THE EFFECTS OF INTERAURAL CROSSTALK
ON STEREO REPRODUCTION
AND
MINIMIZING INTERAURAL CROSSTALK IN NEARFIELD
MONITORING BY THE USE OF A PHYSICAL BARRIER:
Part 2 APPENDICES 1-10

2420-B (B-1 0)
(See also: Part 1 ,
Preprint #2420-A)

Timothy M. Bock
Crown International, Inc.
Elkhart, Indiana

D. (Don) B. Keele, Jr.
Techron, Division of Crown International, Inc.
Elkhart, Indiana

**Presented at
the 81st Convention
1986 November 12-16
Los Angeles, California**

AES

AN AUDIO ENGINEERING SOCIETY PREPRINT

The Effects of Interaural Crosstalk on Stereo Reproduction

and

Minimizing Interaural Crosstalk in Nearfield Monitoring by the Use of a Physical Barrier; PART 2

Timothy M. Bock
Crown International, Inc.
Elkhart, Indiana 46517

D. (Don) B. Keele, Jr.
Techron, Div. of Crown International, Inc.
Elkhart, Indiana 46517

APPENDIX 1: List of Recordings that Image Well

The following list of recordings have been found to image well on the barrier setup. The list is in no way comprehensive, and represents only those recordings that the authors have in their own collection or have had personal contact with.

For reasons of compactness, the listing is of compact discs only. In most cases, the equivalent can be found on either LP or cassette.

Performer(s): ZZ Top
Recording Title: Eliminator
Company: Warner
Catalog Number: 9 23774-2
Best Track Selections: Tracks 4, 7
Music Style: Rock

Performer(s): Donald Fagen
Recording Title: The Nightfly
Company: Warner
Catalog Number: 23696-2
Best Track Selections: All, especially Tracks 2, 4, 8
Music Type: Rock
Comments: Track 8 is tops!

Performer(s): James Moorer
Recording Title: Digital Domain
Company: Electra
Catalog Number: 9 60303-2
Best Track Selections: Most
Comments: Tracks 1, 3 (Lions are Growing) are extremely good!
Music Type: Computer synthesized sounds and Sound Effects

Performer(s): Papa Doo Run Run
Composer(s): Beach Boys
Recording Title: Good Vibrations
Company: Telerc
Catalog Number: CD-70501
Best Track Selections: All, especially tracks 5, 7
Music Type: Rock
Comments: Track 7 is Tops!
Performer(s): Herbie Hancock
Recording Title: Future Shock

Company: Columbia
Catalog Number: CK 38814
Best Track Selections: Tracks 4, 6
Music Type: Rock
Comments: Track 6 is tops!

Performer(s): Berlin Or. Suitner
Composer(s): Beethoven
Recording Title: Symphony No. 9 (Complete)
Company: Denon
Catalog Number: 38C37-7021
Best Track Selections: All
Music Type: Classical

Performer(s): Pink Floyd
Recording Title: Dark Side of the Moon
Company: EMI
Catalog Number: CDP 7460012
Best Track Selections: Tracks 2 & 3 are knockouts! The alarm clock going off in 3 will knock your socks off!
Music Type: Rock

Performer(s): Pepe Romero; Amsterdam Conc.
Composer(s): Tarrega; Saint-Saens
Recording Title: Hear The Light
Company: Phillips
Catalog Number: ?
Best Track Selections: Tracks 7, 8
Music Type: Classical
Comments: Track 7 has noticeable reverb effect

Performer(s): Philadelphia Orchestra; Cleveland Orchestra
Composer(s): Saint-Saens; Tchalkovsky; Beethoven, Gerswin; Stravinsky
Recording Title: Sampler Vol. II
Company: Telarc
Catalog Number: CD-80102
Best Track Selections: Tracks 14-18
Music Type: Classical

Performer: Dave Grusin
Composer(s): Stewart; Grusin; Ritenour
Recording Title: Jazz Sampler Vol. I
Company: GRP
Catalog Number: GRP-D-9509
Best Track Selections: Tracks 2, 3, 4
Music Type: Jazz
Comments: Tracks 3, 4 are Tops!

Performer(s): Thelma Houston & Pressure Cooker
Recording Title: I've Got The Music In Me
Company: Sheffield Lab
Catalog Number: CD-2
Best Track Selections: All good
Music Type: Rock

Performer(s): The Alan Parsons Project
Recording Title: I. Robot
Company: Mobile Fidelity Sound Lab
Catalog Number: MFCD 804
Best Track Selections: Most
Music Type: Rock

Performer(s): Ron Tutt; Jim Keltner
Recording Title: The Sheffield Track Record/
The Sheffield Drum Record
Company: Sheffield Lab
Catalog Number: CD-14/20
Best Track Selections: Tracks 5, 6
Music Type: Instrumental
Comments: Drum Solos!

Performer(s): Varied
Recording Title: Creme De La Creme
Company: Sheffield Lab
Catalog Number: CD-CRM
Best Track Selections: Most
Music Type: Rock

Performer(s): Don Dorsey
Recording Title: Bachbusters
Company: Telarc
Catalog Number: CD-80123
Best Track Selections: Most
Music Type: Synthesized Bach selections

APPENDIX 2: Geometric and Timing Relationships for Stereo Listening

Interaural Distance-Time Relationships for a Spaced-Speaker Listening Setup

Interaural distance-time relationships for a spaced-speaker listening setup can be derived quite easily, as we will show. Fig. 41 illustrates a normal spaced-speaker setup with the five basic dimensions we will use for this derivation. As can be seen, H is the distance between a listener's ear; D is the distance between the loudspeakers; aD is the perpendicular distance from the listener's ears to the loudspeakers; and d_1 and d_2 are the direct and interaural signals, respectively, from the listener's ear to the loudspeaker. Pythagoras tells us that:

$$d_1 = \sqrt{(aD)^2 + \left(\frac{D}{2} - \frac{H}{2}\right)^2}$$

which, after multiplying, becomes:

$$d_1 = \frac{D\sqrt{(4a^2 + 1)}}{2} \sqrt{1 - \frac{2H}{D\,(4a^2 + 1)} + \frac{H^2}{D^2\,(4a^2 + 1)}}$$

and, after deleting the last term in the square root may be approximated by:

$$d_1 = \frac{D\sqrt{(4a^2 + 1)}}{2} \left(1 - \frac{H}{D\,(4a^2 + 1)}\right)$$

For d_2,

$$d_2 = \sqrt{(aD)^2 + \left(\frac{D}{2} + \frac{H}{2}\right)^2}$$

which becomes the approximation:

$$d_2 = \frac{D\sqrt{(4a^2 + 1)}}{2} \left(1 + \frac{H}{D\,(4a^2 + 1)}\right)$$

Therefore,

$$d_2 - d_1 = \frac{H}{\sqrt{(4a^2 + 1)}}$$

For $\theta = 60^0$, $a = \frac{\sqrt{3}}{2}$ and $d_2 - d_1 = \frac{H}{\sqrt{(4a^2 + 1)}}$

$$= \frac{H}{\sqrt{\frac{4(3)}{4} + 1}} = \frac{H}{2}$$

which is one-half the width of the head!

The approximation:

$$\frac{H}{\sqrt{(4a^2 + 1)}}$$

is valid only if:

$$\frac{H^2}{D^2(4a^2 + 1)} \ll 1 \qquad \text{or} \qquad H^2 \ll D^2(4a^2 + 1)$$

As a check, assume H to be 6.75 inches, (approximate distance between the human ears), D to be 120 inches (typical studio monitoring setup), and the angle between the loudspeakers to be 60°.

$$\frac{H^2}{D^2(4a^2 + 1)} = \frac{(6.75)^2}{(120)^2[4(\frac{\sqrt{3}}{2}) + 1]} = \frac{45.563}{57{,}600.00} = 0.001$$

$$0.001 \ll 1\ !$$

Allowable Listener Head Movement for the Barrier Listening Setup

Theoretically, the maximum distance that the listener can move from the barrier and still perceive a 180° sound stage is intimately tied in with the size of the barrier and the distance between the loudspeakers, as can be seen in Fig. 42. Although we have not yet formally measured this to test against the theoretical, we estimated during testing the distance to be about that which was theorized.

Looking at fig. 42, one readily notices the existence of three similar triangles which meet at a point that the interaural crosstalk intersects. Side adjacents of the triangles represent the maximum distance that the listener can move from the barrier (z + Y), and the width of the barrier (x - y). T is the thickness of the barrier; H is the distance between the human ears; and D is the distance between the loudspeakers. Because the triangles are similar:

$$\frac{D}{X} = \frac{H}{Z} = \frac{T}{Y} \quad \text{or} \quad Z = \frac{HX}{D} \text{ and } Y = \frac{TX}{D}$$

Thus, the maximum distance that the listener can move from the barrier is

$$\text{maximum distance} = \frac{HX}{D} + \frac{TX}{D} = \frac{X(H+T)}{D}$$

Analysis of this equation shows that an increase in the maximum distance can be effected by either an increase in X or T, or a decrease in D (H is a constant). In other words, increasing the width or thickness of the barrier, and/or decreasing the distance between the loudspeakers, increases the distance that the listener's ears can be from the barrier.

Geometric and Timing Relationships for Spaced-Speaker Listening Setup

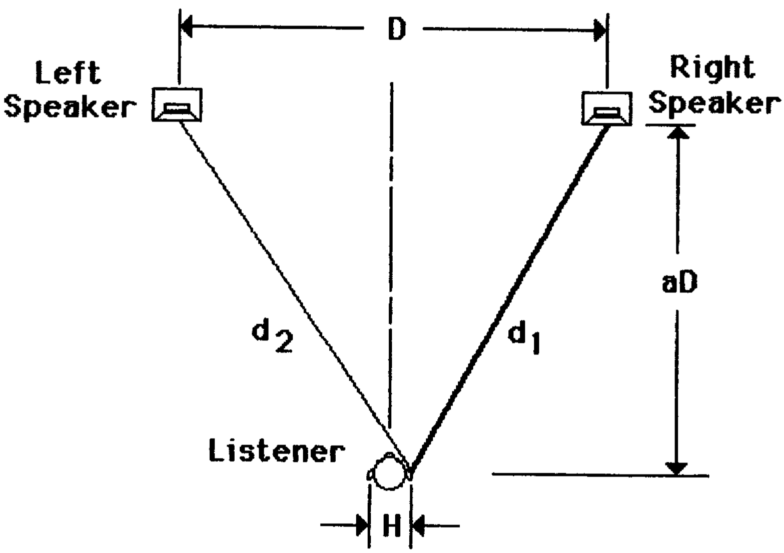

FIG. 41

Allowable Listener Head Movement for the Barrier Listening Setup

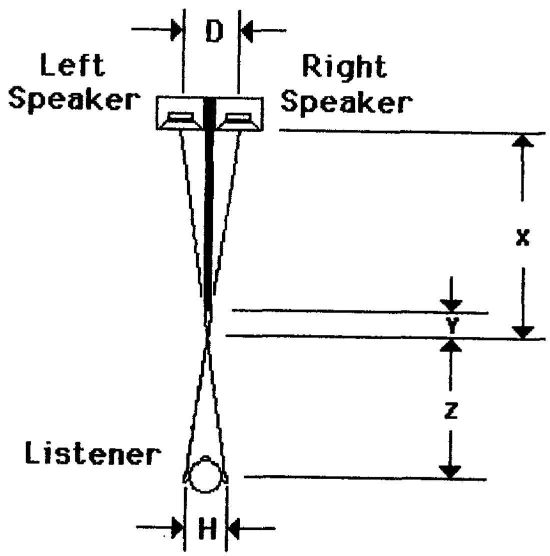

FIG. 42

APPENDIX 3

Theoretical Sound Field at Listener's Ears for Amplitude Panned Signals in a Normal Spaced-Speaker Stereo Listening Setup

Data is shown for the theoretical effects of interaural crosstalk, on the sound field that exists at the listeners ear positions, for an amplitude panned signal. A center located head is assumed. Both time and frequency response data is shown.

