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January 2, 2001

Mr. Milford Smith
Chair, DAB Subcommittee
National Radio Systems Committee
c/o National Association of Broadcasters
1771 N Street, N.W.
Washington, D.C. 20036

Dear Milford:

Attached you will find a copy of iBiquity Digital's recent experimental test report to the FCC concerning tests conducted in Las Vegas using KWNR-FM. We are supplying this report to the NRSC in order to ensure your subcommittee is fully informed of the progress of iBiquity's IBOC testing. Please do not hesitate to contact me if you have any questions.

Sincerely,

Albert Shuldiner

Counsel for iBiquity Digital Corporation

Enclosures

cc: David Layer
E. Glynn Walden

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iBiquity Digital Corporation Experimental Test Report on IBOC DAB Field Tests Using KWNR-FM, Las Vegas, Nevada

1. Overview

This report documents the results of recent FM hybrid IBOC DAB field tests conducted in Las Vegas, Nevada by iBiquity Digital Corporation's ("iBiquity") predecessor USA Digital Radio, Inc. ("USADR"). These results are important because they further verify the performance of a physical implementation of the design under real-world conditions. The tests illustrate that the DAB audio quality exceeds that of an existing analog FM signal, and shows that IBOC DAB offers coverage comparable to existing analog service.

2. Definitions and Assumptions

2.1. DAB Signal

The DAB signal used for these tests is equivalent to the signal used in previous tests reported to the Commission by USADR. The desired hybrid IBOC signal is comprised of an analog FM host and a baseline DAB signal. The analog FM host signal, present in all tests, is unchanged. The total power in the baseline DAB signal is 22 dB below the total power in the analog host. The DAB signal was generated using an FM IBOC DAB exciter. Figure 1 depicts a spectral representation of the FM hybrid. The rectangular areas contain the DAB subcarriers, and the triangular area comprises the analog host FM signal.

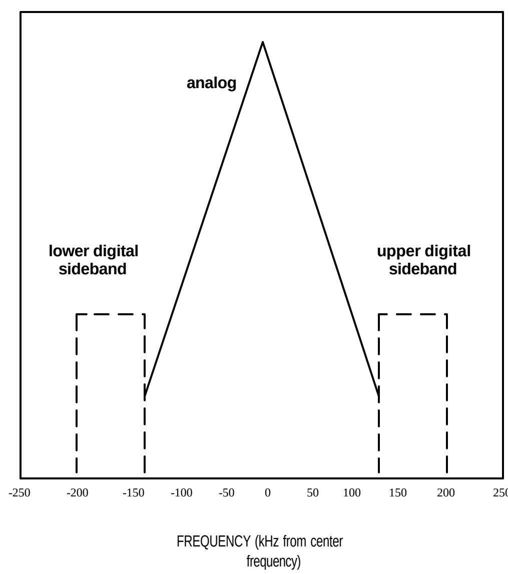

Figure 1 - FM Hybrid IBOC Spectrum

2.2. Digital Coverage

The IBOC DAB system employs a time-diversity blend function which allows graceful degradation of the digital signal as the receiver nears the edge of a station's coverage. When the primary digital signal is sufficiently corrupted, the receiver blends to analog audio.

Performance in a given environment is measured using block error rate.[1] The receiver uses this metric to determine the appropriate time to commence a blend to analog. As the digital signal approaches TOA,[2] blending will occur with increasing frequency. The edge of digital coverage is defined as the point at which the receiver no longer blends back to digital.

3. Test Setup

3.1. Transmitter Test Sites

KWNR, a Class C FM commercial radio station which broadcasts 92.0 kW Effective Radiated Power ("ERP"), with a transmitter power output of 29 kW at 95.5 MHz in the Las Vegas, Nevada metropolitan area, was used for the Digital Coverage test. The transmitter is located at 36^{o} 00' 31" N latitude and 115^{o} 00' 22" W longitude.

The total power in the DAB sidebands is 25 dB + 25 dB = 22 dB below the analog host.

