Coexistence of S-Band Radar and Mobile Networks

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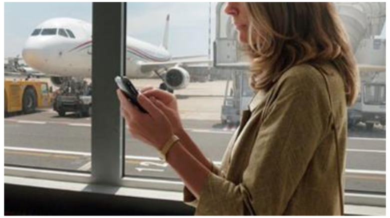


Radar

Lte™


48°22'56.2"N
11°48'06.2"E
~1.5km
48°18'39.2"N
11°48'51.5"E
Lerchenfeld
Lohmühle
Attaching
Schwaig
Hallbergmoos
Oberding
Goldach
Aufkirchen
Notzing

ITU radio regulations in the 2.5 GHz to 3.1 GHz band

Band 7: 2.620 2.690
Band 69: 2.570 - 2620

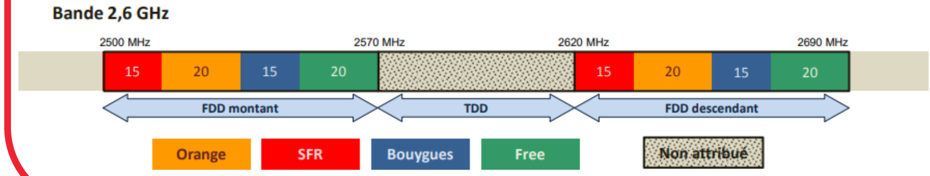
Band S: 2.700 3.100

Earth exploration satellite, radio astronomy

2.5 GHz to 2.69 GHz Mobile		2.70 GHz to 2.90 GHz Aeronautical radionavigation	2.90 GHz to 3.10 GHz Radionavigation

→ f

Lte™

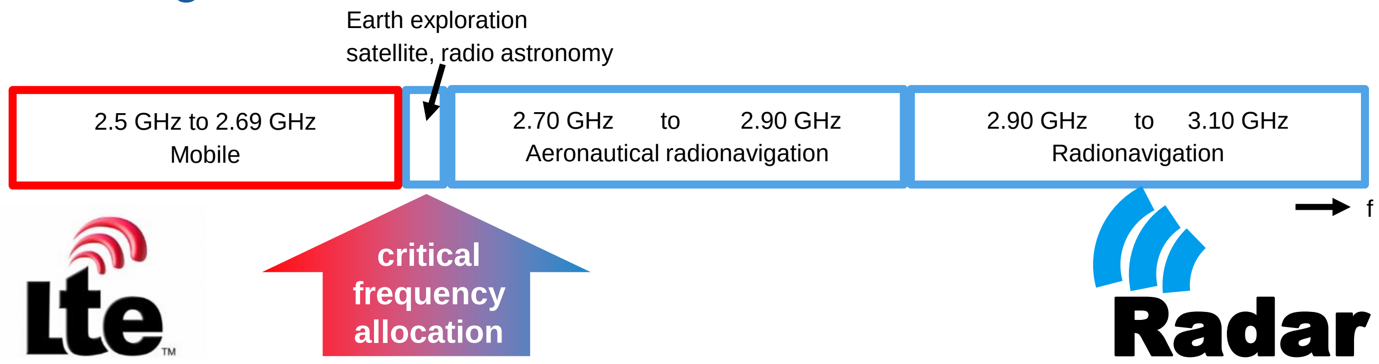


Radar

Frequency and bandwidth

- Often frequency hopping
- several MHz
- depends on radar system

ITU radio regulations in the 2.5 GHz to 3.1 GHz band



Additional co-existence:

Band 42 and 43: ASR operates at 3.6 GHz 3.9 GHz. US Public Safety makes use of 50 MHz in this spectrum

C-band Radar and 802.11ac

Unlicensed National Information Infrastructure (U-NII) Devices, LTE-U,Wi-Fi in the 5 GHz band

…

Worldwide Usage of the 2.6 GHz Band - Operators

Country	Operator using 2.6 GHz
Germany	Telekom, Vodafone, o2
UK	EE
Norway	Telenor, Netcom
USA	Sprint
Sweden	3 Sweden, Net4Mobility, Telia Sweden
France	Bouygues, Free Mobile, Orange France, SFR
China	China Mobile, China Telecom

Poland, Chile, Estland, Finland, Hong Kong, Italy, Columbia, Kuwait, Litauen, New Zealand, Austria, Singapore, Spain, Russia ...

3,2 billion LTE subscriptions worldwide, 521 commercially launched LTE networks (Q1 2018) in 170 countries.

422 operators use the FDD mode only
51 operators use the TDD mode only
23 operators use both LTE FDD and TDD modes

data source: www.gsacom.com

LTE Networks
and
Radar Systems

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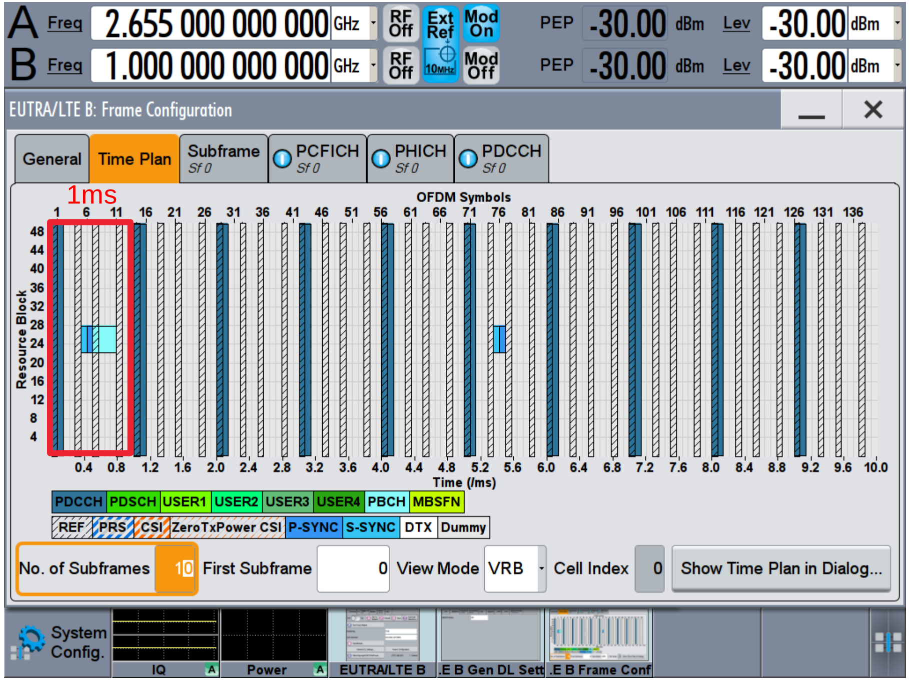
LTE FDD Downlink Frame

- How does an LTE frame look like?
  - Frame duration = 10 ms
  - Subframe duration = 1 ms

- What has to happen in order to
  - Disturb a frame ?
  - Lower the CQI ?
  - Lower the throughput ?
  - Take the network down ?

LTE FDD Downlink (DL)
Frame Structure Type 1



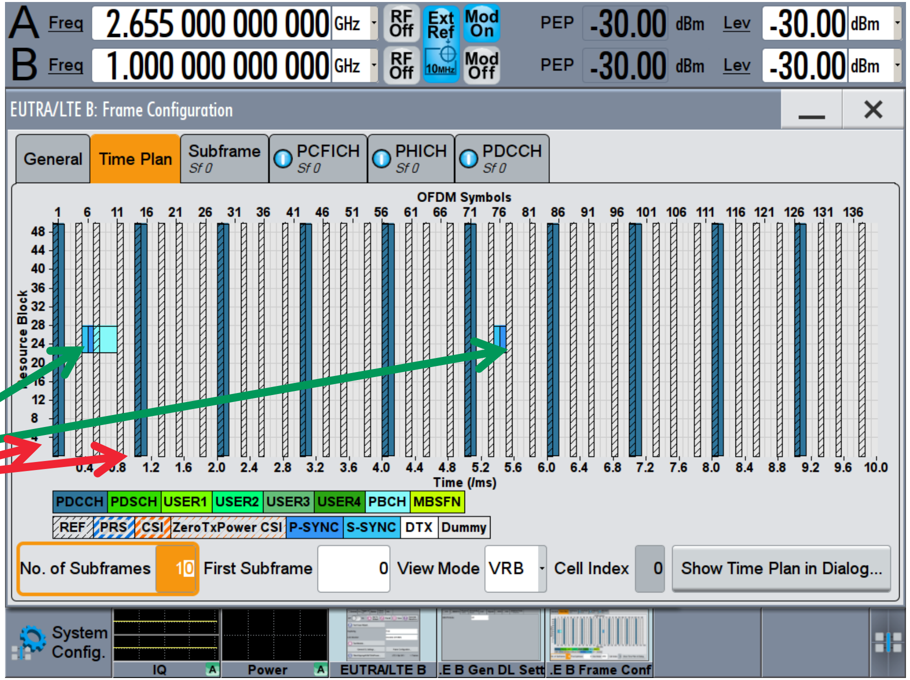
LTE FDD Downlink Frame: disturbances?

