



High Frequency (≥ 450 MHz) Antenna Gain, Directionality, and Impedance Test

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1 Introduction

Note: Nothing in this standard supercedes applicable laws and regulations.

Note: In the event of conflict between the English and domestic language, the English language shall take precedence.

Note: In the event of a conflict between the text of this standard and the documents cited herein, the text of this standard takes precedence.

1.1 Purpose.

The purpose of this test is to determine antenna gain, directionality, and impedance in the frequency bands listed in Appendix B (Tables B1 and B2). Gain refers to the ratio of the magnitude of an antenna radiation pattern compared to that of a reference antenna. Directionality refers to the uniformity of an antenna radiation pattern. This document specifies requirements and test procedures for verification of high frequency (≥ 450 MHz) antenna system performance for all General Motors vehicles marketed and sold around the world. This document applies to passenger vehicles and trucks. In this document, an active antenna is defined as an antenna system where any part of it requires electrical power from the vehicle to function as specified. A passive antenna is defined as an antenna that requires no power; whose gain is derived solely from the actual antenna structure.

1.2 Applicability.

This test procedure shall apply to all passive and active antennas. This procedure is applicable to the development and validation of antenna systems for new vehicle programs as well as design changes for current vehicles.

1.3 Remarks.

The requirements stated in this document supercede all Component Technical Specifications (CTS), Subsystem Technical Specifications (SSTS), Vehicle Technical Specifications (VTS), and Global Infotainment Standards (GIS) that pertain to antenna systems in the frequency bands listed in Appendix B (Table B1 and B2).

Note: This document is one out of a series of global antenna documents, which specify antenna test and validation requirements. The complete series consists of this document (GMW16261), and the following others depending on antenna content. GMW16039 specifies the Satellite Digital Audio Radio Service (SDARS) Reception Ride Test, which is conducted exclusively by General Motors personnel. If the Antenna under Test contains more than one antenna element, or contains active circuitry, then GMW15649 shall be applicable. If the Antenna under Test (AUT) also receives AM/FM bands, then GMW15648, GMW15649, GMW15650 and GMW16273 shall be applicable as well. Radio Frequency (RF) cable and connectors are specified in GMW16640. Additional antenna information can be found in the Infotainment Global Subsystem Leadership Team (GSSLT) documents GIS-91A, GIS-92A, GIS-93A, GIS-94A and GIS-99A. Electromagnetic Compatibility (EMC) requirements can be found in GMW3091, GMW3097, and GMW3172. Definitions of Near-Field and Far-Field shall follow IEEE Standard (Std) 145-2013.

2 References

Note: Only the latest approved standards are applicable unless otherwise specified.

2.1 External Standards/Specifications.

ISO 17025 IEEE Std 145-2013

2.2 GM Standards/Specifications.

GMW3091	GMW15648	GMW16039
GMW3097	GMW15649	GMW16273
GMW3172	GMW15650	GMW16640

2.3 Additional References.

- CTS
- GIS-91A
- GIS-92A
- GIS-93A

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- GIS-94A
- GIS-99A
- SSTS
- VTS

3 Resources

3.1 Facilities.

Spherical Near Field (SNF) and Far Field (FF) ranges are allowed, and addressed in this text. Field uniformity measurements should be taken as necessary to confirm range performance.

3.1.1 Calibration.

The test facilities and equipment shall be in good working order and shall have a valid calibration label.

3.1.2 Alternatives.

Alternative test facilities and equipment may also be used. However, all measuring variables as specified in this standard shall be determined correctly with respect to their physical definition.

3.1.3 Far Field (FF).

The High Frequency (HF) gain test facility shall be an open air environment with a minimum 100 m radius clear space around the Vehicle under Test (VUT). Site shall be 10 km from any transmitting station > 10 kW in the applicable frequency band(s) listed in Appendix B (Tables B1 and B2). Regional spectrum usage permission may be required for transmission in these bands.

