Field Report
AM IBOC Nighttime Compatibility

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This report contains results from field tests designed to assess the analog compatibility of nighttime operation of iBiquity Digital Corporation's AM HD Radio™ system. Earlier this year, iBiquity completed an analytical study of AM HD Radio compatibility with existing analog AM broadcasting. The results of that study were presented in a previous report. This report contains the results of field tests conducted to corroborate the results of the analytical study and to provide real world evidence of the compatibility of the AM HD Radio system with analog AM broadcasts at night.[1]

1 Summary

These compatibility assessments were initiated in response to concerns raised by the National Radio Systems Committee and the Federal Communications Commission questioning whether the AM HD Radio system would cause severe disruptions to analog AM nighttime broadcasts. Contrary to the concerns expressed by broadcasters, listeners and regulators, this report, in combination with iBiquity's previous report on the analytical study, demonstrates that the AM HD Radio system will not have a significant impact on most AM stations' existing analog listeners. The conclusions from this report can be summarized as follows:

- This report confirms the conclusion from the analytical study that the introduction of nighttime AM HD Radio broadcasts should not increase interference to AM stations' analog groundwave signals, except at the edge of analog coverage.
- The field tests discussed herein indicate that the AM HD Radio system has a lower potential to impact analog skywave broadcasts than had been assumed.
- An undesired HD Radio groundwave signal has the potential to impact a desired first adjacent skywave signal in a narrow ring around each undesired IBOC station. Inside of this region, most receivers would not be able to receive a desired skywave signal due to interference from the undesired analog groundwave signal. Outside of this region, groundwave IBOC has less impact on the desired skywave signal than existing analog groundwave and skywave interference.
- Undesired skywave IBOC signals have a greater potential to impact desired analog skywave signals. In this case, the introduction of IBOC will not interfere with skywave in a particular geographic area. Instead, the undesired skywave IBOC signal will decrease the amount of time that a listener will be able to receive the already unreliable analog skywave signal. Because this type of IBOC interference occurs in areas with severe levels of analog interference, the number of listeners to skywave broadcasts in these areas is extremely limited.

Based on these conclusions from the field tests, iBiquity has determined the introduction of IBOC, even if it does increase skywave interference, will have an impact on very few listeners.

[1] A separate report on AM IBOC nighttime digital coverage is being presented concurrently with this submission.

2 Overview of Field Tests

iBiquity's internal analysis indicated the introduction of nighttime AM HD Radio would present different interference risks depending on the characteristics of the existing analog stations. For example, channels characterized by many local stations tend to suffer from high levels of co-channel analog interference and already have relatively small service areas. This would mask any negative effects from the introduction of HD Radio. In contrast, clear channel stations generally are relatively free from co-channel interference and have more extensive service areas. Thus, clear channel stations have a greater risk of interference from HD Radio. In order to concentrate on the area with the greatest risk of interference, this nighttime field test program focused on two first adjacent stations: WOR, New York, 710 kHz, and WLW, Cincinnati, 700 kHz. Each of these stations transmits 50 kW at night and is at the low end of the band and thus has excellent primary ground coverage. Each station also has secondary skywave coverage.

The field tests described in this report were conducted in two separate phases. Phase 1 was conducted during August 2002. Phase 2 was conducted during December 2002. The testing was divided into two phases to account for the different nighttime propagation conditions that exist in the AM band between summer and winter. As is described in greater detail in Section 3 below, the tests were designed to consider the HD Radio system's impact on both analog groundwave and analog skywave broadcasts.

As Figure 1 demonstrates, existing allocations in the AM band result in a pattern with adjacent channels interlaced and overlapping. 20 kHz analog bandwidth signals are assigned every 10 kHz. The introduction of AM HD Radio signals will place digital energy in the sidebands of the first adjacent analog signal. This increases the risk of interface to AM analog broadcasts and was the focus of this field testing.

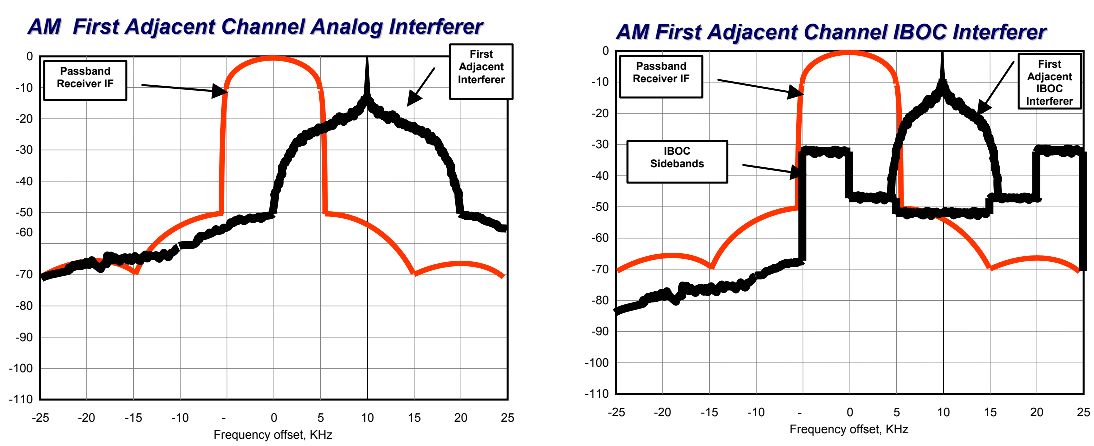

Figure 1: AM Signals with Analog and Digital Interferers

3 Test Methodology

3.1 Field Testing

The nighttime field tests were designed to evaluate the potential impact of the AM HD Radio system for three types of listening conditions:

1. *Effects of Undesired Digital Skywave Interference to Desired Groundwave Analog Reception (S2G)*:
   This type of interference occurs when the receiver is located close to the desired station, within its groundwave signal area, and the interferers are the skywave component of a distant undesired station.
2. *Effects Of Undesired Digital Groundwave Interference On Desired Skywave Analog Reception (G2S)*:
   This type of interference occurs when the receiver is located distant from the desired station, within its skywave signal area, and the interferers are the groundwave component of a local undesired station.
3. *Effects Of Undesired Digital Skywave Interference On Desired Skywave Analog Reception (S2S)*:
   This type of interference occurs when the receiver is located distant from the desired station, within its skywave signal area, and the interferers are also distant skywave stations.

Audio recordings of analog broadcasts with and without HD Radio interferers were made at specified locations intended to capture the effects of S2S, S2G and G2S interference. Propagation modeling software was used to locate geographic locations where these effects could be observed over a sufficient range of D/Us to create recordings where IBOC interference was expected to be inaudible (+10 D/U) to clearly audible (-10 D/U) for the three specified interference scenarios. To test the effects of the automotive omni directional whip antenna versus the common directional ferrite loop antenna employed in home Hi-Fi, portable and boombox receivers, additional off-axis testing locations were chosen where recordings could be made to show the benefits of the directional characteristic of the AM loop antennas. The benefits of a directional loop type AM antenna apply to all locations except those in a direct line between the desired and undesired stations. These recordings were subjectively evaluated to determine the effects of both analog and IBOC interference.

