Data Communications Company

Dual Band Communications Hub

Joint HAN Radio Testing Methodology

Including Real Life Testing Methodology Addendum

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Document Control Heading

Revision History

Revision Date	Summary of Changes	Changes Marked	Version Number
08/03/18	First Draft with JTM 3.1 071212017 and RLTM as addendum with reworded introduction	No	3.2 draft 2
16/03/18	Correction of JTM 3.1 TRS formula error identified by the CSPs	No	3.2 draft 3
19/03/18	Adjust formatting and add watermark	No	3.2 draft 4
04/04/18	Formatting and RLTM annex lettering changes following feedback	Yes	3.2 draft 5
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24/06/2020	Updates to Sec 3.2.1, 4.2.2, 5.2.1 & 5.2.3. Annex-F Added. Clarifying TRS changes	No	3.4

Table of Contents

1 Introduction

The Joint Test Methodology has been prepared and updated as one of the DBCH CSP deliverables in PR023 which is a DCC Project Request for the development of the Dual Band Communications Hub Detailed Specification. The Joint Testing Methodology describes a lab based method by which the HAN performance can be measured and demonstrated against success criteria described in Annex B. Annex A to D are from the JTM3.1.

An addendum has been added in Annex E which describes a less accurate but simpler field based Real Life Testing Methodology which can also be used to measuring the HAN performance. It can also be used to measure the performance of devices other than Communications Hubs.

Other than the introduction this document has been collated verbatim from the source JTM and RLTM as a DCC controlled document to form part of a wider industry reference document.

2 Definitions

The definitions of TRP and TRS have been based on 3GPP standards, an international standard for mobile phone handsets. The translation of the surface integral values to discrete sums is ideal, and further input is needed from test houses to align the distribution of data points to the method of data collection. This may require minor changes to this document, but will result in a procedure that is simpler to implement in real life, with improved repeatability across units and test house.

2.1 Symbols

Symbol	Description
BWCHAN	Channel Bandwidth
dBm	dB relative to 1 milliwatt
dBr	dB relative to peak power
dBW	dB relative to 1 watt
GHz	Gigahertz
Hz	Hertz
kHz	kilohertz
MHz	megahertz
mW	milliwatt

Symbol	Description
ms	millisecond
P_H (P_V)	Radiated output power measured using a horizontal (vertical) polarised antenna
EIS_H (EIS_V)	Radiated sensitivity of horizontally (vertically) polarised radiated power

2.2 Acronyms

Symbol	Description
BWCHAN	Channel Bandwidth
ERP	Effective Radiated Power
JTM	Joint Test Methodology
RLTM	Real Life Testing Methodology
DBCH	Dual Band Communications Hub
HAN	Home area network
TRP	Total Radiated Power
TRS	Total Radiated Sensitivity
MAPL	Maximum Achievable Path Loss
ETSI	European Telecommunications Standards Institute
CSP	Communication Service Provider
PER	Packet Error Rate
MHF	RF port similar to uFL but not under protected patent
UUT	Unit Under Test
RIT	Radio Integration Testing
FAR	Fully Anechoic Room

3 Document Purpose

The Joint HAN Testing Methodology (JTM) document is to provide:

1. An analysis of the Ofcom Smart Meter HAN 868MHz RF Coverage Campaign report.
2. Define Radio performance Parameters to be measured
3. Method of Parameter measurement
4. Success Criteria following technical workshops (CSP/DCC/BEIS attendees) on 27th September 2017

3.1 Performance Parameter definition

The derivation of performance parameters for Sub GHz ZigBee radios took into account the prescribed ETSI standard for the Sub GHz range namely EN300 220 which stipulates:

- Effective Radiated Power (ERP) ≤14dBm for ZigBee
- Receiver Sensitivity ≤ - 97dBm

The above measurements cannot be used to define the performance requirements of DBCH Sub GHz ZigBee radio. ERP is the measure radiated power in one direction where the maximum is, and an isotropic performance is needed as the location of HAN devices relative to the DBCH cannot be prescribed. To obtain a better performance matrix with full 360° angular resolution, the mobile telecommunications standard 3GPP 34.114 is to be used. This more accurately measures design antenna performance which greatly impacts range/coverage

In addition, to maximise the sub GHz HAN range, the receiver sensitivity needs to be as close to chipset minimum as possible, and to validate the unit design a receiver characteristic that incorporates the antenna design and coupling should be used

3.2 HAN Test Methodology - Sub GHz and 2.4 GHz ZigBee

3GPP 34.114 is the basis for the methodology for measuring radiated power and sensitivity. Simplifications of the integral calculations have been defined in sections 5.1 and 5.2 and should be used in preference to 3GPP.

3.2.1 ZigBee HAN Radiated Performance

- TRP- Total Radiated Power
- TRS- Total Radiated Sensitivity

Angular resolution defined by standard is 15˚ in 3GPP 34.114 but to ensure that there are no nulls or peaks in the antenna radiation pattern are missed a resolution of 10˚ is to be used for the transmitted power tests.

The time taken to measure a single TRS datum point is significantly longer than the corresponding TRP datum. To derive the angular resolutions within the 3GPP standard, lengthy simulations and analysis were preformed to conclude on a reasonable angular resolution to capture representative distribution. The JTM leverages this expertise and work.

Therefore, as a complete spherical analysis of the UUT has been recorded by the TRP testing, angular resolution for TRS is lowered to 30°, which is the maximum angular resolution that allows using the TRS approximation formula provided in 3GPP 34.114.

The spherical distribution of the antenna radiation pattern has already been captured at 10° resolution, and as the receiver chain uses the same antenna and transceiver there will be no difference in the distribution, only the magnitude. 30° provides sufficient points to get a calculation of the surface integral but keeps the cost and time to perform measurements to achievable levels, and is the maximum angular resolution that allows using the TRS approximation formula provided in 3GPP 34.114.

The following will form the agreed approach for testing TRP/TRS

- *Measures will be done in*
    - *Two polarisations (horizontal & vertical)*
    - Three *planes (X/Y/Z)*
    - *360^o spatial coverage*
- *Angular resolution for radiated measurements shall be of*
    - *10° for transmitter power measurements*
    - *30° for receiver sensitivity measurements*

All measurements to be conducted in an anechoic chamber by an approved test house. Anechoic chambers should be Fully Anechoic Room (FAR) varieties, conforming to EN 50147-3.

Relevant test house credentials will be detailed in the draft Test Report in Annex D, but test houses should be accredited to ISO/IEC 17025 standards as a minimum.

4 HAN Radio Testing Methodology

The following radio solutions will be tested, when applicable (i.e. when present in the tested device)

- HAN radio - 2.4 GHz band
- HAN radio - Sub-GHz band
    - 863 – 870 MHz
    - 870 – 876 MHz
    - 915 – 921 MHz

The Sub-GHz bands are presented here as detailed in ZigBee specifications. However, the UUT (DBCH, meters and other HAN devices) will not implement all the channels in these bands. Consequently, testing will be done based on the list of channels to be used detailed in Annex A.

4.1 Overview of tests to be conducted

	Power Measurement	Sensitivity Measurements	Standards
HAN Sub-GHz band	TRP	TRS	IEEE 802.15.4 ETSI EN 300 220 ERC 70-03 IR2030 3GPP 34.114
HAN 2.4GHz band	TRP	TRS	IEEE 802.15.4 ETSI EN 300 328 ERC 70-03 IR2030 3GPP 34.114

Values of the table above to be populated for each band under test

4.2 General test conditions

4.2.1 Test Environment

Radiated measurements tests' localisation must comply with the following requirements

1. All radio requirements will be conducted in an anechoic chamber anechoic chambers should be FAR varieties, conforming to EN 50147-3.

These requirements apply to Channel Noise measurements as well as TRS and TRP.

Device positioning relatively to measurement system

The position of the UUT must comply with the following requirements

- The UUT will be positioned on a support capable of rotating at least 360° in XY axis, and 180° in Z axis.
- Antennas used in chambers are modified log periodic antennas which have a broad directivity, so close alignment tolerances are not significant. UUT & Measurement Antenna vertical positions must be aligned to a tolerance of +/-10cm.

4.2.2 Polarisation requirements

- Measures will be done in
  - Two polarisations (horizontal & vertical)
  - 360º spatial coverage
- Angular resolution for radiated measurements shall be of
  - 10° for transmitter power measurements

  30° in the theta plane, and 30° increments in the phi plane for receiver sensitivity measurements. This correlates to 72 (eg 6x12) sample points across the XY, YZ and XZ planes.

4.2.3 Temperature and humidity

Power source

The UUT shall be tested using an external DC power source (the Power Supply Unit). The normal test voltage for the equipment shall be the nominal voltage for which the equipment was designed.

Temperature & Humidity

The normal temperature and humidity conditions for tests shall be any convenient combination of temperature and humidity within the following ranges:

- Temperature: +15 °C to +35 °C
- Humidity: 20 % to 75 %

4.2.4 Frequencies to use for measurements

All measurements shall be carried out at 3 relevant frequencies for each band within the equipment's intended operating range: a “low frequency”, a “medium frequency” and a “high frequency”.

Values for these frequency reference points are detailed in the table below:

Radio Band	Bottom frequency	Middle frequency	Top frequency
HAN - 2.4GHz	2405	2440	2480

Radio Band	Bottom frequency	Middle frequency	Top frequency
HAN - Sub GHz (Band 1)	863.25	866.05	868.45
HAN - Sub GHz (Band 2)	869.05	871.05	872.85
HAN - Sub GHz (Band 3)	915.35	916.55	917.75

A recap of all ZigBee bands is provided in Annex A

4.2.5 Power

Measurements of TRP transmitter parameters shall be performed at the highest power level setting at which the transmitter is designed to operate or allowable under regulations in a production live environment.