The closest first adjacent and co-channel FM transmitting facilities to KWNR are located past its 60 dBu contour, and do not significantly impact its coverage. As such, first adjacent and co-channel compatibility testing using KWNR as the digital source is precluded.

3.2. Station Configuration

KWNR was modified, as shown in Figure 2, to generate the FM hybrid IBOC DAB signal. Figure 3 shows that, when the source audio enters the DAB exciter, it is split into two paths.

The first path routes the audio out of the DAB exciter to the DAB audio processor. The processed audio is then returned to the DAB exciter, where audio encoding and DAB modulation is applied to produce the digital portion of the hybrid signal. The output of the DAB exciter is then amplified by a linear HPA, before being routed to the high-power combiner.

The second path routes the audio to the diversity delay for blend before sending it to the analog audio processor. The processed analog audio is then input to the analog FM exciter and FM transmitter to produce the host portion of the hybrid signal. Finally, the analog host portion is combined with the DAB to produce the final IBOC FM hybrid signal.

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[1] Blocks are simply large groups of information bits at the input to the audio decoder. Each block has an assigned cyclic redundancy check ("CRC"). If the block's CRC is incorrect, the block is deemed in error.

[2] **T**hreshold **O**f **A**udibility

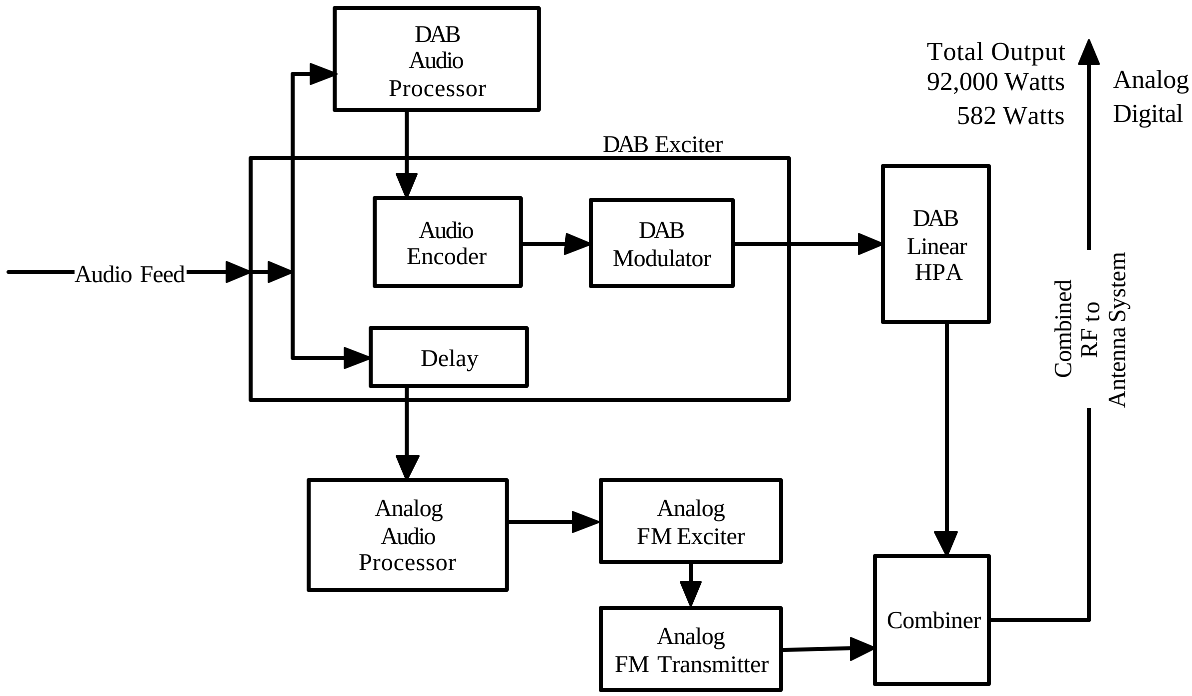

Figure 2 - Diagram of Typical FM Transmitter Setup

3.3. Van Configuration

Mobile test platforms were created to collect data while performing field tests. Test vans were equipped to support the equipment and interfaces shown in Figure 3. Test data was acquired and stored using iBiquity's Field Test PC application. Table 1 describes the manufacturer and model number of the test equipment in the van.

