narda Safety Test Solutions

Application Note | SRM-3006

5G FR1 Exposure measurement with extrapolation

The case study presented in this application note was originally developed for the IEC TR 62669 Ed 3. The purpose of this case study was to compare the extrapolated results of the actual maximum exposure delivered by different methods described in B.8.5 (IEC 62232:2022) and Annex E (IEC 62232:2022) of the standard IEC 62232.

1 Description of evaluation sites

Measurements were performed at four different operational NR FR1 sites. At each site a single MP (measurement point) has been selected a priori. Neither spatial averaging nor spatial maximum search was applied. The MPs were selected with the objective, that only one sector of the examined base station dominates the expected exposure. At site A another base station was so close that its potential contributions were small but not negligible. There was a line sight between the examined base station and the MPs at all sites.

The centre frequency of the NR base stations was 3,54 GHz. The subcarrier spacing was 30 kHz and the bandwidth was 100 MHz. The base stations were operating in TDD mode with 70 % downlink time. Each sector antenna of the base station had 64 ports. The configured maximum power per port was 5 W. The maximum gain of the traffic beams was 23,3 dBi. For the broadcast signals 4 beams were configured. Their maximum gain was 21 dBi. There was no power control activated at the base station. There was no boosting of resource elements of broadcast signals activated.

The BS maximum configured transmitted power is 320 W. Four of the factors used to calculate the extrapolation factor F_{extBeam} according to B.8.5 (IEC 62232:2022) are:

- F_{TDC} = 0,7 (i.e. 70 %)
- F_{PR}= 0,25 according to the CDF from similar sites and literature
- F_{BW} = 3276 according to table E.11 (IEC 62232:2022)
- F_{B} =1 no boosting of broadcast signals

The extrapolation factor F_{extBeam} according to B.8.5 (IEC 62232:2022) depends on the directions from the relevant sectors to the MPs. In table 1 you can find the angles, the angle dependent attenuations and maximum gain of the traffic beam envelopes and broadcast beam envelopes and the resulting F_{extBeam} for the four sites. The elevation angles were calculated by the distance and height differences between the centre of the relevant sector antenna and the MPs. The distance and the azimuth angles were derived from a map and were checked with Binoculars with laser range finder and compass. The vertical and horizontal attenuations were added to obtain the angle dependent attenuations because no data was available for the combination of both angles.

Table 1 – Description of test site parameters including F_{extBeam}

Site reference		A	B	C	D
BS configured maximum transmitted power	(W)	320	320	320	320
Distance between the BS and the MP	(m)	428	58	265	282
Elevation angle from antenna to MP	(°)	3,1	25,5	7,3	10,0
Azimuth angle difference between direction of the sector and direction to the MP	(°)	48,0	-41,0	1,0	-35,0
Vertical traffic attenuation	(dB)	0,16	20,76	0,52	0,53
Horizontal traffic attenuation	(dB)	12,51	5,65	4,50	1,34
Maximum traffic gain	(dBi)	23,30	23,30	23,30	23,30
Traffic gain	(dBi)	10,63	-3,11	18,28	21,43
Vertical broadcast attenuation	(dB)	2,85	20,95	0,34	3,13
Horizontal broodcast attenuation	(dB)	8,86	5,07	2,42	4,56
Maximum broadcast gain	(dBi)	21,00	21,00	21,00	21,00
Broadcast gain	(dBi)	9,29	-5,02	18,24	13,31
F_{extBeam}		1,36	1,55	1,01	6,49

The position of the MP and the BS (base station) used for site A are shown on Figure 1. The environment type was suburban with residential buildings with a ridge height of 9 meters approximately.

