APPENDIX F.4

LDR FM Hybrid Performance

Lucent Digital Radio, Inc.

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Advanced Technologies

Multimedia Perception Assessment Center

LDR FM Hybrid Performance

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Introduction

This report describes procedures and results from a subjective study conducted by Lucent's Multimedia Perception Assessment Center for Lucent Digital Radio. End-user testing was conducted between January 19thth and January 21stth, 2000. This study was designed to solicit Mean Opinion Scores (MOS) from the general public concerning analog FM transmission under both static and dynamic multipath impaired conditions.

Six FM receivers were included in this study. Two were automobile radios: the Ford Visteon XWIF-18C870 and the Sony XR-2390 receivers. Three were home receivers: (a) Pioneer SX-205; (b) Sony CFD-S47; and (c) Denon TU-1500RD. All receivers were selected to represent a broad range of receivers currently available in the commercial market.

Ninety-six participated in this study. Participants were evenly divided by gender and varied in age, but were all under the age of 50. Participants were chosen from the general public. Listening was conducted in sound rooms that were configured to acoustically simulate extremely quiet environments (28-35 dBA).

All recordings were supplied by Lucent Digital Radio. CD source material was selected to be representative of typical broadcast material, including both female and male voices and complex instrumental samples (see Appendix B – Selection of Processing of Audio Samples for FM analog and FM-IBOC subjective testing). Female and male speech samples were also included. Table 1 lists the RF channel conditions used in this experiment.

Table 1: Summary of conditions for FM Impairment Test

Average Signal Strength (dBm)	Static Condition	Multipath Condition*
-72.0	ANO1	ARF1
-62.0	ANO2	ARF2
-54.5	ANO3	ARF3
-47.0	ANO4	ARF4
-42.0	ANO5	ARF5
-32.0	ANO6	ARF6
-9.0 D/U	CN01	CRF1
-1.5 D/U	CNO2	CRF2
6.0 D/U	CNO3	CRF3
18.5 D/U	CNO4	CRF4
31.0 D/U	CNO5	CRF5
Output SNR (AWQP)(dB)		
55dB	ENO1	ERF1
45 dB	ENO2	
35 dB	ENO3	ERF3
25 dB	ENO4	

*** Rural Fast Rayleigh, 13.1 Hz Doppler**

Methodology

Testing of receivers was conducted in round-robin fashion. Because listeners' scores are typically influenced by all of the sound samples presented in a listening session, it was important to pair each radio with at least 2 other radios to minimize the risk of obtaining inflated or deflated scores for a particular radio. Participants were divided into 6 groups, with each group listening to sound samples received by two radios. Each radio was presented to two groups. Therefore, 32 participants rated sound-cuts received by each radio. For example, Group 1 participants listened to sound samples received by the Visteon and the Denon and Group 2 participants listened to samples received by the Sony XR-2390 and the Denon. Thus, by combining Group 1 and Group 2's listening experience, a total of 32 participants listened to samples received by the Denon. Table 2 lists Receivers and Participant Groups.

Table 2: Test Plan

Participant Group	Visteon XWIF-18C870	Sony XR-2390	Pioneer SX-205	Denon TU-1500RD	Panasonic RF-FX430	Sony CFD-S47
Group 1 (n = 16)	x			x		
Group 2 (n = 16)		x		x		
Group 3 (n = 16)		x			x	
Group 4 (n = 16)	x				x	
Group 5 (n = 16)			x			x
Group 6 (n = 16)			x			x

