Study of the Performance Degradation of the Belgian S-band Air Surveillance Radars due to the Interference of Upcoming 4G Technologies

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Abstract:	This test report is the result of a study on the co-exitence of S-band radars and upcoming 4G telecommunication services. This study was carried out by Intersoft Electronics (IE) and commissioned by the Belgian Institute for Postal services and Telecommunications (BIPT). It reports on the results of the measurement campaigns performed on all S-band radar types currently managed by Belgocontrol and Defence. Potential mitigation measures are proposed in order to establish co-exitence of S-band radars and 4G services. A restricted issue of this report can be consulted on demand at BIPT.

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007	24-Jun-11	Final report, confidential version	All	EM/MV
008	24-Jun-11	Final report, public version	All	MV

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GLOSSARY OF TERMS

3GPP	3rd Generation Partnership Project
4G	4th Generation
ACP	Azimuth North Pulse
AGL	Above Ground Level
AM	Amplitude Modulation
AMSL	Above Mean Sea Level
ARP	Azimuth Reference Pulse
ASR	Airport Surveillance Radar
AWACS	Airborne Warning And Control System
AWGN	Additive White Gaussian Noise
BAF	Belgian Air Force
BB	Broadband
BIPT	Belgian Institute for Postal services and Telecommunications
BW	Bandwidth
CCDF	Complementary Cumulative Distribution Function
COTS	Commercial Off The Shelf
CW	Continuous wave
dB	Decibel
dBsm	Square meter in decibels (RCS)
DC	Directional Coupler
DECT	Digital Enhanced Cordless Telecommunications
DHM	Data Handling Module
Downlink	The signal path from base-station to user equipment
E-UTRA	Evolved Universal Terrestrial Radio Access
EBBE	Beauvechain
EBBR	Brussels
EBLG	Liège
EC	European Community
EIRP	Equivalent Isotropically Radiated Power
EMC	Electro Magnetic Compatibility
EMCD	EMC Directive
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplexing
FM	Frequency Modulation
FOF	Frequency Offset
GSM	Global System for Mobile Communications
HS	Harmonised Spectra
IE	Intersoft Electronics
IF	Intermediate Frequency
IMP	Inter-Modulation Product
inter-modulation	Creation of inter-modulation products at base-station side
Inter-Modulation	Creation of Inter-Modulation Products in radar reception bandwidth
IP3	Inter-modulation Product of the 3rd order
IT	Internet Technology
ITU	International Telecommunications Union
L-band	Band for Long range air surveillance radar (1215-1400 MHz)
LAN	Local Area Network
LNA	Low Noise Amplifier
LTE	Long Term Evolution
LVD	Low Voltage Directive
MOD	Modulator

MRD	Multi Radar Display
N/A	Not Applicable
NG	Noise Generator
NM	Nautical Mile, unit of distance
OFDMA	Orthogonal Frequency-Division Multiple Access
OOB	Out-Of-Band
PA	Power Amplifier
PAPR	Peak to Average Power Ratio
PBCH	Physical Broadcast Channel
Pd	Probability of detection
Pfa	Probability of False Alarms
PHICH	Physical Hybrid Automatic Repeat Request Indicator Channel
PRF	Pulse Repetition Frequency
PTR	Protector
QAM	Quadrature Amplitude Modulation
R&TTE	Radio and Telecommunications Terminal Equipment
Radar	Radio Detection And Ranging
RASS-R	Radar Analysis Support Systems – Real-time measurements
RASS-S	Radar Analysis Support Systems – Site measurements
RB	Resource Block
RBW	Resolution Bandwidth
RCS	Radar Cross Section
RF	Radio Frequency
RMS	Root Mean Square
RTG698	Radar Target Generator
RUT	Radar Under Test
RX	Receiver
RX PTR	Receiver Protector
S-band	Band for Short range and ASR radar (2700-2900 MHz)
SA	Spectrum analyser
SG	Signal Generator
SLC	Side Lobe Cancellation
SNR	Signal-to-Noise ratio
spurious emissions	Unwanted OOB emissions of test equipment, e.g. signal generators
Spurious Emissions	Unwanted OOB emissions of LTE BS and UE in the spurious domain
STAR	S-band Terminal Approach Radar
STC	Sensitivity Time Control
TA	Terminal Approach
TAR	Terminal Approach Radar
TDD	Time Division Duplexing
TS	Technical Specification
TX	Transmitter
UAV	Unmanned Aerial Vehicle
UMTS	Universal Mobile Telecommunications System
Uplink	The signal path from user equipment to base-station
US	United States
VCC	Vanuytven Clutter Canceller
VNA	Vector Network Analyser
VPD	Vertical Polar Diagram
WIFI	Wireless Fidelity
YIG filter	Yttrium-Iron-Garnet filter

EXECUTIVE SUMMARY

The Belgian Institute for Postal services and Telecommunications (BIPT) commissioned Intersoft Electronics (IE) to assess the performance degradation of the Belgian S-band radars due to interference of upcoming 4G communication technologies. The study was carried out preliminary to the auction of the allocated spectrum bands by BIPT end of 2011.

4G services will use the 2600 MHz frequency band which encroaches the low end of the S-band (2700-2900 MHz) which is used for Terminal Approach Radar (TAR) services. From studies already carried out abroad, it is clear that the Long Term Evolution (LTE) technology will interfere in the S-band if no mitigation measures are taken.

The impact on radar performance of three different **interference mechanisms** has been studied.

- The effect of the LTE carrier signals impacting on the radar's broadband receivers (driven to saturation). This is called Blocking, whereby the signal to noise ratio (SNR) of the radar is decreased.
- The effect of an increased noise floor due to the unwanted emissions in the spurious domain from LTE base-stations (BS) and user equipment (UE).
- The creation of Inter-Modulation products (IMPs) in the radar receiver. This effect increases the noise floor just as Spurious Emissions do. Therefore, all three mechanisms reduce the SNR and **will degrade** the radar's capability of detecting aircraft (known as probability of detection or Pd).

The effects of Blocking, Spurious Emissions and Inter-Modulation on the Pd have been tested on all types of S-band radars currently managed by Belgocontrol and Defence. The **results** of these tests were in line with results obtained in studies from abroad. However, it was observed that the effect of Inter-Modulation on the radar is more significant than the effect of Blocking.

The most straightforward **mitigation measure** is filtering, both at the radar and 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 far too 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 safety-of-life services (air traffic control (ATC)), it is strongly advised to add those bands to the list of protected bands and impose a more stringent maximum power level for Spurious Emissions.

During this study, measurements were only done on the radar. However, another severe interference that should be investigated is on the BS – in relation to **inter-modulation from co-located BS.** This interference mechanism is usually dealt with as Spurious Emissions but requires additional study on the BS. Recent updates of the ETSI 3GPP technical specification TS 136.104 (BS) indicate that all telecommunications services using co-located BS self-imposed stringent norms in order to protect themselves for this kind of interference. Because radar are highly sensitive receivers at height (line of sight to the BS), it is advised to consider them also as co-located systems. As a consequence, it should be verified and ensured by 4G service providers that BS (spurious) emissions in the radar band, caused by Inter-Modulation (including inter-modulation resulting from BS co-location), remain below a power level providing sufficient protection for radars.

1. SCOPE

BIPT commissioned IE to assess the performance degradation of the Belgian S-band radars due to interference of upcoming 4G communication technologies. The study was carried out preliminary to the auction of the allocated spectrum bands by BIPT end of 2011. The time frame of the study was bounded between the 23th of March and the 20th of June 2011.

This test report summarizes the results obtained on the different operational S-band radars in Belgium, i.e. TA-10, ASR-9 and STAR2000. For these radar types, measurement campaigns were carried out at Beauvechain, Brussels and Liège respectively. The test report was updated after each campaign and resulted in this final report. It can be read together with the test plan IE-TP-00348-004 Test plan Study BIPT. The test numbers mentioned in this report as *test 0x* refer to the test plan.

The test sheets annexed to the test plan were used during testing. Colour codes in the test sheets refer to frequency bands on Figure 1.1. This figure sketches the bands for 4G technologies encroaching the radar S-band. The main existing Time Division Duplex (TDD) technology is WiMAX and the main existing Frequency Division Duplex (FDD) technology is LTE. The FDD downlink band is assigned to LTE base-stations (BS) and the FDD uplink band to LTE user equipment (UE). The TDD band is bi-directional. In the scope of this study, the terms uplink and downlink are used from the telecommunications point of view and not from the radar's. This means that with uplink the signal path from UE to BS is denoted and with downlink the reverse.

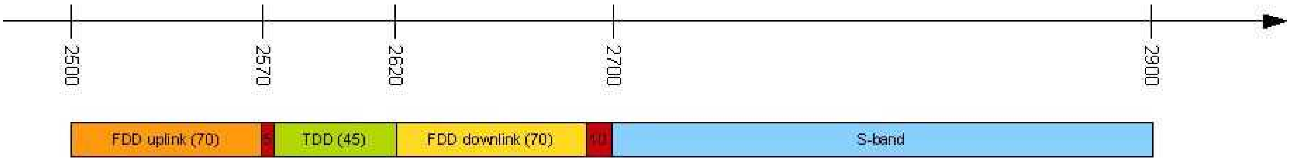


Figure 1.1: 4G bands encroaching radar S-band

From Figure 1.1 it is clear that new 4G telecommunications services will occupy the 2600 MHz band next to the S-band in which TAR operate. Because TAR provide safety-of-life services, it is very important that possible interference is studied and measured. This study can lead to the right mitigation measures and/or specifications to be defined so that 4G telecommunications services and TAR services can co-exist.

The topic of 4G versus S-band radar coexistence is still being studied internationally and discussed in the specific working groups.

2. APPROACH

2.1. General test set-up

Figure 2.1 shows a block diagram of the general test set-up. Four main parts can be distinguished: the radar receiver chain, target injection, interference injection and data extraction. The main equipment are signal generators (SGx), a noise generator (NG) and the radar target generator (RTG). The blocks in dotted lines were used for amplifying and filtering the generated signals and were not present for all tests. Filtering the test signals was sometimes necessary to suppress spurious emissions from the generator or IMPs created in the set-up. Amplifying was often done to overcome insertion losses. Concise signal handling is important in order to distinguish which interference mechanism causes an observed performance degradation. The care to be taken and the different circumstances at different radar sites (injection points, injection losses, receiver sensitivity) forced us each time to modify the set-up accordingly. Figure 2.1 Shows the set-up as it was applied at Beauvechain. Modifications on the set-up made in Brussels and Liège are indicated in the relevant sections in this report [3.2. and 3.3.].

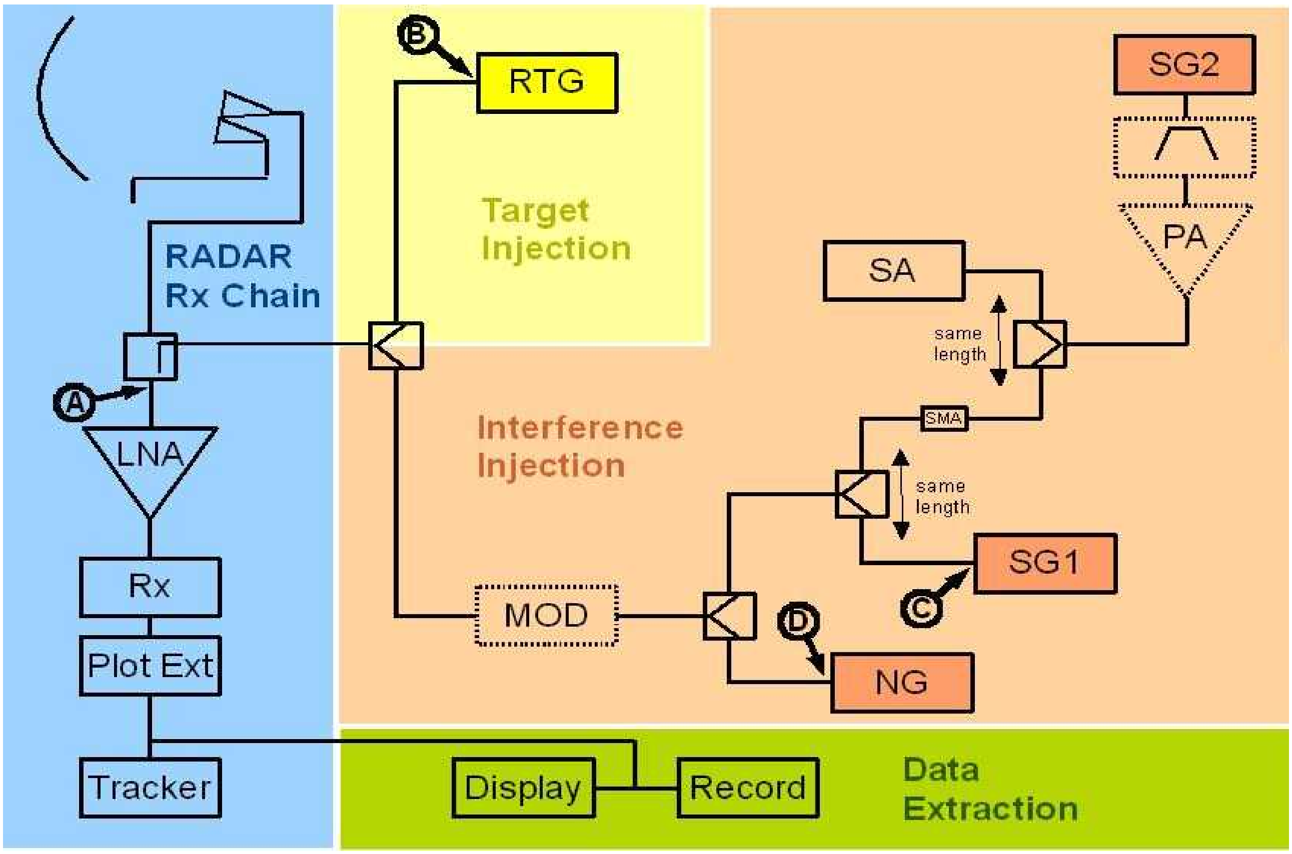


Figure 2.1: Test set-up as applied at Beauvechain

In the radar receiver chain, the injection and data extraction points are respectively determined in front of the LNA and behind the plot extractor. Injecting before the LNA is the best way to include whole the receiver chain in the measurements. On the TA-10 and STAR2000 there are no other components between the antenna and the LNA. Only 1 dB cable loss should be taken into account. For the ASR-9 the receiver configuration is slightly different. Refer to Figure 3.14 for more details.

Plot data is used for analysis rather than track data. The tracker executes algorithms that built the tracks of targets. From track data it cannot be determined accurately when the radar starts to loose detections. The Multi Radar Display (MRD3) with its History statistics tool is used for displaying and evaluating Pd degradation [Figure 2.2]. A, B, C and D are calibration points.

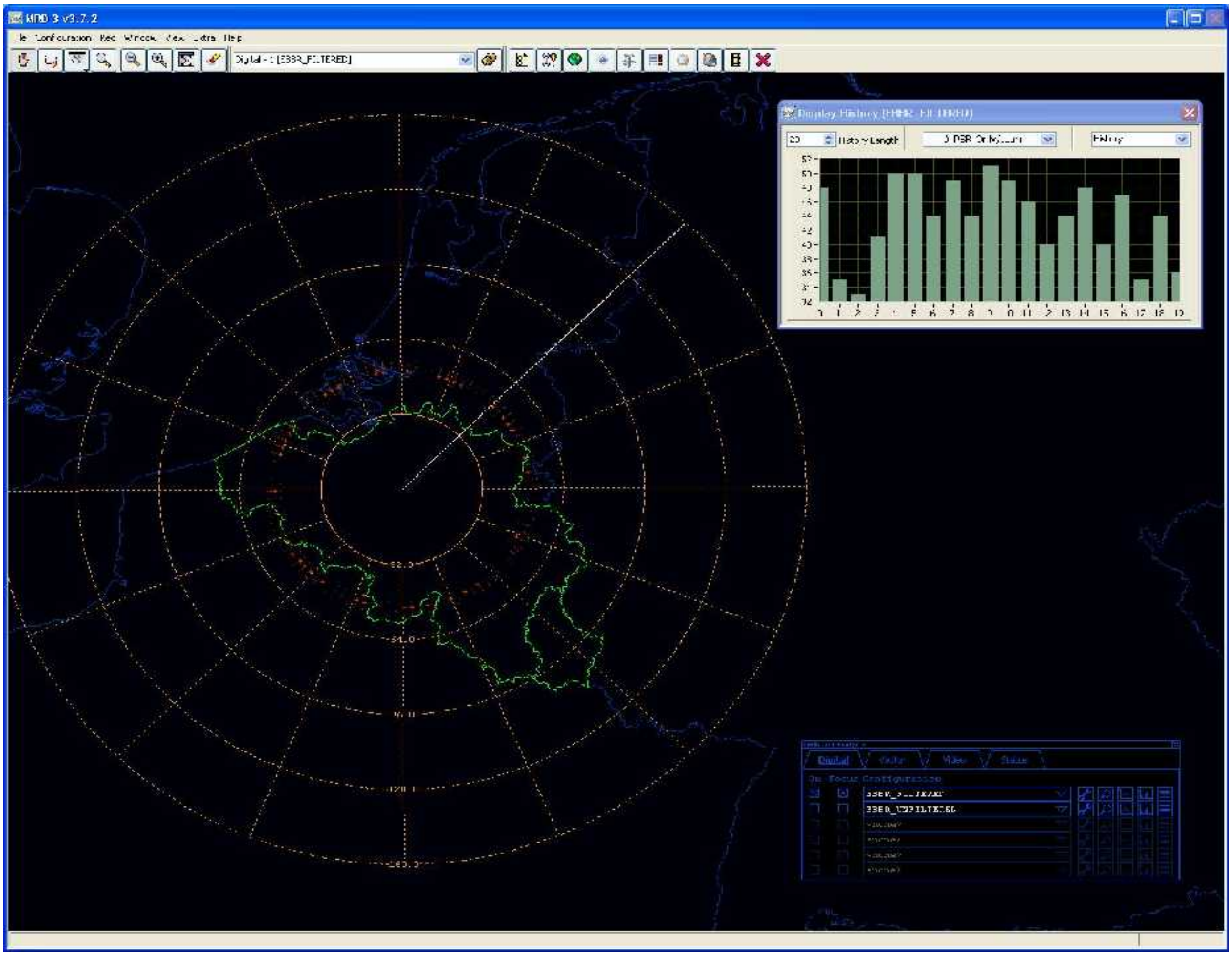


Figure 2.2: MRD3 display with scan history

Table 1 lists the instruments used for signal generation and verification.

Rhode & Schwarz SMB100A 6 GHz signal generator
HP 8683D 2,3-13 GHz signal generator
Agilent 4438c 1-6 GHz signal generator (used for 64QAM)
Broadband Noise Jammer
Rohde & Schwarz FSP 13,6 GHz Spectrum analyser
Power Amplifier
Filters [restricted annex 2]
RTG698

Table 1: List of instruments

SG1 in the set-up was the R&S SMB 100A. For SG2 the HP and the Agilent were used. The latter was particularly interesting because of its ability to generate OFDM/64QAM signals conforming the ETSI standard. The spectrum analyser (SA) was added to the set-up for verifying the signal of SG2. When testing Inter-Modulation, the SA was used to verify that the RMS power levels of both signals were equal. By using cables with equal losses, SG2 had equal insertion loss than SG1 and the SA was at the same level. In some tests, a power amplifier (PA) was used because of the limited power of SG2. Filters were used to filter out the spurious emissions of SG2. In order to adjust power levels, attenuators were used and also the modulator (MOD) of the RTG.

2.2. Generation and injection of interference

The interference injected was the sum of different signals. On Figure 2.1 it can be observed how the signals of SG1, SG2 and NG were combined. Three different mechanisms of interference were tested:

- **Blocking**: the effect of amplifier saturation in the receiver of the radar under test (RUT). An in-band LTE signal can saturate broadband amplifiers, typically the LNA, before the IF filter. With Blocking in this study is not meant the effect of triggering the receiver protector limit device. Tests on Blocking at different frequency offsets result in the protection level curve. This curve gives the power threshold at which radar degradation starts to occur as a function of frequency offset.
- Desensitisation through unwanted LTE emissions in the spurious domain or **Spurious Emissions**, raising the noise floor in the RUT's reception bandwidth.
- Desensitisation through **Inter-Modulation**: in-band LTE signals create IP3 products in the RUT's reception bandwidth. Note that also the BS itself can generate and transmit IP3 products. These are considered as Spurious Emissions of the BS and tested as such. Refer to section 4.2.

