# HD Radio™ Single Frequency Network Field Test Results

# WD2XAB Baltimore & WKLB Boston

**Revision 01.14**

**July 26, 2011**

## TRADEMARKS



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# 1 Scope

This document describes the results of field testing for the iBiquity implementation of Single Frequency Network (SFN) technology on the following stations under experimental license:

- Baltimore, Maryland market: WD2XAB / WD2XAB-FM1 (these results were previously reported in [2] and are included here for completeness)
- Boston, Massachusetts market: WKLB-FM / WKLB-FM1

# 2 Referenced Documents

[1] iBiquity Digital Corporation, “HD Radio Single Frequency Network Broadcast Test Plan & Results,” Rev. 00.04, November 5, 2009.

[2] iBiquity Digital Corporation, “HD Radio Single Frequency Network Interim Field Test Results – WD2XAB,” Revision 01.06, November 5, 2010.

# 3 Executive Summary

With funding from the NAB FASTROAD Technology Advocacy Program and in accordance with the previously submitted HD Radio Single Frequency Network Broadcast Test Plan [1], iBiquity Digital Corporation constructed and field tested two FM band digital radio Single Frequency Networks (SFNs).

iBiquity established the first SFN in the Baltimore, Maryland market using two test stations: main site WD2XAB and booster site WD2XAB-FM1. Both sites were individually and collectively field characterized for their HD Radio signal coverage [2].

iBiquity built and tested the second SFN with the assistance of Greater Media Boston. iBiquity constructed an SFN booster site in Andover, Massachusetts (WKLB-FM1) to supplement the WKLB-FM main site in Needham, Massachusetts.

Each SFN consisted of a main site transmitting a hybrid HD Radio signal and a booster site which transmitted:

- in the case of WD2XAM-FM1, only the digital portion of a hybrid HD Radio signal;
- in the case of WKLB-FM1, either the digital portion of a hybrid HD Radio signal or both the digital and analog portions of a hybrid HD Radio signal with a digital-to-analog power ratio of the booster established experimentally, so as to provide limited analog service near the booster site without excessively interfering with the analog signal emanating from the main site.

The field test results presented in this report characterize the following:

- Digital performance:
  - Main site alone
  - Booster site alone
  - Main and Booster sites together
- Analog compatibility:
  - Digital-only booster carrier interference to main host analog (near booster)
  - Hybrid booster analog carrier interference to main analog carrier

These tests demonstrate that HD Radio SFNs provide broadcasters with the ability to selectively extend digital coverage within their protected contour without compromising the existing HD Radio digital service area. They further demonstrate that the main site analog signal may or may not be receivable near the booster site depending upon the type of analog receiver used. Finally, they demonstrate that, for certain receivers, using a hybrid booster can help restore analog service near the booster site compared to digital-only booster operation.

# 4 Performance Testing – Baltimore[1]

## 4.1 Transmitter Locations

The map of the Baltimore, Maryland metropolitan area in Figure 4-1 shows the main transmitter site (WD2XAB, 93.5 MHz) in the lower left and the booster transmitter site (WD2XAB-FM1) in the upper right.

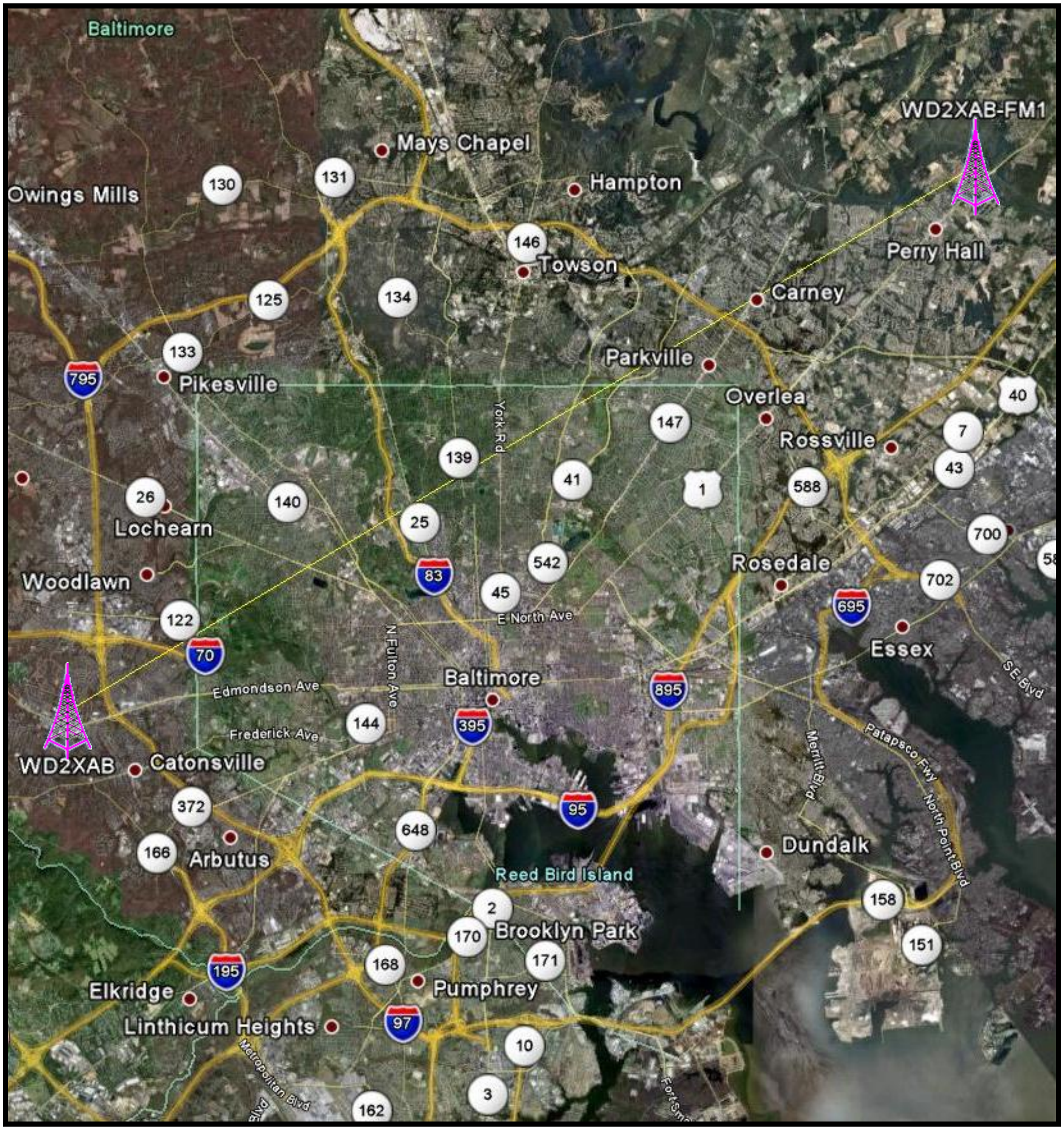



*Figure 4-1: Map of the Baltimore, Maryland Metropolitan Area*

[1] The information in this Section is extracted from Section 3 of [2].

# 5 Trial Test Runs and Selection of Test Areas[2]

ComStudy propagation prediction software was used to identify areas of potential overlap of the two signals. Areas in white were *predicted* to receive the HD Radio signal. Separate test runs (green and yellow dots) by the iBiquity test van on the main transmitter (Figure 5-1) and booster transmitter (Figure 5-2) refined the individual areas of coverage. A green dot indicates the *measured* HD Radio signal reception.