Physical Downlink Control Channel (PDCCH):
carries among others the downlink allocation information

Physical Control Format Indicator Channel (PCFICH):
used to signal the length of the PDCCH

The synchronization signals (PSS and SSS)
for the UE to discover the LTE cell and do the initial synchronization

LTE FDD Downlink (DL)
Frame Structure Type 1



Pulses that hit PDCCHs,
or the PSS / SSS may
cause system degradation

S-Band Radar : typical Radar Parameters

Radar

Frequency	2.7, …, 2.9 GHz
Transmit power	2 kW - 20 MW
Maximum range	100 km - 500 km
Antenna opening angle	0.4° - 2.5°
Pulse duration	< 1 µs – 400 µs With frequency diversity of 10-20 MHz
Pulse period	< 1 ms – 4 ms
Antenna rotation time	5 rounds/min - 15 rounds/min
Antenna gain	25 dBi - 40 dBi

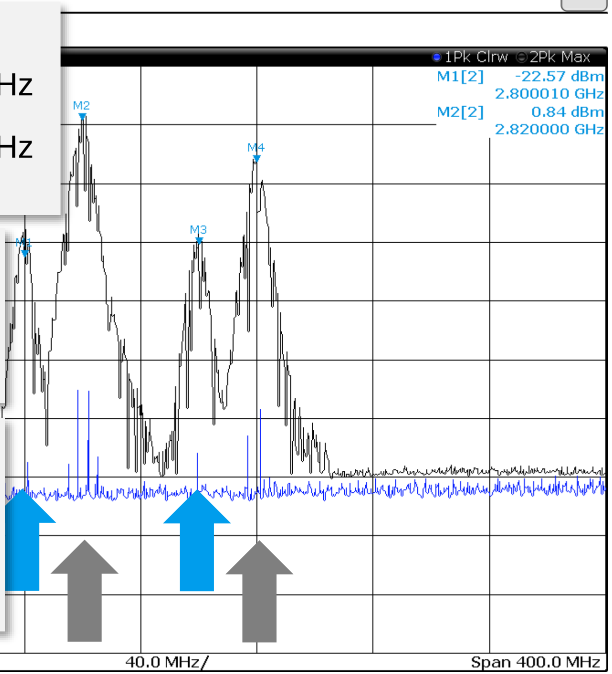
German Airbase Büchel (near Koblenz)

Check radar specification and/or **analyze** the radar

S-Band Radar Spectrum Allocation

Airport Measurements

Radar



Two radar systems

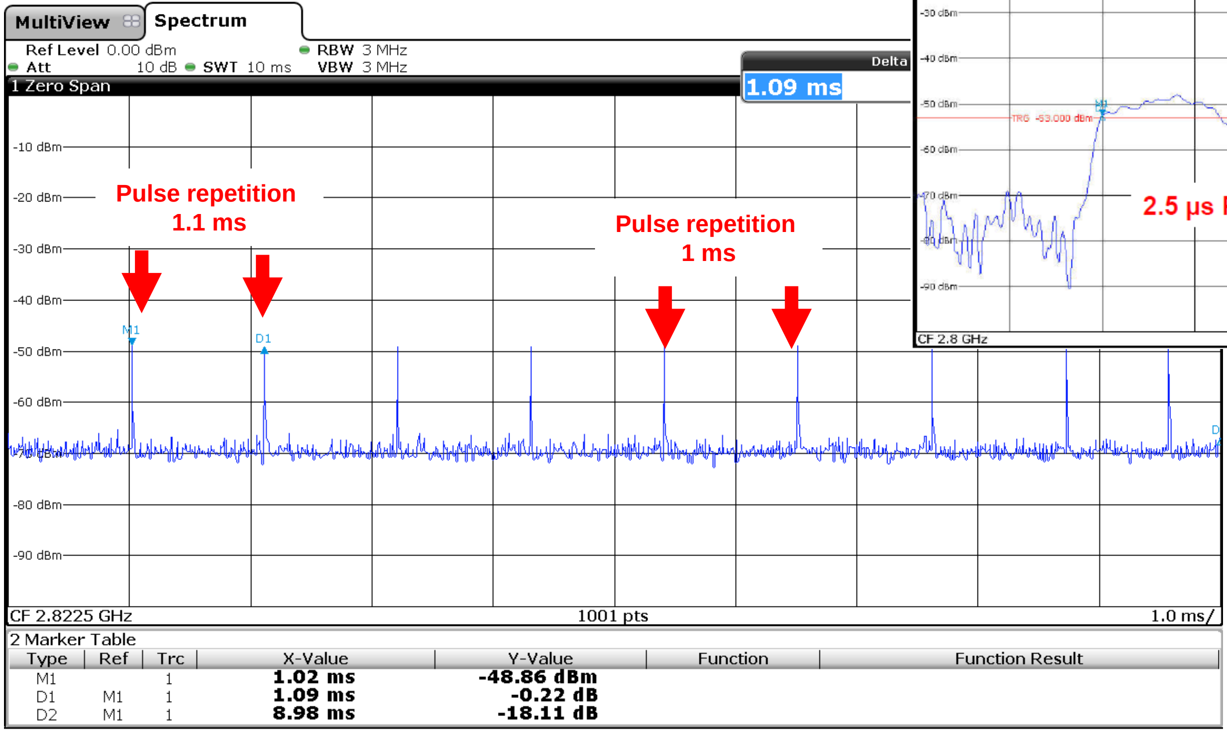
- operating at 2.82 GHz / 2.88 GHz
- operating at 2.80 GHz / 2.86 GHz

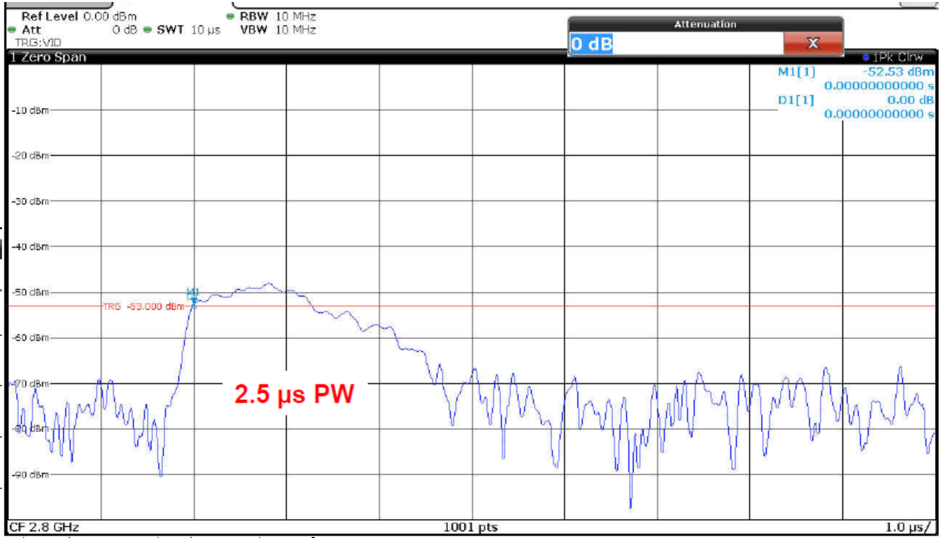
Recording using an IQ recorder

Replay possibility in the lab using a vector signal generator

S-Band Radar Pulse

Airport Measurements





Interference Scenarios and Performance indicators

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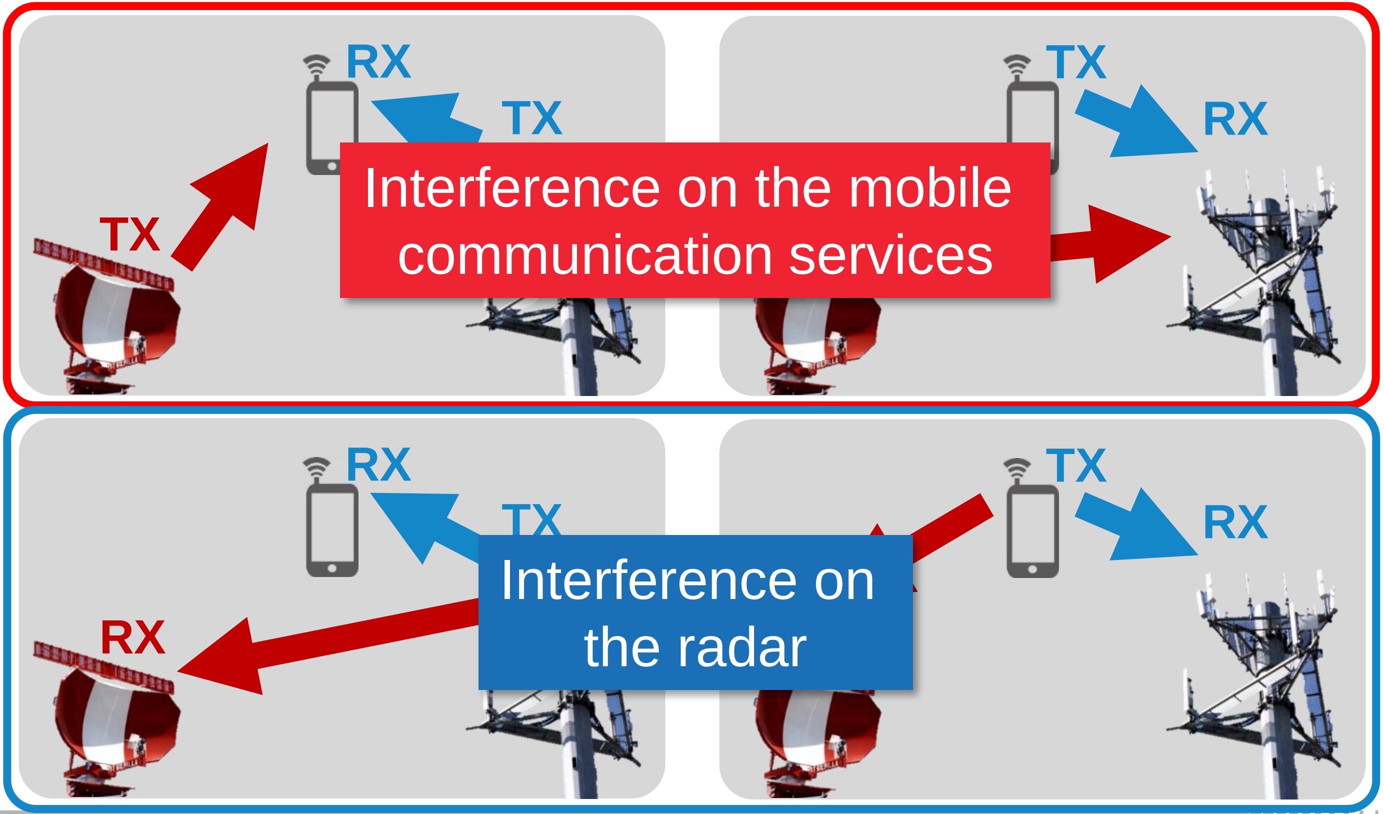
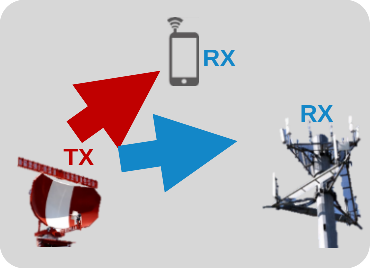
Interference Scenarios : two types



