ECC Report 344

Sharing and compatibility studies of Security Scanners (SScs) within frequency range 60-82 GHz

approved 7 October 2022

0 EXECUTIVE SUMMARY

This Report contains sharing and compatibility studies between mmWave Security Scanners and existing services/systems operating in the 60-82 GHz band and in the adjacent bands. Installations of SScs in airports are considered in the studies as this is considered a valid use case scenario for thorough investigations.

This Report describes typical cases including worst-case scenarios with point-to-point Fixed Services, Automotive Radar Amateur Service and amateur-satellite services, in presence of Security Scanners that can operate indoors and outdoors. Two different types of Security Scanners were considered and different building types and entry losses.

This Report focusses only on minimum coupling loss studies.

The minimum coupling loss studies have been done for sharing frequencies with point-to-point Fixed Services, Automotive Radar and Amateur Services and two different types of Security Scanners.

For sharing with Fixed Service:

- The study with the Continuous Wave Scanner (SSc #1) Security Scanner shows no risk of interference for indoor operation towards the Fixed Service when operating in the 69.89-79.89 GHz frequency band with a peak e.i.r.p. of 7 dBm;
- The Burst of chirps Scanner (SSc #2) was studied in two candidate bands 71-76 GHz and 76.5-80.5 GHz with a peak e.i.r.p. emission of 19 dBm, with both indoor and outdoor operation. The study concluded that operation in the band 71-76 GHz causes harmful interference towards the Fixed Service for both indoor and outdoor operation. No harmful interference is caused towards the Fixed Service when operating in the band 76.5-80.5 GHz, for both indoor and outdoor operation assuming 23 dB out-of-band attenuation.

  Considering the outdoor scenarios (SSc #2 in co-channel), depending on the building type and attenuation, additional studies might be required including simulations to estimate the risk of interference more accurately.

  Instead of MCL studies and worst-case assumptions like these scenarios, a more complex calculation and simulation, e.g. using Monte Carlo simulation may be needed and additional studies may be necessary e.g. using clutter-loss and terrain models for different models of SScs operating in-band and in outdoor scenarios.

For sharing with Automotive Radar:

- The study shows no risk of interference of SSc #1 and SSc #2 when operated indoor. There is a potential risk of interference of SSc #2 (with higher output power) when operated outdoor, as shown by the MCL calculations. However, the timing of the transmit signal of SSc #2 and the consideration of the receive windows (see ECC Report 262 [8]) of Automotive Radars is not taken into account in this MCL study, but could help to reduce the possible interference when the SSc #2 is operated outdoor. Results of measurement in Figure 44 show that the noise power is comparable when SSc#1 is switched on and that the SSc #1 has no influence.

For sharing with Amateur Services:

- There is no risk of interference according to the Minimum coupling loss calculations for both indoor and outdoor scenarios.

Table 1 summarises the outcome of this Report.

Table 1: Sharing and compatibility studies of Security Scanners operation in the band 60-82 GHz results

Type of SSc	Frequency	e.i.r.p	Security Scanner Scenario	Service	Risk of interference
SSc #1 (Note 2)	60-82 GHz	7 dBm	Indoor	Fixed Service Automotive Radar	**No**

Type of SSc	Frequency	e.i.r.p	Security Scanner Scenario	Service	Risk of interference
				Amateur Services	
SSc #2 (Note 3)	71-76 GHz	19 dBm	Indoor	Fixed Service	**Yes** (Note 4)
SSc #2 (Note 3)	71-76 GHz	19 dBm	Outdoor	Fixed Service	**Yes**
SSc #2 (Note 3)	71-76 GHz	19 dBm	Indoor Outdoor	Automotive Radar Amateur Services	**No**
SSc #2 (Note 3)	76.5-80.5	19 dBm	Indoor Outdoor	Fixed Service Amateur Services	**No** (Note 1)
SSc #2 (Note 3)	76.5-80.5	19 dBm	Outdoor	Automotive Radar	**Yes**
SSc #2 (Note 3)	76.5-80.5	19 dBm	Indoor	Automotive Radar	**No**

Note 1: assuming 23 dB out-of-band attenuation
Note 2 operating frequency bandwidth of 10 GHz
Note 3 operating frequency bandwidth of 1.5 GHz
Note 4 risk of interference for building types: thermally efficient with building entry loss (BEL) 1%, traditional building with BEL 10%, traditional building with BEL 1% (where the BEL values are taken into account as provided by Recommendation ITU-R, P.2109-01 at 70-71 GHz, table 5 [11])

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
CEPT	European Conference of Postal and Telecommunications Administrations
ECC	Electronic Communications Committee
SScs	Security Scanners
ECA	European Common Allocation
CW	Continuous Wave
FSK	Frequency Shift Keying
TX	Transmitter
RX	Receiver
MCL	Minimum Coupling Loss
FMCW	Frequency Modulated Continuous Wave
BWCF	BWCF bandwidth Correction Factor
MG	Modulation Gain
POL	Polarisation
BEL	Building Entry Loss

1 INTRODUCTION

This Report provides the result of the sharing and compatibility studies conducted for the introduction of the mmWave Security Scanners (SScs) in the frequency band 60-82 GHz by ensuring the protection of existing services/systems operating in the same and adjacent bands.

2 ALLOCATIONS AND APPLICATIONS IN THE BAND 60-82 GHZ AND IN THE ADJACENT BANDS

2.1 FREQUENCY BAND ALLOCATION AND USE

Table 2 provides an extract from the current ERC Report 25, European Common Allocation (ECA) Table [1]

Table 2: Current European Common Allocation extraction

RR Region 1 Allocation and RR footnotes applicable to CEPT	European Common Allocation and ECA Footnotes	ECC/ERC harmonisation measure	Applications	Standard
60-64 GHz				
FIXED INTER-SATELLITE MOBILE 5.558 RADIOLOCATION 5.559, 5.138	FIXED INTER-SATELLITE MOBILE 5.558 RADIOLOCATION 5.559, 5.138	ECC/REC/(09)01 ECC/DEC/(09)01 ERC/REC/70-03 ERC/REC/70-03 ECC/DEC/(11)02 ERC/REC/70-03 ERC/REC/70-03	Fixed ISM ITS Non-specific SRDs Radiodetermination applications Wideband data transmission systems	EN 302 217 EN 302 686 EN 305 550 EN 302 372 EN 302 729 EN 302 567
64-65 GHz				
FIXED INTER-SATELLITE MOBILE except aeronautical mobile 5.547 5.556	FIXED INTER-SATELLITE MOBILE except aeronautical mobile 5.547 5.556	ECC/REC/(05)02 ECC/DEC/(09)01 ERC/REC/70-03	Fixed ITS Radio astronomy Wideband data transmission systems	EN 302 217 EN 302 686 EN 302 567
65-66 GHz				
EARTH EXPLORATION-SATELLITE FIXED INTER-SATELLITE MOBILE except aeronautical mobile	EARTH EXPLORATION-SATELLITE FIXED INTER-SATELLITE	ECC/REC/(05)02 ECC/DEC/(09)01 ERC/REC/70-03	Fixed ITS Land mobile Wideband data transmission systems	EN 302 217 EN 302 686 EN 302 567

RR Region 1 Allocation and RR footnotes applicable to CEPT	European Common Allocation and ECA Footnotes	ECC/ERC harmonisation measure	Applications	Standard
SPACE RESEARCH 5.547	MOBILE except aeronautical mobile SPACE RESEARCH 5.547			
66 GHz - 71 GHz				
INTER-SATELLITE MOBILE 5.553 5.558 MOBILE-SATELLITE RADIONAVIGATION RADIONAVIGATION-SATELLITE 5.554 5.559AA	INTER-SATELLITE MOBILE 5.553 5.558 MOBILE-SATELLITE RADIONAVIGATION RADIONAVIGATION-SATELLITE 5.554		Wideband data transmission systems	
71 GHz - 74 GHz				
FIXED FIXED-SATELLITE (SPACE-TO-EARTH) MOBILE MOBILE-SATELLITE (SPACE-TO-EARTH)	FIXED FIXED-SATELLITE (SPACE-TO-EARTH) MOBILE MOBILE-SATELLITE (SPACE-TO-EARTH)	ECC/REC/(05)07	Fixed	ETSI EN 302 217-1
74 GHz – 75.5 GHz				
BROADCASTING BROADCASTING-SATELLITE FIXED	BROADCASTING BROADCASTING-SATELLITE FIXED	ECC/REC/(05)07 ECC/DEC/(11)02 ERC/REC 70-03	Fixed Radiodetermination applications Space research	ETSI EN 302 217-1 ETSI EN 302 372 ETSI EN 302 729

RR Region 1 Allocation and RR footnotes applicable to CEPT	European Common Allocation and ECA Footnotes	ECC/ERC harmonisation measure	Applications	Standard
FIXED-SATELLITE (SPACE-TO-EARTH) MOBILE Space Research (space-to-Earth) 5.561	FIXED-SATELLITE (SPACE-TO-EARTH) MOBILE Space Research (space-to-Earth) 5.561			
75.5 GHz - 76 GHz				
BROADCASTING BROADCASTING-SATELLITE FIXED FIXED-SATELLITE (SPACE-TO-EARTH) MOBILE Space Research (space-to-Earth) 5.561	BROADCASTING BROADCASTING -SATELLITE FIXED FIXED-SATELLITE (SPACE-TO-EARTH) Amateur Amateur-Satellite 5.561 ECA35	ECC/REC/(05)07 ECC/DEC/(11)02 ERC/REC 70-03	Amateur Amateur-satellite Fixed Radiodetermination applications Space research	ETSI EN 302 217-1 ETSI EN 302 372 ETSI EN 302 729
76 GHz – 77.5 GHz				
RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-Satellite Space Research (space-to-Earth) 5.149	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-Satellite Space Research (space-to-Earth) 5.149	ECC/DEC/(11)02 ERC/REC 70-03 ERC/REC 70-03 ECC/DEC/(04)03 ECC/DEC/(16)01 ERC/REC 70-03	Amateur Amateur-satellite Radio astronomy Radiodetermination Applications Radiolocation (civil) Railway applications SRR TTT	ETSI EN 302 372 ETSI EN 302 729 ETSI EN 301 091 ETSI EN 302 264 ETSI EN 301 091 ETSI EN 303 360
77.5 GHz - 78 GHz				
AMATEUR	AMATEUR		Amateur Amateur-satellite Radio astronomy	

RR Region 1 Allocation and RR footnotes applicable to CEPT	European Common Allocation and ECA Footnotes	ECC/ERC harmonisation measure	Applications	Standard
AMATEUR-SATELLITE RADIOLOCATION 5.559B Radio Astronomy Space Research (space-to-Earth) 5.149	AMATEUR-SATELLITE RADIOLOCATION 5.559B Space Research (space-to-Earth) 5.149	ECC/DEC/(11)02 ERC/REC 70-03 ECC/DEC/(04)03	Radiodetermination Applications SRR	ETSI EN 302 372 ETSI EN 302 729 ETSI EN 302 264
78 GHz - 79 GHz				
RADIOLOCATION Amateur Amateur-Satellite Radio Astronomy Space Research (space-to-Earth) 5.149 5.560	RADIOLOCATION Amateur Amateur-Satellite Radio Astronomy Space Research (space-to-Earth) 5.149 5.560	ECC/DEC/(11)02 ERC/REC 70-03 ECC/DEC/(04)03	Amateur Amateur-satellite Radio astronomy Radiodetermination Applications Radiolocation (civil) SRR	ETSI EN 302 372 ETSI EN 302 729 ETSI EN 302 264
79 GHz - 81 GHz				
RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-Satellite Space Research (space-to-Earth) 5.149	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-Satellite 5.149	ECC/DEC/(11)02 ERC/REC 70-03 ECC/DEC/(04)03	Amateur Amateur-satellite Radio astronomy Radiodetermination Applications Radiolocation (civil) SRR	ETSI EN 302 372 ETSI EN 302 729 ETSI EN 302 264
81 GHz - 84 GHz				
FIXED 5.338A FIXED-SATELLITE (EARTH-TO-SPACE)	FIXED 5.338A FIXED-SATELLITE	ECC/REC/(05)07	Amateur Amateur-satellite Fixed	ETSI EN 302 217-1

RR Region 1 Allocation and RR footnotes applicable to CEPT	European Common Allocation and ECA Footnotes	ECC/ERC harmonisation measure	Applications	Standard
MOBILE MOBILE-SATELLITE (EARTH-TO-SPACE) RADIO ASTRONOMY Space Research (space-to-Earth) 5.149 5.561A	(EARTH-TO-SPACE) MOBILE MOBILE-SATELLITE (EARTH-TO-SPACE) RADIO ASTRONOMY Space Research (space-to-Earth) 5.149 5.561A	ECC/DEC/(11)02 ERC/REC 70-03	Radio astronomy Radiodetermination Applications	ETSI EN 302 372 ETSI EN 302 729

3 SSCS IN THE BAND 60-82 GHZ

3.1 TECHNICAL CHARACTERISTICS OF SSCS OPERATING IN THE 60-82 GHZ BAND

3.1.1 General

In this Report, two different types of security scanners in the band of 60-82 GHz are considered. SScs operate like a radar but with high resolution in range, azimuth and elevation. Due to the low distances to be covered, the systems typically have output power levels in the range of < 20 dBm. The two types of systems, including technical parameters are described in the next section.

3.1.2 Transmitter Output Power / Radiated Power

There are mainly two types of security scanners, continuous wave and pulsed based systems, which use different power levels and waveforms.

Continuous Wave Scanner (SSc #1) radiates an equivalent isotropically radiated power (e.i.r.p.) that is given by its specified and verified peak output power of 1 dBm corresponding to 1.3 mW multiplied with the antennas gain of 6 dBi resulting in a peak value of 7 dBm e.i.r.p. i.e. with respect to the decision on Automotive Radar and its associated peak limit of 55 dBm e.i.r.p the SSC#1 has a power 48 dB below that of Automotive Radar.

Burst of chirps Scanners (SSc #2) radiates an equivalent isotropically radiated power (e.i.r.p.) that is given by its specified and verified peak output power of 10 dBm corresponding to 10 mW multiplied with the antenna gain of 6 dBi resulting in a peak value of 16 dBm e.i.r.p. (where worst cases are considered in the calculations in this Report with 19 dBm e.i.r.p) according to the latest information given by industry.

3.1.3 Operating frequency

SSc #1 is transmitting in the frequency range of 69.89 -79.89 GHz. At any time, it is either transmitting a CW (continuous wave) signal from a single antenna, or it is not transmitting any signal. During measurement acquisition, only one of the 3008 transmitting antennas (96 antennas per cluster) is emitting a signal, while all the other antennas do not radiate. SSc #1 receives and processes each single antenna TX signal with all RX antennas.

SSc #2 system can operate in the 71-75 GHz and 76.5-80.5 GHz bands. The system is transmitting a sequence of chirp waveforms with instantaneous down-conversion. After this the processing is taking place. Details of timing are given in section 3.1.4.

3.1.4 Transmitter Signal

Figure 1 shows the SSc #1 waveform. It consists out of 128 distinct frequency steps with a CW signal at the frequencies listed above. Each occupies a duration of 240.64 µs. The total transmitting time is <32 ms per panel.

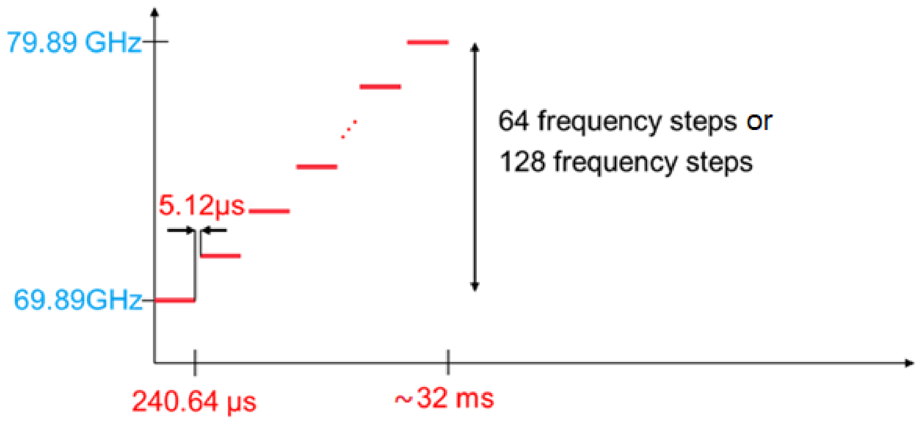

Figure 1: SSc #1 waveform

The SSc #2 system transmits a burst of about 200 to 400 Chirps. Each chirp duration is 20 μs with 5 μs pause in between and a bandwidth of 1.5 GHz to 4 GHz.

The SSc #2 transmitted waveform is depicted in Figure 2.

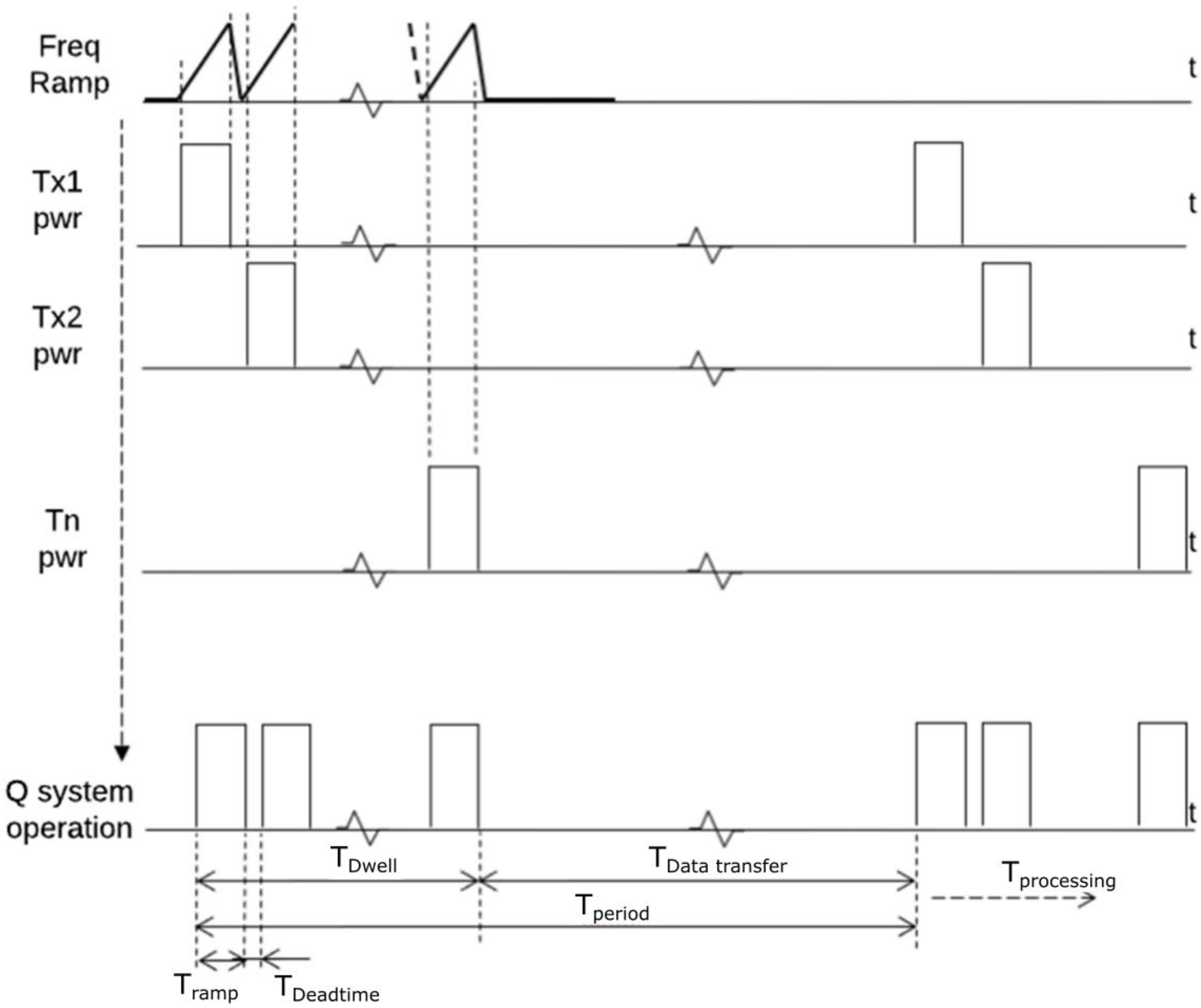

Figure 2: SSc #2 waveform

The chirp ramp is a linear frequency ramp from the lower frequency limit of the band (e.g. 76.5 GHz) to the upper limit (e.g. 80.5 GHz)

Typical time parameter (see figure above) values are:

- The dwell time duration is: $T_{Dwell} = 5 - \text{ms}$;
- The data transfer time duration is: $T_{Data\ transfer} = 90 - 95\ \text{ms}$ respectively;
- The total system period time duration is: $T_{period} = 100\ ms$;
- The Linear Frequency Modulated (LFM) chirp ramp time duration is: $T_{ramp} = 20\mu s$;
- The deadtime duration between successive LFM chirps is: $T_{Deadtime} = 5\mu s$;
- The time duty cycle: $\text{DC}_{\text{Time}} = 4 - 8\%$.

