5G EMF MEASUREMENT ASPECTS

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ROHDE&SCHWARZ

Make ideas real

AGENDA

- ► EMF Measurements - standardization and regulatory perspective
- ► EMF measurement scope
- ► 5G technology aspects & why is it challenging for EMF?
- ► Various concepts for 5G EMF verification
- ► R&S 5G EMF solutions

WHY EMF MEASUREMENTS?

- EMF = **e**lectro**m**agnetic **f**ield: unit [V/m]
- Measure the human exposure to electromagnetic fields, especially in sensitive areas like schools…
- Provide evidence, that the exposure to electromagnetic fields is below a certain threshold (defined by law or regulators)
- Dispel doubts / avoid health and safety concerns of the population to avoid delays of 5G NR rollouts

EMF MEASUREMENT – GENERAL ASPECTS

Task:

Check compliance with limits for human exposure to electro-magnetic fields and provide the facts for risk communication

Frequency and code selective measurements can:

- Distinguish between services
- Distinguish between operators
- Allocate emissions to different sites and sectors
- Measure small signals in the vicinity of strong signals
- Measure complex modulations correctly

EMF – POLITICAL SITUATION

EMF: lot of discussions and political debates about health aspects on EMF, especially now with 5G. Just two statements: ICNIRP and ARPANSA (Australia)

RF effects on the body and health implications

RF EMFs have the ability to penetrate the human body, with the main effect of this being a rise in temperature in the exposed tissue.

The human body can adjust to small temperature increases in the same way as it does when undertaking exercise and performing sporting activities. This is because the body can regulate its internal temperature. However, above a certain level (referred to as the threshold), RF exposure and the accompanying temperature rise can provoke serious health effects, such as heatstroke and tissue damage (burns).

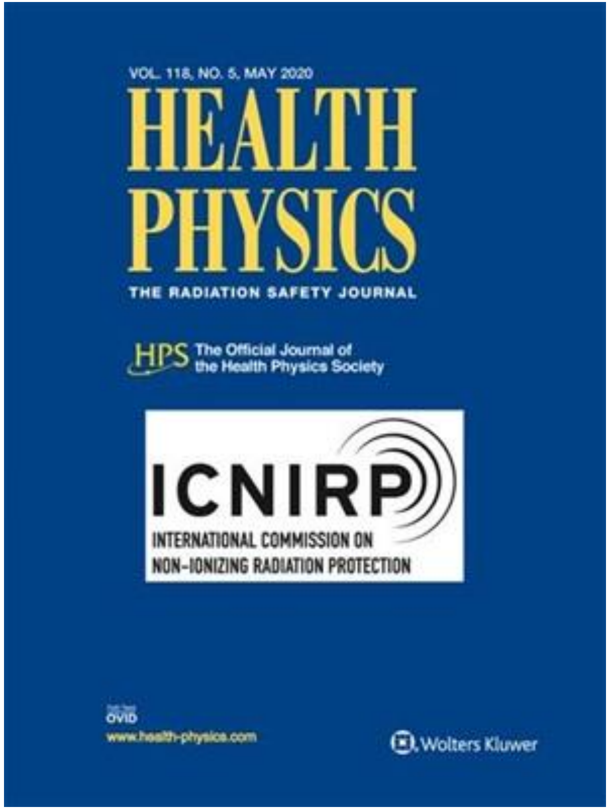
Another general characteristic of RF EMFs is that the higher the frequency, the lower the depth of penetration of the EMFs into the body. As 5G technologies can utilise higher EMF frequencies (>24 GHz) in addition to those currently used (<4 GHz), power from those higher frequencies will be primarily absorbed more superficially than that from previous mobile telecommunications technologies. However, although the proportion of power that is absorbed superficially (as opposed to deeper in the body) is larger for the higher frequencies, the ICNIRP (2020) restrictions have been set to ensure that the resultant peak spatial power will remain far lower than that required to adversely affect health. Accordingly, 5G exposures will not cause any harm providing that they adhere to the ICNIRP (2020) guidelines.

WHAT IS EMF AND WHY IS IT IMPORTANT?

World Health Organization

A number of national and international organizations have formulated guidelines establishing limits for occupational and residential EMF exposure. The exposure limits for EMF fields developed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) - a non-governmental organization formally recognised by WHO, were developed following reviews of all the peer-reviewed scientific literature, including thermal and non-thermal effects. The standards are based on evaluations of biological effects that have been established to have health consequences. The main conclusion from the WHO reviews is that EMF exposures below the limits recommended in the ICNIRP international guidelines do not appear to have any known consequence on health.

EMF STANDARDIZATION: ICNIRP



Reference:

Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz)

International Commission on Non-Ionizing Radiation Protection (ICNIRP)[1] **Author Information**

Health Physics: May 2020 - Volume 118 - Issue 5 - p 483-524
doi: 10.1097/HP.0000000000001210

EMF STANDARDIZATION

International:

- „**ICNIRP Guidelines** For Limiting Exposure To Time-Varying Electric, Magnetic, And Electromagnetic Fields (Up To 300 GHz)„
- **IEC 62232:** Determination of RF field strength and SAR in the vicinity of radio-communication base stations for the purpose of evaluating human exposure
- Report **ITU-R SM.2452-0** Electromagnetic field measurements to assess human exposure

Europe (examples):

- **1999/519/EC:** COUNCIL RECOMMENDATION on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz)
- **2013/35/EC:** Directive on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields)
- **ECC Recommendation (02)04:**
  Measuring Non-Ionizing Electromagnetic Radiation (9 kHz – 300 GHz)
- **EN 50413:** Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz – 300 GHz)
- **EN 50400:** Basic standard for wireless telecommunication networks when put into service
- **EN 50492:** Basic standard for the in-situ measurement of electromagnetic field strength related to human exposure in the vicinity of base stations
- In addition different national standards apply, which are partially more strict

EMF STANDARDISATION: ICNIRP – DERIVED LIMITS

ICNIRP example, limits depending on exposure time (peak or permanent) and on frequency range. => detailed limits see tables within the ICNIRP document

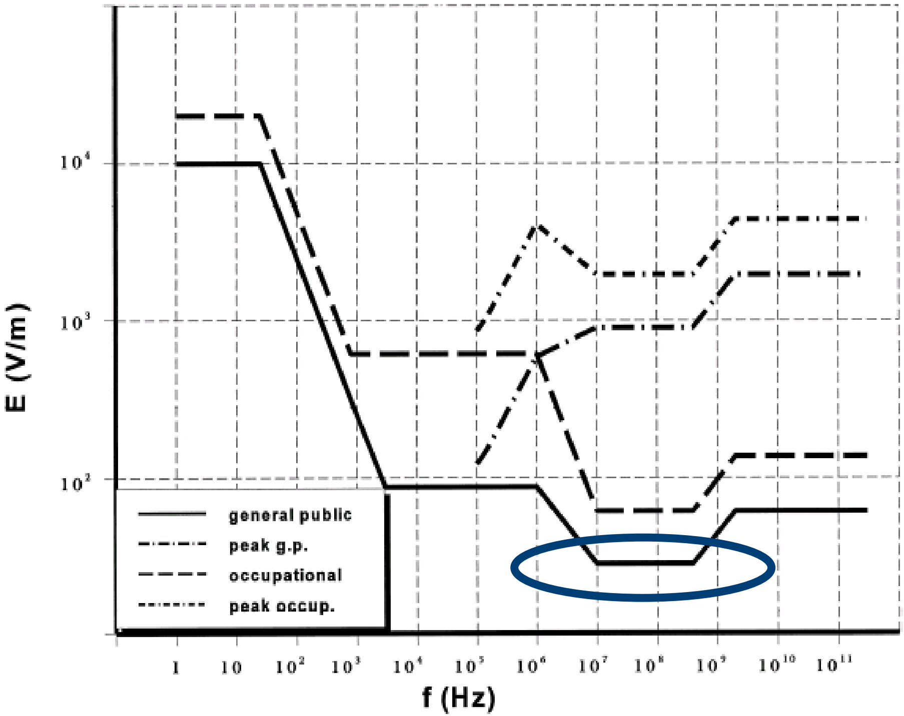


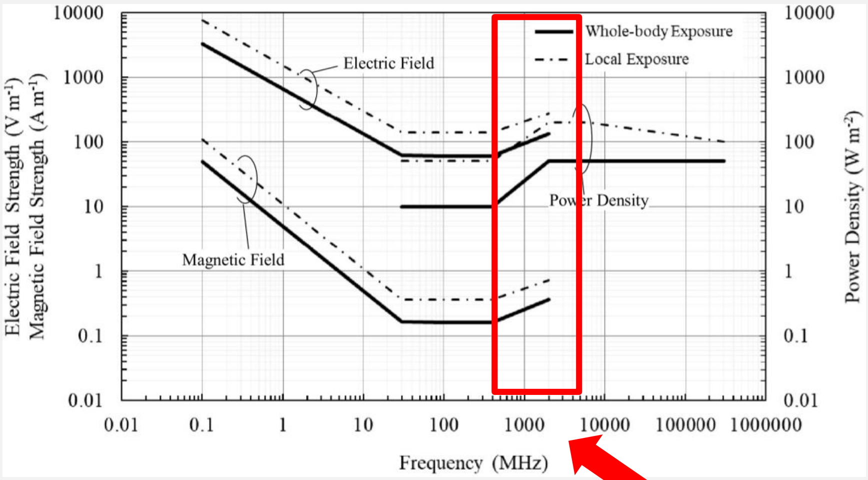
Fig. 1. Reference levels for exposure to time varying electric fields (compare Tables 6 and 7).

Important zone for us: Wireless technologies in the frequency range 100MHz – 6 GHz

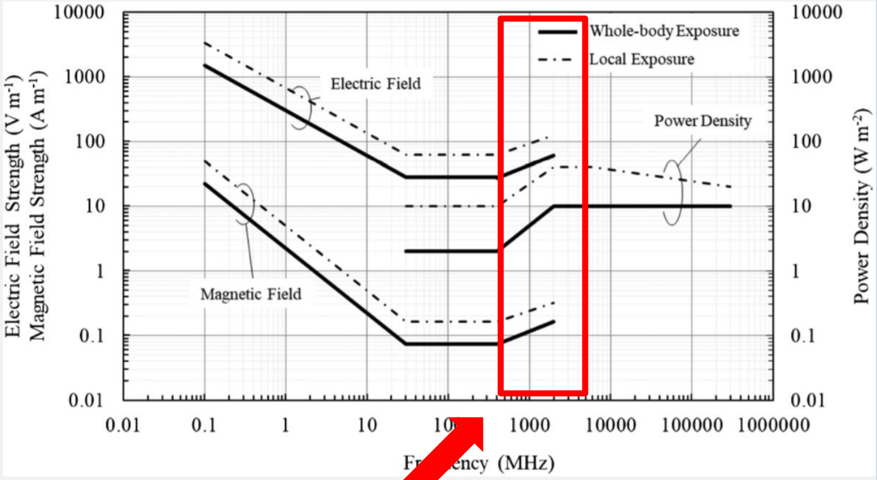
- **Measurement time: Average over 6 minutes**

EMF STANDARDIZATION: ICNIRP – LIMITS

Occupational exposure



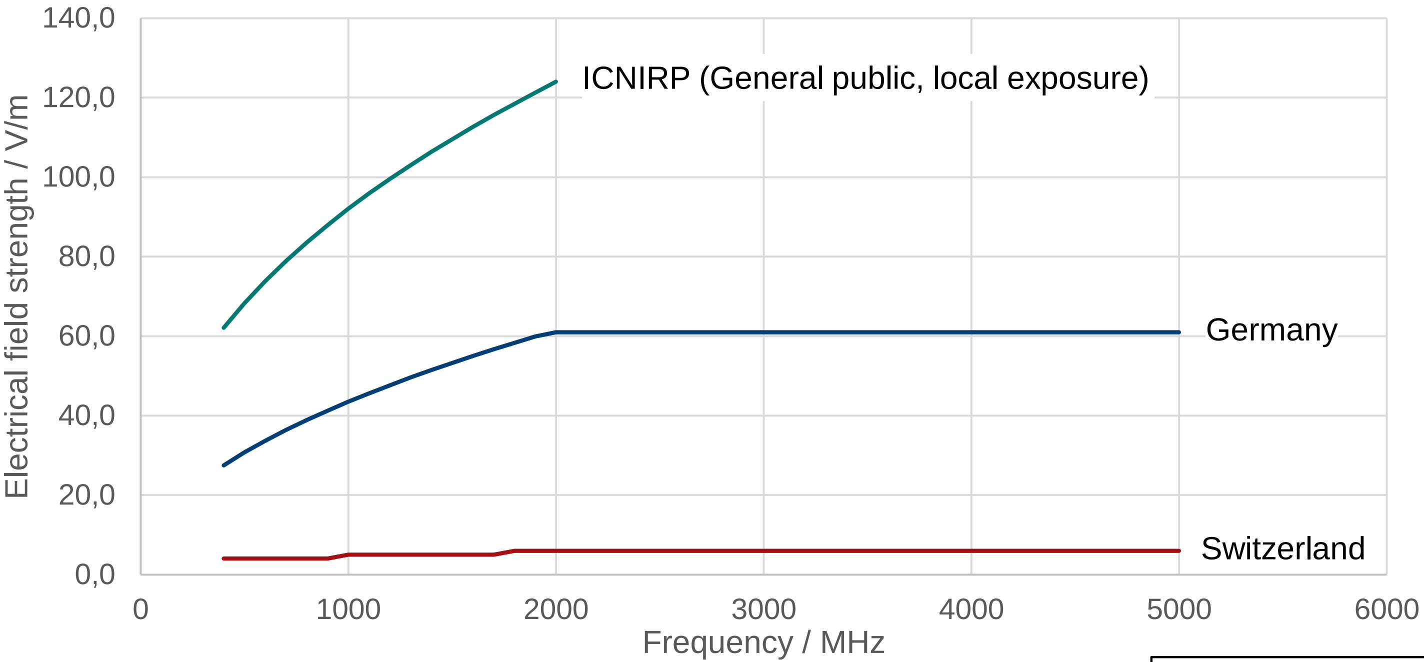
General public exposure



Frequencies of interest for mobile communication

- ► Time averaged exposure (≥ 6 min) to electromagnetic fields (100 kHz – 300 GHz)
- ► Unperturbed RMS values

EMF STANDARDIZATION: COUNTRY REGULATION



Bundesministerium der Justiz und für Verbraucherschutz | Bundesamt für Justiz

26. BImSchV
Verordnung über elektro-magnetische Felder
Stand: 14.8.2013

- ▶ German regulation more strict than ICNIRP
- ▶ Swiss regulation much more strict than ICNIRP