Table 1 below details the receivers considered for this test:[2]

Class of Receiver	Manufacturer	Model No.
Auto OEM	Delphi Corporation	09394139
Auto Aftermarket	Pioneer	KEH-1900
Home Hi-Fi	Technics	SA-EX110
Moderately Priced Boombox	Sony Corporation	CFS-522
High End Portable	G.E.	SUPERADIO7-2887A

[2] The first four receivers are the same units used previously in NRSC sponsored testing.

The two automotive receivers represent a widely used Original Equipment Manufacturers (OEM) receiver and a top selling aftermarket receiver. Both of these receivers employ highly selective IF filters, thus minimizing adjacent channel analog interference and sensitivity to the HD Radio system's digital carriers. The Boombox, Home Hi-Fi, and G.E. SUPERADIO receivers are a class of receivers with less selective IF filtration and directional loop antennas. Together, these five receivers typify the general population of receivers in use.

Ultimately, in the subjective testing program the number of receivers evaluated was reduced to three. The Home Hi-Fi receiver and the aftermarket auto receivers were not used as the performance and design characteristics of these receivers were met with the OEM auto radio, the boombox and the high end portable.

Figure 2 shows all the test locations (Undesired → Desired). Field tests were conducted during summer (August) and winter (December) 2002 to determine whether seasonal variances in skywave effects on the AM band would influence the results. In particular, it was felt that less favorable nighttime skywave propagation conditions in the summer months might mask some level of IBOC impact on analog skywave listening. As is detailed below, the field tests indicated that the determining factor for IBOC interference is the level of analog interference for the desired and undesired stations. The change in season does not change the interference levels where IBOC has a potential to impact analog skywave, but it might change the frequency of finding and location of areas with the greatest potential for an impact.[3]

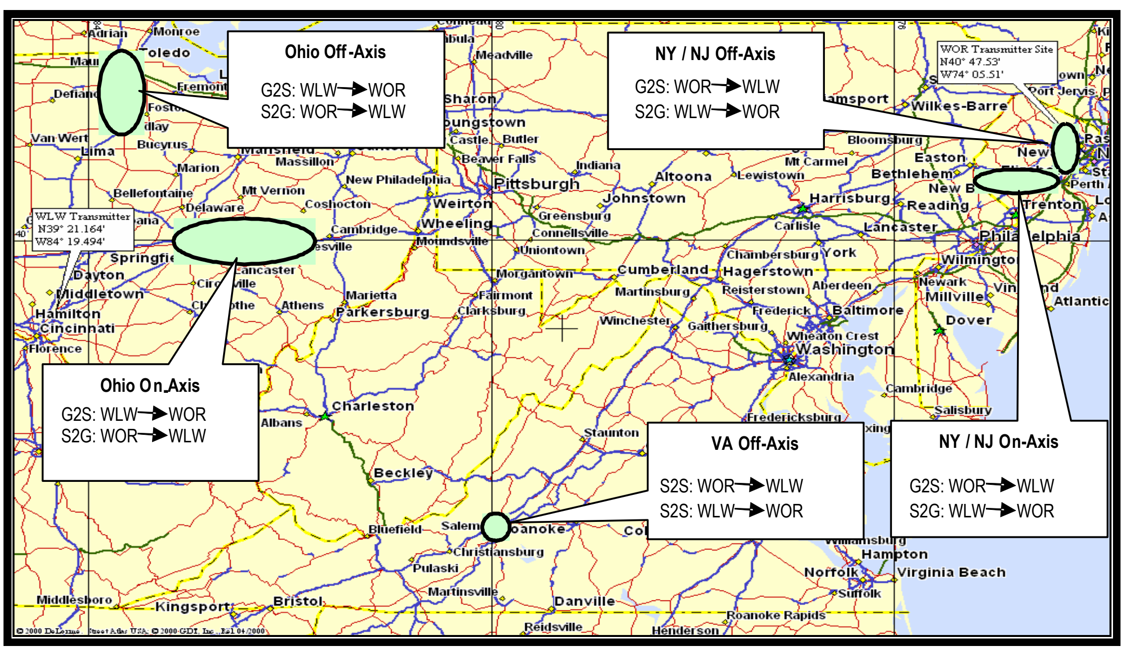

Figure 2 Nighttime Test Location Map

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[3] Details on the compatibility field test procedures are in Appendix A.

3.1.1 Skywave to Groundwave Tests

Field test locations for S2G interference were selected to investigate areas where both analog and IBOC interference were expected to impact listening. These areas were located on the fringe of the primary groundwave coverage area for both WOR and WLW. This region looks like a “ring” around each station’s primary groundwave coverage area in which the desired groundwave to undesired skywave interference (D/U) ratio is between -10 dB and +10 dB.

3.1.2 Groundwave to Skywave Tests

In the case of G2S interference the field tests were located close to the undesired station in order to be within the groundwave service area. The test receivers were tuned to the distant skywave desired signal.

3.1.3 Skywave to Skywave Tests

S2S testing was conducted in southwestern Virginia where it was predicted that both WOR and WLW would have good skywave coverage. The location was selected to minimize any effects from 720 kHz WGN, Chicago and 690 kHz CBF, Montreal. It had the added benefit of being located off the axis between the stations, thus providing in one location off axis directional results for the portable and boom box and non-directional results of the automotive receivers.

Figure 3 shows the location of the S2S measurement point in Virginia overlaid on a map that predicts the D/U ratio between WLW (Desired) and WOR (Undesired). The red color near WLW shows where the D/U ratio for WLW is greater than 20 dB. The S2S measurement point, located in an area shown in a lighter shade of blue, is predicted to have a positive D/U for WLW of 2 dB.

