ECC REPORT 128

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within the European Conference of Postal and Telecommunications Administrations (CEPT)

COMPATIBILITY STUDIES BETWEEN PSEUDOLITES AND SERVICES IN THE FREQUENCY BANDS 1164–1215, 1215–1300 AND 1559–1610 MHz

Dublin, January, 2009

0 EXECUTIVE SUMMARY

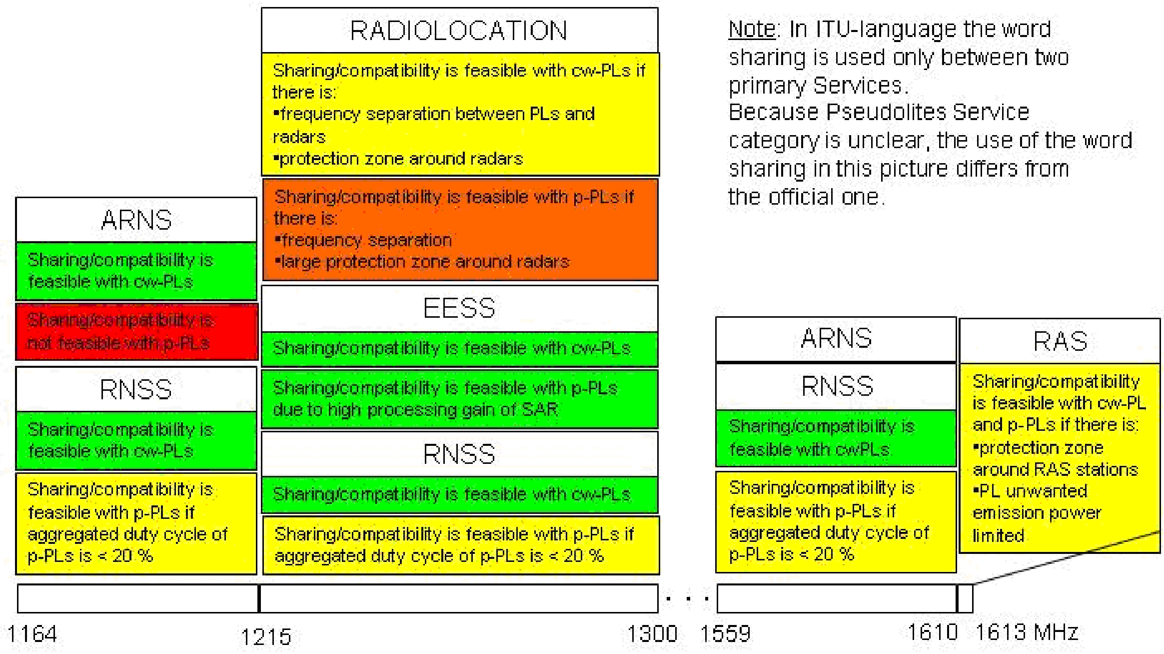
Pseudolites (Pseudo satellites, PLs) are ground based radio transmitters that transmit a RNSS-like navigation signal. They are intended to be complementary to RNSS systems and transmit on the same frequency bands 1164-1215, 1215-1300 and 1559-1610 MHz as RNSS systems.

There are several other Radio Services and Radio Navigation Service itself that could be affected because of uncontrolled use of Pseudolites therefore it was decided to conduct sharing/compatibility studies between Pseudolites and Services on the frequency bands 1164-1215, 1215-1300 and 1559-1610 MHz.

The purpose of this report is the study of the above mentioned co-existence. In sections 1 and 2 an overview and characteristics of Pseudolites are presented. Sections 3 overviews the RNSS spectrum and section 4 explains characteristics of the victim Systems on these bands. In section 5 the necessary compatibility studies are summarised and at last in section 6 conclusions are drawn. More detailed information of the studies can be seen in relevant annexes of this report.

For information, the Excel workbook of the MCL calculations and the SEAMCAT files used for the calculations for the study are available in a zip-file at the www.ero.dk (ERO Documentation Area) next to this Report.

The main conclusions are presented also below:



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LIST OF ABBREVIATIONS

A/D	Analog-to-Digital
AGC	Automatic Gain Control
ARNS	Aeronautical Radio Navigation Service
C/A	Coarse Acquisition
CW	Continuous Wave (radar)
EESS	Earth Exploration Satellite Service
DME	Distance Measuring Equipment
EIRP	Effective Isotropic Radiated Power
GILT	Galileo Initiative for Local Technologies
GJU	Galileo Joint Undertaking
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
LAAS	Local Area Augmentation System
LOS	Line of Sight
MCL	Minimum Coupling Loss
mEXPRESS	mobile in-EXhibition PRovision of Electronic Support Services
NLOS	Non Line of Sight
PFD	Power Flux Density
PL	Pseudolite (coined from "Pseudo (RNSS) Satellite)
PRN	Pseudo-Random Noise
RDS	Radio Determination Service
RLS	Radio Location System
RNSS	Radio Navigation Satellite Service (ITU)
SAR	Synthetic Aperture Radar
S/I	Signal to Interference Ratio
SIS	Signal in Space, i.e. transmissions from RNSS satellites
SNIR	Signal to Noise Plus Interference Ratio
VOR	VHF Omni-directional Range

1 INTRODUCTION

Pseudolites (Pseudo satellites, PLs) are ground based radio transmitters that transmit a RNSS-like navigation signal. It requires users to have modified RNSS-receivers to receive these signals. It is expected that these RNSS receivers have minor changes compared to today's RNSS receivers and it is therefore possible to extend the satellite navigation technology to difficult environments like indoors with high accuracy and cost effectively.

Pseudolites are intended to be complementary to RNSS systems. To assure the best interoperability and compatibility with RNSS systems and to allow the technology to be used to its full potential, the frequency and regulatory issues need to be clarified.

The European Commission Committee 98/34 18th January 2007 Mandate addressed to CEN, CENELEC and ETSI is to Establish Space Industry Standards, which includes pseudolites.

2 OVERVIEW AND CHARACTERISTICS OF PSEUDOLITES

2.1 Introduction

Global Positioning System (GPS) [1] providing Radionavigation Satellite Service has become commonplace among consumers and industrial users. The increasing importance of global positioning is highlighted by the decisions by the European Space Agency and the European Union to develop the Galileo and EGNOS systems. However, there are many difficult environments where positioning is needed, but where the current or planned global systems cannot provide the necessary accuracy or reliability due to degradation of visibility to the satellites. These environments include difficult geographic areas, urban canyons, large industrial facilities and indoor areas where consumers spend 95% of their time. Usable RNSS coverage is typically less than ~55% in urban areas and close to 0% indoors.

The lack of an accurate and reliable GPS signal in these environments makes it difficult to capture the most attractive benefits and business potential of positioning. Many new services would be made possible by extending the accuracy and coverage of global positioning to these difficult environments. Pseudolite technology is one possibility that can address these shortcomings by providing additional ranging signals and by improving geometry. To enable simultaneous reception of both satellite and pseudolite signals, interference issues must be carefully addressed.

Other methods of providing indoor location based positioning have been developed by the 3GPP community, whereby RNSS signals and supporting information to assist calculation of position are transmitted by the 3GPP networks - termed A-RNSS (Assisted-RNSS). These technologies are in the process of being rolled out.

Assisted RNSS technology uses the existing RNSS signals, without the need to provide additional terrestrial based RNSS like signals to aid positioning, and are targeted mainly for urban and (light) indoor situations, where coverage from the RNSS satellites is poor. A-RNSS receiver requires aiding information, which is provided through the 3GPP network transmissions, without this data they will not work well in environments where the satellites are significantly obscured. There are no additional RF transmissions from A-RNSS technology and therefore no compatibility issues to address. Pseudolites usage within the same indoor geographic areas as A-RNSS might, also require special consideration since A-RNSS might be a victim from the impact of pseudolites. These possible impacts are considered within this report.

It is assumed in this report that A-RNSS will be used extensively by the mobile community for mass market access for location based services. Pseudolites, on the other hand, are mainly targeted for non-mass market but more professional markets where improved accuracy is required to enhance safety etc. Pseudolites do provide a much improved general accuracy. The increased accuracy is necessary in some specific environments, such as docking a ship, or the remote control of vehicles in challenging environments.

2.2 Application overview of pseudolite scenarios

A wide variety of applications where pseudolite transmitters have been used in augmenting the GPS constellation have been exploited. Such applications can be:

- Machine control at mining sites
- Terrestrial deformation monitoring applications
- Positioning of goods and vehicles (also indoors)
- Improving signal coverage in cities with tall buildings
- Maritime applications e.g. harbours.

In principle, pseudolites can replace the satellite constellation wherever the satellite signals are completely unavailable or have reduced visibility, such as indoors, in road tunnels, etc. A-RNSS, on the other hand, can be used in areas where there are weak satellite signals available, but can not be used in areas where the level of satellite signals is too weak even for high sensitivity receivers.

Example applications for A-RNSS and/or Pseudolites could be e.g.:

- Sports – tracking players in the field / arena; both A-RNSS and Pseudolites could operate here
- Entertainment – tracking actors, cameras and items in studios; it is likely that pseudolite could predominate here since A-RNSS operation depends on whether the radio frequency attenuation of the building materials is low enough and that there are significant apertures to the outside.
- Fairs **–** Guiding visitors, tracking VIPs usually in an enclosed building; Pseudolites might be a predominate possible, but also A-RNSS could be considered if enough satellite signals were available to enable mass market use.

A comprehensive summary of the pseudolite technology and applications can be found in e.g. Wang [2]. Information on A-RNSS is available through the 3GPP standards forum and through the developed ETSI technical specifications.

From the variety of applications three typical scenarios for PL-network architectures as shown can be derived, which form the basis for compatibility investigations:

Scenario	Description	Service Area	RF power	Remarks
A	Indoor	Building	Low (-70 dBm)	PLs only
B	Restricted propagation conditions	Urban canyon Several buildings	Low to high	PL and Signal in Space (SIS)
C	Combined reception over large Service Area	Airport services, Harbour	High (0 dBm)	PL and SIS

Table 2.1: Generic Pseudolite scenarios

It is assumed that following operational requirements have been established for PLs:

1) all PLs in an area are controlled by the same entity.

2) the PLs coverage for each scenario is limited to a maximum set radius

3) that 1 to 6 PLs might be seen at any one location

4) that the signals must be positively monitored.

PLs must address interference concerns for the participating receiver (one that is using the PLs), but also for non-participating receivers as well, such as A-RNSS or civil aircraft at low altitude, when they are local to an area using PLs.

2.3 Signal characteristics

A pseudolite signal could be chosen in the ITU allocated RNSS ARNS band from 1559-1610 MHz. A second transmission frequency could also be implemented through a radionavigation service allocation in the band 1215-1260 MHz. Dual frequency navigation messages allow the user to correct for ionospheric propagation effects and are incorporated in GPS-NAVSTAR, GLONASS and Galileo. Originally, this second channel was generally designed for military usage, but now has an accessible civil L2 signal. A third civil signal for GNSS systems could be located in the band 1164-1215 MHz, within a portion of the radio frequency spectrum that is allocated internationally for aeronautical radio-navigation services.

2.4 Current situation

Currently there are no national regulations concerning the use of PLs, Pseudolites are not providing a RNSS service therefore they have to be identified within other ITU service definitions. The PL-technology has been identified as one core technology for the implementation of Galileo local components.

There are several activities already performed, ongoing or planned that involve PLs. These activities cover several application domains and are often related to the European EGNOS and Galileo developments [3].

Bodies like the European Space Agency (ESA), EC, the Galileo Joint Undertaking (GJU) and the GNSS Supervisor Authority (GSA) were coordinating and funding a number of PL related activities. Some examples are given below.

- NAVIndoor 1 (ESA) [12]
- NAVIndoor 2 (ESA) [13]
- Galilei (EC) [14]
- GILT (GJU, EC) [15]
- mEXPRESS (EC) [16]
- Development of EGNOS pseudolites (ESA) [17]
- GEM (GJU) [18]
- GATE (DLR) [19]
- MARUSE (GSA)
- SEA GATE (DLR-Germany) http://www.sea-gate.de/e_index.html

The activities mentioned above indicate that the PL-technology is a technology that is intended to be an integral part of the European satellite and radio navigation systems.

Therefore, frequency usage as well as the regulatory issues for terrestrial PLs in the frequency bands allocated to RNSS should be addressed as soon as possible in order to allow the technology to be used to its full potential and at the same time assuring the interoperation and compatibility with the GNSS systems.

2.5 Application scenarios for Pseudolites

2.5.1 Overview on Pseudolite usage

Pseudolites are intended to improve the availability of positioning service in areas of critical radio propagation such as indoors and, to a certain degree, urban canyons. RNSS satellites do not provide sufficient power flux density (PFD) to overcome major obstacles that attenuate the radio frequency wave front.

The most critical performance issue with respect to PLs is their potential interference to other related RNSS but there are also other factors affecting the performance of the PL network system described in the following sections.

2.5.2 The Near-Far Problem

Because the RNSS satellites are far away and their antenna broadcast beam is shaped, the received RNSS signal power varies only slightly over the earth coverage (above 5° elevation angle). The PLs on the other hand are near-by and the PL received power varies with $20 \log_{10} R$, where R is the range between the PL and the user's receiving antenna. Thus, if the average PL received signal power is made to match that of the satellite at one range, it will dominate at another range while being too weak at yet another. The effect of this is that, unless carefully designed, the PL signal will act as a strong jammer to the satellite signals at short range and the PL signal will be too weak to be useful at long range.

The near-far problem highlights two major problems related to the pseudolite usage. First, the problem must be solved so that pseudolites can be utilized in practical applications. Secondly, any pseudolite signals must be carefully controlled so that receivers that are not part of the PL constellation are not disturbed or jammed by pseudolite signals. The potential solutions to the near-far problem are described in the following.

2.5.3 Potential Near-Far Problem Solutions

In order to solve the near-far problem, three signal diversity options provide partial solutions – frequency offsets, different PRN codes and/or signal pulsing. The use of all three options is possible.

Frequency Offsets

Frequency offsets can either be in-band or out-of-band. In-band offsets have the advantage that the same receiver front-end can be used, which minimizes inter-frequency biases when comparing PL measurements to satellite measurements. Out-of-band frequency offsets would usually require a different receiver front-end, which increases receiver cost and can create an inter-frequency bias problems. However, this solution could eliminate PL interference to RNSS entirely.

Different PRN Codes

The PL signal structure must be modified with respect to the GPS signal structure to minimize the interference to the RNSS signals. Using different PRN codes in a RNSS family of codes would minimize the impact on receiver design. For instance there are about 700 usable codes in the GPS C/A code family. There are also many usable wideband codes compatible with the GPS P-codes. Using a different code family should be avoided to minimize receiver design modifications. Longer codes or ones with higher chipping rates are desirable.

Typical mass market GNSS receivers may not be capable of interpreting pseudolite signals.

However, the near-far problem cannot be solved using different PRN codes alone. There is not enough dynamic range separation between codes. If codes from the RNSS code family are used, the modification must also include provisions to minimize cross-correlation with the RNSS-codes. The AGC dynamic range of RNSS receivers can vary considerably; some as low as 10dB, others typically limited to >22dB (derived from the cross-correlation between different PRN codes) and up to 30dB in the best case.

Signal Pulsing

Signal pulsing is the most effective interference solution, using low-duty cycle, higher power pulses. This is because RNSS receivers are naturally robust against low-duty cycle pulsed interference. The PL signal only interferes when a pulse is present. The down side of low-duty cycle pulses is that PL signal reception is degraded by the square of the duty cycle, which dictates the necessary PL peak power required for the desired radius of operation. Pulsing at low duty cycles is a necessity no matter what signal structure is chosen, unless larger frequency offsets are used.

However, because of the autocorrelation properties of the C/A code, very low-duty cycles are not possible. The pulses must cover most of the code sequence during a reasonable receiver processing time interval. This becomes a problem when the number of PLs is increased. It is possible for pulses from multiple PL's to "collide" when received by the user, causing PL to PL interference, or even total blanking. It is important to control the relative pulse timing between PL's such that for a receiver, pulse T1 seen at distance d1, does not conflict with T2 at distance d2, where c is speed of light ($T_1 + d_1/c \neq T_2 + d_2/c \;\forall\; d_1, d_2$ in range of PL's). This is accomplished rather easily by staggering the timing of the PLs provided that the pulsing scheme allows that. However, a pseudo random pulse pattern may not allow it entirely, but a few collisions would be acceptable if the resulting signal loss is minor.

<u>Overview of existing pulsing schemas</u>

RTCM SC-104

The most commonly used pulsing schema is the one defined by the RTCM-104 committee in 1986 [4]. This schema defines 11 possible slots in a C/A code epoch. A pulse is transmitted in one of these slots during each epoch. As one C/A code epoch corresponds to 1023 chips during a period of 1 ms, each pulse transmission will be 93 chips or about 90.91 µs long. The active slots are defined by a fixed sequence which repeats every 200 ms, and as each 10^{th} period two pulses are sent the average duty cycle sums up to 10%.

Most pseudolite work has been carried out using the RTCM-104 pulsing schema. Some existing receivers are able to track the satellites and pseudolite signals simultaneously using this schema. To reduce the average duty cycle the pulsing schema can be modified by making the pulse lengths shorter and pulse duty cycles of 6-7% still provides reliable tracking by most existing receivers.

RTCA SC-159

The Special Committee SC-159 of RTCA proposed a pulsing scheme for the LAAS system in [5].

The pulse positions of RTCA are determined by the output of a shift register, which results in the pulses being more pseudo-randomly distributed compared to the RTCM schema. The number of pulses within a given interval is therefore not constant. That means, for example, that more or less than one pulse can occur within the period of 1ms. Each pulse transmission will be 14 code chips, or about 13.69 µs long, and as the number of pulses in one second is 1997, the average pulse duty cycle can be derived as 2.733%.

The RTCA pulsing schema causes difficulties for standard receivers. Most standard receivers have difficulties in acquiring such a signal, and once acquired the receivers tend to lose the lock. These problems probably origin from the low duty cycle in combination with the long gaps between pulses. About 12% of the pulses are separated by a gap longer than 1ms and the longest gaps exceed 3ms.

Galileo pulsing schemas

Some research has been done on defining a pulsing schema suitable for Galileo signals. In [6] several aspects of a new pulsing schema are analysed. However, more studies are needed before an optimal pulsing schema for the Galileo signal can be defined.

2.5.4 The impact of a Continuously Transmitting Pseudolites

Presently available commercial civilian GPS receivers can track signals arriving to the receiver's antenna with interfering RF power levels up to -120 dBm assuming an otherwise interference free environment. Adjusting the PL transmission power so that the receiver signal level at the near boundary is –120 dBm would allow non-participating receivers to operate outside this boundary.

It is assumed here that the pseudolites use different RNSS pseudorandom codes in their CDMA signal and that the set of codes from those assigned to the provision of the RNSS signal in space. It is assumed that the PL can co-ordinate a set of PRN for these devices to use.

It is also assumed that the area inside the near boundary is not accessible to the general public. The ratio of far boundary to the near boundary for a receiver with a dynamic range of 21dB can be determined from the free-space propagation formula in this instance as:

$$20 \cdot \log\left(\frac{r_f}{r_n}\right) = 21 \qquad (1)$$

which gives approximately 1:11 ratio.

Therefore, only relatively small areas may be covered by continuously transmitting pseudolites without causing interference to non-participating users. For example, if the PL antenna is installed so that it allows a near boundary at 10 m, the far boundary would be at 110 m distance from the PL. If a shaped gain antenna pattern is used, the general area where non-participating users would be jammed can be minimised, however in the direction of main antenna gain non-participating users would see an increase in the area being jammed. Therefore, overall the same area would be affected.

2.5.5 The impact of a Pulsed Pseudolites

To overcome the near-far problem it has been suggested to transmit the pseudolite signal in short, strong pulses. During the pseudolite pulse, a non-participating receiver would be saturated by the strong signal, but between the pulses the non-participating GNSS receiver can track the satellite signals without interference. There is however an upper limit on how much pulse interference any given receiver can tolerate before it begins to lose track of satellite signals. The limit is dependent on receiver implementation (number of A/D converter bits and/or AGC characteristics). The subject is analysed in [7], where the formula presented below is derived for receivers with a single-bit A/D converter. The formula calculates the average post-correlation S/I under the influence of a saturating pulsed signal.

$$\left(\frac{S}{I}\right)_{average} = 10\log_{10}\left(\frac{s_{typ}(1-d)}{p\cdot d+(1-d)}\right) \quad [\mathrm{dB}] \qquad (2)$$

where;

$$s_{typ} = 10^{\left(\frac{S}{I}\right)_{typ}/10}, \qquad (3)$$

where $\left(\frac{S}{I}\right)_{typ}$ in dB represents the typical SNIR at the correlator output when only thermal noise and GNSS interfering signals are considered.

$$p = 10^{\left(\frac{P}{I}\right)/10}, \qquad (4)$$

where $\left(\frac{P}{I}\right)$ in dB represents the pseudolite pulsed power output to thermal noise and GNSS interfering signal power ratio at the correlator.

d is the duty cycle ($0 \le d \le 1$).

While the post-correlation S/I is 17dB in typical receiver, and 6dB is required to maintain lock, this analysis suggests that a single-bit receiver would tolerate about a 20% duty cycle before interference causes signals to be lost. Empirical tests suggest that much higher duty cycles (35-40%) can be used in practical implementations. However, perhaps the most relevant guidance comes from [5] where it is stated that an airborne receiver must withstand interference of pulsed duty cycle of 10% (+20dBm).

The subject of interference is analyzed in great detail in [7], [9] and [10].

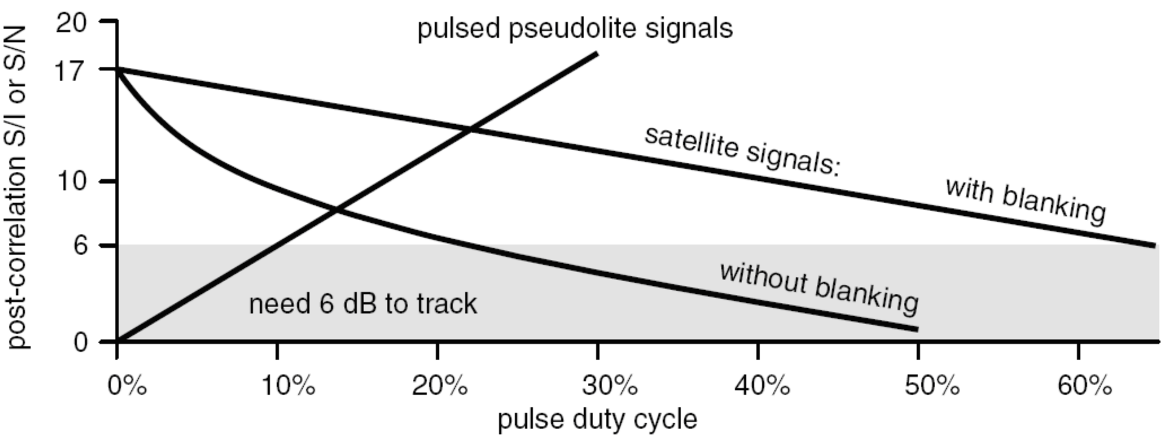


Figure 2.1: Pseudolite pulse duty cycle trade-off (picture copied from [7]).

2.5.6 Example of practical results for the band 1559-1610 MHz

Near/far performance tests for a pulsed pseudolite transmissions are reported in [7]. In those example tests two consumer GPS receivers were able to track satellite signals and perform position fixes at 18 cm distance from a pulsed pseudolite transmitting at +26 dBm power and 12.5% duty cycle. At the same time, the pulsed signal was measured in an aircraft at 18 km distance. The author describes the interference effect as: "The only interference detected was the unavoidable loss of satellite signal power due to the 12% duty cycle of the pulsed transmissions themselves. This loss produced a barely visible change on the signal strength graphs as the PL transmitter was enabled and disabled."

Space Systems Finland has been involved in pseudolite research for the past few years. The developed pseudolites (GPS-L1) have been used in various setups; providing additional ranging signals to outdoor applications as well as pseudolite-only positioning in indoor locations. Tests have been performed with a radio license from the Finnish Communications Regulatory Authority. In the experiments we have used COTS GPS receivers.

The tests show that a PL system can be set up so that disturbance to non-participating receivers is avoided. This is done by carefully adjusting PL signal power levels so that receivers in the test area (or outside it) are not jammed by too strong signals. The used C/A codes must also be selected from those not currently in use. A COTS receiver with modified firmware can track and utilise live GPS satellites to output navigation solutions at the same time as the same receiver is used to output raw measurements from pseudolite signals. Recent development on the receiver market makes it possible to embed suitable algorithms onto the receiver board, as well as allowing us to go outside the ordinary 1-32 PRN range.

Interference tests using both continuous and pulsed signals have been performed in the SSF laboratory. In these tests the pseudolite signal was connected to a receiver using cables, and an antenna cable splitter and an outdoor GPS patch antenna allowed the receiver to track GPS satellites at the same time. With continuous signals, the pseudolite signal level can be set at -120 dBm while tracking satellite signals at -130 dBm or above. If the PL signal level is increased to -115 dBm, satellite signal tracking and acquisition still works. When PL signal level is -110 dBm, the receiver (iTrax03) begins to track cross-correlation peaks of the strong PL signal, and satellite signal tracking is disturbed.

Tests with pulsed signals (3% duty cycle) confirm theory, as pulsed signals must be set 15dB stronger than an unpulsed signal to reach the same signal level and to get tracked by the receivers. All tested receivers are able to track the pulsed signal without problems or noticed interference to satellite tracking. The tests also confirm that after a certain signal level the power peak level seen by the receiver’s correlators will remain constant. The pulsed pseudolite signal comes to view at ~ -115dBm (at the same level as GPS satellite signals as the GPS patch antenna had a gain of 20 dB). Increasing the pseudolite power with 60dB causes no problems in tracking satellite signal and normal positioning output of the tested receivers.

2.6 Necessary technical parameters for the compatibility studies

2.6.1 Technical parameters of the Pseudolites

Pseudolite system	Necessary bandwidth [MHz]	Tx power [dBm]	Duty cycle [%]	Additional losses,eg. indoor usage [dB]	Pseudolite antenna height [m]	Maximum antenna gain [dBi]	EIRP [dBm] (CW or during pulse)	Numbe r of PLs	Usage area
Pseudolite; CW	2- 10	-70	100	0	10	11	-59	4-6	Outdoors
Pseudolite; CW	2- 10	-70	100	8 dB *	5-20	11	-59	6	Indoors
Pseudolite; pulsed	2- 10	0	7-10	0	10	11	11	1	Outdoors
Pseudolite; pulsed	2- 10	0	20-35	0	10	11	11	4-6	Outdoors

* Indoor attenuation 8 dB taken from CEPT BWA buildings analysis report.

Table 2.2: Example Pseudolite parameters for the compatibility studies

2.6.2 Typical antenna pattern(s) of Pseudolite

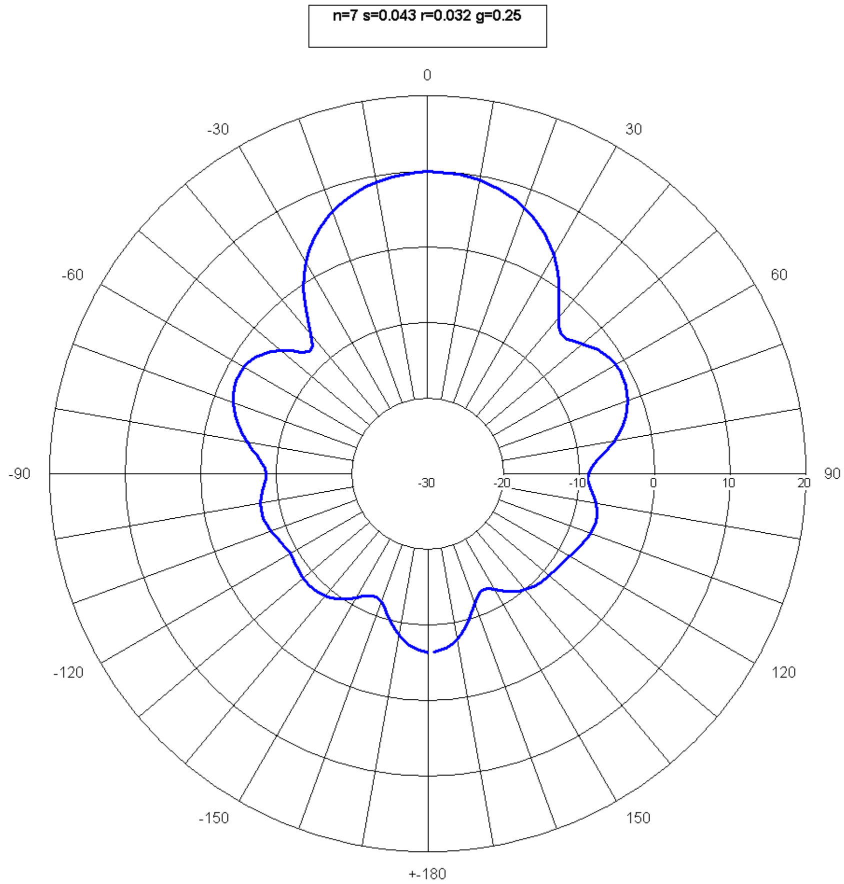


Figure 2.2: Typical horizontal antenna pattern of pseudolites

In this case a helix antenna is used and the vertical antenna pattern is symmetrical to the horizontal one.

2.6.3 Compatibility criteria

The pseudolite transmitter acts here only as an interfering emitter. Interference to any baseline system receiver is not considered in this report.

3 OVERVIEW OF FREQUENCY SPECTRUM ALLOCATED TO RNSS

3.1 Allocations and use of frequency spectrum

The frequency band allocations to RNSS are

- 1164–1215 MHz (space-to-Earth)
- 1215–1300 MHz (space-to-Earth)
- 1559–1610 MHz (space-to-Earth)
- 5010–5030 MHz (space-to-Earth)

All of them are allocated with a primary status to RNSS.

Pseudolites are low power devices that operate co-frequency with the provision of RNSS signals from satellites in space (SIS). At the time the report was developed, there was no plan to use the band 5010-5030 MHz for pseudolites.

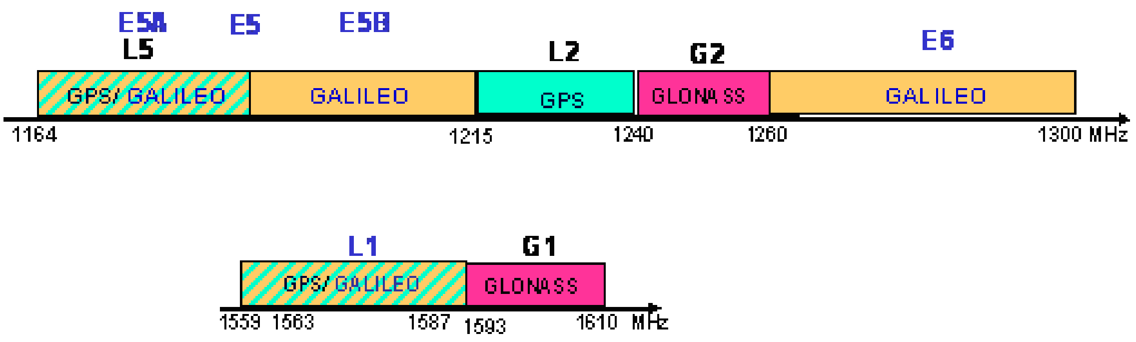


Figure 3.1: Frequency bands allocated to RNSS and their present use by RNSS-systems

3.2 RNSS bands in the Radio Regulations (RR 5)

According to the ITU Radio Regulations article 5 the RNSS bands and adjacent bands to RNSS are allocated to other Services in all Regions as follows:

- 960 - 1 164 MHz AERONAUTICAL RADIONAVIGATION, AM(R)S
- 1 164 - 1 215 MHz AERONAUTICAL RADIONAVIGATION
- 1 215 - 1 240 MHz EARTH EXPLORATION-SATELLITE (active), RADIOLOCATION, SPACE RESEARCH (active), RADIONAVIGATION by footnote 5.331
- 1 240 - 1 300 MHz EARTH EXPLORATION-SATELLITE (active), RADIOLOCATION, SPACE RESEARCH (active), Amateur), RADIONAVIGATION by footnote 5.331
- 1 300 - 1 350 MHz AERONAUTICAL RADIONAVIGATION**,** RADIOLOCATION
- 1 535 - 1 559 MHz MOBILE-SATELLITE (space-to-Earth)
- 1 559 - 1 610 MHz AERONAUTICAL RADIONAVIGATION
- above 1610 MHz RADIOASTRONOMY, MOBILE SATELLITE, AERONAUTICAL RADIONAVIGATION

4 PARAMETRES AND CHARACTERISTICS OF EXISTING SYSTEMS IN RNSS-BANDS

4.1 Systems in the Aeronautical Radio Navigation Service (ARNS)

4.1.1 System overview of DME (ref. Federal Radionavigation Plan 1999)

Distance Measuring Equipment (DME) is a transponder-based radio navigation technology that measures distance by timing the propagation delay using radio signals. Aircrafts use DME to determine their distance from a land-based transponder by sending and receiving pulse pairs (interrogation). The ground stations are in many cases co-located with VORs (VHF Omni-directional Range).

DME operates in 960-1027, 1033-1087 and 1093-1215 MHz sub-bands of the 960-1215 ARNS band. The RNSS band 1164-1215 MHz shares this part of the allocation band, where the DME receiver on aircraft receives the transponder replies.

The DME transponder transmissions can have a significant aggregate duty cycle affect if viewed from a high altitude. A ground based PL enabled receiver local to a DME transponder in the band 1164-1215 may see a maximum aggregate pulse environment of around 3%.