Participant Training and Testing

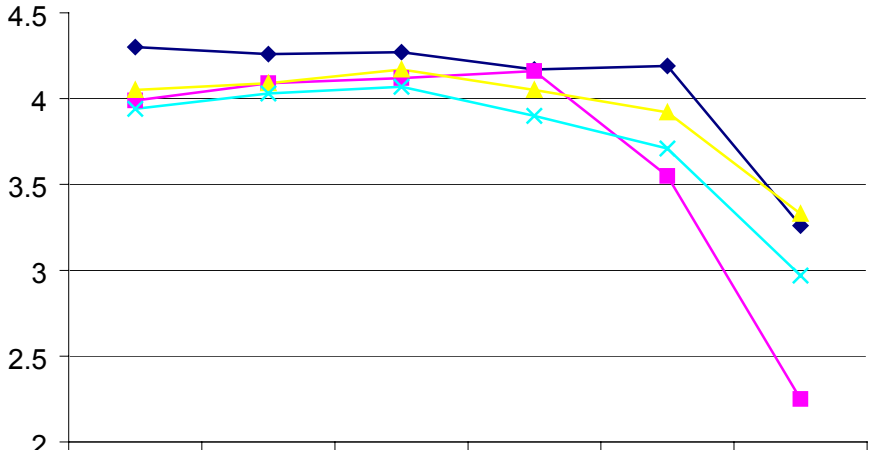
Participants were told that they would be listening to sound samples and rating them for overall quality. Samples were played over Sennheiser HD-600 headphones. Before testing, participants were given information about the kinds of impairments they would hear during the test. They listened to three practice samples (a clean audio recording, a moderately impaired audio recording and a highly impaired audio recording) and were shown how to use the data collection software to register their responses. Participants were encouraged to concentrate on the "quality of the transmission" when rating each sound sample, and were discouraged from rating samples based on whether they "liked" the particular genre of music.

Presentation of samples was randomly determined. For a single trial, participants heard a single sound sample and rated it on the ITU-R recommended 5-point "Quality" Mean Opinion Score (MOS) scale (5 =Excellent; 4 = Good; 3 = Fair; 2 = Poor; 1 = Bad).

Results

Figure 1 shows MOS as a function of signal levels in static conditions. For all receivers, MOS scores remain consistent between conditions ANO6 and ANO3. Participants' ratings begin to drop in the ANO2 condition, and are substantially degraded by the ANO1 condition. Table 3 shows Mean Opinion Scores of static conditions, divided by sound sample.

Figure 1: ACR Mean Opinion Scores vs. Average RF Signal Level in Static Conditions



	ANO6	ANO5	ANO4	ANO3	ANO2	ANO1
Denon	4.3	4.26	4.27	4.17	4.19	3.26
Panasonic	3.99	4.09	4.12	4.16	3.55	2.25
Pioneer	4.05	4.09	4.17	4.05	3.92	3.33
Sony Home	3.94	4.03	4.07	3.9	3.71	2.97

Table 3: ACR Mean Opinion Scores of static conditions by sound sample

Mean Opinion Scores (5=Excellent; 4=Good; 3=Fair; 2=Poor; 1=Bad)								
Receiver	Condition	Classical Instrumental	Classical Female	Classical Male	Rock Instrumental	Rock Female	Rock Male	Total MOS
Denon	ANO6	4.31	4.63	4.44	3.5	4.5	4.44	4.30
	ANO5	4.31	4.35	4.38	3.69	4.29	4.50	4.19
	ANO4	4.31	4.25	4.10	4.06	4.38	4.44	4.17
	ANO3	4.19	4.19	4.50	3.38	4.06	4.69	4.27
	ANO2	4.19	4.25	4.56	3.69	4.00	4.44	4.26
	ANO1	3.13	2.56	3.63	3.13	2.94	4.19	3.30
Panasonic	ANO6	4.06	4.18	4.25	3.12	4.44	3.94	3.99
	ANO5	3.94	4.63	3.94	3.31	4.29	4.44	4.09
	ANO4	3.94	4.24	4.63	3.59	4.56	3.82	4.12
	ANO3	4.06	4.63	3.94	3.69	4.35	4.31	4.16
	ANO2	3.69	3.76	3.94	2.94	3.44	3.53	3.55
	ANO1	2.47	1.81	2.24	2.25	2.12	2.63	2.25
Pioneer	ANO6	3.95	4.38	4.18	3.44	4.36	3.88	4.08
	ANO5	4.06	4.03	4.50	3.36	4.56	4.13	3.99
	ANO4	3.79	4.56	4.23	3.81	4.10	4.56	4.12
	ANO3	4.13	3.97	4.44	3.49	4.31	4.03	3.96
	ANO2	3.54	4.31	4.18	3.81	3.38	4.44	3.84
	ANO1	3.56	2.23	3.75	3.38	3.00	4.03	3.28
Sony CFD-S47	ANO6	4.00	3.58	4.69	3.16	4.31	4.11	3.94
	ANO5	3.63	4.44	4.16	3.56	4.11	4.31	4.03
	ANO4	4.00	4.16	4.25	3.47	4.50	4.11	4.07
	ANO3	3.58	4.38	3.84	3.38	4.00	4.25	3.90
	ANO2	3.81	3.58	3.88	3.16	3.94	4.00	3.71
	ANO1	3.26	2.25	3.00	3.38	2.37	3.63	2.97