The data was generated using an Excel spreadsheet model running on an Apple Macintosh computer. Model variables entered included: speaker spacing, speaker level, speaker polarity, speaker delay, head to speaker distance, and head lateral location. All levels are referenced to the loudspeakers one-meter level. The standard stereo setup of Fig. 7 is assumed in every simulation.

Several values of level imbalance were modeled. These values are noted on each figure. Note the reduction in comb filtering peak-to-peak amplitude, in both ears frequency response, as the signal is panned farther and farther to the side. Also note that the frequencies of the comb filter peaks and notches do not change when the signal is amplitude panned.

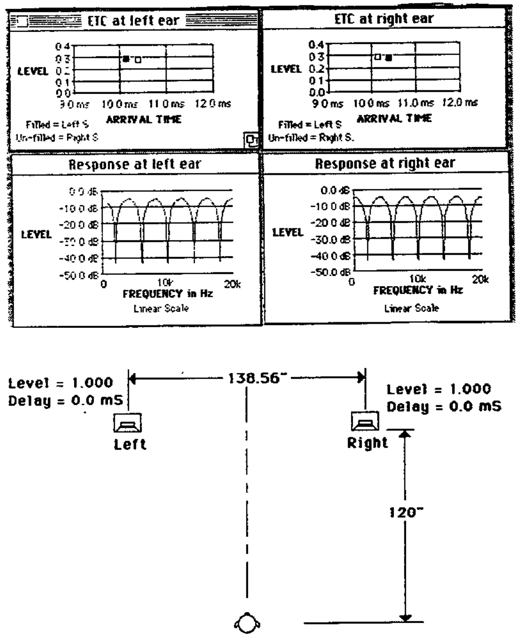

Fig. 43. Time and frequency responses at ear locations, for equal levels in each speaker (centered image). Note the heavy comb filtering in the frequency response of both ears.

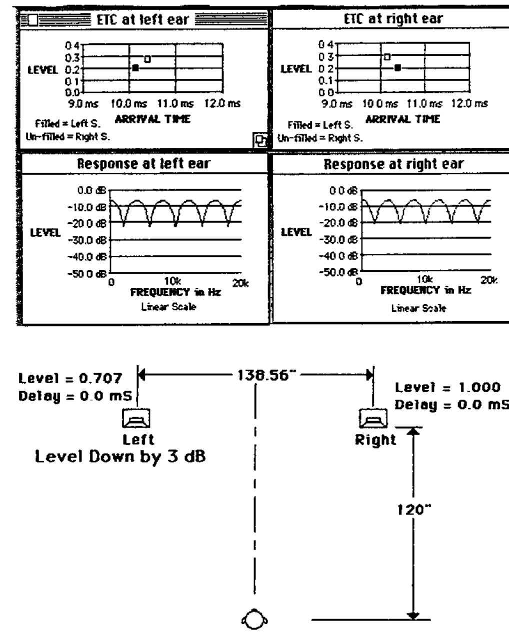

Fig. 44. Time and frequency responses at ear locations, for left channel down 3 dB (right pan).

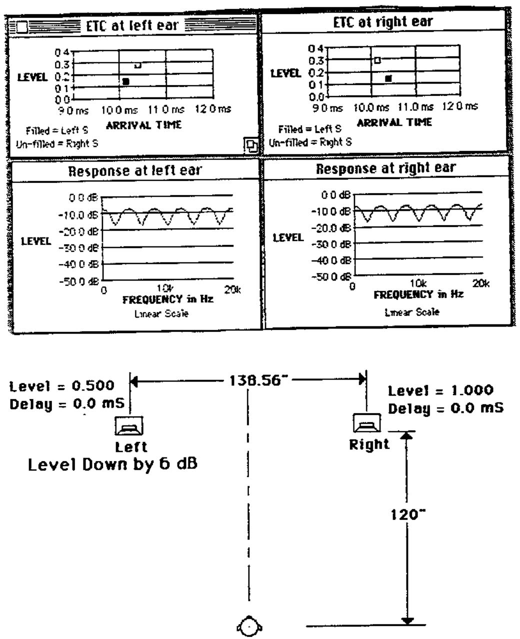

Fig. 45. Time and frequency responses at ear locations, for left channel down 6 dB (right pan).

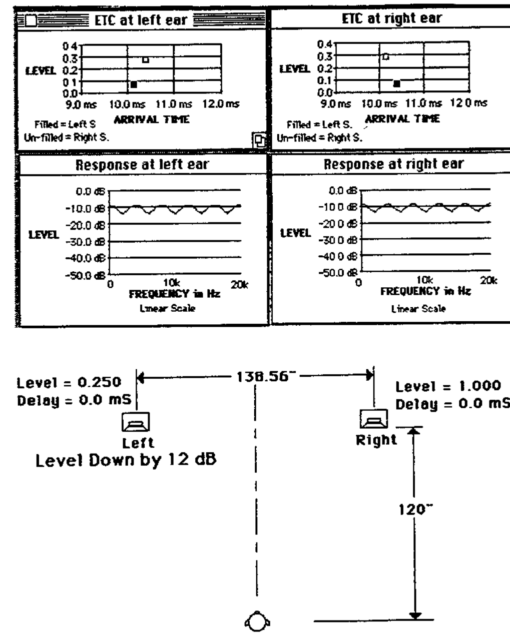

Fig. 46. Time and frequency responses at ear locations, for left channel down 12 dB (right pan).

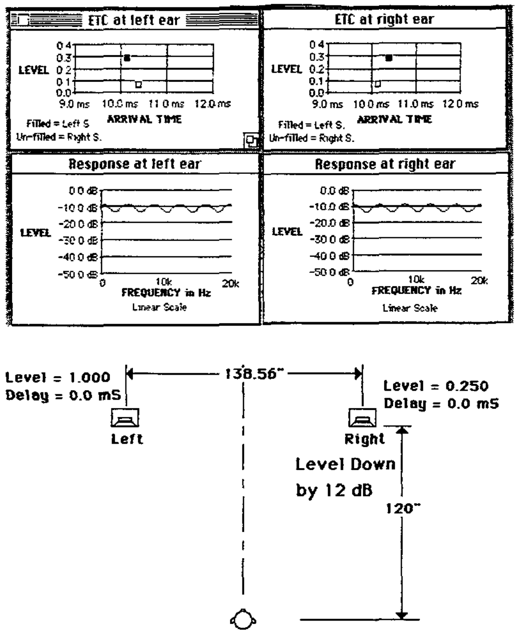

Fig. 47. Time and frequency responses at ear locations, for right channel down 12 dB (left pan).

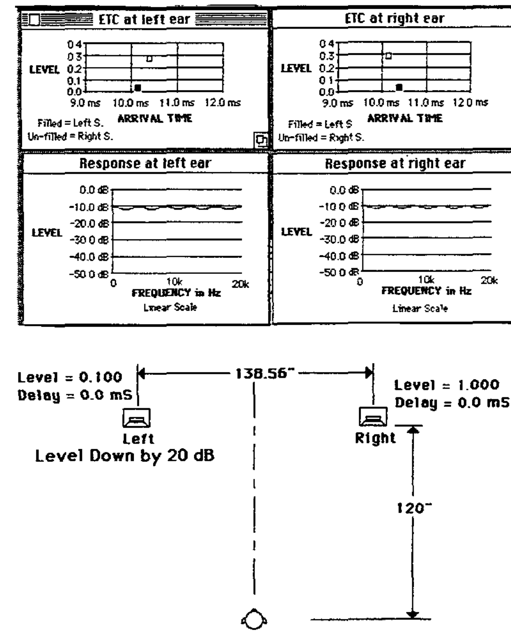

Fig. 48. Time and frequency responses at ear locations, for left channel down 20 dB (right pan).

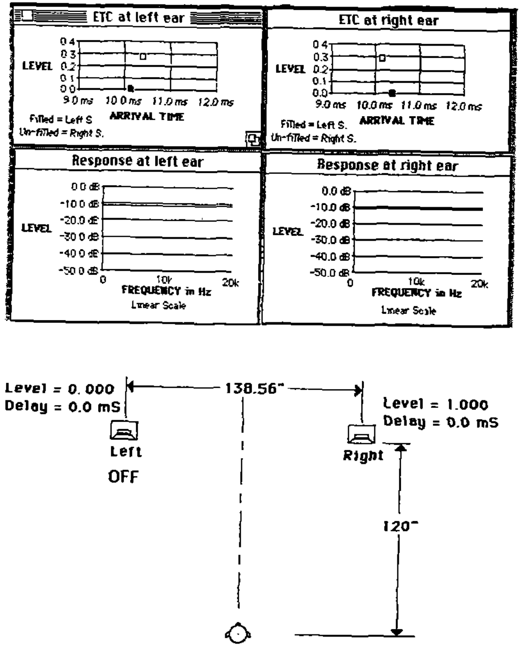

Fig. 49. Time and frequency responses at ear locations, for left channel off (full right pan). Note absence of comb filtering in both ear's frequency responses.

APPENDIX 4

Theoretical Sound Field at Listener's Ears for Delay Panned Signals in a Normal Spaced-Speaker Stereo Listening Setup

Data is shown for the theoretical effects of interaural crosstalk, on the sound field that exists at the listeners ear positions, for a delay panned signal. A center located head is assumed. Both time and frequency response data is shown.

The data was generated using an Excel spreadsheet model running on an Apple Macintosh computer. Model variables entered included: speaker spacing, speaker level, speaker polarity, speaker delay, head to speaker distance, and head lateral location. All levels are referenced to the loudspeakers one-meter level. The standard stereo setup of Fig. 7 is assumed in every simulation.

Several values of differential delay were modeled. These values are noted on each figure. Note that the frequencies of the comb filter peaks and notches changes heavily under the effects of delay panning. Note also that the peak-to-peak amplitude of the comb filtering does not change as a result of delay panning (see following comment).

Be aware that the visual changes in notch level are a result of the graphing process and not the modeled process. The levels of the notches change because their frequencies do not correspond exactly with the sampled data points.

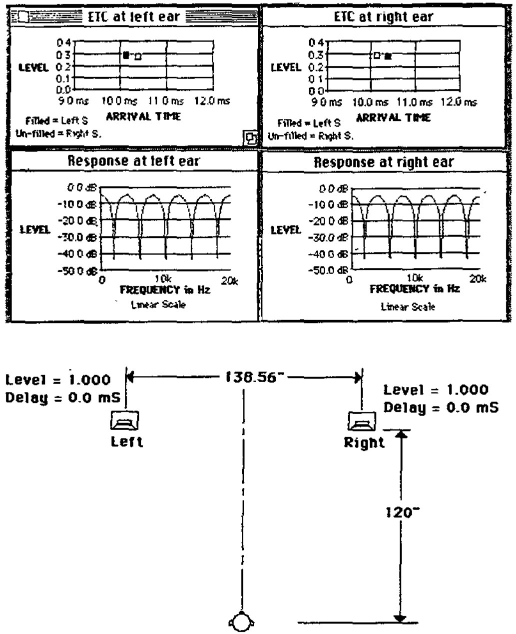

Fig. 50. Time and frequency responses at ear locations, for equal levels in each speaker (centered image).