3.1.5 Antenna heights and shielding

The antenna aperture (W × H) of a single SSc #1 panel is 987 mm × 2115 mm with a height above ground of 122 - 2237 mm.

The antenna aperture (W × H) of SSc #2 system is two-line arrays in "T" structure. The horizontal aperture is 50 cm to 2 m and the vertical aperture is 1-2 m. The height of the "T" structure base can be from 25 cm to 2.5 m above ground level.

3.2 SECURITY SCANNERS DEPLOYMENT MODEL

Security Scanners at mm waves are in operation at airports and fulfil fast security checks. Table 3 summarises the Security Scanners (SScs) deployment model and specifies the total number of instantaneously transmitting devices within CEPT that may become in operation. At each airport, 20 security scanners are considered a typical deployment.

In 2020, there were 321 airports listed across CEPT, from which United Kingdom (34), Italy (30), Germany (28), France (23), Greece (16), Turkey (16), Norway (16) cover ~50%. The total number of air passengers is 1.043 billion.

The deployment model considers two parts. One part is the deployment of long range (often pulse based) security scanners, the other part considers SScs at security checks which are short range with lower power. For the long-range, SScs the number of airports and devices is of interest.

Table 3: Deployment of long-range SScs

	Number
Number of airports across CEPT	321
Number of SScs at a single airport (a typical deployment)	20
SScs devices operating in 68-82 GHz spectrum	6420

The example of long range SScs deployment model includes:

- Early warning for concealed weapons and explosive belts, threats identification and alerts;
- Wide open area detection coverage, indoor and outdoor, up to 400 cubic meters (see Figure 3);
- Undisturbed public flow inspection, a non-gate solution;
- Autonomous real-time artificial intelligence (AI) classification;
- Concurrent multi-threat detection and tracking.

While there are short range SScs that only cover a distance of below typically 1-2 meters like the SSc #1, there are longer range SScs like the SSc #2 where the typical antenna pattern and covered area is shown in Figure 3.

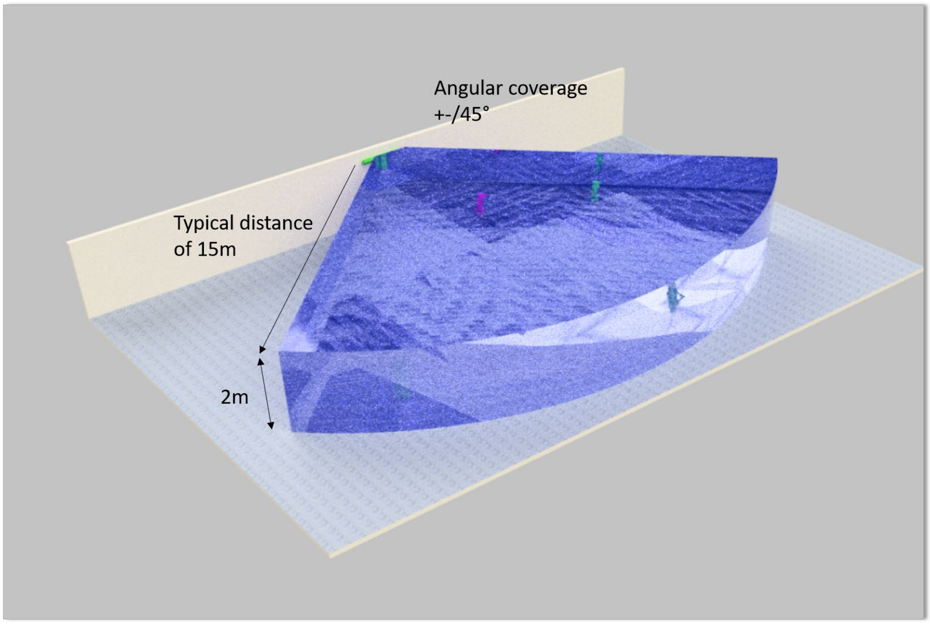

Figure 3: SSc #2 coverage

For the short range SScs, the number of passengers is of interest as this defines the number of scans to be taken and to estimate the air utilisation rate. As the number of airports and passengers is not consistently distributed the worst case scenario has been selected, which is the busiest airport.. This results in the highest air utilisation rate of the SSc.

United Kingdom with the highest number of passengers in CEPT (264 million passengers in 2017) has been selected. From UK, London/Heathrow (LHR) has 78 million passengers per year [2]. By considering a number of 20 security checkpoints, the number of SSc scans and the air utilisation rate can be estimated per day.

Table 4: Deployment model of short range SScs

	Number
LHR number of air passengers (2017)	77987 million
LHR number of air passengers (2017) per day	213663
Security check lanes = number of potential SScs	20
Estimated Number of Scans per day per SSc	213663 / 20
RF activity per two panel device per scan (ms)	64 ms
RF activity per SSc per day (second/day)	683.7 second/day
RF activity per SSc per day (%)	0.79%

4 METHODOLOGY AND APPROACH USED IN SHARING AND COMPATIBILITY STUDIES

4.1 METHODOLOGY

4.1.1 General Coexistence Model

The methodology used to study coexistence between Security Scanners (SScs) and any other service within the frequency band is the Minimum Coupling Loss (MCL) method by considering multiple SScs in the same area. The victim receiver and the transmitter are assumed to be at the same height and the emissions hit the victim's antenna boresight.

First, a basic propagation model with variable path loss depending on the deployment scenario is used. Then, building attenuation is incorporated in order to account for walls/windows between the indoor SSc and the outdoor victim receiver.

The MCL analysis evaluates the required separation distance with the receiver, above which the victim performance is not affected by the presence of the interferer. The receiver interference threshold can be evaluated using I/N protection criteria.

In case of I/N protection criteria the interference threshold at receiver input I_R is evaluated as:

$$I_R\,[dBm] = N_R\,[dBm] + I/N[dB] \qquad (1)$$

Where:

- N_R: receiver noise floor;
- I/N: The ratio of acceptable interference level and receiver noise;
- I_R: interference threshold at receiver input.

The receiver noise floor N_R for a receiver temperature of $T = 290K$ can be calculated as:

$$N_R = -113.83\frac{dBm}{MHz} + 10\log_{10}(B_R[MHz]) + NF_R[dB]) \qquad (2)$$

Where:

- B_R: receiver bandwidth in MHz;
- NF_R: receiver Noise figure.

In case of Frequency Modulated Continuous Wave (FMCW) receivers and direct down-conversion to intermediate frequency (IF) $B_R = 2\,B_{IF}$ is used (see ECC Report 315 [3]).

The MCL for zero receiver antenna gain is evaluated as the path loss which is necessary to reduce the interfering signal to stay below the interference threshold I_R as defined above in (1).

$$MCL\,[dB] = e.i.r.p._I\ \ [\text{dBm}] + \text{BWCF}[\text{dB}] - I[dBm] \qquad (3)$$

Where :

- $e.i.r.p._I$: is the mean equivalent isotropic radiated power of the interfering signal from SSc;
- BWCF: is the bandwidth correction factor corresponding to the ratio between victim receiver bandwidth B_R and SSc interfering bandwidth.

In case of pulsed SScs, the BWCF according to ECC Report 315 [3] shall be taken into account. In case of FMCW receivers, in place of the bandwidth correction factor it is also appropriate to use the modulation gain (MG), which expresses the victim receiver interference suppression due to the presence of the IF filter after the down-conversion stage of the victim receiver (see ECC Report 315, annex 4 [3]).

The polarisation POL mismatch of the antennas shall be taken into account.

In case of indoor scenarios the building entry loss $BEL\ [dB]$ shall be considered.

In case of multiple security scanners in an area which can be considered to interfere with a single service (e.g. multiple SScs at an airport security checkpoint and one service pointing towards the security checkpoint) the combination of all SScs shall be considered.

The isotropic radiated power for zero receiver antenna gain is defined as:

$$e.i.r.p._I = e.i.r.p._{IMax}\ [dBm] + P_V[dB] + POL[dB] + BEL\ [dB] \quad (4)$$

Where:

- P_V: Normalised radiation pattern in the direction of the victim.

Thus, the MCL becomes:

$$MCL\ [dB] = e.i.r.p._{IMax}\ \ [\mathrm{dBm}] + \mathrm{BWCF}[\mathrm{dB}] + P_V[dB] + POL[dB] + BEL[dB] - I_R[dBm] \quad (5)$$

Finally, the Generic Free Space Path Loss model gives the minimum distance d for the MCL:

$$FSPL[dB] = 20 \cdot \log(d[m]) + 20 \cdot \log\left(\frac{4\pi \cdot f[MHz]}{c}\right) \quad (6)$$

$$d[km] = 10^{\frac{MCL[dB]-32.44-20\cdot\log(f[MHz])}{20}} \quad (7)$$

4.1.2 Indoor and Outdoor Scenarios

This Report considers SScs in two different scenarios:

1. indoor deployment and
2. outdoor deployment.

Recommendation ITU-R P.2109-1 [11] is considered which describes the prediction of building entry loss. The recommendation considers two different kinds of building, a “thermally efficient” building which leads to higher building entry loss and a “traditional” building which has less entry loss, in comparison with thermally efficient buildings, due to different building materials.

At horizontal incidence, different probabilities for building entry losses provided by Recommendation ITU-R. P.2109-01 at 70-71 GHz are taken into account as shown in Table 5.

Table 5: BEL values

Probability p	Traditional building	Thermally efficient building
p = 1%	BEL = 3.3 dB	BEL = 10.9 dB
p = 10%	BEL = 7.8 dB	BEL = 26.1 dB
p = 50%	BEL = 22.9 dB	BEL = 52.1 dB

4.2 SHARING WITH FIXED SERVICE

Due to the low power of SScs, a general MCL calculation is done where one is installed at an indoor site in normal operation. This can be for example at an airport where SScs are installed at security checkpoints. The MCL method is used, and the separation distance is calculated where one SSc with its specific modulation is operated.

The victim FS receiver is assumed to be positioned on a building, whereas the SSc transmitter is located either in another building for indoor use cases or outside for outdoor use cases, both in boresight of the FS RX. For simplicity, a height difference of 15 m between the two is assumed. The indoor deployment scenario is shown in Figure 4. For simplicity, it is assumed that the point-to-point (PP) FS link is pointing towards the horizon, but field deployments can have both down- and up-tilted antennas.

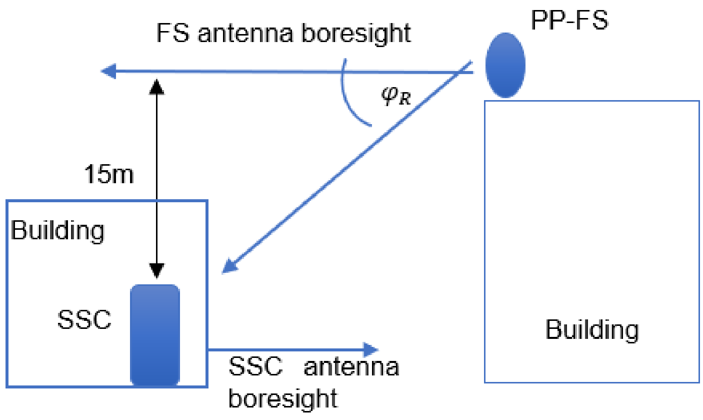

Figure 4: PP-FS Scenario (SSc indoor)

The MCL analysis evaluates the interference thresholds at the receiver antenna input I_R below which the victim performance is not affected by the presence of the interferer. The receiver interference threshold can be evaluated using I/N protection criteria.

In case of I/N protection criteria the interference threshold at receiver input I_R is evaluated as in (1).

The MCL is evaluated as the path loss which is necessary to reduce the interfering signal to stay below the interference threshold I_R as defined above in (1).

$$MCL\ [dB] = e.i.r.p._I + BWCF - OOB_{att} - \mathrm{BEL}(\theta)[\mathrm{dB}] + G_{FS}(\theta)[dB] - I_R \quad (8)$$

Where:

- $e.i.r.p._I$: is the mean equivalent isotropic radiated power density of the interfering signal from SSc;
- BWCF [dB]: is a bandwidth correction factor calculated as ratio between the FS bandwidth and the bandwidth of the interference $10 \cdot \log\left(\frac{BW_{FS}}{BW_I}\right)$;
- OOB_{att} [dB]: is a out-of-band attenuation factor if the services operate in adjacent bands;
- $\mathrm{BEL}(\theta)$ is the building entry loss value due to walls/windows between the SSc and FS at the elevation angle θ. Note that the BEL is removed for outdoor use cases;
- $G_{FS}(\theta)$ is the FS gain antenna gain in the direction of the interferer at the incident angle θ.

The BEL is modelled according to Recommendation ITU-R P.2109-1 [11] and the elevation angle of the path at the building façade is the same as FS incident angle, i.e. θ.

The FS antenna pattern is the same as the one used in ECC Report 315 [4], given in ETSI EN 302 217-4 (cf. Figure 40). The antenna is a Class 3 assuming a maximum gain of 43 dBi, although higher gain antennas are typically deployed. Figure 5 shows the obtained FS antenna gain as a function of the separation distance between the SSc emitter and FS receiver for a height difference of 15 m.

If the direction of the interferer in the vertical plane, φ_R, (boresight offset angle) is zero and the SSc is in line of sight, the entire antenna gain would need to be counted (43 dBi) to calculate the interference threshold after antenna. This scenario is very unlikely to happen, as there must be nothing obstructing the line of sight for a separation distance of 3 km, which would be necessary to be in the main lobe of the antenna (see Figure 4).

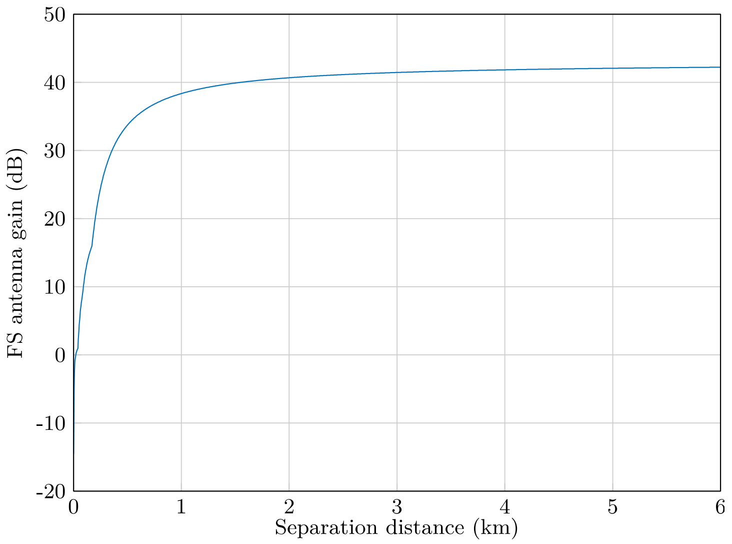

Figure 5: FS antenna gain as function of separation distance between the SSc emitter and FS receiver for a height difference of 15 m

Table 6 summaries the parameters used for the MCL study.

Table 6: Summary of FS and SScs parameters used for MCL calculation

MCL Parameters	
FS Receiver noise floor	-75 dBm
FS BW	1250 MHz
FS Allowed Long-term interference to noise ratio (I/N)	-20 dB
FS Noise Figure	8 dB
SSc #1 e.i.r.p.	7 dBm
SSc #1 BW	10 GHz
SSc #1 BWCF	$10 \cdot \log\left(\frac{1.25}{10}\right) = -9$ dB
SSc #2 e.i.r.p.	19 dBm
SSc #2 BW	1.5 GHz
SSc #2 BWCF	$10 \cdot \log\left(\frac{1.25}{1.5}\right) = -0.8$ dB
SSc #2 out-of-band attenuation	23 dB

Using the parameters from Table 6, the receiver interference threshold for a temperature of $T = 290\ K$ before antenna calculates to:

$$I_R\ [dBm] = \frac{I}{N} + N = -20 - 113.83\ dBm + 10\log(1250\ MHz) + 8dB = \ -94.9\ dBm \quad (9)$$

4.2.1 Sharing with Fixed Service of SSc #1 indoor

A frequency dependent duty cycle scheme is used in the SSc #1, which is a wideband device using an FSK signal. Each CW step has a duration of 240.64 µs. The duration of the entire 128 steps FSK signal is 32 ms with a repetition rate of 250 ms (duty cycle of ~7.8%) for two cycles, which is a single scan. After two cycles the device is switched off and the image processing is performed. The image processing takes 3 seconds. In addition, SSc #1 has 45° polarisation, which may result in 3 dB polarisation correction factor depending on the FS station. However, this is not considered here since a dual polarised FS link is assumed.

The scenario considered is described above. The SSc #1 itself is built out of antenna clusters that face each other. During operation each TX antenna will transmit the FSK signal.

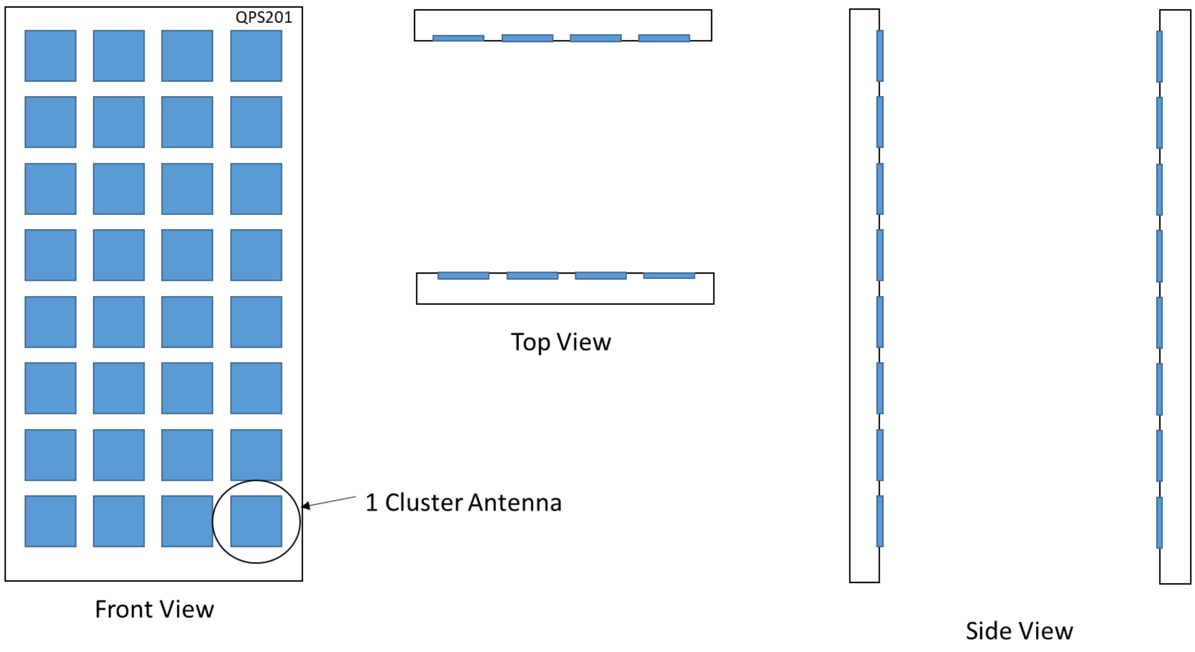

Figure 6: SSc #1 front, top and side view

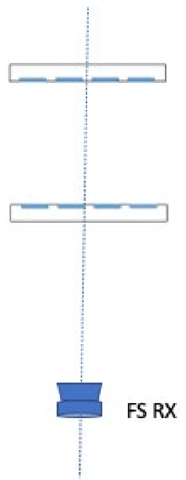

Figure 7: Top view of interference scenario with 0 degree azimuth misaligment

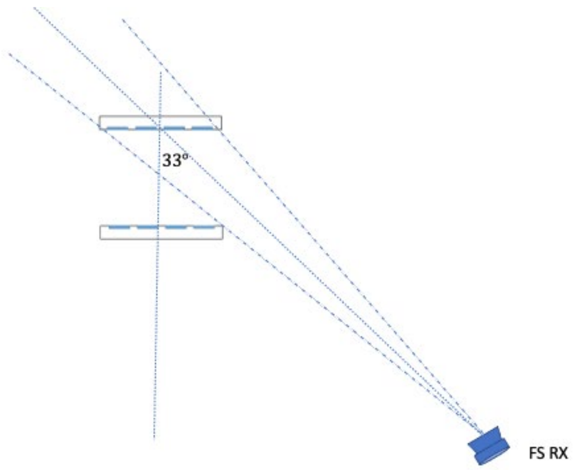

Figure 8: Top view of interference scenario with 33 degree azimuth misaligment

Due to the geometric setup itself there is direct line of sight into a TX antenna only under certain geometric conditions. Where the incident angle is 33.2° all number of antennas can be seen. At an incident angle of 0° no antennas can be seen.

