HD Radio™ Compatibility and Performance with Existing FM Analog Transmission at Elevated Digital Carrier Levels

Test Procedure

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1. Scope

1.1. System Overview

The iBiquity Digital Corporation HD Radio™ system is designed to permit a smooth evolution from current analog amplitude modulation (AM) and frequency modulation (FM) radio to a fully digital in-band on-channel (IBOC) system. During this transition period, the system may be operated in hybrid mode, where digital and analog signals compatibly co-exist. In order to ensure minimal impact on existing analog transmissions, lab and field testing were performed, and standard digital to analog power ratios were set for AM and FM transmission. These ratios were based upon the subjective evaluation of signal to noise in representative analog receivers with host or adjacent interference versus digital system performance. A digital to analog power ratio of -20 dB was set for the FM HD Radio hybrid system mode MP1.

1.2. Recent Observations

Since these tests were performed 5 years ago, over 1000 commercial HD Radio stations have gone on the air, and thousands of commercial HD Radio receivers are in public use. In real-world implementation, the edge of coverage for HD radio reception is reduced relative to the subjective tune-out point of the analog signal. This is especially true for FM HD Radio signals received in residential and commercial buildings, which suffer from structural attenuation and multipath. A recent test by iBiquity Digital showed typical residential dwelling attenuation in excess of 10 dB and more than 20 dB for some commercial buildings. In order to provide robust digital service to homes and businesses within their protected contours, broadcasters have requested a study to determine the feasibility of increasing the ratio of the digital to analog power. Of significant importance in the design of a viable IBOC system is the compatibility with existing analog service.

1.3. Goals

This test plan specifies the hardware, software and procedures necessary to collect data (for later evaluation) to characterize the performance improvement and subjective audible effect of a 10 dB elevation of IBOC carrier power on first adjacent analog reception.

2. Test Environment

In order to fully characterize the full impact of an HD Radio carrier power increase of 10 dB from a level of -20 dBc (relative to the analog carrier) to -10 dBc, interference scenarios, both typical and worst case will be tested. In addition, performance data will be collected to show the improvement in coverage that the power increase affords. These tests will take place with the following representative scenarios:

2.1. Station Spacing

Tests will be conducted with short spaced stations that have the greatest potential to be impacted by a first adjacent interferer. In order to establish a benchmark, properly spaced stations should be tested as well.

2.1.1. Short Spaced 1st Adjacents

- Worst Case Scenario

2.1.2. Properly Spaced 1st Adjacents

- Typical

2.2. Station Classes

The following class to class interference scenarios will be tested as these are the simplest to implement with available facilities meeting the spacing requirements.

2.2.1.	Class B IBOC Interferer	→	Class B Desired
2.2.2.	Class B IBOC Interferer	→	Class C1 Desired
2.2.3.	Class "Super B" IBOC Interferer	→	Class B Desired
2.2.4.	Class "Super B" IBOC Interferer	→	Class A Desired

Performance characterizations will be conducted on the above classes and also the class listed below.

2.2.5. Class A IBOC

2.3. Types of Terrain

The audible effect of a first adjacent analog or IBOC interferer is largely dependent upon local topography. Three geographic areas that exhibit various terrain characteristics have been chosen.

2.3.1. Connecticut / New York (Appalachian Foothills / Seashore)

- Characterizes the effect of terrain shielding and multipath on FM signals at the fringe of reception

2.3.2. Detroit (Plains)

- Characterizes the effect of 1st Adjacent IBOC interference in the absence of other impairments

2.3.3. Los Angeles (Sierra Nevada Basin)

- Characterizes the effect of 1st Adjacent IBOC interference from "grandfathered" hi-power Class B's in the western desert.

Locations in areas predicted to present DU's of +6 dB will be chosen. Prior to the test, specific points will be selected on the basis of actual measurements.

The following stations will be used for performance characterization only.

2.3.4. Northern New Jersey (WDHA)

- Characterizes Class A performance with terrain shielding.

2.3.5. New Jersey Shore (WJRZ + WRAT)

- Characterizes Class A performance with no terrain impairments.

2.4. Desired Station Formats

For the compatibility tests, desired stations of diversified formats were chosen. This is important because dense, highly processed audio such as rock music will effectively mask white-noise like first adjacent interference, unlike talk or classical programming.

2.5. Types of Tests

Both host and first adjacent compatibility tests will be run. The performance of the HD Radio interferer as a desired station will be evaluated at IBOC power ratios of -10 and -20 dBc.

2.6. Fixed Compatibility and Performance Tests

2.6.1. Fixed Compatibility

The test vehicle will be parked at a location showing high signal levels and a +6 dB desired to undesired ratio.

The audio from a “boombox” (mounted on a non-conducting table outside the vehicle) and six other radios will be recorded for a total of 3 hours. The IBOC interferer will be cycled every half-hour from -20 dBc to -10 dBc digital to analog power ratio. The Collector software will be used to capture RF signal characteristics correlated to the recorded audio.

It is advantageous to have the desired station broadcast similar if not identical program material for each set of recordings made with the interferer’s digital to analog ratio at -10 dBc and -20 dBc. Whenever possible, even if the recording must be made at night, the program material should be repeated. If this is possible, only 1 hour of recording will be made, switching the interferer’s IBOC power ratio from -20 dBc to -10 dBc on the half hour.

3. Receiving Test Bed

Figure 1 shows the iBiquity "Great White" test van configured to split a single 31" vertical whip antenna to a spectrum analyzer and 6 typical consumer receivers. One additional portable "boombox" receiver will use its own antenna for the compatibility tests. The left channel of each receiver feeds an input of a multitrack PC-Based audio recorder. GPS position and Spectrum Analyzer data are also recorded by the software application "The Collector". This software will also be used to record position, spectral and digital receiver status for the performance tests.

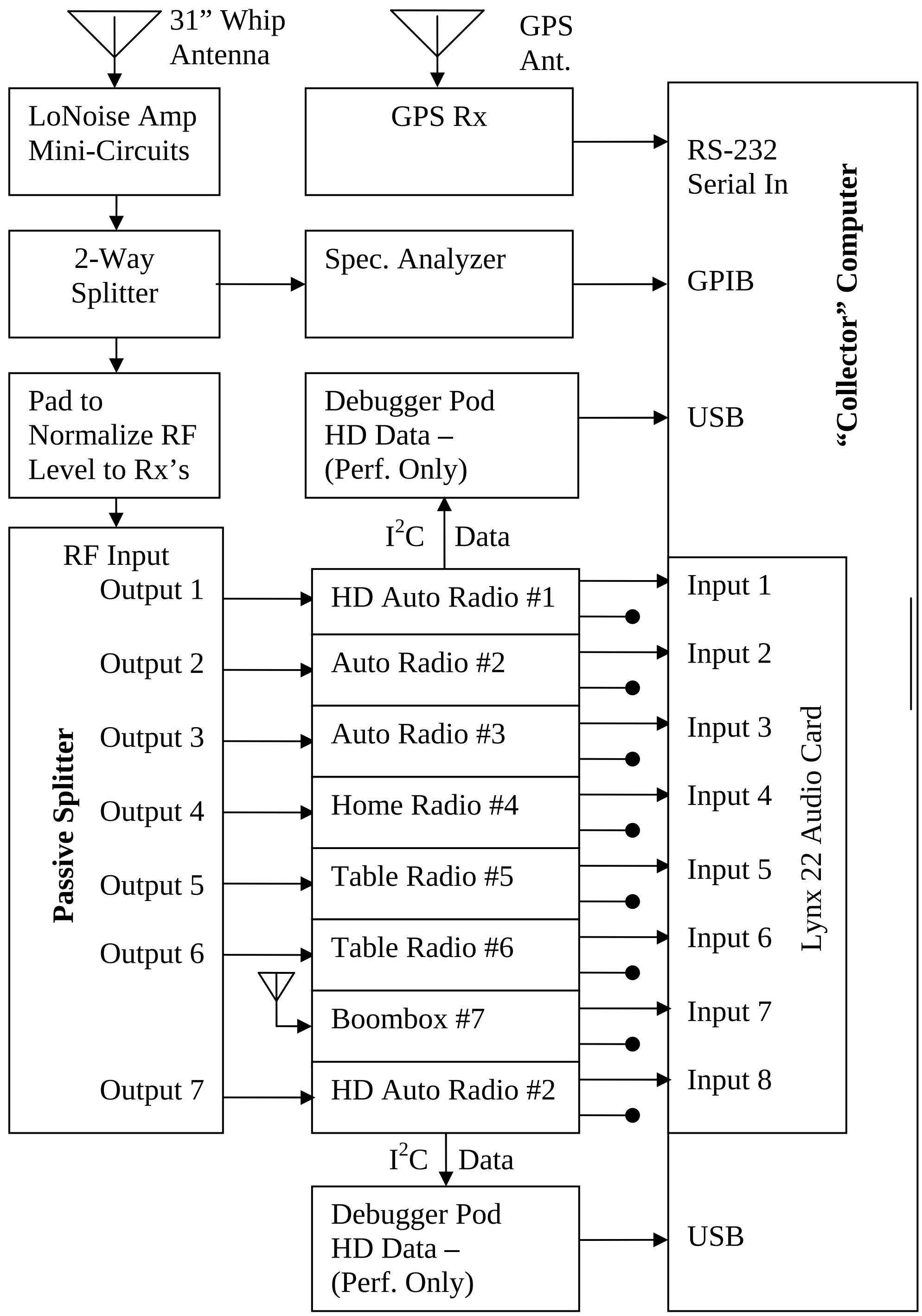


Figure 1 - Compatibility / Performance Test Bed

3.1. Test Receivers

3.1.1. Compatibility

Analog receivers (and one HD receiver set to analog mode) most typical of those available after market and from OEM's will be tested. Seven radios will be evaluated. Only the left channel needs to be recorded, as the station certainly has blended to mono in the fringe areas of these tests.

3.1.2. Performance

Only the HD Receiver(s) will be tested. Mode information will be collected for later mapping.

Analog Rx	Make	Model	Serial Number	Type
1 (HD Auto)	JVC	HDR-1		HD Auto
2 (Auto)	Pioneer	DEH-1800		Auto
3 (Auto)	Delphi	?????		Auto
4 (Home)	Onkyo	TX-SR504		Home
5 (Table)	Bose	WRCC1	39751351626679AC	Table Top
6 (Table)	Tivoli	Model 2		Table Top
7 (Boombox)	Sony	ZX-H10CP		Boombox
8 (HD Auto)*	JVC	HDR-1		HD Auto

* (2nd HD Rx for Performance Measurements)

Table 1 - Compatibility Test Radio Receivers

3.2. Test Data Collection Hardware / Software

The data collection computer consists of a PC running the Software Audio Workshop (SAW) multitrack audio recording application and custom iBiquity "The Collector" software. The "Collector" is capable of recording GPS location, Spectrum Analyzer data (a 400 point capture), and information from the I^2C buss of specifically configured HD radios. Mode (analog/digital) and other parameters from the receiver(s) are captured every second.

The SAW application correlates the data with up to 8 tracks of recorded audio by feeding SMPTE timecode to the Collector. This synchronization allows the reviewer to attribute any audio anomalies to external influences, such as waveform disturbances or low signal level. This audio will later be subjectively evaluated.

For compatibility testing, the RF spectral record ensures that specific audio cuts are recorded at precise desired to undesired field intensity ratios.

For performance characterization, the receiver mode and GPS position data captured every second can be translated into a digital/analog multicolor "bread crumb" trail, for map overlays.

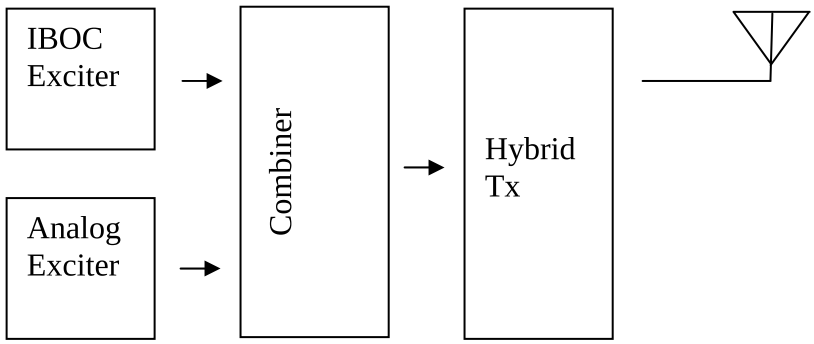
4. Transmission System

4.1. High Power Hybrid Transmission Combining Methods

HD Radio transmission systems that are to be used at low IBOC power ratios are not generally high power combined. The large amount of digital power required precludes the use of a high level 10 dB IBOC / 0.5 dB analog hybrid combiner. The remaining available combining systems are as follows:

4.1.1. Low Level Combining (Used @ KROQ / LA)

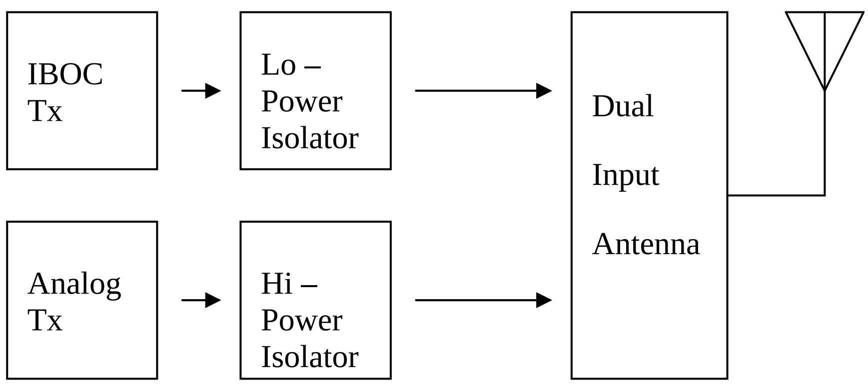
- Uses a single linearized transmitter to amplify the entire hybrid signal. May be used efficiently by Class A and low power class B and C3 stations if transmitter has enough headroom.