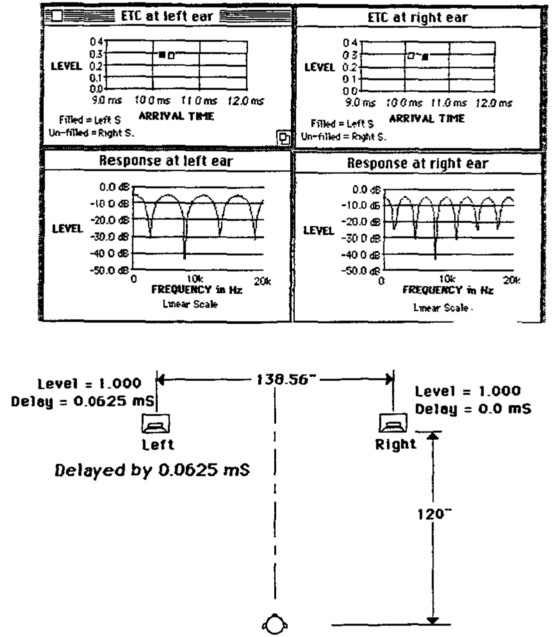

Fig. 51. Time and frequency responses at ear locations, for left channel delayed by 0.0625 msecs (pan right).

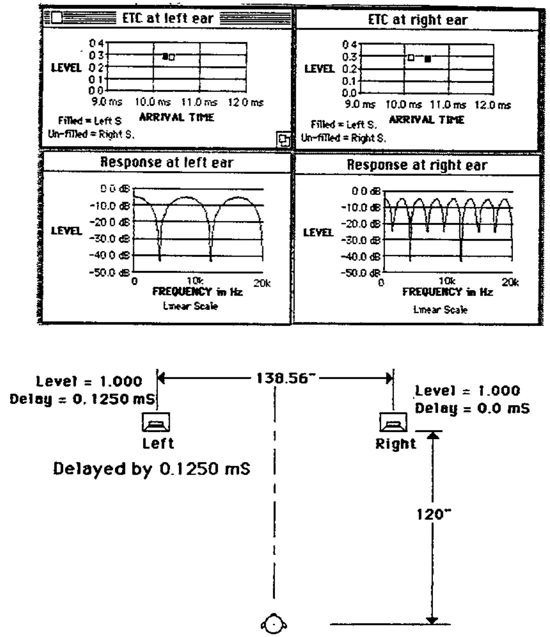

Fig. 52. Time and frequency responses at ear locations, for left channel delayed by 0.1250 msecs (pan right). Note that the combing in the left ear is getting better the closer the ear gets to the center of the setup.

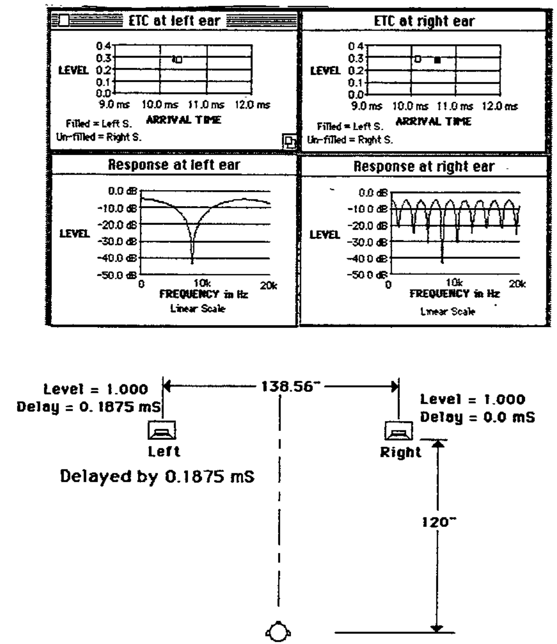

Fig. 53. Time and frequency responses at ear locations, for left channel delayed by 0.1875 msecs (pan right).

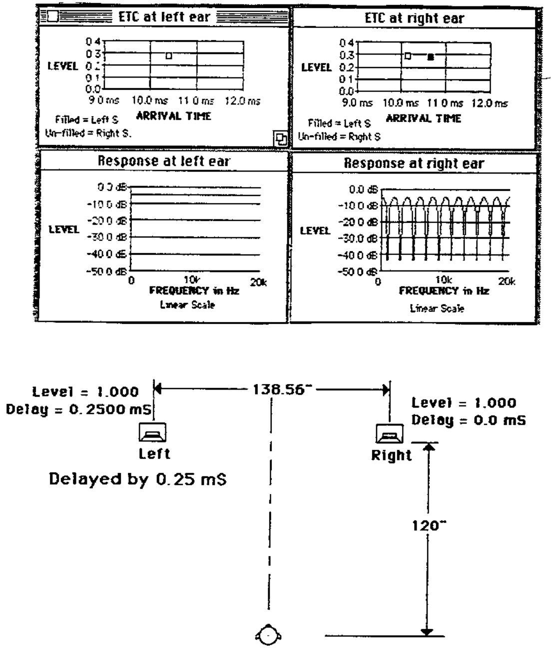

Fig. 54. Time and frequency responses at ear locations, for left channel delayed by Ø.25 msecs (pan right). With this value of delay, the direct and crosstalk signals arrive coincedently at the left ear, thus making the frequency response flat.

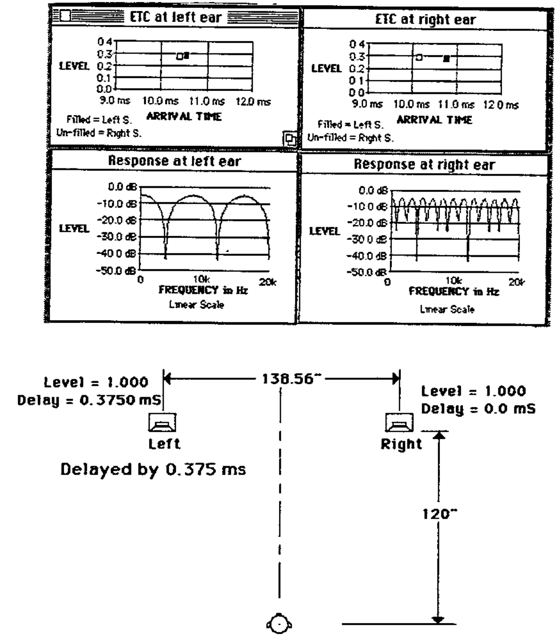

Fig. 55. Time and frequency responses at ear locations, for left channel delayed by Ø.375 msecs (pan right).

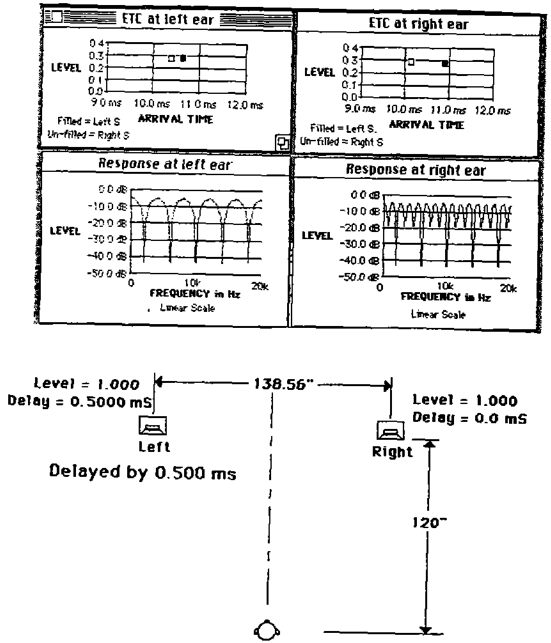

Fig. 56. Time and frequency responses at ear locations, for left channel delayed by 0.500 msecs (pan right).

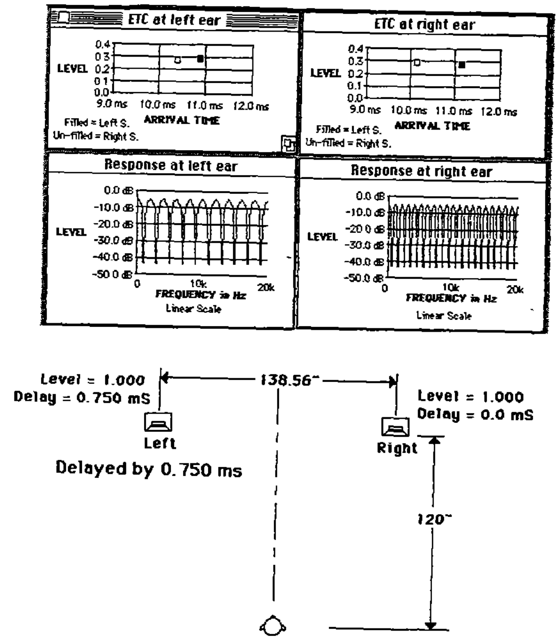

Fig. 57. Time and frequency responses at ear locations, for left channel delayed by 0.750 msecs (pan right).

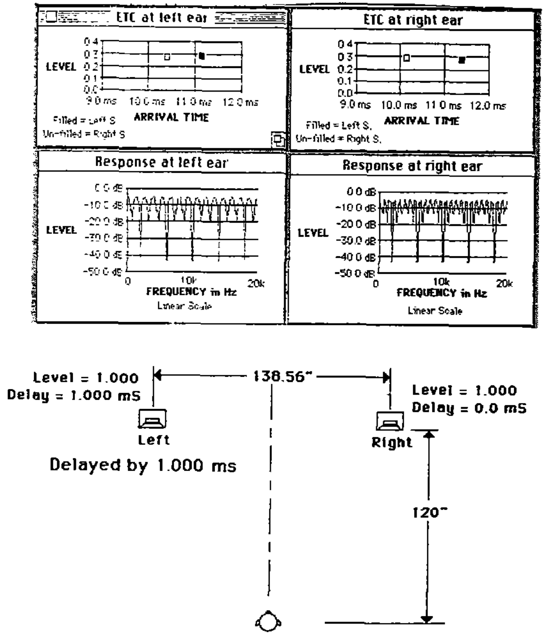

Fig. 58. Time and frequency responses at ear locations, for left channel delayed by 1.000 msecs (pan right). The response in both ears is heavily comb filtered with close frequency spacing for the peaks and dips.

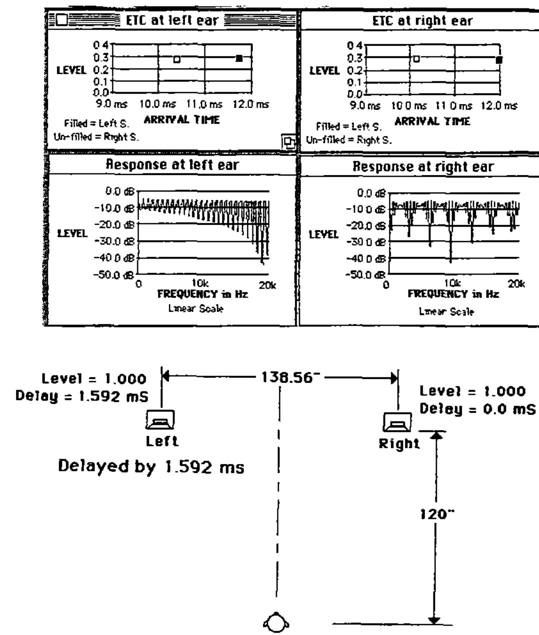

Fig. 59. Time and frequency responses at ear locations, for left channel delayed by 1.592 msecs (pan right). The response in both ears is heavily comb filtered with close frequency spacing for the peaks and dips.

