AM Nighttime Compatibility Study Report

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iBiquity Digital Corporation has prepared this report to analyze the impact of the introduction of nighttime AM IBOC broadcasting on existing analog AM service. It is a culmination of an extensive 12 month study of the interference in the nighttime band including work by Xetron Corp., which characterized the receivers and made recordings; the Advanced Television Technology Center (ATTC), which scored by Absolute Category Rating Mean Opinion Score (MOS)[1] the recordings; Metker Radio Consulting, which generated the maps and ran the statistics based on the MOS and iBiquity Engineering, which developed the algorithms tying the MOS to coverage and managed the overall study. iBiquity's previous reports on AM IBOC focused solely on daytime service. In order to address industry questions about the impact of IBOC on the more unpredictable AM nighttime environment, iBiquity undertook two initiatives. The first effort involved a detailed analytical study predicting IBOC interference from combined skywave and groundwave signals affecting analog AM groundwave nighttime service. This study determined the amount of impact IBOC would have on listener perception of analog AM in a station's primary service area. The results of that study are detailed herein. The second effort involved nighttime field observations covering (i) digital groundwave interference into an analog skywave desired signal, (ii) digital skywave interference into an analog skywave desired signal and (iii) digital skywave interference into a groundwave desired signal. Part of the second effort; the skywave interference into a desired analog groundwave signal, was designed to confirm the results of the analytical study. These field results will be presented in a separate report.

This study shows that the complete conversion of the AM band to IBOC at night has minimal impact to groundwave nighttime service. The conclusions are:

- The results assume 100% of the stations convert to IBOC in North America, which will take many years to occur – well after most receivers are able to enjoy the much upgraded digital sound.
- The impact is restricted to the fringe areas of a station's reception area – outside the Night Interference Free (NIF) limit in the 1-3 mV/m range for most stations;
- IBOC has no measurable impact on local channels;
- IBOC has minimal impact on regional and clear channels;
- IBOC impacts just 5% of potential listeners near edge of coverage on average per channel using a Delphi or equivalent receiver;
- Directional antennas in portable and boom-box receivers help null out interference – more than compensating for lack of IF filtering which pass more adjacent channel energy than typical narrower filters in omni-directional automobile installations;
- The impact is limited to areas where the analog is already impaired from analog co-channel and adjacent channels.

I. Overview

This analytical study was designed to produce a qualitative assessment of the groundwave nighttime analog coverage of every AM station in the United States and the potential impact on that coverage from the full introduction of IBOC on every station. As is described in greater

[1] See Appendix B for definition

detail herein, this study produced a Mean Opinion Score (MOS) rating of the nighttime groundwave service area for every licensed AM station in the United States operating between 540 and 1600 kHz. The study was structured to provide MOS scores for both existing analog service and analog service after the introduction of IBOC. Based on this information, maps were generated for every AM channel showing the station's MOS score as a function of coverage before IBOC, with IBOC and any change in MOS score that resulted from the complete conversion of the band to IBOC.

In order to provide a comprehensive and realistic overview of existing analog conditions, the study included all co-, first and second adjacent channel groundwave and skywave signals from all North American (Caribbean, Mexican, U.S. and Canadian) stations and how each impacted the test receivers. The study created a worst case scenario by assuming all North American stations had converted to hybrid AM IBOC broadcasting. This assumption maximized the potential IBOC interference.

The receivers used in this study were a Delphi narrowband automotive radio that represents the best case for weak signal reception at night and a Sony boombox receiver that represents a less expensive class of receivers. Receivers that are intended for distant ("DX") or weak signal reception at night have similar characteristics to the Delphi's performance with an important exception that portable DX receivers have antenna directivity which further reduces undesired signals. This entire class of receivers therefore will have less impact from IBOC than the results shown herein for the Delphi. Thus, the results discussed are *ultimate worst case* because they do not take this directionality into account. Receivers such as the Sony boomboxes, home Hi-Fi and clock radios typically are not well suited for weak signal reception and thus were not studied as extensively as the Delphi. However, for completeness, iBiquity included the NRSC-selected Sony boombox receiver. Due to the complexity with respect to the positioning of the receiver, the directionality of this radio could not be included in the study. Thus, the results for the Sony receivers also are *ultimate worst case in that in all cases it was assumed the receivers are in a direct line between the transmitters*.

II. General Observations

The maps produced in the study yield a great deal of information about the current North American AM allocations system and the potential effects of adding IBOC transmissions to the band. The study confirms the accepted conclusion that for the vast majority of the AM stations, the existing level of analog co-channel interference is the limiting factor in AM nighttime coverage. The study also shows that these levels of co-channel interference are much greater than the levels of IBOC induced from first adjacent channels and thus hide or "mask" the impact of the conversion to IBOC. Although this masking effect from analog co-channel interference is widespread, it is particularly pronounced on local (Class C) channels. These stations experience such high levels of nighttime co-channel analog interference that their existing nighttime service areas are severely constricted – not due to lack of signal, but rather high levels of co-channel interference. Thus, the introduction of IBOC on adjacent channels has little impact on these already constricted service areas.

In contrast, stations with large service areas next to relatively crowded channels were most likely to be impacted by adjacent channel hybrid IBOC transmissions. This is particularly evident with

Class A stations that enjoy coverage areas well outside their Arbitron markets at night but that are next to regional or local channels that have a much higher signal level (from the addition of all the stations on the channel). Stations with large service areas typically have some or all of the following characteristics: high soil conductivity, are allocated to the low end of the AM band, and/or have 10 kW or greater transmitters. Even in these cases of potentially greater impact from IBOC, the interference effects should not have a significant impact on listeners or station revenues as the areas affected are distant to the station and thus fall outside the station's Arbitron market.

For most stations, the area of MOS score reduction resembles a "doughnut" pattern: i.e. no affect in the center of the station's service area; a minor decrease in MOS where the station is achieving an MOS score between 2 and 3; a small decrease in MOS where the MOS approaches 2; and an insignificant difference where the MOS is 1 or less. Finally, at or near the edge of coverage, there is no reduction.

III. Study Methodology

A. Receiver Characterizations

The study commenced with receiver characterizations at Xetron. Xetron conducted lab tests on the Technics SA-EX110 home, Pioneer KEH-1900 auto, Sony Boombox and Delphi auto receivers used in the NRSC testing program. The testing program subjected the radios to a sufficient range of input analog interference conditions that resulted in producing audio ranging from very clean to very impaired in the presence of white noise, co-channel and first and second adjacent channel interference. These tests were then repeated with hybrid IBOC interferers. See Appendix A for details on the test and the process followed at Xetron.

To manage the number of recordings, maps and statistics, two of the four receivers were chosen to continue in the study. The Technics was not used since it is an AC only powered indoor home receiver and thus was not a good candidate for nighttime listening away from local noise sources assumed in the study. The Sony has similar filter characteristics to the Technics and can run off of battery power so it was selected over the Technics. The Pioneer exhibited similar characteristics to the Delphi but is not as common in the market, so the Delphi was chosen over the Pioneer.

Since over 53% of the AM stations are talk, news or sports formats[2], voice and voice-over cuts were chosen for the study. Voice-over is a form of audio containing voice with a musical background similar to what is played during advertisements. Pure music was not selected since its higher density would skew the results toward a lower IBOC and higher analog interference impact. Therefore, any station that plays music will be impacted less than predicted by this study. A mixture of voice and voice over audio cuts was used as the interferer or undesired (i.e. co-channel, 1st or 2nd adjacent), thus reducing the number of cuts one would listen to in order to determine the MOS of each Desired to Undesired ("D/U") ratio score.

B. Overview of MOS Scores vs. Listener Acceptability

A series of subjective evaluations were conducted at the ATTC using the selected receivers characterized at Xetron. Recruited listeners were asked to provide MOS ratings for various

[2] Source: National Association of Broadcasters

desired to undesired co-, 1st and 2nd adjacent interfering stations while listening to the Delphi and Sony receivers. In addition, they were queried as to whether they would continue listening to the station if they were (i) committed/motivated listeners or (ii) casual listeners. Based on the results of these tests it was possible to determine what percentage of listeners would turn off a radio at a particular MOS score.

The graphical representation of the MOS turn off point is presented in Figure 1 below.

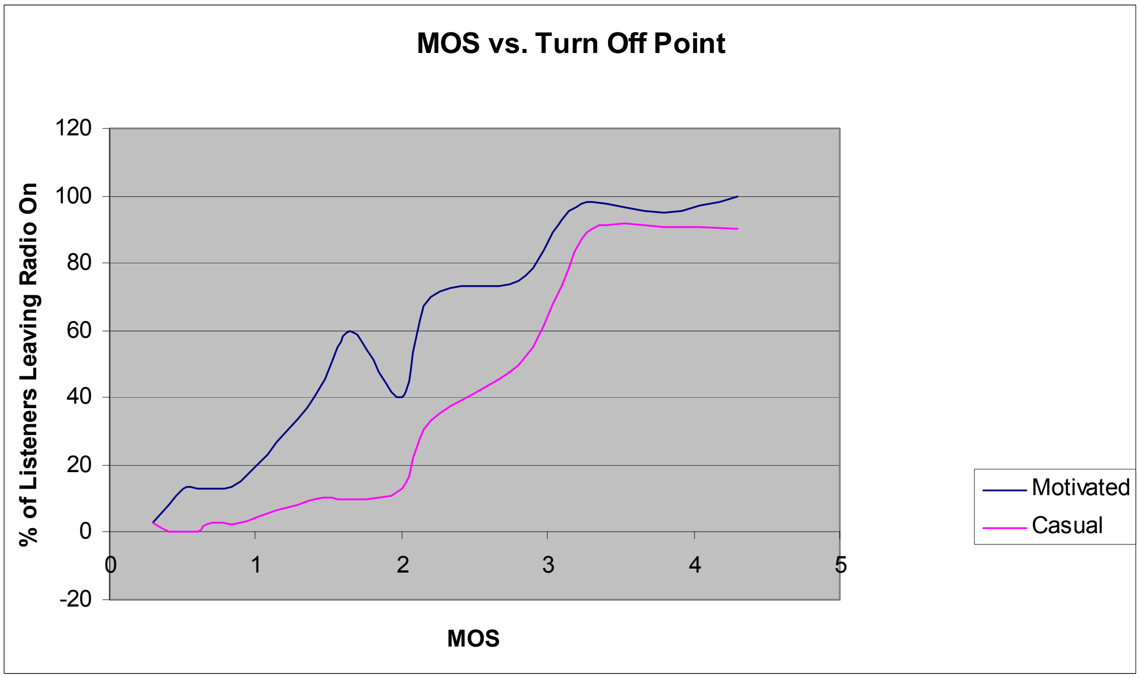

Figure 1: MOS turn off point

There is generally little listener tune-out until the MOS rating falls below 3.0 points. The point where 50% of the casual listeners tune-out is at an MOS rating of approximately 2.5. For motivated listeners, the turn-out point is closer to a 2.0 MOS score[3]. These threshold levels correlate well with previous testing done for FM acceptability. An MOS difference of less than 0.5 points has been deemed to not be statistically significant by audio experts.

Therefore, where the MOS scores are 3.0 or greater, a radio station should meet the needs of both the casual and committed listener. Scores below 3.0 show a slow drop off of motivated listeners, while the casual listeners fall off more quickly. See Appendix B for details on the subjective test methodology followed at the ATTC.

C. Overview of Calculation of MOS Rating

MOS was calculated for each receiver using a signal-to-noise ratio (SNR) relationship of desired signal to the square root of the sum of the squares of all the undesired signals from co-channel and adjacent channels (second and first) as well as the noise of the front end of the receiver. The

[3] Figure 1 illustrates a "spike" at an MOS score of approximately 1.8. iBiquity believes this was a reaction to a particular audio selection and should not detract from an obvious increase in listener dissatisfaction below a 2.0 score.

result is an effective SNR that can be used to calculate the MOS based on the listening tests described above for the receiver. See Appendix C for more details.

D. Overview of Mapping Methodology

The FCC's accepted propagation model was adapted to a grid-based analysis in order to obtain detailed signal information at each location in the United States. Signal strength maps were generated using 50% skywave field strength curves[4] summed with M3 metric curve[5] ground data. Instead of computing contours, a 410 x 901 element grid was drawn over the entire Continental US, Southern Canada, Northern Mexico and the Caribbean which resulted in 4 minute by 4 minute (approximately 4 mile by 4 mile) "squares" in latitude and longitude which provide detailed signal information at each location nationwide. The total groundwave and skywave signals from all nearby, relevant stations were computed in each square, including the total signal and highest single station contributor. Signal strength (mV/m), co-channel D/U and first adjacent channel D/U maps were then made for each frequency with this same 4 x 4 mile resolution. Based on receiver filter characteristics which impact receiver MOS in the presence of co-channel, first and second adjacent interferers, maps showing MOS of the existing analog only environment were generated by applying the mathematical equation that translates all the interferers to an equivalent signal-to-noise ratio as described in Appendix D. This process was repeated with all of the stations (including Canada, Mexico and the Caribbean) transmitting IBOC. Next, a difference, or "change in MOS" map was generated for each frequency showing the impact on MOS following the total conversion of nighttime broadcasting to IBOC. Finally, population data was overlaid on each square from the 2000 Census data as described in Appendix D.

The grid approach, while more computationally expensive than contour analysis, produces data with a fine degree of granularity that is much better for computing combined groundwave and skywave signals. This approach is also ideal for determining signal and interference for any location across the United States and for analyzing population and other statistics of the entire frequency band. These advantages combine to produce a model of the AM allocation scenario that can be used to produce many different quantitative metrics and conclusions on the impact of IBOC on the AM band.

IV. Summary of the Effects on MOS after the Complete Conversion to IBOC

The effects of all stations transmitting IBOC in the AM band can be summarized by graphing MOS value vs. potential listener impact. Further resolution is possible by analyzing reserved channel types such as clear, regional and local frequencies. Figure 2 shows the average MOS impact on all channels (540-1600) in the aggregate and specifically clear, regional and local

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[4] The NIF for the stations used in the representative examples are computed using conventional FCC methodology as specified in the rules for the Federal Communications Commission, 47 C.F.R. § 73.190, with the exception that the 50% (50% of the time) skywave curves were used in lieu of the FCC's 10% (10% of the time) methodology. The use of the FCC's 50% curves results in values that show a weaker interfering signal and thus a lower computed NIF value. The lower NIF results in a larger predicted service contour for the station of interest. This larger service area as represented by a lower NIF contour, experiences more interference than the smaller 10% contour, and thus tends to have a higher change in MOS value. The use of the 50% skywave curves therefore shows a worst case scenario for IBOC interference at the NIF**.**

[5] As specified in the rules for the Federal Communications Commission, 47 C.F.R. § 73.190.

channels[6] if all stations converted to IBOC for the Delphi receiver. The graph shows the cumulative percentage of potential listeners impacted on a per channel basis. In other words, the sum of the potential listeners impacted as a function of a reduction in MOS on each channel (thus all stations impacted) represented by the graphed local, regional, clear channels and entire band as indicated are shown as a percent, averaged and totaled from right to left. The 0.5 MOS reduction point shown on the X axis is typically defined as the minimum threshold for a noticeable change in audio quality and is highlighted on the graph. Thus, the total percentage of potential listeners per channel living within a station's 0.5 mV/m nighttime contour and having an impact of 0.5 MOS points ***or greater*** after all stations convert at night is just 5% if the receiver listened to is a Delphi. Figure 3 shows the same graphs for the Sony receiver but at the 5 mV/m contour since this is typically where the Sony receiver is listenable. It shows more impact than the Delphi due to its wider bandwidth intermediate filter (IF) filter characteristics. The Sony receiver, with its directional antenna[7], at most receiving locations has a significant advantage over the Delphi that is not represented in this study and the two graphs summarizing MOS impact. This directionality advantage is available anywhere in the coverage area except in a straight line intersecting the desired and undesired stations since the antenna has a "figure 8" gain pattern and thus would null out the undesired station. Taking this directionality into account will move the Sony all channel, clear, regional and local lines to the left, closer to the Delphi receiver results and thus decreasing the impact percentage. Below is a summary of each line on the graphs:

Clear Channels:

An examination of the clear channel allocations, when considering either receiver shows approximately the same percentage of total population impacted as the average of all channels. The clears have less overall population coverage since there are fewer stations per clear channel, even though each station has more coverage. Many of the clear channels are adjacent to each other in the band and are separated from the high signal level local channels. The clear stations that are first adjacents are also separated by distance which helps reduce interference.

Regional Channels:

The regional channels experience slightly lower levels of average population impacted for both receivers. This is due to the relatively large number of Class B stations with sufficient power to have significant nighttime coverage and thus a large population base per channel in strong signal areas (urban coverage) when compared to the clear channels and thus a smaller impact per channel. This is offset by the fact that some of the regional channels are first adjacent to local channels that have a very high interference level and thus higher levels of IBOC sideband energy. However, overall the impact is minimal as shown in the graphs for both receivers.

Local Channels:

The local channels are the most unique in the group. The impact of IBOC is not measurable. This is due to the limited coverage each station has at night and the number of stations on each channel. The existing co-channel undesired stations produce far more analog ground and

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[6] As specified in the rules of the Federal Communications Commission, 47 C.F.R. § 73.25 through 73.27

[7] Portable receivers like the Sony, employing directional antennas, can significantly boost the quality of the received audio by either orienting the antenna to improve reception or null out interference. This study represents the worst case for IBOC interference as it does not take into account the benefits of a directional antenna.

skywave interference than all the first adjacent IBOC signals. This is what pushes the NIF limit to very high signal levels for this group of stations.

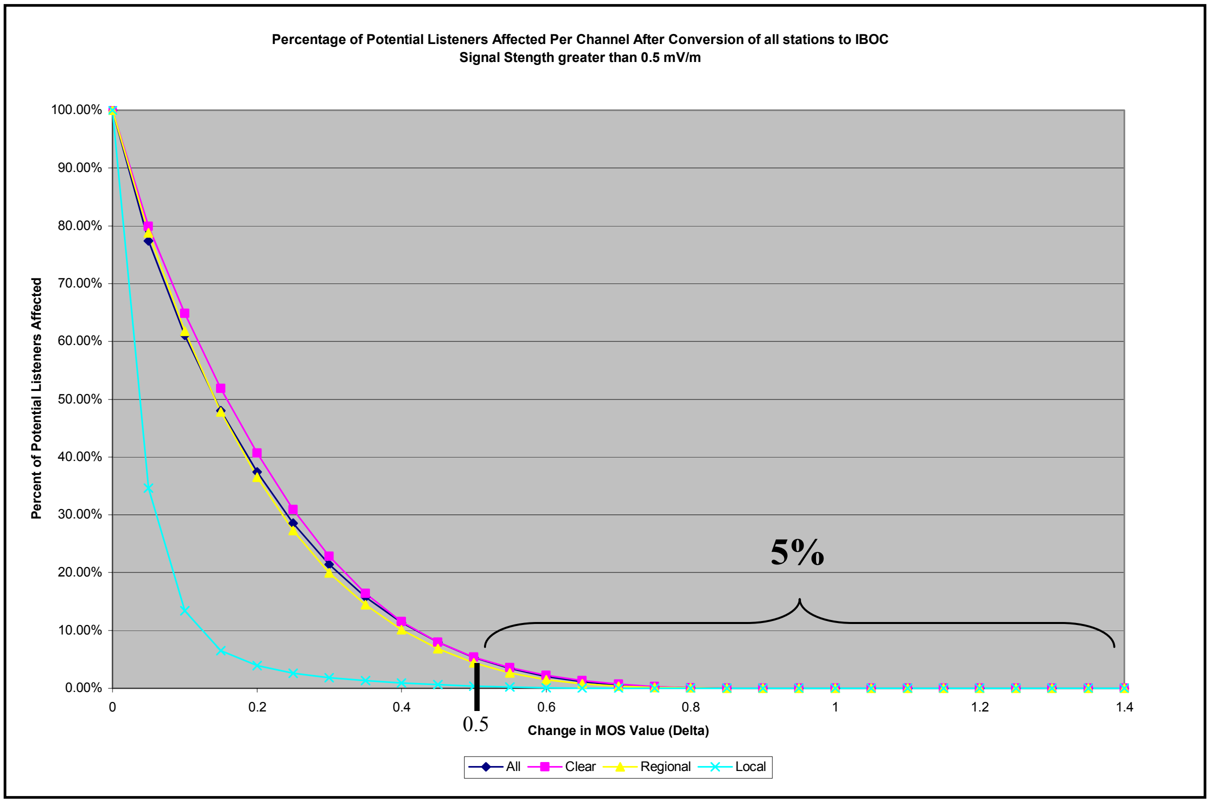

Figure 2: Cumulative Percentage of Average Potential Listeners Affected per Channel – Delphi Receiver

MOS Impact vs. Signal Strength:

As shown in Figure 4 and Figure 5, the majority of the audio quality impact for all AM channels occurs at signal strength of less than 3 mV/m for the Delphi and 2.5 mV/m for the Sony. The impact is small (less than 0.5 MOS points) and thus is outside the areas where most nighttime listening takes place and is below the night interference free limit of most stations. These figures show the population values placed into a change in MOS vs. electric field (signal strength) histogram. The change in MOS values have been cumulatively summed, while the E-field values are normal histogram bins (see Appendix D). Thus, for a given E-field and change in MOS value, the population total that experiences roughly that E-field and has a change in MOS value as specified *or above* is shown. As an example, the Delphi histogram shows at 1 mV/m, only 175,000 people (light blue on the scale) on average per channel across the entire United States have more than a 0.5 MOS impact after all stations have converted to IBOC. This is a very small fraction of the total potential listeners on each channel which typically are well above 50 million and is well below the NIF for nearly all stations. For the Sony receiver at 1 mV/m and 0.5 change in MOS, the population impacted by this minimum threshold of being able to distinguish the impact is just 500,000 people (deep orange on the scale) or just 1% of the potential listeners. As with the above population statistics, this does not take into account the receiver's directional antenna characteristics which will decrease the impact. Thus, the impact is limited to low signal strengths and a limited number of potential listeners.

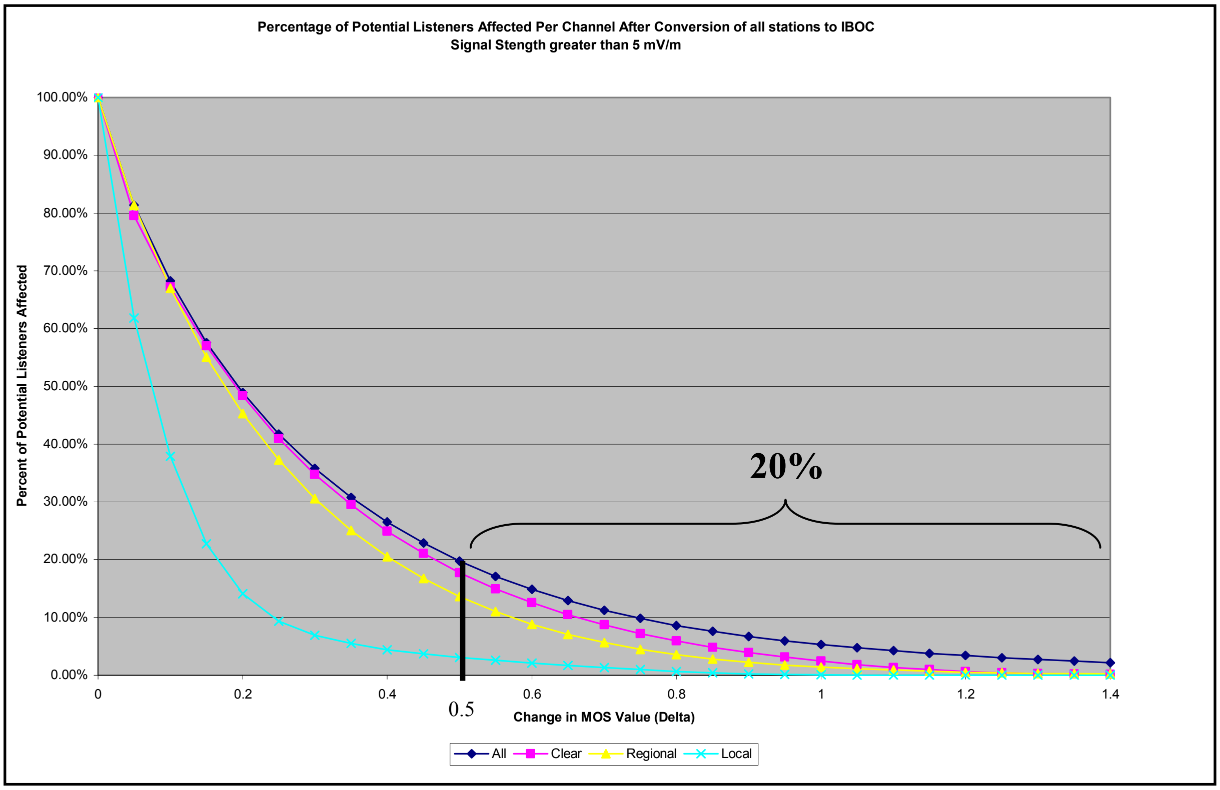

Figure 3: Cumulative Average Potential Listeners Affected per Channel – Sony Receiver

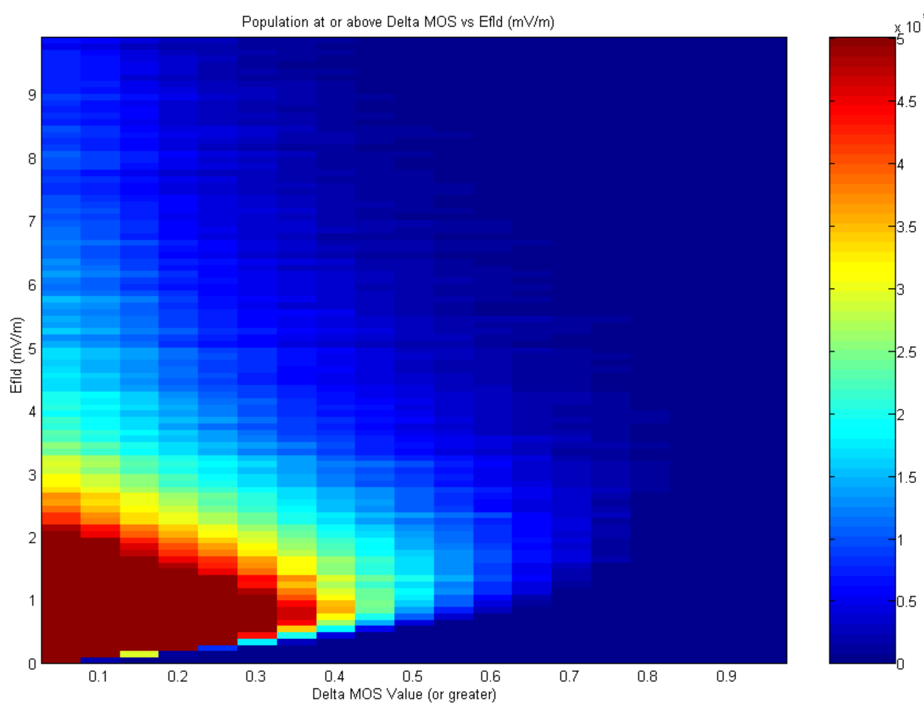

Figure 4: Population Impacted as a Function of Change in MOS vs E-Field – Delphi Receiver

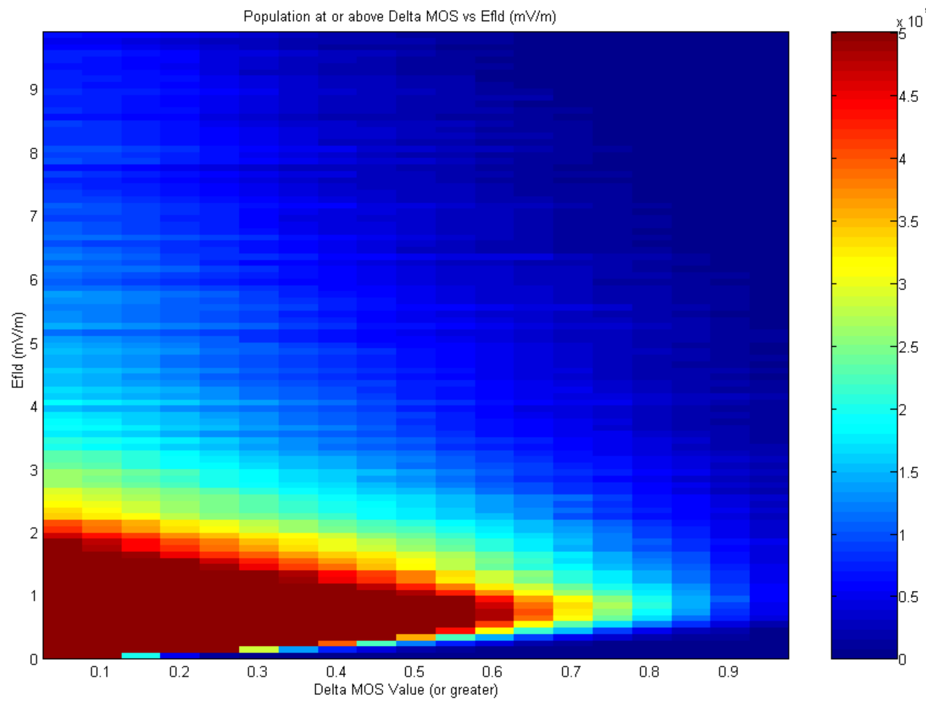

Figure 5: Population Impacted as a Function of Change in MOS and E-Field – Sony Receiver

V. Examples of MOS Impact on Selected Channels and Stations

Included below are seven examples of typical, best case and worst case conditions as well as representative channel examples. Only the Delphi receiver maps are presented since the receive antenna is omni-directional. See Appendix E for details on why the Sony receiver is not included in the examples.

