5G MEASUREMENTS FOR REGULATORY AGENCIES

Application Brochure | Version 01.00

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This application brochure demonstrates how to use the R&S®PR200, R&S®EM200 and R&S®UMS400 monitoring receivers to perform typical 5G measurements required by regulators.

INTRODUCTION

In the ever-evolving field of wireless communications technology, international organizations are periodically setting new standards. The fifth generation of mobile networks, 5G New Radio (NR), promises unprecedented speed, reliability and connectivity. Along with the rollout of 5G networks, the regulatory authorities responsible for ensuring compliance with the new standard must adapt their measurement procedures. International guidelines on how measurement procedures should be defined and performed in 5G networks are often delayed and not yet available. As a provider of state-of-the-art spectrum monitoring equipment, Rohde & Schwarz offers the necessary guidance for 5G measurements in this application brochure.

Compared to its predecessors, the utilization of radio beams at the base transceiver stations (BTS) in 5G networks introduces an entirely new set of considerations encompassing compliance, coverage, interference and the measurement of service quality. Further key enhancements such as dynamic resource block allocation in response to momentary traffic demands, independent placement of synchronization signal blocks (SSB) within a channel, and interference management in time division duplex (TDD) networks constitute the backbone of 5G's advanced capabilities.

However, these new concepts pose multiple challenges for regulatory agencies tasked with ensuring compliance and minimizing undesired emissions – especially in face of staffing and budget limitations. The main challenge for the regulation of 5G systems is that a majority of the measurements are "over the air" (OTA) measurements. Thus, technicians entrusted with such measurement tasks find themselves navigating through a variety of radio landscapes, characterized by location-dependent variations (urban versus suburban) and mission-specific demands. Measurement equipment must seamlessly operate across a wide spectrum of scenarios, ranging from close proximity to transmission masts with very high signal levels to distant interfering signals with very low levels.

This application brochure is intended to serve as a comprehensive guide to performing reliable 5G measurements using modern Rohde & Schwarz monitoring receivers, such as the R&S®PR200 portable monitoring receiver, the R&S®EM200 digital compact receiver and the R&S®UMS400 universal monitoring system. Through real-world examples, various 5G measurements conducted by regulatory authorities are demystified, enabling them to carry out their mandated duties.

Considering current global deployment trends, this application brochure focuses on the 5G FR1 frequency band (sub-7.125 GHz).

MEASUREMENT CHALLENGES IN 5G

When performing OTA measurements of 5G NR signals, an understanding of the RF layer is essential in order to ensure successful measurements and valid results. This chapter contains an overview of the RF characteristics of 5G NR signals that are relevant for measurements.

RF characteristics and frame structure

5G NR uses OFDM modulation with a 15 kHz or 30 kHz subcarrier spacing in FR1. A channel can be up to 100 MHz wide.

Most frequency bands used by 5G technology are defined as time division duplex (TDD) bands. This means that base stations (BS) and user equipment (UE) transmit on the same frequency, but in different timeslots. The ratio between downlink and uplink time is variable and can be configured by the network operator.

One RF frame is 10 ms long and consists of 10 subframes of 1 ms length. A transmission slot is 14 OFDM symbols long (up to 1 ms), part of which are used for downlink signals, and the rest for uplink signals.

The smallest physical resource is known as a resource element (RE). It consists of one OFDM subcarrier for the duration of one OFDM symbol. All information is transmitted in so-called resource blocks (RB). One RB consists of a group of 12 adjacent OFDM subcarriers and has the length of the downlink part of a slot (typically around 600 µs to 800 µs).

Downlink signals

Among their various signals, base stations of all cellular network technologies transmit the following types of information:

Broadcast signals: These signals contain information identifying the network and the base station. Broadcast signals can be received across the whole cell. Mobile devices use them to find out which network is receivable at their particular location during a network scan. 2G transmits the broadcast signal continuously on timeslot 0. 4G transmits it discontinuously at the center of the signal bandwidth.

In 5G NR, broadcast signals are transmitted as short bursts every 10 ms, 20 ms or 40 ms. They occupy only part of the channel bandwidth (3.6 MHz or 7.2 MHz), and they are not necessarily transmitted on the center frequency.

Broadcast signals are very useful for regulators and network operators as they provide a basis for standardized measurements. In GSM, for example, the broadcast signal is always sent at full power, so it is an ideal signal for making power and coverage measurements. In 5G NR systems, however, they may be transmitted with different antenna characteristics than traffic signals and hence cannot easily be used for measurements of the transmitted power.

Synchronization signals: These signals enable connected user equipment (UE) to perform time synchronization to the network. In 5G NR, these signals are transmitted together with the broadcast signals in a so-called synchronization signal block (SSB).

Reference signals: Among other purposes, these signals enable the UE to synchronize exactly to the frequency of the BS. In OFDM networks, the UE also uses these signals to measure and compensate for frequency-selective level differences due to reflections.

In 5G NR, reference signals are transmitted regularly for the duration of one OFDM symbol over the whole channel bandwidth, but not using all OFDM subcarriers. These bursts are known as channel state information reference signals (CSI-RS).

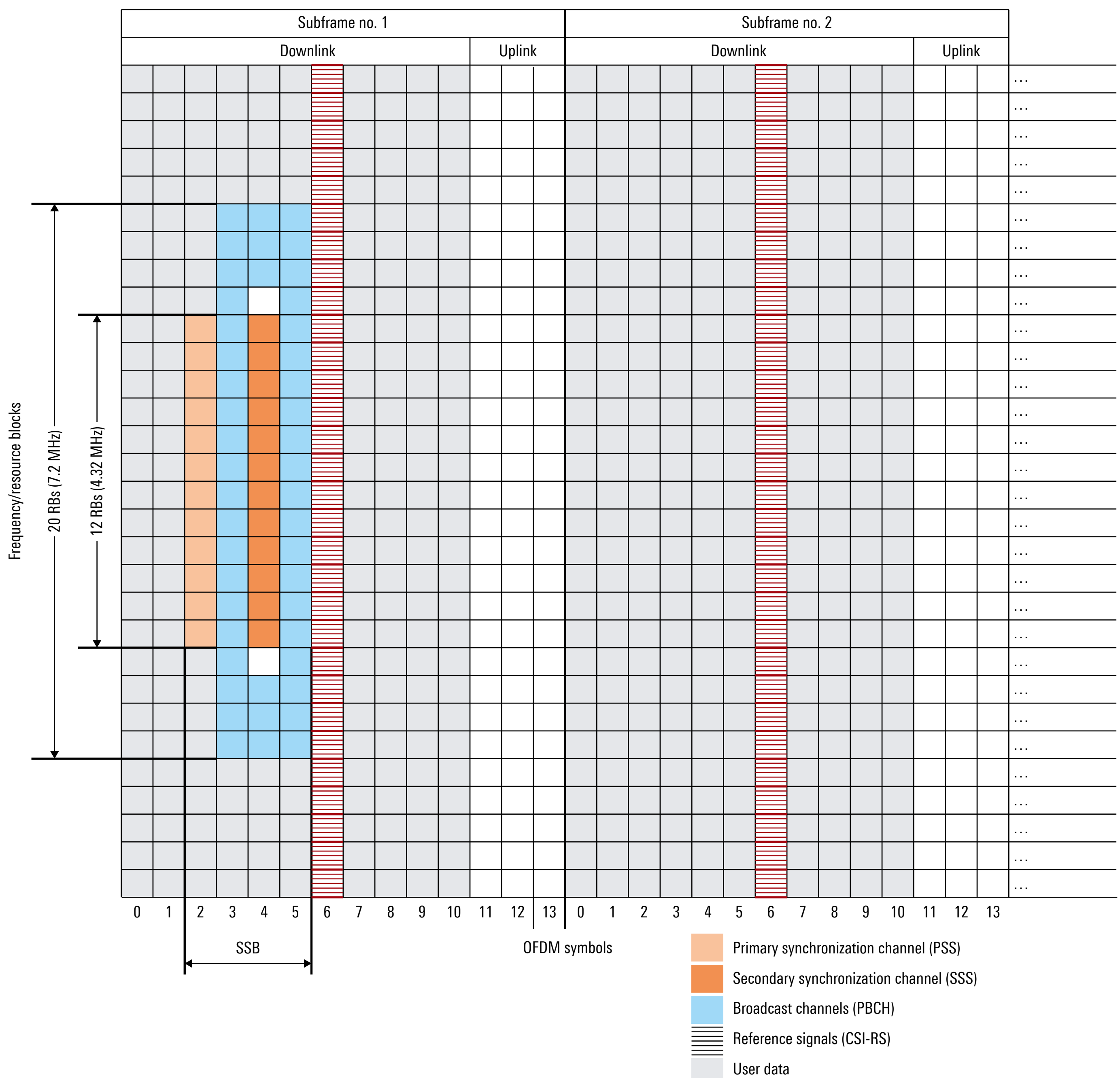
Traffic signals: These signals carry the user traffic. In other cellular technologies, base stations can serve multiple UEs at a time. In the 5G NR system, traffic signals for active users are grouped in resource blocks (RB). The so-called "scheduler" decides how to pack the RBs for multiple active users into a 5G NR frame. It can be configured to prefer time or frequency separation. Thus, one user might get up to the whole channel width, but for a short time, or only a fraction of the channel width, but for a longer time. In the first case, the whole available transmit power can be used to serve one distant user. In the second case, each user gets only part of the transmit power, but multiple users can be served in parallel.

Fig. 1 shows a typical example of a 5G NR subframe structure in FR1. The station is configured for one SSB. As mentioned above, SSBs are only transmitted every 10 ms, 20 ms or 40 ms, which means they do not appear in each subframe or slot.

As far as measurements are concerned, this dynamic spectrum allocation has the following consequences:

- The total received RF power over the whole channel varies constantly. Thus, the maximum possible power cannot be measured in the time domain unless it can be ensured that all RBs are occupied.
- The current bandwidth changes over time, and the maximum bandwidth may only be occupied during transmission of synchronization bursts, unless the base station is fully loaded with traffic and the scheduler assigns all available RBs to users.

