Lighting the path to 5G

“Electromagnetic field and the future of telecommunications. Research. Monitoring. Domestic and foreign experience”

December 2019 Warsaw National Stadium

Johann Saustingl

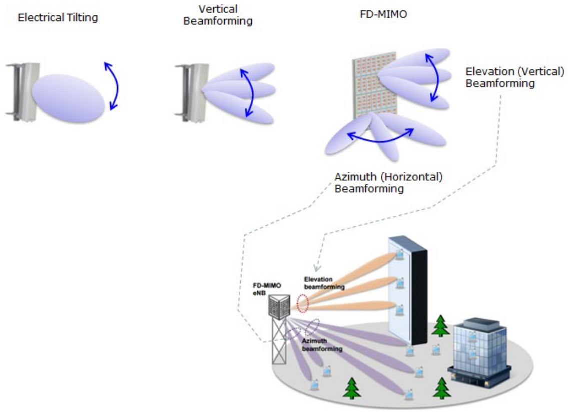
EMF Instruments Narda Safety Test Solutions

Measuring instruments for
electric and magnetic fields
broadband or selective
from 0 Hz to 90 GHz

Agenda:

Limits
5G Technologies, Beam forming
Safety on workplaces solutions
Safety general public proposals

- 5G (short for 5th Generation) is a frequently used term for certain advanced wireless systems.
- Industry association 3GPP defines any system using "5G NR" (5G New Radio) software as "5G“



European Limits / ICNIRP (OCCUPATIONAL)

Table 6 Reference levels for occupational exposure to time-varying electric and magnetic fields (unperturbed rms values).

Frequency range	E-field strength ($V m^{-1}$)	H-field strength ($A m^{-1}$)	B-field (μT)	Equivalent plane wave power density S_{eq} ($W m^{-2}$)
up to 1 Hz	—	1.63×10^5	2×10^5	—
1–8 Hz	20 000	$1.63 \times 10^5/f^2$	$2 \times 10^5/f^2$	—
8–25 Hz	20 000	$2 \times 10^4/f$	$2.5 \times 10^4/f$	—
0.025–0.82 kHz	$500/f$	$20/f$	$25/f$	—
0.82–65 kHz	610	24.4	30.7	—
0.065–1 MHz	610	$1.6/f$	$2.0/f$	—
1–10 MHz	$610/f$	$1.6/f$	$2.0/f$	—
10–400 MHz	61	0.16	0.2	10
400–2000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	$0.01f^{1/2}$	$f/40$
2–300 GHz	137	0.36	0.45	50

Notes:
1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any 6-minute period.
4. For peak values at frequencies up to100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding 100 kHz see Figures 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width, does not exceed 1000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-minute period (f in GHz).
7. No E-field value is provided for frequencies <1 Hz, which are effectively static electric fields. Electric shock from low impedance sources is prevented by established electrical safety procedures for such equipment.

European Limits / ICNIRP (GENERAL PUBLIC)

