EX PARTE OR LATE FILED

ORIGINAL

CEA
Consumer Electronics Association
A sector of EIA

2500 Wilson Boulevard
Arlington, VA 22201-3834
(703) 907-7500
FAX (703) 907-7501

NATIONAL RADIO SYSTEMS COMMITTEE

National Association of NAB BROADCASTERS®

1771 N Street, NW
Washington, DC 20036-2891
(202) 429-5346
FAX (202) 775-4981

ORIGINAL

May 12, 2000

MAY 12 2000

Ms. Magalie Roman Salas
Secretary
Federal Communications Commission
445 Twelfth Street, S.W.
Washington, D.C. 20554

Re: Digital Audio Broadcasting Systems and their Impact on the Terrestrial Radio Broadcast Service, MM Docket No. 99-325, RM-9395

Dear Ms. Salas:

The National Association of Broadcasters ("NAB")[1] and the Consumer Electronics Association ("CEA")[2] submit the attached documents of the DAB Subcommittee of the National Radio Systems Committee ("NRSC") into the above-referenced proceeding on Digital Audio Broadcasting ("DAB") Systems. NAB and CEA are the co-sponsors of the NRSC, the objective of which is to serve as the definitive technical standards-setting body for free, over-the-air radio broadcasting systems in the United States.

Attached are copies of *Evaluation of USA Digital Radio's Submission to the NRSC DAB Subcommittee of Selected Laboratory and Field Test Results for its FM and AM Band IBOC System* and *Evaluation of Lucent Digital Radio's Submission to the NRSC DAB Subcommittee of Selected Laboratory and Field Test Results for its FM and AM Band IBOC System.* These evaluations were adopted by the NRSC's DAB Subcommittee for USA Digital Radio and Lucent Digital Radio's IBOC systems on April 8, 2000.

No. of Copies rec'd 0+1
List ABCDE

1 NAB is a nonprofit, incorporated association of television and radio stations and networks which services and represents the American broadcast industry.

2 CEA, an independent trade association and a sector of the Electronic Industries Association, is the principal trade association of the consumer electronics industry. CEA members design, manufacture, distribute and sell a wide variety of consumer electronics equipment, including radio broadcast receivers.

We believe the reports will provide the Commission with valuable information regarding the development of IBOC DAB and prove useful in the ongoing proceeding. Any questions can be addressed to the undersigned.

Respectfully submitted,

Valerie Schulte
National Association of Broadcasters
1771 N Street, N.W.
Washington, D.C. 20036
(202) 429-5430

Ralph Justus
Consumer Electronics Association
2500 Wilson Boulevard
Arlington, VA 22201
(703) 907-7500

Attachments

CEA
Consumer Electronics Association
A sector of EIA
2500 Wilson Boulevard
Arlington, VA 22201-3834
(703) 907-7500
FAX (703) 907-7501

NATIONAL
RADIO
SYSTEMS
COMMITTEE

National Association of
NAB
BROADCASTERS®
1771 N Street, NW
Washington, DC 20036-2891
(202) 429-5346
FAX (202) 775-4981

DAB Subcommittee

EVALUATION OF USA DIGITAL RADIO'S SUBMISSION TO THE NRSC DAB SUBCOMMITTEE OF SELECTED LABORATORY AND FIELD TEST RESULTS FOR ITS FM AND AM BAND IBOC SYSTEM

Report from the
Evaluation Working Group
Dr. H. Donald Messer, Chairman

(as adopted by the Subcommittee on April 8, 2000)

Sponsored by the Consumer Electronics Association and the National Association of Broadcasters

Table of Contents

1 INTRODUCTION **4**

1.1 NRSC DAB SUBCOMMITTEE GOALS AND OBJECTIVES 5
1.2 EVALUATION PROCESS DECISIONS MADE 5
1.2.1 Test guidelines would be established *5*
1.2.2 Formation and functioning of the Evaluation Working Group *5*
1.2.3 Agreements on IBOC system scope and NRSC reporting of its evaluations *6*
1.3 MUCH WORK DONE; MUCH WORK LEFT TO DO 7

2 CONCLUSION **8**

3 DISCUSSION OF FINDINGS **9**

3.1 CRITERIA USED FOR EVALUATION 9
3.2 FM IBOC SYSTEM EVALUATION – FINDINGS 9
3.2.1 Criterion 1 – Audio quality *10*
3.2.2 Criteria 2, 3 – Service area, durability *10*
3.2.3 Criterion 4 – Acquisition performance *13*
3.2.4 Criterion 5 – Auxiliary data capacity *13*
3.2.5 Criterion 6 – Behavior as signal degrades *14*
3.2.6 Criterion 7 – Stereo separation *14*
3.2.7 Criterion 8 – Flexibility *15*
3.2.8 Criterion 9 – Host analog signal impact *15*
3.2.9 Criterion 10 - Non-host analog signal impact *16*
3.3 AM IBOC SYSTEM EVALUATION – FINDINGS 19
3.3.1 Criterion 1 – Audio quality *19*
3.3.2 Criteria 2, 3 – Service area, durability *19*
3.3.3 Criterion 4 – Acquisition performance *20*
3.3.4 Criterion 5 – Auxiliary data capacity *21*
3.3.5 Criterion 6 – Behavior as signal degrades *21*
3.3.6 Criterion 7 – Stereo separation *21*
3.3.7 Criterion 8 – Flexibility *22*
3.3.8 Criterion 9 – Host analog signal impact *22*
3.3.9 Criterion 10 - Non-host analog signal impact *22*

APPENDIX A – DAB SUBCOMMITTEE GOALS & OBJECTIVES **24**

APPENDIX B – IBOC DAB SYSTEM TEST GUIDELINES – PART I – LABORATORY TESTS **25**

APPENDIX C – IBOC DAB SYSTEM TEST GUIDELINES – PART II – FIELD TESTS **26**

APPENDIX D – IBOC DAB SYSTEM EVALUATION GUIDELINES **27**

APPENDIX E – NRSC IBOC SYSTEM EVALUATION MATRIX **28**

APPENDIX F – USADR SUBMISSION – TESTS SUBMITTED **29**

APPENDIX G – ANALYSIS OF FM IBOC SERVICE AREA LAB TEST DATA **30**

APPENDIX H – GRAPHICAL REPRESENTATION OF L+R AND L-R FOR AUDIO FILES TP1_DAB.WAV, TP2_DAB.WAV, TP3_DAB.WAV **31**

APPENDIX I – USADR IBOC DAB TO HOST FM TEST REPORT REVIEW **32**

APPENDIX J – INFORMATION ON SIGNAL LEVELS AND NOISE **33**

APPENDIX K – SIGNALS AND NOISE IN RURAL AREAS 34

APPENDIX L – AM COMPATIBILITY RESULTS – USADR AM IBOC SYSTEM 35

APPENDIX M – USADR COMMENTS ON THIS EVALUATION REPORT 36

List of tables

TABLE 1. EWG EVALUATION CRITERIA 9
TABLE 2. FM IBOC TEST RESULTS SUBMITTED BY USADR PERTAINING TO AUDIO QUALITY 10
TABLE 3. FM IBOC TEST RESULTS SUBMITTED BY USADR PERTAINING TO SERVICE AREA AND DURABILITY 11
TABLE 4. FM IBOC TEST RESULTS SUBMITTED BY USADR PERTAINING TO BEHAVIOR AS SIGNAL DEGRADES 14
TABLE 5. FM IBOC TEST RESULTS SUBMITTED BY USADR PERTAINING TO HOST ANALOG SIGNAL IMPACT 15
TABLE 6. FM IBOC OBJECTIVE TEST RESULTS SUBMITTED BY USADR PERTAINING TO NON-HOST ANALOG SIGNAL IMPACT 16
TABLE 7. FM IBOC SUBJECTIVE TEST RESULTS SUBMITTED BY USADR PERTAINING TO NON-HOST ANALOG SIGNAL IMPACT 18
TABLE 8. AM IBOC TEST RESULTS SUBMITTED BY USADR PERTAINING TO AUDIO QUALITY 19
TABLE 9. AM IBOC TEST RESULTS SUBMITTED BY USADR PERTAINING TO SERVICE AREA AND DURABILITY 19
TABLE 10. AM IBOC TEST RESULTS SUBMITTED BY USADR PERTAINING TO NON-HOST ANALOG SIGNAL IMPACT ... 23

List of figures

FIGURE 1. IMPAIRMENT OBSERVATIONS COMPARING DELCO ANALOG RECEIVER AND USADR FM IBOC RECEIVER OVER SELECTED REGIONS OF THE FIELD TEST RADIAL 13

1 INTRODUCTION

This report is submitted to the National Radio Systems Committee's Digital Audio Broadcasting Subcommittee from its Evaluation Working Group (EWG) in accordance with procedures that were established by the Subcommittee during meetings in 1999.