APPENDIX 5

Theoretical Sound Field at Listener's Ears for a Centered Signal in a Normal Spaced-Speaker Stereo Listening Setup with Lateral Shifts in Listener Head Position

Data is shown for the theoretical effects of interaural crosstalk, on the sound field that exists at the listeners ear positions, for lateral shifts in the position of the listener's head. Both time and frequency response data is shown.

The data was generated using an Excel spreadsheet model running on an Apple Macintosh computer. Model variables entered included: speaker spacing, speaker level, speaker polarity, speaker delay, head to speaker distance, and head lateral location. All levels are referenced to the loudspeakers one-meter level. The standard stereo setup of Fig. 7 is assumed in every simulation.

Several values of head shift were modeled. These values are noted on each figure. Note that lateral head shifts change both the amplitude and frequency characteristics of the comb filtering at both ears.

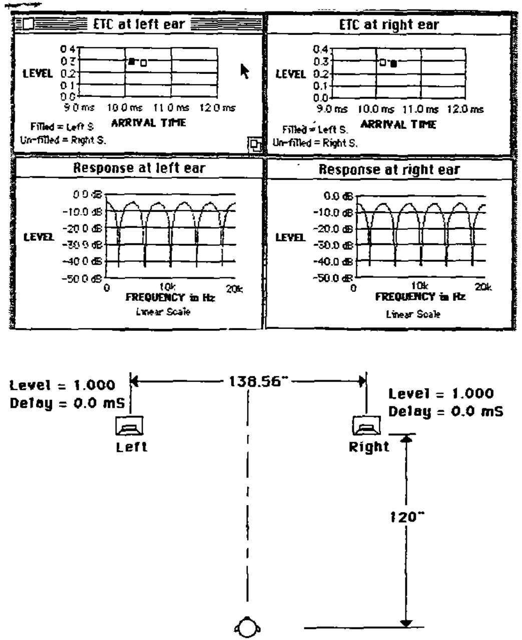

Fig. 60. Time and frequency responses at ear locations, for equal levels in each speaker (centered image) with the head centered.

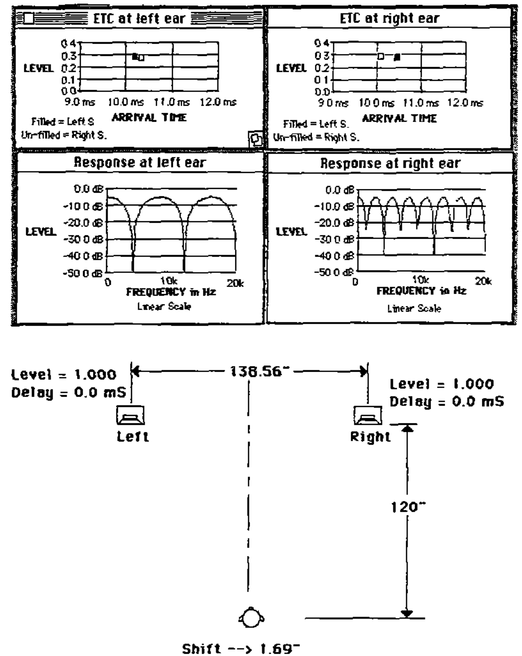

Fig. 61. Time and frequency responses at ear locations, for equal levels in each speaker (centered image) with the head shifted to the right 1.69 inchs (one-forth head width).

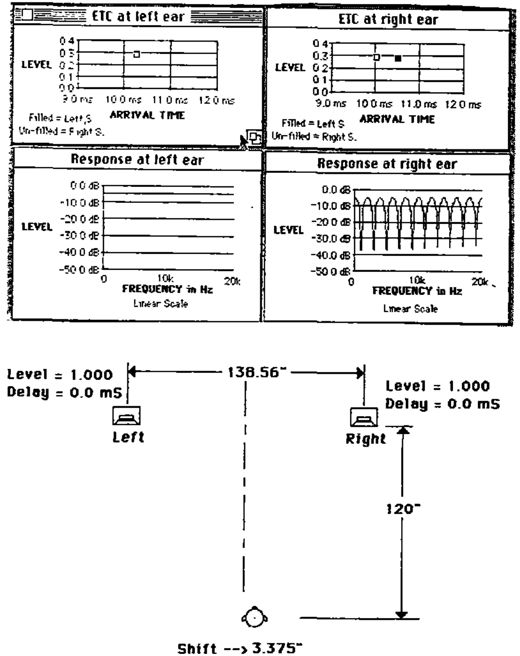

Fig. 62. Time and frequency responses at ear locations, for equal levels in each speaker (centered image), with the head shifted to the right 3.375 inchs (one-half head width). Note that this shift places the listeners left ear on the center line and thus the direct and crosstalk signals arrive at the same time.

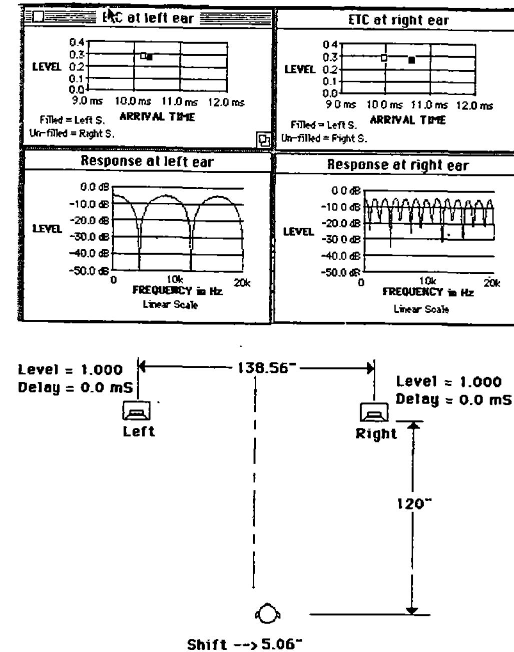

Fig. 63. Time and frequency responses at ear locations, for equal levels in each speaker (centered image), with the head shifted to the right 5.06 inchs (three-forths head width).

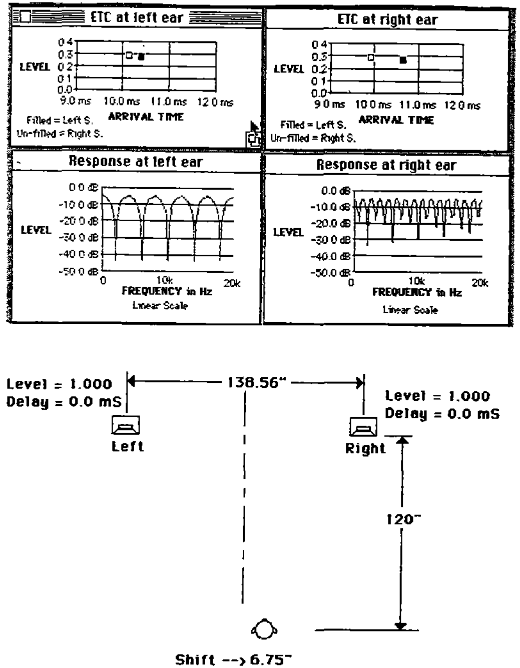

Fig. 64. Time and frequency responses at ear locations, for equal levels in each speaker (centered image), with the head shifted to the right 6.75 inchs (one head width).

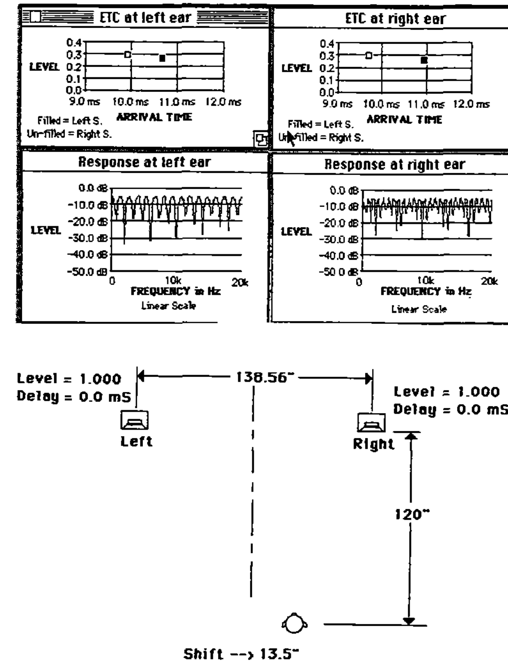

Fig. 65. Time and frequency responses at ear locations, for equal levels in each speaker (centered image), with the head shifted to the right 13.5 inchs (two head widths).

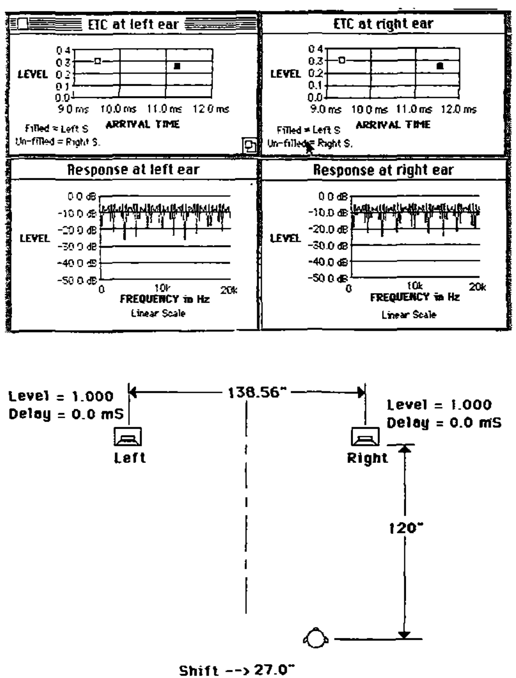

Fig. 66. Time and frequency responses at ear locations, for equal levels in each speaker (centered image), with the head shifted to the right 27.0 inchs (four head widths).

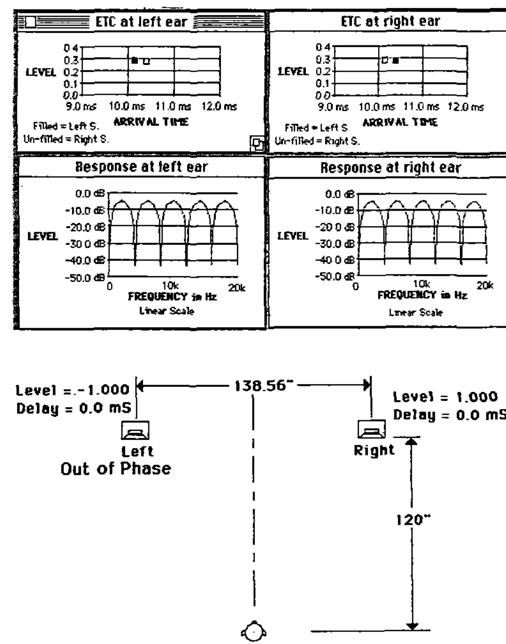

Fig. 67. Time and frequency responses at ear locations, for equal levels in each speaker, but out of phase, with the head centered.

APPENDIX 6

Theoretical Sound Field at Listener's Ears for a Spaced-Speaker Stereo Listening Setup with Central Reflective Barrier

Data is shown for the theoretical effects of interaural crosstalk, on the sound field that exists at the listeners ear positions, for the standard stereo setup of Fig. 7, but with a reflective barrier added along the center line. Both time and frequency response data is shown.

The data was generated using an Excel spreadsheet model running on an Apple Macintosh computer. Model variables entered included: speaker spacing, speaker level, speaker polarity, speaker delay, head to speaker distance, and head lateral location. All levels are referenced to the loudspeakers one-meter level.