Figure 2 shows MOS as a function of signal level in rural fast Rayleigh multipath. Receivers tested in these conditions were the Sony XR-3490 and the Visteon XWIF-18C870. Again, there is a marked drop in MOS scores between ARF6 and ARF1, especially for Sony. Table 3 shows Mean Opinion Scores of multipath conditions, divided by sound sample.

Figure 2: ACR Mean Opinion Scores vs. Average RF Signal Level in Rural Fast Rayleigh Multipath

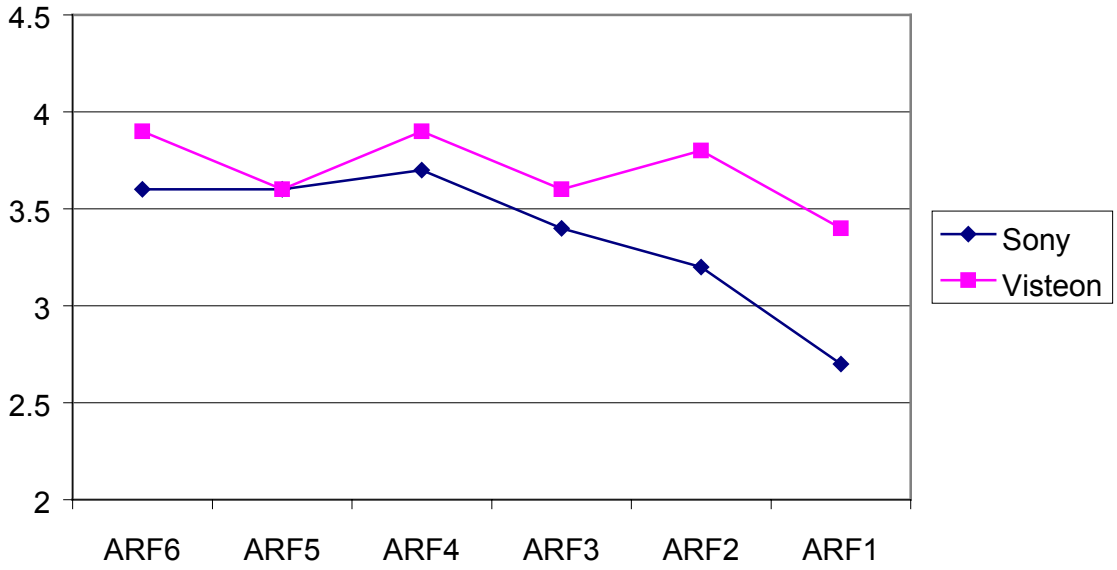


Table 3: ACR Mean Opinion Scores of Rural Fast Rayleigh Multipath conditions by sound sample