3.1.4 Spherical Near Field (SNF).

The High Frequency (HF) gain test facility shall be a spherical near field system inside a semi-anechoic chamber. See Appendix A, Figure A4. The semi-anechoic chamber should have a minimum measured normal incidence reflectivity of 30 dB to 45 dB across the test frequency range.

3.2 Equipment.

External calibration laboratories that are accredited to ISO 17025 shall be used to calibrate applicable equipment that is used for the testing outlined in this procedure.

3.2.1 Far Field Gain and Directionality: Required Equipment.

3.2.1.1 Transmit antenna(s) to cover the necessary frequency range (See Appendix B) with a Voltage Standing Wave Ratio (VSWR) < 2.5:1.

3.2.1.2 The reference antenna(s) to cover the necessary frequency range (See Appendix B) with a VSWR < 2.0:1. A log periodic antenna (e.g., ETS Model 3148 or equivalent) shall be used for all bands up to 2 GHz. All gain values shall be normalized to an isotropic radiator (i.e., gain shall be expressed in dBi or dBic units).

3.2.1.3 A spectrum analyzer and a receiver or network analyzer that covers the necessary frequency range (See Appendix B).

3.2.1.4 RF Signal Generator that covers the necessary frequency range (See Appendix B) (not needed when using a network analyzer).

3.2.1.5 RF amplifier that covers the necessary frequency range (See Appendix B) (not needed when using a network analyzer).

3.2.1.6 Dual Channel RF Power Meter (not needed when using a network analyzer).

3.2.1.7 Dual Directional Coupler (not needed when using a network analyzer).

3.2.1.8 A 50 Ω , 3 dB attenuator on the receive path.

3.2.1.9 Receive test feedline cable (connecting the AUT/reference antenna to the spectrum analyzer/receiver) consisting of a 2.5 m to 10.0 m length of RG58 low loss coaxial cable (equivalent or better) covered full length with CAPCON EMI suppressant tubing (or equivalent).

3.2.1.10 A vehicle turntable with a positioning accuracy of 1 degree minimum resolution.

3.2.1.11 A turntable covering structure (optional). If any structure is used to cover the vehicle turntable, it shall exhibit a through loss (S21) of ≤ 0.5 dB.

3.2.2 Spherical Near Field Gain and Directionality: Required Equipment.

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3.2.2.1 Transmit antennas (probes) to cover the necessary frequency range (See Appendix B). Transmit antenna type shall be short dipoles capable of transmitting and receiving two orthogonally polarized signals, in both amplitude and phase.

3.2.2.2 Reference antennas (monopole, Standard Gain Horn (SGH), log periodic, or Double-Ridge Waveguide Horn (DRG)) to cover the necessary frequency range (See Appendix B) with a VSWR < 2.0:1. All gain values shall be normalized to an isotropic radiator and expressed in dBi units.

3.2.2.3 Six (6) m radius arch (as measured from the center of the turntable) with 103 probes mounted every 1 degree (used to transmit and receive RF fields, for elevation angles -10 degrees to +90 degrees from the horizon). A laser positioning system may be mounted to the top of the arch to aid in centering the AUT on the turntable (optional).

3.2.2.4 Probe Array Controller (PAC) that covers the necessary frequency range (See Appendix B).

3.2.2.5 Projector to display probe data from the PAC (optional).

3.2.2.6 Two RF Signal Generators controlled by the measurement system.

3.2.2.7 A 50 Ω , 3 dB (for passive AUTs) or 20 dB (for active AUTs) attenuator on the receive path.

3.2.2.8 Receive test feedline cable (connecting the AUT/reference antenna to the PAC) consisting of a 2.5 m to 10.0 m length of Semflex HPT-450 cable (or equivalent), covered with an appropriate length of CAPCON EMI suppressant tubing (or equivalent).

3.2.2.9 Vehicle turntable with a positioning accuracy of 1 degree minimum resolution.

3.2.2.10 RF absorber to cover exposed areas of turntable to minimize reflections.

3.2.2.11 Moveable walls with RF absorber to eliminate reflections (optional, depending on chamber). Field uniformity measurements shall be made to determine the need for additional absorber.

