

# Coexistence Test of LTE and Radar Systems

## Application Note

### Products:

- R&S®CMW500
- R&S®SMW200A
- R&S®TSMW
- R&S®IQR
- R&S®ARB Toolbox Plus
- R&S®TS6650
- R&S®SMBV100A
- R&S®FSL
- R&S®OSP

Air Traffic Control (ATC) radar, military Air Traffic Surveillance (ATS) radar and meteorological radar operate in S-Band frequency range. In fact 4G communication systems such as Long Term Evolution (LTE) make also use of these frequencies. Test and measurement of their coexistence is absolutely essential as performance degradation of mobile devices and networks and even malfunction of ATC radars has been proven.

This application note describes LTE and S-Band radar coexistence test and measurement. It addresses LTE user equipment, base stations and S-Band radars and presents test solutions.

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# 1 Introduction

Air Traffic Control (ATC) radar, military Air Traffic Surveillance (ATS) radar and meteorological radar operate in S-Band frequency range, which has been defined by IEEE as all frequencies between 2 to 4 GHz. Next to aviation and weather forecast, several different maritime radars worldwide also operate in this frequency band. The excellent meteorological and propagation characteristics make the use of this frequency band beneficial for radar operation. And not just for radar. These frequencies are of special interest also for wireless communications. In fact, 4G communications systems such as UMTS long-term evolution (LTE) make use of these frequencies as well.

The 3rd Generation Partnership Project (3GPP) and standardization body behind LTE started its work on this new technology back in 2004. Four years later, in December 2008, the work on the initial version of the standard was finished and published as part of 3GPP Release 8 for all relevant technical specifications. With the version from 07/2013 of the LTE standard there are in total 41 frequency bands specified. Some of these frequency bands are fairly close to operational S-Band radar systems which demand coexistence tests, measurements and verification to ensure proper functioning of both radar and mobile communication.

Coexistence is not only of major interest in case of different systems operating in the spectral and regional neighborhood. As known from mobile communication, interference between base stations can also occur in presence of another base station operating in the same regional area. Automotive radar systems may also face coexistence challenges. With any deployed radar sensor for automotive safety applications such as blind spot detection, pedestrian protection or automated cruise control, the noise floor for other radar sensors operating in the same spectral band and regional area increases and detection becomes more difficult. These systems therefore have to be tested in presence of similar radar signals.

This application note describes potential issues concerning S-Band radar systems and LTE signals from base stations / mobile devices operating close-by. It addresses frequency allocation of these systems, explains the performance degradation or malfunction that can be expected and describes test and measurement solutions for interference test of radar and LTE networks in detail.

## 2 Mobile Networks and Radar Systems

Continuously increasing mobile data traffic and the demand for higher data throughput of mobile devices requires higher spectral efficiency or the extension of allocable frequencies, hence more bandwidth. For example in 2G mobile communication, the Global System for Mobile Communications (GSM) a bandwidth of 200 kHz per channel was specified. In comparison, LTE defines a bandwidth of 20 MHz per channel.

LTE is supposed to operate in two different modes, Frequency Division Duplex (FDD) and Time Division Duplex (TDD). Both duplex modes are using different frequency bands worldwide. With the latest version of the LTE standard there are in total 29 frequency bands for FDD and 12 frequency bands for TDD. Table 1 lists the LTE FDD frequency bands, where the ones falling into the S-Band frequency range are marked in yellow. The frequency bands that are fairly close to any operational S-Band radar system are highlighted.

E-UTRA Band	Uplink in MHz			Downlink in MHz			E-UTRA Band	Uplink in MHz			Downlink in MHz		
1	1920	-	1980	2110	-	2170	18	815	-	830	860	-	875
2	1850	-	1910	1930	-	1990	19	830	-	845	875	-	890
3	1710	-	1785	1805	-	1880	20	832	-	862	791	-	821
4	1710	-	1755	2110	-	2155	21	1447.9	-	1462.9	1495.9	-	1510.9
5	824	-	849	869	-	894	22	3410	-	3490	3510	-	3590
6	830	-	840	875	-	885	23	2000	-	2020	2180	-	2200
7	2500	-	2570	2620	-	2690	24	1626.5	-	1660.5	1525	-	1559
8	880	-	915	925	-	960	25	1850	-	1915	1930	-	1995
9	1749.9	-	1784.9	1844.9	-	1879.9	26	814	-	849	859	-	894
10	1710	-	1770	2110	-	2170	27	807	-	824	852	-	869
11	1427.9	-	1447.9	1475.9	-	1495.9	28	703	-	748	758	-	803
12	699	-	716	729	-	746	29	N/A	-	N/A	717	-	728
13	777	-	787	746	-	756	30	2305	-	2320	2345	-	2360
14	788	-	798	758	-	768	31	452.5	-	457.5	462.5	-	467.5
17	704	-	716	734	-	746							

Table 1: LTE FDD frequency bands; frequency bands within S-Band are marked yellow

LTE base stations (BS) may be disturbed through radar systems. Depending on the ATC or ATS radar system a power of up to 7000 MW EIRP is transmitted. The blocking requirements of the LTE BS and mobile have therefore also to comply with these figures; taken into account the distance of the BS or UE. TS36.141 defines the blocking performance requirement for wide area BS as described in Table 2.

Operating Band	Centre Frequency of Interfering Signal [MHz]	Interfering Signal mean power [dBm]	Wanted Signal mean power [dBm]	Interfering signal centre frequency minimum frequency offset from the lower (higher) edge [MHz]	Type of Interfering Signal
1-7, 9-11, 13, 14, 18, 19, 21-23, 24, 33-43	(F <sub>UL_low</sub> -20) to (F <sub>UL_high</sub> +20)	-43	P <sub>PREFSENS</sub> +6dB*	See table 7.6-2	See table 7.6-2
	1 to (F <sub>UL_low</sub> -20) (F <sub>UL_high</sub> +20) to 12750	-15	P <sub>PREFSENS</sub> +6dB*	—	CW carrier

Table 2: Blocking performance requirement for Wide Area BS [1]

The user equipment (UE) may even be closer to a radar system. According to 3GPP TS36.521-1 out-of-band blocking parameters are defined as shown in Table 3.

E-UTRA band	Parameter	Units	Frequency			
			range 1	range 2	range 3	range 4
1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43	$P_{\text{interferer}}$	dBm	-44	-30	-15	-15
	$F_{\text{interferer}}$ (CW)	MHz	$F_{\text{DL\_low}} -15$ to $F_{\text{DL\_low}} -60$	$F_{\text{DL\_low}} -60$ to $F_{\text{DL\_low}} -85$	$F_{\text{DL\_low}} -85$ to +1 MHz	-
2, 5, 12, 17	$F_{\text{interferer}}$	MHz	-	-	-	$F_{\text{UL\_low}} - F_{\text{UL\_high}}$

Note: For the UE which supports both Band 11 and Band 21 the out of blocking is FFS.

Table 3: Out-of-band blocking parameters [1]

In 3GPP TS36.521-1 [1] the test purpose of "TC 7.6.2 Out-of-band blocking" is described with an "Unwanted CW interfering signal falling more than 15 MHz below or above the UE receive band, at which a given average throughput shall meet or exceed the requirement...". Under minimum conformance requirements the throughput is mentioned to be "≥95% of the maximum throughput of the reference measurement channel".

As shown in several measurements, disturbance of LTE networks occurs through S-Band radar, such as degradation of performance due to lower throughput indicated by an increasing block error rate (BLER). Throughput reduction is unlikely, but not a major drawback. However spectral efficiency, power reduction and costs are of great importance for any mobile network operator. Therefore disturbance through other signals is therefore of great interest.

Unlike mobile communication, radar is not defined by a global specification. Thus, many different systems applying different waveforms, frequencies and bandwidth are deployed and operate nearly autonomously to detect the desired kind of target. For a radar engineer, bandwidth is also one of the key parameters when defining the radar system, as bandwidth defines range resolution. Depending on the radar, bandwidth can range from nearly zero (just a carrier frequency, CW radar) to measure radial velocity up to several GHz for high resolution range measurements (e.g. Ultra Wideband Radar, UWB).

The 2.7 GHz to 2.9 GHz frequency band is primarily allocated to aeronautical radio navigation, i.e. ground based fixed and transportable radar platforms for meteorological purposes and aeronautical radio navigation services. Operating frequencies of these radars are assumed to be uniformly distributed throughout S-Band [4]. The two frequency bands for mobile communication and aeronautical radio navigation are very closely located; hence coexistence has to be proven.