Interference on the Mobile Service



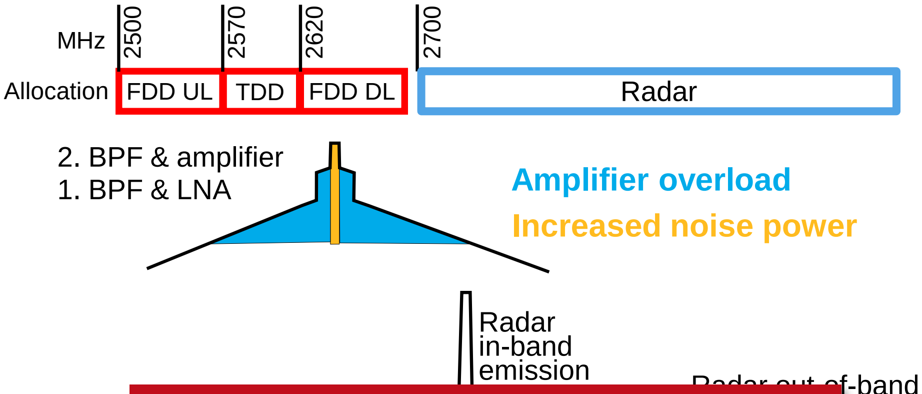
TX

Radar
2700 MHz to 2900 MHz

RX

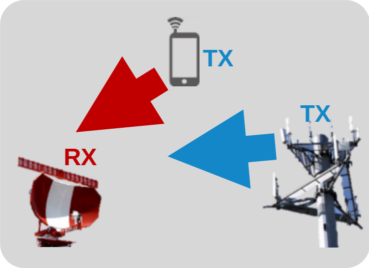
Mobile terminal (MT)
in-band < 2690 MHz
out-of-band > 2690 MHz

Base station (BS)
in-band < 2690 MHz
out-of-band > 2690 MHz



- signal and synchronization loss
- throughput reduction

Interference on the Radar



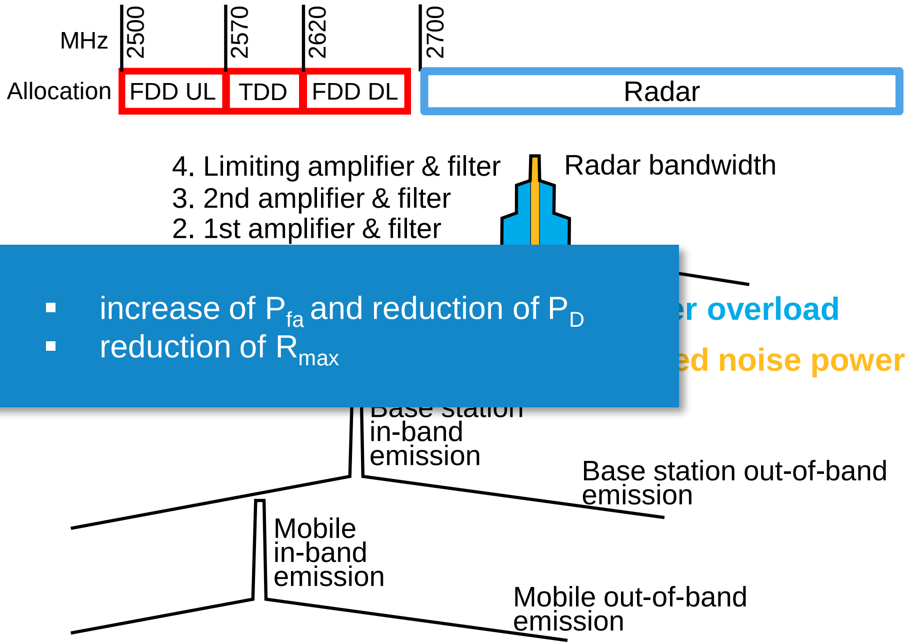
TX

Mobile terminal (MT)
Operating LTE band 7,
2620 - 2690 MHz

Base station (BS)
in 2620 – 2690 MHz

RX

Radar	
in-band	> 2700 MHz
out-of-band	< 2700 MHz



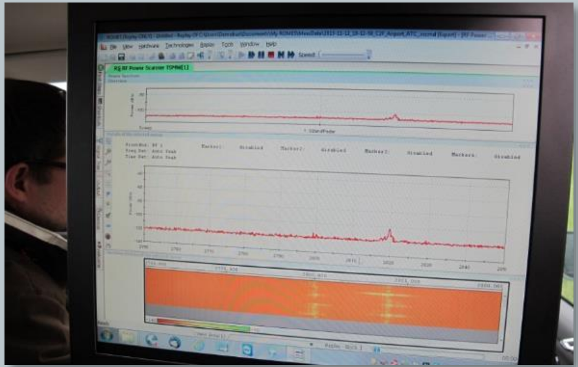
- increase of P_{fa} and reduction of P_D
- reduction of R_{max}

Performance Indicators and Measurement Needs

- **Radar**
  - Increase of P_{fa} and reduction of P_D
  - reduction of R_{max}
- **Key Performance Indicators** to be measured at the radar system are
  - MDS, P_D and R_{max}
- Using a radar target generator that generates “reference targets” with defined RCS at certain range and Doppler
- Adding on top interference (e.g. LTE signals)

- **LTE**
  - signal and synchronization loss
  - throughput reduction
  - increased EVM and network degradation
- **Key Performance Indicators**
  - **UE Downlink (DL)**
    Data Throughput, BLER, Channel Quality Indicator
  - **UE Uplink (UL)**
    Error Vector Magnitude
- Using a Base Station Emulator and a Vector Signal Generator to generate arbitrary interference signals

Measurements of a Radar impacting a LTE system



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Test of the Mobile Terminal in Presence of a Radar

Measurement Needs

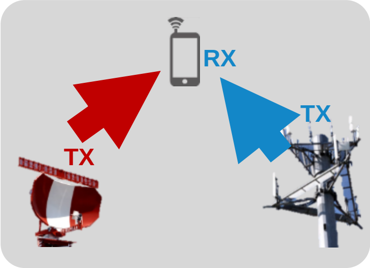
- **UE Downlink**
  - Data Throughput
  - BLER
  - Channel Quality Indicator
- **UE Uplink**
  - Error Vector Magnitude

Equipments two possibilities:

(I) Base Station Emulation, Record and Replay of a Radar Signal
- LTE Signaling: Base Station Emulator
- Field radar RF Recording with Spectrum Analyzer and replay using a Signal Generator

(II) Base Station Emulation and RF Environment Signal Generation
- LTE Signaling: Base Station Emulator
- Synthetic Signals: Pulse Sequencer Software with a Vector Signal Generator (generates an arbitrary radar RF environment)

(I) Base Station Emulation and Record and Replay of a Radar Signal



- Base Station Emulator

  - LTE-FDD / TDD RF Generator, RF Analyzer
  - Network Emulation, Protocol Test
  - End-to-End application Test on the field

  - Mobile connected according to receive sensitivity level test

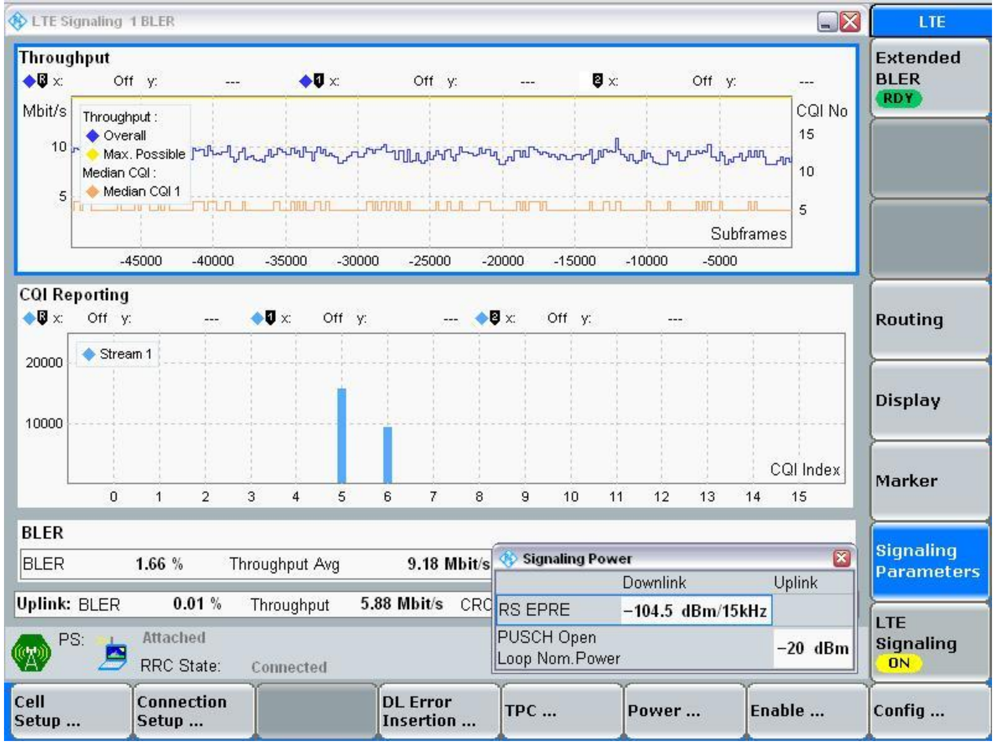
(7.3 in 3GPP's technical specification 36.521-1)