3.2.2.12 Ramps to elevate vehicle antenna above the measurement system horizon.

3.2.2.13 Monopod to elevate reference antennas and ground plane above measurement system horizon and allow certain reference antennas to be pointed straight up, towards the chamber ceiling (SGHs, etc.)

3.2.3 Antenna System Impedance.

This test requires a network analyzer capable of covering the necessary frequency range (See Appendix B).

3.3 Test Vehicle/Test Piece.

3.3.1 AUT Status.

The AUT shall be in a production ready state and have passed all applicable component-level tests. The AUT is comprised of any of the following: Receiver antenna cable, passive matching network (passive module), active matching network (active module), antenna cable interconnects, and the antenna element(s).

3.3.2 AUT Modifications.

AUT modifications are not allowed for validation purposes, except for the passive antenna sample. The production intent radome, seal and lead-in(s) shall be present on the antenna assembly under test.

3.3.3 AUT Mounting Facility.

AUT assembly shall be measured, mounted on a vehicle in the production intent location. The attachment scheme shall be the same as that of the production intent design. Fasteners shall be tightened to the specified torque, using a calibrated torque wrench.

3.4 Test Time.

The following test times are provided as guidance for most standard validation work. For non-standard validation or measurement work, consult test personnel for time estimates based on actual testing to be performed.

Calendar time:	4 d (GMK) 2 d (GMNA)
Test time:	12 h (GMK) 12 h (GMNA)
Coordination time:	8 h (GMK) 4 h (GMNA)

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3.5 Test Required Information.

3.5.1 Test Properties.

The minimum test information shall contain:

- General Motors vehicle number
- Antenna manufacturer
- AUT module and antenna cable part numbers and serial numbers
- Hardware revision description
- Software revision (if applicable)

3.5.2 Test Site.

The minimum test site information shall contain:

- Test site software revision
- Name of test site
- Date tested
- Time tested

3.5.3 Supplier Conducted Testing.

Supplier facilities shall provide test equipment and setup information, including reference measurement history for a minimum of one year, in addition to the information required in 3.5.1 and 3.5.2. Spread in reference measurements should be no > 1.0 dB.

3.6 Personnel/Skills.

Test personnel shall have a working knowledge of spectrum analyzers, network analyzers, test receivers, antennas, antenna range protocol, and other RF equipment. A working knowledge of computers and data spreadsheets is also required.

4 Procedure

4.1 Preparation.

4.1.1 Equipment Warm-up Time.

All test equipment shall be switched on for a minimum of 30 minutes before any measurements begin.

4.2 Conditions.

4.2.1 Environmental Conditions.

4.2.1.1 Noise Floor.

Test signals generated on site must be 40 dB minimum above the ambient noise floor of the test spectrum analyzer or receiver when measured with the reference antenna.

4.2.2 Test Conditions.

Deviations from the requirements of this standard shall have been agreed upon. Such requirements shall be specified on component drawings, test certificates, reports, etc. Consult Antenna Bill of Material (BOM) Family Owner (BFO) and GM Antenna Technical Fellow regarding deviations.

4.2.2.1 Elevation Angular Reference.

For this test procedure, when elevation angles are referenced, 90 degrees represents a look angle towards the horizon, while 0 degrees represents a look angle towards zenith. For gain measurements utilizing a ground plane, the 1 m straight edge ground plane shall lie in the horizontal plane.

4.2.2.2 Far Field Specific Test Conditions.

4.2.2.2.1 Transmit Antenna.

Transmit antennas shall be mounted on a fiberglass/plastic structure with the axis located 2 m to 4 m above the range surface and positioned between 50 m to 250 m from the center of the turntable with a bore sight angle of < 5 degrees.

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4.2.2.2.2 AUT Setup.