4.1.2. Dual Input Antenna

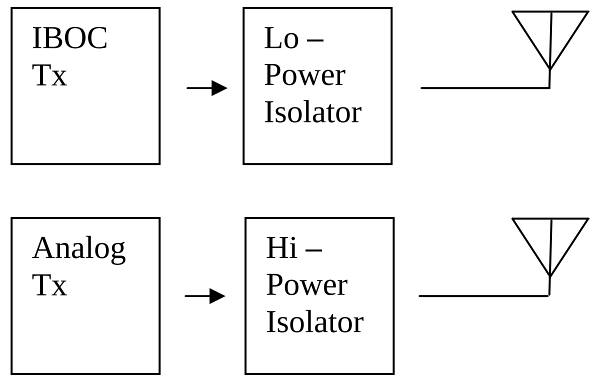
(Used @ WCSX / Detroit, WJRZ / Manahawkin & WRAT / Point Pleasant)

- Stations previously operating with a high power combined system may elect to use their old high power IBOC transmitter with a dual input antenna and ferromagnetic isolators for the digital and analog.



4.1.3. Dual Antennas (Used @ WKCI / New Haven, KOST / LA & WDHA, Dover, NJ)

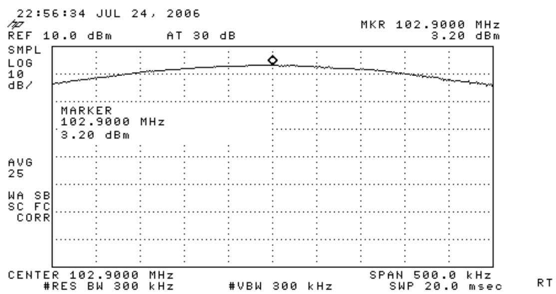
- Same as Dual input antenna, except radiators designed expressly for this purpose should be used to maintain pattern circularity and vertical pattern consistency for the IBOC ratio. Field ratio should be verified for each radial. Isolators may not be necessary.



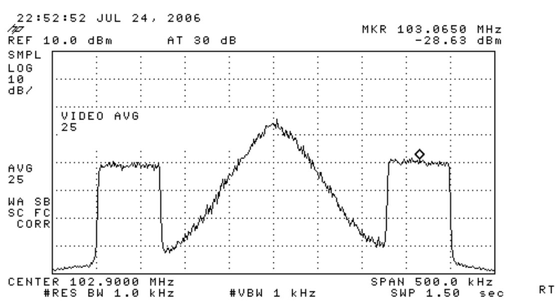
4.2. Power Ratio Measurement Methods

The following methods may be used to set the correct hybrid power ratio for each type of combining.

1. Low, Mid & High Level Combining
   - Sample Transmitter Forward Power
   - Turn IBOC carriers OFF
   - Set Spectrum Analyzer to 300 kHz RBW / 300 kHz VBW
   - Set Span to 500 kHz / Frequency to Operating Frequency
   - Average 100 sweeps of forward sample from antenna feed
   - Record power in dBm of analog carrier



   - Turn IBOC carriers ON
   - Set Spectrum Analyzer to 1 kHz RBW / 1 kHz VBW
   - Set Span to 500 kHz / Frequency to Operating Frequency + 165 kHz
   - Average 100 sweeps of forward sample from antenna feed
   - Record power in dBm of this 1 kHz "slice" of digital carriers



   - Add 21.45 to this number and subtract the result from the analog power to get the analog/digital ratio

2. Dual Input Antenna & Dual Antenna
   - Use manufacturer's performance information for antenna gain, transmission line and isolator losses to calculate optimum power
   - Draw radials to each compatibility test location on a map.
   - Locate 3 accessible points on each radial at 2 to 10 miles from the tower.
   - Use the procedure outlined in 1 and 2 to calculate digital to analog power ratio in the field. (Sample antenna feed)
   - Readjust digital power at the transmitter as necessary to obtain the proper ratio for this radial. Note the digital transmitter power necessary to obtain the proper ratio(s) for the current radial.

4.3. NRSC 5A Compliance Measurement Method

NRSC5A / FCC 73.317 Out of band emission measurements may be made on the digital transmitter by operating it into a dummy load and connecting a forward power sample to a spectrum analyzer. Set the spectrum analyzer to the operating frequency with a span of 2 MHz and an RBW and VBW of 1 kHz. Average 50 sweeps and examine the spectrum. Since there is no carrier present, the flat top of the IBOC sidebands must be used as a reference. In this RBW, the power in a 1 kHz "slice" of sideband will normally be -41.45 dBc for a -20 dBc digital/analog power ratio. By setting this scale, the out of band products can be measured. Figure 2 shows a typical spectrum

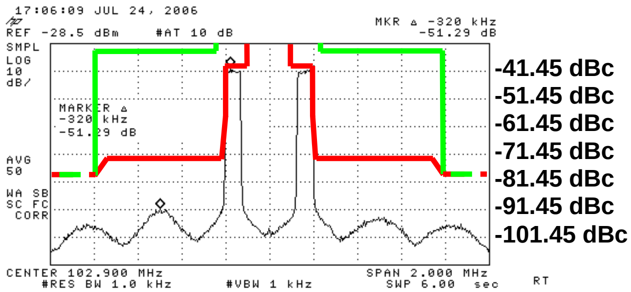


Figure 2 - Out of Band Emission Compliance

(Green = FCC Part 73.317) / (Red = NRSC 5A)

If the analog carrier is present for these measurements, a spectrum analyzer or vector signal analyzer capable of at least 110 db dynamic range may have to be employed. This would require a vertical scale of 15 dB per division instead of 10 dB.

5. Test Station Selection

A spreadsheet of all United States FM stations was sorted by distance to first adjacent interferers. Stations having the largest number of short spaced interferers were identified. The best candidates in three geographic areas were selected. Three stations capable of being implemented and meeting these criteria were chosen as HD Radio interferers for the compatibility tests. The format of the desired station is important, because highly processed audio may mask any noise from a first adjacent interferer. Additional stations (KROQ, Los Angeles / WDHA, Dover, NJ / WJRZ, Manahawkin, NJ / WRAT, Point Pleasant, NJ) were chosen for performance testing only.

Call Sign	Freq MHz	City	St.	Cl	Power Combine Method	Latitude	Longitude	Analog ERP Watts	IBOC ERP @-20 dBc Watts	IBOC ERP @-10 dBc Watts	AGL m	GL m	AMSL m	HAAT m
WCSX	94.7	Detroit	MI	B	Dual Input Antenna	N42-27-13	W83-09-50	13500	135	1350	287	201	488	289.56
WKCI	101.3	New Haven	CT	B	Space Combined Antenna	N41-26-01	W72-56-45	12000	Analog Antenna		177	202	379	277.03
								IBOC Ant	90	900	154	202	356	254.03
KOST	103.5	Los Angeles	CA	B	Space Combined Antenna	N34-13-32	W118-03-52	12500	Analog Antenna		137	1706	1843	959.62
								IBOC Ant	42	420	46	1706	1752	868.62
KROQ	106.7	Los Angeles	CA	B	Common Amplifier	N34-09-50	W118-11-46	6500	65	650	86	531	617	231.34
WDHA	105.5	Dover	NJ	A	Space Combined Antenna	N40-51-19	W74-30-42	1000	Analog Antenna		96	258	354	177.03
								IBOC Ant	10	100	92	258	350	173.03
WJRZ	100.1	Manahawkin	NJ	A	Common Amplifier	N39-47-54	W74-12-10	1700	17	2 Input IBOC In	143	6	149	138.74
					Dual Input Antenna				Same Amp	170				
WRAT	95.9	Point Pleasant	NJ	A	Dual Input Antenna	N40-10-15	W74-01-42	4000	40	400	88	2	90	80.53

Table 2 – Undesired Interferer (Compatibility)

Desired Test (Performance) Stations

5.1. Test Locations

The following locations have been predicted to exhibit a desired to undesired interferer ratio of 6 dB

5.1.1. WKCI (New Haven, CT) as IBOC Interferer

- WPDH (Poughkeepsie, NY as Desired Analog)

Black = WPDH@54 dBu F50/50 Green = WKCI@48dBu F50/10 Red = WPDH/WKCI DU = 0 to +10 dB

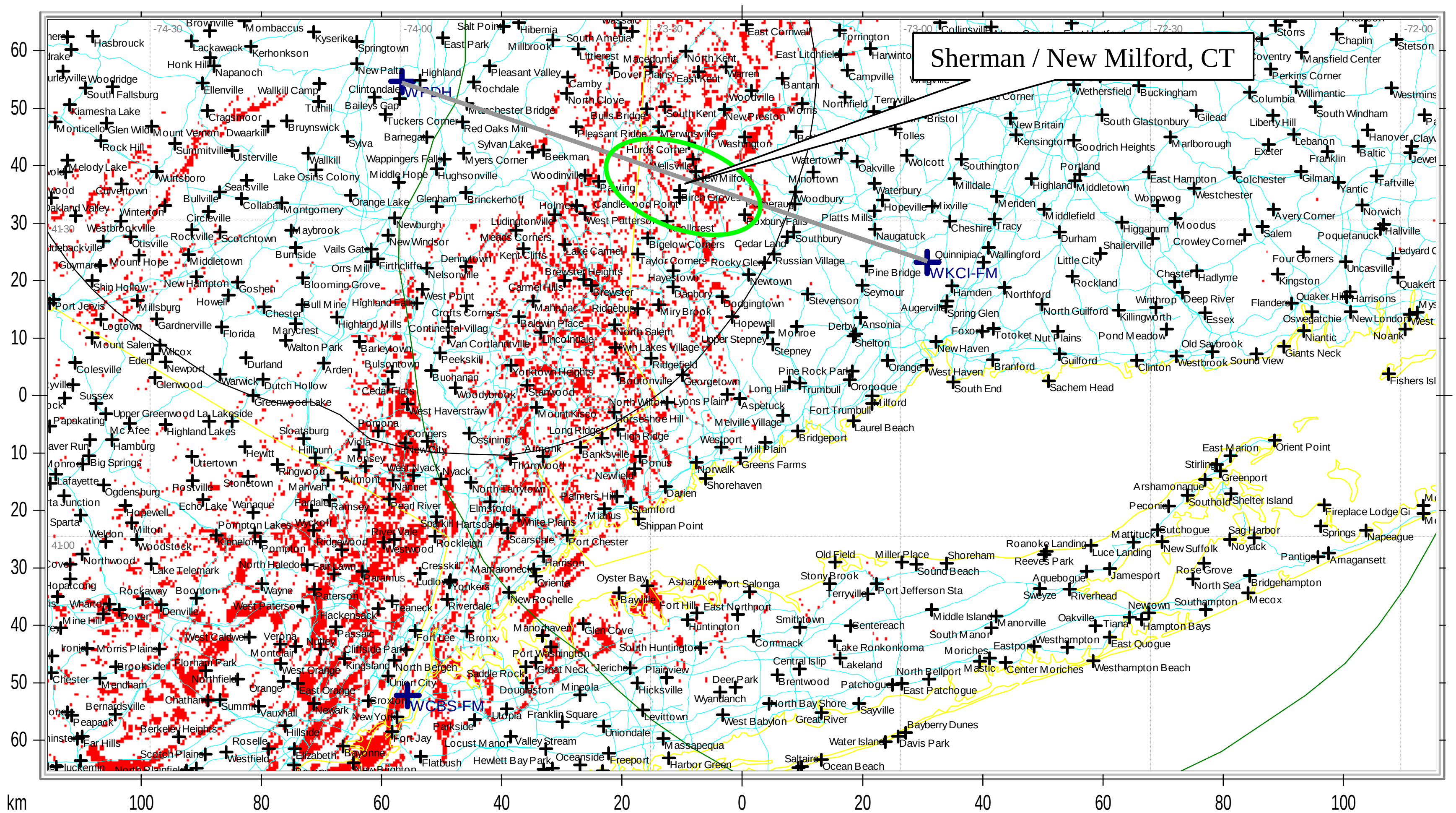


Figure 3 - WKCI / WPDH Compatibilty (DU = 0 to +10)

