



## HAC T-COIL SIGNAL TEST REPORT

**FCC CFR47 PART 20.19  
ANSI C63.19-2011**

*For*  
**Smartphone**

**FCC ID: BCG-E3232A  
Model Name: A2097**

**Report Number: 12204447-S2V3  
Issue Date: 9/6/2018**

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NVLAP LAB CODE 200065-0

**Revision History**

| Rev. | Date      | Revisions                            | Revised By   |
|------|-----------|--------------------------------------|--------------|
| V1   | 7/26/2018 | Initial Issue                        | --           |
| V2   | 7/30/2018 | Updated §4.1 and §8.1                | Nathan Sousa |
| V3   | 9/6/2018  | Corrected model number on cover page | Dave Weaver  |
|      |           |                                      |              |

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## 1. Attestation of Test Results

|                      |                                        |
|----------------------|----------------------------------------|
| Applicant Name       | APPLE, INC.                            |
| FCC ID               | BCG-E3232A                             |
| Model Name           | A2097                                  |
| Applicable Standards | FCC 47 CFR § 20.19<br>ANSI C63.19-2011 |
| HAC Rating           | T4                                     |
| Date Tested          | 5/1/2018 to 7/26/2018                  |
| Test Results         | Pass                                   |

UL Verification Services Inc. tested the above equipment in accordance with the requirements set forth in the above standards. All indications of Pass/Fail in this report are opinions expressed by UL Verification Services Inc. based on interpretations and/or observations of test results. Measurement Uncertainties were not taken into account and are published for informational purposes only. The test results show that the equipment tested is capable of demonstrating compliance with the requirements as documented in this report.

**Note:** The results documented in this report apply only to the tested sample, under the conditions and modes of operation as described herein. This document may not be altered or revised in any way unless done so by UL Verification Services Inc. and all revisions are duly noted in the revisions section. Any alteration of this document not carried out by UL Verification Services Inc. will constitute fraud and shall nullify the document. This report must not be used by the client to claim product certification, approval, or endorsement by NVLAP, NIST, any agency of the Federal Government, or any agency of any government (NIST Handbook 150, Annex A). This report is written to support regulatory compliance of the applicable standards stated above.

|                                                                                                               |                                                                                                     |
|---------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|
| Approved & Released By:<br> | Prepared By:<br> |
| Dave Weaver<br>Operations Leader<br>UL Verification Services Inc.                                             | Nathan Sousa<br>Test Engineer<br>UL Verification Services Inc.                                      |

## 2. Test Methodology

The tests documented in this report were performed in accordance with ANSI C63.19-2011 Methods of Measurement of Compatibility between Wireless Communications Devices and Hearing Aids and FCC published procedure

KDB 285076 D01 HAC Guidance v05

KDB 285076 D02 T-Coil testing for CMRS IP v03

KDB 285076 D03 HAC FAQ v01

TCB workshop updates

## 3. Facilities and Accreditation

The test sites and measurement facilities used to collect data are located at

|                      |                      |
|----------------------|----------------------|
| 47173 Benicia Street | 47266 Benicia Street |
| SAR Lab C            | SAR Lab 2            |

UL Verification Services Inc. is accredited by NVLAP, Laboratory Code 200065-0.

## 4. Calibration and Uncertainty

### 4.1. Measuring Instrument Calibration

The measuring equipment used to perform the tests documented in this report has been calibrated in accordance with the manufacturers' recommendations, and is traceable to recognized national standards.

| Name of Equipment            | Manufacturer  | Type/Model                  | Serial No.    | Cal. Due Date |
|------------------------------|---------------|-----------------------------|---------------|---------------|
| ABM Probe                    | SPEAG         | AM1DV3                      | 3083          | 1/15/2019     |
| ABM Probe*                   | SPEAG*        | AM1DV3*                     | 3092*         | 7/20/2018*    |
| Data Acquisition Electronics | SPEAG         | DAE4                        | 1357          | 2/8/2019      |
| Radio Communication Tester   | R & S         | CMW 500                     | 125236        | 3/28/2019     |
| iMac                         | Apple         | 21.5-inch, Late 2015        | FNQS83J5GG77  | N/A           |
| AP                           | Apple         | AirPort Express             | C86J4AC0DV2R  | N/A           |
| DAC                          | Sound Devices | USBPre 2                    | HB11173410003 | N/A           |
| AP                           | Cisco         | AIR-CAP3702I-A-K9           | FCW1925NNPJ   | N/A           |
| Series Wireless Controller   | Cisco         | WLAN 2500 Series Controller | PSZ1901CMV    | N/A           |
| Network Hub                  | Linksys       | NH1005                      | R8730G403203  | N/A           |
| Switch                       | Netgear       | ProSafe Plus Switch         | 29B9273A50BF5 | N/A           |

#### Note(s):

\*: AM1DV3 Probe Serial No. 3092 was not used outside its calibration dates.

## 4.2. Measurement Uncertainty

### Measurement Uncertainty for Audio Band Magnetic Measurement

| Error Description                                     | Uncertainty values (±%) | Probe Dist. | Div. | c <sub>i</sub><br>ABM1 | c <sub>i</sub><br>ABM2 | Std. Unc. |           |
|-------------------------------------------------------|-------------------------|-------------|------|------------------------|------------------------|-----------|-----------|
|                                                       |                         |             |      |                        |                        | ABM1 (±%) | ABM2 (±%) |
| Probe Sensitivity                                     |                         |             |      |                        |                        |           |           |
| Reference level                                       | 3.0                     | N           | 1    | 1                      | 1                      | 3.0       | 3.0       |
| AMCC geometry                                         | 0.4                     | R           | √3   | 1                      | 1                      | 0.2       | 0.2       |
| AMCC current                                          | 1.0                     | R           | √3   | 1                      | 1                      | 0.6       | 0.6       |
| Probe positioning during calibration                  | 0.1                     | R           | √3   | 1                      | 1                      | 0.1       | 0.1       |
| Noise contribution                                    | 0.7                     | R           | √3   | 0.0143                 | 1                      | 0.0       | 0.4       |
| Frequency slope                                       | 5.9                     | R           | √3   | 0.1                    | 1.00                   | 0.3       | 3.5       |
| Probe System                                          |                         |             |      |                        |                        |           |           |
| Repeatability / drift                                 | 1.0                     | R           | √3   | 1                      | 1                      | 0.6       | 0.6       |
| Linearity / Dynamic range                             | 0.6                     | R           | √3   | 1                      | 1                      | 0.4       | 0.4       |
| Acoustic noise                                        | 1.0                     | R           | √3   | 0.1                    | 1                      | 0.1       | 0.6       |
| Probe angle                                           | 2.3                     | R           | √3   | 1                      | 1                      | 1.4       | 1.4       |
| Spectral processing                                   | 0.9                     | R           | √3   | 1                      | 1                      | 0.5       | 0.5       |
| Integration time                                      | 0.6                     | N           | 1    | 1                      | 5                      | 0.6       | 3.0       |
| Field disturbance                                     | 0.2                     | R           | √3   | 1                      | 1                      | 0.1       | 0.1       |
| Test Signal                                           |                         |             |      |                        |                        |           |           |
| Reference signal spectral response                    | 0.6                     | R           | √3   | 0                      | 1                      | 0.0       | 0.4       |
| Positioning                                           |                         |             |      |                        |                        |           |           |
| Probe positioning                                     | 1.9                     | R           | √3   | 1                      | 1                      | 1.1       | 1.1       |
| Phantom positioning                                   | 0.9                     | R           | √3   | 1                      | 1                      | 0.5       | 0.5       |
| EUT positioning                                       | 1.9                     | R           | √3   | 1                      | 1                      | 1.1       | 1.1       |
| External Contributions                                |                         |             |      |                        |                        |           |           |
| RF interference                                       | 0.0                     | R           | √3   | 1                      | 0.3                    | 0.0       | 0.0       |
| Test signal variation                                 | 2.0                     | R           | √3   | 1                      | 1                      | 1.2       | 1.2       |
| Combined Std. Uncertainty (ABM field)                 |                         |             |      |                        |                        | 4.1       | 6.1       |
| Expanded Std. Uncertainty (%)                         |                         |             |      |                        |                        | 8.1       | 12.3      |
| Notes for table                                       |                         |             |      |                        |                        |           |           |
| 1. N - Nomal                                          |                         |             |      |                        |                        |           |           |
| 2. R - Rectangular                                    |                         |             |      |                        |                        |           |           |
| 3. Div. - Divisor used to obtain standard uncertainty |                         |             |      |                        |                        |           |           |

## 5. Test Procedure

ANSI C63.19-2011, Section 7

This document describes the procedures used to measure the ABM (T-Coil) performance of the WD. In addition to measuring the absolute signal levels, the A-weighted magnitude of the unintended signal shall also be determined. In order to assure that the required signal quality is measured, the measurement of the intended signal and the measurement of the unintended signal must be made at the same location for all measurement positions. In addition, the RF field strength at each measurement location must be at or below that required for the assigned category.

Measurements shall not include undesired properties from the WD's RF field; therefore, use of a coaxial connection to a base station simulator or non-radiating load may be necessary. However, even then with a coaxial connection to a base station simulator or non-radiating load there may still be RF leakage from the WD, which may interfere with the desired measurement. Pre-measurement checks should be made to avoid this possibility. All measurements shall be done with the WD operating on battery power with an appropriate normal speech audio signal input level given in Table 7.1. If the device display can be turned off during a phone call then that may be done during the measurement as well.

Measurements shall be performed at two locations specified in A.3, with the correct probe orientation for a particular location, in a multistage sequence by first measuring the field intensity of the desired T-Coil signal (ABM1) that is useful to a hearing aid T-Coil. The undesired magnetic components (ABM2) must be measured at the same location as the desired ABM or T-Coil signal (ABM1), and the ratio of desired to undesired ABM signals must be calculated. For the perpendicular field location, only the ABM1 frequency response shall be determined in a third measurement stage. The flow chart in Figure 7.3 illustrates this three-stage, two orientation process.

The following steps summarize the basic test flow for determining ABM1<sup>1</sup> and ABM2<sup>2</sup>. These steps assume that a sine wave or narrowband 1/3 octave signal can be used for the measurement of ABM1.