Fig. 1: Example structure of the 5G NR subframe



Beamformed signals

The term "cellular network" refers to a network that enables end user mobility by covering a geographical area with overlapping cells. Each cell is the coverage area of a particular BTS antenna. In 2G, 3G and 4G networks, the signal to each mobile device is transmitted across the whole cell. However, especially in 5G networks above 1 GHz, active antenna systems (AAS) are commonly used that consist of dipole arrays and allow the signal to each mobile device to be transmitted only to a small area containing the connected device.

5G antennas still have a coverage area, but the actual signals of AAS stations are designed to use the minimum amount of power and are transmitted as beams. For example, an active 5G antenna mounted on a tower can direct multiple beams towards mobile devices on the ground or in neighboring buildings. To accurately measure the power of these "beamformed" signals, the receiver must be near the center of the beam (inside the main lobe). Hence, you need to know where the beam is before you can measure it.

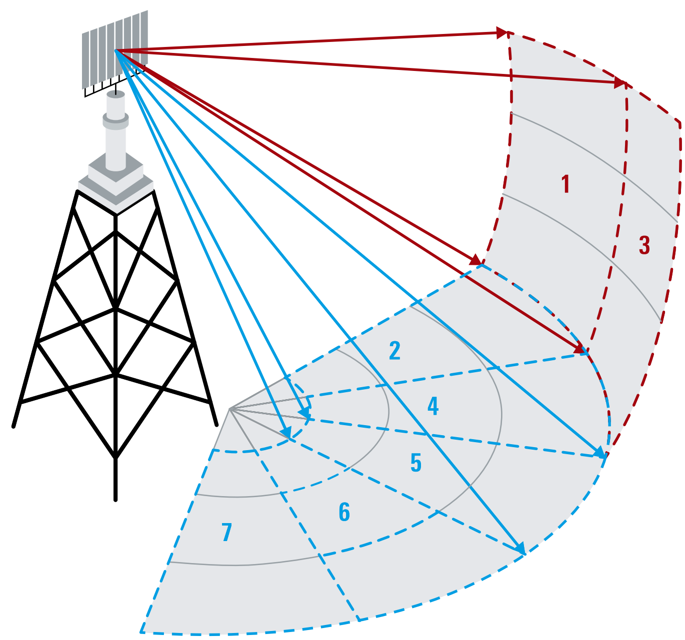
5G AAS stations use different beam types (SSB, CSI-RS and traffic beams) – each with very different spatial behavior.

Broadcast signals

A 5G cell can be configured to transmit only one SSB, which then has a horizontal opening angle of the whole sector (typically 120°). If active antennas are used in the frequency range below 7.125 GHz (FR1), up to eight separate SSB beams can be configured. They are transmitted in sequence, each one in a different direction. The sector is divided into smaller areas – e.g. a grid pattern. Each area has its own SSB beam.

With 2G, 3G and 4G, it is enough to know the center frequency of the signal in order to measure it.

Fig. 2: Example of a 5G cell with seven SSBs



In 5G, all transmissions are discontinuous and may be beamformed. This means you must also know which beam you want to measure, where to find it, and when to measure it.

For example, to measure the power of SSB 3 shown in Fig. 2, the receiver's antenna must be located near the beam axis and the measurements must be made only when this SSB is active.

Such measurements require the receiver to be synchronized with the beam timing.

Note: You can also detect a 5G signal outside the beam footprint, but this cannot be used for a quantitative measurement because the received level is not representative for the beam.

Traffic signals

5G NR stations using AAS can direct a traffic beam to the user within a wide horizontal and vertical angle range. Using the information on the received signal strength that the UE reports to the base station, the traffic beam can continuously follow a moving mobile. If multiple users are active at the same time, the base station can even transmit multiple traffic beams in different directions (see Fig. 3).

As a result of the dynamic allocation of resource blocks and beamforming of traffic signals, their behavior appears to be random – especially in space and time. This makes them difficult to measure.

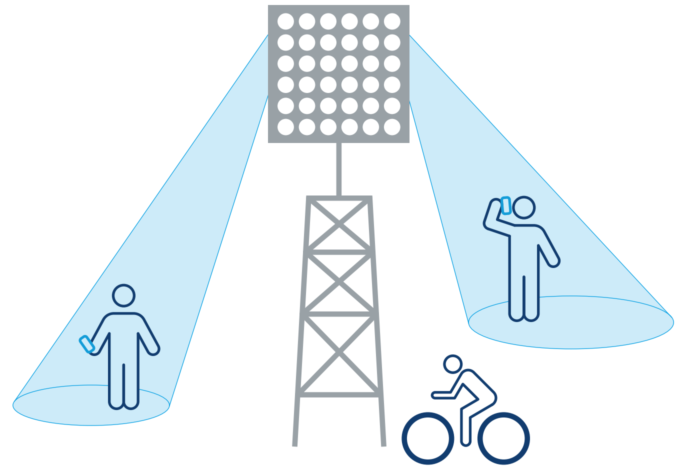
No conducted measurements

BTS equipment used by previous generations is generally physically separate from the antenna and even has a test port. The transmitter is often located at the base of the mast or tower and the test port is easily accessible for conducted measurements. Especially the limits for unwanted emissions were defined at the transmitter output and hence could be easily measured directly. The total radiated power (TRP) can be calculated and used for compliance checks.

5G stations using AAS combine the BTS equipment and antenna array into a single unit, which is usually located at the top of a mast or tower. Typically, there is no test port. Limits for unwanted emissions for AAS systems are defined as the total radiated power, which is equivalent to the power at the transmitter output.

The absence of a test port means that all measurements must be performed over the air (OTA). Various concepts exist for estimating TRP based on effective isotropic radiated power (EIRP) measurements, but it is essential for such measurements to be accurate and reproducible, preferably using uncomplicated methods. For regulators, there is often the need to perform measurements while the base station is in normal operation. This rules out the possibility to configure the station in a defined test mode, which would make OTA measurements much easier.

Fig. 3: 5G NR base station with AAS serving multiple users



New measurement challenges require new tools and methods

As described previously:

- Beamformed signals are defined within three domains (frequency, time and space).
- Conducted measurements are generally not possible – only OTA.
- All beams are discontinuous and 5G has a new concept for broadcast signals.
- A single cell may contain multiple SSB and traffic beams, each with different characteristics.
- It is essential to know what, where and when to measure.

5G requires tools and methods that enable such measurements – especially with simultaneous visualization of the time and frequency domains. This application brochure demonstrates how to use the R&S®PR200, R&S®EM200, and R&S®UMS400 receivers to perform the typical measurements required by regulators.

BENEFITS OF ROHDE & SCHWARZ MONITORING RECEIVERS

Radio signals are typically measured using test receivers, spectrum analyzers or monitoring receivers. The choice of device depends on the signal environment. In anechoic chambers, the controlled environment allows the use of highly sensitive test receivers. Conducted measurements have a known signal path, so spectrum analyzers with no built-in attenuators, filters or amplifiers can be used. For OTA measurements, however, the unknown radio environment means that Rohde & Schwarz monitoring receivers, with their built-in preselection, architecture and advanced measurement functions, have significant advantages over the other devices.

Key advantages are:

- Filters, amplifiers and attenuators are built in, so no extra components are required to ensure that signals are displayed/measured with an optimal dynamic range.
- Two parallel signal paths allow for simultaneous observation of the zero span and real-time spectrum.
- Gated measurement mode allows all measurements (spectrum, level, etc.) to be limited to a specified time gate only.
- On board GNSS enables geopositioning of measurements and exact time synchronization with the 5G signal.
- Applications can be automatically or manually configured for common conditions.

R&S®PR200 portable monitoring receiver

The R&S®PR200 is a handheld monitoring receiver that reliably detects, analyzes and locates signals from 8 kHz to 8 GHz with up to 40 MHz real-time bandwidth. Its frequency range can be extended up to 20 GHz with the R&S®HE400DC handheld directional antenna and up to 33 GHz with the R&S®HE800-DC30 handheld directional antenna, both with an integrated downconverter. Optimized for field operations, the R&S®PR200 provides a perfect balance between RF performance, speed and operability.

R&S®EM200 digital compact receiver

The R&S®EM200 is a cost-efficient monitoring receiver and direction finder in a compact format. It features 40 MHz real-time bandwidth and covers the frequency range from 8 kHz to 8 GHz. This range can be extended up to 20 GHz with the R&S®CS-MC20 microwave converter. The R&S®EM200 supports angle-of-arrival direction finding from 20 MHz to 6 GHz. It comes with an easy-to-operate graphical user interface and its small form factor allows easy integration in just a few steps.

R&S®UMS400 universal monitoring system

The R&S®UMS400 universal monitoring system features a compact outdoor housing for a wide range of spectrum monitoring and radiolocation applications, including event monitoring and temporary missions in remote areas. Similar to the R&S®PR200 and the R&S®EM200, it offers 40 MHz real-time bandwidth over the frequency range from 8 kHz to 8 GHz. This range can be extended up to 20 GHz with the R&S®CS-MC20 microwave converter.

R&S®PR200 portable monitoring receiver

R&S®EM200 digital compact receiver

R&S®UMS400 universal monitoring system

TYPICAL 5G MEASUREMENT TASKS FOR REGULATORS

This section describes typical 5G measurement tasks performed by regulators and provides configuration sequences for setting up the measurements. There is a simple convention to differentiate the types of keys used.

[…] refers to a hard key with a fixed function. For example: [App], [App Config], [Freq], [Spectrum], [Marker].

"…" refers to a soft key below the display, which can offer various functions. For example: [Spectrum] – "Span" – Select 40 MHz from the list.

For keys that have no text label, icons are shown.

Note: The software options required for the measurement tasks in this application brochure are listed in the ordering information at the end of this document.

The keys and functionality mentioned in this application brochure (e.g. [App], [Marker], [Trace], "Detector", Zoom, Measurement time) are described in further detail in the respective operating manuals.

General signal monitoring and checking compliance with license parameters

The following parameters and characteristics must be measured by regulators ranked by their relevance:

- Center frequency
- Bandwidth
- Technology
- SSB frequency
- Number of SSBs
- Sideband emissions of the whole signal
- Sideband emissions of the SSBs
- Verification of coverage at a specific location

Step-by-step procedures to determine the above parameters with the R&S®PR200, R&S®EM200 and R&S®UMS400 are described in the following sections. In all examples, we start from the factory preset state of the instrument.

