

**EUROPEAN ORGANISATION FOR THE
SAFETY OF AIR NAVIGATION**



DFS Deutsche Flugsicherung GmbH



**Study of the maximum allowable
aggregate Power Flux Density
of the Emissions of Space Stations
in the Radio Navigation-Satellite
Service for the Protection
of Radars operating in the Band
1215 – 1300 MHz**



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Abstract

The purpose of this study is to provide background material to support the standardisation of the maximum allowable aggregate Power Flux Density (PFD) of the Emissions of Space Stations in Radio Navigation-Satellite Service for the Protection of Radars operating in the Band 1215 – 1300 MHz. To determine the interference susceptibility of a Radar against such emissions, a variety of simulated signal types are fed into the signal path of a Radar station owned by DFS. For the sake of the universal applicability of the results to other Radars operating in this band, the simulated signals are centered around the center frequency (1259 MHz) of the Radar used for the measurements. The impact of the simulated interference signals was investigated primarily by determination of the loss of the probability of detection of targets, compared with the second undisturbed channel of the Radar at 1343 MHz. The results of the interference susceptibility measurements show, that the PFD limit to protect Radars of the analysed type should be $-164 \text{ dB(W/m}^2\text{)}$ in any 1 MHz. Furthermore the limit for the Interference to Noise (I/N) ratio should be -18 dB . These limit values would keep the loss of P_D below 1 % and the increase of noise and the increase of the minimum discernable signal level below 1 dB.

Keywords

L-band Radar, Power Flux Density Limit, Interference Susceptibility Measurements, Satellite Navigation Systems, GPS, GLONASS, GALILEO, DFS

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TABLE OF CONTENTS

DOCUMENT IDENTIFICATION SHEET	ii
DOCUMENT APPROVAL	iii
DOCUMENT CHANGE RECORD.....	iv
EXECUTIVE SUMMARY.....	1
1. INTRODUCTION.....	6
2. REQUIREMENTS.....	6
3. APPROACH	7
3.1 Description of the Radar used for the Measurements.....	7
3.2 Description of the Satellite navigation signals used for the measurements.....	7
4. RESULTS / FINDINGS	9
4.1 Considerations about the Radar antenna	9
4.2 Interference impact on the Radar receiver.....	10
4.2.1 Considerations about the differences between various signal types	10
4.2.2 Considerations about potential saturation of the low noise amplifier	10
4.2.3 Measured impact at the IF stage output	10
4.3 Interference impact on Radar processing	13
4.4 Interference conditions in Germany	17
5. CONCLUSION / RECOMMENDATIONS	19
6. REFERENCES	21
APPENDIX A – DESCRIPTION OF RADAR AND MEASUREMENT SET-UP.....	22
APPENDIX B – THEORETICAL BACKGROUND	30
APPENDIX C – ABBREVIATIONS	32
APPENDIX D – SELECTED MEASUREMENT RESULTS.....	34

EXECUTIVE SUMMARY

PURPOSE

The ITU World Radiocommunication Conference 2000 (WRC-2000) invited with its Resolution 606 the Radiocommunication Sector to conduct, as a matter of urgency and in time for WRC-03, the appropriate technical, operational and regulatory studies, including an assessment of the need for a power flux-density limit concerning the operation of radionavigation-satellite service (space-to-Earth) systems in the frequency band 1 215-1 300 MHz in order to ensure that the radionavigation-satellite service (space-to-Earth) will not cause harmful interference to the radionavigation and the radio-location services.

The purpose of this study is to provide background material to support the definition of the maximum allowable aggregate Power Flux Density of the Emissions of Space Stations in Radio Navigation-Satellite Service for the protection of Radars operating in the Band 1215 – 1300 MHz

METHOD

For this purpose a variety of simulated satellite navigation signals are fed into the signal path of a Radar station owned by DFS operating at 1259 MHz. For the sake of the universal applicability of the results to the Radars operating in this band, the simulated signals are centered around 1259 MHz. The impact of the simulated interference signals is investigated primarily by determination of the loss of the probability of detection of targets, compared with the second undisturbed channel of the Radar at 1343 MHz.

CONCLUSIONS / RECOMMENDATIONS

The results of the interference susceptibility measurements show, that the Power Flux Density limit to protect Radars of the analysed type should be $-164 \text{ dB(W/m}^2\text{)}$ in any 1 MHz. Furthermore the limit for the Interference to Noise (I/N) ratio should be -18 dB . These limit values would keep the loss of Probability of Detection (PD) below 1 % and the increase of noise and the increase of the minimum discernable signal level below 1 dB.

German civil ATC Radars make use of the band 1250 to 1260 MHz. Within this band, at the time of the study (August – September 2001), the only satellite navigation signal that could be received, is transmitted by a GLONASS satellite with the channel number 10. Only one German ATC Radar is using a center frequency near this GLONASS channel. Despite, a loss of probability of detection of 20 to 30 % could be possible, an impact was not detected in the past. The reason for this is, that people responsible for this Radar were not aware of the problem and only a narrow angle segment with a width of 1° to 2° , is potentially affected. It is obvious, that the situation will become more severe, the moment GLONASS satellites using the channels 11 and 12 will be used again. On the other hand, after the year 2005, GLONASS will not use any more the channels 8 to 12. This will improve the situation for the German ATC Radars. For German military Radars using the band 1215 to 1250 MHz and 1260 to 1300 MHz, the signals of GLONASS-L2, GPS-L2 and GALILEO-E6 will be a threat. The situation may be comparable in other countries.

1. INTRODUCTION

In ITU, CEPT and ICAO, theoretical evaluation of maximal RNSS Power Flux Density (PFD) to protect L-band Radar were presented. All presentations noted the huge discrepancy (30 to 40 dB) between the PFD produced by existing GPS and GLONASS satellites on the Earth's surface and theoretical PFD values derived from radar interference protection limit as stipulated by ITU-R Recommendation M.1461. To date, there is no report of interference to L-band Radar and therefore there is no convincing explanation to explain the discrepancy. Therefore the only way to determine what is the real necessary PFD to protect L-band Radar is through measurement.

Specifically, the aim and main tasks of the study are:

To determine the RNSS PFD necessary to protect the L-band Radar by following means:

- Measurement of RNSS (GLONASS L1-C/A, GPS L2-C/A, GPS L2-P and Galileo E6) simulated signal impact on a typical L-band ATC Radar located in Germany
- To consider the output at the front-end receiver to determine interference impact on front-end receiver and to determine I/N ratio at this stage.
- To consider the output after the Radar processing to evaluate the interference impact on Radar processing (Probability of detection, P_D and probability of false alarm, P_{FA}).
- To compare the result with expected real RNSS PFD and with the calculated PFD limit and to evaluate PFD limit to be proposed in ICAO and CEPT/ITU.

2. REQUIREMENTS

The work comprises the following work packages (WPs):

WP 1 Preparation of measurement:

- To prepare the measurements, laboratory tests are conducted to find the optimal way to simulate the satellite navigation signals.
- For the calculation of the Power Flux Density PFD from a measured interference power, the insertion loss between the antenna and the interface, where the interference signal will be fed in later needs is determined. For this purpose, the loss of the wave guide and other components in front of the low noise amplifier is to be determined. The results are validated by measurement of the received power of a test signal transmitted via air.

WP 2 Conduction of measurements:

Measurement of the impact of simulated satellite navigation signals on a typical primary Radar receiver by injection of the simulated interference signals in the signal path of the Radar:

- Determination of the interference impact on the receiver.
- Gathering of data like spectra of the signals, increase of the noise floor and recording of data provided by the sensor data processor etc. Simultaneously recording of data from undisturbed channels, like second primary Radar channel and secondary Radar.

WP 3 Measurement Analysis and Conclusion:

The measured and recorded data in WP2 are processed and evaluated in order:

- to determine the interference impact on Radar processing (PD, PFA) by comparing the detection performance before and after the injection of the interference signal
- to determine the maximal PFD limit to protect L-band Radar using SASS-C 5.2
- to compare the result with expected real RNSS PFD using SASS-C 5.2
- to make recommendation for EUROCONTROL, ICAO, ITU and CEPT

3. APPROACH

3.1 Description of the Radar used for the Measurements

For the measurements, a DFS owned primary Radar station of the type SREM (Surveillance Radar Equipment, details see Appendix A) is has been used. For operational reasons the Radar station Grosshaager Forst near Munich (Germany) has been selected to carry out the measurements. This is one out of six Radar stations of type SRE-M currently used by DFS. The selected Radar station has two primary Radar channels, one with a center frequency of 1259 MHz (in the band under consideration of 1215 to 1300 MHz) and one at 1343 MHz (outside this band). In addition a Secondary Surveillance Radar (SSR) is co-located. Simulated interference signals were only fed in the 1259 MHz channel, whereas the 1343 MHz channel serves as a reference. The simulated interference signals were fed-in in front of the Low Noise amplifier (LNA) by means of a directional coupler (see Appendix A). From the signal power of these signals the values of the associated Power Flux Density (PFD) at the antenna and the Interference to Noise power (I/N) within the intermediate frequency bandwidth were determined (calculations see Appendix B). For this purpose great care was taken to determine the insertion loss between the input of the LNA and the antenna accurately. Furthermore the transfer function between the input of the LNA input and the output of the intermediate frequency stage was measured (Appendix A).

3.2 Description of the Satellite navigation signals used for the measurements

Simulated satellite navigation signals of different bandwidths, according to the various cases (GPS-L2, GLONASS-L2, as well as Galileo E6, see Fig. 1 and Tab. 1) were used to artificially interfere with the target echoes received by a Radar station).

The Radar channel used for the investigations (1259 MHz) is not centered with any of the currently existing or planned satellite signals under consideration. At least theoretically, a randomly picked Radar anywhere in the world in the frequency range 1215 to 1300 MHz could operate on the same center frequency as any of the satellite signals discussed here. For this reason and to asses the worst case the simulated satellite navigation signals were centered with the center frequency to the Radar channel at 1259 MHz (see Tab. 1, sources: for GPS properties see ITU-R M.1088 [Ref. 7], for GLONASS ITU R M.1317 [Ref. 8]).

According to the result of the WRC2000 [Ref. 9], GALILEO E6 will make use of the band 1260 to 1300 MHz. The actual signal properties were in August 2001 still under discussion. Binary phase shift keying (BPSK) and Binary Offset Carrier Modulation (BOC) as well as various code clock frequencies had been proposed.

For the interference susceptibility measurements, a BPSK modulated signal with a code clock frequency of 20.46 MHz centered around 1279 MHz was chosen. Such a signal could be easily generated by the available signal generator and makes use of an approx. 40 MHz broad frequency range, which fits well in the band allocated for Galileo E6 at WRC2000 (Fig. 1).

