ATSC Recommended Practice: ATSC 3.0 Field Test Plan (A/326)

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Table of Contents

Index of Figures

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1. SCOPE

This document presents the objectives of, and general methodology for, conducting field tests of the ATSC 3.0 over-the-air (OTA) terrestrial digital television (DTV) system. The physical layer of this DTV standard provides a comprehensive and flexible tool-box of configuration options and features for digital broadcast transmission, and allows broadcasters to pursue many different modulation and coding configurations (see Annex B). The intention of this document is to summarize and describe RF field environment performance test processes and provide analysis for manufacturers attempting to verify functionality of their receiver's physical layer design or for broadcasters trying to evaluate coverage and service in their market. This document should be used by manufacturers and broadcasters to ensure their field testing is conducted with a consistent methodology.

The scope of the work includes field performance of reception, demodulation, and recovery of the transmitted data. However, the scope of the work herein is *not* concerned with the decoded data signals except when these signals are used as a means to determine that the data has been correctly recovered (e.g., viewing video to determine error threshold).

The following is the recommended methodology and procedures to verify ATSC 3.0 receiver design performance in the field as well as to provide broadcasters with assurance of DTV coverage and service for transmission modes that might be used in various system deployments that employ outdoor, indoor, portable, pedestrian, and mobile reception.

1.1 Introduction and Background

This document presents the recommended objectives and methodology for the development of ATSC 3.0 field test plans. Such plans facilitate the gathering of field data of DTV systems in order that useful conclusions about broadcast DTV signal coverage, service area, and receivability may be obtained. While tests and measurements may be conducted for certain and specific reasons and objectives by those performing the tests, the resultant field test data may be analyzed by others for completely different reasons and objectives. Consequently, it is recommended that all tests and measurements documented herein be conducted and data gathered using this set of principles and general procedures in order that data analysis from a variety of different tests and their resultant conclusions are both consistent and meaningful. Care should be taken in describing exact field test parameters, conditions, and assumptions in order to provide the best opportunity for accurate and proper sharing of the resulting data.

The ATSC 3.0 physical layer has many configurations, and multiple transmission modes that may be used in field tests. This document includes recommended test processes, including basic diagrams of the equipment interconnection that should be used to perform the test, the test signal parameters under which the devices under test (DUT) are configured, the RF test parameters to be measured, and the test methodology to be employed in gathering measured data performance in the field. Results of these tests should indicate realistic performance levels of devices in the market, and should also aid broadcasters in their network planning efforts (e.g., coverage and service evaluation).

The DUT(s) employed in these field tests may also have different device types, ranging from experimental implementations to fully integrated units with display screens, and can include both professional and consumer products. Tests in this document should, if possible, accommodate all device types. Data error thresholds can be determined with different measurements, either *objectively* with data bits / packets or *subjectively* with observation of errors in motion pictures.

1.2 Testing Objectives

This document provides recommendations for the development of field test plans to meet the following objectives. DTV Field Test Plan implementations may focus on certain aspects of these objectives depending upon the immediate requirements of the testing entity. The five different types of reception (outdoor, indoor, portable, pedestrian, and mobile) often have overlapping objectives. However, there are important differences between the five different types of reception that are also described in this document.

Testing may be conducted for specific goals and objectives that include, but are *not* limited to, the following:

- Identify and statistically characterize propagation variables that exist throughout a variety of urban, suburban, and rural RF environments, including inside buildings.
- Measure *actual* "service" (reception capability) versus *predicted* "coverage" (signal strength) in a variety of field environments.
- Obtain a statistically-meaningful correlation between field strength and service for better outdoor and indoor DTV service prediction through uniform data-gathering test *methodologies*, test *procedures* and test *equipment*.
- Determine desired-to-undesired (D/U) ratios for the resolution of interference considerations (e.g., CCI, ACI, "taboo" channels, etc.) among ATSC 1.0, ATSC 3.0, LTE, and other signals.
- Collect data useful in verifying and improving the DTV system performance.
- Compare various system modulation/coding configurations.
- Compare one digital transmission system to another (e.g., ATSC 1.0 versus ATSC 3.0).
- Compare various DTV broadcast facilities.
- Compare SFN network parameters.
- Compare various ATSC 3.0 transmission and receiving components.
- Compare different generations of ATSC 3.0 transmission and receiving components.
- Determine indoor reception characteristics in a variety of urban, suburban, and rural RF environments, including determining signal loss and signal quality degradation compared to outdoor reception.

The goal is to provide a uniform series of test methodology and procedures that allow data from one test to be easily and accurately compared with results of other tests conducted by various organizations in different locations at different times.

1.3 Organization

This document is organized as follows:

- Section 1 – Outlines the scope of this document and provides a general introduction.
- Section 2 – Lists references and applicable documents.
- Section 3 – Provides a definition of terms, acronyms, and abbreviations for this document.
- Section 4 – Introduction to field performance testing

- Section 5 – Field test measurement methodologies
- Section 6 – Field test measurement procedures
- Annex A – ATSC 3.0 Overview
- Annex B – Test signal configuration settings examples

2. REFERENCES

All referenced documents are subject to revision. Users of this Recommended Practice are cautioned that newer editions might or might not be compatible.

The following documents, in whole or in part, as referenced in this document, contain specific provisions that should be followed in order to facilitate implementation and application of this Recommended Practice.

[1] IEEE: "Use of the International Systems of Units (SI): The Modern Metric System," Doc. SI 10, Institute of Electrical and Electronics Engineers, New York, N.Y.

[2] United States Code of Federal Regulations Title 47, Part 73.686 – "Coverage Measurements", www.gpo.gov.

[3] United States Code of Federal Regulations Title 47, Part 73.622 – "DTV Allocations", www.gpo.gov.

[4] United States Code of Federal Regulations Title 47, Part 73.625 – "DTV Coverage of Principal Community and Antenna Systems", www.gpo.gov.

[5] ATSC: "ATSC: A/321, System Discovery and Signaling," Doc. A/321:2016, Advanced Television System Committee, Washington, D.C., 23 March 2016

[6] ATSC: "ATSC Standard: Physical Layer Protocol," Doc. A/322:2016, Advanced Television System Committee, Washington, D.C., 7 September 2016.

[7] "Digital HDTV Grand Alliance System Record of Test Results," submitted to the FCC Advisory Committee on Advanced Television Service (ACATS) by Advanced Television Test Center, Inc., Advanced Television Evaluation Laboratory of the Communications Research Centre (Industry Canada), Cable Television Laboratories, Inc., Systems Subcommittee Working Party 2, Association for Maximum Service Television, Inc., Public Broadcasting Service, Hitachi America, Ltd., and IBM; October 1995. http://apps.fcc.gov/ecfs/comment/view?id=154611

[8] ATSC: "ATSC Recommended Practice: Developing DTV Field Test Plans," Doc. A/75, Advanced Television System Committee, Washington, D.C., 26 July 2001.

[9] ETSI TR 101 290: "Measurement Guidelines for DVB Systems", V1.2.1 (2001-05) European Broadcasting Union, www.etsi.org.

3. DEFINITION OF TERMS

With respect to definition of terms, abbreviations, and units, the practice of the Institute of Electrical and Electronics Engineers (IEEE) as outlined in the Institute's published standards [1] are used. Where an abbreviation is not covered by IEEE practice or industry practice differs from IEEE practice, the abbreviation in question will be described in Section 3.2 of this document.

3.1 Compliance Notation

This section defines compliance terms for use by this document:

should – This word indicates that a certain course of action is preferred but not necessarily required.

should not – This phrase means a certain possibility or course of action is undesirable but not prohibited.

3.2 Acronyms and Abbreviations

The following acronyms and abbreviations are used within this document.

A/D	Analog-to-Digital
ACI	Adjacent Channel Interference
AGC	Automatic Gain Control
AGL	Above Ground Level
ALP	ATSC 3.0 Link-Layer Protocol
ATSC	Advanced Television Systems Committee
AWGN	Additive White Gaussian Noise
BCH	Bose-Chaudhuri-Hocquenghem
BER	Bit Error Rate
BICM	Bit Interleaved Coded Modulation
BP	Bandpass
BSR	Baseband Sampling Rate
C/I	Carrier-to-Interference ratio
C/N	Carrier-to-Noise ratio
C-POL	Circular Polarization
CCI	Co-Channel Interference
CCIR	Consultative Committee on International Radio
CFO	Carrier Frequency Offset
CRC	Cyclic Redundancy Check
CTI	Convolutional Time Interleaver
dBm	dB above 1 mW
dBμV	dB above 1 μV
D/A	Digital-to-Analog
D/U	Desired/Undesired ratio
DTV	Digital Television, *nominally* ATSC 1.0
DUT	Device Under Test
E-POL	Elliptical Polarization
ERP	Effective Radiated Power
FCC	Federal Communications Commission
FDM	Frequency Division Multiplexing
FEC	Forward Error Correction
FFT	Fast Fourier Transform
GI	Guard Interval
GPS	Global Positioning System
HAAT	Height Above Average Terrain
HAGL	Height Above Ground Level
HD	High Definition

H-POL Horizontal Polarization
HTI Hybrid Time Interleaver
IF Intermediate Frequency
IP Internet Protocol
IP3 Third-Order Intermodulation Products
ITI International Telecommunications Union
kHz kilo Hertz
L1 Layer 1
LAPR Licensed-to-Average Power Ratio
LDM Layered Division Multiplexing
LDPC Low-Density Parity Check
LTE Long Term Evolution
Mbps Megabits per second
MHz Mega Hertz
MIMO Multiple Input Multiple Output
MISO Multiple Input Single Output
NoC Number of Carriers
NUC Non-Uniform Constellations
OFDM Orthogonal Frequency Division Multiplexing
OTA Over The Air
PAPR Peak-to-Average Power Ratio
PER Packet Error Rate
PHY Physical Layer
PLP Physical Layer Pipe
PRBS Pseudo-Random Bit Sequence
QAM Quadrature Amplitude Modulation
QPSK Quadrature Phase Shift Keying
RF Radio Frequency
RMS Root Mean Square
Rx Receiver
SD Standard Definition
SFN Single Frequency Network
SISO Single Input Single Output
SNR Signal-to-Noise Ratio
STL Studio Transmitter Link
TASO Television Allocation Study Organization
TDCFS Transmit Diversity Code Filter Set
TDM Time Division Multiplexing
TI Time Interval
TOA Threshold of Audibility
TOV Threshold of Visibility
TPO Transmitter Power Output

Tx	Transmitter
TxID	Transmitter Identification
UDP	User Datagram Protocol
UHD	Ultra High Definition
UHF	Ultra High Frequency
USB	Universal Serial Bus
VHF	Very High Frequency
V-POL	Vertical Polarization
VSWR	Voltage Standing Wave Ratio

4. OBJECTIVES

4.1 Field Test Types

Field tests attempt to encompass as much real-world environment as possible. To debug possible issues in a receiver as well as to evaluate their RF performance in a variety of actual conditions, a variety of different types of field tests can be considered. In order to optimize field testing using a variety of methods and techniques, the following definitions are helpful.

4.1.1 Coverage Testing

Coverage is defined as the determination of actual field strengths measured in the field for a given transmission facility. There are generally three purposes for coverage measurements:

1) Verify the proper functioning of the transmit antenna (azimuth and elevation patterns, etc.).
2) Provide supplementary data for *terrain* attenuation algorithms that could be used for spectrum allocation planning and estimation of potential interference.
3) Provide supplementary data for propagation prediction algorithms (e.g., free-space, Longley Rice, TIREM, CRC-Predict, ITU P1546-3, etc.)

Coverage measurements are conducted using the standardized test methods described in Section 73.686 of the FCC Rules and Regulations (see references in Section 2). These standardized test methods, which typically use antennas calibrated to a standard dipole and placed at 9.1 meters (30 feet) height AGL, are used worldwide for verifying coverage, verifying transmit antenna radiation patterns, and providing data to develop propagation algorithms used for the planning factors for allocating broadcast station spectrum.

Coverage tests are often carried out in formal fashion with measurements made along radials, arcs, grids and clusters. Typically, only field strengths are recorded at a large number of test sites throughout the desired area.

A transmitter “proof of performance” should be conducted prior to commencement of the field test to ensure the best signal possible is radiating from the transmitter site.

Limited coverage tests may be planned to achieve particular goals and objectives such as determining that a directional transmit antenna pattern is achieved or maintained, or to measure the effects of terrain that blocks broadcast signals in certain areas. Such tests will not predict overall coverage.

4.1.2 Service Testing

Service or “**Receivability**” testing for purposes of this document is defined as the process of determining the conditions under which digital television signals can be received and decoded in various actual operating conditions. Such operating conditions include any location where digital devices are normally used for entertainment and information for short and long periods of time. These operating conditions include use of antennas selected as those likely to be used with the receiving mode or modes under test.

Service (Receivability) measurements typically use digital devices designed to be connected to recording equipment to obtain signal level, margin-to-threshold, error rate, equalization characteristics, RF channel characteristics, and other information. These measurements can employ a variety of calibrated receive antennas (commercial or consumer) for various lengths of testing time and may not be as easily repeatable as the more formal coverage measurements. Moreover, receivers can be prototype, commercial, or consumer types of units.

All receivers used in field testing should be characterized prior to commencement of the field test to ensure the optimum performance of the receiver will accurately reflect service results. At the very least, white noise threshold and dynamic range (overload and sensitivity) should be performed. Other helpful receiver information, if available, would be CCI, ACI, and multipath performance.

