White Paper
SFN Experiences in NYC

April, 2011

➢ SFN Introduction

Abstract

This white paper highlights the challenges encountered and results achieved in implementing an SFN system with WMBC in New York City. An analysis of the design, implementation, and field test results are presented.

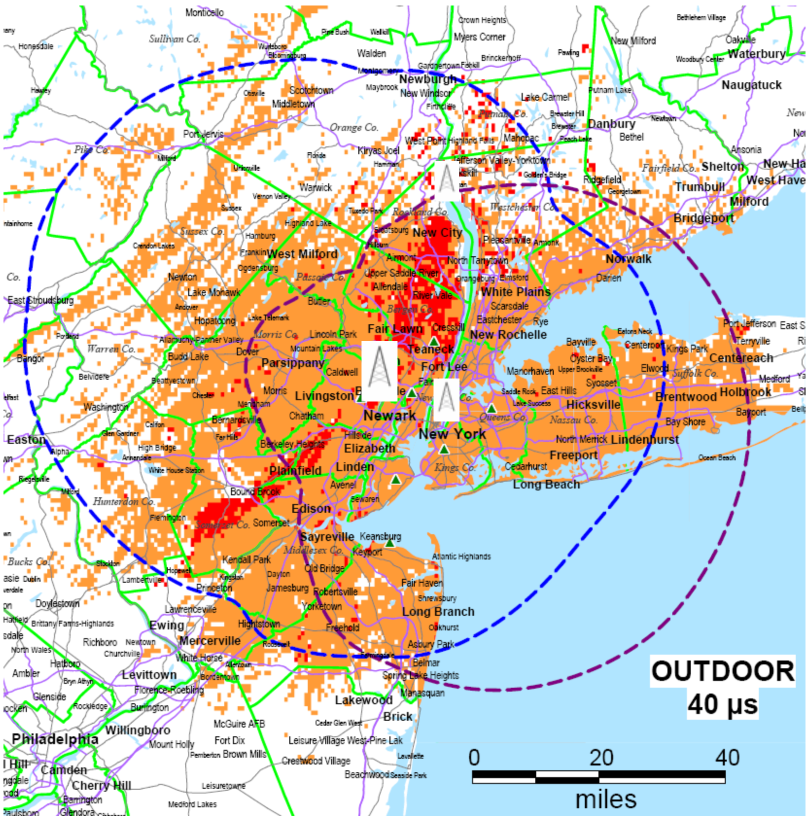


Figure 1:

40usec SFN coverage map

Why implement a SFN?

We begin by asking the simple question, “Why would a Broadcaster want to implement an SFN system?” For WMBC, the answer was clear. They had several target viewing areas in NYC that were not being adequately covered by their main DTV transmitter located in northern NJ. This was primarily due to existing terrain shielding limitations produced by the New York City skyline.

Adding a second transmitter on top of the Empire State Build (ESB) in SFN mode with their main transmitter in northern NJ significantly increased signal reception in targeted areas like Queens and Brooklyn.

Synchronization of the two transmitter signals was essential as the 2nd transmitter added at the Empire State Building created substantial signal overlap with the main transmitter as shown in the coverage and interference map of Figure 1. The dashed blue line shows the coverage contour of the main Tx in NJ, the dashed purple line the contour for the Tx added to the ESB.

➢ SFN Introduction (cont.)

What is a SFN?

A Single Frequency Network (SFN) is made up of two or more transmitters simultaneously broadcasting the same time-synchronized signal over the same frequency to achieve greater signal coverage and reception. The SFN at WMBC was implemented according to the ATSC A/110B "Synchronization Standard for Distributed Transmission" which added a framing structure to allow precise timing of the signals.