In summary:

- The EWG developed evaluation criteria and a System Evaluation Guidelines document that delineated the manner in which evaluations would be conducted;
- The basis for conducting tests and reporting results by a proponent were contained in two other NRSC DAB Subcommittee documents: one on laboratory tests, the other on field tests;
- The EWG, in designing the basis for its evaluations, developed a two dimensional table that arrayed the individual tests in the laboratory and field test guidelines documents with the ten basic evaluation criteria agreed upon;
- IBOC system proponents agreed to tender submissions on December 15, 1999;
- For each submission, an evaluation report (such as this one) would be developed;
- The NRSC's evaluation would be a comparison of the IBOC system(s) performance with the current performance of analog radio in the FM and AM broadcasting bands.

The Chairman expresses his hearty thanks to the 20 or so members of the EWG. An enormous amount of work was done, on a voluntary basis for most of the members, since early March 1999. The EWG membership included representatives of the broadcasting industry, the receiver manufacturing industry, the proponent organizations, and staff and consultants from NAB and CEA. With respect to the last category, special thanks goes to David Layer of NAB for carrying the brunt of the development of the documentation, taking care of the minutes of the telcon and full meetings of the working group, and contributing significantly to the analysis.

This report is organized as follows:

- Introduction: this section briefly reviews the process and events leading up to the generation of this evaluation report;
- Conclusion: a statement of the EWG's conclusion regarding the USADR IBOC submission including suggestions for future work;
- Discussion of Findings: a detailed presentation of the data submitted, analysis performed, and conclusions reached, organized according to evaluation criteria established by the EWG;
- Appendices: supplemental information including analyses performed by the EWG during the course of its evaluation.

1.1 NRSC DAB SUBCOMMITTEE GOALS AND OBJECTIVES

The NRSC's DAB Subcommittee established goals and objectives on May 14, 1998 for the work to be done by it as a result of the re-activation of the Subcommittee (see Appendix A for the complete Goals and Objectives statement).

What the primary objective is:

The purpose of the current NRSC effort is to determine if current generation IBOC technology is a significant improvement over the analog systems currently in use. In other words, the evaluative quest is to determine if the current state-of-the-art of IBOC technology merits the conclusion that continuing to pursue IBOC technology, through all its technical and regulatory ramifications, is in the interest of U.S. listeners.

What is not an objective of the current work:

The work that has been done by the Subcommittee since mid-1998 has not dealt in any way with comparing the performances of different IBOC systems. This is due primarily to the fact that there have been no comparative tests (neither planned nor conducted) between different systems as would be necessary for valid comparisons to be made.

1.2 EVALUATION PROCESS DECISIONS MADE

From mid-1998 up to and including a meeting of the NRSC DAB Subcommittee that took place on April 17, 1999, several important decisions were made that established the construct of the overall evaluation process. These are summarized in this section.

1.2.1 Test guidelines would be established

The NRSC developed detailed laboratory and field test guidelines, which would explain to proponents the tests and information the NRSC deemed necessary for evaluating IBOC systems. These were developed by the DAB Subcommittee's Test Guidelines Working Group, Mr. Andy Laird, Chairman, during the second half of 1998 and early in 1999. They were approved by the Subcommittee in early 1999 (and are included with this report as Appendices B and C).

In construct, the recommended test protocols in the Guidelines documents were similar to those from an earlier EIA/NRSC DAB test process (conducted during the 1994-95 time frame), refined from then and dealing solely with testing of IBOC systems. The various test protocols include ways of eliciting IBOC system performance and the effects of the IBOC digital carriers on its host and adjacent channel analog (and digital) signals, and vice versa.

1.2.2 Formation and functioning of the Evaluation Working Group

In early 1999 the EWG was established, having its first meeting in early March 1999. An initial report was submitted to the Subcommittee at its April 1999 meeting in the form of the first version of a System Evaluation Guidelines document (complementary to the test guidelines documents mentioned

above). Subject to the incorporation of a few points of modification, the document was approved at the April 17th meeting (see Appendix D).

The EWG then developed ten (10) system evaluation criteria. These covered, at a high level directly related to broadcasting, those areas upon which the comparison with analog radio broadcasting would be based.

The working group also developed a cross-reference table between all the individual test protocols of the laboratory test and field test guidelines documents and each of the 10 evaluation criteria. This work was completed subsequent to the April 17th Subcommittee meeting, and the resulting table is being used in the evaluation of this current submission by USADR (see Appendix E).

1.2.3 Agreements on IBOC system scope and NRSC reporting of its evaluations

Five important provisions were agreed to at the April 17th Subcommittee meeting that bear on the submission of information to the NRSC DAB Subcommittee and on the reporting of the evaluation:

1. ***Complete hybrid (IBOC) system:*** any submission must document a full system, that is, one that is capable of IBOC operation in both the AM and FM broadcasting bands.

2. ***Data on an "all digital" system not evaluated at this time:*** although the ultimate objective for terrestrial radio broadcasting is likely to be full conversion to digital transmission, it is recognized that this will take many years as the conversion of thousands of stations takes place. Therefore, even though all proponents are working on "all digital" designs as part of their efforts, a decision was made to limit the current evaluation to the more pressing (and presumed more difficult) "hybrid IBOC" aspect of the conversion.

3. ***Only the performance of the IBOC system will be evaluated:*** several aspects of IBOC implementation are not to be evaluated, for example, the extent of transmitter conversion required and the expected cost of receivers. In summary, the technical and performance aspects of the system are to be evaluated. This includes the performance of the digital carriers as well as the impact the digital carriers have on a station's own host analog signal as well as on adjacent channel signals.

4. ***The NRSC will generate a separate report for each system submitted:*** in line with the decision to evaluate with respect to analog performance, and not to compare performance among digital systems, a separate evaluation report will be produced for each system for which system descriptions and data are submitted. This report, thus, deals exclusively with the USADR system in comparison with today's AM and FM modulation in their respective broadcasting bands.

5. ***Submission date - December 15, 1999:*** December 15, 1999 was agreed to by the proponents as the submission date for system descriptions and test data at the April 17, 1999 Subcommittee meeting. (USADR tendered their submission on December 15, 1999.)

On December 8, 1999, one of the proponents (LDR) informed the NRSC that they would be unable to make a submission on December 15, 1999, and instead would like to make a submission on January 24, 2000, coinciding with the comment deadline in the FCC's NPRM on terrestrial DAB. The DAB Subcommittee, at its January 8, 2000 meeting, agreed to accept a submission from LDR on that date, and in addition, USADR was also given an additional two week submission "window," following the 1/24/00 LDR submission date.

1.3 MUCH WORK DONE; MUCH WORK LEFT TO DO

The DAB Subcommittee and its Test Guidelines Working Group expended considerable effort in identifying the tests (specified in the Field Test and Lab Test Guidelines) that a proponent needs to perform, in order for the NRSC to be able to determine if a system is significantly improved over analog services. While some tests may be more vital in achieving this end than others, they all play a part in the process—each specified test is important and offers a unique insight into system performance.