Example 1: Typical Clear Channel

WLS is on a clear channel (890 kHz) and thus enjoys a large area of clear signal at night with only three other co-channel stations on the air after sunset as shown in Figure 6. The bands of colors represent different E-field strengths in mV/m per the key on the lower left corner of the figure. Figure 7 shows an enlarged four state signal strength of WLS. However, WLS is adjacent to 900 kHz, which has over 15 regional stations within 500 miles of Chicago as shown in Figure 8. Wideband receivers in these areas, such as Toledo Ohio and central Wisconsin have problems receiving WLS today. The current MOS for the region is shown in Figure 9. The color codes show that at the 2 mV/m WLS NIF contour, the MOS is approximately 2 points. Beyond this region, the interference from adjacent channels starts to degrade the groundwave signal to a point where skywave is dominant.

After IBOC is adopted by all of the stations on 900 kHz, WLS' MOS score at the periphery of its service area will be impacted but this area is well outside of the Chicago Arbitron market as shown in Figure 10. Also note that the NIF is inside the area of highest impact which peaks at an MOS change of only 0.5 points between 60 and 70 miles from the station. Finally, the greatest change in MOS score occurs between 1 and 3 mV/m signal strength areas which are received primarily outside away from power lines, bridges and other sources of signal interference and degradation.

Other clear channels adjacent to regional channels that would be expected to have results similar to 890 kHz exist in the AM band. These include 640 kHz (KFI, Los Angeles) next to 630 kHz; 670 kHz (WSCR, Chicago) next to 680 kHz; 720 kHz (WGN, Chicago) next to 730 kHz; 780 kHz (WBBM, Chicago) next to 790 kHz and 1210 (WPHT, Philadelphia) next to 1220 kHz. Clear channels that are adjacent to only clear channels include 650 kHz (WSM, Nashville), 660 kHz (WFAN, New York), 760 kHz (WJR, Detroit), 770 kHz (WABC, New York) , 830 kHz (WCCO, Minneapolis), 880 kHz (WCBS, New York), and 1030 kHz (WBZ, Boston). This group of channels generally does not receive as great an impact as the group adjacent to the regional channels since there are greater distances between the clear stations on adjacent frequencies and the overall signal density of the first adjacent clear channel is lower due to a lower number of stations.

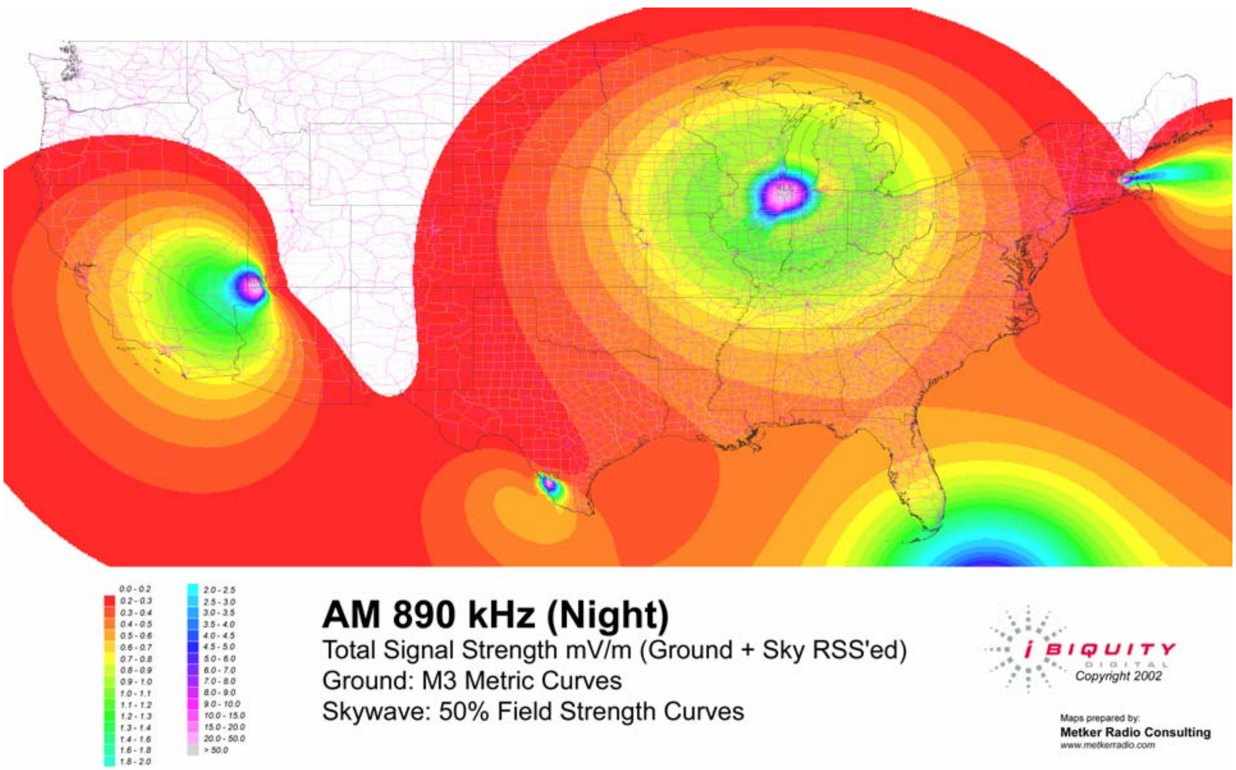

Figure 6: Nighttime Nationwide Signal Strength of the 890 kHz Channel

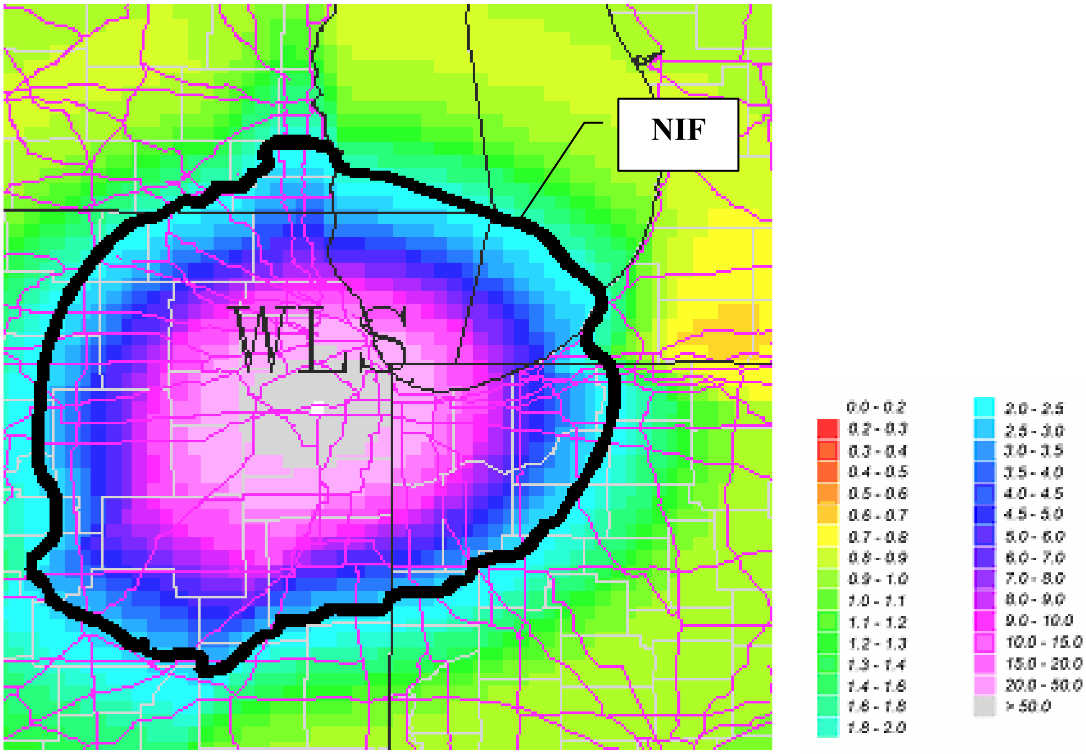

Figure 7: Signal Strength of WLS, 890 kHz, Chicago, IL with 2.1 mV/m NIF Contour (black line)

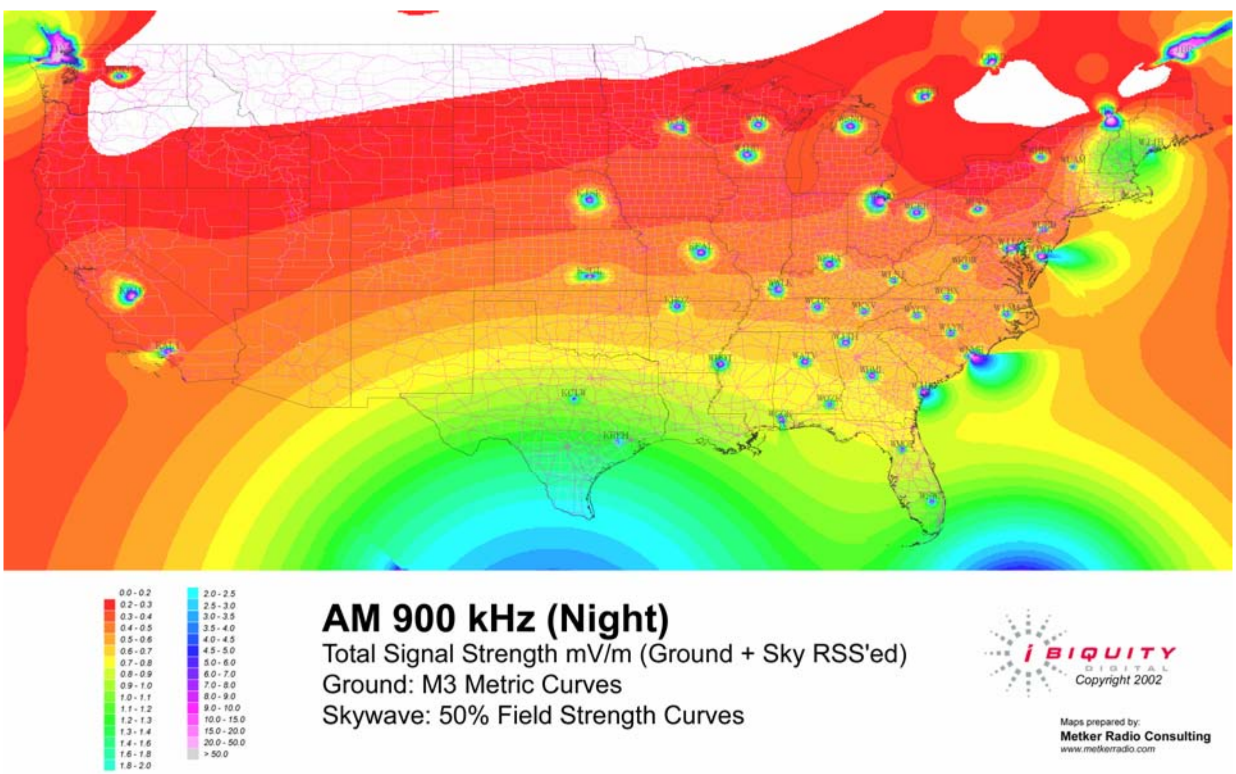

Figure 8: Nighttime Nationwide Signal Strength of the 900 kHz Channel

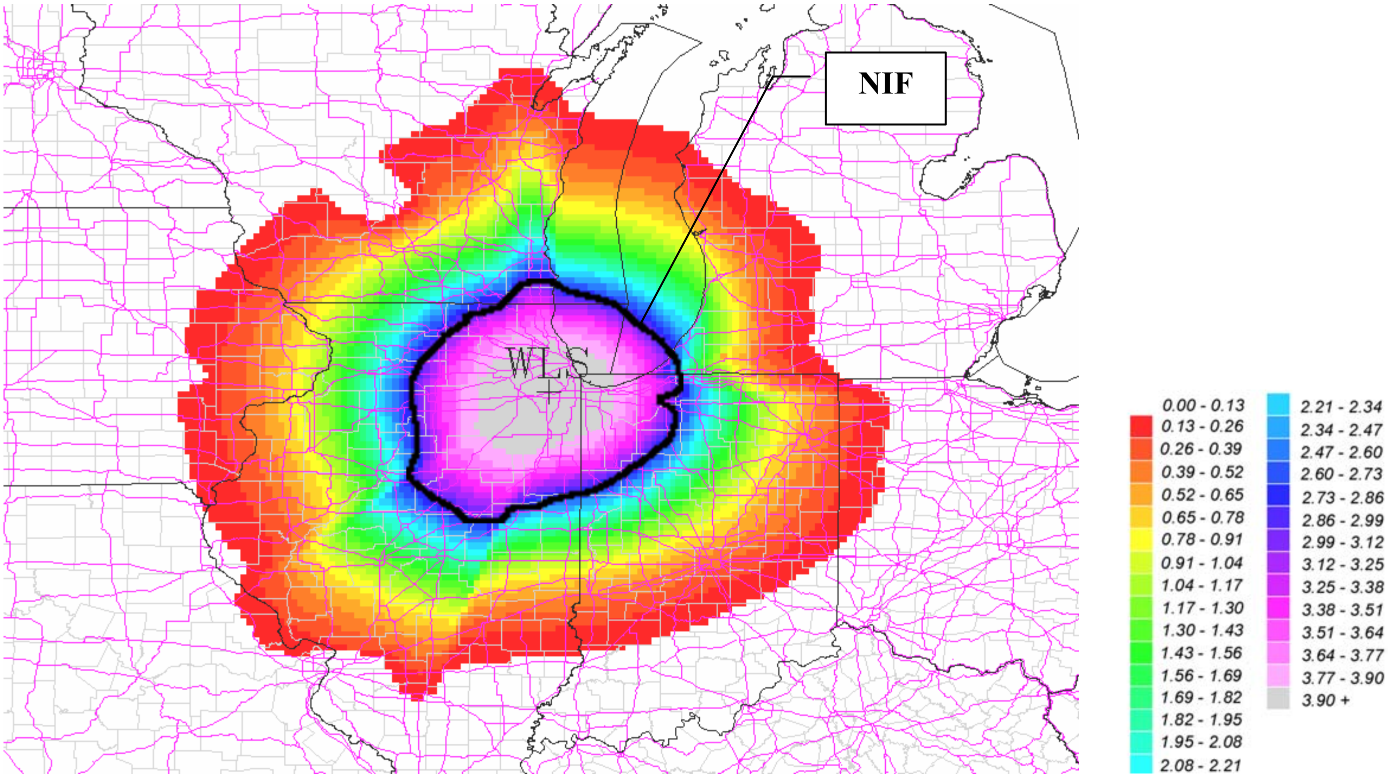

Figure 9: WLS, 890 kHz, Chicago, Present analog MOS & 2.1 mV/m NIF Contour – Delphi Receiver

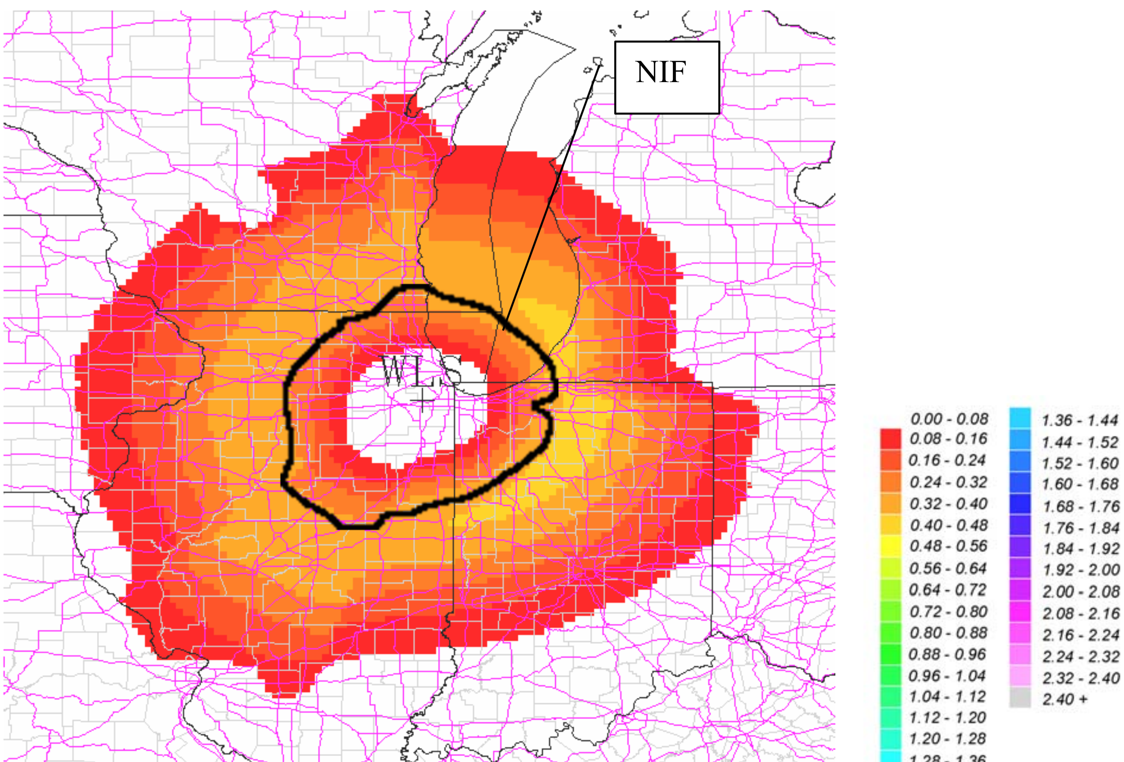

Figure 10: WLS, 890 kHz, Chicago, 2.1 mV/m NIF Contour & Δ MOS rating after all stations convert to IBOC – Delphi Receiver

Example 2: Typical Regional Channel

Figure 11 depicts one of the regional channels, 1260 kHz. This figure shows insignificant changes in MOS ratings over land with MOS changes approaching 0.8 in the Pacific and Atlantic oceans.

Figure 12 shows a typical regional station, WSUA in Miami, Florida on 1260 kHz. Figure 13 shows WSUA's present analog MOS ratings. The present MOS score is greater than 3.0 within the NIF. Figure 14 shows the change in MOS ratings after full scale implementation of IBOC. As can be seen, there is no change within the NIF contour and minimal throughout the entire land area. The interesting red circular area in the Ocean is caused by a combination of up to seven first adjacents in the South East US on 1270 kHz combining over the ocean to raise the interference level such that there is a very slight decrease in MOS. Other stations on regional channels exhibit similar behavior including WSBT, South Bend, Indiana and KALE, Richland Washington both on 960 kHz. Several of the West coast stations have a higher MOS reduction, but most of the additional change is confined over the Pacific Ocean such as for KFWB, 980 kHz, Los Angeles, California and KVNR 1480 kHz, Santa Ana, California.