- a. A validation of the test setup and instrumentation may be performed using a TMFS or Helmholtz coil. Measure the emissions and confirm that they are within the specified tolerance.
- b. Position the WD in the test setup and connect the WD RF connector to a base station simulator or a non-radiating load as shown in Figure 7.1 or Figure 7.2. Confirm that equipment that requires calibration has been calibrated, and that the noise level meets the requirements given in 7.3.1.
- c. The drive level to the WD is set such that the reference input level specified in Table 7.1 is input to the base station simulator (or manufacturer's test mode equivalent) in the 1 kHz, 1/3 octave band. This drive level shall be used for the T-Coil signal test (ABM1) at  $f = 1$  kHz. Either a sine wave at 1025 Hz or a voice-like signal, band-limited to the 1 kHz 1/3 octave, as defined in 7.4.2, shall be used for the reference audio signal. If interference is found at 1025 Hz an alternative nearby reference audio signal frequency may be used.<sup>46</sup> The same drive level will be used for the ABM1 frequency response measurements at each 1/3 octave band center frequency. The WD volume control may be set at any level up to maximum, provided that a signal at any frequency at maximum modulation would not result in clipping or signal overload.
- d. Determine the magnetic measurement locations for the WD device (A.3), if not already specified by the manufacturer, as described in 7.4.4.1.1 and 7.4.4.2.

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<sup>1</sup> **Audio Band Magnetic signal - desired (ABM1):** Measured quantity of the desired magnetic signal

<sup>2</sup> **Audio Band Magnetic signal - undesired (ABM2):** Measured quantity of the undesired magnetic signal, such as interference from battery current and similar non-signal elements.

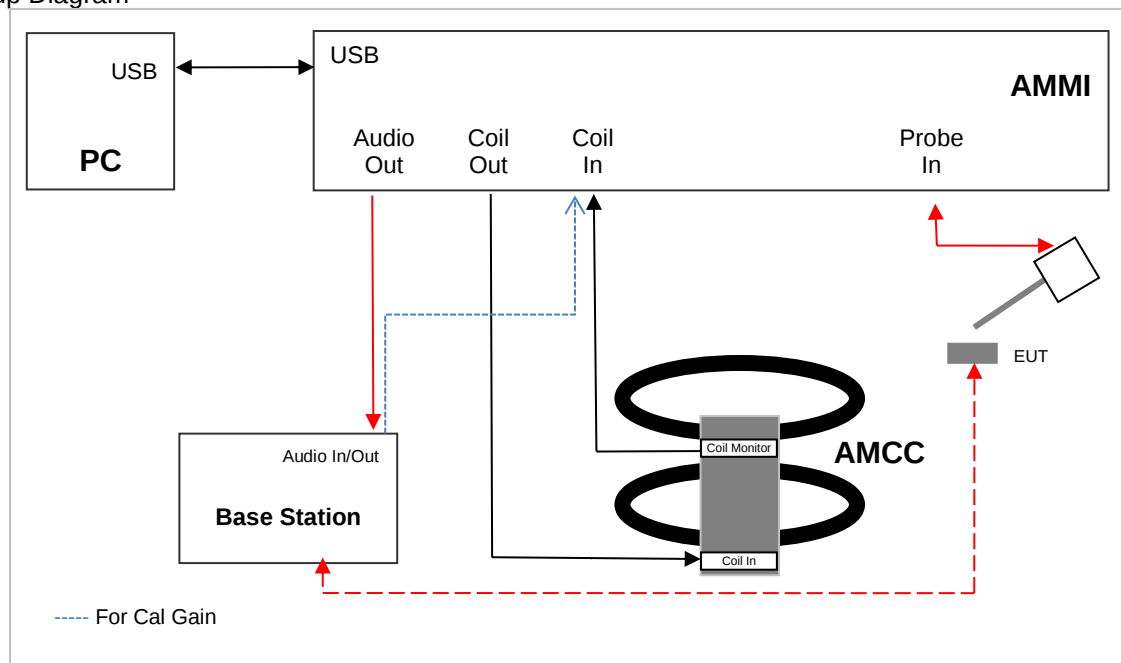
- e. At each measurement location, measure and record the desired T-Coil magnetic signals (ABM1 at  $f_i$ ) as described in 7.4.4.2 in each individual ISO 266-1975 R10 standard 1/3 octave band. The desired audio band input frequency ( $f_i$ ) shall be centered in each 1/3 octave band maintaining the same drive level as determined in item c) and the reading taken for that band.

Equivalent methods of determining the frequency response may also be employed, such as fast Fourier transform (FFT) analysis using noise excitation or input–output comparison using simulated speech. The full-band integrated or half-band integrated probe output, as specified in D.9, may be used, as long as the appropriate calibration curve is applied to the measured result, so as to yield an accurate measurement of the field magnitude. (The resulting measurement shall be an accurate measurement in dB A/m.)

All measurements of the desired signal shall be shown to be of the desired signal and not of an undesired signal. This may be shown by turning the desired signal ON and OFF with the probe measuring the same location. If the scanning method is used the scans shall show that all measurement points selected for the ABM1 measurement meet the ambient and test system noise criteria in 7.3.1.

- f. At the measurement location for each orientation, measure and record the undesired broadband audio magnetic signal (ABM2) as specified in 7.4.4.4 with no audio signal applied (or digital zero applied, if appropriate) using A-weighting and the half-band integrator. Calculate the ratio of the desired to undesired signal strength (i.e., signal quality).
- g. Obtain the data from the postprocessor, SEMCAD, and determine the category that properly classifies the signal quality based on Table 8.5.

Test Setup Diagram

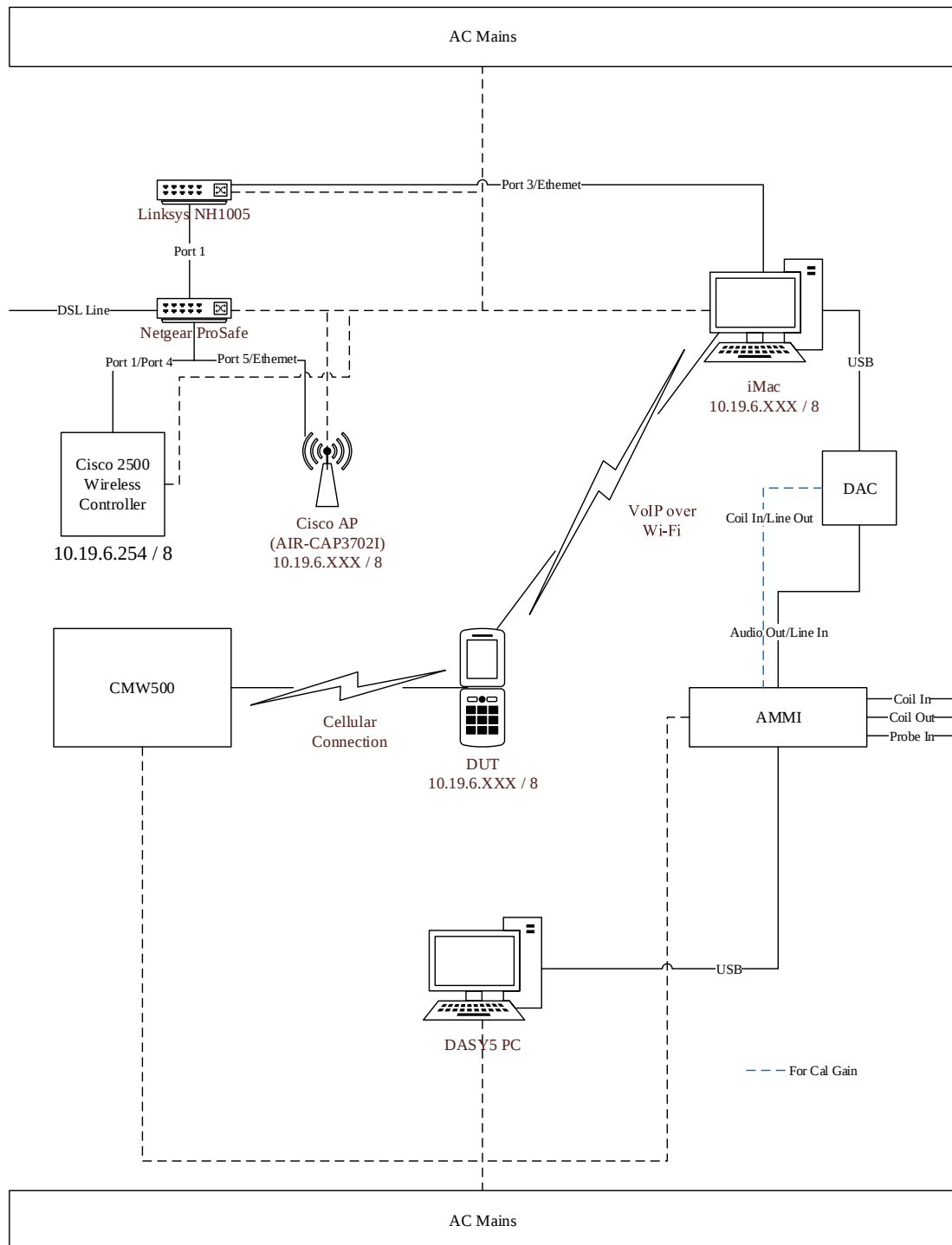


## 5.1. Over the Top (OTT)

The test procedure for OTT testing is identical to the section above, except for how the signal is sent to the DUT, as outlined in the diagram below.

The AMMI is connected to an external ADC (Analog to Digital Converter) and the ADC is connected to the iMac via USB. The iMac is connected to the Internet via Ethernet and the DUT is connected to the Internet via Wi-Fi. Using the DUT's OTT application, a VoIP call is established with the iMac. The test signal is sent from the DASY5 PC to the AMMI, from the AMMI to the ADC, from the ADC to the iMac, and finally to the DUT.

To exercise the license antenna, the DUT was simultaneously connected to an external AP and to a mobile base station. This is essentially the manufacturer's test mode method (C63.19 2007 §6.2.3) but with the audio wired signal injection replaced by the Wi-Fi connection.



## 6. Audio Level and Gain Measurements

### CDMA

No correction gain factors were measured for CDMA due to the Rohde & Schwarz CMW500, hosting a calibrated audio board. The gains used to measure CDMA are set to 100.

### W-CDMA/GSM

No correction gain factors were measured for W-CDMA/GSM due to the Rohde & Schwarz CMW500, hosting a calibrated audio board. The gains used to measure W-CDMA/GSM are set to 100.

### VoLTE

No correction gain factors were measured for VoLTE due to the Rohde & Schwarz CMW500, hosting a calibrated audio board. The gains used to measure VoLTE are set to 100.

