ATSC 3.0 Automotive Field Tests

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***Abstract*—NEXTGEN TV services are poised to deliver not only enhanced video and audio but also data streams using an IP protocol stack. This allows television broadcasters to address new business models and use cases such as data delivery to automotive applications. This report examines preliminary automotive reception field tests to prove viability of using NEXTGEN TV for automotive applications. The prototype receivers were 4-diversity and single diversity demodulators coupled with NEXTGEN TV protocol stack software implementation in Android OS. Field test results in both Phoenix AZ and Santa Barbara, CA show good reception of audio/video media even at highway speeds along with ancillary non-real time data and thus show NEXTGEN TV is capable to support the automotive industry with a broadcast automotive infotainment service and/or fleet management.**

***Index Terms*—ATSC 3.0, NEXTGEN TV, automotive, field tests, digital terrestrial broadcasting.**

I. Introduction

NEXGEN TV is the public name for the latest suite of broadcast standards from ATSC, a.k.a ATSC 3.0. The suite of standards are listed in A/300 are publicly available [6] . ATSC's A/53 standard [4] was designed to replace analog NTSC grade 3 reception for stationary devices only. It was first published in 1995 and adopted by the FCC in 1996. ATSC developed A/153 [5] (a.k.a. ATSC M/H) to address mobility. It was first published in 2009 and was designed for mobile services using a portion of A53's payload. Success of the ATSC M/H standard was mixed for a variety of reasons, both technical and business related. ATSC 3.0 suite of standards is now an Orthogonal Frequency Division Multiplexed (OFDM) based broadcast emission with very strong Low-Density Parity Check (LDPC) based Forward Error Correction (FEC) that supports mobile reception. This paper investigates that aspect of mobile support for automotive applications. Work was conducted by Sony Semiconductor, Sony Home Entertainment and Sound products of America (SHES-A), Pearl TV consortium Phoenix Partners, and News Press and Gazette broadcasting to investigate the feasibility of ATSC 3.0 for the automotive industry. UniMas is a member of Pearl TV Phoenix Partnership and the local affiliate KFPH-CD was instrumental in providing NEXTGEN TV emission in Phoenix. KSBB enabled transmission in Santa Barbara to test a variety of terrains. Both transmissions simultaneously contained a stationary service and an automotive service operating with a more robust quality of service (QoS) configuration. Stationary reception was configured to match ATSC 1.0 RF contour ranges (15dB SNR).

The goal of this field test was to examine a possible automotive service mode to ensure that ATSC 3.0 can be of value to broadcasters and automotive manufacturers. Use-cases for a robust automotive mode include vehicle software updates, navigation aids (map updates), infotainment solutions, and so on.

Sony Semiconductor has developed a new world-wide demodulator chip (CXD2885GG-W named CLOVER) that supports diversity using maximal ratio combining (MRC) with 4 tuner / demodulators. That chip along with software written by SHES-A was used in this field test with a variety of antenna combinations. One combination shows performance of ATSC 3.0 with a diverse set of antenna types to prove operation of the system, rather than received signal strength on any given antenna. Another combination used the same antenna type for each tuner input to investigate reliability of performance in a practical receiver solution.

Results from Phoenix testing show the difference in antennas, not necessarily difference in antenna position in a vehicle are beneficial. High gain antennas support reception in low signal strength areas whereas passive antennas support reception in high signal strength areas. The antennas were a mix of omni-directional and directional and were mounted outside the vehicle so that the effects of signal angle of arrival could be reduced.

Single-diversity case was tested with a USB dongle solution developed by SHES-A for comparison to the 4-diversity results. Sony Semiconductor has also developed a world-wide demodulator chip (CXD6801GL named LUKE) with one tuner / demodulator combination. This solution cannot take advantage of the multiple antennas, but it is a common practical solution. Performance is still impressive.

This paper investigates how the ATSC 3.0 (NEXTGEN TV) standard can support multiple services, shows an example configuration for automotive service, tests the configuration with separate solutions in a variety of markets, terrains and drive conditions, tests simultaneous delivery of non-media essence files in non-real time and draws conclusions of NEXTGEN TV automotive service viability.

II. ATSC A/322 Standard

ATSC 3.0 A/322 physical layer protocol standard [2] has a wide range of physical layer operating points in terms of

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payload and required received signal strength. A graphic of these operating points is provided in Figure **II.1**. The ATSC 1.0 operating point is shown with a six-point black star at 15dB SNR. Operating points for ATSC M/H are shown with three five-point black stars located at 3, 5 and 8dB SNR. ATSC 3.0 is shown with multi-color indicators located close to the Shannon Limit (plotted in blue).

A mobile service operating below 5dB SNR could use, for example, modulation and coding rates (ModCods) of 16QAM or QPSK with low code rates as indicated with Type-A LDPC codes of code rate 7/15 and below (see A/322 Table 6.5) [2]. A stationary service with its operating point of around 15dB SNR could use ModCods above 16QAM and high code rates as indicated with Type-B LDPC codes of code rate 8/15 and above (see A/332 Table 6.7) [2].

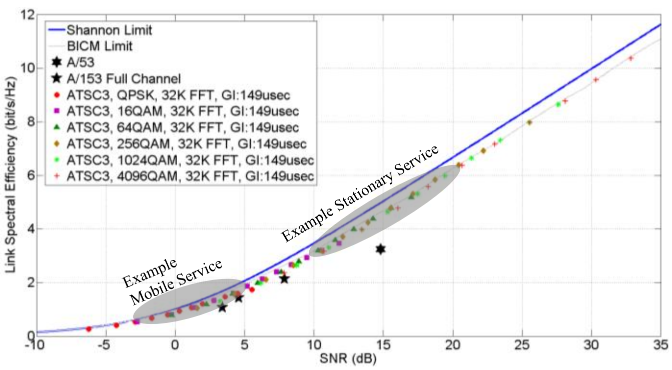

Figure II.1 ATSC Operating Points

In ATSC 3.0, multiple operating points can be emitted (broadcast) simultaneously, this is called Multiple PLP (MPLP) operation. The choice of operating points depends on what Quality of Service (QoS) is desired. For a mobile service, a low SNR operating point (for example < 5dB) is beneficial for wider coverage and robustness to interference. For a stationary service, a higher SNR operating point (for example >15dB) to support higher payloads is beneficial. The physical layer functional blocks in the MPLP case is shown in Figure **II.2**. The blue boxes indicate functional block outputs.

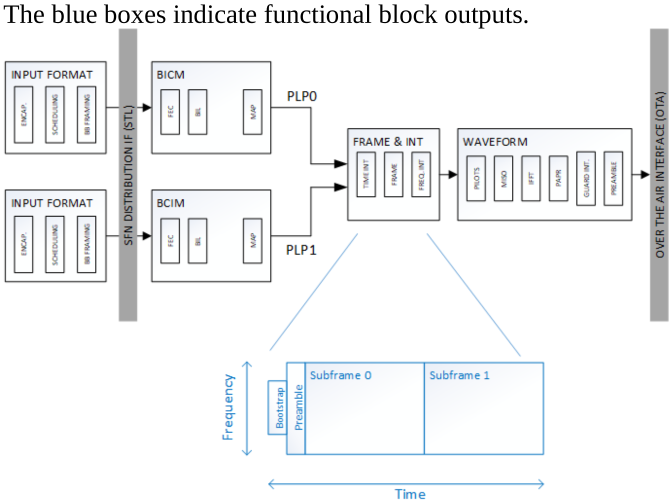

Figure II.2 PHY Functions

Here PLP0 operating point could be from the example mobile service area in Figure **II.1**. PLP1 operating points could be from the example stationary service area in Figure **II.1**.