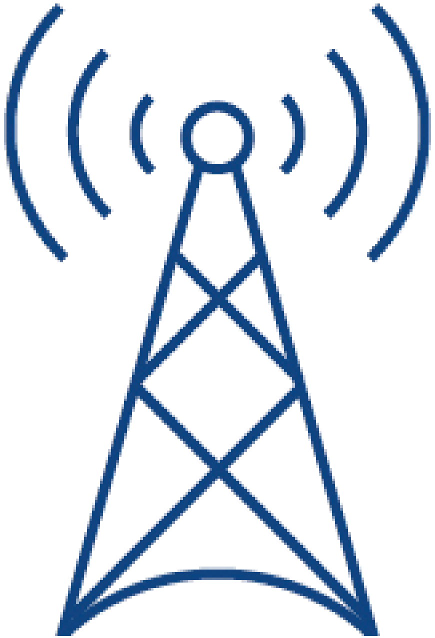
814.710

Verordnung über den Schutz vor nichtionisierender Strahlung (NISV)

vom 23. Dezember 1999 (Stand am 1. Juni 2019)

Der Schweizerische Bundesrat,

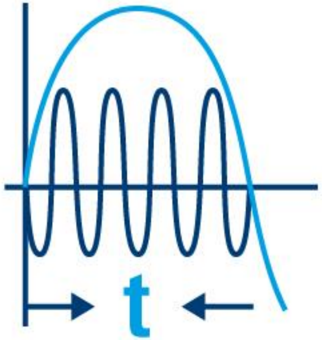
EMF STANDARDIZATION



Influence of ElectroMagnetic Fields (EMF) on humans

Depends on

- Frequency
- Field strength / power density
- Exposure time
- Modulation
- Co-located and other ambient radio sources



Challenge: the physics is fact, but no standardized test procedures and no standardized limits. Depending on national guidelines and may differ between countries

EMF MEASUREMENT SCOPE

SCOPE OF EMF TESTING

Below about 6 GHz, where EMFs penetrate deep into tissue (and thus require depth to be considered)

Above 6 GHz, where EMFs are absorbed more superficially (making depth less relevant)

Indoor

Outdoor

Short and long term measurement

Conformance with regulations

Comparison of different transmitter

Data for public information

Statistical data

Application scenarios

SCOPE OF EMF: SAR AND NEAR FIELD VS FAR FIELD

Near field versus far field

	Reactive Near Field	Radiated Near Field	Far Field
Distance*	0 to $\lambda/4$	$\lambda/4$ to $2D^2/\lambda$	$> 2D^2/\lambda$
E vertical H ?	No	Nearly	Yes
E,H $\propto$ 1/r	No	No	Yes
Z_F=E/H	$\neq 377\ \Omega$	$\approx 377\ \Omega$	$= 377\ \Omega$
Measurement	E and H	E or H	E or H

*: Strongly depending on the antenna; D: Largest antenna diameter, λ: Wavelength (λ [m]= 300/f [MHz])

In most cases:

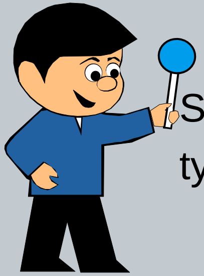
- **For field strength > 30 MHz only E or H-field is sufficient**
- **SAR measurements are performed in the reactive near field** (e.g. body worn devices)

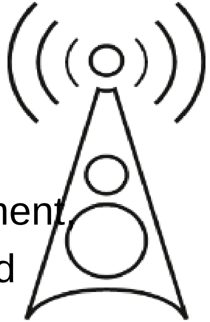
SAR is measured with specific setups, artificial head and non-electric liquid. Several adaptation parameters needed to emulate free space resistance Z_F.

VARIOUS EMF MEASUREMENTS: FAST EMF SURVEY

Features

- "EMF snapshot"
- Estimation of EMF situation
- Fast and brief overview of relevant transmitters
- Defined measurement location
- Equipment: broadband meter, personal monitor and spectrum analyzer





Single measurement, typically handheld

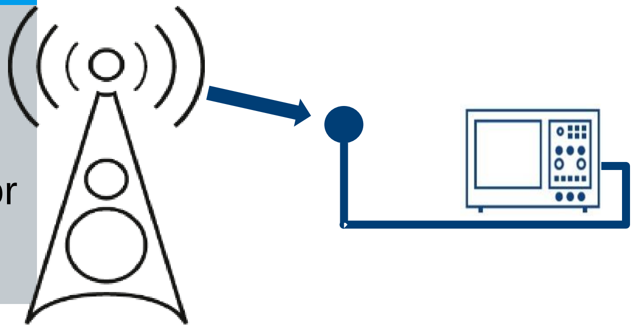
Application

- Live results (live presentations to give a realistic view)
- Fast analysis ahead of detailed investigation
- **Automatic and accurate field evaluation** by isotropic antenna, including all directions and polarizations. ~9kHz – 6 GHz range

VARIOUS EMF MEASUREMENTS: TRANSMITTER SITE ANALYSIS

Features

- Measurement dedicated to a single transmitter
- Analysis of worst case
- Detailed settings for signal parameters: either known TX behavior or assumption based

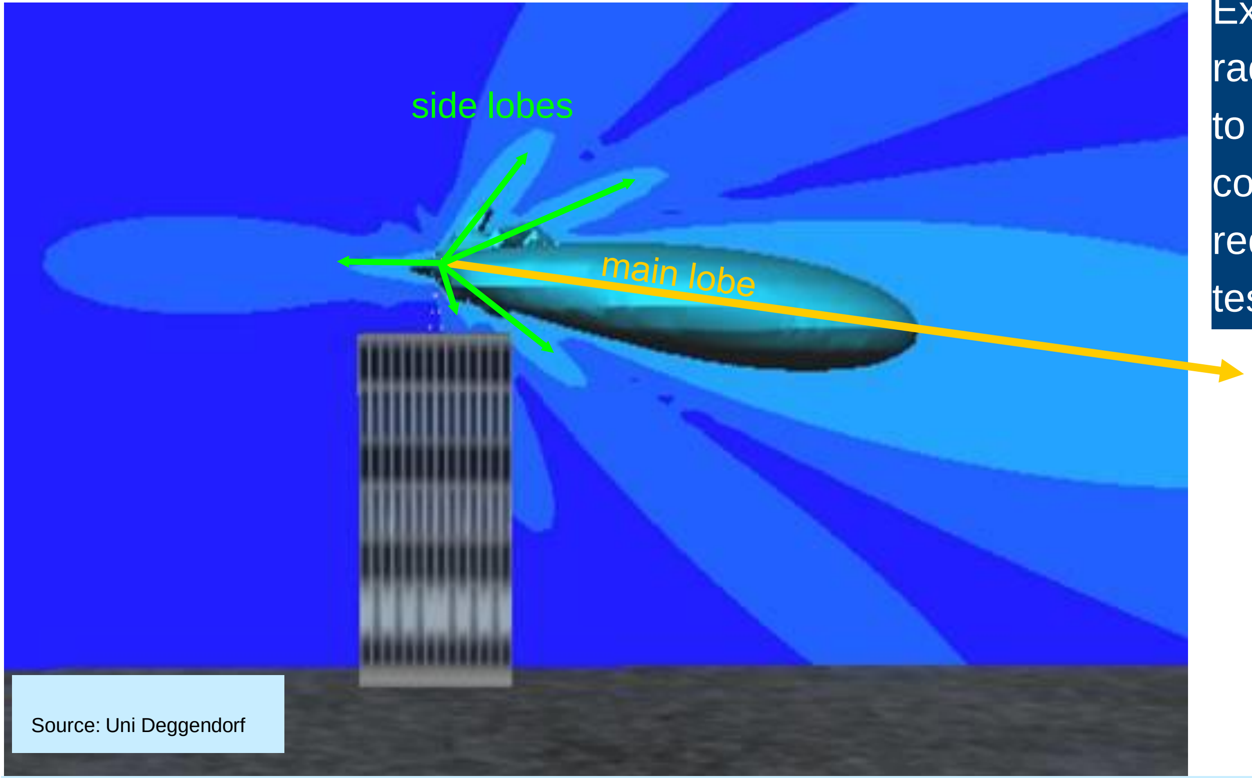


Application

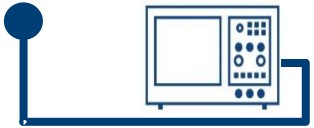
- Measurement when transmitter is put into operation or modified
- Verification of safety distance
- Public concern about an antenna location

Meticulous planning of measurements, theory is known, test strategy according to objectives and regulations

VARIOUS EMF MEASUREMENTS: TRANSMITTER SITE ANALYSIS



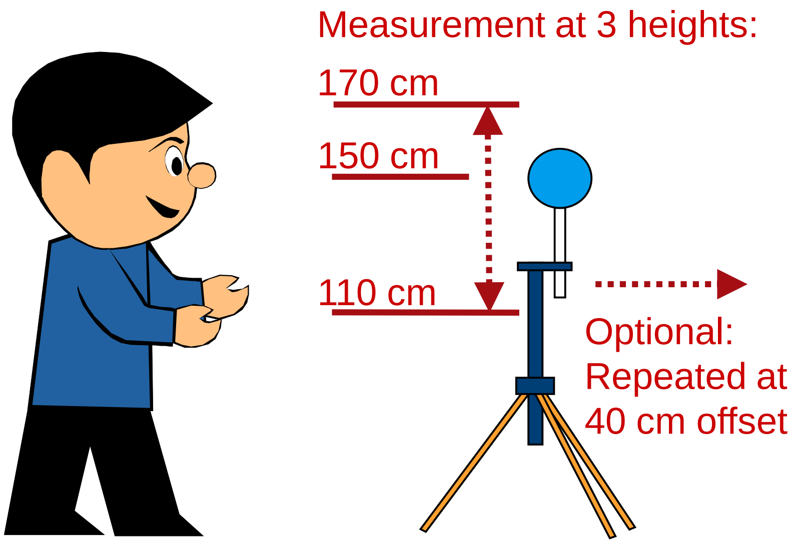
Example: we know the antenna radiation pattern and we want to measure in the "worst case condition" => test strategy required, where to place the test antenna?



Field distribution of a directional antenna on elevated site, typical sectored antenna site used in 2G/3G or 4G with vertical and horizontal directivity.

EMF MEASUREMENT - MULTIPOINT METHOD

- Referenced by standards (EN50400, EN50492)
- Measurement points represents the human body
- Maximum Total Exposure Ratio (TER) of all measurement points
- Complete frequency range covered in one measurement
- Isotropic measurement
- 1 m separation acc. EN 50400to reflecting objects (EN50492: 0,5 m)
- Multipoint Method acc. EN50492



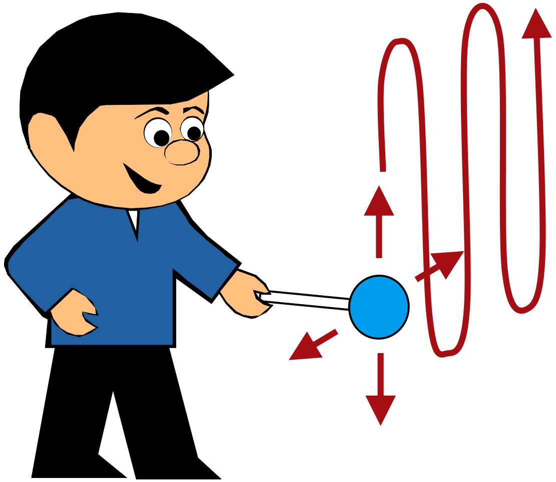
EMF MEASUREMENT - STIRRING METHOD

Recommended e.g. by Switzerland

Measurement procedure evaluates the spatial maximum field

Features:

- Handheld measurement
- Scan of area by antenna movement
- Only one service at a time



VARIOUS EMF MEASUREMENTS: COMPLETE SCENARIO

Complete site scenario: e.g. multiple RATs, multiple PLMN, time averaging

- Measurement dedicated to a certain position
- Accurate measurement of different RAT, parameters, operators, etc.
- Coverage of wide frequency range and time averaging methods

Application

- Measurement acc. ICNIRP (6 minutes average)
- Data acquisition for exposure maps or statistical data
- Analysis on general exposure
- Data for public relation work

VARIOUS EMF MEASUREMENTS: LONG TERM ANALYSIS

Typically fixed installed sites, owned by regulatory bodies

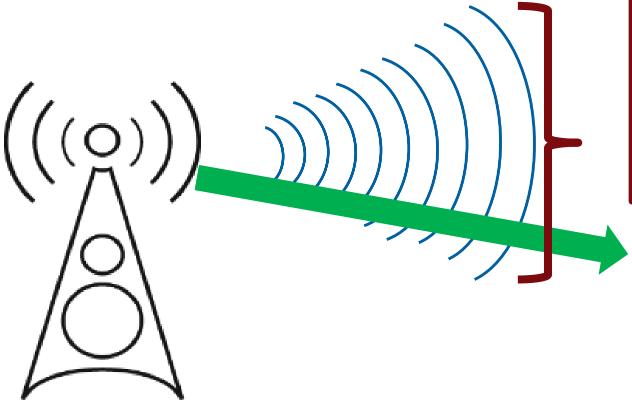
Features

- Evaluates emissions over hours, days, weeks or months
- Shows the chronology of different services
- Analysis of overall emissions and per service
- Fully automatic operation

Application

- Proves validity of short term measurement
- Ensures trust in measurement data
- Tool of enhanced risk communication
- Online access allows broadly based public participation

EMF MEASUREMENTS - SIMPLIFIED



Frequency selective: Measure power on overall signal, i.e. RSSI

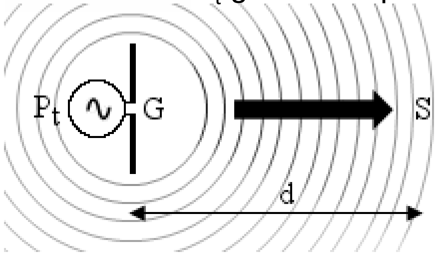
Code selective: Measure power on known signal, i.e. reference signal, RSRP