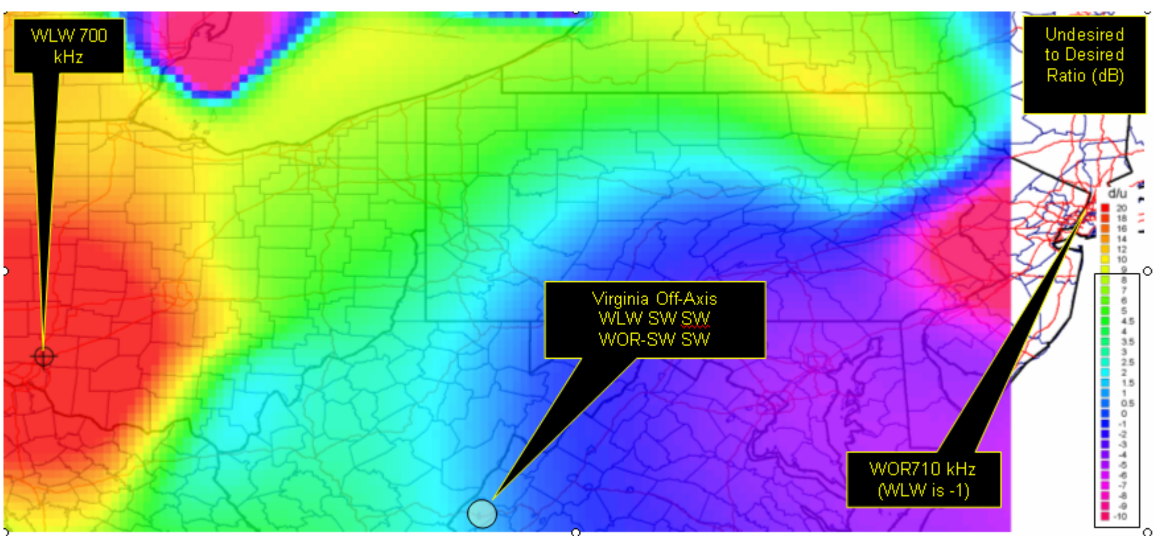


Figure 3: S2S Measurement location overlaid on a map depicting the D/U ratio between WLW (D) and WOR (U)

3.2 Subjective Listening Tests

On axis and off axis field recordings of S2G, G2S, and S2S interference were subjectively evaluated with IBOC off and IBOC on. The evaluations were conducted using automotive grade speakers in a sound treated listening facility. Because the nature of these nighttime AM tests was fundamentally different than previous subjective evaluations iBiquity has conducted, the subjective evaluation methodology was significantly modified. The subjective evaluation of these nighttime AM audio samples presented two challenges. First, due to the low audio quality of analog AM, the standard ACR MOS methodology would have resulted in all scores being compressed in a narrow range. Second, the standard ACR MOS methodology looks for changes in audio quality but does not provide any information on the motivation of the listener. The modifications to the methodology that were undertaken were designed to address both these concerns.

With regard to the issue of listener motivation, it is important to consider that in the case of FM analog and, to some extent, daytime AM, listeners are motivated by a desire to hear certain content but also by a desire for appropriate levels of audio quality. This is significantly different than AM analog nighttime service, which is characterized by fairly marginal audio quality. Nighttime analog AM listeners are motivated by a desire to hear certain content rather than by an expectation of quality. Under these circumstances, it can be expected that listeners will accept reduced audio quality until a point at which listeners will turn off the radio. Based on these observations, the subjective evaluation program was structured to identify that threshold when reduced audio quality would cause listeners to tune out rather than to identify subtle changes in audio quality.

In order to focus on thresholds for tuning out the programming rather than changes in audio quality, the ACR-MOS scale was modified. The ACR-MOS rating scale used in previous iBiquity tests asks participants to focus solely on one dimension, sound quality, while making their decision. The categories (Excellent, Good, Fair, Poor and Bad) were designed to be evenly spaced. The rating scales used for this AM nighttime study, however, asked participants to consider two dimensions simultaneously: (a) the extent to which impairments are heard (5 = No impairments heard; 4 = Impairments heard, but not bothersome; 3 = Significant impairments heard; 2 = Significant, disruptive impairments; 1 = complete failure) and (b) whether they would continue to listen to the sound sample depending on their perceived motivation. In this test the categories were not chosen to be evenly spaced. They are, instead, distinct decision points. Participants needed to choose between them considering their “state of mind” as well as the level of impairment heard in the sample.[4]

To better interpret the subjective results, an analysis of the data was undertaken to determine the critical point at which a majority of listeners would no longer choose to listen, even when motivated to do so. Because listeners of nighttime AM radio have a high tolerance for interference, understanding the level of interference that will cause the listener to turn off the radio or change the channel is extremely relevant to the analysis of the impact of IBOC service. The analysis of the subjective results indicated that at the 2.6 level, approximately 50% of listeners would keep the radio on. Below that 2.6 point, a majority of listeners claim they would turn off the program. Based on this

[4] Details on the subjective methodology are contained in a report titled “Subjective Methodology and Results of AM Nighttime Transmission Testing” submitted by Ellyn Sheffield, PhD (Subjective Report) and attached hereto as Appendix B.

finding, the results presented herein include a reference to this 2.6 threshold or "tune out" point.

4 Test Results

On balance, the subjective evaluations produced results that were more favorable than had been anticipated. Prior to the tests, there had been concern among some broadcasters and listeners that the introduction of nighttime AM IBOC would create widespread interference to analog AM. As is described in greater detail throughout this section, the subjective evaluation program demonstrated that the introduction of nighttime AM IBOC will have little or no impact on analog listening in the majority of cases.

The test results demonstrate that the existing analog D/U ratio is the best indicator of the areas where IBOC may impact analog listening and that IBOC has the greatest potential to impact analog listening in areas of moderate analog interference. Generally, areas with weak analog interference, +10 dB D/U or less interference (+10 dB or higher), receive acceptable analog reception today. The introduction of IBOC does not have a significant impact in these areas. In areas of strong analog interference (-10 dB D/U or lower) analog reception is already compromised, and subjective evaluations indicated most listeners would no longer listen to a station under those conditions. As a result, the introduction of IBOC cannot be expected to have any meaningful impact in these areas. iBiquity has focused its analysis on the mid range to identify areas where analog listening may be acceptable and where the introduction of IBOC has a potential to impact those broadcasts. Overall, the evaluations indicate the introduction of IBOC in the areas with moderate analog interference will have a minor, but likely acceptable, impact on analog listeners. Even in those situations where the introduction of IBOC reduces listener perception of the analog audio, the subjective evaluations indicate most listeners will continue to listen to the existing analog broadcast.

When analyzing the results, it is important to consider the type of receiver used. The tests demonstrated that the introduction of nighttime AM IBOC will have a different impact on different analog receivers. In certain scenarios, narrowband analog receivers designed to filter out significant levels of analog interference will also provide greater resistance to IBOC interference. At the same time, receivers with directional antennas have the ability to overcome a significant amount of IBOC interference for off axis listening, even if the receiver has a wideband filter.

A complete report on the results of the subjective evaluation is presented in Appendix B. The following sections discuss the results of the subjective evaluation for all three test scenarios (G2S, S2G and S2S). After identifying the analog D/U ratios that are most likely to be susceptible to IBOC interference, these sections also discuss where these interference levels are expected to be found. By identifying the frequency and location of these potentially problematic interference levels, this report helps quantify the impact on actual listeners. At the same time, this analysis helps correlate the subjective results with iBiquity's previous analytical study. The subjective results were used to identify the interference levels most likely to result in IBOC interference to analog broadcasts. When these interference levels from the subjective evaluations were plotted on the maps used for the analytical study, they correlated with the areas of potential interference identified in that study.