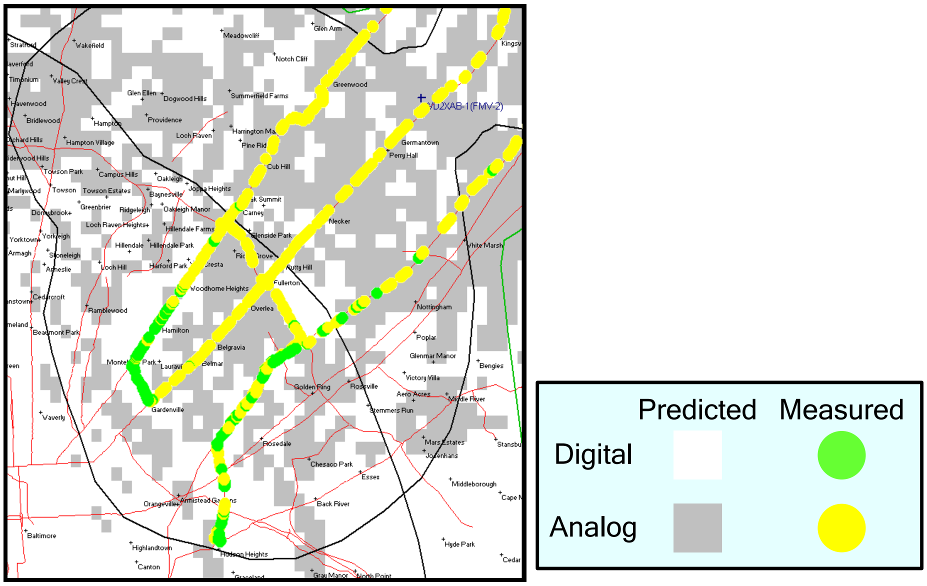



***Figure 5-1: Main Transmitter Only***

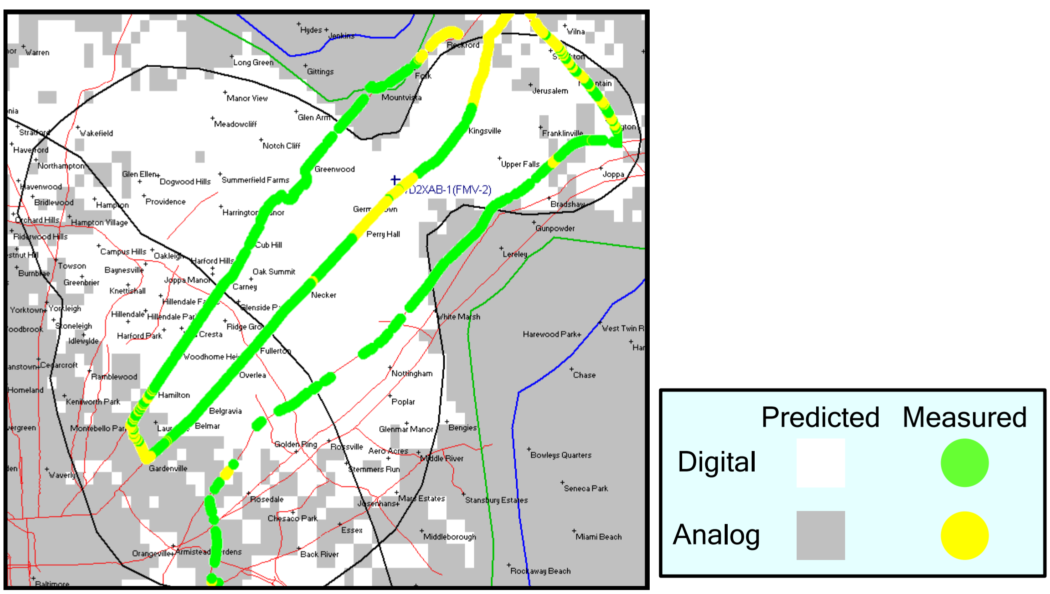



***Figure 5-2: Booster Transmitter Only***

[2] The information in this Section is extracted from Section 4 of [2].

The map shown in Figure 5-3 was the record for the actual first test runs on the synchronized (but not time-aligned) system; the map shown in Figure 5-4 was the prediction for the ideal performance from the individual test runs. For comparison purposes, the circled area (Harford Road) fared much better in the prediction than in the actual test run.

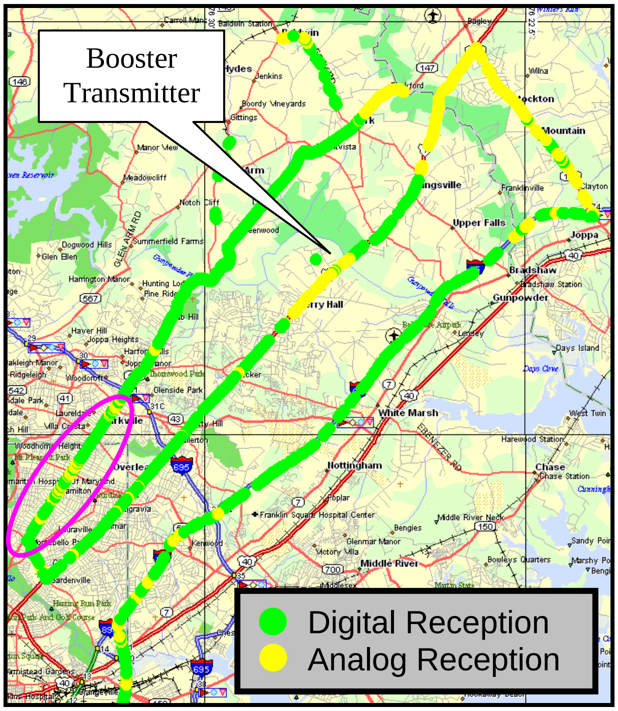



***Figure 5-3: Main and Booster – Actual Test Runs on the Synchronized System (Not Time-Aligned)***

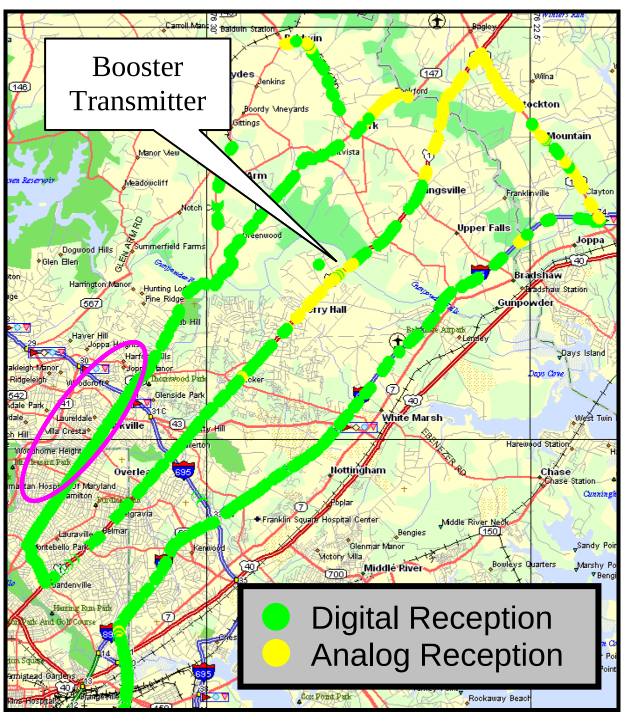



***Figure 5-4: Main and Booster – Predicted Ideal Performance***

# 6 Time Alignment[3]

The Harford Road area was chosen as the area most likely to experience signal overlap and the iBiquity test van was driven to an area located in the center of signal overlap.

The spectrum nulled out at intervals of 49 kHz, as shown in the plot in Figure 6-1.

