EMF MEASUREMENTS IN 5G NR

ROHDE & SCHWARZ

Make ideas real

CONTENTS

1   MOTIVATION AND INTRODUCTION

1.1   Electromagnetic radiation concerns in 5G NR

5G and the associated new technologies such as beamforming and frequencies above 3 GHz have raised a large number of discussions among the population. In 5G NR, beamforming is applied to almost all signals, in particular on data channel related signals (PDSCH etc.) and synchronization signals (SSB).

Fig. 1: 5G NR cell with PCI 321 is divided into several synchronization beam areas (SSB)
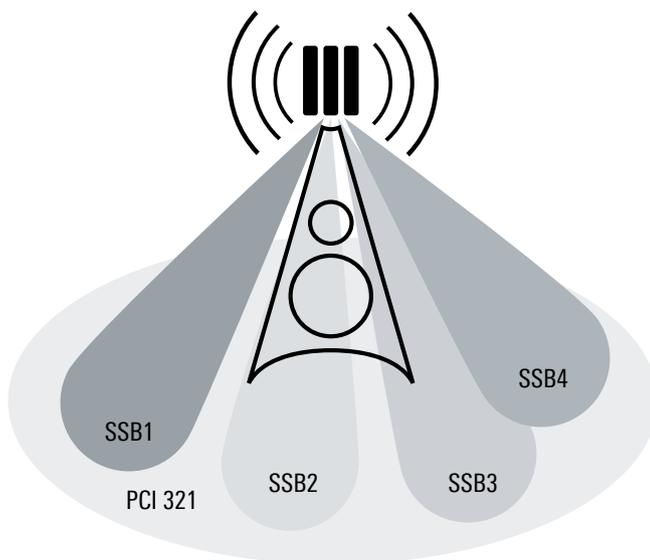
3GPP defined new bands such as n77 and n78 (3200 MHz to 4200 MHz) that raise health concerns, in particular with regard to increased electromagnetic radiation resulting from higher frequencies combined with beamforming. Consequently, the 5G rollout is slowing down in several countries until it is proven that the radiation is below a certain country-specific threshold.

To continue the network rollout, dynamic spectrum sharing between LTE and 5G NR in already used frequency bands could be a good compromise to provide 5G NR but use existing antennas without beamforming. In the case of dynamic spectrum sharing, specific LTE subframes are omitted to allow the insertion of 5G NR signal components. Furthermore, dynamic spectrum sharing provides much less usable spectrum. Because of these facts, dynamic spectrum sharing is not as efficient as a 5G NR rollout based on 3.5 GHz with beamforming antenna arrays in terms of the data that can be achieved. Nevertheless, the radiated power is also increasing, and operators and governments have to ensure that the total radiated power (and electromagnetic pollution) is below a certain threshold.

Fig. 2: Dynamic spectrum sharing, overlapping LTE and 5G NR carrier in the frequency domain
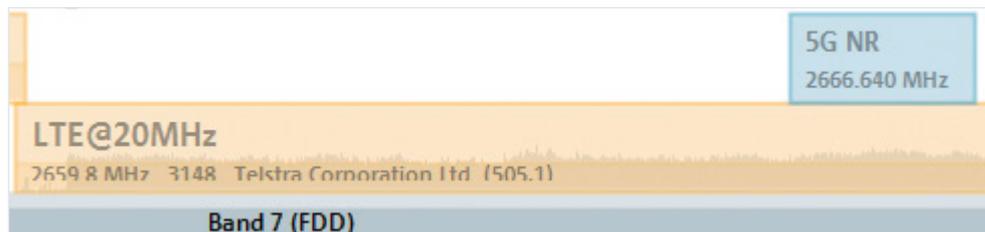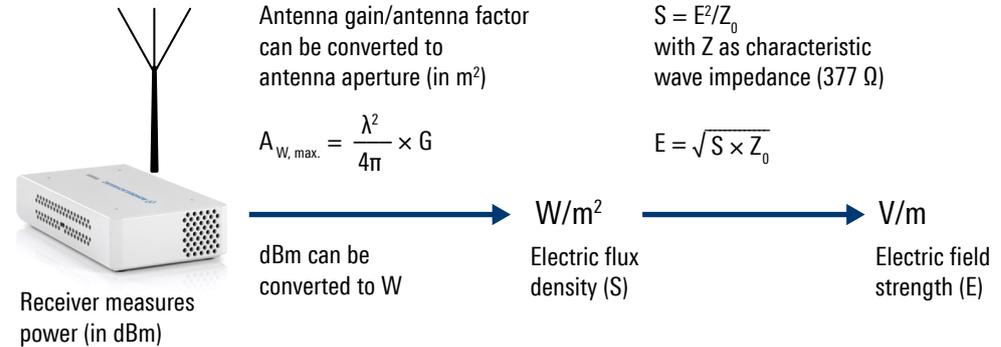
1.2   Measures for electromagnetic pollution

