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Use of radionavigation-satellite service receiver characteristics in assessment of interference from pulsed sources in the 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz frequency bands

> M Series Mobile, radiodetermination, amateur and related satellite services



Telecommunication

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REPORT ITU-R M.2496-0

Use of radionavigation-satellite service receiver characteristics in assessment of interference from pulsed¹ sources in the 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz frequency bands

(Questions ITU-R 217-2/4 and ITU-R 288/4)

(2021)

1 Introduction

Recommendation ITU-R M.1787 provides descriptions of systems and networks in the radionavigation-satellite service (RNSS) and technical characteristics of transmitting space stations operating in the bands 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz, which are referred to as the "1-GHz RNSS bands" in this Report. Recommendations ITU-R M.1905, ITU-R M.1902, ITU-R M.1903 and ITU-R M.1904 provide technical and operational characteristics of, and protection criteria for, receiving stations in the RNSS (space-to-Earth and space-to-space) operating in the 1-GHz RNSS bands. Recommendation ITU-R M.1901 provides guidance on the ITU-R Recommendations related to RNSS systems and networks operating in the frequency bands 1 164-1 215 MHz, 1 215-1 300 MHz, 1 559-1 610 MHz, 5 000-5 010 MHz and 5 010-5 030 MHz.

For the purpose of providing protection criteria for RNSS systems, several RNSS receiver types for particular applications were described in the above referenced M-Series Recommendations. Some of the technical parameters contained in these Recommendations are related to the RNSS receiver front-end characteristics.

This Report is intended to provide further information on RNSS receiver front-end characteristics, including the appropriate usage of these parameters in interference evaluations. This Report also provides the associated consideration of pulsed interference models for RNSS receivers.

This Report also contains two Annexes. Annex 1 addresses the determination of input saturation level for RNSS receivers. Annex 2 presents measurement and simulation studies on the interference impact to one type of high-precision RNSS receiver from scanning pulsed transmissions. Annex 2 provides technical rationale for some updates that are reflected in § 4.1.4 of Report ITU-R M.2220-1.

2 Overview of RNSS receivers

Since RNSS receiver manufacturers are competing to improve their receivers' function and performance, RNSS receiver designs have been evolving rapidly. Thus, it is not possible to describe the comprehensive characteristics of RNSS receivers. Therefore, only a functional block diagram of a representative RNSS receiver is illustrated in Fig. 1, taking into account that most RNSS receiver designs employ digital signal processing.

¹ Pulsed interference is used here to mean interference which consists of bursts of transmission followed by periods of non-transmission. Compatibility with RNSS is a function of the burst power and duration, and the transmission duty cycle.

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The preamplifier generally consists of a band-pass filter and a low-noise amplifier (LNA), which reduce out-of-band interference levels and set the receiver's noise figure.

The downconverter converts the input radio frequency (RF) signal to intermediate frequencies (IF). The IF section may also contain automatic gain control (AGC) to provide adequate dynamic range.

2.1 Preamplifier

The LNA can be characterized by multiple parameters. One important characteristic is the "1 dB compression point", at which the LNA is considered to have gone into compression and lost its linearity. At received power levels below this point, a linear relationship can be seen in the plot of LNA output power level versus LNA input power level. As the input power level increases, the 1 dB compression point is eventually reached where this linear relationship is lost and the output power level decreases from its expected linear gain. This phenomenon is often referred to as saturation of the LNA.

The 1 dB compression point is traditionally used to define the point of the start of saturation of the LNA and specified as the point where the output power level decreases by 1 dB from the normal expected linear gain plot. The LNA is designed to be used below the 1 dB compression point, i.e. within its linear region. The LNAs of different RNSS receivers typically have different 1 dB compression point levels.

The recovery time period begins when the interference level exceeds the 1 dB compression point of the LNA and ends when the interference level drops below this level.

2.2 Downconverter

The down conversion of the incoming signal from preamplifier to IF is achieved by mixing the incoming amplified signal with a reference signal from a local oscillator (LO). A mixer is usually followed by a bandpass filter to suppress the unwanted emissions and harmonics.

2.3 Intermediate frequency section

Automatic gain control is typically implemented within the IF section. The AGC is a variable gain amplifier which adapts its gain to reduce quantization losses. Given the IF filter bandwidth and the number of A/D converter bits, there is an optimal gain at any given point in time depending on the received signal. Digitized IF signals are produced at the output of the A/D converter.