The following software/firmware was used to simulate the VoLTE server for testing:

| Firmware          | License Keys | Software Name         |
|-------------------|--------------|-----------------------|
| V3.7.30 for LTE   | KS500        | LTE FDD R8 SIG BASIC  |
|                   | KS550        | LTE TDD R8 SIG BASIC  |
|                   | KA100        | IP APPL ENABLING IPv4 |
|                   | KA150        | IP APPL ENABLING IPv6 |
| V3.7.20 for Audio | KAA20        | IP APPL IMS BASIC     |
|                   | KM050        | DATA APPL MEAS        |
|                   | KS104        | EVS SPEECH CODEC      |

### VoWi-Fi

No correction gain factors were measured for VoWi-Fi due to the Rohde & Schwarz CMW500, hosting a calibrated audio board. The gains used to measure VoWi-Fi are set to 100.

| Firmware          | License Keys | Software Name         |
|-------------------|--------------|-----------------------|
| V3.7.30 for WLAN  | KS650        | WLAN A/B/G SIG BASIC  |
|                   | KS651        | WLAN N SIG BASIC      |
|                   | KA100        | IP APPL ENABLING IPv4 |
|                   | KA150        | IP APPL ENABLING IPv6 |
| V3.7.20 for Audio | KAA20        | IP APPL IMS BASIC     |
|                   | KM050        | DATA APPL MEAS        |
|                   | KS104        | EVS SPEECH CODEC      |

### Over the Top (OTT)

For EDGE, HSPA, Ev-Do, LTE, and Wi-Fi, the linear gain levels listed below were used. The results below are based on a reference input level of -20 dBm0. Granted, the C63.19-2011 interpretation for T-coil audio levels for LTE states that an input reference level of -16 dBm0 should be used, we, the test lab, opted for -20 dBm0 for LTE due to it being a more conservative input reference level.

The adjusted gain measurements are based on an external Analogue to Digital Converter (ADC), where the signal is sent from the AMMI to the ADC, then to the DUT via Wi-Fi.

To calibrate the ADC, three .wav audio files (sine wave, 1 kHz voice, and 300 to 3 kHz voice) are sent from the DASY5 PC to the AMMI, then to the ADC. The Helmholtz resonator measures the field strength, which represents the AMMI to ADC input sensitivity. After determining the input sensitivity, the adjusted linear gain values can then be calculated.

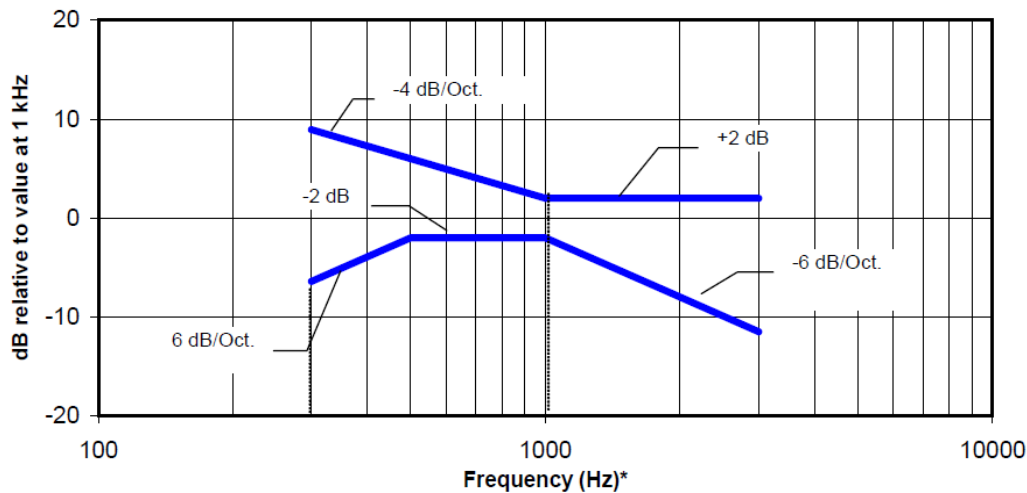
| Signal Type       | Audio Level<br>[dBm0] | Gain<br>[dB] | Gain<br>[linear] |
|-------------------|-----------------------|--------------|------------------|
| Voice 1 kHz       | -20.00                | 29.72        | <b>30.62</b>     |
| Voice 300 - 3 kHz | -20.00                | 35.57        | <b>60.05</b>     |

## 7. T-coil Measurement Criteria

### 7.1. Frequency Response

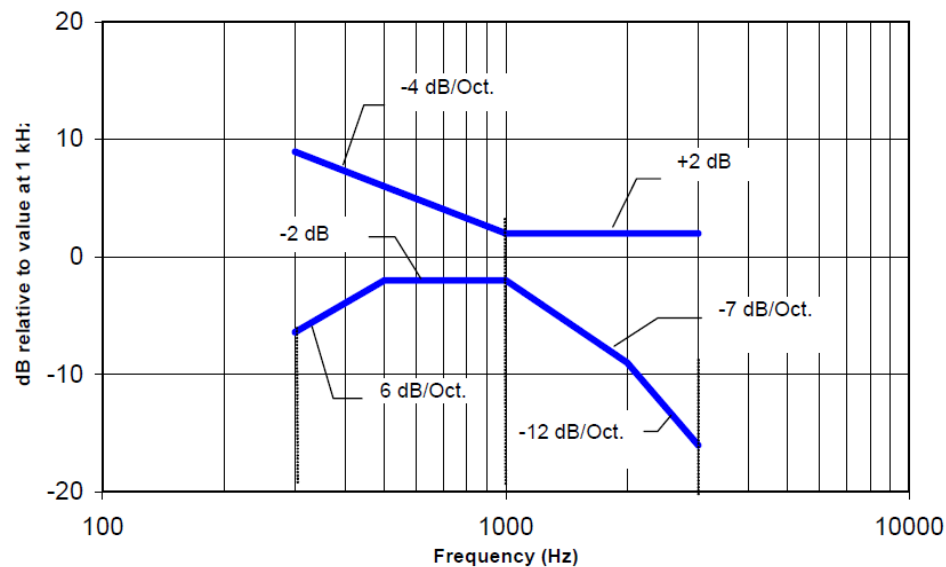
The frequency response of the axial component of the magnetic field, measured in 1/3 octave bands, shall follow the response curve, over the frequency range 300 Hz to 3000 Hz.

Figure 8.1 and Figure 8.2 provide the boundaries for the specified frequency. These response curves are for true field strength measurements of the T-Coil signal. Thus the 6 dB/octave probe response has been corrected from the raw readings.



NOTE—The frequency response is between 300 Hz and 3000 Hz.

**Figure 8.1—Magnetic field frequency response for WDs with field strength  $\leq -15$  dB (A/m) at 1 kHz**



NOTE—The frequency response is between 300 Hz and 3000 Hz.

**Figure 8.2—Magnetic field frequency response for WDs with a field that exceeds  $-15$  dB(A/m) at 1 kHz**

## 7.2. Signal to Noise

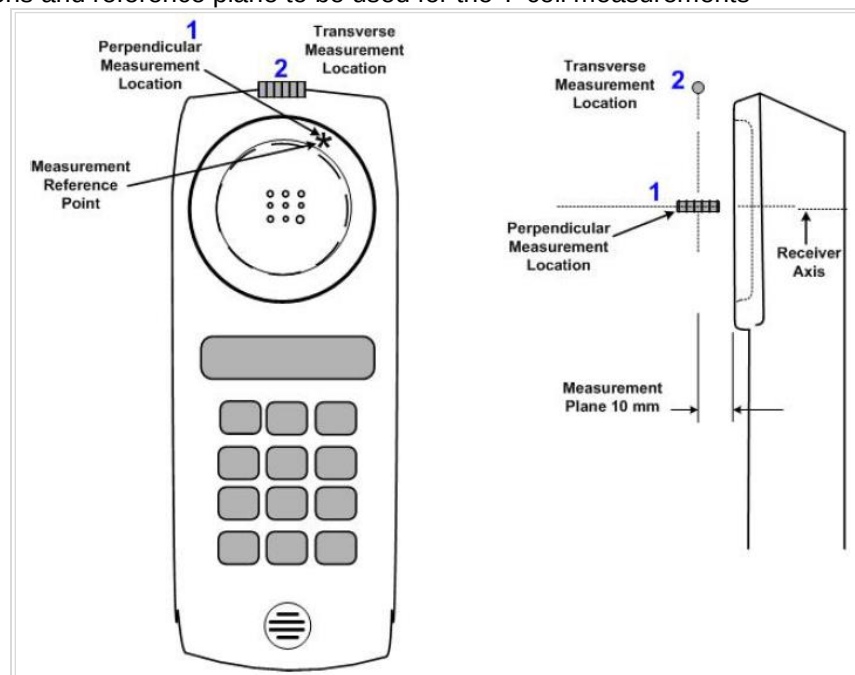
This specifies the signal-to-noise quality requirement for the intended T-Coil signal from a WD. The worst signal to noise of the two T-Coil signal measurements, as determined in Clause 7, shall be used to determine the T-Coil mode category per Table 8.5.

Only the RF immunity of the hearing aid is measured in T-Coil mode. It is assumed that a hearing aid can have no immunity to an interference signal in the audio band, which is the intended reception band for this mode. So, the only criterion that can be measured is the RF immunity in T-Coil Mode. This is measured using the same procedure as for the audio coupling mode and at the same levels as specified in 6.4.

**Table 8.5—T-Coil signal-to-noise categories**

| Category    | Telephone parameters<br>WD signal quality<br>[(signal + noise)-to-noise ratio in decibels] |
|-------------|--------------------------------------------------------------------------------------------|
| Category T1 | 0 dB to 10 dB                                                                              |
| Category T2 | 10 dB to 20 dB                                                                             |
| Category T3 | 20 dB to 30 dB                                                                             |
| Category T4 | >30 dB                                                                                     |

Measurement locations and reference plane to be used for the T-coil measurements



## 8. Device Under Test

|                  |                                 |
|------------------|---------------------------------|
| Normal operation | Held to head                    |
| Back Cover       | The Back Cover is not removable |

