

LTE and Bluetooth® in-device coexistence with WLAN

Application Note

Products:

- R&S® CMW500
- R&S® DST200
- R&S® AMS32

Modern mobile phones can support cellular and noncellular wireless communications standards at the same time. This means, however, that the subsystems must operate in very close proximity to each other within a single device (in-device coexistence). The resulting high level of reciprocal leakage can at times cause considerable interference.

This application note employs preliminary theoretical analysis and demonstrates how the problems of in-device coexistence can be measured. Exemplary, the effects of LTE and Bluetooth® traffic on the WLAN performance of a commercially available smartphone are examined. These examples will also enable the reader to design tests for complementary scenarios.

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Note: In this application note, the R&S®CMW500 wideband radio communication tester is referred to as the CMW500 or CMW. The R&S®DST200 RF diagnostic chamber is referred to as the DST200 and the R&S®AMS32 OTA measurement software as AMS32.

1 Introduction

Modern mobile phones can support cellular and noncellular wireless communications standards at the same time. A mobile can communicate with hands-free equipment via Bluetooth® or with a computer or a router via WLAN during GSM, UMTS or LTE calls. The requirement for various radio systems to operate with antennas in close proximity to one another is called "in-device coexistence."¹

Simultaneous collocation of various radio systems is a longstanding issue, and international frequency plans and limits for RF leakage into other frequency domains provide especially good organization in this area. A new aspect, however, has been introduced by the sometimes very close proximity of various antennas and feed systems in modern mobile phones (or automotive communication modules and tablets, for example). The effects of transmit signals on other receivers are unavoidably many times greater than is the case with individual spatially separated devices.

Section 2 of this application note starts off by describing the principle problems to be expected from this close proximity.

Section 3 covers practical measurements. A test case is used to examine the effects of LTE and Bluetooth® traffic on the WLAN performance of a commercially available smartphone.

The versatily configurable R&S®CMW500 wideband radio communication tester is used for all measurements. The CMW500 is especially ideal for coexistence measurements, as it supports all major cellular and noncellular standards and can operate two different radio systems simultaneously.

The proposed test setup includes the portable R&S®DST200 RF diagnostic chamber. It was developed with relatively small dimensions especially for carrying out OTA measurements ²(such as in-device coexistence measurements) directly in the lab instead of in large shielded chambers. Nevertheless, the DST200 offers the necessary spacing between DUT and measurement antenna to meet the far-field conditions. Mostly, smaller "shielded boxes" cannot ensure this. In this case, measurement results will be rarely reproducible.

Section 4 discusses the R&S®AMS32 OTA measurement software, which makes it possible to automate the manual measurements described in section 3. The AMS32 software also manages a remote-controllable 3D positioner, which is available for the DST200 diagnostic chamber. The positioner can place a DUT in any spatial position in the center of the chamber in a computer-controlled, reproducible manner, e.g. in an area of maximum sensitivity or influence.

¹ When the antennas of stationary radio systems are operated close to each other (in terms of wavelength), it is generally referred to as "antenna collocation". In-device coexistence is a special case of this scenario.

² OTA: over-the-air measurements

2 Case studies for coexistence problems

The primary problem of any in-device coexistence situation is that the emissions from one system's antenna have a strong presence on that of the other. In this application note, we concentrate on the main problem of the TX signal of one radio system (interferer) directly interfering with the RX signal of another (victim).³

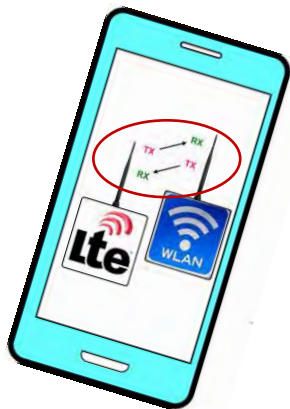


Fig. 2-1: In-device coexistence e.g., LTE and WLAN in a smartphone.

The coupling between the affected antennas (antenna isolation) is approximately equal to free-field attenuation **a**. This is, for example, approximately 15 dB with a separation of 5 cm at 2.4 GHz and approximately 20 dB at 5.5 GHz (see Fig. 2-2).

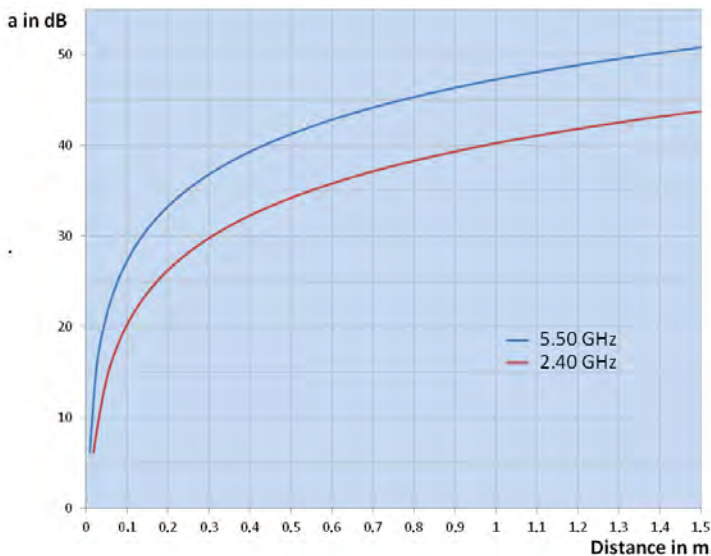


Fig. 2-2: Free-field attenuation **a** between two antennas at 2.4 GHz and 5.5 GHz.

³This application note does not cover additional effects such as the occurrence of mixing products, reverse mixing or inter and/or cross-modulation.

That means that a +10 dBm signal transmitted at 2.4 GHz from antenna 1 is received at approximately –5 dBm by antenna 2 if it is situated five centimeters away with the same orientation.

(This only applies to antennas with 0 dBi gain. The level is somewhat lower in practice, as installation positions alter antenna patterns.)

The foreign TX signal increases the noise power at the affected receiver, which has a negative impact on the signal/noise ratio. The RX sensitivity appears to decrease – an occurrence dubbed "desensitization". As with common sensitivity tests, bit error, block error or packet error rate are used as figure of merit (FOM).

The above-mentioned unfavorable ratios occur primarily in the following scenarios:

- Two radio systems occupy neighboring frequencies and carrier **leakage** occurs.
- The **harmonics** of one transmitter fall on frequencies used by another system.
- Two radio systems share the **same frequencies**.

The above-mentioned scenarios should be reviewed first when examining an unknown device, as they directly determine priority frequencies for measurement.

The cellular and noncellular standards do establish limits for the unavoidable emissions of DUTs outside their operating frequencies, and certain overload immunity against external signals must also be guaranteed. Commercial devices surely meet both requirements if they have passed a conformance test (e.g. "WiFi-Certified"). However, the actual amplitude of signals foreign to a system due to in-device coexistence is significantly greater than the maximum interferer levels verified in such conformance tests. It is the responsibility of device manufacturers to eliminate or at least mitigate the resulting receiver interference.

We also run into the general problem of high interferer levels causing receiver overdrive (blocking)

RX blocking differs from the three previously described situations in that the blocking is rarely frequency-dependent. This is a case of pure overloading of the RX preamplifier and/or mixer. A powerful interferer signal "occupies" the input range entirely, and there is practically no room left for a weak wanted signal.

This application note examines the interaction of LTE and Bluetooth® with WLAN, as this system combination is extremely widespread for smartphones. (These examples will enable the reader to design tests for complementary scenarios as well.)

The observations are limited to examples of LTE and Bluetooth® acting as interferers with WLAN as the victim. In general, various wireless communications standards always interfere with one another. This is why practical analysis always requires examination of the "opposite direction."

2.1 Leakage into adjacent channels

Leakage into adjacent radio bands is very probable at both ends of the 2.4 GHz ISM band.

In addition to others, the much used WLAN and Bluetooth[®] radio communication services operate in the license-free ISM⁴ band. LTE Band 40 lies very closely to the lower end of the ISM band and LTE band 7, follows, albeit with somewhat more separation, its upper end (see Fig. 2-3).

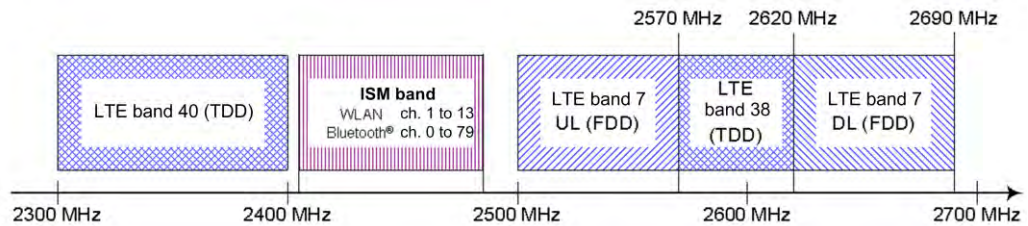


Fig. 2-3: The 2.4 GHz ISM band and adjacent LTE bands.

Let's start by examining the level resulting from the coexistence of LTE and WLAN in, for example, a smartphone. LTE is the interferer, WLAN the victim.

The maximum LTE transmit level of a mobile phone is +23 dBm. An antenna isolation of 15 dB leaves +8 dBm on the neighboring WLAN antenna. The WLAN reference sensitivity level in this case, for example, is -80 dBm (depending on bandwidth and modulation). The out-of-band emissions must not exceed -86 dBm (94 dBc) in order to keep the LTE share at least 6 dB under the WLAN reference sensitivity level. This is unrealistic, and the ETSI standard [5] requires only 20 dBc of separation.

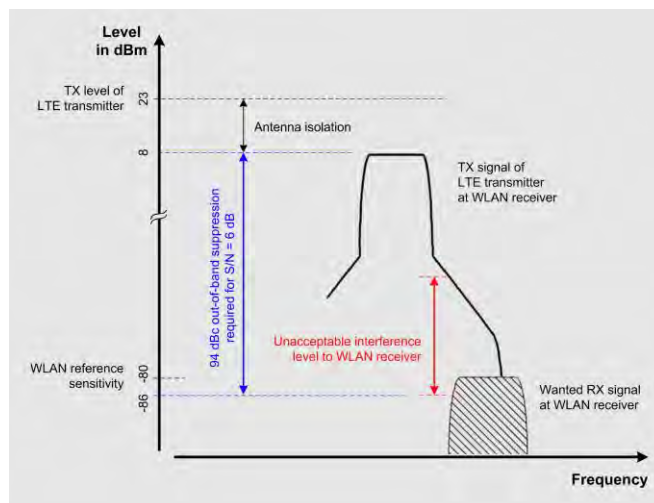


Fig. 2-4: In-device level study on interference between LTE-TX and WLAN-RX.

⁴ Industrial, scientific and medical band

Only measurements, however, can show the extent, to which WLAN reception is actually impaired, as it also depends on the actual scope of antenna isolation and de facto LTE signal transmit power. Additionally, both LTE Band 40 and WLAN use time division duplexing (TDD) and are not correlated with each other i.e., it can be beneficial for transmit and receive windows to overlap only some of the time, especially if this is managed by a chipset.

2.2 Harmonics fall in user bands

Numerous 3rd harmonics of LTE mobile phone uplink signals fall directly in WLAN channels in the 5 GHz ISM band (see Fig. 2-5). These harmonics often fail to decay due to short antenna distances.

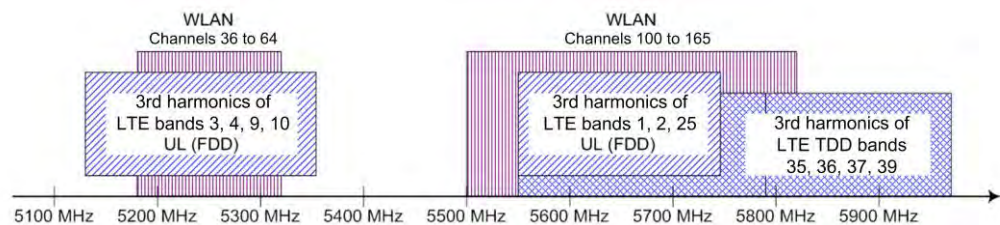


Fig. 2-5: LTE harmonics in the 5 GHz ISM band.

Fig. 2-6 shows the relationship (again) between the LTE TX and WLAN RX levels at the maximum allowable limits for this situation.

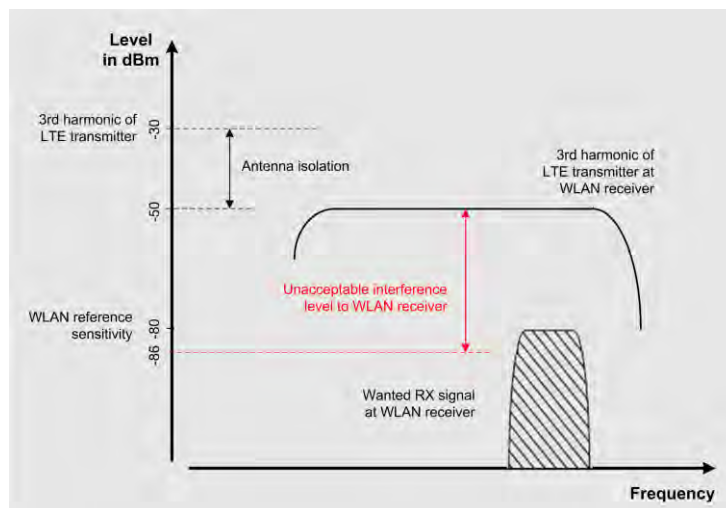


Fig. 2-6: In-device interference caused by LTE harmonics.

