Alignment of Measurement Procedures IEC 60118-13 and ANSI C63.19

EHIMA REPORT TR2018-01

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Abstract

In order to find a common measurement method for IEC60118-13 and ANSI C63.19 standards, the Output Related Interference Level (*ORIL*) of **17 hearing aids** was measured in **one GTEM cell** with the hearing aids in **12 *Orientations*** relative to the illuminating electromagnetic wave. Comparing **seven *EvaluationMethods*** the goal was to find a *Method* which gets the final ORIL result curve close to that of a ***ReferenceMethod*** but uses a minimum number of *Orientations*. The most accurate *Method* (in this paper called MaxSum_12 *Method*) developed by Stephen Julstrom et al. using 12 *Orientations* and a *MaximumSumCalculation* showes the highest final *ORIL* curve of all *Methods* (WorstCase) and was taken as *ReferenceMethod*.
The investigation showed that our present IEC *Method* with its 4 *Orientations* and a *MaxHoldEvaluation* is not suitable for measurements up to 6GHz because it underestimates the WorstCase *ORIL* of the hearing aids. Our favorite ***NewMethod*** is the Modd max. *Method* which uses 6 *Orientations* and a *MaxHoldEvaluation*.
In order to measure old devices with the *NewMethod* about the same as with the present IEC *Method* the FieldStrenghts of the present IEC *Method* should be changed

- from (90, 50, 35)V/m at (0.7…0.96, 1.4…2.0, 2.0…2.7)GHz
- to (60, 40, 30)V/m at (0.6…0.96, 1.4…2.0, 2.0…6.0) GHz.[1]

[1] To be prepared for future requirements, tests were performed at 0.6…6 GHz, although the TestFrequencies of the Standards' next editions will be 0.65…2.7 GHz only.

Revision History

Revision Number	Date	Comments
0.1	2017-10-26	Initial release EMI WG
0.3	2018-01-11	Added paragraph 3.2, Summary, editorial changes
0.4	2018-02-11	Editorial changes
0.5	2018-03-06	Pictures edited
0.7	2018-05-03	Textual improvements & clarifications
0.8	2018-05-14	Textual improvements & clarifications
0.9	2018-05-22	Pre-final version (EMI WG)
1.0	2018-05-24	Final version (TC Secretary)
1.1	2018-05-25	Minor editorial changes

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Glossary

AM
Amplitude modulated

EM
Electro magnetic

EvaluationMethod / Method
Method processing the results of *ORIL* measurements of a HA in several *Orientations* to make up a single final *ORIL* result curve (*ORIL* vs. frequency curve)

FieldStrength
E-fieldstrength

HA
Hearing aid

MaxHoldEvaluation
EvaluationMethod: At every frequency the max. ORIL of a HA measured in several Orientations is used as ORIL result.

Orientation
Orientation of a HA within a GTEM cell relative to the propagation direction of the EM wave.

ORIL
Output related interference level: a HA's output when exposed to RF

RF
Radio frequency

Sensitivity
Sensitivity vs. *RF*

Contents

1 Introduction

1.1 Measurements

1.1.1 IO-Curves

We measured the IO-Curves (ORIL vs. *FieldStrengthLevel*) of every HA at the 3 frequencies: 900, 2700, 5200 MHz in order to see if the **device is linear** which is the case if:

$$\frac{\Delta ORIL}{\Delta L_E} = 2,\ L_E : \textit{FieldStrengthLevel} \qquad : (1)$$

In other words:
The variation in recovered audio is twice the associated variation in RF sensitivity (both in dB).

1.1.2 ORIL-curves

We measured the ORIL-Curves (ORIL vs. frequency) of every HA in every Orientation (see 1.1.3) at *FieldStrengthLevels* where the device appeared linear at the following TestFrequencies:

- $0.6 \le f$ / GHz < 1.4
- $1.4 \le f$ / GHz < 2.0
- $2.0 \le f$ / GHz < 3.0
- $3.0 \le f$ / GHz ≤ 6.0

with $f = f_0 \cdot 1.01^n$

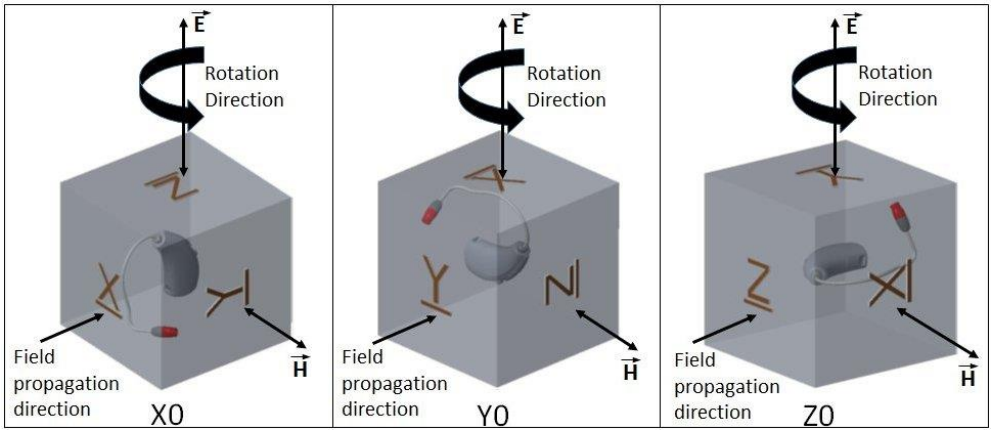
1.1.2.1 Procedure

For * = X|Y|Z

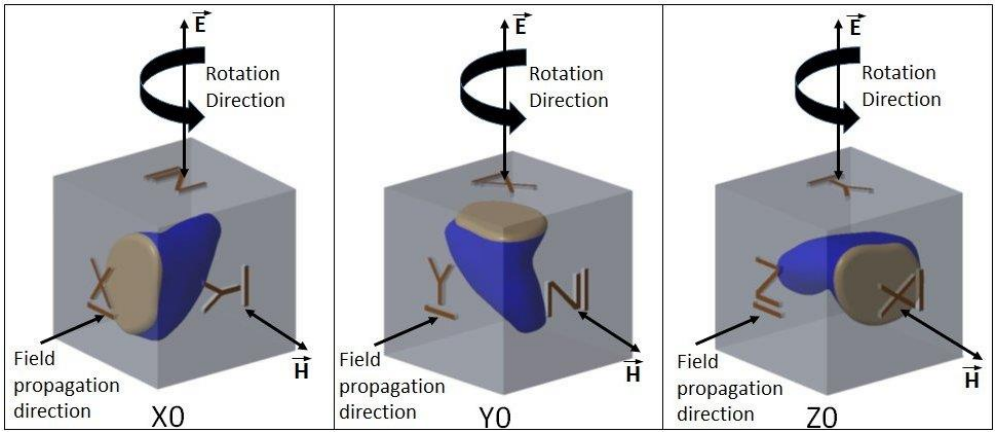
1. measure ORIL of the HA placed on Turntable in Orientation *0 as shown in Figure 1
2. turn the HA around the Global z-Axis (E-Field vector) by steps of 90° and measure ORIL in Orientations *90, *180, *270

1.1.3 Orientations

For the MaxSum Methods Stephen Julstrom et al. use a special labeling for the Orientation of a HA relative to the PropagationDirection of the EM wave.



BTEs and RICs



ITEs

Figure 1: JulstromOrientations

Rem.:
GTEM's X-Axis = field propagation direction
GTEM's Y-Axis = H-Field direction
GTEM's Z-Axis = E-Field direction

1.2 Evaluations

From the measurements to evaluate the final ORIL curve we used 3 Julstrom Methods and 4 Conservative Methods.

1.2.1 Julstrom Methods

1.2.1.1 MaxSum_12 (Reference)

Using the 12 Julstrom-Orientations and a MaxSumCalculation, which by theory and from previous investigations has shown to be the WorstCase and was used as Reference furtheron:

$$ORIL_{\text{MaxSum\_12}} = \max\left[ORIL_{\text{MaxSum\_even}}, ORIL_{\text{MaxSum\_odd}}\right]$$

1.2.1.2 MaxSum_even

Using the first set of 6 (out of 12) Julstrom-Orientations and a MaxSumCalculation:

$$ORIL_{\text{MaxSum\_even}} = 20 \cdot \lg\left[10^{\frac{\max[ORIL[\text{X90}],ORIL[\text{X270}]]}{20}} + 10^{\frac{\max[ORIL[\text{Y90}],ORIL[\text{Y270}]]}{20}} + 10^{\frac{\max[ORIL[\text{Z90}],ORIL[\text{Z270}]]}{20}}\right]$$

1.2.1.3 MaxSum_odd

Using the complementary set of 6 Julstrom-Orientations and a MaxSumCalculation:

$$ORIL_{\text{MaxSum\_odd}} = 20 \cdot \lg\left[10^{\frac{\max[ORIL[\text{X0}],ORIL[\text{X180}]]}{20}} + 10^{\frac{\max[ORIL[\text{Y0}],ORIL[\text{Y180}]]}{20}} + 10^{\frac{\max[ORIL[\text{Z0}],ORIL[\text{Z180}]]}{20}}\right]$$

1.2.2 Conservative Methods

1.2.2.1 Overall max.

For comparison we're using the Overall max. Method taking the maximum of all ORIL measurements:

$$ORIL_{\text{Overall max.}} = \max\begin{bmatrix} ORIL[\text{X0}], ORIL[\text{X90}], ORIL[\text{X180}], ORIL[\text{X270}], ORIL[\text{Y0}], ORIL[\text{Y90}], \\ ORIL[\text{Y180}], ORIL[\text{Y270}], ORIL[\text{Z0}], ORIL[\text{Z90}], ORIL[\text{Z180}], ORIL[\text{Z270}] \end{bmatrix}$$

1.2.2.2 Meven max.

This Method takes the maximum ORIL of the Orientations of the MaxSum_even Method:

$$ORIL_{\text{Meven max.}} = \max\left[ORIL[\text{X90}], ORIL[\text{X270}], ORIL[\text{Y90}], ORIL[\text{Y270}], ORIL[\text{Z90}], ORIL[\text{Z270}]\right]$$

1.2.2.3 Modd max.

This Method takes the maximum ORIL of the Orientations of the MaxSum_odd Method:

$$ORIL_{\text{Modd max.}} = \max\left[ORIL[\text{X0}], ORIL[\text{X180}], ORIL[\text{Y0}], ORIL[\text{Y180}], ORIL[\text{Z0}], ORIL[\text{Z180}]\right]$$

1.2.2.4 IEC max.

This is our present Method defined in IEC60118-13:2016:

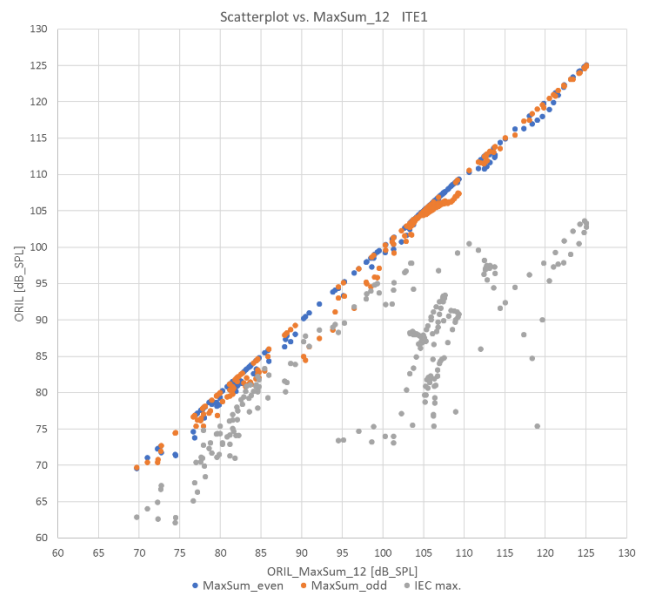
$$ORIL_{\text{IEC max.}} = \max\left[ORIL[\text{X0}], ORIL[\text{X90}], ORIL[\text{X180}], ORIL[\text{X270}]\right]$$

2 Ranking of Methods

2.1 Scatterplots

For a qualitative comparison of the JulstromMethods (with MaxSum-Calculation) vs. our present Standard's IEC max. Method we use Scatterplots (i.e. two-dimensional x-y-Diagrams):
Assuming the MaxSum_12 as the most accurate Method (ReferenceMethod) its values are used for the x coordinate of the points while for the y-coordinates we use the values of the ComparisonMethodes MaxSum_even, MaxSum_odd and IEC max. (results of all devices see Appendix).
The closer the results of a ComparisonMethode meets the results of the ReferenceMethod the nearer its curve gets to a 45° diagonal through the Origin.

The scatterplot presented in Pic. 1 illustrates the span of results when comparing the different methods with the MaxSum_12 method. The conclusion that can be drawn from the scatterplot is that the IEC max method at some measurement points is significantly different than the MaxSum_12 method. The IEC max and MaxSum_12 is represented by light grey and blue points, respectively.

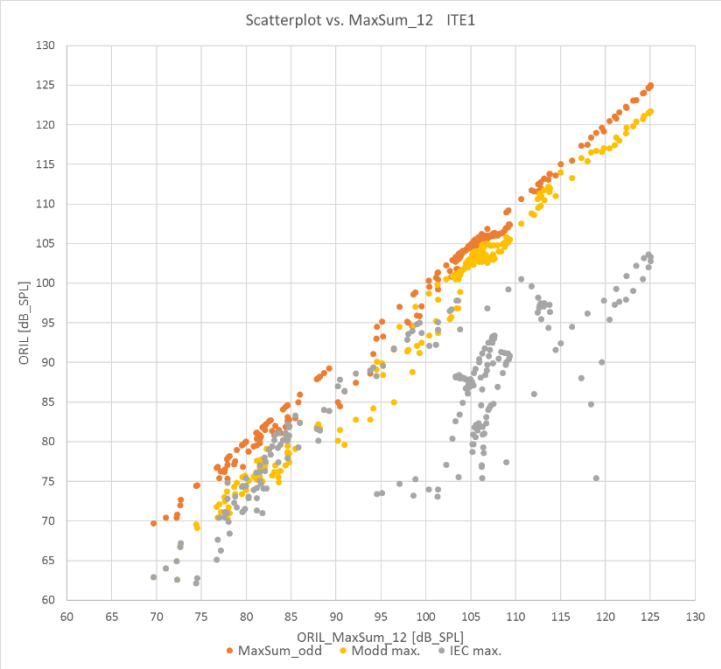


Pic. 1: Scatterplot as shown in the Appendix

Scatterplots for all hearing aids tested can be found in the Appendix.

2.2 Scatterplot including Modd max. Method

As an added comparison of methods, the following Pic. 2 includes the Modd max. data. From this scatterplot it can be seen that results of the Modd max. Method shows more consistency with the MaxSum_12 than the IEC max. Method. The Modd max. and IEC max. results are represented by yellow and light grey points, respectively.



Pic. 2: Scatterplot additionally showing results of Modd max. Method

2.3 Comparison of FreqRangeMaxDifferences

In paragraph 2.1 we did a graphical comparison of MaxSum_even, MaxSum_odd and IEC max. vs. MaxSum_12 (**Reference**) Method. This comparison qualitatively showed that MaxSum_odd Method is closer to the Reference than the MaxSum_even Method.
Problem of the graphical comparison is that we cannot show all Methods in a diagram because it becomes unclear.
That's why we need a quantitative approach.
A suitable way quantifying differences between a ComparisonMethode and the Reference-Methode is:

For every Methode (**M*m*, *m* = 1…6**), every HA (**HA*n*, *n* = 1…17**) and every FrequencyRange (**FR*o*, *o* = 1…6**)

1. determine the FrequencyRangeMaxima (FRM)

   $FRM_{\mathrm{M}m,\ \mathrm{HA}n,\ \mathrm{FR}o} = \max\left[IRIL_{\mathrm{M}m,\ \mathrm{HA}n}[f] \right]$, with the 6 FrequencyRanges

   FR1: 0.6 ≤ f / GHz < 1.4
   FR2: 1.4 ≤ f / GHz < 2.0
   FR3: 2.0 ≤ f / GHz < 3.0
   FR4: 3.0 ≤ f / GHz ≤ 4.0
   FR5: 4.0 ≤ f / GHz ≤ 5.0
   FR6: 5.0 ≤ f / GHz ≤ 6.0

2. calculate the FrequencyRangeMaxDifference (FRMD) of the ComparisonMethode (**CM*m*, *m* = 1…5**) vs. the ReferenceMethod (**RM**=MaxSum_12) in the FrequencyRange FR*o*

   $FRMD_{\mathrm{CM}m,\ \mathrm{HA}n}[\mathrm{FR}o] = FRM_{\mathrm{CM}m,\ \mathrm{HA}n}[\mathrm{FR}o] - FRM_{\mathrm{RM},\ \mathrm{HA}n}[\mathrm{FR}o]$

   Rem.:
   In paragraph 3.2 for every HearingAid and every FrequencyRange we've listed the FreqRangeMax of every Methode (see diagrams "Ranking1: FRM") and compared the FreqRange-MaxDifference of the ComparisonMethods vs. our ReferenceMethod MaxSum_12 (see diagrams "Ranking2: FRMD").

For every ComparisonMethode and for every HA calculate the MeanFrequencyRangeMaxDifference of all FrequencyRanges

3. $FRMD_{\mathrm{mean},\ \mathrm{CM}m,\ \mathrm{HA}n} = \frac{1}{6}\sum_{o=1}^{6} FRMD_{\mathrm{CM}m,\ \mathrm{HA}n}[\mathrm{FR}o]$

For every ComparisonMethode calculate the AverageFrequencyRangeMaxDifference of all HAs:

4. $FRMD_{\mathrm{avg},\ \mathrm{CM}m} = \frac{1}{17}\sum_{n=1}^{17} FRMD_{\mathrm{mean},\ \mathrm{CM}m,\ \mathrm{HA}n}$

2.3.1 Result

With the AverageFreqRangeMaxDifference we now have a criteria and find out which ComparisonMethode is closest to our ReferenceMethod MaxSum_12 (for a 100% match the AverageFreqRangeMaxDifference of a ComparisonMethode would be 0).
By that the ranking is:

Method	$N_{Orientations}$	*FreqRangeMax Difference* $_{avg}$	*Ranking*
MaxSum_odd	6	-0.7	1
MaxSum_even	6	-0.8	2
Overall max.	12	-3.3	3
Modd max.	6	-4.2	4
Meven max.	6	-4.3	5
IEC max.	4	-6.3	6

Table 1: Ranking of Methods[2]

2.3.2 Details

		MeanFreqRangeMaxDiff vs. MaxSum_12. (ref.)					
HA	*DUT \ Method*	MaxSum_even	Meven max.	MaxSum_odd	Modd max.	Overall max.	IEC max.
1	BTE1	-0.6	-4.0	-0.1	-2.0	-2.0	-2.0
2	BTE2	-2.5	-5.9	-0.2	-2.8	-2.6	-2.6
3	BTE3	-0.8	-3.8	-0.4	-3.0	-2.7	-3.0
4	BTE4	-1.0	-5.0	-0.1	-3.7	-3.7	-5.3
5	BTE5	-0.2	-3.3	-1.8	-4.8	-3.0	-4.3
6	BTE6	-0.2	-1.3	-1.1	-3.2	-1.2	-6.1
7	BTE7	-0.4	-3.7	-0.3	-3.3	-2.8	-3.6
8	ITE1	-0.4	-3.2	-0.7	-4.4	-3.0	-11.4
9	ITE2	-1.5	-4.4	-0.1	-3.4	-2.8	-3.9
10	ITE3	-1.3	-5.2	0.0	-4.2	-4.0	-5.4
11	ITE4	-0.1	-4.7	-0.9	-5.8	-4.7	-13.8
12	ITE5	-0.8	-4.6	-0.9	-4.0	-4.0	-10.3
13	ITE6	-1.0	-4.2	-0.2	-2.9	-2.8	-9.7
14	RIC1	-0.5	-4.0	-0.1	-4.1	-3.8	-3.9
15	RIC2	-0.6	-5.8	-1.9	-7.7	-5.0	-8.5
16	RIC3	-0.7	-5.1	-2.0	-6.9	-4.1	-8.4
17	RIC4	-0.6	-4.7	-1.0	-5.6	-4.2	-5.2
	Average of 17HAs	-0.8	-4.3	-0.7	-4.2	-3.3	-6.3

Table 2: Sum of all FreqRangeMaxDifferences vs. MaxSum_12 (Reference)

[2] Rem.: We finally chose the Modd max. *Method* because the MaxSum *Methods* generally have the (rare) problem with an omnidirectional Sensitivity that results are calculated 9.54dB higher than in reality (see 2.4) and the Overall max. *Method* uses 12 Orientations.

2.4 Problem of MaxSum_odd *Method*

According 2.3 the MaxSum_odd *Method* would be our favorite *Method* but it takes the ORILs measured in 3 orthogonal directions and sums them up according to 1.2.1 > MaxSum_odd:

$$ORIL_{\text{MaxSum\_odd}} = 20 \cdot \lg\left[10^{\frac{\max[ORIL[+X1],ORIL[-X1]]}{20}} + 10^{\frac{\max[ORIL[+Y1],ORIL[-Y1]]}{20}} + 10^{\frac{\max[ORIL[+Z1],ORIL[-Z1]]}{20}}\right]$$

The problem with this MaxSumCalculation used for MaxSum_odd[3] *Method* arises if a HA exhibits an RF sensitivity directivity less than that of an ideal dipole antenna (e.g. the HA's wiring making up an antenna structure that is more omnidirectional than a dipole).

If we measure the ORIL in the 6 JulstromOddOrientations and evaluate it by

- any of the above mentioned *ConservativeMethods* (e.g. Modd max. *Method*) we end up with *MaxHoldCurve* of all *JulstromOddOrientations*.
- the *MaxSumCalculation* may end up a maximum of 9.54dB higher in detected audio interference, representing 4.77 dB higher implied RF sensitivity. Informal testing (separate from this study) on a small number of specially prepared test devices with complex antenna structures indicated that more typically, the overestimation of the *MaxSumCalculation* was about half this amount, indicating a roughly similar underestimation by the simple maximum..

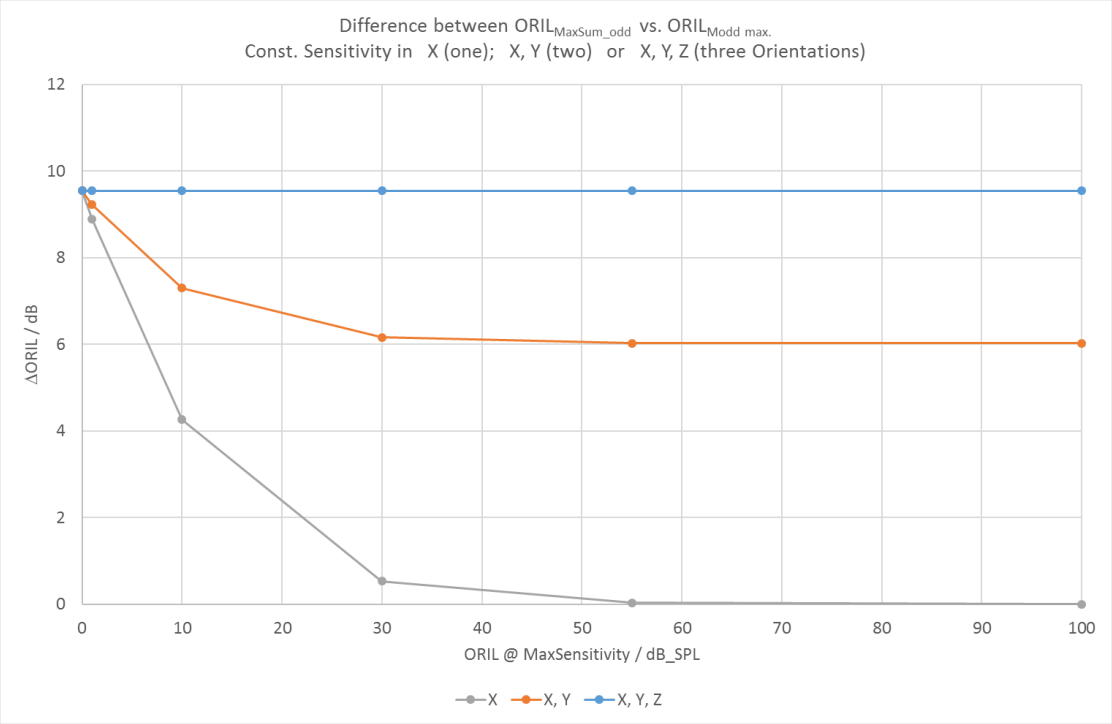
The more there is an imbalance in the *Sensitivity* among the measured orientations and the higher is the dominant Sensitivity (ORIL at MaxSensitivity), the less is this effect.

2.4.1 Result

Therefore our favorite[4] *Method* is Modd max. using the 6 ORIL curves measured in the MaxSum_odd's Orientations but instead of a MaxSumCalculation does a *MaxHoldEvaluation*.

[3] Generally with all JulstromMethods
[4] We are not looking at Overall max. *Methode,* because it needs 12 *Orientations*.

2.4.2 Details



Pic. 3: Differences between MaxSum_odd and Modd max. results (values see Table 3)

ORIL/dB$_{SPL}$ when SensitivityVector parallel E-Field	Orientations of Const. Sensitivity	*ORIL* /dB$_{SPL}$ *HA-Orientation* X	Y	Z	*Method* MaxSum_odd	Modd max.	dB *Difference*
0	X	0	0	0	9.5	0.0	9.54
1		1	0	0	9.9	1.0	8.89
10		10	0	0	14.3	10.0	4.26
30		30	0	0	30.5	30.0	0.53
55		55	0	0	55.0	55.0	0.03
100		100	0	0	100.0	100.0	0.00
0	X, Y	0	0	0	9.5	0.0	9.54
1		1	1	0	10.2	1.0	9.22
10		10	10	0	17.3	10.0	7.30
30		30	30	0	36.2	30.0	6.16
55		55	55	0	61.0	55.0	6.03
100		100	100	0	106.0	100.0	6.02
0	X, Y, Z	0	0	0	9.5	0.0	9.54
1		1	1	1	10.5	1.0	9.54
10		10	10	10	19.5	10.0	9.54
30		30	30	30	39.5	30.0	9.54
55		55	55	55	64.5	55.0	9.54
100		100	100	100	109.5	100.0	9.54

Table 3: Differences between MaxSum_odd and Modd max. results

2.5 Change of IEC-*FieldStrengths*

In the following we calculate the *FieldStrengths* for our favorite Modd max. *Method* using the 6 JulstromOddOrientations: X0, X180, Y0, Y180, Z0, Z180 in order to get the same results as with the present IEC60118-13:2016 Standard's *Method* IEC max. using 4 Orientations: X0, X90, X180, X270.

From the IO-Curves at the *AppliedFieldStrengths* we see that the relationship between ORIL and FieldStrengthLevel is (seeTable 4):

$$\frac{\Delta ORIL}{\Delta L_E} = 1.75.$$

This supports the generally accepted approach[5]:

$$\frac{\Delta ORIL}{\Delta L_E} = 2$$

or:

$$\Delta L_E = \frac{\Delta ORIL}{2}.$$

In the FrequencyRanges of 600…1400, 1400...2000 and 2000…3000 we've got the MaxSum_odd and Modd max. as well as IEC max. ORIL results for all devices.
Therefore we may calculate the Change of Modd max. *FieldStrengths*
to yield the same results[6] as IEC max.:

$$\Delta L_{E,\,\text{Modd max.}} = \frac{ORIL_{\text{Modd max.}} - ORIL_{\text{IEC max.}}}{2}$$

and with the Mean of all HAs

$$\Delta L_{E,\,\text{Modd max., mean}} = \frac{1}{17}\sum_{n=1}^{17} \Delta L_{E,\,\text{Modd max., HA}n}$$

we may calculate

$$L_{E,\,\text{Modd max.}} = L_{E,\,\text{IEC max.}} + \Delta L_{E,\,\text{Modd max., mean}}.$$

2.5.1 Result

In order to get nearly the same results with our favorite Modd max. *Method* as with the present IEC60118-13:2016 Standard's *Method* IEC max., the present IEC-*FieldStrengths* of (90, 50, 35)V/m at (**0.7**…0.96, 1.4…2.0, 2.0…2.7)GHz should be changed to (75, 40, 30)V/m at the proposed (slightly extended) FrequencyRange of (**0.65**…0.96, 1.4…2.0, 2.0…2.7) GHz.

[5] this change of ORIL vs. *FieldstrengthLevel* relationship is supported by the knowledge that demodulation usually takes place at non linear elements with a diode's characteristic. In reality devices may have different behavior especially at higher *Fieldstrengths* but for our average calculation this is not relevant.
[6] average, using many HAs

2.5.2 Details

		ΔORIL/ΔL_E																
DUT		BTE1	BTE2	BTE3	BTE4	BTE5	BTE6	BTE7	ITE1	ITE2	ITE3	ITE4	ITE5	ITE6	RIC1	RIC2	RIC3	RIC4
f /GHz	0.9	2.1	1.5	2.3	1.5	0.7	2.1	1.6	2.0	1.7	1.8	2.0	0.3	0.5	1.6	2.4	5.5	1.9
	2.7	2.0	2.0	2.0	0.8	2.3	2.5	2.3	1.9	2.3	1.6	5.0	1.1	0.1	1.2	1.9	2.2	2.0
	5.2	0.2	2.1	2.3	0.3	2.2	0.0	1.8	1.9	2.0	1.4	1.8	2.0	2.1	1.1	1.5	0.0	2.0
average		1.75																

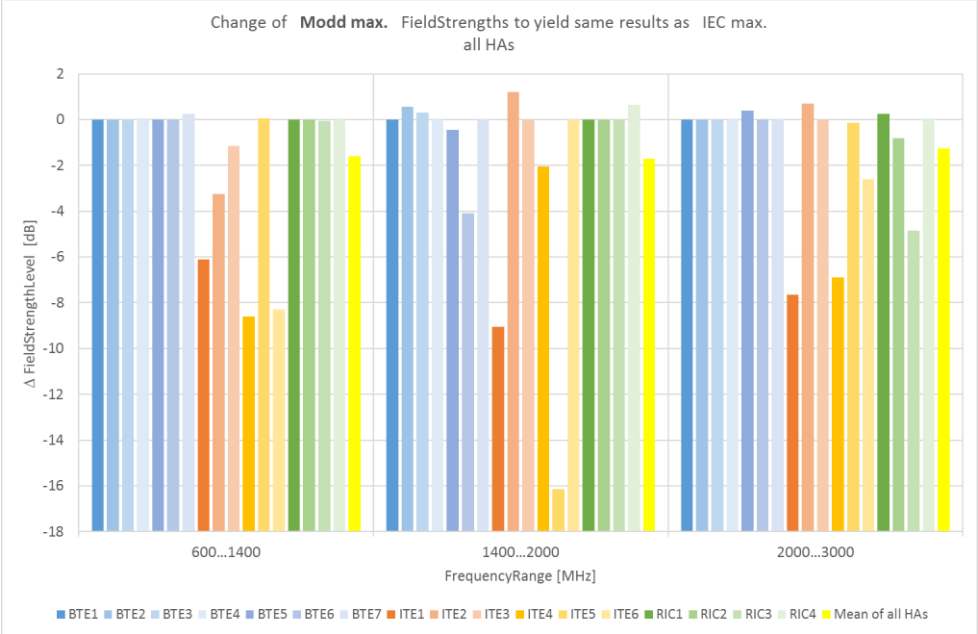
Table 4: Change of ORIL vs. FieldStrengthLevel changes - all HearingAids (values)

	Change of FieldStrength ΔL_E / dB																			
F-Range / MHz	BTE1	BTE2	BTE3	BTE4	BTE5	BTE6	BTE7	ITE1	ITE2	ITE3	ITE4	ITE5	ITE6	RIC1	RIC2	RIC3	RIC4	Mean of all HAs	Mean BTEs	Mean ITEs	Mean RICs
600…1400	0.0	0.0	0.0	0.0	0.0	0.0	0.3	-6.1	-3.3	-1.2	-8.6	0.1	-8.3	0.0	0.0	-0.1	0.0	-2	0	-5	0
1400…2000	0.0	0.6	0.3	0.0	-0.4	-4.1	0.0	-9.1	1.2	0.0	-2.1	-16.2	0.0	0.0	0.0	0.0	0.6	-2	-1	-4	0
2000…3000	0.0	0.0	0.0	0.0	0.4	0.0	0.0	-7.7	0.7	0.0	-6.9	-0.2	-2.6	0.3	-0.8	-4.8	0.0	-1	0	-3	-1

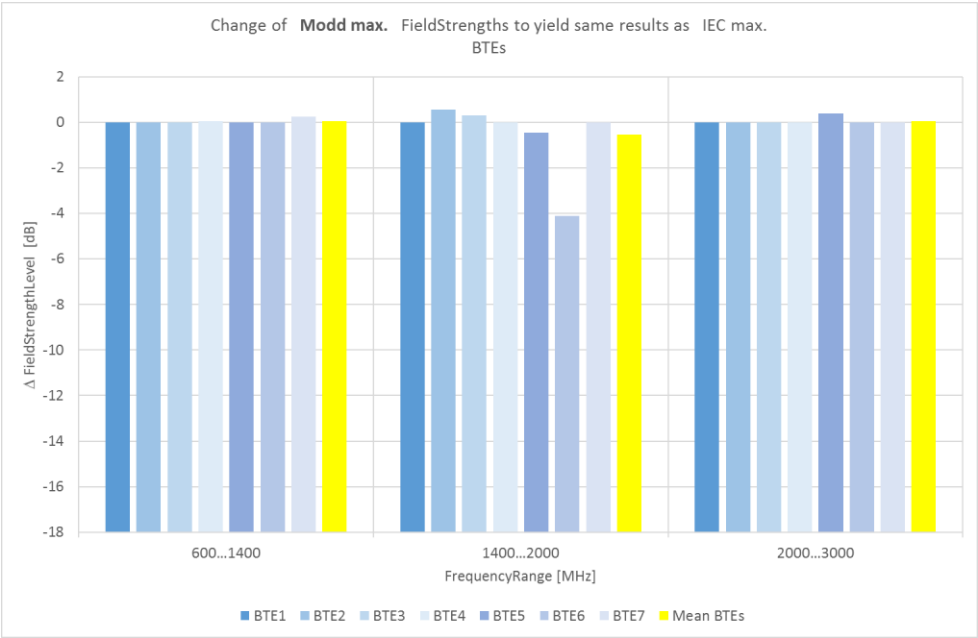
Table 5: Change of Modd max. FieldStrengths - all HearingAids (values)

old (IEC max.)					new (Modd max.)		
FreqRange	E_1	L_{E1}	ΔL_E	L_{E2}	FreqRange	E_2	$E_{2,suggest}$
MHz	V/m	$dB_{V/m}$	dB	dB_V/m	MHz	V/m	V/m
700…960	90	39	-2	37	650…1400	75	75
1400…2000	50	34	-2	32	1400…2000	41	40
2000…2700	35	31	-1	30	2000…3000	30	30

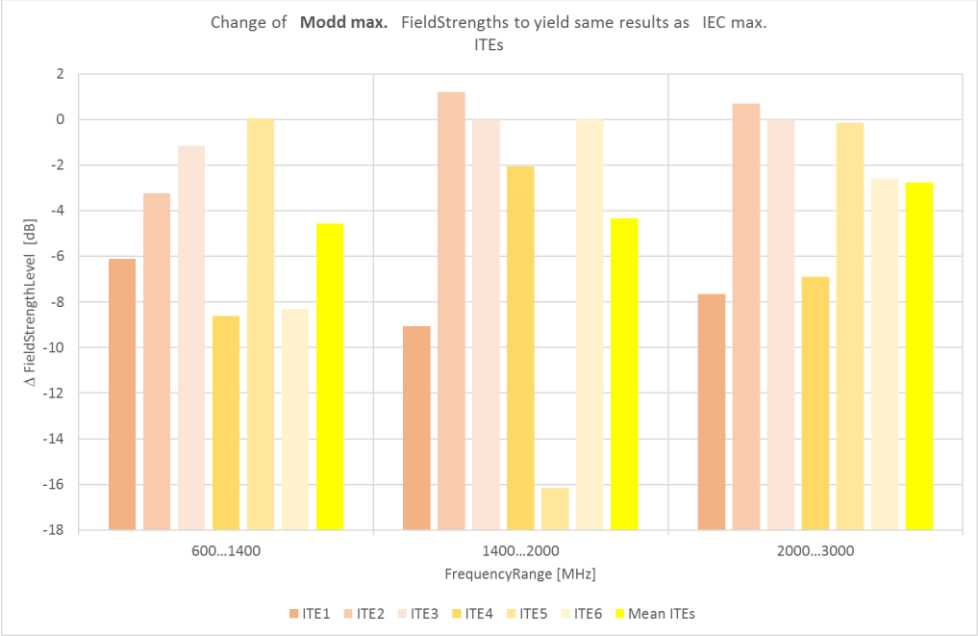
Table 6: Proposal for IEC60118-13 Change of FieldStrengths if we use Modd max. Method



Pic. 4: Change of FieldStrengths - all HearingAids



Pic. 5: Change of FieldStrengths – BTEs



Pic. 6: Change of FieldStrengths – ITEs

Pic. 7: Change of FieldStrengths – RICs

2.6 Conclusion

We measured the ORIL of 17 hearing aids in one GTEM cell with the hearing aids in 12 Orientations relative to the illuminating electro magnetic wave and processed the results via seven *EvaluationMethods*. Then we used the most accurate *Method* developed by Stephen Julstrom et al. (in this paper called MaxSum_12 *Method*) for a comparison and ranking of the 6 other *Methods*.

The MaxSum_odd *Method* using 6 Orientations and the *MaxSumCalculation* was closest to the MaxSum_12 *Method* but had the problem that in case of a HA having an omnidirectional RF-Sensitivity the final result curve would be 9.54dB higher than the *MaxHoldCurve* of all Orientations.

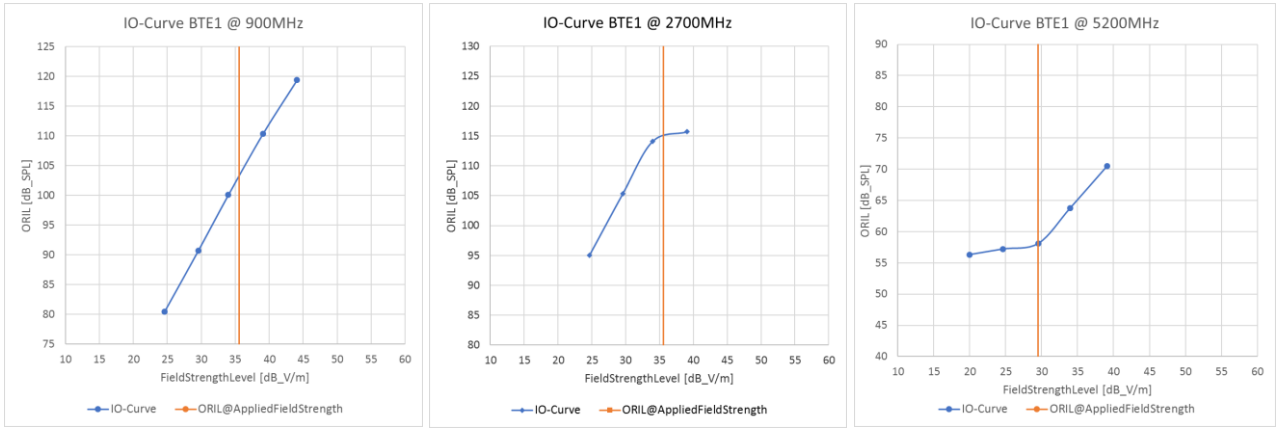
Therefore our **favorite *Method*** is the Modd max. *Method* which uses the same *Orientations* as the MaxSum_odd *Method* and does a *MaxHoldEvaluation* instead of the *MaxSumCalculation*.

In 2.5 we suggested to **change the *FieldStrengths*** from present (**90**, **50, 35**)V/m to (**75**, **40, 30**)V/m originally at (**0.7**...0.96; 1.4…2.0, 2.0…2.7)GHz when using Modd max. *Method*.
This point was discussed at the EHIMA-EMI-WG meeting in Odense, 2017-10-23/24, and it was suggested to go for (**60**, 40, 30)V/m at a frequency Range of (**0.65**…0.96, 1.4…2.0, 2.0...2.7)GHz.
Subsequently there was a consensus of IEC/TC29/WG13 and ANSI_C63.19 WG on these *FieldStrengths* and FrequencyRange especially because there never was any negative feedback from the customers so far.
Anyway if we run into problems with these Standards' requirements we may go to higher *TestFieldStrengths* in subsequent editions of the Standards.

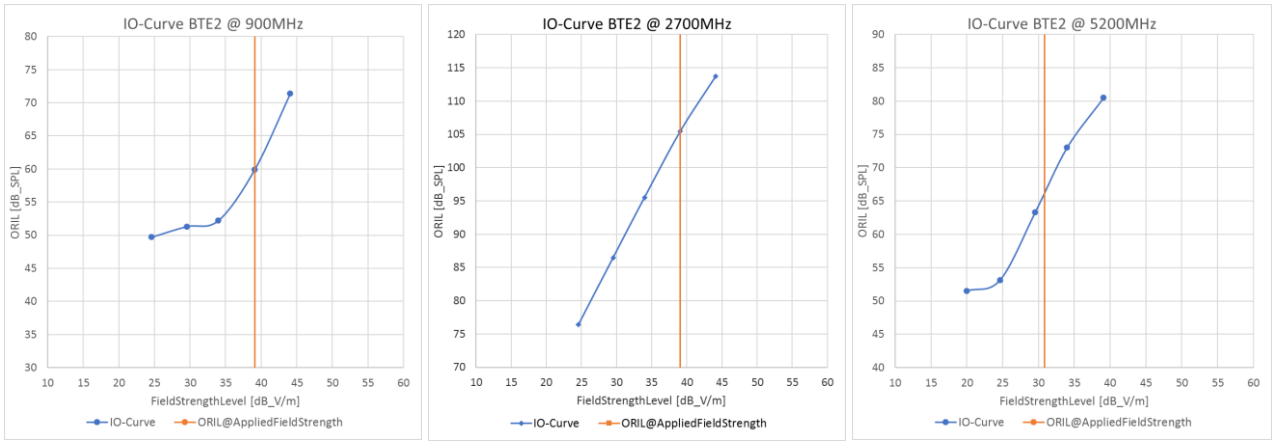
3 Device specific Results [7]

3.1 IO-Curves

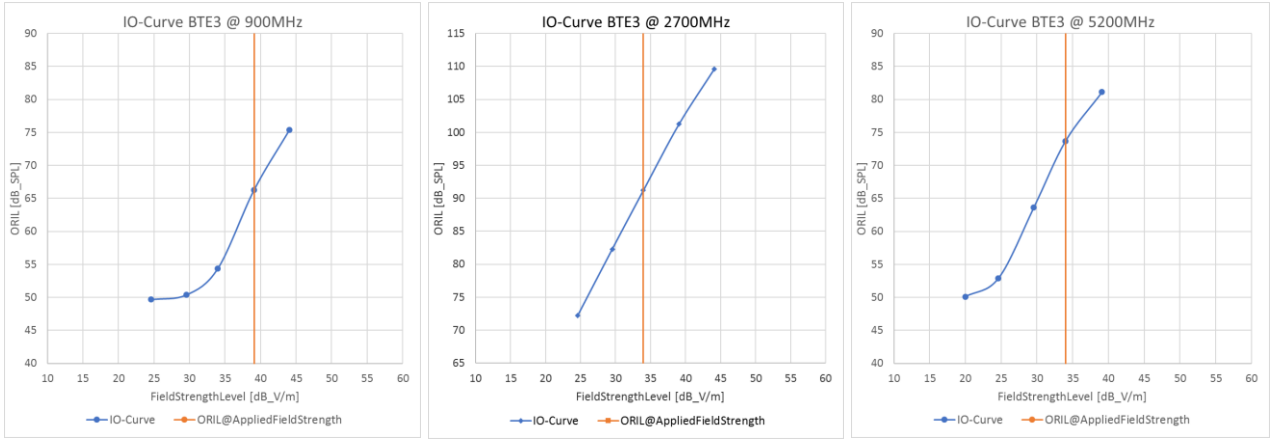
These are the IO-Curves described in 1.1.1 showing ORIL as a dependency of the *FieldStrengthLevel*. The orange line indicates the *FieldStrengthLevel* applied for the given hearing aid at the given frequency range.