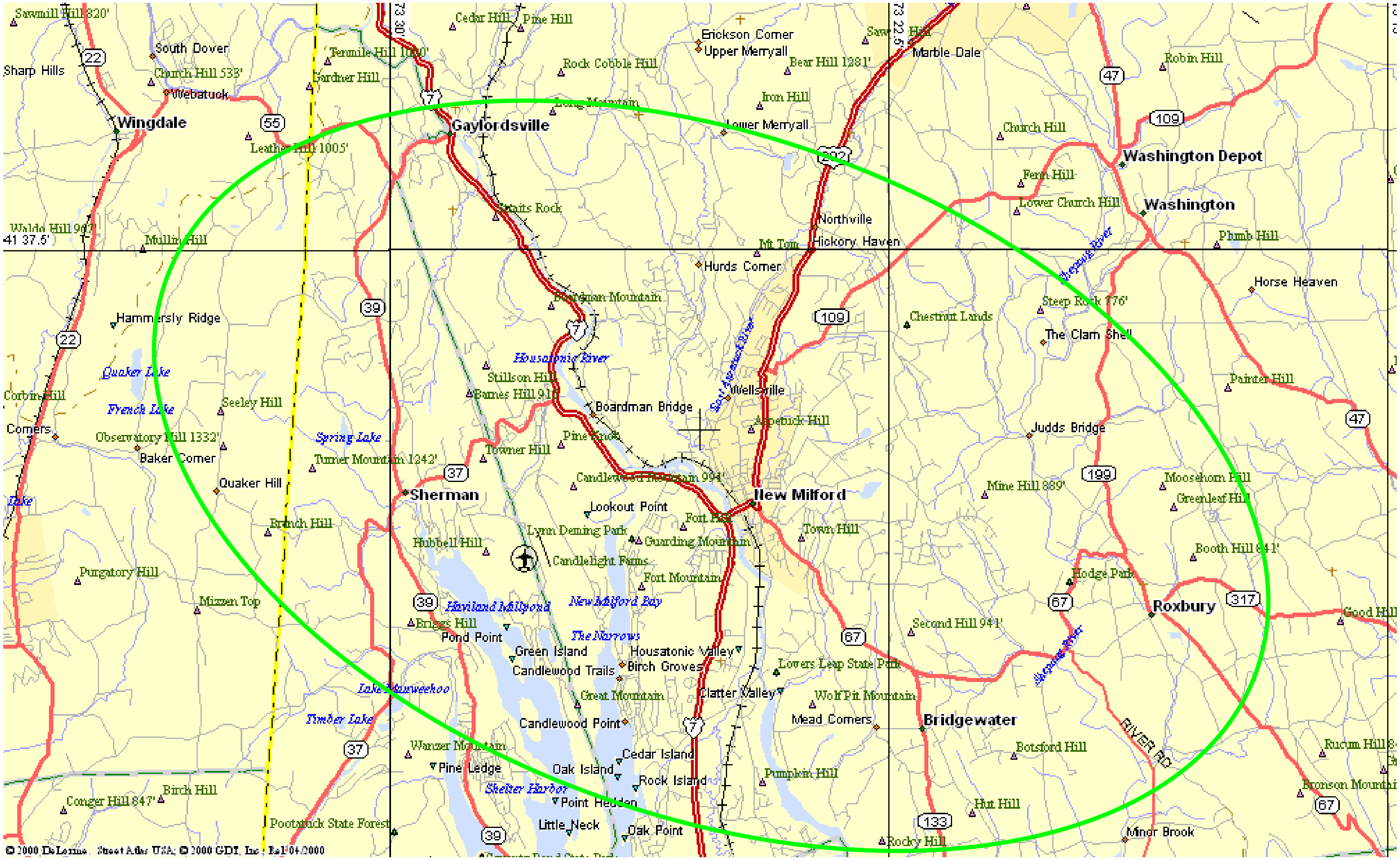


Figure 4 - WKCI / WPDH Compatibility (Detail)

- WCBS (NYC as Desired Analog)

Black = WCBS@54 dBu F50/50 Green = WKCI@48dBu F50/10 Red = WCBS/WKCI DU = 0 to +10 dB

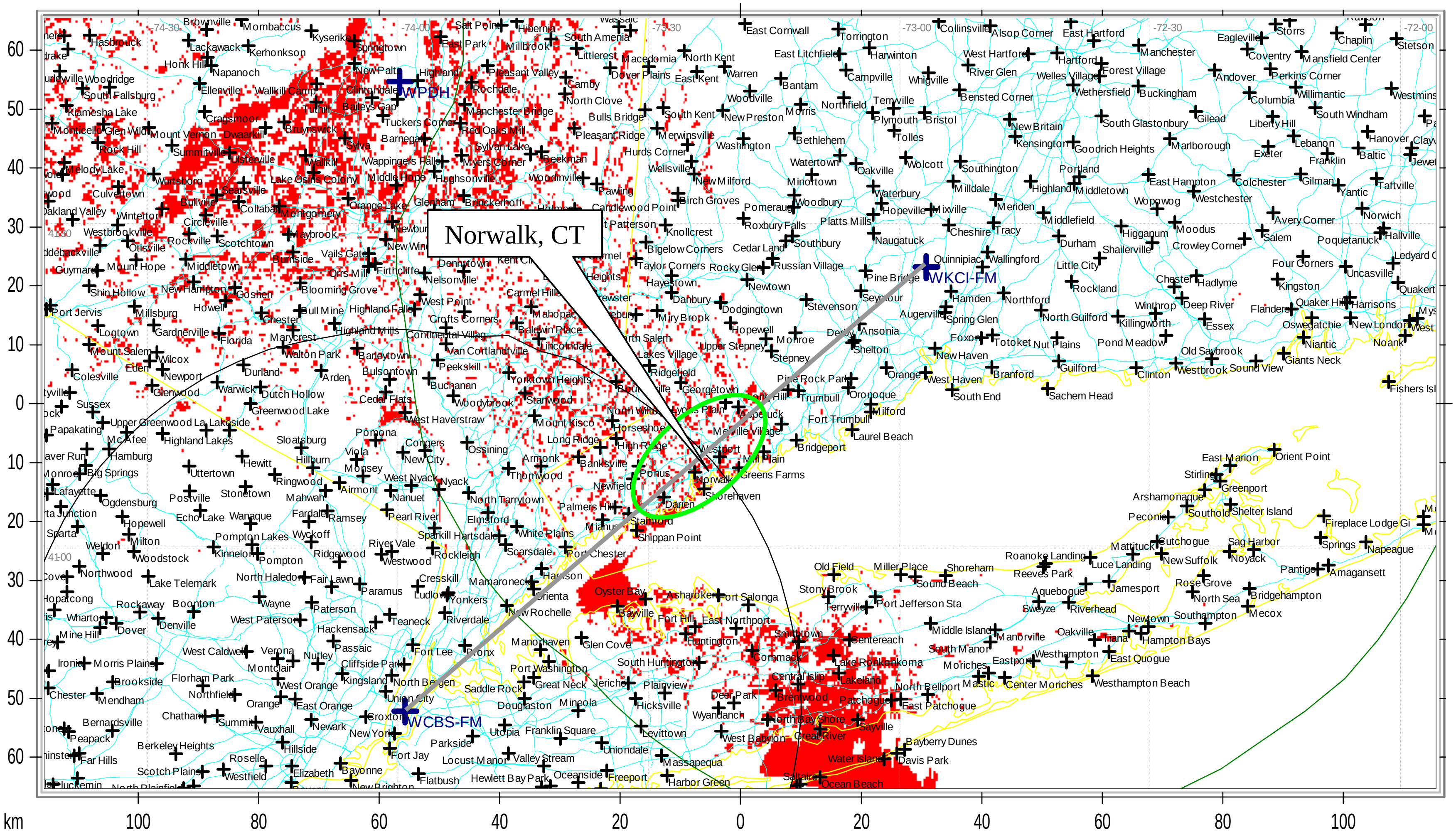


Figure 5 - WKCI / WCBS Compatibility (DU = 0 to +10)

Figure 6 - WKCI / CBS Compatibility (Detail)

- WWBB (Providence, RI as Desired Analog)

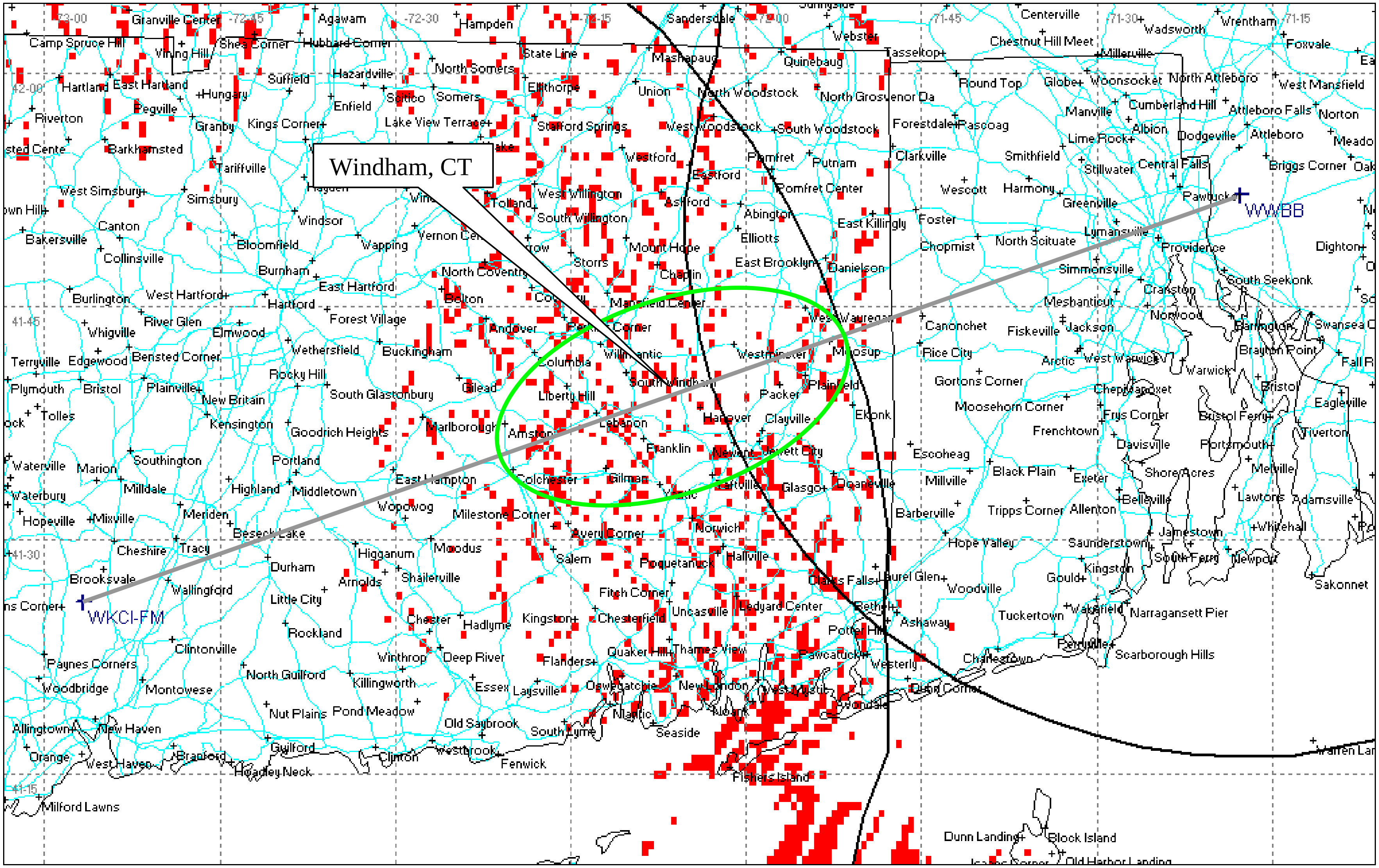


Figure 7 - WKCI / WWBB Compatibility (DU = 0 to +10)

Figure 8 - WKCI / WWBB Compatibility (Detail)

Figure 9 - WKCI Performance Routes

5.1.2. WCSX (Detroit, MI) as IBOC Interferer

- WCEN (as Desired Analog)

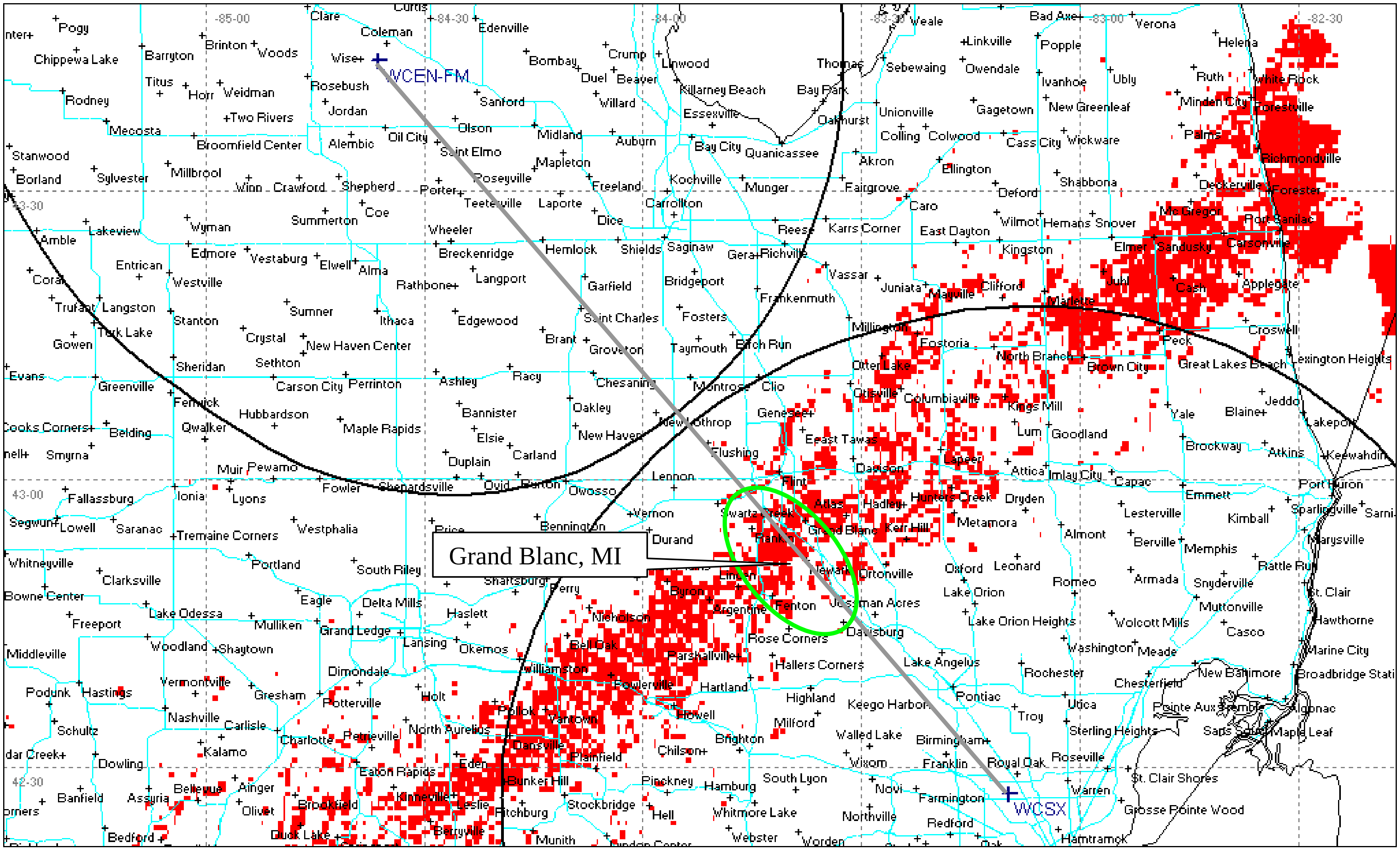


Figure 10 - WCSX / WCEN Compatibility (DU = 0 to +10)