According to Table 1 in ETSI TR 103 664 [9], the antenna has 76° beam width. For reference, a 6 dBi antenna pattern generated using Recommendation ITU-R F.699 [10] is shown in Figure 9. This simulated antenna pattern is taken into account for the MCL worst-case study. It should be noted that this simulated antenna pattern deviates for the 33° scenario by approximately +2 dB at an angle of 33° from the measured antenna pattern shown in ANNEX 2:.

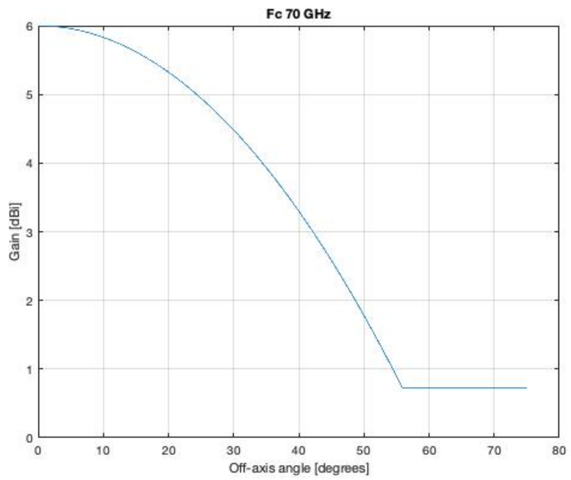

Figure 9: Antenna Pattern C_antenna of SSc #1

Depending on the distance of the PP-FS to the SSc (H_PPFS-SSc (see Figure 10)), the area A with antennas that can be seen varies. The area A is described by H‘ (where H‘ depends on the incident angle) and D, the width of the SSc panel.

$$A = D \cdot H' \tag{10}$$

With:

$$\tan(\propto_{vert}) = \frac{H'}{W} \tag{11}$$

It follows:

$$A = D \cdot W \tan(\propto_{vert}) \quad (12)$$

The maximum area that can be seen is $A = D \cdot H'$ and shows a number of maximum 32 antenna clusters. The scaling factor Ant_{seen} is calculated by the number of antenna clusters seen out of the 32 antenna clusters and is proportional to the area seen by the PP-FS antenna.

At an incident angle of 54.5° and higher, the entire array can be seen because $W \cdot \tan(54.5°)$ = 2.11 m which becomes greater than the height of the panel.

Any incident angle smaller than 54.5° shows less area of the array.

Formula:

$$Ant_{seen} = \frac{(D \cdot W \tan(\propto_{vert}))}{D \cdot H} \cdot 32 \quad (13)$$

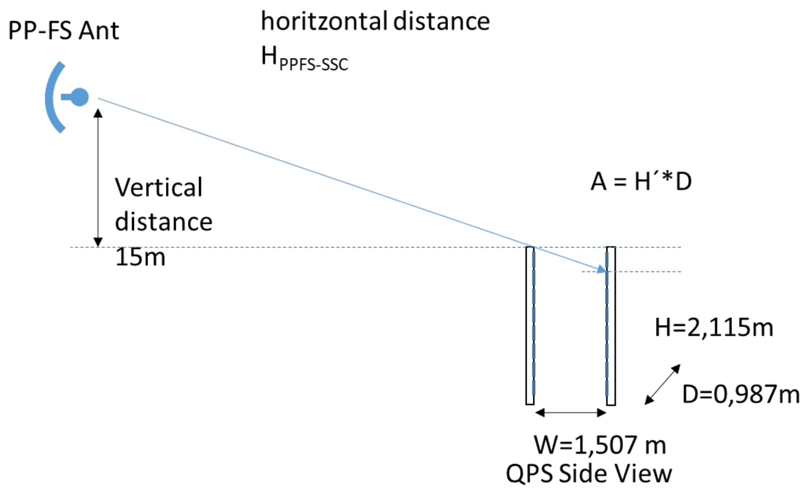

Figure 10: Figure to calculate the number of antennas seen by the PP-FS antenna

Using the scenario and dimensions of the SSc #1 from Figure 10, from the incident angle, the corresponding attenuation from the SSc antenna pattern, the corresponding scenario distance, the antennas seen and finally the correction factor C_{angle} can be calculated by:

$$C_{angle} = 10\ log10(\frac{Ant_{seen}}{32}) \quad (14)$$

In addition the SSc #1 antenna radiation pattern is taken into account by $C_{antenna}$.

Table 7: SSc #1 correction factors by geometrical setup and antenna

Incident Angle (degree)	C_antenna [dB]	C_angle (dB)	Corresponding scenario distance (m)	Antenna clusters seen (Ant_seen) (number)
90.00	> 20.0	0.00	0.00	32.00
80.00	> 20.0	0.00	2.64	32.00
70.00	20.0	0.00	5.46	32.00
60.00	14.0	0.00	8.66	32.00

Incident Angle (degree)	C_antenna [dB]	C_angle (dB)	Corresponding scenario distance (m)	Antenna clusters seen (Ant_seen) (number)
50.00	11.0	-0.65	12.59	27.53
40.00	6.0	-2.18	17.88	19.38
30.00	3.8	-3.80	25.98	13.34
20.00	2.0	-5.80	41.21	8.41
16.70	1.9	-6.64	50.00	6.93
10.00	1.0	-8.95	85.07	4.07
8.50	0.5	-9.67	100.37	3.45
4.30	0.0	-12.65	199.49	1.74
2.85	0.0	-14.44	301.31	1.15
2.15	0.0	-15.67	399.55	0.87
1.71	0.0	-16.67	502.45	0.69
1.43	0.0	-17.44	600.88	0.58
1.23	0.0	-18.10	698.62	0.50
1.07	0.0	-18.70	803.12	0.43
0.96	0.0	-19.20	899.85	0.39
0.86	0.0	-19.65	999.27	0.35
0.43	0.0	-22.66	1998.65	0.17
0.29	0.0	-24.43	3001.85	0.12
0.22	0.0	-25.67	3997.36	0.09
0.17	0.0	-26.64	4999.62	0.07
0.14	0.0	-27.44	6001.64	0.06

Based on a geometrical approach where the relative position between the interferer and the victim is taken into account, the FS antenna gain varies. The FS antenna gain is taken into account based on the distance.

The MCL results are obtained for the SSc #1 for different p values used in the BEL model in thermally efficient and traditional buildings. The p value (1%, 10%, 50%) is the probability with which the building entry loss is not exceeded.

The below figure shows the distance calculated by the MCL including all PP-FS and SSc #1 data.

Figure 11 shows the results for the different building types.

The figure can be interpreted such that as long as the minimum separation distance is below the actual distance line (red), there is no risk of interference.

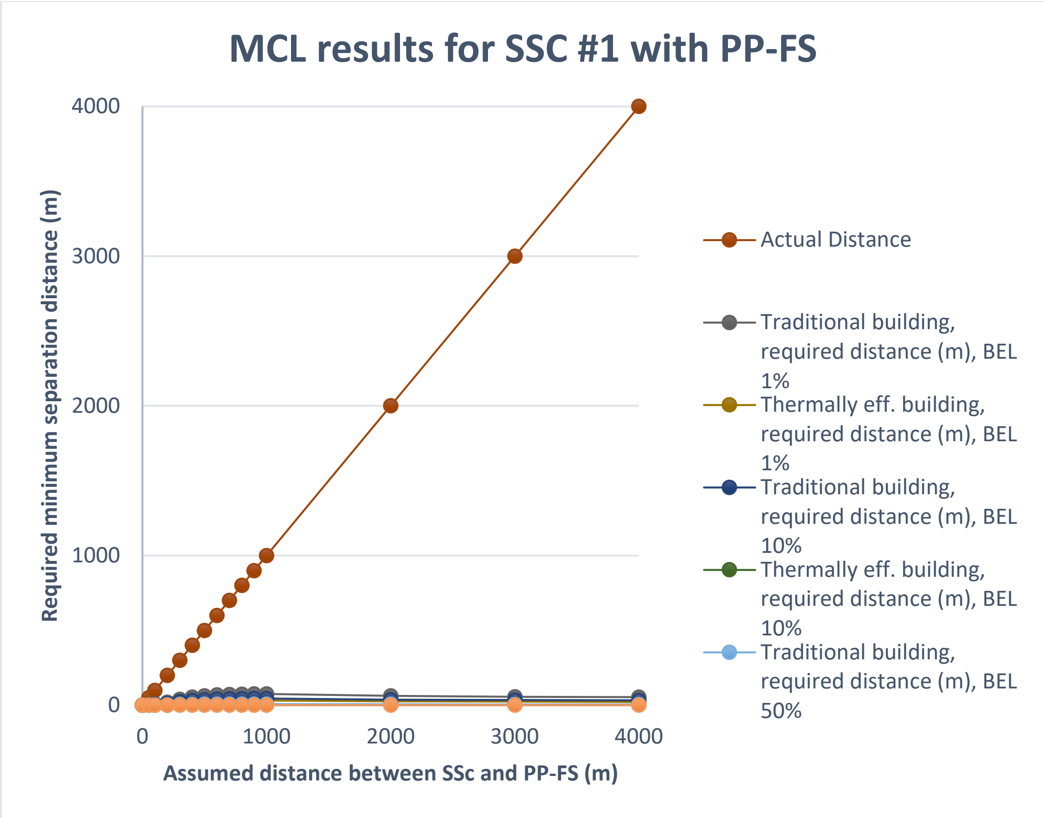

Figure 11: MCL results for SSc #1 with PP-FS in the scenario with 0 degree azimuth misaligment

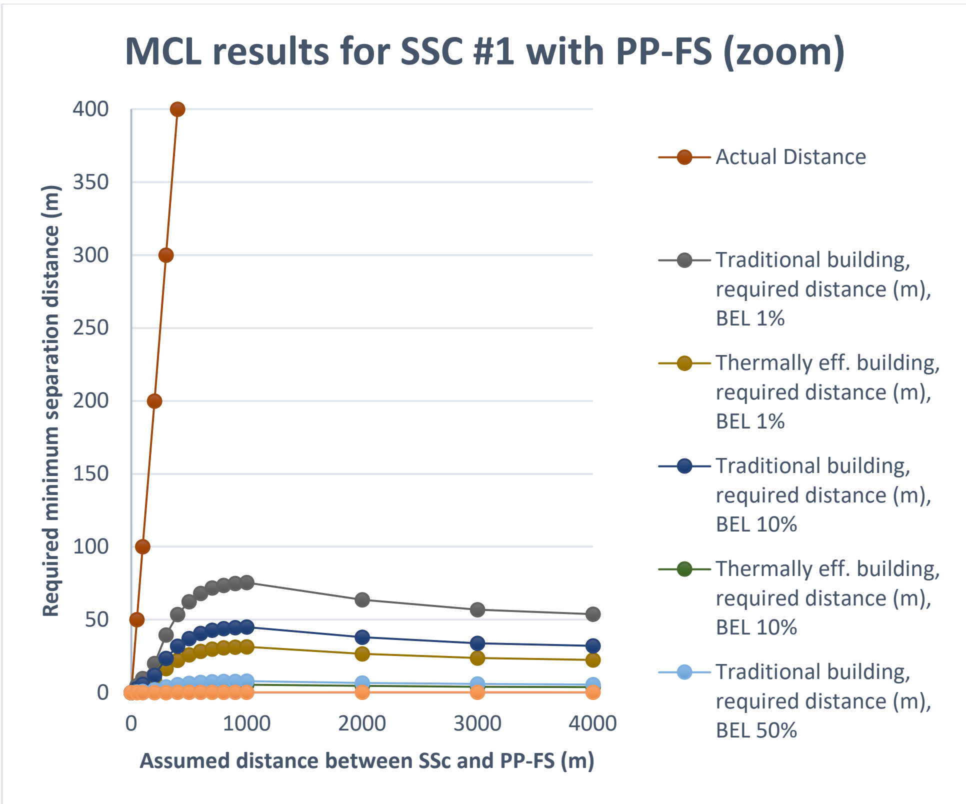

Figure 12: MCL results for SSc #1 with PP-FS in the scenario with 0 degree azimuth misaligment. (zoom to 400 m required minimum distance)

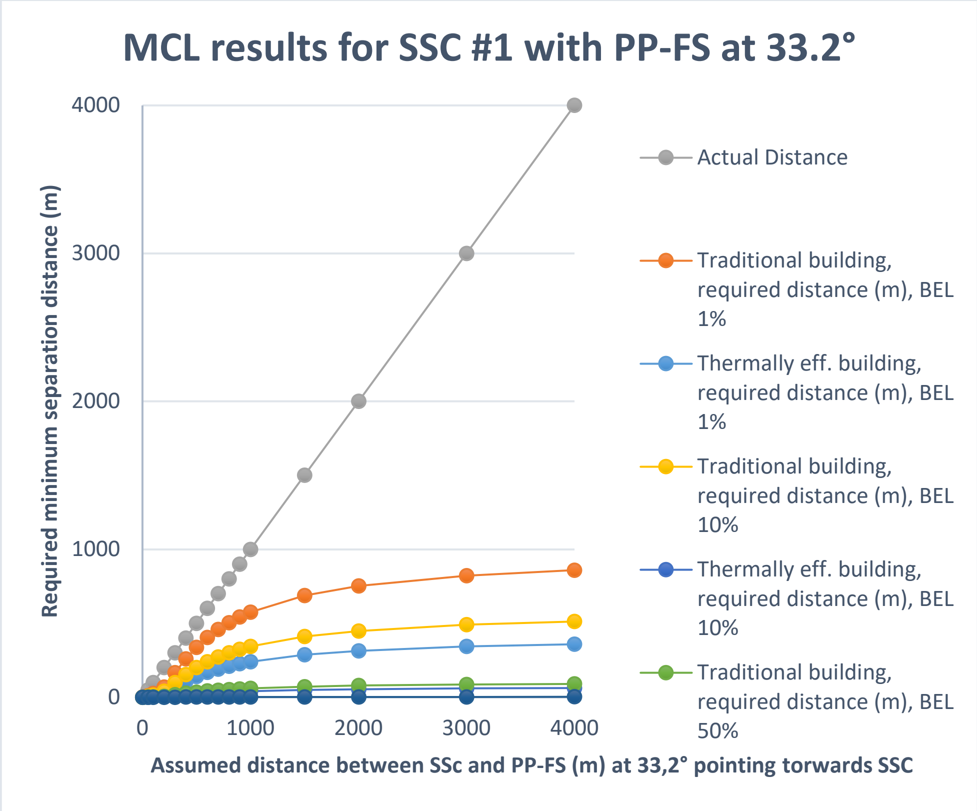

Figure 13: MCL results for SSc #1 with PP-FS in the given scenario with 33.2 degrees azimuth misaligment

In this case even when p=1% and traditional buildings are considered separation distances of a few meters are calculated. In case of higher output power these systems could result in larger separation distances. Separation distances of several hundred meters, result in a variation of the elevation which impacts the clutter loss model that can be used. The elevation dependent clutter loss model according to Recommendation ITU-R P.2108-0 [5] for a frequency range of 60-90 GHz can be considered as well. According to Recommendation ITU-R P.2108-0, an additional loss L_{ctt} is calculated which can be added to the transmission loss or basic transmission loss. Clutter loss will vary depending on clutter type, location within the clutter and movement in the clutter. However, this case is not relevant for this Report, therefore it is not studied.

4.2.2 Sharing with Fixed Service of SSc #2 outdoor in band and adjacent band

Coexistence of outdoor in band and adjacent band SSc #2 with PP-FS is presented in this section. A general calculation is done where the of SSc #2 is installed at either indoor or outdoor site in normal operation. This can be for example where the SSc #2 is installed just before or within the entrance of any public facility such as an airport terminal. The MCL method is used, and the separation distance is calculated.

The Fixed Service is PP-FS links operating in E-Band (71-76 GHz & 81-86 GHz). The PP-FS antennas are often installed on rooftops in urban areas. The same scenario as with SSc #1 is considered, where a PP-FS link is installed on a rooftop where a SSc #2 is installed indoor. In addition an outdoor scenario by the entrance of public facilities are considered and depicted in Figure 14.

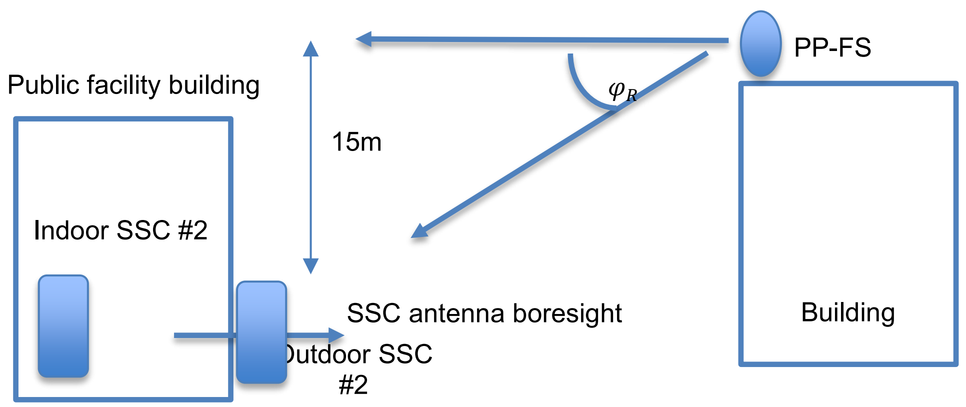

Figure 14: PP-FS Scenario #2 (SSc #2 outdoor)

Adjacent band situation

SSc #2 keeps a distance (in frequency) from the FS bands (71-76 GHz and 81-86 GHz) of at least 0.5 GHz as depicted in the following schematic:

76 GHz	500 MHz Guard band	Operating frequency band 76.5 … 78.5 (centre) …. 80.5 GHz	500 MHz Guard band	81 GHz

Figure 15: SSc operating frequency band and adjacent band

Figure 15 shows the operating frequency band and the adjacent bands. The operating frequency band used by the SSc #2 system is at a centre frequency of 78.5 GHz with maximum bandwidth (BW) up to 4 GHz. The guard bands are at least 500 MHz each.

The MCL calculation parameters summary is presented in Table 10.

Table 8: MCL calculation parameters summary #2

MCL Parameters	Value
PP-FS Receiver noise power density typical (=NRX): Table 11 in ITU-R F.758-7 [6]	-106 dBm/MHz
PP-FS Receiver Noise Figure typical	8 dB
PP-FS Receiver reference bandwidth: ECC Report 315 [4]	1250 MHz
SSc #2 peak e.i.r.p.	19 dBm
Maximum SSc #2 BW (worst case)	4 GHz
Out-of-band attenuation	23 dB

The parameters for the PP-FS are taken from Recommendation ITU-R F.758-7.

To calculate the overlap in time and frequency, additional parameters of the SSc #2 are given in Table 11.

Table 9: Additional SSc #2 Parameters for MCL calculation

Parameter	Value
Centre frequency	78.5 GHz
Bandwidth (BW)	4.0 GHz
Minimum Bandwidth	1.5 GHz
The resulted minimum SSc #2 frequency:	76.5 GHz
The resulted maximum Q-MSS frequency	80.5 GHz
Rx bandwidth (after the mixer):	$B_{VQ} = 10\ MHz, or + 70\ dB(Hz)$
Equivalent noise in the receiver (before processing):	$N_Q = KT \cdot B_{VQ} = -174 + 70 = -104\ dBm$
System period time	100 ms

Additional losses due to out-of-band transmission that are applied are shown in Table 12.

Table 10: Out-of-band attenuation correction for SSc #2

Parameter	Out-of-band attenuation correction	Unit	Value
L_{ooB}	The out-of-band attenuation from ETSI EN 303 883-1. (Further large mitigation margin of increased attenuation to >>32dB exists due to the frequency roll-off of the PP-FS receiver is cos with roll-off of 1% according to ETSI EN 302 217-2 V3.1.1 (2017-05))	dB	23

With these numbers, the PP-FS antenna pattern, the incident angle, the required MCL and distance can be calculated which is shown in Table 12. In Table 13, results for operation of in-band with FS are shown.