Tests on Blocking and Inter-Modulation were performed in two ways: using continuous wave (CW) and using broadband signals. Initially, frequency modulated (FM) signals with and without amplitude modulation (AM) were used as broadband signals. However, the 64QAM signals generated using the Agilent generator were compliant with the ETSI standard and therefore much better represent the real LTE signals. FM and AMFM signals were only used during the first measurement campaign at Beauvechain.

At Beauvechain, two different 64QAM signals were used: one containing load data and another one without load data. Figure 2.3 shows the frequency spectrum of these signals. Figure 2.4 and Figure 2.5 show the signals in the time domain with and without load data respectively. The latter contains only control data and drops 65 dB at the channels reserved for load data. Refer to restricted annex 1 for more detailed information on these signals.

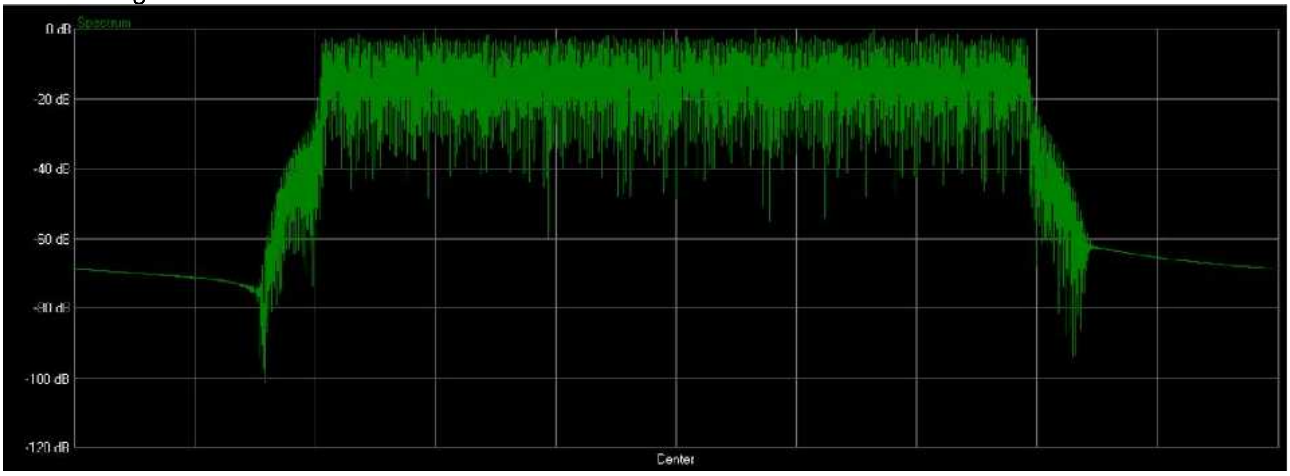


Figure 2.3: 64QAM signal for LTE FDD with load, frequency domain

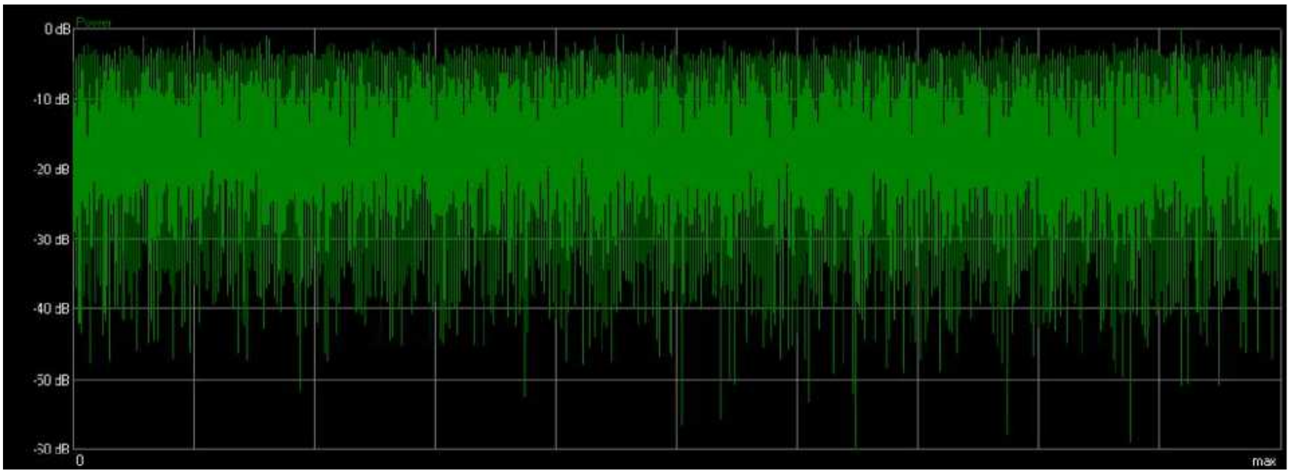


Figure 2.4: 64QAM signal for LTE FDD with load, time domain

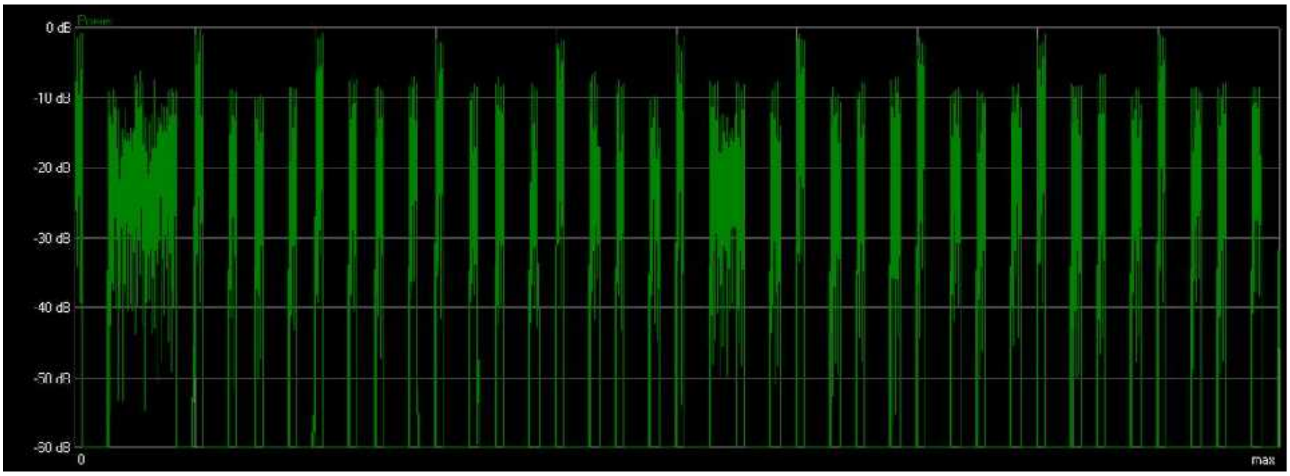


Figure 2.5: 64QAM signal for LTE FDD without load, time domain

For **tests on Spurious Emissions**, AWGN and the 64QAM signal with load were used. AWGN was generated all over the S-band using the broadband noise jammer. The 64QAM signal was set at defined frequency offsets.

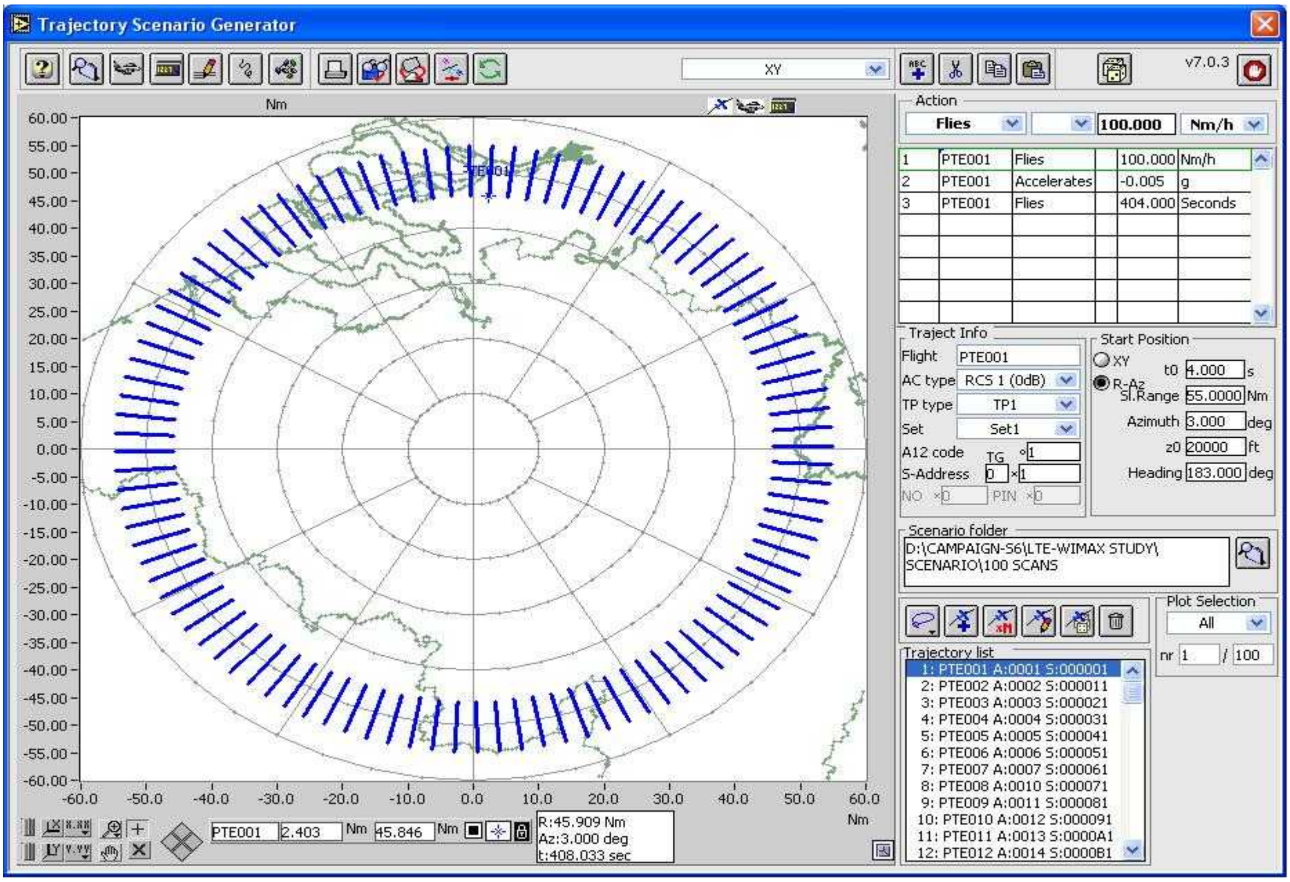
Table 2 summarizes which signals were used in which tests. FM, FMAM and 64QAM without load were only used during the first measurement campaign (TA-10, Beauvechain).

Test	**CW**	**AWGN**	*FM*	*AMFM*	**64QAM (load)**	*64QAM (no load)*
1. **Blocking CW**	x					
2. **Spurious**		x			x	*x*
3. **Inter-Modulation CW**	x					
4. **Blocking BB**			*x*	*x*	x	*x*
5. **Inter-Modulation BB**				*x*	x	
6. **Environment**				*x*	x	

Table 2: Applied test signals

2.3. RTG scenario for life Pd evaluation

The radar target scenario is generated and compiled in the Radar Target Generator (RTG698). The RTG receives Azimuth Control Pulses (ACPs), Azimuth Reference Pulses (ARPs) and trigger for synchronization. The scenario contains 100 targets flying radially towards the radar. Figure 2.6 shows this scenario in the trajectory scenario generator.



Action: Flies 100.000 Nm/h

1	PTE001	Flies		100.000	Nm/h
2	PTE001	Accelerates		-0.005	g
3	PTE001	Flies		404.000	Seconds

Traject Info

Flight PTE001
AC type RCS 1 (0dB)
TP type TP1
Set Set1
A12 code TG °1
S-Address 0 ×1
NO ×0 PIN ×0

Start Position

○ XY
● R-Az
t0 4.000 s
Sl.Range 55.0000 Nm
Azimuth 3.000 deg
z0 20000 ft
Heading 183.000 deg

Scenario folder
D:\CAMPAIGN-S6\LTE-WIMAX STUDY\SCENARIO\100 SCANS

Plot Selection All
nr 1 / 100

Trajectory list
1: PTE001 A:0001 S:000001
2: PTE002 A:0002 S:000011
3: PTE003 A:0003 S:000021
4: PTE004 A:0004 S:000031
5: PTE005 A:0005 S:000041
6: PTE006 A:0006 S:000051
7: PTE007 A:0007 S:000061
8: PTE008 A:0010 S:000071
9: PTE009 A:0011 S:000081
10: PTE010 A:0012 S:000091
11: PTE011 A:0013 S:0000A1
12: PTE012 A:0014 S:0000B1

PTE001 2.403 Nm 45.846 Nm

R:45.909 Nm
Az:3.000 deg
t:408.033 sec

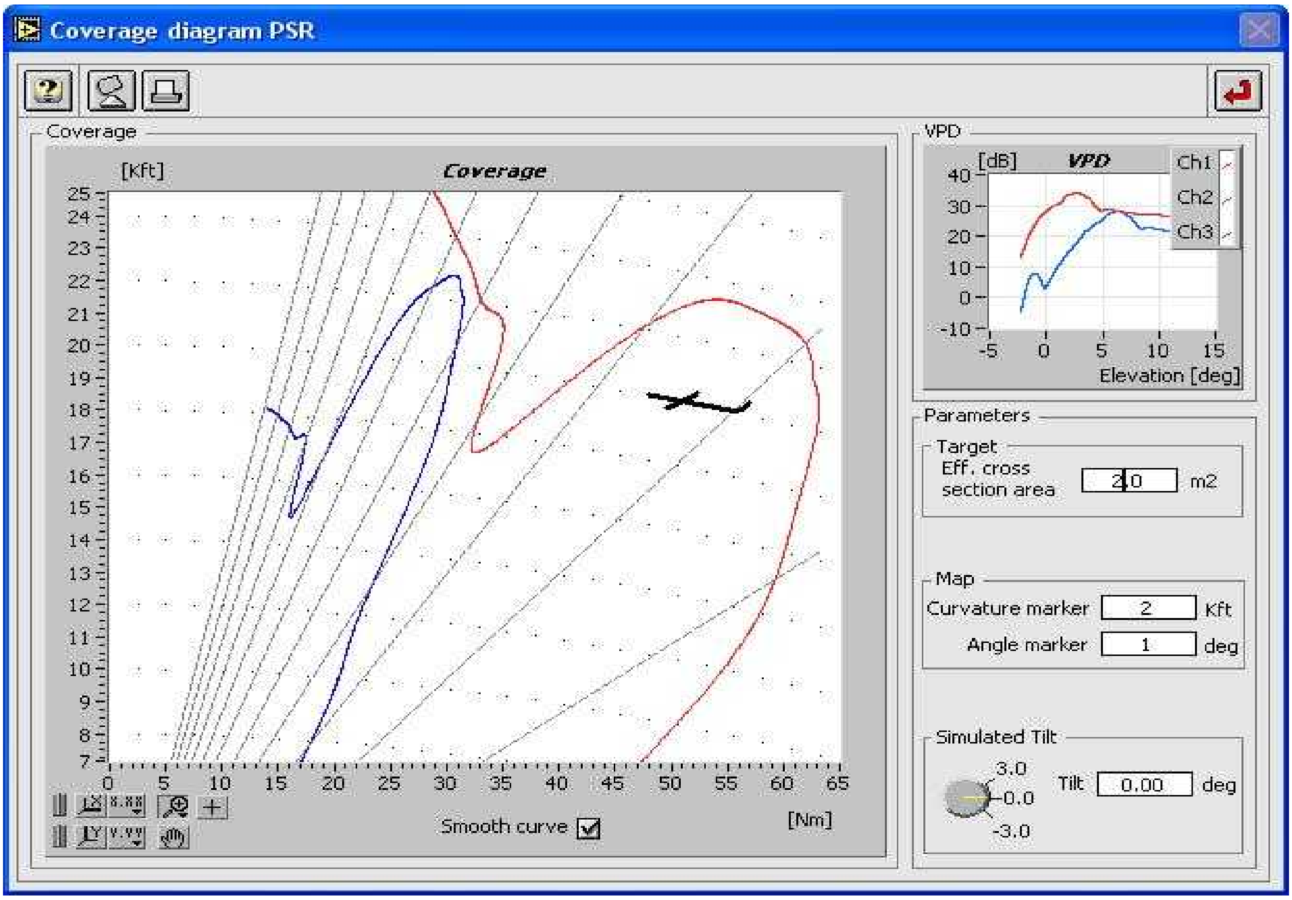
Figure 2.6: Trajectory scenario containing 100 radially flying targets

Table 3 summarizes the scenario parameters. The end range was set earlier than stated in the test plan in order to reduce the deviation of reflected power of the targets down to 0,2 dB. The speed of the targets was kept constant in order to reduce fluctuation of the Pd due to Doppler straddling losses. Sampling losses still occur when range cells are not centred on the pulse. However, these were averaged out by the vast number of test targets injected.

Start range	55 NM
End range	48 NM
Speed	100 NM/h (51.4 m/s or 925Hz Doppler @2700MHz)
Altitude	20.000 feet
Rotation speed	4 sec
Number of scans	100
Swerling Case	0

Table 3: Trajectory parameters

The position of the trajectories is chosen at the outskirts of the coverage volume where the RUT's antenna gain is quasi constant [Figure 2.7]. This will reduce the effect of the range in the radar equation on the received power of the target return. This power is quasi constant during the scenario, deviating peak to peak with only 0,2 dB.



Smooth curve ☑

Target

Eff. cross section area 2.0 m2

Map

Curvature marker 2 Kft

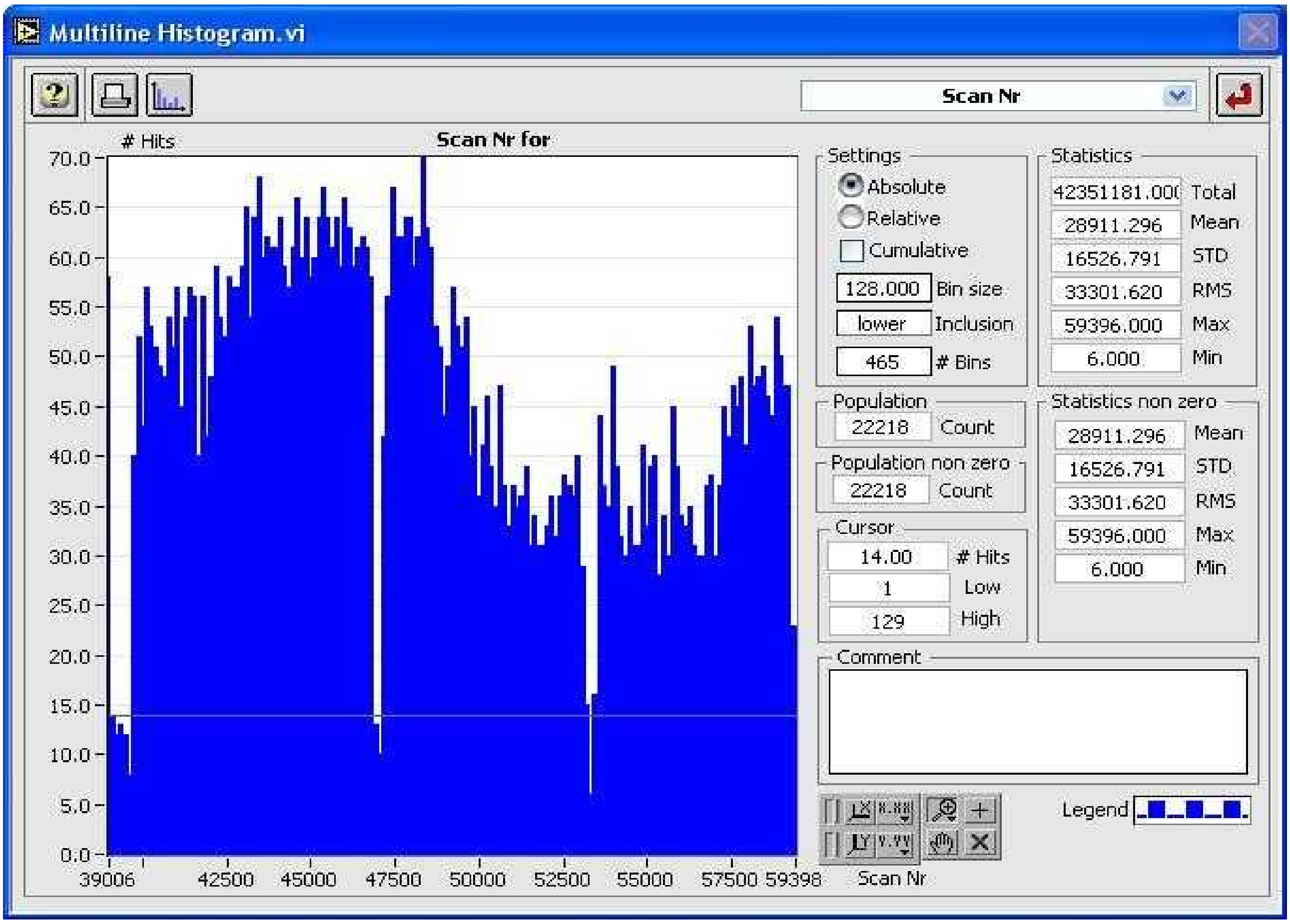
Angle marker 1 deg

Tilt 0.00 deg

Figure 2.7: Coverage diagram

A probability of detection (Pd) of 60% was defined by adjusting the radar cross section (RCS) of the targets. This is the point were the radar receiver has a high sensitivity and performance degradation can be observed very well. This approach was proposed by QinetiQ in [1]. Inserting 0,5 dB extra loss resulted in a degradation of the Pd from 60 down to 35%. This proves that the test set-up was very well capable to spot a degradation of target detection. This technique allowed to read the point of degradation with a 1 dB accuracy.