### 8.1. Air Interfaces and Operating Mode

| Air Interface                                                                                                                                      | Bands (MHz)        | Type | C63.19 Tested | Simultaneous Transmitter                                                                                             | OTT Testing Required? Name of Voice Service | GSM 1900 MHz Power Reduction |
|----------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|------|---------------|----------------------------------------------------------------------------------------------------------------------|---------------------------------------------|------------------------------|
| GSM                                                                                                                                                | 850                | VO   | Yes           | Wi-Fi and BT                                                                                                         | NA                                          | NA                           |
|                                                                                                                                                    | 1900               |      |               |                                                                                                                      |                                             | No                           |
|                                                                                                                                                    | GPRS/EDGE          | VD   | Yes           | Wi-Fi and BT                                                                                                         | FaceTime <sup>2</sup>                       | NA                           |
| W-CDMA (UMTS)                                                                                                                                      | 850                | VO   | Yes           | Wi-Fi and BT                                                                                                         | NA                                          | NA                           |
|                                                                                                                                                    | 1700               |      |               |                                                                                                                      |                                             |                              |
|                                                                                                                                                    | 1900               |      |               |                                                                                                                      |                                             |                              |
|                                                                                                                                                    | HSPA               | VD   | Yes           | Wi-Fi and BT                                                                                                         | FaceTime <sup>2</sup>                       | NA                           |
| CDMA                                                                                                                                               | 800                | VO   | Yes           | Wi-Fi and BT                                                                                                         | NA                                          | NA                           |
|                                                                                                                                                    | 1900               |      |               |                                                                                                                      |                                             |                              |
|                                                                                                                                                    | EVDO               | VD   | Yes           | Wi-Fi and BT                                                                                                         | FaceTime <sup>2</sup>                       | NA                           |
| LTE - FDD                                                                                                                                          | 700 (B12/13/14/17) | VD   | Yes           | Wi-Fi and BT                                                                                                         | Yes <sup>1</sup><br>FaceTime <sup>2</sup>   | NA                           |
|                                                                                                                                                    | 850 (B5/26)        |      |               |                                                                                                                      |                                             |                              |
|                                                                                                                                                    | 1700 (B4/66)       |      |               |                                                                                                                      |                                             |                              |
|                                                                                                                                                    | 1900 (B2/25)       |      |               |                                                                                                                      |                                             |                              |
|                                                                                                                                                    | 2300 (B30)         |      |               |                                                                                                                      |                                             |                              |
|                                                                                                                                                    | 2600 (B7)          |      |               |                                                                                                                      |                                             |                              |
| LTE - TDD                                                                                                                                          | 2500 (B38/41)      | VD   | Yes           | Wi-Fi and BT                                                                                                         | Yes <sup>1</sup><br>FaceTime <sup>2</sup>   | NA                           |
| Wi-Fi                                                                                                                                              | 2450               | VD   | Yes           | WWAN and BT                                                                                                          | Wi-Fi calling<br>FaceTime <sup>2</sup>      | NA                           |
|                                                                                                                                                    | 5200 (U-NII-1)     |      |               |                                                                                                                      |                                             |                              |
|                                                                                                                                                    | 5300 (U-NII-2A)    |      |               |                                                                                                                      |                                             |                              |
|                                                                                                                                                    | 5500 (U-NII-2C)    |      |               |                                                                                                                      |                                             |                              |
|                                                                                                                                                    | 5800 (U-NII-3)     |      |               |                                                                                                                      |                                             |                              |
| BT                                                                                                                                                 | 2450               | DT   | NA            | WWAN and Wi-Fi                                                                                                       | NA                                          | NA                           |
| Type<br>VO: Legacy Cellular Voice Service<br>DT: Digital Transport only (no voice)<br>VD: IP Voice Service over Digital Transport<br>BT: Bluetooth |                    |      |               | Note:<br><sup>1</sup> Ref Lev in accordance with the July 2012 VoLTE interpretation<br><sup>2</sup> Ref Lev -20 dBm0 |                                             |                              |

## 9. HAC (T-coil) Test Results

### 9.1. Antenna Investigation

All testing was performed on the Upper Antennas (ANT2 for WWAN, ANT4 for WLAN 2.4GHz, and ANT 6 for WLAN 5GHz). Spot checks were performed on the Lower Antennas (ANT1 for WWAN, ANT3 for WWAN and WLAN 2.4GHz, ANT5 for WLAN 5GHz) and one (1) Upper Antenna (ANT4 for WWAN), when applicable, to confirm that there were no unexpected variations between the antennas, a difference of 3dB was used as the threshold.

| Mode:                                                            | Channel and Frequency | Bandwidth/ Data Rate | Antenna | Orientation    | ABM1 dB(A/m) | ABM2 dB(A/m) | Ambient Noise dB(A/m) | Freq. Response (dB) | ABM SNR (dB) | T-Rating | Delta |
|------------------------------------------------------------------|-----------------------|----------------------|---------|----------------|--------------|--------------|-----------------------|---------------------|--------------|----------|-------|
| GSM 850<br>Voice Codec<br>Speechcodec Low                        | 190<br>836.6 MHz      | N/A                  | ANT2    | z (Axial)      | 11.65        | -5.07        | -55.41                | 1.45                | 39.72        | T4       | -1.90 |
|                                                                  |                       |                      |         | y (Transverse) | 12.43        | -8.20        | -55.41                |                     | 40.15        | T4       |       |
|                                                                  |                       |                      | ANT1    | z (Axial)      | 16.02        | -13.85       | -55.79                | 2.00                | 51.12        | T4       |       |
|                                                                  |                       |                      |         | y (Transverse) | 8.45         | -11.74       | -55.63                |                     | 41.62        | T4       |       |
| W-CDMA Band IV<br>Voice Narrowband<br>AMR Codec: 4.75 kbit/s     | 1413<br>1732.6 MHz    | N/A                  | ANT2    | z (Axial)      | 12.26        | -25.04       | -55.84                | 1.22                | 58.78        | T4       | -6.76 |
|                                                                  |                       |                      |         | y (Transverse) | 6.04         | -26.95       | -55.67                |                     | 48.30        | T4       |       |
|                                                                  |                       |                      | ANT1    | z (Axial)      | 16.33        | -31.80       | -55.84                | 1.76                | 60.88        | T4       |       |
|                                                                  |                       |                      |         | y (Transverse) | 6.91         | -31.52       | -55.67                |                     | 55.06        | T4       |       |
|                                                                  |                       |                      | ANT3    | z (Axial)      | 15.89        | -31.57       | -55.84                | 0.96                | 60.20        | T4       | -6.59 |
|                                                                  |                       |                      |         | y (Transverse) | 7.77         | -31.97       | -55.67                |                     | 54.89        | T4       |       |
|                                                                  |                       |                      | ANT4    | z (Axial)      | 12.61        | -31.91       | -55.84                | 2.00                | 59.62        | T4       | -6.06 |
|                                                                  |                       |                      |         | y (Transverse) | 6.95         | -31.66       | -55.67                |                     | 54.36        | T4       |       |
| CDMA2000 BC10<br>RC1 / SO3 1/8 FR<br>Voice Codec: 8K EVRC<br>Low | 580<br>820.5 MHz      | N/A                  | ANT2    | z (Axial)      | 17.37        | -29.18       | -55.41                | 2.00                | 64.92        | T4       | -2.57 |
|                                                                  |                       |                      |         | y (Transverse) | 8.74         | -28.00       | -55.41                |                     | 53.20        | T4       |       |
|                                                                  |                       |                      | ANT1    | z (Axial)      | 16.87        | -27.55       | -55.41                | 1.66                | 62.37        | T4       |       |
|                                                                  |                       |                      |         | y (Transverse) | 10.29        | -32.22       | -55.41                |                     | 55.77        | T4       |       |
| LTE Band 7<br>EVS<br>2.8/5.9 kbit/s                              | 21100<br>2535 MHz     | 20 MHz<br>QPSK       | ANT2    | z (Axial)      | 15.60        | -31.51       | -55.67                | 1.71                | 61.13        | T4       | -2.56 |
|                                                                  |                       |                      |         | y (Transverse) | 6.19         | -30.97       | -55.49                |                     | 52.17        | T4       |       |
|                                                                  |                       |                      | ANT1    | z (Axial)      | 14.74        | -32.44       | -55.67                | 1.56                | 60.72        | T4       |       |
|                                                                  |                       |                      |         | y (Transverse) | 8.39         | -28.46       | -55.49                |                     | 54.73        | T4       |       |
|                                                                  |                       |                      | ANT3    | z (Axial)      | 15.97        | -30.59       | -55.83                | 1.78                | 60.93        | T4       | 1.79  |
|                                                                  |                       |                      |         | y (Transverse) | 5.93         | -25.32       | -55.62                |                     | 50.38        | T4       |       |
|                                                                  |                       |                      | ANT4    | z (Axial)      | 16.20        | -29.10       | -55.83                | 1.77                | 59.64        | T4       | 1.53  |
|                                                                  |                       |                      |         | y (Transverse) | 8.20         | -27.22       | -55.62                |                     | 50.64        | T4       |       |
| LTE Band 41<br>EVS<br>2.8/5.9 kbit/s                             | 40620<br>2593 MHz     | 20 MHz<br>QPSK       | ANT2    | z (Axial)      | 18.07        | -21.19       | -55.67                | 2.00                | 55.05        | T4       | -0.42 |
|                                                                  |                       |                      |         | y (Transverse) | 3.95         | -20.45       | -55.49                |                     | 47.45        | T4       |       |
|                                                                  |                       |                      | ANT1    | z (Axial)      | 16.54        | -22.57       | -55.83                | 2.00                | 58.71        | T4       |       |
|                                                                  |                       |                      |         | y (Transverse) | 4.83         | -20.34       | -55.62                |                     | 47.87        | T4       |       |
|                                                                  |                       |                      | ANT3    | z (Axial)      | 17.38        | -20.93       | -55.83                | 2.00                | 54.45        | T4       | -0.25 |
|                                                                  |                       |                      |         | y (Transverse) | 6.29         | -20.06       | -55.62                |                     | 47.70        | T4       |       |
|                                                                  |                       |                      | ANT4    | z (Axial)      | 11.83        | -23.74       | -55.83                | 2.00                | 55.01        | T4       | -2.02 |
|                                                                  |                       |                      |         | y (Transverse) | 9.93         | -23.95       | -55.62                |                     | 49.47        | T4       |       |
| 802.11b<br>EVS<br>2.8/5.9 kbit/s                                 | 1<br>2412 MHz         | CCK<br>11 Mbps       | ANT4    | z (Axial)      | 10.25        | -29.29       | -55.75                | 0.83                | 57.82        | T4       | -8.15 |
|                                                                  |                       |                      |         | y (Transverse) | 3.58         | -26.86       | -55.62                |                     | 50.72        | T4       |       |
|                                                                  |                       |                      | ANT3    | z (Axial)      | 16.42        | -32.27       | -55.75                | 0.78                | 59.85        | T4       |       |
|                                                                  |                       |                      |         | y (Transverse) | 7.13         | -31.50       | -55.62                |                     | 58.87        | T4       |       |
| 802.11a<br>EVS<br>2.8/5.9 kbit/s                                 | 36<br>5180 MHz        | BPSK<br>6 Mbps       | ANT6    | z (Axial)      | 16.20        | -25.96       | -55.82                | 1.09                | 63.20        | T4       | -8.04 |
|                                                                  |                       |                      |         | y (Transverse) | 6.33         | -31.53       | -55.63                |                     | 51.35        | T4       |       |
|                                                                  |                       |                      | ANT5    | z (Axial)      | 17.29        | -32.24       | -55.75                | 1.39                | 59.39        | T4       |       |
|                                                                  |                       |                      |         | y (Transverse) | 9.92         | -31.31       | -55.62                |                     | 60.53        | T4       |       |

## 9.2. Codec Investigation

An investigation between the various codec configurations (Low/Mid/High bit rates for Narrowband, Wideband, and EVS) and specific parameters are documented (ABM1, ABM2, S+N/N, frequency response) to determine the worst-case bit rates for each voice service type. The table below compares the varying codec configurations.

