J

Appendix J

Summary of MOS Interpretation Test

August 7, 2001

iBiquity Digital Corporation

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1. Rationale

This test was designed to provide a context for the scores derived from the subjective evaluation program. For all ACR-MOS tests, participants subjectively evaluate audio samples based on five categories: Excellent; Good; Fair; Poor; Bad. Answers from the participants are later translated into numerical values (5 through 1) for the purpose of computing mean opinion scores from individual scores. There are two pieces of information that can be derived from evaluating mean scores. First, it is possible to characterize participants' experience with the audio in an absolute sense (i.e., a score anywhere around 4.0 $\pm.x$ indicates most people found the audio to be "good"). Second, it is possible to compare scores in a relative sense (i.e., a score of "good" [4.0 $\pm.x$] is better than a score of "fair" [3.0 $\pm.x$]). While evaluating participants' responses in these two ways is quite reasonable, iBiquity believes that it is equally important for the NRSC to understand audio scores in relation to the point at which the average listener would no longer listen to the broadcast. Although the test methodology used for the NRSC test program was not designed to answer directly this question, iBiquity conducted this additional test to determine at what MOS score the average listener would turn off the radio or change the station.

2. Methodology

Dynastat conducted a study in order to determine the point at which the average listener would no longer listen to a radio signal. To correlate participants' mean opinion scores to the "leave-on/turn-off" point, participants listened to audio samples and were asked (i) to provide an MOS score and (ii) to state whether they would keep the station on or turn it off. Twenty males and twenty females of varying ages participated in this study (See Appendix H for participant data). Participants listened to 84 sound samples, all of which came from other parts of this NRSC test program. Samples were chosen based solely on the MOS value assigned by participants from prior tests. Half of the samples was composed of music selections (classical and rock) and half was composed of speech selections. The order of presentation was randomly determined for each participant.

3. Summary of Results

In order to derive an average "keep-on/turn-off" point, a point was selected at which more than 50% of the listeners indicated they would turn off the radio for a particular type of music. Table 1 below provides the results for each of the three genres tested. Participants were more likely to continue to listen to music at slightly lower MOS levels than they were speech.

Sound Sample Type	MOS Score
Rock	2.0
Classical Music	2.1
Speech	2.3

Table 1: MOS Score at Which an Average Listener Would Turn Off the Radio

4. Use of the Results

This average "turn-off" point can be used to help interpret MOS scores for both performance and compatibility tests. However, based on the subjects used for this test, these results should be restricted to interpret MOS scores related to main channel audio. Because this test used general population participants, it cannot be used reliably to interpret SCA results. In order to provide similar results for SCA receivers, it would be necessary to have participants drawn from the audience most likely to use SCA receivers. It is quite likely that listeners who use SCA receivers would have different expectations of audio quality than the general public. That difference in expectations would not be apparent from this test that used only general population participants.

K

Appendix K

Ticker Test

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1. Introduction and Rationale

The "Ticker Test" was designed to analyze the durability of digital and analog signals by measuring the number and severity of temporal impairments participants hear while listening to typical radio broadcasts in each format. The Ticker Test was modeled after an informal 1999 NRSC listening test in which expert listeners were asked to report the number of times they heard impairments (e.g., ticks, pops, clicks, etc.) over long selections of audio samples. This methodology represents a particularly valuable means of allowing participants to characterize very long audio segments, which are representative of real-world listening experiences. It compliments MOS tests, which rely on evaluating short segments in a wide range of conditions.

2. Ticker Test

The methodology used in this experiment was similar to the 1999 NRSC test, but was modified to add another dimension. In addition to recording the number of impairments heard, participants were asked to characterize the impairments they heard as "small" or "large". Audio samples used in this test were taken from the recordings made during the field test radials for WETA and WPOC. The audio chosen represented medium to strong signal coverage within the WETA and WPOC coverage areas. These stations were chosen because of their large, Class B coverage areas and their contrasting program material (i.e., classical at WETA and country at WPOC). Approximately 40 total minutes of broadcast programming was chosen from four drive test radials within each station's core coverage area. In order to create a reasonable, non-fatiguing subjective evaluation task for participants, iBiquity chose continuous, four to six minute audio sample segments recorded starting at ten miles from each transmitter site and moving out along each selected radial. For WETA, audio samples came from radials at 90, 180, 270, and 315 degrees. For WPOC, audio samples came from radials at 45, 90, 180 and 270 degrees. Because the audio samples were selected from mobile tests, only samples from the Delphi, Pioneer and iBiquity (IBOC) receivers were used for this test.

3. ACRM

Unlike ACRM tests, the Ticker Test did not directly ask participants to rate audio quality. Instead it asked them to quantify the number of impairments they heard in a given audio segment. While this information is valuable as a stand-alone measure, it also is useful to be able to map the impairments participants reported to an overall quality measure, such as the MOS. In order to do this, over 100 15-second segments from the 4-minute audio segments were created. Segments were chosen by a committee of three listeners by reviewing the Delphi analog recordings. Half of these segments were classified as moderately impaired (either consisting of a few severe impairments or several light impairments), the other half were classified as severely impaired (consisting of heavy and/or many light impairments). Impairments could be from original source material, noise, interference, audio processing or artifacts. Companion samples from the Pioneer and IBOC receivers were taken from the identical time period as those selected

from the Delphi recordings. These samples also were sent to Dynastat, where participants were asked to rate them based on the MOS 5-point quality scale.

4. Summary of Methodology

In the Ticker Test, individual participants listened to audio taken from 3 of the 8 radials. For each location, they listened to all three receivers (IBOC, Dephi and Pioneer). Thus, results for each location are based on a "within-subject" measure. In total, participants listened to 9 audio streams (3 locations x 3 receivers), or approximately 36 minutes of audio. Participants were asked to report all small and large impairments they heard in the audio stream by pressing one of two response keys (i.e., F1 for small, F2 for large). After listening to each audio stream, they were encouraged to take a short break before proceeding to the next trial.

See **Attachment H** for a full description of the test methodology used at Dynastat.

5. Summary of Results

In order to aggregate results, all minor, or soft impairments participants reported were classified as "weak", and all large, or loud impairments were classified as "severe". Figure 1 shows the number of temporal impairments averaged over participants that were reported for each 4-minute segment. As is evident from this figure, participants heard over 4-5 times the number of impairments on the analog segments that they heard on the IBOC segments. Even more importantly, the number of severe impairments participants reported hearing on the analog segments was 6-7 times greater than on IBOC segments.

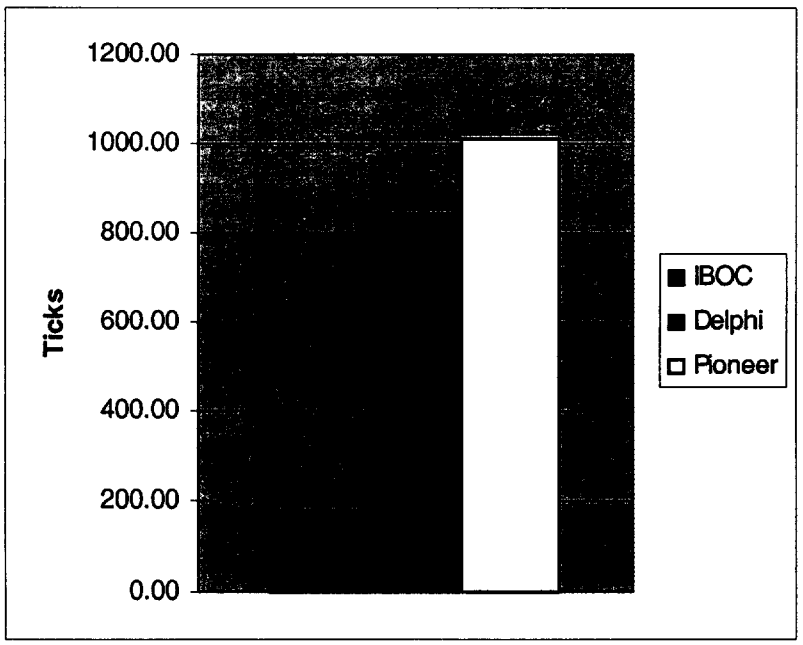


Figure 1: Number of temporal impairments (ticks) heard on average by location

Figures 2 through 9 chart the test results as a function of time. The number of impairments heard by all participants was averaged for each second. For example, if 5 out of 25 people reported hearing 10 small impairments during second "21", the average score for second "21" would be 10/25 or .4. Each figure represents the performance of the IBOC, Delphi and Pioneer receivers at one location. Small and Large impairments are reported separately in these figures.

