ADVANCED TELEVISION TECHNOLOGY CENTER

Digital Audio Broadcasting

Digital Performance of the iBiquity Digital IBOC System in the AM Band

Summary of Test Results

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Table of Contents

Table of Contents ii
List of Tables iii
List of Figures iv
1. Introduction 1
1.1. Scope 1
2. Summary of Methodology 2
3. Description of the Test System and Parameters 4
3.1. Test Bed Description 4
3.2. AM Band Signals 4
3.2.1. Desired Analog 4
3.2.2. Desired Hybrid 5
3.2.3. Undesired Analog Interferer 5
3.2.4. Undesired Hybrid Interferer 5
3.2.5. Additive White Gaussian Noise 6
3.2.6. Impulse Noise 6
4. Description of Test Receivers 7
5. Digital Performance Results Summary 8
5.1. IBOC Performance in the Presence of AWGN (NRSC B) 8
5.2. IBOC Performance in the Presence of Impulse Noise (NRSC C) 9
5.3. IBOC Performance in the Presence of Adjacent and Co-Channel Interference (NRSC D) 20
5.4. IBOC Acquisition Performance (NRSC F) 29
6. Acknowledgements 30

List of Tables

Table 5-1 Objective Performance in AWGN Conditions 8
Table 5-2 Subjective Performance in AWGN Conditions..... 8
Table 5-3 Objective Performance in Impulse Noise Conditions (NRSC C) 10
Table 5-4 Subjective Performance in Impulse Noise Conditions (NRSC C) 10
Table 5-5 Objective Performance with Adjacent and Co-Channel Interferers 21
Table 5-6 Subjective Performance in Adjacent and Co-Channel Interference Conditions 21
Table 5-7 Objective Acquisition Performance..... 29

List of Figures

Figure 5-1 IBOC BLER & Mode vs. C/No in AWGN Channel Conditions 9
Figure 5-2 IBOC BLER & Mode vs. Avg-Peak in 120Hz Impulse Noise Channel Conditions 12
Figure 5-3 IBOC BLER & Mode vs. Avg-Peak in 120Hz Impulse Noise and Lower First Adjacent Channel Conditions 13
Figure 5-4 IBOC BLER & Mode vs. Avg-Peak in 330Hz Impulse Noise Channel Conditions 13
Figure 5-5 IBOC BLER & Mode vs. Avg-Peak in 330Hz Impulse Noise and Lower First Adjacent Channel Conditions 14
Figure 5-6 IBOC BLER & Mode vs. Avg-Peak in 510Hz Impulse Noise Channel Conditions 14
Figure 5-7 IBOC BLER & Mode vs. Avg-Peak in 510Hz Impulse Noise and Lower First Adjacent Channel Conditions 15
Figure 5-8 IBOC BLER & Mode vs. Avg-Peak 1200Hz Impulse Noise Channel Conditions 15
Figure 5-9 IBOC BLER & Mode vs. Avg-Peak in 1200Hz Impulse Noise and Lower First Adjacent Channel Conditions 16
Figure 5-10 IBOC BLER & Mode vs. Avg-Peak in 1800Hz Impulse Noise Channel Conditions 16
Figure 5-11 IBOC BLER & Mode vs. Avg-Peak in 1800Hz Impulse Noise and Lower First Adjacent Channel Conditions 17
Figure 5-12 IBOC BLER & Mode vs. Avg-Peak in 2000Hz Impulse Noise Channel Conditions 17
Figure 5-13 IBOC BLER & Mode vs. Avg-Peak in 2000Hz Impulse Noise and Lower First Adjacent Channel Conditions 18
Figure 5-14 IBOC BLER & Mode vs. Avg-Peak in Pseudo-Random Impulse Noise Channel Conditions 18
Figure 5-15 IBOC BLER & Mode vs. Avg-Peak in Pseudo Random Impulse Noise and Lower First Adjacent Channel Conditions 19
Figure 5-16 IBOC BLER & Mode vs. D/U in Co-Channel Interference Conditions . 25
Figure 5-17 IBOC BLER & Mode vs. D/U in Single First Adjacent Interference Conditions 26
Figure 5-18 IBOC BLER & Mode vs. D/U in Dual First Adjacent Interference Conditions 26
Figure 5-19 IBOC BLER & Mode vs. D/U in Single 2nd Adjacent Interference Conditions 27
Figure 5-20 IBOC BLER & Mode vs. D/U in Simultaneous Lower Second and Upper First Adjacent Interference Conditions 27
Figure 5-21 IBOC BLER & Mode vs. D/U in Dual Second Adjacent Interference Conditions 28
Figure 5-22 IBOC BLER & Mode vs. D/U in Lower Third Adjacent Interference Conditions 28

1. Introduction

This report contains the results of tests conducted by the Advanced Television Technology Center (ATTC) on the **iBiquity Digital AM In-Band On-Channel (IBOC) Digital Audio Broadcasting (DAB) System** during the period of August through November 2001.

1.1. Scope

The results reported in this document are collectively referred to as *Digital Performance Testing*. The objective of digital performance testing is to quantify the performance of the IBOC DAB system under varied RF channel conditions. The IBOC signal is subjected to a wide variety of interference and RF channel conditions. For each condition, the performance of IBOC is quantified.

2. Summary of Methodology

This document contains only a summary of test methodologies. For an in-depth discussion of test objectives, methodologies, setups and procedures, the reader is encouraged to examine the complete Test Plan in ATTC Document No. 01-23[1].

The performance of the iBiquity Digital IBOC system was quantified under varied RF channel conditions. In each of these channel conditions, IBOC performance was characterized & quantified in a three-step process.

In the first step, the IBOC Block Error Rate (BLER) and "Mode" were measured as a function of the channel condition's severity. For example, in adjacent channel interference conditions, the power level of the interferer was stepped through a wide range of levels. At each step, IBOC BLER and Mode were measured. In most cases, the interferer was eventually increased to a level at which IBOC data could no longer be recovered without errors. When the demodulated data contained errors, this represented a *transition region* in IBOC operation.

For the iBiquity AM IBOC system, there are two transition regions of interest. The first transition region is labeled the "enhanced-core transition" for the purposes of this report. In this region, the enhanced data stream of the iBiquity system can no longer be recovered without errors. The second transition region is labeled the "blend-to-analog" transition. In this region, the core data stream of the iBiquity system can no longer be recovered without errors. At the conclusion of the first characterization step, these two transition regions were illustrated in a plot of Enhanced BLER vs. channel condition severity and Core BLER vs. channel condition severity.

In addition to the BLER measurements described above, mode measurements were performed simultaneously. The iBiquity AM IBOC system has two distinct "modes". In digital mode, compressed digital audio is recovered. In analog mode, traditional analog AM audio is recovered. In some cases, the receiver alternated between recovering digital audio and analog audio over a period of time. In these cases, this state of operation was termed "mixed mode" for the purposes of this report.

The second step in the characterization of IBOC performance involved the generation of audio recordings for further subjective evaluation. After the two transition regions described above were identified and plotted, the audio output of the IBOC receiver was recorded at a point 2dB *before* each transition region. For example, if a transition region was identified with an interferer at a –10dB D/U, a

[1] Digital Audio Broadcasting, IBOC Laboratory Test Procedures – AM Band, Document No. 01-23, Revision 1.0, November 2001, Advanced Television Technology Center, Inc.

recording was generated with the interferer at a –8dB D/U. This recording may be used to examine IBOC audio performance just before the enhanced-core transition or blend-to-analog transition.

In the third step of the IBOC performance characterization, analog reference recordings were generated. In this step, the outputs of conventional analog AM receivers were recorded under identical channel conditions (but with IBOC removed from the spectrum). These recordings may be used to compare the performance of IBOC with conventional analog AM performance under similar channel conditions.

The audio recordings generated in steps two and three were edited by ATTC to remove extraneous material such as silence between the test samples. The test samples were also edited so each had the same overall perceptual loudness as every other sample. These edited recordings were made available to Dynastat, Inc. for subsequent subjective evaluation.

This three step process of plot generation and audio recording was repeated for a variety of NRSC specified channel conditions.

3. Description of the Test System and Parameters

3.1. Test Bed Description

The ATTC DAB Test Bed configuration is described in detail in ATTC Document No. 01-01[2]. The Test Bed was used to numerically quantify Block Error Rate (BLER) and produce digital audio recordings under various test conditions.

The performance of the ATTC Test Bed was verified according to the proof of performance plan detailed in ATTC Document No. 01-20[3]. The results of the proof are documented in ATTC Document No. 01-01[2].

3.2. AM Band Signals

3.2.1. Desired Analog

In all cases, the desired analog AM signal had the following characteristics:

1) Main Carrier: 1080 kHz
2) Power: A "moderate" signal level was used in all cases; However, the definition of moderate signal *power* varies according to the radio under test, as follows:
   a) Delphi automobile receiver: -62dBm
   b) Pioneer automobile receiver: -62dBm
   c) Sony portable receiver: -70dBm
   d) Technics home Hi-Fi receiver: -69dBm
   e) IBOC prototypical receiver: -70dBm
3) Pre-emphasis: NRSC-1 standard[4]
4) Bandwidth: 10kHz
5) Peak positive modulation: 96%
6) Peak negative modulation: 96%
7) Test dependent audio material as follows (refer to test plan for complete cut list and processor presets)
   i) **Objective Performance Tests:** Twain audio cut; Music Heavy dynamic range processing
   ii) **Subjective Performance Tests:** Various selections from the NRSC audio cut list; Dynamic range processing appropriate for each cut

[2] Digital Audio Broadcasting, Test Bed Proof of Performance Record, Document No. 01-01, Revision 2.0, November 2001, Advanced Television Technology Center, Inc.
[3] Digital Audio Broadcasting, Test Bed Proof of Performance Plan, Document No. 01-20, Revision 2.0, November 2001, Advanced Television Technology Center, Inc.
[4] NRSC AM Preemphasis/Deemphasis and Broadcast Audio Transmission Bandwidth Specifications, National Radio Systems Committee

3.2.2. Desired Hybrid

The desired hybrid signal contained both analog and digital carriers, as generated by an iBiquity IBOC exciter in AM hybrid mode. The analog portion of the signal is identical to the desired analog signal described in 3.2.1, with the following exception:

4) Bandwidth: 4.5kHz

The digital portion of the signal contained both "enhanced" and "core" data streams, utilizing modulation proprietary to iBiquity Digital Corporation.

3.2.3. Undesired Analog Interferer

An undesired analog AM interferer signal had the following characteristics:

1) Main Carrier:
   a) Lower 3rd Adjacent: 1050kHz
   b) Lower 2nd Adjacent: 1060kHz
   c) Lower 1st Adjacent: 1070kHz
   d) Co-channel: 1080kHz
   e) Upper 1st adjacent: 1090kHz
   f) Upper 2nd adjacent: 1100kHz
2) Power: specified as a D/U ratio in dB units, where 'D' is the desired channel signal power, and 'U' is the undesired channel signal power (both in dBm units). By convention, a *negative* D/U ratio indicates that the interferer has *more* power than the desired signal.
3) Pre-emphasis: NRSC-1 standard[4]
4) Bandwidth: 10kHz
5) Peak positive modulation: 96%
6) Peak negative modulation: 96%
7) Audio material: Twain audio cut; Music Heavy dynamic range processing (refer to test plan[1] for additional details)

3.2.4. Undesired Hybrid Interferer

The undesired hybrid interferer signals contained both analog and digital carriers, as generated by an iBiquity IBOC exciter in AM hybrid mode. The analog portion of the signal is identical to the undesired analog interferer described in 3.2.3, with the following exception:

4) Bandwidth: 4.5kHz

The digital portion of the signal contained both "enhanced" and "core" data streams, utilizing modulation proprietary to iBiquity Digital Corporation.

3.2.5. Additive White Gaussian Noise

In certain performance tests, the addition of Additive White Gaussian Noise (AWGN) was specified. The AWGN signal was generated by an industry standard RF noise generation instrument, with the addition of an AM bandpass filter (330kHz-2.5MHz) inline. This bandpass filter served to limit the instrument's otherwise wideband AWGN to the AM frequency range.

3.2.6. Impulse Noise

In certain performance tests, the addition of impulse noise was specified. This impulse noise was generated using a pulse-gated 1050kHz CW signal (at 30kHz below the desired channel center frequency). The pulse duration was 5μs. The pulses occurred at either fixed repetition rates or pseudo-randomly, as specified.

4. Description of Test Receivers

The following receivers were used for the analog reference recordings:

Radio Model No:	Serial No:
Delphi 09394139 (OEM Automotive)	89DDSTM103490265
Pioneer KEH-1900 (Aftermarket Automotive)	UHHI086599UC
Technics SA-EX110P-K (Home Hi-Fi)	GX9DA84758
Sony CFD-S22 (Portable Boombox)	0005122

The Sony receiver was modified by the Consumer Electronics Association (CEA) to accommodate a wired RF input at AM frequencies. The automotive receivers utilized "dummy loads" at the receiver input terminals. These dummy loads are identical to the loads used by radio manufacturers to simulate a typical AM antenna system in an automobile (these dummy loads are commercially available).

