International Global Navigation Satellite Systems Association
IGNSS Conference 2016

Colombo Theatres, Kensington Campus, UNSW Australia
6 – 8 December 2016

Interference Mitigation and Preserving Multi-GNSS Performance

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ABSTRACT

The PNT market's thirst for performance is placing more emphases on tracking every possible GNSS signal in increasingly difficult conditions. Tracking additional signals requires increasing the RF bandwidth which can leave the system more susceptible to interference. At the same time the once-quiet neighbouring RF spectrum is being used for an increasing number of applications. Working near these noisy neighbours is adding constraints to system designers and integrators working with GNSS.

A series of tests were conducted to see if NovAtel's OEM719 GNSS receiver with its Interference Toolkit could mitigate the out of band interference from a Globalstar transceiver on the GPSL1 band as effectively as the combination of a cavity filter and the OEM628. Without any form of mitigation or protection, both NovAtel receivers will lose lock on GPS L1 signals when the Globalstar transceiver is broadcasting in close proximity to the GNSS antenna. However, using a cavity filter very effectively preserves performance. The main disadvantages of the cavity filter besides size, weight and cost are that to be effective the passband is often narrow and doesn't allow for full tracking of BeiDou or GLONASS L1 signals, and two or more cavity filters need to be used together for multi-frequency applications like RTK.

NovAtel's Interference Toolkit was able to detect and mitigate the impact of the Globalstar broadcasts on the OEM719's GPSL1 tracking as effectively as the cavity filter.

KEYWORDS: GNSS, interference, Globalstar, mitigation

1. INTRODUCTION

The bands adjacent to the protected GNSS spectrums at L1, L2 and L5 are increasingly being utilized for control, communications and data transfer. Licenced out of band (OOB) communications systems such as Globalstar, Iridium and LTE signals can cause tracking problems with precision GNSS receivers with wideband RF frontends. These are unintentional jammers operating in their assigned frequencies that output power many times that of the relatively weak GNSS signals being received from satellites. There is no legal recourse to have these signals shutoff, so the user is left with having to relocate their antenna or to introduce in-line filters in the hope that it will mitigate the effect of the transmitter on the GNSS receiver. One strategy for mitigating the effect of OOB on GNSS receivers is to limit the RF power from out of band by using bandpass filters. A cavity filter is a type of bandpass filter that can provide very good close-in rejections and are commonly used in base stations, fixed installations and laboratories.

This paper's objective is to determine if NovAtel's new OEM719 with the Interference Toolkit is as effective as a L1 cavity filter at mitigating Globalstar out-of-band interference on GPSL1 signals. The first step was to see what the effects of the Globalstar signal were on a wideband, high precision GNSS receiver such as NovAtel's popular OEM628 and its new OEM719. Next a cavity filter was placed in front of the OEM628 while the Interference Toolkit's High Dynamic Range (HDR) mode was activated on the OEM719 to determine if the interference effects of Globalstar could be mitigated. The cavity filter was already known to be very effective at mitigating Globalstar interference, but the OEM7's Interference Toolkit's performance was unknown.

The test setup placed the GNSS and Globalstar antennas with a clear view of the sky. The Globalstar transmissions were fed directly into test GNSS receivers, rather than broadcast the signal and possibly jam nearby GNSS receivers and antennas. A sufficient attenuation was selected to duplicate at Globalstar signal being broadcast approximately 1 to 3 metres from a GNSS antenna, which is a common scenario for vehicle or aircraft mounted systems.

2. TEST DESCRIPTION AND EQUIPMENT

2.1 Test Description

Tests were conducted with live signals to determine if the OEM719 with the Interference Toolkit's HDR mode could mitigate out-of-band L1 interference from a Globalstar data transceiver as effectively as a cavity filter. An OEM719 using the Interference Toolkit was compared against an OEM628 with a cavity filter. The test setup is shown in Figure 1.

The Globalstar GSP-1720 data transceiver receive line was connected directly to an Antcom GAT-17QP antenna, while the transmit line was attenuated by 20 dB (to simulate normal power levels) and fed into a splitter and combined with GNSS signals from an active NovAtel GPS-702-GGL L1/L2 GNSS antenna. The combined Globalstar/GNSS signals were split off to an OEM719 running the Interference Toolkit and an OEM628 with a cavity filter. The receivers were set to use GPSL1 only and were run in single-point position mode with no corrections or assistance.

The tests were conducted with the antennas setup with a clear view of the sky. The OEM628 and OEM719 were run through a sequence of tests of ½ hour (1800 second) duration. Data was collected simultaneously from both receivers. Since the tests were run at a variety of times and days with the GPS constellation changing, it is important to judge the performance of each mitigation technique based on the performance of the OEM628 with the cavity filter.