According to LTE Standard TS 36.101 [1], out-of-band emissions are allowable from $1 \text{ GHz} \leq f < 12.75 \text{ GHz}$ up to -30 dBm . An antenna isolation of 20 dB (higher due to higher frequencies), results in a worse case of -50 dBm at the WLAN receiver. This value is 30 dB over the WLAN reference sensitivity level of approximately -80 dBm (for

1 Mbit/s). The interfering harmonics are present at all times, as LTE uses frequency division duplexing in the above-mentioned bands.

However, the harmonic RF leakage of advanced DUTs is usually considerably lower than the allowable limits. Again, measurements are the only tool for establishing the extent, to which WLAN reception is actually impaired.

2.3 Identical frequency ranges

Bluetooth® and WLAN 802.11b/802.11g both work without correlation in the 2.4 GHz ISM band and generally use a common antenna.

Bluetooth® frequency hops with 1 MHz spacing between 2402 MHz and 2480 MHz and has a bandwidth of 1 MHz.

WLAN uses fixed frequencies. The lowest WLAN channel (channel 1) has a center frequency of 2412 MHz; the top channel in Europe (channel 13) has a center frequency of 2472 MHz.

The following pattern applies to center frequencies:

WLAN channel 1 \triangleq 2412 MHz \triangleq Bluetooth® channel 11

WLAN channel 2 \triangleq 2417 MHz \triangleq Bluetooth® channel 16

etc.

Bluetooth® and WLAN theoretically occupy the same frequencies at times, and it would seem that significant reciprocal impairment is inevitable. Bluetooth®, however, features an intelligent hopping mechanism (adaptive frequency hopping, AFH), which avoids occupied frequencies. On the other hand, WLAN initially monitors the frequency it requires and waits until it is free to transmit. Measurement is again the only way to determine the actual extent of impairment.

The CTIA's "Test Plan for RF Performance Evaluation of Wi-Fi Mobile Converged Devices" [2] includes an extensive table of frequency combinations requiring verification. This table contains (only) detailed frequencies of wireless communications standards that could interfere with WLAN traffic. The table can be used as a basis for clarifying in advance which measurements are mandatory for a given system combination.

2.4 Desensitization (self-interference)

In-device coexistence measurements determine desensitization i.e., the reduction of RX sensitivity due to a powerful interferer signal. As with standard sensitivity test, error rate measurements have been adopted as the figure of merit. Packet error rate (PER) is measured for WLAN.

The blue curve in [Fig. 2-7](#) shows the typical WLAN PER progression without interferer influence. As soon as the RX signal falls below a minimum input level, there is a significant error rate increase.

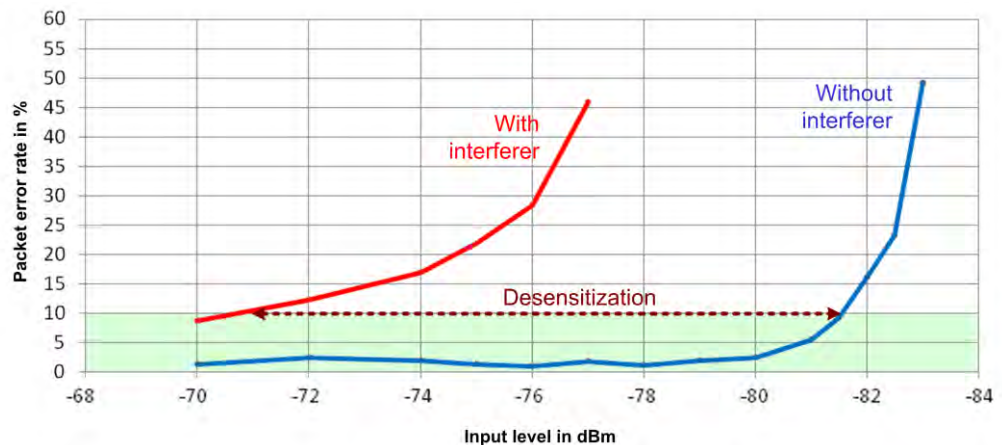


Fig. 2-7: Typical PER progression with and without interferers (WLAN 802.11g, 20 MHz bandwidth)

Adding an interferer signal (e.g. a cellular interferer) shifts, as it were, the blue curve to the left. A certain measurement scenario produced the progression shown in red.

To determine the degradation of the RX sensitivity a first measurement determines the RX input level for 10 % PER⁵. This level is named the "receiver sensitivity" [2] or the "intermediate sensitivity level". It is an individual value which can differ between different DUTs by several dB.

To achieve a PER of 10 % in presence of an interferer, a much higher receiver input level is required. This value is called the "effective intermediate sensitivity level" EIS.

The desensitization is calculated from the difference:

$$\begin{aligned} & \text{"10% PER level" with interferer (EIS)} - \text{"10% PER level" without interferer} \quad \text{or} \\ & \text{effective intermediate sensitivity level} - \text{intermediate sensitivity level} \end{aligned}$$

In Fig. 2-7, for example, without interferer, an input signal of -81.5 dBm is required for PER = 10 %.)

With a certain interferer applied, the wanted signal - in the example - has to be -71 dBm for PER = 10 %.

The desensitization is calculated to $-71 \text{ dBm} + 81.5 \text{ dBm} = 10.5 \text{ dB}$.

Desensitization is "naturally" dependent on the field strength of the interferer at the victim's antenna. It could be that a radio link to the victim could not be established at certain frequencies and levels, even when the transmit power of the interferer is

⁵ To prove the minimum receiver sensitivity a different procedure is defined in the conformance tests. For a fixed RX input level (the reference sensitivity level) the PER has to be below or the throughput above a certain limit. For example, the reference sensitivity level for LTE in band 1 using a bandwidth of 5 MHz is -100 dBm.

reduced. In such instances, desensitization measurements must begin with very low interferer signals.

Measurements with the CMW500 wideband radio communication tester

The CMW500 wideband radio communication tester is used to carry out the desensitization measurements in this application note.

- ▶ The measurements do require basic instrument operating skills but no specialist-level expertise.

The initial step of desensitization measurements is to establish a radio link (duplex connection) to the victim using CMW RF channel 1 (measurement channel). If the objective is to determine the desensitization of a WLAN DUT, the operator must first measure the PER without interferers and record the level at PER = 10% [2] as the intermediate sensitivity. The WLAN input level must then be increased by approx. 30 dB on the tester to avoid losing the connection when the interferer is applied.

The operator now uses CMW RF channel 2 to activate the interferer at a defined frequency and power setting. The operator again measures the victim PER with an initially high wanted signal and then gradually reduces it. The level at a PER of 10% is the effective intermediate sensitivity (EIS). The desensitization of the DUT is the difference of the EIS and the intermediate reference sensitivity.

All processes that have to run simultaneously on the CMW are designated as "tasks."

Signaling mode is used for all measurements i.e., radio links between the CMW tester and the DUT are established and controlled via air interface (not control cables and test ports).

That means that the WLAN Signaling task (for the victim) and the LTE or Bluetooth® Signaling task (according to interferer) are always required for the measurements.

The interferer is represented by the relevant DUT TX signal. The LTE (or Bluetooth®) TX Meas. task must be initiated in the CMW to ensure the interferer transmits continuously.

The WLAN PER packet error rate task measures WLAN RX sensitivity reduction.

Fig. 2-8 shows the four active tasks (indicated in yellow) in the CMW task bar during WLAN PER measurements with an LTE interferer.



Fig. 2-8: Active tasks for an in-device coexistence measurement.

The blue color of the WLAN PER softkey indicates that this task is running in the foreground i.e., that it takes up the entire screen.

(The two inactive tasks in this figure, **LTE Ext. BLER** and **WLAN Multi Eval.**, enable users to carry out in-depth analysis of the DUT's signals and characteristics.)

Throughput

Absolute throughput measurements are less suitable for determining desensitization, as different DUTs may use different correction algorithms. This makes it impossible to compare the results directly.

Relative throughput measurements (comparison of the situation with or without interferers), in contrast, can be an indispensable figure of merit, as WLAN has a collision avoidance mechanism (carrier sense multiple access / collision avoidance, CSMA / CA). If a WLAN TX detects that a radio channel is occupied, it waits until the channel is available. By this, the PER remains unaltered while the throughput decreases.

The following rough correlation exists for desensitization and throughput (for WLAN / OFDM at the reference sensitivity level):

Desensitization	Throughput
0 dB to 10 dB	100 % to 50 %
10 dB to 20 dB	50 % to < 10 %
20 dB to 30 dB	down to 0 %

Table 2-1: Desensitization and throughput.

Table 2-1 indicates that practically no radio communications are possible with desensitization over 20 dB. However, this applies only to an input signal with the minimum reference sensitivity level.

It is correct that (only) the RX sensitivity has worsened by 20 dB. There may be no impairment for wanted signals that are much higher than 20 dB over the reference sensitivity of the DUT. In any case, desensitization of more than 30 dB is generally intolerable in practice, when the wanted signal is subjected to fading during mobile use.

3 Measurements

3.1 Over-the-air (OTA) measurements

The use of any sort of RF test ports on the DUT would alter the electrical termination of the RF components in the antenna feed system. It would also change the propagation conditions and the reciprocal influence of the radio systems under examination. For this reason, the air interface (OTA) in a shielded chamber is used for all in-device coexistence measurements. This also serves to keep clear of other signals such as those from WLAN access points installed in the lab.

Air interface measurements require somewhat of a delicate touch. Coexistence measurements require two radio links for control, i.e. twice as much diligence on the part of the operator.

- The RF path attenuation is considerably higher than with conducted measurements.
- OTA measurement results are not only dependent on distance. They are also influenced by the positioning of the DUT in relation to the test antenna.

Reproducibility:

In practice, a DUT might have to be removed from the shielded chamber in the middle of a measurement series, in order to reestablish a radio link manually. After such interruptions, it is necessary to return the device to its precise original position.

For coexistence measurements, however, reproducibility does not mean that the measurement path must be exactly calibrated. It is only important that good measurements can be carried out at RF input levels for PER about 10%. If the path attenuation is compensated imprecisely, a PER of 10% will be detected at, for example, higher values than the expected sensitivity level. This has no impact on the measurement, as the influence of path attenuation disappears when desensitization is calculated:

$$(EIS + \text{path attenuation}) - (\text{intermediate sensitivity level} + \text{path attenuation}) = \\ EIS - \text{intermediate sensitivity level}$$

Since the position of the antennas in the DUT to each other remains unchanged, reciprocal immission and desensitization are in no way affected by the position of the DUT in the test chamber. (This applies as long as none of the subsystems under testing actively or passively modify the antenna characteristics on their own.) This means that only the DUT position in relation to the test antenna (measurement path) must be maintained at all times. Since very low signal levels are being measured, it is recommended to find the position that affords the best tester reception of the DUT wanted signal level.

To make it transmit continuously, the tester must maintain a duplex RF link via an interferer path to the interferer radio system in the DUT. Just as the measurement path, the interferer RF path does not require exact calibration.

DUT distance to the test antenna

The Wi-Fi test specifications for WLAN stipulate that a minimum distance of 1.20 m should be maintained between DUT and test antenna for OTA measurements at the frequencies being used [3]. This is, however, actually required only for 3-dimensional Wi-Fi certification measurements.

Users can manage with considerably less test separation, as the measurement path does not impact the reciprocal influence of the DUT's radio systems. Consideration, however, must be made in order that the measurements are being carried out under what are known as far-field conditions. This is achieved with an approximate test distance of $2\pi/\lambda$ i.e., starting from about 5 cm at 2.4 GHz. In addition, the electrical field of the transmit radio waves must be as homogeneous as possible. This can be maintained by starting from about three times the minimum separation i.e., from approximately 15 cm.

A small antenna distance offers the following advantages:

- A smaller, more cost-efficient shielded chamber can be used.
- The measurements can be carried out at a "normal" working table thanks to a smaller shielded chamber.
- There is less RF measurement path attenuation than when the DUT is placed far away from the antenna i.e., the test equipment must deliver significantly less RF power.

If the chamber is too small, the measurements are made under near-field conditions. The DUT and test antennas influence each other, and even minimum position alterations result in significant deviations in the measurement results. That means that they are not easily reproducible.

The R&S®DST200 RF diagnostic chamber used in this application note offers all of the above-mentioned advantages.



Fig. 3-1: DST200 diagnostic chamber in use.