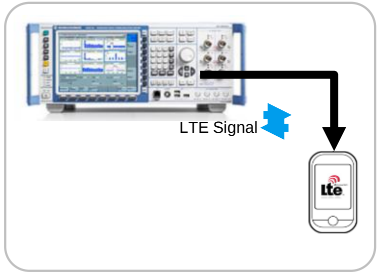
  - DL 51.021 Mbit/s, 64 QAM, 100 RB
  - UL 4.565 Mbit/s, QPSK, 75 RB

RB: Resource Block
DL: Downlink
UL: Uplink

LTE Throughput Measurement

No radar present





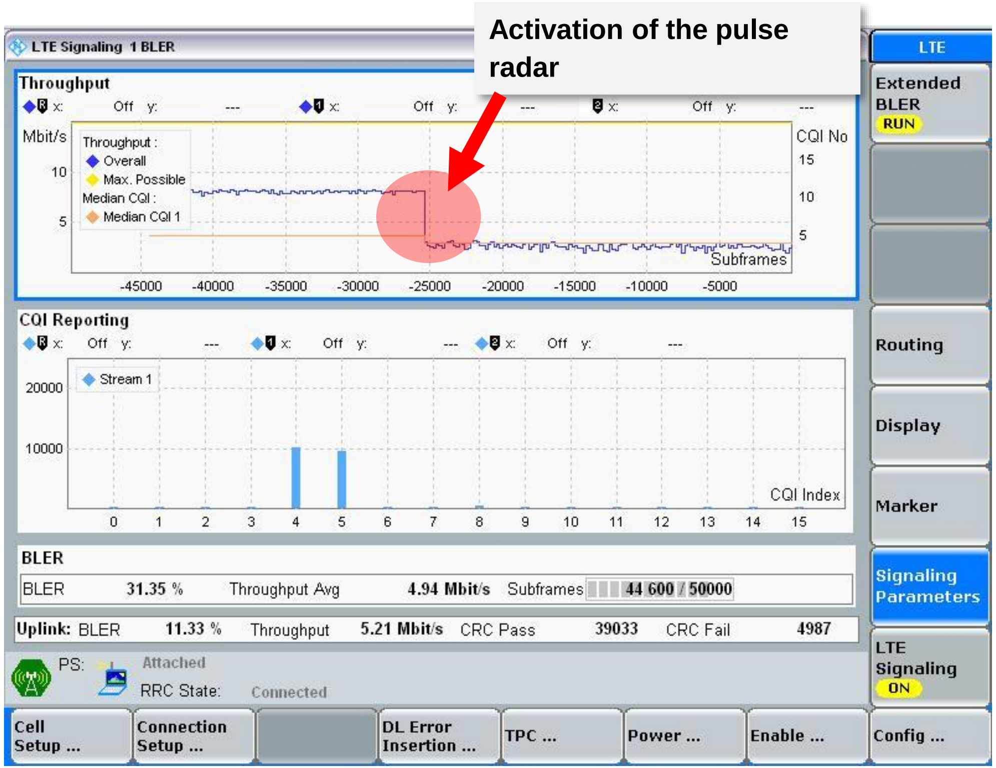
LTE base station
RS EPRE:-104.5 dBm/15kHz
CQI of 5-6

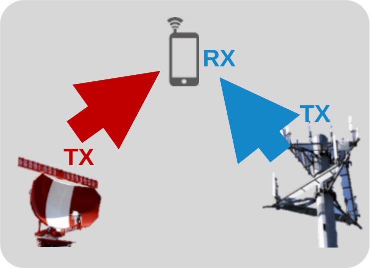
Mobile terminal
Max power (+23 dBm)
Follow wideband

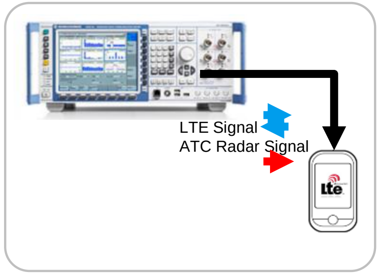
RS EPRE: energy per resource element (EPRE) of the reference signal (RS)
CQI: Channel Quality Indicator

LTE Throughput Measurement

Radar present





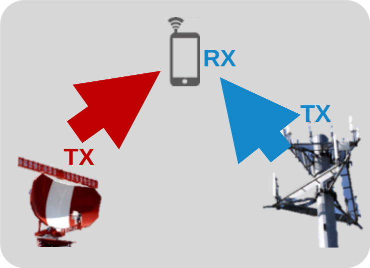


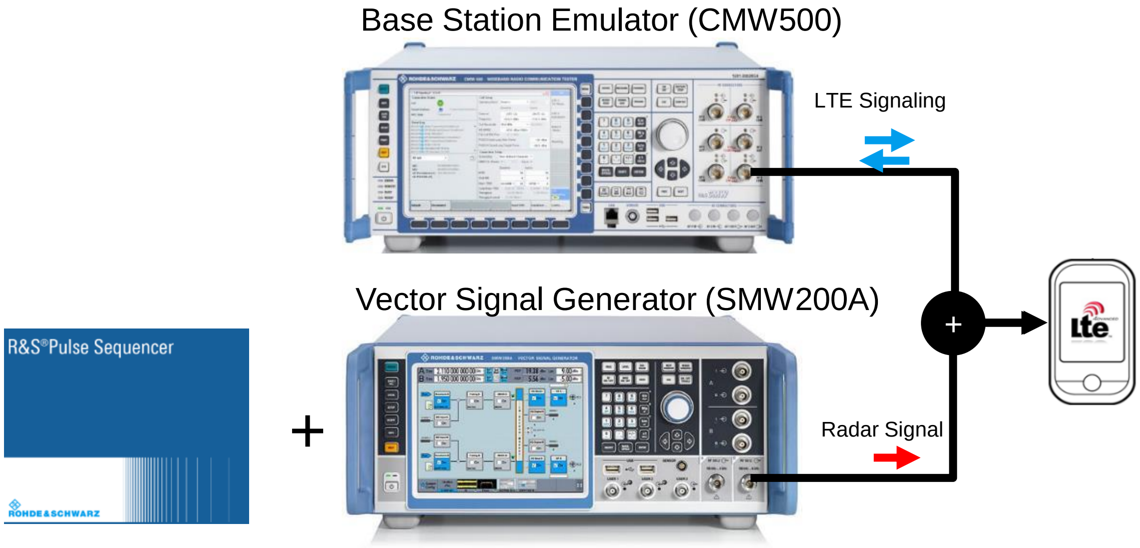
Replay of I/Q radar data
Radar frequency: 2.700 GHz
Power: -40 dBm

LTE base station
RS EPRE:-104.5 dBm/15kHz
CQI of 4-5

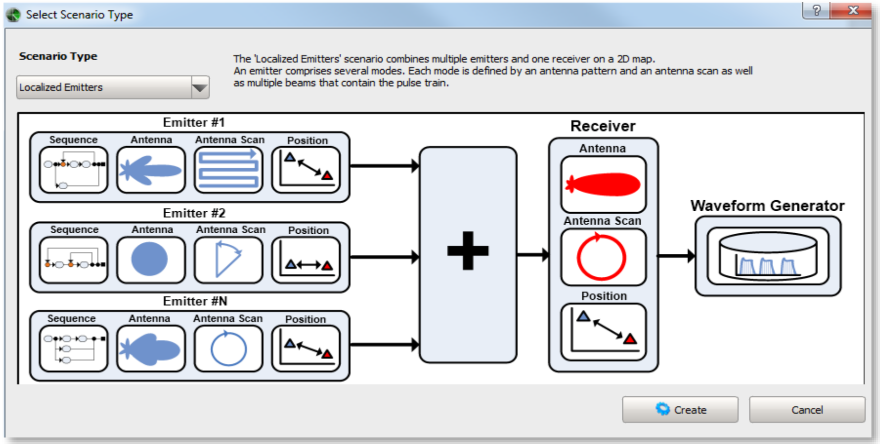
Mobile terminal
Max power (+23 dBm)
Follow wideband

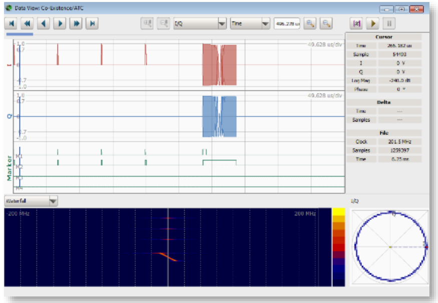
(II) Base Station Emulation and Synthetic Radar Environment Signal Generation