4.1.2 Necessary technical parameters of the airborne DME receiver systems for the compatibility studies

Frequency [MHz]	Aircraft receiver height [m]	Maximum antenna gain towards terrestrial PL’s [dBi]	DME receiver bandwidth [kHz]	Noise figure [dB]	Number of PLs in the vicinity of the DME receiver	Compatibility criterion for pseudolites
1164-1215	100	4.5	650	3	–4-5	Aggregate pfd -144.5 dBW/m²/MHz*
1164-1215	12192	4.5	650	3	100.1000.10000	Aggregate pfd -144.5 dBW/m²/MHz*

* Derived from the aggregated PFD in ITU-R Resolution 609

Table 4.1: Technical parameters of DME systems and pseudolite assumptions

4.1.3 Typical antenna pattern(s) of aircraft DME systems

Elevation angle (degrees)	Antenna gain including circular-to-linear polarization mismatch $G_r/G_{r,\,max}$ (dB)	Elevation angle (degrees)	Antenna gain including circular-to-linear polarization mismatch $G_r/G_{r,\,max}$ (dB)	Elevation angle (degrees)	Antenna gain including circular-to-linear polarization mismatch $G_r/G_{r,\,max}$ (dB)
–90	–17.22	22	–10.72	57	–15.28
–80	–14.04	23	–10.81	58	–15.49
–70	–10.51	24	–10.9	59	–15.67
–60	–8.84	25	–10.98	60	–15.82
–50	–5.4	26	–11.06	61	–16.29
–40	–3.13	27	–11.14	62	–16.74
–30	–0.57	28	–11.22	63	–17.19
–20	–1.08	29	–11.29	64	–17.63
–10	0	30	–11.36	65	–18.06
–5	–1.21	31	–11.45	66	–18.48
–3	–1.71	32	–11.53	67	–18.89
–2	–1.95	33	–11.6	68	–19.29
–1	–2.19	34	–11.66	69	–19.69
0	–2.43	35	–11.71	70	–20.08
1	–2.85	36	–11.75	71	–20.55
2	–3.26	37	–11.78	72	–20.99
3	–3.66	38	–11.79	73	–21.41
4	–4.18	39	–11.8	74	–21.8
5	–4.69	40	–11.79	75	–22.15
6	–5.2	41	–12.01	76	–22.48
7	–5.71	42	–12.21	77	–22.78
8	–6.21	43	–12.39	78	–23.06
9	–6.72	44	–12.55	79	–23.3
10	–7.22	45	–12.7	80	–23.53
11	–7.58	46	–12.83	81	–23.44
12	–7.94	47	–12.95	82	–23.35
13	–8.29	48	–13.05	83	–23.24
14	–8.63	49	–13.14	84	–23.13
15	–8.97	50	–13.21	85	–23.01
16	–9.29	51	–13.56	86	–22.88
17	–9.61	52	–13.9	87	–22.73
18	–9.93	53	–14.22	88	–22.57
19	–10.23	54	–14.51	89	–22.4
20	–10.52	55	–14.79	90	–22.21
21	–10.62	56	–15.05		

Table 4.2: Typical antenna pattern of aircraft DME system according to the Rec. ITU-R M.1642-1

4.1.4 Compatibility criteria

According to the ITU-R Resolution 609 the protection of the ARNS from harmful interference can be achieved if the value of the equivalent pfd (epfd) produced by all the space stations of all RNSS (space-to-Earth) systems in the 1 164 - 1 215 MHz band does not exceed the level of -121.5 dB(W/m^2) in any 1 MHz band. Pseudolite transmissions are not included within this aggregate limit which corresponds to interference to noise ratio (I/N ≈ 0) of about zero in the DME receiver input.

Such a high interference level may be acceptable between two co-primary services but is not sufficient between Pseudolites and ARNS. A suitable approach could be found from the ITU-R rec. F.1094. According to this recommendation 1 % of all interference can be allocated to Secondary Services and other interference sources. If we apportion half of this 1 % share to Pseudolites we come to a value of 0.5 %, which corresponds to an I/N (long term interference) ratio of -23 dB.

The protection criterion retained is therefore an aggregate pfd of -144.5 dBW/m²/MHz.

4.2 Systems in the Radio Navigation Satellite Service (RNSS)

4.2.1 System overview of GNSS (Global Navigation Satellite Systems)

Global Navigation Satellite Systems (GNSS) are navigation satellite systems that work under allocation of RNSS, and that provide positioning service with regional or global coverage. A GNSS allows small electronic receivers to determine their location (longitude, latitude, and altitude) within a few meters using time signals transmitted along a line of sight by radio from satellites.

When writing this report (2008) the GPS is the only fully operational GNSS. The GLONASS is a GNSS in a process of being restored to full operation. The European GALILEO positioning system is a next generation GNSS in the initial deployment phase, scheduled to be operational in 2013. There are also plans of few other GNSSs in Asia.

More detailed information on the RNSS systems may be found in relevant ITU-R M series recommendations (e.g. ITU-R M.1317).

The GPS and GALILEO systems are considered in this report.

4.2.2 Necessary technical parameters for the compatibility studies

Technical parameters as well as protection criteria may be found in the following ITU-R recommendations.

M.[Char-Rx3]	1164-1215	User Rx	RNSS user receiver characteristics in 1164-1215 MHz band and their protection criteria.
M.[1088_New]	1215-1300	User Rx	RNSS user receiver characteristics in 1215-1300 MHz band and their protection criteria.
M.[1477_New]	1559-1610	User Rx	RNSS user receiver characteristics in 1559-1610 MHz band and their protection criteria.

Two different applications have been considered in this report:

- Ground based receivers
- Airborne receivers

4.2.2.1 Band 1164-1215 MHz

Parameter (units)	**Ground based**	**Air-navigation receiver**
Signal frequency range (MHz)	1207.14 ± 12 (Note 14)	1176.45 ± 12
Navigation data bit/symbol rates (bps/sps)		
Maximum receiver antenna gain in upper hemisphere (dBi)	+3	+3 (circular) (Note 2)
Maximum receiver antenna gain in lower hemisphere (dBi)	−10	–5 (linear) (Note 3)
RF filter 3 dB bandwidth (MHz)	24	24.0
Pre-correlation filter 3 dB bandwidth (MHz)	20.46	20.46
Receiver system noise temperature (K)	330	727
Tracking mode threshold power level of aggregate narrow-band interference at the passive antenna output (dBW) (Note 1)	−150	–154.8 (Notes 4, 5)
Acquisition mode threshold power level of aggregate narrow-band interference at the passive antenna output (dBW) (Note 1)	−156	–158.7 (Notes 4, 6)
Tracking mode threshold power density level of aggregate wideband interference at the passive antenna output (dB(W/MHz)) (Note 1)	−140	–144.8 (Notes 4, 5)
Acquisition mode threshold power density level of aggregate wideband interference at the passive antenna output (dB(W/MHz)) (Note 1)	−146	–148.7 (Notes 4, 6)
Receiver input compression level (dBW)	−100	–114 (Note 7)
Receiver survival level (dBW)	−17	0 (Note 8)
Overload recovery time (s)	1	1×10^{-6}

NOTE 1 – Narrow-band interference signal bandwidth < 700 Hz. Wideband is greater than 1 MHz. Thresholds for intermediate bandwidths are under study.

NOTE 2 – The maximum upper hemisphere gain applies for an elevation angle of 75º or more with respect to the antenna horizontal plane.

NOTE 3 – The maximum gain value in the lower hemisphere applies at 0º elevation. For elevation angles between 0º and –30º, the maximum gain decreases with elevation angle to –10 dBi at –30º and remains constant at –10 dBi for elevation angles between –30º and –90º.

NOTE 4 – When used in the ITU-R M.1318-1 interference evaluation model, the threshold value is inserted in Line (a) and 6 dB (the safety margin, as described in Annex 1 of recommendation ITU-R M.[CHAR-RX3]) is inserted in Line (b) of the evaluation template.

NOTE 5 – The continuous RFI threshold value applies to airborne receiver operations above 20 000 feet altitude above MSL. The tracking mode values for airborne operations below 2 000 feet altitude above ground level are -144.3 dBW (narrowband) and -134.3 dB(W/MHz) (wideband).

NOTE 6 – The continuous RFI threshold value applies to airborne receiver operations above 20 000 feet altitude above MSL. The acquisition mode values for airborne operations below 2 000 feet altitude above ground level are –144.5 dBW (narrowband) and –134.5 dB(W/MHz) (wideband).

NOTE 7 – The input compression level is for power in the 20 MHz pre-correlator bandwidth.

NOTE 8 – The survival level is the peak power level for a pulsed signal with 10% maximum duty factor.

NOTE 14 - This receiver type operates on one carrier frequency with two quadrature signal components – one with 10.23 MHz PRN chip rate, and the other with 2.046 MHz rate

Table 4.3: Technical characteristics and protection criteria for RNSS receivers (space-to-Earth) operating in the band 1164-1215 MHz according to the ITU-R Rec M.[CHAR-RX3]

4.2.2.2 Band 1215-1300 MHz

Parameter (units)	**Indoor positioning**	**Others**	**General purpose #1**	**Air-navigation receiver (Note 9)**	**General purpose #2**
Signal frequency range (MHz)	1227.6±12	1278.75±21	1227.6±12	1246+0.4375*K ±5.11 (K=-7,..,6) (Note 7)]	1268.52±12
Navigation data bit/symbol rates (bps/sps)				50	
Maximum receiver antenna gain in upper hemisphere (dBi)	6	6	6	7 (Note 10)	3
Maximum receiver antenna gain in lower hemisphere (dBi)	6	6	6	–10	–10
RF filter 3 dB bandwidth (MHz)				30	24
Pre-correlation filter 3 dB bandwidth (MHz)				20	20.46
Receiver system noise temperature (K)				400	330
Tracking mode threshold power level of aggregate narrowband interference at the passive antenna output (dBW)	–193	–119	–158	–149 (Note 8)	–150
Acquisition mode threshold power level of aggregate narrowband interference at the passive antenna output (dBW)	–199	–125	–164	–155 (Note 8)	–156
Tracking mode threshold power density level of aggregate wideband interference at the passive antenna output (dB(W/MHz))	–150	–121	–139	–140 (Note 8)	–140
Acquisition mode threshold power density level of aggregate wideband interference at the passive antenna output (dB(W/MHz))	–156	–127	–145	–146 (Note 8)	–146
Receiver input compression level (dBW)				–80	–100
Receiver survival level (dBW)				–1	–17
Overload recovery time (s)				$(1\text{-}30)*10^{-6}$	1

NOTE 7 – This receiver type operates on several carrier frequencies simultaneously. The carrier frequencies (MHz) are defined by fc=1 246.0 +0.4375*K, where K= –7 to +6 (RNSS signals).

NOTE 8 – This threshold should account for all non-RNSS aggregate interference. The value does not include a safety margin 6 dB.

NOTE 9 – Given values represent typical characteristics of receivers. Under certain conditions more rigid values for some parameters could be required (e.g. recovery time after overload, threshold values of aggregate interference etc)..

NOTE 10 – Minimum receiver antenna gain at 5 degrees elevation angle is –4.5 dBi

Table 4.4: Technical characteristics and protection criteria for RNSS receivers (space-to-Earth) operating in the band 1215- 1300 MHz according to the ITU-R Rec M.[1088_NEW]

4.2.2.3 Band 1559-1610 MHz

Application (see § 3.1) **Parameter (units)**	**A-RNSS**	**General purpose**	**General Purpose #2**	**Indoor positioning**	**High precision* (Notes 8, [15])**
Signal frequency range (MHz)	1575.42±12	1575.42±12	1561.098 ± 2.046 1589.742 ± 2.046	1575.42±12	1575.42±12
Navigation data bit/symbol rates (bps/sps)					
Maximum receiver antenna gain in upper hemisphere (dBi)	0.0	6	3	6	+3.0
Maximum receiver antenna gain in lower hemisphere (dBi)	0.0	6	−10	6	-5.0 (Note 7)
RF filter 3 dB bandwidth (MHz)	30.69	± 16	5	± 16	30.69
Pre-correlation filter 3 dB bandwidth (MHz)	20.46	± 1	4.096	± 1	20.46
Receiver system noise temperature (K)	513	645	330	645	513
Tracking mode threshold power level of aggregate narrow-band interference at the passive antenna output (dBW)	–156.9 (Note 1)	–152	−150	–184	–157.4 (Note 1)
Acquisition mode threshold power level of aggregate narrow-band interference at the passive antenna output (dBW)	–156.9 (Note 1)	–158	−156	–190	–157.4 (Note 1)
Tracking mode threshold power density level of aggregate wideband interference at the passive antenna output (dB(W/MHz))	–146.9 (Note 1)	–136	−140	–142	–147.4 (Note 1)
Acquisition mode threshold power density level of aggregate wideband interference at the passive antenna output (dB(W/MHz))	–146.9 (Note 1)	–142	−146	–148	–147.4 (Note 1)
Receiver input compression level (dBW)			−70	-100	[-135]
Receiver survival level (dBW)			−20	-17	[-10]
Overload recovery time (s)			1	1	[$25.0*10^{-6}$]

NOTE 1 – A continuous narrow-band interference signal is considered to have a bandwidth less than 700 Hz. A continuous wideband interference signal is considered to have a bandwidth greater than 1 MHz. For interference signal bandwidths between 700 Hz to 1 MHz, see Fig. 2-1. These values are for GPS C/A code and not intended for use in environments with significant pulsed interference.

NOTE 7 – The listed maximum lower hemisphere gain value applies for angles of less than +10º elevation.

NOTE 8 – The characteristics and protection levels provided in this column also apply to RNSS receivers that are designed to operate in specialized RNSS applications (e.g., single-frequency ground networks, and precision navigation). (See Section 3.1 High-precision definition above.)

[Note 15: The criteria in this column also apply to a high precision receiver with the following characteristics: maximum receiver antenna gain of +6.0 dB in both hemispheres; and RF filter 3 dB bandwidth of 32 MHz. At the time the report was written, ITU-R was still working on these elements]

Table 4.5: Technical characteristics and protection criteria for RNSS receivers (space-to-Earth) operating in the 1 559-1 610 MHz band according to the ITU-R Rec M.[1477_NEW]

4.2.3 Typical antenna pattern(s) of the RNSS receiver

A 0 dBi omnidirectional antenna is assumed in calculations and simulations.

4.2.4 Compatibility criteria

Maximum narrowband or wideband interference levels are defined in the above mentioned recommendations.

The protection criteria are for noise like interference signals. In addition RNSS receivers are subjected to pulsed RF interference from Radiolocation radars and ARNS transmitters. A pulsed Pseudolite system could also be a source of such interference.

In section 2.5.3 the impact of a pseudolite using a pulsed signals, the analysis suggests that a single-bit receiver would tolerate about a 20% duty cycle before interference causes signals to be lost. For the purpose of this report we could consider this value as a compatibility criterion. It means that if a GNSS receiver receives more than two saturating signals from pulsing PLs (duty cycle 10 %) simultaneously, the criterion is exceeded.

4.3 Systems in the Radio Determination Service (RDS)

4.3.1 System overview of Radio Determination Service (ref. rec. ITU-R M.1463-1)

The band 1215-1400 MHz is used by many different types of radars on fixed and transportable platforms. Radiodetermination functions performed in the band include long range search tracking and surveillance. Radar operating frequencies can be assumed to be uniformly spread throughout the band 1215-1400 MHz.

The radars operating in the 1215-1400 MHz band use a variety of modulations including continuous wave (CW) pulses, frequency modulated (chirped) pulses and phase coded pulses.

Cross-field, linear beam and solid state output devices are used in the final stages of the transmitters. The trend in new radar systems is toward linear beam and solid state output devices due to the requirement of Doppler signal processing. Also, the radars deploying solid state output devices have lower transmitter peak output power and higher pulsed duty cycles approaching 50% when operating on a single channel (a single channel may consist of three or four discrete frequencies in a 10 MHz bandwidth). There is also a trend towards frequency agile type radar systems which will suppress or reduce interference.

Typical transmitter RF emission bandwidths of radars operating in the 1215-1400 MHz band range from 0.5 to 2.5 MHz. Transmitter peak output powers range from 45 kW (76.5 dBm) for solid state transmitters up to 5 MW (97 dBm) for high power radars using klystrons.

The newer generation radar systems use digital signal processing after detection for range, azimuth and Doppler processing. Generally, included in the signal processing are techniques used to enhance the detection of desired targets and to produce target symbols on the display. The signal processing techniques used for the enhancement and identification of desired targets also provides some suppression of low-duty cycle interference, less than 5%, that is asynchronous with the desired signal. Also, the signal processing in the newer generation radars using chirped and phase coded pulses produces a processing gain for the desired signal and may also provide suppression of undesired signals.

Some of the newer low-power solid state transmitters use high-duty cycle multiple receiver channel signal processing to enhance the desired signal returns. Some radar receivers have the capability to identify RF channels that have low undesired signals and command the transmitter to transmit on those RF channels.

A variety of types of antennas are used on radars operating in the 1215-1400 MHz band. Newer generation radars using reflector type antennas have multiple horns. Dual horns are used for transmit and receive antennas to improve detection in surface clutter. Also, multiple-horn stack-beam reflector antennas are used for three-dimensional radars. The multiple horn antennas will reduce the level of interference. Distributed phased array antennas are also used on some radars in the band 1215-1400 MHz. The distributed phase array antennas have transmit/receive modules mounted on the antenna. Also, radars using phased array antennas generally have lower side-lobe levels than reflector type antennas, and have a narrow scanning beam in elevation, or use the digital beam-forming principles.

Since the radars in the 1 215-1 400 MHz band perform search, track, and long range surveillance functions the antennas scan 360° in the horizontal plane. Horizontal, vertical and circular polarizations are used.

4.3.2 Necessary technical parameters for the compatibility studies

Radar	Frequency [MHz]	Noise bandwidth [MHz]	Noise figure [dB]	Vertical scan [deg.]	Radar antenna height [m]	Antenna maximum gain [dBi]	Antenna polarisation	Antenna beamwidth [deg.]	Protection criterion
S3	1215-1400	4,4 - 6,4	4,7	-1 - +19	15 - 35	38,2	horizontal	3,2	I/N = -6
S5	1215-1400	1,25 -0,625	2,6	-6 - +20	15 - 35	38,5	horizontal	2,2	I/N = -6

Table 4.6: Typical radar parameters for the compatibility studies

The radar antenna height does not appear in the ITU-R recommendations. Radar antennas are assumed to be above the local clutter. A typical antenna height of 15 to 35 m above the ground was assumed in the studies.

4.3.3 Antenna pattern(s) of the RDS system

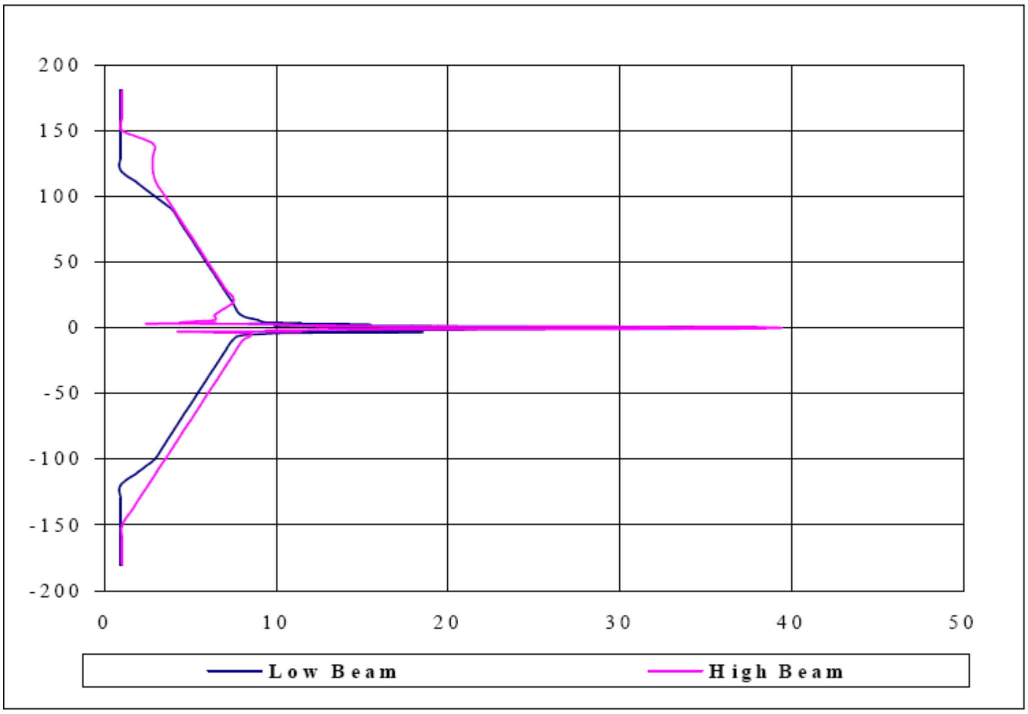


Figure 4.1: Typical horizontal antenna pattern of a primary radar

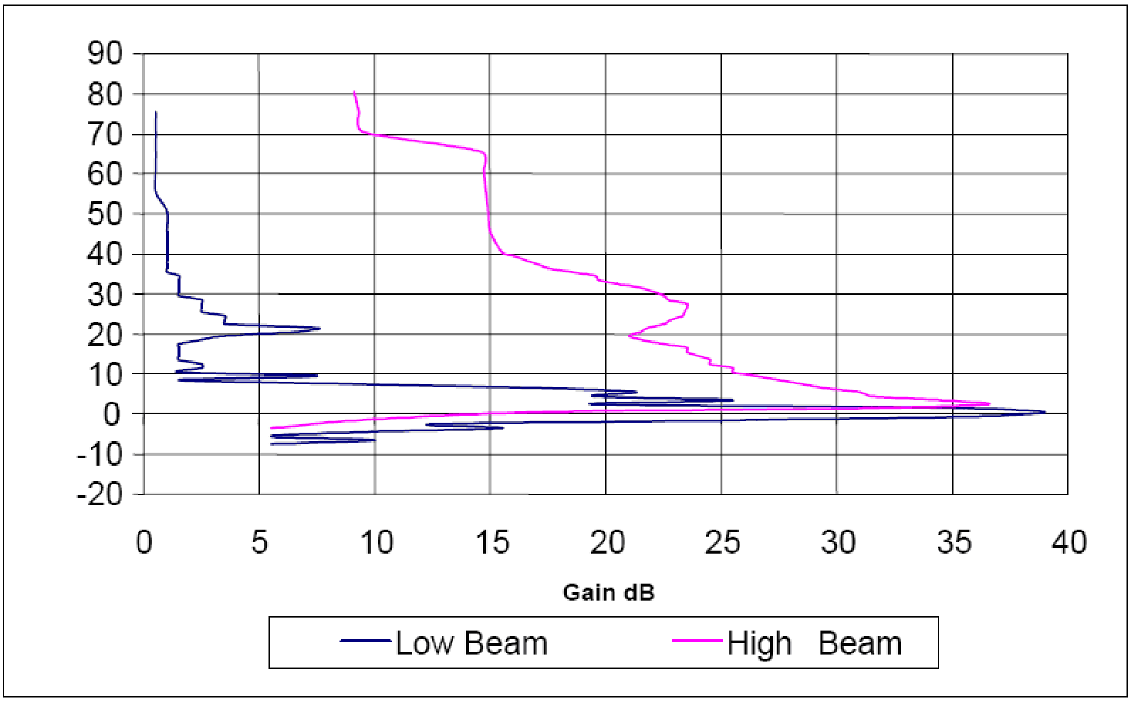


Figure 4.2: Vertical antenna pattern of a primary radar

4.3.4 Compatibility criteria

According to the Rec. ITU-R M.1463-1 considering c) and recommends 3 and 4, the radio determination service is a safety service as specified by No. 4.10 of the Radio Regulations (RR) and harmful interference to it cannot be accepted. In the case of continuous (non-pulsed) interference, an interfering signal power to radar receiver noise power level, I/N, of –6 dB should be used as the required protection level for the radio determination radars, and that this level represents the net protection level if multiple interferers are present.

The text in the overview of RDS section suggests that because of the signal processing techniques, radars can cope with low-duty cycle (less than 5%) asynchronous interference. However the duty cycle of a single PL is of the order of 7 - 10 % and the duty cycle of whole PL-system is of the order of 20 - 35 %. That is why it will be assumed in the first instance that the interference from pseudolite signals is continuous from the radar receiver point of view.

4.4 Systems in the Earth Exploration Satellite Service (EESS)

4.4.1 System overview of EESS (ref. ITU-R Rec. RS.1166-3)

The ITU-R RR article 5 allocates the bands 1215-1240 and 1240-1300 MHz to active Earth Exploration-Satellite Service. The systems are called space borne active imaging radar sensors or Synthetic Aperture Radars (SARs).

SARs are used in space to typically produce radar image maps of the terrain below as the spacecraft motion creates a synthetic aperture over a typical aperture time of only 0.2-1.5s.

4.4.2 Necessary technical parameters for the compatibility studies (ref. ITU-R rec. RS.1347)

System	Pulse bandwidth [MHz]	Maximum antenna gain [dBi]	Antenna orientation [deg. from nadir]	Antenna polarization	Orbital altitude [km]	Minimum desired signal * [dBm]	Noise level [dBm] *	Compatibility criterion
SAR 1	40	36.4	20	linear, vertical/ horizontal	400	-156.5	-97.7	I/N = -6
SAR 2	15	33	35	linear horizontal	568	No information	No information	I/N = -6

* **Ref. ITU-R RS.1166-3**

Table 4.7: Typical SAR parameters for the compatibility studies

4.4.3 Typical antenna pattern(s) of the EESS system

The EESS systems see the interference only from the antenna main beam. The maximum antenna gain is mentioned in the table. With this assumption the typical antenna pattern is not required.

4.4.4 Compatibility criteria (ref. ITU-R rec. RS.1166-3)

The interference criterion for synthetic aperture radars is an interference-to-noise ratio (I/N) of –6 dB, which corresponds to a 10% performance degradation of the standard deviation of SAR pixel power. The radius of a SAR antenna footprint is 10 - 20 kilometres.

5 COMPATIBILITY STUDIES

5.1 Methodology

In this report each Radio Service, which was considered to be affected, had an own section. Each section included a small explanation of the Service and systems used, and required compatibility parameters were collected to tables from where they are easy to find. In this section the parameters are used for compatibility studies and for each service a summary table is presented.

In the beginning a simple Minimum Coupling Loss method (MCL) is used and a separation distance between interfering Pseudolite and victim system is calculated. The first assumption of the interference risk is also given. In the second phase a statistical, SEAMCAT (Version 3.1.42), simulation is constructed; first a correlated case to see, that results are in line with MCL, and then a full statistical approach to describe the real world as well as possible.

As said, a summary table for consideration is presented in this section, but more detailed information for the studies can be found from the annexes of this report.

5.2 Impact of Pseudolites on RNSS

The required parameters were collected to an Excel sheet, which calculated the separation distances between continuously transmitting PLs and victim RNSS system. There are two calculations (rows) of each victim systems. First calculation with free space loss, and the other calculation, where the agreed 8 dB indoor attenuation is added. A more detailed explanation of the calculations is available in the Annex 1 and the Excel workbook, but a summary of separation distances between the interfering pseudolite and victim RNSS system are presented in Figure 5.1.

Even the worst case separation distances seem to be rather short, from few tens of centimetres to about 15 meters, the average being about four meters for acquisition and about 2 meters for tracking. The indoor case is naturally the most susceptible to PL interference, but the indoor positioning will probably be based on network assistance (see the ARNSS case in the Figure 5.1) and the sensitivity to interference during acquisition is then much less.

MCL calculations between pulsed pseudolites and RNSS receiver were not conducted, because it was assumed that an RNSS receiver can survive with pulse transmitting pseudolites if the aggregated duty cycle of all PLs in the vicinity of RNSS receiver is less than 20 %.

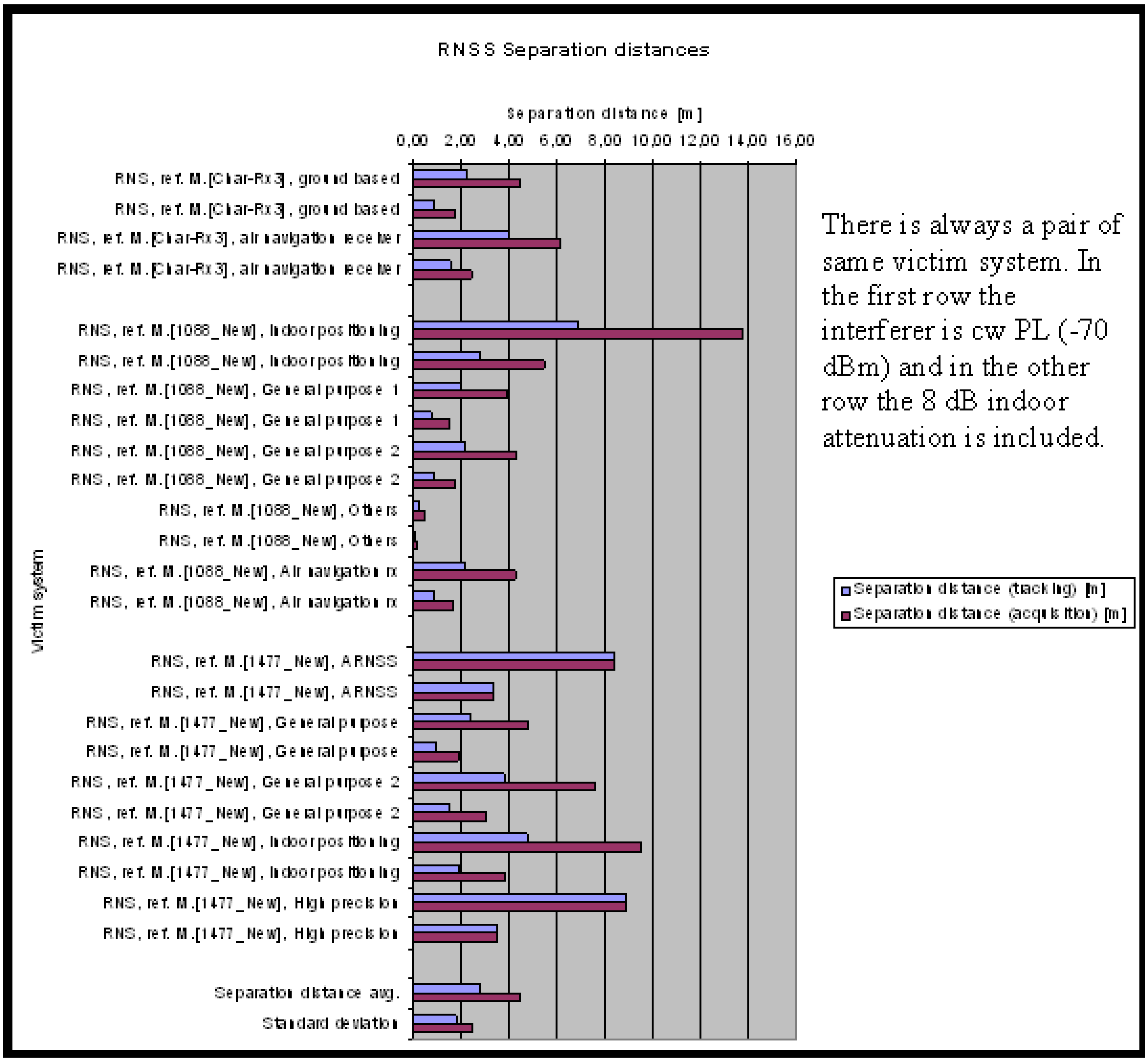


Figure 5.1: Separation distances between the interfering pseudolite and victim RNSS systems.

For SEAMCAT simulations the receiver noise bandwidth, system noise temperature and threshold power density level of aggregate wideband interference in the tables in section 4 were converted to an I/N value. This value was first used in the SEAMCAT correlated cases to check the similarity of separation distances with MCL-calculations. If the correlated case was in line with the MCL-calculation, a statistical SEAMCAT simulation could be conducted. In the Table 5.1 below one may see the summary of the RNSS simulations.

In the first rows in the table one can see that the correlated cases give about the same results than MCL. Here should be noted that this is not quite the case with all RNSS receivers. This is probably because of approximate input values given in the RNSS recommendations.

Statistical simulations between continuously transmitting (-70 dBm) pseudolites and RNSS receivers show that the interference probability is very low.

Detailed simulations between pulsed pseudolites and RNSS receiver were not conducted, because it was assumed that an RNSS receiver can survive with pulse transmitting pseudolites if the aggregated duty cycle of all PLs in the vicinity of RNSS receiver is less than 20 %. However it has been shown that intra system interference is unlikely due to the cross correlation isolation.

See the Annex 1 for more details.

Frequency	Interfering System	Victim Service and System	SEAMCAT scenario	SEAMCAT Conclusions
1176 MHz	CW PLs (-70 dBm)	RNSS (Air-navigation)	Single PL, correlated case; no distributions; I/N criteria -10,1dB; separation distance (Victim Rx - Interfering Tx) is 6,2m	Interference probability jumps to 1 on PLs Pwrlevel of -70 dBm
1227 MHz	CW PLs (-70 dBm)	RNSS (General purpose 1)	PL to RNSS General purpose 1 receiver (tracking); MCL case with I/N criteria 1,7dB and separation distance 1,94m	Interference probability jumps to 1 on PLs Pwrlevel of -70 dBm
1575 MHz	CW PLs (-70 dBm)	RNSS (A-RNSS)	PL to ARNSS correlated case with I/N criteria -7,3 dB and separation distance 8,41 meters	Interference probability jumps to 1 on PLs Pwrlevel of -70 dBm
1575 MHz	CW PLs (-70 dBm)	RNSS (High precision)	PL to RNSS High precision receiver correlated case with I/N criteria -7,8 dB and separation distance 8,91 m	Interference probability jumps to 1 on PLs Pwrlevel of -70 dBm
1176 MHz	CW PLs (-70 dBm)	RNSS (Air-navigation)	6 continuously transmitting PLs to a RNSS receiver in acquisition mode. PL transmitter density is 0.1 1/km², protection distance 10m, activity factor 100% and I/N criteria -10dB	Interference probability 0 %
1176 MHz	CW PLs (-70 dBm)	RNSS (Air-navigation)	6 CW PLs to RNSS rx (acquisition); PL transmitter density 6 1/km², PLs indoors and victim RNSS rx outdoors, protection distance 10m, activity factor 100%; I/N criteria -10dB	Interference probability 0,3%
1227 MHz	CW PLs (-70 dBm)	RNSS (General purpose 1)	6 CW PLs to a RNSS General purpose 1 receiver (tracking); PL transmitter density 0.1 1/km², protection distance 10m, activity factor 100% and I/N criteria 1,7dB	Interference probability 0 %
1227 MHz	CW PLs (-70 dBm)	RNSS (Indoor positioning)	6 CW PLs to a RNSS Indoor positioning receiver (acquisition); Both PLs and RNSS receiver indoors. PL transmitter density 6 1/km², protection distance 10m, activity factor 100% and I/N criteria –15,3dB	Interference probability 0,7%
1575 MHz	CW PLs (-70 dBm)	RNSS (A-RNSS)	6 active CW PLs to A-RNSS receiver; PLs and RNSS receiver outdoors; PL transmitter density 6 1/km², protection distance 10m, antenna heights 10m, activity factor 100%; I/N criteria –7,3dB	Interference probability 1,56%
1575 MHz	CW PLs (-70 dBm)	RNSS (A-RNSS)	6 active CW PLs to A-RNSS receiver; PLs and RNSS receiver outdoors; PL transmitter density 0.1 1/km², protection distance 10m, antenna heights 10m, activity factor 100%; I/N criteria –7,3dB	Interference probability 0%
1575 MHz	CW PLs (-70 dBm)	RNSS (High precision)	6 CW PLs to RNSS receiver (High precision). PL density 6 1/km², protection distance 10m, activity factor 100%, antenna heights 10m; I/N criteria -7,8dB	Interference probability 1,48%
1575 MHz	CW PLs (-70 dBm)	RNSS (High precision)	6 CW PLs to RNSS receiver (High precision). PL density 0.1 1/km², protection distance 10m, activity factor 100%, antenna heights 10m; I/N criteria -7,8dB	Interference probability 0 %

Table 5.1: Summary of the SEAMCAT results

5.3 Impact of Pseudolites on ARNS

Minimum Coupling Loss calculations show that continuously transmitting, low power (-70 dBm) Pseudolite, either indoor or outdoor, does not interfere a DME receiver onboard aircraft provided that the distance between the pseudolite and the aircraft is less than 20 metres. The case is different when a high power (0 dBm), pulsing

Pseudolite is considered. In a worst case a single pulsing Pseudolite may exceed the I/N of -23 dB interference threshold for a DME receiver flying at an altitude of 12000 meters, up to a 160 kilometres distance. It should also be noted that already a single pulsing PL causes a much higher PFD than -141.5 dBW/MHz/m² in the DME receiver.

