# Appendix L

## AM Hybrid IBOC DAB Field Test Results

1. Overview

The USADR AM IBOC DAB system has been carefully designed to provide superior digital audio performance while minimizing the impact to existing analog signals. In the initial phase of development, the system was modeled and simulated to verify that the resulting design would exhibit acceptable performance in an environment comprised of both analog and IBOC signals. As the development has progressed, the computer models have been replaced by hardware and software implementations of AM IBOC DAB exciters and receivers. These exciters and receivers allow for verification of system performance in the field.

The goals of the USADR AM field testing program are four fold: (1) Demonstrate significant improvements over current analog audio quality; (2) Demonstrate robustness of the digital signal in the harsh AM environment (e.g., robustness to interferers as well as channel impairments); (3) Demonstrate coverage areas large enough such that significant numbers of listeners currently receiving analog broadcasts will be able to receive digital broadcasts; and (4) show that the hybrid IBOC DAB signal is compatible with existing analog signals.

This appendix describes the procedures being used for AM field testing, and provides preliminary results. These tests are important because they verify the performance of a physical implementation of the design under real-world conditions.

2. Definitions and Assumptions

2.1. DAB Signal

The desired hybrid IBOC signal is comprised of an analog AM host and a DAB signal. Both the analog AM and DAB signals are generated using a USADR AM IBOC DAB exciter for further amplification by existing analog transmitters. Figure L-1 depicts a spectral representation of the AM hybrid IBOC signal.

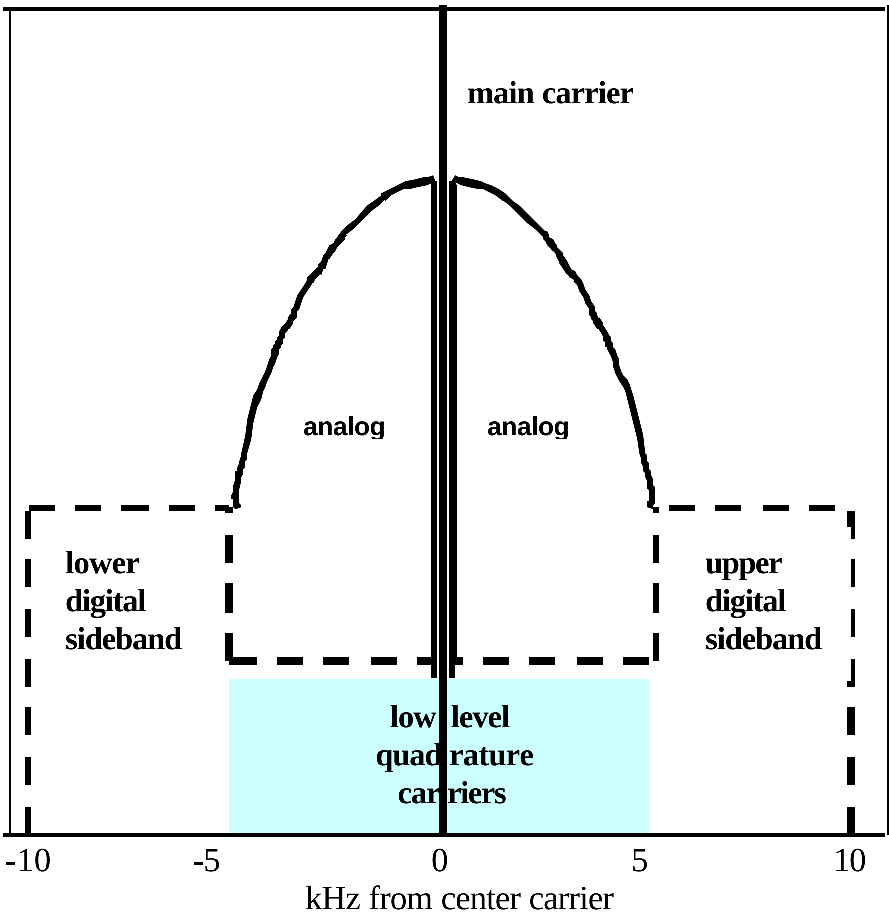


**Figure L-1 - AM Hybrid IBOC Spectrum**

2.2. Digital Coverage

The USADR 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.[1]

The receiver uses the block error rate[2] metric to determine the appropriate time to commence a blend to analog. As the received signal degrades, blends will occur with

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1 Refer to Appendix I for a discussion of USADR's time-diversity blend function.

2 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.