Antenna factor K

We measure the power at a known antenna (antenna factor K) and convert into fieldstrength

$$S = g\frac{P_t}{4\pi d^2}$$

TX antenna with gain g and power P_t generates power flux S (=ExH)



$$S = \frac{E^2}{Z_0} = Z_0 \cdot H^2$$

With Z_0 = 377Ω we can convert S as W/m^2 into E as V/m

$$A_e = P/S\,\frac{\lambda^2 G}{4\pi}$$

Effective area A_e, when P = RX power, S = flow density and G = antenna gain

UNIT CONVERSION TABLE

Given quantity [unit]	Desired quantity [unit] S [W/m²]	S [mW/cm²]	S [µW/cm²]	E [V/m]	H [A/m]
S [W/m²]	1 × S	0.1 × S	100 × S	$\sqrt{(S_{eq} \times 377)}$	$\sqrt{(S_{eq} / 377)}$
S [mW/cm²]	10 × S	1 × S	1000 × S	$\sqrt{(S_{eq} \times 3770)}$	$\sqrt{(S_{eq} / 37.7)}$
S [µW/cm²]	0.01 × S	0.001 × S	1 × S	$\sqrt{(S_{eq} \times 3.77)}$	$\sqrt{(S_{eq} / 37700)}$
E [V/m]	$E_{eq}^2 / 377$	$E_{eq}^2 / 3770$	$E_{eq}^2 / 3.77$	1 × E	$E_{eq} / 377$
H [A/m]	$H_{eq}^2 \times 377$	$H_{eq}^2 \times 37.7$	$H_{eq}^2 \times 37700$	$H_{eq} \times 377$	1 × H

EMF MEASUREMENTS – FLUX OR ELECTRIC FIELD

Two methods for EMF:
- Electric flux density in W/m^2
- Electric field strength in V/m

Receiver measures power (in dBm)

Antenna gain/antenna factor can be converted to antenna aperture (in m^2)

$$A_{W,\,max.} = \frac{\lambda^2}{4\pi} \times G$$

dBm can be converted to W

→ W/m^2

Electric flux density (S)

$S = E^2/Z_0$ with Z as characteristic wave impedance (377 Ω)

$$E = \sqrt{S \times Z_0}$$

→ V/m

Electric field strength (E)

EMF MEASUREMENTS – ISOTROPIC ANTENNA

We use the model of an isotropic antenna: P_{TX} is sent over a perfect sphere
=> power density is equal over the surface

Real antennas have a directivity / gain => power density is higher in some direction.
=> We define the equivalent isotropic radiated power as:

$$\mathbf{EIRP(\theta,\Phi) = G_{TX}(\theta,\Phi) \cdot P_{Tx}=10^{(g/10)}\cdot P_{TX}}$$

G = antenna gain factor; g = antenna gain in dBi

EMF MEASUREMENTS – ISOTROPIC ANTENNA

$$EIRP(\theta,\Phi) = G_{TX}(\theta,\Phi) \cdot P_{TX} = 10^{(g/10)} \cdot P_{TX}$$

We may use this formula to calculate the E-field + security distances

Or simplified the electric field strength at a distance d is given as:

$$S = \frac{G_{TX} \cdot P_{TX}}{4 \cdot \pi \cdot d^2} = \frac{E^2}{Z_0} \quad in\ [\frac{W}{m^2}]$$

$$\Rightarrow$$

$$E = \frac{\sqrt{30 \cdot G_{TX} \cdot P_{TX}}}{d} \text{ in } [\frac{\mathrm{V}}{\mathrm{m}}]$$

Example: calculate the E-fieldstrength for a transmitter (P_{TX} = 14 Watt, g = 17dBi) at 50m distance:

1.) calculate EIRP: EIRP = $10^{(17/10)}$*14 = 701.7 Watt

2.) calculate flux/power density (@50m): $S = \frac{701.7}{4 \cdot \pi \cdot 50^2}$=0,0223 W/m^2

3.) calculate E at a distance of 50m: $E = \frac{\sqrt{30 * 701.7}}{50} = 2{,}9\ V/m$

Typically we use those formulas to calculate the „security“ distance:
e.g. we set a E limit of 42 V/m (=ICNIRP limit at ~930MHz) => distance d ~ 3.5m

HOW TO MEASURE HUMAN EXPOSURE?
CODE VS. FREQUENCY SELECTIVE MEASUREMENT MODE

Pure power spectrum measurements

No identifaction of carriers

Convert to electrical field strength [V/m]

PCI	SSB Idx	SS-RSRP
387	6	-76.1
386	6	-78.6
388	6	-72.2
387	5	-79.0
386	5	-78.4
388	5	-61.8
387	4	-81.4
386	4	-78.2
388	4	-74.0
387	3	-76.5
386	3	-81.8
388	3	-77.0
387	2	-79.5
386	2	-62.2
388	2	-80.6

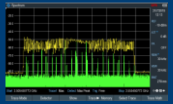
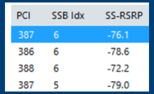
Considered to be the preferred method in Europe for 5GNR

Identify, decode carriers and beams

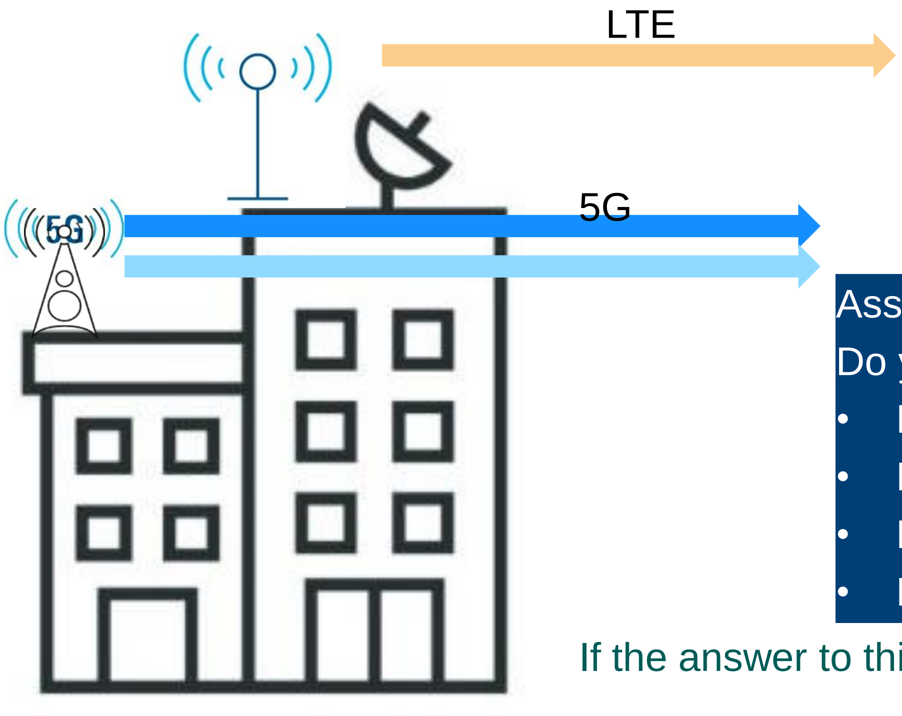
Determine precise signal power levels

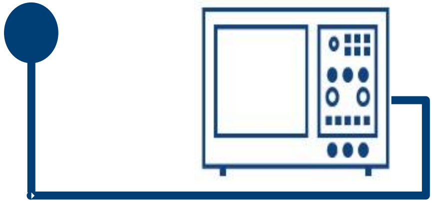
Convert to electrical field strength [V/m]

WHAT EMF METHOD SHOULD BE USED WHEN?

EMF Measurement method	Frequency-selective 	Code-selective  PCI SSB Idx SS-RSRP 387 6 -76.1 386 6 -78.6 388 6 -72.2 387 5 -79.0
Method complexity	Simple, direct measurement	More complex, post processing
What EMF result is reported?	Current emission (load?)	Maximum possible emission
Identified radiation component	Sum of all emissions (no details)	Per operator, technology, site, sector, SSB beam (due to decoding)
Granularity of EMF result	Emission result (limit passed/failed)	Detailed results available (emissions vs coverage optimization possible)
Target user group	Monitoring authorities / Office for emission protection, …	Regulators, network operators, infrastructure suppliers, service companies
Adoption for 5G		METAS (CH) recommends method as reference

5G EMF + LEGACY RAT EMF, WHAT WE WANT TO MEASURE?





Assumption: site with multiple installations:
Do you agree that we want to measure:

- EMF on RAT_A from operator A
- EMF on RAT_B from operator A
- EMF on RAT_A from operator B
- Etc.?

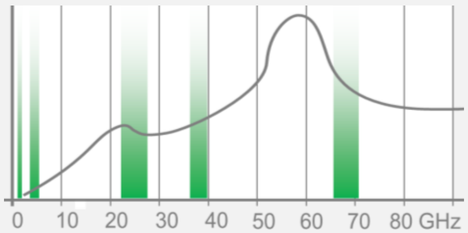
If the answer to this question is “yes“ => code selective EMF

If the answer to this question is “no“ => pure RSSI spectral analysis is sufficient e.g. (broadband meters, handheld SPA)

5G TECHNOLOGY ASPECTS – CHALLENGES FOR EMF

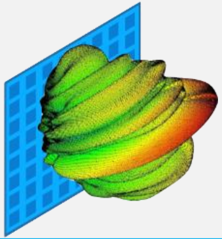
5G KEY TECHNOLOGY COMPONENTS
NR BUILDS ON FOUR MAIN PILLARS

New Spectrum



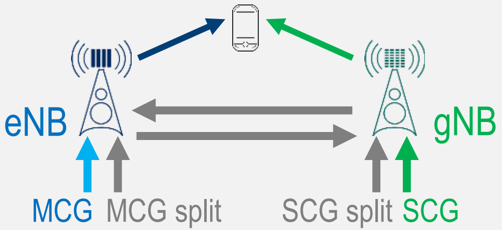
- < 1GHz
- ~ 3.5 GHz
- ~ 26/28/39 GHz

Massive MIMO & Beamforming



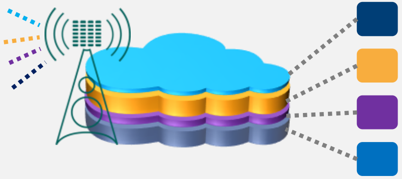
- Hybrid beamforming
- > 6GHz also UE is expected to apply beam steering

Multi-Connectivity



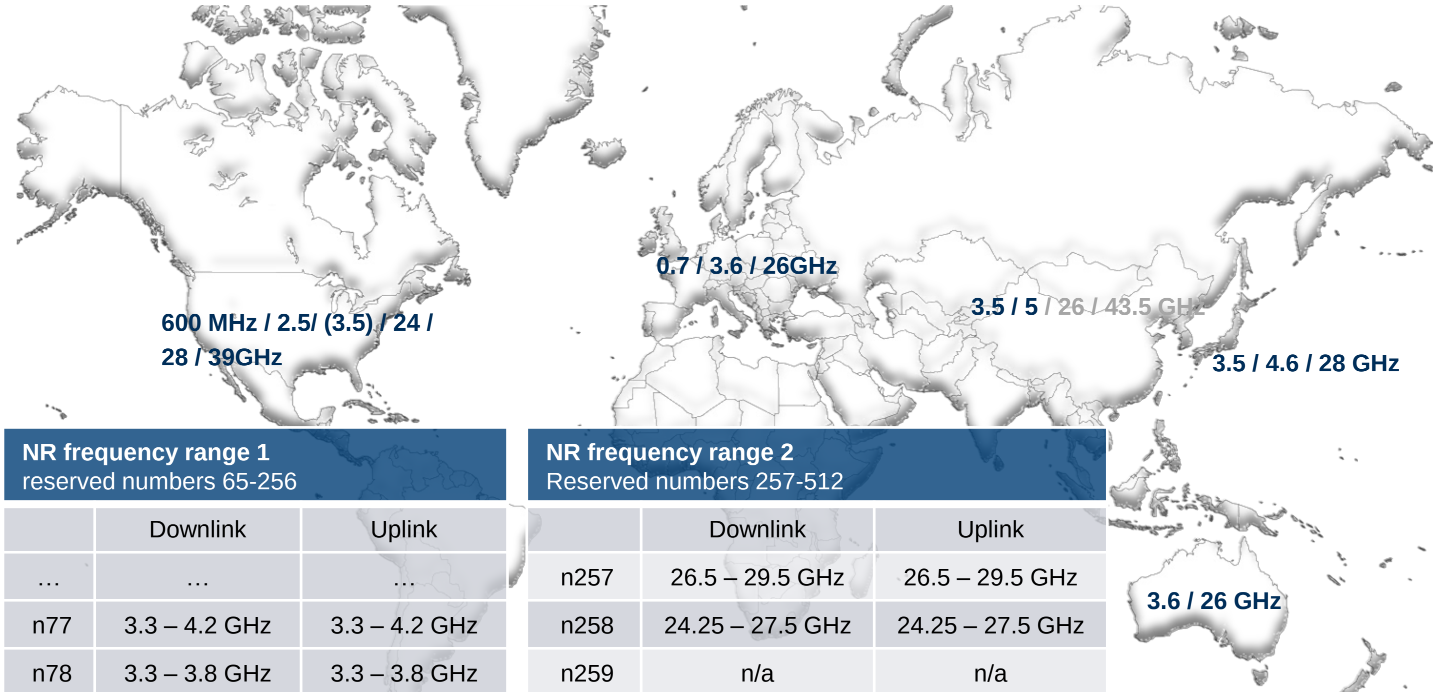
Initially based on Dual Connectivity with E-UTRA as master

Network flexibility - virtualization



- Flexible physical layer numerology
- Network Slicing
- NFV/SDN

FREQUENCY ASPECTS FOR 5G



NR frequency range 1
reserved numbers 65-256

	Downlink	Uplink
…	…	…
n77	3.3 – 4.2 GHz	3.3 – 4.2 GHz
n78	3.3 – 3.8 GHz	3.3 – 3.8 GHz
n79	4.4 – 5.0 GHz	4.4 – 5.0 GHz
…	…	…

NR frequency range 2
Reserved numbers 257-512

	Downlink	Uplink
n257	26.5 – 29.5 GHz	26.5 – 29.5 GHz
n258	24.25 – 27.5 GHz	24.25 – 27.5 GHz
n259	n/a	n/a
n260	37 – 40 GHz	37 – 40 GHz

Europe
- 700 MHz
- 3.4 - 3.8 GHz
- 24.25 - 27.5 GHz

China
- 2.5 – 2.6 GHz
- 3.3 - 3.6 GHz
- 4.8 - 5.0 GHz
- 24.75 - 27.5GHz (study)
- 37 - 43.5 GHz (study)