The most important characteristics of this DST200 diagnostic chamber:

- With its operating range of 700 MHz to 6 GHz in the standard configuration, the DST200 covers all important radio standards (the frequency range can be expanded to 300 MHz to 18 GHz)
- The high shielding figure of > 110 dB allows leakage-free measurements even for extremely low signal levels (e.g. for GPS receivers)
- Virtually free-field conditions at the test position minimize the parasitic loads and any resulting detuning of the antenna
- Wide-ranging accessories (various test antennas, feedthrough panels, switch matrices, amplifiers) meet all requirements

In particular, there are different brackets for holding the DUT. Fig. 3-2 shows, for example, the manual 3D positioner. With two labeled rotation axes, any desired spatial position of a DUT can be reproducibly set up. The bracket has an open design, so the DUT's operating elements (buttons, switches, touchscreen) remain accessible.

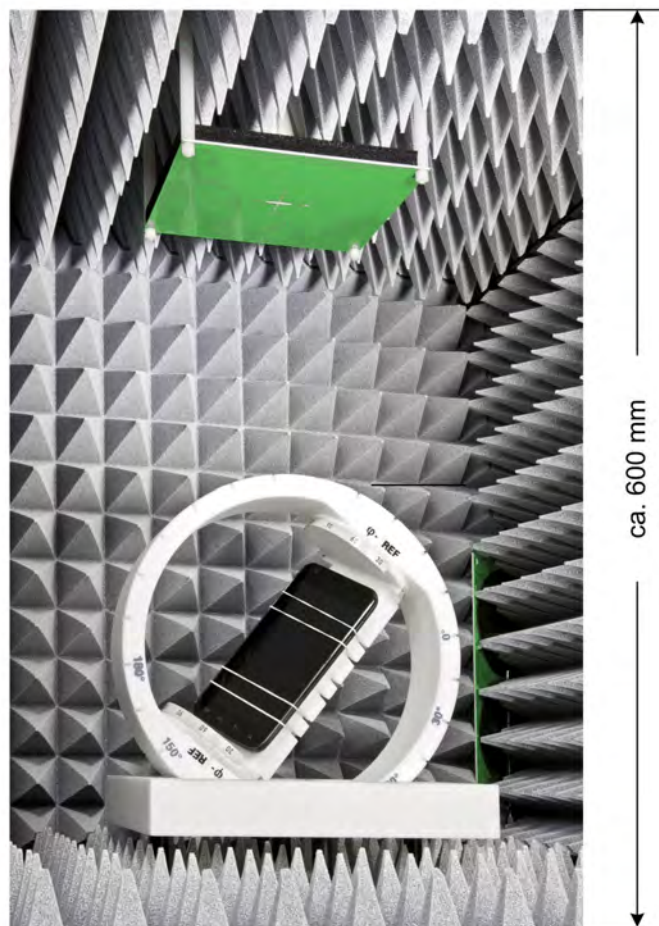


Fig. 3-2: Manual positioner of the DST200 diagnostic chamber.

Antennas and antenna polarization:

The green printed board at the top in [Fig. 3-2](#) is the DST-B210 test antenna, via which the PER measurements on the victim are made. In the right rear corner in the lower half of the figure, you see one of the two DST-B272 communications antennas (upright). (The second one is behind the positioner.) Both communications antennas maintain the radio link between the CMW tester and the interferer radio system.

Since measurements are taken at the DUT's sensitivity limit, it is essential to keep the path attenuation between the DUT and the test antenna as low as possible. This is generally achieved using a horizontal test position.

The DST-B210 measurement antenna at the top of the chamber (see [Fig. 3-2](#)) contains two linearly polarized antennas. From outside the chamber, each of the two polarization directions can be accessed via separate N connectors. They are labelled "FB" (front-back) for polarization from the front to the back of the DST200 and "LR" (left-right) for polarization from side to side.

The antennas in the DUT for cellular radio networks (GSM, UMTS, LTE) are likewise usually linearly polarized. They are almost always positioned parallel to the lengthwise or widthwise side of the DUT.

- ▶ Make your DUT start transmitting and determine in which spatial position you achieve an optimal receive level on the CMW500 tester. The difference between the best and the poorest polarization is typically approx. 13 dB.

▶

Antennas for noncellular networks (WLAN, Bluetooth®) can be circularly polarized. These signals are usually measured just as well with the linearly polarized test antenna. The loss when using a combination of a circular transmit antenna and a linear receive antenna (and vice versa) is only approx. 3 dB. With a circularly polarized antenna in the DUT, however, the rotary direction is what matters. Here too, the difference between the orientations is typically 13 dB. So, for optimal coupling, the DUT may have to be placed face down.

The DST-B272 interferer communications antennas at the bottom and the right in the diagnostic chamber are intended for the interferer connection. These antennas used in combination are quasi crosswise polarized and measure uncritically each offered field. By this, no deep receive minima occur in the interferer communication path at any DUT position. Although the optimal measurement position of the DUT might differ from the position with the lowest attenuation for the interferer path, the power levels of CMW and DUT are sufficient to maintain a stable link.

The automated positioner offers something special (see [Fig. 3-3](#)).

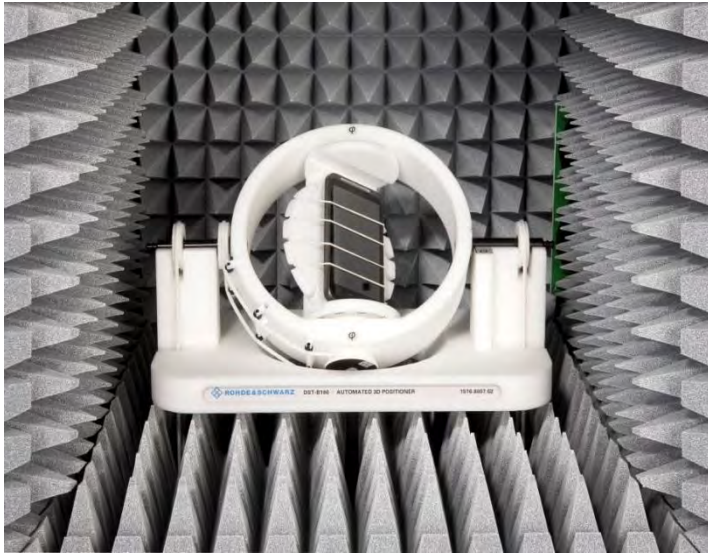


Fig. 3-3: Automated positioner in the DST200 diagnostic chamber.

You can use this positioner together with the AMS32 OTA measurement software to bring the DUT into any spatial position by remote control. In particular the positions for maximal or minimal RF leakage and receive sensitivity, for example, can be determined automatically by program control.

(The AMS32 OTA measurement software will be discussed in section 4 of this application note, starting on page 31.)

3.2 Test setup

Fig. 3-4 shows a first test setup for the desensitization measurements. It is especially well suited for low chamber attenuations. Test setup 1 requires no external components. This set up is used in this application note for the WLAN-PER measurements in the 2.4 GHz band.

A CMW500⁶ acts as tester. It maintains a bidirectional radio link simultaneously on each of the RF channels 1 and 2.

RF channel 1 is the measurement channel; the WLAN packet error ratio (PER) will be measured on this channel later. You have a choice of two test antennas; Polarization with each is linear, but - antenna to antenna - is offset 90°.

⁶ Fig. 3-4 shows a CMW with basic frontend. A CMW with advanced frontend is suitable for all measurements in the same way.

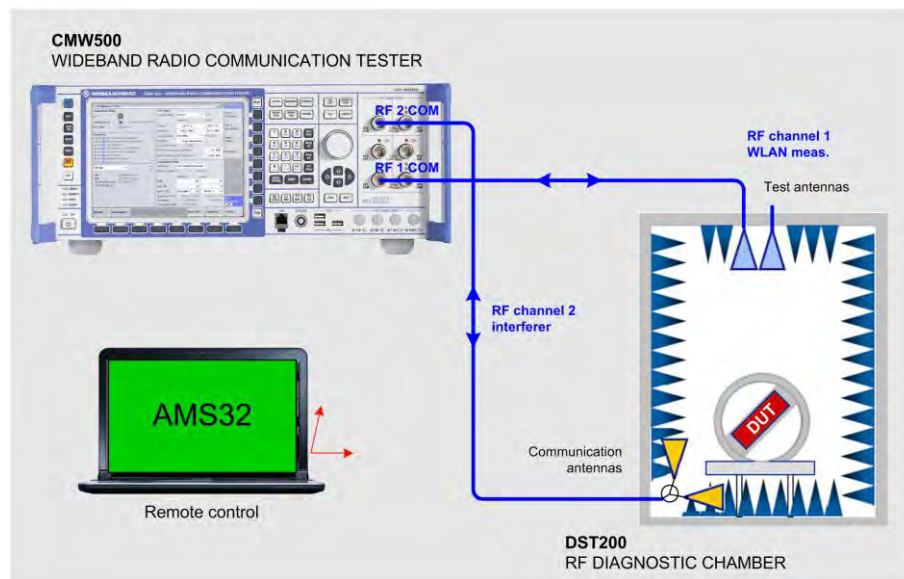


Fig. 3-4: Test setup 1 for desensitization measurements.

RF channel 2 is the interferer channel (in this application note, LTE or Bluetooth®). To be more precise, it is the LTE or Bluetooth® transmit signal in the DUT alone that represents the interferer. The channel 2 signal from the CMW to the DUT is only necessary for maintaining the radio link. In order not to influence the WLAN measurement, the CMW transmits with relatively low power here. For the interferer, two differently polarized communications antennas are interconnected in the diagnostic chamber in order to avoid minima in the antenna pattern when the DUT is in any test position.

The AMS32 OTA measurement software can be used for remotely controlled measurements. It controls the CMW as well as the DUT's position in the diagnostic chamber. In Fig. 3-4, this is indicated by the PC and the two red arrows pointing outward from it.

Fig. 3-5 shows a second, expanded test setup. Here, the RF channel 1 measurement path is split for the directions from and to the DUT.

RF 1 OUT now serves as TX port, and RF 1 COM only as RX port. Depending on the requirements, this allows you to insert amplifiers into the path to the DUT or the path to the CMW, or (as in Fig. 3-5) in both directions in order to partially compensate for the chamber attenuation.

We recommend this setup for measurements with high chamber attenuations, e.g. if the frequencies are high. At 5 GHz, the OTA path losses are approx. 6 dB to 10 dB above the attenuation at 2 GHz. For this reason, in this application note, test setup 2 is used for PER measurements in the 5 GHz band⁷.

⁷ For the measurements in this application note, ZX60-V62+ amplifiers (Mini-Circuits) were used.

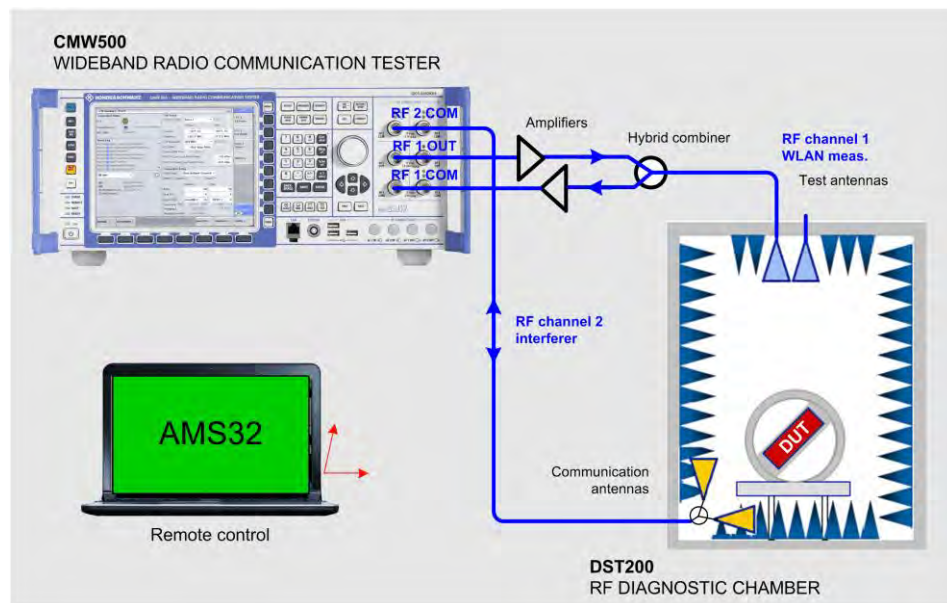


Fig. 3-5: Test setup 2 for desensitization measurements.

Specifically for test systems, Rohde & Schwarz offers the R&S[®] OSP-B151 switching unit. For OTA measurements, it can be equipped with up to four amplifier modules, each with typ. 33 dB gain in the range from 700 MHz to 6 GHz.

Together with the CMW options for the corresponding radio access technologies, test setups 1 and 2 cover all common combinations of cellular and noncellular radio standards and measure potentially occurring coexistence problems. Test setups 1 and 2 fulfill the CTIA recommendations [2].