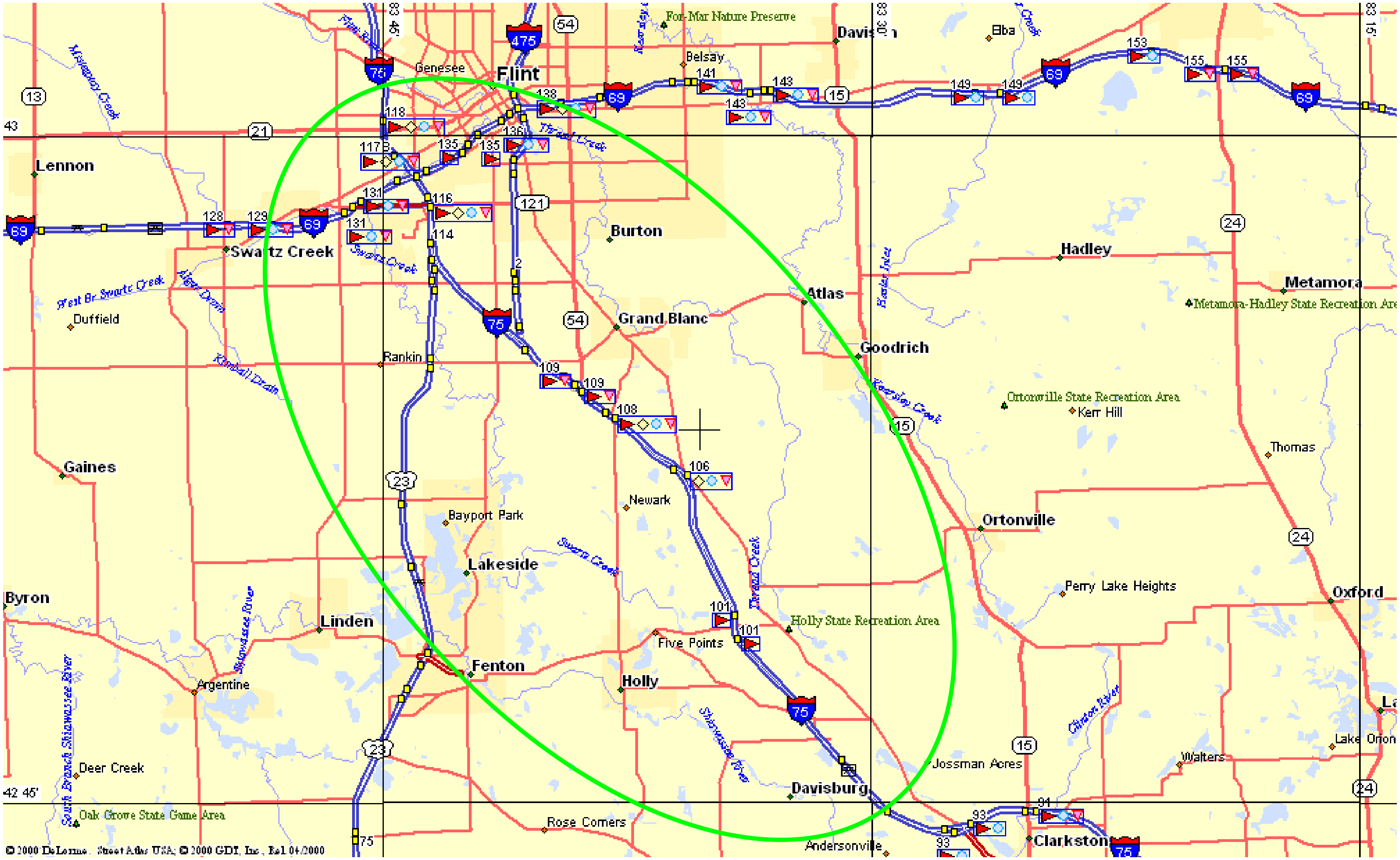


Figure 11 - WCSX / WCEN Compatibility (Detail)

- WMMQ (as Desired Analog)

Black = WMMQ@54 dBu F50/50   Green = WCSX@48dBu F50/10   Red = WMMQ/WCSX DU = 0 to +10 dB

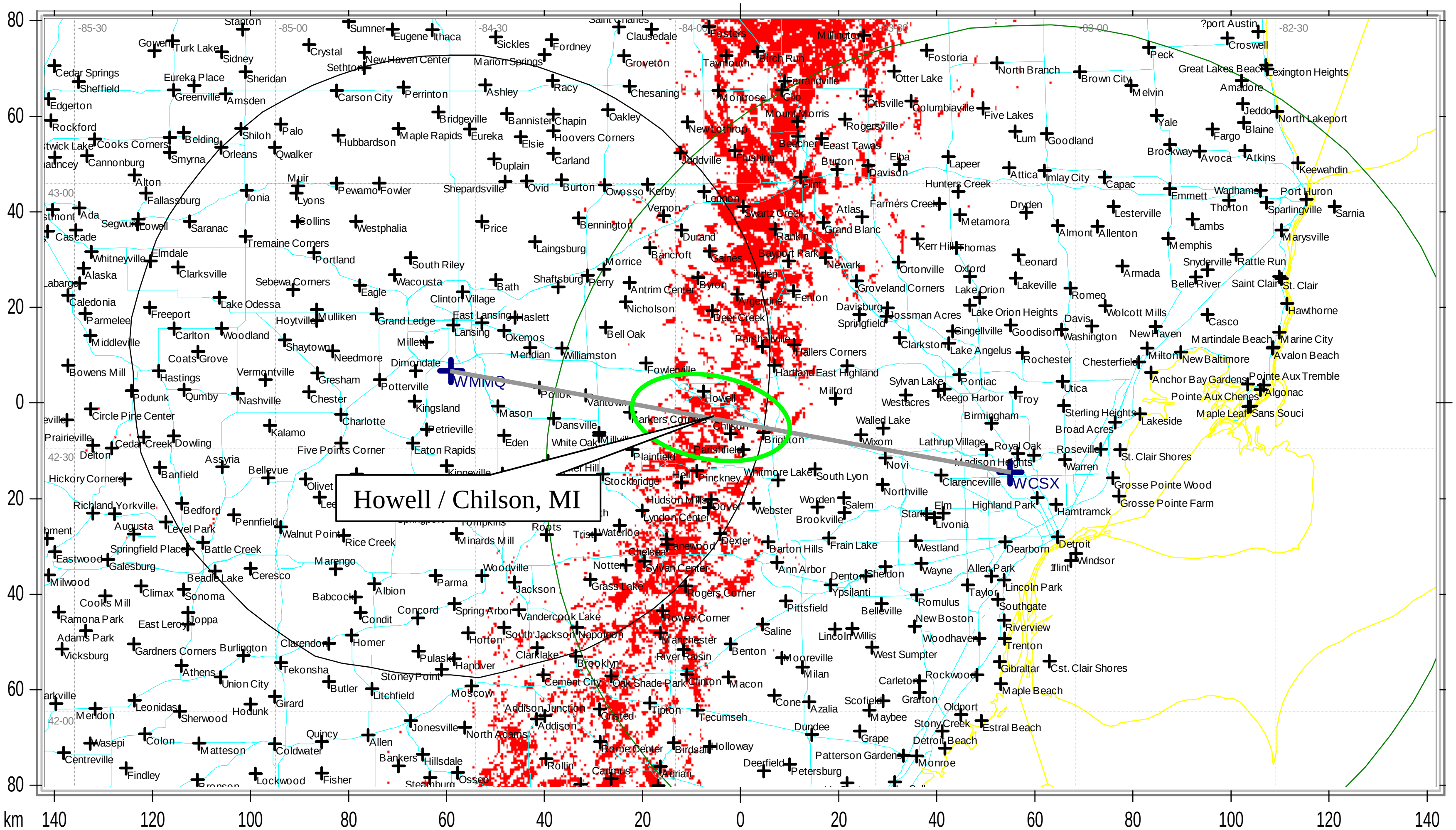


Figure 12 - WCSX / WMMQ Compatibility (DU = 0 to +10)

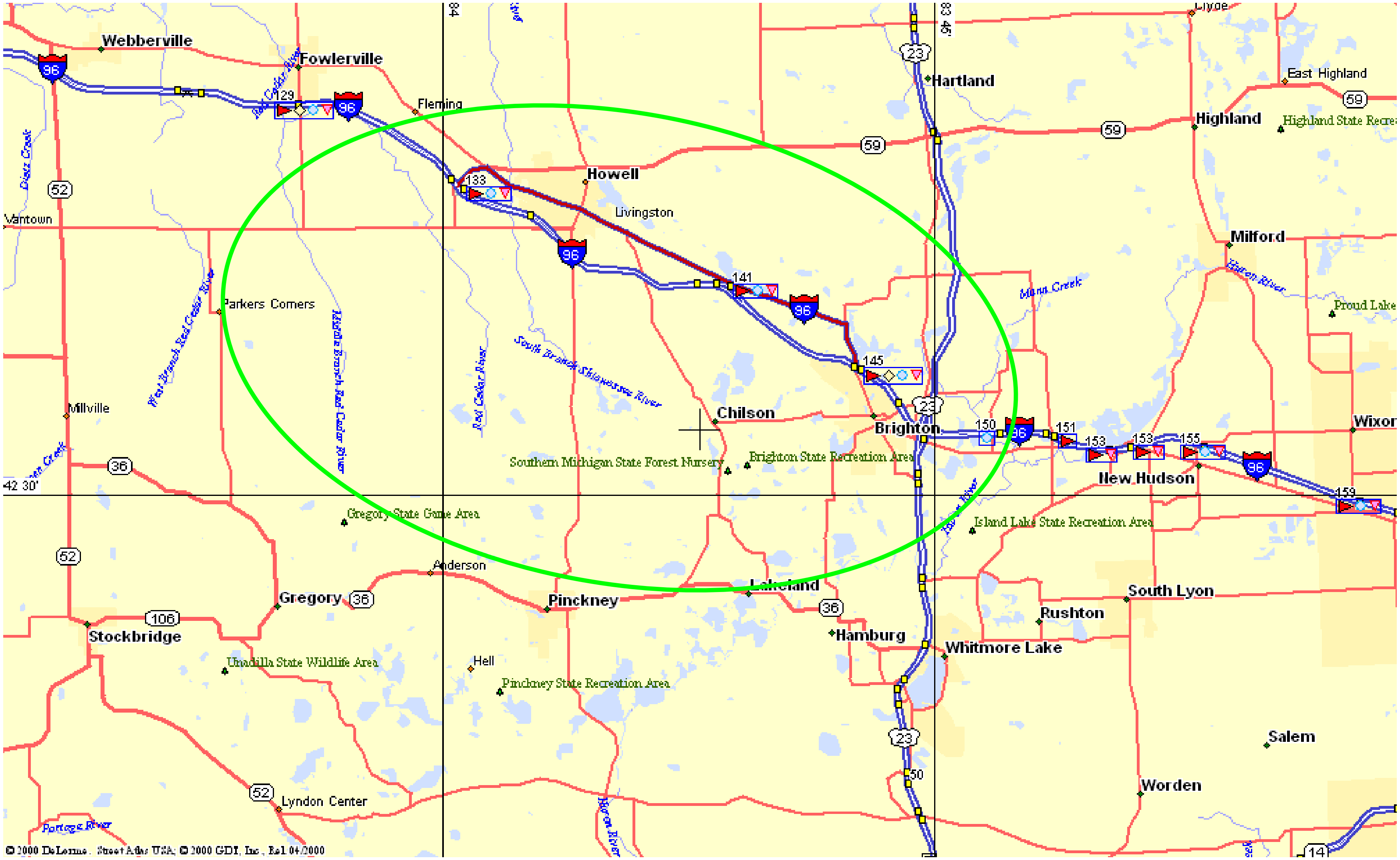


Figure 13 - WCSX / WMMQ Compatibility (Detail)

- WXKR (as Desired Analog)