4.2.6 Transmitter mode of operation

For the purpose of the measurements required, there should be a facility to operate the transmitter in an un-modulated state. The method of achieving an un-modulated carrier frequency, or special types of modulation patterns may also be decided by the provider and where applicable the test laboratory, the details of which modulation patterns shall be described and stated.

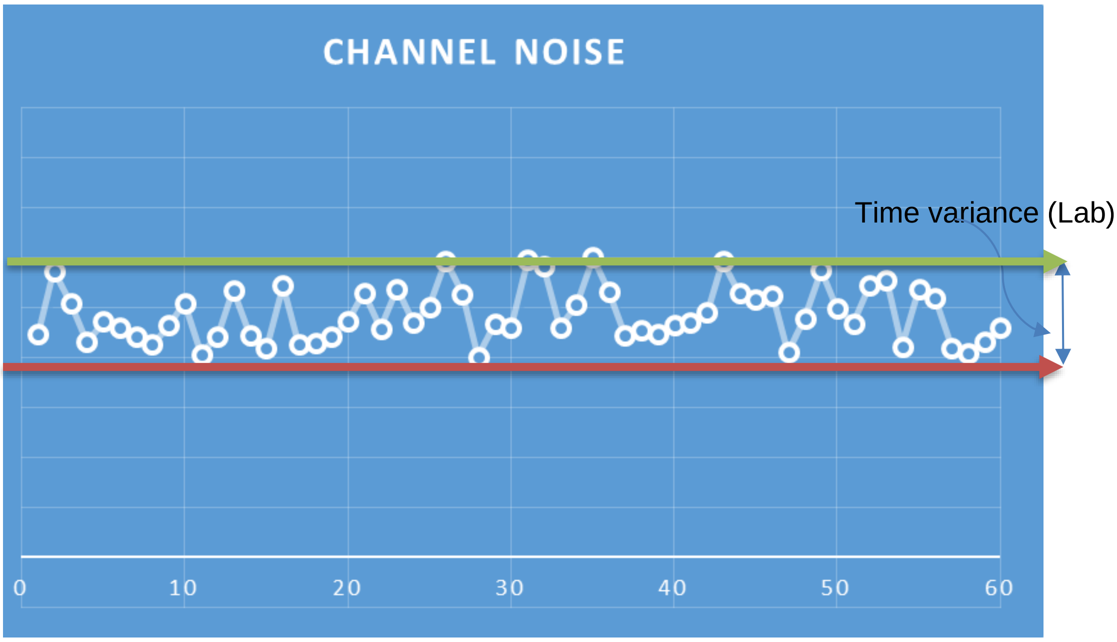
The CW/unmodulated pattern is the normal mode of test. If a modulated pattern in used, then having sufficient variation in the pattern helps identify when transmitted bits are missed. When using non-CW schemas, the DCC should be notified for approval.

4.3 Time variance of channel noise

The time variance of channel noise is measured to determine the measurement uncertainty of TRP and TRS measurements

1. Set spectrum analyser to have channel bandwidth equating to 300 kHz (Sub GHz channel width).
2. Set centre frequency to frequency under test.
3. Using calibrated source, transmit at reference power level of -97dBm
4. Record signal amplitudes for a period equating to 1 measurement for every 512 ZigBee data bits so about every 2.5ms. A minimum of 30 seconds elapsed time is required.
5. Median, min/max figures to be recorded
6. Median should equal reference power level, but max-min indicates noise level in channel

   Standard deviation of data set also recorded



The above channel noise is measured for each frequency used to determine TRP and TRS values. The graph above is only used for illustrative purposes, and does not represent real noise data, hence no values of parameters shown.

5 Test Descriptions

5.1 TRP

Definition

The total power transmitted by an antenna taking both vertical and horizontal isotropic power densities P_V and P_H (defined at a given distance from the source) into account is integrated over all angles as follows where both polarisations are added together.

$$TRP = \int_{-\pi}^{\pi}\int_{0}^{\pi}\left(P_V G_\theta(\theta,\phi) + P_H G_\theta(\theta,\phi)\right)\sin\theta \, d\theta d\phi$$

Equation [1]

To calculate TRP in real life, a sum is required of measured points rather than an integral. Therefore above can be represented by equation 2, where P_V represents the radiated power measured from a vertically polarised reference source, and P_H from a horizontally polarised source. The discrete approximation of this within 3GPP would then define TRP as;

$$TRP = \frac{\pi}{2NM}\sum_{n=0}^{N-1}\sum_{m=0}^{M-1}\left[P_H(\theta_n,\varphi_m) + P_V(\theta_n,\varphi_m)\right].\sin\theta_n$$

Equation [2]

The TRP requires an integral over the surface area of a sphere. To define this mathematically this requires a double integral. If you think of the sphere as the world this is integrated over 360 degrees round the equator and 180 degrees from the South Pole to the North Pole. As you move from the equator to the pole the circumference of the slice decreases. To account for this a Sin (θ) is used in the equation.

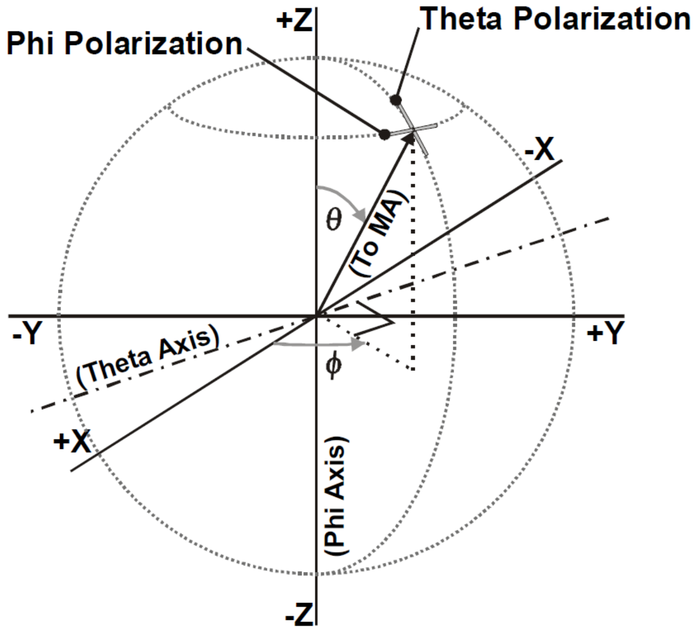


Figure 1 Relationship of Phi and Theta polarizations to measurement angles

The diagram above shows the relationship between elevation θ_n and azimuthal φ_m angles and xyz Cartesian planes.

Data is required at uniform angular intervals in theta and phi. There are N intervals theta (θ_n) from 0 to π radians, and M intervals in phi (φ_m) from 0 to 2π radians. N an M are chosen to reflect the correct angular intervals specified, in this case N =18, M= 36.

To avoid multiple measurements at the N/S points, sample points only need be recorded for N_i = 1 to N-1, and M_j = 0 to M-1. Thus no data is recorded at positions corresponding to θ_n = 0 and 180, nor at φ_m = 360, where the Sin value would be zero.

Therefore 612 discrete measurement points will be recorded for each polarisation. In total 1228 radiated power measurements will be taken.

The final measured distribution of radiated powers (a single point equating to the sum of the linear horizontal and vertical polarised powers, $P_H(\theta_n, \varphi_m) + P_V(\theta_n, \varphi_m)$ and then expressed in dBm) will be presented in a 3D graphical format, with the form factor representing a sphere as befits an isotropic antenna. Any nulls or lobes should be avoided, and these will result in a reduced calculated TRP figure. A point to note is that points plotted on the 3D graph are linear averages of horizontal and vertical polarised data, but the TRP figure calculated by equation 2 sums all the individual values rather than average values.

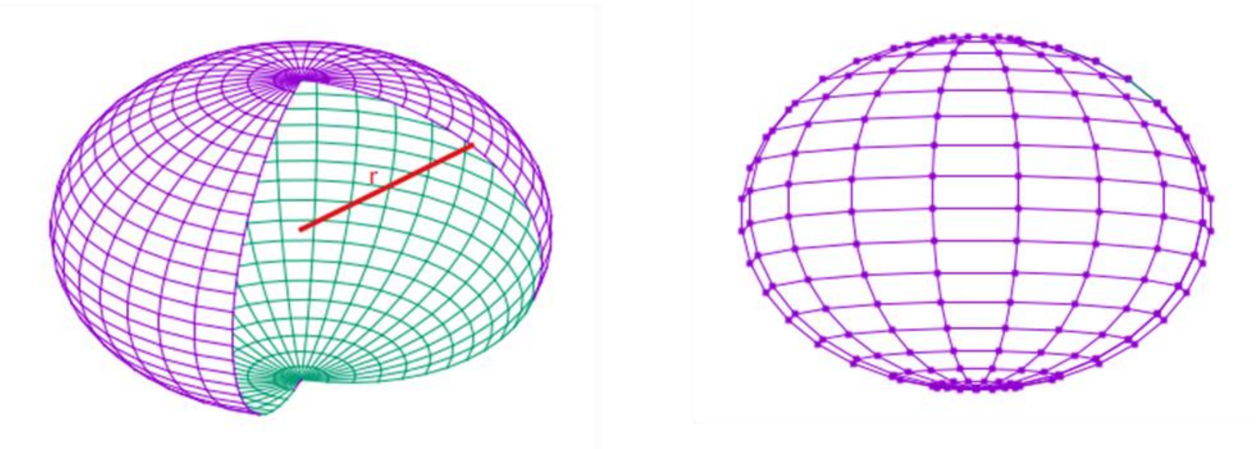


Figure 2 Figure 1 3D representations of TRP, format depending of plotting package