Tab. 1: Properties of simulated signals

Signal	Properties of the real signals / Status of the signal	Properties of the simulated signals (centered around the Radar frequency of 1259 MHz)
GPS-L2 C/A-Code	$f_{HF} = 1227.6$ MHz, $f_C = 1.023$ MHz	$f_{HF} = 1259$ MHz $f_C = 1.023$ MHz
	To be implemented on GPS IIR-M satellites as well as on future satellite types like IIF and III. First satellite with this option to be launched in 2003, full constellation in 2008	
GPS-L2 P-Code	$f_{HF} = 1227.6$ MHz, $f_C = 10.23$ MHz	$f_{HF} = 1259$ MHz $f_C = 10.23$ MHz
	Currently active	
GLONASS-L2 C/A-Code	$f_{HF} = 1246 + k \cdot 0.4375$ MHz, where the k is the channel number k = -7 to 12 (after 2005: -7 to +4) $f_C = 0.511$ MHz	$f_{HF} = 1259$ MHz $f_C = 0.511$ MHz
	Currently active	
GALILEO-E6	$f_{HF} = 1278.75$ MHz $f_C = 20.46$ MHz	$f_{HF} = 1259$ MHz $f_C = 20.46$ MHz
	One among other options to be implemented in the future. Operational in 2008	

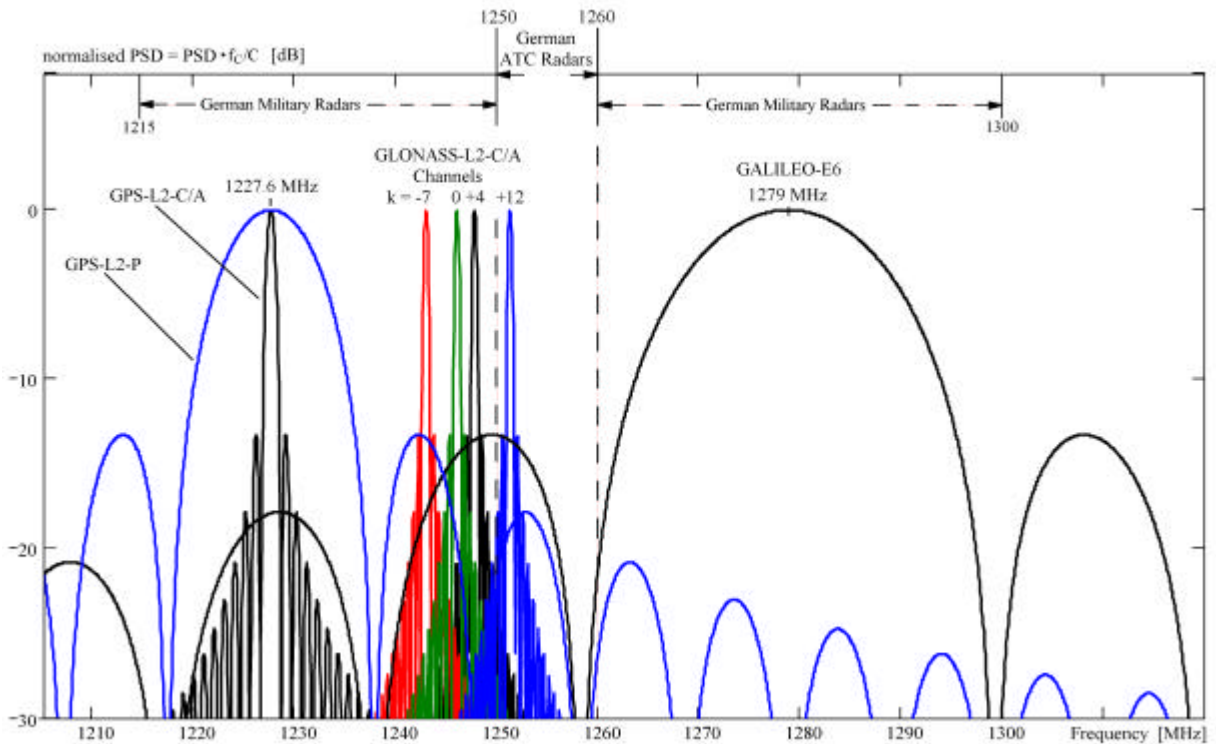


Fig. 1: Spectra of satellite navigation signals in the frequency band under consideration (1215 to 1300 MHz)

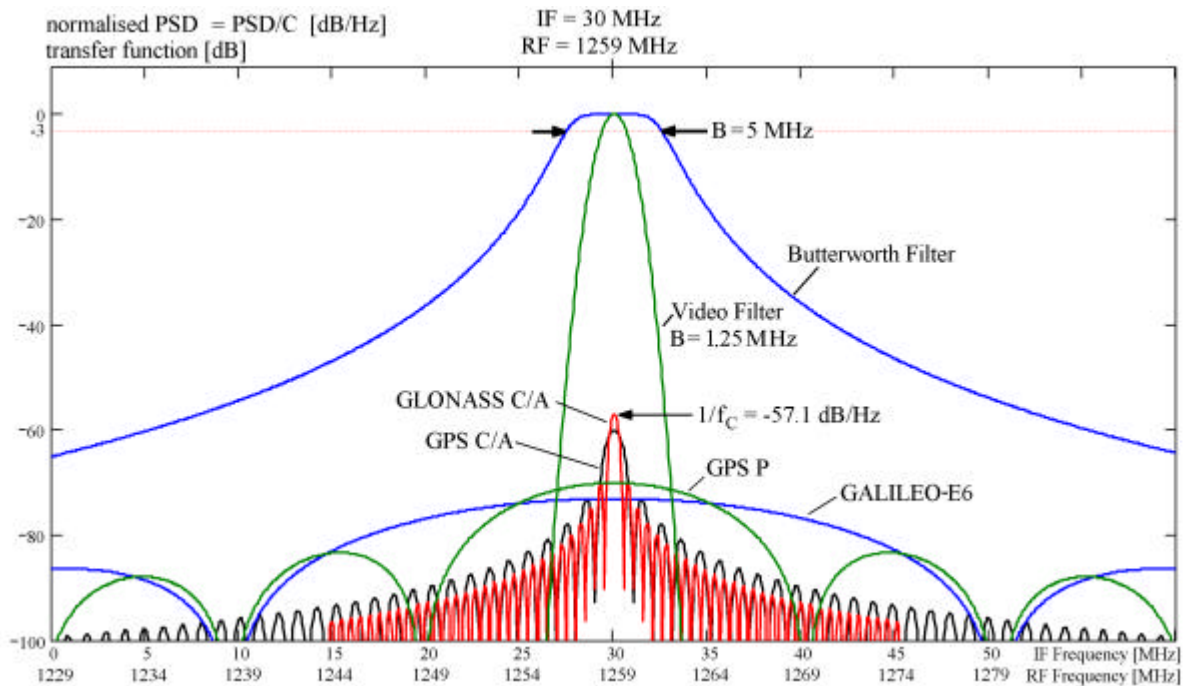


Fig. 2: Spectra of the used Interference Signals and Transfer Functions

4. RESULTS / FINDINGS

The impact of the signals is investigated as follows:

At first the spectrum of the received signals at the output of the Low Noise Amplifier as well as at the output of the IF-stage are examined in the undisturbed as well as in the disturbed case. In this way the filtering of the interference signal and the increase of the noise floor can be judged (see section 4.2). After having determined the range of values of the power levels to be used to rise the noise floor between 1 and 20 dB, the various interference signals (as described in section 3.2) are applied for one hour per each step of power level. During this time, the target reports are evaluated by means of the SASS-C software (see section 4.3).

4.1 Considerations about the Radar antenna

The figures Fig. 13, Fig. 14 and Fig. 15 (in Appendix A) present various views of the Radar's antenna pattern. The half power beam width of the azimuth cut is extremely low (1.1°). Therefore it is unlikely that the signals of more than one navigation satellite are received simultaneously and their power is aggregated. The Radar is able to switch between four different beam types (Pencil Beam, COSEC² beam, Combined Beam No. 1 and Combined Beam No.2). A so-called Range Azimuth Generator is programmed to switch between these beam types in such a way, that the received clutter is minimised. Satellite signals received by the Pencil Beam with its high gain of 38.6 dBi (at an elevation of 0.7°), pose the biggest interference threat.

4.2 Interference impact on the Radar receiver

4.2.1 Considerations about the differences between various signal types

In general, the impact of an interference signal is the higher, the higher its power within the bandwidth of the desired signal is. Usually the IF bandwidth (in this case 5 MHz) is regarded as the bandwidth of the desired signal for a Radar. But for Radars using Klystrons, the IF bandwidth usually is much broader than it would be necessary concluding from the pulse width of the Radar. Therefore, there may arise a difference between the theoretically predicted impact by means of the calculated value of the power within IF bandwidth, and the real occurring impact. The reason for this is the high uncertainty of the center frequency of the transmitter, which is hopping from pulse to pulse due to the special properties of Klystrons. But after the down-conversion in the baseband by means of mixing the received signal with the signal of an oscillator (COherent Oscillator = COHO) which has been tuned to the actual transmitting frequency, the Radar signal usually can be filtered with a video filter, narrower than the IF bandwidth (1.25 MHz in this case).

As explained in detail in Annex C, the maximum of the Power spectral Density (PSD) of the satellite navigation signals (considered in this study) is inversely proportional to the code clock frequency f_c . That means, that for a signal with a given total power C , the PSD as well as the PFD ($PFD = PSD / \text{effective antenna area}$) are the higher, the lower f_c is. To cause the same impact, the signal power C (transmit power of the satellite or power of the simulator) of broadband signals need to be much higher than the power of narrow band signals.

4.2.2 Considerations about potential saturation of the low noise amplifier

The 1 dB compression point of the low noise amplifier of SREM Radar is $-30 \text{ dBm} = -60 \text{ dBW}$ referenced to the LNA input. The attenuation between antenna output and LNA input for the considered Radar is 5.7 dB (Appendix A, Fig. 17). Therefore, the power level of a signal at the antenna port must be 5.7 dB stronger to be able to saturate the LNA. That means, it must have a power of -54.3 dBW . The satellite navigation systems under consideration signals are much weaker. For example, a single GLONASS satellite has a nominal signal power of -161 dBW , referenced to the output of an antenna with 0 dBi gain. If a maximum Radar antenna Gain of 38.6 dB is assumed (see Appendix A and Fig. 15), the received power of one GLONASS satellite would be -122.4 dBW . Therefore, there is a safety margin of 68.1 dB left.

4.2.3 Measured impact at the IF stage output

Fig. 3 and Fig. 4 show the spectra of a typical narrow band (GLONASS C/A) and a typical wide band (GALILEO E6) satellite navigation signal at the output of the IF stage. It is striking that the narrow GLONASS C/A signal passes the channel of the Radar near undistorted, while only the center part of the main lobe of the broadband Galileo E6 signal can be seen at this interface. The GALILEO E6 signal behaves more similar to white noise (power spectral density constant within the bandwidth under consideration) than the GLONASS L2 signal.

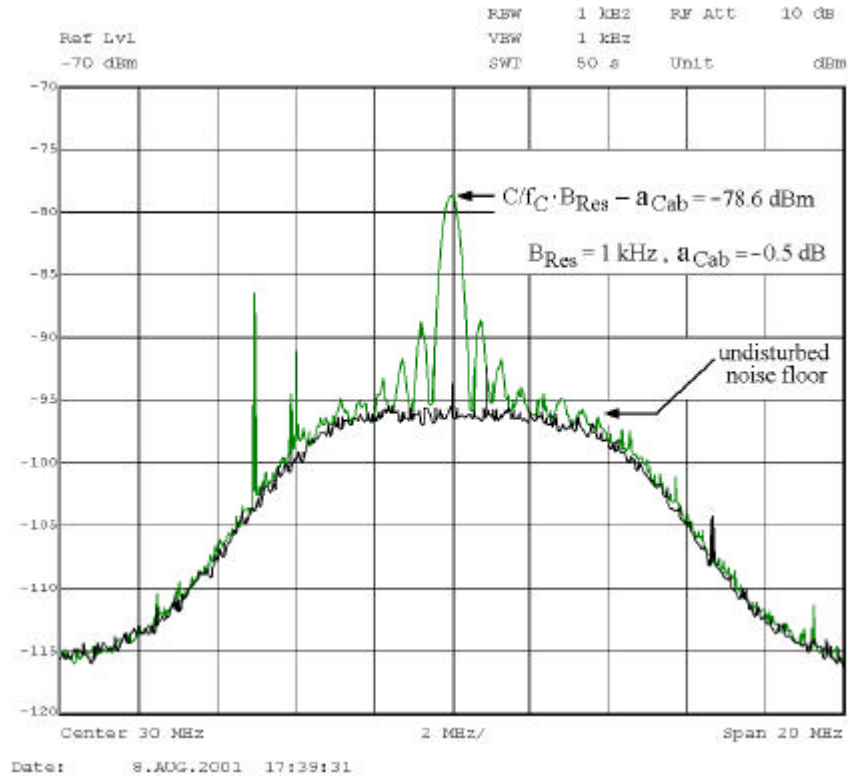


Fig. 3: GLONASS L2 C/A signal at the output of at IF stage (IF = 30 MHz, resolution bandwidth 1 kHz)

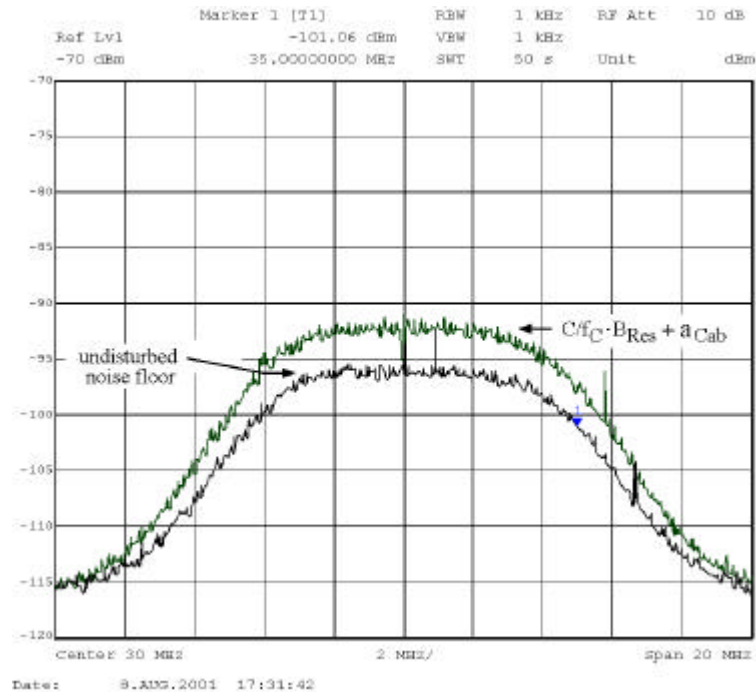


Fig. 4: Galileo E6 signal at the output of at IF stage (IF = 30 MHz, resolution bandwidth 1 kHz)

The spectra depicted in Fig. 3 and Fig. 4 were measured with a resolution bandwidth of $B_{Res}=1$ kHz. The measurement cable had a loss of $a_{Cab}=-0.5$ dB. The undisturbed noise floor at the IF stage according to the Fig. 3, Fig. 4 is about -96.5 dBm/kHz = -96.5 dBW/MHz. Taken into account a insertion gain of 45.4 dB between antenna and output of the IF stage (Fig. 17), this corresponds to a noise floor referenced to the antenna output of -141.9 dBW/MHz (-111.9 dBm/MHz).