A full codec investigation was performed on one LTE FDD and one LTE TDD band; another full codec investigation was performed on one W-CDMA band. Spot checks were then performed on the worst case bit rate from Narrowband, Wideband, and EVS to confirm that there were minimal variations between frequencies/bands.

The highlighted results below were determined to be the worst case codec configuration(s) for LTE and W-CDMA.

| Codec Investigation |                 |        |        |                 |        |        |              |     |      |                |                                      |
|---------------------|-----------------|--------|--------|-----------------|--------|--------|--------------|-----|------|----------------|--------------------------------------|
| Codec State         | AMR-NB (kbit/s) |        |        | AMR-WB (kbit/s) |        |        | EVS (kbit/s) |     |      | Orientation    | Band/Channel/<br>Bandwidth           |
|                     | 4.75            | 7.4    | 12.2   | 6.6             | 15.85  | 23.85  | 2.8/5.9      | 9.6 | 24.4 |                |                                      |
| ABM1 (dB/m)         | 17.06           | 17.79  | 17.74  | 11.64           | 13.17  | 14.01  |              |     |      | z (Axial)      | W-CDMA<br>Band II<br>CH. 9400        |
| ABM2 (dBA/m)        | -32.59          | -32.90 | -31.74 | -27.50          | -29.52 | -29.52 |              |     |      |                |                                      |
| SNR (dB)            | 63.99           | 63.90  | 53.77  | 56.35           | 53.86  | 59.54  |              |     |      |                |                                      |
| Freq. Response (dB) | 1.72            | 2.00   | 2.00   | 1.76            | 1.63   | 1.34   |              |     |      |                |                                      |
| ABM1 (dB/m)         | 9.02            | 10.23  | 9.46   | 10.83           | 8.49   | 8.66   |              |     |      | y (Transverse) | W-CDMA<br>Band II<br>CH. 9400        |
| ABM2 (dBA/m)        | -29.29          | -28.65 | -30.25 | -31.46          | -27.27 | -27.41 |              |     |      |                |                                      |
| SNR (dB)            | 53.25           | 55.24  | 54.72  | 53.76           | 51.38  | 51.52  |              |     |      |                |                                      |
| ABM1 (dB/m)         | 12.26           |        |        |                 | 14.48  |        |              |     |      | z (Axial)      | W-CDMA<br>Band IV<br>CH. 1413        |
| ABM2 (dBA/m)        | -25.04          |        |        |                 | -29.11 |        |              |     |      |                |                                      |
| SNR (dB)            | 58.78           |        |        |                 | 60.97  |        |              |     |      |                |                                      |
| Freq. Response (dB) | 1.22            |        |        |                 | 1.47   |        |              |     |      |                |                                      |
| ABM1 (dB/m)         | 6.04            |        |        |                 | 8.44   |        |              |     |      | y (Transverse) | W-CDMA<br>Band IV<br>CH. 1413        |
| ABM2 (dBA/m)        | -26.95          |        |        |                 | -27.19 |        |              |     |      |                |                                      |
| SNR (dB)            | 48.30           |        |        |                 | 50.56  |        |              |     |      |                |                                      |
| ABM1 (dB/m)         | 12.86           |        |        |                 | 14.24  |        |              |     |      | z (Axial)      | W-CDMA<br>Band V<br>CH. 4183         |
| ABM2 (dBA/m)        | -25.37          |        |        |                 | -26.88 |        |              |     |      |                |                                      |
| SNR (dB)            | 60.27           |        |        |                 | 60.70  |        |              |     |      |                |                                      |
| Freq. Response (dB) | 1.39            |        |        |                 | 1.62   |        |              |     |      |                |                                      |
| ABM1 (dB/m)         | 7.02            |        |        |                 | 9.78   |        |              |     |      | y (Transverse) | W-CDMA<br>Band V<br>CH. 4183         |
| ABM2 (dBA/m)        | -27.10          |        |        |                 | -27.16 |        |              |     |      |                |                                      |
| SNR (dB)            | 49.16           |        |        |                 | 51.76  |        |              |     |      |                |                                      |
| ABM1 (dB/m)         | 15.15           |        |        | 15.90           |        |        | 18.02        |     |      | z (Axial)      | LTE Band 4<br>CH. 20175<br>20 MHz BW |
| ABM2 (dBA/m)        | -30.52          |        |        | -30.01          |        |        | -33.56       |     |      |                |                                      |
| SNR (dB)            | 62.61           |        |        | 60.48           |        |        | 63.19        |     |      |                |                                      |
| Freq. Response (dB) | 1.63            |        |        | 1.09            |        |        | 1.45         |     |      |                |                                      |
| ABM1 (dB/m)         | 6.99            |        |        | 9.01            |        |        | 8.88         |     |      | y (Transverse) | LTE Band 4<br>CH. 20175<br>20 MHz BW |
| ABM2 (dBA/m)        | -29.99          |        |        | -30.81          |        |        | -31.30       |     |      |                |                                      |
| SNR (dB)            | 50.83           |        |        | 52.22           |        |        | 56.82        |     |      |                |                                      |

## Codec Investigation (continued)

| Codec Investigation |                 |        |        |                 |        |        |              |        |        |                |                                       |
|---------------------|-----------------|--------|--------|-----------------|--------|--------|--------------|--------|--------|----------------|---------------------------------------|
| Codec State         | AMR-NB (kbit/s) |        |        | AMR-WB (kbit/s) |        |        | EVS (kbit/s) |        |        | Orientation    | Band/Channel/<br>Bandwidth            |
|                     | 4.75            | 7.4    | 12.2   | 6.6             | 15.85  | 23.85  | 2.8/5.9      | 9.6    | 24.4   |                |                                       |
| ABM1 (dB/m)         | 17.09           | 19.28  | 18.84  | 18.79           | 17.29  | 19.47  | 15.60        | 17.90  | 19.67  | z (Axial)      | LTE Band 7<br>CH. 21100<br>20 MHz BW  |
| ABM2 (dBA/m)        | -29.84          | -31.41 | -31.07 | -31.79          | -27.48 | -31.87 | -31.51       | -26.67 | -32.33 |                |                                       |
| SNR (dB)            | 63.19           | 62.97  | 63.55  | 63.38           | 64.45  | 64.80  | 61.13        | 64.60  | 65.24  |                |                                       |
| Freq. Resposne (dB) | 1.00            | 1.63   | 1.41   | 0.91            | 1.12   | 0.77   | 1.71         | 1.93   | 1.78   |                |                                       |
| ABM1 (dB/m)         | 9.48            | 11.20  | 11.20  | 9.78            | 10.44  | 10.33  | 6.19         | 12.12  | 9.18   | y (Transverse) | LTE Band 7<br>CH. 21100<br>20 MHz BW  |
| ABM2 (dBA/m)        | -27.57          | -29.85 | -28.96 | -30.92          | -33.29 | -32.58 | -30.97       | -30.40 | -26.67 |                |                                       |
| SNR (dB)            | 54.06           | 55.94  | 54.72  | 54.09           | 55.50  | 55.20  | 52.17        | 56.63  | 57.64  |                |                                       |
| ABM1 (dB/m)         | 18.07           |        |        | 16.66           |        |        | 16.25        |        |        | z (Axial)      | LTE Band 12<br>CH. 23095<br>10 MHz BW |
| ABM2 (dBA/m)        | -28.93          |        |        | -32.25          |        |        | -32.26       |        |        |                |                                       |
| SNR (dB)            | 64.47           |        |        | 61.89           |        |        | 62.13        |        |        |                |                                       |
| Freq. Resposne (dB) | 1.68            |        |        | 1.97            |        |        | 2.00         |        |        |                |                                       |
| ABM1 (dB/m)         | 9.63            |        |        | 11.73           |        |        | 11.25        |        |        | y (Transverse) | LTE Band 12<br>CH. 23095<br>10 MHz BW |
| ABM2 (dBA/m)        | -33.35          |        |        | -24.05          |        |        | -30.23       |        |        |                |                                       |
| SNR (dB)            | 55.00           |        |        | 56.08           |        |        | 58.11        |        |        |                |                                       |
| ABM1 (dB/m)         | 17.58           |        |        | 15.38           |        |        | 18.30        |        |        | z (Axial)      | LTE Band 26<br>CH. 26865<br>15 MHz BW |
| ABM2 (dBA/m)        | -30.66          |        |        | -29.69          |        |        | -31.57       |        |        |                |                                       |
| SNR (dB)            | 61.38           |        |        | 60.04           |        |        | 63.22        |        |        |                |                                       |
| Freq. Resposne (dB) | 1.85            |        |        | 2.00            |        |        | 1.72         |        |        |                |                                       |
| ABM1 (dB/m)         | 8.78            |        |        | 7.56            |        |        | 9.12         |        |        | y (Transverse) | LTE Band 26<br>CH. 26865<br>15 MHz BW |
| ABM2 (dBA/m)        | -29.08          |        |        | -29.05          |        |        | -30.41       |        |        |                |                                       |
| SNR (dB)            | 55.00           |        |        | 53.74           |        |        | 57.75        |        |        |                |                                       |
| ABM1 (dB/m)         | 18.54           | 17.95  | 18.58  | 17.78           | 19.27  | 19.18  | 18.07        | 14.64  | 15.54  | z (Axial)      | LTE Band 41<br>CH. 40620<br>20 MHz BW |
| ABM2 (dBA/m)        | -26.55          | -26.05 | -25.67 | -25.10          | -22.42 | -25.93 | -21.19       | -20.74 | -21.13 |                |                                       |
| SNR (dB)            | 60.62           | 60.56  | 61.89  | 60.04           | 62.04  | 60.76  | 55.05        | 56.04  | 57.02  |                |                                       |
| Freq. Resposne (dB) | 0.81            | 1.21   | 0.99   | 0.79            | 1.43   | 1.40   | 2.00         | 2.00   | 2.00   |                |                                       |
| ABM1 (dB/m)         | 11.11           | 10.66  | 10.95  | 8.73            | 9.62   | 11.94  | 3.95         | 9.19   | 9.77   | y (Transverse) | LTE Band 41<br>CH. 40620<br>20 MHz BW |
| ABM2 (dBA/m)        | -26.74          | -26.89 | -26.56 | -26.72          | -27.14 | -26.45 | -20.45       | -20.36 | -20.56 |                |                                       |
| SNR (dB)            | 52.56           | 53.36  | 53.83  | 53.31           | 53.39  | 53.04  | 47.45        | 51.32  | 51.49  |                |                                       |