The DUT is controlled by the CMW in a test mode. For cellular mobile phones, a special test SIM card is inserted. This card can be ordered from Rohde & Schwarz, for example. For noncellular standards, there are manufacturer-specific options. However, in particular not all Bluetooth[®] modules can switch to test mode from outside (anymore). For this reason, for Bluetooth[®] measurements, an alternative method to activate the interferer in the DUT is described in section 3.4.3 on page 26.

3.3 Determining path attenuation

Even if it is unimportant for calculating the desensitization, you generally want to know approximately which levels are applied to the DUT. This is the only way to avoid overloads and underloads, which can lead to an interruption of the radio link between the DUT and the tester.

The following procedures generally assume that the WLAN antenna in the DUT exhibits roughly the same radiation characteristics as the LTE antenna. Since LTE mobile stations maintain their maximum output power of 23 dBm quite exactly, the WLAN measurement channel is examined using the LTE uplink signal. To determine

the path attenuation for measurements in the 2.4 GHz WLAN band, it makes sense to use an LTE signal in neighboring band 7, which is supported by most devices in Europe.

- Wire your test setup (1 or 2).

Compensation of the path attenuations is now carried out in three steps.

1. Evaluating the measurement path attenuation

- On the CMW, select the **LTE** Signaling task, and press *Config*.
- If you are using test setup 1, switch both the TX1 path and the RX1 path in the CMW to RF 1 COM. With test setup 2, switch the TX1 path to RF 1 OUT and the RX1 path to RF 1 COM. These settings are temporary. LTE will be operated via RF channel 2 later. This channel is not yet activated here.
- As initial value, set the external output and input attenuation for RF1 on the CMW to 40 dB minus the gain of each amplifier used (see [Fig. 3-6](#)).

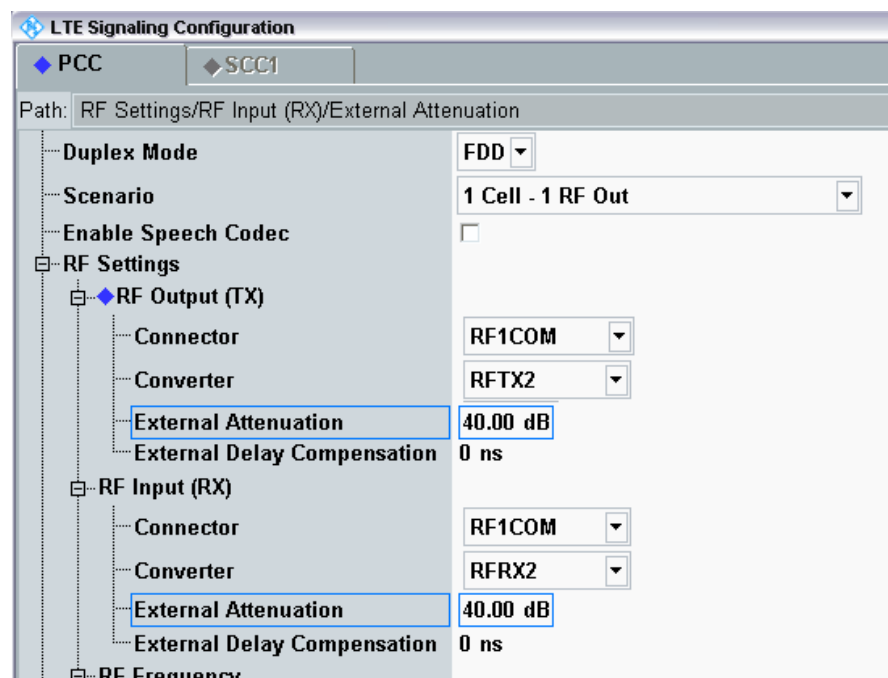


Fig. 3-6: First estimated path attenuation (test setup 1, without amplifier).

- Set up an LTE link between the CMW and the DUT. Set the DUT's uplink power to Maximum (see [Fig. 3-7](#)).

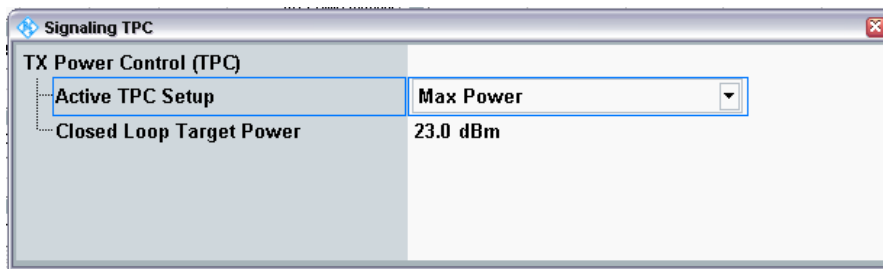


Fig. 3-7: Setting the DUT to maximum uplink power.

- Start the multi evaluation task on the CMW.

In the TX measurement display, you will see the DUT's TX power received by the CMW (see Fig. 3-8).

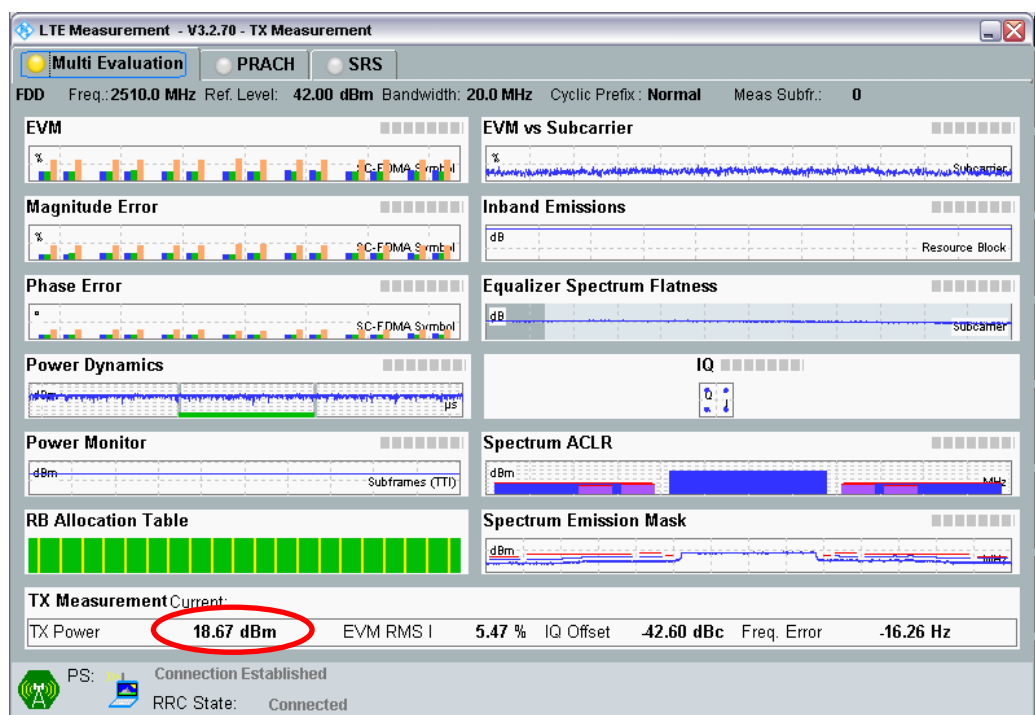


Fig. 3-8: Display of the LTE uplink level on the CMW (path compensation not yet correct).

- Bring the DUT into a spatial position in which the receive level on the CMW becomes maximal. This may not be the later WLAN measurement position.
- Calculate a correction value from the TX power value shown in the measurement display and the nominal LTE power of 23 dBm.
Example: $23 \text{ dBm} - 18.67 \text{ dBm} = 4.33 \text{ dB}$
- On the CMW, correct the external attenuation of the **input** path for RF1.
- In this example, the initially set external attenuation = 40 dB. The new external attenuation is:
 $40 \text{ dB} + 4.33 \text{ dB} = 44.33 \text{ dB}$

- Change the external **output** attenuation by the same amount. The displayed TX power is now correct:

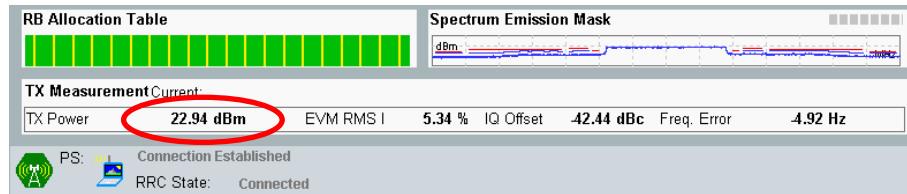


Fig. 3-9: Display of the LTE uplink level after correct path compensation.

- End the LTE Multi Evaluation and the LTE Signaling task.

2. Transferring the calculated values to the WLAN settings

- On the CMW, select the **WLAN** Signaling task, and press *Config*.
- If you are using test setup 1, switch TX1 and RX1 in the CMW to RF 1 COM. With test setup 2, switch the TX1 path to RF 1 OUT and the RX1 path to RF 1 COM.
- Transfer the path attenuations determined for LTE to WLAN.

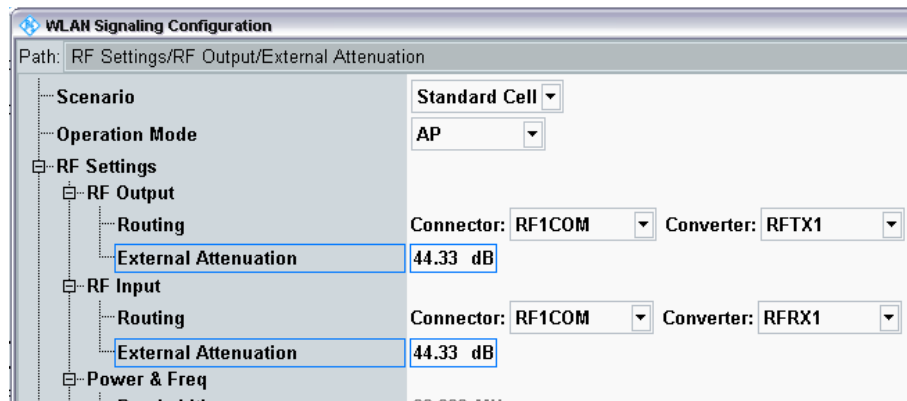


Fig. 3-10: Transferring the LTE attenuations to the WLAN configuration.

In this example, the path attenuations for output and input are the same (test setup 1).

- Set up a WLAN link between the CMW and the DUT.
- Start the WLAN PER task on the CMW.
- Bring the DUT into a position in which the received level on the CMW becomes maximal. This is now the optimal WLAN measurement position that will be used from now on.
- End the WLAN PER and the WLAN Signaling task.

3. Compensating the interferer communication path (DUT in the measurement position)

- On the CMW, select the WLAN Signaling task (again), and press *Config*.
- Switch TX2 and RX2 in the CMW to RF 2 COM.
- As initial value, set the external output and input attenuation for RF2 COM on the CMW to 40 dB.
- Set up an LTE link between the CMW and the DUT. Set the DUT's maximum LTE uplink power again (via the TPC control).
- Start the multi evaluation task on the CMW.
- Calculate and correct the communication path's attenuation using the level displayed on the CMW.

To be precise, the set offsets apply only to the frequency used (here 2510 MHz) and the DUT used. However, since no exact path attenuations are needed for calculating the desensitization, the paths will not be newly compensated for measurements in the 5 GHz range.

3.4 Measurement results

The following sections will show measurement results taken from currently available smartphones. One example for each of the scenarios described in section 2 will be demonstrated. However, this limitation by no means implies that no other coexistence problems are to be expected with the DUTs.

In practice, in the entire frequency range used, it must first be clarified (e.g by bit- or packet-error measurements) which interferences occur even without the second radio subsystem. Internal self-interference may be caused by oscillator signals and their harmonics, as well as by system and computer clocks and their mixing products.

The examples given in this section involve manual measurements. The desensitization measured in each case is not directly transferable to other DUTs. There are too many individual factors to be considered:

- What self-interference is already present?
- Which radio standards are active?
- Which transmit powers occur?
- How well are harmonics and adjacent channel leakages suppressed?
- Which antenna isolation can be found?
- How robust is the RX design?
- What filters are installed, etc.

It is important to identify all problem scenarios. This is why automatic measurements are preferred over manual measurements.

After determining the above, the next step is to take measurements and vary the parameters:

- What impairments occur?
- In which operating states should measurements be taken?
- At what levels and frequencies should measurements be taken?
- Are the determined impairments tolerable?

The ultimate aim is to eliminate, or at least mitigate, the detected influences.

3.4.1 Leakage into adjacent channels

This example determines the leakage of an LTE interferer at the upper limit of band 40 into the WLAN channels 1 (low), 6 (middle) and 13 (high) in the 2.4 GHz ISM band. The measurements are first taken using test setup 1 (see page 17). To increase the level of the CMW transmit signal for WLAN, an amplifier like the one in test setup 2 is sometimes used.