The figures graphically demonstrate the impairments participants reported hearing during the segments. Notice that the IBOC impairments are fairly evenly distributed throughout the segments, indicating that, in general, participants were reporting low-level, uniform impairments. In contrast, the impairments from analog segments were more defined, clustered more heavily around certain points. This pattern indicates that the impairments were more likely to be "rapid-fire" sounds, as would be found in multipath environments. Additionally, some MOS scores from the 15-second audio segments were mapped to the impairment profiles to show the correlation between participants' reports of temporal impairments and the quality rating they assigned. As is evident, the quality ratings for all receivers were often worse when more "clustered ticks" were reported.

Figure 10 shows mean opinion scores participants gave to all of the 15-second audio segments taken from the 4-minute audio samples. Again, the labels "moderately impaired" and "severely impaired" refer to the rough, pre-test classification of the audio sample versions from the *Delphi* receiver. It is possible that the other receivers' audio samples could exhibit better or worse quality. Notice that in both moderately and severely impaired cases, the IBOC receiver consistently scored over 4.1, indicating that participants were satisfied with the level of audio they heard, in spite of reporting occasional temporal impairments. In contrast, in moderately impaired conditions, the analog receivers scored only between 3.1 and 3.4, and in severely impaired conditions received scores of between 2.4 and 2.7, indicating that participants were significantly less satisfied with the quality of this reception.

Taken together, results from the Ticker and ACRM experiments show that participants not only clearly hear temporal impairments over long periods of time, but that the quality ratings they assign the audio samples are directly affected by the frequency and magnitude of these impairments. The greater the number of impairments and the greater the severity, the more listeners rate impairments as an issue. Thus, it may be reasonable to map consumers' opinions of audio quality to the number of temporal impairments they hear over time. Furthermore, unlike other impairments, which may have less powerful impacts on consumer acceptance (e.g., constant low-level noise), listeners do not appear to habituate to temporal impairments. As shown in the figures below, IBOC demonstrates a significantly lower incidence of temporal impairments as compared to FM analog transmission-reception systems – even in core coverage areas. This shows the marked improvement in quality and durability that IBOC offers over current FM analog transmission systems.

Figure 2: WETA Radial 90: 10 to 13.3 miles from Transmitter (Location 1)

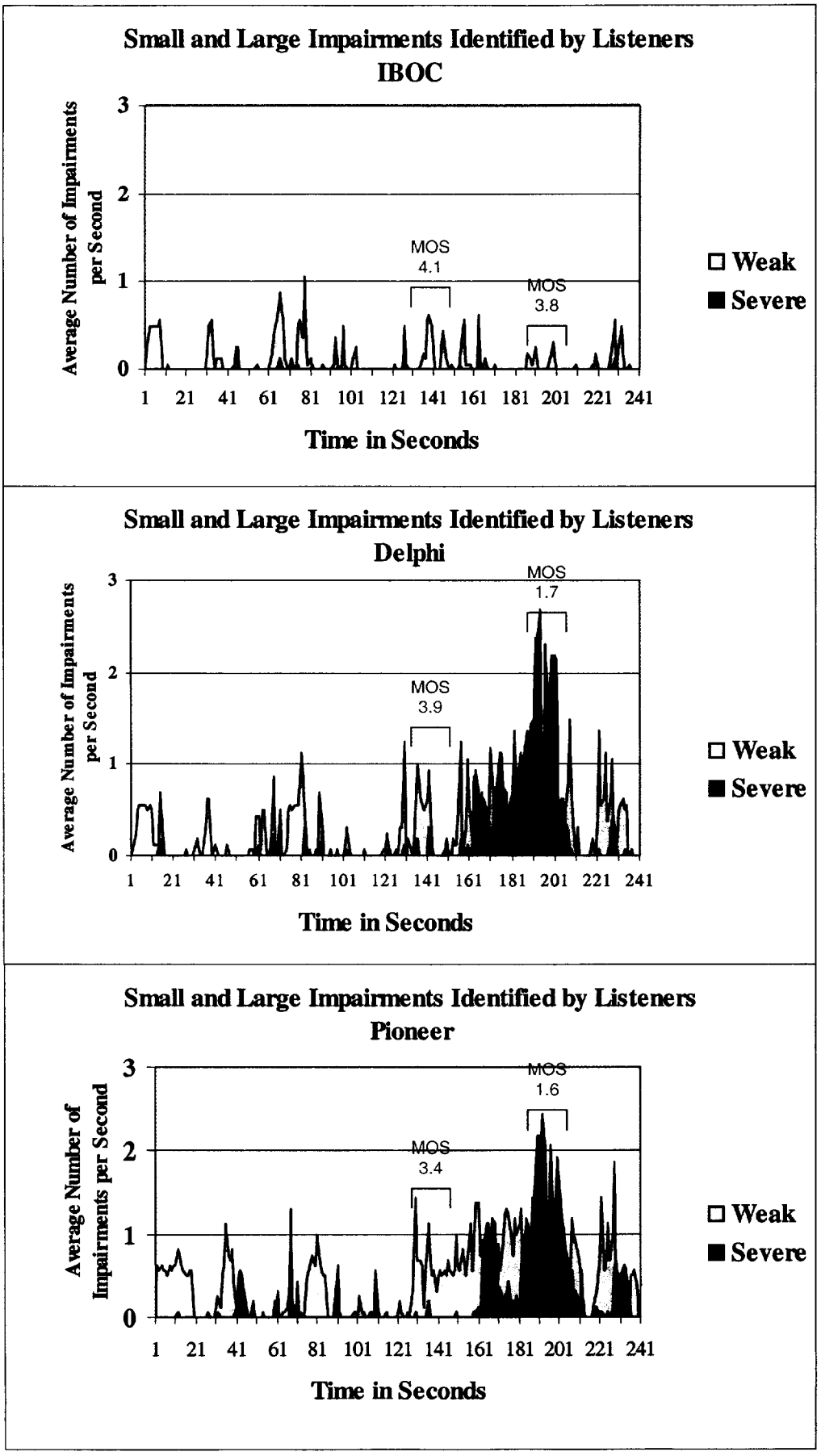


Figure 3: WETA Radial 180: 10.2 to 14.6 miles from transmitter (Location 2)