4.1 Sky-to-Ground

Figure 4 summarizes the results for the sky-to-ground tests.[5] As would be expected, in the case of weak interference, the introduction of IBOC does not impact the analog signal. In the mid range, the introduction of IBOC reduces the subjective evaluation score, but it remains above the tune out threshold. In areas of strong interference, however, there was a degradation in audio quality that went from an acceptable level to below the threshold for tune out. As is explained in greater detail below, however, these strong interference levels would be found at or beyond the desired station's NIF.[6] As a result, the impact from the introduction of IBOC would be felt only in fringe areas outside the station's primary service area.

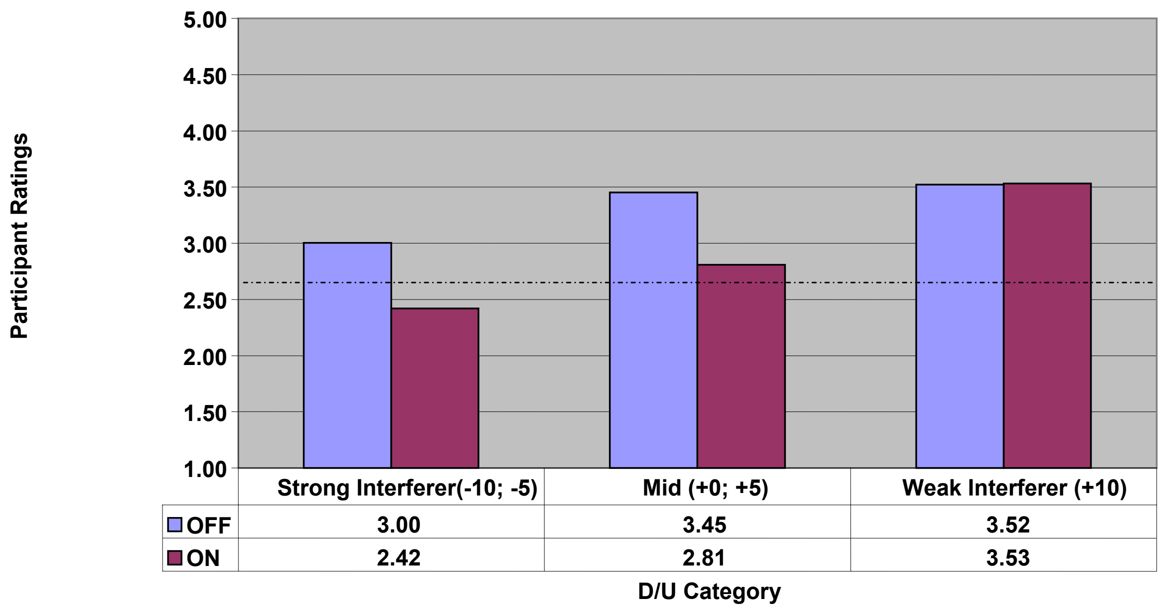


Figure 4: Sky-to-Ground

When testing the impact of WOR's digital skywave signal on WLW's groundwave analog service, it was necessary to go outside the WLW NIF to obtain the required D/U ratios. This field work confirmed potentially problematic interference levels will not be found inside a station's primary service area. The strong, desired groundwave signal is not impacted by undesired skywave interference except in fringe coverage areas. Figure 5 shows WLW's signal strength plot with the theoretical NIF overlaid at 2.7 mV/m

[5] Figures 4, 9 and 11 graphically depict the effect of IBOC on existing analog signals. The audio samples were placed into 3 groups, depending on their signal strength: (a) "strong interferer", including D/U ratios of -10 and -5 dB; (b) "mid", including D/U ratios of +0 and +5 dB, and (c) "weak interferer", or a D/U ratio of +10 dB. The dotted line added to the figures is the 2.6 demarcation point: above the line, the majority of listeners would keep the program on. Below the line, the majority would turn it off.
[6] Although Class A stations do not have a defined NIF, iBiquity has calculated NIF for these Class A stations using the same methodology used for Class B and Class C stations.

(25% exclusion rule) and the locations of the field test recordings. Even at these locations, a positive D/U ratio was recorded for a vast majority of the time. It can be expected that recordings made with those positive D/U ratios would have been above the ACR cutoff point.

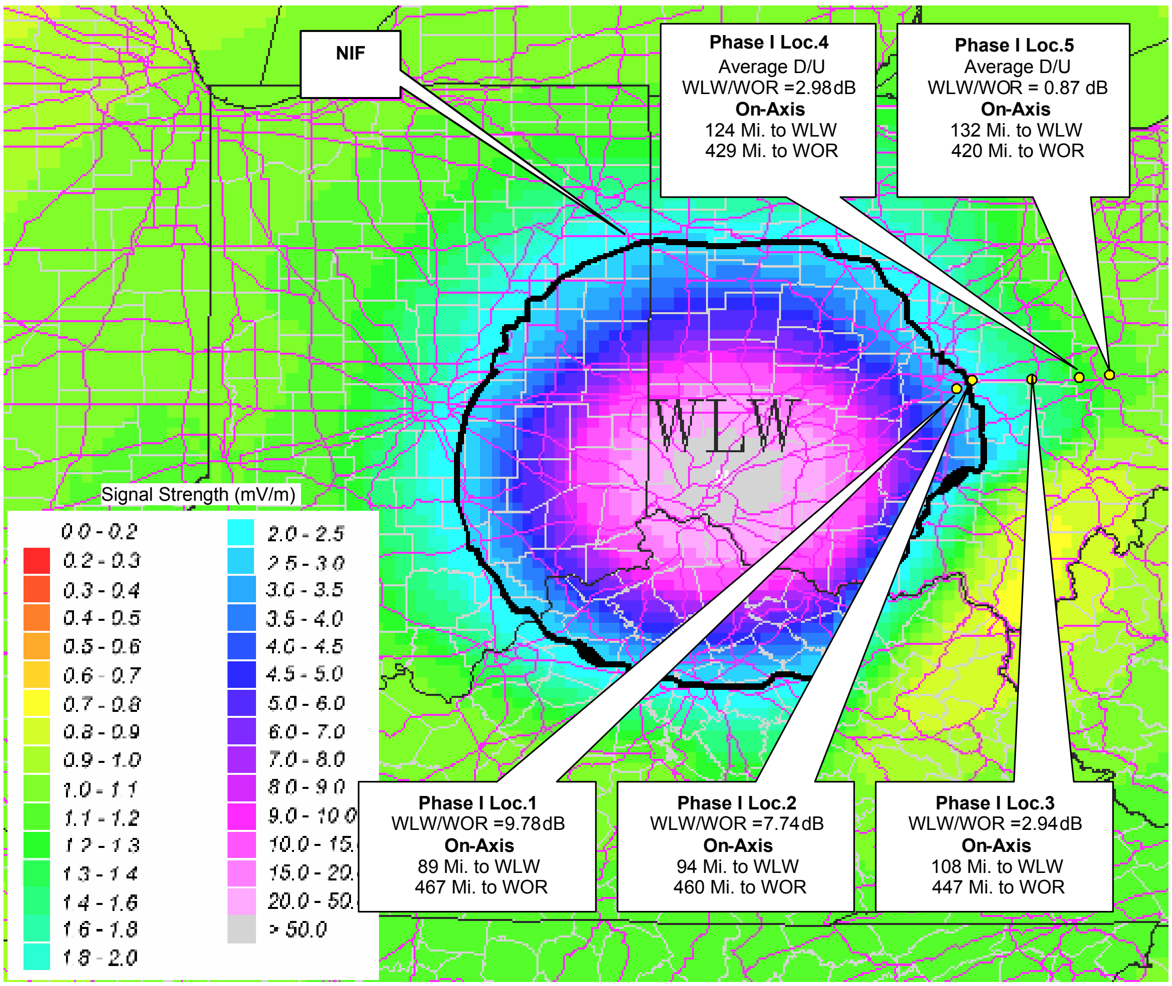


Figure 5: WLW Nighttime Signal Strength Map with NIF of 2.7 mV/m and Field Test Recording Locations overlaid