III. Transmitter Setup

To support Doppler considerations for automotive use-cases, the FFT size should be selected with carrier spacing large enough to tolerate high speeds. 8K FFT carrier spacing for 6MHz channels is just over 843Hz. For RF TV channel 17 operating at 491MHz center frequency, that should support maximum vehicle speeds of 515m/s (1152 MPH) using QPSK at 2/15 coderate in 8K FFT. For RF TV channel 35 operating at 599MHz center frequency, that should support maximum vehicle speeds of 422m/s (944 MPH) using QPSK at 2/15 coderate. Guard interval selection should take account the environment echo delays. For the field testing areas selected, there are some rolling hills, rural canyons and light urban canyon terrain causing small echo delays, and a selection of 1024 sample Guard Interval supporting 148 μsec echoes should be more than enough to ensure no echoes occur outside the guard interval. Other physical layer parameters are listed in the next section.

A. *Phoenix Transmitter*

KFPH-CD UniMas affiliate in Phoenix, AZ was able to configure their ATSC 3.0 transmitter for multiple PLPs. Their station is carrying other network affiliates signals of KTVW-DT Univision, KPNX (NBC affiliate), KPHO (CBS affiliate) and a test program for a total of 5 programs. For this test, they put KFPH-CD on PLP0 for robust reception and the NBC and CBS affiliates on PLP1 for capacity to cover ATSC 1.0 contour range. KFPH-CD transmitter is located on top of South Mountain with 15kWatts of Effective Radiated Power (ERP) on RF channel 35 (599 MHz center frequency).

Specific parameters of the channel configuration are shown in Table **III.1**.

B. *Santa Barbara Transmitter*

KSBB-CD News Press & Gazette in Santa Barbara was also able to configure their ATSC 3.0 transmitter for multiple PLPs. Their station is carrying 4 digital channels. PLP0 has LLS and channel 17.3 media essence only. PLP1 has 17.1 (with a broadcaster application), 17.2 (also with a broadband application), and 17.4 (with an NRT broadcaster application). Separate from the public media streams, an NRT object delivery on 17.3 was sent for testing of non-media essence related file reception.

For this test, program 'ATCst3' channel 17.3 (KIFI-TV) was put on PLP0 for robust reception and the programs 'ATCst2' channel 17.2 (KNPN-LD), 'ATCst1' channel 17.1 (KEYT-TV) and 'ATCst4' channel 17.4 (KYAV-LD) was put on PLP1 for stationary service to cover ATSC 1.0 contour range. KSBB-CD transmitter is located on top of Miramonte Hill with 15kWatts of Effective Radiated Power (ERP) on RF channel 17 (491 MHz center frequency).

Specific parameters of the channel configuration are shown in Table **III.1**.

C. *Transmission Configuration*

Table III.1 Transmission Parameters

Parameter	PLP0 (Mobile)	PLP1 (Stationary)
Subframe	0	1
FFT Size	8K	16K
Pilot Pattern	6_4	12_4
Pilot boost	4	
Guard Interval	G5_1024 (148us)	
Preamble Mode	(Basic: 3, Detail: 3) Pattern Dx = 3	
Frame Length	155 msec	
# of Symbols	41	39
Frequency Interleaver	On	On
Time Interleaver	Hybrid Mode 16 FEC Blocks 1 TI Block (51.1msec time spread)	Hybrid Mode 63 FEC Blocks 2 TI Block (47.8msec time spread)
Modulation	16 QAM	256 QAM
Code Rate	7/15	10/15
Code Length	64K	
Bit Rate (Mbps)	3.093	18.166
Required C/N (dB) (AWGN)	5.2	17.1

These parameters were used in both locations.

IV. Driving Routes and Signal Coverage

Signal strength coverage areas of particular transmitters can be obtained from www.rabbitears.info and the Phoenix transmitter coverage is shown in Figure **IV.1**. Areas of white indicate signal strength below 41dBu using the Longley-Rice model. Very weak signal strength areas in red are of interest to ATSC 3.0 with the lower SNR operating point of PLP0. Drive routes were chosen with these red areas of interest.

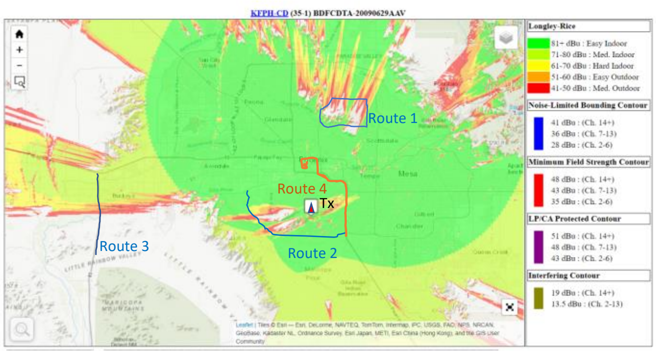

Figure IV.1 Phoenix Signal Coverage and drive routes

For Phoenix, three drive routes were originally selected as shown in Figure **IV.1** with blue lines. Route 1 was a circle around Paradise Valley, north of Camelback Mountain, a total distance of about 19 miles. Route 2 was on Route 202 highway south of South Mountain, a total distance of approximately 16 miles. Route 3 was on Highway 85 on the west side of Phoenix between I-10 and I-8 Interstates, and the total distance was approximately 11 miles.

These proposed drive routes were subject to improvisation during the visit. A fourth route turned out to be useful that tested downtown Phoenix and an I-10 freeway tunnel under Central Avenue showed remarkable reception results. This route shown in dark orange in Figure **IV.1**, has a total distance of approximately 22 miles.

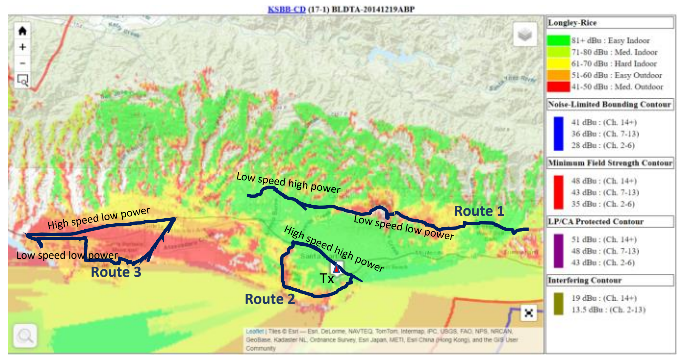

Figure IV.2 Santa Barbara Signal Coverage and drive routes

For Santa Barbara, three drive routes were selected as shown in Figure **IV.2** with dark blue lines. Route 1 was on Highway 192, a total distance of approximately 20 miles. Route 2 was a circle around the transmitter on Miramonte Hill , a distance of approximately 4.5 miles. Route 3 was a circle through UCSB on the north side of town, a distance of approximately 11 miles.

Routes were driven twice to capture the difference between active and passive antennas. The intent was to test the four reception scenarios listed below.

1. High power above -50dBm, highway speed above 55 MPH
2. High power above -50dBm, low speed below 45 MPH
3. Low power below -50dBm highway speed above 55 MPH
4. Low power below -50dBm low speed below 45 MPH

Phoenix drive Route 1 can exercise all 4 of those scenarios with varying signal strengths in one single drive route. Other areas are selected to duplicate these speed options in different markets.

V. Receiver Setup

A. Hardware

The 1-diversity USB dongle receives its RF signal through a single antenna via F-connector and is then passed into Sony Semiconductor's CXD6801GL chip. Once a television frequency is tuned and the demodulator is configured for that selected standard, the demodulator outputs data into formatted, fixed-length, 188-Byte, divided-ALP (ATSC 3.0 Link-layer Packets in the case of ATSC 3.0 selection) packets. Output data is then streamed across a USB 2.0 interface using a separate transport stream-to-USB bridge chip.

