A Report for

Pearl TV

Regarding

Fixed Reception Field Test for the ATSC3 Single Frequency Network in Phoenix, AZ

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PURPOSE

Pearl TV (**Pearl**) is a business organization of U.S. broadcast companies with a shared interest in exploring forward-looking broadcasting opportunities, including innovation of ways to promote local broadcast television content and develop digital media and wireless platforms for the broadcast industry. Pearl's membership, comprising more than **750** network-affiliated TV stations, consists of *nine* of the largest broadcast companies in America including: Cox Media Group, the E.W. Scripps Company, Graham Media Group, Hearst Television Inc., Meredith Local Media Group, Nexstar Media Group, Gray Television, Sinclair Broadcast Group and TEGNA, Inc. Currently, Pearl TV member stations reach nearly **85%** of the TV viewing audience in America in 49 of the top 50 markets with a total of more than **750** stations in **184** markets.

Part of this mission involves promotion of forward-looking broadcast interests and opportunities by highlighting the capabilities of **NEXTGEN TV** powered by the groundbreaking ATSC 3.0 standard. This involves helping its broadcast owners and partners begin the transition from the original over-the-air (OTA) ATSC1 digital television (DTV) technology adopted by the Advanced Television Standard Committee (ATSC) in **November 1995** to the new **ATSC3** DTV standard adopted in **January 2018**. Another important goal is to promote the state-of-the-art capabilities of the ATSC3 standard in order to build new advanced business and revenue opportunities for **Pearl** participants. Part of this work, to identify new and innovative services that leverage the unique characteristics of ATSC3, is evaluating Single Frequency Network (SFN) technology. A well-designed SFN can provide better signal coverage, program service, and reception margin over a television station's entire Designated Market Area (DMA).

This preliminary experimental work, undertaken by Meintel, Sgrignoli, and Wallace (**MSW**) at the request of **Pearl**, was conducted in Phoenix, AZ in late **February 2021** and early **March 2021** using the UHF television signal of KASW-DT (**KASW**). **KASW** is a full-power TV station that is owned and operated by Scripps Broadcasting. The station is affiliated with the CW Network and licensed to Phoenix, AZ. It provides service throughout the Phoenix Designated Market Area (DMA). **KASW** currently transmits an over-the-air (OTA) ATSC3 signal on physical **CH 27** from its main transmitter on South Mountain (*about* **8** miles south of downtown Phoenix). And, as part of this SFN field trial a single smaller synchronized remote transmitter strategically located on Shaw Butte Mountain was added to transmit in concert with the South Mountain main transmitter. The SFN transmitter on Shaw Butte is located approximately **18** miles north of the South Mountain transmitter antenna farm. The goal of this specific field test was to validate the functionality and performance of the remote synchronized SFN transmitter. In addition, an evaluation of its ability to provide adequate signal levels and signal quality including robust reception (i.e., service with increased margin) in the shadowed areas "behind" (i.e., north of) Shaw Butte Mountain and Squaw Peak Mountain was also desired.

The purpose of this document is to describe the SFN ATSC3 field test goals, setup, and results.

BACKGROUND INFORMATION

The overarching purpose of this field evaluation (i.e., *fixed outdoor* field test) is to describe the methodology of evaluating the OTA signal coverage (field strength), service (reception), and service margin (robustness) of this **two**-transmitter SFN testbed specifically in the shadow of both Shaw Butte Mountain and Squaw Peak Mountain.

The main **KASW** transmitter, which currently uses UHF CH 27 (*virtual* PSIP CH **61**) on 551 MHz, is a full-power **445** kW *horizontally*-polarized signal and a **110** kW *vertically*-polarized signal facility that is located on the South Mountain Antenna Farm. For this SFN test, a single remote synchronized transmitter was also located in Phoenix on Shaw Butte Mountain radiating an **18.5** kW *horizontally*-polarized signal and a **4** kW *vertically*-polarized signal. Each of the two SFN transmitters in the Phoenix area received the same Studio-to-Transmitter Link (STL) signal carrying Internet Protocol (IP) data. This data was properly processed by each exciter, producing a system of two synchronized (frequency and time) SFN transmitters that provided enhanced OTA signal level and quality to the greater Phoenix metropolitan area.

It is noted that **KASW** transitioned from CH 49 (pre-repack) to CH 27 (post-repack) during Phase 1 (**November 30, 2018**) of the spectrum repack. This recent spectrum repack by the Federal Communications Commission (FCC) required the 600 MHz television broadcast spectrum (RF channels 38 – 51) to be repurposed for wireless services, which forced many stations to relocate their RF channels within the newly-defined UHF television band (i.e., CH 2 – CH 36). CH 37 is still reserved for Radio Astronomy.

The primary field test goal was to evaluate the SFN system's radiated signal quality and determine reception performance throughout the shadow regions just north of Shaw Butte Mountain and Squaw Peak Mountain *with* and *without* the SFN technology active.

Pearl retained the consulting firm of **MSW** to perform this Phoenix SFN field test, which included providing a fully equipped and staffed field test vehicle, a data gathering process (including the SFN system validation), data analysis, and a written report. Initial SFN *system* evaluation was performed to verify proper operation of the SFN system. The field test (including transmitter and vehicle calibration) was performed during the period from **February 20, 2021** through **March 9, 2021**, inclusive.

MSW provided the following services:

1) Created a field test plan, including the design of a single PLP test data stream
2) Created an Excel spreadsheet for manual data entry of the test site data
3) Provided a fully-equipped test vehicle with two experienced data gatherers
4) Gathered and archived the measured field data
5) Analyzed the field test data
6) Provided a written report (this document) describing the test objectives, methodology and results

More details are contained in the "Field Test Plan" section of this report.

Electronic files are available upon request that include a PDF file of the written field test report and an Excel data spreadsheet file of the raw data.

OBJECTIVES

This fixed location field measurement program, described in the written field test plan created by **MSW** and agreed upon by **Pearl**, has the following specific objectives:

1) *Evaluate* the SFN transmitted *signal quality* and *synchronization properties*.

2) *Evaluate* SFN performance in shadowed areas just north and east of the Shaw Butte transmitter by measuring ATSC3 absolute outdoor *coverage* (field strength), *service* (reception), and *service margin* (reception overhead) for the single PLP test data stream, with and without the SFN active, at two omni-directional receive antenna heights (**12'** and **30'**) above ground level (AGL).

3) *Evaluate* SFN performance by determining relative *coverage*, *service*, and *service margin* for the single PLP test data stream, with and without the SFN active, and at two omni-directional receive antenna heights (12'AGL an 30' AGL), in order to evaluate the improvement and effectiveness of ATSC3 SFN technology.

4) *Identify* any observed coverage, service, or margin problems in the shadowed SFN service area (e.g., widespread weak signal levels, significant multipath, or destructive self-interference or adjacent channel interference), and evaluate the cause, *if possible*, of any reduced reception performance.

Note that this DTV field test was designed to be statistically-meaningful in a relatively small service region of the entire Phoenix DMA. A total of **40** test sites were visited in a small reception area just north and east of the synchronized repeater site. Any qualitative signal or performance anomalies observed at a test site were also noted and analyzed along with the statistical quantitative signal level, service, and reception margin for all of the test sites as well as specific regions of grid test sites.

FIELD TEST TRANSMITTER DESCRIPTION

The primary **KASW** CH 27 transmitter (TX1), which is part of a two-transmitter SFN design, is *elliptically* polarized (E-POL) with an effective radiated power (ERP) of **445** kWatts for the horizontal-polarization component and ≈**111** kW for the vertical-polarization component (i.e., ≈**25**% V-POL to H-POL ratio). The signal is transmitted from **South Mountain** about **8** miles south of downtown Phoenix using a top-mounted *directional* slot antenna (cardioid pattern pointing north) with **0.95** degrees of electrical beam tilt and a height above average terrain (HAAT) of **1807**'.

The one remote synchronized SFN repeater is located about **18.2** miles north of the main transmitter site. Its location is on top of Shaw Butte Mountain in order to fill-in the shadow area just north of this location so that a larger and more consistent field strength value in this area of Phoenix was available.

The SFN repeater (TX2) is *elliptically* polarized with an ERP of **18.5** kW for the horizontal-polarization component and ≈**4** kW for the vertical-polarization component (i.e., ≈**21.4**% V-POL to H-POL ratio). It is transmitted from a side-mounted *directional* antenna (cardioid pattern pointing north) on Shaw Butte Mountain in Phoenix with **1.5** degrees of electrical beam tilt and an HAAT of about **879**'.

Each of the two SFN transmitters in the Phoenix area received the same Studio-to-Transmitter Link (STL) signal carrying Internet Protocol (IP) data from the **KASW** Scripps studio in Phoenix. The South Mountain main transmitter received the STL-TP signal via fiber network while the Shaw Butte Mountain synchronized repeater received its STL-TP signal via microwave from the South Mountain facility.

A summary of the transmitter parameters for both SFN transmitters is shown in **Table A1-1**. The locations of these SFN transmitters are shown on the map in **Figure A1-1**. Both of the directional SFN transmitter antennas provide precisely-controlled coverage and service in the Phoenix market over relatively-flat terrain with a number of small mountains scattered in the valley that was a consideration for this SFN-verification field test. The *directional* transmit antenna azimuth patterns of these two transmitters are shown in **Figure A1-2**.

During the **KASW** DTV field measurements, both transmitted SFN signals were verified to have acceptable in-band transmitted signal quality as determined by its Modulation Error Ratio (MER). For both transmitters, the MER was *better* than 30 dB and the out-of-band spectral energy was within compliance of the FCC emissions mask (-47 dB_{DTV} on bandedge 500 kHz "shelves").

Likewise, given some of the limitations in commercial measurement test equipment, **MSW** verified to the best of its ability that the *synchronization quality* of the repeater signals, as affected by the GPS reference sources, was believed to be operating correctly so that no observable reception degradation was caused by phase noise or frequency-drift from these various sources.

The frequency synchronization, which is dependent on GPS frequency lock circuitry at both transmitter sites, was measured in the field by finding a calibration test location where both SFN transmitter signals could be received at **50'** AGL with a *directional* antenna. This provided the best chance of obtaining a reasonably strong and relatively undistorted signal (i.e., with minimal multipath), and which were delayed from one another by 1 µsec to 2 µsec. This produced a 0.5 MHz to 1 MHz spectrum magnitude ripple in the received signal of about **10** dB. This spectrum ripple was carefully measured on the spectrum analyzer with an expanded span, and it was found to be stable over at least a **10**-second period. This indicates that the long-term frequency-lock stability between the two SFN transmitters using the GPS-sourced frequency source was good with *virtually* no frequency drift of the echo nulls caused by these signals, thus allowing for minimal dynamic self-interference at test sites where both the main and repeated signals are received. **Figure A1-3** shows plots of the combined effect of the two SFN signals at this special SFN frequency-lock test site.

Phase noise or phase jitter is an important signal parameter that, if severe enough, could degrade error-free signal demodulation and decoding. While there is currently **no** *direct* means to measure an exciter's signal phase noise, an *indirect* means was used in the field. The selection of the single-PLP test signal's ModCod parameters was such that the expected Additive White Gaussian Noise (AWGN) data error hardware threshold was **16.5** dB. By finding two separate test locations where line-of-sight (LOS) using a 50' AGL directional antenna to *each* respective SFN transmitter would provide a mostly undistorted signal, the additive white noise threshold was carefully measured with the ATSC3 commercial reference receiver. It was determined that both transmitter signals were observed to have a **16.7** dB threshold, which indicates that there was not any significant phase noise or phase jitter in either of the two SFN transmitters. The absence of any significant clock jitter is also *assumed* from this measurement test since that too would likely degrade the AWGN data error threshold.

Finally, using the TxID signal capability of ATSC3 (set to -9 dB with respect to the Preamble signal power), the SFN repeater on Shaw Butte Mountain radiated signal ***delay*** was measured at a test site where both transmitters could simultaneously be received with comparable signal levels. It was verified that **11** μsec of *delay* was applied to the Shaw Butte Mountain transmitter's radiation signal (compared to that of the South Mountain signal) as part of the SFN system design.

FIELD TEST VEHICLE DESCRIPTION

For this field test, **MSW** provided the field test vehicle that contained a pneumatic mast capable of reaching at least **30'** AGL, a motorized pan and tilt head, an AC generator power source, and a variety of electronic test equipment installed in 19" racks. **Table A2-1** in **Appendix A** summarizes all of the important parameters in the field test vehicle reception system. **Figure A2-1a** shows the exterior of the test vehicle while **Figure A2-1b** shows the interior with all of the test equipment installed. The vehicle's electronic system block diagram of the reference test equipment used for outdoor measurements is illustrated in **Figure A2-2**.

The test vehicle employed a GPS unit to determine the exact location (latitude and longitude, in fractional degrees) of each test site, allowing the distance and bearing back to the transmit site to be calculated as part of the data entry spreadsheet. The GPS coordinates also provided accurate site location information for a computer mapping program in order to subsequently identify and plot exact test site locations for the written report.

A broadband UHF (CH 14 – CH 51) *omni-directional* 75-Ohm commercial antenna was used for these fixed outdoor (i.e., non-mobile, non-indoor) field test measurements on CH 27. The antenna was a Spectrum Co Ltd omni-directional antenna (model Omni Master) that was previously measured and calibrated by the manufacturer for horizontal-polarization gain performance in an anechoic chamber. The amount of vertical-polarization gain, if any, of this antenna is unknown. This relatively small (13" x 13" x 5.1") and light-weight (3.1 lbs) round antenna has a relatively flat gain (0 dBi ± 1 dB) over a large UHF frequency range (470 – 860 MHz), and exhibits fairly good circularity (within 2 dB peak-to-peak) that reasonably replicates a true circular azimuth pattern. This test antenna is compact in size, and also has good impedance matching that provides a VSWR between 1.2 and 1.8. The 75-Ohm antenna output port was connected directly to the 50-Ohm measurement system via coaxial cable, thereby creating a small amount of mismatch loss which was deemed to be acceptable for this field test.

This omni-directional test antenna was mounted on the top of the test vehicle's mast, thus minimizing the effects of the metal mast's pneumatic base that resides underneath it. Pictures of the omni-directional UHF antenna internal components as well as mast-mounting on the test vehicle are shown in **Figure A2-3a** and **Figure A2-3b.** The antenna was then was then able be raised from its 12' AGL height to 30' AGL, allowing measurements at both heights to be made. Antenna performance plots are included in **Figure A2-3c** and **Figure A2-3d**.

While this omni-directional antenna, which can be used in both *fixed* and *mobile* field testing, did *not* necessarily simulate what a viewer might currently use on a roof or in an attic of a single-family residence for outdoor reception of UHF signals (at least not currently), it did allow a type of worst-case measurement and analysis methodology to be achieved for SFN performance evaluation. Since multiple desired SFN signals can arrive from different directions at any given test site, the omni-directional antenna did *not* discriminate against one SFN signal over another, and therefore fully took advantage of the ATSC3 system's SFN reception capability. However, this antenna did also accept undesired multipath echo signals from all directions as well, which allowed equalizer performance observation and evaluation in *severe* static and dynamic multipath conditions at many test sites.

At the end of the SFN field test, a brief experiment was performed with a *directional* antenna to see if service and margin could be achieved or improved in locations with severe multipath, some of which was dynamic. In doing so, a Digitenna directional antenna was temporarily utilized in this experiment for comparison purposes. This antenna was a small, compact broadband (CH 7 – CH 51) consumer antenna (Model DT-S) that utilized a low-loss balun, provided good impedance matching, and had reasonable directivity. It had about 4 dBd of gain and 10 dB of front-to-back ratio, and realistically simulated what a viewer might use on the roof or in the attic of a single-family residence for outdoor reception of both high-VHF and UHF signals. A picture of this high-VHF/UHF combination antenna is shown in **Figure A2-3e**.

The *dipole factor*, which varies inversely with channel frequency, allows direct mathematical conversion between field strength (in dBμV/m) of the electromagnetic waves at the input to a dipole antenna and signal power (in dBm) at its output. The CH 27 dipole factor value (based on a 50-Ohm test system impedance) that was used in field strength value (in dBμV/m) determination at *each* test site was **+128.2** dBμV/m – dBm. In addition to this dipole factor value, the field strength was calculated using the antenna gain (in dBd), the test vehicle RF net distribution system gain (in dB), the user-selected variable attenuator value (in dB), and the measured signal power level (in dBm within a 6 MHz bandwidth).

The *system gain* in the test vehicle was made up of a double-shielded 50-Ohm down-lead coaxial cable (enclosed in a plastic Nycoil sheath) and a 50-Ohm low-noise RF amplification system. This amplification system included a variable 1-dB step (0 – 110-dB range) input attenuator, a robust low-noise RF amplifier (20 dB minimum gain Low Noise Amplifier), and a 4-way splitter (7.0 dB loss). The attenuator was manually adjusted at each test site to typically provide a signal level at the spectrum analyzer and the ATSC3 receiver of about -50 dBm. The system's amplified output simultaneously fed the incoming DTV signals to a reference ATSC3 receiver for data monitoring and a spectrum analyzer for RF signal level measurements.

Signal power was measured with a Rohde & Schwarz spectrum analyzer (FSH-4) using 6 MHz *bandpower markers*, and therefore represented an *average* (integrated) power across the entire 6 MHz DTV channel. A built-in tracking generator in this spectrum analyzer was used in the test vehicle to measure the overall system gain on CH 27.

An ETRI/Cleverlogic ATSC3 commercial receiver, in conjunction with ETRI/AGOS PC software (IMAS), was employed in this field test to determine DTV reception status (service and margin). This unit contains an ATSC3 tuner with OFDM demodulation and decoding circuitry for DTV signal reception and monitoring capability (including TxID capability). Both data error rates (e.g., forward error correction block error rates on the control computer) and video/audio decoding capability (for display on the control computer) are available from this unit. Additionally, this commercial receiver provided other measurement parameters (e.g., RF signal level, MER for each PLP, RF spectrum plot, channel impulse response, TxID response, and the ATSC3 physical layer signaling data parameters transmitted along with the signal).

Proper operation of this test receiver, including measuring the PLP data stream SNR *error threshold*, was verified in the field prior to the start of the data gathering using the same PLP Mod-Cod RF test signal that was employed for the official OTA testing. Error threshold was determined to be **16.7** dB, which was within 0.2 dB of the expected laboratory-measured threshold.

Additionally, the test vehicle's RF signal sensitivity (i.e., data error threshold) at CH 27 was carefully measured for the test PLPs *prior* to the start of the field test using a relatively unimpaired RF test signal (i.e., with a 50' AGL directional antenna). This calibration test provided an expected minimum RF signal level for data error threshold for the PLP under near-ideal propagation conditions. This white noise threshold for the single PLP determined the minimum limit on SNR thresholds that could exist in the field with potentially distorted OTA signals. The block diagram in **Figure A2-2** illustrates the equation for calculating the received field strength and also identifies the individual parameters that describe the calibrated components.

The variable input attenuator located just before the RF amplifier also provided the means to determine the DTV service site margin by attenuating the received signal in 1-dB increments to just *above* threshold of data errors for a given PLP. This threshold level is dependent on: (1) the test vehicle's measured noise floor as determined by the RF distribution amplifier (corrected for the spectrum analyzer's internal noise floor for better accuracy), and (2) the system SNR error threshold for the given PLP's Mod-Cod parameter selection.

When signal levels are attenuated during testing and the SNR data error threshold (i.e., non-zero FEC error counter values) is reached for the PLP Mod-Cod under test, the situation is described as being either at the threshold of visibility (TOV) or the threshold of audibility (TOA), depending on the desired type of signal that was being monitored. The SNR transition in ATSC3 from error-free (perfect picture and sound) to all-error (pixelized picture and muted sound) conditions is very steep, and referred to as the "digital cliff effect". For ATSC1 (which has only single PLP capability), TOV and TOA occur essentially at the same 15-dB SNR value for the white noise data error threshold. However, ATSC3 allows many significantly different thresholds for PLPs when different Mod-Cod parameters are employed by the user, and therefore TOV and TOA do not necessarily occur at the same SNR value if the system designer chooses one of these signals (e.g., audio) to be more robust. However, it should be remembered that one PLP, with its given capacity and robustness, can carry multiple video and/or audio streams. This type of commercial receiver allows either video/audio programming or the FEC decoder to determine service. In this field test, the FEC counters were utilized to determine service rather than video and audio material. **Figure A2-4** is a picture of this ATSC3 commercial receiver.

Strong interference from other DTV signals was *not* originally anticipated in this particular field test since the main SFN transmitter transmits a **445** kW ERP signal (comparable to other nearby radiated DTV signals) and a very robust RF amplifier was used in the test vehicle's receive system. Nevertheless, an *optional* tunable UHF bandpass filter was available in the field test vehicle in case there had been any unexpected excessive signal interference present from nearby sources that were affecting field measurements. **Figure A2-5** illustrates an example of a tunable-bandwidth bandpass filter that resided in the test vehicle.