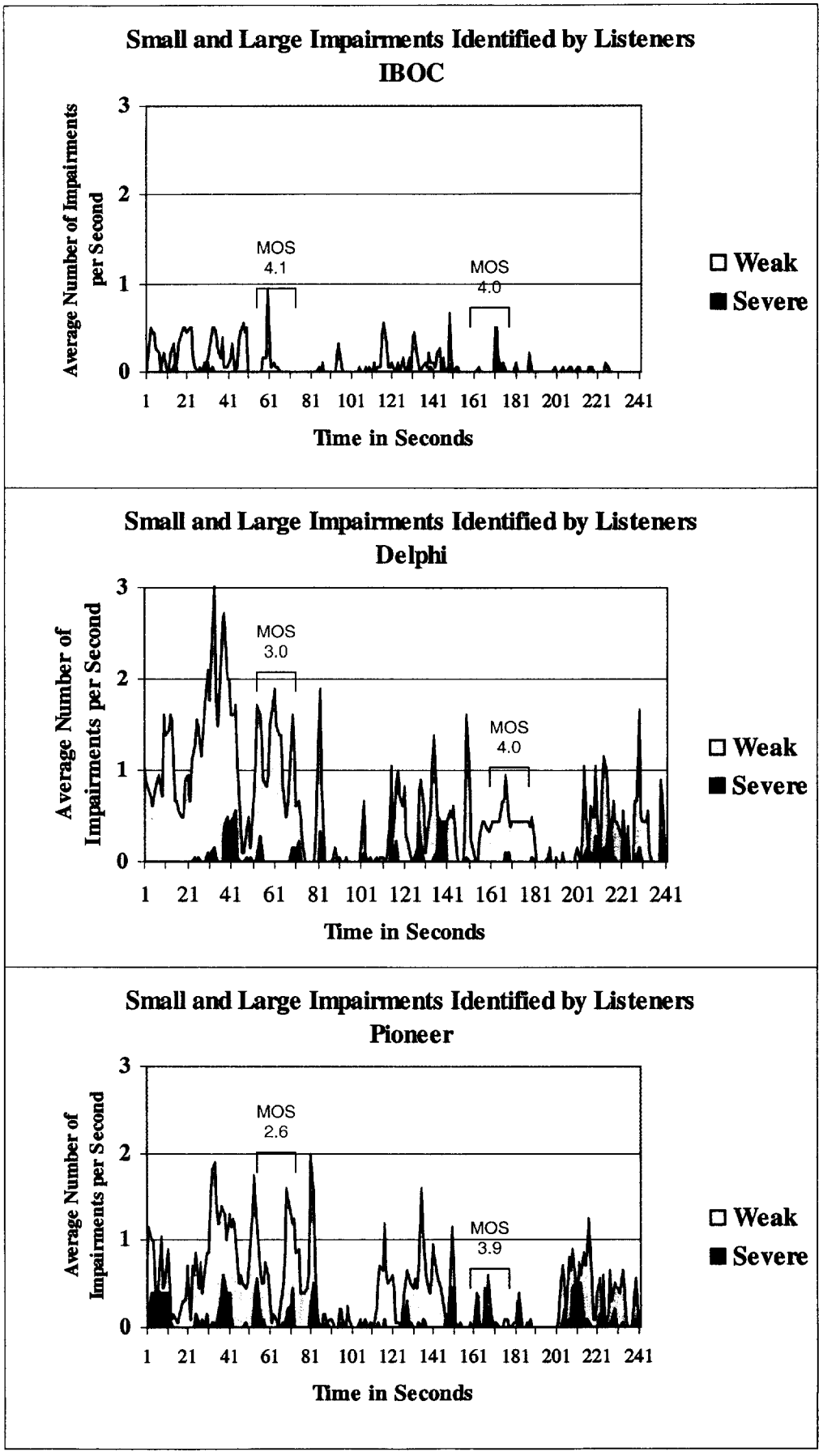


Figure 4: WETA Radial 270: 10.1 to 14.0 miles from transmitter (Location 3)

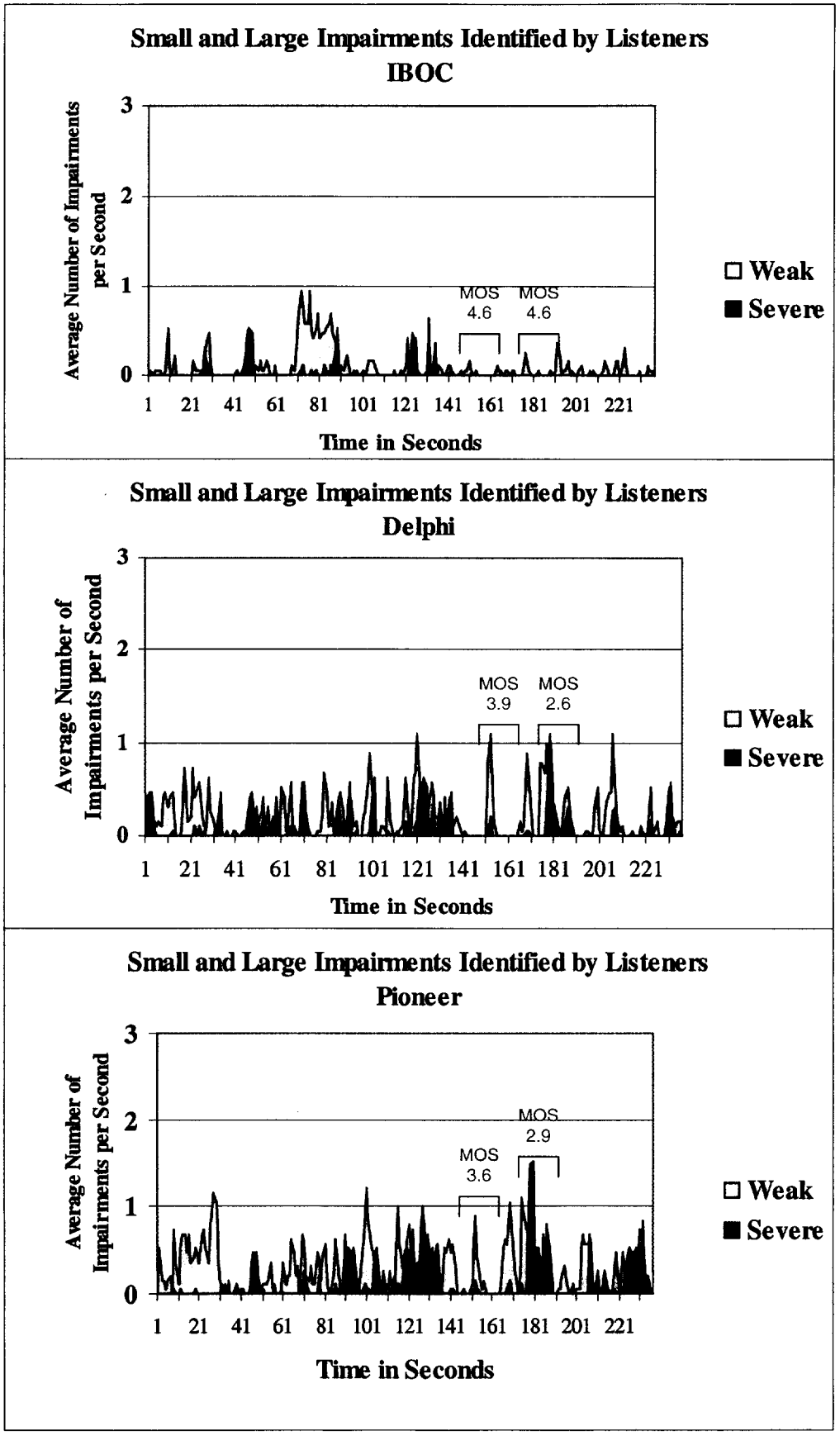


Figure 5: WETA Radial 315: 10.1 to 14.2 miles from the transmitter (Location 4)