The 4-diversity USB dongle receives its RF signal through four pairs of UHF and VHF antennas via SMA-style connectors which are then passed into Sony Semiconductor's CX2885GG-W chip. This chip contains four digital television tuners, four multi-region digital television demodulators, as well as an integrated CPU and USB 2.0 bridge functions. Both the CX2885GG-W, as well as the dongle's supporting hardware, were designed for automotive-grade environments. In these test cases presented, all four tuners and demodulators are enabled, utilizing 4-diversity Maximum Ratio Combining (MRC) technology. Demodulated output signals are formatted into ALP packets and then streamed over the USB 2.0 interface to an external host (Nvidia Shield TV Pro in these tests). Provisions for increased USB VBUS supply current over USB Type-C were included into the board's hardware design allowing the dongle to be completely powered from a single USB Type-C host device.

B. Software

The software for the Sony Semiconductor evaluation platform is a windows-based solution for tuning and logging demodulator and RF data, combined with GPS coordinates from a USB connected GPS receiver. This software solution does not decode the ALP data that is being output from the demodulator.

To supplement this, SHES-A provided their Android based ATSC3 receiver prototype software JAVA code running on Nvidia 'Shields' with Android 8.0 OS. This prototype software solution has the capability to decode and render ATSC3 defined HEVC formatted video and Dolby AC-4 formatted audio delivered by either ROUTE or MMTP protocols. In addition, the SHES-A software supports Non-Real Time (NRT) data delivery via ROUTE into flash memory for broadcaster applications as well as an Electronic Service Guide.

The Android prototype software can process data received from a variety of sources. In the case of the testing presented here, the sources were the USB dongles (1-diversity and 4-diversity) mentioned above in Section A which deliver ALP data in fixed length (188byte) packets using a proprietary protocol from Sony Semiconductor. This fixed length ALP data is received over a USB 2.0 interface.

In addition to A/V decoding and rendering, the prototype software supports capture and replay of this ALP data, as well as conversion to IP data in a pcap formatted file. This capability allows for post optimization of receiver software code or playback to exhibit robust behavior in an automotive environment where packet and signal loss is common. It also allows for post analysis of the extent to which packet and signal loss impact video, audio reception and NRT data reception.

In order to support conversion to IP based pcap format, the prototype software makes use of the PTP timestamp and plpId (physical layer pipe identifier) data that Sony Semiconductor includes in ALP extension headers. By separating ALP data in each PLP and having accurate timing information, pcap conversions can be fed to a DekTec DTU-315 (or similar) modulator. RF playback allows for any ATSC3 receiver to then replay the semi-realistic automotive environment data. Note that only semi-realistic playback is possible since incomplete or corrupted ALP data packets are removed.

C. Field Test configuration

A test vehicle was prepared with the wiring diagram shown in Figure **V.1**.

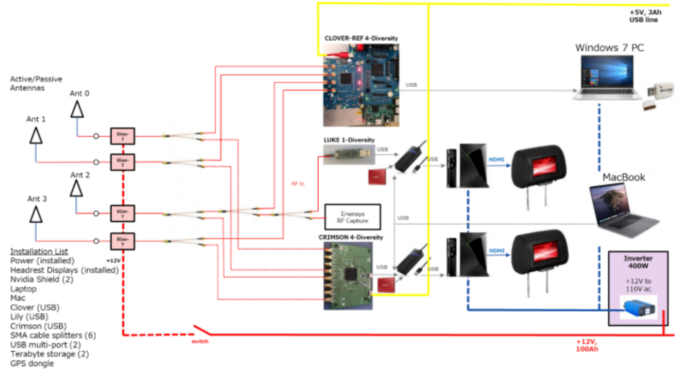

Figure V.1 Receiver installation

This allowed comparisons of Sony Semiconductors evaluation board which recorded demodulator registers approximately every 0.5 second intervals to Sony San Diego team's evaluation board and to a 1-diversity USB dongle solution as well. GPS locations were captured together with Sony Semiconductor's logs to record location with performance. For playback of the channel conditions, RF recording was also captured with Enensys RFCatcher tool and was always connected to antenna #2. Sony San Diego evaluations of 4-diversity and 1-diversity included recording of ALP data for capturing media streams from the broadcaster.

Signal splitting was done with Bingfu 4G LTE antenna adapter splitter cable with 50 ohm 'low loss' RG316 cable of 15cm in length. It should be noted that this splitter causes signal loss of approximately 6dB, which would not be expected in a commercial implementation.

The antennas used in Phoenix are listed in Table **V.1**, and antennas used in Santa Barbara are listed in Table **V.2**

Table V.1 Phoenix Antennas

Tuner 0: Active CarTV Tuner Dipole, 25dB Gain	Dark Orange color PLOTS
Tuner 1: Active King OA8501 Directional, high Gain	Gold color PLOTS
Tuner 2: Active Continu.us CA-1500 Omni-Directional, 20dB Gain	Green color PLOTS
Tuner 3: Passive Chaowei DVB66, 5dB Gain	Blue color PLOTS

The results of Table **V.1** clearly show about a 20dB disparity between antennas. The active antennas #1 and #2 did not behave as passive antennas when power was off. Results show those two antennas did not pass any signal when there was no power.

Table V.2 Santa Barbara Antennas

Tuner 0: Funke ADSC 410, ~16dB Gain	Dark Orange color PLOTS
Tuner 1: Funke ADSC 410, ~16dB Gain	Gold color PLOTS
Tuner 2: Funke ADSC 410, ~16dB Gain	Green color PLOTS
Tuner 3: Funke ADSC 410, ~16dB Gain	Blue color PLOTS

Here, the active antennas behaved as passive antennas when power was off. Each drive route was done twice to gain insights for passive and active antenna performance.

VI. Results

Both PLP's data (ALP) were recorded along with demodulator lock status at each position. Four-diversity results from the Sony Semiconductor evaluation board are shown in the figures with map backgrounds. PLP0 with its 5dB operating point clearly performs better with reception in more locations.

Green indicates no BCH errors and red indicates one or more BCH errors, i.e. the FEC block is in error.

A. High signal strength area

This drive route has diffraction signals on the east side of South Mountain shown by the PLP0 ALP errors in red, a tunnel of I-10 highway where it crosses Central Avenue and some tall buildings in downtown Phoenix. PLP0 performance was impressive, especially in the tunnel. It is hypothesized that signal ducting was occurring in the tunnel because broadcast television was actively being watched half-way through the tunnel.

Both PLPs were recorded and demodulator lock was recorded at each position. PLP0 results are shown in Figure **VI.1** and PLP1 results are shown in Figure **VI.2**. The tunnel is located in the top left-hand corner of the drive route. Green indicates no packet errors and red indicates more than one packet error.