Center frequency and occupied bandwidth

The center frequency and the occupied bandwidth are key parameters of any signal. In 5G, they are needed to check whether the signal is within its assigned RF channel, which is one of the license-relevant parameters.

Because the scheduler of a 5G NR base station assigns resource blocks according to momentary traffic demands, the resulting signal varies in level and occupied bandwidth. To determine the center frequency, a max hold trace of the signal is recorded sufficiently long to capture moments where all resource elements have been used at least once.

Since 5G NR uses OFDM, the resulting spectrum is rectangular. In these cases, the occupied bandwidth (OBW) is defined as the difference between the lowest and highest subcarrier, which is easy to measure with markers.

Expected bandwidth is below 40 MHz

- [App] – "Receiver"
- [Freq] – "Center Freq" – Set a value roughly to the center frequency of the assigned channel
- [Spectrum] – "Span" – Set a value up to 10% wider than the assigned channel
- [Disp] – "Layout" – Spectrum
- [Disp] – "Ranges" – Auto Range (reduce manually if the trace exceeds the top of the display)
- [Trace] – "Trace Mode" – Mode = "Max Hold"
- [Marker] – "Add" – Spectrum Marker – Set to the left edge of the signal
- [Marker] – "Add" – Delta to M1 – Set to the right edge of the signal

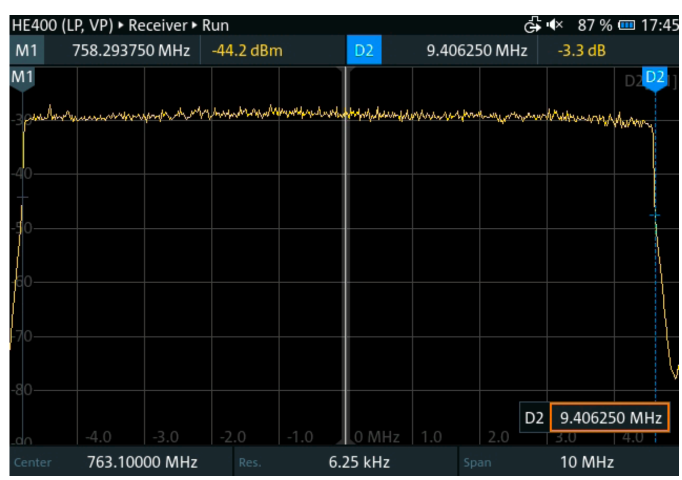


Fig. 4: Bandwidth and center frequency measurement of signals narrower than 40 MHz

The occupied bandwidth is the reading of the delta marker (9.40625 MHz). The center frequency is:
marker M1 + ½ · delta marker D2
(758.29375 MHz + ½ · 9.40625 MHz = 762.996875 MHz).

Note: Although the marker frequencies are shown with a resolution of one screen pixel, the actual accuracy of the bandwidth and frequency measurement is limited by the resolution bandwidth (RBW) of the receiver (6.25 kHz in Fig. 4), which may be wider. It is therefore not reasonable to record the measurement result with the frequency resolution of the marker readouts. It should be rounded at least to the nearest value considering the RBW. In the example in Fig. 4, a sensible value for the bandwidth would be 9.4 MHz and 763.0 MHz for the center frequency.

Expected bandwidth is above 40 MHz

- [App] – "PScan"
- [App Config] – "Scan Range" – Set the start and stop frequency to cover the assigned channel plus about 10%
- [Disp] – "Layout" – RF Spectrum
- [Trace] – "Trace Mode" – Mode = "Max Hold"
- [Marker] – "Add" – Spectrum Marker – Set to the left edge of the signal
- [Marker] – "Add" – Delta to M1 – Set to the right edge of the signal

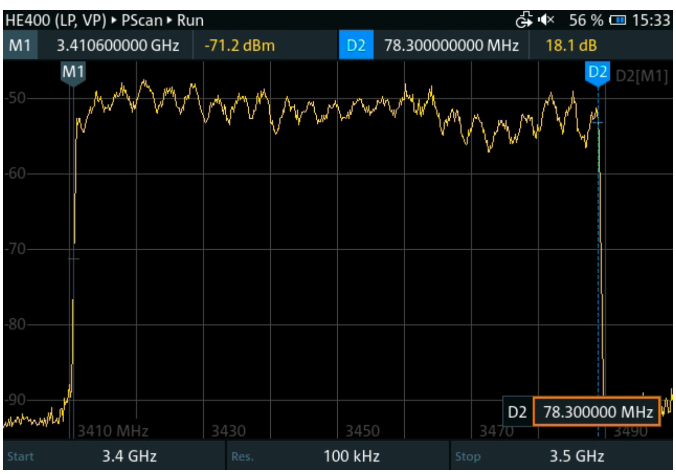


Fig. 5: Bandwidth and center frequency measurement of signals wider than 40 MHz

The occupied bandwidth is the reading of the delta marker D2 (78.3 MHz). The center frequency is:
marker M1 + ½ · delta marker D2
(3.4106 MHz + ½ · 78.3 MHz = 3.44975 MHz).

Note: As before, the measurement should be rounded to the nearest RBW value. In the example in Fig. 5, a sensible value for the center frequency would be 3.45 GHz.

Technology

From the spectrum point of view, 5G NR signals look very similar to LTE signals:

- Both technologies use OFDM modulation, so the max hold spectrum has a rectangular shape.
- Both technologies apply dynamic allocation of spectrum resources, so arbitrary groups of subcarriers are switched on and off depending on the current traffic.
- Both technologies transmit broadcast and synchronization signals in short bursts.

First approach: separation by bandwidth

The occupied bandwidth determined in the section „Center frequency and occupied bandwidth" can give an indication of the used technology:

If the occupied bandwidth (OBW) is higher than 20 MHz, it is a 5G NR signal.

If the OBW is up to 20 MHz, it could be 5G NR or LTE. In this case, further investigation is necessary.

Second approach: identification of broadcast and synchronization bursts

In LTE, the broadcast channel is transmitted regularly in the center of the used frequency channel, and it is 1.08 MHz wide.

In 5G NR, the SSB is also regularly transmitted, but it can be at different frequency positions inside the used frequency channel. For an OBW up to 20 MHz, it is 3.6 MHz wide. For higher OBWs, it is 7.2 MHz wide.

The easiest way to identify the broadcast burst is using the polychrome spectrum (see Fig. 6):

- [App] – "Polychrome Spectrum"
- [Freq] – "Center Freq" – Set to the center frequency of the assigned channel
- [Spectrum] – "Span" – Set to the channel width
- [Disp] – "Ranges" – Auto Range (reduce manually if the trace exceeds the top of the display)

If there is heavy traffic on the channel, it will be difficult to detect a broadcast signal, where positions 1 and 2 could be vaguely suspected to be an SSB signal (see Fig. 6).

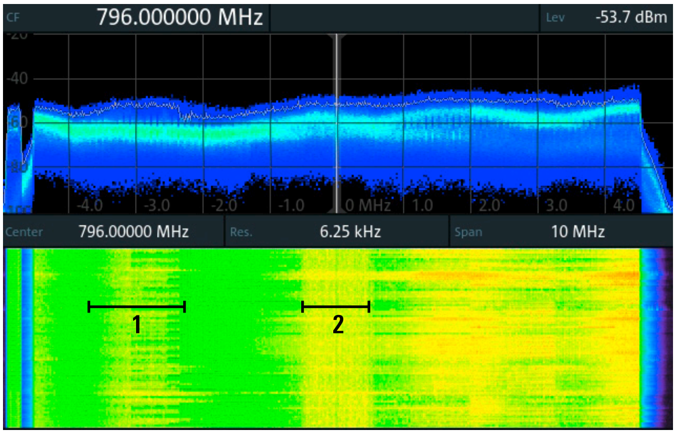


Fig. 6: Polychrome display of a possible 4G or 5G signal to detect broadcast block

A more reliable way to detect broadcast and synchronization information is by recording the spectrum with a high time resolution via the history mode and analyzing it offline:

- ► [App] – "Receiver"
- ► [Freq] – "Center Freq" – Set to the center frequency of the assigned channel
- ► [Spectrum] – "Span" – Set to channel width
- ► [Disp] – "Ranges" – Auto Range (reduce manually if trace exceeds top of display)
- ► [Spectrum] – "Config" – Meas Mode = Periodic, Meas Time = Manual 100 µs

The spectrogram is now scrolling away faster than we can analyze.

Press to activate the history mode and stop live display.

Use the wheel to scroll through the history until a 1.08 MHz wide block can be seen in the center (in case of LTE) or a 3.6 MHz wide block anywhere inside the channel.

Fig. 7: Detection of a broadcast burst in an LTE signal (red circle in spectrogram)

The bandwidth of the signal can be measured by placing markers:

- ► [Marker] – "Add" – Spectrum Marker – Set to the left edge of the suspected burst
- ► [Marker] – "Add" – Delta to M1 – Set to the right edge of the suspected burst

Of course, the burst in Fig. 7 could possibly be a block of traffic that just happens to have a 1.08 MHz bandwidth. More evidence that it is in fact a broadcast burst can be obtained by proving it appears at regular intervals (in case of LTE, every 10 ms). This is done by placing two markers as waterfall lines in the spectrogram (see Fig. 8):

- ► [Marker] – "Add" – Waterfall line – Set to one occurrence of the burst
- ► [Marker] – "Add" – Waterfall line – Set to the next occurrence of the burst

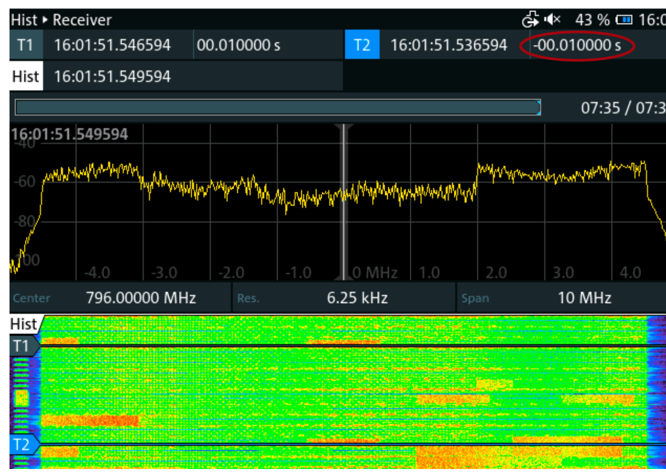


Fig. 8: Measuring the periodicity of suspected broadcast bursts (red circle)

Bursts that are different in bandwidth (not 1.08 MHz or 3.6 MHz), or do not appear every 10 ms, 20 ms or 40 ms, are not broadcast or synchronization bursts.