The field test vehicle's actual *antenna gain* and downlead coaxial *cable loss* (which includes the step attenuator's fixed insertion loss when 0 dB is selected) did *not* meet the overly optimistic FCC UHF planning factors (see OET Bulletin 69) that were assumed for the ATSC1 system threshold. At present, these same FCC ATSC1 planning factors are in place for ATSC3 deployment. However, the current FCC UHF planning factor values of 10-dB antenna gain at 30' AGL and 4-dB downlead cable loss are typically *not* achievable with consumer hardware in practice. When considering that the 0 dBi (-2.2 dBd) gain omni-directional antenna was used in this field test, service was very likely to be less than that assumed in the FCC planning factors. However, field strength, service, and margin measurements that were made using this test setup were still useful, with the understanding that the measured reception sensitivity in this test could likely have been less than what it would have been had all of the theoretical FCC planning factors been met.

It should be noted that in actual applications that use practical and cost-effective consumer components, the receive system in a viewer's home typically does *not* meet the assumed FCC planning factors anyway since these factors do NOT include any margin whatsoever for lower antenna gain, longer cable lengths (> 50') that cause higher cable loss, and any added splitter loss (for feeding multiple television receivers). Therefore, this type of field test allowed a *pseudo-worst-case* measurement and evaluation to be made.

Table A2-2 includes a list of the primary test equipment that is used in the field test vehicle.

FIELD TEST PLAN

The following sections outline the primary test measurements that were performed for the SFN system evaluation on **CH 27** in special regions of the Phoenix metropolitan area. The field test methodology *generally* followed the procedures used in the past, including field work performed during the Grand Alliance tests in Charlotte, NC during 1994 and 1995, the Model HDTV Station tests in Washington DC during the late 1990s, and during subsequent numerous **MSW** broadcaster field tests around the country since then.

Note that this field test was not considered to produce a significant statistically-large sample size (100) for an entire DMA region. However, it did produce a statistically-meaningful result, with its sample size of **40**, for the small terrain-blocked (i.e., “shadowed”) area just north and east of Shaw Butte Mountain. All the measurements focused on ATSC3 DTV coverage, service, and reception margin results in this important region and how they were affected by the presence of this single-frequency network. In addition to the statistical data analysis, important trends were hypothesized from the test results, which will allow the broadcast industry to evaluate the benefits of SFN technology for use in new broadcast businesses in the future.

MEASUREMENT OVERVIEW

This SFN measurement program consisted of **40** fixed *outdoor*-only test sites selected across portions of the **KASW** DMA.

MSW provided the following items or services:

1) A fully-equipped and calibrated field test vehicle
2) Two experienced field test data gatherers
3) A written *customized* field test plan and data spreadsheet for fixed (*non*-mobile) outdoor reception
4) An Excel spreadsheet for manual data entry of GPS coordinates, signal levels, margin data, etc.
5) *Proposed* fixed reception field test sites (approved by Pearl)
6) *Proposed* single PLP Mod-Cod field test signal design (approved by Pearl)
7) Expert data analysis, data archiving and data organization
8) A written field test report

Pearl provided the following:

1) Technical information regarding the SFN transmitter facilities
2) Operational control of SFN transmission system

There were 4 sets of measurements made on CH 27 at each test site: 1 PLP with the SFN inactive and 1 PLP with the SFN active, with these two measurements made at *each* of the two receive antenna heights (12’ AGL and 30’ AGL). Each measurement set included field strength, service, and margin parameters. The variable input attenuator was adjusted to provide an *approximate* -50 dBm/6 MHz *nominal* signal level (if possible) at the spectrum analyzer input, which minimized the chance of RF amplifier overload. The precise value of the signal level measured on the spectrum analyzer (dBm), along with the dipole factor (dBµV/m-dBm), the user-selected attenuator setting (dB), the antenna gain (dBd), and net test vehicle system gain (dB) that was measured previously during calibration was used to automatically and accurately calculate the received DTV field strength for the PLP test stream. Finally, the maximum amount of attenuation (using the *calibrated* manual step attenuator) that allowed error-free reception was obtained, which determined the site service margin for the test PLP.

An *omni*-directional antenna was selected for use in this ATSC3 SFN field test in order to take full advantage of the SFN design that can provide multiple synchronized signals for a receiver from various directions. A *directional* antenna, which has a larger passive gain due to its directivity, would provide more signal strength and therefore mitigate some of the multipath static and/or dynamic effects. This would likely provide a larger percentage of error-free reception test sites and higher service margin values (6 dB – 8 dB). However, a procedure for antenna aiming at each test site was considered to be an issue since if the directional antenna was pointed at the main transmitter to achieve its maximum received signal level, the advantage with the SFN ON possibly would be mitigated, and if the antenna was pointed at the nearest remote transmitter to maximize that signal, then the main signal level with the SFN OFF possibly would be hindered. Readjusting the antenna orientation for each part of the test procedure (e.g., SFN ON and SFN ON) was deemed to be unacceptable since a future ATSC3 viewer was highly unlikely to perform such a task in actual practice (e.g., using a mechanical or electronic rotor). Also, not all television stations would necessarily use SFN technology, and those that did might not use the same remote SFN transmitter sites, both of which would significantly complicate matters. Therefore, **MSW** and **Pearl** both agreed to use an *omni*-directional antenna to allow signals from different directions equal access to the ATSC3 reference receiver. This decision also provided a type of *worst-case* reception scenario since a low-gain omni-directional antenna would typically provide lower RF signal levels with significant static and dynamic multipath echoes.

MODULATION-CODING (MOD-COD) PARAMETERS

A single PLP test data stream was selected to be transmitted as a 6 MHz ATSC3 RF signal. The selected ModCod parameter values of this test signal represent a specific AWGN noise threshold (≈**16.5** dB according to the ATSC group) that provides somewhat comparable service as the current ATSC1 system. Since the new ATSC3 system encompasses 21st century technology advances, it is more efficient than the ATSC1 system, and therefore allows a **24.04** Mbps data rate to be achieved in the 6 MHz television RF channel rather than just the 19.4 Mbps data rate.

There are a lot of signal parameters from which to choose in the ATSC3 physical (PHY) layer transmission system, including 3 Orthogonal Frequency Division Multiplexing (OFDM) FFT sizes, 6 quadrature amplitude modulation (QAM) constellation schemes, 12 Low Density Parity Code (LDPC) forward error correction (FEC) code rates, and 2 LDPC code lengths. Time Division Multiplexing (TDM) is a mandatory feature of the ATSC3 system, which allows multiple PLP data streams to be transmitted in a single RF signal, with each PLP sharing its own time slice, or layer in the case of Layer Division Multiplexing (LDM). Each PLP has its own specific Mod-Cod (FEC rate and constellation modulation) pair that determines the robustness (i.e., SNR threshold value) and data rate. More information can be obtained from the A/322 ATSC3 Standard (“Physical Layer Protocol”) and the A/327 ATSC3 Recommended Practice (“Guidelines for the Physical Layer Protocol”). For this field test, *no* TDM was used as a single PLP was employed.

Table 1 below shows the *basic* physical layer transmission parameters of the single ATSC3 PLP that was used in this SFN field test while **Table A3-1** in **Appendix 3** is a detailed summary of all the pertinent ATSC3 physical layer parameters.

Table 1 Basic field test signal parameters.

System Parameter	PLP0	Units
Frame Length	≈ 250	ms
FFT Size	16K	subcarriers
Scattered Pilot Pattern	SP8_4	---
Guard Interval	222.2	**µs**
Modulation	256QAM	---
Coding Rate	9/15	---
Interleaving Type	CTI	---
Data Rate	24.04	Mbps
Error Threshold	16.50	dB

MEASUREMENT METHODOLOGY

MSW proposed to use a facsimile of the measurement methodology typically employed in fixed outdoor DTV field tests since 1994. Field strength (signal coverage), service availability (error-free reception), and service margin (overhead) are the parameters that often provide the basic service information required by television stations to determine their market reach to OTA viewers. Each of these parameters was statistically determined with careful field measurements that employed calibrated test equipment installed in the **MSW** test vehicle.

The two synchronized ATSC3 transmitters were radiating their nominal DTV signal power levels while transmitting typical programming material. Test measurements included at each test site were: (1) signal power measurement (in dBm) for field strength calculation (using dipole factor, antenna gain, variable attenuator setting, and test vehicle system gain), (2) 30-second *error-free* service determination (analysis for all test sites, regardless of field strength) using the LDPC forward error correction (FEC) error counter rather than identifying visual and aural errors, (3) 30-second *error-free* system performance index (SPI) determination (analysis for only sites with signal strength above the known PLP data-error- threshold levels), and (4) service margin determination (in dB) of data error threshold (if it existed). Measurements were conducted *with* and *without* the SFN active at both 12' AGL and 30' AGL receive antenna heights.

Generally, a received signal field strength value is greater as the receive antenna is raised higher above the ground. While this is *not* universally true (e.g., certain multipath conditions can cause the opposite effect), it does occur a significant majority of the time. Whenever comparing DTV service (field strength, service availability, and margin) at various receive antenna heights (e.g., 12' AGL or 30' AGL), the analysis shows there is *typically* degradation of signal coverage and service at the lower antenna heights. This underscores the different types of viewer reception conditions that typically occur in the field (e.g., a one-story rooftop-mounted antenna, a two-story attic-mounted antenna, or an indoor antenna on any floor of the building).

The old paradigm of 30' AGL receive antennas has been questioned for a long time (e.g., at the very least since the early 1990s when the ATSC1 system was initially developed, tested, and deployed). Performing field tests using a 30' AGL receive antenna allows direct field data comparison to the well-established FCC field strength prediction curves, most Longley-Rice field strength prediction simulations implemented in the past, and both analog and digital field testing that was performed over many years.

However, some of the more recent field test data gathered at lower receive antenna heights has provided further insight to DTV service for what many in the broadcast industry believe is currently a more typical viewer reception situation (i.e., lower receive antenna heights such as between 15' AGL and 20' AGL). While the higher 30' AGL antenna position typically provides the best opportunity for reception (i.e., statistically), the lower antenna height location during testing provides a basic *worst-case* statistical scenario in addition to a better representation of what is believed to be more likely antenna placement for most homes (for both outdoor and indoor antennas).

In addition to utilizing these two receive antenna height positions (12' AGL and 30' AGL) in this SFN field test, an *omni*-directional antenna was selected to be used instead of the traditional *directional* antenna since this field test is focused on evaluating the reception performance <u>difference</u> between a single transmitter and multiple synchronized transmitters. With multiple transmitters providing the same identical synchronized signal, the omni-directional antenna can simultaneously receive signals from different directions depending on the relative locations of the receiver and the multiple transmitters. While most typical OTA viewers may not be using omni-directional antennas in the near future when ATSC3 deployment begins in earnest, this field test tried to ascertain and evaluate the effects and benefits of SFN technology. The use of a *low-gain* omni-directional receive antenna (compared to a higher-gain directional antenna) provided a lower received signal level from each transmitter (6 dB to 8 dB lower). However, it also allowed signals to be received from multiple SFN transmitters with minimal discrimination due to its azimuth pattern circularity, which improved DTV reception. This was considered to be a "worst-case" scenario compared to the use of a directional antenna (i.e., with directive passive gain) that is specifically pointed at the expected strongest received signal. Of note is the fact that the omni-directional antenna consequently also did not discriminate against multipath echoes that arrived from any direction, thereby providing more severe static and dynamic multipath-distorted signals to the ATSC3 receiver.

Therefore, a *calibrated* commercial omni-directional antenna mounted on top of the test vehicle's pneumatic mast was be used to accurately measure (and sometimes plot) the 6 MHz DTV spectral signals. Since the antenna was omni-directional, there was no need for antenna adjustment (i.e., directional aiming) for maximum signal strength which is the norm when a directional antenna is mounted on the pan-and-tilt head of a pneumatic mast.

Data error threshold was determined at every test site for the PLP test stream, both *with* and *without* the SFN active. SFN activation and deactivation was accomplished remotely by turning the SFN system ON and OFF from the test vehicle. Data error *thresholds* were accomplished by manually attenuating the desired DTV signal in 1-dB steps via the test vehicle's calibrated *input* attenuator, which preceded the low-noise preamplifier, until data errors were observed on the ATSC3 receiver software screen due to the test vehicle system's noise floor (i.e., the signal level was decreased until the ATSC3 PLP system error threshold SNR had been reached). In other words, the receive system noise floor was conveniently determined by the RF amplifier's output noise rather than by adding noise from an external white noise generator. The <u>last</u> attenuator setting (in dB) that provided *error-free* DTV reception for at least 30-seconds conservatively determines the threshold. Both the signal power level (as received) and the vehicle's noise power level (with the desired signal removed) were carefully measured (each in a 6 MHz bandwidth) to determine this SNR threshold value. Additionally, the maximum amount of attenuation (in dB) that could be applied while maintaining *error-free* reception is defined as *service margin*.

When determining service margin in a field test using this methodology, there is a caveat to consider. During evaluation of site margin when there is *external* noise or signal interference present at a test site (in addition to the vehicle's internal white noise), the margin method employed in this type of field testing attenuates *both* the external noise and interference as well as the desired signal instead of just the desired signal only as would occur during a desired signal fade (i.e., the <u>ratio</u> of the desired and undesired signals remains the same as the attenuator is adjusted). Therefore, in an evaluation of the effects of external noise and interference signals, this test method has limitations. In other words, in a typical situation where the transmitted desired signal were to fade on its own at a given test site, without the external interference and noise levels decreasing, less margin might exist than measured in this test. Nevertheless, this method does provide performance information on the desired signal fade margin relative to *internal* receiver white noise (i.e., weak signal reception performance in the presence of existing external propagation and internal white noise conditions).

When the SFN was active, the transmitted TxID test signal beneath the Preamble symbol(s) was also active (9 dB *below* the desired and robust Mode 1 Preamble signal level) and monitored by the commercial ATSC3 test receiver. Since each SFN transmitter had a unique code, the *normalized* TxID amplitude (0 dB) and delay (0 µsec) of the strongest SFN transmitter signal at any test site was identified and recorded in the spreadsheet. Any additional measurable SFN transmitter TxID signals at a given test site that was within **17** dB of the strongest TxID signal was also identified and recorded in the spreadsheet. This was done at all the field test sites, and was helpful in evaluating the Guard Interval for future SFN applications in this area.

All of these measured and calculated values described in this section were recorded in the **MSW** Excel data spreadsheet (*with* and *without* SFN activation) at every test site, thus providing statistical coverage, service, and margin data analysis.

MEASUREMENT LOCATIONS

MSW selected, with agreement from Pearl, **40** proposed measurement test sites. In general, one type of region of interest in SFN field tests is typically areas where the main transmitted signal level is likely to be small but is also expected to noticeably increased (by more than **5** - **10** dB) when the SFN is activated. Another type of region of interest is where two or more SFN transmitter signals are expected to be nearly identical in amplitude and delay since they can possibly arrive out of phase and therefore *reduce* the combined RF signal levels.

As mentioned above, visiting **40** test sites in certain selected regions of the DMA that were expected to be affected by this SFN design is believed to be a statistically-meaningful sample size for a relatively small (but important) area of the Phoenix DMA. This sample size provided information, both general and specific, regarding the effectiveness of the SFN design under a variety of reception conditions.

The goal of this field test was **not** to determine a good statistical analysis of the *entire* Phoenix DMA. Rather, all of the selected test sites were located in the known shaded area behind Shaw Butte Mountain (i.e., to the north and to the east) for signals radiating from South Mountain. Therefore, the test site locations were close together and typically spaced within a couple of miles apart, and they provided information about specific regions (e.g., terrain obstructed, urban and suburban characteristics with local building and foliage clutter, etc.) that are of interest to the broadcast engineer. This allowed direct investigation into the of the SFN effectiveness on service reception by comparing field strength, service, and margin with the SFN active and inactive.

The location of the **40** test sites ranged in distance from *about* ≈**18** miles to ≈2**5** miles from the main **KASW** transmitter site, mostly behind (i.e., to the north and east of) Shaw Butte Mountain. While the field test plan generally provided proposed test sites, the final precise location of each test site was determined by the field crew at the time of arrival as current conditions on the ground dictated acceptable test site locations (e.g., parking availability, construction, traffic, safety issues, overhead obstructions, etc.).

Figure A3-1 illustrates these visited test sites on a map while **Table A3-2** includes a *general* location overview of the test sites and the grid distance ranges from the main transmitter on South Mountain. **Table A3-3** provides information on distances and terrain obstructions from each SFN transmitter to each test site. Note these are terrain obstructions only and do ***not*** include any nearby local clutter (e.g., buildings, water towers, heavy foliage, etc.).

MEASUREMENT PROCEDURES

The following is a general description of the step-by-step logistical test procedures employed in the SFN field test.

Outdoor Test Procedure

1. Plot test locations on electronic road maps *prior* to the start of testing.
2. Plan each test day's work to achieve the maximum results with the least amount of drive time.
3. At the start of *each* test day, confirm proper operation of the transmitter and field test vehicle equipment.

   a. Verify test vehicle power source and GPS receiver functionality.
   b. Verify sufficient test vehicle gas and oil, tire tread, and (if present) generator oil.
   c. Verify all transmitters are operating properly:
      i. ERP
      ii. In-band MER (> 33 dB)
      iii. Stop-band shelves (>-47 dB_{DTV})
      iv. SFN frequency lock stability
   d. Verify and *record* test vehicle system gain, in dB (downlead input to spectrum analyzer input).
   e. Verify and *record* test vehicle noise floor, in dBm/6 MHz.
   f. Verify input attenuator functionality, in dB (10 dB steps and 1 dB steps).
   g. Verify proper operation of test vehicle's DTV receivers, monitors, and remote controls (use an existing DTV signal in the proper frequency band).
   h. Verify availability of most recent version of data-gathering Excel spreadsheet.
   i. Verify proper operation of remote SFN activation control (ON and OFF).
4. At *each* measurement test site, perform the following:
   a. Confirm the feasibility of *safely* parking the test vehicle and raising the antenna mast to the desired height above ground level without encountering obstructions such as tree limbs or overhead wires. When using a directional antenna, the mast's rotor "stop" position needs to be considered when deciding which direction the truck is pointing.
   b. If the location is *not* suitable for testing, move to closest suitable location.
   c. Employing GPS, determine the exact coordinates (in *fractional* degrees) of the test site location, and record them in the spreadsheet for subsequent calculation of the distance (in miles) and bearing (in degrees) <u>to</u> the main transmitter <u>from</u> the test site. *Record* a description of the test site (e.g., nearby cross streets along with name of the town), and include the type of buildings present (residential or commercial, 1-story or 2-story, frame or brick, etc.), any nearby hills/mountains, nearby foliage, heavy street traffic in the area, and any nearby power lines. Note and *record* weather conditions (temperature, sunny, mostly sunny, partly cloudy, mostly cloudy, cloudy, rain, drizzle, fog, sleet, snow, wind, lightning, etc.).
   d. If not already mounted and connected, attach the appropriate test antenna to the pneumatic *mast*, and connect it to mast's coaxial feedline.
   e. Record comments relative to any anomalous observations regarding the test site surroundings.
   f. Raise mast and antenna to the 30' AGL above ground level. If an *omni*-directional antenna is used in this test, no rotation of the test antenna for *maximum* DTV signal strength as measured on the Spectrum Analyzer is required. If a directional antenna is being used, rotate the antenna for maximum signal gain.
   g. Turn OFF <u>all</u> SFN remote repeaters so that only the main transmitter is radiating a DTV signal.
   h. Perform DTV measurements with the calibrated test antenna for <u>all</u> PLP test signals:
      i. Adjust the variable input attenuator to achieve an RF system DTV output level of *about* -50 dBm/6 MHz (if possible) at the spectrum analyzer to minimize amplifier

overload. If a -50 dBm/6 MHz signal level cannot be achieved, adjust the attenuator to 0 dB. Verify and *record* the input attenuator setting (dB).

ii. With the same attenuator value selected above, measure and record the *exact* average power in 6 MHz of the received DTV signal at the spectrum analyzer input (using the spectrum analyzer's bandpower markers). *Record* comments of any RF signal spectral anomalies (tilt, ripple, etc.) and signal-level variations (approximate level swings in dB, speed in seconds) over the test time period that DTV reception is being monitored.

iii. Monitor reception for at least 30 seconds to determine if *error-free* service is available for the PLP under test (FEC error rate, if available; otherwise, video/audio observation).

iv. Automatically calculate (in spreadsheet) DTV RMS field strength (in dBμV/m) using the system parameters (antenna gain, dipole factor, input attenuator, and RF system gain).

v. Automatically calculate (in spreadsheet) the SNR value using system parameters (signal power in 6 MHz, noise power in 6 MHz, and input attenuation).

vi. ONLY WHEN SFN IS ACTIVE: Monitor TxID signal in test receiver. Identify and *record* the SFN transmitter with the <u>largest</u> TxID signal level, normalizing its amplitude (0 dB) and delay (0 μs). Also record the *relative* <u>amplitude</u> and <u>delay</u> of any other SFN transmitter signals that are within **17** dB of the largest TxID signal.

vii. *Optionally* record spectrum analyzer plot (20 MHz span, 10 dB/div), especially if the spectrum is significantly distorted or any significant *interference* signals are present. Describe the type of any large interferer signals, such as DTV, FM radio, LTE, impulse noise, etc., and if an *optional* bandpass filter or notch filter is able to remove the interference and subsequently improve DTV reception and margin.

viii. *Optionally* record the measurement software screen (PC screen capture).

ix. If error-free service is available, increase input attenuator value (in 1-dB steps) to lower the signal level until just *above* TOV (i.e., last attenuator setting where reception is still error-free), and *record* the attenuator setting (i.e., site margin). Note any increase of accumulated data errors from any nearby passing traffic.

i. Turn **ON** <u>all</u> synchronized SFN remote repeaters so that they are radiating a DTV signal, and repeat step 4h.