A sample containing a large number of measurements needs to be taken to develop statistically valid results. By adhering to a standard set of service test procedures consistent with this document, data obtained from these tests can be used to develop a statistical database from which a level of service can be derived.

4.1.3 Channel Characteristics Testing

Channel Characteristics testing has the specific meaning, for the purpose of this document, to determine RF propagation channel characterization (e.g., channel impulse response) and is accomplished by the detailed measurement of specific signal conditions at specific times and in specific locations using specific fixed and movable antennas.

In some cases, special transmitter identification codes (TxID) can be embedded “underneath” normal data as a “sub-signal” that allows special test equipment to extract them from the noise-like DTV signal, uniquely identifying a transmitter (e.g., as in a SFN deployment), and then provide existing channel characteristics such as channel impulse response. Generally, detailed channel characteristic measurements use a variety of methods that provide the effects of channel impairments such as signal level variations, impulse noise, in-band interference, and multipath.

4.1.4 Single Frequency Network Testing

Single Frequency Network (SFN) reception is defined as reception from one or more synchronized transmitters (e.g., RF carrier, symbol frequency, and packet arrival timing) radiating identical signals that statistically provide increased signal levels with reduced chances of signal cancelation.

In SFN applications, it is possible that multiple received signals of equal amplitude can create severe multipath conditions, allowing for the possibility of destructive interference, i.e., weak signal conditions. Therefore, SFN techniques also allow the multiple transmitters to radiate different signals that have been linearly modified by Transmit Diversity Code Filter Sets (TDCFS) that pre-distort the common waveforms using linear all-pass filters in such a fashion that minimizes the cross-interference among the transmitted signals over the entire reception area. SFNs are applicable and beneficial to all five reception cases described above and defined below.

Testing involves identification and level measurement of individual transmitter signals, composite signals, as well as the relative signal arrival timing over a region of overlapping transmitted signals.

4.2 ATSC 3.0 Reception Scenarios, Goals, and Objectives

Five different DTV receiving scenarios have been identified for possible field testing, and are briefly described below. Gathering data in the field for five of these cases allows comparison to coverage (field strength) and service (reception) propagation prediction models.

4.2.1 Fixed Outdoor

Fixed outdoor reception is defined as reception by a stationary receiver and receive antenna. Typically, this includes either a roof-top mounted antenna (with or without a rotor) or a fixed-location attic antenna.

Test site selection is typically chosen to be on radials, arcs, grids, and clusters.

4.2.2 Fixed Indoor

Fixed indoor reception is defined as reception by a stationary receiver and a fixed-location receive antenna inside a building structure.

Test site selection is always a challenge for indoor testing because it involves finding either public buildings (office building, malls, etc.) with accessible rooms available for testing or private buildings (e.g., houses, condos, apartments, etc.) with owners who are both “willing and able” to meet the challenges of indoor testing and the testing group’s schedule.

An additional challenge is that indoor testing requires moving enough equipment into this location to make meaningful tests without it being logistically impractical.

4.2.3 Portable

Portable reception is defined as reception by a receiver that can be moved from place to place, that uses a *self*-contained receiving antenna, but that remains stationary during operation.

Test sites can be either indoor or outdoor, as desired.

4.2.4 Pedestrian

Pedestrian reception is defined as reception by a receiver that is moving at no more than 5 km/hour (3.1 miles/hour). Typically, this is a receiver that may be used while walking, or a hand-held receiver where occasional and frequent short movements occur.

As an example, a person walking 3 km/hour (1.9 miles/hour) can create multipath RF signals at 695 MHz with Doppler frequencies of about 2 Hz (Doppler frequencies of 0.5 Hz at 177 MHz).

Test sites can be either indoor or outdoor, as desired.

4.2.5 Mobile

Mobile reception is defined as reception by a receiver that is moving at greater than 5 km/hour (3.1 mph). Typically, this is a receiver used in a vehicle moving faster than walking speed.

As an example, a vehicle traveling 120 km/hour (74.4 miles/hour) can create multipath RF signals at 695 MHz with Doppler frequencies about 77 Hz.

A general goal is to study and evaluate mobile system and/or hardware performance in the field in a variety of propagation environments and service (case) models.

4.3 Test Signals

ATSC 3.0 has a multitude of modulation and coding configurations from which to select for field testing. The availability of many transmission modes allows broadcasters to optimize their channel for their market environment, the particular application, and the type of receiver device. A large range of tradeoffs between payload data rate and robustness is possible. A field test plan should precisely specify what type of test signals to employ during testing, and what exact transmission parameters are to be used.

If only one PLP is used in field testing, the bit rate of this video test signal should nearly fill the available bit capacity of the channel to maximize the accuracy of visual error probability. A test signal such as the moving HD zone plate provides a significant challenge to any error concealment algorithms in DTV receivers, and facilitates visual recognition of the observer. This type of subjective test signal excels in quick field error measurements when other, more accurate objective error measurement techniques are not available.

If use of more than one type of test signal is desired for field testing in order to simultaneously evaluate various data rate versus robustness options, then *multiple* PLPs can be employed. This is referred to as TDM. Use of multiple PLPs avoids the necessity of having to change the transmitter signal mode remotely from the field test vehicle for every different test configuration. However, this requires the use of a test receiver that can allow the observer to select which PLP to be received and evaluated for reception and site margin. See Annex B for some *examples* of transmission modes that represent various reception situations that might be used in commercial broadcast applications.

The test signal used to assess *channel response* has different needs than the other test signals. In the field environment, the channel could be Rayleigh or Rician. The test signal repetition rate should be short enough to characterize time-varying channels, yet be long enough to cover the expected multipath. Using a TxID signal with appropriate decoding test equipment is preferable.

The types of test signals described below are encapsulated within ATSC 3.0 physical layer signals as defined in the ATSC standard. They can be employed during field tests for particular types of tests, and fall into multiple categories:

1) A typical test signal with general video and audio program material which can be used for either coverage or *subjective* service testing.
2) A special test signal with repetitive test video and audio programming that have special desired characteristics (e.g., moving HD zone plate that encompasses nearly all of the data stream for easy visual detection of errors), and that can be used for either coverage or *subjective* service testing.
3) A special test signal pseudo-random data stream that can be used for objective bit error or packet error measurements as detected internally by the DTV receiver or externally by error testing equipment, and that can be used for either coverage or service testing.
4) A typical or special test signal, as described in the three paragraphs above, that has a special transmitter ID (TxID) signal embedded within, and that can be used for propagation channel response testing (e.g., amplitude and echo delay characteristics). It should be noted that this transmitter ID signal can be added to any of the other ATSC 3.0 test signals described above.

The test plan should clearly identify the specific test signal(s) to be transmitted and received during the course of testing, and the type of test data that is expected to be extracted from them.

4.3.1 In-Service Measurements

In-service is defined as being available for regular program viewing by the general audience. In-Service measurements will use the commercial or non-commercial DTV signal itself (e.g., live television) with no modifications and with appropriate sound to enable evaluation of reception quality.

4.3.2 Out-of-Service Measurements

Out-of-service is defined as not being available for regular program viewing. Out-of-service measurements may use video test signals or specially tailored data test signals. These test signals should occupy the same RF television channel spectrum and have the same average power as a nominal DTV signal, but may be tailored for specific out-of-service measurements such as channel characterization or BER/PER error threshold measurements.

A common test signal is a repetitive video test sequence (e.g., moving high-definition circular zone plate) with appropriate sound to enable easy evaluation of the program stream errors on a device with video and audio presentation. Care should be taken that the data input consists of a seamless loop that does not create a disturbance in the video or audio during the “wrap around” time.

4.4 Field Test Scheduling

When practical, field measurements should be timed such that diurnal, seasonal and climatic propagation variations can be correlated to coincident service and channel characteristics measurements in a given reception area.

It should be noted that anomalous results may be obtained for measurements that are taken during inclement weather. Consequently, measurements should not be scheduled during dynamic weather conditions.

4.5 Field Test Duration

The duration of field tests are defined according to the receiving scenario (e.g., fixed outdoor, fixed indoor, portable, pedestrian, and mobile) and the type of test to be performed (e.g., coverage, service, and channel characteristic). The duration of a field test can include the following time periods: seasonal (months or years), very long term (days or months), diurnal (1-day during sunrise and sunset hours), long term (minutes or hours), short term (seconds to minutes) and very short term (seconds to less than a second).

Test duration including both observation intervals and unimpaired reception period are selected to adequately capture the desired number of measurements. The Test Plan should set the unimpaired reception period.

While these field test measurements are often not considered to be long term, there should be enough time in the field at a test site to account for any short-term RF signal fading characteristics. It is recommended that a minimum three-minute sample of reception be used, regardless of the time interval that errors are reported. For instance, if packet errors are reported every 1 second, they should be monitored continuously for 3 minutes, resulting in 180 consecutive and contiguous measurement time intervals.

Longer measurement times can be accommodated in the test plan should there be necessary requirements to do so. For instance, a 24-hour testing period or longer could be accommodated if diurnal (i.e., day/night transition) effects on propagation and reception are desired. Likewise, performing tests for very long periods at a fixed location, such as a year, could provide long-term seasonal propagation and reception effects information.

4.6 Test Site Description

A description of site conditions for any field test is essential for each location in which field test measurements are made.

For all fixed test sites, the test plan should include documentation of the location of each site with geographic coordinates (i.e., latitude and longitude) to the nearest second (or better), address, distance and bearing to transmitter, surrounding area (photographs), nature of buildings including their construction type, vegetation, weather conditions at time of test, and, if possible, specific marking of the pavement or ground where the measurement was taken or the center of the coverage run or cluster measurements.

Pedestrian and mobile field tests should include the testing paths traversed, the general types of environments, and maps created with latitude and longitude data indicating specific routes.

4.7 Safety

The measurement platform, antenna, mast, and coaxial feedline represent potential safety hazards from electrical shock and/or falling objects. For this reason, it is imperative that the paramount criterion for measurement site selection is worker safety.

Accordingly, all measurement sites should be free of overhead power lines, steeply sloped terrain, wet surfaces, high winds, thunderstorms, and other natural or man-made obstructions or conditions which could threaten the safety of persons or property. The test plan should require that operators should be trained in proper safety procedures.

5. MEASUREMENT METHODOLOGIES

5.1 Coverage Measurement

Coverage measurements are made at a series of test sites to ascertain the signal level distribution across a large area that serves as a broadcast market. The following is a recommendation for establishment of procedures to be performed at each selected site.

5.1.1 Site Selection Criteria

Since coverage is determined by the *statistical* distribution of individual data point measurements, it is necessary to select individual location measurement sites at which multiple measurements can be conducted over a specified area. These measurements are referred to as “individual location cluster measurements.”

Typically, individual measurement sites are selected such that the elevated antenna may be accurately positioned at discrete intervals around the perimeter of an area of approximately 9 square meters. Cluster measurements should include a minimum of five, evenly distributed, measurement points to capture data over an area of approximately 9 square wavelengths. If multiple frequencies are to be measured at one location, the cluster measurement area should be defined as 9 square meters (3 meters per side). Suggested patterns would include those described in Section 5.1.3.1 as shown in Figure 5.1.

5.1.1.1 Market Coverage Measurement Sites

Coverage measurements are to be conducted at specific points along multiple radials and arcs. Radials should extend from the transmitter location to the limit of predicted noise-limited coverage. A minimum of eight, reasonably evenly spaced, radials should be measured. Measurement radials should be oriented so as to traverse representative terrain and population centers. These radials should also include reception areas selected for service testing where practicable.

5.1.2 Field Test Facility

5.1.2.1 Vehicle

For fixed measurements, an instrumentation vehicle should have a telescoping mast that is capable of elevating a rotatable standard reference antenna to a height of 9.1 m (30') AGL.

This vehicle should also be equipped with a means for implementing cluster measurements when individual site measurements are desired.

Support hardware should be available such as AC generator with multiple circuit breakers, GPS receiver with distance and bearing calculations, laptop computer, electronic map software, etc.

For mobile measurements, an instrumentation vehicle should have means for roof-top mounting of one or more small mobile antennas, with coaxial feedlines inside the vehicle to the test equipment. Testers should be aware of the influence of the surface of the test vehicle on the characteristics of the mounted small antennas which acts as a substantial ground plane. Space is required for the test equipment capable of providing signal level measurement, propagation channel characteristics, and *optionally* ATSC signal reception. Again, support hardware should be available such as a power source for the test equipment, a GPS receiver with distance and bearing calculations, a laptop computer, electronic map software, etc.

5.1.2.2 Equipment

Equipment includes the following:

a) Calibrated, horizontally polarized, reference antenna(s), UHF and VHF.
b) Calibrated antenna balun (if necessary—depends upon reference antenna type in use) and antenna/coax impedance matching network.
c) Calibrated coaxial RF distribution system, which may include a bandpass filter (in special cases where the transmitted power is significantly lower than the value expected in normal operation), low-noise amplifier, RF splitter (if multiple outputs are used for simultaneous field strength measurements at different frequencies), and/or optional instrumentation devices.
d) Calibrated spectrum analyzer with band-power markers covering the appropriate frequency range for determining strongest signal reception antenna orientation (azimuth) and signal level as well as for RF spectrum display image capture and/or recording. (A spectrum analyzer with internal signal or sweep generator may be used for calibration of the measurement setup).
e) Differentially corrected GPS receiver.
f) Computers, printers, etc., as desired.
g) Integrated data acquisition system to collect and store measurement data and tester's comments on electronic non-volatile media.
h) Optional receiving antenna(s) and polarization modes.
i) Camera to record test site and surrounding area.