5.1.1 Layout

Test layout is detailed below, and is meant to represent all possible use cases independently of which SKU is concerned

- Interfaces that do not apply for this test are highlighted by a red cross

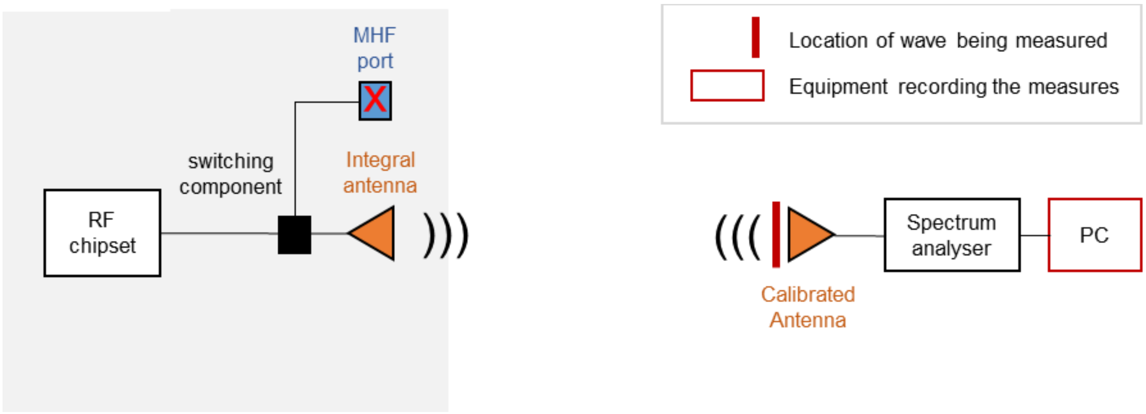


Figure 3 Test layout for TRP measurements

5.1.2 Procedure to measure TRP

All devices are setup according to layout, and measured using following procedures for each polarisation of the calibrated source/antenna.

1. All devices are setup according to layout
2. The UUT tested radio is set to continuously transmit
3. Power received by the Calibrated Antenna is measured while rotating the UUT accordingly
4. TRP value is calculated using equation [2] and documented in the Test Results document

5.2 TRS

5.2.1 Definition

The TRS is defined as a minimum threshold power that can be received, averaged over vertical (θ) and horizontal polarisations (φ). Test parties will refer to 3GPP 34.114 for further precisions on TRS definition.

3GPP 34.114 provides an approximation formula for the TRS which is as follows:

$$TRS = \frac{2NM}{\pi \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} \left[\frac{1}{EIS_{\theta}(\theta_n, \varphi_m)} + \frac{1}{EIS_{\varphi}(\theta_n, \varphi_m)} \right] \sin(\theta_n)}$$

Equation [3]

The above approximation formula can be used where measurements are made according to a uniform spherical mesh consisting of N layers along θ and M layers along φ. In addition and as stated in Section 3.2, the maximum angular resolution along both θ and φ that allows using this approximation formula in 3GPP 34.114 is 30°, which corresponds to N≥6 and M≥12. The EIS values in the formula are the Horizontal and Vertical components of the measured signal.

Should a non-uniform mesh be used or the angular resolution be higher than 30° (coarse uniform mesh), a more detailed approach is provided in Appendix F.

5.2.2 Layout

The test layout is detailed below, and is meant to represent all possible use cases. For clarification purposes:

1. Interfaces that do not apply for this test are highlighted by a red cross
2. The Signal Generator needed to generate ZigBee formatted messages will be provided to the test lab by the product vendor.

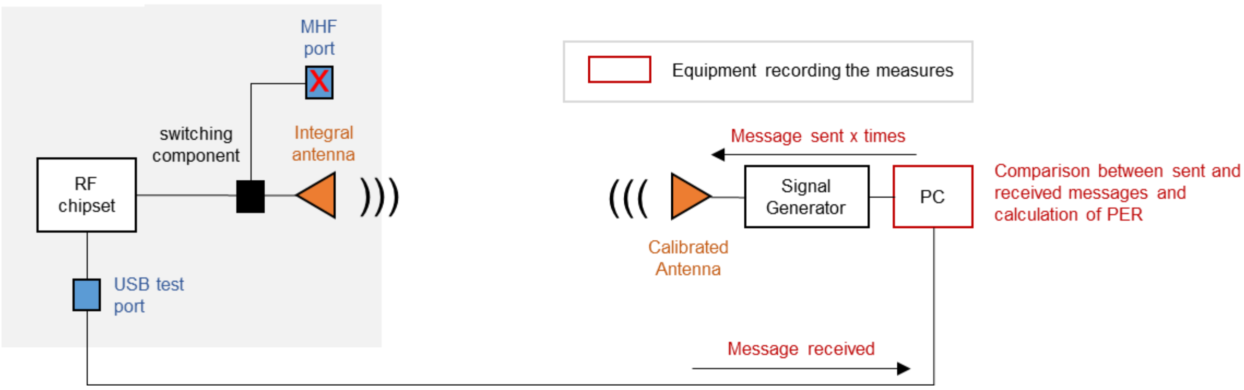


Figure 4 Test layout for TRS measurements

5.2.3 Procedure to measure TRS

All devices are setup according to layout, and measured using following procedures for each polarisation of the calibrated source/antenna.

1. A ZigBee formatted message is transmitted to the calibrated antenna for transmission to the UUT. (Transmitter equipment and antenna calibration certificates with any tolerances to be included in report.)
2. Message should be at least 512 bits long
3. Message should be repeated 1000 times for PER calculation
4. PC connected to the UUT compares the message received by the chipset to the transmitted version.
5. If errors are present to packets, the message is identified as corrupt and the Packet Error Count incremented by 1
6. On completion of 1000 packets transmitted, if packet error count is less than 10, a PER < 1% has been achieved.
7. If PER < 1%, then reduce the amplitude of the signal sent through the Calibrated Antenna and repeat from step 1
8. When PER ≥ 1%, the power is recorded and the UUT is moved to the next angular position where the measurement is repeated

When plotting the TRS values using a graphical format, each point should represent the inverse sum of the horizontal and vertical polarised data points, explicitly:

$$\frac{1}{EIS_{\theta}(\theta_n, \varphi_m)} + \frac{1}{EIS_{\varphi}(\theta_n, \varphi_m)}$$

6 Annex A: Sub GHz ZigBee bands recap

The channel numbering is defined in ZigBee documentation (14-0382) Annex D: MAC and PHY Sub-Layer Clarifications, European Sub-GHz FSK PHY Specification. Section D.12.2.1.3.1 defines the Channel Numbering;

Channel numbers are assigned as follows:

(ChanCenterFreq = ChanCenterFreq0 + NumChan * ChanSpacing)

where ChanCenterFreq0 is the first channel centre frequency in MHz, ChanSpacing is the separation between adjacent channels in MHz, and NumChan is the channel number from 0 to TotalNumChan–1.

For the 863 MHz - 876 MHz band

- TotalNumChan = 63
- ChanSpacing = 0.2
- NumChan goes from 0 to 62
- ChanCenterFreq0 = 863.25

For the 915 MHz - 921 MHz band

- TotalNumChan = 27
- ChanSpacing = 0.2
- NumChan goes from 0 to 26
- ChanCenterFreq0 = 915.35

Channel No:	868MHz Band	Channel No:	868MHz Band	Channel No:	915MHz Band
0	863,25	25	868,25	0	915,35
1	863,45	26	868,45	1	915,55
2	863,65	27	868,65	2	915,75
3	863,85	28	868,85	3	915,95
4	864,05	29	869,05	4	916,15
5	864,25	30	869,25	5	916,35
6	864,45	31	869,45	6	916,55
7	864,65	32	869,65	7	916,75
8	864,85	33	869,85	8	916,95
9	865,05	34	870,05	9	917,15
10	865,25	35	870,25	10	917,35
11	865,45	36	870,45	11	917,55
12	865,65	37	870,65	12	917,75
13	865,85	38	870,85		
14	866,05	39	871,05		
15	866,25	40	871,25		
16	866,45	41	871,45		
17	866,65	42	871,65		
18	866,85	43	871,85		
19	867,05	44	872,05		
20	867,25	45	872,25		
21	867,45	46	872,45		
22	867,65	47	872,65		
23	867,85	48	872,85		
24	868,05				

7 Annex B: DBCH sub GHz Success Criteria

Introduction

The RedM and Ofcom HAN trial reports provide equipment capability assumptions that are then used to assess HAN coverage. These values are a reflection of transmit power and receiver sensitivity and are usually quoted in units of dB, with transmit power being positive and receiver sensitivity negative. The RedM and Ofcom reports defined a variable called “Maximum Allowed Path Loss” that was a measure of the conducted transmit power, conducted receiver sensitivity, equipment losses and planning margin. Conducted transmit power and conducted receiver sensitivity are a measure of performance as measured from the radio chip via a wired connection as opposed to from the device containing the radio chip via wireless connection. MAPLs calculated on this basis were used for HAN coverage modelling, and were derived as follows:

- 2.4GHz – conducted MAPL 103dB [transmit 10dB, receive -93dB]; losses 2 lots of 2dB (antenna gain); planning margin 10dB; so MAPL = 103dB-4dB-10dB=89dB (this is the value used in the RedM model to derive 70% HAN coverage)
- Sub GHz – conducted MAPL 120dB [transmit 14dB, receive -96dB]; losses 2 lots of 3dB (antenna gain); planning margin 10dB (8.6dB fading, plus 1.4dB other losses); so MAPL=120dB-6dB-10dB=104dB (this is the value that was used in the Ofcom report to derive 96.5% HAN coverage)

Recent work by DCC and BEIS to clarify MAPL values and how to assure them has redefined the calculation of MAPL such that it excludes the planning margin. The MAPLs described in JTM (v3.0 and later) are now given as: >=99dB (2.4GHz) and >= 108dB (Sub GHz). This means that for HAN coverage modelling a planning margin of 10dB for 2.4GHz and 8.6dB for Sub GHz needs to be subtracted from the MAPL values in JTM. The 10dB planning margin for Sub GHz was adjusted to 8.6dB on the basis of the fading measurements taken as part of the Ofcom trial. Further details of HAN coverage modelling methodology can be found in the RedM and Ofcom HAN trial reports.