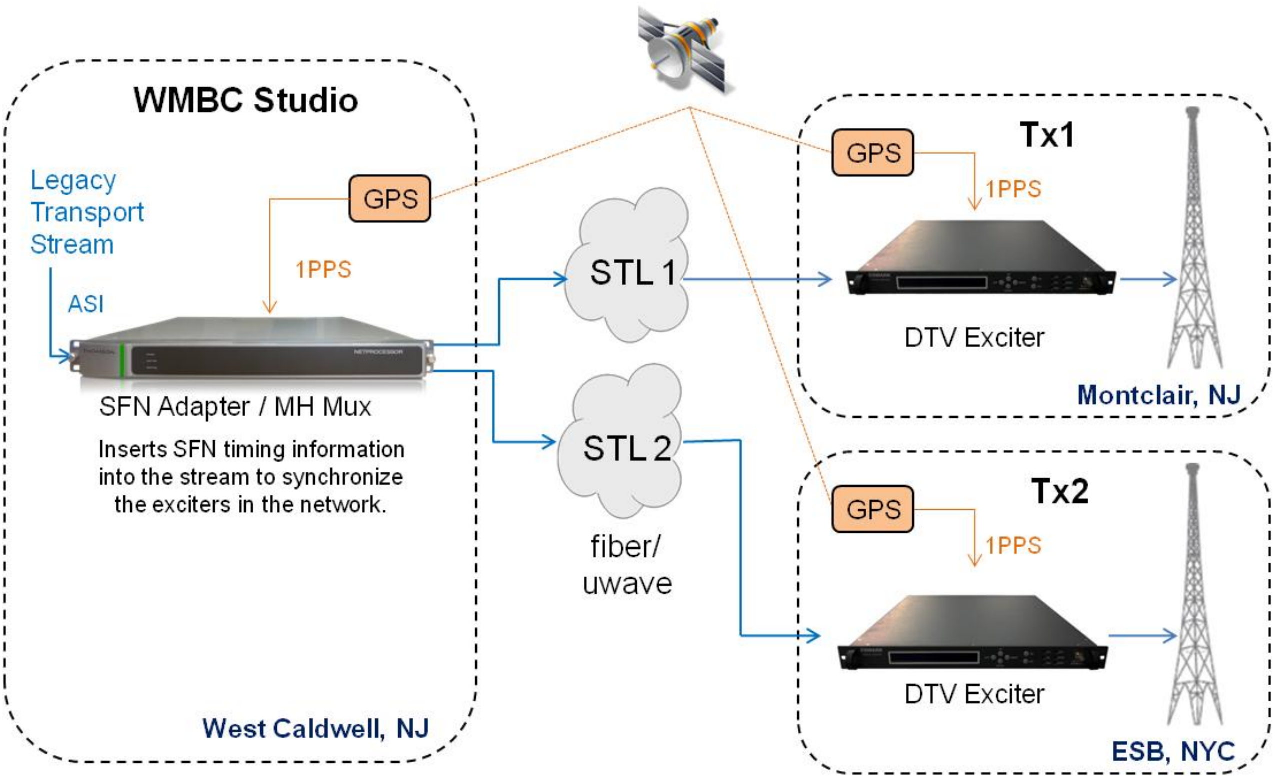


Figure 2: Basic SFN Architecture

How does an SFN system work? In order to synchronize all the transmitters in a SFN, a SFN Adapter or Mobile Multiplexor, such as the TVN 9030 NetProcessor, is installed at a stations Broadcast studio or Network Operations Center (NOC), as shown in Figure 2. The SFN Adapter is responsible for inserting the appropriate timing information packets (DTxP) into the transport stream that will then go out to all the transmitters in the network via their existing STL links. The exciters receive the timing information and are able to synchronize their emissions via their common 1PPS GPS time reference.

➢ SFN Synchronization

SFN Timing and Achieving Synchronization

Conceptually, it's important to understand that the "synchronization" all takes place within the exciters, independent of when packets are sent from the SFN Adapter, when they arrive at each exciter, or any differences that may exist in the STL network or processing delays. Figure 3 provides an overview of the SFN timing. Understanding the timing becomes simple when we appreciate that all the exciters are synchronized to the 1PPS, and that they "buffer" their input signals, "waiting" for the appropriate time to emit based on two key parameters contained in the DTxP. These two parameters, configurable in the NetProcessor, are the Max Delay (which is the same for all transmitters) and the Tx Delay (which is unique for each transmitter). The Max Delay (100 ms for WMBC) is set to be an order of magnitude greater than all the STL Network and Processing delays combined. Each transmitter waits the Max Delay (100ms) to emit their signals, thus "synchronizing" their outputs. Beyond this synchronization, an additional Tx Delay may be uniquely specified for each transmitter to control the interference pattern within the SFN. Figure 3 shows the Tx Delay for Tx1 as 0 us and Tx2 as 40 - the delays implemented in the WMBC SFN system.

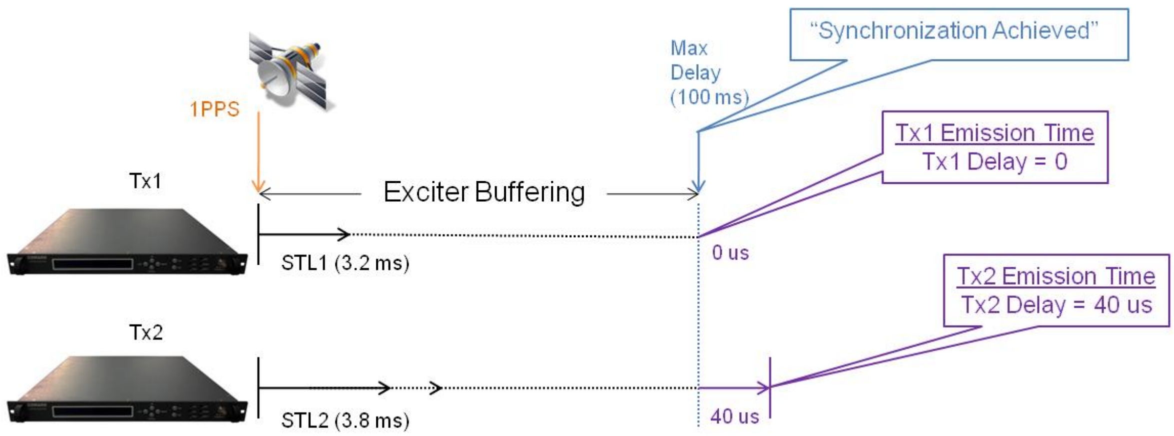


Figure 3: SFN Timing

So with a basic understanding of what an SFN system is, the next question we will ask is "How do we measure and verify the timing in an SFN system?" Figure 4 shows the modulated RF output signals from two transmitters that are not synchronized {on two separate channels of a digital scope, one yellow and the other pink}. A quick visual inspection shows no correlation between the two signals. When we put these same two transmitters into SFN mode, we get the coherent output signals shown in Figure 5. In this case the exciters are in SFN lock (both delaying for Max Delay) with no additional Tx delays and the "synchronization" is visibly obvious.

Figure 4: MFN, No Synchronization

Figure 5: SFN Synchronization, no delay

➢ SFN Synchronization (cont.)

Figure 6 shows the same two transmitters but now with a Tx delay of 2 us applied to the yellow trace transmitter. When these two signals combine together over the air, they produce the null pattern spectrum as shown in Figure 7. Notice the 12 nulls that occur within the 6 MHz signal, each null being 0.5 MHz wide corresponding to the (1/0.5 MHz) or 2 us time delay.