Figure 2.8 illustrates how the power level that corresponds to a defined degradation of Pd was determined. The histogram shows the Pd versus scan number. Note that the values on the X-axis denote sector messages and one scan contains 128 sectors. Therefore the bin size is set to 128.



Scan Nr

Settings
● Absolute
○ Relative
☐ Cumulative
128.000 Bin size
lower Inclusion
465 # Bins

Statistics
42351181.00 Total
28911.296 Mean
16526.791 STD
33301.620 RMS
59396.000 Max
6.000 Min

Population
22218 Count

Population non zero
22218 Count

Cursor
14.00 # Hits
1 Low
129 High

Statistics non zero
28911.296 Mean
16526.791 STD
33301.620 RMS
59396.000 Max
6.000 Min

Comment

Figure 2.8: Determination of Pd degradation

At the start and at the end a Pd of 55% can be observed. The initial power of the interference was set based on results from previous tests and a Pd of 55% was observed. At x = 42000 the interference was rejected and the Pd raised to 60%. When the interference was injected again with 1 dB more power the Pd degraded down to 30%. Restoring the power level of the interference resulted in a Pd up to 55%. As such the power level corresponding with the defined degradation of Pd was found.

The dips in the histogram correspond with the restart of the RTG scenario. These dips do not go down to zero Pd because there were a few targets of opportunity traffic in the range of the scenario.

3. RESULTS

Respectively, the results of the measurement campaigns on TA-10, ASR-9 and STAR2000 radars are explained. For the first campaign (TA-10, Beauvechain) more details about the way of work are given in section 3.1. The methodology also applies for the following measurement campaigns on the ASR-9 and STAR2000.

The tests carried out on all RUTs are:

- Blocking: CW (test 01) and BB (test 04)
- Inter-Modulation: CW (test 03) and BB (test 05)
- Spurious Emissions (test 02)

The test on the simulated environment (test 06) has only been carried out on the TA-10 due to its limited added value.

3.1. Measurement Campaign TA-10 Beauvechain

The measurement campaign on the TA-10 radar at Beauvechain was conducted from Wednesday 4th of May until Friday 6th of May. According to the test plan, it was intended to perform all tests at both the RUT's operating frequencies. However, in order to switch frequency, it would be necessary to replace the wave guide duplexer. The time frame did not allow this rebuild and comparable results were expected on the other frequency. Therefore tests were only performed at a single frequency

Before starting the tests, the set-up was calibrated and insertion losses of the different signals were measured. The set-up was as depicted in Figure 2.1 with the modulator included. The PA and YIG filter were added during the tests using broadband signals. Table 4 gives an overview of the insertion losses at the RUT's operating frequency for the different signals injected. The measured losses were rather high due to the loss of the coupler before the LNA, being 40 dB.

Source	**Calibration Points in set-up [Figure 2.1]**	**Insertion Loss at RUT's Operating Frequency [dB]**
Targets	A - B	56,0
Interference	A - C	55,6
Noise	A - D	52,3

Table 4: Insertion losses, TA-10 Beauvechain

The Vector Network Analyser (VNA) curve gives the insertion loss at the point of injection as a function of frequency offset [Figure 3.1]. The blue curve was measured using RASS-S tools and verified and validated by an in the field measurement (green curve). The RUT was jammed at different offset frequencies and the received power measured at the injection point before the LNA.

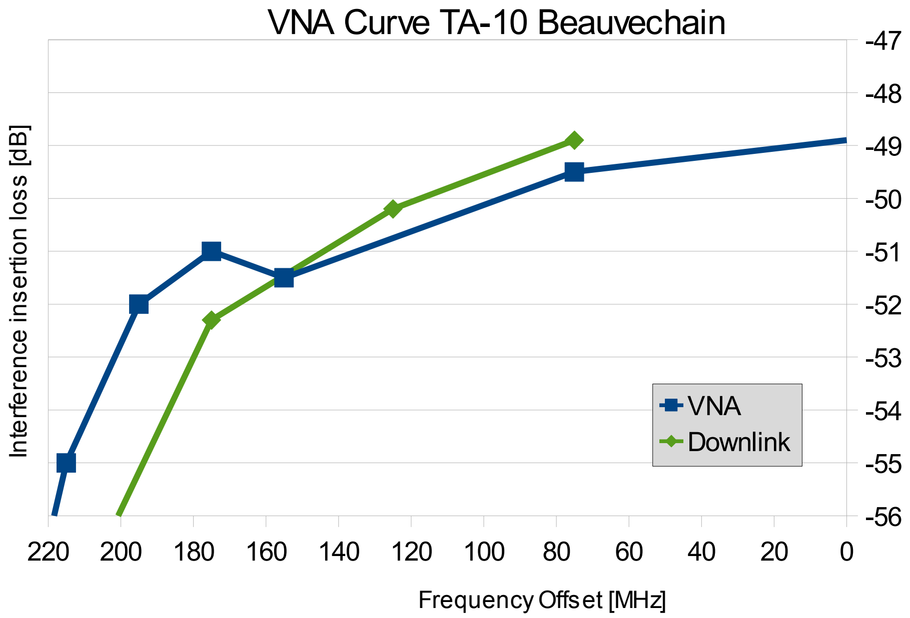


Figure 3.1: VNA Curve, TA-10 Beauvechain

3.1.1. Blocking

3.1.1.1. Single-tone compression (Test 01)

Blocking was tested using a single-tone CW signal at different frequency offsets. Figure 3.2 shows the protection level curve obtained from the measurements. The curve is corrected according to the VNA curve in Figure 3.1. **The protection level curve is rather flat at -28 dBm from an offset frequency of 40 to 200 MHz.**

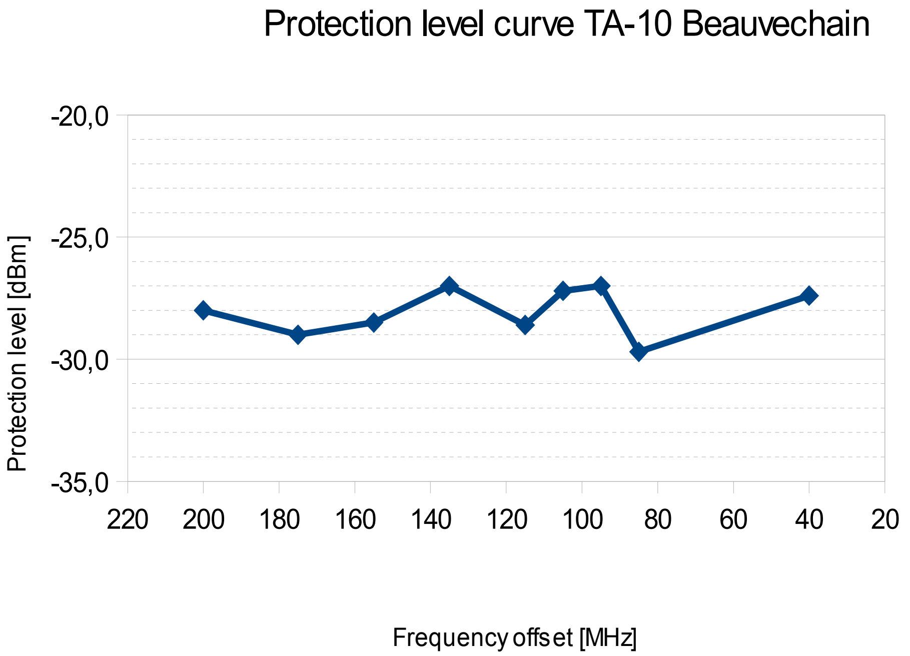


Figure 3.2: Protection level curve, TA-10 Beauvechain (CW)

The dynamic range of the Rhode & Schwarz signal generator was verified to confirm that the interference mechanism triggered with this test was indeed Blocking and not desensitization through spurious emissions of the signal generator. The dynamic range of the Rhode & Schwarz at 40 MHz offset (smallest offset used) is 88 dB. -28 dBm -88 dB = -116 dBm, i.e. 4 dB below the level of desensitization through Spurious Emissions using AWGN (test 02).

Another indication for the interference mechanism triggered is the clutter map recovery time. When Spurious Emissions from the interference source, i.e. the signal generator, fall in the RUT's IF band, the clutter maps increase promptly and recover slowly. This slow recovery ensures not to saturate the receiver with strong clutter reflections. Consequently, when spurious emissions from the signal generator would have been hit, the Pd would have restored slowly too. Cutting of the interference source resulted however in immediate recovery of Pd.

3.1.1.2. Interference from a single base-station (Test 04)

In test 01 (section 3.1.1.1.) the effect of Blocking was investigated using CW signals at different offset frequencies and the protection level curve was the result of these measurements [Figure 3.2]. In test 04 the same effect was investigated using broadband signals instead of CW in order to get a more realistic simulation of an LTE BS. The different applied broadband signals were:

- a frequency sweep (FM)
- an amplitude modulated FM sweep (AM/FM) with 60% modulation depth, which is similar to the modulation depth of 64QAM
- a 64QAM signal for LTE FDD with load
- a 64QAM signal for LTE FDD without load

Table 5 summarizes the obtained Blocking levels for the different applied signals. These values also take into account the correction according to the VNA curve in Figure 3.3.

Applied Signal	**Centre Frequency Offset / Bandwidth [MHz]**	**RMS Power Level for Pd Degradation [dBm/5MHz]**
FM	95 / 20	-32
FM/AM60%	95 / 20	-36
64QAM with load	95 / 10	-50
64QAM without load	95 / 10	Not measurable

Table 5: Pd degradation through Blocking (BB), TA-10 Beauvechain

When using the 64QAM signal without load only a few test targets were degraded. This is because the signal is chopped in the time domain. Refer to Figure 2.5 for the temporal behaviour of this signal. In between the control data there is no interference at all. Injecting this time domain chopped signal results in sectoral spiral like noise bands on the PPI, only hitting a few targets.

The dynamic range of the Agilent signal generator was limited to 65 dB (the spectrum of the signal depicted in Figure 2.3 drops with 65 dB outside its band). A YIG filter was used to attenuate the spurious emissions of the generator. With the RMS power of the signal at -50 dBm/5MHz, the spurious level of the 64QAM signal is at -115 dBm/5MHz or -122 dBm/MHz. With desensitization through Spurious Emissions starting at -115,6 dBm/MHz using the 64QAM signal with load, it is better to filter of the 64QAM signal when testing Blocking.

Remarkable is the difference between the effects of Blocking using CW versus the LTE signal. One could assume that this LNA in particular might be more limited by the peak power rather then the RMS value of the LTE signal. Another type of LNA of the newer generation STAR2000 did not show this effect.

3.1.2. Desensitization through Spurious Emissions (Test 02)

The effect of unwanted out of band (OOB) LTE emissions (Spurious Emissions) was investigated using three different signals:

- a broadband noise jammer (AWGN), injecting from 2700 to 2900 MHz
- a 10 MHz wide 64QAM signal with load and centre frequency at 2680 MHz
- the same signal without load

Table 6 summarizes the obtained levels for desensitization through Spurious Emissions for the different signals applied. The obtained power level resulting in the defined degradation of Pd using the 64QAM signal without load corresponds to the result obtained with the broadband noise jammer. When using the 64QAM signal with load, the power level for the same degradation of Pd was 3 dB lower.

Applied Signal	RMS Power Level for Pd Degradation [dBm/MHz]
BB noise jammer, 2700-2900 MHz	-112,0
64QAM without load, 2675-2685 MHz	-112,6
64QAM with load, 2675-2685 MHz	-115,6

Table 6: Pd degradation through Spurious Emissions, TA-10 Beauvechain

For all tests on desensitization through Spurious Emissions, a slow clutter map recovery was reflected in a slow Pd recovery when cutting of the interference source. For this RUT the clutter map recovers at a rate of 0,2 dB per scan. Clutter map recovery rate is however set by the manufacturer and might/will be different (mostly faster) on other systems.

3.1.3. Desensitization through Inter-Modulation

3.1.3.1. Inter-Modulation of CW signals (Test 03)

The effect of IP3 products created in the RUT's reception bandwidth was investigated using CW signals at offset frequencies as defined in the test plan. Table 7 summarizes the obtained power levels for desensitization through Inter-Modulation. The levels of the lower and upper frequency are the same.

Frequency Offset 1 [MHz]	Frequency Offset 2 [MHz]	Power Level for Pd Degradation [dBm]
30	60	-46,3
40	80	-47,8
50	100	-48,3
100	200	-48,3

Table 7: Pd degradation through Inter-Modulation (CW), TA-10 Beauvechain

3.1.3.2. Inter-Modulation of broadband signals (Test 05)

Following to test 03 on Inter-Modulation using CW signals, the same interference mechanism was tested using LTE alike broadband signals. Table 8 summarizes the obtained RMS power levels.

Applied Signal 1	Frequency Offset 1 / Bandwidth 1 [MHz]	Applied Signal 2	Frequency Offset 2 / Bandwidth 2 [MHz]	RMS Power Level for Pd Degradation [dBm/5MHz]
FM	95 / 20	FM	190 / 10	-51,8
FM/AM60	95 / 20	FM	190 / 10	-51,8
64QAM with load	95 / 20	FM	190 / 10	-52,6

Table 8: Pd degradation through Inter-Modulation (BB), TA-10 Beauvechain

Unlike with CW, when IMPs occur at distinct frequency offsets, with broadband signals IMPs are spread all over the S-band. High peaks occur randomly in the LTE signals and inter-modulate at all present frequencies in the signals.

3.1.4. Accumulated environmental interference (Test 06)

For this test the 4G environment nearby the radar site was simulated. For every potential 4G BS site within a range of 10 km the received power from it at the RUT's antenna was calculated. Coordinates of existing GSM-UMTS masts/supports were used [Figure 3.3]. This is a realistic assumption because the government imposes 4G service providers to use the existing infrastructure if possible.

Figure 3.3: GSM-UMTS masts/supports within a 10 km perimeter at Beauvechain

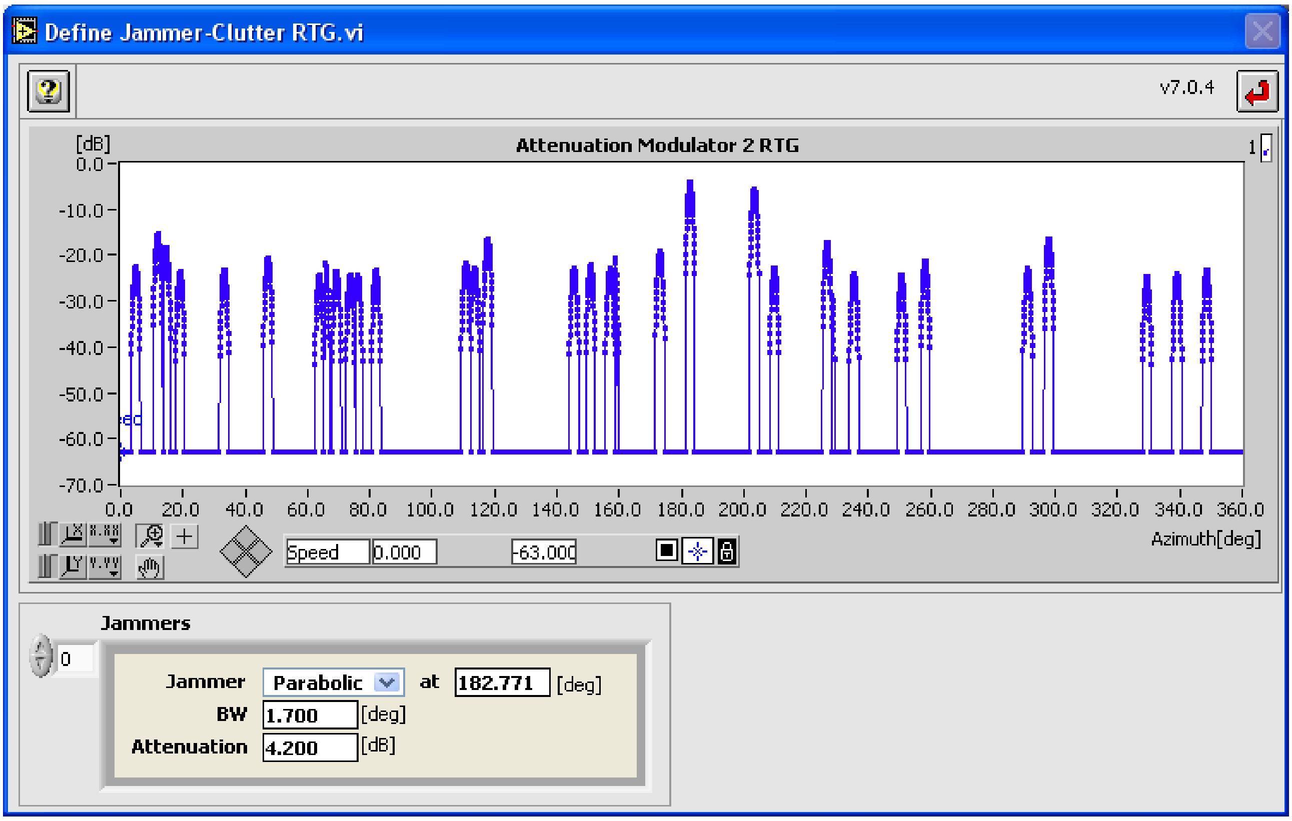
The following parameters were taken into account:

- the elevation angle of each LTE BS antenna relative to the RUT's antenna
- the distance of each LTE BS antenna relative to the RUT's antenna
- the roll off of the RUT's vertical polar diagram (VPD)

Based on these parameters, the path loss and gain reduction were calculated. Although the available VPD curves provided by Defence and Belgocontrol were not really up to date, a good approximation could be made [restricted annex 6].

The free space propagation model was used in the calculations. This propagation model was preferred over the ITU P-452 model. The latter is a model used in telecommunications for guaranteeing communication. That was not the scope of this study. This study was carried out because of possible safety issues and therefore a conservative model like free space was preferred.

Once the received powers at the RUT's antenna were determined, this data was used to create a jammer power profile versus azimuth [Figure 3.4]. Jammers are stronger on shorter range and higher in the RUT's antenna beam. For example the masts at 182 and 203 degrees, which are respectively at 1271 m / 0,7 deg and 1683 m / 1,2 deg, act like very strong jammers.