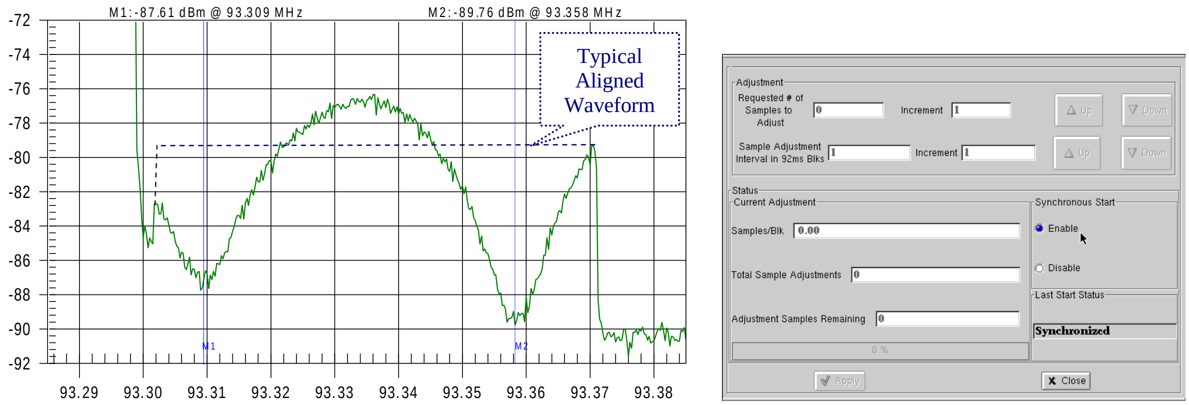
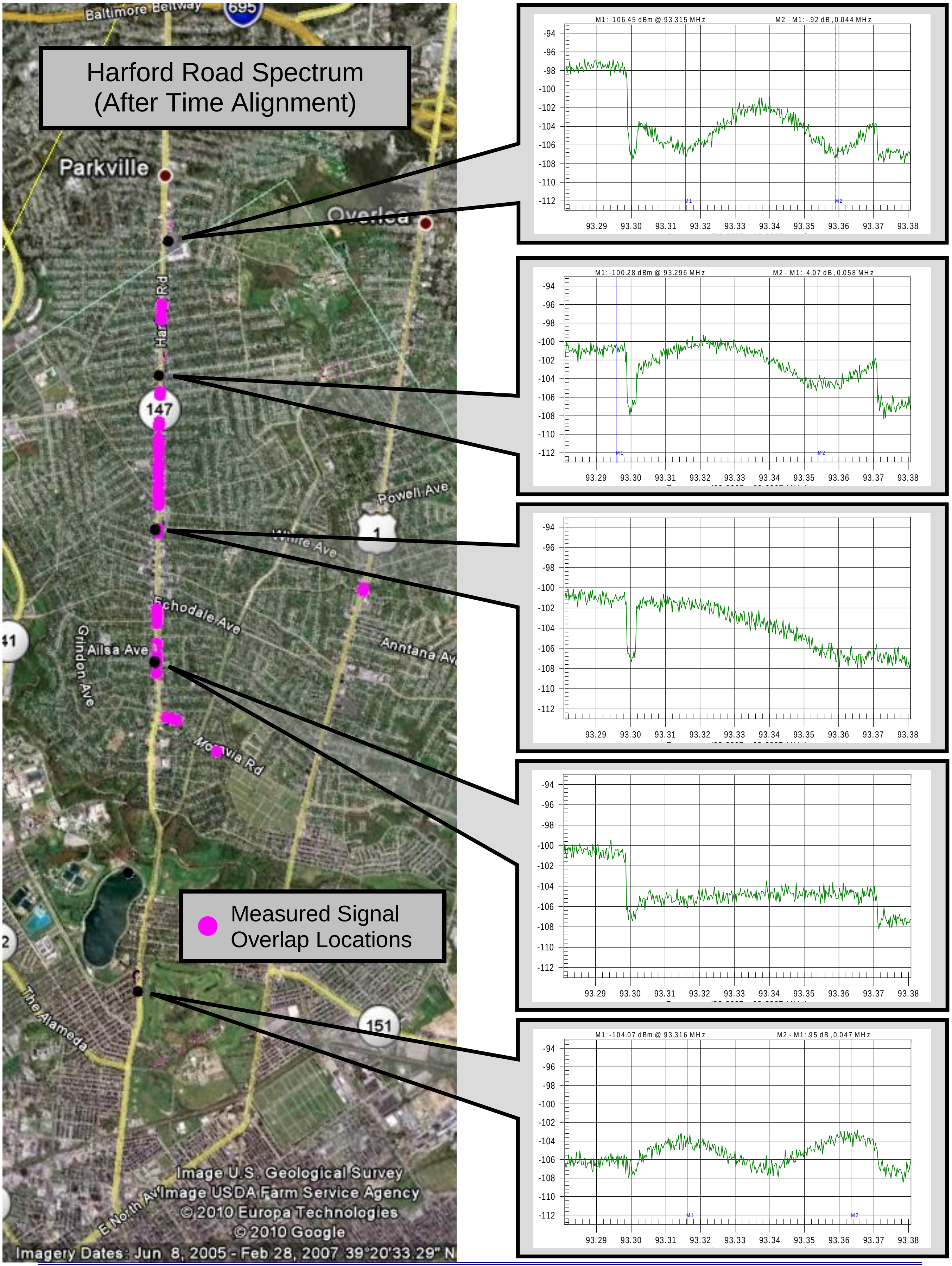



***Figure 6-1: 20-microsecond Misalignment / 3.7 Miles Delay Spread and Exgine Delay Adjustment Window***

This corresponds to a delay spread of 20 microseconds. Since light travels one mile in 5.37 microseconds, this means that the overlap point is 3.7 miles closer to the booster transmitter site than the main transmitter site.

A delay offset of 20 microseconds was added to the booster's digital signal transmission to cause the digital frames from each transmitter to align. Spectra were obtained at a number of locations on Harford Road and these spectra show the alignment at the points of overlap (see next page).

[3] The information in this Section is extracted from Section 5 of [2].


Harford Road Spectrum
(After Time Alignment)
Measured Signal
Overlap Locations
Baltimore Beltway
695
Parkville
Overlea
Har Rd
147
Powell Ave
1
White Ave
Echodale Ave
Anntana Av
Grindon Ave
Ailsa Ave
Moravia Rd
The Alameda
151
E North Av
Image U.S. Geological Survey
Image USDA Farm Service Agency
© 2010 Europa Technologies
© 2010 Google
Imagery Dates: Jun 8, 2005 - Feb 28, 2007 39°20'33.29" N
M1: -106.45 dBm @ 93.315 MHz
M2 - M1: -.92 dB, 0.044 MHz
M1: -100.28 dBm @ 93.296 MHz
M2 - M1: -4.07 dB, 0.058 MHz
M1: -104.07 dBm @ 93.316 MHz
M2 - M1: .95 dB, 0.047 MHz
-94
-96
-98
-100
-102
-104
-106
-108
-110
-112
93.29
93.30
93.31
93.32
93.33
93.34
93.35
93.36
93.37
93.38

# 7 Performance after Time Alignment[4]

Following the alignment procedure, test runs were repeated and improved performance was indicated in the overlap areas as shown in Figure 7-1, Figure 7-2, and Figure 7-3.