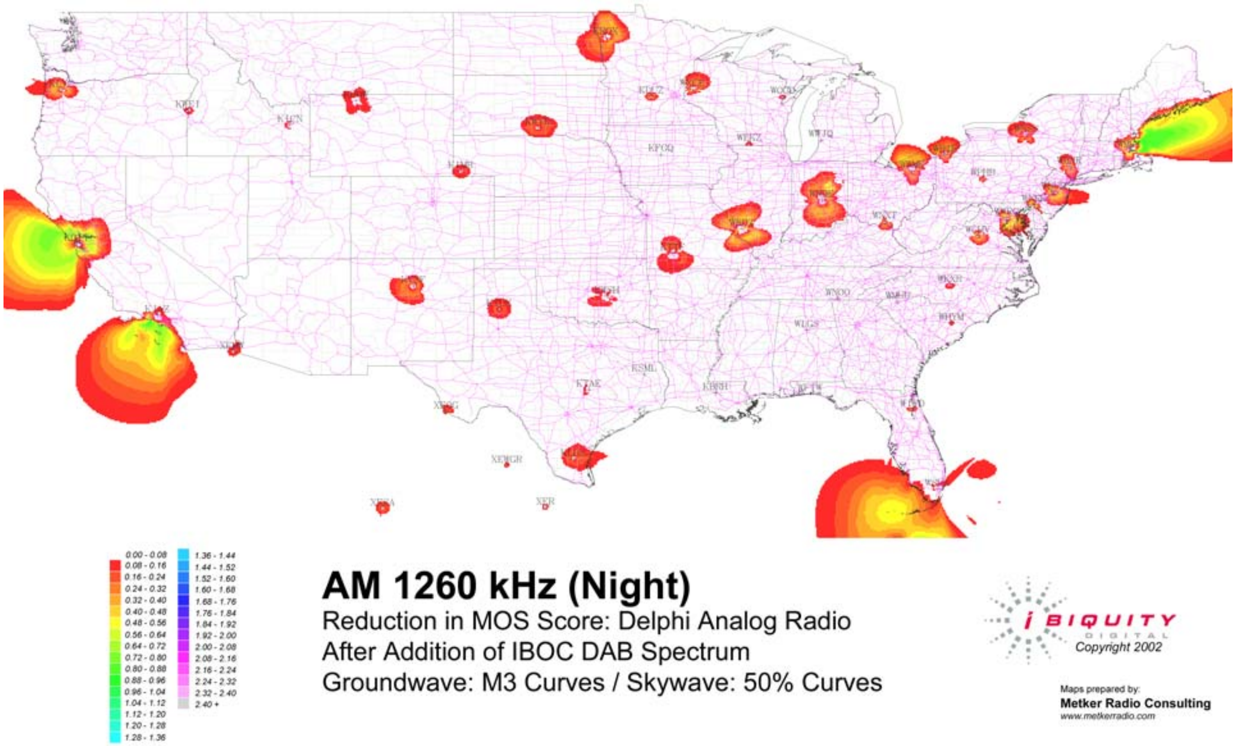

Figure 11: Depicts a Regional Channel

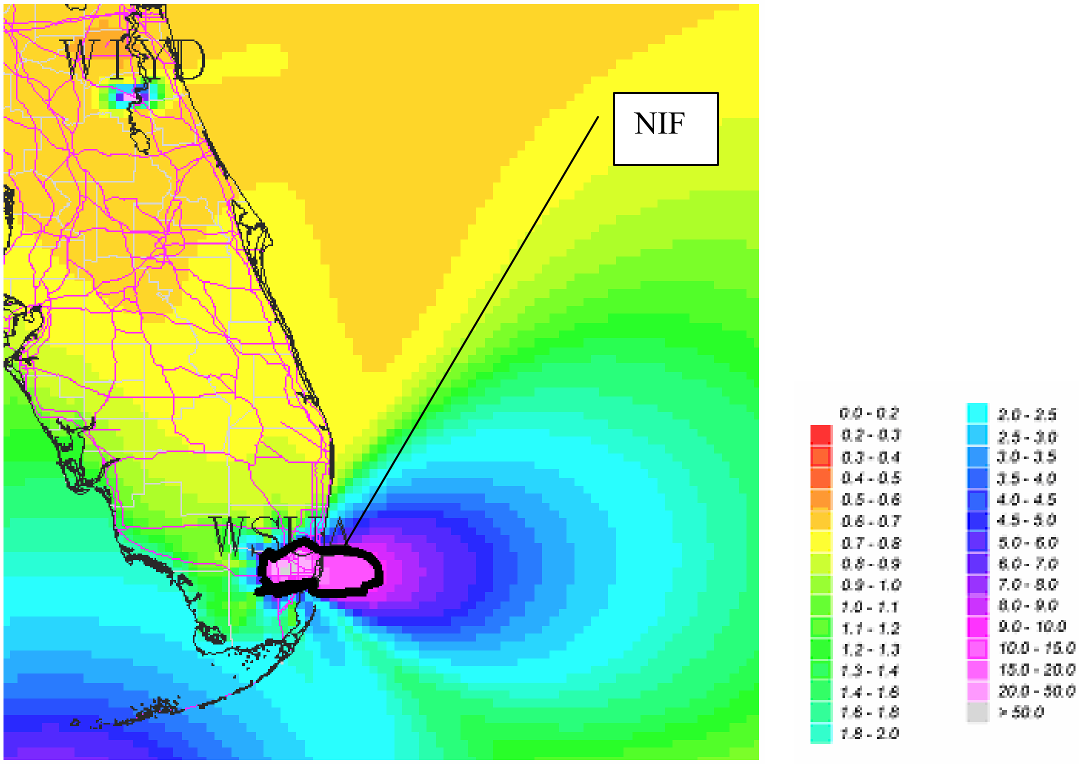

Figure 12: Signal Strength of WSUA, 1260 kHz, Miami, FL with 15.7 mV/m NIF Contour (black line)

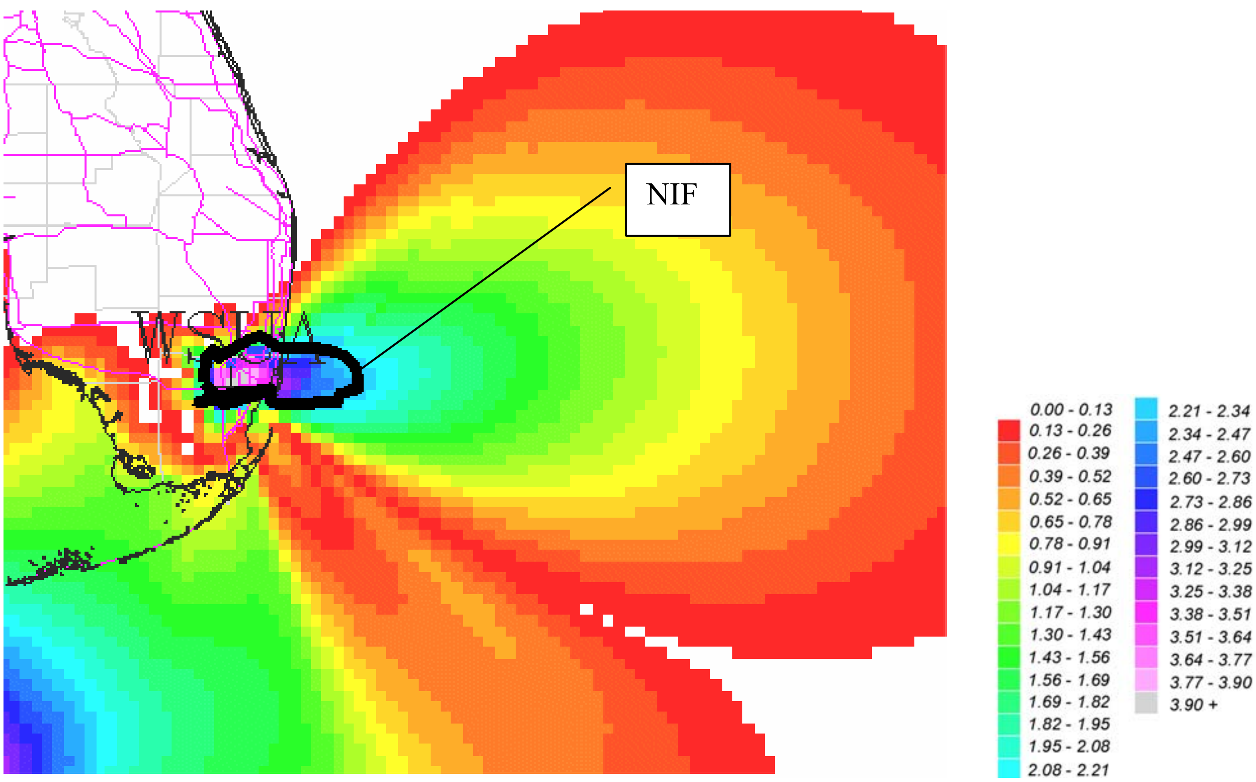

Figure 13: WSUA, 1260 kHz, Miami, Present analog MOS & 15.7 mV/m NIF Contour – Delphi Receiver

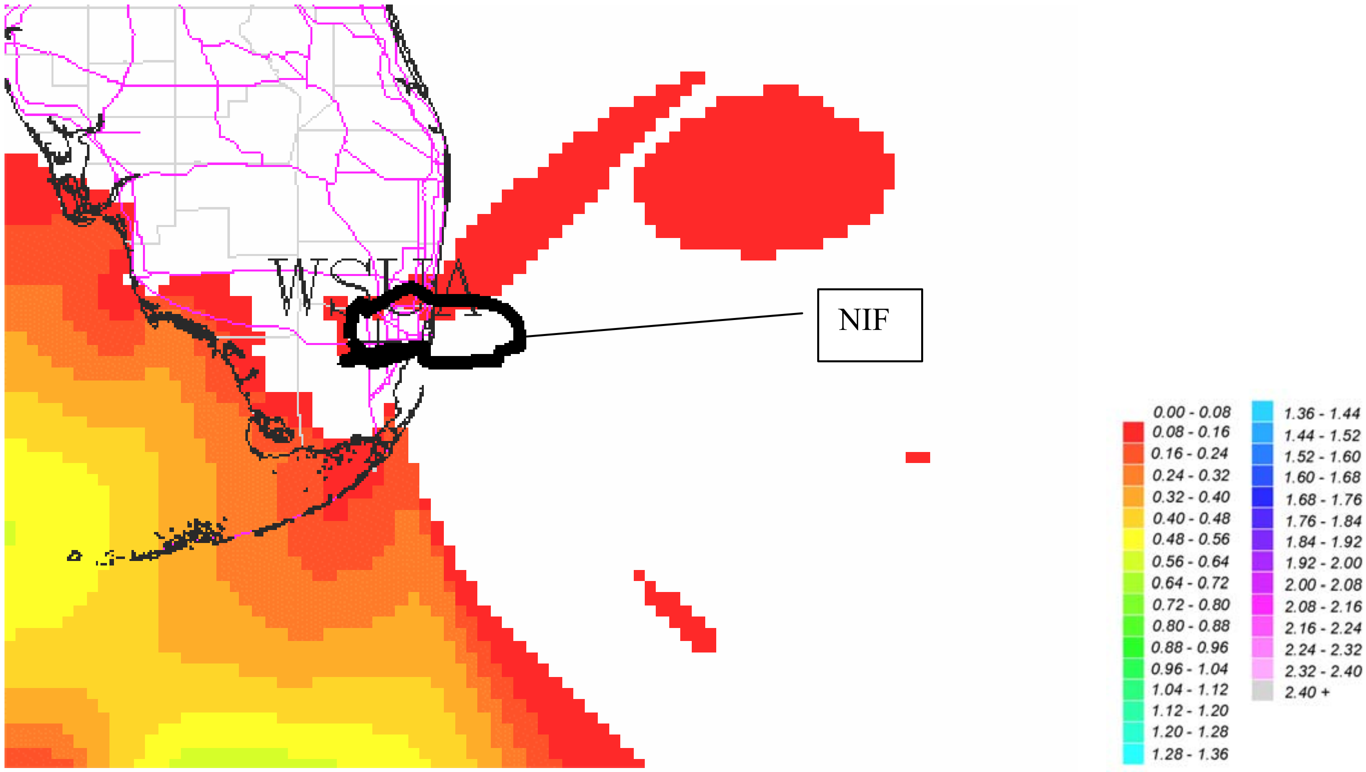

Figure 14: WSUA, 1260 kHz, Miami, 15.7 mV/m NIF Contour & Δ MOS rating after all stations convert to IBOC – Delphi Receiver

Example 3: Typical Local Channel

Figure 15 shows the signal strength of one of the FCC designated local channels, 1400 kHz. The Figure shows the overall "background" signal level on 1400 kHz is above 1.5 mV/m for over a third of the country due to more than 170 stations on this frequency at night.. Due to the crowding and each station's low power, the MOS drops off close to the station as shown in Figure 16 and as a result, the area impacted from the conversion to IBOC is very minimal as shown in Figure 17. This figure clearly demonstrates that the existing levels of co-channel interference mask the effects of IBOC as less than 15% of the stations have any impact at all. Many of these stations just have an impact over water and the impact is less than 0.16 MOS points which is not statistically significant. Other local channels that will experience similar impacts include 1230 kHz and 1340 kHz with over 160 stations each and 1450 kHz with over 170 stations.

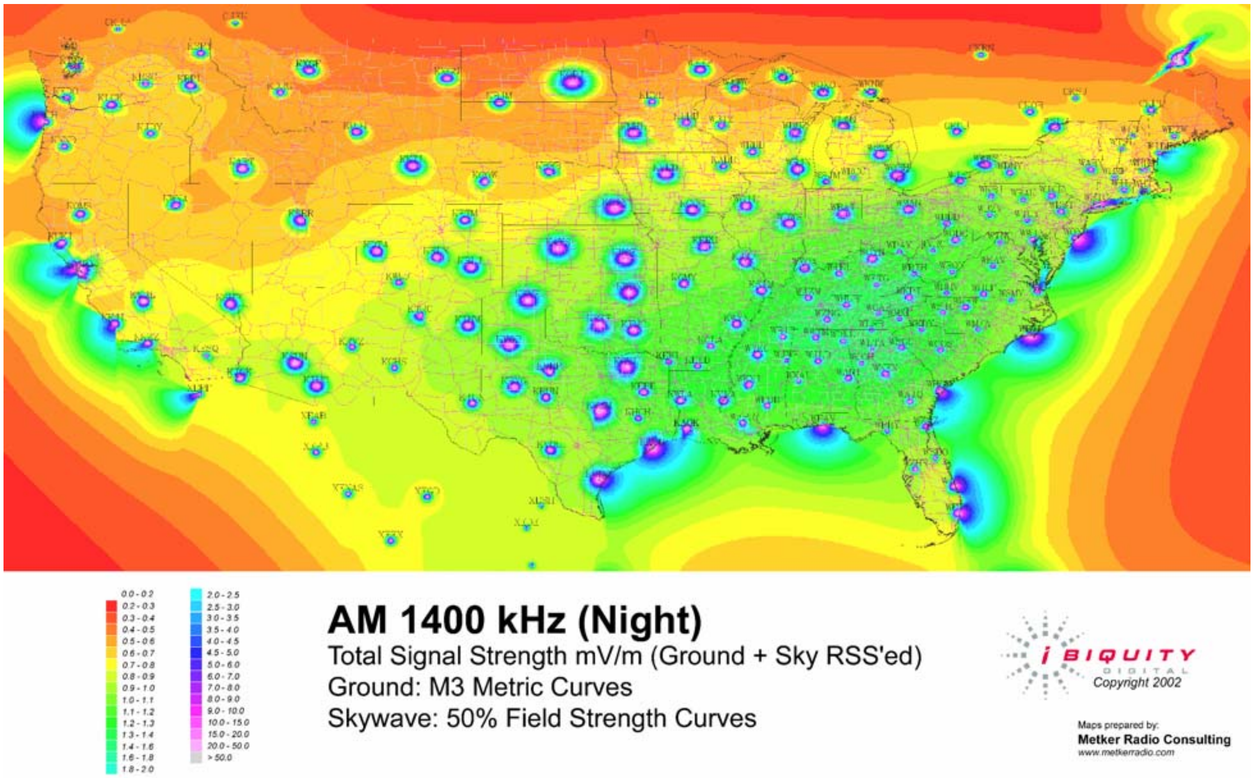

Figure 15: Nighttime Nationwide Signal Strength of the 1400 kHz Channel

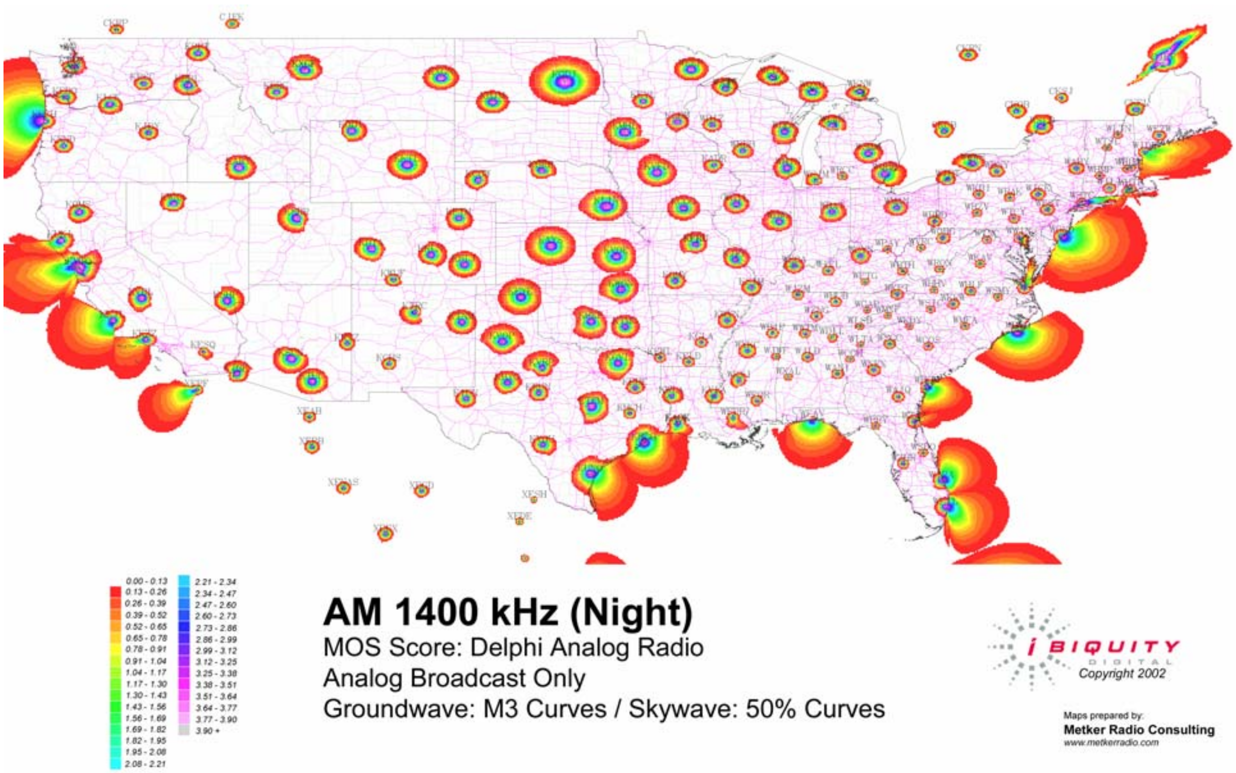

Figure 16: Existing MOS of a Typical Local Channel

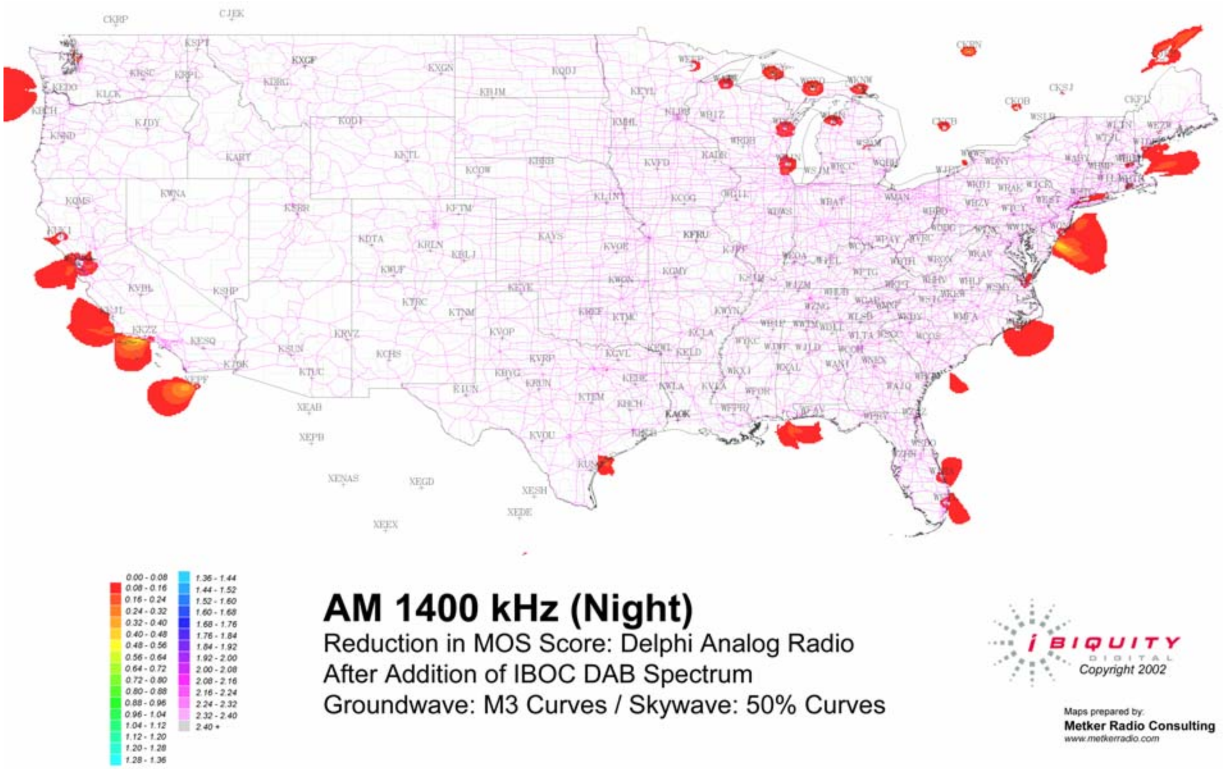

Figure 17: MOS Reduction of a Typical Local Channel

Example 4: Channel at the low end of the AM band

Figure 18 shows the effects of signals at the low end of the band. Most of the stations are much less than 50 kW except for KFI, Los Angeles which expends most of its energy over the Pacific Ocean. Figure 19 shows that stations have large service areas and typically have insignificant MOS rating losses. The worst case is KFI, where over water, a green area is observed depicting a 0.8 loss in MOS rating points. The areas over land experience negligible interference increase. Other similar channels include 590 kHz which includes a number of stations with no impact as shown in Figure 20.

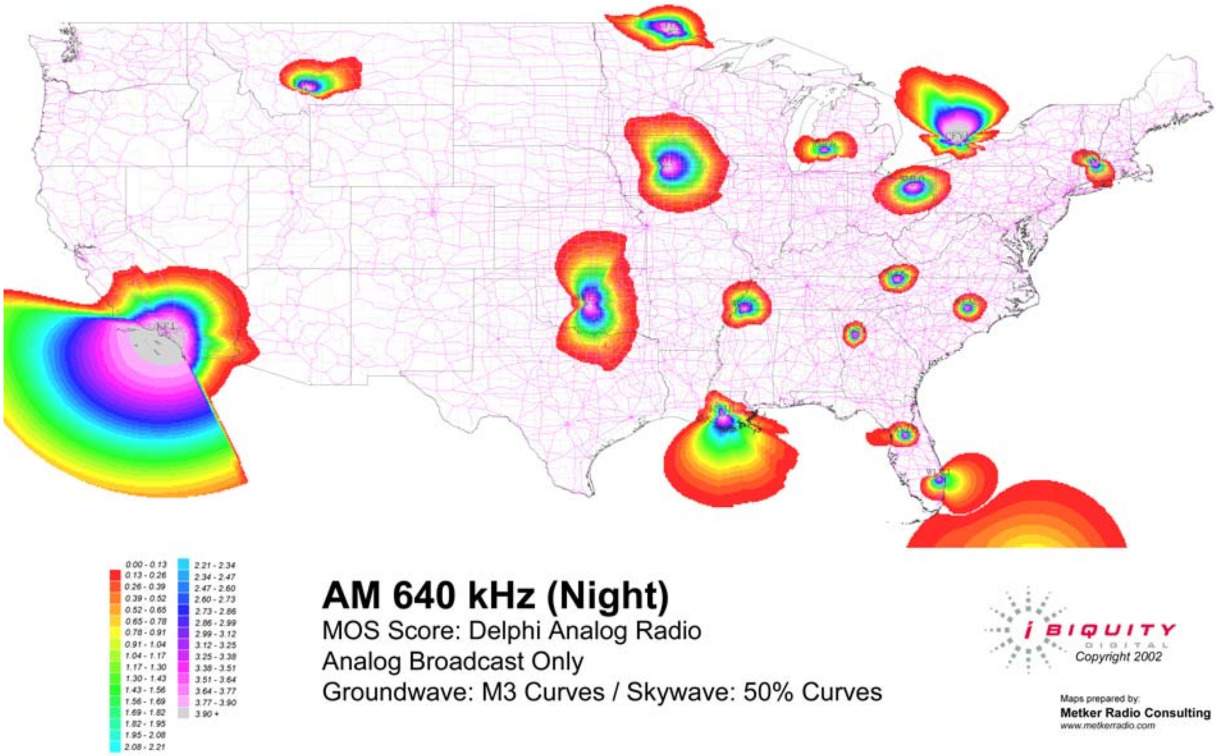

Figure 18: Existing MOS on 640 kHz, a Typical Low End of the Band Channel

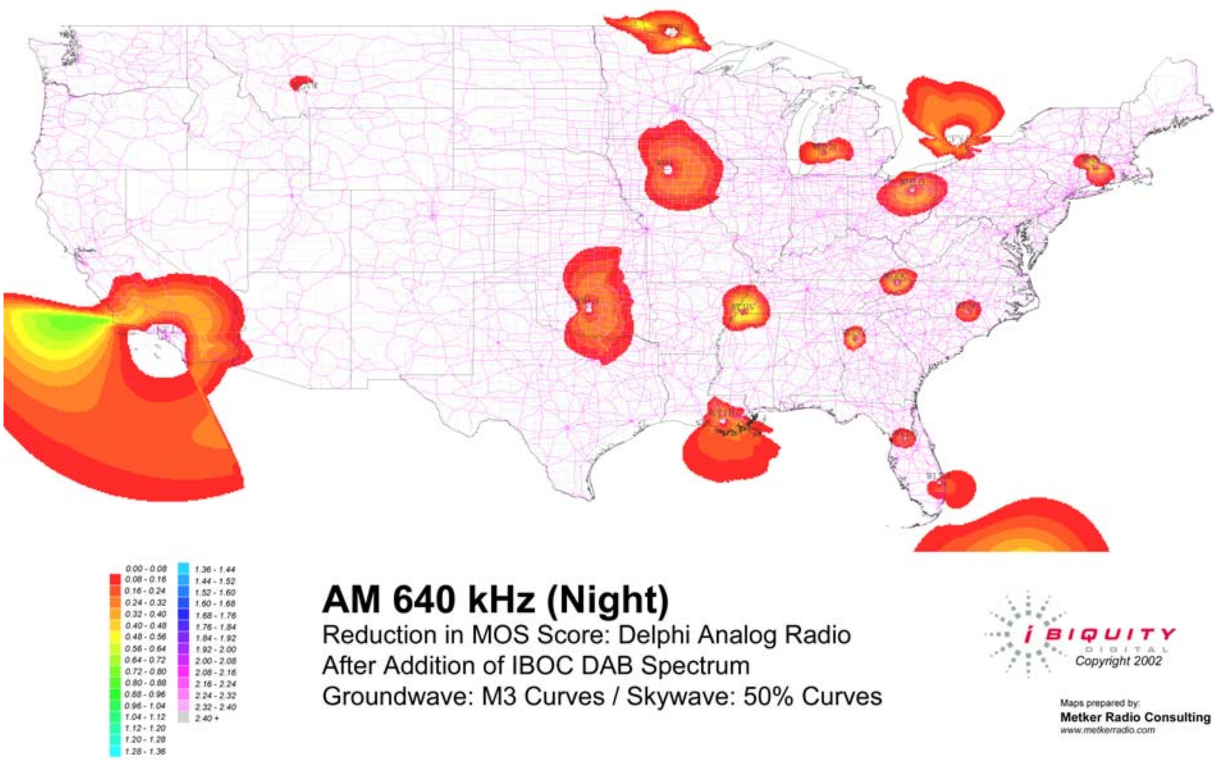

Figure 19: MOS Reduction on 640 kHz, a Typical low End of the Band Channel

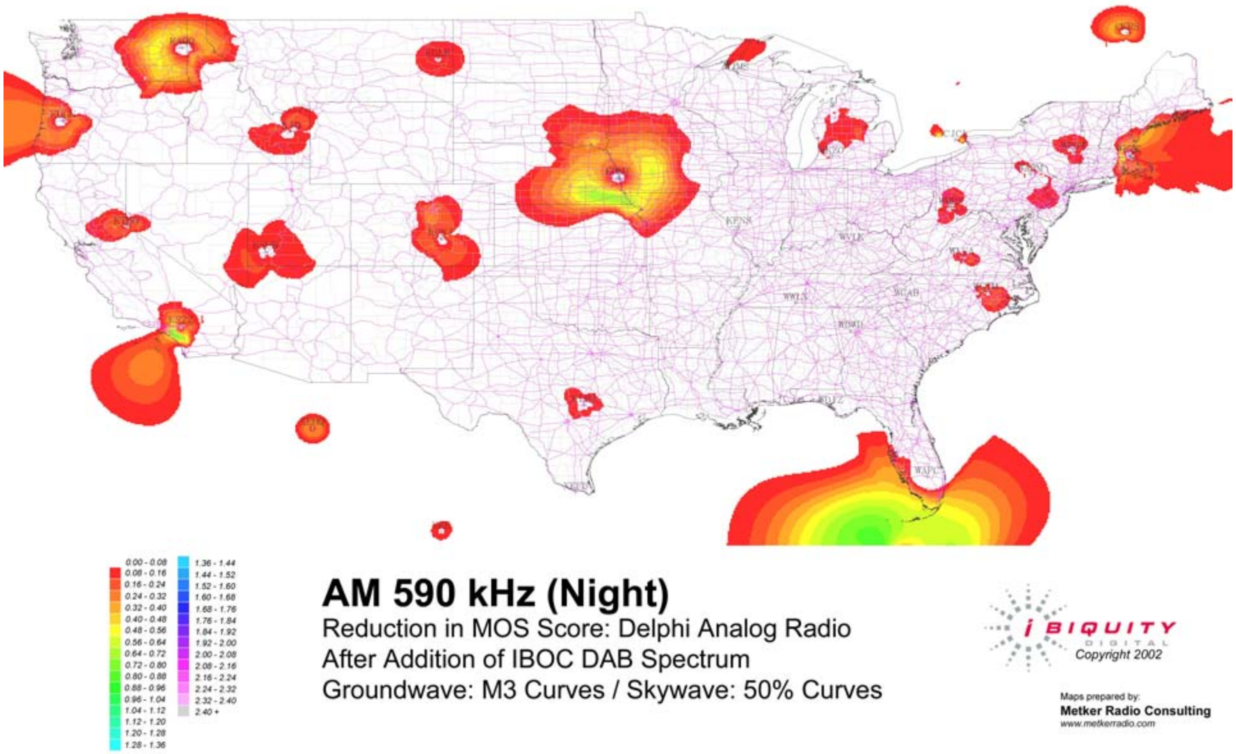

Figure 20 MOS Reduction on 590 kHz, a Typical Low End of the Band Channel

Example 5: A relatively clear channel adjacent to a local crowded channel

The worst case example for a clear channel is when it is adjacent to a local channel. The high level of adjacent channel signal when converted to IBOC can be received on narrowband receivers such as the Delphi, as shown in Figure 21 for 1500 kHz. Adjacent to 1500 kHz on 1490 kHz are close to 180 local stations that, when combined, bring the “background” interference above 1.5 mV/m in the eastern part of the US, as shown in Figure 22. WTOP 1500 kHz, Washington DC shown in Figure 23 will thus be impacted if all of these local stations on 1490 kHz adopt IBOC at night, as shown in Figure 24 and Figure 25. Even with this high level of interference, the largest MOS change is under 0.8 MOS points over the Chesapeake Bay. Note that this region has a poor audio quality to start with; less than 1.8 MOS points with existing analog, and is well outside the NIF of 1.6 as shown.