The Field Test PC provides a Graphical user interface ("GUI"), as shown in Figure 4. This application controls and collects data from three sources:

- GPS receiver
- Spectrum analyzer
- DAB receiver

3.3.1. GPS Receiver Data and Processing

The following data is collected by the GPS receiver over an RS-232 interface:[3]

- GPS time
- GPS position (latitude and longitude)

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3 RS-232 is an industry standard serial communications link used by PCs and test equipment.

During setup, the operator enters the position of the transmitter. Current latitude and longitude are then taken directly from the GPS receiver and displayed. The application uses this information to compute and display the current distance from the transmitter.

3.3.2. Spectral Data and Processing

The following data is collected by the Spectrum Analyzer over a GPIB interface:[4]

- Lower first adjacent signal level
- Upper first adjacent signal level
- Lower second-adjacent signal level
- Upper second-adjacent signal level
- Desired signal level

This data is then displayed directly by the Field Test PC application.

3.3.3. DAB Receiver Data and Processing

The following data is collected from the DAB receiver over an RS-232 interface:

- Desired signal strength
- DAB receiver audio mode (digital or analog)
- Cumulative blend counter, which increments whenever the receiver changes its blend status.

3.3.4. PC Application

This application displays new data from each device every eight seconds. All data shown on the display is also stored to a file. The data stored in this file is then re-formatted to generate a strip-chart recording, which plots the variation of select parameters with time over the length of the test.

3.3.5. Video Processing and Storage

Video cameras are mounted on the front and back of each test van. The outputs from each camera, along with the video display from the spectrum analyzer, are multiplexed into one image by a quad-screen controller, and recorded on videotape. The operator keeps logs to coordinate the stored images with the data collected by the Field Test PC application.

3.3.6. Audio Processing and Storage

During Digital Coverage Testing, the Akai DR8 digital audio recorder simultaneously records audio from the Delco and IBOC receivers. All audio and video equipment is controlled manually.

[4] GPIB is a communications protocol and interface used by PCs to communicate with test equipment.

Type	Manufacturer	Model
Spectrum Analyzer	Hewlett Packard	HP-8591
Video Multiplexer	Capture	CPT-MQ4
VCR	AVE	RT195
Video Camera(s)	Marshall	V1212BNC
GPS Receiver	Garmin	GPS II
Digital Recorder	Akai	DR8 Hard Disk
Car Stereo	Delco	16195167