Sub GHz HAN Performance Success Criteria

Within the Ofcom report the acronym MAPL has been used for Mean Average Path Loss. The more usual use of this term is for Maximum Achievable Path Loss. The former implies that a margin is required for fading. The latter is the difference between the TRP and the TRS, and is the correct reference for lab based measurements;

MAPL ≥ 108 dB
MAPL = TRP-TRS

The above is the acceptance criteria and will be evidenced by test report indicating achieved TRP and TRS values. All the performance targets above are inclusive of manufacturing tolerances.

As guidance, the expected individual TRS and TRP levels are shown below. Whilst individually part of a success criteria, it is important to achieve a good balance as if a UUT has exceptional good TRS, but poor TRP then the unit would be able to hear commands sent to it, but the sending unit would never receive the response or expected data.

Note that the individual TRP and TRS limits may not add up to the overall MAPL requirement above. For DBCH units, the exact TRP and TRS measured values will be available in the Communication Hub Data Sheets available via DCC.

$$TRP \geq 9\ dBm$$

$$TRS \leq -97\ dBm$$

Note that these values are included for guidance to ensure that all units in a HAN can interoperate correctly. If HAN units diverge from these values to a great extent, then in installations when units are at the extreme of range, there is a possibility that one unit can only hear but not be heard, or vici versa.

For Dual Band Communication Hubs (DBCH), the units deployed in South and Central regions do not have a success criteria attributed for the 915-921 MHz band due to isolation needed between the HAN and the WAN cellular radio impacting the RF properties.

2.4 GHz Performance Success Criteria

Compared to single band HAN devices, there should be no quantifiable degradation in the 2.4 GHz performance parameters being measured for the UUT.

$$\boxed{\begin{array}{c} MAPL \geq 99\ dB \\ MAPL = TRP\text{-}TRS \end{array}}$$

The above is the acceptance criteria and will be evidenced by test report indicating achieved TRP and TRS values.

The MAPL 99dB figure has been obtained from the BEIS coverage model outlined in the introduction to this Annex, and aligns with existing datasheets for SB units Values have been included in this document to ensure there is no reduction in performance from DB to SB.

As guidance, the expected individual TRS and TRP levels are shown below

$$\text{TRP} \geq 3.5 \text{ dBm}$$

$$\text{TRS} \leq -95 \text{ dBm with PER} < 1\%$$

Note that these values are included for guidance to ensure that all units in a HAN can interoperate correctly. If HAN units diverge from these values to a great extent, then in installations when units are at the extreme of range, there is a possibility that one unit can only hear but not be heard, or vici versa.

8 Annex C: JTM Requirements and Relationship to Ofcom

Analysis: Ofcom Smart Meter HAN 868MHz RF Coverage Campaign report

In order to define a methodology with repeatable results that meets the Joint Test Methodology (JTM) requirements, the outcome of the Ofcom report requires further technical analysis to define radio performance parameters suitable for testing in a laboratory environment that can be equated to the Ofcom conclusions.

Analysis

The Ofcom report derived the path loss (due to slow/fast fading) from field measurements and by statistically modelling to determine "in-door" range and "outdoor" range for Low power Sub GHz radio bands, but confined to a single frequency channel namely 869.4-869.65 MHz.

Methodology

This comprised of a calibrated transmitted continuous wave (CW) signal source and signal fade measurements taken at a number of locations within each multiple dwelling unit (MDU) building using a spectrum analyser and antenna, mounted on a purpose fabricated rotating arm tripod.

16 MDUs were visited with an average of 20 link measurements carried out for each site.

In addition signal coverage range measurement were undertaken at the 5 larger MDU sites to determine the potential distance an 868MHz signal can travel in the environment around an MDU in order to assess the interference implications.

Derivations

1. Communication Hub should be transmitting at max 14dBm (25mW) and should achieve path loss of 104dB (+8.6dB fast fade margin to reflect the tolerance to real life HAN installation radio and propagation condition for maintenance of reliable communication link between CH and end devices). A fuller derivation of the 104dB requirement is outlined in the BEIS commentary section at the end of this Annex.
2. Path loss shall be measured between the devices antennas and no internal DBCH losses or other factors (e.g. planning margins) can be included in the link budget.
3. Maximum transmit power of 25mW as stated in CHTS applies to power from communication hub antennas in compliance with Ofcom's IR2030. This requirement further refines transmit power as a maximum effective radiated power (ERP). As ERP is the maximum power in any one direction for a dipole antenna, the maximum TRP levels that can be supported with an isotropic antenna will be lower by 2.15dBm.

BEIS Commentary

The RedM and Ofcom HAN trial reports provide equipment capability assumptions that are then used to assess HAN coverage. These values are a reflection of transmit power and receiver sensitivity and are usually quoted in units of dB, with transmit power being positive and receiver sensitivity negative. The RedM and Ofcom reports defined a variable called “Maximum Allowed Path Loss” that was a measure of the conducted transmit power, conducted receiver sensitivity, equipment losses and planning margin. Conducted transmit power and conducted receiver sensitivity are a measure of performance as measured from the radio chip via a wired connection as opposed to from the device containing the radio chip via wireless connection. MAPLs calculated on this basis were used for HAN coverage modelling, and were derived as follows:

- 2.4GHz – conducted MAPL 103dB [transmit 10dB, receive -93dB]; losses 2 lots of 2dB (antenna gain); planning margin 10dB; so MAPL = 103dB-4dB-10dB=89dB (this is the value used in the RedM model to derive 70% HAN coverage)
- Sub GHz – conducted MAPL 120dB [transmit 14dB, receive -96dB]; losses 2 lots of 3dB (antenna gain); planning margin 10dB (8.6dB fading, plus 1.4dB other losses); so MAPL=120dB-6dB-10dB=104dB (this is the value that was used in the Ofcom report to derive 96.5% HAN coverage)

Recent work by DCC and BEIS to clarify MAPL values and how to assure them has redefined the calculation of MAPL such that it excludes the planning margin.

The MAPLs described in JTM (v3.0 and later) are now given as:

- ≥99dB (2.4GHz) [see section 2.4 GHZ PERFORMANCE SUCCESS CRITERIA in Annex B]
- ≥108dB (Sub GHz). [see section SUB GHZ HAN PERFORMANCE SUCCESS CRITERIA in Annex B].

This means that for HAN coverage modelling a planning margin of 10dB for 2.4GHz and 8.6dB for Sub GHz needs to be subtracted from the MAPL values in JTM. The 10dB planning margin for Sub GHz was adjusted to 8.6dB on the basis of the fading measurements taken as part of the Ofcom trial. Further details of HAN coverage modelling methodology can be found in the RedM and Ofcom HAN trial reports.

9 Annex D: Test Report Structure

Note that while the measured values are based on standard tests, the requirements for using ZigBee protocols, and a high degree of automation in the measurement of TRP and TRS will restrict the candidate list of suitable independent test houses.

Various manufacturers in the Smart Metering environment have facilities within their labs that provide this level of automation and with suitable ZigBee test equipment, but are not classed as independent.

Device Type	
Manufacturer	
Model Number	
Date of test	
Test House	
Credentials (eg ISO9001, ISO 14001, ZigBee approved, ISO 17025)	
RF Equipment, serial numbers, calibration dates	
Temperature	
Humidity	
Calibration of transmitter power (and tolerances)	

Graphical outputs

TRP and TRS – Spheres with points evenly distributed. Examples shown below, but exact format dependent on graphical platform supported by test house.