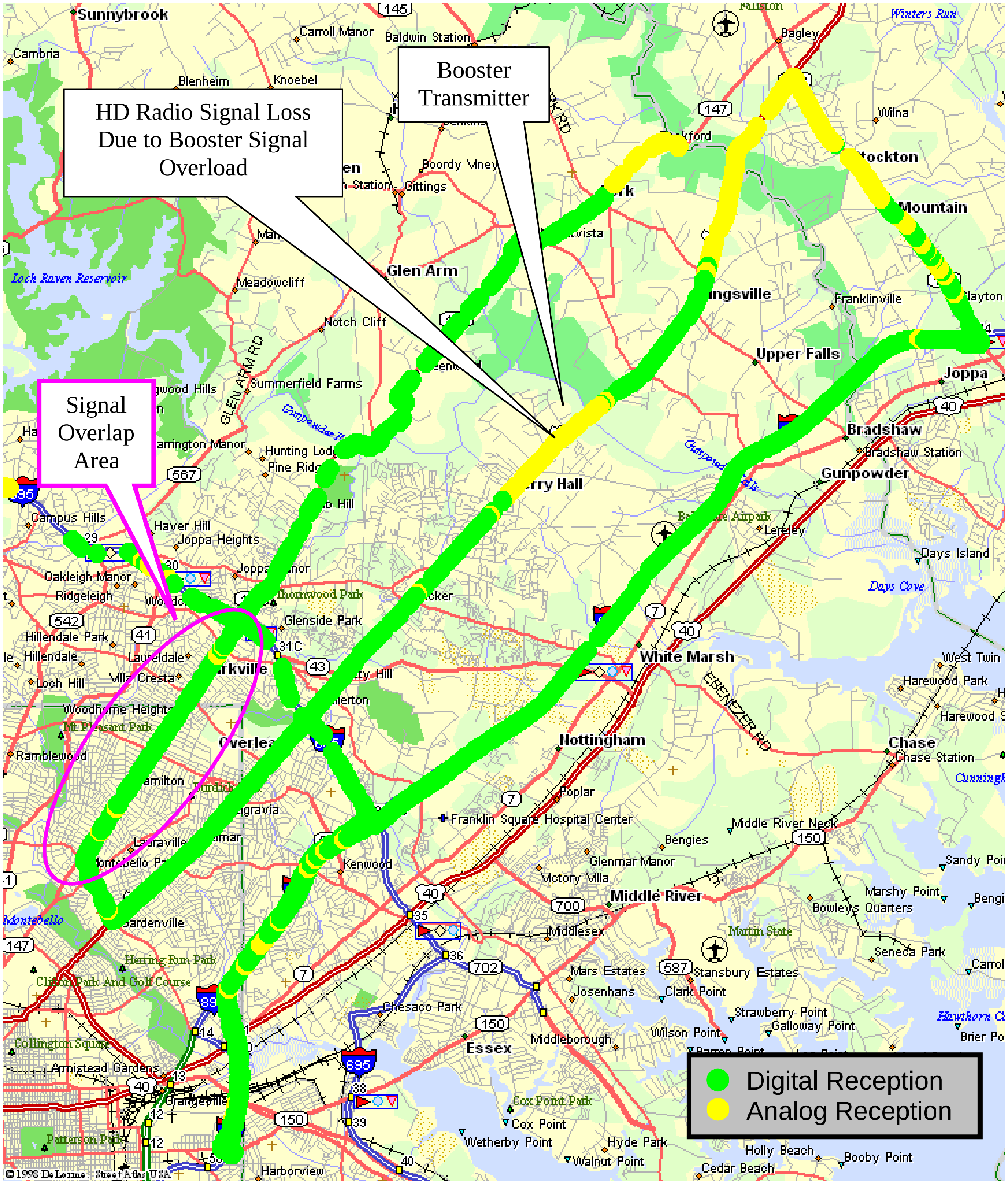



*Figure 7-1: Main and Booster – HD Radio Signal Coverage after Time Alignment*

[4] The information in this Section is extracted from Section 6 of [2].

Figure 7-2 and Figure 7-3 exhibit expanded views of signal overlap areas.

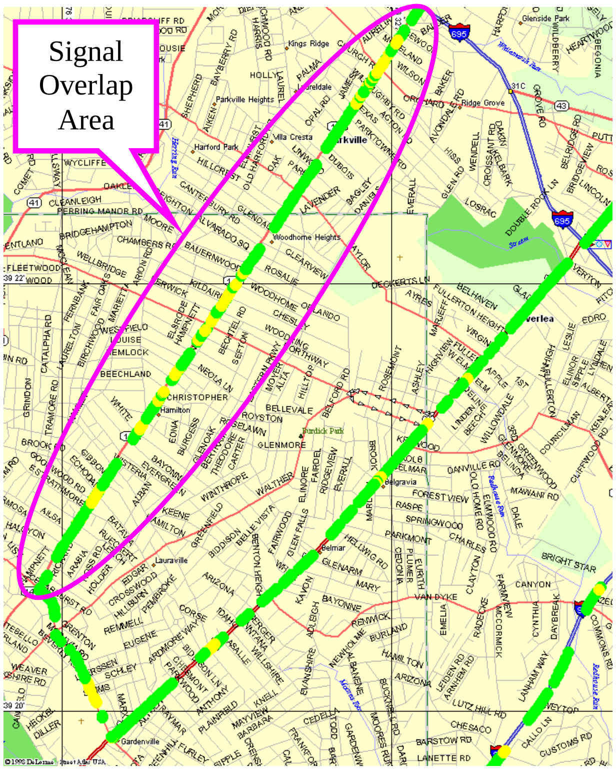



***Figure 7-2: HD Radio Signal Coverage before Time Alignment***

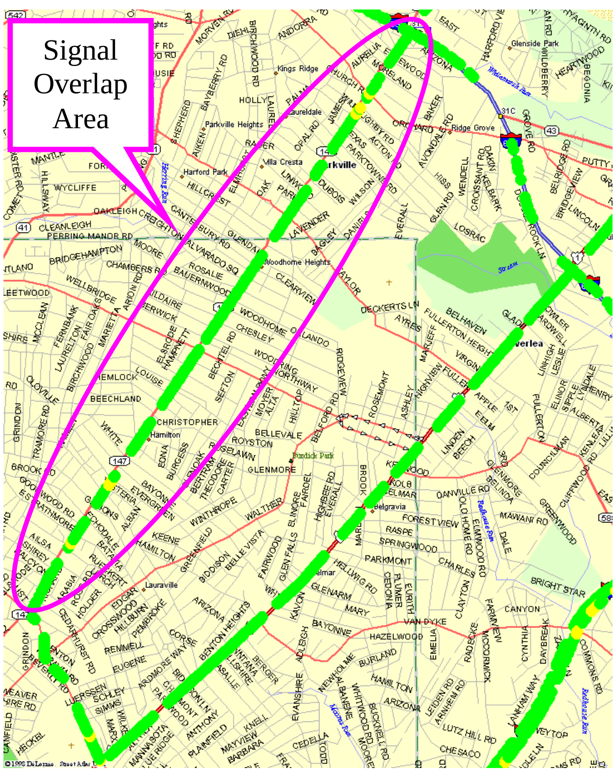



***Figure 7-3: HD Radio Signal Coverage after Time Alignment***

# 8 Performance Testing – Boston

## 8.1 Transmitter Locations

The map of the Boston, Massachusetts metropolitan area shown in Figure 8-1 shows the main transmitter site (WKLB, 102.5 MHz) in the lower left and the booster site (WKLB-FM1) in the upper left. The distance between the sites is 23.7 miles.