Define Jammer-Clutter RTG.vi

v7.0.4

Speed 0.000 -63.000

Jammers

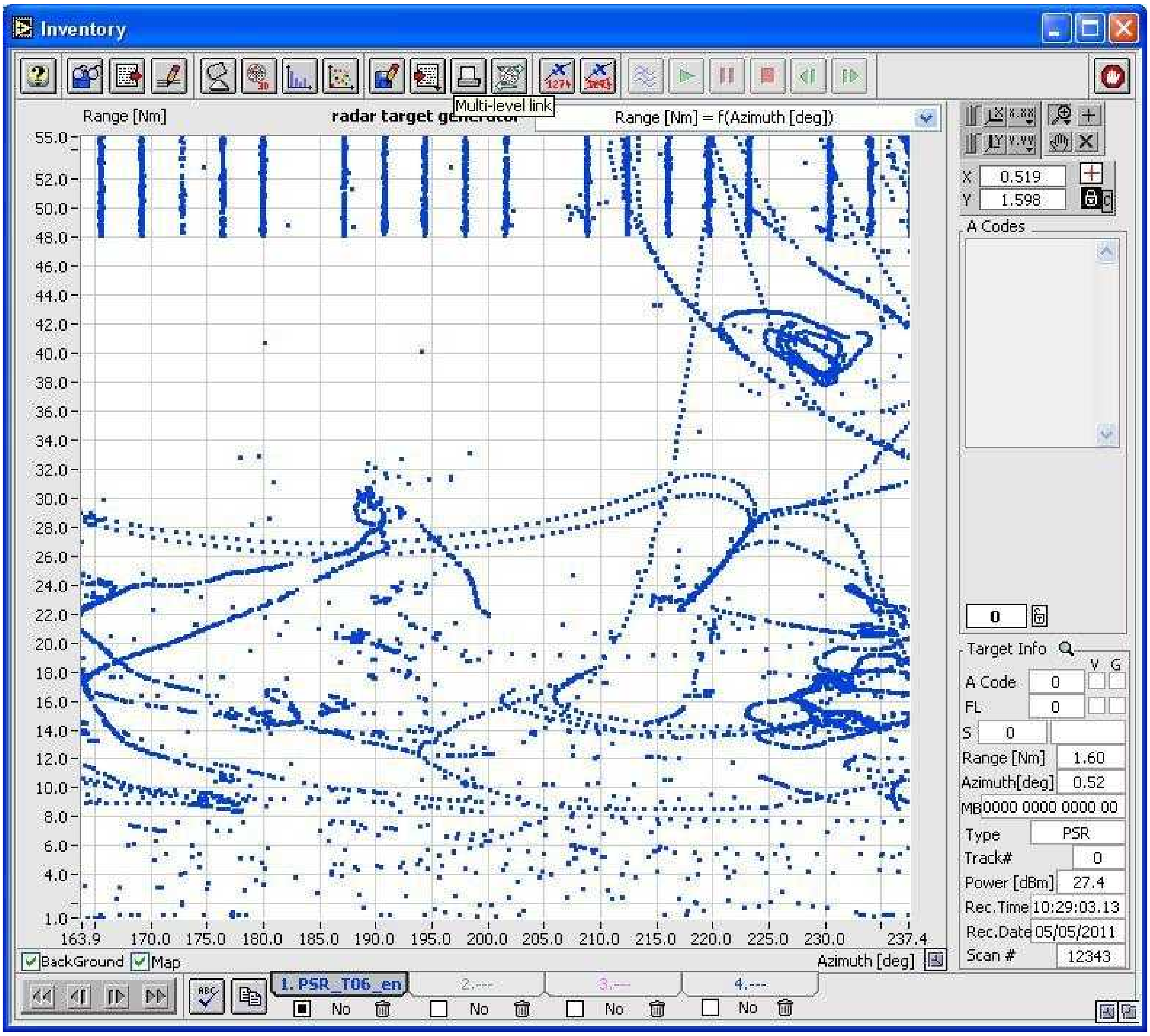
0

Jammer Parabolic at 182.771 [deg]

BW 1.700 [deg]

Attenuation 4.200 [dB]

Figure 3.4: Jammer power profile versus azimuth



X 0.519
Y 1.598

A Code	0
FL	0
S	0
Range [Nm]	1.60
Azimuth[deg]	0.52
MB	0000 0000 0000 00
Type	PSR
Track#	0
Power [dBm]	27.4
Rec.Time	10:29:03.13
Rec.Date	05/05/2011
Scan #	12343

Figure 3.5: Loss of plot data in opportunity traffic

Figure 3.5 shows a Range-Azimuth view of a sector of the scenario with injected targets (radial tracks on top) and opportunity traffic. It can be observed that where the scenario target is not detected due to a simulated LTE interference, there is also loss of plot data on slow moving opportunity traffic (e.g. at azimuth 183 deg). These are small RCS targets flying at low speed and altitude. Compare for instance Figure 3.3, 3.4 and 3.5. There is a strong jammer on short distance at azimuth 183, resulting in a loss of the simulated target at 48-55 NM and loss of plots in the tracks at ranges 24-26 NM.

3.1.5. Isolation curves

3.1.5.1. From specifications to additional required isolation

Table 9 gives an overview of the calculated additional isolation requirements for an LTE BS at 1 km range and 0 degrees elevation. In this table the measured power levels (**protection levels**) are compared to the **specifications** mentioned in ETSI 3GPP technical specifications TS136.101 (UE) and TS136.104(BS). This comparison gives the **isolation needed** to be compliant. The specification on the maximum power output for Spurious Emissions (BS and UE) is very relaxed. For UE, ETSI 3GPP TS136.101 mentions -30 dBm for unprotected bands and -50 dBm for protected bands (1 MHz RBW). The S-band is not protected but in Table 9 measurement results are interpreted both, according to the current level for unprotected bands and according to the level for protected bands (between brackets). If UE meets the specification for protected bands, it can be assumed that in the S-band they will be far below the specification for non-protected bands. However, with the specifications as they are, it is allowed for UE to emit in the spurious domain up to a power level of -30 dBm. For BS, the discrepancy between non protected and protected bands is even greater: -30 dBm versus -86 dBm (1 MHz RBW) [section 4.2].

	Blocking	**Spurious Emissions BS**	**Inter-Modulation**	**Spurious Emissions UE**
Specification	61dBm/5MHz max allowed eirp BS	-30dBm/MHz max at BS output = -12dBm eirp if 18 dBi gain antenna is used	61dBm/5MHz max allowed eirp BS	-30 (-50)dBm/MHz max at UE output = -30 (-50)dBm eirp if 0 dBi gain antenna is used
Protection level	-50dBm/5MHz	**-115dBm/MHz**	**-53dBm/5MHz**	**-115dBm/MHz**
Isolation needed	111dB	103dB	114dB	85 (65)dB
RUT antenna gain at 0 (BS) / -1,3 (UE) deg elevation	27dBi			21dBi
Path loss at 1km	101dB			
Multiple antenna interference (4)	6dB			N/A
Multipath	4dB			
Additional isolation required	47dB @ 85 MHz offset	**39dB in IF band**	**50dB @ 85 MHz offset**	**9 (-11)dB in IF band**

Table 9: Calculated isolation requirements, TA-10 Beauvechain

The additional isolation required is calculated for each interference mechanism, i.e. Blocking, Spurious Emissions from BS, Inter-Modulation and Spurious Emissions from UE. The **protection levels** in Table 9 for Blocking, Spurious Emissions (same for BS and UE) and Inter-Modulation were obtained in tests 04, 02 and 05 respectively, using the 64QAM FDD LTE signal with load [refer to tables 5, 6 and 8].

The protection level relative to the **specification** gives the total **isolation needed**. In order to calculate the additional isolation required on top of the isolation which is already present, the antenna gain of the RUT, the path loss, multiple antenna interference (only for BS) and multipath have to be taken into account.

The RUT's antenna gain at the peak of the beam is 34 dBi. Considering a 4G antenna at equal elevation / height (AMSL) with the RUT's antenna on a distance of 1 km, the elevation angle is 0 degrees. According to the VPD roll off curve there is 6 dB loss at 0 degrees. Taking into account a cable loss of 1 dB, the antenna gain of the RUT is 27 dBi at an elevation of 0 degrees. An end user however, standing on the ground at 1 km distance from the RUT is at an elevation of -1,32 degrees. This corresponds to 12 dB gain reduction [restricted annex 6], resulting in 21 dBi. These **RUT antenna gains are added** to the isolation needed.

There is already a great deal of the isolation needed present in the form of path loss. According to Formula 3.1, the free space path loss for S-band radars is 101 dB at 1km. This **path loss is deducted** from the isolation needed.

$$L=20\log(4\Pi d/\lambda)$$

Formula 3.1

With L = loss; d = distance; λ = wavelength

4G BS sites will typically be shared between the operators. As there will be at least 3, possibly 4 telecommunications providers in Belgium, **6dB is added due to multiple antenna interference enhancement.**

Multipath can enhance or degrade the interference depending on the combination of different phases. It can occur through several mechanisms (e.g. tropospheric scatter, hydrometeor scatter, diffraction, refraction, ducting) which depend on the specific geographical and meteorological circumstances. It is not possible to take multipath effects into account rationally. However, in order to significantly enhance the interference, multipath signals have to reach the RUT's antenna with high power and in phase with the line-of-sight path signal. Therefore **4 dB is added for multipath enhancement**.

After calculating back from the point of measurement (before LNA) towards the point where the specifications are imposed (BS antenna output), the required additional isolation is obtained. This number indicates how much power isolation will be required on top of the already present isolation.

Note that uncertainty concerning interference losses and enhancements can be excluded by monitoring or measuring the power that a BS receives from the radar.

Table 9 gives the specific power budget for one LTE site shared by 4 service providers on the one hand and a single end terminal on the other hand, both at a distance of 1 km from the RUT. The obtained levels for additional isolation required can easily be calculated to other ranges using Formula 3.1. Figure 3.6 shows isolation curves for BS interferences (Blocking, Spurious Emissions and Inter-Modulation) and for UE interference (Spurious Emissions).

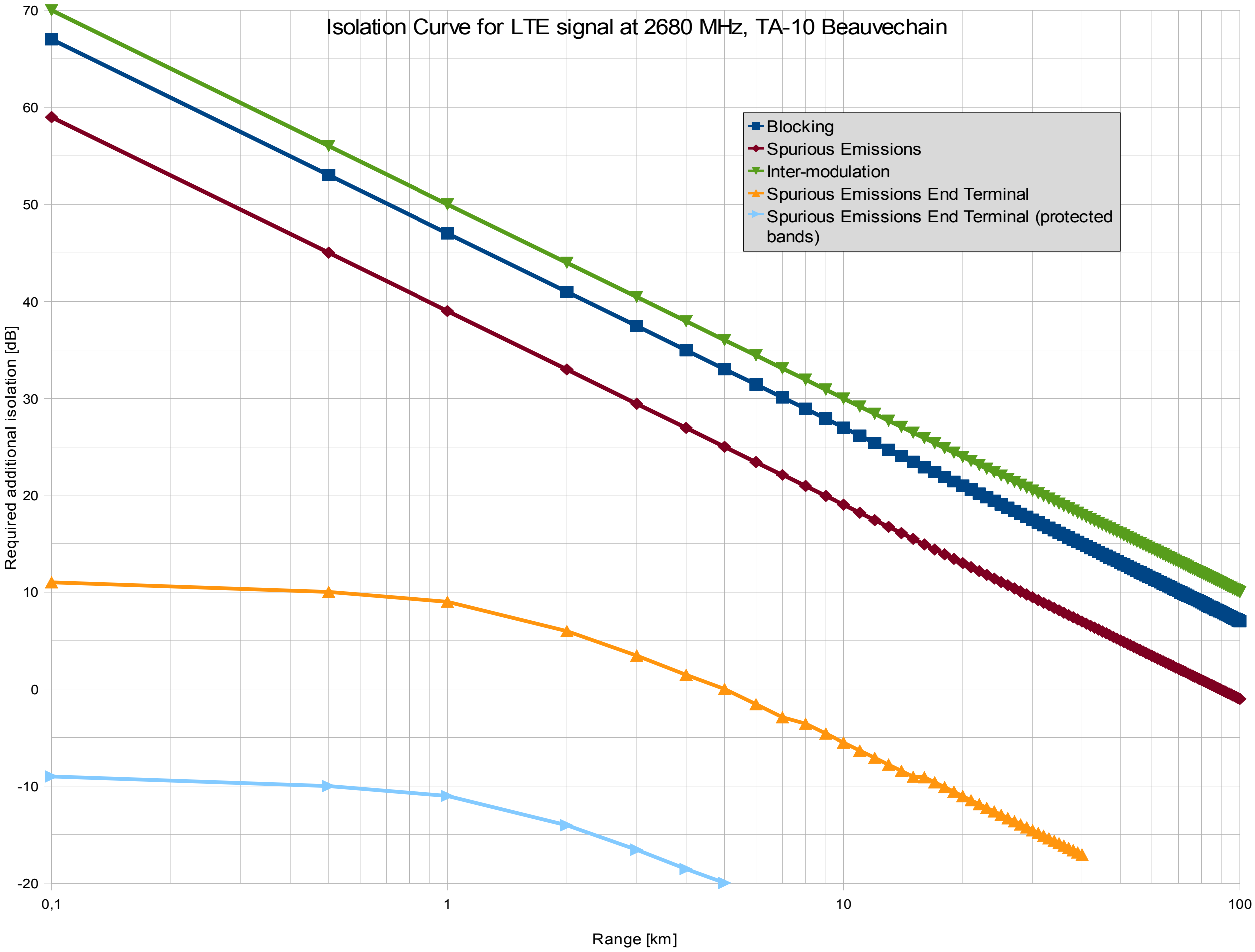


Figure 3.6: Isolation curve for LTE signal at 2680 MHz, TA-10 Beauvechain

3.1.5.2. Important remarks considering isolation curves

It should be noted that there are a few BS site specific parameters that will influence the isolation curves. Therefore, conclusions based on these figures are not easy to draw. Concerning the isolation curves for the interferences from BS, the required additional isolation will deviate as a function of

- the **elevation** (angle) of the BS antenna relative to the radar antenna
- the **number of BS sites in the radar beam**
- the **FDD Downlink band occupation** of the BS site

Deviation due to the elevation of the LTE antenna relative to the radar antenna will be marginal. LTE antenna sites at higher elevations will transmit higher in the radar's antenna beam, where the antenna gain increases, resulting in more additional isolation required. Similarly, less additional isolation will be required for LTE antenna sites at lower elevations. Typically, both radar sites and telecommunications antenna sites are located on top of mountains or high buildings in order to have optimal line-of-sight. For example at Beauvechain, when considering current GSM-UMTS masts up to 10 km range, 8 out of 34 masts are at elevations higher than 0 degrees (maximum 0,5 degrees). Others are below 0 degrees elevation (minimum -0,8 degrees). For the Beauvechain radar site specifically, this elevation deviation results in an isolation deviation of +2 to -3,5 dB.

Figure 3.7 and Figure 3.8 illustrate the potential problem of an accumulated interference from many masts at the same azimuth. Figure 3.7 shows a 1,2 degrees sector from Beauvechain, 30 km towards Brussels where there is a high density of BS. This sector is even smaller than the 3 dB beamwidth of the TA-10. Figure 3.8 is a detail of this sector in Brussels with the present GSM-UMTS sites indicated. In total, 25 sites are located within this sector. They will not all be visible to the radar at Beauvechain but based on the clutter recording [Figure 3.9], it can be stated that a considerable number will be. The clutter recording shows ground reflections from the radar signal and gives as such a good indication of the visibility of potential masts.

Figure 3.7: 1,2 degrees sector from Beauvechain towards Brussels

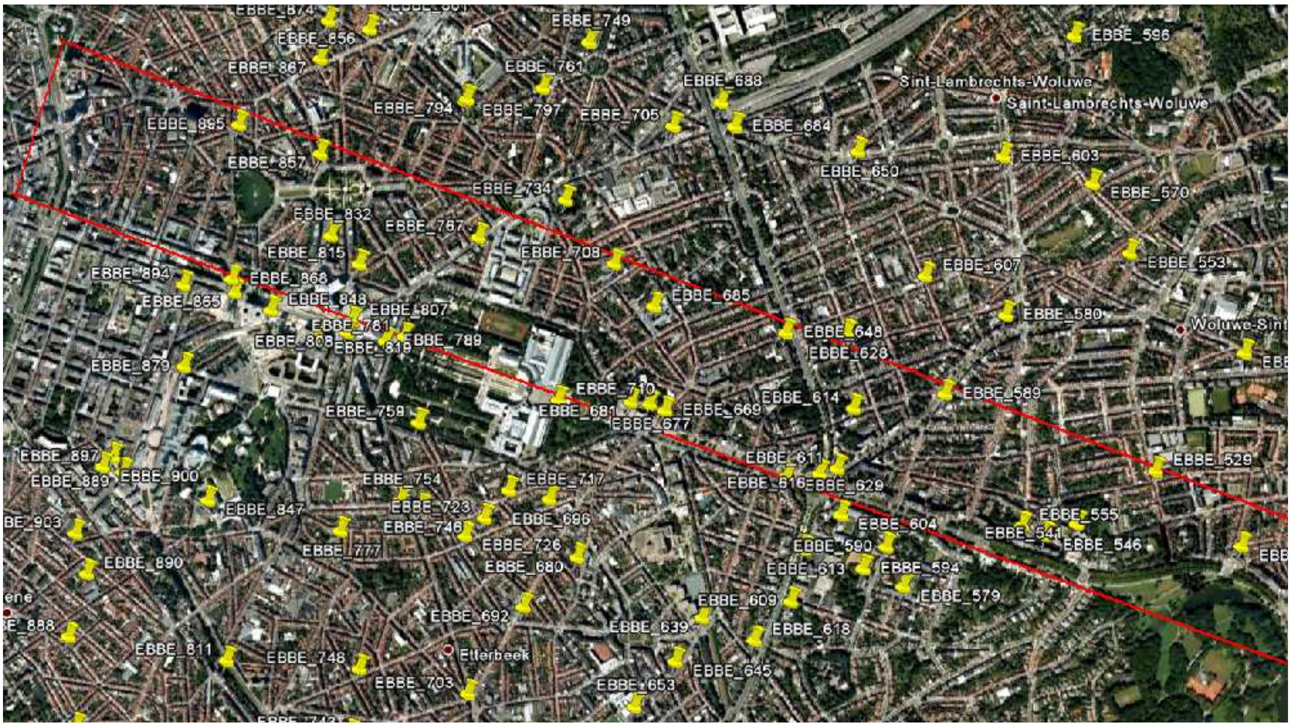


Figure 3.8: Detail from 1,2 degrees sector with present GSM-UMTS sites

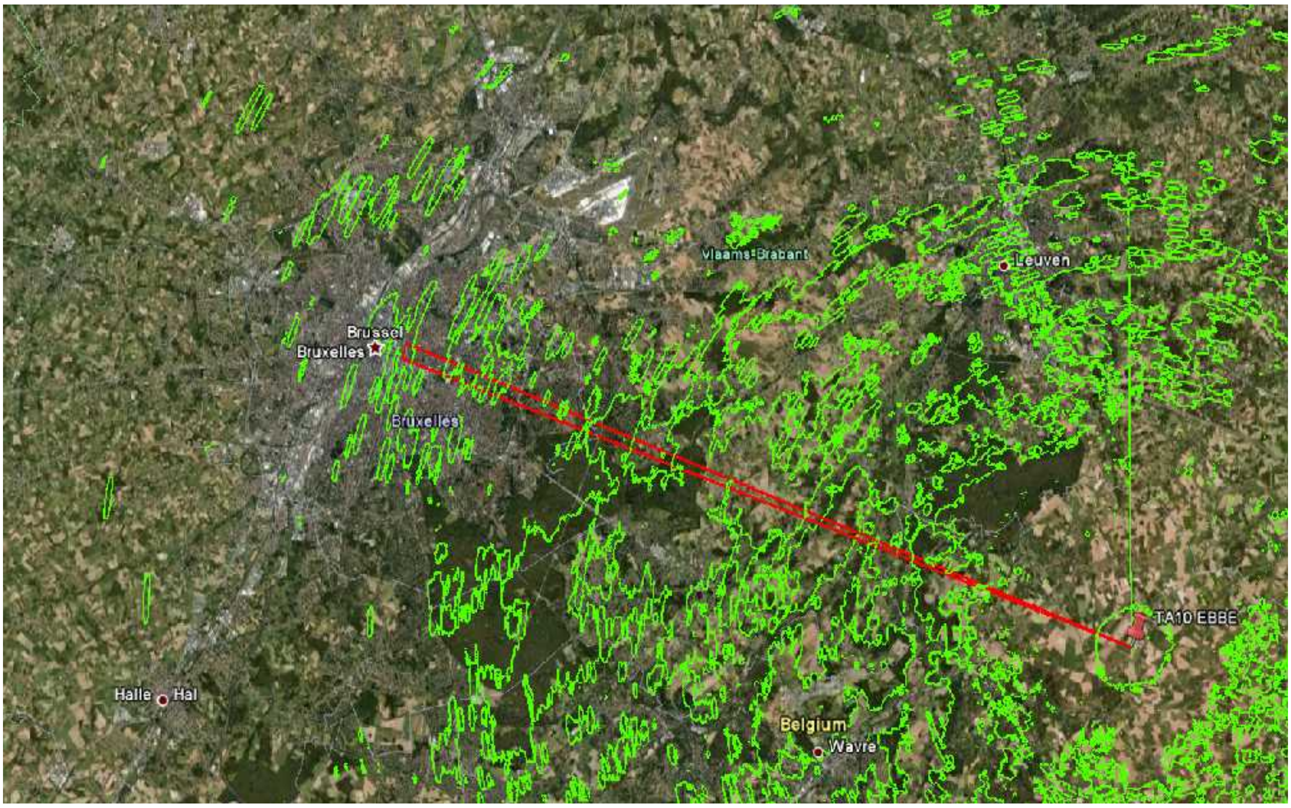


Figure 3.9: Clutter map detail, Beauvechain

BS Isolation curves are drawn in the assumption of 4 times 5 MHz occupation (multiple antenna interference). However, it is more likely that the occupation of the FDD Downlink band will be 3 times 20 MHz or 4 times 15 MHz [6]. Because the specifications are expressed in dBm/5MHz and for consistency, protection levels for Blocking and Inter-Modulation were measured over the same RBW. When drawing conclusions regarding mitigation measures, it is however important to take the bandwidth of the LTE signals and the FDD Downlink band occupation into account. In case at a certain shared BS site, 60 MHz of the FDD Downlink band is occupied, this will result in 11 dB “multiple antenna interference” instead of 6 dB as assumed in the isolation curves in this report. Measurements using LTE signals with different bandwidths have been done on the STAR2000 at Liège. Refer to section 3.3.1.2. No measurements where performed for Inter-Modulation using LTE signals with different bandwidths. Here it is expected that multiple antenna interference will be minor because there it are the peak power levels that create the IMPs. Blocking on the contrary, relates to the RMS power of LTE signals.