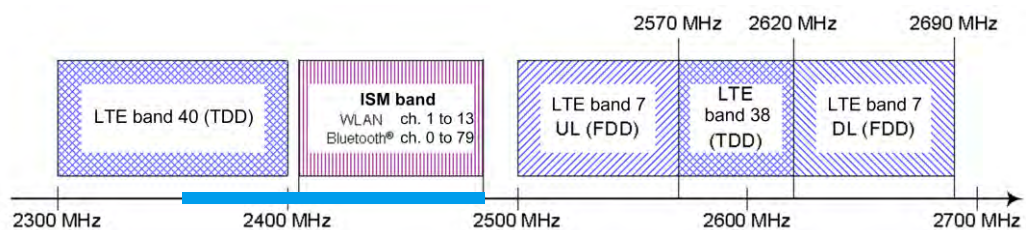


Fig. 3-11: Tested frequency segment (blue).

Band 40 is intended especially for TDD⁸ LTE. The interferer occupies a bandwidth of 20 MHz. The WLAN channels (victims) examined operate with OFDM and a bandwidth of approx. 25 MHz.

Fig. 3-12 on shows the measured desensitization at maximum interferer level (23 dBm) in various frequency combinations.

The vertical axis here and in the following figures indicates the frequencies of LTE band 40, while the horizontal axis indicates the WLAN frequencies. The measurement results of different frequency combinations can thus be presented in a straightforward manner.

Green areas represent frequency combinations with little or no impairment of the radio systems. Yellow areas show combinations with considerable coexistence problems, while red areas indicate combinations that cannot coexist at all (see Table 2-1 on page 11).

⁸ Time division duplex: Uplink and downlink share the same frequency in time division multiplexing.

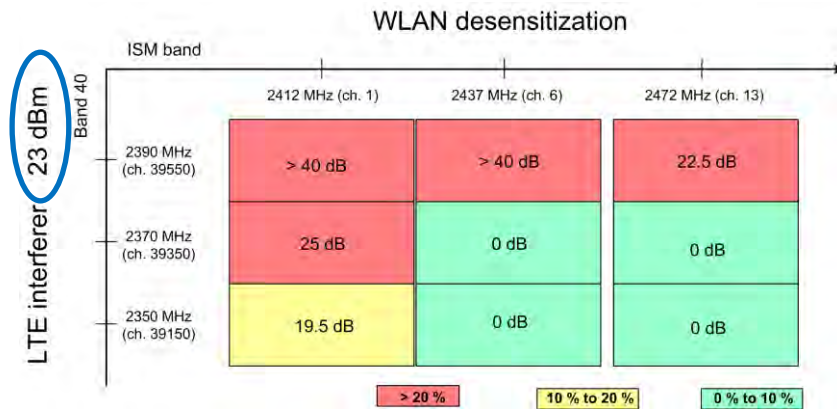


Fig. 3-12: Effects of an LTE interferer with 23 dBm on a WLAN victim.

You can see here that with an interferer frequency of 2390 MHz (i.e. directly at the band edge) and 23 dBm interferer level in the entire WLAN band, communications are no longer possible.

If you reduce the interferer level by 10 dB (to 13 dBm), you get a scenario like the one shown in Fig. 3-13:

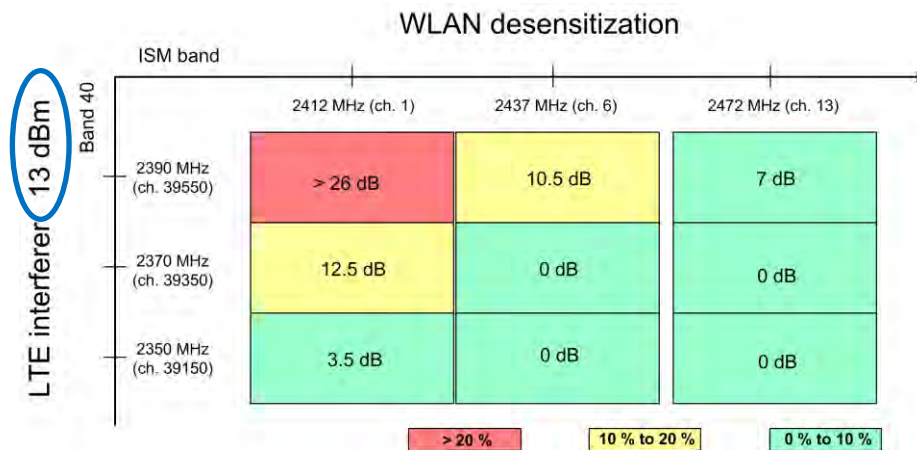


Fig. 3-13: Effects of an LTE interferer with 13 dBm on a WLAN victim.

Simultaneous use of frequencies at the band edges by interferer and victim remains impossible. Even in the respective "next" channel, one can still expect problems.

A further decrease of the interferer level by 10 dB (to 3 dBm) still prevents interferer and victim from using the frequencies at the band edges simultaneously (see Fig. 3-14). The remaining channels are now no longer affected.

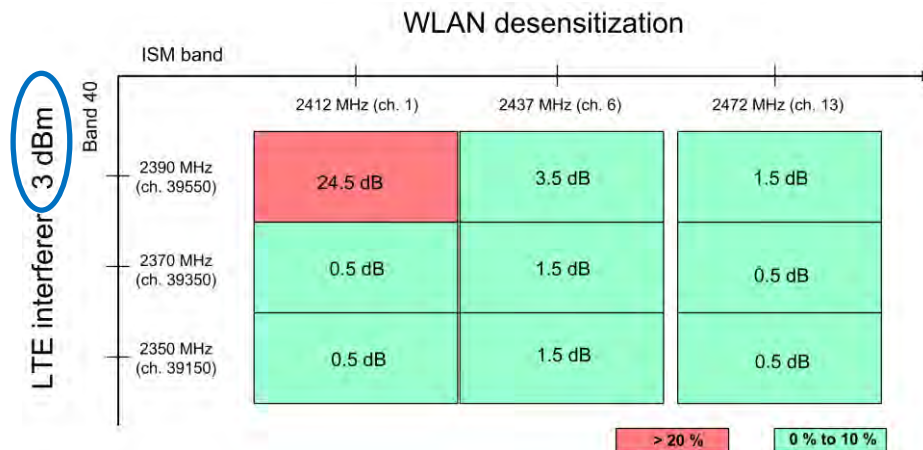


Fig. 3-14: Effects of an LTE interferer with 3 dBm on a WLAN victim.

Although some distance to LTE band 7 is maintained at the upper limit of the ISM band, you can imagine that a similarly strong desensitization occurs there. The situation may become even more critical by the FDD uplink signal transmitting continuously in LTE band 7⁹.

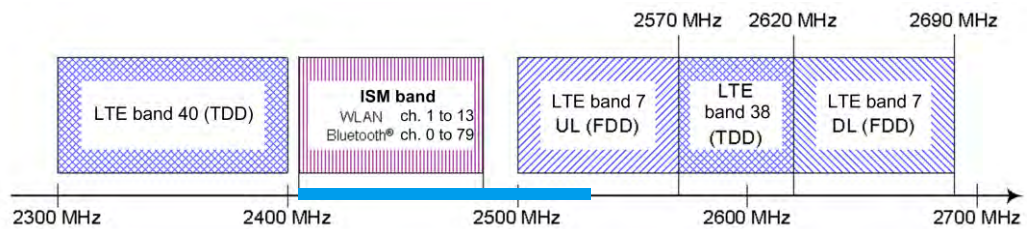


Fig. 3-15: Comparable situation at the upper end of the ISM band.

The obtained measurement results foreshadow that probably also conversely, the WLAN signal significantly impairs an LTE link at the band limits. This is not examined in this application note. The measurement procedure is basically the same.

3.4.2 Harmonics fall in user bands

This example determines the leakage of the 3rd harmonic of an LTE interferer at a frequency of 1760 MHz in band 3 into WLAN channels 48, 52, 56, 60 and 64 in the 5 GHz ISM band. The measurements are taken using test setup 2.

The fundamental frequency of the interferer, an FDD signal, has a bandwidth of 20 MHz. The WLAN channels (victims) examined operate with OFDM and likewise a bandwidth of approx. 20 MHz.

⁹ FDD: frequency division duplex: continuous signals in both directions on discrete frequencies.

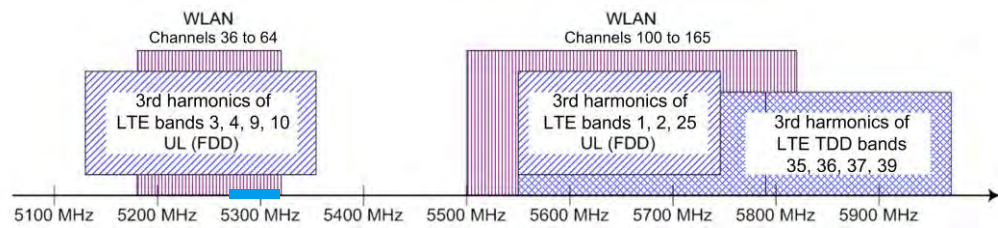


Fig. 3-16: Tested frequency segment (blue).

Fig. 3-17 shows the measured desensitization at the interferer levels of 23 dBm, 13 dBm and 3 dBm.

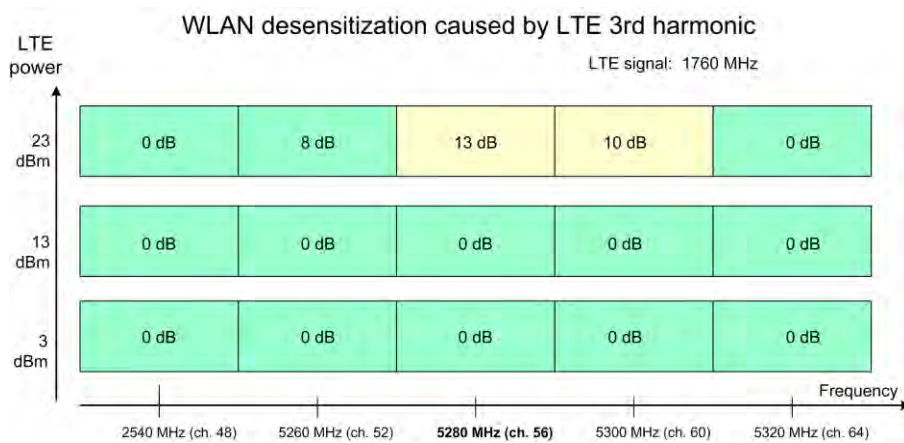


Fig. 3-17: Effects of the 3rd harmonic of an LTE interferer on an WLAN victim.

The tripling of the bandwidth at the interferer's 3rd harmonic is clearly recognizable. With maximum power of the 1st harmonic, radio traffic in the WLAN channels is slightly affected. Assuming that the LTE radio rarely works with its maximum output power, the measured desensitization could be tolerated.

3.4.3 Identical frequency ranges

Bluetooth® and WLAN 802.11b/802.11g both work without correlation in the 2.4 GHz ISM band and generally use a common antenna.

WLAN uses fixed frequencies. The lowest WLAN channel (channel 1) has a center frequency of 2412 MHz; the top channel in Europe (channel 13) has a center frequency of 2472 MHz. Bluetooth® frequency hops with 1 MHz spacing between 2402 MHz and 2480 MHz. Both standards operate in time division duplex (TDD).

Bluetooth® and WLAN potentially do occupy the same frequencies at times, and it would seem that significant reciprocal impairment is inevitable.

We (again) consider WLAN the victim and Bluetooth® the interferer.

Coexistence can again be measured using test setup 1 or 2. To be able to control the Bluetooth® part in the DUT with the CMW, however, the DUT must be switched to test

mode. With modern smartphones, this is not always possible "from outside". This is why we show a simple alternative method here in order to get Bluetooth® to transmit continuously (see Fig. 3-18).

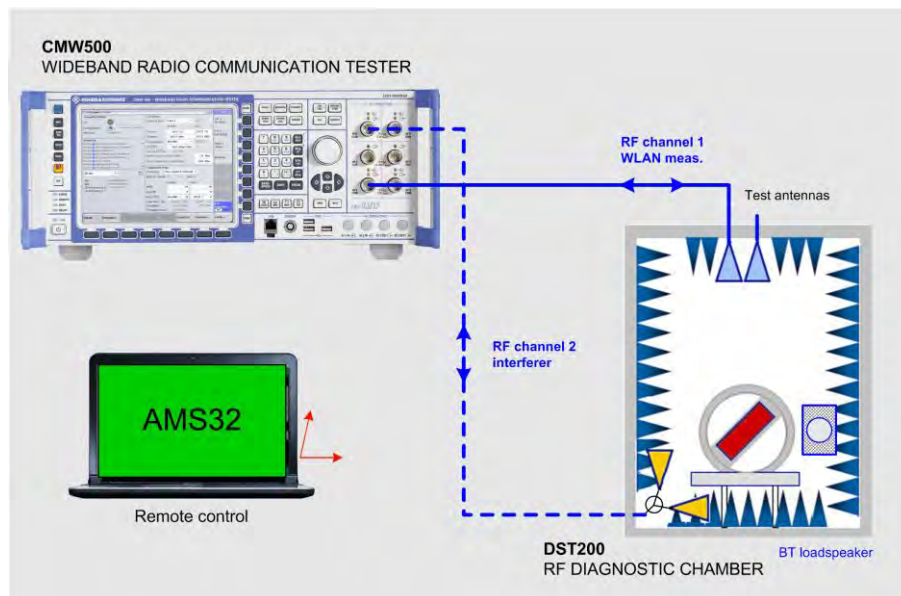


Fig. 3-18: Bluetooth® loudspeaker in the diagnostic chamber.