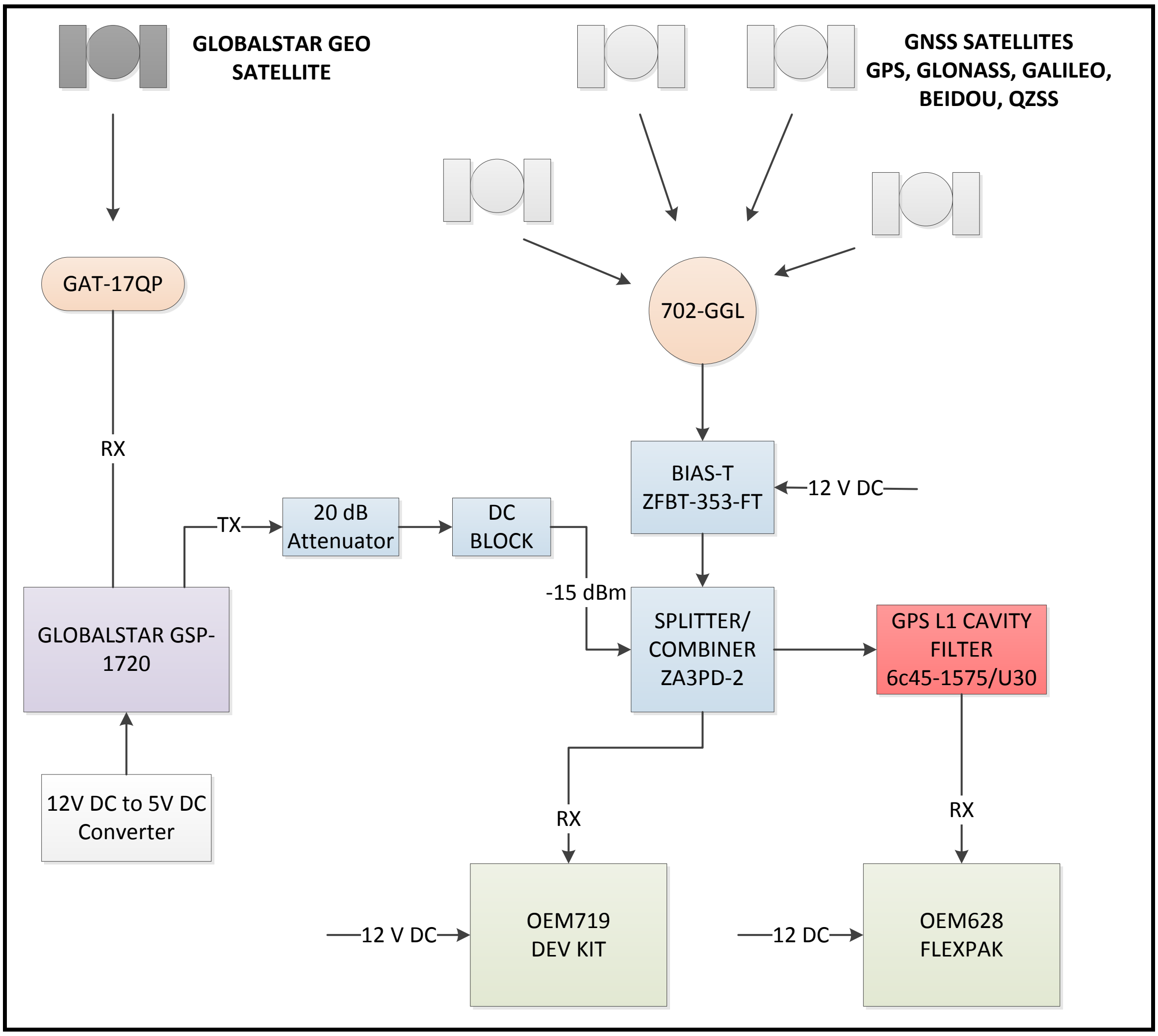

Figure 1. Test Setup Block Diagram

2.2 Equipment

2.2.1 OEM628

The NovAtel OEM628 is a triple frequency receiver capable of tracking all GNSS constellations and signals including GPS, GLONASS, Galileo, BeiDou and QZSS. It features 120 available channels. The same receiver was used throughout the tests.

2.2.2 OEM719

The NovAtel OEM719 receiver is capable of tracking all GNSS constellations and signals on four frequency bands including GPS, GLONASS, Galileo, BeiDou and QZSS with 555 available channels. The same receiver was used throughout the tests.

2.2.3 Globalstar GSP-1720 Transceiver

The Globalstar GSP-1720 Transceiver is a Satellite Data/Voice module for bi-directional digital communications between a mobile earth station (where the transceiver is located) and a Globalstar satellite. It handles Packet, Asynchronous and Voice communications and is intended for remote locations where normal land line and cellular communications are not available. The Globalstar network provides services that allow users to tie into the internet (packet mode) or public switched telephone networks (asynchronous mode). During testing asynchronous mode was used. A command was used to force the receiver to attempt to connect to a telephone number. The specified maximum-transmit power for the GSP-1720 module is +31 dBm EIRP (Equivalent Isotropically Radiated Power). The module typically consumes 3.65 W at 5V Input during transmit. The receive line from the GSP-1720 was connected to Antcom GAT-17QP antenna, while the transmit line was attenuated and connected to a splitter/combiner and fed into the two GNSS receivers under test.

2.2.4 Globalstar Antenna, Antcom GAT-17QP

This passive antenna manufactured by Antcom has a transmit band of 1610 to 1626.5 MHz and a receive band of 2483.5 to 2500.0 MHz. It has two SMA RF connectors, one each for transmit and receive. For this test, the receive connector was connected via a 5 m RF cable to the receive connector on the Globalstar GSP-1720 transceiver. The GAT-17QP has an average transmit gain at the zenith of +5.7 dBic and -2 dBic at 10 degrees above the horizon and has an average receive gain at the zenith of +5.1 dBic and -2.0 dBic at 10 degrees above the horizon.