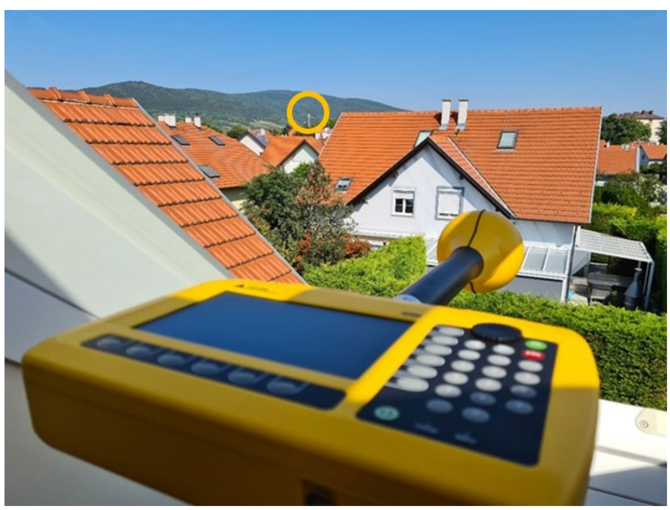


Figure 1 – Measurement situation at site A

The same BS as for site A was used for site B. The position of the MP and the BS for site B are shown on Figure 2. The MP was at a car park. There was a two-storey building in the back of the measuring point at a distance of 20 m approximately.

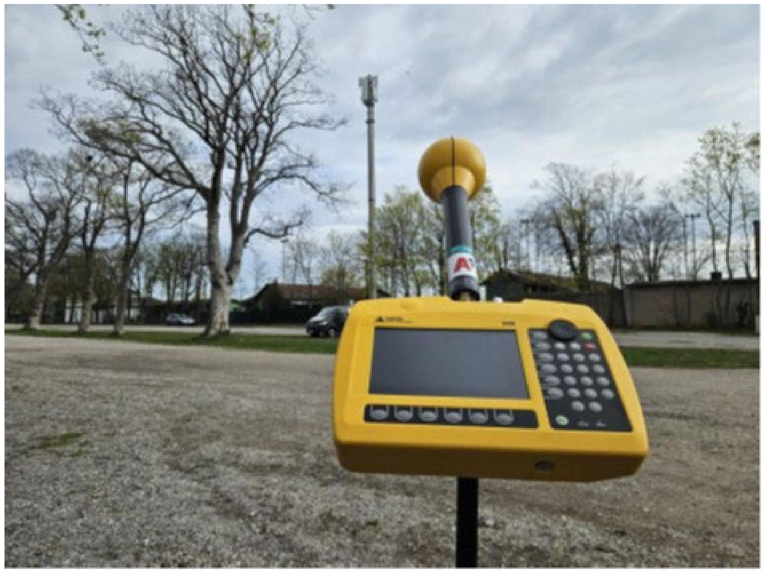


Figure 2 – Measurement situation at site B

The position of the MP and the BS for site C are shown on Figure 3. The environment type was moderate urban.

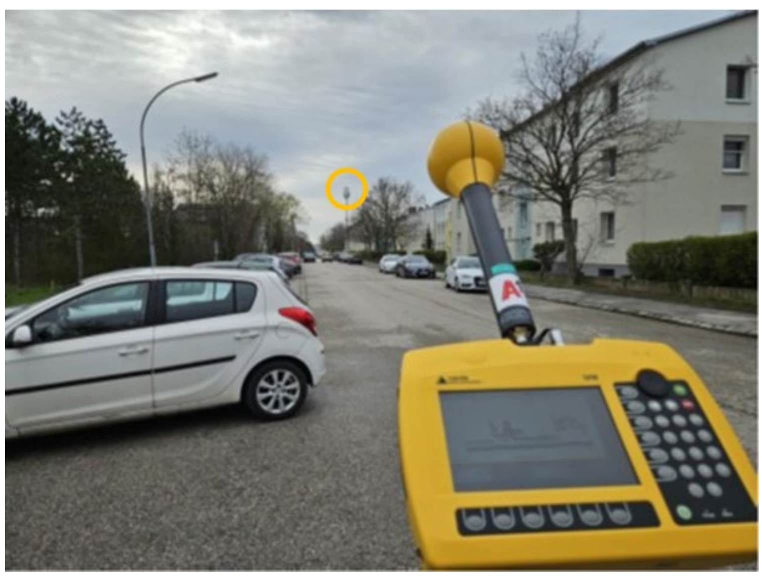


Figure 3 – Measurement situation at site C

The position of the MP and the BS are shown on Figure 4. The environment type was rural.

