RECOMMENDATION ITU-R RS.1347[*]

# FEASIBILITY OF SHARING BETWEEN RADIONAVIGATION-SATELLITE SERVICE RECEIVERS AND THE EARTH EXPLORATION-SATELLITE (ACTIVE) AND SPACE RESEARCH (ACTIVE) SERVICES IN THE 1 215-1 260 MHz BAND

(Question ITU-R 218/7)

(1998)

The ITU Radiocommunication Assembly,

*considering*

a) that the radionavigation-satellite (space-to-Earth) service is allocated on a primary basis in the 1 215-1 260 MHz frequency band;

b) that active spaceborne sensors operating in the Earth exploration-satellite and space research services are allocated on a secondary basis, according to Footnote S5.333, in the 1 215-1 300 MHz frequency band;

c) that sharing studies have shown compatibility between the radionavigation-satellite service receivers, including L5 receivers, and active spaceborne sensors in the acquisition and tracking phases (refer to annex);

d) that compatibility tests have demonstrated compatibility between the radionavigation-satellite service GPS receivers in the tracking phase and synthetic aperture radars (refer to annex),

*recommends*

**1** that, in view of *considering* c) and d), sharing be considered feasible between the radionavigation-satellite service and spaceborne synthetic aperture radars in the 1 215-1 260 MHz frequency band.

ANNEX

## Potential interference from spaceborne active sensors into radionavigation-satellite service receivers in the 1 215-1 260 MHz band

## 1 Introduction

The 1 215-1 260 MHz frequency band is allocated to the radionavigation-satellite service (RNSS) and is used by both the Global Positioning System (GPS) and the Global Navigation Satellite System (GLONASS-M). The 1 215-1 300 MHz band is used by spaceborne active microwave sensors under the provisions of Footnote S5.333 of the Radio Regulations. The only active sensor requiring use of this band is the synthetic aperture radar (SAR). This annex presents the compatibility analyses of typical spaceborne synthetic aperture radars (SARs) into GPS and GLONASS-M receivers for both acquisition and tracking phases and presents the compatibility test results between the SAR and GPS for the tracking phase. In addition, the GPS L5 is under consideration for this band.

## 2 Technical characteristics of a spaceborne SAR

The technical characteristics for two standard synthetic aperture radars which use the 1 215-1 300 MHz band are given in Table 1. The parameters of these systems offer a range of possible characteristics to use as representative for an operational SAR. The characteristics chosen in this analysis are those which would result in the worst case interference to a radionavigation-satellite service receiver.

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[*] Radiocommunication Study Group 7 made editorial amendments to this Recommendation.

## 3 Characteristics and protection criteria of GPS and GLONASS-M systems

Recommendation ITU-R M.1088 gives the characteristics and system description for the Global Positioning System (GPS) to be used in assessing sharing between other services and a GPS receiver. Recommendation ITU-R M.1317 gives the characteristics and system description for the Global Navigation Satellite System (GLONASS-M) to be used in assessing sharing between a GLONASS-M receiver and other services. The GPS L5 is under consideration for this band. The characteristics of GPS L5 have been presented as being similar to those of the GPS Coarse Acquisition (C/A) code described in Recommendation ITU-R M.1088. Operation of GPS L5 is expected to behave as the GPS C/A code in the presence of interference signals.

TABLE 1

**Technical characteristics of spaceborne synthetic aperture radars in the 1 215-1 300 MHz band**

| | Standard SAR 1 | Standard SAR 2 |
|---|---|---|
| Peak radiated power (W) | 3 200 | 1 200 |
| Pulse modulation | Linear FM Chirp | Linear FM Chirp |
| Pulse bandwidth (MHz) | 40.0 | 15.0 |
| Pulse duration (µs) | 33.8 | 35.0 |
| Pulse repetition rate (pps) | 1 736.0 | 1 607.0 |
| Duty cycle (%) | 5.9 | 5.6 |
| Maximum antenna gain (dBi) | 36.4 | 33.0 |
| Antenna orientation (degrees from nadir) | 20.0 | 35.0 |
| Antenna polarization | Linear vertical/horizontal | Linear horizontal |
| Orbital altitude (km) | 400 | 568 |