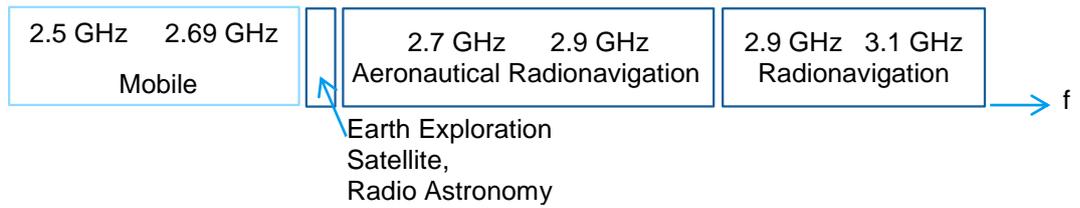


Figure 2-1: International Telecommunication Union Radio Regulations in the band of 2.5 GHz to 3.1 GHz [3]

Presence of LTE signals and less selective filters in the radar receiver can cause significant interference or even damage. This can be indicated by false target detection or by the high power state of the receiver protector. The latter can occur when LTE signals and spurious emissions are very strong and received by the radar. In the case of weaker signals or signals outside the nominal receiver bandwidth the radar could go into compression and produce non-linear responses or react by raising the Constant False Alarm Rate (CFAR) threshold. Thereby present targets can be lost in further measurements and targets with low power echoes cannot be detected, hence the maximum detection range or probability of detection is degraded [6].

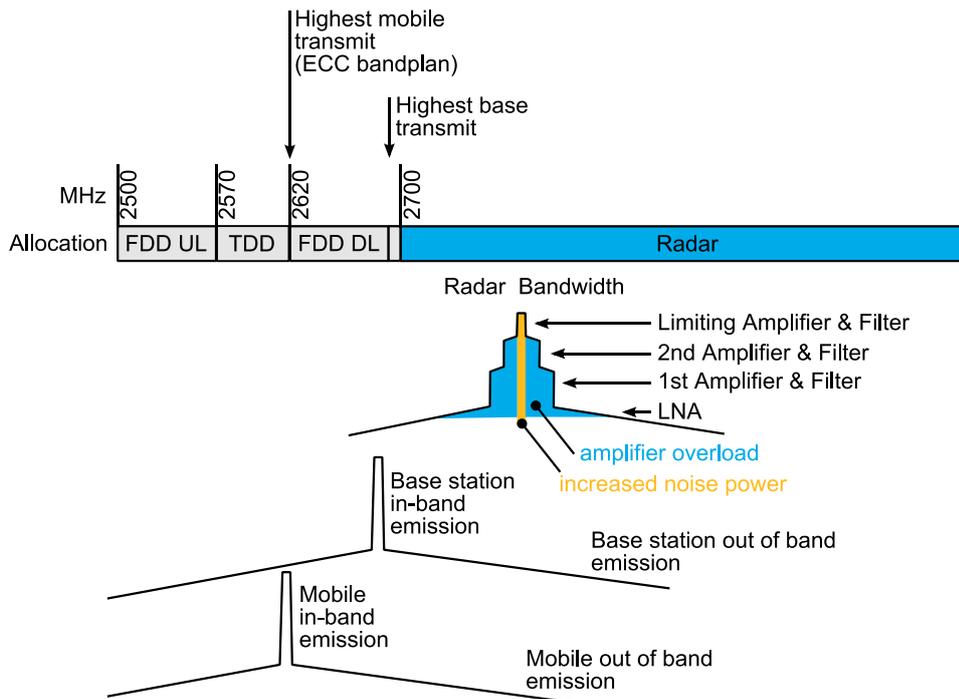


Figure 2-2: Radar Amplifier Chain in the Frequency Domain and Out-Of-Band and In-Band Interference

Test and measurement solutions were developed to apply different synthetic as well as recorded signals to both LTE networks and S-Band radar systems. These test solutions allow verification of proper functionality and in the case of interference or even malfunction.

## 2.1 Air Traffic Control Radar

There are many different types of Air Traffic Control (ATC) radar deployed worldwide. Beside the frequency allocation, typical transmit power, antenna gain, maximum ranges, opening angles of the antenna in horizontal or vertical direction, pulse duration, pulse repetition frequency, duration time of a single turn of the antenna are of interest.

To get a feeling what type of signal and which power could disturb the receiver of the LTE mobile or base station, the table below gives an overview of typical values.

Parameter	Typical Values
Transmit Power	2 kW - 20 MW
Maximum Range	100 km - 500 km
Horizontal Antenna Opening Angle	0.4° - 2.5°
Pulse duration	< 1 $\mu$ s - 400 $\mu$ s (most ATC radars use double pulses, e.g. 2 x 1 $\mu$ s or 2 x 2 $\mu$ s) Every single pulse is transmitted at a different frequency (frequency diversity) in a distance of about 10-20 MHz
Pulse period	< 1ms - 4ms
Antenna rotation time	5 rounds/min - 15 rounds/min
Antenna gain	25 dBi - 40 dBi

Table 4: Typical ATC radar parameters values

Some ATC radars also have different pulse waveform modes. The ASR-E for example can operate in between 2.7 GHz and 2.9 GHz with 1 $\mu$ s and 2x 45 $\mu$ s pulse duration and different antenna rotation times, e.g. 15 rounds/min or 12 rounds/minute [10].

For a successful test it is essential to know the radar or disturbing signal in detail and either to rebuild it using an arbitrary waveform file generator or to record and to replay the signal as described in this application note.

## 3 Hardware and Software Requirements

### 3.1 Mandatory Requirements

For chipset and wireless device testing the R&S®CMW500 Wideband Radio Communication Tester is widely used throughout the industry. The unique design as a flexible hardware platform enables the design engineer to use it for protocol and signaling test, but also for RF parametric tests of transmitter and receiver performance of a mobile terminal.



Figure 3-1: R&S CMW500 Wideband Radio Communication Tester

Hardware requirements:

- R&S®CMW500
- Mini-UICC Test Card, supp. 3GPP SIM/USIM/ISIM/CSIM (acc.)

Software requirements:

- CMW LTE Signaling Version (LTE 3.2.70)
- CMW General Purpose RF
- LTE FDD R8, TX measurement, uplink (SL)
- LTE FDD R8, SISO, basic signaling (SL)
- LTE R8, SISO, advanced signaling (SL)

For the entire R&S®CMW500 product configuration it is referred to the ordering information at the end of this application note.

### 3.2 Optional Hardware and Software Requirements

Optional hardware and software requirements enhance test and measurement possibilities. Using the equipment below additional tests such as recorded RF

spectrum can be tested against LTE signaling using the CMW500. Also large waveform files (\*.wv-files) can be replayed using SMW200A.

Optional hardware and software requirements:

- R&S®SMW200A
- R&S®TSMW
- R&S®IQR
- R&S®ARB Toolbox Plus Windows
- R&S®CMW Z-10 RF Shield Box
- RF Combiner
- RF Attenuator

### 3.2.1 Vector Signal Generator

For Signal Generation the vector signal generator R&S®SMW200A is used which enables enhanced possibilities to verify selective filtering, BLER and throughput with the CMW500, when adding a certain signal, e.g. jamming signal or radar signal. It is also possible to use the R&S®SMBV100A as an interferer.



Figure 3-2: R&S SMW200A Vector Signal Generator

### 3.2.2 Universal Radio Network Analyzer and Data Recorder

R&S®TSMW Universal Radio Network Analyzer is used as a digital I/Q baseband receiver which received data is stored on a R&S®IQR data recorder.



Figure 3-3: R&S TSMW and R&S IQR

Using the equipment above, arbitrary waveforms can be generated, as well as recorded I/Q data can be replayed to perform coexistence tests of any present signal and S-Band radar signal in particular.

### 3.2.3 ARB Toolbox

The ARB Toolbox Plus is an easy-to-use, feature packed software package that is used for many ARB waveform related tasks, Figure 3-4. This software is the successor of the ARB Toolbox which is bundled with the 1GP88 application note [7] and the CDM Toolbox, described in application note 1GP96 [11].

This software is used for

- creating ARB waveform files from custom IQ data,
- import of data from MATLAB .mat files,
- graphical evaluation of waveform content,
- resampling or filtering of waveforms,
- creation of analog modulated signals as ARB files,
- editing marker data in waveform files,
- creation of complex multi carrier scenarios.

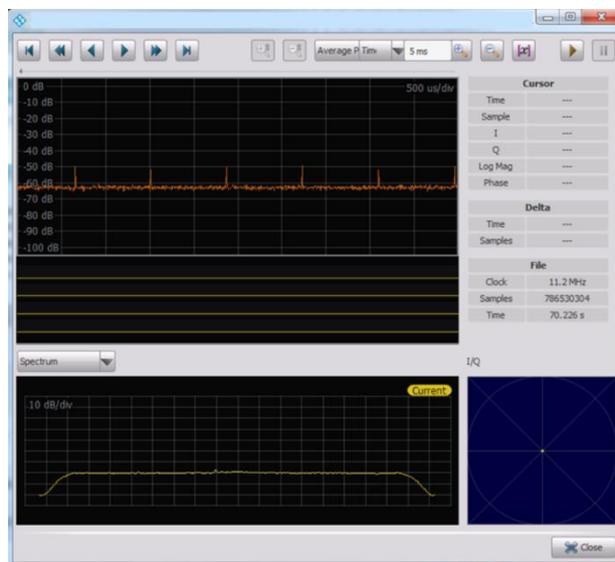


Figure 3-4: ARB Toolbox Plus replaying recorded I/Q data (ATC radar)

### 3.2.4 RF Shield Box

The R&S®CMW-Z10 RF shielding box offers excellent shielding effectiveness, superior coupling characteristics and can be used for frequencies up to 6 GHz. In this measurement the DUT is placed inside the shielding box as depicted in Figure 4-1.