5.1.2.3 Receive Antenna

Any receive antenna used for coverage measurement should be calibrated with respect to a standard (reference) dipole tuned to the desired test signal frequency and then mounted on a mast at the prescribed height above ground (9.1 meters or 30 feet). Documentation for the antenna (e.g., gain, azimuth and elevation pattern, impedance, etc.) should be included in the test report.

Antennas for coverage measurements are normally oriented towards the transmission tower, which means in the direction of maximum signal level.

For purposes other than coverage, in some instances, *optional* measurements may be made with the antenna oriented in other directions. Such measurements are also recorded with the antenna orientation data field indicating the directions.

5.1.3 Measurement Data Set

Measurement data should include, but not be restricted to, the following information:

a) Field strength (minimum, maximum, and median value) in dBµV/m.
b) GPS coordinates of test location.
c) Distance and bearing to transmitting antenna location.
d) Ground elevation at measuring location.
e) Date, time of day, topography, and weather observations.
f) Azimuth orientation (with respect to North) of receiving antenna for maximum field strength.
g) A detailed equipment list specifying each measurement antenna, measuring instrument, and system component, its manufacturer, type, serial number, rated accuracy and date of most recent calibration by either its manufacturer or a qualified calibration laboratory.
h) A detailed block diagram of the coverage survey measurement system.
i) A detailed description of the procedure, date, time, and tabulated data for the pre-test field calibration check of each of the coverage survey system components conducted at the beginning of each measurement cycle.

5.1.3.1 Number of Measurement Points

The number of measurement points in the coverage area is a function of the following issues:

a) Radials ("Community" adapted from [2] 47 CFR 73.686):

   A minimum of eight reasonably evenly spaced radials with a minimum of 15 points per radial should be measured. Measurement points are selected to begin at a distance of 16.1 kilometers (10 miles) from the transmitter location and are to be repeated at intervals of 3.2 kilometers (2 miles) to the maximum distance at which measurements are to be made. The total number of measurements locations, per radial, should not be fewer than 15 but should be approximately equal to $0.1\times(P)^{1/2}$ if this number is greater than 15, where "P" is the population of the community of interest. Care may be taken when choosing the number of points as some points on a radial might be in inaccessible locations (e.g., the ocean). If the purpose of testing is for FCC, then refer to [2]. If the purpose of testing is personal, then a smaller number of points and radial positions can be chosen for practical reasons.

   A "cluster" of five "spot" measurements may be made. For this purpose, the "cluster" is defined as one identifiable initial measurement point and at least four additional measurement points within a distance of the initial measurement point as specified in Figure 5.1.

b) Arcs: Arcs should be normally measured around the full 360º azimuth, except where terrain prohibits. Individual selection points should be made at 20º spacing or less.

c) Individual location cluster measurements: A minimum of five, evenly spaced, measurement points should be used.

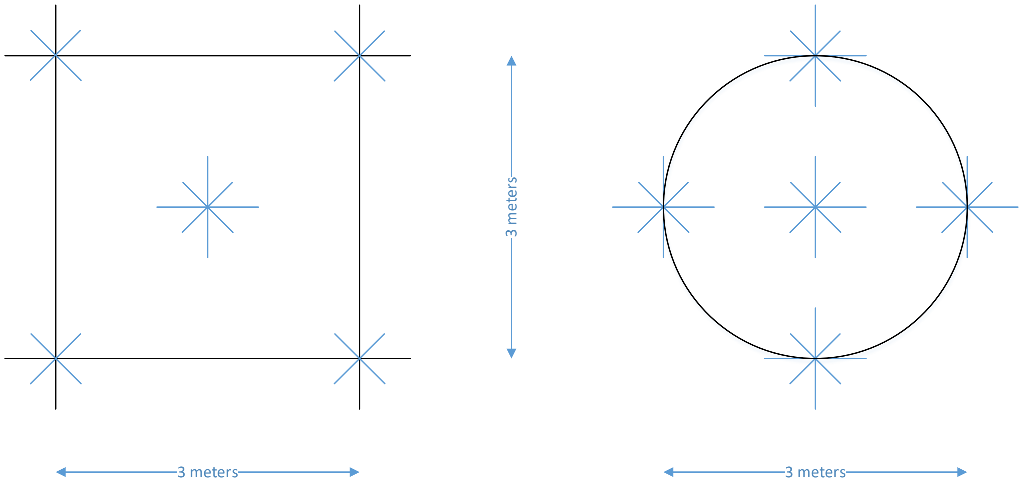


Figure 5.1 Cluster Measurement 5-point arrangements.

5.1.4 Measurement Methodology

5.1.4.1 Signal Power Definition

Digitally-modulated television signal power can be measured with a swept-tuned spectrum analyzer with band-power marker capability, and should cover the expected frequency and amplitude range of interest. ATSC 3.0 signal levels are defined as the average power within the defined RF channel that is employed (e.g., 6, 7, or 8 MHz).

5.1.4.2 Antenna Height

Outdoor coverage (field strength) measurements are conducted at an antenna height of 9.1 meters (30 feet) above ground level (AGL). This height is the same value used by the FCC in their rules for many years.

Other heights (e.g., 20’, 15’, or 5’) can be additionally measured to provide supplementary information. In fact, lower height measurements may be quite useful for characterizing reception cases other than fixed location television services.

5.1.4.3 Field Test Duration

Coverage measurements are normally conducted for short periods of time, that is, the time it takes to perform a cluster of 5 measurements within 3 square meters. The purpose of the cluster is to *average* out the effect of multipath and nearby signal path obstructions that could otherwise adversely affect the measured value. Fixed position coverage measurements over long periods of time (hours, days, months, years) provide useful information about the effect of weather, seasons and diurnal (day-night) variations.

5.1.5 Data Analysis Consideration

Tabular database formats are the preferred form of data collection. The format should be compatible with mainstream data base and spreadsheet software, and is to be described in detail in the Test Report.

Observer's measurement observations are often valuable in determining the cause of any anomalies in test results and should be included in a comments column or as footnotes in the Test Report.

Digital photographic records are important ways to describe a site condition in some detail. In addition to the surrounding area, photographs should be made of the test setup itself in relation to the surrounding environment (i.e., the truck placement within the test area site).

Spectrum display images provide insight into the condition of the signal that is measured as well as the spectrum in which the signal is located. When practical, spectrum records of the measured signal should be made for each major measurement set and should include a wideband display (e.g., 20 MHz or greater) of the spectrum containing the desired test signal as well as adjacent channel signals. Coverage data should be used for pair-wise comparison of actual field strength versus calculated field strength.

5.2 Service Measurement

The following descriptions apply to all receiving modes (see Coverage Measurement in Section 5.1) except where noted. Certain measurement procedures may vary with the selection of the receiving mode.

If coverage measurements are desired at sites where service measurements are conducted, a set of cluster measurements should be conducted according to the procedures in Section 5.1. If coverage and services measurements are desired at the same location, it is recommended that they are performed at essentially the same time.

5.2.1 Site Selection Criteria

Service measurement sites are selected based upon predetermined criteria specified in the Field Test Plan, and are typically made in such a manner that they simulate real-world receiving situations. In order to obtain statistically-meaningful results, there should be enough data sample points measured to reflect the actual performance of the measured system. Practical considerations lead to a range of 50 to 100 sites, although reasonable statistical confidence intervals may require significantly more (e.g., 200 to 400 sites).

Service measurements may include a statistical bias to certain geographical locations, such as well-populated areas or regions with certain challenging terrain (e.g., hilly, forested, urban canyons, etc.). In such cases, the density of test sites might be greater than in other areas within the testing region.

By choosing testing locations that exhibit particular propagation impairments, the results of the test may be biased. For example, service measurements may also include a bias towards one or more particular reception factors such as multipath, aircraft flutter (near airports), or effects of building walls or trees. When a service test is biased in such a manner, rather than randomized site selection, it should be noted as such in the test results and database.

Service measurements may include various geographical locations, such as well-populated areas or regions with certain challenging terrain (e.g., hilly, forested, urban canyons, etc.). Typically, the following *types* of sites are considered for DTV field tests:

1) Radials: increasing distance from transmitter at constant azimuth angle (evaluation of varying terrain with varying distance and varying transmitter elevation pattern)
2) Arcs: constant distance from transmitter with varying azimuth angle (evaluation of varying terrain with constant distance or variations in transmitting antenna azimuth pattern)

3) Grids: rectangular-shaped pattern with ≈ 1-mile spacing (e.g., short-spaced propagation variability with suburban terrain clutter effects)
4) Clusters: rectangular-shaped pattern with ≈ 0.5-mile spacing (e.g., very short-spaced propagation variability with urban terrain clutter effects)

5.2.2 Field Test Facility

The receive site facility is designed to document the propagation channel's characteristics of signal interference, multipath, and impulse noise. Equipment is selected and assembled according to test plan goals and objectives.

5.2.2.1 Vehicle

A similar vehicle to the one described for coverage testing can be used for fixed site measurements.

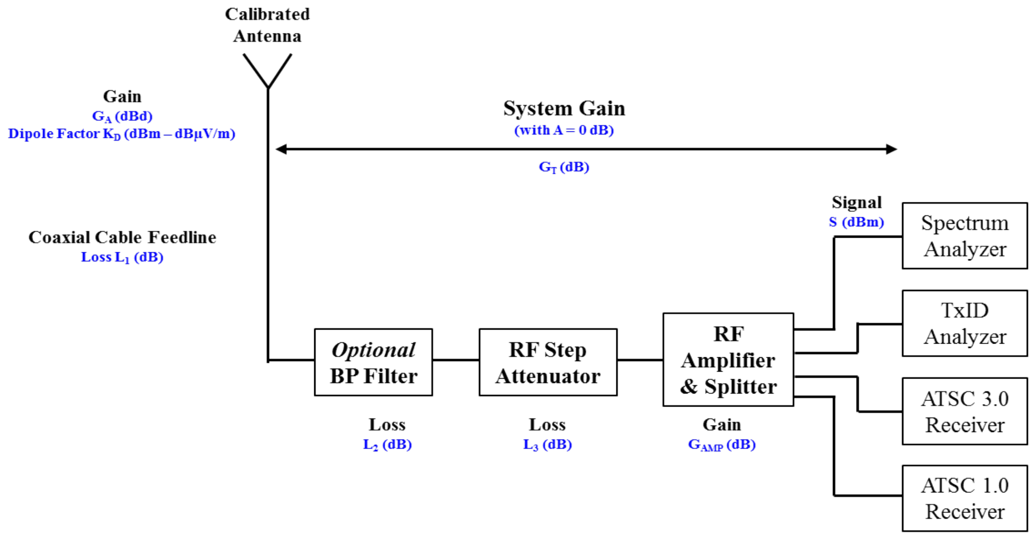
5.2.2.2 Equipment

A detailed list of equipment for a coverage field test facility is recommended, although service measurement test plans may not need the full complement to accomplish their objectives. Important elements include the following:

- **Block Diagram**: A block diagram showing the components of the measured signal path should be provided with the test report. An example of a block diagram of a field test vehicle is shown in Figure 5.2. Field strength (F_s) is as defined in Figure 5.2.
- **Operational Dynamic Range**: The dynamic range and noise figure of the entire test facility and its components should be determined and documented. The net system gain from down-lead input to spectrum analyzer input, known as the vehicle *system gain*, should be calibrated for accurate calculation of received signal *field* strength.
- **Antenna**: The antenna that is employed for service measurements should be:
  i) An example of a typical antenna for the particular application being evaluated
  ii) Calibrated (e.g., gain, 3-dB azimuth points, front-to-back ratio, etc.) by the factory, on a range or in an anechoic chamber, or by comparative measurement with a standard reference dipole while at an open area site with minimal ground clutter nearby using the desired radiated RF test signal
  iii) Routinely checked to determine that it is still performing as predicted
- **Antenna mount:** Outdoor masts should allow for measurements to be made at 30' AGL (9.1 meters) and at any azimuth direction. If mounted on a vehicle for remote testing, a compressed air-operated extendible pneumatic mast with an integral rotor allows raising and lowering of the antenna at each site. A remotely-controlled rotor mounted at the top of the mast would allow adjustment (i.e., pointing) of the receive antenna for maximum signal level. An optional mast-mounted compass would facilitate determination of the antenna azimuth when optimized for maximum received signal level. A plastic "coiling" sheath (Nycoil) to protect the downlead coaxial cable is beneficial.
- **Down-lead System Components**: Any baluns, cables, amplifiers, filters, attenuators, combiners, splitters, and other devices that could affect the measured signal each should be documented and calibrated. Robust components should be designed into the receive system, such as high IP3 amplifiers, well-shielded (e.g., double-shielded braid and foil) downlead cables, well-isolated splitter outputs, and flat passband, low insertion loss bandpass filters (in special cases, such as when a field test is performed using a transmitter power much lower than expected in normal use). When professional antennas are not employed, care should be taken to minimize VSWR effects through a careful selection of

amplifiers and attenuators located as close to the antenna as possible. An impedance matching device should be used, if necessary, at the output of the antenna or the input of the amplifier. NOTE: the vehicle test system can primarily employ either 50-Ohm or 75-Ohm impedance components, but may require impedance matching (conversion) components placed at appropriate locations within the system (e.g., as needed at antenna output or receiver input).