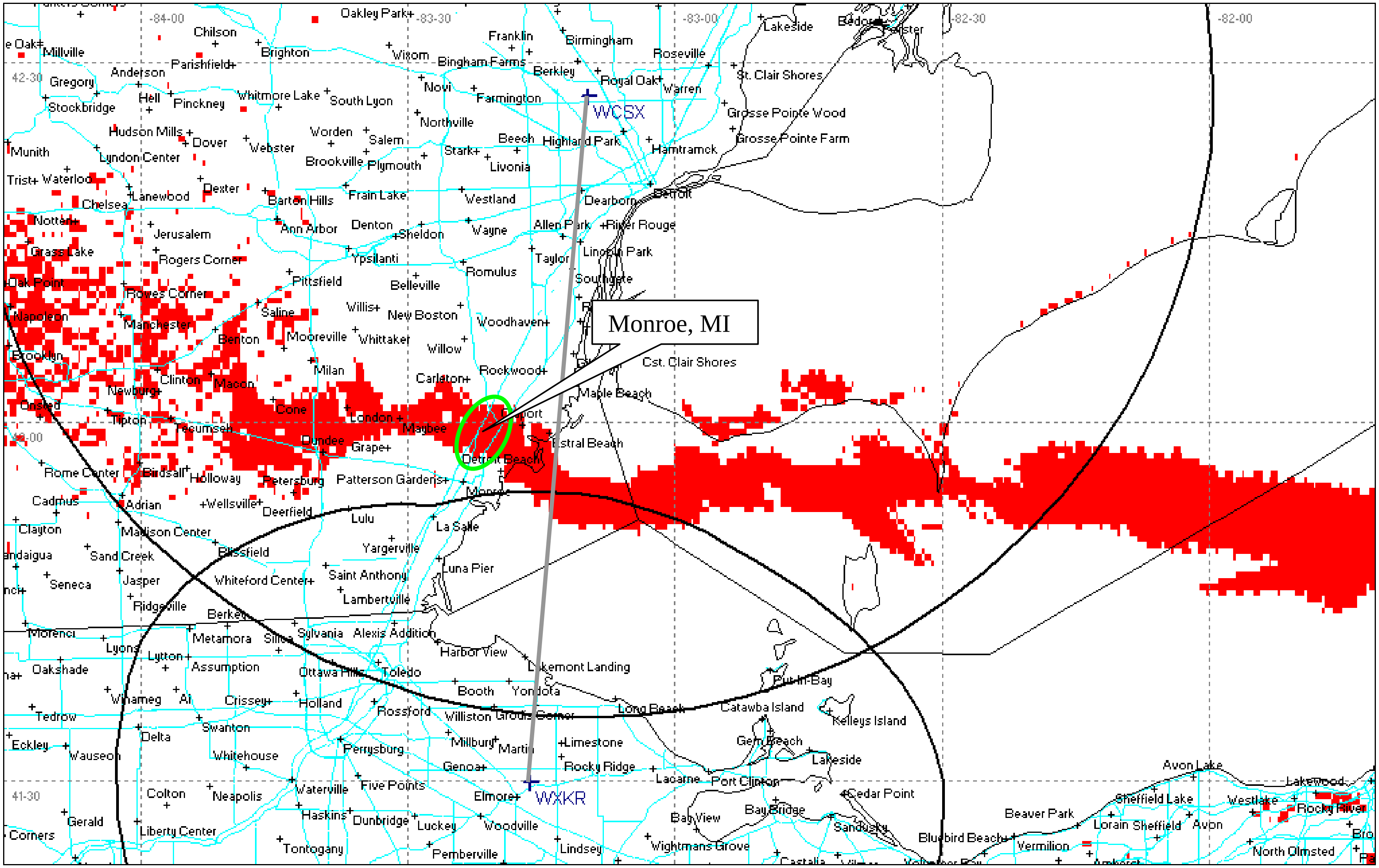


Figure 14 - WCSX / WXKR Compatibility (DU = 0 to +10)

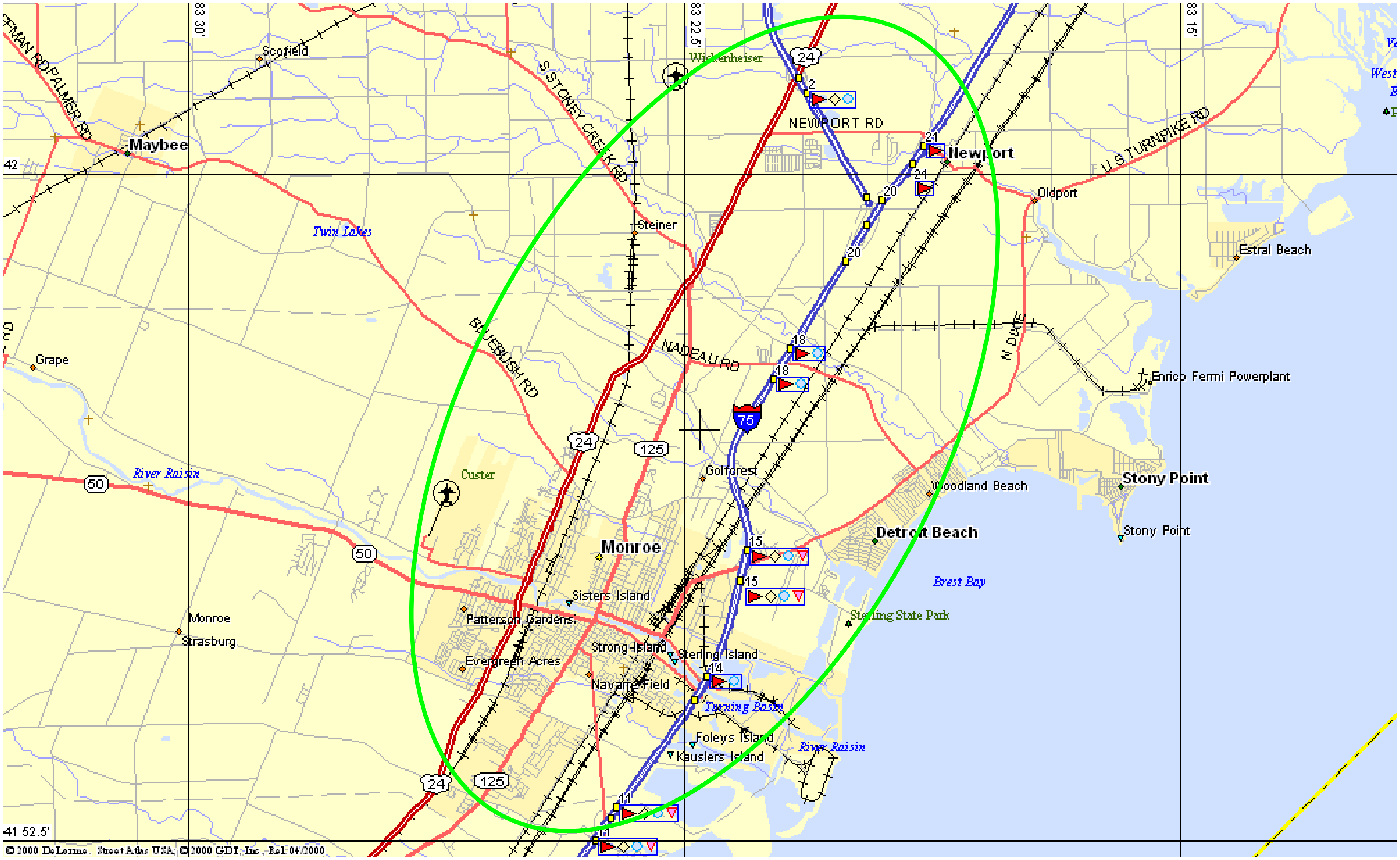


Figure 15 - WCSX / WXKR Compatibility (Detail)

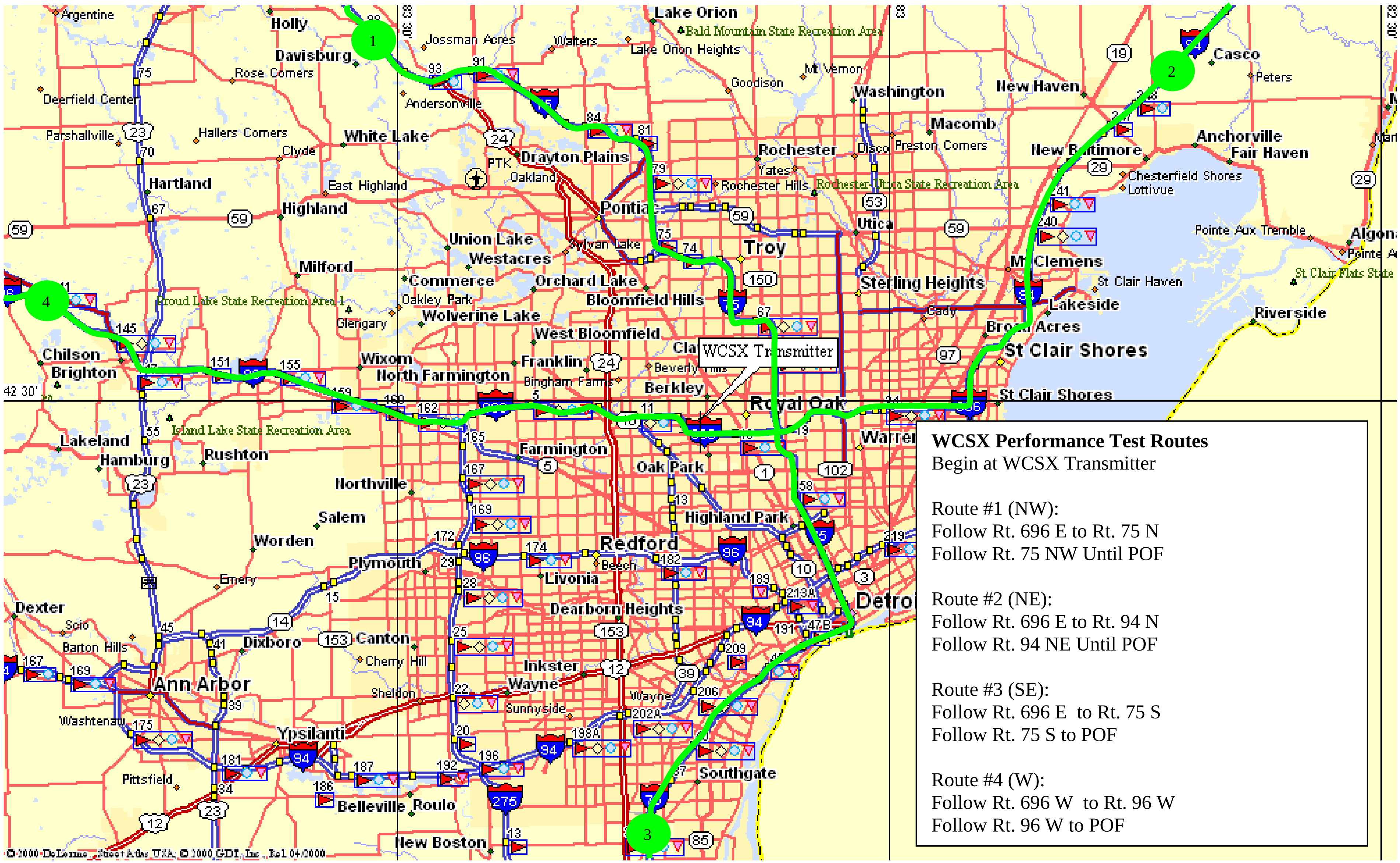


Figure 16 - WCSX Performance Routes

5.1.3. KOST (LA, as IBOC Interferer)

- KTMQ (as Desired Analog)

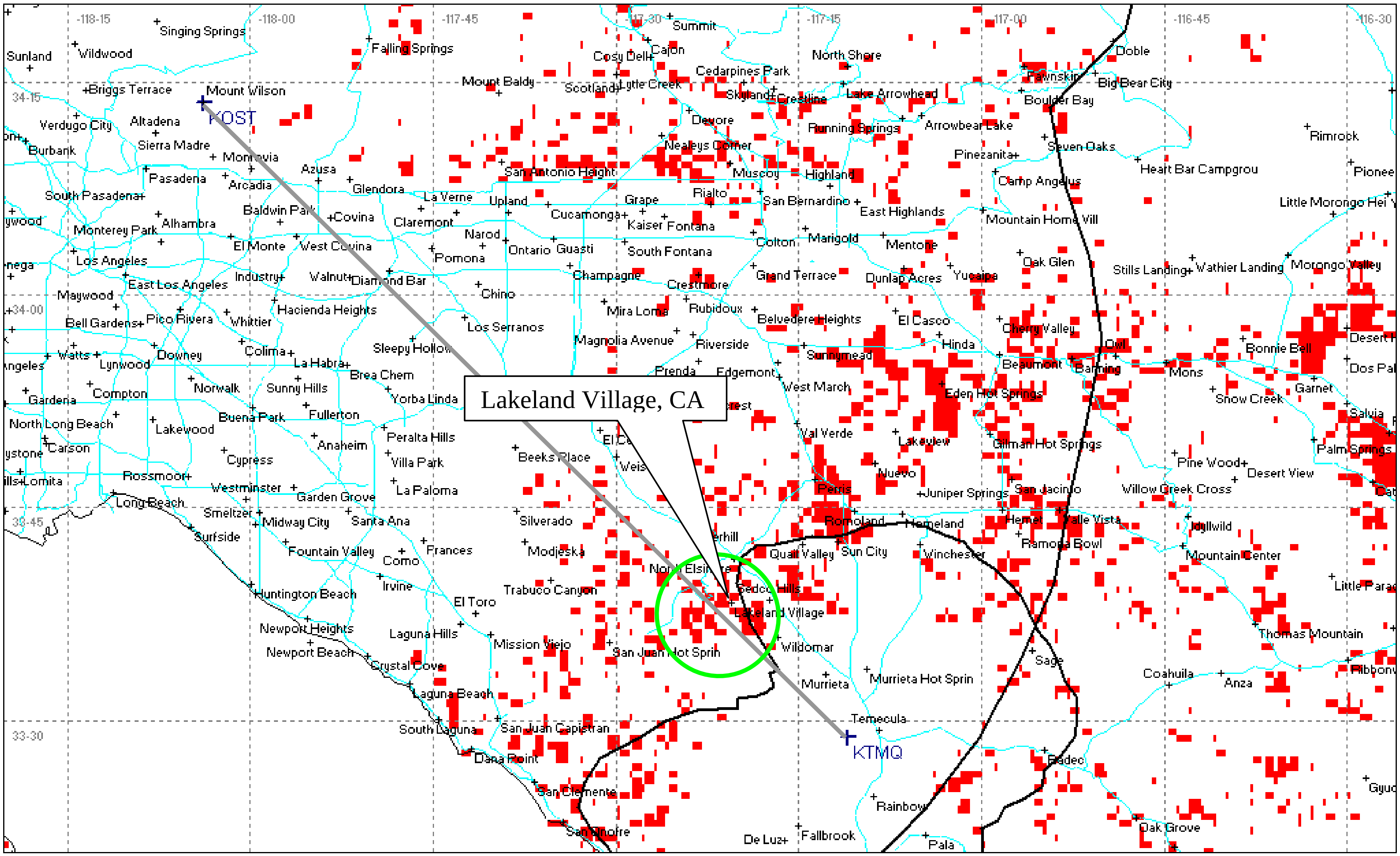


Figure 17 - KOST / KTMQ Compatibility (DU = 0 to +10)