Table 1 – Test Equipment Manufacturer and Model numbers

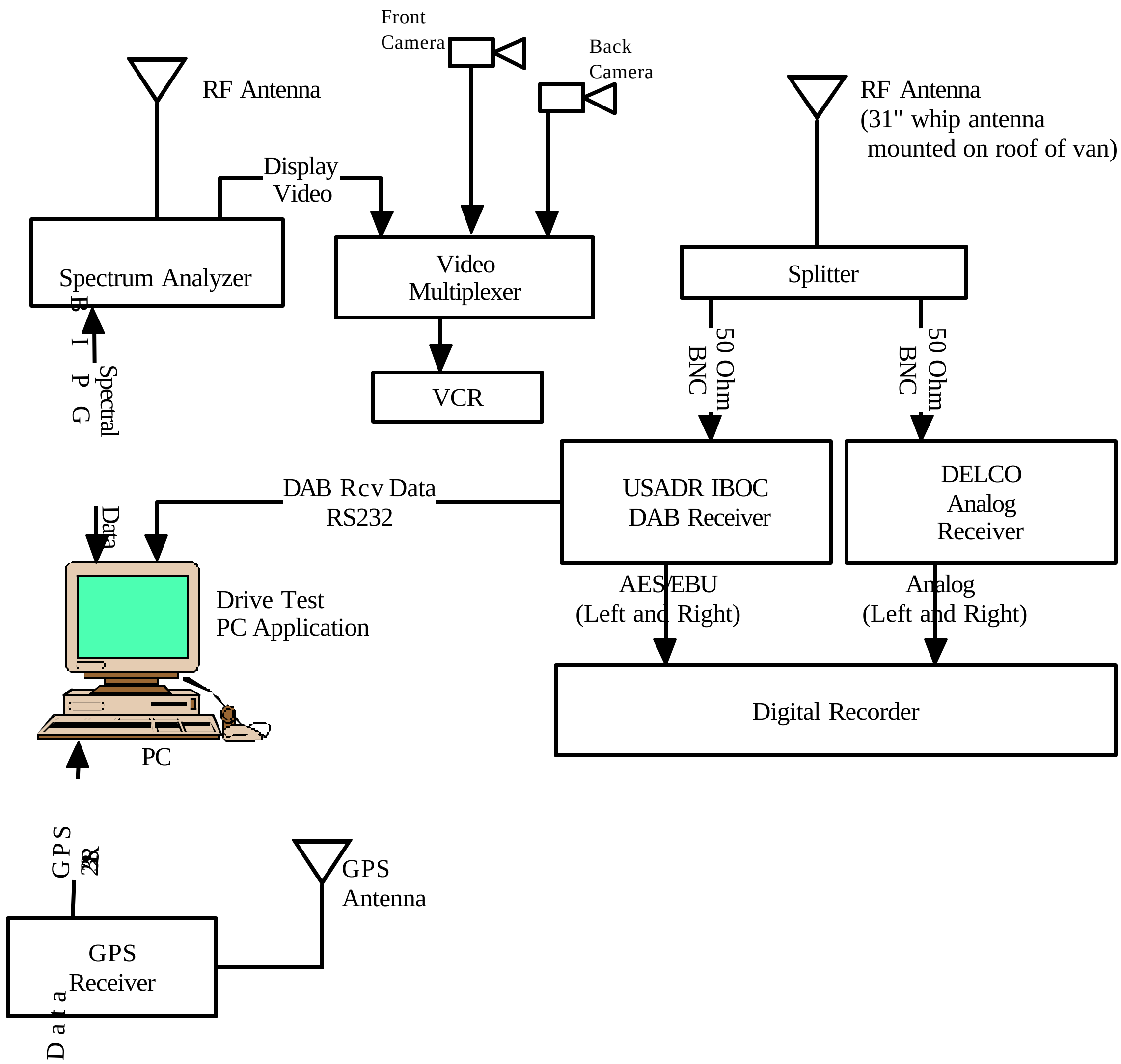

Figure 3 - Test Van Equipment Setup

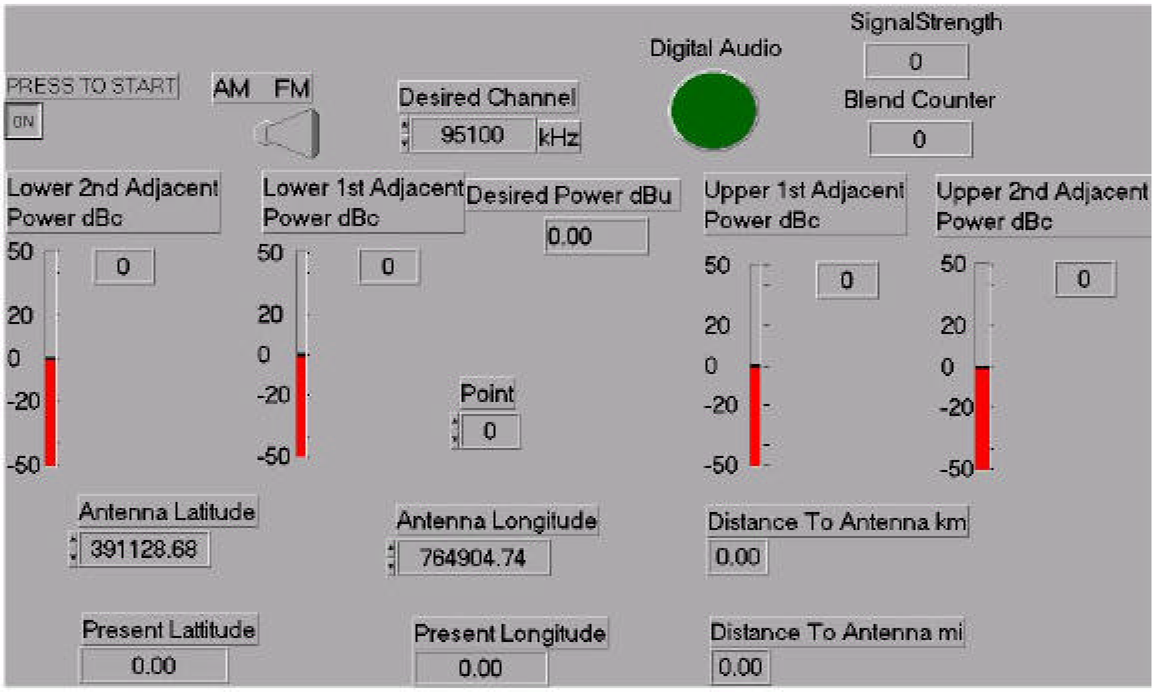

Figure 4 - Field Test PC Application Display (GUI)

4. Digital Coverage Test

4.1. Overview

This test measures the digital coverage of the KWNR hybrid IBOC signal. During the testing the following information was stored:

- Data from the Field Test PC application
- Video from the spectrum analyzer
- Video from the front and back cameras
- Audio from the Delco and IBOC receivers

4.2. Route Selection

The following steps were followed to create the routes traveled by the test vans:

- Radials were plotted for eight azimuth lines from the transmitter site.
- Driving instructions from commercial mapping software were obtained for each route.
- Efforts were made to route the van through areas of varying terrain to study the effects of elevation and obstruction on the digital signal. Of particular interest was the possible constructive effect of RF reflections.

4.3. Test Procedure

a) At the starting location, tune the PC, the IBOC receiver, and the Delco receiver to the desired operating frequency. Enter the GPS coordinates of the transmitter site into the PC. Load the recording media into the Digital Audio Recorder, set the analog audio levels, and label the audio cut. Place a tape into the VCR and setup to record.

b) All notes, tapes, and data should have the same time reference, which is derived from the GPS. Be sure all clocks are synchronized.

c) Simultaneously begin recording on the VCR, Digital Audio Recorder, and PC.