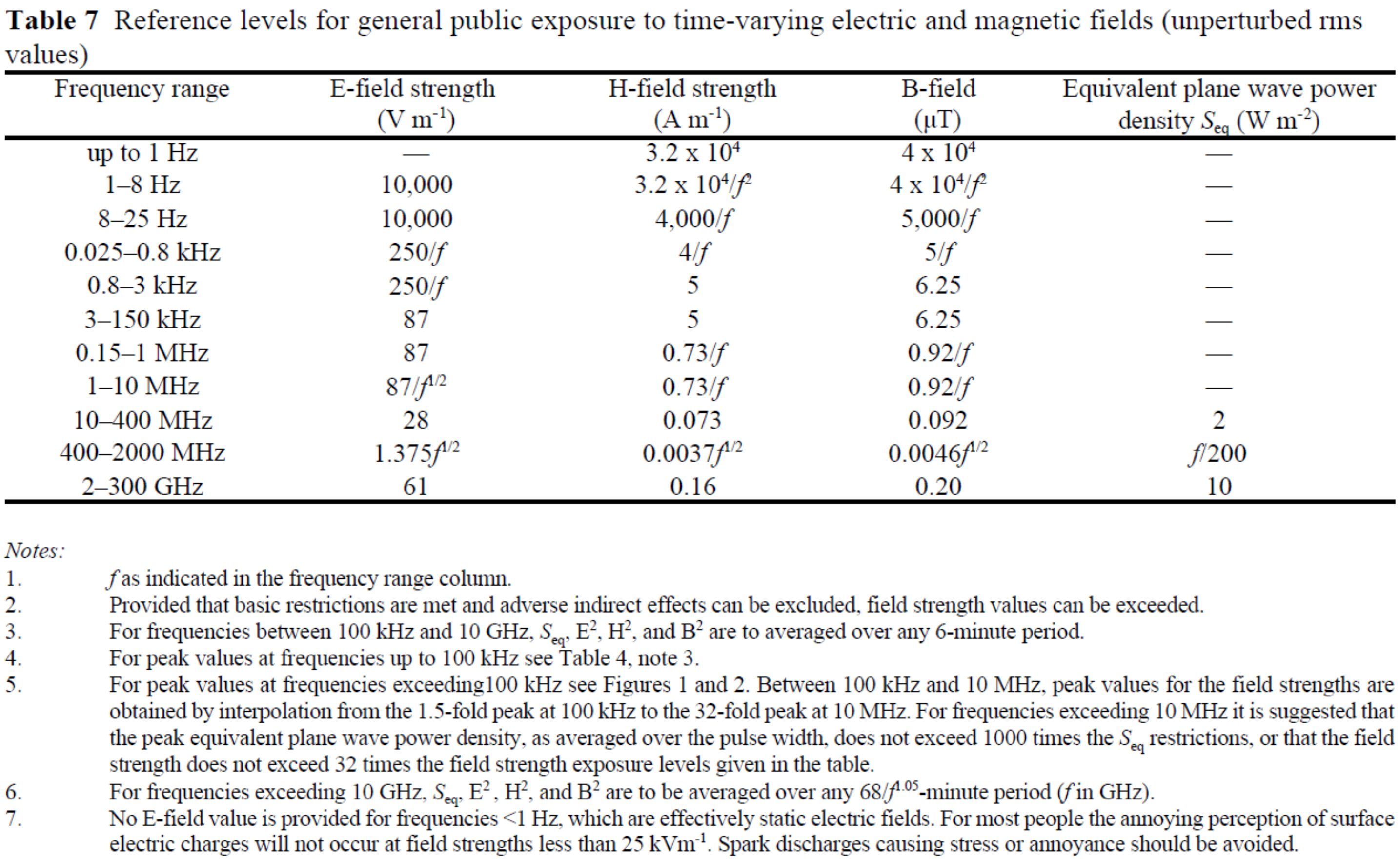


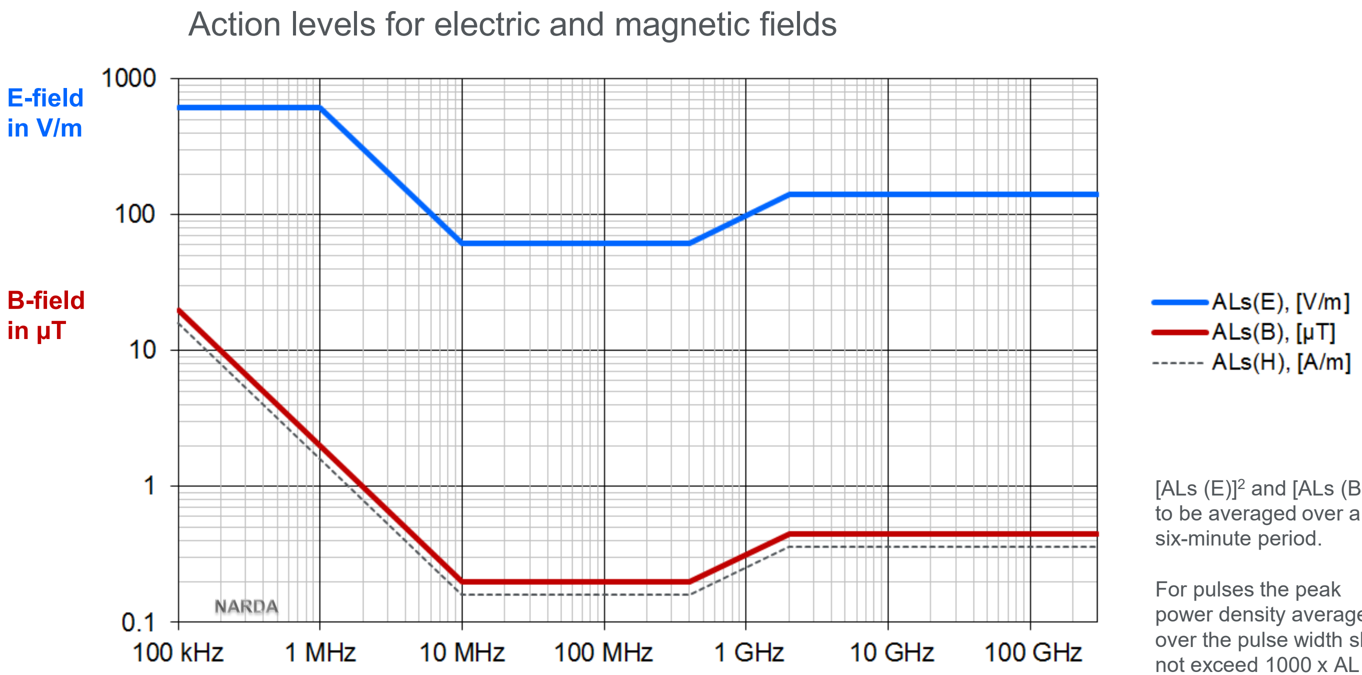
Table 7 Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values)

Frequency range	E-field strength ($V\ m^{-1}$)	H-field strength ($A\ m^{-1}$)	B-field (μT)	Equivalent plane wave power density S_{eq} ($W\ m^{-2}$)
up to 1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8–25 Hz	10,000	$4{,}000/f$	$5{,}000/f$	—
0.025–0.8 kHz	$250/f$	$4/f$	$5/f$	—
0.8–3 kHz	$250/f$	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	$0.73/f$	$0.92/f$	—
1–10 MHz	$87/f^{1/2}$	$0.73/f$	$0.92/f$	—
10–400 MHz	28	0.073	0.092	2
400–2000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2–300 GHz	61	0.16	0.20	10

Notes:

1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to averaged over any 6-minute period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding100 kHz see Figures 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width, does not exceed 1000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-minute period (f in GHz).
7. No E-field value is provided for frequencies <1 Hz, which are effectively static electric fields. For most people the annoying perception of surface electric charges will not occur at field strengths less than 25 kVm^{-1}. Spark discharges causing stress or annoyance should be avoided.

Limits chart Annex III B1



$[ALs\ (E)]^2$ and $[ALs\ (B)]^2$ to be averaged over a six-minute period.