Measurements that demonstrate that electromagnetic pollution is below a certain threshold are called electromagnetic field (EMF) measurements.

There are two established measures for EMF measurements:
▶ Electric flux density in W/m²
▶ Electric field strength in V/m

Both measures are based on power measurements (in dBm). By applying the antenna factor (in dB/m) and/or the antenna aperture (in m²), power measurements can be converted into either electric flux density or electric field strength.

Fig. 3: Relationship of power, electric flux density (S) and electric field strength (E)

Antenna gain/antenna factor can be converted to antenna aperture (in m²)

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

dBm can be converted to W

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

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

W/m² Electric flux density (S)

V/m Electric field strength (E)

Receiver measures power (in dBm)

The antenna aperture is measured in m². It can be visualized as an increasing antenna surface with increasing antenna gain. The larger the antenna surface, the more electromagnetic energy is captured. A passive receiver measures the received power in dBm based on signal-specific RSRP values, which can easily be converted into W by removing the logarithmic scale. The relation of both value is in W/m² and is called electric flux density (S).

With air being the propagation medium for electromagnetic waves in this case, the corresponding characteristic wave impedance Z of 377 Ω can be used in order to convert into electric field strength in V/m by a square root operation.

# 2   5G NR SIGNAL STRUCTURE – A COMPLETELY NEW APPROACH

In previous cellular technologies (LTE, LTE-M, NB-IoT), cell-specific synchronization and reference signals were used. Always-on reference signals were spread over the entire spectrum for precise channel estimation.

5G NR is a completely new approach regarding cell-specific signals. 5G NR only broadcasts a minimum amount of cell-specific signals with a known sequence that can be measured by a calibrated measurement receiver. All other signals are UE specific; their appearance in the frequency and time domain is related to data traffic.

The only always-on signal is the synchronization signal block (SSB). As shown in Fig. 4, each SSB occupies 240 subcarriers (frequency domain) and 4 symbols (time domain). It contains primary and secondary synchronization signals (PSS and SSS) and the physical broadcast channel (PBCH).

As in LTE, the PSS and SSS in 5G NR represent the physical cell identity (PCI), and the PBCH carries the master information block (MIB) plus a few additional payload bits.

Fig. 4: 5G NR synchronization signal block
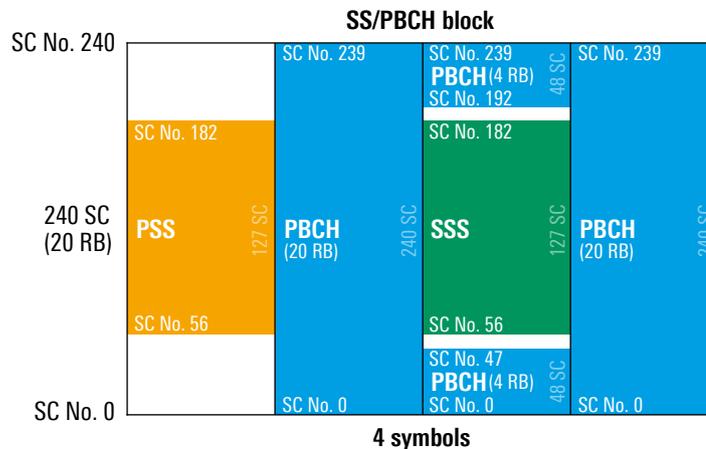
If we zoom into the subcarriers (Fig. 5), we also see demodulation reference signals (DM-RS). The DM-RS are used by the UE for channel estimation to demodulate the PBCH. The positions of the DM-RS signals across the PBCH are determined by the PCI.