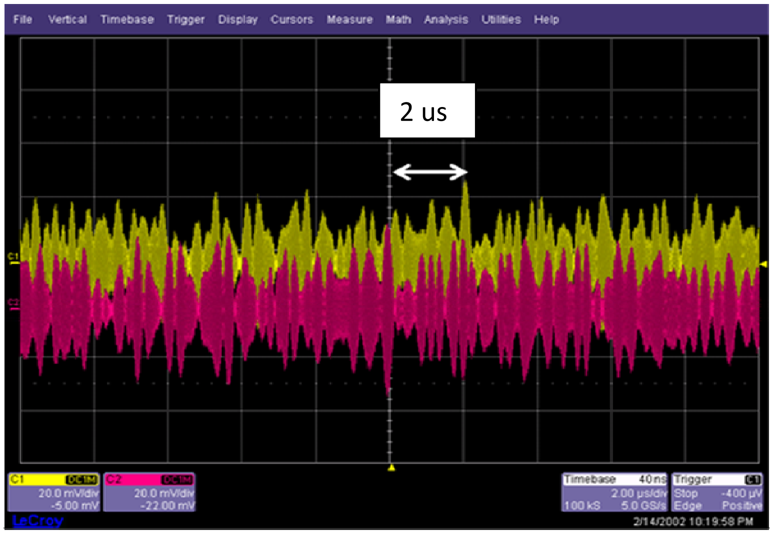


Figure 6: SFN Synchronization, 2 us delay

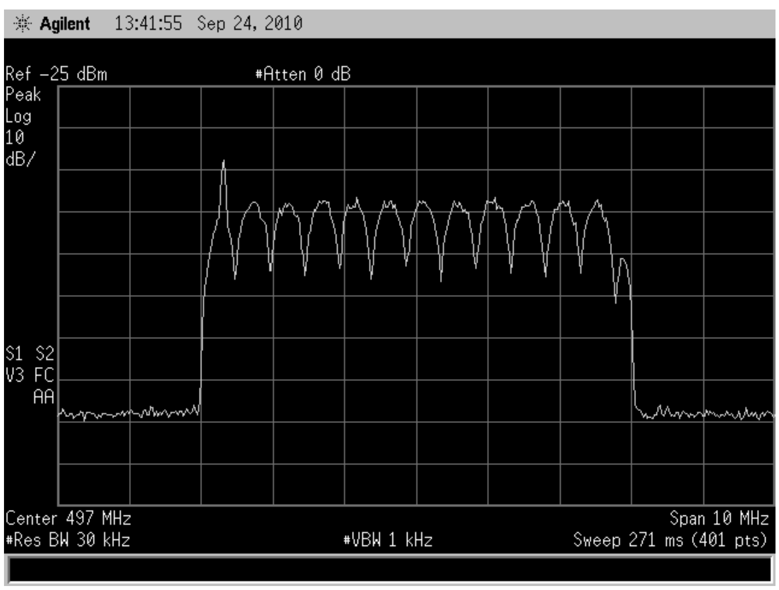


Figure 7: 12 nulls of 0.5 MHz width

➢ SFN Design & Implementation

SFN Design

The WMBC SFN System Design was performed by Bob du Treil of the du Treil, Lundin, and Rackley consulting firm. The main goal in designing a SFN is to increase signal coverage and reception in desired locations while minimizing and managing the effects of destructive interference. A sound system design is "critical yet difficult" due to the many challenges, limitations and assumptions involved in modeling, simulating and predicting coverage and interference.

WMBC operates on DTV channel 18 (494-500MHz) and all coverage studies were conducted for their specific channel. It should also be noted that the main transmitter located in Montclair, NJ is a Comark DCX Paragon MSDC-IOT with a transmitter power output (TPO) of 26.6kW and a corresponding ERP of 1MW. Based on coverage and interference studies, the second transmitter installed at the ESB location is an Elite-1000 series solid state with a TPO of 3.4kW and a corresponding ERP of 90kW. Both transmitter systems incorporate the ADAPT-IV 8-VSB DTV exciter that is fully compatible with ATSC's SFN and Mobile DTV.

Figure 8 shows just a few of the many coverage/interference maps that were generated to determine the optimal SFN system timing. The blue dashed line represents the contour of the NJ transmitter while the purple dashed line shows the contour for the ESB transmitter. Areas predicted to have good reception are highlighted in orange while areas predicted to have bad reception are shown in red. Notice how the predicted areas of bad reception change as the time delay between the two transmitter sites changes from 0 to 40 to 90 us in the coverage maps as we move from left to right.

Figure 8: SFN coverage / interference maps

➢ SFN Design & Implementation

In addition to the coverage and interference prediction analysis, the WMBC design also utilizes a directional antenna specifically mounted on the Empire State Building to minimize un-wanted radiation towards New Jersey. The antenna is mounted on a wall just above a parapet on the east side of the Empire State Building as shown in Figure 9. In this way, the building acts as a RF shield to further reduce the un-wanted radiation towards New Jersey and West.

Figure 9: ESB Antenna mounting

Directional Antenna mounted on east-side of the Empire State Building – utilizes building as an "RF shield" to reduce unwanted radiation towards the west.

SFN Implementation

Once the SFN system design was complete, it was time to move on to the installation and commissioning of the SFN system components. Upon installing the 9030 NetProcessor SFN adapter at the Studio and the second Tx at the ESB, the question soon became, "How are we going to make reliable measurements to verify the system timing is correct before switching the system on-air?" So the ESB Tx was left running into a load until the SFN timing could be verified.