All four receivers were characterized by CEA and delivered directly to ATTC.

The IBOC system consisted of the AM IBOC exciter (software version 3.06/ah5.2?) and IBOC receiver (software version 3.06/ah5.2).

5. Digital Performance Results Summary

5.1. IBOC Performance in the Presence of AWGN (NRSC B)

Table 5-1 summarizes the channel conditions included in tests of *IBOC performance in the presence of AWGN*. For this test series, IBOC BLER and Mode were measured as a function of a variable C/No ratio. The AWGN power level was increased (i.e. C/No decreased) until the IBOC enhanced and core data streams could no longer be recovered without errors. Figure 5-1 illustrates the measured BLER & Mode vs. C/No in the transitional regions of IBOC operation.

In addition to the plots of objective data, audio recordings were made at points 2dB *before* the enhanced-core transition and blend-to-analog transition regions. For these tests, the audio output of the IBOC receiver was recorded. The actual recording points are illustrated by the vertical lines of Figure 5-1. Table 5-2 enumerates the test conditions for each of these recording points.

Table 5-1 Test Scenarios for Objective Performance in AWGN Conditions

#	Desired	AWGN Level
7101	Hybrid: Moderate	Variable

Table 5-2 Test Scenarios for Subjective Performance in AWGN Conditions

#	Desired	Record Point AWGN Level	Receiver	Audio
7201	Hybrid: Moderate	Enh-Core Trans - 2 dB	IBOC	Santana
7202	Hybrid: Moderate	Enh-Core Trans - 2 dB	IBOC	Riverdance
7203	Hybrid: Moderate	Enh-Core Trans - 2 dB	IBOC	Ibert
7204	Hybrid: Moderate	Enh-Core Trans - 2 dB	IBOC	FemaleA1
7205	Hybrid: Moderate	Blend-to-Analog - 2 dB	IBOC	Santana
7206	Hybrid: Moderate	Blend-to-Analog - 2 dB	IBOC	Riverdance
7207	Hybrid: Moderate	Blend-to-Analog - 2 dB	IBOC	Ibert
7208	Hybrid: Moderate	Blend-to-Analog - 2 dB	IBOC	FemaleA1

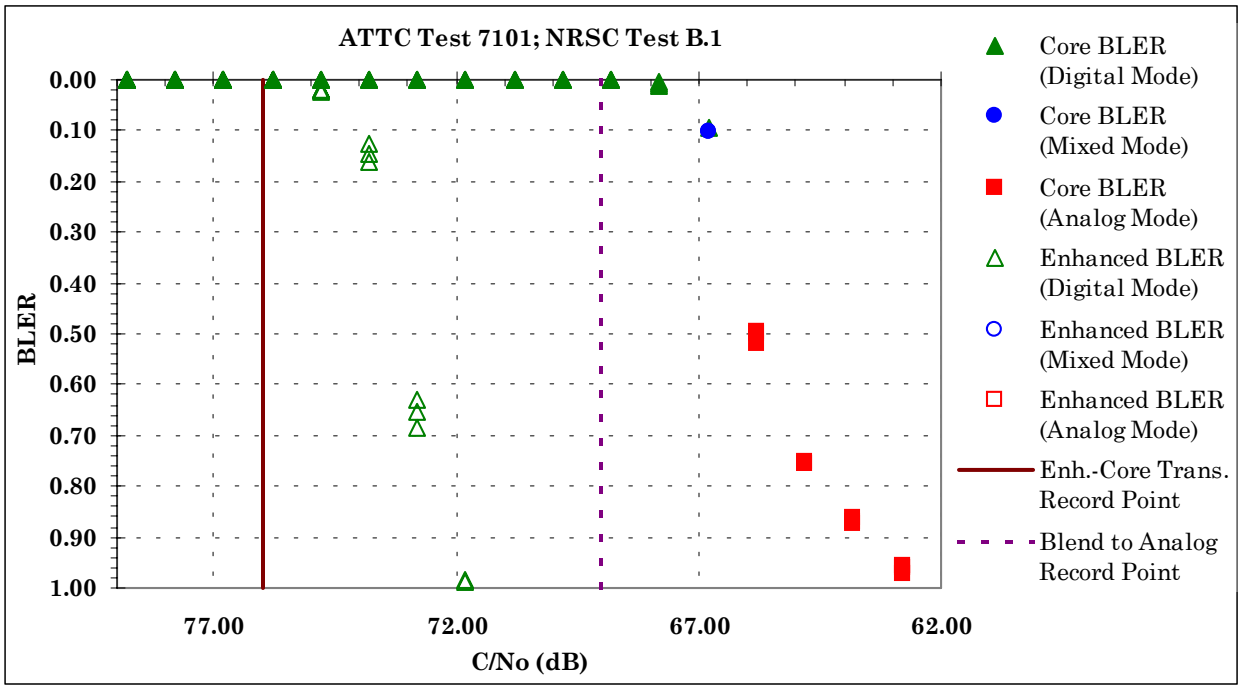

Figure 5-1 IBOC BLER & Mode vs. C/No in AWGN Channel Conditions

5.2. IBOC Performance in the Presence of Impulse Noise (NRSC C)

Table 5-3 summarizes the channel conditions included in tests of *IBOC performance in the presence of impulse noise*. For this test series, IBOC BLER and Mode were measured as a function of impulse noise peak power. The impulse noise peak power level was increased until the IBOC enhanced and core data streams could no longer be recovered without errors. Figure 5-2 through Figure 5-15 illustrate the measured BLER & Mode vs. Avg-Peak[5] in the transitional regions of IBOC operation, for various impulse noise repetition rates.

In addition to the plots of objective data, audio recordings were made at points 2dB *before* the enhanced-core transition and blend-to-analog transition regions, in channel conditions with impulse noise repetition rates of 120Hz, 510Hz and 1800Hz. These tests recorded the audio output of the both the IBOC receiver and selected analog reference receivers. The actual recording points are illustrated by the vertical lines of Figure 5-2 through Figure 5-15. Table 5-4 enumerates the test conditions for each of these recording points.

In cases with a +6dB lower 1st adjacent interferer present, it was found that enhanced data could not received, regardless of the impulse noise level. In these cases, it was not possible to identify an enhanced-core transition region, and the

[5] In this case, Avg-Peak refers to the ratio of average desired signal power to peak impulse noise power. Because the *peak* impulse noise power is measured (instead of average power), the traditional D/U nomenclature is not appropriate in this context.

corresponding subjective audio recordings were not applicable. Consequently, Figure 5-3, Figure 5-7 and Figure 5-11 illustrate only one subjective recording point, at the blend-to-analog transition region.

Table 5-3 Test Scenarios for Objective Performance in Impulse Noise Conditions (NRSC C)

#	Lower 1st Adjacent	Desired	Impulse Peak Pwr	Rep Rate
7301		Hybrid: Moderate	Variable	120 Hz
7302	Hybrid: +6dB	Hybrid: Moderate	Variable	120 Hz
7303		Hybrid: Moderate	Variable	330 Hz
7304	Hybrid: +6dB	Hybrid: Moderate	Variable	330 Hz
7305		Hybrid: Moderate	Variable	510 Hz
7306	Hybrid: +6dB	Hybrid: Moderate	Variable	510 Hz
7307		Hybrid: Moderate	Variable	1200 Hz
7308	Hybrid: +6dB	Hybrid: Moderate	Variable	1200 Hz
7309		Hybrid: Moderate	Variable	1800 Hz
7310	Hybrid: +6dB	Hybrid: Moderate	Variable	1800 Hz
7311		Hybrid: Moderate	Variable	2000 Hz
7312	Hybrid: +6dB	Hybrid: Moderate	Variable	2000 Hz
7313		Hybrid: Moderate	Variable	Pseudo-Random
7314	Hybrid: +6dB	Hybrid: Moderate	Variable	Pseudo-Random

Table 5-4 Test Scenarios for Subjective Performance in Impulse Noise Conditions (NRSC C)

#	Lower 1st Adjacent	Desired	Recording Point Impulse Peak Pwr	Receiver	Rep Rate	Audio
7401		Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	120 Hz	Clapton
7402		Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	120 Hz	Clapton
7403		Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	120 Hz	Bach
7404		Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	120 Hz	Bach
7405		Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	120 Hz	Ballet Woman
7406		Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	120 Hz	Ballet Woman
7407		Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	120 Hz	MaleA1
7408		Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	120 Hz	MaleA1
7409		Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	120 Hz	Cole
7410		Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	120 Hz	Cole
7411		Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	120 Hz	Carmen
7412		Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	120 Hz	Carmen
7413		Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	120 Hz	Camera
7414		Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	120 Hz	Camera
7415		Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	120 Hz	FemaleA1
7416		Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	120 Hz	FemaleA1
7417	Hybrid: +6 dB	Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	120 Hz	Debussy
7418	Analog: +6 dB	Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	120 Hz	Debussy
7419	Hybrid: +6 dB	Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	120 Hz	CSNY
7420	Analog: +6 dB	Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	120 Hz	CSNY
7421	Hybrid: +6 dB	Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	120 Hz	Riverdance
7422	Analog: +6 dB	Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	120 Hz	Riverdance
7423	Hybrid: +6 dB	Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	120 Hz	MaleB4
7424	Analog: +6 dB	Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	120 Hz	MaleB4
7425	Hybrid: +6 dB	Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	120 Hz	EWF
7426	Analog: +6 dB	Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	120 Hz	EWF
7427	Hybrid: +6 dB	Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	120 Hz	Ibert
7428	Analog: +6 dB	Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	120 Hz	Ibert
7429	Hybrid: +6 dB	Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	120 Hz	WTOP

#	Lower 1st Adjacent	Desired	Recording Point Impulse Peak Pwr	Receiver	Rep Rate	Audio
7430	Analog: +6 dB	Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	120 Hz	WTOP
7431	Hybrid: +6 dB	Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	120 Hz	FemaleB2
7432	Analog: +6 dB	Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	120 Hz	FemaleB2
7433		Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	510 Hz	Clapton
7434		Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	510 Hz	Clapton
7435		Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	510 Hz	Bach
7436		Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	510 Hz	Bach
7437		Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	510 Hz	Ballet Woman
7438		Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	510 Hz	Ballet Woman
7439		Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	510 Hz	MaleA1
7440		Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	510 Hz	MaleA1
7441		Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	510 Hz	Cole
7442		Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	510 Hz	Cole
7443		Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	510 Hz	Carmen
7444		Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	510 Hz	Carmen
7445		Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	510 Hz	Camera
7446		Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	510 Hz	Camera
7447		Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	510 Hz	FemaleA1
7448		Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	510 Hz	FemaleA1
7449	Hybrid: +6 dB	Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	510 Hz	Debussy
7450	Analog: +6 dB	Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	510 Hz	Debussy
7451	Hybrid: +6 dB	Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	510 Hz	CSNY
7452	Analog: +6 dB	Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	510 Hz	CSNY
7453	Hybrid: +6 dB	Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	510 Hz	Riverdance
7454	Analog: +6 dB	Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	510 Hz	Riverdance
7455	Hybrid: +6 dB	Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	510 Hz	MaleB4
7456	Analog: +6 dB	Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	510 Hz	MaleB4
7457	Hybrid: +6 dB	Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	510 Hz	EWF
7458	Analog: +6 dB	Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	510 Hz	EWF
7459	Hybrid: +6 dB	Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	510 Hz	Ibert
7460	Analog: +6 dB	Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	510 Hz	Ibert
7461	Hybrid: +6 dB	Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	510 Hz	WTOP
7462	Analog: +6 dB	Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	510 Hz	WTOP
7463	Hybrid: +6 dB	Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	510 Hz	FemaleB2
7464	Analog: +6 dB	Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	510 Hz	FemaleB2
7465		Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	1800 Hz	Clapton
7466		Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	1800 Hz	Clapton
7467		Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	1800 Hz	Bach
7468		Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	1800 Hz	Bach
7469		Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	1800 Hz	Ballet Woman
7470		Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	1800 Hz	Ballet Woman
7471		Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	1800 Hz	MaleA1
7472		Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	1800 Hz	MaleA1
7473		Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	1800 Hz	Cole
7474		Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	1800 Hz	Cole
7475		Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	1800 Hz	Carmen
7476		Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	1800 Hz	Carmen
7477		Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	1800 Hz	Camera
7478		Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	1800 Hz	Camera
7479		Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	1800 Hz	FemaleA1
7480		Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	1800 Hz	FemaleA1
7481	Hybrid: +6 dB	Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	1800 Hz	Debussy
7482	Analog: +6 dB	Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	1800 Hz	Debussy
7483	Hybrid: +6 dB	Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	1800 Hz	CSNY
7484	Analog: +6 dB	Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	1800 Hz	CSNY
7485	Hybrid: +6 dB	Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	1800 Hz	Riverdance
7486	Analog: +6 dB	Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	1800 Hz	Riverdance
7487	Hybrid: +6 dB	Hybrid: Moderate	Enh-Core Trans - 2dB	IBOC	1800 Hz	MaleB4
7488	Analog: +6 dB	Analog: Moderate	Enh-Core Trans - 2dB	Delphi/Sony	1800 Hz	MaleB4