Passive AUT may be tested with the vehicle off. Active antennas without feedline (phantom) power feed shall be tested with the vehicle in accessory mode or vehicle running. Active antennas with feedline (phantom) power feed shall be tested with power supplied by an appropriate Direct Current (DC) source and bias T. Ensure all unnecessary vehicle functions are turned off.

4.2.2.2.3 Supported Polarizations.

Far field test polarizations and elevation angles are listed in Table 1.

Table 1: FF Test Polarizations and Elevation Angles

Band	Polarization	Elevation Angle (degrees)
Mobile Bands	Vertical	87
China Digital Television (CDTV)	Horizontal and Vertical	87

4.2.2.3 Spherical Near Field Specific Test Conditions.

4.2.2.3.1 In systems that measure only the upper hemisphere, the entire radiating element of the AUT shall be positioned at or above the horizon height of the system, but within the calculated minimum sphere (see 4.3.5.5) for the corresponding test frequencies.

4.2.2.3.2 Each probe measures two spherically orthogonal polarized signals, in both amplitude and phase. The data is measured for every one degree rotation of the turntable, for each probe.

4.2.2.3.3 Passive antennas may be tested with the vehicle off. Active antennas without feedline (phantom) power feed shall be tested with the vehicle in accessory mode or vehicle running. Active antennas with feedline (phantom) power feed shall be tested with power supplied by an appropriate DC source and bias T. Ensure all unnecessary vehicle functions are turned off.

4.2.2.3.4 Spherical near field test polarizations and elevation angles are listed in Table 2.

Table 2: SNF Test Polarizations and Elevation Angles

Band	Polarization	Elevation Angles (degrees)
Mobile Bands	E_{θ}	90, 87, 86, 85, 84, 80, and 70
GNSS (GPS, GLONASS, BEIDOU and GALILEO)	RHCP	0, 4, 8, 10, 12, 16, 20, 30, 40, 50, 60, 70, and 80
SDARS (SXMh-SAT) Satellite	LHCP	30, 35, 40, 45, 50, 55, 60, 65, and 70
SDARS (SXMh-TER) Terrestrial	E_{θ}	90, 85, and 80
China DTV (CDTV)	E_{θ} and E_{ϕ}	90, 87, 85, 80, and 70
Dedicated Short Range Communication (DSRC)	E_{θ}	80, 85, 90 and 96

LHCP Left Hand Circular Polarization
RHCP Right Hand Circular Polarization

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4.3 Instructions.

4.3.1 Far Field Reference Measurements.

Reference antenna amplitude measurements shall be made for each polarization listed in Table 1, at the corresponding test frequencies in Appendix B. Care shall be taken to perform reference antenna measurements with the same range weather conditions as the AUT measurements. The reference antenna(s) shall be mounted on a fiberglass/plastic structure. The reference antenna(s) shall be located on the range centerline $1.75\text{ m} \pm 0.25\text{ m}$ in front of the turntable and $1.50\text{ m} \pm 0.05\text{ m}$ above the turntable surface. The reference antenna shall be oriented with its primary radiation pattern parallel to the range centerline. See Appendix A, Figure A1.

4.3.1.1 Feedline Cabling.

The test feedline cable shall be used to connect the reference antenna to the spectrum analyzer, network analyzer, or receiver and supported horizontally above the turntable surface using a foam block or fiberglass tripod for 1 m minimum, behind (downrange) the reference antenna. The spectrum analyzer and any associated equipment shall be located on the turntable surface 2.5 m minimum, behind (downrange) the reference antenna. See Appendix A, Figure A1. Connection shall be made to the reference antenna using a 3 dB attenuator.

4.3.1.2 Additional Test Configurations.

If additional equipment is needed to activate a diversity system, then the equipment shall be included in the reference antenna path.

4.3.1.3 Powered Antenna Configuration.

If the AUT requires the use of a bias T, it shall be connected to the test feedline between the AUT connection and the attenuator, and remain in place for all reference and AUT measurements. The bias T should be connected to the AUT first followed by the appropriate attenuator, so that the attenuator is always at the AUT end of the test feedline.