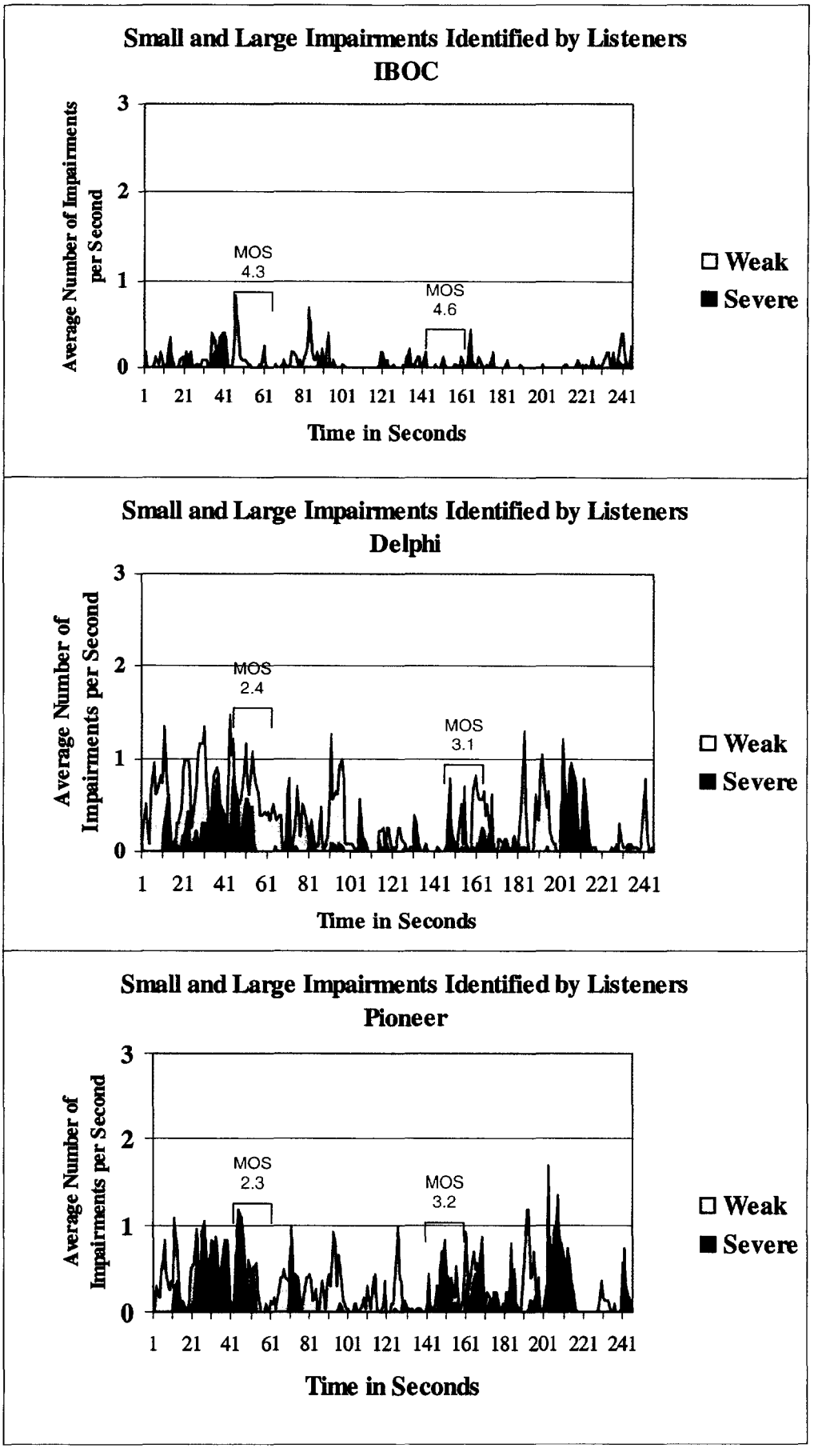


Figure 6: WPOC Radial 45: 10.0 to 11.7 miles from the transmitter (Location 5)

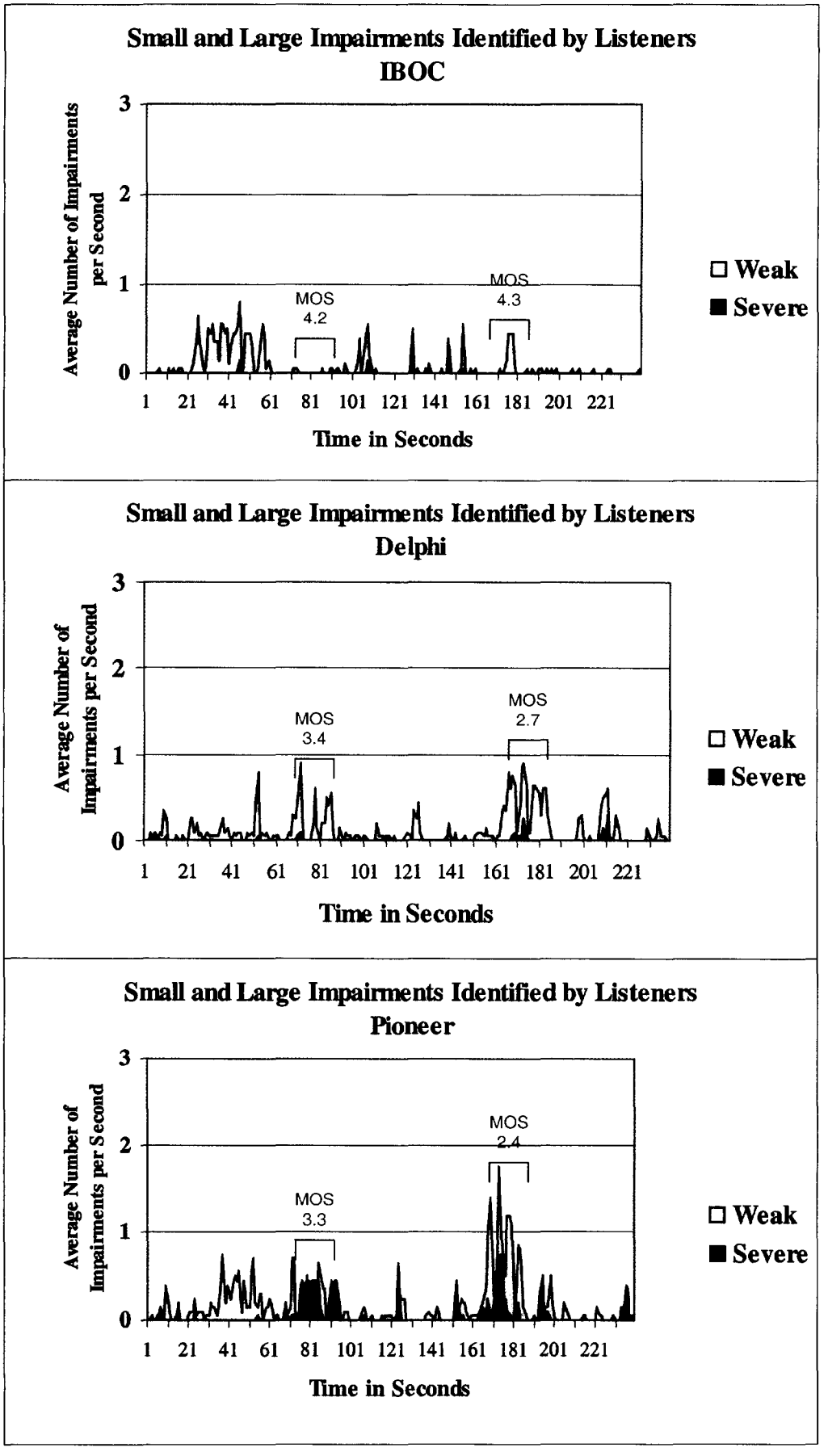


Figure 7: WPOC Radial 90: 10.1 to 11.1 miles from the transmitter (Location 6)