AGC loop characteristics may change over time, mainly due to temperature variation sensitivity.

In most RNSS receiver designs, the AGC loop or A/D converter is likely to be saturated before interference power levels are increased to the point of LNA saturation. When the A/D is saturated, the desired signal is completely suppressed.

It should also be noted that some RNSS receivers use a relatively slow AGC that may not respond to low-duty cycle pulses quick enough to avoid clipping. Some lower cost receivers use 1-bit A/D converters (hardware-limiting) with no AGC. In this case, clipping always occurs when input levels get too high.

Since the AGC saturation level depends on the receiver design, it is difficult to provide a single representative value for most receiver types in Recommendations ITU-R M.1902, ITU-R M.1903, ITU-R M.1904 and ITU-R M.1905. However, this AGC saturation level is considered to be closely related to the saturation level referred to in Recommendation ITU-R M.2030.

3 Use of parameters in RNSS receiver characteristics

Depending on whether pulsed interference or continuous interference is received, the assessment of the impact on the RNSS receiver would be different. In this section, the RNSS receiver characteristics which are related to pulsed interference are mainly discussed.

3.1 IF section design

When the cost reduction of RNSS receivers is a key design goal, the use of simple A/D converters with a small number of bits such as single-bit A/D converters is often considered. Single-bit A/D converters generally work when the dominant component of IF section input is thermal noise, since the received power levels of wanted RNSS satellite signals are smaller than the thermal noise level of RNSS receivers. However, for a single-bit A/D converter, the effect of quantization errors may need to be carefully examined, depending on the interference environment of the intended RNSS receivers.

In the case of RNSS receivers with a multi-bit A/D converter, the thresholds for the extra bits are set at certain points in the Gaussian noise distribution. AGC is used to maintain these thresholds since actual values corresponding to such points in the Gaussian noise distribution vary with time, temperature, and environment. This is typically achieved by sensing the fraction of time when the threshold is exceeded and adjusting the AGC gain to keep this fraction within specified levels. For example, if an interfering signal exceeds the thermal noise level, the AGC will react by reducing the overall receiver gain. Since the wanted RNSS signal levels will also be reduced in the process, navigation capability of such RNSS receivers may be lost depending on this reduction level.

3.2 Saturation level regarding pulsed interference evaluation

Analytical pulsed interference models are provided in Recommendation ITU-R M.2030. In these models, RNSS receiver pulse saturation is discussed. The definition of the N_{LIM} parameter in Recommendation ITU-R M.2030 should be considered to recognize how pulse saturation is defined in these analytical models. The N_{LIM} parameter is described as "ratio (unitless) of receiver analogue-to-digital (A/D) saturation level to 1 σ noise voltage established by automatic gain control (AGC)". This description means that pulse saturation as defined in Recommendation ITU-R M.2030 is not directly related to the LNA 1 dB compression point, but rather to A/D saturation.

It should be noted that the LNA 1 dB compression point as explained above, should not be confused with the "Receiver input saturation level (dBW)" in Recommendations ITU-R M.1901, ITU-R M.1902, ITU-R M.1903, ITU-R M.1904 and ITU-R M.1905. The receiver input saturation levels contained in Recommendations ITU-R M.1902, ITU-R M.1903, ITU-R M.1904 and ITU-R M.1905 are defined in Recommendation ITU-R M.1901-2 as follows: "The minimum power level at the output of the

receiver's passive antenna, from pulsed sources, at which either the receiver linear gain is compressed or the receiver is saturated at any point in the receiver processing circuitry from the first gain stage through the analogue-to-digital converter".

It should also be noted that the receiver input saturation level, is closely related to the design of the A/D converter and AGC (i.e. IF section design). This level varies with the gain levels of the IF section and is difficult to be generalized with the types of RNSS receivers categorized in Recommendations ITU-R M.1902, ITU-R M.1903, ITU-R M.1904 and ITU-R M.1905. Hence, receiver input saturation level due to interference that is pulsed is best determined via testing. See Annex 1 for an example test method.

NOTE – In this section, the description of RNSS receivers not employing a pulse-blanking technique is given. As can be found in §§ 2.2.1 and 2.2.4.1 of Report ITU-R M.2220, some RNSS receivers such as airborne RNSS receivers, which are intended to be operated in high pulsed RFI environments, employ pulse-blanking techniques. For RNSS receivers employing a pulse-blanking technique, a different pulse saturation model should be considered. Details can be found in § 2.3.1 of Report ITU-R M.2220. It should also be noted that pulse-blanking threshold levels are typically the same as the receiver noise level or a few dB higher.