US
- 600 MHz
- 2.4 GHz
- [CBRS band (3.5GHz)]
- 27.5 - 28.35 GHz
- 37.0 - 40 GHz

Australia
- 3.6 GHz
- 26 GHz

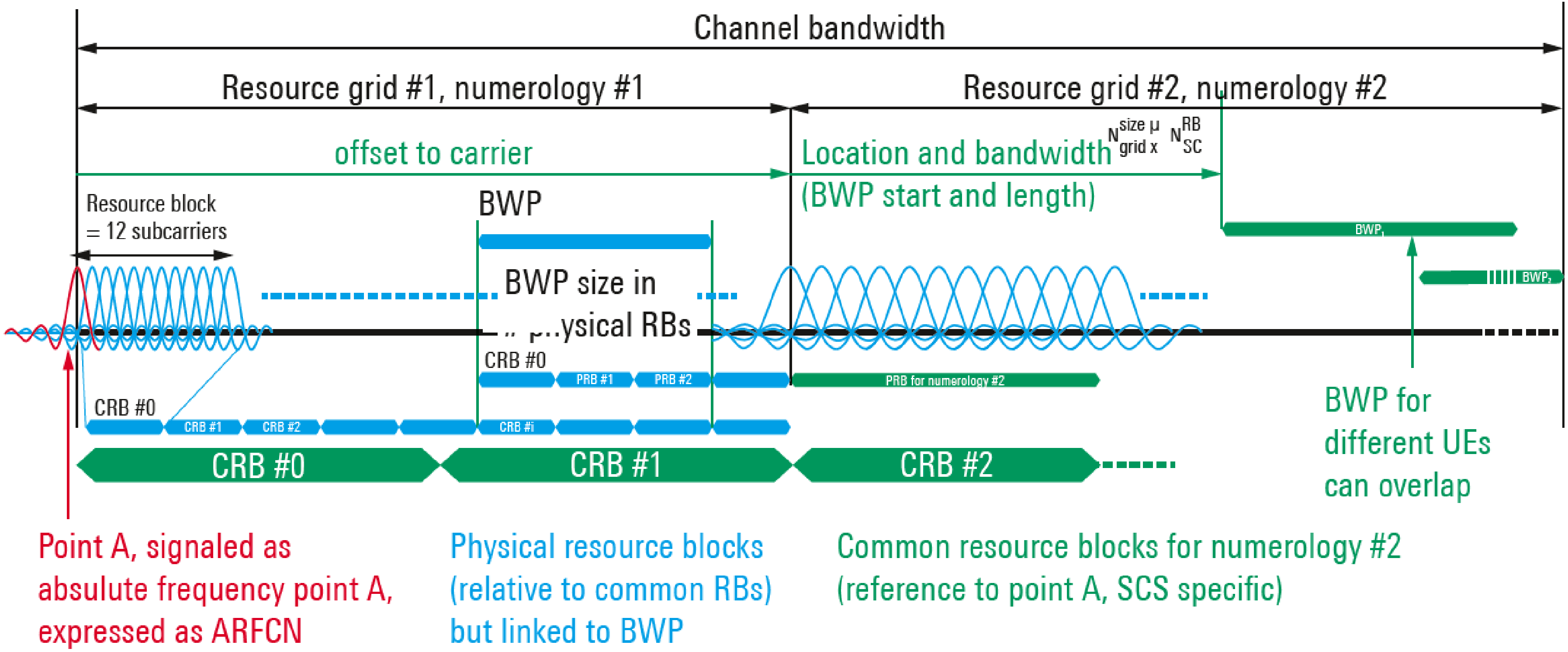
Korea
- 3.42 - 3.7 GHz
- 26.5 – 28.9 GHz

Japan
- 4.4 - 4.9 GHz
- 28 GHz

5G NR F-OFDMA FEATURES FLEXIBLE NUMEROLOGIES

Subcarrier spacing (kHz)	15	30	60	120	240
Symbol duration (µs)	66.7	33.3	16.7	8.33	4.17
CP duration (µs)	4.7	2.3	1.2 (normal) 4.13 (extended)	0.59	0.29
Max. nominal bandwidth (MHz)	50	100	100 for FR1 200 for FR2	400	400
Max. FFT size	4096	4096	4096	4096	4096
Symbols per slot	14	14	14 12 (extended CP)	14	14
Slots per subframe	1	2	4	8	16
Slots per frame	10	20	40	80	160

5G NR – RESOURCE GRID DETAILS



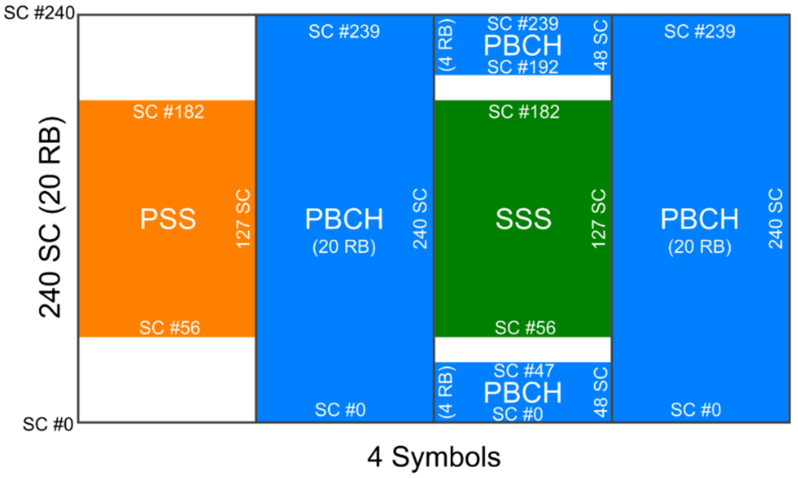
5G NEW RADIO (NR) OFFERS A FLEXIBLE AIR INTERFACE
SUMMARY OF KEY PARAMETERS

Parameter	FR1 (410 MHz – 7.125 GHz)	FR2 (24.25 – 52.6 GHz)
Carrier aggregation	Up to 16 carriers	
Bandwidth per carrier	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 90, 100MHz	50, 100, 200, 400 MHz
Subcarrier spacing	15, 30, 60 kHz	60, 120, 240 (not for data) kHz
Max. number of subcarriers	3300 (FFT4096 mandatory)	
Modulation scheme	QPSK, 16QAM, 64QAM, 256QAM; uplink also supports π/2-BPSK (only DFT-s-OFDM)	
Radio frame length	10ms	
Subframe duration	1 ms (alignment at symbol boundaries every 1 ms)	
MIMO scheme	Max. 2 codewords mapped to max 8 layers in downlink and to max 4 layers in uplink	
Duplex mode	TDD, FDD	TDD
Access scheme	DL: CP-OFDM; UL: CP-OFDM, DFT-s-OFDM	

SS/PBCH BLOCKS – SSB AS SYNCHRONIZATION SIGNAL IN 5G

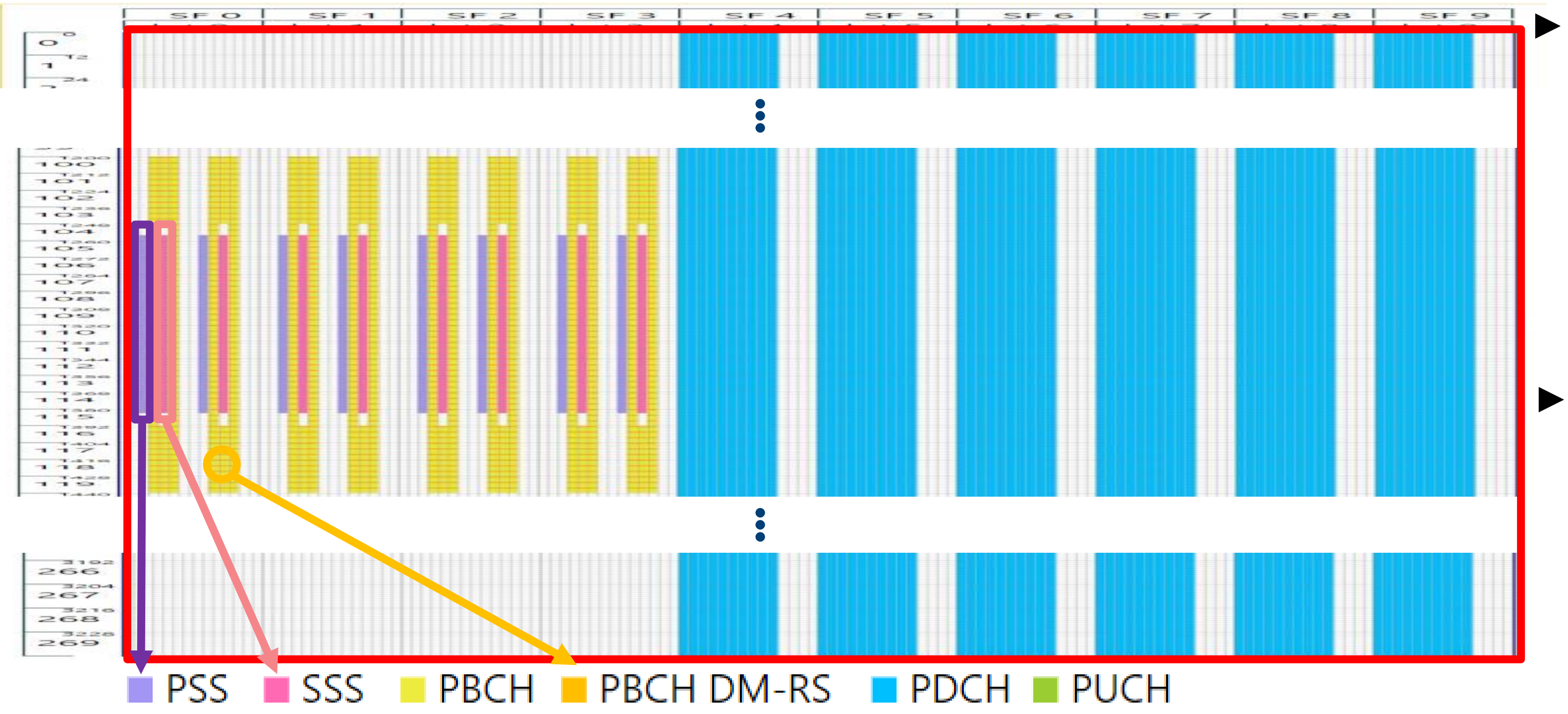
- In the time domain, an SS/PBCH block consists of 4 OFDM symbols, numbered in increasing order from 0 to 3 within the SS/PBCH block, where PSS, SSS, and PBCH with associated DM-RS occupy different symbols
- In the frequency domain, an SS/PBCH block consists of 240 contiguous subcarriers with the subcarriers numbered in increasing order from 0 to 239 within the SS/PBCH block.
- Two SS/PBCH block types:
  - Type A (15kHz and 30kHz)
  - Type B (120 and 240 kHz)

SS/PBCH block



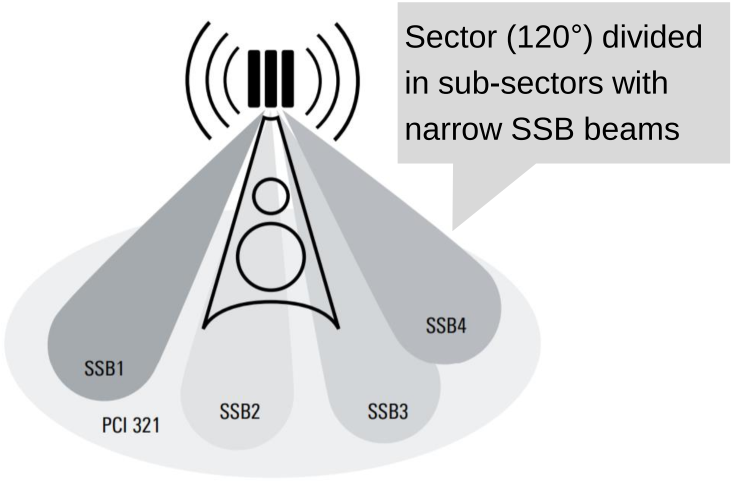
- Like in LTE the Cell ID can be determined from the used PSS/SSS sequences

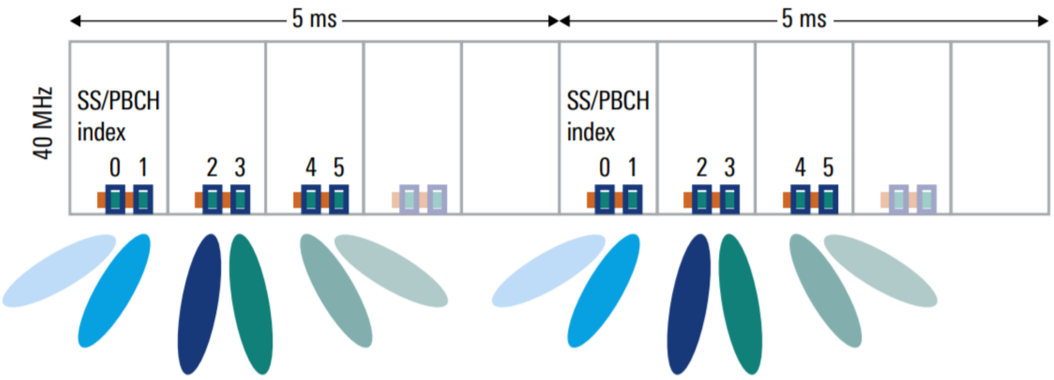
5G EMF – SSB AS THE ONLY ALWAYS ON-AIR SIGNAL



- A dedicated portion of the signal will be measured, assigned to a dedicated part of the network.
- Extrapolation need to be done to reflect the worst case of the whole signal.