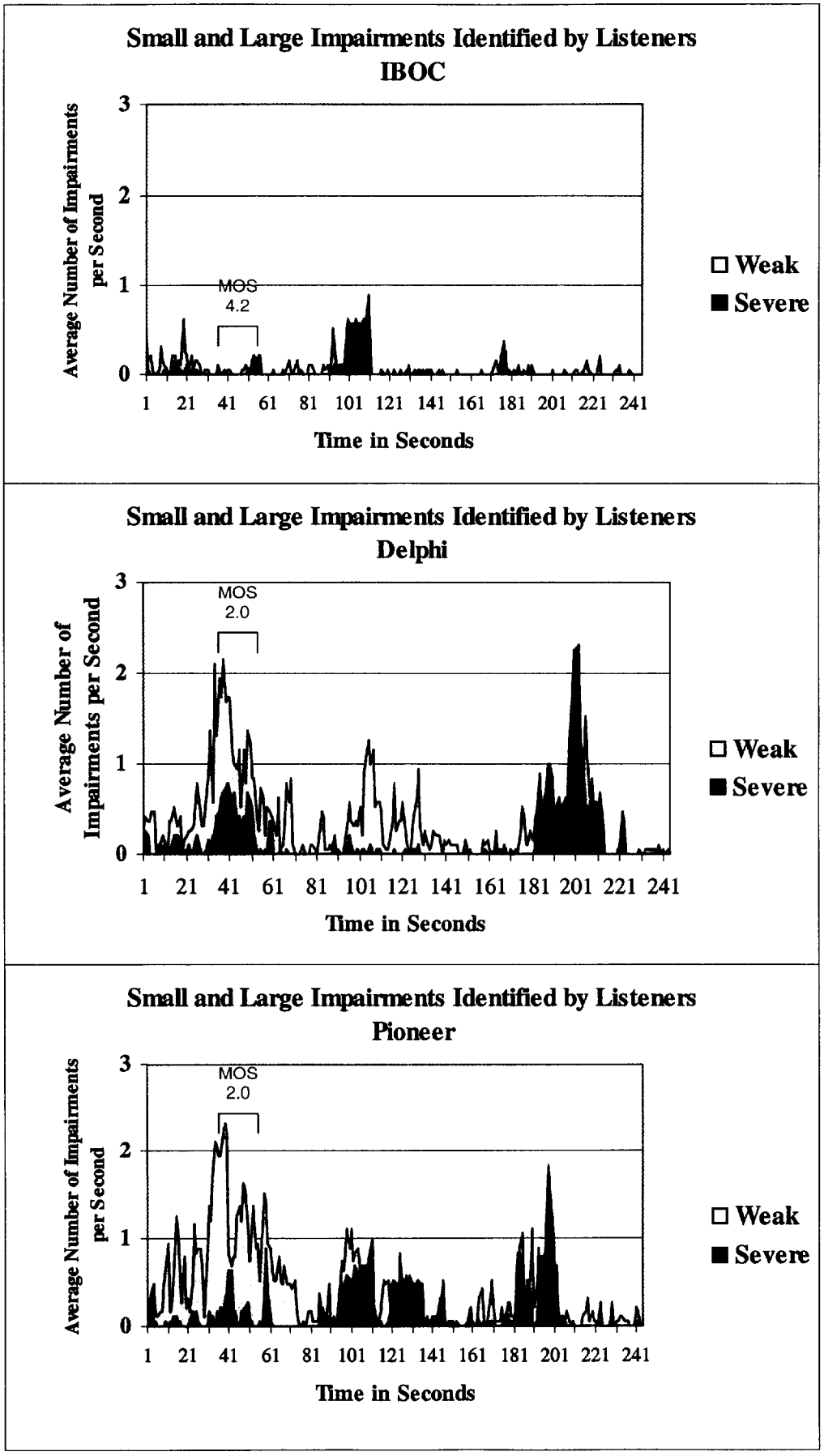


Figure 8: WPOC Radial 180: 10.0 to 12.9 miles from the transmitter (Location 7)

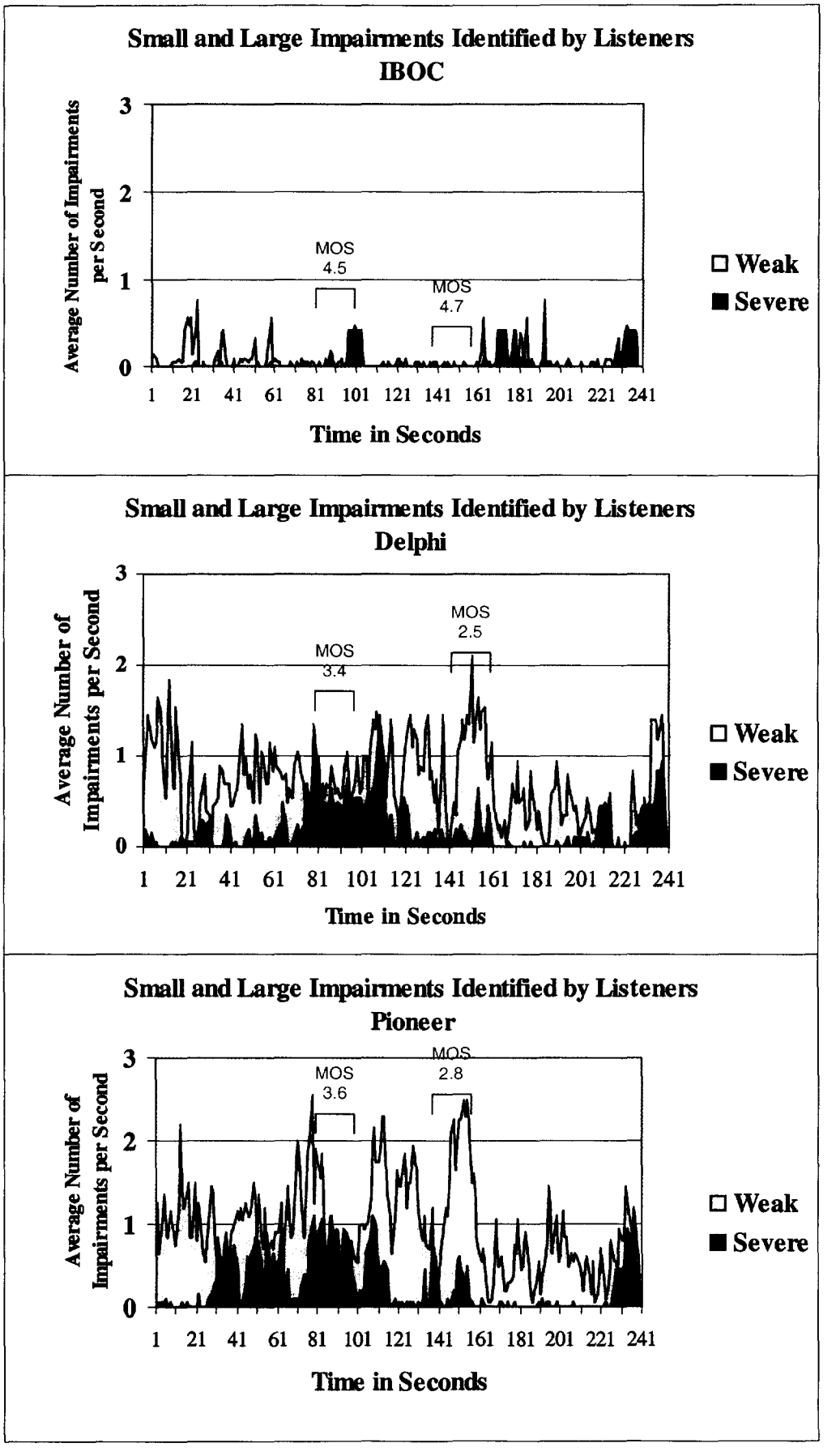


Figure 9: WPOC Radial 270: 10.0 to 14.6 miles from the transmitter (Location 8)