#	Lower 1st Adjacent	Desired	Recording Point Impulse Peak Pwr	Receiver	Rep Rate	Audio
7489	Hybrid: +6 dB	Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	1800 Hz	EWF
7490	Analog: +6 dB	Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	1800 Hz	EWF
7491	Hybrid: +6 dB	Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	1800 Hz	Ibert
7492	Analog: +6 dB	Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	1800 Hz	Ibert
7493	Hybrid: +6 dB	Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	1800 Hz	WTOP
7494	Analog: +6 dB	Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	1800 Hz	WTOP
7495	Hybrid: +6 dB	Hybrid: Moderate	Blend-to-Analog - 2dB	IBOC	1800 Hz	FemaleB2
7496	Analog: +6 dB	Analog: Moderate	Blend-to-Analog - 2dB	Delphi/Sony	1800 Hz	FemaleB2

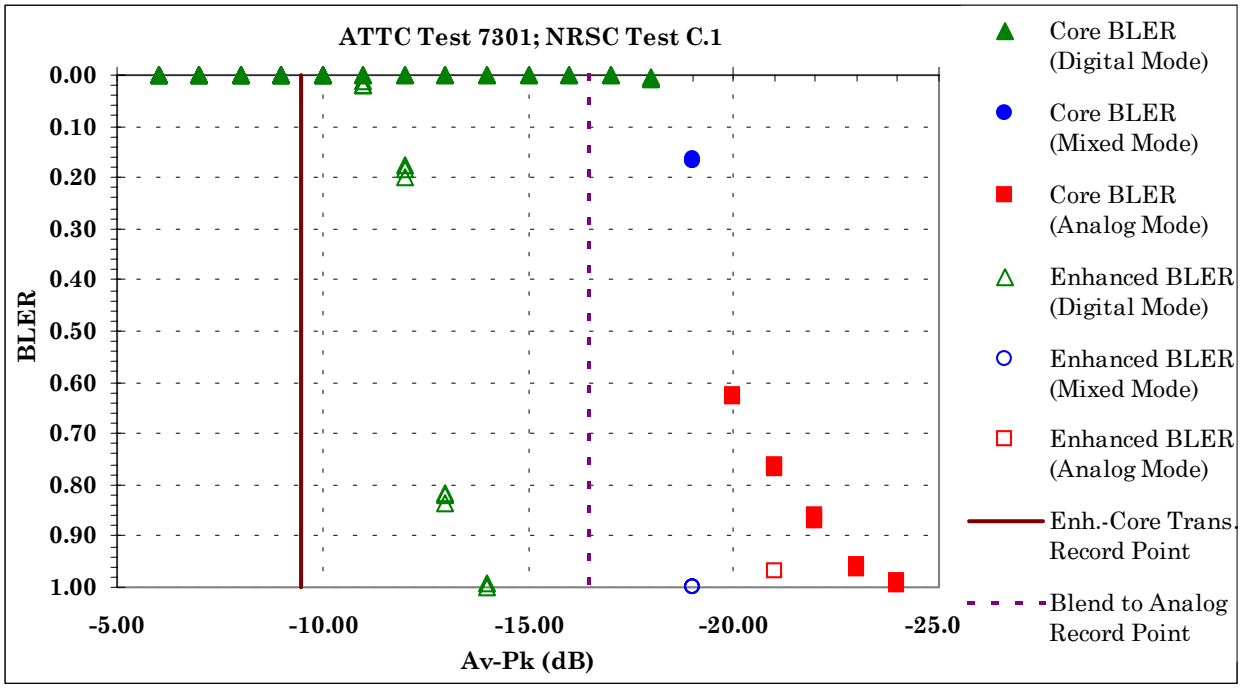

Figure 5-2 IBOC BLER & Mode vs. Avg-Peak in 120Hz Impulse Noise Channel Conditions

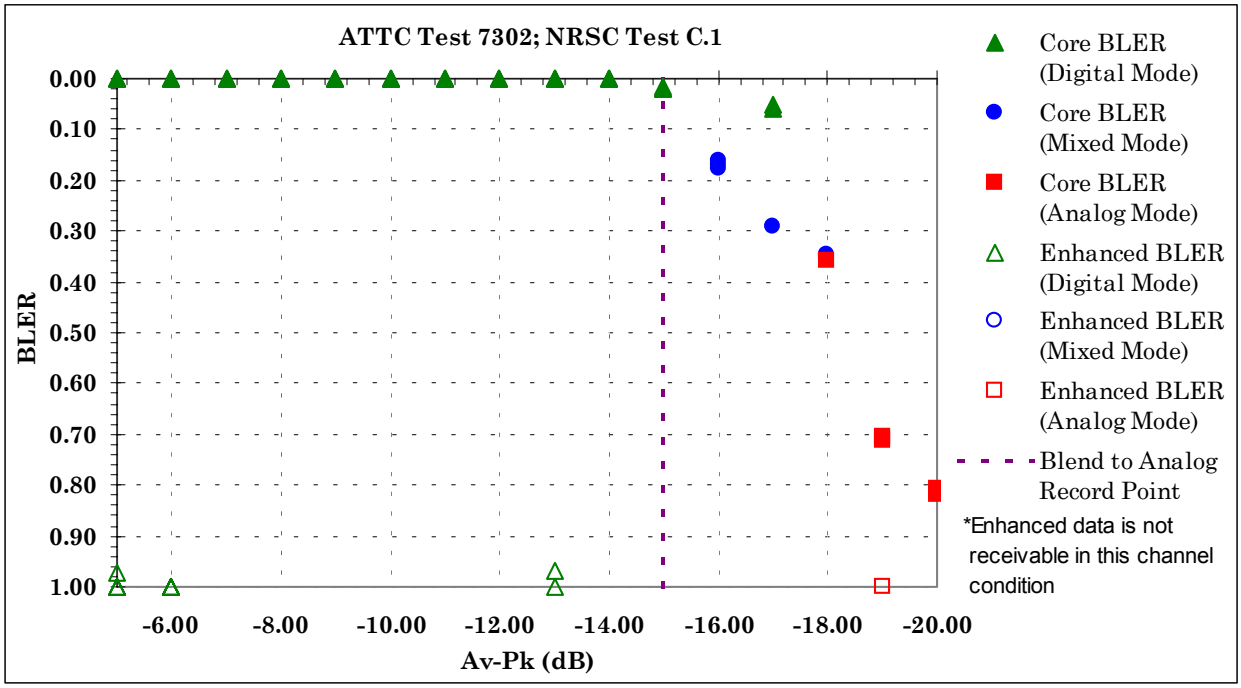

Figure 5-3 IBOC BLER & Mode vs. Avg-Peak in 120Hz Impulse Noise and Lower First Adjacent Channel Conditions

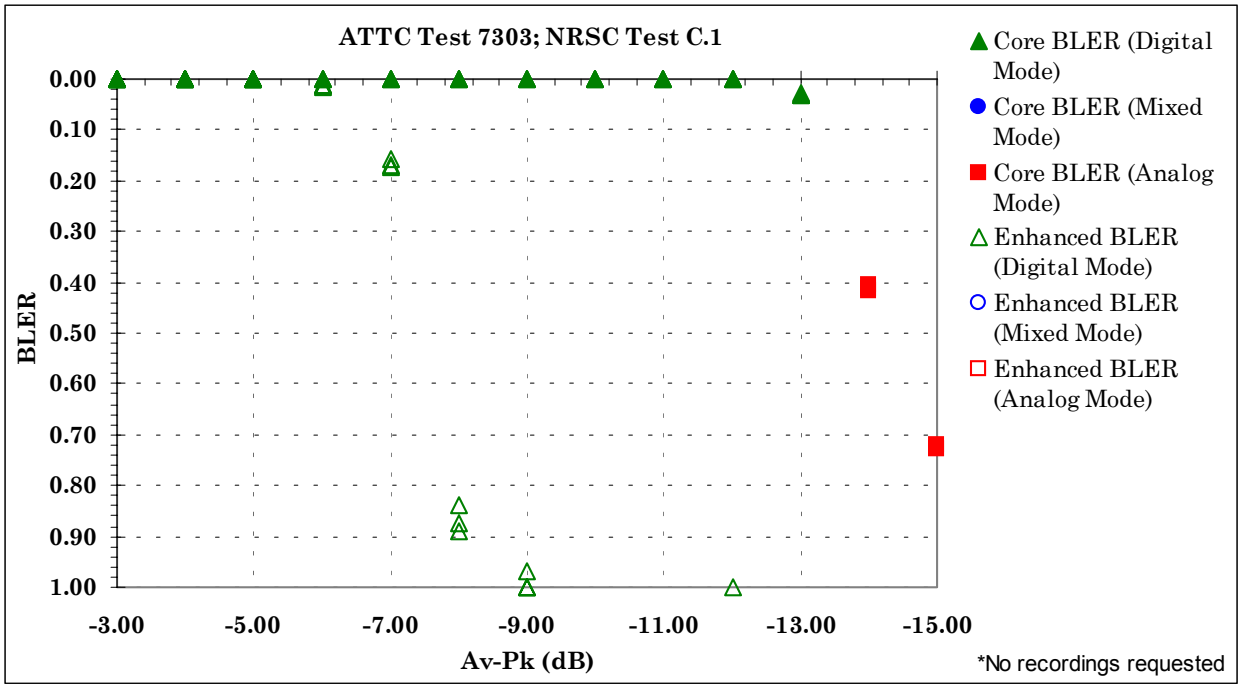

Figure 5-4 IBOC BLER & Mode vs. Avg-Peak in 330Hz Impulse Noise Channel Conditions

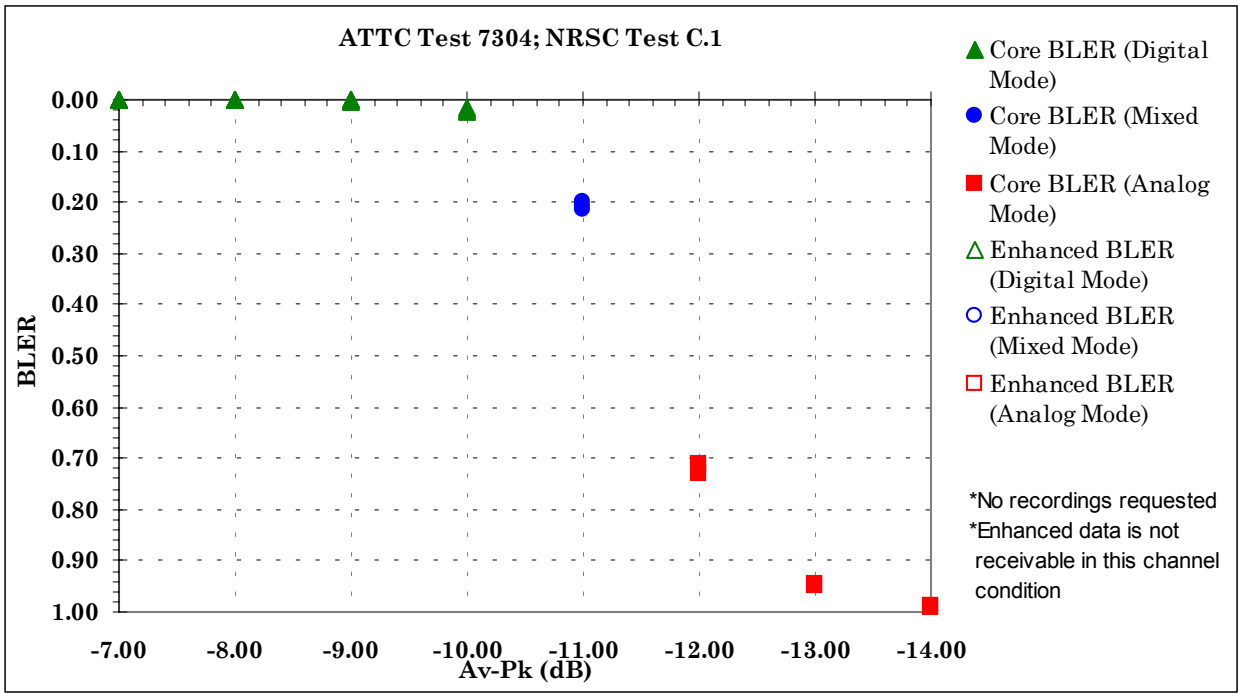

Figure 5-5 IBOC BLER & Mode vs. Avg-Peak in 330Hz Impulse Noise and Lower First Adjacent Channel Conditions