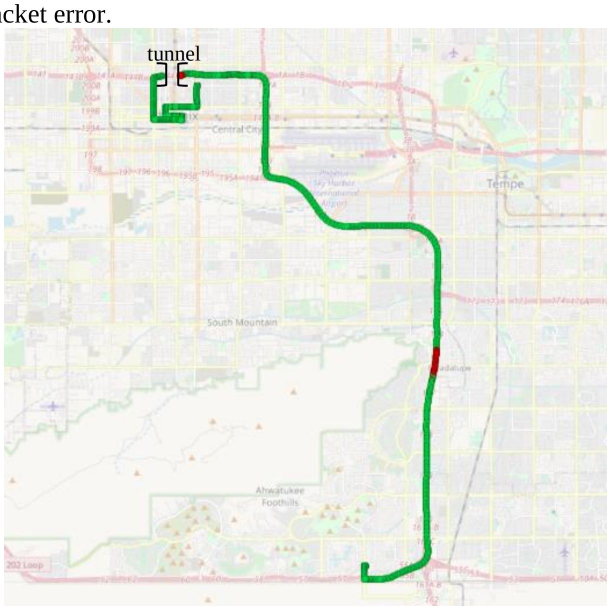

Figure VI.1 Strong Signal PLP0 drive route

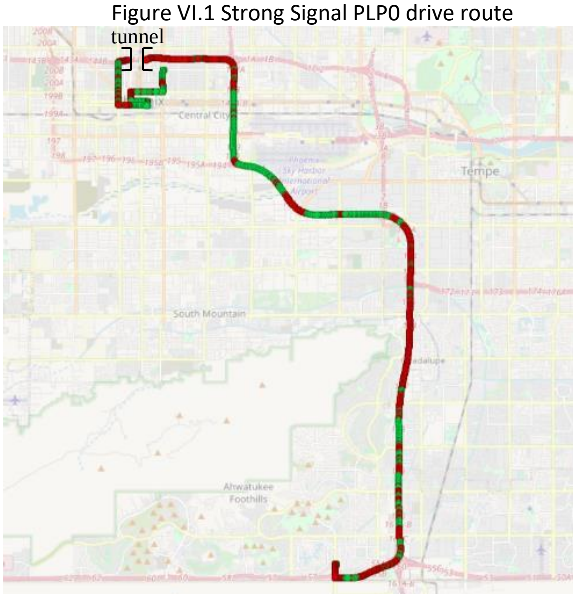

Figure VI.2 Strong Signal PLP1 drive route

PLP0 with mobile service shows superior performance when there is sufficient signal strength. Furthermore, the sign al strength was available in almost all tested locations, with the exception of the diffraction location east of South Mountain. This correlates well to the signal diffraction indicated with a smear of red going across the east side of Interstate 10 of drive Route 4 in Figure **IV.1**. The purpose of this drive route was to have high signal power available while testing various receptions speeds. There was a little bit of urban canyon environment, but not too difficult.

Received signal strength and corresponding SNR for all 4 tuner/demodulators are shown in Figure **VI.3**. Consistently strong signal strength of over -50 dBm with spikes to -30 dBm is seen from the active antennas. SNR is nicely correlated with received signal strength where SNR is on top and received signal strength is on the bottom.

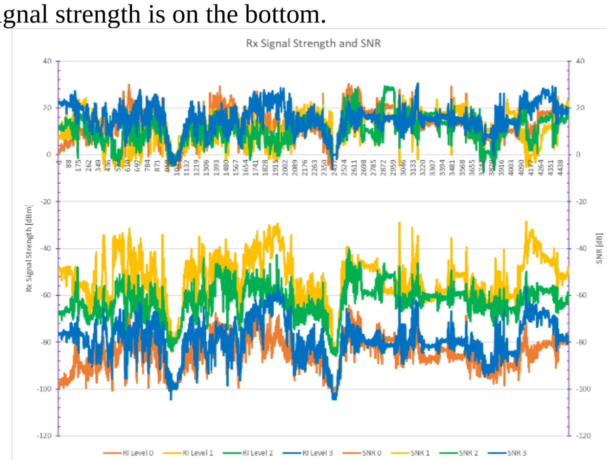

Figure VI.3 Strong Signal received signal strength and SNR

The specific low SNR regions correspond to the diffraction zone on Interstate-10 highway and the tunnel under Central Avenue and a few places in downtown Phoenix.

SNR comparisons to packet errors vs. time is shown in Figure **VI.4**. PLP0 of automotive service operating at 5dB SNR has errors in orange and PLP1 of stationary service operating at 15dB SNR has errors in gray. Clearly there are more errors in PLP1 with the many gray packet error counts. This graph is compelling to show robust automotive reception throughout a market where there is strong received signal energy because there are very few PLP0 errors, which are shown in orange. Two separate horizontal lines indicate the QoS thresholds of 15dB (gray) in PLP1 and 5dB (orange) in PLP0.

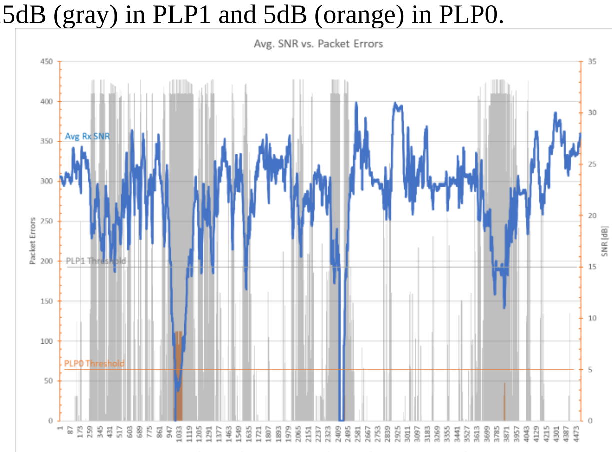

Figure VI.4 Strong Signal SNR and Packet Errors

The orange packet error counts show up in the diffraction area in the beginning of the drive and the tunnel in the middle of the drive. SNR drops a little in the downtown area drive but not enough to produce errors. Even when the SNR is above 15dB SNR, packet errors exist in PLP1 due to other channel conditions. PLP0 proves to be very robust.

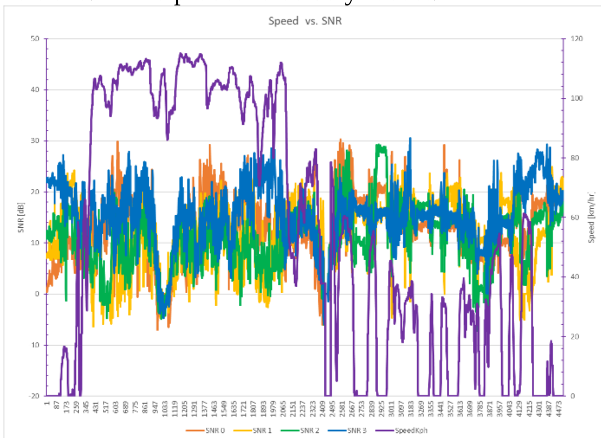

Figure VI.5 Strong Signal SNR and Speed

Figure **VI.5** shows SNR and speed vs. time. High speed is seen on the highway in the first part of the drive followed by low speed travel throughout downtown area. There is no direct correlation between SNR and speed. Even at high speeds, there is no packet loss and SNR tracks the received signal strength.

This is reasonable given the OFDM parameter configuration of 8K FFT with 16QAM and coding rate of 7/15 being robust enough to tolerate these speeds of over 100km/hr. Packet errors are a result of low received signal strength (subsequently once the SNR recovered there were no packet errors) and not the speed of the vehicle.

B. Mixed signal strength

In Phoenix, drive Route 1 includes all 4 reception scenarios of signal strength and speed. Both PLPs were recorded and demodulator lock was recorded at each position. Four-diversity results from the Sony Semiconductor evaluation board are plotted vs. vehicle position. PLP0 results are shown in Figure **VI.6** and PLP1 results are shown in Figure **VI.7**. PLP0 with 5dB operating point clearly performs better with reception in more locations. Green indicates no BCH errors and red indicates one or more BCH errors, i.e. the FEC block is in error.