For pulses the peak power density averaged over the pulse width shall not exceed 1000 x AL = 32 x AL for field strength

5G frequency

Major physical parameter of mobile networks

Band	f (GHz)	Common name	Subset of band	Uplink / Downlink[B 1] (GHz)	Channel bandwidths[5] (MHz)
n257	26	LMDS		26.50 – 29.50	50, 100, 200, 400
n258	24	K-band		24.25 – 27.50	50, 100, 200, 400
n260	39	Ka-band		37.00 – 40.00	50, 100, 200, 400
n261	28	Ka-band	n257	27.50 – 28.35	50, 100, 200, 400
Band	f (GHz)	Common name	Subset of band	Uplink / Downlink[B 1] (GHz)	Channel bandwidths[5] (MHz)

	2G GSM	3G UMTS	4G LTE	5G NR
RF Frequency	< 3 GHz	< 6 GHz	< 6 GHz	< 6 GHz & > 24 GHz
RF Bandwidth	200 kHz / carrier	5 MHz / carrier	Up to 20 MHz / carrier	< 6 GHz up to 100 MHz/carrier > 24 GHz up to 400 MHz/carrier
Data rate	9.6 kB/s	384 kB/s	150 MB/s	10 GB/s
Latency		~ 100 ms	~ 30 ms	~ 1 ms

All values typical values, deviation and overlapping possible

5G applications

Major focus of mobile networks

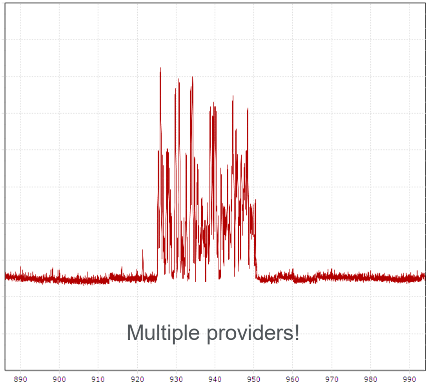
	2G GSM	3G UMTS	4G LTE	5G NR
Application	• Voice • Data • SMS	• Voice • Internet • SMS	• Voice • Video • Fast mobile internet	• Voice • 4K / 8K-Videos • Ultra fast mobile internet • Massive Machine Type Communications M2M • Ultra-Reliable and Low Latency • Industry 4.0 • Internet of Things IoT • Car to car communication • Broadcasting?
Propagation	MIMO (base station only)	MIMO (base station only)	MIMO	Massive MIMO Beamforming