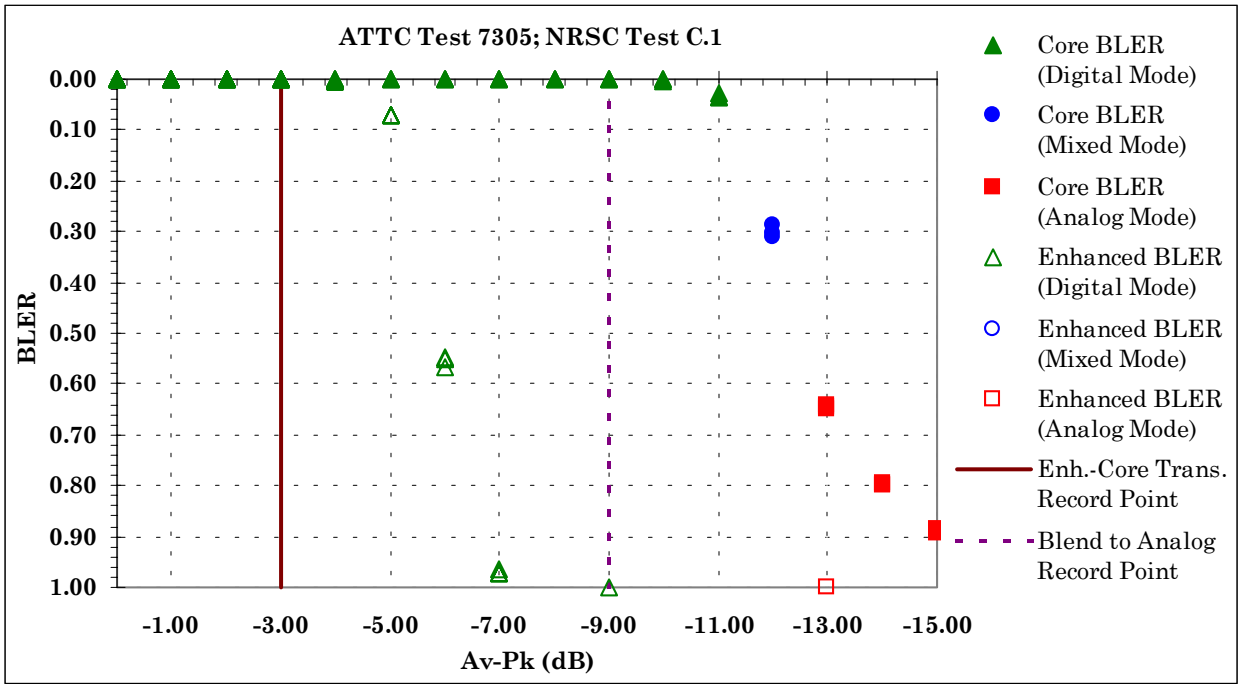

Figure 5-6 IBOC BLER & Mode vs. Avg-Peak in 510Hz Impulse Noise Channel Conditions

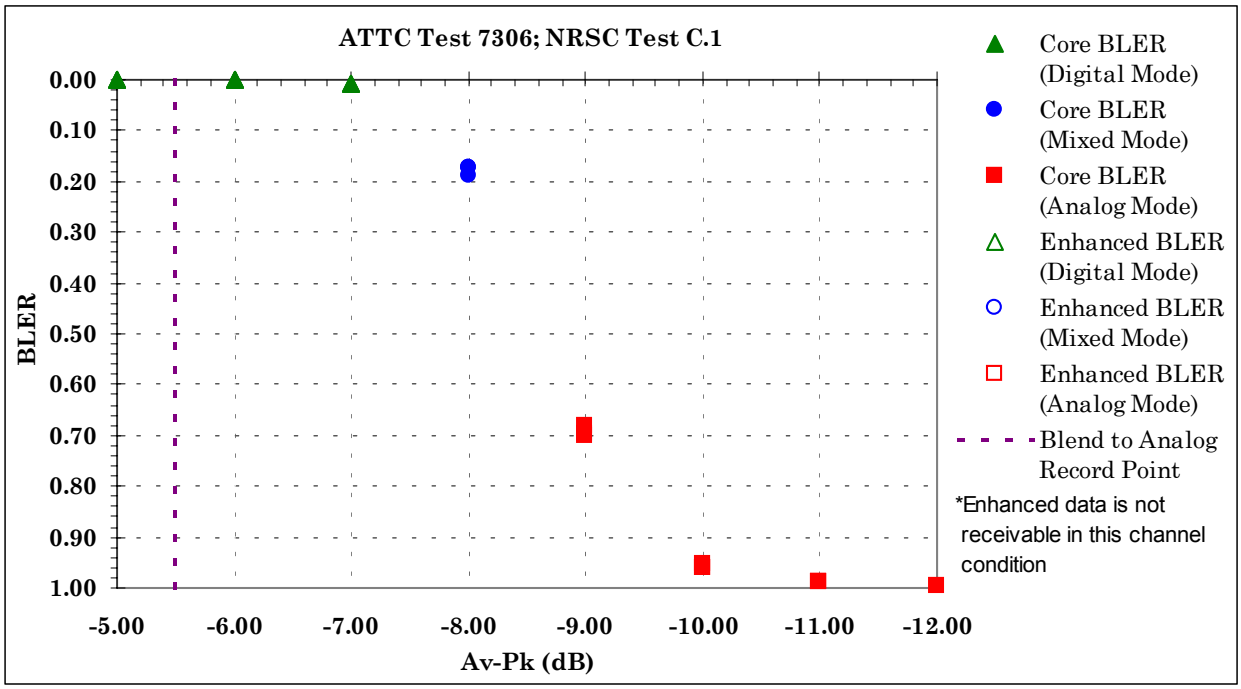

Figure 5-7 IBOC BLER & Mode vs. Avg-Peak in 510Hz Impulse Noise and Lower First Adjacent Channel Conditions

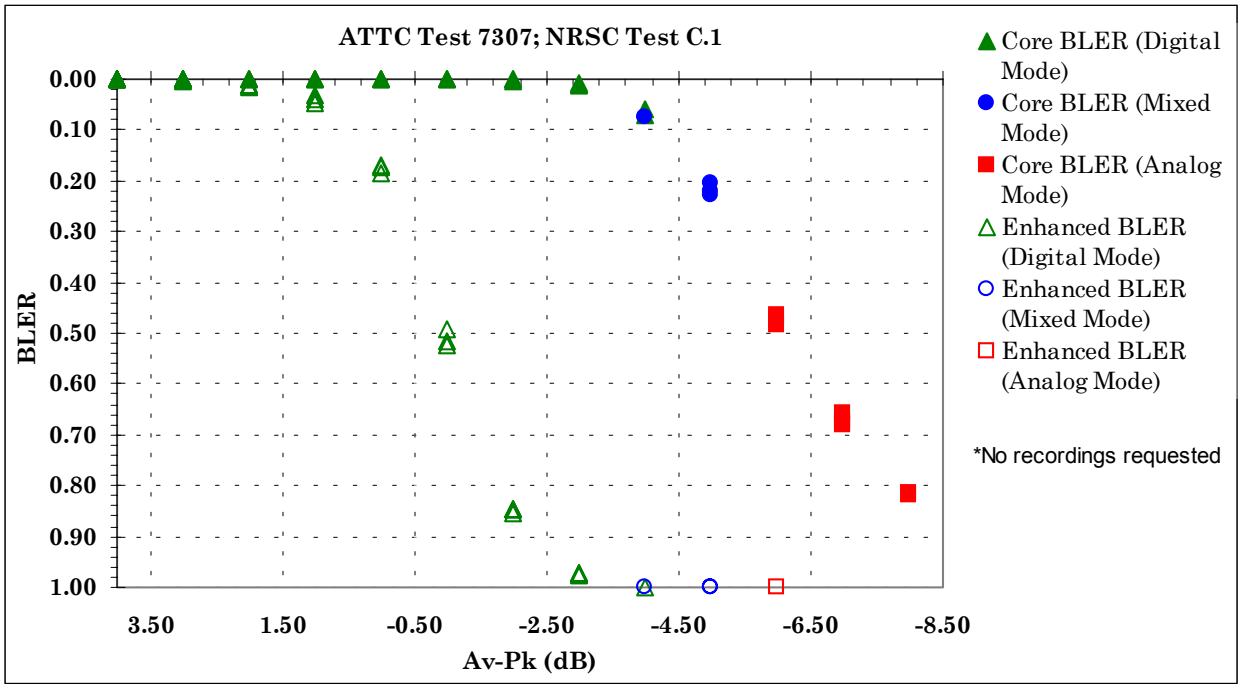

Figure 5-8 IBOC BLER & Mode vs. Avg-Peak 1200Hz Impulse Noise Channel Conditions

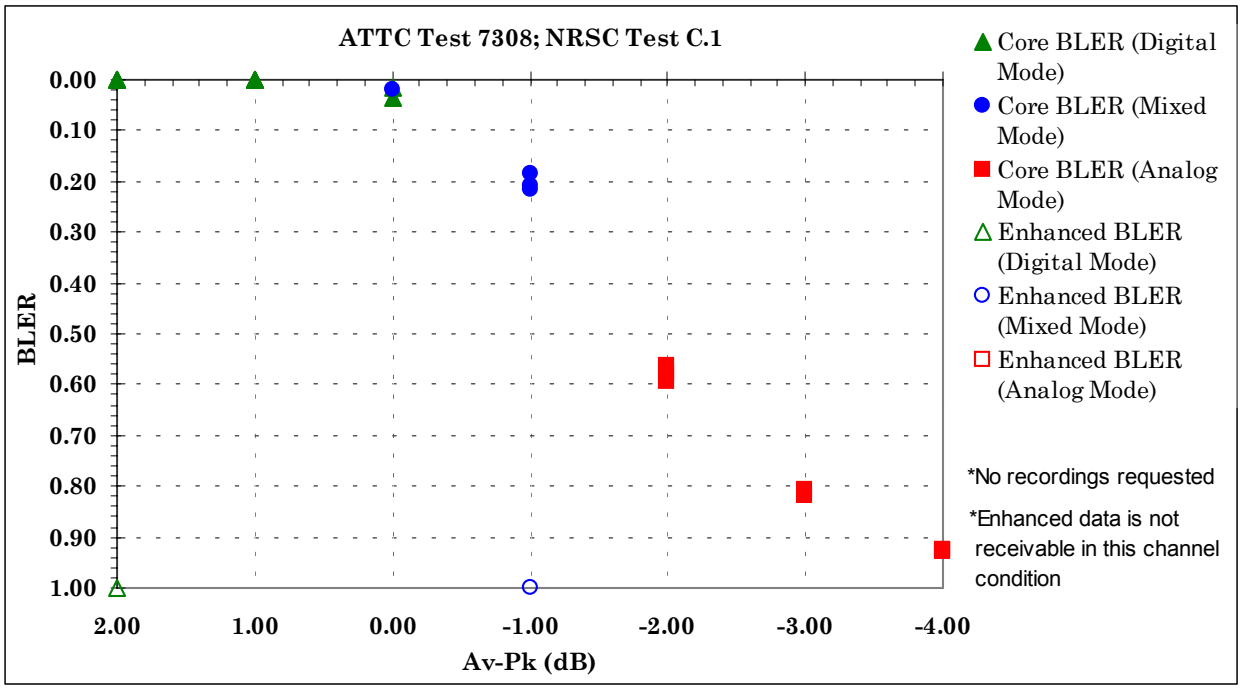

Figure 5-9 IBOC BLER & Mode vs. Avg-Peak in 1200Hz Impulse Noise and Lower First Adjacent Channel Conditions

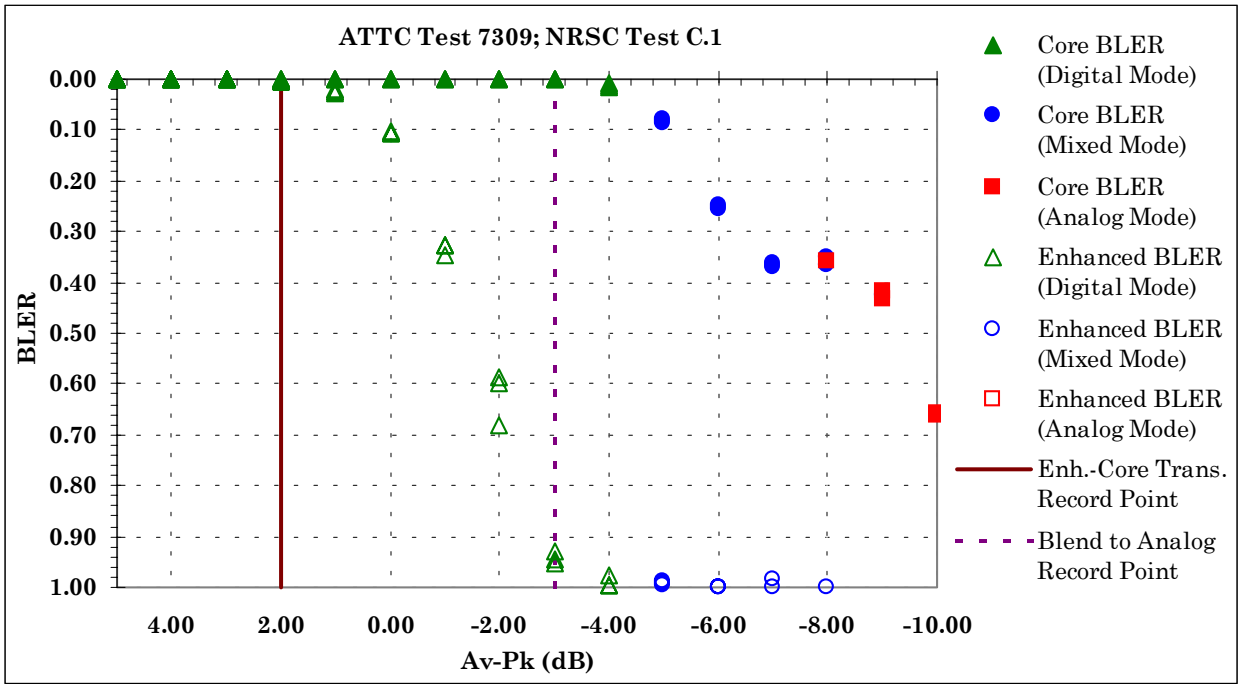

Figure 5-10 IBOC BLER & Mode vs. Avg-Peak in 1800Hz Impulse Noise Channel Conditions