3.3 Overload recovery time

When an RNSS receiver is saturated due to a strong interference level, it takes a certain period of time for the RNSS receiver to return to normal functionality, even after the removal of such strong interference. This period of time is known as 'overload recovery time' and varies as a function of receiver implementation.

It is known that, in general, the time required to recover from pulse saturation is proportional to the degree of overload above the saturation level. In Recommendations ITU-R M.1902, ITU-R M.1903, ITU-R M.1904 and ITU-R M.1905, this is referred to as 'overload recovery time', and the worst-case time durations in the foreseeable pulse interference environment are listed.

3.4 Consideration of associated pulsed interference model

Recommendation ITU-R M.2030 provides an evaluation method for pulsed interference from relevant radio sources, other than in the RNSS, to RNSS receivers. It describes an analytic method that is applicable to all types of RNSS receivers. A modification to this method has been discussed that takes into account the temporal variation of the pulsed peak power due to rotating antenna beams of certain interference sources, such as some EESS scatterometers. This concept proposed to apply a reduction factor called Dynamic Duty Cycle Factor (DDCF), as a means to reduce the estimated level of RFI to RNSS receivers as described in § 4.1.3 of Report ITU-R M.2220-0 (09/2011). The 2010 study for that Report indicated that DDCF could provide a reasonable model of the response for one unique type of RNSS receiver (known as 'semi-codeless') to such a pulsed interference source. However, recent analysis, as presented in Appendix B, shows DDCF is not generally applicable to other types of RNSS receivers, and this updated information is reflected in § 4.1.4 of Report ITU-R M.2220-1.

4 Summary

This Report provides information on technical characteristics of RNSS receivers operating in the 1-GHz RNSS bands, focusing on the receiver input saturation in particular. This Report also includes additional descriptions regarding the usage of the parameters contained in the current set of ITU-R M-Series Recommendations for the 1-GHz RNSS bands. It also provides studies on the interference impact on one type of high-precision RNSS receiver from scanning pulsed transmissions, which is the technical basis for the updated DDCF information in § 4.1.4 of Report ITU-R M.2220-1.

Annex 1

Determination of receiver input saturation level

It was pointed out in § 3.2 that Recommendation ITU-R M.2030 refers to the pulse saturation level as being related to the receiver input saturation level. This in turn is closely related to the design of the A/D converter and the automatic gain control (AGC) (i.e. IF section design). This saturation level varies with the gain levels of the IF section and is difficult to generalize. Currently, the reference for how one might determine this receiver input saturation level does not exist and, therefore, a test methodology to determine this level may be useful.

The test to measure the input saturation level is based on the injection of an additive pulsed interference signal of a fixed duty cycle and adjustable power level. As the pulsed interference power is increased, the carrier-to-noise ratio (C/N_0) will pass through the following three zones:

- Zone 1: The average pulsed interference power² is orders of magnitude less than the receiver thermal noise power, and the interference caused degradation, $\Delta C/N_0$, is negligible.
- Zone 2: The average pulsed interference power is comparable to the receiver thermal noise power, but its peak power is less than the receiver saturation level. The degradation of C/N_0 grows with increasing interference power.
- Zone 3: The peak pulsed interference power is greater than the receiver saturation level. $\Delta C/N_0$ is fairly constant at D_s , the saturation degradation, with increasing interference power.

The pulsed power level at the point where Zone 2 transitions into Zone 3 is the saturation level. Figure 2 depicts graphically how the C/N_0 degrades with increasing interference power.

² The term 'average pulsed interference power' is defined as: The power from the interference source (referenced to the RNSS receiver's preamplifier input and within the receiver's RF filter bandwidth) averaged over one transmit period, including pulse on time and pulse off time.

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FIGURE 2 Degradation of *C*/N₀ as a function of interference power

Example saturation measurement method

1 Pulsed interference parameters

This measurement can be made with a wide range of pulse duty cycle and waveforms. For example, to simulate the transmissions from a representative EESS SAR sensor, SAR B2, as provided in Recommendation ITU-R RS.2105, the following parameters would be used:

Pulse repetition frequency: 3 778 Hz

Pulse duty cycle: 0.068

Waveform: Linear frequency chirp

Chirp width: 28 MHz

Center frequency: 1 236.5 MHz

This set of parameters is both necessary and sufficient to specify the EESS source being simulated.