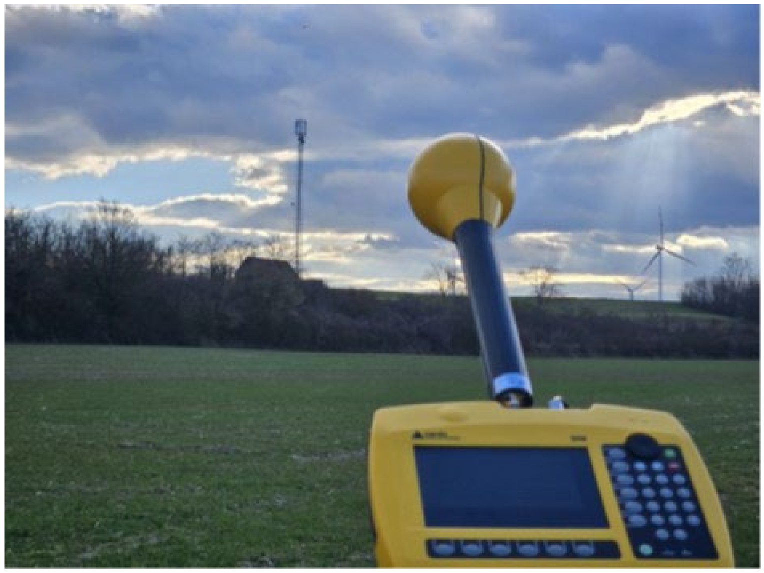


Figure 4 – Measurement situation at site D

2 Evaluation process

The purpose of this case study was to compare the extrapolated results of the actual maximum exposure delivered by the following methods described in B.8.5 (IEC 62232:2022) and Annex E (IEC 62232:2022):

- calculation assuming free space environment;
- measurement under forced maximum traffic load;
- extrapolation based on decoded SSS measurements;
- extrapolation based on analog SSB measurements;
- extrapolation based on the traffic time slots in the SSB frequency range.

All measurements were done using a predefined measurement routine that ran automatically with the same calibrated measurement instrument. All measurements, except the SSS decoding, were performed during a 60 s time period with forced maximum traffic load into the direction of the MP, see E.8.2.1, E.8 and B.4.2.5.4.2 (IEC 62232:2022).

3 Methodology

Actual maximum exposure estimation using free space calculation

The actual maximum exposure is calculated directly using the free space formula described in B.2.2 (IEC 62232:2022) and using the transmitted power, gain and distance.

Table 2 – Actual maximum power density using free space calculation

Site		A	B	C	D
Distance	(m)	428	58	265	282
Traffic gain	(dBi)	10,63	-3,11	18,28	21,43
Calculated power density	(mW m^{-2})	0,281	0,647	4,271	7,789

Frequency selective measurement with forced maximum traffic load

These measurements were performed according to B.4.2.5.4.2(IEC 62232:2022). Maximum traffic was simulated with the application nPerf on an unshaped profile over a download duration of 60 s. The mobile phone that forced the traffic load was located at a distance of more than 1,5 m from the measuring antenna according to item g) in B.4.2.5.4.2 (IEC 62232:2022). It was checked that it was connected to the expected Cell ID (PCI) and beam. It was also checked by measurements that the uplink had no relevant influence on the measurement results.

There was no power control activated in the base station. The traffic load was very close to the maximum traffic load because several nPerf runs showed similar results. The measurement based on analog SBB measurement showed that not all traffic slots were used but otherwise only negligible traffic was sent to other users. This was only possible for BTS with little to no traffic. Thus, it is assumed the measured power density is the configured maximum power density multiplied by F_{TDC} = 0,7, see 1.

The RMS trace of the spectrum analyser was averaged over 30 s and integrated from 3.490 MHz to 3.590 MHz. After multiplication with F_{PR} = 0,25, see 1, we obtain the estimation of the actual maximum power density at the MPs.

Table 3 – Actual max. power density with maximum traffic load

Site		A	B	C	D
Maximum power density	(mW m^{-2})	6,540	10,33	34,22	27,53
Actual max. power density	(mW m^{-2})	1,635	2,583	8,555	6,883

Extrapolation based on SSB decoding

These measurements were performed according to E.8.2.1.2 (IEC 62232:2022). Only the strongest beam of the relevant sector was evaluated. The other beams and sectors were negligible. About eight isotropic decoder runs were performed. The maximum value of all 8 runs was selected as the measurement result.