Table 11: SSc #2 Outdoor MCL Results in the adjacent band

Scenario Distance (m)	FS_ant (dB)	Incident Angle (°)	MCL (dB)	required Distance (m)
15	-0.7	90.0	89.4	9.0
50	3.6	17.5	93.7	14.7
100	11.1	8.6	101.1	34.6
200	19.8	4.3	109.9	95.2
300	27.5	2.9	117.6	231.1
400	31.4	2.1	121.5	360.4
500	33.7	1.7	123.8	470.6
600	35.3	1.4	125.3	562.2
700	36.4	1.2	126.4	638.5
800	37.2	1.1	127.3	702.4
900	37.8	1.0	127.9	756.4

Scenario Distance (m)	FS_ant (dB)	Incident Angle (°)	MCL (dB)	required Distance (m)
1000	38.4	0.9	128.4	802.7
1500	39.9	0.6	130.0	959.2
2000	40.7	0.4	130.7	1048.5
3000	41.5	0.3	131.5	1146.1
4000	41.8	0.2	131.9	1198.3
5000	42.1	0.2	132.1	1230.8
6000	42.2	0.1	132.3	1252.9

Table 12: SSc #2 Outdoor MCL Results In-band

Scenario Distance (m)	FS_ant (dB)	Incident Angle (°)	MCL (dB)	required Distance (m)
15	-0.7	90.0	112.4	133.6
50	3.6	17.5	116.7	219.4
100	11.1	8.6	124.1	515.4
200	19.8	4.3	132.9	1416.5
300	27.5	2.9	140.6	3439.1
400	31.4	2.1	144.5	5363.5
500	33.7	1.7	146.8	7003.9
600	35.3	1.4	148.3	8368.2
700	36.4	1.2	149.4	9502.8
800	37.2	1.1	150.3	10453.8
900	37.8	1.0	150.9	11258.8
1000	38.4	0.9	151.4	11947.2
1500	39.9	0.6	153.0	14275.9
2000	40.7	0.4	153.7	15605.5
3000	41.5	0.3	154.5	17058.8
4000	41.8	0.2	154.9	17835.5
5000	42.1	0.2	155.1	18318.4
6000	42.2	0.1	155.3	18647.6

Compared to the calculation from SSc #1 the graph has been calculated for SSc #2. As shown in Figure 16 the required outdoor distance stays below the actual distance in the adjacent band scenario. Consequently, there is no risk of interference. The in-band scenario shown in Figure 17 shows the required outdoor distance exceeds the actual distance, resulting in a risk of interference.

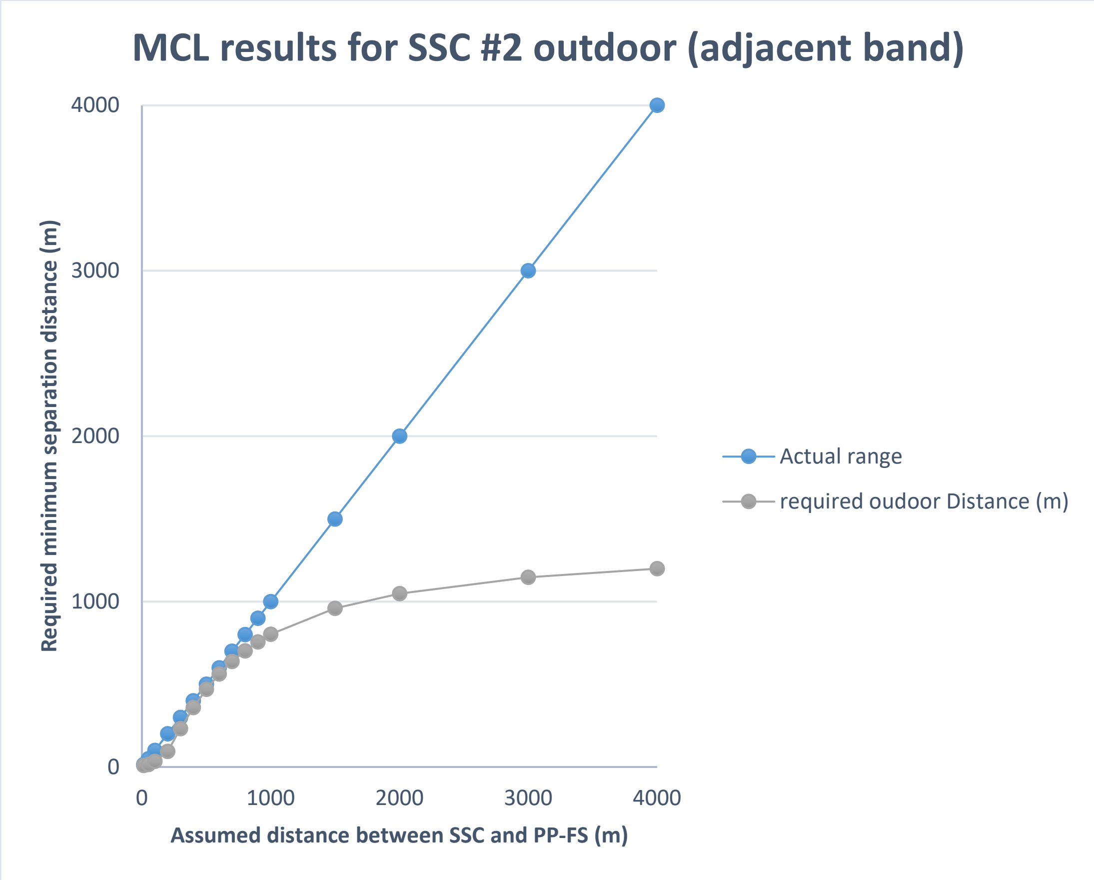

Figure 16: SSc #2 Outdoor MCL adjacent band results

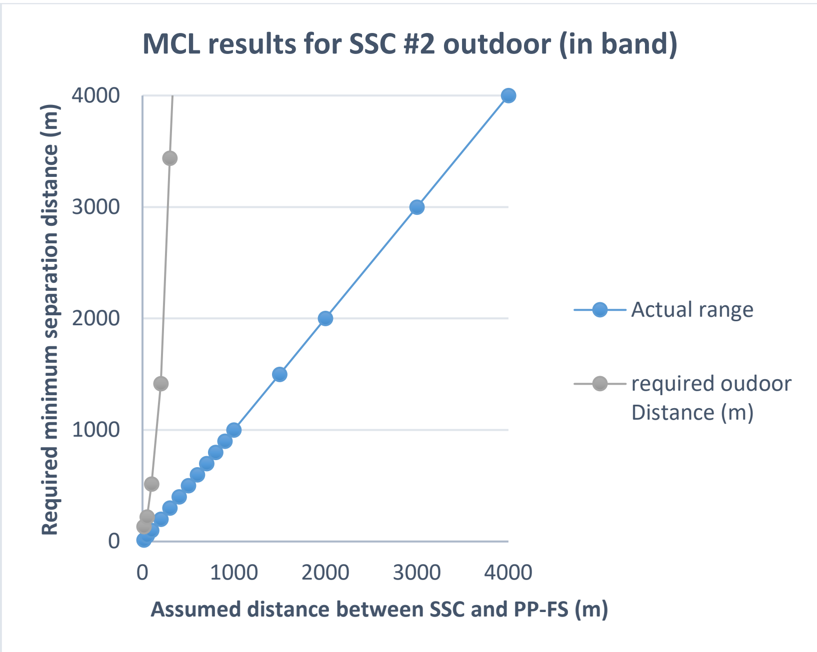

Figure 17: SSc #2 Outdoor MCL in band results

4.2.3 Sharing with Fixed Service of SSc #2 indoor

The indoor scenario for SSc #2 is considered. The same MCL calculations as above are done. In addition, the different BEL p values of 1%, 10% and 50% are considered.

Table 15 shows the calculated adjacent band results of SSc #2 in traditional buildings with a p value of 1%. Table 16 shows the calculated in-band results of SSc #2 in traditional buildings with a p value of 1%.

Table 13: SSc #2 indoor with BEL of p=1% in traditional buildings in the adjacent band scenario

Scenario Distance (m)	FS_ant (dB)	MCL (dB)	MCL (Indoor 1%, trad.)	Trad. building, required distance (m), BEL 1%
15	-0.7	89.4	86.1	6.1
50	3.6	93.7	90.4	10.1
100	11.1	101.1	97.8	23.7
200	19.8	109.9	106.6	65.1
300	27.5	117.6	114.3	158.0
400	31.4	121.5	118.2	246.5
500	33.7	123.8	120.5	321.8
600	35.3	125.3	122.0	384.5
700	36.4	126.4	123.1	436.7
800	37.2	127.3	124.0	480.4
900	37.8	127.9	124.6	517.3
1000	38.4	128.4	125.1	549.0
1500	39.9	130.0	126.7	656.0
2000	40.7	130.7	127.4	717.1
3000	41.5	131.5	128.2	783.9
4000	41.8	131.9	128.6	819.5
5000	42.1	132.1	128.8	841.7
6000	42.2	132.3	129.0	856.9

Table 14: SSc #2 indoor with BEL of p=1% in traditional buildings in-band

Scenario Distance (m)	FS_ant (dB)	MCL (dB)	MCL (Indoor 1%, trad.)	Trad. building, required distance (m), BEL 1%
15	-0.7	89.4	109.1	86.7
50	3.6	93.7	113.4	142.4

Scenario Distance (m)	FS_ant (dB)	MCL (dB)	MCL (Indoor 1%, trad.)	Trad. building, required distance (m), BEL 1%
100	11.1	101.1	120.8	334.5
200	19.8	109.9	129.6	919.4
300	27.5	117.6	137.3	2232.2
400	31.4	121.5	141.2	3481.3
500	33.7	123.8	143.5	4546.0
600	35.3	125.3	145.0	5431.5
700	36.4	126.4	146.1	6167.9
800	37.2	127.3	147.0	6785.1
900	37.8	127.9	147.6	7307.6
1000	38.4	128.4	148.1	7754.5
1500	39.9	130.0	149.7	9266.0
2000	40.7	130.7	150.4	10128.9
3000	41.5	131.5	151.2	11072.3
4000	41.8	131.9	151.6	11576.4
5000	42.1	132.1	151.8	11889.8
6000	42.2	132.3	152.0	12103.5

Calculating the MCL values for traditional and thermally efficient buildings for the different p values of 1%, 10% and 50% results in Figure 18 and Figure 19 for the adjacent band and in band scenario respectively.

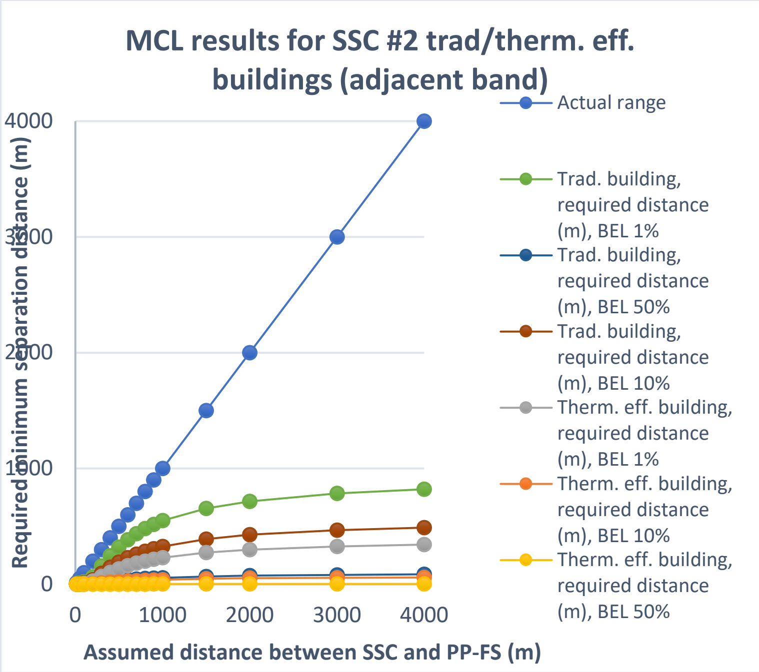

Figure 18: MCL results for SSc #2 in traditional and termal efficent buildings in the adjacent band scenario for p=1%, 10% and 50%

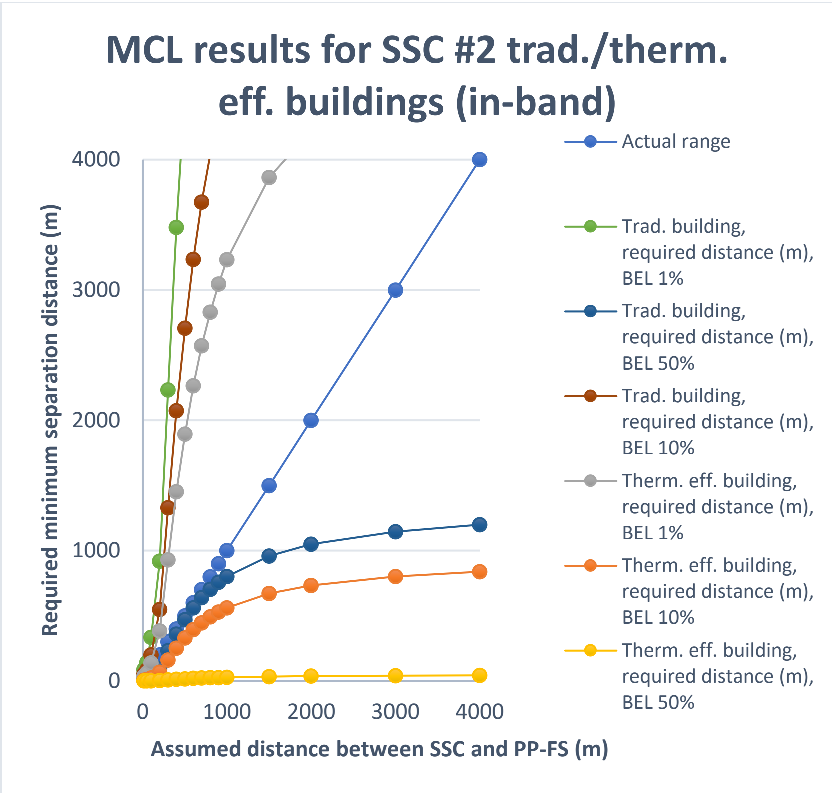

Figure 19: MCL results for SSc #2 in traditional and thermal efficient buildings in-band for p=1%, 10% and 50%

As the calculated values stay below the actual range line in the adjacent band scenario, there is no risk of interference.

On the other hand, the in-band scenario required separation distances exceeded the actual distance for certain BEL values and building types, therefore no compatibility for these BEL values in these building types can be achieved.

4.2.4 Conclusions for FS MCL studies

MCL studies have been performed with FS for the 2 different types of SScs. The study with the SSc #1 shows no risk of interference for indoor operation towards the FS when operating in the 69.89 GHz to 79.89 GHz frequency band with a peak e.i.r.p. of 7 dBm. The SSc #2 was studied in 2 candidate bands 71-76 GHz and 76.5-80.5 GHz with a peak e.i.r.p. emission of 19 dBm, with both indoor and outdoor operation. The study concluded that operation in the band 71-76 GHz causes harmful interference towards the FS for both indoor and outdoor operation. No harmful interference is caused towards the FS when operating in the band 76.5-80.5 GHz, for both indoor and outdoor operation assuming 23 dB OOB attenuation.

Instead of MCL studies and worst-case assumptions like these scenarios, a more complex calculation and simulation, e.g. using Monte Carlo simulation may be needed and additional studies may be necessary e.g. using clutter-loss and terrain models for different models of SScs operating in-band and in outdoor scenarios.

4.3 SHARING WITH AUTOMOTIVE RADAR

Automotive radar operates in a frequency band of 76-77 GHz and 77-81 GHz. These types of sensors use similar signals as SScs, namely FMCW, Chirp Sequence, FSK, MFSK, Phase Coded signals and in future also wideband modulated signals such as OFDM are under considerations.

More detailed information on automotive radars can be found in ECC Report 262 [8].

ECC Report 262, table 3 [8] summarises typical technical parameters of automotive radars. The table has been shortened to the most important parameters for the MCL calculation.

Table 15: Typical technical parameters of automotive radars

	Front Long range	Front Mid range	Front-side Mid and short range	Rear-side Mid and short range
Antenna polarisation	Horizontal vertical diagonal	Horizontal vertical		
Rx typical noise figure	15 dB			
Rx IF bandwidth (before analog-digital conversion)	Slow FMCW: up to 200 kHz Fast FMCW: up to 15 MHz.			
Rx IF typical noise floor (before analog-digital conversion)	N = 10 log10 (k T B) + NF with reference bandwidth B = 1 MHz			
Rx IF bandwidth, B_IF (after signal processing)	500 kHz – 25 MHz			

From the list of radars with different IF bandwidth three exemplary Rx IF bandwidth have been selected to calculate the interference threshold with antenna.

The interference threshold is calculated by:

$$I_{LRR}[\text{dBm}] = -113.83 + 10 \cdot \log\_10\,(B\_IF\,) + \text{NF} - \frac{I}{N} = -107.8\text{ dB} \quad (15)$$

Where:

- $\frac{I}{N} = -6\ \mathrm{dB}$ (based upon Recommendation ITU-R M.1461-2 and ECC Report 315).

Table 16: Interference threshold for different automotive radar sensors

#	Parameter	Unit	
I_{LRR}	Interference threshold with antenna (500 kHz IF BW)	dBm	-107.8
I_{MRR}	Interference threshold with antenna (5 MHz IF BW)	dBm	-97.8
I_{SRR}	Interference threshold with antenna (15 MHz IF BW)	dBm	-93.1

Table 18 shows the interference thresholds for different automotive radar sensors. The MCL calculations for the long range radar (LRR) are sufficient.

4.3.1 Sharing with Automotive Radar (SSc #2 indoor)

In the indoor scenario it is considered that the SSc #2 is boresight to the automotive radar and the antenna main beams face each other.

Figure 20: Scenario SSc (indoor) and automotive radar

For this scenario the automotive radar antenna parameters from ECC Report 315 are used where the antenna gains is $G_0 = 25\ \mathrm{dB}$ at half power azimuth beam width of $\theta_{3Az} = 10°$ and half power vertical beam width of $\theta_{3AEl} = 6°$.

The following calculations uses the antenna azimuth pattern, $G_{LRR}(\theta)$, as given in Figure 21. It originates from ECC Report 262 [8] for automotive LRR.

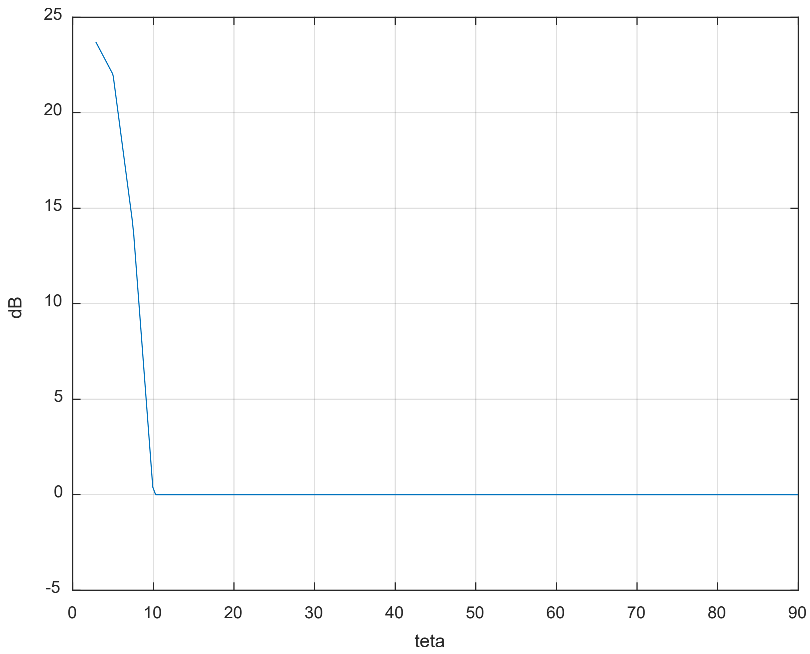

Figure 21: Automotive radar receiver azimuth antenna pattern $G_{LRR}(\theta)$

In addition to the automotive radar receiver antenna pattern in azimuth, the gain in range is shown in Figure 22.