2 Test set-up

An Agilent E4438 Arbitrary Waveform Generator could generate such a test chirp. Its output would then be added to a simulated RNSS signal using an RF power combiner, which would then be directly coupled to the antenna LNA of the test RNSS receiver, bypassing the antenna element.

3 Calibration

Although the RF spectrum analyser is the standard instrument for RF power measurements, it is poorly suited for pulsed power measurements. A diode-type power detector connected to an oscilloscope provides a measure of interference power as a function of time. The detector would be calibrated with a continuous-wave source. Once the peak power from the RF Generator has been determined, lower peak powers would be obtained by attenuation.

4 Data collection

The estimation of C/N_0 is done by the RNSS receiver, typically at a rate of 1 Hz. The measurements could be averaged over a 5-minute span to reduce the fluctuations sufficiently to observe changes on the order of 0.1 dB.

Annex 2

Studies on the interference impact to one type of high-precision RNSS receiver from scanning pulsed transmissions

1 Introduction

The observation time of a scatterometer, τ_{obs} , refers to the time during which its scanning beam is illuminating the receiver. The 2010 study referenced in § 3.4 above claimed that the ratio term τ_{obs}/T_{TC} could be used in estimating the strong-pulse effect of a scanning beam EESS transmitter on an RNSS receiver. However, this claim has been shown to not be generally valid for estimating the actual C/N_0 seen by the receiver. The actual C/N_0 is instantaneous and will degrade during periods of illumination from the scanning beam and not degrade when not illuminated.

Certain RNSS receivers are known as "semi-codeless" because they use the L1 signal carrier to aid the L2 tracking loops. Such an RNSS receiver can filter the L2 code and carrier measurements with a time constant exceeding 20 seconds. This approach using L1 carrier aiding is required because the receiver does not know the L2 authorized code *a priori*, so it must square the signal to detect the code edges. The signal-to-noise degradation from squaring makes carrier and code recovery impossible without time information from the L1 signal. When the time constant is equal to or less than the scan time, T_{TC} , the two studies presented below in § 2 show that the calculation of the effective degradation of C/N_0 should take into account the L2 tracking loop bandwidth.

With the addition of the L2 civilian code of the L2C signal to newer GPS satellites, it has become possible to track code and carrier in the 1 215-1 300 MHz band without aiding from L1 signals. A key advantage of such receivers is that they are not 'semi-codeless' and therefore can implement wider code tracking loop bandwidths. The trend in recent years is for RNSS receivers that utilize signals in the 1 215-1 300 MHz band to be implemented in this way.

2 Measurement and simulation studies

Section 2.1 below contains measurement results of scatterometer-like transmissions on the SF3000 RNSS receiver showing that DDCF does not account for the instantaneous variations caused by the interfering scanning beam. DDCF can provide insight into the C/N_0 degradation when extensive post-processing averaging (5 minutes in this case) is used. However, such extensive post-processing averaging would conceal the instantaneous degradation that will affect navigation performance. To understand the effect of code loop bandwidth on the instantaneous C/N_0 variations, the simulation described in § 2.2 was undertaken.

2.1 Measurement study

This section presents the results of two sets of radio frequency interference (RFI) measurements from gated, pulsed interference caused by high-power scatterometers into one type of high-precision RNSS receiver currently in production.

2.1.1 Measurement test setup

The characteristics of the scatterometer used in this test use RFI input levels that are 17 dB higher than what existing and planned scatterometers would generate at the RNSS receiver LNA input. This high level of scatterometer interference power was used to ensure that the pulse saturation level of the RNSS receiver was exceeded, thereby pushing the operation into Zone 3 (see Fig. 2) and creating easily observable C/N_0 degradation effects for further analysis.

Table 1 lists the parameters of the RNSS receiver and of the generated pulsed interference test signal. The RNSS receiver characteristics closely match those in the column "High Precision semi-codeless receiver" in Table 1-1 of Recommendation ITU-R M.1902. Figure 3 below shows the test setup used to collect these measurements.