A satellite navigation signal starts to significantly increase the noise floor, if the maximum of its PSD of C/f_C (Carrier power divided by code clock frequency, see Appendix B, this corresponds to $C/f_C B_{Res}$, if measured with a spectrum analyser with a selected resolution bandwidth of B_{Res} , see Fig. 3 and Fig. 4) reaches the value of the undisturbed noise floor. With a given effective antenna are of 15.15 dBm² (Pencil beam, see Tab. 6), this threshold of -141.9 dBW/MHz corresponds to a PFD of approx. -157 dB(W/(m²MHz)). The Fig. 5 depicts the measured increase of the noise floor caused by a simulated GLONASS C/A signal versus its PFD value. It can be easily seen, that the noise floor starts to increase at a PFD value of -166 dB(W/(m²MHz)) and the increase reaches a value of 3 dB, as expected, at -157 dB (W/(m²MHz)).

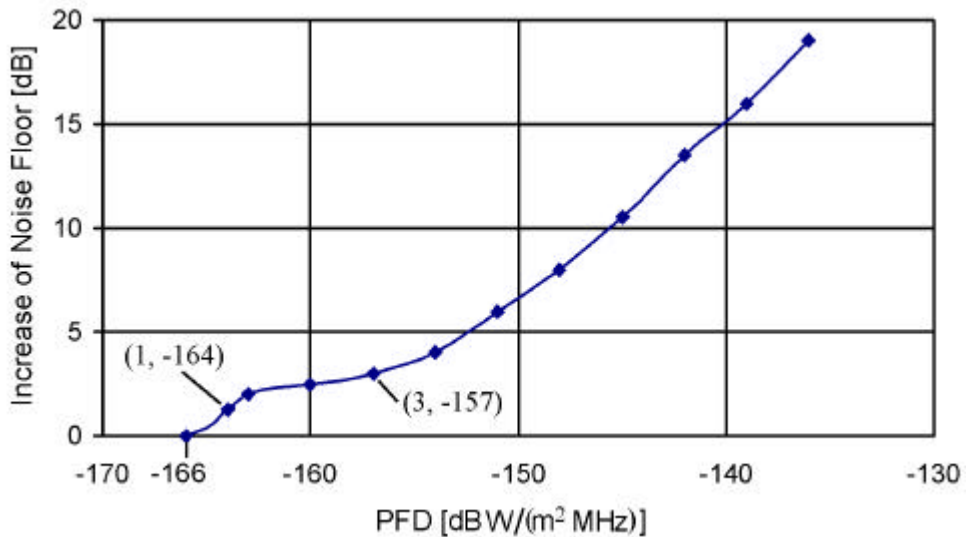


Fig. 5: Increase of the noise floor caused by a simulated GLONASS C/A signal versus its PFD value

Fig. 6 shows a plot of the Minimum discernable signal as a function of the increase of the noise floor. It is fairly obvious, that the MDS is increasing by approximately 1 dB per 1 dB increase of the noise floor level. In Fig. 5 it can be seen that at a PFD value -164 dB(W/(m²MHz)), the noise floor is increased by about 1 dB. This causes the MDS according to Fig. 6 to rise about 0.8 dB.

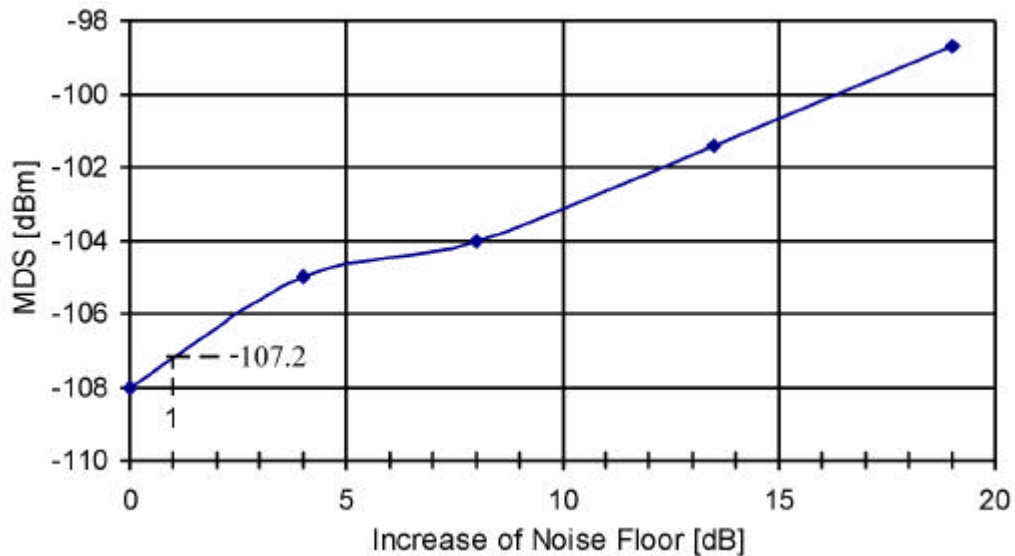


Fig. 6: MDS versus increase of noise floor

4.3 Interference impact on Radar processing

For a variety of power levels of the simulated satellite navigation signal the loss in probability of detection has been determined. To simulate the impact of a satellite navigation system realistically, it was assumed that a maximum number of 12 satellites can be received simultaneously. The signals from these twelve satellites were expected to be received from 12 almost equally separated directions. Moreover, it was assumed, that an individual satellite is only received within an angle sector with a width corresponding to approximately twice the half power beam width of the Radar i.e. within a sector of 2° . To simulate this scenario, the signal generator was switched on by a trigger signal output by the Radar. (The measurement set-up is described in detail in Appendices A, Fig. 12).

From the power levels selected at the signal generator, the corresponding PFD and I/N values referenced to the antenna were calculated. For this purpose, the loss values of measurement cables, wave guide sections as well as the effective area of the antenna had to be determined (see Appendix A, Fig. 12 and Fig. 17). To determine the relevant effective antenna area, the following assumption was made: Out of the four different beam types that can be selected for this Radar (Pencil Beam, COSEC² beam, Combined Beam No. 1 and Combined Beam No.2 see Fig. 14 and Fig. 15), the Pencil Beam with its maximum Gain of 38.6 dBi at an elevation angle of 0.7° has been selected as a worst case. The reason is, that a satellite signal received by the pencil beam with its high gain would have the strongest impact. Furthermore to determine the interference power I , within the IF bandwidth B of the Radar, the ratio of signal power within the B and the Carrier Power C was calculated (Appendix B).

The power of the interference signal was increased in steps of 6 dB for the measurements. Radar data were recorded for one hour for every single signal level that was selected. From the recorded data, the Probability of Detection (P_D), was determined for the disturbed channel (1259 MHz), as well as for the undisturbed channel (1343 MHz) using the SASS-C software. The difference of the P_D between these two channels was regarded as the loss of P_D caused by the interference signal.

It should be mentioned, that received echoes were rather produced by big aircraft with Radar cross sections greater than the reference value of 4 m^2 , for which the performance of the Radar is specified (Tab. 6). The value of the P_D loss was normalised to the P_D of the undisturbed channel to calculate the loss in percent (note not in percentage points). Tab. 2 shows the results of an evaluation of the recorded Radar data for interference with a simulated GLONASS C/A signal. Note a PFD value of $-160 \text{ dB(W/(m}^2\text{MHz))}$ caused a loss of P_D of 1.13 %. In Tab. 2 and the table in Appendix D shows that the undisturbed P_D usually varies between 86 % and 93 %. The target value for the P_D specified by EUROCONTROL is 90 %. That means that there is no margin left for a degradation by interference left. Therefore the loss of P_D due to interference should be kept below a minimum detectable value of 1 %.

Carrier Power (Signal Generator)	Corresponding PFD (Antenna)	Noise Increase (LNA/IF)	I/N within IF band width B = 5 MHz	P_D	Loss of P_D
dBm	$\text{dBW/m}^2/\text{MHz}$	dB	dB		
undisturbed				88.12 %	N/A
-74	-136	19	7.6	64.76 %	-26.51 %
undisturbed				88.41 %	N/A
-80	-142	13.5	1.6	74.22 %	-16.05 %
undisturbed				87.83 %	N/A
-86	-148	8	-4.4	77.65 %	-11.59
undisturbed				88.16 %	N/A
-92	-154	4	-10.4	82.82 %	-6.06 %
undisturbed				88.13 %	N/A
-98	-160	2.5	-16.4	87.13 %	-1.13 %

Tab. 2: Typical results for interference with simulated GLONASS C/A signal

Fig. 7 and Fig. 8 present plots of the loss of P_D as a function of the PFD for the four different signals (detailed measurement results see Appendix C). GLONASS C/A and GPS C/A are the signals with the most severe impact. It can be seen in Fig. 7 that with these two signals the P_D starts to degrade significantly at PFD values in the order of $-164 \text{ dB(W/(m}^2\text{MHz))}$. The diagrams in Fig. 5 and Fig. 6 show that such a PFD value causes an increase of the noise floor of about 1 dB and an increase of the MDS in the same order (0.8 dB). An increase of the MDS of 0.8 dB would cause a reduction of the Radar's maximum Range (143 NM in the undisturbed case) of 6.8 NM (12.3 km), which is almost not acceptable.

It turned out during the measurements that in the first five minutes after switching on the simulated interference signal with a sufficient power level the P_D started to degrade rapidly, but recovered again after the increased noise due to the interference had caused an adjustment of the clutter map. To investigate this effect more deeply, the data gathered during the first five minutes and the data recorded within the 55 succeeding minutes have been evaluated separately to calculate the P_D . Judging from the diagrams in Fig. 7, Fig. 8, Fig. 9 and Fig. 9, the effect is clearly obvious at power levels causing a high degradation, but is rather small near the interference threshold (especially in Fig. 8).