All values typical values, deviation and overlapping possible

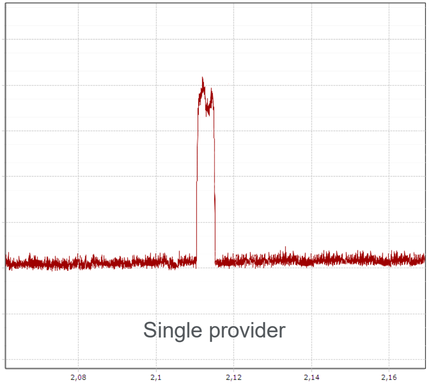
5G signal bandwidth

Mobile networks in frequency domain

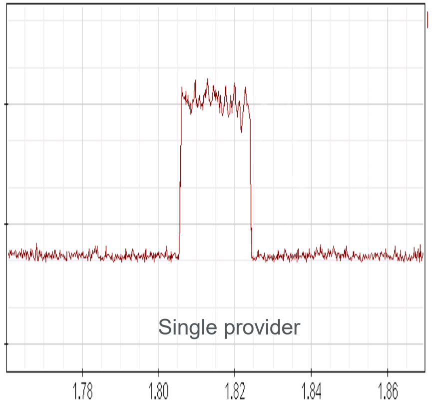
2G, 200 kHz bandwidth per carrier



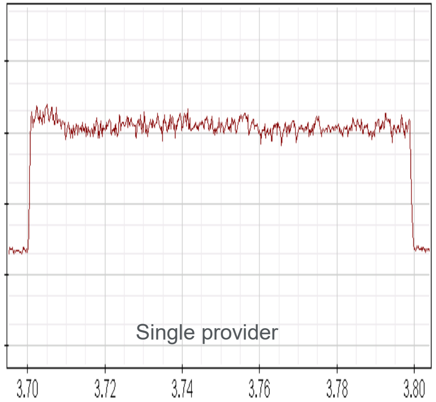
3G, 5 MHz maximum bandwidth



4G, 20 MHz maximum bandwidth



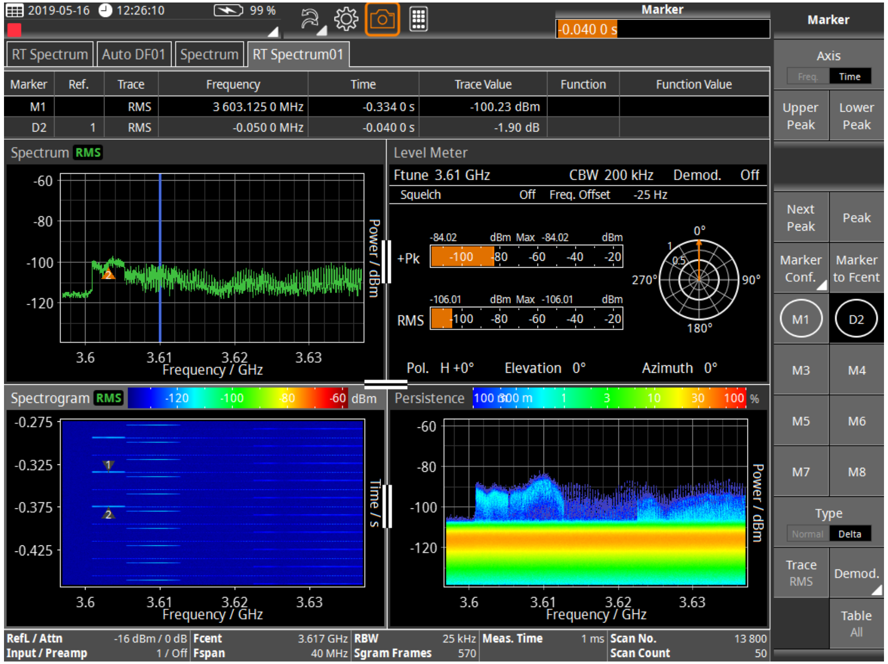
5G, 100 MHz maximum bandwidth @ < 6 GHz

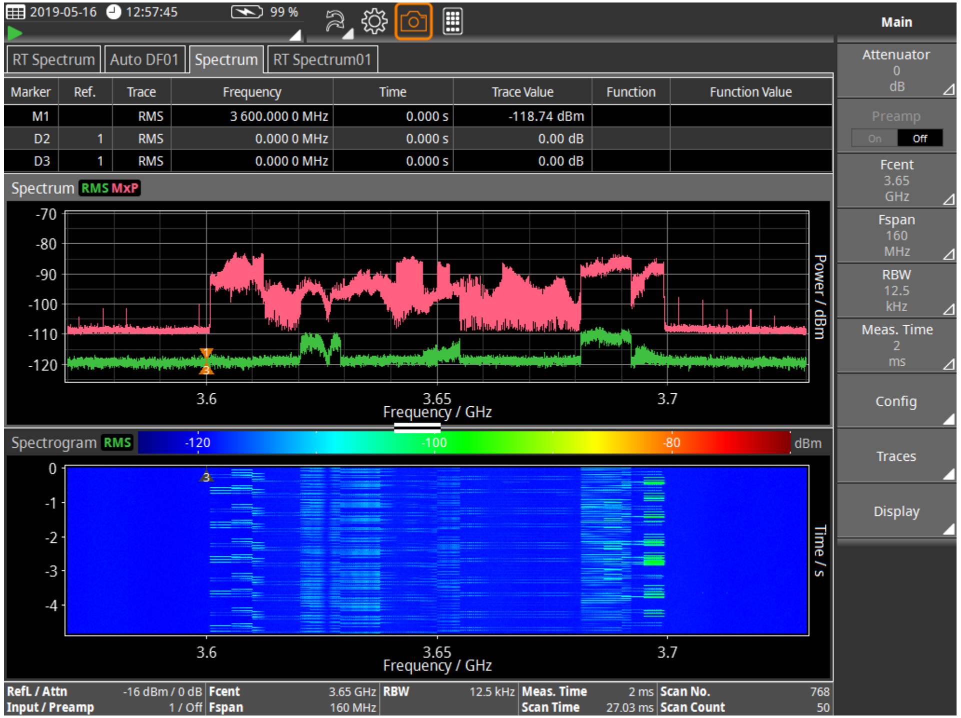


Fspan 108 MHz

5G signal bandwidth

5G Signal ZTE
University Györ Hungary





5G, Beam Forming and Massive MIMO

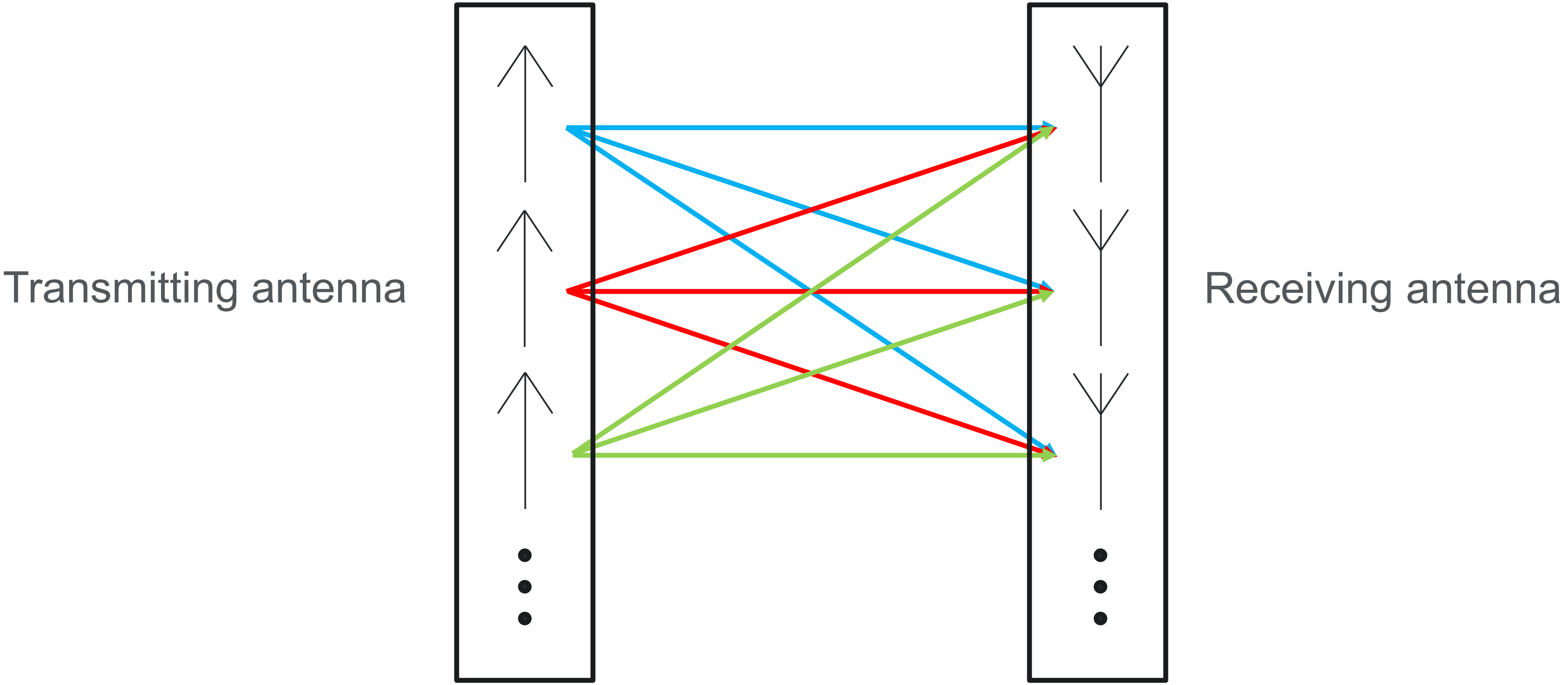
5G, Beam Forming and Massive MIMO

When talking about 5G also Beam Forming and Massive MIMO are mentioned. What is the relationship between 5G, Beam Forming and Massive MIMO?