Figure 3-5: RF Shield Box

## 4 Test & Measurement of LTE Mobiles

LTE Mobiles are tested in presence of recorded radar signals and in presence of synthetic rebuild radar signals using arbitrary waveform generator (ARB). This chapter addresses how to record radar signals, and describes the measurement setup and methods.

### 4.1 Recording of Radar Signals

In order to test somewhat real-world conditions an S-Band radar signal is recorded and played back on the desired frequency while performing a throughput test or receive sensitivity test on LTE-capable terminal that is for example operational in Band 7. The ATC radar signal is recorded at an airport using R&S®TSMW Universal Network Scanner.

In this context the TSMW is tuned to the desired S-Band radar frequency to capture the RF signal, perform the down conversion and thus convert the RF signal to IQ data. As the amount of data can exceed the internal memory, R&S®IQR recorder is connected via an internal interface directly to the TSMW. The IQ data can now be streamed to the IQR and is stored on the 1 TByte harddrive.

The recorded I/Q data is transferred in the \*.wv format to the R&S®CMW500 or R&S®SMW200A either via an USB-stick or Ethernet connection.

For RF spectrum recording please see Application Note 1SP16 [2].

### 4.2 Measurement Setup

There are three possibilities to setup the measurement devices for coexistence tests:

1. Use the CMW with basic RF frontend and a HF combiner,
2. the CMW and SMW with HF combiner,  
or
3. the CMW with advanced RF frontend.

In the first solution the Device Under Test (DUT) is connected as depicted in Figure 4-2.

RF 3 OUT is transmitting the radar signal which has been recorded.

RF 1 COM is in signaling mode connecting the DUT to the CMW500. Using an RF combiner both signals are routed to the DUT.

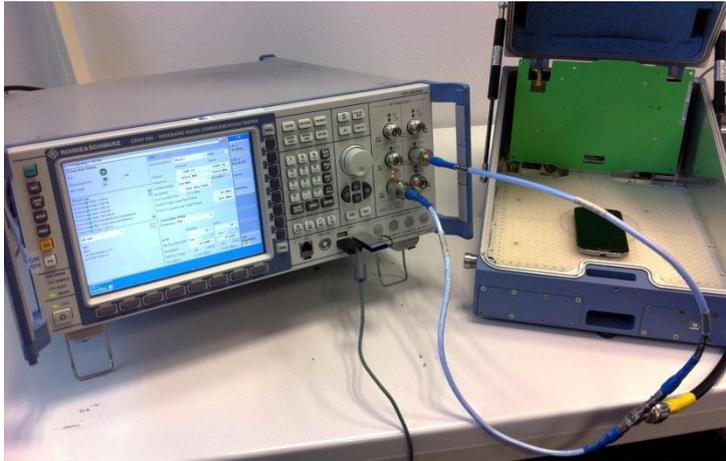


Figure 4-1: Measurement Setup using CMW500 and a LTE DUT

NOTE:



The RF output power of the DUT **should not exceed the input limits** of the RF 3 OUT connector. Please add a proper RF attenuator (e.g. 10 dB) in case the DUT transmits high power.

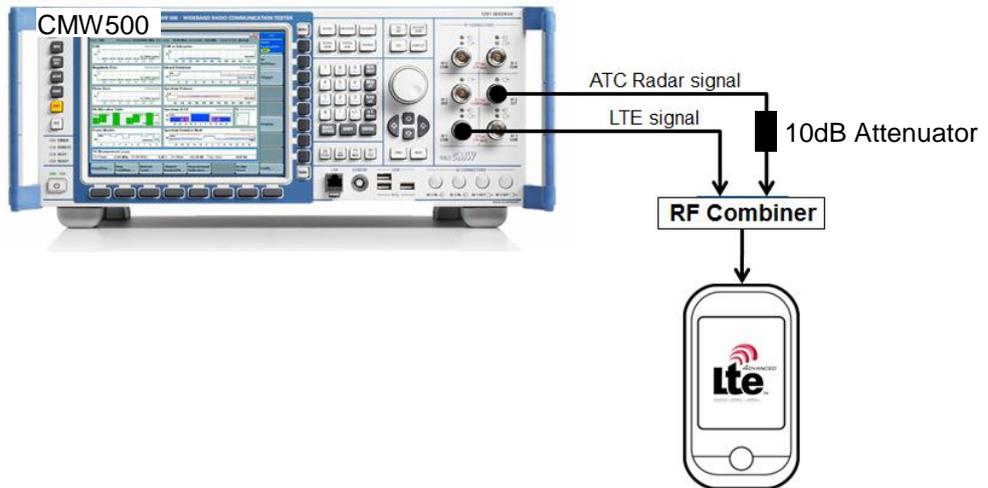


Figure 4-2: CMW500 and DUT Setup for LTE and S-Band Radar coexistence tests

Figure 4-2 shows the configuration in case of a CMW500 with a RF frontend with basic functionality (product type CMW-S590A).

Another solution is to use the vector signal generator SMW200A as source of the disturbing signal. The SMW200A has selectable predefined signals available, such as pulse or CW signals which can also be used to verify coexistence. This setup also

enhances flexibility to change the settings of the disturbing radar signal, as both screens are visible simultaneously. The test setup is shown in Figure 4-3.

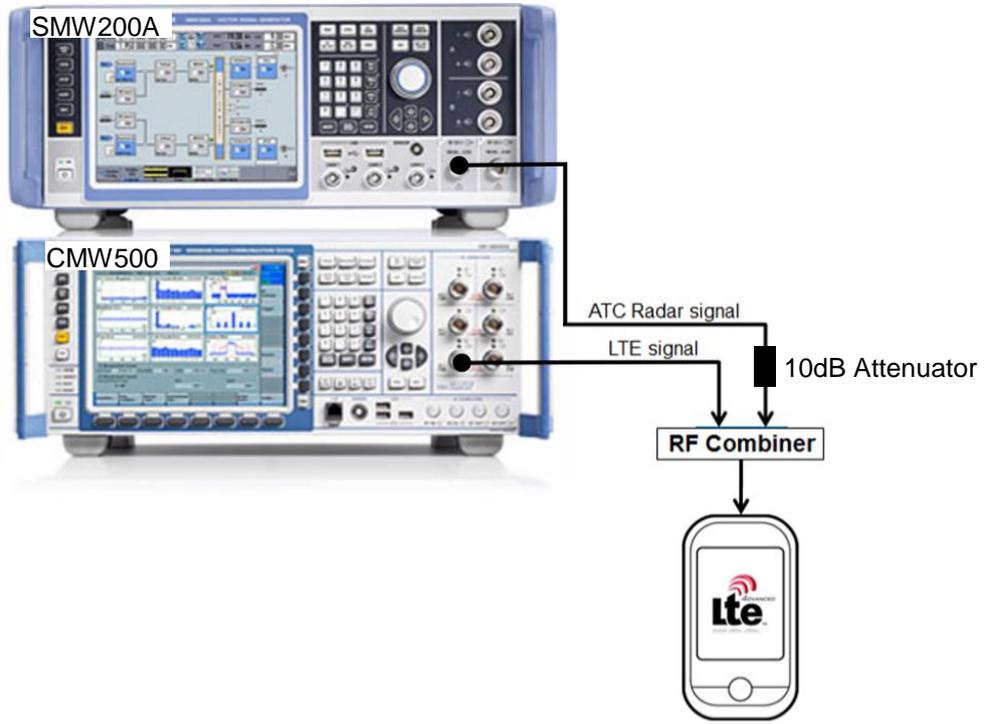


Figure 4-3: CMW500, SMW200A and DUT Setup for LTE and S-Band Radar coexistence tests

A third option is to use a CMW500 with the advanced frontend, RF Frontend (Advanced) R&S CMW-B590D.

The interference signal is then routed to the same RF connector as the LTE uplink / downlink signal. This setup reduces hardware and setup complexity and saves time and cost.



Figure 4-4: CMW500 with advanced RF frontend and DUT

## 4.3 Measurement Configuration

After connection setup, start the CMW500 LTE signaling and perform the throughput and BLER test **without** presence of any other signal with the parameters, described in section 4.3.1.

In a second step the same test will be performed **in presence** of the radar signal as described in section 4.3.2.

Comparing throughput and CQI measurements of section 4.3.1 and section 4.3.2 gives a result about the performance of the DUT.