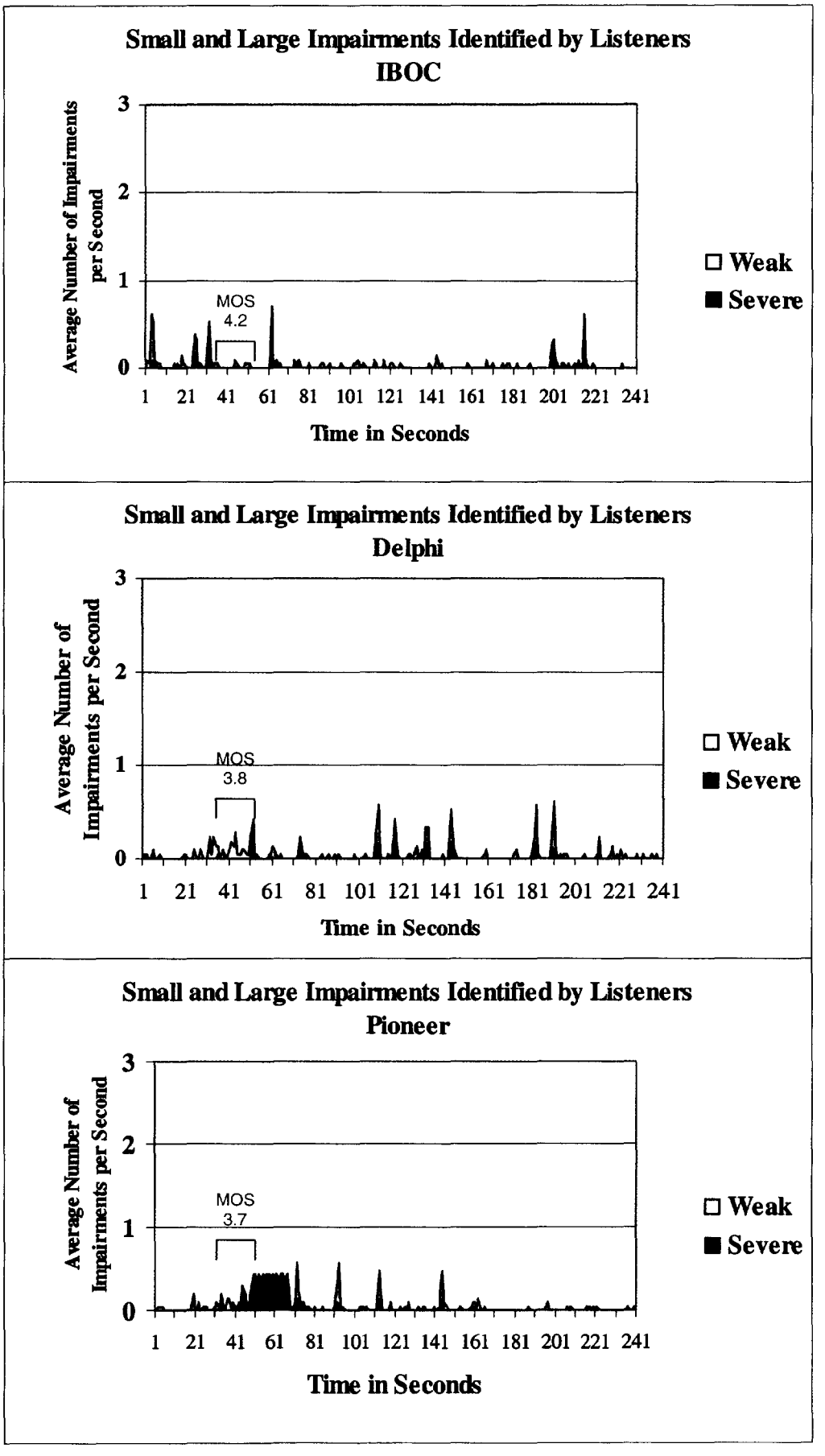
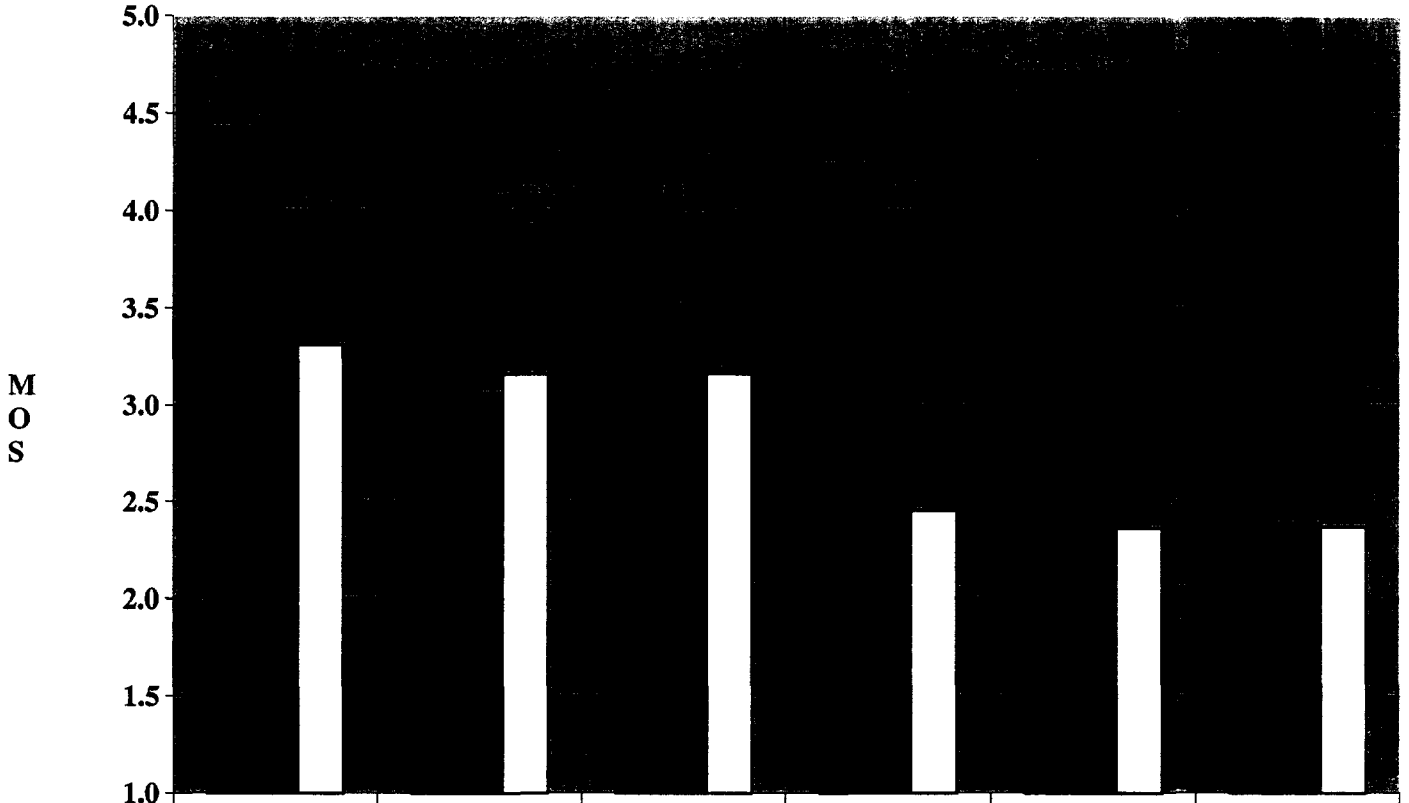


Figure 10 - MOS Scores for Audio Segments Selected From Ticker Test



	Classical	Country	Speech	Classical	Country	Speech
■ IBOC	4.4	4.3	4.1	4.2	4.3	4.2
■ Delphi	3.4	3.1	3.2	2.7	2.7	2.4
□ Pioneer	3.3	3.2	3.2	2.5	2.4	2.4

L

Appendix L

Study of the Present Levels and Instances of First Adjacent Channel Interference

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August 2001

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Overview

In 1998 iBiquity Digital Corporation contracted with Moffett, Larson and Johnson, Inc. (MLJ) and dataworld to develop a methodology for determining the existing levels of interference in the FM band. Studies were conducted on all licensed commercial and non-commercial stations on each of the 100 allocated FM channels. These studies were used as part of iBiquity's ongoing research into the performance of IBOC systems in the existing levels of analog FM interference[1]. Concurrent with the NRSC testing program, iBiquity contracted with dataworld to update the information.