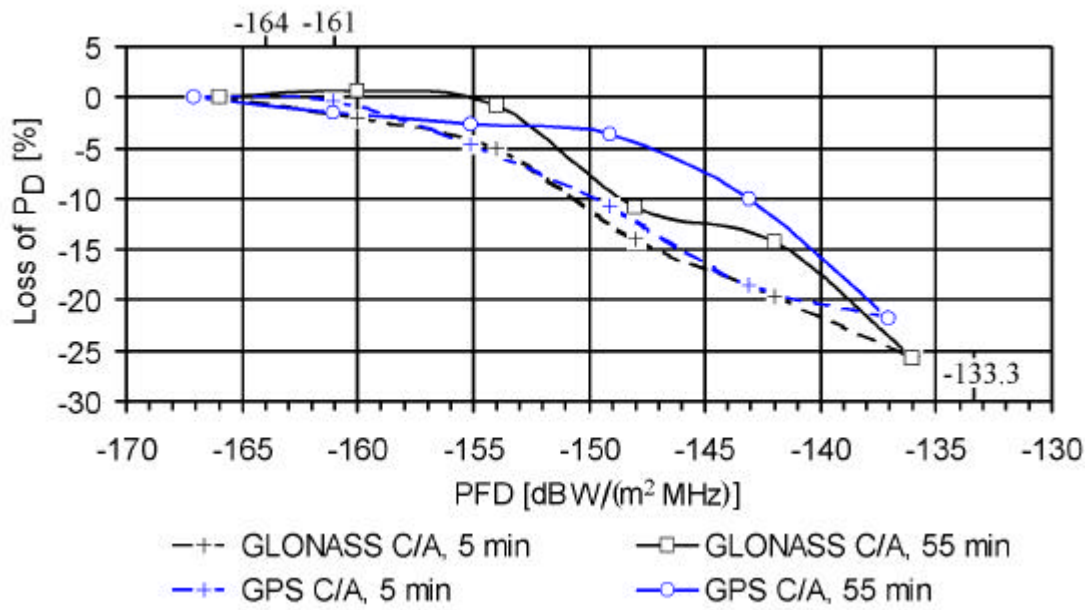


Fig. 7: Loss of P_D versus PFD for GLONASS C/A and GPS C/A

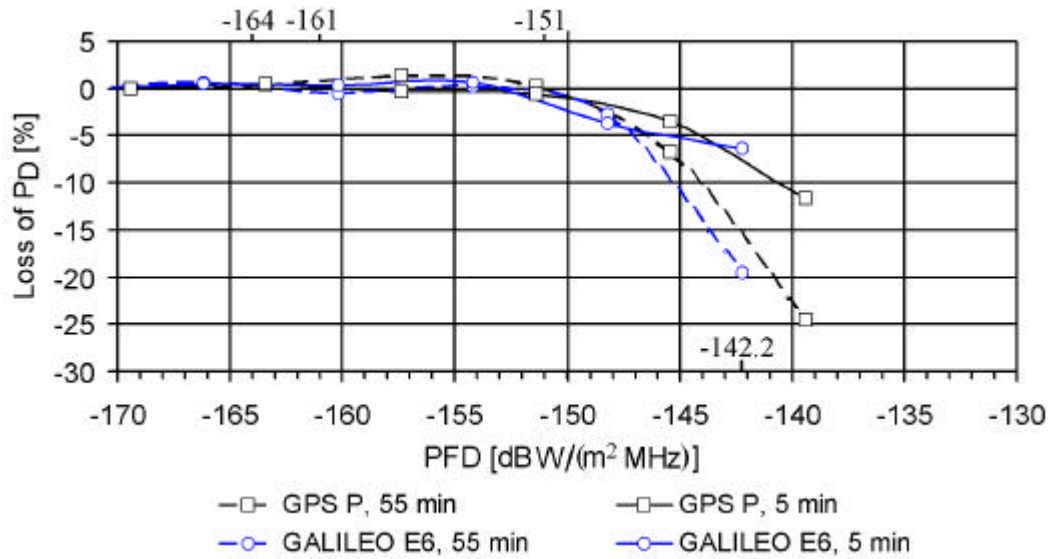


Fig. 8: Loss of PD vs. PFD for GPS P and GALILEO E6

In Fig. 9 and Fig. 10 of the loss of Probability of Detection (P_D) as a function of the I/N ratio is depicted for the various signals. While for GLONASS C/A and GPS C/A, the P_D starts already to degrade at an I/N values of -18 dB, for GPS/P and GALILEO E6, the P_D starts to degrade not below -3 dB.

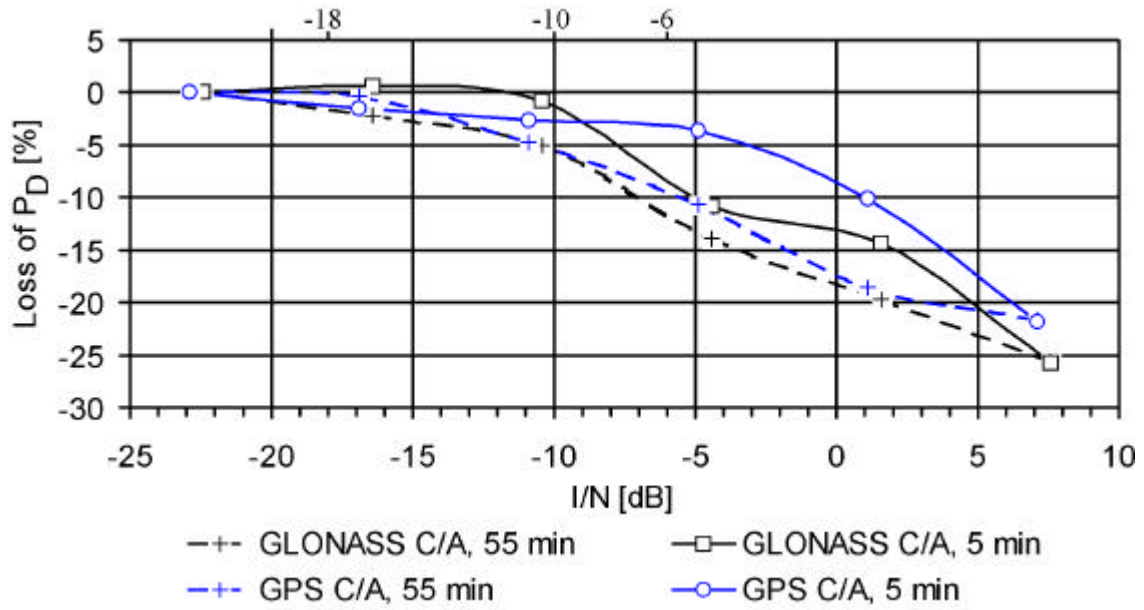


Fig. 9: Loss of P_D versus I/N for GLONASS C/A and GPS C/A

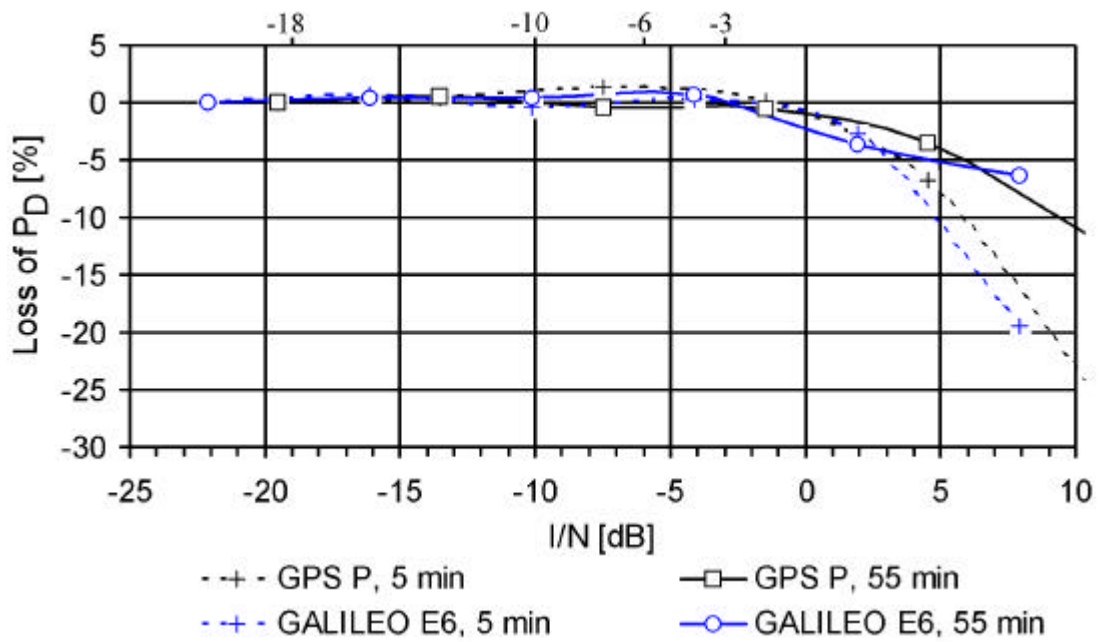


Fig. 10: Loss of P_D vs. I/N for GPS P and GALILEO E6

Tab. 3: Determined Interference thresholds

Signal Type	PFD-Threshold	I/N -Threshold
GLONASS C/A	-164 dB(W/(m ² MHz))	-18 dB
GPS C/A	-164 dB(W/(m ² MHz))	-18 dB
GPS P	-151 dB(W/(m ² MHz))	-3 dB
GALILEO E6	-151 dB(W/(m ² MHz))	-3 dB

Concerning the impact of the simulated interference signals on the Probability of False Alarm, P_{FA} , the following has been found out: Interference signals exceeding the interference threshold caused false targets at the raw video display (Fig. 19). But the tracking software was able to eliminate nearly every single one. To appear as a valid target a potential target has to appear at 5 revolutions of the antenna and has to fit into a track. This condition can not be fulfilled by a noise-like interference signal.

According to ITU Doc 8D/18 [Ref. 4], the maximum PFD per satellite is for a GLONASS C/A code signal -133.3 dB(W/(m²MHz)) and -142.2 dB(W/(m²MHz)) for GPS P signal. The above described results therefore suggest a considerable impact due to such signals on Radars operating at the same center frequency. According to Fig. 7 a loss of P_D of 20 to 30 % for GLONASS C/A and according to Fig. 8 a loss of P_D of 5 to 15 % for GPS P, could be expected. Note: This loss is only caused within angle sectors, where a navigation satellite is received.

4.4 Interference conditions in Germany

From the measurement results describe in section 4.3, it could be concluded that the signals transmitted by existing satellite navigation systems have a considerable impact on Radars. Nevertheless, in Germany such an impact has not been detected in the past. As mentioned above, the German L-band ATC Radars are within the band 1250 to 1260 MHz. As can be seen from Fig. 1, and Tab. 4 only the signals of the GLONASS satellites 10, 11 and 12 are within the band 1250 to 1260 MHz. Only one of these satellites, namely satellite No. 10 is currently (August - September 2001) active. Tab. 4 contains the list for the center frequencies of the six German ATC Radars in this band. Only the Radar "Schmooksberg", one of six German ATC Radars in this band with a center frequency of 1251 MHz could be affected by GLONASS (Tab. 4). A comparison of the spectrum of the GLONASS channel 10 with the IF transfer function of the Radar "Schmooksberg" (Fig. 11) shows, that the spectrum is not centered with the Radar channel. That means that this Radar benefits from a certain off-tune rejection (w.r.t to the video filter transfer function, not w.r.t. the IF filter transfer function depicted in Fig. 11). In the past there was no impact by GLONASS on this Radar detected. This could be for several reasons:

- Only a narrow angle segment with a width of 1° to 2°, could be affected
- People responsible for this Radar were not aware of the problem
- Radar is using a second channel at 1349 MHz which is not affected

Unfortunately this Radar was not yet available for this study, but it is recommended to investigate the impact on this Radar in the near future.

It is obvious, that the situation will become more severe, the moment GLONASS satellites using the channels 11 and 12 will be used again. On the other hand, after the year 2005, GLONASS will not use any more the channels 8 to 12. This will improve the situation for the German ATC Radars.