### 4.3.1 BLER and throughput measurement without disturbing signal

For the test, the maximum throughput and Channel Quality Indicator (CQI) of 15 was determined adapting to the Reference Sensitivity Level (TS 36.521-1, 7.3) test. Therefore OFDMA Channel Noise Generation (OCNG) has to be enabled in the R&S CMW500 in order to simulate the existence of other users. The Active TPC Setup has to be set to "Max Power" to ensure that the mobile (UE) power reaches its maximum. In difference to TS 36.521-1, 7.3 the modulation scheme 64QAM in the DL and 16QAM in the UL has to be selected. This ensures a maximum throughput at a given sensitivity.

1. Start CMW500 and start the Signal Generator
  - Press: SIGNAL GENERATOR
  
2. Start LTE Signaling 1
  - Select: LTE Signaling 1
  - Press: ON
  
3. Select LTE Signaling 1 and change the signaling properties to
  - Operating Band 7
  - Cell Bandwidth 20.0 MHz
  - Connection Setup: Modulation 64 QAM Downlink, 16 QAM Uplink
  
4. Start the LTE Signaling and wait for DUT to establish the connection.
  
5. On successful connection, change the PCC frequency to
  - Frequency: 2680.0 MHz

6. Change the Connection Setup to

- Scheduling: CQI, Follow WB

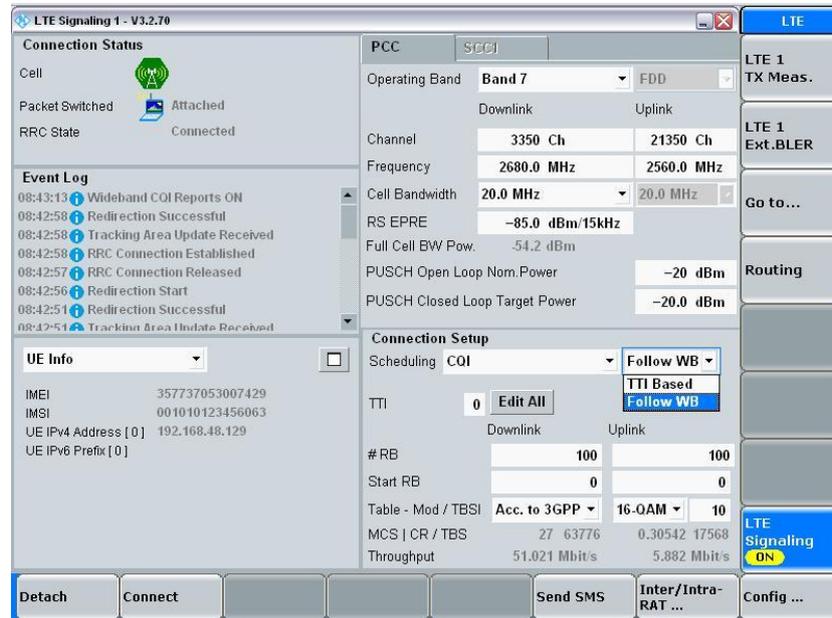


Figure 4-5: CMW Settings

7. Perform the BLER measurement by pressing

- LTE 1 Ext. BLER

8. Change the Signaling Parameters of the DUT to Max Power

- Press: Signaling Parameters
- Press: TPC
- Change "Active TPC Setup" to: Max Power

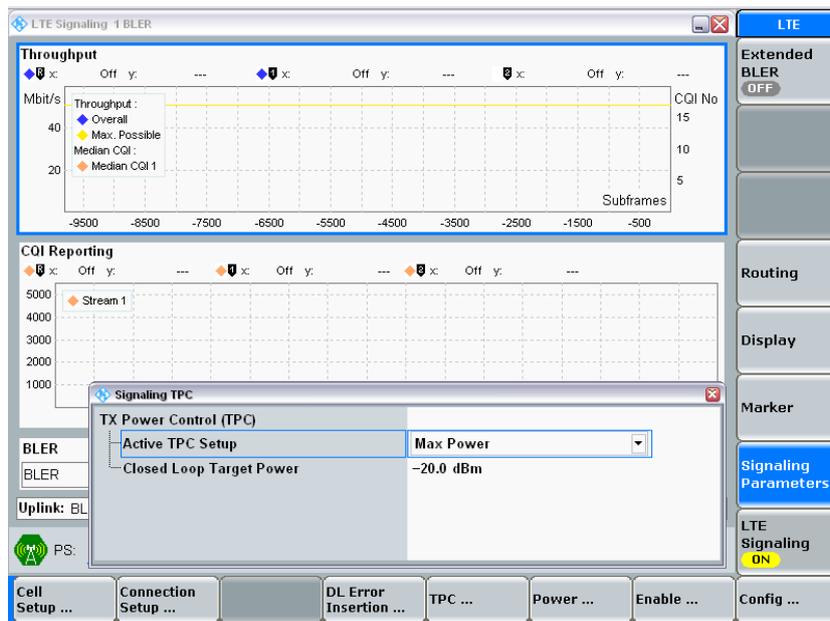


Figure 4-6: Active TCP Setup

9. Change the BLER Configuration to Single Shot

- Press: Config
- Select "Repetition": Single
- Change "No. of Subframes": 50000

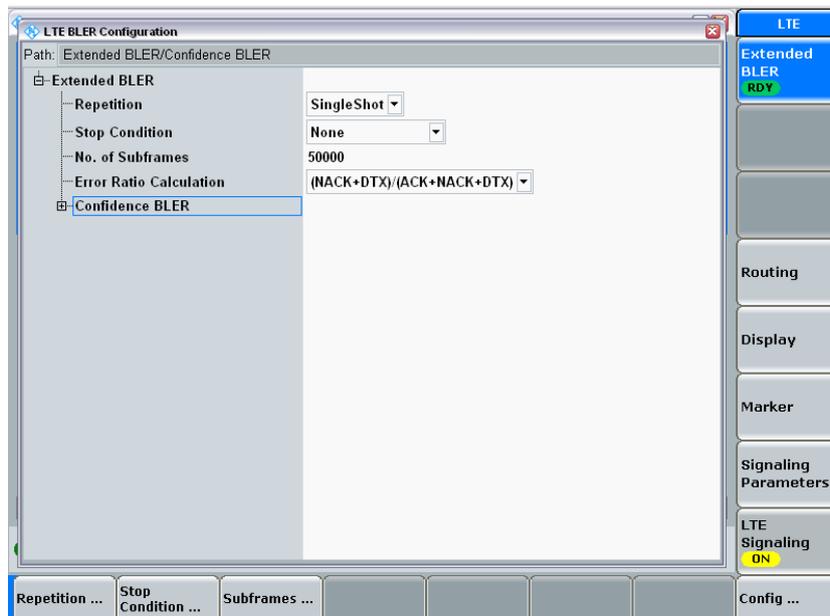


Figure 4-7: BLER Configuration

10. Start BLER Measurement

- Press: MEASURE
- Select: Extended BLER 1
- Press: ON

11. During the BLER Measurement:

- Change the RS EPRE to a threshold value where the CQI toggles between two desired values.

For example: high RS EPRE power results in a high CQI of 14 / 15. Lower power represents a more realistic CQI of 5 to 7. Repeat the BLER measurement in that purpose which satisfies your measurement needs.

In our example, Figure 4-8 shows that the RS EPRE was set to -104.5 dBm/15kHz, which resulted in a CQI toggling between 5 and 6. The average throughput was measured to be 9.18 Mbit/s and a BLER of 1.66%. This is a realistic value which is also measured in the field.



Figure 4-8: BLER Measurement and Cell Setup

These CMW settings are kept for further tests in presence of a disturbing radar signal.

### 4.3.2 BLER and throughput measurement with disturbing signal

Perform the throughput and BLER test **with** presence of a radar signal. Therefore CMW or SMW200A are used to replay a synthetic radar signal or a recorded ATC radar signal. Both methods are explained.

In case of recorded I/Q data, verify the power settings of the I/Q file. Therefore the R&S®FSW Signal Analyzer can be used to set the correct power settings of the ARB signal.

Keep the CMW500 settings from measurement described in section 4.3.1. Setup the SMW200A signal generator or CMW500 signal generator to replay a recorded radar signal or any other desired ARB signal as described below in section 4.3.2.1 or 4.3.2.2.

### 4.3.2.1 CMW General Purpose RF Generator

The CMW500 has a General Purpose RF Generator option, which allows to route two different signals through a single RF connector. The LTE Signaling is routed through the RF1COM connector with the RFTX1 converter. The General Purpose RF Generator, which replays the radar pulse signal is routed through the same connector, but using the RFTX2 converter as depicted in Figure 4-9.