Three situations were modeled: amplitude panning, delay panning, and lateral head shift. Note that with the barrier present, the signal time arrivals change in lockstep. The barrier uncouples the crosstalk (and replaces it with a reflection) and thus makes the delayed signal much more well behaved. Compare these responses with the corresponding responses in Appendices 3, 4, and 5.

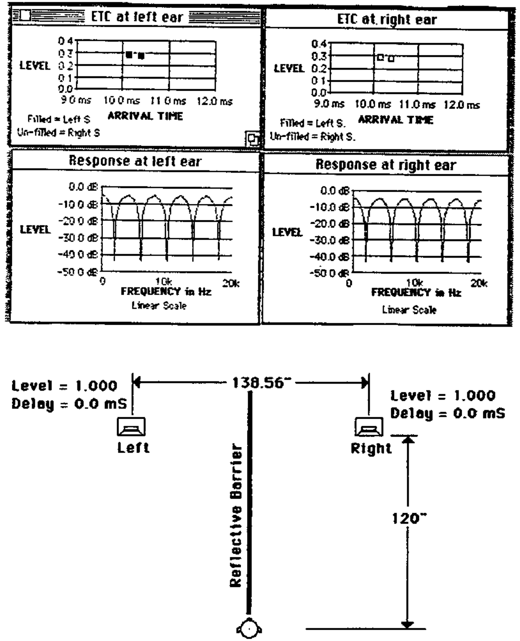

Fig. 68. Time and frequency responses at ear locations, for equal levels in each speaker (centered image), with the head centered.

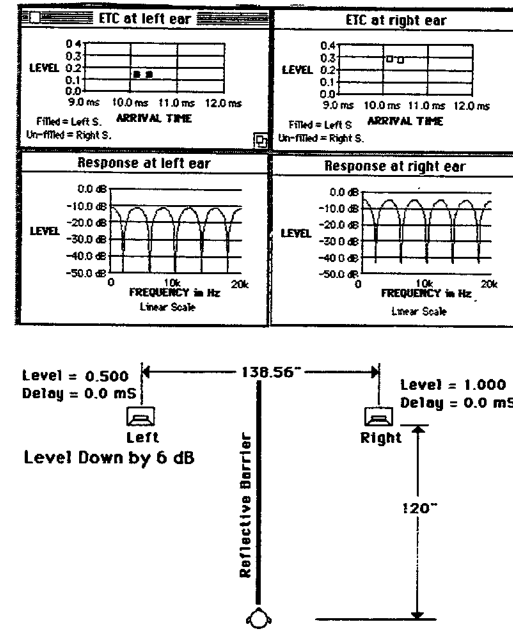

Fig. 69. Time and frequency responses at ear locations, for left channel down 6 dB (right pan). Note that the response comb filtering did not change, but only the left ear's response shifted down 6 dB.

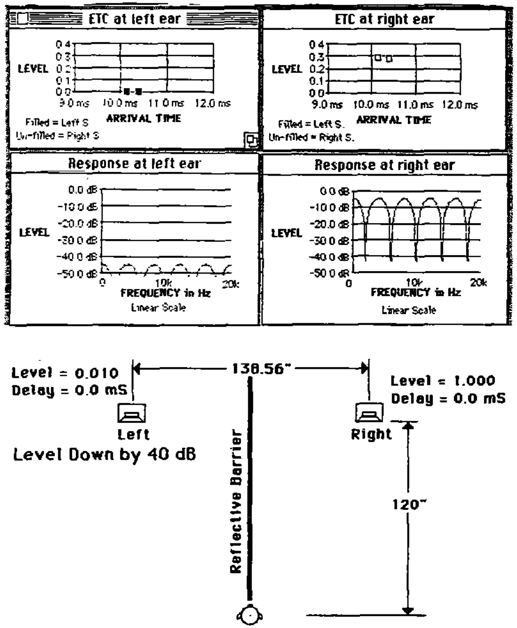

Fig. 70. Time and frequency responses at ear locations, for left channel down 40 dB (nearly full right pan). Note that the response comb filtering did not change, but only the left ear's response shifted down 40 dB.

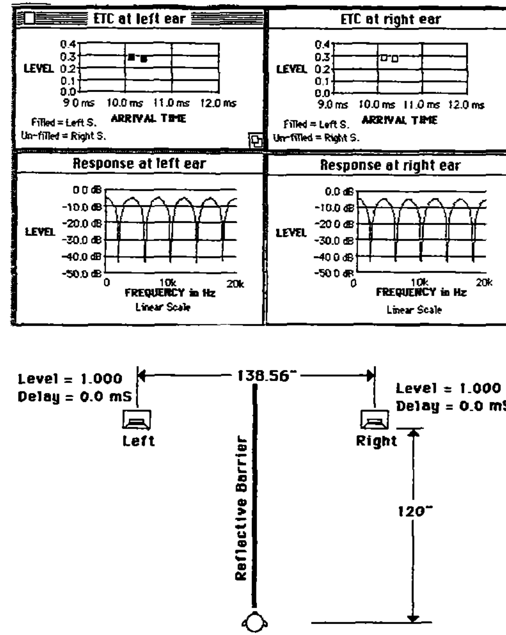

Fig. 71. Time and frequency responses at ear locations, for equal levels in each speaker (centered image), with the head centered. Repeat of Fig. 68 for reference.

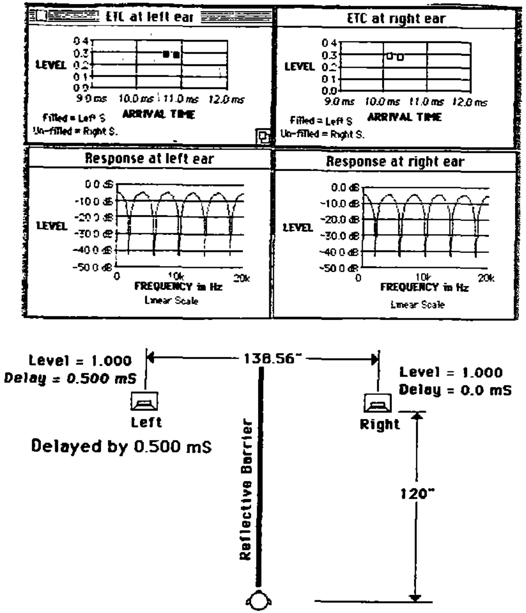

Fig. 72. Time and frequency responses at ear locations, for equal levels in each speaker (centered image), but with left channel delayed by 0.500 msecs (right pan). Note that frequency response did not change in either ear but the signal arrival times did change.

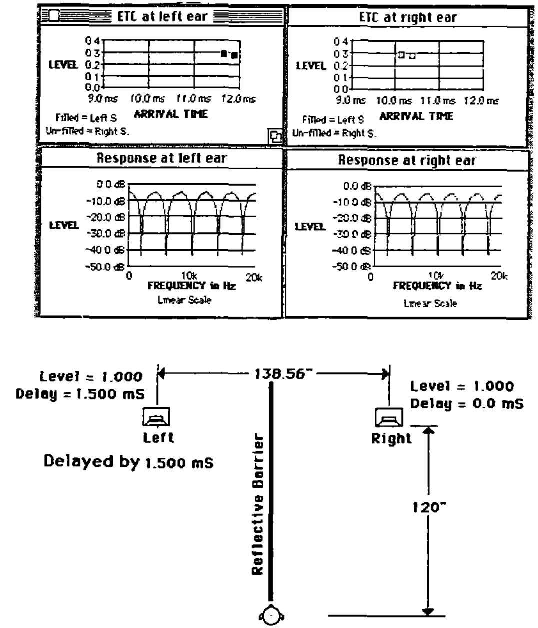

Fig. 73. Time and frequency responses at ear locations, for equal levels in each speaker (centered image), but with left channel delayed by 1.500 msecs (right pan). Note that frequency response did not change in either ear but the signal arrival times did change.

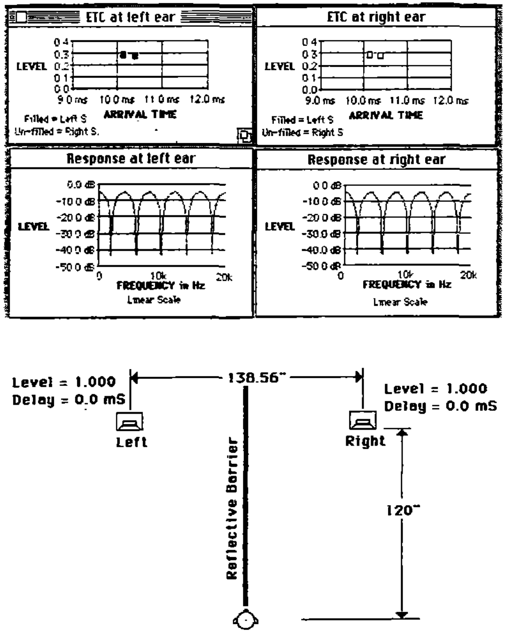

Fig. 74. Time and frequency responses at ear locations, for equal levels in each speaker (centered image), with the head centered. Repeat of Fig. 68 for reference.

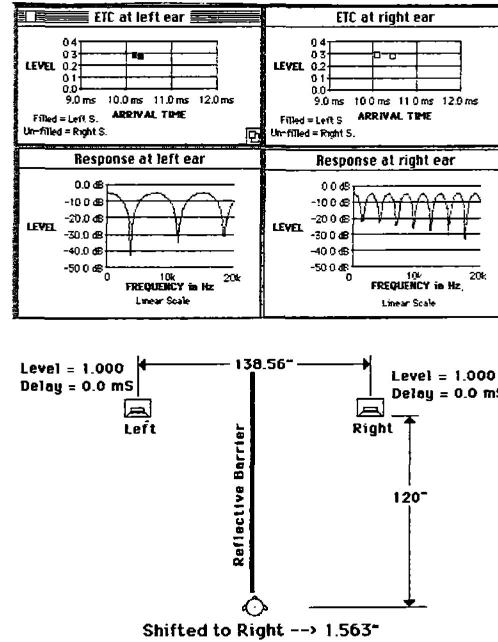

Fig. 75. Time and frequency responses at ear locations, for equal levels in each speaker (centered image), with the head shifted to the right 1.563 inchs (one-forth head width). Note that the time arrivals in the left ear are moving closer together, while the right ear's are moving farther apart.

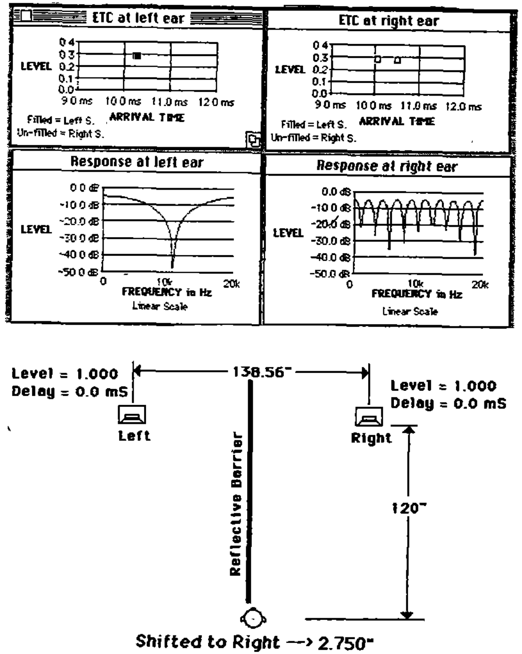

Fig. 76. Time and frequency responses at ear locations, for equal levels in each speaker (centered image), with the head shifted to the right 2.750 inchs. Note that the time arrivals in the left ear are moving closer, while the right ear's are moving farther apart.