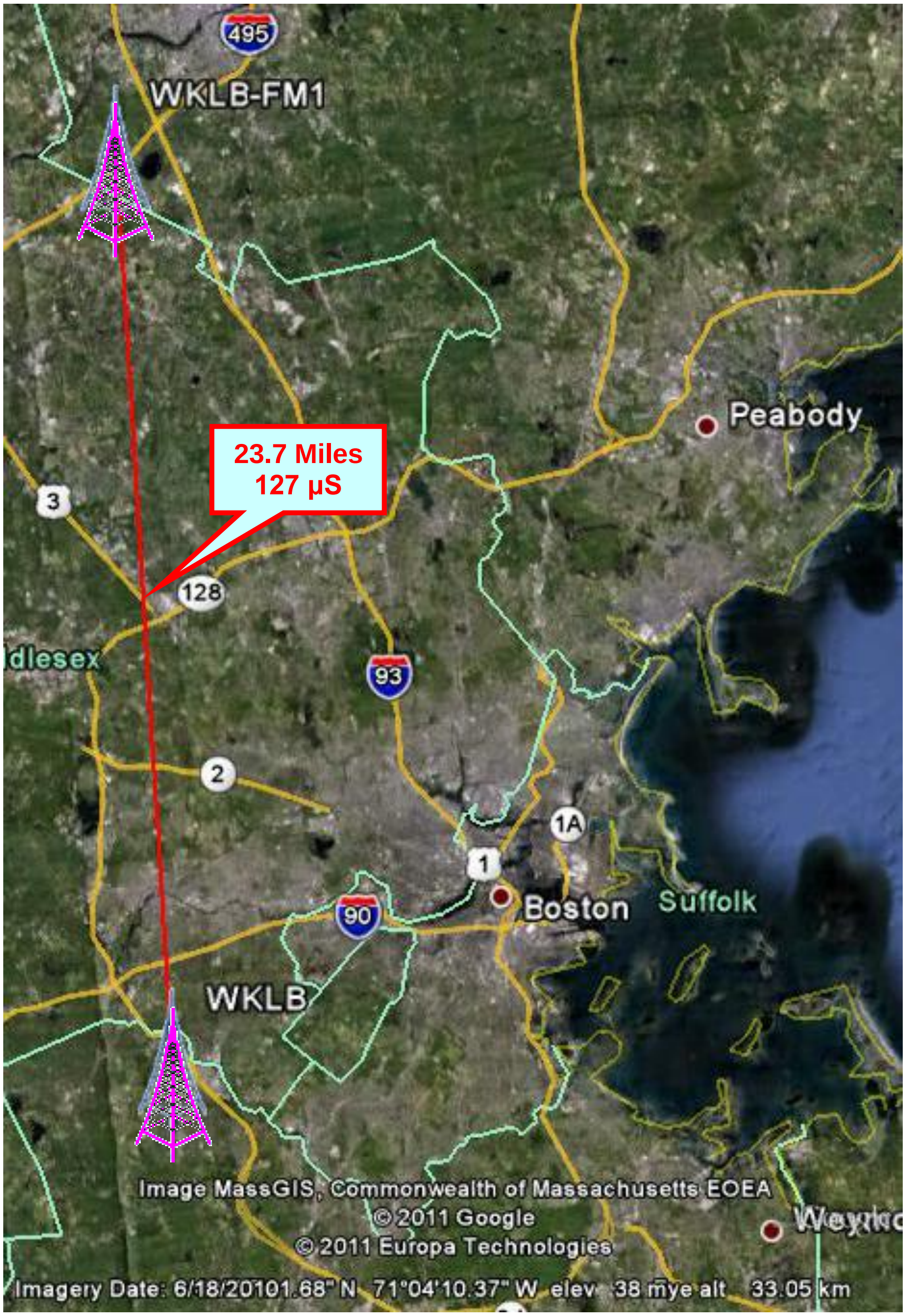



*Figure 8-1: Map of the Boston, Massachusetts Metropolitan Area*

The WKLB main transmitter site operates with an Effective Radiated Power (ERP) of 14 kW at a Height above Average Terrain (HAAT) of 272 meters. The station normally takes advantage of the recent IBOC power increase of six decibels authorized by the Federal Communications Commission (FCC) and operates with a digital-to-analog power ratio of -14 dBc. Due to the proximity of the test booster site, the digital power was reduced to the previous level of -20 dBc.

The map in Figure 8-2 characterizes the predicted digital coverage of the WKLB main transmitter site, operating at -20 dBc digital-to-analog power ratio. It can be seen from the green and yellow field test measurements that WKLB's main digital signal meets or exceeds the predicted coverage.

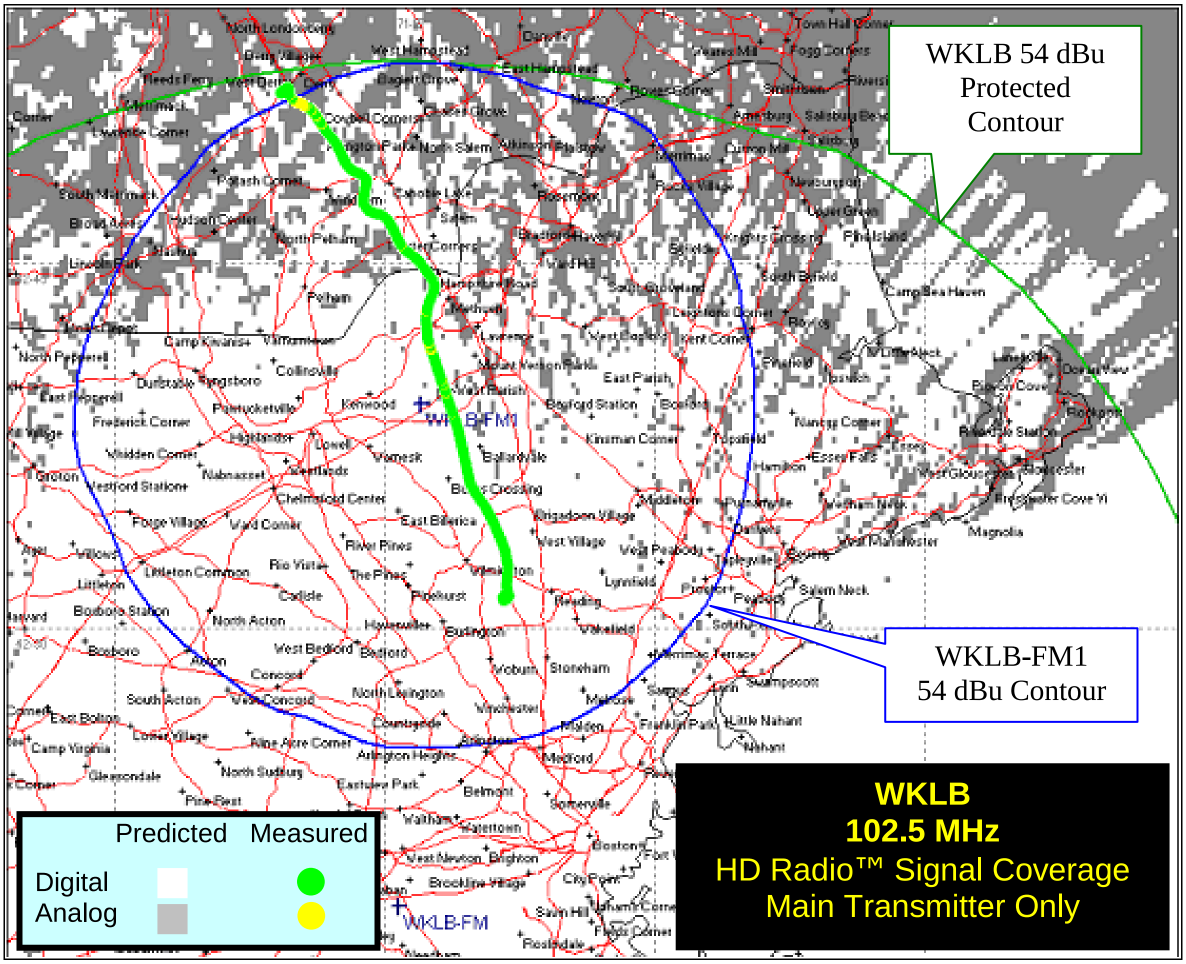



***Figure 8-2: Predicted Digital Coverage of the WKLB Main Transmitter Site***

Greater Media obtained experimental authority to construct an on-channel booster facility at their site in Andover, MA. The facility is currently leased to the WGBH Educational Foundation, which operates station WCRB (99.5 MHz) at that location. WCRB has elected to broadcast their digital signal from a licensed auxiliary antenna that is positioned lower on the tower, freeing up one of the two polarizations of the top-mounted dual-input antenna. The radiator is sufficiently broadband to accommodate the frequency differential of three MHz with minimal reflected power. A ferrite circulator was added to improve isolation.