SSB frequency

As mentioned in the section Broadcast signals, the SSB in a 5G NR system can be located at different frequency positions inside the used channel. As some of the further measurements must be performed on the SSB, its frequency must be determined.

- [App] – "Receiver"

Channel width is less than 40 MHz

- [Freq] – "Center Freq" – Set to the center frequency of the assigned channel

Channel width is above 40 MHz

- [Freq] – "Center Freq" – Set to the start of the assigned channel
- [Disp] – "Ranges" – Auto Range (reduce manually if the trace exceeds the top of the display)
- [Spectrum] – "Config" – Meas Mode = Periodic, Meas Time = Manual, time = 200 µs

Press ⏯ to activate the history mode.

Look for a frequency block that is 3.6 MHz or 7.2 MHz wide and appears every 10 ms, 20 ms or 40 ms. Use the wheel to scroll through the history and use frequency markers to verify the bandwidth of the suspected blocks:

- [Marker] – "Add" – Spectrum Marker – Set to the left edge of the suspected burst
- [Marker] – "Add" – Delta to M1 – Set to the right edge of the suspected burst

Fig. 9: Suspected 5G NR SSB, but with wrong bandwidth (red circle)

The suspected block in Fig. 9 is in fact not an SSB, because it is only 5.8 MHz wide.

If the channel width is greater than 40 MHz, shift the measurement to the next 40 MHz:

- [Freq] – "Center Freq" – Increase by 40 MHz

Now bursts with 7.2 MHz bandwidth become visible. Check the periodicity with the waterfall lines in the spectrogram:

- [Marker] – "Add" – Waterfall line – Set to one occurrence of the burst
- [Marker] – "Add" – Waterfall line – Set to the next occurrence of the burst

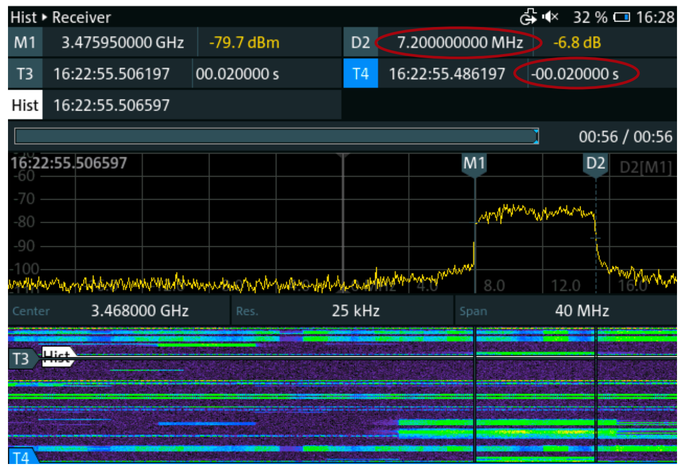


Fig. 10: SSB bursts of a 5G NR signal with 7.2 MHz bandwidth and 20 ms period (red circles)

The SSB frequency is M1 + ½ · D2. In our example (see Fig. 10), this is 3.47595 GHz + ½ · 7.2 MHz = 3.47955 GHz.

Number of SSBs

As mentioned in the section Broadcast signals, a 5G NR station can be configured to use one to eight SSBs. If multiple SSBs are configured, they are transmitted in sequence and measurements must be performed on the SSB with the highest level because that is the beam pointing in the direction closest to the measurement location.

- [App] – "Gated Spectrum"
- [Freq] – "Center Freq" – Set to the SSB frequency
- [Spectrum] – "Span" – Set to 10 MHz
- [Dem/Bw] – "Bw" – Set to 8 MHz (to cover the whole SSB bandwidth of 7.2 MHz)
- [Disp] – "Ranges" – Spectrum Auto Range
- [Disp] – "Ranges" – Magnitude Auto Range
- [App Config] – "Gate Period" – 20 ms (or 40 ms)

Count the bursts in the sequence. Note that the bursts have equal length. In the example in Fig. 11, there are six SSBs.

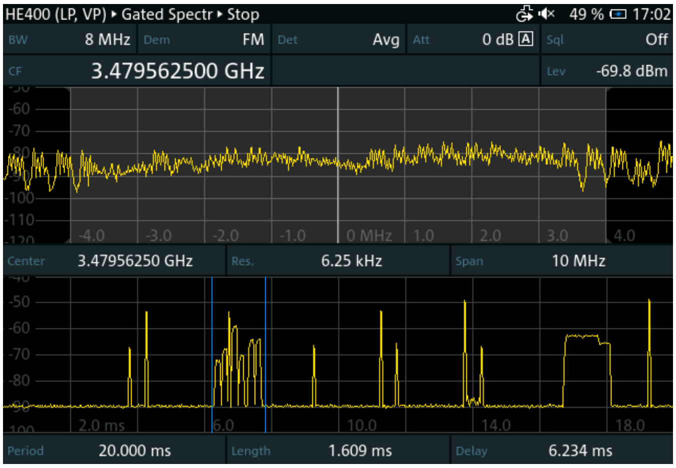


Fig. 11: Determination of SSB number at a 5G NR station transmitting six bursts

Confusion may arise from the fact that the spectrum shown during the gate limits is not the expected 7.2 MHz wide signal (see Fig. 11). This may be due to other signals being transmitted during the SSB sequence, or from adjacent 5G base stations. In Fig. 11, there is a short pulse between SSB 2 and SSB 3. To check the properties of this burst, the analysis can be reduced in time:

- [Disp] – "Zoom" – Expand the region of the SSBs with 
- [App Config] – "Gate Length" and "Gate Delay" – Set to cover the burst of interest.

Note: If you reduce the gate length too much, the error message "Gate length is too low for spectrum" appears. This is due to the FFT calculation that limits the time resolution at a defined frequency resolution. To reduce the possible gate length further, you may increase the resolution bandwidth as follows:

- [Spectrum] – "Resolution" – Auto = off, increase to the next higher value

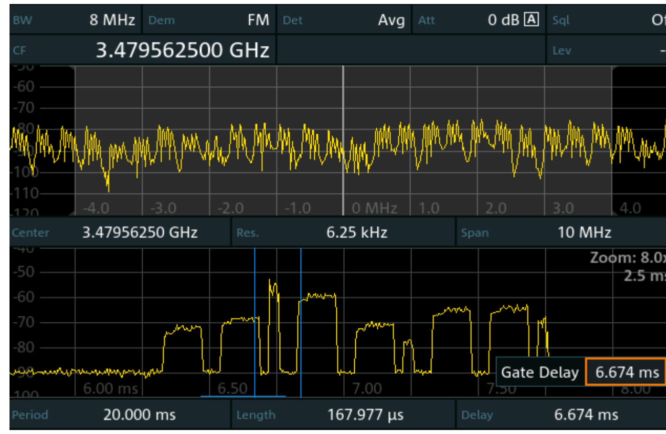


Fig. 12: Example of a non-SSB burst inside the timeslot where SSBs are transmitted

The burst selected by the gate markers in Fig. 12 is more than 10 MHz wide, so it cannot be an SSB.

Unwanted SSB emissions

Unwanted sideband emissions of the SSB are usually not relevant for regulators since they remain inside the assigned channel and therefore can only interfere with the base station's own downlink signal. However, significantly high unwanted SSB emissions or asymmetric sideband emissions may indicate faults in the base station's RF units. As a possible consequence, user equipment (UE) may not be able to decode the 5G signal even though the received level is sufficiently high.

- [App] – "Gated Spectrum"
- [Freq] – "Center Freq" – Set to the SSB frequency
- [Spectrum] – "Span" – Set to 20 MHz (to cover the SSB and the out-of-band frequency range)
- [Dem/Bw] – "Bw" – Set to 8 MHz
- [Disp] – "Ranges" – Spectrum Auto Range
- [Disp] – "Ranges" – Magnitude Auto Range
- [App Config] – "Gate Period" – 20 ms (or 40 ms)
- [App Config] – "Gate Length" and "Gate Delay" – Set to cover the SSB of interest
- [Spectrum] – "FFT Det" – Spectrum 1 = RMS, Spectrum 2 = RMS

Disconnect the antenna. This allows recording a trace showing the receiver noise.

- [Trace] – "Select" – Select T2
- [Trace] – "Trace Mode" – T2 – Freeze = on

Reconnect the antenna.

- [App Config] – "Run Single" until an SSB burst is shown in the spectrum window.

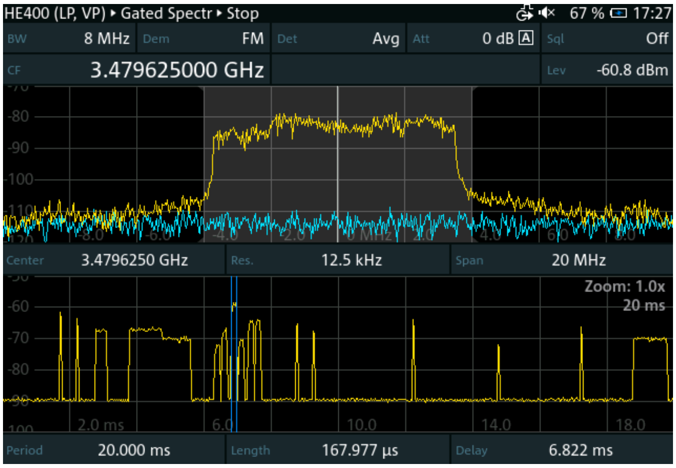


Fig. 13: Example of unwanted sideband emissions from SSB 3

In Fig. 13, unwanted SSB emissions can be seen up to 8 MHz from the center frequency in the upper sideband, and up to about 6 MHz in the lower sideband. Further away, the receiver noise masks any emissions coming from the base station. The level of the sideband emissions shown in the example can be regarded as normal.