- **ATSC3 Receiver:** The receiver used for the service measurements should be described in detail. It should have tuning capability for the desired channel(s) to be tested (e.g., VHF and UHF), and provide either video or audio output to either internal or external display devices. It would also preferably provide internal status indicators (e.g., various lock and frame errors) that can be polled by the testing computer software. The receiver should have supporting calibration documentation, particularly AWGN threshold for each transmission mode to be tested. These thresholds should be carefully measured and documented prior to the start of field testing. The receiver may employ either internal or external video and audio decoding and playback units.
- **Other Measurement Equipment:** Other equipment used for service measurements that provide data for the test report should be documented and should have supporting documentation and test results. This includes the spectrum analyzer with band-power markers that are used to measure desired signals as well as any undesired or noise signals expected during the field test (e.g., vehicle amplifier noise, impulse noise, ATSC 1.0, ATSC 3.0, LTE, etc.).
- **Support Equipment**: Support hardware facilitates data gathering, and should be available to those doing the testing, including, but not limited to, AC power generator with ample capacity (for all test equipment), computers, test equipment control, data gathering, map software, terrain profile software, data archiving spreadsheet, data storage (USB hard drive or USB memory sticks), GPS receivers (precise site location), and adequate air conditioning and heating (as needed dependent upon the season).



$$F_S\,(dB\mu V/m) = S(dBm) - G_T(dB) + A_T\,(dB) + K_D\,(dB\mu V/m - dBm) - G_A(dB)$$

where: $S \equiv$ average signal power in RF Channel Bandwidth at spectrum analyzer input (dBm)

$G_T \equiv$ total system gain of truck with attenuator A = 0 dB

$A_T \equiv$ total loss of coaxial feedline + BP filter + RF Step Attenuator (dB) = $L_1 + L_2 + L_3$

$K_D \equiv$ dipole factor for give RF test channel center frequency (dBμV/m)

$G_A \equiv$ antenna forward gain over λ/2 matched-impedance dipole for given RF test channel (dBd)

Figure 5.2 Example of a typical block diagram of service measurement vehicle.

5.2.2.3 Receive Antenna

Antennas for service and channel characterization measurements may be professional, commercial, or consumer products as selected to meet the goals and objectives of the Field Test Plan. Antennas used for these types of tests are typically employed in an "in-service" setting. In addition to being used for 30' AGL mast measurements, they are also used only a few feet above the floor or ground and relatively close to people and nearby surrounding objects (e.g. indoor, portable, and pedestrian tests). These antennas should be mounted in a manner that allows the testing personnel to easily and repeatedly point, tilt and position the antenna with accuracy and to record meaningful results from such movements. Antennas may be oriented in an optimal (maximum signal or most easily received signal) or non-optimal position (as might be used for a single setting but receiving signals from multiple directions). Antennas for service and channel characterization measurements include but are not limited to the following classes and orientation:

a) Measurement with an outdoor antenna at 9.1 m (30') AGL can be used. The antenna can be either commercial or consumer in nature. Orientation via a remote-controlled rotor may be optimal (e.g., maximum signal level) or non-optimal, and should be so indicated in the database.
b) An indoor antenna that is associated with a fixed receiving installation, and when used for service or channel characterization measurements, is typically a consumer style antenna. The antenna can be a dipole antenna or one with multiple elements

providing additional gain and directivity. It should be characterized for gain and pattern with respect to a dipole, and mounted about 1.5 meters (5 feet) above the floor. This class of antenna may be used in an optimal or non-optimal orientation according to the field test plan, and should be indicated in the database. It should be noted that the antenna's performance characteristics may markedly change in the indoor environment from measured values made in a controlled test environment.

c) An indoor antenna, associated with a portable receiving application, and used for service or channel characterization measurements is normally a consumer style antenna that may be designed as non-directional (monopole) or directional (dipole or multiple element). It should be characterized for gain and pattern with respect to a dipole. Portable antennas are normally positioned about 1 meter (3.3 feet) above the floor (ground) and may be oriented in an optimal or non-optimal position according to the field test plan and indicated in the database.

d) An antenna associated with pedestrian use can be considered to be of random directional characteristics with little or no gain. If *possible*, the antenna should be characterized for gain and pattern with respect to a dipole, and mounted about 1.8 meters (6 feet) above the floor. Because of the relative insensitivity (gain) of the antennas used in pedestrian applications, the orientation is normally considered to be non-optimal.

e) Antennas associated with mobile applications are normally considered to be non-directional (monopole or similar design) and mounted in fixed positions on vehicles in a manner to maximize their exposure to radio signals. Mobile antennas should be characterized for gain with respect to a dipole. The orientation of an antenna used in mobile applications is considered to be undefined (none or non-optimal).

5.2.3 Measurement Data Set

More than one set of measurements can be obtained during a service measurement. One is highly recommended while the other is peripheral, in nature, which enhances or describes a particular reception condition in more detail. It should be noted that some of the measurement parameters are only found inside the receiver (often in data registers), and are only available in those receivers which provide a means to extract them.

The recommended data set includes:

1) Site location details (geographical coordinates, distance from transmitter)
2) Speed (for mobile testing)
3) Date and Time of day (which provides any seasonal and diurnal effects present)
4) Description of building in which, or around which, measurements are made
5) Nature of area surrounding test site (e.g., urban, suburban, rural, type of terrain, vegetation, etc.)
6) Detailed location of antenna height above ground level (HAGL)
7) Antenna orientation (with respect to North)
8) Calibration of measurement system (i.e., system net gain, including antenna gain)
9) Antenna description (e.g., dipole, directional)
10) Antenna polarization (e.g., V-POL, H-POL)
11) Measured spectrum analyzer signal strength (average power, in dBm)

12) Measured internal receiver AGC or signal strength from internal receiver registers (gain in dB or average power in dBm)
13) Noise floor of test vehicle system (average power, in dBm)
14) Noise added receiver SNR at threshold (in dB)
15) Measured internal receiver SNR as received (in dB, when available)
16) Measured internal receiver SNR at threshold (in dB, when available)
17) Measured margin (i.e., amount of total attenuation before threshold of errors occurs, in dB)
18) Packet error rate (PER), after LPDC and after BCH or CRC (if used), when available.
19) Any large *undesired* adjacent channel interference signals (DTV, LTE, etc.)
20) Description of possible cause of failure at sites with no reception or at sites with less than expected reception performance (e.g., minimal margin)

Other measurement sets may include:

1) Test site street address
2) Observed subjective audio and/or video impairments
3) Log of activity
4) Spectrum plots of unusual desired or undesired signal characteristics
5) Describe in detail any other measurements made during the service measurements
6) Channel Response (when available)

5.2.4 Measurement Methodology

The following general procedures outline a typical service measurement process.

5.2.4.1 Signal and AWGN Power Definitions

Digitally-modulated television signal power and AWGN power measurements should be made using a suitable device that accurately measures average power in the entire RF channel bandwidth (e.g., 6, 7, or 8 MHz) bandwidth. This measurement can be made with a swept-tuned spectrum analyzer with band-power marker capability, and should cover the expected frequency and amplitude range of interest.

5.2.4.2 Error Threshold Determination Measurements

For DTV, transmission or propagation impairments are not directly visible on the screen or heard in the sound until the impairments cause outages or loss of ability to demodulate or properly decode data. Since powerful error correction techniques are used, all digital DTV data transmission systems have a "cliff effect", i.e., a sharp transition with signal level where the video and audio go from perfect error-free picture and sound to all-error frozen (or blank) video and muted sound. This steep transition often will occur in less than 1 dB of signal level drop when white noise impairment is present (e.g., noise floor of a DTV receiver), making it difficult to rate DTV with a subjective impairment scale (such as the 5-point subjective ITU-R scale, formerly referred to as the CCIR subjective impairment scale).

Instead, it is more useful to rate the DTV reception based on *objectively* measured BER or PER. If no error information is available from the test receiver, the number of impairment-caused "hits" observed on the video screen or in the audio within a given period of time can be used to *subjectively* determine threshold. A "hit" is defined as an obvious visible or audible artifact caused by propagation impairments or interference or noise.

Therefore, two general methods exist for determination of DTV error threshold:

1) Subjective viewing of video and listening of audio

2) Objective measurement of synchronization codes and payload data errors

5.2.4.2.1 Subjective Threshold Methodology

Subjective determination of threshold uses the receiver's decoded video and audio to determine the onset of payload data error threshold. Once RF propagation impairments cause enough data errors to overrun the FEC coding process (LDPC, BCH, interleaving, etc.), video and audio impairments become obvious to observers.

However, it is noted that the subjective method of determining threshold is made more difficult by recent developments in scalable video coding/compression where the high-detailed video components are sent in a separate PLP (i.e., data stream) from the low-detailed components, with the low-detailed components transmitted using more robust coding. If scalable video is employed in the test signal (e.g., in-service measurements), the task of determining threshold is more difficult.

If no other means exists to objectively measure payload data threshold errors, the subjective viewing of the receiver's video and audio is the only means possible. This can be accomplished using actual on-line broadcast programming provided by a commercial or non-commercial station, or it can be accomplished with off-line repetitive video and audio program material (e.g., moving HD zone plate that facilitates identifying data errors due to minimal error concealment success).

5.2.4.2.2 Objective Threshold Methodology

Objective determination of threshold is the preferred method (if available) since it is easier to measure due to use of test equipment to make the measurement, and results in more repetitive and consistent results.

However, it is not guaranteed that all DTV receivers that are tested will have provisions for built-in error measurement capability or have output data streams that can be measured by external error measurement test equipment. DTV receivers may take many forms (prototypes, commercial equipment, consumer equipment with or without video screens, etc.), with each form providing differing levels of sophisticated signal monitoring. Typically, prototype receivers offer many observable signal points within them, while commercial receivers may offer less, and consumer receivers even less than this. Therefore, the different error thresholds that exist in the reception of ATSC 3.0 signal may not all be available from a receiver that is under test.

The following describes possible threshold parameters that *might* be available in ATSC 3.0 receivers via internal register interrogation.

1) Synchronization Errors
   a) Bootstrap signal (CFO lock)
   b) Preamble-Basic (CRC errors)
   c) Preamble-Detail (CRC errors)
2) Payload data errors
   a) After LDPC (FEC frame errors)
   b) After BCH, if used (BCH frame errors)
   c) After CRC, if used (CRC Frame errors)

The test plan should specify which of the above synchronization and payload data error thresholds should be tested for the specific receiver that is being evaluated. Field test procedures should be general enough to apply to all device types mentioned above.

It should be determined at least once, however, that the objective methodology compares well with the subjective methodology. In other words, the final FEC block that provides the payload data error is what determines whether the video and audio is error free or not. Therefore, verification of agreement between the objective and subjective methods should be performed in order to provide confidence in the accuracy of the objective method.

5.2.4.3 Error Threshold Definition

The ultimate goal for error threshold determination is to provide consistent and repeatable results for any and all of the potential services that might be conveyed by the ATSC 3.0 system. However, when using video to determine TOV, it depends upon the type of video (SD versus HD versus UHD), how much detail and motion is involved, and how much of the data steam is being used to convey the particular program that is being used for testing. Therefore, instead of using a specific error rate (e.g., 2.5 transport packet errors per second) as in ATSC 1.0, the definition of error threshold will be determined by the most recent desired signal level that provided error-free performance (i.e., data reception).

Also for consistency and repeatable results among various field tests, it is recommended to determine data error threshold using a **3-minute** sample period. If during the three minutes, errors are observed (either subjectively or objectively) due to an increase in impairments (e.g., multipath, CCI, ACI, impulse noise, etc.) or a decrease in desired signal level (e.g., fading), then the signal level should be increased via a reduction in the attenuator value that is part of the receive site test system, and the measurement window repeated.

5.2.4.4 Site Margin Definition

Site margin is defined as the amount of attenuation that can be placed in the desired signal path prior to the receiver without introducing data errors to the received signal. Errors are caused by a known amount of white noise in the receive circuitry, whether present due to measurable RF amplifier output noise or intentionally added from a white noise source. It is understood that this method of determining site margin for the desired DTV signal does not represent exactly what minimum desired signal level could occur in the field in the presence of existing interfering signals since the increased RF attenuation will reduce all of the signals (desired and undesired) together, leaving the C/I ratios the same. Nevertheless, this method provides a margin value compared to white noise as well as a relative means of determining stability of a desired signal in a given propagation environment.

Unlike laboratory tests where stable signals allow precision impairment testing (e.g., 0.1 dB or 0.25 dB steps), testing site margin in the field is more complicated due to the always-present signal variations due to fading. Therefore, this test parameter is measured by increasing the signal level step attenuator or the AWGN noise attenuator in **1 dB** steps to determine site margin.

5.2.4.5 Antenna Class, Height, Orientation, and Polarization

The antenna is selected and used according to the reception mode (fixed, portable, pedestrian and mobile).

5.2.4.6 Calibration Measurements

Calibration measurements should be made of test system components at the beginning of each test day to determine that the facility is performing properly. A known test signal is typically used to simulate the expected *unimpaired* real-world signals and calibrate the test equipment, including the receive system gain, attenuation steps, and test receiver thresholds.

5.2.4.7 DUT Functionality Test

Each DUT that is to be field tested should have its basic functionality verified before testing is to commence. This includes basic error-free operation on the desired channel(s) to be tested as well as any internal (e.g., AGC, lock indicators, error registers, SNR values, channel description, etc.) or external (e.g., video and audio, etc.) signals required for testing.

Periodic and routine checks should be performed to ensure proper operation throughout the entire test time.

5.2.4.8 DUT Performance Test

Each DUT that is to be tested in the field should have a minimal performance evaluation to ensure its performance is within acceptable bounds by the manufacturer or the provider. While a thorough laboratory test evaluation is always helpful, a minimal performance evaluation, especially on site just prior to commencement of field testing, will ensure that operation has not been hindered by shipping.