These conclusions from the field are consistent with the results of the analytical study previously present. Figure 6 shows the predicted differential analog MOS rating for WLW from the previous study. The field test locations are added to this map. As can be seen the required interference levels were found in the yellow color area where impact is predicted to be the greatest (changes in MOS score of 0.4 to 0.48 points).

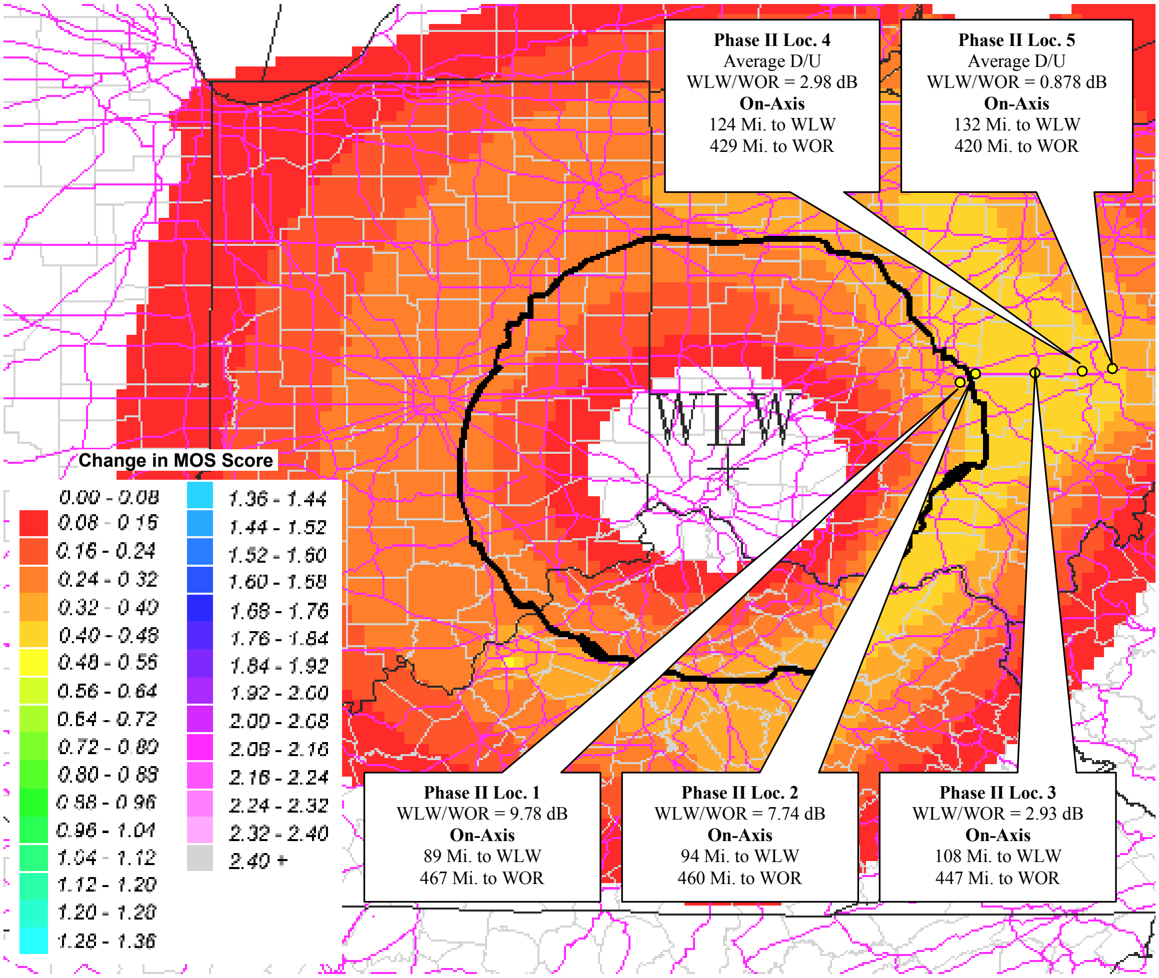


Figure 6: Predicated Change in WLW Nighttime (based on Delphi Receiver) MOS due to IBOC with NIF and Field test Recording Locations overlaid

The results of tests conducted in New York and New Jersey to assess the impact of WLW's digital skywave on WOR's analog groundwave signal further confirm these conclusions. The WOR test points are shown in Figure 7 plotted against the WOR signal strength and theoretical NIF. The test points for WOR also are near or outside the NIF, except for Phase I location 5 which had a D/U on average above +20 dB. At that level, it would be expected that IBOC would have no impact. The rest of the field test points had positive or slightly positive D/Us, except for a few instances where the WLW skywave peaked and WOR groundwave experienced interference from its own skywave, such as at location 2, the furthest point out. Since the D/U remained positive and thus above the affected D/U region inside the NIF, WOR's primary groundwave coverage area would not have been impacted.