Methodology

The updated study was conducted within the station's 44 dBu "noise limited" contour and includes data for both the 54 dBu protected and the 44 dBu noise limited contours. For a derivation of the noise limited contour, see Supplement A to this appendix. To produce the overall interference studies, propagation curves based on the FCC's rules are used to calculate desired and undesired field strength. The F(50,50) curves are used for desired service field strength, and the F(50,10) curves are used for the undesired signals. Only licensed facilities are considered. Stations' licensed effective radiated power, antenna height and antenna patterns are used in the calculations.

Coverage and interference studies were conducted using the Station's FCC licensed allocation. Licensed facilities were used in order to avoid the problem of multiple FCC database entries and ongoing license changes. Each station was studied as a desired station. In the study, field strength is calculated at the center of "bins" or "cells" two minutes of latitude and longitude on a side surrounding the station (approximately 4 square miles). The results of the desired field strength F(50,50) calculations are stored in a matrix for each channel. The undesired, F(50,10) field strength for each channel is calculated at the bin center and stored in a matrix. The undesired values are calculated as long as the predicted field strength exceeds 44 dBu. The values from the desired and undesired matrices are used for analysis of the levels of co- and adjacent channel interference in the FM band.

Desired signal levels below 44dBu were not included in the study. Interference in a bin is determined from the desired and undesired matrices. Interfering values were calculated to the 24 dBu level, 20 dB below the studied contour. The values of the desired and interfering adjacent channels are used in determining levels and geographic areas of interference.

dataworld used the data to create a graph depicting the areas of first adjacent channel interference for the 54 and 44 dBu contour. Figure 1 shows the first adjacent channel interference incidence on all FM stations. The Desired to Undesired (D/U) First Adjacent Channel ratio is on the X axis and the percentage coverage area affected by existing analog interference is on the Y axis. Table 1 shows the parsed data used to create the graph.

Result

The chart below accurately depicts levels of interference in the FM Band. As expected, the percentage of overall coverage area subject to first adjacent channel interference increases with nominal maximum D/U. Furthermore, if the actual area of coverage is assumed to extend to the 44 dBu contour, instances of first adjacent channel interference increase substantially over that predicted at the 54 dBu contour.

[1] For more details see the USADR Petition for Rulemaking, Appendix D, December 12, 1998

First Adjacent Channel Interference
Incidence of Interference on All FM Stations

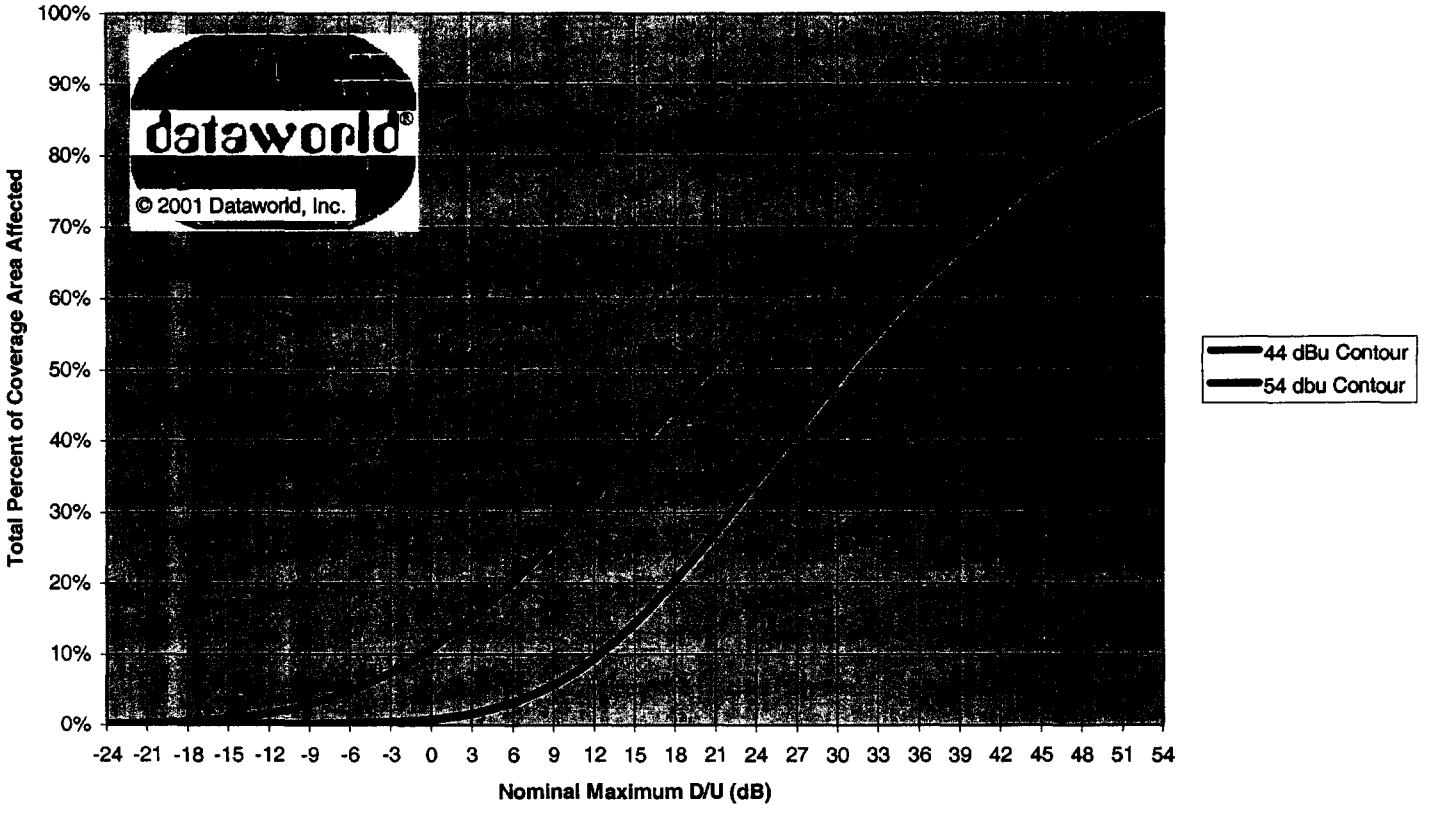

Table 1		
Total FM Coverage Area Impacted		
Nominal D/U Max	54 dbu contour	44 dBu Contour
-24	0.01%	0.15%
-21	0.01%	0.27%
-18	0.02%	0.50%
-15	0.03%	0.94%
-12	0.06%	1.72%
-9	0.11%	2.97%
-6	0.19%	4.81%
-3	0.34%	7.37%
0	0.71%	10.75%
3	1.55%	15.01%
6	3.10%	20.13%
9	5.62%	25.92%
12	9.32%	32.14%
15	14.25%	38.54%
18	20.28%	44.89%
21	27.08%	51.04%
24	34.27%	56.90%
27	41.52%	62.40%
30	48.56%	67.51%
33	55.26%	72.20%
36	61.51%	76.46%
39	67.24%	80.26%
42	72.45%	83.59%
45	77.10%	86.38%
48	81.17%	88.69%
51	84.70%	90.60%
54	87.59%	92.15%
999	97.09%	97.21%

Supplement A

Derivation of FM Noise Limited Coverage Contour

Traditionally, the field strength of 34 dBu (50 μV/M) has been used to depict the extent of noise limited FM coverage. This value may be appropriate in some cases but use of the value appears to overstate coverage. Values for coverage contours may be derived with assumptions for type and grade of service. For example, receivers may be indoors or outdoors, stationary or mobile, and may operate in a high or low RF noise environment. Service also depends on whether reception is in a mono or stereo mode. There is a substantial signal to noise ratio (S/N) penalty for stereo operation; the theoretical loss is 22 dB[2].

Unfortunately, there is very little data that can be used to derive a noise limited contour value and such data often shows wide ranges in values. This is particularly true for determinations of ambient noise, which varies substantially between locations. In this study it is assumed that outdoor receiving antennas are used and no allowance is made for indoor antennas.