d) Follow driving instructions for the selected radial. Proceed to the end of the planned route, or to a point several miles beyond the edge of digital coverage.

e) Close all files, and remove and mark all tapes.

f) Repeat steps a) through e) for all radials.

4.4. Test Results

4.4.1. Overview

The results of the tests conducted with a transmitted IBOC power output of 582 watts are summarized by the IBOC coverage profile shown in Maps A and B. These Maps, using data recorded by the Field Test PC application, color code the audio mode of the IBOC receiver along each of the eight KWNR field test radials. Map A overlays data on a color coded terrain elevation matrix and Map B uses a computerized prediction of received signal strength. The audio mode colors signify three main regions of IBOC coverage:

- Region 1 (green or black) indicates the portion of the radial where digital audio is uninterrupted;

- Region 2 (yellow) indicates the portion of the radial where the audio is blending between analog and digital;

- Region 3 (red) indicates the portion of the radial where digital audio is no longer available, and the receiver has blended to analog.

The test data is presented via strip-chart recording. The strip-chart recording, comprised of data logged by the Field Test PC application, is shown in Graph KWNR – "X" degrees.[5] The strip chart displays the variation of select parameters with time over the entire length of the radial.[6] The "X" axis of

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5 "X" Denotes the approximate polar orientation in degrees of each radial about the transmission axis.