Pic. 8: IO-Curves BTE1

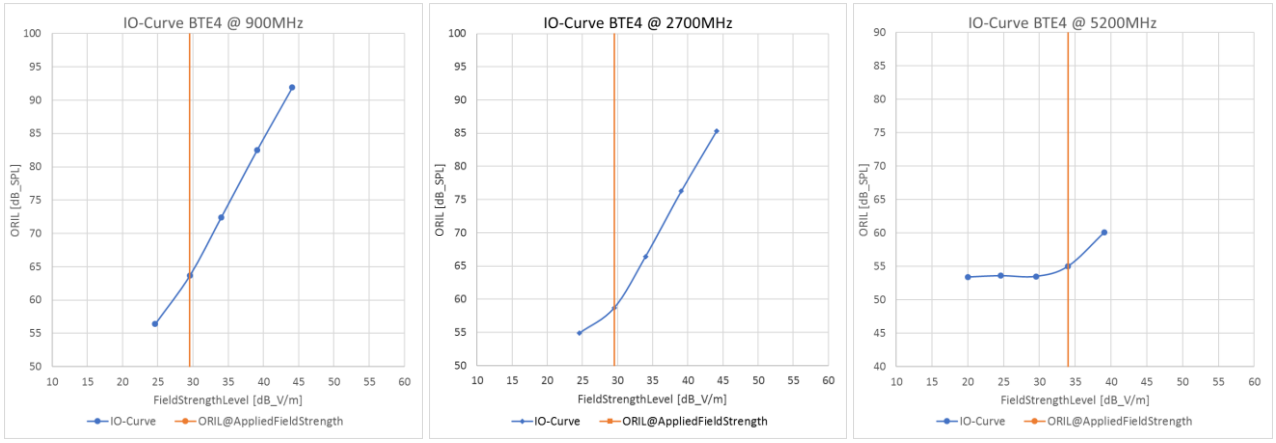


Pic. 9: IO-Curves BTE2

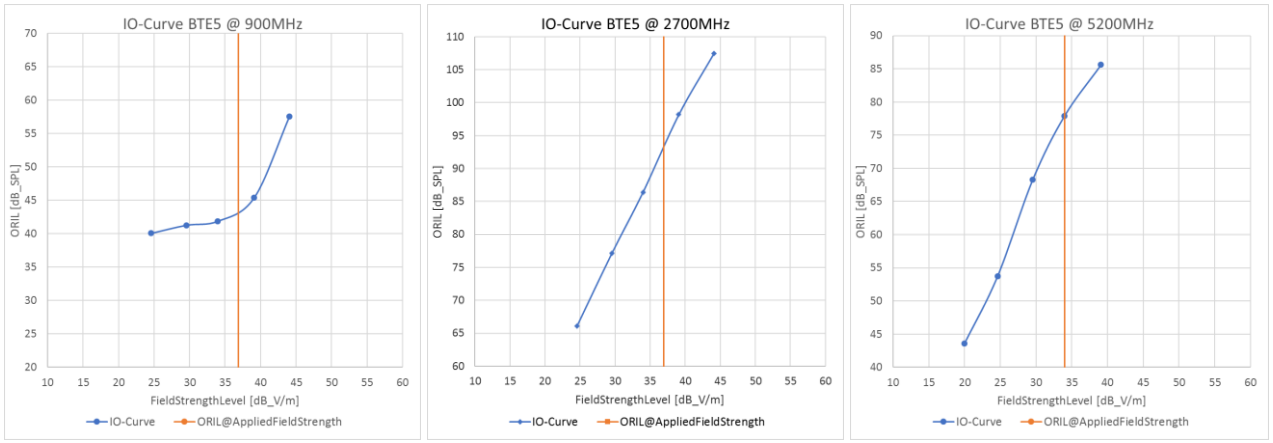


Pic. 10: IO-Curves BTE2

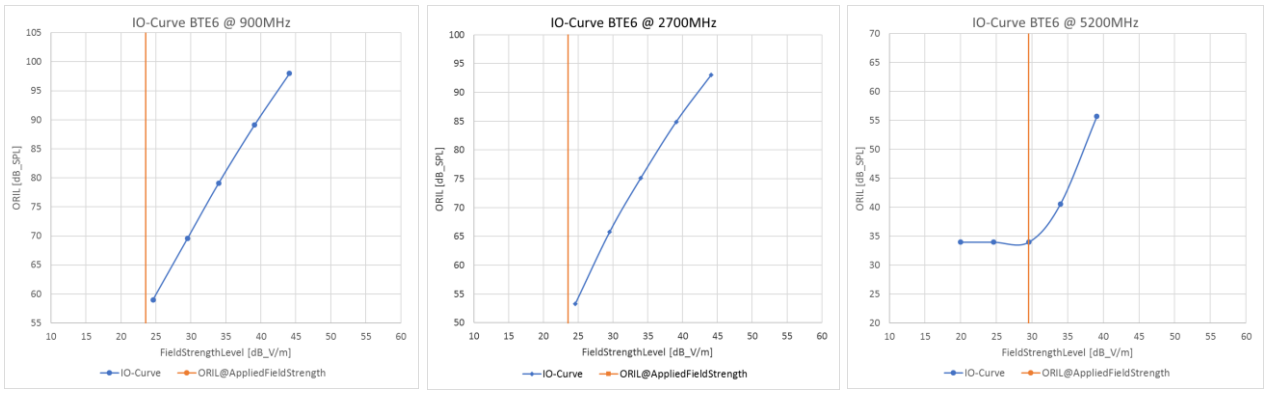
[7] For the sake of clarity we are using different ranges of the IO curve scales but the resolution is the same.



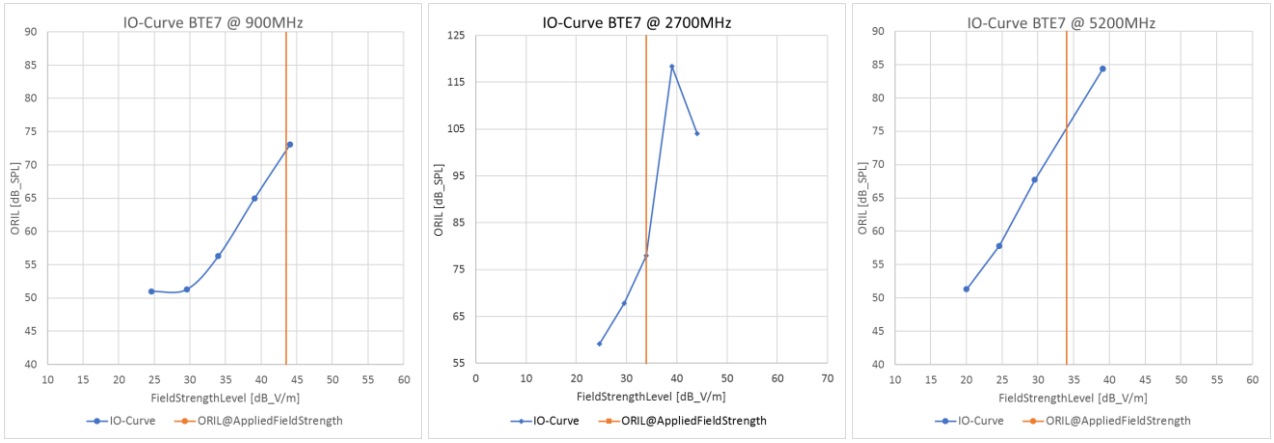
Pic. 11: IO-Curves BTE4



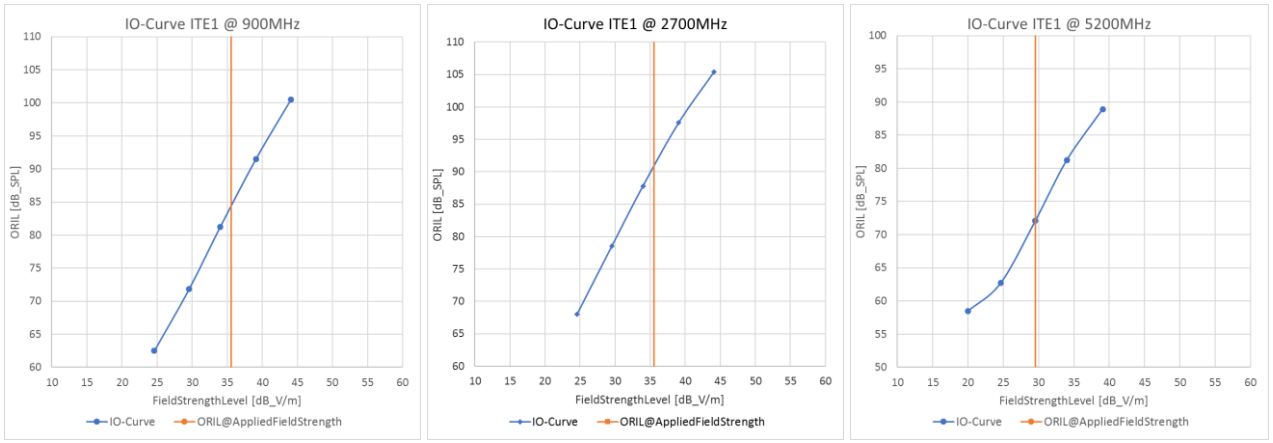
Pic. 12: IO-Curves BTE5



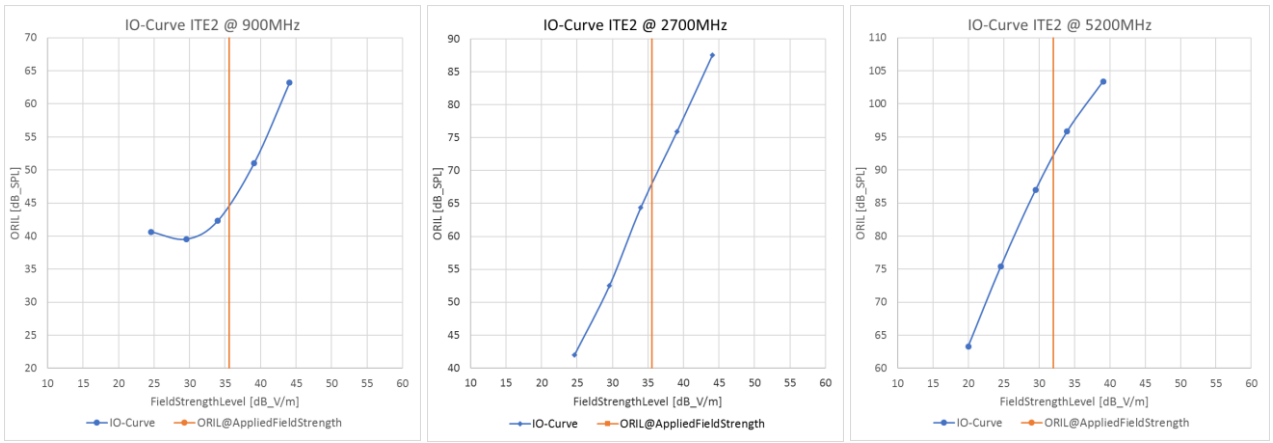
Pic. 13: IO-Curves BTE6



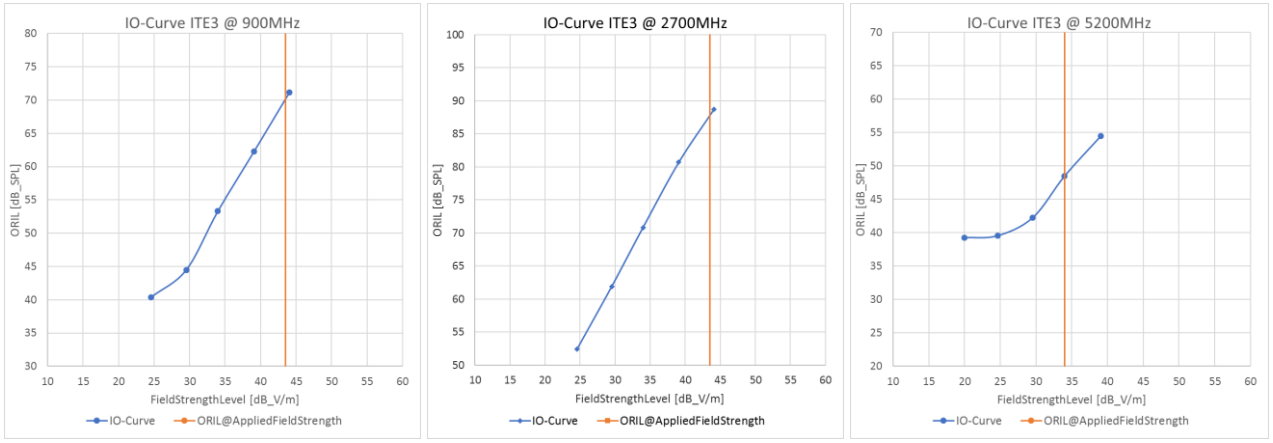
Pic. 14: IO-Curves BTE7



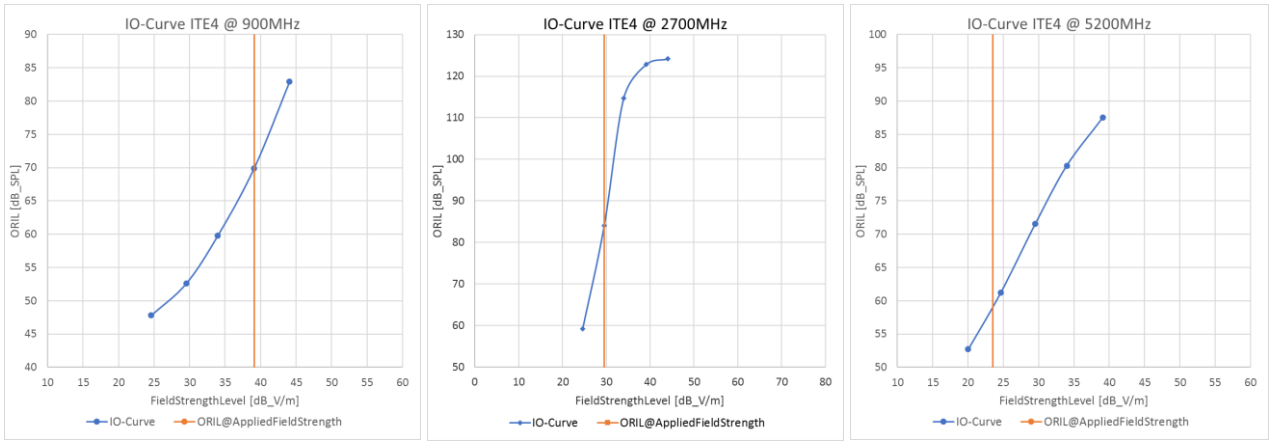
Pic. 15: IO-Curves ITE1



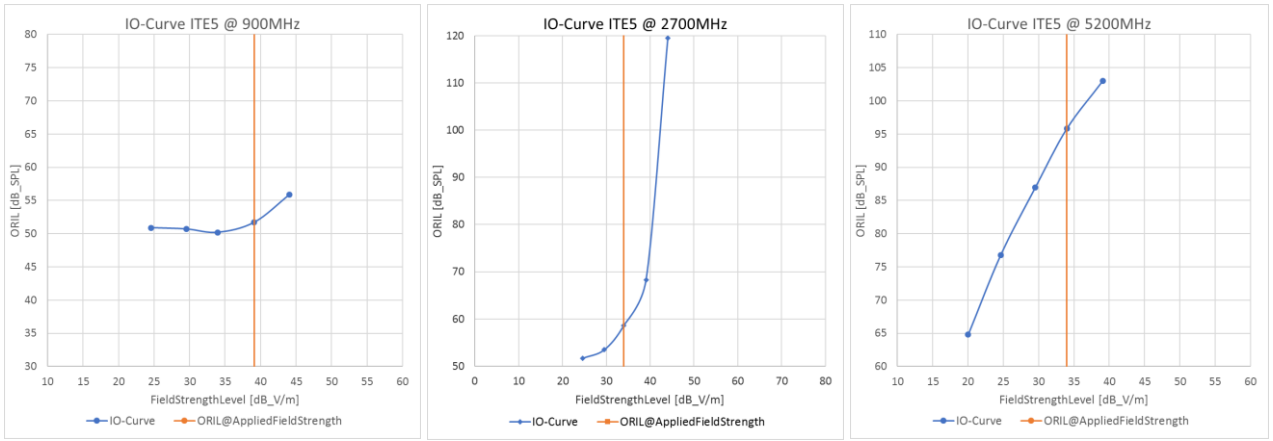
Pic. 16: IO-Curves ITE2



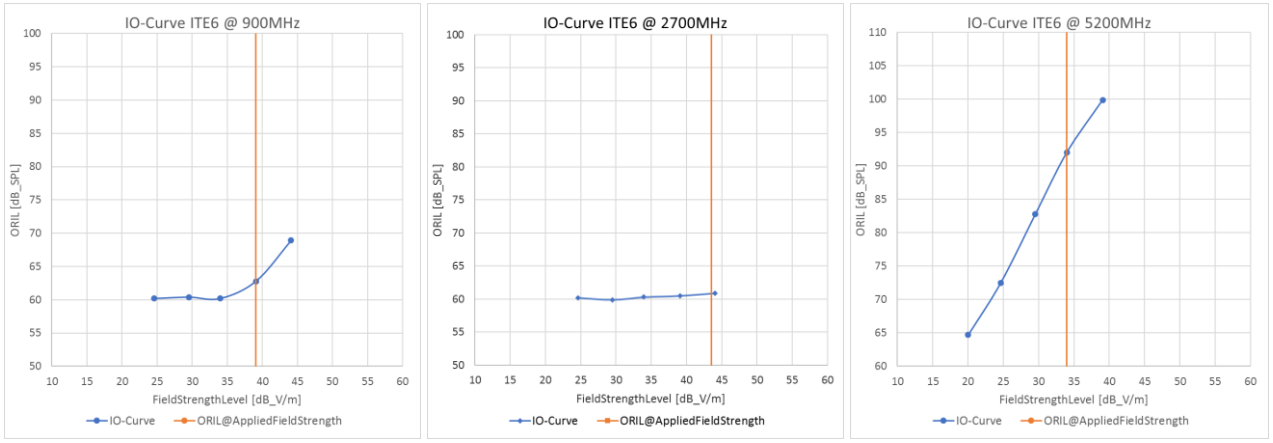
Pic. 17: IO-Curves ITE3



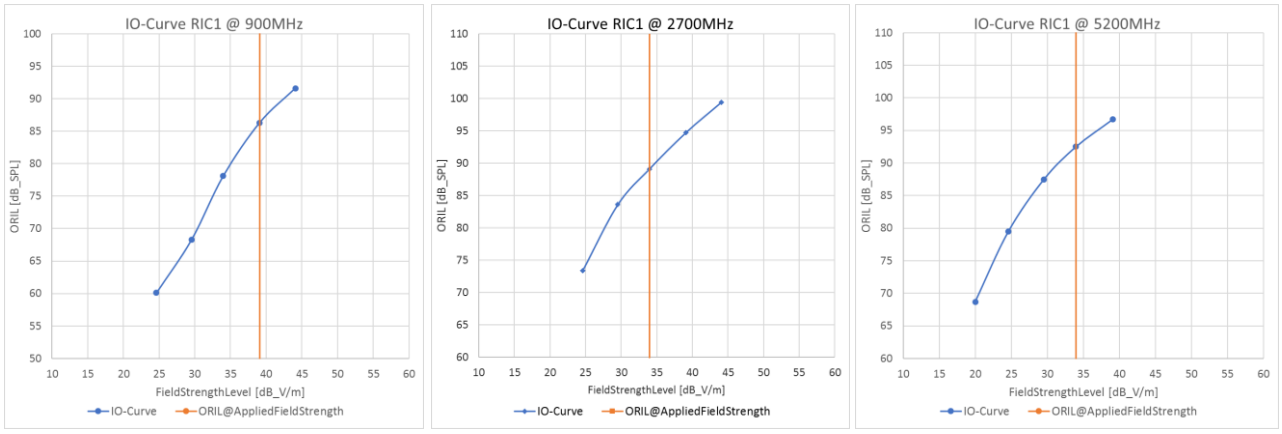
Pic. 18: IO-Curves ITE4



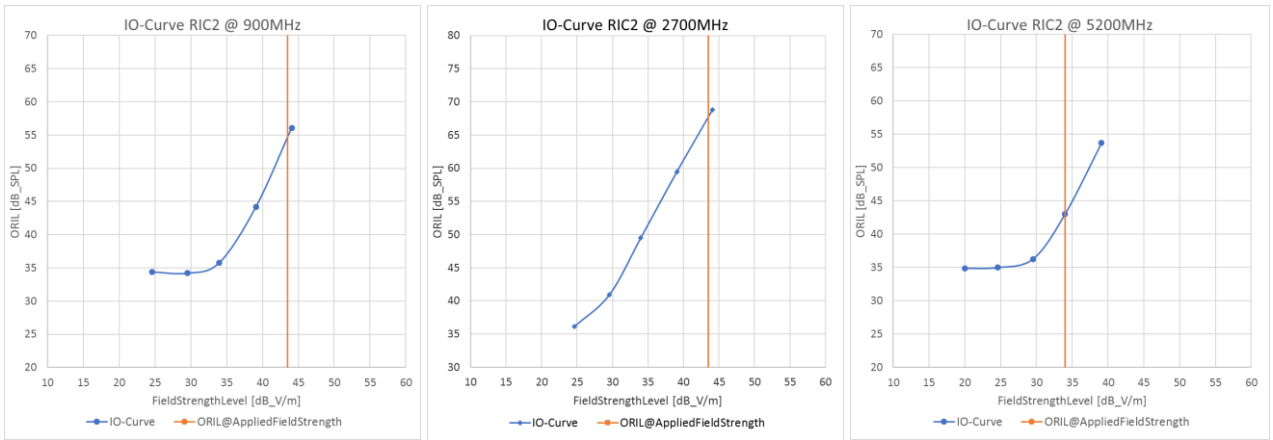
Pic. 19: IO-Curves ITE5



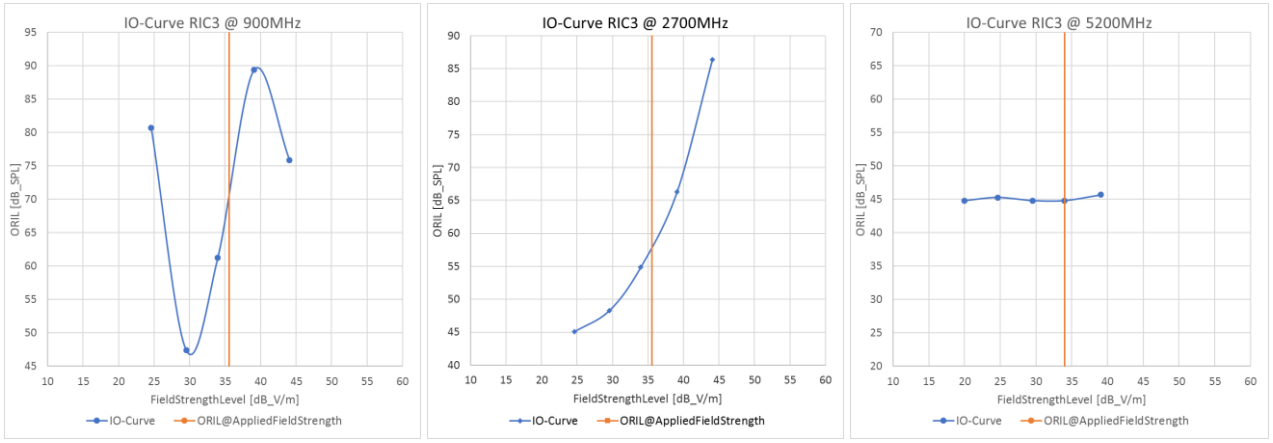
Pic. 20: IO-Curves ITE6



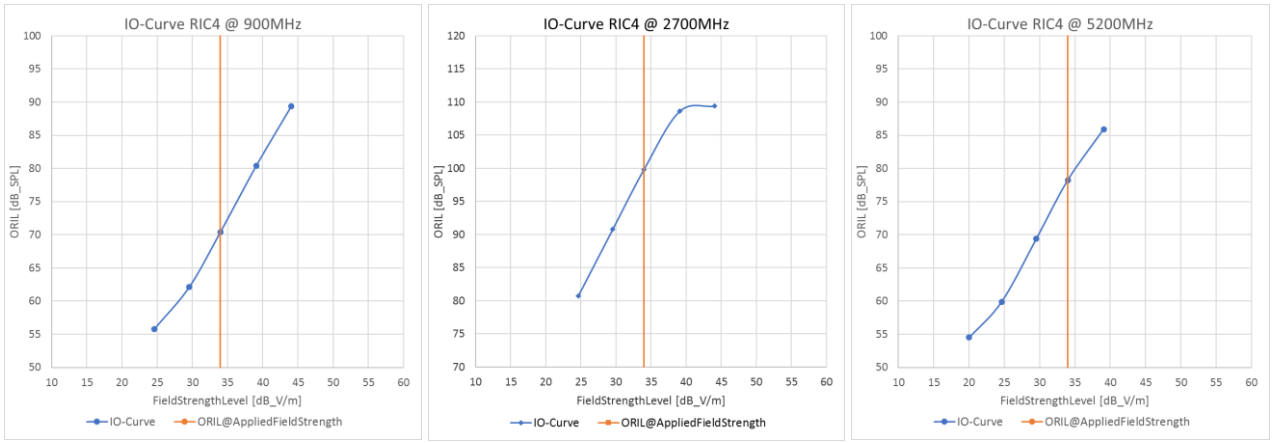
Pic. 21: IO-Curves RIC1



Pic. 22: IO-Curves RIC2



Pic. 23: IO-Curves RIC3

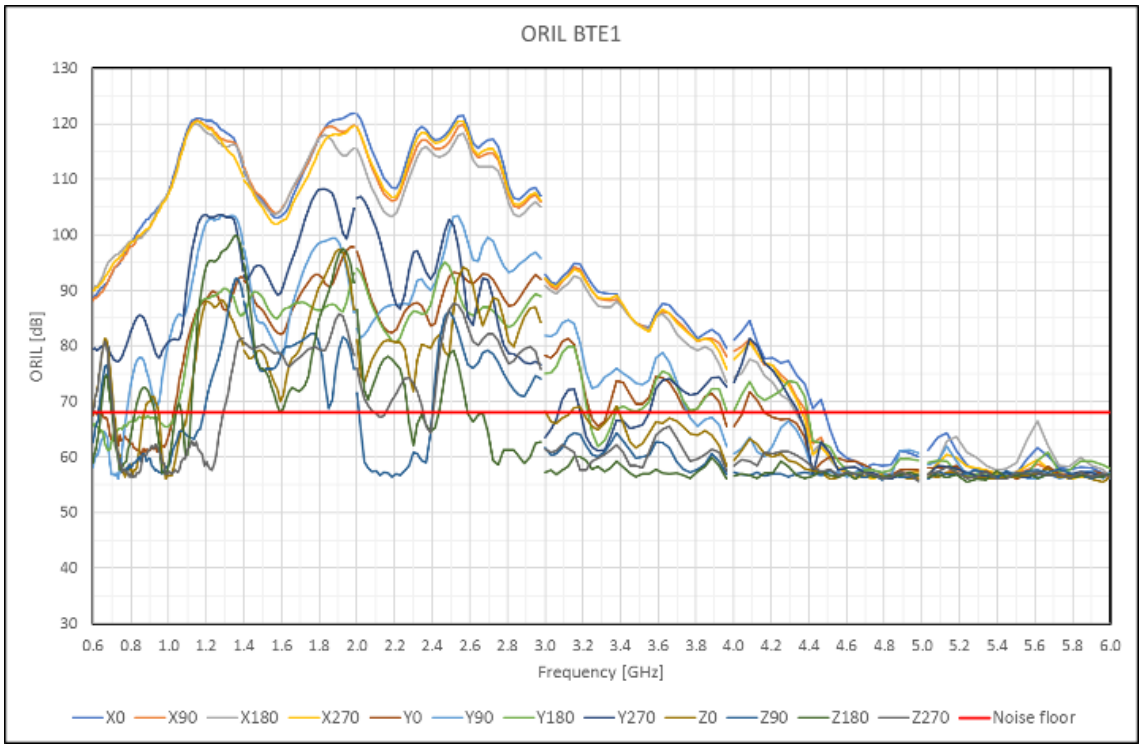


Pic. 24: IO-Curves RIC4

3.2 ORILs

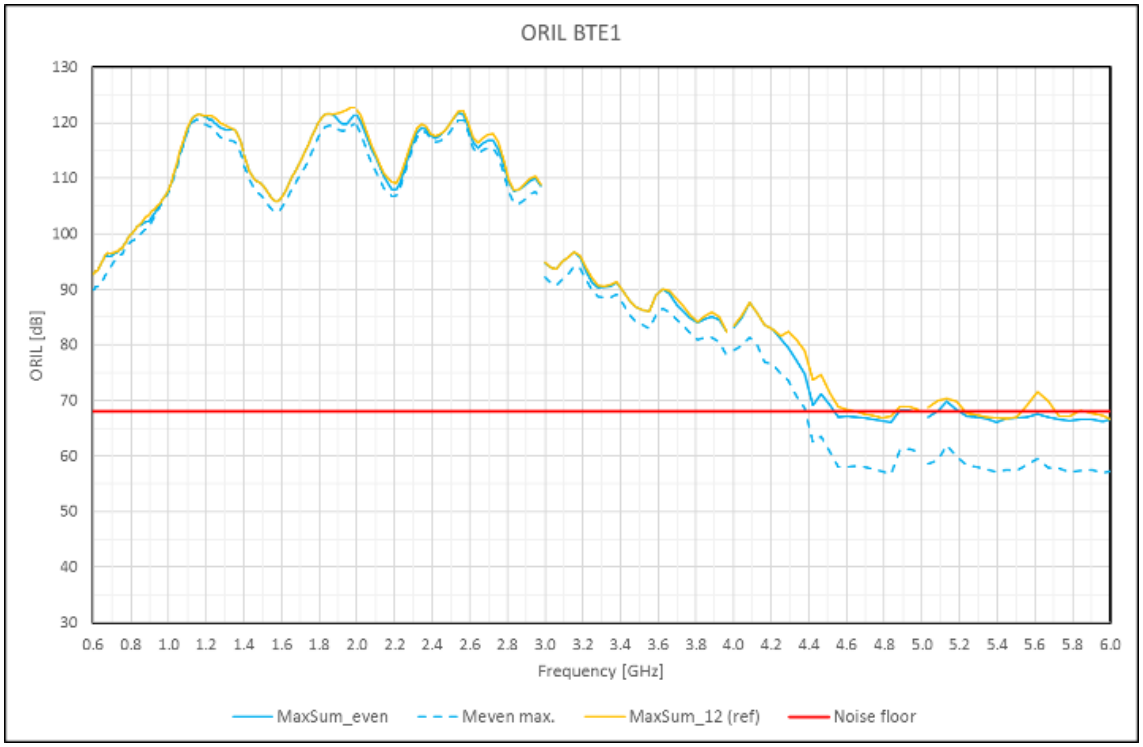
Subsequent paragraphs show measurement (see 1.1.2) and evaluation results (1.2.1; 1.2.2; 2.3).

3.2.1 BTE1

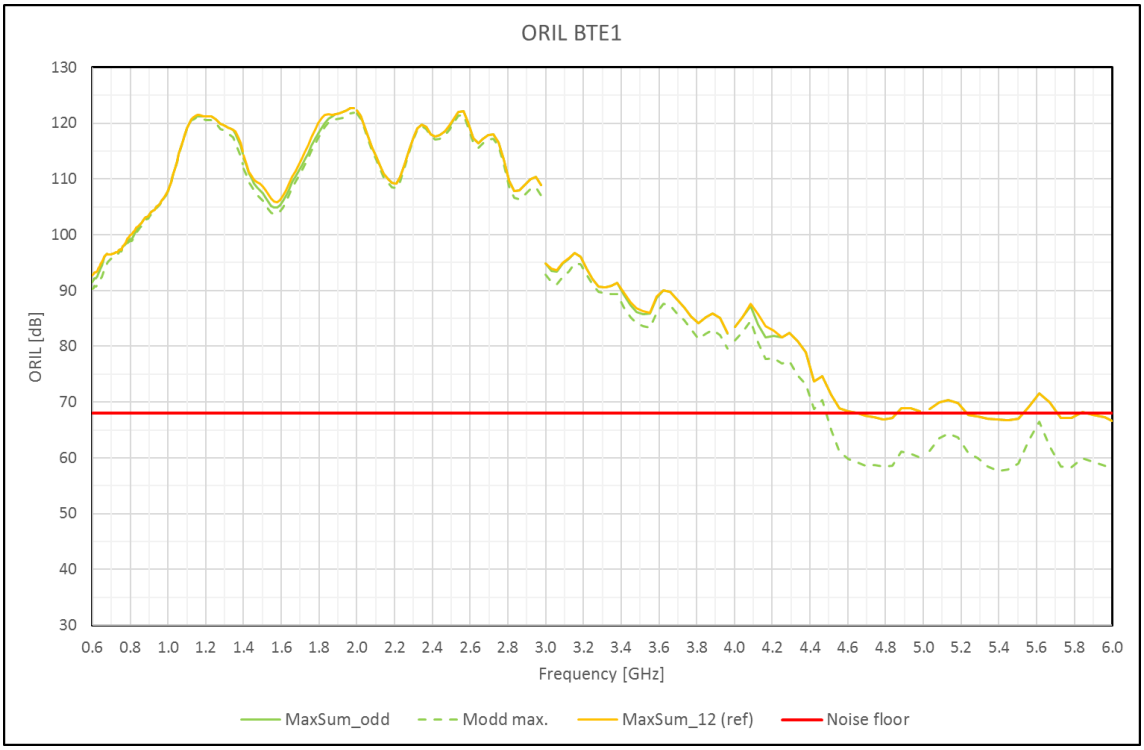


All measurements

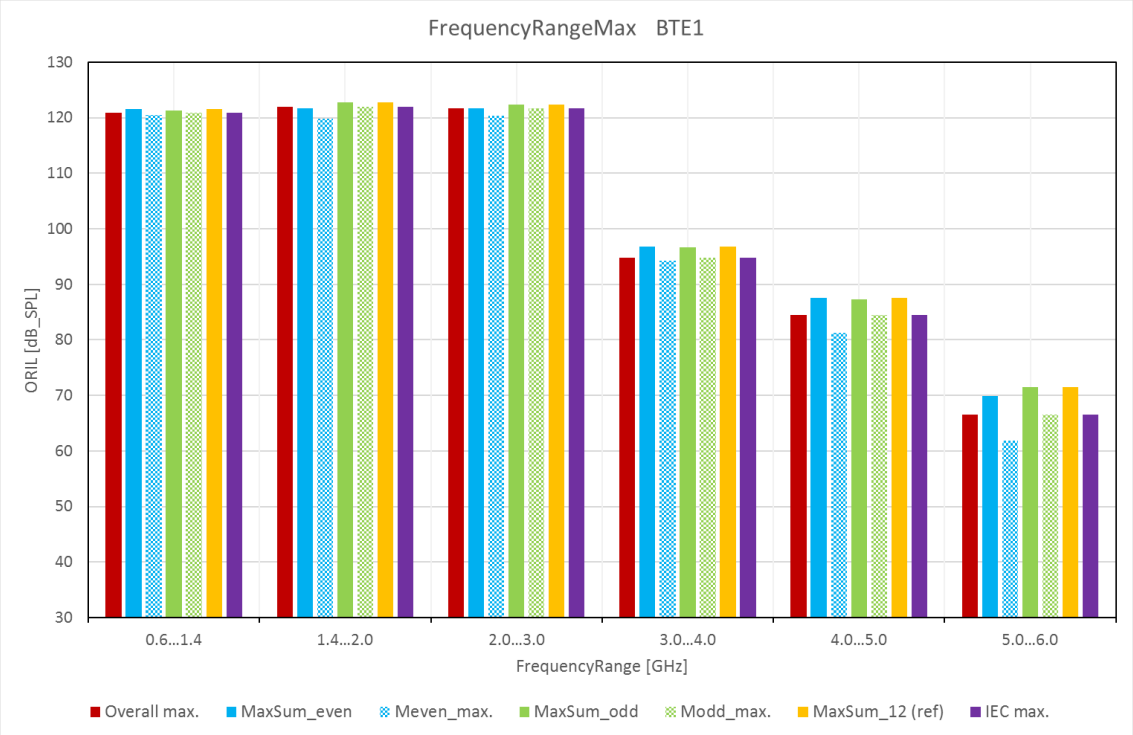
Evaluation1: Overall max., IEC max., MaxSum_12



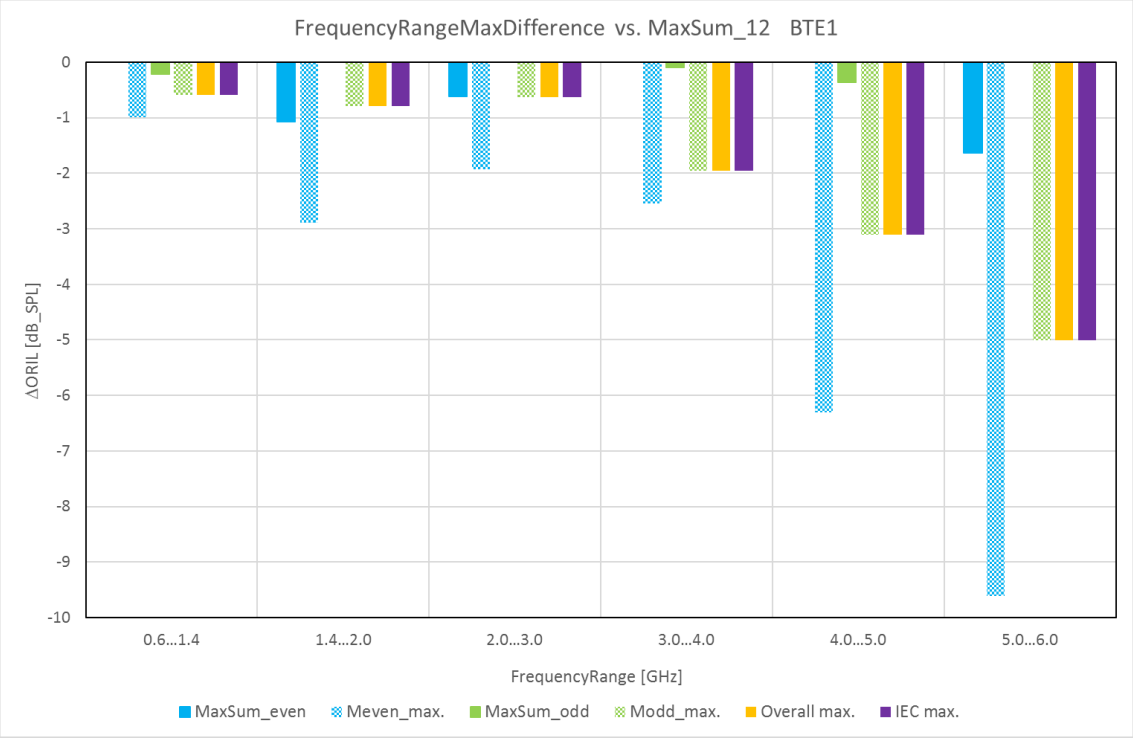
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