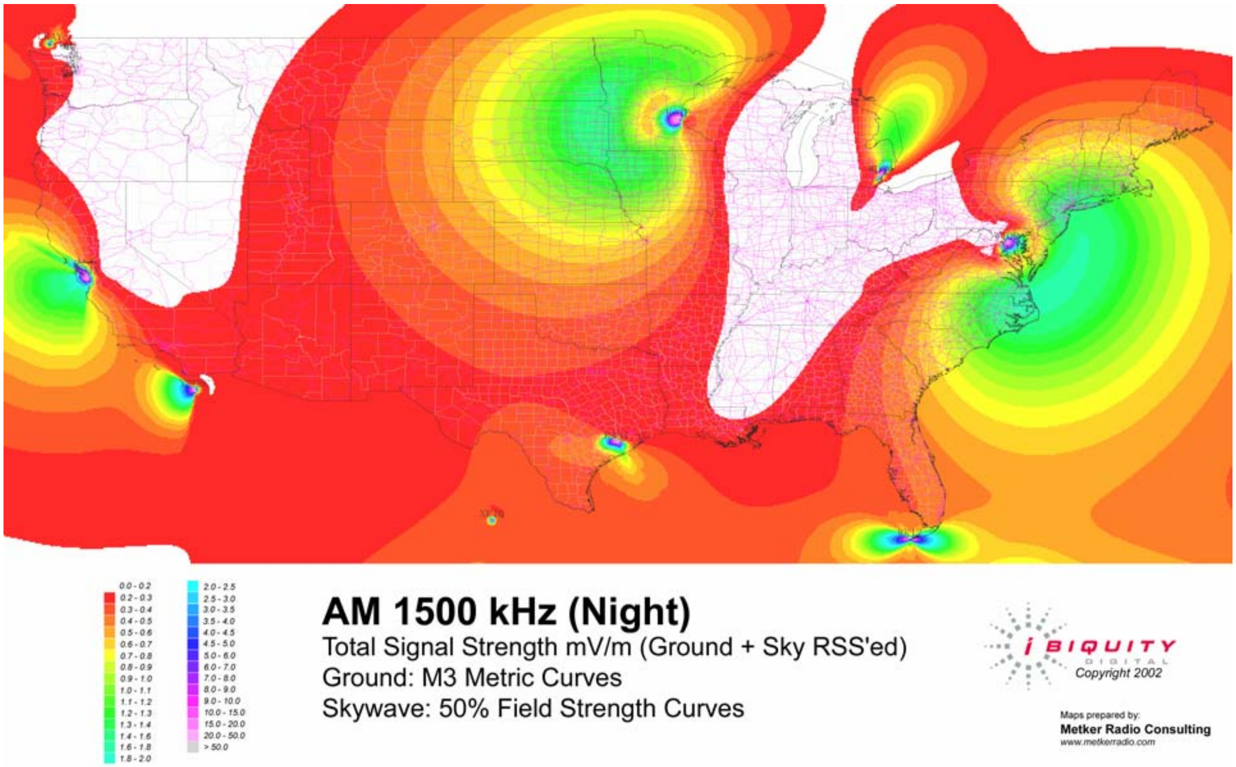

Figure 21: A relatively clear channel 1500 kHz next to a local channel

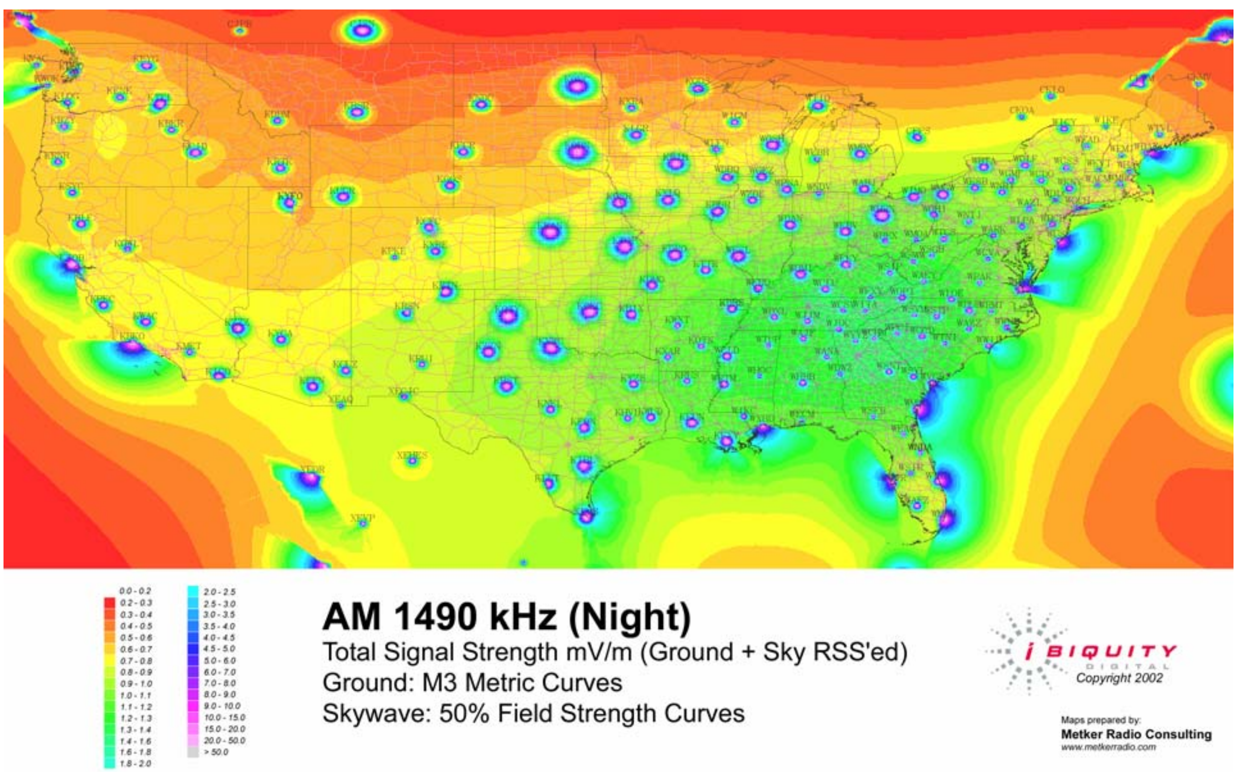

Figure 22: A local channel adjacent to 1500 kHz

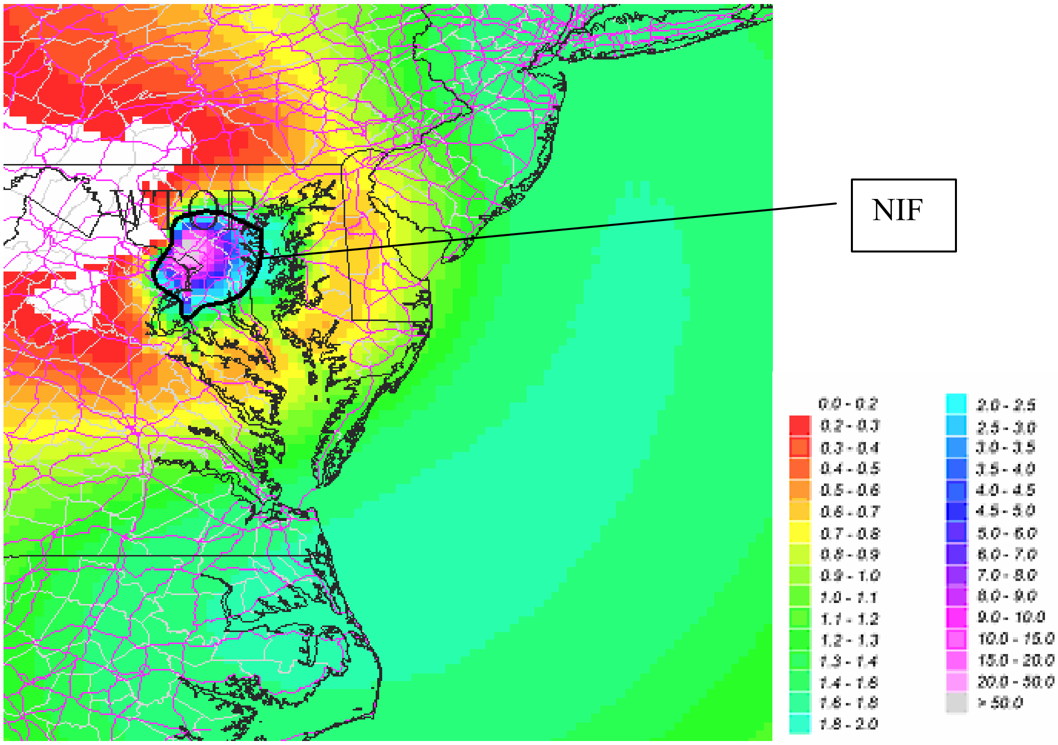

Figure 23: Signal Strength of WTOP, 1500 kHz, Washington DC with 1.6 mV/m NIF Contour (black line)

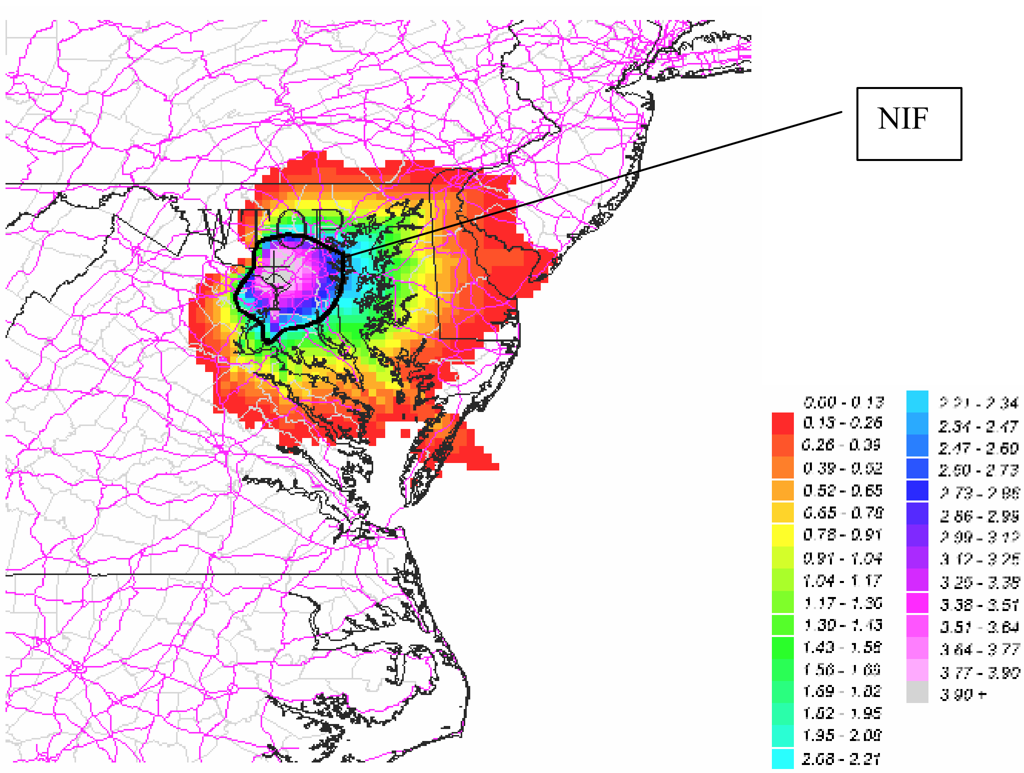

Figure 24: WTOP, 1500 kHz, Washington, Present analog MOS & 1.6 mV/m NIF Contour – Delphi Receiver

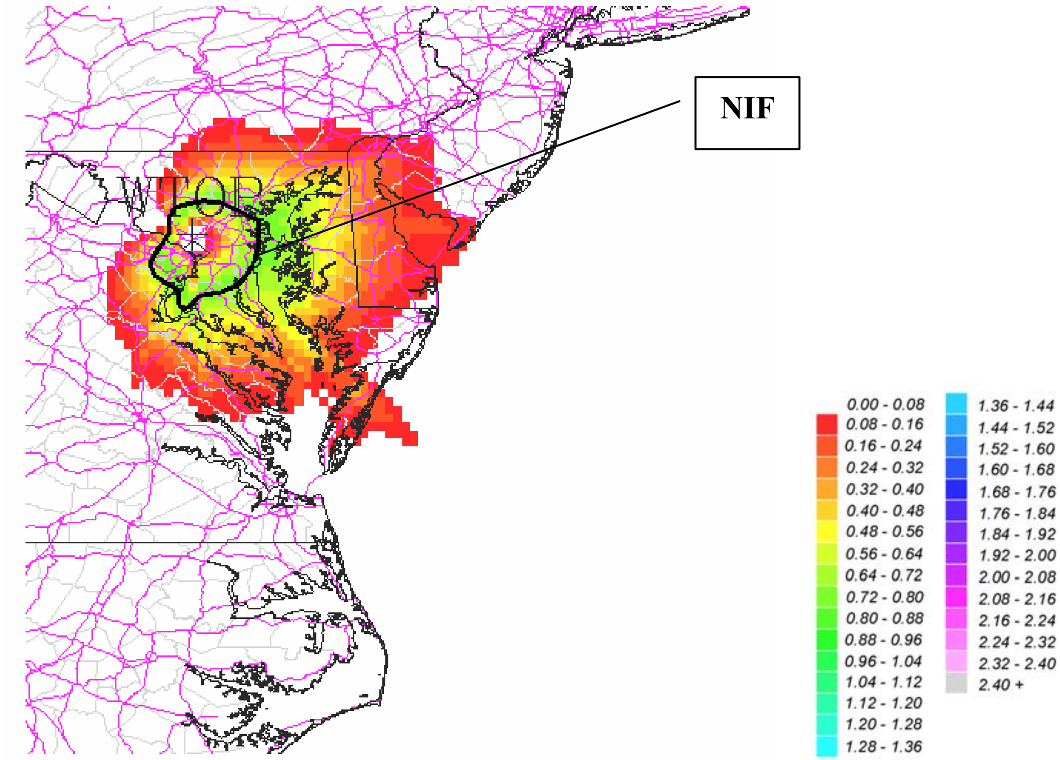

Figure 25: WTOP, 1500 kHz, Washington, 1.6 mV/m NIF Contour & Δ MOS rating after all stations convert to IBOC – Delphi Receiver

Example 6: Least impact Example

In the West, KOAL, Price, Utah shown in Figure 26 and Figure 27 is an example of a station that has relatively good nighttime coverage but has no meaningful impact from the conversion of the AM band to IBOC at night as shown in Figure 28. The impacted areas are well beyond the NIF and are less than 0.16 MOS points. Due to distances to first adjacents, this station enjoys virtually no degradation. There are many stations like KOAL which have extensive coverage and very minimal or no impact such as KTCT, 1050 kHz, San Mateo, CA; WAKR, 1590 kHz, Akron, OH and WARM, 590 kHz, Scranton, PA. This is in addition to the hundreds of small Class C and Class B stations on the local and regional channels that have no impact due to the high levels of analog co-channel interference.

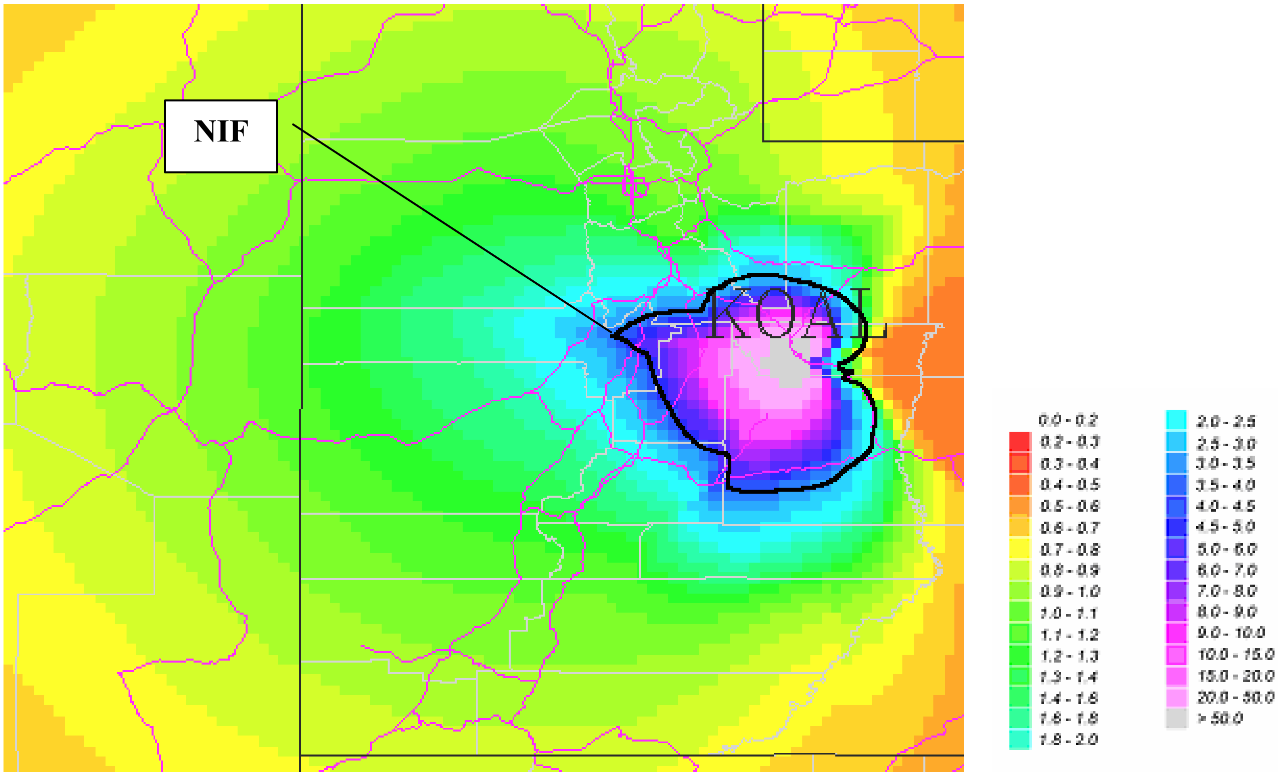

Figure 26: Signal Strength of KOAL, 750 kHz, Price, UT with 4.6 mV/m NIF Contour (black line)

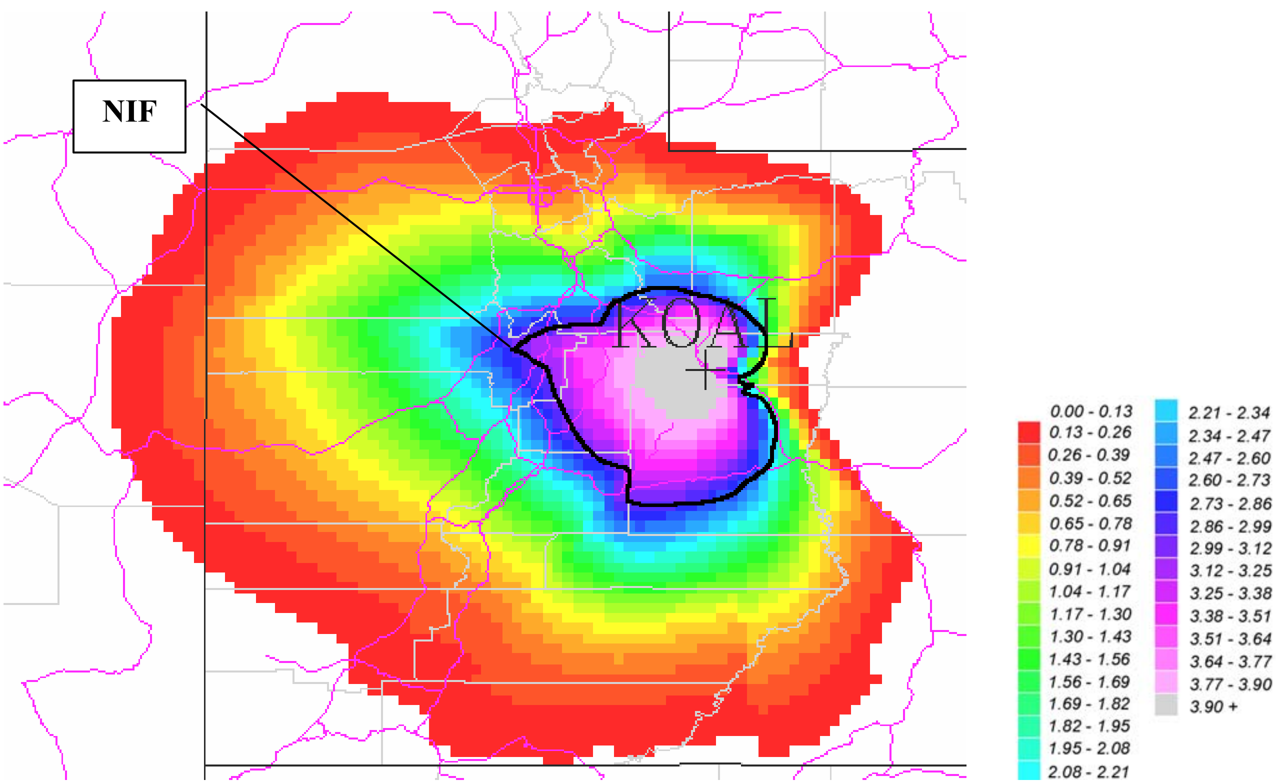

Figure 27: KOAL, 750 kHz, Price, UT, Present analog MOS & 4.6 mV/m NIF Contour – Delphi Receiver

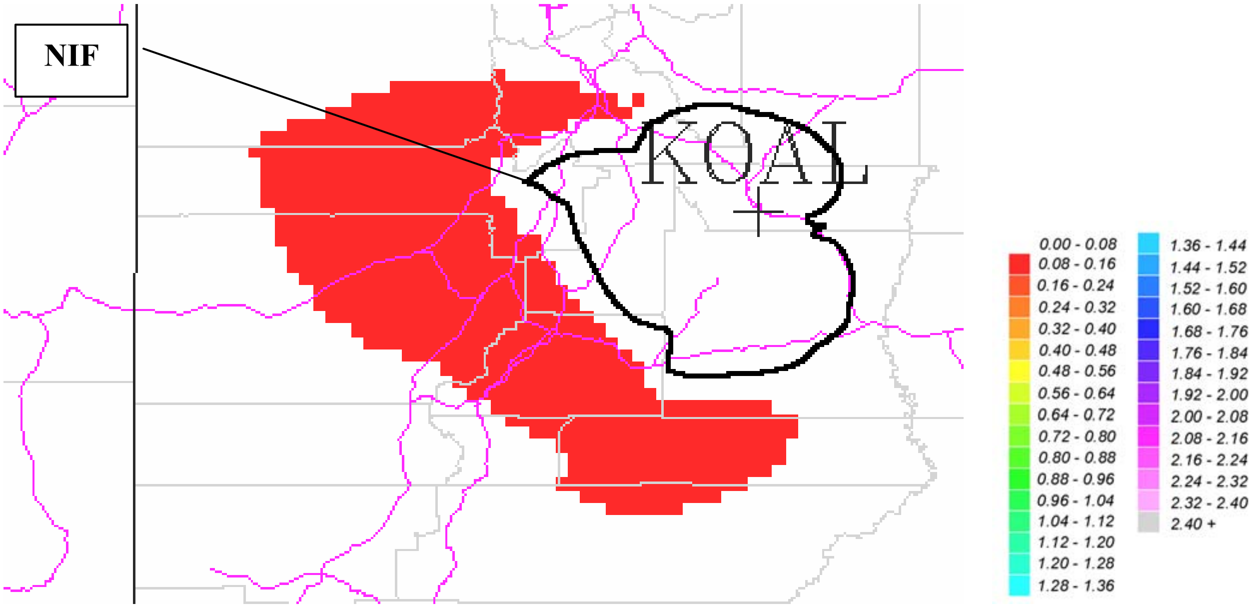

Figure 28: KOAL, 750 kHz, Price, UT, 4.6 mV/m NIF Contour & Δ MOS rating after all stations convert to IBOC – Delphi Receiver

Example 7: Worst case Example

WGCI, 1390 kHz Chicago, shown in Figure 29, is an example of a station with loss due to the implementation of IBOC. WGCI is impacted because it is adjacent to 1400 kHz (see Figure 16) which has over 140 stations on it, all adding up to a high level of interference. If these stations all convert to IBOC, they will impact WGCI. Figure 30 shows WGCI's present analog MOS ratings and the NIF contour. This figure shows that WGCI achieves an MOS rating of 2.4 at its NIF contour. Figure 31 shows that after all stations convert to IBOC, the MOS rating will be impacted by up to 0.8 MOS points. This represents a worst case scenario, where near the edge of WCGI's coverage, a limited number of cells are impacted above the 0.5 significant MOS threshold after total conversion of all stations to IBOC. Since it is a regional Class B station, it covers more than the city of license at night and thus has a fairly large area of coverage that can be impacted. Other stations with this type of impact are also regional Class B stations such as KPTT, 630 kHz, Reno, NV and KABL, 960 kHz, Oakland, CA. Many stations have significant impacts on the East and West Coasts, but the impacts are primarily restricted to areas over the ocean due to excellent conductivity of salt water.