2.2.5 GNSS Antenna, NovAtel GPS0702-GGL L1/L2 Antenna

A standard NovAtel GPS-702-GGL GNSS antenna was used as input to the splitter/combiner of the test system and served both GNSS receivers during the test. The GPS-702-GGL is an active antenna with 29 dB LNA Gain. Designed for precise positioning, it has a stable phase centre and gain roll-off from zenith to horizon of 13 dB for GPS L1 and 11 dB for GPS L2.

2.2.6 RF splitter/combiner, Mini-Circuits ZA3PD-2

The RF signals from the GPS-702-GGL GNSS antenna and the Globalstar GSP-1720 transceiver were combined and then split to the NovAtel OEM628 and OEM719 GNSS receivers using an RF splitter/combiner. The GNSS antenna signal had a 5 dB loss across the splitter/combiner to each GNSS receiver connection. The Globalstar signal had a 44 dB loss across the attenuator and splitter/combiner to each GNSS receiver connection, at its 1618 MHz central frequency.

3. RF SIGNALS USED

This test was concerned with the effect Globalstar uplink signals at 1618 MHz would have on the OEM628 and OEM719 GPSL1 (1575.42 MHz) tracking performance.

3.1 GPS L1

The GPS L1 signal was monitored during this test since it is still the most commonly tracked signal. Figure 2 shows the L1 pre-decimation spectrum (red) output from the OEM719

receiver. The GPS L1 signal is centred at 1575.42 MHz and the small bump centred at that frequency represents the combined power of the C/A spread spectrum signals from the GPS satellites. The bright green spectrum lines centred on 1575 MHz is the post-decimation spectrum plot for GPS L1 only. The two green vertical lines at 1610 to 1619 MHz show the minimum and maximum licenced frequencies respectively for the Globalstar uplink.

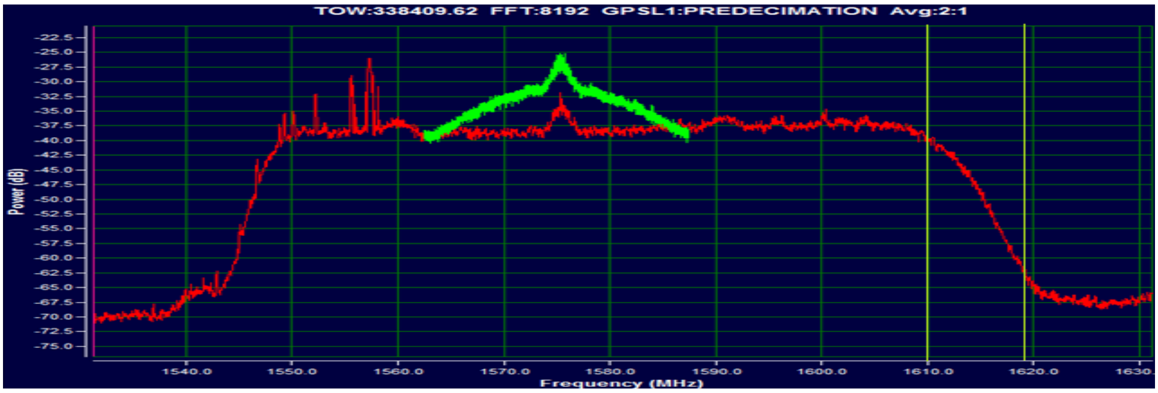

Figure 2. OEM719 L1 Spectrum from the Interference Toolkit – Pre-Decimation and GPSL1 Post-Decimation

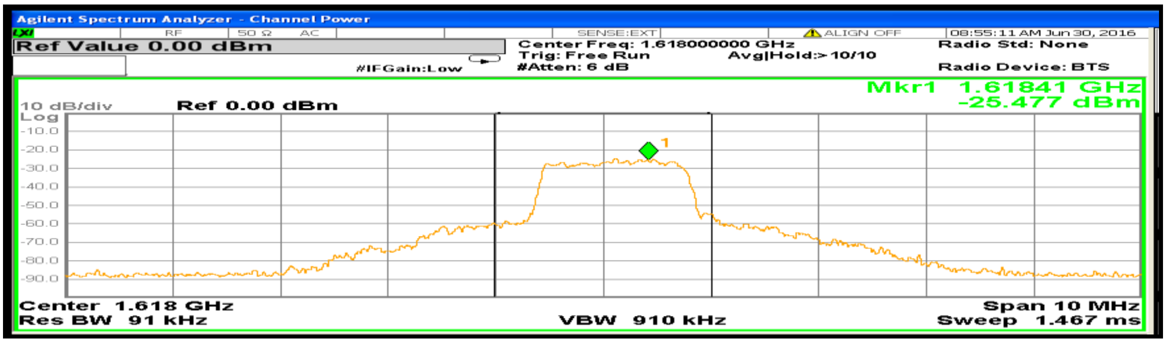

Figure 3. Power Spectral Density of Globalstar Test Signal – 1618 MHz

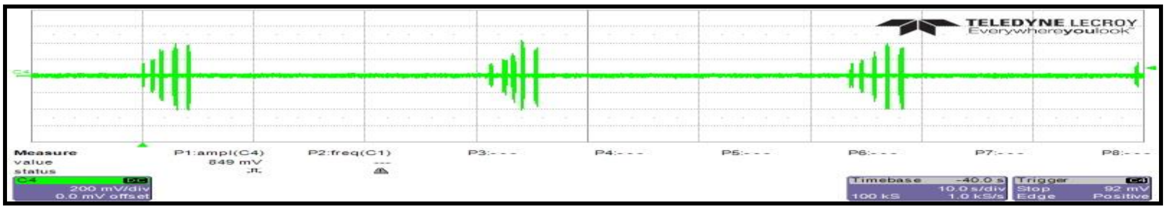

Figure 4. Globalstar Test Signal – Signal Pulses while trying to link to satellite