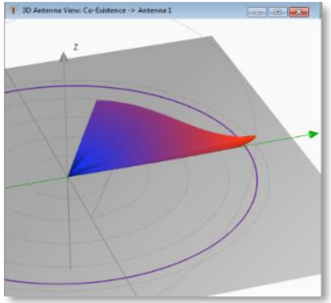


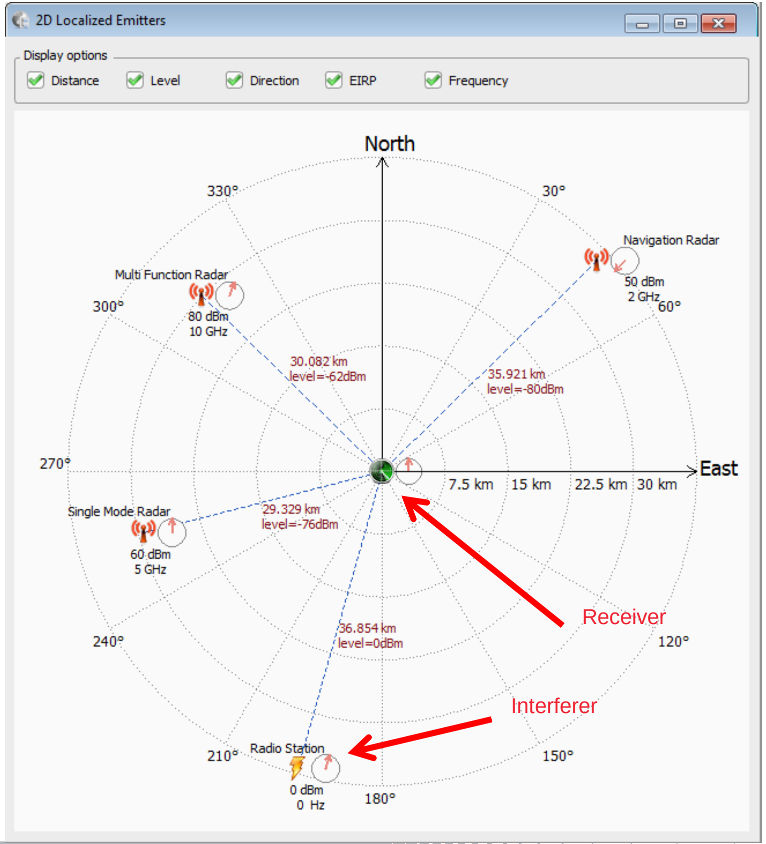


RF Environment: Pulse Sequencer Software



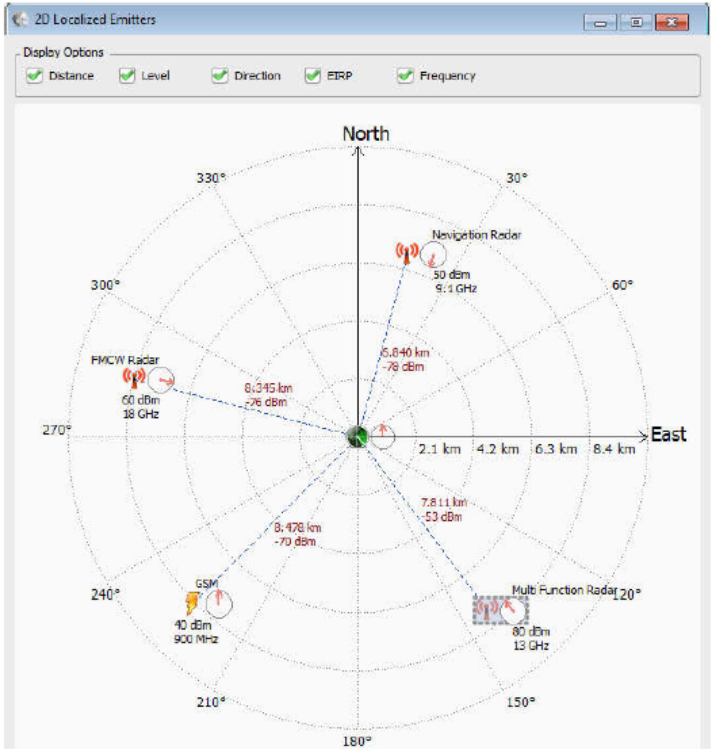






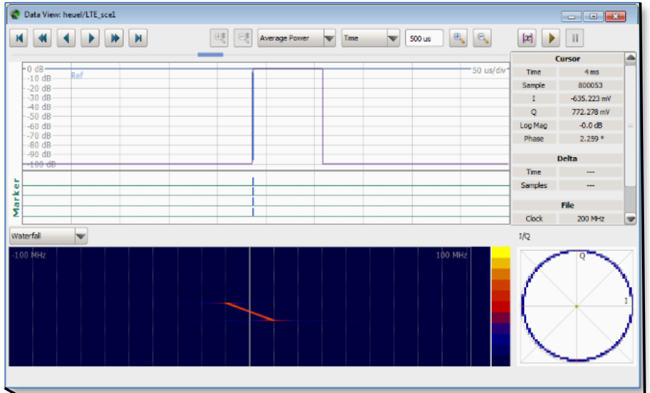
RF Environment: Pulse Sequencer Software

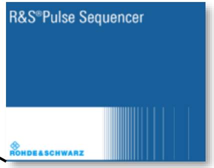
- 3 Emitters
  - Antenna Pattern & Scan
  - EIRP of Emitter
  - Emitter Waveform
  - Carrier Frequency
- Receiver
  - Receiver Antenna & Scan
- Localization
  - x/y/z coordinates of Emitter & Receiver
- Attitude
  - Bearing and Elevation Angle of Emitter and Receiver antenna pointing
- Interferer
  - WinIQSim2 waveform e.g. LTE
- Propagation Model
  - Free space loss assumption
- Simulation Scenario
  - All players at same time



UE DL: BLER and Throughput Measurement

- Generate a pulse signal which hits each PDCCH
- What power and frequency is necessary to disturb the DL completely?





+

Base Station Emulator CMW500, LTE Settings and UE Report

Full Cell BW Power: -57.2 dBm

RS EPRE: -85 dBm/15kHz

RSRP: 56 (-85 ... 84 dBm)

RSRQ: 19 (-10.5 ... -10 dB)

LTE Signaling

Vector Signal Generator SMW200A

Pulsed Chirp

LFM: 20 MHz, On: 72 µs,

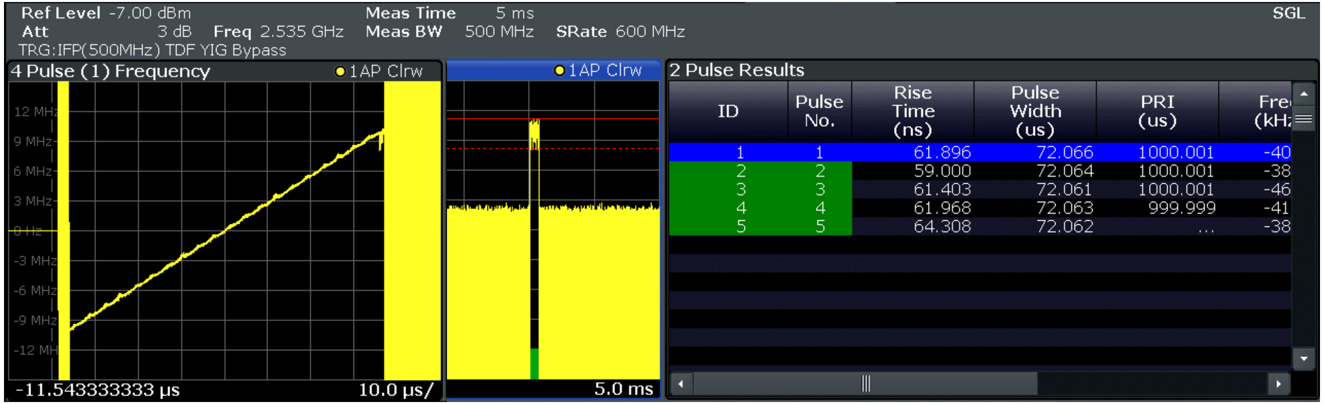
PRI: 1ms, Repetition: 10

Tigger on LTE Frame 1

Radar Signal

Disturbing Signal, Radar in Long Range Mode

- Signal should be similar or alike an ATC radar signal which operates in long range mode
  - LFM, long pulse, low PRI
  - May include the antenna pattern, antenna turn, position etc.



UE DL: Throughput Measurement Results

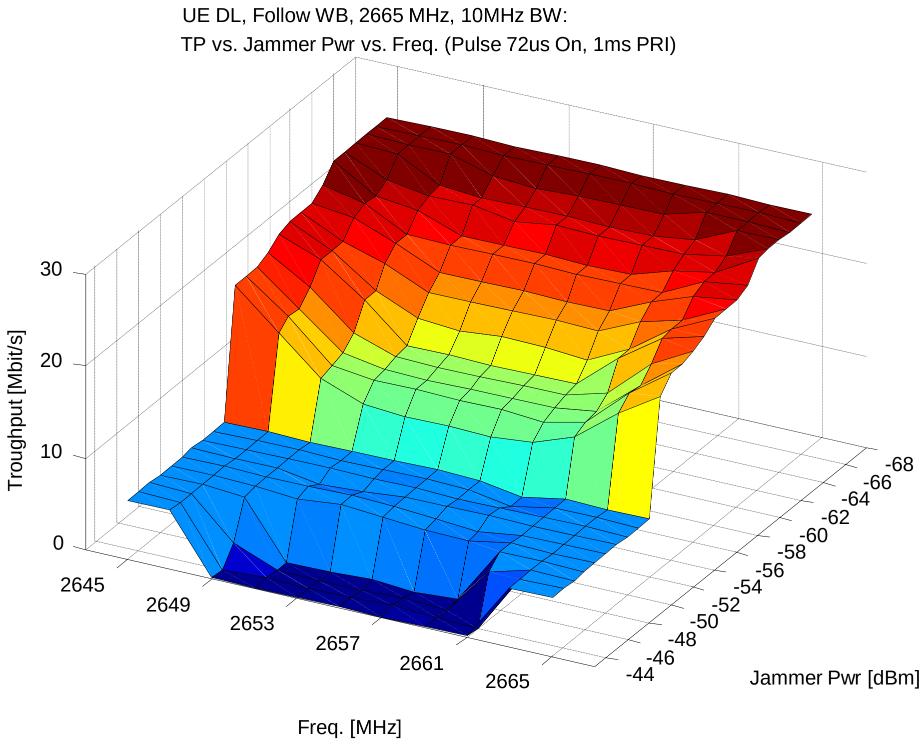
ATC Radar in long range mode

Pulsed Chirp

- LFM: 20 MHz, On: 72 µs,
- PRI: 1ms, Repetition: 10

LTE Signaling

- DL 64 QAM, UL QPSK,
- DL Band 7, 2665 MHz
- Full Cell BW Power: -57.2 dBm
  RS EPRE: -85 dBm/15kHz
  RSRP: 56 (-85 ... 84 dBm)
  RSRQ: 19 (-10.5 ... -10 dB)