The isolation curves for UE flatten at shorter range because the end terminal gets lower in elevation when it comes closer to the radar. The end terminal is assumed to be at an elevation of 2 meter above ground level (AGL). However, it should be noted that close to the radar, for example in an airport building, UE can interfere higher in the beam. On top of this, the curves drawn on Figure 3.6 represent only one single end terminal. When for instance a set of 100 end terminals are in line-of-sight, these curves increase with 20 dB. Note that for UE the orange curve corresponds to the current regulations. The blue curve indicates the virtual situation if the specifications on Spurious Emissions in the S-band would be the same for protected bands.

3.1.6. Conclusions on measurements on the TA-10 at Beauvechain

Three interference mechanisms causing radar performance degradation have been investigated:

- Blocking
- desensitization through OOB Spurious Emissions from LTE BS and UE
- desensitization through creation of IMPs in the RUT's reception bandwidth

Figure 3.10 summarizes the results of the tests on the different interference mechanisms, carried out using CW and differently modulated signals. The exact numbers can be consulted in restricted annex 1.

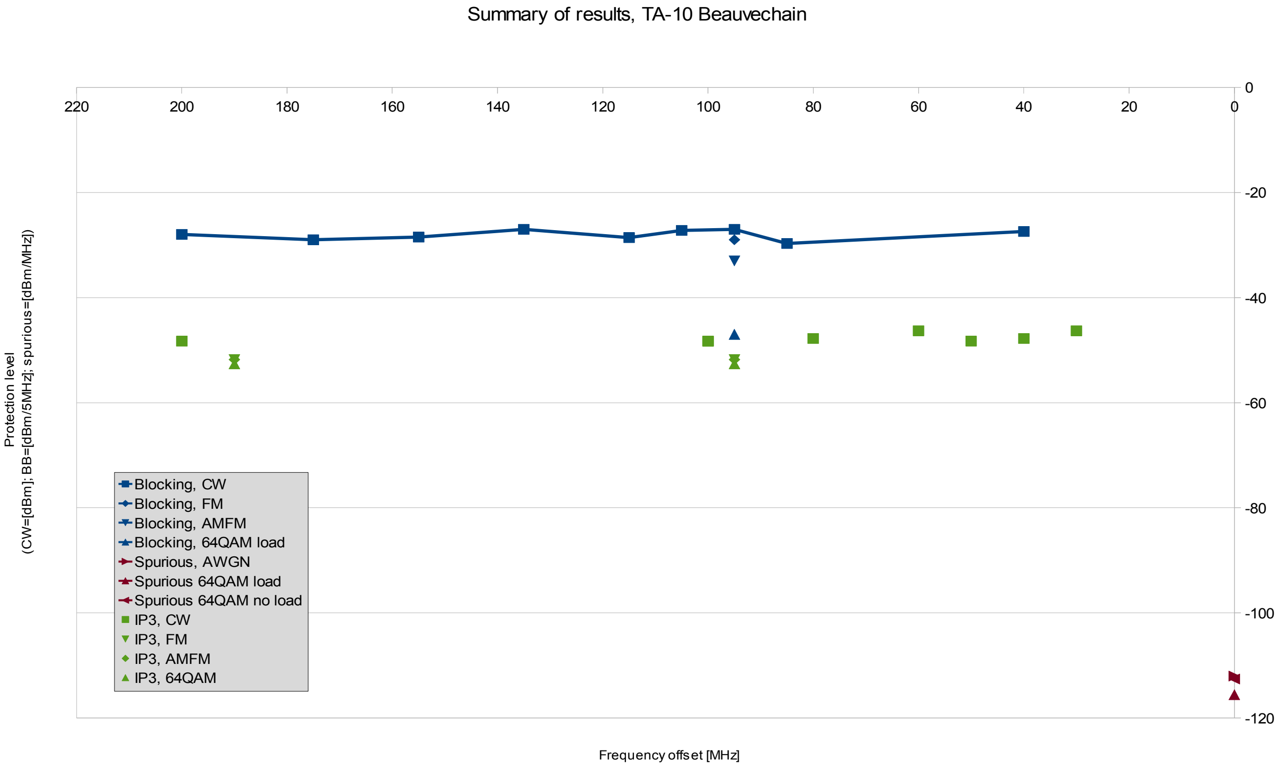


Figure 3.10: Summary of results, TA-10 Beauvechain

Blocking has been tested using CW and modulated broadband signals respectively. The test using CW signals resulted in the protection level of -28 dBm for frequency offsets from 200 to 40 MHz. The 22 dB difference with the 64QAM signal is possibly due to the specific characteristics of the LNA. It is already an aged technology and its dynamic range is rather limited. This causes it to go relatively fast into saturation, already using CW (10 dB sooner than the younger STAR2000). When using broadband signals, modulated at high speeds, saturations occurs much sooner.

Desensitization through Spurious Emissions was found to be -115,6 dBm/MHz using the 64QAM LTE FDD signal with load.

Inter-Modulation causes Pd degradation before Blocking does.

An LNA, that receives 0 dBm signal power from the LTE base station, would require an input IP3 intercept point of +56 dBm to avoid intermodulation products of -112dBm in the RUT's IF band. Seen the current available technology this is not an option and filtering before the LNA will be required. It is not easy to predict, but nevertheless possible, that despite the extra loss the filter will have, a positive effect on the Pd of the radar can be observed. Besides, when filtering LTE interferences, the filter will also remove other interference sources (electromagnetic smog).

3.2. Measurement Campaign ASR-9 Brussels

The measurement campaign on the ASR-9 radar at Brussels was conducted from Monday 16th of May until Tuesday 17th of May. Tests were carried out on the lower operating frequency. The test set-up was slightly modified as depicted on Figure 3.11. The YIG filter and PA (in dotted blocks) were used during tests on Blocking and Inter-Modulation using broadband signals.

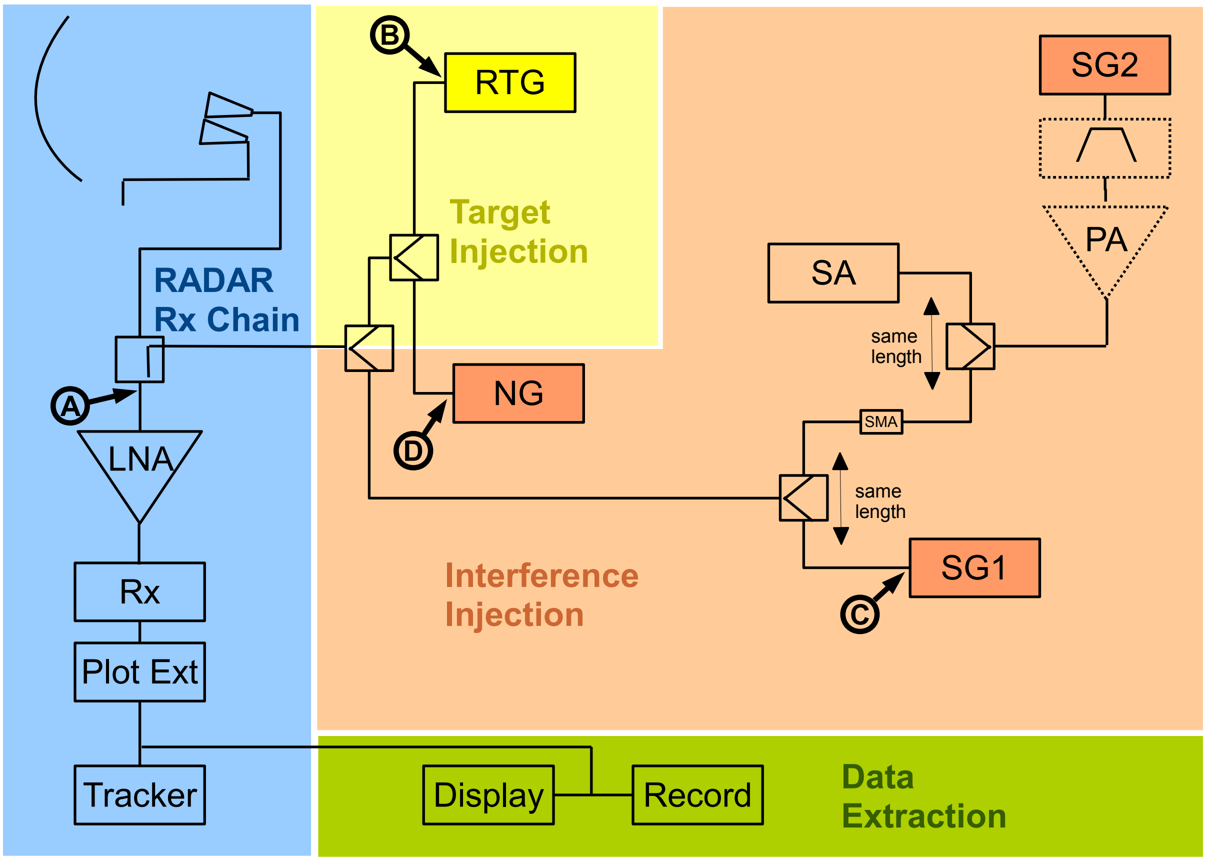


Figure 3.11: Test set-up as applied at Brussels

Table 10 gives an overview of the insertion losses at the RUT's operating frequency for the different signals injected. The value of the injection attenuation of the coupler could not be measured because it is a wave guide component. The attenuation mentioned on the coupler was taken into account.

Source	**Calibration Points in set-up [Figure 2.1]**	**Insertion Loss at RUT's Operating Frequency [dB]**
Targets	A - B	59,2
Interference	A - C	38,7
Noise	A - D	59,2

Table 10: Insertion losses, ASR-9 Brussels

The VNA curve was flat all over the frequency range in which tests were carried out. Therefore, no corrections had to be done as was done for the TA-10.

Due to the specific receiver configuration of the ASR-9, it was not possible to inject just before the LNA. Figure 3.12 shows that between the injection point on coupler DC4 and the LNA are a series of wave guide components such as a circulator, receiver protector (Rx PTR), STC, beam switch and filter. All these components can have (small) losses but these cannot be measured. The LNA is completely integrated in the wave guide.

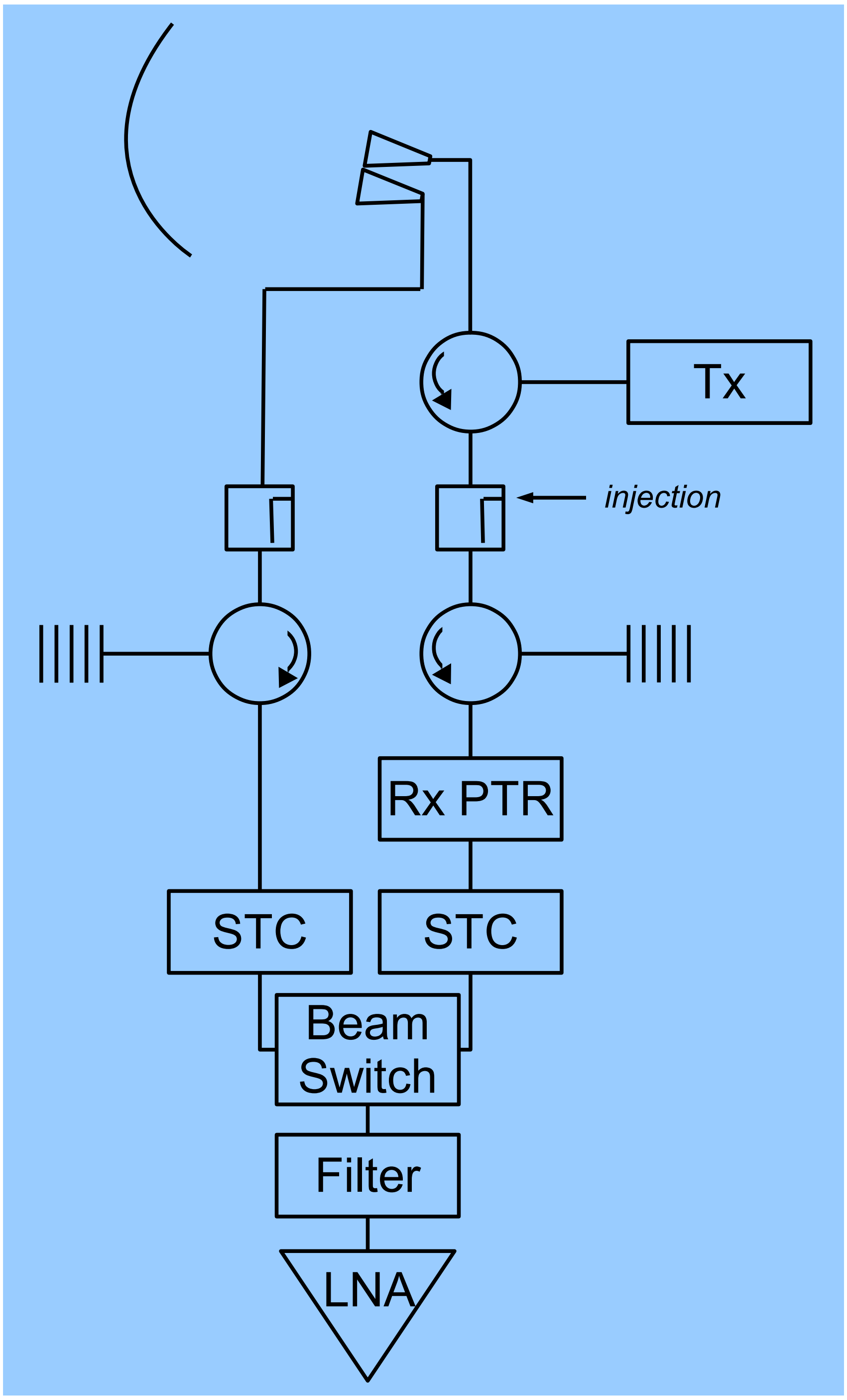


Figure 3.12: Receiver chain ASR-9

The 4 cavity wave guide filter before the LNA [Figure 3.13] made the measurements during this campaign difficult, for some tests impossible. Figure 3.14 shows its attenuation in function of frequency offset.

Figure 3.13: 4 cavity wave guide filter, ASR-9 Brussels

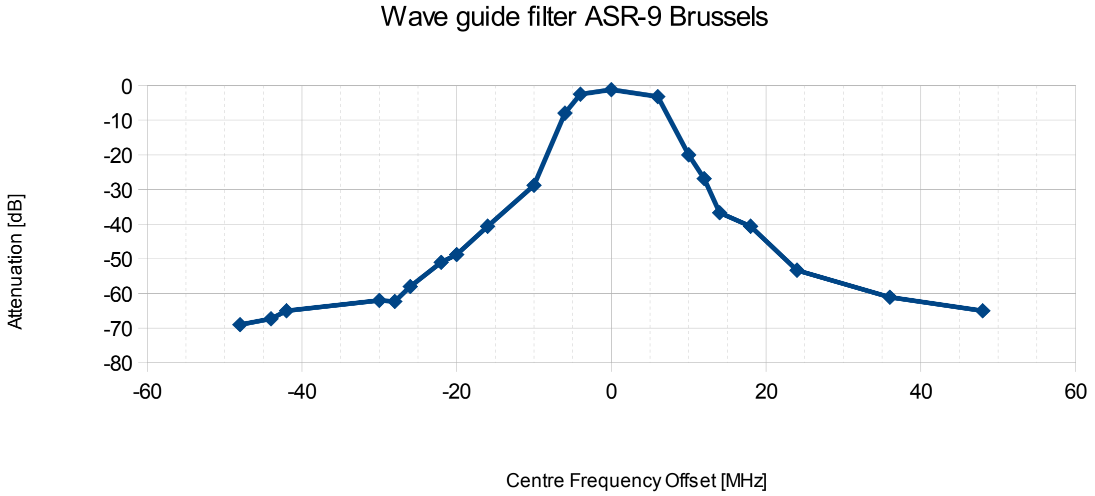


Figure 3.14: Characteristics of the 4 cavity wave guide filter on the ASR-9 at Brussels

Although this filter impeded the measurements, it could be useful to mitigate Blocking and Inter-Modulation. As a required additional isolation of 53 dB was calculated for Blocking [Table 13], at least 25 MHz offset is needed to obtain the required isolation with this filter [Figure 3.14].

3.2.1. Blocking

3.2.1.1. Single-tone compression (Test 01)

Blocking was tested using CW signals at different frequency offsets, resulting in the protection level curves depicted on Figure 3.15. The blue curve shows the protection level measured at the input of the LNA. It assumes the wave guide filter has no loss for the radar signal. This curve takes into account the attenuation of the 4 cavity wave guide filter at different frequency offsets. At frequency offsets larger than 10 MHz, the present wave-guide filter attenuated the injected signals so strong that the effect of Blocking could no longer be generated. Additional frequencies close to the RUT's operational frequency were tested in order to pass the filter and record some useful measurements. The dynamic range of the Rhode & Schwarz signal generator of 77 dB at 5 MHz offset was enough to do these measurements.

In red is the protection level at the input of the wave guide filter. Note that for frequency offsets greater than 10 MHz, this curve is not based on measurements. It is assumed that until an offset of 80 MHz blocking occurs at the same power level as measured at 10 MHz offset.

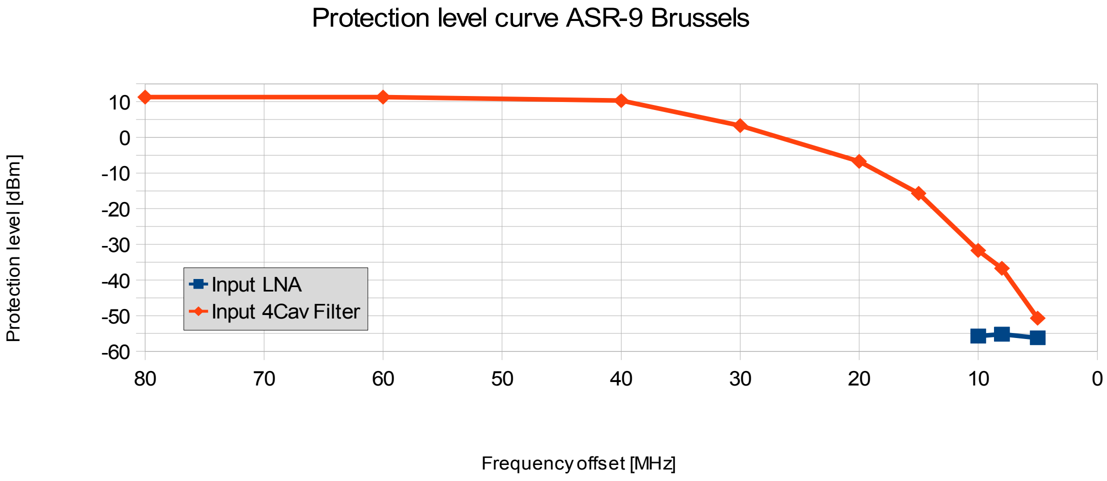


Figure 3.15: Protection level curve at LNA input, ASR-9 Brussels (CW)

Note that if the protection level at the input of the LNA is compared to the receiver curve [Error: Reference source not found] it becomes clear that this level for Blocking is similar to the receiver saturation point. Because these results were obtained at small frequency offsets, it is possible that not the LNA but an IF amplifier was saturated.

3.2.1.2. Interference from a single base-station (Test 04)

Using a 64QAM signal with load, Blocking could not be tested. The presence of the wave guide filter forced us to select a centre frequency close to the RUT's operating frequency. When moving to greater offset frequencies, the filter did its job, attenuating the injected interference and as such preventing Blocking. On the other hand, the spurious emissions from the Agilent signal generator forced us to select a centre frequency further away from the RUT's operating frequency. Injecting the interference too close to the operational frequency causes desensitization due to the spurious emissions of the signal generator falling in the IF band of the RUT and not Blocking.