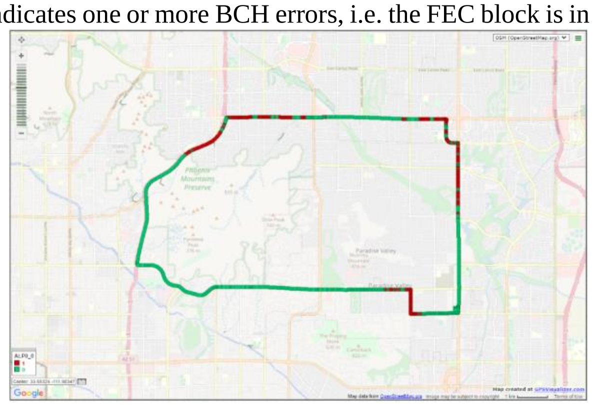

Figure VI.6 Mixed Signal PLP0 drive route

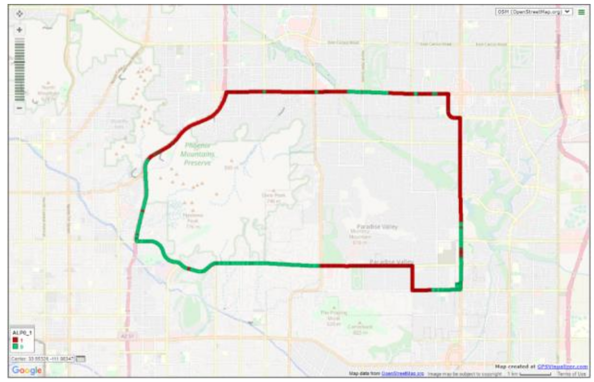

Figure VI.7 Mixed Signal PLP1 drive route

Received signal strength and corresponding SNR for each antenna are shown in Figure **VI.8**. Received signal strengths vary from below -90 dBm to about -40 dBm. SNR is correlated with received signal strength where SNR is on top and received signal strength is on the bottom.

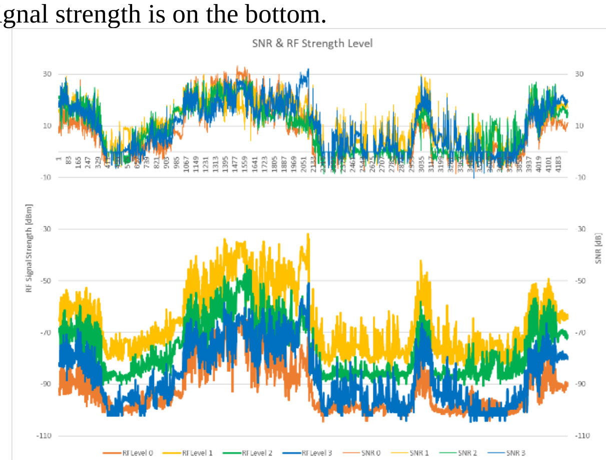

Figure VI.8 Mixed Signal received signal strength and SNR

Here, the low received signal strength contributes to the packet errors. Channel conditions or speed were not the dominant contributors to that error count. When there was not enough signal strength to demodulate the signal, output ALP packets have errors. Otherwise, when there is enough signal strength, correct ALP packets result.

This drive route had periods of strong signal strength, followed by very low signal strength due to the shadowing effects of Camelback Mountain blocking the signal from South Mountain. There was hope to have at least 5dB of signal strength, but the results prove the signal strength was lower. This just provides justification for a Single Frequency Network (SFN) to fill-in the areas north of Camelback Mountain.

The areas of no reception even for PLP0 correlate to the shadow areas (white and red areas) crossing drive Route 1 shown in Figure **IV.1**.

SNR comparisons to packet errors vs. time are shown in Figure **VI.9**. PLP0 of the automotive service operating at 5dB SNR shows errors in orange and PLP 1 of stationary service operating at 15dB SNR shows errors in gray. Clearly there are more errors in PLP1. PLP0 was more robust, but still suffered in very low signal strength locations.

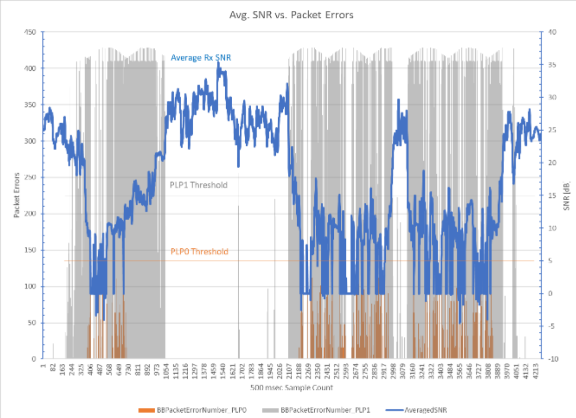

Figure VI.9 Mixed Signal SNR and packet errors

In this drive Route 1 there was also interference and multipath impacts performance in PLP1 as indicated with the gray error counts shown even when average SNR is above 15dB. Error counts for PLP0 do not follow this pattern though, as the lower modulation order and coderate help protect the data.

Generally, 4-diversity works advantageously as the maximal ratio combining will use the best reception signals, which could be receiving better signal strength due to angle of arrival or position on the vehicle. If a vehicle is driving away, a rear-facing antenna will pick up stronger signal that a forward-facing antenna.

C. *Low signal strength*

In Santa Barbara, the Highway 192 drive route tested low speed and low reception strength in mountain terrain. It also tested antennas of the same type. Both PLPs were recorded and demodulator lock was recorded at each position. Four-diversity results from the Sony Semiconductor evaluation board are plotted vs. vehicle position. PLP0 results are shown in Figure **VI.10** and PLP1 results are shown in Figure **VI.11**. PLP0 with 5dB operating point clearly performs better with reception in more locations. Green indicates no BCH errors and red indicates one or more BCH errors, i.e. the FEC block is in error.

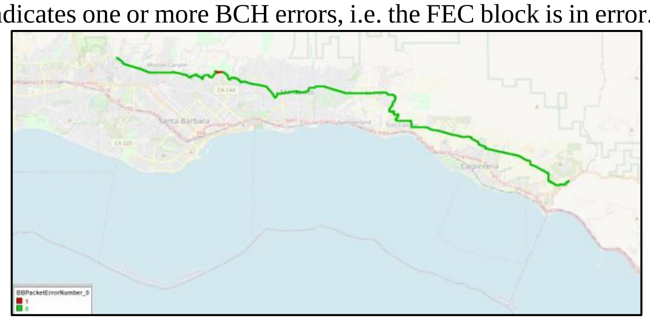

Figure VI.10 Low Signal PLP0 drive route

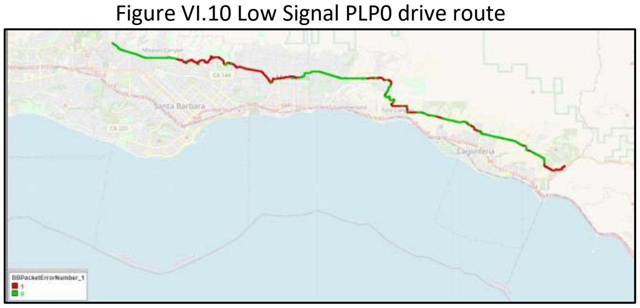

Figure VI.11 Low Signal PLP1 drive route

Received signal strength and corresponding SNR for each antenna are shown in Figure **VI.12**. SNR is correlated with received signal strength where SNR is on top and received signal strength is on the bottom. The signal strength averages -70 dBm with lows around -80 dBm and only at the end of the drive does it increase to around -50 dBm.

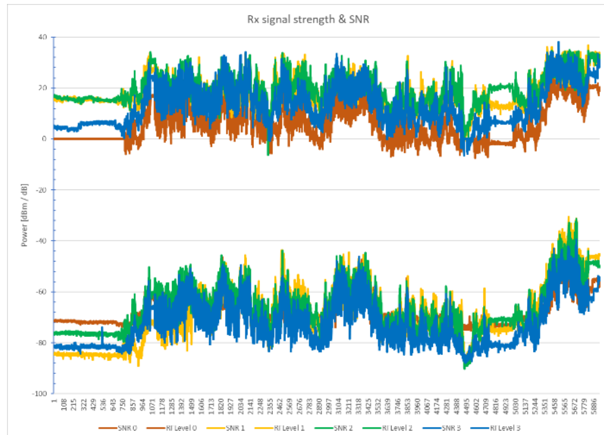

Figure VI.12 Low Signal received signal strength and SNR

Despite the received signal strength being so low a majority of the time, demodulation was successful with 5dB operating point in PLP0 to render error free reception.