It is important to point out that the two transmitters are roughly 14 miles (22 km) apart. This means that a signal leaving the Montclair Tx would take 22km/ (3e8m/sec) ~ 76 us to arrive at the ESB. And if we delay the ESB emission 40 us relative to Montclair, this means that the Montclair signal should look like a ~36us (76-40) post ghost as compared to the ESB signal. Measuring this ~36 us time delay became our test criteria. Three different measurement approaches were employed.

➢ SFN Design & Implementation

Figure 10 shows the test setup used at the ESB. With the ESB into a load, a receive antenna was mounted on the west side of the building to pick up the Montclair signal. This signal was filtered, amplified and then compared on a digital oscilloscope to an ESB signal coupled directly off the output stack of the ESB Tx. An "SFN Test Signal" (attenuated PN sequence) was sent by the exciters that allowed the scope to trigger on and measure the actual time delay between the two signals.

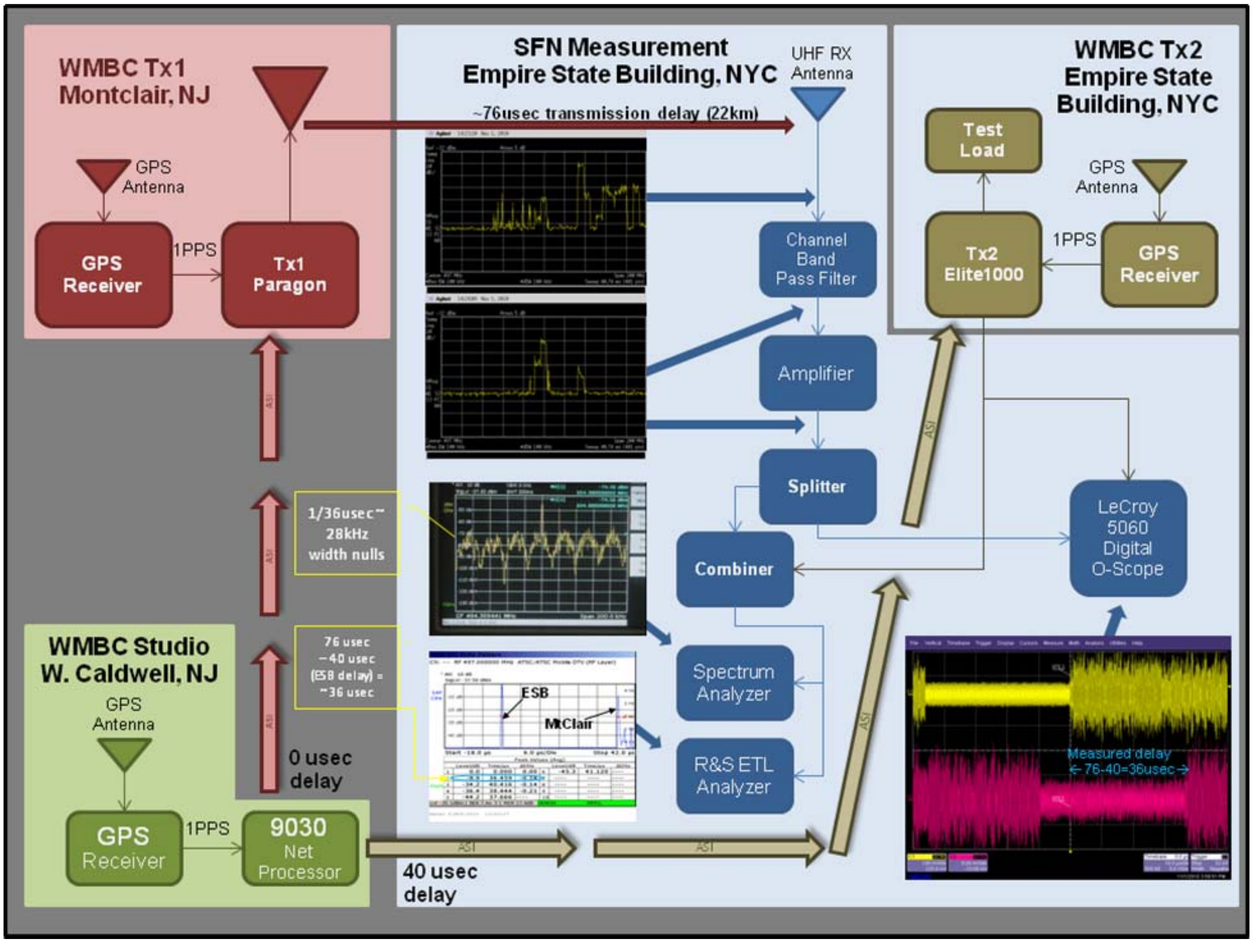


Figure 10: ESB Test setup to verify ~36 us time delay

This measurement showed us in real time that the pink trace (Montclair signal) was ~36 us delayed from the ESB signal (pink trace). We then combined the two signals and measured the resulting null pattern with a spectrum analyzer and further confirmed the time delay of ~36us with null widths of 28 kHz (1/28kHz ~36 us time delay). And finally, we ran the combined signals into an ETL analyzer which further confirmed the ~36us delay with its echo pattern measurement.

➢ SFN Real World Testing

SFN Field Test – Site Locations

With the SFN timing verified via three different approaches, we felt confident that we could switch the SFN system on-air, which we did on November 2, 2010. One week later, we invited Dennis Wallace of the Meintel, Scrignoli, & Wallace consulting firm, to conduct outdoor SFN field measurements. MSW supplied their van with a 30ft mast to take measurements at eight pre-selected locations in and around the NYC/NJ area as shown in Figure 11.