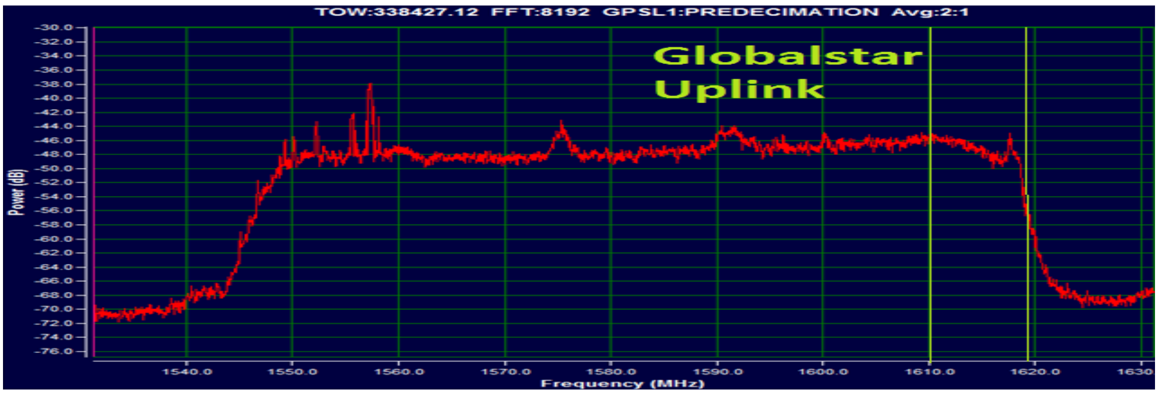

Figure 5. Globalstar effect on OEM719 L1 Band at 1618 MHz

3.2 Globalstar

Globalstar is a service offering satellite low-rate data and voice communications using a network of Low Earth Orbit (LEO) satellites. The telephone service is useful for remote locations without cellular service, while the two way data service is widely used for commercial facility control and remote data transmission. A series of emergency locators and handheld satellite messaging products are also offered on the consumer market. Current licensed bands in North America include the uplink channel (1610 to 1618.725 MHz – 8.725 MHz band), for modem/handset to Satellite, and the downlink channel (2483.5 to 2500 MHz – 16.5 MHz band).

The uplink band sits near the upper L1 pass band of the NovAtel OEM628 and OEM719 GNSS receivers. The Globalstar signal power was measured at the output to the OEM719 of the splitter/combiner using a spectrum analyzer. An average channel power over 2 MHz at 1618 MHz is -15.8 dBm, and the power spectral density is -78.8 dBm/Hz (Figure 3).

Figure 4 shows the pulsed nature of the Globalstar transmissions as the GSP-1720 transceiver attempts to communicate with the Globalstar satellites. The transceiver would attempt to communicate approximately every 30 seconds, but of course could not establish a link since the signal was being injected into the GNSS test receivers and not out the antenna.

The effect of the Globalstar transmissions on the OEM719 L1 spectrum can be seen in Figure 5. The peak power in the Globalstar band (green lines) is -44.6 dB at 1617.6 MHz and the power at 1610 MHz is -45.8 dB for power increase of 0.8 dB from 1610 to 1617.6 MHz. Normally, when the Globalstar is not transmitting, the power drop over this frequency range is 18.5 dB.

4. INTERFERENCE MITIGATION METHODS

Several hardware and digital interference mitigation methods are available to mitigate out of band interference. The cavity filter can be configured as a bandpass filter and is very effective at attenuating signals outside of its passband. Digital filters available on the OEM719 include notch filters and bandpass. Additionally the receiver can be put into HDR mode where the receiver applies a halfband decimation filter and operates with enhanced gain settings.

4.1 Hardware Cavity Filter

The K&L cavity filter shown in Figure 6 was used during this test along with the OEM628 GNSS receiver. It has a single 42.4 MHz wide passband from 1553.39 MHz to 1595.81 MHz. The centre frequency cavity filter is 1574.60 MHz, which is close to the GPSL1 centre frequency of 1575.42 MHz. When it was not being used, a simple barrel RT adapter was attached between the two RF cables.

The filter response for the cavity filter is shown in Figure 7. There is a 77 dB drop from the passband to the measurement floor (-80 dB) over 65 MHz. There is a 2 dB loss across the input and output connectors of the cavity filter.

4.2 Software High Dynamic Range (HDR) Mode

The High Dynamic Range (HDR) mode on-board the OEM7 receivers is designed to improve robustness under in-band and out of band interference. HDR mode is a combination of receiver settings, including configuring the RF front-end for better linearity, redistributing gain across multiple stages within the signal processing chain and adjusting which bits of the high resolution ADCs on board the OEM7 are utilized (Gao and Kennedy, 2016). The cost of the improved robustness to interference provided by HDR mode is increased power consumption.