Minimal receiver tests should include measurement of robustness to random noise (i.e., white noise threshold) and dynamic range (i.e., overload and sensitivity). Additional useful information should include co-channel and adjacent-channel performance of the receiver, in the presence of various interference sources that may include ATSC 1.0, ATSC 3.0, and LTE.

5.2.4.9 Service Measurements

Measurement data is obtained according to prescribed methods and specific procedures described for each measurement in the written test plan. Note when and why measurements cannot be taken at a specific site.

The test plan should be designed to allow measurements to capture data in order to show the non-uniformity (“burstiness”) or uniformity of errors over time. The test period should be representative of typical reception conditions, and all data taken should be recorded. While short term testing is describing herein, the length of time should be long enough to account for short term fading conditions that would allow a worst case reception and margin measurement to be made and documented.

5.2.4.10 Site Conditions

Site conditions and environment are recorded as a documentation of the measurement site. Site conditions are not measurements but may be later used to confirm or repudiate that an accurate measurement was taken, or help subsequently convey information to facilitate explanation of reception failure.

For outdoor testing, details of the surrounding area are important (e.g., vegetation, buildings, hills/mountains, water towers, bridges, power lines, etc.).

For indoor testing, details of building construction as may be observed or are known are recorded. A measurement may be repeated if the site condition indicates that the data may be suspect, and if the procedure allows for the repeat.

5.2.4.11 Documentation of Results

Results are documented in a manner such that the data may be efficiently processed and analyzed at a later time. A spreadsheet can be used to enter the measurement data in a logical fashion, therefore allowing some immediate calculations to be made to help the observer identify field strength and SNR values. From this data, complete data analysis can subsequently be performed, and any desired reports written.

5.2.4.12 Accuracy Review

Data is immediately reviewed at the point of measurement for accuracy and reasonableness, but not to the point of discarding data that may appear to be counterintuitive. Confirmation of data reasonableness may be made through observations, notes, comparison to expected values, and additional non-mandatory measurements.

Unexpected results can also be noted, with possible causes of these unexpected results included as well. Unexpected results can also trigger additional optional testing if it is believed the cause of failure can be determined.

5.2.4.13 Field Test Duration

For stationary service measurements, the test duration should be a minimum of a **3-minute** sample period for each data threshold evaluation. During that time single (averaged over the period) or multiple measurements may be made according to the field test plan, using the threshold determination methodology described in the field test plan.

5.2.5 Data Analysis Considerations

Part of the development of measurement methodology and specific test procedures includes the consideration of collecting and recording of data. Measurement data should be entered (recorded) into a database where its *structure* is designed for efficient interchange as well as consideration of the kinds of processing and analysis expected to be subsequently conducted. Also important is consideration of how the data might be used in comparison with other tests to be performed at later times and in other locations.

During a “pass/fail” test, an unimpaired signal should be received over a continuous length of time in order for the test reception to “pass.” Typically, this length of time will be at least **three minutes**. However, all data (measurements and site condition records) should be preserved even if the test reception is judged to “fail” or the data is not used in the initial analysis process.

Tabular database formats are the preferred form of data collection. The format should be compatible with mainstream data base or spreadsheet software and is to be described in detail in the Test Report.

Analysis can take on various forms, depending on the particular objectives of the field test. The following are some analyses that could be performed for *stationary* reception testing (e.g., outdoor, indoor, portable), but not limited to:

1) Coverage
    a) Field strength analysis for certain types of test site locations, such as radials, arcs, grids, clusters, etc. as well as certain types of terrain conditions (urban, suburban, rural, flat, hilly, heavy vegetation, over-water paths, etc.). Field strength is *calculated* from the measured signal power as well as the receive system parameters (antenna gain, downlead cable loss, attenuator value, and amplifier gain).
    b) Statistical analysis such as median, average, minimum, maximum, standard deviation, etc.
    c) Provides a general idea of signal coverage without regard to other impairments (such as multipath, impulse noise, other man-made noise, etc.) or interference (such as co-channel, adjacent channel, etc.).
2) Overall Service
    a) Reception analysis for error-free conditions in a broadcast service area regardless of signal strength, and is therefore directly related to the possible number of viewers in a given market or specific part of a market.
    b) Statistical analysis such as percentage of total sites where error-free reception occurred.

  - c) Provides a general idea of reception service.

3) System performance index
   - a) Reception analysis for error-free conditions at sites where the signal was strong enough to provide enough signal level to overcome the receiver SNR threshold for a given transmission mode.
   - b) Statistical analysis of the percentage of sites with successful reception when the field strength is greater than the minimum value for a given transmission configuration.
   - c) Provides a general idea of system performance in the presence of real-world impairments (e.g., multipath) and interference (CCI and ACI) when the desired signal is above its minimum required signal level for a given transmission configuration.
4) Site Margin
   - a) Reception analysis for error-free conditions compared to the white noise floor at a receive site.
   - b) Statistical analysis of margin such as median, average, minimum, maximum, standard deviation, etc. for total service area or a special segment of the total service area (e.g., radials, arcs, grids, clusters, special sites, etc.). Site margin statistics are often determined by using only those sites that had some margin (i.e., sites that had error-free reception to begin with) and excluding sites that had zero margin.
   - c) Determination of site margin by broadband receiver signal attenuation is only an indication of the amount of desired signal above threshold, but does NOT indicate the amount of signal attenuation allowable in the presence of other potential interference signals since all signals (i.e., desired and undesired) are attenuated the same amount during this test.
   - d) Provides an indication of reliability in a given area by determining the amplitude (in dB) of the signal above the data threshold for a given transmission configuration.
5) Margin versus field strength curves (curve fitting to statistically predict minimal field strengths for successful reception)
   - a) Graphical description of reception characteristics of margin plotted dB for dB against decreasing sorted values of received field strength in order to provide a direct comparison of *actual* reception margin compared to *ideal* reception margin (straight line "dB per dB"). Ideal reception margin depends only on received signal strength, with no consideration to impairments and interference.
   - b) Extending the "best fit" straight line to zero margin provides an indication of minimum field strength expected for the particular transmission configuration (which includes any receiver implementation error, as determined in a lab measurement with an unimpaired signal).
   - c) Any deviation from the straight line extension to zero margin from the expected minimum field strength is an indication of the performance degradation of the receiver or transmission system due to impairments and/or interference in real-world applications.
   - d) Provides an indication of predictability of reception performance versus signal level predictions.
6) Comparison of ATSC 3.0 and ATSC 1.0 systems
   - a) Direct service and margin comparison of the ATSC 1.0 transmission system field performance versus the ATSC 3.0 transmission system.

    b) Statistical *differential* analysis of overall service, system performance index, site margin, etc.
    c) Provides an indication of improved RF reception performance of the transmission systems.
7) Comparison of ATSC 3.0 modulation and coding configurations
    a) Direct service and margin performance comparison between various transmission configurations of the ATSC 3.0 system that broadcasters or receiver manufacturers want to test.
    b) Statistical *differential* analysis of overall service, system performance index, site margin, etc.
    c) Provides an indication of system performance tradeoff between payload data rate versus robustness.
8) Cause of failure statistics
    a) Failure analysis for transmission system configuration for any and all reception failures encountered in the field, such as bootstrap lock, L1-Basic preamble lock, L1-Detail preamble lock, LDPC data error, BCH or CRC data error, weak signal, multipath, interference, etc.
    b) Statistical analysis such as percentage of failed sites due to a particular reception failure, including the generic "undetermined" category.
    c) Provides indication of the severity level of a reception failure in the field (e.g., inability to lock versus signal level just below data threshold) and reception failure causes (e.g., multipath, impulse noise, undesired signal interference, etc.).
9) Fixed and portable indoor analysis
    a) Field strength
        i) Overall statistics (minimum, maximum, average, median, standard deviation, etc.)
        ii) Outdoor versus indoor (e.g., height differential, building attenuation, etc.)
    b) Service
        i) Overall service statistics (percentage)
        ii) Statistics per building, per floor, per rooms on a floor within a building, per location within a room, per specific side of a building (facing towards or away from transmitter), etc.
        iii) Statistics per antenna type
        iv) Statistics per signal mode/configuration
        v) Ease of antenna adjustment
        vi) Margin versus field strength curve
        vii) Comparison of ATSC 1.0 and ATSC 3.0 modes/configurations

The following are some analyses that could be performed for *non-stationary* reception testing (e.g., pedestrian, mobile), but not limited to:

1) Pedestrian analysis
    a) Field strength
        i) Comparison of indoor and outdoor field strength
    b) Service
        i) Comparison of indoor and outdoor reception

ii) Comparison of various ATSC 3.0 modes/configurations
iii) Minimum field strength sensitivity for error-free reception

2) Mobile analysis
   a) Field strength
      i) Overall statistics (minimum, maximum, average, median, standard deviation, etc.)
      ii) Urban versus suburban versus rural
   b) Service
      i) Overall successful reception rate
      ii) SNR threshold degradation due to noise enhancement
   c) Field strength versus service statistics

Observer's measurement observations are often very valuable in describing anomalies in test results and should be included in a comments column or as footnotes in the Test Report.

Digital photographic records are important ways to explain a site condition in some detail. In addition to the surrounding area, photographs should be made of the test setup itself in relation to the surrounding environment, such as the view in the direction in which the antenna has been pointed.

Spectrum display images provide insight into the signal conditions that is measured as well as the spectrum in which the signal is located. When practical, spectrum records of the measured signal should be made for each major measurement set and should include a wideband display (e.g., 20 MHz or more) of the spectrum containing the desired signal.

5.3 Channel Characteristics Measurement

The RF propagation channel characteristics at a site describe the received signal condition. In addition to indicating parameters like received signal strength, the channel characteristics describe other aspects of the received signal such as impulse response, and particularly multipath conditions as they change with time. A received signal at a particular location will be impacted by the particular location's surroundings, man-made or naturally-occurring in the transmission path, undesired signal interference, externally-induced noise, and the receiving antenna (type, height, orientation).

The received signal at any location generally includes components that took different propagation paths from the transmitter to the receiver. This condition is commonly called "multipath." The principal or "main" component (sometimes referred to as the predominant signal), normally defined as the strongest of the multipath components, may be the direct-path signal from the transmitter to the receiver if the path is unobstructed. However, depending on the location, one of the reflected signals could be the strongest if the predominant signal component has greater attenuation due to some obstruction (e.g., in a non-line-of-sight condition).

The time positions of the other signals are typically referenced to the predominant signal (i.e., the strongest). Thus if the direct path is obstructed, there can be signals that *appear* to arrive earlier than the main signal as well as signals that arrive after the main signal. These are called leading (pre-echoes) and lagging (post-echoes), because the signal leads or lags the main signal, respectively. Very rarely are these echoes static. Usually, they vary continuously in amplitude and/or delay with time, and the condition is consequently called dynamic multipath. If the strongest signal varies in amplitude such that another signal becomes stronger (i.e., a new "predominant" channel exists), then the reference for the time offset of the other reflections changes (sometimes referred to as a "bobbing" channel). This may appear to indicate that the distribution of the multipath in time has changed when actually only the relative amplitudes of the components varied.

In normal circumstances the receiving antenna characteristics and orientation will affect the degree of received multipath. Consequently, the impact of the choice of antenna and its orientation should be clearly understood when recording any signal for later analysis.

There are several purposes for determining channel characteristics at test sites:

1) Create a set of *statistics* of occurrence of various forms and levels of signal degradation. Data to satisfy this purpose requires correlation with system performance field tests so that its significance to receiver performance can be assessed. In addition, the data recorded should allow cataloging of characteristics (e.g., echo length, amplitude, and time variability) for study of correlation among individual signal parameters.
2) Provide information *records* of challenging sites for testing new and improved DTV designs in the field. In this case, as above, the data recorded should allow cataloging of characteristics (e.g., echo length, amplitude, and time variability) so that records of sites of particular interest can be retrieved. If data is taken specifically for use in receiver development, there should be some "standard normal" sites, some with average multipath, some with long pre-echoes and/or post-echoes, some dynamic, and some static. Since it is logical to test the ATSC 3.0 receivers for easy, moderate, and tough sites, there should be criteria to classify sites for later selection for field testing. Those criteria could be based on:
    - Static or dynamic nature of echoes
    - Close-in (< 1 µs), near (< 5 µs), average (< 20 µs), or far (>20 µs) echoes for both pre-and post-echoes
    - Strong echoes (0 to -3 dB echo strength), moderate echoes (-3 dB to -12 dB echo strength), and weak echoes (< -12 dB echo strength)
    - Localized (discrete) or spread (dispersed) echoes

Cataloging by these criteria allows the designer to select relevant signals, and also allows selection of a range of signals for comparative testing of receivers.

Documenting these RF propagation characteristics according to the specification of certain parameters listed previously can be accomplished by cataloging them in tabular form. These channel characteristics can be determined by transmitting a transmitter identification signal (TxID) as part of a ATSC 3.0 signal, and then using specialized test equipment to retrieve the TxID signal to characterize the propagation path (channel impulse response). From this channel response, cataloguing of the site's RF reception can be performed.

However, another option is to record the actual RF signal, which allows both subsequent computer analysis and reproduction of the RF signal for input to receivers in the laboratory. The reproduction of a recorded ATSC 3.0 signal for input to a prototype, commercial, or consumer receiver will allow simulated field testing under laboratory conditions.