In table 5.2 the summary of MCL-calculations can be seen and more detailed calculations are available in Annex 2.

Frequency Band	Intefering System	Victim Service and System	MCL Separation Distance	MCL Conclusions
1164-1215 MHz	CW PLs (-70 dBm)	ARNS, DME rx	20 metres	Interference probability low
1164-1215 MHz	CW PLs indoor	ARNS, DME rx	7 metres	Interference probability very low
1164-1215 MHz	pulsing PLs (0 dBm)	ARNS, DME rx	160 km	Interference probability very high
Note: Already a single pulsing PL can cause a PFD of more than -141,5 dBW/MHz/m^2 in a DME Rx				

Table 5.2: PLs to ARNS separation distance calculated using MCL-method

In a single entry, correlated case of SEAMCAT simulation, one can see that the separation distance between pulsing Pseudolite and DME receiver is about 160 kilometres being consistent with the MCL-calculation.

In statistical simulation about a 400 by 400 kilometres area is considered. One thousand pulsing Pseudolites were transmitting in area. Six Pseudolites transmitted in one location and total density of transmitters was 0,00625 transmitters/km². The SEAMCAT concluded to an interference probability of 98 %.

For more details, see Annex 2. From the translation curve in this Annex 2 it can also be seen that interference from low power, continuously transmitting Pseudolites, is negligible.

Frequency	Intefering System	Victim Service and System	SEAMCAT models	SEAMCAT Conclusions
1176 MHz	CW PLs (-70 dBm)	ARNS, DME rx	Single PL correlated case; no distributions used; separation distance 0,02km; I/N criteria -23dB	Interference probability jumps to 1 on PLs Pwrlevel ~-70 dBm, which is in line with the MCL calculations
1176 MHz	CW PLs (-70 dBm)	ARNS, DME rx	6 active CW PLs in DME rx vicinity; density 0,0625 tx/km2 (=10 000 PLs in DME coverage), DME altitude 100m	Interference probability 0%
1176 MHz	CW PLs (-70 dBm)	ARNS, DME rx	6 active CW PLs in DME rx vicinity; density 0,00625 tx/km2 (=1000 PLs in DME coverage), DME altitude 100m	Interference probability 0%
1176 MHz	Pulsed PLs (0dBm)	ARNS, DME rx	Single PL correlated case; no distributions used; distance between VicRX and IntTX 160 km	Interference probability jumps to 1 on PLs Pwrlevel of 0dBm, which is in line with the MCL calculations
1176 MHz	Pulsed PLs (0dBm)	ARNS, DME rx	Pulsed PLs in DME rx vicinity density 0,000625 (=100 PLs in DME coverage), altitude 12000m	Interference probability 98 %
1176 MHz	Pulsed PLs (0dBm)	ARNS, DME rx	Single p-PLs; density 0,000625, altitude 12000m	Interference probability 17 %

Table 5.3: Summary of SEAMCAT simulation results

5.4 Impact of Pseudolites on RDS (RNS and RLS)

Due to the high antenna gain and sensitivity of radars the separation distances calculated using MCL-method, are rather large already in the case of low power continuous wave pseudolites being about 450 meters in the radar antenna main beam. In the case of pulsing pseudolite the distance is unacceptably large, 75 kilometres (beyond the radio horizon – the pseudolite is no longer in visibility from the radar) from the radar antenna main beam and about 13 kilometres from the antenna sidelobes.

The correlated SEAMCAT simulations in the next Table 5.4 show similarity to MCL-calculations if we take into account the small diffraction loss added to the MCL-results in pulsed PL case. The statistical SEAMCAT approaches show very high interference probabilities of the order of 30 - 90 %.

For more details see the Annex 3.

Frequency Band [MHz]	Intefering System	Victim Service and System	MCL Separation Distance	MCL Conclusions
1 215 - 1 300	CW PLs (-70 dBm)	RDS, radar rx, ant. Mainbeam	450 metres	Interference probabability low
1 215 - 1 300	CW PLs (-70 dBm)	RDS, radar rx, ant. Sidelobe	10 metres	Interference probability very low
1 215 - 1 300	CW PLs indoor	RDS, radar rx, ant. Mainbeam	200 metres	Interference probabability low
1 215 - 1 300	CW PLs indoor	RDS, radar rx, ant. Sidelobe	10 metres	Interference probability very low
1 215 - 1 300	pulsing PLs (0 dBm)	RDS, radar rx, ant. Mainbeam	75 kilometres	Interference probability very high
1 215 - 1 300	pulsing PLs (0 dBm)	RDS, radar rx, ant. Sidelobe	13 kilometres	Interference probability very high

Table 5.4: PLs to RDS (radar) separation distance calculated using MCL-method

Frequency Band [MHz]	Intefering System	Victim Service and System	SEAMCAT models	SEAMCAT Conclusions
1215 - 1300	CW PLs (-70 dBm)	RDS S5	Single PL correlated case; no distributions used; separation distance 0,45km; I/N criteria -6dB	Interference probability jumps to 1 on PLs Pwrlevel of -70 dBm, which is in line with the MCL case
1215 - 1300	CW PLs (-70 dBm)	RDS S5	6 PLs in RDS rx vicinity (density 0,003, activity factor 100%); I/N criteria -6dB	Interference probability 0,045%
1215 - 1300	CW PLs (-70 dBm)	RDS S5	6 PLs in RDS rx vicinity (density 0,1, protection distance 100m, activity factor 100%); I/N criteria -6dB	Interference probability 1,4%
1215 - 1300	Pulsed PLs (0 dBm)	RDS S5	Single pulsed PL correlated case; no distributions used; separation distance 75km; I/N criteria -6dB	Interference probability jumps to 1 on PLs Pwrlevel of ~-26 dBm, which is in line with the MCL case after the diffraction loss (-26,6dBm) is taken into account
1215 - 1300	Pulsed PLs (0 dBm)	RDS S5	Single pulsed PL to radar S5, antenna height is 15m, activity factor 100%, protection distance 100m, density 0,003, I/N=-6dB	Interference probability 84%
1215 - 1300	Pulsed PLs (0 dBm)	RDS S5	Single pulsed PL to radar S5, antenna height 15 meters, activity factor 100%, protection distance 10km, density 0,0001, I/N= -6dB	Interference probability 7%

Table 5.5: PLs to RDS (radar) summary of SEAMCAT simulation results

5.5 Impact of Pseudolites on EESS

Here only the EESS satellite main beam case needs to be considered. According to the MCL-calculation a single high power, pulsing pseudolite does interfere neither of the EESS systems. However the criterion may be exceeded if many pulsing pseudolite systems transmit simultaneously in the EESS antenna main beam (about 20 x 20 km).

See Annex 4 for more details.

Frequency Band [MHz]	Intefering System	Victim Service and System	MCL Separation Distance	MCL Conclusions
1 215 - 1 300	pulsing PLs (0 dBm)	EESS active, SAR 1	425 kilometres	Interference probability very low
1 215 - 1 300	pulsing PLs (0 dBm)	EESS active, SAR 2	693 kilometres	Interference probability very low

Table 5.6: PLs to EESS separation distance calculated using MCL-method

Frequency Band [MHz]	Intefering System	Victim Service and System	SEAMCAT models	SEAMCAT Conclusions
1215 - 1300 MHz	pulsing PLs (0 dBm)	EESS SAR1	Single pulsed PL in SAR1 rx vicinity, correlated case, separation distance 425km	Interference probability jumps to 1 on PLs Pwrlevel of 0dBm; in line with the MCL case
1215 - 1300 MHz	pulsing PLs (0 dBm)	EESS SAR1	Single pulse transmitting PL to SAR1; uniform distributions (PL transmitter density 0,0025 1/km2); Interference probability in 0,105%	Interference probability 0,1 %
1215 - 1300 MHz	pulsing PLs (0 dBm)	EESS SAR1	Six pulse transmitting PLs to SAR1; Uniform distributions (PL transmitter density 0,015 1/km2)	Interference probability 2,1 %
1215 - 1300 MHz	pulsing PLs (0 dBm)	EESS SAR2	Single pulsed PL in SAR2 rx vicinity, correlated case, separation distance 693km	Interference probability jumps to 1 on PLs Pwrlevel of 0dBm; in line with the MCL case
1215 - 1300 MHz	pulsing PLs (0 dBm)	EESS SAR2	Single pulse transmitting PL to SAR2; Uniform distributions (PL transmitter density 0,0025 1/km2	Interference probability 0 %
1215 - 1300 MHz	pulsing PLs (0 dBm)	EESS SAR2	Six pulse transmitting PLs to SAR2; Uniform distributions (PL transmitter density 0,015 1/km2)	Interference probability 0%

Table 5.7: PLs to EESS SAR1 and SAR2, summary of SEAMCAT simulation results

5.6.1 Impact of Pseudolites on RAS in the band 1610-1613 MHz

A separation distance between the pseudolite location and a radio astronomy station depending on the unwanted emission power of the pseudolite falling within the RAS band would be sufficient to protect the RAS station from detrimental interference.

Figure 5.2 shows the unwanted emission power spectral density vs the separation distance for a radio astronomy station located in France, assuming a flat terrain and a 0 dBi antenna gain for both the RAS station and the pseudolite (the pseudolite is assumed not to be pointed towards the RAS station). Recommendation P.452-13 was used with a time percentage of 2% to derive this figure.

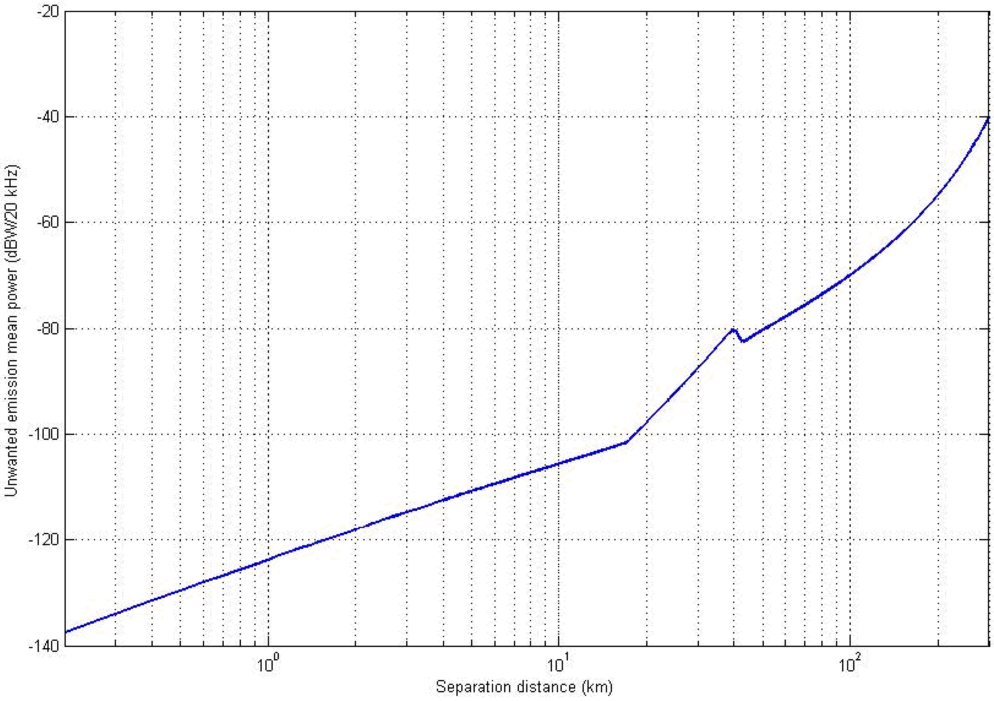


Figure 5.2: Unwanted emission power spectral density vs the separation distance for a radio astronomy station located in France

The peak emission power of pulsed pseudolites is 0 dBm in 2 to 10 MHz, associated with a duty cycle of 7 to 10%. The maximum mean power spectral density in the RNSS band is therefore -60 dBW/20 kHz. As an example, assuming 30 dB attenuation due to the waveform and a possible additional output filter, the unwanted mean emission power would be around -90 dBW/20 kHz, leading to separation distances of around 25 km.

This generic case may be considered as a worst case scenario since it does not take into account any terrain particularities. In practice, the separation distance should be calculated on a case by case basis using the actual terrain particularities existing around the radio astronomy station. The next Figures 5.3 and 5.4 show the required unwanted emission mean power (in dBW/20 kHz) around the location of Nançay in France, taking into account the terrain elevation around the RAS station. Still assuming a 30 dB rejection for unwanted emissions, only the dark blue area around the RAS station would have to be avoided.

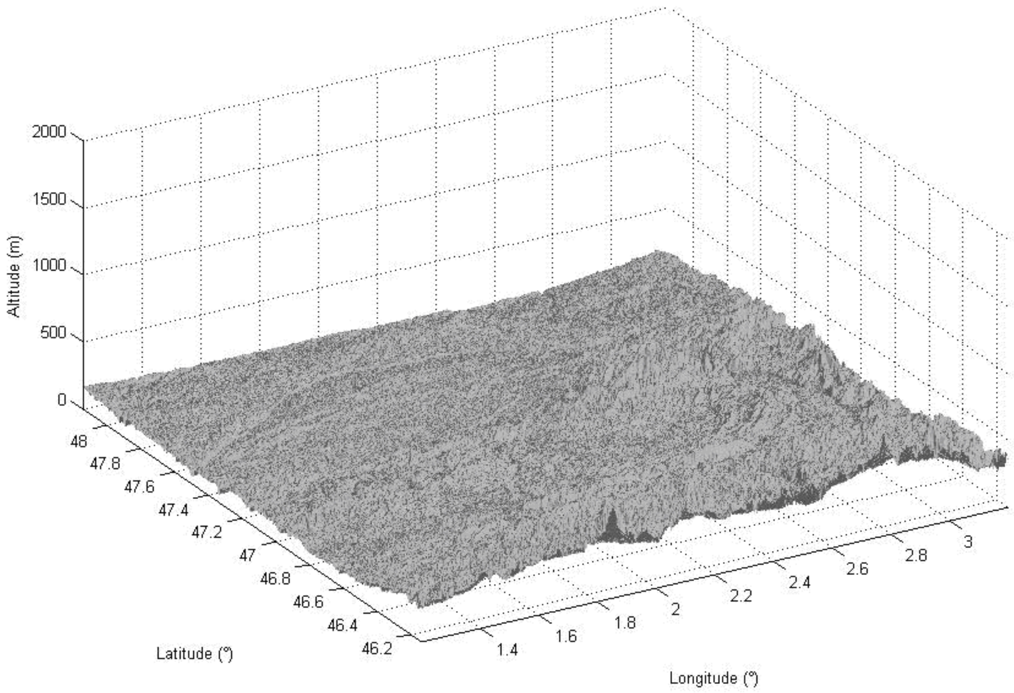


Figure 5.3: Terrain elevation around the RAS station

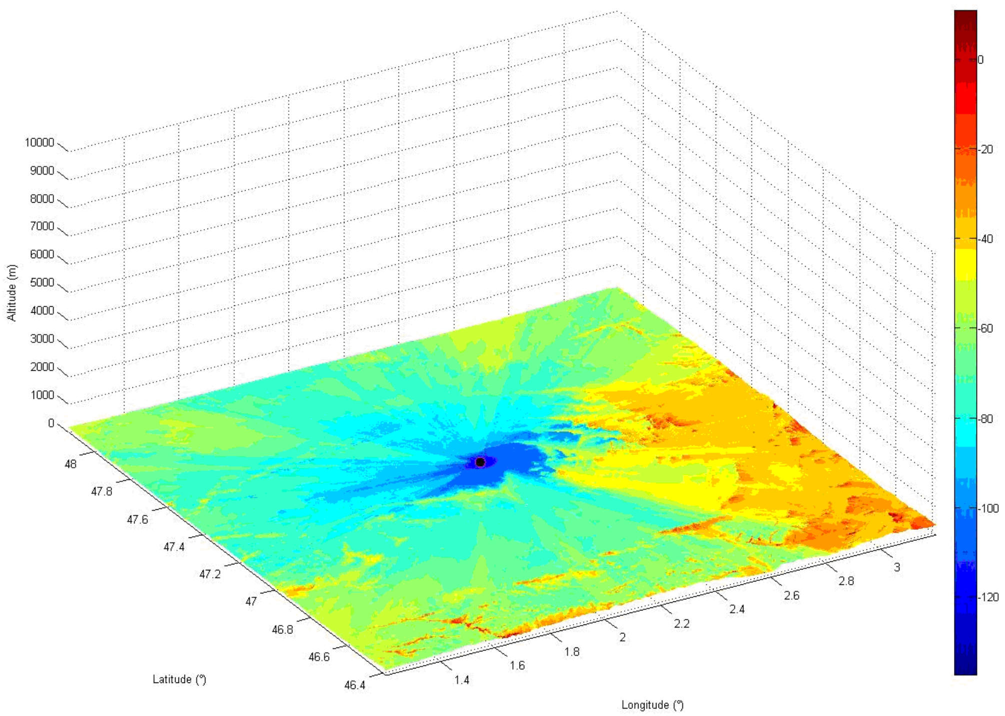


Figure 5.4: Required unwanted emission mean power (in dBW/20 kHz) around the location of Nançay in France, taking into account the terrain elevation around the RAS station

6 CONCLUSIONS

6.1 Band 1164-1215 MHz, ARNS

Aeronautical Radio Navigation Service (ARNS) is a safety related service and should be carefully protected from interference. The protection criterion is I/N = - 6 dB and does not include any relaxation for example as function of time (Fractional Degradation of Performance, FDP). The ARNS receivers are located on board aircraft on all altitudes up to 12000 meters and the radio propagation environment is already rather difficult.

An aggregated PFD limit of -144.5 dBW/m²/MHz to protect ARNS from RNSS was assumed.

Because of the low power level of continuously transmitting Pseudolites and natural separation distances between ARNS one can conclude that sharing/compatibility is feasible with this kind of pseudolites.

Sharing/compatibility between Pulse transmitting Pseudolites and ARNS are not feasible.

6.2 Band 1164-1215 MHz, RNSS

Radio Navigation Satellite Systems are spread spectrum systems. Because of the code gain, the RNSS receiver tolerates wideband interference up to the receiver noise level. The EIRP levels of continuously transmitting Pseudolites are low and separation distances between RNSS receivers and Pseudolites are few meters.

The RNSS receiver tolerates also to some extent pulsed interference. The RNSS receiver saturates during the interfering pulse, but after short recovery time can receive the slightly degraded satellite signals. According to the theory the maximum acceptable pulse duty cycle for all pulsing pseudolites in the vicinity of RNSS receiver is 20 %.

Sharing/compatibility between continuously transmitting Pseudolites and RNSS are feasible.

Sharing/compatibility between pulse transmitting Pseudolites and RNSS is feasible if the duty cycle of all pulsing pseudolites seen by the RNSS receiver is less than 20 %.

6.3 Band 1215-1300 MHz, RDS

Radiodetermination Service (RDS) is a safety related service and should be carefully protected from interference. The protection criterion considered is I/N = - 6 dB to be met 100% of the time.

Due to the high antenna gain and sensitivity of radars the separation distances are rather large already in the case of continuously transmitting Pseudolites, becoming unacceptable in the case of pulse transmitting Pseudolites.

Sharing/compatibility between Pseudolites and Radio determination Service is possible if

1) There is a frequency separation between Pseudolites and radars

or

2) There is a separation distance between Pseudolites and radars.

6.4 Band 1215-1300 MHz, EESS

An EESS system scans the surface of the Earth with its antenna main beam. During scan the antenna footprint is about 20 km x 20 km area. One single pulse transmitting Pseudolite in the antenna footprint can not cause interference to EESS systems. If the number of Pseudolites in the footprint increases aggregated average interference power level in the EESS receiver may be exceeded.

Sharing/compatibility between continuously transmitting Pseudolites and EESS is feasible.

Sharing/compatibility between pulse transmitting Pseudolites and EESS is also feasible due to the high processing gain of the SAR system

6.5 Band 1215-1300 MHz, RNSS

Radio Navigation Satellite Systems are spread spectrum systems. Because of the code gain, the RNSS receiver tolerates wideband interference up to the receiver noise level. The EIRP levels of continuously transmitting Pseudolites are low and separation distances between RNSS receivers and Pseudolites are few meters.

The RNSS receiver tolerates also to some extent pulsed interference. The RNSS receiver saturates during the interfering pulse, but after short recovery time can receive the slightly degraded satellite signals. According to the theory the maximum acceptable pulse duty cycle for all pulsing pseudolites in the vicinity of RNSS receiver is 20 %.

Sharing/compatibility between continuously transmitting Pseudolites and RNSS is feasible.

Sharing/compatibility between pulse transmitting Pseudolites and RNSS is feasible if the duty cycle of all pulsing pseudolites seen by the RNSS receiver is less than 20 %.

6.6 Band 1559-1610 MHz RNSS

Radio Navigation Satellite Systems are spread spectrum systems. Because of the code gain, the RNSS receiver tolerates wideband interference up to the receiver noise level. The EIRP levels of continuously transmitting Pseudolites are low and separation distances between RNSS receivers and Pseudolites are few meters.

The RNSS receiver tolerates also to some extent pulsed interference. The RNSS receiver saturates during the interfering pulse, but after short recovery time can receive the slightly degraded satellite signals. According to the theory the maximum acceptable pulse duty cycle for all pulsing pseudolites in the vicinity of RNSS receiver is 20 %.

Sharing/compatibility between continuously transmitting Pseudolites and RNSS are feasible.

Sharing/compatibility between pulse transmitting Pseudolites and RNSS is feasible if the duty cycle of all pulsing pseudolites seen by the RNSS receiver is less than 20 %.

6.7 Band 1610-1613 MHz, RAS

Sharing/compatibility between Pseudolites and Radio Astronomy Service is possible if

1) **There is a separation distance (protection zone) between Pseudolites and Radio Astronomical Station.**

and/or

2) **The unwanted emission power in the Radio Astronomy band is limited.**

6.8 Summary of the conclusions

The main conclusions are collected band by band and Service by Service to the following picture.

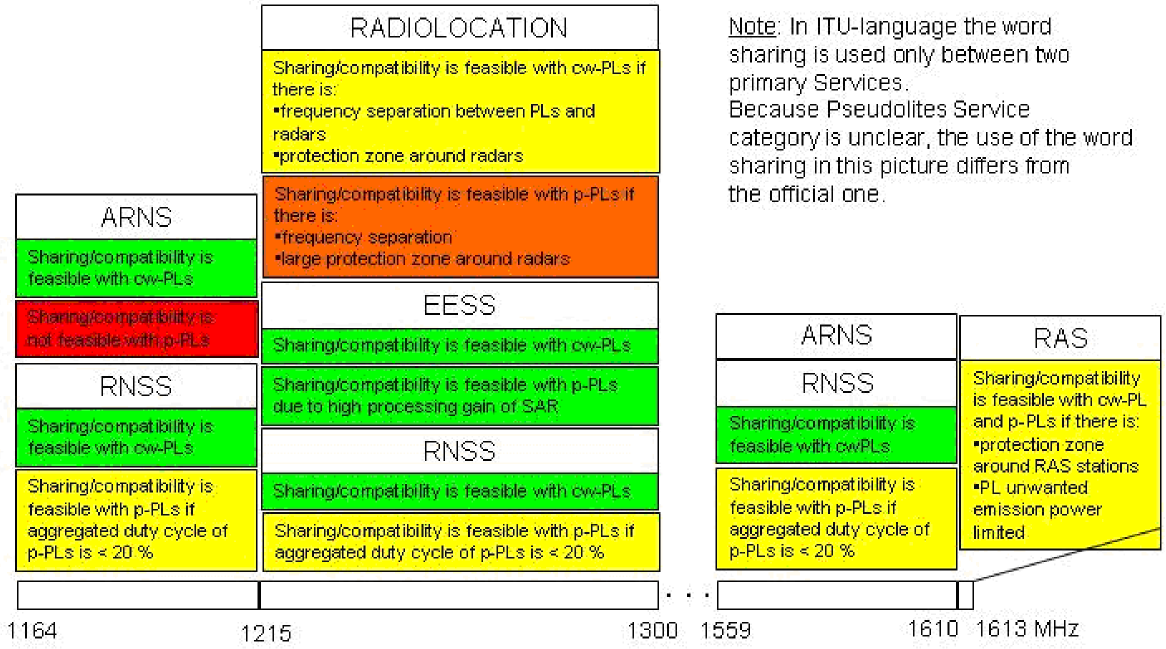
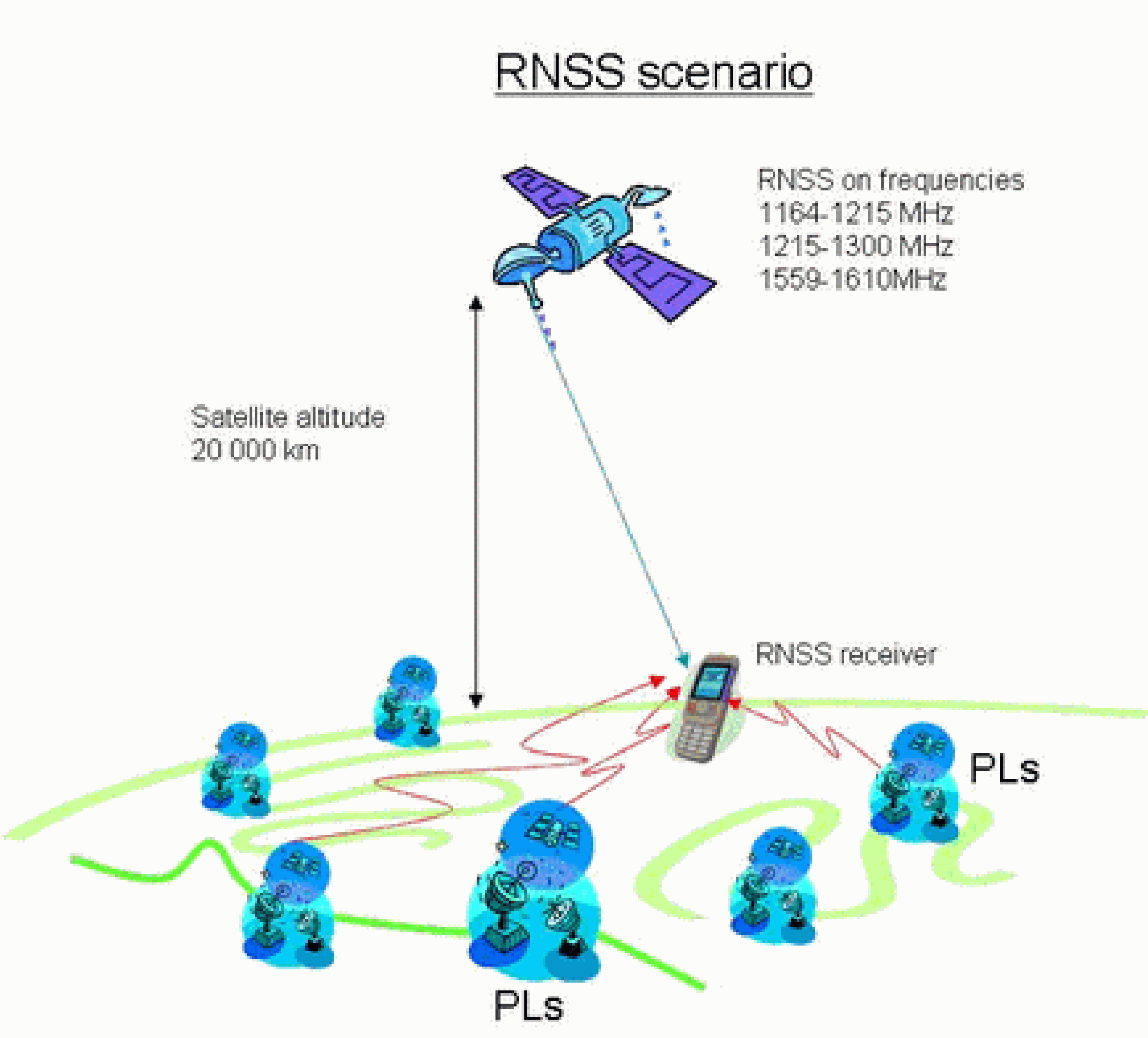


Figure 6.1*:* Main conclusions of the sharing/compatibility studies

ANNEX 1: IMPACT OF PSEUDOLITES ON RNSS



A1.1 Introduction

The impact of Pseudolites on RNSS is evaluated considering a simple scenario depicted in the Figure above. First the separation distance required by a RNSS receiver operating in the presence of an unwanted Pseudolite signal, and vice versa, is determined by the Minimum Coupling Loss (MCL) method for each considered system scenario. After the MCL calculations SEAMCAT simulations are conducted in order to further investigate the interference probability between the two systems.

The protection criteria of RNSS are for noise like interference signals. In addition RNSS receivers are subjected to pulsed RF interference e.g. from Radiolocation radars and ARNS transmitters. A pulsed Pseudolite system can also be a source of such interference. In the main document (section 2.5.3) it is noted that that a single-bit RNSS receiver would tolerate about a 20% duty cycle before interference causes signals to be lost. This value could be considered as a compatibility criterion for pulse transmitting Pseudolites. Thus, if a RNSS receiver receives more than two saturating signals from pulsing PLs (duty cycle 10 %) simultaneously, the criterion is exceeded. In these evaluations the theoretical maximum acceptable duty cycle for all pulsing Pseudolites in the vicinity of a RNSS receiver is considered to be 20%. (Although, empirical tests suggest that in practice duty cycles of 35-40% can be used.)

A1.2 MCL calculations

The separation distances between the interfering Pseudolite and victim RNSS system are calculated first by the MCL method and the obtained results are presented in Table A1.1.

	Frequency [MHz]	Bandwidth [MHz]	TX [dBm]	Addit. attenuation. eg.	TX antennagain [dBi]	Typical wanted signal level [dBm]	RX bandwidth [MHz]	Rx noise temperature [K]	Rx noisefigure [dB]	RX antenna gain [dBi]	Noise floor in PL bandwidth [dBm]	Rx noise floor [dBm]	Wideband int. power density level (tracking) [dBm]	Wideband int. power density level (acquisition) [dBm]	I/N [dB] tracking	I/N [dB] acquisition	Separation distance (tracking) [m]	Separation distance (acquisition) [m]	Victim Service and system
CW PL	**1207**	**10**	**-70**	**0**	**11**	**-138**	**24**	**330**	**3,3**	**0**	**-100,7**	**-96,9**	**-96,20**	**-102,20**	**0,7**	**-5,3**	**2,22**	**4,42**	RNS, ref. M.[Char-Rx3], ground based
CW PL, indoor	1207	10	-70	8	11	-138	24	330	3,3	0	-100,7	-96,9	-96,20	-102,20	0,7	-5,3	**0,88**	**1,76**	
CW PL	**1176**	**10**	**-70**	**0**	**11**	**-138**	**24**	**727**	**5,4**	**0**	**-98,6**	**-94,7**	**-100,99**	**-104,90**	**-6,2**	**-10,1**	**3,95**	**6,20**	RNS, ref. M.[Char-Rx3], air navigation receiver
CW PL, indoor	1176	10	-70	8	11	-138	24	727	5,4	0	-98,6	-94,7	-100,99	-104,90	-6,2	-10,1	**1,57**	**2,47**	
CW PL	**1227**	**10**	**-70**	**0**	**11**	**-150**	**24**	**330**	**3,3**	**0**	**-100,7**	**-96,9**	**-106,20**	**-112,20**	**-9,3**	**-15,3**	**6,90**	**13,76**	RNS, ref. M.[1088_New], indoor positioning
CW PL, indoor	1227	10	-70	8	11	-150	24	330	3,3	0	-100,7	-96,9	-106,20	-112,20	-9,3	-15,3	**2,75**	**5,48**	
CW PL	**1227**	**10**	**-70**	**0**	**11**	**-140**	**24**	**330**	**3,3**	**0**	**-100,7**	**-96,9**	**-95,20**	**-101,20**	**1,7**	**-4,3**	**1,94**	**3,88**	RNS, ref. M.[1088_New], General purpose 1
CW PL, indoor	1227	10	-70	8	11	-140	24	330	3,3	0	-100,7	-96,9	-95,20	-101,20	1,7	-4,3	**0,77**	**1,54**	
CW PL	**1227**	**10**	**-70**	**0**	**11**	**-140**	**24**	**330**	**3,3**	**0**	**-100,7**	**-96,9**	**-96,20**	**-102,20**	**0,7**	**-5,3**	**2,18**	**4,35**	RNS, ref. M.[1088_New], General purpose 2
CW PL, indoor	1227	10	-70	8	11	-140	24	330	3,3	0	-100,7	-96,9	-96,20	-102,20	0,7	-5,3	**0,87**	**1,73**	
CW PL	**1278**	**10**	**-70**	**0**	**11**	**-140**	**24**	**330**	**3,3**	**0**	**-100,7**	**-96,9**	**-77,20**	**-83,20**	**19,7**	**13,7**	**0,23**	**0,47**	RNS, ref. M.[1088_New], Others
CW PL, indoor	1278	10	-70	8	11	-140	24	330	3,3	0	-100,7	-96,9	-77,20	-83,20	19,7	13,7	**0,09**	**0,19**	
CW PL	**1246**	**10**	**-70**	**0**	**11**	**-140**	**30**	**400**	**3,8**	**0**	**-100,2**	**-95,5**	**-95,23**	**-101,23**	**0,2**	**-5,8**	**2,15**	**4,29**	RNS, ref. M.[1088_New], Air navigation rx
CW PL, indoor	1246	10	-70	8	11	-140	30	400	3,8	0	-100,2	-95,5	-95,23	-101,23	0,2	-5,8	**0,86**	**1,71**	
CW PL	**1575**	**2**	**-70**	**0**	**11**	**-150**	**31**	**513**	**4,4**	**0**	**-106,6**	**-94,7**	**-102,03**	**-102,03**	**-7,3**	**-7,3**	**8,41**	**8,41**	RNS, ref. M.[1477_New], ARNSS
CW PL, indoor	1575	2	-70	8	11	-150	31	513	4,4	0	-106,6	-94,7	-102,03	-102,03	-7,3	-7,3	**3,35**	**3,35**	
CW PL	**1575**	**2**	**-70**	**0**	**11**	**-140**	**32**	**645**	**5,1**	**0**	**-105,9**	**-93,9**	**-90,95**	**-96,95**	**2,9**	**-3,1**	**2,40**	**4,78**	RNS, ref. M.[1477_New], General purpose
CW PL, indoor	1575	2	-70	8	11	-150	32	645	5,1	0	-105,9	-93,9	-90,95	-96,95	2,9	-3,1	**0,95**	**1,90**	
CW PL	**1575**	**2**	**-70**	**0**	**11**	**-140**	**5**	**330**	**3,3**	**0**	**-107,7**	**-103,7**	**-103,01**	**-109,01**	**0,7**	**-5,3**	**3,80**	**7,58**	RNS, ref. M.[1477_New], General purpose 2
CW PL, indoor	1575	2	-70	8	11	-140	5	330	3,3	0	-107,7	-103,7	-103,01	-109,01	0,7	-5,3	**1,51**	**3,02**	

CW PL	**1575**	**2**	**-70**	**0**	**11**	**-150**	**32**	**645**	**5,1**	**0**	**-105,9**	**-93,9**	**-96,95**	**-102,95**	**-3,1**	**-9,1**	**4,78**	**9,54**	RNS, ref. M.[1477_New], indoor positioning
CW PL, indoor	1575	2	-70	8	11	-150	32	645	5,1	0	-105,9	-93,9	-96,95	-102,95	-3,1	-9,1	**1,90**	**3,80**	
CW PL	**1575**	**2**	**-70**	**0**	**11**	**-140**	**31**	**513**	**4,4**	**0**	**-106,6**	**-94,7**	**-102,53**	**-102,53**	**-7,8**	**-7,8**	**8,91**	**8,91**	RNS, ref. M.[1477_New], High precision
CW PL, indoor	1575	2	-70	8	11	-140	31	513	4,4	0	-106,6	-94,7	-102,53	-102,53	-7,8	-7,8	**3,55**	**3,55**	
												Separation distance avg.					**2,79**	**4,46**	
	Cells filled by yellow color = there is no definite input in the relevant recommendations; the data is only concluded											**Standard deviation**					**1,78**	**2,41**	

Table A1.1: Pseudolites to RNSS receiver interference calculation using the MCL method

In the MCL calculations the used RX antenna gain [dBi] towards interference is 0dBi in all the cases. The Interference-to-Noise I/N Ratios (in Table A1.1) are used in the SEAMCAT simulations as the compatibility criterion.