Table 4 – Actual max. power density based on SSS decoding

Site		A	B	C	D
Power density per RE	(μW m^{-2})	0,9426	1,976	5,755	2,203
F_{extBeam}		1,36	1,55	1,01	6,49
Act. max power density	(mW m^{-2})	0,736	1,759	3,330	8,192

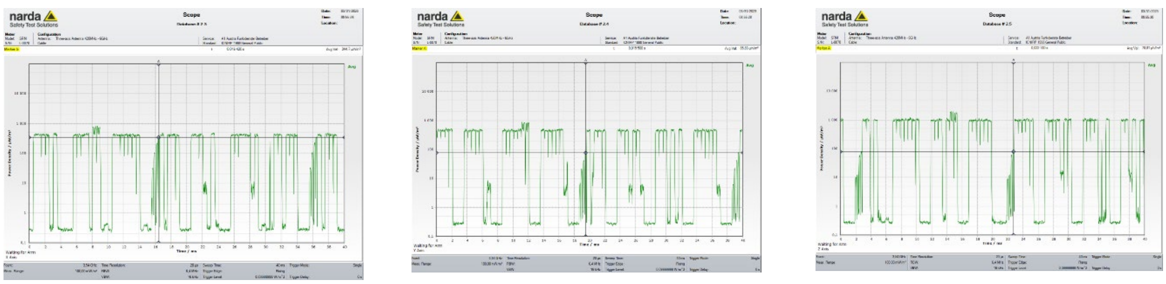
Extrapolation based on analog measurement of the SSB

These measurements were performed according to E.8.2.1.3.2 (IEC 62232:2022). Since the zero-span mode of a spectrum analyser is used, the results of the three axis of the isotropic measurement antenna are obtained by three separate measurements. The measurement bandwidth was 6,4 MHz. The result per resource element (RE) is obtained by multiplying the measured power density by 30 kHz / 6,4 MHz, see item f) in E.8.2.1.3.1. (IEC 62232:2022). Final results are summarized in Table 5.

Table 5 – Actual max. power density based on analog SSB measurement

Site		A	B	C	D
Power density on x-axis in 6,4 MHz BW	(µW m^{-2})	91,61	344,7	976,4	55,92
Power density on y-axis in 6,4 MHz BW	(µW m^{-2})	51,78	85,83	83,78	157
Power density on z-axis in 6,4 MHz BW	(µW m^{-2})	49,8	78,81	18,96	192,56
Power density on total in 6,4 MHz BW	(µW m^{-2})	193,19	509,34	1079,1	405,48
F_{extBeam}		1,36	1,55	1,01	6,49
Act. max power density	(mW m^{-2})	0,707	2,125	2,927	7,068

Figure 5 shows an example of measurement diagrams captured on the SA for site B.



x-axis **y-axis** **z-axis**

Figure 5 – Zero span measurement with spectrum analyser

Extrapolation based on the traffic time slots in the SSB frequency range

This method uses zero span measurements. Instead of the SSB beams time slots with maximum traffic load are evaluated. The measurements were taken during forced maximum traffic load. We expect a constant power density in the down link time slots which are not used for the SSB beams. As shown in Figure 5, some two time slots once in 40 ms show even higher power densities. These are TRS slots (CSI-RS for Tracking, helps to ensure that the UE remains time and frequency synchronised). To avoid unnecessary overestimation the power density of the down link traffic time slots was used for the evaluation.

Table 6 – Actual max power density based on traffic time slots in the SSB frequency range

Site		A	B	C	D
Power density on x-axis in 6,4 MHz BW	(µW m^{-2})	395,1	420,8	5231	232,1
Power density on y-axis in 6,4 MHz BW	(µW m^{-2})	296,4	449,7	2144	867,3
Power density on z-axis in 6,4 MHz BW	(µW m^{-2})	242	958,2	1237	1147
Power density on total in 6,4 MHz BW	(µW m^{-2})	933,5	1828,7	8612	2246,4
Act. max power density	(mW m^{-2})	2,509	4,914	23,143	6,037

