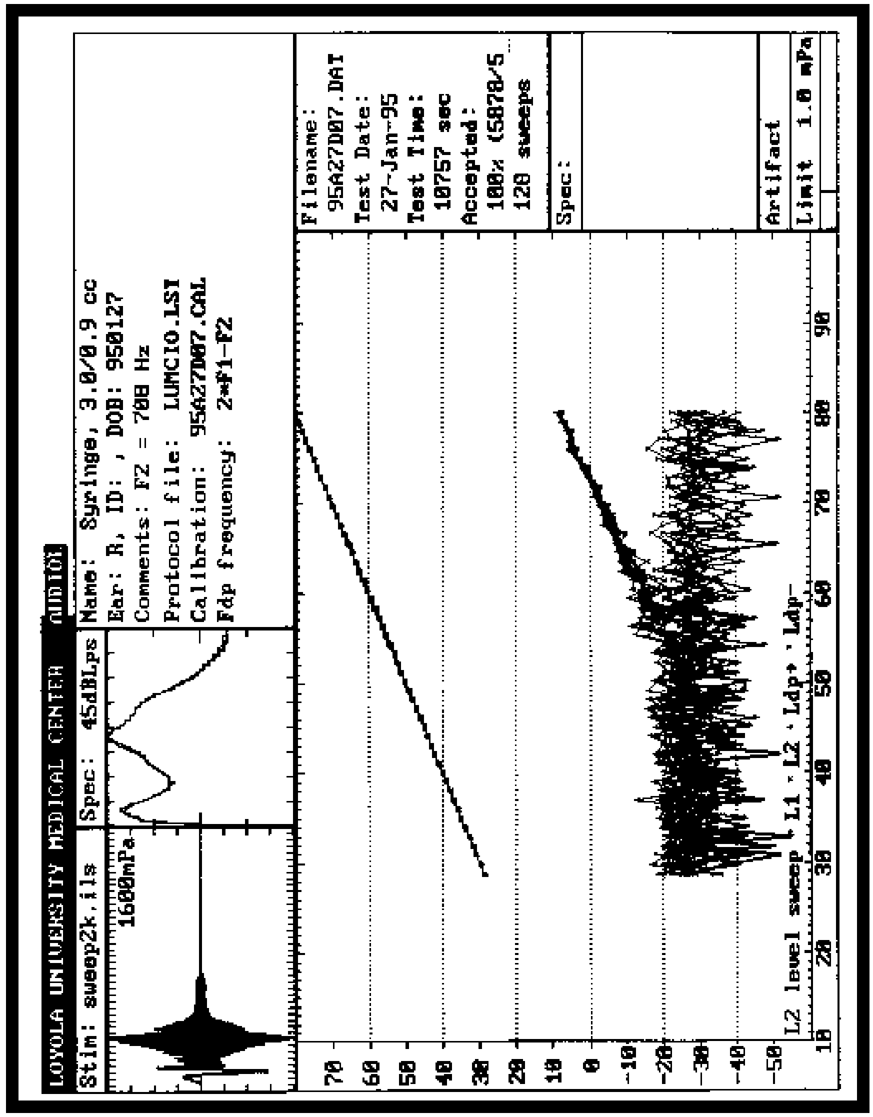

Figure 11 **Input/Output function obtained in a 3.0-cc capacity syringe adjusted to 0.9 cc (10 replications) [see Figure 12].**

Figure 12 illustrates 10 replications of a DPOAE-Gram obtained. The amplitude as a function of time (upper left) indicates some transducer ringing. The frequency spectrum (Center top) indicates some resonances (poles) as well as zeroes or anti-resonances particularly in the frequency region near 8 kHz. This is documented in the main DPOAE-Gram, through decreased primary signal level amplitudes plotted as the top lines. Under these conditions, in a 3.0-cc capacity syringe adjusted to a volume of 1.0 cc, this instrument did not yield distortion products exceeding 0-dB SPL. However, because this instrument is sensitive and able to measure very small sound-pressure levels, one can document signal-to-noise ratios on the order of 30 dB in the frequency region of 500 Hz to 1000 Hz. No significant instrument distortion is noted in the frequency region approximating 2 kHz, although distortion peaks are noticeable between 2500 and 8000 Hz.