The on-channel booster operates with an Effective Radiated Power of 27 watts, digital, as authorized by the FCC. For one set of tests, a synchronized analog FM transmission of three watts was added to potentially mitigate interference to the main station's host signal near the booster. This resulted in a digital-to-analog power ratio for the booster of approximately 9.5 dBc.

The map in Figure 8-3 characterizes the predicted digital coverage of the WKLB Main Transmitter site plus the Booster site.

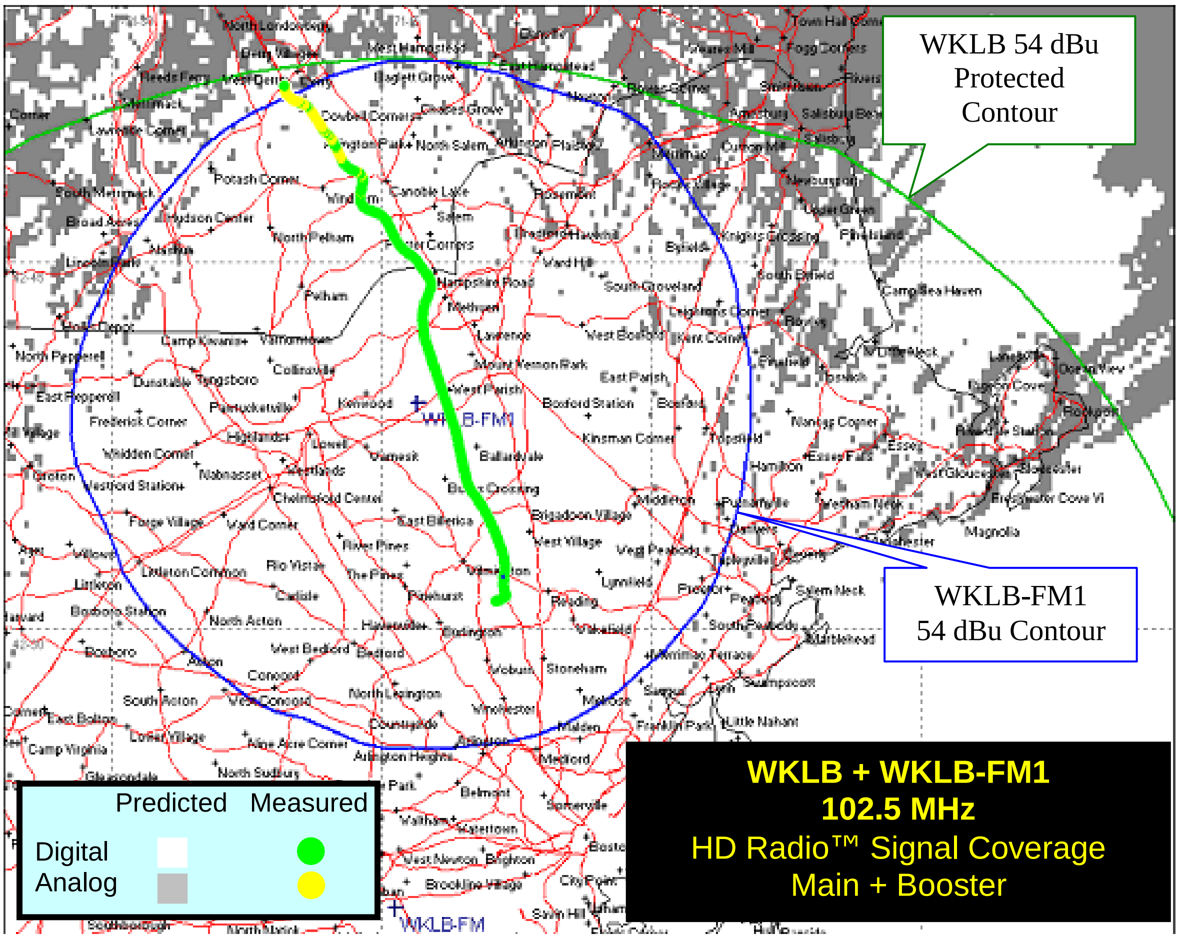



***Figure 8-3: Predicted Digital Coverage of the WKLB Main Transmitter Site plus the WKLB-FM1 Booster Site***

Since the test booster site falls well within the station's normal coverage area, any signal augmentation by the booster was expected to be minimal. The booster *does* improve coverage in signal-shadowed areas in Andover, as shown when comparing Figure 8-4 with Figure 8-5.

***Figure 8-4: IBOC Coverage without Booster***

***Figure 8-5: IBOC Coverage with Booster***

The booster and the main site are only about 24 miles apart. For analog FM signals, locating two on-channel transmission sites this close without terrain shielding would not even be feasible because of destructive multipath-like interference in signal overlap regions. For time-aligned HD Radio applications, however, the digital transmissions from the main and booster sites combine to reinforce and provide even more robust digital reception. Adding an appropriate amount of time delay to the booster signal causes the main and boosted digital portions of the IBOC signals to synchronize and augment coverage in these areas.