RF signals can be recorded or captured in the field:

- The ATSC 3.0 RF signal can be recorded live for a minimum of **60** seconds and subsequently played back in the laboratory to test the receivers using the particular transmission standard that was originally recorded.
- The ATSC 3.0 RF signal, with a TxID signal embedded, can be recorded for a minimum of **60** seconds and subsequently played back in the laboratory and analyzed on a TxID analyzer.

- Long-term testing may also be appropriate.

5.3.1 Site Selection Criteria

Locations may be selected using the same criteria, as when making service measurements, or locations may be biased towards specific impairments. When biased, locations may be selected based on an expectation of "easy", "average" and/or "difficult" receiving conditions.

If biased, the type of bias needs to be noted in a database. Some site selections may be made only for their expected future benefit to test improved receivers or systems.

Recording of signals should particularly be performed when the receiver under test fails to meet the acceptable performance criteria. This will enable analysis of the channel and may lead to an understanding of why the receiver cannot lock or operates above the expected threshold. Recording at a statistically-meaningful sample of sites will also gather information as to whether the impairments present occur with high or low probability. This information can help in the manufacturer's decision to attack the impairments via design improvements. Observations of possible receiver overload should also be recorded.

5.3.2 Field Test Facility

5.3.2.1 Vehicle

The vehicle employed in this test can be the same as used in the service measurements.

5.3.2.2 Equipment

The test equipment employed in this test can be identical to the service measurement test, except that a piece of test equipment to measure the transmitter ID signal is required.

5.3.2.3 Receive Antenna

The receive antenna used for channel characteristics measurements can be of the same type and calibration as the directional antenna employed in the service measurement.

When designing an RF capture system or a channel measurement system, care should be taken so that the signal can be accurately reproduced at a later time. See Section 5.1.4 and 5.2.4 for equipment selection guidelines.

5.3.3 Measurement Data Set

The measurement set is the site's RF propagation characteristics and/or the collection of captured RF signals.

5.3.4 Measurement Methodology

The following general methodologies outline a typical channel response measurement process. Channel characteristics measurements are made for short durations (a minimum time of **60** seconds, but typically 3 – 5 minutes) for this reason.

5.3.4.1 Capture of Channel Characteristics: Direct Method

An optional ATSC 3.0 technology allows a transmitter ID signal to be synchronously embedded into the transmitted signal "underneath" the normal data with little effect on the payload data. It can then subsequently be recovered with appropriate specialized test equipment that employs powerful correlation techniques to provide an RF propagation channel impulse response. A minimum capture time of **60 seconds** is recommended.

5.3.4.2 Capture of Channel Characteristics: Indirect Method

The equalization inferential method may be used if the direct method is not available. The receiver's equalization information obtained from the various OFDM pilots are saved to allow characterization by calculating the multipath.

However, this method does not work well in the presence of severe multipath echoes that extend beyond the guard interval.

5.3.4.3 Antenna Height

The location of the antenna is typically the 30' AGL height to match that of the coverage tests, thus providing channel characteristics for a representative application. However, this particular height that was typically used starting in the late 1950s with the TASO study can be modified to any height that is deemed appropriate for typical building construction in a given location. A lower height can be tested in order to determine differences in signal strength, multipath propagation, and interference environments due to the increased local ground clutter (terrain, buildings, etc.).

5.3.4.4 RF Signal Recording

The ATSC 3.0 RF signal should be recorded for a minimum of **60 seconds**. Care should be taken to not overload the front end data acquisition (i.e., the A/D converter) during the recording process.

5.3.4.5 Field Test Duration

For capturing channel characteristics, the test duration can be any range that is suitable to both the field test plan and storage capability of the test equipment. Channel characteristics measurements are made for short durations (a minimum time of **60** seconds, but typically 3 – 5 minutes) for this reason.

5.3.5 Data Analysis Considerations

5.3.5.1 Channel Characteristics

The captured signal provides data suitable for analysis to include at least echo length, phase, and amplitude (channel impulse response). Results can be analyzed to determine the complexity of the impairments and what improvements are needed to acquire such a channel. The RF capturing device should output a data file convertible to a form used in common software simulation and analysis programs.

Statistical analysis of the propagation echo amplitudes, delays, and dynamic aspects can be performed on the site data.

5.3.5.2 RF Signal Recordings

The recorded RF signals can be fed directly to receivers to evaluate the effects on design improvements or adjustments on receivers' performance with the signals recorded under all the various selection criteria described previously. The signal can also be fed simultaneously to a number of receivers to compare their performance under exactly the same channel conditions. Reception performance of various receiver designs can be analyzed based on the type of impairments recorded from the field.

Likewise, the signal can be employed in computer simulation programs in order to test new receiver designs in software before they are put into hardware.

6. MEASUREMENT PROCEDURES

All measurement procedures begin with pre-field test planning:

1) Document *transmitter* site hardware characteristics

   a) Transmitter site location coordinates (e.g., latitude and longitude)
   b) Hardware (e.g., block diagram components such as data sources, STLs, exciter, intermediate power amplifier, high power amplifier, harmonic filter, emission mask filter, feedline, antenna, antenna gain, azimuth and elevation patterns/polarization, etc.).
   c) Signal (e.g., data modes and configurations, TPO, ERP, adjacent channel emission mask compliance, signal SNR quality, etc.)
2) Document *receive* site hardware characteristics
   a) Test site location coordinates (e.g., latitude and longitude), including street names/route numbers for mobile/outdoor pedestrian, and building names/addresses for fixed indoor, portable, and (indoor) pedestrian.
   b) Hardware description (e.g., block diagram of components such as calibrated test antenna, impedance matching devices, coaxial feedlines, step attenuators, amplifiers, splitters, receivers, GPS devices, manual and automated test equipment, computers, etc.)
   c) Signal (e.g., minimum field strength sensitivity measurement capability for various data modes and configurations, antenna gain/azimuth pattern/polarization, AWGN thresholds, measurement parameters available, etc.)

6.1 Coverage Measurements

6.1.1 Fixed Outdoor Procedure

1) Plot sites to be visited (e.g., radials, arcs, grids, clusters) on computer maps.
2) At start of test day, confirm proper operation of transmitter and field test vehicle equipment, calibrate field test truck, and record if transmit antenna is H-POL, E-POL, or C-POL.
3) At each measurement location:
   a) Confirm feasibility of raising antenna to 30 feet AGL without encountering obstructions such as tree limbs or overhead wires.
   b) If site is not suitable for testing or is unreachable, move to closest suitable location (within 0.5 mile).
   c) Attach antenna to mast, connect feedline, and raise antenna to 30 feet AGL.
   d) Determine test site location coordinates (latitude and longitude, in fractional degrees), as well as distance (miles) and bearing (degrees) to transmitter. Record results together with a description of the test site, weather conditions, and date/time. *Optionally* plot terrain profile between transmitter and test site.
   e) Using a spectrum analyzer, orient antenna for maximum average ATSC 3.0 signal strength (in dBm), and record this azimuth angle (in degrees) and record the antenna orientation sensitivity.
   f) Record the spectrum analyzer average signal power level (in dBm) for this first cluster measurement point.
   g) Repeat measurement for 4 other cluster measurement points.
   h) Calculate and record equivalent *average* field strength (in dBμV/m) of the five cluster measurement points using average power (dBm), down-lead coaxial cable loss, power-to-voltage conversion, dipole factor, and antenna gain.

i) Record any comments relative to any anomalous observations.
j) Lower antenna, and proceed to next test site.

6.2 Service Measurements

6.2.1 Fixed Outdoor Procedure

1) Plot sites to be visited (e.g., radials, arcs, grids, clusters) on computer maps.
2) At start of test day, confirm proper operation of transmitter and field test vehicle equipment, and calibrate field test truck equipment.
3) Record RF channel number and transmit antenna polarization (H-POL, E-POL, or C-POL).
4) At each measurement location:
   a) Confirm feasibility of raising antenna to 30 feet AGL without encountering obstructions such as tree limbs or overhead wires.
   b) If site is not suitable for testing or is unreachable, move to closest suitable location (within 0.5 mile).
   c) Attach antenna to mast, connect feedline, and raise antenna to 30 feet AGL.
   d) Determine test site location coordinates (latitude and longitude, in fractional degrees), as well as distance (miles) and bearing (degrees) to transmitter. Record results together with a description of the test site, weather conditions, and date/time. *Optionally* plot terrain profile between transmitter and test site.
   e) Using a spectrum analyzer, orient antenna for maximum average RF signal strength (in dBm), and record this azimuth angle (in degrees) and record the antenna orientation sensitivity.
   f) Adjust the field test vehicle's system input RF attenuator to achieve an RF system output level of about -50 dBm into the test receiver (after the amplifier/splitter combination), and record the attenuator setting (in dB).
      i) Confirm that no signal overload conditions exist in the RF system amplifier (from the combination of desired and undesired signals).
      ii) If an overload condition exists due to ACI:
         1. Lower the desired signal below -50 dBm (but not too close to the expected SNR threshold) until errors cease.
         2. *Optionally* create and record a 20 MHz (or 50 MHz, if necessary) spectrum plot.
         3. If errors persist even at the attenuated signal level, add the optional band-pass filter (in front of the amplifier) to remove most of the offending undesired signals, and repeat with -50 dBm signal level.
   g) Record the spectrum analyzer average signal power level (in dBm).
   h) Calculate and record equivalent average field strength (in dBμV/m) using average power (dBm), RF system gain, input attenuation, power-to-voltage conversion, dipole factor, and antenna gain.
   i) Determine and record SNR of received signal.
      i) Measure field test vehicle's system noise floor (in dBm) at amplifier/splitter output with no input signal (i.e., fully attenuated by input attenuator).
      ii) Calculate received signal's SNR.
   j) Determine reception:

i) After selecting the desired data stream in the receiver, observe PER from receiver (objectively) or video from display (subjectively) for **3 minutes** to determine if any errors occurred.
ii) Note number of "hits" (i.e., error bursts) that occurred during this time period and any signal strength variations (higher and/or lower).

k) Record receiver data that is available (e.g., SNR, PER, channel response, etc.).
l) Determine site margin:
   i) Lower the signal in **1-dB** steps until just above threshold of errors.
   ii) Observe PER from receiver (objectively) or video from display (subjectively) for **3 minutes** to determine if any errors occurred.
   iii) If errors observed, raise signal by **1-dB** and repeat observation window.
m) Record any receiver data at threshold that is available (e.g., SNR, PER, channel response, etc.).
n) Record the site margin (in dB) as the attenuator value just above threshold.
o) Record any comments relative to any anomalous observations.
p) Archive data on backup storage device.
q) Lower antenna, and proceed to next test site.

6.2.2 Fixed Indoor Procedure

1) Plot sites to be visited (e.g., urban, suburban) on computer maps, typically 5 – 35 miles away from transmitter).
2) At start of test day, confirm proper operation of transmitter and field test vehicle equipment, and calibrate indoor test equipment.
3) Record RF channel number and transmit antenna polarization (H-POL, E-POL, or C-POL).
4) Determine test site location coordinates (latitude and longitude, in fractional degrees), as well as distance (miles) and bearing (degrees) to transmitter. Record results together with a description of the test site, weather conditions, and date/time. *Optionally* plot terrain profile between transmitter and test site.
5) Perform a complete 30' AGL outdoor measurement just outside the house, as close as possible, using the procedures above (Section 6.2.1) for outdoor measurements. NOTE: if an additional set of data is desired at 12' or 15' AGL, it can be documented as well as the 30' AGL data.
6) Select the room and location within the room to be tested (*perhaps* one that already has a television receiver using an indoor antenna), and set up indoor antenna on a tripod. Otherwise, select a room and a location within the room where TV viewing would be expected or desired.
7) Document the test site:
   a) Building age and type (1-storey, 2-story, split level, house, apartment/condo, mobile home, etc.).
   b) Building construction materials (brick, frame, siding, metal, metallic screening, etc.).
   c) Specific room location within the building (floor, corner, middle, windows, etc.)
   d) Direction the room is facing.
8) Attach the indoor antenna to the tripod, and place in an appropriate location within the room about 5' above the floor.

9) Perform same test procedures as described in the outdoor field test Section 6.2.1 (4e – 4p).
10) Pack up and proceed to next test site.

6.2.3 Portable Procedure

1) Similar to indoor test, except:
   a) Antenna cannot be rotated due to internal location of receive antenna
   b) Site margin cannot be tested

6.2.4 Pedestrian Procedure

1) Plot test locations on electronic road maps *prior* to the start of testing, providing a reasonable match to the desired measurement sites and objectives.
2) At the start of each test day, confirm proper operation of the transmitter and field equipment (i.e., Calibration Tests).
3) Verify test receivers are operational.
4) At each pedestrian test site:
   a) Set up test equipment at ***initial*** pedestrian route.
   b) Record test site description:
      i) Location coordinates (latitude and longitude, in fractional degrees) as well as street address, if possible.
      ii) Distance (miles) and bearing (degrees) to transmitter
      iii) Record description of the test site, weather conditions, and date/time.
      iv) *Optionally* plot terrain profile between transmitter and test site.
   c) Perform complete outdoor measurement at 30' AGL per Section 6.2.1 for subsequent comparison to indoor field strengths and reception characteristics.
   d) Perform and document complete ***stationary*** measurement with ***reference*** receiver and reference antenna (external or internal):
      i) Signal level using a spectrum analyzer (external antenna) or internal receiver signal meter (using built-in antenna)
      ii) Calculate field strength using appropriate system parameters
      iii) SNR (if available from receiver)
      iv) Packet error rate for **3-minute** sampling period (if available from receiver)
      v) Repeat for all desired test signals and test antennas.
   e) Initialize ***pedestrian*** receiver(s) and *optional* auto logging equipment
   f) Start logging reception data (moving slower than 3 mph):
      i) Signal level (and optionally calculated field strength)
      ii) SNR (if available from receiver)
      iii) Packet error rate for **3-minute** sampling period (if available from receiver)
      iv) Repeat for all desired test signals and test antennas
   g) Repeat for each type of test signal (i.e., particular modulation and coding parameters)
5) Proceed to next test site.