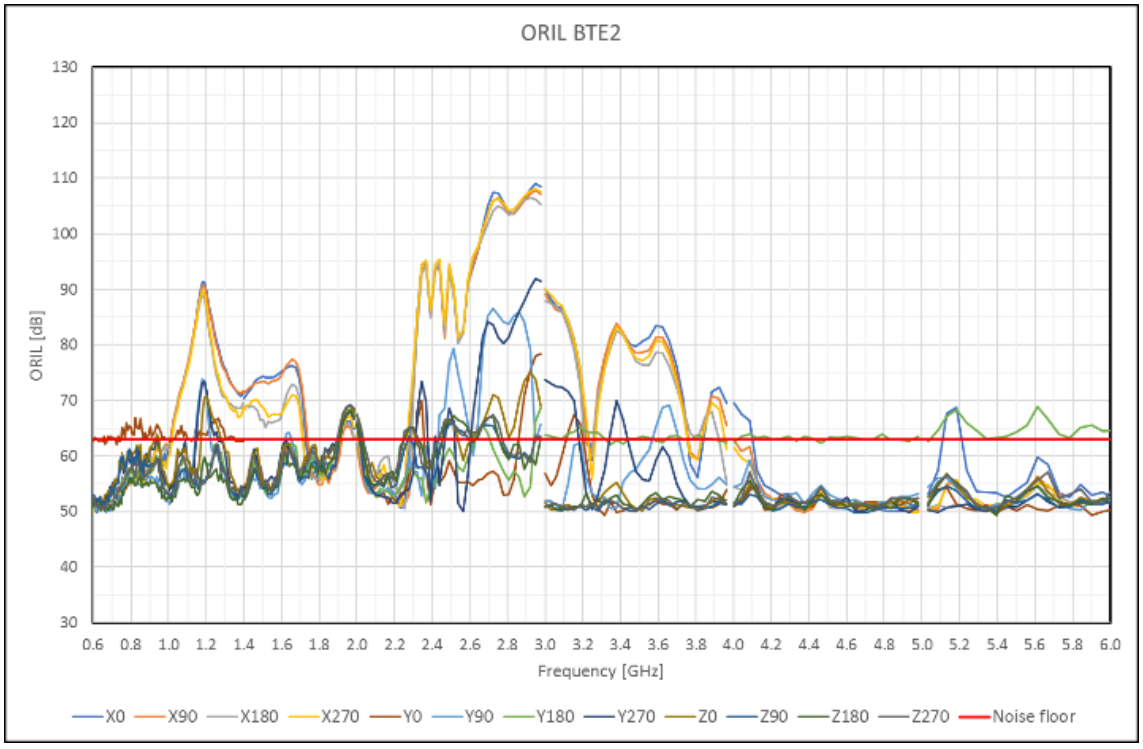
Ranking1: FRM



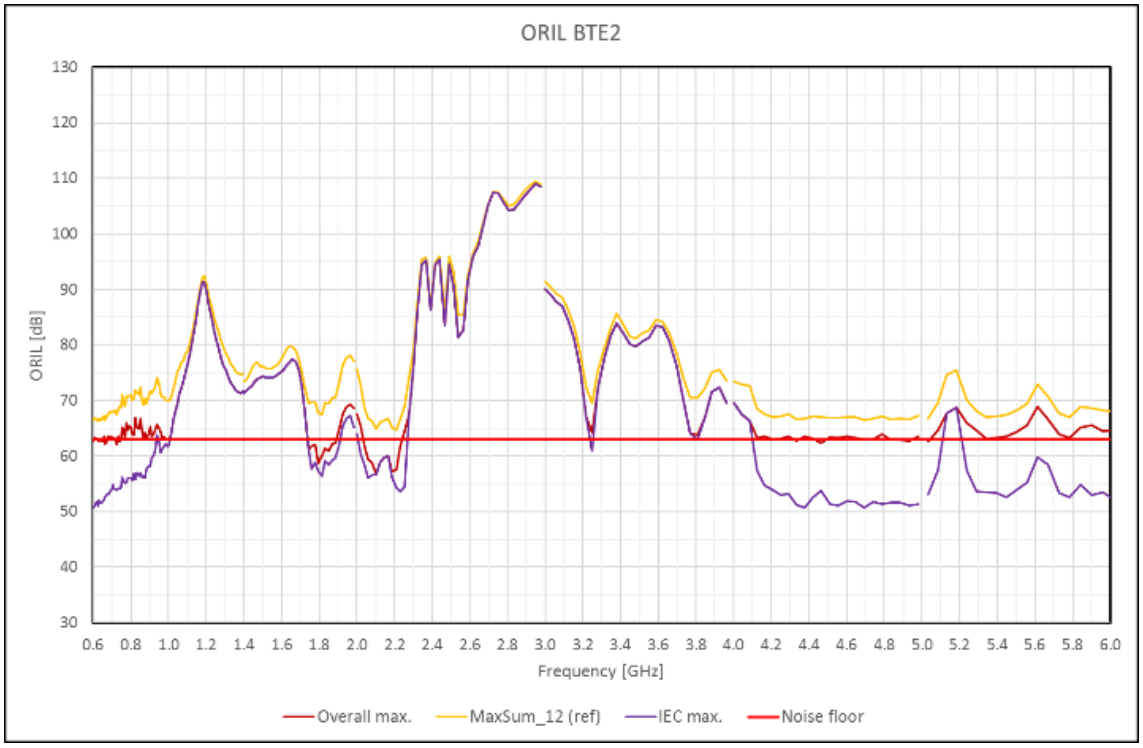
Ranking2: FRMD

Pic. 25: ORILs BTE1

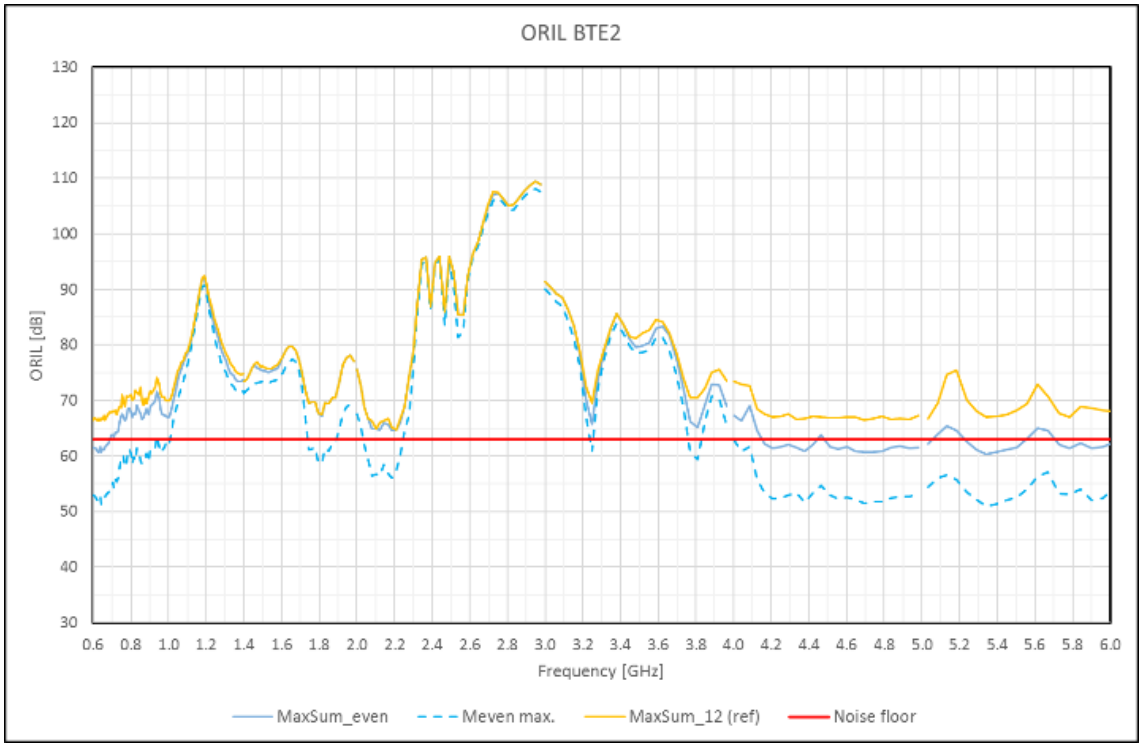
3.2.2 BTE2



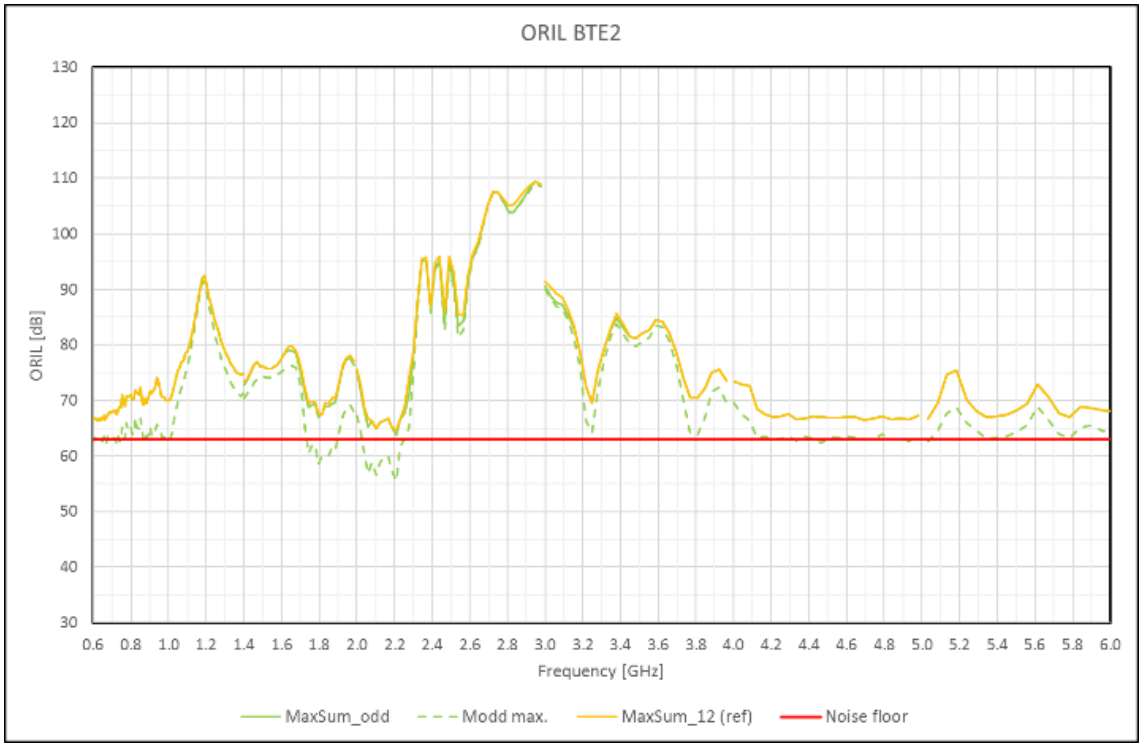
All measurements



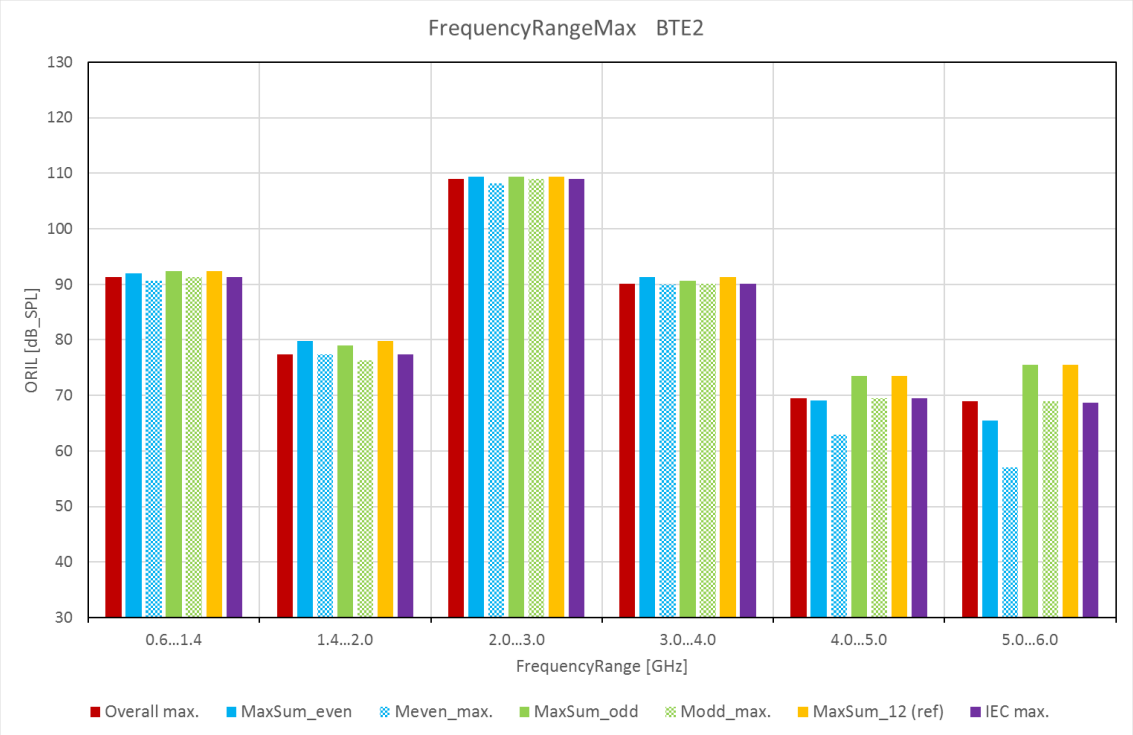
Evaluation1: Overall max., IEC max., MaxSum_12



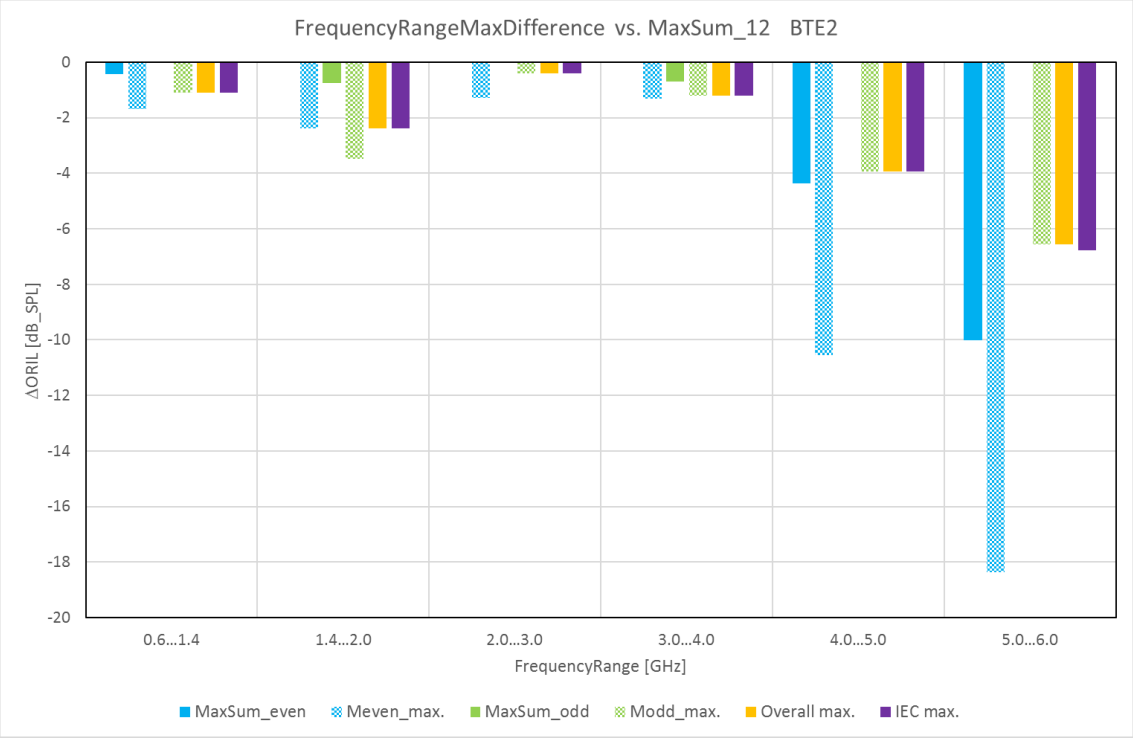
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



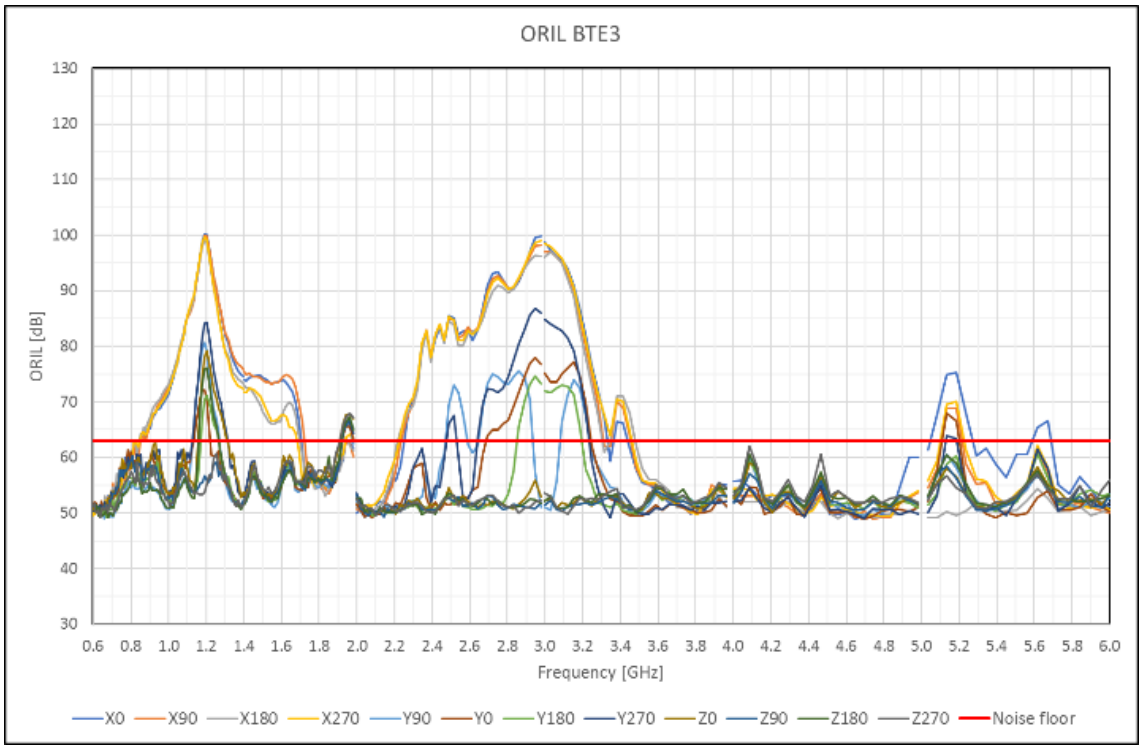
Ranking1: FRM



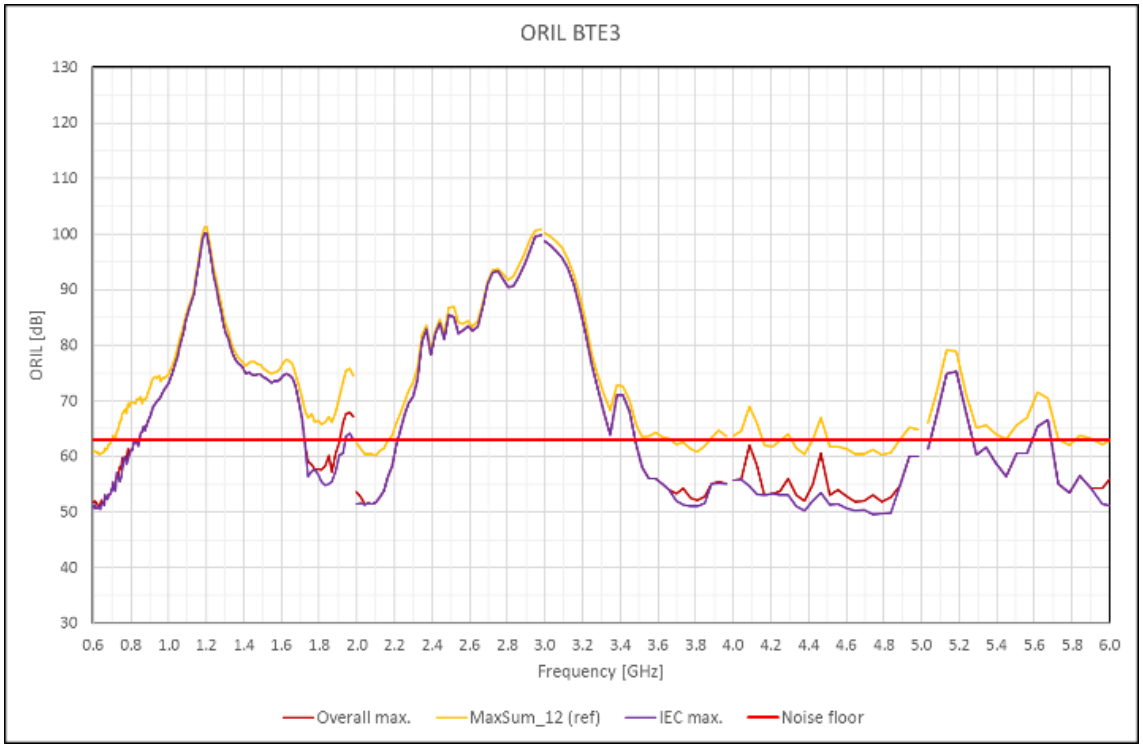
Ranking2: FRMD

Pic. 26: ORILs BTE2

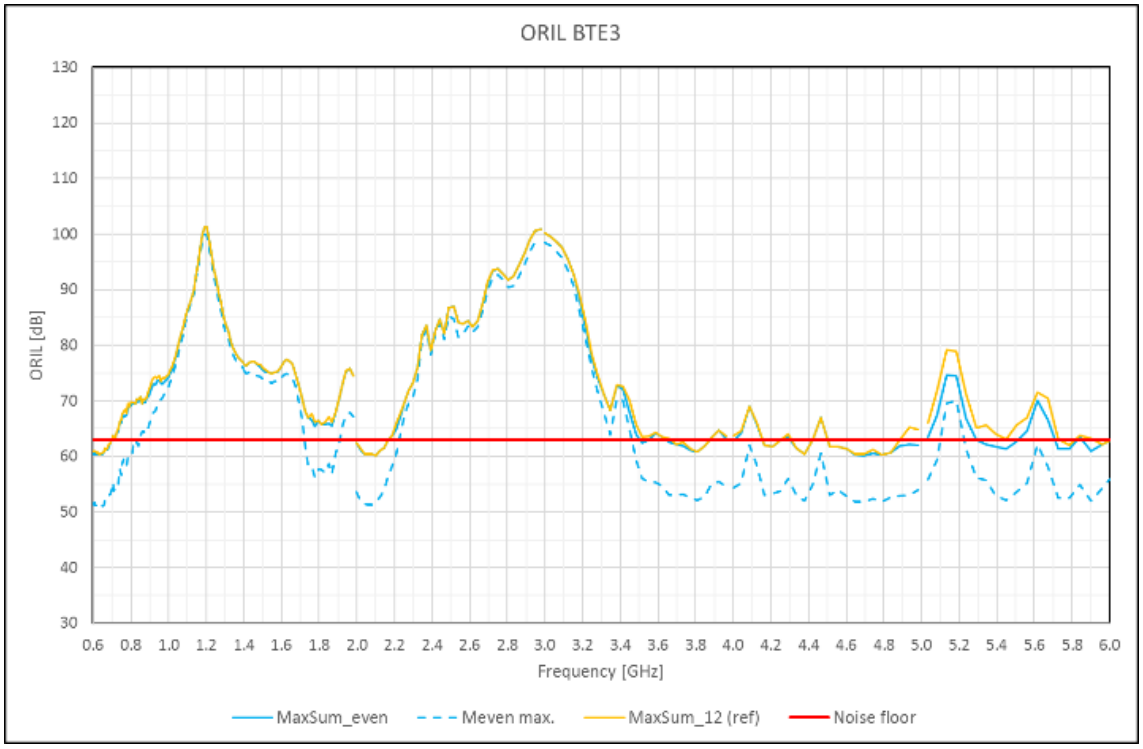
3.2.3 BTE3



All measurements

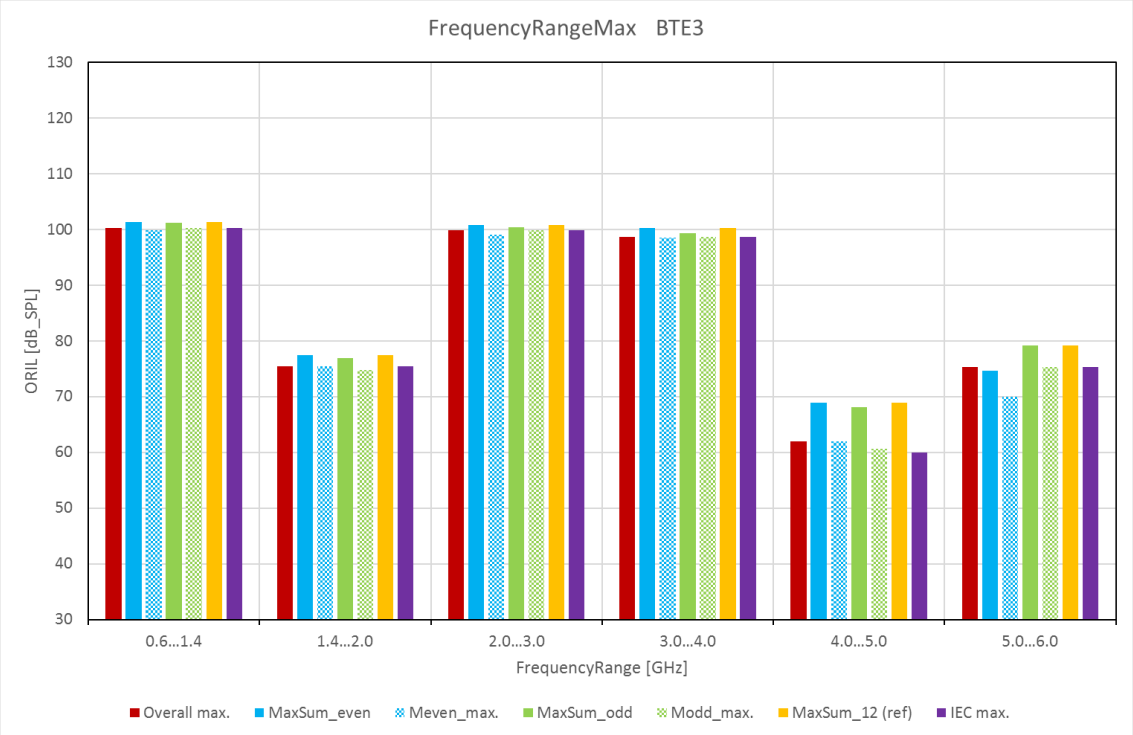


Evaluation1: Overall max., IEC max., MaxSum_12

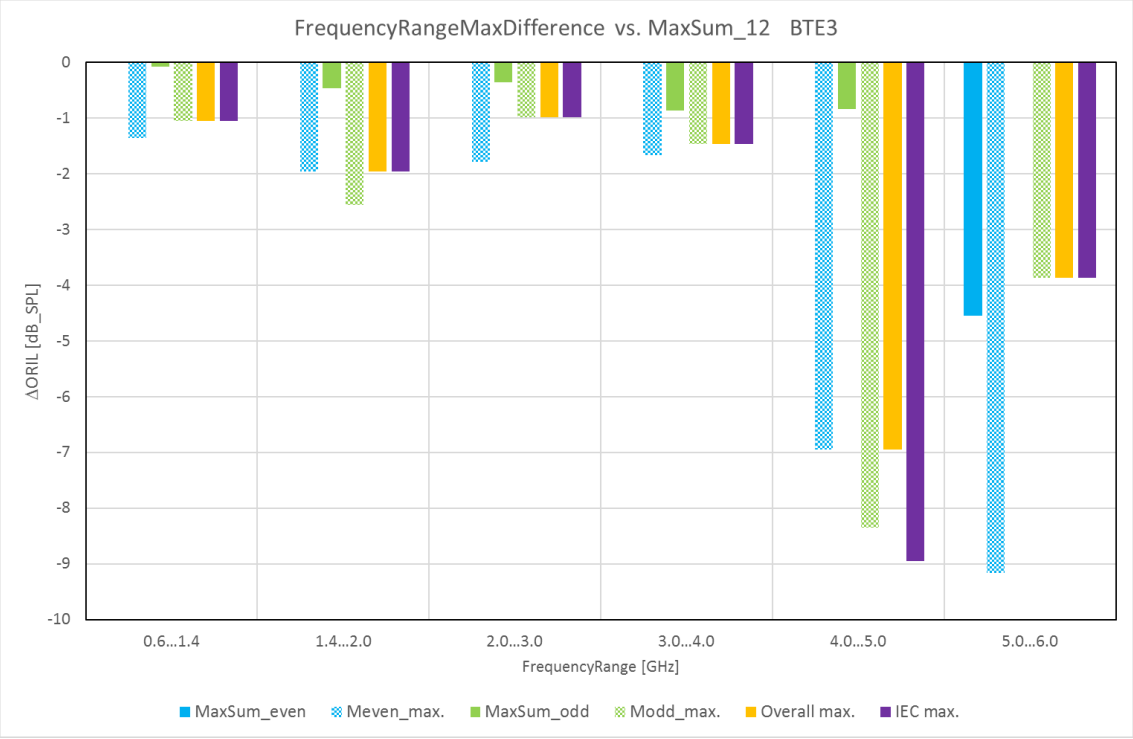


Evaluation2: MaxSum_even, Meven max., MaxSum_12

Evaluation3: MaxSum_odd, Modd max., MaxSum_12



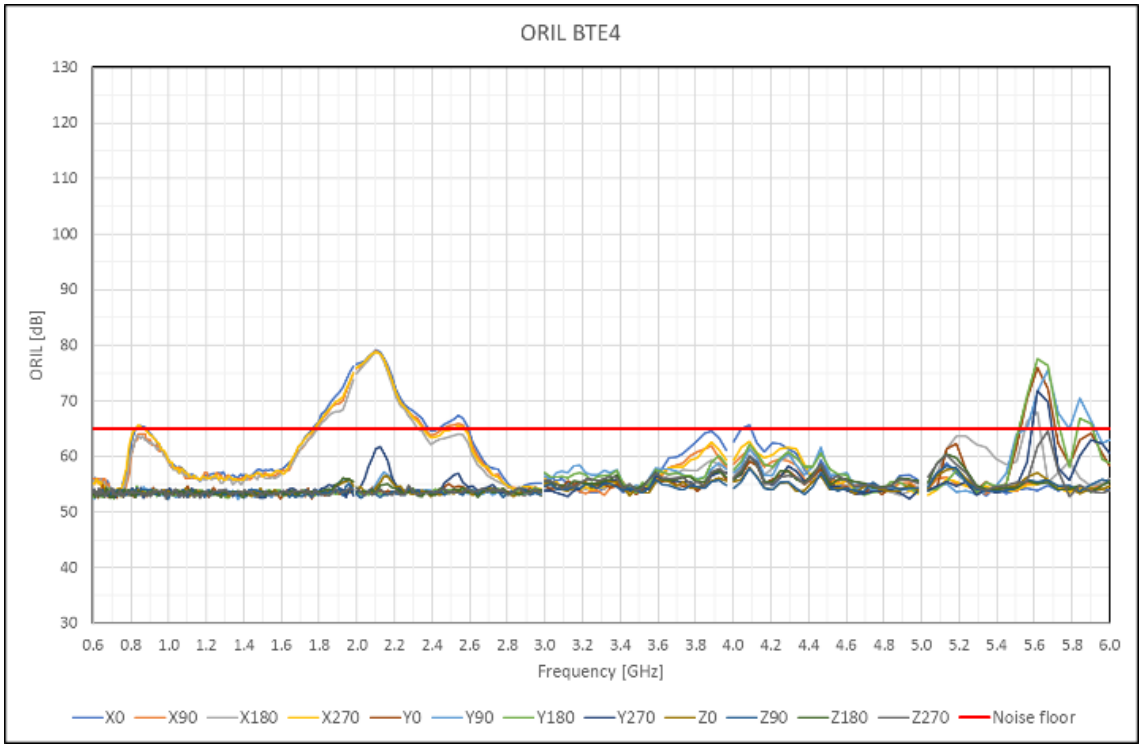
Ranking1: FRM



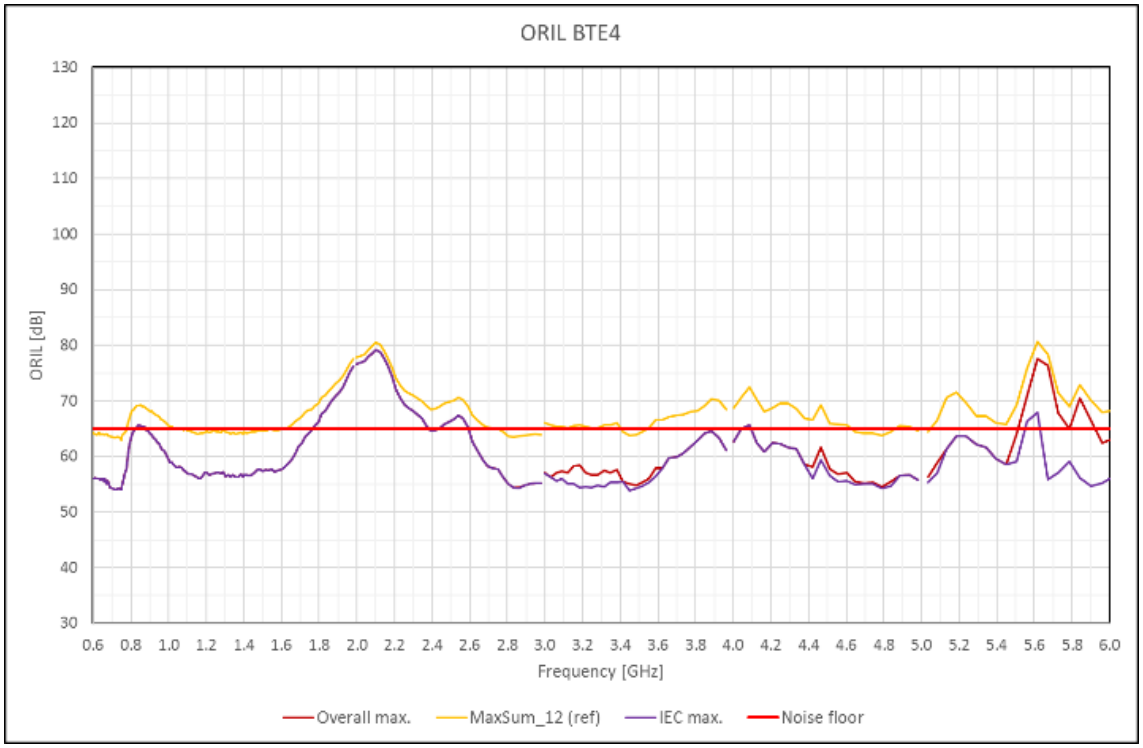
Ranking2: FRMD

Pic. 27: ORILs BTE3

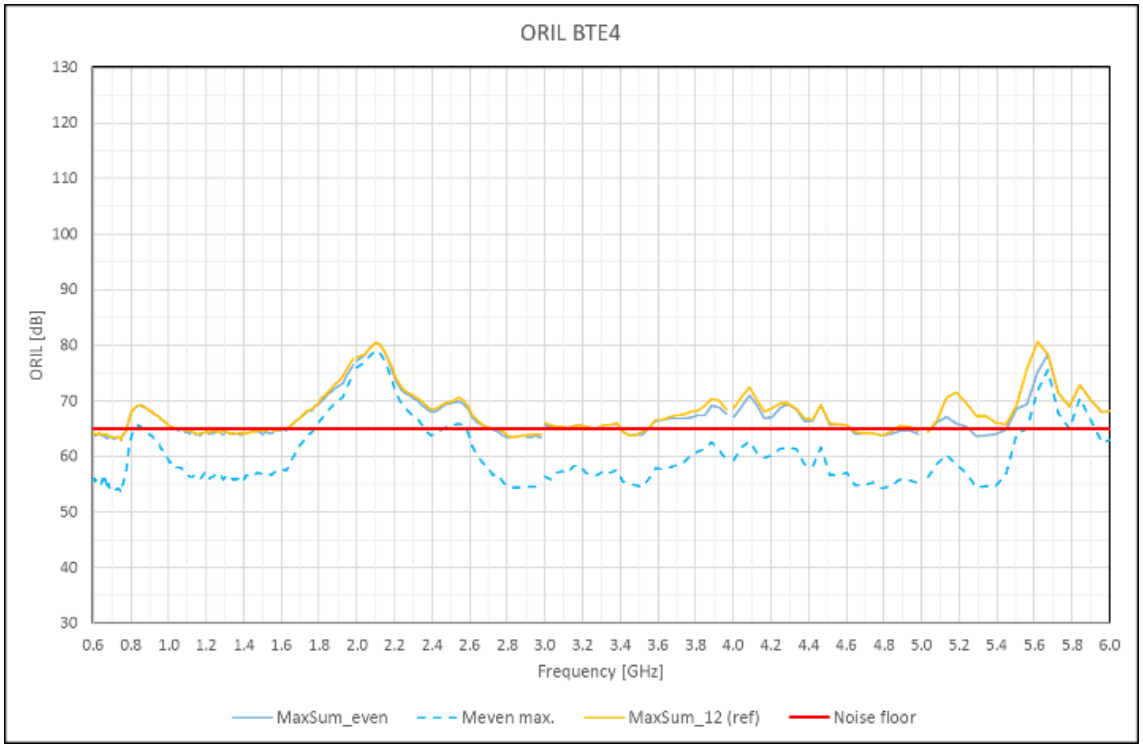
3.2.4 BTE4



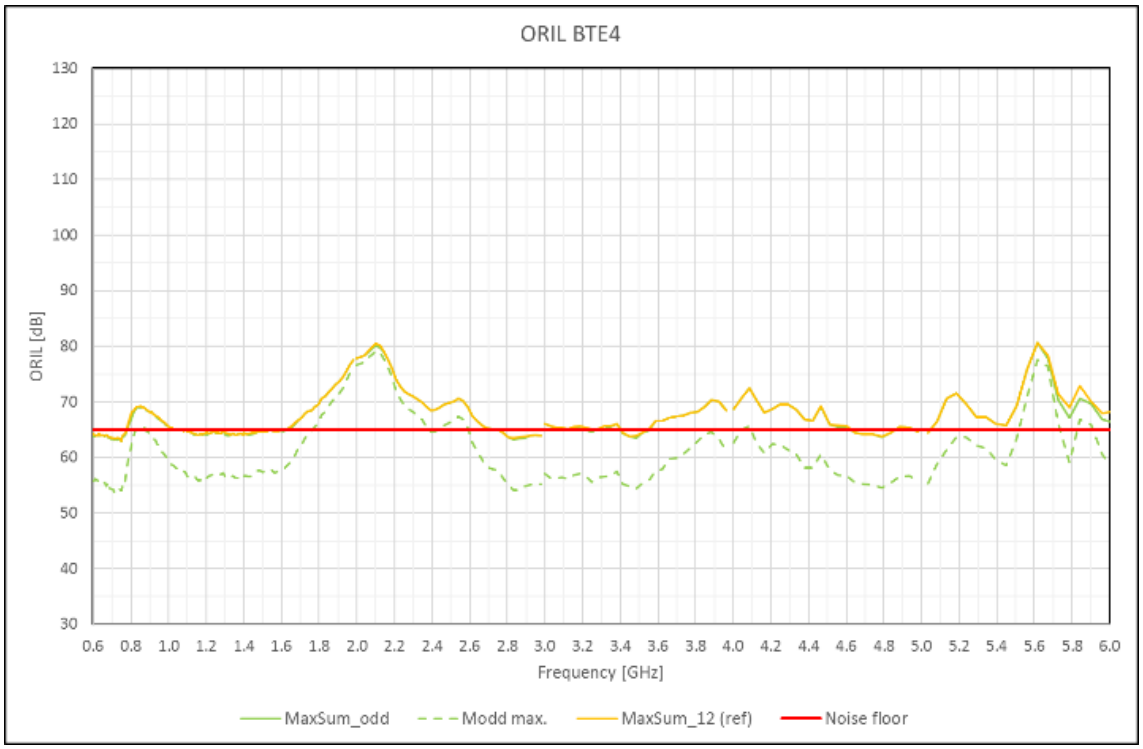
All measurements



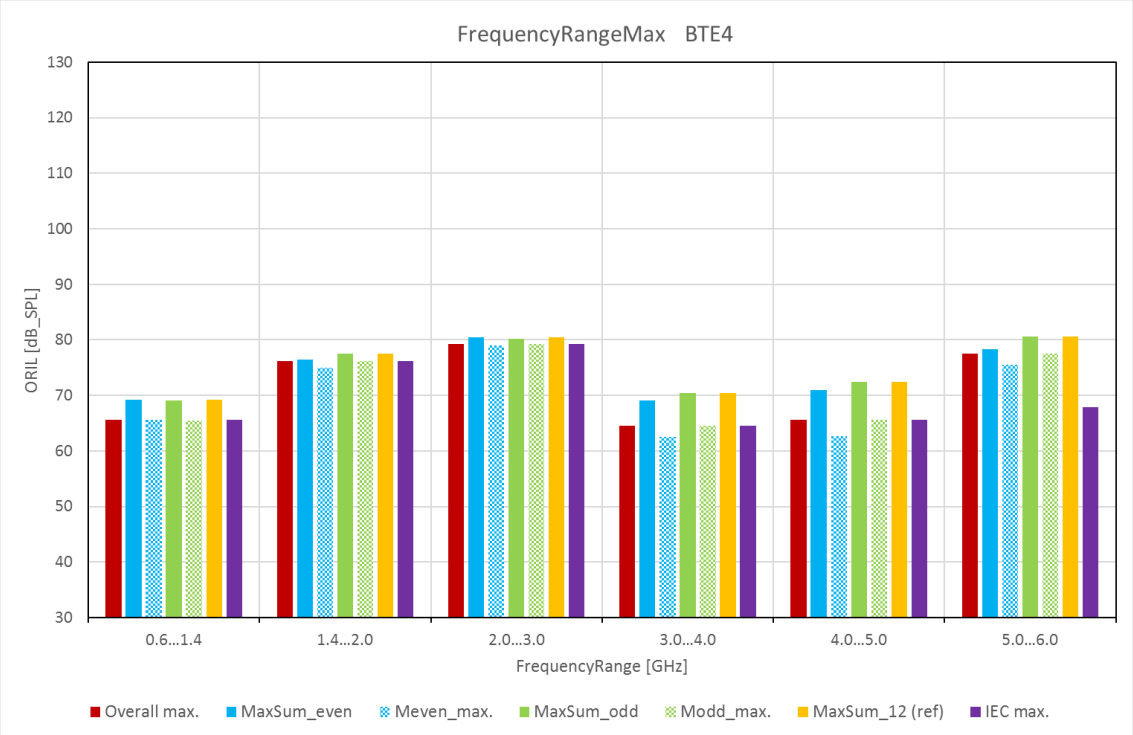
Evaluation1: Overall max., IEC max., MaxSum_12



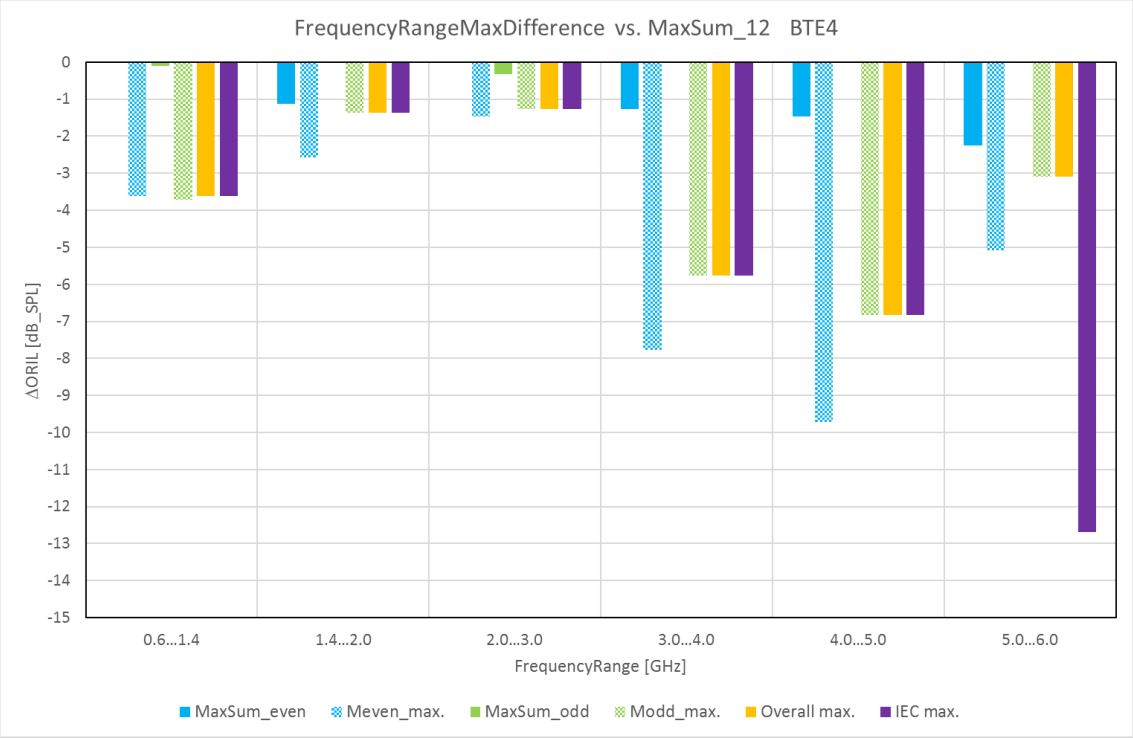
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