Fig. 5: 5G NR synchronization signal block with increased zoom factor

DM-RS PBCH
PSS PBCH SSS PBCH
DM-RS PBCH
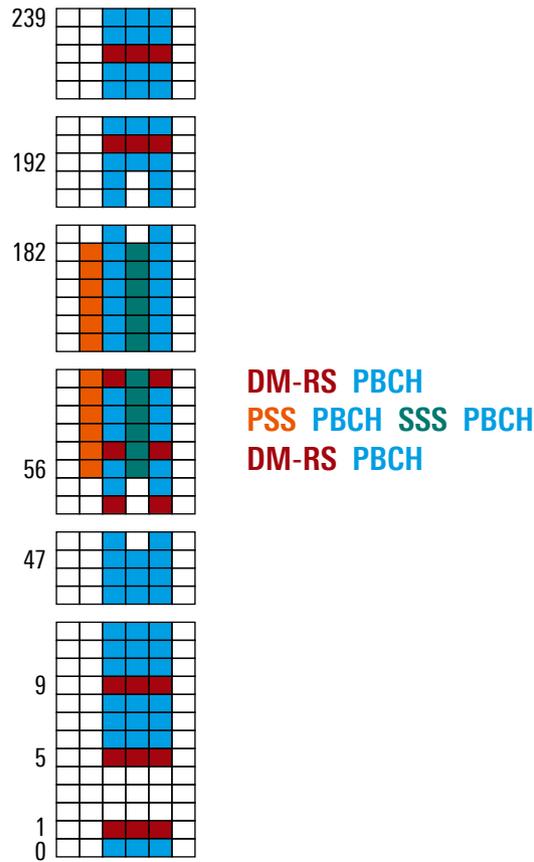
SSBs are transmitted periodically from each cell. 3GPP has defined five transmission patterns: case A to case E. The frequency range, the maximum number of SSB transmissions, the subcarrier spacing and the start OFDM symbols define the cases.

SSBs are organized in burst sets, with a burst set consisting of one or more SSBs. $L_{max.}$ denotes the maximum number of SSBs that can be configured for the different cases. For higher frequencies the number is significantly higher ($L_{max.}$ = 64) than for the frequency range below 1 GHz ($L_{max.}$ = 4), which reflects the need for more and smaller beams in the cm/mm wave spectrum. Each SSB has an index with an increasing number from 0 to $L_{max.}$ − 1.

The periodicity (Fig. 6 shows 20 ms) can vary between 5 ms and 160 ms (5, 10, 20, 40, 80, 160 ms). The 3GPP standard recommends using a periodicity of 20 ms for cell-defining SSBs. Higher periodicities such as 80 ms or 160 ms are preferably used for SSBs in mmWave networks in order to allow more time for the transmission of a higher number of SSBs in cases D and E.

Fig. 6: Periodically broadcasted synchronization signal blocks
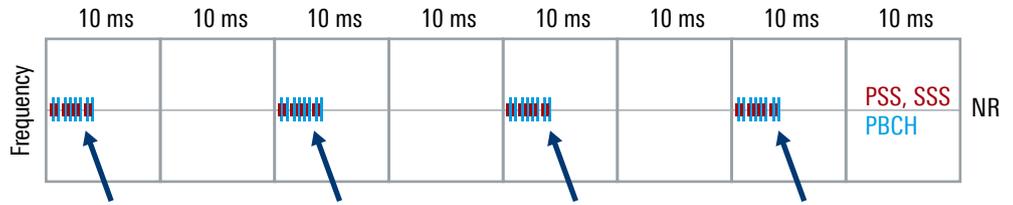
As explained in section 1, beamforming is an essential method to overcome the increasing path loss when using higher frequencies. This is also used for the SSBs that can be individually beamformed and preferentially cover a certain geographical area.

In the following example (Fig. 7), one cell is transmitting six SSBs (L = 6), meaning the SSB is transmitted six times, each time with a different value of the SSB index. If SSB beamforming is enabled, each SSB is transmitted on different spatial beams (here color-coded).