Tests have been issued using a 1,4 MHz bandwidth 64QAM signal with load at offset frequencies of 20, 10 and 8 MHz and different power levels up to the maximum possible. A YIG filter has been used to try to attenuate the spurious emissions of the signal generator. However, this filter was not selective enough. In order to be useful, it should have a better selectivity than the wave guide filter. Such a filter was not available.

3.2.2. Desensitization through Spurious Emissions (Test 02)

The effect of unwanted OOB WiMAX/LTE emissions was investigated using two different signals:

- a broadband noise jammer (AWGN), injecting from 2700 to 2900 MHz
- a 10 MHz wide 64QAM signal with load and centre frequency at 2680 MHz

Table 11 summarizes the results for tests on desensitization through Spurious Emissions.

Applied Signal	RMS Power Level for Pd Degradation [dBm/MHz]
BB noise jammer, 2700-2900 MHz	-103,7
64QAM with load, 2675-2685 MHz	-105,7

Table 11: Pd degradation through Spurious Emissions, ASR-9 Brussels

The effect on the meteorological channel was visible on the video starting from -74 dBm/MHz for a broadband noise jammer [green dots on Figure 3.16].

Figure 3.16: Video from meteorological channel, ASR-9 Brussels

3.2.3. Desensitization through Inter-Modulation

When testing the creation of IMPs in the RUT's reception bandwidth, again we were faced with the wave guide filter attenuating the injected interference. Injecting dual tone CW signals at 10 and 20 MHz offset resulted in a degradation of Pd. At greater offset frequencies, the power needed to cause degradation could not be reached with the available signal generators. Even by adding the PA, the power of the interference could not be increased high enough.

3.2.3.1. Inter-Modulation of CW signals (Test 03)

Table 12 summarizes the obtained levels for desensitization through **Blocking** during tests on Inter-Modulation.

Frequency Offset 1 [MHz]	**Frequency Offset 2 [MHz]**	**RMS Power Level for Pd Degradation after the Coupler [dBm]**
10	20	-25,7

Table 12: Pd degradation due to Blocking during test on Inter-Modulation (CW), ASR-9 Brussels

Note that the power level of -25,7 dBm was measured after the wave guide coupler, so before the wave guide filter. If the attenuation of the wave guide filter is taken into account, the power levels at 20 and 10 MHz offset drop respectively with 48,8 and 28,8 dB, resulting respectively in power levels of -74,5 and -54,5 dBm at the input of the LNA. The level at 10 MHz offset is the same level as measured for Blocking. Therefore we can conclude that during this measurement a degradation of Pd was observed due to Blocking and not due to the creation of an IP3 product in the RUT's IF band.

3.2.3.2. Inter-Modulation of broadband signals (Test 05)

The test was performed at 28, 20, 15 and 13 MHz offset (lower frequency offset) without result due to the presence of the wave guide filter.

3.2.4. Isolation curves

Protection levels in Table 13 are calculated at the input of the LNA, so taking into account the wave guide filter. The present filter makes measurements for Inter-Modulation impossible.

Refer to section 3.1.5. for more explanation on isolation requirements calculations and important remarks regarding isolation curves.

	Blocking	**Spurious Emissions BS**	**Spurious Emissions UE**
Specifications	61dBm/5MHz max allowed eirp BS	-30dBm/MHz max at BS output = -12dBm eirp if 18 dBi gain antenna is used.	-30(-50)dBm/MHz max at BS output = -30(-50) dBm eirp if 0 dBi gain antenna is used.
Protection level	**-56dBm (CW)**	**-106dBm/MHz**	**-106dBm/MHz**
Isolation needed	117dB	94dB	76 (56)dB
RUT antenna gain at 0 (BS) / -1,3 (UE) deg elevation	27dBi		21dBi
Path loss at 1km	101dB		
Multiple antenna interference (4)	6dB		N/A
Multipath	4dB		
Additional isolation required	53dB @ 2690 MHz	30dB in IF band	0 (-20)dB in IF band

Table 13: Calculated isolation requirements, ASR-9 Brussels

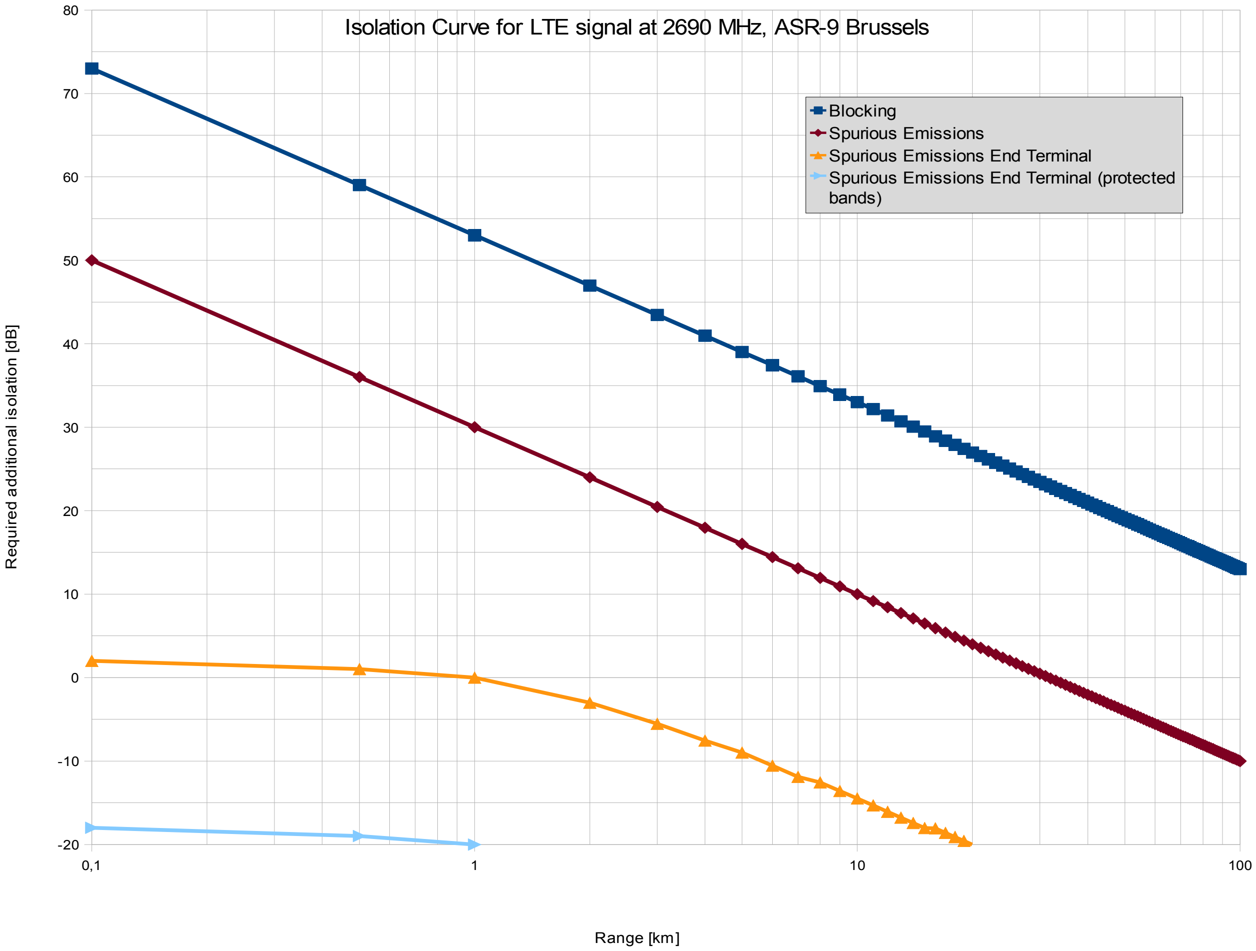


Figure 3.17: Isolation curve for LTE signal at 2690 MHz, ASR-9 Brussels

Again, note that the blue curve indicates the virtual situation if the specifications on Spurious Emissions in the S-band would be the same for protected bands.

3.2.5. Conclusions on measurements on the ASR-9 at Brussels

The presence of a 4 cavity wave guide filter makes it impossible to do measurements for Blocking at greater frequency offsets than 10 MHz. Blocking tests using CW indicated a power level of -56 dBm. Based on this result and the known characteristics of the present wave-guide filter, it is recommended to shift the lower operating frequency of the ASR-9 radar and respect at least 25 MHz offset.

Inter-Modulation could not be tested due to the present wave guide filter. It was not possible to inject dual tones with large enough power levels to create an IP3 product in the RUT's IF band. A test close to the operating frequency (where the wave-guide filter attenuates less) resulted in degradation due to Blocking.

The RMS power level for Spurious Emissions was found to be at -104 dBm/MHz.

Spurious Emissions were visible on the meteorological channel starting from -74 dBm/MHz (RMS). The meteorological channel will not be affected as long as proper mitigation measures are taken for the aircraft channels.

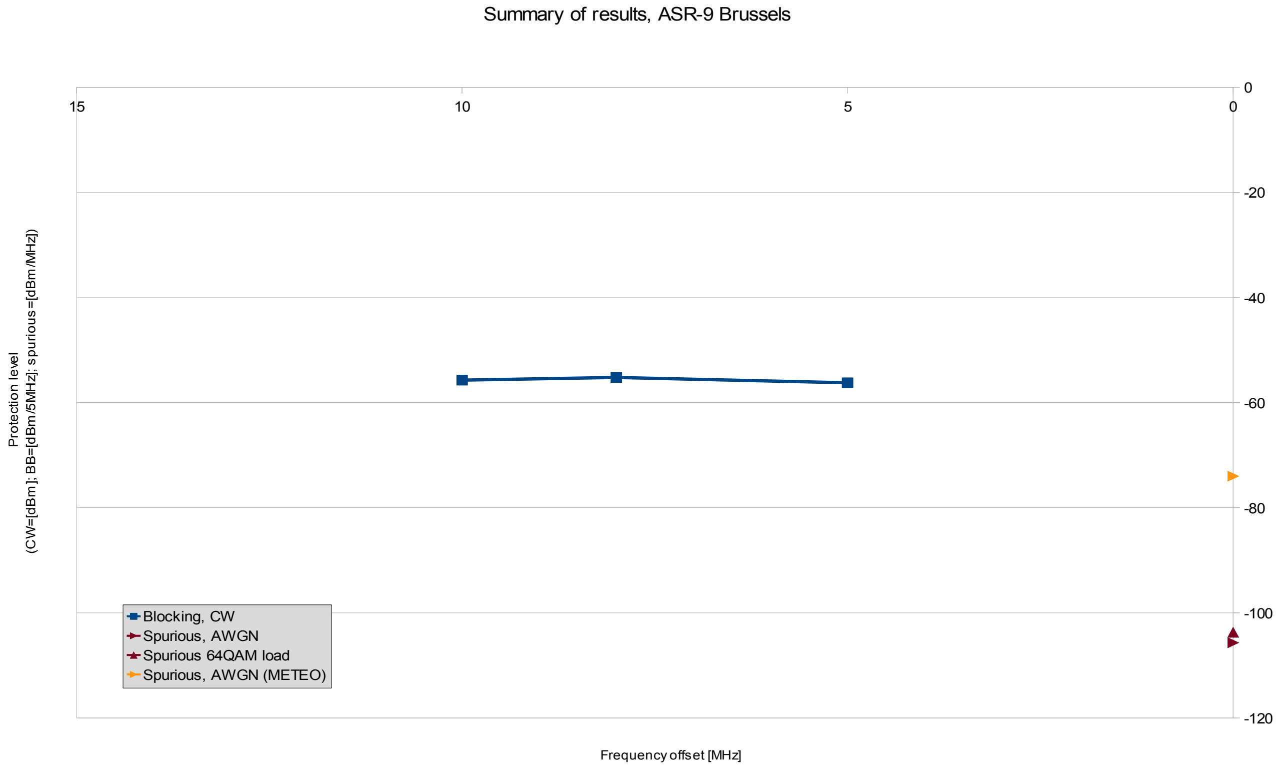


Figure 3.18: Summary of results, ASR-9 Brussels

This radar already has a filter to remove the interference for Blocking and Inter-Modulation. This filter may still be considered as state-of-the-art since there has been little improvement on wave guide technology over the past 20 years. Still, in the current configuration, this filter does not provide sufficient isolation for LTE on the present operating frequencies.

3.3. Measurement Campaign STAR2000 Liège

The measurement campaign on the STAR2000 at Liège was performed from 30th to 31th of May 2011. The set-up was adjusted according to Figure 3.19. Calibration point C was also used for injecting AWGN.

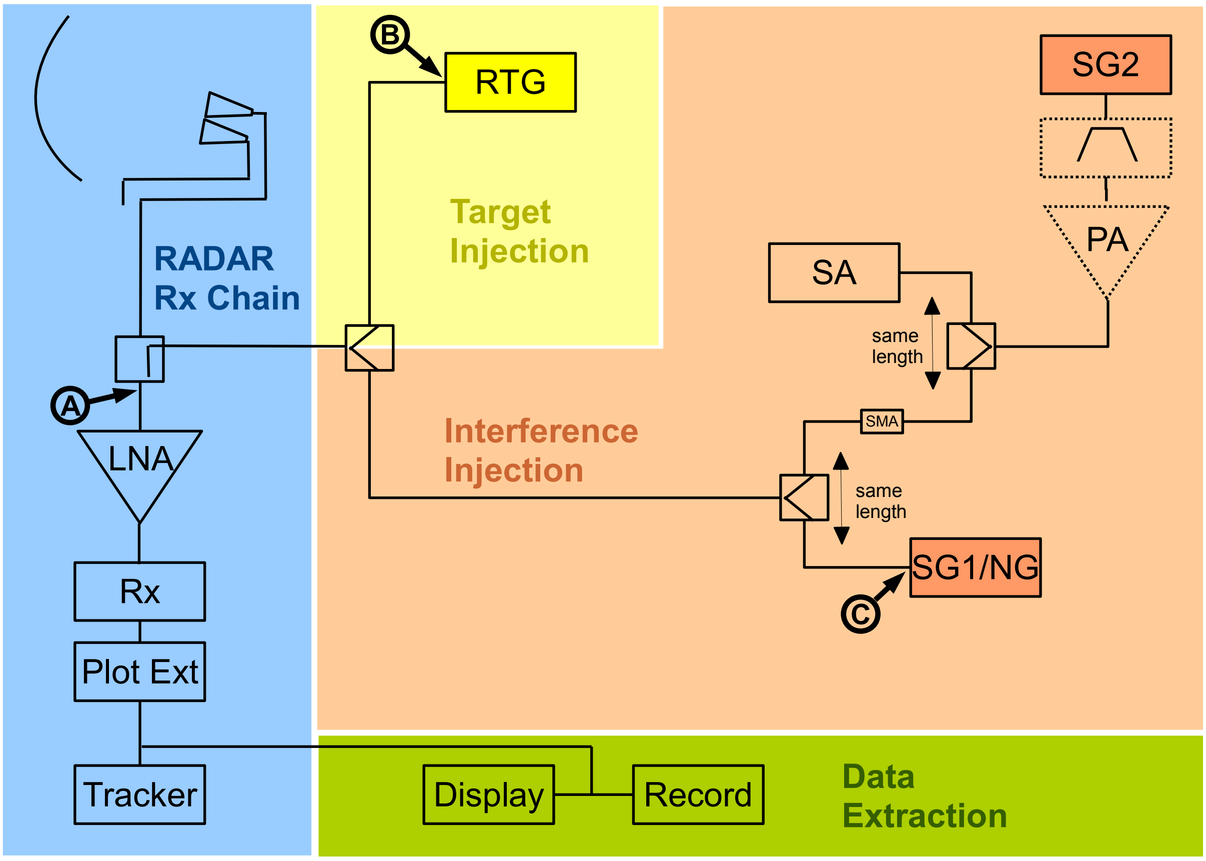


Figure 3.19: Test set-up as applied at Liège

Source	**Calibration Points in set-up [Figure 2.1]**	**Insertion Loss at RUT's Operating Frequency [dB]**
Targets	A - B	30,8
Interference / Noise	A - C	28,8

Table 14: Insertion losses, STAR2000 Liège

The VNA curve was flat all over the frequency range in which tests were carried out. Therefore, no corrections had to be done as was done for the TA-10.

3.3.1. Blocking

3.3.1.1. Single-tone compression (Test 01)

Tests on Blocking using CW signals were performed with offset frequencies ranging from 20 MHz to 260 MHz. Figure 3.20 summarizes the results.

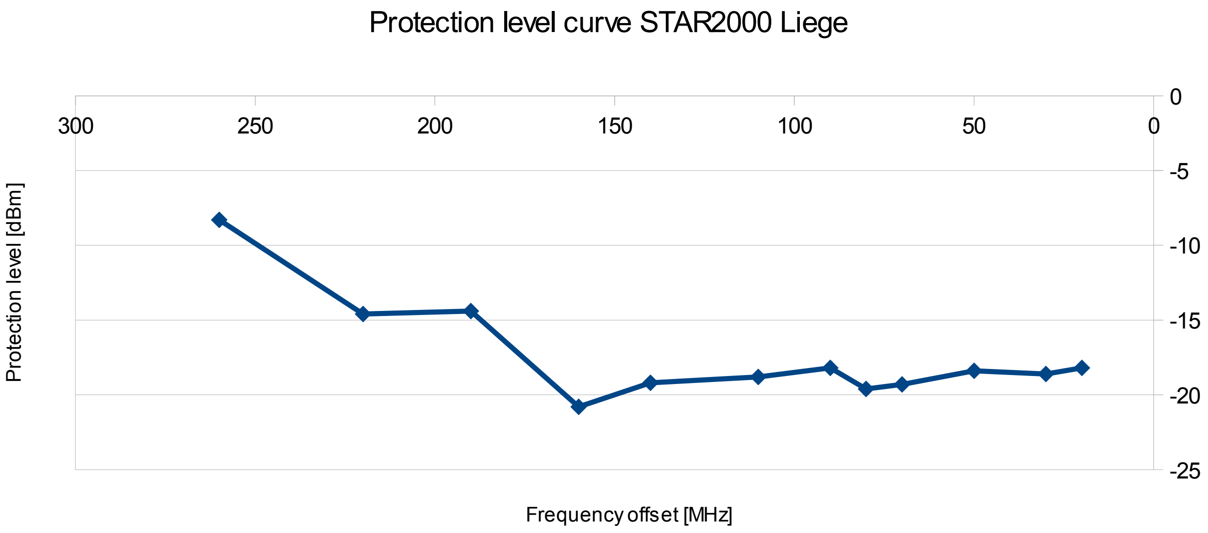


Figure 3.20: Protection level curve for Blocking (CW), STAR2000 Liège

From 20 to 160 MHz offset, the curve is rather flat at -19 dBm. At offset frequencies higher then 160 MHz, the protection level increases. Although the LNA is a broadband amplifier, its bandwidth is off course limited.

It was not possible to measure closer to the RUT's operating frequency due to the limitations of the available filters and the limited dynamic range of the generator. The level of spurious emissions of the generator was hit.

3.3.1.2. Interference from a single base-station (Test 04)

Tests for Blocking using the 64QAM signal with load were done using bandwidths of 5, 10 and 20 MHz at different frequency offsets. This approach was new compared to previous measurement campaigns and indicated the broadband nature of LTE. The peak to average power ratio (PAPR) is not the same for signals of different bandwidths. However, the expected 3dB difference was measured when doubling the LTE signal bandwidth. Table 15 summarized the results.

Frequency Offset [MHz]	**Bandwidth [MHz]**	**RMS Power Level for Pd Degradation [dBm/5MHz]**
80	5	-18
80	10	-21
80	20	-24
140	5	-20
140	10	-23
140	20	-26
200	20	-24

Table 15: Pd degradation through Blocking, STAR2000 Liège

In the scope of radar performance degradation due to Blocking, it should be emphasized that the **bandwidth of the LTE signals is determinative**. The FDD Downlink frequency band is 70 MHz in total and will be auctioned in blocks of 15 or 20 (and 5) MHz. However, as telecommunication service providers typically share masts (this is even imposed by the government), it will be likely that from a single BS site LTE signals will be emitted all over the FDD Downlink band. Calculating the protection level for the complete FDD

Downlink band of 70 MHz results in an RMS power level of -31,5 dBm/70MHz. This worst case (but realistic) scenario will require 11,5 dB more isolation compared to the mentioned power levels expressed in dBm/5MHz. Isolation curves are drawn in the assumption of 4 times 5 MHz occupation (multiple antenna interference). However, it is more likely that the occupation of the FDD Downlink band will be 3 times 20 MHz or 4 times 15 MHz [6]. This will result in 11 dB “multiple antenna interference” instead of 6 dB for BS sites shared by all the service providers. Therefore, **isolation curves should be interpreted taking into account the FDD Downlink band occupation**. The influence of the LTE signal bandwidth on isolation curves has been emphasized in section 3.1.5.2. Important remarks considering isolation curves.