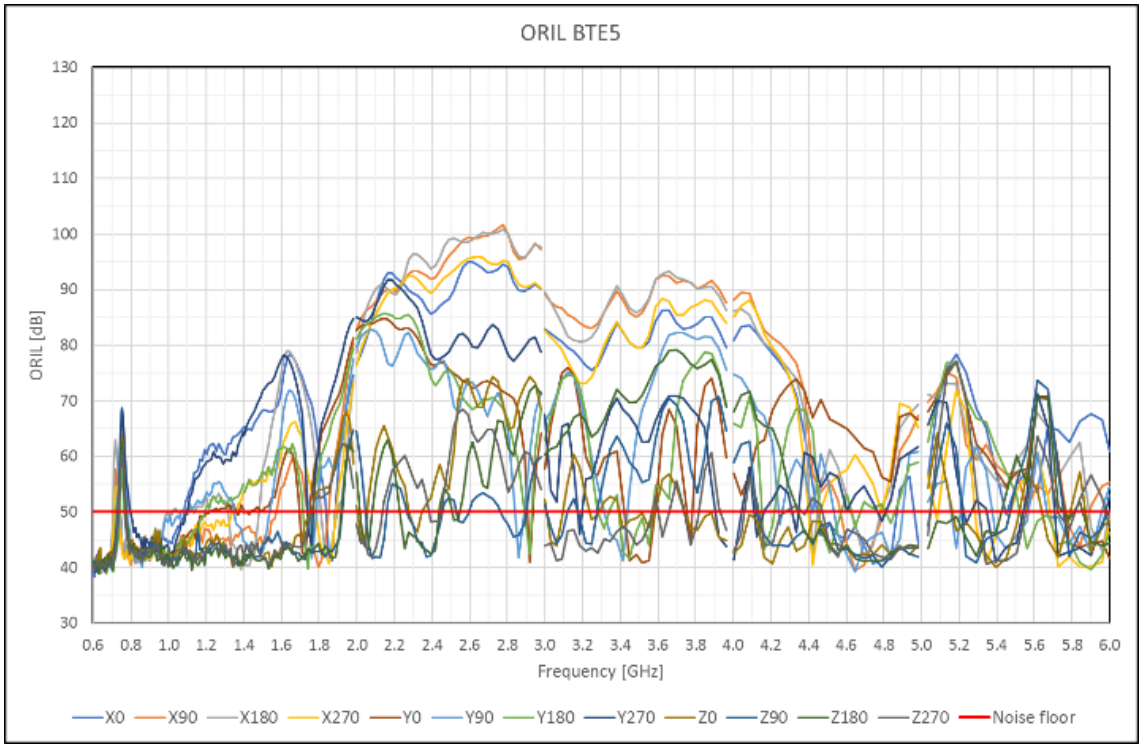
Ranking1: FRM



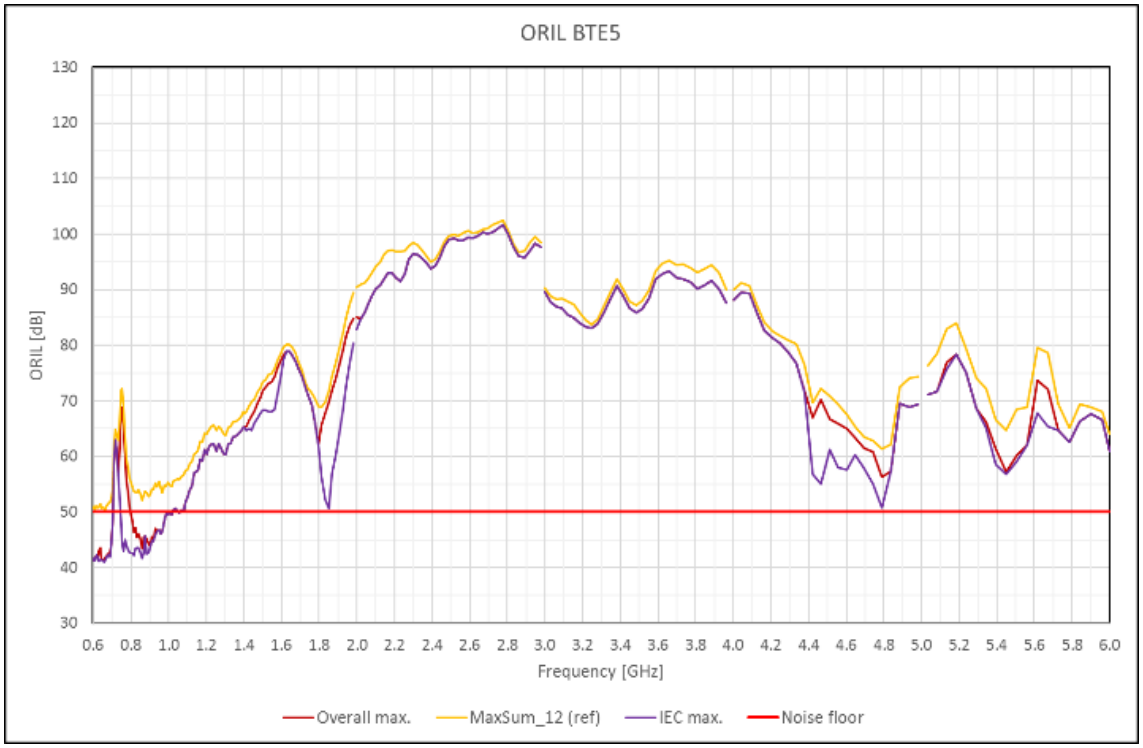
Ranking2: FRMD

Pic. 28: ORILs BTE4

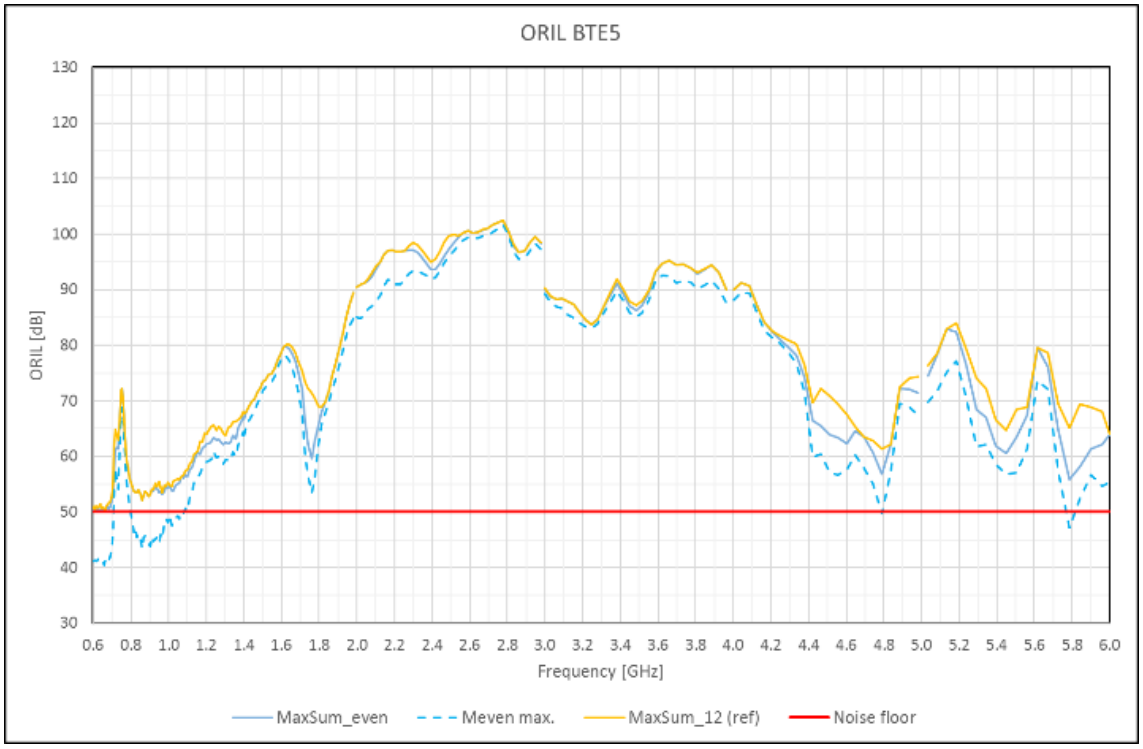
3.2.5 BTE5



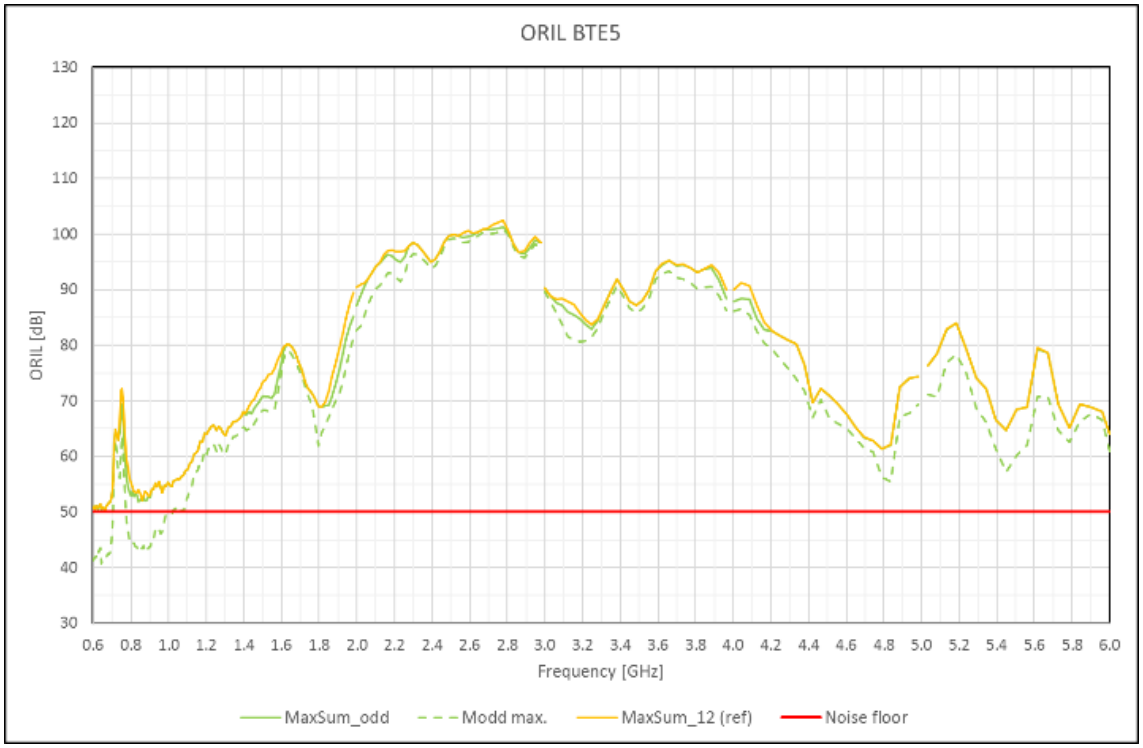
All measurements



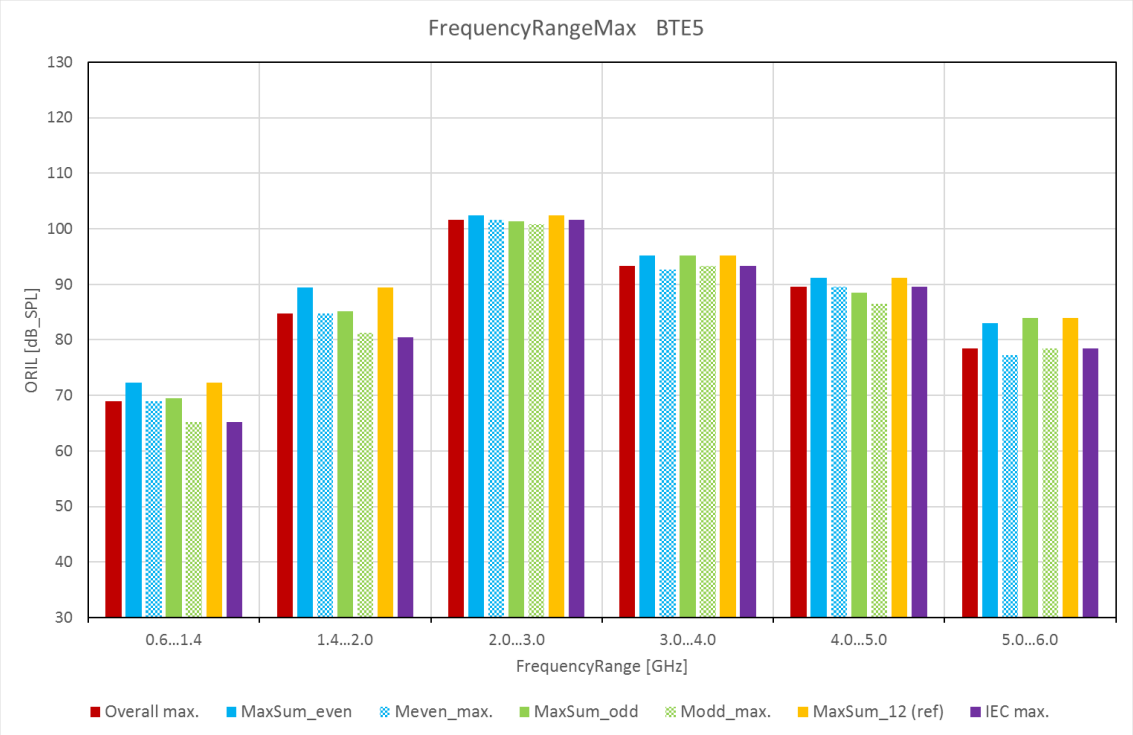
Evaluation1: Overall max., IEC max., MaxSum_12



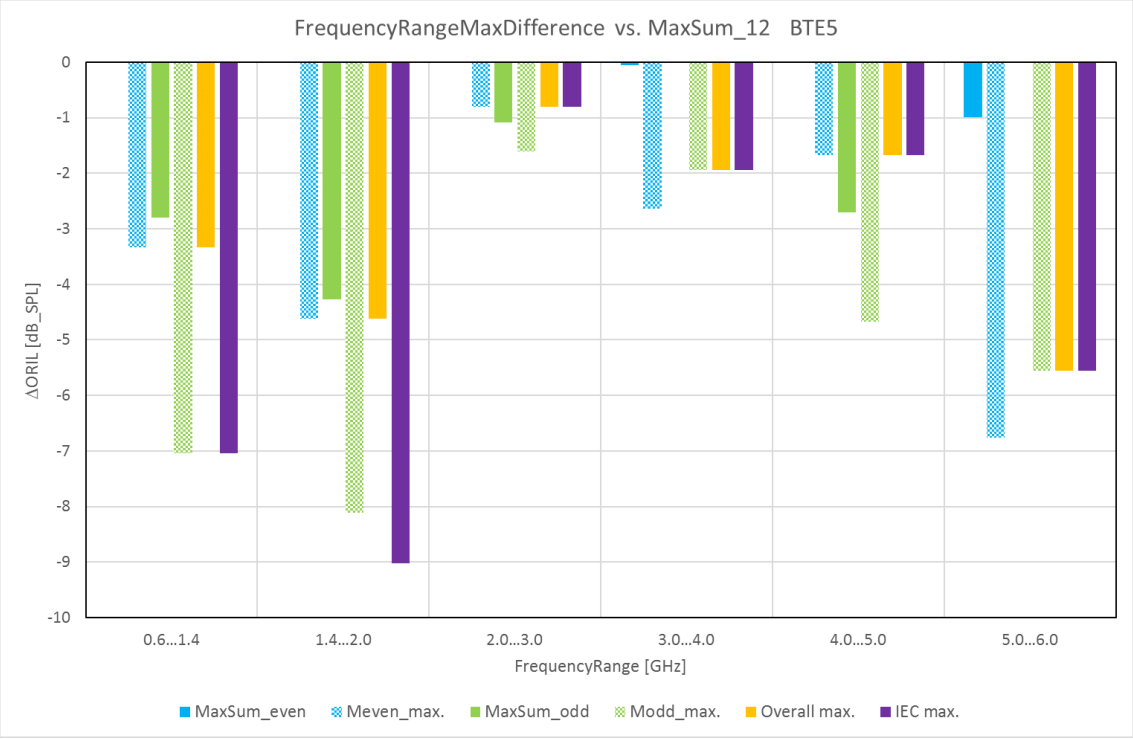
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



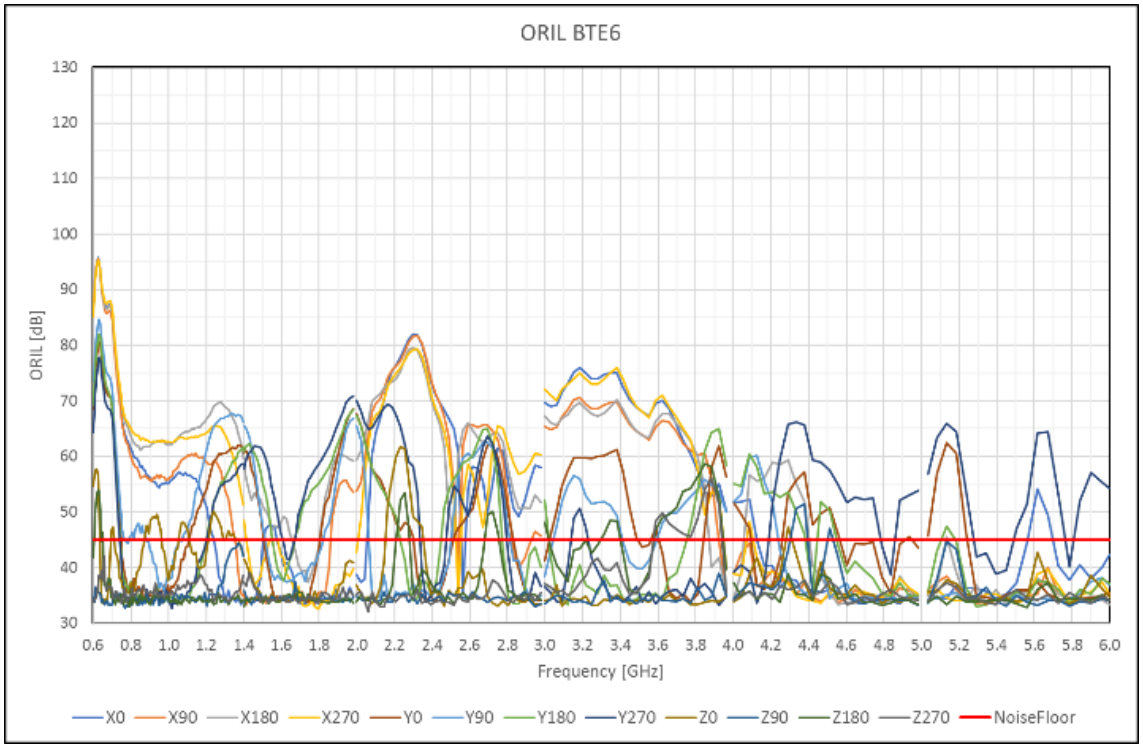
Ranking1: FRM



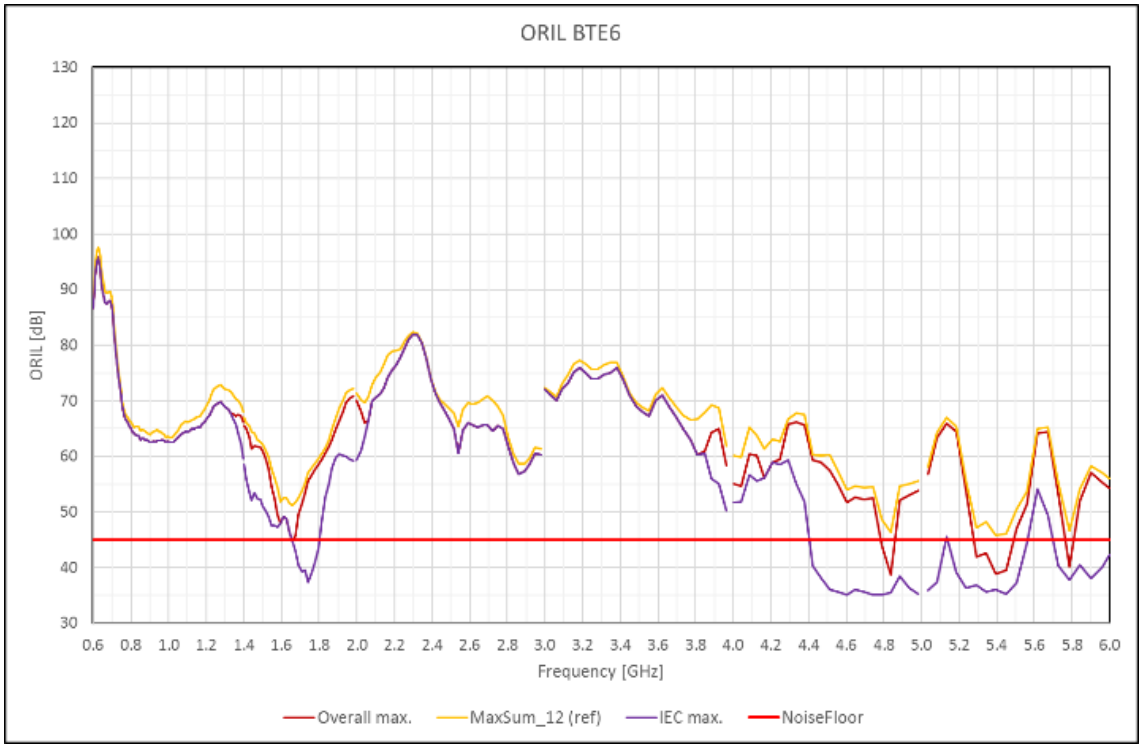
Ranking2: FRMD

Pic. 29: ORILs BTE5

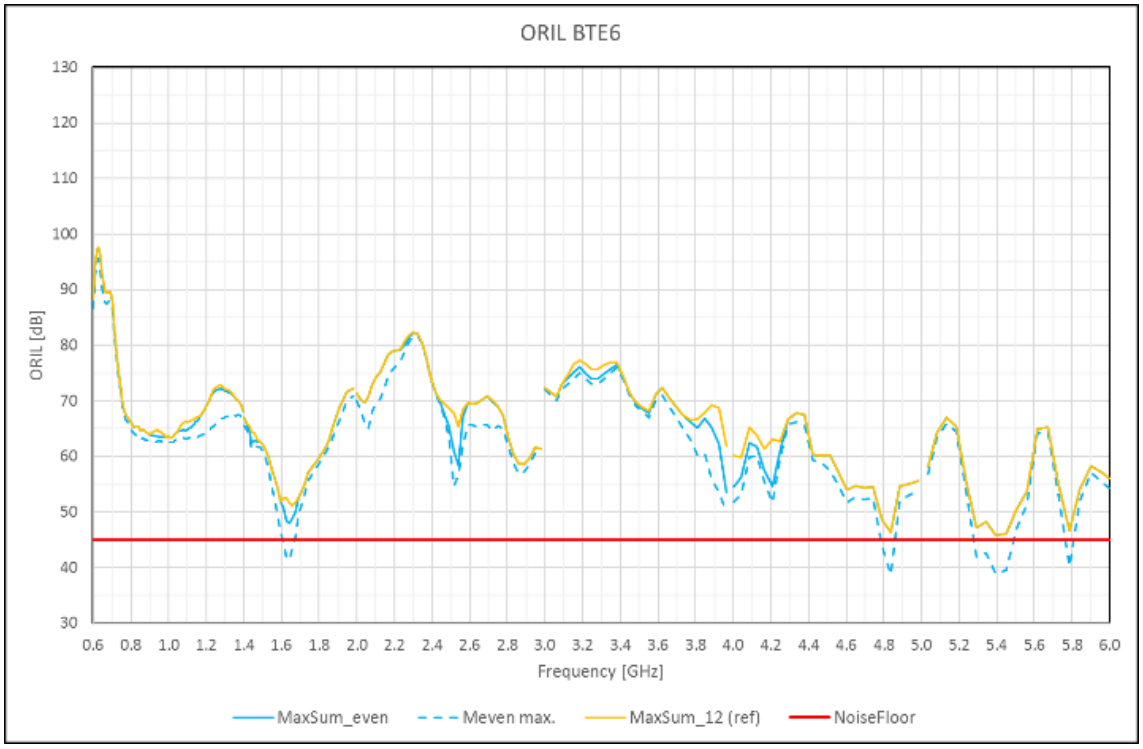
3.2.6 BTE6



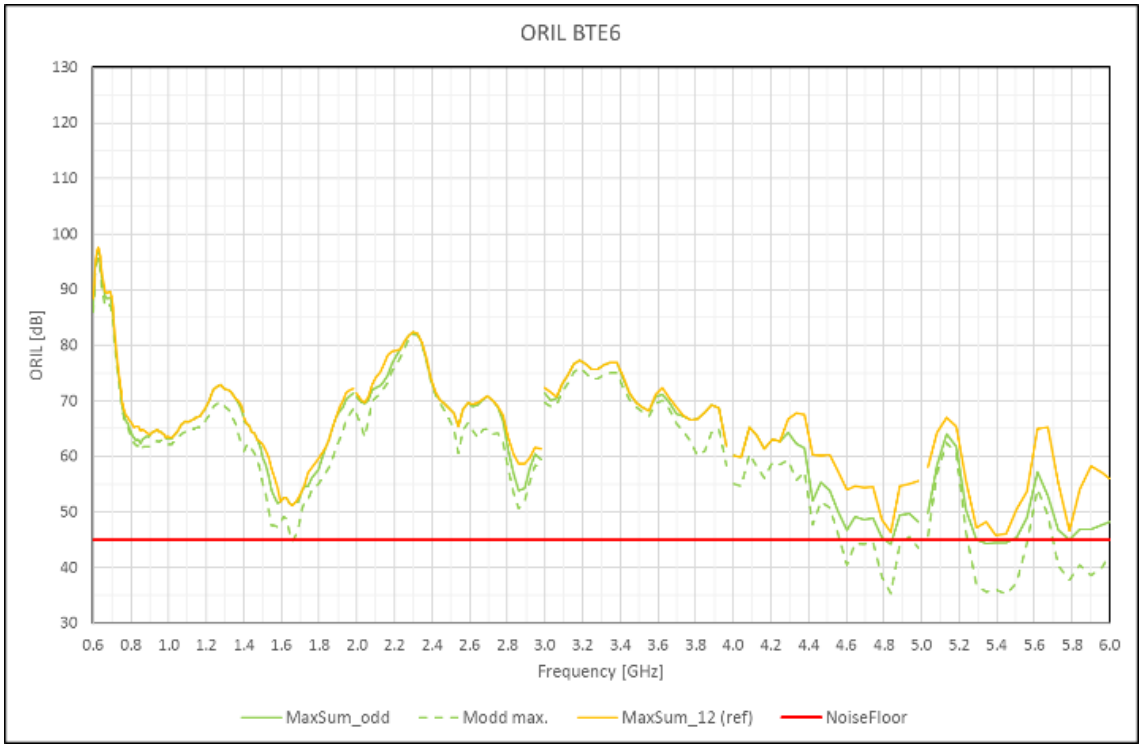
All measurements



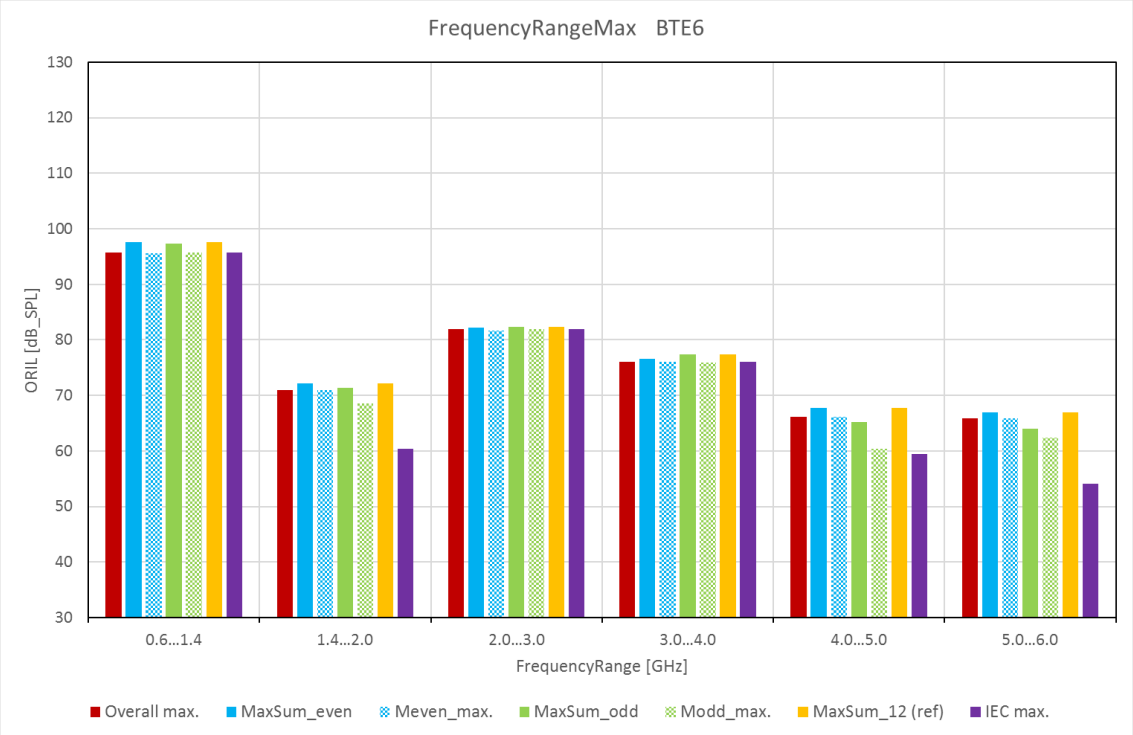
Evaluation1: Overall max., IEC max., MaxSum_12



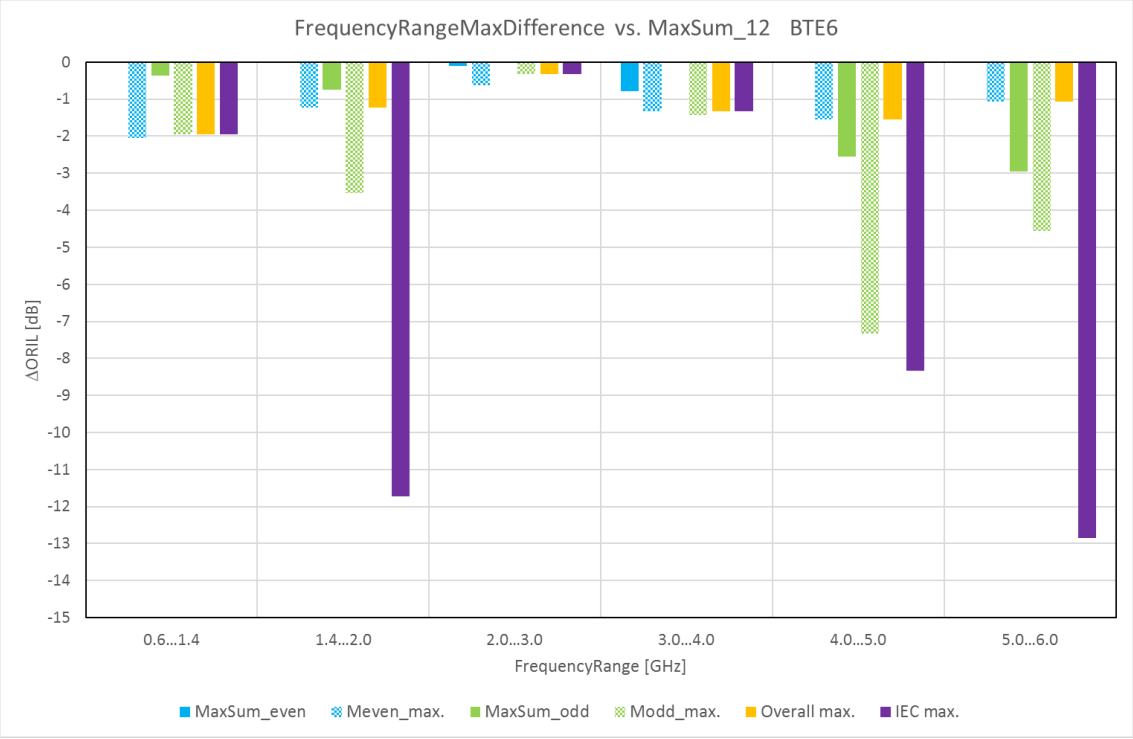
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



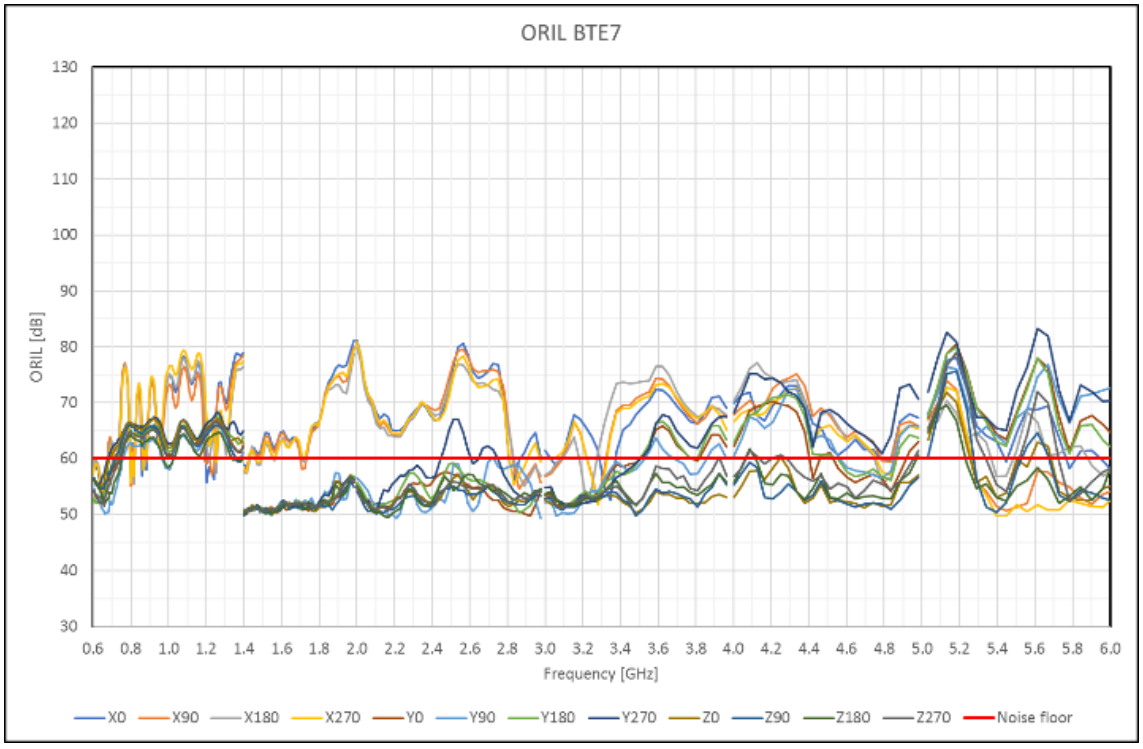
Ranking1: FRM



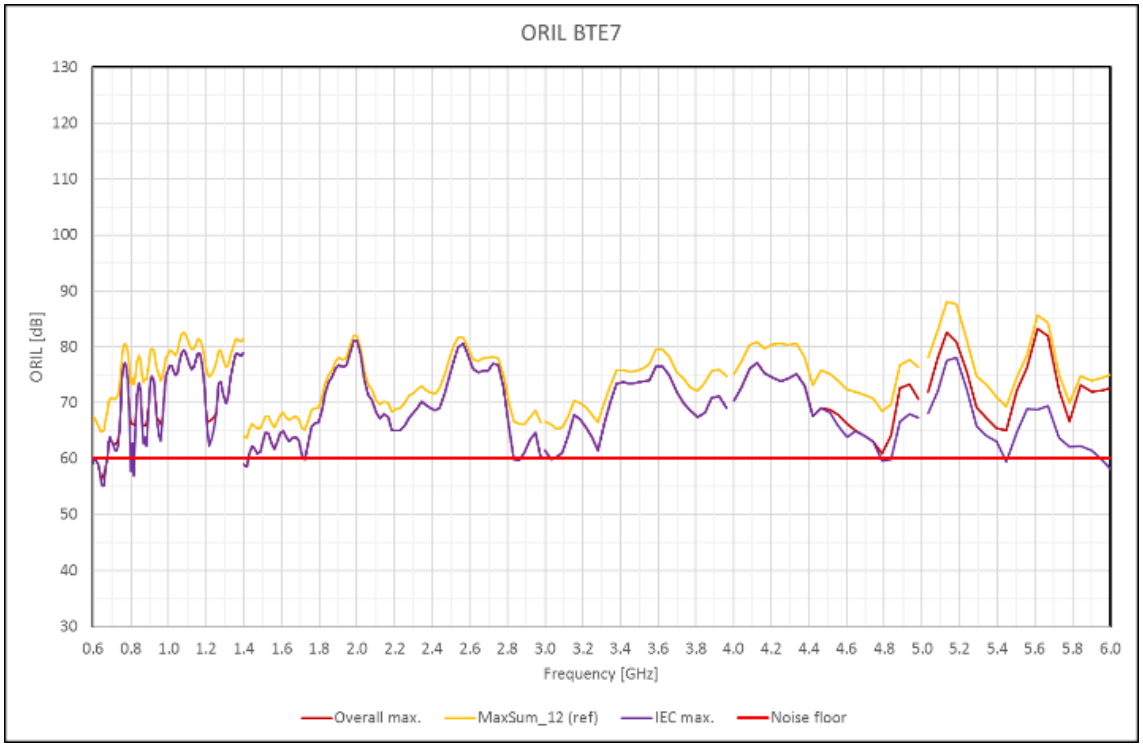
Ranking2: FRMD

Pic. 30: ORILs BTE6

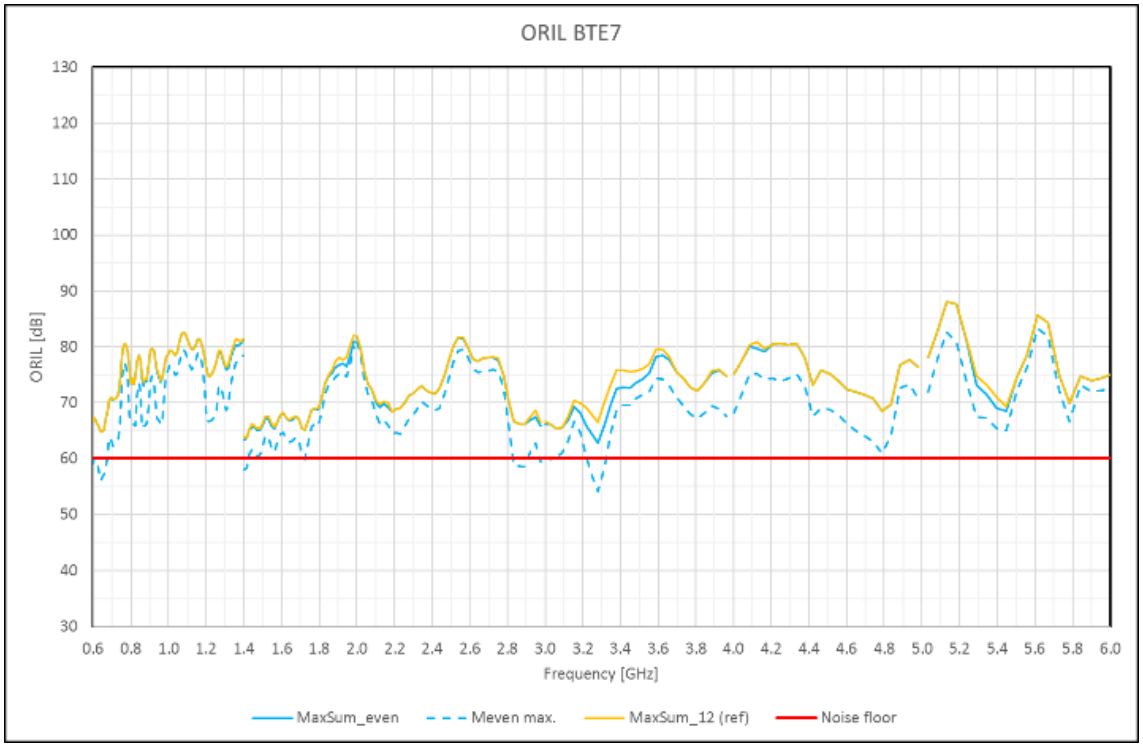
3.2.7 BTE7



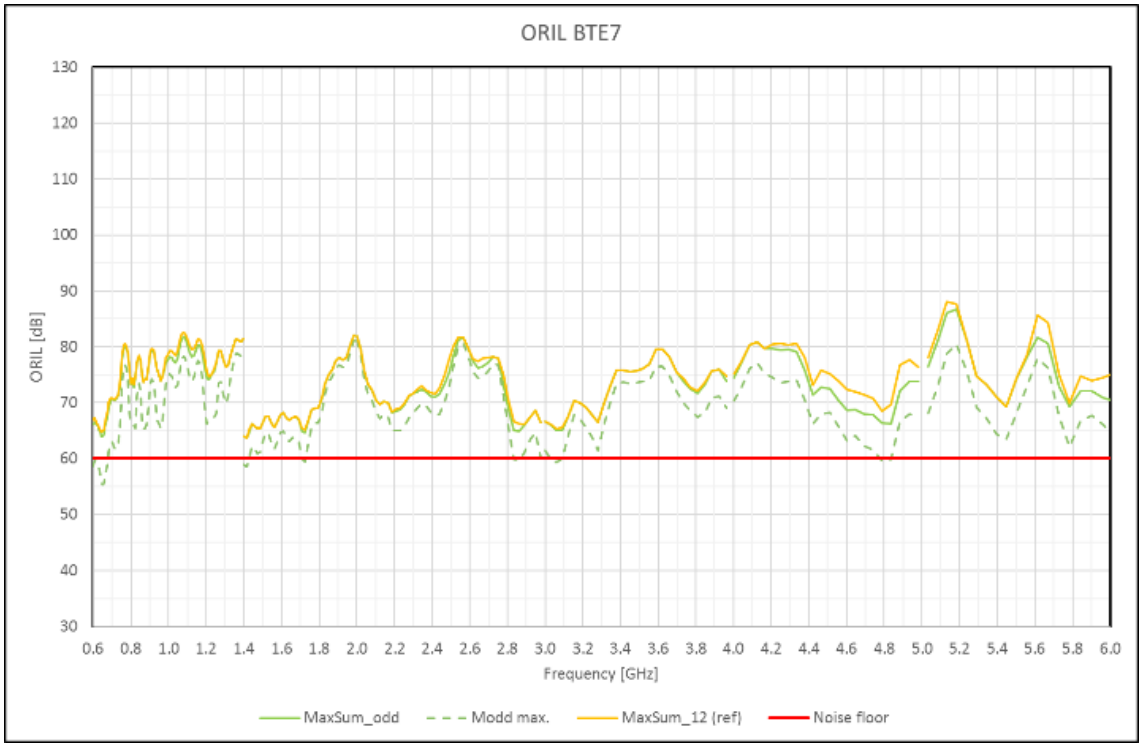
All measurements



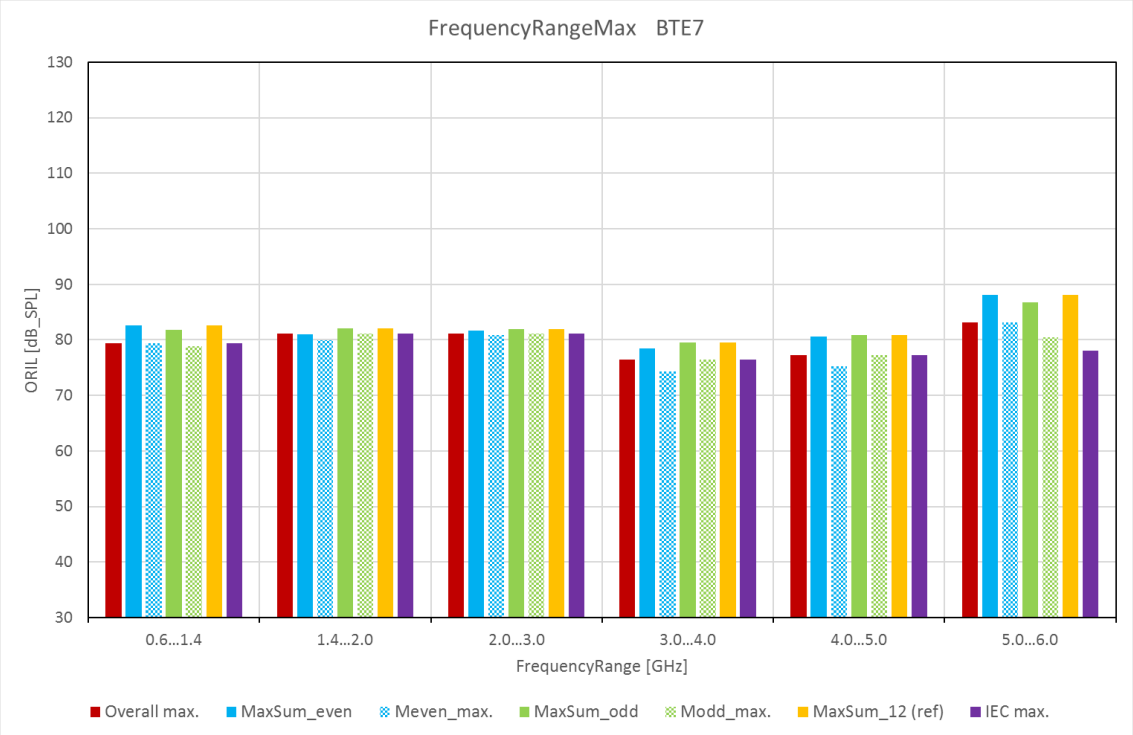
Evaluation1: Overall max., IEC max., MaxSum_12