RNSS receiver parameters	Values for test		
Receiver system thermal noise, Tsys	469 K		
Antenna maximum gain, G	3 dBi (same as high precision receiver in Recommendation ITU-R M.1902)		
Power max. survive, average	-10 dBW		
Power max. survive, peak	-10 dBW		
Power for saturation at LNA input	-95 dBW		
Saturation recovery time, T	0.5 µs		
L2P code tracking loop bandwidth	0.04 Hz		
L2P code tracking loop update rate	10 Hz		
L2P code tracking loop order	1 st order		
L2 carrier tracking loop bandwidth	0.15 Hz		
L2 carrier tracking loop update rate	10 Hz		
L2 carrier tracking loop order	1 st order		
Pulsed interference test signal parameters	Values for test		
Pulse power into LNA	-80 dBW		
Pulse duty cycle	0.105		
Pulse repetition rate	3 500 PPS		
Chirp center frequency	1 227.6 MHz		
Chirp rate	2 MHz		
T cycle	4 seconds		

TABLE 1

Test conditions and RNSS receiver parameters

FIGURE 3 EESS simulated waveform test setup



A discussion of the test conditions and the SF3000 RNSS receiver is as follows. The SF3000 GNSS receiver input pulse saturation level of -95 dBW is 35 dB higher than an SBAS receiver. When considering the scatterometers transmitted power characteristics, the SF3000 receiver with its G/T_s would receive a maximum of -95.6 dBW from existing and planned scatterometers. This corresponds to Zone 2 in Fig. 2 and is below the input saturation level of the SF3000 receiver; therefore, pulse saturation from scatterometer transmissions would not occur. For the SF3000 receiver, this scatterometer transmit power level was chosen to create observable τ_{obs} of sufficient length which would not otherwise occur.

The E4438 RF Signal Generator has an arbitrary waveform feature that allows it to produce the simulated interference chirp waveforms as well as gate the chirps to simulate a periodic pulse over repeating 4-second cycle times. The RF Power Detector is a calibrated, passive detector capable of measuring the peak pulse power.

The Navlabs GPS simulator generates both the L1 and L2 signals from a constellation of 8 GPS satellites. PRN 17 was used throughout this test for the sake of repeatability, although the same results are expected for any PRN. The test setup produced a received peak power above the RNSS receiver input compression point for two observation times, namely 0.3 and 1.0 seconds, thus recording two sets of measurements.

The RNSS receiver produced estimates of C/N_0 at a 10-Hz rate. The resultant values were then fed into a low-pass filter whose output was sampled once per second and the sample was sent out the receiver's serial port 10 times per second. The nominal C/N_0 (no interference present) for the RNSS receiver was 40.72 dB-Hz. The test interference source used a pulse duty cycle of 10.5% ($\Delta C/N_0 \sim 1$ dB for N_{LIM} =1).

2.1.2 Measurement results

Figures 4, 5 and 6 below show the measurement results. Note that the measurement resolution is 0.25 dB.

Figure 4 shows the C/N_0 with τ_{obs} set to zero, i.e. no interference. The zero-interference case is necessary to establish a baseline against which degradation can be measured and it shows how C/N_0

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varies with time in the absence of pulsed interference. Note that for this zero-interference case, the C/N_0 fluctuation was typically in a ± 0.25 dB range while occasionally reaching ± 0.5 dB. This fluctuation is caused by receiver noise and quantization effects and is typical in RNSS receivers.



FIGURE 4
Pulsed RFI impact for 0 ms observation time





Figure 5 shows the C/N_0 with τ_{obs} set to 300 ms. The measurement results in Fig. 5 show that sometimes the RFI event was captured (C/N_0 dropped to 40 dB-Hz), but for the 300 ms observation time the effect is not obvious. This is because the level of degradation is small due to the 1-second averaging. On the other hand, when the observation time, τ_{obs} was set to 1 s, the measurement results in Fig. 6 show that the RFI event was captured once every 4 seconds (C/N_0 dropped to 40 dB-Hz or lower, sometimes as low as 39 dB-Hz).





One reason application of the ratio term, $\tau_{obs}/T_{TC,,}$ may have been sufficient in the 2010 analysis is that those specific semi-codeless receivers implemented long time-averaging (i.e. calculated estimates of C/N_0 at a 0.1-Hz rate or slower (no more than once every 10 seconds)). Figures 4, 5 and 6 are zoomed in to show a typical 100 second span so that the time domain detail may be seen.