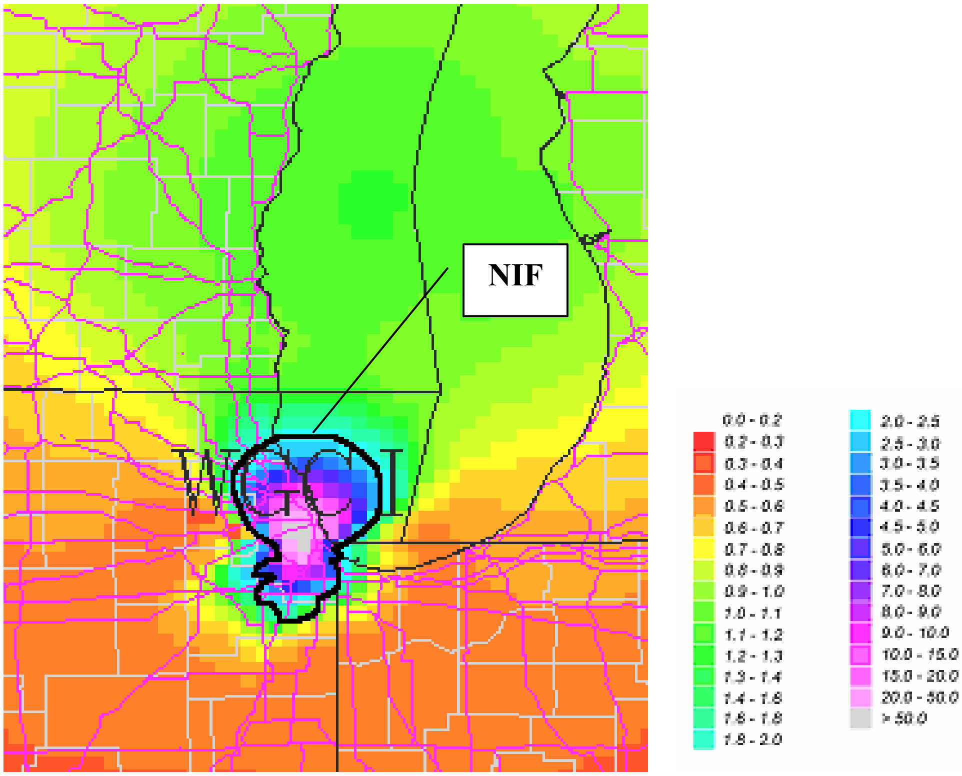

Figure 29: Signal Strength of WGCI, 1390 kHz, Chicago, IL with 2.5 mV/m NIF Contour (black line)

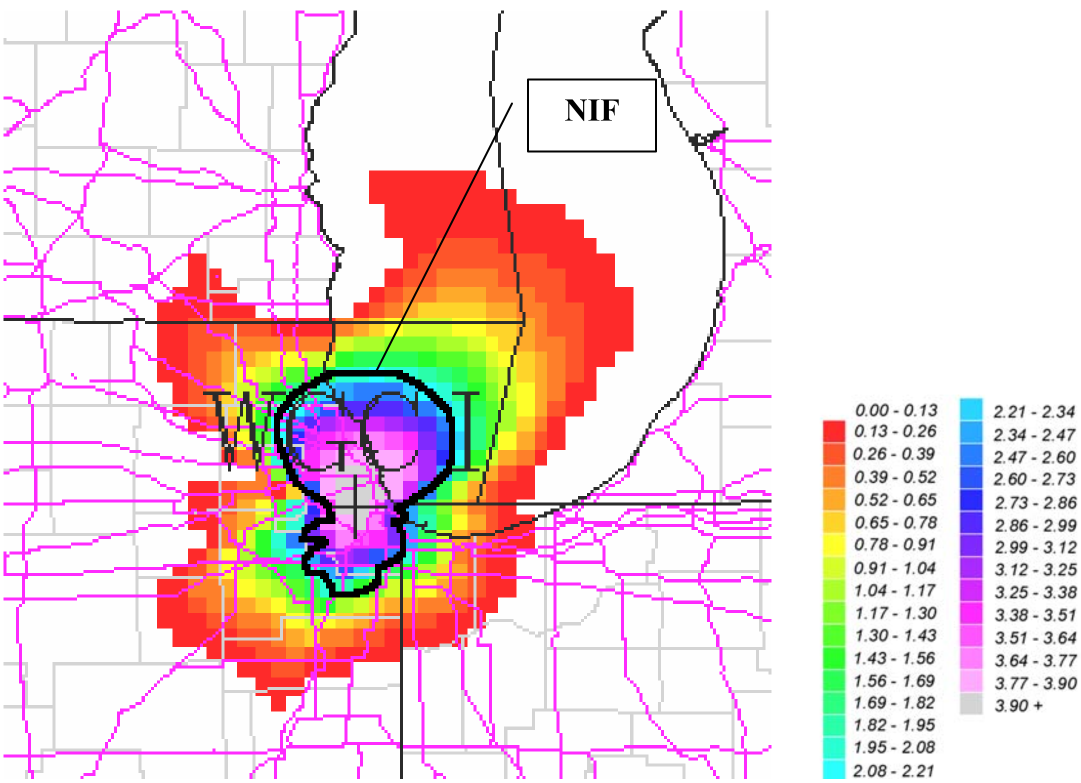

Figure 30: WGCI, 1390 kHz, Chicago, IL, Present analog MOS & 2.5 mV/m NIF Contour – Delphi Receiver

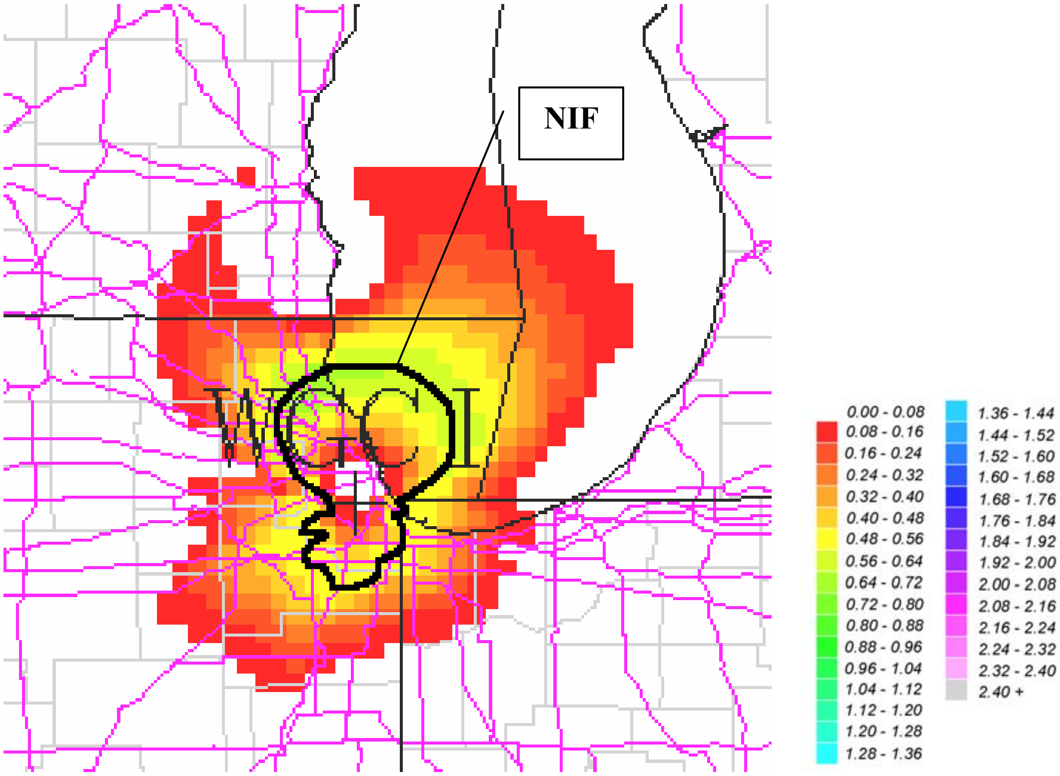

Figure 31: WGCI, 1390 kHz, Chicago, IL, 2.5 mV/m NIF Contour & Δ MOS rating after all stations convert to IBOC – Delphi Receiver

VI. Summary

The study shows the 100% conversion to IBOC at night in the AM band in North American minimally impacts the groundwave service area of a radio station. This impact is minimal for auto receivers due to their filter characteristics and boom box and other directional receivers due to the antenna gain/rejection characteristics. This is a worst case study that minimizes existing analog interference because it assumes the Sony radio is on battery power out of doors and that both receivers are away from all local noise sources and areas that degrade the signal. Both of these conditions are on the steady increase today. Also making this a worst case study is the fact that the Sony receiver was assumed to have an omni directional antenna, which is not true. In reality, its directional antenna easily nulls out an interfering station as long as the receiver is not on a direct line drawn through each station. Most of the impact from IBOC is also restricted to the lower audio quality regions between 1 and 3 MOS points where the number of existing listeners is low. Therefore, even though the results of this study are conservative since it overestimates the extent of the interference, it still shows the impact from the introduction of IBOC is minimal.

The clear channel stations still enjoy a large area of groundwave coverage well in excess of their market and NIF at night even if they are adjacent to more crowded regional or local channels. Regional stations are impacted the most since they have good groundwave service at night but tend to be on more crowded portions of the band. But even these stations are not impacted a great amount (less than 0.5 MOS points) and generally do not have much impact within their NIF which is usually well outside their city of license. Finally, local channels are the least impacted due to the high level of co-channel interference.

Overall, the complete conversion to IBOC at night will not noticeably degrade primary groundwave service in a vast majority of listening areas.

Appendix A
Desired to Undesired Lab Testing & Recording Procedures

1. Overview

This document describes the setup and testbed used for making analog compatibility audio recordings of iBiquity's Digital AM In Band On Channel (IBOC) Digital Audio Broadcast (DAB) system performed at Xetron Corporation. The Xetron tests generated digital audio recordings of the system under various levels of noise, co, and adjacent channel conditions. The recordings were subsequently delivered to the Advanced Television Technology Center (ATTC) for subjective evaluation.

2. Lab Testing

The Xetron Corporation, Cincinnati, OH, conducted laboratory tests on four receivers that were used in the NRSC testing program. The four receivers are detailed in Table A-1. The testing program subjected the radios to a sufficient range of desired to undesired signal interference ratios (D/U) that resulted in producing MOS scores ranging from ≥ 4 to ≤ 1 in the presence of noise, co, first and second adjacent channel interference. These tests were then repeated with hybrid IBOC interferers.

Laboratory recordings were made with the analog receivers subjected to analog and hybrid interference where the D/U ratios were varied over a nine step scale. The scale is anchored at one end by virtually no impact by the undesired and at the other end by severe impact by the undesired. The recordings were made on three of the receivers with the desired signal at the equivalent of the 20 mV/m contour. This strong signal is required to mask the internal noise of the receiver and to assure that each undesired signal is alone in its contribution to the desired. Recordings were made of analog and hybrid IBOC interference from co-channel, 1^{st}, 2^{nd} and noise. To reduce the number of audio cuts, adjacent channel recordings were made of interference on one side of the center channel since the receiver characterizations showed little difference between the upper vs. lower passband response of these radios. Also, the co-channel and noise recordings were made with digital off since host digital impact is significantly than each interferer. The number of recordings works out as follows:

1^{st} and 2^{nd} Adjacents:
3 receivers X [2 recordings (voice and voice over) per D/U digital on] X [2 recordings (voice and voice over) per D/U digital off] X [9 D/U set points] X [2 (1^{st} and 2^{nd} adjacents)] = 216 recordings of adjacents.

Co-channel and Noise sources:
1 receiver (the Pioneer was chosen) X [2 recordings (voice and voice over) per D/U digital off] X [9 D/U set points] X [2 (co-channel and noise)] = 36 recordings

Therefore, the total number of recordings made at Xetron was 252 for the three receivers combined.

3. Test Procedures

- The test receivers used in the subjective recordings.

Table A - 1 Test Receivers[1]

Receiver Name	Model	Serial Number
Delphi Test Receiver	9394139	DDSTM103490268
Pioneer Test Receiver	KEH-1900	UHHI086722UC
Sony Test Receiver	CFD-S22	1192338
Technics Test Receiver	SA-EX110	GY8JA38798

- The Xetron DAB testbed performance was calibrated and verified daily by means of proof of performance tests

- The desired signal RF level for the subjective recordings was 20 mV/m, this corresponds to the following recommended RF levels injected into the test receivers.

Table A - 2 Recommended RF Levels

Receiver	Recommended RF Level
Delphi 9394139	-50 dBm
Pioneer KEH-1900	-50 dBm
Technics SA-EX110	-57 dBm
Sony CFD-S22	-64 dBm

- For the subjective recordings, voice and voice-over cuts were used as the audio program material for the desired signal. The interferer signal audio consisted of a voice-over cut, which was looped several times or White Gaussian noise.

- All the audio cuts used in the testing program were taken off the main console at KYW, prior to processing. All cuts were pre-processed, at the Xetron laboratory, using the Orban 9200 Optimod. The settings used on the 9200 Optimod are described in Section 3 below.

- For both the desired and undesired pre-processing, the unprocessed audio was played using the DENON CD player, and its AES/EBU output signal was passed through the 9200 Optimod. The AES/EBU outputs of the Orban 9200 Optimod were connected to the digital input of the Lynx One audio card for recordings. Once the processed recordings were completed, they were each cropped to the section of interest. These cropped files were then written to CD in stereo 16 bit, 44.1 kHz format for use in the subjective testing.

- The modulation levels used for both the desired and undesired signals were +125/-100%.

[1] These receivers were previously characterized as part of iBiquity's submissions to the NRSC, January 4, 2002

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- For the injected noise recordings, White Gaussian noise was generated by the testbed and combined with an analog desired signal. The audio CD used for this test contained a track of MATLAB-generated Gaussian noise at f_s = 44.1 kHz, normalized to –9 dBFS. The right and left audio channels (I and Q after up-conversion) were white and mutually independent. The center frequency of the I/Q modulator was set to f_c + 50 Hz to eliminate any audible beat between the residual I/Q modulator carrier and the desired carrier.

- The level of the injected White Gaussian noise was characterized by measuring the RF noise power in a 5 kHz bandwidth centered at 1 MHz. This measurement was performed using the band power marker and RMS averaging functions of the HP 89441A Vector Signal Analyzer. The level of the noise was adjusted using the testbed switchable attenuators, such that the noise was swept from –41.3 dBc/Hz to –81.3 dBc/Hz in 4 dB increments.

4. Equipment Settings

1.1.1.1.1 Orban 9200 Optimod Settings

- Modified the General Purpose Medium preset.
- Modified per the suggestions of Robert Orban and Greg Ogonowski of Orban, Inc. These modifications are indicated by the highlighted text.

<u>Under Setup:</u>

I/O CALIB:
- DIG IN CALIB:
  - INPUT: Digital
  - DI MODE: DIG-S
  - DI REF VU: -15.0 dB
  - DI REF PPM: -7.0 dB
- DIG OUT CALIB:
  - DIGITAL OUT:
    - DO 100%: -3.6 dBFS
    - DO RATE: 44.1 kHz
    - DO SYNC: external
    - HF DELAY: off
    - HF SHELF: off

TEST:
- MODE: operate

BANDWIDTH:
- HP FLTR: 50 Hz
- LP FLTR: 4.5 kHz or NRSC

ST CHASSIS: No
NITE MODE: disabled
POS PEAK: 125%

<u>Under "04-COMP TEST 3/02", Modify:</u>

EQ:
- LF GAIN: +6.0 dB
- MF GAIN: -1.5 dB
- HF CURVE: 0
- HF GAIN: 18.0 dB
- EXPERT EQ MENU:
  - LF EQ:
    - DJ BASS: off
    - LF FREQ: 82 Hz
    - LF WIDTH: 1.0 oct
    - LF GAIN: +6.0 dB
  - MF EQ:
    - MID BASS: 0 dB
    - MF FREQ: 1036 Hz
    - MF WIDTH: 1.0 oct
    - MF GAIN: -1.5 dB
  - HF EQ:
    - HF CURVE: 0
    - HF GAIN: 18.0 dB
  - SYS BANDWIDTH:
    - HI PASS: 50 Hz
    - LO PASS: NRSC

FULL CONTROL:
- AGC: on
- AGC DRIVE: 11
- AGC REL: 2.0 dB/S
- GATE THR: -40 dB
- BASS COUPL: 50 %
- MB DRIVE: 12
- MB RELEASE: fast
- MB CLIP: +2.4
- DWNEXP THR: off
- HF CLIP: 0.0 dB
- EXPERT CONTROL:
  - 5B INPUT DRIVE:
    - B1 DRIVE: +1.5 dB
    - B2 DRIVE: +0.0 dB
    - B3 DRIVE: +0.0 dB
    - B4 DRIVE: +0.0 dB
    - B5 DRIVE: +0.0 dB
  - 5B OUTPUT MIX:
    - B1 OUT: -1.5 dB
    - B2 OUT: +0.0 dB
    - B3 OUT: +0.0 dB
    - B4 OUT: +0.5 dB
    - B5 OUT: +1.0 dB
  - FINAL CLIP:
    - FINAL CLIP: +1.5

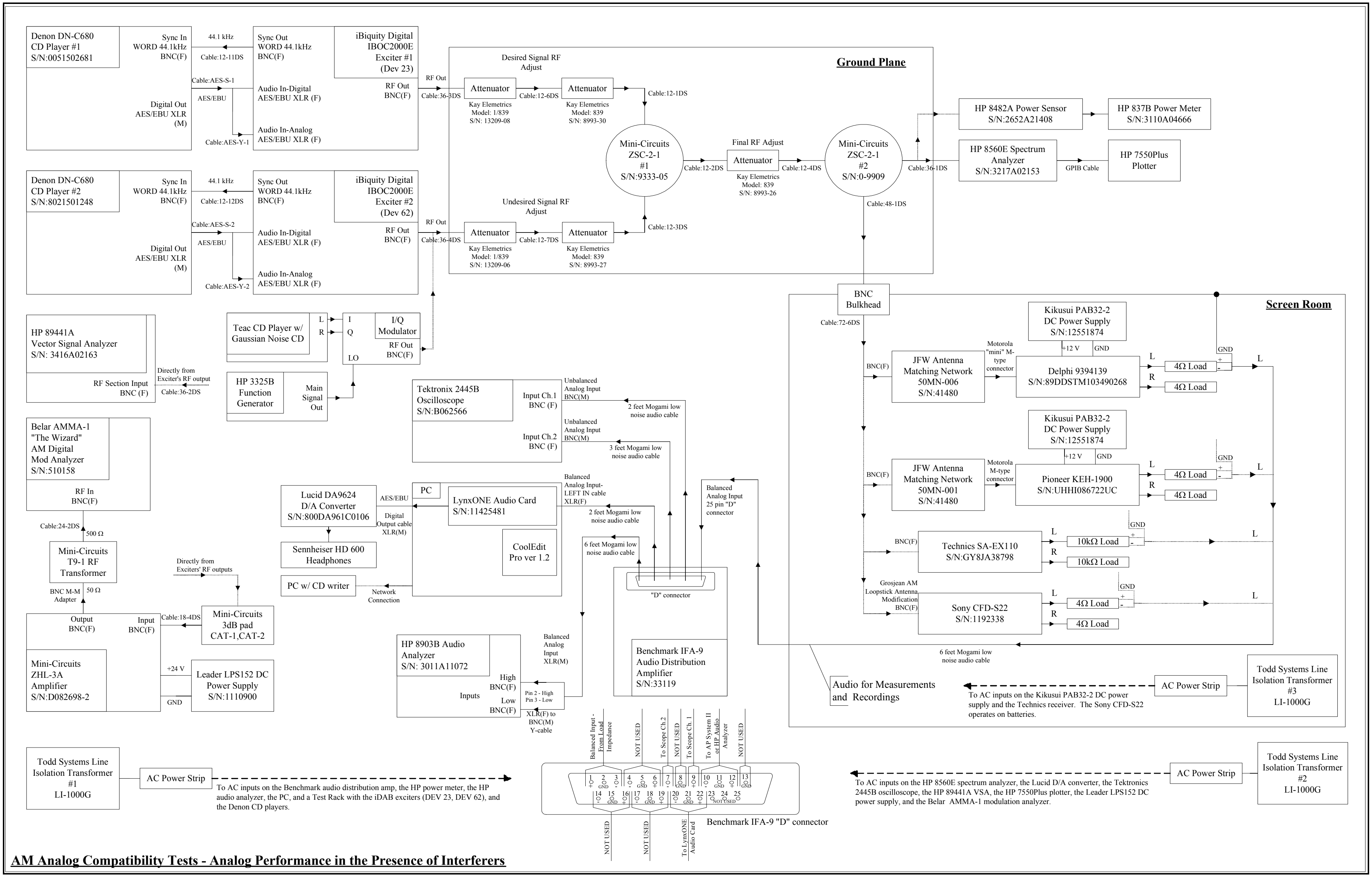
5. Test Matrix

- The subjective recordings made follow the test matrix outlined below.

Table A - 3 AM Analog Compatibility: Testing Matrix

Test Scenario		
Scenario	Interferer Type	D/U, dB
Upper 1st Adjacent Interferer	Analog and Hybrid	-16, -12, -8, -4, 0, +4, +8, +12, +16
		(Additional D/U's on Sony Rx only: +20, +24)
Lower 2nd Adjacent Interferer	Analog and Hybrid	-24, -20, -16, -12, -8, -4, 0, +4, +8, +12, +16
		(Additional D/U on Delphi Rx only: -28)
Co-Channel Interferer (For the Pioneer only)	Analog	0, 4, 8, 12, 16, 20, 24, 28, 32, 36, 40
Gaussian Noise Interferer (For the Pioneer only)	Analog	–41.3 dBc/Hz to –81.3 dBc/Hz in 4 dB

5.1. Testbed Diagram



Appendix B

Subjective Audio Methodology
By Ellyn Sheffield, Ph.D.

1. Objectives of the Subjective Audio Study

This study was designed to subjectively evaluate the impact that IBOC has on co-channel, first and second adjacent AM analog stations. Recordings were generated by Xetron Corporation in their Cincinnati laboratory facilities. These recordings included 231 audio samples recorded from two analog AM receivers under various reception conditions. Subjective tests were conducted at the Advanced Television Test Center (ATTC). Data from this subjective audio evaluation was used provide a realistic view of potential analog listening for all AM stations. That is, Mean Opinion Scores (MOS) were collected for various impairment conditions and used to generate detailed interference ratios characterizing the listening experience for analog AM radio stations.
The Sony Boombox and the Delphi Auto radio were selected for adjacent channel testing as they represent the wide and narrow IF filter bandwidths which dictates the amount of interference within the receiver's passband. The recordings from the Pioneer were used for co-channel and noise evaluations.

2. Subjective Audio Methodology

The impact of AM IBOC on an analog AM signal was measured in two ways. First, 120 consumers chosen from the general population were asked to rate the quality of the audio they hear from IBOC-off and IBOC-on segments on an MOS 0-5 point scale. These results provided a statement about the overall quality of the signal under different transmission conditions. Second, consumers were asked to judge whether they would listen to the radio transmission or switch to another station given that the audio would neither improve nor deteriorate. These results provided threshold information, exposing the point at which consumers would no longer listen to the broadcast.

3. Experimental Design

Table B-1 shows the experimental design of the study. The total experimental design included 9 D/U levels (-16, -12, -8, -4, 0, +4, +8, +12, +16). Because the number of D/U ratios x IBOC On/Off x Genre x Receivers would have yielded too many sound samples for participants to listen to in one test, participants were divided into 3 experimental groups. Each group listened to 231 samples, including samples from 3 of the 9 D/U ratios for 1st & 2nd adjacent interference, samples with Co-Channel or Noise interference and Anchor samples. Each experiment, including training and testing took approximately 2 hours for each participant to complete.