Unwanted emissions from traffic signals

More interesting for regulators are unwanted sideband emissions from traffic signals. This is because such emissions can reach into adjacent frequency bands and cause interference to neighboring radio services. Two issues, however, prevent regulators from measuring these unwanted emissions over the air during normal operation of the base station:

- The limits for unwanted emissions from 5G stations using active antenna systems (AAS) are defined as the total radiated power (TRP), which is the emitted RF power integrated over the whole sphere around the antenna. This definition was chosen in order to compare these systems in an equal manner to systems using passive antennas, where unwanted emission limits are measured at the transmitter output. Since 5G AASs do not have a test point between the transmitter output and the antenna, the TRP would have to be measured by moving the measurement antenna around the base station antenna and integrating the results. It is obvious that this is not possible in practice. An estimate of the TRP could possibly be obtained using measurements performed by drones, however the back of the transmit antenna cannot be accessed.
- The highest unwanted emissions only appear when the station is fully loaded with traffic and all resource blocks are transmitted with full power. During normal operation, this occurs extremely rarely and measurement devices with more than 100 MHz real-time bandwidth are required. It would also be necessary to set the base station to an appropriate test mode.

Methods to measure unwanted emissions from 5G AAS stations are still under development by the ITU and CEPT.

As with the SSBs, an estimate of the sideband emissions, specifically in case of spectral anomalies, may still be possible with the R&S®PR200, R&S®EM200 and R&S®UMS400 using the following procedure. The measurement must be performed close to the base station.

- [App] – "PScan"
- [App Config] – "Scan Range" – Set the center frequency to the center of the assigned channel, set the span to cover the whole assigned channel plus about 10% to each side.
- [Disp] – "Layout" – RF Spectrum
- [Gain] – "Att" – Auto = off (adjust the manual attenuation so that the overload indication just disappears)
- [Disp] – "Ranges" – Auto Range (reduce manually if necessary)
- [Trace] – "Trace Mode" – T1 Mode = "Max Hold"

Use a UE (e.g. a standard smartphone) that supports the 5G technology of the provider operating the station under investigation. Position the UE about 20 m to 50 m behind the measurement antenna and start downloading a large file (alternatively: start a speed test from the operator of the base station that is available on the internet).

Wait long enough for the spectrum to completely build up into a rectangular shape.

After the download:

- [Trace] – "Trace Mode" – Freeze = on
- [Trace] – "Show Trace" – Spectrum 2 = on
- [Trace] – "Select" – T2
- [Trace] – "FFT Det" – T2 = "Positive Peak"

Disconnect the antenna to record the receiver noise level on trace 2.

- [Trace] – "Trace Mode" – T2 Mode = "Max Hold"

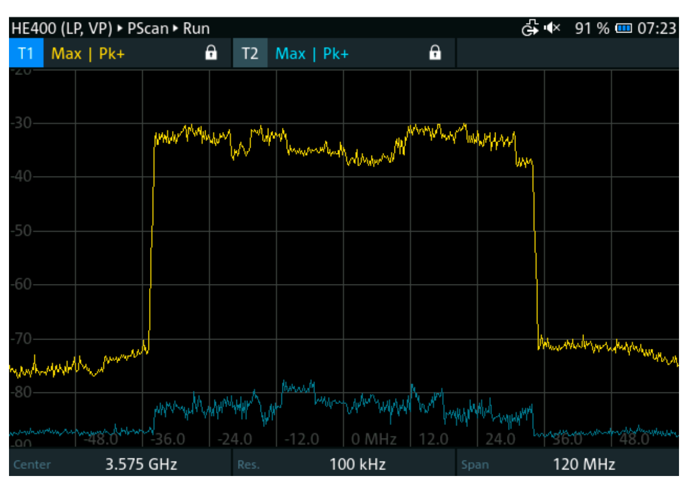


Fig. 14: Estimation of unwanted sideband emissions during traffic

There is a chance that even with a disconnected antenna, a remaining 5G signal is visible on trace 2, like in the example in Fig. 14. This is because the signal is also received via the open antenna input of the receiver. However, this is not critical as this trace is merely recorded to see the limitations of the measurement due to the receiver noise, which is only evaluated outside the 5G channel.

In many cases, sideband emissions will not be visible as they are below the receiver noise. Shoulder attenuations of 30 dB or less may indicate that at least one of the power amplifiers in the AAS is faulty.

Verification of local coverage

The coverage area of a 5G network is usually measured during drive tests with decoding equipment. However, many interference reports, in which customers claim that they cannot use the network, although they should be well inside the predicted coverage area, are in fact due to local weakness of the field strength. This may be caused by shading effects from buildings between the nearest base station and the customer, or even by the nearest base station not being operable.

As a first step when investigating these cases, the regulator may determine whether the 5G field strength at the specific location exceeds the minimum requirements defined by the 3GPP standard. This can be done by measuring the SSB level and extrapolating it to the full channel width to simulate a situation with full traffic load.

- [App] – "Gated Spectrum"
- [Freq] – "Center Freq" – Set the SSB center frequency
- [Spectrum] – "Span" – 10 MHz
- [Dem/BW] – "BW" – 8 MHz
- [Disp] – "Ranges" – Auto Range (reduce manually if necessary)
- [App Config] – "Gate Period" – 20 ms (40 ms)
- [Disp] – "Zoom" – Expand the region of the SSBs with 
- [App Config] – "Gate Length" and "Gate Delay" – Set to cover the strongest SSB
- [App Config] – "Config" – Persistent Gated Mode = on

The persistent gated mode allows time gated measurements that are performed only during the selected gate in the time domain. With the persistent gated mode enabled, the following measurements are conducted:

- [App] – "Channel Power"
- [Spectrum] – "FFT Det" – Spectrum 1 = RMS
- [App Config] – "Config" – PScan Mode = off

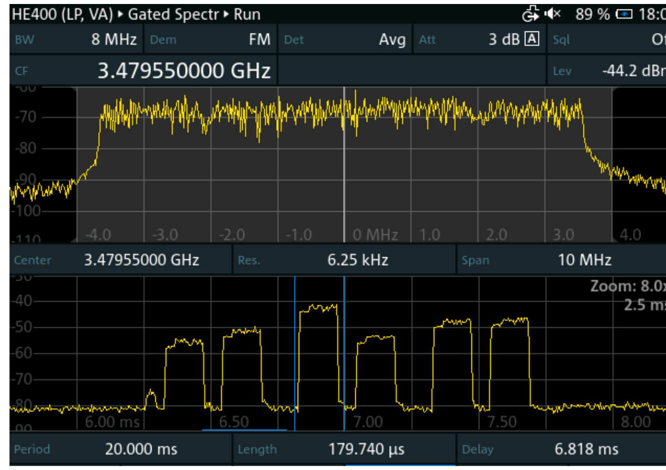


Fig. 15: Gated spectrum settings for measurement of strongest SSB

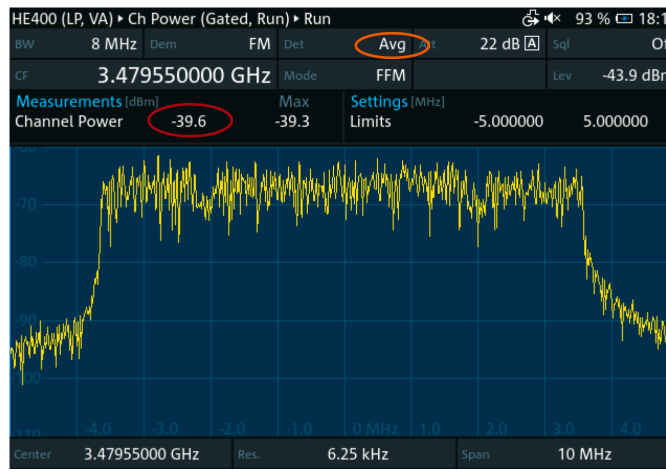


Fig. 16: Measurement of the SSB channel power (red circle) in persistent gated mode

The result is displayed numerically as the "Channel Power" in dBm (see Fig. 16). Be sure that no other (traffic) signals are present next to the SSB during the measurement. If necessary, activate the history mode via the  button to freeze the measurement at a suitable time when only the SSB is visible.

Note: Do not be confused by the "Avg" detector that is showing at the top of the display (orange circle). This detector only applies to the level that is displayed as "Lev" in the line below. The channel power measurement uses the selected RMS detector.

The measurement result is only the channel power of the SSB. The following formula can be applied to extrapolate this result to a situation with full traffic load:

$$P_{tot} = P_{SSB} + 10 \cdot \log\left(\frac{BW_{CH}}{8\ MHz}\right)$$

where

P_{tot} Extrapolated total received power of the 5G signal with maximum traffic load in dBm

P_{SSB} Measured received power of the strongest SSB signal in dBm

BW_{CH} Assigned channel bandwidth in MHz

The following formula can be applied to convert the total received power into field strength:

$$E = P_{tot} + k + 107\ dB$$

where

P_{tot} Extrapolated total received power of the 5G signal with maximum traffic load in dBm

k Antenna factor of the measurement antenna in dB/m

The result can then be compared to the minimum required field strength agreed with the provider or defined in the relevant 3GPP standard.

Note: The power level of the selected SSB could also be measured using a marker function. Instead of switching to the channel power app, use:

- [Marker] – "Add" – Zero Span Marker

Use the wheel or arrow keys to set the marker at the beginning of the selected SSB.

- [Marker] – "Config" – Marker Level = on

This places a second marker (Z2) in the time domain window. Use the wheel or the arrow keys to place the marker at the end of the selected SSB. The measurement detector is set to RMS via:

- [Trace] – "Detector" – Trace Det = RMS

After switching back to "Marker", the result is shown at the bottom as "Marker level Z1, Z2".

This alternate measurement method has the disadvantage that the result may be influenced by traffic signals outside the demodulation bandwidth because the 8 MHz demodulation bandwidth filter used to calculate the time domain trace is not rectangular.