- **Initially neither Beam Forming nor Massive MIMO depend on 5G**
- **Beam Forming and Massive MIMO are already used in modern WiFi-routers, some 4G installations etc.**
- **5G can be used also without those technologies**
- **But it is expected, that most 5G installations will be using both, Massive MIMO and Beam Forming**
- **Beam Forming and Massive MIMO require an array of multiple antennas so they are mostly used together**

Massive MIMO

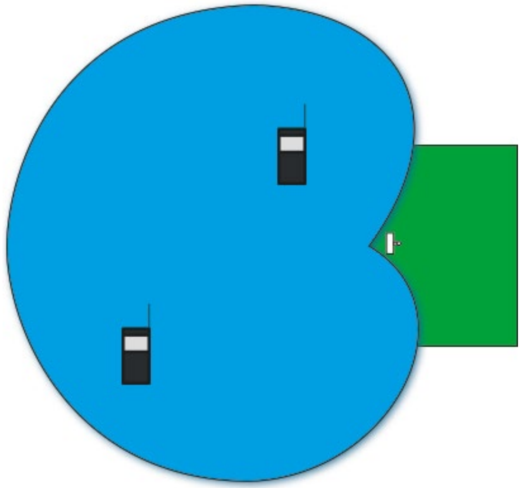
(multiple input and multiple output) antennas increases sector throughput and capacity density using large numbers of antenna. In use for mobile radio applications since 2G (GSM base station).



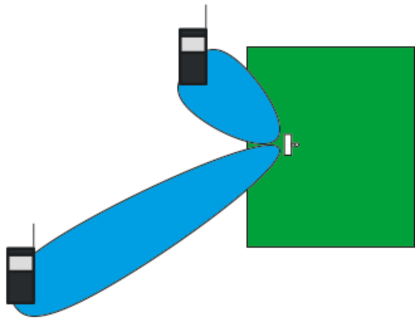
Beam Forming

is used to direct radio waves to a target. This is achieved by combining elements in an antenna. This improves signal quality and data transfer speeds because of the improved signal quality and avoids fading effects. Beamforming can also improve the antenna gain.

Horizontal pattern of a segment antenna (120°) **without** beamforming

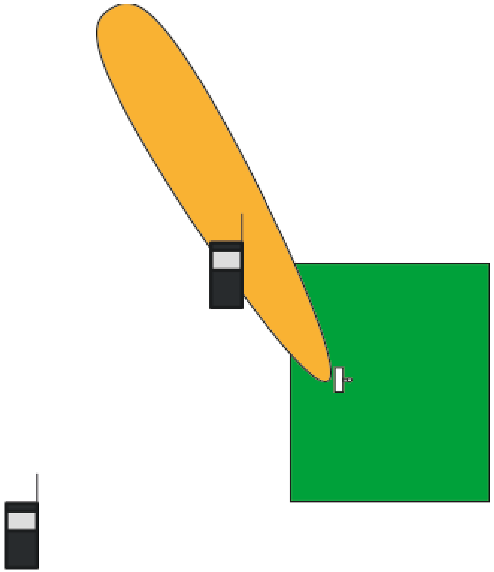


Horizontal pattern of a segment antenna **with** beamforming

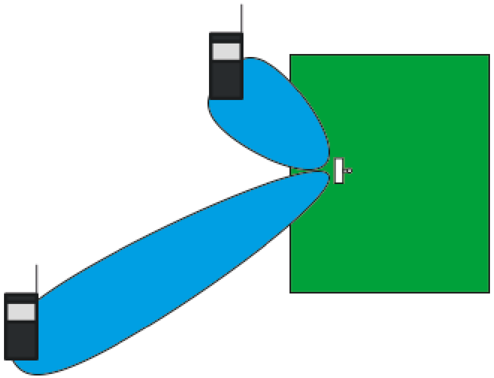


Beam Forming can be used for multiple purpose:

E.g.: Scanning the sector by the "signalization signal", connecting phones

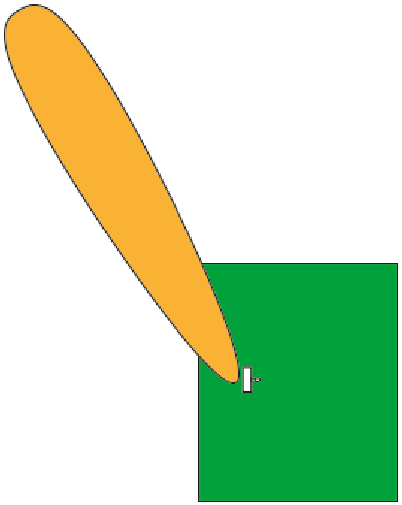


Focusing the "traffic signal" to the terminal device for optimum connectivity

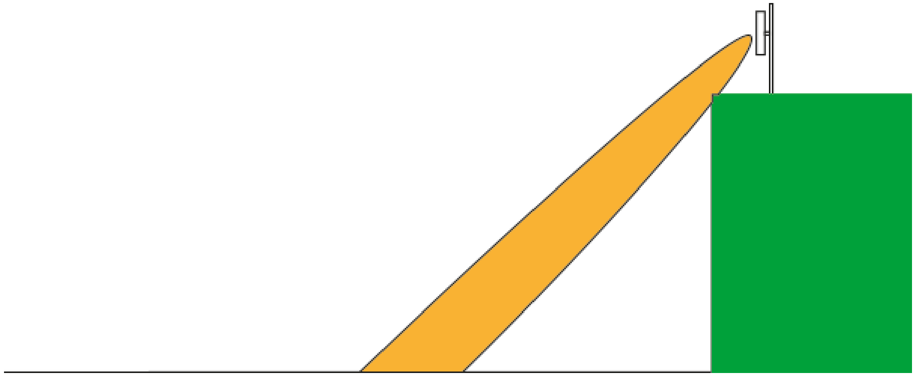


Beam Forming is available for:

Horizontal scanning



Vertical scanning

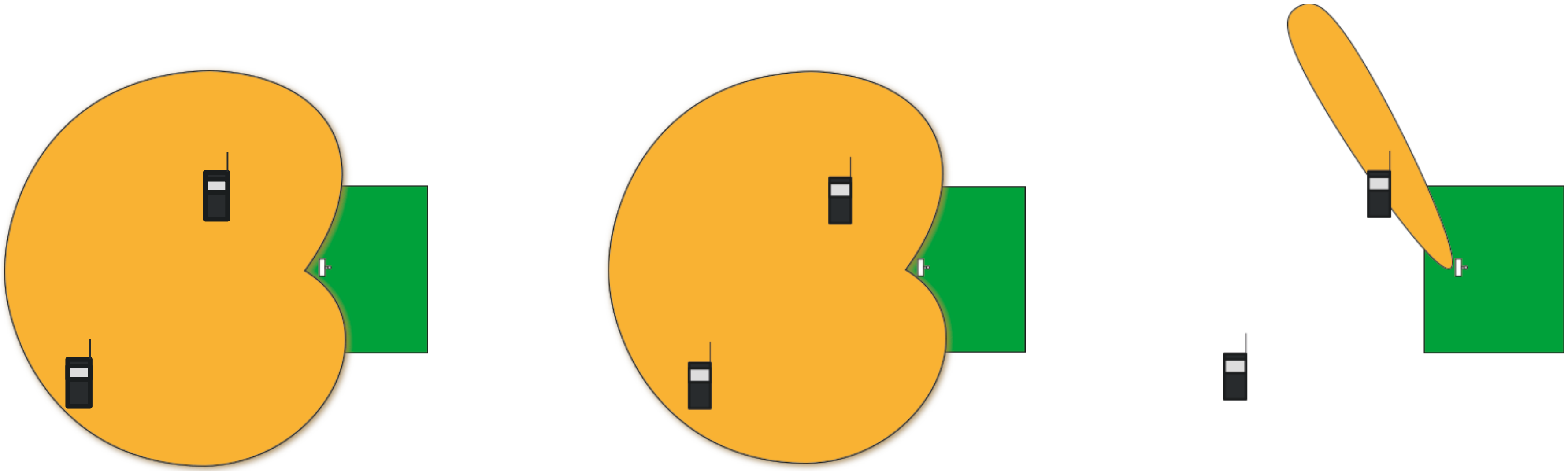


For 5G the following configurations are expected:

Signalization without beam forming
Traffic without beam forming

Signalization without beam forming
Traffic with beam forming

Signalization with beam forming
Traffic with beam forming



What is the impact of 5G to measurements of electromagnetic fields?

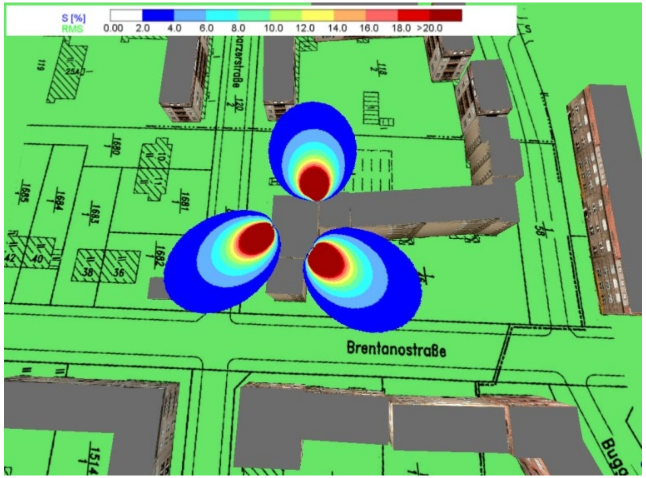
Personal protection at workplace

- Signal parameters as: modulation, crest factor and signal shape are not critical to RadMan 2 or Nardalert S3
- As 5G will use also frequencies > 24 GHz with relevant output power, models with an upper frequency limit of 6 or 8 GHz should be avoided
- As the beam can change its direction, the personal monitor should always be worn on the body and should not be left behind

Definition of safety zones

Typically the worst-case scenario is base for defining safety or exclusion zones

- This can be simulated by EFC-400 or
- For a measurement and the extrapolation to the worst-case scenario Narda has proposed two measurement procedures based on SRM-3006 (more information see next pages “Environmental measurements”).



Environmental measurements, current exposure

- NBM-550 and 520 are able to cover all future frequencies of 5G up to 90 GHz
- NBM products are able to measure the current fieldstrength and are able to present the result in e.g. V/m of mW/cm² or directly in % of standard
- SRM-3006 can do the equivalent up to 6 GHz, but is also able to distinguish between different services
- An extension of SRM-3006 to frequencies at 28 GHz is foreseen

Battery:	Ext. Power	GPS:	48°27'29.9" N	Ant:	3AX 0.4-6G	SrvTbl:	EU Full Band
16.05.19	12:21:43		9°13'48.9" E	Cable:	---	Stnd:	ICNIRP GP

Table View: Condensed

Index	Service	Max	Avg
8	BandV	0.256 %	0.233 %
9	GSM-R	0.015 %	0.009 37 %
10	GSM	0.224 %	0.202 %
11	L-Band	0.024 %	0.021 %
12	DECT	0.006 48 %	0.005 48 %
13	UMTS-TDD	0.038 %	0.035 %
14	UMTS	0.022 %	0.019 %
15	W-LAN	0.042 %	0.038 %
16	ISM	0.009 12 %	0.007 51 %
17	5G	0.102 %	0.093 %
	Others	1.739 %	1.687 %
	Total	5.012 %	4.856 %