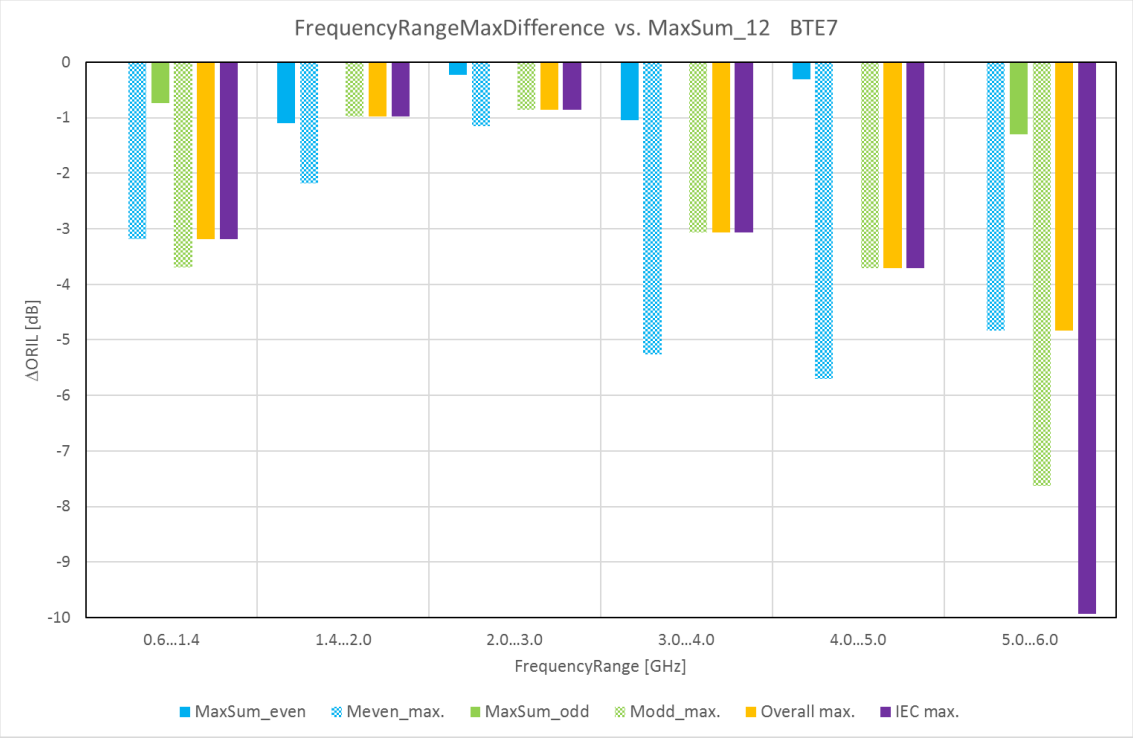
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



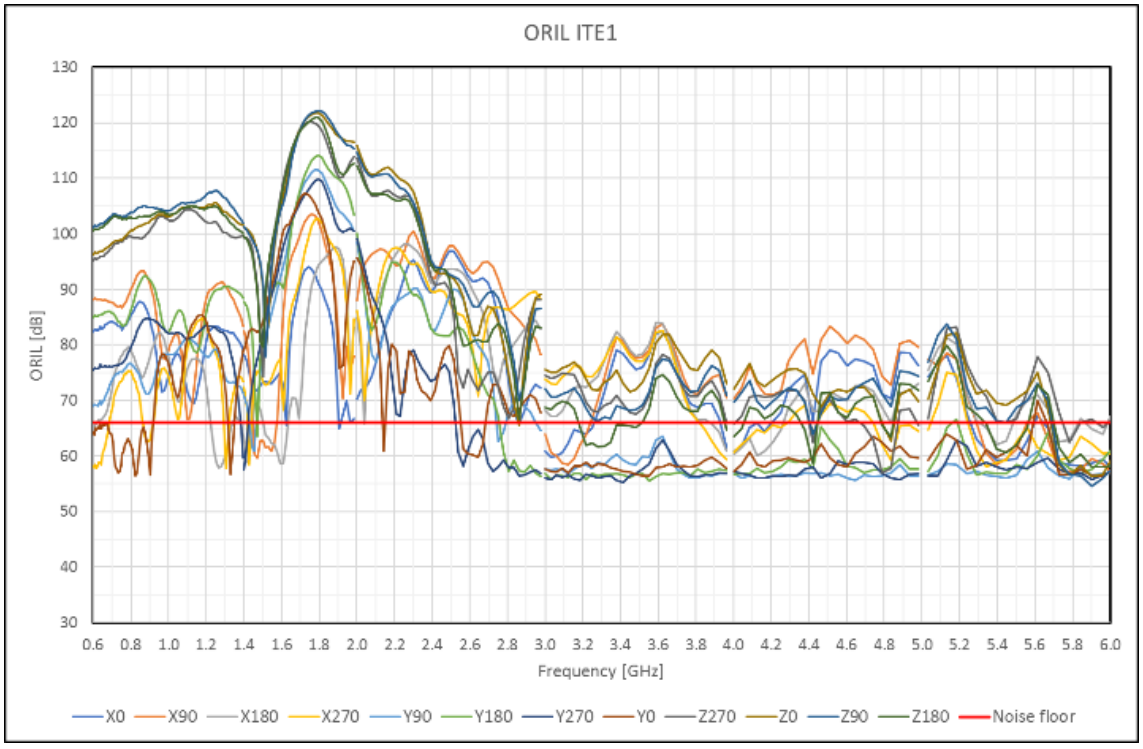
Ranking1: FRM



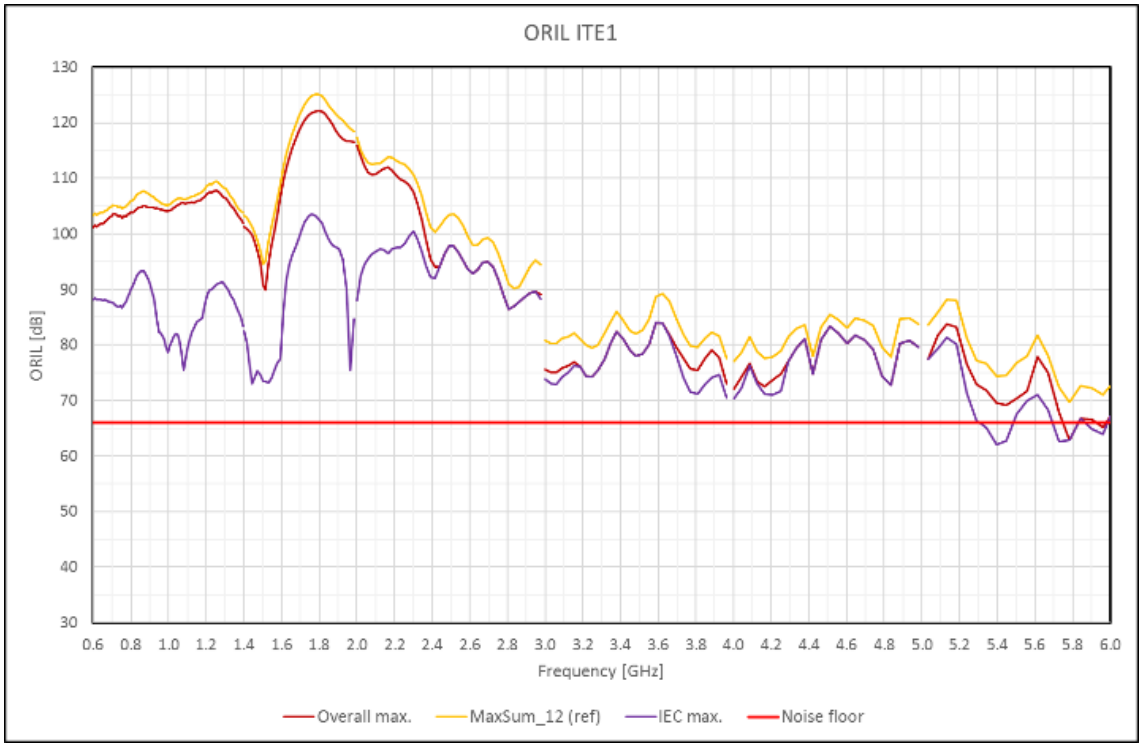
Ranking2: FRMD

Pic. 31: ORILs BTE7

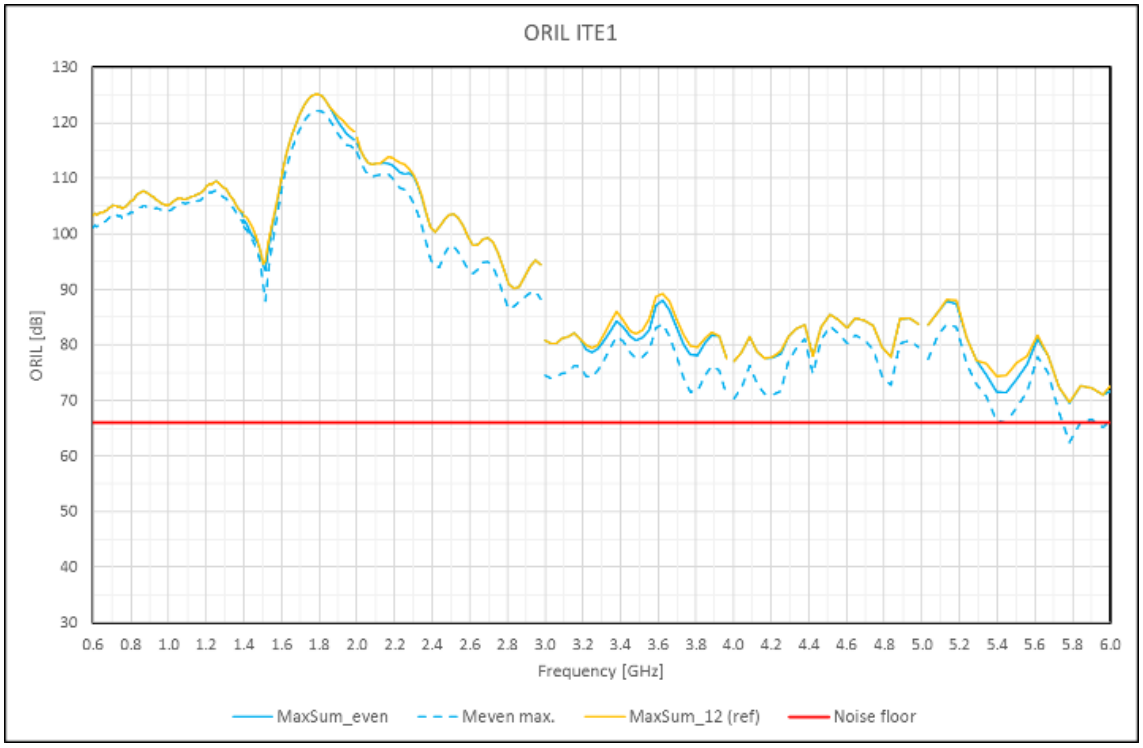
3.2.8 ITE1



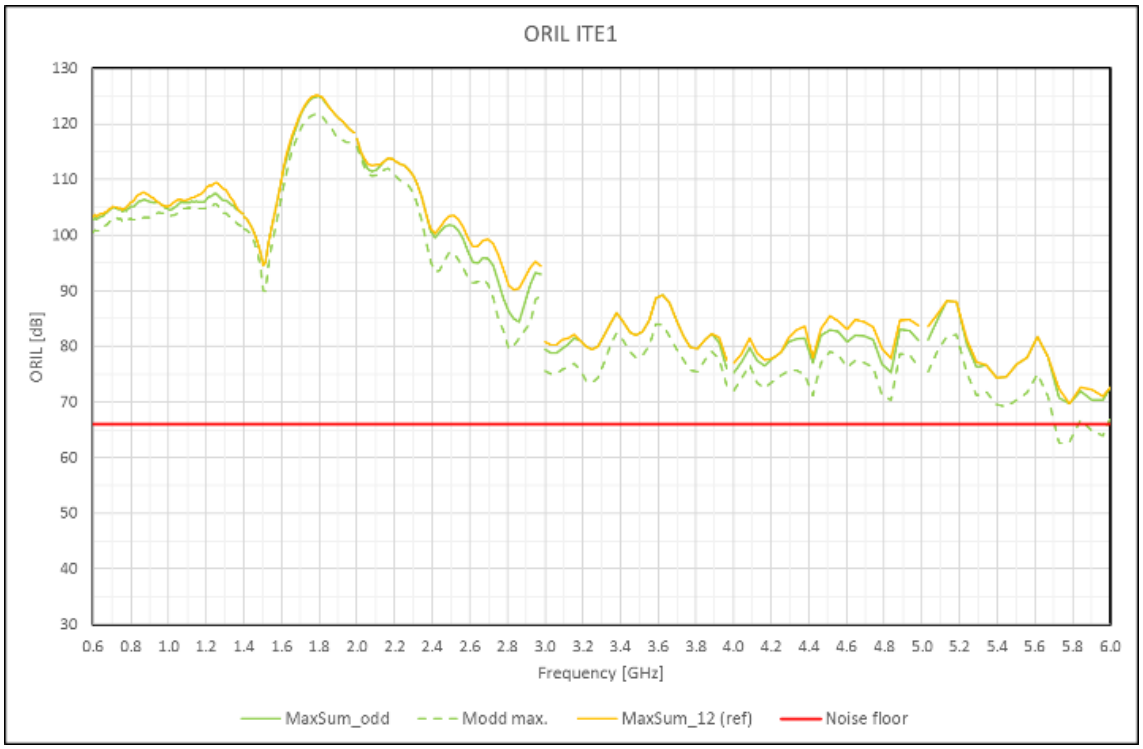
All measurements



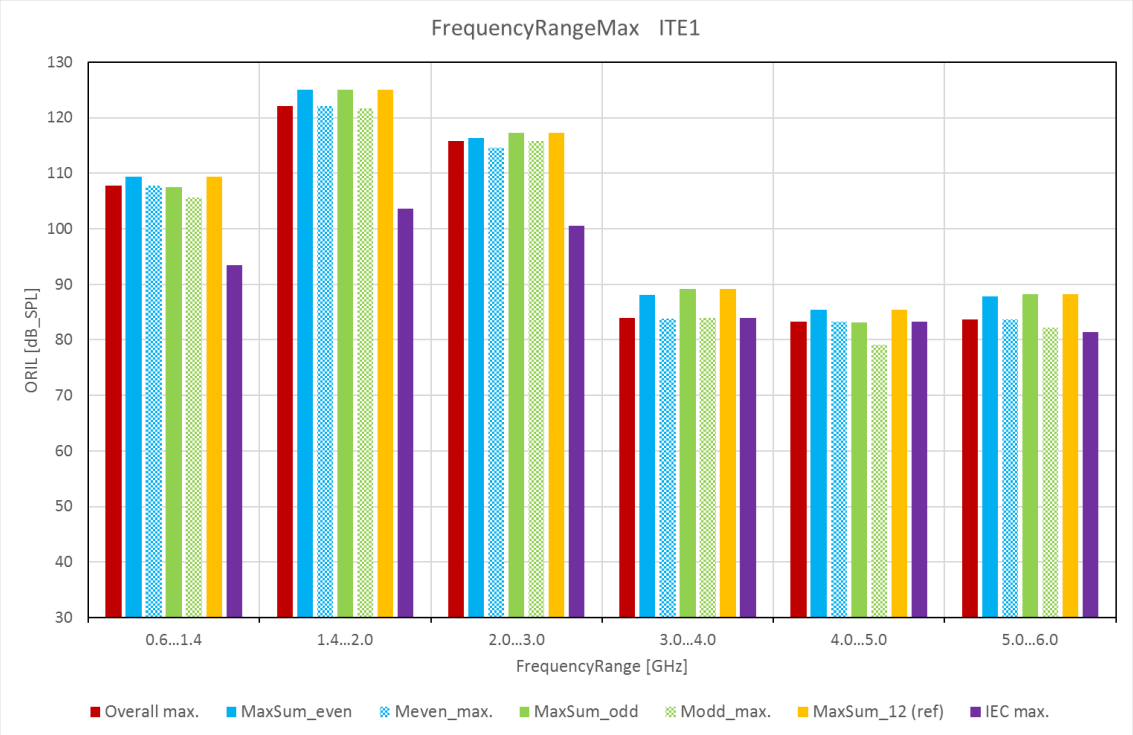
Evaluation1: Overall max., IEC max., MaxSum_12



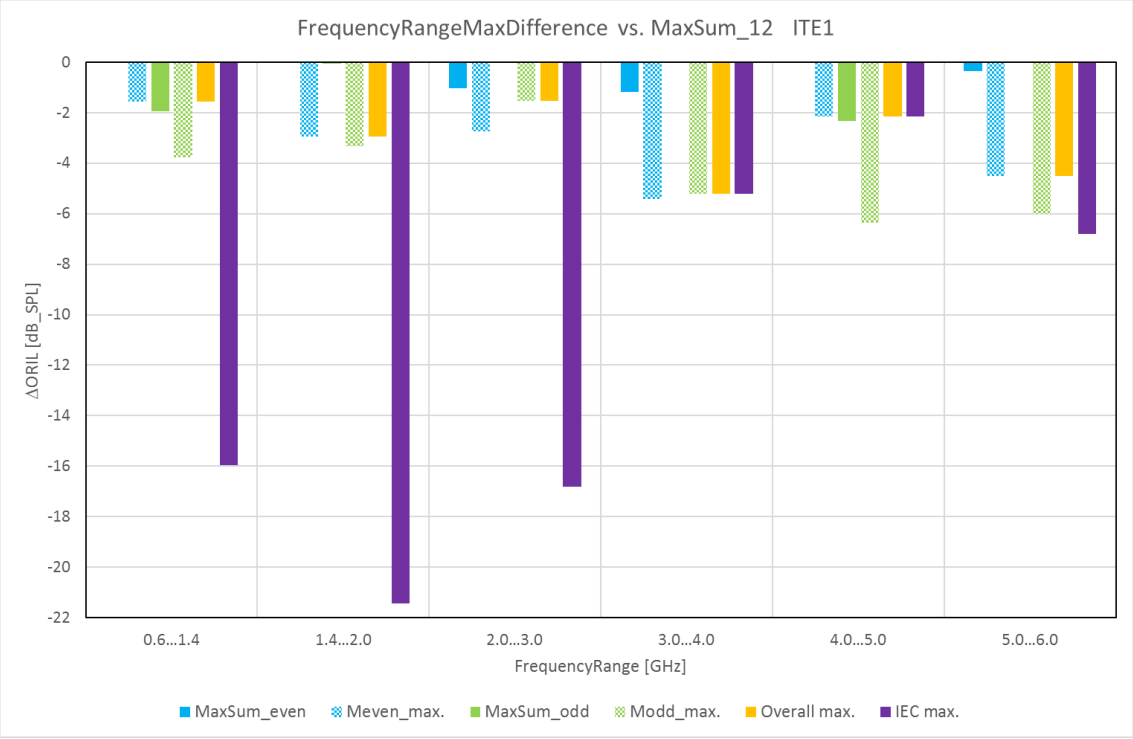
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



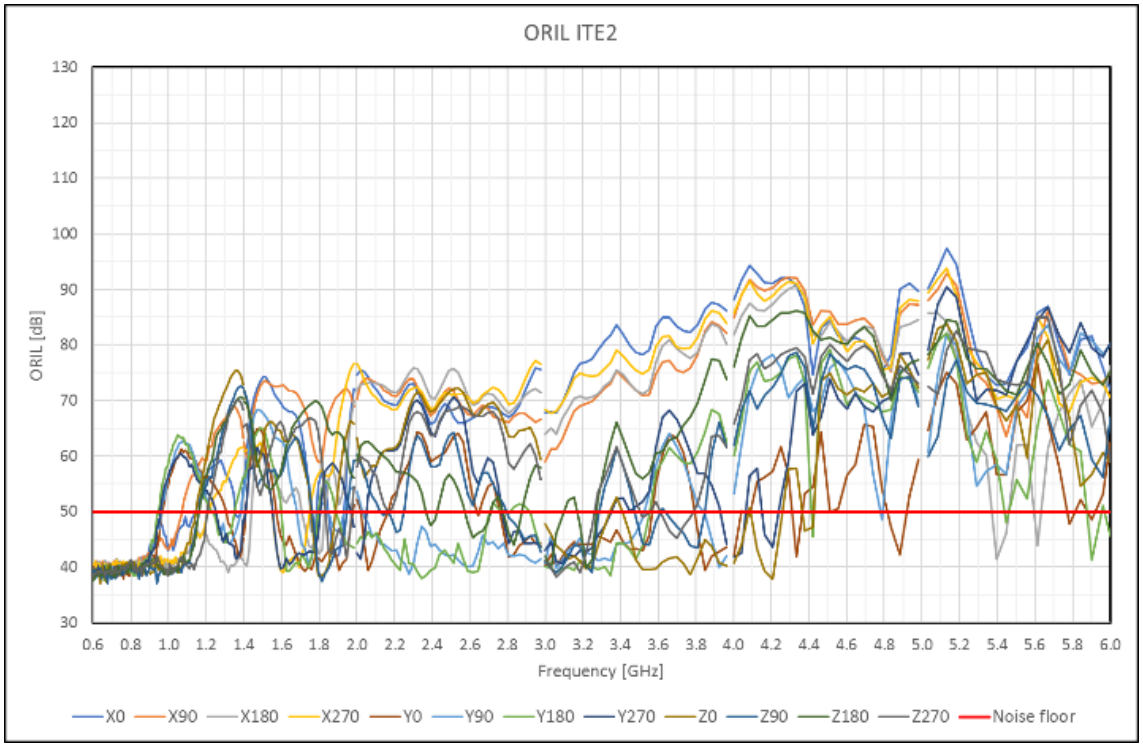
Ranking1: FRM



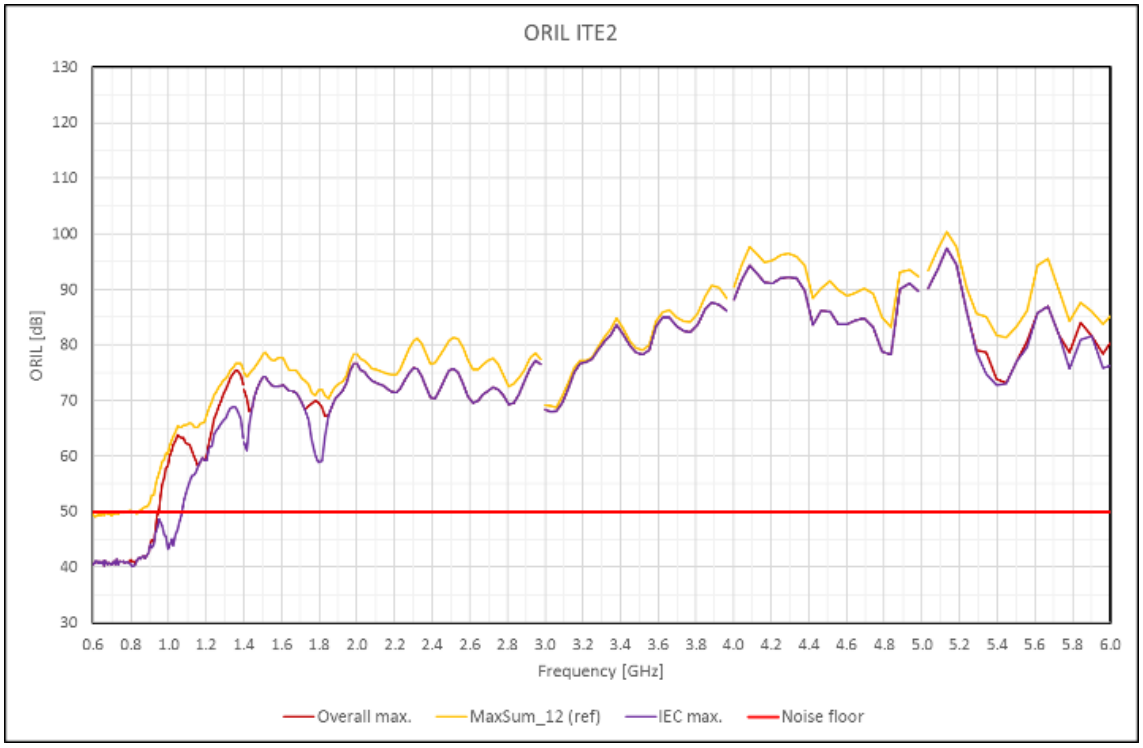
Ranking2: FRMD

Pic. 32: ORILs ITE1

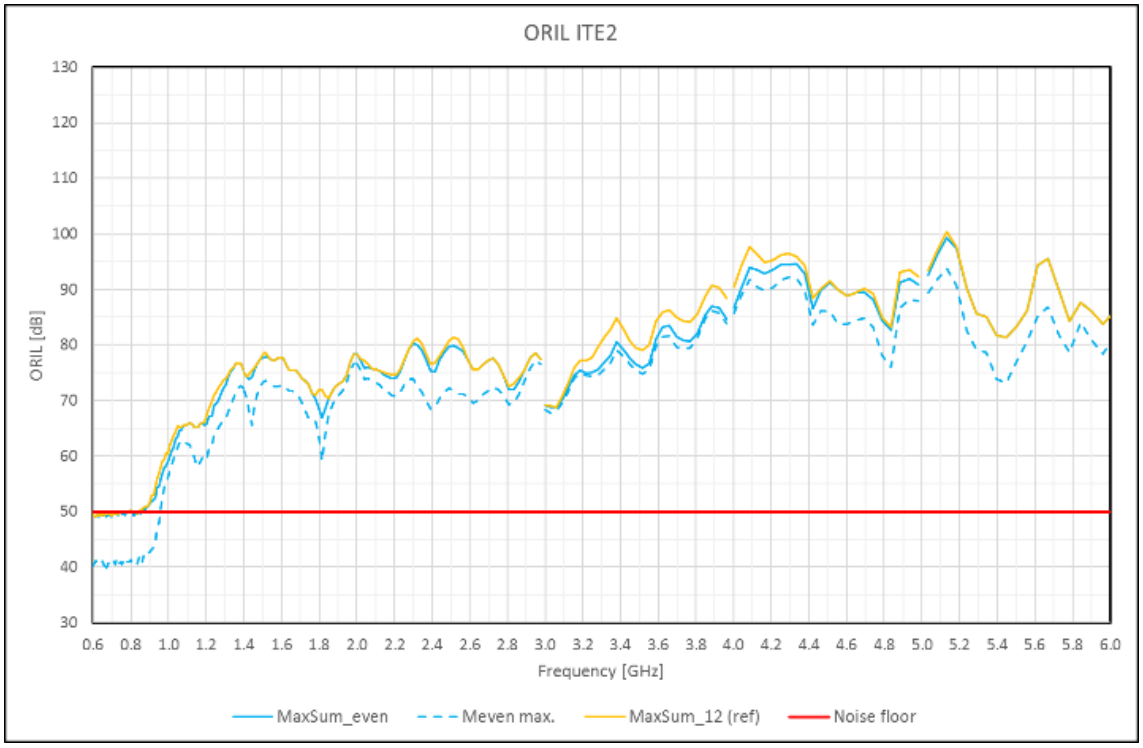
3.2.9 ITE2



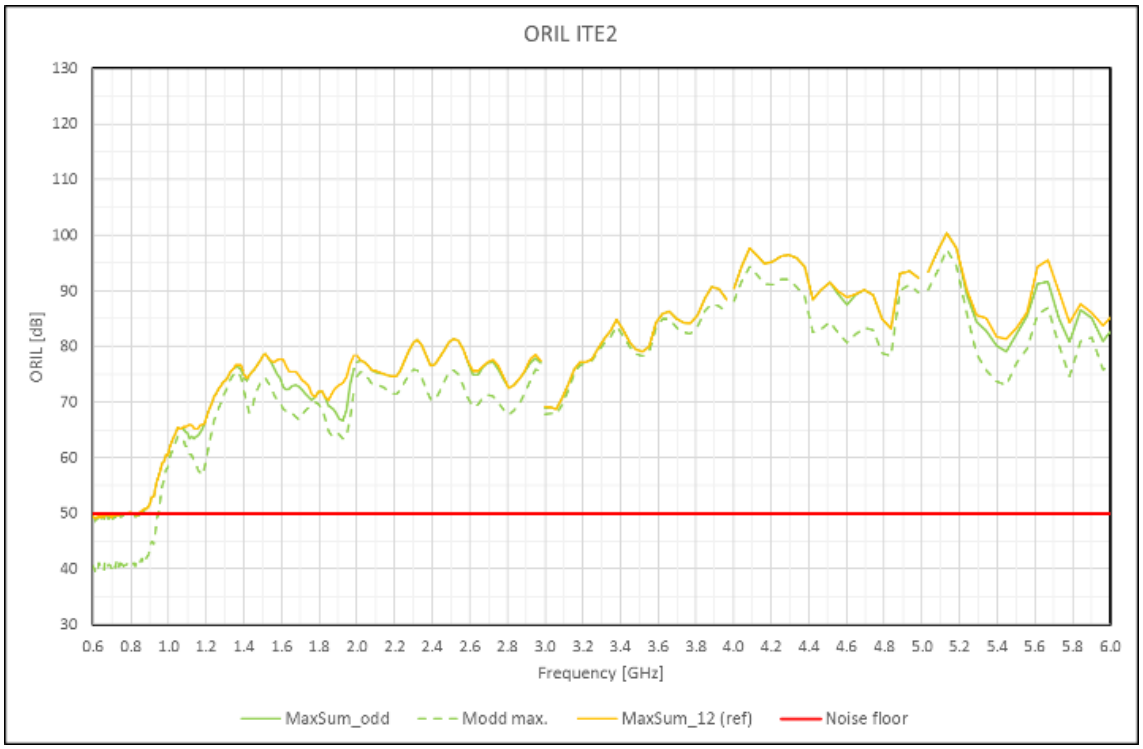
All measurements



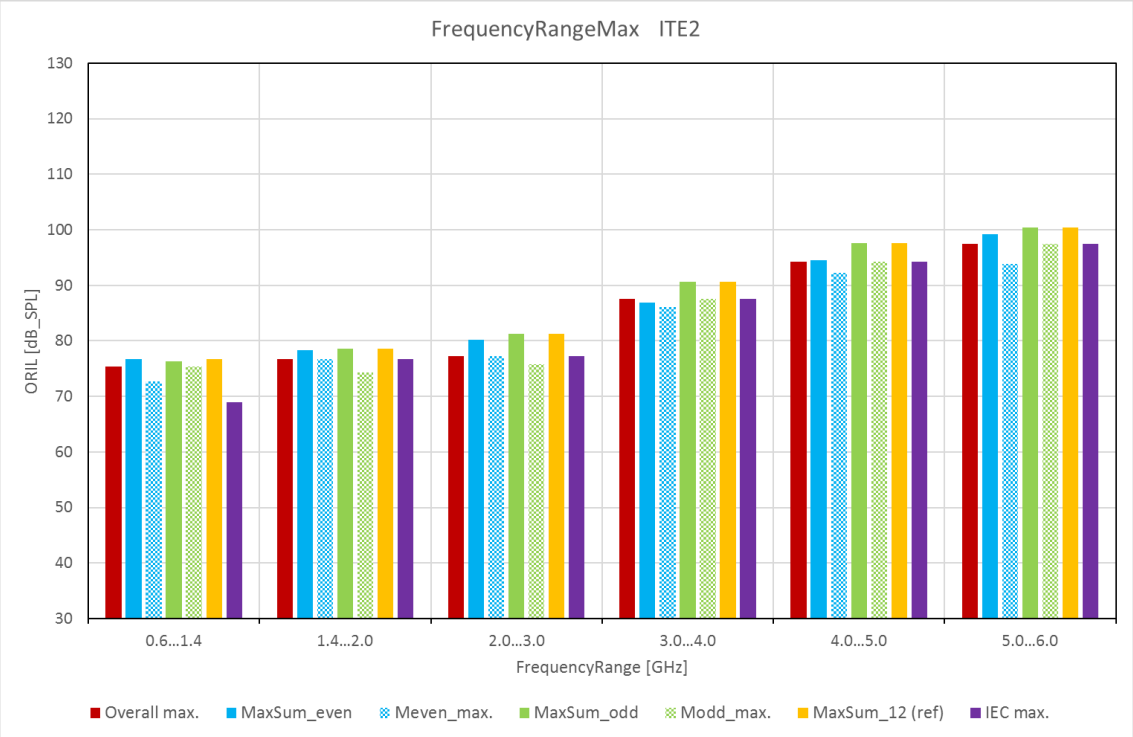
Evaluation1: Overall max., IEC max., MaxSum_12



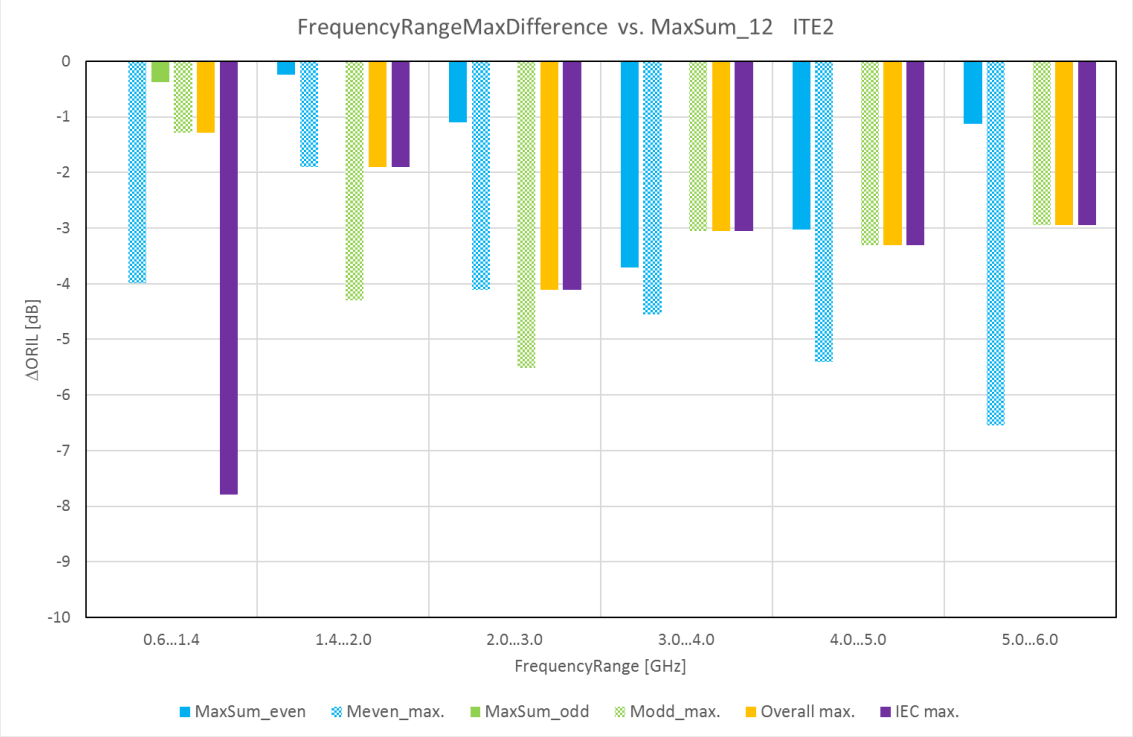
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



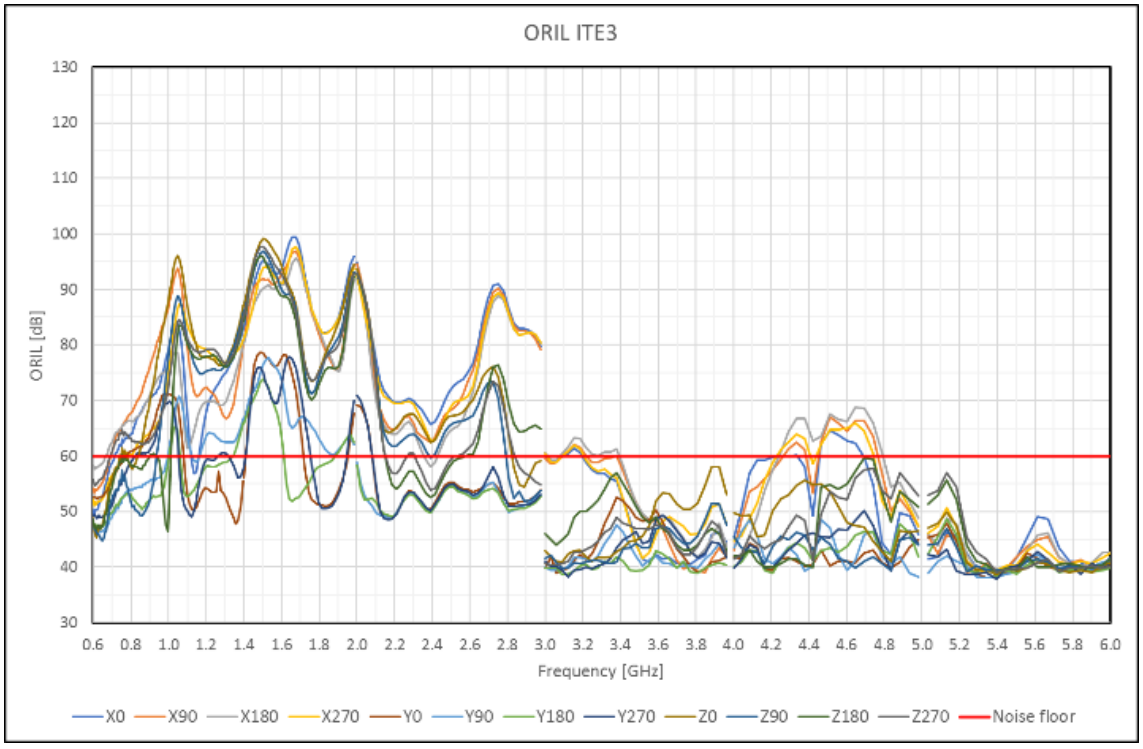
Ranking1: FRM



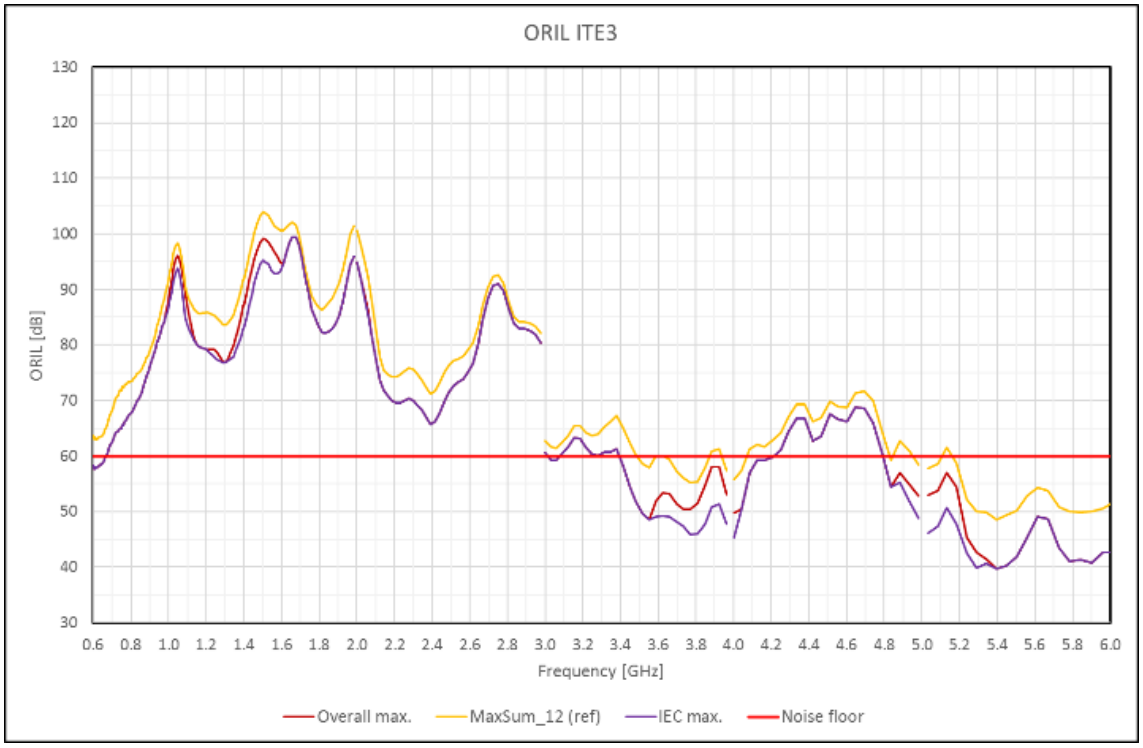
Ranking2: FRMD

Pic. 33: ORILs ITE2

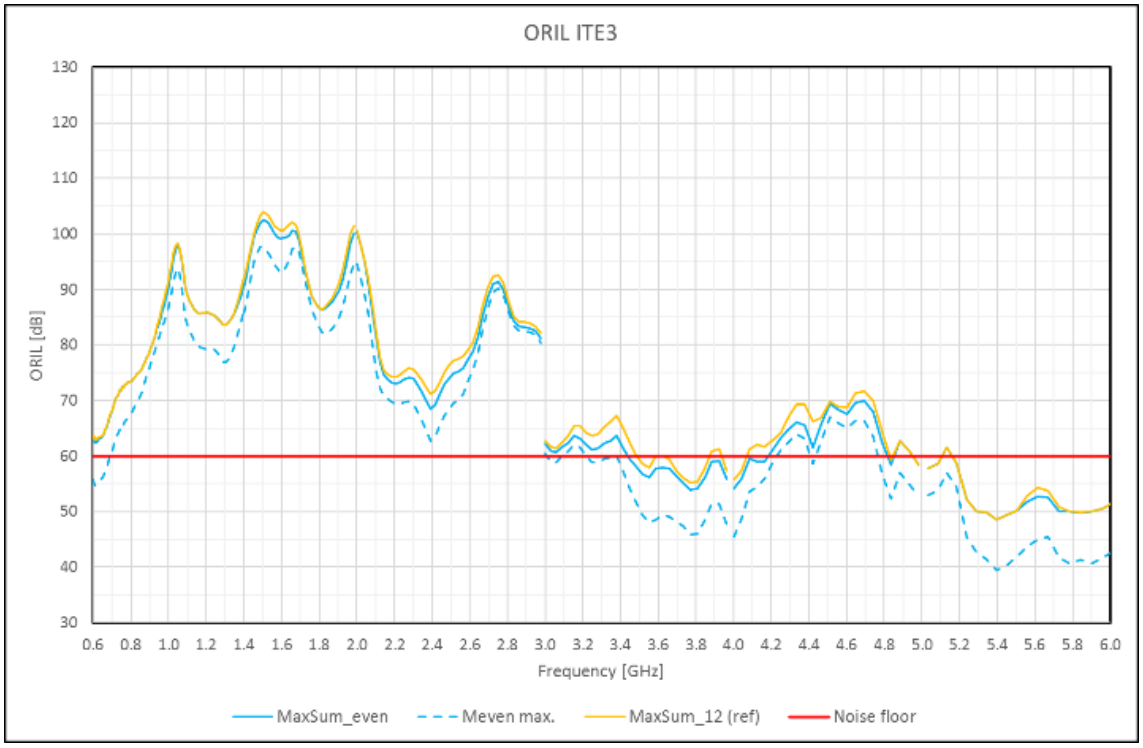
3.2.10 ITE3



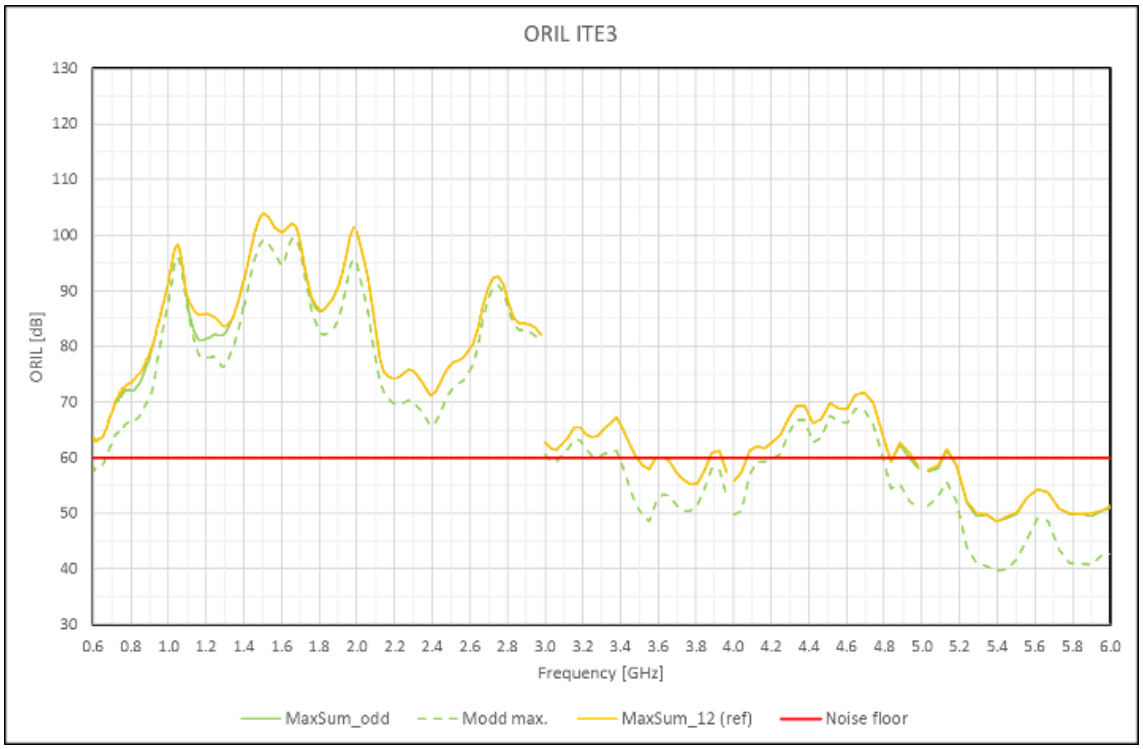
All measurements



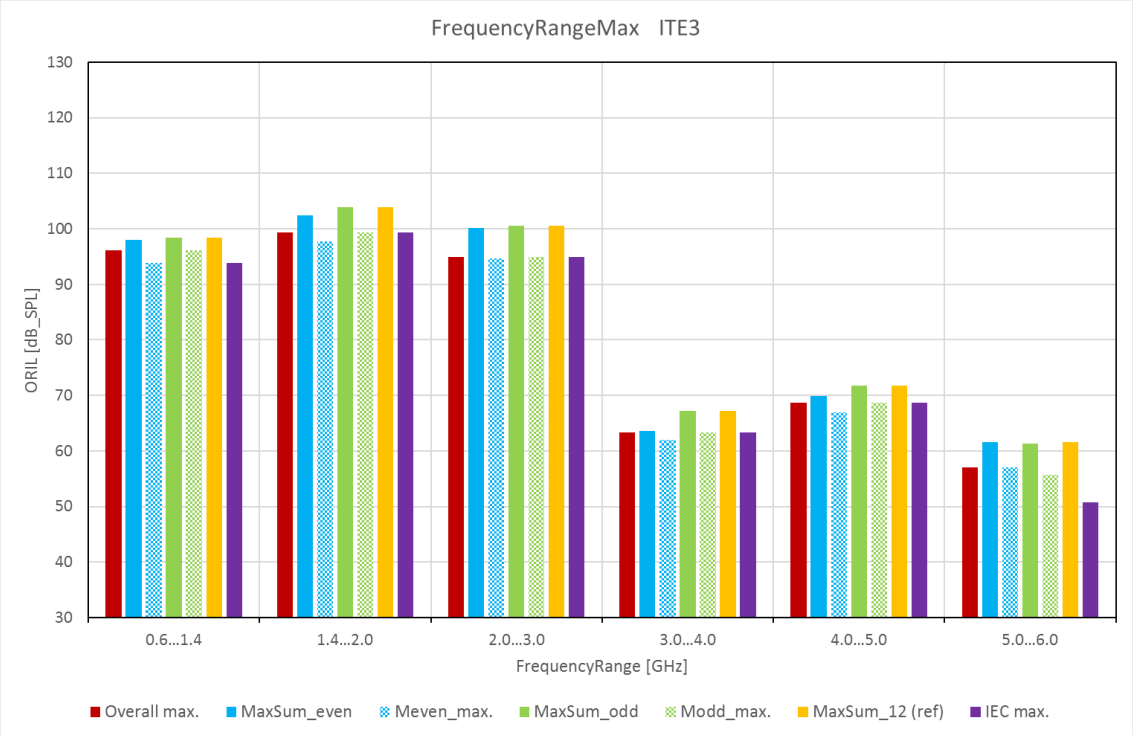
Evaluation1: Overall max., IEC max., MaxSum_12