5G EMF – SSB AND BEAMFORMING ASPECTS

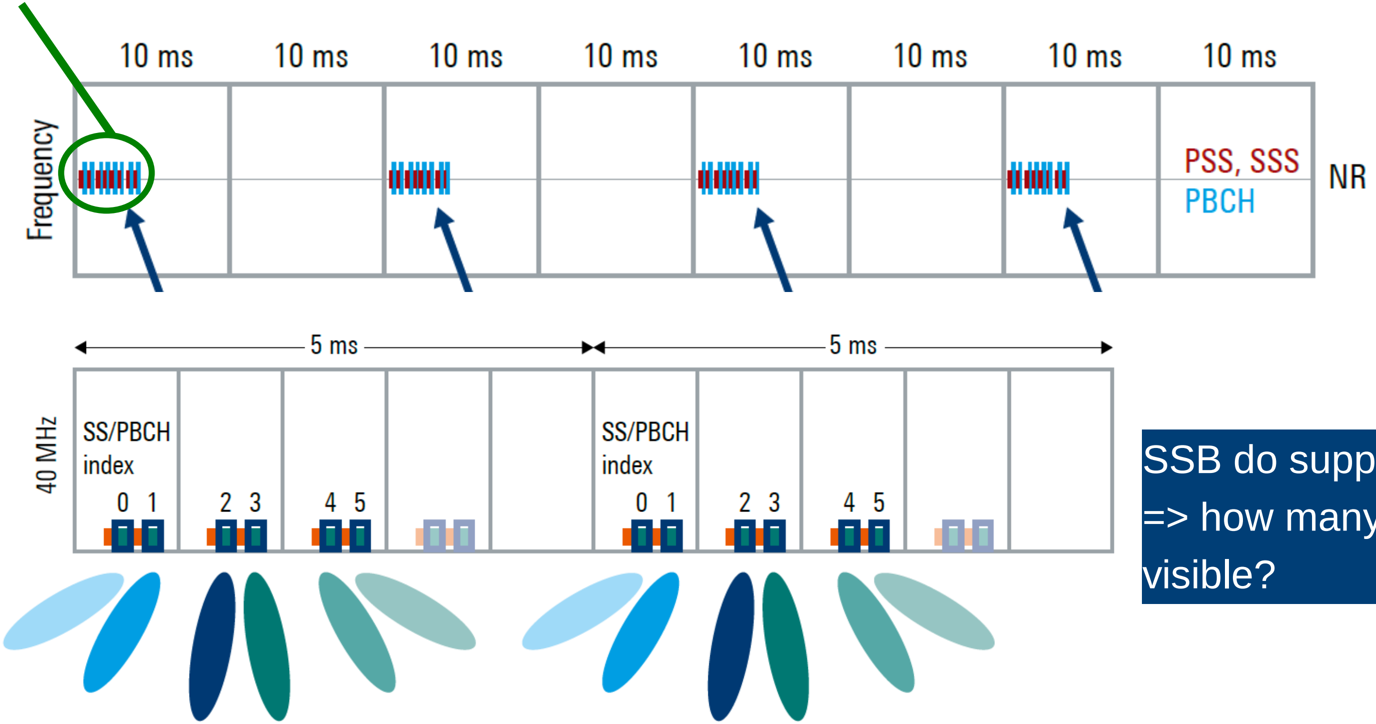




- ► 5G NR uses beamforming to overcome the path loss for synchronization (SSBs) and data signals
- ► Intelligent antenna arrays create very narrow but high-gain beams to focus the power on a certain area to increase SINR and received power
- ► This can create field strength hotspots in the very narrow main lobes of the beams

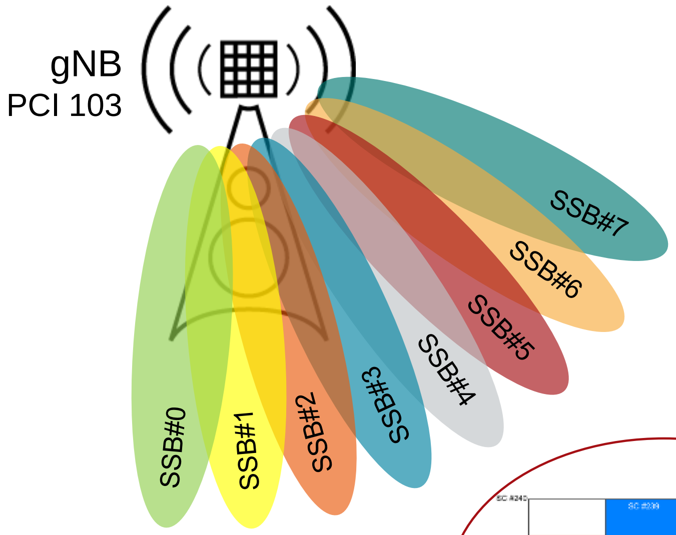
WHY IS 5G NR MORE CHALLENGING REGARDING EMF EXPOSURE?

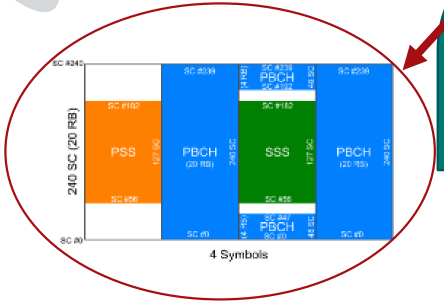
SSBs are organized in SSB burst sets. L = number of SSBs, depending on frequency, subcarrier spacing and configuration. L_{max} ranges from 4 .. 64.



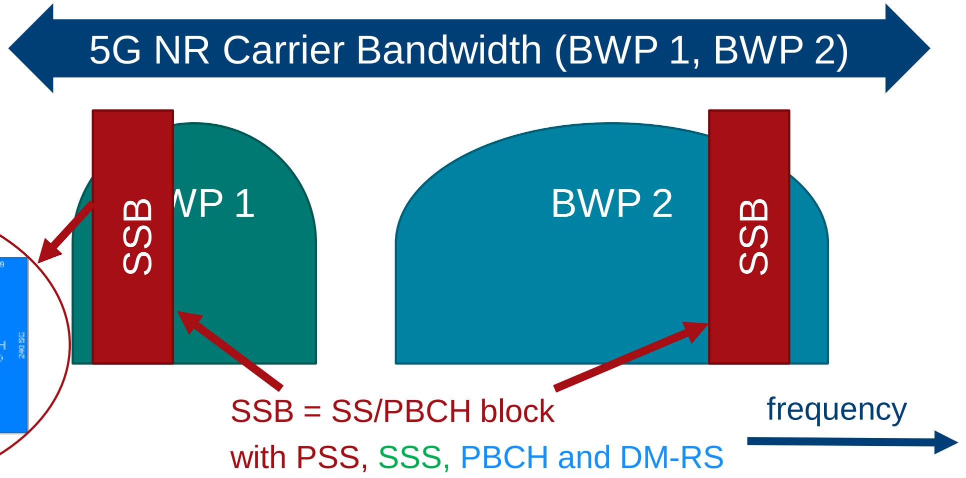
SSB do support beamforming.
=> how many SSB beams are visible?

WHICH SIGNAL TO CHOOSE FOR CODE-SELECTIVE EMF MEASUREMENTS?





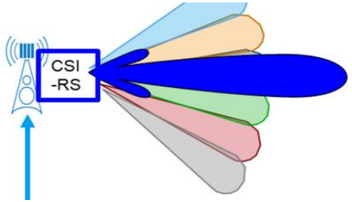
- ▶ Always-on signal required!
- ▶ Known signal sequence required!
- ▶ Signal has to be beamformed!
- ▶ **Signals of the Synchronization Block (SSB) fulfill the requirement**



5G EMF NEED FOR EXTRAPOLATION FACTORS

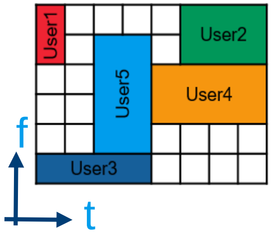
► **Beam / gain offset between SSB and data beams**

It is expected, that data / UE specific beams have a much lower beamwidth and / or more power compared to SSB beams to further increase the SINR. The corresponding data have to requested from the network operators or infrastructure suppliers.



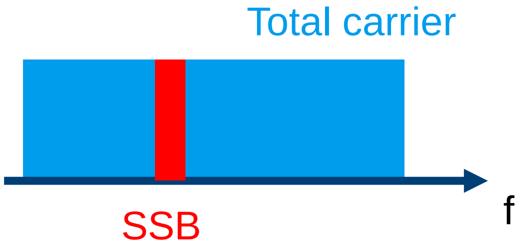
► **Uplink and downlink relation factor**

In the case of TDD, the relation between uplink and downlink significantly affects the radiated power by the gNodeB. In the case, more slots are reserved for uplink, the radiated power decreases. The relation factor depends on the network configuration, which has to be requested from the network operators. An exception are NSA networks, where the 5G NR carrier may be used for downlink only.



► **Projection of synchronization signal block power on the total 5G NR carrier spectrum**

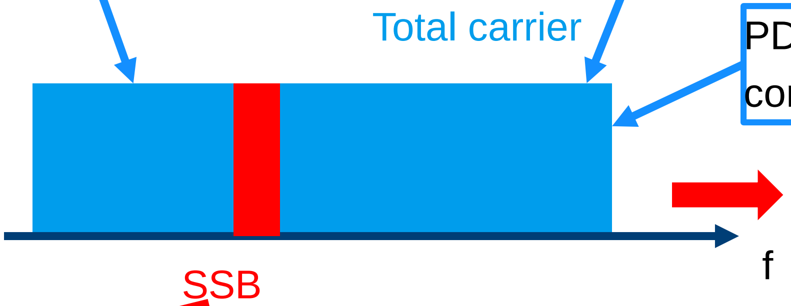
Synchronization signal blocks only have a bandwidth of 3.6 …7.2 MHz depending on the subcarrier spacing. The total bandwidth of 5G NR carrier can be up to 400 MHz. This requires another extrapolation factor, which can be requested from the operators or be determined by using a mobile phone with an active subscription for the particular 5G NR network.



WHY IS 5G NR MORE CHALLENGING REGARDING EMF EXPOSURE?

There are no a priori known reference signals in the PDSCH area

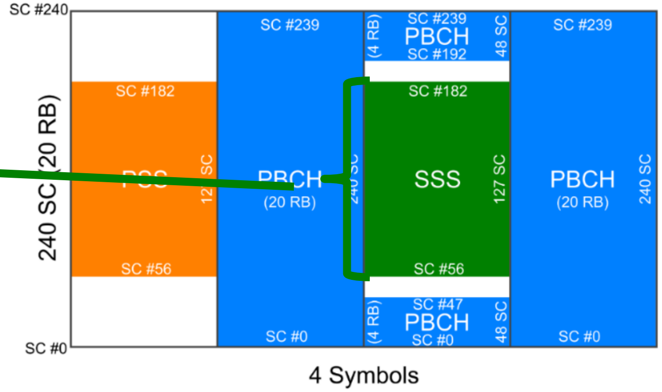
5G is packet switched, thus RB power is only measurable, when active traffic



PDSCH may use different beams compared to SSB

A linear spectral extrapolation from SSB to total channel bandwidth power does not work!

The SSB is the only „“always on“ signal in 5G. For EMF exposure, we have to measure the RSRP of the secondary sync signal, i.e. the SSS RSRP.



WHY IS 5G NR MORE CHALLENGING REGARDING EMF EXPOSURE?

Scenario 1: cell fully loaded, traffic channel power = SSB block power

A linear spectral extrapolation from SSB will work fine, EMF value derived from SS-RSRP

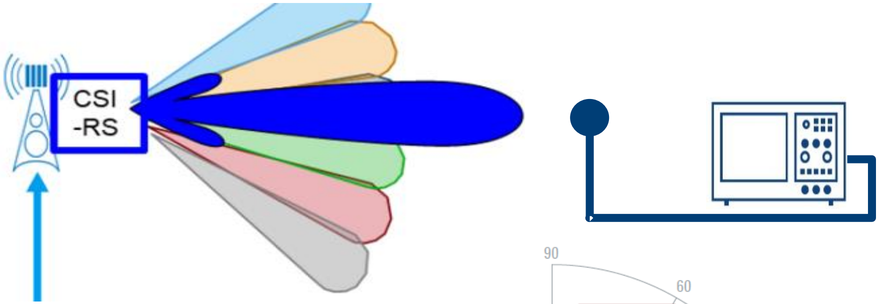
Scenario 2: cell partly loaded or traffic channel power < SSB block power

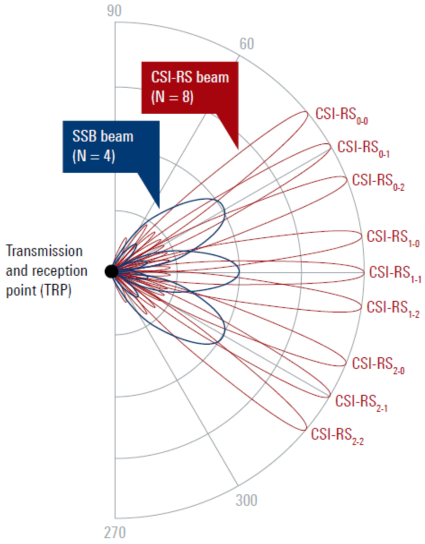
A linear spectral extrapolation from SSB will give an EMF that is higher as in reality

Scenario 3: cell fully loaded and/or traffic channel power > SSB block power

A linear spectral extrapolation from SSB will give an EMF that is lower as in reality

WHY IS 5G NR MORE CHALLENGING REGARDING EMF EXPOSURE?



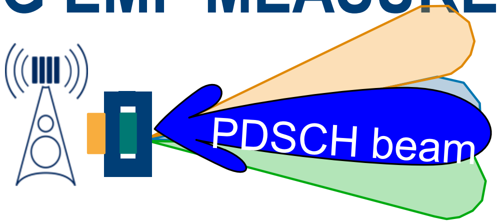


EMF test strategy:

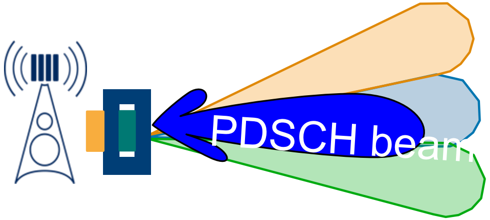
- A priori information about the site, e.g. beam configuration?
- Which beams are visible?
- What is the worst case condition? E.g. peak beam direction and max power?
- Obtain information from data sheet, e.g. radiation pattern and max TX power

5G supports beamforming. There are SSB beams and optionally PDSCH beams. Different gain is possible, PDSCH beams are UE specific and beams may show different directivity.

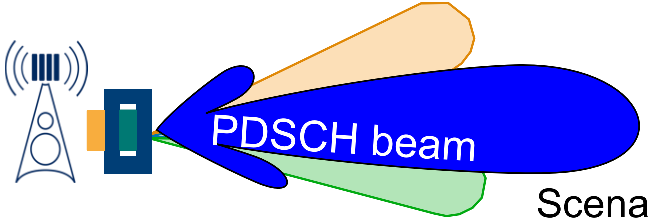
5G EMF MEASUREMENT:



Scenario 1: PDSCH beam = SSB beam in direction & power. Linear extrapolation from SS-RSRP gives realistic EMF value

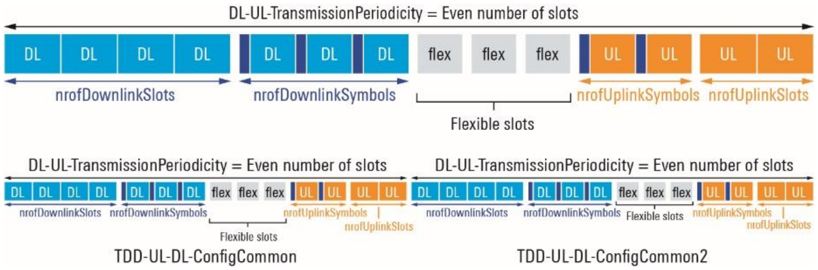


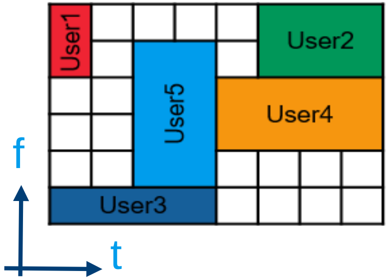
Scenario 1: PDSCH beam ≠ / < SSB beam in direction and/or power. Linear extrapolation from SS-RSRP results in EMF value higher as real



Scenario 2: PDSCH beam ≠ / > SSB beam in direction and/or power. Linear extrapolation from SS-RSRP results in EMF value lower as real

WHY IS 5G NR MORE CHALLENGING REGARDING EMF EXPOSURE?