SNR comparisons to packet errors vs. time is shown in Figure **VI.13**. PLP0 of automotive service operating at 5dB SNR shows errors in orange and PLP1 of stationary service operating at 15dB SNR shows errors in gray.

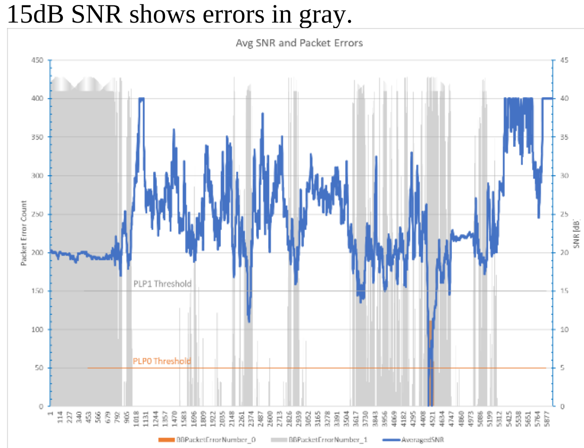

Figure VI.13 Low Signal SNR and packet errors

Clearly there are more errors in PLP1, even when the average SNR was above 15dB. PLP0 was more robust, even though there are packet errors, the receiver never lost demodulator lock. In this result there is also interference and multipath with negative impacts against performance, but the 4-diversity tuner works to combine low SNR reception and constructively add signal strengths when possible which is why the receiver keeps lock and continue demodulating even when one tuner has less than 5dB SNR.

D. *Active vs. Passive antenna*

One of the discoveries of this field test is that the active antennas did not pass signal when they were off. The powered function acted as an on/off switch rather than a passive vs. active switch. The clear difference is the received signal strength from active vs. passive antennas in Santa Barbara highway 192 plotted as shown in Figure **VI.14** and Figure **VI.15**.

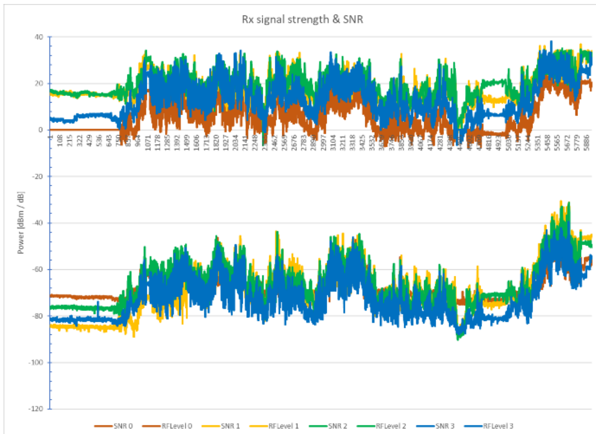

Figure VI.14 Active Antenna signal strength

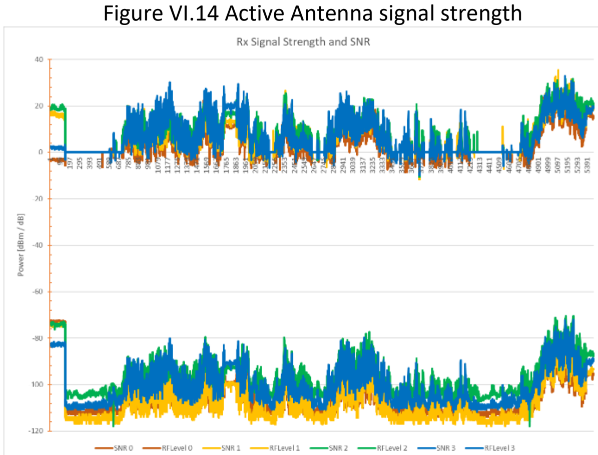

Figure VI.15 Passive Antenna signal strength

Clearly all received signal strengths are shown to drop by 30 dB in the left part of Figure **VI.15** when in power is turned off.

As expected, the average SNR is a bit lower for the passive antenna case as shown in Figure **VI.17**. At the beginning of the passive antenna run, the antennas were powered and it can be seen when power is turned off; the SNR drops to zero as received signal strength goes below -100 dBm. After which, when signal strength gets above -100 dBm, SNR starts being reported with successful demodulation.

Active antennas are beneficial, but depending on channel conditions, if there is strong signal the antenna gain section will become non-linear and result in inter-symbol interference (ISI) well before a tuner can compensate. In those conditions, a passive antenna will benefit.

The impact of active vs. passive antennas on errors are shown in Figure **VI.16** and Figure **VI.17**. Active antennas provide benefit when channel conditions have low signal strength, but passive antennas benefit in high signal strengths, depending on the channel conditions. Either way, having a QoS PLP with 5dB operating point clearly benefits reception with either active or passive antennas.

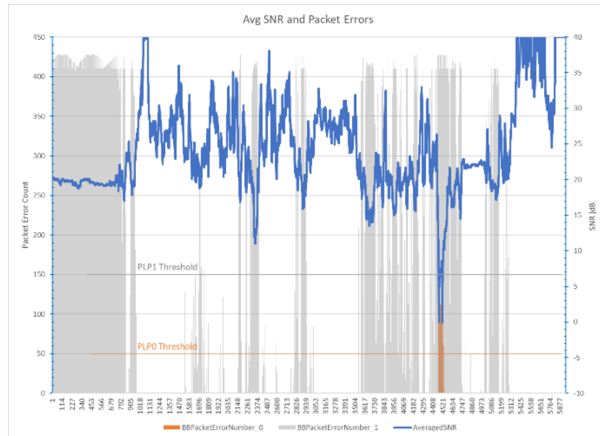

Figure VI.16 Active Antenna packet errors

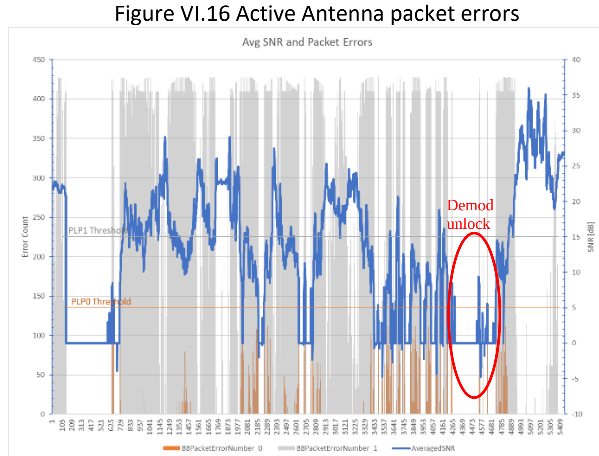

Figure VI.17 Passive Antenna packet errors

With the passive antenna, when the received signal strength is low, the SNR drops to zero and no demodulation takes place. The demodulator loses lock and does not output any ALP data. This is indicated when the average SNR is zero and there are no ALP errors (gray or orange lines as circled in red in Figure **VI.17**).

Active antennas perform better, but to accommodate all channel conditions of strong and weak signal strength, it could be beneficial to have a mix of active and passive antennas.

E. 1-Diversity vs.4-Diversity

The USB dongle-based solution that was connected to one selected antenna showed similar SNR patterns to the 4-diversity but with more variance coming from the one antenna. Starting with Phoenix driving Route 1, the USB dongle used the active omni antenna, where the difference of 4-diversity is seen with the average SNR being larger than any 1-diversity SNR in Figure **VI.18**. The 4-diversity SNR is plotted in blue and the 1-diversity SNR is plotted with green columns. Data capturing of the 1-diversity USB dongle was not as fast (at every 10 seconds) as the 4-diverisity at every 500msec, hence the green line spacing. Further, the SNR of the 1-diversity followed the SNR results of that particular demodulator connected to the same antenna.