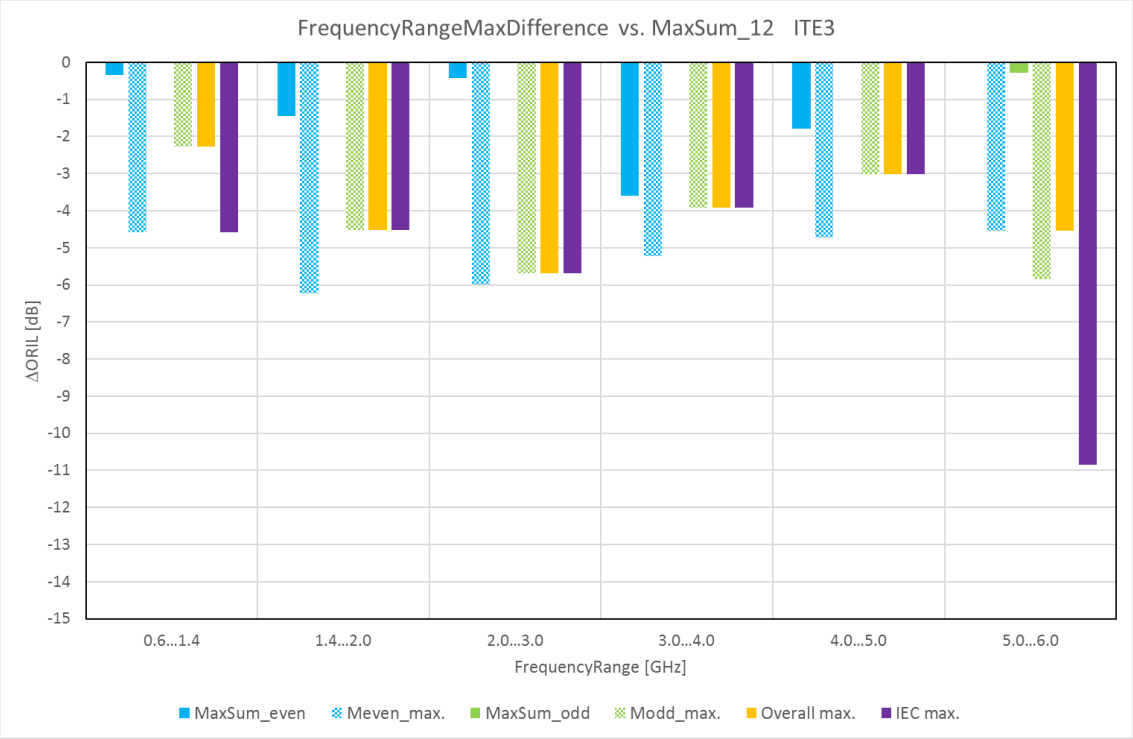
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



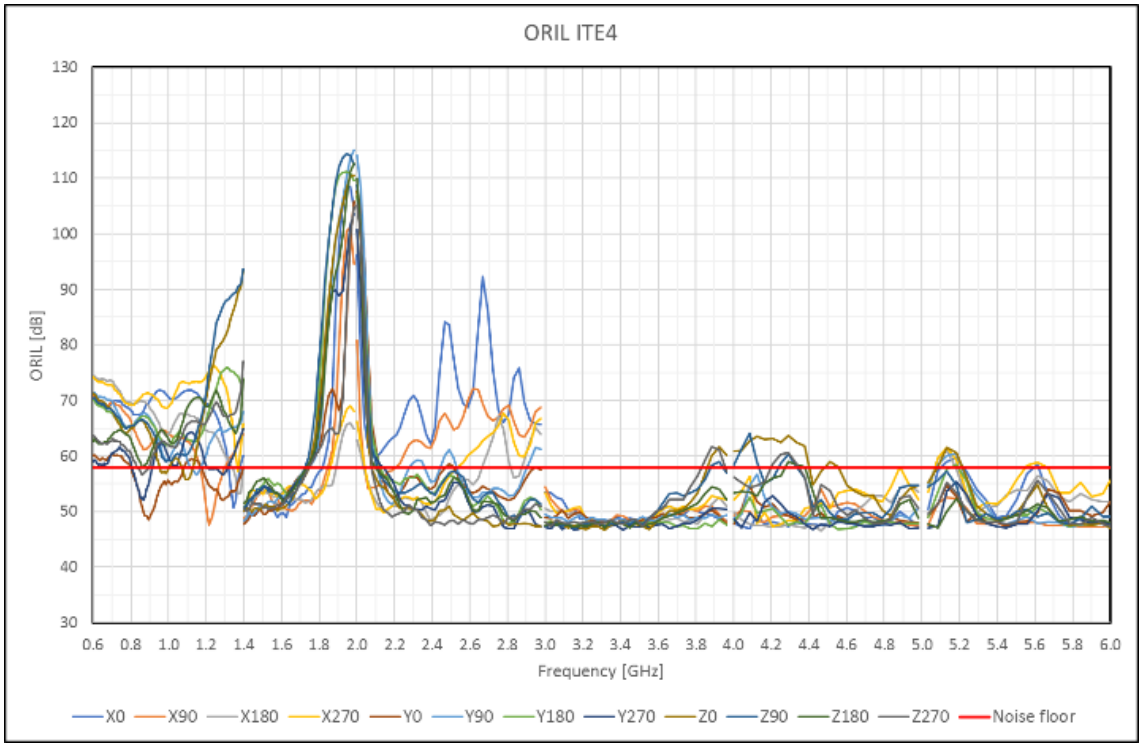
Ranking1: FRM



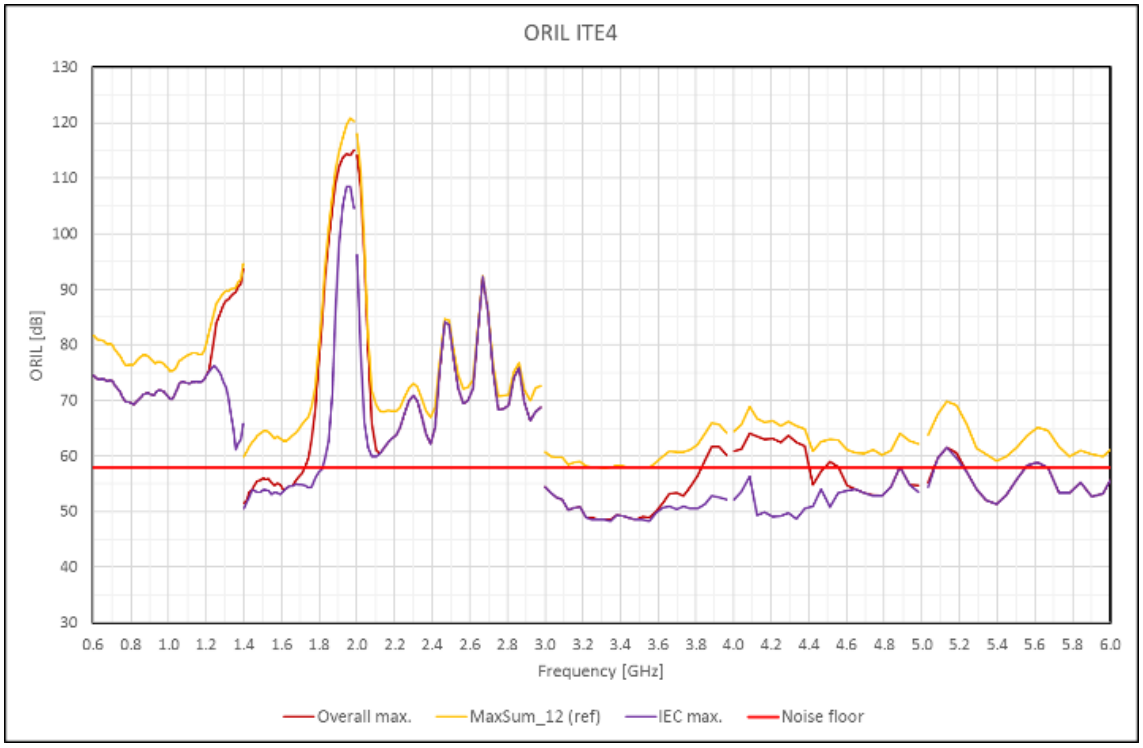
Ranking2: FRMD

Pic. 34: ORILs ITE3

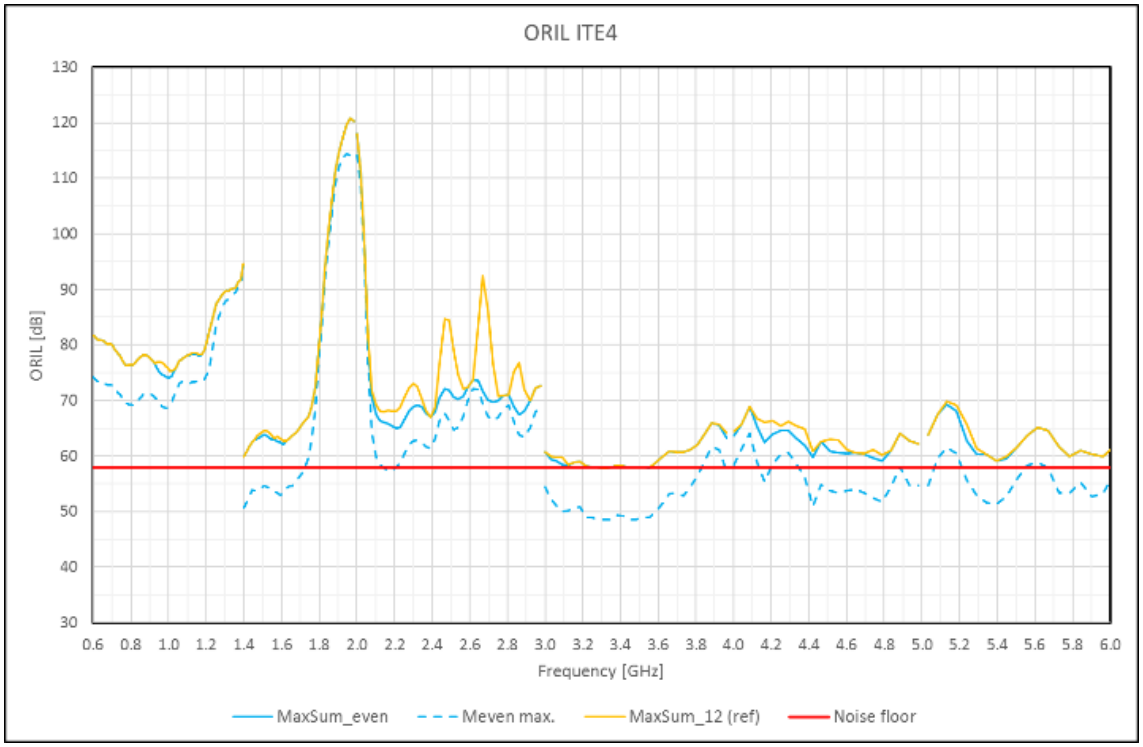
3.2.11 ITE4



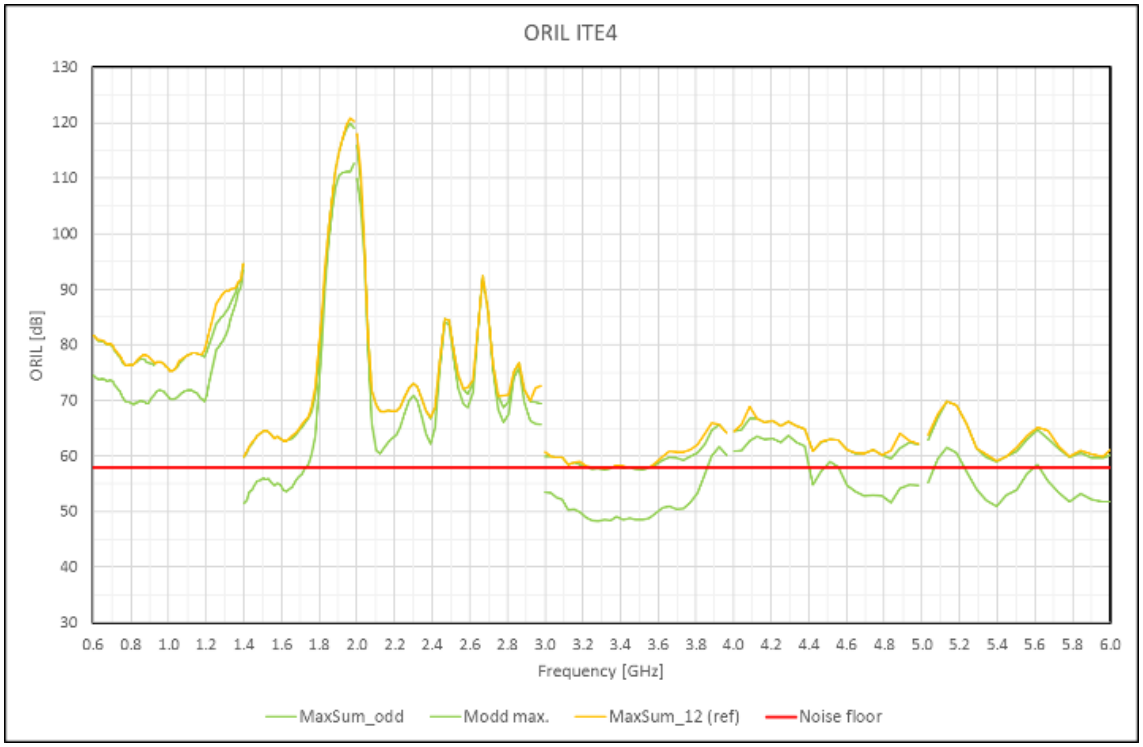
All measurements



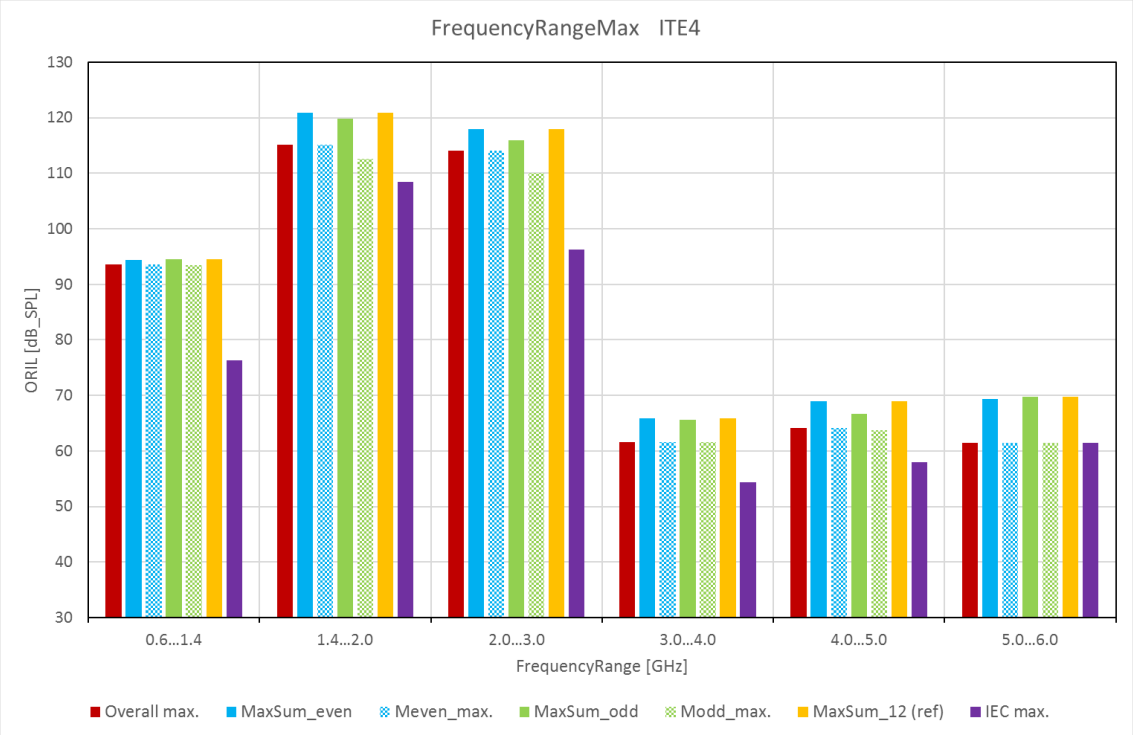
Evaluation1: Overall max., IEC max., MaxSum_12



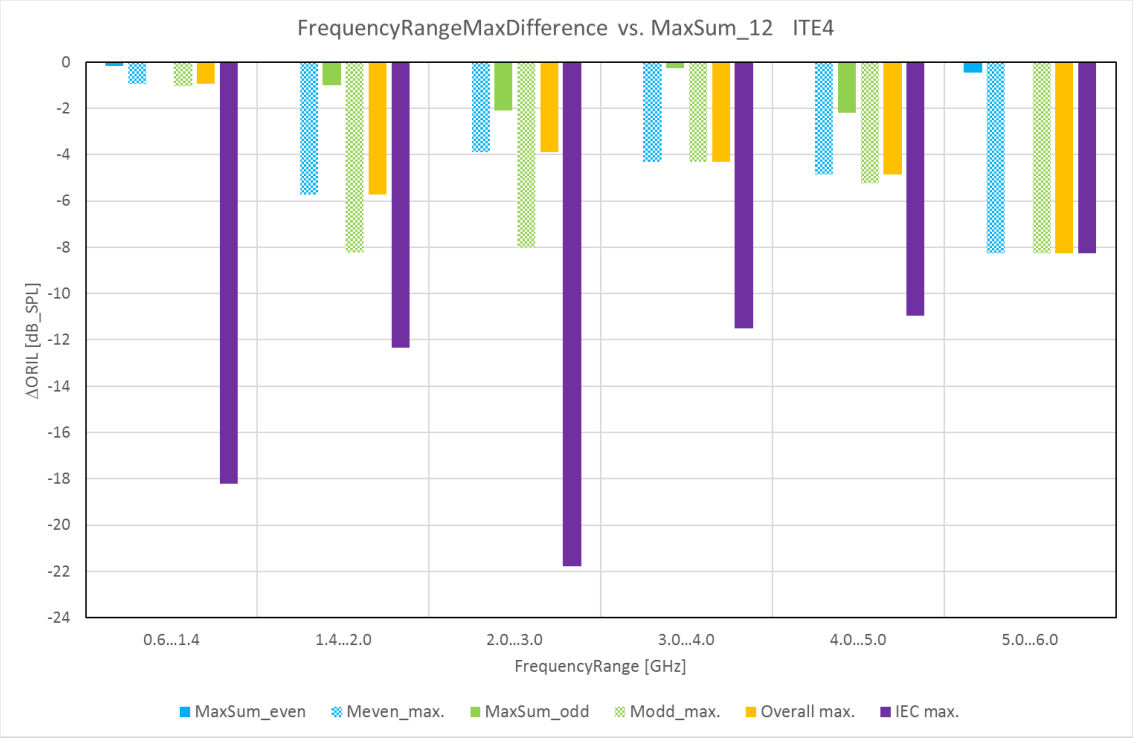
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



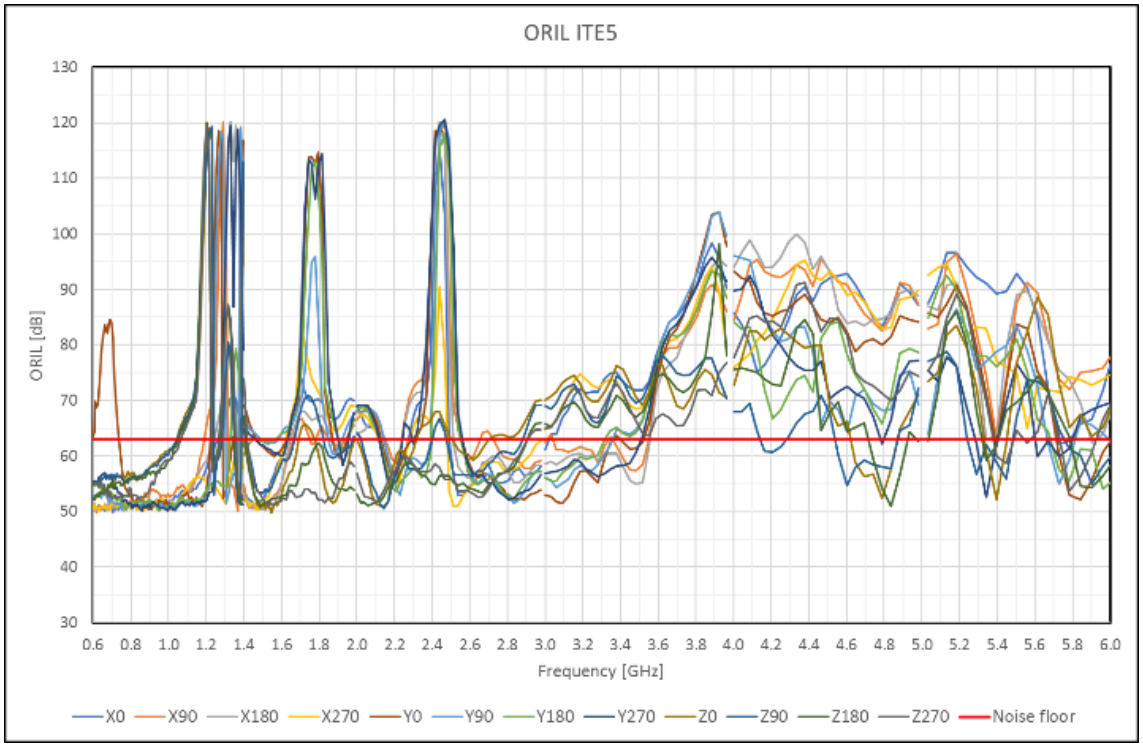
Ranking1: FRM



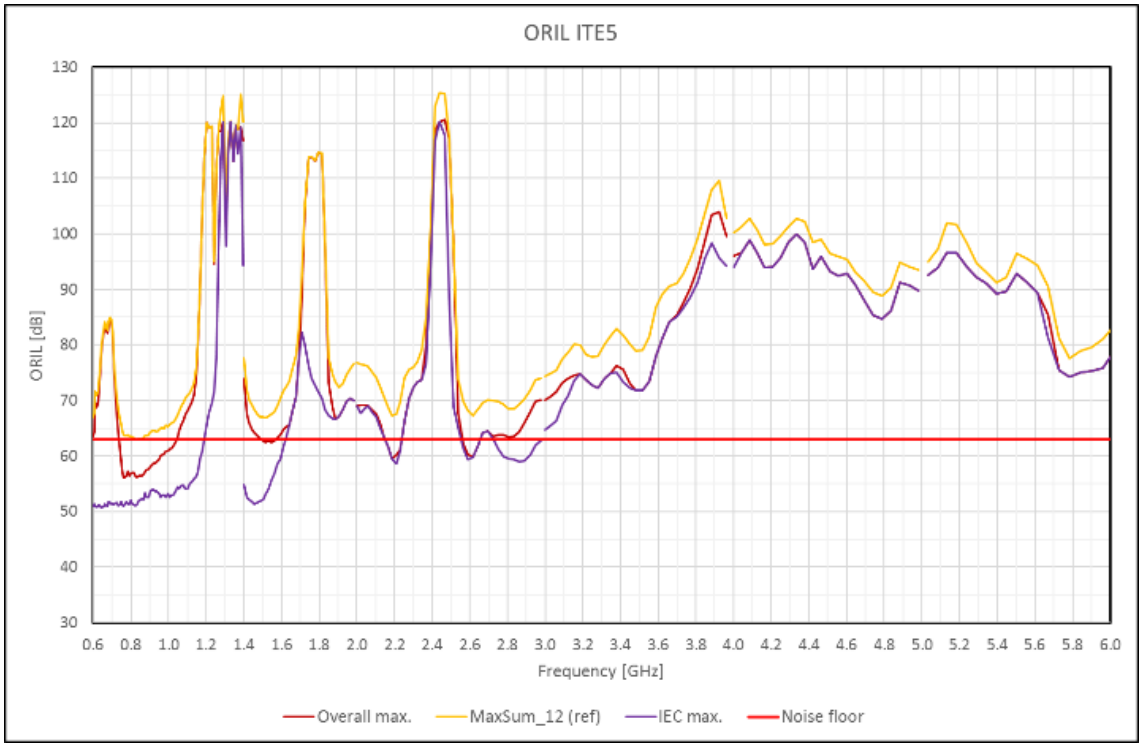
Ranking2: FRMD

Pic. 35: ORILs ITE4

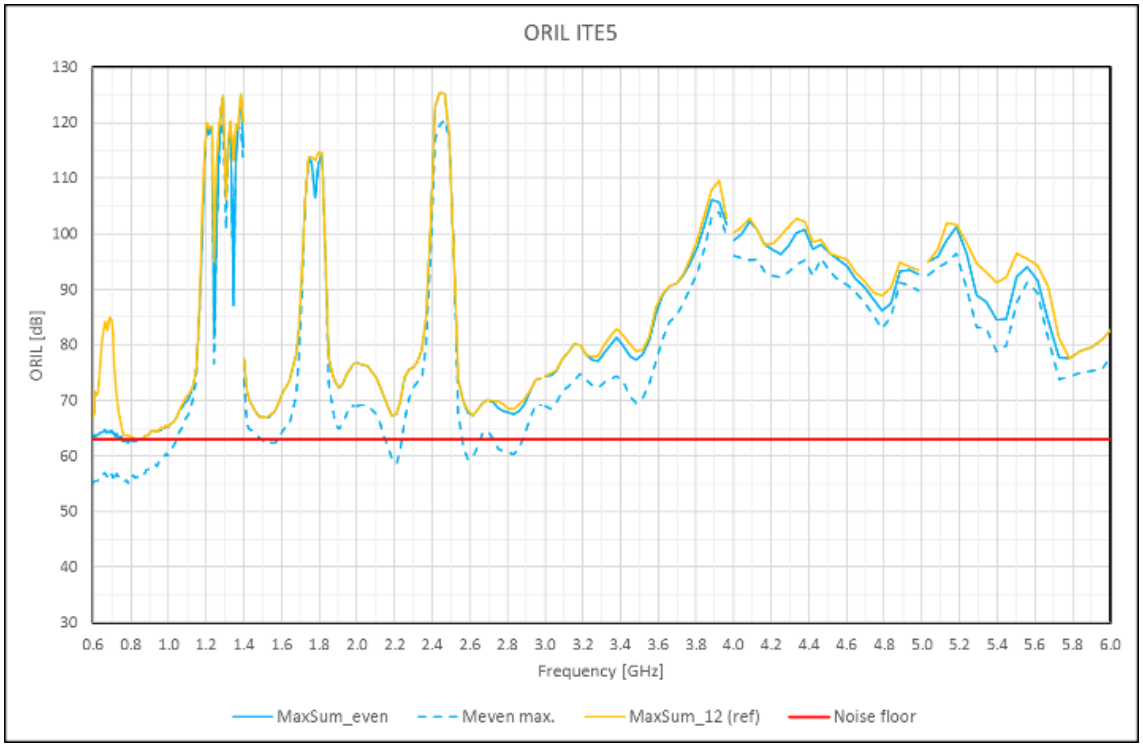
3.2.12 ITE5



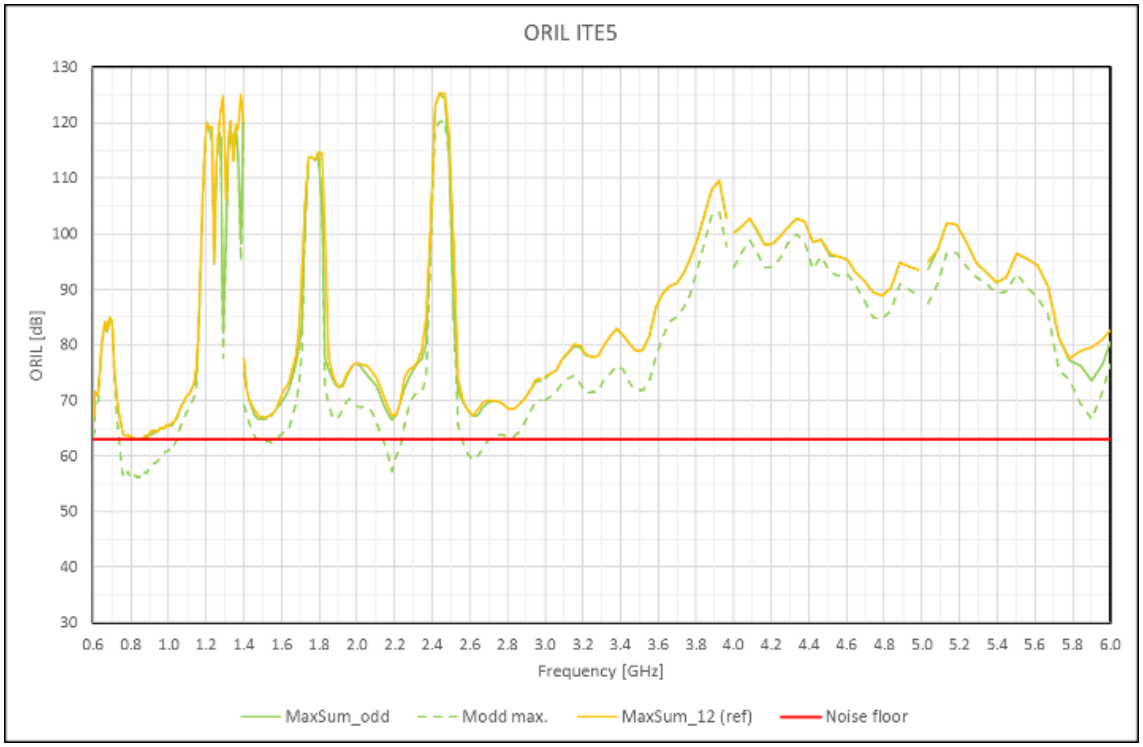
All measurements



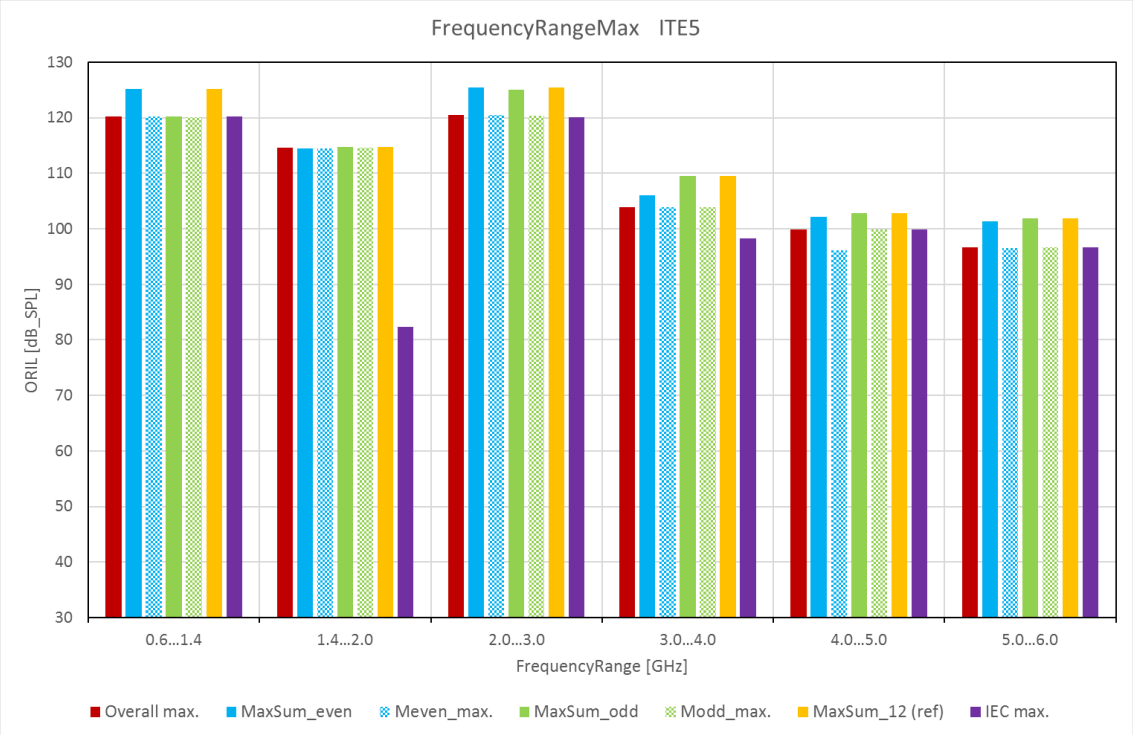
Evaluation1: Overall max., IEC max., MaxSum_12



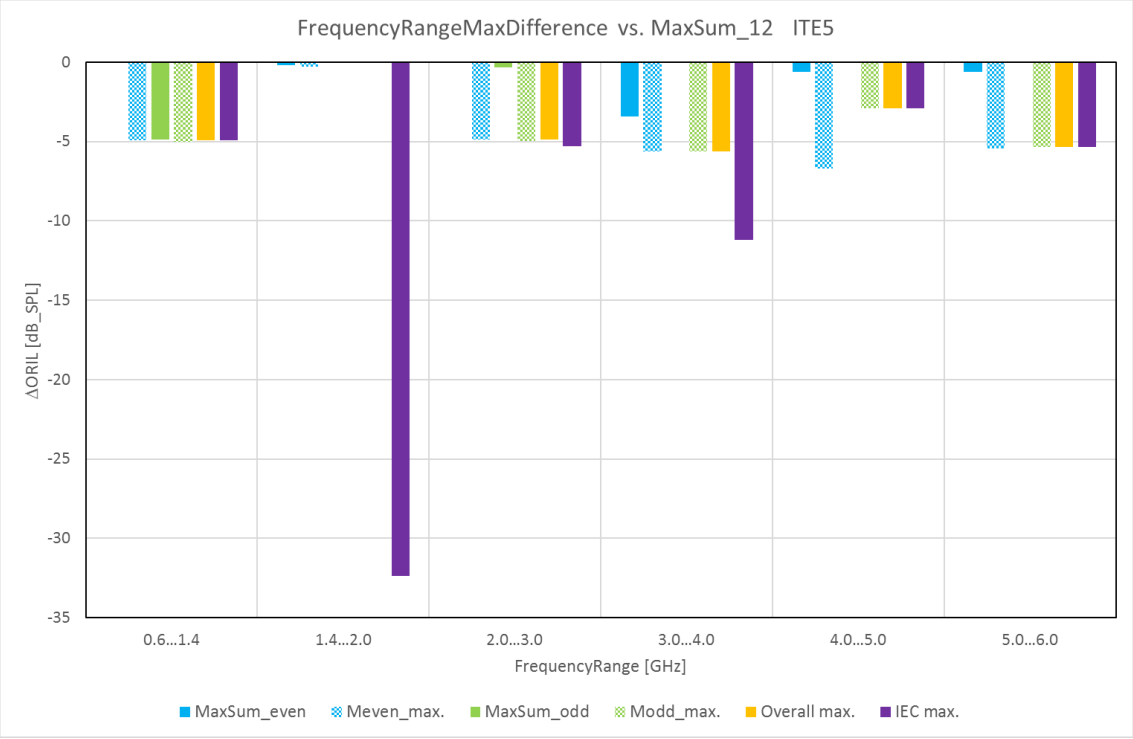
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