5. Lower mast and antenna to the 12' AGL above ground level, and repeat step 4h and step 4i.
6. Verify that all data is properly logged in the data spreadsheet and archived in memory storage.
7. Prepare vehicle for travel, carefully proceed to next measurement location, and repeat the above steps.

TEST RESULTS

GENERAL OVERVIEW

The *raw* field test reception data from all of the visited test sites in the shadowed reception region is summarized in **Table A4-1** while a *summary* of the statistically analyzed data test results from all **40** test sites is shown in **Table A4-2**. The field strength levels, service status, and service margin values recorded in these tables were all determined with the calibrated *reference* test equipment in the field test vehicle (which included the UHF *omni*-directional test antenna, a variable step attenuator, amplified RF system distribution equipment, an ATSC3 commercial receiver, and a spectrum analyzer).

This test focused on a **single** PLP data stream using only two receive antenna heights (12' AGL and 30' AGL) to determine if the main (high-power) transmitter signal not only provided *coverage* and *service* on its new post-repack RF channel. However, it also focused on the amount of improved reception performance the SFN system provided in locations primarily situated "behind" Shaw Butte Mountain where the main signal is "shaded". It is important to note that this **40**-site field test is considered statistically-meaningful because all **40** test sites were selected to cover the relatively small area of the entire DMA in order to determine if the SFN was effective in improving reception from the shadowed South Mountain signal.

It is important to understand that this fixed (i.e., *non*-mobile) outdoor field test provides results that only reflect viewer outdoor reception and *not* indoor or mobile reception. Actual viewer experience will ultimately be affected by the type of consumer reception equipment (antennas, feedline cables, amplifiers or splitters, etc.) that is employed in the home. Likewise, not only the type of equipment used, but how it is set up by the viewer (e.g., antenna placement and aiming, inappropriate use of amplified indoor antennas, etc.) will also affect reception capability.

OVERALL COVERAGE, SERVICE, AND MARGIN ANALYSIS

Signal Coverage analysis deals with the determination of the DTV signal field strength (in dBμV/m) at each visited test site, and is represented by a statistical *median* value of all visited test sites. As described earlier, the signal field strength at the antenna input (i.e., antenna active elements) is determined indirectly by an antenna dipole-factor calculation using the measured average signal power level (in 6 MHz) inside the test vehicle along with its calibrated receive system gain.

This analysis parameter is a figure of merit that provides a good idea of the overall signal coverage across a specific region (or DMA) provided by a transmitter with a given set of parameters (ERP, HAAT, antenna azimuth and elevation patterns, antenna signal polarization, etc.). If a station changes transmitter parameters (e.g., due to maximization) or even RF channel (e.g., spectrum repack), this median field strength provides an updated "figure of merit" for possible signal reception.

Service Availability (SA) analysis deals with the determination of error-free DTV reception at each visited test site, and is represented by a statistical *percentage* value of all visited test sites. As described earlier, error-free reception in this field test is defined as observing 30 seconds of no data errors (if using data error counters), or by 30 seconds of no observed video or audio error "hits" (if using picture and sound).

This analysis parameter is a figure of merit for how many viewers might be expected to receive the desired signal, and therefore view the programming if tuned to this desired RF channel. This parameter does ***not*** take into account the exact cause of any reception failures, such as weak signal levels (i.e., signal below the TOV value of a PLP), severe multipath (static or dynamic), or signal interference (e.g., co-channel or adjacent channel DTV signals or 2nd order or 3rd order intermodulation from FM radio signals). However, the perceived cause of any reception failure, as determined by the on-board engineering staff, is included in the data archiving for potential subsequent analysis.

System Performance Index (SPI) analysis deals with the determination of error-free DTV reception at each visited test site that has sufficient signal field strength, and is represented by a statistical *percentage* value involving only sites with field strengths above the PLP white noise data error thresholds. In other words, it is the same as service availability, except that it only performs a statistical percentage analysis on test sites with signal levels above the PLP error thresholds which are required for error-free reception, and does *not* consider sites where the signal strength is too weak (i.e., below the data threshold SNR).

This analysis parameter is a *figure of merit* of the new ATSC3 physical layer performance as it does *not* count any reception failures for test sites with signal levels that are too weak to overcome the user-selected PLP robustness.

Service Margin analysis deals with the determination of the amount of DTV RF signal attenuation (in dB) at each visited test site that can be tolerated before error-free reception is lost, and is represented by a statistical *median* value of all visited test sites. This margin value is limited by the test vehicle's *internal* white noise floor, which determines signal sensitivity (i.e., SNR threshold). The minimum signal level for error-free reception was precisely measured in the field test vehicle during calibration using a local clean ATSC3 reference, and subsequently recorded in the spreadsheet. The minimum signal field strength required for each PLP, which is dependent on the specific test vehicle's antenna gain, overall system gain, and noise floor, may or may not reflect the typical situation in a viewer's home. The FCC's planning factors described in OET Bulletin 69 reflect parameters that describe a so-called "typical" home distribution system for each of the three television bands (low-VHF, high-VHF, and UHF), but the Bulletin's data error threshold value of 15 dB currently only describes the requirement for the legacy ATSC1 system (i.e., 8-VSB).

This analysis parameter is a *figure of merit* for the reliability of reception, with a larger margin value indicating a better chance of long-term error-free reception.

Table A4-2 contains a *summary* data analysis, and allows quick and easy direct comparison of all four analysis parameters for each PLP stream under two conditions: **(1)** with only the main transmitter radiating the ATSC3 signal (SFN OFF), and **(2)** with the SFN repeater transmitter also radiating a synchronized ATSC3 signal (SFN ON). Quick and easy RF performance comparison can be ascertained from this single PLP data stream that was used in this field test, showing any benefits or detriments that the addition of the synchronized repeater creates. Using data from this table, the field test results will be described below.

FIELD STRENGTH

The *median* field strength for these **40** test sites with the SFN **OFF** was observed to be **79.5**dBµV/m (30' AGL) and **70.2** dBµV/m (12' AGL) while with the SFN **ON** it was determined to be **95.3** dBµV/m (30' AGL) and **86.7** dBµV/m (12' AGL). A significant number of test sites had a RF signal level *increase* of at least 1 dB due to SFN technology (**33** for 30' AGL and **36** for 12' AGL) and many had an increase of at least 10 dB or more (**24** for 30' AGL and **26** for 12' AGL). An important side note is that SFN ON condition never caused, at either receive antenna height, a decrease of RF signal level from that of SFN OFF (i.e., no SFN broadband short-echo cancelation occurred). This is *not* surprising since this type of cancellation does not occur often in practice, and is considered a statistical "corner case".

From these results, it is clear that even at *both* receive antenna heights the median RF signal levels with SFN ON were well above the **53.6** dBµV/m minimum field strength value needed for error-free reception in the test vehicle that used a low-gain *omni*-directional antenna. The high level of field strength with SFN active is expected since the selected test sites were specifically located in areas where the benefit of SFN technology could be easily measured and verified. Even

As a matter of fact, all **40** test sites with or without the SFN were deemed to have enough received signal strength at 30' AGL for *potential* error-free reception in the test vehicle for each receive antenna height, thus making the SPI percentage the same as the SA percentage. At 12' AGL, all 40 test sites had enough signal level for potential error-free reception with the SFN active, and all but **3** of the test sites had enough received signal strength with the SFN OFF for *potential* error-free reception (and the **3** sites that were below the error threshold just missed the required level by less than **4** dB). It should be noted that this field test conservatively employed a single-PLP test stream with a measured data-error threshold level of **16.7** dB (rather than the equivalent ATSC1 15-dB threshold), and that the truck did *not* meet the FCC planning factor of **40.0** dBµV/m (for CH 27) primarily due to the low-gain (-2.2 dBd) omni-directional antenna instead of a 10 dBd directional antenna.

However, the addition of the SFN transmitter on Shaw Butte Mountain significantly increased the probability of successful reception since it provided an ≈**16** dB increase in the median RF signal level at both antenna heights across this shadowed region. A significant increase in signal level not only increases the chance of outdoor reception in difficult reception areas but also increases the chance of future indoor, handheld, and mobile reception as well.

Also, from the TxID measurement results, *every* test site had a measurable signal (i.e., within 17 dB of the larger SFN signal) from <u>each</u> SFN transmitter. A vast majority of the test sites were observed to have the closer Shaw Butte Mountain transmitter as the larger received signal (**32** sites for 30' AGL), which further explains the significant increase in RF signal level with the SFN ON. This is further corroborated by the fact that of the **40** test sites that were visited, **28** of these sites had at least one or more terrain obstructions (using the 0.6 deg Fresnel zone as a reference) for the main South Mountain transmitter signal while only **7** had one or more terrain obstructions.

These results indicate that the SFN design goal to greatly reduce the effects of signal shadowing due to local mountains was successful in the Phoenix northern metropolitan market (i.e., **18 – 20** miles from South Mountain, and **12 – 15** miles north of downtown Phoenix).

SERVICE AND SERVICE PERFORMANCE INDEX

The service availability with the SFN OFF was observed to be **57.5**% (30' AGL) and **60.0**% (12' AGL) while with SFN ON it was determined to be **80.0**% (30' AGL) and **75.0**% (12' AGL). It can be seen that that was an overall *increase* in the service percentages for both receive antenna heights (**22.5**% for 30' AGL and **15.0**% for 12' AGL), which indicates improved service in this shadowed region for the given SFN design. However, it must be noted for reference that without the SFN, more than 50% of the sites had reception, often with good margin.

However, while the primary focus of this field test was to validate the SFN design and its effectiveness in improving reception in the shadow areas to the north and northeast of the Phoenix downtown area, there was also a desire to evaluate the performance of the ATSC3 system as it pertains to use in an SFN. Two issues become important. The first important issue is that **8** of these sites failed to decode error-free when the SFN was active, especially given that all **40** test sites had sufficient field strength at 30' AGL to provide error-free decoding. The second important issue is that **5** sites could not be decoded when the SFN was active despite the fact that error-free reception occurred with the SFN OFF. A summary of this situation will be described in the "Failure Analysis" section of this report, but complete research into these aspects goes beyond the scope of the current project work.

For 30' AGL measurements, where all of the test sites had sufficient field strength for both SFN ON and SFN OFF, system performance index was the same as service availability. For 12' AGL measurements, with only 3 sites slightly below threshold for SFN OFF, the SPI value was slightly higher (64.9% versus 60.0%).

SERVICE MARGIN

The *median* margin with the SFN OFF was observed to be **33** dB (30' AGL) and **20** dB (12' AGL) while with SFN ON it improved to **39.5** dB (30' AGL) and **30.5** dB (12' AGL). A net improvement of about **6.5** dB (30' AGL) and **10.5** dB (12' AGL) was observed for this particular SFN design and field test site selection. These are very good margin numbers due to the use of SFN, especially when considering a low-gain *omni*-directional antenna was used for reception.

The statistical margin numbers shown above are calculated for each test site with SNR ON and SNR OFF. However, it should be noted that the margin increase at each test site due to the use of SFN is only compared when ***both*** scenarios (SFN ON and SFN OFF) exhibit error-free reception. Nevertheless, the above median margin increases are significant improvements in this SFN deployment.

SFN ECHO ANALYSIS

Analysis was performed on the SFN echoes that were created by the presence of the SFN's two synchronized transmitter signals, and is shown in **Table A4-4** for the 30' AGL case where both transmitters were active (i.e., SFN ON). The amplitude and delay of the artificially-generated SFN echoes were measured by the professional receiver decoding the unique TxID codes (1001 and 1002) that each transmitter transmitted 9 dB beneath their respective Preamble signal. Since the signal radiation time between the two SFN signals was adjusted to be **11** µsec (Shaw Butte Mountain later than South Mountain), and the propagation time from South Mountain to Shaw Butte Mountain was longer than this value, it was not surprising to see that the Shaw Butte signal often arrived *before* the South Mountain signal at many of the locations. The determination of whether the echo appeared as a pre-echo or a post-echo to the receiver was dependent on the relative amplitude of each signal and the difference in terrain between the two signal paths since pre-echoes and post-echoes are typically referenced to the largest signal arriving at the receive antenna.

The measured echo delays varied from **-126.9** µsec to **+136.3** µsec, and were well within the SFN system's **222.2** µsec guard interval / cyclic prefix, and validated the SFN system design. The median echo delay was determined to be **61.2** µsec. However, it should be noted that it is believed that a few of the TxID delay measurements may have been anomalous, with values that appear to be much larger than the differential propagation distances plus selected repeater delay would warrant. If so, the stated echo delay range included above may be greater than what actually occurred in the field.

Since the test sites in the shadowed region were situated much closer to the Shaw Butte Mountain transmitter, this signal arrived at the test sites earlier than the South Mountain signal. However, despite being much closer than the main South Mountain transmitter, the Shaw Butte Mountain transmitter signal level was the larger signal at only **32** of the test sites rather than all **40** test sites. It also must be remembered that the ERP of the South mountain transmitter was 13.8 dB above the Shaw Mountain transmitter.

REGIONAL COVERAGE, SERVICE, & MARGIN ANALYSIS

The breakdown of various *types* of field test sites (e.g., radials, arcs, and grids) is typically employed to directly isolate certain *regions* of the DMA in the analysis process, especially in the overlap coverage areas between the main transmitter and the remote SFN synchronized transmitters. However, the goal of this focused field test was to identify and quantify coverage (signal level), service (reception), or service margin (overhead) obtained from SFN operation in two *particular* and relatively *small* regions that were shadowed from the South Mountain main transmitter. One was located to the north and behind Shaw Butte Mountain (grid G01) and the other was located to the east and behind Squaw Peak (grid G02).

This analysis is very similar to that described in the previous section, except that instead of evaluating the entire **40** test-site group as a single entity, only specific regions (i.e., 2 grids: G01 and G02) within the DMA are individually analyzed statistically as a group that provide insight into any difference in the locations of these two groups. This provides insight into the operation *without* and *with* SFN techniques, as determined by the careful selection of these shadowed test grid locations (**24** sites per the northern grid G01 and **16** sites per the eastern grid G02).

Table A4-5 shows the statistical results for the test sites based on specific regions of the DMA as broken down into the two grids: G01 (**24** sites) and G02 (**16** sites). The results from this table will be briefly described below.

The median 30' AGL field strength for each of these grid sites was *comparable* with the SFN ON (**96.6** dBµV/m for G01 and **94.2** dBµV/m) and with the SFN OFF (**79.1** dBµV/m for G01 and **80.2** dBµV/m). The significant *increase* in field strength, which both grids experienced due to the SFN, was slightly greater (**3.5** dB) for the northern grid G01 (**17.5** dB) than the eastern grid G02 (**14.0** dB), but both Grids experienced excellent increases in field strength with the current SFN design. Similar results were obtained for the 12' AGL scenarios, except with lower RF levels due to the signal strength loss that statistically occurs with a lower receive antenna height. The overall results of the SFN measurements again indicate a good increase in signal coverage with this SFN design.

The service percentages for the two grids at 30' AGL were noticeably different despite the comparable field strengths, although the relatively small number of test sites (**24** sites in G01 and **16** sites in G02) in each grid exacerbated the difference. Grid G01 fared better than Grid G02 with SFN ON (**87.5**% for G01 and **50.0**% for G02) as well as with SFN OFF (**66.7**% for G01 and **37.5**% for G02). However, the service increase was comparable for Grid G01 and G02 (**10.8**% and ≈**12.5**%, respectively). Again, 12' AGL results were not that different. These results show that Grid G02 had a bit more challenging propagation effects than Grid G01 since the signal levels were not that different. One possibility is that the effects of an omni-directional antenna could possibly have an effect on this difference due to increased dynamic multipath on this high-data rate 16.7 dB data threshold PLP test data stream. Again, care must also be exercised when dealing with percentages that describe relatively few test sites.

Finally, the gain in service margin in these two grids at 30' AGL is a mixed result. For Grid G01, significant value of **13.0** dB was observed. However, for Grid G02, a **-1.0** dB margin gain was observed (i.e., a decrease of 1 dB). This result stems from the fact that **4** of the **5** test sites that experienced reception with SFN OFF but did *not* have any reception with SFN ON were in Grid G02. This greatly affected the margin values in this grid considering that there were not many test sites in Grid G02 (only **16**). Based on the increase in field strength increase in Grid G02, the margin increase *would* have likely been **13** dB as well had it not been for these 4 anomalous failed test sites for SFN ON.

Potential causes for the reception failures with SFN ON will be covered later in this document.

MARGIN VERSUS FIELD STRENGTH ANALYSIS

One other statistical analysis tool that is often utilized to describe DTV system performance in a given market is the margin-versus-field-strength plot. Strong received signal levels exhibit large SNR values in receivers and thus potentially have larger service margins above the SNR threshold (at TOV). A useful plot that is often used for reception analysis is created by first *sorting* the received field test data for a given RF data signal according to field strength (in dBµV/m), from strong signals down to weak signals. Then the service margin (in dB) is plotted on the vertical y-axis while the corresponding field strength (in dBµV/m) is plotted on the horizontal x-axis.

For sites with *strong* mostly unimpaired signals that can be received error free, the margin is *large*. As the received signal level decreases at other sites, the margin theoretically decreases dB for dB, producing a straight line on a log-log plot until it reaches the horizontal axis. If a straight line is drawn through a "best fit" of this data curve, and then it is extrapolated to the horizontal axis where the margin is zero (i.e., at TOV where there is no error-free reception), the straight line estimate should cross near the test vehicle's minimum field strength value for specific PLP under test in the RF channel. A straight line in this type of plot is a good indicator that field strength is *reliable* in predicting both service and service margin.

In practice, variations from a straight line (typically in the downward direction indicating reduced margin) result from received signal levels varying (i.e., fading or "breathing" due to multipath or even nearby traffic) during the measurement service margin time interval (e.g., 30 seconds), causing a *worst-case* margin to be obtained. In other words, these additional site conditions effectively degrade the receiver's unimpaired signal sensitivity (i.e., TOV) measurement. Another possibility that can cause margin reduction is equalization of large echoes (i.e., equalizer noise enhancement) or the presence of interference (DTV-into-DTV, impulse noise, or FM radio interference).

A margin-versus-field-strength plot was created for *each* of the two receive antenna heights and for each of the two SFN conditions (ON and OFF), for a total of four plots. **Figure A4-1a-d** contains these 4 plots. Note that all of the plots generally travel in the negative direction, *essentially* dB for dB as expected, except for the previously described variations.

The 30' AGL measurements have the "straightest" decreasing curves (i.e., minimal deviations) for both SFN OFF and SFN ON due to their larger field strength values and less likely severe multipath conditions, which is the main reason for the high percentage of error-free service for all test sites. There are slight deviations in these two curves, for the reasons described above, and the curves tend to slightly "widen" (i.e., more margin deviation) as the signal level decreases (i.e., SNR decreases) and approaches data threshold. The failed sites at 30' AGL (**8** sites for the SFN ON condition and **17** sites for the SFN OFF condition) can be seen as dots on the x-axis.

On the other hand, the 12' AGL measurements have more test points located on the horizontal axis since there were more failed sites (i.e., no error-free reception) at this lower height. More significant multipath, particularly dynamic multipath, was present due to the lower receive antenna height, and moving traffic. Note that these two curves (SFN ON and SFN OFF) are *not* as "straight" as those of the 30' AGL measurements but rather they are wider due to the greater variation in service margin due to the varying propagation conditions (e.g., lower signal levels and/or the presence of *dynamic* multipath). Nevertheless, the lines are still relatively straight and indicate that service margin is largely predictable with signal strength.