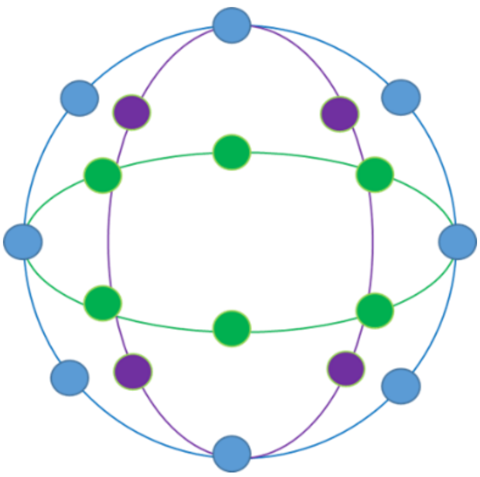


Figure 5 3D TRS polar plot

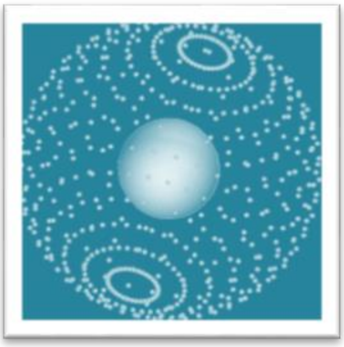
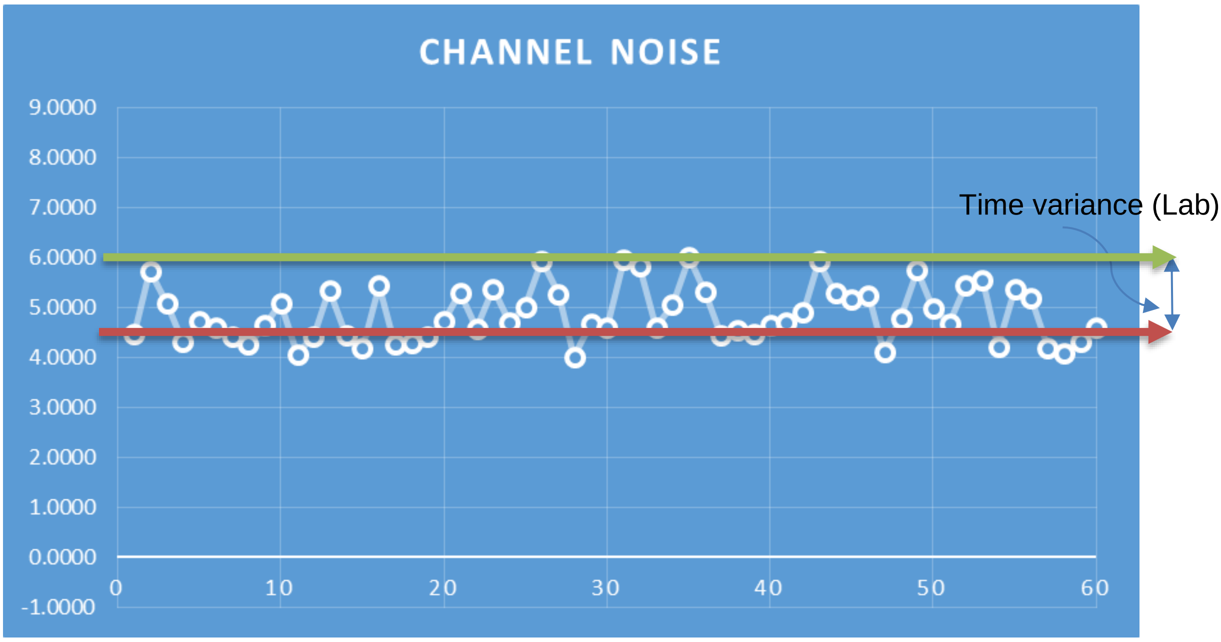


Figure 6 3D TRP polar plot using discrete data points.

- One TRS and one TRP graph for the middle frequency in each required frequency band; 8 in total.
- Graph of temporal signal noise levels (if available in selected test house)
- 1 graph with line graph for middle measurement in each band



In the above example the channel noise for Channel X would be;

Channel Noise	Ch X
Median	4.7dBm
Min	4.01dBm
Max	6.00dBm
Noise (lab) Max-Median	1.30dBm
Standard deviation	0.55

Data;

Excel file of recorded data.

Tables of TRP, TRS, MAPL, noise median, delta noise values for each frequency

Harmonic average for channel noise across all frequencies.

MAPL = (TRP – TRS) ± (Harmonic noise average)

10 Annex E Addendum Real Life Testing Methodology - Validating Smart Metering HAN Device Propagation Performance in Real Life Environments

This Methodology is included as an addendum to JTM in order that the documents are held as a set.

The document was authored by BEIS and reviewed by DCC, CSPs and via TBDG 868 Sub Group. The version included in this addendum is Version 1.1 dated 16th March 18. Review history and approvals is shown in the original document.

10.1 Introduction

This document is based on the real life testing methodology that was originally developed as part of real life dual band communications hub testing (Sub GHz) in July/ August 2017. Subsequent discussions between BEIS, DCC, CSPs, communications hub manufacturers and iWireless highlighted the need to refine and reinforce some aspects of this methodology, principally:

- Broadening the scope to allow testing of other devices and not just communications hubs
- Clarifying how MAPL is calculated from the measurements
- Clarifying the need for repeatable test environments

This document sets out the objectives, approach and reporting for Real Life Testing of Han devices at 2.4GHz and Sub GHz.

Test Objectives

- To quantify the signal levels (in dB) at which the HAN device fails to operate at the required performance level (PER 1%)
- To link the measured signal levels using CW with those reported by the HAN device (eg RSSI)

The measurement approach is to perform the same two measurement methods at each location: (1) continuous wave using calibrated antennas and test equipment; and (2) RSSI and PER using HAN devices.

This measurement data can then be used to compare with results from JTM (joint test methodology, a lab based technique) and also as an input for HAN coverage modelling.

It is important to note that these measurement approaches will capture the maximum envelope of performance of a HAN device (in dB) in a real life environment. They will not capture the effects of things such as interference. HAN coverage modelling can be used to make allowance for these effects through use of planning margins.

The measurement approaches are based on industry standard measurements based on CW, RSSI and PER.

10.2 Definitions

10.2.1 Symbols

BWCHAN	Channel Bandwidth
dBm	dB relative to 1 milliwatt
dBr	dB relative to peak power
dBW	dB relative to 1 watt
GHz	gigahertz

Hz	hertz
kHz	kilohertz
MHz	megahertz
mW	milliwatt
ms	millisecond
P_H (P_V)	Radiated output power measured using a horizontal (vertical) polarised antenna
EIS_H (EIS_V)	Radiated sensitivity of horizontally (vertically) polarised radiated power

10.2.2 Acronyms

ERP	Effective Radiated Power
JTM	Joint Test Methodology
RLTM	Real Life Test Methodology
DBCH	Dual Band Communications Hub
HAN	Home area network
TRP	Total Radiated Power
TRS	Total Radiated Sensitivity
MAPL	Maximum Achievable Path Loss
MCWPL	Median Continuous Wave Path Loss
ETSI	European Telecommunications Standards Institute
CSP	Communication Service Provider
PER	Packet Error Rate
MHF	RF port similar to uFL but not under protected patent
UUT	Unit under Test
RSSI	Received Signal Strength Indication

CW	Continuous Wave
RF	Radio Frequency

10.3 Document Purpose

The Real Life Testing Methodology (RLTM) document is to provide:

1. An overview of measurements to be performed
2. The methodology for measurements
3. The methodology to calculate MAPL

10.3.1 Overview of Measurements

The following measurements (with supporting rationale) are required:

- Continuous wave (CW) measurement of signal strength
    - Used to derive a calibrated value of pathloss which is used to determine MAPL from other measured values
- CW measurement of received signal strength time variance
    - Short and long sample intervals provide information on signal variation that can be used when comparing MAPL values to those measured using JTM
- Unit under test (UUT) measurement of received signal strength indication (RSSI) and packet error rate (PER)
    - These values are required to determine MAPL for the UUT

10.3.2 Measurement methodology

The methodologies can be found in the following sections:

- CW pathloss and time variance – Annex RA
- UUT – Annex RB

10.3.3 Calculation of MAPL

This can be found in Section 10.4.

10.4 HAN Radio Testing Methodology

The following radio solutions will be tested, when applicable (i.e. when present in the UUT)

- 2.4 GHz band
- Sub-GHz band

- 863 – 870 MHz
- 870 – 876 MHz
- 915 – 921 MHz

The Sub-GHz bands are presented here as detailed in ZigBee specifications. However, the UUT (DBCH, meters and other HAN devices) will not implement all the channels in these bands. Consequently, testing will be done based on the list of channels to be used detailed in Annex RC.

10.4.1 General test conditions

10.4.1.1 Test Environment

The test environment should as far as possible be a building with the following characteristics:

- restricted public access (to minimise variability in measurement results)
- minimum WiFi activity if possible (to minimise time spent finding suitable measurement locations)
- absence of unusual RF activity (eg building should NOT be an RF test lab, or a building where RF testing is undertaken) (to minimise time spent finding suitable measurement locations)
- limited scope for changes to RF environment during testing (to minimise time spent finding suitable measurement locations)
- ability to clearly define and revisit test locations (in case there are anomalies that require revisit)
- limited scope for doors and windows to be frequently opened/ closed while measurements are undertaken (to minimise variability in measurement results)
- minimum human activity/ footfall (to minimise variability in measurement results)

For the avoidance of doubt, open locations such as fields etc. are not suitable test environments. In addition, buildings under construction should be avoided. The fabric and construction of the building is not important so long as suitable path loss values (commensurate with the MAPL of the HAN device) can be achieved.

The environmental conditions should be recorded (e.g. Temperature, Humidity and Pressure values as well as general weather conditions) for each of the above bullets for further consideration should any concerns be raised after the tests are completed and analysed

10.4.1.2 Frequencies to use for measurements

Where possible, subject to local interference conditions, one of the following frequencies should be used. Where possible the quietest channel should be as close as possible to one of those used in JTM testing. This assumes that both test devices have the capability to select the specific channels.

Radio Band	Bottom frequency (MHz)	Middle frequency (MHz)	Top frequency (MHz)
HAN - 2.4GHz	Single channel only,		

HAN - Sub GHz (Band 1)	863.25	866.05	868.45
HAN - Sub GHz (Band 2)	869.05	871.05	872.85
HAN - Sub GHz (Band 3)	915.35	916.55	917.75

10.4.1.3 Power

Measurements shall be performed at the highest power level setting at which the transmitter is designed to operate in a production live environment. For Sub GHz HAN ZigBee devices consideration should be given to how any automatic power control (a feature of ZigBee) affects the ability to set the highest power level.

10.4.2 CW and UUT tests

For each Rx location the following test sequence should be executed:

- CW time variance test (long sample period)
- CW pathloss measurement
- UUT pathloss measurement
- CW time variance test
- CW time variance test (short sample period)

Please refer to annexes RA and RB for detail on the above measurements. At least 5 measurements (corresponding to 5 different locations) that are suitably spaced on the relevant curves (see Section 5) should be recorded. It is important to note that it may be necessary to measure 2-3 locations to record one of these 5 suitably spaced measurements, and time should be allowed for this. In practice this means that 10-15 locations may need to be measured.