A1.3 SEAMCAT simulations

The SEAMCAT simulations are conducted in order to determine the statistical compatibility between the Pseudolite and Radio Navigation Satellite Systems (RNSS). First the consistency between the SEAMCAT scenario and the MCL calculations is checked by a simple correlated simulation case without any distributions. After this a more realistic scenario is depicted by full statistical simulations. The simulation characteristics as well as the relevant parameters for the studied RNSS services are presented in the following sections.

<u>Propagation model</u>

In addition to open areas pseudolites are used in cluttered environments where the satellite signals are completely unavailable or have reduced visibility. Thus, for ground-to-ground cases, the used propagation model is the Extended Hata (as implemented in SEAMCAT). In ground-to-space and space-to-ground cases, as well as in the initial MCL simulations, LOS conditions are assumed and the Free Space Loss model (as implemented in SEAMCAT) is applied. The default attenuation values of the Extended Hata model are shown in Figure A1.1.

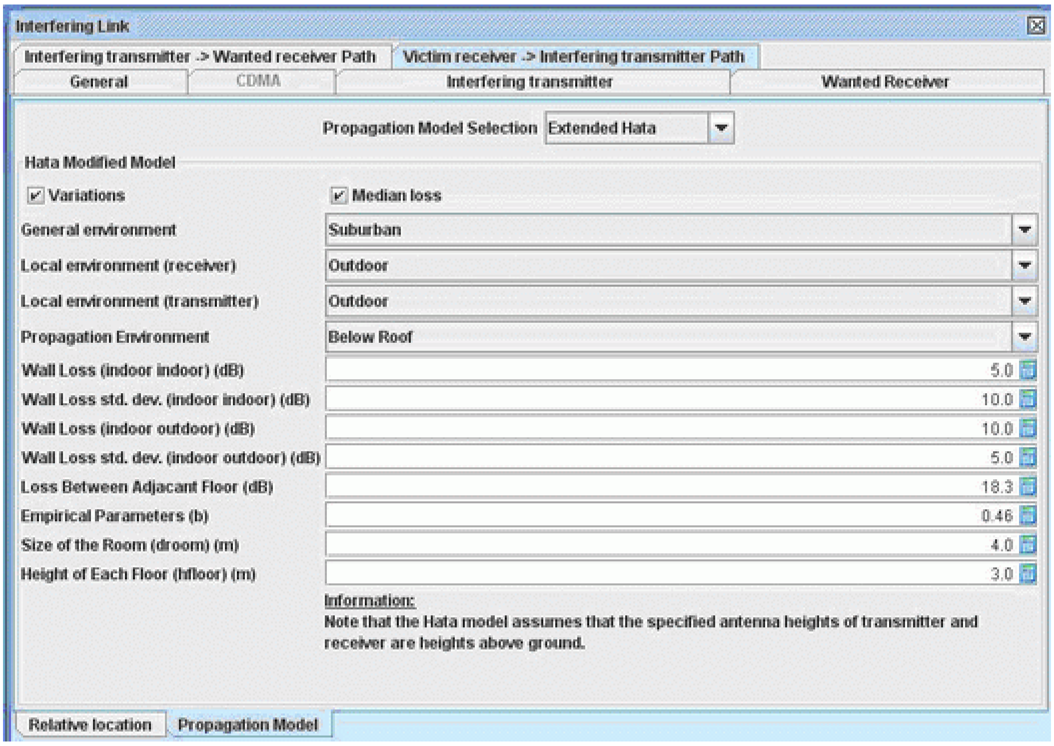


Figure A1.1: Default SEAMCAT attenuation parameters of the Extended Hata propagation model

Model	Frequency range	Distance range	Typical application area
P.1546 model	30 MHz - 3 GHz	1-1000 km	Broadcasting and other terrestrial services, typically considered in cases with high mounted transmitter antenna (e.g. above 50-60 m)
Extended Hata	30 MHz - 3 GHz	Up to 100 km	Mobile services and other services working in non-LOS/cluttered environment
Extended Hata-SRD	30 MHz - 3 GHz	Up to 300 m	Short range links under direct-LOS assumption, important: **antenna heights up to 3 m**
Spherical diffraction	Above 3 GHz	Up to and beyond radio horizon	Interference on terrestrial paths in predominantly open (e.g. rural) areas
Free Space Loss	Above 30 MHz	LOS-limited	Fixed links and other systems/paths were direct-LOS could be assumed

Table A1.2: SEAMCAT propagation models

The relevant simulation parameters for the RNSS services are taken from the ITU-R draft recommendations (see Table A1.1) and the summary of the simulation scenarios is presented in Table A1.3.

SEAMCAT parameters	Victim: RNSS receiver	Interfering System: CW PLs
Frequency [MHz]	1176, 1207, 1227 and 1575	
Transmit power P_{TX} [dBm]	-	-70
Noise floor [dBm]	Noise floor in PL bandwidth (Table A1.1)	
Bandwidth [MHz]	5 - 32 (for each system see Table A1.11)	2 or 10
Antenna azimuth [deg]	0...360° uniform distribution	0...360° uniform distribution
Antenna height [m]	2	2 (rx), 10 (tx)
Antenna peak gain [dBi]	0	11 (Tx)
Interference criteria	Interference-to Noise ratio, I/N [dB] (see Table A1.1, tracking / acquisition)	
Distance between **InterferingTx -Victim Rx**	• MCL case: see TableA1.1, separation distance (tracking / acquisition) • Otherwise uniform distribution in the simulation area • Victim Rx-Tx: 20 000 km	

Propagation model	• MCL and space-to-ground cases: Free Space
	• Otherwise: Extended Hata, Suburban (below roof)
	  o both interfering PL and Victim RNSS Rx and Tx outdoor
	  o interfering PL Rx and Tx indoors and victim Rx outdoors	

Interfering transmitters	• MCL case: Single transmitter
	• Otherwise: 6 active CW PLs
	  o density 0,1 tx/km^2, protection distance 10 or 100 m
	  o density 1tx/km^2, protection distance 10 or 100 m
	  o high density trial: 6 tx/km^2, protection distance 10 or 100 m	

Table A1.3: SEAMCAT simulation scenario parameters for RNSS services

The parameters for RNSS transmitters are not required in the simulations, since the desired received signal strength (dRSS) of the wanted signal is set manually (fixed value). Thus, the interference evaluations are made using desired signal strength values for each system. The used dRSS values are given in Table A1.1 as the typical wanted signal values for each service.

Examples of the graphical simulation scenarios are given in Figure A1.2.

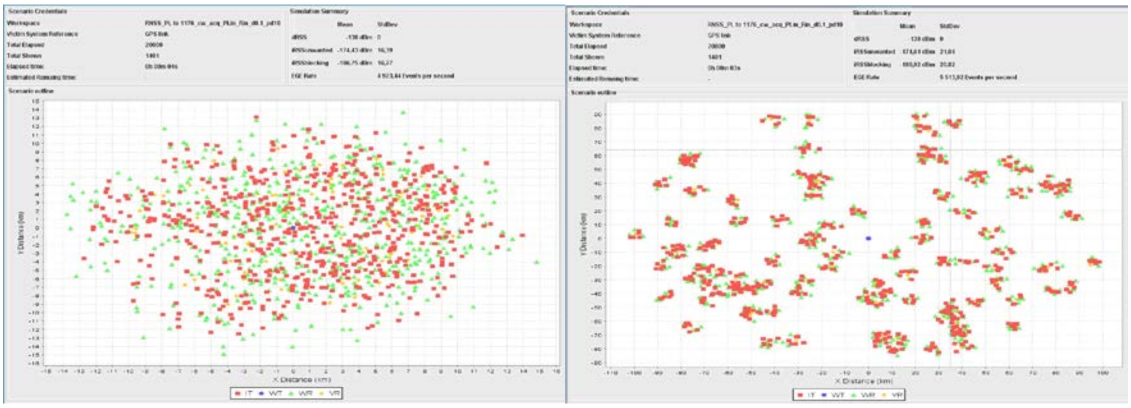


Figure A1.2: Example of simulation scenarios for RNSS receivers with simulation radius 10km and 100km, respectively. (red dots=actively transmitting PL (6 PLs in each PL system), blue dot=RNSS Tx, green dots=PL receivers, yellow dots=RNSS receivers)

<u>RNSS Air-navigation receivers (space-to-Earth) operating in the band 1164-1215 MHz</u>

In the simulations both, the interfering PL and victim RNSS, systems are assumed to operate on same 1176 MHz frequency. [ITU-R rec M.[CHAR-RX3]]

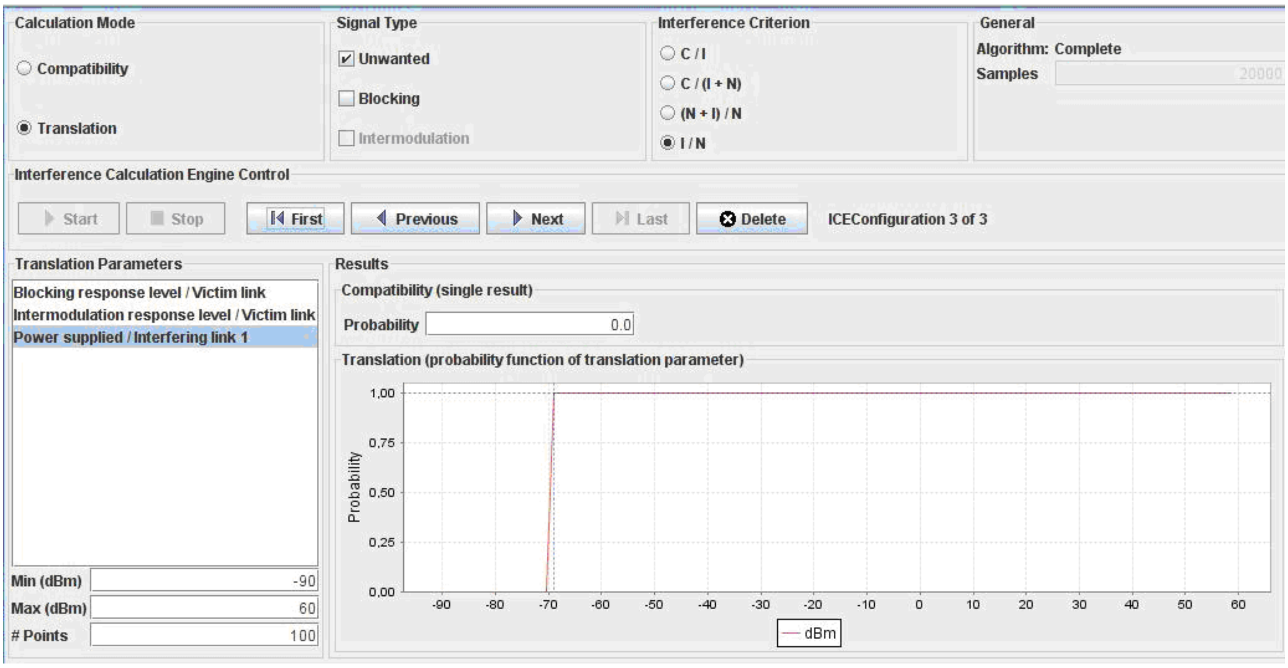


Figure A1.3: PL to RNSS; MCL case with I/N criteria -10dB and separation distance 6,2m (acquisition mode) (ref. RNSS_PL to 1176_cw_MCL_acq.sws)

The correlated case results for the RNSS receiver in acquisition mode (see Figure A1.3) reveal that simulation scenario is consistent with the MCL calculations as the interference probability jumps to 1 at PL transmit power level of -70dBm.

In the statistical simulations both the interfering transmitter and the interfered RNSS receiver are uniformly distributed in the simulated area. The results of the statistical approach (for the RNSS receiver in acquisition mode) are presented in Table A1.4, and two examples in Figures A1.4 and A1.5. The results are evaluated for interfering PL densities of 0.1, 1 and 6 active PLs per square kilometre. The evaluations are made using both indoor and outdoor propagation scenarios as implemented in SEAMCAT.

Interference probability **1 176 MHz RNSS Air-navigation (acquisition)** **%**	**Propagation; Extended Hata (suburban, below roof), Propagation model parameters (SEAMCAT default values)**			
	Interfering PL Rx+Tx and Victim RNSS Rx+Tx outdoor		**Interfering PL Rx and Tx indoors and victim Rx outdoors**	
Protection distance [m]	**10**	**100**	**10**	**100**
PL Tx density 0.1 Tx/km^2	**0**	**0**	**0**	**0**
PL Tx density 1 Tx/km^2	**0.195**	**0.055**	**0.04**	**0.01**
PL Tx density 6 Tx/km^2	**1.015**	**0.485**	**0.225**	**0.09**

Table A1.4: SEAMCAT simulation results for RNSS Air-navigation receivers

It can be seen that the interference probability in CW Pseudolite scenarios remains low (0-1%) both indoor and outdoor cases with PL densities 0.1-6 Tx/km^2. As the PL density increases (6 PL/km^2) the probability of interference inherently rises, although remaining at 1% or below in all the scenarios.

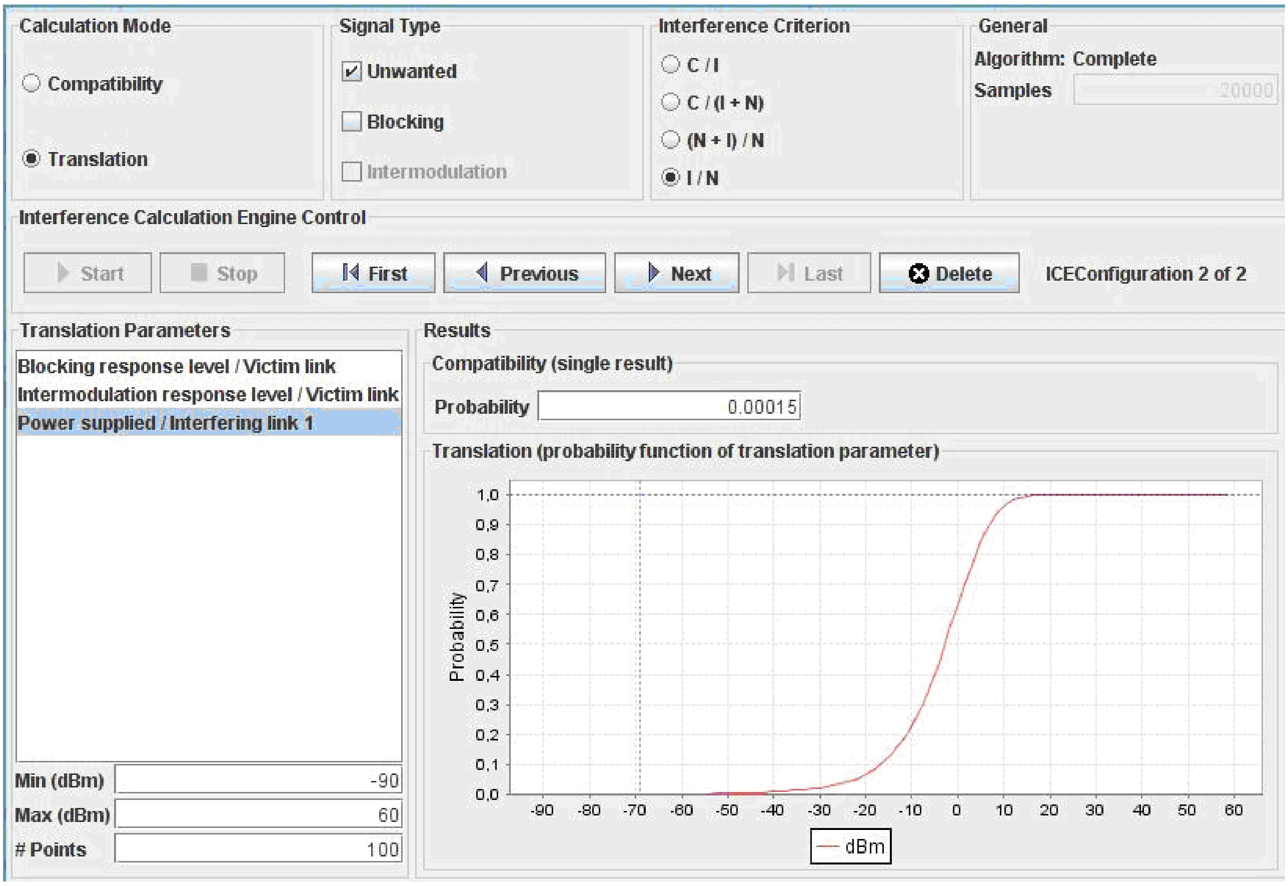


Figure A1.4: 6 continuously transmitting PLs to a RNSS receiver in acquisition mode. PL transmitter density is 0.1 1/km², protection distance 10m, activity factor 100% and I/N criteria -10dB (RNSS_PL to 1176_cw_acq_pd10_d0.1_out.sws). Interference probability is ~0%.

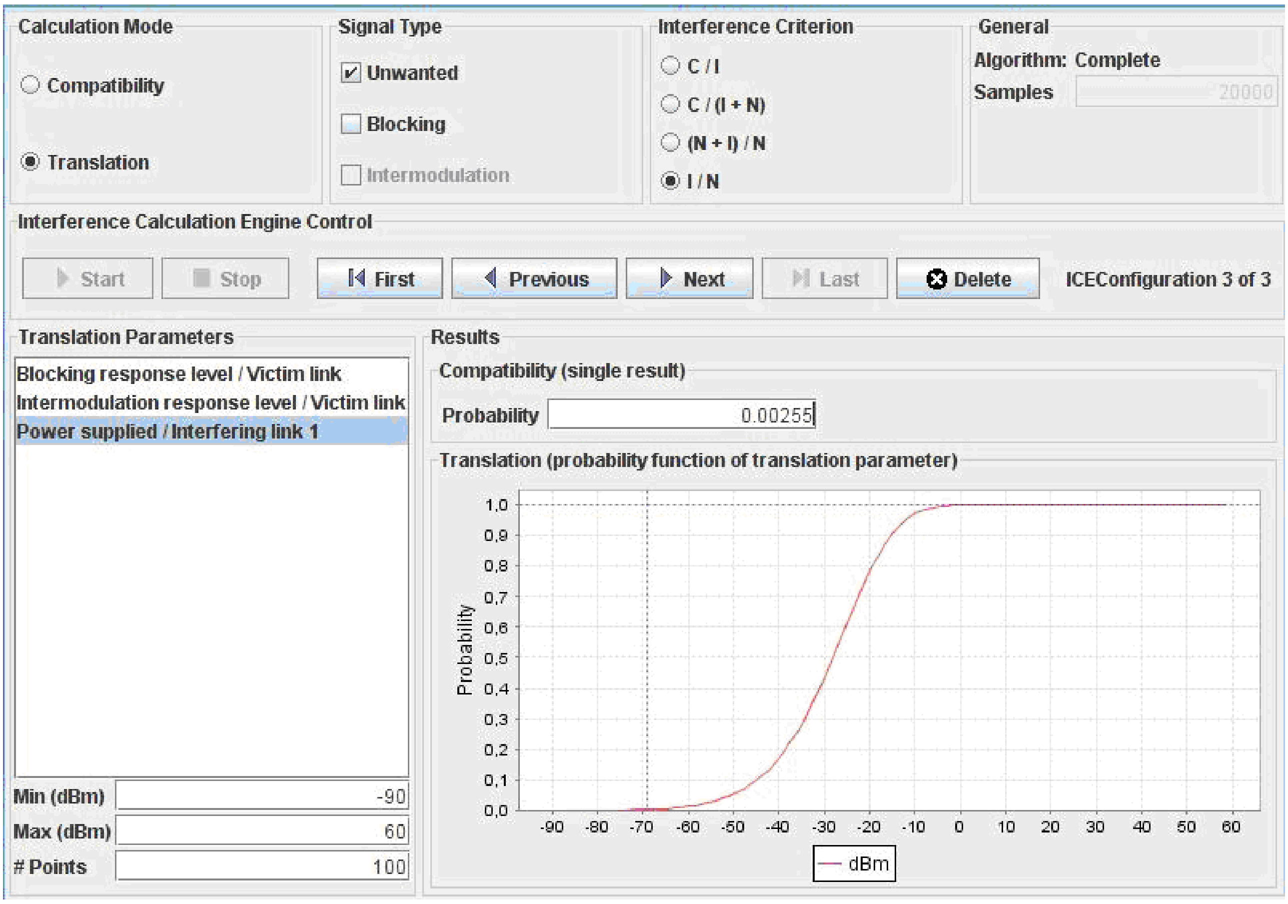


Figure A1.5: 6 continuously transmitting PLs to a RNSS receiver in acquisition mode. PL transmitter density is 6 1/km², PLs are located indoors and victim RNSS receiver outdoors, protection distance 10m, activity factor 100% and I/N criteria -10dB (Ext.Hata suburban, below roof propagation). Interference probability is ~0.3% (RNSS_PL to 1176_cw_acq_pd10_d6_in.sws).

A1.4 SEAMCAT Conclusions (1164-1215 MHz)

In the simulated CW Pseudolite scenarios the interference probability remains very low both indoor and outdoor scenarios with PL densities 0.1-6 Tx/km^2 and protection distances 10-100 meters. Thus, sharing / compatibility between continuously transmitting Pseudolites and RNSS is feasible.

Considering the pulsed Pseudolite case, it has been stated in the main document that a RNSS receiver tolerates to some extend also pulsing interference. According to the theory the maximum acceptable pulse duty cycle for all pulsing pseudolites in the vicinity of RNSS receiver is 20 %. Thus, according to this, sharing /compatibility between pulsed PL and RNSS receiver is feasible if the duty cycle of all pulsing Pseudolites seen by the RNSS receiver is less than 20 %.

<u>RNSS - General purpose 1 receivers (space-to-Earth) operating in the band 1215-1300 MHz</u>

In the simulations both, the interfering PL and the victim RNSS receivers are assumed to operate on the same 1227 MHz frequency. The correlated case is consistent with the MCL results (Figure A1.6). [ITU-R Rec M.[1088_NEW]]

The results of the statistical approach are gathered in Table A1.5.

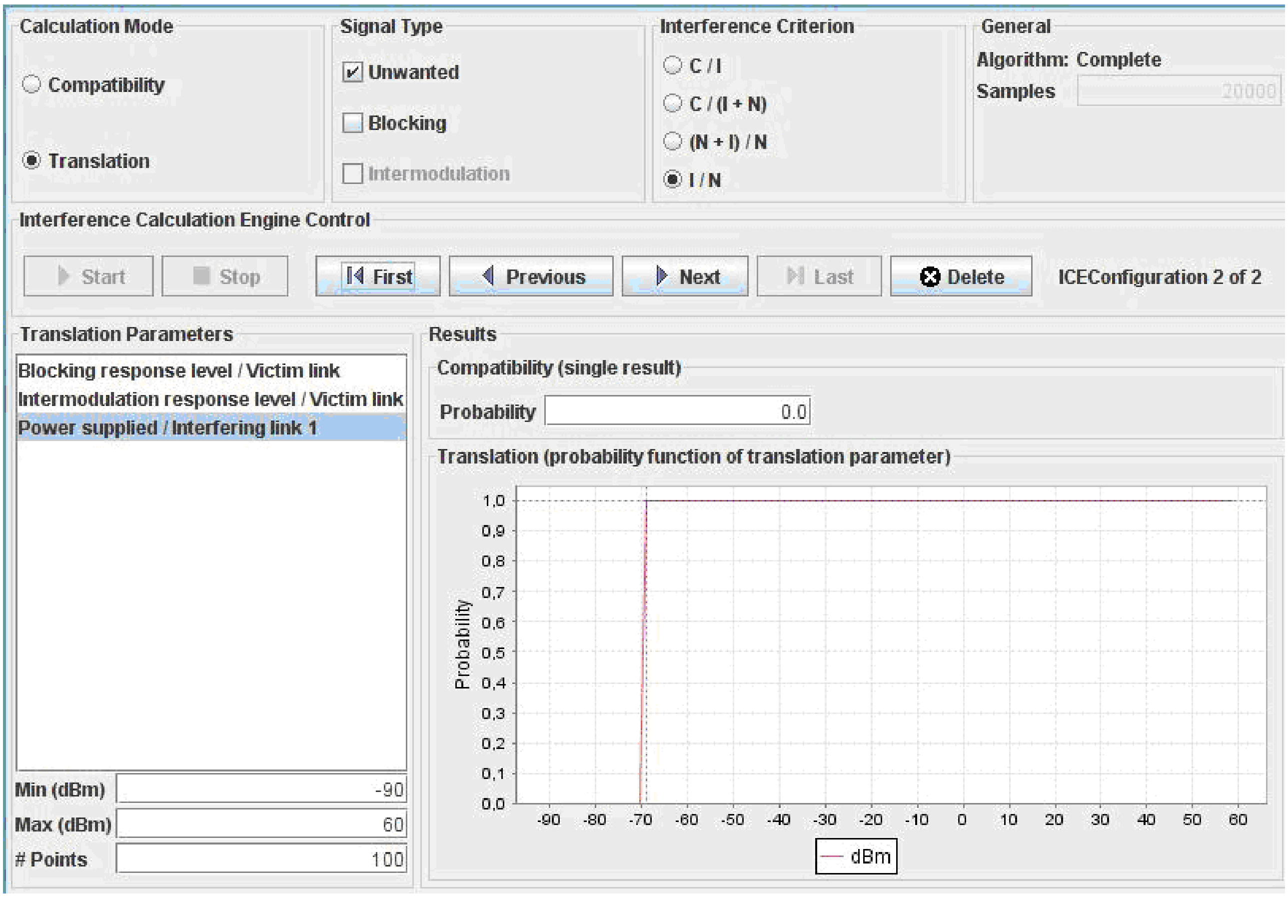


Figure A1.6: PL to RNSS General purpose 1 receiver (tracking); MCL case with I/N criteria 1.7dB and separation distance 1.94m (ref. RNSS_PL to 1227_cw_MCL_track_general1.sws).

Interference probability 1227 MHz RNSS general purpose 1 (tracking) %	Propagation; Extended Hata (suburban, below roof), Propagation model parameters (SEAMCAT default values)			
	Interfering PL Rx+Tx and Victim RNSS Rx+Tx outdoor		Interfering PL Rx and Tx indoors and victim Rx outdoors	
Protection distance [m]	**10**	**100**	**10**	**100**
PL Tx density 0.1 Tx/km^2	**0**	**0**	**0**	**0**
PL Tx density 1 Tx/km^2	**0**	**0**	**0**	**0**
PL Tx density 6 Tx/km^2	**0.005**	**0**	**0**	**0**

Table A1.5: SEAMCAT simulation results for RNSS General purpose receivers

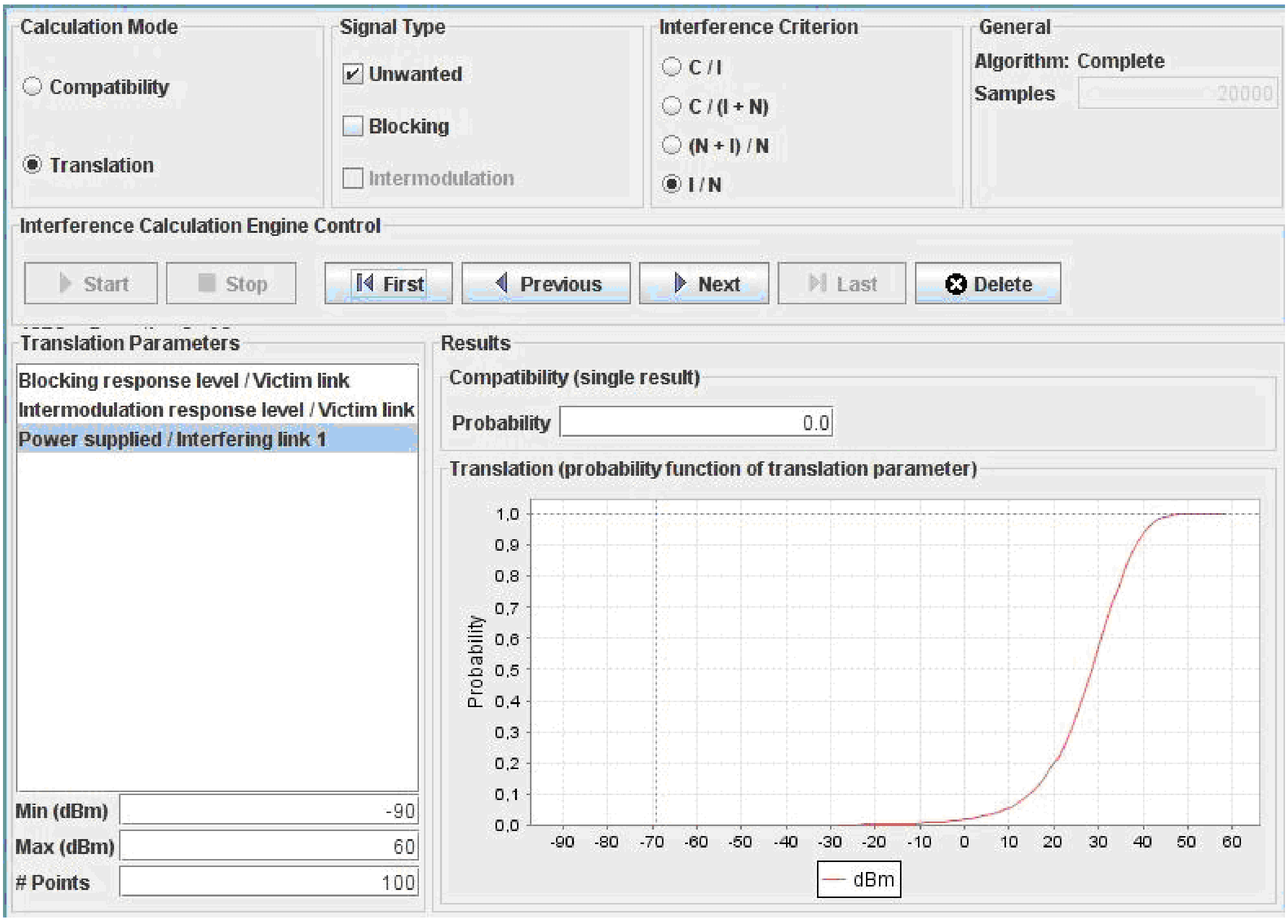


Figure A1.7: 6 continuously transmitting PLs to a RNSS General purpose 1 receiver (tracking); PL transmitter density is 0.1 1/km², protection distance 10m, activity factor 100% and I/N criteria 1.7dB (RNSS_PL to 1227_cw_track_general1_pd10_d0.1_out.sws). Interference probability is 0%.

It can be seen that the CW Pseudolites do not cause interference to RNSS General purpose 1 receivers.

<u>Indoor case: RNSS General purpose 1 receivers</u>

The simulation scenario is similar to the outdoor case, except the additional indoor attenuation of 8dB is applied to the scenario. In the correlated case the interference probability jumps to one on PL transmit power level of –78dBm, which is in line with the MCL calculations.

Interference probability **1227 MHz RNSS general purpose 1 / Indoor (tracking)** **%**	**Propagation; Extended Hata (suburban, below roof), Propagation model parameters (indoor-outdoor –8dB, other attenuations 0dB)**			
	Interfering PL Rx+Tx and Victim RNSS Rx indoors		**Interfering PL Rx and Tx outdoors and victim Rx indoors**	
Protection distance [m]	**10**	**100**	**10**	**100**
PL Tx density 0.1 Tx/km^2	**0**	**0**	**0**	**0**
PL Tx density 1 Tx/km^2	**0**	**0**	**0**	**0**
PL Tx density 6 Tx/km^2	**0**	**0**	**0**	**0**

Table A1.6: SEAMCAT simulation results for RNSS General purpose 1 receivers / indoors

From the results in Table A1.6 it is seen that the interference probability remains 0% in each case.