Fig. 7: Example of SSB transmissions
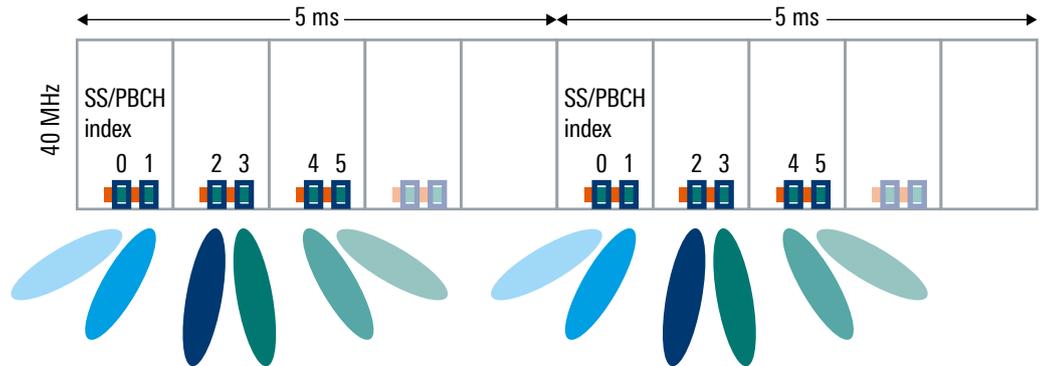
3 EMF MEASUREMENT PROCEDURES

3.1 Frequency versus code-selective measurements in 5G NR

Two fundamentally different measurement methods with several advantages and disadvantages are used for EMF measurements. Which procedure is applied depends on country-specific regulations, which in most cases are defined by federal institutes or similar organizations.

Frequency-selective measurement procedures are based exclusively on power spectrum measurements. Unlike the code-selective procedure, the received signals are neither decoded nor assigned to any technology, operator or cell, and the signal-specific power and interference are taken into account. This method is definitely the closest in terms of determining the total received power at a certain location, but there are some practical arguments that make the method less attractive than code-selective measurements.

▶ The power spectrum of wideband carriers typically changes extremely quickly over time. It is possible to work with envelopes on the power spectrum, but using an isotropic antenna (as required in some countries) is difficult. An isotropic antenna is able to capture the power omnidirectionally and from all polarizations. It can be controlled e.g. by a PC, which sends the commands to change the measured polarization at exactly the right time. The isotropic antenna has a certain hysteresis for changing the polarization. During this time, the power spectrum can easily change by 5 dB or 10 dB depending on the cell load and other factors.

▶ Another reason is the measurement receivers themselves. Most of them can only simultaneously capture a spectrum of max. 20 MHz or 40 MHz. If more spectrum is requested, they have to retune the frontend and repeat the power spectrum measurement while the power spectrum is continuously changing due to traffic, fading etc. Therefore, the power spectrum is never captured simultaneously and no unique maximum of the received power spectrum can be found.

▶ When performing a code-selective measurement, the antenna is typically pivoted to determine the maximum received power within a certain area or room. Code-selective measurement receivers can typically automatically detect the center frequency of the carrier. They are measuring on defined signals and can distinguish between the signal itself and noise. They deliver one single measurement value (e.g. SS-RSRP) either per PCI or SSB, which is more constant and much easier to handle when searching for the maximum. It is also possible to see the carriers, PCIs and SSBs that contribute to the total received power/field strength.

As explained in section 2, 5G NR only provides a minimum of cell-specific signals (SSBs). A significant part of the spectrum is ignored since only UE specific signals can occur in the other parts of the spectrum. In order to project the SSB power on the maximum radiated power, several extrapolation factors are needed, which are described section 3.2.

3.2 Code-selective measurements and extrapolation factors

3.2.1 History of EMF measurements – LTE

In the case of wireless services, frequency-selective measurements often have to be combined with specialized measurement methods for various radio services (in particular for WCDMA and LTE) depending on country-specific regulations. These methods allow an exact extrapolation to the maximum system utilization and the allocation of the emissions to the appropriate base station.