Interference hunting

In addition to determine the general signal parameters of 5G NR signals to verify license compliance, one of the most challenging measurement tasks is interference hunting at 5G NR base stations. The following sections provide step-by-step instructions on the required settings for the R&S®PR200, R&S®EM200 and R&S®UMS400 when hunting typical interference signals.

5G base stations allow internal measurements of the remaining RF level on unused resource blocks. This feature can be used by the operator to detect and classify interference.

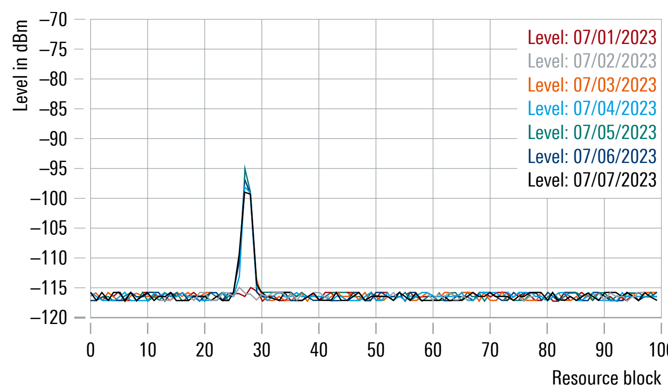


Fig. 17: Example of RAN interference report

Fig. 17 shows an example of a narrowband interferer between resource blocks 25 and 28. It appeared on July 3 (the reports from before are without interference). The average level of the interference at the base station's receiver input is around –96 dBm. This kind of report from the operator provides valuable information for the regulator because it helps choosing the appropriate methodology and instrument settings for the following interference hunting scenarios.

Note: The descriptions given represent typical examples. Actual situations may differ and/or include other interfering signals that may require slightly different settings.

Continuous narrowband interferers

These interferers may come from electronic devices such as power supplies, LANs, LEDs or Sat-TV installations. Their level usually degrades with higher frequencies, making them most common in bands below 1 GHz. But sometimes they also appear in higher bands. Harmonics from narrowband radio services may also appear as interferers in the higher frequency bands used by 5G systems.

- [App] – "Polychrome Spectrum"
- [Freq] – "Center Freq" – Set to the frequency of the disrupted resource blocks reported by the operator
- [Disp] – "Ranges" – Auto Range (adjust manually if necessary)

If the overall received level is not too high (the receiver shows 0 dB attenuation), the sensitivity can be enhanced via:

- [Gain] – "Amp" – Low Noise

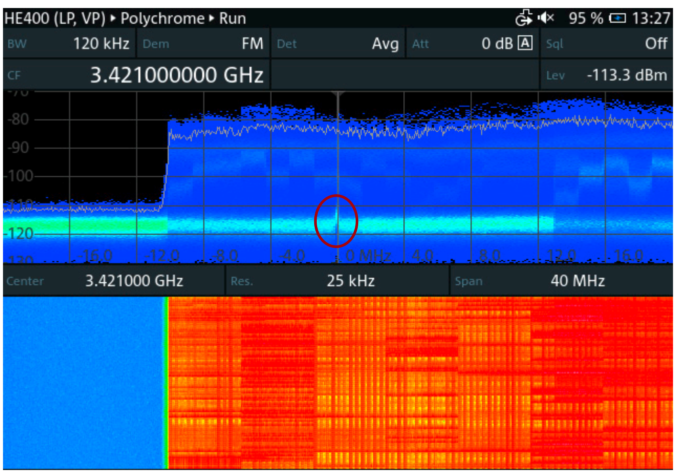


Fig. 18: Polychrome spectrum of a 5G NR signal disrupted by a narrowband signal (red circle)

With the polychrome spectrum shown in Fig. 18, narrowband interferers can often be seen although their level may be much lower than the level of the 5G signal. However, level measurements of the interferer and the use of the level tone function as a bearing aid are not possible due to the superimposed 5G signal. To enable these possibilities, use the following settings:

- [App] – "Gated Spectrum"
- [Dem/BW] – "BW" – 10 MHz
- [Disp] – "Ranges" – Spectrum Auto Range
- [Disp] – "Ranges" – Magnitude Auto Range

First, we need to locate the uplink slots:

- [Trace] – "Select" – Select the time domain trace T4 on the lower half of the screen
- [Trace] – "Trace Mode" – "Max Hold"

Now there should be times with (nearly) no signals. Once these regions become visible, freeze the trace via:

- [Trace] – "Trace Mode" – Freeze = on
- [App Config] – "Gate Length" and "Gate Delay" – Set to cover one of the uplink gaps

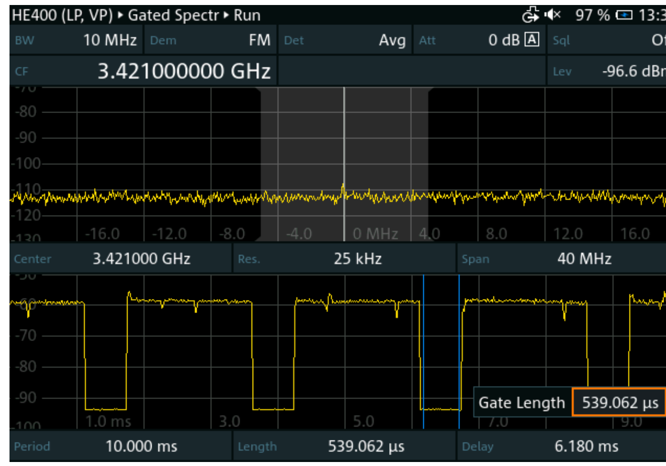


Fig. 19: Selection of 5G uplink slots in gated spectrum measurement

Now we can concentrate on the interfering signal by limiting our measurements to the selected uplink time only (see Fig. 19):

- [App Config] – "Config" – Persistent gated mode = on
- [App] – "Receiver"
- [Gain] – "Att" – Auto = off, set to 0 dB
- [Gain] – "Amp" – Low Noise

With this sensitive setting, the receiver may only be overloaded by the 5G downlink signal, but as we measure only during uplink slots, the overload indication can be ignored.

Now, we can use the demodulation bandwidth to focus on the interferer. It is often helpful to reduce the span and zoom into the signal as follows:

- [Spectrum] – "Span" – Reduce until the message "Gate length is too low for spectrum" appears, then increase by one step
- [Spectrum] – "Resolution" – Auto = off, reduce to lowest possible value
- [Dem/BW] – "BW" – Reduce so that the interfering signal is just covered

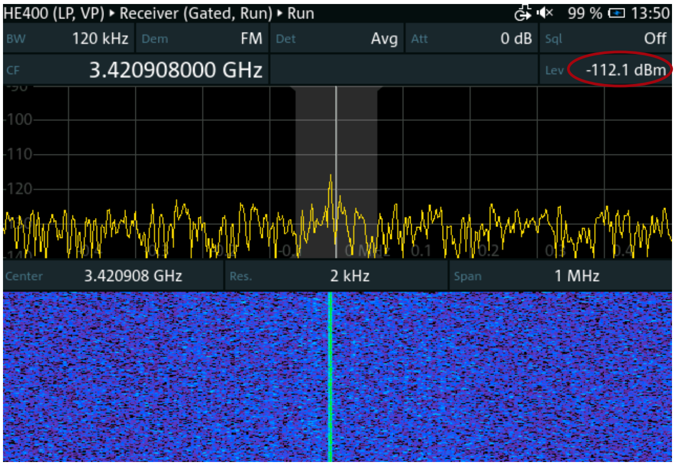


Fig. 20: Isolated measurement of a narrowband interferer inside a 5G channel

This setting allows correct measurement of the interferer level (red circle in Fig. 20) and using bearing aids such as the level tone function:

▶ [Dem/BW] – "Tone" – on

If the disrupted RF channel is heavily used, the uplink slot may often be occupied by signals from the user equipment, possibly masking an interfering signal. If that traffic cannot be switched off during interference hunting, the gate length can be reduced to the time gap (guard interval) between the uplink and downlink.

To enable very short gate lengths, you must first increase the resolution bandwidth with:

▶ [Spectrum] – "Resolution" – Auto = off, increase to next higher value

This is due to the dependency of the time and frequency resolution in the FFT theory. Fig. 21 shows an example with a gate length of only 40 µs.

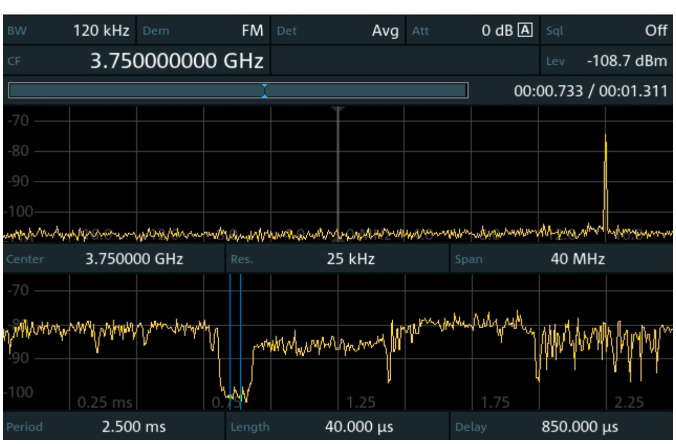


Fig. 21: Unmodulated interfering carrier signal in the guard interval between uplink and downlink

Noise-like interferers

Many electrical and electronic devices produce noise-like interference. Its bandwidth usually extends beyond the frequency limits of a 5G channel and all measurements take place in adjacent frequency ranges. One typical noise-like interferer is (unwanted) radiation of signals from cable TV distribution networks. This occurs especially in the 700 MHz range.

First, we determine whether the interferer is best visible at the lower or upper boundary of the 5G channel (see Fig. 22).