Isotropic

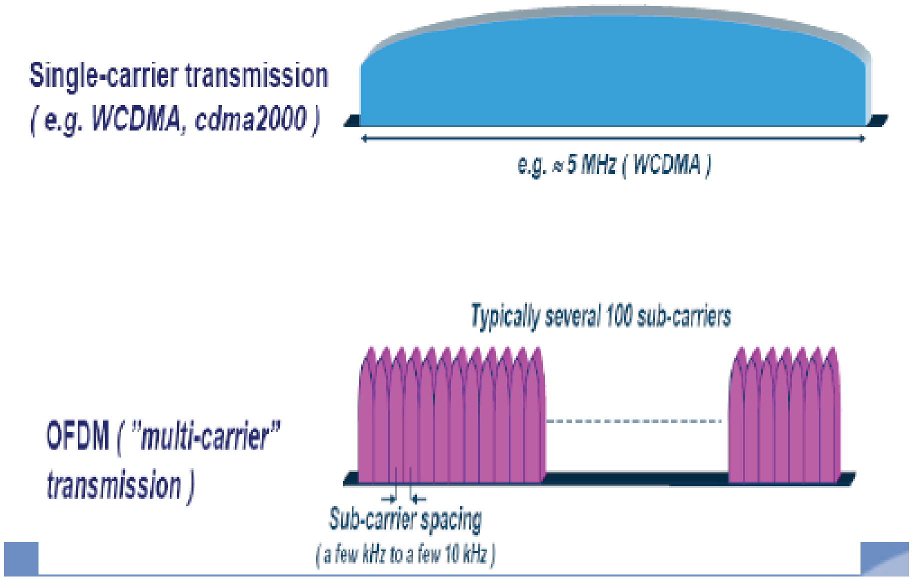
				Sweep Time:	3.255 s	Progress:	
MR:	1 000 %	RBW:	200 kHz (Auto)	Noise Suppr.:	Off	No. of Runs:	1 257
						AVG:	6 min

Personal protection for general public
How to get a maximum for traffic dependent signal ?

UMTS 3G Solution

DOWNLINK DATA TRANSFER

- OFDM (Orthogonal-Frequency-Division-Multiplexing) air-interface for LTE.
  OFDM is a particular form of multi-carrier modulation (MCM) i.e. a parallel transmission method which divides an RF channel into several narrower bandwidth sub-carriers (typically 15 kHz).

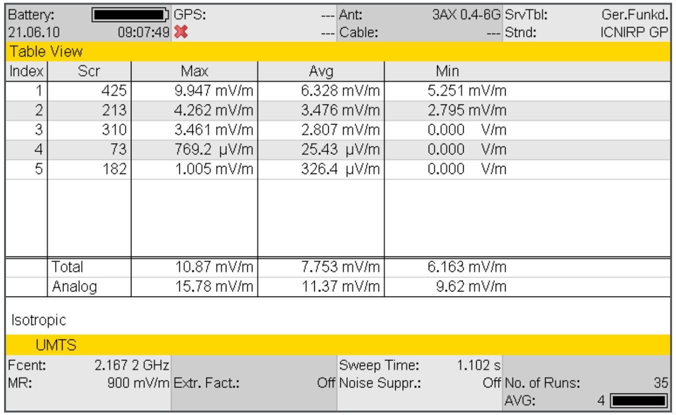


UMTS Decoding

UMTS mode:

- The total value is the sum of all measured P-CPICH pilot signals that are identified by its Scrambling Codes.
- Extrapolation factor can be added manually to account for the maximum possible exposure level.
- Analog value shows the actual field exposure at the time of measurement. It is a function of the traffic load.

Short form	Name	Power (typ.)	Characteristic
P-CPICH	Primary Common pilot channel	33 dBm	permanent on
P-CCPCH	Primary common control physical channel	28 dBm	600 µs on, 67 µs off
P-SCH	Primary synchronization channel	30 dBm	67 µs on, 600 µs off
S-SCH	Secondary synchronization channel	30 dBm	67 µs on, 600 µs off