4 Reporting

The Table 7 shows the estimated actual maximum power density for the four sites and five methods in absolute values:

Table 7 – Comparison of the absolute actual maximum power density values

Site		A	B	C	D
Calculation under free space conditions	(mW m^{-2})	0,281	0,647	4,271	7,789
Channel power during max. traffic load	(mW m^{-2})	1,635	2,583	8,555	6,883
Extrapolation SSS decoder	(mW m^{-2})	0,736	1,759	3,330	8,192
Extrapolation analog SSB	(mW m^{-2})	0,707	2,125	2,927	7,068
Extrapolation traffic time slots	(mW m^{-2})	2,509	4,914	23,143	6,037

The Table 8 shows the estimated actual maximum power density for the three sites and for methods in decibels relative to the forced maximum traffic method.

Table 8 – Comparison of the relative actual maximum power density results

Site		A	B	C	D
Calculation under free space conditions	(dB)	-7,6	-6,0	-3,0	0,5
Channel power during max. traffic load	(dB)	0,0	0,0	0,0	0,0
Extrapolation SSS decoder	(dB)	-3,5	-1,7	-4,1	0,8
Extrapolation analog SSB	(dB)	-3,6	-0,8	-4,7	0,1
Extrapolation traffic time slots	(dB)	1,9	2,8	4,3	-0,6

5 Technical outcome

The forced maximum traffic load method is used as the reference method because it was the most reliable and accurate method at the time of the measurements. In future - with more active users - it might however be more difficult to attract all traffic into the direction to the measurement point.

The free space calculation showed significantly different results. It does not regard reflections. The unavoidable reflections increase the average power density in a volume of a cube with an edge length of some wave lengths around the measuring point. The amount of power density increase depends highly on the actual environment and the angle attenuation relative to boresight. At MPs with high angle attenuation the expected power density increase due to reflections is high too. In this case reflectors are likely exposed with higher power densities compared to the MP itself. For the four sites A, B, C and D the horizontal angle attenuations were 12,51, 5,65, 4,5 and 1,34 dB (respectively). Note that there is a good correlation between the horizontal angle attenuation and the measurement results. Since the measurements were taken only at a single point, we expect several dBs of additional uncertainty in a reflective environment. Also note that site D was the only site in rural environment with no relevant reflectors. Here the calculation is very close to the measurement.

Since only two cuts of the antenna gain patterns were available the gain into the actual direction was estimated by subtracting the horizontal and the vertical attenuation from the boresight gain. This estimation is not the exact gain into the actual direction and might explain a part of the difference between both methods. The uncertainty of the measurement device may explain a part of the difference between both methods too.

The extrapolation based on SSS decoder and analog SSB measurement are very close together. It is worth to mention that the analog SSB measurement can't distinguish between several cells while the SSS decoder can. In this campaign this was not an issue because only one cell was relevant. In urban environment we observe lower values compared to the reference. Possible reasons are that FextBeam is only correct under free space conditions and that the bandwidth extrapolation is also only correct under free space conditions. In rural environment at site D the results are very close to the reference.

The extrapolation based on the traffic time slots in the SSB frequency range showed higher values compared to the reference. The values would be even higher if the time slots with maximum power density would have been used. A possible reason is that the bandwidth extrapolation is only correct under free space conditions. In rural environment at site D the result is very close to the reference.

Authors: Manfred Ruttner, A1 Telekom Austria AG
Helmut Keller, Narda Safety Test Solutions GmbH

Narda Safety Test Solutions GmbH
Sandwiesenstrasse 7
72793 Pfullingen, Germany
Phone +49 7121 97 32 0
info@narda-sts.com

Narda Safety Test Solutions
North America Representative Office
435 Moreland Road
Hauppauge, NY11788, USA
Phone +1 631 231 1700
info@narda-sts.com

Narda Safety Test Solutions S.r.l.
Via Benessea 29/B
17035 Cisano sul Neva, Italy
Phone +39 0182 58641
nardait.support@narda-sts.it

Narda Safety Test Solutions GmbH
Beijing Representative Office
Xiyuan Hotel, No. 1 Sanlihe Road, Haidian
100044 Beijing, China
Phone +86 10 6830 5870
support@narda-sts.cn

www.narda-sts.com