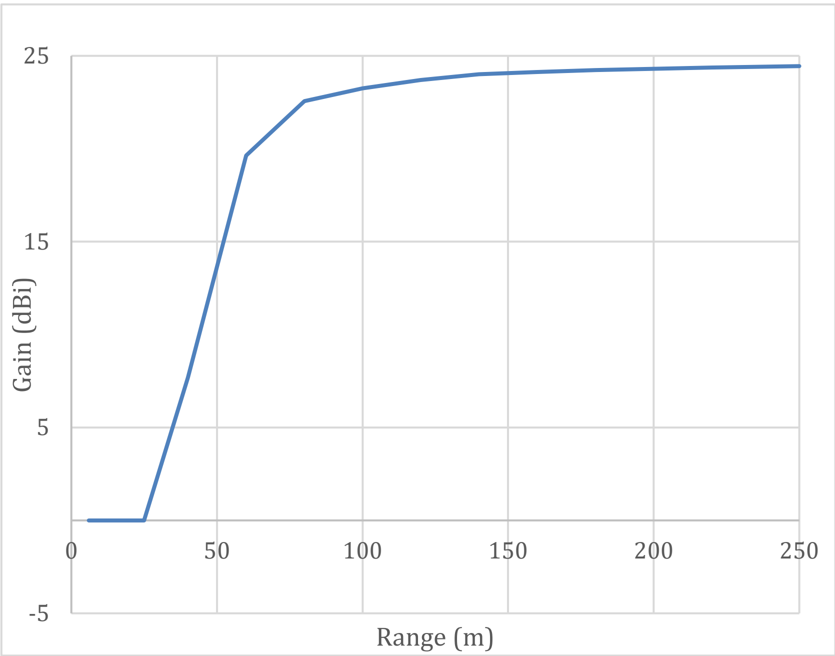

Figure 22: Automotive radar antenna gain vs range

The duty cycle (DC) of the automotive LRR was not considered in this calculation. The modulation gain (MG) is considered and shown below in Table 19.

Table 17: Additional parameters for MCL calculation (automotive radar)

#	Parameter	Unit	
MG_{LRR}	Modulation gain = BW correction factor (BWCF)	dB	-31.8
Pol	Polarisation	dB	-3
BEL	Building Entry Loss, Traditional Building, p=0.5	dB	-23

The modulation gain MG_{LRR} is calculated for the worst-case bandwidth (1.5 GHz) of interference. The maximum requested bandwidth of 4.0 GHz will reduce the interference by another 4.3 dB.

The final calculation for the MCL is as follows:

$$\mathrm{MCL} = \mathrm{e.i.r.p.} + G_{LRR} + Pol + MG_{LRR} + BEL + L_{ooB} - I_{LRR} \quad (16)$$

The MCL results for SSc #2 in different buildings are shown in Table 20.

Table 18: MCL results for SSc #2 and automotive radar (indoor)

Distance (m)	G_LRR (dBi)	TetaR (deg)	PhiR (deg)	MCL (Trad. Build, 50%, Indoor)	min Distance (Trad. Build, 50%, Indoor)	MCL (Trad. Build, 10%, Indoor)	min Distance (Trad. Build, 10%, Indoor)	MCL (Trad. Build, 1%, Indoor)	min Distance (Trad. Build, 1%, Indoor)
6	0.0	90.0	90.0	64.1	0.5	79.3	2.8	83.8	4.7
8	0.0	48.6	48.6	64.1	0.5	79.3	2.8	83.8	4.7
10	0.0	36.9	36.9	64.1	0.5	79.3	2.8	83.8	4.7
12	0.0	30.0	30.0	64.1	0.5	79.3	2.8	83.8	4.7
15	0.0	23.6	23.6	64.1	0.5	79.3	2.8	83.8	4.7
20	0.0	17.5	17.5	64.1	0.5	79.3	2.8	83.8	4.7
25	0.0	13.9	13.9	64.1	0.5	79.3	2.8	83.8	4.7
40	7.7	8.6	8.6	71.8	1.2	87.0	6.8	91.5	11.4
60	19.6	5.7	5.7	83.7	4.7	98.9	26.8	103.4	45.0
80	22.6	4.3	4.3	86.6	6.5	101.8	37.5	106.3	63.0
100	23.2	3.4	3.4	87.3	7.1	102.5	40.6	107.0	68.2
120	23.7	2.9	2.9	87.8	7.4	103.0	42.8	107.5	71.9
140	24.0	2.5	2.5	88.1	7.7	103.3	44.4	107.8	74.5
160	24.1	2.1	2.1	88.2	7.8	103.4	45.0	107.9	75.6
180	24.2	1.9	1.9	88.3	7.9	103.5	45.5	108.0	76.4
200	24.3	1.7	1.7	88.4	8.0	103.6	45.9	108.1	77.1

Distance (m)	G_LRR (dBi)	TetaR (deg)	PhiR (deg)	MCL (Trad. Build, 50%, Indoor)	min Distance (Trad. Build, 50%, Indoor)	MCL (Trad. Build, 10%, Indoor)	min Distance (Trad. Build, 10%, Indoor)	MCL (Trad. Build, 1%, Indoor)	min Distance (Trad. Build, 1%, Indoor)
220	24.4	1.6	1.6	88.4	8.0	103.6	46.3	108.1	77.7
250	24.4	1.4	1.4	88.5	8.1	103.7	46.7	108.2	78.3

As the calculated values stay below the actual range line, there is no risk of interference in these scenarios.

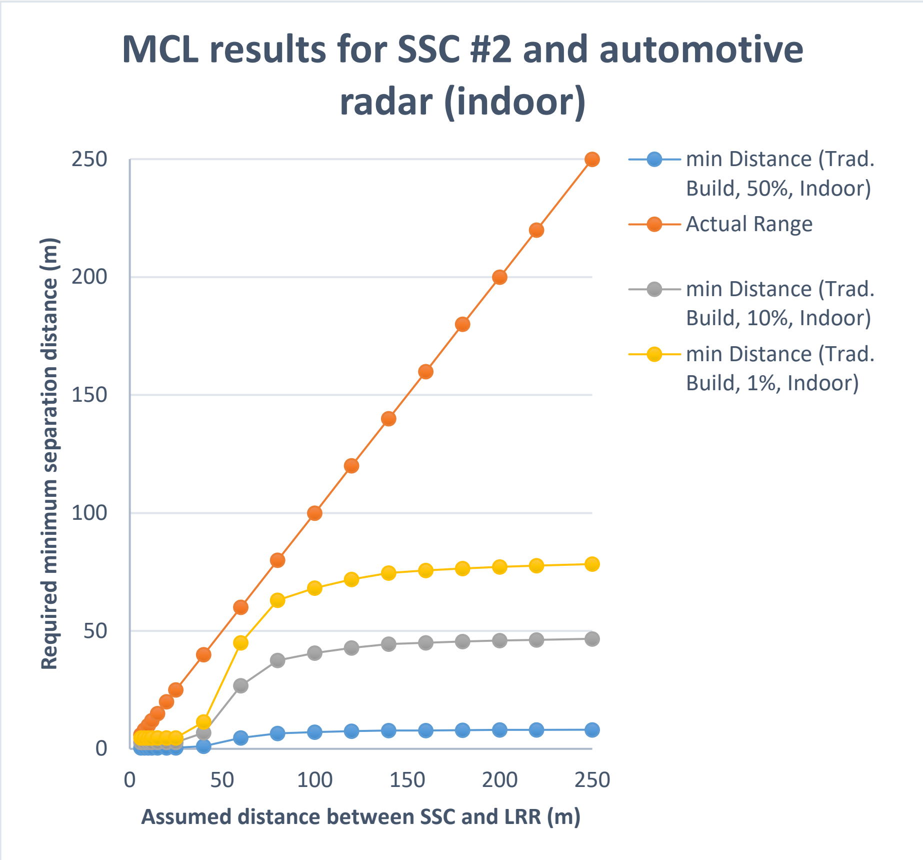

Figure 23: MCL results for SSc #2 and automotive radar (indoor)

4.3.2 Sharing with Automotive Radar (SSc #2 outdoor)

A realistic worst-case scenario of SSc #2 deployment is within the near side lobes of the automotive LLR where its boresight is directed towards its target, see Figure 24. The off-boresight distance X_{OB} is shown in the following top-view outdoor scenario in Figure 25. The scenario of SSc #2 interfering the LRR boresight is unlikely because SSc #2 protect entrances and is therefore installed in different positions. There are no LRR targets exactly behind SSc #2 deployment, but shifted by X_{OB}.

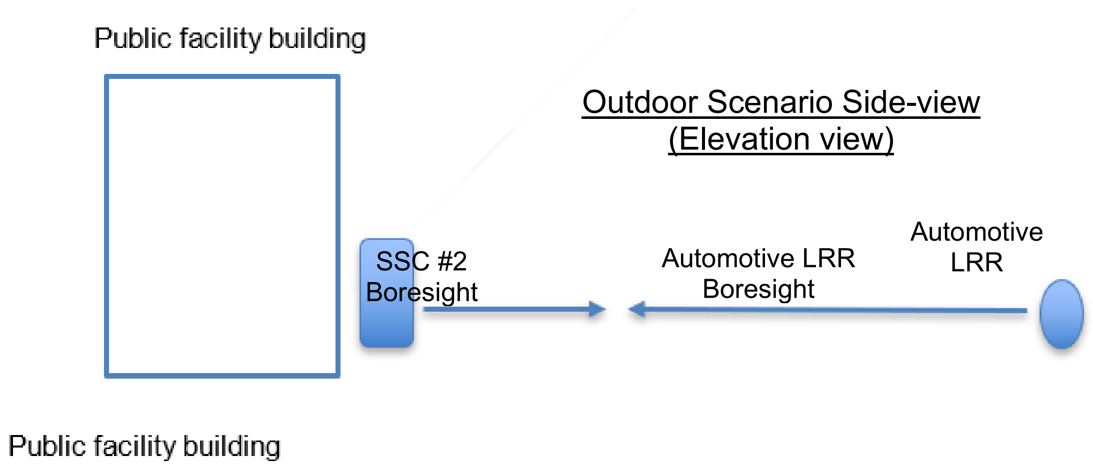

Figure 24: Boresight scenario with SSc #2 and automotive LRR

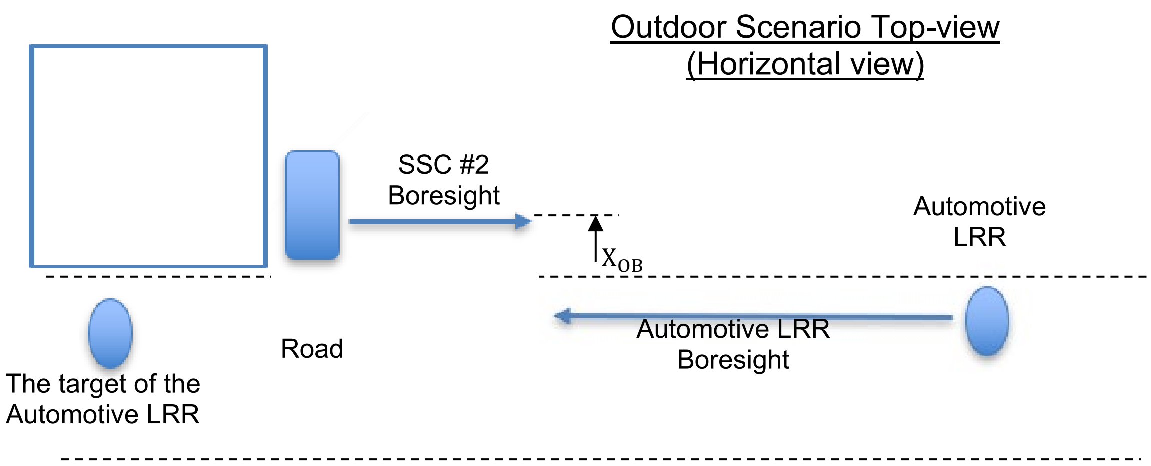

Figure 25: Typical scenario with SSc #2 at an entrance

The SSc #2 is looking towards the automotive radar at angle θ, where:

$$\theta = 180/\pi \cdot \arcsin\left(\frac{X_{OB}}{R}\right). \quad (17)$$

With:

- R: is the automotive victim range from SSc #2 location;
- X_{OB}: is the offset between the automotive antenna broadside and the SSc #2 location. An offset of $X_{OB} \geq 5\text{m}$ is sufficient to obtain the following MCL results based upon the automotive antenna patterns defined in ECC Report 262 [8] see Figure 21 and Figure 22.

ECC Report 262 considers the illumination time of the radars that are facing each other. In this case, the SSc #2 is facing the automotive radar for a time of 8 ms. During that time both signals may overlap in time and/or frequency and could disturb their further processing after down-conversion in the automotive radar.

In this Report the MCL is used and the duration of the overlap in time is considered to be 100%. Therefore, no correction factor in illumination time where the radars are facing is other or are not facing each other is considered. This is different in ECC Report 262 [8] where more complex simulations were done.

Considering the same parameters as for the indoor case, but without building loss and the additional antenna pattern considerations yield to the following Table 21.

Table 19: Additional parameters for MCL calculation (outdoor)

#	Parameter	Unit	
MG_{LRR}	Modulation gain = BW correction factor (BWCF)	**dB**	-31.8
Pol	Polarisation loss	**dB**	-3
B	Building Loss, Traditional Building	**dB**	0

Finally, the MCL can be calculated by

$$\mathrm{MCL} = \mathrm{e.i.r.p.} + \mathrm{G\_LRR} + DC_{time,LRR} + Pol + MG_{LRR} + B + L_{ooB} - I_{LRR} \quad (18)$$

Table 20: MCL results for SSc #2 and automotive radar (outdoor)

Actual distance R (m)	Gain LRR antenna, G_LRR (dBi)	Teta(R)	Phi(R)	MCL Outdoor (m)	min Distance, Outdoor (m)
6	0.0	90.0	90.0	92.1	12.2
8	0.0	48.6	48.6	92.1	12.2
10	0.0	36.9	36.9	92.1	12.2
12	0.0	30.0	30.0	92.1	12.2
15	0.0	23.6	23.6	92.1	12.2
20	0.0	17.5	17.5	92.1	12.2
25	0.0	13.9	13.9	92.1	12.2
40	7.7	8.6	8.6	99.8	29.6
60	19.6	5.7	5.7	111.7	117.1
80	22.6	4.3	4.3	114.6	164.0
100	23.2	3.4	3.4	115.3	177.6
120	23.7	2.9	2.9	115.8	187.2
140	24.0	2.5	2.5	116.1	194.0
160	24.1	2.1	2.1	116.2	196.8
180	24.2	1.9	1.9	116.3	198.9
200	24.3	1.7	1.7	116.4	200.7
220	24.4	1.6	1.6	116.5	202.2
250	24.4	1.4	1.4	116.5	203.9

As the calculated values reach separation distances that are greater than the actual distance there is chance of interference in these scenarios.

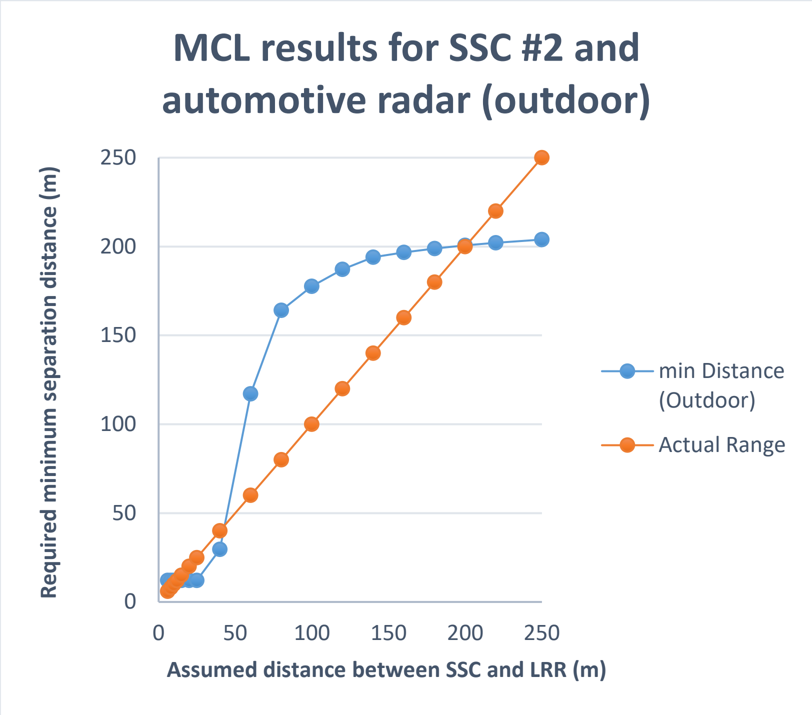

Figure 26: MCL results for SSc #2 and automotive radar (outdoor)

4.3.3 Conclusions for Automotive radar MCL studies

MCL studies have been performed with automotive radar for the two different types of SScs.

There is no risk of interference of SSc #1 and SSc #2 indoor. There appears risk of interference when SSc #2 (with higher output power) is operated outdoor.

In ECC Report 262 [8] infrastructure radars were considered, which work similar to SSc #2. In contrast to the MCL calculations used in this Report, ECC Report 262 shows a more comprehensive study using also the receive windows of automotive radars and the overlap of transmit signals in time, frequency and space.

This is not taken into account in this MCL study, but could offer possibility to automotive radars to operate in presence of SSc #2 outdoor.

4.4 SHARING WITH AMATEUR RADIO SERVICES

The amateur and amateur-satellite services have secondary and primary allocations within the range of study between 76 and 81 GHz. Whilst past use has been inhibited by equipment availability, ongoing experimentation, high performance frequency sources and innovative adaptation of commercial chipsets has led to growth in activity which can be currently categorised as:

- Weak-signal reception of Narrowband (e.g. CW-Morse or Voice) terrestrial operations in harmonised sub-bands (including over earth-moon-earth (EME) paths and through non-geostationary amateur-satellite transponders);
- Growing use of wider bandwidth modes, such as Digital Amateur TV (DATV) and data links;
- Usage of fixed beacon transmitting stations for propagation research and equipment alignment.

In general, most amateur stations are currently portable low-power highly directional systems. In order to maximise long-range communications, operation is often from elevated locations where they can achieve terrestrial line of sight contacts up to 50 km. Antennas operate at elevated angles for EME and satellite operations.

For terrestrial operations, amateur stations are usually tripod mounted around 2 m to 5 m above ground and are rotatable in azimuth. The operating sites are usually in non-built up locations on high ground with uncluttered visibility. For EME and amateur-satellite service activities the antennas will be capable of pointing skyward.

The same scenario as of SSc with PP-FS is considered with Amateur Services, namely the Amateur Service Antenna is to be considered at a certain distance and 15 m above the SSc (see Figure 27).

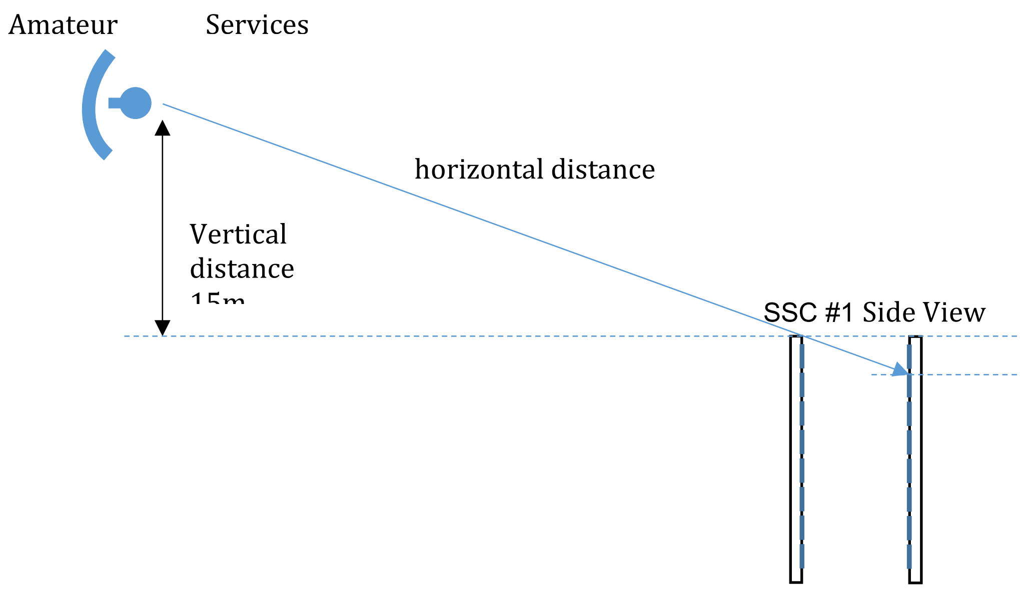

Figure 27: Amateur Services and SSc Scenario

Recommendation ITU-R M.1732-1 [9] provides generic characteristics of stations operating in the Amateur Service for use in sharing studies. However, they are not very specific for the 76-81 GHz frequency range. Therefore, the present Report considers the appropriate amateur and amateur-satellite service characteristics as used in ECC Report 315 [10] and summarised in Table 23.