10.4.3 Prerequisites

The following are recommended before undertaking RLTM:

- JTM 3.0 Tx test measurements
- JTM 3.0 Rx test measurements + Calibrated RSSI
- PER and RSSI per packet debug capability from the Rx UUT

10.5 Calculating UUT MAPL

10.5.1 Overview

Two methods can be used to derive MAPL:

- Method 1 - Coarse – gives a coarse indication of MAPL (but which may differ by a few dB from MAPL measured by JTM)
- Method 2 – Fine – gives a fine indication of MAPL

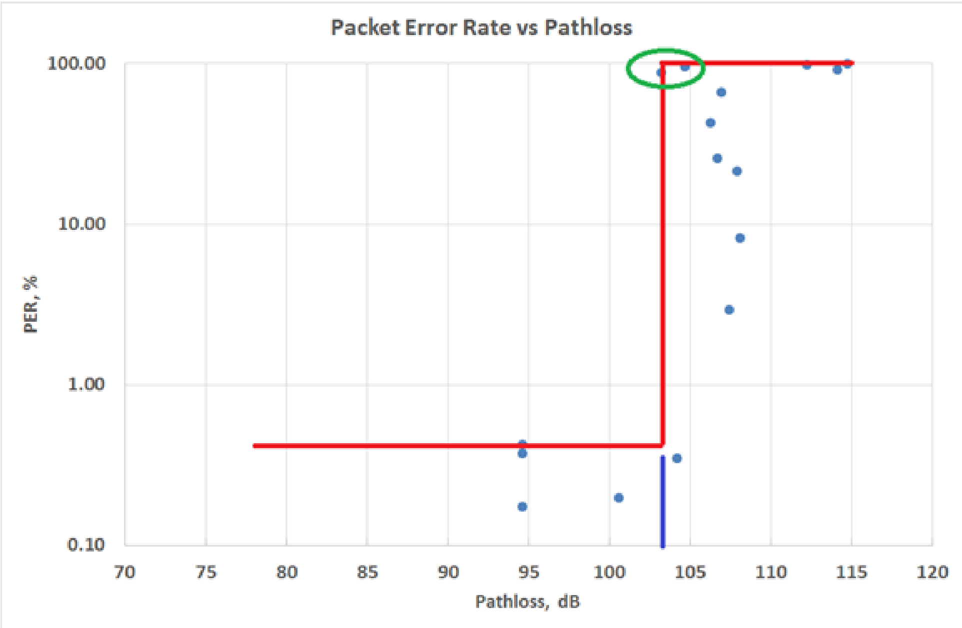
These methods are described in greater detail below. The coarse test can be used where the analysis tools to undertake the Fine method are not available, or where a potentially larger deviation from JTM results is acceptable.

10.5.2 Method 1 - Coarse

The steps are as follows:

- Plot PER against CW path loss
- Find the CW path loss value that corresponds to PER < 1% using best fit curve if there are sufficient data points. If there are insufficient data points a worst case envelope curve approach should be used.

It is generally not possible to do a regression based "best fit" as the number of measurement points is too few. Instead a manual worst case envelope approach should be adopted, as shown below deduce MAPL (as per the blue vertical line below). Noting the transition from 0% to 100% PER and therefore across the 1% PER threshold can be as little as 2-3dB (see section 5.3) then the uncertainty in the MAPL value could also be a few dB. A 1% PER threshold is commensurate with a reliable communications link, and is an industry norm.



10.5.3 Method 2 - Fine[1]

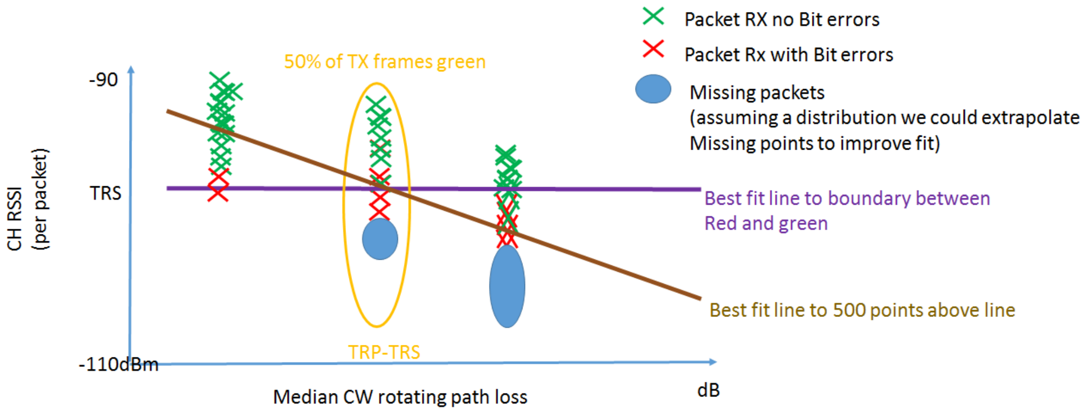
Referring to the diagram below, the steps are as follows:

- Plot UUT RSSI values against CW path loss
- Plot a line through the RSSI clusters corresponding to the midpoint of the cloud
    - Each cloud (vertical set of points) corresponds to a measurement run with the UUT (eg rotating the UUT at a given location as per Annex RB)
- Find the point on the line that corresponds to 50% PER, and read off the path loss which is the MAPL

[1] This is a new analysis technique and it may be necessary to update this document once practical experience has been gained. Those undertaking these tests are encouraged to share suggested improvements with DCC.

o Where possible a mathematical tool should be considered to undertake this analysis

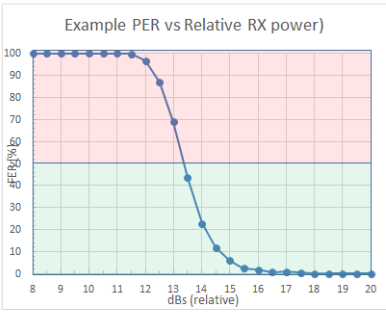
Presentation of data : 2
RSSI vs Median CW path loss (rotating CH)

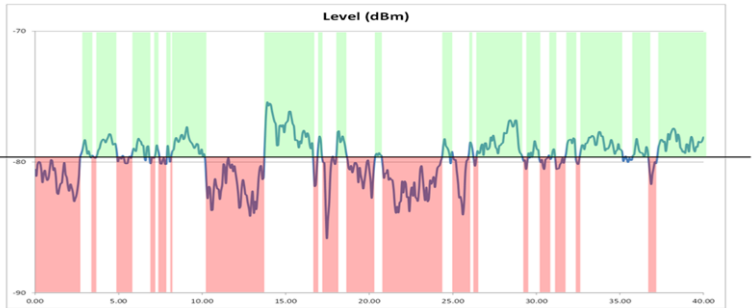


The rationale for this measurement is given below. As can be seen from the plot on the left below PER goes from 0 to 100% in a 2-3dB interval. As such, picking the PER 50% is a safer indicator of MAPL.

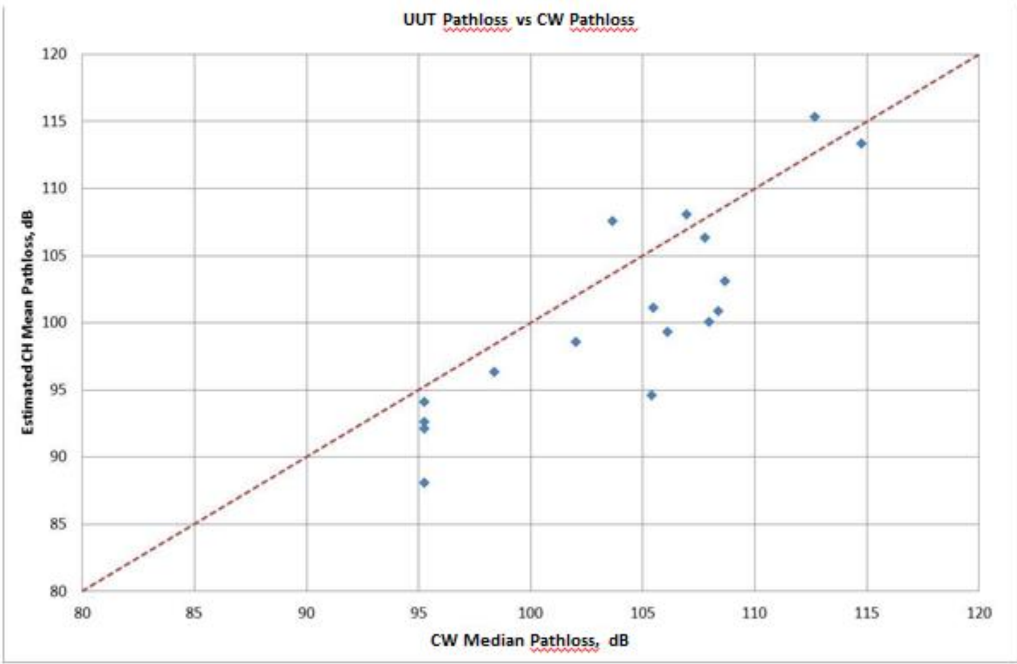
Expected performance at MCWPL = MAPL (information only)

- As the MCWPL is a median half the point will be above and half below the median due to time variance.
- Best achievable PER is 50%





In addition, the following UUT RSSI vs CW path loss plot should be generated:



10.6 Annex RA: CW Testing Methodology

Two sets of equipment are used: a transmitter at one end and a receive system at the other end. This section provides an overview of the test equipment and how the measurements are obtained. All test equipment should be chosen with the expected UUT receiver sensitivity in mind. In addition, tolerances of test equipment should be quoted in any test reports.