RNSS - Indoor positioning receivers (space-to-Earth) operating in the band 1 215-1 300 MHz

In the simulations both, the interfering PL and the victim RNSS receivers are assumed to operate on the same 1227 MHz frequency. In the correlated case the results are consistent with the MCL calculations. The results of the statistical approach are gathered in Table A1.7. [ITU-R Rec M.[1088_NEW]]

Interference probability **1 227 MHz RNSS Indoor positioning (acquisition)** **%**	**Propagation; Extended Hata (suburban, below roof)** **Indoor-outdoor attenuation 8dB (Std. 5dB)**					
	Interfering PL Rx+Tx and Victim RNSS Rx indoors		**Interfering PL Rx and Tx outdoors and victim Rx indoors**		**Interfering PL Rx and Tx and victim Rx outdoors**	
Protection distance [m]	**10**	**100**	**10**	**100**	**10**	**100**
PL density 0.1 Tx/km^2	**0.02**	**0.01**	**0.02**	**0**	**0.045**	**0.035**
PL density 1 Tx/km^2	**0.13**	**0.075**	**0.195**	**0.09**	**0.475**	**0.19**
PL density 6 Tx/km^2	**0.745 ***	**0.365**	**1.1**	**0.62**	**2.765**	**1.5**

Table A1.7: SEAMCAT simulation results for RNSS Indoor positioning receivers

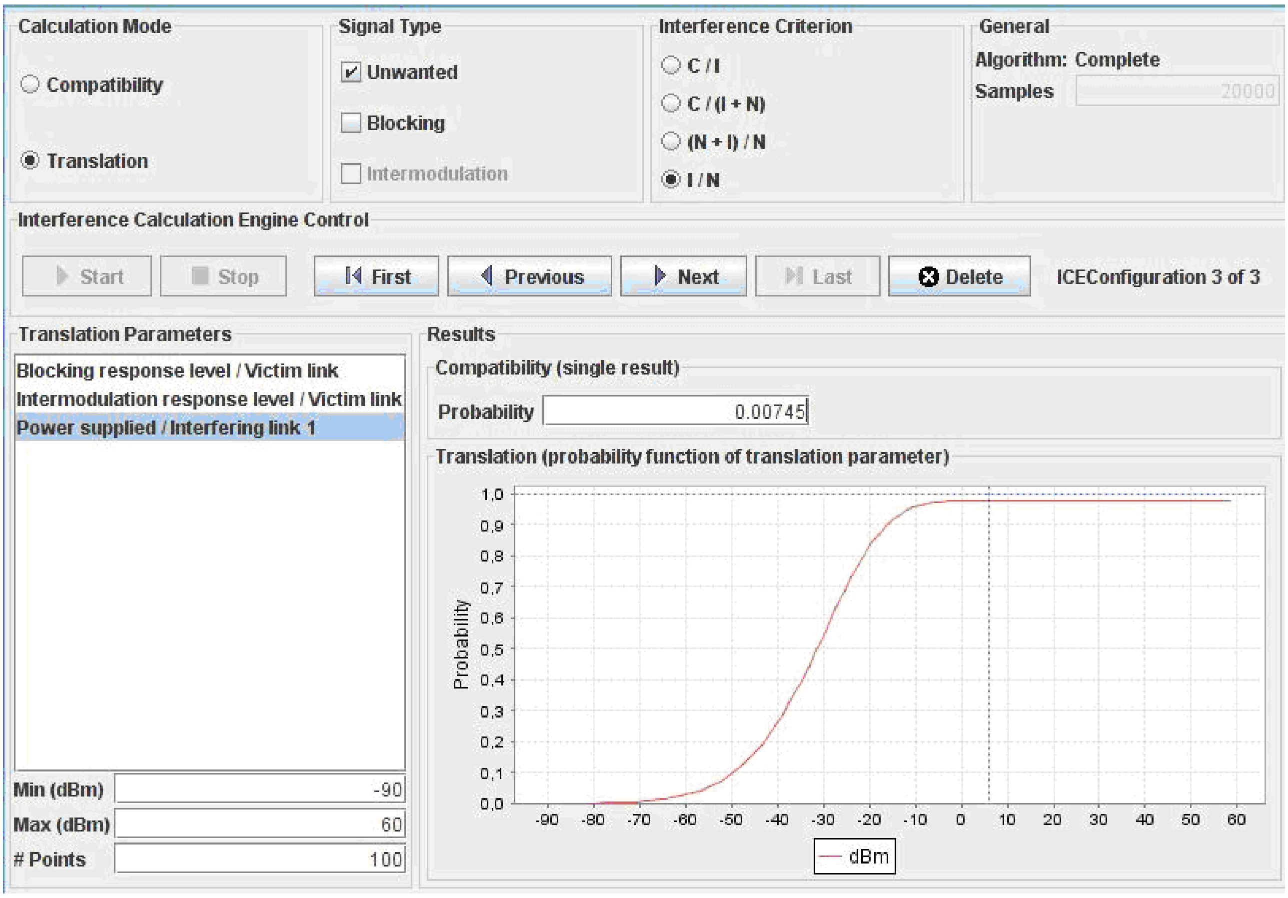


Figure A1.8: 6 continuously transmitting PLs to a RNSS Indoor positioning receiver (acquisition mode); Both the PL system and RNSS receiver are indoors. PL transmitter density is 6 1/km², protection distance 10m, activity factor 100% and I/N criteria –15.3dB (* RNSS_PL to 1227_cw_indoorPos_acq_pd10_d6_all_in.sws). Interference probability is 0.7%

It can be seen that the interference probabilities between the CW Pseudolites and RNSS Indoor positioning receivers remain low in all the simulated scenarios with PL densities 1-6 Tx/km^2.

A1.5 SEAMCAT Conclusions (1215-1300 MHz)

Based on the obtained MCL and statistical simulation results, it can be concluded that sharing/compatibility between continuously transmitting Pseudolites and RNSS receivers is feasible in this frequency band. Between pulse transmitting Pseudolites and RNSS, sharing/compatibility is feasible if the duty cycle of all pulsing Pseudolites seen by the RNSS receiver is less than 20 %.

<u>A-RNSS receivers operating in the band 1559-1610 MHz</u>

In the simulations both, the interfering PL and the victim RNSS receivers (A-RNSS) are assumed to operate on the same 1575 MHz frequency. The I/N criteria for tracking and acquisition is the same for the A-RNSS services.

The correlated simulation case (Figure A1.9) is consistent with the MCL calculations and the results of the statistical approach are presented in Table A1.8 and example of the statistical results in Figures A1.10. [ITU-R rec M.[1477_NEW]].

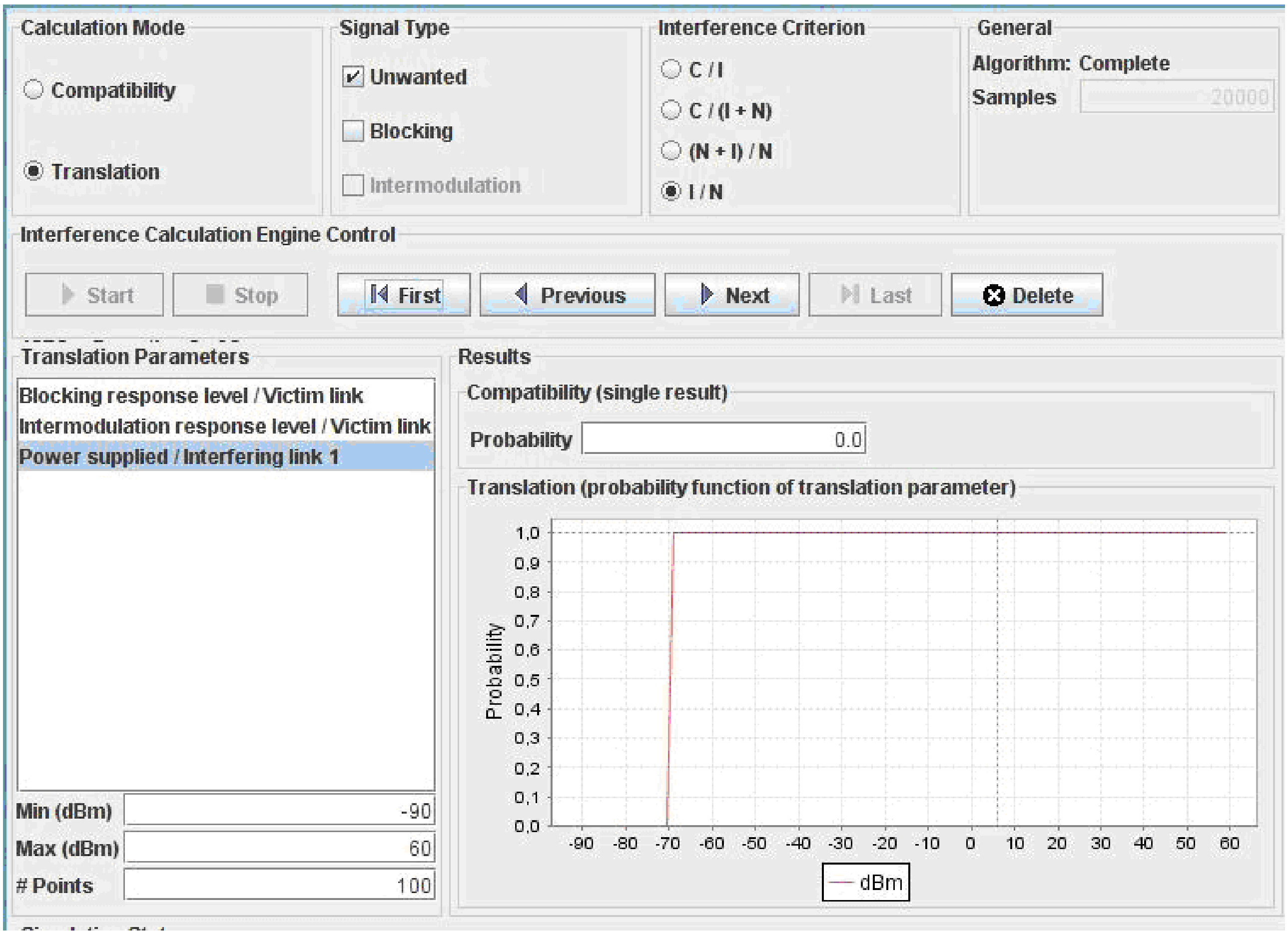


Figure A1.9: PL to RNSS 1575 MHz; MCL case with I/N criteria -7.3 dB and separation distance 8.41 meters (ref. RNSS_PL to 1575_cw_MCL_arns.sws)

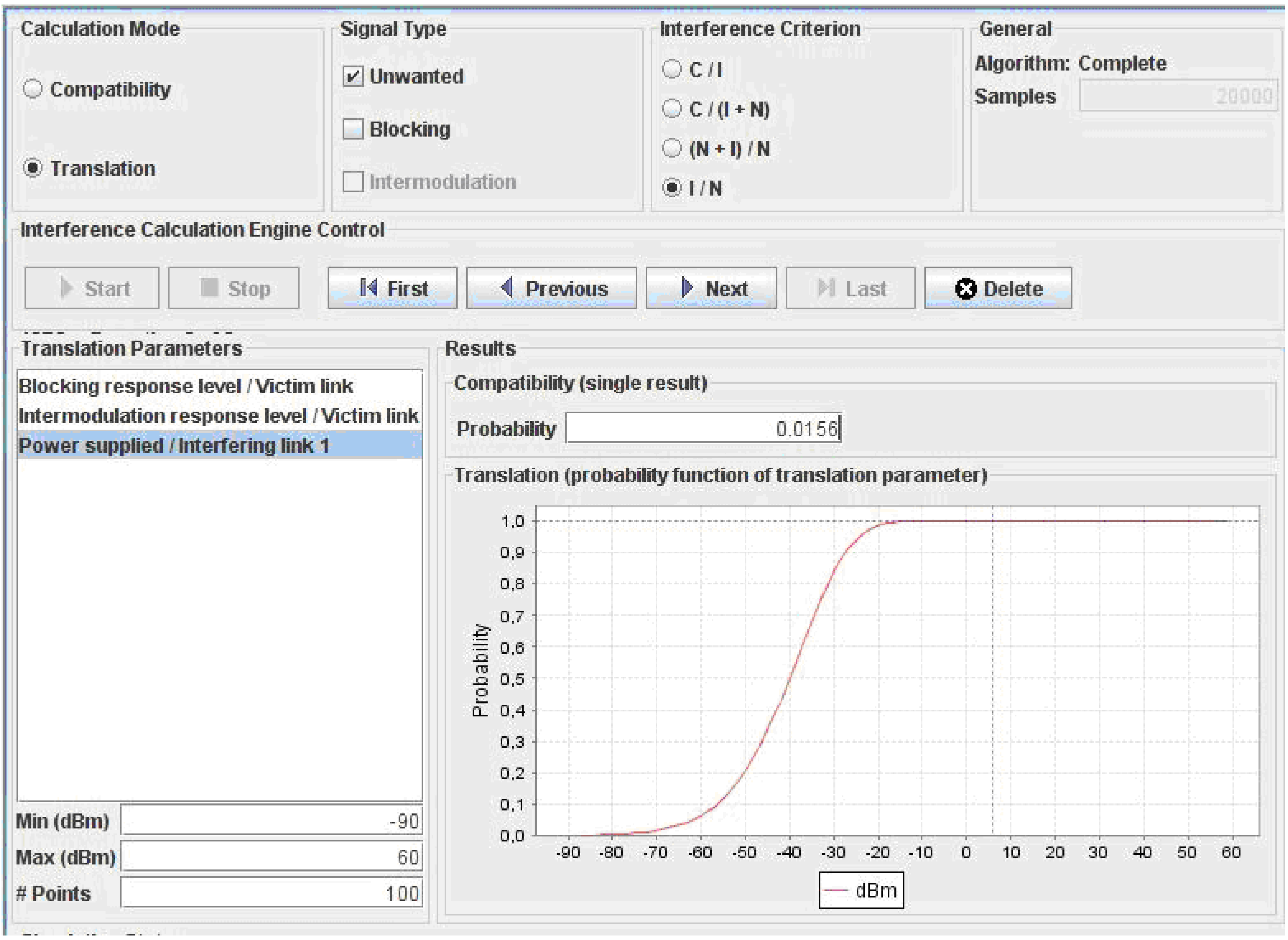


Figure A1.10: 6 active continuously transmitting PLs to A-RNSS receiver; Both PL system and RNSS receiver are outdoors. PL transmitter density is 6 1/km², protection distance 10m, antenna heights 10m, activity factor 100% and I/N criteria –7.3dB (*RNSS_PL to 1575_cw_arns_pd10_d6_out.sws). Interference probability is 1.56%

Interference probability 1575 MHz A-RNSS receivers % (Antenna heights 10m)	**Propagation; Extended Hata (suburban, below roof), Propagation model parameters (indoor-outdoor –8dB, other attenuations 0dB)**			
	Interfering PL Rx+Tx and Victim RNSS Rx outdoors		**Interfering PL Rx and Tx indoors and victim Rx indoors**	
Protection distance [m]	**10**	**100**	**10**	**100**
PL Tx density 0.1 Tx/km^2	**0.015**	**0.015**	**0.005**	**0.005**
PL Tx density 1 Tx/km^2	**0.3**	**0.135**	**0.03**	**0.01**
PL Tx density 6 Tx/km^2	**1.56 ***	**0.815**	**0.175**	**0.145**

Table A1.8: SEAMCAT simulation results for A-RNSS receivers

From the results in Table A1.8 it can be seen that the interference probability remains low 0-1.5% in all the simulated cases. If the receiver antenna heights are lowered to 2 meters, the interference probabilities drop e.g. the highest 1.56% probability decreases to 0,04% and others to 0%.

RNSS High precision receivers (space-to-Earth) operating in the band 1 559-1 610 MHz

In the simulations both, the interfering PL and the victim RNSS receivers (High precision) are assumed to operate on the same 1575 MHz frequency. The correlated case is consistent with the MCL calculations (Figure A1.7) and the results of the statistical approach are presented in Table A1.9 and Figure A1.10. Ref. [ITU-R rec M.[1477_NEW]]

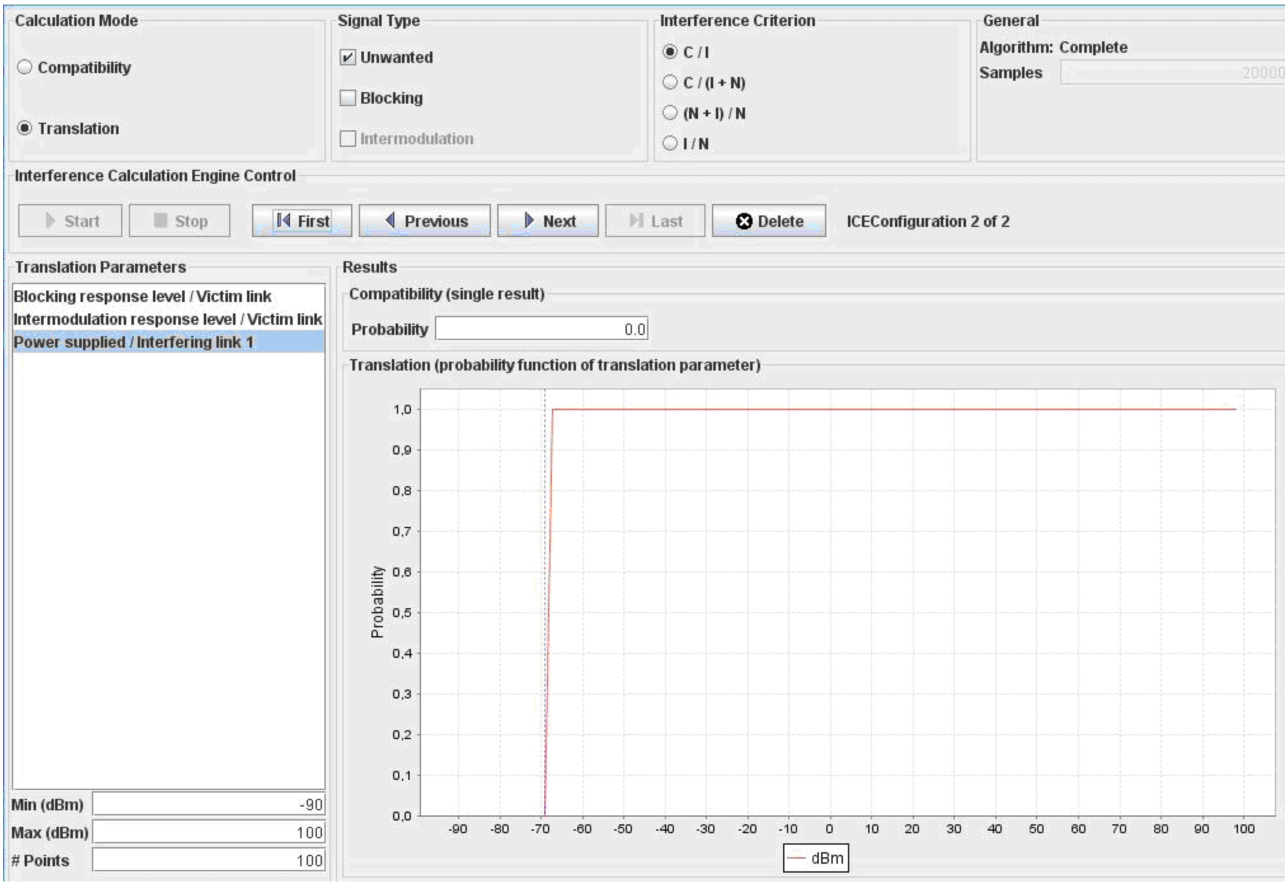


Figure A1.11: PL to RNSS 1575 MHz; MCL case with I/N criteria -7.8 dB and separation distance 8.91m (ref. RNSS_PL to 1575_cw_MCL_hp.sws)

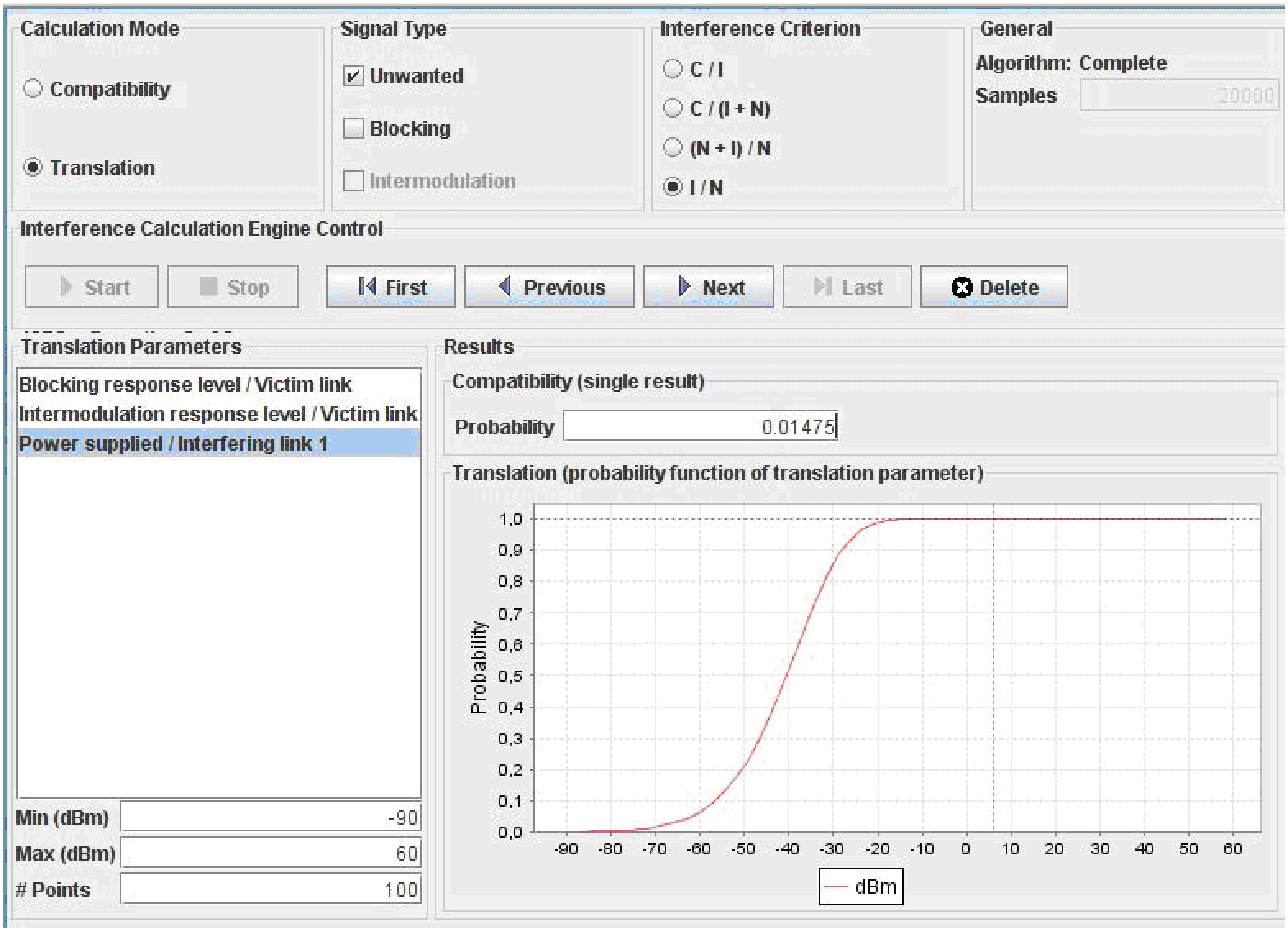


Figure A1.12: 6 continuously transmitting PLs to a RNSS receiver (High precision). PL transmitter density is 6 1/km², protection distance 10m, activity factor 100%, antenna heights 10m and I/N criteria -7.8dB. Interference probability is 1.48% for the outdoor case (RNSS_PL to 1575_cw_hp_pd10_d6_out.sws *)

Interference probability 1575 MHz High precision receivers % (Antenna heights 10m)	**Propagation; Extended Hata (suburban, below roof), Propagation model parameters (indoor-outdoor –8dB, other attenuations 0dB)**			
	Interfering PL Rx+Tx and Victim RNSS Rx outdoors		**Interfering PL Rx and Tx indoors and victim Rx indoors**	
Protection distance [m]	**10**	**100**	**10**	**100**
PL Tx density 0.1 Tx/km^2	**0.04**	**0.01**	**0**	**0**
PL Tx density 1 Tx/km^2	**0.225**	**0.12**	**0.035**	**0.015**
PL Tx density 6 Tx/km^2	**1.475 ***	**0.805**	**0.155**	**0.135**

Table A1.9: SEAMCAT simulation results for A-RNSS receivers

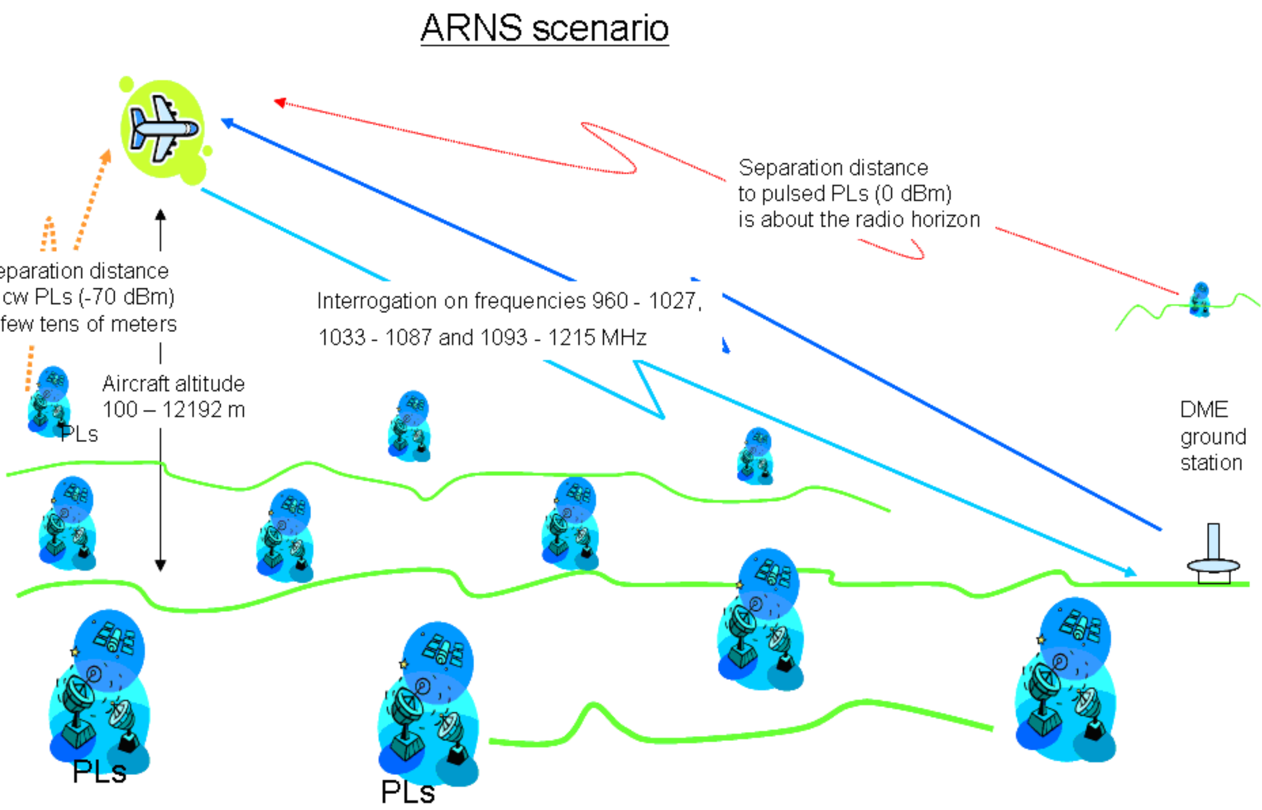
The interference probabilities of the CW Pseudolite scenarios are low both indoor and outdoor cases with PL densities 0.1-6 Tx/km^2 and 10 meters antenna height. With two meter receiver antenna heights the probabilities are ~0%.

A1.6 SEAMCAT Conclusions (1559-1610 MHz)

In all the correlated cases the interference probability jumps to one on the Pseudolites power level of -70dBm, which is in line with the computed MCL results. In the simulated CW Pseudolite scenarios in suburban settings the interference probabilities are very low and it can be concluded that sharing/compatibility between continuously transmitting Pseudolites and RNSS services is feasible in this band.

Between pulse transmitting Pseudolites and RNSS sharing/compatibility is feasible if the duty cycle of all pulsing pseudolites seen by the RNSS receiver is less than 20 %.

ANNEX 2: IMPACT OF PSEUDOLITES ON ARNS



A2.1 Introduction

Aeronautical Radio Navigation Service (ARNS) is a safety related service and should be carefully protected from interference and the protection criterion should be met 100% of the time. The impact of Pseudolites on ARNS is evaluated considering a scenario depicted in the Figure above. First the separation distance required by a ARNS receiver operating in the presence of an unwanted Pseudolite signal, and vice versa, is determined by the Minimum Coupling Loss (MCL) method for each considered system scenario. After the MCL calculations SEAMCAT simulations are conducted in order to further investigate the interference probability between the two systems.

A2.2 MCL calculations

The calculated separation distances between the interfering Pseudolite and the victim ARNS system are presented in Table A2.1. The results of the Minimum Coupling Loss method present the isolation required between the interferer and victim in order to ensure interference free operation. The results are a worst case analysis, providing therefore a spectrally inefficient result for scenarios of a statistical nature. Thus, statistical approach is taken afterwards by SEAMCAT simulations.

Intefering system	Pseudolite / CW	Pseudolite CW / indoor	Pseudolite pulsing	Pseudolite pulsing, PFD
Frequency [MHz]	1176	1176	1176	1176
Bandwidth [MHz]	10	10	10	10
TX [dBm]	**-70**	**-70**	**0**	**0**
Duty cycle [%]	NA	NA	NA	NA
aditional attenuation, eg. indoor usage	0	8	0	0
TX antenna height [m]	10	10	10	10
TX antenna gain [dBi] towards the victim	0	0	11	11
Separation distance [km]	**0,02**	**0,007**	**160**	**50**
Free Space loss [dB]	59,87874635	50,76010724	137,9405461	127,8375465
Long term (20 %) diffraction loss [dB]	0	0	3,225767782	0
PFD the receiving site [dBW/MHz/m^2)	-147,32	-146,20	-144,38	**-134,28**
Victim Service and system	ARNS RX in airplane	ARNS RX in airplane	ARNS RX in airplane	ARNS RX in airplane
Intefered signal level at Rx bw [dBm]	-80	-80	-80	-80
RX bandwidth [MHz]	0,65	0,65	0,65	0,65
Rx noisefigure	3	3	3	3
Rx antenna height [m]	10	10	12000	10000
RX antenna gain [dBi] towards inteference	4,5	4,5	4,5	4,5
Rx noise floor [dBm]	-112,8708664	-112,8708664	-112,8708664	-112,8708664
TX/RX BW correction factor	-11,87086643	-11,87086643	-11,87086643	-11,87086643
Interfering signal level at Rx bw [dBm]	-137,2496128	-136,1309737	-137,5371803	-124,208413
I/N [dB]	**-24,37874635**	**-23,26010724**	**-24,66631387**	**-11,33754652**
Compatibility criterion	I/N = -23	I/N = -23	I/N = -23	I/N = -23
PFD criterion	< -144,5 dBW/MHz/m^	< -144,5 dBW/MHz/m^2	< -144,5 dBW/MHz/m^2	< -144,5 dBW/MHz/m^2
Inteference risk (single entry)	**Low**	**Very low**	**Very high**	**> -144,5 dBW/MHz/m^2**

Table A2.1: Pseudolites to ARNS interference calculation using the MCL method

As seen from the MCL results, the separation distances of the pulsing pseudolites are rather large reaching beyond the horizon. Thus, the resulting diffraction loss needs to be taken into account when comparing the SEAMCAT simulation results to the MCL calculations.

A2.3 SEAMCAT simulations

The SEAMCAT simulations are performed in order to determine the statistical compatibility between the Pseudolite and Aeronautical Radio Navigation Service (ARNS) systems. First the consistency between the SEAMCAT scenario and the MCL calculations is checked by a simple correlated simulation case without any distributions. After this a full statistical approach is taken to describe a real life scenario as well as possible. The relevant simulation characteristics and parameters for the studied ARNS are presented in Table A2.2. Both the interfering PL and the victim ARNS system are assumed to operate in the same 1 176 MHz frequency.

The coverage area, seen by the DME receiver, is considered to be about a 400 times 400 square kilometres. In this area the number of Pseudolites is assumed to be 100, 1000 or 10000, corresponding to PL transmitter densities 0.000625, 0.00625 and 0.0625 respectively. The simulated duty cycle is 100% in the CW PL case and the DME receiver (i.e. the aircraft altitude) is assumed to be either 100 or 12000 meters in the simulations.

SEAMCAT parameters	Victim: ARNS, DME receiver	Interfering System: CW or Pulsed PLs
Frequency [MHz]	1 176	
Transmit power P_{TX} [dBm]	-	-70 or 0
Noise floor [dBm]	-113	
Bandwidth [MHz]	0,65	2 or 10
Antenna azimuth [deg]	0...360º uniform distribution	0...360º uniform distribution
Antenna elevation [deg]	0º	0º
Antenna height [m]	100...12 000	10
Maximum antenna gain [dBi]	4,5	11 (Tx)
Interference criteria	Interference-to Noise ratio, I/N=-23dB	
Distance between InterferingTx -Victim Rx	• MCL case: separation distance (see Table A2.1) • Otherwise: depends on the aircraft altitude (100 / 12000 meters)	
Propagation model	• In MCL case and between ARNS Rx-Tx and ARNS Rx-PL Tx: Free Space • Extended Hata, Suburban (below roof) between PL Rx-Tx o both interfering PL and Victim ARNS outdoors	
Interfering transmitters in DME coverage	• MCL case: Single transmitter • Otherwise: o 100 uniformly distributed PLs, density 0,000625 Tx/km^2 o 1000 uniformly distributed PLs, density 0,00625 Tx/km^2 o 10000 uniformly distributed PLs, density 0,0625 Tx/km^2	

Table A2.2: SEAMCAT simulation scenario parameters for PL to ARNS (DME receivers)

The Distance Measuring Equipments (DMEs) are used in aircrafts to determine the distance to the land-based transponder. Since the interfered receiver is airborne, LOS propagation conditions between the interfered receiver and interfering PL transmitter are assumed. Thus, the Free Space Loss model (as implemented in SEAMCAT) is used in the simulations.

The used DME receiver blocking response and PL transmitter emissions mask are presented in Figures A2.1 and A2.2, respectively.