Mean Opinion Scores (5=Excellent; 4=Good; 3=Fair; 2=Poor; 1=Bad)								
Receiver	Condition	Classical Instrumental	Classical Female	Classical Male	Rock Instrumental	Rock Female	Rock Male	Total MOS
Sony XR-2390	ARF6	2.44	2.41	2.88	2.94	2.19	3.38	2.70
	ARF5	3.19	2.38	3.00	3.75	3.25	3.88	3.24
	ARF4	3.06	2.69	3.44	3.69	3.50	4.13	3.42
	ARF3	3.19	2.88	4.00	4.00	3.56	4.56	3.70
	ARF2	3.31	3.00	3.81	3.56	3.63	4.19	3.58
	ARF1	3.25	2.88	3.69	3.81	3.94	4.25	3.64
Visteon XWIF-18C870	ARF6	3.13	2.59	3.88	3.18	3.88	3.47	3.35
	ARF5	3.47	3.19	4.18	3.19	4.29	4.25	3.77
	ARF4	3.50	3.24	2.75	3.71	3.94	4.12	3.55
	ARF3	4.18	2.94	4.35	3.25	4.35	4.50	3.94
	ARF2	3.44	2.94	4.00	3.41	4.06	3.88	3.62
	ARF1	3.88	2.94	4.41	3.19	4.12	4.63	3.87

Tables 4 and 5 show participants' ratings of FM sound samples with 1st adjacent channel interference. Notice that Table 4 does not include multipath interference, whereas Table 5 does. In Table 4, the 4 home receivers are listed; in Table 5 the 2 auto receivers are listed. Total mean opinion scores are listed in the far-right column.

Table 4: ACR Mean Opinion Scores of conditions with 1st adjacent channel interference

Mean Opinion Scores (5=Excellent; 4=Good; 3=Fair; 2=Poor; 1=Bad)								
Receiver	Condition	Classical Instrumental	Classical Female	Classical Male	Rock Instrumental	Rock Female	Rock Male	Total MOS
Denon	CNO5	4.38	4.31	4.44	3.81	4.25	4.75	4.32
	CNO4	3.81	4.38	4.19	3.75	4.06	4.44	4.10
	CNO3	3.69	3.88	3.75	3.50	3.44	4.06	3.72
	CNO2	3.25	3.31	4.13	3.06	3.94	3.81	3.58
	CNO1	1.88	1.50	1.88	2.00	1.69	1.44	1.73
Panasonic	CNO5	4.06	4.69	4.06	3.44	4.12	4.19	4.09
	CNO4	4.19	4.29	4.63	3.24	4.56	4.00	4.14
	CNO3	3.76	4.38	4.06	3.44	4.18	4.25	4.01
	CNO2	3.69	3.53	4.00	3.12	3.19	3.76	3.55
	CNO1	3.41	2.13	3.18	2.94	2.47	3.44	2.93
Pioneer	CNO5	4.38	4.00	4.63	3.08	4.63	4.26	4.00
	CNO4	3.74	3.94	3.97	3.69	3.95	4.13	3.90
	CNO3	3.63	2.05	3.88	3.15	2.81	3.90	3.15
	CNO2	2.46	1.75	1.97	3.19	1.51	3.38	2.21
	CNO1	1.75	1.36	1.81	2.67	1.31	1.85	1.86
Sony CFD-S47	CNO5	3.68	4.38	4.26	3.69	4.26	4.13	4.07
	CNO4	3.75	2.68	4.31	3.05	3.75	3.84	3.53
	CNO3	2.42	2.06	2.21	3.31	1.95	3.75	2.58
	CNO2	2.56	1.63	2.13	2.74	1.81	2.32	2.20
	CNO1	1.11	1.06	1.05	1.44	1.11	1.13	1.14

Table 5: ACR Mean Opinion Scores of Rural Fast Rayleigh Multipath conditions with 1st adjacent channel interference