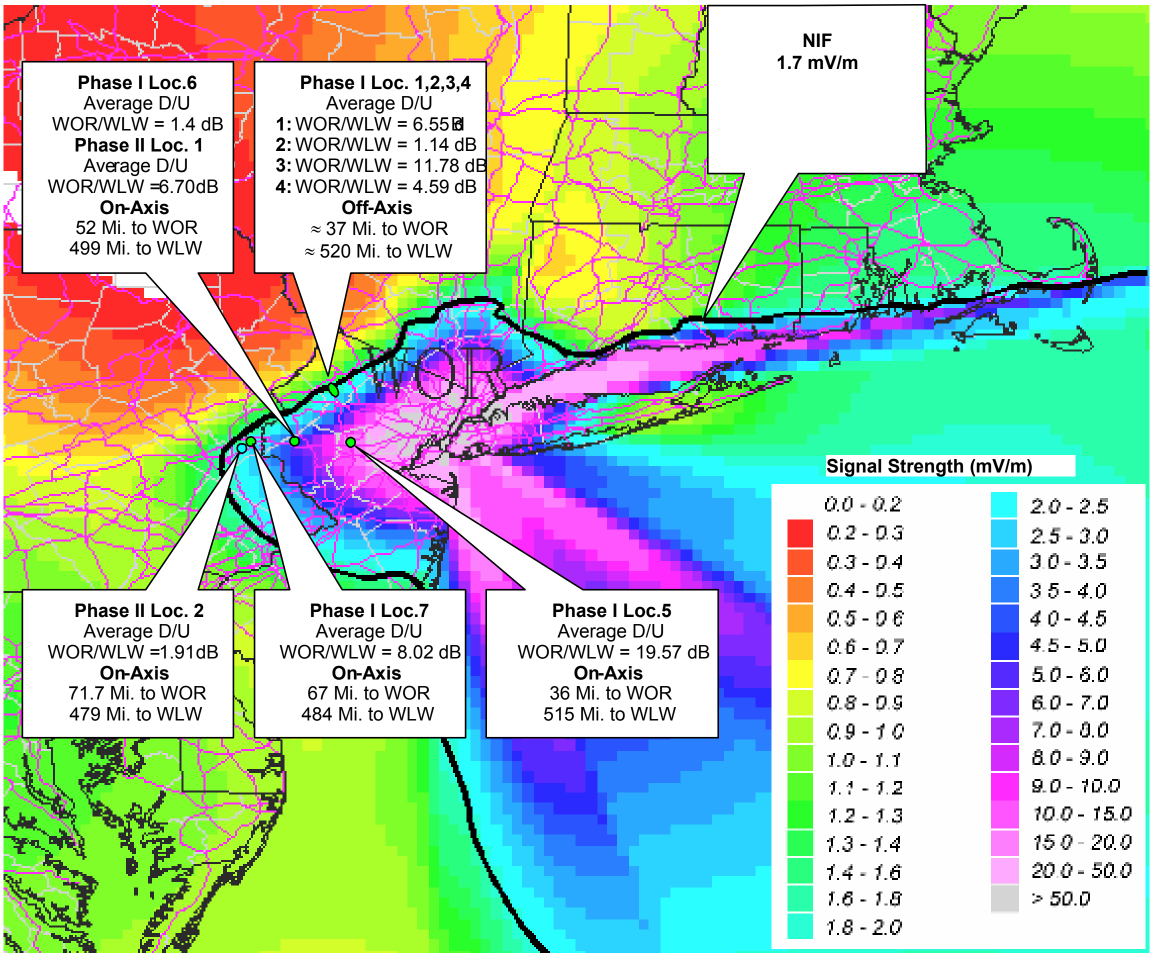


Figure 7: WOR's Nighttime Signal Strength mV/m Map with NIF of 1.7 mV/m and Field Test Recording Locations overlaid

As was the case for WLW, the WOR field tests were conducted near the region where the audio quality scores were predicted to be the most impacted. Figure 8 shows the predicted impact of IBOC from iBiquity's previous analytical study. The areas of greatest impact are indicated in yellow and green. Nearly the entire region predicted to be impacted by a change in MOS of 0.55-0.64 (green color) is outside WOR's NIF.

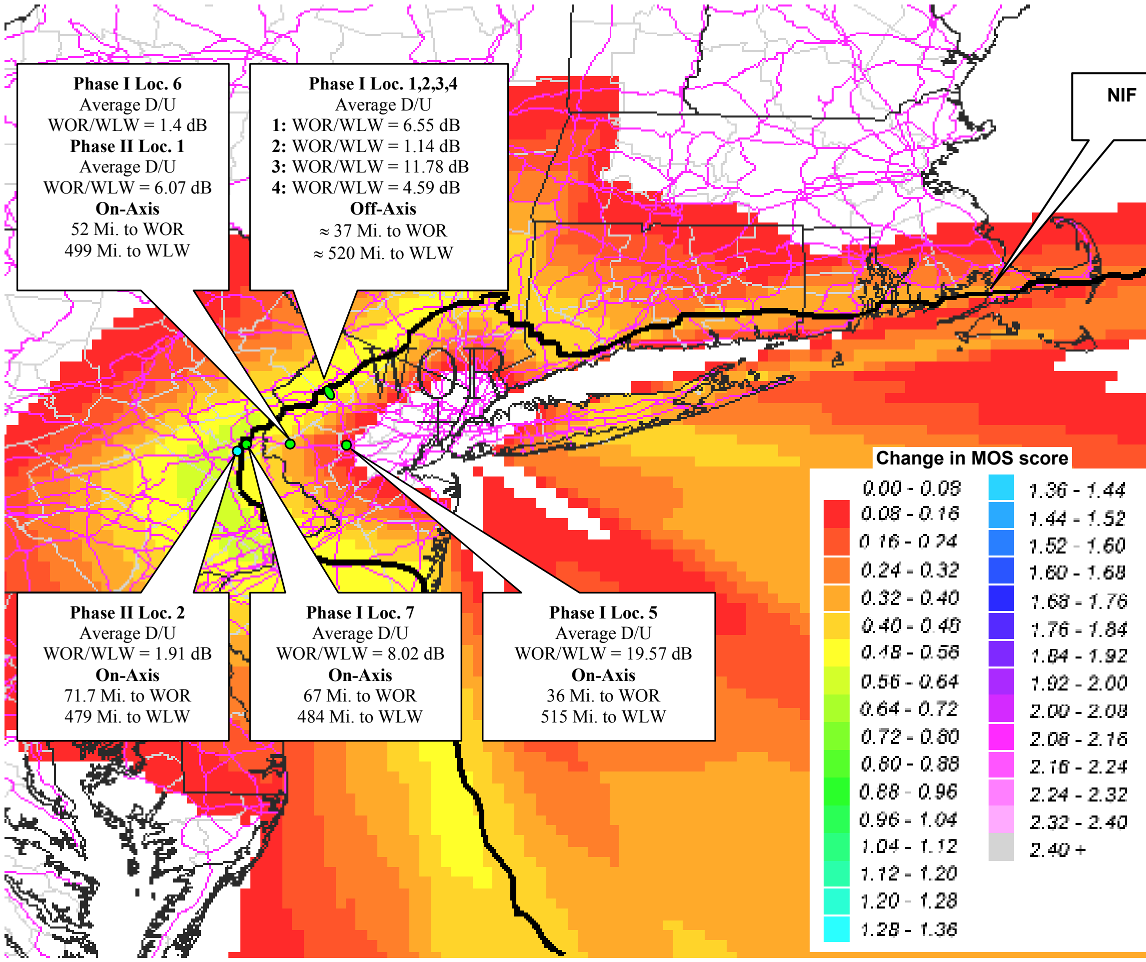


Figure 8: Predicted Change in WOR Nighttime (based on Delphi Receiver) MOS due to IBOC with NIF and Field test Recording Locations overlaid

4.2 Groundwave Interference to Skywave

Because weak skywave signals are unstable and unpredictable, it is difficult to assess the impact of AM IBOC groundwave on skywave reception. Figure 9 presents the subjective evaluation results for ground-to-sky interference. The results indicate the introduction of groundwave IBOC signals will not have a meaningful impact on analog skywave service. The subjective evaluation confirmed that the introduction of IBOC will have the largest impact in the mid range. Even at this level, however, the introduction of IBOC will not cause listeners to tune out. With strong analog interference, the skywave signal is so degraded that it is at the tune out threshold. At this point, the additional degradation resulting from the introduction of IBOC is not meaningful. iBiquity believes the results for weak interferer represent an anomaly in the data. It would have been expected that the weaker interference would have resulted in higher scores for both IBOC OFF and IBOC ON conditions but this was not the case. iBiquity assumes that either the programmatic content or the unusual quality of these particular audio samples resulted in an unusually low score.