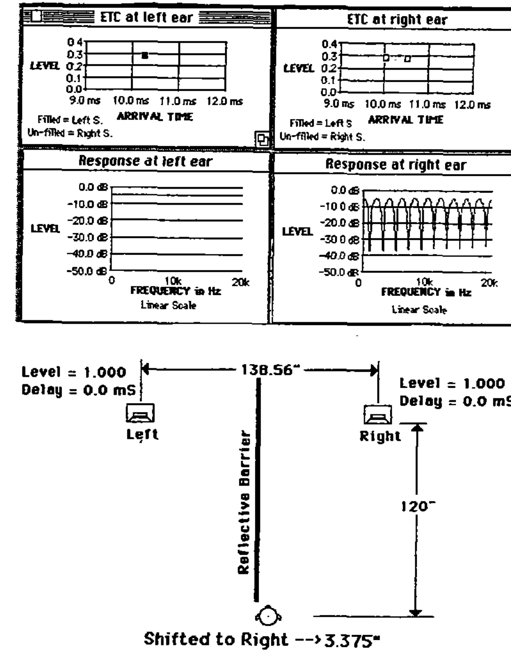

Fig. 77. Time and frequency responses at ear locations, for equal levels in each speaker (centered image), with the head shifted to the right 3.375 inchs (one-half headwidth). Note that the time arrivals in the left ear are coincedent, thus making a flat response in that ear. The head cannot shift any farther to the right without bringing the left ear on the right side of the boundary.

APPENDIX 7

Theoretical Sound Field at Listener's Ears for a Close Spaced-Speaker Stereo Listening Setup with Central Reflective Barrier

Data is shown for the theoretical effects of interaural crosstalk, on the sound field that exists at the listeners ear positions, for the standard stereo setup of Fig. 7, but with a reflective barrier added along the center line, and the speakers spaced closer together. Both time and frequency response data is shown.

The data was generated using an Excel spreadsheet model running on an Apple Macintosh computer. Model variables entered included: speaker spacing, speaker level, speaker polarity, speaker delay, head to speaker distance, and head lateral location. All levels are referenced to the loudspeakers one-meter level.

Two speaker spacings were modeled: 15" apart, and 6" apart (side by side). At the close spacing, amplitude panning and delay panning were modeled. Note that the frequencies of the dips and peaks of the comb filtering go up as the spacing of the speakers is decreased. With the 6" spacing, the frequency of the first dip in the frequency response is above the range of human hearing. Spacing the speakers close together allows the use of a reflective barrier, which increases the apparent sensitivity and maximum acoustic output of the loudspeakers by 6 dB.

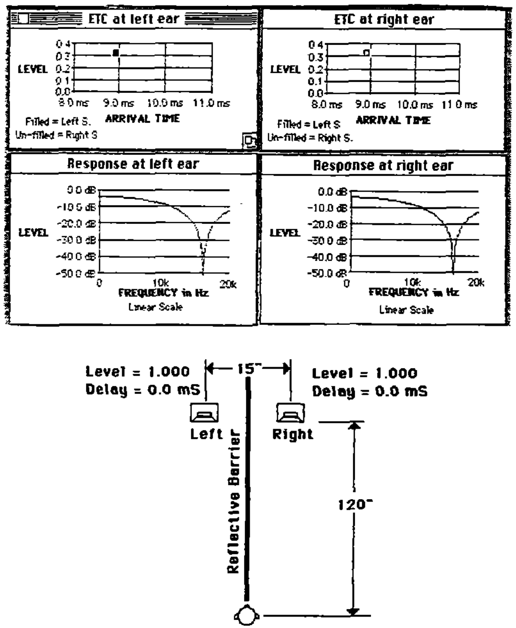

Fig. 78. Time and frequency responses at ear locations, for equal levels in each speaker (centered image), with the head centered, and the speakers spaced at 15". The direct and reflected signals reach the ear within about 30 usecs. This interval is so small that the two arrivals in the time display appear as one. Observe that there is only one comb filter dip in the frequency response at approximately 16 kHz.

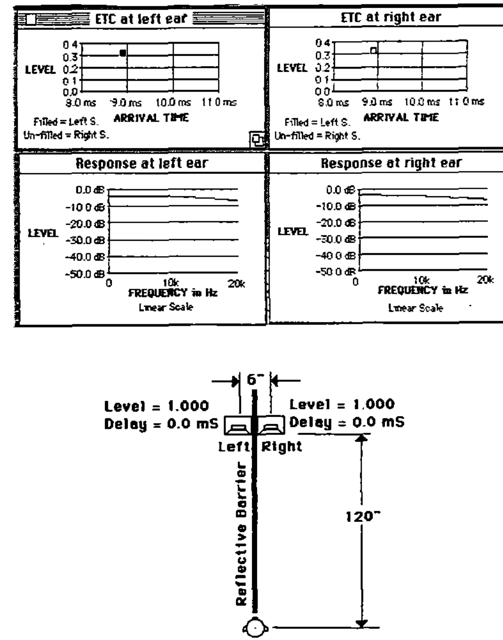

Fig. 79. Time and frequency responses at ear locations, for equal levels in each speaker (centered image), with the head centered, and the speakers placed side-by-side with a center-to-center spacing of 6". The direct and reflected signals reach the ear within about 18 usecs. This interval is so small that the two arrivals in the time display appear as one. Observe that first comb filter dip in the frequency response is above 20 kHz and thus the frequency response below 20 kHz is quite flat.

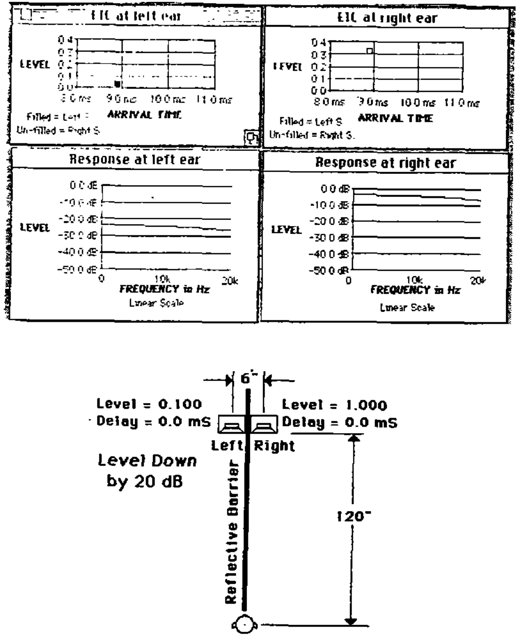

Fig. 80. Time and frequency responses at ear locations for left channel down 20 dB. Other conditions same as Fig. 79. Note how close these simulations are to the ideal responses in Fig. 8.

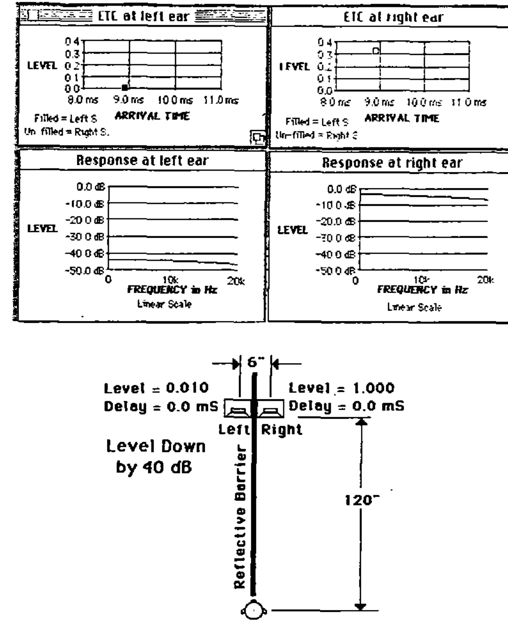

Fig. 81. Time and frequency responses at ear locations, for left channel down 40 dB. Other conditions same as Fig. 79.

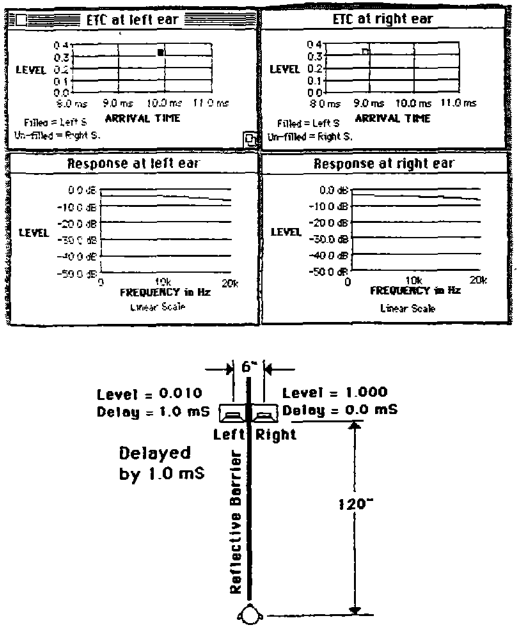

Fig. 82. Time and frequency responses at ear locations, for left channel delayed by 1.0 msec. Other conditions same as in Fig. 79. Note that the frequency response is uneffected by the delay.

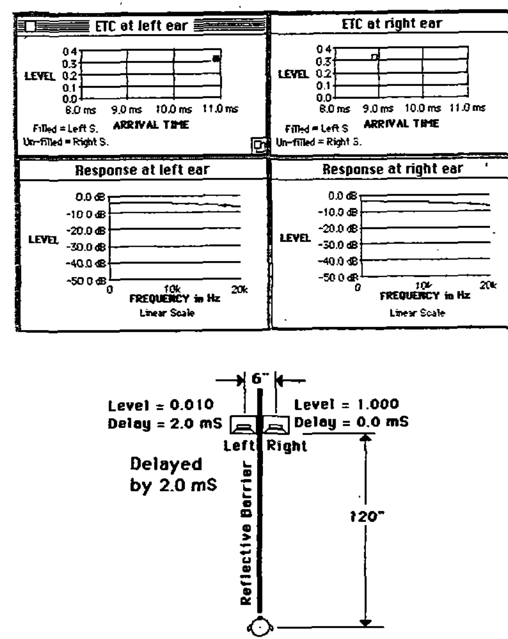

Fig. 83. Time and frequency responses at ear locations, for left channel delayed by 2.0 msec. Other conditions same as in Fig. 79. Note that the frequency response is uneffected by the delay.

APPENDIX 8

Measurement Results for Standard Stereo Setup in Lab

This appendix contains the results of measurements taken on a standard stereo listening setup, using small loudspeakers. The Radio Shack Realistic Minimus-7 loudspeaker was used for all the measurements. All measurements were taken in a lab environment with no special treatment to reduce reflections.

Sound Field at Listener's Ears for Normal Spaced-Speaker Stereo Listening Setup

The loudspeakers were set up in a standard equilateral triangle with 4 ft (1.22 m) spacing between the speakers and listener location.

Measurements were made of the sound field that exists at the listener's location (listener assumed centered). Data was gathered primarily at the right ear and center head locations. Both time (0 to 13 msecs) and frequency response (100 to 20 kHz) data was gathered. Three combinations of speaker on-off configurations were analyzed: 1) left speaker on only (crosstalk signal), 2) right speaker on only (direct signal), 3) both speakers on (direct plus crosstalk signals).

Sound Field Measurements with the Use of Wig Head

A wig head was used, in the above setup, to model the effects of the human head on the interaural crosstalk.