6.2.5 Mobile Procedure

1) Determine test routes for the day.
2) At start of test day, confirm proper operation of transmitter and field test vehicle equipment, calibrate truck equipment, etc.

3) Record RF channel number and transmitter antenna polarization (H-POL, E-POL, or C-POL).
4) Drive to location of initial route test site.
5) Determine initial route test site location coordinates (latitude and longitude, in fractional degrees), as well as distance (miles) and bearing (degrees) to transmitter. Record results together with a description of the test site, weather conditions, and date/time.
6) After initializing receiver(s) and auto logging equipment, start logging reception data:
    a) File name
    b) Test city
    c) Route number
    d) RF test channel(s)
    e) Data mode test signal modulation and coding parameters
    f) GPS time and date codes
    g) GPS data (latitude and longitude, speed)
    h) RF signal level
    i) Various error indicators (bootstrap, L1-Basic Preamble, L1-Detail Preamble, LDPC, BCH/CRC)
7) Begin driving pre-assigned route, periodically verifying proper operation of logging operations.
8) Arrive at final route test site, and terminate data logging.
9) Determine final route test site location coordinates (latitude and longitude, in fractional degrees), as well as distance (miles) and bearing (degrees) to transmitter. Record results together with a description of the test site, weather conditions, and date/time.
10) Archive data on backup storage device.
11) Proceed to next initial route site.

6.3 Channel Characteristics Measurements

6.3.1 Fixed Outdoor Procedure

1) Plot sites to be visited (e.g., radials, arcs, grids, clusters) on computer maps.
2) At start of test day, confirm proper operation of transmitter (including TxID code insertion) and field test vehicle equipment, and calibrate field test truck equipment.
3) Record RF channel number and transmit antenna polarization (H-POL, E-POL, or C-POL).
4) At each measurement location:
    a) Confirm feasibility of raising antenna to 30 feet AGL without encountering obstructions such as tree limbs or overhead wires.
    b) If site is not suitable for testing or is unreachable, move to closest suitable location (within 0.5 mile).
    c) Attach antenna to mast, connect feedline, and raise antenna to 30 feet AGL.
    d) Determine test site location coordinates (latitude and longitude, in fractional degrees), as well as distance (miles) and bearing (degrees) to transmitter. Record results together with a description of the test site, weather conditions, and date/time. *Optionally* plot terrain profile between transmitter and test site.

e) Using a spectrum analyzer, orient antenna for maximum average RF signal strength (in dBm), and record this azimuth angle (in degrees).

f) Adjust the field test vehicle's system input RF attenuator to achieve an RF system output level of about -50 dBm into the test receiver (after the amplifier/splitter combination), and record the attenuator setting (in dB).

i) Confirm that no signal overload conditions exist in the RF system amplifier (from the combination of desired and undesired signals).

ii) If an overload condition exists due to ACI:

1. Lower the desired signal below -50 dBm (but not too close to the expected SNR threshold) until errors cease.
2. *Optionally* create and record a 20 MHz (or 50 MHz, if necessary) spectrum plot.
3. If errors persist even at the attenuated signal level, add the optional band-pass filter (in front of the amplifier) to remove most of the offending undesired signals, and repeat with -50 dBm signal level.

g) Record the spectrum analyzer average signal power level (in dBm).

h) Calculate and record equivalent average field strength (in dBµV/m) using average power (dBm), RF system gain, input attenuation, power-to-voltage conversion, dipole factor, and antenna gain.

i) Using a TxID analyzer, measure and record the various pre-echo and post echo signal amplitudes and delays.

j) Record any comments relative to any anomalous observations.

k) Archive data on backup storage device.

l) Lower antenna, and proceed to next test site.

6.3.2 Fixed Indoor Procedure

The procedure is *similar* to the fixed outdoor procedure, except that location of receiving antenna within the building should be determined: the floor (which affects its height above ground level), the specific room to be tested, its exact location within the room, and its height above the floor.

6.3.3 Portable Procedure

The procedure is the *same* as that used for fixed indoor testing.

6.3.4 Pedestrian Procedure

The procedure is sameas that used for fixed indoor testing, with possible addition of antenna movement.

6.3.5 Mobile Procedure

1) Plan routes to be measured on computer maps.
2) At start of test day, confirm proper operation of equipment:
   a) Transmitter (including TxID code insertion).
   b) Field test vehicle equipment.
   c) Calibrate field test truck equipment.
3) Record RF channel number and transmit antenna polarization (H-POL, E-POL, or C-POL).
4) Record RF channel response as field test vehicle travels pre-planned route at *slow* or *moderate* speeds:
   a) Signal strength measurement in dBm using spectrum analyzer.

b) Signal channel propagation response in amplitude (dB) and delay (μsec), using TxID analyzer.

5) Repeat for remaining test routes.

Annex A: ATSC 3.0 System Description

A.1 OVERVIEW

In the future, broadcasters anticipate providing multiple wireless-based services in addition to traditional television. The ATSC 3.0 standard allows for such use. Instead of transmitting to only television sets as in the past, they may choose to multiplex multiple services into one RF channel, and transmit them to a diverse group of reception devices that may employ portable, pedestrian, and mobile reception in addition to fixed outdoor and indoor reception.

The ATSC 3.0 system has a complex physical layer that provides significant amounts of flexibility. A simplified overview of the system is shown in Figure A.1.1.

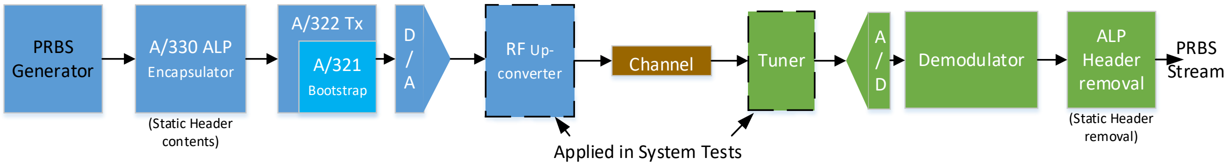


Figure A.1.1 Simplified ATSC 3.0 physical layer transmission system block diagram

The flexibility of the ATSC 3.0 system not only allows for this service multiplexing, but does so with the ability to tradeoff data rate for robustness depending on the desired goals. Each service is encapsulated in Physical Layer Pipe(s) (PLP), with up to a maximum of 64 PLPs allowed in one ATSC 3.0 signal.

To get the desired flexibility of data rate and performance, significant amounts of data processing are performed, particularly in the form of robust synchronization signals (bootstrap), signaling components (Preambles), and complex forward error coding and modulation constellations (Payload Data). The ATSC 3.0 standard defines a *data frame* structure within the physical layer that contains three basic components (all consisting of OFDM symbols) that are time-multiplexed together, as shown in Figure A.1.2. They are:

1) Bootstrap
2) Preamble (made up of L1-Basic and L1-Detail structures)
3) One or more subframes

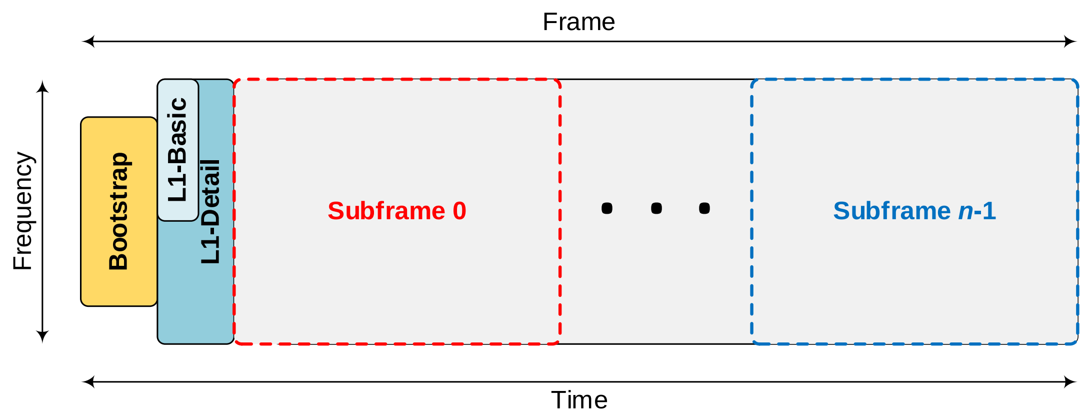


Figure A.1.2 Data framing and subframe structure.

Each frame begins with a Bootstrap signal to identify the presence of the signal, followed by a Preamble signal to indicate the exact makeup of the frame, and then followed by one or more subframes that can carry payload data of different robustness and data rate. Impairments are equally likely to occur in the Bootstrap symbols, the Preamble symbols, and the subframe data symbols.

A.2 BOOTSTRAP

The bootstrap signal is situated at the beginning of *each* data frame to facilitate the initial acquisition of the frame. It is a known signal made up of a series of OFDM symbols that creates a universal robust entry point into the system, with error resiliency at very low signal levels as well as in the presence of strong multipath (e.g., -6 dB SNR in Rayleigh echo channels). Each OFDM symbol is 500 µsec, and the *current* bootstrap signal has 4 symbols for a total duration of 2 msec. The bootstrap signal is designed to be flexible, with the possibility for future expansion if needed.

The bootstrap signal has multiple symbols with fixed characteristics that are known to all receivers (6.044 Msamples/second, 4.5 MHz bandwidth, 2048 FFT, 500 µsec symbol duration). The bootstrap signals a minimal set of parameters that enable the decoding of the L1-Basic portion of the frame's preamble.

Bootstrap symbol #0 is a synchronization symbol that enables service discovery, coarse time synchronization, frequency offset estimation in receivers, and the major/minor system version of the transmitted signal. The remaining bootstrap symbols (#1, #2, #3) each carry 8 signaling bits. Symbol #1 signals the first Emergency Alert bit, the minimum time to the next frame (50 msec to 5.7 seconds), and the system bandwidth (6, 7, 8, >8 MHz). Symbol #2 signals the second Emergency Alert bit and the baseband sampling rate for the remainder of the frame. Symbol #3 signals the L1-Basic preamble structure and decoding information (FFT size, guard interval length, pilot density, and coding level). A phase inversion is applied to the frequency domain sequence for the final bootstrap symbol in order to signal the conclusion of the bootstrap. This allows future lengthening of the bootstrap signal in the future, while maintaining backward compatibility for legacy receivers.

Receivers use the bootstrap as the first stage of frequency and timing synchronization, and create a bootstrap synchronization indicator. If an error occurs in any of the four bootstrap symbols, the entire frame (i.e., all subframes) may be lost. If the receiver provides access to this indicator from an external device such as a computer, this signal may be useful in field testing to identify synchronization performance.

A.3 PREAMBLE

The preamble immediately follows every bootstrap signal, and therefore also occurs once every data frame. It is comprised of one or more OFDM symbols, and contains control signaling that describes the remainder of the data frame, including identification of the contents. Its role is to convey physical layer, i.e., Layer 1 (L1), signaling that is needed to access the payload data carried by PLPs. There are a variety of robustness levels for preamble symbols, with error resiliency at weak signal levels and in the presence of multipath (e.g., -6 dB to +25 dB SNR in Rayleigh echo channels).

The Preamble contains two parts: L1-Basic and L1-Detail. L1-Basic, which is confined to the first Preamble symbol, has a fixed length of 200 bits, and signals parameters that enable decoding of L1-Detail as well as the initial processing of the first subframe. L1-Detail has a variable length as needed, carrying a larger number (200 – 65528) of signaling bits than L1-Basic to signal configuration parameters that describe the remaining subframe payload data (including PLP decoding).

The two L1 Preamble sub-signals are heavily processed for selectable amounts of robustness. They are encoded by LDPC codes with code length 16,200 bits long and independently mapped to constellations ranging from QPSK to 256-NUC. For each Preamble sub-signal, there are seven modes available with different LDPC code rates and constellations. For added diversity, various time and frequency interleaving is performed to mitigate burst errors and signal fading. Preamble symbols are less robust than bootstrap symbols, but more robust than data payload symbols.

Each of these two sections of the Preamble has a detection indicator associated with it regarding the hierarchal synchronization and decoding of the data. If an error occurs in a Preamble symbol, the subframe data may or may not be affected, depending on the severity of the loss (e.g., due to signal loss or severe multipath). Therefore, if a receiver provides access to these indicators from an external device such as a computer, these signals may be useful in field testing to identify synchronization performance.

A.4 SUBFRAMES

The remainder of the data frame consists of one or more subframes that are concatenated in time, each carrying error-coded, QAM-modulated, and optionally time-interleaved PLPs. Multiple PLPs can be placed in each sub-frame. Each subframe has a subframe type associated with it, related to its robustness. The Bootstrap signal and the Preamble signal are both very robust compared to the Payload Data, which can vary with chosen modulation and coding parameters.

The ATSC 3.0 standard includes FEC and interleaving as means to protect the signal against impairments, and provide varying degrees of robustness. The payload data can use different constellation modes, time and frequency interleaving parameters, and FEC codes that enable data rate versus robustness tradeoffs for different services.