Tab. 4: Frequency list of German L-band ATC Radars and list of GLONASS L2 channels

Frequency List of German ATC Radars		Center frequencies of GLONASS L2 channels	
Name of the Radar station	Frequency	Channel No. K	L2-Frequency [MHz]
Schmooksberg	1251 MHz	-7	1242.938
Nordholz	1253 MHz	-6	1243.375
Auersberg	1253 MHz	-5	1243.813
Neunkircher Höhe	1257 MHz	-4	1244.250
Deister	1259 MHz	-3	1244.688
Grosshaager Forst	1259 MHz	-2	1245.125
		-1	1245.563
		0	1246.000
		1	1246.438
		2	1246.875
		3	1247.313
		4	1247.750
		5	1248.188
		6	1248.625
		7	1249.063
		8	1249.500
		9	1249.938
		10	1250.375
		11	1250.813
		12	1251.250

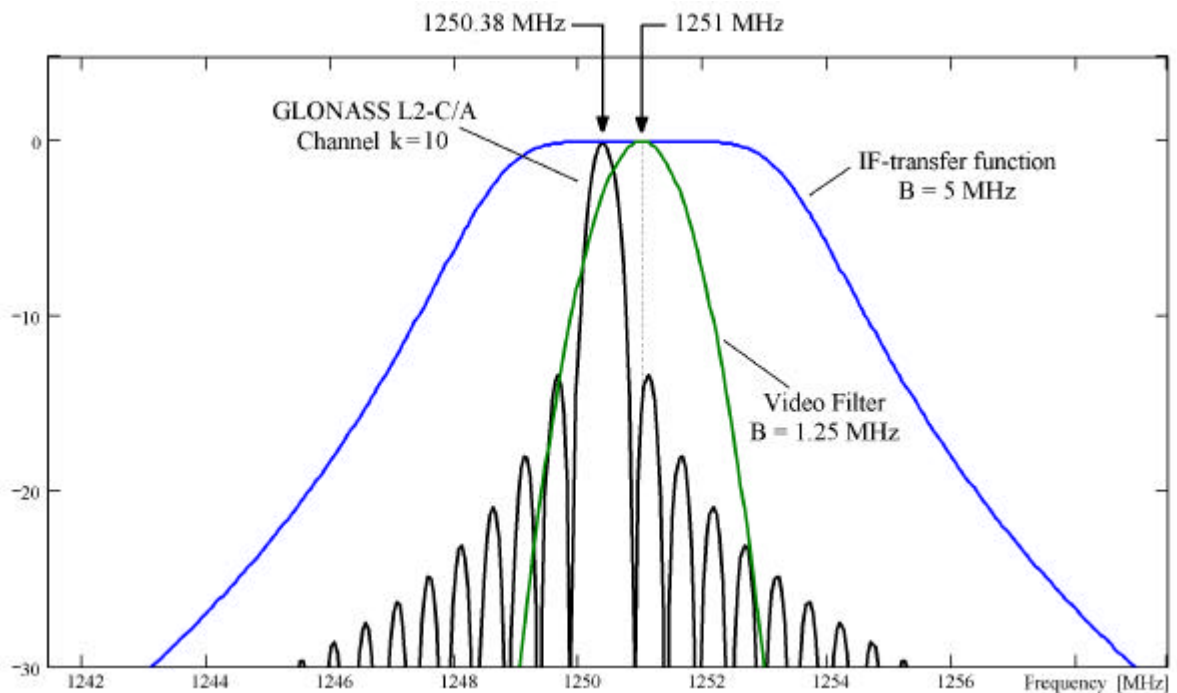


Fig. 11: Comparison of GLONASS channel k=10 and Radar channel at 1251 MHz

In Germany, military Radars are making use of the bands adjacent to the frequency range 1250 to 1260 MHz (Tab. 5). By comparison of Tab. 5 with Tab. 4 and Fig. 1, it becomes obvious, that these military Radars are more likely to be affected by interference of signals of GLONASS-L2, GPS-L2 and GALILEO E6, than civilian ones.

Tab. 5: Service allocations of Radars in Germany in the band under consideration

Frequency Band	Service
1215 –1250	Military radar
1250 –1260	Civil ATC
1260 –1300	Military Radar

5. CONCLUSION / RECOMMENDATIONS

The purpose of this study was to provide background material to support the standardisation of the maximum allowable aggregate Power Flux Density of the Emissions of Space Stations in Radio Navigation-Satellite Service for the Protection of Radars operating in the Band 1215 to 1300 MHz. For this purpose, measurements have been conducted to determine the interference threshold of an ATC Radar of the German Air Navigation Services DFS operating at 1259 MHz. For the sake of the universal applicability of the results to the Radars operating in this band, the simulated signals are centered around 1259 MHz. The impact of the simulated interference signals was investigated primarily by determination of the loss of the probability of detection of targets, compared with the second undisturbed channel of the Radar at 1343 MHz.

The results of the interference susceptibility measurements show, that the Power Flux Density limit to protect Radars of the analysed type should be $-164 \text{ dB(W/m}^2\text{)}$ in any 1 MHz. Furthermore the limit for the Interference to Noise (I/N) ratio should be -18 dB . These limit values would keep the loss of P_D below 1 % and the increase of noise and the increase of the minimum discernable signal level below 1 dB.

German civil ATC Radars make use of the band 1250 to 1260 MHz. Within this band, at the time of the study (August – September 2001), the only satellite navigation signal that could be received, is transmitted by a GLONASS satellite with the channel number 10. Only one German ATC Radar is using a center frequency near this GLONASS channel. Despite, a loss of probability of detection of 20 to 30 % could be possible, an impact was not detected in the past. The reason for this is, that people responsible for this Radar were not aware of the problem and only a narrow angle segment with a width of 1° to 2° , is potentially affected. It is obvious, that the situation will become more severe, the moment GLONASS satellites using the channels 11 and 12 will be used again. On the other hand, after the year 2005, GLONASS will not use any more the channels 8 to 12. This will improve the situation for the German ATC Radars. For German military Radars using the band 1215 to 1250 MHz and 1260 to 1300 MHz, the signals of GLONASS-L2, GPS-L2 and GALILEO-E6 will be a threat. The situation may be comparable in other countries.

6. REFERENCES

- [Ref. 1] „Assessment of the interference from RNSS into Radars in the 1215 –1300 MHz Band“, ITU Doc 8B/64-E/8D/93-E, 14 th of May 2001
- [Ref. 2] “Protection of ATC-Radars operating in the Band 1215 – 1300 MHz from Emissions of Space Stations in the Radio navigation-Satellite Service”, SPG 13-14,
- [Ref. 3] “Study on 2700 MHz – 2900 MHz frequency band sharing between existing Aeronautical Radar Equipment and planned Digital ENG/OB and Digital Aeronautical Telemetry Services”, W. L. Randeu, H. Schreiber, Technical University of Graz, May 2001
- [Ref. 4] “RNSS characteristic in the band 1215 to 1300 MHz”, ITU Doc 8D/18-E, 10 th of October 2000
- [Ref. 5] “Procedures for determining the potential for interference between Radars operating in the Radio Determination Service and systems in other services“ ITU-R M.1461.
- [Ref. 6] “Characteristics of and protection criteria for Radars operating in the Radio Determination Service in the Frequency Band 1215 – 1400 MHz”, ITU-R M.1463.
- [Ref. 7] “Considerations for sharing with systems of other services operating in the bands allocated to the Radionavigation Satellite Service (GPS , ITU-R M.1088, 1994
- [Ref. 8] “Considerations for sharing between systems of other services operating in the bands allocated to the Radionavigation Satellite and Aeronautical Radio Navigation Services and the Global Navigation Satellite System (GLONASS-M), ITU-R M.1317, 1997
- [Ref. 9] „Final Acts of World Radio Conference WRC-2000“, International Telecommunication Union, Geneva, 2000

APPENDIX A – DESCRIPTION OF RADAR AND MEASUREMENT SET-UP

The type of the Radar that was used for the test is called SREM (Surveillance Radar Equipment Medium range). The Tab. 6 presents the technical properties of such a Radar.

Tab. 6: Technical Data of the SREM Radar

Type of Radar		SREM (upgraded SRE-M5)
Two channels		2 center frequencies in the frequency range 1250 to 1350 MHz 41, or 67 or 78 MHz separated
(Grosshaager Forst)		(1259 MHz /1343 MHz)
Pulse duration		2 μ s
Pulse repetition frequency		320 to 475 Hz
Maximum range		143 NM, with RCS of 4 m ² , $P_D \geq 80 \%$, $P_{FA} = 10^{-6}$
Transmitter:		
Transmitter manufacturer / type		DASA / SREM
Transmitter technology		Klystron
Transmitter peak power		2.5 MW
Antenna:		
4 Beams: Pencil, Cosec ² , Combined No. 1, Combined No. 2:		
Combined beam No.1 (transmit beam)		35.6 dB
Pencil beam		38.6 dB
=> effective antenna area (Pencil Beam)		15.15 dBm ²
Cosec ² beam		34.3 dB
Combined beam No.2		35.0 dB
Tilt		1.7° mechanical tilt
Azimuth 3 dB width		1.1°
Cone of silence		107.8°
Antenna rotation		5.157 rpm => 11.635 sec / rotation
Polarisation		vertical / circular
Receiver:		
Receiver manufacturer / type		Alenia / TWRPM (Target and Weather Receiver and Processor)
Intermediate frequency		30 MHz
Receiver noise figure		9 dB
HF-receiver bandwidth:	-3 dB	10 MHz
IF-Receiver bandwidth :	-3 dB	4.9 MHz
	-40 dB	40 MHz
Video Filter Type		Gaussian

Video Bandwidth	-3 dB	1.25 MHz
Noise Power within IF bandwidth		-98 dBm
Minimum Discernable signal, MDS		-108 dBm
Sensitivity Time Control (STC)		0 to 63.5 dB attenuation in 0.5 dB steps
Low Noise Amplifier (LNA), Gain		36 dB
LNA, Noise Figure		1.8 dB
LNA, 1 dB compression		-30 dBm at LNA input
1 dB compression, referenced to antenna output		-24.3 dBm = -54.3 dBW
Typical insertion loss between antenna output and LNA input (Grosshaager Forst)		5.7 dB
Typical insertion gain between antenna output and IF output (Grosshaager Forst)		45.4 dB
Nominal Probability of detection (P_D)		≥ 80
Nominal False Alarm Rate (CFAR)		10^{-6}
Type of Doppler processing		MTD Filter Bank with 6 or 8 channels, depending on selected PRF
Angle accuracy / resolution (S/N = 10 dB)		$2^\circ / 0.16^\circ$
Range accuracy / resolution (S/N = 10 dB)		80 m / 463 m

Radars of this type have an antenna with two exciters which are connected with two different channels per frequency. One exciter has, in combination with the reflector a COSEC² antenna diagram, while the other has a pencil-shaped diagram. The exciters are connected to two different signal channels per frequency. These two channels are inter-connected two times: just after the antenna by a fixed combiner (K1, in Fig. 12) and a second time by a controllable so-called beam-combiner (K2 in Fig. 12). In combination with an individual phase shifter in front of each combiner, it is possible to switch between the COSEC² antenna diagram, the pencil diagram and two combined diagrams (Fig. 14). To select one of these four Diagrams, four different values can be selected for the phase offset of the second phase shifter φ_2 and coupling factor K2 of the second combiner (beam combiner) (Tab. 7). This fact makes it difficult to determine the insertion loss between antenna and LNA input, here called wave guide loss a_{WG} .