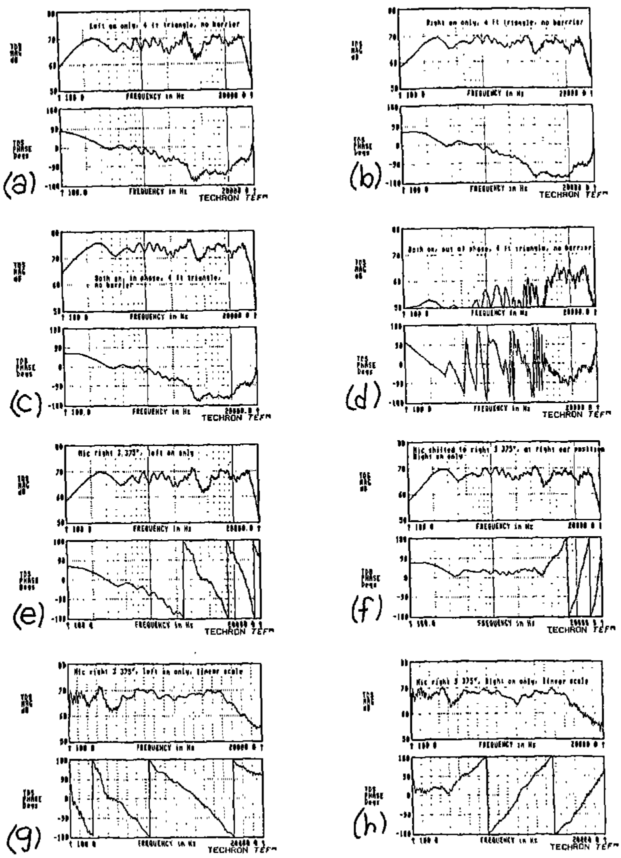

Fig. 84. Frequency response curves taken at the center head and right ear positions (shifted to right 3.375"). Both magnitude and phase curves are shown for each condition. (a) Left speaker on only, center of head. (b) Right speaker on only, center of head. (c) Both speakers on, center of head. (d) Both speakers on, but out of phase, center of head. (e) Left on only, right ear. (f) Right on only, right ear. (g) Left on only, right ear, linear scale. (f) Right on only, right ear, linear scale.

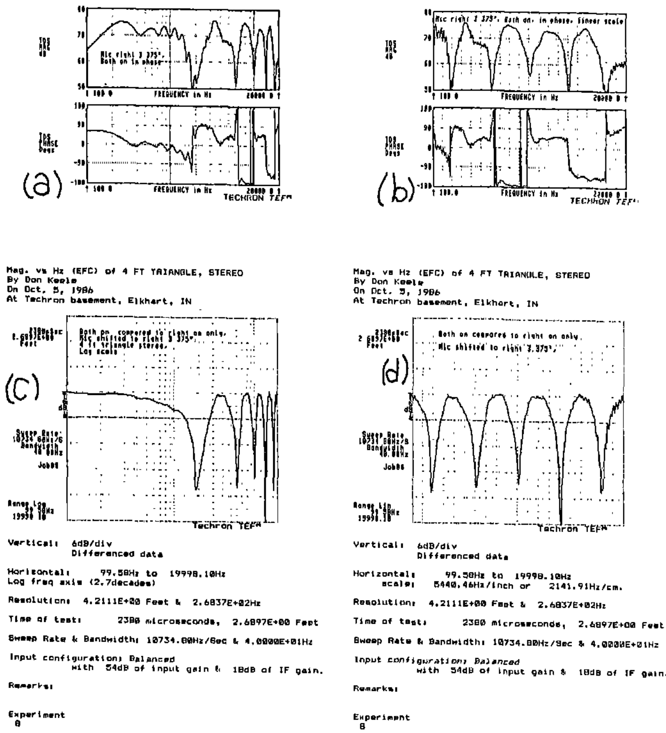

Fig. 85. Frequency response curves taken at the right ear location, with both speakers on (direct plus crosstalk signals). Note the severe comb filtering. The crosstalk signal arrives at 250 usec after the direct sound. This causes comb filtering with dips at 2 kHz, 6 kHz, 10 kHz, etc. (a) Magnitude and phase curves, log scale. (b) Linear scale. (d) Response curve showing the direct effects of the crosstalk. The curve is a result of taking the dB magnitude difference between the both-speakers-on condition and the right-on-only condition. Log scale. (d) Linear scale.

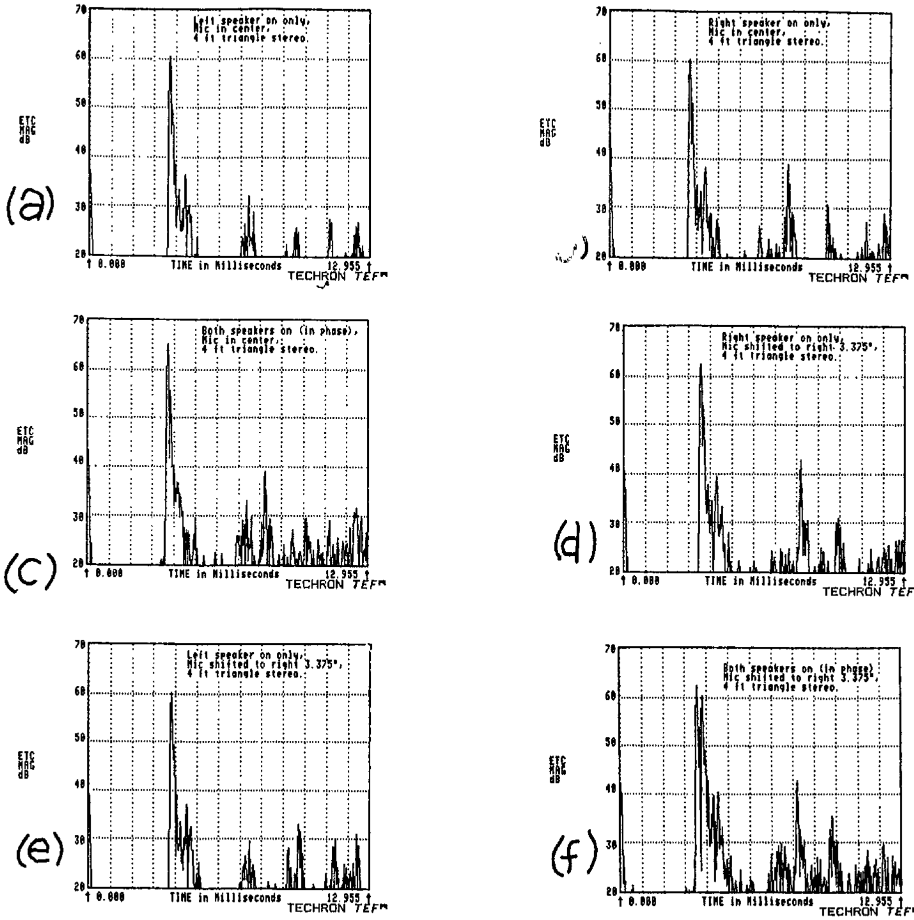

Fig. 86. Time response curves (ETC's) taken at the center head and right ear locations for the three possible speaker on-off combinations. (a) Left speaker only, center of head. (b) Right on only, center head. (c) Both on, center head. (d) Right on only, right ear. (e) Left on only, right ear. (f) Both on, right ear.

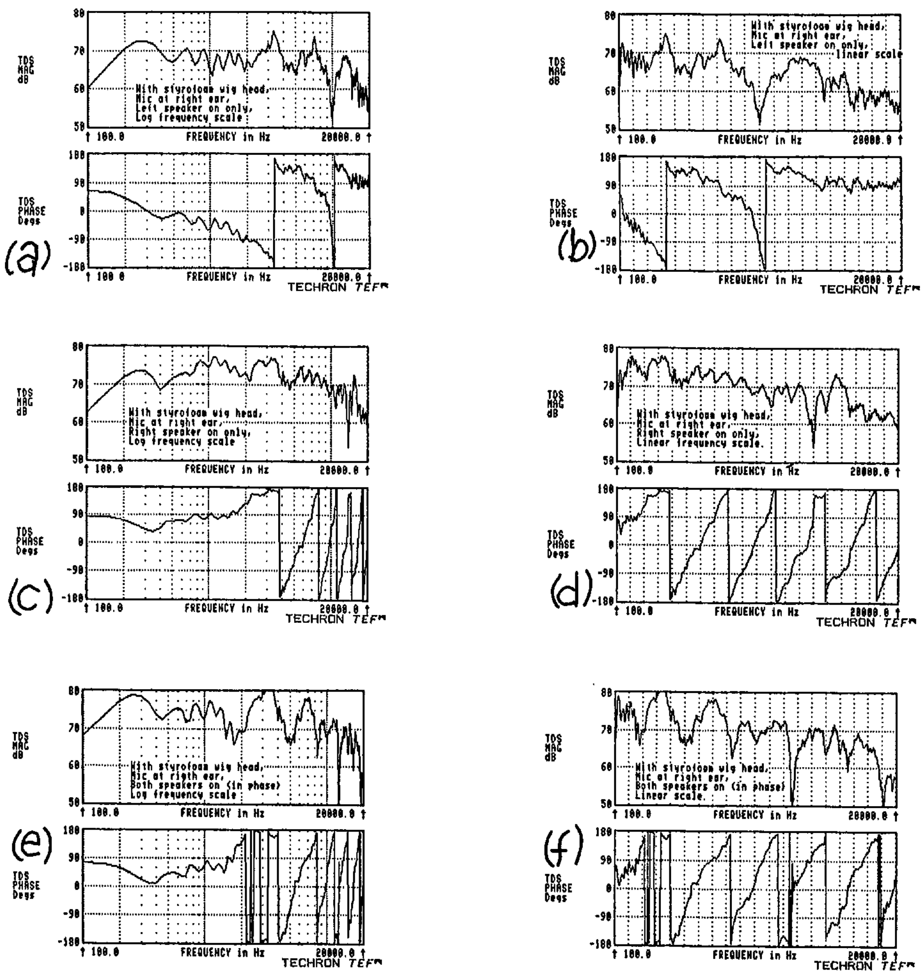

Fig. 87. Measurements taken, at right ear location, with styrofoam wig head to simulate presence of human head. Dual sets of magnitude and phase frequency response data was taken. Log scale on left and linear scale on right. (a) Left speaker on only, log scale. (b) Left on only, linear scale. (c) Right on only, log scale. (d) Right on only, linear scale. (e) Both on, log scale. (f) Both on, linear scale. Even with the wig head present, the comb filtering is still evident, although at a lower amplitude (e), (f).

APPENDIX 9

Measurement Results for Recording Studio Control Room

This appendix contains the results of measurements taken in the control room of a recording studio (Chicago Trax Recording, Chicago, IL). See additional comments in section 6.2 (some of which are repeated here).

Measurements of the effects of interaural crosstalk were made on the loudspeaker monitors in a recently constructed recording studio control room. Sound field measurements were made both with and without the presence of a live human model. A sub-minature Knowles microphone was inserted in the entrance of the ear canal for the live model measurements.

As before, sets of measurements were taken with each monitor speaker on individually and then both operating. The measurements were taken at typical mixing-listening points to the rear of the mixing console. Two sets of measurements were taken: 1) the sound fields at the mixer's ears and center head position without the mixer being present and 2) the sound pressure at the mixer's right ear with the mixer present at five different locations behind the console. The sound pressure was measured at the entrance of the mixer's right ear canal including the effects of head diffraction, head shadowing and pinna transformations [19].