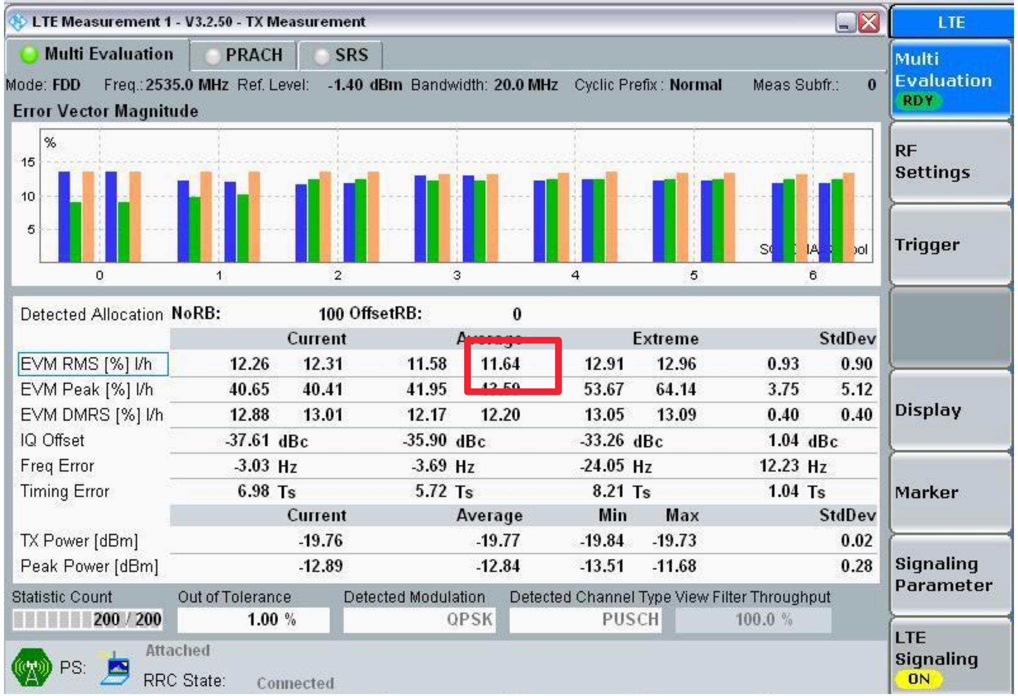
UE UL: EVM Measurement Results

FDD, QPSK

- Same setup, but EVM uplink measurement using the base station emulator

- AWGN 3.84 MHz BW present, power level -57 dBm

- Avg EVM: 11.64 %



UE UL: EVM Measurement Results

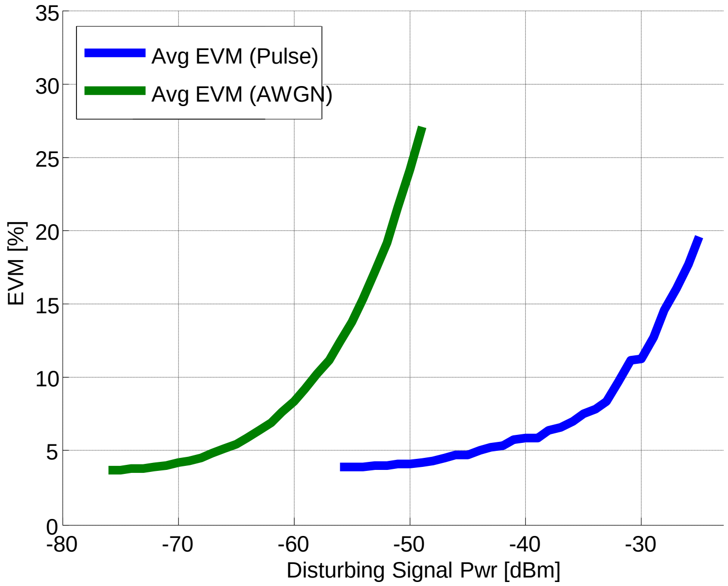
FDD, QPSK

- Same setup, but EVM Uplink Measurement using CMW500

- **AWGN** 20 MHz BW present (using Vector Signal Generator SMW200A
- **Pulse 1 µs, 200 µs PRI** (using Vector Signal Generator SMW200A)

- **Center frequency** 2535 MHz

- **Interference Power level** varied
  - Any higher power level resulted in “out of sync” of the UL channel.



Measurements of LTE signal impacting a Radar

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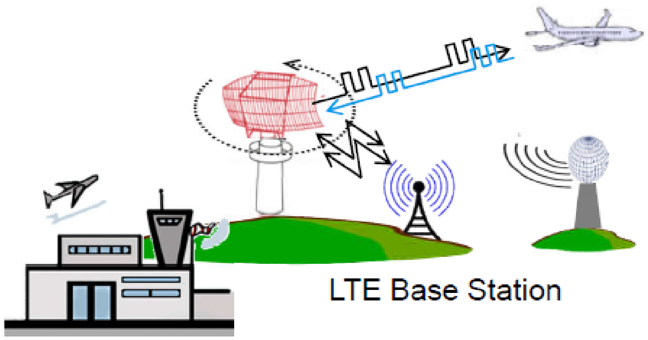
Test of the Radar in presence of LTE signals

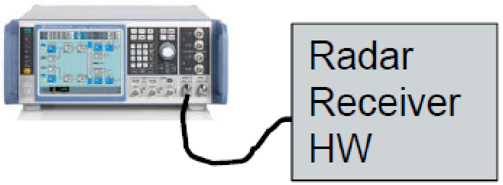
Conducted Receiver Test

- LTE Base Station Emulation & radar signal using a Signal Generator (SMW, SMBV)

Rotating Primary surveillance antenna



Test Case for radar receiver



- Rotating primary radar antenna at airport is interfered by LTE signals for example

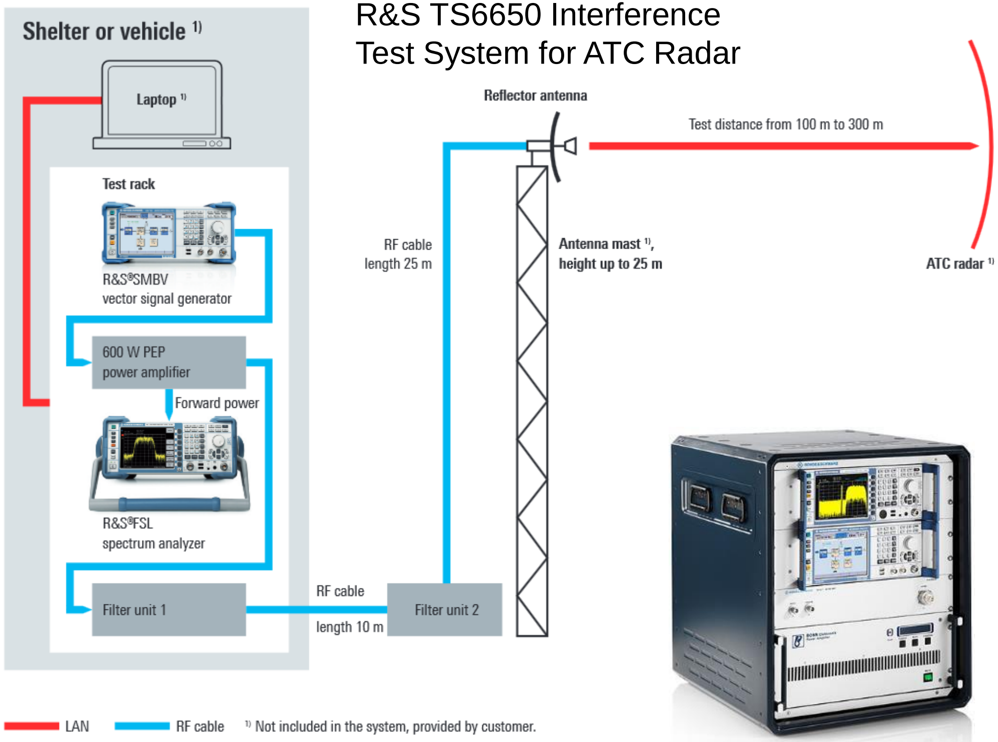
- Generate Radar Signal and interference signal and perform a conducted test
- Include real world effects like antenna patterns and turns, noise,….