Tab. 7: States of the phase shifters and beam combiners necessary to select a special antenna beam

K1	φ_1	K2	φ_2	Selected Beam
$\frac{1}{4}$	-90°	$\frac{1}{4}$	180°	COSEC ² Beam
$\frac{1}{4}$	-90°	0	arbitrary	Combined 1, Transmit
$\frac{1}{4}$	-90°	adjustable	adjustable	Combined 2
$\frac{1}{4}$	-90°	$\frac{3}{4}$	0°	Pencil Beam

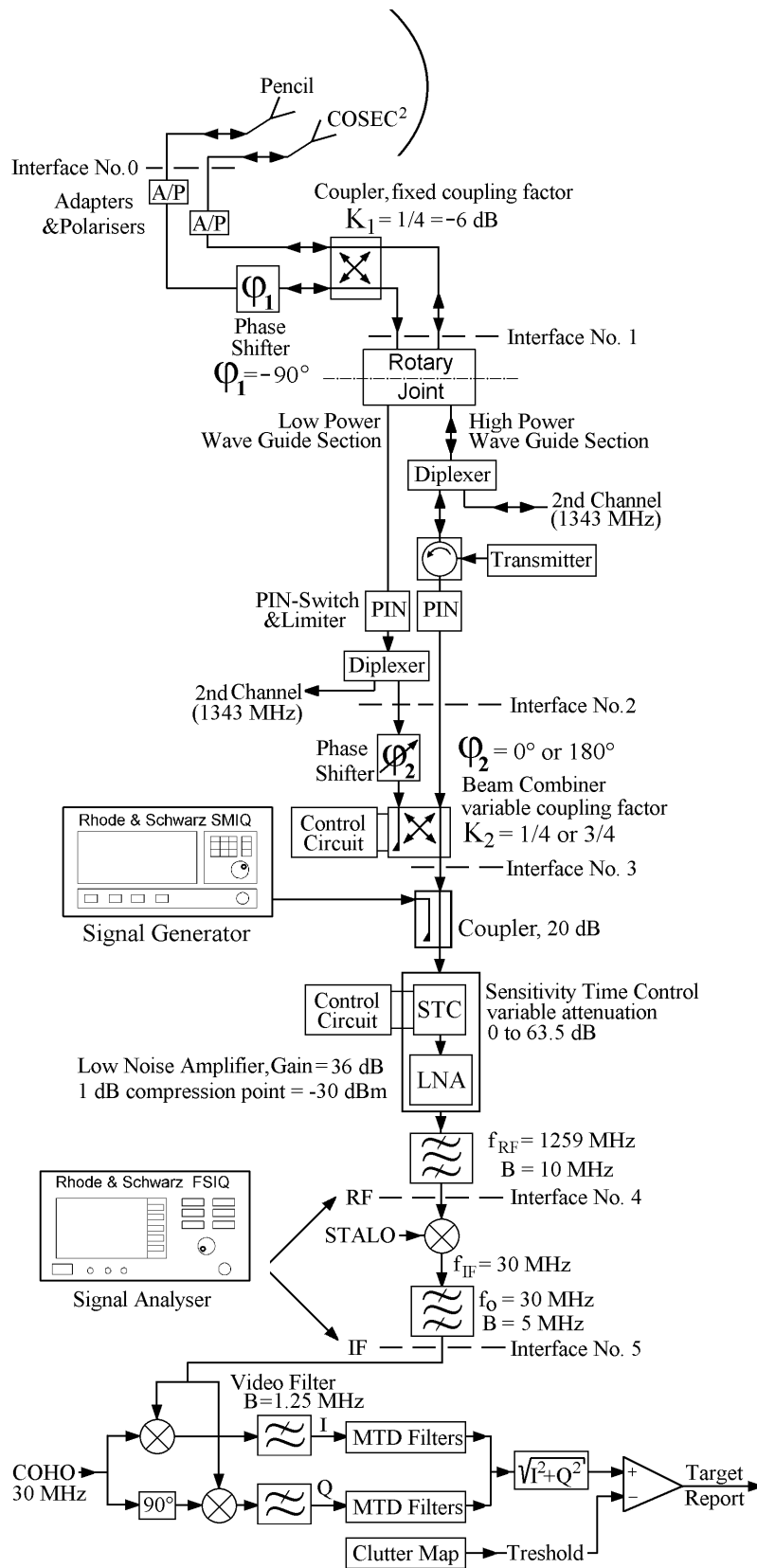


Fig. 12: Block diagram of the Radar and measurement set-up

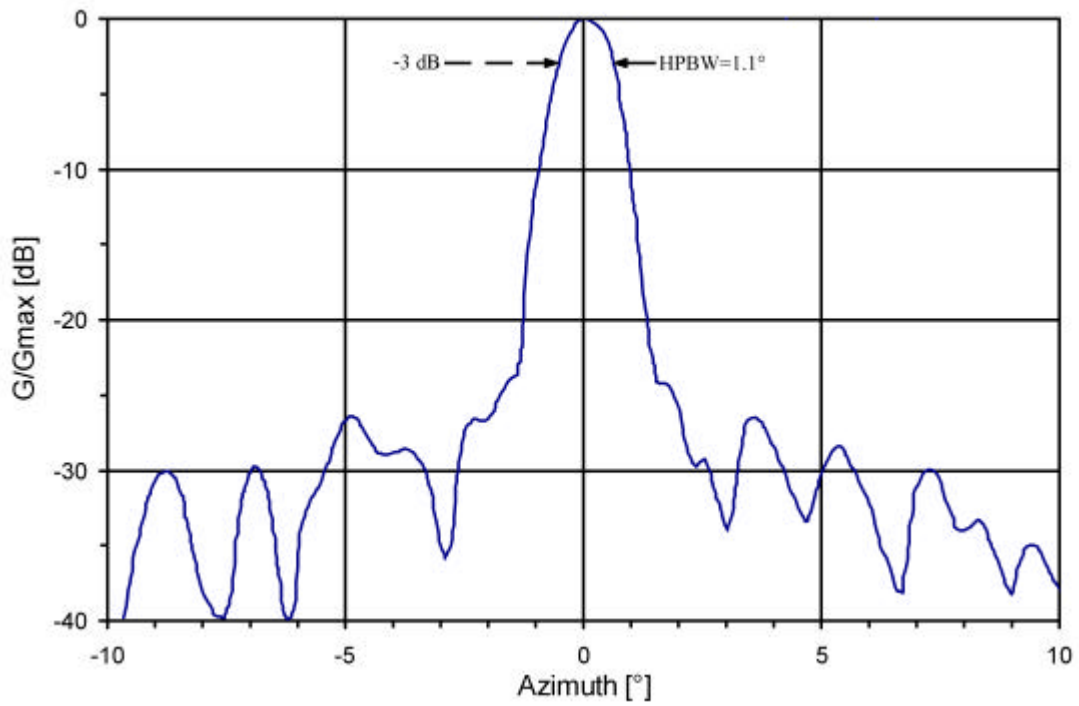


Fig. 13: Azimuth cut of the antenna diagram of the Radar

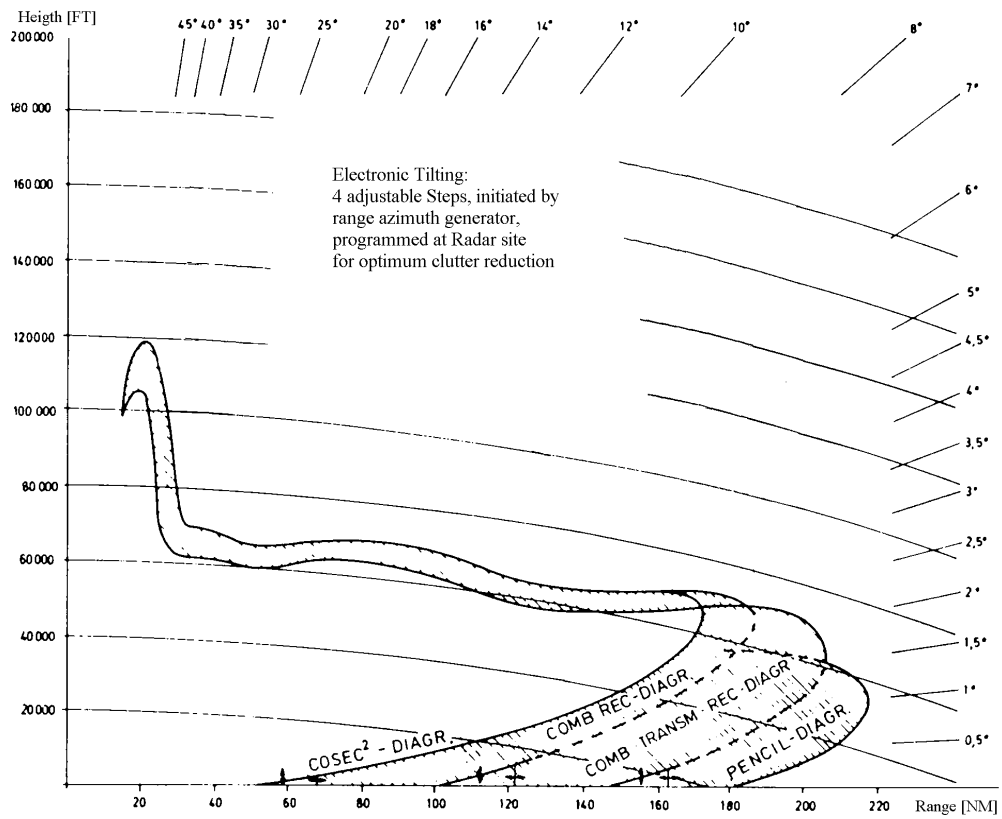


Fig. 14: Coverage Diagram

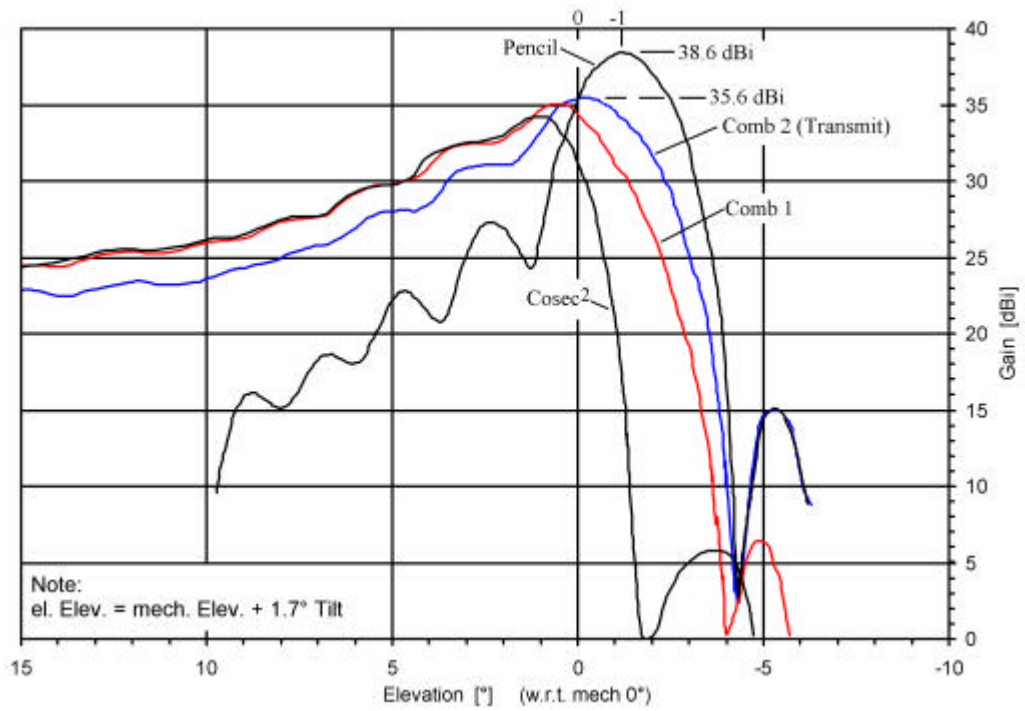


Fig. 15: Elevation cut through the four different antenna diagrams of the Radar

The Fig. 16 shows a diagram of the measured transfer function between the LNA input and the output of the IF-stage. It can be well simulated by a Butterworth filter of the order 3 with a bandwidth of 5 MHz.