Press Signal Generation and select the "General Purpose RF Generator". Inside the General Purpose RF Generator:

- Select: Routing > Converter: RFTX2

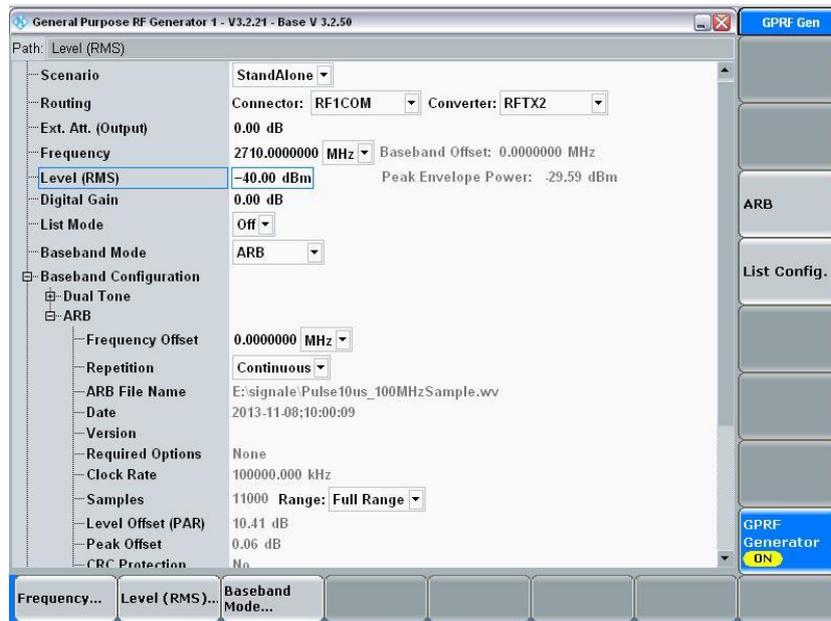
Set the desired frequency where your radar signal should to be transmitted. In this example a frequency of 2710 MHz has been set. The frequency which should be selected depends on your needs and the environment. Authority allows radars to operate as close as 2.7 GHz to LTE signals, see Figure 2-1.

- Set: Frequency: 2710 MHz

The power level of the radar signal depends on your personal experiences in the environment. In our measurement campaign we could measure a radar pulse power of up to 0 dBm in a non-restricted area in about 1-2 km away from the radar and around the airport. In greater distance and depending on the environment (e.g. buildings or trees shadowing the radar signal), power of up to -40 dBm could be measured.

Therefore a Level (RMS) of -40 dBm has been set in this example.

- Set: Level (RMS): -40.00 dBm



Select the Baseband Mode and file to replay. This file has been generated using the ARB Waveform Toolbox Plus, [7].

- Select: Baseband Mode: ARB
- Press: ARB > "Select ARB File"

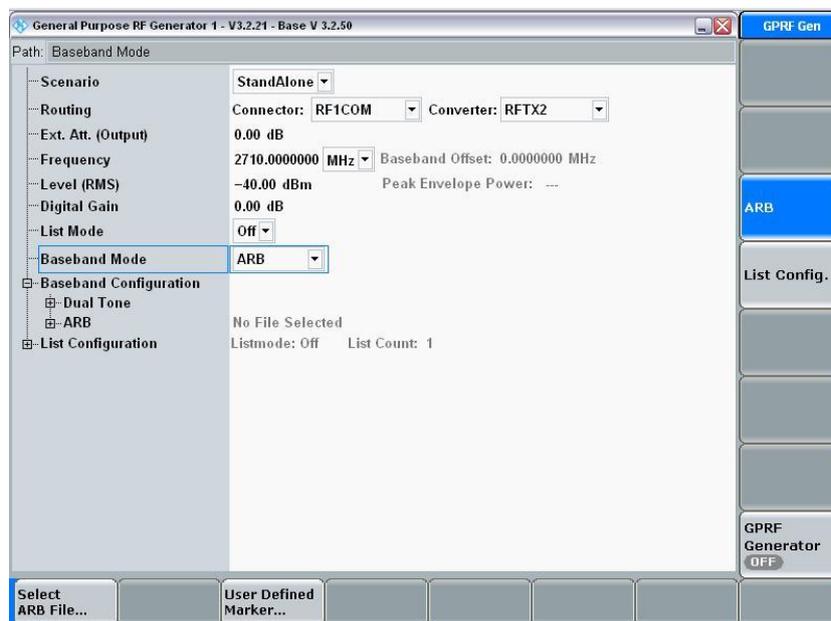


Figure 4-9: CMW General Purpose RF Generator Settings

Switch back to the LTE BLER measurement and perform the throughput measurement.

Start BLER Measurement

- Press: MEASURE
- Select: Extended BLER 1
- Press: ON

Compare the results to the measurement without present radar signal.

The presence of the radar signal reduced the throughput of the LTE DUT dramatically. As soon as the radar signal was switched on, the throughput dropped down and the BLER increased as shown in Figure 4-10.

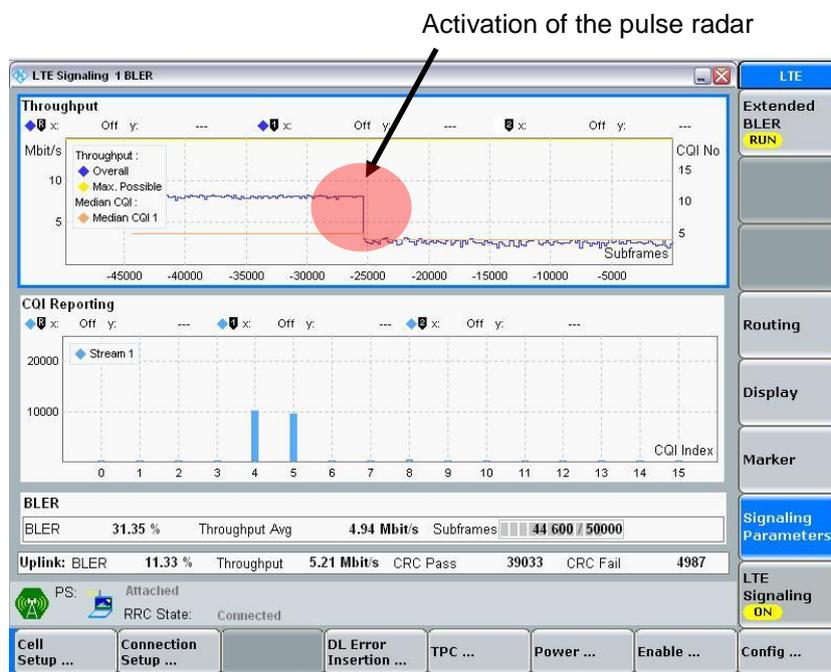


Figure 4-10: Throughput measurement when the pulse radar became active

NOTE:



The disturbing signal properties depend on your needs and experiences. As described in chapter 2 there are many different types of radar deployed. Pulse durations between 1µs and 400 µs are typically used and depend on the radar. Long pulse duration usually accompanies pulse compression.

In this example setup a short uncompressed pulse was used, as this is applied by ATC radar very often. The radar signal was created using R&S ARB Waveform Toolbox Plus [7].

### 4.3.2.2 SMW Signal Generator Arbitrary Waveform Generator

Another possibility is to use the Arbitrary Waveform Generator of the SMW200A signal generator.

The waveform replayed in this example was recorded at an airport. In case the recorded waveform is too long, extraction and wrapping is also possible using ARB Waveform Toolbox PLUS [7].

1. To replay the waveform, start the SMW200A, preset the vector signal generator and open the ARB configuration dialog of path A and load the desired waveform.

- Press: PRESET
- Press: Baseband A > ARB
- Load the desired waveform (e.g. in this document named SRadar10MHz, Figure 4-11)

Start replaying the waveform by switching the ARB state to on

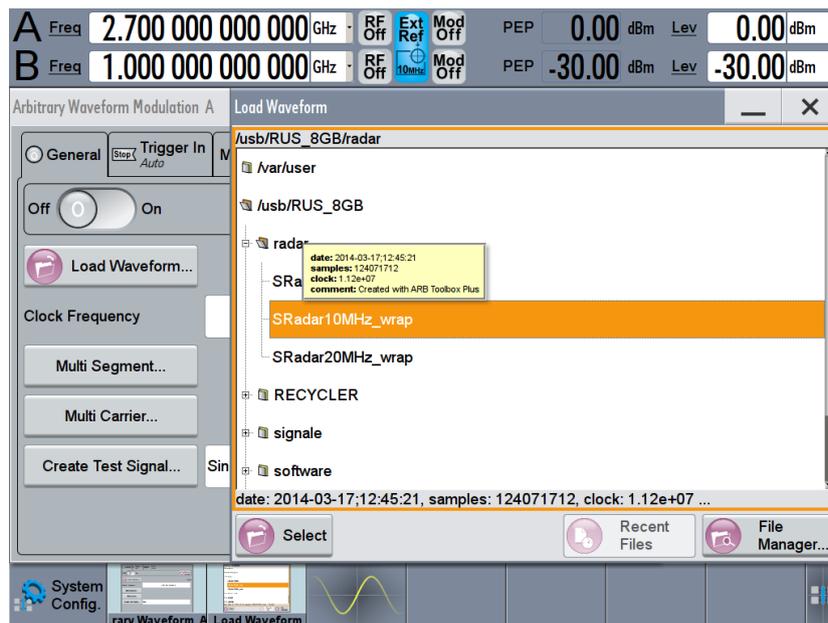


Figure 4-11: Waveform Selection for ARB

2. Set the RF frequency to 2.7 GHz or any other desired interferer frequency within the frequency range supported by the SMW200A (100 kHz...3/6 GHz).
3. Set the RF power level to the desired value and activate the SMW200A RF output.