GPS and GLONASS-M receivers are susceptible to both pulsed and continuous interference for both acquisition and tracking phases. In the case of potential interference from a SAR, the interference falls into the category of pulsed interference. Pulsed interference can affect an RNSS receiver in two ways: by causing preamplifier saturation or preamplifier burnout. The principle interference effect is that the pulsed interference causes limiting in the receiver. This occurs when a signal level is received that is strong enough to cause the high-level limiter diode, located in the RF front-end of the receiver, to saturate in order to prevent burnout of the following receiver stages. When this limiting occurs, the relatively low desired signal would be blocked during the transmission pulse period and any recovery time that is necessary for the RNSS receiver. If this period of lost signal is short relative to the GPS information bit length, there should be no appreciable impact on the performance of the receiver. The other possible interference effect occurs when either the peak or average RF power level is high enough to cause the diode to fail. If this occurs, preamplifier burnout is possible and damage to the receiver may occur. The relevant technical characteristics for the two RNSS systems are summarized in Table 2. The saturation power level (preamplifier limiting level) and the power level required for preamplifier burnout for each of the systems is also given in Table 2. Also in the acquisition phase, the spaceborne SAR at orbit altitudes illuminates a given location on Earth in the mainbeam for only 1-2 seconds, which is typically less time than required for acquisition.

Any pulsed signal power level received that is below the preamplifier limiting levels of the RNSS receivers is assumed to have a negligible effect on the performance of the receiver since the SAR transmitted pulse period is relatively short compared to the RNSS information bit length and the SAR transmitter duty cycle is very low.

TABLE 2

**Characteristics and protection criteria for navigation user equipment of the GPS and GLONASS-M systems**

| | GPS | GLONASS-M |
|---|---|---|
| Carrier frequencies (MHz) | 1 227.6 | 1 237-1 261 |
| RF 3 dB filter bandwidth (MHz) | ± 17.0 | ± 20.0 |
| Polarization | RHC | RHC |
| Maximum antenna gain (dBi) | 0.0 | 0.0 |
| Preamplifier burnout level (average) (dBW) | 0.0 | -1.0 |
| Preamplifier burnout level (peak) (dBW) | 10.0 | 0.0 |
| Preamplifier limiting level (dBW) | -70.0 | -80.0 |

# 4 Compatibility analyses

## 4.1 Compatibility analysis with consideration of SNR degradation

The first step in analysing the interference potential from a spaceborne SAR to a GPS or GLONASS-M receiver is to determine if the peak signal power from the SAR is great enough to cause the high-level clipper diode to fail and possibly cause preamplifier burnout and damage the receiver. The maximum interfering signal power levels received from a spaceborne SAR occur when an RNSS receiver is located in the mainbeam of the SAR antenna. The peak interfering signal power levels from a SAR into a GPS or a GLONASS-M receiver are calculated in Table 3. The calculations assume co-frequency operation.

These levels for maximum peak power at the receiver input of an RNSS receiver are well below the levels that would cause the high-level clipper diode to fail. Thus, the emissions from a spaceborne SAR will not cause high-level clipper diode burnout or damage to either a GPS or GLONASS-M receiver. The interfering signal level at the GPS receiver input at which the diode will saturate and cause a temporary loss of signal is -70 dBW. For the acquisition phase, this level is 6 dB lower, or -76 dBW. Even in the worst case configuration, this interfering signal level will not be reached.

The interfering signal level at the GLONASS-M receiver input at which the diode will saturate and cause a temporary loss of signal is -80 dBW. In the worst case configuration depicted in Table 3, this interfering signal level may be exceeded by 1.5 dB due to the transmissions of a SAR. Taking into account the fan-beam shape of the SAR antenna, the resultant necessary off-axis angle to produce 1.5 dB of discrimination is 0.28°. A simulation of 15 000 orbits was run (400 km altitude, 57° inclination) to determine how often a stationary GLONASS-M receiver would be within 0.56° of the SAR antenna mainbeam (0.28° on either side). The results showed that this would occur for less than 0.0019% of the time. This means that an interfering signal level greater than the diode saturation level would be received for less than 2 seconds per day assuming this worst case interference situation. The compatibility analysis for the GLONASS-M showed that the service should be compatible with multiple spaceborne SAR interference sources, up to four SARs illuminating the GLONASS receivers in the mainbeam of the SAR at the same time, assuming the cumulative duty factor is 20% for four SARs. Given the small number of spaceborne SARs likely to be in orbit and in operation at the same time, and also given the likely diversity in orbital altitudes, orbital velocities, and orbital periods of the SARs from different administrations, the probability is extremely low that four or even two spaceborne SARs will illuminate a GLONASS-M receiver at the same time. Further, two or more SARs would never simultaneously observe the same scene because the resulting mutual interference would preclude acquisition of usable data.