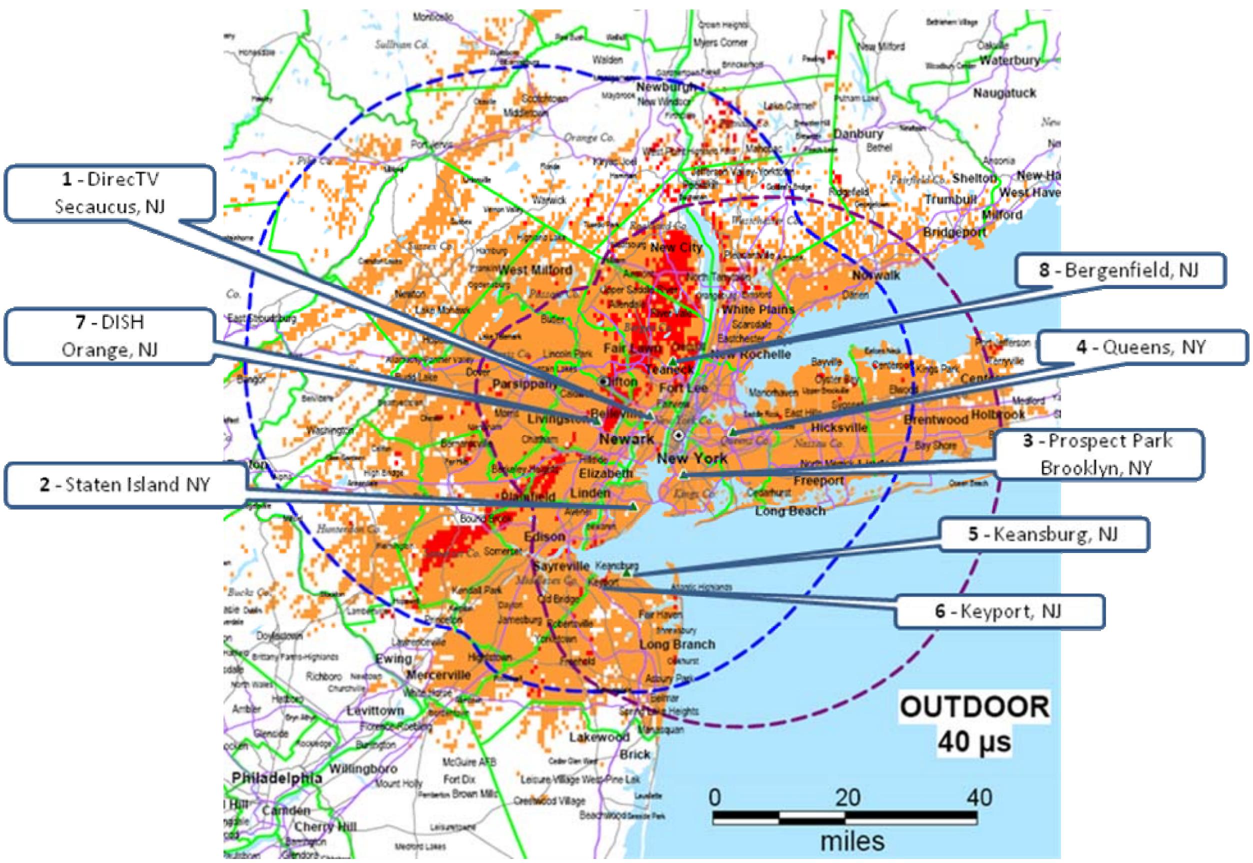


Figure 11: SFN Measurement Test site locations

These eight test site locations were chosen based upon predicted field strength levels and timing relationships between the signals from each transmitter. In addition, some sites were chosen based upon areas of demographic interest and the off-air pickup locations for both DirecTV and Dish Network.

➢ SFN Real World Testing (cont.)