4.3.2 Spherical Near Field Reference Measurements.

The spherical near-field system collects two orthogonal amplitude and phase data sets. This data is used to create the desired reference antenna polarity for each test frequency listed in Appendix B.

4.3.2.1 Reference Measurement Conditions.

Care shall be taken to perform reference antenna measurements with the same range conditions as the AUT measurements. The reference antenna(s) shall be mounted on either a non-conductive tripod or 1 m straight edge ground plane. The reference antenna(s) shall be located in the center of the turntable with absorber covering the rest of the surface. Log periodic, SGHs, and DRGs shall be aimed with the primary radiation pattern oriented normal to the horizontal plane. Monopoles on a ground plane shall be oriented with the axis of the antenna normal to the horizontal plane.

4.3.2.2 Feedline Cabling.

The test feedline cable shall be used to connect the reference antenna to the PAC and routed to the floor as soon as possible. The feedline is connected to the RF ports inside the turntable which run underneath the turntable and connect to the PAC. Connection shall be made to the reference antenna using a 3 dB (for passive AUTs) or 20 dB (for active AUTs) attenuator.

4.3.2.3 Powered Antenna Configuration.

If the AUT requires a bias T, the bias T and AUT required attenuator (either 3 dB or 20 dB) shall be connected to the test feedline and remain in place for all reference and AUT measurements. The bias T should be connected to the AUT first, followed by the appropriate attenuator, so that the attenuator is always at the AUT end of the test feedline.

4.3.2.4 Bias T Configuration.

The bias T utilized for reference measurements shall have the DC port de-energized, with a short applied to simulate the low impedance of a voltage source.

4.3.3 Antenna Measurement Frequencies.

Test frequencies for all bands are listed in Appendix B (Tables B1 and B2).

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4.3.4 Far Field Measurement Conditions.

4.3.4.1 Spectrum Analyzers shall be set to 20 kHz frequency span, 10 kHz $\pm$ 1 kHz resolution bandwidth and 10 kHz $\pm$ 1 kHz video bandwidth. Set the unit to peak detection mode and ensure the maximum value is captured.

4.3.4.2 Network analyzers shall be set to 10 kHz IF bandwidth, -13 dBm power, and auto time (independent of the frequency range). The output signal of the network analyzer is additionally amplified (+25 dB) with an external amplifier.

4.3.4.3 Antenna feedlines or power cables exiting the vehicle shall be RF isolated with a covering of CAPCON EMI suppressant tubing or have a minimum of three Type-73 ferrite cores installed on the cable with care taken to suspend the cores between the vehicle and the turntable deck. All vehicle doors shall be closed during measurements. The AUT vehicle shall be in a customer usable state (meaning seats shall be in their upright positions, trim pieces installed, as appropriate). If the vehicle is equipped with a sunroof, roof rack, targa roof, convertible top, etc., its state and presence shall be noted in the test data. Camouflage tint is not recommended due to its potentially conductive nature.

4.3.4.4 Reference measurements should be made the same day as the AUT measurements. Reference measurements shall have the same weather conditions and test equipment setup as the AUT measurements (same precipitation, temperature within 20 °C, no changes/movement of test equipment).

4.3.4.5 AUT amplitude measurements shall be made for each polarity (vertical and horizontal) at all test frequencies. Data shall be taken at a minimum of one degree increments for the complete 360 degree rotation.

4.3.4.6 The test vehicle shall be positioned on the turntable so that the AUT is located as near to the center of the turntable as possible.

4.3.4.7 AUT measurements shall be taken either at the receiver connection of the vehicle antenna cable or at the AUT pigtail connector.