A comparison of the test results which USADR has included in its submission with what is requested in the guidelines reveals that a substantial amount of information important to this evaluation has not been provided. USADR, at the time of its submission, indicated that due to time constraints involved with meeting internal system development objectives, its submission would include data taken only from its existing test program. Even though the specific tests detailed in the NRSC test guidelines were not performed, the USADR submission is valuable in helping the DAB Subcommittee work towards its present goal of comparing IBOC performance to analog system performance. It represents a considerable effort on the part of the proponent as well as providing the most complete technical "glimpse" of its system yet offered to the industry.

A comparison of the tests included in USADR's submission with the tests specified in the NRSC's Lab and Field Test Guidelines indicates the following number of tests were conducted. For FM lab tests, of the 67 specified in the guidelines, at least partial results were submitted for 18. For FM field tests, of the 12 tests specified in the guidelines, partial results for 5 were submitted. For AM lab tests, of the 25 specified tests, partial results on 8 were submitted. Finally, for the AM field tests, of the 8 specified tests, partial results for 1 were submitted.

The evaluation described in this report focuses on the information which was provided, and in some instances notes the absence of important data or factors not included in a test which, if present, would have offered additional valuable (if not vital) information. Clearly, additional information will be needed before the EWG, and ultimately the DAB Subcommittee, can be in a position to establish with technical rigor whether IBOC is a significant improvement over today's analog services. This report represents the very best efforts of the EWG to evaluate the data submitted by USADR in light of the fact that specific NRSC test guidelines were not followed.

2 CONCLUSION

The basic conclusion: the "state-of-the-art" for IBOC technology indicates the reasonable probability of substantial improvement for broadcast listening compared to current analog performance in the AM and FM broadcasting bands.

USADR's submission should be considered as a "sample point" to aid in determining whether the current IBOC "state-of-the-art" is good enough to have interested parties in the U.S. believe that this avenue for the implementation of digital radio is the path to pursue. USADR notes in the introduction to its report that recent system improvements may not be reflected in the test results submitted. Therefore, it is reasonable to conclude that what the NRSC received from USADR for evaluation purposes represents a lower bound on performance.

Also, as noted elsewhere in this report, a significant number of the recommended tests from the Subcommittee's laboratory and field test guidelines were neither conducted, nor reported, nor was there an adequate substituted test procedure that would permit us to evaluate results according to one or more of the ten agreed upon evaluation criteria.

These lacunae have compelled the EWG to qualify its basic conclusion, and made it impossible to state unequivocally that USADR's IBOC technology provides a significant advance over current analog system performance in the AM and FM broadcasting bands.

Nevertheless, in the aggregate, after analyzing all the material supplied to us by USADR, it is reasonable to state that USADR's IBOC technology appears to be headed in a direction that in the near future will benefit listeners with significantly better performance than is now possible with analog techniques for the ten major evaluation criteria used to represent system performance. As discussed in detail in the next section, these evaluation criteria include audio quality, extent of service area, signal degradation behavior under weak signal conditions for IBOC performance, as well as the effect of an IBOC signal on analog reception in ordinary analog receivers.

Based upon this evaluation, the EWG is optimistic that USADR is on the proper track to develop IBOC DAB systems with the potential to significantly improve AM and FM radio broadcasting in the U.S. Encouragement is hereby given to USADR that it continue to develop its systems and test them in accordance with independent test procedures crafted in cooperation with the broadcast and consumer electronics industries.

3 DISCUSSION OF FINDINGS

In this section, the details of USADR's submission to the NRSC are presented, organized according to how each part of the submission relates to the EWG's evaluation criteria. After presenting the data, a review of the EWG analysis, followed by the conclusions which were arrived at are then given.

Note that since the tests and results described in the USADR submission were organized differently from the DAB Subcommittee's test guidelines documents, the first step in this process was for the EWG to determine how the submitted information corresponded to the tests specified in the guidelines (Appendix F). In the sections which follow, slightly modified versions of the tables in Appendix F are presented for each criteria, indicating for each submitted result the location of data/graph information (in the submission), any corresponding audio recordings submitted, and how that result would be compared against the existing analog service (indicated in the "analog benchmark" column).

3.1 Criteria used for evaluation

The EWG established 10 criteria to use for evaluating IBOC submissions. These criteria fall into two general categories: "IBOC receiver" results, which apply to data obtained directly from the IBOC receiver (*e.g.*, unimpaired audio quality of an IBOC signal, service area and durability of the IBOC signal, etc.); and, "Analog receiver" results, which address the compatibility of the IBOC signal with existing analog receivers.

Table 1 lists the evaluation criteria according to category. Refer to Appendix E for a detailed description of each criterion, as well as for a matrix which illustrates which tests (contained in the test guidelines) have a bearing upon which criteria.

Table 1. EWG evaluation criteria

IBOC RECEIVER RESULTS	ANALOG RECEIVER RESULTS
Audio quality	Host analog signal impact
Service area	Non-host analog signal impact
Durability	
Acquisition performance	
Auxiliary data capacity	
Behavior as signal degrades	
Stereo separation	
Flexibility	

3.2 FM IBOC system evaluation – findings

Since receiving the USADR submission on December 15, 1999, the EWG has undertaken an extensive review and analysis of the FM IBOC system test results and information presented. The results of this review are presented here in detail, organized according to evaluation criteria.

3.2.1 Criterion 1 – Audio quality

Table 2 lists the test results submitted by USADR pertaining to audio quality of their FM IBOC system. In this context, audio quality refers to the *unimpaired* audio quality of the system i.e. the audio quality absent any channel impairments or interfering signals.

Table 2. FM IBOC test results submitted by USADR pertaining to audio quality

test no. (gudelines)	data/graphs	audio recordings	benchmark	comments
K2 (lab) – DAB quality – subjective assessment report of unimpaired IBOC audio quality vs. analog FM	• ~~Tbl. G-2 (pg. 4)~~ – Wave file description (DAB quality transmission test)	FM_DAB_DS.wav FM_DAB_PJ.wav FM_DAB_SV.wav FM_DAB_DS_PJ_SV.wav	• ~~Included with submission~~ – audio files FM_ANALOG_DS.wav FM_ ANALOG _PJ.wav FM_ ANALOG _SV.wav FM_ ANALOG _DS_PJ_SV.wav	• Analog benchmark recordings made with Denon TU-680NAB receiver • No subjective evaluation performed on DAB recordings

Note that in addition to the audio recordings listed in Table 2, there are several additional audio recordings of the FM IBOC system included in the USADR submission. EWG group members have all, to varying degrees, listened to this material and shared their anecdotal experiences with one another regarding it. Unfortunately, this anecdotal evidence of audio quality is not sufficiently rigorous that the EWG can use it as the basis for a conclusion regarding this criterion.

A thorough test of audio quality requires statistically meaningful subjective testing with a variety of program audio sources and a variety of listener subjects. Since in this context, "audio quality" is a measure of the best performance the system can offer, subjective listening evaluation should not be left entirely to average listeners. Expert listening evaluation of system fidelity is also an important component of the decision making process.

No subjective test data was submitted to the NRSC by USADR for review. USADR states in its submission, in Appendix B, p.5, that

> During the standardization process, MPEG performed numerous listening tests to assess the audio quality of AAC. It is difficult to specify audio-coded performance in terms of traditional audio measurement techniques such as frequency response, distortion, and dynamic range; therefore audio codecs are psychoacoustically compared against a CD reference. In these double-blind tests, human testers are given the opportunity to compare compressed against non-compressed segments of the selection and make judgements as to the quality of the compressed segment. In tests designed to replicate the worst case signals, the AAC codec at 96 kbps has proven to be almost indistinguishable from the original selection. For the most extreme cases, the difference in the compressed signal is audible, but not considered a major issue for listeners.

USADR acknowledges that perceptual audio compression schemes are imperfect, and argues that the imperfections are far outweighed by the improvements in performance obtained by a digital system.