FAILURE ANALYSIS

Failure analysis is an important part of field test evaluation in that it provides good information and insight as to the various causes that prevent error-free DTV reception. Even in a statistically-meaningful test (e.g., typical 100 test sites across the entire DMA) where performance statistics of site data are important and useful, *specific* anecdotal analysis of failed sites is also enlightening in order to determine if there are any propagation issues either naturally-occurring or caused by the SFN system, which if understood could lead to improved SFN designs.

The critical pieces of equipment in the field test vehicle (e.g., RF amplifier and reference receiver) were carefully verified during the field vehicle calibration. A clean single-PLP ATSC3 signal was used to calibrate the truck system gain and accurately determine the white noise error threshold. This noise threshold test signal also verified proper operation of the entire test vehicle system. The signal power level of -50 dBm was used for calibration since that was approximately the maximum *desired* signal level (±5 dB) used by the data gatherers to manually adjust the variable attenuator so that the nominal incoming RF signal was limited to this value.

The reference amplifier in the truck was very robust, and therefore not likely to overload due to undesired adjacent channel signals and cause false power readings, especially with the use of manual gain control at the input to the RF amplifier. However, a CH 27 tunable bandpass filter was on-board for *optional* insertion in front of the amplifier for diagnostic reasons at any test site (especially the 5 revisited test sites) by the field test crew if they thought there could *possibly* be any adjacent channel overload. In this SFN field test, no performance changes were observed in the test vehicle when the bandpass filter was temporarily employed.

Any anomalous reception behavior at a test site was identified and described (with words, spectral plots, TxID plots, etc.) to the best of the ability of the data gatherers. If any anomalies were observed at a test site, spectrum plots and screenshots were taken and archived.

Failure analysis is typically performed by identifying the failure mode(s) that were observed by the data gatherers at the test sites, such as: weak signal (below TOV), static or dynamic multipath, co-channel or adjacent channel television signal interference, FM radio signal interference, impulse noise, consumer electronic equipment electromagnetic interference (EMI), or any combination of these. This type of analysis provides good insight into both coverage and service trends in a broadcaster's market.

At UHF frequencies, impulse noise and FM radio interference is unlikely. Since this was an *outdoor* UHF field test rather than an indoor test, consumer electronic device EMI is highly unlikely. That leaves weak signal, multipath propagation, and adjacent channel interference as leading contenders for possible causes of failed reception in this field test. These will be addressed in the following sections.

While the field test plan called for measurements to be made at both 30' AGL and 12' AGL, this failure analysis will ***focus*** on the 30' AGL measurements at test sites where there was plenty of signal strength (i.e., levels above data error threshold), and where reception was successful with *only* the main South Mountain transmitter but failed when the SFN was active with the Shaw Butte Mountain repeater signal present. That is, the SFN system, while improving reception at a significant majority of non-SFN failed sites, actually degraded reception at a small number of test sites that had sufficient field strength. Therefore, at the end of the formal field test data gathering process, a handful (5) of test sites that exhibited this SFN-degradation condition were selected to be **revisited** in order to gather more information that might shed light on the cause of reception *degradation* by the SFN system.

In addition to repeating the exact same measurements with the same *omni*-directional antenna at 30' AGL, additional testing was performed by inserting a tunable bandpass filter centered at CH 27 (minimize adjacent channel interference energy) as well as the *directional* consumer antenna (minimize naturally-occurring multipath) described earlier in this document. The filter, while having a bandwidth at least 6 channels wide and therefore not protecting against interference from N±3 adjacent channels, it did reduce the overall potential interference energy from the entire UHF band. The directional antenna, with a 3-dB beam width of about ±45 degrees and a front-to-back ratio greater than 10 dB, minimized multipath arriving from the side and back of the antenna.

Table A4-6 contains a data summary of the revisited sites. These **5** revisited sites were: **G01-10**, **G02-08**, **G02-09**, **G02-12**, and **G02-13**. Only one of these revisited test sites (**G02-13**) had terrain obstructions to the South Mountain main transmitter site, while a different singular test site (**G01-10**) had a terrain obstruction to the Shaw Butte Mountain Tx repeater site.

SIGNAL LEVEL CONDITIONS

Weak signal levels can be caused by lack of sufficient transmitter ERP, severe terrain between the transmitter and receiver, or just ground "clutter" near the receiver site that blocks the desired signal. Another possible cause of weak signal in SFN systems can be due to synchronized repeater RF signals arriving at a site at essentially the same time as the main transmitter RF signal and then adding together in a destructive fashion (i.e., 180 degrees out of phase) to cancel the signal. The probability of this happening is *not* very common, and in statistics these rare instances are referred to a "corner" cases. In this SFN field test, no sites were observed to have SFN ON signal strength *weaker* than the main transmitter alone (i.e., no RF signal cancelation occurred).

For all 5 of these revisited test sites, the signal level was ample to provide an SNR value above the required 16.7 dB measured error threshold performed at the start of the field test. This means that the received field strengths resulted in levels at all 5 revisited test sites that should have large been enough to overcome the white noise threshold for error-free reception, with either the SFN active or inactive. The revisited site locations were *essentially* at the same locations as the original measurements, with conditions on the ground at the time of the revisits dictating how close the two measurement sites were located.

However, as a point of reference, the difference in field strengths at the five *original* test sites with SFN ON and SFN OFF was minimal (less than **3** dB) and at **4** of these five sites the difference was ≈ 0 dB. This means that the main transmitter signal from South Mountain was much larger than the Shaw Butte repeater signal at **4** of these **5** sites and almost equal at the last site, despite the difference in distance to the respective transmitter sites.

With the *omni*-directional antenna, the Shaw Butte repeater signal was observed, according to TxID measurements, to be anywhere from **6** dB to **14** dB below the South Mountain signal while the directional antenna was able to lower the variance of Shaw Butte repeater signal strength to between **13** dB and **17** dB. Nevertheless, when active, the SFN signals failed to achieve reception at 30' AGL at all 5 of these sites when using the *omni*-directional antenna. However, the *directional* antenna was able to provide error-free reception at three of these sites. The two sites that failed with the directional antenna (G02-12 and G02-13) was observed to still exhibit dynamic multipath like the omni-directional antenna, which was severe enough to cause errors in the high-data rate, less robust PLP data stream.

MULTIPATH CONDITIONS

In this field test, multipath was a contributor to site failures for the single PLP data stream. Typically, multipath is primarily mitigated by the use of a Guard Interval (GI) in Orthogonal Frequency Division Multiplexing (OFDM). No significantly long echoes were observed in the field test region that came close to that of the selected Guard Interval value (1536 samples equal to 222.2 μsecs), which means that there no InterSymbol Interference (ISI) occurred. However, multipath causes InterCarrier Interference (ICI), that is, the overlap of the Fast Frequency Transform (FFT) individual subcarriers with one another which requires an amplitude and phase frequency-domain equalizer utilizing the various inserted reference pilots to remove this linear distortion in order for proper constellation decoding. RF carrier and subcarrier clock synchronization as well as precision FFT timing are also critical for error-free reception.

Since a low-gain omni-directional antenna was used to receive an SFN signal from any direction in order to make better use of the multiple synchronized signals, significantly more naturally-occurring multipath (static and dynamic) was present at the input to the ATSC3 reference receiver than if a directional antenna was used. However, since this field test utilized an omni-directional antenna on the test vehicle parked on the side of a street, there was *dynamic* multipath present from nearby traffic than would be experienced with a directional antenna mounted 30' AGL on a building with greater distance from street traffic.

At many of the failed test sites, the data constellation would be "breathing" significantly in a semi-random (even pulsating) fashion in both amplitude (burst movements in radial direction) and phase (burst movements in rotational direction). It is believed that this type of impairment, which would be easily handled by more robust PLP data streams (which can handle mobile or handheld reception), was *not* able to be handled by this lesser robust high-data stream which is meant to be used for mostly static (i.e., low-Doppler pseudo-static) signal reception. However, it is believed that there may be more to this situation than just dynamic multipath alone.

After repeating the usual the usual site measurements with the omni-directional antenna, it was temporarily replaced with the directional antenna on top of the test vehicle at about the same 30' AGL height. It was observed that the reference receiver's measured channel impulse response (CIR) for the directional antenna indicated less severe multipath than that of the omni-directional antenna due to its directivity, thereby allowing improved channel equalization against ICI. Three of the previously five SFN-degraded reception test sites exhibited error-free reception with the directional antenna. However, two of the sites still had *dynamic* multipath effects that prevented error-free reception. During this experiment, the data constellation "breathing" greatly decreased for the 3 improved sites, with the entire constellation looking crisp and clean. However, this did *not* occur at the last two revisited test sites that did not have error-free reception.

The evaluation of these **5** revisited test sites provided partial answers to the cause of the SFN-induced reception degradation, but further detailed investigation of this phenomenon was beyond the scope of this current field test. It should be noted that, based on past field experience, better statistical reception results would very likely have been obtained, even with an *omni*-directional antenna, if a more *robust* PLP data stream (e.g., SNR < 10 dB) had been used. Likewise, a directional antenna located at 30' AGL (or even only 20' AGL) on a roof or in the attic of a building and away from nearby traffic would also likely have increased the statistical reception results.

SUMMARY

Pearl commissioned **MSW** to perform an ATSC3 SFN field test in Phoenix, AZ, specifically for the purpose of verifying proper operation of their two-transmitter SFN utilizing **KASW** CH 27. A **445** kW H-Pol ERP (**111** kW V-Pol ERP) transmitter on South Mountain radiated the main signal from its existing tower and an **18.5** kW H-Pol ERP (**4** kW V-Pol ERP) transmitter radiated a synchronized signal from Shaw Butte Mountain utilizing an existing American Tower facility. **MSW** created a **Pearl**-accepted *test plan*, performed onsite data-gathering and data archiving, analyzed the measured data, and provided this detailed written field test report. The primary objective was to determine the amount of *improvement* that could be gained from the use of an SFN system in terms of field strength (level and consistency), service (error-free reception), and service margin (stable reception) in the Butte Mountain shadow region, and thus verify proper SFN system operation and performance.

The fully-equipped **MSW** field test vehicle (e.g., *omni*-directional UHF antenna, RF distribution system, ATSC3 commercial receiver, and spectrum analyzer) was utilized to make measurements at **40** test sites in two shadowed areas: one grid (Grid 01) was primarily north of the Shaw Butte repeater site while the other grid (Grid 02) was primarily east of the Shaw Butte repeater site. Test site distances varied between **18** – **25** miles from the main transmitter and about **1** – **10** miles from the Shaw Butte Mountain repeater site.

An *omni*-directional receive antenna was selected for mounting on the field vehicle's mast during this ATSC3 SFN field test. This was done in order to take full advantage of the SFN design so that this antenna could provide the ATSC3 receiver with essentially equal access to all received synchronized signals from various directions. A *directional* antenna would have provided more (≈ 6 – 8 dB) signal strength and mitigated some of the naturally-occurring multipath effects, but it could also potentially have reduced some of the SFN advantage. Reorienting a directional antenna for each *part* of the test procedure (e.g., SFN OFF and SFN ON) was deemed unacceptable for this field test since viewers are unlikely to reorient their antenna, especially if not all television stations are using the same remote SFN transmitter locations (if they even deployed an SFN system at all).

Additionally, using a low-gain omni-directional antenna for measurements made at two different receive antenna heights (30' AGL and 12' AGL) also provided a type of *worst-case* reception scenario (12' AGL for an attic antenna on a single-story residential structure) and a *best-case* reception scenario (30' AGL for a rooftop antenna on a two-story residential structure). The omni-directional antenna at any height typically allows more static and dynamic multipath echoes to reach the receiver, thus providing a challenging reception environment.

The ATSC3 test signal employed in the Phoenix SFN field test consisted of a single high-data-rate PLP data stream that may be representative in future broadcast television applications (particularly the early deployment days). **Table 2** below contains the most pertinent test signal parameters.

Table 2 Basic field test parameters.

System Parameter	PLP0	Units
Frame Length	≈ 250	ms
FFT Size	16K	subcarriers
Scattered Pilot Pattern	SP8_4	---
Guard Interval	222.2	µs
Modulation	16QAM	---
LDPC Inner Code Length & Rate	64K, 9/15	**---**
Outer Code	BCH	---
Interleaving Type / Length	CTI / 256 rows	---
Data Rate	24.04	Mbps
Measured AWGN Error Threshold	16.5	dB

However, it should be noted that high-data-rate data streams are expected to be deployed in more benign fixed reception scenarios, such as having an outdoor or attic *directional* antenna at 20' AGL or 30' AGL, and *not* located at a very close proximity to vehicular traffic that causes increased *dynamic* multipath. The brief anecdotal experiment at five test sites that used a *directional* antenna while still situated near busy traffic showed very promising results in that stable error-free reception became much more likely.

This *outdoor-only* field test[1] in the shadowed regions provided evaluation of the SFN design and verification of its operating status. It should be noted that these test were not long-term tests variability tests (e.g., diurnal, seasonal) but rather location variability tests (e.g., wide-spread area with different terrain and local clutter). The following summary statements provide insight into the test results.

(1) The SFN provided a significant increase in the median field strength in the shadowed regions for *both* 30' AGL (≈**16** dB) and 12' AGL (≈**17** dB) receive antenna heights.

(2) The SFN provided a significant increase in the number of sites with error-free reception both 30' AGL (≈**23**%) and 12' AGL (≈**15**%) receive antenna heights. Error-free reception was determined using the LDPC FEC error-correction circuit's error detection capability rather than by video evaluation. The SFN provided slightly better performance in the northern grid (G01) than the eastern grid (G02).

(3) The SFN provided a significant increase in the margin of those sites already with error-free reception (without the SFN) for both 30' AGL (≈**7** dB) and 12' AGL (≈**11**dB) receive antenna heights, thus increasing reception reliability.

(4) The median *field strength* and *service margin* was about 8 dB to 9 dB higher for receive antenna heights 30' AGL than 12' AGL for both SFN ON and SFN OFF, as would be expected statistically. However, error-free reception (i.e., service) was comparable for both reception heights, which was primarily due to the unexplained 5 sites at 30' AGL where the SFN degraded reception. Nevertheless, placing antennas at higher locations still is desirable for better reception.

(5) All of the SFN-induced echo delays measured at these specific **40** test sites were well within the **222.2** µsec guard interval selected for this test. Of the **40** test sites visited, pre-echoes were observed at **17** of the sites while post-echoes were observed at **23** of the sites. These results were based on both the relative amplitudes of the received signals as well as the signal propagation delays coupled with the repeater timing delay that was part of the SFN system design.

(6) The SFN provided margin for sites with error-free reception that was *essentially* proportional to the received signal level as evidenced by the site-margin-versus-field-strength curves for both 30' AGL and 12' AGL receive antenna heights.

[1] *Indoor reception was **not** statistically evaluated during this SFN field test nor was mobile reception. These field test results only reflect conditions with an outdoor omni-directional antenna (**except** for including a directional antenna at the 5 revisited test sites).*

(7) Failure analysis shows that the SFN provided error-free reception for **14** test sites where none had existed before. However, there were **5** test sites where the SFN caused loss of reception. While further investigation will be required in the future regarding the specific cause of lost reception, it was observed that at least *part* of the reason is due to *dynamic* signal behavior.

The outdoor field test data results are briefly *summarized* below in **Table 3** and **Table 4** below for all **40** test sites. More detailed test results can be found in the tables and plots contained in **Appendix 4**.

Table 3 Brief SFN Field Test Comparison Performance Summary.

Reception Parameters	SFN Status	30' AGL	12' AGL	Units
Median Field Strength	SFN ON SFN OFF Δ(SFN ON – SFN OFF)	**95.3** **79.5** **15.8**	**86.7** **70.2** **16.5**	dB
Service Availability	SFN ON SFN OFF Δ(SFN ON – SFN OFF)	**80.0** **57.5** **22.5**	**75.0** **60.0** **15.0**	%
Service Performance Index	SFN ON SFN OFF Δ(SFN ON – SFN OFF)	**80.0** **57.5** **22.5**	**75.0** **64.9** **15.0**	%
Median Service Margin	SFN ON SFN OFF Δ(SFN ON – SFN OFF)	**39.5** **33.0** **6.5**	**30.5** **20.0** **10.5**	dB

Table 4 SFN Site Comparison Performance Summary at **30**' AGL.

SFN ON	SFN OFF	# of Sites	% of Sites
Reception	**Reception**	18	45.0
Reception	**Failure**	14	35.0
Failure	**Reception**	5	12.5
Failure	**Failure**	3	7.5
TOTAL Reception Sites		**40**	**100.0**

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As with any challenging task, *many* individuals are typically involved. This field test was no different. The following individuals were involved in the planning, test site selection, implementation, data analysis, and written report for this DTV field test:

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Bob Chase, Engineer (**Pearl**)

Don Thomas, Engineer (**KASW**)

Brad Singleton, Engineer (**KASW**)

Ryan Steward, Engineer (**KASW**)

Dennis Wallace, Engineering Consultant (**MSW**)

Bill Meintel, Engineering Consultant (**MSW**)

David Meintel, Engineering Consultant (**MSW**)

Gary Sgrignoli, Engineering Consultant (**MSW**)

APPENDIX 1 DTV Transmitter Site Parameters

Table A1-1 Essential DTV transmitter facility parameters used in the SFN field test.

SFN Transmitter Parameter	KASW (Tx1) Main Transmitter	KASW (Tx2) Repeater	Parameter Units
Designated Market Area	**Phoenix**	**Phoenix**	-----
Zone	**2**	**2**	-----
Station Owner	**Scripps**	**Scripps**	-----
Broadcast Network Affiliation	**CW**	**CW**	-----
Transmitted Signal	**ATSC3**	**ATSC3**	-----
Station Facility ID Number	**7143**	**7143**	-----
Station TSID	**203**	**203**	-----
TxID (when used)	**1001**	**1002**	-----
Site Location: Town	**South Mountain, Phoenix**	**Shaw Butte, Phoenix**	-----
Site Location: Latitude[1]	**33.333611**	**33.596389**	deg, N
Site Location: Longitude[1]	**-112.063056**	**-112.092778**	deg, W
Virtual Channel Number[2]	**61**	**61**	-----
Pre-Repack Physical RF Channel	**49**	**---**	-----
Post Repack Physical RF Channel	**27**	**27**	-----
Center Frequency	**551**	**551**	MHz
Center Frequency Wavelength	**1.79**	**1.79**	feet
Transmitter Manufacturer / Model	**Comark Parallax**	**Comark Parallax**	-----
Exciter Manufacturer / Model	**Teamcast Vortex II**	**Teamcast Vortex II**	-----
Transmission Line Type	**6-1/8" Rigid**	**1-5/8"Heliax**	Ohms
Transmission Line Impedance	**75**	**50**	Ohms
Antenna Manufacturer	**Dielectric**	**ERI**	-----
Antenna Model #	**TFU-17ETT / VP-R 4C190**	**i230ECW-8-27**	-----
Antenna ID	**1006461**	**1006192**	-----
Antenna Type (slot, panel, batwing, etc.)	**Slot**	**Cavity-backed**	-----
Antenna Mounting Location (top, side)	**Top**	**Side**	-----
Antenna Impedance	**75**	**50**	Ohms
Antenna Signal Polarization	**E-POL**	**E-POL**	-----
Antenna Pattern	**Directional**	**Directional**	-----
Antenna Max Antenna Pattern Azimuth	**55**	**104 & 336**	deg (wrt north)
Antenna Beam Tilt	**0.95**	**1.50**	deg
Antenna Site Elevation (AMSL)	**810** **2656.8**	**599.3** **1965.7**	meters feet
Radiation Center (AGL)	**98.5** **323.1**	**69.0** **226.3**	meters feet
Radiation Center (AMSL)	**908.5** **2979.9**	**668.3** **2192.0**	meters feet
Radiation Height Above Average Terrain	**550.9** **1807.0**	**268.0** **879.0**	meters feet
Effective Radiated Power (ERP): Horizontal Polarization Vertical Polarization V-pol / H-pol Ratio	 **445** **111** **25.0**	 **18.5** **4.0** **21.4**	 kW, ERP kW, ERP %
Relative Signal Emission Timing Delay	**0**	**11**	µsec

Note 1: These coordinates represent the NAD 83 system.

Note 2: All sites have the same virtual channel number since they all synchronized and transmit an identical signal.