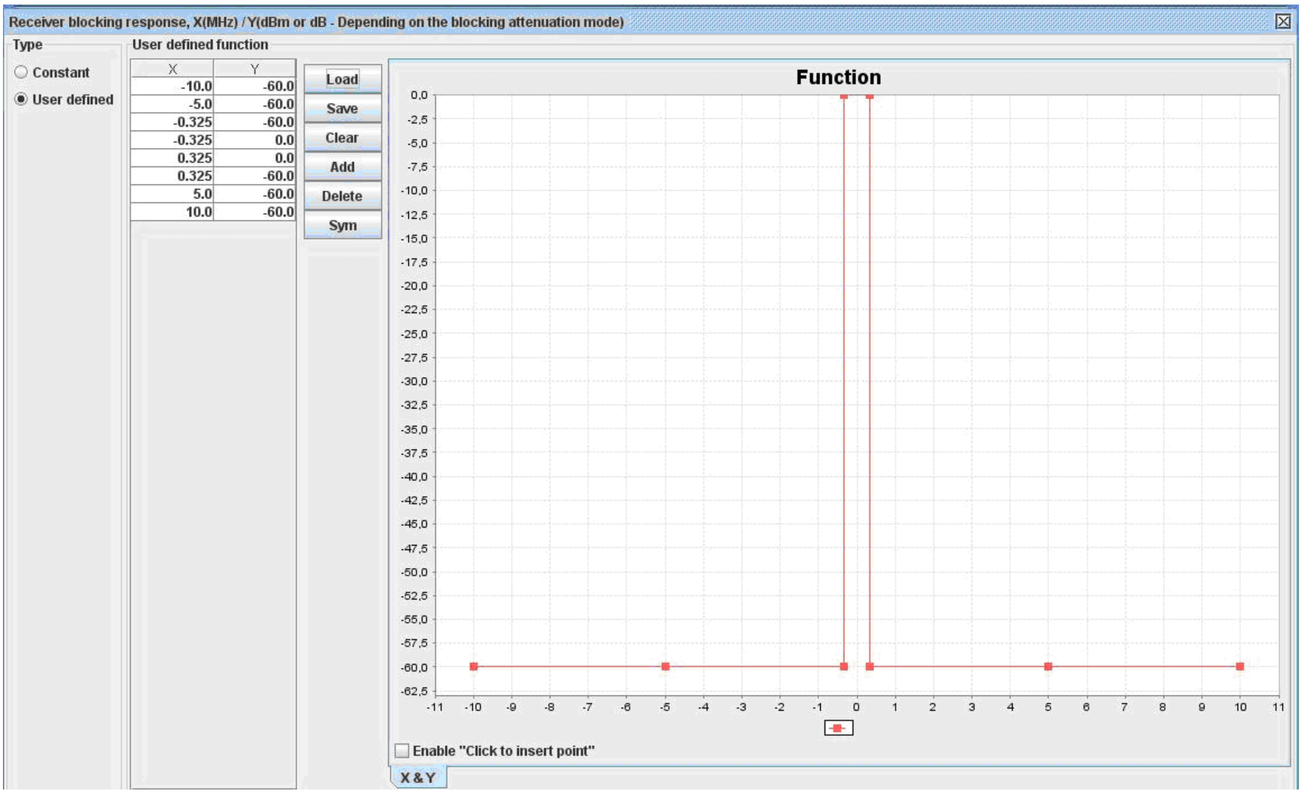


Figure A2.1: ARNS, DME receiver blocking response

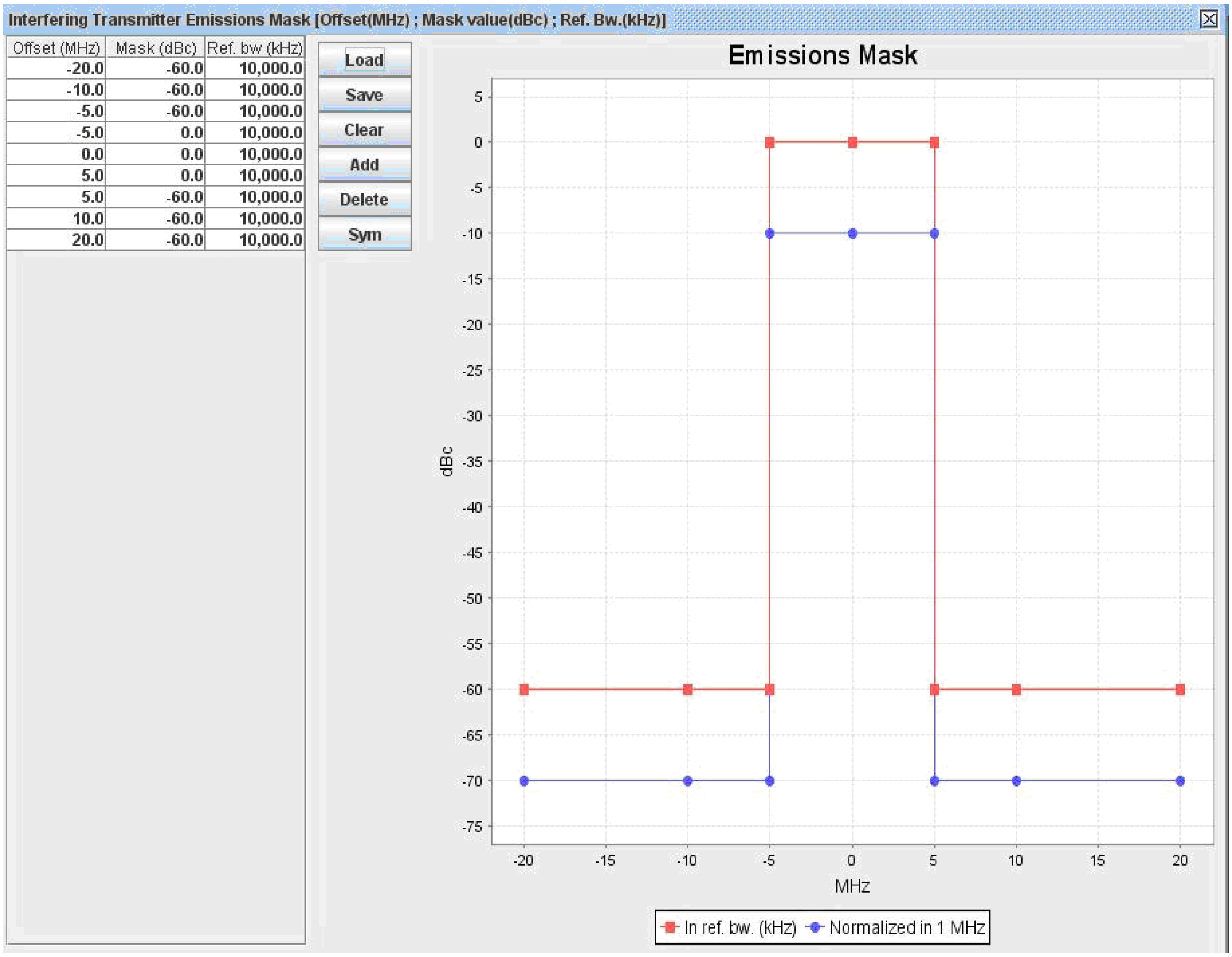


Figure A2.2: PL transmitter emissions mask

A2.4 CW PLs to DME receivers operating in the band 1164-1215 MHz

In the following simulations both, the interfering PLs and the victim ARNS service are assumed to operate on the same 1176 MHz frequency. In the continuously transmitting Pseudolite case, the correlated simulation is consistent with the MCL calculations, Figure A2.3.

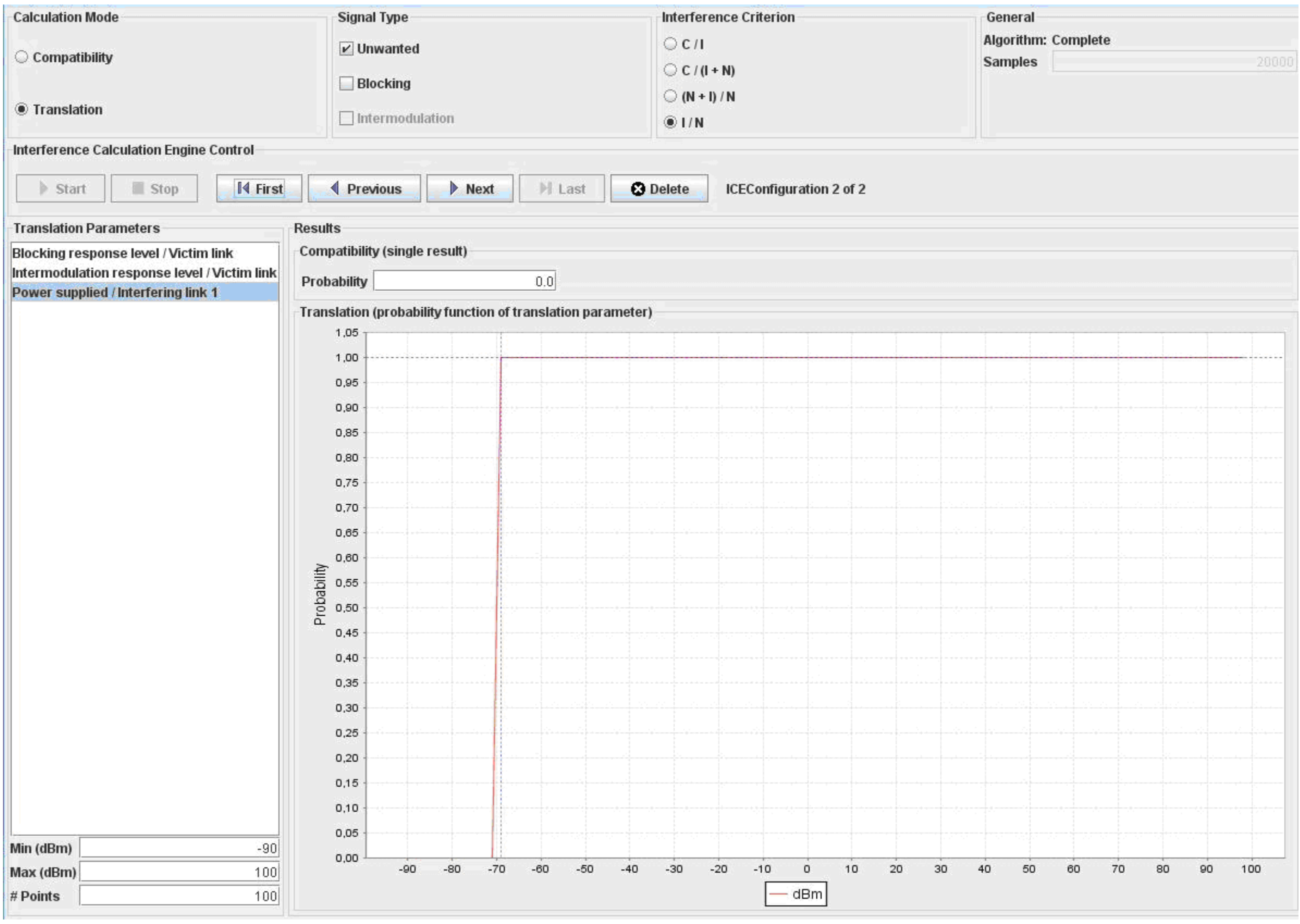


Figure A2.3: PL to ARNS; MCL case with I/N criteria -23dB and separation distance 20m (ref. ARNS_PL to 1176_MCL_0.02km.sws)

In the continuously transmitting (CW) Pseudolite scenario the interference probability is very low due to the low transmit power level (-70 dBm) and small natural separation distances. Thus, a continuously transmitting low power PL, neither indoor nor outdoor, hardly interfere a DME receiver onboard aircraft and sharing and/or compatibility between continuously transmitting Pseudolites and ARNS is feasible as seen from the following Figures.

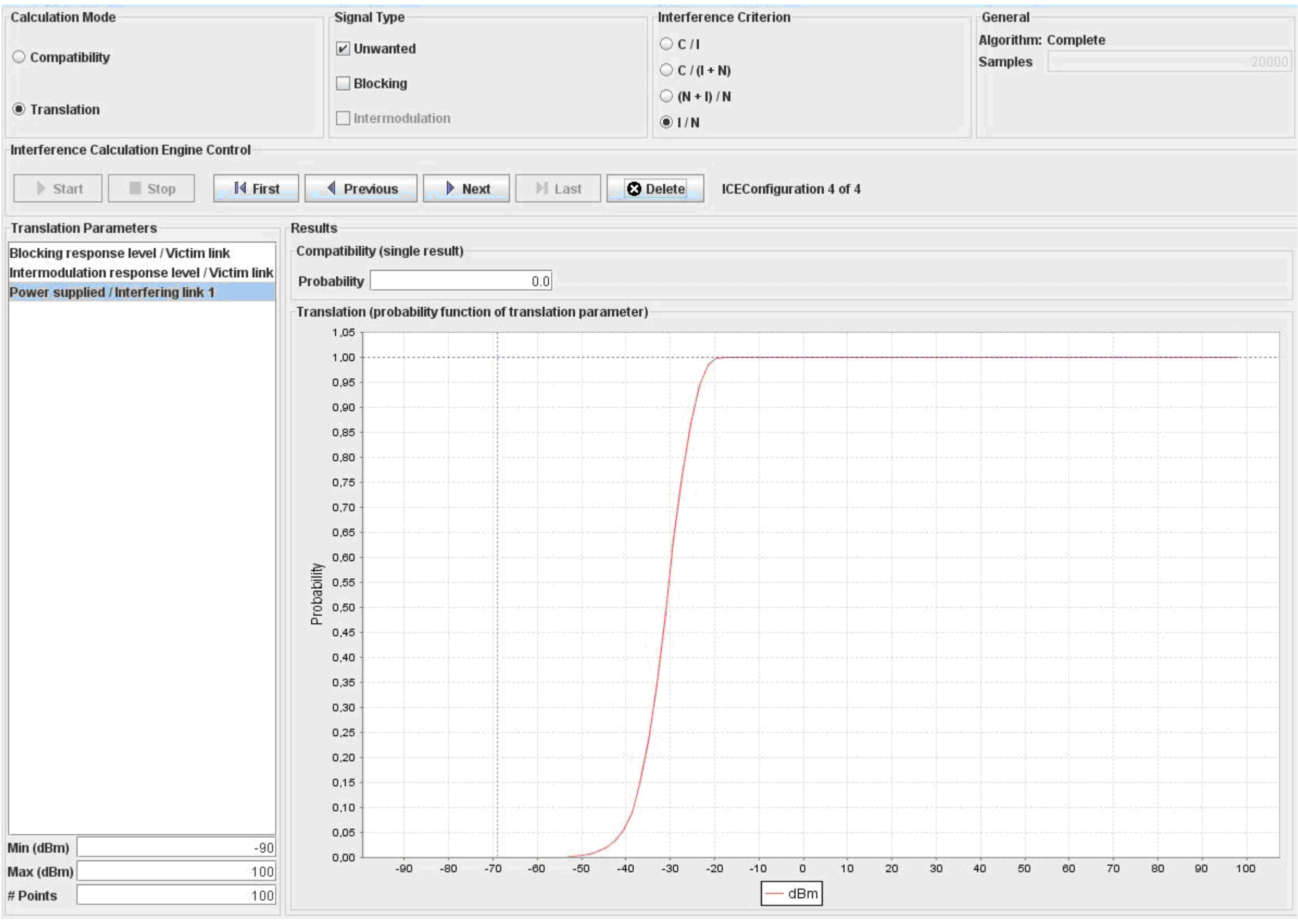


Figure A2.4: CW PLs in DME receiver vicinity (100m altitude). The I/N criteria is -23dB, PL activity factor 100% and PL density 0.0625 tx/km² (=10000 PLs in DME coverage area). Interference probability is 0% (ref. ARNS_PL to 1176_0.02km_6tx_100m_0.0625.sws)

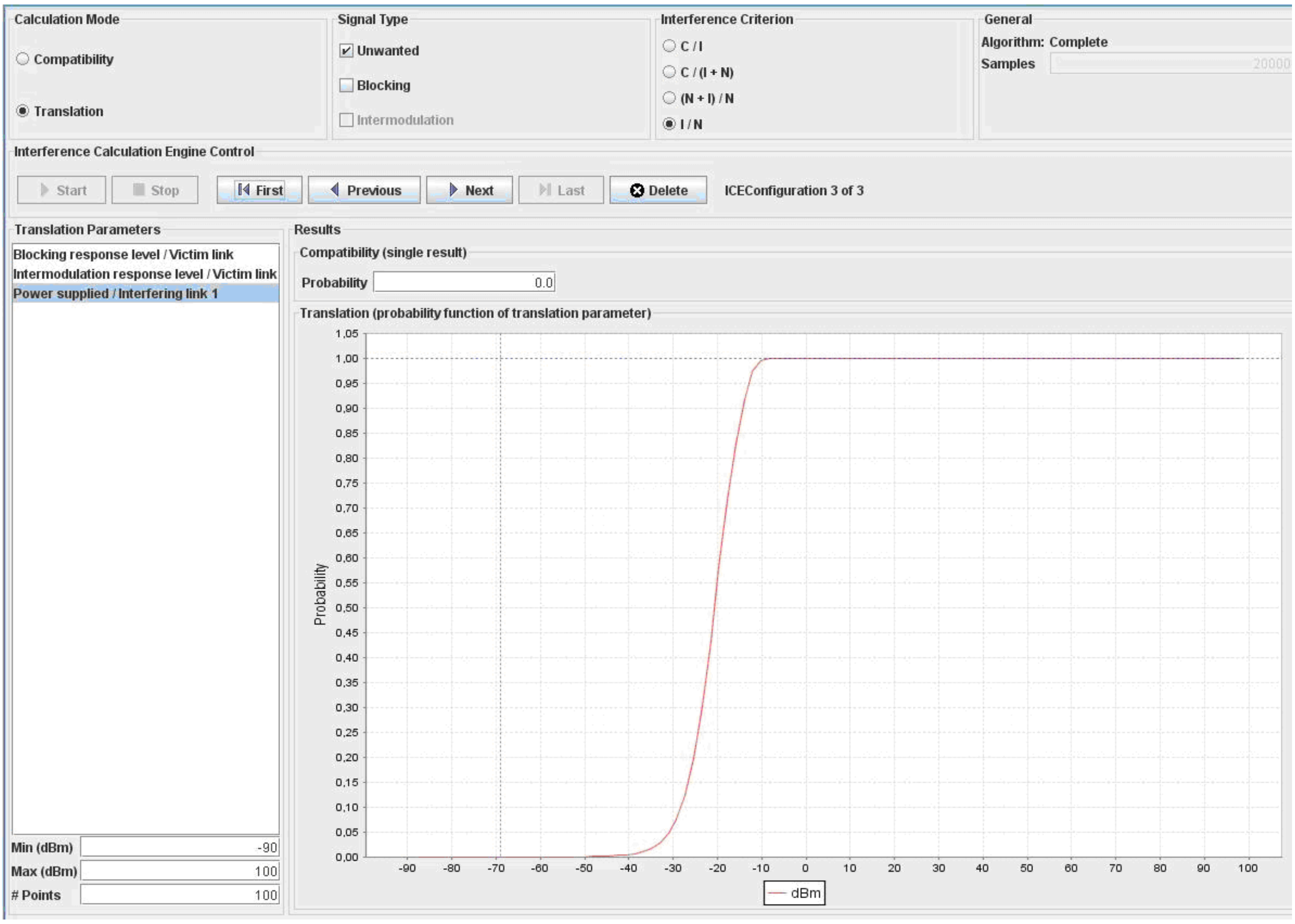


Figure A2.5: CW PLs to DME receiver (100m altitude). The I/N criteria is -23dB, PL activity factor 100% and PL density 0.00625 tx/km² (=1000 PLs in DME coverage area). Interference probability is 0% (ref. ARNS_PL to 1176_0.02km_6tx_100m_0.00625.sws)

A2.5 Pulsed PLs to DME receivers operating in the band 1164-1215 MHz

In the correlated simulation case (MCL) of a pulsing pseudolite with separation distance 160km, the probability jumps to one on the PL transmit power level of 0dBm, which is in line with the MCL calculations (Figure A2.4).

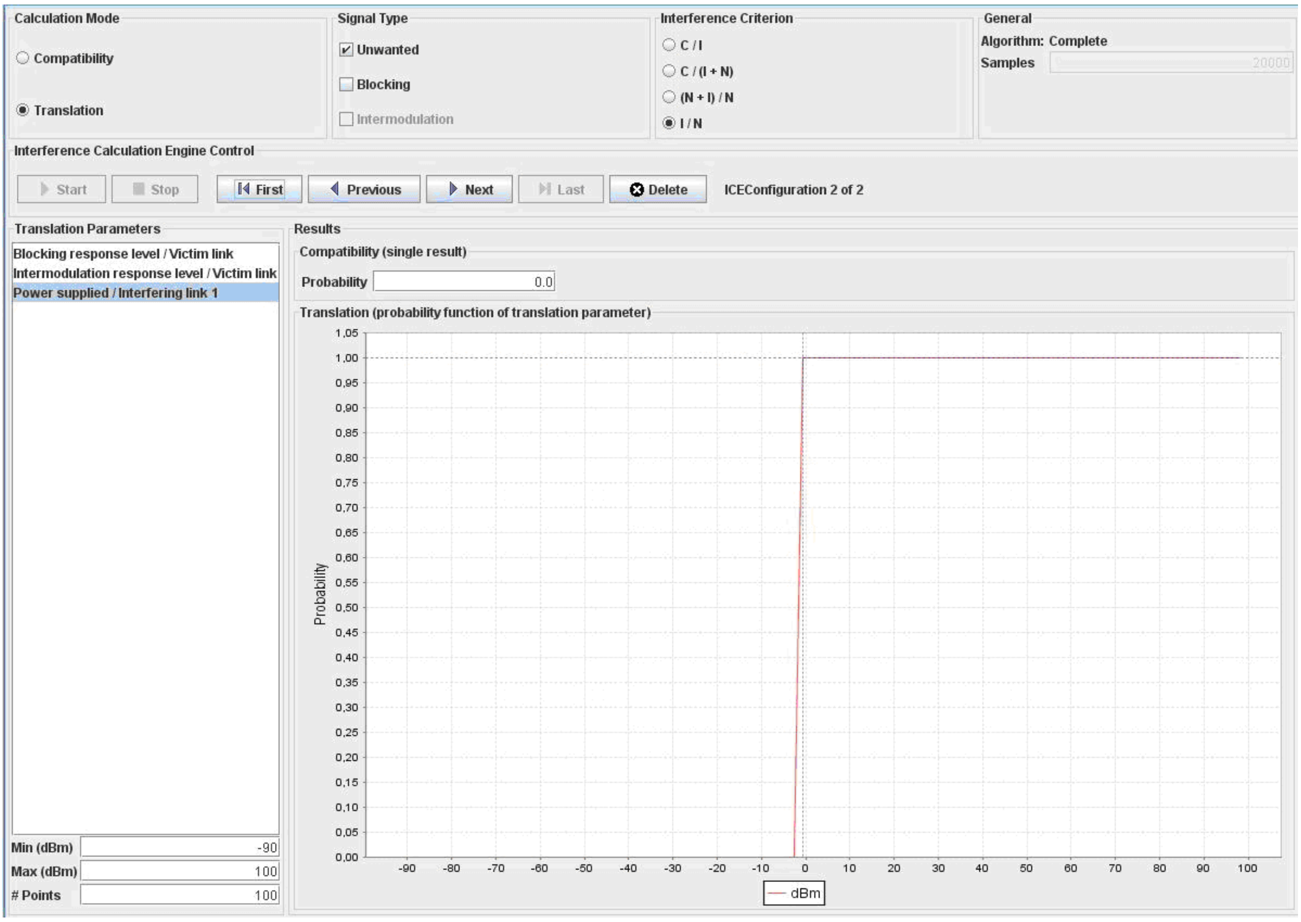


Figure A2.6: MCL case with I/N criteria -23dB and separation distance 160km (ref. ARNS_PL to 1176_MCL_160km.sws)

For ARNS the compatibility criteria is aggregate power flux density of -144.5 dBW/m²/MHz. However, already a single pulsing PL can cause a PFD more than -121.5 dBW/MHz/m² in the DME receiver at lower altitudes. At higher altitudes a single pulsing Pseudolite can cause interference to a DME receiver in an aircraft up to 65 kilometres.

Interference probability **1 176 MHz ARNS, DME receiver %**		**Propagation; Free space and Extended Hata (suburban, below roof), interfering PL Rx+Tx and Victim ARNS, DME Rx outdoors**	
Rx height (Aircraft altitude)	**PL Tx density (6 active PLs / system)**	**CW PL**	**p-PL**
12 000 m	0.000625 Tx/km^2	**0**	**98**
	0.00625 Tx/km^2	**0**	**100**
	0.0625 Tx/km^2	**0**	**100**
100 m	0.000625 Tx/km^2	**0**	**100**
	0.00625 Tx/km^2	**0**	**100**
	0.0625 Tx/km^2	**0**	**100**

Table A2.3: SEAMCAT simulation results for RNSS Air-navigation receivers; protection distance is 100 meters in each case

The SEAMCAT simulations imply that in case of a high power (0 dB) pulsing Pseudolite, the interference probability is very high in all the simulated cases (e.g. results in the following Figures and Table A2.3). With single pulse transmitting Pseudolite and DME in 12000 meter altitude the interference probability is 17%, Figure A2.8.

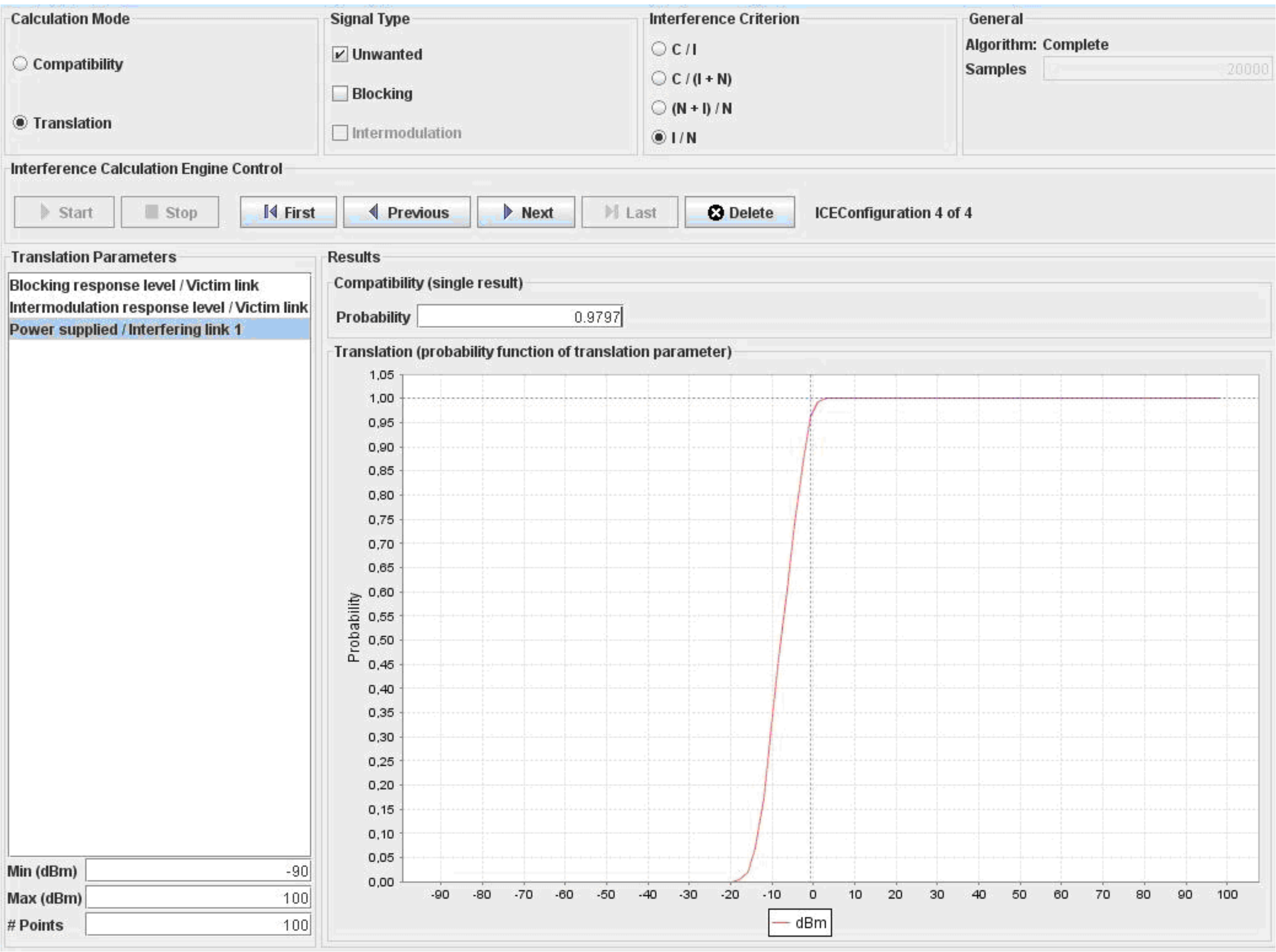


Figure A2.7: Pulsed PLs in DME receiver vicinity (in 12000m altitude). I/N criteria is -23dB, PL activity factor 100% and PL density 0.000625 tx/km² (=100 PLs in DME coverage). Interference probability is 98% (ref. ARNS_pPL to 1176_160_0.000625_100tx_12000.sws)

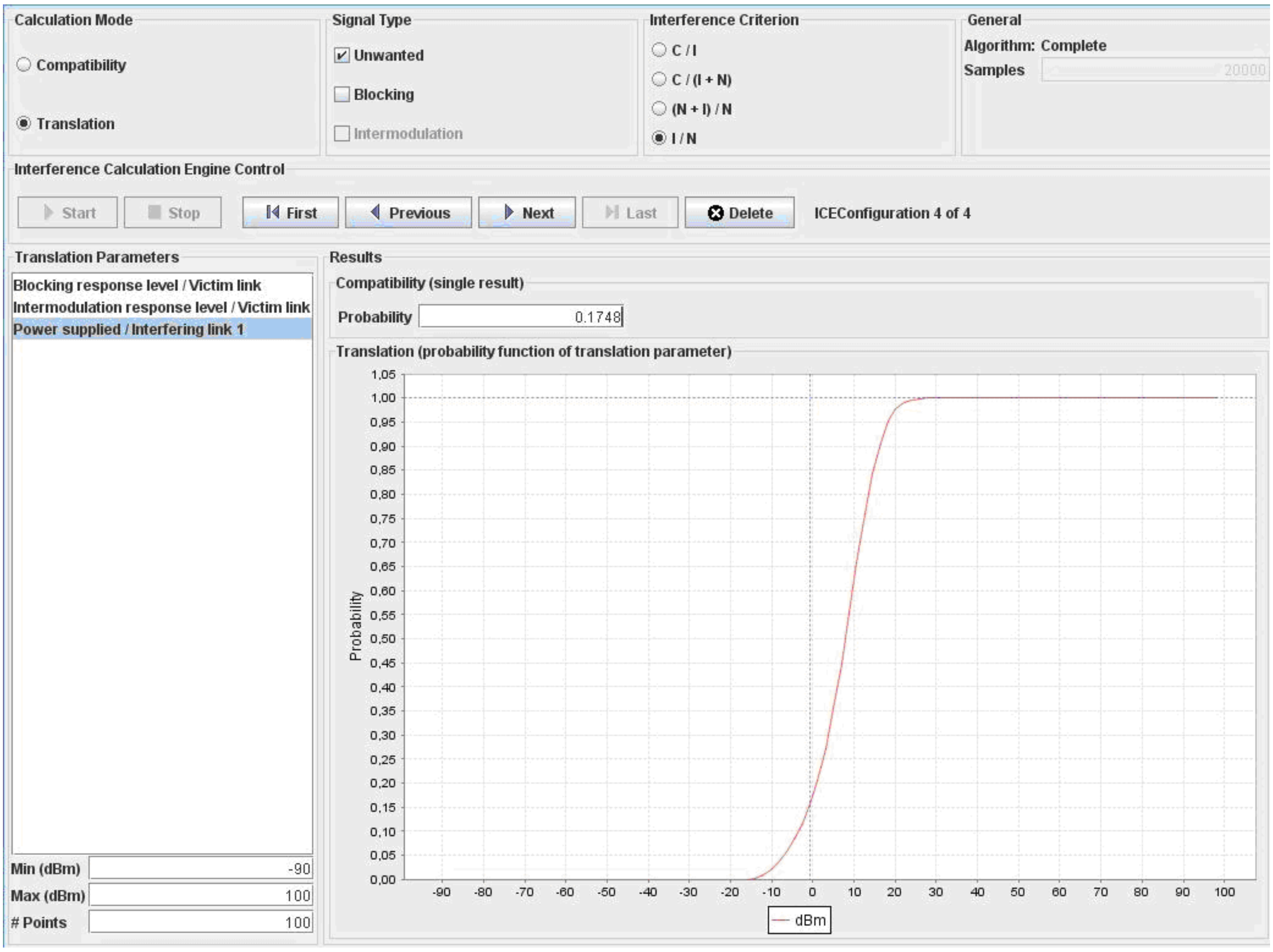


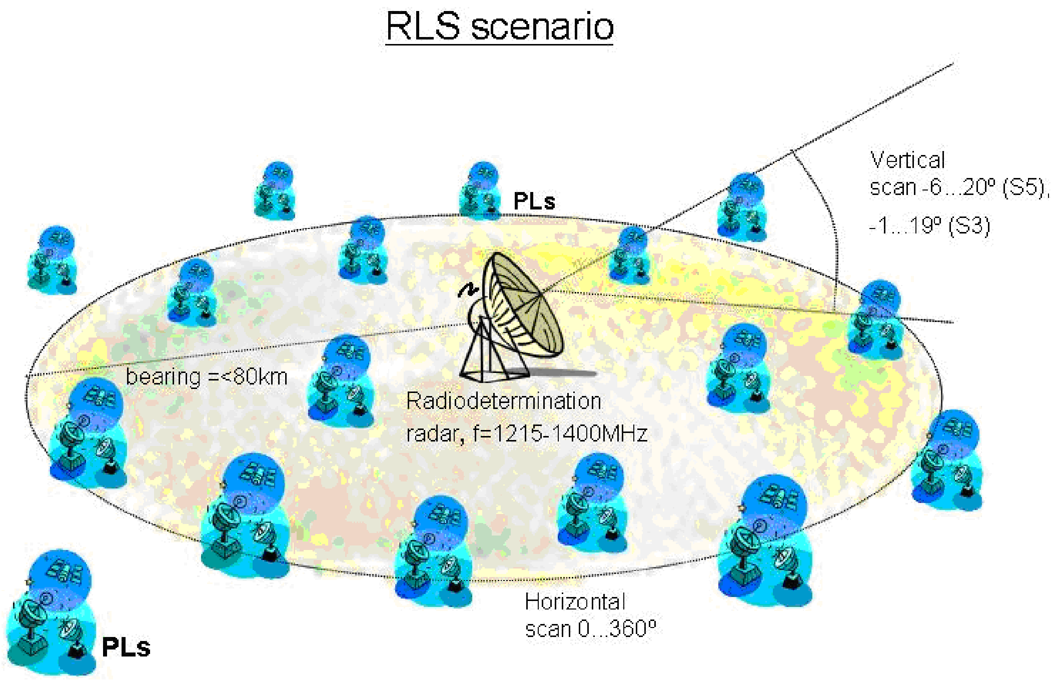
Figure A2.8: Single pulsed PL in DME receiver vicinity (12000m altitude). The I/N criteria is -23dB, PL activity factor 100% and PL density 0.000625 tx/km². Interference probability is ~17% (ref. ARNS_pPL to 1176_160_0.000625_single_12000.sws)

A2.6 SEAMCAT Conclusions

The Aeronautical Radio Navigation Service (ARNS) protection criterion is I/N=-23 dB, which should be met 100% of the time. In the simulated continuously transmitting (CW) Pseudolite scenario the interference probability is very low, because of the low power level of the CW Pseudolite and very low natural separation distances. Thus, sharing and/or compatibility between continuously transmitting Pseudolites and ARNS are feasible.