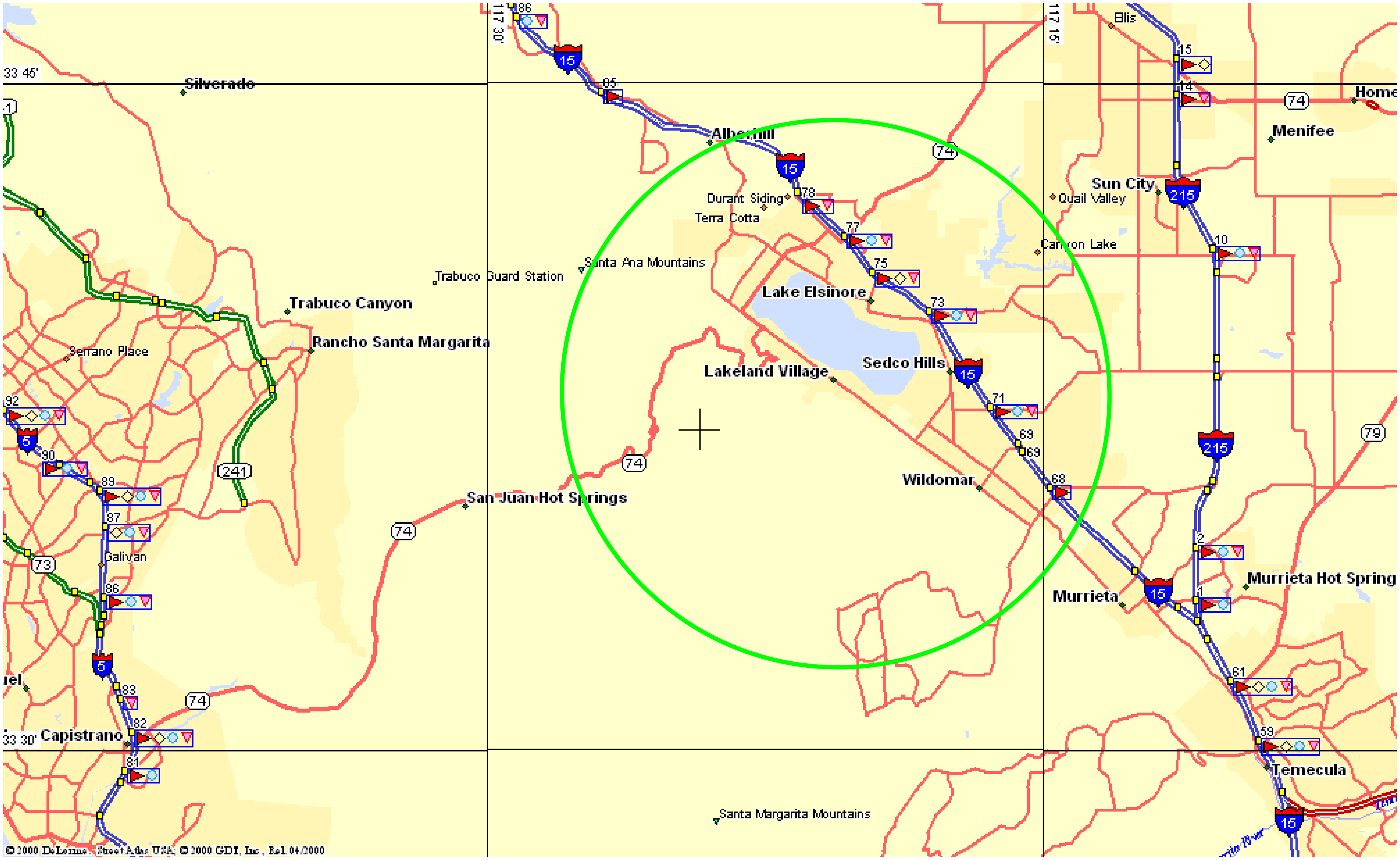


Figure 18 - KOST / KTMQ Compatibility (Detail)

- KSCF (as Desired Analog)

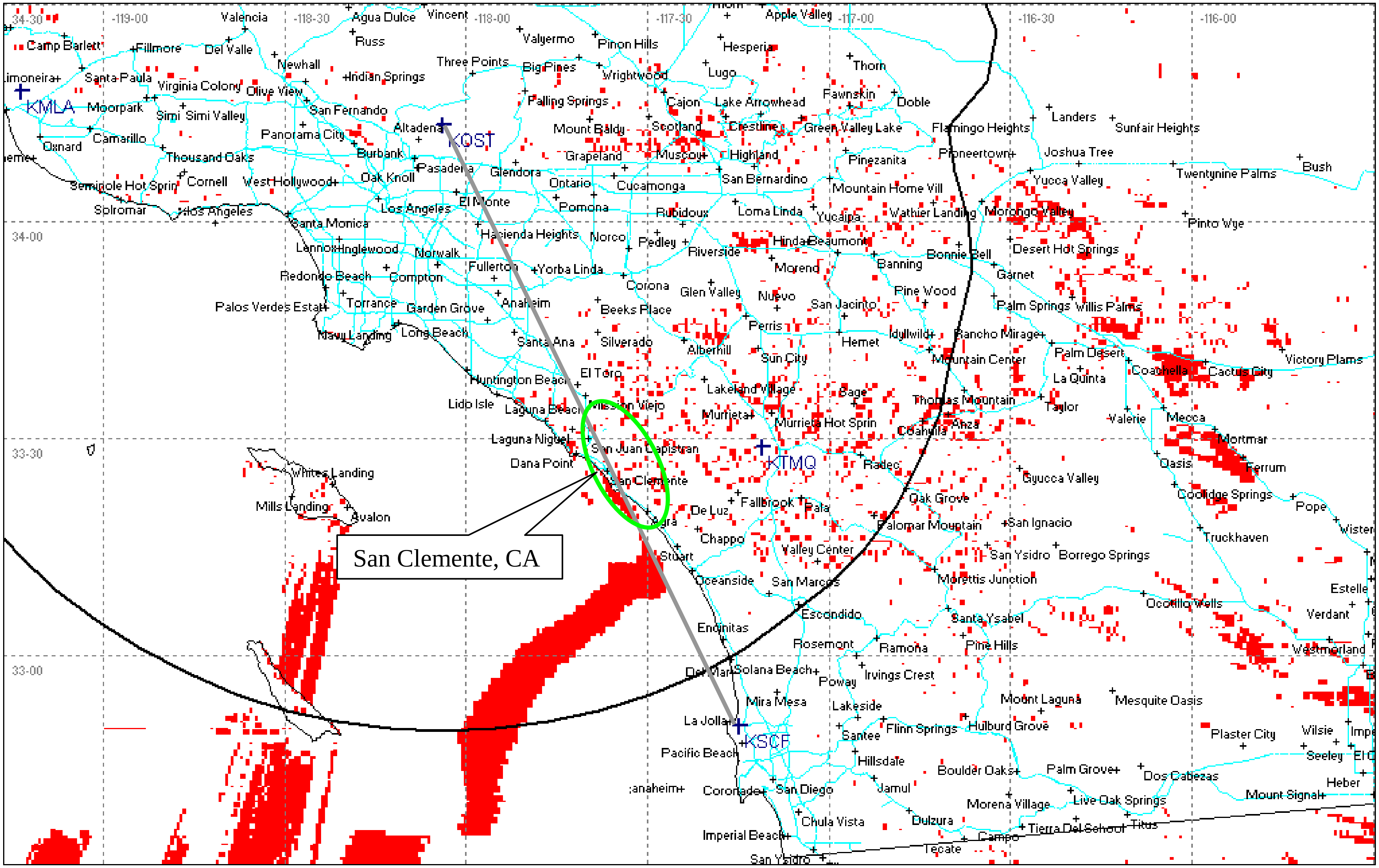


Figure 19 - KOST / KSCF Compatibility (DU = 0 to +10)

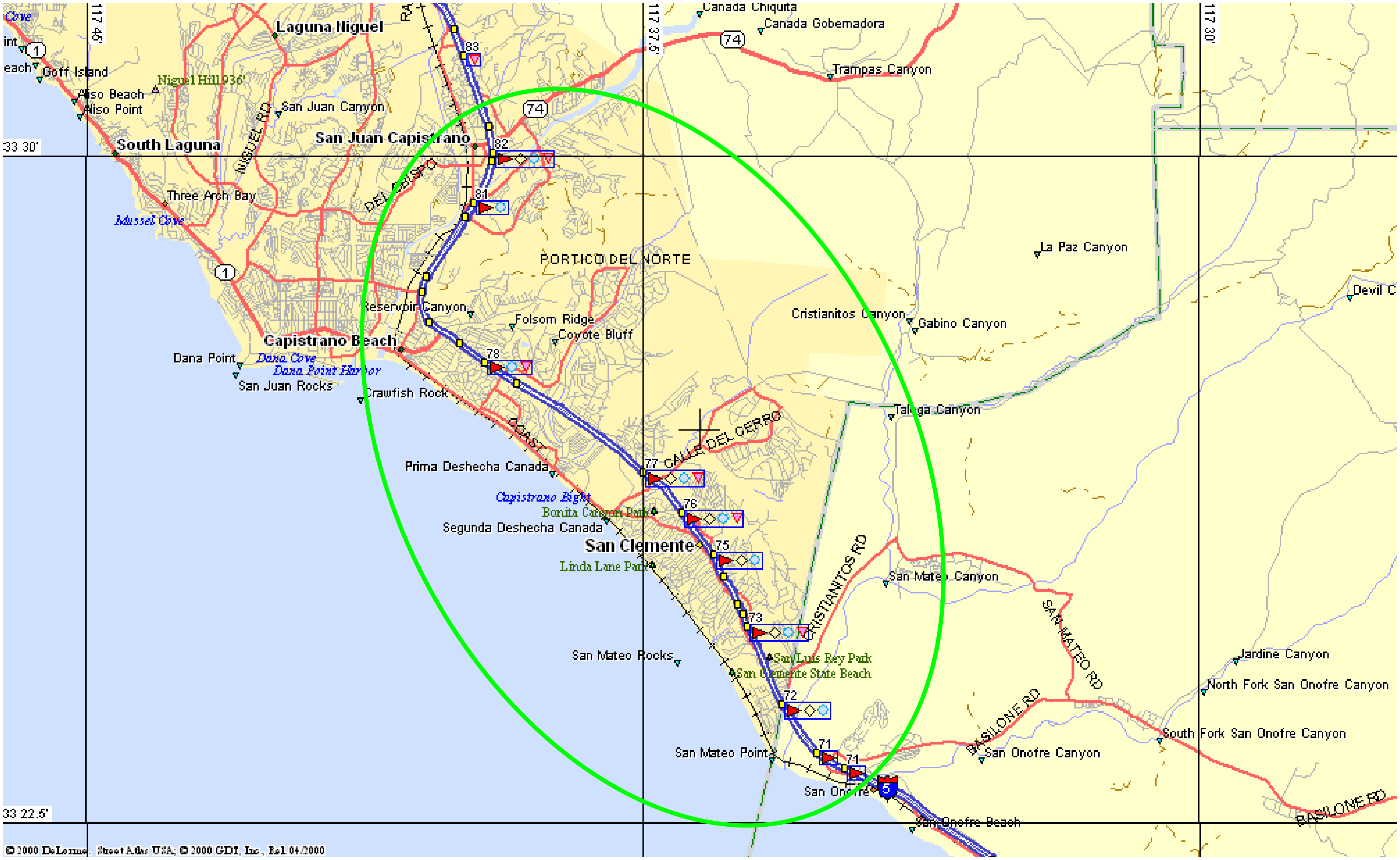


Figure 20 - KOST / KSCF Compatibility (Detail)

KVYB (as Desired Analog)