Table B-1: Experimental Design of Experiments 1-3

Experiment Session	Type of Interferer	Number of Cuts					
		D/U	1st & 2nd Adj	Receivers	IBOC On/Off	Sample Genre Speech or Voice Over (VO)	Total
Part 1 MOS	Adjacent Co-Channel & Noise Anchors	3 9	2 --	2 1	2 1	1 Speech 1 VO 1 VO	48 9 20
Part 2a Threshold	Adjacent Co-Channel & Noise Anchors	3 9	2 --	2 1	2 1	1 Speech 1 VO 1 VO	48 9 20
Part 2b Threshold	Adjacent Co-Channel & Noise Anchors	3 9	2 --	2 1	2 1	1 Speech 1 VO 1 VO	48 9 20
						Total	**231**

4. ACR Methodology and Threshold Questions

The experiment was divided into two parts. For Part 1, the methodology replicated all testing procedures used during iBiquity's NRSC test program, with the exception of using an expanded 6-point MOS scale. Table 2 describes the MOS Category and numerical equivalent. Participants heard audio samples, one-by-one, and were asked to rate the quality of each sample, from Excellent to Failure. Using this expanded scale allowed consumers to judge when a sample had failed completely.

Table B-2: Definition of MOS Scale

MOS Category	Numerical Equivalent
Excellent	5
Good	4
Fair	3
Poor	2
Bad	1
Failure*	0

* Participants were told that "failure" rating meant they believed the transmission had completely failed and could not be listened to under ANY circumstance. In contrast, a rating of "bad" indicated that a sample did not meet the participant's standards, but that it did not fail completely.

In part 2, participants listened to all of the audio recordings again and were asked to judge whether they would keep listening to the transmission or turn it off. Part 2 was divided into two subsections: 2A – Casual listening; and 2B – Motivated listening. For Part 2A, the experimenter read the following scenario to participants:

"Suppose you are in your car, flipping around from station to station for something to listen to. You aren't looking for anything in particular to listen to, you are just flipping around. You come across the following radio broadcast. The audio from this broadcast

will stay the same over time…that means it won't ever improve, but it won't ever get worse. Would you continue to listen to this station or flip to another station? Remember, you are only judging the ***quality*** *of the transmission*."

This scenario was intended to elicit consumer reaction when participants are merely listening in a casual way, "flipping" from one station to another.

For Part 2B, the experimenter read the following instructions:

"Suppose you are in your car listening to your favorite news show or sports broadcast. The program is one that you really are interested in and have been looking forward to hearing. The audio from this broadcast will stay the same over time…that means it won't ever improve, but it won't ever get worse. Would you continue to listen to this station or turn to another station? Remember, you are only judging the ***quality*** *of the transmission."*

This scenario was intended to elicit consumer reaction when participants are listening in a determined, directed way (i.e., listening to their favorite station).

5. Participants

Experiments were conducted at ATTC over a 15-day period. Table B-3 describes participants' demographics. In 3 experiments, 132 participants were tested. Data from 12 participants were not used: in 4 cases, participants rating vectors did not conform to the vectors of ratings from the group of participants within their experiment; in 8 cases participants did not finish their test session (several due to power outages; 2 due to experimenter error; 2 for personal reasons, etc.).

Table B-3: Participants used in Experiments

Age Group	Female	Male
16-29	15	16
30-40	15	17
41-50	15	15
51-65	15	12
Total	**60**	**60**

6. Training Period and Screening

Training included a brief orientation to the software used to collect data. In order to minimize the risk of biasing participants, training samples were not played prior to testing. Screening was performed after data collection takes place. A post-hoc statistical test was conduced for each participant to ensure that individual participants' pattern of rating correlated positively to the pattern of ratings found in the group. This eliminated participants who, for whatever reason, could not or did not follow instructions properly.

7. Test Facility Setup

Two rooms were configured for listening, located in a quiet space with no aural or visual distractions*. Participants were seated in a highback chair, located in a pre-determined position within the room, and instructed not to move or relocate the chair during the course of the experiment. Participants registered their opinions using a small, palm-held trackball that operates in a manner similar to a standard computer mouse.

All audio samples were presented to the listener over speakers via computer workstations configured with digital audio cards, D/A converters and linear audio power amplifiers. Speakers were chosen over headphone listening in order to more closely simulate the listening experience of consumers in the real world. For each test session, the experimenter chose between several types of speakers using a switchbox, hidden from the test participant. All of the speakers were consumer grade devices appropriate for the specific audio samples under test. For examples, audio samples that originated from an automobile receiver were presented to the listener using consumer grade automobile speakers. Similarly, audio samples that originated from the "boombox" receiver were presented using the loudspeakers that were built into the actual boombox. Table B-4 lists the speaker manufacturers.

Table B-4: Speakers included in the experiments

Receiver	Speakers	Model
Delco/Pioneer Auto RX	Optimus (Tandy)	Cat. #12-1733
Sony Boombox	Sony	CDF-S22/32

* Rooms were visited and approved for this test by a member of the NRSC Sub-committee.

Appendix C
Combining Noise and Interference to Determine MOS Scores for an AM Receiver

Brian Kroeger, D.Sc.
Chief Scientist, iBiquity Digital Corporation
Scott Metker, Ph.D.
Metker Radio Consulting

Signal and interference levels were computed over various regions of interest for groundwave and skywave signals using models in accordance with FCC methodology. These signal and interference values were combined using the formulas presented in this study to determine overall effects of interference to be expected. Both the effects of the present levels of analog interference, and changes in received SNRs that could result from the full scale implementation of the IBOC technology were then characterized.

The effects of multiple interferers were next analyzed and characterized. Subjective audio testing using a Mean Opinion Score (MOS) methodology was used to determine the effects of interference on the listener. Due to the selectivity of the IF filter in the AM receiver, adjacent channel interferers have less of an effect on the overall MOS than interfering signals of the same strength on the co-channel. This is a function of the selectivity of the receiver's IF filter.

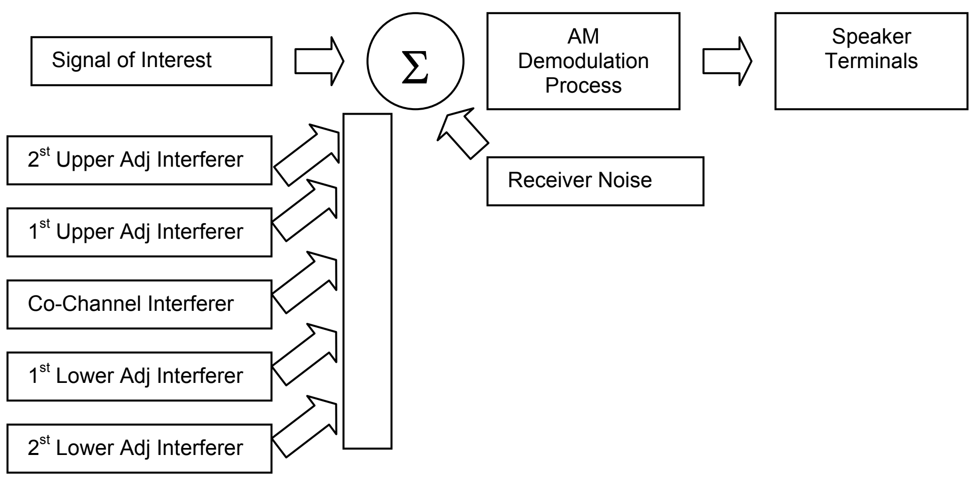


Figure C - 1 AM Receiver with Adjacent and Co-Channel Interferers

The ***effective*** MOS score is due to a combination of interferers. The model depicted in Figure C - 1 can be interpreted mathematically to compute an effective SNR and MOS. This relationship is described as follows:

$$SNR_{effective} = 20\log\left[\frac{d}{\sqrt{(u_{-2})^2 \cdot f_{-2} + (u_{-1})^2 \cdot f_{-1} + (u_0)^2 \cdot f_0 + (u_{+1})^2 \cdot f_{+1} + (u_{+2})^2 \cdot f_{+2} + u_{nf}^2}}\right]$$

$$MOS_{effective} = function(SNR_{effective})$$

where the following terms are defined:

d	= desired signal (mV/m)
$u_{-2}, u_{-1}, u_0, u_{+1}, u_{+2}$	= undesired signal (mV/m) for 2nd lower adjacent, 1st lower adjacent, co-channel, 1st upper adjacent, and 2nd upper adjacent interfering stations, respectively u_{nf} = the internal noise in the receiver (mV/m).
$f_{-2} \cdots f_{+2}$	= Channel attenuation for 2nd lower through 2nd upper interferers representing the power attenuation applied to interferers due to receiver IF filter
$SNR_{\text{effective}}$	= Effective combined signal to noise ratio in dB.
$MOS_{effective}$	= a function of $SNR_{\text{effective}}$ established through subjective MOS scoring.

The interference terms in denominator of the log expression are summed based on the assumption the interfering signals are uncorrelated. The computation of effective SNR for arbitrary values of d and u involves defining the proper values of f_{-2} through f_{+2}. Each of these values represents an attenuation factor that represents the overall transfer function of the adjacent signal's ability to pass through the IF filter and cause interference or degradation at the audio output. This effective SNR determines the overall MOS score resulting from multiple interferers. The more selective the IF filter, the lower the value of f for adjacent channels. Thus, 2nd adjacent channels should have values of f that are much closer to zero than 1st adjacent channels, due to the fact that the IF filter will do a better job of filtering out these signals.

Determination of Channel Attenuation Factors

The channel attenuation factors are used to weight and combine the different interferers. Specifically different levels of noise, cochannel, first adjacent, or second adjacent signals produce different amounts of degradation resulting in different MOS scores. Although overall SNR can be measured and used as an objective metric for determining degradation, this may not be the best method of determining audio quality degradation. This is because 2 different interference sources can be set at the same SNR in 2 separate tests, but can result in different MOS scores when 2 tests are compared subjectively. For instance a listener may find that audio crosstalk from a voice audio source is more objectionable than white noise at the same SNR. Therefore it is desirable to weight the noise sources according to their subjective degradation, and not necessarily SNR. This is accomplished through MOS scoring of each of the interfering sources over a range of SNR levels. The contribution of each interference source is then weighted such that it is combined as an equivalent white noise source. This results in an equivalent SNR where total interference and noise is assumed to be an equivalent level of white noise applied at the receiver input. Then the MOS score can be interpreted as a function of the SNR for each interference source. Linearity and superposition is assumed for determining the effects of a combination of interference sources. This is explained in the following example.

Assume a particular SNR for white noise results in an MOS score of 2. Assume also that another, possibly different, level of SNR for AM co-channel crosstalk results in an MOS score of 2. If the white noise SNR is reduced by x dB to result in an MOS score of 1, then the SNR reduction by the same x dB of the AM co-channel crosstalk should also result in an MOS score of 1. Furthermore, if the white noise and AM co-channel crosstalk noise were reduced to one half (-3 dB) their original power and added together, the combination should also result in an MOS score of 2. This property of linearity and superposition allows combining of the weighted interference sources to get the effective SNR needed to estimate the overall effective MOS score.

The relative weight, or attenuation factor f, is determined by finding the relative levels of each interference source resulting in a particular reference MOS score (e.g. pick reference MOS score of 2.5). The white noise case has no attenuation factor since it is used as the reference from which the equivalent MOS score is obtained. The attenuation factors *F* are therefore computed as the difference in input signal level (dB) between white noise and the particular interference source producing the reference MOS score (e.g., 2). The value of *F* and is related to value f using the following formula:

$$f = 10^{F/10}$$

where *F* represents each channel's attenuation in dB due to the receiver IF filter and *f* represents the corresponding power attenuation.

Results of Subjective MOS Evaluation:
Figure C - 2 shows the results of MOS evaluation of the effects of white noise added to the received signal. The D/U values in the plot are the ratios of the desired AM-modulated signal power to the undesired white noise power measured in a 5 kHz predetection noise bandwidth. The particular values of D/U are in dB. It is verified that the MOS scoring of the noise is a good fit to the solid hypothesis curve, which will be used as a reference to gauge the relative effects of other interfering sources. It is further assumed that the white noise effects are mostly independent of receiver type since this noise is within the passband of any receiver.

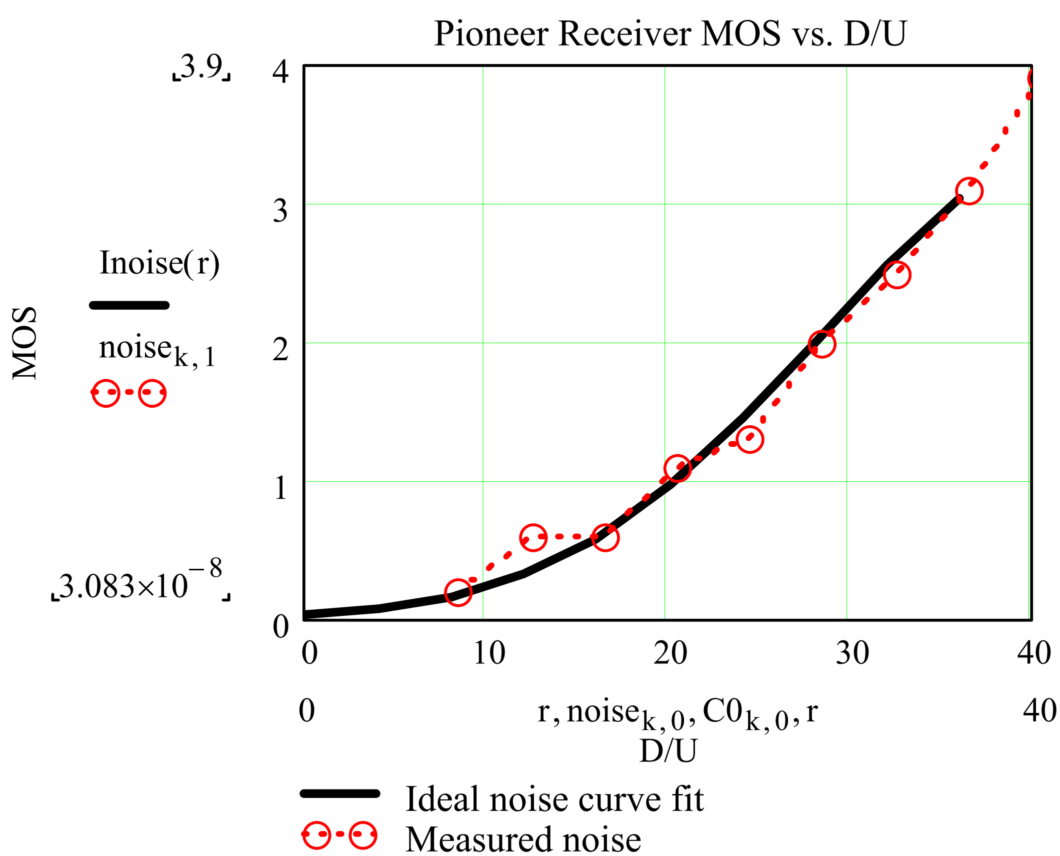


Figure C - 2 **Subjective evaluation of white noise fit to hypothesis reference noise (interference) curve.**

Figure C - 3 shows the effects of a cochannel interferer on the MOS score over a range of D/U values. Although the MOS scoring appears somewhat noisy, a reasonably good curve fit can be made to the scored values. The difference in D/U (dB) between this curve fit and the reference curve yields the attenuation factor for cochannel interference. It is further assumed that these cochannel effects are mostly independent of receiver type since most of the interference is within the passband of any receiver.

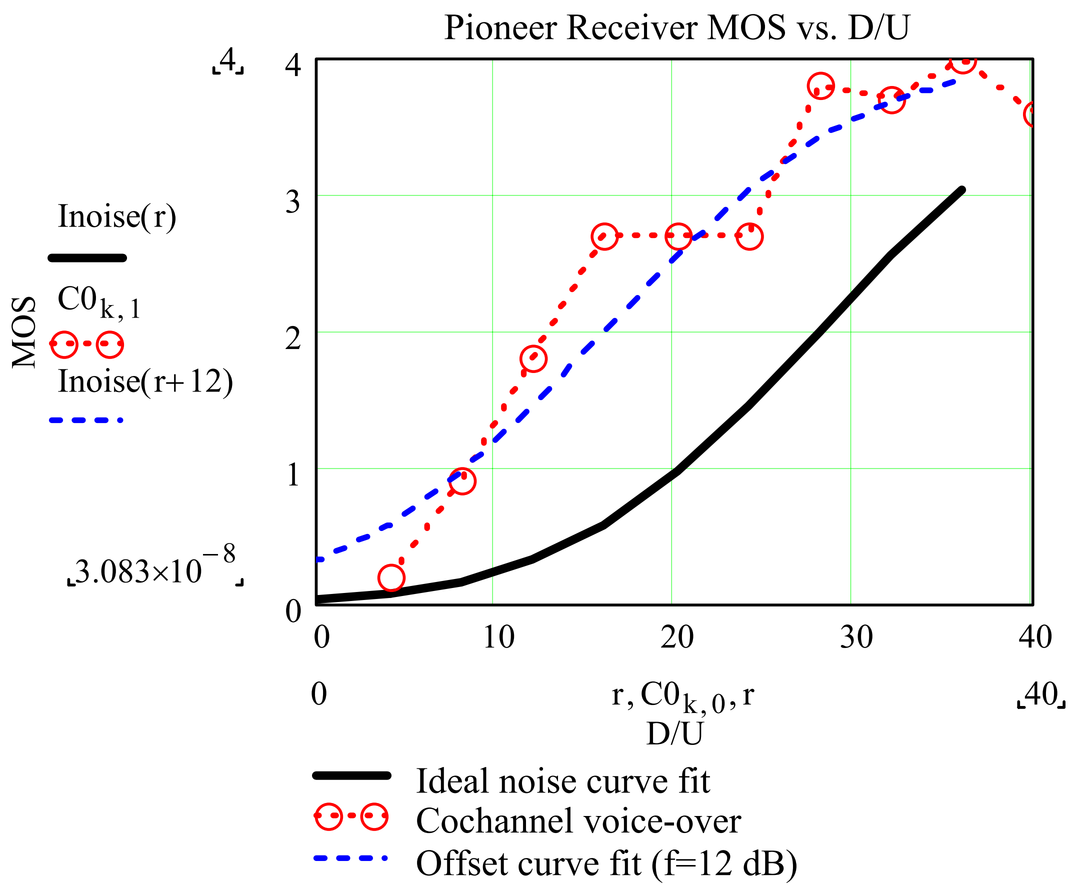


Figure C - 3 Subjective evaluation of a cochannel interferer on MOS score. The difference in D/U for these results versus the reference white noise curve is the attenuation factor for a cochannel interferer.

Figure C - 4 shows the effects of a first adjacent interferer on the MOS score over a range of D/U values. Two cases are characterized where DAB is off and on. Although the MOS scoring appears somewhat noisy, reasonably good curve fits can be made to the scored values. The effects of the first adjacent interferer are dependent on the selectivity of the particular receiver.

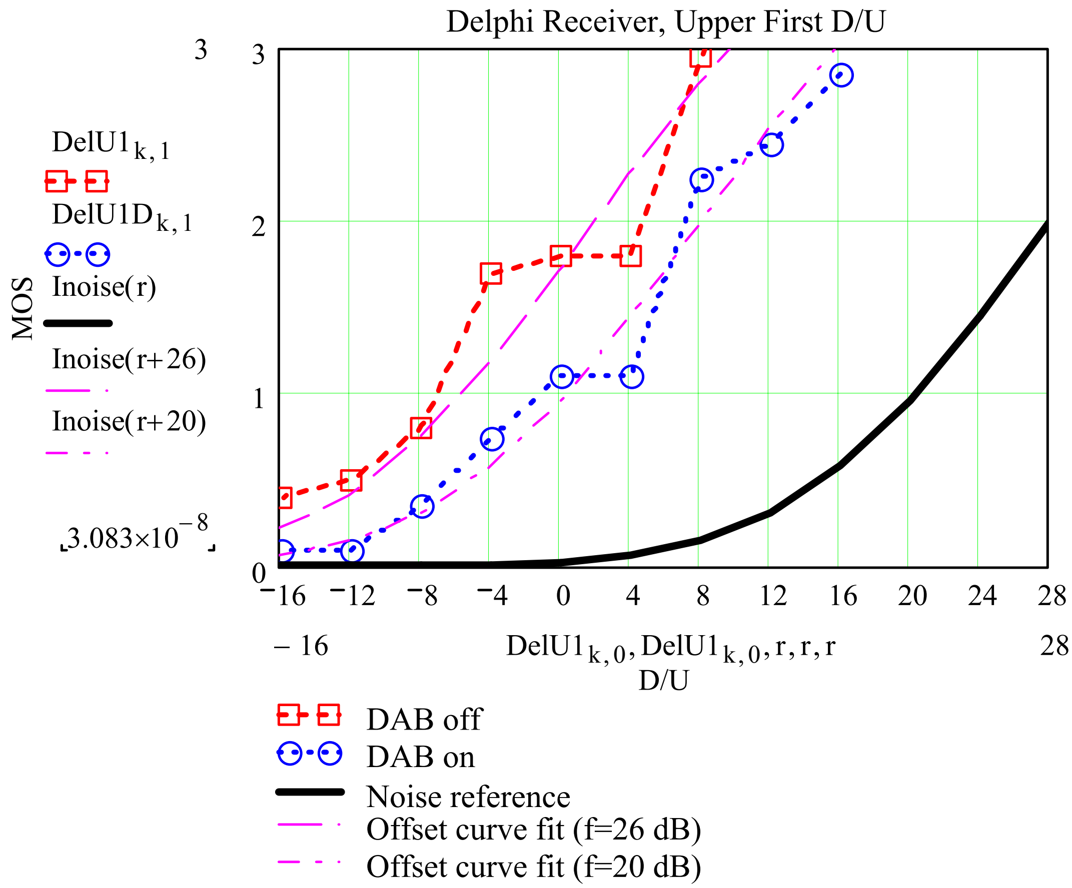


Figure C - 4 Subjective evaluation of an upper first adjacent interferer (DAB off and DAB on) for the Delphi receiver. The difference in D/U for these results versus the reference white noise curve is the attenuation factor.

Figure C - 5 shows the effects of a second adjacent interferer on the MOS score over a range of D/U values. Two cases are characterized where DAB is off and on. Although the MOS scoring appears somewhat noisy and could benefit from more samples below -24 D/U, a curve fits can still be estimated from the available data. The effects of the second adjacent interferer are dependent on the selectivity of the particular receiver.

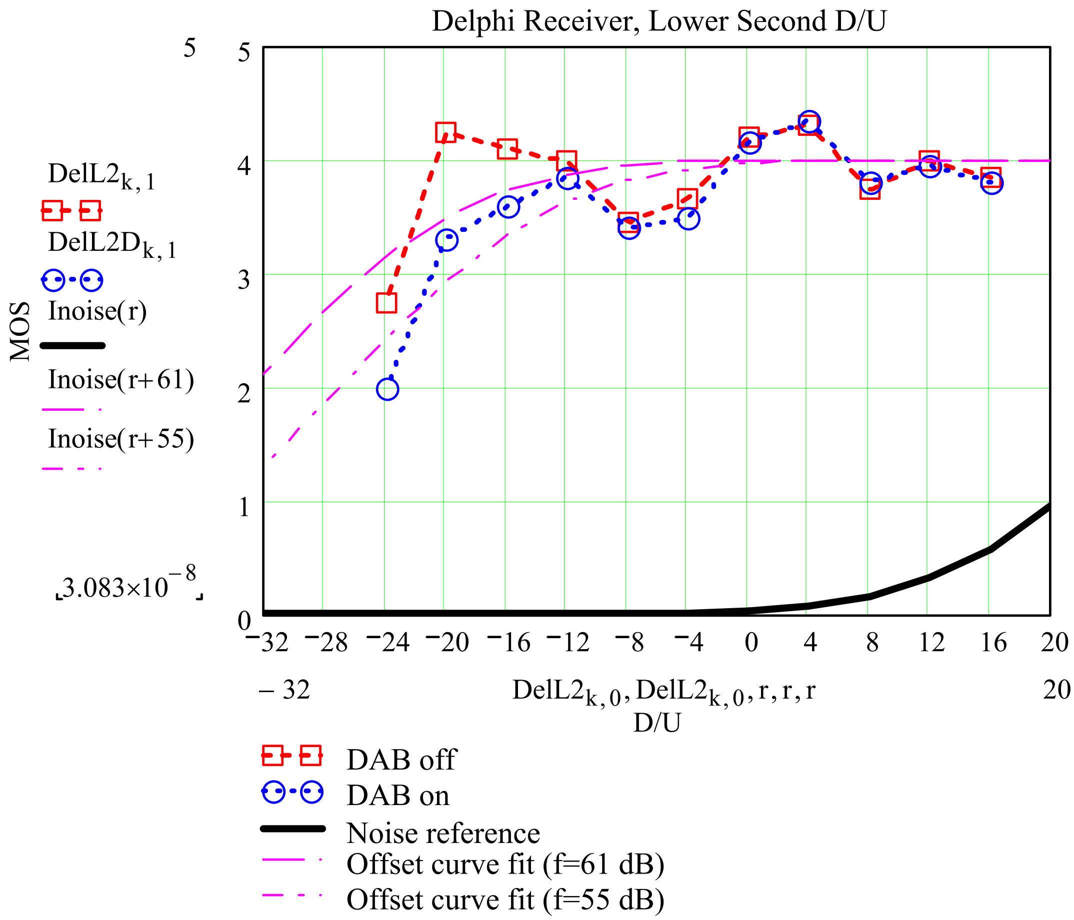


Figure C - 5 Subjective evaluation of a lower second adjacent interferer (DAB off and DAB on) for the Delphi receiver. The difference in D/U for these results versus the reference white noise curve is the attenuation factor.

Figure C - 6 and Figure C - 7 show the effects of first and second adjacent interferers on the Sony receiver. Two cases are characterized where DAB is off and on.