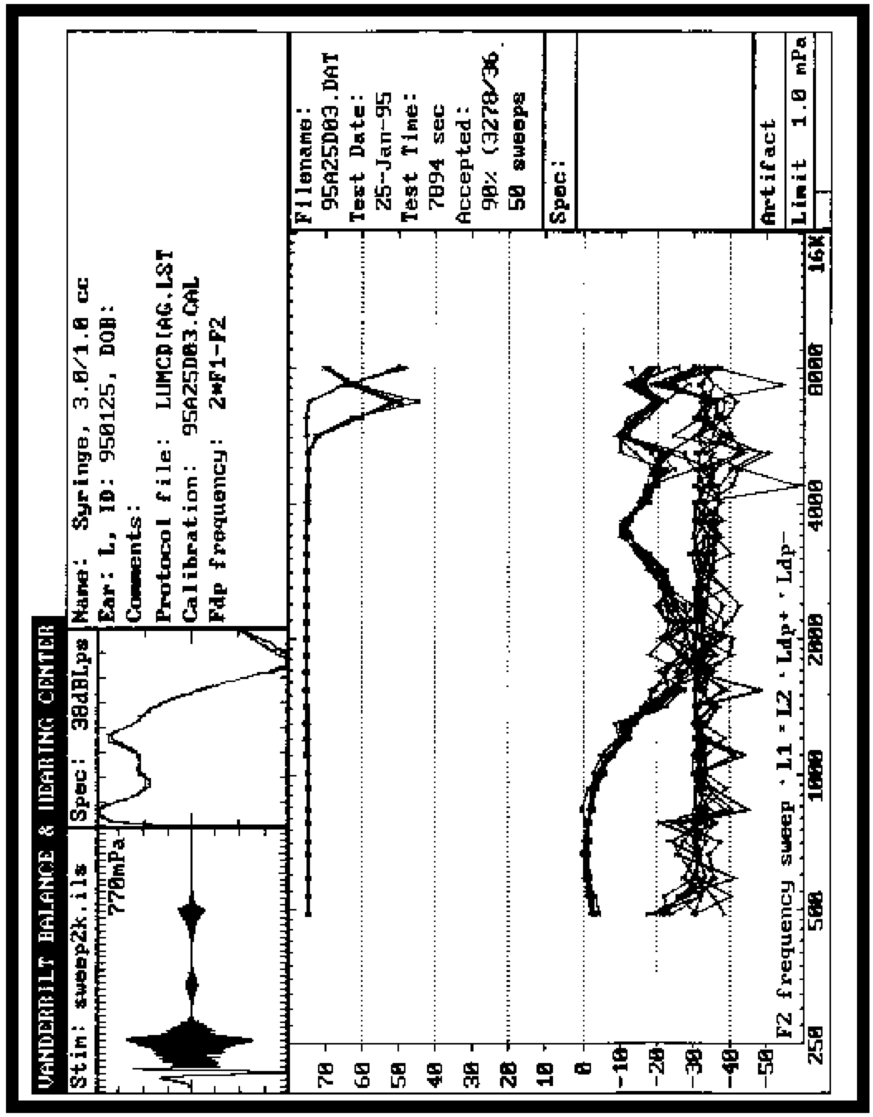

Figure 12 **DPOAE-Gram obtained in a 3.0-cc capacity syringe adjusted to a 1.0-cc volume**.

Figure 13 illustrates 10 replications of a DPOAE-Gram obtained in a 3.0-cc capacity syringe adjusted to a volume of 2.0 cc. A distinct anti-resonance is noted between 2 and 4 kHz, and this also is manifested in the amplitude fluctuations of the primary frequencies. Moreover, in this particular instance, we note that a distortion peak coincides with the frequency region at which the null or anti-resonance occurs. This is repeated near 8000 Hz. Peak distortion products in the low frequencies, less than 1000 Hz, approximate -10-dB SPL, but they are still more than 20 dB greater than the noise floor (which drops to -50-dB SPL in spots). Relative to the data shown in Figure 12, the cavity volume has been increased by increasing the length of the cavity. The anti-resonance near 3 kHz in Figure 13 is more pronounced than that found in Figure 12, near 2 kHz.