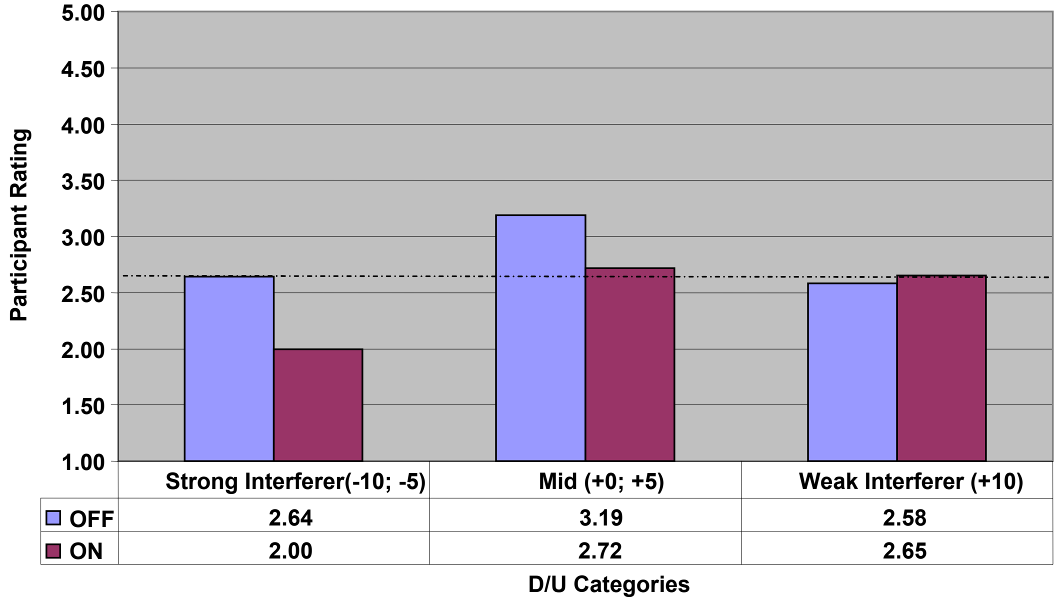


Figure 9: Ground-to-Sky

The field tests indicated any potentially problematic interference levels are found far from the desired skywave station transmitter and inside the service area of the undesired station. The measurement points for the desired WLW skywave signal were located inside WOR's NIF. Outside the WOR NIF there was insufficient impact from the undesired WOR signal. Similarly, it was necessary to approach the Cincinatti service area before undesired WLW groundwave impacted a desired WOR skywave signal. iBiquity's analysis indicates, and as is illustrated in Figure 10, G2S interference creates a ring around the undesired station where the D/U ratios become increasingly negative. This increases crosstalk to the weaker, desired skywave signal. Inside the ring, analog groundwave masks the desired skywave signal. Outside the ring, the desired skywave signal remains listenable, even after the introduction of IBOC on the undesired first adjacent channel. The width and location of this ring of impact depends on each receiver's ability to filter the overlapping first adjacent analog signal.[7]

[7] See Section 3.4 below for a more detailed discussion of the impact of receivers and antennas on skywave reception.

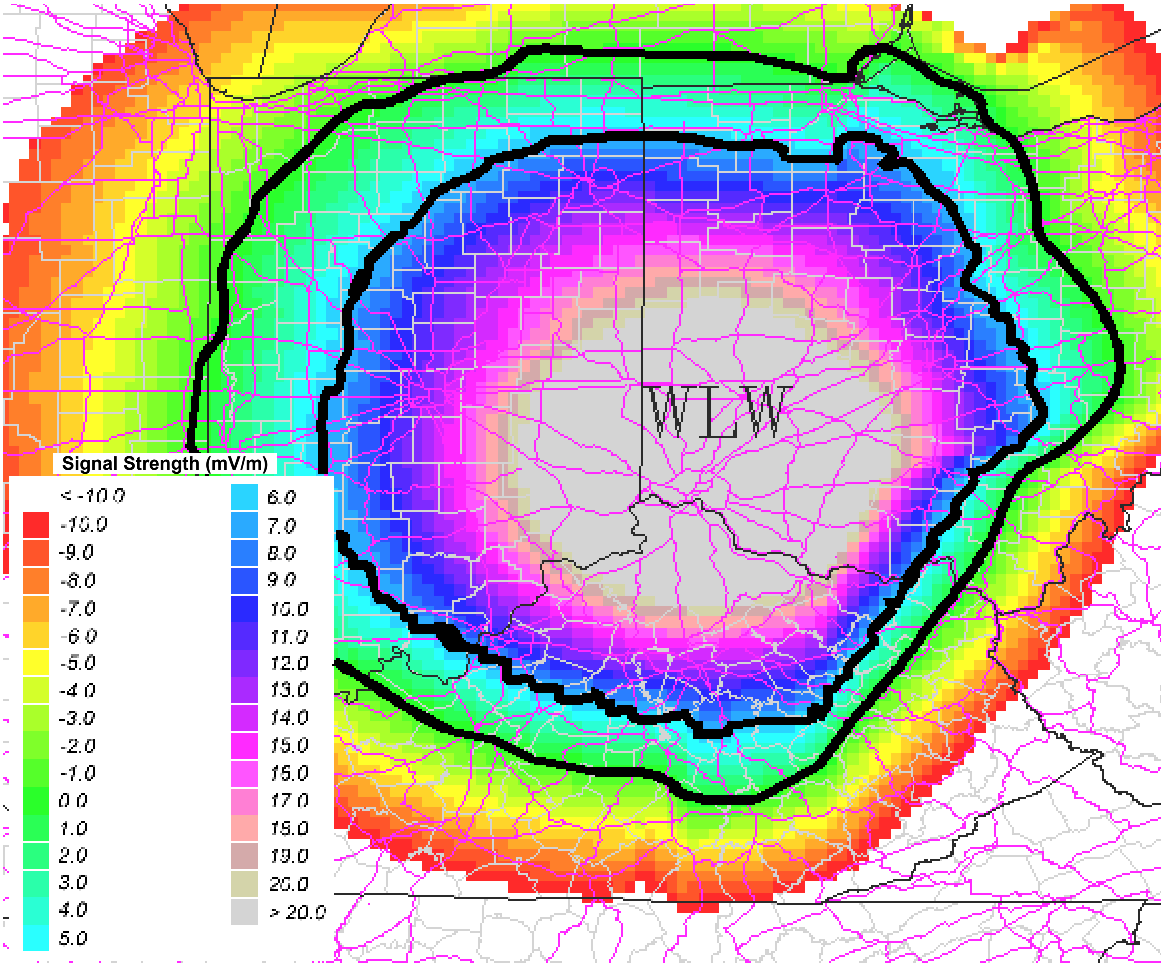
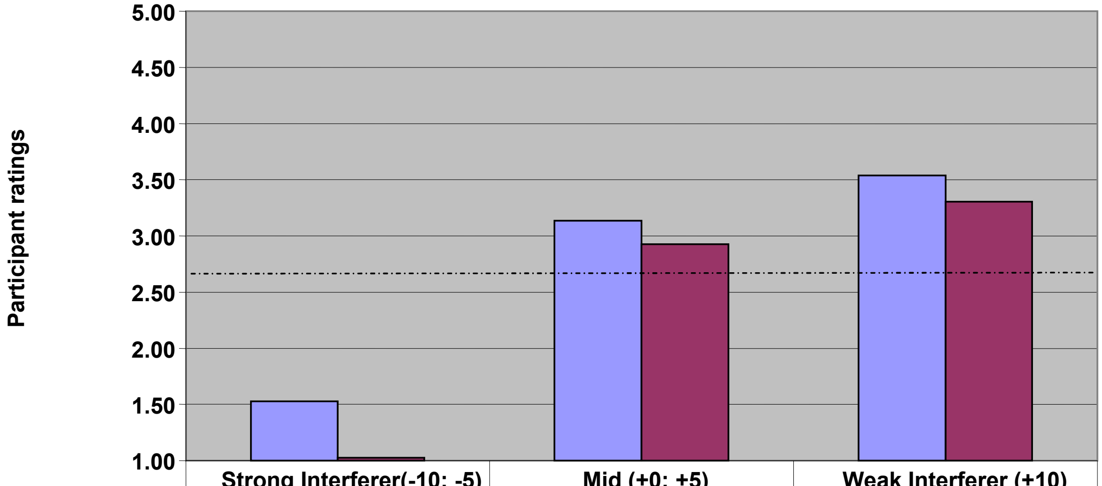