The cumulative SNR from the MRC algorithm combining the 4 demodulator outputs is plotted in dark orange in Figure **VI.18**. The individual demodulator SNR's constructively add when the incoming signal is complementary (same phase as another antenna) to create a higher total SNR almost always and there is a very large gain in a few areas.

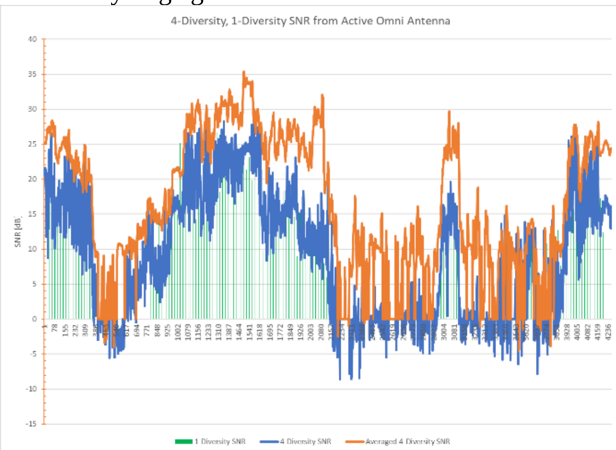

Figure VI.18 Diversity SNR Gain

The behavior of the USB dongle being sourced from one antenna showed that a burst of errors would happen and then lose ALP stream lock. Some time would be needed to recapture ALP lock and then settle down.

A similar pattern can be seen in Phoenix driving Route 4. Here the USB dongle solution was connected to the passive omni antenna. Figure **VI.19** shows the similar pattern of 4-diversity average SNR being greater than any 1-diversity SNR. Again, the 4-diversity SNR is plotted in blue and 1-diversity SNR plotted in green columns that almost match the 4-diversity gain SNR.

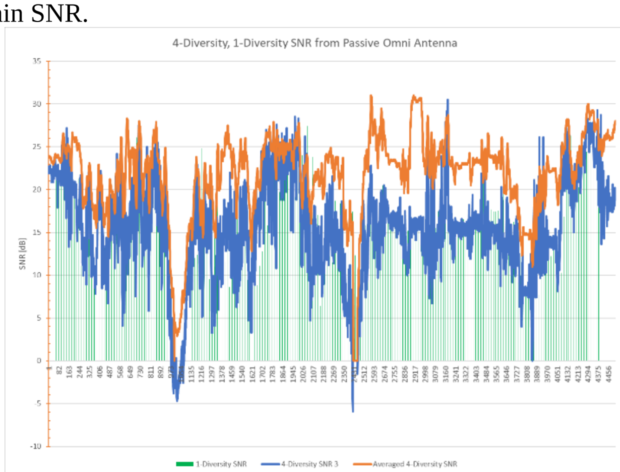

Figure VI.19 Diversity SNR Gain - trial 2

It makes sense that the USB dongle is dependent on the one connected antenna. When there is no other antenna source to pick up a different angle of arrival or separate phase of the incoming waveform, performance is entirely dependent on that single antenna.

When there is decent received signal strength, the USB dongle works as designed. But having 4-diversity allows demodulators to keep lock on at least one incoming signal. Plus, if the incoming signals are cohesive in nature, then SNR can complement for added benefit as shown in the dark orange plots. With non-cohesive incoming signals, if signal strength decreases below the QoS operating point (e.g., 5dB for PLP0) on some antennas, reception can still continue with antennas that receive stronger signal. Diversity can only help reception.

F. Generalized receiving behavior

How can this field test apply to other locations?

The data can be combined in a way to show errors when demodulators are locked. Any errors that occur when demodulators are locked indicate performance issues not due to low signal strength and possible are due to channel conditions. Using the results from all driving routes, the data can be blended in received signal strength bins vs. speed in [km/hr] and plotted.

Sorting out the errors that are due to low received signal strength (no ALP lock) and plotting the percentage of correctly received packets vs. speed shows the remaining errors which are due to channel effects of multipath and Doppler. Those are the errors that are interesting and can show sensitivity levels for the different PLP configurations. Figure **VI.20** shows the percentage of valid PLP0 ALP packets and Figure **VI.21** shows the percentage of valid PLP1 ALP packets, with received signal strength (shown on the y-axis) vs. speed (shown on the x-axis at the top).

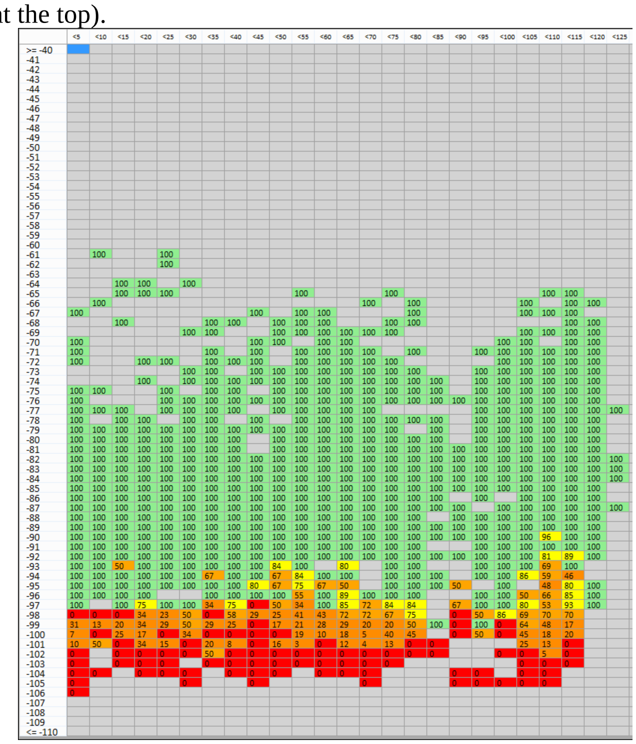

Figure VI.20 Amalgamated PLP0 results

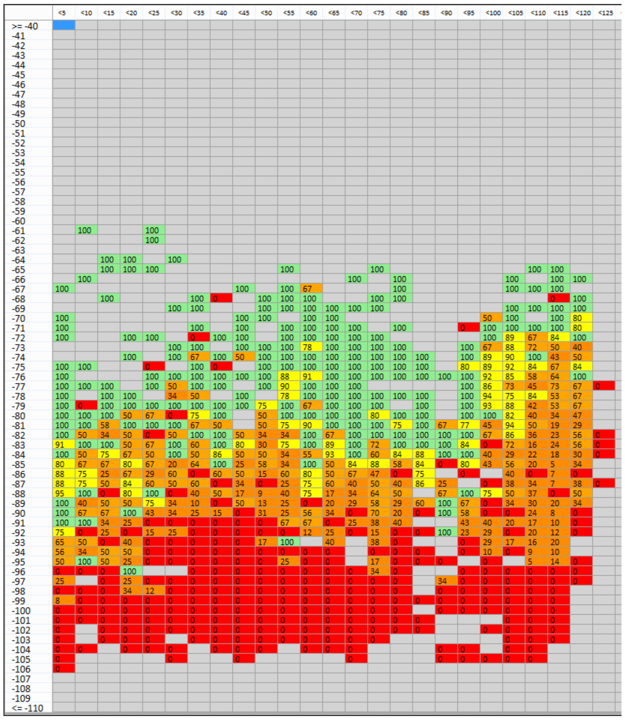

Figure VI.21 Amalgamated PLP1 results

First note that PLP0 with the low operating point can tolerate the high Doppler. PLP1 operating at 15dB SNR shows more orange cells (probability of errors) at the high Doppler. This matches the mobile reception results of similar second-generation broadcast systems as reported in [1].