In the ATSC 3.0 system, the FEC block consists of two systematic codes that protect a baseband packet: an inner code and an optional outer code. Since both codes are systematic, the generated parity bits are just appended to the original baseband packet to create a FEC frame, as shown in Figure A.4.1.

The use of the inner LDPC code is mandatory (i.e., it cannot be turned off). However, the length of the code can be selected from two values: 16,200 bits or 64,800 bits. To provide for additional variable robustness versus data rate, twelve different LDPC code rates can be selected (robust 2/15 through high-data rate 13/15). The 16,200 bit length LDPC codes have lower latency but less robustness while the 64,800 bit length LDPC codes have the opposite effect (ATSC recommends use of the 64,800 bit length LDPC codes, whenever possible, for more robustness).

The use of the outer systematic code has three options: (1) use a BCH 12-bit error correction code, (2) use a 32-bit CRC error detection code, or (3) use no outer code.

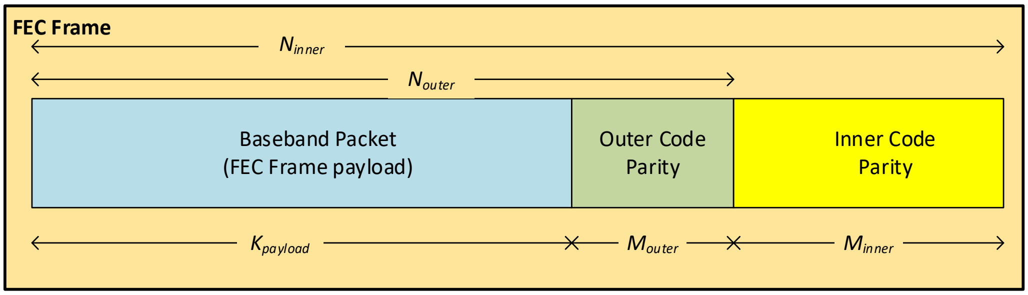


Figure A.4.1 FEC coding.

Of interest in field testing is the objective identification of error-free reception as well as the determination of a given PLP error threshold when a signal is purposely attenuated during a site margin test. Each of these two codes (inner and outer) has a detection indicator associated with it regarding decoding of the payload data. Therefore, if a receiver provides access to these indicators from an external device such as a computer, they may be useful in field testing to identify data decoding performance. However, it should be noted that only one, if any, of the outer codes can be active at a time, depending on the configuration of the outer code.

Annex B: Configuration Settings Examples

B.1 DEVICE UNDER TEST CONFIGURATIONS

Table B.1.1 Example DUT Configurations Representing a Variety of Possible Test Transmission Modes for Consideration

	Parameter	Configuration 1	Configuration 2	Configuration 3	Configuration 4	Configuration 5	Configuration 6
Testing Reference	Verification and Validation test stream	VV600-P6S1	VV601-P6S1	VV602-P6S1	VV603-P6S1	VV604-P6S1	VV605-P6S1
Bootstrap	Channel Bandwidth	6 MHz	6 MHz	6 MHz	6 MHz	6 MHz	6 MHz
	Sample Rate	6.912 MHz	6.912 MHz	6.912 MHz	6.912 MHz	6.912 MHz	6.912 MHz
Input Formatting	ALP Packet Length	1200 byte 2^{23}-1 PRBS +8byte UDP Header +20byte IPv4 Header +2byte ALP Header	1200 byte 2^{23}-1 PRBS +8byte UDP Header +20byte IPv4 Header +2byte ALP Header	1200 byte 2^{23}-1 PRBS +8byte UDP Header +20byte IPv4 Header +2byte ALP Header	1200 byte 2^{23}-1 PRBS +8byte UDP Header +20byte IPv4 Header +2byte ALP Header	1200 byte 2^{23}-1 PRBS +8byte UDP Header +20byte IPv4 Header +2byte ALP Header	1200 byte 2^{23}-1 PRBS +8byte UDP Header +20byte IPv4 Header +2byte ALP Header
	Baseband Packet Length ($K_{payload}$)	47328 bits	PLP 0: 21408 bits PLP 1: 47328 bits	PLP 0: 21408 bits PLP 1: 25728 bits	21408 bits	43008 bits	1992 bits
BICM Parameters	PLP FEC type	BCH + 64800 LDPC	PLP 0: BCH+64800 LDPC PLP 1: BCH+64800 LDPC	PLP 0: BCH+64800 LDPC PLP 1: BCH+64800 LDPC	BCH + 64800 LDPC	BCH + 64800 LDPC	BCH + 16200 LDPC
	PLP FEC Codelength	64800	PLP 0: 64800 PLP 1: 64800	PLP 0: 64800 PLP 1: 64800	PLP 0: 64800	64800	16200
	PLP Code Rate	11/15	PLP 0: 5/15 PLP 1: 11/15	PLP 0: 5/15 PLP 1: 6/15	5/15	10/15	2/15
	PLP Modulation (QAM NUC)	64	PLP 0: QPSK PLP 1: 64	PLP 0: QPSK (core PLP) PLP 1: 16 (Enhanced PLP)	16	256	QPSK

	Parameter	Configuration 1	Configuration 2	Configuration 3	Configuration 4	Configuration 5	Configuration 6
Testing Reference	Verification and Validation test stream	VV600-P6S1	VV601-P6S1	VV602-P6S1	VV603-P6S1	VV604-P6S1	VV605-P6S1
	PLP Size	1467351	PLP 0: 259200 PLP 1: 1198800	PLP 0: 1355209 PLP 1: 1355209	1133237	1467351	1133237
	PLP Time Interleaver mode	Convolutional	Hybrid	Convolutional	Convolutional	Convolutional	Convolutional
	PLP CTI Depth	1024 rows non-extended		1024 rows non-extended	1024 rows non-extended	1024 rows non-extended	1024 rows non-extended
	PLP CTI Memory[1] [cells]	523776		523776	523776	523776	523776
	PLP HTI inter sub-frame		PLP 0: 0 PLP 1: 0				
	PLP HTI # TI Blocks		PLP 0: 1 PLP 1: 6				
	PLP HTI # Max FEC Blocks		PLP 0: 8 PLP 1: 120				
	PLP HTI # FEC Blocks		PLP 0: 8 PLP 1: 111				
	PLP HTI Memory[2] [cells]		PLP 0: 291600 PLP 1: 226800				
	PLP HTI Cell interleaver		PLP 0: On PLP 1: On				
OFDM parameters	Frame Length Mode	Symbol aligned	Symbol aligned	Symbol aligned	Time aligned	Symbol aligned	Symbol aligned
	# Sub Frames	1	1	1	1	1	1
	# PLPs	1	2	2	1	1	1

[1] Convolutional Time Interleaver (CTI) memory = # rows * (# rows – 1)/2[cells]

[2] Hybrid Time Interleaver (HTI) depth = Block interleaver memory + Convolutional interleaver memory
Block Interleaver memory = #rows * #FEC blocks = (LDPC codelength/log2(modulation) * #FEC blocks)
Convolutional Interleaver memory = ((#rows/#TI blocks+1) * #FEC blocks) * (#TI blocks * (# TI blocks -1)/2)
HTI depth = (#rows * #FEC blocks)+(((#rows/#TI blocks+1) * #FEC blocks) * (#TI blocks * (# TI blocks -1)/2))*2+1)[cells]
Time Interleaver depth = (#symbols/sub-frame) * (FFT size / (Baseband Sample Rate(BSR) / #PLPs)) * (1+GI Ratio)
Time Interleaver depth = (Interleaver depth [cells] / NoC) * (FFT size/(BSR / #PLPs)) * (1+GI ratio)

	Parameter	**Configuration 1**	**Configuration 2**	**Configuration 3**	**Configuration 4**	**Configuration 5**	**Configuration 6**
Testing Reference	Verification and Validation test stream	VV600-P6S1	VV601-P6S1	VV602-P6S1	VV603-P6S1	VV604-P6S1	VV605-P6S1
	LDM	off	off	On	off	Off	Off
	LDM injection level	0	0	-4dB	0	0	0
	Channel Bonding	Off	Off	Off	Off	Off	Off
	MIMO/MISO/SISO	Subframe 1: SISO	Subframe 1: SISO	Subframe 1: SISO	Subframe 1: SISO	Subframe 1: MISO (N=64, M=2)	Subframe 1: SISO
	FFT Size	Subframe 1: 32K	Subframe 1: 32K	Subframe 1: 16K	Subframe 1: 8K	Subframe 1: 32K	Subframe 1: 8K
	Guard Interval	Subframe 1: GI5_1024(148usec)	Subframe 1: GI5_1024(148usec)	Subframe 1: GI5_1024(148usec)	Subframe 1: GI6_1536(222usec)	Subframe 1: GI5_1024(148usec)	Subframe 1: GI6_1536(222usec)
	NoC (# of data carriers)	Subframe 1: 27649 (reduced carriers =0)	Subframe 1: 27649 (reduced carriers =0)	Subframe 1: 13825 (reduced carriers =0)	Subframe 1: 6913 (reduced carriers =0)	Subframe 1: 27649 (reduced carriers =0)	Subframe 1: 6913 (reduced carriers =0)
	Scattered Pilot Pattern	Subframe 1: SP24_2	Subframe 1: SP24_2	Subframe 1: SP6_2	Subframe 1: SP4_2	Subframe 1: SP24_2	Subframe 1: SP4_2
	SP boost	Subframe 1: 2.43	Subframe 1: 2.43	Subframe 1: 1.7	Subframe 1: 1.51	Subframe 1: 2.43	Subframe 1: 1.51
	# Payload Symbols	Subframe 1: 54	Subframe 1: 54	Subframe 1: 108	Subframe 1: 189	Subframe 1: 54	Subframe 1: 189
	Subframe Length	Subframe 1: 264.0 msec	Subframe 1: 264.0 msec	Subframe 1: 272.0 msec	Subframe 1: 266.0 msec	Subframe 1: 264.0 msec	Subframe 1: 266.0 msec
	First Subframe Boundary Symbol	Subframe 1: Yes	Subframe 1: Yes	Subframe 1: Yes	Subframe 1: Yes	Subframe 1: Yes	Subframe 1: Yes
	Last Subframe Boundary Symbol	Subframe 1: Yes	Subframe 1: Yes	Subframe 1: Yes	Subframe 1: Yes	Subframe 1: Yes	Subframe 1: Yes
	PLP Multiplexing[3]	Subframe 1: TDM	Subframe 1: TDM	Subframe 1: LDM	Subframe 1: TDM	Subframe 1: TDM	Subframe 1: TDM
	Channel Occupancy (Scheduler regulated)	Subframe 1: 100%	Subframe 1, PLP 0: 18% Subframe 1, PLP 1: 82%	Subframe 1: 100%	Subframe 1: 100%	Subframe 1: 100%	Subframe 1: 100%
	Frequency Interleaver	On	On	On	On	On	On

[3] PLP_ID, PLP_Size, PLP_Type, PLP_Start, Num_subslices and subslice_Interval settings may vary.

	Parameter	Configuration 1	Configuration 2	Configuration 3	Configuration 4	Configuration 5	Configuration 6
Testing Reference	Verification and Validation test stream	VV600-P6S1	VV601-P6S1	VV602-P6S1	VV603-P6S1	VV604-P6S1	VV605-P6S1
	PAPR	Off	Off	Off	Off	Off	Off
Preamble Parameters	L1 Basic Mode	Mode 3	Mode 1	Mode 1	Mode 1	Mode 3	Mode 1
	L1 Detail Mode	Mode 3	Mode 1	Mode 1	Mode 1	Mode 3	Mode 1
	FFT	32K	32K	16K	8K	32K	8K
	Reduced Carriers	0	0	0	0	0	0
	Guard Interval	GI5_1024	GI5_1024	GI5_1024	GI6_1536	GI5_1024	GI6_1536
	SP_Dx	12	12	6	4	12	4
	# Preamble Symbols	1	1	1	2	1	2
	Frame Length[4]	266 ms	266 ms	276.5185 ms	275 ms	266 ms	270.8148 ms
	Data Rate [Mbps][5]	15.8204	PLP 0: 0.6439 PLP 1: 19.2159	PLP 0: 0.32373 PLP 1: 7.7812	5.4447	28.7527	1.0289
	Approximate SNR[6] under AWGN channel [dB] (considering power boosting)	9.9 dB	PLP 0: -1.3 PLP 1: 14.7	PLP 0: 1.7 PLP 1: 10.3	3.4	17.5	-4.9

Gray shaded rows are calculation results given by respective parameter choices.

[4] Frame Length = Bootstrap Length (2ms) + Preamble Length + Subframe Length = 2ms + (FFT_size_preamble + GI_preamble)*#preamble_symbols/6912 ms + (FFT_size_payload + GI_payload)*#payload_symbols/6912 ms. For example, frame length for configuration 1 = 2ms + (32768+1024)*1/6912 ms + (32768+1024)*53/6912 ms = 266ms

[5] Data Rate [Mbps] = PLP_Size*Code_rate*log2(constellation size)*BCH_efficiency/Frame_length. For example, data rate for Configuration 1 = 1440445*11/15*log2(16)*{(64800*11/15-192)/(64800*11/15)}/266ms = 15.82 Mbps.

[6] For approximate SNR calculation, SNR threshold should be first obtained without pilot boosting. Then, SNR normalization according to pilot boosting should be performed. For example, the required SNR for configuration 1 is calculated by two steps: 1) SNR threshold = 9.5023 dB, 2) power normalization according to pilot boosting = 9.5032 dB + 10*log10(31648.70/28822.33) = 9.9 dB

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