A small battery-operated Bluetooth® loudspeaker is placed inside the diagnostic chamber as radio partner for the DUT. After pairing the DUT with the loudspeaker, you start up e.g. an MP3 player on the DUT and the interferer is established. (A Bluetooth® option in the CMW is then no longer required.) With this test setup, you cannot control the interferer's level, but it suffices for an orientation measurement.

The result of a first measurement is surprising. Fig. 3-19 shows two PER measurements: the blue curve without and the red curve with a Bluetooth® interferer.

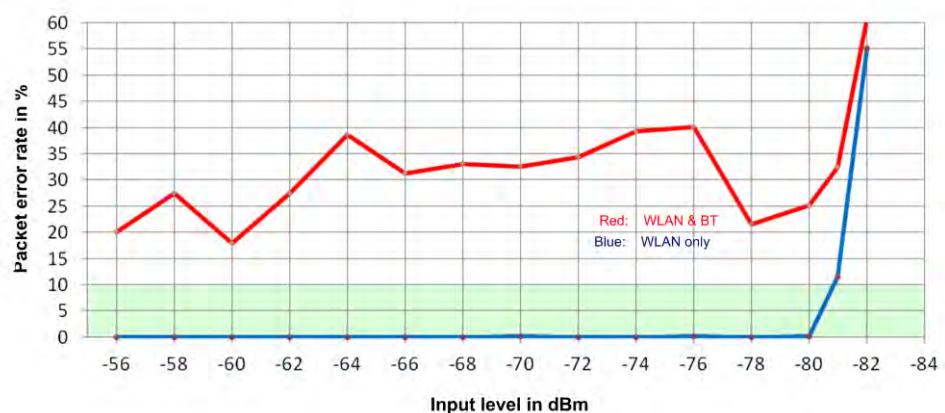


Fig. 3-19: PER measurement without (blue) and with Bluetooth® interferer (red).

It is not at all possible to determine a desensitization here, because the packet error rate in the presence of the Bluetooth® signal is always well over 10 %, even if the wanted signal is high.

This is no wonder, considering the occupancy of the spectrum. Fig. 3-20 shows how Bluetooth® alone takes up the entire ISM band.

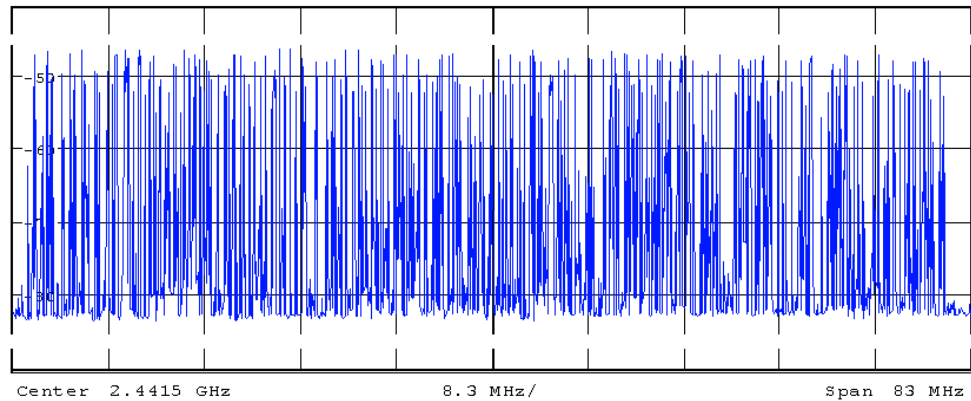


Fig. 3-20: Bluetooth® occupancy of the ISM band (on the spectrum analyzer).

If you start a WLAN now, the two spectra are superimposed on each other:

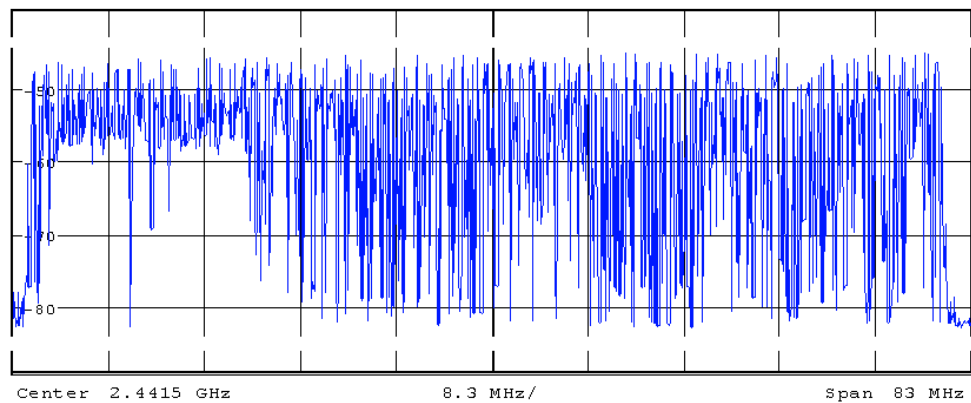


Fig. 3-21: Superposition of WLAN (at the lower end of the band) and Bluetooth®.

It is interesting that the WLAN packet error rate here is not poorer. The reason for this is that WLAN, before it occupies a channel, checks whether the channel is free. If this is not the case, it waits a while and then checks again. A WLAN burst is sent only at the moment when the Bluetooth® hopping does not occupy the WLAN channel.

This example demonstrates that the PER as sole figure of merit does not suffice, at least here. Because conflicts are partially avoided by waiting, the PER shows a slight increase, but the data throughput decreases extremely. The transmission of 2000 packets of 1000 bytes during the entire measurement series requires here approx.

255 s, which is equivalent to a data rate of only 7.8 kbyte/s. In this case, it is very useful to measure and specify not only the packet error rate but also the throughput.

A different DUT delivers other results. Fig. 3-22 shows two PER measurements again; the blue curve has been determined without, the red curve with Bluetooth® interferer.

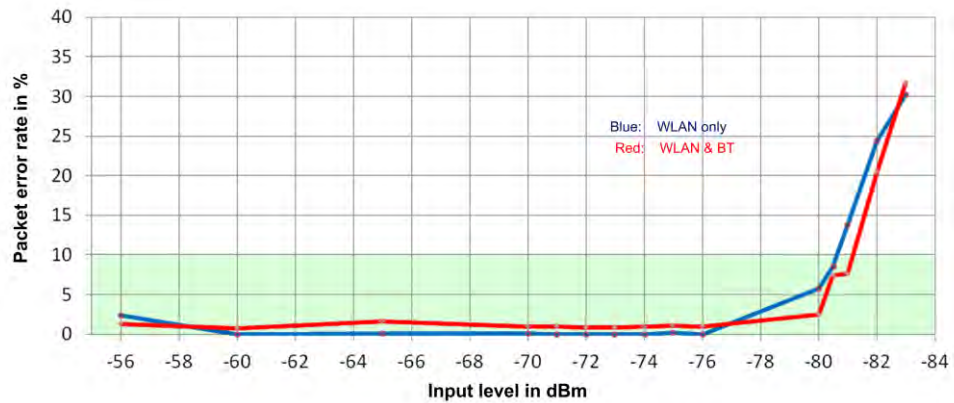


Fig. 3-22: PER measurement without (blue) and with Bluetooth® interferer (red).

Here (within the scope of measurement uncertainty), no differences in the magnitude and the progression of the PER values between the uninterfered and interfered scenario are ascertained, nor is a decrease in throughput detectable.

A look at the spectrum explains this situation:

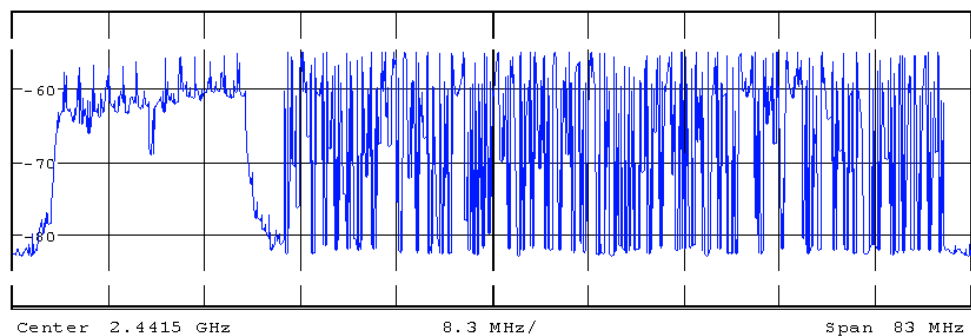


Fig. 3-23: Coexistence of the WLAN (at the lower end of the band) and Bluetooth® spectra.

With this DUT, Bluetooth® keeps the WLAN channel free and restricts itself to the upper two-thirds of the ISM band. This does not result in any disadvantages, except that the used frequencies are hopped somewhat more often.

This technique of keeping occupied frequencies free is called adaptive frequency hopping (AFH). But it only functions when sufficient alternatives are available. If the 2.4 GHz ISM band is occupied with 25 MHz signals, the resource frequency is exhausted.

Test advice: With the DUT first tested, initially Bluetooth® and then WLAN had been activated. When the activation sequence was reverse, adaptive frequency hopping functioned with this model as well.

4 OTA Measurement software AMS32

The comprehensive system software R&S® AMS32 supports various test applications inside the R&S® DST200 and larger RF diagnostic chambers. Predefined tests are performed in compliance with the CTIA Test Plan for Mobile Station Over The Air (OTA) Performance [3]. Individual tests and sequences can also be created easily.

AMS32 was developed for controlling the R&S® TS8991 OTA Performance Test System [7] - for nearly all OTA performance measurements on wireless devices. For the different applications, the TS8991 can control a broad range of instruments e.g. generators, radio communication testers, spectrum and network analyzers, power meters, and devices for RF switching and amplification and a position controller.

However, the software packages are also best suited for only a subset of the many predefined tests, which requires only a few of the instruments mentioned above (e.g. only one CMW Radio Communication Tester for the desensitization tests).

For more detailed information, refer to the AMS32 Getting Started Tutorial [8]. The latest information concerning AMS32 releases can be found on the web home page of Rohde & Schwarz under www.emc32.rohde-schwarz.com.

The following sections concentrate on examples of OTA measurements of the

- Intermediate Sensitivity and the
- Co-Existence Desensitization (Desense).

4.1 AMS32 OTA measurements

Fig. 4-1 shows a block diagram of the OTA measurement system supported by the AMS32 software.

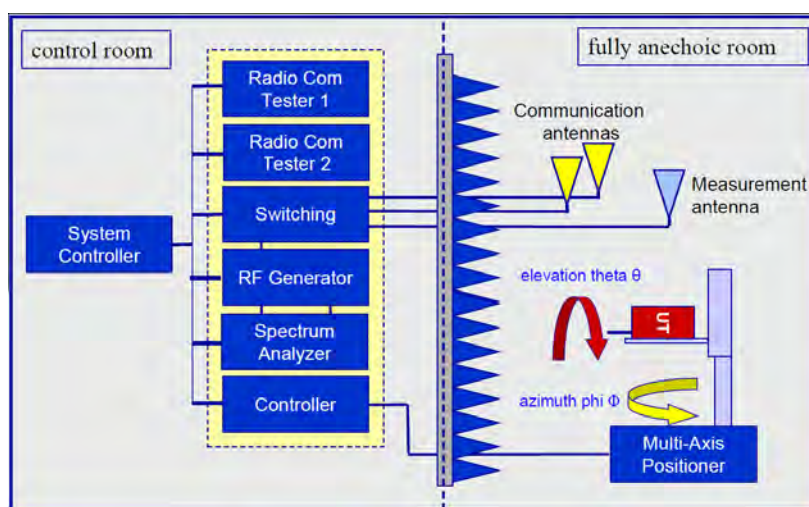


Fig. 4-1: Block diagram of an AMS32 OTA Test System

For the "control room" many possible instruments are listed. Fig. 4-2 shows the complete number of supported devices:

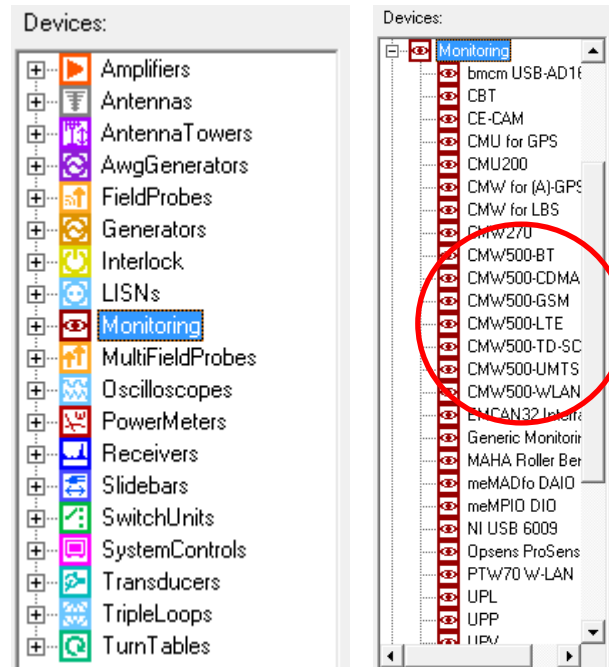


Fig. 4-2: Devices supported by the AMS32 software

For the In-device coexistence tests, only one CMW500 is required equipped with the cellular and noncellular options corresponding to victim and interferer. One CMW instrument includes both Radio Com Tester 1 and 2 in Fig. 4-1. In addition, amplifiers and a turn table might be applicable.