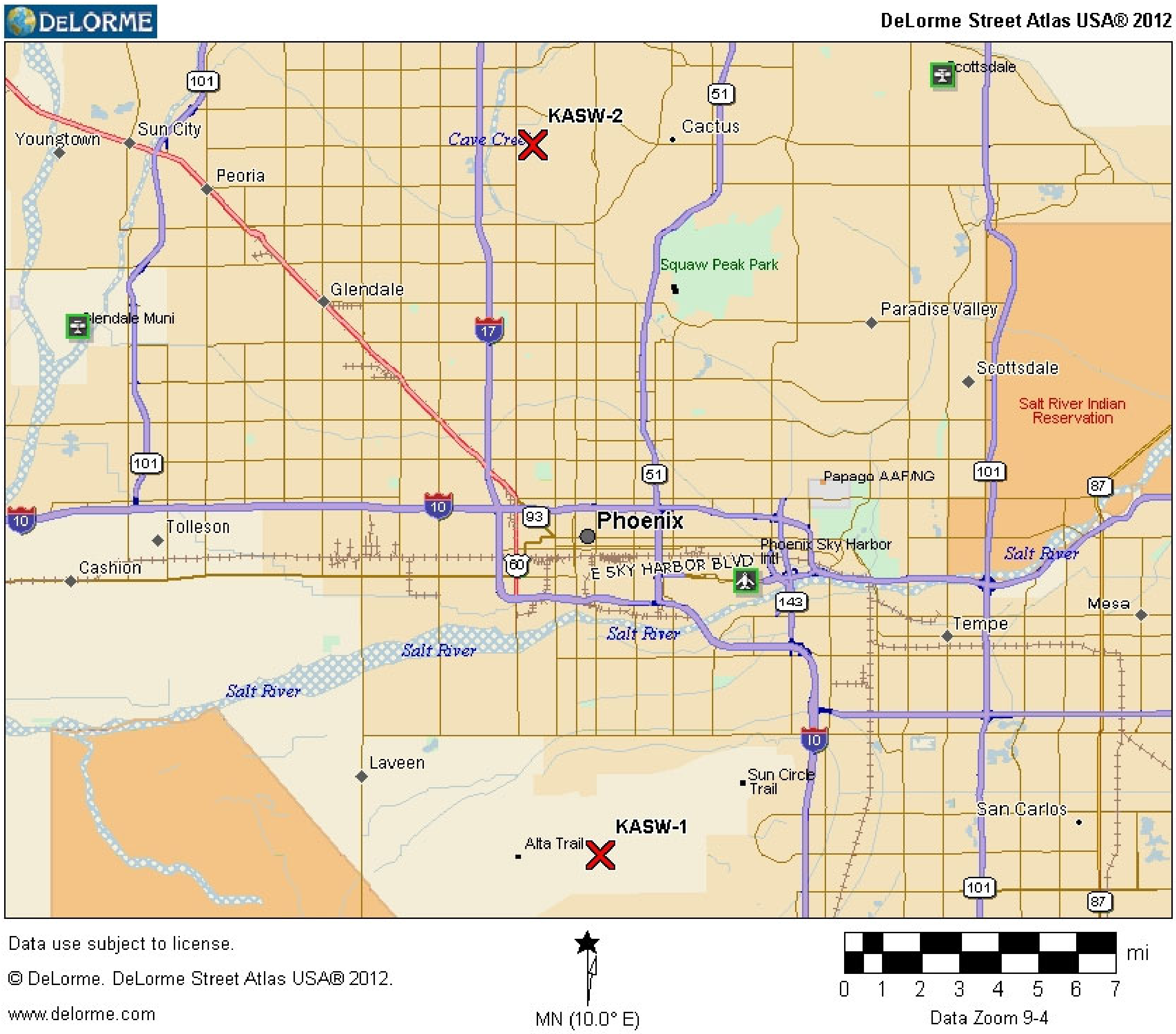


Figure A1-1 Two SFN transmitters: Main plus 1 synchronized Repeater (18.2 miles apart).

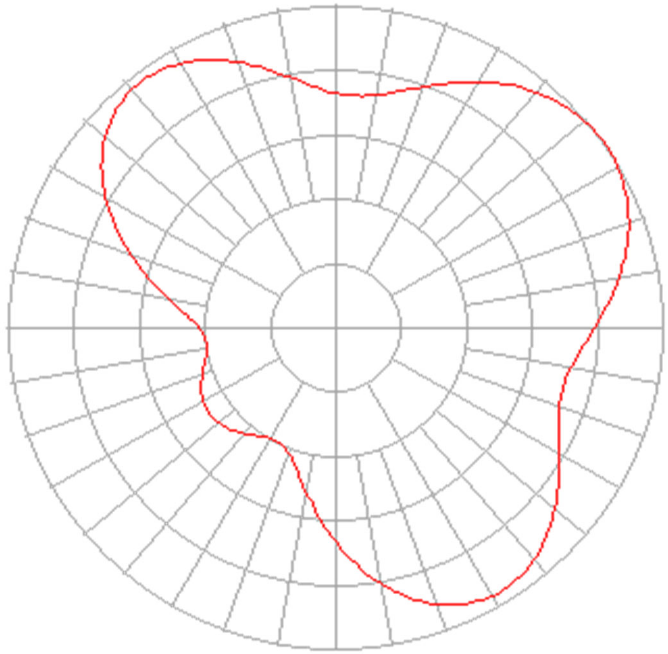


Figure A1-2a KASW-1 CH 27 main transmitter antenna azimuth pattern (South Mountain).

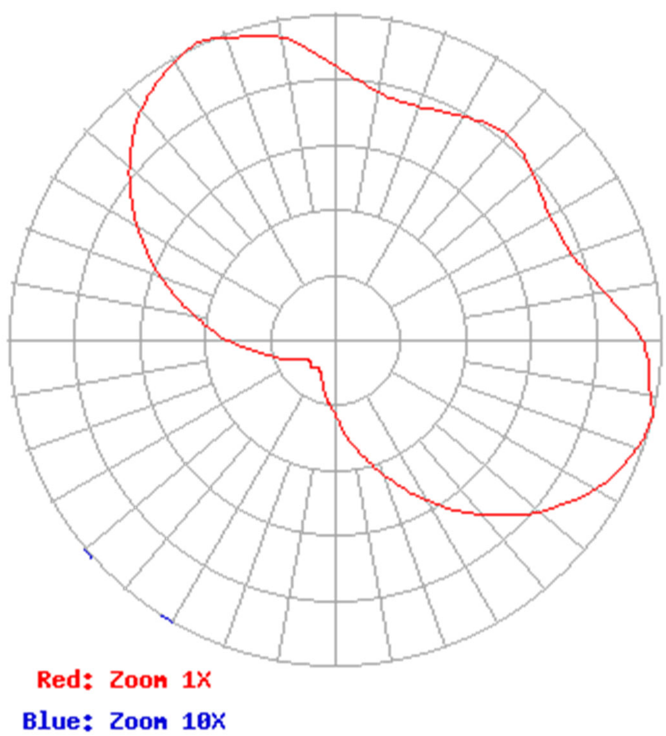


Figure A1-2b KASW-2 CH 27 synchronized repeater antenna azimuth pattern (Shaw Butte).

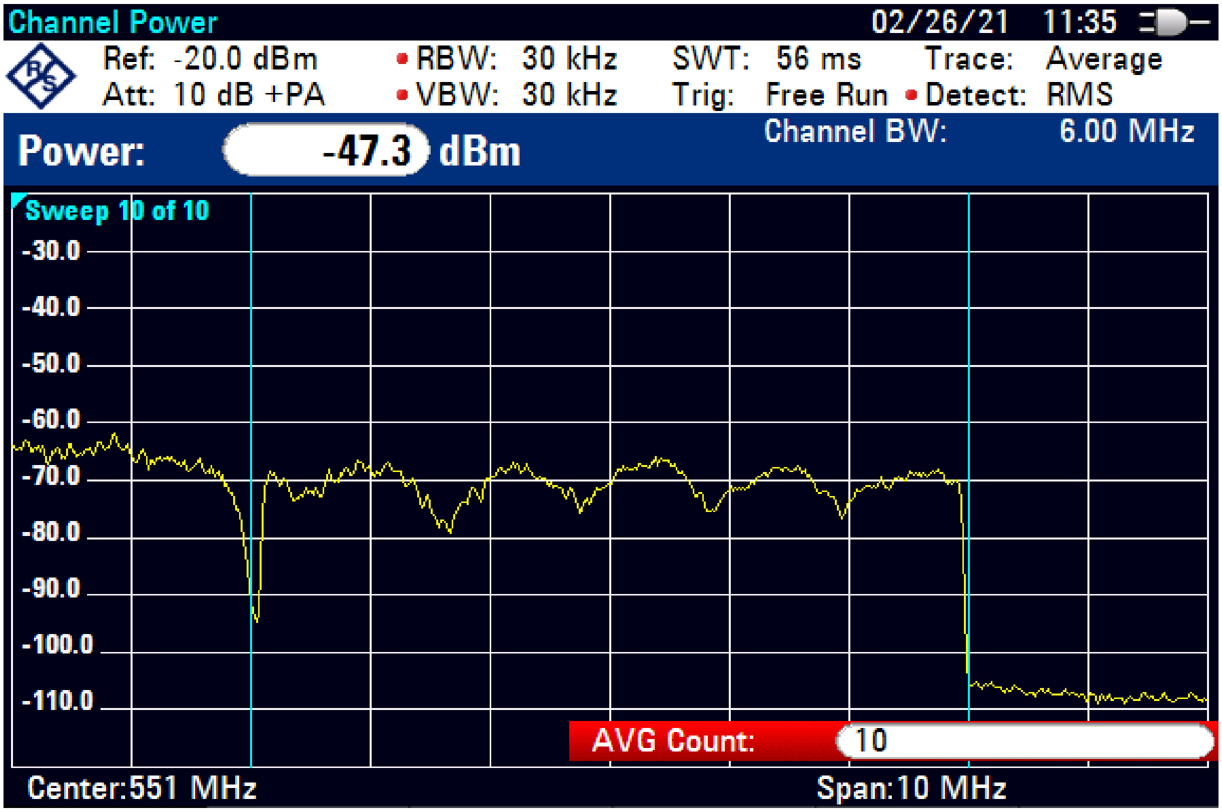


Figure A1-3a KASW CH 27 SFN frequency stability test: spectrum analyzer (South Mountain & Shaw Butte).

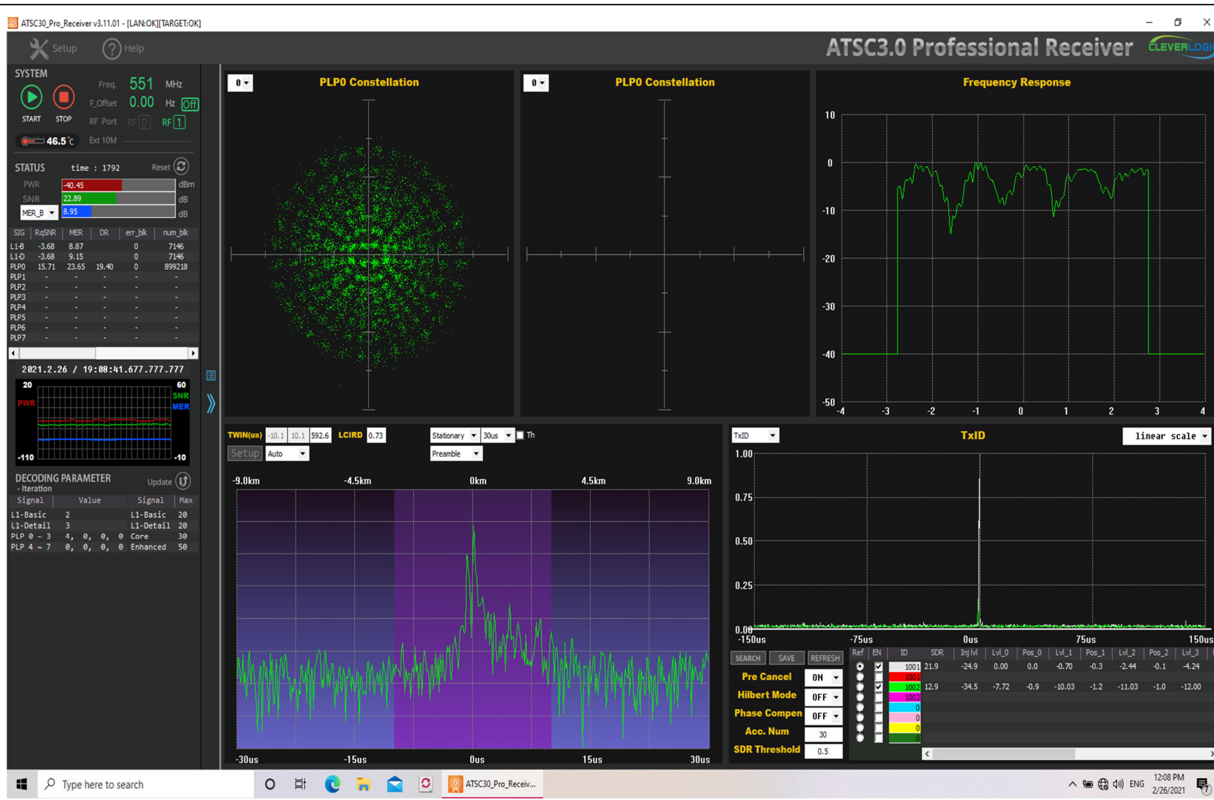


Figure A1-3b KASW CH 27 SFN frequency stability test: Pro-receiver (South Mountain & Shaw Butte).

APPENDIX 2 DTV Field Test Vehicle Description

The field test vehicle shown in **Figure A2-1a** and **Figure A2-1b** was used for this field test. The test vehicle was fully-equipped with RF test equipment (directional antenna, RF distribution system, spectrum analyzer, DTV receivers, video and audio monitors, GPS receiver, and computer), along with an adequate AC power generation, pneumatic mast height extension, remote-control azimuth rotor capability, and AC power generation.

Table A2-1 Summary of ATSC3 Field Test Vehicle *Receive* System Parameters.

Receive Parameters	KASW	Units
Physical Channel	**27**	-----
Virtual Channel	**61**	
Test Channel Center Frequency	**551**	MHz
Antenna Type	**Commercial**	-----
Antenna Pattern	**Omni-Directional**	-----
Antenna Brand	**Spectrum Co Ltd.**	-----
Antenna Model	**Omni-Master**	-----
Antenna Location (height above ground level)	**12' & 30'**	feet, AGL
Antenna Gain	**-2.2**	dBd
Antenna Front/Back Ratio	**≈ 0**	dB
Optional Tunable Bandpass Filter: 3-dB BW 60-dB BW	**≈30** **≈36**	MHZ MHz
Test Vehicle *Net* System Gain (with Atten = 0 dB)	**+6.3**	dB
Test Vehicle *Net* Noise Floor	**-87.0**	dBm/6 MHz
ATSC3 Tx Data Bitrates	**24.04**	Mbps
ATSC3 Tx AWGN Threshold (measured)	**16.70**	dB
Field Strength Dipole Factor	**+128.2**	dBµV/m – dBm
Test Vehicle Threshold Field Strength [1]	**+53.6**	dBµV/m
FCC Threshold Field Strength [2]	**40.0**	dBµV/m

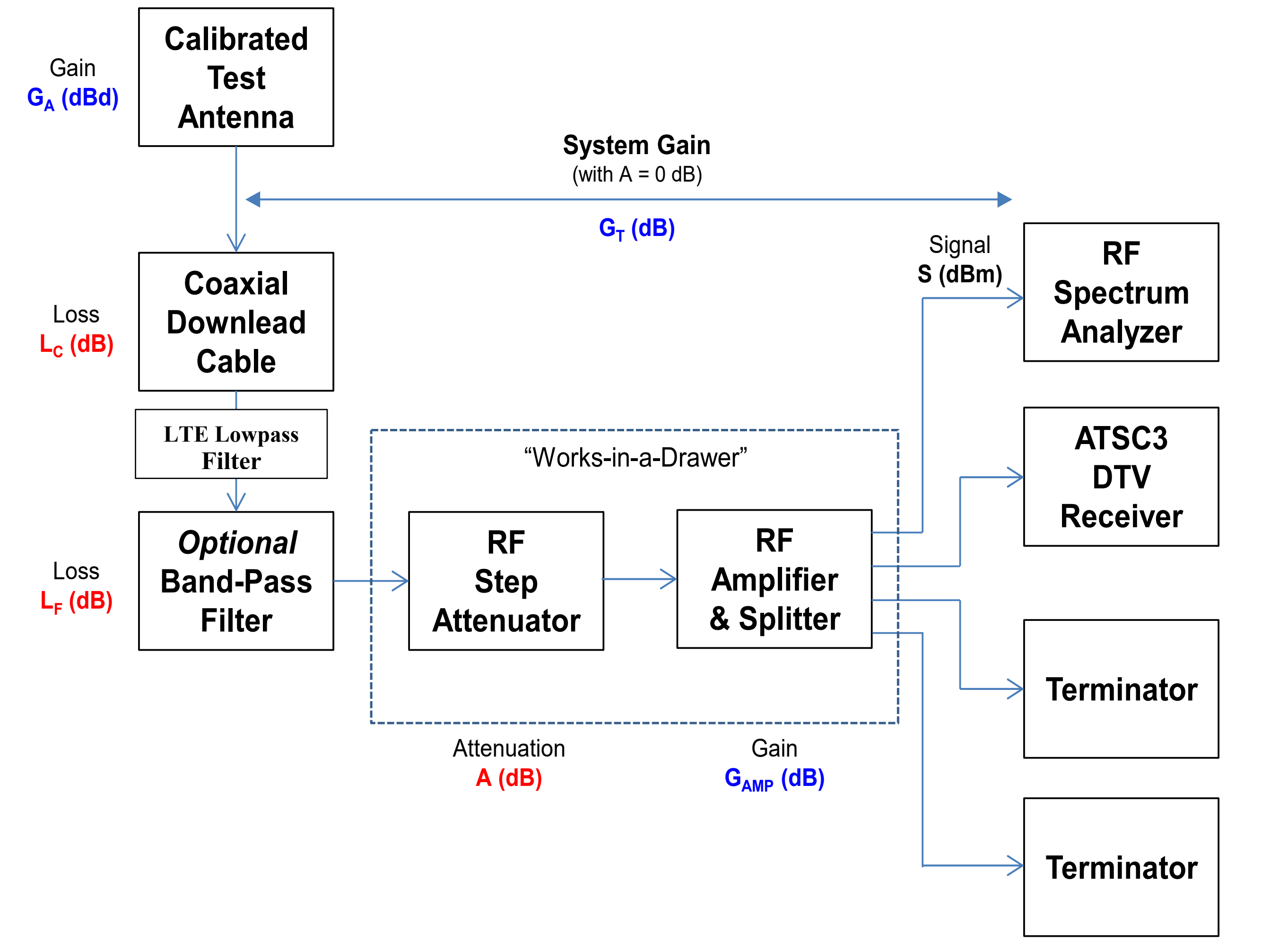
[1] Dependent on test vehicle's system parameters (antenna gain, system gain, noise floor, and DTV receiver TOV threshold).

[2] FCC UHF planning factors are described in OET Bulletin 69 for the ***ATSC1*** system, which includes the following parameters:

UHF dipole factor (based on RF channel *center* frequency)
10 dBd antenna gain
4 dB cable loss
7 dB Rx noise figure
15 dB SNR_{TOV}.

Figure A2-1a Field test vehicle *exterior* photo.

Figure A2-1b Field test vehicle *interior* photo.



$$FS\ (dB\mu V/m) = S\ (dBm) - G_T(dB) + A\ (dB) + K_D\ (dB\mu V/m - dBm) - G_A\ (dBd)$$

where
- $S \equiv$ signal level in 6 MHz bandwidth at spectrum analyzer input (in dBm)
- $G_T \equiv$ total system gain of truck with attenuator A = 0 dB (in dB)
- $A \equiv$ manual attenuator loss (in dB)
- $K_D \equiv$ dipole factor for given RF test channel center frequency (in dBμV/m - dBm)
- $G_A \equiv$ antenna forward gain over λ/2 matched-impedance dipole for given RF test channel (in dBd)

Figure A2-2 DTV field test receive system block diagram used for *outdoor* reception testing.