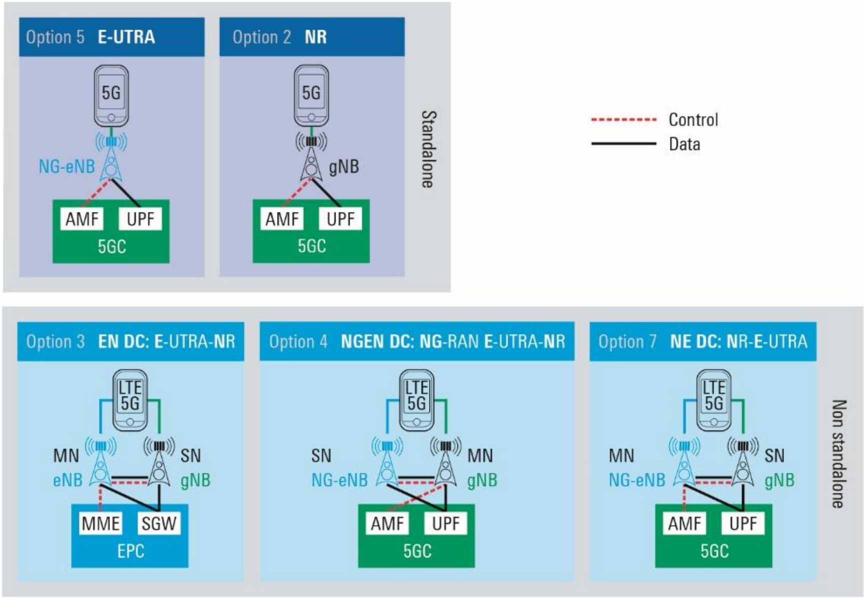


EMF test strategy:

- A priori information about UL/DL configuration
- TDD relation factor

5G supports TDD mode. => gated measurement is needed and we need a compensation factor to take into account the UL/DL-configuration

WHY IS 5G NR MORE CHALLENGING REGARDING EMF EXPOSURE?



EMF test strategy:
- A priori information about NSA or SA deployment
- LTE + NR relation factor

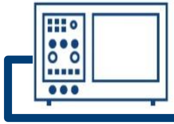
Measure LTE & NR EMF?

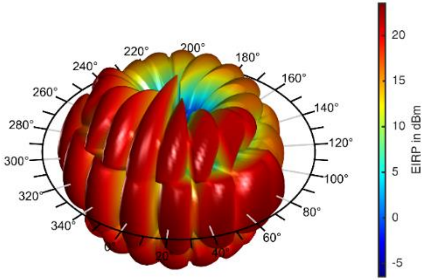
5G supports multi-connectivity. Non standalone or standalone modes are possible.

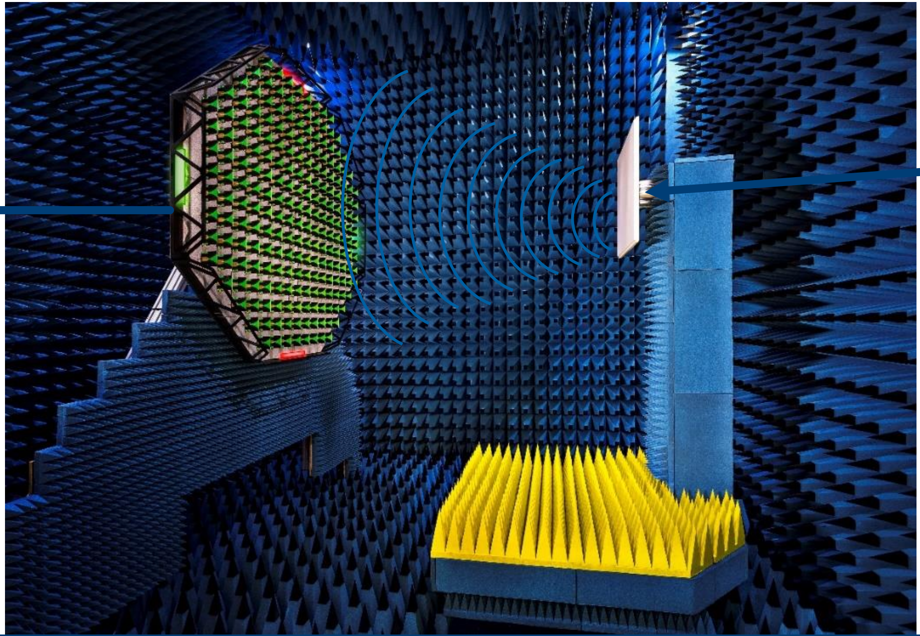
DIFFERENCES 4G / 5G

Feature	4G	5G
EMF conformance test	In-situ	Anechoic chamber > 7 GHz, undefined < 7 GHz
Antenna pattern	Fixed, equal for signalling and all data	Beam forming
Typ. beam pattern	Azimut: 60° or 360° Elevation: ≈ 10°	Depending on type of signal and antenna
Frequency range	400 MHz to 6 GHz	FR1: 400 MHz to 7 GHz, FR2: 28 GHz, 38 GHz, (43, 47, beyond)
RF bandwidth	≤ 20 MHz	≤ 100 MHz (FR1), ≤ 400 MHz (FR2)
Signalling	In mid of frequency band, always on, same pattern as data	At fixed frequencies, not necessarily in same band, beam constant or scanning
Reference symbols	Cell specific, always tranmitted, distributed over the bandwidth	Flexible and configurable reference signal concept. Only SSB is “always on“

5G EMF MEASUREMENT: LAB BASED, E.G. R&S PWC200







TS 38.104 base station conformance: test mode

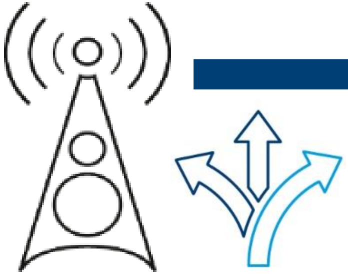
We obtain reliable EMF measurements under well-known conditions!

EMF test in a full anechoic chamber:

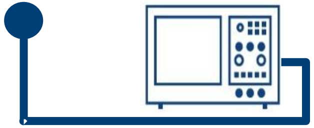
- Base station is applied to use a test mode: RF parameters are well known
- Measurements in anechoic (FAC), shielded and calibrated setup: ERP, TRP, radiation pattern etc.

5G EMF: CHALLENGE

5G flexibility



EMF$_{measured}$



Extrapolation (not standardised)

EMF$_{adjusted}$

verification

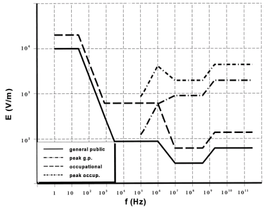


Fig. 1. Reference levels for exposure to time varying electric fields (compare Tables 6 and 7).

EMF measurement based on e.g.:

- Frequency & bandwidth
- code or spectrum selective
- Single or multiple RAT EMF
- Single or multipoint
- Snapshot or time averaging

EMF correction based on e.g.:

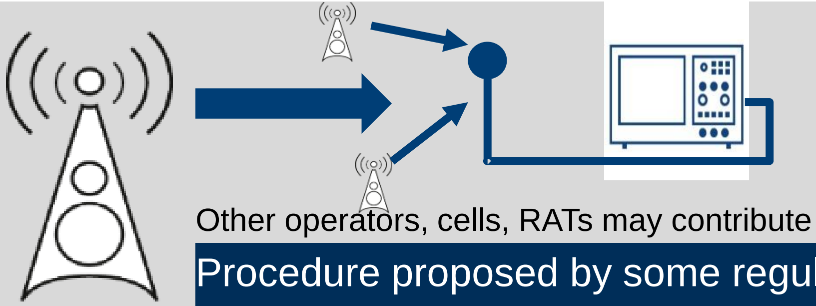
- Methodology on how to apply adjustment parameters
- Beamforming aspects
- TDD correction
- Traffic assumption

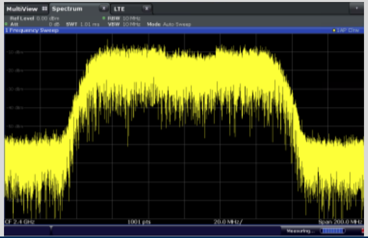
Reliable & repeatable approach based on physics

Worst case emulation based on assumption & agreements

5G EMF – VARIOUS METHODS ACCORDING TO INTERNATIONAL ORGANISATIONS / REGULATORS

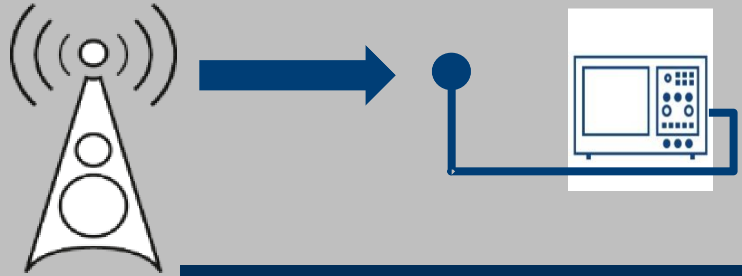
5G EMF MEASUREMENT: REGULATORY PERSPECTIVE





Spectral scan: single measurement, measure E_{BW}

Procedure proposed by some regulators to measure the general EMF exposure, independent on RAT and operator and based on single snapshot only



ICNIRP: T_{avg} = 6min

IEEE: T_{avg} = 30min

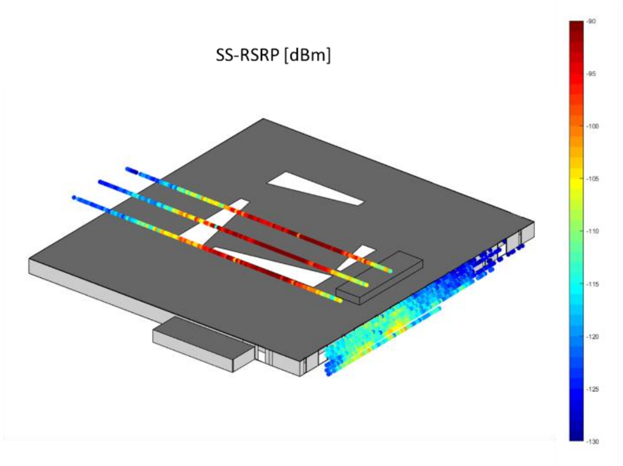
$$E_{BW,avg} = \sum_{t=0}^{T_{avg}} \int_{f_{min}}^{f_{max}} E_{RE}$$

Spectral scan proposed by some regulators: measure E_{RE} per resource element over full bandwidth. Time averaging performed to eliminate the floating traffic error in 5G, assume cell is loaded with traffic

5G EMF MEASUREMENT: REGULATORY PERSPECTIVE

Approach: Site verification: Given is a EMF limit. Measure 5G NR power to check whether transmitter fulfils EMF regulation.

Example: drone test of a factory using 3.7GHz private 5G network. If no agreement can be made, an emission limit of 32 dBµV/m/5MHz should be used in 3 meters height at the border of the license area. The limit corresponds to an RSRP of -138.8 dBm



5G EMF MEASUREMENT: REGULATORY PERSPECTIVE

Approach: Site verification: Given is a EMF limit. Measure 5G NR power to check whether transmitter fulfils EMF regulation.

1. step: define sector power as SSB power extrapolated over the channel bandwidth

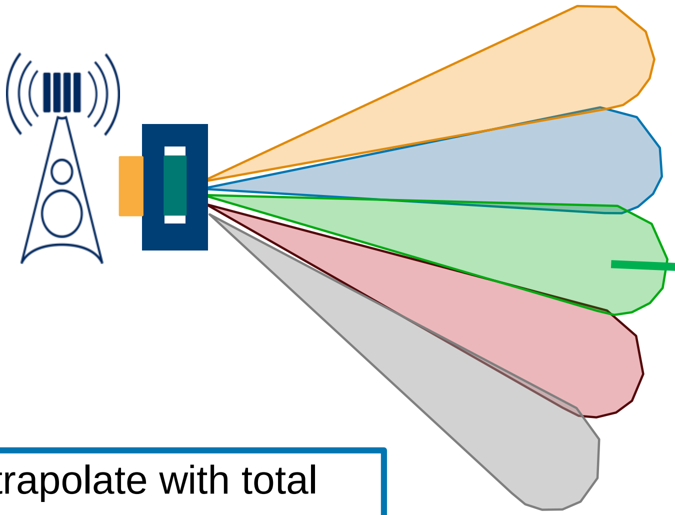
$$P_{SP} = P_{SS-RSRP} + 10\log N_{sc}$$

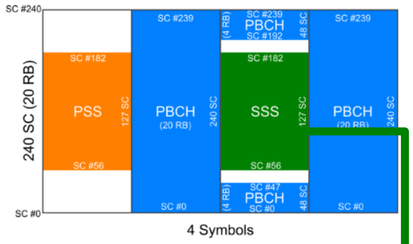
2. step: calculate SSB power limit according to given EMF threshold. Formulas used from ITU handbook of spectrum monitoring (e.g. antenna gain, receiving line loss, polarziation loss, propagation loss, etc.)

$$e.i.r.p. = P_r - G_r + R_{loss} + X_{pol} + L_{prop}$$

$$P_{SS-RSRP} = E_{thresh} + 10\cdot\log\frac{BW}{5} - 10\log N_{sc} + G_{ant} - 20\cdot\log F_{carrier} - A_{cable} - A_{pol} - 77.23$$

5G EMF MEASUREMENT: REGULATORY PERSPECTIVE

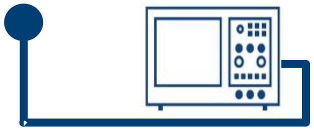




Drawback: unlikely that a real gNB transmits with max power in one single beam only