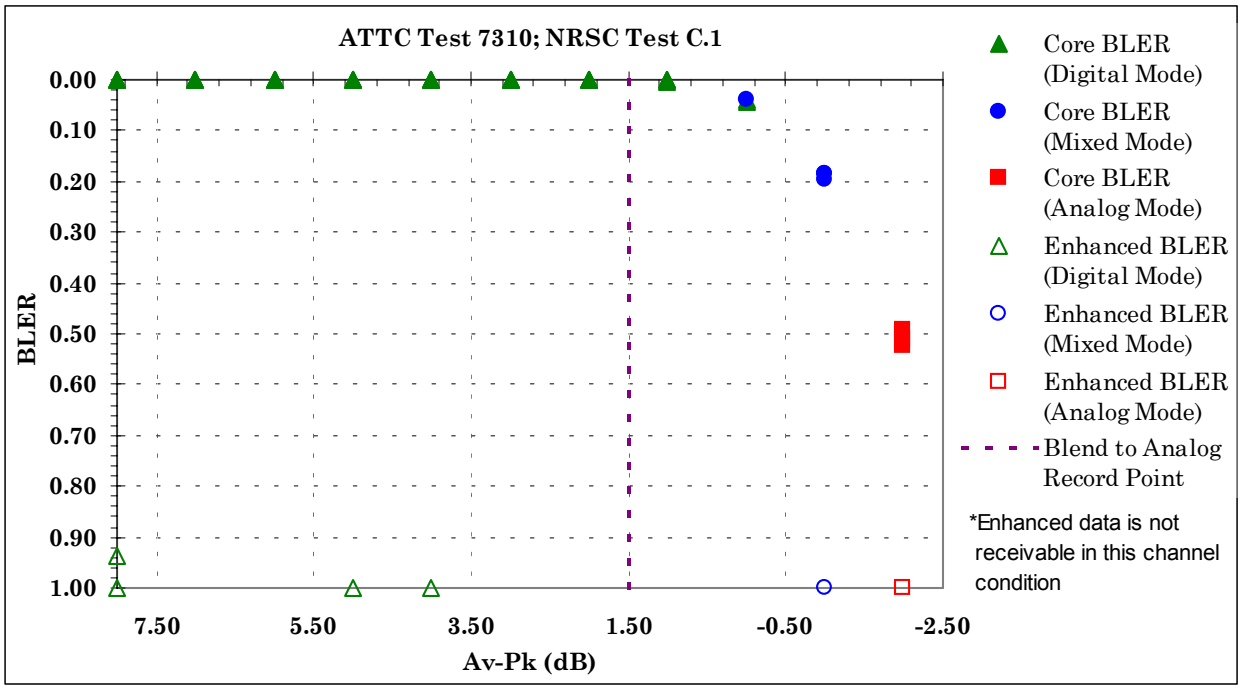

Figure 5-11 IBOC BLER & Mode vs. Avg-Peak in 1800Hz Impulse Noise and Lower First Adjacent Channel Conditions

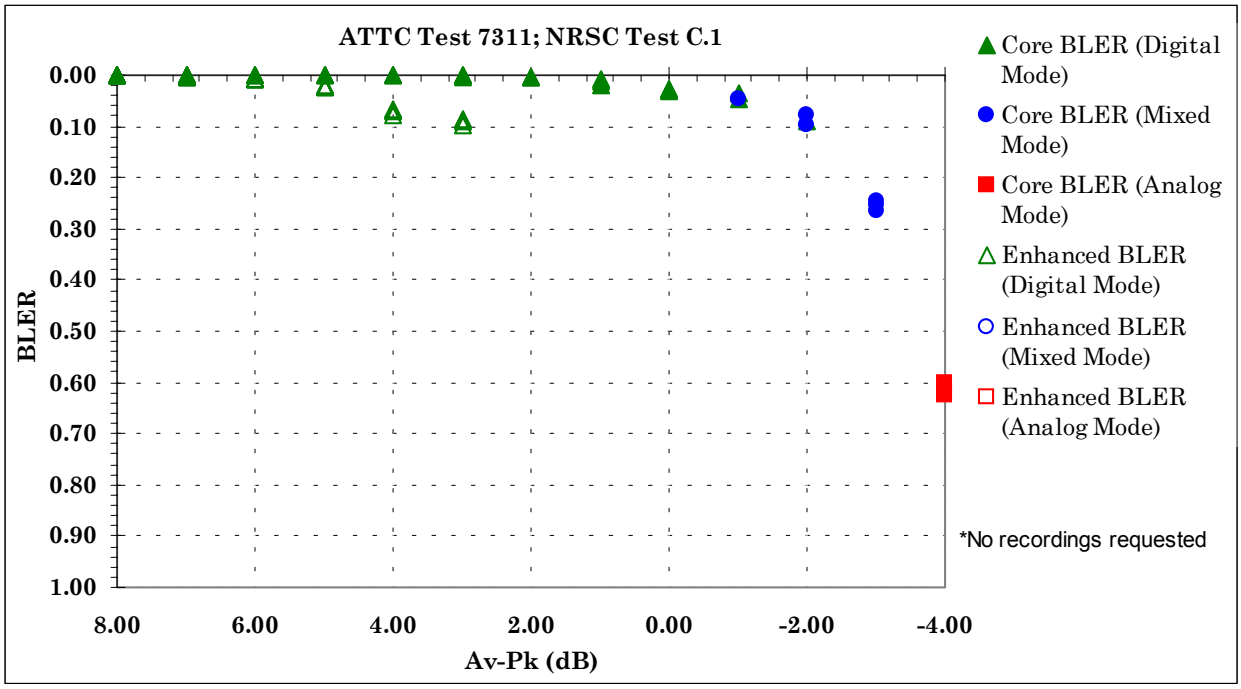

Figure 5-12 IBOC BLER & Mode vs. Avg-Peak in 2000Hz Impulse Noise Channel Conditions

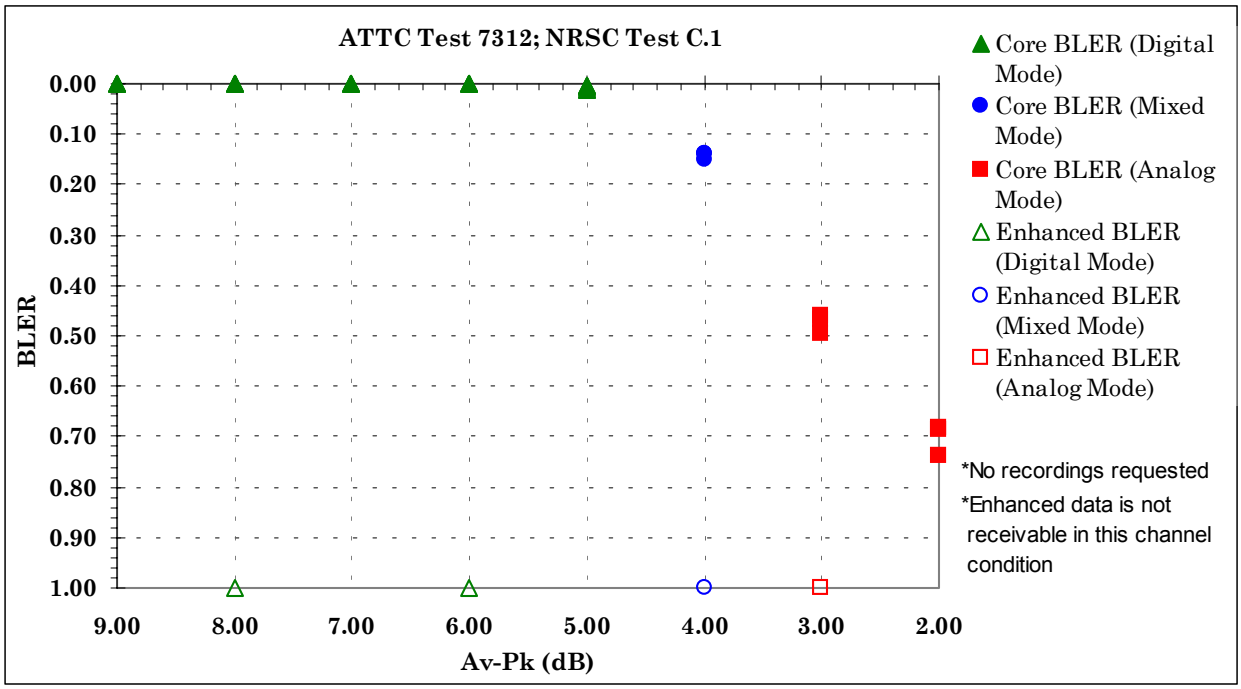

Figure 5-13 IBOC BLER & Mode vs. Avg-Peak in 2000Hz Impulse Noise and Lower First Adjacent Channel Conditions

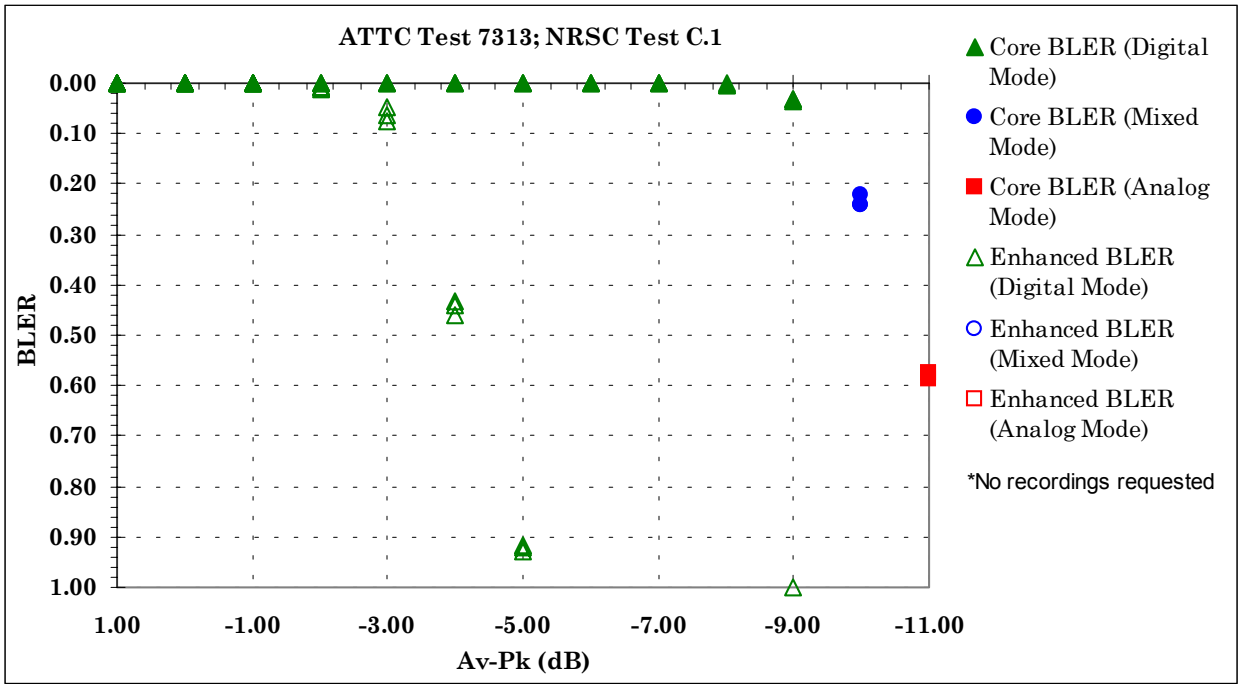

Figure 5-14 IBOC BLER & Mode vs. Avg-Peak in Pseudo-Random Impulse Noise Channel Conditions