Terrestrial stations in the Amateur Service and Amateur-Satellite Service have identical technical characteristics, except for the (variable) positive elevation angle of the receiver antenna.

Table 21: Examples of Amateur and Amateur Satellite Service characteristics in the band 76-81 GHz (parameters as in ECC Report 315)

Parameter	CW-Morse	SSB Voice	NBFM Voice	DATV
Receiver IF bandwidth (kHz)	0.5	2.7	15	4000
Typical Feeder Loss (dB)	1	1	1	1
Antenna gain (dBi)	36–42 (typically: 40)	36–42 (typically: 40)	36–42 (typically: 40)	36–42 (typically: 40)
Antenna polarisation	Horizontal, Vertical	Horizontal, Vertical	Horizontal, Vertical	Horizontal, Vertical
Receiver Noise Figure (dB)	3–7 (typically 4)	3–7 (typically 4)	3–7 (typically 4)	3–7 (typically 4)

The same antenna pattern as for PP-FS is considered.

The interference threshold is calculated by:

$$I_{HAM}[\mathrm{dBm}] = -113.83 + 10 \cdot \log_{10}(B_{IF}) + NF + FEED_{LOSS} + I/N \quad (19)$$

Where:

- NF is 4 dB, FEED_LOSS is 1dB;
- B_{IF} is considered according to Table 23;
- I/N is -6 dB.

The derived value of I_{HAM} is given in Table 24.

Table 22: Interference threshold for different Amateur Radio Services

#	Parameter	Unit	
I_{HAM_CW}	Interference threshold without antenna (0.5 kHz IF BW)	dBm	-147.8
I_{HAM_SSB}	Interference threshold without antenna (2.7 kHz IF BW)	dBm	-140.5
I_{HAM_NBFM}	Interference threshold without antenna (15 kHz IF BW)	dBm	-133.1
I_{HAM_DATV}	Interference threshold without antenna (4 MHz IF BW)	dBm	-108.8

The summary of the considered MCL parameters in addition to the antenna patterns and scenario in correspondence with the PP-FS scenario are shown in Table 25.

Table 23: Summary of Amateur services and SScs parameters used for MCL calculation

Parameter	Value
CW Receiver noise floor	-141.8 dBm
CW IF BW	0.5 kHz
Noise Figure	4 dB
I/N	-6 dB
Feed Loss	1 dB
SSc #1 e.i.r.p.	7 dBm
SSc #1 BW	10 GHz
SSc #1 BWCF	10log(0.5kHz/10GHz)=-73 dB
SSc #2 e.i.r.p.	19 dBm
SSc #2 BW	1.5 GHz
SSc #2 BWCF	10log(0.5kHz/1.5GHz)=-64.8 dB
SSc #2 POL	-3 dB

In Table 24, CW signals have the lowest IF bandwidth. These signals are considered in the MCL calculations whose results are shown in Figure 28 for the same building types as in the PP-FS calculations.

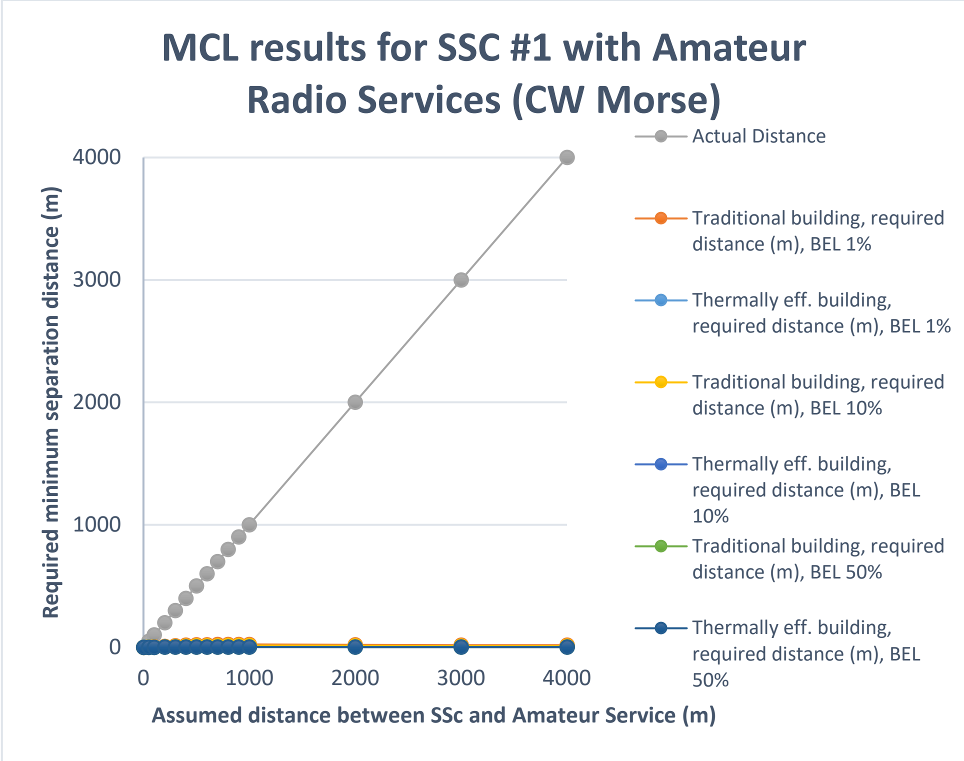

Figure 28: SSc #1 and Amateur Radio Services (CW)

A zoom into the separation distance (y-axis) is given in Figure 29.

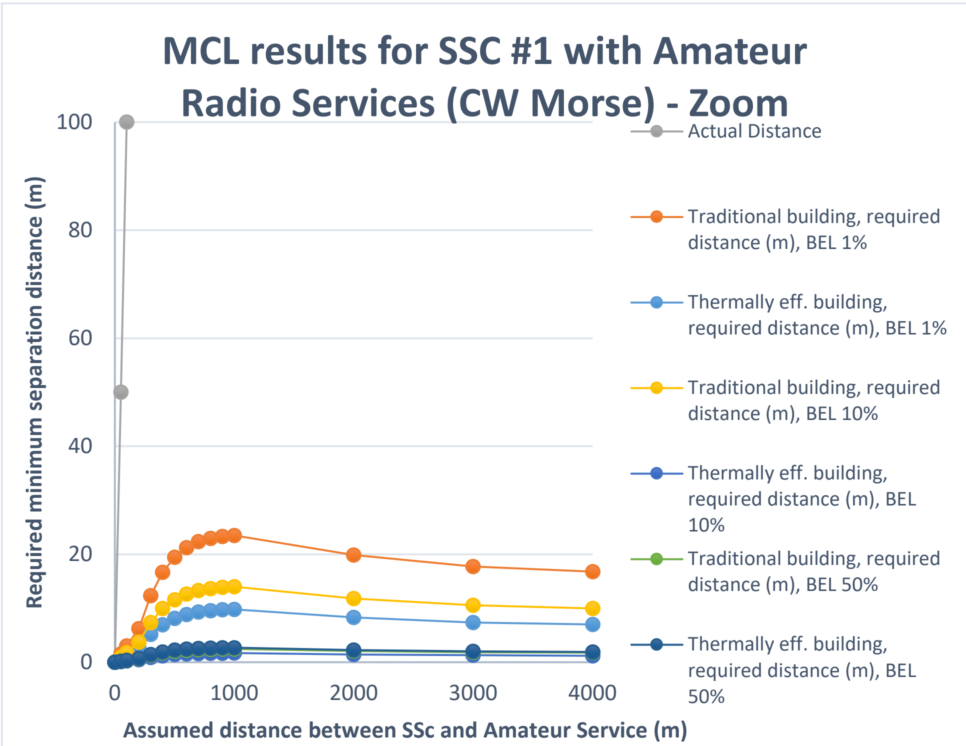

Figure 29: SSc #1 and Amateur Radio Services (CW) - zoom to 100 m separation distance

Table 27 shows the results from the MCL calculation in table format. The calculated required distance for a worst-case scenario with the lowest BEL of 1% (3.3 dB) is below each scenario distance.

Table 24: MCL results for SSc #1 and CW Amateur Radio Service considering a traditional building with 1% BEL

Scenario Distance (m)	e.i.r.p. (dBm)	MCL	Traditional building, required distance (m), BEL 1%
0	7	-41.53	0.04
50	7	-73.63	1.55
100	7	-79.42	3.02
200	7	-85.72	6.23
300	7	-91.63	12.31
400	7	-94.26	16.67
500	7	-95.59	19.41
600	7	-96.35	21.21
700	7	-96.80	22.34
800	7	-97.03	22.92
900	7	-97.18	23.32
1000	7	-97.24	23.48
2000	7	-95.77	19.84
3000	7	-94.78	17.69
4000	7	-94.31	16.76

The MCL calculation results for SSc #2 and Amateur Services according to the MCL parameters given in Table 25 are shown in Figure 30 and Figure 31 for indoor and outdoor scenarios.

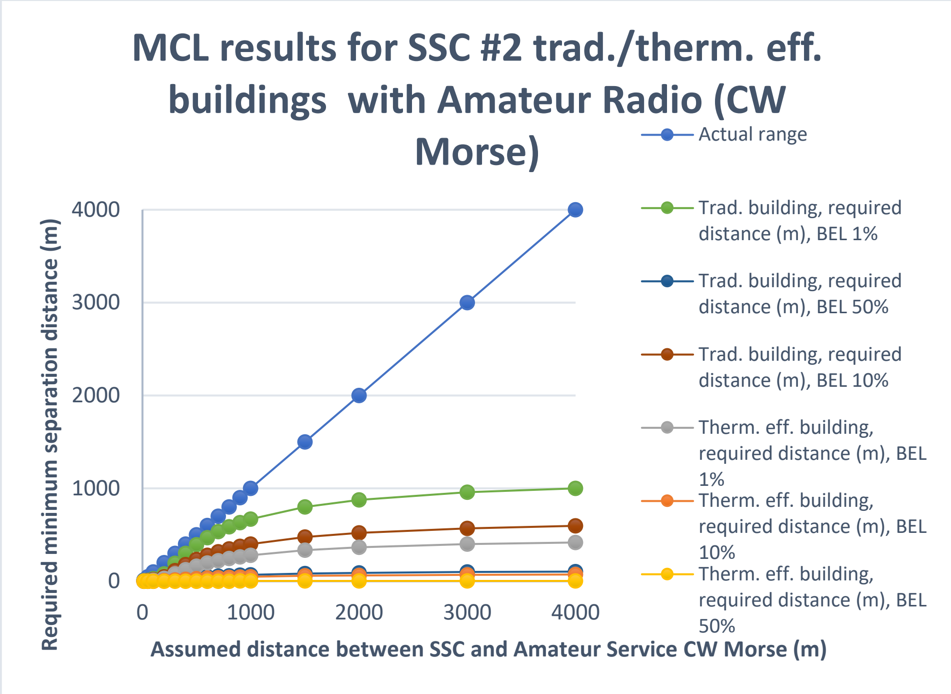

Figure 30: MCL results for indoor SSc #2 and CW Amateur Services (trad./therm. eff. Buildings)

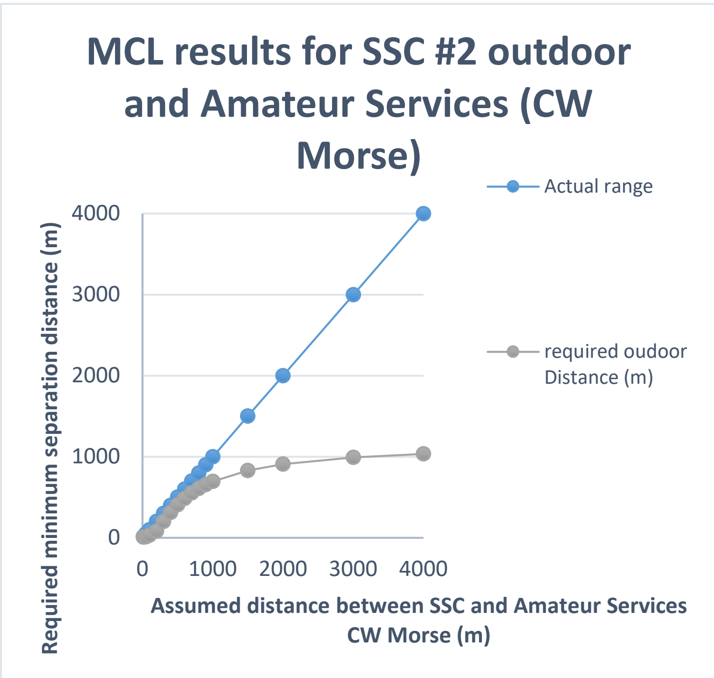

Figure 31: MCL results for indoor SSc #2 and outdoor CW Amateur Services

According to the worst-case consideration no impact of SSc on Amateur Services in the frequency range of 76-81 GHz is observed.

4.4.1 Conclusions for Amateur and Amateur-satellite Services MCL studies

MCL studies have been performed with amateur and amateur-satellite services for the two different types of SScs. There is no risk of interference according to the MCL calculations for both indoor and outdoor scenarios.

5 CONCLUSIONS

This Report contains sharing and compatibility studies between mmWave Security Scanners and existing services/systems operating in the 60-82 GHz band and in the adjacent bands. Installations of SScs in airports are considered in the studies as this is considered a valid use case scenario for thorough investigations.

This Report describes typical cases including worst-case scenarios with point-to-point Fixed Services, Automotive Radar Amateur Service and amateur-satellite services, in presence of Security Scanners that can operate indoors and outdoors. Two different types of Security Scanners were considered and different building types and entry losses.

This Report focusses only on minimum coupling loss studies.

The minimum coupling loss studies have been done for sharing frequencies with point-to-point Fixed Services, Automotive Radar and Amateur Services and two different types of Security Scanners.

For sharing with Fixed Service:

- The study with the Continuous Wave Scanner (SSc #1) Security Scanner shows no risk of interference for indoor operation towards the Fixed Service when operating in the 69.89-79.89 GHz frequency band with a peak e.i.r.p. of 7 dBm;
- The Burst of chirps Scanner (SSc #2) was studied in two candidate bands 71-76 GHz and 76.5-80.5 GHz with a peak e.i.r.p. emission of 19 dBm, with both indoor and outdoor operation. The study concluded that operation in the band 71-76 GHz causes harmful interference towards the Fixed Service for both indoor and outdoor operation. No harmful interference is caused towards the Fixed Service when operating in the band 76.5-80.5 GHz, for both indoor and outdoor operation assuming 23 dB out-of-band attenuation.

  Considering the outdoor scenarios (SSc #2 in co-channel), depending on the building type and attenuation, additional studies might be required including simulations to estimate the risk of interference more accurately.

  Instead of MCL studies and worst-case assumptions like these scenarios, a more complex calculation and simulation, e.g. using Monte Carlo simulation may be needed and additional studies may be necessary e.g. using clutter-loss and terrain models for different models of SScs operating in-band and in outdoor scenarios.

For sharing with Automotive Radar:

- The study shows no risk of interference of SSc #1 and SSc #2 when operated indoor. There is a potential risk of interference of SSc #2 (with higher output power) when operated outdoor, as shown by the MCL calculations. However, the timing of the transmit signal of SSc #2 and the consideration of the receive windows (see ECC Report 262 [8]) of Automotive Radars is not taken into account in this MCL study, but could help to reduce the possible interference when the SSc #2 is operated outdoor. Results of measurement in Figure 44show that the noise power is comparable when SSc#1 is switched on and that the SSc #1 has no influence.

For sharing with Amateur Services:

- There is no risk of interference according to the Minimum coupling loss calculations for both indoor and outdoor scenarios.

Table 25 summarises the outcome of this Report.

Table 25: Sharing and compatibility studies of Security Scanners operation in the band 60-82 GHz results

Type of SSc	Frequency	e.i.r.p	Security Scanner Scenario	Service	Risk of interference
SSc #1 (Note 2)	60-82 GHz	7 dBm	Indoor	Fixed Service Automotive Radar	**No**

Type of SSc	Frequency	e.i.r.p	Security Scanner Scenario	Service	Risk of interference
				Amateur Services	
SSc #2 (Note 3)	71-76 GHz	19 dBm	Indoor	Fixed Service	**Yes** (Note 4)
SSc #2 (Note 3)	71-76 GHz	19 dBm	Outdoor	Fixed Service	**Yes**
SSc #2 (Note 3)	71-76 GHz	19 dBm	Indoor Outdoor	Automotive Radar Amateur Services	**No**
SSc #2 (Note 3)	76.5-80.5	19 dBm	Indoor Outdoor	Fixed Service Amateur Services	**No** (Note 1)
SSc #2 (Note 3)	76.5-80.5	19 dBm	Outdoor	Automotive Radar	**Yes**
SSc #2 (Note 3)	76.5-80.5	19 dBm	Indoor	Automotive Radar	**No**

Note 1: assuming 23 dB out-of-band attenuation
Note 2 operating frequency bandwidth of 10 GHz
Note 3 operating frequency bandwidth of 1.5 GHz
Note 4 risk of interference for building types: thermally efficient with building entry loss (BEL) 1%, traditional building with BEL 10%, traditional building with BEL 1% (where the BEL values are taken into account as provided by Recommendation ITU-R, P.2109-01 at 70-71 GHz, table 5 [11])

ANNEX 1: EXEMPLARY MEASUREMENT OF COEXISTENCE BETWEEN SSC AND AUTOMOTIVE RADAR

A1.1 METHODOLOGY FOR MEASUREMENTS SSCS AND AUTOMOTIVE RADAR

Coexistence between SSc and Automotive Radars shall be investigated in the probability, that the SSc interferes automotive radar sensors when operating in a portion of the occupied band.

The worst case scenario would be the creation of artificial ghost targets (malfunction of the automotive sensor) or a blind sensor (due to increased noise floor).

A1.1.1 Ghost targets

A target, which is in reality not there (and which is not caused by signal processing), but caused by interference, will be detected and it is called a ghost target. This may be caused by a copy of the transmitted signal, which falls into the receiver bandwidth of the automotive radar sensor. For this scenario to happen, the timing, signal and the frequency have to match perfectly, and the echo power has to exceed a certain limit. During the transmission of the radar signal, a time delayed and/or Doppler shifted copy of this signal has to appear at the receiver with a certain echo power, that reaches the detection threshold. The interferer signal therefore has to be alike the original radar signal and show enough signal power.

A1.1.2 Increased noise floor

High power broadband CW signals, also broadband CW noise like signals with certain power that fall into the receiver bandwidth, may increase the noise floor of the radar and reduce the amount of Signal-to-Noise ratio of a target. This may cause targets with small Radar Cross Section (RCS) to disappear as the Signal-to-Noise ratio of the echoes is reduced. For this scenario to happen, a continuous broadband noise like signal or signal which spreads over all frequencies after an FFT with the bandwidth of the radar receiver and high signal power has to be transmitted.

For verification of the theoretical and simulated considerations, we used a configurable state of the art radar sensor, which operates in the 77 GHz band. The radar under test has two transmit antennas and eight receive antennas. The transmitted signal (bandwidth and chirp duration) is configurable.

A1.2 INTRODUCTION

Let be assumed an SSc model SSc #1 and a radar sensor with linear frequency modulated signals operating from 76-77 GHz with 1 GHz bandwidth from which a worst case of twelve frequency steps according to the datasheet fall into the same bandwidth.

The total transmission duration of the twelve consecutive frequency steps is calculated as follows:

The total transmission of each frequency through all antennas: 240.64 µs + 5.12 µs (switching time between two adjacent frequencies). Hence, the duration of transmission of these twelve CW frequency steps, which may interfere an automotive radar signal corresponds to:

245.76 µs * 12 = 2.95 ms

from which the system actively transmits: 240.64 µs * 12 = 2.882 ms

The signal that may appear at the RF will look qualitatively as depicted in Figure 32. An upchirp from an automotive radar covers a frequency band from 76 to 77 GHz within 20 ms. The SSc #1 will keep a certain frequency for 240.64 µs and then change to its next step. There is the possibility for several steps to fall into the bandwidth of the radar sensor, depending on the similarity of chirp rates and timing.