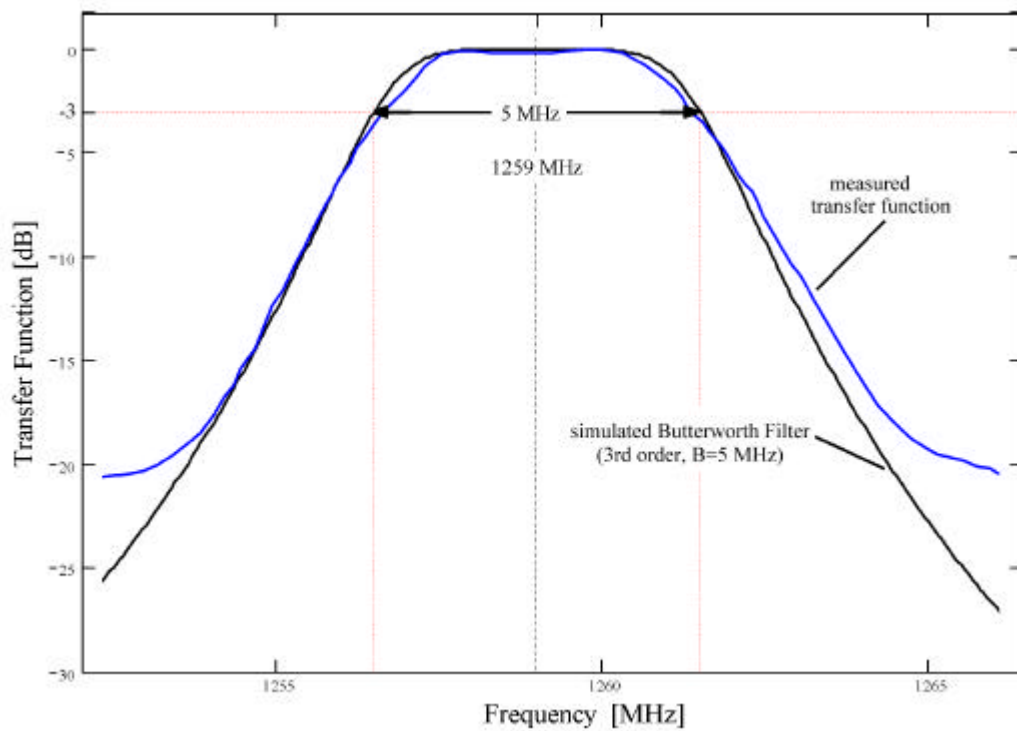


Fig. 16: Measured and simulated transfer function of the Radar

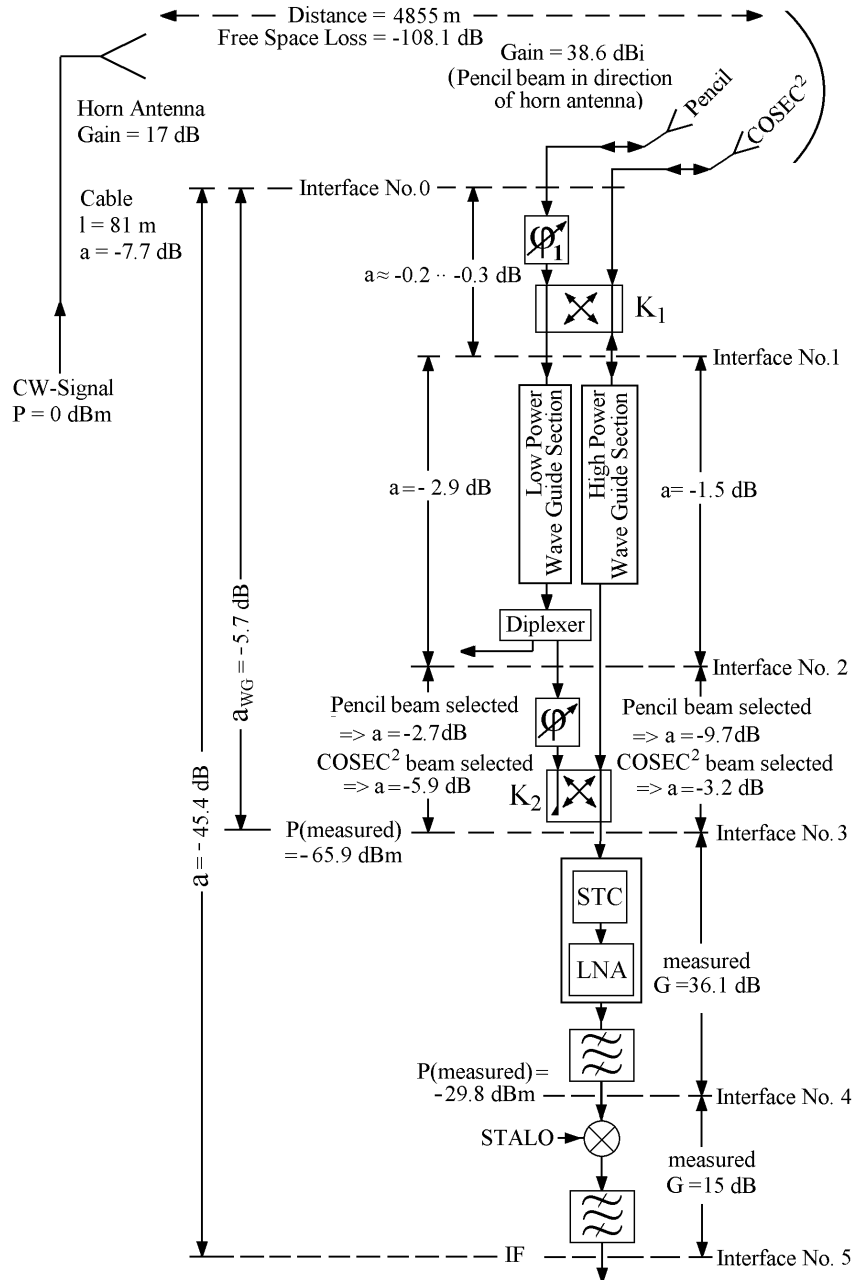


Fig. 17: Determination of the relevant attenuation values

The interference signal is fed into the signal path by means of a 20 dB coupler in front of the low noise amplifier Fig. 12. To be able to calculate the Power Flux Density (PFD) at the antenna, great care has been taken to determine the insertion loss of the signal path between antenna and the input of the LNA (a_{WG}). As described above, signals received by the antenna through two different signal paths, a high power section and a low power section and are coupled together at two different locations (combiner K1 and combiner K2). Moreover, the coupling factor of the second coupler is switchable.

Fortunately the value of a_{WG} needs to be determined only for the case when the pencil beam is selected, since the pencil beam has the highest gain and therefore represents the worst case for an interference scenario. In this case the attenuation between the low power section input and the output of the beam combiner ($K2 = -2.7$ dB) is much lower than the attenuation between high power section input and the output of the beam combiner ($K2 = -9.7$ dB).

The attenuation values measured for the individual sections of the signal paths between antenna and LNA have been taken into account to determine the total insertion loss a_{WG} . For the short wave guide section between the first combiner (K1) and the antenna horns an assessment of 0.2 to 0.3 dB loss was made. In this way a total value for a_{WG} of -5.7 dB could be determined. This value has been checked by measuring the received power level of a test signal transmitted from the location of a test transponder approx. 4.8 km apart at the LNA input (see Fig. 17).

The satellite navigation signals are simulated by modulating a pseudo noise code with suitable code clock frequency onto a carrier. The type of modulation that is used is binary phase shift keying (BPSK). The signal generator that was used is SMIQ from Rhode & Schwarz in combination with the IQ-Modulator AMIQ.

This device allows to download a pseudo noise code sequence that has been generated previously with the associated software.

The signals of the individual satellites can only be received while the main beam of the Radar sweeps across the satellite under consideration. To take this into account, the following scenario has been assumed:

- Satellite signals are only received while the main lobe of the Radar antenna with a half power beam width of approx 2° sweeps across the satellite position
- A maximum number of 12 simultaneously received satellites is assumed

To simulate this scenario, a trigger signal for the signal generator has been generated by means of the definition of maps describing sectors with a width of 2° for 12 directions. These directions are selected in such a way that high traffic can be expected in the according sector (Radar performance monitor in display Fig. 18). The trigger signal is used to switch the interference signal coming from signal generator "on" an "off".

To check that this triggering of the interference signal is working correctly, the interference power level of a simulated GLONASS C/A signal has been set to a very high value to cause false targets and the target plot has been evaluated. Fig. 19 shows the false targets caused by a simulated interference signal with a power level corresponding to a PFD value of -136 dB(W/(m²MHz)). Which corresponds to an I/N value of $+7.6$ dB.

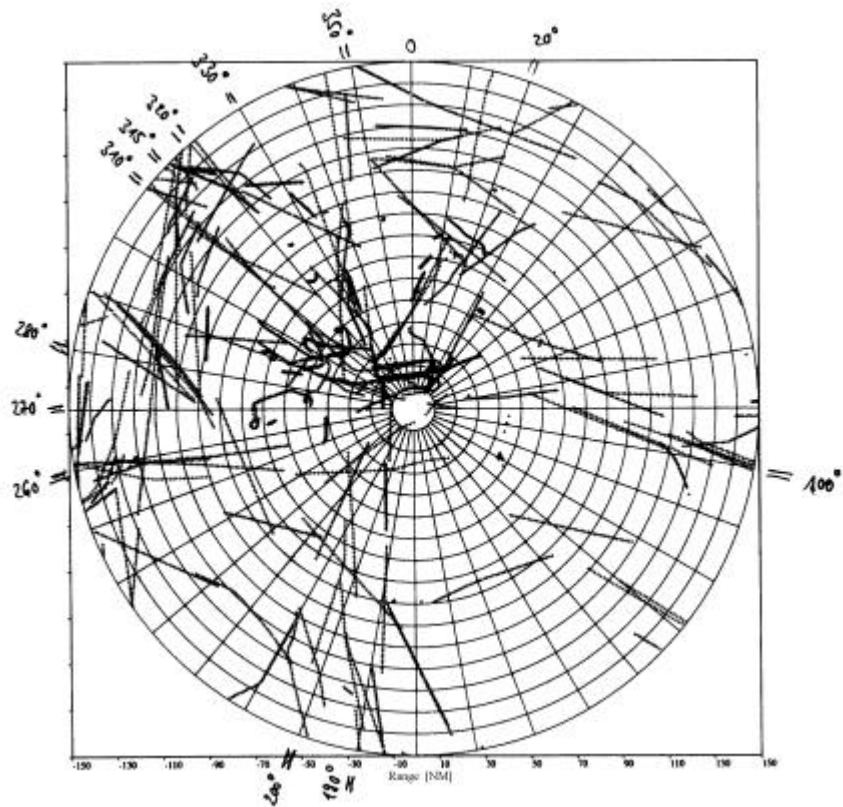


Fig. 18: Selected directions with high traffic

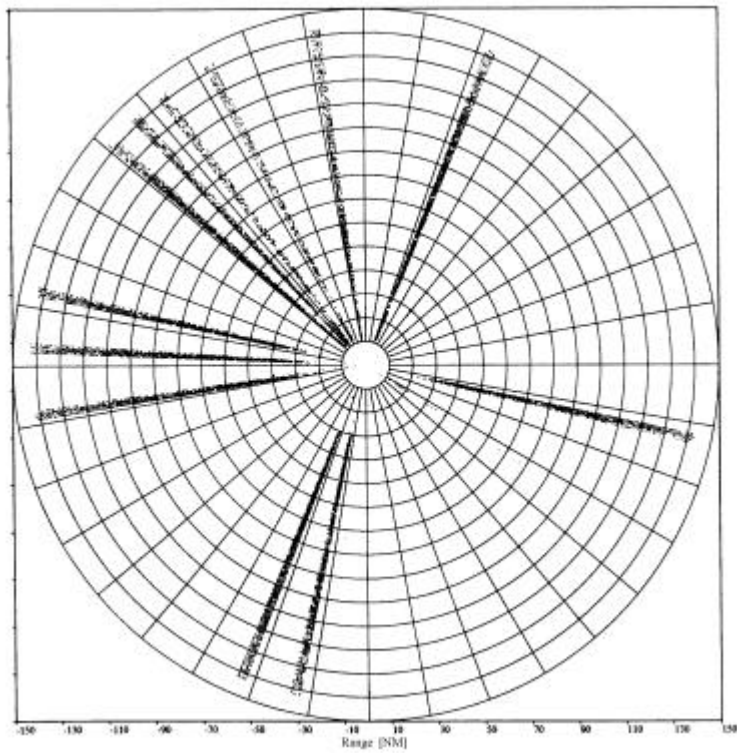


Fig. 19: False targets, caused by the simulated interference signal (PFD = $-136 \text{ dB(W/(m}^2\text{MHz))}$)

APPENDIX B – THEORETICAL BACKGROUND

The Power Spectral Density (PSD) of a satellite navigation signal, i.e. a carrier which is being binary phase modulated with a pseudo noise code can be described as follows:

$$PSD(f) \approx \frac{C}{f_c} \cdot SINC^2\left(\frac{P}{f_c}(f - f_{Sat})\right) \quad [W/Hz] \quad \text{Eq. 1}$$

With:

C : Power of the un-modulated carrier in W, equivalent to the integral of the PSD over all frequencies

f_c : code clock frequency in Hz (e.g. 1.023 MHz in the case of GPS C/A code)

f_{Sat} : Center frequency of the satellite signal

(Note: Eq. 1 is not valid for other modulation schemes that are also in discussion for GALILEO, like raised cosine BPSK or Binary Offset Carrier (BOC)).