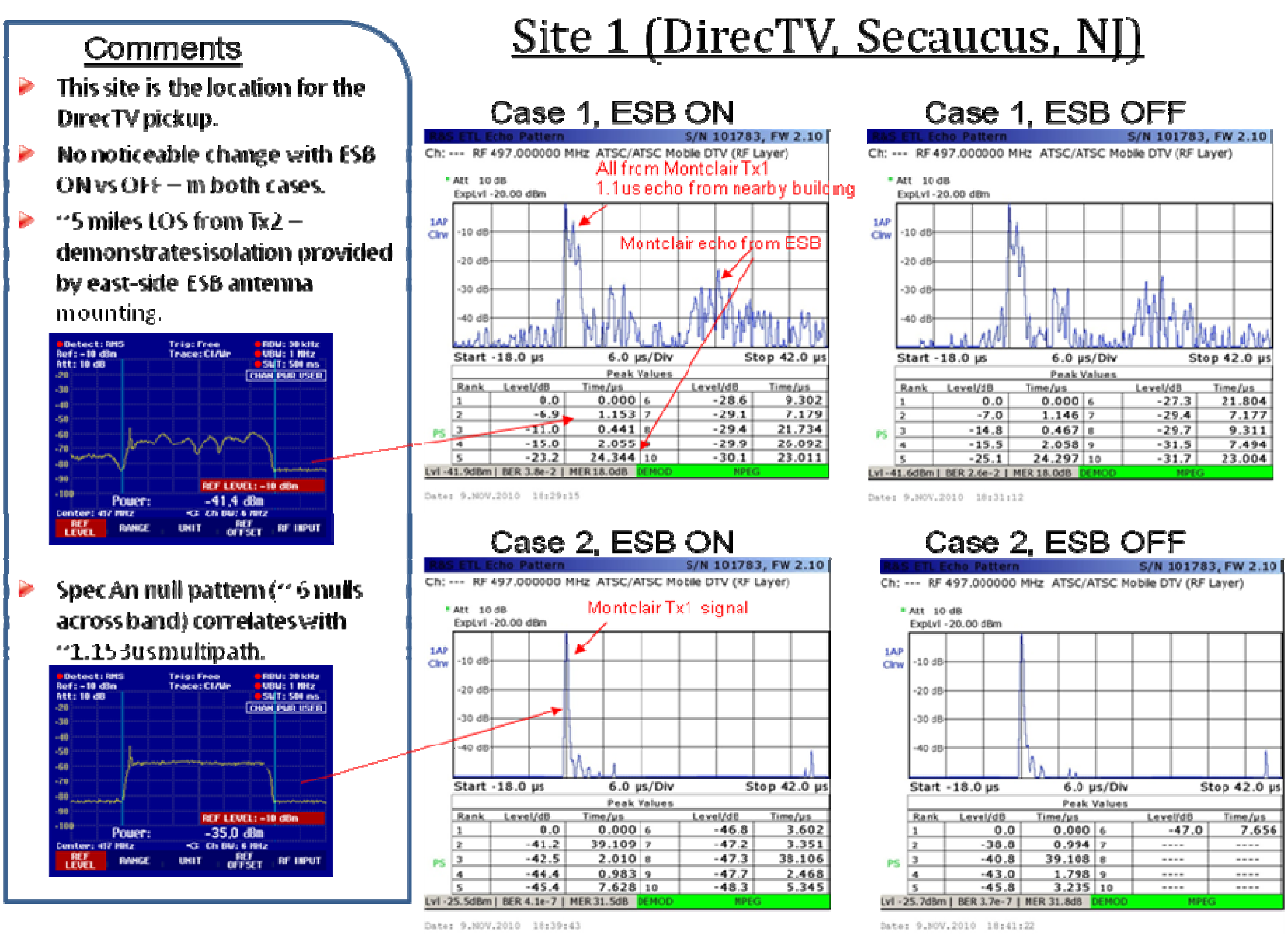
SFN Field Test Measurements

At each location, a log periodic directional antenna (mounted on top of a 30 ft. mast) was orientated in two different directions and a set of measurements were made with the ESB Tx2 both ON and OFF. Case 1 measurements were made with the antenna orientated toward the ESB - with the ESB Tx both ON and OFF. Case 2 measurements were made with the antenna orientated toward the Montclair - with the ESB Tx both ON and OFF.

Measurements at each of the site locations included: 1) ETL Echo profile analysis, 2) spectrum analyzer, and 3) receiver margin. At each site, we dialed down the gain (received RF signal level) feeding the receivers until they started taking hits to find their threshold of visibility. This allowed us to measure the receiver margin both with and without the ESB Tx turned on.

Site 1 – Secaucus, NJ

This site is the location for the DirecTV off-air pickup and is approximately 5 miles West (line of sight) from ESB (Tx2). Field tests revealed that there were no noticeable changes with ESB ON vs. OFF in both cases – notice the same multipath profile exists (for both Case 1 & 2 below) with ESB ON and OFF. This site demonstrates the enhanced isolation provided by the east side ESB antenna mounting and RF shielding produced by the building.



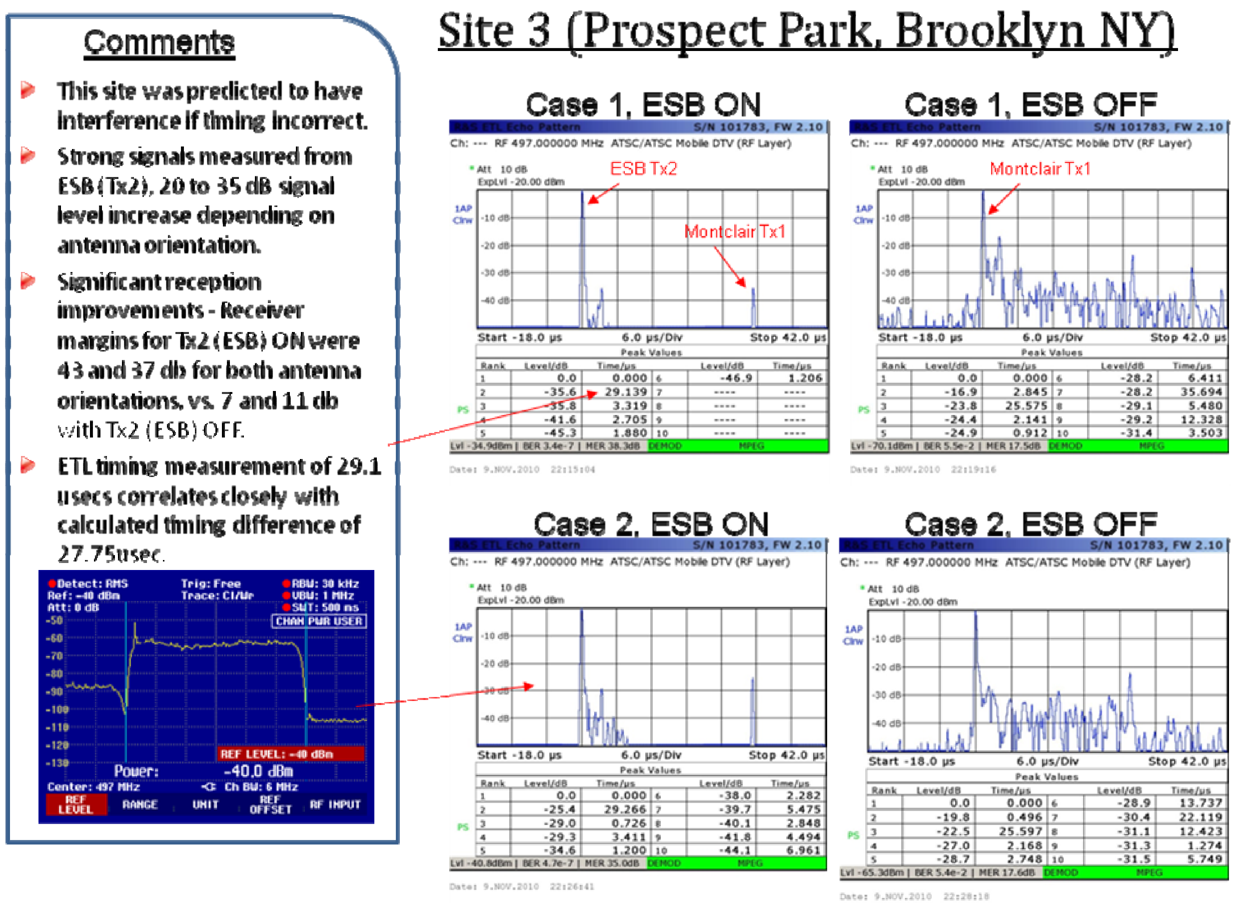
➢ SFN Real World Testing (cont.)