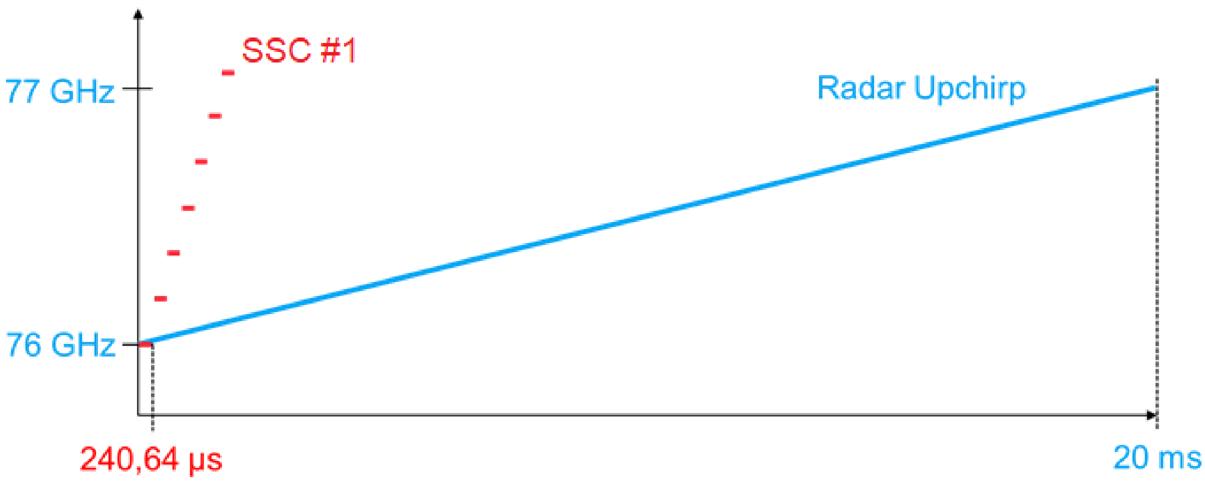

Figure 32: SSc #1 Signal and FMCW Radar Signal

The following worst-case conditions is to be assumed:

- the timing between the radar transmitter and interferer signal match (such that the disturbing signal falls into the bandwidth of the radar receiver);
- the radar samples and digitizes the very short disturbing signal;
- the disturbing power is sufficient;

Under these conditions, one example would be;

- The SSc #1 transmits at a frequency of 76.0279273914290 GHz while the radar is sweeping from 76 to 76.5 GHz and is actually at a frequency of 76.015895391429 GHz for example. The automotive radar then down-converts the disturbing signal with its instantaneous sweep frequency. The resulting beat frequency would be varying from several Hz offset to several MHz in the duration of 240.64 µs. This is because, the SSc #1 does not change frequency but the automotive radar does;
- Figure 33 shows the result, seen by an automotive radar when there is a SSc #1 signal and a real echo signal present. The entire duration of the downconversion is 20 ms;
- A real radar echo signal delayed by a certain duration (usually in the domain up to 2 µs => 300 m (see range equation $R = \frac{c}{2}\tau$)) and shifted by a certain Doppler shift (a 76.5 GHz automotive radar measures a target with a radial velocity of 100 m/s at a Doppler frequency shift of 51 kHz (see Doppler Equation: $\frac{f_D}{f} = \frac{2v_r}{c}$));
- Both contribute to a certain beat frequency shift in the several kHz domain. In the picture, the "real echo" is drawn with a delay of approximately 240 µs. In reality, this is much less (< 2 µs), but this value cannot be drawn on the selected scale. However, a big difference between the downconverted " SSc #1 signal" and a "real radar echo" signal can be seen;
- Considering this, the SSc #1 signal, which is depicted with 12.032 MHz bandwidth in Figure 33 would contribute even less to the Fourier Spectrum, as the sampling frequency of the automotive radar is much lower than 12.032 MHz.

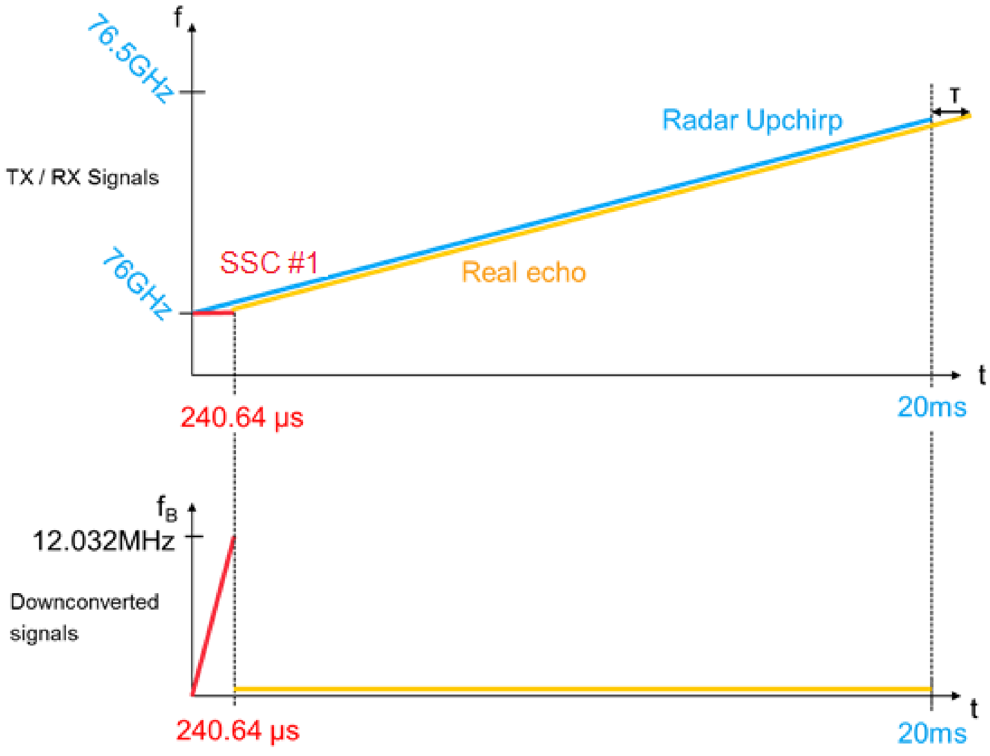

Figure 33: Received and downconverted signals

- A Fast Fourier Transformation over the downconverted signals will show the frequency spectrum. Local maxima are detected as targets.
- As shown in the example above:
  - In case the entire SSc #1 signal would fall into the receiver bandwidth of the radar, it would still contribute little over the entire spectrum, because real radar echo targets have a constant beat frequency which is in addition much less than the SSc #1 signal and therefore falls only partially (if so) into the bandwidth of the radar receiver.
  - In addition, the signal power of the SSc is extremely low (see numbers above) compared to a radar echo signal from a car or pedestrian.
- The same theoretical considerations hold for Chirp Sequence (CS) signals. These signals are much shorter than 20 ms (approx. 10 µs - 100 µs) and the receiver bandwidth needs therefore to be wider, because the beat frequency is mainly dominated by the signal propagation time. Using a Chirp Sequence waveform a SSc #1 signal would contribute more to the entire spectrum. But compared to FMCW, CS signal processing does an integration of hundreds of consecutive chirps. Therefore, if a single chirp sequence signal were affected by the SSc, the final spectrum for radar echo detection would not recognize this due to the high integration gain of the consecutive chirps.

A1.3 RADAR RECEIVER BANDWIDTH

It can be seen from Figure 33, that a signal of 240.64 µs duration with a bandwidth of 12.032 MHz could fall into the radar bandwidth.

But the bandwidth of the radar sensor is typically much smaller, because it is just necessary to measure the maximum beat frequencies for which the radar is designed for. Typically, an automotive radar can measure an unambiguous range of up to 250 m and has an unambiguous radial velocity interval of +-100 m/s.

In case of a radar with the following parameters, a target in the worst-case range / radial velocity would cause beat frequencies which are much lower than MHz.

Table 26: 77 GHz Radar with FMCW signal

Radar Signal	Target	Beat frequencies
f_0: 77 GHz	Range: 250 m	upchirp: 134.7599 kHz
f_sweep: 1 GHz	rad. vel: 100 m/s	downchirp: -32.0222 kHz
T_chirp: 20 ms		

These calculations show that the occurring beat frequencies are in in the domain of hundred kHz. Hence a receiver bandwidth of just 140 kHz would be sufficient for this radar.

In this case even much less (just 1/85 portion of the signal) than 240.64 µs would fall into the radar receiver. In case of a chirp sequence, with much higher chirp rate, the occurring beat frequencies are much higher.

Table 27: 77 GHz Radar with CS signal and high bandwidth

Radar Signal	Target	Beat frequencies
f_0: 77 GHz	Range: 40 m	upchirp: 10.7254 MHz
f_sweep: 1 GHz	rad. vel: 100 m/s	downchirp: -10.7254 MHz
T_chirp: 0.025 ms		

A signal with a chirp rate of 25 µs and the bandwidth of up to 1 GHz is usually used for short range operation. The sensor has therefore several modes e.g. long range / short range implemented.

In the long-range mode, automotive radar sensors make use of less signal bandwidth. A typical bandwidth of 100 MHz as used in long range mode results and a target at 250 m range results in approximately 6.7 MHz beat frequency.

Table 28: 77 GHz Radar with CS signal and low bandwidth

Radar Signal	Target	Beat frequencies
f_0: 77 GHz	Range: 250 m	upchirp: 6.7227 MHz
f_sweep: 0.1 GHz	rad. vel: 100 m/s	downchirp: -6.6199 MHz
T_chirp: 0.025 ms		

This subchapter has shown what receiver bandwidth may occur in an automotive radar sensor. The maximum bandwidth of 12.032 MHz of the SSc #1, which may fall into the radar receiver does often not entirely fall into the radar. However, it strongly depends on the radar sensor, radar signal, sampling rate, receiver bandwidth.

In typical state of the art radars, the receiver bandwidth is in the domain of several MHz only, as the calculations have shown.

A1.4 SIMULATION RESULTS

An automotive radar signal processing was implemented and a target with known range, radial velocity, and typical SNR of 25 dB as they occur usually has been placed in 50 m range with 10 m/s.

The simulation uses the following radar signal:

- FMCW;
- 20 ms duration;
- bandwidth of 1 GHz.

To show the theoretically explained influence of a disturbing signal on the radar echo signal and the entire spectrum, several different simulations were performed:

1 Pure noise was added to the radar echo signal. The simulation was run 1000 times with the spectrum integrated. No interferer was present. The result is shown below. The target is clearly visible.

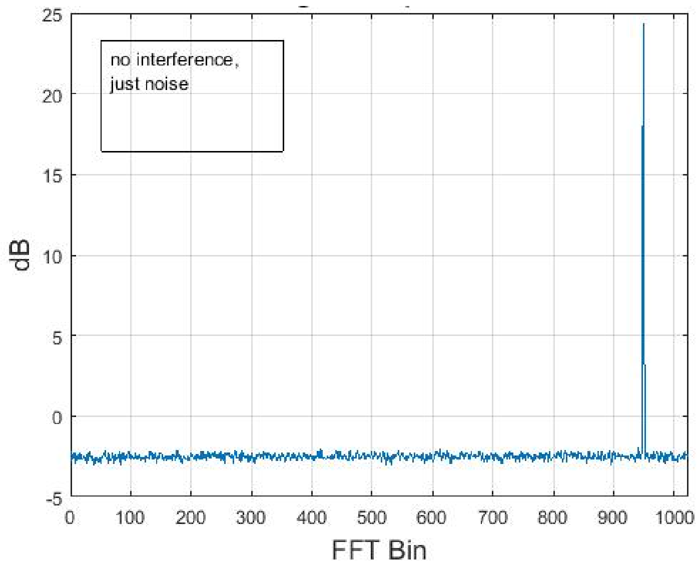

Figure 34: No interferer present

2 In addition, a perfectly matching CW signal with the duration of 20 ms (the entire radar chirp is also 20 ms) and a very high power of 0 dBm was simulated. It can be seen that the SNR of the echo is reduced by several dB and the CW signal spreads over the entire spectrum. This was explained in the theoretical part of this Report.

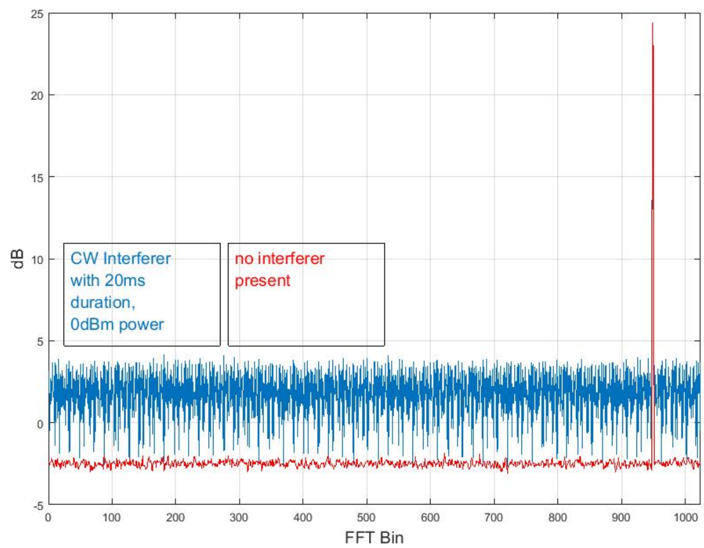

Figure 35: Interferer with the same duration as the radar signal and high power present

3 Instead of the very strong interferer, an interferer with the low power (SSc #1) was simulated. The duration is still kept to 20 ms (in reality this is 240.64 µs maximum). It can be seen that there is no influence anymore on the spectrum, nor on the SNR of the target.

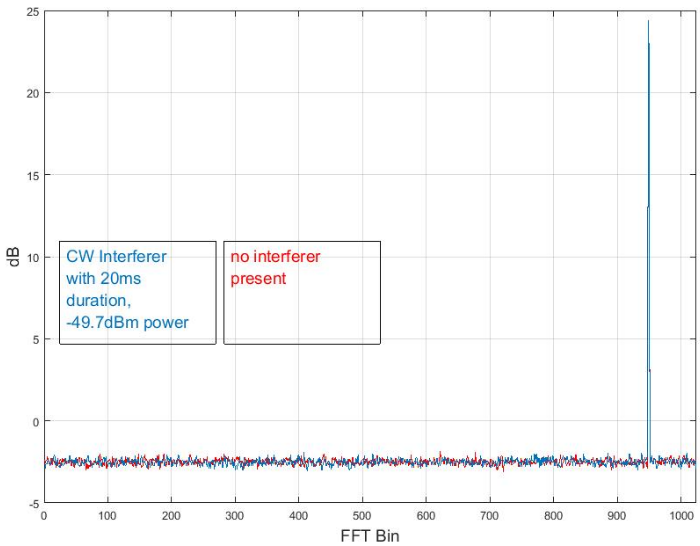

Figure 36: Interferer with the same duration as the radar signal, but less power present

4 The CW signals with low power and short duration are present. Again, there is no influence on the target or spectrum.

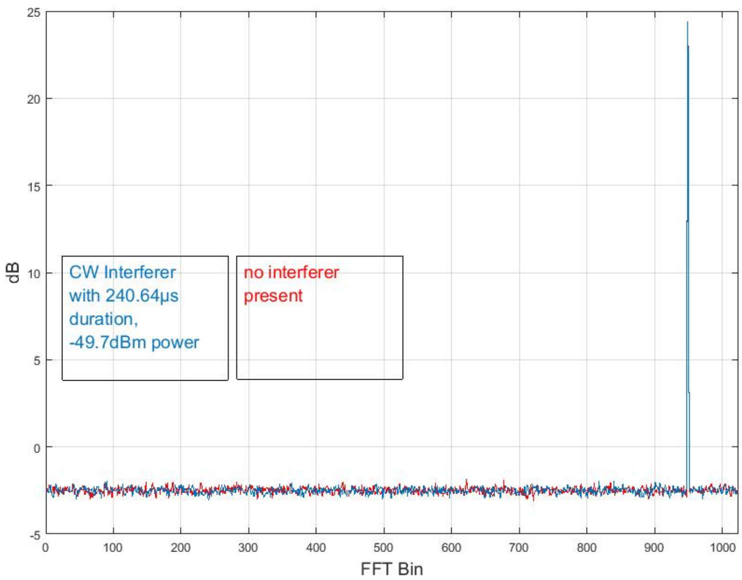

Figure 37: Interferer with low level and duration of the SSc #1 signal present

The simulation results show that in case an CW signal is disturbing an FMCW radar signal:

- SNR of the target is reduced when a high power CW signal with matching duration is present (the CW signal spreads over the entire FFT spectrum);
- no influence is available, in case of a low CW power even with matched signal duration;
- no influence is available, in case of low CW power and short CW signal duration.

The same simulations have been performed for a target with 90 dB SNR. The same results can be seen compared to the target with 25 dB SNR. Within the spectrum, there is no additional noise and no reduction of the target SNR when a very short disturbing signal is present.

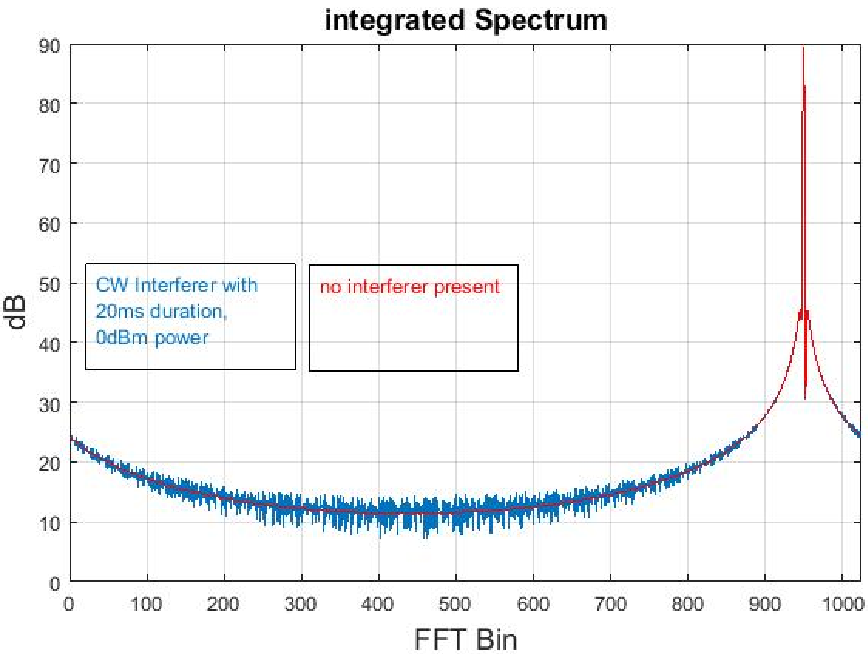

Figure 38: Interferer with high level and duration of the radar signal present

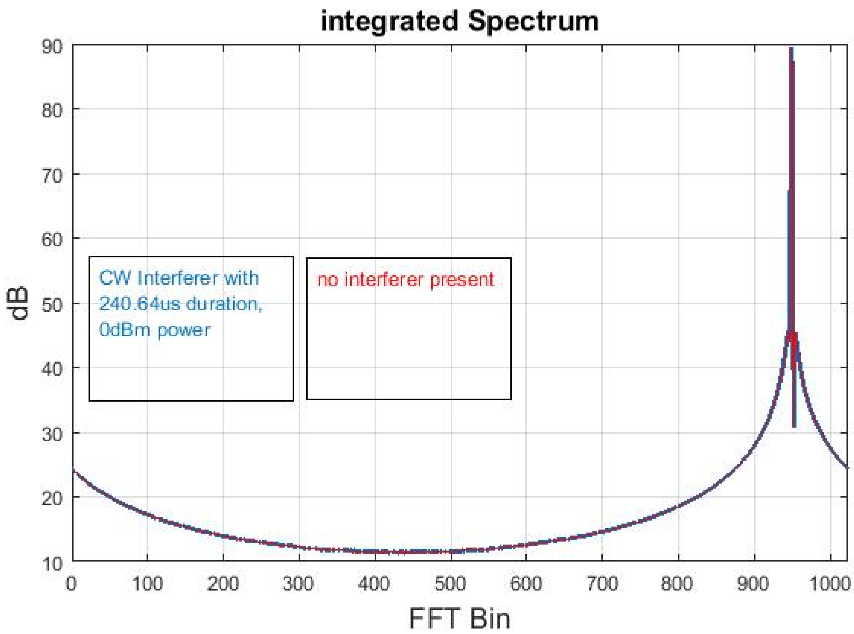

Figure 39: Interferer with high level and duration of the SSc #1 signal present

The simulations considered a worst-case scenario where a short range continuous wave SSc #1 transmitted towards an automotive radar. Although this scenario is unlikely by nature, as there are no automotive radars in use within airports, it needs to be still considered from an interference point of view.