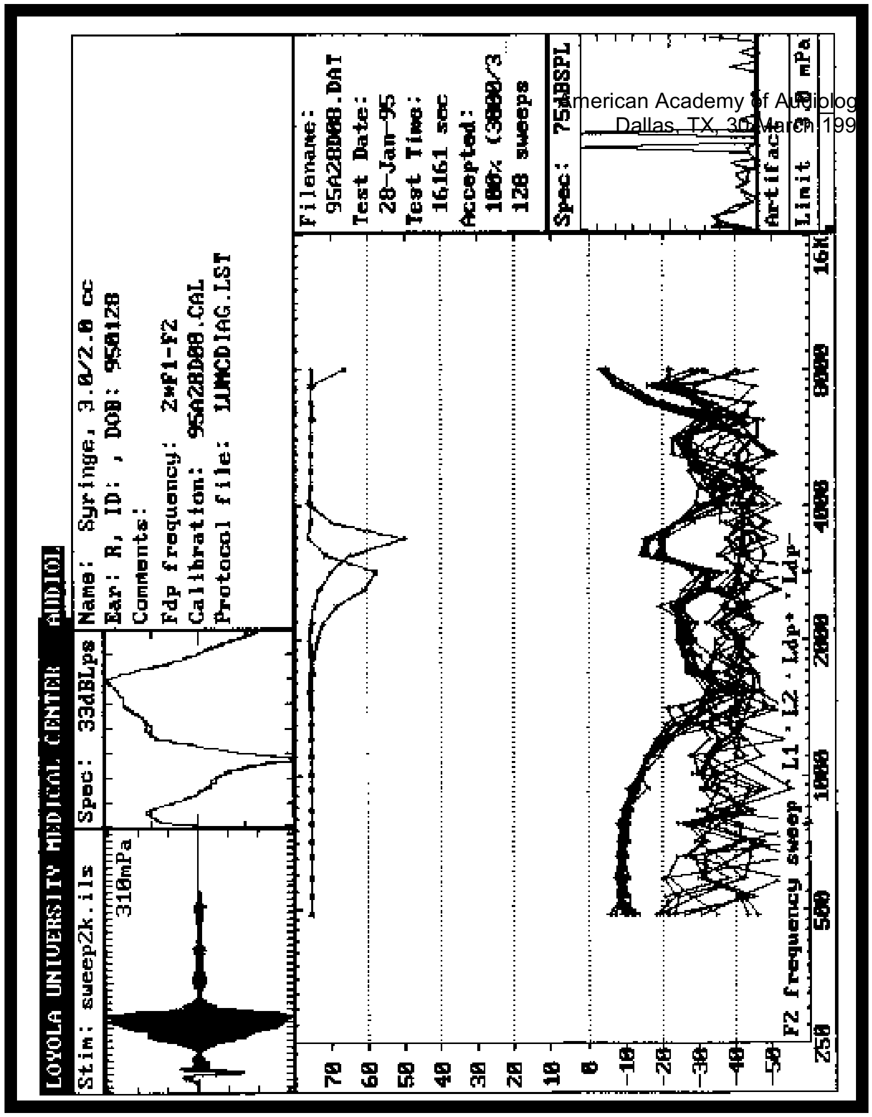

Figure 13 **DPOAE-Grams obtained in a 3.0-cc capacity syringe adjusted to a 2.0-cc volume.**

Figure 14 illustrates the TEOAE obtained in a 3.0-cc capacity syringe adjusted to a 0.9-cc volume. While the amplitude as a function of time characteristics indicate ringing, and there also is a resonant peak near 3500 Hz, followed by a sharp drop out, so that little energy is present beyond 6 kHz, there is no identifiable artifact in this tracing.