Site 3 – Brooklyn, NY – Prospect Park

This site was predicted to have interference if the SFN timing was incorrect. Field tests revealed strong signals measured from ESB (Tx2) with a 20 to 35dB improvement in received signal level depending on antenna orientation.

Receiver margins showed significant improvement with the ESB Tx turned ON. Margins increased from 7 to 43 db with the antenna orientated towards ESB (Tx2), and from 11 to 37 db with the antenna orientated towards Montclair (Tx1).

Timing measurement of 29.1 µS correlated closely with the calculated timing difference of 27.75 µS.



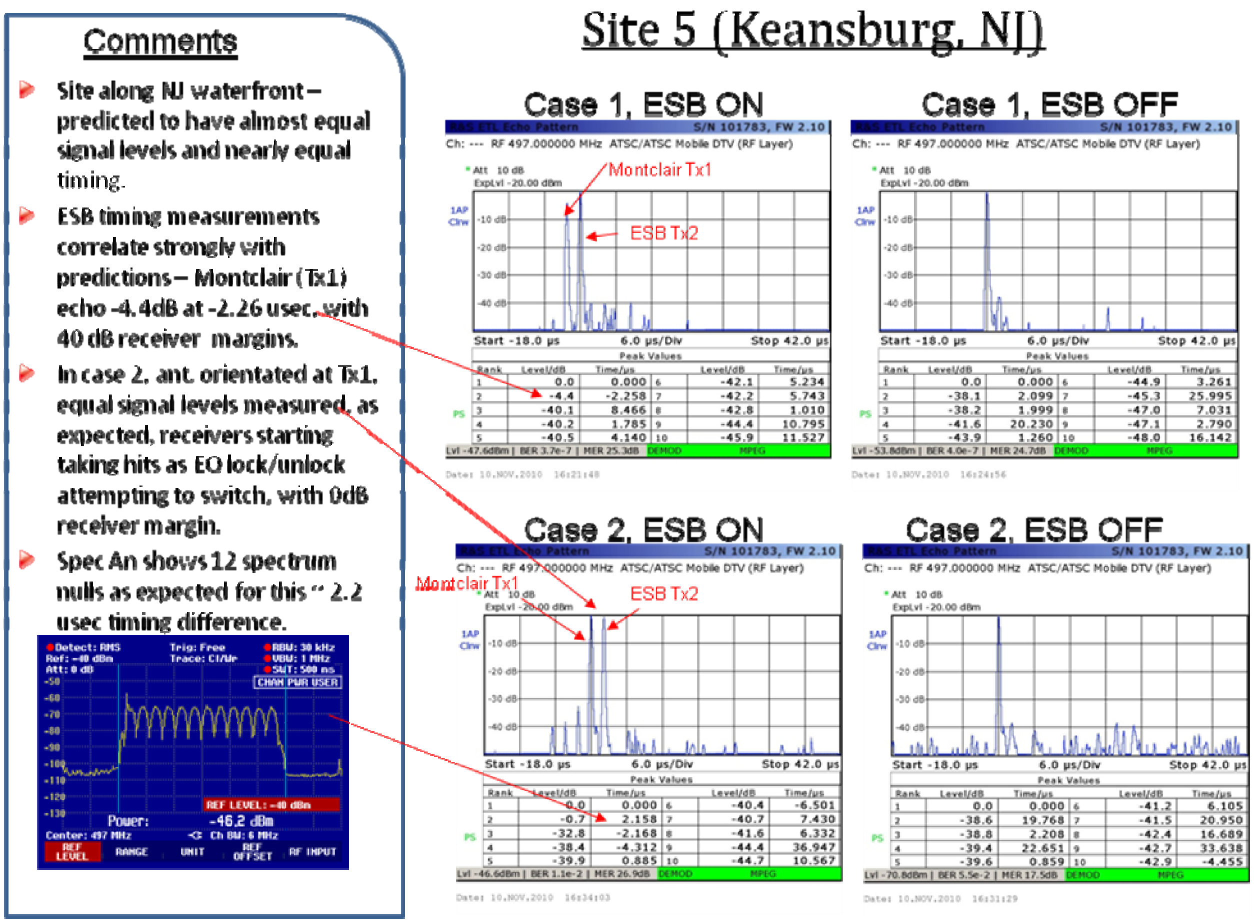
➢ SFN Real World Testing (cont.)

Site 5 – Keansburg, NJ – Beachway Ave

This site was situated along the NJ waterfront and was predicted to have almost equal signal levels and nearly equal timing. The ESB (Tx2) timing measurements correlated strongly with the predictions.