Conclusion: the EWG does not have sufficient information to determine if the audio quality of the USADR FM IBOC system represents a significant improvement over analog FM. However, many EWG members are encouraged that the submitted audio samples suggest the system is, at the very least, comparable in audio quality to analog FM. It is recommended that USADR perform and publish thorough subjective testing of system fidelity in comparison to analog FM, in any future testing of its system.

3.2.2 Criteria 2, 3 – Service area, durability

Table 3 lists the test results submitted by USADR pertaining to service area and durability of their FM IBOC system. These two criteria have been combined in this section because they essentially share the same list of tests (from the test guidelines) from which conclusions can be drawn.

Table 3. FM IBOC test results submitted by USADR pertaining to service area and durability

test no. (gudelines)	data/graphs	audio recordings	benchmark	comments
B1 (lab) – AWGN, linear channel, no interferers	• ~~Tbl. C-5 (pg. 13)~~ – BLER vs. Cd/No (around digital TOA operating point) • Fig. C-4 (pg. 14) – BLER vs. Cd/No	audio1.wav (linear chnl)	• ~~Analytical comparison to analog~~ – estimate IBOC "digital TOA service area" by calculating analog field strength at digital TOA operating point, and compare this to analog protected contour • Subjective – assuming "perfect" IBOC up to digital TOA (i.e. that IBOC receiver output would be judged "imperceptible" from transmitter to digital TOA point), audio recordings of Delco output subjective evaluation in Table C-5 applies	• ~~Audio material~~ - 3 NRSC critical audio cuts (Dire Straits, Pearl Jam, Suzanne Vega) • Audio recordings are of Delco receiver output at digital TOA operating point, with digital sidebands turned off
B3 (lab) – AWGN, multipath fading channel, no interferers		audio2.wav (UF) audio3.wav (US) audio4.wav (RF) audio5.wav (TO)		
B4 (lab) – AWGN, multipath fading channel, 1st adj. channel interferer	• ~~Tbl. C-5 (pg. 13)~~ – BLER vs. Cd/No (around digital TOA operating point)	audio6.wav (UF, -6) audio7.wav (UF, -18) audio8.wav (UF, -24) audio9.wav (UF, -30)		
E2 (lab) – D→D compatibility – multipath fading channel, single 1st adj. chnl. interferer	• ~~Fig. C-5 (pg. 17)~~ – BLER vs. Cd/No			
E1 (lab) – D→D compatibility – multipath fading channel, co-channel interferer	• Tbl. C-5 (pg. 13) – BLER vs. Cd/No (around digital TOA operating point) • Fig. C-6 (pg. 18) – BLER vs. Cd/No	audio11.wav (UF, -10) audio12.wav (UF, -20)		
E4 (lab) – D→D compatibility – multipath fading channel, single 2nd adj. chnl. interferer	• Tbl. C-5 (pg. 13) – BLER vs. Cd/No (around digital TOA operating point) • ~~Fig. C-7 (pg. 19)~~ – BLER vs. Cd/No	audio10.wav (UF, +20)		
B1 (field) – Strong signal with low interference (low multipath) B2 (field) – Strong signal with low interference (strong multipath)	• Tbl. H-2 (pg. 14)– FM IBOC performance matrix • ~~Fig. H-6, H-8 (pgs. 12, 15)~~ – IBOC coverage radial maps • ~~Fig. H-7 (pg. 13)~~ – Test radial "strip chart"	TP1_DAB.wav (IBOC all digital - no blending) TP2_DAB.wav (IBOC mixed digital/analog) TP3_DAB.wav (IBOC mostly all analog)	• Impairment observations – IBOC and Delco receiver outputs compared over three 5-minute intervals (comparison files are TP1_Delco.wav, TP2_Delco.wav, TP3_Delco.wav)	• Host station – WETA-FM 90.9 MHz, 75 kW ERP • ~~Audio material~~ – Audio of opportunity from WETA-FM

The EWG intended to evaluate these criteria separately for IBOC audio performance and IBOC auxiliary data capacity. USADR submitted no information about the auxiliary data aspects of their system, so this evaluation is limited to consideration of IBOC audio performance.

For the lab results shown in Table 3, USADR submitted block error rate (BLER) information versus digital carrier signal-to-noise power spectral density ratio (Cd/No) for various operating conditions. USADR states that the 1% BLER operating point represents the "digital threshold of audibility" (digital TOA) and that for BLER values less than 1% the IBOC audio is unimpaired and not blending to analog.[1] The EWG performed an analysis using the BLER information provided, attempting to relate the BLER values to a predicted service area (assuming typical transmission parameters – see Appendix G). This analysis suggests that the distance to the contour representing digital TOA, in each case provided, appears to be greater than the distance to the corresponding analog protected contour.

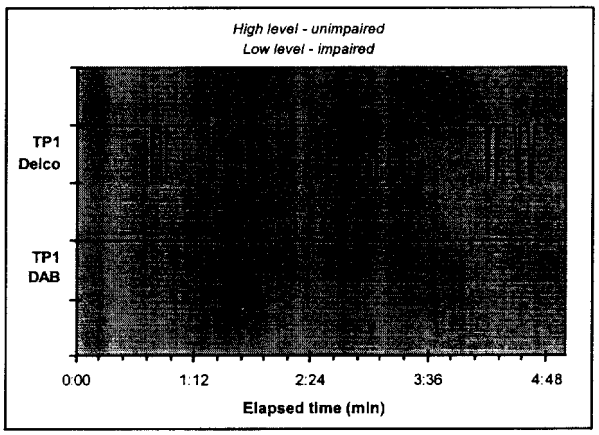
In addition, USADR subjectively evaluated the audio quality of analog FM at the digital TOA operating point for each of the cases considered. In each case, USADR's subjective evaluation

[1] The USADR FM IBOC system employs a "blend to analog" (i.e. the IBOC receiver audio output switches from the digital signal to the analog signal) when the digital errors increase to some specific (but unspecified) threshold. USADR indicates that the TOA of its FM IBOC digital system occurs in the vicinity of 1% BLER, stating in Appendix C, p.7, footnote 7 (of the USADR submission) that "extensive testing has indicated that a block error rate of 0.01 (1%) is indeed representative of TOA." See also Appendix B, pg. 6, Section 2.4 (of the USADR submission), for a discussion of the USADR "blend" feature.

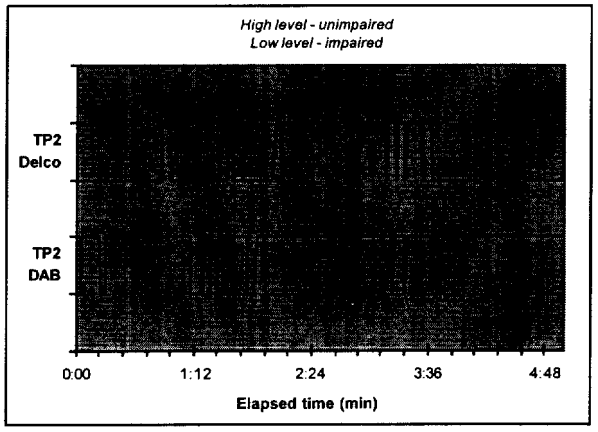
determined that, at the point where the digital signal begins to degrade, the corresponding analog audio already exhibits audible degradation. Consequently, since up to that point the IBOC audio is assumed to be unimpaired, greater service area and durability are implied for the IBOC audio than for analog FM under these conditions.