Figure 6. K&L GPSL1 Cavity Filter

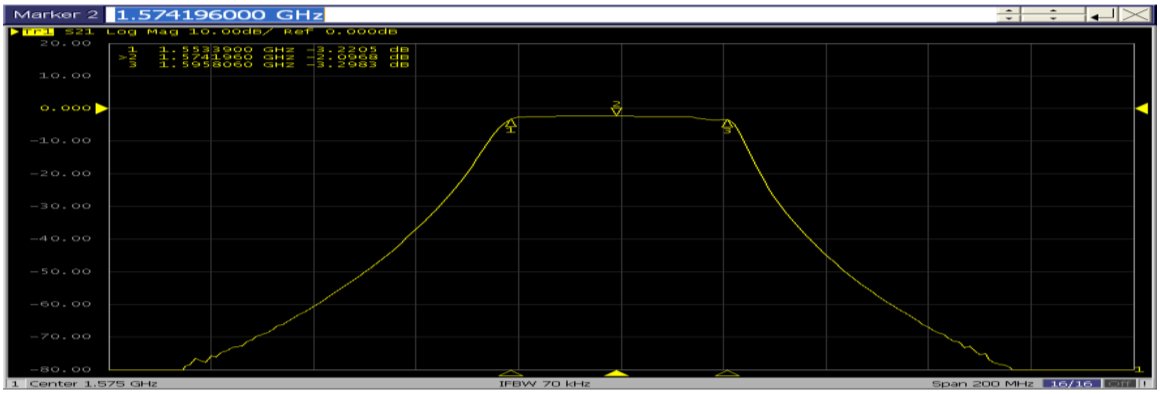

Figure 7. K&L GPSL1 Cavity Filter Filter Response

5. TEST RESULTS

Several test metrics were selected to study the effect of the Globalstar transmission on the NovAtel OEM628 and OEM719 GNSS receivers and the effectiveness of the mitigation techniques.

5.1 Performance Indicators

Various NovAtel format receiver output messages were used to compute the following performance indicators:

5.1.1 Lock breaks and Loss of Lock

A lock break occurs when a GPS L1/CA observation has a reset in lock-time and a loss of lock is counted when a GPSL1 C/A observation is expected but absent from the observation.

5.1.2 Average C/N$_0$

This is an average of the carrier to noise values for all of the GPS L1 C/A observations.

Average C/N_0 is in dB-Hz. A large jump in C/N_0 can be a result of a change in signal power or the noise floor. Often it is a result of the sudden loss or gain of one or more satellites, especially satellites near the horizon, where C/N_0 values are lower due to the 11 dB antenna gain difference between zenith and horizon.

5.1.3 Number of GPS L1 Signals Tracked

This is the number of GPS L1 C/A observations (satellite signals) actively tracked by the receiver.

5.1.4 Horizontal position and height

The position analysis is based on UTM northing and easting values along with the orthometric height (above mean sea-level). All values are in metres and differences between the positions for the OEM628 and OEM719 indicates one receiver is mitigating the interference better than the other. Normally over the 30 minute tests, there should not be more than 1 to 2 metres variation for the single point positions and 2 to 3 metres for the heights. Large variations are usually indicative of tracking difficulties caused by the interference.

5.2 Processing Methodology

Data was processed with a 10 degree elevation cut-off, meaning that no GPS L1 data below 10 degrees elevation was used in the processing. Since the data was collected with a clear view of the sky above 5 degrees elevation, any loss of satellites or significant degradation of signal quality should be a result of the interference. Some degradation (minimal) of signal quality may be due to multipath from rooftop structures and the adjacent buildings.

5.3 GPSL1, No Interferer, No Mitigation

As a baseline, the first test was conducted without the Globalstar interferer and without any mitigation methods on either receiver. Figure 8 shows the spectrum plot for L1 from the OEM719 during the test. The spikes between 1550 and 1560 MHz are L-Band signal always present at the test location. The small bump at 1575.43 is a result of the C/A code from the GPS satellites and there is some noise/signals present in the GLONASS L1 band around 1600 MHz. This plot is typical of the RF noise conditions seen at the test location and shows a relatively benign environment.

The tracking statistics are given in Table 1. One lock break occurred on both receivers when PRN28 went below the tracking elevation cut-off angle. The average C/N_0 is about 2.2 dB higher for the OEM719, but standard deviations are similar. Figure 9 shows the average C/N_0 for both receivers versus GPS time of week. The step-like plot features are a result of PRN28 falling below the 10 degree mask angle, followed a few minutes later by PRN25 rising above it. The number of GPS L1 signals tracked by both receivers is identical as shown in Figure 10 and in Table 1.

Reviewing the horizontal position plot in Figure 11 and the position statistics in Table 2 shows that the single-point positions for both receivers are very similar during the 0.5 hour test. Mean positions are within 1.0 cm of each other. Their standard deviations and min-max

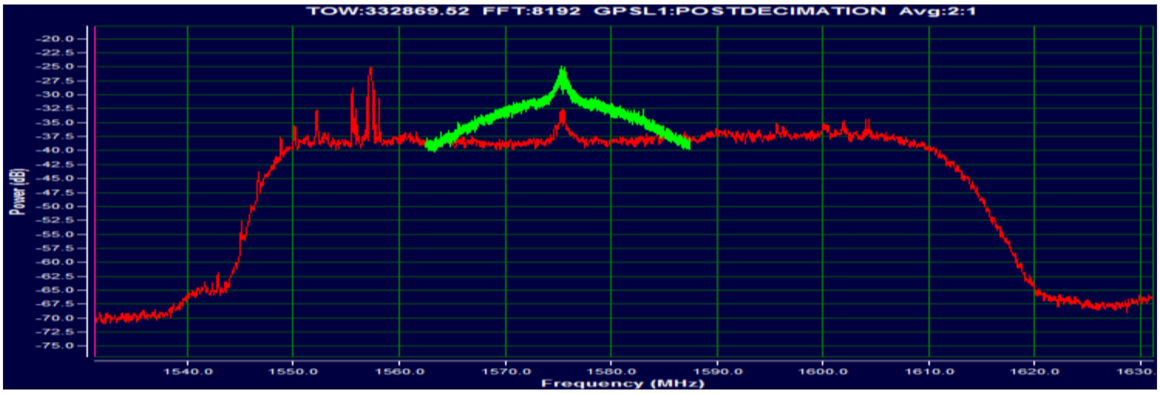

Figure 8. OEM719 Interference Toolkit L1 predecimation spectrum (red) and GPSL1 post decimation spectrum (green) – no interferer and no mitigation