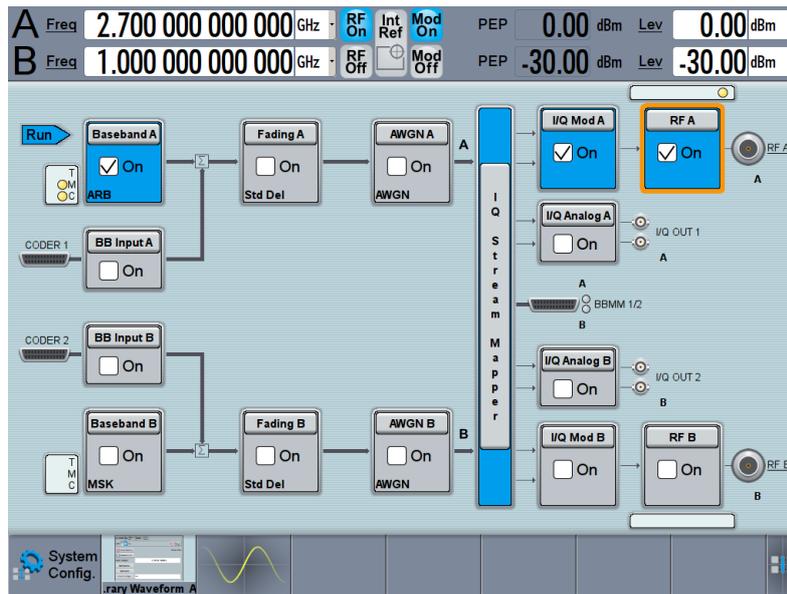


Figure 4-12: Frequency Setting

4. Rerun the BLER measurement at the CMW500 by pressing

- Press: MEASURE
- Select: Extended BLER 1
- Press: ON

The output of the BLER measurement is shown in Figure 4-13. The throughput dropped down to about 6 Mbit/s in equidistant intervals, i.e. when the radar pulse was transmitted into the direction of the DUT.

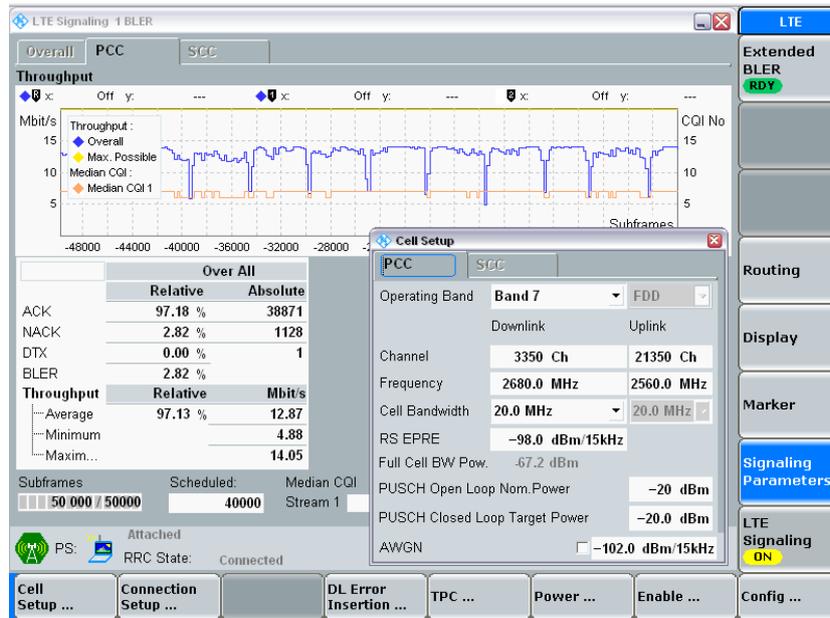


Figure 4-13: BLER measurement in presence of a radar signal

Please note that the required RS EPRE power changed in this CMW/SMW setup due to cabling and losses. In this case a HF combiner was used, which introduced approximately 6 dB loss. To get comparable results to the measurement method explained by using the CMW ARB this loss has to be taken into account.

One method to measure the cabling loss is to use the TX measurement offered by the CMW500. By setting the DUT to "max power" the cabling and connection losses can be determined.

Depending on the application, the DUT can be tested against any present signal. This can also include jamming signals.

Therefore the ARB I/Q file has to be loaded in the SMW200A or CMW500 ARB and replayed. During replay a sensitivity test, throughput, BLER measurement or other tests can be performed using CMW500.

## 5 Test & Measurement of Radar Systems

Any radar system operating close to LTE S-Band frequencies should be tested against interference. Rohde & Schwarz carried out several tests on S-Band ATC radars and could see significant performance reduction of these security relevant systems.

Therefore a test system was developed, which allows testing and verification of planned base station sites, which will operate close to S-Band radar systems, e.g. at airports.

The test methods described allows performing **real time radar tests**. The test setup is based on a modular concept, adaptable to other interference test scenarios and placed in the field. Hence, the radar can operate without any downtime during test. The test system is placed in front of the radar system in a distance of 100 m to 300 m and pointed towards the radar or into the desired direction of the base station planned, Figure 5-1.

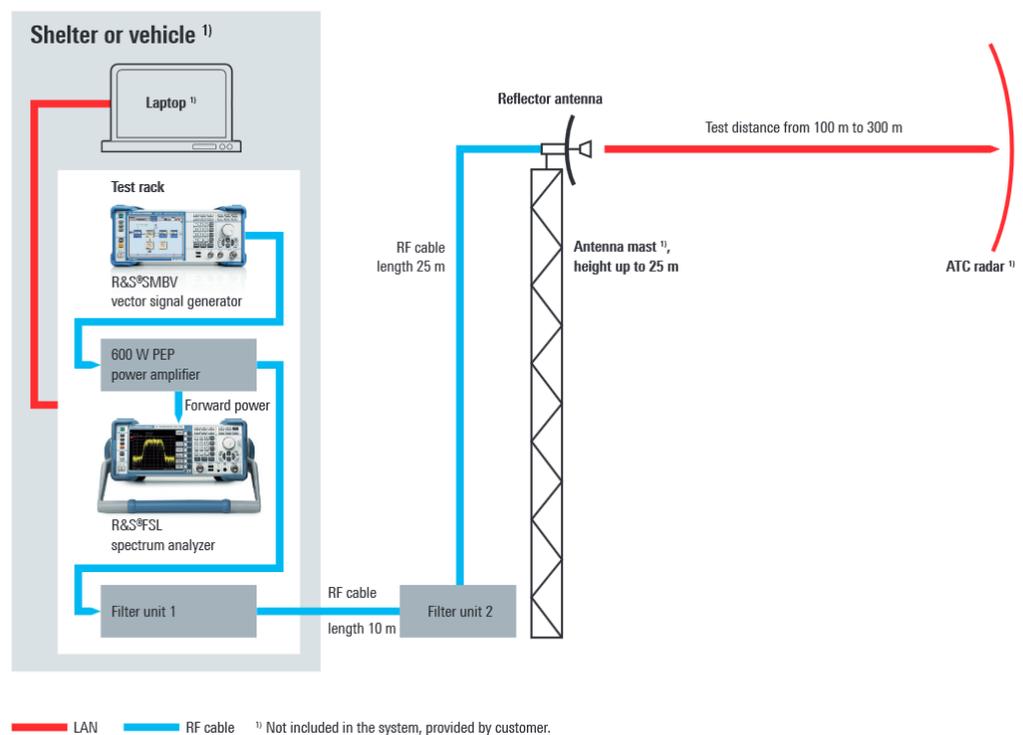


Figure 5-1: Radar Test Setup

### 5.1 Test System Description

The Test System R&S TS6650 consists of the following devices depending on the required and equipped functionality [5]:

- Spectrum Analyzer R&S FSL,

- Signal Generators R&S SMBV100A,
- Switch and Control Platform R&S OSP,
- Filter Unit R&S TS-FILT,
- RF Amplifier,
- Antenna with mounting kit,
- RF cable,
- other system cabling

The vector signal generator SMBV supports frequency from 9 kHz up to 6 GHz, with an RF bandwidth of up to 160 MHz supports 3GPP LTE FDD and TDD, 3GPP FDD/HSPA/HSPA+, GSM/EDGE/EDGE Evolution, TD-SCDMA, WLAN, WiMAX™ and all other important digital standards, Figure 5-2.



Figure 5-2: SMBV100A Vector Signal Generator

The FSL spectrum analyzer covers a frequency range from 9 kHz to 18 GHz and is lightweight and compact for on-site installation, maintenance and service.



Figure 5-3: FSL Spectrum Analyzer

The R&S®OSP open switch and control platform is designed for fast and easy implementation of RF switch and control tasks. A number of optional modules make the R&S®OSP ideally suited for a wide range of applications from simple RF switch functions to automatic path switchover in complex RF test systems such as EMC systems.