Regarding the field test results, USADR collected data on system performance along six radials originating at a class-B public radio station in Washington, D.C., WETA-FM. They submitted data for one of these six radials (the northeastern radial), consisting of a strip-chart like presentation of field strengths and IBOC audio signal mode (i.e. digital or analog),[2] as well as IBOC and analog receiver audio recordings. These recordings were made for the duration of the test drive; the submitted audio selections are from three portions of the test drive, in geographic regions where the system remained fully in digital mode, where it toggled between IBOC digital audio and analog-blend audio modes, and where the system was primarily in analog blend mode (referred to in the submission as TP1, TP2, and TP3, respectively).[3]

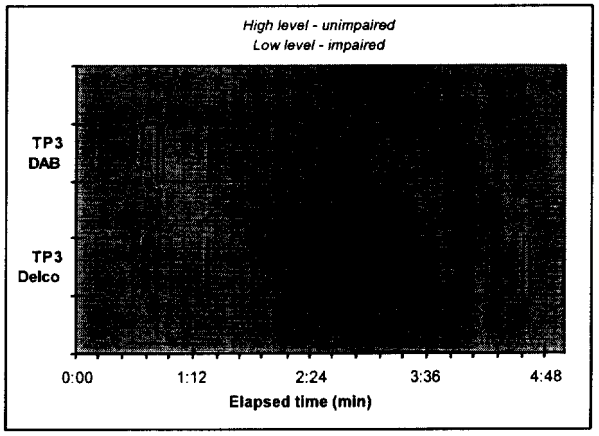
Several members of the Evaluation Working Group listened to the paired recordings and logged times when they heard audio impairment events. This "impairment observation" analysis indicates that mobile IBOC system reception is more durable than mobile analog FM reception under the demonstrated conditions (Figure 1).



(a) over region TP1



(b) over region TP2



(c) over region TP3

[2] See Appendix H, Fig. H-7, pg. 13, of the USADR submission.

[3] Refer to Appendix H, pgs. 12, 13, and 15 (of the USADR submission) where coverage maps and the strip chart presentation are given.

Figure 1. Impairment observations comparing Delco analog receiver and USADR FM IBOC receiver over selected regions of the field test radial

The audio sample taken nearest the transmitter site ("TP1") was recorded starting approximately 25 km away from the transmitter and 69 minutes into the test. Between the transmitter site and the first submitted audio sample, the strip chart indicates a high degree of durability, in that no transitions to analog occurred. This suggests that the digital signal is quite robust within the actual 60 dBu coverage area of the host station. However, the test route used on the one submitted radial includes a particular combination of urban and suburban land use, east coast terrain, and co-and adjacent channel interferers affecting the reception of a single station in a single market. A future review process would benefit from the submission of a rigorous and carefully planned battery of drive tests that sample a representative variety of stations and reception conditions across the country.

A final note - because the USADR system is designed to avoid egregious digital artifacts with its blend to analog feature, it is likely that the sounds which accompany the failure of some digital audio systems will not be audible in the USADR hybrid IBOC systems. Similarly, the well known digital "cliff effect" is eliminated with this design approach.

Conclusion – service area: additional field and lab testing, in accordance with the NRSC test guidelines, are needed before the EWG can arrive at any definitive conclusions regarding FM IBOC service area. However, based on the information presented, and on the analyses performed by the EWG and described above, the USADR FM IBOC system digital service area (i.e. the area where the IBOC receiver does not blend to analog) appears to be at least as extensive as analog FM in a mobile environment.

Conclusion – durability: the EWG is encouraged by the apparent ability of the system to maintain continuous digital performance over a 55 km distance in the example field trial radial submitted by USADR. However, a more rigorous demonstration of audio durability will be required to support a finding that USADR's IBOC FM durability is significantly better than analog FM under most or all reception conditions. Insufficient information was submitted to render a finding on the durability of an auxiliary data stream or the effects of trading off audio and auxiliary data bandwidth.

3.2.3 Criterion 4 – Acquisition performance

USADR did not submit any test results pertaining specifically to the acquisition performance of their FM IBOC system. However, they note in the system information portion of their submission that the "blend" feature of their system guarantees by design that a receiver will "...instantaneously acquire the analog signal."[4] In other words, the acquisition performance of an IBOC receiver is essentially the same as experienced with an analog FM receiver.

Conclusion: based on this information, the EWG concludes that the acquisition performance of the USADR FM IBOC system, by design, is comparable to that of analog FM.

3.2.4 Criterion 5 – Auxiliary data capacity

[4] See footnote 1.

USADR did not submit any test results pertaining specifically to the auxiliary data capacity of its FM IBOC system. They do indicate that this system incorporates two main types of auxiliary services, ancillary services (up to 120 kbps) and opportunistic data services (up to 32 kbps).[5]

Conclusion: the EWG cannot formulate any meaningful conclusions about the auxiliary data capacity of the USADR FM IBOC system due to a lack of information.

3.2.5 Criterion 6 – Behavior as signal degrades

Table 4 lists the test results submitted by USADR pertaining to behavior as signal degrades of their FM IBOC system.

Table 4. FM IBOC test results submitted by USADR pertaining to behavior as signal degrades

test no. (gudelines)	data/graphs	audio recordings	benchmark	comments
(Supplement to system description information) B1 (field) – Strong signal with low interference (low multipath) ? B2 (field) – Strong signal with low interference (strong multipath) ?	None	blend_audio.wav (Appendix B) TP1_DAB.wav (IBOC all digital - no blending) TP2_DAB.wav (IBOC mixed digital/analog) TP3_DAB.wav (IBOC mostly all analog)	• Benchmark audio is included in audio file blend_audio.wav – this file demonstrates blending in an impaired environment	• No corresponding "mode signal" information provided with audio file; listener cannot tell exactly when blending occurs.

The audio recording "blend_audio.wav" which USADR indicates is an example of its FM IBOC system blending back and forth between analog and digital, was not accompanied by supplemental information (such as time indices corresponding to blend events, or a simultaneous recording of the host analog signal as received by an analog receiver) to allow for a rigorous study of behavior as signal degrades, or for a rigorous comparison to analog FM. The field test audio recordings listed in Table 4, on which impairment observations were conducted (see Figure 1 above), did include some of this information, and the EWG's analysis of this suggests that blending to analog avoids "unearthly" egregious digital artifacts as well as the well-known digital "cliff effect."

Conclusion: due to its blend-to-analog design, and given that USADR has placed the threshold for blend to analog such that blending occurs before "cliff effect" digital failure, the EWG concludes that the behavior of the USADR FM IBOC system as the signal degrades is comparable to that of analog FM.

3.2.6 Criterion 7 – Stereo separation

The EWG was able to analyze three ".wav" digital audio recordings of the field tests (corresponding to locations TP1, TP2, and TP3) for the purpose of evaluating stereo separation.[6] Note that it is difficult to appraise the digital stereo separation when separate audio processing has been used for the digital and analog program channels (as was the case here), and without the original program material to refer to (also the case here).

[5] See Appendix B, pg. 10 (of the USADR submission), for information on USADR FM IBOC auxiliary data services.

[6] Specifically, TP1_DAB.wav, TP2_DAB.wav, and TP3_DAB.wav. See also footnote 3 of this report.

Each of these recordings is five minutes long and was recorded at progressively greater distances from the transmitting station. TP1 has no digital impairments (i.e. is entirely digital audio), while TP3 is almost entirely blended to analog. The "L&R" audio from the IBOC receiver and the Delco analog receiver were mixed to "L+R" and "L-R." The resulting four signals were then plotted in time and amplitude. The plots are shown in Appendix H of this report.

Plots for TP1 and TP2 show that the separation for the digital signal is the same as for the analog signal. The plots for TP3, which represent the most distant site from the transmitting station for which information was given, show that the analog receiver L-R signal is slightly reduced compared to analog L-R shown on the TP1 and TP2 plots. The TP-3 digital signal (with many blends to analog) has good separation.

Conclusion: based on the limited observations made, stereo separation in the IBOC receiver appeared to be at least as good as the simultaneously recorded analog receiver output. However, the EWG cannot formulate any definitive conclusions about the stereo separation of the USADR FM IBOC system based solely on this, and more information is required.

3.2.7 Criterion 8 – Flexibility

In their submission, USADR indicates that their FM IBOC design supports "...auxiliary data services that will upgrade existing analog FM subsidiary communications authorizations (SCAs) by offering much higher availability, reliability, and robustness."[7] Also, USADR is developing an "all-digital" IBOC technology which complements their hybrid design and offers additional performance and service benefits.