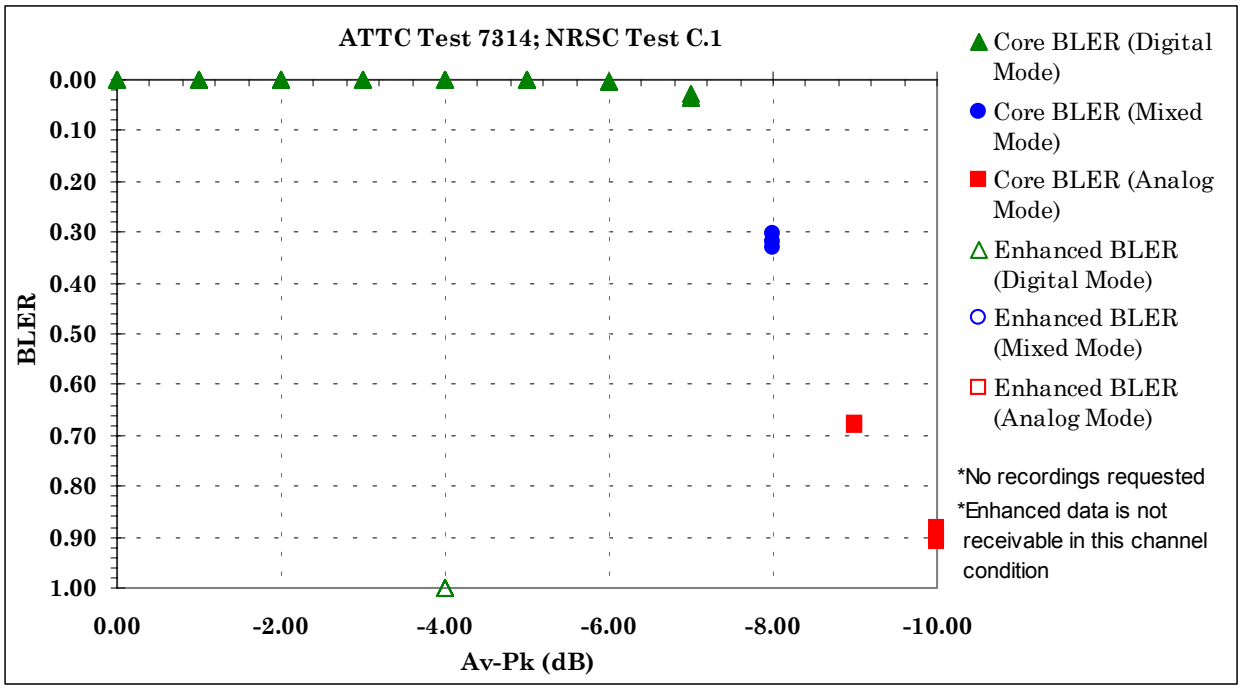

Figure 5-15 IBOC BLER & Mode vs. Avg-Peak in Pseudo Random Impulse Noise and Lower First Adjacent Channel Conditions

5.3. IBOC Performance in the Presence of Adjacent and Co-Channel Interference (NRSC D)

Table 5-3 summarizes the channel conditions included in tests of *IBOC performance in the presence of adjacent and co-channel interference*. For this test series, IBOC BLER and Mode were measured as a function of Desired-to-Undesired (D/U) ratio[6]. The interfering signal's power level was increased until the IBOC enhanced and core data streams could no longer be recovered without errors. Figure 5-16 through Figure 5-22 illustrate the measured BLER & Mode vs. D/U in the transitional regions of IBOC operation, for various configurations of adjacent and co-channel interferers. Table 5-5 enumerates each of these interference configurations.

In addition to the plots of objective data, audio recordings were made at points 2dB *before* the enhanced-core transition and blend-to-analog transition regions. These tests recorded the audio output of the both the IBOC receiver and selected analog reference receivers. The actual recording points are illustrated by the vertical lines of Figure 5-16 through Figure 5-22. Table 5-6 enumerates the test conditions for each of these recording points.

In cases with a +6dB upper 1st adjacent interferer present, it was found that enhanced data could not received, regardless of the level of other interferers in the channel. In these cases, it was not possible to identify an enhanced-core transition region, and the corresponding subjective audio recordings were not applicable. Consequently, Figure 5-18 and Figure 5-20 show only one subjective recording point, at the blend-to-analog transition region.

In the case of co-channel interference (ATTC Test 7501), it was found that the enhanced-core and blend-to-analog transition regions occurred at the same point (enhanced and core data was lost simultaneously). In this case, subjective recordings were made at only one D/U ratio, as illustrated in Figure 5-16.

In the case of lower third adjacent channel interference (ATTC Test 7507), it was not possible to cause a failure of the IBOC core data stream (the test bed hardware did not have enough RF power available to exceed a –44dB D/U ratio). This test bed power limit is illustrated in Figure 5-22.

[6] D/U refers to the ratio of Desired to Undesired signal power, where the Undesired signal is an adjacent or co-channel interferer. By convention, a *negative* D/U indicates that the undesired signal has *more* power than the desired signal. D/U ratios are always specified in dB units.

Table 5-5 Test Scenarios for Objective Performance with Adjacent and Co-Channel Interferers

#	Lower 3rd Adjacent	Lower 2nd Adjacent	Lower 1st Adjacent	Desired	Upper 1st Adjacent	Upper 2nd Adjacent	Co-Channel
7501				Hybrid: Moderate			Hybrid: Variable
7502			Hybrid: Variable	Hybrid: Moderate			
7503			Hybrid: Variable	Hybrid: Moderate	Hybrid: +6dB		
7504		Hybrid: Variable		Hybrid: Moderate			
7505		Hybrid: Variable		Hybrid: Moderate	Hybrid: +6dB		
7506		Hybrid: Variable		Hybrid: Moderate		Hybrid: 0dB	
7507	Hybrid: Variable			Hybrid: Moderate			

Table 5-6 Test Scenarios for Subjective Performance in Adjacent and Co-Channel Interference Conditions

#	Lower 3rd Adjacent	Lower 2nd Adjacent	Lower 1st Adjacent	Desired	Upper 1st Adjacent	Upper 2nd Adjacent	Co-Channel	Receiver	Audio
7601				Hybrid: Moderate			Hybrid: E.C. -2dB	IBOC	Fagen
7602				Analog: Moderate			Analog: E.C. -2dB	Pioneer - Technics	Fagen
7603				Hybrid: Moderate			Hybrid: POB -2dB	IBOC	Fagen
7604				Analog: Moderate			Analog: POB -2dB	Pioneer - Technics	Fagen
7605				Hybrid: Moderate			Hybrid: E.C. -2dB	IBOC	Saito
7606				Analog: Moderate			Analog: E.C. -2dB	Pioneer - Technics	Saito
7607				Hybrid: Moderate			Hybrid: POB -2dB	IBOC	Saito
7608				Analog: Moderate			Analog: POB -2dB	Pioneer - Technics	Saito
7609				Hybrid: Moderate			Hybrid: E.C. -2dB	IBOC	Richmond
7610				Analog: Moderate			Analog: E.C. -2dB	Pioneer - Technics	Richmond
7611				Hybrid: Moderate			Hybrid: POB -2dB	IBOC	Richmond
7612				Analog: Moderate			Analog: POB -2dB	Pioneer - Technics	Richmond
7613				Hybrid: Moderate			Hybrid: E.C. -2dB	IBOC	FemaleC10
7614				Analog: Moderate			Analog: E.C. -2dB	Pioneer - Technics	FemaleC10
7615				Hybrid: Moderate			Hybrid: POB -2dB	IBOC	FemaleC10
7616				Analog: Moderate			Analog: POB -2dB	Pioneer - Technics	FemaleC10
7617			Hybrid: E.C. -2dB	Hybrid: Moderate				IBOC	Fleetwood
7618			Analog:	Analog:				All 4	Fleetwood

#	Lower 3rd Adjacent	Lower 2nd Adjacent	Lower 1st Adjacent	Desired	Upper 1st Adjacent	Upper 2nd Adjacent	Co-Channel	Receiver	Audio
			E.C. -2dB	Moderate					
7619			Hybrid: POB -2dB	Hybrid: Moderate				IBOC	Fleetwood
7620			Analog: POB -2dB	Analog: Moderate				All 4	Fleetwood
7621			Hybrid: E.C. -2dB	Hybrid: Moderate				IBOC	Stravinsky
7622			Analog: E.C. -2dB	Analog: Moderate				All 4	Stravinsky
7623			Hybrid: POB -2dB	Hybrid: Moderate				IBOC	Stravinsky
7624			Analog: POB -2dB	Analog: Moderate				All 4	Stravinsky
7625			Hybrid: E.C. -2dB	Hybrid: Moderate				IBOC	Imagine
7626			Analog: E.C. -2dB	Analog: Moderate				All 4	Imagine
7627			Hybrid: POB -2dB	Hybrid: Moderate				IBOC	Imagine
7628			Analog: POB -2dB	Analog: Moderate				All 4	Imagine
7629			Hybrid: E.C. -2dB	Hybrid: Moderate				IBOC	Male C5
7630			Analog: E.C. -2dB	Analog: Moderate				All 4	Male C5
7631			Hybrid: POB -2dB	Hybrid: Moderate				IBOC	Male C5
7632			Analog: POB -2dB	Analog: Moderate				All 4	Male C5
7633			Hybrid: E.C. -2dB	Hybrid: Moderate	Hybrid: +6dB			IBOC	REO
7634			Analog: E.C. -2dB	Analog: Moderate	Analog: +6dB			All 4	REO
7635			Hybrid: POB -2dB	Hybrid: Moderate	Hybrid: +6dB			IBOC	REO
7636			Analog: POB -2dB	Analog: Moderate	Analog: +6dB			All 4	REO
7637			Hybrid: E.C. -2dB	Hybrid: Moderate	Hybrid: +6dB			IBOC	Debussy
7638			Analog: E.C. -2dB	Analog: Moderate	Analog: +6dB			All 4	Debussy
7639			Hybrid: POB -2dB	Hybrid: Moderate	Hybrid: +6dB			IBOC	Debussy
7640			Analog: POB -2dB	Analog: Moderate	Analog: +6dB			All 4	Debussy
7641			Hybrid: E.C. -2dB	Hybrid: Moderate	Hybrid: +6dB			IBOC	WTOP
7642			Analog: E.C. -2dB	Analog: Moderate	Analog: +6dB			All 4	WTOP
7643			Hybrid: POB -2dB	Hybrid: Moderate	Hybrid: +6dB			IBOC	WTOP
7644			Analog: POB -2dB	Analog: Moderate	Analog: +6dB			All 4	WTOP
7645			Hybrid: E.C. -2dB	Hybrid: Moderate	Hybrid: +6dB			IBOC	MaleA1
7646			Analog: E.C. -2dB	Analog: Moderate	Analog: +6dB			All 4	MaleA1
7647			Hybrid: POB -2dB	Hybrid: Moderate	Hybrid: +6dB			IBOC	MaleA1
7648			Analog:	Analog:	Analog:			All 4	MaleA1

#	Lower 3rd Adjacent	Lower 2nd Adjacent	Lower 1st Adjacent	Desired	Upper 1st Adjacent	Upper 2nd Adjacent	Co-Channel	Receiver	Audio
			POB -2dB	Moderate	+6dB				
7649		Hybrid: E.C. -2dB		Hybrid: Moderate				IBOC	Grant
7650		Analog: E.C. -2dB		Analog: Moderate				Technics-Sony	Grant
7651		Hybrid: POB -2dB		Hybrid: Moderate				IBOC	Grant
7652		Analog: POB -2dB		Analog: Moderate				Technics-Sony	Grant
7653		Hybrid: E.C. -2dB		Hybrid: Moderate				IBOC	Bach
7654		Analog: E.C. -2dB		Analog: Moderate				Technics-Sony	Bach
7655		Hybrid: POB -2dB		Hybrid: Moderate				IBOC	Bach
7656		Analog: POB -2dB		Analog: Moderate				Technics-Sony	Bach
7657		Hybrid: E.C. -2dB		Hybrid: Moderate				IBOC	Ballet Woman
7658		Analog: E.C. -2dB		Analog: Moderate				Technics-Sony	Ballet Woman
7659		Hybrid: POB -2dB		Hybrid: Moderate				IBOC	Ballet Woman
7660		Analog: POB -2dB		Analog: Moderate				Technics-Sony	Ballet Woman
7661		Hybrid: E.C. -2dB		Hybrid: Moderate				IBOC	MaleB4
7662		Analog: E.C. -2dB		Analog: Moderate				Technics-Sony	MaleB4
7663		Hybrid: POB -2dB		Hybrid: Moderate				IBOC	MaleB4
7664		Analog: POB -2dB		Analog: Moderate				Technics-Sony	MaleB4
7665		Hybrid: E.C. -2dB		Hybrid: Moderate	Hybrid: +6dB			IBOC	Santana
7666		Analog: E.C. -2dB		Analog: Moderate	Analog: +6dB			Technics-Sony	Santana
7667		Hybrid: POB -2dB		Hybrid: Moderate	Hybrid: +6dB			IBOC	Santana
7668		Analog: POB -2dB		Analog: Moderate	Analog: +6dB			Technics-Sony	Santana
7669		Hybrid: E.C. -2dB		Hybrid: Moderate	Hybrid: +6dB			IBOC	Carmen
7670		Analog: E.C. -2dB		Analog: Moderate	Analog: +6dB			Technics-Sony	Carmen
7671		Hybrid: POB -2dB		Hybrid: Moderate	Hybrid: +6dB			IBOC	Carmen
7672		Analog: POB -2dB		Analog: Moderate	Analog: +6dB			Technics-Sony	Carmen
7673		Hybrid: E.C. -2dB		Hybrid: Moderate	Hybrid: +6dB			IBOC	Camera
7674		Analog: E.C. -2dB		Analog: Moderate	Analog: +6dB			Technics-Sony	Camera
7675		Hybrid: POB -2dB		Hybrid: Moderate	Hybrid: +6dB			IBOC	Camera
7676		Analog: POB -2dB		Analog: Moderate	Analog: +6dB			Technics-Sony	Camera
7677		Hybrid: E.C. -2dB		Hybrid: Moderate	Hybrid: +6dB			IBOC	FemaleB2
7678		Analog:		Analog:	Analog:			Technics-	FemaleB2