Measure $E_{RE,SSB}$ = SSS RSRP

1 beam



Extrapolate with total gain versus SSB gain normalization

$$\propto = \frac{G_{max}}{G_{SSB}}$$

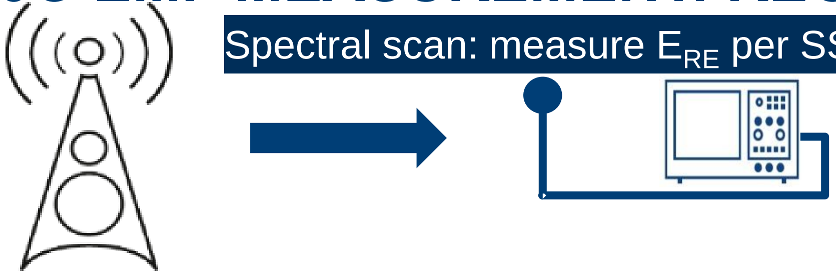
Extrapolate to full bandwidth

$$E_{max} = \sqrt{\propto} \cdot \sqrt{12 N_{RB}} \cdot E_{RE,SSB}$$

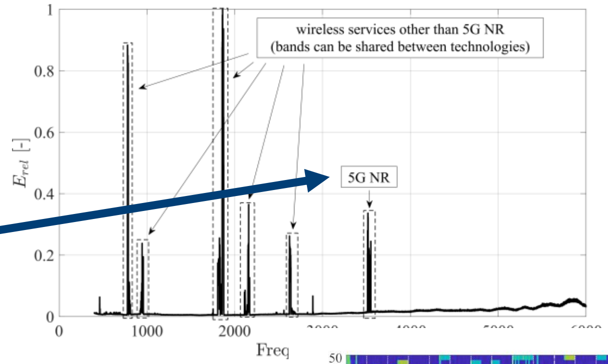
Source: Uni Gent

Maximum exposure: Measure SSB EMF, extrapolate to full bandwidth and take into account the maximum gain as compensation factor. Time averaging and multipoint possible to search for maximum

5G EMF MEASUREMENT: REGULATORY PERSPECTIVE



Spectral scan: measure E_{RE} per SSB + post processing (optionally)



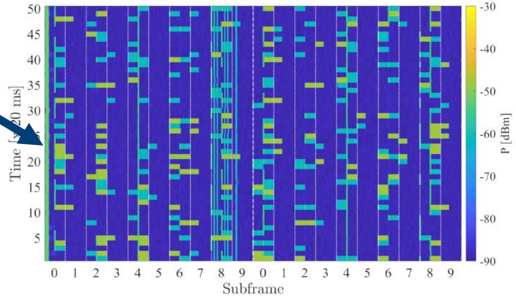
5 steps method to align to reality:

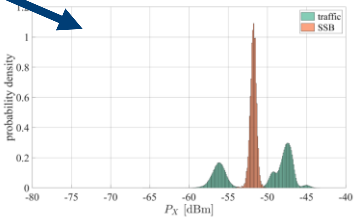
Pure spectral scan:

- Spectrum overview, fast scan
- Locating the SS burst, with RBW settings locate SSB
- Obtaining the field level per RE of the SSB
- Measuring the instantaneous field level (=time averaging + histogram and load considerations)

Extrapolate to emulate worst case:

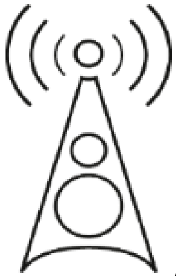
- Post-processing (TDD use factor, max gain correction, different beams)



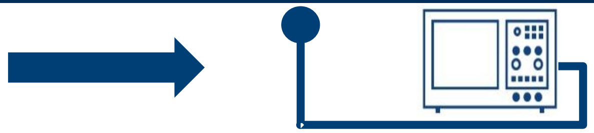


Source: Uni Gent

5G EMF MEASUREMENT: REGULATORY PERSPECTIVE



EMF measurements a practical guideline on procedure and equipment (source ITU)

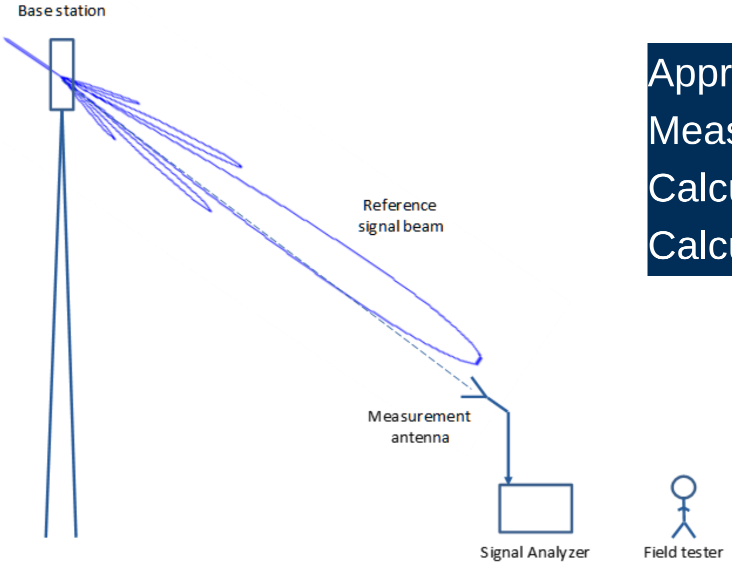


A practical guideline released by the ITU:

- Measure the squared, isotopic and weighted RMS value of the electric and/or the magnetic field strength at any position in the area of interest where humans are likely to be exposed.
- Use only moderate or no spatial averaging around each position.
- Make sure that the humans to be exposed are not present during the measurements.
- Exclude any position from the measurements where the distance to conductive objects is less than 0.5 m.
- Use an RMS integration time, which is not longer than the maximum permissible integration time.
- Measure over a time span, which is long enough to ensure that the maximum exposure over time will occur within this time span.
- Use the maximum exposure value of all positions and over the complete observation time as the final exposure result. If this result is less than unity, the exposure in area of interest is permissible.

Source: Report ITU-R SM.2452-0 (06/2019)

5G EMF MEASUREMENT: REGULATORY PERSPECTIVE



Approach:

Measure e.i.r.p

Calculate TRP by known directivity D

Calculate the carrier TRP by extrapolating

Challenges:

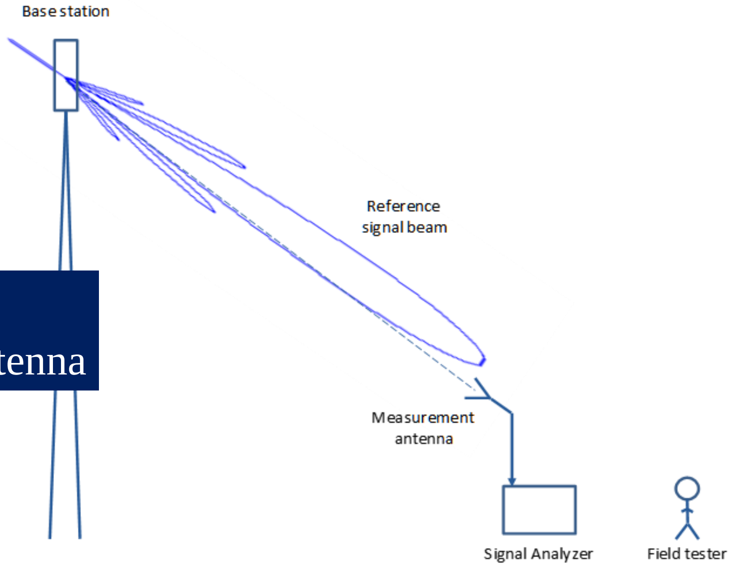
- Measurement location not in peak beam direction
- Base station in test mode is not suitable
- Directivity of base station vs. measurement antenna should be known
- Power scaling should be known
- Measurement uncertainty

Source: 3GPP
Document 1C/4-E
Document 5D/135-E

5G EMF MEASUREMENT: REGULATORY PERSPECTIVE

1. step: measure EIRP (=based on SSB reference signals).
r = distance, G = RX antenna gain

$$EIRP_{test}(\theta_2,\varphi_2) = \frac{P_{rx}(4\pi r)^2}{G(\theta_2,\varphi_2)\lambda^2}$$



2. step: calculate TRP based on directivity D
$D(\theta_1,\varphi_1)$, directivity at the direction towards the measurement antenna

$$TRP_{test} = \frac{EIRP_{test}(\theta_2,\varphi_2)}{D(\theta_1,\varphi_1)}$$

3. step: calculate TRP based on power scaling
C is a scaling factor to account for the power scheduled to the test signal to the power scheduled for the complete carrier signal

$$TRP = TRP_{test}C$$

Source: 3GPP
Document 1C/4-E
Document 5D/135-E

5G EMF MEASUREMENT: REGULATORY PERSPECTIVE

$$E_{i,h} = E_{i,max}^{SSS(RE)} \cdot K_i(\varphi_i, \theta_i)$$

Electric field strength per cell i and operator h

$$K_i(\varphi_i, \theta_i) = K_i^{SSS(RE)} \cdot K_i^{antenna}(\varphi_i, \theta_i) \cdot K_i^{stat} \cdot K^{duplex}$$

Global extrapolation factor (two polarizations)

SSS extrapolation factor, taking into account permitted power and beam configuration

Antenna correction factor (radiation pattern difference between SSB and total signal)

Beam statistic correction (when dynamic beams)

TDD adaptation factor

$$E_{i,max}^{SSS(RE)} = \max\left(\sqrt{\sum_j \left(E_{i,j}^{SSS(RE)}\right)^2}\right)$$

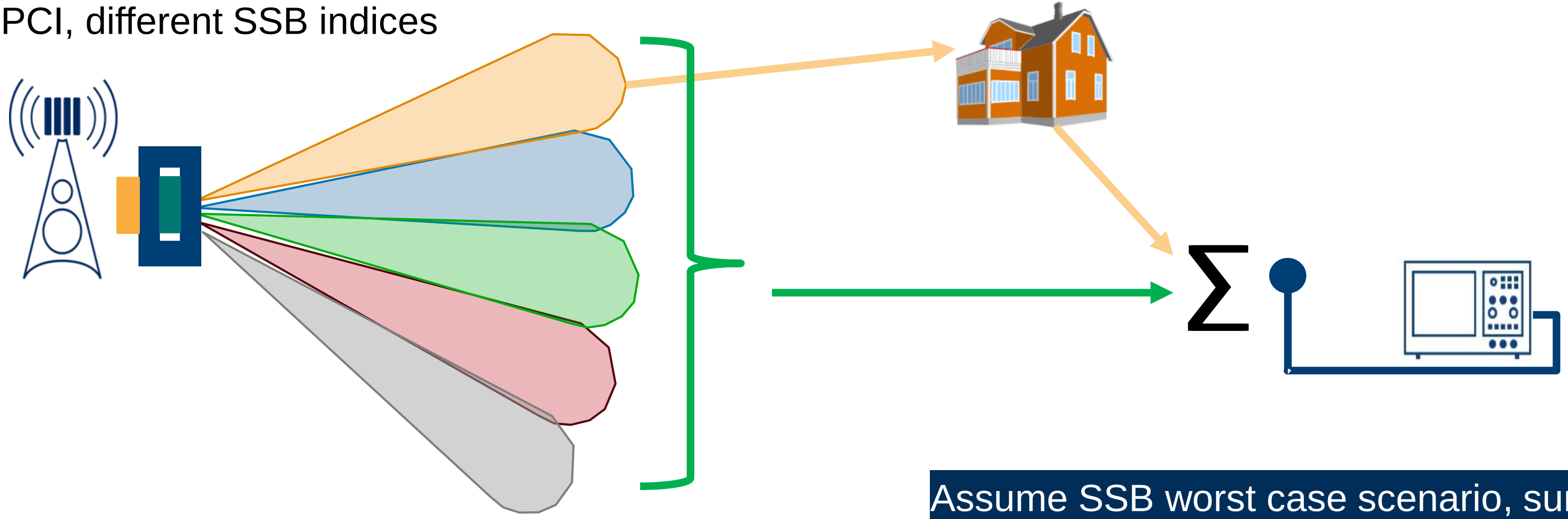
Spatial maximum of the quadratic sum of the SSS field strength

Electric field strength per resource element of SSS of cell i and sum of all SSB indexes j

Source: METAS

5G EMF MEASUREMENT: REGULATORY PERSPECTIVE

Same PCI, different SSB indices



Assume SSB worst case scenario, sum all SSB power and multipath receptions

$$E_{i,max}^{SSS(RE)} = \max\left(\sqrt{\sum_{j}\left(E_{i,j}^{SSS(RE)}\right)^{2}}\right)$$

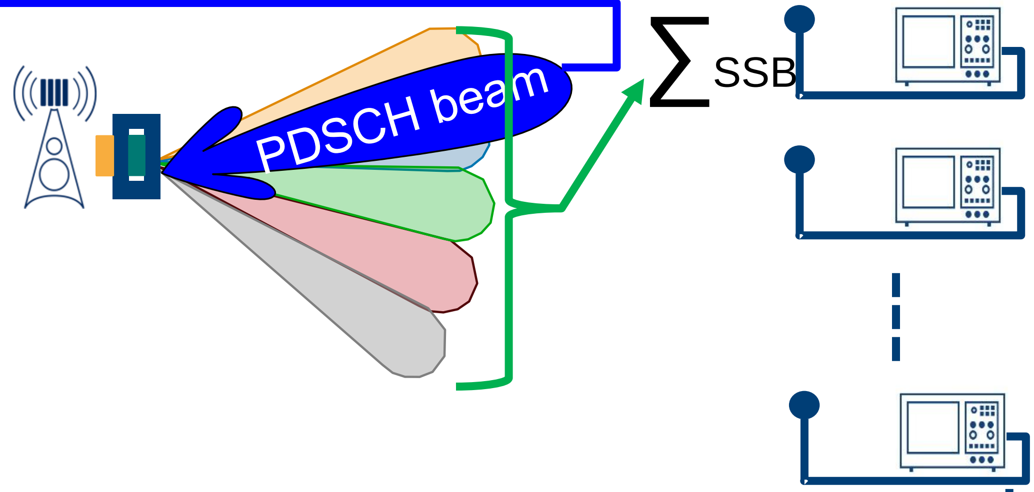
Source: METAS

5G EMF MEASUREMENT: REGULATORY PERSPECTIVE

$$K_i(\varphi_i,\theta_i) = K_i^{SSS(RE)} \cdot K_i^{antenna}(\varphi_i,\theta_i) \cdot K_i^{stat} \cdot K^{duplex}$$

= maximum ERP (datasheet)

$$K_i^{SSS(RE)} = \sqrt{\frac{P_{i,permitted}}{P_i^{SSS(RE)}}}$$



= sum all SSB (including multipath) + measure at different locations => max search

Source: METAS

PDSCH beams may be different from SSB beams. => involve maximum ERP as extrapolation. Summ all SSB indexes and multipath receptions and measure @ different locations. Search maximum.