4.3.5 Spherical Near Field Measurement Conditions.

4.3.5.1 Antenna feedlines or power cables exiting the vehicle shall be RF isolated with a covering of CAPCON EMI suppressant tubing or have a minimum of three Type-73 ferrite cores installed on the cable with care taken to suspend the cores between the vehicle and the turntable deck. All vehicle doors shall be closed during measurements. The AUT vehicle shall be in a customer usable state (i.e., seats shall be in their upright positions with trim pieces installed, as appropriate). If the vehicle is equipped with a sunroof, roof rack, targa roof, convertible top, etc., its state and presence shall be noted in the test data. Camouflage tint is not recommended due to its potentially conductive nature. If the vehicle has a diversity system, each antenna is measured separately and processed together with a macro to form the composite plot.

4.3.5.2 Reference measurements shall be made once a month.

4.3.5.3 AUT amplitude and phase measurements shall be made using two orthogonal polarizations. The desired test polarization (vertical, horizontal, Left Hand Circular Polarization (LHCP), or Right Hand Circular Polarization (RHCP)) shall then be calculated at all test frequencies. Data shall be taken at a minimum of one degree increments for the complete 360 degree rotation.

4.3.5.4 The test vehicle shall be positioned on the turntable so that the AUT is located as near to the center of the turntable as possible, and centered vertically above, but near, the measurement system horizon height.

4.3.5.5 Minimum Sphere is an imaginary sphere, whose center is located at the origin of the measurement system. The entire AUT must be located inside of the minimum sphere for SNF far-field gain calculations to be valid. Requirements for Minimum Sphere must be calculated, based on the particular characteristics of the system in question, to determine correct minimum sphere dimension.

4.3.5.6 AUT measurements shall be made by connecting to the AUT feedline at either the coax input to the vehicle receiver or the AUT lead-in.

4.3.6 Antenna System Impedance.

4.3.6.1 Network Analyzer Settings.

Network analyzers shall be calibrated for an S11 measurement with minimal adapter changes between calibration and measurement. Impedance magnitude and phase measurements shall be made between the start and stop frequencies specified in Appendix C, Table C1. A minimum of 200 data points should be taken in the specified frequency interval.

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4.3.6.2 AUT Connections.

The test feedline cable connecting the network analyzer to the AUT shall not exceed 3 m in length. The total length of any adapter(s) and/or extension cable used to connect the Network Analyzer test cable to the AUT feedline shall not exceed 8 cm in length. Any electrical delay differences between calibration and measurement shall be compensated in the measurement data. All measurements shall be made at the receiver connection of the vehicle production antenna cable. AUT signal path should include all production intent components and wire routing.

4.3.6.3 Test Conditions.

The test vehicle shall be located in a clear area with a minimum 3 m distance (including vertical) from any surface of the vehicle to a surrounding object. All doors, roof panels and decklids shall be closed and the vehicle shall be in a customer usable state. All test equipment shall be kept a minimum 1 m distance away from the AUT.

4.3.6.4 Electrical Accommodations.

Impedance measurements on all active antenna systems shall be performed with the AUT powered off and on. While there is no requirement for power off, this test mode is required to ensure that the active components of the AUT are operating.

4.3.7 Active Antenna Measurements.

For antenna elements connected to active circuitry, the antenna element shall be isolated to determine its passive performance, absent the active circuitry. In all cases, active antenna pattern measurements shall be taken from the vehicle receiver antenna connection. Passive antenna pattern shall also be measured to determine the passive antenna element gain, as follows.

4.3.7.1 Direct Passive Antenna Pattern Measurement Method.

A passive antenna sample shall be made from the production antenna, that directly connects the electrically isolated antenna element(s) to a short pigtail with an SMA, or equivalent, laboratory grade connector. Remaining active circuitry in the active antenna shall be properly terminated. Passive antenna gain measurements will be taken at the end of the AUT lead-in (pigtail). Pigtail losses shall be provided by the supplier, at the appropriate test frequencies listed in Appendix B. Provided pigtail losses shall be added directly to the pattern measurement of the passive element.