Conclusion: The amount of flexibility which this system ultimately supports cannot be established at this time. By its very nature, IBOC technology involves a number of tradeoffs between such aspects of performance as coverage, robustness, and flexibility. Only when the final system parameters which best balance these parameters are chosen will it be possible to competently judge the flexibility of the system.

3.2.8 Criterion 9 – Host analog signal impact

Table 5 lists the test results submitted by USADR pertaining to host analog signal impact of their FM IBOC system.

Table 5. FM IBOC test results submitted by USADR pertaining to host analog signal impact

[7] See Appendix B, pg. 9 (of the USADR submission).

test no. (gudelines)	data/graphs	audio recordings	benchmark	comments
L1 (lab) – IBOC "digital-to-host analog" compatibility performance – host analog main channel audio, linear channel	• ~~Tbl. E-12 (pg. 22)~~ – Differences caused by digital IBOC to the analog host for a linear channel • Figs. E-7,8 (pgs. 20, 21) – Differences in (audio SNR, THD+N) caused by digital IBOC to the analog host	(none)	• ~~Included in results~~ – results are presented as the *difference* between parameter values (audio SNR, THD+N) with digital sidebands present versus values with digital sidebands absent.	• 100,000K noise may be having a "masking" effect on differences • Absolute values not provided, only differences
L2 (lab) – IBOC "digital-to-host analog" compatibility performance – host analog main channel audio, fading channel	• Tbl. E-8 (pg. 9) – FM interference subjective scenarios – digital into host analog compatibility	audio1B.wav audio2B.wav audio3B.wav	• Included with submission – audio files audio1A.wav, audio2A.wav, audio3A.wav (respectively) – same test conditions but with no digital sidebands present	• 100,000K noise may be having a "masking" effect on differences ? • Compatibility recordings provided for one receiver only (Delco) • Recordings for urban fast scenario included; urban slow scenario recordings made but not included
B3 (field) – Strong signal with low interference – Host main channel audio compatibility	• Tbl. H-4 (pg. 24)– Host compatibility test point matrix • Fig. H-9 (pg. 20) – 1st adj., host compatibility test points map	Delco_WPOC.wav Yamaha_WPOC.wav Philips_WPOC.wav	• Benchmark audio is included in audio recordings listed at left – digital sidebands were switched on and off in 15 sec, 30 sec, and 1 min intervals during recording	• No IBOC receiver performance corresponding to these test points was provided

Analysis by EWG group members of the submitted field test audio suggests that the presence of the digital carriers is not noticeable on the host audio signal for the receivers tested. Of greater significance for this particular criterion are the lab test results, done objectively by measuring the difference in S/N ratio of the analog host with and without the DAB carriers present.

In its analysis of the provided lab test results, the EWG questioned whether the 100,000K additive white Gaussian noise (AWGN) used in the lab measurements could have been masking the effect the presence the digital carriers may have been having on the host audio S/N ratio (see Appendix I). USADR indicated that this noise value had been selected as the average noise level experienced by listeners in the U.S. based on its proprietary study. Appendices J and K include information on signal levels and noise submitted by one EWG group member; in Appendix J, it is shown that noise level assumptions can have a significant impact on the minimum (level) receivable DAB signal.

It is evident, from discussions held within the EWG, that USADR feels strongly that their use of 100,000K noise in lab compatibility tests is appropriate, since in their view this models the average environment listeners encounter. The EWG feels this level of noise, which could have a masking effect on the behavior being looked for, inhibits the investigation being conducted. Furthermore, the EWG feels that additional data of this sort, taken without added noise, is necessary in order to truly establish the level of interference on the host analog signal due to the presence of the digital carriers.

Conclusion: the desired channels for all of the lab host compatibility tests were subject to AWGN at a level of 100,000 K. Based on the analysis presented in Appendix I of this report, it is clear that with the 100,000 K noise, all but the most significant interference to the host analog or adjacent channels could be masked. Additional measurements, without added noise, are needed to rigorously establish the effect that the digital carriers have on the analog host.

3.2.9 Criterion 10 - Non-host analog signal impact

Table 6 and Table 7 list the objective and subjective test results (respectively) submitted by USADR pertaining to the non-host analog signal impact evaluation criterion.

Table 6. FM IBOC objective test results submitted by USADR pertaining to non-host analog signal impact

test no. (gudelines)	data/graphs	audio recordings	benchmark	comments
F1 (lab) – IBOC "digital-to-analog" compatibility performance in a linear channel – co-channel	• ~~Tbl. E-11 (pg. 19)~~ – Differences caused by digital IBOC to the analog host w/co-chnl. interference • Figs. E-5, 6 (pgs. 17, 18) – Differences in (audio SNR, THD+N) caused by digital IBOC to the analog host w/co-chnl. interference	(none)	• ~~Included in results~~ – results are presented as the *difference* between parameter values (audio SNR, THD+N) with digital sidebands present versus values with digital sidebands absent.	• 100,000K noise may be having a "masking" effect on differences • Absolute values not provided, only differences
F2 (lab) – IBOC "digital-to-analog" compatibility performance in a linear channel – single 1st adj. interferer F4 (lab) – " " – single 2nd adj. interferer	• Tbl. E-9 (pg. 13) – Differences caused by digital IBOC to the analog host w/single adj. chnl. interference • ~~Figs. E-5, 6 (pgs. 17, 18)~~ – Differences in (audio SNR, THD+N) caused by digital IBOC to the analog host w/ single adj. chnl. interference	(none)	• Included in results – results are presented as the *difference* between parameter values (audio SNR, THD+N) with digital sidebands present versus values with digital sidebands absent.	• 100,000K noise may be having a "masking" effect on differences • Absolute values not provided, only differences • Results presented for both upper and lower 1st. and 2nd adj. channels
F3 (lab) – IBOC "digital-to-analog" compatibility performance in a linear channel – dual 1st adj. interferer F5 (lab) – " " – single 2nd adj. with single 1st adj. interferer F6 (lab) – " " – dual 2nd adj. interferer	• ~~Tbl. E-10 (pg. 16)~~ – Differences caused by digital IBOC to the analog host w/dual 1st adj. chnl. interference • Figs. E-3, 4 (pgs. 14, 15) – Differences in (audio SNR, THD+N) caused by digital IBOC to the analog host w/ dual adj. chnl. interference	(none)	• ~~Included in results~~ – results are presented as the *difference* between parameter values (audio SNR, THD+N) with digital sidebands present versus values with digital sidebands absent.	• 100,000K noise may be having a "masking" effect on differences • Absolute values not provided, only differences • Results presented for upper 1st and upper 2nd adj., upper 1st and lower 2nd adj.

Table 7. FM IBOC subjective test results submitted by USADR pertaining to non-host analog signal impact