See the R&S®TS-EMF product brochure (PD 0758.2777.12) and www.rohde-schwarz.com/product/ts-emf.

For these code-selective EMF measurements in LTE, the measurement receiver measures on cell-specific synchronization and reference signals, decodes the PCI and optionally the operator and other layer 3 messages. In this case, the received power can be clearly allocated to a certain cell, carrier and band. Synchronization and reference signals are also a very good approximation of the maximum received/radiated power since they are spread over the entire spectrum and are not power boosted (at least in lower transmission modes).

When it comes to higher transmission modes in LTE, beamforming is applied on UE specific signals whose power offset to standard reference signals and location in the time and frequency domain is unknown to a passive, calibrated receiver. In this case, extrapolation factors are applied to project the total radiated power, usually assuming the worst case of power boosting of the UE specific signals.

3.2.2 Extrapolation factors for EMF measurements in 5G NR

With a minimum of broadcasted cell-specific signals and layer 3 messages, similar factors have to be applied for reliable 5G NR EMF measurements. Fundamental extrapolation factors are:

▶ **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 than SSB beams to further increase the SINR. The corresponding data has to be requested from the network operators or infrastructure suppliers.

Fig. 8: UE specific signal component (CSI-RS) is transmitted with higher power compared to SSB beams
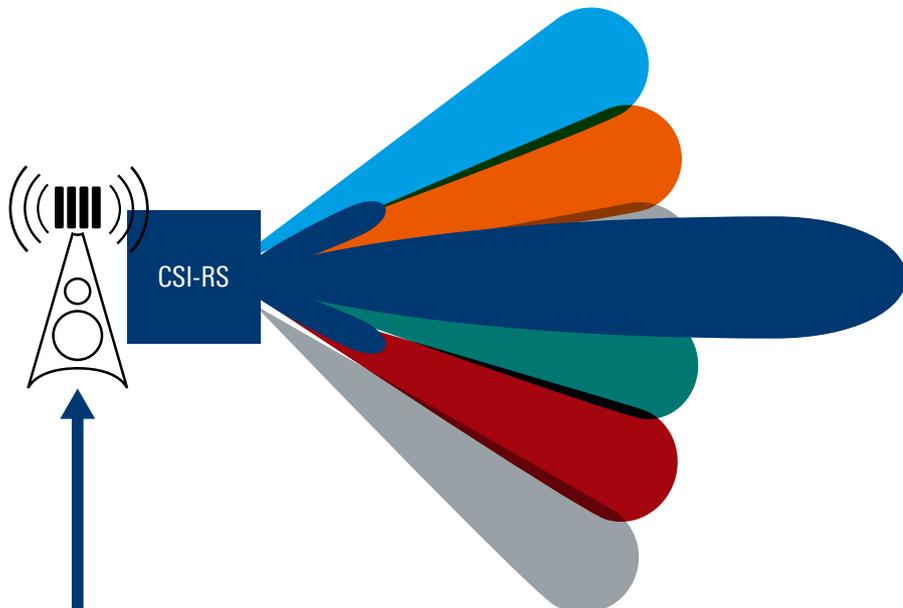
Fig. 9: UE specific signal component (CSI-RS) is transmitted using extremely narrow beams compared to SSB beams
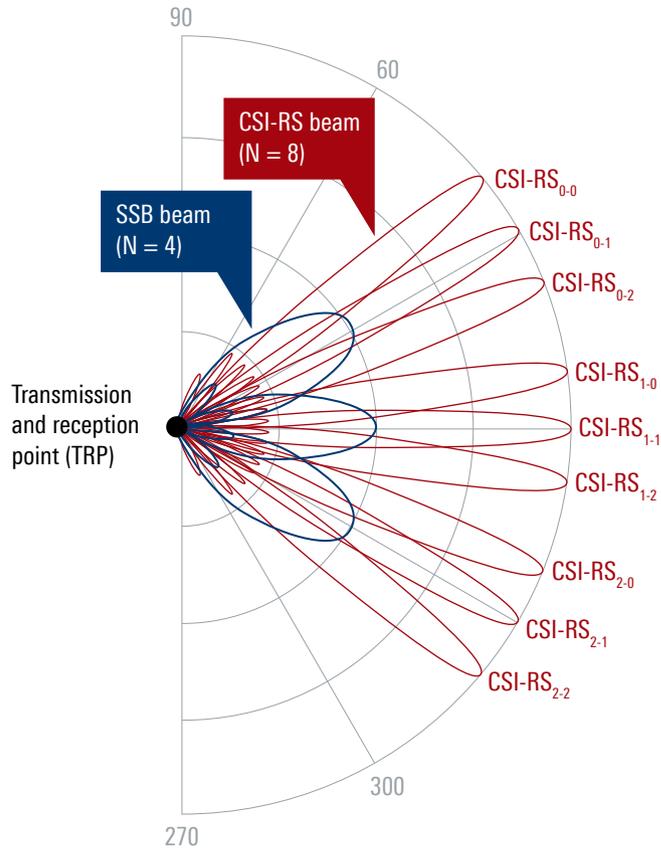
► **Uplink and downlink relation factor**
In the case of TDD, the relation between uplink and downlink significantly affects the power radiated by the gNodeB. In the event that more slots are reserved for the uplink, the radiated power decreases. The relation factor depends on the network configuration that has to be requested from the network operators. An exception are NSA networks, where the 5G NR carrier is used for downlink only.