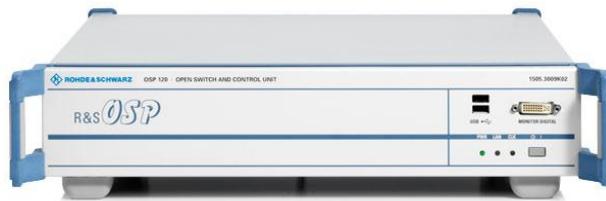


Figure 5-4: Open Switch and Control Platform R&S OSP

The R&S@TS-FILT is a customized product especially for this system. It protects the system against high power radar pulses and suppresses all spurious and noise signals from the amplifier by minimum 90 dB. Two relays give the possibility to remove the filter from the transmission path for out of band transmission.

Using these main components Rohde & Schwarz developed a radar test system as depicted in Figure 5-1. An additional laptop, power amplifier, filter units and antenna complete the system for S-Band radar tests. The rack is transportable by two persons and is placed at the base of the mast in a vehicle or a shelter.

## 5.2 Supported Scenarios

The test system for LTE and WiMAX interference test on ATC radars is located in a distance of 100 m to 300 m from the radar, depending on the local situation. It simulates the interference of several LTE and WiMAX base stations. The following scenarios are supported:

Basic test scenario for LTE Node BS (base stations):

- Up to different 20 LTE Node BS with 61 dBm EIRP PEP each, with minimum 1 km distance to the radar
- Configurable bandwidth between User, 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, 20 MHz for each base station signal, up to a total signal bandwidth of 120 MHz
- Generation of realistic LTE modulation with possibility of TDD or FDD mode and different traffic load. For the maximum distance and maximum field strength the crest factor of a scenario is limited to 15 dB.
- Availability of standard ETSI 3GPP test models for the basic test signal configuration. Possibilities of individual adaptation of the LTE signal parameters.

Basic test scenario for LTE User equipment:

- Up to different 20 LTE devices with 33 dBm each, located in minimum 100 m distance and a total crest factor up to 15 dB.

Basic test scenario for WiMAX:

- Up to different 20 WiMAX TDD base stations with 61 dBm EIRP PEP each.

- Configurable bandwidth between User, 1.75 MHz, 3.5 MHz, 7 MHz, 14 MHz, 28 MHz, for each base station signal, up to a total signal bandwidth of 120 MHz
- Availability of standard test models for the basic test signal configuration. Possibilities of individual adaptation of the WIMAX signal parameters.

For each different scenario to be applied the customer can create a setup composed out of several individually configured signal setups defined directly at the signal generator. The setup is transferred and stored in the control software at the laptop. This allows the maximum flexibility in signal definition. For the test the signal file is transferred back to the signal generator and transmitted.

A special feature of the test system besides its flexibility is the immunity against radar power received by the antenna during transmission of the interference signals at the same time. If the receive antenna is directly illuminated by the radar field strengths up to 1500 V/m can occur. The received radar power in the frequency range 2.72 GHz to 3.1 GHz is reflected while the interference signal is transmitted with low attenuation.

Other signal scenarios, different from the ones described above, are available on request and are partly already available with the described test system. As an example the number of base stations, base station power, distance of the base stations to the radar and distance of the test system to the radar depend on each other. Also mixtures of LTE and WiMAX or of LTE Node Bs and user equipment are possible. The limiting factor is the field strength at the radar, the crest factor of maximum 15 dB and a total bandwidth of 120 MHz. A detailed check of the customer requirements is possible.

## 5.3 TS6650 Radar Interference Tester Setup

The tester has to be setup on site. Please ensure to have a clear, easily accessible and non-slippery site. Connect the test system to single phase power supply of 230-240 VAC / 50/60 Hz complying with national regulations at the site where the system is installed.

Ensure that the power switches on all devices in the Test System are in the ON position and the Test System is connected to a suitable power supply outlet.

The FSL, the SMBV100A vector signal generator and the OSP have their own power switches on the front panel accessible and a main switch at the rear side of the instrument.

The TS-FILT Filter Unit is a passive system part and has no switch.

The power amplifier has only a main power switch on the front panel.

### 5.3.1 Waveform File Structure

Depending on your application a waveform has to be created and played back using the SMBV vector signal generator. Figure 5-5 shows the basic waveform file structure for LTE and WiMAX settings. The system is able to generate LTE/WiMAX base

stations or user equipment signals and transmit them with a directional antenna to the radar transceiver.

Initially the LTE and / or WiMAX settings are set and saved. By each setting a waveform can be extracted. Using the multi Carrier settings these waveforms are combined to a Multi Carrier Waveform file, which is replayed by the system, Figure 5-5.

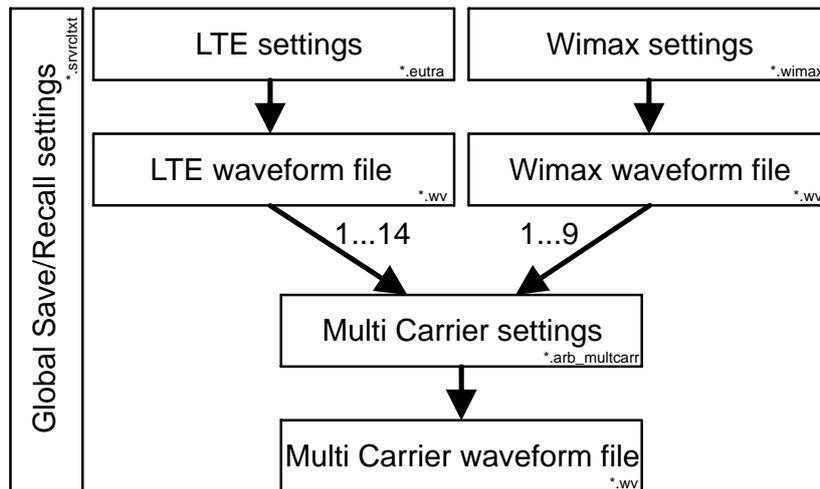


Figure 5-5: Waveform file structure

When generating the waveform, note that the crest factor depends also on the Base Station ID. For a low crest factor, ensure to set a different Base Station ID for each waveform generated. As an example, the crest factor of two different waveforms has been measured.

The crest factor of a single base station is depicted in Figure 5-6. An average power of -20 dBm and a crest factor of 12 dB haven been measured. In the time domain a peak envelope power of -8 dBm are shown.

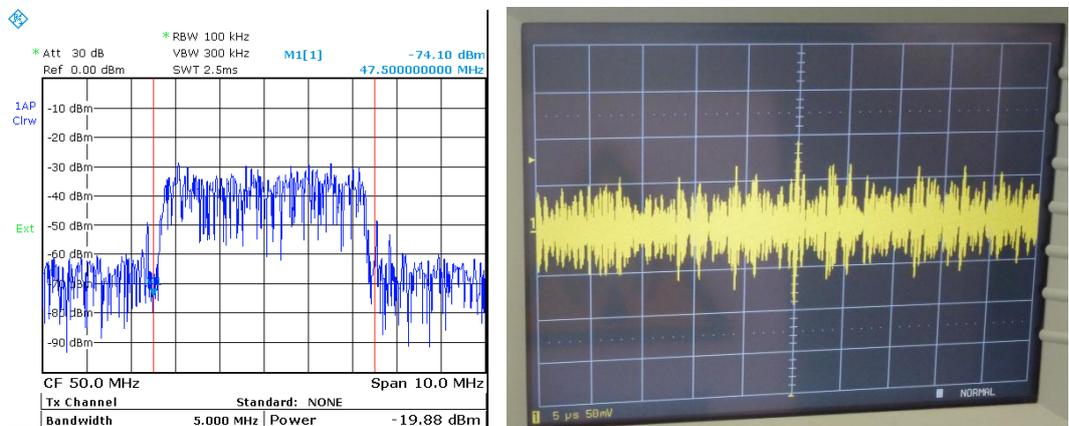


Figure 5-6: Crest fact of a single base station

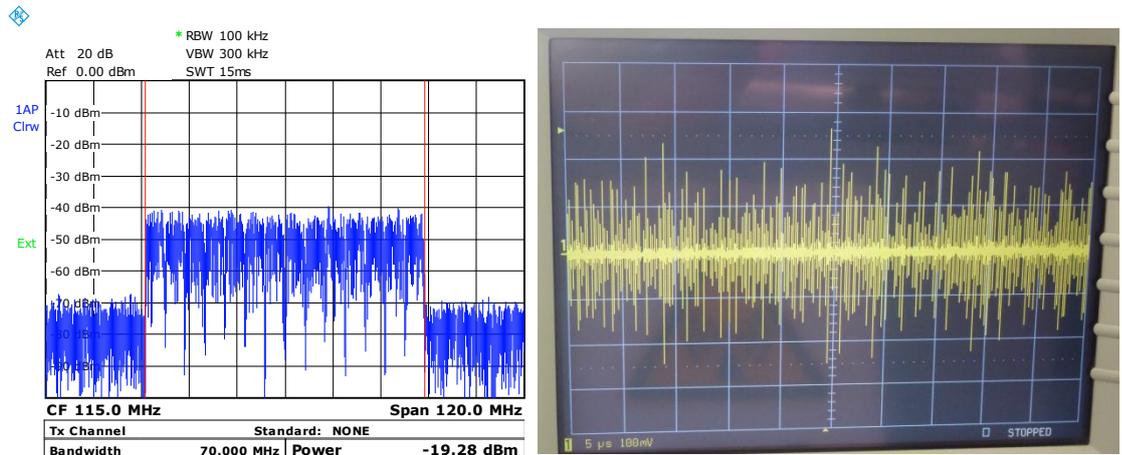


Figure 5-7: Crest factor of 14 base stations

In a second measurement, 14 base stations have been generated, each with a bandwidth of 5 MHz, FDD mode and the modulation scheme 64 QAM. The resulting frequency and time domain signals are shown in Figure 5-7.