In case 1 (antenna pointed to ESB), the Montclair (Tx1) echo was -4.4dB at -2.26 µS with 40dB receiver margins.

In case 2 (antenna pointed to Montclair), near equal signal levels were measured as expected, with the same timing delay of ~2.2 µS. Receivers in case 2 started taking hits as the equalizer went into a lock/unlock mode attempting to switch in the 0dB receiver margin condition.

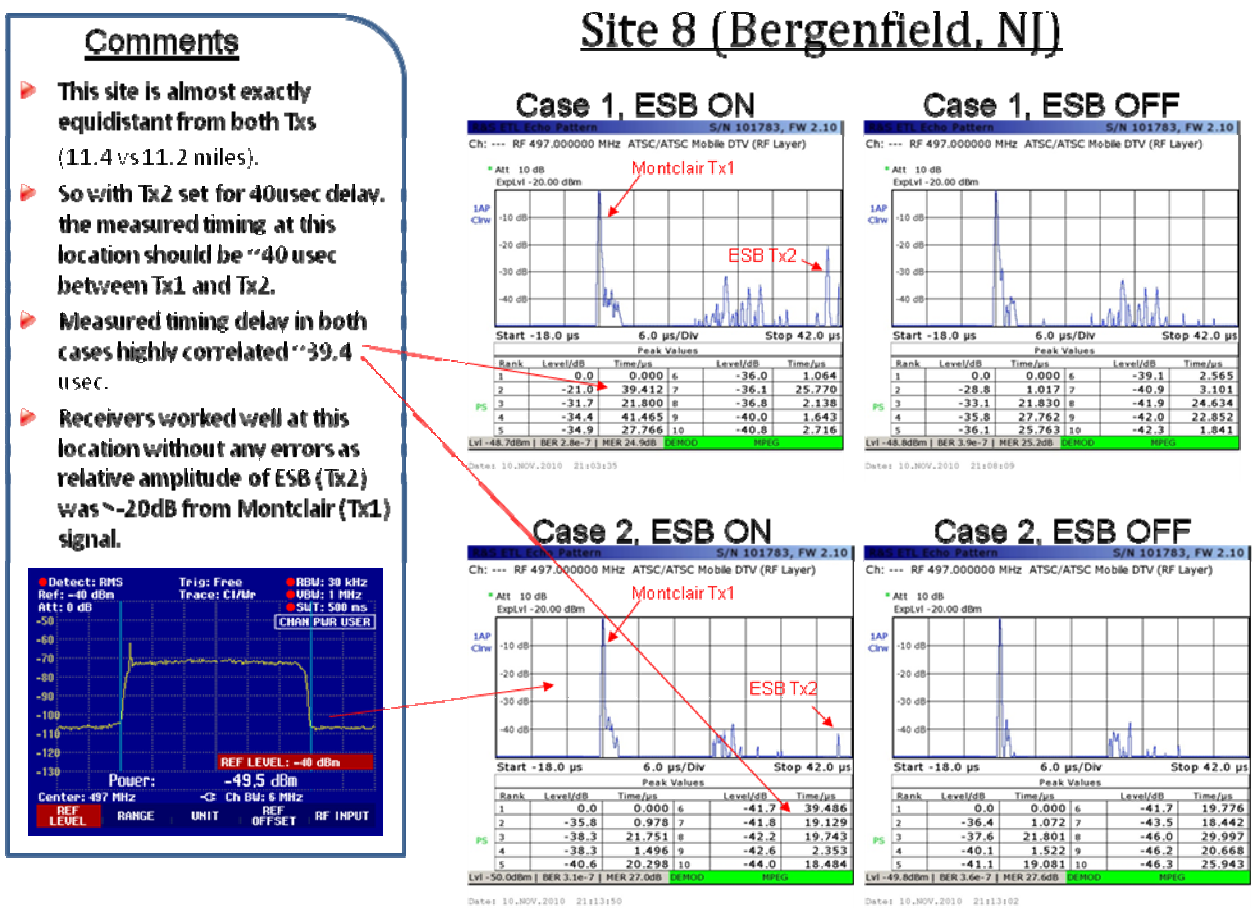


➢ SFN Real World Testing (cont.)

Site 8 – Bergenfield, NJ – Windsor Park

This site is almost exactly equidistant from both SFN transmitter sites (11.4 vs. 11.2 miles). Therefore with ESB (Tx2) set for 40 µS delay, the measured timing at this location was very closely correlated with 39.4 µS between Tx1 and Tx2.

Receivers worked well at this location without any errors as relative amplitude of the ESB (Tx2) was >-20dB from the Montclair (Tx1) signal.



➢ SFN Real World Testing (cont.)

Conclusions

WMBC achieved the goal of increasing signal reception in targeted viewer areas like Brooklyn and Queens (~ 36dB and 19dB improved receiver margins respectively) while maintaining acceptable coverage and receiver performance elsewhere using Comark's SFN technology.

SFN field test measurements demonstrated high correlation with predicted values – verifying system modeling, design and implementation

Acknowledgements

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Special thanks to Dennis Wallace of Meintel, Scrignoli, and Wallace consulting firm for providing the Field Test Measurement data and results presented in this paper.

What Makes Comark Unique?

Comark Communications has an unparalleled history in broadcasting. With over 40 years of innovation and continuous service, we have been delivering leading-edge analog and digital television systems worldwide. Comark has won multiple awards and is the only transmitter vendor to win a technical Emmy for transmitter technology. So whether you are looking for a simple starter kit to get an ATSC Mobile DTV signal on the air or a full-blown package with integrated network management, redundancy, and factory integration and test, Comark has you covered.

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