4.2 Test configuration

Measurement classes are used in AMS32 to distinguish either which subsystem (OTA, EMI or EMS) and which measurement type (radiated or conducted) has to be performed. Using this procedure allows all tests which have been made for a given DUT to be logically grouped together. Fig. 4-3 shows the currently available classes.

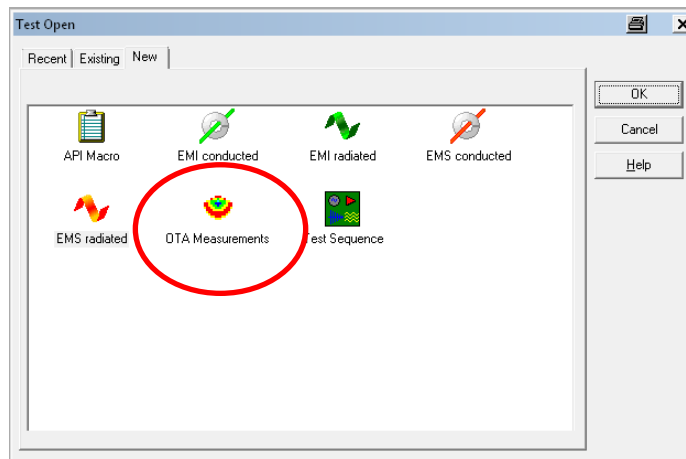


Fig. 4-3: Measurement Classes in the AMS32 software

For sensitivity and in-device coexistence select the *OTA Measurements*.

Templates

Test settings typically depend on the individual test suite. Mostly, a default setting is already done according to CTIA Test Plan. These settings are stored together in a file called *Test Template* for an OTA Auto test. Typically this file has the name of type of the measurement and the communication standard, for example *Sensitivity GSM*.

The principle of using templates has the advantage that the complete measurement parameter definition does not have to be done every time before starting a measurement.

Three templates for OTA measurements are predefined:

- Radiated Power Mobile Phone.
- Sensitivity Mobile Phone including in-device Coexistence.
- Radiated Power Passive Antenna.

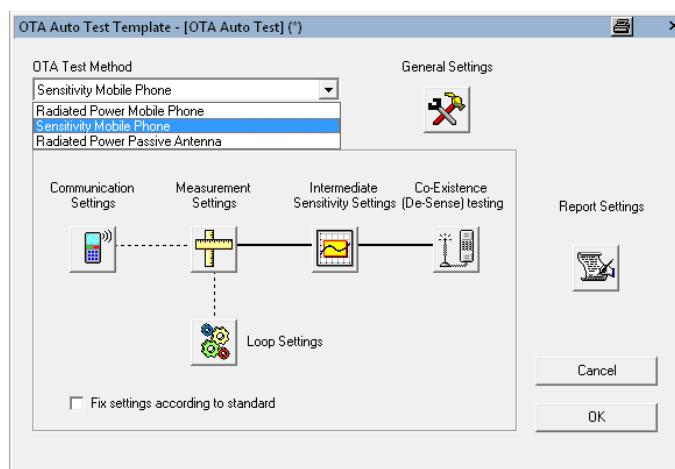


Fig. 4-4: AMS32 configuration menu for Sensitivity and Co-Existence measurements

For the intermediate sensitivity and coexistence / de-sense testing, *Sensitivity Mobile Phone* shall be selected.

There are 5 common settings for both Sensitivity and Co-Existence measurements:

- General Settings.
- Communication Settings.
- Measurement Settings.
- Loop Settings.
- Report Settings.

In the *General Settings* (on top of [Fig. 4-4](#)), the hardware setup, the mobile phone and measurement standard, and the DUT positions are defined.

In the *Communication Settings*, the parameters used by the communication tester (CMW500) are entered. They are needed to control the instrument fully automatically. [Fig. 4-5](#) shows some of them for the WLAN standard (excerpt for the AMS32 help popup).

Data Rate	Allows to select the data rate to be set on the PTW70 when establishing the link. Data rates are identified by a number used as such in PTW70 control and the explicit data rate in parenthesis. For certain data rates, two distinct configurations with long or short preambles may be selected.
Packet Size	Length in byte of one packet exchanged between the Communication Tester and the DuT. This parameter is not of crucial importance as it does not affect the measurement directly, but it has to be passed to the instrument for programming.
Packet Interval	Time in ms between two packets. May be used for making sure making sure the DuT will not have problems with too high packet rates. Also, may be used for simulating reproducible conditions exist in the radio link. With this parameter set to 0, packets will be passed as fast as possible.
MAC Address of DuT	MAC address of the DuT. The correct address must be passed to AMS32 if connecting in infrastructure test mode (with authentication). It can be omitted when connecting in ad-hoc mode. The MAC address must consist of 14 characters, starting by a leading "0X" plus twelve additional hexadecimal characters (0 - 9, A - F)
Number of packets	Number of packets to use for a measurement. This field will be displayed for Radiated power configurations only, as for Sensitivity tests, this parameter is modified during the test and is included in part of the <i>Measurement Settings</i> sub-dialog.
Connect in ad-hoc mode	Connection between the PTW70 and the DuT can be made either in infrastructure mode, in which a protocol stack including association and authentication procedures is set up, or in the so-called ad-hoc mode, which leads to a peer-to-peer connection. Wherever possible (the DuT must support this mode), an ad-hoc mode connection is the preferred one for Sensitivity tests, because

Fig. 4-5: Communication settings for WLAN (section)

The *Measurement Settings* depend on the selected *Test Method*. In case of the sensitivity measurements, they show how to step to the target package error rate (see [Fig. 4-6](#)).

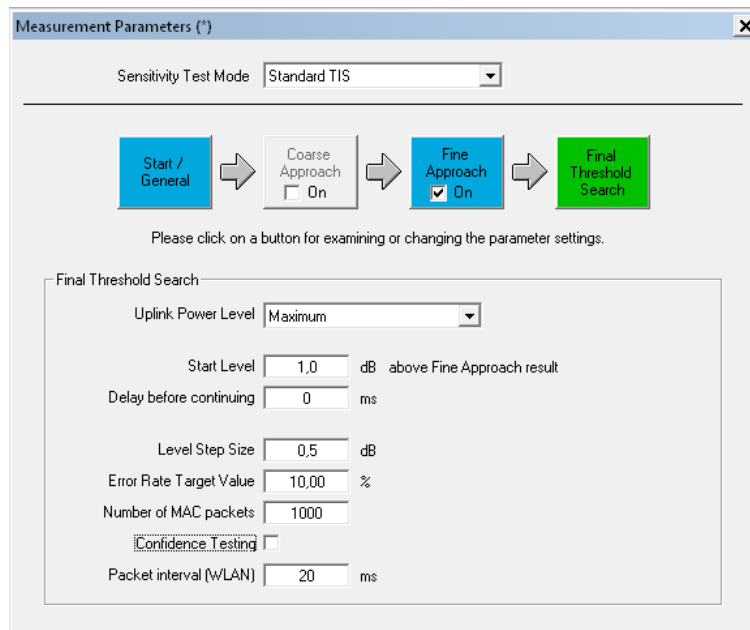


Fig. 4-6: Measurement settings for typical BER / PER measurements

The *Loop Settings* define the frequency and position steps. Fig. 4-7 shows an example for WLAN 11.g (channel 6):

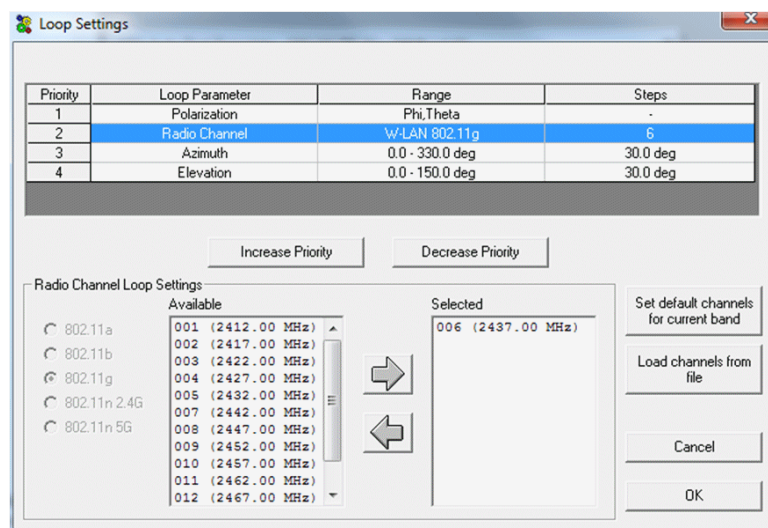


Fig. 4-7: Frequency and position steps for a WLAN measurement loop

The *Report Settings* are described later in this application note.

In addition to the 5 common settings above, there are further parameters to enter which depend on whether an intermediate sensitivity or a coexistence test shall be executed. The corresponding setting windows are opened by clicking the *Intermediate Sensitivity* or the *Co-Existence* icon in the test template configuration window Fig. 4-8 on page 36 respectively.

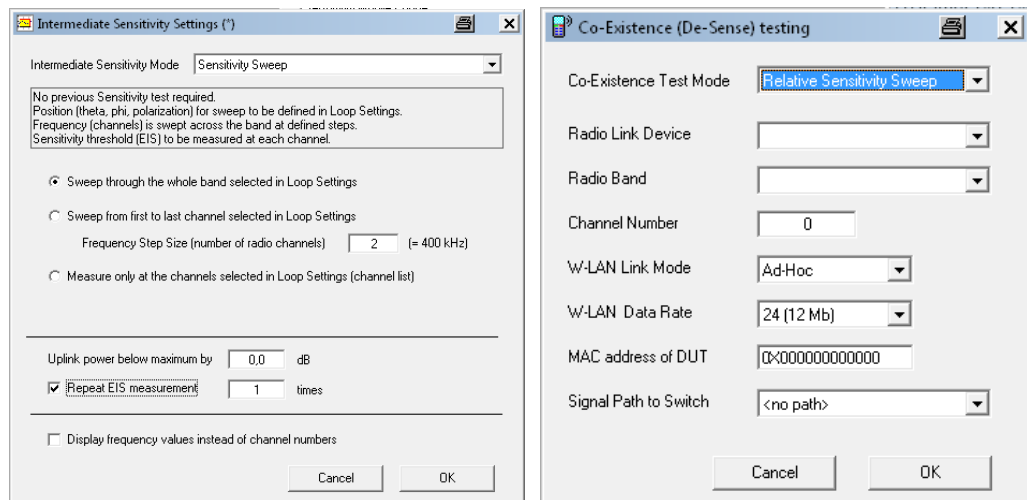


Fig. 4-8: Individual settings for Intermediate Sensitivity and Co-Existence tests

If these last entries are made, the test configuration is complete.

4.3 Running a test

Once configured, an OTA test consists of the following 3 steps:

- Starting the test.
- Checking the results.
- Creating a measurement report.

A test is started by clicking the Start / Forward button in the Test Control Bar (see Fig. 4-9).



Fig. 4-9: Control Toolbar of the AMS32

Once started, a check is done whether all required measurement devices can be addressed. If at least one device is not accessible a dialog is opened which shows a list of all inaccessible devices. The operator has now the possibility to either stop the measurement or to continue the measurement in the simulation mode.

If the measurement is continued, the operator is prompted to switch on the mobile phone and wait for synchronization. Then a call can be setup from the mobile or by the CMW. When the call is established, the operator is prompted to close the door of the shielding chamber and to continue the test.

During a run the measurement can be paused or to stopped.

When the *Pause* symbol in the test control toolbar is selected, the AMS32 will continuously repeat the measurement on the current EUT position. The test will be continued by clicking on the Start / Forward button.