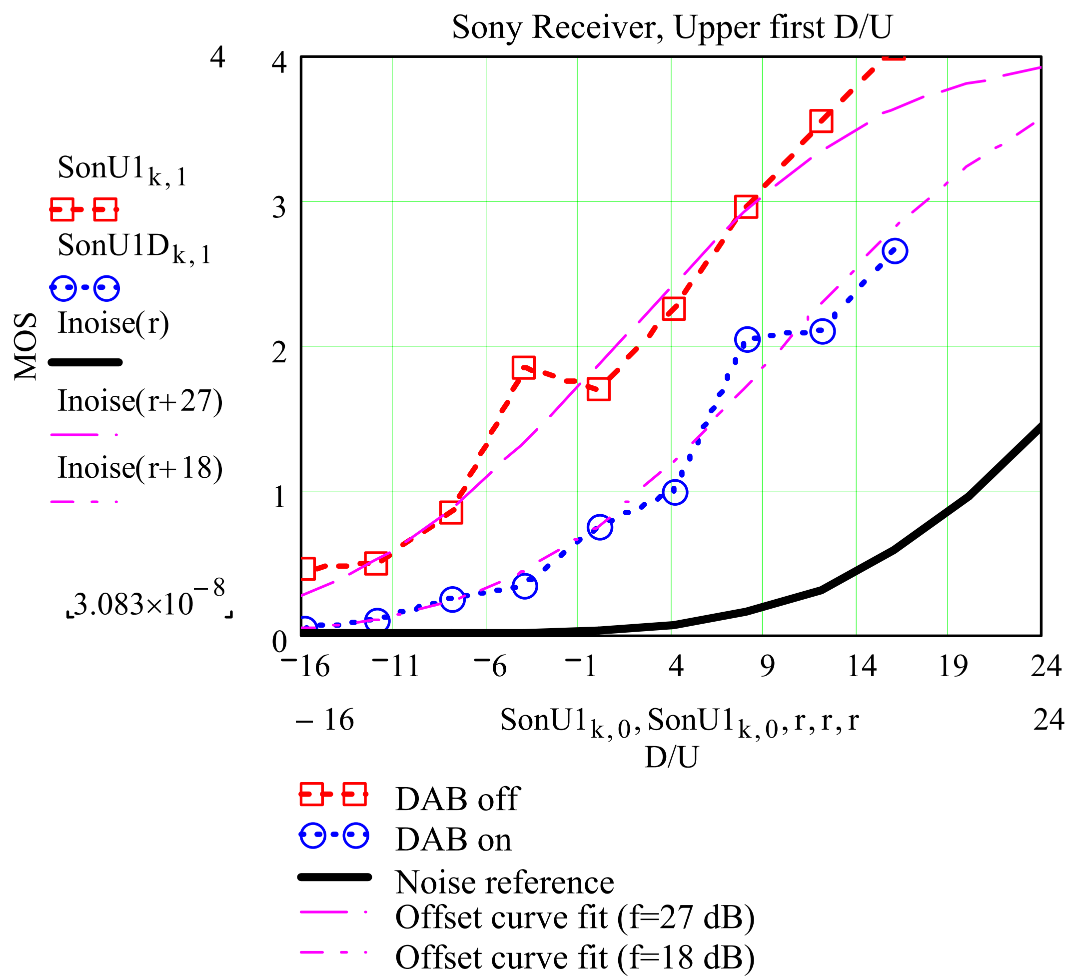


Figure C - 6 Subjective evaluation of an upper first adjacent interferer (DAB off and DAB on) for the Sony receiver. The difference in D/U for these results versus the reference white noise curve is the attenuation factor.

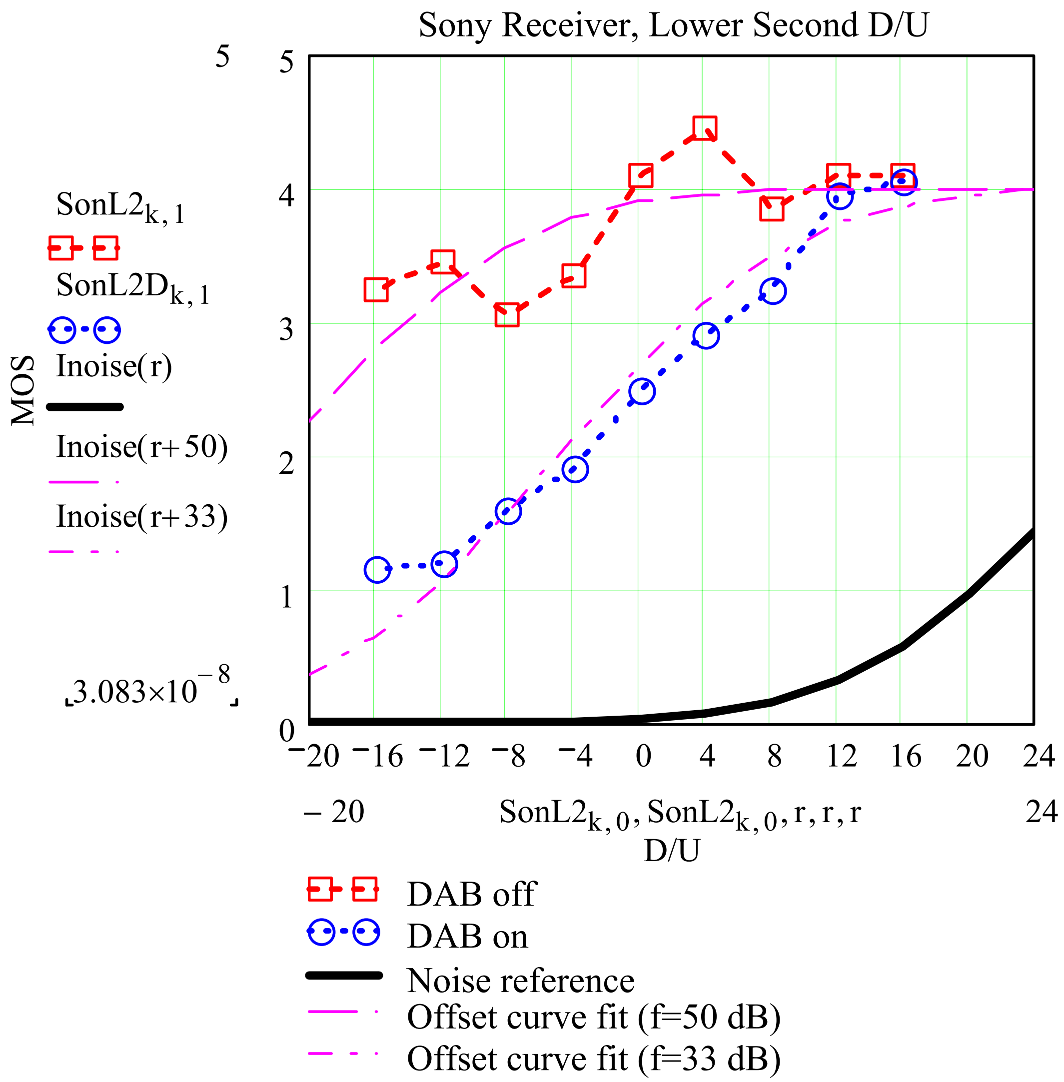


Figure C - 7 Subjective evaluation of a lower second adjacent interferer (DAB off and DAB on) for the Sony receiver. The difference in D/U for these results versus the reference white noise curve is the attenuation factor.

The attenuation factors computed from the results of the subjective MOS evaluations just described are summarized in Table C - 1and Table C - 2. It is assumed that the attenuation factors for lower first adjacent interferers are the same for upper first adjacent interferers for the same receiver. Similarly, it is assumed that the attenuation factors for upper second adjacent interferers are the same for a lower second adjacent interferers. Table 1 presents the attenuation factor in dB, while Table C - 2 presents the equivalent multiplicative factor. These attenuation factors are used in the computation of the effects of multiple interferers in a coverage area.

Table C - 1

Attenuation factors in dB for Cochannel "CO", Lower and Upper First adjacent interferers "LI" and "U1", and Lower and Upper Second adjacent interferers "L2" and "U2".

fdB :=

"Atten. factor"	"Delphi, A"	"Delphi, D"	"Sony, A"	"Sony, D"
"L2"	61	55	50	33
"L1"	26	20	27	18
"C0"	12	12	12	12
"U1"	26	20	27	18
"U2"	61	55	50	33

Table C - 2

Equivalent multiplicative attenuation factors.

f =

"Multiply factor"	"Delphi, A"	"Delphi, D"	"Sony, A"	"Sony, D"
"L2"	7.943×10^{-7}	3.162×10^{-6}	1×10^{-5}	5.012×10^{-4}
"L1"	2.512×10^{-3}	0.01	1.995×10^{-3}	0.016
"C0"	0.063	0.063	0.063	0.063
"U1"	2.512×10^{-3}	0.01	1.995×10^{-3}	0.016
"U2"	7.943×10^{-7}	3.162×10^{-6}	1×10^{-5}	5.012×10^{-4}

Appendix D

Propagation Studies and Map Generation

Scott Metker, Ph.D.

1. Overview

This report details a new methodology that uses existing FCC rules and propagation formulas to produce maps of signal strength, co-channel and adjacent channel D/U ratios in a tiled or matrix presentation. The data contained in each tile then can be post-processed with other data to provide additional information such as quality of service or Mean Opinion Scores (MOS) and population analysis.

The signal levels and interference data contained in each matrix was then translated into the present analog MOS ratings for all US broadcast and MOS ratings following the total conversion of the AM broadcast band to hybrid IBOC transmissions.

2. Background

The current FCC guidelines for the AM broadcast spectrum have evolved over the last century with the emphasis on producing the maximum number of stations while limiting interference. The AM radio band is unique from other allocations regulated by the FCC due to several important factors.

- The AM band is one of the oldest bands regulated by FCC, resulting in an exceedingly complex allocation scenario with a large number of radio stations subject to grandfathered rulemaking and measurement augmentations to the theoretical models.
- AM radio propagation occurs in two primary modes: groundwave (occurring at all times) and skywave (occurring at nighttime). The FCC regulations governing these two modes have evolved separately and have created two distinct allocation scenarios.
- The channels are allocated in an interlaced assignment plan where the energy from one channel overlaps one half of its adjacent channel assignment. As a result, stations on adjacent frequencies can interfere with each other.

This implied mandate of protecting radio spectrum has created an environment where these complex and varied rules are applied to both new stations and those stations changing their broadcast power or pattern. This environment is based almost exclusively upon **the computation of contours of constant signal strength** and determining whether levels of interference at points on these contours (or directly at the station of interest) violate predefined limits. The FCC rules and computational engines are designed to produce a single, regulated measure: PASS or FAIL.

3. A Grid Based Solution

3.1. Overview of the Approach

In this study the FCC's accepted rules and propagation model were adapted to a grid-based analysis for this study. These maps are similar to the maps currently used in FM evaluations. Structured grids are useful in computational methods as they represent a simple way of storing complex information from multiple sources.

In this study, a 410 x 901 element grid was drawn over the entire United States (based upon a 4-minute interval in latitude and longitude). The total groundwave and skywave signals from all nearby, relevant stations were computed at each point on the grid. This approach was considerably more computationally expensive than most contour analysis, but it produced a wealth of data for later post-processing. Figure D - 1 shows a close-in view of a single station and clearly shows the granularity of the grid used in the analysis.

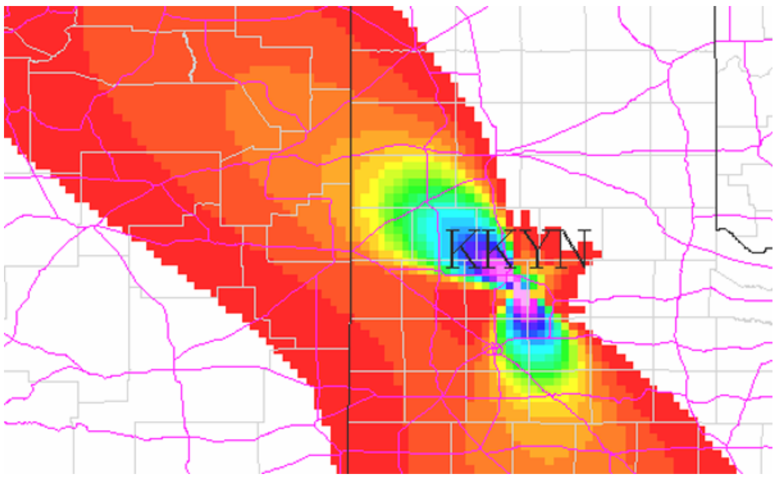


Figure D - 1 Zoomed in View of Grid Granularity

The grid based approach, produced a model that is more useful for combining groundwave and skywave signals than the traditional contours of equal signal strength method. With the grid approach, signal and interference levels can be determined for locations all over the United States. These types of composite metrics were used to produce maps depicting a MOS measure in cells of approximately 4 X 4 miles for the existing analog environment and following the total conversion to IBOC.

This study produced a database that provided a matrix of 369,410 cells each containing the following data:

- Total RSS'ed groundwave signal strength (all stations)
- Groundwave signal strength of strongest contributor
- Call sign and AM database record number of strongest contributing groundwave station
- Total RSS'ed skywave signal strength (all stations)
- For maximum skywave contributor
    - Skywave signal strength (maximum skywave signal)
    - Call sign and AM database record number
    - For maximum groundwave contributor at same point
    - Skywave signal strength of maximum groundwave contributor at same point

- Call sign and AM database record number

Data contained within each grid point was used to produce maps for every AM station within the Continental United States depicting signal strength; co-channel, first and second adjacent channel D/U ratios, and MOS ratings[1] (see Appendix C). The books are printed; one page per channel with 107 pages covering 540 to 1600 kHz. Each page presents tiled cell data for each US licensed stations on the channel. Mapping data is visually represented at each grid point by converting the data to representations as colored tiles. The color is used to convey individual station information such as signal strength, interference D/U ratios, or MOS ratings[2].

3.2. Methodology and Assumptions Used in the Study:

3.2.1. Grid Determination

The 4 x 4 minute interval in latitude and longitude grid size was determined to be granular enough to interpret the data without unduly overtaxing computational capability. For exceedingly small stations, the grid granularity might produce some issues; however, it gives a good picture of the signal distribution from each station. The strength of any given noise or signal source was assumed to be constant over a given cell. A variety of groundwave and skywave signals were computed and summed at each grid point. In addition, data at each point was captured as described in Section 3.1.

3.2.2. Groundwave

All groundwave signals were computed using the methodology outlined in 47 CFR 73.183 and 73.184. The signal strength from each station is computed using the FCC's antenna models and database in combination with the M3 metric curves as detailed in § 73.184[3] . A radial is drawn from each grid point to each nearby contributing station, and the attenuation factor and radiation from each antenna array is computed based on its unique path to the grid point (and unique mix of ground conductivities).

Groundwave signals from multiple sources were RSS summed at each grid point in the survey. The total signal strength was captured at each point, as well as the call sign and signal strength of the dominant signal. This allowed the rapid calculation of the coverage area of the "signal of interest" within a geographic region. It was assumed that the highest contributing station is the signal of interest.

3.2.3. Skywave

All skywave signals (signal of interest and interfering signals) in the study were determined using the formulas in MM Docket 88-508. However, the 50% skywave levels were used for all signals rather than the modified 10% levels. Signal strength from all stations within a 1500 mile radius of each grid point was RSS'ed at each of the study

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[1] Three separate sets of books were generated for MOS ratings. The books depict the present analog MOS ratings, the MOS ratings following the conversion of all stations to hybrid IBOC, and the change (delta) in MOS following the IBOC conversion.

[2] The conversion of data contained within each matrix to MOS ratings is covered in Appendix C. The MOS ratings are covered in Appendix B.

[3] The1991 M3 metric curves were used for all stations

points. The 50% limits were used based on the assumption that this study would have a significant number of interferers RSS'ing at many locations and that the time-variance of skywave attenuation factor for different stations is not necessarily correlated. Thus, the 10% limits could over predict interference from multiple stations, assuming that the signal from each is simultaneously at a near maximum value at all times when these signals are RSS combined.

Two data points were stored in addition to the total signal strength for the skywave signal. First, the call letters and signal strength of maximum skywave contributor were stored at each data point (similarly to the groundwave study). Secondly, the skywave signal level[4] of the maximum groundwave contributor at the same point was computed. This signal was used in post-processing to discount the skywave contribution of the strongest groundwave contributor in the case of any overlap. It ensures that skywave signals are used only to compute interference and not counted as signal of interest. For further information on skywave propagation see Annex A.

3.2.4. Signal of Interest Determination

Signal of interest is used differently in maps depicting total signal strength vs. maps depicting D/U ratios.

- For **maps depicting total signal strength**, the signal of interest is determined to be the **single strongest signal** at each point on the grid. This determination of "signal of interest" occurs even if the maximum groundwave signal drops below a receivable level. This determination can be made in various types of post-processing if necessary. The highest contributing signal value (and the contributing station's call sign) are recorded for each grid point.
- For **maps depicting D/U ratios**, the signal of interest is computed **using only groundwave propagation**, thus, when computing coverage or signal of interest, the skywave component of the station of interest is neither assumed as signal or interference.

3.2.5. Combining of Signals

As described in Section 3.1, each point on the grid contains several different data values that can be used to generate other data. Groundwave and skywave signals were separately RSS'ed, and the total signal strength (if needed) is determined by RSS'ing the total groundwave and skywave signals. Co-channel, first adjacent and second adjacent channel interference is independently calculated by summing all interfering signals using the RSS method. The upper and lower adjacents are simply RSS'd into a single value for the adjacent channel interference maps.

3.2.6. Population Analysis

The United States population (2000 Census) was used to determine the total population that would lie within the square for each of the grid points. The resulting dataset

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[4] Within the 0.5 mV groundwave contour, a station's own skywave signal is typically negligible and not the strongest contributor.

(population per grid point) was used in population vs. field strength and MOS histograms.

3.3. Methodology for Computation of NIF (Night Interference Free Values)

The computation of Night Interference Free levels was determined using the following methodology for the purposes of this study

- **Assumptions**
  (1) 50% Skywave Curves used for skywave propagation
  (2) 25% RSS exclusion used for NIF computation

- **Process for Computing NIF**
  (1) The skywave signal of all interfering stations on the same and 1st adjacent frequencies were computed. The co-channel interferers were multiplied by 20.0 and the 1st adjacent interferers were multiplied by 2.0 in accordance with FCC guidelines for co-channel and 1st adjacent interference computations for NIF calculations.
  (2) The resulting values were sorted from strongest to weakest.
  Each value is in turn is RSS'd into a running RSS value (from strongest station to weakest). The process stops at the point that any station on the list has a total signal strength less than 25% of the RSS'd running sum (which could contribute no more than 3.1% to the running RSS value due to the squaring and summing of terms). Since the stations were sorted by their interference contribution, all other stations have a weaker value and are ignored

- **Differences from FCC Model**
  The 50% skywave curves were used in the computation of interfering skywave signals (differing from the 10% values used by the FCC). Since the 50% skywave curves were used for all results in the study, this was judged as being consistent within this report.

  However, this assumption is more of a worst case scenario for the IBOC computations. The 50% values result in a weaker interfering signal; this has the result of reducing the computed NIF value, resulting in a larger contour of interest for the station of interest. This larger contour experiences more interference than the smaller contour (at its outer edges), and thus, tends to have higher delta MOS values.

4. Computation of Population Metrics

The advantage of the grid-based approach comes when it is combined with Geographic Information Systems (GIS) and other datasets such as population or square mileage. GIS systems enable multiple sources of geographically oriented data to be combined for both map-making and computational analysis. The main strength of GIS systems is that they automate many of the complex tasks involved with combining datasets over different types (contours, grids, and points).

One example of such a computation is the calculation of population receiving various signal strength levels. The signal strengths computed in this study are over a regularly spaced grid whereas population is usually presented as a series of irregularly spaced "population centroids", each representing the population in the vicinity of the point. Areas of higher population tend to have more centroids, allowing areas of high population to have a higher resolution than areas of low population.

4.1. Source Data

All computations based on population coverage and population change are based upon the 2000 Census of Population and Housing. The specific files used for the computation of population were the Summary File 1 State Files for all contiguous US states (excluding Hawaii and Alaska for the purposes of this survey) released by the U.S. Census Bureau in 2001.

The summary file data is presented hierarchically within the flat ASCII data files released by the US Census. Each record in a State Summary File 1 is preceded by a Geographic Component code, which indicates the summary level. The main summary hierarchy is presented in Table D-1. For example, under each 040 entry (the first line in the file, which only appears once per file), many 050 records appear. Under each of these records appear multiple 060 labeled records. Each successively lower numbered record is a sum of the higher number records immediately following it.

Table D-1 - Geographic Component Codes in State Summary Files

Geo Component #	Level of Detail
040	State 1
050	State-County 2
060	State-County-County Subdivision
070	State-County-County Subdivision-Place/Remainder
080	State-County-County Subdivision-Place/Remainder-Census Tract
091	State-County-County Subdivision-Place/Remainder-Census Tract-Block Group
101	State-County-County Subdivision-Place/Remainder-Census Tract-Block Group-Block

In order to effectively sum population over the small 4 minute grids used in this study, the lowest level general population records were used (geographic component #101), which is recorded at the block level.

4.2. Basic Steps for Aggregating Population Information

(1) For each state-specific file, records were extracted with a geographic component equal to 101 (summing records with different geographic component numbers would result in double counting of data). The data was then placed into a single file (containing the results from all from all of the Census 2000 State Summary File 1 values).

(2) Based on the latitude and longitude entry on these records, the population was translated to the 410 x 901 grid used for all mapped results in the study. Each of the records was found to lie nearest to a single grid point or eliminated if it fell outside the range of the study (-126 to -66 degrees longitude, 25 to 50 degrees latitude). In the case that multiple records were found to lie at the same grid point, the values were summed to generate a population total at the point.

(3) The resulting grid was used to conditionally sum population results when compared to similar data such as electric field strength or computed MOS value.

4.3. Delta MOS vs. Impacted Population Histograms

One of the metrics used in this report is the delta MOS histogram (see main report, Figures 4 and 5). It shows the % of total population that would experience a given change in MOS after the introduction of IBOC signal across the entire frequency band. This graph is produced by combining the delta MOS values computed on each of the 410 x 901 points computed for the maps with the population at each point and computing a histogram. The histogram process consists of dividing the delta MOS spectrum into number bins spanning 0.05 of a point. The population at each grid point is summed and added into the appropriate bin based on the delta MOS experienced at that point.

The final result is a collection of bins, where each bin indicates the total population experiencing a change in MOS between MOS_{hist} and $MOS_{hist}+0.05$, where MOS_{hist} is the value of the bin. These histograms are then converted to a cumulative histogram where the value of each cumulative bin is computed from the value of all histrogram bins at and above the indicated values. Equation (1) shows the formula for this process where *n* represents the number of the bin being considered (bins are numbered sequentially starting from 0 to 0.05, proceeding to 0.05 to 0.1, and so on).

$$MOS_{cummulative}(n) = \sum_{i=n}^{\max} MOS_{hist}(i) \quad (1)$$

Figure D-2 shows an example of Delta MOS histogram. The graph is a cumulative histogram, meaning that for a given delta MOS value on the x-axis, the corresponding % population value found on y-axis represents the population experiencing delta MOS *or higher*. For example, the graph shows that for all station types (the “All” line), 61% of the population would experience a change in MOS of 0.1 or greater. However, this figure by itself is not meaningful, since a change in MOS of less than 0.5 would not be detectible by a large majority of the population and thus 0.1 MOS change would not be audible.

Receiver scenario and cutoff are two parameters of great importance with these graphs. For example, Figure D-2 shows the results for the Delphi receiver (meaning that MOS was computed using the Delphi receiver and IF filter model). Additionally, Figure D-2 was computed using an electric field cutoff of 0.5 mV/m. This means only areas across the US with a signal of interest above 0.5 mV/m were considered for the purposes of this histogram.

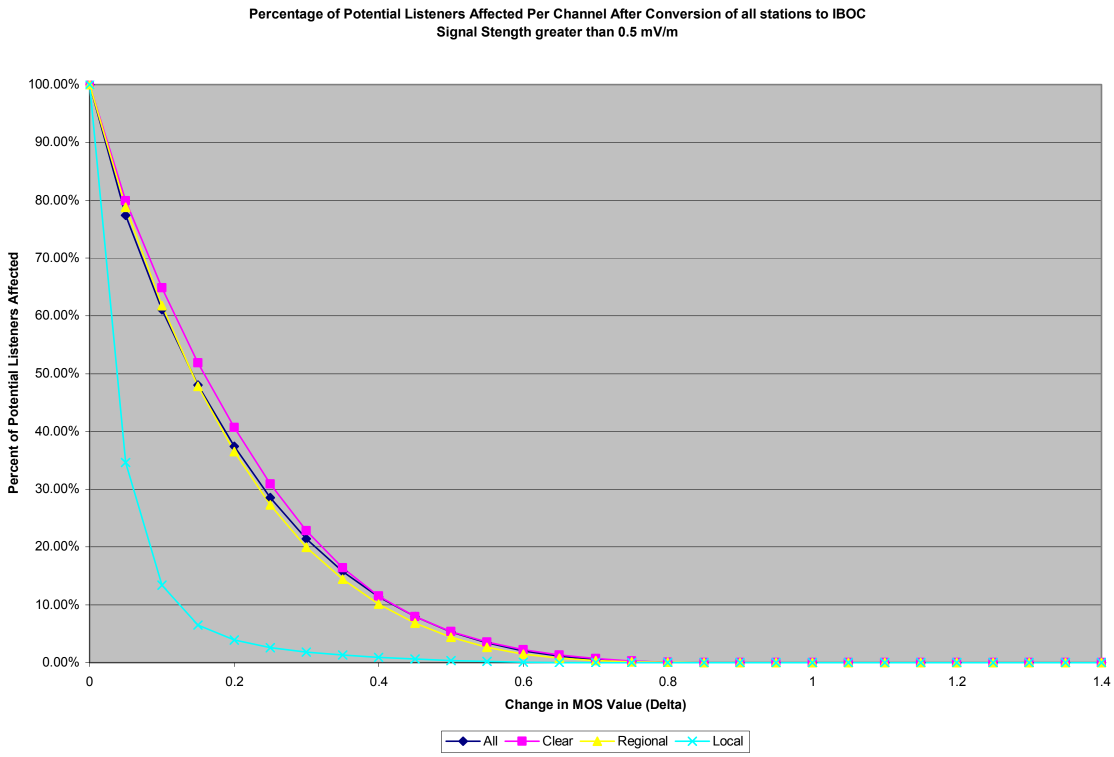

Figure D - 2 Delta MOS vs. Population Histrogram (Delphi Receiver - 0.5 mV cutoff)

Annex A to Appendix D
Skywave Propagation Overview

At night, another mode of propagation is possible for AM radio signals. This second mode is called skywave propagation and occurs when lower frequency radio signals such as AM radio signals bounce off the ionosphere and return to earth. The FCC model for skywave propagation is outlined in MM Docket 88-508 which outlines the formulas adopted by the FCC in 1991.