Mobile reception is the most challenging condition for FM broadcasting in that Raleigh fading causes 10 to 20 dB changes is signal level. To compensate for these fading conditions automotive receiver manufacturers typically employ techniques for dynamic blend to monaural, frequently at high signal levels to improve recovered Signal to Noise Ratio, SNR. For purposes of this study it is assumed that threshold for mono reception is used for mobile reception. For service to fixed receivers stereo reception is assumed.

Field strength is first calculated for the FM threshold in the absence of noise. Field strength may then be adjusted upward for various conditions and grades of service. To perform calculations, noise factors are taken the Reference Data for Engineers[3], location factors from the CCIR and time factors from the FCC's curves. Time and location reliability are assumed to be log-normally distributed. Short term Rayleigh or multipath fading is based on based on EIA Multipath Characterization Tests, Salt Lake City, 1993.

In this study outdoor antennas are assumed for home reception with a net antenna system gain is assumed to be 3 dB[4]. The reliability factors are added independent, particularly time and location reliability and it would be more appropriate to root sum square (rss) the standard deviations and derive the standard deviation for overall reliability. The method used is more conservative and results in a higher coverage value.

Table1 shows the field strength calculations for three coverage conditions:

1) Rural mobile with fading
2) Suburban – median location and 90% of the time
3) Outdoor stereo median location and 90% of the time

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[2] NAB Engineering Handbook, English Edition, p 1145
[3] Jordan, E.C., ed. Reference Data for Engineers, Ratio, Electronics, Computer and Communications, pp 34-5 to 34-9
[4] The value used by the Commission in the recent DTV planning for low VHF TV.

General Assumptions:

1) Carrier to noise ratio (C/N): The standard should be the threshold for mono reception
2) Ambient Noise factor = F_a Noise environment may be equivalent to rural or suburban; receiver noise contribution is negligible. Noise reference temperature = T_0.
3) Base Antenna Gain on a half wave diplole receiving antenna. G = Antenna gain
4) Noise equivalent bandwidth = B

Formulas:

F_a = Ambient Noise in dB above kT_0B (dBW)[5]
N = Noise level – 10 log(B) + F_a-204 (dBW)
P_r = Required received power = N+C/N (dBW)
F = Field Strength = P_r + 20 Log (F_{mhz}) – 5 + G (dBu)

Assumed Values:

B = 200 kHz
T_0 = 290° K
F_{mhz} = 98 MHz
C/N = 13 dB[6]

Threshold Field Strength (all values rounded to nearest dB) for Fa =0

N = 53 +- 204+-151 dBW
P_r = -151 + 13 = -138 dBW
F + -122 + 40 + 105 = 7 dBu

Other Factors Included in Contour Calculation:

Height Factor 9.1 m to 1.5m = 9 dB[7]
Long term Fading = based FCC on FCC Curves assuming Log normal distribution
Rayleigh Fading = Fading caused by multipath[8]
Terrain Reliability Factor = Log Normal Fading e.g. 11 dB (90% of Locations)[9]
Stereo Operation = 22 dB[10]

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5 Reference Data For Engineers, Electronics, Computers and Communications, 7th Ed. p 34-5 to 34-9
6 Often assumed to be 10 dB for wideband FM, 13 dB yields S/N □35 dB including pre-emphasis & de-emphasis. See Schwartz, M; Information Transmission Modulation and Noise.
7 Based on TASO see NAB Handbook 7th Ed. p 339 & FCC Report R –6406 "Technical Factors Affecting the Assignment of Facilities in the DPLMRS", (Carey Report). Note: Plane Earth loss = 20 Log (9.1/1.5) = 15.7 dB
8 Based on EIA Multipath Characterization Tests, Salt Lake City, 1993
9 CCIR Recommendation 370-5, Geneva, 1986
10 NAB Engineering Handbook, 7th Ed., p 1145

Table 1
Noise Limited Field Strength Calculations

1) Rural Mobile – 90% of Time & Locations with Rayleigh Fading

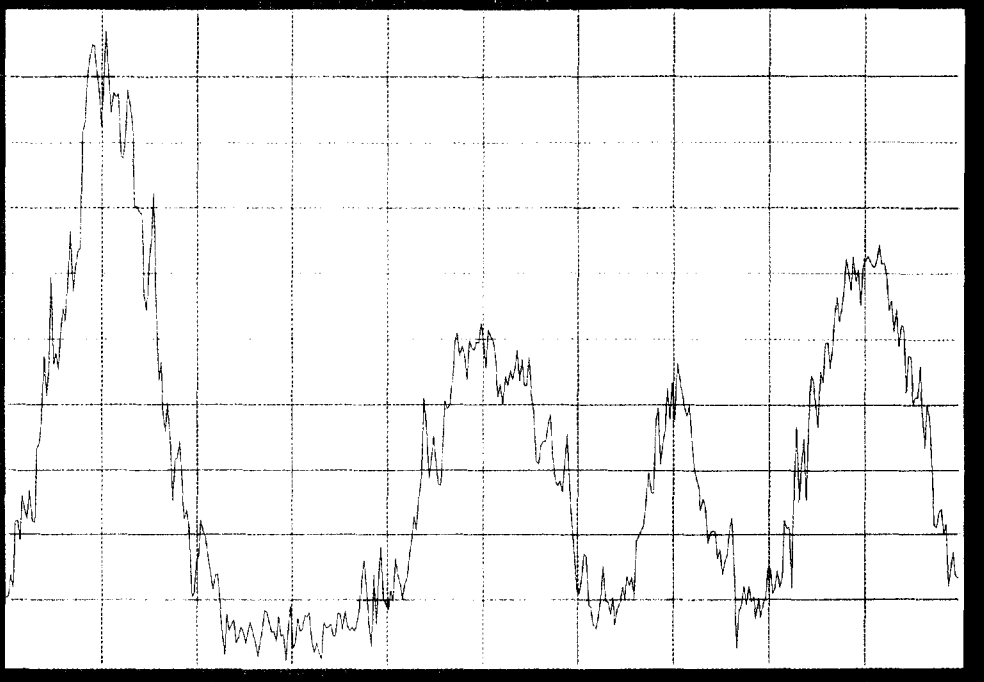
Factor	Condition	Field Strength	Calculation
Field Strength	Threshold	7	dBu
Ambient Noise (F_a)	Rural (quiet locations)	6	dB
Height Factor	9.1m to 1.5m	9	dB
Long Term Fading	90% of Time (60km)	4	dB
Rayleigh Fading		7	dB
Location Reliability Factor	90% of Locations	11	dB
System Antenna Gain		0	dB
S/N Adjustment		0	dB
Coverage Contour		44	dBu

2) Suburban Mobile – Median Location, 90% of the Time & Rayleigh Fading

Factor	Condition	Field Strength	Calculation
Field Strength	Threshold	7	dBu
Ambient Noise (F_a)	Suburban	24	dB
Height Factor	9.1m to 1.5m	9	dB
Long Term Fading	90% of Time (60km)	4	dB
Rayleigh Fading		7	dB
Location Reliability Factor	50% of Locations	0	dB
System Antenna Gain		0	dB
S/N Adjustment		0	dB
Coverage Contour		51	dBu

3) Outdoor Stereo – Median Location & 90% of the Time

Factor	Condition	Field Strength	Calculation
Field Strength	Threshold	7	dBu
Ambient Noise (F_a)	Rural (quiet locations)	6	dB
Height Factor	9.1m to 1.5m	0	dB
Long Term Fading	90% of Time (60km)	7	dB
Rayleigh Fading		0	dB
Location Reliability Factor	90% of Locations	0	dB
System Antenna Gain		3	dB
S/N Adjustment	Stereo	22	dB
Coverage Contour		39	dBu



Point #5
Rt. 25A - Northport
Shopping Ctr.

WHTZ = 47.20 dBu
WRCH = 43.70 dBu
D/U = 3.50 dB