3.3.2. Desensitization through Spurious Emissions (Test 02)

Table 16 summarizes the results for tests on desensitization through Spurious Emissions.

Applied signal	RMS Power Level for Pd Degradation [dBm/MHz]
BB noise jammer, 2700-2900 MHz	-107,6
64QAM with load, 2630-2670 MHz	-106,3

Table 16: Pd degradation through Spurious Emissions, STAR2000 Liège

Note that on the STAR2000, the power level obtained with a broadband jammer is lower than the level obtained with the 64QAM signal. This was different on the TA-10 and ASR-9. The reason for this is the different mechanism of clutter map recovery, typical for this type of radar.

3.3.3. Desensitization through Inter-Modulation

3.3.3.1. Inter-Modulation of CW signals (Test 03)

In normal operational mode, the STAR2000 switches between two operational frequencies. Therefore, two different methods of testing were used for Inter-Modulation.

- First, the RUT was left in its normal operational mode and two tones were generated between the operating frequencies, generating IP3 products on both operating frequencies. This resulted in a degradation at a power level of -46,1 dBm.
- Because it was not possible at that time to switch the RUT to a single operating frequency, the set-up was slightly modified so that the upper operating frequency could be jammed using a CW signal. On the upper radar frequency, a Pd of 0 was observed and all detections were done on the lower. The YIG filter was used for the filtering of the 64QAM signal in order not to hit the spurious level.

Table 17 summarizes the results.

Frequency Offset 1 [MHz]	Frequency Offset 2 [MHz]	RMS Power Level for Pd Degradation [dBm]
1/3 between RUT's frequencies	2/3 between RUT's frequencies	-46,1
70	140	-46,6
80	160	-46,6
90	180	-46,6

Table 17: Pd degradation through Inter-Modulation (CW), STAR2000 Liège

3.3.3.2. Inter-Modulation of broadband signals (Test 05)

Tests on Inter-Modulation using the 64QAM signal with load were done after the RUT was switched to single frequency operation. Two different methods were applied:

- First the Agilent was used to generate two 64QAM LTE FDD signals, each 10 MHz wide, creating IP3 products in the RUT's IF band [Figure 3.21]. The power level of degradation was -43,8 dBm/5MHz (RMS).

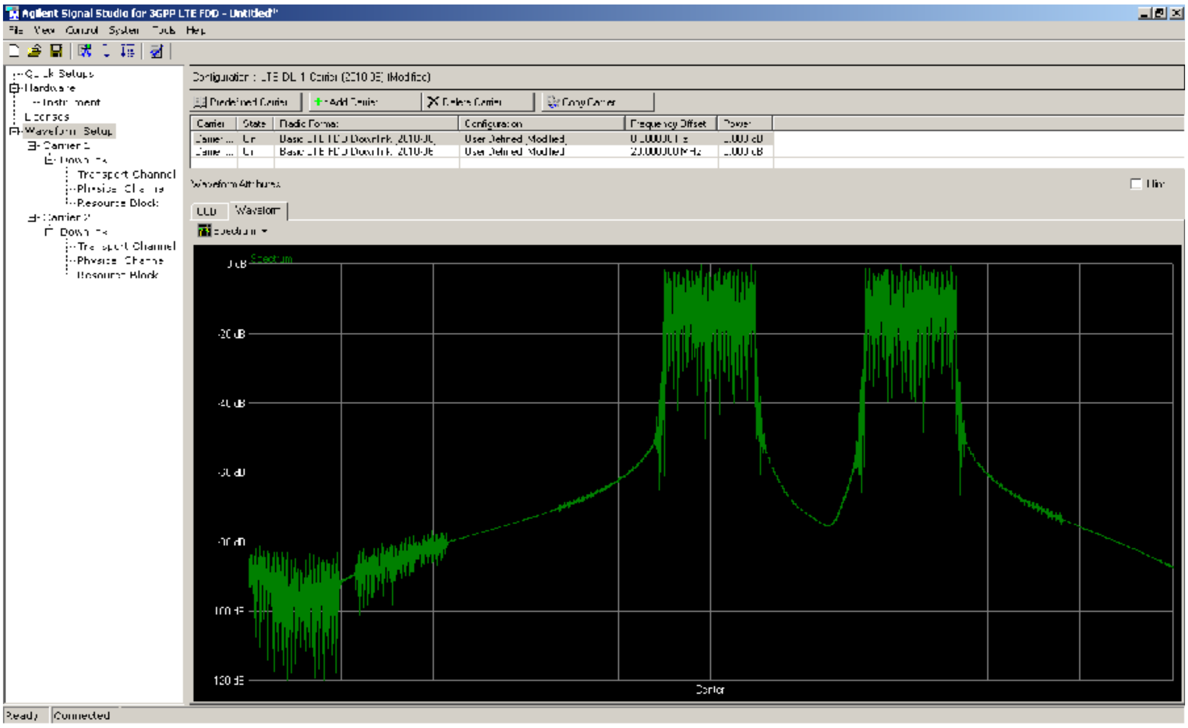


Figure 3.21: 64QAM LTE FDD signals used for Inter-Modulation test

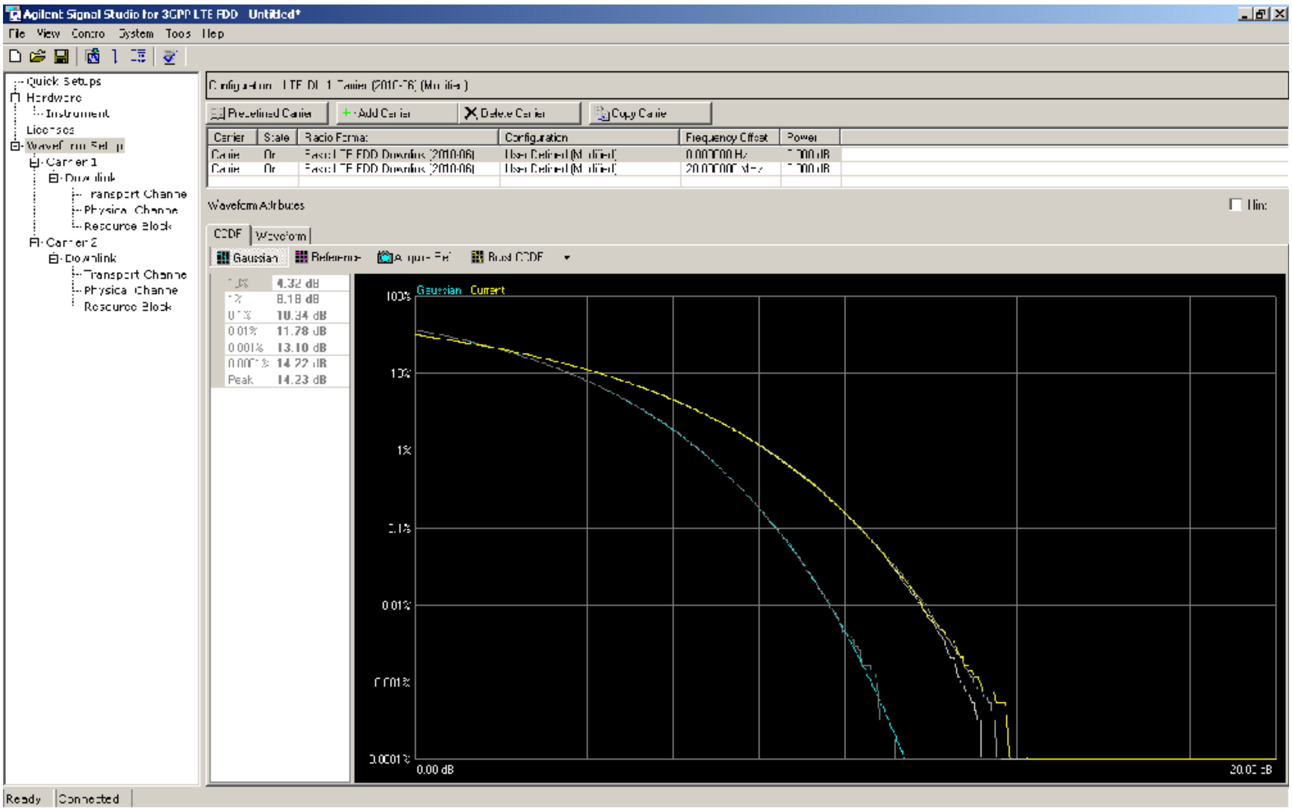
- Next, when replacing one of the two 64QAM signals with a CW tone, degradation was observed 1 dB sooner. This power level remained unchanged when moving to greater frequency offsets.

Table 18 Summarizes the results.

Applied Signal 1	**Frequency Offset 1 / Bandwidth 1 [MHz]**	**Applied Signal 2**	**Frequency Offset 2 / Bandwidth 2 [MHz]**	**RMS Power Level for Pd Degradation [dBm/5MHz]**
64QAM	40 / 10	64QAM	20/10/11	-43,8
64QAM	40 / 10	CW	20	-44,8
64QAM	140 / 10	CW	70	-44,8
64QAM	160 / 10	CW	80	-44,8

Table 18: Pd degradation through Inter-Modulation (BB), STAR2000 Liège

It is particularly interesting to compare these levels with those obtained for Inter-Modulation using two CW tones, which were lower, so degradation occurred earlier. This difference of circa 2,5 dB can be explained when looking closer at the 64QAM signal. Figure 3.22 Shows the complementary cumulative distribution function (CCDF) curve of the applied signal. On this curve it can be observed that high peaks occur only now and then. For instance, peaks 10 dB above the average power level occur only 0,1% of the time. The combination with another peak of at least 10 dB is only 0,0001%. Because Inter-Modulation is a third order effect (IP3), these 10 dB peaks will create spots of 30 dB. They could be observed clearly on the IF-video output of the radar. The odds may be small but the effect can be strong, depending on how fast the clutter map of the radar can recover.



10%	4.32 dB
1%	8.18 dB
0.1%	10.34 dB
0.01%	11.78 dB
0.001%	13.10 dB
0.0001%	14.22 dB
Peak	14.23 dB

Figure 3.22: CCDF curve of 10MHz wide 64QAM LTE FDD signal

High peaks, occurring in a random fashion in the 64QAM signal, cause the clutter maps to raise immediately. The next antenna scan, the clutter maps start to recover at a certain rate and keep recovering until they are completely recovered are another pair of peaks occurs at that specific clutter cell. So the clutter maps can recover quite well. When using CW tones however, the tones are always there at a specific clutter cell and there is no recovery. Consequently, degradation is observed earlier when using CW tones.

If the speed of the recovery of the clutter maps was adjustable, it could be used to further reduce the effect of LTE.

3.3.4. Isolation curves

Table 19 summarizes the isolation requirements for the STAR2000. Figure 3.23 gives the isolation curves.

Refer to section 3.1.5. for more explanation on isolation requirements calculations and important remarks regarding isolation curves.

	Blocking	**Spurious Emissions BS**	**Inter-Modulation**	**Spurious Emissions UE**
Specification	61dBm/5MHz max allowed eirp BS	-30dBm/MHz max at BS output = -12dBm eirp if 18 dBi gain antenna is used.	61dBm/5MHz max allowed eirp BS	-30(-50)dBm/MHz max at BS output = -30(-50)dBm eirp if 0 dBi gain antenna is used.
Protection level	-20dBm/5MHz	-108dBm/MHz	-44dBm/5MHz	-108dBm/MHz
Isolation needed	81dB	96dB	105dB	78dB
RUT antenna gain at 0 (BS) / -1,3 (UE) deg elevation	27dBi			21dBi
Path loss at 1km	101dB			
Multiple antenna interference	6dB			N/A
Multipath	4dB			
Additional isolation required	17dB @ 20 MHz offset	32dB in IF band	41dB @ 33 MHz offset	2(-18)dB

Table 19: Calculated isolation requirements, STAR2000 Liège

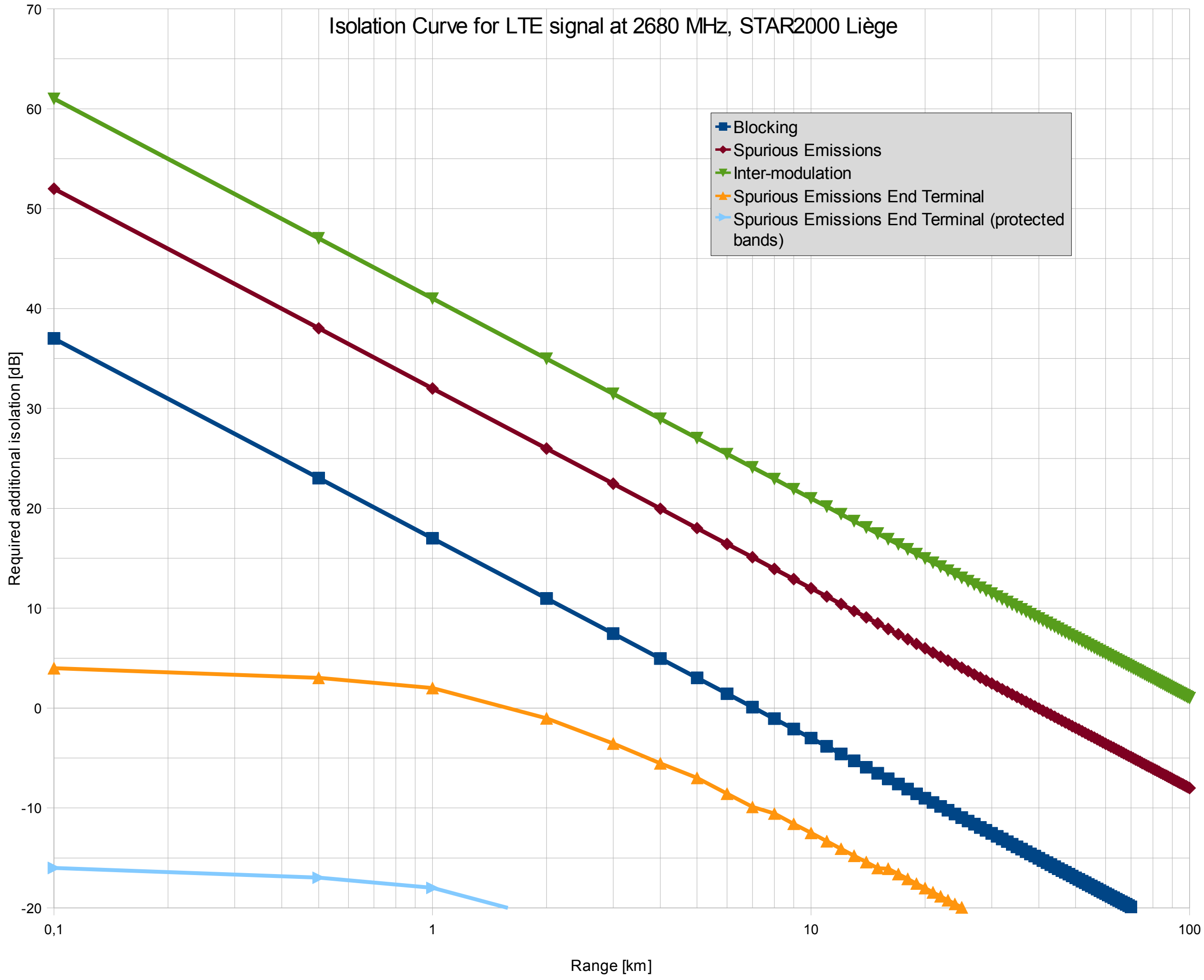


Figure 3.23: Isolation curve for LTE signal at 2680 MHz, STAR2000 Liège

3.3.5. Conclusions on measurements on the STAR-2000 at Liège

Figure 3.24 summarizes the results of the measurements on the STAR2000.

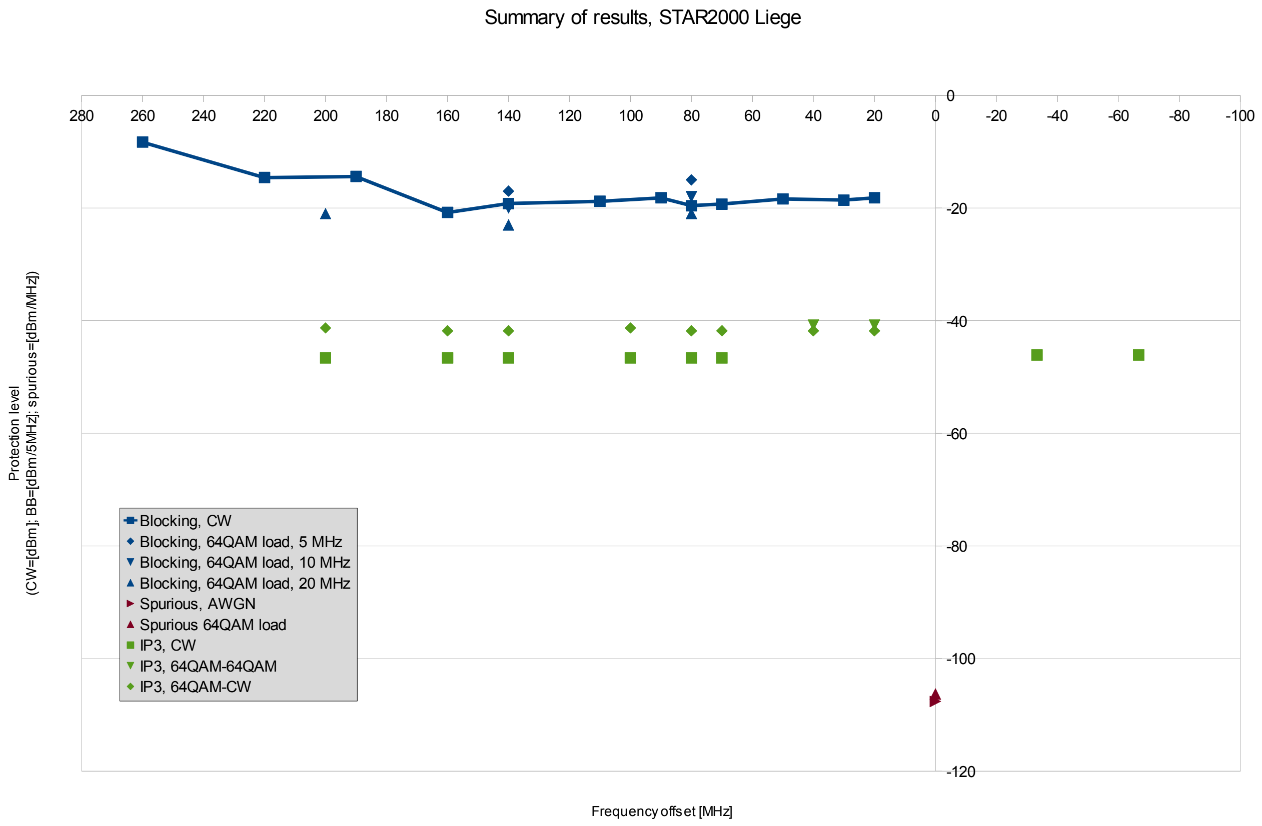


Figure 3.24: Summary of results, STAR2000 Liège

For Blocking, the protection level is constant at -19 dBm for frequency offsets from 20 to 160 MHz. For greater offsets, the curve tends towards higher levels. This is due to the “limited” bandwidth of the LNA.

Testing Blocking, using modulated broadband signals with different bandwidths indicates that the protection level turns more stringent (lower) when the occupation of the LTE FDD Downlink band increases.

The difference between CW and high speed modulated broadband signals observed on the TA-10 was not observed on the STAR2000. The latter is a pulse compression radar, meaning that it transmits a long pulse with limited power. On reception, the pulse is compressed to raise the power (typically 20 dB). A pulse compression radar digitally increases the dynamic range of its receiver.

Creation of IMPs in the receiver reception bandwidth occurs sooner when using CW signals compared to 64QAM signals. This is due to the spread in time and frequency of the peak powers in the signal.

Spurious Emissions...

4. CONCLUSIONS AND CO-EXISTENCE ISSUES

As a result of the previous testing there are five important elements to consider to have LTE co-exist with S-band radars.