5G EMF MEASUREMENT: REGULATORY PERSPECTIVE

$$K_i(\varphi_i,\theta_i) = K_i^{SSS(RE)} \cdot K_i^{antenna}(\varphi_i,\theta_i) \cdot K_i^{stat} \cdot K^{duplex}$$

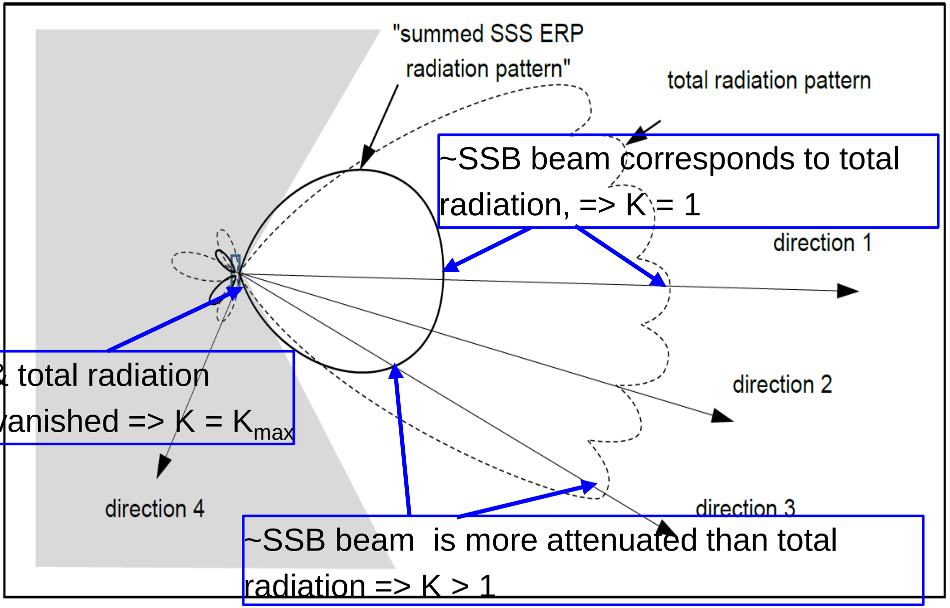
$$K_i^{\text{antenna}}(\varphi_i,\theta_i) = \begin{cases} 1 & \text{if } A_i^{\text{SSS(RE)}}(\varphi_i,\theta_i) < 10 \\ & \text{and } A_i^{\text{SSS(RE)}}(\varphi_i,\theta_i) \le A_i^{\text{total}}(\varphi_i,\theta_i) \\ A_i^{\text{SSS(RE)}}(\varphi_i,\theta_i)/A_i^{\text{total}}(\varphi_i,\theta_i) & \text{if } A_i^{\text{SSS(RE)}}(\varphi_i,\theta_i) < 10 \\ & \text{and } A_i^{\text{SSS(RE)}}(\varphi_i,\theta_i) > A_i^{\text{total}}(\varphi_i,\theta_i) \\ K_{i,\max}^{\text{antenna}} & \text{if } A_i^{\text{SSS(RE)}}(\varphi_i,\theta_i) \ge 10 \end{cases}$$

with

Attenuation = max. in all directions / current SSB Power

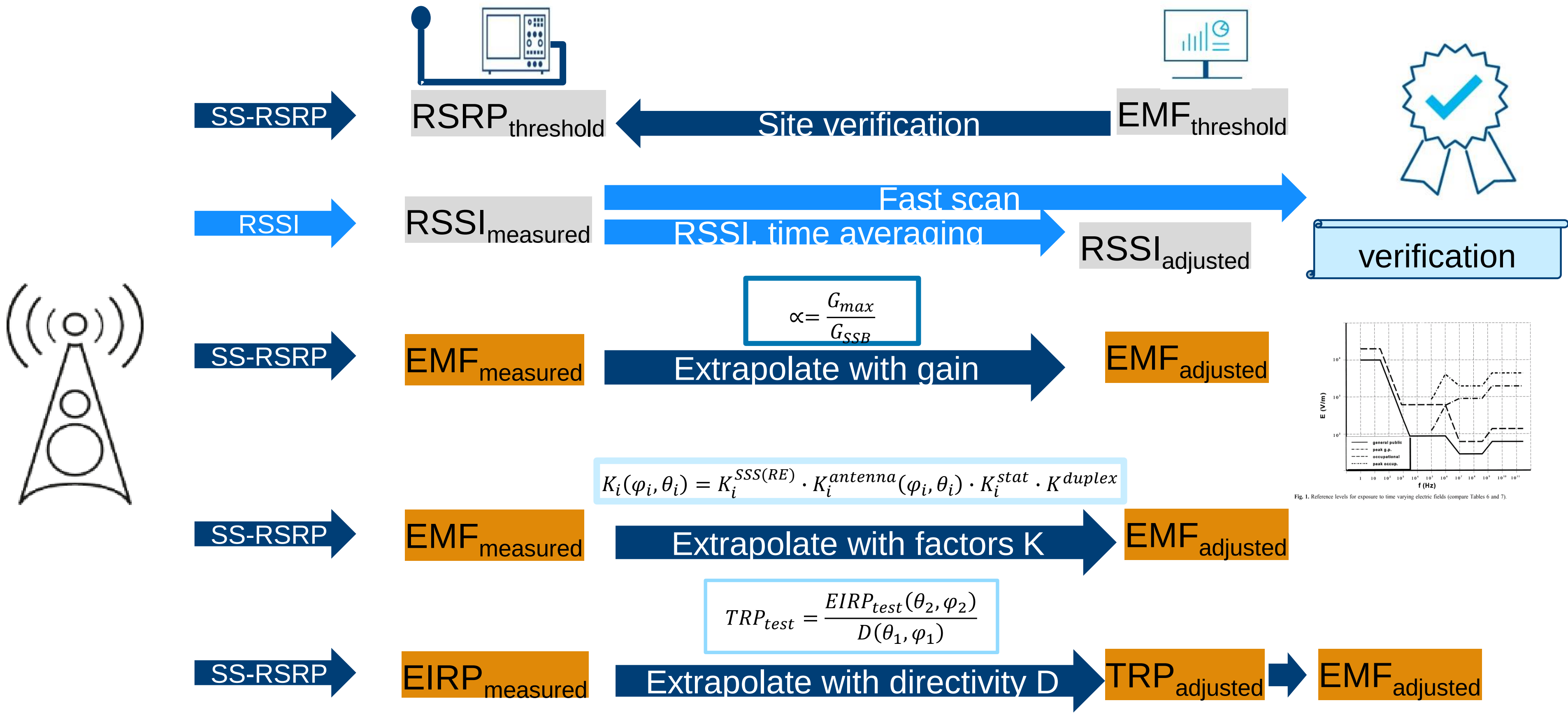
$$A_i^{\text{SSS(RE)}}(\varphi_i,\theta_i) = \sqrt{\frac{P_i^{\text{SSS(RE)}}}{P_i^{\text{SSS(RE)}}(\varphi_i,\theta_i)}}$$

Source: METAS



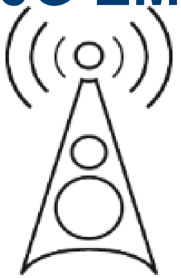
To compensate various measurement scenarios, difference between SSB radiation pattern and total radiation pattern, a antenna correction factor is applied

5G EMF: SHORT SUMMARY OF VARIOUS REGULATORY PROPOSALS

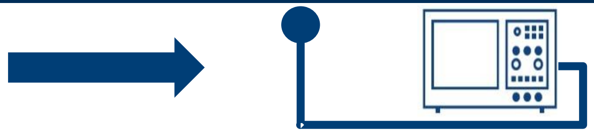


EMF MEASUREMENT SOLUTIONS

5G EMF MEASUREMENT: REGULATORY PERSPECTIVE



EMF measurements a practical guideline on procedure and equipment (source ITU)

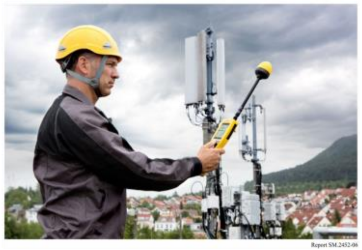


Source: Report ITU-R SM.2452-0 (06/2019)

Not yet part of this ITU report

Personal monitor

- Fast scan
- Small freq. span & averaging
- reduced GUI
- Used for personal protection



Broadband meter

- Shaped probe: direct EMF
- RMS value only
- reduced GUI
- Used for EMF only
- Diode or thermal probes @high PAPR is challenging!

Spectrum analysis

- High flexibility
- Large freq. span and various antenna
- advanced GUI
- Not only for EMF
- Decoding or demodulation of RAT?

Code selective (e.g. scanner or advanced SPA)

- Highest flexibility
- Large freq. span and various antenna
- advanced GUI
- EMF and drive testing or spec. analysis possible
- Decoding or demodulation possible

EMF MEASUREMENT

R&S®FSH + FSH-K105 option + TSEMF antenna

Perform measurements conforming to ICNIRP or according to local authority limit

Fast and easy configuration using R&S®InstrumentView software

Measurement procedures should be applied:

- Multipoint method
- Stirring method

MEASUREMENT PROCEDURE OF CODE-SELECTIVE EMF MEASUREMENTS IN 5G

TSMA6 + QualiPoc Android result

Post processing by measuring party / service company

Apply test antenna gain / antenna factor

- ▶ Automatically detect all 5G carriers on air
- ▶ Decode PCI, SSB index and MIB
- ▶ Conduct power measurements on synchronization signals

[V/m]
Electrical field strength per **SSB**

Sum up all SSBs and calculate an electrical field strength value **per PCI**

[V/m]
Electrical field strength per **PCI**

Search for max. field strength per PCI by pivoting the antenna and applying max. hold function

[V/m]
Electrical field strength (total)

Apply extrapolation factors for converting sync signal power to total power →
Country specific regulations

MEASUREMENT SETUP R&S®TSMA6 WITH QualiPoc Android

EMF values

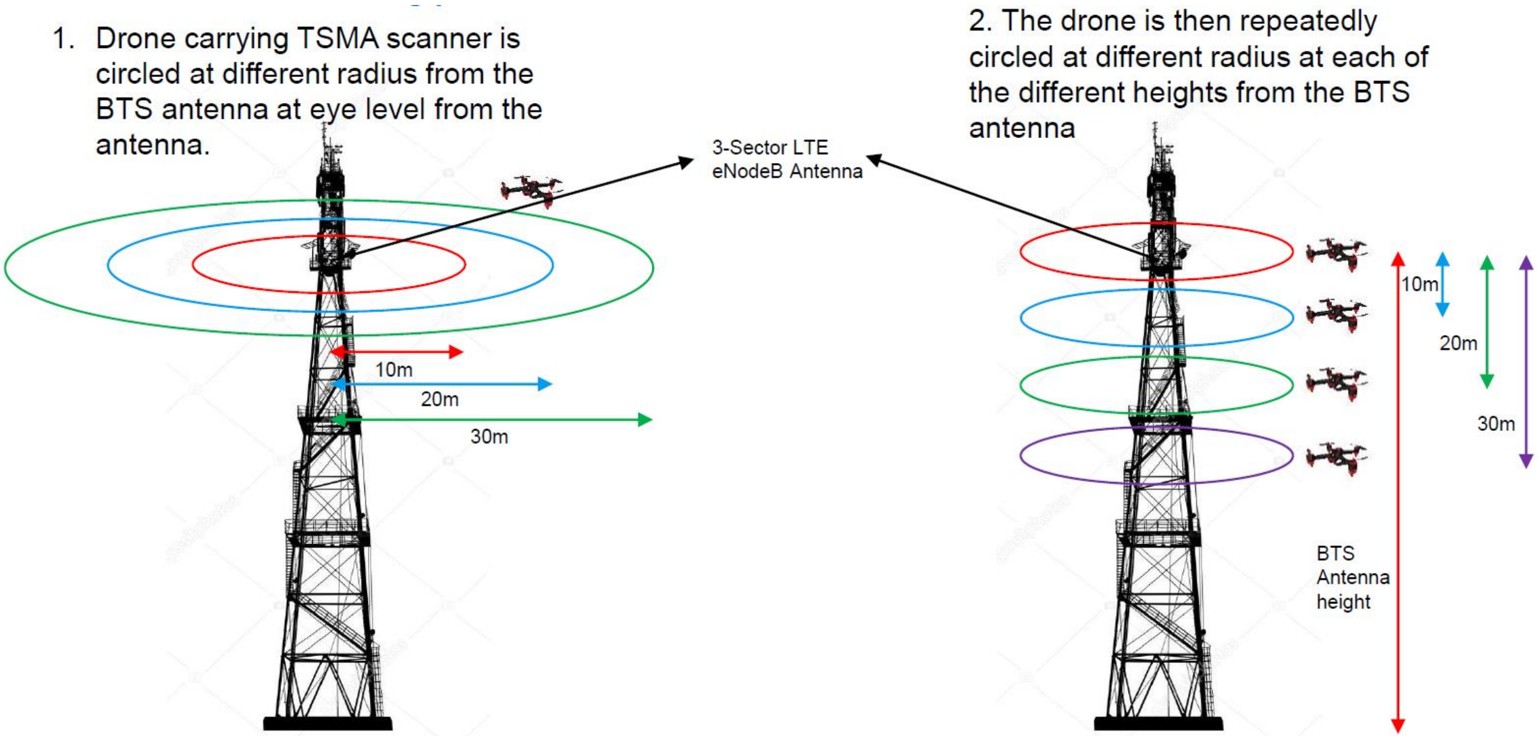
TSMA6 (passive scanning receiver + PC)

- **Passive, calibrated receiver with highest achievable accuracy** ([V/m] is a linear value!)
- Automatically detect 5G NR PCIs / SSBs
- Decode and measure the received power of SSBs (beams) of all detected PCIs

QualiPoc Android connected via Bluetooth

- **Android® app for smartphones or tablets for UE-based and scanner-based measurements**
- Compute and display electrical field strength [mV/m] over all 5G NR SSBs
- Set max. hold data points
- Export measured / calculated values

SITE VERIFICATION USING DRONES



Example of a test scenario to verify the radiation pattern of an installed antenna site using a TSMA scanner mounted on a drone.

THANK YOU

Link to the electronic R&S technology book on 5G
www.rohde-Schwarz.com/5G

Additional information – please contact your local R&S representative in your country

Or direct contact for specific question on this presentation

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THANK YOU!

“Details matter, it's worth waiting to get it right.”

Steve Jobs (1955-2011)