Fig. 10: Flexible scheduling of user data (uplink and downlink) across the frequency and time domain
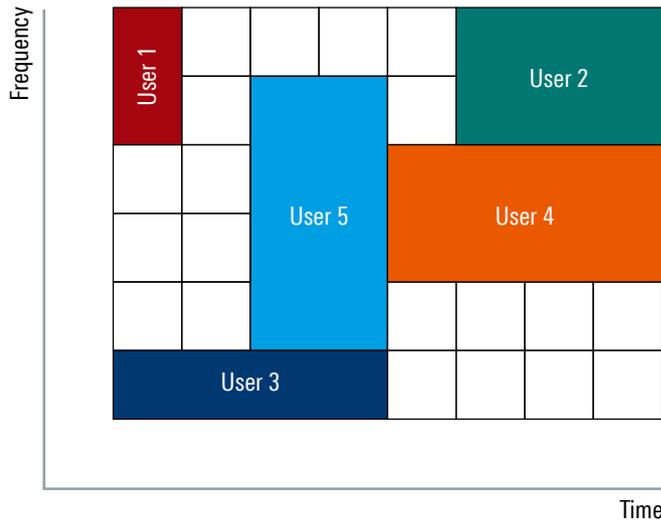
► **Projection of synchronization signal block power on the total 5G NR carrier spectrum**
Synchronization signal blocks only have a bandwidth of 3.6 MHz to 56 MHz depending on the subcarrier spacing. The total bandwidth of 5G NR carrier can be up to 400 MHz. This requires another extrapolation factor, which can be requested from the operators or determined using a mobile phone with an active subscription for the particular 5G NR network.

4 RADIATED POWER/POWER EMISSION MEASUREMENTS

4.1 Current emission measurements

Current emission measurements are typically based on frequency-selective measurements. They are carried out using spectrum analyzers.

The aim is to measure the emission and average it over a period of six minutes (depending on country-specific regulations), taking into account time-dependent factors such as cell load.