Table 2 and Fig. 7 contain statistics from measurements made with the above test set-up averaged over five minutes to demonstrate that the selected observation span is not anomalous and to show the performance in the absence of simulated interference signals, i.e. the $\tau_{obs} = 0$ case. These results show that when there is no RFI present, the 5-minute averaged C/N_0 is just above 40.7 dB. This is the interference-free operating point of the GPS receiver. Figure 7 shows how the C/N_0 is degraded as the interference period increases from 0 to 4 seconds.

TABLE	2
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Summary results of pulsed RFI test, 5-minute average

	$ au_{obs} = 0 \text{ ms}$ (No RFI/Chirp Off)	$\tau_{obs} = 300 \text{ ms}$	$\tau_{obs} = 1 s$
Average of C/N_0	40.72 dB-Hz	40.49 dB-Hz	40.20 dB-Hz
Standard deviation of C/N_0	0.219 dB-Hz	0.301 dB-Hz	0.525 dB-Hz
Maximum C/N ₀	41.25 dB-Hz	41.25 dB-Hz	41.25 dB-Hz
Minimum C/N ₀	40.25 dB-Hz	39.5 dB-Hz	39.0 dB-Hz

FIGURE 7 Pulsed RFI test results averaged over 5 minutes



2.2 Simulation study

This section describes the simulation study of the effect of scatterometer pulsed signals on RNSS receivers with different receiver code tracking loop bandwidths. The simulation results were then compared with the analytical results based on DDCF.

2.2.1 Simulation introduction

Studies done in 2010 indicated that the effect of a scatterometer could be mathematically approximated by computing a new pulse duty cycle, PDC_{eff} , which was reduced by the factor τ_{obs}/T_{cy} , i.e. the duty cycle of the scan. This factor has come to be known as the Dynamic Duty Cycle Factor or DDCF. The empirical measurements made in 2010 supporting the DDCF calculations were performed assuming τ_{obs} was a small percentage of T_{cy} . Table 2 shows that the standard deviation for $\tau_{obs} = 300$ ms is greater than that for $\tau_{obs} = 0$ ms, and that the standard deviation for $\tau_{obs} = 1$ s is greater still. This effect on standard deviation combined with the 4 second periodic structure seen in Fig. 6 shows that DDCF does have a dependence on τ_{obs} and on how quickly the receiver responds to the illuminating beam, thereby demonstrating that DDCF is not generally applicable.

This simulation explores the relationship between the receiver code tracking loop bandwidth (the common measure of how quickly the receiver will be affected by an interferer) and PDC_{eff} .

2.2.2 Simulation methodology

The simulation modelled the behaviour of the code tracking loop as a filter for an RNSS receiver subject to gated, pulsed interference from a representative scanning EESS transmitter with a received interference signal level high enough to cause degradation of the receiver's C/N_0 performance ratio. The receiver filter's transfer function is that of a first-order loop. The input was degraded by a factor of 1/(1-PDC) during the observation time, τ_{obs} , and set as 1 (i.e. no reduction in C/N_0) during the remainder of the cycle. The filter update rate of 20 Hz was chosen to correspond with the 20 Hz position fix rate of the SF3000 receiver. The filter output was plotted without smoothing or integration so as to reflect the instantaneous C/N_0 .

Parameters from Scatterometer 2 as shown in Table 3 were used for this simulation. Although Scatterometer 2 can operate at a range of centre frequencies between 1 215 MHz and 1 300 MHz, this simulation used a centre frequency of 1 227 MHz so that the entire pulse pair was within the receive bandwidth. Having all of the pulse energy within the receive bandwidth maximizes the degradation of the receive process, resulting in a worst-case scenario.

TABLE 3

Scatterometer 2 parameters

Parameter	Values		
Scan cycle time, T_{cy} (s)	4		
Pulse duty cycle, PDC	0.105		
Observation time, τ_{obs} (s)	0,4		
Simulated τ_{obs} (s)	0.2, 0.4, 1, 2, 3, 3.5, 4		
Centre frequency (MHz)	1227		
Modulation	Linear FM chirp		
Chirp width (MHz)	1		
Pulse pair frequency (Hz)	3500		

2.2.3 Simulation results

Figures 8, 9, 10 and 11 show the tracked C/N_0 for simulated receiver code tracking loop bandwidths (BW) of 0.05 Hz, 0.1 Hz, 0.2 Hz and 1.0 Hz, respectively. As these Figures show, the fluctuation of C/N_0 caused by the scanning was reduced when the simulated loop filter's bandwidth was reduced. This is as expected because the first-order loop model has a lowpass characteristic, and a narrower loop bandwidth would have a greater effect on reducing the peak-to-average C/N_0 variation. However, from an overall receiver performance perspective, the sensitivity to noise and pulsed interference that wider loop bandwidths exhibit is typically traded-off for the benefits of wider loop bandwidth including faster, unaided RNSS signal acquisition and the ability to maintain signal tracking during high-dynamic receiver motion. The figures clearly demonstrate that the receiver code tracking loop bandwidth cannot be disregarded and must be taken into account in the analysis of RNSS receiver C/N_0 degradation due to pulsed interference.