TABLE 3

**Maximum interfering signal power levels from SAR into GPS and GLONASS-M receivers**

| | Interference to GPS | | Interference to GLONASS-M | |
|---|---|---|---|---|
| | SAR 1 | SAR 2 | SAR 1 | SAR 2 |
| Centre frequency (MHz) | 1 227.6 | 1 227.6 | 1 250.0 | 1 250.0 |
| Peak radiated power (dBW) | 35.1 | 30.8 | 35.1 | 30.8 |
| Transmitter antenna gain (dB) | 36.4 | 33.0 | 36.4 | 33.0 |
| Distance (km) | 427.5 | 709.3 | 427.5 | 709.3 |
| Space loss (dB) | 146.8 | 151.2 | 147.0 | 151.4 |
| Receiver antenna gain (dB) | 0.0 | 0.0 | 0.0 | 0.0 |
| Polarization mismatch loss (dB) | 3.0 | 3.0 | 3.0 | 3.0 |
| Maximum received interference power (peak) (dBW) | -78.3 | -90.4 | -78.5 | -90.6 |

Even in the case where the signal level causes the front-end to saturate and a temporary loss of the RNSS signal occurs, there will be no appreciable impact on the performance of the receiver if the SAR transmitted pulse period plus the RNSS receiver recovery time are relatively short compared to the RNSS information bit length. If a recovery time of 1 µs is assumed for the receiver, the transmission from one SAR would remove about 6% of the RNSS signal during the time that the receiver is saturated.

(SAR pulse width + RNSS recovery time) * SAR pulse repetition frequency = 6.04%

When the RNSS receiver is saturated (> 70 dBW for GPS), the signal is essentially lost during the width of the interfering pulse plus any front end recovery time. The GPS navigational data rate is†50 bits/s and is mod-2 added to the P-code or C/A code PRN sequence of 10.23 MHz or†1.023 MHz, respectively, before phase modulation onto the 1 227.6 MHz tone. Thus the GPS navigational data bit period is 20 ms long, and during this bit period there are over 204 K P-code chip periods, and from 25 to 43 SAR pulses transmitted. The fraction of signal power lost during the bit period is then equal to the ratio of the combined width of the interfering pulse plus any GPS front end recovery time for both acquisition and tracking phases over the interpulse period. The SNR degradation ΔSNR in dB is the ratio of the SNR with interference present to the SNR with no interference and is given by the following:

$$\Delta\mathrm{SNR} = 10 * \log\left(1 - \frac{\mathrm{PW} + \mathrm{RT}}{\mathrm{IPP}}\right) \tag{1}$$

where PW is the SAR pulse width, RT is the GPS recovery time, IPP is the interpulse period of the SAR, and the argument of the log function is greater than zero. Assuming that the GPS recovery time is from 1 to 30 µs, the SNR degradation for the range of SAR 1 pulsewidths and PRFs yields values from -0.1 to -0.6 dB.

The SIR-C phased array antenna contains distributed high power amplifiers (HPAs) for amplification and transmission of the 1.25 GHz signal. The HPA dc power is gated on only during the transmit event, and is gated off during the interpulse period. The HPAs are class C devices in that they are powered to transmit only during the presence of the input pulse. Since these devices are powered off during the interpulse period, there is no interpulse noise present from the spacecraft.

## 4.2 Compatibility analysis with consideration to GPS receiver tracking loop gain

### 4.2.1 Introductory assumptions

We present here below a compatibility study between spaceborne synthetic aperture radars (SARs) and GPS services in L2 band, i.e. around 1 227.6 MHz with consideration to the GPS receiver tracking loop gain.

Since no precise information is available at this time about the L2 P code acquisition phase neither for receivers able to track Y/P codes nor for codeless or semicodeless receivers, the analysis below will be limited to interference into GPS L2 receivers in tracking mode.

### 4.2.2 Information contained in the reference documents

The document ITU-R 7-8R/14 presents a typical spaceborne radar to be used for future Earth observation missions. The centre frequency of the SAR may be somewhat different from that of the GPS receiver, but we consider in the analysis a worst case where the SAR centre frequency would be in the middle of the GPS receiver band.

The peak power is 3 200 Watts, the bandwidth 10, 20 or 30 MHz, with a linear chirp modulation, the pulse repetition rate is 1 395 or 1 736 pulses per second. The maximum pulse duration is 33.8 µs.