▶ [App] – "PScan"

▶ [App Config] – "Scan Range" – Center Freq = center of the 5G channel, Span = twice the channel bandwidth

▶ [Disp] – "Ranges" – Auto Range

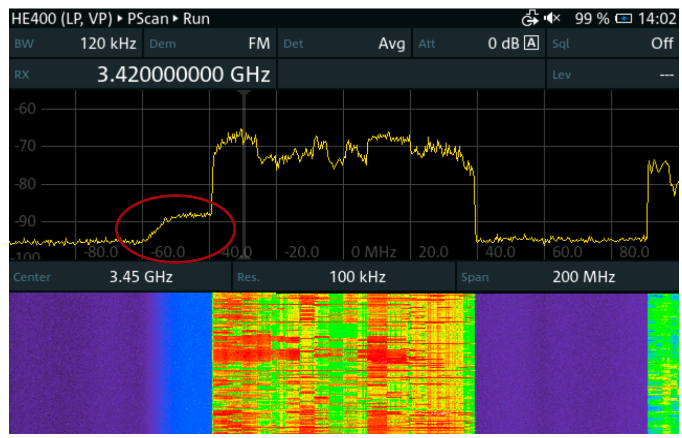


Fig. 22: Detection of noise-like interferer outside the 5G channel (red circle)

Locating the interference is preferably handled in the receiver mode while concentrating on the frequency range where the interferer was best visible.

▶ [App] – "Receiver"

▶ [Freq] – "Center freq" – Set to the frequency, where the interferer was best visible in the previous measurement

▶ [Spectrum] – "Span" – Reduce until the 5G signal is no longer covered (only the interferer is visible)

▶ [Gain] – "Att" – Auto = off, set to 0 dB

▶ [Gain] – "Amp" – Low Noise

Depending on the measurement location, the receiver may indicate overloading with these settings. Also, the noise-like interfering signal may be misinterpreted as unwanted sideband emissions of the 5G signal. Both issues can be solved by limiting our measurement to the uplink time.

- ► [App] – "Gated Spectrum"
- ► [Dem/BW] – "BW" – 10 MHz
- ► [Disp] – "Ranges" – Spectrum Auto Range
- ► [Disp] – "Ranges" – Magnitude Auto Range
- ► [Trace] – "Select" – Select the time domain trace T4 on the lower half of the screen
- ► [Trace] – "Trace Mode" – Max Hold

Now, there should be times with (nearly) no signals. Once these regions become visible, freeze the trace via:

- ► [Trace] – "Trace Mode" – Freeze = on
- ► [App Config] – "Gate Length" and "Gate Delay" – Set to cover one of the uplink gaps
- ► [App Config] – "Config" – Persistent gated mode = on

As shown in Fig. 23, we can return to receiver mode and continue locating the interfering signal. If it represented unwanted sideband emissions from the 5G base station, no remaining signal would be visible with these settings.

Again, we can use the level tone as a bearing aid:

- ► [Dem/BW] – "Tone" – on

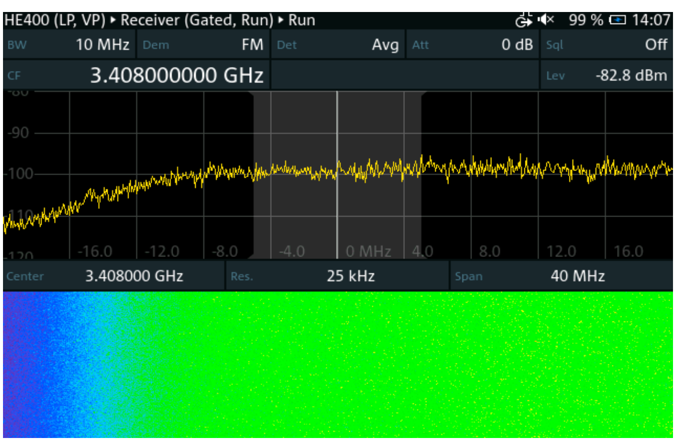


Fig. 23: Isolated measurement of a noise-like interfering signal

Note: Unlike with narrowband interferers, reducing the span or measurement bandwidth does not improve the visibility (signal-to-noise ratio) of a noise-like signal. This is because changes in resolution bandwidth equally affect both the interferer and the receiver noise.

Pulsed interferers

This type of interference may also come from electronic devices, or involve unwanted harmonic emissions from pulsed radio services on lower frequencies. Often, faulty communications equipment leads to transmissions on frequencies other than the assigned bands, thereby causing interference in 5G bands.

The spectrum of a pulsed interferer may extend beyond the 5G channel limits. In this case, it is best visible in the polychrome display (use the setup described in section Continuous narrowband interferers).

Level measurements and the possibility to use bearing aids, and cases where the spectrum of the interferer is completely within the 5G channel, require the measurement to be limited to the uplink slot only:

- ► [App] – "Gated Spectrum"
- ► [Freq] – "Center Freq" – Set to the center of the 5G channel
- ► [Dem/BW] – "BW" – 10 MHz
- ► [Disp] – "Ranges" – Spectrum Auto Range
- ► [Disp] – "Ranges" – Magnitude Auto Range

First, we need to locate the uplink slots:

- ► [Trace] – "Select" – Select the time domain trace T4 on the lower half of the screen
- ► [Trace] – "Trace Mode" – Max Hold

Without interference, there should be times with (nearly) no signals. Once these regions become visible, freeze the trace with

- ► [Trace] – "Trace Mode" – Freeze = on
- ► [App Config] – "Gate Length" and "Gate Delay" – Set to cover one of the uplink gaps

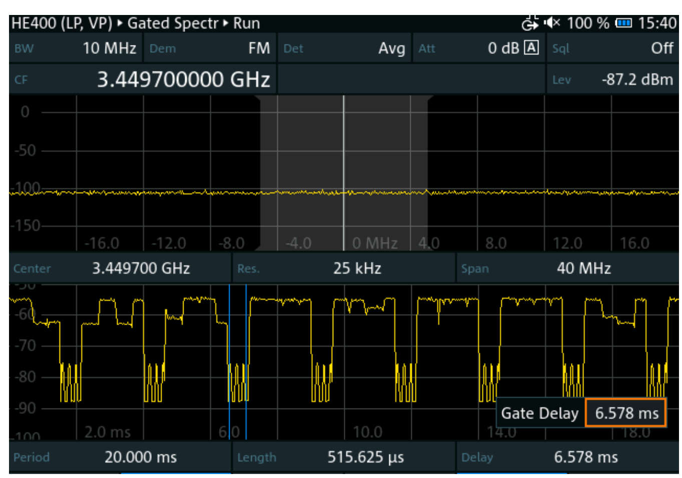


Fig. 24: Finding the uplink slots in a 5G signal with a pulsed interferer inside

Due to the presence of the interferer, it may be that the level of the uplink slots does not drop to the receiver noise level, but instead shows the interfering pulses. This can make it more difficult to detect the uplink slots, especially if the pulse period of the interferer is less than 6 ms, like in the example in Fig. 24. Nevertheless, the regularity of the uplink slots and their equal length can help in finding them.

Now, we can limit the following measurements to the selected gate time only:
- ▶ [App Config] – "Config" – Persistent gated mode = on

The actual location and measurement of the interferer are handled again in receiver mode:
- ▶ [App] – "Receiver"

If the pulsed signal covers only part of the 5G channel (e.g. from pulsed digital systems):
- ▶ [Freq] – "Frequency" – Center freg = frequency of maximum level of the interferer
- ▶ [Dem/BW] – "BW" – 40 MHz
- ▶ [Disp] – "Ranges" – Auto Range

A good setting to use the level tone as a bearing aid is (see Fig. 25):
- ▶ [Dem/BW] – "Level Det" – Peak
- ▶ [Dem/BW – "Tone" – on
- ▶ [Dem/BW] – "Config" – Meas Mode = Continuous, Meas Time = manual 10 ms (or higher)

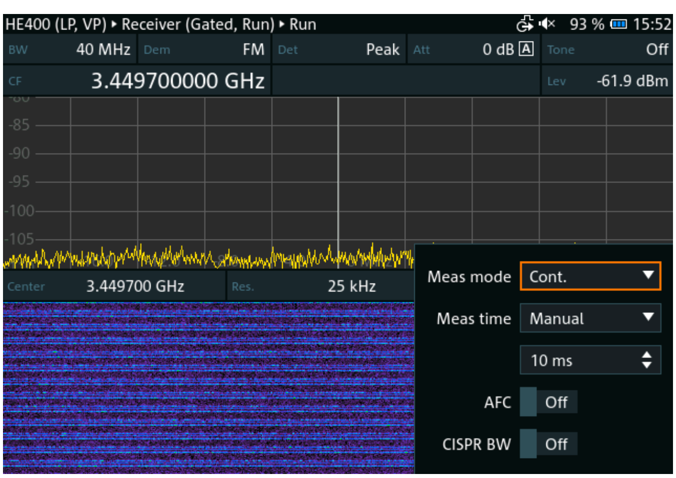


Fig. 25: Settings to locate a pulsed signal inside a 5G channel

Co-channel mobile communications networks

Countries may allocate spectrum for mobile communications networks (MFCN) differently. Often, providers can select the preferred technology themselves. This may lead to co-channel interference, especially in border regions if the two countries use different MFCN technologies in the same frequency band.

There are different constellations of this interference scenario that can affect the applicable settings for the R&S®PR200, R&S®EM200 and R&S®UMS400:

Interfering signal is wider than the wanted signal or has a different center frequency

In this case, one of the spectral edges of the interfering signal is outside the wanted channel (either above or below). To find it, use the following settings:
- ▶ [App] – "Polychrome Spectrum"
- ▶ [Freq] – "Center Freq" – Set to channel edge of the wanted system where the interfering signal overlaps
- ▶ [Disp] – "Ranges" – Auto Range

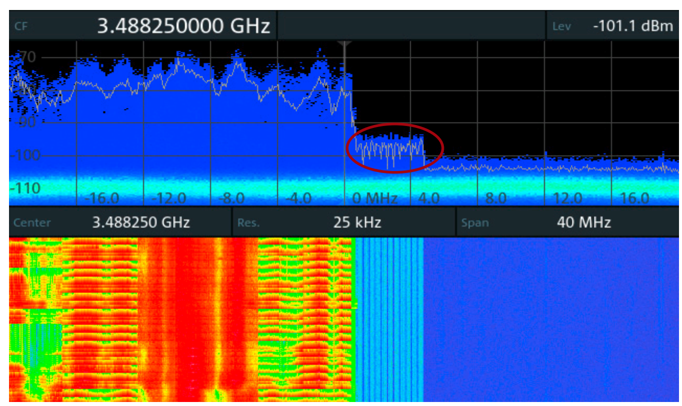


Fig. 26: Interfering signal extends beyond the wanted channel (red circle)

The exact upper frequency limit of the interfering signal in Fig. 26 can be measured with a frequency marker.