## 5.4 Measurement Results

The TS6650 has been setup at an airport and has been used for ATC radar test in presence of LTE signals, Figure 5-8.



Figure 5-8: TS6650 Radar Test System

Measurements performed have shown that out-of-band and in-band interference mechanisms can become critical and cause ATC radar to become blind in certain azimuth sectors and under certain conditions, e.g. when broadcasting an LTE [6] or

WiMAX signal towards the radar. This causes a reduction in the probability of detection and the radar to lose targets. Study [8] addresses “challenging case” and “typical case” scenarios of 4G networks at airports, and describes and concludes mitigation techniques.

Figure 5-9 shows a radar plot from [9] using the TS6650 radar test system. The probability of detection  $P_d$  is reduced due to the presence of a 4G signal; the aircraft even disappeared from the radar screen.

Due to these results, coexistence of radar and 4G networks should be tested.

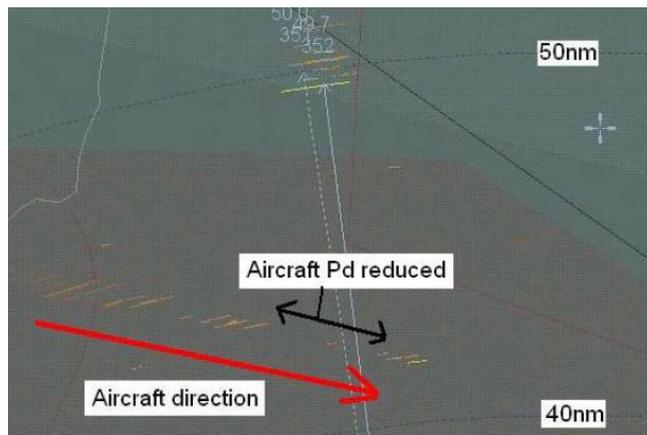


Figure 5-9: 4G Signal at 2685 MHz [9]

## 6 Mitigation Techniques

Different approaches can mitigate disturbances on radar and 4G base stations. One approach is to reduce transmit power at the base station and radar. Also increasing frequency separation or distance between the two services is a solution. However, these two ideas reduce maximum range of the radar and coverage of the base station and frequency selection may be impossible due technical restrictions. Avoiding to let mobile service base station antennas point at towards S-Band radar is one approach to mitigate. Also, the improvement of receiver selectivity, filtering of transmitter signals, and reduction of unwanted spurious emissions on both sides allows coexistence.

The latter would be the most straightforward mitigation measure, both at the radar and base station (BS) side. To avoid receiver saturation through inter-modulation and blocking a filter can be placed on the radar's receiver before the Low Noise Amplifier (LNA). At the BS side, a filter can be placed on the transmitter close to the antenna to suppress the out-of-band (OOB) LTE emissions in the spurious domain. Furthermore, a revision of the ETSI 3GPP technical specifications TS 136.101 (UE) and TS 136.104 (BS) is recommended. Currently, these standards impose flexible power levels for Spurious Emissions in non-protected bands, while these levels are much more stringent in the protected bands. Because the S-band (and also the L-band) is used for security and safety services a more stringent maximum power level for Spurious Emissions should be defined.

In any case, test and measurement of radar, LTE base stations and user equipment is necessary to confirm spectral emission masks and prove robustness against other coexisting signals.

## 7 Literature

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## 8 Ordering Information

Designation	Type	Order No.
Vector Signal Generator	R&S®SMW200A	1412.0000.02
Frequency Options, RF path A 100 kHz to 3 GHz	R&S®SMW-B103	1413.0004.02
Frequency Options, RF path A 100 kHz to 6 GHz	R&S®SMW-B106	1413.0104.02
Baseband Generator with ARB (64 Msample) and Digital Modulation (realtime), 120 MHz RF bandwidth	R&S®SMW-B10	1413.1200.02
ARB Memory Extension to 512 Msample	R&S®SMW-K511	1413.6860.02
ARB Memory Extension to 1 Gsample	R&S®SMW-K512	1413.6919.02
Baseband Main Module, one I/Q path to RF	R&S@SMW-B13	1413.2807.02
Baseband Extension to 160 MHz RF bandwidth	R&S@SMW-K522	1413.6960.02
Interference Test System for ATC Radar Systems	R&S@TS6650	1519.6705.02
IQ recorder (SSD) with touch screen	R&S@IQR100	1513.4600K10
IQ recorder with touch screen (75 MSa/s)	R&S@IQR100	1513.4600.10
SSD memory pack 1,9 TByte 400MByte/s	R&S@IQR-B119F	1513.4723.19
IQR SW for configuring of the TSMW via LAN, incl. AGC (SL)	R&S@IQR-K1	1513.4730.02
Software for controlling generators with IQR	R&S@IQR-K2	1513.4752.02
Import/Export of I/Q and meta data files via USB and LAN	R&S@IQR-K101	1517.5001.02
GPS Data recording on the IQR as meta data file	R&S@IQR-K102	1517.5018.02
Graphical display of GPS data (IQR)	R&S@IQR-K103	1517.5024.02
Ref. level controlled recording/replay of RF signals f. AGC	R&S@IQR-K104	1517.5182.02
Power supply module, 10-30V DC, 200VA, BW2010	R&S@PSDC-B200	1513.4617.02
TSMW / IQR Case 3U, 19" for drive test, incl. integration	R&S@IQR-CAS1	1513.4652.02
Carrier Trolley with inlet for IQR, TSMW and accessories	R&S@IQR-Z6	1516.4360.02
TSMW High Performance Scanner	R&S@TSMW	1503.3001K03

TSMW High Performance Scanner	R&S®TSMW	1503.3001.03
Digital I/Q Streaming Software Option for TSMW	R&S®TSMW-K1	1503.3960.02
IQ Interface for R&S IQR	R&S®TSMW-B1	1514.4004.02
TSMW AC power supply	R&S®TSMW-Z1	1503.4608.02
CMW Wideband Radio Communication Tester	R&S®CMW500	1201.0002K50
R&S®CMW500 Basic Assembly (mainframe), 70MHz to 3.3GHz (sel.)	R&S®CMW-PS503	1208.7154.02
Baseband Meas. Unit, 1GByte memory, H100A (sel.)	R&S®CMW-S100A	1202.4701.02
Baseband Interconnection, flexible link, H550B (sel.)	R&S®CMW-S550B	1202.4801.03
RF Converter (TRX), H570B (sel.)	R&S®CMW-S570B	1202.5008.03
RF Frontend, basic functionality, H590A (sel.)	R&S®CMW-S590A	1202.5108.02
CMW500 Frontpanel With Display/Keypad, H600B (sel.)	R&S®CMW-S600B	1201.0102.03
Baseband Generator, 1GByte memory, H110A (HW opt.)	R&S®CMW-B110A	1202.5508.02
Signaling Unit Wideband (SUW), for WCDMA/LTE, H300B (HW opt.)	R&S®CMW-B300B	1202.6304.03
Extra RF Converter (TRX), H570B (hw opt.)	R&S®CMW-B570B	1202.8659.03
Extra RF Frontend, basic functionality, H590A (hw opt.)	R&S®CMW-B590A	1202.8707.02
LTE FDD R8, TX measurement, uplink (SL)	R&S®CMW-KM500	1203.5501.02
LTE FDD R8, SISO, basic signaling (SL)	R&S®CMW-KS500	1203.6108.02
LTE R8, SISO, advanced signaling (SL)	R&S®CMW-KS510	1203.9859.02
Mini-UICC Test Card, supp. 3GPP SIM/USIM/ISIM/CSIM (acc.)	R&S®CMW-Z04	1207.9901.02

## About Rohde & Schwarz

Rohde & Schwarz is an independent group of companies specializing in electronics. It is a leading supplier of solutions in the fields of test and measurement, broadcasting, radiomonitoring and radiolocation, as well as secure communications. Established more than 75 years ago, Rohde & Schwarz has a global presence and a dedicated service network in over 70 countries. Company headquarters are in Munich, Germany.

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## Environmental commitment

- Energy-efficient products
- Continuous improvement in environmental sustainability
- ISO 14001-certified environmental management system



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