Spectrum Co LTD

Omni Master

Frequency Range:
470 – 806 MHz

75-Ohm Impedance

Gain:
0 dBi (±1 dB)

VSWR:
2.0 dB average

Output Connector:
Female F

Size:
13” x 13” x 5.1”
330 x 330 x 130 mm

Weight:
3.1 lbs
1.4 kg

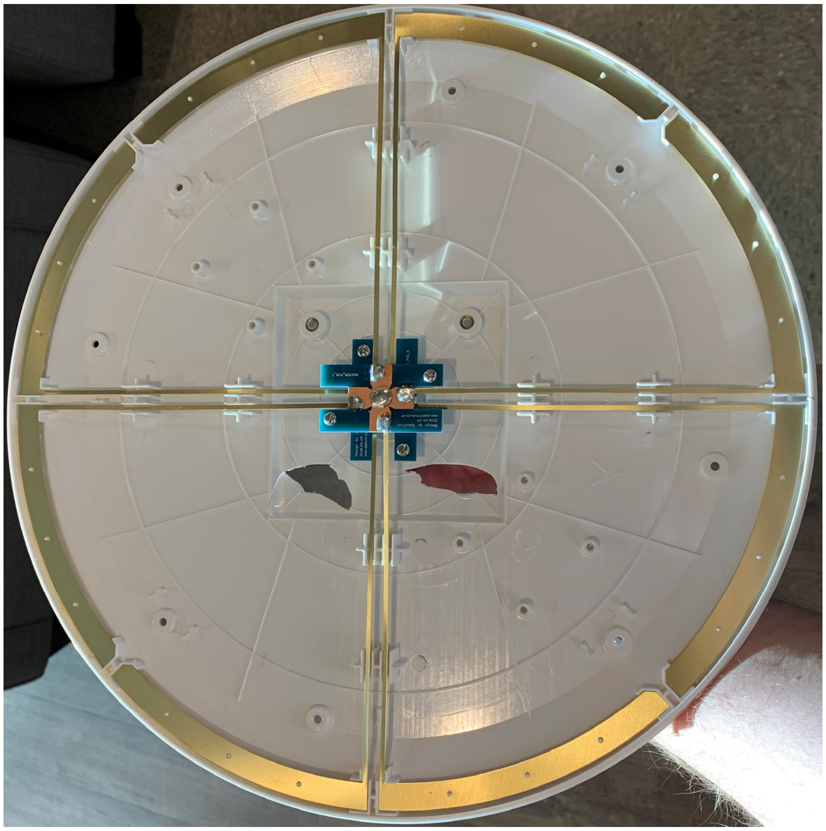


Figure A2-3a *Internal* component view of DTV field test vehicle system UHF omni-directional antenna.

Figure A2-3b UHF *omni*-directional antenna mounted on top of field test vehicle’s mast.

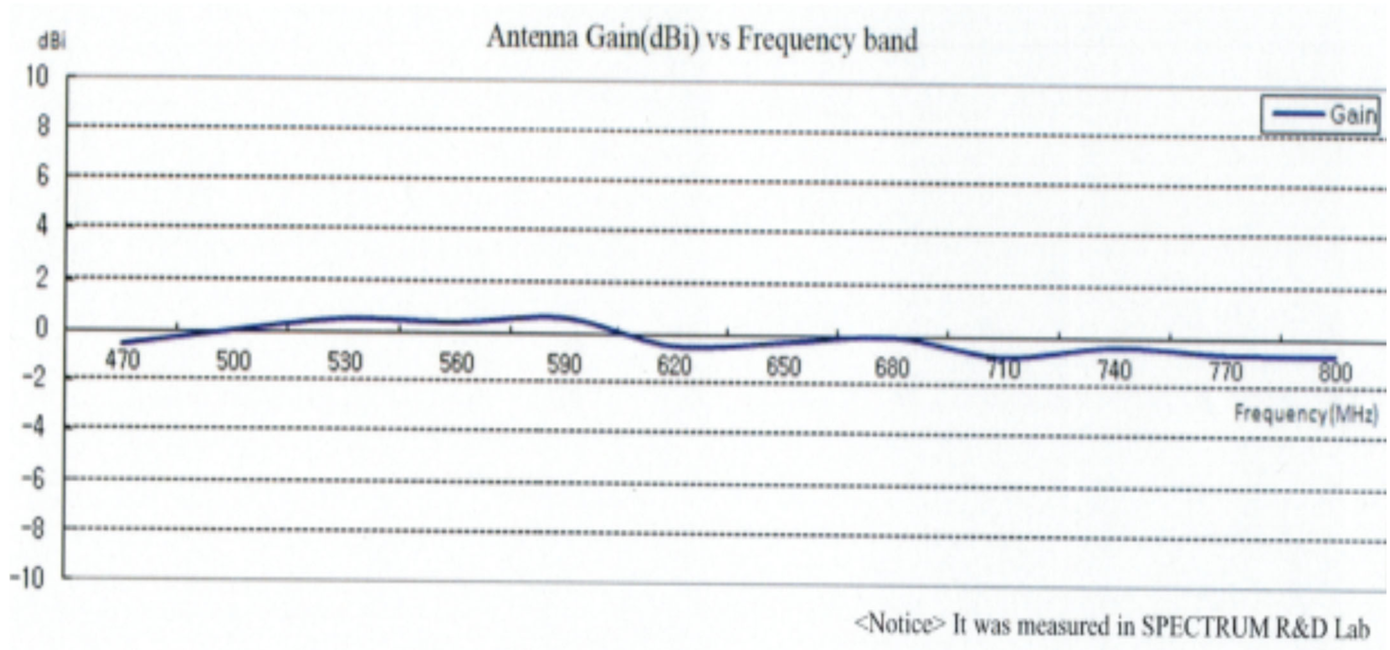


Figure A2-3c Spectrum Co Omni Master UHF omni-directional antenna gain versus frequency plot.

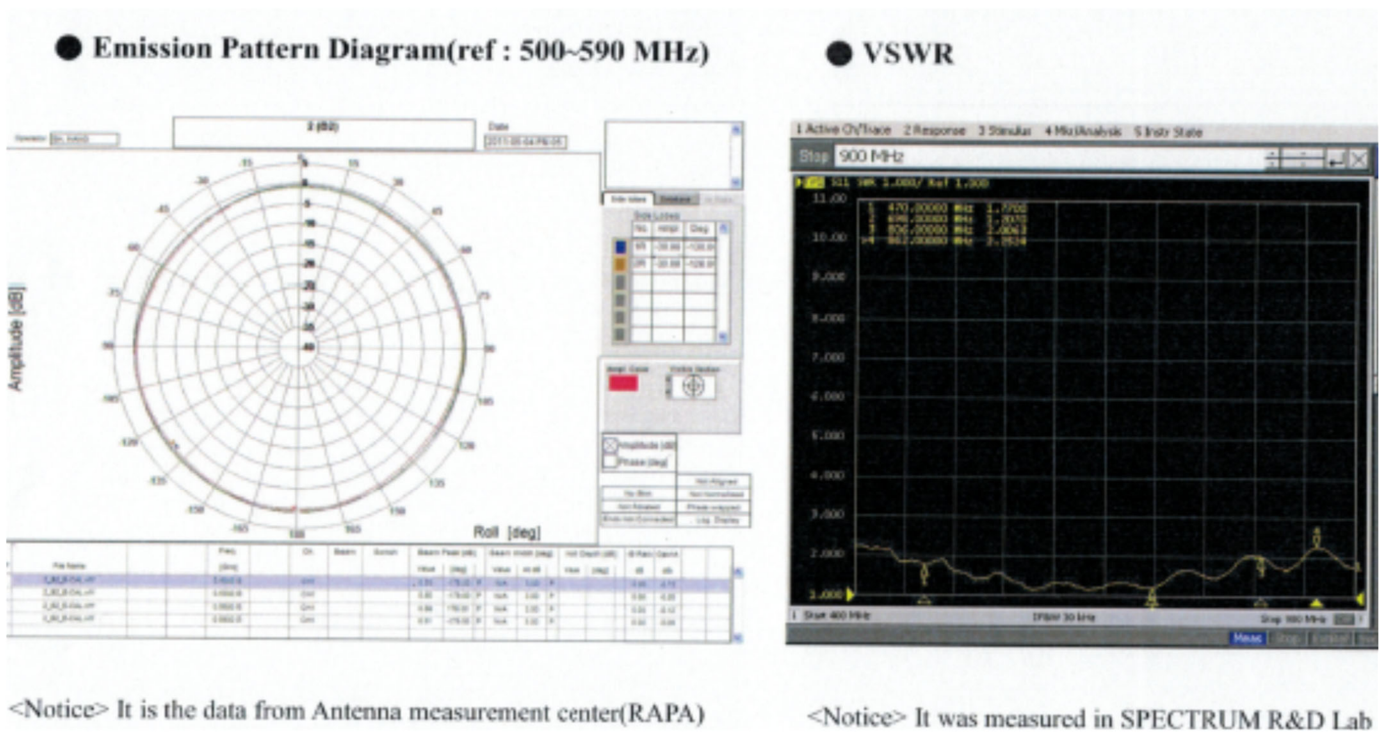


Figure A2-3d Spectrum Co Omni Master UHF omni-directional antenna azimuth emission plot.

Figure A2-3e DTV field test vehicle system high-VHF/UHF *directional* antenna (Digitenna DT-S).

Figure A2-4 DTV field test vehicle system reference DTV Receiver (ETRI/Cleverlogic ATSC3

Figure A2-5 *Optional* K&L 50-Ohm tunable UHF band-pass filter (front & side views).

Table A2-2 Field test vehicle's list of test equipment.

Component	Manufacturer	Model #	Comments
Receive Antenna	Spectrum Co	Omni Master	Omni-directional, 0 dBi gain
LTE Low-Pass Filter	Channel Master	CM3201	75-Ohm, 700 MHz bandwidth
Coaxial Cable	Belden	LMR-240	50-Ohm, double-shielded coax
Step Attenuator	JFW	50DR-001-SMA	50-Ohm, 1-dB step, 0 – 110 dB
RF Channel Bandpass Filter	K & L	5BT-500/1000-5-N/N	50-Ohm, tunable UHF band (500 MHz – 1000 MHz) 5-section filter, Shape Factor 2.2:1 to 3.5:1 ≈30 MHz 3-dB BW, ≈36 MHz 20-dB BW 1-dB max insertion loss Mechanically-tuned Chebyshev filter response
RF Amplifier	Mini Circuits	ZFL-1000VH+	50 Ohms, +20 dB minimum gain 4.5 dB NF; >+38 dBm IP3, 15 Vdc/320 ma
Splitter	Mini Circuits	ZFSC-4-1	50-Ohm, 4-way, BNC connectors
Spectrum Analyzer	Rohde & Schwarz	FSH-4	3.6 GHz BW, RF preamp, BP markers
ATSC3 Commercial Receiver	Cleverlogic	CL-AR3000	AGOS IMAS software (Ver 22.15 Build 8012) Firmware 2019.07.02; FPGA 2018.08.02 S/N: CL1803APRN020F
GPS Receiver	Global Sat	BU-353S4	NEMA compatible, 12-Vdc
Control Computer	Custom	N.A.	Windows 10 PC with Excel (32-bit)

APPENDIX 3 Field Test Plan Details

Table A3-1 ATSC3 single-PLP- field test signal (Mod-Cod) transmission parameters.

Parameter	Description	PLP #0	Units
Bootstrap	Major Version	0	*
	Minor Version	0x0190	*
	Bootstrap Symbols	4	symbols
	Emergency Alarm Wakeup	0	*
	System Bandwidth	6	MHz
	Baseband Sampling Rate Coefficient	2 (6.912)	* (MHz)
	Minimum Time to Next Frame	250	msec
	Frame Length (with Bootstrap)	≈ 250	msec
Preamble	Preamble Structure: FFT	16k	samples
	Preamble Structure: Guard Interval	GI7_1536 / 222.2	* / µsec
	Preamble Structure: Pilot Dx	Dx_4	*
	Preamble Reduced Carriers	0	*
	L1-Basic Mode	1	
	L1-Detail Size Bytes / Cells	N/A.	bytes/cells
	L1-Detail Mode	1	*
	Time Info Flag	nsec unit	*
	# of Preamble Symbols	1	*
	Frame Length Mode (alignment)	Symbol	*
Subframe	Multiplexing	NONE	*
	Number of Subframes	1	*
	FFT Size	16k	samples
	Reduced Subcarrier	0	*
	Guard Interval	GI7_1536 / 222.2	* / µsec
	Number OFDM Payload Symbols	95	symbols
	Scattered Pilot Pattern	SP8_4	*
	Scattered Pilot Boost	0.0	dB
	SBS First	ON	*
	SBS Last	ON	*
	Frequency Interleaver	ON	*
	# of PLPs	1	*
	Available Data Cells (Dummy Cells)	1,263,053 (0)	cells
Subframe PLPS	PLP ID #	0	*
	Low-Level-Signaling Flag	ON	*
	Layer	Core	*
	Start	0	*
	Size (PLP)	1,263,000	cells
	FEC Type	LDPC/BCH	*
	FEC Code Length	64,800	bits
	QAM Modulation Order	256	*
	LDPC FEC Code Rate	9/15	rate
	Time Interleaver Mode	CTI Mode	*
	Time Interleaver Extended	OFF	*
	Convolutional Time Interleaver Depth	1024	*
	Convolutional Time Interleaver Type	Non-Dispersed	*
	Number of Slices	N/A	*
	Subslice Interval	N/A	*
	Cell Interleaver	---	*
	Inter Subframe	---	*
	Number of TI Blocks	---	*
	Number of FEC Blocks Max	---	*
	Number of FEC Block	---	*
	LDM Injection Level	N/A	dB
General	Data Rate (Pseudo Random Sequence)	24.04	Mbps
	Modulation[1]	OFDM	*
	Occupied Bandwidth[2]	5.83	MHz
	Simulated AWGN Threshold SNR	15.7	dB
	Measured AWGN Threshold SNR [3]	16.7	dB
	TxID Number (Tx #1 and Tx #2)	1001 / 1002	*

[1] COFDM is Coded Orthogonal Frequency Domain Modulation.
[2] Occupied bandwidth is the bandwidth that contains 95% of the RF signal power.
[3] Test vehicle's reference Rx measured threshold.

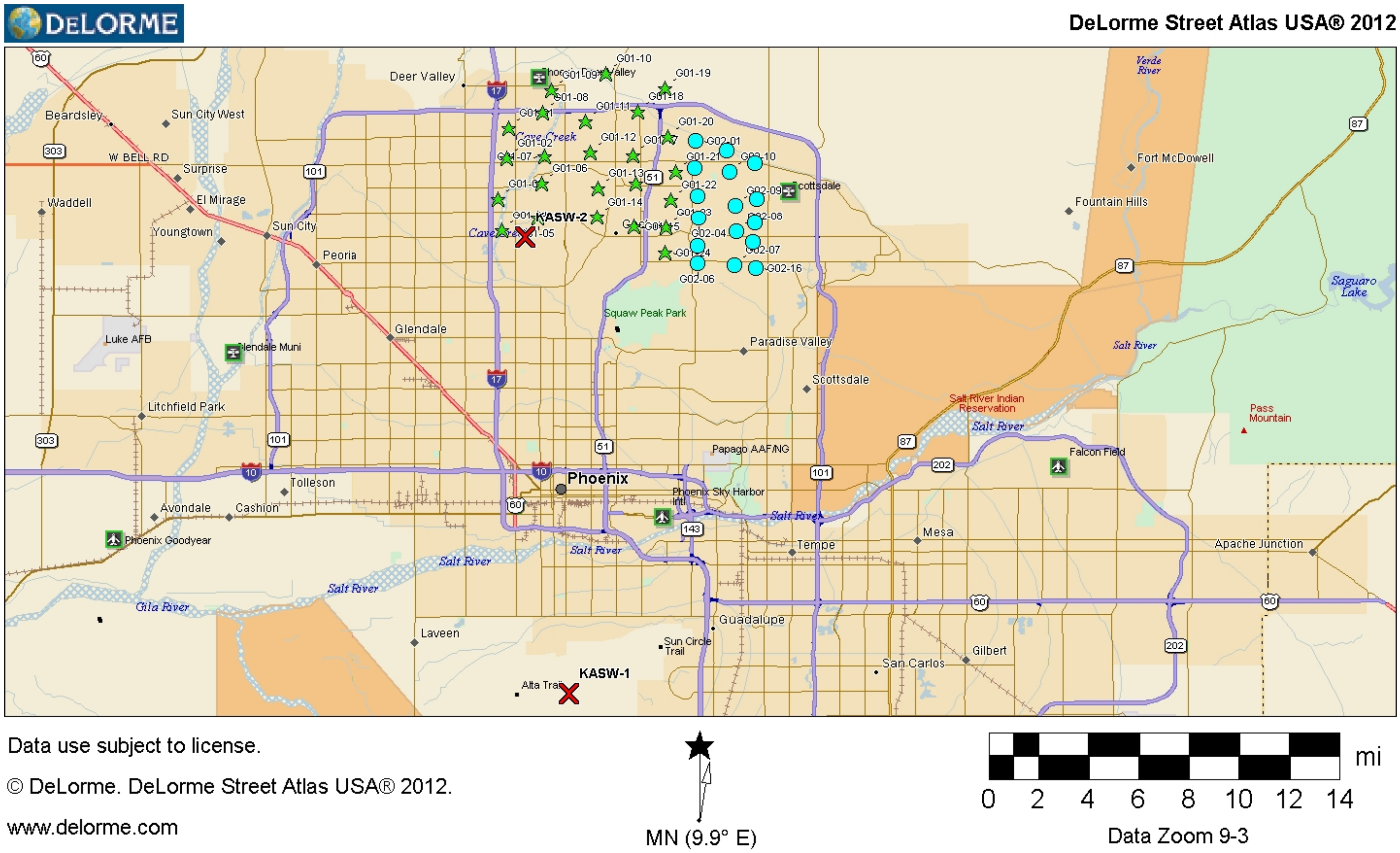


Figure A3-1a Map of *all* field test sites (2 grids). The "red X's" denote the 2 synchronized SFN transmitter sites.

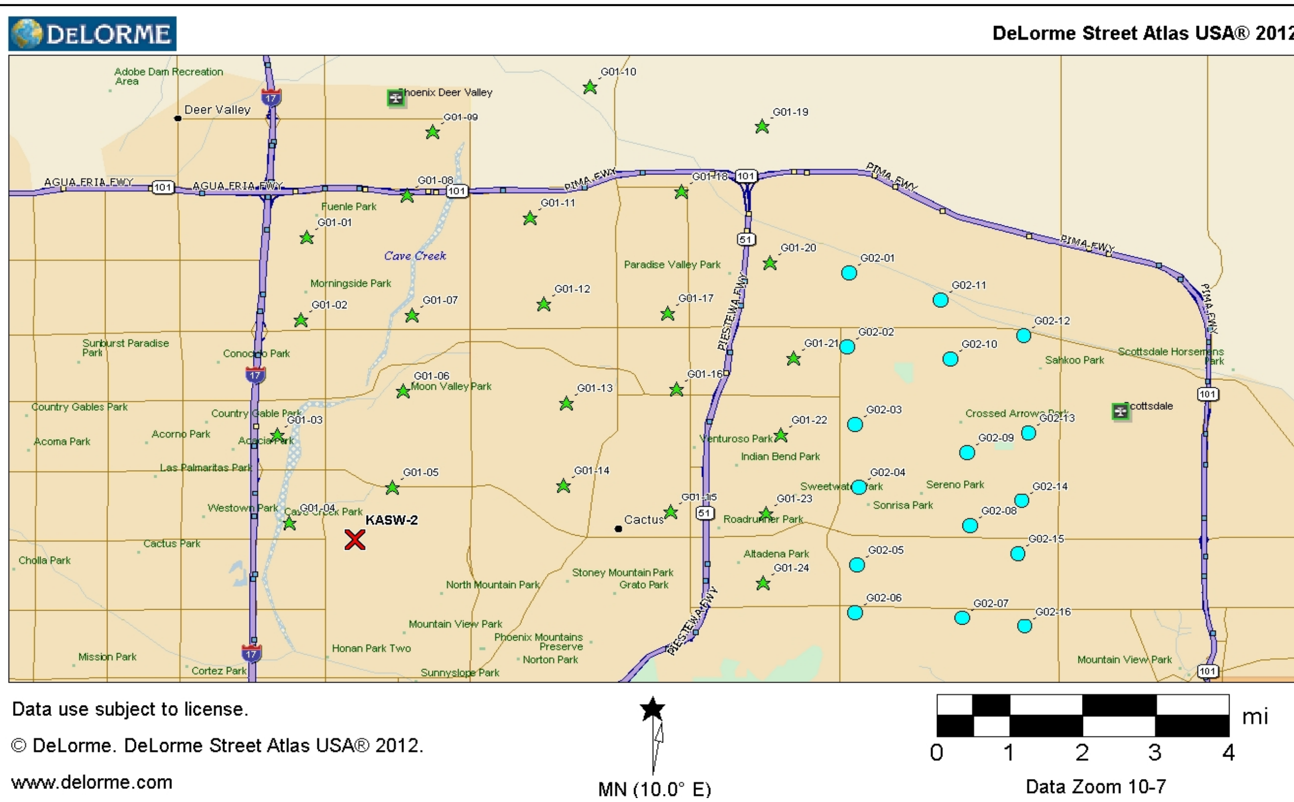


Figure A3-1b Expanded map of *all* field test sites (2 grids). The "red X" denotes Shaw Butte transmitter site.