Interfering signal is inside the wanted signal

Finding the "inner" frequency limit of the interfering signal (inside the wanted signal) could be handled with the following settings:
- ▶ [App] – "Gated Spectrum"
- ▶ [Freq] – "Center Freq" – Set to the center of the SSB
- ▶ [Dem/BW] – "BW" – 5 MHz (slightly narrower than the SSB)
- ▶ [Disp] – "Ranges" – Spectrum Auto Range
- ▶ [Disp] – "Ranges" – Magnitude Auto Range

Again, we need to locate the uplink slots. An alternative to the method described in section Pulse interferers is given below:

- [Disp] – "Zoom" – Expand the region of the SSBs with 
- [App Config] – "Gate length" – 500 µs
- [App Config] – Set to 100 µs before the first SSB. This is usually the uplink time slot

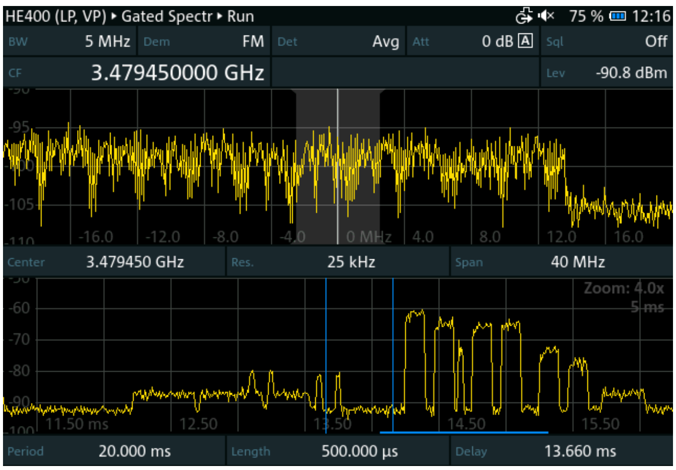


Fig. 27: Setting the gate in the uplink slot just before the first SSB

In the example in Fig. 27, there are signals inside the selected time gate, but they originate from the interfering signal.

Again, if the uplink slot is heavily occupied with signals from the user equipment, the gate length can be reduced to the guard interval between the uplink and downlink, after increasing the resolution bandwidth via:

- [Spectrum] – "Resolution" – Auto = off, increase to next higher value

See Fig. 21 for an example.

Now, we can limit the following measurements to the selected gate time only:

- [App Config] – "Config" – Persistent gated mode = on

The actual location and measurement of the interferer are then handled again in receiver mode (see Fig. 28):

- [App] – "Receiver"
- [Disp] – "Ranges" – Auto Range
- [Freq] – "Center Freq" – Change with the wheel or the arrow buttons until the spectrum edge of interferer is in the center

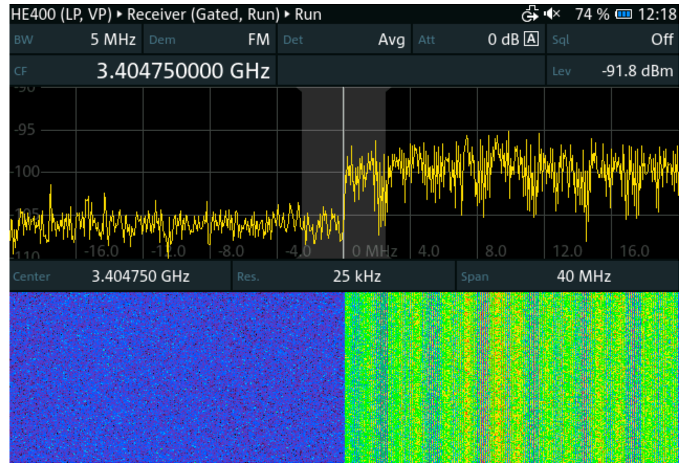


Fig. 28: Finding the inner frequency edge of a co-channel interferer

Unsynchronized 5G TDD networks

TDD operation commonly used with 5G NR technology requires all base stations to be exactly time-synchronized. If the signal from an adjacent base station is delayed, it may fall into the uplink time of an affected base station, causing interference. Since inside a network, the frequency, bandwidth and technology are the same for all base stations, such interference could be detected only by measuring the received signal with extremely high time resolution in order to check the uplink time for additional signals arriving a few µs late. The minimum measurement time of the R&S®PR200, R&S®EM200 and R&S®UMS400 is limited to 100 µs, but this is only due to the limited speed with which the screen can be refreshed. Internally, the R&S®PR200, R&S®EM200 and R&S®UMS400 measure much faster, so that a time offset between two MFCN signals could be determined down to a resolution of 1 µs. However, for this, we need to record a short sequence of the signal and analyze it offline.

- [App] – "Receiver"
- [Freq] – "Center Freq" = center frequency of the wanted channel
- [Gain] – "Amp" – Low Noise (if possible without overload indication)
- [Spectrum] – "Config" – Meas Mode = periodic
- [Spectrum] – "Config" – Meas Time = manual 100 µs
- [Disp] – "Ranges" – Auto Range

Now we want to record I/Q data:

-  – "Rec Type" – Wide IQ
- "Config" – Buffer size = 1.5%. This limits the recording to 20 ms, thereby keeping the resulting file size to a minimum
- Press  again to start recording
- Press  again after about two seconds to stop recording

Now we analyze the recording:
- ► [App] – "IQ Analysis"

In the standard setting, one line in the waterfall display represents 100 μs in time. To view only one uplink slot with high time resolution:

Turn the wheel until the replay line is inside an uplink slot.
- ► [Spectrum] – "Config" – Meas Time = 10 μs

Turn the wheel again until the uplink slot is visible. In Fig. 29 we can see a delayed signal from another base station falling into the uplink slot.

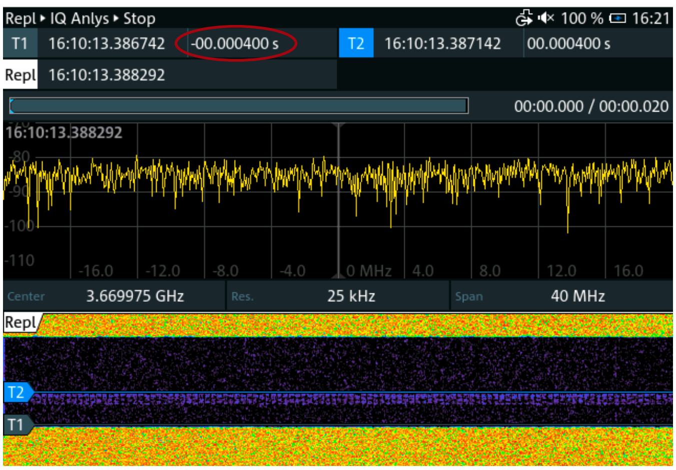


Fig. 29: Detection of a delayed 5G signal from an unsynchronized base station

The delay time can be measured using:
- ► [Marker] – "Add" – Waterfall line (this becomes T1)

Turn the wheel to set T1 to the beginning of the uplink slot.
- ► [Marker] – "Add" – Waterfall line (this becomes T2)

Turn the wheel to set T2 to the end of the delayed signal.

The time delay is shown on the top of the screen next to T1 (red circle in Fig. 29). In the example above, the delay is 400 μs.

There are two possible reasons for signals from other base stations to arrive so late that they interfere with the uplink slot:
- ► The interfering station is nearby, but due to a fault it is operating out of sync.
- ► The interfering station is far away, but can still be received due to specific propagation.

In our example, 400 μs corresponds to a distance of 120 km. At this distance, other base stations should normally not be receivable. This makes unsynchronized operation of a nearby base station more likely. However, there are propagation effects, where signals in the 3.5 GHz range can travel very large distances, even over the horizon. One of these effects is ducting, which occurs mostly during the summer and across bodies of water.

FURTHER 5G MEASUREMENT POSSIBILITIES

In certain situations, one may require specific information that the receiver cannot provide or encounter difficulties that hinder conventional measurement processes. The following table provides some examples of such situations along with possible solutions.

Situation	Description	Rohde & Schwarz solution
Dense 5G environment or border regions	5G BTS from multiple operators. You need an overview of the 5G cells and their IDs. Cell parameters could be useful. A vehicle mounted solution would be beneficial (fast drive test).	R&S®ROMES with 5G scanner and 5G mobile
Monitoring urban 5G network performance	Assessing quality of service is out of scope for any receiver. Provide QualiPoc mobiles to your staff and log 5G QoS as they move around a city. Data from the mobiles can indicate which areas need further investigation, e.g. with a portable receiver.	QualiPoc smartphone based measurement system
Identifying a signal of interest (SOI)	The SOI is an illegal, unknown or interfering signal that you cannot identify via other means. Analysis of the signal may provide clues to the identity of the signal source.	R&S®CA100IS signal analysis software
Inaccessible 5G BTS or coverage area	Accessing the BTS and/or coverage area requires too much time/effort/resources, e.g. 5G BTS mounted high on a tower, or terrain/fences/buildings limiting freedom of movement.	R&S®AMS real monitoring system

ORDERING INFORMATION

Designation	Type	Order No.
Monitoring receivers		
Portable monitoring receiver	R&S®PR200	4500.5002.02
Digital compact receiver	R&S®EM200	4108.3005.02
Universal monitoring system	R&S®UMS400	4501.9001.02
Software options		
Panorama scan	R&S®CS-PS	4500.7070.02
Polychrome spectrum	R&S®CS-PC	4500.7040.02
Time domain measurement	R&S®CS-ZS	4500.7111.02
I/Q snapshot recording, replay and analysis	R&S®CS-IQ	4500.7270.02

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5G measurements for regulatory agencies
Data without tolerance limits is not binding | Subject to change