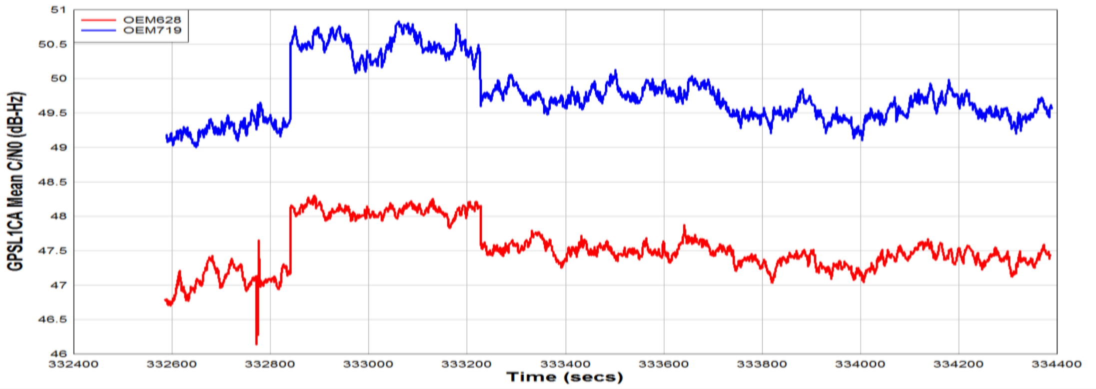

Figure 9. GPSL1 average C/N_0 for test receivers – no interferer and no mitigation

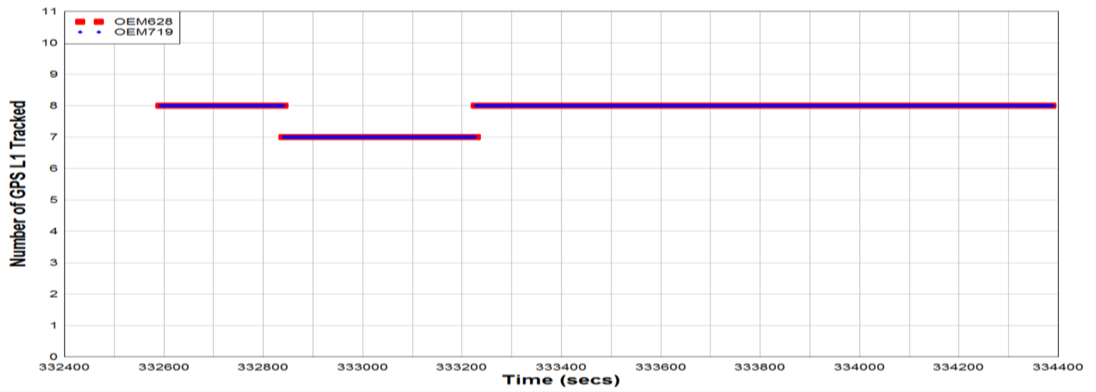

Figure 10. Number of GPSL1 satellites tracked – no interferer and no mitigation

	OEM628				OEM719			
	Lock Breaks	Loss of Lock	Avg C/N_0 (dB-Hz)	# GPS SVs	Lock Breaks	Loss of Lock	Avg C/N_0 (dB-Hz)	# GPS SVs
Count	0	1			0	1		
Min			46.14	7			49.00	7
Max			48.31	8			50.84	8
Mean			47.53	7.78			49.77	7.78
StDev			0.35	0.41			0.43	0.41
Range			2.17	1			1.84	1