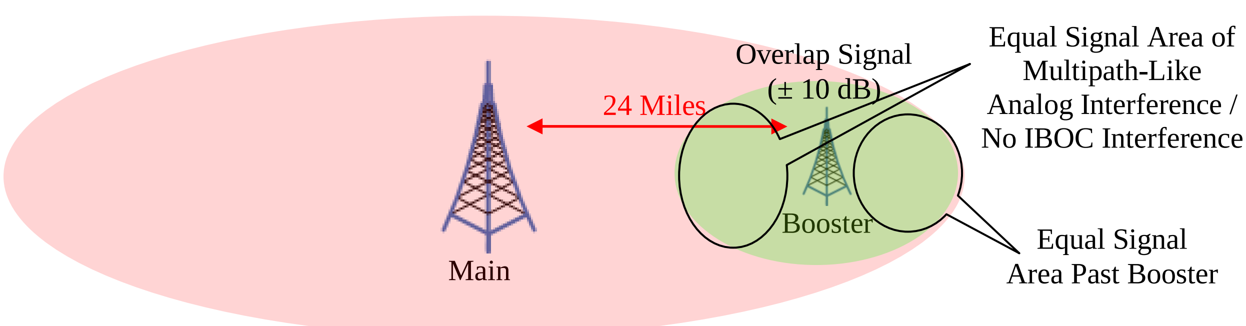



***Figure 8-6: Interference Effects***

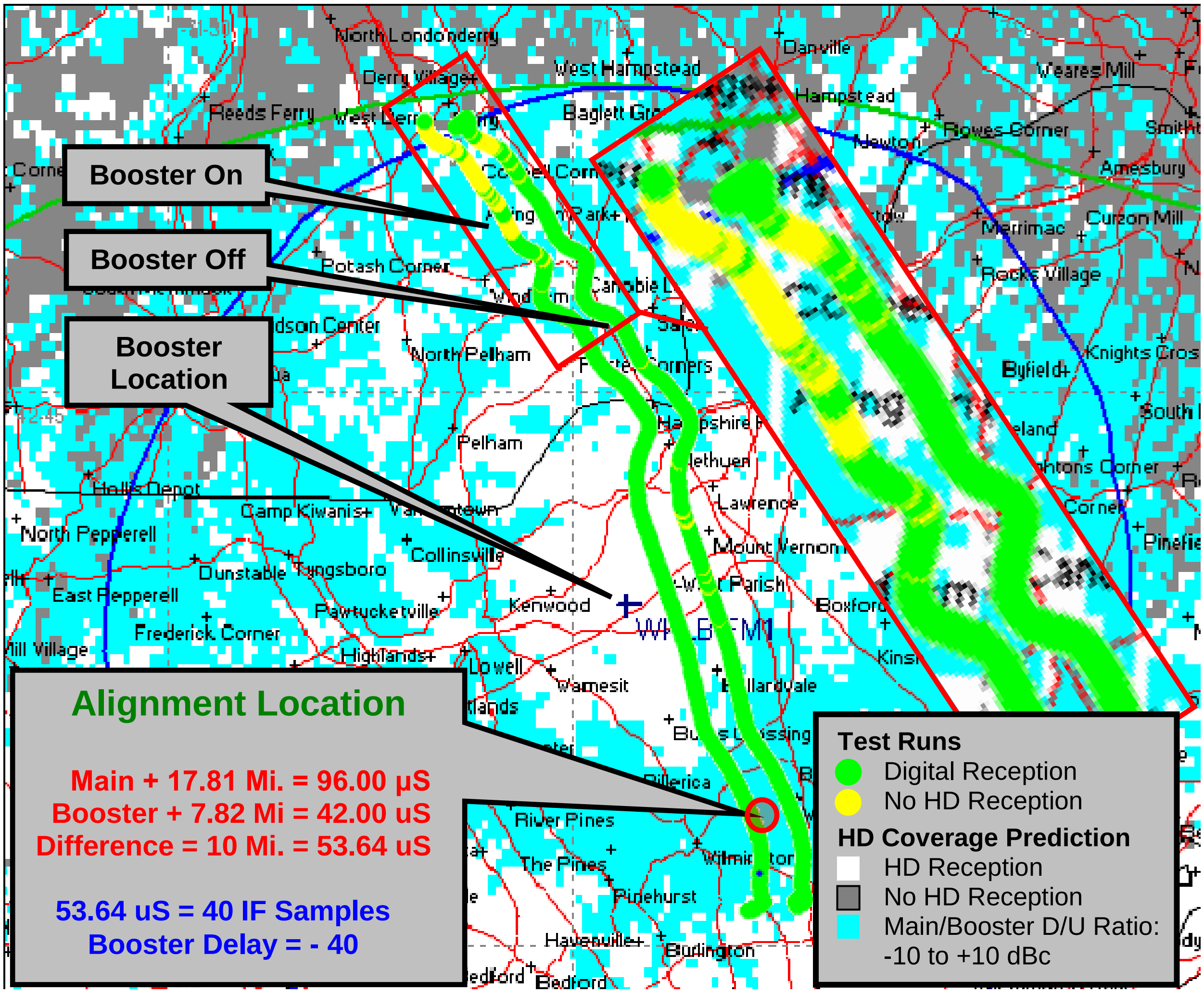



***Figure 8-7: Interference Effects – Separate Test Runs on a Single Map***

Figure 8-7 shows two separate test runs (of the same route) side-by-side on a single map: one made with the booster on (left track) and one made with the booster off (right track). A close-up view of these runs is shown in the rectangular box to the right.

Note in Figure 8-7 that there are no signal outages in the area between the sites, with signal reinforcement occurring in these areas. The edge-of-coverage performance with the booster on is worse than that of the main site alone. Since time alignment was set in the overlap area *between* the two sites, areas of equal signal level *past* the booster will not be time-aligned, as the delay is close to the theoretical maximum allowable of 75 µS. Overlap on both sides of the booster rarely occurs in real-world implementations, however.

# 9 Digital Booster Compatibility with Main Host Analog (Boston)

The first test of iBiquity's SFN implementation in Baltimore used a digital-only booster transmitter with no analog signal component (the only analog signal in this SFN was emanating from the main site). This implementation may cause interference to the main transmitter's analog signal near the booster site as the digital-to-analog power ratio can become quite large.

The Boston facilities provided an ideal test bed for this scenario (i.e., determining the impact of a digital-only booster on reception of the analog portion of a hybrid IBOC signal from the main site, near the booster site). Since the overlap region of the Boston facilities between the main and booster site transmitters is extensive, the potential for analog host interference (by the digital-only booster) near the booster site in some wideband receivers is very high.

On the basis of propagation prediction studies, a route along I-93 close to the booster was chosen for this test.

The effective digital-to-analog power ratio at the receiver varied from -6 dBc to +20 dBc along this route as the distance to the booster decreased from 5.65 miles to 1.3 miles and then increased to four miles as the route passed the booster site as shown in Figure 9-1. The booster can be seen near the top and to the left of the route, near the white marker.

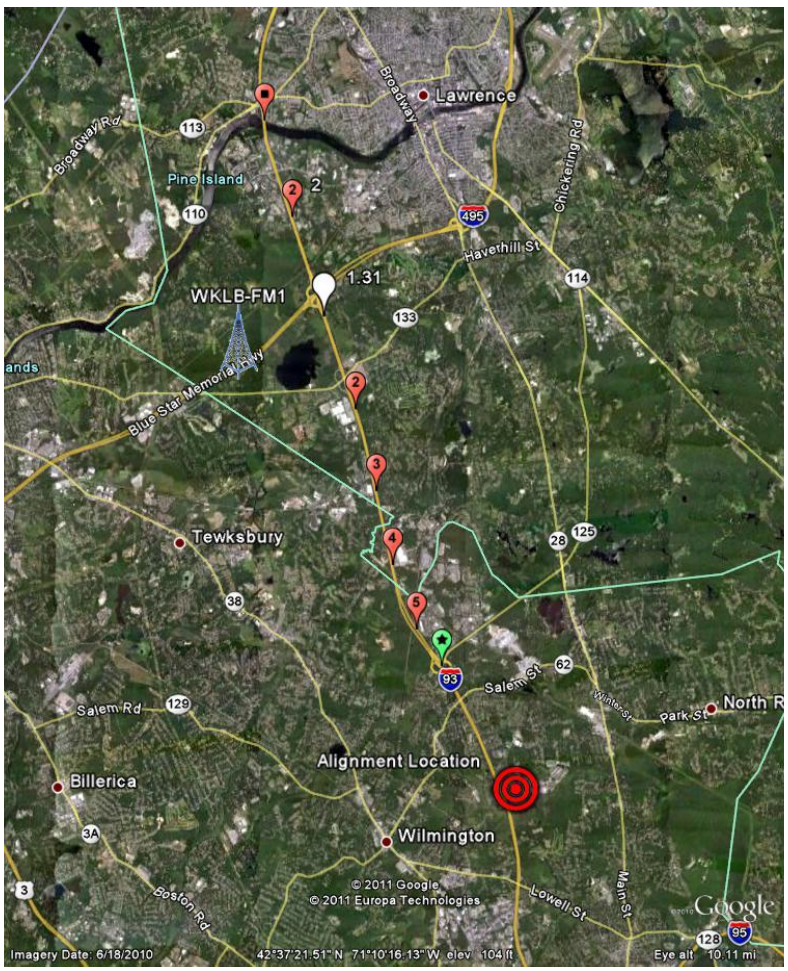



*Figure 9-1: Test Route for Determining Impact of Digital-only Booster on Analog Reception*

The chart below characterizes the predicted effective digital-to-analog power ratio along the route.