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- Desired signal strength, in dBu (red)
- Upper (blue) and lower (yellow) first adjacent signal strength, in dBu
- Upper (black) and lower (magenta) second-adjacent signal strength, in dBu
- Distance from the transmitter, in km (orange)
- Receiver audio mode, digital or analog (green)

the chart displays elapsed time. For the radials that were measured with the test van traveling toward the transmitter, the time is shown in reverse so that the distance is always increasing to the right of the chart. The "Y" axis displays both Signal Strength in dBu (left scale) and Distance from Transmitter in km (right scale).

A couple of observations can be made regarding these strip charts:

The traces of the first adjacents do not accurately represent the actual interference environment over much of the radial, since the DAB sidebands are included in adjacent channel measurements. The upper and lower first adjacent traces are each about 25 dB below the desired signal, because this is the level of each DAB sideband relative to its host.

Also, the transition from Region 1 (digital) to Region 2 (blend) occurs as a result of a significant drop in received signal strength. When cross-referenced to the corresponding terrain profile, it is clear that blending begins at a point that experiences extreme terrain shadowing. In fact, the signal profile closely approximates the terrain profile, indicating that signal strength is proportional to elevation. It is well known that the Las Vegas, Nevada metropolitan area is located in a "bowl" shaped desert valley. As can be seen in the terrain profiles, the mountainous areas encircling the city often totally block the line of sight KWNR FM signal.

4.4.2. <u>Comparison of IBOC Coverage to Existing Analog Signal Levels</u>

To provide context to the measured IBOC coverage shown in Map A, USADR has superimposed the test radials on a map which predicts the analog signal levels of KWNR.

This map, generated using propagation prediction software, displays the predicted analog signal strength at a given location using color-coded pixels. For example, green areas correspond to signal levels in the 50 to 59 dBu range; a location on the innermost portion of the green area would have a signal strength of 59 dBu, while a location on the outer edge of the green area would have a signal strength of 50 dBu.

The strip-chart recording of Graphs KWNR-X can be used to confirm the validity of the propagation predictions in Map B. Graph KWNR-X indicates that the IBOC receiver begins to blend at desired signal levels of about 45 dBu. Map B shows that blends for most radials commence in the center of the light-blue region, which corresponds to a 45 dBu signal level. Therefore, actual field measurements verify that the signal-strength prediction Map of Map B is indeed accurate.

4.4.3. <u>Comparison of Measured Digital Performance with Existing Analog Service</u>

Besides showing that the IBOC receiver begins to blend at a signal level of about 45 dBu, Map B illustrates that the edge of digital coverage lies beyond the 40 dBu signal level, and that solid, unperturbed digital coverage extends to the 50 dBu signal level. It can be shown from Map B that IBOC digital coverage is comparable to existing analog coverage. To further interpret these results, the data collected at each test point is discussed below.

4.4.3.1 Region 1, Uniform Digital Coverage

Performance in this region is characterized by uninterrupted, virtual CD-quality digital audio. Region 1 extends beyond signal strengths of 50 dBu, and is indicated in Map A by green radials and Map B by black radials. The field test data shows that the FM hybrid IBOC system covers a huge area with no lapses in digital coverage; the audio is completely free of degradation due to noise, multipath and interference that typically plagues existing analog service.

A comparison of the analog and digital channels of the sample audio at the LVCC test point shows that, while the analog receiver suffers from the effects of noise and multipath, the IBOC receiver delivers unimpaired, virtual CD-quality audio. Not only is the digital audio free of impairments when analog audio is not; the digital audio quality is superior to analog, even when the analog audio is unimpaired.

4.4.3.2 Region 2, Blend Area

This region is located just beyond the point of the initial blend to analog. Performance around Region 2 is characterized by recurrent blending between analog and digital audio. This region is located near the 45 dBu signal level, at the first black-to-yellow transitions on the test radial of Maps A and B.

A comparison of the analog and digital audio recorded in this region demonstrates the seamless performance of the blend function, and indicates that the IBOC receiver, even while recurrently blending, delivers audio quality which is superior to the analog receiver. In fact, analog audio from the IBOC receiver often sounds better than audio from the analog receiver, due largely to proprietary FM demodulation techniques developed by iBiquity to mitigate the effects of multipath.