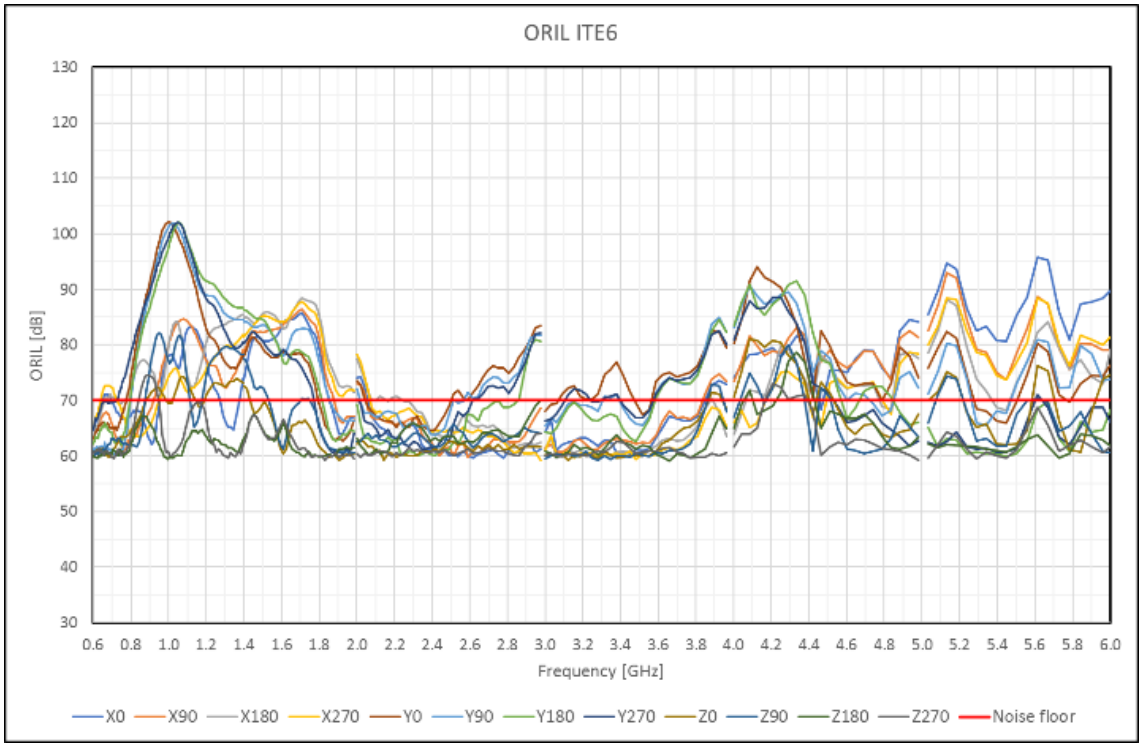
Ranking1: FRM



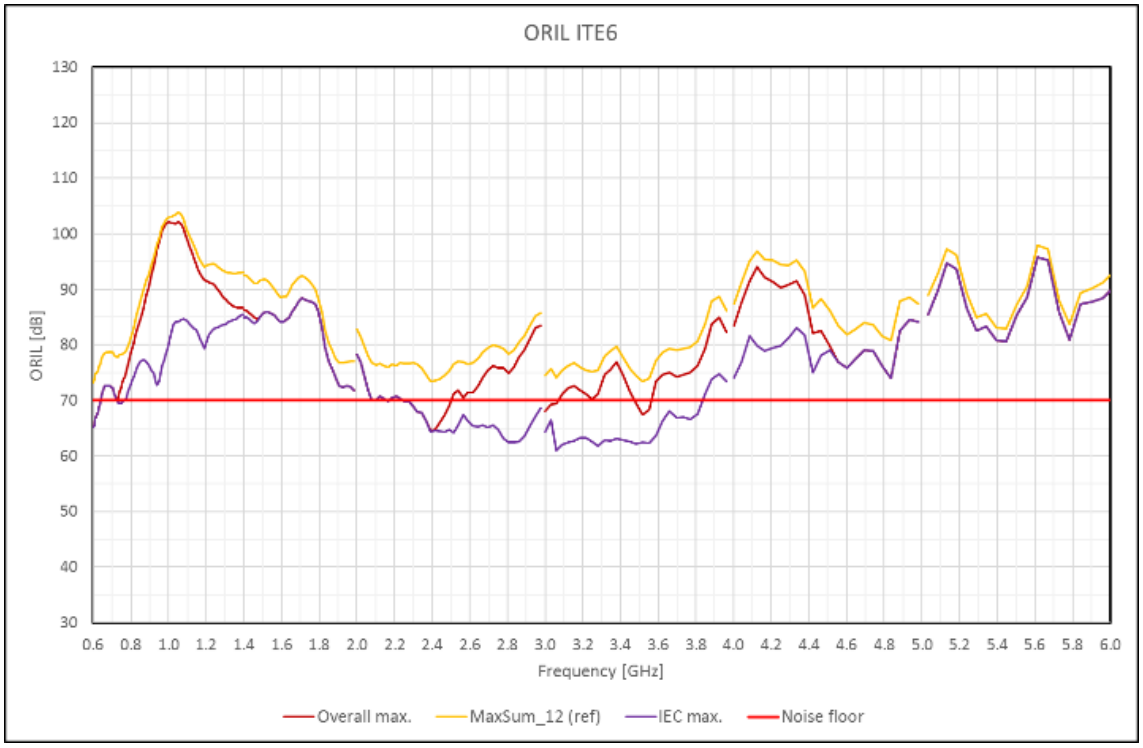
Ranking2: FRMD

Pic. 36: ORILs ITE6

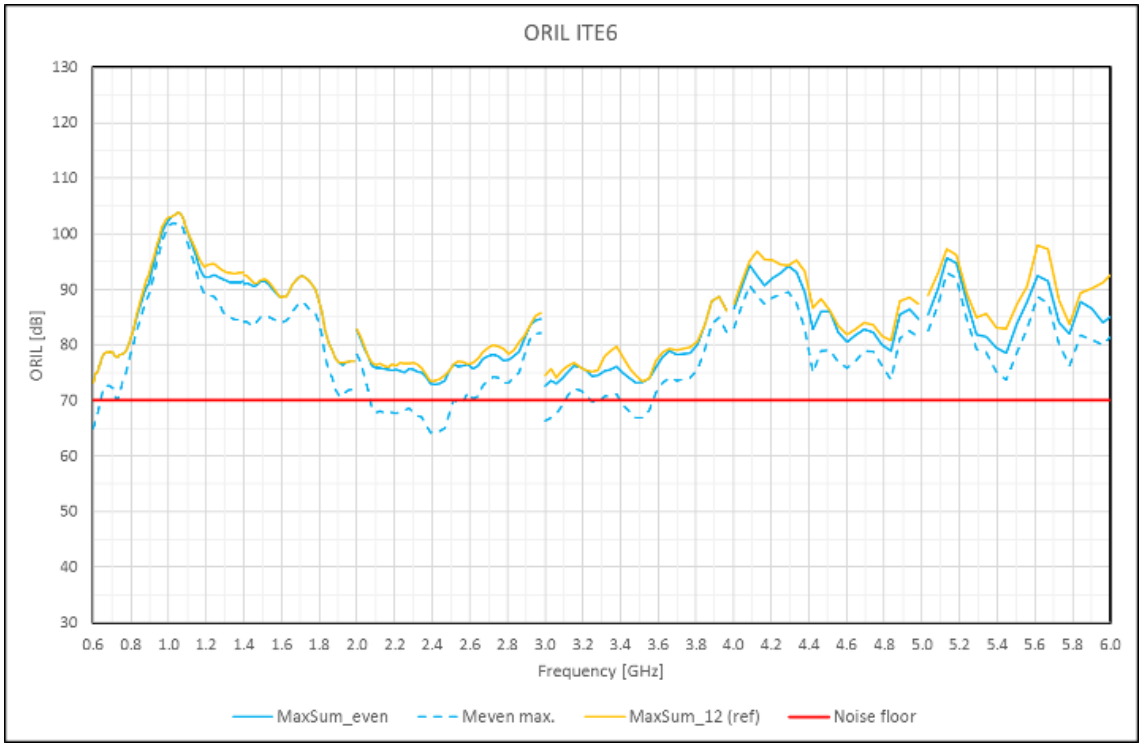
3.2.13 ITE6



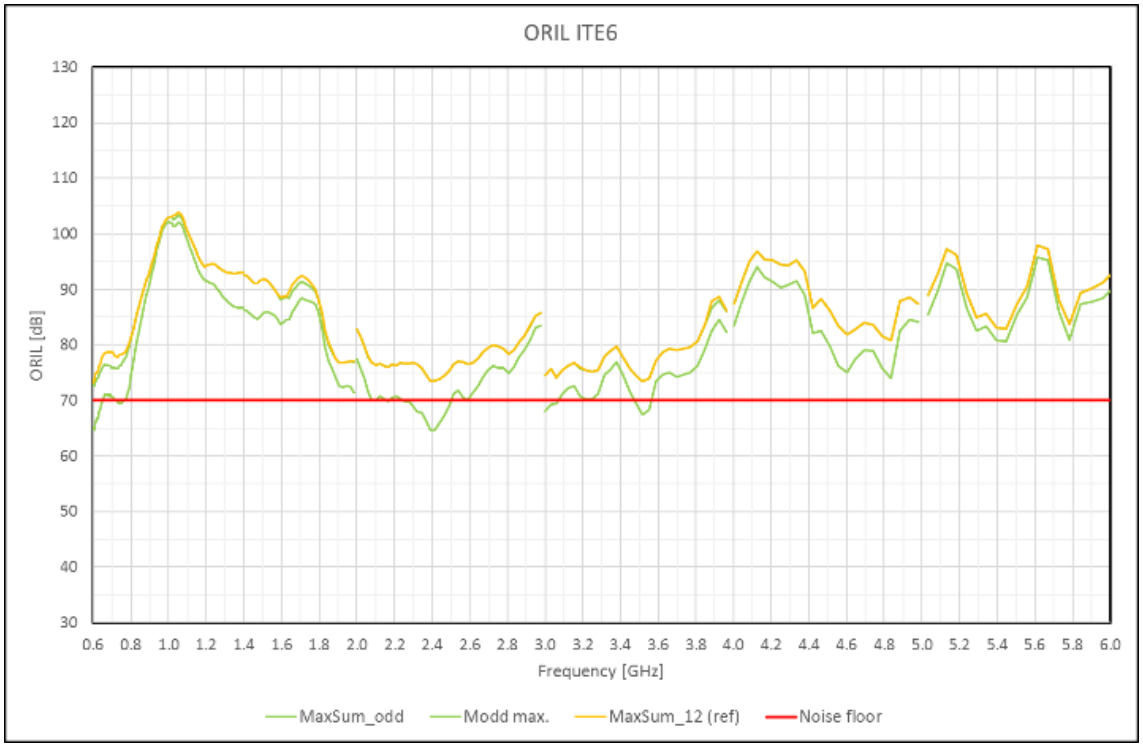
All measurements



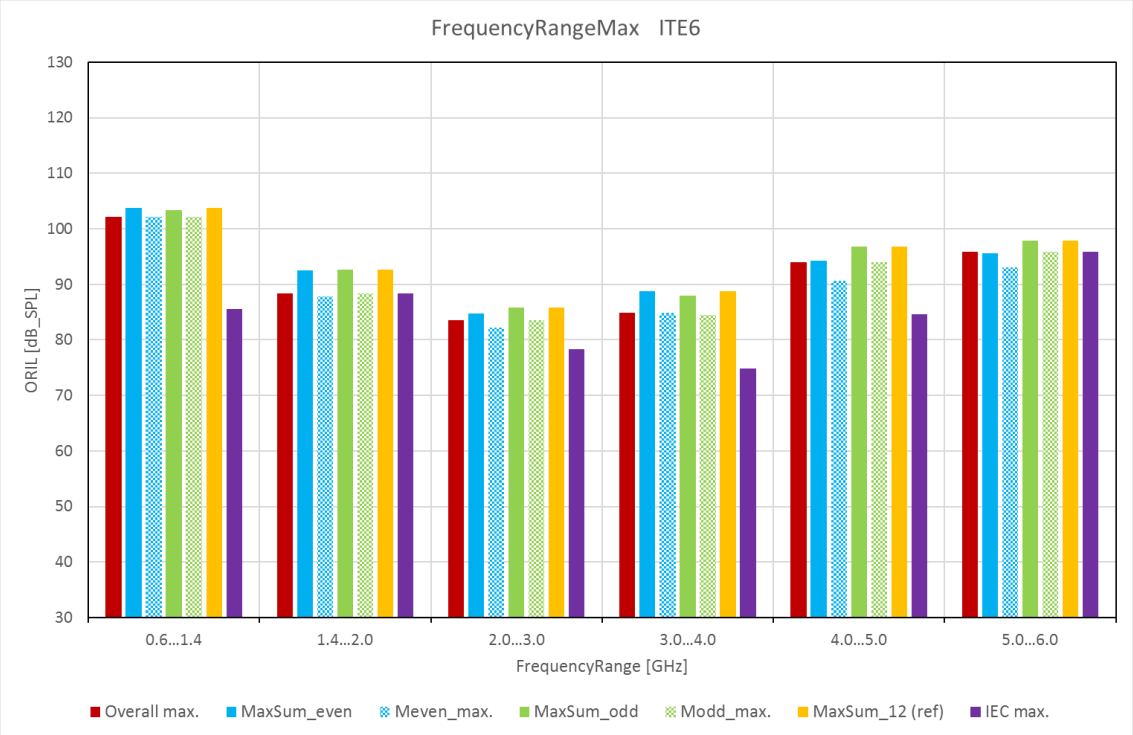
Evaluation1: Overall max., IEC max., MaxSum_12



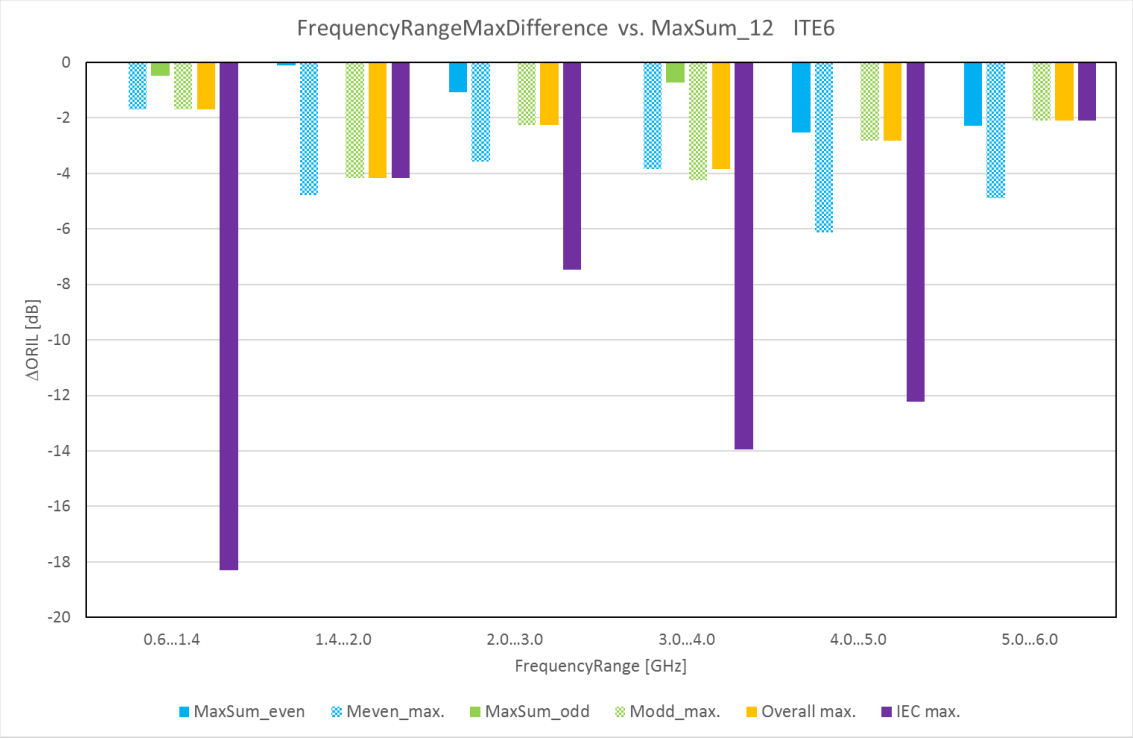
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



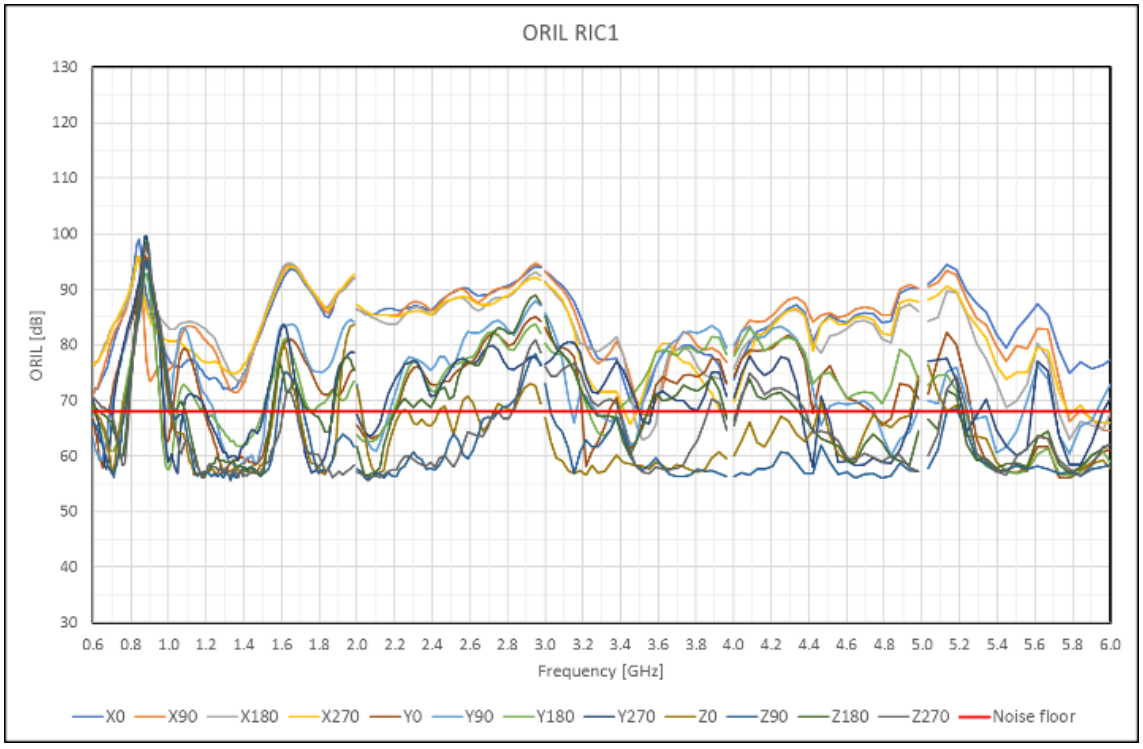
Ranking1: FRM



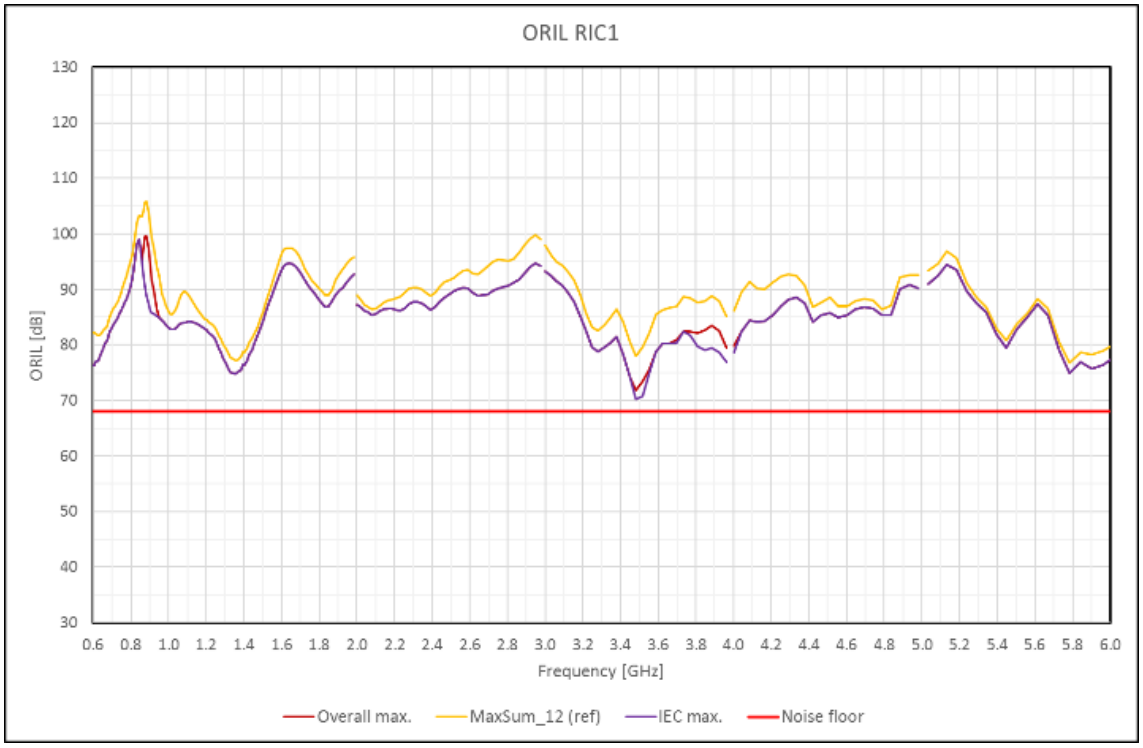
Ranking2: FRMD

Pic. 37: ORILs ITE6

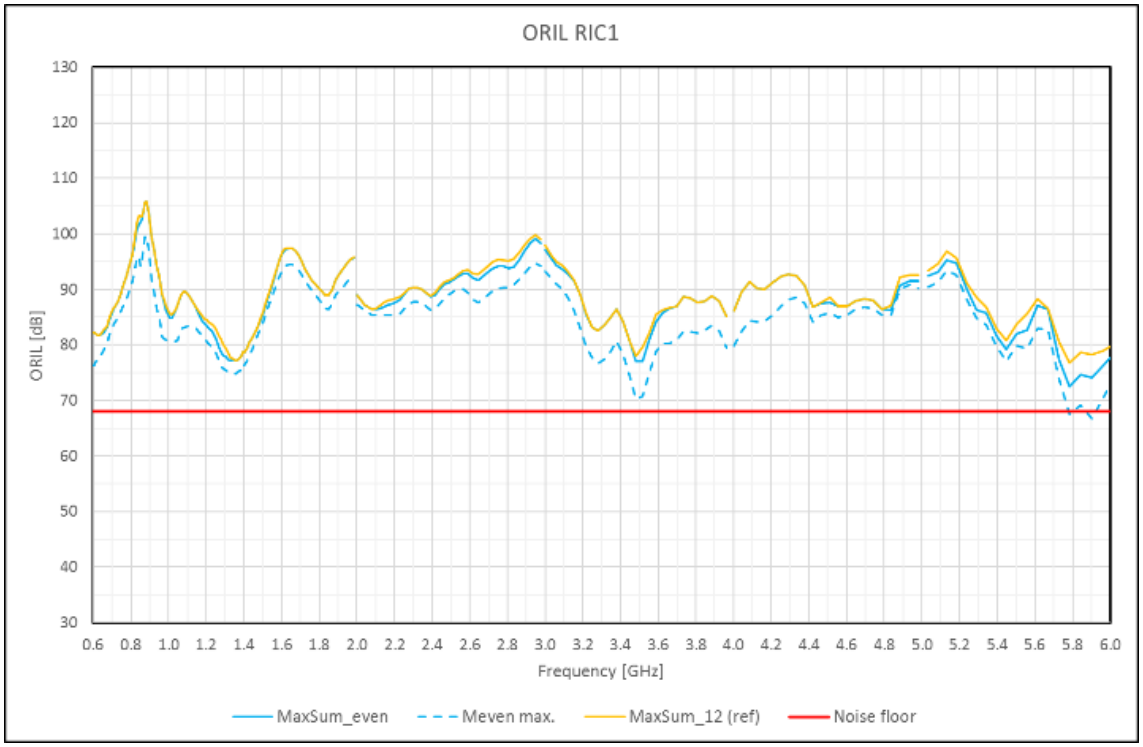
3.2.14 RIC1



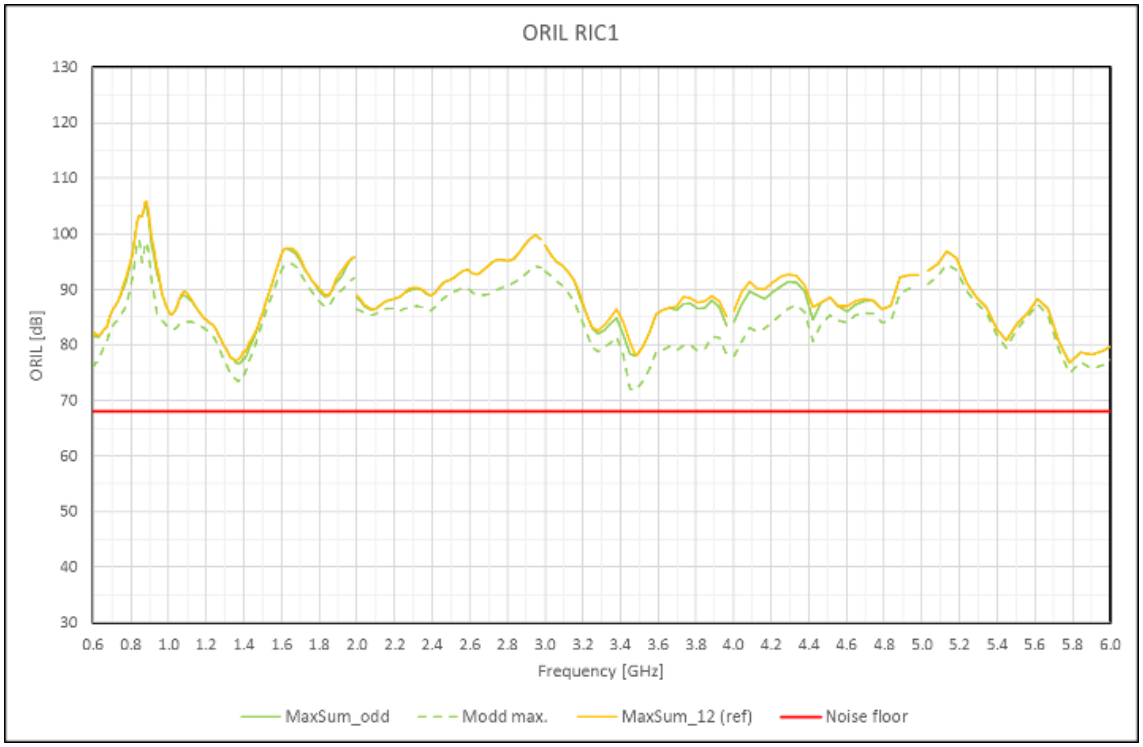
All measurements



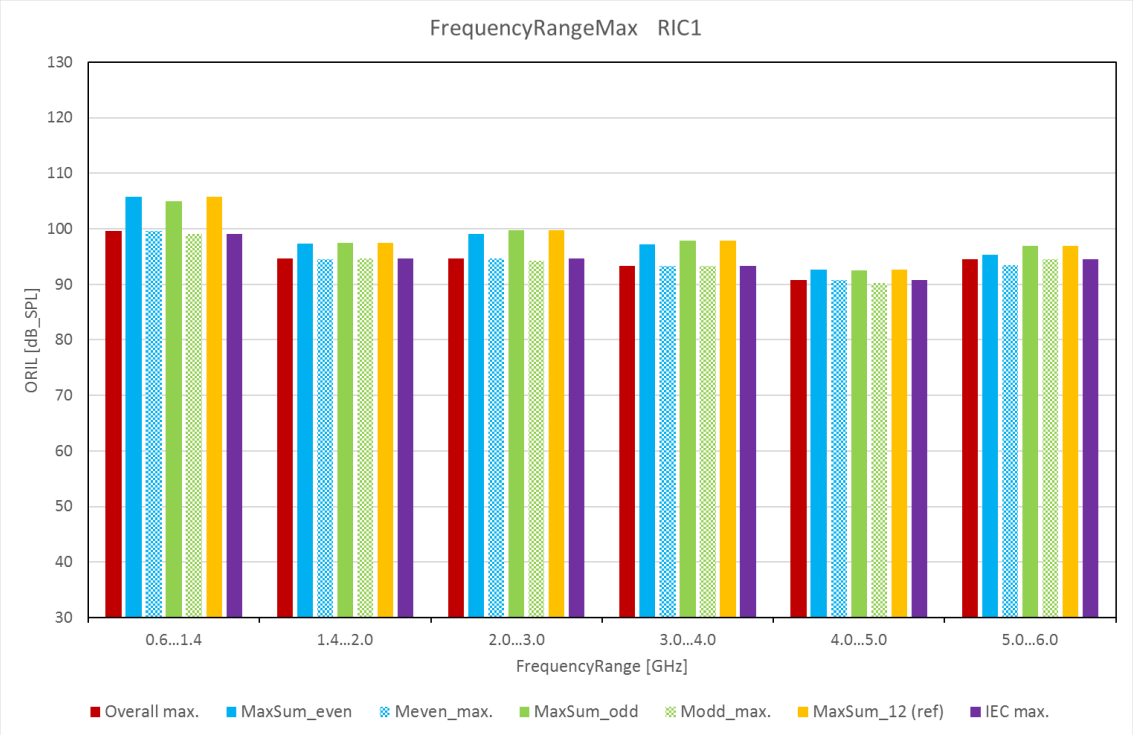
Evaluation1: Overall max., IEC max., MaxSum_12



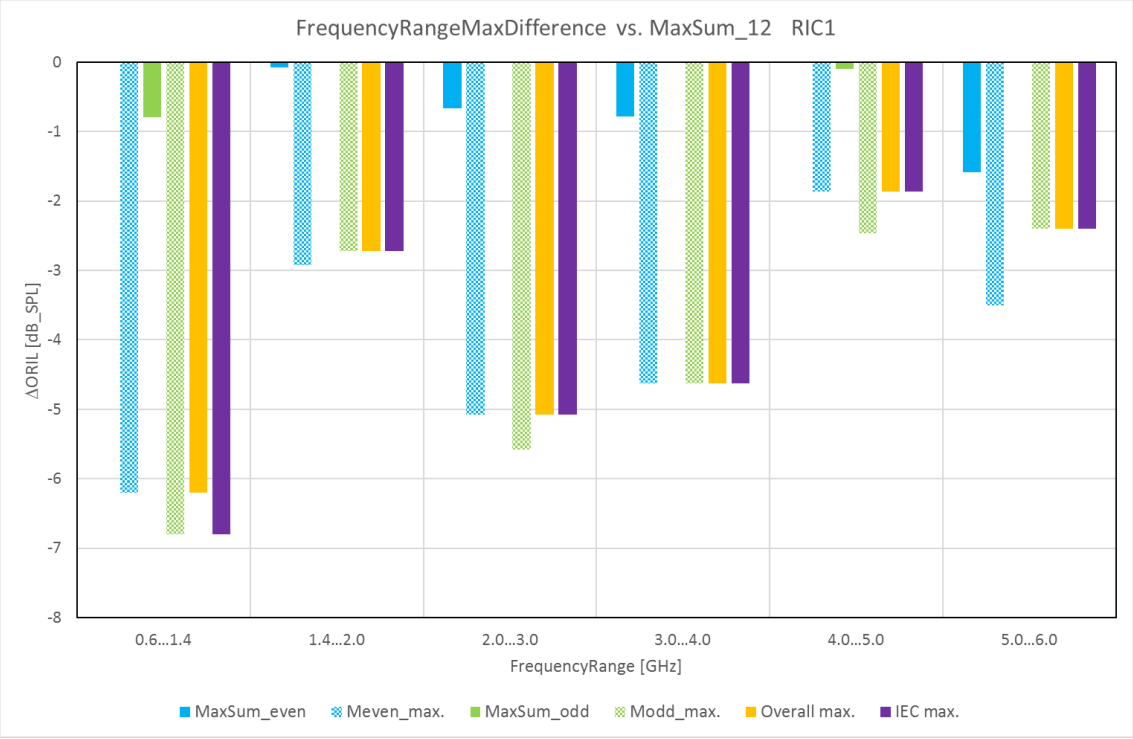
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



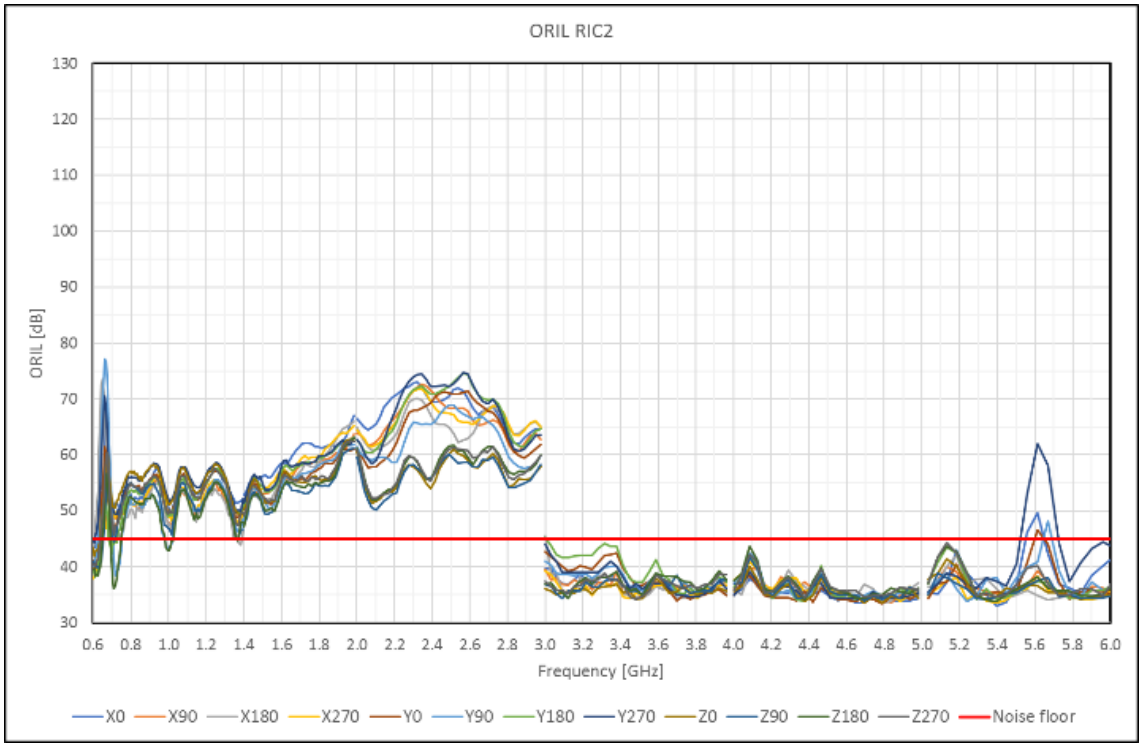
Ranking1: FRM



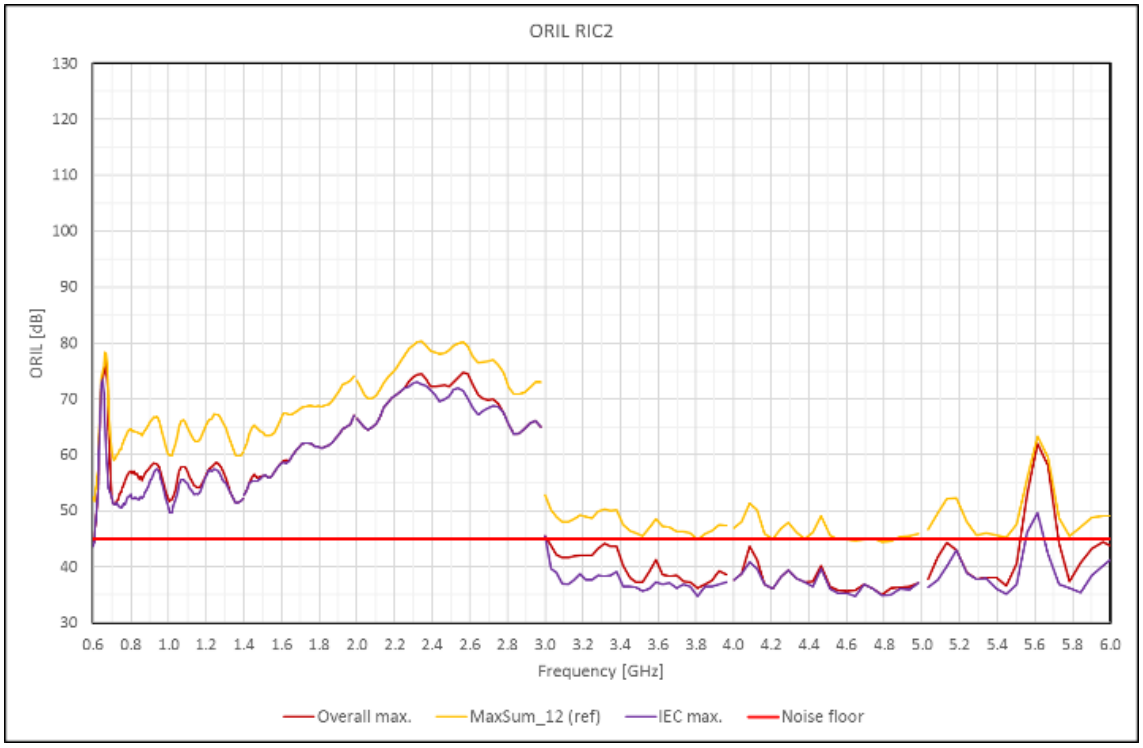
Ranking2: FRMD

Pic. 38: ORILs RIC1

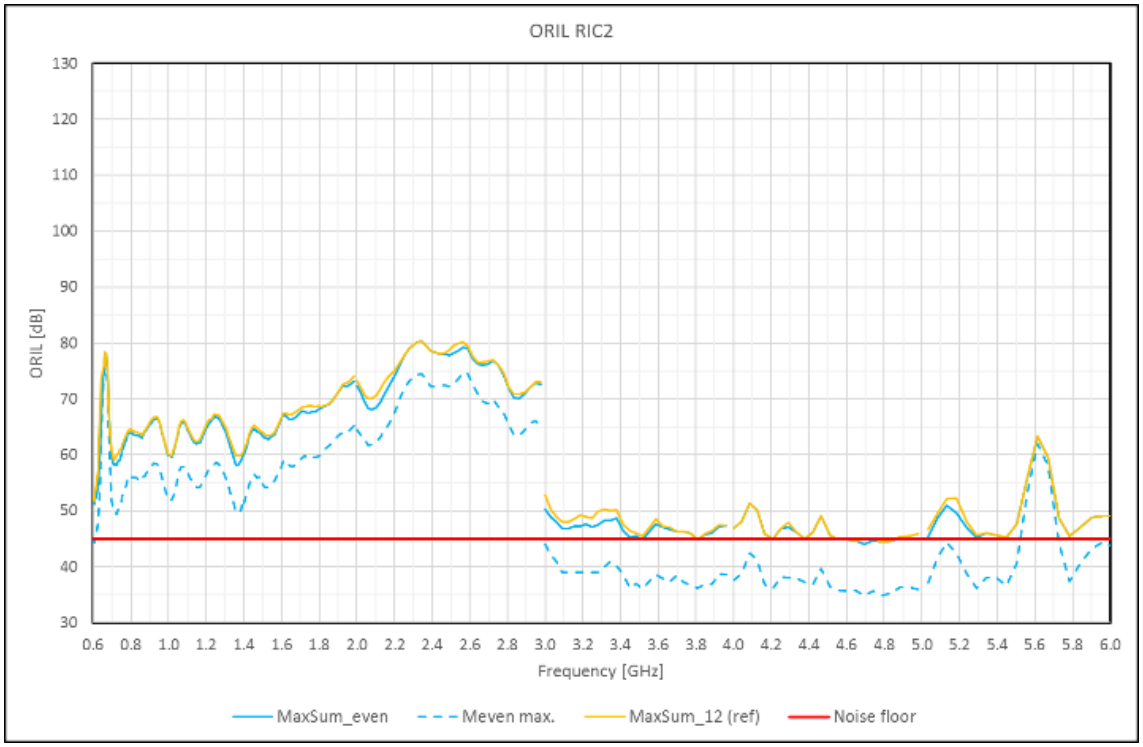
3.2.15 RIC2



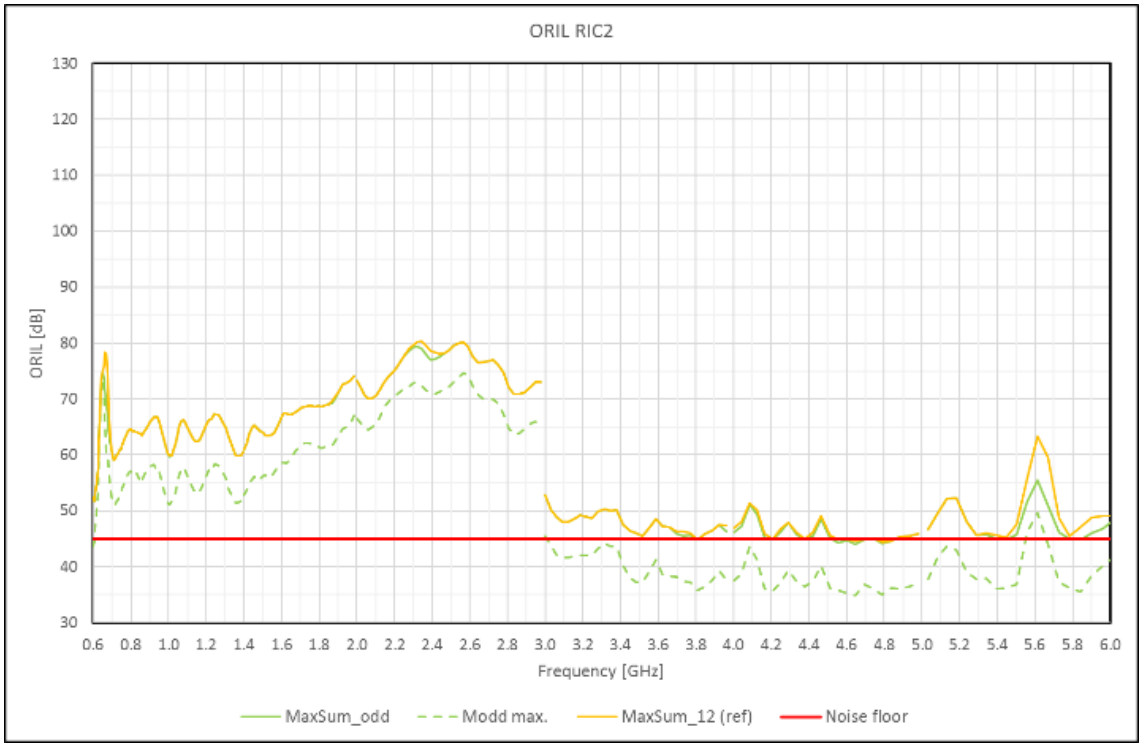
All measurements



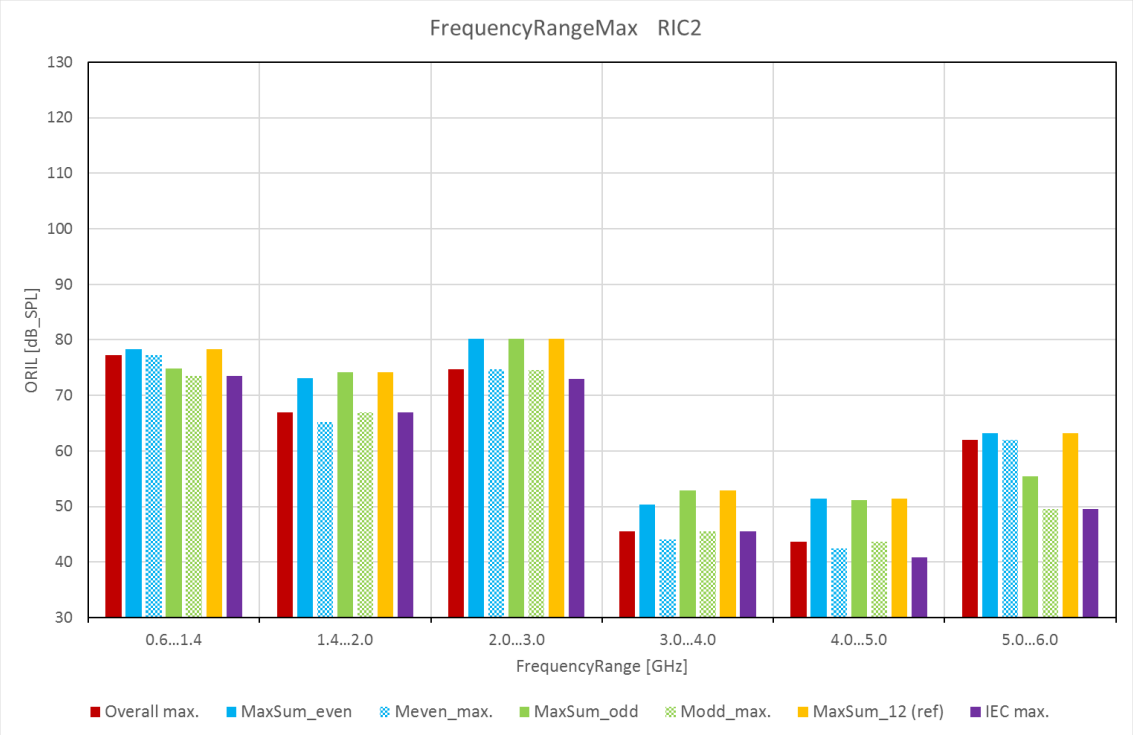
Evaluation1: Overall max., IEC max., MaxSum_12



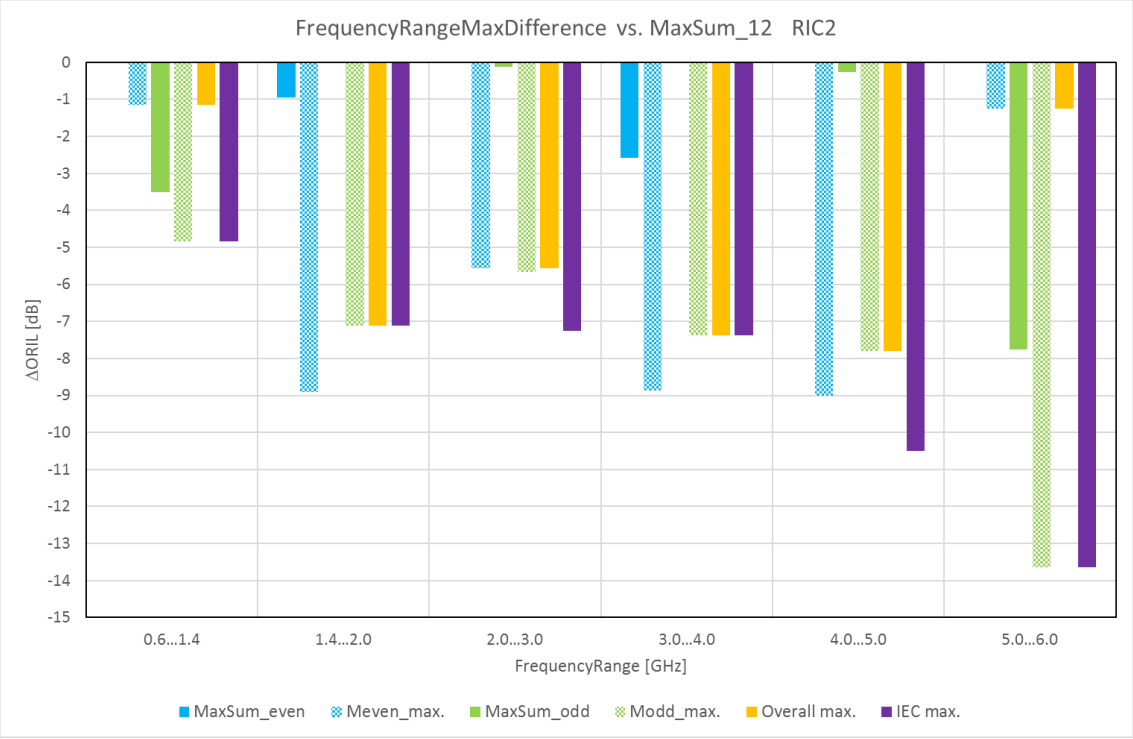
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