4.2 Maximum emission measurements

It is expected that code-selective measurements will be the preferred method for maximum emission measurements in Europe. When measuring and subsequently calculating the maximum radiation, worst-case scenarios have to be considered when defining the extrapolation factors.
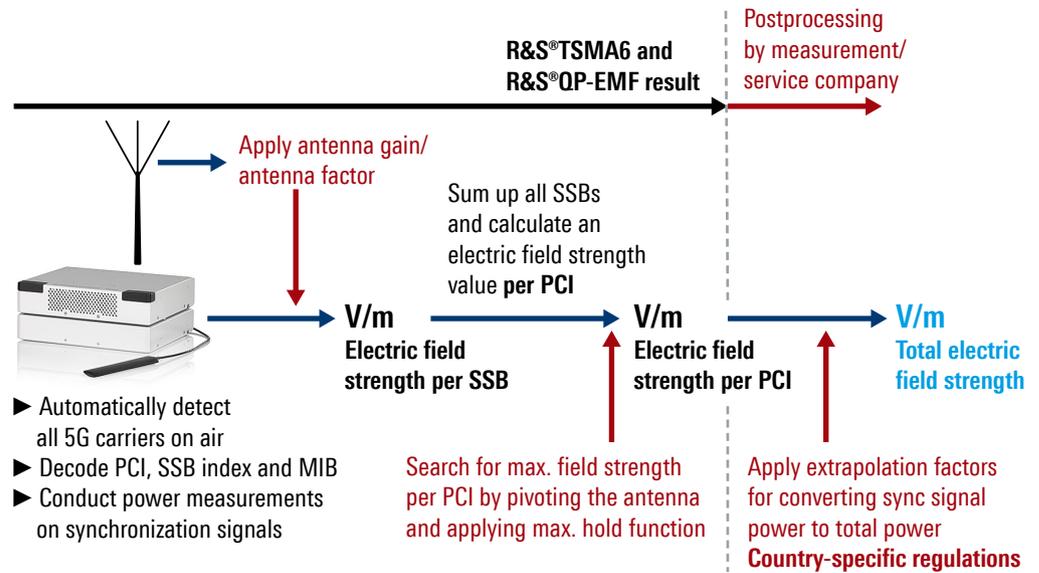
Extrapolation factors such as gain offsets and uplink/downlink relation factors are cell-specific, which requires that the measurement system outputs PCI specific EMF values in mV/m, which are the baseline for applying the extrapolation factors in a postprocessing routine.

The R&S®TSMA6 autonomous network scanner is an example of a measurement system that is capable of performing code-selective maximum emission measurements in 5G NR. It is able to automatically detect 5G NR carriers, decode and measure on SSBs and PCIs. By applying the antenna factor (has to be provided by a .csv file) and summing up all SSBs per PCI, a unique result is available in mV/m per PCI.

In theory, any antenna with sufficient gain in dBi or antenna factor in dB/m data can be used. Both dimensions can be imported into the measurement software described below.

As mentioned above, maximum emission measurements are considering the worst-case scenario, which requires searching for the maximum EMF value in a certain area by pivoting the antenna.

Fig. 11: Typical EMF measurement procedure for code-selective maximum emission measurements in 5G NR

R&S®TSMA6 and R&S®QP-EMF result

Postprocessing by measurement/ service company

Apply antenna gain/ antenna factor

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

V/m
Electric field strength per SSB

V/m
Electric field strength per PCI

V/m
Total electric field strength

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

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

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

The software that supports EMF measurements is QualiPoc Android, and the smartphone or tablet is connected to the R&S®TSMA6 measurement receiver via Bluetooth®. The software captures the code-specific RSRP value from the receiver and performs all mathematical operations to convert dBm into V/m. It directly outputs power or electric field strength values.

Fig. 12: R&S®TSMA6 and Android smartphone connected via Bluetooth®

The software features an EMF specific graphical user interface and EMF measurement specific functions to help the user find the electric field strength maximum by providing a max. hold function (by selecting and marking a cell).

Fig. 13: "Select cell" and "Mark cell" help the user find the maximum field strength (max. hold function)