Table A3-2 Description of test site *regions* (radials and grids) for the **40**-site field test.

Test Regions	Type of Test Sites	# of Sites	# of Terrain Obstructions		Test Site Distance [1]	*Median* Group Distance to Main Tx
(Name)	(*)	(#)	(Tx1)	(Tx2)	(With Respect to Main Tx)	(miles)
G01	Grid	24	14	5	North of Shaw Butte Mountain (18.0 – 24.7 miles)	21.3
G02	Grid	16	12	0	East of Shaw Butte Mountain (17.9 – 22.6 miles)	20.3
-----	-----	**40**	**26**	**5**	-----	**20.5**

Note 1: **KASW** CH 27 includes a main DTV transmitter on **South Mountain** and a synchronized on-channel remote transmitter on **Shaw Butte Mountain**.

Note 2: 26 *Terrain* obstructions for Tx1 (South Mountain) and **5** terrain obstructions for Tx2 (Shaw Butte Mountain) are considered; local "clutter" not included.

Table A3-3 Terrain Obstructions from each SFN transmitter site to each test site.

Test Site Name	Tx1		Tx2	
	Distance To Site	# of Terrain Obstruction	Distance To Site	# of Terrain Obstruction
G01-01	22.6	0	4.4	0
G01-02	21.5	0	3.2	0
G01-03	19.9	0	1.8	0
G01-04	18.6	0	0.9	0
G01-05	19.0	1	0.9	0
G01-06	20.3	1	2.2	0
G01-07	21.4	2	3.3	0
G01-08	23.1	0	5.0	0
G01-09	24.0	1	6.0	0
G01-10	24.7	0	7.3	1
G01-11	22.8	1	5.2	0
G01-12	21.6	1	4.3	0
G01-13	20.2	0	3.5	1
G01-14	19.0	0	3.0	0
G01-15	18.7	1	4.3	0
G01-16	20.5	1	4.9	0
G01-17	21.6	0	5.4	1
G01-18	23.3	0	6.7	0
G01-19	24.4	2	8.1	0
G01-20	22.5	1	6.9	1
G01-21	21.2	3	6.5	0
G01-22	20.1	2	6.0	1
G01-23	18.9	2	5.6	0
G01-24	18.0	2	5.6	0
G02-01	22.6	0	7.8	0
G02-02	21.5	2	7.3	0
G02-03	20.5	3	7.0	0
G02-04	19.6	1	6.9	0
G02-05	18.5	1	6.9	0
G02-06	17.9	1	6.9	0
G02-07	18.3	1	8.4	0
G02-08	19.5	0	8.4	0
G02-09	20.5	0	8.5	0
G02-10	21.7	1	8.5	0
G02-11	22.5	2	8.7	0
G02-12	22.4	0	9.6	0
G02-13	21.1	2	9.3	0
G02-14	20.1	1	9.1	0
G02-15	19.4	2	9.1	0
G02-16	18.5	2	9.2	0
Minimum	**17.9**	**0**	**0.9**	**0**
Maximum	**24.7**	**3**	**9.6**	**1**
Median	**20.5**	**1**	**6.6**	**0**
# of sites = LOS	-----	**14**	-----	**35**
# of sites <> LOS	-----	**26**	-----	**5**

APPENDIX 4 FIELD TEST DATA

Table A4-1a SFN Field Test *Raw* Data Summary for 30' AGL.

Test Site Description			Terrain		SFN ON			SFN OFF			Δ = SFN ON – SFN OFF		
Site Name (*)	Dist to Tx1 (miles)	Bear To Tx1 (deg)	Tx1 Obs (*)	Tx2 Obs (*)	Field Strength (dBμV/m)	Service Status (Y/N)	Service Margin[1] (dB)	Field Strength (dBμV/m)	Service Status (Y/N)	Service Margin[1] (dB)	Field Strength (dBμV/m)	Service Change (*)	Service Margin[1] (dB)
G01-01	22.6	174.0	0	0	102.5	YES	46	94.0	YES	40	8.5	SAME	6
G01-02	21.5	173.5	0	0	108.1	YES	53	97.5	YES	43	10.6	SAME	10
G01-03	19.9	172.0	0	0	106.8	YES	52	90.3	YES	36	16.5	SAME	16
G01-04	18.6	172.0	0	0	95.1	YES	38	92.8	YES	37	2.3	SAME	1
G01-05	19.0	176.4	1	0	102.1	YES	46	55.9	NO	0	46.2	GAIN	---
G01-06	20.3	177.0	1	0	105.5	YES	51	74.1	NO	0	31.4	GAIN	---
G01-07	21.4	177.5	2	0	96.5	YES	42	68.2	NO	0	28.3	GAIN	---
G01-08	23.1	177.6	0	0	95.4	YES	39	83.6	YES	28	11.8	SAME	11
G01-09	24.0	178.5	1	0	92.3	YES	35	86.9	YES	32	5.4	SAME	3
G01-10	**24.7**	**183.5**	0	1	**82.2**	NO	0	**82.2**	YES	**26**	**0.0**	LOSS	
G01-11	22.8	181.7	1	0	100.7	YES	45	76.5	YES	17	24.2	SAME	28
G01-12	21.6	182.3	1	0	104.4	YES	50	64.8	NO	0	39.6	GAIN	---
G01-13	20.2	183.4	0	1	78.1	NO	0	69.8	NO	0	8.3	SAME	---
G01-14	19.0	183.5	0	0	74.4	NO	0	58.0	NO	0	16.4	SAME	---
G01-15	18.7	188.0	1	0	98.8	YES	44	81.8	YES	26	17.0	SAME	18
G01-16	20.5	187.6	1	0	98.9	YES	43	82.5	YES	28	16.4	SAME	15
G01-17	21.6	186.9	0	1	96.4	YES	37	95.9	YES	40	0.5	SAME	-3
G01-18	23.3	186.8	0	0	103.2	YES	47	96.7	YES	42	6.5	SAME	5
G01-19	24.4	189.1	2	0	96.8	YES	42	68.2	NO	0	28.6	GAIN	---
G01-20	22.5	190.2	1	1	88.7	YES	33	88.5	YES	33	0.2	SAME	0
G01-21	21.2	191.6	3	0	88.9	YES	33	76.3	YES	21	12.6	SAME	12
G01-22	20.1	191.8	2	1	81.2	YES	25	67.7	YES	11	13.5	SAME	14
G01-23	18.9	191.9	2	0	98.6	YES	43	72.4	YES	14	26.2	SAME	29
G01-24	18.0	192.4	2	0	94.7	YES	39	63.2	NO	0	31.5	GAIN	---
G02-01	22.6	192.9	0	0	94.6	YES	38	94.0	YES	39	0.6	SAME	-1
G02-02	21.5	193.5	2	0	95.8	YES	40	86.9	YES	32	8.9	SAME	8
G02-03	20.5	194.5	3	0	93.8	YES	38	71.4	NO	0	22.4	GAIN	---
G02-04	19.6	195.3	1	0	96.3	YES	41	70.5	NO	0	25.8	GAIN	---
G02-05	18.5	196.1	1	0	92.7	YES	37	73.1	NO	0	19.6	GAIN	---
G02-06	17.9	196.7	1	0	84.7	NO	0	66.4	NO	0	18.3	SAME	---
G02-07	18.3	201.1	1	0	94.6	YES	39	73.3	NO	0	21.3	GAIN	---
G02-08	**19.5**	**200.0**	0	0	**95.8**	NO	0	**95.0**	YES	**40**	**0.8**	LOSS	---
G02-09	**20.5**	**198.9**	0	0	**100.2**	NO	0	**99.0**	YES	**44**	**1.2**	LOSS	---
G02-10	21.7	197.2	1	0	95.9	YES	40	95.0	YES	40	0.9	SAME	0
G02-11	22.5	196.2	2	0	87.6	YES	31	77.2	NO	0	10.4	GAIN	---
G02-12	**22.4**	**199.4**	0	0	**88.1**	NO	0	**87.5**	YES	**33**	**0.6**	LOSS	---
G02-13	**21.1**	**200.8**	2	0	**91.7**	NO	0	**88.2**	YES	**34**	**3.5**	LOSS	---
G02-14	20.1	201.5	1	0	77.2	YES	19	68.7	NO	0	8.5	GAIN	---
G02-15	19.4	202.2	2	0	95.3	YES	39	83.2	NO	0	12.1	GAIN	---
G02-16	18.5	203.7	2	0	89.9	YES	33	69.2	NO	0	20.7	GAIN	---

1 Any site margin that is *greater* than 0 dB indicates *error-free* service was available at this test site.

Table A4-1b SFN Field Test *Raw* Data Summary for 12' AGL.

Test Site Description			Terrain Obs		SFN ON			SFN OFF			Δ = SFN ON – SFN OFF		
Site Name (*)	Dist to Tx1 (miles)	Bear To Tx1 (deg)	Tx1	Tx2	Field Strength (dBµV/m)	Service Available (Yes/No)	Service Margin[1] (dB)	Field Strength (dBµV/m)	Service Available (Yes/No)	Service Margin[1] (dB)	Field Strength (dBµV/m)	Service Change (*)	Service Margin[1] (dB)
G01-01	**22.6**	**174.0**	0	0	**89.0**	**NO**	**0**	**70.9**	**Yes**	**12**	**18.1**	**LOSS**	---
G01-02	21.5	173.5	0	0	109.1	Yes	54	95.2	Yes	41	13.9	SAME	13
G01-03	19.9	172.0	0	0	107.6	Yes	53	83.8	Yes	29	23.8	SAME	24
G01-04	18.6	172.0	0	0	89.7	Yes	33	87.6	Yes	34	2.1	SAME	-1
G01-05	19.0	176.4	1	0	97.4	Yes	40	50.0	NO	0	47.4	GAIN	---
G01-06	20.3	177.0	1	0	102.7	Yes	49	69.2	Yes	11	33.5	SAME	38
G01-07	21.4	177.5	2	0	81.7	Yes	26	59.2	NO	0	22.5	GAIN	---
G01-08	23.1	177.6	0	0	85.9	Yes	29	71.5	Yes	14	14.4	SAME	15
G01-09	24.0	178.5	1	0	98.1	Yes	42	85.5	Yes	31	12.6	SAME	11
G01-10	24.7	183.5	0	1	68.9	NO	0	68.9	NO	0	0.0	SAME	---
G01-11	22.8	181.7	1	0	93.0	Yes	37	63.9	NO	0	29.1	GAIN	---
G01-12	21.6	182.3	1	0	101.9	Yes	47	64.0	NO	0	37.9	GAIN	---
G01-13	20.2	183.4	0	1	73.7	NO	0	68.5	NO	0	5.2	SAME	---
G01-14	19.0	183.5	0	0	70.2	NO	0	50.5	NO	0	19.7	SAME	---
G01-15	18.7	188.0	1	0	81.7	Yes	24	73.6	Yes	18	8.1	SAME	6
G01-16	20.5	187.6	1	0	88.9	Yes	32	70.7	Yes	15	18.2	SAME	17
G01-17	21.6	186.9	0	1	88.9	Yes	33	88.5	Yes	34	0.4	SAME	-1
G01-18	23.3	186.8	0	0	90.2	Yes	34	83.2	Yes	28	7.0	SAME	6
G01-19	24.4	189.1	2	0	92.3	Yes	37	64.1	NO	0	28.2	GAIN	---
G01-20	22.5	190.2	1	1	79.4	Yes	24	76.2	Yes	22	3.2	SAME	2
G01-21	21.2	191.6	3	0	76.0	Yes	19	64.1	Yes	5	11.9	SAME	14
G01-22	20.1	191.8	2	1	73.4	Yes	18	62.9	Yes	8	10.5	SAME	10
G01-23	18.9	191.9	2	0	85.4	Yes	30	61.3	Yes	5	24.1	SAME	25
G01-24	18.0	192.4	2	0	72.7	Yes	15	52.1	NO	0	20.6	GAIN	---
G02-01	22.6	192.9	0	0	88.1	Yes	30	84.9	Yes	30	3.2	SAME	0
G02-02	21.5	193.5	2	0	80.2	Yes	23	69.6	Yes	12	10.6	SAME	11
G02-03	20.5	194.5	3	0	84.1	Yes	27	63.5	NO	0	20.6	GAIN	---
G02-04	19.6	195.3	1	0	93.0	Yes	38	59.7	NO	0	33.3	GAIN	---
G02-05	18.5	196.1	1	0	86.4	Yes	31	71.3	Yes	15	15.1	SAME	16
G02-06	17.9	196.7	1	0	70.3	NO	0	58.4	NO	0	11.9	SAME	---
G02-07	18.3	201.1	1	0	88.2	Yes	32	65.3	NO	0	22.9	GAIN	---
G02-08	**19.5**	**200.0**	0	0	**90.3**	**NO**	**0**	**88.1**	**Yes**	**33**	**2.2**	**LOSS**	---
G02-09	**20.5**	**198.9**	0	0	**89.6**	**NO**	**0**	**89.3**	**Yes**	**34**	**0.3**	**LOSS**	---
G02-10	21.7	197.2	1	0	87.0	Yes	30	84.7	Yes	30	2.3	SAME	0
G02-11	22.5	196.2	2	0	80.5	Yes	22	73.6	Yes	17	6.9	SAME	5
G02-12	**22.4**	**199.4**	0	0	**77.8**	**NO**	**0**	**77.0**	**Yes**	**22**	**0.8**	**LOSS**	---
G02-13	21.1	200.8	2	0	86.4	NO	0	73.6	NO	0	12.8	SAME	---
G02-14	20.1	201.5	1	0	69.2	Yes	11	63.0	NO	0	6.2	GAIN	---
G02-15	19.4	202.2	2	0	85.6	Yes	29	73.9	Yes	17	11.7	SAME	12
G02-16	18.5	203.7	2	0	87.8	NO	0	69.8	NO	0	18.0	SAME	---

1 Any site margin that is *greater* than 0 dB indicates *error-free* service was available at this test site.

Table A4-2 ATSC3 SFN Field Test Analysis Results: *Overall[1] Summary* (**40** test sites).

Test Parameters	SFN	30' AGL	12' AGL	Units
Physical RF Test Channel # / Center Frequency	-----	CH 27 / 551		# / MHz
TX1 ERP (H-POL) / (V-POL)	-----	445 / 111		kW
TX2 ERP (H-POL) / (V-POL)	-----	18.5 / 4		kW
TX1 / TX2 HAAT	-----	1807.0 / 879.0		feet
TX1 / TX2 Beam Tilt	-----	0.95 / 1.50		degrees
Tx1 Test Site Distance Range (min / median / max)	-----	17.9 / 20.5 / 24.7		miles
Tx2 Test Site Distance Range (min / median / max)		0.9 / 6.6 / 9.6		miles
Test Signal Parameters	-----	16k FFT; SP8_4, 222.2 us GI 16QAM, 9/15 LDPC & BCH, CTI-1024		*
Payload Data Rate	-----	24.04		Mbps
Expected SNR @ TOV for AWGN (simulation)	-----	15.7		dB
Measured SNR @ TOV for AWGN (laboratory)	-----	16.7		dB
Test Van Minimum Required Field Strength	-----	53.6		dBµV/m
FCC Minimum Field Strength (ATSC1)	-----	40.0		dBµV/m
Median Received Field Strength[1]	ON	95.3	86.7	dBµV/m
	OFF	79.5	70.2	dBµV/m
	ON - OFF	15.8	16.5	dB
Service Availability[1]	ON	80.0	75.0	%
	OFF	57.5	60.0	%
	ON - OFF	22.5	15.0	%
System Performance Index[1]	ON	80.0	75.0	%
	OFF	57.5	64.9	%
	ON - OFF	22.5	15.0	%
Median Service Margin[2]	ON	39.5	30.5	dB
	OFF	33.0	20.0	dB
	ON - OFF	6.5	10.5	dB

Note 1: Statistics were calculated using all **40** test sites together.

Note 2: Median margin values for each channel were calculated using *only* sites with successful reception (i.e., margin > 0 dB).

Table A4-3 SFN Site Comparison Performance Summary at **30**' AGL.

SFN ON	SFN OFF	# of Sites	% of Sites
Reception	Reception	18	45.0
Reception	Failure	14	35.0
Failure	Reception	5	12.5
Failure	Failure	3	7.5
TOTAL Reception Sites		**40**	**100.0**

Table A4-4 Summary of SFN **ON** transmitter Echo Results at **30' AGL** for all **40** test sites.

Test Site Name	Intervening Terrain Obstructions		SFN Echo Amplitude	SFN Echo Delay	SFN Largest Signal	SFN Echo Type	SFN Field Strength	SFN Service Margin	SFN Signal *Increase*
(*)	Tx1	Tx2	(dB)	(µsec)	(*)	(*)	(*)	(*)	(dB)
G01-01	0	0	-9.7	+86.7	Repeater	Post-Echo	102.5	46	8.5
G01-02	0	0	-10.8	+86.4	Repeater	Post-Echo	108.1	53	10.6
G01-03	0	0	-15.7	+85.4	Repeater	Post-Echo	106.8	52	16.5
G01-04	0	0	-0.1	+83.3	Repeater	Post-Echo	95.1	38	2.3
G01-05	**1**	0	-16.5	**-37.2**	Repeater	**Pre**-Echo	102.1	46	46.2
G01-06	**1**	0	-16.6	**-44.3**	Repeater	**Pre**-Echo	105.5	51	31.4
G01-07	**2**	0	-17.3	**-105.5**	Repeater	**Pre**-Echo	96.5	42	28.3
G01-08	0	0	-11.2	+86.2	Repeater	Post-Echo	95.4	39	11.8
G01-09	**1**	0	-3.8	+85.6	Repeater	Post-Echo	92.3	35	5.4
G01-10	**0**	**1**	**-13.5**	**-65.1**	**Main**	**Pre**-Echo	**82.2**	**0**	**0.0**
G01-11	**1**	0	-16.9	+59.8	Repeater	Post-Echo	100.7	45	24.2
G01-12	**1**	0	-17.4	**+136.3**	Repeater	Post-Echo	104.4	50	39.6
G01-13	0	**1**	-5.9	+71.2	Repeater	Post-Echo	78.1	**0**	8.3
G01-14	0	0	-14.1	**-30.8**	Repeater	**Pre**-Echo	74.4	**0**	16.4
G01-15	**1**	0	-14.3	+65.8	Repeater	Post-Echo	98.8	44	17.0
G01-16	**1**	0	-13.7	+71.8	Repeater	Post-Echo	98.9	43	16.4
G01-17	0	**1**	-16.6	**-3.0**	**Main**	**Pre**-Echo	96.4	37	0.5
G01-18	0	0	-5.1	+77.7	Repeater	Post-Echo	103.2	47	6.5
G01-19	**2**	0	-17.1	**-35.3**	Repeater	**Pre**-Echo	96.8	42	28.6
G01-20	**1**	**1**	-11.3	**-66.7**	**Main**	**Pre**-Echo	88.7	33	0.2
G01-21	**3**	0	-10.5	+67.3	Repeater	Post-Echo	88.9	33	12.6
G01-22	**2**	**1**	-11.6	+63.7	Repeater	Post-Echo	81.2	25	13.5
G01-23	**2**	0	-15.4	**-7.7**	Repeater	**Pre**-Echo	98.6	43	26.2
G01-24	**2**	0	-16.7	**+136.3**	Repeater	Post-Echo	94.7	39	31.5
G02-01	0	0	-10.2	**-67.9**	**Main**	**Pre**-Echo	94.6	38	0.6
G02-02	**2**	0	-8.4	+65.0	Repeater	Post-Echo	95.8	40	8.9
G02-03	**3**	0	-17.6	**+136.3**	Repeater	Post-Echo	93.8	38	22.4
G02-04	**1**	0	-17.5	**-45.6**	Repeater	**Pre**-Echo	96.3	41	25.8
G02-05	**1**	0	-15.2	+99.5	Repeater	Post-Echo	92.7	37	19.6
G02-06	**1**	0	-16.5	+88.1	Repeater	Post-Echo	84.7	**0**	18.3
G02-07	**1**	0	-17.4	**+136.3**	Repeater	Post-Echo	94.6	39	21.3
G02-08	**0**	**0**	**-6.7**	**-48.6**	**Main**	**Pre**-Echo	**95.8**	**0**	**0.8**
G02-09	**0**	**0**	**-4.7**	**-53.2**	**Main**	**Pre**-Echo	**100.2**	**0**	**1.2**
G02-10	**1**	0	-6.4	**-59.3**	**Main**	**Pre**-Echo	95.9	40	0.9
G02-11	**2**	0	-11.1	+62.5	Repeater	Post-Echo	87.6	31	10.4
G02-12	**0**	**0**	**-11.9**	**-57.3**	**Main**	**Pre**-Echo	**88.1**	**0**	**0.6**
G02-13	**2**	**0**	**-0.7**	+51.8	Repeater	Post-Echo	**91.7**	**0**	**3.5**
G02-14	**1**	0	-7.3	+47.6	Repeater	Post-Echo	77.2	19	8.5
G02-15	**2**	0	-17.5	**-126.9**	Repeater	**Pre**-Echo	95.3	39	12.1
G02-16	**2**	0	-17.1	**-67.6**	Repeater	**Pre**-Echo	89.9	33	20.7
Minimum	0	0	-17.6	-126.9	---	---	74.4	19.0	0.0
Maximum	3	1	-0.1	136.3	---	---	108.1	53.0	46.2
Average	1	0.125	-12.2	+25.7	---	---	94.1	39.9	14.5
Median	1	0	**-13.6**	**+61.2**	---	---	**95.3**	**39.5**	**12.4**
# of sites = 0	**14**	**35**	---	---	---	---	---	---	---
# of sites > 0	**26**	**5**	---	---	---	---	---	---	---

Note: The signal propagation transit time *between* the main transmitter and repeater transmitter sites is about: 18.2 miles * 5.4 µsecs/mile = **98.3** µsecs

Note: The South Mountain signal was the largest signal at only **8** of the test sites while the Shaw Butte Mountain transmitter was the largest signal at **32** sites.