Test equipment calibration status should be noted and it is also good practice to confirm test equipment calibration before and after field tests.

10.6.1 *In situ* Validation of the CW Transmitter – conductive test

At the start of each day of testing and before measurements are recorded, the test engineer performs a quick validation of the transmitter to ensure that the correct signal levels are transmitted and that no damage to the equipment (cable, amplifier) had occurred during transit. Sufficient time should be allowed for the test equipment to warm up unless it has been proven to be temperature stabilised.

This test is a conductive test as illustrated in **Figure 5** and consists of connecting the transmitter to the receiver via the actual test cables (and inclusion of a 30dB attenuator pad to prevent damage to the spectrum analyser) and determining whether the settings on the Signal Generator have remained as expected.

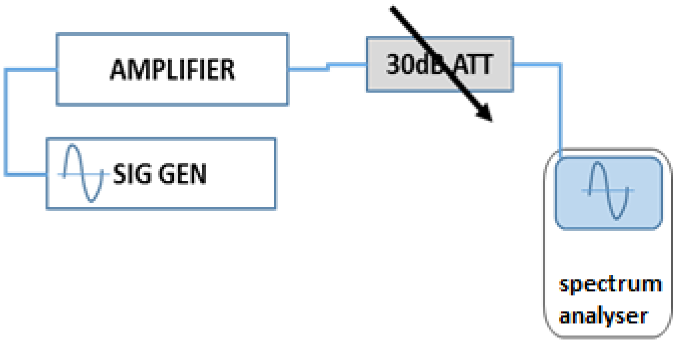


Figure 5 Test setup during the in situ TX validation

10.6.2 *In situ* Validation of the Full CW System – short distance test

The conductive test above will have established that the transmitter is operating at the specified power and frequency. The next validation is to establish that the full system is working as expected – including the antennas and the feeder at the RX end. Rotation of the arm may also be needed for accurate equipment validation.

In order to run this test, both transmitter and receiver are placed within a short distance of each other (approximately 2m-3m) as illustrated in Figure 6.

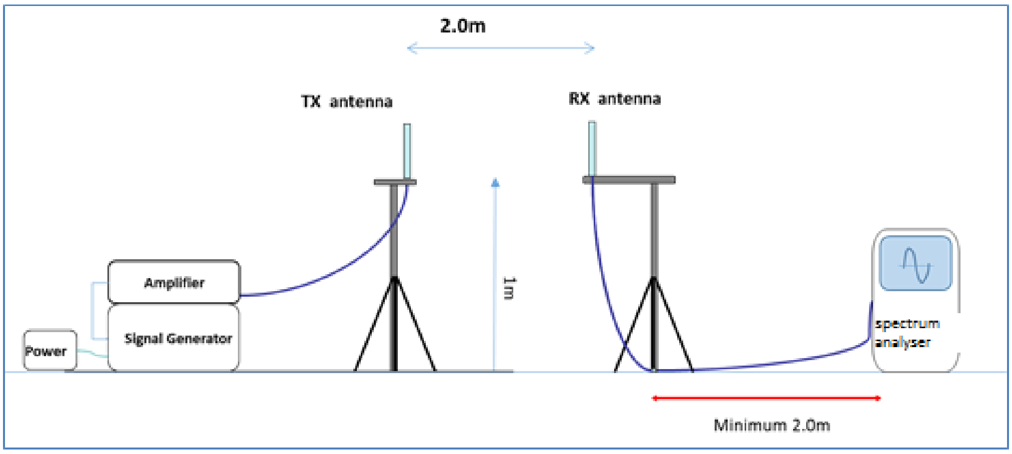


Figure 6 Test setup during the full system validation

Once this test is completed and the engineer is satisfied that the levels measured at the spectrum analyser are as expected, the system is kept connected and moved by the engineers to the various locations within the survey site.

Determining the optimum location for the RX UUT involves an element of trial and error. In order to collect good quality data for analysis It is suggested to carry out a number of trial runs to determine the location at which the PER is just starting to increase from 0%. Tests should then be conducted at or around this location. A further two tests should also be conducted initially with the UUT approximately 1 to 2 metres nearer the TX UUT and the second where the UUT is approximately 1 to 2 metres further away from the TX UUT.

10.6.3 Doing the CW Measurements

10.6.3.1 Searching for quietest channel for Testing

A continuous spectrum scan is recorded (with a Max Hold trace display) during a walk around the location. At the end of the walk, a decision is taken about which frequency to test based on finding a quiet area of the spectrum. The noise level at the location on the chosen channel should be recorded. At occasional intervals during the day of testing, further scans are performed to identify any new radio activity in the band. After the noise is measured and before the location for the test it is confirmed it is advisable to carry out a dry run to confirm that this is the optimum location for the PER tests - see B1.2 Location of Rx UUT

10.6.3.2 Setting up the Transmitter

Figure 7 shows how the transmitter is setup.

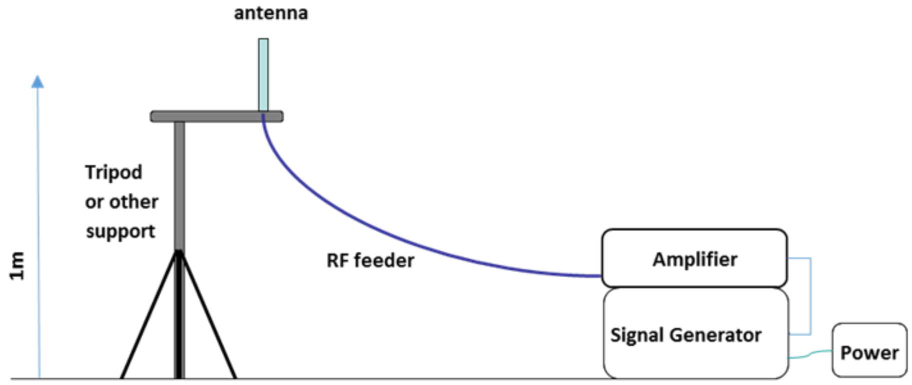


Figure 7: TX setup using a tripod [Change the height to 1m]

Both transmitter and receiver are setup at a height of 1m above ground.

10.6.3.3 Setting up the Receiver

A spectrum analyser is used to record the variations in signal strength whilst the antenna is rotated around the tripod's rotation point as illustrated in Figure 8. The antenna should be mounted 0.5m from the midpoint (e.g. 1m diameter swept area) and this is the same for 2.4GHz and Sub GHz testing. The spectrum analyser will be set on zero span so that the time trace can be captured at the test frequency. The measurement lasts for 40 seconds.

Figure 8: Equipment Configuration of Receiver setup

To limit the effect of body loss on the total path loss, the engineers should stand back at least 2m from the receive antenna whilst the test is being performed. All fire, escape, cabinets or storage room doors etc between the TX and RX should be closed to ensure maximum signal attenuation is recorded between the two ends of the link.

During the 40 second measurement, the receive antenna is rotated around the tripod axis to capture for signal fades at the test location. To produce movement of the antenna, the mount on top of the tripod is designed in such a way that it can be rotated through 360 degrees by the engineer by way of a long cord. The antenna is thus rotated at a constant pace over the test period.

10.6.3.4 Antenna Height

Antennas at both terminals were mounted on a support structure at a nominal 1m (at base of antenna) from the ground.

10.6.3.5 Polarisation

Both TX and RX antenna should be omni-directional dipole antennas and were kept vertical throughout the testing regardless of which floors they were on.

10.6.4 Converting Received Signal strength into transmission pathloss

The measurements are carried out using an unmodulated Continuous Wave signal (CW) The received signal levels are subsequently converted into basic transmission pathloss (dB) between the transmitter and the receiver end points using the following parameters during the conversion:

Parameter	**Symbol**	**Example Value**	**Origin**
Transmit Power	Ptx	-12.2dB	Signal Generator setting
Amplifier gain	$AMPtx$	38.8dB	Measured during validation
Received Power	Prx	Variable	Measured
Transmitter feeder loss	$LFtx$	2.4dB	Lab measured
Receiver feeder loss	$LFrx$	1.5dB	Lab measured
Antenna gains	Gtx	1.24dBi	Manufacturer spec (Appendix B)
RX antenna gain	Grx	1.24dBi	Manufacturer spec (Appendix B)

Table 1- Measurement equipment parameters that should be captured, with example values

The basic formula used to convert received signal strength to pathloss L is:

$$L = (Ptx + AMPtx + Gtx - LFtx) - (Prx - Grx + LFrx)$$

Note that the combined terms for the transmit power are validated at the start of the testing and small adjustments are sometimes made to the signal generator power in order to keep the total transmit power consistent throughout all of the sites. Median values should be used

10.6.5 Target pathloss

Since pathloss is not a directly measurable quantity, engineers will need to use trial and error to find locations corresponding to the target pathloss (JTM derived MAPL for the UUT). The locations are then refined by adjusting the position of the receiver nearer or further away from the TX location so that the target pathloss is attained (once the received signal strength data was processed using the formula in (1) above).

Despite best effort, and due to the nature of RF propagation in an indoor environment being difficult to predict, finding the locations that produce the target pathloss is not always a simple task.

10.6.6 Time Variance Measurement

For each measurement location the following time variance measurements should be taken for Sub GHz:

- To set 10 micro second samples gives a sweep time of approximately 5 milliseconds. To set 5 millisecond samples gives a sweep time of approximately 3 seconds. A sweep time of 1 minute gives approximately 100 millisecond samples. So sweep lengths of 5 milliseconds, 3 seconds and 1 minute should be considered
- ZigBee Bit Rate (100Kb/s) = 1 point every 10uS per point
- ZigBee packet Rate (100kb/s x 512 bits) = 5.12mS per point
- Long term : 1 minute sweep (1001 points) = 60mS per point
- RWB = 300Khz, VBW = 300Khz, Span = 0Hz
- Sweep time : maximum supported by analyser for 1 point at required time interval.