◢ Forcing ☐
✳ Freeze ☐
▢ Screenshot
🔖 Add text marker
📷 Add photo marker
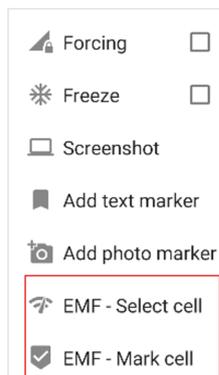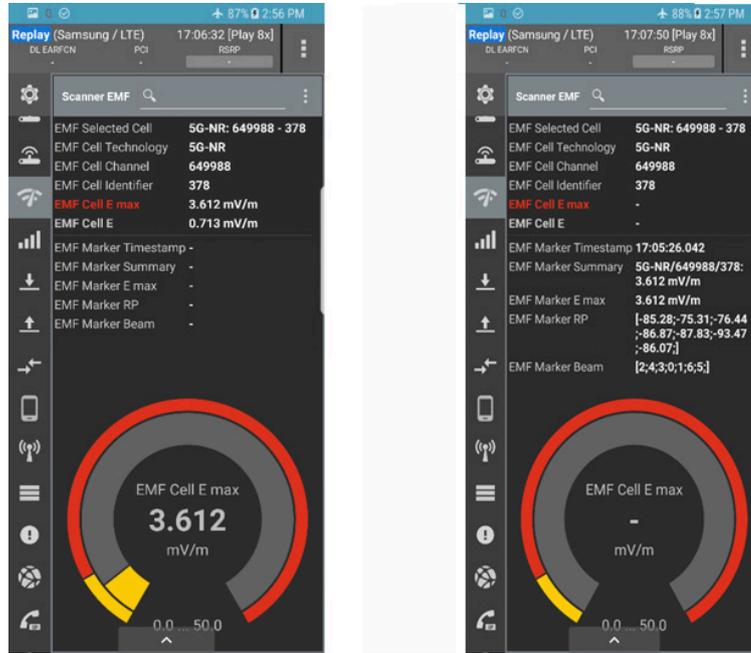📶 EMF - Select cell
☑ EMF - Mark cell

Fig. 14: QualiPoc screenshots when searching for the max. electric field strength in mV/m (left) and marking the cell after the maximum is found (right)

In practice, the user selects a certain cell (PCI-based), pivots the antenna to find the maximum electric field strength (Fig. 14, left) in a certain area, and then marks the cell. Marking the cell (Fig. 14, right) provides a PCI specific measurement summary and adds the EMF specific measurement data to a .csv file that can be exported for further postprocessing (e.g. applying extrapolation factors or adding field strength values from other technologies).

Real-time EMF measurement values are also available as shown in the screenshot below.

Fig. 15: PCI and SSB based real-time EMF measurement values in mV/m

5   ORDERING INFORMATION

Designation	Type	Order No.
Autonomous mobile network scanner	R&S®TSMA6	4900.8005.02
Battery pack, includes two batteries (R&S®MNT-BP89WH)	R&S®TSMA6-BP	4900.9001.02
Carrying bag	R&S®TSMA6-ZCB2	3630.7695.02
AC power supply	R&S®TSMA6-Z1	4901.0550.02
5G NR scanning	R&S®TSMA6-K50	4901.0966.02
Simultaneous measurement in all bands	R&S®TSMA6-KAB	4901.0708.02
QualiPoc scanner license	R&S®QP-SCANNER	1900.5794.04
QualiPoc Android software for RF optimization	R&S®DV-RF	1900.3033.02
QualiPoc option for EMF measurements	R&S®QP-EMF	1900.5959.06
Single-port ultrawideband antenna, 698 MHz to 3800 MHz, with magnetic mount	R&S®TSME-Z15	3652.7281.02
Log-periodic antenna module, 450 MHz to 8 GHz	R&S®HE400LP	4104.8402.02
Basic handheld directional antenna (antenna handle)	R&S®HE400BC	4104.6000.04
N to SMA adapter cable	R&S®TSMA6-ZHE4	4900.9660.02

6   ABBREVIATIONS/ACRONYMS/INITIALISMS

Abbreviation	Description
CSI-RS	channel state information reference signals
DM-RS	demodulation reference signals
EMF	electromagnetic field
MIB	master information block
NR	new radio
OFDM	orthogonal frequency division multiplex
PBCH	physical broadcast channel
PCI	physical cell identity
PDSCH	physical downlink shared channel
PSS	primary synchronization signals
RB	resource block
SSB	synchronization signal block
SSS	secondary synchronization signals
SS-RSRP	secondary synchronization (signal) reference signal received power
TRP	transmission and reception point
UE	user equipment/user entity

Rohde & Schwarz

The Rohde & Schwarz electronics group offers
innovative solutions in the following business fields:
test and measurement, broadcast and media, secure
communications, cybersecurity, monitoring and network
testing. Founded more than 80 years ago, the independent
company which is headquartered in Munich, Germany,
has an extensive sales and service network with locations
in more than 70 countries.

www.rohde-schwarz.com

Rohde & Schwarz customer support

www.rohde-schwarz.com/support

3608442252

3608.4422.52 01.00 PDP 1 en