Note: G01-10, G02-08. G02-09. G02-12, & G02-13 are **revisited** sites; only G02-12 and G02-13 sites did **not** have error-free reception with a *directional* antenna.

Table A4-5 SFN Statistical Field Test Analysis Results: *Regional Summary* (**40** sites).

Site Groups	Test Parameter	Units	30' AGL Results			12' AGL Results		
*	*	*	SFN ON	SFN OFF	Δ On-Off	SFN ON	SFN OFF	Δ On-Off
G01 Northern Grid	Median Field. Strength	dBμV/m	96.6	79.1	17.5	88.9	69.0	19.9
24 sites	Service	%	87.5	66.7	10.8	83.3	62.5	20.8
21.3 miles	Median Margin	dB	43.0	30.0	13.0	33.0	18.0	15.2
G02 Eastern Grid	Median Field. Strength	dBμV/m	94.2	80.2	14.0	86.4	72.4	14.0
16 sites	Service	%	50.0	37.5	12.5	50.0	31.3	18.7
20.3 miles	Median Margin	dB	38.0	39.0	**-1.0**	29.5	22.0	7.5
TOTALS	Median Field. Strength	dBμV/m	**95.3**	**79.5**	**15.8**	**86.7**	**70.2**	**16.5**
40 sites	Service	%	**80.0**	**57.5**	**22.5**	**75.0**	**60.0**	**15.0**
20.5 miles	Median Margin	dB	**39.5**	**33.0**	**6.5**	**30.5**	**20.0**	**10.5**

Table A4-6 Failure analysis summary: SFN ON versus SFN OFF for **30' AGL** measurements

Test Site Name	Receive Antenna Type	SFN ON Reception Parameters			SFN OFF Reception Parameters			SFN Transmitters Echo Profile Comments
		Field Strength	SNR Received	Site Margin	Field Strength	SNR Received	Site Margin	
(*)	(Omni, Dir)	(dBμV/m)	(dB)	(dB)	(dBμV/m)	(dB)	(dB)	(*)
G01-10	Omni Test #1	82.2	45.3	**0**	82.2	45.3	26	-13.5 dB, 65.1 us **Pre**-Echo
Tx1: **24.7** miles **0** obstructions	Omni Test #2	91.4	54.5	**36**	91.4	54.5	36	-14.6 dB, 134.1 us **Pre**-Echo
Tx2: **7.3** mi **1** obstruction	Dir Test	95.7	58.8	**41**	95.8	58.9	41	-16.6 dB, 20.8 us **Post** Echo
G02-08	Omni Test #1	95.8	58.9	**0**	95.0	58.1	40	-6.7 dB, 48.6 us **Pre**-Echo
Tx1: **19.5** miles **0** obstructions	Omni Test #2	94.2	57.3	**0**	94.0	57.1	40	-10.3 dB, 48.3 us **Pre**-Echo
Tx2: **8.4** miles **0** obstructions	Dir Test	98.8	61.9	**44**	98.9	62.0	45	-16.6 dB, 82.2 us **Post**-Echo
G02-09	Omni Test #1	100.2	63.3	**0**	99.0	62.1	44	- 4.7 dB, 53.2 us **Pre**-Echo
Tx1: **20.5** mi **0** obstructions	Omni Test #2	100.4	63.5	**0**	100.0	63.1	46	-12.7 dB, 53.5 us **Pre**-Echo
Tx2: xx miles **0** obstruction	Dir Test	103.4	66.5	**48**	103.5	66.6	49	-15.8 dB, 96.9 us **Pre** Echo
G02-12	Omni Test #1	88.1	51.2	**0**	87.5	50.6	33	-11.9 dB, 57.3 us **Pre**-Echo
Tx1: **22.4** mi **0** obstructions	Omni Test #2	87.4	50.5	**0**	87.0	50.1	33	-13.6 dB, 57.0 us **Pre**-Echo
Tx2: **9.6** miles **0** obstruction	Dir Test	100.5	63.6	**0**	100.4	63.5	46	-15.6 dB, 57.0 us **Pre** Echo
G02-13	Omni Test #1	91.7	54.8	**0**	88.2	51.3	34	-0.7 dB, 51.8 us **Post** Echo
Tx1: **21.1** miles **2** obstructions	Omni Test #2	91.6	54.7	**0**	90.1	53.2	36	-5.6 dB, 51.5 us **Pre**-Echo
Tx2: **9.3** mi **0** obstructions	Dir Test	93.5	56.6	**0**	93.6	56.7	40	-12.8 dB, 51.5 us **Pre** Echo

Note: "Omni" refers to *omni-directional* receive antenna; "Dir" refers to *directional* antenna.
"Omni Test #1" reflects the *original* test site visit while "Omni Test #2" and "Dir Test" reflect a test site *revisit*.

Note: During the revisits, the omni-directional antenna was measured again as a reference, and results were not always identical to first visit.

Note: In all **5** cases above, Main (Tx1) signal was the largest SFN signal except for **G02-13** (where almost a 100% echo was present: -0.7 dB).

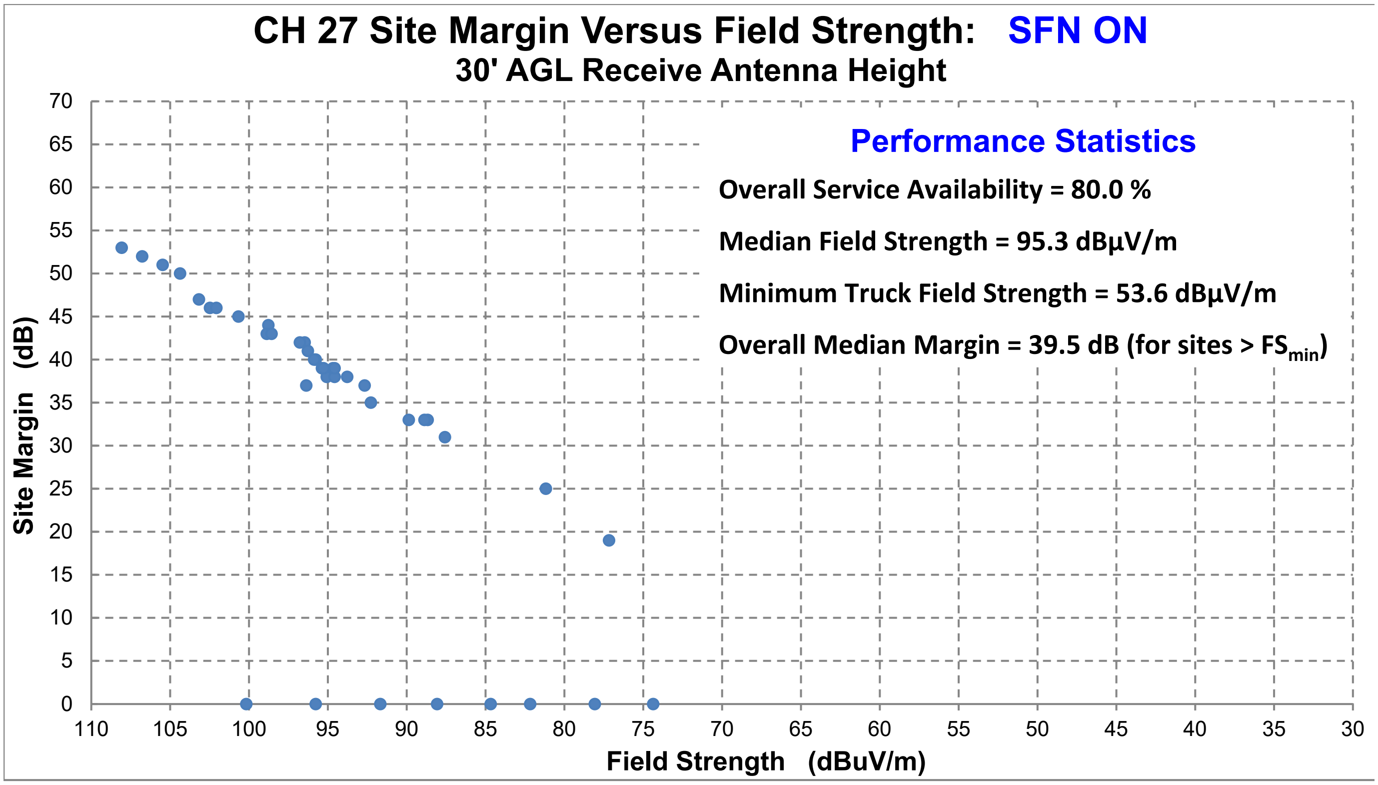


Figure A4-1a CH 27 Margin versus Field Strength plot at 30' AGL (*with* SFN).

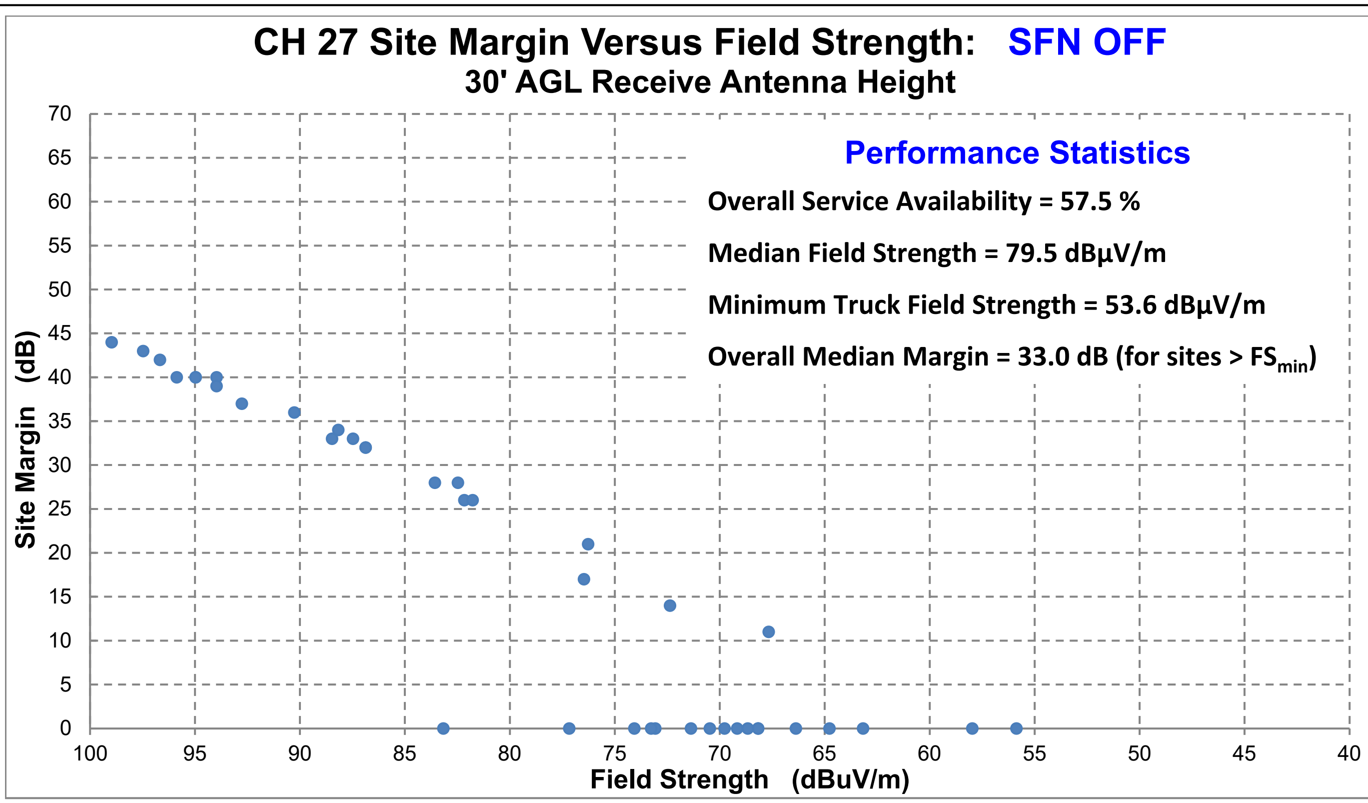


Figure A4-1b CH 27 Margin versus Field Strength plot at 30' AGL (*without* SFN).

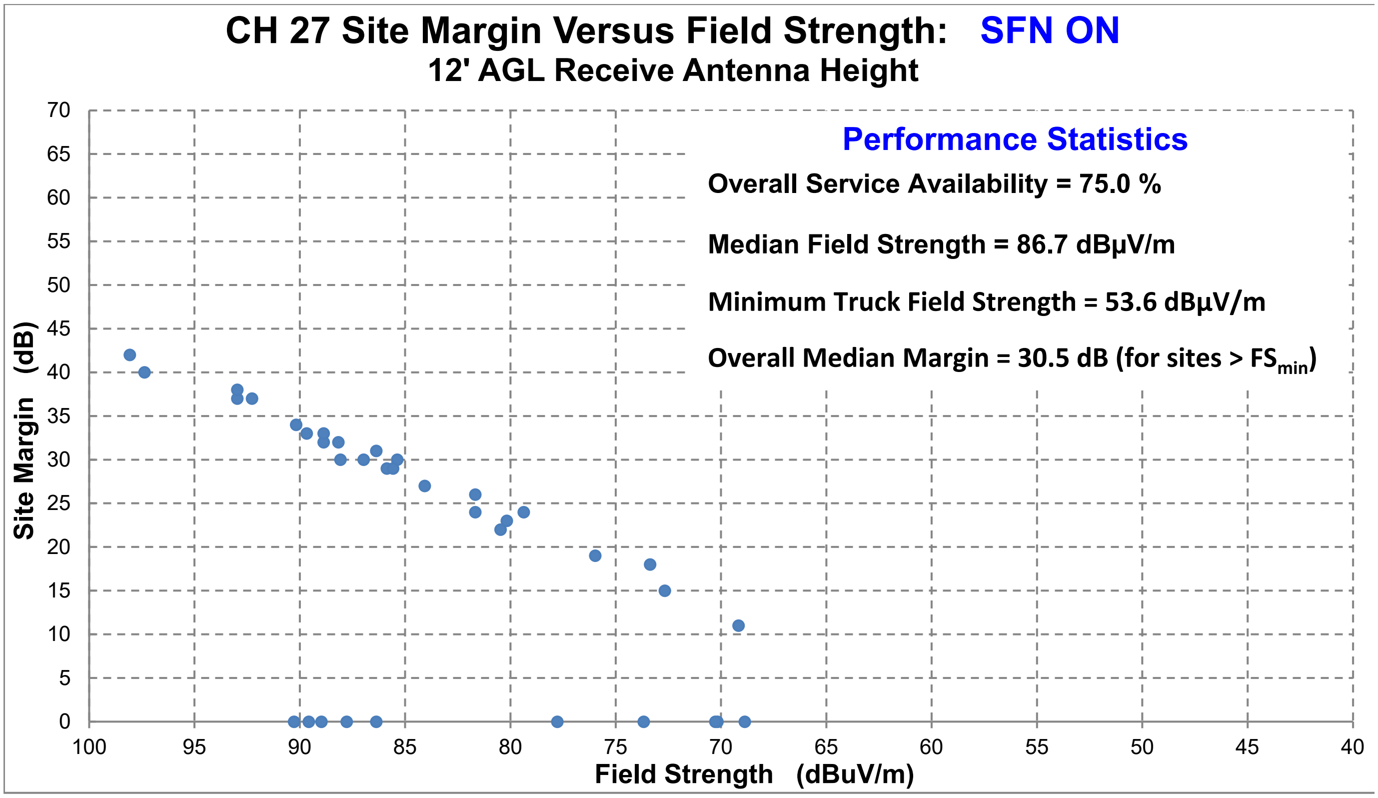


Figure A4-1c CH 27 Margin versus Field Strength plot at 12' AGL (*with* SFN).

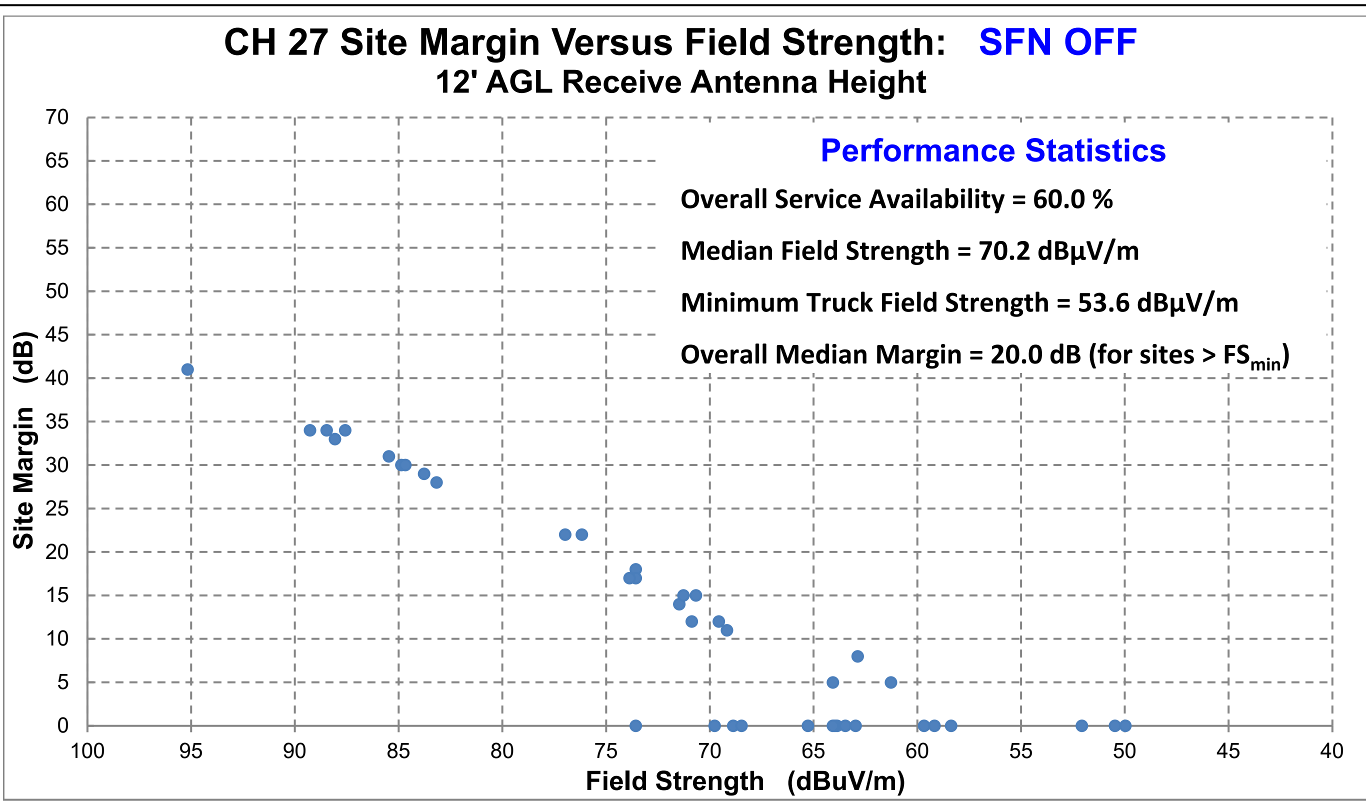


Figure A4-1d CH 27 Margin versus Field Strength plot at 12' AGL (*without* SFN).