test no. (gudelines)	data/graphs	audio recordings	benchmark	comments
G1 (lab) – IBOC "digital-to-analog" compatibility performance in a multipath fading channel – co-channel	• ~~Tbl. E-7 (pg. 9)~~ – FM interference subjective scenarios – co-channel	audio4B.wav (+20 dB D/U)	• ~~Included with submission~~ – audio file audio4A.wav	• Compatibility recordings provided for one receiver only (Delco) • Recordings for urban fast scenario submitted; urban slow scenario recordings made but not submitted • Only upper 1st adj. recordings submitted – lower 1st. adj. recordings made but not submitted (for single 1st adj. tests)
G2 (lab) – IBOC "digital-to-analog" compatibility performance in a multipath fading channel – single 1st adjacent	• ~~Tbl. E-5 (pg. 8)~~ – FM interference subjective scenarios – single interferer	audio5B.wav (+14 dB D/U) audio6B.wav (+6 dB D/U) audio7B.wav (-2 dB D/U)	• ~~Included with submission~~ – audio files audio5A.wav, audio6A.wav, and audio7A.wav (respectively)	
G3 (lab) – IBOC "digital-to-analog" compatibility performance in a multipath fading channel – dual 1st adjacent	• ~~Tbl. E-6 (pg. 9)~~ – FM interference subjective scenarios – dual interferers	audio8B.wav (+14 dB D/U) audio9B.wav (+6 dB D/U) audio10B.wav (-2 dB D/U)	• ~~Included with submission~~ – audio files audio8A.wav, audio9A.wav, and audio10A.wav (respectively)	
C1 (field) – Single interferer – 1st adjacent, at FCC limit (low multipath) C3 (field) – Single interferer – 1st adjacent, above FCC limit (low multipath)	• ~~Tbl. H-3 (pg. 22)~~ – 1st adj. compatibility test point matrix • ~~Fig. H-9 (pg. 20)~~ – 1st adj., host compatibility test points map	Delco_WMMR40.wav Yamaha_WMMR40.wav (-14 dB D/U) Delco_WMMR54.wav Yamaha_WMMR54.wav (+14 dB D/U) Delco_WFLS40.wav Yamaha_WFLS40.wav (-34 dB D/U) Delco_WFLS54.wav Yamaha_WFLS54.wav (0 dB D/U)	• Benchmark audio is ~~included~~ in audio recordings listed at left – DAB carriers were switched on and off in 15 sec, 30 sec, and 1 min intervals during recording	• These test results can be used to assess upper 1st adjacent compatibility only since both non-host signals are upper 1st adjacent. • No IBOC receiver performance corresponding to these test points was provided

Tests F1-F6 (lab): all of the tabulated results of the digital-to-analog compatibility tests were presented as the "difference" in noise levels caused by analog interferers versus the noise caused by hybrid IBOC interferers. Even though absolute noise values would have been more helpful to the EWG in its evaluation, the tabulated results in the submission indicate that some receivers could suffer a signal-to-noise degradation of 6 to 7 dB when one or more IBOC adjacent channel interferers are present. And, as in the host compatibility measurements discussed in the previous section, the 100,000K noise may be masking (to an extent unknown) the effect of the digital carriers.

Tests G1-G3 (lab): although it is beyond the scope of the EWG to conduct subjective listening tests, an informal analysis of the submitted audio cuts indicate that the listening discomfort caused by a IBOC hybrid interferer(s) on a co-channel or 1st adjacent channel(s) in the presence of multi-path fading is essentially the same as that caused by analog interferers. Again, the potential masking effect of the 100,000K noise must be factored in to the interpretation of these results.

Tests C1, C3 (field): for these tests, audio recordings were made in a stationary environment using both Delco and Yamaha receivers. The receivers were placed at locations with fixed signal strengths of 40 and 54 dBu for the observed stations. While monitoring the observed stations, the IBOC digital sidebands of a first adjacent channel interferer were periodically turned on and off and recordings were made of the observed station's audio. The only instances of being able to hear the IBOC sidebands were in conditions well beyond the point-of-failure of the observed station. (The observed station's noise and distortion level was already so high that the additions of the 1st adjacent channel digital sidebands, although audible, resulted in no additional annoyance.)

Conclusion: the submitted results look potentially encouraging, however, more complete information using measurements with less (or no) added noise is required before a definitive conclusion can be reached regarding non-host compatibility.

3.3 AM IBOC system evaluation – findings

Since receiving the USADR submission on December 15, 1999, the EWG has undertaken an extensive review and analysis of the AM IBOC system test results and information presented. The results of this review are presented here in detail, organized according to evaluation criteria.

3.3.1 Criterion 1 – Audio quality

Table 8 lists the test results submitted by USADR pertaining to audio quality of their AM IBOC system.

Table 8. AM IBOC test results submitted by USADR pertaining to audio quality

test no. (gudelines)	data/graphs	audio recordings	benchmark	comments
K2 (lab) – DAB quality – subjective assessment report of unimpaired IBOC audio quality vs. analog AM	(mentioned in Sect. 4.5, Appendix L, pg. 13)	AM_DAB_DS.wav AM_DAB_PJ.wav AM_DAB_SV.wav AM_DAB_DS_PJ_SV.wav	• ~~Included with submission~~ – audio files NRSC_Analog_Narrow_DS.wav NRSC_Analog_Narrow_PJ.wav NRSC_Analog_Narrow_SV.wav NRSC_Analog_Narrow_DS_PJ_SV .wav	• Recordings actually made in the field • Analog benchmark recordings are NRSC reference chain AM cuts • No subjective evaluation performed on DAB recordings

The AM IBOC system design offers a compelling case for being significantly better than its analog predecessor. Inherent noise and interference in AM reception and AM's limited bandwidth are clearly overcome by the AM IBOC waveform. However, no subjective evaluation results were submitted demonstrating this.

Conclusion: by virtue of the AM IBOC system design, the EWG would expect the best audio quality for this system to be a significant improvement over analog AM, due to its inherent greater audio frequency response, its inherent 2-channel stereo capability, and to the elimination of noise and interference characteristic of analog AM reception. However, the EWG does not have sufficient information to determine conclusively if the audio quality of the USADR AM IBOC system represents a significant improvement over analog AM. As was true for their submitted FM IBOC data, it is recommended that USADR perform and publish thorough subjective testing of system fidelity in comparison to analog AM in future test programs.

3.3.2 Criteria 2, 3 – Service area, durability

Table 9 lists the test results submitted by USADR pertaining to service area and durability of their AM IBOC system.

Table 9. AM IBOC test results submitted by USADR pertaining to service area and durability

test no. (gudelines)	data/graphs	audio recordings	benchmark	comments
B1 (lab) – AWGN, linear channel, no interferers	• ~~Tbl. K-1 (pg. 7)~~ – BLER vs. Cd/No (around digital TOA operating point) • Fig. K-7 (pg. 12) – BLER vs. Cd/No	(none)	• ~~Analytical comparison to analog~~ – estimate IBOC "digital TOA service area" by calculating analog field strength at digital TOA operating point, and compare this to analog protected contour	
D1 (lab) – IBOC "digital-to-digital" compatibility performance – linear channel, w/co-chan. interferer D2 (lab) – " " – single 1st adj. interferer	• ~~Tbl. K-2 (pg. 8)~~ – BLER vs. interference level • Tbl. K-3 (pg. 11)– BLER in the presence of AWGN and interference vs. Cd/No • Fig. K-5 (pg. 9) – TOA as a function of co-chnl. vs. 1st adj. chnl. interference • ~~Fig. K-7 (pg. 12)~~ – BLER vs. Cd/No	(none)		• Measurements with both lower 1st adj. and co-channel also made
D3 (lab) – IBOC "digital-to-digital" compatibility performance – linear channel, w/simultaneous upper and lower 1st adj. interferers	• Tbl. K-2 (pg. 8) – BLER vs. interference level • ~~Fig. K-6 (pg. 10)~~ – TOA as a function of upper 1st. adj. chnl. vs. lower 1st adj. chnl. interference	(none)		
B1 (field) – System performance within protected contour and low interference (day)	• Fig. L-5 (pg. 11) – WD2XAM IBOC coverage map • ~~Fig. L-6 (pg. 12)~~ – Test radial "strip chart"	(none)		• Host station – WD2XAM, Cincinnati, OH (Xetron experimental station)

The submitted lab results, consisting of BLER measurements versus various operating parameters, can be analytically compared to analog AM performance in a manner similar to that done for FM IBOC (see Appendix G of this report). Such an analysis is being undertaken by the EWG but was not completed in time for inclusion in this report.

According to an analysis of this lab data done by USADR,[8] IBOC DAB system performance in the presence of first and co-channel interferers is "entirely outside the envelope set by the protected contours," while in the presence of strong dual 1st adjacent channel interferers the system "...will cover the majority of the regions currently covered by today's analog systems." They add that for the dual 1st adjacent case, "...based on interference studies...this situation is rare during daytime operation but may occur at night due to skywave propagation effects." While these conclusions have not been confirmed by the EWG, clearly they suggest that further characterization of this performance (the dual 1st adjacent case in particular) is in order.