These figures also show the sensitivity difference between PLP0 and PLP1 correlating around 10dB. But PLP1 also indicates a much higher error rate even with decent signal strength. This indicates that QoS PLP is not configured for automotive reception, only stationary.

In these tests PLP0 payload was 3Mbit/sec. Broadcasters can tradeoff payload vs. robustness in their markets with this type of graph. If receivers can tolerate the channel with decent sensitivity and reliably receive all data no matter what vehicle speeds, would more capacity be of interest? Or would they keep that robustness and tune PLP1 for more robust reception? These tradeoffs can be examined for each business case.

VII. NRT File Delivery

Delivering files of any sort is a key use-case for broadcasters, especially for an automotive customer who would like to update an entire fleet of vehicles with new firmware. Verification of robust file reception outside media essence without adverse effects in the media is required. In Santa Barbara, a simple picture was sent with the time to show when that file was sent. Signaling of this file uses ROUTE protocol described in A/331 [3].

Just before 8am in the morning of Nov 25th, the signaling of the S-TSID looked like


```
<S-TSID xmlns="tag:atsc.org,2016:XMLSchemas/ATSC3/Delivery/S-TSID/1.0/" xmlns:fdt="urn:ietf:params:xml:ns:fdt"
xmlns:afdt="tag:atsc.org,2016:XMLSchemas/ATSC3/Delivery/ATSC-FDT/1.0/">
  <RS dIpAddr="239.255.17.3" dPort="8000" sIpAddr="10.172.17.50">

...AFTER VIDEO AND AUDIO DESCRIPTION...

    <LS bw="100000" tsi="231">
      <SrcFlow>
        <EFDT>
          <FDT-Instance afdt:efdtVersion="7" Expires="3846789000" afdt:maxTransportSize="0"/>
        </EFDT>
      </SrcFlow>
    </LS>
  </RS>
</S-TSID>
```


The next minute the S-TSID signaling changed to:


```
<S-TSID xmlns="tag:atsc.org,2016:XMLSchemas/ATSC3/Delivery/S-TSID/1.0/" xmlns:fdt="urn:ietf:params:xml:ns:fdt"
xmlns:afdt="tag:atsc.org,2016:XMLSchemas/ATSC3/Delivery/ATSC-FDT/1.0/">
  <RS dIpAddr="239.255.17.3" dPort="8000" sIpAddr="10.172.17.50">

...AFTER VIDEO AND AUDIO DESCRIPTION...

    <LS bw="100000" tsi="231">
      <SrcFlow>
        <EFDT>
          <FDT-Instance afdt:efdtVersion="8" Expires="3846844800" afdt:maxTransportSize="403317">
            <fdt:File Content-Length="403317" Content-Location="NPG-11_25_8A.png" Content-Type="image/png" TOI="10003"/>
          </FDT-Instance>
        </EFDT>
        <Payload codePoint="128" formatId="1" frag="0" order="true"/>
      </SrcFlow>
    </LS>
  </RS>
</S-TSID>
```


The extracted S-TSID sections show a Transport Session Identifier (TSI) of 231. That is where the NRT file will be delivered. There is a new file 'NPG-11_25_8A.png" being sent. Careful signaling is required. HELD signaling should not be used, only indicate a separate file is being delivered in the Source Flow XML with the Extended-FDT element. The TOI value cannot be zero '0' as that indicates SLS. The example provided here is TOI value '10003'.

To confirm this analysis, the Rx logs were examined.


```
2020-11-25 08:00:57.149 14127-14270/com.sony.tv.app.atsc3receiver2_0 D/BroadcastData:  gap add initial to /NPG-11_25_8A.png.new
2020-11-25 08:00:57.149 14127-14270/com.sony.tv.app.atsc3receiver2_0 V/BroadcastData: Allocate memory for NRT file: /NPG-
11_25_8A.png.new with memory requirement: 403317
2020-11-25 08:00:57.149 14127-14270/com.sony.tv.app.atsc3receiver2_0 V/BroadcastData: Create NRT file from middle of receiving during a
write session: /NPG-11_25_8A.png.new
2020-11-25 08:00:57.784 14127-14293/com.sony.tv.app.atsc3receiver2_0 D/StorageController:    FileName: /NPG-11_25_8A.png.new Content
Length: 403317
2020-11-25 08:01:30.536 14127-14270/com.sony.tv.app.atsc3receiver2_0 D/BroadcastData: Attempting to write a NRT file whilst one already
exists that we are writing. Will return this one/NPG-11_25_8A.png.new
2020-11-25 08:01:30.712 14127-14294/com.sony.tv.app.atsc3receiver2_0 D/MainController: File received: /NPG-11_25_8A.png
```


The receiver has received signaling to allocate memory for the NRT file of size 403317. Roughly 33 seconds later, the complete file was written into memory. The picture received was as below.

The S-TSID indicates that 100 kHz bandwidth was allocated and it took 33 seconds to completely receive the file. Checking the math: 400 kBytes = 3,200,000 bits. At 100,000 bits/sec bandwidth that should take around 32 seconds. Therefore, we could confirm correct operation. This file was captured on the first transmission, no carousel of data was needed.

VIII. Future Testing

Results indicate that diffractions and signal shadowing from mountains affected proper reception even with a high QoS PLP operating at 5dB. To get close to 100% market coverage, a Single Frequency Network (SFN) is required. Testing automotive performance in SFN's could indicate full coverage of a market and provide viable automotive business models. Reception is very robust at 5dB QoS, but there is no compensation for no signal strength. Furthermore, to reach long drive on highways, perhaps an even greater QoS at 0 dB SNR could provide longer reaches.

Sensitivity results depend on antenna selection and different antennas would like to be tested. Channels 17 and 35 were used here and span the UHF band well, so a repeat of this field test with different antennas could show correlation to sensitivity levels.

IX. Conclusion

Automotive field testing indicates that an ATSC 3.0 solution, physical layer configuration along with upper layer protocol stack can provide robust reception of data at all vehicular speeds. The data in this case was video / audio media, but ATSC 3.0 can deliver any kind of IP data as was tested with a picture file. There was no correlation of packet errors to speed in any scenario. PLP0 had a clear improvement in operating performance that can be seen in the lower number of packet errors of PLP0 compared to the high packet error counts of stationary service QoS in PLP1. This field test shows that broadcasters can transmit both high throughput stationary services as well as robust automotive services simultaneously to target a diverse set of receiving devices. Delivery of data of any kind (infotainment, software updates, navigation maps, etc.) is robust and reliable.

Sony's CXD2885GG chip is shown to have decent sensitivity for each tuner along with good implementation of MRC algorithm to combine 4-diversity inputs of different antennas. Absolute sensitivity levels are subject to calibration of cable losses, splitters, tuner noise figure, etc. Performance of the PLPs depended on the channel conditions and environment, but clearly the performance of the 5dB operating point in PLP0 far surpassed that of PLP1 which models ATSC 1.0 operating point of 15dB SNR.

Diversity only helps. Diversity in antenna selection (active and passive) and diversity in antenna count (2 or more) to receive incoming signals from many different angles and enable complementary SNR gains when possible.

The goal was to prove a viable automotive solution for data delivery. With the proper configuration, the data here shows ATSC 3.0 can deliver and support that business use case.

Acknowledgment

The authors would like to thank all the colleagues at Sony Semiconductor and our broadcast friends at Pearl TV consortium, and News Press and Gazette staff. Their help in this field test was instrumental to ensure proper testing and success.

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[3] ATSC Signaling, Delivery, Synchronization, and Error Protection, ATSC A/331, January 2021
[4] ATSC 1.0, ATSC A/53, Parts 1-6, January 2007
[5] ATSC M/H, ATSC A/153, Part 1, March 2013
[6] https://www.atsc.org/atsc-documents/type/3-0-standards/

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