Within a bandwidth B very smaller than the distance between the first minima of the PSD (i.e. $B \ll 2 \cdot f_c$) according to Eq. 1, such a signal appears as white noise with a spectral density I_o corresponding to the maximum of the PSD:

$$I_o = PSD(f = f_{Sat}) \approx C \cdot T_C = \frac{C}{f_c} \quad [W/Hz] \quad \text{Eq. 2}$$

With:

I_o : equivalent noise power density in W/Hz

The interference power I_B of a satellite navigation signal received within the bandwidth of a Radar B can be described as follows:

$$I_B = C + a_{Cable} + a_{Comb} + S_B / C - a_{WG} \quad \text{Eq. 3}$$

With:

I_B : Interference power within the IF-Bandwidth (e.g. $B = 5$ MHz), in dBm or dBW

C : Power of the un-modulated carrier of the signal at the signal generator, in dBm or dBW

a_{Cable} : Attenuation of the cable between signal generator and the combiner used to feed in the signal in the Radar in dB

a_{Comb} : Coupling factor of the combiner in dB (e.g. -20 dB)

a_{WG} : Wave Guide; loss of signal path between antenna and input of Low Noise Amplifier (e.g. 5.7 dB)

S_B/C : Quotient of the signal power within the IF-bandwidth (e.g. $B = 5$ MHz) and the carrier power in dB

Where:

$$S_B/C = \frac{\int_{f_{Sat}-\frac{B}{2}}^{f_{Sat}+\frac{B}{2}} PSD(f) df}{C} \quad \text{Eq. 4}$$

The noise power within the bandwidth B can be assessed as follows:

$$N_B = N_o (291K) + B + F_{Noise} \quad \text{Eq. 5}$$

With:

N_B : Noise power within the Bandwidth B (e.g. $B = 5$ MHz), in dBm or dBW

N_o : Noise power within the 1 Hz at room temperature in dBm or dBW (e.g. -174 dBm/Hz)

B : Bandwidth in Hz

With a value for N_o of -174 dBm/Hz and $B = 5$ MHz, and a Noise Figure F_{Noise} of 9 dB, a noise power value of $N = -98$ dBm is obtained within the IF-bandwidth of 5 MHz.

The I/N ratio within the IF-bandwidth B can be obtained by subtracting Eq. 5 from Eq. 3:

$$I/N = \frac{I_B}{N_B} \quad [dB] \quad \text{Eq. 6}$$

The Power Flux Density, PFD at the antenna can be calculated from a given value for the carrier power C of the simulated interference signal as follows:

$$PFD = C + a_{Cab} + a_{Comb} - a_{WG} + S_{1M}/C - A_w \quad [dB (W / (MHz \cdot m^2))] \quad \text{Eq. 7}$$

With:

S_{1M}/C : Quotient of the interference power within a reference bandwidth of 1 MHz and the carrier power of the interference signal, in dB

Where:

$$S_{1M}/C = \frac{\int_{f_{Sat}-\frac{1}{2}MHz}^{f_{Sat}+\frac{1}{2}MHz} PSD(f) df}{C} \quad \text{Eq. 8}$$

A_{eff} : Effective antenna aperture in dBm^2 , calculated from the maximum antenna gain.

With:

$$A_{eff} = G \cdot \frac{I}{4p} \quad [m^2] \quad \text{Eq. 9}$$

For this application the maximum gain of the pencil beam of 38.6 dBi, an the center frequency of the Radar of 1259 MHz are used. This yield to $A_{eff} = 15.15 \text{ dBm}^2$.

Tab. 8: Some characteristic parameters for the various satellite navigation signals

Signal Type	$1/f_c$	S_{1M}/C	S_B/C
	Spreading factor	Normalised 'power within 1 MHz'	Normalised 'power within IF bandwidth B = 5 MHz'
GLONASS C/A	-57.1 dB/Hz	-0.4 dB	-0.1 dB
GPS C/A	-60.1 dB/Hz	-1.1 dB	-0.2 dB
GPS P	-70.1 dB/Hz	-9.9 dB	-3.2 dB
GALILEO E6	-73.1 dB/Hz	-12.70 dB	-5.8 dB

The Equations Eq. 3 to Eq. 7 are in line with the methodology for the determination of interference to Radars from systems in other services described in ITU-R M.1461 [Ref. 5].

APPENDIX C – ABBREVIATIONS

ATC:	Air Traffic Control
BPSK:	Binary Phase Shift Keying
C/A:	Coarse/Acquisition Code of GPS or GLONASS
C:	Carrier Power
CFAR:	Constant False Alarm Rate
COHO	Coherent Oscillator
COSEC ² :	antenna beam with a Cosecans squared shape
E6:	One among other signal types of the European satellite navigation system GALILEO
f_c :	Code clock frequency of a satellite navigation signal
HPBW:	Half Power Beam Width
I/N:	ratio of Interference power and Noise power within the IF bandwidth

IF:	Intermediate Frequency
ITU:	International Telecommunication Union
k:	number of an individual channel of the GLONASS system
LNA:	Low Noise Amplifier
MDS:	Minimum Discernible Signal
MTD:	Moving Target Detection
P:	Precise Code of GPS or GLONASS
P_D :	Probability of Detection
P_{FA} :	Probability of False Alarm
PFD:	Power Flux Density
PN:	Pseudo Noise
PSD:	Power Spectral Density
RF:	Radio Frequency
Rpm:	Rotations Per Minute
S_{1M} :	Power within 1 MHz bandwidth
SASS-C:	Surveillance Analysis Support System for ATC Centre
SREM:	Surveillance Radar Equipment Medium range
STALO	Stabile Local Oscillator
STC:	Sensitivity Time Control

APPENDIX D – SELECTED MEASUREMENT RESULTS

GLONASS-L2 C/A

C (Signal Gen) dBm	a _{Cab} +a _{Comb} dB	C (LNA) dBm	a _{WG} dB	C (Ant) dBm	S _{B/C} dB	S _B (Ant) dB	S _{1M/C} dB	S _{1M} (Ant) dBm	S _{1M} (Ant) dBW	A _{eff} dBm ²	PFD dBW (m ² MHz)	N _B dBm	S _B /N _B I/N dB	P _D undist. 5 min %	P _D undist. 55 min %	P _D dist. 5 min %	P _D dist. 55 min %	(dist. -undist.) 5 min % points	(dist. -undist.) 5 min absolute %	(dist. -undist.) 55 min % points	(dist. -undist.) 55 min absolute %
-104	-22	-126	-5.7	-120	-0.1	-120	-0.4	-121	-151	30	15.2	-98	-22.4	90.91	89.41	93.13	90.44	2.22	0.00	1.03	0.00
-98		-120		-114		-114		-115	-145				-16.4	82.35	89.97	82.8	91.52	0.45	-2.15	1.55	0.58
-92		-114		-108		-108		-109	-139				-10.4	86.23	90.86	84.14	91.21	-2.09	-5.00	0.35	-0.75
-86		-108		-102		-102		-103	-133				-4.4	91.37	89.97	80.84	81.23	-10.53	-13.95	-8.74	-10.86
-80		-102		-96.3		-96.4		-96.7	-127				1.6	91.03	89.85	75.32	78.05	-15.71	-19.70	-11.8	-14.28
-74		-96		-90.3		-90.4		-90.7	-121				7.6	90.68	89.19	69.72	67.22	-20.96	-25.56	-21.97	-25.79
-68		-90		-84.3		-84.4		-84.7	-115				13.6								

GPS-L2 C/A:

C (Signal Gen) dBm	a _{Cab} +a _{Comb} dB	C (LNA) dBm	a _{WG} dB	C (Ant) dBm	S _{B/C} dB	S _B (Ant) dB	S _{1M/C} dB	S _{1M} (Ant) dBm	S _{1M} (Ant) dBW	A _{eff} dBm ²	PFD dBW (m ² MHz)	N _B dBm	S _B /N _B I/N dB	P _D undist. 5 min %	P _D undist. 55 min %	P _D dist. 5 min %	P _D dist. 55 min %	(dist. -undist.) 5 min % points	(dist. -undist.) 5 min absolute %	(dist. -undist.) 55 min % points	(dist. -undist.) 55 min absolute %
-104	-22	-126	-5.7	-120	-0.1	-121	-0.4	-121	-151	30	15.2	-98	-22.5	91.64	92.03	93.73	93.9	2.09	0.00	1.87	0.00
-98		-120		-114		-115		-115	-145				-16.5	90.66	89.8	92.39	90.29	1.73	-0.40	0.49	-1.54
-92		-114		-108		-109		-109	-139				-10.5	86.28	91.98	84.31	91.38	-1.97	-4.71	-0.6	-2.69
-86		-108		-102		-103		-103	-133				-4.5	89.67	91.15	82.19	89.72	-7.48	-10.67	-1.43	-3.62
-80		-102		-96.3		-96.5		-97.4	-127				1.5	95.74	92.27	80.07	84.83	-15.67	-18.55	-7.44	-10.09
-74		-96		-90.3		-90.5		-91.4	-121				7.5	89.23	90.09	72.03	72.34	-17.2	-21.62	-17.75	-21.78
-68		-90		-84.3		-84.5		-85.4	-115				13.5								

GPS-L2 P:

C (Signal Gen) dBm	a _{Cab} +a _{Comb} dB	C (LNA) dBm	a _{WG} dB	C (Ant) dBm	S _{B/C} dB	S _B (Ant) dB	S _{1M/C} dB	S _{1M} (Ant) dBm	S _{1M} (Ant) dBW	A _{eff} dBm ²	PFD dBW (m ² MHz)	N _B dBm	S _B /N _B I/N dB	P _D undist. 5 min %	P _D undist. 55 min %	P _D dist. 5 min %	P _D dist. 55 min %	(dist. -undist.) 5 min % points	(dist. -undist.) 5 min absolute %	(dist. -undist.) 55 min % points	(dist. -undist.) 55 min absolute %
-104	-22	-126	-5.7	-120	-0.1	-124	-0.4	-130	-160	30	15.2	-98	-25.5	94.52	91.55	94.13	91.89	-0.39	0.00	0.34	0.00
-98		-120		-114		-118		-124	-154				-19.5	92.92	89.91	92.9	90.78	-0.02	0.40	0.87	0.59
-92		-114		-108		-112		-118	-148				-13.5	91.82	92.49	92.71	92.49	0.89	1.39	0.00	-0.37
-86		-108		-102		-106		-112	-142				-7.5	90.69	90.11	90.48	89.93	-0.21	0.20	-0.18	-0.58
-80		-102		-96.3		-99.5		-106	-136				-1.5	94.24	92.77	87.5	89.88	-6.74	-6.74	-2.89	-3.48
-74		-96		-90.3		-93.5		-100	-130				4.5	91.43	91.68	68.61	81.33	-22.82	-24.53	-10.35	-11.66
-68		-90		-84.3		-87.5		-94.2	-124				10.5								

GALILEO E6:

C (Signal Gen) dBm	a _{Cab} +a _{Comb} dB	C (LNA) dBm	a _{WG} dB	C (Ant) dBm	S _{B/C} dB	S _B (Ant) dB	S _{1M/C} dB	S _{1M} (Ant) dBm	S _{1M} (Ant) dBW	A _{eff} dBm ²	PFD dBW (m ² MHz)	N _B dBm	S _B /N _B I/N dB	P _D undist. 5 min %	P _D undist. 55 min %	P _D dist. 5 min %	P _D dist. 55 min %	(dist. -undist.) 5 min % points	(dist. -undist.) 5 min absolute %	(dist. -undist.) 55 min % points	(dist. -undist.) 55 min absolute %
-104	-22	-126	-5.7	-120	-0.1	-126	-0.4	-133	-163	30	15.2	-98	-28.1	92.37	92.06	94.28	92.26	1.91	0.00	0.2	0.00
-98		-120		-114		-120		-127	-157				-22.1	92.49	91.09	95.02	91.7	2.53	0.67	0.61	0.45
-92		-114		-108		-114		-121	-151				-16.1	92.68	92.37	94.2	92.92	1.52	-0.42	0.55	0.38
-86		-108		-102		-108		-115	-145				-10.1	90.07	91.41	92.25	92.22	2.18	0.30	0.81	0.67
-80		-102		-96.3		-102		-109	-139				-4.1	95.21	93.3	94.53	90.09	-0.68	-2.72	-3.21	-3.65
-74		-96		-90.3		-96.1		-103	-133				1.9	91.67	91.31	75.71	85.68	-15.96	-19.49	-5.63	-6.38
-68		-90		-84.3		-90.1		-97	-127				7.9								