Test of the Radar in Presence of LTE Signals

Over The Air Receiver Test – LTE power emission

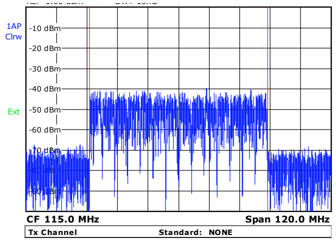
pointed towards the radar

R&S TS6650 Interference Test System for ATC Radar



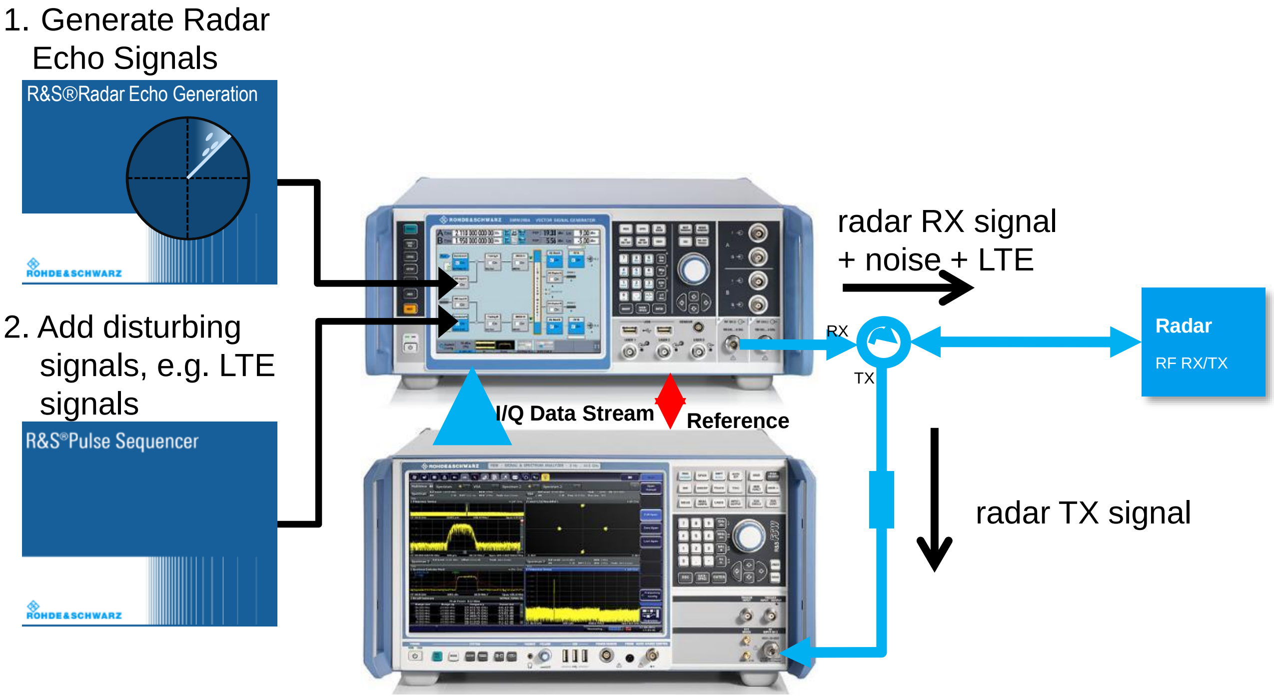
Replay of LTE base station signals

- 1 to 14 base stations
- Each 5 MHz bandwidth
- FDD mode
- 64 QAM scheme
- Up to 600 W PEP



REG: test of the Radar in presence of LTE Signals

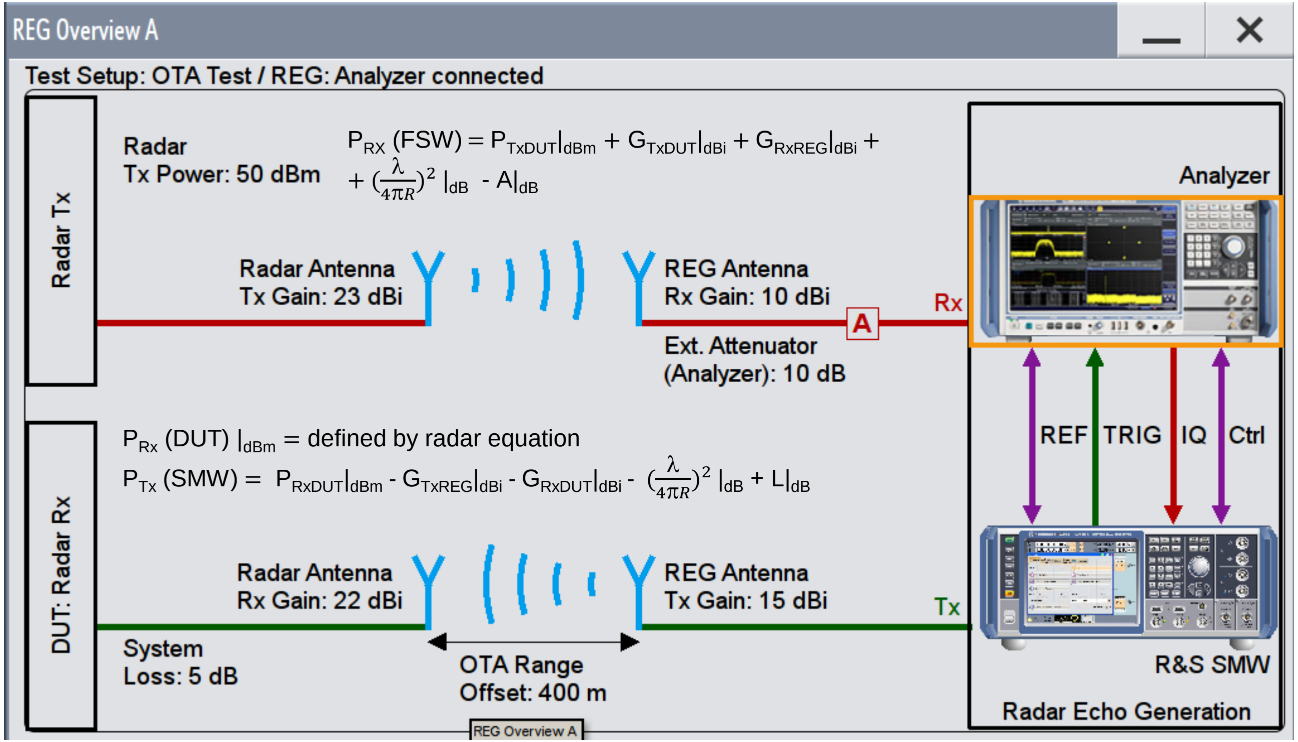
Over the air + complete radar test - with a Radar Echo Generator



REG : key specifications and features

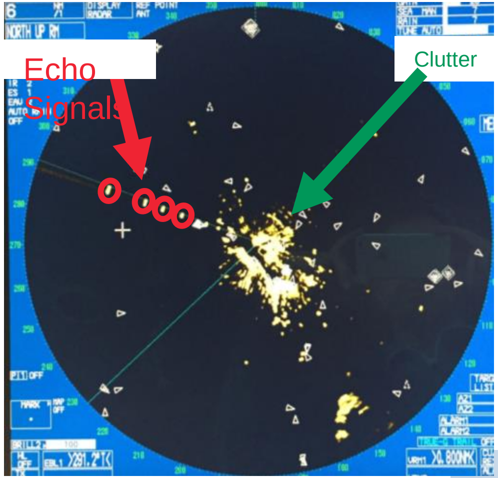
- Special RADAR GUI that allows to include radar parameters
- Supported Test Setup
  - Conducted or over the air (OTA)
  - Receiver test only (i.e. SMW200A alone) or together with FSW
- Maximum number of targets 24 (6 per SMW-B14)
- Target Types
  - Moving (one way, round trip) / Static
- Moving and static objects combined
- Maximum Velocity of an object 750 m/s
- Maximum Doppler of an object 190 kHz
- Blind zone: around 2000 m / 0 m in ambiguity mode
- Maximum Range: 10 000 km
- RF output
- Update Rapower and time delay of echo of moving objects are updated according to speed te for moving targets
  - Output power: 10 kHz
  - Update rate range: 2 MHz

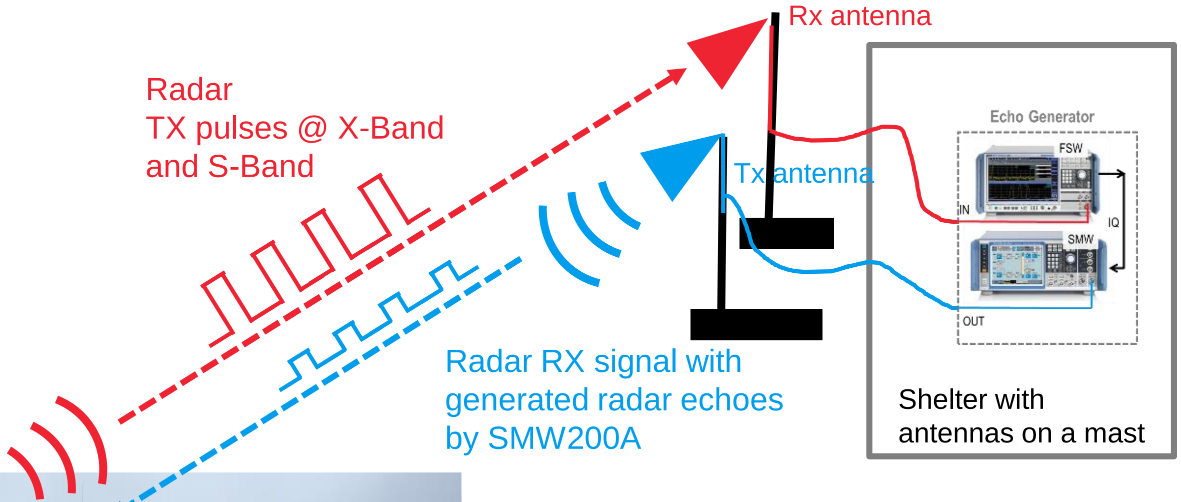
Test Concept - Setup for echo leveling via radar equation