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

WD2XAM, an experimental, 10 kW station operating at a frequency of 1660 kHz, is currently being used for initial AM field testing. The transmit antenna is located at Xetron Corporation in Cincinnati, Ohio, at a longitude of 84° 28' 40" W and a latitude of 39° 18' 16" N. Xetron is performing tests to obtain coverage results along eight radials. The radials were chosen to correspond to approximately 45 degree increments in azimuth around the transmitter. The radials covered a wide variety of reception environments including urban, suburban, rural, heavy industrial/business, light industrial/business, and residential. A wide variety of road types were encountered, including divided highway, two-lane non-divided highway, high traffic non-highway, and light traffic non-highway.

### 3.2. Station Configuration

Figure L-2 shows the equipment configuration that is being used to generate the transmitted signal. The source material to be played was recorded on a CD. The Denon DN-C680 CD player sampling frequency was synchronized to the oscillator in the USADR exciter to prevent data underflow or overflow errors for the audio encoder. Synchronization was accomplished by inputting a 44.1 kHz signal from the exciter to the CD player external synchronization input. The CD player output was input to the an Orban Optimod 9200 audio processor. The processed source material was input to the USADR exciter via an AES/EBU connection. The audio signal was encoded by the exciter, and the hybrid DAB signal, containing the analog and digital components, was generated.

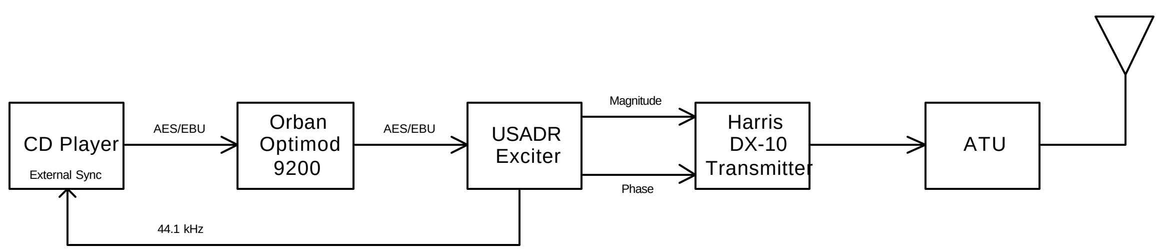


**Figure L-2 - Diagram of Xetron AM Transmitter Setup**

The USADR exciter produced magnitude and phase components that are input to a DX-10 transmitter supplied by Harris Corporation. The phase signal was input to the external oscillator input on the Harris DX-10. The magnitude signal produced by the exciter contains the DC bias needed for AM broadcasting. Although the Harris DX-10 transmitter usually provides the DC bias, the modulation index and the level of the digital signal relative to the analog signal could be conveniently and precisely controlled by having the exciter provide it.

A modulation index was adjusted to be consistent with normal operating levels (-99, +125%). This level refers to the modulation of the analog signal only. The modulation levels were checked by observing the Harris DX-10 transmitter modulation-monitor sample signal, and the signal received at the test van, with an oscilloscope.

The signal from the Harris DX-10 transmitter was sent to the antenna tuning unit (ATU) using a 580 foot section of Andrew LDF6-50 Heliax coaxial cable. The output from the antenna tuning unit was input to the transmit antenna. Central Tower Corporation supplied the transmit antenna, which is 150 feet high and base-fed. The antenna has a ground system consisting of 120, 150' buried radials.

### 3.3. Van Configuration

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

The signal was received through a 31" whip antenna mounted on top of the test van. The antenna was connected to the receiver using a 4.5 foot piece of RG62 coaxial cable, which has a characteristic impedance of 93 ohms. This particular antenna and cable were used because they are typical of equipment on many automobiles.

The Field Test PC provides a graphical user interface ("GUI"), similar to that shown in Figure L-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)

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.

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

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 output 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 is capable of simultaneously recording audio from the Delco and USADR IBOC receivers. For First-Adjacent and Host Compatibility Testing, the digital audio recorder is capable of simultaneously recording audio from all analog test receivers and the USADR IBOC receiver. All audio and video equipment is controlled manually.