### 9.3. VoLTE Air Interface Investigation

Using the data from §9.2, further testing was performed on the LTE bands where a complete codec bit rate investigation was performed. The objective of these measurements is to ensure that changing the frequency and modulation, whilst using the worst case codec configuration for that particular band, yields no unexpected variation.

| Mode:                                | Channel and Frequency | Bandwidth (if applicable) | Modulation | Orientation    | ABM1 dB(A/m) | ABM2 dB(A/m) | Ambient Noise dB(A/m) | Freq. Response (dB) | ABM SNR (dB) | T-Rating |
|--------------------------------------|-----------------------|---------------------------|------------|----------------|--------------|--------------|-----------------------|---------------------|--------------|----------|
| LTE Band 7<br>EVS<br>2.8/5.9 kbit/s  | 20850<br>2510 MHz     | 20 MHz                    | QPSK       | z (Axial)      | 17.69        | -27.75       | -55.67                | 1.43                | 62.89        | T4       |
|                                      |                       |                           |            | y (Transverse) | 10.73        | -28.40       | -55.49                |                     | 55.43        | T4       |
|                                      | 21100<br>2535 MHz     | 20 MHz                    | QPSK       | z (Axial)      | 15.60        | -31.51       | -55.67                | 1.71                | 61.13        | T4       |
|                                      |                       |                           |            | y (Transverse) | 6.19         | -30.97       | -55.49                |                     | <b>52.17</b> | T4       |
|                                      | 21350<br>2560 MHz     | 20 MHz                    | QPSK       | z (Axial)      | 17.31        | -31.61       | -55.67                | 2.00                | 62.49        | T4       |
|                                      |                       |                           |            | y (Transverse) | 8.89         | -29.71       | -55.49                |                     | 53.80        | T4       |
|                                      | 21100<br>2535 MHz     | 20 MHz                    | 16QAM      | z (Axial)      | 15.76        | -28.22       | -55.67                | 2.00                | 61.65        | T4       |
|                                      |                       |                           |            | y (Transverse) | 7.35         | -29.29       | -55.49                |                     | 54.59        | T4       |
| LTE Band 41<br>EVS<br>2.8/5.9 kbit/s | 39750<br>2506 MHz     | 20 MHz                    | QPSK       | z (Axial)      | 15.94        | -31.18       | -55.83                | 1.47                | 59.32        | T4       |
|                                      |                       |                           |            | y (Transverse) | 8.71         | -29.10       | -55.62                |                     | 50.81        | T4       |
|                                      | 40185<br>2549.5 MHz   | 20 MHz                    | QPSK       | z (Axial)      | 15.27        | -30.66       | -55.83                | 1.71                | 59.19        | T4       |
|                                      |                       |                           |            | y (Transverse) | 6.76         | -28.10       | -55.62                |                     | 49.25        | T4       |
|                                      | 40620<br>2593 MHz     | 20 MHz                    | QPSK       | z (Axial)      | 18.07        | -21.19       | -55.67                | 2.00                | 55.05        | T4       |
|                                      |                       |                           |            | y (Transverse) | 3.95         | -20.45       | -55.49                |                     | <b>47.45</b> | T4       |
|                                      | 41055<br>2636.5 MHz   | 20 MHz                    | QPSK       | z (Axial)      | 11.88        | -30.16       | -55.83                | 2.00                | 59.91        | T4       |
|                                      |                       |                           |            | y (Transverse) | 7.39         | -28.67       | -55.62                |                     | 49.59        | T4       |
|                                      | 41490<br>2680 MHz     | 20 MHz                    | QPSK       | z (Axial)      | 12.32        | -29.94       | -55.83                | 2.00                | 59.42        | T4       |
|                                      |                       |                           |            | y (Transverse) | 8.96         | -27.63       | -55.62                |                     | 49.97        | T4       |
|                                      | 40620<br>2593 MHz     | 20 MHz                    | 16QAM      | z (Axial)      | 16.57        | -30.89       | -55.83                | 2.00                | 62.46        | T4       |
|                                      |                       |                           |            | y (Transverse) | 6.49         | -28.37       | -55.62                |                     | 48.77        | T4       |

## 9.4. VoWi-Fi Codec Investigation

An investigation between the various codec configurations (NB, WB, and EVS) and specific parameters are documented (ABM1, ABM2, S+N/N, frequency response) to determine the worst-case bit rates for each voice service type. The table below compares the varying codec configurations.

Using the data from §9.2, it has been established that the Low codec configurations for Narrowband, Wideband, and EVS bit rates were the worst case for IP based telephony; thus we limited our investigation to the lowest bit rates for Narrowband, Wideband, and EVS in the U-NII Bands.

| Mode:                                                  | Channel and Frequency | Modulation | Data Rate | Antenna | Orientation    | ABM1 dB(A/m) | ABM2 dB(A/m) | Ambient Noise dB(A/m) | Freq. Response (dB) | ABM SNR (dB) | T-Rating |
|--------------------------------------------------------|-----------------------|------------|-----------|---------|----------------|--------------|--------------|-----------------------|---------------------|--------------|----------|
| 802.11a<br>Voice Wideband<br>AMR Codec: 6.6 kbit/s     | 36<br>5180 MHz        | BPSK       | 6 Mbps    | ANT6    | z (Axial)      | 17.74        | -27.56       | -55.78                | 1.24                | 62.80        | T4       |
|                                                        |                       |            |           |         | y (Transverse) | 10.32        | -30.65       | -55.48                |                     | 56.90        | T4       |
| 802.11a<br>Voice Narrow band<br>AMR Codec: 4.75 kbit/s | 36<br>5180 MHz        | BPSK       | 6 Mbps    | ANT6    | z (Axial)      | 15.63        | -27.07       | -55.78                | 0.87                | 63.66        | T4       |
|                                                        |                       |            |           |         | y (Transverse) | 10.36        | -31.21       | -55.48                |                     | 57.21        | T4       |
| 802.11a<br>Voice EVS<br>2.8/5.9 kbit/s                 | 36<br>5180 MHz        | BPSK       | 6 Mbps    | ANT6    | z (Axial)      | 16.20        | -25.96       | -55.82                | 1.09                | 63.20        | T4       |
|                                                        |                       |            |           |         | y (Transverse) | 6.33         | -31.53       | -55.63                |                     | <b>51.35</b> | T4       |

## 9.5. VoWi-Fi Air Interface Investigation

Using the data from §9.4, further testing was performed on the remaining 802.11 modes. The objective of these measurements is to ensure that changing the modulation, bandwidth, and data rate, whilst using the worst case codec configuration measured in §9.4, yields no unexpected variations.

| Mode:                                         | Channel and Frequency | Modulation | Data Rate | Antenna | Orientation    | ABM1 dB(A/m) | ABM2 dB(A/m) | Ambient Noise dB(A/m) | Freq. Response (dB) | ABM SNR (dB) | T-Rating |
|-----------------------------------------------|-----------------------|------------|-----------|---------|----------------|--------------|--------------|-----------------------|---------------------|--------------|----------|
| 802.11b<br>Voice EVS<br>2.8/5.9 kbit/s        | 1<br>2412 MHz         | DSSS       | 1 Mbps    | ANT4    | z (Axial)      | 14.20        | -30.71       | -55.75                | 1.61                | 61.60        | T4       |
|                                               |                       |            |           |         | y (Transverse) | 9.28         | -28.79       | -55.62                |                     | 54.03        | T4       |
| 802.11b<br>Voice EVS<br>2.8/5.9 kbit/s        | 1<br>2412 MHz         | CCK        | 5.5 Mbps  | ANT4    | z (Axial)      | 16.79        | -32.73       | -55.75                | 1.24                | 62.21        | T4       |
|                                               |                       |            |           |         | y (Transverse) | 7.82         | -27.89       | -55.62                |                     | 52.77        | T4       |
| 802.11b<br>Voice EVS<br>2.8/5.9 kbit/s        | 1<br>2412 MHz         | CCK        | 11 Mbps   | ANT4    | z (Axial)      | 10.25        | -29.29       | -55.75                | 0.83                | 57.82        | T4       |
|                                               |                       |            |           |         | y (Transverse) | 3.58         | -26.86       | -55.62                |                     | 50.72        | T4       |
| 802.11a<br>Voice EVS<br>2.8/5.9 kbit/s        | 36<br>5180 MHz        | QPSK       | 18 Mbps   | ANT6    | z (Axial)      | 16.19        | -28.29       | -55.83                | 1.32                | 62.82        | T4       |
|                                               |                       |            |           |         | y (Transverse) | 10.73        | -31.31       | -55.62                |                     | 57.98        | T4       |
| 802.11a<br>Voice EVS<br>2.8/5.9 kbit/s        | 36<br>5180 MHz        | 64QAM      | 54 Mbps   | ANT6    | z (Axial)      | 17.94        | -27.77       | -55.83                | 0.49                | 63.21        | T4       |
|                                               |                       |            |           |         | y (Transverse) | 9.28         | -28.08       | -55.62                |                     | 55.31        | T4       |
| 802.11n 20 MHz<br>Voice EVS<br>2.8/5.9 kbit/s | 36<br>5180 MHz        | MCS0       | 6.5 Mbps  | ANT6    | z (Axial)      | 17.62        | -26.00       | -55.83                | 0.19                | 65.77        | T4       |
|                                               |                       |            |           |         | y (Transverse) | 10.63        | -29.40       | -55.62                |                     | 56.03        | T4       |
| 802.11n 20 MHz<br>Voice EVS<br>2.8/5.9 kbit/s | 36<br>5180 MHz        | MCS3       | 26 Mbps   | ANT6    | z (Axial)      | 18.28        | -28.36       | -55.83                | 1.17                | 65.69        | T4       |
|                                               |                       |            |           |         | y (Transverse) | 9.47         | -30.30       | -55.62                |                     | 56.90        | T4       |
| 802.11n 20 MHz<br>Voice EVS<br>2.8/5.9 kbit/s | 36<br>5180 MHz        | MCS7       | 65 Mbps   | ANT6    | z (Axial)      | 19.41        | -28.00       | -55.83                | 1.41                | 65.24        | T4       |
|                                               |                       |            |           |         | y (Transverse) | 10.27        | -30.91       | -55.62                |                     | 57.47        | T4       |
| 802.11n 40 MHz<br>Voice EVS<br>2.8/5.9 kbit/s | 38<br>5190 MHz        | MCS0       | 6.5 Mbps  | ANT6    | z (Axial)      | 16.94        | -27.51       | -55.83                | 0.20                | 65.14        | T4       |
|                                               |                       |            |           |         | y (Transverse) | 10.54        | -23.47       | -55.62                |                     | 56.72        | T4       |
| 802.11n 40 MHz<br>Voice EVS<br>2.8/5.9 kbit/s | 38<br>5190 MHz        | MCS3       | 26 Mbps   | ANT6    | z (Axial)      | 16.99        | -27.02       | -55.83                | 1.54                | 65.39        | T4       |
|                                               |                       |            |           |         | y (Transverse) | 9.95         | -30.28       | -55.62                |                     | 57.03        | T4       |
| 802.11n 40 MHz<br>Voice EVS<br>2.8/5.9 kbit/s | 38<br>5190 MHz        | MCS7       | 65 Mbps   | ANT6    | z (Axial)      | 15.66        | -28.45       | -55.83                | 0.29                | 63.22        | T4       |
|                                               |                       |            |           |         | y (Transverse) | 11.35        | -27.84       | -55.62                |                     | 53.87        | T4       |
| 802.11a<br>Voice EVS<br>2.8/5.9 kbit/s        | 40<br>5200 MHz        | BPSK       | 6 Mbps    | ANT6    | z (Axial)      | 18.68        | -28.92       | -55.83                | 1.42                | 64.68        | T4       |
|                                               |                       |            |           |         | y (Transverse) | 11.12        | -29.82       | -55.62                |                     | 55.19        | T4       |

### Note:

802.11g mode is covered by 802.11a/n mode for having the same data rates.