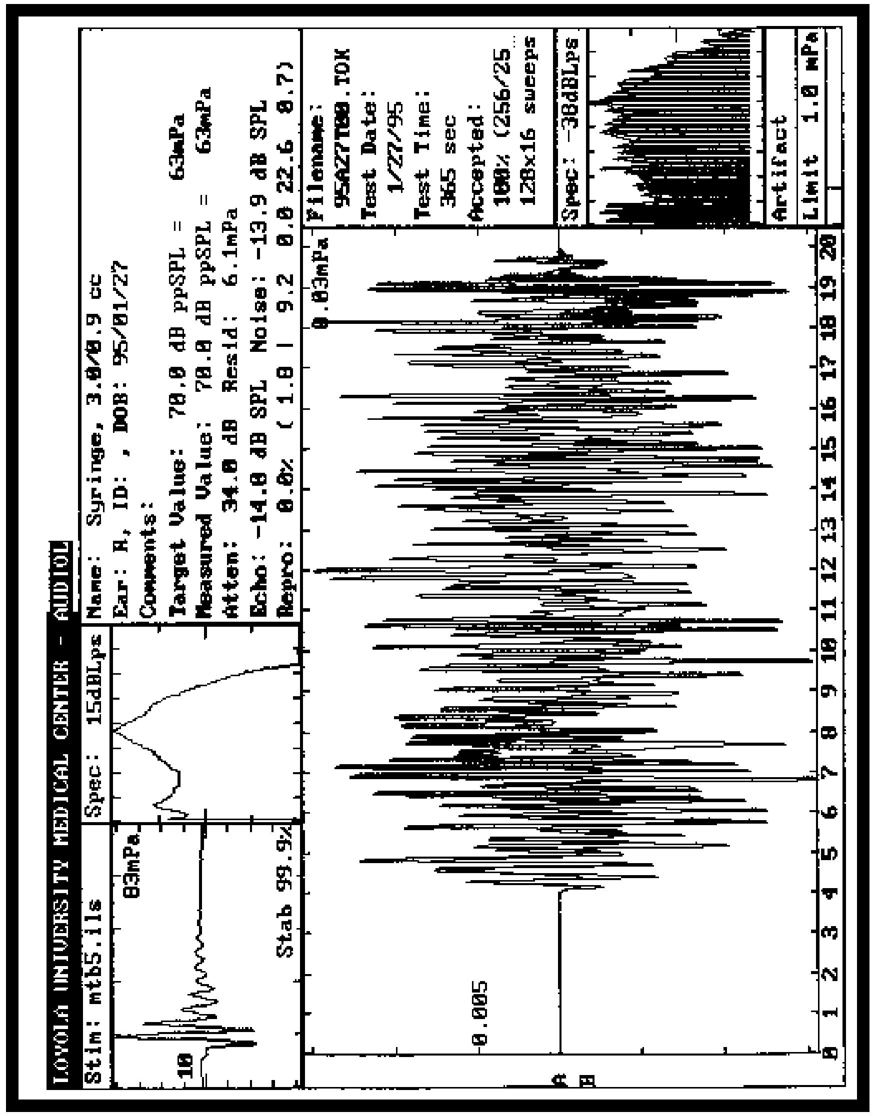

Figure 14 **TEOAE-Gram obtained in a 3.0-cc capacity syringe adjusted to an effective volume of 1.0 cc**.

Figure 15 shows the TEOAE measured in a 5.0-cc capacity syringe adjusted to a 1.0-cc volume. The amplitude as a function of time characteristics indicate considerable transducer ringing. In addition, the frequency spectral characteristics indicate that the signal energy is essentially low-pass filtered at 5 to 6 kHz and there is a resonant peak at about 3500 Hz. There also appears to emerge a small "island" of distortion in the 3500 to 6000 Hz region.