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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 L-1 – Test Equipment Manufacturer and Model numbers**

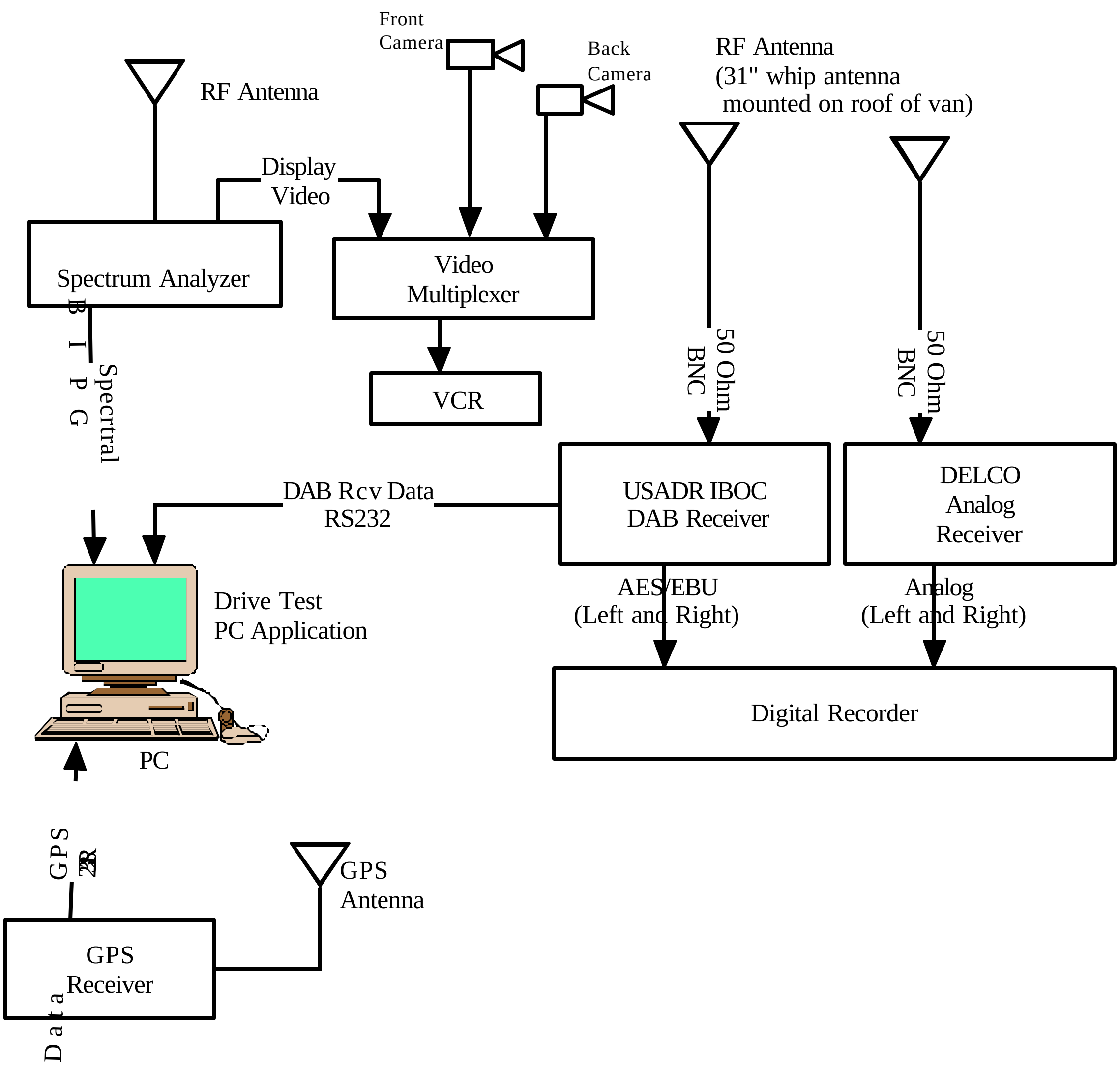


**Figure L-3 - Test Van Equipment Setup**

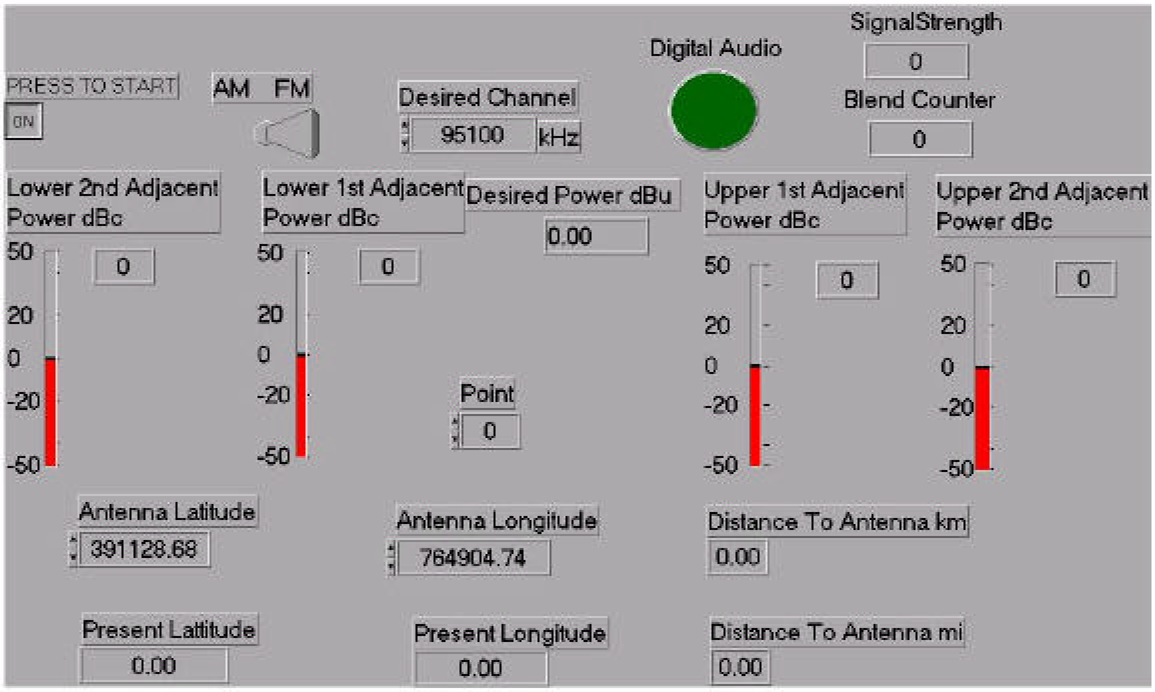


**Figure L-4 - USADR Field Test PC Application Display (GUI)**

## 4. Digital Coverage Test

### 4.1. Overview

This test measured the digital coverage of the WD2XAM hybrid IBOC signal. During the test 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 USADR IBOC receivers

### 4.2. Route Selection

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

- Radials were plotted for the selected azimuth lines from the transmitter site.
- The shortest driving routes were selected to approximate the desired radials.[5]
- Driving instructions from commercial mapping software were obtained for each route.
- Efforts were made to route the van through areas of varying terrain, with urban and suburban population densities.

[5] Preferences were given to major roads along each route.

### 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. Preliminary Test Results

Figure L-5 shows preliminary results of the coverage tests performed thus far. This map, using data recorded by the Field Test PC application, color codes the audio mode of the IBOC receiver along each field test radial. The colors signify three main regions of IBOC coverage:

- Region 1 (Green) 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.

IBOC field performance may be further illustrated by analyzing the full suite of test data recorded along each of the radials. For illustration purposes, USADR has selected one of these radials for analysis in this report: the radial that runs northeast along Route 71 away from Cincinnati.

The test data, presented via strip-chart recording comprised of data logged by the Field Test PC application, is shown in Figure L-6. The strip chart displays the variation of select parameters with time over the entire length of the radial. The following parameters are included on the strip chart:

- Desired signal strength, in mV/m (red)
- Upper (blue) and lower (yellow) first-adjacent signal strength, in mV/m
- Upper (black) and lower (magenta) second-adjacent signal strength, in mV/m
- Distance from the transmitter, in km (orange)

- Receiver audio mode, digital or analog (green)