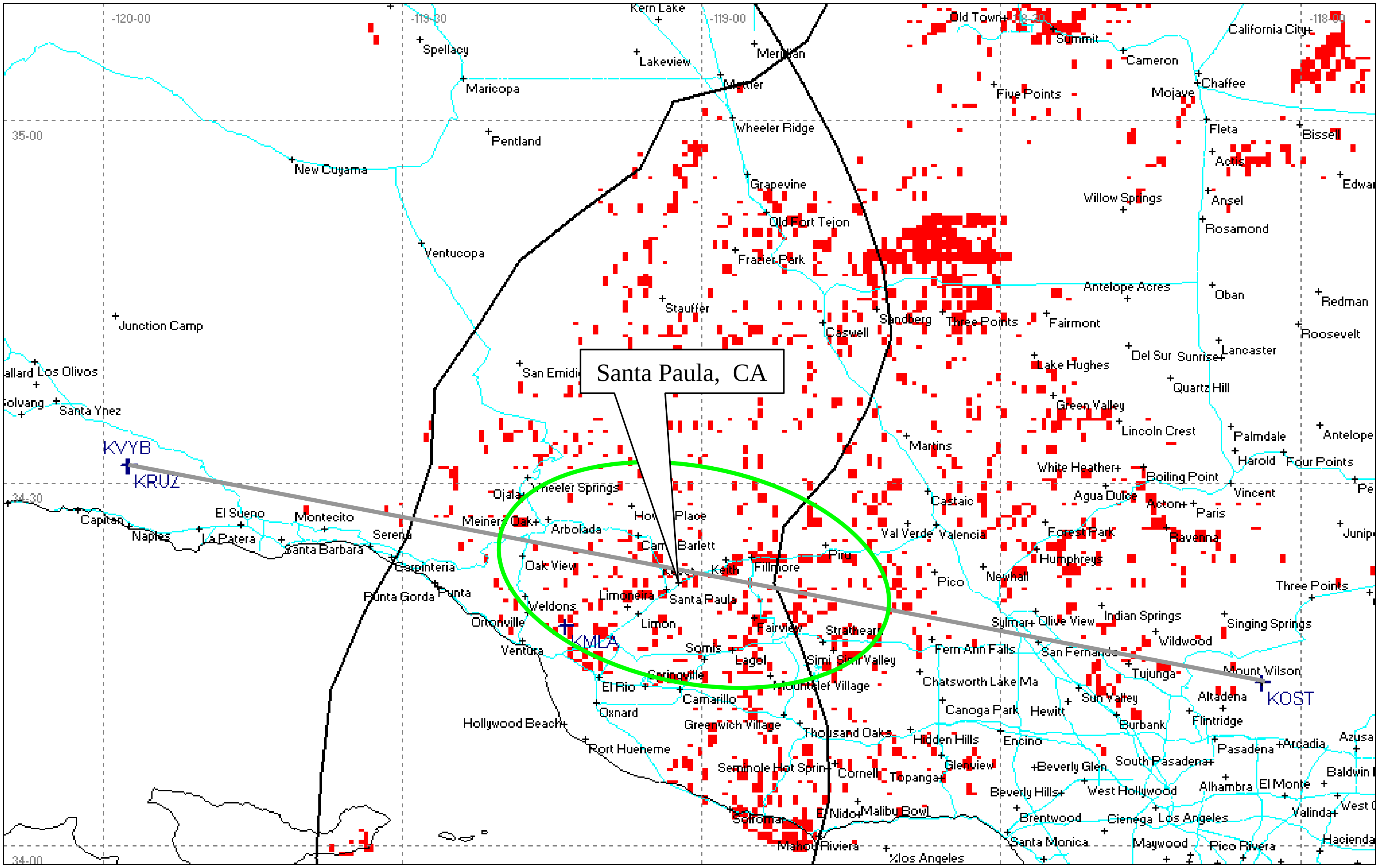


Figure 21 - KOST / KVYB Compatibility (DU = 0 to +10)

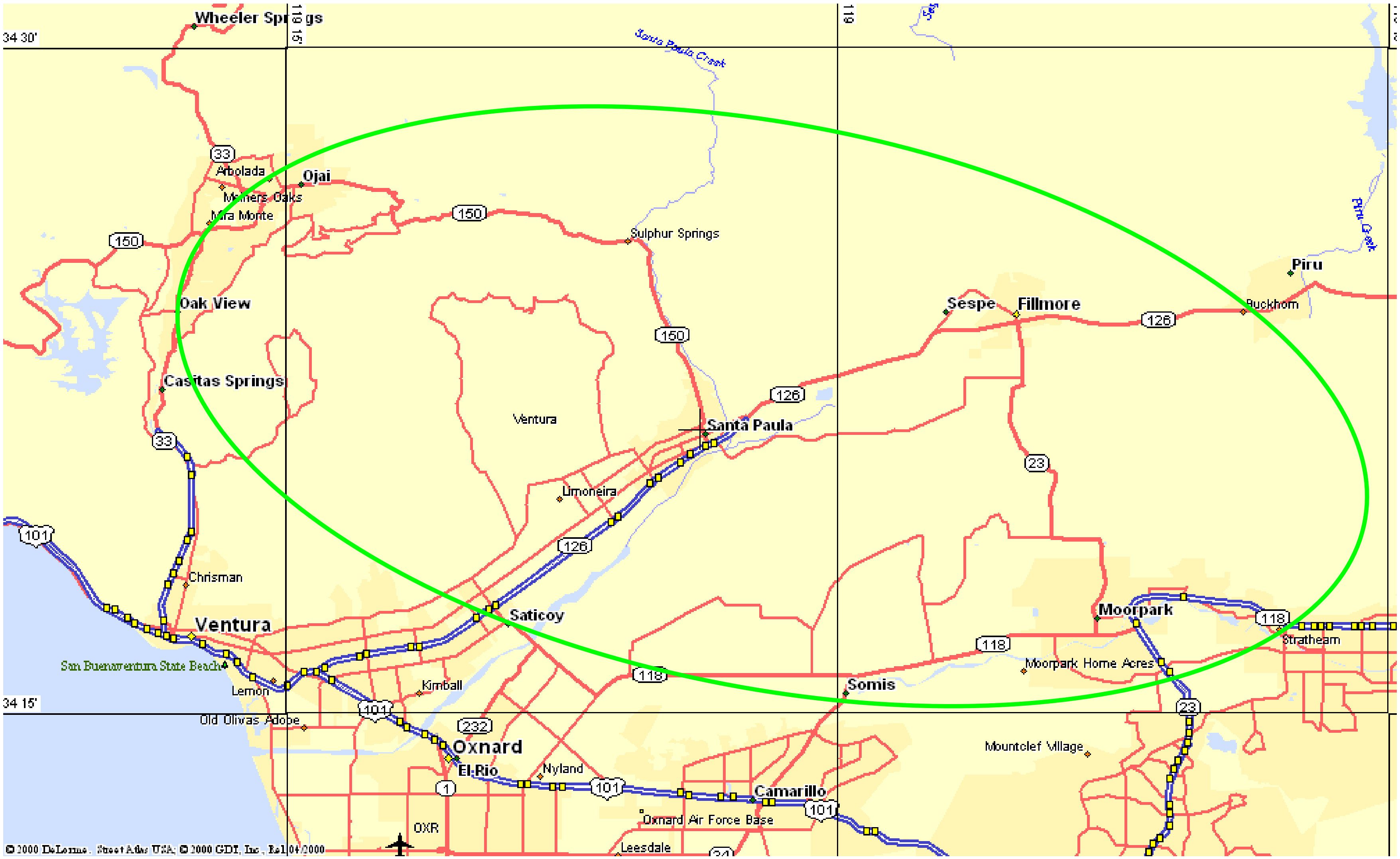


Figure 22 - KOST / KVYB Compatibility (Detail)