EDITORIAL NOTE AT PRESS TIME (Oct. 21, 1986)

This preprint is getting too large! We are going to include only two of the most interesting figures from the complete Appendix 9 measurement set (8 pages of figures removed). Included here, are pinna measurements at the center console position, and console left, which is 20" to the left of console center.

Interested readers desiring the complete set of measurements should write or call me at:

Don Keele
Techron, Div. Crown International
1718 W. Mishawaka Rd.
Elkhart, In 46517

(219) 294-8300

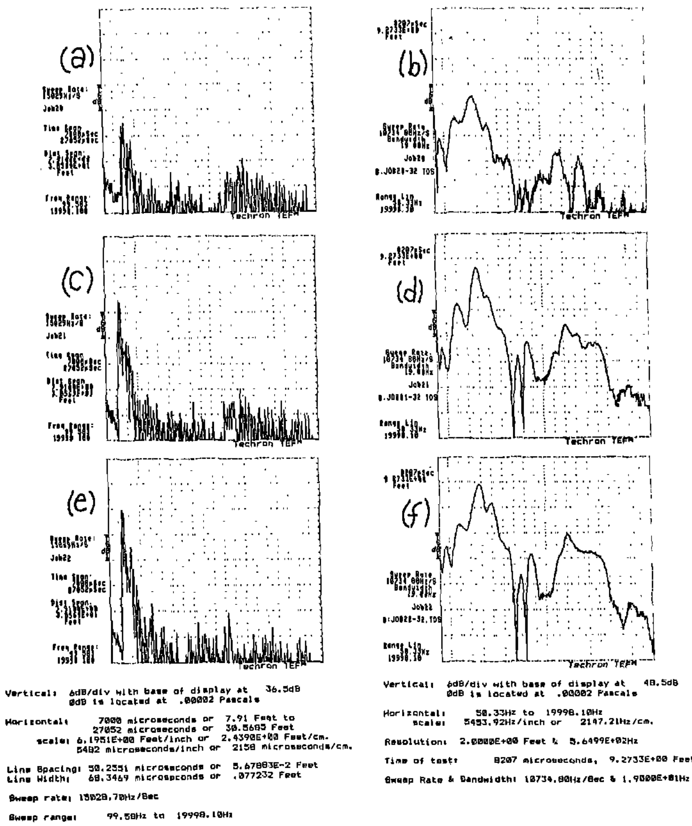

Fig. 88. Measurements of the response at the entrance to the right ear canal, for a listener centered behind the console. Both time (ETC, 7 to 27 msecs) and frequency (EFC, 50 Hz to 20 kHz) response measurements are shown. (a) ETC, left speaker on only (crosstalk signal). (b) EFC, left on only (crosstalk). (c) ETC, both speakers on (direct + crosstalk signals). (d) EFC, both on (direct + crosstalk). (e) ETC, right on only (direct signal). (f) EFC, right on only (direct). Slight comb filtering is evident in (d) when both monitors are on. Refer to Fig. 36 for difference measurements for all positions.

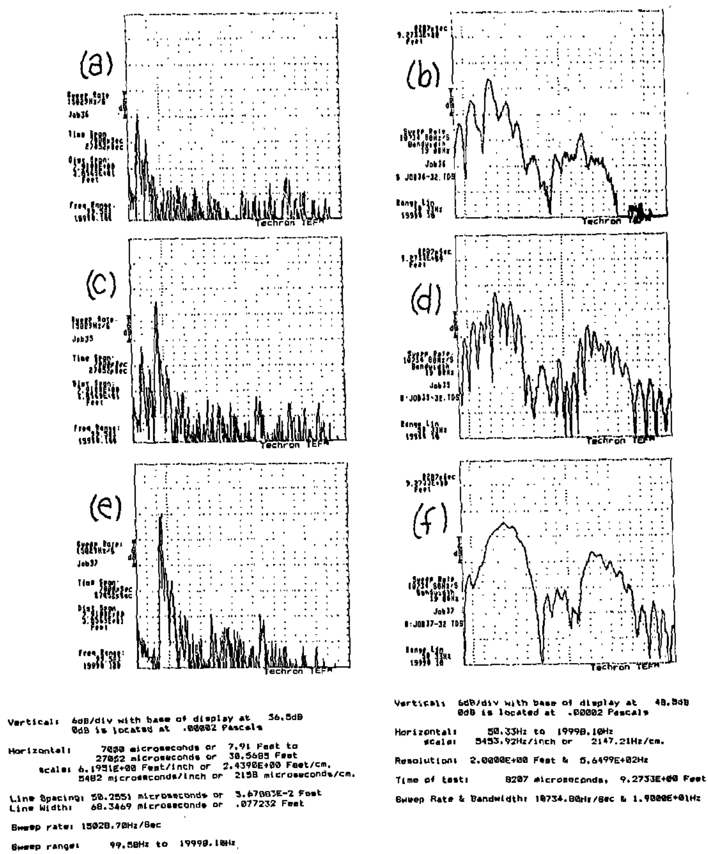

Fig. 89. Measurements of the response at the entrance to the right ear canal, for a listener shifted to the left 20" from console center. Both time (ETC, 7 to 27 msecs) and frequency (EFC, 50 Hz to 20 kHz) response measurements are shown. (a) ETC, left speaker on only (crosstalk signal). (b) EFC, left on only (crosstalk). (c) ETC, both speakers on (direct + crosstalk signals). (d) EFC, both on (direct + crosstalk). (e) ETC, right on only (direct signal). (f) EFC, right on only (direct). Severe comb filtering is evident in (c) and (d) when both speakers are on. Refer to Fig. 36 for difference measurements for all positions.

APPENDIX 10

Measurement Results for Recommended Barrier Listening Setup

This appendix contains the results of measurements taken on the split speaker-stand style barrier listening setup. See additional comments in section 6.3 (some of which are repeated here).

Measurements were made on the split speaker-stand barrier setup to access the following parameters: the amount of crosstalk rejection (channel separation), frequency response, energy-time response, and reduction of room reflections. The Techron TEF System 10/12 was used for all the measurements. All the raw measurements are displayed in Appendix 10.

In every case the sound field at the listener's ear was measured but with the listener absent. The microphone was oriented parallel to the barrier and aimed towards the tweeter of the loudspeaker. The microphone was located so that its diaphragm was 3" (76.2 mm) shifted laterally from the barrier and 5" (127.0 mm) to the rear of the barrier. This is the approximate location of a listener's ear if he/she were there.

The barrier consisted of a 72" (H) x 30" (D) x 0.75" plywood board. The speakers (Minimus-7's) were placed on either side of the barrier, with their tweeters against the board. The mic to speaker distance was 30". The speakers were 40" above the floor.

EDITORIAL NOTE AT PRESS TIME (Oct. 21, 1986)

This preprint is getting too large! We are going to include only two of the most interesting figures from the complete Appendix 10 measurement set (4 pages of figures removed). Included here the frequency and time curves for the barrier setup.

Interested readers desiring the complete set of measurements should write or call me at:

Don Keele
Techron, Div. Crown International
1718 W. Mishawaka Rd.
Elkhart, In 46517

(219) 294-8300

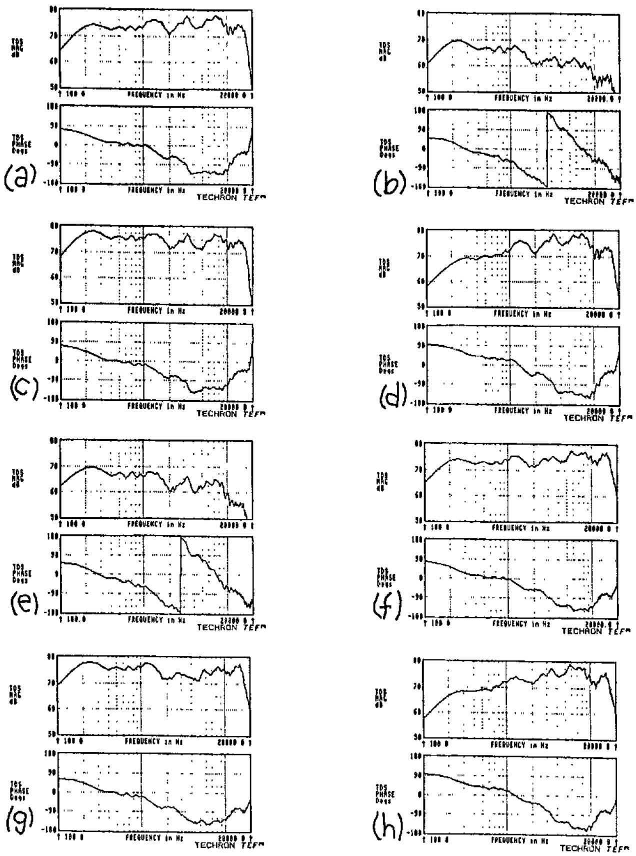

Fig. 90. Frequency responses (both magnitude and phase from 100 Hz to 20 kHz) taken on the barrier listening setup. (a) Mic on left, left speaker on only. (b) Mic left, right on only. (c) Mic left, both on. (d) mic left, both on, out of phase. (e) Mic right, left on only. (f) Mic right, right on only. (g) Mic right, both on. (h) Mic right, both on, out of phase. Note the very mild effects of the crosstalk with both speakers on (c), (g).

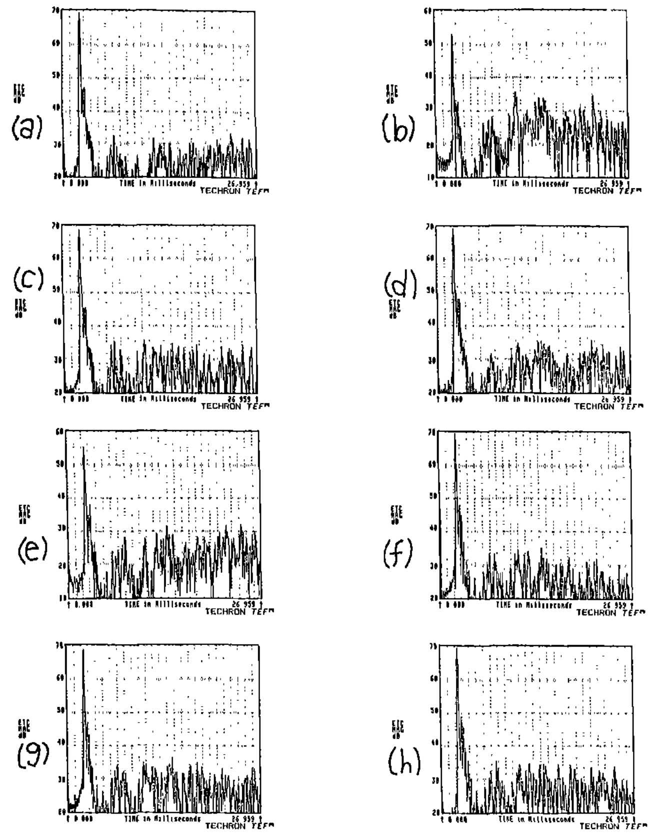

Fig. 91. Time responses (ETC's from Ø to 27 msecs generated from a 2ØØ Hz to 15 kHz sweep) taken on the barrier listening setup. Note that the vertical top-of-scale SPL value changes due to TEF autoscaling. (a) Mic on left, left speaker on only. (b) Mic left, right on only. (c) Mic left, both on. (d) mic left, both on, out of phase. (e) Mic right, left on only. (f) Mic right, right on only. (g) Mic right, both on. (h) Mic right, both on, out of phase. These ETC curves indicate a crosstalk rejection of about 15 dB (from 68 dB down to 53 dB SPL, compare (a) with (b)).