Clicking the *Stop* symbol will abort the test. When starting again, the test will be continued at the last position of the previous test run.

After a measurement has been completed, the measurement result is displayed graphically. A tabular representation could be selected as well.

4.4 Test results

Fig. 4-10 presents the result of an intermediate sensitivity test. This measurement shows the actual minimum receiver input level needed to measure a given packet error rate (e.g. 10 %) without any cellular or non-cellular interferer.

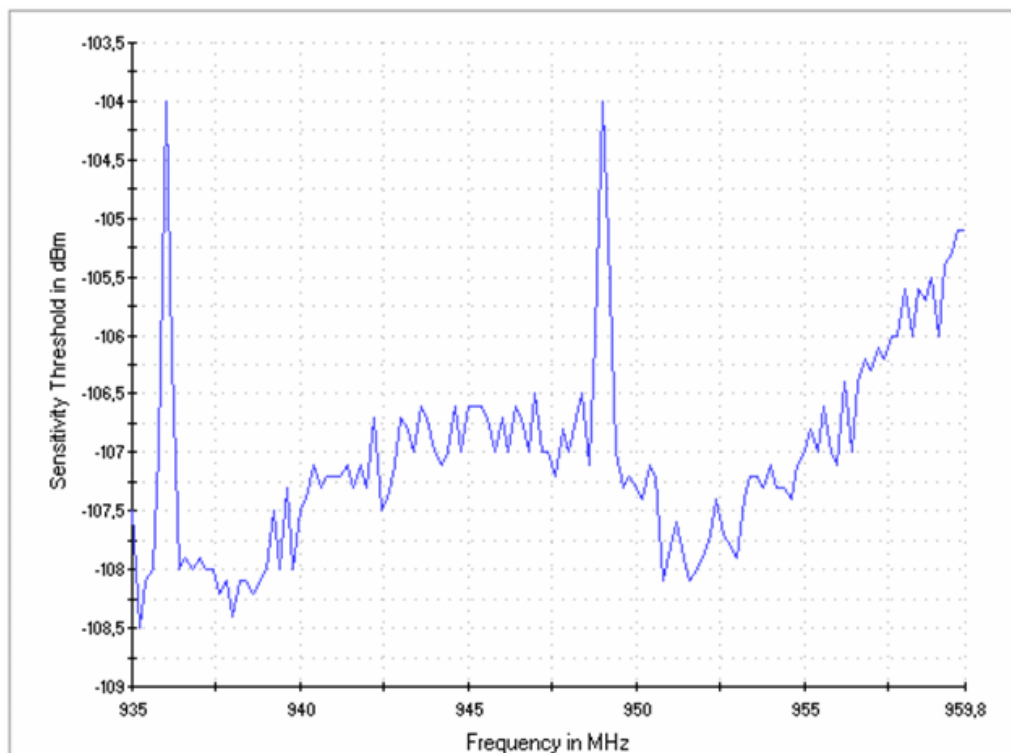


Fig. 4-10: Actual sensitivity of a GSM EUT

The plot documents the self-interference of the DUT caused by harmonics of the GSM system clock of 13 MHz.

Fig. 4-10 shows that even a degradation of only about 4 dB can be detected precisely. Moreover it demonstrates the advantages of a program controlled automatic loop. Manual tests at discrete frequencies could overlook such peaks easily.

Fig. 4-11 displays a desensitization result. There are 4 traces for 4 different positions of the DUT in the DST200 chamber, 4 traces with and 4 without interferer.

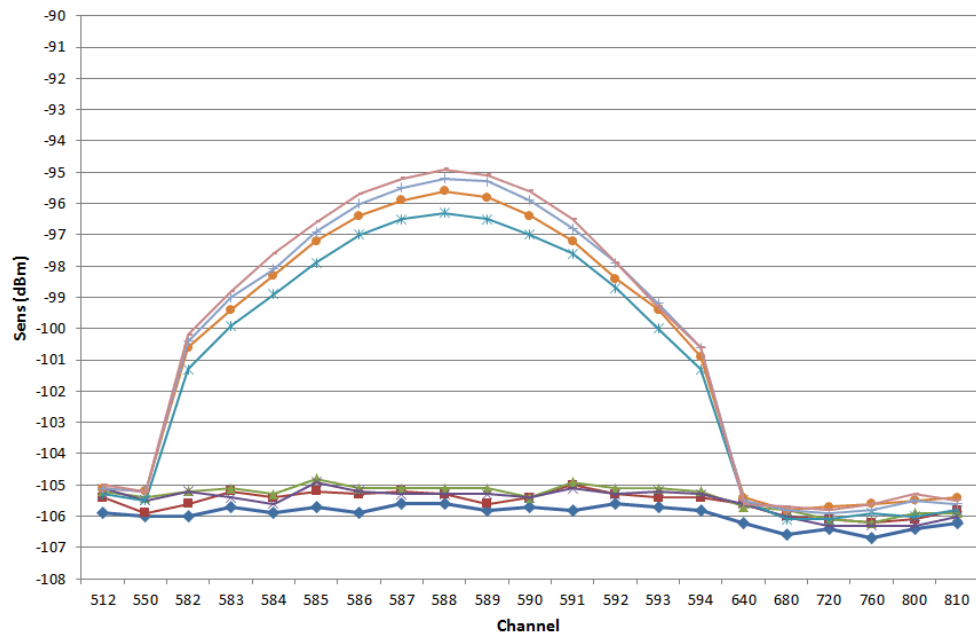


Fig. 4-11: Desensitization measurement result on PCS channels

Here the interfering signal was the jittered clock of the camera inside the device under test. We see a degradation of the RX sensitivity of about 10 dB. This violates the limits of the ETSI standard regarding the stipulated sensitivity, and will influence the cellular traffic.

As expected the desensitization caused by internal interferers is independent of the DUT spatial position in the shielded chamber.

4.5 Measurement reports

Open the *Report Settings* window by clicking the icon in the configuration menu of the test templates (Fig. 4-4 on page 33).

The report function of the AMS32 software collects all measured test data such as graphics or numeric results, test environments, EUT information and hardware setup in one document. The report layout can be customized in the *Report Settings*, and the result file is saved in different standard formats (see Fig. 4-12).

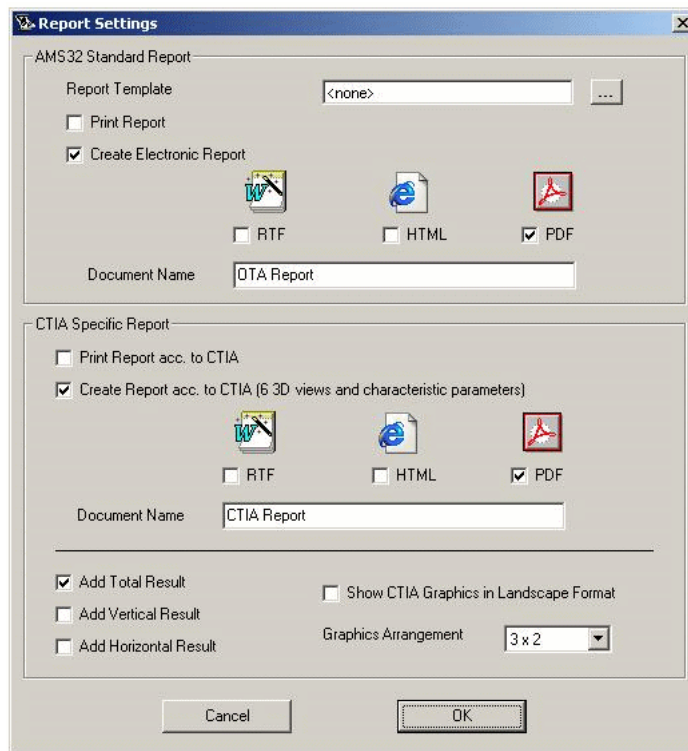


Fig. 4-12: Customizing the measurement report

Especially the product optimization process for a wireless device requires many cycles with repeated measurements of the same test condition. The import and display of previous result graphs immediately show the effects of design changes and improvements.

5 Summary and outlook

The purpose of this application note was to show that when different radio systems coexist within one device and operate simultaneously, considerable interference occurs with certain frequency combinations. These disturbances can be described as a decrease in RX sensitivity (desensitization).

The CMW wideband radio communication tester from Rohde & Schwarz allows such effects to be precisely measured e.g. in the R&S® DST200 diagnostic chamber. Measurement results are reproducible because the DUTs can exactly be positioned.

AMS32 software allows to automatically run the coexistence measurements over complete frequency bands and all possible power levels, which could be done only for single frequencies and levels within the scope of this application note.

It can be seen that BER or PER measurement results do not suffice as the only figure of merit for desensitization. It is absolutely essential to measure the current throughput.

Although over-the-air measurements in a shielded chamber are required in order to obtain objective reproducible results, they do not reflect the physical reality. The results of the measurements taken with the door of the diagnostic chamber open turned out to be poorer than the results when the chamber was closed. This can be explained, at least for WLAN, by the DUT's performance being decreased not only by the strong interferer inside the DUT but also by the significantly weaker signals e.g. from access points in the vicinity.

To reduce the radio systems' interference, a number of measures can be taken:

Design measures:

- Decoupling the antennas in the DUT. This is achieved by placing the antennas as far apart from each other as possible, by providing shielding elements and by different polarization.
- Reducing unwanted emissions. This is done by suppressing harmonics more strongly, improving the linearity of the analog stages in the respective TX and installing additional filters.
- Implementing a robust design of the analog stages in the respective RX.

These principles are already implemented in advanced equipment. The following measures may be of further help.

Improved communication techniques:

- Avoiding adjacent channels at band edges
- Assigning timeslots to the different users
- Minimizing the respective transmit power

These measures are much more complex; an optimization for one user implicitly means a disadvantage for one or more other users.

Dividing the ISM band between a WLAN and a Bluetooth® user (as described in section 3.4.3) only works if there is a low load in the ISM band. This will no longer

function when as few as three WLAN channels of 25 MHz bandwidth each are established next to each other. The capacity of a radio network will also be reduced to a certain extent when particular free channels are not used.

Also the avoidance of collisions in the WLAN access mode (carrier sense multiple access, CSMA) and in adaptive frequency hopping with Bluetooth® will decrease the original channel capacity. In this case, the resource time assigned for each user will diminish, and throughput will decline correspondingly. But the channel load is optimal, because no rejected packets have to be retransmitted.

There is a two-edged effect with the transmit power of the radio users. High transmit power always means a better signal-to-noise (S/N) ratio, i.e. better, more reliable transmission for the individual user. Conversely, it means a poorer S/N ratio for all other users in the same radio network. (This is why the transmit power for mobile phones in today's networks are individually set by the corresponding base stations.) A further reduction to the benefit of another radio network would be an unreasonable disadvantage to a user.

If WLAN and Bluetooth® are generated in one chip, it is possible to take the different needs into account and e.g. distribute the frequencies. The situation is different between cellular and noncellular networks: in practice, there is no exchange of information, e.g. about the occupancy of frequencies at band limits.

Recent efforts are aimed at setting up this very type of information exchange. That is, the current channel occupancy is to be reported to a higher layer in the protocol stack of the cellular networks in order to avoid certain frequencies or change levels if necessary [1]. As the radio resources cannot be enlarged arbitrarily, the best way to use the capacity of the overall spectrum optimally is to reduce interference. Measurements as shown in this application note are the essential first step.

6 Literature

- [1] **3GPP. 2011.** TR 36.816. *Study on signalling and procedure for interference avoidance for in-device coexistence, rel 11.* December 2011.
- [2] —. **2014.** TS 36.101. *Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (EUTRA); User Equipment (UE) radio transmission and reception, V12.5.0.* September 2014.
- [3] **CTIA. 2015.** *Test Plan for RF Performance Evaluation of Wi-Fi Mobile Converged Devices, Rev 2.0.* February 2015.
- [4] —. **2014.** *Test Plan for Wireless Device Over-the-Air Performance / Method of Measurement for Radiated RF Power and Receiver Performance, Rev. 3.2.4.* September 2014.
- [5] **Marvell Semiconductor. 2010.** *Yes! Wi-Fi and Bluetooth® Can Coexist in Handheld Devices.* March 2010.
- [6] **Rohde & Schwarz. 2014.** Application Note 1MA154. *LTE Base Station Tests according to TS 36.141.* January 2014.
- [7] —. Data Sheet. *TS8991 OTA Performance Test System.*
- [8] —. Getting Started. *AMS32.*

7 Ordering Information

Designation	Type	Order No.
Wideband Radio Communication Tester	R&S® CMW500	1201.0002K50
RF Diagnostic Chamber	R&S® DST200	1510.9047.02
OTA Measurement Software, basic package	R&S® AMS32	1508.6650.02
Over-the-air OTA Performance Test System	R&S® TS8991	1119.4309.02

Note: The individually required instrument options depend on your application. Please contact your local Rohde & Schwarz sales office for further assistance.

Please send your comments and suggestions regarding this application to <mailto:TM-Applications@rohde-schwarz.com>