The antenna gain is 36.4 dBi; the antenna may scan in elevation from 20 to 55 degrees from nadir. The orbit altitude is 400 km.

The Recommendation ITU-R M.1088 presents the GPS receivers; the minimal power received at 1 227.6 MHz is -136 dBm; the RF filter 3 dB bandwidth is ±17 MHz; an acceptable performance of the receiver can be maintained with spurious incoming signals up to 41 dB above the signal level for the tracking phase, i.e. -95 dBm.

The front end amplifier input power for saturation is -40 dBm.

### 4.2.3 Assumptions concerning the GPS receiver operation

The GPS signals when entering the receiver are well below the noise floor of the equipment; hence the signal which is sampled and coded by the receiver is essentially noise; for an optimum coding, the noise has to be maintained by an automatic gain control loop (AGC) at the analog to digital coder input (ADC) at a constant level which is defined by $\sigma = A/3$, where $\sigma$ is the noise standard deviation and A the saturation level of the ADC.

The AGC loop time constant is assumed to be large compared to input pulse repetition period (716 µs maximum).

The noise input level may be estimated to -97 dBm, with a receiver 4 dB overall noise figure and with an equivalent input bandwidth of 20 MHz.

Hence the equivalent saturation threshold of the ADC corresponds to -87.5 dBm at receiver input. We assume here a 4 bits coder, which corresponds to present receivers designs.

From those hypothesis we can conclude that in steady state operation, the receiver performs the signal + noise coding with a wideband quantification noise added ($Q^2/12$, where $Q$ is the quantification level) 19.3 dB below the noise and with a saturation noise 30 dB below the noise, which is completely negligible.

We also assume a 0 dB antenna gain for the GPS receiver.

### 4.2.4 Interference from SARs into GPS receivers

We consider a receiver located at the Earth level, at a minimum distance of the radar i.e. for the 20° incidence angle of the radar beam.

We consider a worst case where the radar band fully overlaps the GPS receiver band. The satellite-receiver distance is then 424 km.

We assume a 0 dB receiver antenna gain.

The received power at the receiver level is then -45.4 dBm, which is well above the interference threshold of the receiver. This level is below the front end amplifier saturation level, hence this amplifier will not saturate, and we will have saturation at coder level.

We have now to assess the effect on the tracking performance due to this saturation at coder level. First, it is clear that the saturation only occurs during the occurrence of transmit pulses from the radar; we can assume a negligible time for desaturation at this level compared to pulse duration. Since the AGC time constant should be much larger than the input pulse repetition interval, the AGC operates as to maintain a constant overall power at coder input due to saturating pulses when occurring and to nominal signal + noise when the pulses are not present.

We have computed the equivalent power at the coder input due to this kind of input signals, and we have derived the new AGC setting that will be used by the AGC loop, using the following equation:

$$A^2 dc + (1 - dc)\sigma^2 = A^2 / 9 \tag{2}$$

where dc is the radar duty cycle.

From this we derive that in the present case, $\sigma^2 = A^2/18$ i.e. that the AGC setting will be 3 dB larger than previously, due to saturating input pulses added power.

We then can easily conclude on what happens at receiver output due to this; there are three effects we can identify:

– First, the saturating pulses at receiver input are not correlated with the code replica and can be considered as adding supplementary input noise; since the AGC setting differs by 3 dB, the useful GPS PRN signal is reduced by 3 dB while the total input power at ADC input remains constant, due to the AGC loop; we can conclude that the signal to noise ratio will be reduced by 3 dB due to this, leading to a 40% increase in tracking noise.

  Since a 41 dB ratio between the useful signal and continuous spurious signals is allowed by document ITU-R 7-8R/14, which corresponds to interferers larger than the receiver noise by 2 dB, reducing thus the signal to noise ratio by more than 3 dB; we can conclude that in the present case the interfering signal is acceptable.

– Second, the saturating incoming pulses introduce supplementary quantification noise compared to the input signal + noise; this ratio is increased by the above 3 dB difference in AGC setting, leading to a 16.3 dB value in ratio between the input noise and the quantification noise, which is still negligible.

– Third, the operations of correlation in the receiver with the PRN codes replica will be done over a shorter period of time since the useful signal will no longer be correctly coded when saturating pulses are present; for small duty cycles dc, the shape of the correlation function will not be affected but only the level at the output will be reduced by a ratio (1-dc), leading in the present case to a 0.3 dB signal loss which is still acceptable.