Figure 10: 1st adjacent D/U map and G2S overlays for WLW in Ohio showing added Region where WOR is affected by WLW IBOC between the black lines.

4.3 Skywave Interference into Skywave Desired Signal (S2S):

Figure 11 summarizes the subjective evaluation results for sky to sky interference. Again, for both weak and moderate levels of interference, the subjective evaluations confirmed that any degradation IBOC causes will not reduce audio quality below the tune out threshold. In the case of strong interference, the analog signal is so impaired that the introduction of IBOC does not have a meaningful impact. Notwithstanding the extremely low audio quality of the skywave signal in severe interference conditions, iBiquity recognizes that dedicated distance listeners continue to listen even in those conditions. In those cases, the introduction of IBOC may render an already marginal service unlistenable for some skywave listeners. However, because distance listeners are highly motivated to listen, even under extremely adverse analog interference conditions, they may be more tolerant of the additional IBOC interference than a typical listener would be.



	Strong Interferer(-10; -5)	Mid (+0; +5)	Weak Interferer (+10)
OFF	1.53	3.14	3.54
ON	1.03	2.93	3.31

Figure 11: Sky-to-Sky

In the S2S measurements in Virginia, where WOR was the desired signal, the average D/U was positive for WLW and negative for WOR although the variance during the recording times was quite high and changed dramatically over short periods of time. A listener at this location would have to be very determined to continue listening for periods of time greater than 30 seconds as there were periods of time where the signal was unavailable or was replaced with a distant undesired co-channel interferer. Several times, WAQI, 710, Miami was heard instead of the desired WOR signal, creating an Undesired to Undesired (U/U) condition. Assuming the desired signal has sufficient signal strength to overcome the noise and it is not displaced with a second undesired co-channel, the impact of IBOC on existing analog reception in the S2S condition is highly dependent on first adjacent channel D/U. Skywave to skywave field tests were conducted near Roanoke, Virginia with both WLW and WOR used separately as desired stations.

The subjective evaluation results indicate the introduction of IBOC in this situation will impact skywave signals at -5 dB or strong interference levels.[8] Because skywave signal levels vary by time rather than geography, it is difficult to map areas of impact from the introduction of IBOC. Instead, iBiquity analyzed the impact of IBOC in terms of reduced availability of skywave signal.

For example, in a situation where atmosphere conditions are very positive, a skywave signal may be available 95% of the time in a selected area. The addition of IBOC first adjacent skywave interference might reduce the availability to 80%. In other situations,

[8] It is important to note a reduction in subjective score from 1.5 to 1.0 will not have any meaningful impact on listeners. It only represents an even larger population of people who would never listen in the first place.

however, less favorable conditions may limit skywave availability without IBOC to 50%. In that situation, the addition of IBOC interference might reduce skywave availability to 25%. In this situation, however, it would be relevant to consider the viability of a service that is already degraded below the point of acceptability at least 50% of the time.

4.4 Impact of Receivers and Antennas

The subjective evaluations demonstrate a variation in impact from IBOC depending on the type of receiver and the type of antenna used. The narrow IF filtering of the automobile receiver increases its ability to withstand any potential IBOC interference.

Moreover, the narrow IF filtering makes these receivers more effective for receiving distant signals. At the same time, the common directional ferrite loop antenna employed in home Hi-Fis, boomboxes, and portable receivers offers benefits in all locations except those in a direct line between the desired and undesired stations. During the subjective test program, off axis scores for non-automotive receivers showed greater resistance to IBOC interference than auto receivers. Because the vast majority of receivers will operate off axis rather than directly between stations, directional antennas may help mitigate IBOC interference in many situations.

5 Conclusions

Based on the data collected the following conclusions can be drawn from the field tests:

- Interference from IBOC is D/U dependent and is expected to have its greatest impact below 0 dB D/U ratio.
- The primary service area of the station should not be affected by IBOC. The IBOC skywave signal impacts first adjacent groundwave service outside of the NIF, even for clear channel stations with low NIF values. The interference is a ring between where the desired groundwave is strong and where analog is poor, and thus the impact from IBOC is very limited.
- The IBOC groundwave signal impacts first adjacent skywave service in a ring around each undesired IBOC station. Inside of this region, most receivers are impacted from the undesired analog groundwave signal. Outside of this region, groundwave is not dominant.
- Given the time varying nature of skywave to skywave interference the ability to receive skywave signals in the presence of analog or IBOC interference is more a matter of time (signal availability) than geographic location. IBOC introduction is expected to reduce the amount of time skywave service is available, but not disastrously so.
- Boom box and portable receivers have directional antennas and can null-out most of the affects of the 1st adjacent undesired IBOC signal in most locations outside of the axis between the stations.