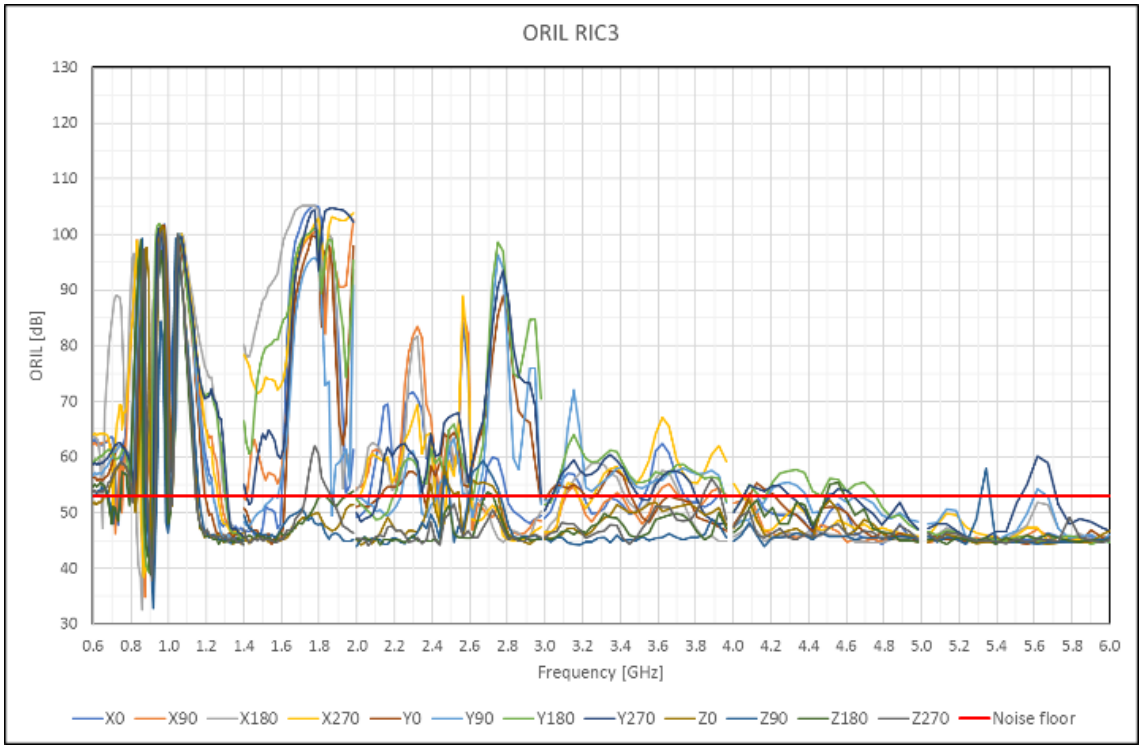
Ranking1: FRM



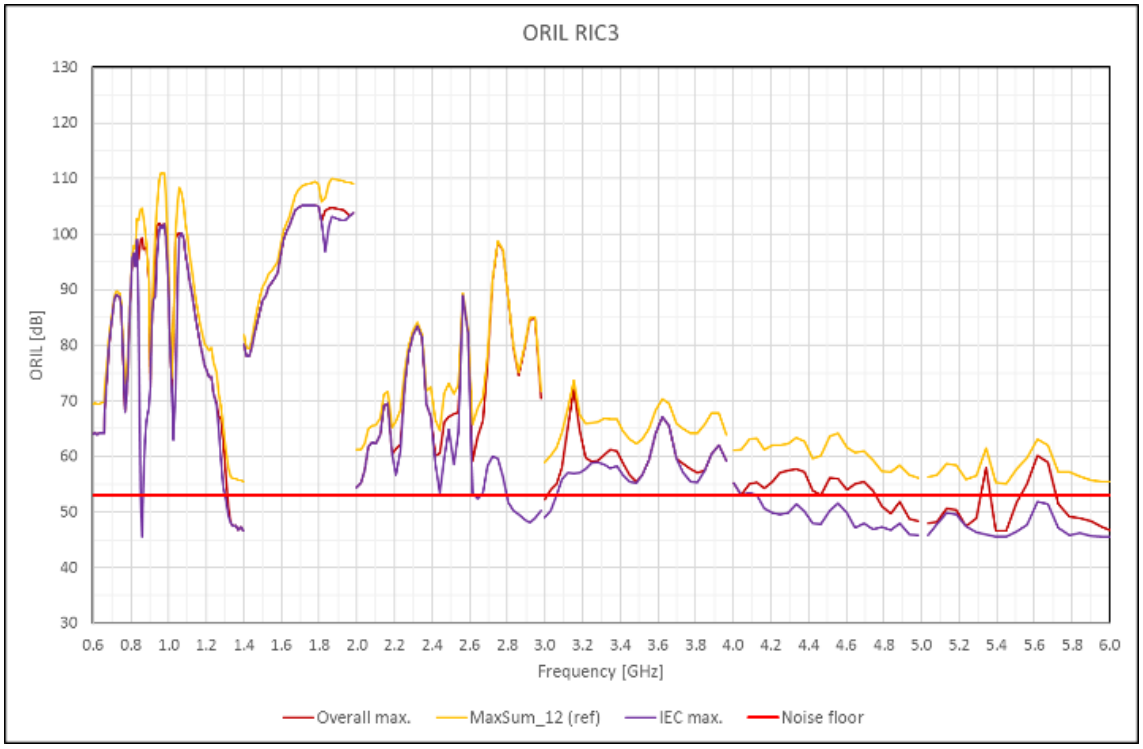
Ranking2: FRMD

Pic. 39: ORILs RIC2

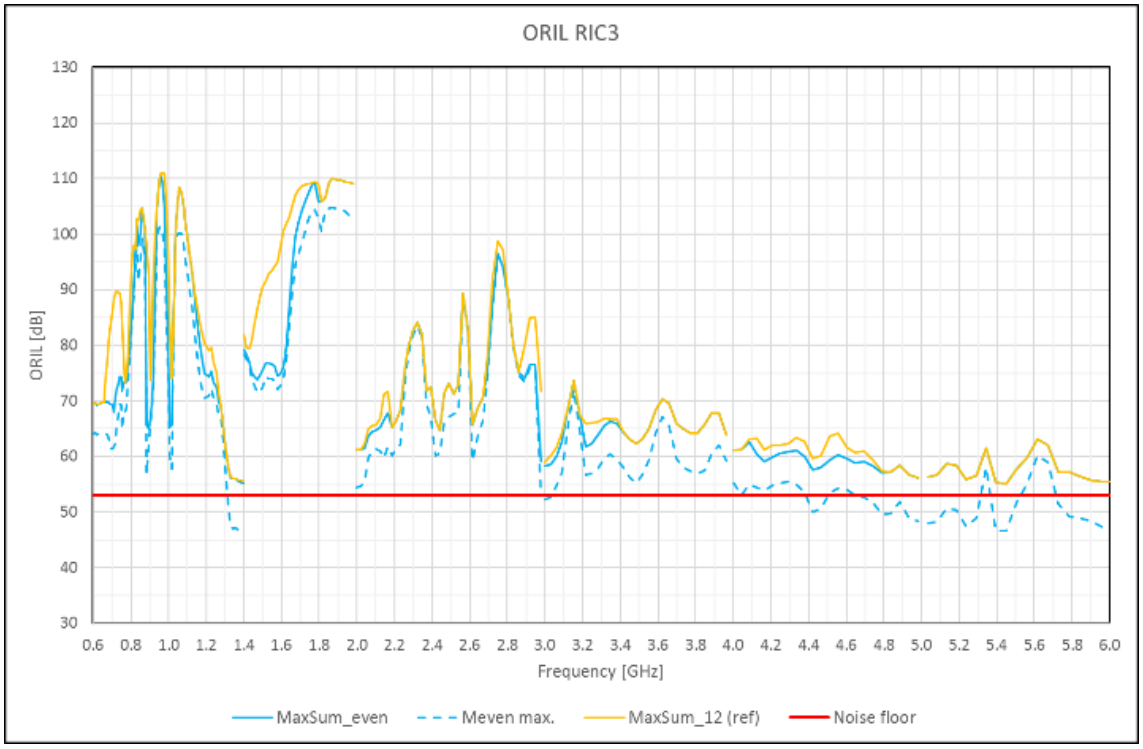
3.2.16 RIC3



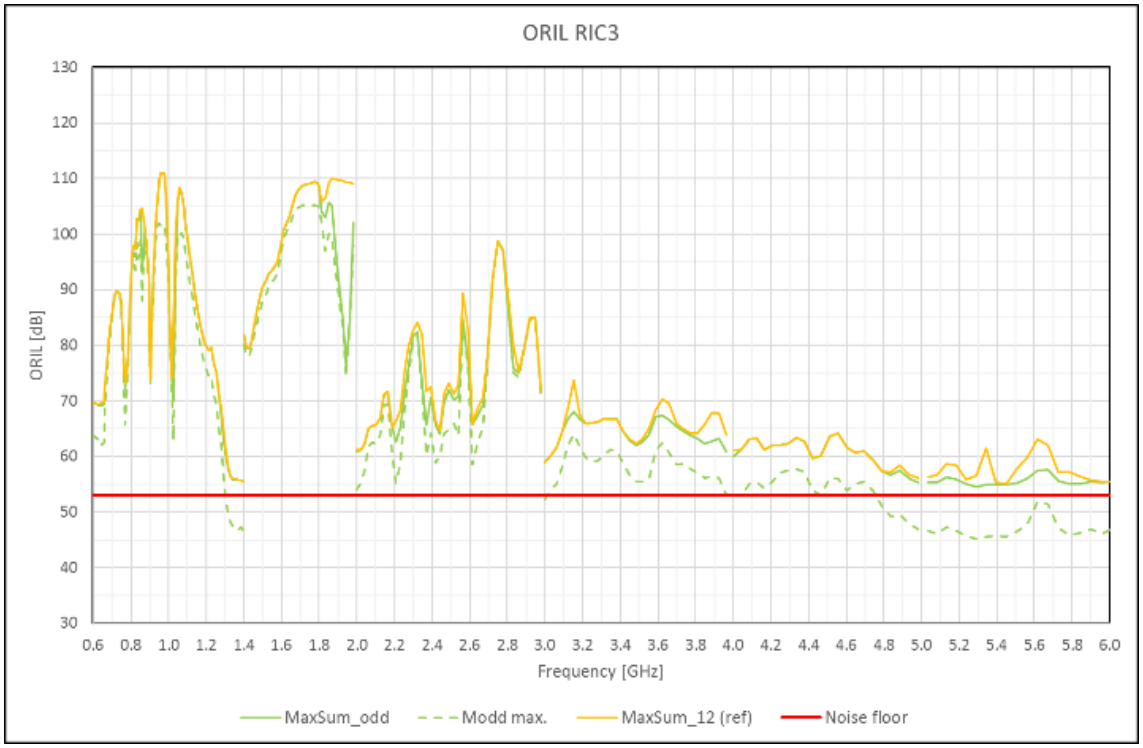
All measurements



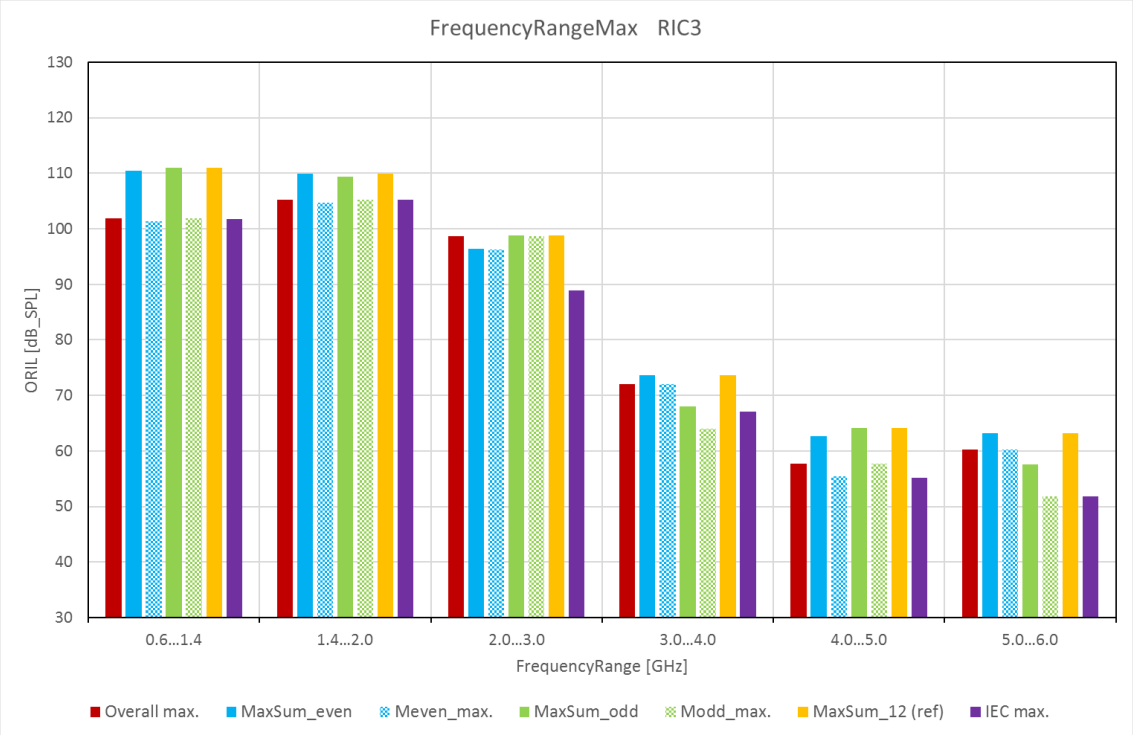
Evaluation1: Overall max., IEC max., MaxSum_12



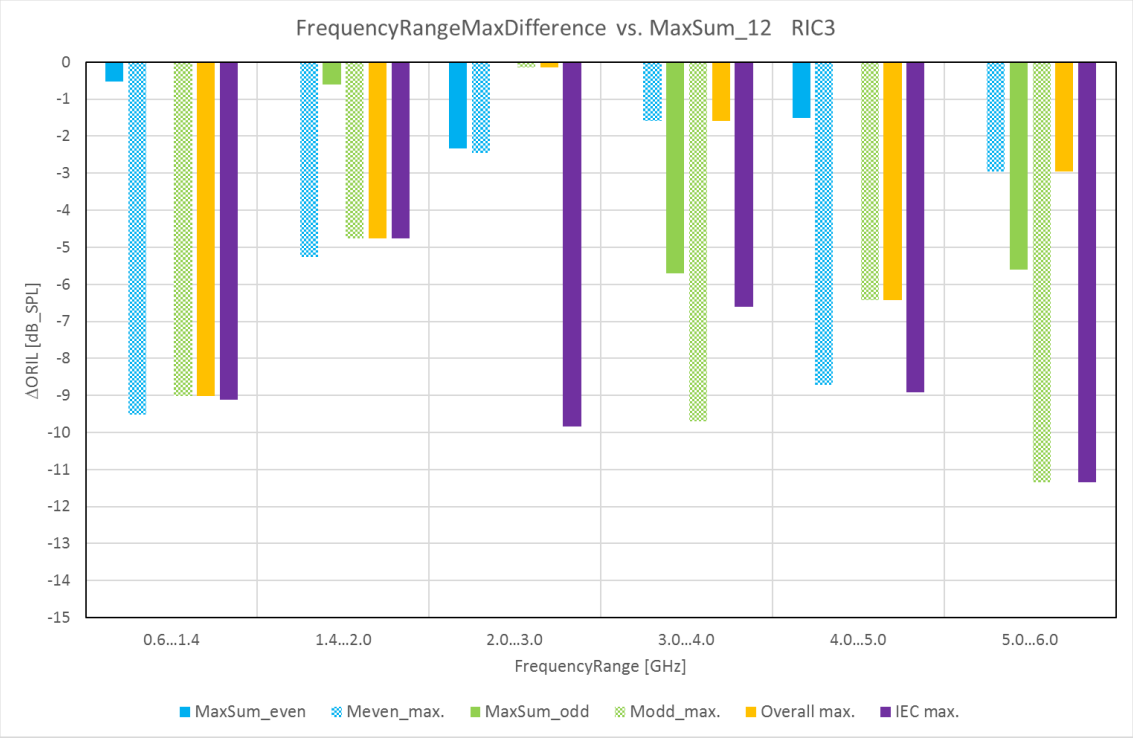
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



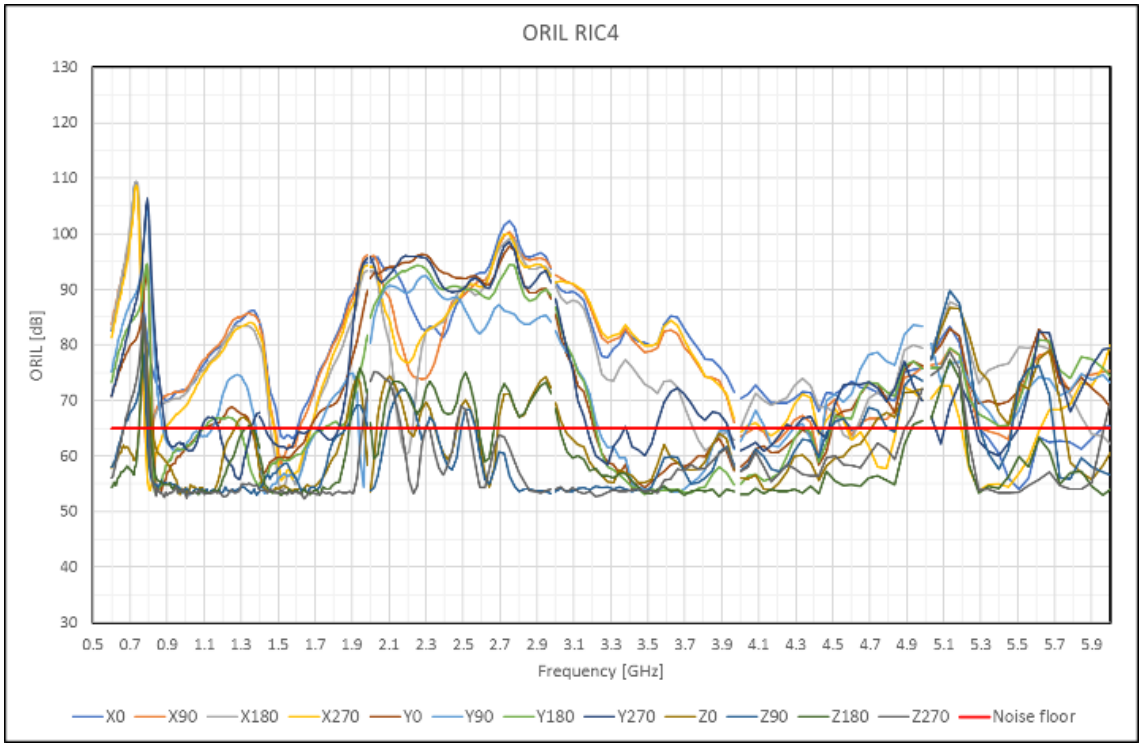
Ranking1: FRM



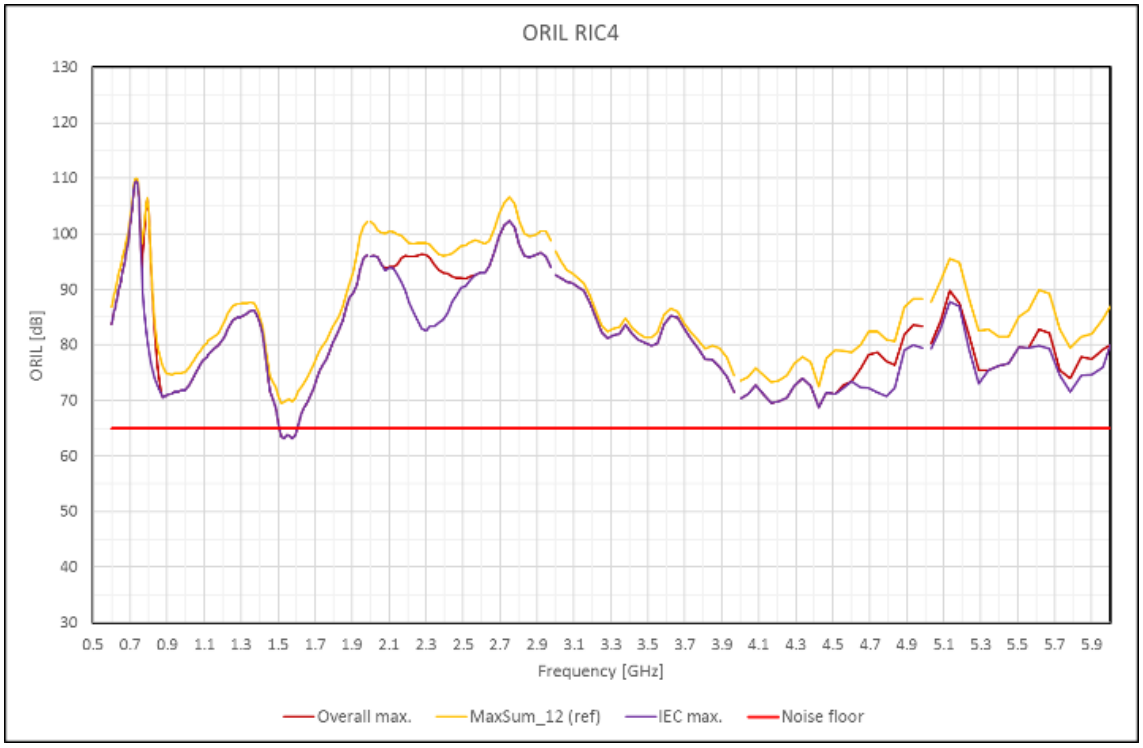
Ranking2: FRMD

Pic. 40: ORILs RIC3

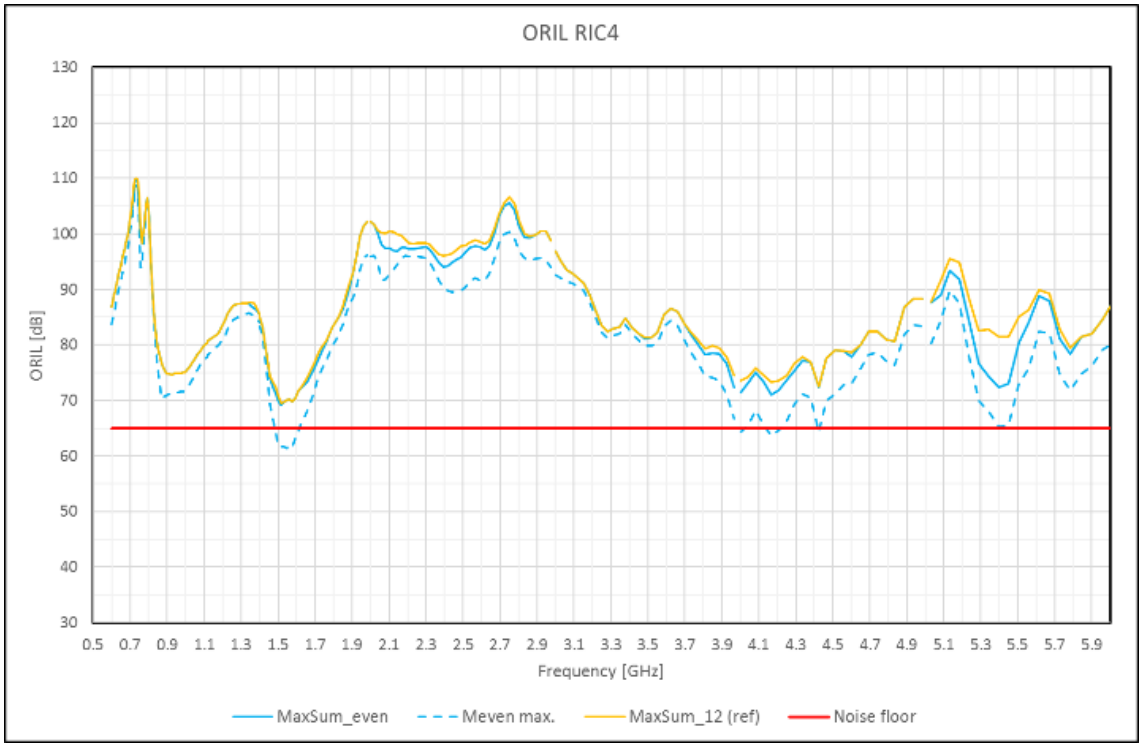
3.2.18 RIC4



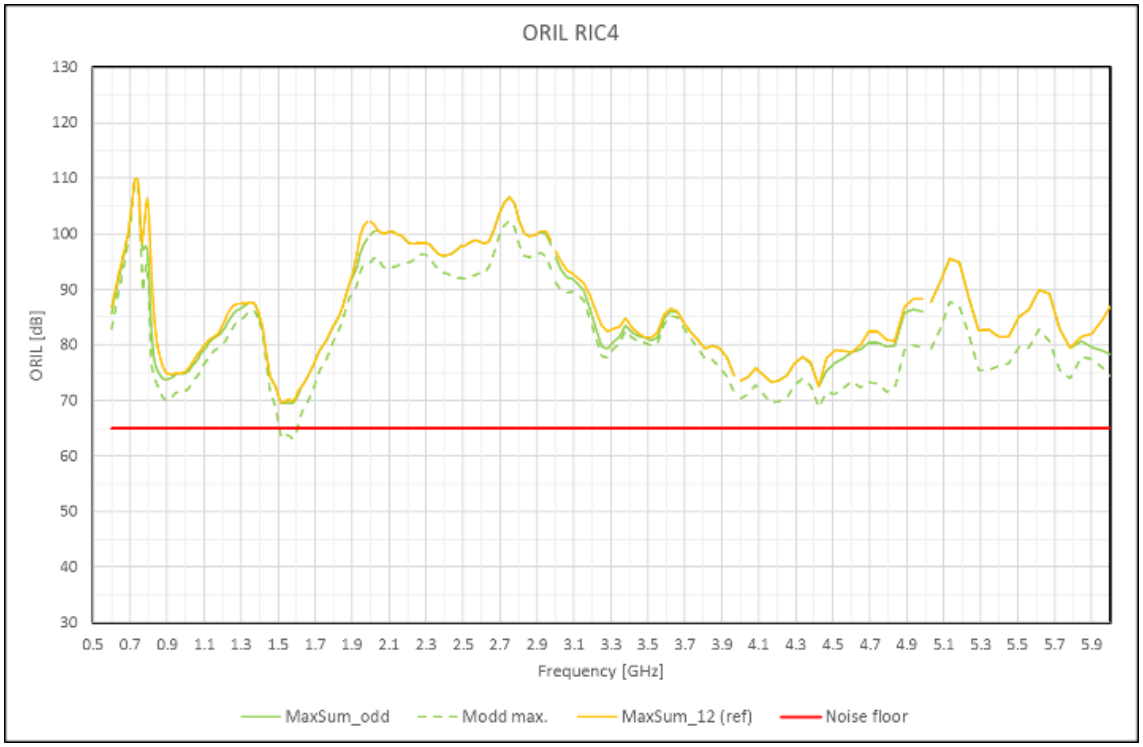
All measurements



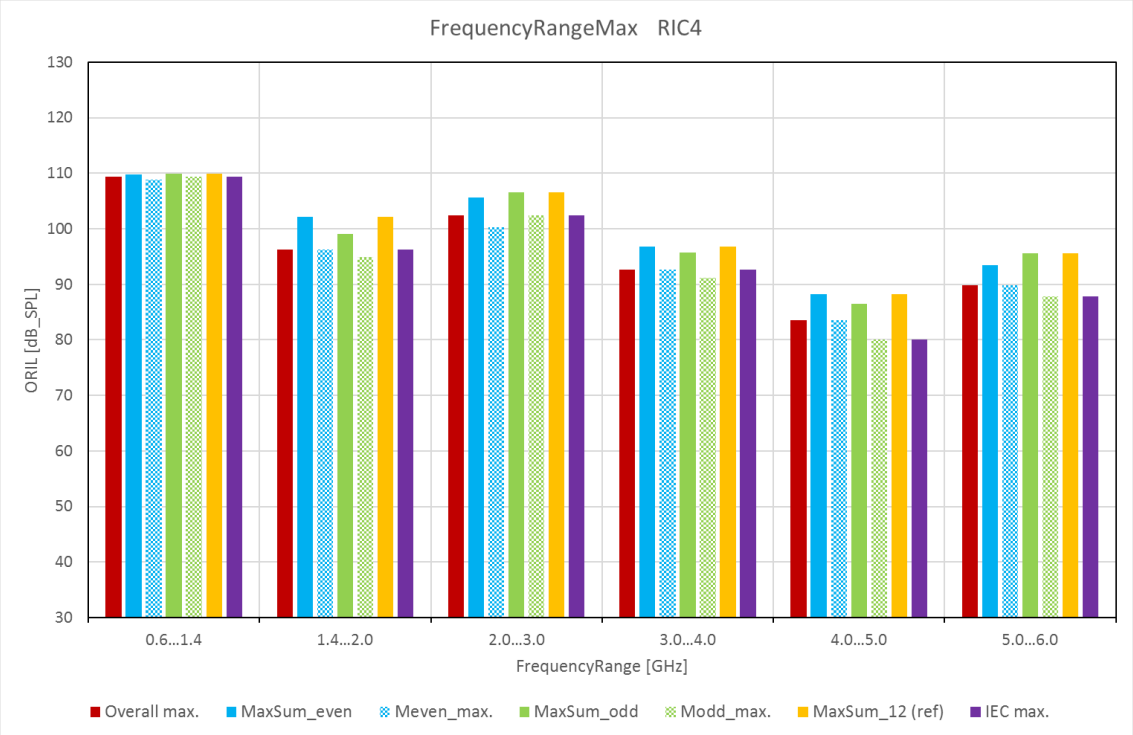
Evaluation1: Overall max., IEC max., MaxSum_12



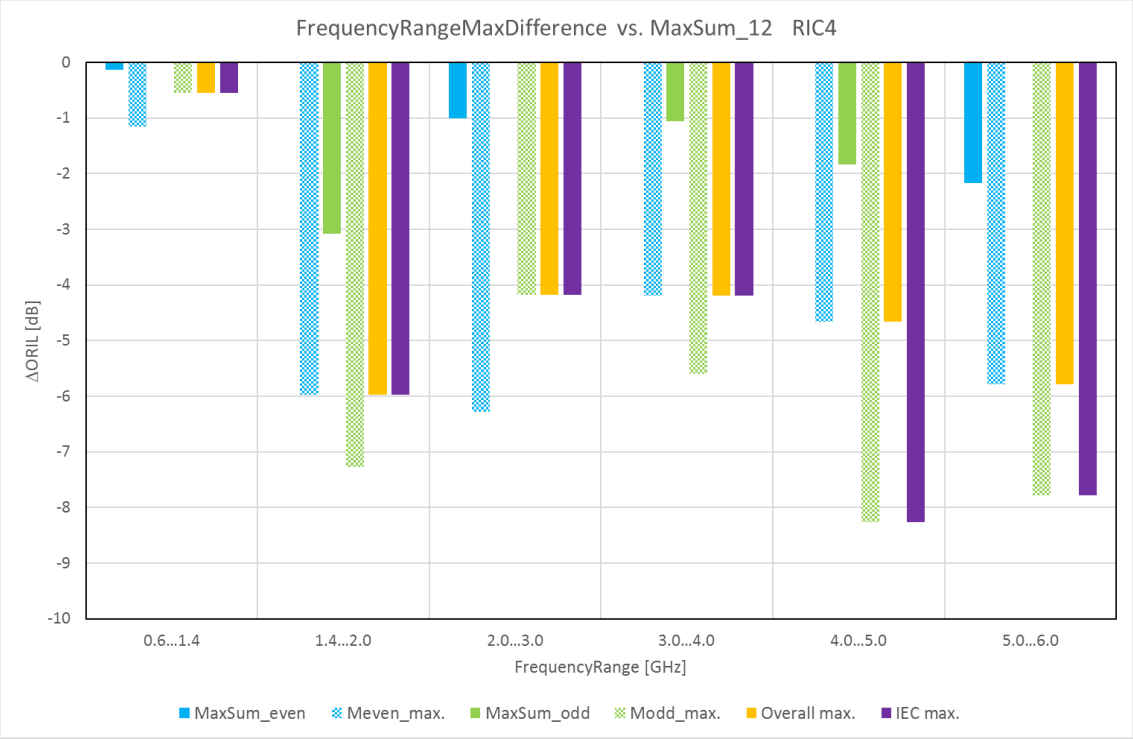
Evaluation2: MaxSum_even, Meven max., MaxSum_12



Evaluation3: MaxSum_odd, Modd max., MaxSum_12



Ranking1: FRM

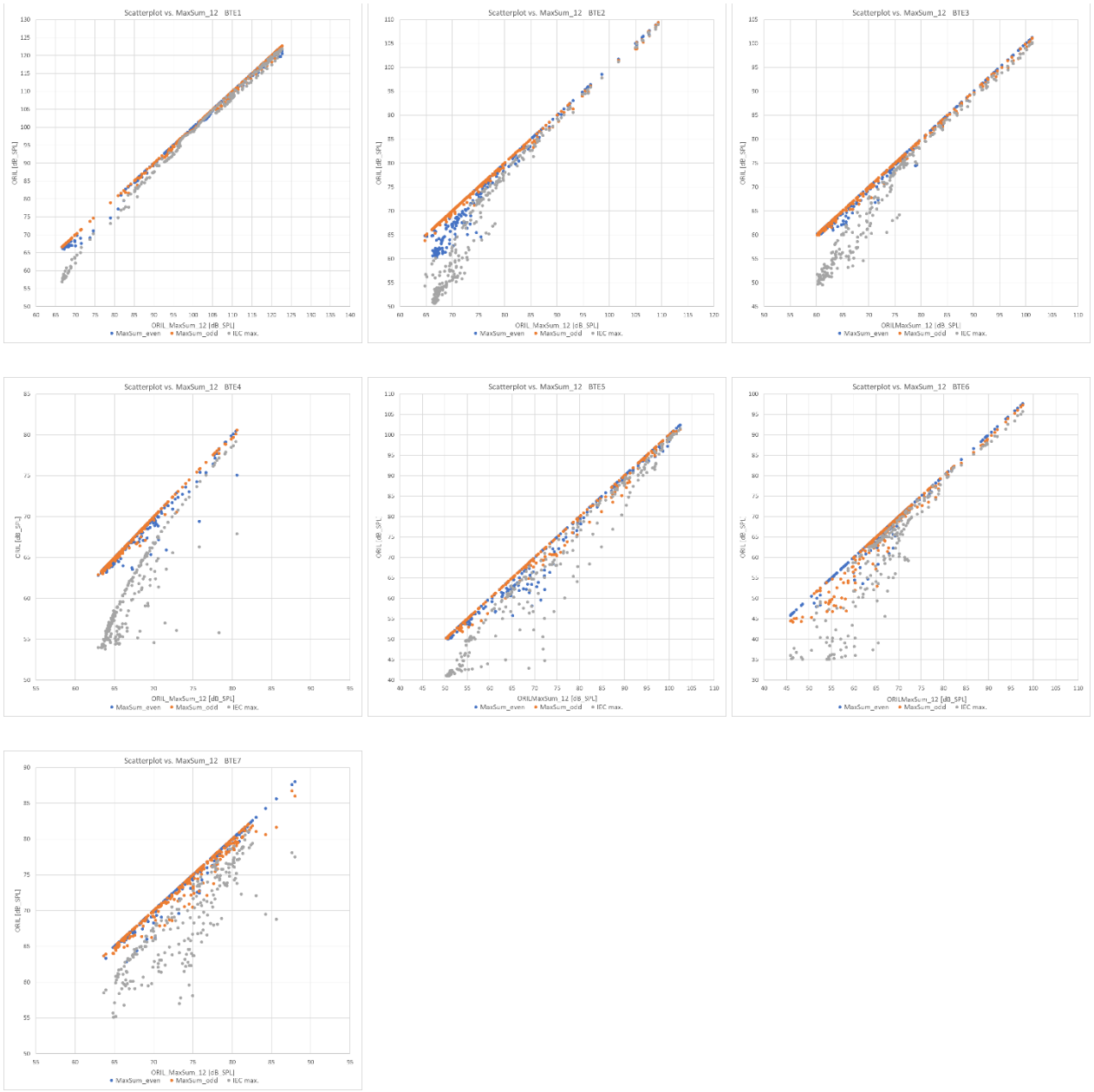


Ranking2: FRMD

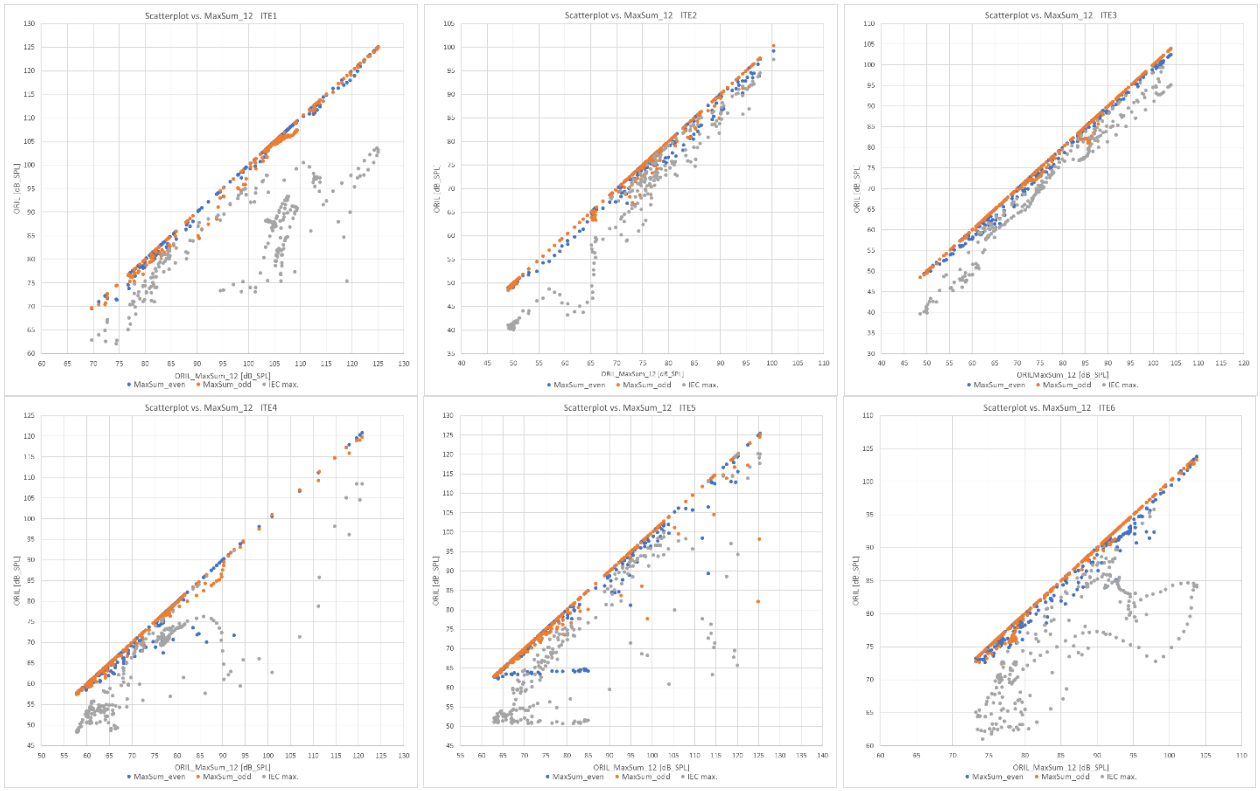
Pic. 41: ORILs RIC4

Appendix A Scatterplots

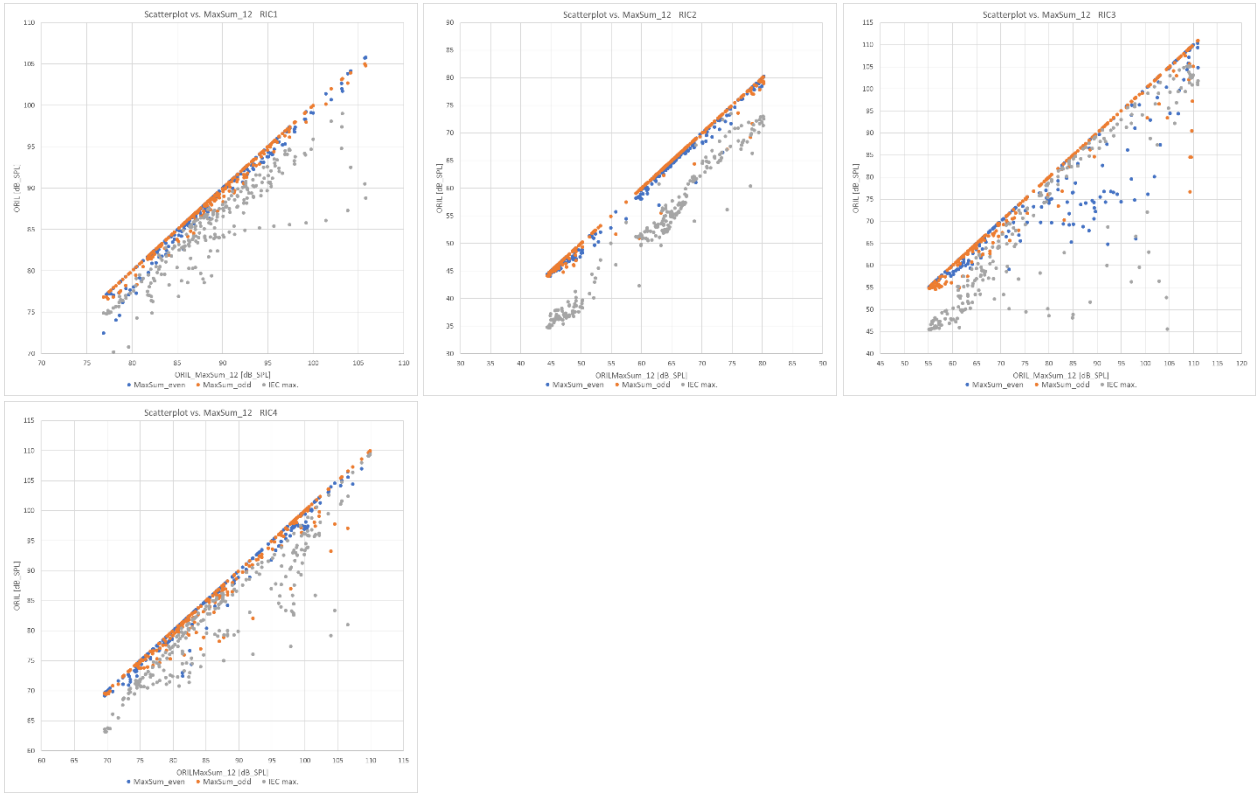
These are the Scatterplots described in 2.1 showing the ranking of the *JulstromMethods* (with MaxSum-Calculation) vs. our present Standard's IEC max. *Method*.



Pic. 42: Scatterplots BTEs



Pic. 43: Scatterplots ITEs



Pic. 44: Scatterplots RICs