The recordings also indicate that, at the point where the digital signal begins to degrade – that is, the blend point – the corresponding analog audio itself exhibits audible degradation. Hence, the analog audio is degraded at signal levels where digital audio degradation is not yet perceptible. The same conclusion was made as a result of the laboratory performance tests; this field data simply confirms those measurements.

4.4.3.3 Region 3, Edge of Digital Coverage

Region 3 is the area past the edge of digital coverage, and the point of the final blend to analog. Performance in region 3 is dominated by analog audio, with a couple of brief blends to digital. This point falls between signal levels of 30 dBu and 40 dBu, at the yellow-to-red transitions of Maps A and B.

At this point, both analog and digital receivers' audio is beyond the point of failure. This field data validates the results of laboratory subjective audio evaluations which indicate that the point of failure for existing analog radio lies between received signal strengths of 30 dBu and 40 dBu. As a result, it is clear that the coverage of the IBOC signal is comparable to that of existing analog service.

Most importantly, these results show the graceful degradation of the IBOC signal. When the digital signal degrades sufficiently, the receiver blends to analog, without subjecting the listener to annoying digital artifacts, drop-outs, and muting. In this manner, the performance of the IBOC signal can never be worse than, and is usually much better than, the performance afforded by existing analog service.

4.4.4. Test Radials

Each of the eight test radials extend outward from the KWNR transmitter site in as straight a line as local highways allow. In any case, distance from the transmitter always increases (or decreases) with time. Due to the wide variance in terrain, analog and digital signal characteristics on each radial are worthy of further description:

- 45º Radial

  The 45º radial run began on Route 15 at the intersection of Range Road just northwest of Nellis Air Force Base. The starting point is located approximately 27 kilometers from the transmitter and does not experience any terrain blockage. Altitude increased from 700 to 900 meters AMSL heading northeast on Route 15 for another 27 kilometers. During this time the digital audio quality showed no impairment, while the analog was distorted by a small amount of the "specular multipath" characteristic of this area. The first blend to analog occurred at 54 kilometers from the transmitter, where the path was in the shadow of a mountain that exceeded the path clearance by 500 meters. The route emerged out of the shadow at 57 kilometers, and reacquired digital audio. The signal remained digital until 64 kilometers, when the route was again shadowed. Heading northeast, blending to analog occurred three more times. At 75 kilometers from the transmitter, the digital signal level dipped below the threshold of detection. As can be seen on the strip chart for the 45º radial, the point of blend to analog uniformly occurs at a level of 40 to 45 dBu. The analog audio quality at this point is sufficiently degraded as to become unlistenable.

- 90º Radial

  The 90º radial run began shortly before crossing the peak of Sunrise Mountain, to the west of Las Vegas. After cresting the peak, the KWNR signal was severely degraded by the shadowing of the immediately adjacent rock outcroppings. Most of the recovered analog transmission at this point was reflected signal, with severe multipath. After emerging from behind Sunrise Mountain, the receiver blended back to digital and remained unimpaired until 48 kilometers from the transmitter on route SSR 167 (eastbound). At this point, the local terrain elevation was approximately 150 meters below a clear transmission path and the received field approached 45 dBu. The receiver blended to analog and remained that way for the remainder of the radial, except for a few transitions to digital from 55 to 65 kilometers. It should be noted that at a distance of approximately 45 kilometers, KWNR inadvertently broadcast 30 seconds of "dead air".

- 135º Radial

  The 135º radial began 58 kilometers from the transmitter on the Arizona side of the Colorado River. This radial was run in a reverse direction (towards the transmitter) due to excessive traffic at Hoover Dam on the way out. Data collection began near the intersection of Route 93 and the road leading to Doran Springs, Arizona. At this point the signal had blended to severely impaired analog. The terrain profile at this point was that of a desert plain, with mountain ranges that shadow the KWNR signal on each side of the river. Nevertheless, moving west on 93, the signal blended to digital at about 45 kilometers from the transmitter. It remained digital for the next 10 kilometers (except for a short blend to analog at 40 kilometers). At 35 kilometers, the mountains to the west of the river were adjacent to the test van and caused a blend to analog, which remained in effect descending into the Colorado River Valley and crossing Hoover Dam. The digital transmission was not reacquired until approximately 15 kilometers from the transmitter (Point 135-1, which is severely obstructed by mountains to the west). The signal remained a robust and unimpaired digital until the radial ended in sight of the transmitting tower.