Regarding the field test results, USADR collected data on system performance along two radials originating at an experimental radio station in Cincinnati, OH, WD2XAM. For the northeastern radial, they submitted a strip-chart like presentation of field strengths and IBOC audio signal mode (i.e. digital or analog).[9] However, no audio recordings were included (which would allow for impairment observations, as were done by the EWG with the corresponding FM data), nor was any information on the analog service area/durability of this experimental station included.

Conclusion (service area and durability): additional measurements are needed to rigorously compare the service area and durability of AM IBOC and analog AM.

3.3.3 Criterion 4 – Acquisition performance

[8] See Appendix K, pg. 7 (of the USADR submission).
[9] See Appendix L, Fig. L-6, pg. 12, of the USADR submission.

USADR did not submit any test results pertaining specifically to the acquisition performance of their AM IBOC system. However, they note in the system information portion of their submission that the "blend" feature of their system "...allows transition from the instantly acquired analog signal to the digital signal when it has been acquired."[10]

Conclusion: based on this information, the EWG concludes that the acquisition performance of the USADR AM IBOC system, by design, is comparable to that of analog AM.

3.3.4 Criterion 5 – Auxiliary data capacity

USADR did not submit any test results pertaining specifically to the auxiliary data capacity of their AM IBOC system.

Conclusion: the EWG cannot conclude anything about the auxiliary data capacity of the USADR AM IBOC system due to a lack of information. USADR is encouraged to develop this capability to the maximum extent possible.

3.3.5 Criterion 6 – Behavior as signal degrades

As was true of USADR's FM IBOC system, the AM IBOC system is designed to avoid egregious digital artifacts with its blend to analog feature, meaning it is likely that the sounds which accompany the failure of some digital audio systems will not be audible in the USADR AM IBOC system. Similarly, the well known digital "cliff effect" is eliminated with this design approach. However, no audio recordings were included in the USADR submission demonstrating this.

Conclusion: due to its blend-to-analog design, and given that USADR has placed the threshold for blend to analog such that blending occurs before "cliff effect" digital failure, the EWG concludes that the behavior of the USADR AM IBOC system as the signal degrades is comparable to that of analog AM.

3.3.6 Criterion 7 – Stereo separation

The AM IBOC system design offers an inherent 2-channel stereo sound capability. Primarily because of time constraints, the EWG elected not to perform an analysis on this parameter similar to the analysis done for FM (Appendix H of this report).

Note that for AM IBOC the NRSC decided, during the development of its test guidelines, that the basis for comparison between IBOC and analog services for the AM band would be the monaural AM service currently offered by the majority of AM broadcasters in the U.S.

Conclusion: by virtue of the AM IBOC system design, the EWG would expect the stereo separation for this system to be a significant improvement over analog AM, due to AM IBOC's inherent

[10] The USADR AM IBOC system employs a "blend to analog" (i.e. the IBOC receiver audio output switches from the digital signal to the analog signal) when the digital errors increase to some specific (but unspecified) threshold. USADR indicates that the TOA of its digital system occurs in the vicinity of 1% BLER, stating in Appendix K, p.2, (of the USADR submission) that "for the USADR AM hybrid IBOC DAB system, the TOA is defined as 0.01 i.e. 1% BLER." See also Appendix I, pg. 2, Section 4 (of the USADR submission), for a discussion of the USADR "blend" feature.

2-channel stereo capability. However, the EWG cannot formulate any definitive conclusions about the stereo separation of the USADR AM IBOC system based solely on this, and more information is required.

3.3.7 Criterion 8 – Flexibility

Two aspects of the USADR AM IBOC system design which bear upon system flexibility are the ability to support auxiliary digital data services (in addition to digital audio), and the ability to migrate to an "all-digital" system design at some point during the transition from analog to digital.

The USADR AM IBOC system reportedly offers modest auxiliary data capacity, however there is no information regarding this in their submission. USADR is developing an "all-digital" IBOC technology which complements their hybrid design and offers additional performance and service benefits.

Conclusion: The amount of flexibility which this system ultimately supports cannot be established at this time, due not only to the fact that the features allowing for flexible operation have not been reported on in the present submission, but also to the fact that the system is still being tested and refined. By its very nature, IBOC technology involves a number of tradeoffs between such aspects of performance as coverage, robustness, and flexibility. Only when the final system parameters which best balance these parameters are chosen will it be possible to competently judge the flexibility of the system.

3.3.8 Criterion 9 – Host analog signal impact

Normally when considering this criterion, the goal is to determine how the presence of the digital carriers affect the reception of the co-located analog "host" signal on existing analog receivers. Ideally, the impact will be slight; the EWG recognizes that it would be unrealistic to expect no impact due to the nature of IBOC system design. Indeed, one of the many challenges that IBOC designers face is how to trade off digital carrier coverage against impact caused to the host analog signal.

In their submission, USADR did not include any test results or information which would provide insight into host analog signal impact in the normal sense. One part of the system information portion of the submission does bear upon this criterion, specifically, the fact that the USADR AM IBOC system requires a reduction in bandwidth of the analog signal, from ±10 kHz to ±4.5 kHz. The EWG has some concerns about this requirement. However, some broadcasters may find this reduced bandwidth an acceptable tradeoff in a transition to digital services.

Conclusion: the EWG cannot conclude anything about the host analog signal impact performance of the USADR AM IBOC system due to a lack of information. However, there is some concern on the part of the EWG with respect to the reduction in analog signal bandwidth required by the AM IBOC system design.

3.3.9 Criterion 10 - Non-host analog signal impact

Table 10 lists the test results submitted by USADR pertaining to the non-host analog signal impact evaluation criterion.

Table 10. AM IBOC test results submitted by USADR pertaining to non-host analog signal impact

test no. (gudelines)	data/graphs	audio recordings	benchmark	comments
F1 (lab) – IBOC "digital-to-analog" compatibility performance in a linear channel – co-channel	• ~~Appendix M, pgs. 18-22~~ – Audio SNR for either analog or hybrid interferer vs. co-chnl. interference level	(none)	• ~~Included with submission~~ – results are presented for both analog and hybrid interferer cases.	• 5 receivers used • Objective data only • Only lower 1st adj. chnl case presented (in single 1st. adj. tests) • Tests Fx, Fy not specified in guidelines
F2 (lab) – IBOC "digital-to-analog" compatibility performance in a linear channel – single 1st adj. interferer	• ~~Appendix M, pgs. 13-17~~ – Audio SNR for either analog or hybrid interferer vs. lower 1st adj. chnl. interference level			
F3 (lab) – IBOC "digital-to-analog" compatibility performance in a linear channel – single 2nd adj. interferer	• ~~Appendix M, pgs. 8-12~~ – Audio SNR for either analog or hybrid interferer vs. lower 2nd adj. chnl. interference level			
*Fx (lab) – IBOC "digital-to-analog" compatibility performance in a linear channel – dual 1st adj. interferer	• ~~Appendix M, pgs. 23-27~~ – Audio SNR for either analog or hybrid interferer vs. 1st adj. chnl. interference level			
*Fy (lab) – IBOC "digital-to-analog" compatibility performance in a linear channel – simultaneous lower 1st adj. and co-channel interferers	• Appendix M, pgs. 28-32 – Audio SNR for either analog or hybrid interferer vs. 1st adj. chnl. interference level			

* These tests were not specified in the system test guidelines.

All of the information presented here is objective in nature; the EWG has plotted the results listed in Table 10 and included these plots in this report (Appendix L). As with host analog signal impact, ideally, the impact on non-host analog signals due to the IBOC digital carriers will be slight; the EWG recognizes that it would be unrealistic to expect no impact due to the nature of IBOC system design. A review of the plots in Appendix L indicates that the non-host analog S/N ratio exhibits a slight but minimal degradation.

Conclusion: an analysis of the submitted non-host analog signal impact test results suggests that there is a slight but minimal degradation to the non-host analog audio S/N ratio, as would be expected for an IBOC-type digital system. However, additional information is required (in accordance with the test guidelines) before a definitive conclusion regarding this criterion can be reached.