#	Lower 3rd Adjacent	Lower 2nd Adjacent	Lower 1st Adjacent	Desired	Upper 1st Adjacent	Upper 2nd Adjacent	Co-Channel	Receiver	Audio
		E.C. -2dB		Moderate	+6dB			Sony	
7679		Hybrid: POB -2dB		Hybrid: Moderate	Hybrid: +6dB			IBOC	FemaleB2
7680		Analog: POB -2dB		Analog: Moderate	Analog: +6dB			Technics-Sony	FemaleB2
7681		Hybrid: E.C. -2dB		Hybrid: Moderate		Hybrid: 0dB		IBOC	Stansfield
7682		Analog: E.C. -2dB		Analog: Moderate		Analog: 0dB		Technics-Sony	Stansfield
7683		Hybrid: POB -2dB		Hybrid: Moderate		Hybrid: 0dB		IBOC	Stansfield
7684		Analog: POB -2dB		Analog: Moderate		Analog: 0dB		Technics-Sony	Stansfield
7685		Hybrid: E.C. -2dB		Hybrid: Moderate		Hybrid: 0dB		IBOC	Ibert
7686		Analog: E.C. -2dB		Analog: Moderate		Analog: 0dB		Technics-Sony	Ibert
7687		Hybrid: POB -2dB		Hybrid: Moderate		Hybrid: 0dB		IBOC	Ibert
7688		Analog: POB -2dB		Analog: Moderate		Analog: 0dB		Technics-Sony	Ibert
7689		Hybrid: E.C. -2dB		Hybrid: Moderate		Hybrid: 0dB		IBOC	Richmond
7690		Analog: E.C. -2dB		Analog: Moderate		Analog: 0dB		Technics-Sony	Richmond
7691		Hybrid: POB -2dB		Hybrid: Moderate		Hybrid: 0dB		IBOC	Richmond
7692		Analog: POB -2dB		Analog: Moderate		Analog: 0dB		Technics-Sony	Richmond
7693		Hybrid: E.C. -2dB		Hybrid: Moderate		Hybrid: 0dB		IBOC	Female C10
7694		Analog: E.C. -2dB		Analog: Moderate		Analog: 0dB		Technics-Sony	Female C10
7695		Hybrid: POB -2dB		Hybrid: Moderate		Hybrid: 0dB		IBOC	Female C10
7696		Analog: POB -2dB		Analog: Moderate		Analog: 0dB		Technics-Sony	Female C10
7697	Hybrid: E.C. -2dB			Hybrid: Moderate				IBOC	Travis
7698	Analog: E.C. -2dB			Analog: Moderate				Technics-Sony	Travis
7699	Hybrid: POB -2dB			Hybrid: Moderate				IBOC	Travis
7700	Analog: POB -2dB			Analog: Moderate				Technics-Sony	Travis
7701	Hybrid: E.C. -2dB			Hybrid: Moderate				IBOC	Messiah
7702	Analog: E.C. -2dB			Analog: Moderate				Technics-Sony	Messiah
7703	Hybrid: POB -2dB			Hybrid: Moderate				IBOC	Messiah
7704	Analog: POB -2dB			Analog: Moderate				Technics-Sony	Messiah
7705	Hybrid: E.C. -2dB			Hybrid: Moderate				IBOC	Imagine
7706	Analog: E.C. -2dB			Analog: Moderate				Technics-Sony	Imagine
7707	Hybrid: POB -2dB			Hybrid: Moderate				IBOC	Imagine
7708	Analog:			Analog:				Technics-	Imagine

#	Lower 3rd Adjacent	Lower 2nd Adjacent	Lower 1st Adjacent	Desired	Upper 1st Adjacent	Upper 2nd Adjacent	Co-Channel	Receiver	Audio
	POB -2dB			Moderate				Sony	
7709	Hybrid: E.C. -2dB			Hybrid: Moderate				IBOC	Male C5
7710	Analog: E.C. -2dB			Analog: Moderate				Technics-Sony	Male C5
7711	Hybrid: POB -2dB			Hybrid: Moderate				IBOC	Male C5
7712	Analog: POB -2dB			Analog: Moderate				Technics-Sony	Male C5

Notes: E.C. = Enhanced-Core Transition Point; POB = Blend-to-Analog Point

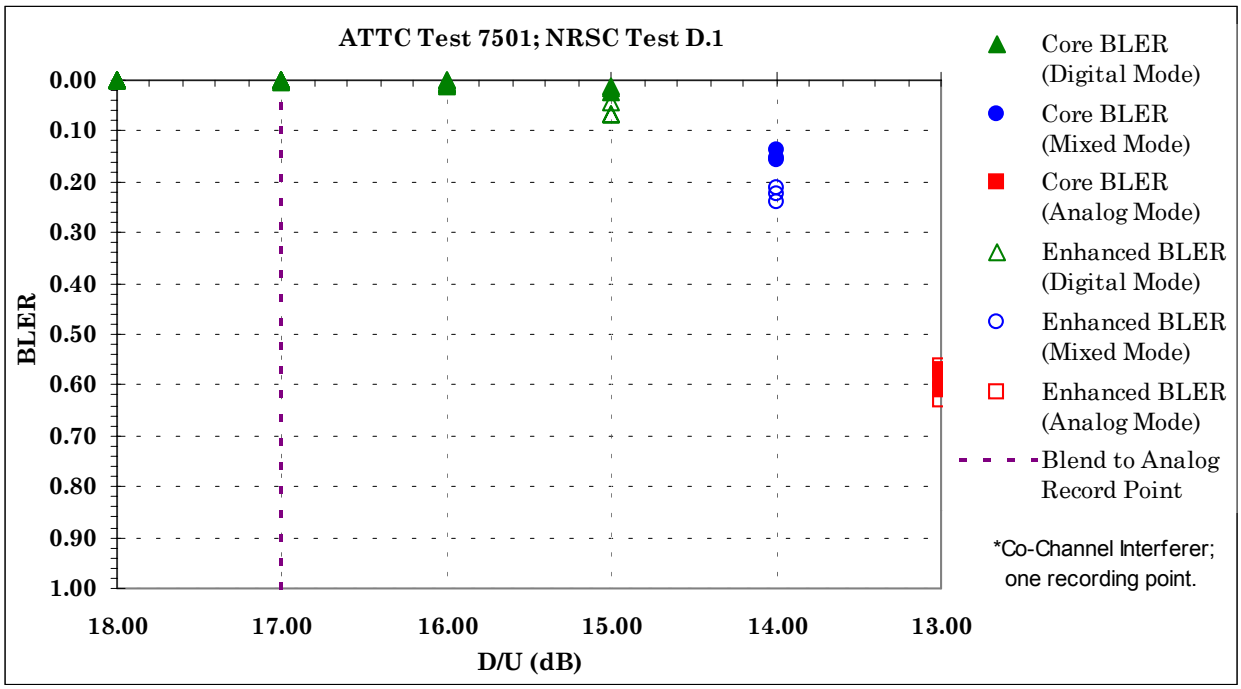

Figure 5-16 IBOC BLER & Mode vs. D/U in Co-Channel Interference Conditions

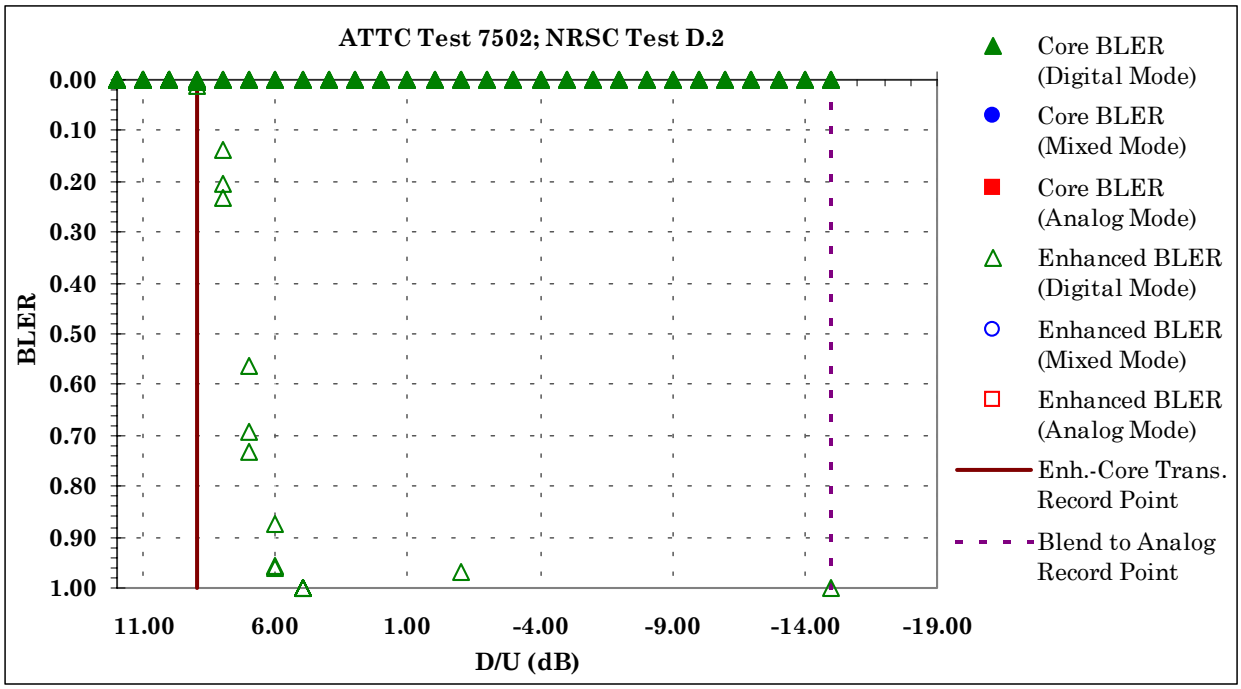

Figure 5-17 IBOC BLER & Mode vs. D/U in Single First Adjacent Interference Conditions

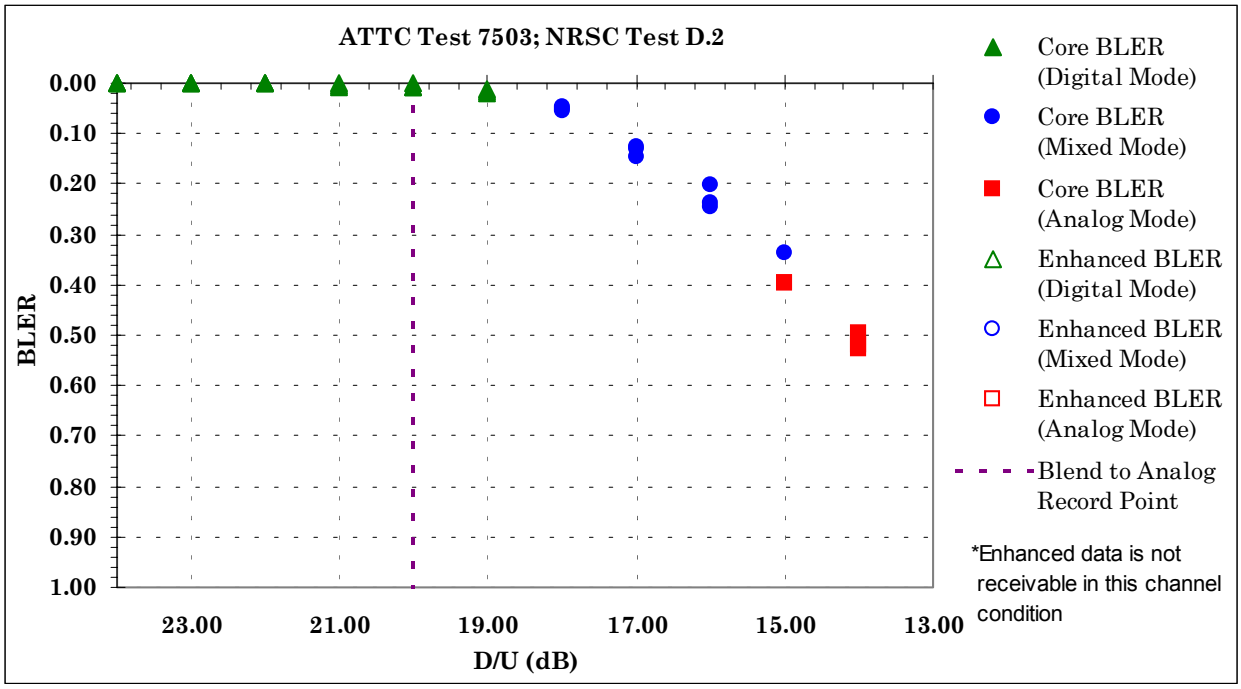

Figure 5-18 IBOC BLER & Mode vs. D/U in Dual First Adjacent Interference Conditions