Table 1. Tracking statistics – no interferer and no mitigation

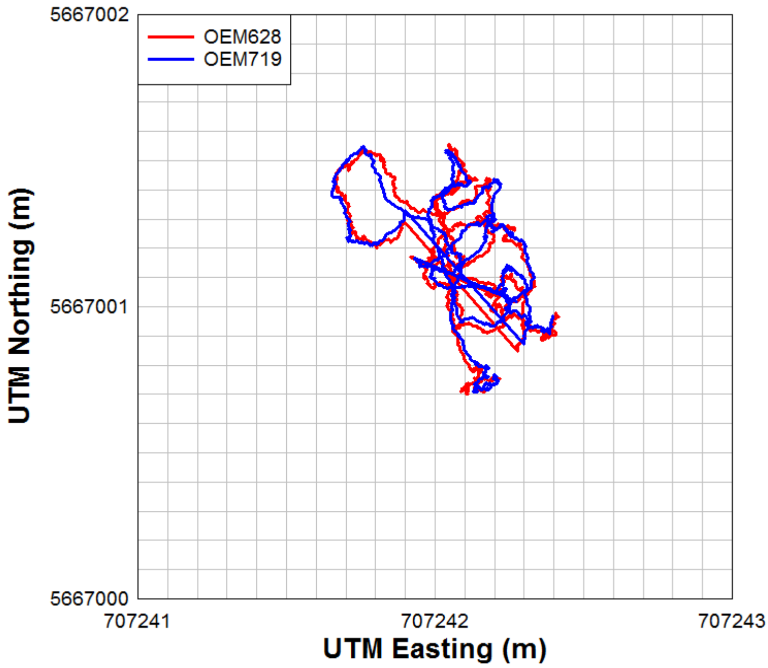

Figure 11. Test receivers UTM positions – no interferer and no mitigation

	OEM628			OEM719		
	Northing (m)	Easting (m)	Height (m)	Northing (m)	Easting (m)	Height (m)
Count	1800	1800	1800	1800	1800	1800
Min	5667000.700	707241.662	1062.808	5667000.707	707241.651	1062.820
Max	5667001.550	707242.432	1065.987	5667001.547	707242.402	1065.905
Mean	5667001.160	707242.087	1064.783	5667001.159	707242.091	1064.797
StDev	0.224	0.169	0.896	0.219	0.176	0.894
Range	0.853	0.770	3.179	0.840	0.750	3.085

Table 2. Positioning statistics – no interferer and no mitigation

range values are very close. These statistics reveal that both receivers perform similarly under the conditions without an interferer present.

5.4 GPSL1, Globalstar Interferer, No Mitigation

The second test conducted was with the Globalstar transceiver transmitting while attempting an uplink. Neither GNSS receiver had any interference mitigation measures enabled. The presence of the Globalstar signal can be seen in Figure 12. On the pre-decimation curve the main signal can be seen at 1618 MHz, while harmonics can be seen at 1591 MHz on the pre-decimation (red) curve and at 1568 MHz on the post-decimation (green) curve.

The tracking statistics are given in Table 3. During this 1800 second test, over 467 losses of lock are observed on the OEM628 while the OEM719 experiences 42 lock breaks and 162 losses of lock. The average C/N_0 are similar to that seen with no Globalstar, however the range values are larger as seen in Figure 13 and Table 3. A sharp fluctuation in average C/N_0 occurs each time the Globalstar transmits. The number of GPS L1 signals tracked by the receivers ranged from 8 to 0 while the Globalstar is broadcasting, as seen in Figure 14. It also shows during the first half of the test, the OEM719 did not drop below 2 satellites tracked, while the OEM628 dropped to 0 on many occasions. During the second half of the test, both

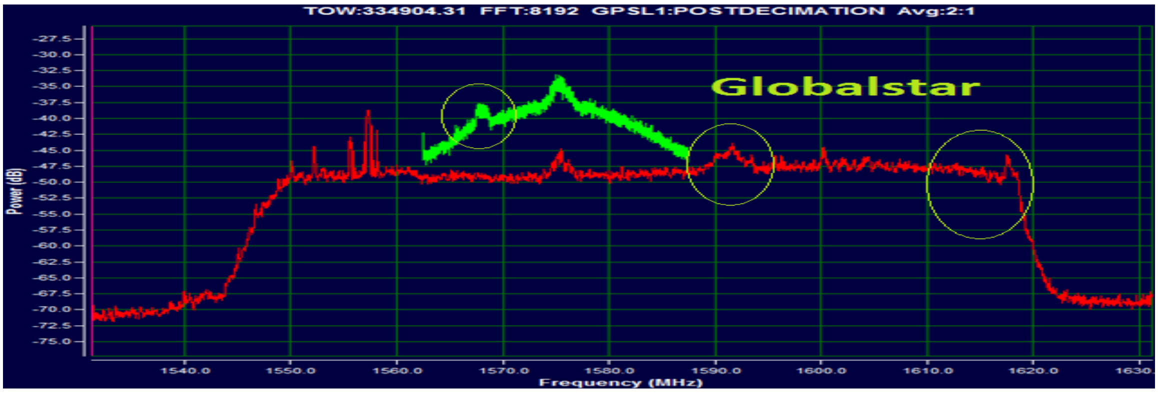

Figure 12. OEM719 Interference Toolkit L1 predecimation spectrum (red) and GPSL1 post decimation spectrum (green) – Globalstar interferer and no mitigation

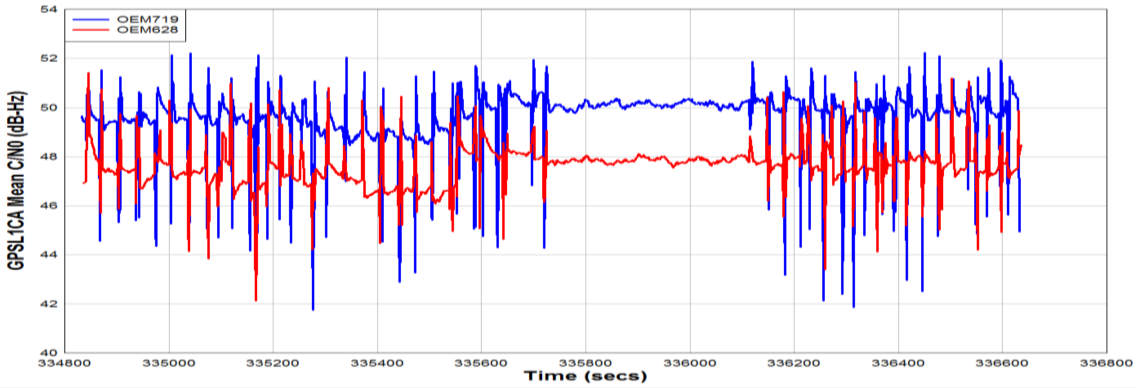

Figure 13. GPSL1 average C/N_0 for test receivers – Globalstar interferer and no mitigation