### 4.2.5 Conclusion based on this compatibility analysis with consider to the GPS tracking loop gain

From the analysis above, we can conclude that the SAR operation as described in Recommendation ITU-R M.1088 is compatible with the GPS receiver performance in L2 band.

The incoming pulses will saturate the ADC but this will not lead to receiver performance unacceptable degradation from the operation of the AGC loop.

This should be true only up to duty cycles around 10% for the SAR, where tracking noise of the GPS receiver should be increased by 50%, due a 4 dB signal to noise degradation.

Beyond this duty cycle limit, the tracking noise increase will be larger, but may still acceptable if we consider the filtering process that may be applied to navigation data.

For this statement, we have to remind first that those effects are quite unlikely since such interference needs that the radar beam be oriented towards the GPS receiver and second we have to remind that such phenomena should occur during very limited periods of time (a few seconds) since the radar beam is very sharp (1 degree in azimuth, or 7.5 km at ground level) and the radar beam ground velocity is close to 6 km/s.

Furthermore, another point to be underlined is that spaceborne radars up to now do not use the 85 MHz of the 1 215-1 300 MHz band, and in case potential harmful interference is feared, SAR could have their centre frequency located in the upper part of this band in order the radar band and the L2 GPS band not to overlap.

With 20 MHz needed for GPS, this would be possible up to SARs bandwidths of 60 MHz.

Further information about GPS receiver would be needed to consolidate this study, particularly about acquisition phase; the study should be also applied to GLONASS receivers.

## 5 GPS/SAR compatibility demonstration

The GPS receiver was set up in full view of the GPS satellites at the JPL test facility. The GPS antenna was connected directly to the GPS receiver, and the GPS was powered up in the L2 P-code mode. The GPS data upon locking up to the GPS satellite data was monitored, and the operators monitored and archived the location data, and the SNR in the tracking loop. The two SIR-C RF racks were set up at the JPL test facility and the GSE was powered up to provide L-band signals at the upconverter output at a level of +18 dBm. Forty feet of RF cable, long enough to reach the attenuators, was connected between the SIR-C GSE racks and the attenuators, with an additional forty feet of RF cable between the attenuators and the directional coupler at the GPS receiver input to yield a peak level of -75 dBW at the input to the GPS receiver, allowing for the directional coupler loss at the GPS receiver input. The GPS antenna to GPS receiver line was disconnected, and a directional coupler was added; the RF cable was connected between the SIR-C GSE racks and the attenuators and RF cable was connected between the attenuators and the directional coupler at the GPS receiver input. The SIR-C radar parameters were set to 40 MHz bandwidth, PRF=1 736 Hz, Pulsewidth=33.8 μs, and level into the GPS at -75 dBW, for maximum duty cycle at nominal operations; the effect upon the GPS receiver was monitored. Voltage SNR measurements for C/A mode and L2-P mode were made by making measurements of a reference signal using maximum attenuation of 121 dB for one minute followed by the interference signal at -75 dBW for one minute. This measurement was repeated for several minutes and averaged. This procedure was repeated for various combinations of radar parameters. One of these parameters was the input signal level. The level was increased to -43 dBW for most of the test steps, 32 dB above the worst case level expected from the spaceborne SAR. This accounts for any GPS antenna gain differentials less than 32 dB. The GPS receiver did not lose lock and the SNR degradation was recorded in Table 4. There was no degradation of position determination accuracy during any of the tests.

Since these tests were run with a prototype of the SAR transmission equipment, the expected levels of interpulse noise emitted from the SAR were being received by the GPS receiver throughout the testing process. There were no incidences of the GPS receiver losing lock or losing position determination accuracy during any of the tests. Thus, it can be concluded that the interpulse noise emitted by the SAR is below the interference threshold level for the GPS receiver.

## 6 Summary

The potential interference typical spaceborne synthetic aperture radars to radionavigation-satellite service (RNSS) receivers was analysed in this annex for both acquisition and tracking phases, taking into account gain differentials, and accounting for the possible inclusion of L5. Two radionavigation-satellite service systems which operate in the 1 215-1 260 MHz band are the Global Positioning System (GPS) and the Global Navigation Satellite System (GLONASS-M). The analysis performed assumed co-frequency operation of the SAR and the RNSS system. The peak signal power levels at GPS and GLONASS-M receivers resulting from SAR transmissions were calculated in the worst case scenario and the resultant levels were found to be well below the levels that would cause preamplifier burnout and possible damage to a GPS or GLONASS-M receiver. In this worst case configuration, the GPS receiver front-end saturation level will never be exceeded.