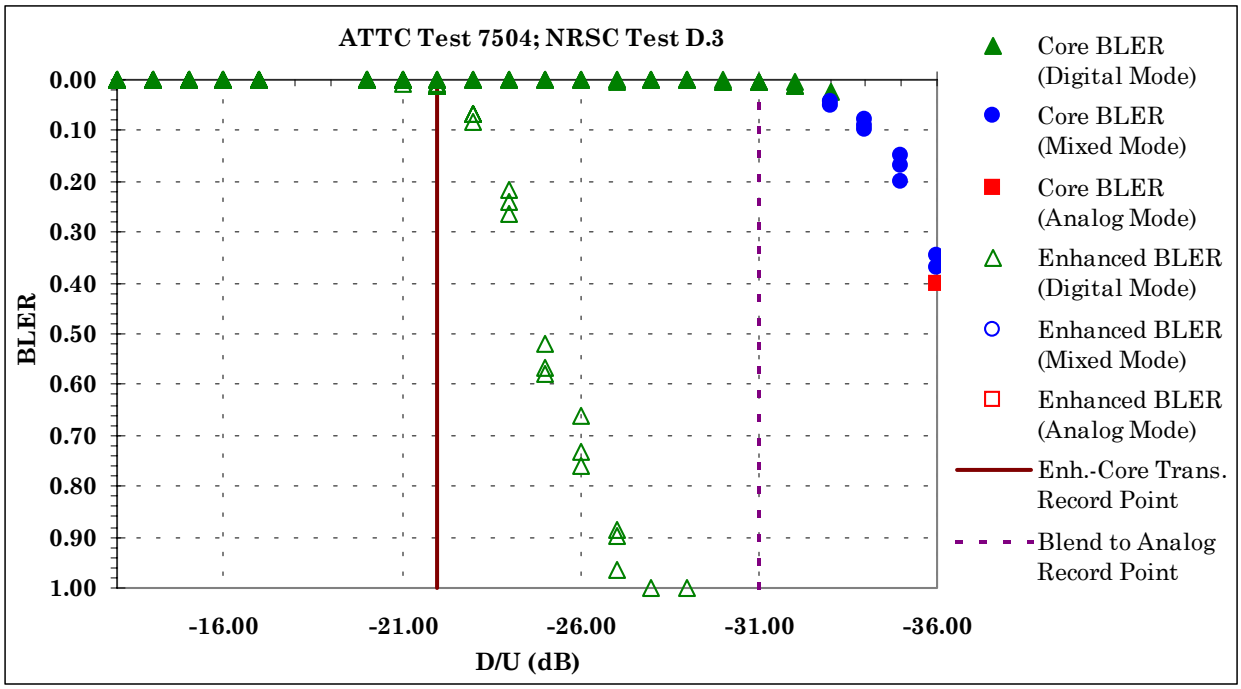

Figure 5-19 IBOC BLER & Mode vs. D/U in Single 2nd Adjacent Interference Conditions

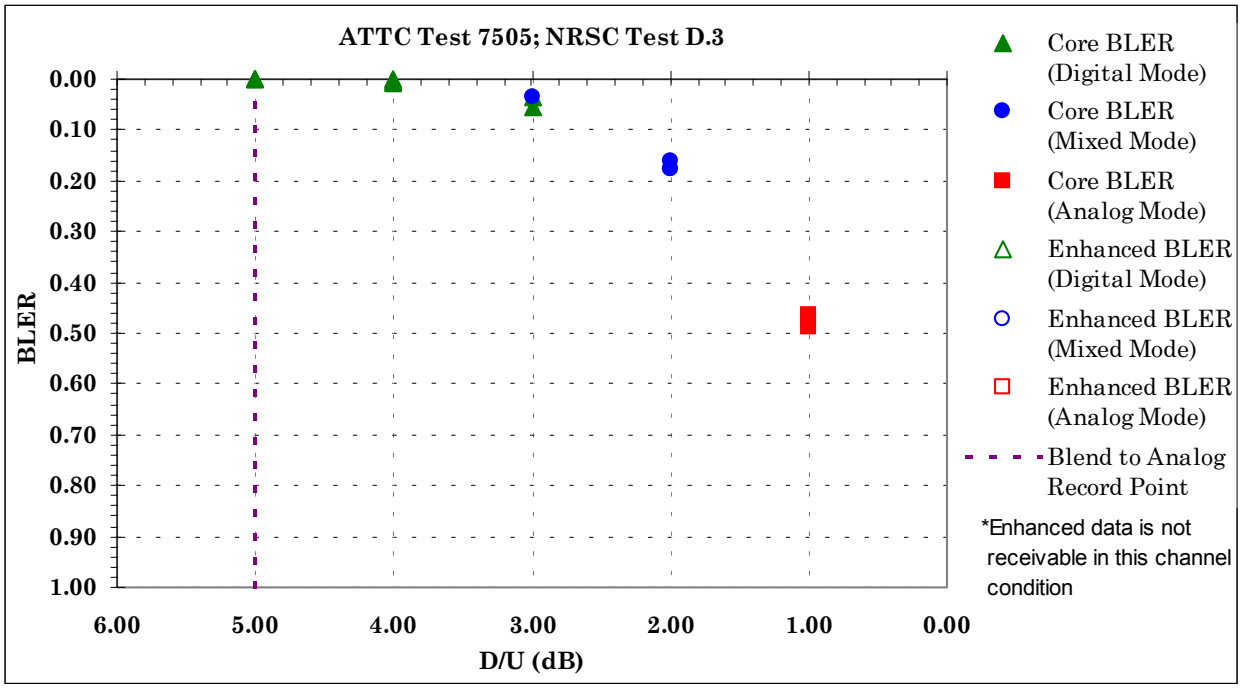

Figure 5-20 IBOC BLER & Mode vs. D/U in Simultaneous Lower Second and Upper First Adjacent Interference Conditions

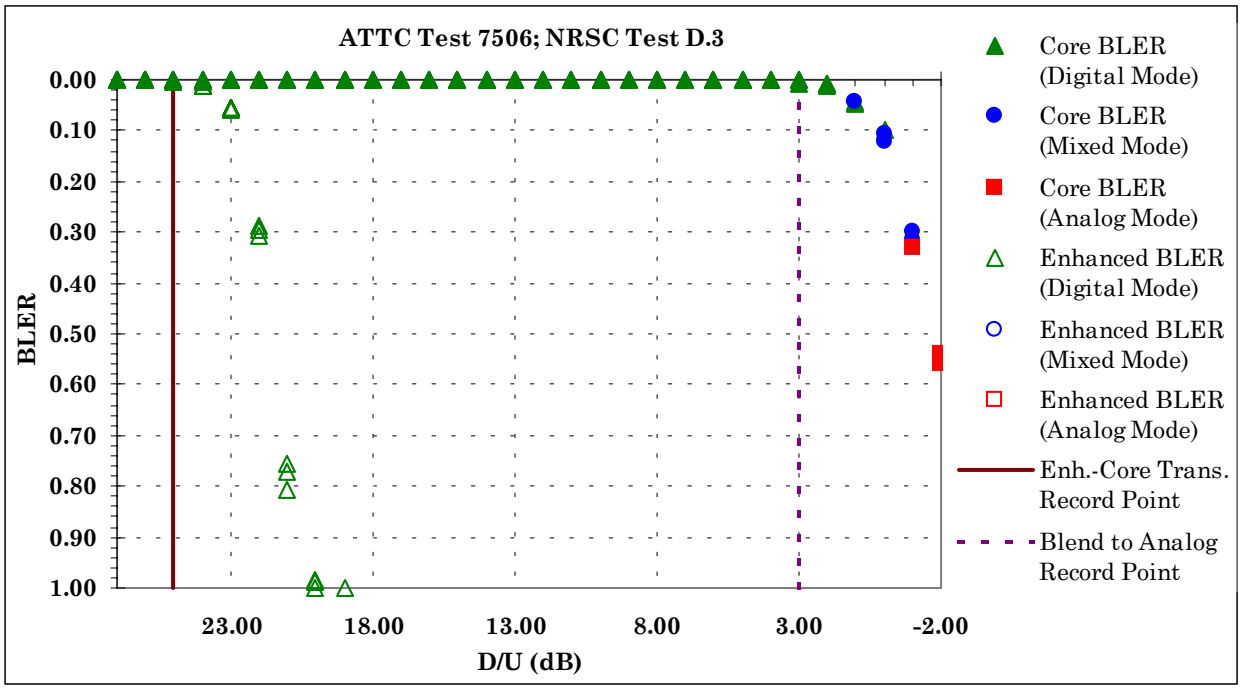

Figure 5-21 IBOC BLER & Mode vs. D/U in Dual Second Adjacent Interference Conditions

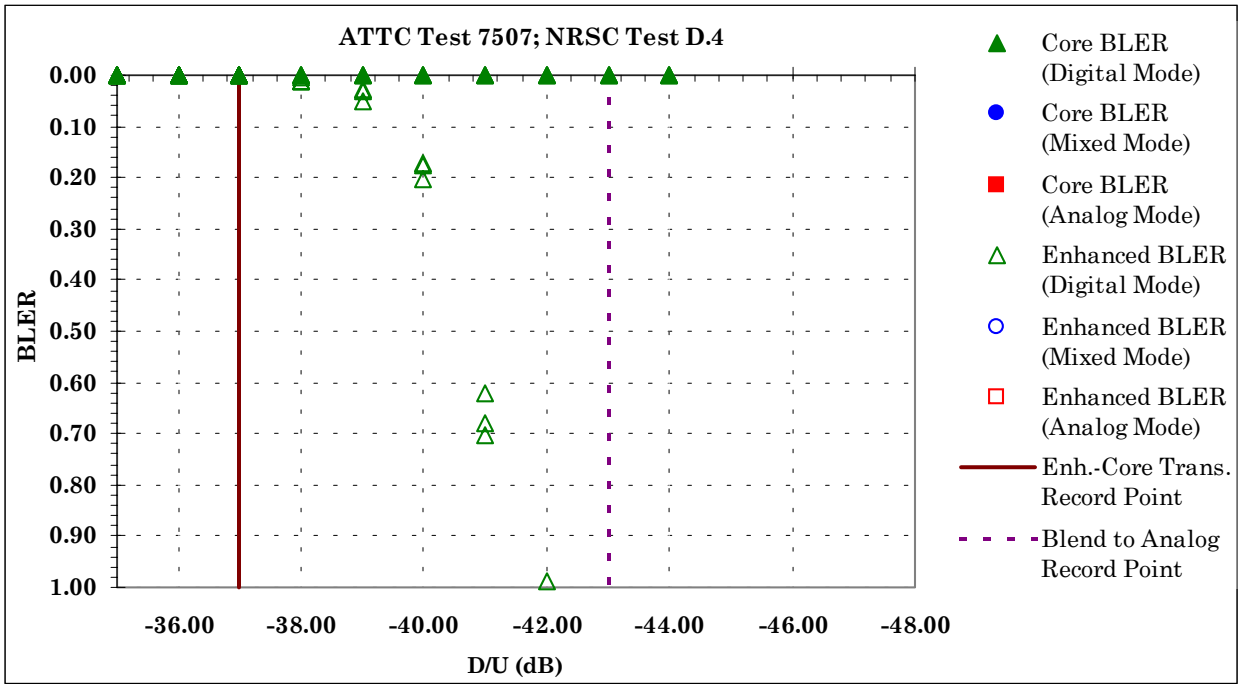

Figure 5-22 IBOC BLER & Mode vs. D/U in Lower Third Adjacent Interference Conditions

5.4. IBOC Acquisition Performance (NRSC F)

Table 5-7 summarizes the results of the objective signal acquisition tests. Each acquisition test was repeated five times, as indicated in the table.

Table 5-7 Objective Acquisition Performance

#	Desired	Interferer	Trial	Acquisition Time	Mode Acquired
7751	Hybrid: Strong	None	1	342ms	Analog
			2	236ms	Analog
			3	261ms	Analog
			4	255ms	Analog
			5	220ms	Analog
7752	Hybrid: Moderate	None	1	284ms	Analog
			2	274ms	Analog
			3	336ms	Analog
			4	232ms	Analog
			5	313ms	Analog
7753	Hybrid: Strong	Hybrid: +6dB, Lower 1st	1	375ms	Analog
			2	271ms	Analog
			3	318ms	Analog
			4	357ms	Analog
			5	317ms	Analog
7754	Hybrid: Moderate	Hybrid: +6dB, Lower 1st	1	336ms	Analog
			2	326ms	Analog
			3	316ms	Analog
			4	298ms	Analog
			5	284ms	Analog

6. Acknowledgements

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