Station Signal – Skywave Angle of Departure
Because skywave propagation includes a signal component that is broadcast considerably above the stations horizontal pattern, the vertical pattern component of the station of interest is computed over several angles of departure. The FCC's guidelines for vertical pattern computation are specified in § 73.160.

Skip Zones
Another interesting feature of the skywave propagation mode is the presence of "skip zones." Unlike groundwave propagation, skywave radiation does not fall off steadily in time. Instead, skywave signal strength is low near a station and rises for points further away. Due to this effect, the field strength of a skywave pattern would look like a doughnut. It is possible that a station might have several "rings" of radiation at a distance due to the presence of multiple skip zones and excessive tower height above 180° (electrical degrees). Figure 1 shows a total field plot for KDKA AM 1020 kHz with both groundwave and skywave signal shown. The red ring appearing in the middle of the map (signal strengths < 0.3 mV/m) is due to the groundwave signal having attenuated before the skywave signal returns from the ionosphere.

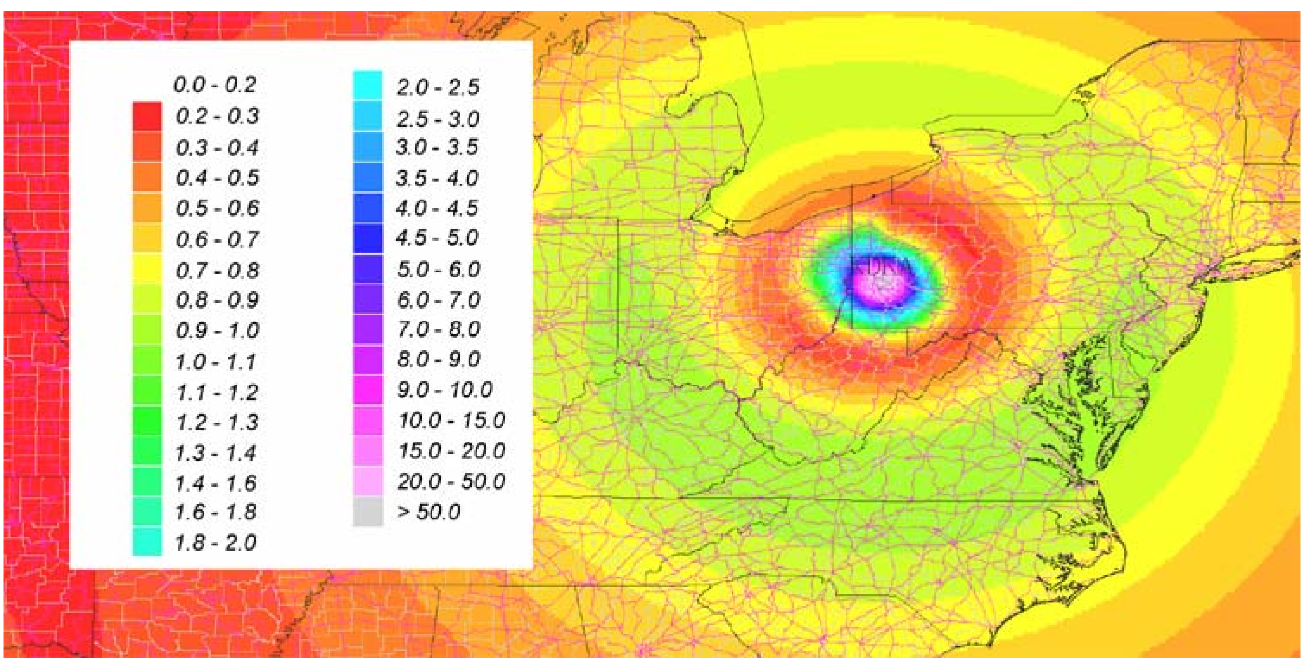

Figure 1: Groundwave and Skywave Signal Combined (mV/m) Showing Skip Zone

Skywave Signal Modifiers
Skywave propagation shows a great amount of variation from week to week for a single station. Originally, the FCC specifications used an average value in the skywave model that assumed that the computed signal strength represented a value that the average signal exceeded 50% of the time. However, MM Docket 88-508 details the reasoning behind adopting a 10% skywave field strength modifier.

Non-Steadily Increasing Skywave Signal
The presence of skywave skip zones complicates skywave analysis. While contours can (and are) used to show coverage areas and where interference might be a factor, the contours do not have the same meaning as groundwave contours. Skywave signal starts at a low value near the station and peaks as the observer moves away. Multiple peaks can occur for electrically tall antennas.

Thus, the contours that are typically drawn in maps represent the outer boundary of the skywave contour for a designated signal strength. Figure 2 shows the total skywave strength (50% rule) at 79.95° longitude (a north-south line running directly through KDKA). Two stars on the graph indicate the points at which the 0.5 mV contour would cross this line. Skywave contours represent the outermost point for a given signal strength; however, no conclusions can be drawn about the signal inside the contour. It could rise significantly higher than the specified contour value, or it might peak only slightly above the specified value. Many smaller stations do not have skywave components that rise above 0.5 mV/m since their signal dies so quickly traveling to and from the ionosphere.

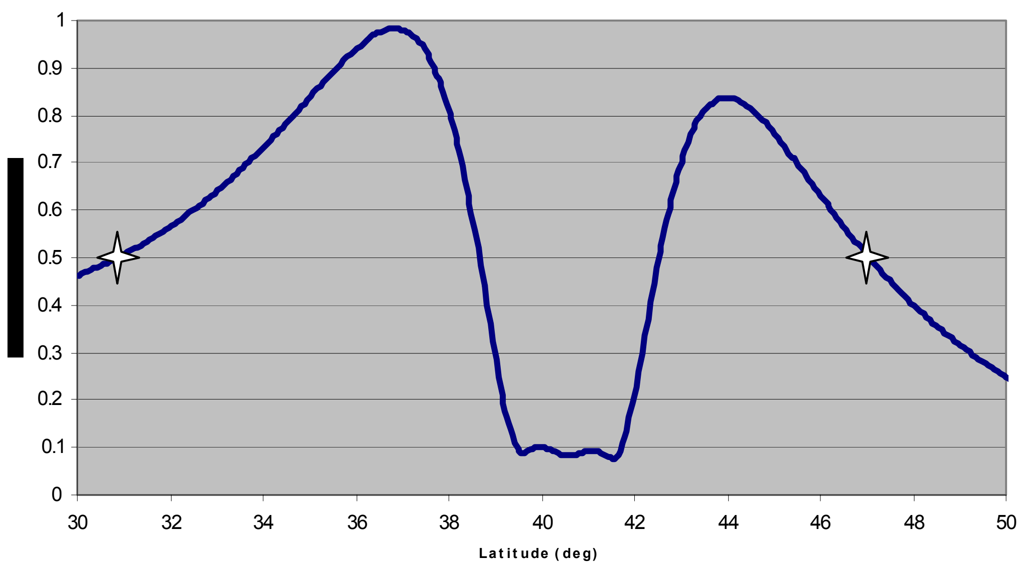

Figure 2: Skywave Signal Strength* as 79.95 Deg Longitude (KDKA)

*Skywave signal does not drop completely to zero at station due to presence of minor background interference from other stations

Appendix E
Effects of Directional Antennas on IBOC Compatibility with Analog

The Sony receiver has a directional antenna, and thus IBOC interference can be nulled out depending on receiver positioning in relation to the desired station and the undesired first adjacent interferers. To illustrate the effect that the directional AM loop antenna has on the area of impact from the conversion of all stations to IBOC, WHAM, 1180 kHz, Rochester New York was studied. WHAM enjoys a relatively clear nighttime channel as shown in the E-field signal strength plot in Figure E-1. The closest stations are in Omaha, Nebraska and Jackson, Mississippi both at or below 1 kW. WHAM has three nighttime first adjacents – WWVA, 1170 kHz, Wheeling, West Virginia as shown in Figure E-2; WOWO, 1190 kHz, Fort Wayne, Indiana and WLIB, 1190 kHz, New York, New York as shown in Figure . The current analog MOS of these four stations is overlaid on WHAM's frequency as shown in Figure . This figure shows the score of the Sony receiver in the Northern New York State region. Both on and off the axis lines are drawn through WHAM. Figure depicts MOS ratings after the total conversion to IBOC. It assumes the Sony has an omni directional antenna. Given that the Sony radio has a directional antenna, Figure is accurate only on a straight line between WHAM and its first adjacent channel interferers. Factoring in the Sony's directional antenna, we see the true change in MOS for WHAM would look something similar to the plot shown Figure rather than uniformly decreasing the MOS across the outer regions of the coverage area. Shown are off axis "dimpled" areas where the receiver's directionality is used as an advantage to null out the first adjacent stations and thus reducing the impact of IBOC. This leaves only the areas on axis where the decrease in MOS is not affected due to positioning of the antenna. Incorporating the receiver positioning calculation and directional antenna characteristics within each grid block was not possible in the study since these complexities would have extended computation time from a day for each map book to a week and still not be accurate.

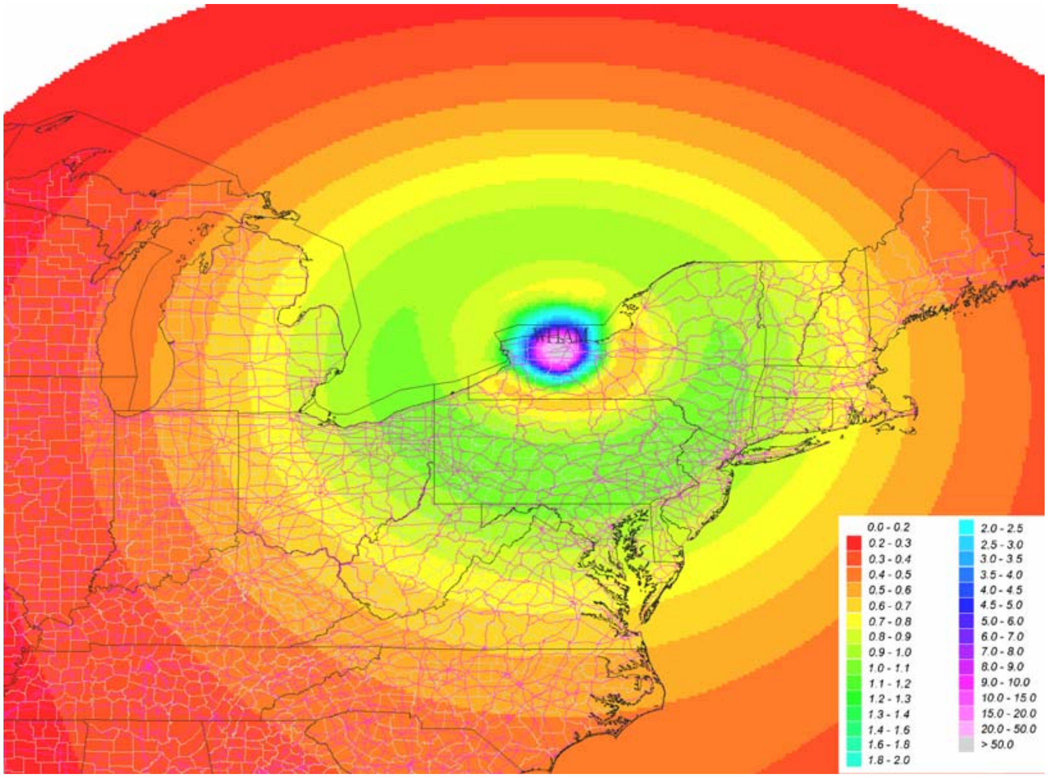

Figure E-1 Signal Strength of WHAM, 1180 kHz, Rochester, NY

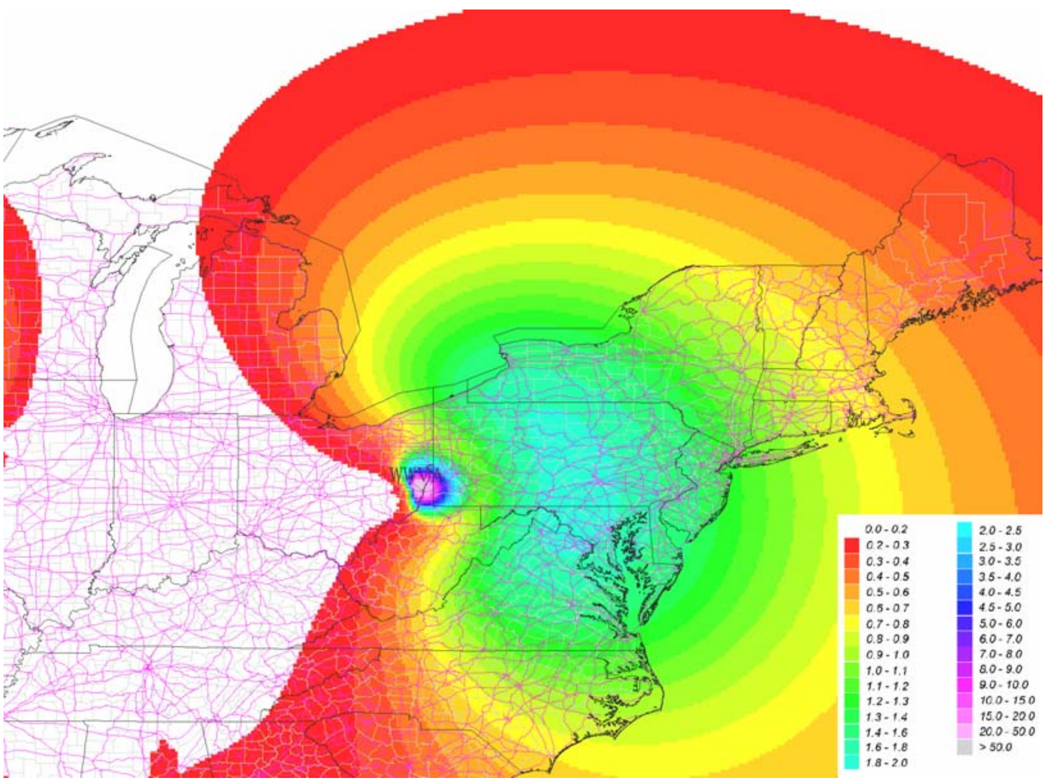

Figure E-2 Signal Strength of 50 kW WWVA, 1170 kHz, Wheeling, West Virginia

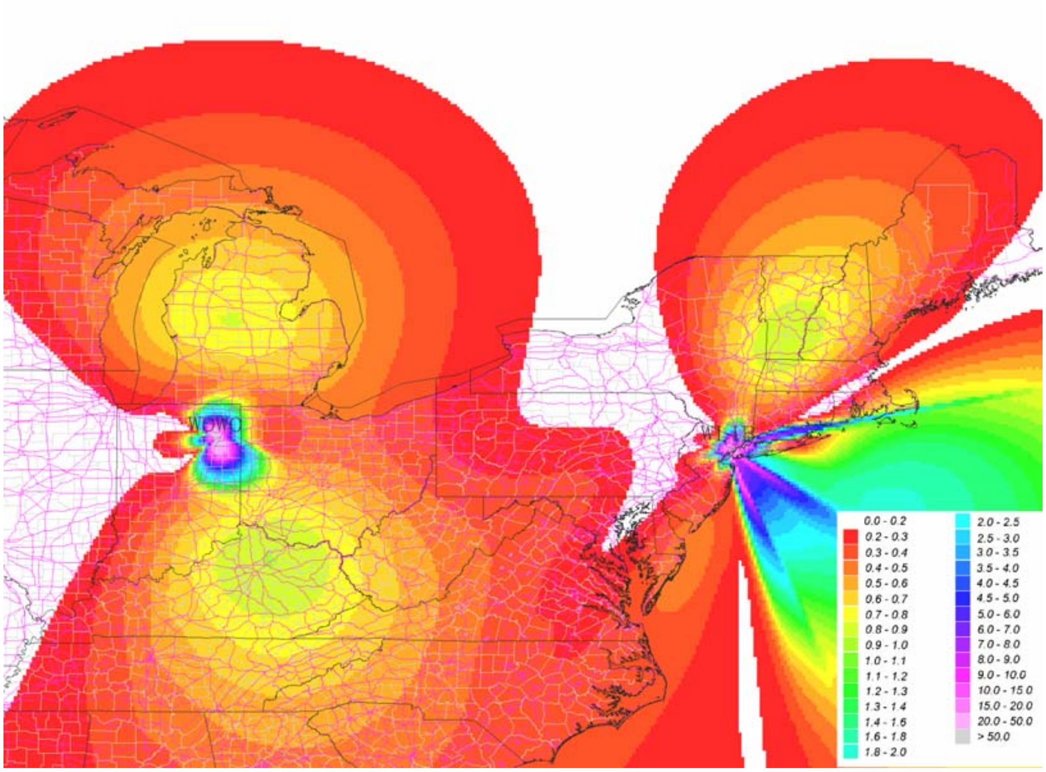

Figure E-3 Signal Strength of 1190 kHz 9.80 kW WOWO, Fort Wayne IN and 30 kW WLIB, New York, New York

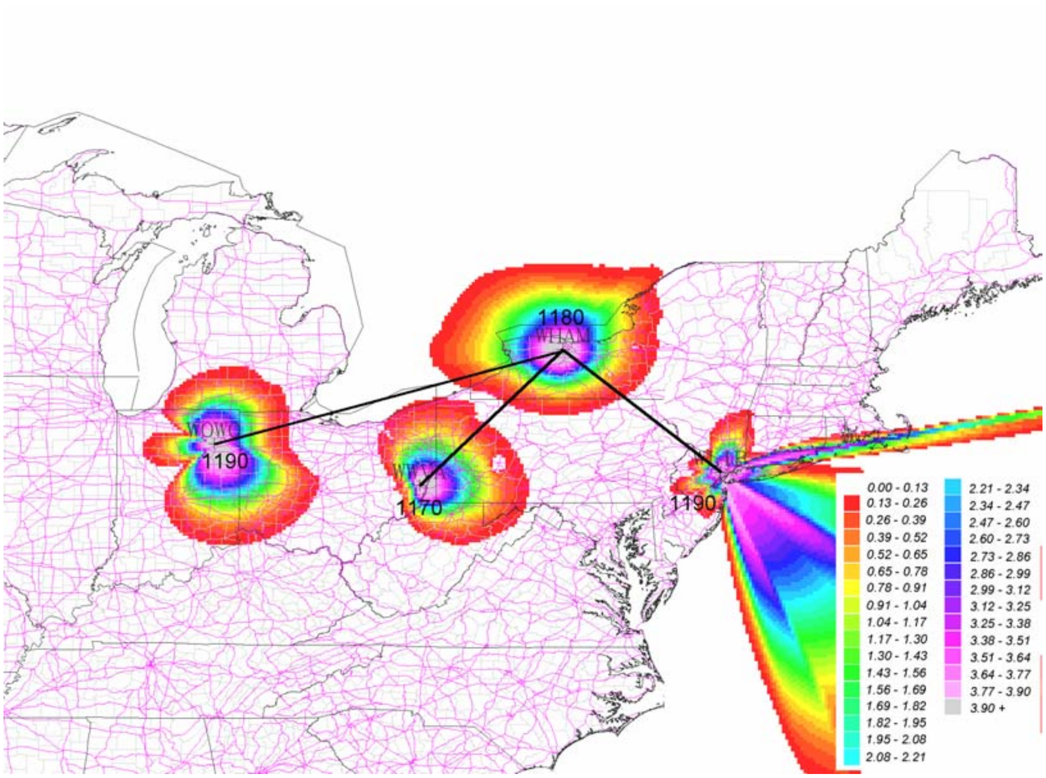

Figure E-4 MOS of Analog Only First Adjacents WOWO, WWVA and WLIB overlaid on WHAM – Sony Receiver

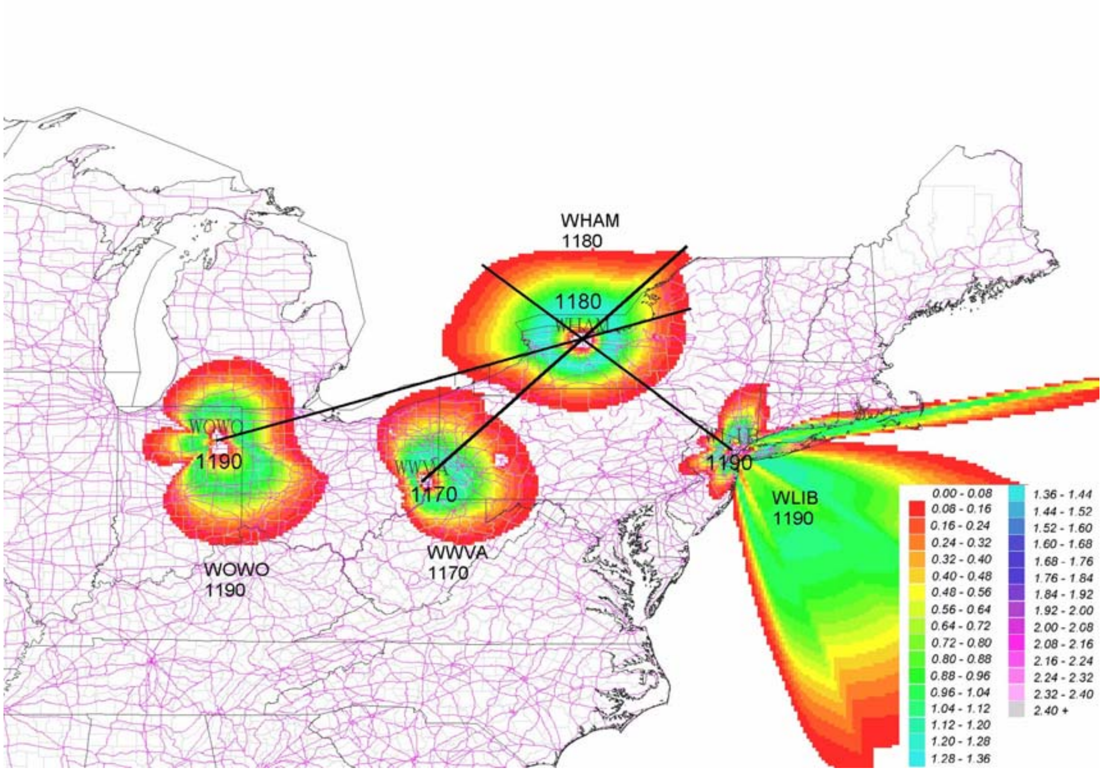

Figure E-5 Change in MOS of WHAM shown with the first adjacents WWVA, WOWO and WLIB overlaid on 1180 kHz Assuming a Omni Directional Antenna on Sony Receiver

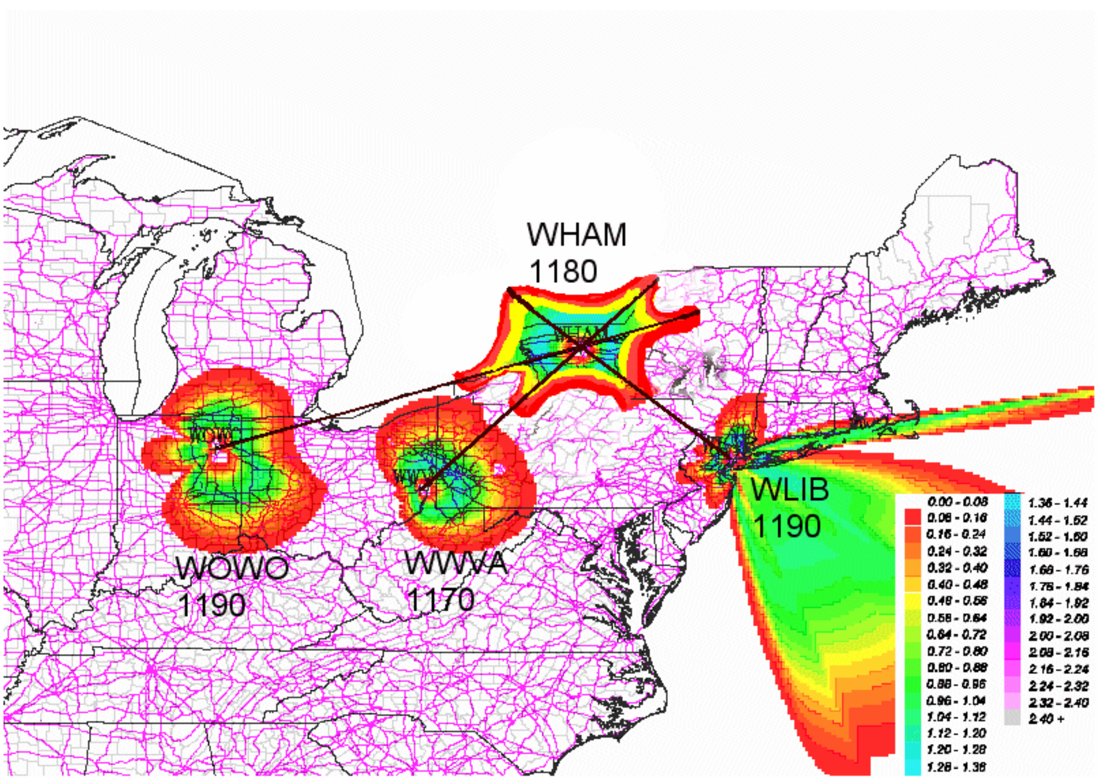

Figure E-6 Change in MOS of WHAM shown with the first adjacents WWVA, WOWO and WLIB overlaid on 1180 kHz, factoring in directionality of Sony Receiver