These time values should be divided by 2.5 for 2.4GHz testing and measurement bandwidth increased as appropriate.

10.6.7 Time variance of channel noise

If it is suspected that other channel activity or noise will alter the results then additional information should be recorded. This could be a repeat of the measurements in section '1.6 Time Variance Measurement' but without the CW transmitter active or other suitable plots to show band activity.

10.7 Annex RB: UUT Testing Methodology

This methodology assumes that CW testing is happening in parallel, and as such the requirement to take noise measurements is not required.

10.7.1 Location of Tx UUT

One UUT is located in the same location as the CW Tx. It should be located at 1m above ground level (the same as the CW Tx antenna).

10.7.2 Location of Rx UUT

The UUT is attached to the arm on the tripod at the opposite end the CW antenna is located at such that it too is 0.5m from the midpoint (this allows a rotation to go through at least 2 wavelengths in linear distance and avoids interaction between the UUT antenna and CW antenna). The UUT should be mountable/ demountable in a repeatable way, ideally through some form of cradle. Use of gaffer tape, cable ties etc on their own is not recommended

- Consideration of the effect of mass of the UUT on the tripod arrangement should also be considered.
- Consideration of cable management is important, as it is necessary to sweep the UUT through at least 360 degrees. Ideally any cables would be fed to the UUT through the centre of the tripod
- Power and communications cable shall be filtered to minimise RF retransmission, optical connection where possible

10.7.3 UUT Settings

The following ZigBee setting should be used for the UUT:

- Message Size – 512 bits

10.7.4 UUT Measurement

The UUT should be rotated on the tripod such that approximately one rotation equates to 1000 packets.

More specifically for dynamic measurements (eg rotating the UUT):

- Static Tx UUT should be positioned with nominal Tx antenna pointing towards Rx UUT.
- Measurement period = 200 seconds (1000 packets at 5 per second= 200 seconds)
- Rotation Speed, ideal should be approximately 40 seconds to match the CW measurements. It may need to be slower to accommodate cables wrapping round the tripod (or could slow CW measurement)
- The following values should be recorded:
  - PER (One value per 1000 packets)
  - RSSI (Up to 1000 values [only for packets received])

In addition the following static measurements are taken:

- 4 positions on Boom (UUT fixed) so 4 orientations, same positions as used for the 4 time variance plots.
- Measure PER + RSSI over 1000 frames for each position.

To limit the effect of body loss on the total path loss, the engineers should stand back at least 2m from the receive antenna whilst the test is being performed. All fire, escape, cabinets or storage room doors etc between the TX and RX should be closed to ensure maximum signal attenuation is recorded between the two ends of the link.

10.8 Annex RC: Sub GHz ZigBee bands recap

The channel numbering is defined in (14-0382). There are several obsolete documents on the subject in the ZigBee Alliance repository this therefore reference and subject change.

1. Powell, C. (14-0382). GB 868 PHY/MAC Technical Specification – Draft
2. Powell, C. (14-0383). Channel Numbering for GB PHY

Channel No:	868MHz Band	Channel No:	868MHz Band	Channel No:	915MHz Band
0	863,25	25	868,25	0	915,35
1	863,45	26	868,45	1	915,55
2	863,65	27	868,65	2	915,75
3	863,85	28	868,85	3	915,95
4	864,05	29	869,05	4	916,15
5	864,25	30	869,25	5	916,35
6	864,45	31	869,45	6	916,55
7	864,65	32	869,65	7	916,75
8	864,85	33	869,85	8	916,95
9	865,05	34	870,05	9	917,15
10	865,25	35	870,25	10	917,35
11	865,45	36	870,45	11	917,55
12	865,65	37	870,65	12	917,75
13	865,85	38	870,85		
14	866,05	39	871,05		
15	866,25	40	871,25		
16	866,45	41	871,45		
17	866,65	42	871,65		
18	866,85	43	871,85		
19	867,05	44	872,05		
20	867,25	45	872,25		
21	867,45	46	872,45		
22	867,65	47	872,65		
23	867,85	48	872,85		
24	868,05				

11 Annex F: TRS for a Non-Uniform Mesh and a Coarse Uniform Mesh

Equation 3 in Section 5.2.1 provides an approximation formula for the TRS which can be used only if measurements are made according to a uniform spherical mesh where the angular resolution does not exceed 30°. Different approaches should be followed if the angular resolution is higher than 30° or if the spherical mesh is non-uniform.

11.1 Coarse Uniform Mesh

If the mesh is uniform but too coarse to use Equation 3 – meaning that the angular resolution exceeds 30° – then the non-approximated formula should be used for the TRS as follows:

$$TRS = \frac{M}{\sin\frac{\pi}{2N}\sum_{n=0}^{N-1}\sum_{m=0}^{M-1}\left[\left(\frac{1}{EIS_{\theta}(\theta_n,\varphi_m)}+\frac{1}{EIS_{\varphi}(\theta_n,\varphi_m)}\right)\sin\frac{(2n+1)\pi}{2N}\right]}$$

Equation [4]

11.2 Non-Uniform Mesh

When taking measurements for calculating the TRS, the calibration of the test signal makes moving the antenna difficult. It is simpler to adjust the orientation of the unit under test. This is simple in 3 planes (XY, XZ, YZ) but becomes highly complex for 30° planar offsets.

One solution to address this issue is to consider a non-uniform spherical mesh i.e. where the number of cells varies from one layer to another. In this case the use of the Sin θ in the harmonic mean calculation provides the mathematical weighting of results to provide an even integral. In this instance, the choice of mesh can be adapted to the test environment to minimise the number of measurements needed, but still provide an even distribution of points (as illustrated in Figure 6).

No formula for the TRS can be derived for a non-uniform mesh as the calculation will be specific to the choice of mesh and no generic formula can therefore be provided. Rather, the TRS integral will need to be split into a sum of sub-integrals for each cell.

Figure 6 below provides an illustration of a non-uniform spherical mesh comprising 18 measurement locations and therefore 18 cells. The approach for the TRS calculation in this particular configuration is provided as an example as well as the TRS formula.

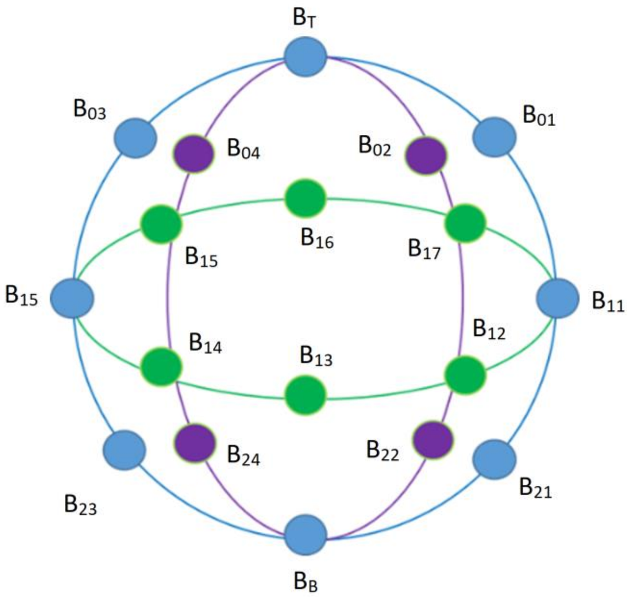


Figure 6 3D TRS polar plot

The table below indicates the angles for the set of 18 points (marked with an X) from Figure 6 that provide an even distribution. If these points only are used, then as these 18 points are evenly spaced without more at the poles of the sphere, a harmonic mean can be used to calculate the TRS.

Theta (θ) / Phi (φ)	0	45	90	135	180	225	270	315
0	X	-	-	-	-	-	-	-
45	X	-	X	-	X	-	X	-
90	X	X	X	X	X	X	X	X
135	X	-	X	-	X	-	X	-
180	X	-	-	-	-	-	-	-

Below is a worked example for the above distribution of points, which can be encoded into a spreadsheet or similar:

1. In total there will be 18 TRS(θ,φ) points required as denoted by X in the table above. With 2 measurements per point – vertical and horizontal polarisation – this equates to 36 measurements.
2. A harmonic mean of the horizontal and vertical polarisations for a specific point shall be used to reduce the data set from 36 values to 18 individual TRS(θ,φ) values expressed in

dBm. This harmonic mean is denoted as *B* and is indicated in Figure 6 for each measurement location.

$$B = \frac{1}{EIS_{\theta}(\theta_n,\varphi_m)} + \frac{1}{EIS_{\varphi}(\theta_n,\varphi_m)}$$

3. If all points in the table above were measured, then the TRS calculation would be based on Equation 3. However Equation 3 cannot be used for a non-uniform mesh and the integral should rather be split into a sum of sub-integrals for each cell. Each sub-integral should then be calculated separately and all the results from these sub-integral calculations be added together to calculate the overall sum, which is provided in Equation 5 below:

$$TRS = \frac{16}{4\left(2-\sqrt{2+\sqrt{2}}\right)A_1 + \left(\sqrt{2+\sqrt{2}} - \sqrt{2-\sqrt{2}}\right)A_2 + \left(\sqrt{2-\sqrt{2}}\right)A_3}$$

Equation [5]

Where:

$$A_1 = B_T + B_B$$

$$A_2 = B_{01} + B_{02} + B_{03} + B_{04} + B_{21} + B_{22} + B_{23} + B_{24}$$

and

$$A_3 = B_{11} + B_{12} + B_{13} + B_{14} + B_{15} + B_{16} + B_{17} + B_{18}$$