- 180º Radial

  The 180º radial began at 60 kilometers from the transmitter in Searchlight, Nevada, and proceeded north on Route 95 to an intersection with Routes 93 and 515. This is another one of the three "reverse" radials that was measured as the test van approached the transmitter site. The digital signal was robust and unimpaired for the duration of the radial.

- 225º Radial

  The 225º radial began on Interstate Route 15 South at the intersection of Route 160. The digital signal remained robust and unimpaired until the test van was about 50 kilometers from the transmitter at a point near the Roach Dry Lake Cutoff. The signal then blended to analog and stayed below the threshold of digital acquisition. As can be seen from the terrain profile, point Map 225-1 (Digital POF) is severely shadowed by two mountain ranges to the north.

- 270º Radial

  The 270º radial began on Route 160 at the intersection of Interstate 15, west of Las Vegas, which sits in a desert valley surrounded by mountains. Heading west on 160 toward the mountains, the digital signal was unimpaired through the extreme terrain of Red Rock Canyon. At that point (270-1, 46 kilometers from the transmitter) the signal blended to analog and remained that way until the radial ended in Pahrump, Nevada.

- 315º Radial

  The 315º radial began on N. Rancho Blvd in Northwest Las Vegas and continued on Interstate Route 95 Northwest. The digital signal stayed robust and unimpaired until the highway curves around a mountain just past the intersection of Route 156. Analysis of the terrain profile reveals the obstruction.

- 360º Radial

  The 360º radial was another radial that was measured in a reverse direction, approaching the transmitter site. Measurements began on of Route 93 South at its intersection with

Route 168. The signal at this point was below digital threshold of detection, and the analog signal quality was severely impaired, due to low signal level. At approximately 80 kilometers, the digital transmission was acquired and mode blending was observed every 5 kilometers until 58 kilometers from the transmitter. At this point (360-1), the overall elevation increased sufficiently to allow for unimpaired reception of the digital signal. The field intensity dropped enough to cause a short blend to analog at 45 kilometers. At this point, the test van was in the direct shadow of an adjacent mountain. From this location, and until the radial ended at the intersection with Interstate Route 15, the signal remained digital and unimpaired.

4.4.5. Summary

Within Region 1, the IBOC signal covers a huge area with no lapses in digital coverage; the audio is completely free of degradation that typically plagues existing analog service. Even in unimpaired conditions, the digital audio quality is superior to analog audio quality.

Within Region 2, the system blend function exploits the availability of both the analog and digital portions of the hybrid signal. The receiver outputs unimpaired digital audio, and seamlessly blends to analog when the digital audio is sufficiently impaired. This maximizes the quality of the audio beyond that of existing analog service.

Within Region 3, the IBOC signal exhibits graceful degradation. When the digital signal deteriorates and the receiver blends to analog, the performance of the IBOC signal mirrors that of existing analog service, without subjecting the listener to muting and annoying digital artifacts.

The results of the Digital Coverage field test have confirmed the findings of extensive simulations and laboratory performance tests: the audio quality of the IBOC digital signal is superior to analog audio quality, and the digital coverage is comparable to that provided by existing analog service.

5. Field Test Summary

These field test results have demonstrated the superior performance of the iBiquity FM hybrid IBOC DAB system in a real-world environment, and have validated the results of extensive simulations and laboratory performance tests. The Digital Coverage tests in this report illustrates that the DAB audio quality exceeds that of an existing analog FM signal, and shows that IBOC DAB offers coverage comparable to existing analog service.

ATTACHMENT A

MAPS AND CHARTS

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