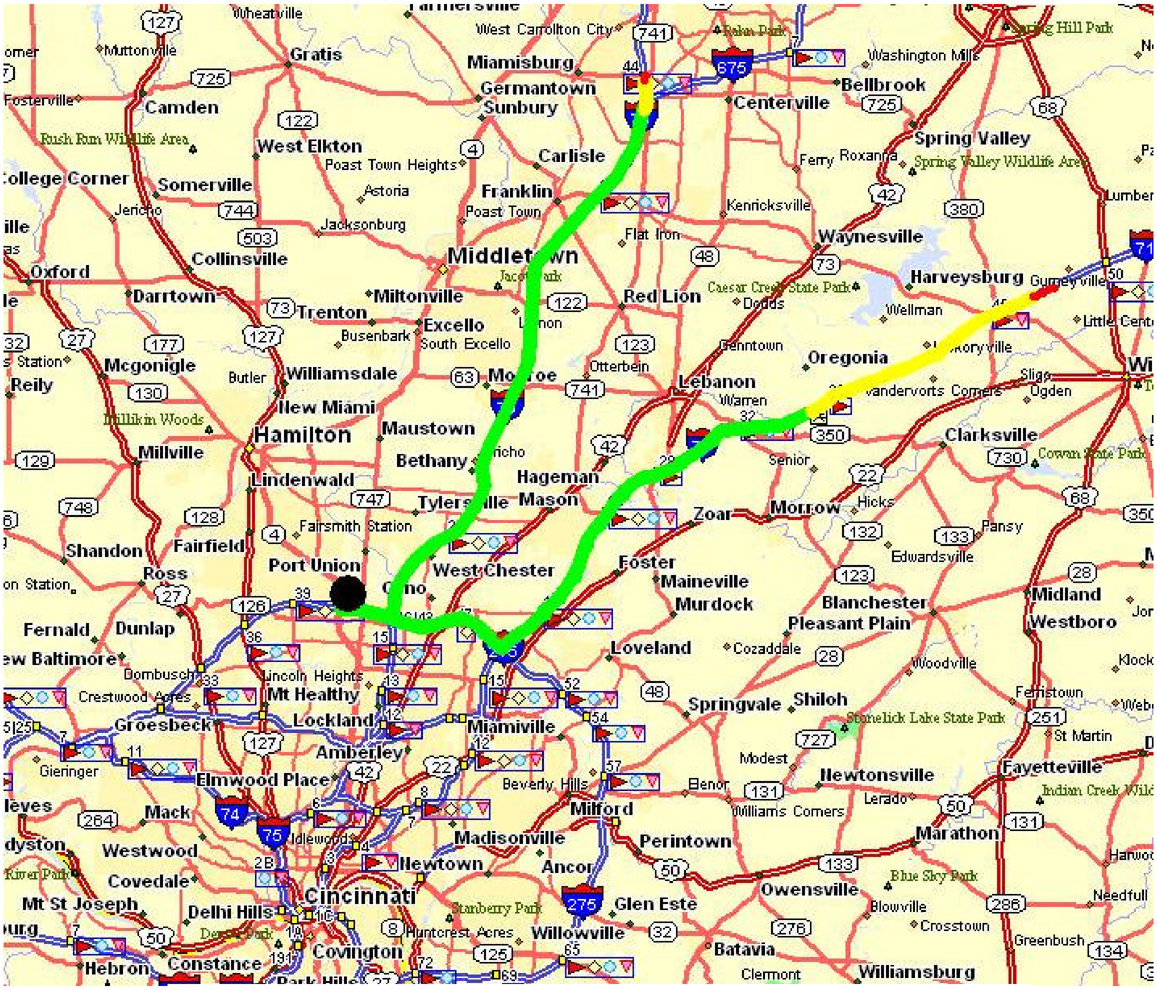

**Figure L-5 WD2XAM AM IBOC Coverage Map**
**(Scale: 1 inch = 10 miles)**

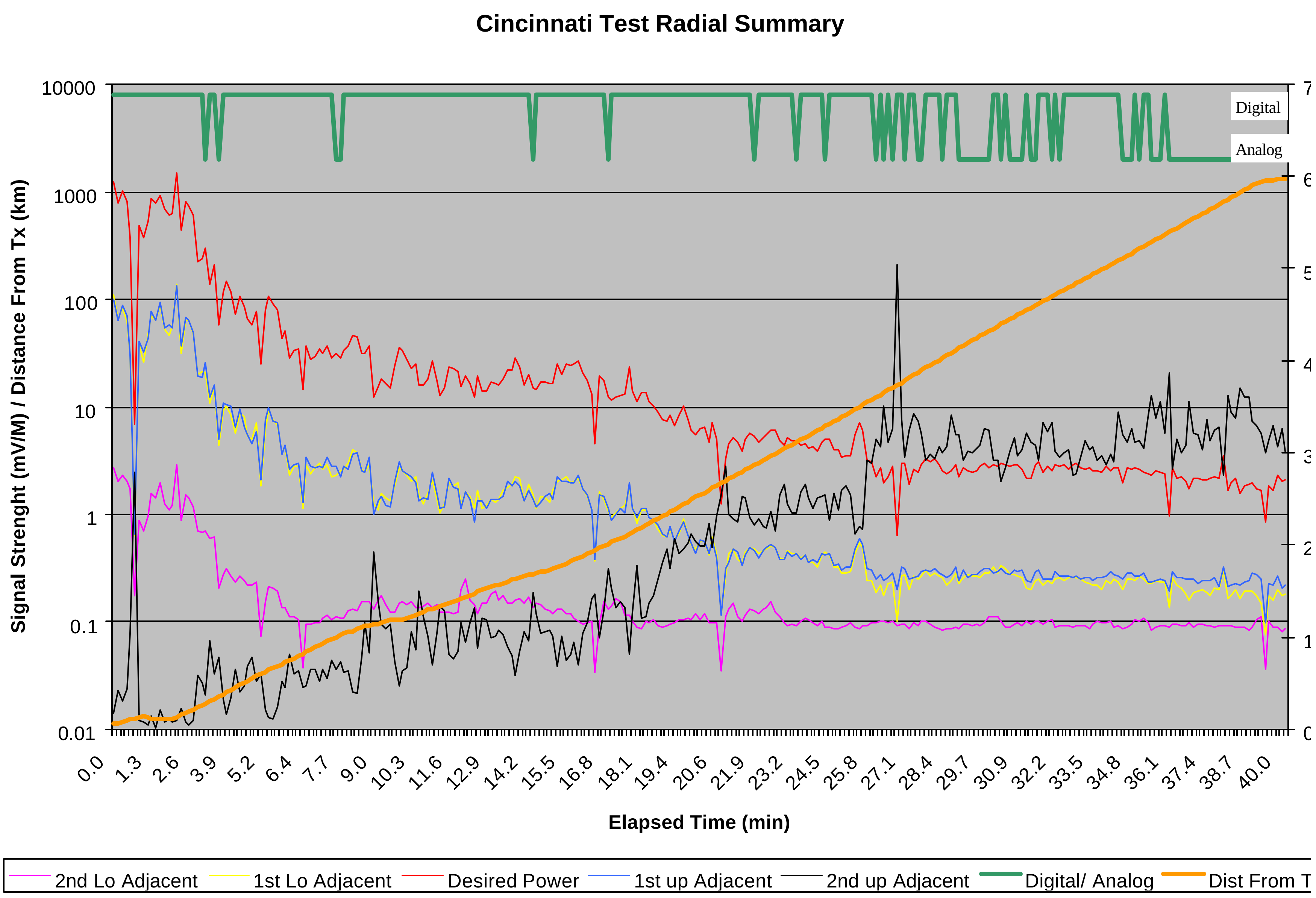


**Figure L-6 WD2XAM AM IBOC Coverage Map**

Conversion of the desired signal level, as measured by the spectrum analyzer in dBm, to field strength in mV/m, was accomplished by taking measurements at several locations using the spectrum analyzer and a Potomac Instruments FIM-41 field strength meter, and calculating an appropriate conversion factor. From these measurements the following conversion formula has been obtained.

Field Strength (V/m) = 3.7 * 10^(Spectrum Analyzer Measurement in dBm / 21).

Figure L-6 shows what appears to be first adjacent interferers, but actually these are only portions of the desired DAB sidebands being measured. However, there does exist a strong second adjacent that becomes stronger than the desired signal at the 25 minute mark (See Figure L-6).

As can be seen from these figures, the coverage of the digital signal extends 50 km from the transmitter. The field strength where the system begins to blend frequently is approximated at 3.3 mV/m and where the signal no longer blends back to digital is approximated at 2.3 mV/m. The occasional outages of the digital signal during the route are due to particularly severe grounded conductive structures.

### 4.5. Audio Quality

Included in this report is a demonstration CD. This CD contains audio clips comparing the digital and analog audio with the original source material. The analog audio was obtained from the NRSC recordings done at WCGA in St. Simons Island, Georgia. The digital information was recorded on a USADR receiver at the WD2XAM test site in clean strong signal conditions near the transmit antenna. When listening to this CD one should pay particular attention to the increased fidelity, frequency response and stereo information of the AM digital audio. Clearly this represents a substantial increase in audio quality over what is currently available with today's analog broadcasts.

## 5. Conclusions

These field tests demonstrate that the USADR AM IBOC system delivered, within a 20 kHz AM channel, a high quality "FM Like" stereo digital broadcast. The DAB signal was free from noise, distortion, and delivered a digital signal to approximately the 3 mV/m signal with minimal blending to analog. Beyond the 2 mV/m signal the receiver operated primarily in the analog mode.

Over the past three years, USADR has performed detailed analyses, run exhaustive simulations, implemented its IBOC design in receivers and exciters, verified the simulations and analyses in laboratory tests, and validated results through real-world field testing. The collective evidence from all of these sources mutually confirms the fact that the USADR AM IBOC DAB system performs as designed, representing a viable path to digital broadcasting.