The simulation results show that there is no impact even when signals overlap in time and frequency. In addition, due to the low power of the devices and low air utilisation rate, there is no interference to be expected.

A1.5 MEASUREMENT RESULTS

For verification of the theoretical and simulated considerations, a configurable state of the art radar sensor, which operates in the 77 GHz band is used. The radar under test has two transmit antennas and eight receive antennas. The transmitted signal (bandwidth and chirp duration) is configurable. The FFT spectrum can be retrieved and saved for evaluation.

Figure 40: Radar Under Test

The radar under test was placed in front of the SSc #1 which was switched on and off respectively to see the effect of the SSc #1.

In measurement #1 the SSc #1 was switched off and the radar just measures the distance to the SSc #1. Several radar FFT spectrums are collected.

In measurement #2, the SSc #1 was switched on. In the normal mode a SSc #1 measurement would be finished within 32 ms, so the SSc #1 was reconfigured to continuously measure and hence continuously transmit. Again, several radar FFT spectrums are collected.

The mean FFT spectra were compared to visualize the effect of the SSc #1 when switched on.

Considering the theoretical considerations from the above sections, one would expect the same FFT spectrum with SSc #1 switched on and SSc #1 switched off, as there is no noticeable contribution to the spectrum due to signal mismatch and low power.

In case the SSc #1 would disturb the radar, one should see an increasing noise floor or ghost targets.

Under these conditions, two measurement runs were recorded, with each different radar signals, which are considered as worst-case scenarios.

Figure 41 shows the SSc #1 and the radar under test in the test environment.

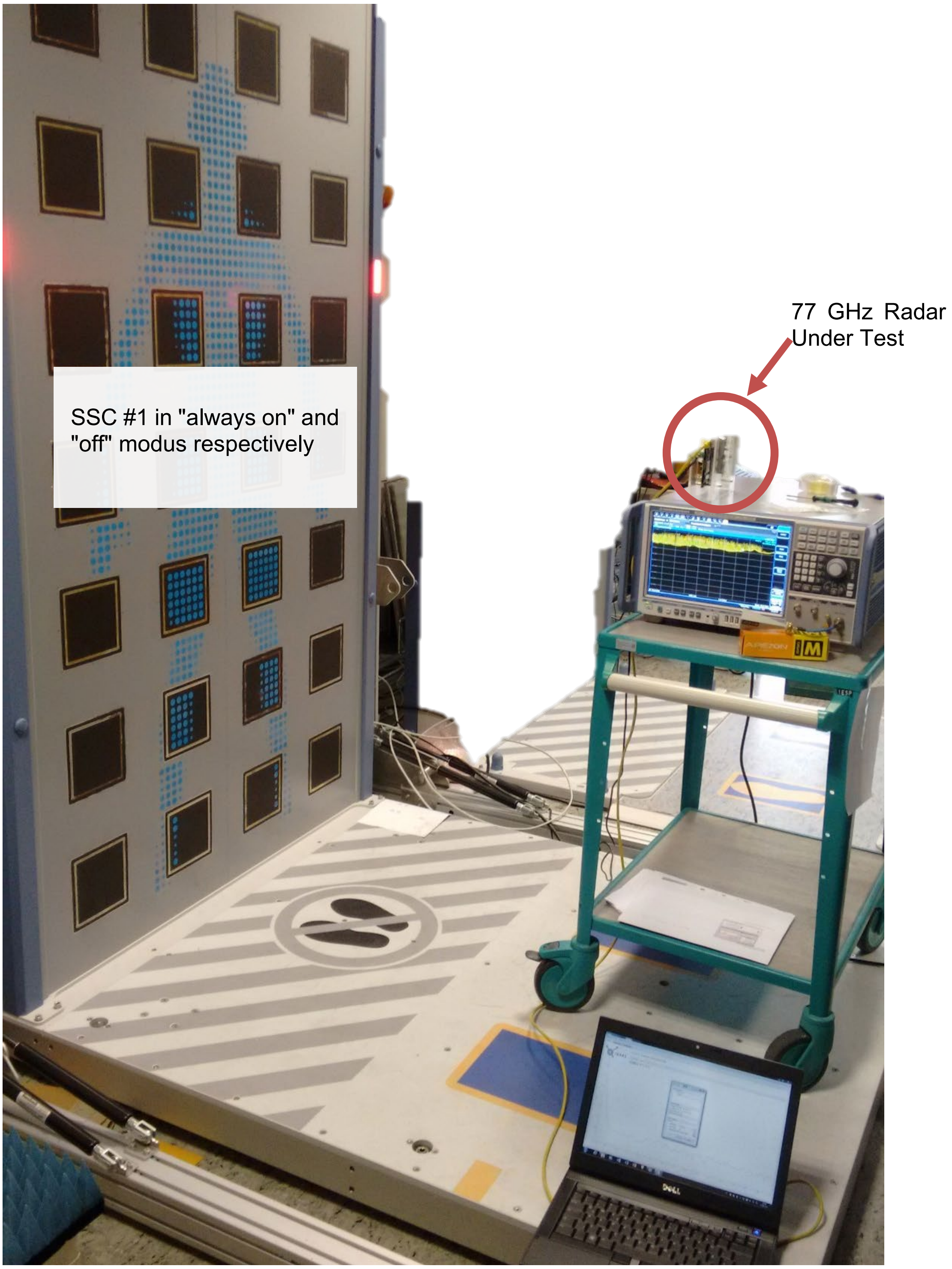

Figure 41: Measurement Setup - SSc #1 and 77 GHz Automotive Radar

A1.5.1 Security Scanner and 77 GHz radar measurement #1

The radar under test was configured to transmit chirp signals with a duration of 240 µs duration and a bandwidth of 500 MHz.

The duration of the chirps match the duration of the SSc #1 signal. This is considered as a worst-case scenario. Hence, the disturbing signal would be as long as the radar echo signal and completely downconverted. A tiny portion (depending on the radar sampling rate) will fall into the receiver and contribute to the spectrum. The transmission power of the SSc #1 is 7 dBm e.i.r.p. As it is extremely low compared to radar echo signals, one will expect no contribution to the spectrum. In addition, it is down-converted partially only and is not a constant beat frequency.

Figure 42 shows a spectrum of the radar sensor over amplitude and range. Several measurements of this spectrum were recorded and the mean power for each range bin was calculated. Then the measurements with SSc #1 on and off respectively were compared in Figure 43.

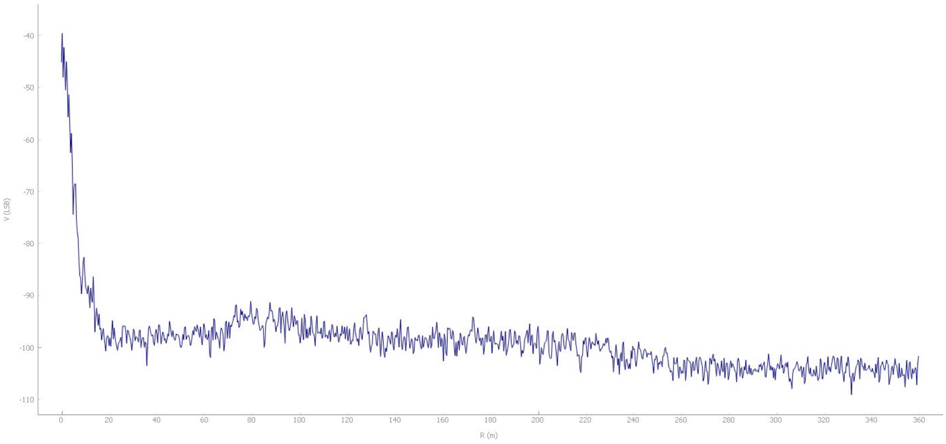

Figure 42: Spectrum, 240 µs chirp with 500 MHz Bandwidth

They show the measurement results. The spectra of the radar sensor look very alike and are not affected by the SSc #1. There is no further contribution of noise and no ghost targets.

A zoom into the first range bins is shown in Figure 44, from which no significant difference can be seen.

A zoom into the medium range bin is shown in Figure 45. It should be mentioned that the radar does not measure any target in that range, because it is located indoors. However, it measures noise in the domain of -95 to -100 dBm. The comparison of our measurements shows that the FFT signals differ, but this is just due to thermal noise and noise of the radar and not due to any disturbance.

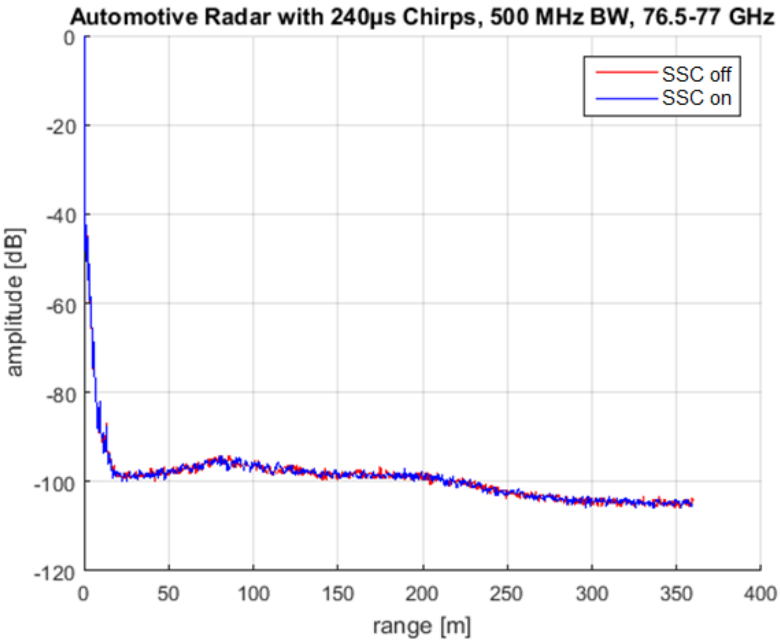

Figure 43: Amplitude over Range when SSc #1 on and off

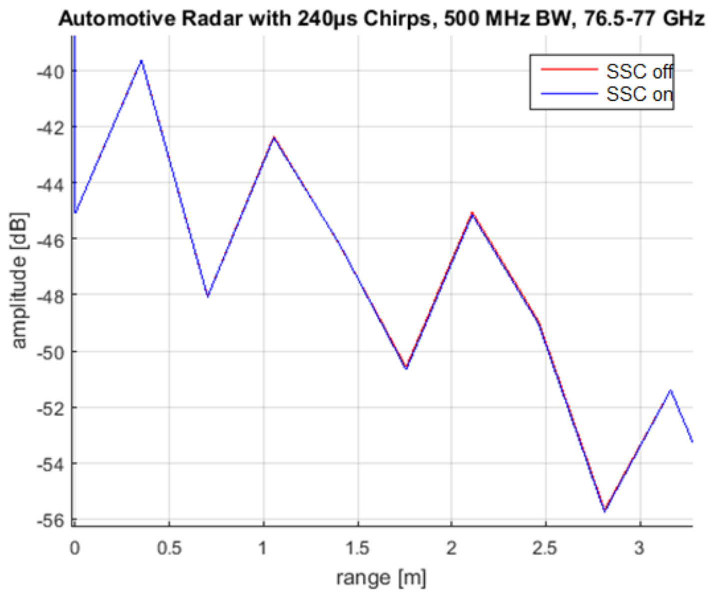

Figure 44: Amplitude over Range (zoomed to the first bins) when SSc #1 on and off

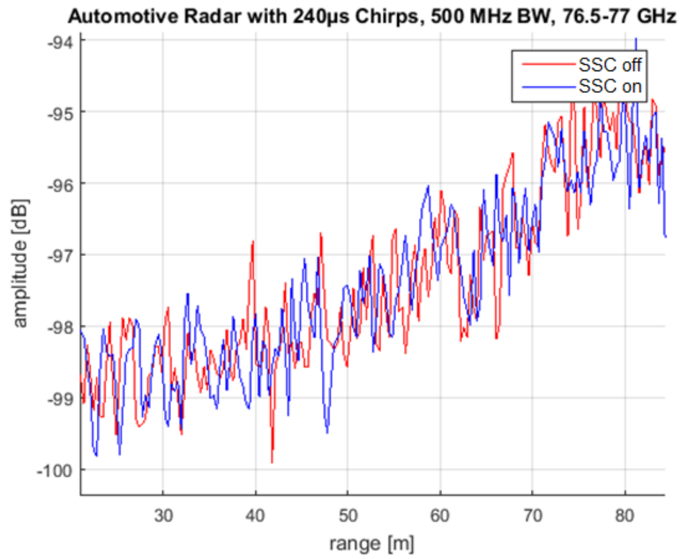

Figure 45: Amplitude over Range (zoomed medium range) when SSc #1 on and off

The noise power was averaged between range bin 1 and range bin 300 and compared for the SSc #1 switched on and off. It can be seen from the result that the noise power is comparable and that the SSc #1 has no influence when switched on.

Noise from Rangebin 1 to 300:

- Average noise level at radar Rx (SSc #1 off): -93.4 dB;
- Average noise level at radar Rx (SSc #1 on): -93.5 dB.

A1.5.2 Security Scanner and 77 GHz radar measurement #2

In a second measurement the radar sensor was configured in such a way that the chirp rate of the waveform matches the chirp rate of the SSc #1. The chirp duration was set to 1600 µs with a bandwidth of 500 MHz. This is considered as the second worst-case scenario, because all consecutive steps of the SSc #1 signal would fall into the radar receiver.

Due to the different signal, maximum range changes and the close range cannot be detected anymore. However, the spectrum can still be measured and used to verify if there is an effect due to interference.

The results are shown below. All figures verify that there is no contribution to the radar spectrum and no visible influence of the SSc #1 on automotive radar. Due to the low signal power of the SSc #1 and the signal processing of the radar, there is no contribution or disturbance effect on the radar.

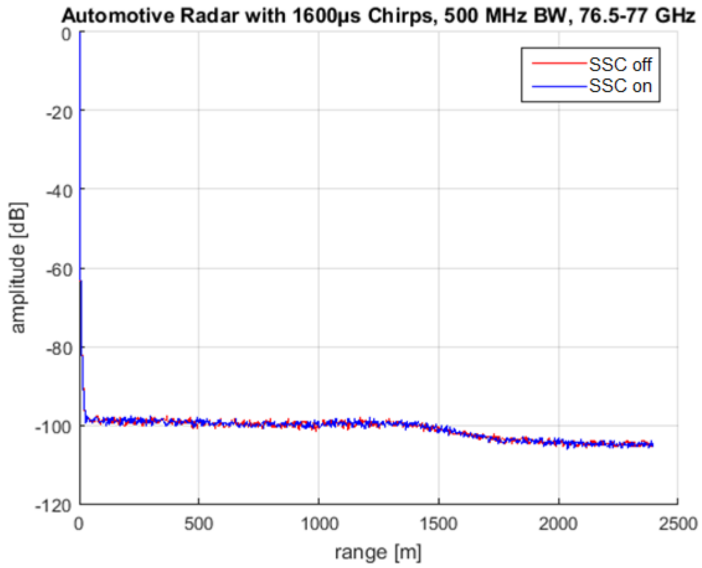

Figure 46: Amplitude over range when SSc #1 on and off

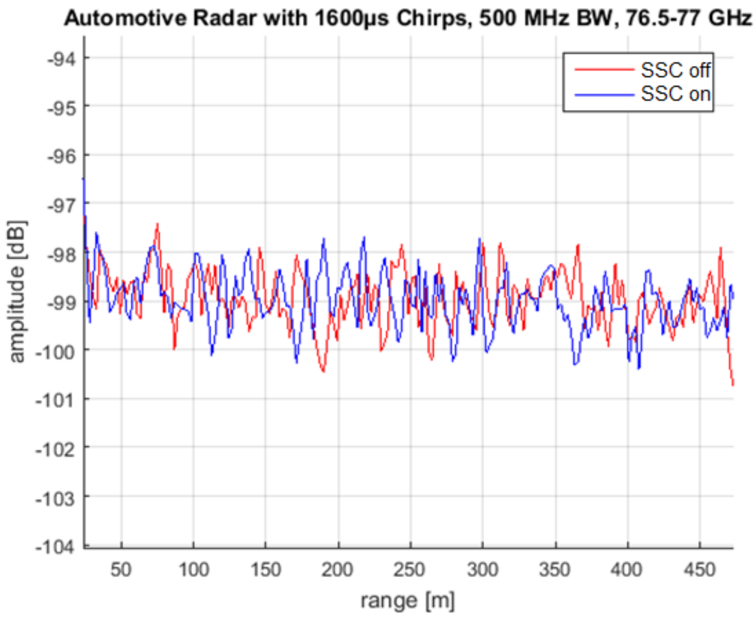

Figure 47: Amplitude over range (zoomed medium range) when SSc #1 on and off

The noise power was averaged between range bin 1 and range bin 1000 and compared for the SSc #1 switched on and off. It can be seen from the result that the noise power is comparable for each measurement and that the SSc #1 has no influence when switched on.

Noise from Rangebin 1 to 1000:

- Average noise level at radar Rx (SSc #1 off): -100.56 dB;
- Average noise level at radar Rx (SSc #1 on): -100.55 dB.

ANNEX 2: MEASURED SSC #1 ANTENNA PATTERN

Measured or simulated antenna pattern for the MCL study were available. An exemplificative measured antenna pattern was provided by a manufacturer for a SSc #1 type. A difference of -2 dB of the measured antenna pattern was found at an angle of 33° compared to the simulated antenna pattern according to ITU-R F.699 [10] with values taken from ETSI TR 103 664 [9].

For reference, Figure 48 shows the measured antenna pattern of SSc #1.

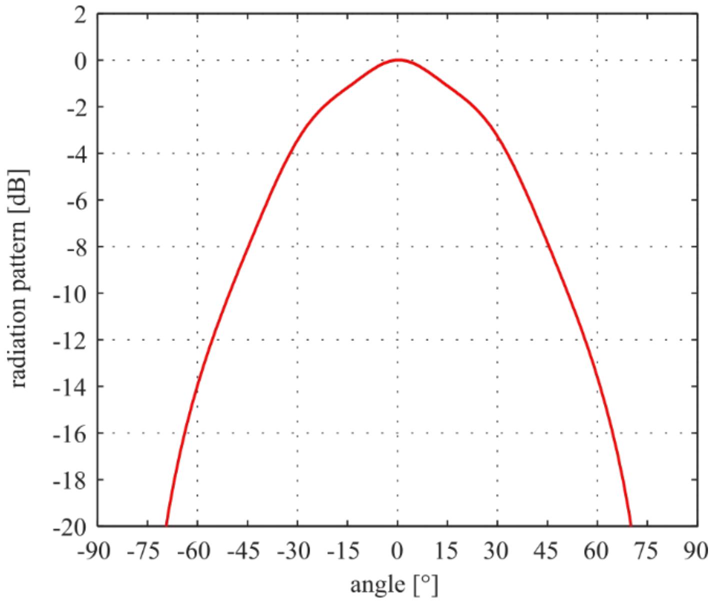

Figure 48: Measured antenna of SSc #1

ANNEX 3: LIST OF REFERENCES

[1] ERC Report 25: “The European table of frequency allocations and applications in the frequency range 8.3 kHz to 3000 GHz (ECA Table)", approved October 2018

[2] “Record number of air passengers carried at more than 1 billion in 2017” (here)

[3] ECC Report 315: "Feasibility of spectrum sharing between High-Definition Ground Based Synthetic Aperture Radar (HD-GBSAR) application using 1 GHz bandwidth within 74-81 GHz and existing services and applications", approved May 2020

[4] Recommendation ITU-R F.758-7: "System parameters and considerations in the development of criteria for sharing or compatibility between digital fixed wireless systems in the Fixed Service and systems in other services and other sources of interference " (11/2019)

[5] ITU-R P.2108-0: “Prediction of clutter loss” (here) (06/2017)

[6] ERC Recommendation 70-03: “Relating to use of Short Range Devices (SRD), Appendix 5: Duty cycle considerations”, approved February2021

[7] ITU Recommendation M.1732: "Characteristics of systems operating in the amateur and amateur-satellite services for use in sharing studies", (01/2017) here (02/2022)

[8] ECC Report 262 “Studies related to surveillance radar equipment operating in the 76 to 77 GHz range for fixed transport infrastructure”

[9] ETSI TR 103 664 “System Reference document (SRdoc); “Security Scanners (SSc) within the frequency range from 60 GHz to 90 GHz”

[10] Recommendation ITU-R F.699, Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to 86 GHz

[11] Recommendation ITU-R P.2109-01: “Prediction of building entry loss”