In the pulse transmitting Pseudolite cases the DME is interfered even in high altitudes. In the simulations the resulting interference probabilities are 100%. Thus, sharing and/or compatibility between pulse transmitting Pseudolites and ARNS, DME receivers is not feasible.

ANNEX 3: IMPACT OF PSEUDOLITES ON RDS



A3.1 Introduction

Radio Determination Service (RDS) is a safety related service and should be carefully protected from interference 100% of the time. The impact of Pseudolites on RDS radars is evaluated considering a scenario depicted in the Figure above. First the isolation i.e. the separation distance required by a RDS receiver operating in the presence of an unwanted Pseudolite signal, and vice versa, is determined by the Minimum Coupling Loss (MCL) method for each considered system scenario. After this statistical SEAMCAT simulations are conducted in order to further investigate the interference probability between the two systems.

A3.2 MCL calculations

The Minimum Coupling Loss method calculates the isolation required between the interferer and victim in order to ensure interference free operation. The method provides a worst case analysis, which is a spectrally inefficient result for scenarios of a statistical nature. Therefore, the statistical approach is taken afterwards by SEAMCAT simulations.

The results of the calculated MCL separation distances between the interfering Pseudolite and the victim RDS system are presented in Table A3.1.

Interfering system	**PL / CW**	**PL / CW**	**PL / CW Indoor**	**PL / CW Indoor**	**Pulsed PL**	**Pulsed PL**
Frequency [MHz]	1 227	1 227	1 227	1 227	1 227	1 227
Bandwidth [MHz]	10	10	10	10	10	10
TX [dBm]	-70	-70	-70	-70	0	0
Duty cycle [%]	NA	NA	NA	NA	NA	NA
Additional attenuation, eg. indoor usage	0	0	8	8	0	0
Efective heigth of the TX antenna [m]	10	10	10	10	10	10
TX antennagain [dBi] towards the victim	11	11	11	11	11	11
Separation distance [km]	**0.45**	**0.01**	**0.2**	**0.01**	**75**	**13**
Free Space loss [dB]	87.2911	54.2269	80.2475	54.2269	131.7281	116.5058
Long term (20 %) diffraction loss [dB]	0	0	0	0	26.6451	2.7727
PFD the receiving site [dBW/MHz/m^2)	-163.36	-130.30	-164.32	-138.30	-137.80	-122.58
Victim Service and system	RL, S5	RL, S5	RL, S5	RL, S5	RL, S5	RL, S5
Interfered signal level at Rx bw [dBm]	-111	-111	-111	-111	-111	-111
Reference bandwidth [MHz]	1.25	1.25	1.25	1.25	1.25	1.25
Rx noisefigure [dB]	2.6	2.6	2.6	2.6	2.6	2.6
Rx antenna heigth [m]	15	15	15	15	15	15
RX antenna gain towards inteference [dBi]	38.5	0	38.5	0	38.5	0
Additional losses, eg. indoor usage	0	0	0	0	0	0
Rx noise floor [dBm]	-110.4309	-110.4309	-110.4309	-110.4309	-110.4309	-110.4309
TX/RX BW correction factor	-9.0309	-9.0309	-9.0309	-9.0309	-9.0309	-9.0309
Interfering signal level at Rx bw [dBm]	-116.8220	-122.2578	-117.7784	-130.2578	-117.9041	-117.3094
I/N at ref. bw	**-6.3911**	**-11.8269**	**-7.3475**	**-19.8269**	**-7.4732**	**-6.8785**
Inteference criterion	I/N<-6	I/N<-6	I/N<-6	I/N< -6	I/N< -6	I/N< -6

	or -12	or -12	or -12	or -12	or -12	or -12
Comments	Radar antenna mainbeam	Radar antenna sidelobe	Radar antenna mainbeam	Radar antenna sidelobe	Radar antenna mainbeam	Radar antenna sidelobe
Inteference risk (single entry)	Low	Very low	Low	Very low	Very high	Very high

Table A3.1: PLs to RDS interference calculation using MCL method

The separation distances are rather large already in case of continuously transmitting Pseudolites, becoming unacceptable in the case of pulse transmitting Pseudolites. This is due to high EIRP of the Pseudolites and high antenna gain and sensitivity of the radars. In the pulsed Pseudolite cases, where the separation distance reaches beyond the horizon, the resulting diffraction loss needs to be taken into account when comparing the SEAMCAT simulation results to the MCL calculations.

A3.3 SEAMCAT simulations

The SEAMCAT simulations are performed in order to determine the statistical compatibility between the Pseudolite and Radio Determination Service (RDS) system radars. First the consistency between the SEAMCAT scenario and the MCL calculations is checked by a simple correlated simulation case without any distributions. After this a full statistical approach is taken to describe the real life scenario as well as possible.

The radar antenna height does not appear in the ITU-R recommendation, but it is assumed to be above the local clutter and a radar antenna height of 15 to 35 m above the ground is assumed in the simulations. Pseudolites on the other hand may operate below the local clutter and, thus, the propagation path between the interfering Pseudolite and victim radar antennas can be either LOS or NLOS. The simulations are conducted by using the Extended Hata (as implemented in SEAMCAT) as well as the Free Space Loss model (as implemented in SEAMCAT).

A3.4 RDS radar S5 operating in the band 1215-1400 MHz

The relevant simulation characteristics and parameters for the studied RDS radars are presented in Table A3.2. Both the interfering PL and the victim radar are assumed to operate in the same 1227 MHz frequency. Besides the indoor loss no additional losses or margins (e.g. wall penetration, implementation margin, etc) are considered. The number of actively transmitting Pseudolites is 6.

SEAMCAT parameters	Victim: RDS, S5 receiver	Interfering System: CW or Pulsed Pseudolites
Frequency [MHz]	1 227	
Transmit power P_{TX} [dBm]	-	-70 or 0
Noise floor [dBm]	-110,4	
Bandwidth (pulse) [MHz]	1.5	2 / 10
Antenna azimuth [deg]	0...360° uniform distribution	0...360° uniform distribution
Antenna elevation [deg]	-6...20° uniform distribution	0°
Antenna height [m]	15...35 (uniform distribution)	10
Maximum antenna gain [dBi]	38.	11 (Tx)
Antenna orientation (deg, from nadir)	20°	
Minimum desired signal [dBm]	-156.5 *	
Interference criteria	Interference-to Noise ratio, I/N=-6dB	
Distance between InterferingTx -Victim Rx	• MCL case: separation distance (see Table A3.1) • Otherwise: uniform	
Propagation model	• In MCL case and between SAR - PLs: Free Space • Between PL Rx and Tx: Extended Hata, Suburban (below roof) o both interfering PL and Victim outdoors	
Interfering transmitters in radar coverage	• MCL case: Single transmitter • Otherwise: o Single transmitter case (density 0,0025 1/km^2) o 6 uniformly distributed PLs (density 0,015 1/km^2)	

Table A3.2: SEAMCAT simulation parameters for PL to RDS (radar S5)

It is indicated in the main document that, from the radar receiver point of view, the interference from the actively transmitting Pseudolites can be taken as continuous and therefore a 100% duty cycle is used in the simulations.

The used DME receiver blocking response and PL transmitter emissions mask are presented in Figures A3.1 and A3.2, respectively.

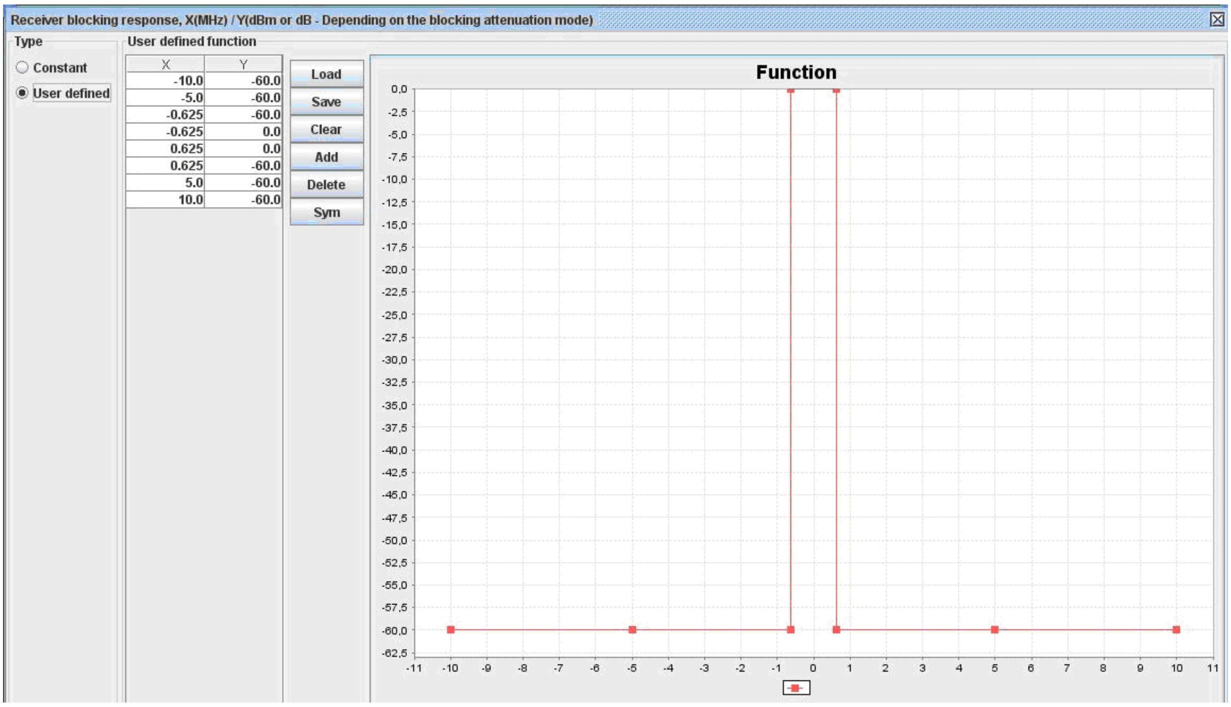


Figure A3.1: RDS, S5 receiver blocking response

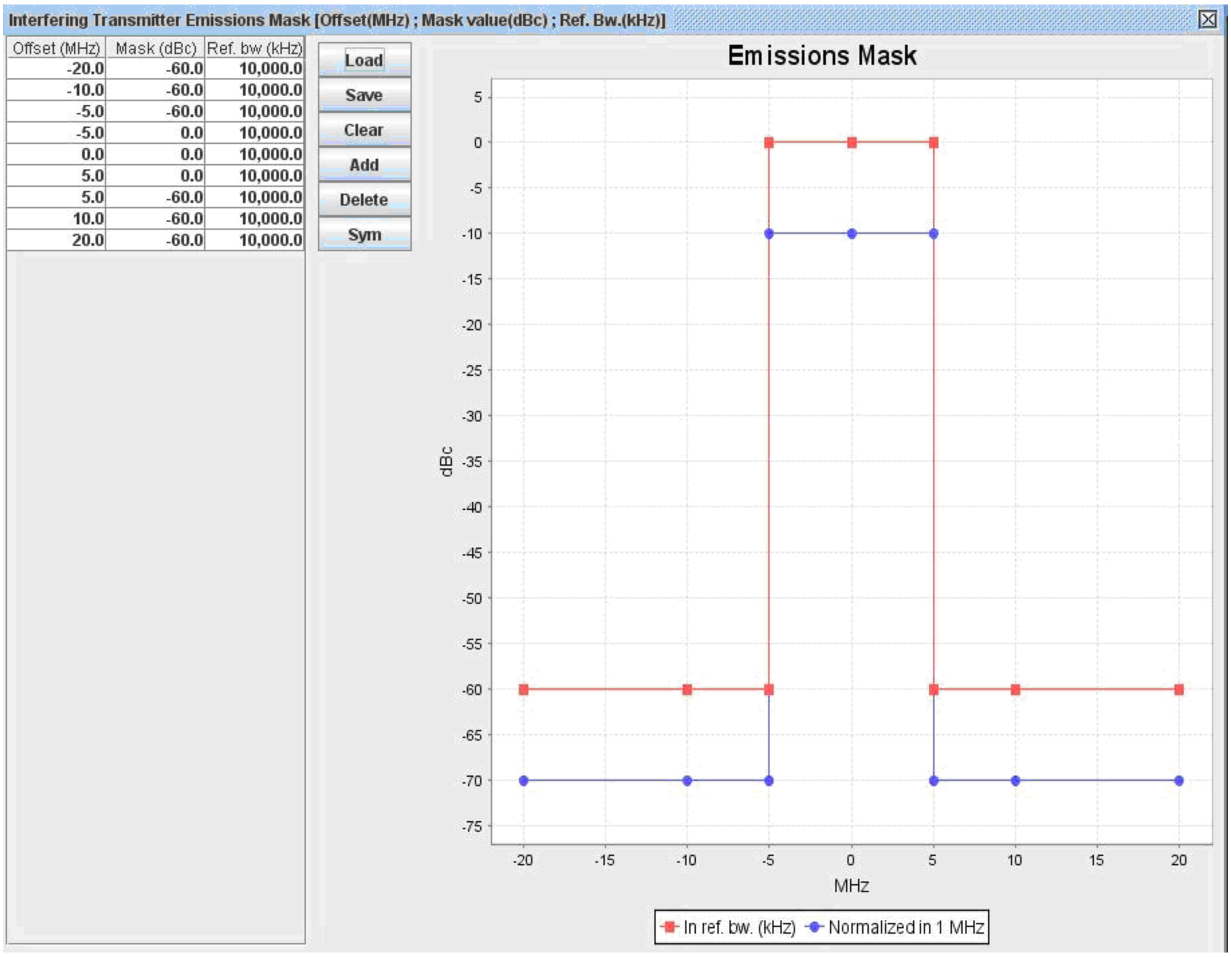


Figure A3.2: PL transmitter emissions mask

The results of the correlated MCL case are shown in Figure A3.3 for the continuously transmitting low power Pseudolite and it can be seen that they are consistent with the MCL calculations.

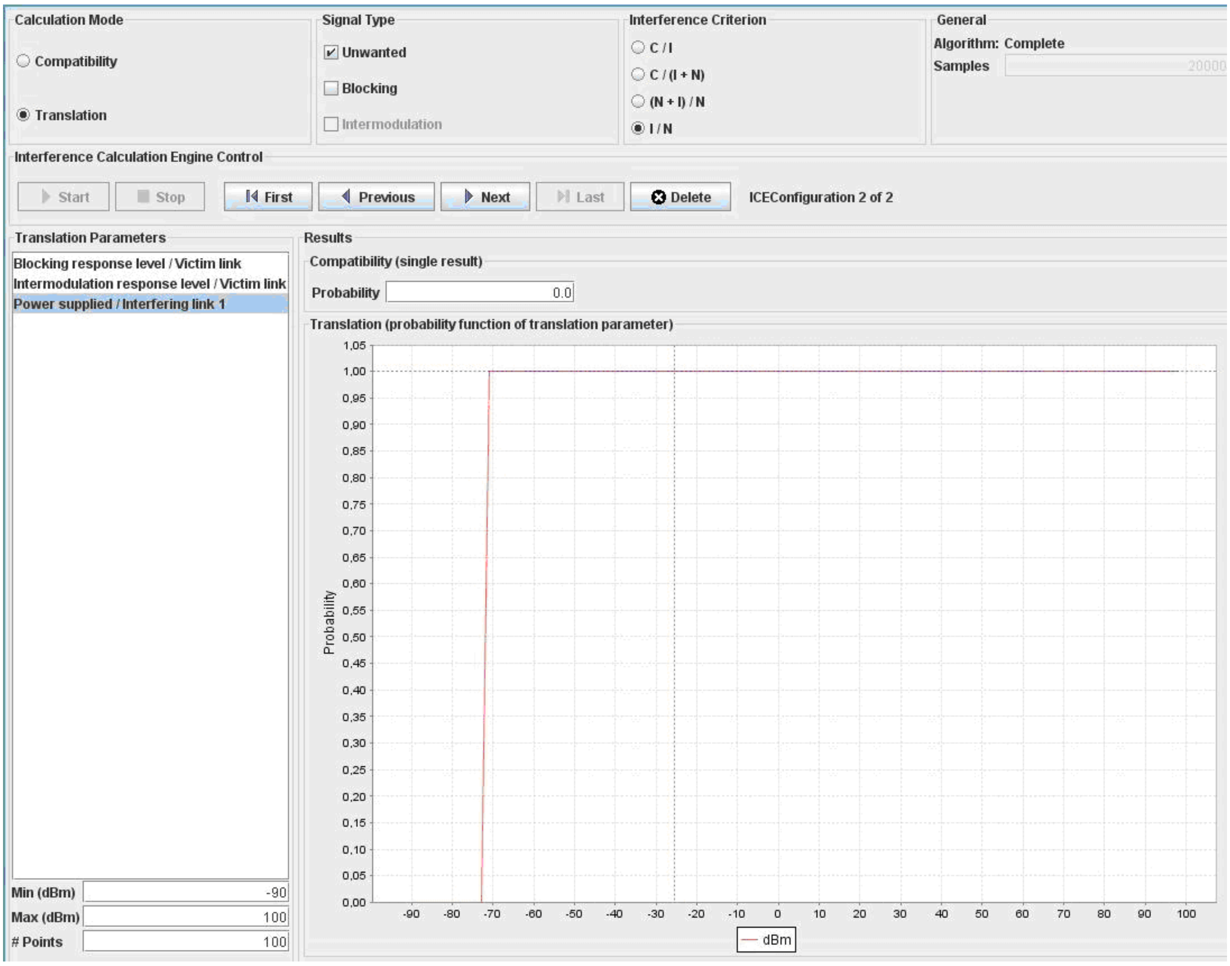


Figure A3.3: Correlated MCL case with single PL in RDS S5 receiver vicinity. I/N criteria is –6dB and separation distance 0.45km, antenna height is 15m (ref. RDS_PL to S5_cw_MCL.sws)

The pulsed Pseudolite case is shown in Figure A3.4. In the pulsed PL case the results are consistent with the MCL calculations after the diffraction loss 26.6dB (see Table A3.1) is taken into account.

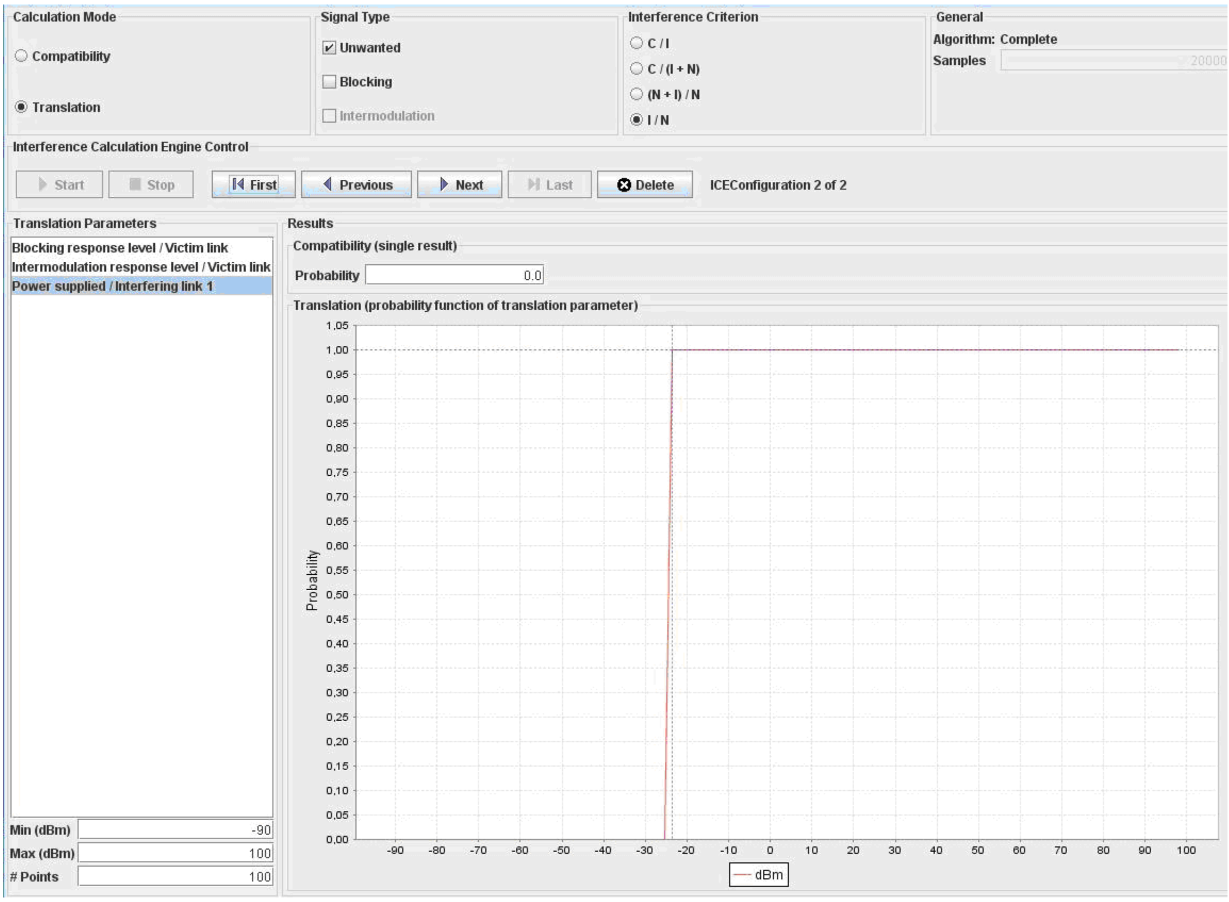


Figure A3.4: Correlated case with single pulsing PL in RDS S5 receiver vicinity. I/N criteria –6dB, separation distance 75km (ref. RDS_PL to S5_pulsed_MCL.sws)

In the statistical SEAMCAT simulations the interfering Pseudolites are assumed uniformly distributed in the simulation area. Since the EIRP levels of the continuously transmitting Pseudolites are low (-70dBm), the resulting interference probabilities in CW Pseudolite scenarios (Figures A3.5 and A3.6) remain very low.

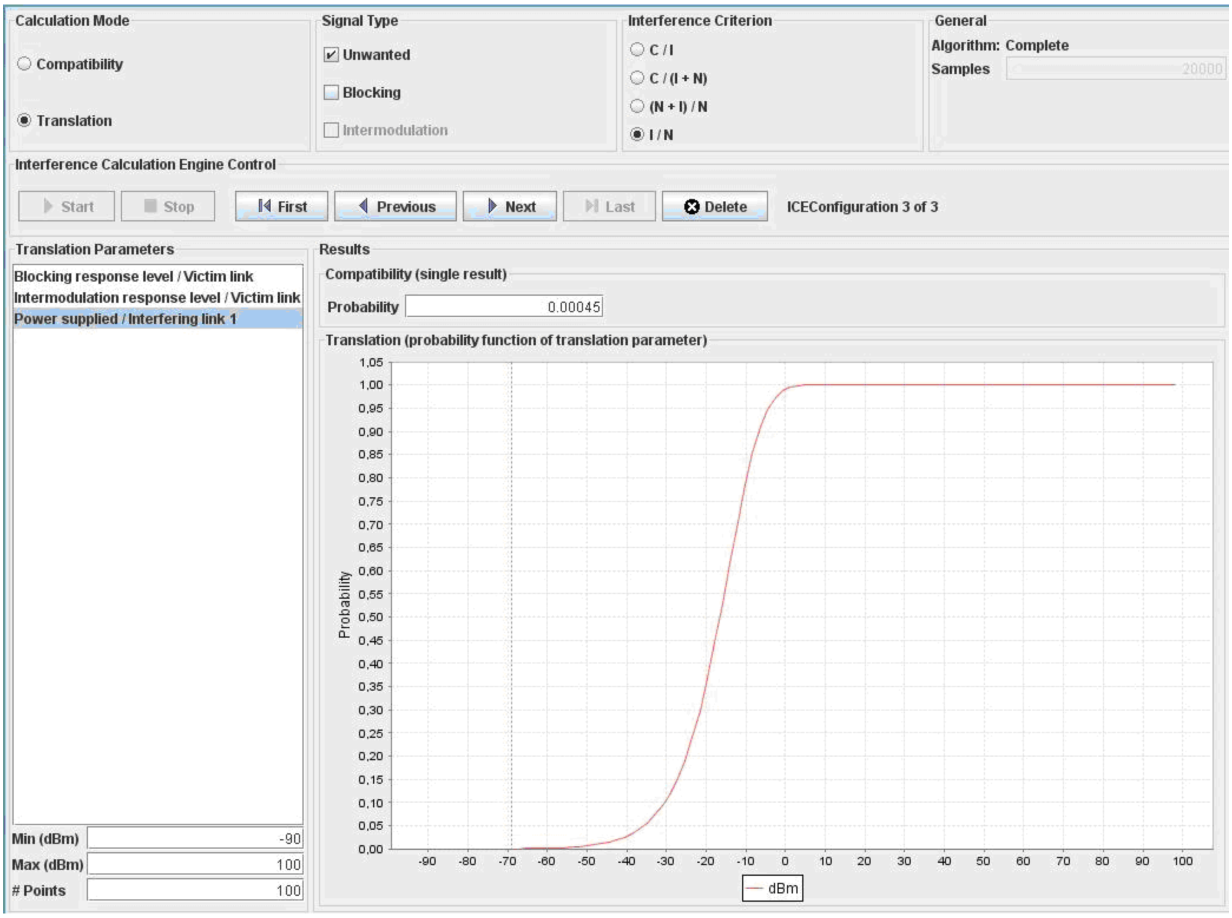


Figure A3.5: 6 CW PLs to radar S5, uniform distribution 0..360º, antenna elevation -6...20deg, (PL density 0.003, activity factor 100%, protection distance 100m, Ext.Hata suburban). The interference probability with I/N criteria -6dB is 0.045% (RDS_PL to S5_cw_6PLs_pd100m_d0.003.sws)

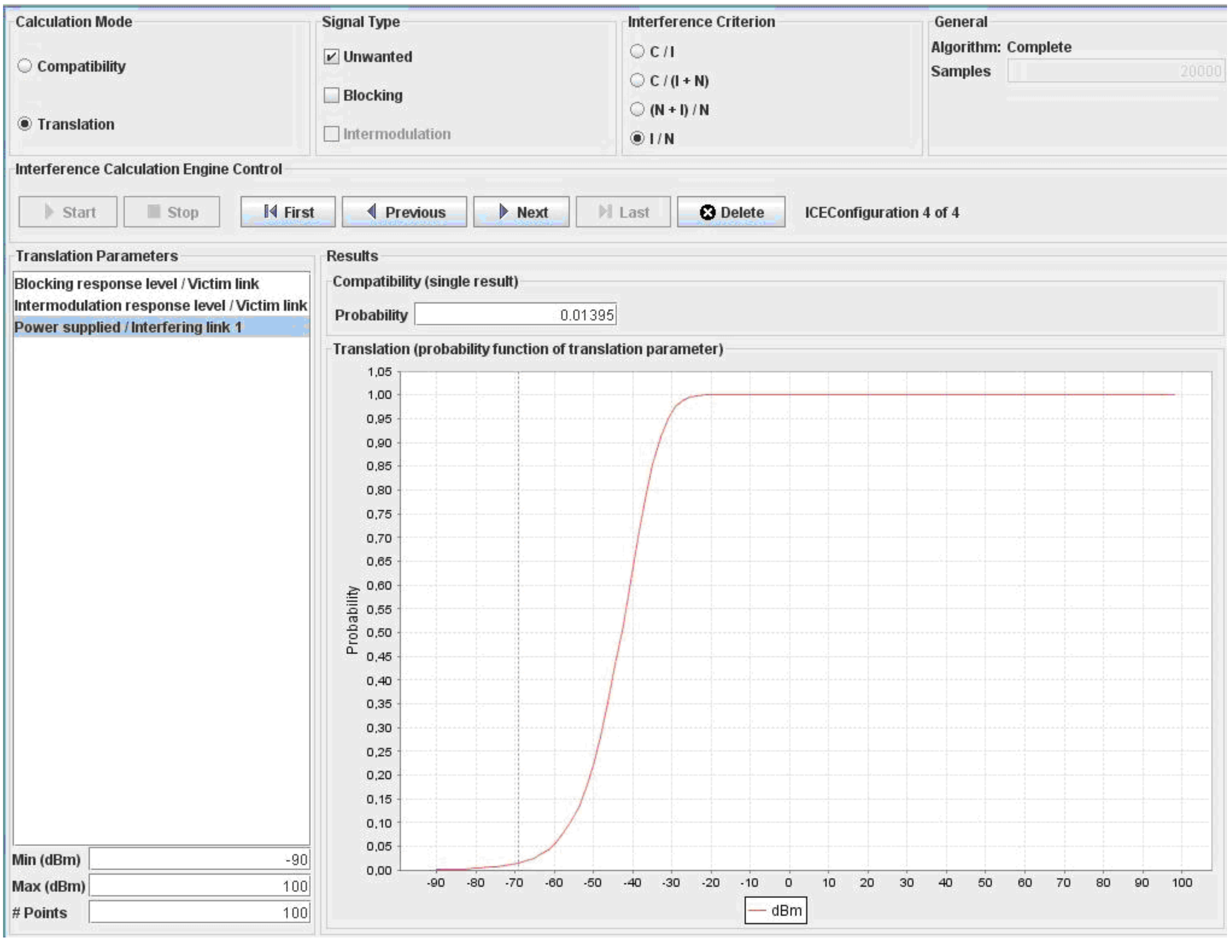


Figure A3.6: 6 CW PLs to radar S5, uniform distribution 0..360º, antenna elevation -6...20deg, (PL density 0.1 1/km2, activity factor 100%, protection distance 100m, Ext.Hata suburban). The interference probability with I/N criteria -6dB is 1.4% (ref. RDS_PL to S5_cw_6PLs_pd100m_d0.1.sws)

In case of a pulsed Pseudolite to RDS radar receiver the transmit power of the interfering Pseudolite is high (0dBm) and if the operational conditions remain the same, the resulting interference probability becomes very high, Figure A3.7.