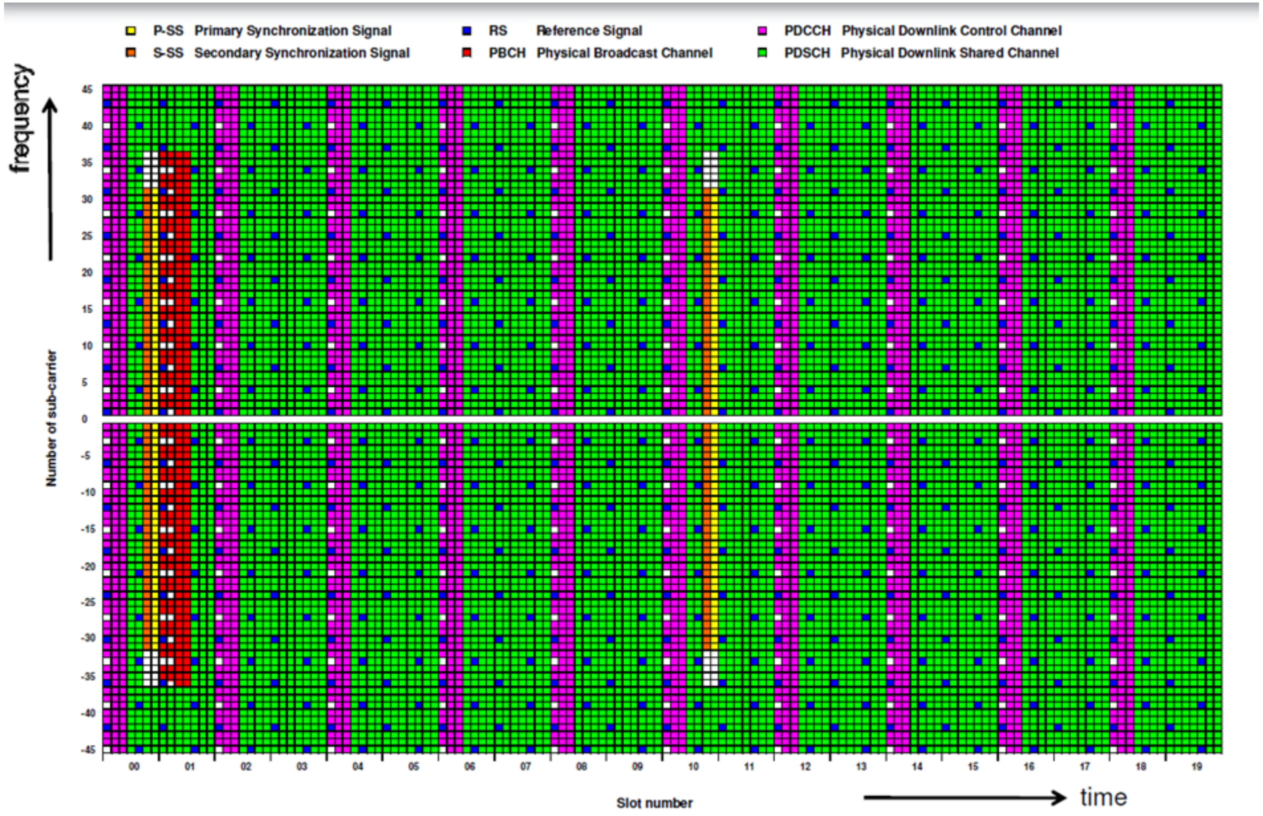


LTE 4G Solution

The code selective measurement makes use of the fact that the primary synchronization signals (P-SS), secondary synchronization signals (S-SS) and reference signals (RS) of LTE base stations are *coded cell-specifically*.

By decoding the signal measured by the receiving antenna, it is possible to split the emissions up and match them to the corresponding cells.

The RS takes on special significance with code selective measurement because they are transmitted permanently.



LTE 4G Solution

LTE:

- Display showing the 3 cell identification (ID) numbers of a LTE base station. Uplink and Downlink happen in two different frequency bands (FDD and TDD mode)

Battery:	Ext. Power	GPS:	48°27'31.6" N	Ant:	---	SrvTbl:	Ger.Funkd.
20.04.12	10:46:52		9°13'50.2" E	Cable:	---	Stnd:	ICNIRP GP

Table View

Index	Cell ID	No. Ant	Act (RS Avg)	Max (RS Avg)	Avg (RS Avg)	Min (RS Avg)
1	0	1	-3.06 dBm	-3.01 dBm	-3.17 dBm	-3.49 dBm
2	4	2	-4.43 dBm	-4.36 dBm	-4.50 dBm	-4.70 dBm
3	8	4	-5.81 dBm	-5.76 dBm	-5.92 dBm	-6.32 dBm
	Total		0.48 dBm	0.51 dBm	0.38 dBm	0.29 dBm
	Analog		-0.02 dBm	0.00 dBm	-0.01 dBm	-0.02 dBm

Single Axis

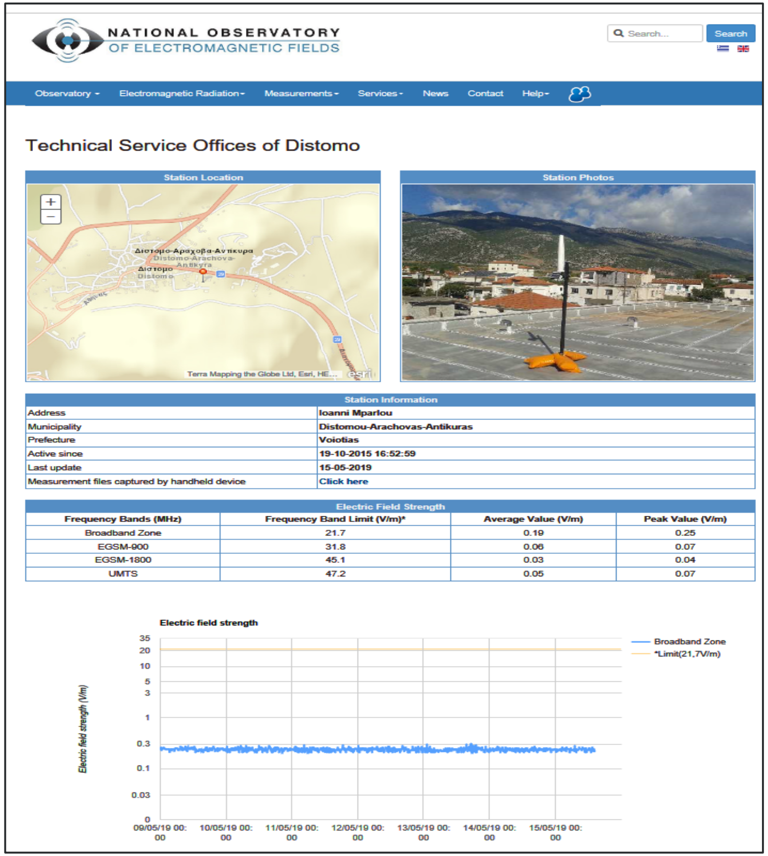
LTE

Fcent:	2.654 3 GHz	CBW:	20 MHz	Sweep Time:	2.443 s	Progress:	
MR:	10 dBm	Extr. Fact.:	1200.000	Noise Suppr.:	Off	No. of Runs:	HOLD
		Cell Sync.:	Sync.	CP Length:	Normal	AVG:	256

5G 24/7 monitoring

Environmental measurements, 24/7 exposure

For 24/7 measurements the area monitor AMB-8059 can measure up to 40 GHz and publish the data into the internet so that public has access to the current radiation level at any time



Environmental measurements, worst case exposure

- The transmitted power of a 5G NR base station depends strongly on the current traffic load and the user behavior
- This means in practice that the current exposure measured within a specific observation time could be much lower than the maximum exposure possible
- Many regulators enforce the extrapolation to the maximum load and to compare this result against the local standard. By this it can be assured, that the actual exposure will not exceed the limits

Environmental measurements, worst case exposure

- The second method is called synchronization demodulation based extrapolation.
- The synchronization demodulation based extrapolation is similar to the options UMTS and LTE of SRM-3006. A description of this method is published under:

https://journals.lww.com/health-physics/Abstract/publishahead/On_The_Assessment_of_Human_Exposure_to.99882.aspx

- This method is not implemented in SRM-3006 yet as the approval of this method by national and international bodies is still pending