802.11ac was not investigated as the modulations and bandwidths are covered by the tested modes.

## 9.6. OTT

The DUT's nested OTT application only supports one (1) codec bit rate, thus no codec investigation is needed.

| Mode:                                    | Channel and Frequency | Bandwidth/ Data Rate | Antenna | Orientation    | ABM1 dB(A/m) | ABM2 dB(A/m) | Ambient Noise dB(A/m) | Freq. Response (dB) | ABM SNR (dB) | T-Rating | Plot Page # |
|------------------------------------------|-----------------------|----------------------|---------|----------------|--------------|--------------|-----------------------|---------------------|--------------|----------|-------------|
| GSM 850<br>EDGE 2 Slots<br>FaceTime      | 190<br>836.6 MHz      | N/A                  | ANT2    | z (Axial)      | 5.20         | -24.50       | -55.62                | 2.00                | 51.29        | T4       | 1-2         |
|                                          |                       |                      |         | y (Transverse) | -2.34        | -28.50       | -55.48                |                     | 41.19        | T4       | 3           |
| GSM 1900<br>EDGE 2 Slots<br>FaceTime     | 661<br>1880 MHz       | N/A                  | ANT2    | z (Axial)      | 5.13         | -25.50       | -55.62                | 2.00                | 51.27        | T4       | 4-5         |
|                                          |                       |                      |         | y (Transverse) | -2.00        | -29.78       | -55.48                |                     | 42.39        | T4       | 6           |
| W-CDMA Band II<br>HSPA<br>FaceTime       | 9400<br>1880 MHz      | N/A                  | ANT2    | z (Axial)      | 5.14         | -25.62       | -55.62                | 2.00                | 51.52        | T4       | 7-8         |
|                                          |                       |                      |         | y (Transverse) | -3.72        | -29.46       | -55.48                |                     | 41.40        | T4       | 9           |
| W-CDMA Band IV<br>HSPA<br>FaceTime       | 1413<br>1732.6 MHz    | N/A                  | ANT2    | z (Axial)      | 5.32         | -25.74       | -55.62                | 2.00                | 52.32        | T4       | 10-11       |
|                                          |                       |                      |         | y (Transverse) | -2.93        | -30.01       | -55.48                |                     | 41.86        | T4       | 12          |
| W-CDMA Band V<br>HSPA<br>FaceTime        | 4183<br>836.6 MHz     | N/A                  | ANT2    | z (Axial)      | 5.66         | -25.55       | -55.62                | 2.00                | 51.13        | T4       | 13-14       |
|                                          |                       |                      |         | y (Transverse) | -2.43        | -28.78       | -55.48                |                     | 41.03        | T4       | 15          |
| CDMA2000 BC0<br>Ev-Do Rev 0<br>FaceTime  | 384<br>836.52 MHz     | N/A                  | ANT2    | z (Axial)      | 6.42         | -25.00       | -55.84                | 2.00                | 51.21        | T4       | 16-17       |
|                                          |                       |                      |         | y (Transverse) | -4.12        | -26.72       | -55.67                |                     | 37.88        | T4       | 18          |
| CDMA2000 BC1<br>Ev-Do Rev 0<br>FaceTime  | 600<br>1880 MHz       | N/A                  | ANT2    | z (Axial)      | 8.11         | -24.67       | -55.84                | 2.00                | 53.60        | T4       | 19-20       |
|                                          |                       |                      |         | y (Transverse) | -2.85        | -28.16       | -55.67                |                     | 38.79        | T4       | 21          |
| CDMA2000 BC10<br>Ev-Do Rev 0<br>FaceTime | 580<br>820.5 MHz      | N/A                  | ANT2    | z (Axial)      | 9.10         | -24.95       | -55.84                | 2.00                | 54.13        | T4       | 22-23       |
|                                          |                       |                      |         | y (Transverse) | -2.26        | -27.96       | -55.67                |                     | 40.69        | T4       | 24          |
| LTE Band 7<br>QPSK<br>FaceTime           | 21100<br>2535 MHz     | 20 MHz               | ANT2    | z (Axial)      | 8.23         | -31.08       | -55.75                | 2.00                | 54.17        | T4       | 25-26       |
|                                          |                       |                      |         | y (Transverse) | 0.21         | -30.32       | -55.58                |                     | 44.78        | T4       | 27          |
| LTE Band 41<br>QPSK<br>FaceTime          | 40620<br>2593 MHz     | 20 MHz               | ANT2    | z (Axial)      | 5.95         | -21.08       | -55.75                | 2.00                | 44.92        | T4       | 28-29       |
|                                          |                       |                      |         | y (Transverse) | -2.40        | -19.28       | -55.58                |                     | 37.09        | T4       | 30          |
| 802.11b<br>FaceTime                      | 1<br>2412 MHz         | CCK<br>11 Mbps       | ANT4    | z (Axial)      | 7.37         | -28.26       | -55.75                | 2.00                | 50.77        | T4       | 31-32       |
|                                          |                       |                      |         | y (Transverse) | -1.29        | -25.22       | -55.58                |                     | 43.55        | T4       | 33          |
| 802.11a<br>FaceTime                      | 36<br>5180 MHz        | BPSK<br>6 Mbps       | ANT6    | z (Axial)      | 7.95         | -23.09       | -55.75                | 2.00                | 51.03        | T4       | 34-35       |
|                                          |                       |                      |         | y (Transverse) | -2.07        | -24.70       | -55.58                |                     | 39.71        | T4       | 36          |
| 802.11a<br>FaceTime                      | 52<br>5260 MHz        | BPSK<br>6 Mbps       | ANT6    | z (Axial)      | 8.77         | -22.18       | -55.75                | 2.00                | 51.76        | T4       | 37-38       |
|                                          |                       |                      |         | y (Transverse) | -1.25        | -23.13       | -55.58                |                     | 40.32        | T4       | 39          |
| 802.11a<br>FaceTime                      | 100<br>5500 MHz       | BPSK<br>6 Mbps       | ANT6    | z (Axial)      | 6.87         | -23.22       | -55.75                | 2.00                | 50.90        | T4       | 40-41       |
|                                          |                       |                      |         | y (Transverse) | 0.05         | -21.97       | -55.58                |                     | 37.86        | T4       | 42          |
| 802.11a<br>FaceTime                      | 149<br>5745 MHz       | BPSK<br>6 Mbps       | ANT6    | z (Axial)      | 2.57         | -23.47       | -55.75                | 2.00                | 50.35        | T4       | 43-44       |
|                                          |                       |                      |         | y (Transverse) | 0.96         | -24.37       | -55.58                |                     | 39.62        | T4       | 45          |

## 9.7. Summary of HAC (T-coil) Test Results

| Mode:                                                         | Channel and Frequency | Bandwidth (if applicable) | Antenna | Orientation    | ABM1 dB(A/m) | ABM2 dB(A/m) | Ambient Noise dB(A/m) | Freq. Response (dB) | ABM SNR (dB) | T-Rating | Plot Page # |
|---------------------------------------------------------------|-----------------------|---------------------------|---------|----------------|--------------|--------------|-----------------------|---------------------|--------------|----------|-------------|
| GSM 850<br>Voice Coder<br>Speechcodec Low                     | 190<br>836.6 MHz      | N/A                       | ANT2    | z (Axial)      | 11.65        | -5.07        | -55.41                | 1.45                | 39.72        | T4       | 1-2         |
|                                                               |                       |                           |         | y (Transverse) | 12.43        | -8.20        | -55.41                |                     | 40.15        | T4       | 3           |
| GSM 1900<br>Voice Coder<br>Speechcodec Low                    | 661<br>1880 MHz       | N/A                       | ANT2    | z (Axial)      | 12.46        | -7.29        | -55.41                | 2.00                | 41.26        | T4       | 4-5         |
|                                                               |                       |                           |         | y (Transverse) | 12.27        | -9.38        | -55.41                |                     | 43.49        | T4       | 6           |
| W-CDMA Band II<br>Voice Wideband<br>AMR Codec: 15.85 kbit/s   | 9400<br>1880 MHz      | N/A                       | ANT2    | z (Axial)      | 13.17        | -29.52       | -55.84                | 1.63                | 59.86        | T4       | 7-8         |
|                                                               |                       |                           |         | y (Transverse) | 8.49         | -27.27       | -55.67                |                     | 51.38        | T4       | 9           |
| W-CDMA Band IV<br>Voice Narrowband<br>AMR Codec: 4.75 kbit/s  | 1413<br>1732.6 MHz    | N/A                       | ANT2    | z (Axial)      | 12.26        | -25.04       | -55.84                | 1.22                | 58.78        | T4       | 10-11       |
|                                                               |                       |                           |         | y (Transverse) | 6.04         | -26.95       | -55.67                |                     | 48.30        | T4       | 12          |
| W-CDMA Band V<br>Voice Narrowband<br>AMR Codec: 4.75 kbit/s   | 4183<br>836.6 MHz     | N/A                       | ANT2    | z (Axial)      | 12.86        | -25.37       | -55.84                | 1.39                | 60.27        | T4       | 13-14       |
|                                                               |                       |                           |         | y (Transverse) | 7.02         | -27.10       | -55.67                |                     | 49.16        | T4       | 15          |
| CDMA2000 BC0<br>RC1 / SO3 1/8 FR<br>Voice Coder: 8K EVRC Low  | 384<br>836.52 MHz     | N/A                       | ANT2    | z (Axial)      | 16.95        | -32.07       | -55.41                | 1.38                | 64.18        | T4       | 16-17       |
|                                                               |                       |                           |         | y (Transverse) | 9.44         | -28.78       | -55.41                |                     | 55.06        | T4       | 18          |
| CDMA2000 BC1<br>RC1 / SO3 1/8 FR<br>Voice Coder: 8K EVRC Low  | 600<br>1880 MHz       | N/A                       | ANT2    | z (Axial)      | 17.33        | -27.65       | -55.41                | 2.00                | 60.74        | T4       | 19-20       |
|                                                               |                       |                           |         | y (Transverse) | 8.67         | -30.51       | -55.41                |                     | 55.26        | T4       | 21          |
| CDMA2000 BC10<br>RC1 / SO3 1/8 FR<br>Voice Coder: 8K EVRC Low | 580<br>820.5 MHz      | N/A                       | ANT2    | z (Axial)      | 17.37        | -29.18       | -55.41                | 2.00                | 64.92        | T4       | 22-23       |
|                                                               |                       |                           |         | y (Transverse) | 8.74         | -28.00       | -55.41                |                     | 53.20        | T4       | 24          |
| LTE Band 4<br>Voice Narrowband<br>AMR Codec: 4.75 kbit/s      | 20175<br>1732.5 MHz   | 20 MHz                    | ANT2    | z (Axial)      | 15.15        | -30.52       | -55.67                | 1.63                | 62.61        | T4       | 25-26       |
|                                                               |                       |                           |         | y (Transverse) | 6.99         | -29.99       | -55.49                |                     | 50.83        | T4       | 27          |