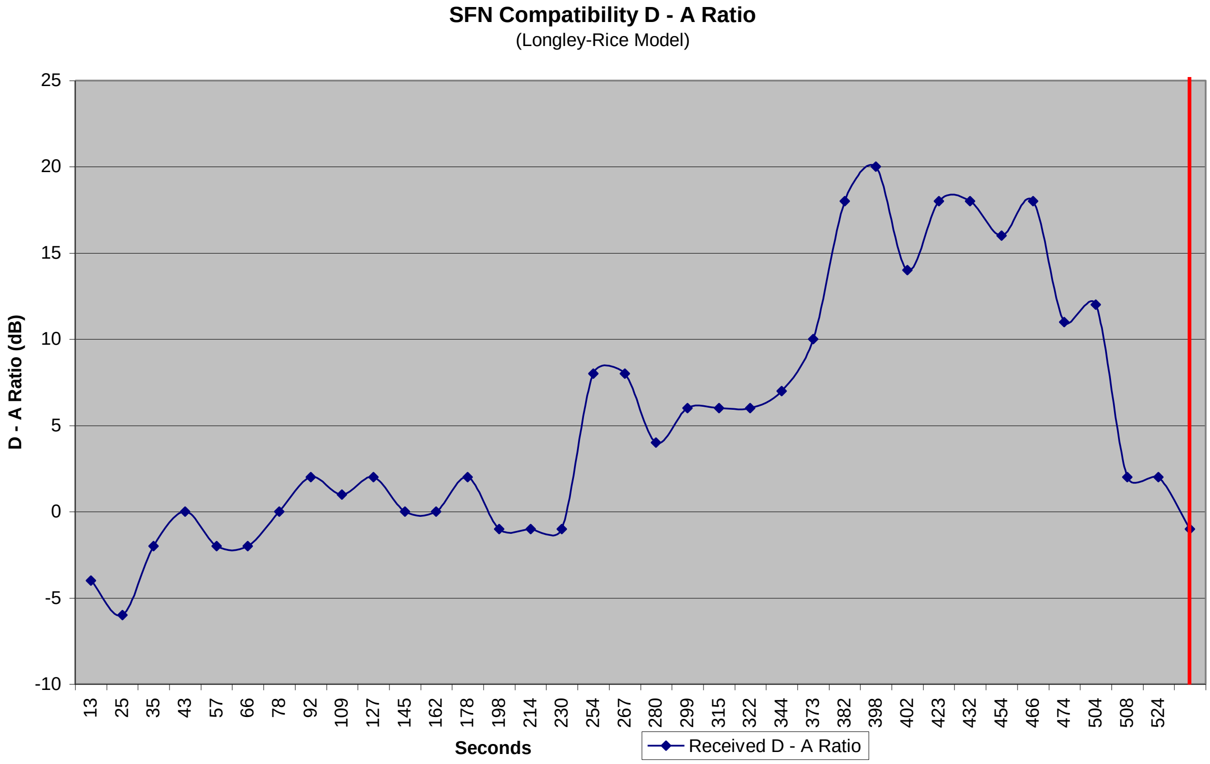



***Figure 9-2: Predicted Effective Digital-to-Analog Power Ratio along the Route***

The iBiquity test van was outfitted with three typical analog automotive receivers and one analog clock radio receiver. The vehicle was driven along the test route at a constant 60 mph and the audio output from the four receivers was simultaneously captured using multi-track recording software on a PC.

Two transmission methods were evaluated:

- A digital-only (i.e., no analog component) booster's effect on the main transmitter's analog signal was recorded on the Chrysler, Delphi, and analog clock radio receivers
- The effect of adding a low-power, synchronized, FM-modulated, analog carrier to abate the host interference by the digital carriers was recorded on all three automotive receivers.

Each receiver's audio was integrated with a Google Earth rendering of the route and an animated, synchronized copy of the chart shown in Figure 9-2. The three resulting video presentations allow the reviewer to subjectively evaluate interference on the older OEM Chrysler and newer Delphi analog receivers.

The Delphi Radio exhibited sufficient selectivity to allow for reception of the analog signal even near the digital-only booster. It has the attributes of a well-designed, modern, analog, and HD Radio automotive receiver. In the "digital-only" booster test, the Delphi was able to filter out most analog interference from IBOC carriers, even at effective levels of +20 dBc. Even with this level of interference rejection, locations closer than one mile from the booster are likely to experience some impairment. (This may not be the case with some of the latest receivers using Finite Impulse Response (FIR) filtering, which are incredibly selective.)

In this same test, the older Chrysler receiver did not fare as well, exhibiting audible interference from the beginning of the run to end of the run. Close to the booster, the audio was all but inaudible. The analog clock radio's audio was not evaluated because of the receiver's extremely poor selectivity.

Hypothetically, the injection of a synchronized, FM-modulated, analog carrier at the booster site could improve the reception of the analog signal coming from the main site (near the booster site). However, this additional analog signal from the booster site gives rise to potential additional interference resulting from interaction with the analog signal from the main site, as outlined in FCC 47 CFR Section 74.1203(c):

> *Interference to Main Station's Signal*
>
> *Because [FM analog] booster stations operate on the same frequency as the primary [FM analog] station, operation of the booster may cause interference to reception of the main station's signal. However, booster stations may not cause interference to reception of the primary station's signal within the community of license. The main station's signal may also cause interference to reception of the booster station. It is up to the licensee of the primary station to decide whether the gain realized by the booster offsets any potential interference.*

During these tests, attempts to mitigate interference by the booster's digital carriers to the main site's analog signal by injecting some synchronized analog at the booster site were met with mixed results. Using this approach, with similar main and booster analog signal levels, all receivers will suffer from the multipath-like interference characterized by FCC 47 CFR Section 74.1203(c). The problem is exacerbated by the efficiency of an excellent transmit antenna at the top of a 320-foot tower. Even the Delphi receiver was unable to mitigate the multipath effect of two combined, co-channel-modulated, FM-hybrid, IBOC signals.

It is important to note, however, that the addition of digital subcarriers from a synchronized IBOC signal to an existing analog booster will in no way degrade the system's existing analog performance. The digital signal will be continuous (assuming proper time alignment) and free of multipath-like interference that plagues analog reception at the point of overlap.

The reader is encouraged to subjectively evaluate the following three videos:

- Digital-only booster @ 27 watts ERP
  - WKLB_SFN_Compat_Dig-Boost_Chrysler.m4v
  - WKLB_SFN_Compat_Dig-Boost_Delphi.m4v
- Hybrid booster @ 27 watts ERP (D) / 3 watts ERP (A)
  - WKLB_SFN_Compat_Hybrid-Boost_Delphi.m4v

# 10 Conclusions

Baltimore tests showed that:

- Single-frequency networks using digital-only boosters selectively expand HD Radio signal coverage;
- Digital time delays between main and booster signals need to be adjusted to account for propagation delays in the overlap regions to minimize inter-symbol interference.

Boston tests showed that:

- Digital coverage is enhanced within the station's protected contour when using a SFN with a digital-only booster;
- Two overlapping, properly aligned and synchronized, digital signals do not degrade HD Radio performance;
- A Delphi automotive receiver with attributes of a well-designed, modern, FM receiver experienced little interference to the main station's host analog signal near an all-digital booster station;
- An older Chrysler automotive receiver and a typical analog clock radio had difficulty receiving the main station's host analog signal near an all-digital booster station.