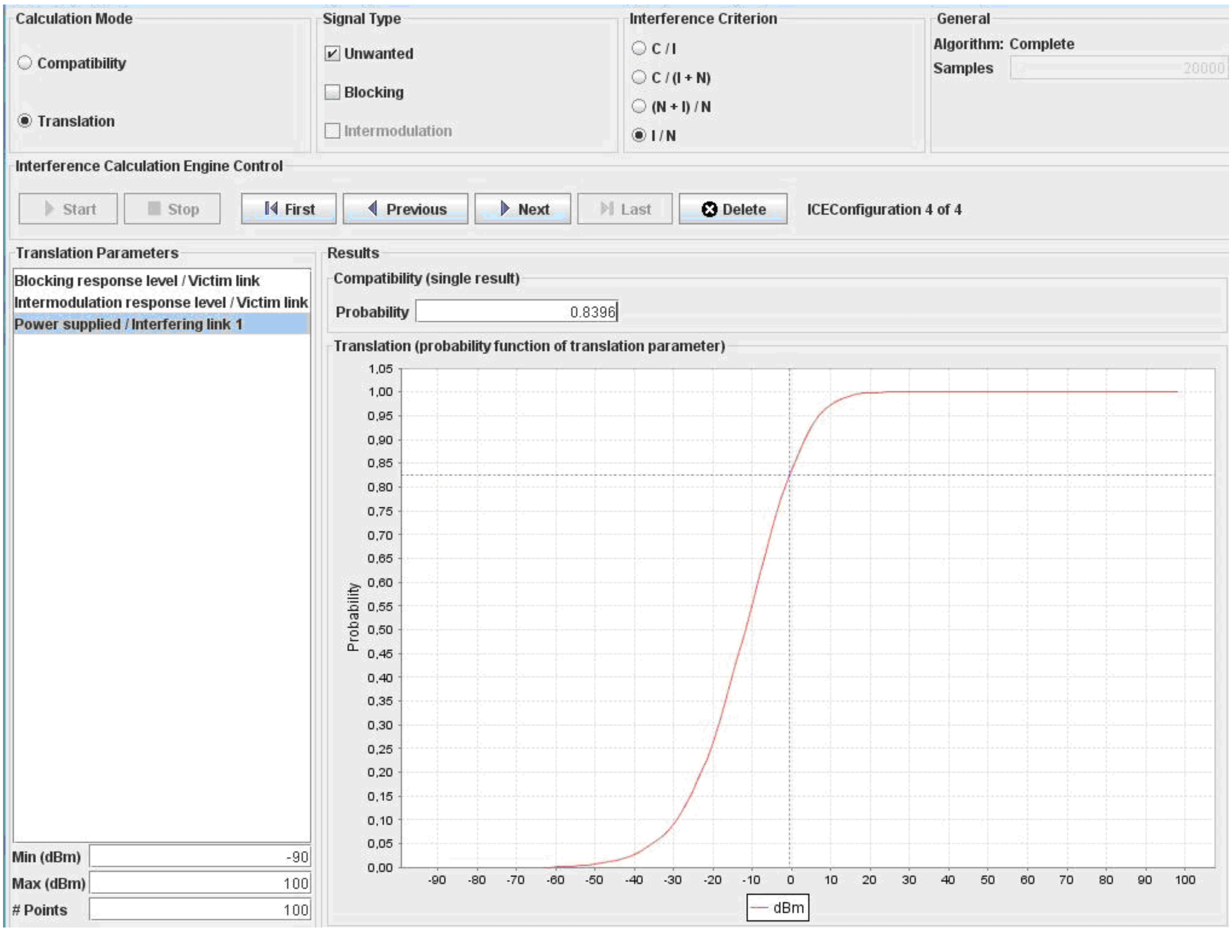


Figure A3.7: Single pulsed PL to radar S5, antenna height is 15m, activity factor 100%, protection distance 100m, density 0.003. The resulted interference probability with I/N criteria of -6dB is 84% (ref. RDS_PL to S5_pulsed_single_pd100_d0.003.sws)

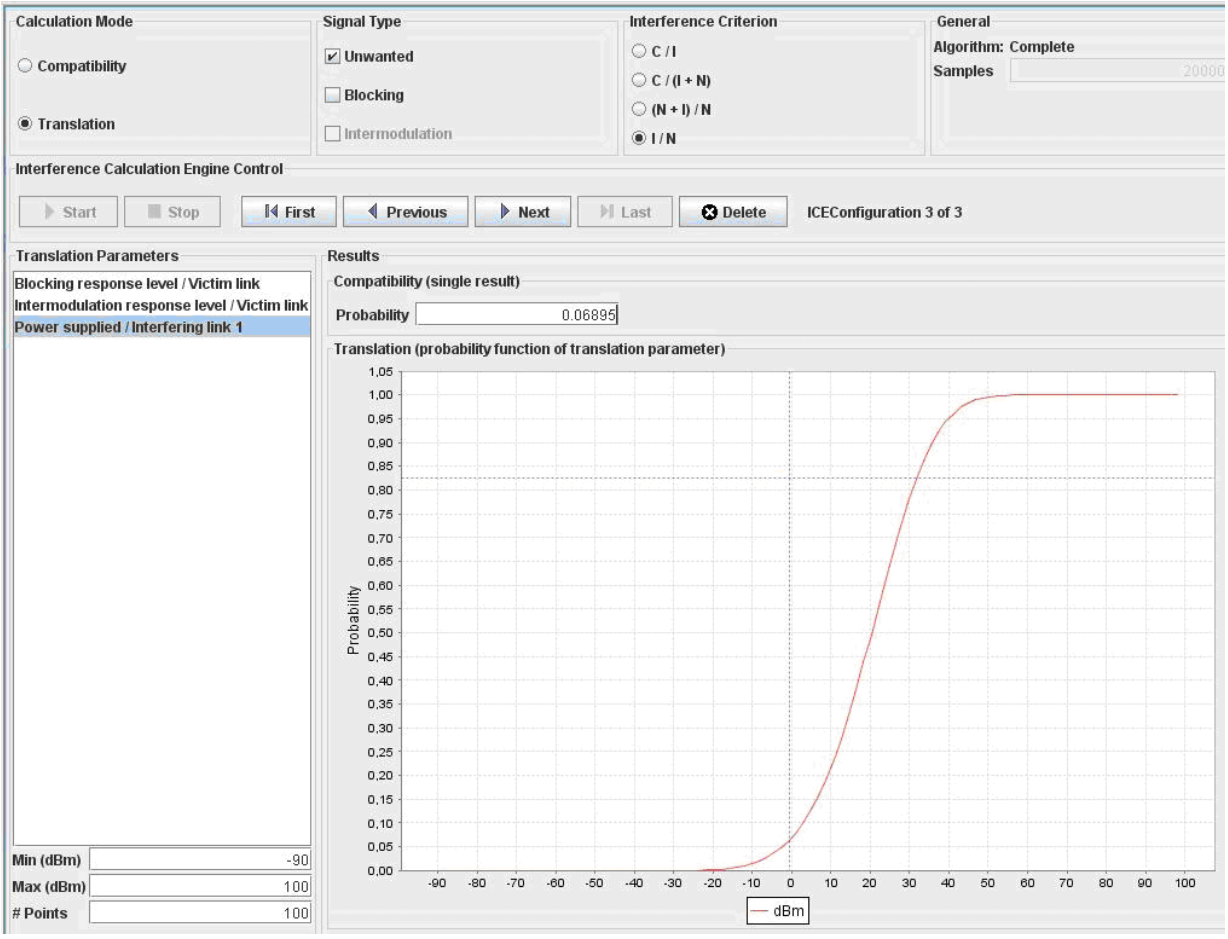


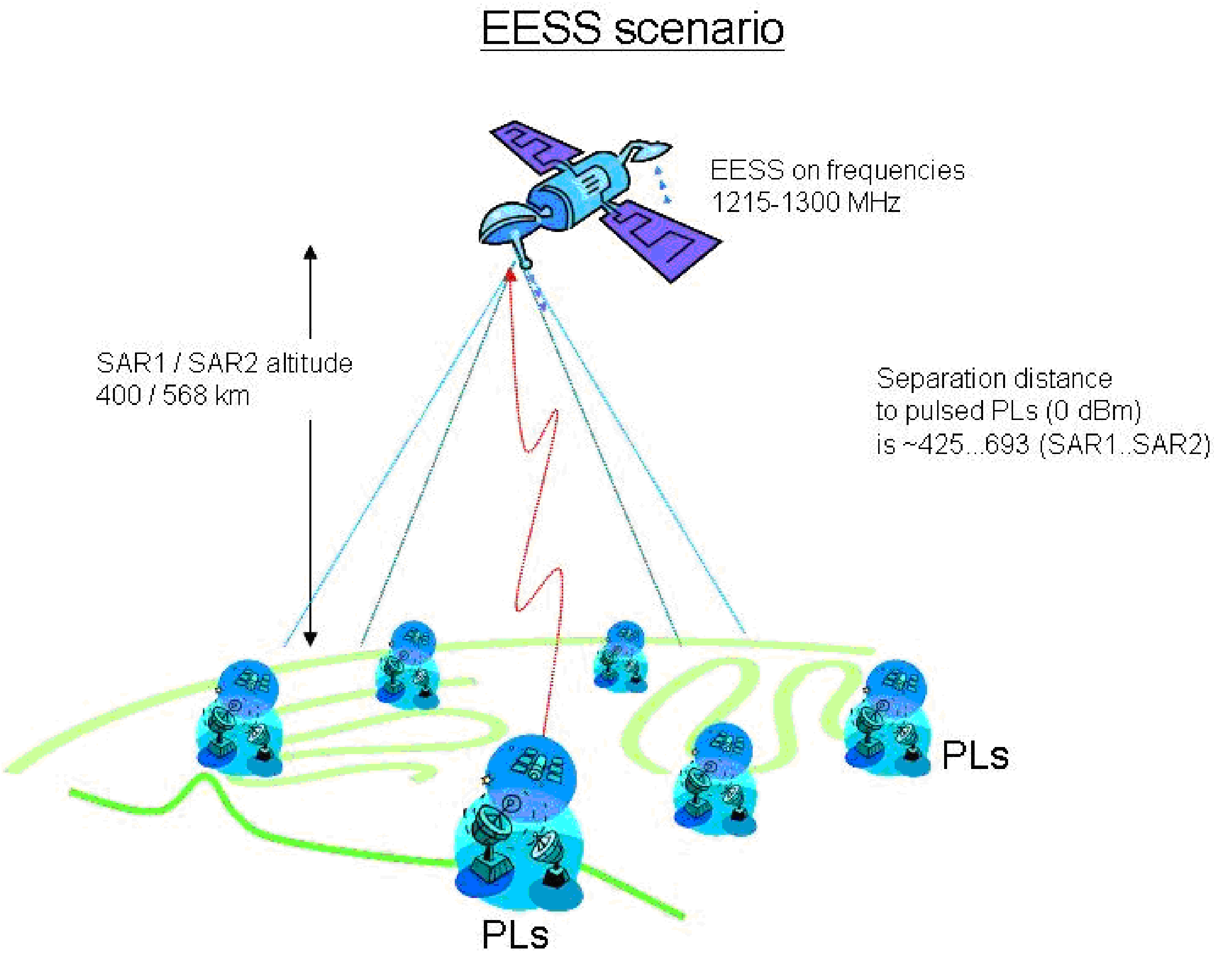
Figure A3.8: Single pulsed PL to radar S5, antenna height 15 meters, activity factor 100%, protection distance 10km, density 0.0001. The resulted interference probability with I/N criteria of -6dB is ~7% (ref. RDS_PL to S5_pulsed_single_pd10km_d0.0001.sws)

A3.5 SEAMCAT Conclusions

Radiodetermination Service (RDS) is a safety related service and should be carefully protected from interference. The protection criterion considered is I/N =-6 dB is to be met 100% of the time. According to the obtained simulation results, the sharing and/or compatibility between continuously transmitting Pseudolites and RDS is possible. In order to guarantee interference free operation, a frequency separation between Pseudolites and radars or an adequate separation distance between the two systems must be implemented.

Between pulse transmitting Pseudolites and RDS radars sharing/compatibility is feasible only if there is frequency separation or large protection zone around the radars.

ANNEX 4: IMPACT OF PSEUDOLITES ON EESS



A4.1 Introduction

The impact of Pseudolites on Earth Exploration-Satellite Service (EESS) systems is evaluated considering a simple scenario depicted in the Figure above. First the separation distance required by a space-borne SAR receiver is computed first by the Minimum Coupling Loss (MCL) and after this SEAMCAT-simulations are conducted in order to further investigate the interference probability between Pseudolites and EESS radars.

A4.2 MCL calculations

The required isolation between the interfering Pseudolite and victim EESS SAR1 and SAR2 systems are calculated by the Minimum Coupling Loss method and the obtained results are presented in Table A4.1. The MCL method provides separation distances required in order to ensure interference free operation in the worst case scenario. These results are although spectrally inefficient for scenarios of a statistical nature and therefore, a more realistic approach is obtained by full statistical SEAMCAT simulations.

Interfering system	**Pseudolite pulsing**	**Pseudolite pulsing**
Frequency [MHz]	1227	1227
Bandwidth [MHz]	10	10
TX [dBm]	**0**	**0**
Duty cycle [%]	NA	NA
Additional attenuation, eg. indoor usage	0	0
TX antenna height [m]	20	100
TX antenna gain [dBi] towards the victim	0	0
Separation distance [km]	**425**	**693**
Free Space loss [dB]	146.946699	151.415559
Long term (20 %) diffraction loss [dB]	0	0
PFD the receiving site [dBW/MHz/m^2)	-163.7	-168.1
Victim Service and System	**EESS, SAR 1**	**EESS, SAR 2**
Interfered signal level at RF bw [dBm]	-90	-90
Interfering signal level at RF bw [dBm]	-146.946699	-151.415559
C/I at RF bandwidth	56.9466986	61.4155595
RX bandwidth [MHz]	40	15
Rx noise figure	0.	0.
Rx antenna height [m]	400000	568000
RX antenna gain [dBi] towards interference	36.	33
Rx noise floor [dBm]	-97.7940009	-102.390874
TX/RX BW correction factor	0	0
Interfering signal level [dBm]	-110.946699	-118.415559
I/N [dB]	**-12.1526977**	**-16.0246854**
Compatibility criterion	I/N = -6	I/N = -6
Interference risk (single entry)	**Very low**	**Very low**

Table A4.1: Pseudolites to EESS, interference calculation using the MCL method

Because of the long distance between the space-borne SAR receivers and ground-based PL transmitters, the continuous transmitting low power Pseudolites do not cause interference to SAR receivers and compatibility evaluations are made to pulsed Pseudolites.

A4.3 SEAMCAT simulations

In the SEAMCAT simulations the statistical compatibility between the Pseudolite and EESS services is studied. The consistency between the SEAMCAT scenario and the MCL calculations is checked by a simple correlated simulation case without any distributions and after this a full statistical scenario is implemented.

The SAR receivers are space-borne, thus line-of-sight visibility between the interfering Pseudolite transmitter and the victim can be assumed. The selected propagation model for the simulations is the Free Space Loss model (as implemented in SEAMCAT). Between the Pseudolite transmit and receive antennas the operational environment is assumed as non-LOS and the Extended Hata model (as implemented in SEAMCAT) is used.

The interference criteria for synthetic aperture radars is an interference-to-noise ratio (*I*/*N*) of –6 dB, which corresponds to a 10% performance degradation of the standard deviation of SAR pixel power. The EESS SAR radar scans the surface of the Earth with its antenna main beam when it sees the interference only from the main beam. Therefore, in these evaluations, only the main lobes of the Synthetic Aperture Radar, SAR1 or SAR2, are considered. The size of the antenna footprint is about 20 km x 20 km.

In the simulations both, the interfering PL and victim SAR receivers are assumed to operate on same 1 227 MHz frequency. The simulation parameters are gathered in Table A4.2.

SEAMCAT parameters	**Victim: EESS, SAR receiver**		**Interfering System: CW or Pulsed PLs**	
	SAR1	**SAR2**	**CW**	**Pulsed**
Frequency [MHz]	1 227			
Transmit power P_{TX} [dBm]	-		-70 or 0	
Noise level [dBm]	-97.7	-102		
Bandwidth (pulse) [MHz]	40	15	2 or 10	
Antenna azimuth [deg]	Polar angle 360º; uniform distribution		0...360º uniform distribution	
Antenna elevation [deg]	0º		0º	
Antenna height [m]	400 000	568 000	10	
Maximum antenna gain [dBi]	36,4	33	11 (Tx)	
Antenna orientation (deg, from nadir)	20º	35º		
Minimum desired signal [dBm]	-156.5 *			
Interference criteria	Interference-to Noise ratio, I/N=-6dB			
Distance between InterferingTx -Victim Rx	• MCL case: separation distance (see Table A4.1) • Otherwise: radar altitude (see. antenna height above)			
Propagation model	• In MCL case and between SAR - PLs: Free Space • Between PL Rx and Tx: Extended Hata, Suburban (below roof) o both interfering PL and Victim outdoors			

Interfering transmitters in SAR coverage	• MCL case: Single transmitter • Otherwise: o Single transmitter case (density 0,0025 1/km^2) o 6 uniformly distributed PLs (density 0,015 1/km^2)

Table A4.2: SEAMCAT simulation parameters for SAR receivers in the bands 1215-1240 MHz and 1240-1300MHz [ref. ITU-R Rec. RS.1347], [*Ref. ITU-R RS.1166-3]

The used SAR1 and SAR2 receiver blocking responses and PL transmitter emissions mask are presented in Figures A4.1, A4.2 and A4.3, respectively.

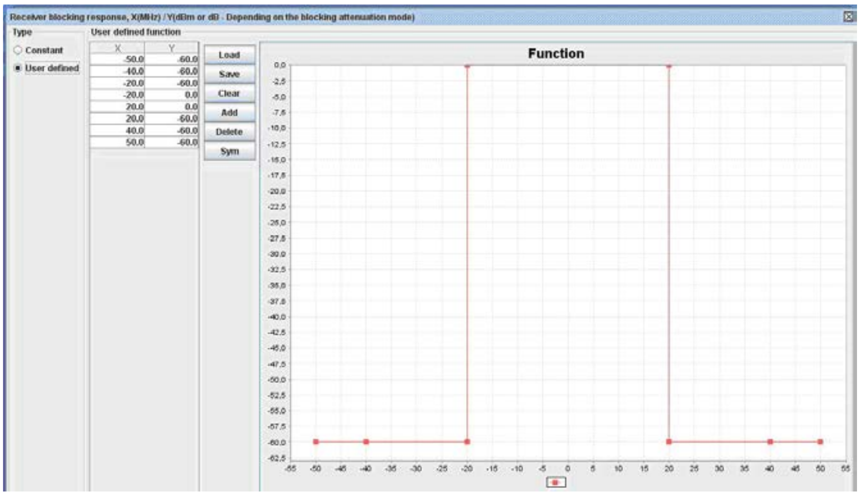


Figure A4.1: EESS, SAR1 receiver blocking response

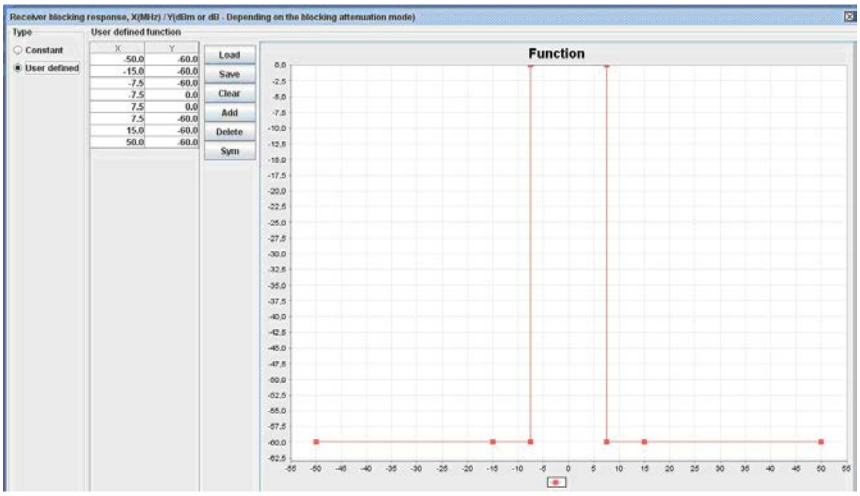


Figure A4.2: EESS, SAR2 receiver blocking response

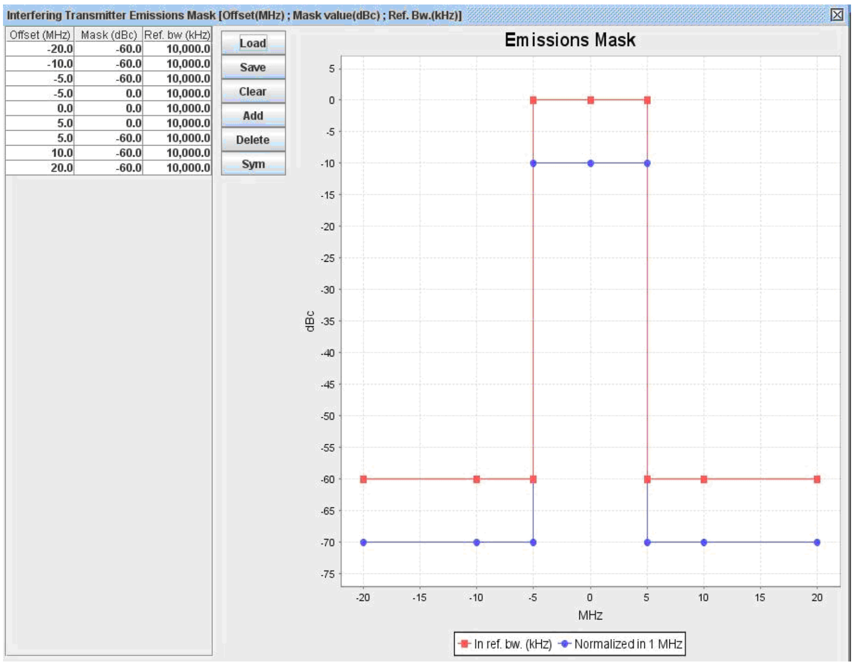


Figure A4.3: PL transmitter emissions mask

EESS (space-to-Earth) SAR1 receivers operating in the band 1215-1300 MHz

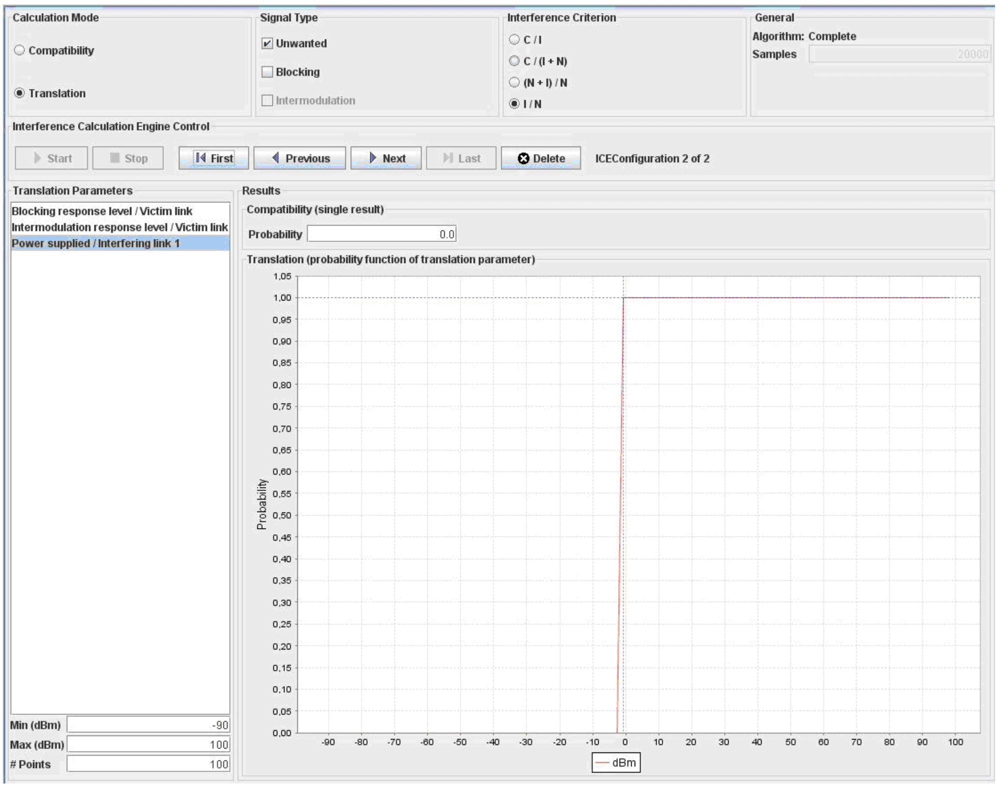


Figure A4.4: Pulsed PL to EESS, space-borne SAR1; Correlated case with I/N criteria -6 dB and separation distance 425km. (EESS_PL to SAR1_pulsed_MCL.sws)

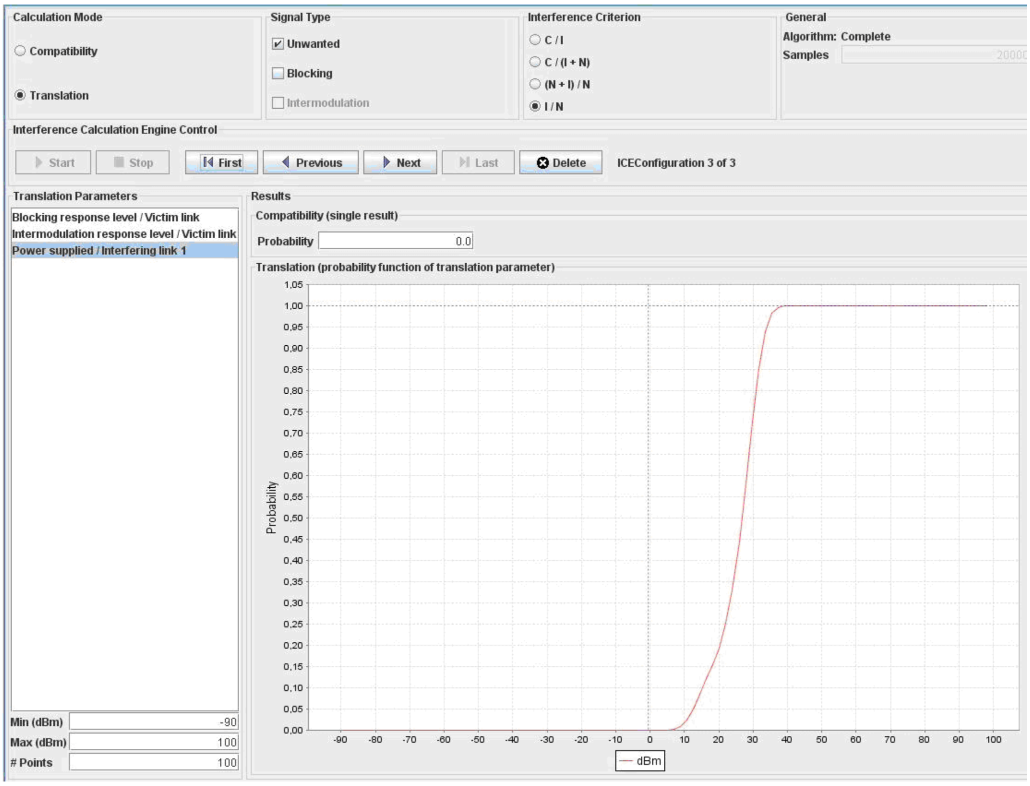


Figure A4.5: Single pulse transmitting PL to SAR1; uniform distributions (PL transmitter density 0.0025 1/km²); Interference probability is 0.105% (EESS_PL to SAR1_pulsed_single_d0.0025.sws)

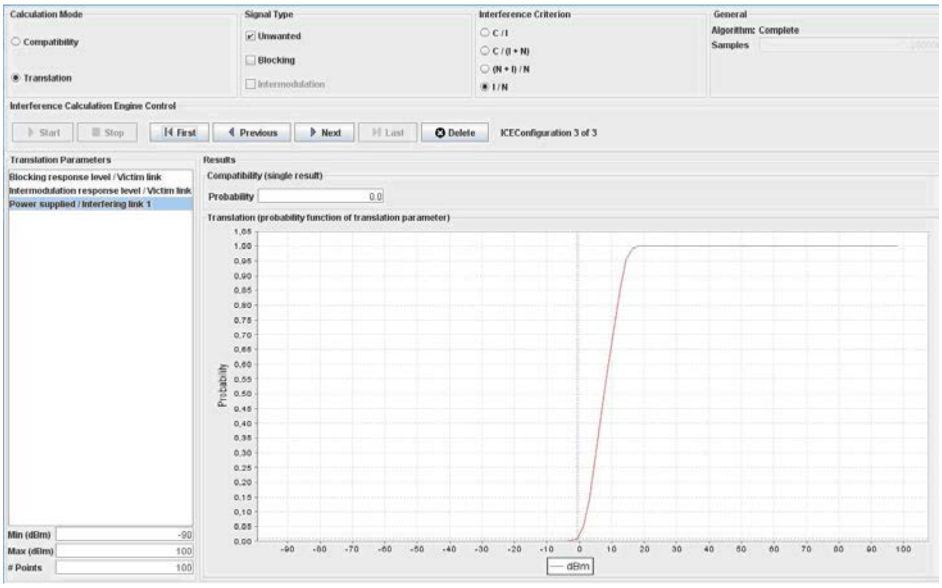


Figure A4.6: Six pulse transmitting PLs to SAR1; Uniform distributions (PL transmitter density 0.015 1/km²); Interference probability is 2.14% (EESS_PL to SAR1_pulsed_6tx_d0.015.sws)

Single pulse transmitting Pseudolite in the SAR1 antenna footprint (PL density 0.0025 1/km²) does not cause interference to the EESS system (Figure A4.5). The situation is the same also in the six pulse transmitting Pseudolites case (with higher PL density of 0.015 Tx/km²) in Figure A4.6. However, as the number of Pseudolites in the radar footprint increases aggregated average interference power level in the EESS receiver may be exceeded.

<u>EESS (space-to-Earth) SAR2 receivers operating in the band 1215-1300 MHz</u>

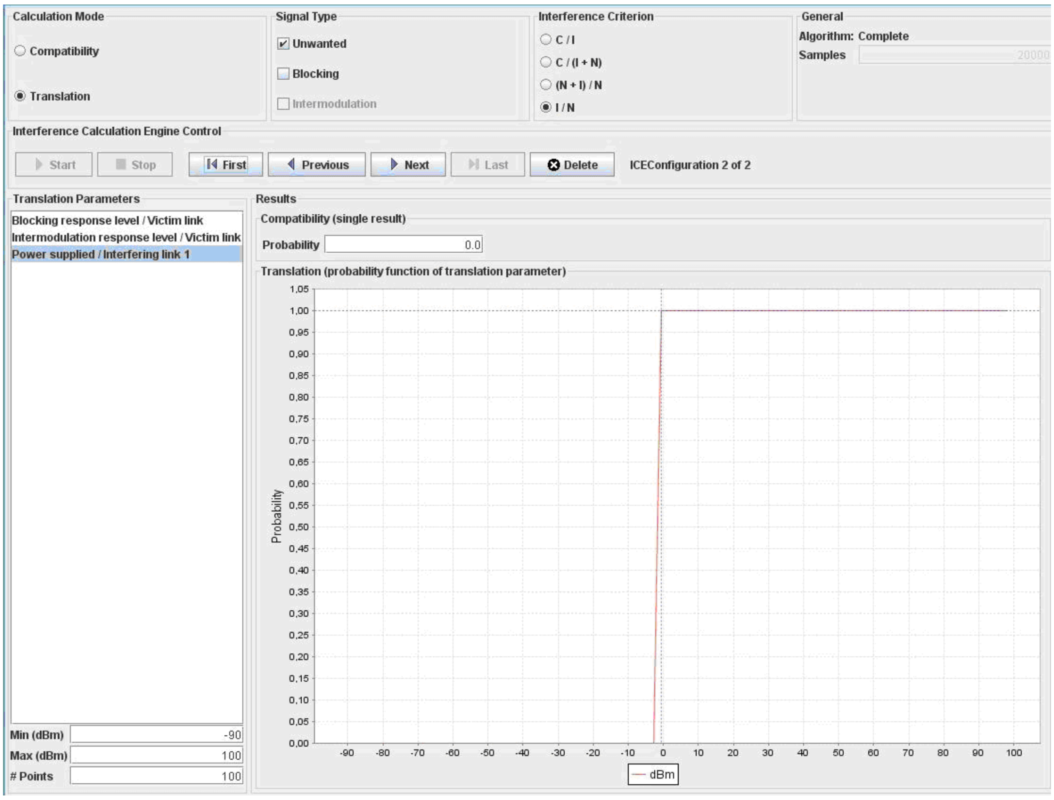


Figure A4.7: Pulsed PL to EESS, space-borne SAR2; Correlated case with I/N criteria -6 dB and separation distance 693km. (EESS_PL to SAR2_pulsed_MCL.sws)

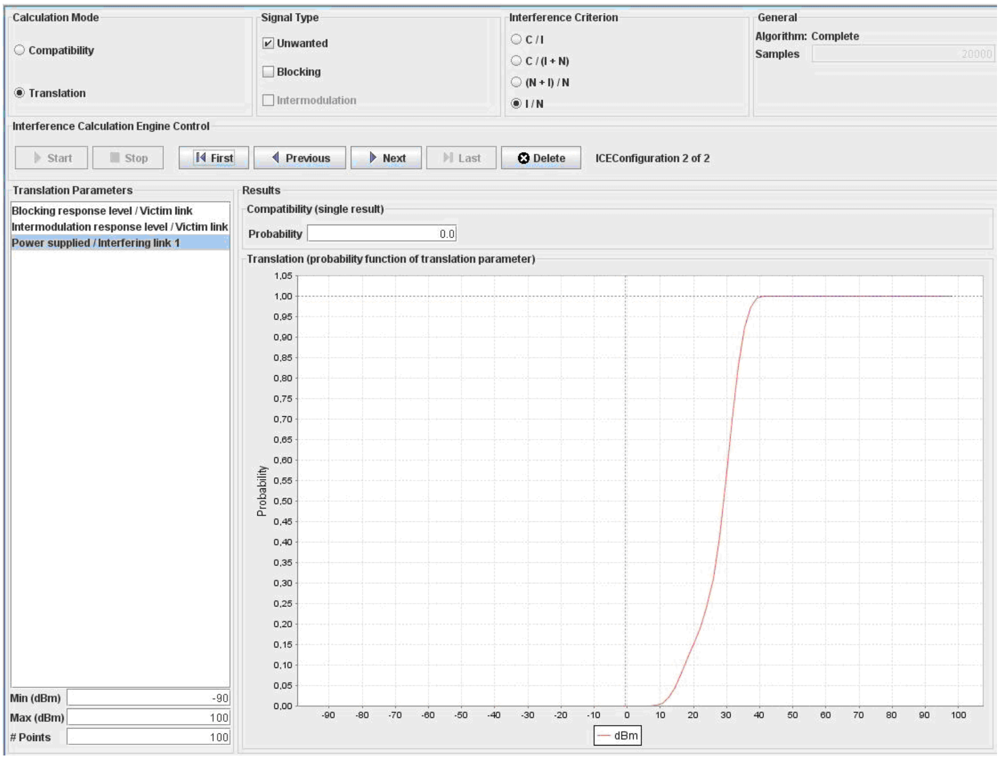


Figure A4.8: Single pulse transmitting PL to SAR2; Uniform distributions (PL transmitter density 0.0025 1/km2); Interference probability 0% (EESS_1PL to SAR2_single_pulsed_d0.0025.sws)

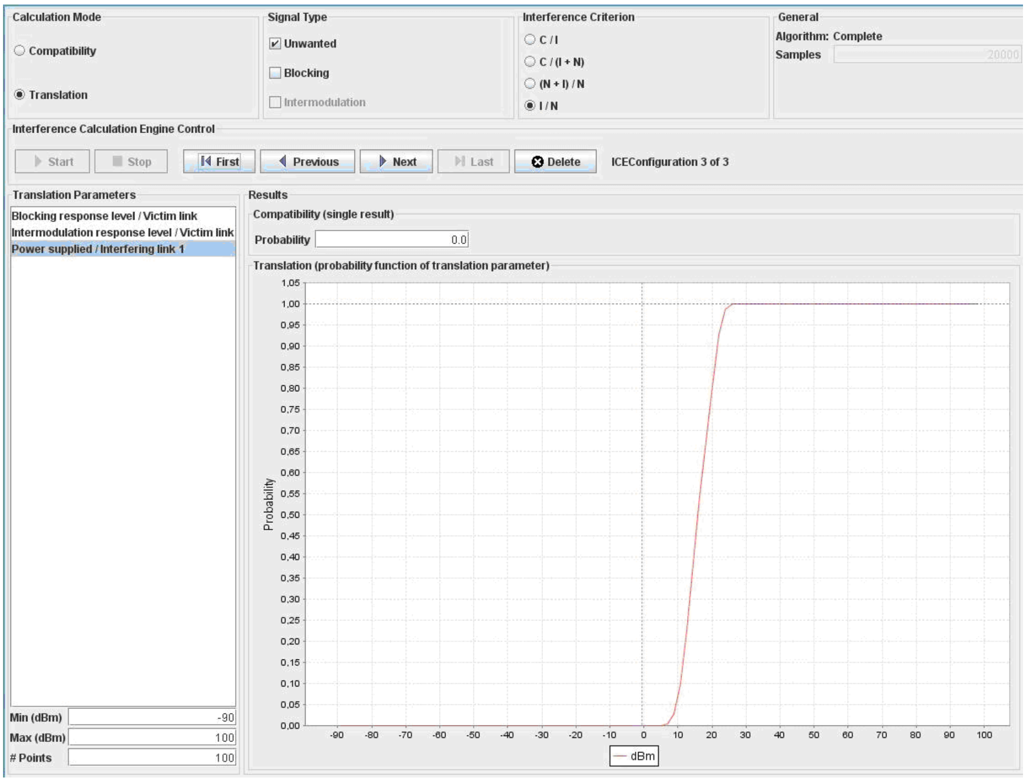


Figure A4.9: Six pulse transmitting PLs to SAR2; Uniform distributions (PL transmitter density 0.015 1/km^2); Interference probability is 0% (EESS_PL to SAR2_6tx_pulsed_d0.015.sws)

Single pulse transmitting Pseudolite in the antenna footprint (density 0.0025 1/km^2) does not cause interference to the EESS, SAR2 system (Figure A4.8) and neither do six pulse transmitting PLs (PL density 0.015 Tx/km^2), Figure A4.9. However, when the number of Pseudolites in the radar footprint increases aggregated average interference power level in the EESS receiver may be exceeded.

A4.4 SEAMCAT Conclusions (1215-1300 MHz)

Continuously transmitting Pseudolites do not cause interference to synthetic aperture radars due to of the long distance between the space-borne SAR receivers and ground-based PL transmitters. The case is similar in case of pulse transmitting Pseudolites. However, as the number of pulsed Pseudolites in the footprint increases, the aggregated average interference power level in the EESS receiver may be exceeded.

Therefore it can be concluded that sharing and/or compatibility between continuously transmitting Pseudolites and EESS SAR receivers is feasible. In the pulse transmitting Pseudolite case sharing/combatibility is feasible if the aggregated average interference from all Pseudolites in the surveillance radar antenna footprint (approximately 20km x 20km area) is limited.

ANNEX 5: REFERENCES

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