4.3.7.2 Derived Passive Antenna Pattern Calculation Method.

The Active Gain Pattern shall be measured per 4.3.7. The Net Active Gain of the active antenna system, calculated per 4.3.8.1., shall be deducted directly from this measurement, at each test frequency listed in Appendix B, to derive the passive antenna gain pattern data.

4.3.8 Net Active Gain Measurement.

Net active gain is defined as the sum of all active gain stages and the losses between the antenna element feed point and the vehicle receiver antenna connection. Net Active Gain shall be given for each test frequency per band listed in Appendix B. Net Active Gain shall be determined using one of the following methods.

4.3.8.1 Direct Net Active Gain Measurement Method.

Vehicle cable/connection losses shall be measured from the antenna pigtail to the vehicle receiver antenna connection and subtracted from active gain of the LNA, determined from active gain measurement per GMW15649.

4.3.8.2 Derived Net Active Gain Calculation Method.

Direct passive antenna pattern measurement shall be taken per 4.3.7.1. Active antenna pattern measurements shall also be taken per 4.3.7. Linear Average Gain (LAG) calculations shall be performed on both the active and passive patterns at the elevations specified in Section 5. Net active gain is defined as the difference of the measured active LAG and the measured passive LAG at each frequency/elevation.

4.3.9 Passive Antenna Pattern Measurements.

For antenna elements that are not connected to active circuitry, the antenna pattern measurement shall be taken from the vehicle receiver antenna connection.

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5 Data

5.1 Calculations.

5.1.1 Gain Standard.

All gain values shall be normalized to the isotropic gain figures provided by the manufacturer or antenna calibration service for the reference antenna.

5.1.2 LAG Calculation.

For each polarization and test frequency, a gain pattern is calculated by subtracting the reference antenna received power (in dBm or dBuV) from each of the 360 AUT received power data points (azimuth angle). The resulting AUT gain is then converted to dBi (or dBic) by adding the reference antenna isotropic gain (in dBi) to the AUT gain in dB. Linear Average Gain (LAG, calculated in linear units) is determined for each gain pattern. The linear average gain is compared to the requirements in 5.2.

5.1.3 Standard Deviation Calculation.

For each test frequency and elevation angle, a gain pattern is calculated by subtracting the reference antenna received signal from each of the 360 AUT amplitude received data points (azimuth angle).

The resulting AUT gain is then converted to dBi (or dBic) by adding the reference antenna isotropic gain (in dBi) to the AUT gain in dB. Linear Average Gain (LAG, calculated in linear units) is determined for each gain pattern as well. Directionality is calculated for each gain pattern using standard deviation (STDEV). STDEV uses the formula:

$$\sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{(n - 1)}}$$

Where:

x_i is the AUT gain at azimuth, i

$\bar{x}$ (x bar) is the AUT LAG

n is the sample size

Note: STDEV is expressed in linear units.

In the case of diversity system, a separate macro is required to process the data collected from each element to create the composite plot. The linear average gain and standard deviation are compared to the requirements in 5.2.

5.2 Interpretation of Results.

5.2.1 Antenna Gain, Directionality and Impedance.

Antenna gain and directionality requirements are listed in Table 3 thru Table 14. Impedance requirements, by means of VSWR calculations, are listed in Table 14.

5.2.2 Mobile Band Gain.

Mobile Band gain shall meet the requirements listed in Tables 3 and 4 for dual-element (Multiple-input and Multiple-output (MIMO)) antennas, or Table 5 for single element (non-MIMO) antennas, when measured at the vehicle receiver antenna connection.

5.2.2.1 Vehicle MIMO Mobile Band Gain Calculation for SNF Measurement.

Gain measurement for MIMO mobile band antennas shall be calculated by Aggregate Linear Average Gain. This calculation begins with linear point gain measurements with respect to an isotropic radiator, in E_θ polarization, at 84 degrees, 85 degrees, 86 degrees and 87 degrees elevation from zenith, and taking the average of all points. This average is then converted to decibels to obtain the corresponding gain value. The calculated gain shall meet the applicable requirements in Tables 3 and 4.

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