### Note:

The radial longitudinal (x axis) measurements are no longer required per ANSI C63.19

## Summary of HAC (T-coil) Test Results (continued)

| Mode:                                                      | Channel and Frequency | Bandwidth (if applicable) | Antenna | Orientation    | ABM1 dB(A/m) | ABM2 dB(A/m) | Ambient Noise dB(A/m) | Freq. Response (dB) | ABM SNR (dB) | T-Rating | Plot Page # |
|------------------------------------------------------------|-----------------------|---------------------------|---------|----------------|--------------|--------------|-----------------------|---------------------|--------------|----------|-------------|
| LTE Band 7<br>EVS<br>2.8/5.9 kbit/s                        | 21100<br>2535 MHz     | 20 MHz                    | ANT2    | z (Axial)      | 15.60        | -31.51       | -55.67                | 1.71                | 61.13        | T4       | 28-29       |
|                                                            |                       |                           |         | y (Transverse) | 6.19         | -30.97       | -55.49                |                     | 52.17        | T4       | 30          |
| LTE Band 12<br>Voice Narrow band<br>AMR Codec: 4.75 kbit/s | 23095<br>707.5 MHz    | 10 MHz                    | ANT2    | z (Axial)      | 18.07        | -28.93       | -55.67                | 1.68                | 64.47        | T4       | 31-32       |
|                                                            |                       |                           |         | y (Transverse) | 9.63         | -33.35       | -55.49                |                     | 55.00        | T4       | 33          |
| LTE Band 26<br>Voice Wideband<br>AMR Codec: 6.6 kbit/s     | 26865<br>831.5 MHz    | 15 MHz                    | ANT2    | z (Axial)      | 15.38        | -29.69       | -55.67                | 2.00                | 60.04        | T4       | 34-35       |
|                                                            |                       |                           |         | y (Transverse) | 7.56         | -29.05       | -55.49                |                     | 53.74        | T4       | 36          |
| LTE Band 41<br>Voice Narrow band<br>AMR Codec: 4.75 kbit/s | 40620<br>2593 MHz     | 20 MHz                    | ANT2    | z (Axial)      | 18.07        | -21.19       | -55.67                | 2.00                | 55.05        | T4       | 37-38       |
|                                                            |                       |                           |         | y (Transverse) | 3.95         | -20.45       | -55.49                |                     | 47.45        | T4       | 39          |
| 802.11b<br>Voice EVS<br>2.8/5.9 kbit/s                     | 1<br>2412 MHz         | CCK<br>11 Mbps            | ANT4    | z (Axial)      | 10.25        | -29.29       | -55.75                | 0.83                | 57.82        | T4       | 40-41       |
|                                                            |                       |                           |         | y (Transverse) | 3.58         | -26.86       | -55.62                |                     | 50.72        | T4       | 42          |
| 802.11a<br>Voice EVS<br>2.8/5.9 kbit/s                     | 36<br>5180 MHz        | BPSK<br>6 Mbps            | ANT6    | z (Axial)      | 16.20        | -25.96       | -55.82                | 1.09                | 63.20        | T4       | 43-44       |
|                                                            |                       |                           |         | y (Transverse) | 6.33         | -31.53       | -55.63                |                     | 51.35        | T4       | 45          |
| 802.11a<br>Voice EVS<br>2.8/5.9 kbit/s                     | 52<br>5260 MHz        | BPSK<br>6 Mbps            | ANT6    | z (Axial)      | 19.32        | -26.46       | -55.82                | 0.90                | 62.90        | T4       | 46-47       |
|                                                            |                       |                           |         | y (Transverse) | 9.30         | -27.58       | -55.63                |                     | 53.30        | T4       | 48          |
| 802.11a<br>Voice EVS<br>2.8/5.9 kbit/s                     | 100<br>5500 MHz       | BPSK<br>6 Mbps            | ANT6    | z (Axial)      | 17.25        | -28.04       | -55.82                | 0.83                | 63.07        | T4       | 49-50       |
|                                                            |                       |                           |         | y (Transverse) | 10.48        | -27.81       | -55.63                |                     | 53.05        | T4       | 51          |
| 802.11a<br>Voice EVS<br>2.8/5.9 kbit/s                     | 149<br>5745 MHz       | BPSK<br>6 Mbps            | ANT6    | z (Axial)      | 18.64        | -31.04       | -55.75                | 0.87                | 64.41        | T4       | 52-53       |
|                                                            |                       |                           |         | y (Transverse) | 9.71         | -31.05       | -55.62                |                     | 59.94        | T4       | 54          |

### Note:

The radial longitudinal (x axis) measurements are no longer required per ANSI C63.19

## 9.8. Worst Case T-Coil Test Plot

Test Laboratory: UL Verification Services Inc., SAR Lab 2

Date: 7/25/2018

### LTE Band 41

Communication System: UID 0, LTE (TDD) (0); Frequency: 2593 MHz; Duty Cycle: 1:1.59956

Phantom section: TCoil Section

DASY5 Configuration:

- Probe: AM1DV3 - 3083; ; Calibrated: 1/15/2018
- Sensor-Surface: 0mm (Fix Surface)
- Electronics: DAE4 Sn1357; Calibrated: 2/8/2018
- Phantom: HAC Test Arch with AMCC; Type: SD HAC P01 BB
- Measurement SW: DASY52, Version 52.10 (0); SEMCAD X Version 14.6.10 (7417)

### T-Coil scan (scan for ANSI C63.19 2011 compliance)/LTE Band 41 ch 40620/y (transversal) 4.2mm 50 x 50/ABM Interpolated SNR(x,y,z) (121x121x1): Interpolated grid:

dx=1.000 mm, dy=1.000 mm

Signal Type: Audio File (.wav) 48k\_voice\_1kHz\_1s.wav

Output Gain: 30.62

Measure Window Start: 300ms

Measure Window Length: 1000ms

BWC applied: 0.16 dB

Device Reference Point: 0, 0, -6.3 mm

#### Cursor:

ABM1/ABM2 = 37.09 dB

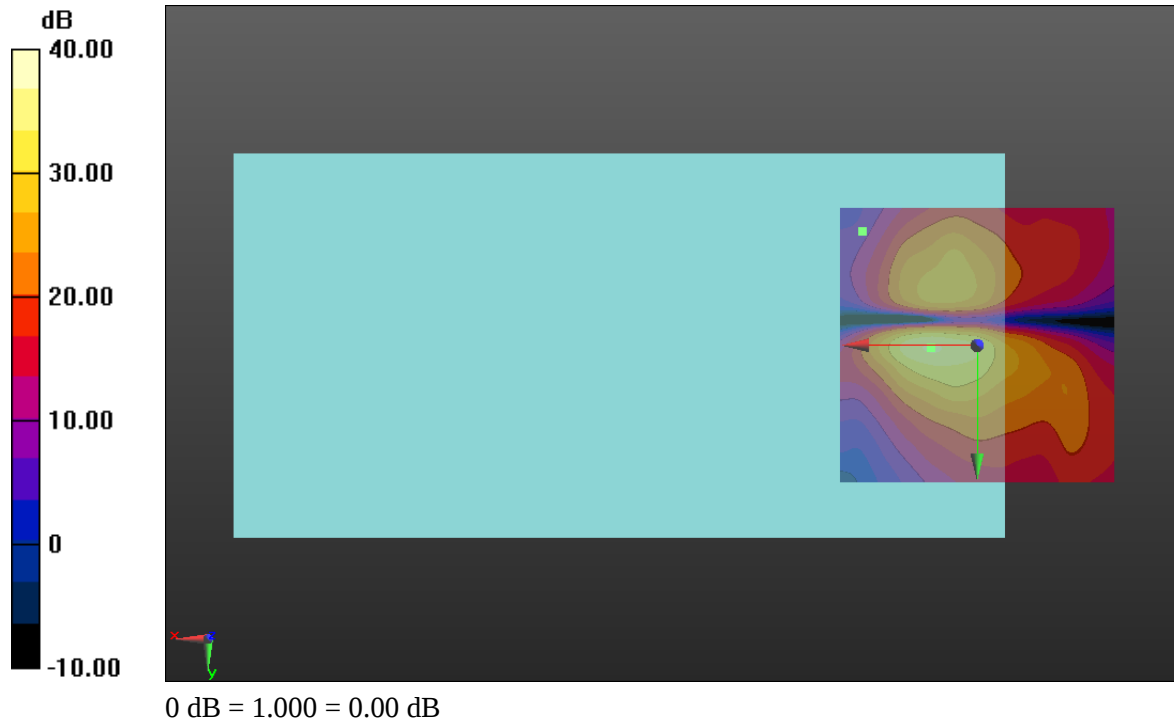
ABM1 comp = -2.40 dBA/m

BWC Factor = 0.16 dB

Location: 8.3, 0.4, 3.7 mm

ABM2 = -19.28 dBA/m

Location: 20.8, -20.8, 3.7 mm



## **Appendix**

**Refer to separated files for the following appendixes**

**12204447-S2V2 Appendix A: HAC T-Coil Setup Photo**

**12204447-S2V2 Appendix B: Frequency Response & SNR Test Plots (OTT)**

**12204447-S2V2 Appendix C: Frequency Response & SNR Test Plots (T-coil)**

**12204447-S2V2 Appendix D: HAC T-Coil Probe Calibration Certificates**

**END OF REPORT**