1. Avoid Blocking and Inter-Modulation products on the radar site
2. Avoid interferences caused by spurious OOB emission of LTE base stations
3. Avoid interferences caused by spurious OOB emission of LTE user equipment
4. Advanced interference protection on the radar site
5. Conformity of IT equipment with EMC requirements

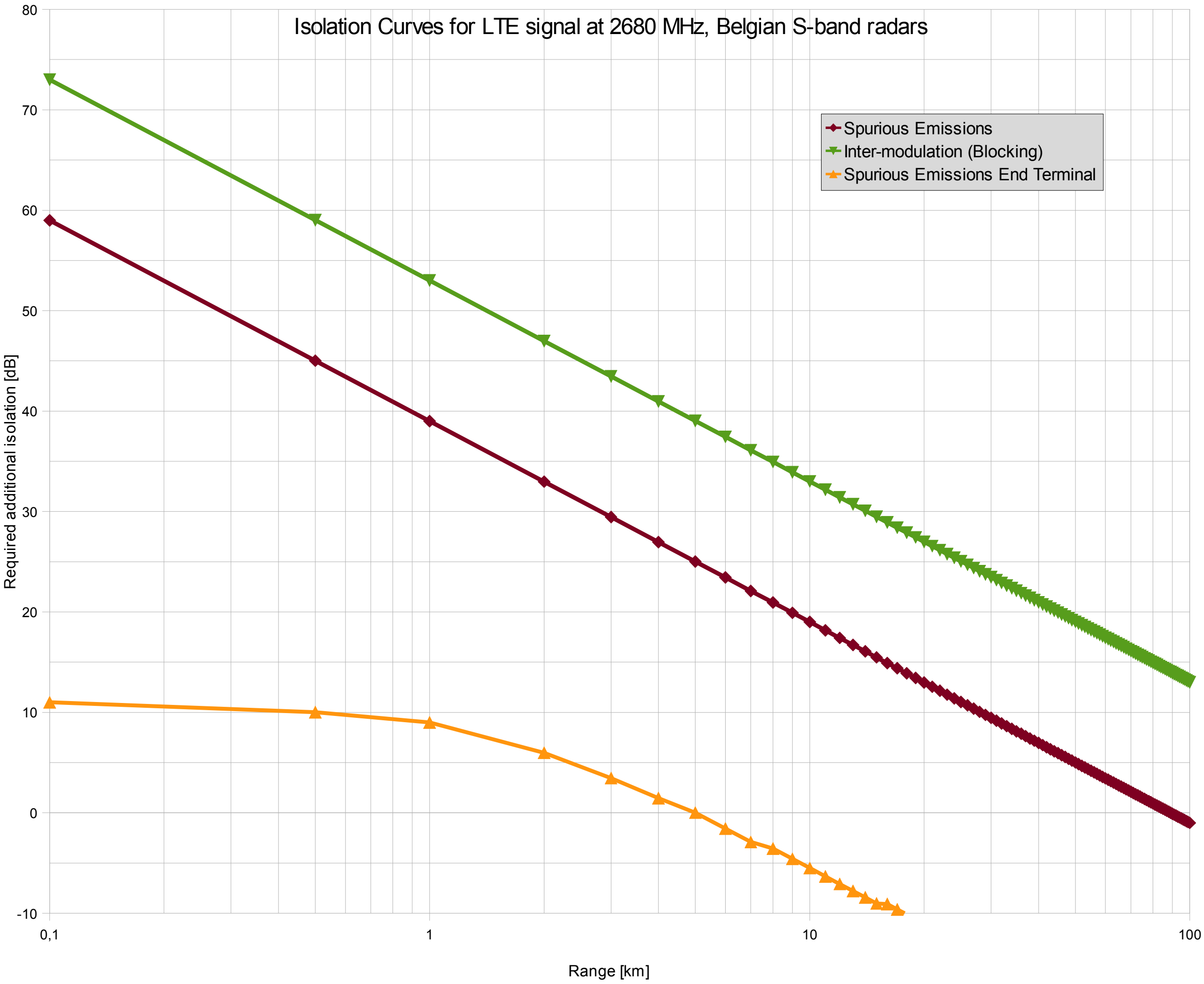


Figure 4.1: Isolation curves for LTE signals at 2680 MHz for Belgian S-band radars

Figure 4.1 summarizes the most stringent isolation curves for Belgian S-band radars. The data indicate that the **problems will be severe if no action is taken to mitigate**.

The problem is not about a few decibels of interference that could be resolved by simple considerations and proper planning and positioning. The vast number of BS to be installed make this impossible to control. Furthermore, there are also transportable radars needed. Indeed not only use the military flying radars operating in the S-band, it could also be required to install a moveable / transportable radar for civil aviation due to unexpected events and in order to continue air services in a safe way. Such **emergency deployment or the required installation of new radars should not be made impossible by installing new 4G technologies**. Indeed it is expected that safety measures required by the fast growing market of Unmanned Aerial Vehicle (UAV) technology will require the installation of additional S-band radar system.

Ignoring this fact would be a big mistake, specially for the LTE operators, as safety will always be the priority and long term interruption of LTE service would occur if all base stations need to be adapted later on. That is why we should focus on solid solutions for the future.

There is such a number of uncertain elements involved that some objective needs to be set before a complete mitigation plan can be discussed.

In the following reasoning it is assumed that no BS will be installed closer than 1 km* from a radar unless special precautions are taken. This perimeter is not limiting the LTE deployment and would not block the operational requirements already committed to the S-band radars.

4.1. Avoid Blocking and Inter-Modulation products on the radar site

The problem of Blocking and Inter-Modulation is caused historically and is not present on all locations in the world. In the US it has always been considered mandatory to install an **interference rejection filter before the LNA** of the radar receiver. Hence the better protection performance of the ASR-9, a typical US design and employed system.

However the **guard band** presently foreseen on the LTE side is not enough to isolate both technologies. It is obvious that the radar operators should be careful using the S-band at the ultimate edge. The lower side of the S-band could be considered as an extra buffer for radars located in urban areas where the density of LTE and other activity (WIFI) can be expected to grow. This would also ease the requirements on the front filter and minimize the loss in terms of SNR.

This measure seems logical and considered unavoidable and easily to obtain for new installations. For existing systems like those examined in this report the cost of relocating in the band is different for each site and should be evaluated by the radar operators.

4.2. Avoid interferences caused by Spurious OOB Emission of LTE base stations

The fact that BS are always positioned on elevated places to obtain a good view to the users and radars need to be located even higher to service their targets means that BS and radars are usually in direct line of sight conditions up to a range greater than 30 km. The sheer number of BS in such coverage also means that no half measures are acceptable and **an improvement on the specification for spurious emissions (ETSI 3GPP TS 136.104) of 40 dB is required.**

It should be noted that serious discrepancies exist in the regulation regarding Spurious Emissions, both for BS and for UE. Before a mitigation measure can be offered the origin of this situation must be understood to correctly estimate the risks involved and possible solution.

4.2.1. Situation of regulations regarding Spurious Emissions

Radio equipment (including GSM) has to fulfil the requirements of the R&TTE Directive (Directive 1999/5/EC). Before the entry into force of that directive (April 7th 2000) radio equipment was in most cases

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* 1 km is a realistic assumption for a protection perimeter based on the results of the tests performed. It is motivated in Annex 7.

subject to (national) type approval and had also to meet the requirements of the EMC Directive (EMCD) and depending on the voltage used the requirements of the Low Voltage Directive (LVD).

The R&TTE Directive includes the requirements of the EMCD and LVD.

European directives refer normally to essential requirements and do not impose strict values for limits to be met. However lists of harmonised standards (HS) under specific directives are published by the European Commission (EC). These HS represent the state of the art and can be used to demonstrate compliance with the requirements of that directive covered by that HS. An equipment complying with an HS enjoys presumption of conformity for the aspects covered by that HS.

The use of higher and higher frequencies creates the need to determine in HS also the values for limits in the higher frequency bands. Although the (R&TTE or EMC) Directives impose not to generate electromagnetic disturbance exceeding the level above which radio and telecommunications equipment or other equipment to operate as intended, there was in the past no real need to verify the disturbances generated in the higher frequency bands. The frequency range the HS covered was therefore limited. The evolution towards equipment using higher frequencies creates the need to adapt the HS.

In any case the conformity of an equipment has to be guaranteed irrespective if HS are used or not.

The spurious emission for GSM and the expected standard for LTE is allowed to be around -30dBm measured at the "*antenna connector*". Previously the allowed interference was about field-strength taking into account the gain of the antenna used to possibly disturb a neighbour. **Considering the expected antenna gain on an LTE BS this level is about 40 dB higher then what is normally allowed under the EMC directive.** Mobile users are possibly still 20 dB or 100 times more noisy than allowed before.

Until recent more stringent limits were laid down by HS frequencies used by other devices similar to GSM, DECT etc. For these privileged family and friendly users the limits on Spurious Emissions is strange enough more stringent than for other frequency bands. Therefore, **the level of protection for services of different safety radio devices including radar are not guaranteed as they are not on the list of "*protected bands*".**

4.2.2. Consequences of inconsistent specifications

It is to be noted that the radar users are the first to suffer from this lack of protection. Indeed they require not only a perfectly clean environment for their frequency. They also scan the antenna across the horizon where all "jammers" are located. Only radio astronomy requires a similar antenna gain and noise free environment but they point their antenna in deep space and only need to guard the side-lobe levels.

Recent experience on long range L-Band radars situated on a mountain and overlooking a city already show the electromagnetic smog created in all directions of populated areas. For these radars the problem is already present and growing rapidly. Fortunately the guard band for these frequencies is bigger and few intermodulation signals of the GSM system interfere with the radar services.

OOB spurious responses entail both, harmonics and IMPs created by the BS. It is very difficult if not impossible to avoid harmonics for the final power amplifier of a radio transmitter. Nevertheless, it is allowed to have a certain level of harmonic signals. Interference with other services is avoided by carefully selected frequency bands for each service under international agreements and with representation of all users (including radar). **However the effect of strong IMPs emerging from competing services in the same frequency band and using high gain antennas in close proximity is very recent and unique to the GSM/LTE users**. As they were the first to be affected they noticed this and regulated only for their own convenience.

The ETSI 3GPP technical specification TS 136.104 also refers to the effect of inter-modulation problems and specifies a limit for these at -30 dBm. Then a complete list of "*protected bands*" follows with exceptionally stringent requirements. Clearly, the telecommunications service providers are aware of the inter-modulation problems that they are causing due to a combination of high power, close distance and large bandwidth multiplying the effect across the guard bands. **One should not confuse these signals of inter-modulation**

of two (or more) transmitters on a co-located antenna with the previously described Inter-Modulation that can occur on the radar site when two received signals mix together. The latter can be resolved by a proper filter at the radar site. The further discussed IMPs created at the BS site and transmitted possibly at the radar frequency cannot be filtered off by the radar as they are on the intended receive frequency.

GSM technology was interfering with other mobile services including DECT on L-band. Despite the offset to radar L-Band, the increase in man-made noise is already severe in populated areas, affecting the quality of L-band long range radar. With the choice of LTE adjacent to S-band radar and LTE using higher modulation schemes the problem will multiply.

Examining the levels self-imposed by the experts in the field of GSM service makes it clear that there can't be any doubt on the flooding of the spurious responses across the S-band radar frequencies. However, there is no dedicated test equipment, nor any test method defined for verification. No warning on the emerging problem will be given when multiple services are combined in close proximity and inter-modulation occurs with the expected high levels. Not only will this occur suddenly due to the speed of deployment of the new technology and the commercial interests driving this. There will also be a severe problem for regulation by the responsible authorities, in this case BIPT.

Indeed even when a strong disturbing signal is affecting the radar service in a specific azimuth and the bearing reveals the responsible BS site, it will not be easy to point out who from the multiple users is in fault. Not only is this hard to measure in its operational environment. The spurious do not exist in a laboratory environment where they are tested one by one. **They can only be generated after field installation by two different providers**. Now imagine that this is a common problem on multiple directions and between multiple owners and it should be clear that it will take much longer to fix this problem than to create it. In the mean while all LTE services will need to be interrupted.

It is clear that **the total installation should respect the protection requirements stated in the EMCD** (not to create electromagnetic disturbance and be immune to electromagnetic disturbances to be expected).

It should be noted that normal testing according to the EMC standard regarding testing on spurious generation of signals for a device will not detect the problem of IMPs. Therefore, **the only solution is to add the radar frequencies (L- and S-band) to the list of *"Table 6.6.4.4.1-1: BS Spurious Emissions limits for BS co-located with another BS". As such, the radar frequencies will* enjoy the same level of protection as co-located radio services. It is the typical 34 dB antenna gain and sensitivity of a radar that makes the BS co-located when placed at a distance less than 30 km away.**

Furthermore, as it is not a trivial matter, **the radar stations**, being the most sensitive sensors for this purpose, **should be equipped with monitor devices to warn for the occurrence and strength of such jamming strobes.** Such feature, called a jamming strobe detector, is standard for military systems. It is possible to upgrade existing radars to have this function and provide an early warning on the degradation of the environment. If the disturbance is noted, at least it can be taken into consideration in terms of air safety and the source can be tracked before too many jammers are present to resolve.

4.3. Avoid interferences caused by Spurious OOB Emission of LTE user equipment

Despite similar specifications as for fixed BS we believe that interferences caused by Spurious OOB Emission of LTE user equipment will not represent a serious problem. There is little chance on IMPs as power is much lower and users are in most cases not in close proximity. End terminals have a very low antenna gain and the antenna is normally not on a high location in direct line of sight to the radar, a natural attenuation will occur (screening).

The density of UE will even be higher then the base stations' but the amount of activity on transmission will be lower. Consequently the noise generated will be evenly scattered and distributed in azimuth.

The UE transmits in the lower side of the 2600 MHz band and have a much greater separation to the radar frequency.

The signals from mobile users are expected more like pulse disturbances, a type of interference that is better suppressed in modern radars. The BS can be active with very high duty cycle, they appear more like continuous signals modulated by noise. The latter is much more difficult to suppress in the radar.

The approach to avoid the interference is the same as for BS: adapt the specifications to protect the radar band. The matter however, is less critical and probably cannot be reinforced due to the nature and quantity of the devices anyway.

It should be avoided that mobiles come too close in range (<1 km) to the radar. Just like for BS, the specifications for UE should be revised.

4.4. Advanced interference protection on the radar site

Finally and as a last resort it is possible to add better suppression in the radar signal processor to protect against interferences that are still likely to occur when the above measures are followed. This due to the sheer quantity of LTE systems expected and the logic that not all will be perfect in line with adapted regulation.

Furthermore, some disturbances can come from across the border where not necessary the same rules apply or can be re-enforced.

Two mechanisms used on military systems, where protection for intentional jamming is needed, could be adopted for new radar extractors. It is also possible but not easy to upgrade the present radar systems with this technology. This report is not the right place to go into details and the concepts are only mentioned for completeness.

- **Pulse interference filters**: Most residue of the intermodulation occurring between LTE signals is expected to be pulsed. At the moment most radars are equipped with a pulse rejection mechanism. Sufficiently strong abnormal pulses (above a certain threshold) are detected and the associated samples removed. A better technique avoids the need for a threshold. Indeed a standard pulse filter cannot distinguish low level interference from normal noise and filter this. The median filter, similar to some image processing filter, is capable of dealing with many more pulses and removes them completely. The technique is very powerful but not documented in standard radar literature.

- **Smart antenna methods**: Side Lobe Cancellation (SLC) is a method used in military radars to suppress active interference by using the combined signals from additional antennas. A similar technique can be used for ATC radars. Most radars for ATC purposes use two antenna beams. On short range the high beam is used in order to suppress strong ground clutter. On longer range, the receiver switches to low beam for maximum sensitivity and low elevation coverage. Both beams are designed with a sharp roll-off on the bottom to reject clutter from the ground. The exact elevation pointing is determined by the radar terrain environment (flat or mountainous) and is fixed. It is possible to electronically change the beam-pointing by combining the two beams and creating a new beam under software control. Such receive beam can skim over the horizon and adapt better to the terrain while rotating. For each azimuth angle a specific elevation angle can be fitted with a suppression notch at different elevation. This allows the strongest jammer to be attenuated by up to 40 dB. In the recent years Intersoft has perfected this method with a design called VCC in order to better reject unstable clutter as is present in the case of wind turbines.

For more information on the use of median filter in the field of radar or VCC technology please contact Intersoft Electronics.

4.5. Conformity of IT equipment with EMC requirements

A BS contains more components than just the transmitter part. Where the radio part has to be compliant with

R&TTE Directive, most other equipment has to be compliant with the EMC Directive. The overall system also has to be compliant with the EMC Directive. These standards impose a level of 40 dBµV/m field strength at 10 m. This translates to hitting the radar noise floor at the range of 1 km if the equipment is in the beam. Therefore it is not feasible to try to impose more stringent standards, as is done in some neighbouring countries, because the quantity of IT equipment will outnumber the number of BS. It is better to impose the emission levels related to the EMC standards at the BS site, where this is still clearly measurable. The exact interference source can as such easily be determined. **Notice that this is not necessarily the last equipment installed.** Limits in existing EMC standards are not sufficient for BS at short distance (< 1 km). In these cases, close cooperation with radar operators and protective measures like not pointing the BS antenna towards the radar will be required.

Some countries want to impose an impossible protection level of -155 dBW/m^2/MHz. This level is 9 dB more stringent than the EMC standards as seen by the radar at 1 km distance. It is not necessary to impose such stringent limit as thousands of IT equipment required to be compliant with the EMC Directive will already be present. It is in practice not possible to measure a too stringent limit.

5. PROPOSED MITIGATION MEASURES

Mitigation measures need to be taken at three different levels in order to obtain the required additional isolation:

- At the **radar side**, filtering must be done to **protect against LTE signals** causing Inter-Modulation in the radar receiver chain and Blocking.
- At the **base-stations**, filtering must be done to **suppress their OOB LTE signals,** Spurious Emissions at the radar frequency band. An effective way to obtain this is to have the exception list of protected frequencies in the **ITU documents (ETSI 3GPP TS 136.104 and 101) updated to include the radar frequencies both for BS and UE.** Installation of BS within a defined perimeter could be done in close cooperation with the radar operator.
- For **user equipment**, it is difficult to take mitigation measures. Care should be taken by radar operators when allowing UE too close to the radars.

The total installation of BS should respect the protection requirements stated in the EMCD (not to create electromagnetic disturbance and be immune to electromagnetic disturbances to be expected), also in the frequency range of the S-band.

In order to determine a solid measurement method for operators, additional study is required concerning inter-modulation created at the BS side.

6. REFERENCES

[1] QinetiQ: Study to establish measurement parameters for testing radar band sharing performance, Oct 2007, QINETIQ/EMEA/TS/CR0705949/1.1

[2] EC: Commission Decision of 13 June 2008 on the harmonization of the 2500-2690 MHz frequency band for terrestrial systems, 13 June 2008

[3] 3GPP: 3rd Generation Partnership Project, Technical Specifications Group Radio Access Network, Evolved Universal Terrestrial Radio Access (E-UTRA), User Equipment (UE) radio transmission and reception (V. 10.2.1), May 2011, 3GPP TS 36,101

[4] 3GPP: 3rd Generation Partnership Project, Technical Specifications Group Radio Access Network, Evolved Universal Terrestrial Radio Access (E-UTRA), Base Station (BS) radio transmission and reception (V. 10.2.0), May 2011, 3GPP TS 36,104

[5] ETSI: EN 301 489-16, V.1.2.1: Electromagnetic compatibility and Radio spectrum Matters (ERM); Electro Magnetic Compatibility (EMC) standard for radio equipment and services; Part 16: Specific conditions for analogue cellular radio communications equipment, mobile and portable, August 2002

[6] BIPT: Auction of the User Rights for Radio Access Systems in the 2500-2690 MHz Band – Information Memorandum, May 2011

7. ANNEXES

Annex 1-6: Restricted

Annexes 1 to 6 are in the restricted issue of this report which can be consulted on demand at BIPT.

Annex 7: Motivation of 1 km protection perimeter

The outcome of this study is that performance degradation of S-band radars due to interference from LTE signals will be severe if no mitigation measures are taken. Several measures were proposed, based on the results of the tests. It is our opinion that the proposed mitigation measures will be adequate up to a certain distance to the radar. From the isolation curves it is clear that close to the radar extremely high additional isolation will be required. Therefore, a “protection perimeter” is proposed. Within this perimeter there should be no base-stations installed and the use of user equipment restricted.

The extend of the protection perimeter is not pinpointed to 1 km. Nevertheless, this is a realistic assumption based on the results of the tests performed. Also from practical point of view 1 km seems to be feasible.

- The height of constructions is limited anyway on and close to airports
- Protection perimeters or radar servitudes are already in place at most airports
- People installing and working on BS sites within 1 km to the radar receive a high dose of electromagnetic radiation from the radar, exceeding health and safety specifications
- Radio equipment from 4G service providers will be interfered on strongly by the radar
- The required filter characteristics are hard, or even impossible, to meet for BS within 1km to the radar
- If the overall BS installation is just within compliance with the EMC Directive, the noise floor of the radar is hit at a distance of circa 1 km.

For UE the problem is expected to be less severe because these have significant lower antenna gain and are typically located lower in the radar beam (more gain reduction). However, the use of mobiles too close in range should be avoided.