In this worst case configuration, the GLONASS-M front-end saturation level will infrequently be slightly exceeded (1.5 dB). Taking into account the antenna pattern and orbital parameters of the SAR, the saturation level of a stationary GLONASS-M receiver could be exceeded for less than 2 s per day. However, since the SAR transmitted pulse width is short and the duty cycle is low, the periods that the GLONASS-M signal could be degraded due to an interfering signal level above the preamplifier limiting level will be relatively short compared to the GLONASS-M information bit length. Thus, there should be no appreciable impact on the performance of the receiver.

The compatibility between the GPS and SAR was successfully demonstrated. The Global Positioning Satellite (GPS) system operates at the centre frequency of 1 227.6 MHz for L2 P-code mode with ±17 MHz receiver bandwidth and C/A code. The L5 may be orthogonally added to L2 in this band, and is expected to have similar characteristics as does the C/A code. The SIR-C spaceborne imaging radar operates at the centre frequency of 1 237.5 MHz for the 40 MHz bandwidth mode at L-band. The peak power level of the SIR-C pulses is much higher than the specified GPS CW limit; however, since the SIR-C pulses interfere with the GPS received PN code only for the short duration of the SIR-C pulsewidth, lock is not lost, and in fact the SNR is degraded only slightly in the presence of the interference pulses and no degradation of position determination accuracy was observed. This test successfully demonstrated that the GPS L2 P-code and C/A code will function nominally in the interference environment imposed by the SIR-C L-band and C-band radars.

TABLE 4

| Effect upon GPS receiver in compatibility demonstration test step configuration | Lock/ No lock | C/A SNR change (dB) | P2 SNR change, (dB) |
|---|---|---|---|
| 40 MHz bandwidth, PRF=1 736 Hz, Pulsewidth=33.8 μs and level into the GPS at -75 dBW, for maximum duty cycle | Lock | -0.9 | -0.8 |
| 40 MHz bandwidth, PRF=1 736 Hz, Pulsewidth=33.8 μs, and the level into the GPS was increased to -65 dBW, for maximum duty cycle | Lock | -0.9 | -0.7 |
| 40 MHz bandwidth, PRF=1 736 Hz, Pulsewidth=33.8 μs and the level into the GPS was increased to -43 dBW (maximum available with 0 dB attenuation), for maximum duty cycle | Lock | -0.8 | -0.3 |
| 40 MHz bandwidth, PRF=2 160, Pulsewidth=33.8 μs and level into the GPS at -43 dBW, for maximum duty cycle at non-nominal operations | Lock | -0.9 | -0.6 |
| 40 MHz bandwidth, PRF=2 160 Hz (highest non-operational PRF available), Pulsewidth=16.9 μs and level into the GPS at -43 dBW, for medium duty cycle at non-nominal operations | Lock | -0.7 | -0.4 |
| 40 MHz bandwidth, PRF=1 395 Hz, Pulsewidth=16.9 μs and level into the GPS at -43 dBW, for low duty cycle | Lock | -0.2 | -0.1 |
| 40 MHz bandwidth, PRF=1 240 Hz (lowest non-operational PRF available), Pulsewidth=33.8 μs and level into the GPS at -43 dBW, for minimum duty cycle at non-nominal operations | Lock | -0.1 | -0.2 |
| 10 MHz bandwidth, PRF=1 240 Hz, Pulsewidth=8.45 μs and level into the GPS at -43 dBW, for extreme low duty cycle and non-overlapping spectra | Lock | -0.3 | +0.1 |
| 40 MHz bandwidth, PRF=2 160 Hz, Pulsewidth=33.8 μs and level into the GPS at -43 dBW, for maximum duty cycle; the front-end GPS filter was substituted for a wide band 550 MHz preselect filter | Lock | -1.4 | -1.4 |
| 40 MHz bandwidth, PRF=2 160 Hz, Pulsewidth=33.8 μs and level into the GPS at -75 dBW, for maximum duty cycle and realistic level from space; the front-end GPS wide band 550 MHz preselect filter was retained | Lock | -1.0 | -1.7 |
| 40 MHz bandwidth at C-band, PRF=2 160 Hz, Pulsewidth=33.8 μs and level into the GPS at -51.5 dBW (highest available for C-band with 0 dB attenuation), for maximum duty cycle and to see the effect of radiating from space at C-band | Lock | -1.5 | -1.5 |