FIGURE 9 Tracked C/N₀ for receiver code loop BW = 0.1 Hz, τ_{obs} = 0.4 s







Some newer RNSS signals (e.g. GPS L2C) are making it possible and advantageous to use wider code tracking loop bandwidths by providing access to the PRN codes. 1 Hz was the widest loop BW used for this study because wider loop BWs exhibited no further increase in peak-to-average degradation. Figure 11 shows the tracked C/N_0 for code tracking loop BW = 1.0 Hz.



FIGURE 11 Tracked C/N₀ for receiver code loop BW = 1.0 Hz, τ_{obs} = 0.4 s

2.2.4 Effective DDCF

The simulation results show that the factor τ_{obs}/T_{cy} (DDCF) can be used as a model of the effective PDC reduction gained from a scanning antenna only when the peak degradation (minimum C/N_0) is close to the average degradation. Therefore, DDCF is not generally applicable. DDCF is only valid when the receiver employs a very narrow (e.g. 0.05 Hz) code tracking loop bandwidth, which is generally not the case for modern RNSS receivers. The simulation results of peak degradation are used to calculate the ratio of PDC to *PDC*_{eff} and summarized as *DDCF*_{eff} in Table 4 and in Fig. 12.

TABLE 4

		Fsamp = 20 Hz	$T_{cy} = 4s$		
		LBW			
τ_{obs} , s	.01 Hz	.05 Hz	.1 Hz	.2 Hz	1.0 Hz
0	0	0	0	0	0
0.2	0.053 7	0.081 0	0.122 5	0.214 3	0.700 9
0.4	0.106 7	0.157 7	0.231 9	0.384 5	0.912 9
1	0.263 6	0.364 0	0.493 8	0.708 6	0.997 9
2	0.517 8	0.639 3	0.768 6	0.921 0	1.000 0
3	0.763 4	0.845 9	0.918 8	0.982 4	1.000 0
3.5	0.882 9	0.928 7	0.965 6	0.993 9	1.000 0
4	1	1	1	1	1

Effective DDCF for PDC = 0.105

DDCF_{eff} for PDC=0.105, T_{cv}=4 sec 1 0,9 0,8 0,7 0,6 -.01 Hz 0,5 - .05 Hz 0,4 – .1 Hz 0,3 -.2 Hz 0,2 - 1.0 Hz 0,1 0 1 2 3 0 4 τ_{obs}, sec

FIGURE 12 *DDCF_{eff}* for several receiver code tracking loop bandwidths

Figure 12 contains plots of $DDCF_{eff}$ for several receiver code loop bandwidths ranging from 0.01 Hz to 1.0 Hz for a PDC of 0.105 and cycle time of 4.0 seconds. The plots show that the relationship between $DDCF_{eff}$ and τ_{obs} is approximately linear for 0.01 Hz code tracking loop BW, but as the BW is increased, the relationship becomes progressively less linear and less aligned with DDCF. (Like the original DDCF, the proposed $DDCF_{eff}$ is not a function of PDC.)

3 Summary

The studies in § 2 provide measured and simulated degradation effects for one type of high-precision RNSS receiver due to interference from a scatterometer interference source. The studies analyse the relationship of the receiver's code tracking loop bandwidth to the factor τ_{obs}/T_{cy} (DDCF). These results make clear that the RNSS receiver's code tracking loop bandwidth plays a significant role in the degradation that gated pulsed RFI, such as from the scanning beam of an EESS scatterometer, can cause.

The simulated and the measured test results both show that C/N_0 degradation changes over the course of the scatterometer beam scan, and that it periodically exceeds that estimated by the application of DDCF. Newer receivers typically have wider code tracking loop bandwidths that intensify this time variation. As such, the applicability of DDCF is limited to certain semi-codeless type receivers and is not generally applicable, as discussed in §§ 4.1.3 and 4.1.4 of Report ITU-R M.2220-1.