Figure 23 - KOST & KROQ Performance Routes

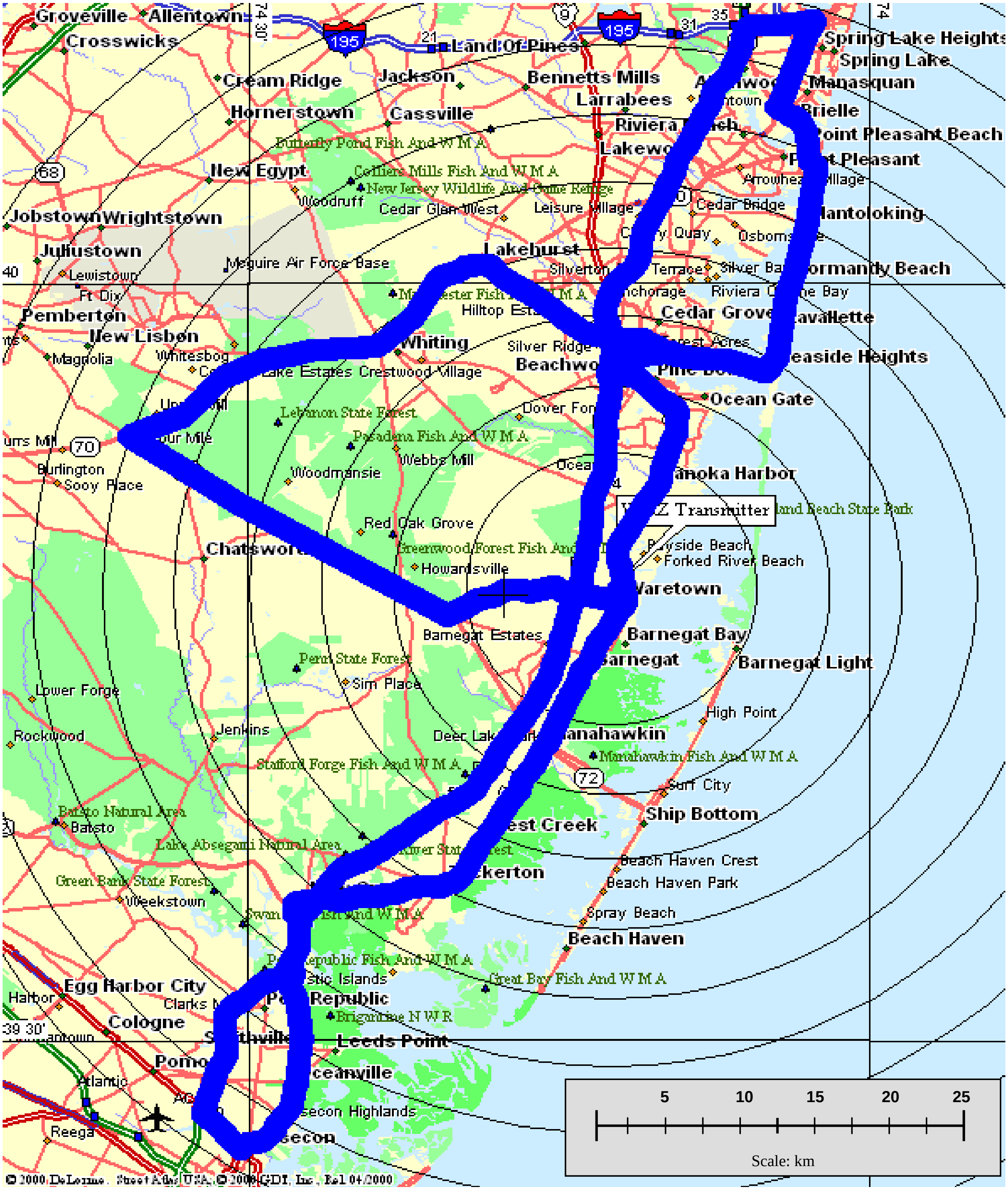


Figure 24 – WJRZ HD Radio™ Performance Loops

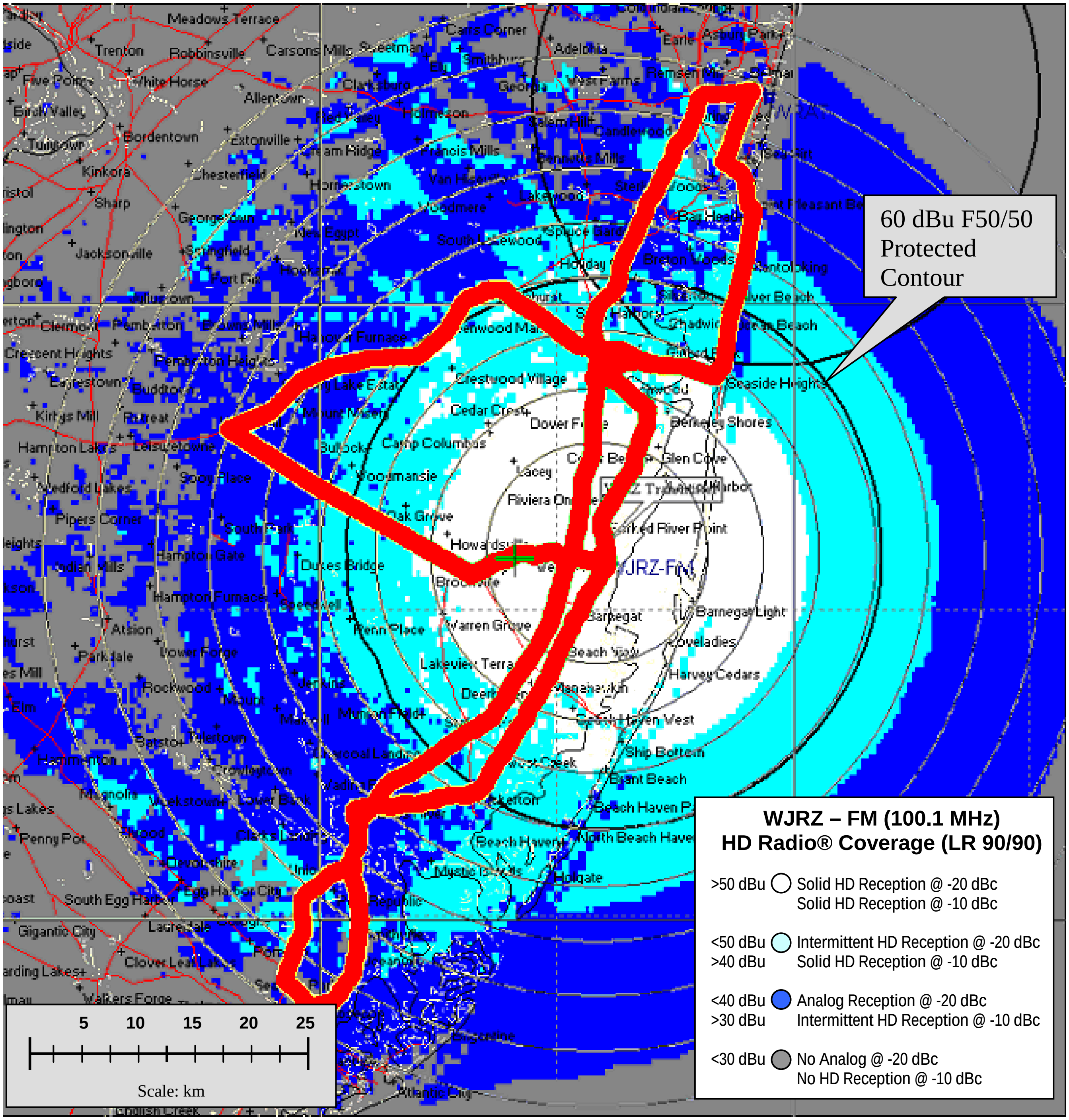


Figure 25 – WJRZ HD Radio™ Performance Loops

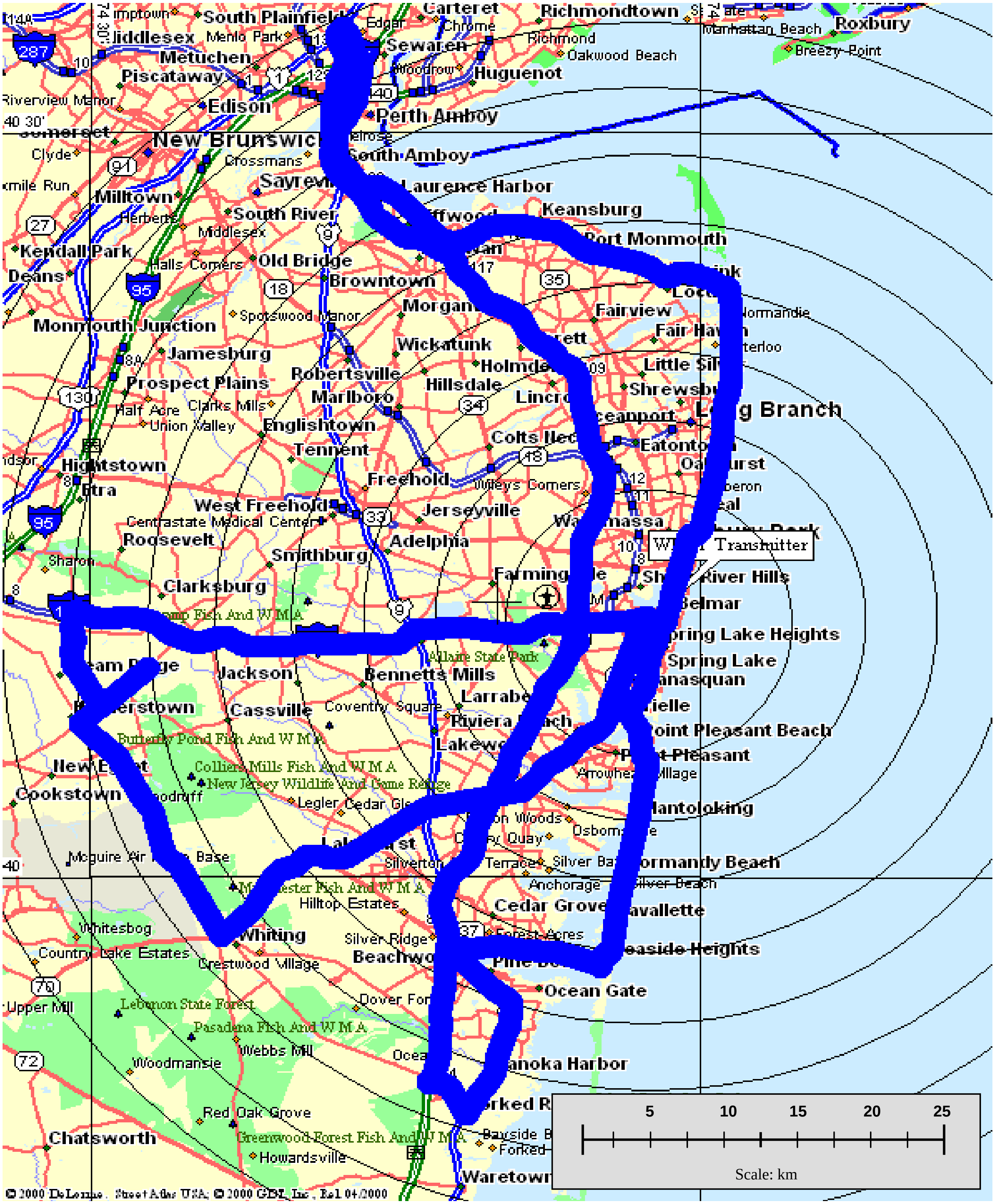


Figure 26 – WRAT HD Radio™ Performance Loops

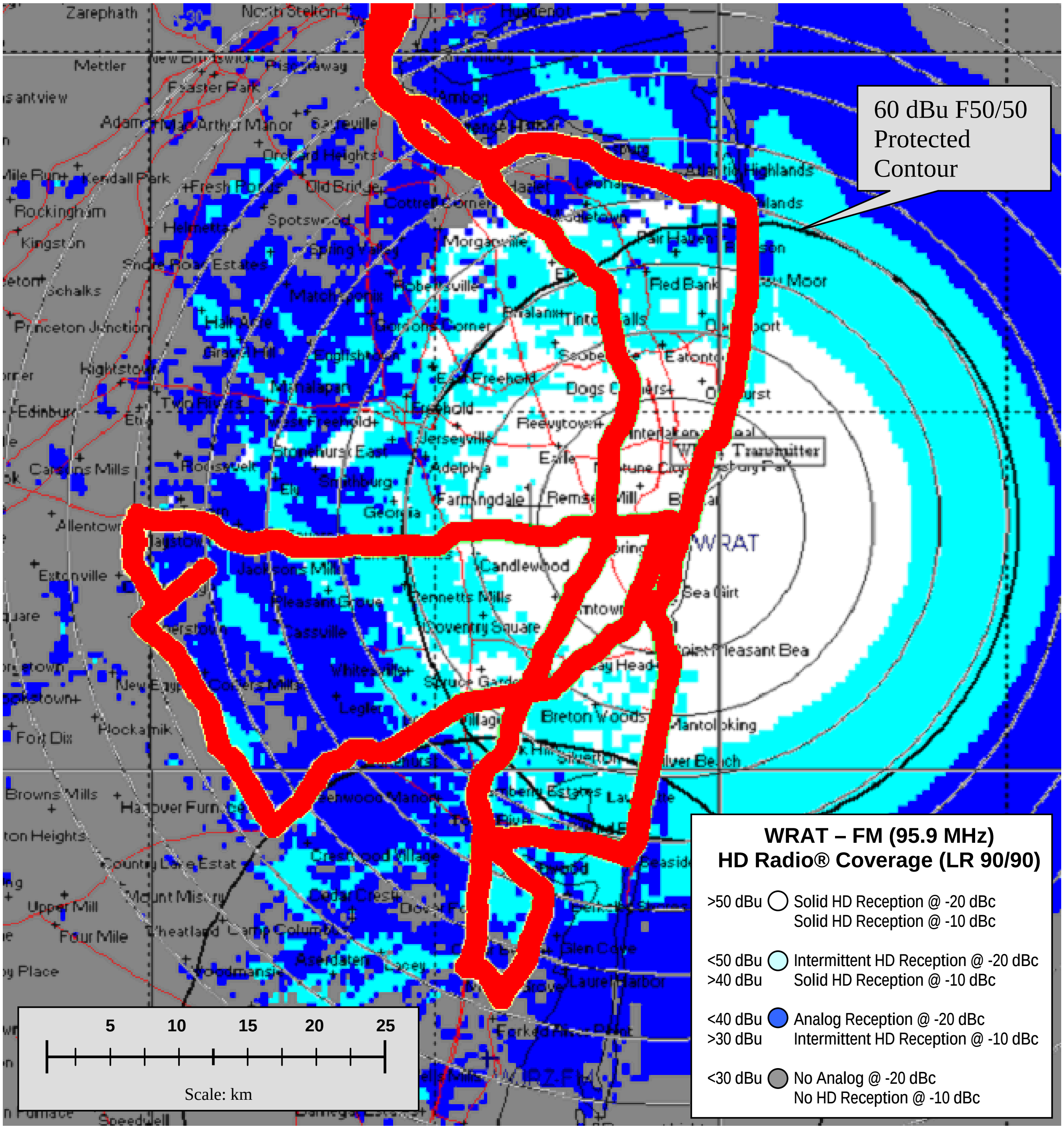


Figure 27 – WRAT HD Radio™ Performance Loops

Test Schedule

5.2. WCSX – January 22 thru January 26, 2007

Day #	Time (AM/PM)	Test Type	Station	Test Location
1/22	AM	Setup	WCSX	WCSX Transmitter
	PM	Host Compatibility	WCSX	2 mi. from Tx
1/23	AM	1st Adjacent Compatibility	WCEN	Grand Blanc, MI
	PM	1st Adjacent Compatibility	WMMQ	Howell, MI
1/24	AM	1st Adjacent Compatibility	WXKR	Monroe, MI
	PM	Performance	WCSX	Route #1 (Rt. I-75 NW From Tx)
1/25	AM	Performance	WCSX	Route #2 (Rt. I-94 NE From Tx)
	PM	Performance	WCSX	Route #3 (Rt. I-75 S. From Tx)
1/26	AM	Performance	WCSX	Route #4 (Rt. I-96 W. From Tx)
	PM			

5.3. WKCI – February 12, 2007 thru February 15, 2007

Day #	Time (AM/PM)	Test Type	Station	Test Location
2/5	AM	Setup	WKCI	WKCI Transmitter
	PM	Host Compatibility	WKCI	Sleeping Giant Park?
2/6	AM	1st Adjacent Compatibility	WCBS	Norwalk, CT
	PM	1st Adjacent Compatibility	WWBB	Windham, CT
2/7	AM	1st Adjacent Compatibility	WPDH	New Milford, CT
	PM	Performance	WKCI	Route #3 (Rt. I-95 W. From Tx)
2/8	AM	Performance	WKCI	Route #2 (Rt. I-95 E. From Tx)
	PM	Performance	WKCI	Route #1 (Rt. I-91 N. From Tx)

5.4. KOST – February 26 thru March 2, 2007

Day #	Time (AM/PM)	Test Type	Station	Test Location
2/26	AM	Setup	KOST	KOST Transmitter
	PM	Host Compatibility	KOST	5 mi. from Tx? Pasadena?
2/27	AM	1st Adjacent Compatibility	KMLA	Moorpark, CA
	PM	1st Adjacent Compatibility	KTMQ KSCF	Lake Village, CA San Clemente,CA
2/28	AM	1st Adjacent Compatibility	KIQQ	Adelanto, CA
	PM	1st Adjacent Compatibility	KVYB	Santa Clara, CA
3/1	AM	Performance (-20 & -10)	KOST & KROQ*	Route #1 (Rt. 210NW. to Rt. 5NW)
	PM	Performance (-20 & -10)	KOST & KROQ*	Route #2 (Rt. 210E to Rt. 10E.)
3/2	AM	Performance (-20 & -10)	KOST & KROQ*	Route #3 (Rt. 110S/Rt. 405SE/ Rt.5SE)
	PM	Performance (-20 & -10)	KOST & KROQ*	Route #4 (Rt. 210/Rt. 10)

Note: Two HD Radio Receivers will be used to simultaneously collect data on KOST & KROQ. Spectral data will be collected for KOST only.

6. Test Procedure

6.1. Transmission System Setup & Proof

6.1.1. Adjust IBOC digital/analog power ratio per section 4.2

6.1.2. Check out of band emissions per section 4.3

6.2. Host Compatibility Testing

6.2.1. Find a suitable multipath-free area about 2 miles from the transmitter.

6.2.2. Observe the interferer's spectrum @ 1kHz RBW / 1kHz VBW – avg. 50X.

6.2.3. Adjust IBOC transmitter power to achieve desired digital to analog ratio.

6.2.4. Set up radios as shown in Figure 3.

6.2.5. Spectrum should look like those in section 3.2.

6.3. First Adjacent Compatibility Testing

6.3.1. Travel to designated areas as shown in maps.

6.3.2. Locate a point at high elevation that shows good signal level and +6 dB DU.

6.3.3. Set up boombox radio on a table and orient for best reception (Figure 3).

6.3.4. Connect audio and DC/AC power to other radio.

6.3.5. Record ½ hour of desired analog station audio/spectrum/gps with the IBOC interferer power ratio at -20 dBc.

6.3.6. Record ½ hour of desired analog station audio/spectrum/gps with the IBOC interferer power ratio at -10 dBc.

6.3.7. *Repeat 7.3.5 & 7.3.6 - 3 times (3 hours total) to record sufficient audio to enable genre to genre comparison of selected recordings.*

6.3.8. Ensure that program material is similar for both recordings

6.4. Performance Testing (Once for Each Radial)

6.4.1. Travel to route start point as shown in map.

6.4.2. Run route and record IBOC station status/audio/spectrum/gps with the IBOC desired power at -20 dBc.

6.4.3. Travel back to route start point. You must run both trials in the same direction!

6.4.4. Run route and record IBOC station status/audio/spectrum/gps with the IBOC desired power at -10 dBc.