Example of a cost guard vessel

Over the air testing with navigation radar in S band





Additional interference signals possible using Pulse Sequencer Software

Summary

- **LTE Networks and S-Band Radar**

- **Interference Scenarios**

- **Measurements Possibilities**
  - LTE Base Station Emulator + Record and Replay
  - LTE Base Station Emulator + Pulse Sequencer Software
  - Radar Target Generation

- **Measurement Results**
  - LTE Mobiles operating at 2.6 GHz with 20 MHz bandwidth

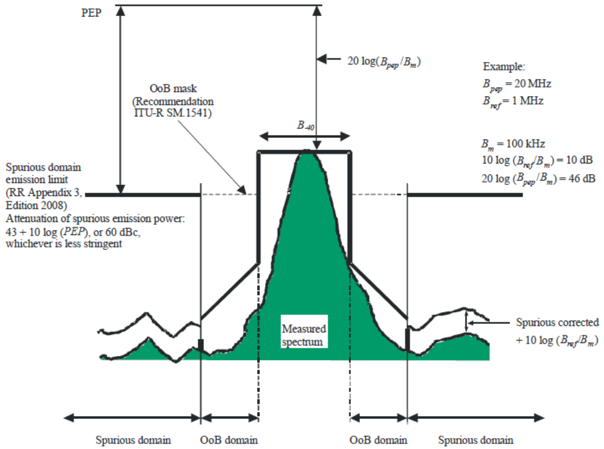
    → throughput reduction, BLER increase, CQI decrease
  - S-Band ATC Radar

    → reduced probability of detection and reduced maximum range

Standards: the context of radar interoperability and coexistence

- Each service power are under regulation (frequency masks) to protect adjacent services
- Performance degradation are due to high spurious, intermodulation, out of band noise

- Recommendations exist
  - to qualify impacts of radar on base stations
  - to qualify commercial radars with similar systems (automotive, maritime)



- But: no recommendation, international standard, or minimum performance requirement exist for radar receiver with regards to interference from other bands

Measuring immunity of a radar receiver to 4G interference

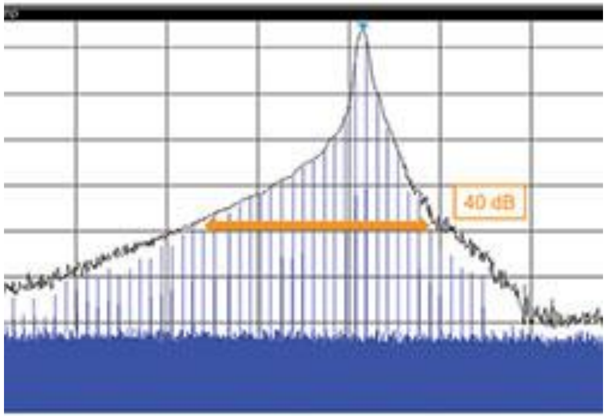
- Assess the Frequency Dependent Rejection performance of radar blocking and selectivity
- *The rejection produced by the receiver selectivity curve on unwanted emission*
- *Used to estimate the minimum frequency and distance separation between receiver and interferer which are required for acceptable receiver performance*

- In a radar receiver, the sensitivity (MDS) is influenced by :
  - Blocking: caused by to a strong signal driving the LNA to compression (non linear range)
  - Selectivity : caused by increasing noise (linear range), reducing the SNR

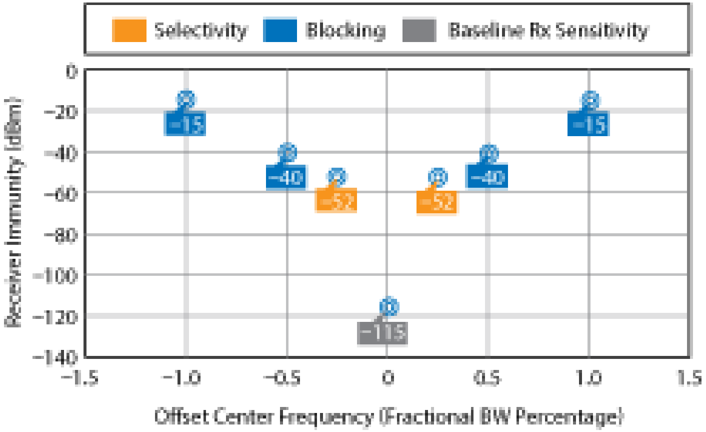
- Blocking : simulated with a Signal Generator, CW, low phase noise, low harmonics
- Selectivity: use a representative noise-like signal, eg 4G/5G

- → perform conducted tests simulating radar echoes and 4G
- → use a cooperative radar system with a radar echo generator + 4G

Method to test the susceptibility of the radar



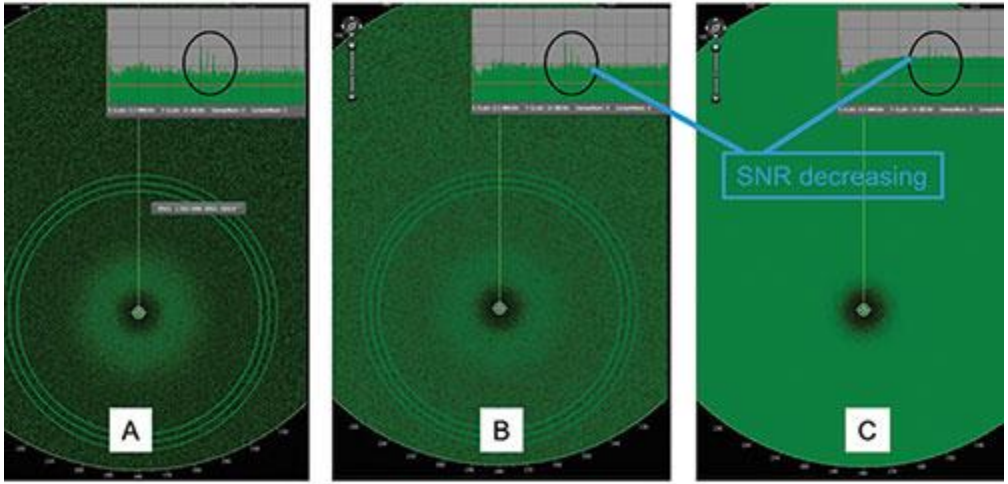
- Use the REG tool and create additional CW, 4G signals
- Set a baseline performance level with the REG to choose a number of detected echoes
- Introduce interference signals: impairments due to
  - LNA compression (blocking)
  - Increased noise into the IF (selectivity)
- Notice the decrease of echoes

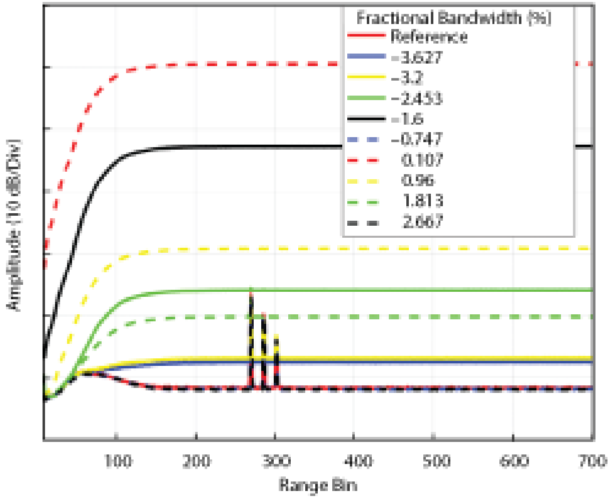


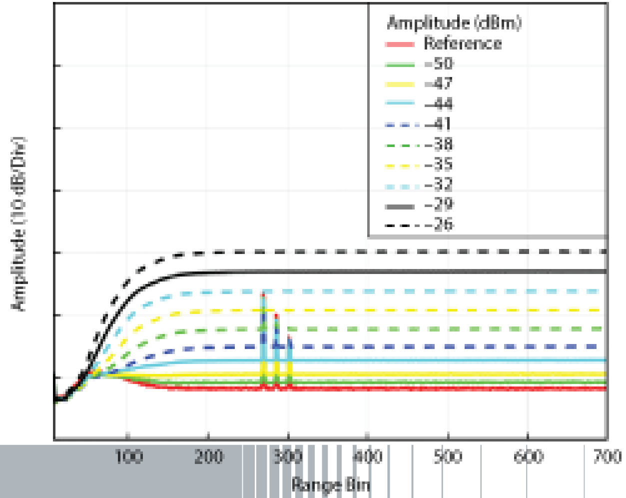
- Determine the BW of the occupied channel (40 dB BW) – mode and tuning frequency
- Plot the FDR (rejection of unwanted emission due to the receiver selectivity) over the radar frequency range

FDR performance plots

- Below: decreasing SNR with increased interferers
- Right:
  - selectivity vs offset frequency
  - selectivity vs amplitude







Results

- Typical radar sensitivity = -90 to -120 dBm
- Interfering level = -50 dBm at the receiver input
- Targets at range bins 270, 287, 302 (baseline, no interference) are not detectable with frequency offsets higher than 2-3 % BW (SNR too low).

- It is now possible to evaluate the potential impact on victim radar
  - Knowing a 4G Base Station characteristics (Eg 2690 MHz, +46 EIRP at 6 km)
  - Knowing Radar Rx at 2,7 GHz -> Base Station is at -0,37% BW offset.
  - Knowing the radar FDR behavior ➔ find the necessary frequency offset or distance separation