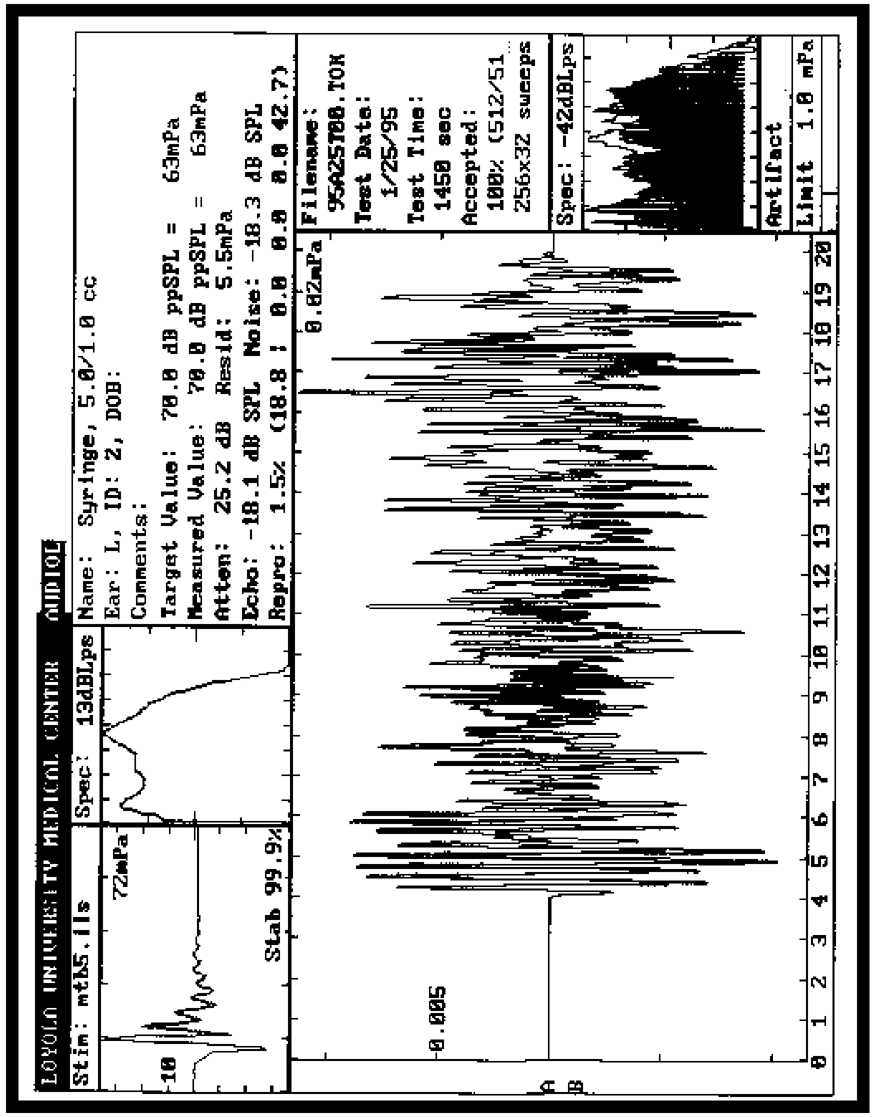

Figure 15 **TEOAE obtained in a 5-cc capacity syringe adjusted to an effective volume of 1.0 cc.**

For the Biologic Instrument, if one ignores the frequencies less than 1500 Hz, then one could postulate some criteria for the differentiation of emissions from instrument distortions. Specifically, in the frequency region of 2000 to 4000 Hz, our observations have not revealed instrument distortions exceeding -10-dB SPL which were sustained over more than 1/3rd. octave. Specifying artifact levels in terms of signal-to-noise ratio may yield an artifactually high number, because the instrument noise floor is so low. The display of measured signal level on the DPOAE-Gram may facilitate identification of instrument problems as does an examination of the spectral characteristics of the signals produced.

CONCLUSIONS

Our observations lead us to conclude that different instruments available in the market produce differing amounts of instrument distortions. These distortions are not readily differentiable from what clinicians may be tempted to identify as emissions in patient populations. Some types of instrument distortions may be identified on the basis of careful signal analysis (such as amplitude as a function of time or frequency spectra of signals used). Identifying instrument distortions as emissions may cause clinicians to fail to identify disease or changes in electrophysiologic function of the auditory system, thus increasing the miss rate and decreasing the cost effectiveness of the application of this measurement. In low-prevalence disease, a missed patient may later be identified as one who has acquired the disease rather than one who has been born with it. One pragmatic approach to minimize the chances of falsely identifying instrument distortions as emissions is to establish criteria for the identification of emissions such that instrument distortions (of magnitudes previously observed) can be excluded. For instruments characterized by large distortion products, these criteria will increase the probability that an electrophysiologically normal system may be identified (erroneously) as an abnormal one. Such an error may not have the same serious clinical consequences as that caused by missing disease, but it nevertheless reduces the cost effectiveness of the measurement, and may result in unecessary follow-up testing. For example, the application of such criteria within the context of newborn hearing screening in our facility resulted in an over-referral rate (or redundant screening) exceeding 70%.

REFERENCES

1. Hotaling, A.J., Blank, C.R., Park, A.H., Matz, G.J., Yost, W.A. & Raffin, M.J.M. (1994); *Distortion-Product Otoacoustic Non-Emissions*. Paper presented at the 20th. Annual Meeting of the American Auditory Society, Halifax, Nova Scotia, Canada, 3 July 1994.

2. Hotaling, A.J., Blank, C.R., Park, A.H., Yost, W.A., Matz, G.J. and Raffin, M.J.M. (1994). *Distortion-Product Masquerades of Emissions.* Poster-Session presentation at the Annual Convention of the American Speech-Language-Hearing Association, New Orleans, LA, 19 November 1994.