Mean Opinion Scores (5=Excellent; 4=Good; 3=Fair; 2=Poor; 1=Bad)								
Receiver	Condition	Classical Instrumental	Classical Female	Classical Male	Rock Instrumental	Rock Female	Rock Male	Total MOS
Sony XR-2390	CRF5	3.44	3.00	4.31	3.31	3.56	4.19	3.64
	CRF4	2.88	3.00	3.50	3.44	3.56	4.06	3.41
	CRF3	2.94	2.44	4.06	3.38	3.56	3.56	3.32
	CRF2	2.75	2.06	3.19	3.81	2.94	3.69	3.07
	CRF1	2.38	1.94	2.31	3.00	2.13	3.13	2.48
Visteon XWIF-18C870	CRF5	3.50	3.35	4.25	3.65	2.88	4.00	3.80
	CRF4	3.71	3.19	4.59	3.44	4.00	4.44	3.96
	CRF3	3.75	3.24	4.25	3.35	3.81	4.00	3.73
	CRF2	3.65	2.63	4.12	3.13	4.35	4.19	3.63
	CRF1	3.06	2.82	3.75	3.24	4.06	4.12	3.31

Table 6 shows MOS in signal to noise conditions, divided by individual sound-samples. Again, total mean opinion scores are listed in the far-right column.

Table 6: ACR Mean Opinion Scores vs. SNR

Mean Opinion Scores (5=Excellent; 4=Good; 3=Fair; 2=Poor; 1=Bad)								
Receiver	Condition	Classical Instrumental	Classical Female	Classical Male	Rock Instrumental	Rock Female	Rock Male	Total MOS
Denon	ENO1	4.25	4.38	4.38	3.63	4.25	4.50	4.23
	ENO2	3.50	3.00	3.25	3.38	3.38	3.94	3.41
	ENO3	2.50	2.19	2.19	2.75	2.13	2.81	2.43
	ENO4	2.19	1.44	2.44	2.50	2.56	2.38	2.25
Panasonic	ENO1	4.19	4.06	4.31	3.53	4.25	3.94	4.04
	ENO2	4.12	4.06	4.35	3.75	4.29	4.06	4.11
	ENO3	3.81	2.47	2.88	3.18	2.44	3.76	3.09
	ENO4	2.53	1.63	1.76	2.56	1.59	2.69	2.12
Pioneer	ENO1	3.72	4.19	4.28	3.88	4.33	4.38	4.12
	ENO2	3.94	3.13	4.00	3.36	3.81	3.90	3.59
	ENO3	3.10	2.69	2.72	3.56	2.18	3.69	2.85
	ENO4	2.44	1.74	2.75	2.38	2.38	2.85	2.38
Sony CFD-S47	ENO1	3.94	3.74	4.44	3.26	4.38	4.00	3.93
	ENO2	2.95	3.69	3.58	3.63	3.37	4.44	3.58
	ENO3	3.13	1.89	3.19	2.89	2.56	3.37	2.83
	ENO4	2.05	1.63	1.47	2.75	1.42	2.50	1.94
Visteon	ERF1	3.88	3.06	4.24	3.25	4.00	4.25	3.79
	ERF3	1.19	1.47	1.44	1.82	1.31	1.47	1.45
Sony Auto	ERF1	3.06	2.56	3.75	3.94	3.63	3.94	3.48
	ERF3	1.81	1.56	2.19	2.06	1.75	2.19	1.93

Table 7: Performance of LDR IBOC system subjected to the first adjacent channel interference and fast rural fading

Mean Opinion Scores (5=Excellent; 4=Good; 3=Fair; 2=Poor; 1=Bad)								
Receiver	Condition	Classical Instrumental	Classical Female	Classical Male	Rock Instrumental	Rock Female	Rock Male	Total MOS
IBOC	AAA	4.05	4.11	3.75	3.58	4.33	3.79	3.94