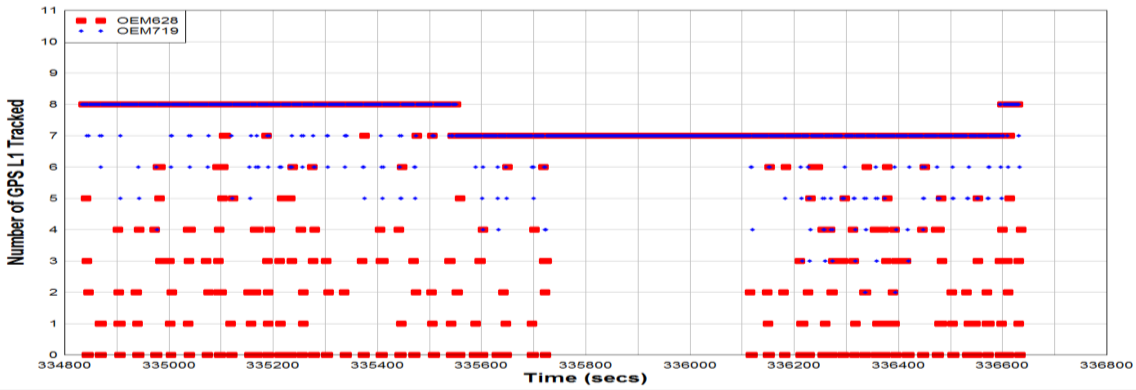

Figure 14. Number of GPSL1 satellites tracked – Globalstar interferer and no mitigation

	OEM628				OEM719			
	Lock Breaks	Loss of Lock	Avg C/N_0 (dB-Hz)	# GPS SVs	Lock Breaks	Loss of Lock	Avg C/N_0 (dB-Hz)	# GPS SVs
Count	1	467			42	162		
Min			42.13	0			41.74	2
Max			51.41	8			52.22	8
Mean			47.57	6.20			49.58	7.23
StDev			0.77	2.57			1.26	0.80
Range			9.28	8			10.48	6

Table 3. Tracking statistics – Globalstar interferer and no mitigation

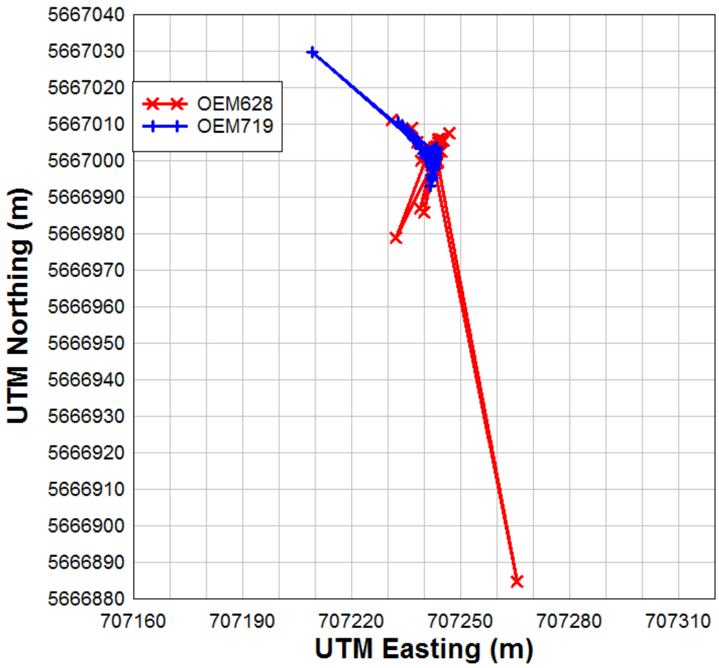

Figure 15. Test receivers UTM positions – Globalstar interferer and no mitigation

	OEM628			OEM719		
	Northing (m)	Easting (m)	Height (m)	Northing (m)	Easting (m)	Height (m)
Count	1800	1800	1800	1800	1800	1800
Min	5666884.589	707231.065	1036.726	5666993.002	707209.073	1038.249
Max	5667011.083	707265.453	1267.125	5667029.666	707243.424	1070.904
Mean	5666999.899	707242.441	1063.391	5666999.956	707242.317	1063.456
StDev	3.364	1.164	5.783	1.420	1.155	1.242
Range	126.494	34.388	230.399	36.663	34.350	32.655

Table 4. Positioning statistics – Globalstar interferer and no mitigation

receivers consistently lost most or all of their satellites during the Globalstar broadcasts. A closer examination reveals that the OEM628 typically lost more satellites during the interference that than the OEM719, which did not fall below 2 satellites tracked.

The horizontal position results are shown in Figure 15. Overall results are worse than without interference. The OEM628 has the largest position jump of about 130 metres. The position statistics in Table 4 show the effects of the larger position variations during the test. The height min-max range is 231 m versus 3 m without interference.

5.5 GPSL1, Globalstar Interferer, With Mitigation

The final test conducted used the K&L cavity filter between the OEM628 and antenna to attenuate the Globalstar signal while the OEM719 was put into HDR mode. Figure 16 shows the L1 spectrum while in HDR mode during a Globalstar broadcast. The red line is the pre-decimation view. No post-decimation view was generated during this test.

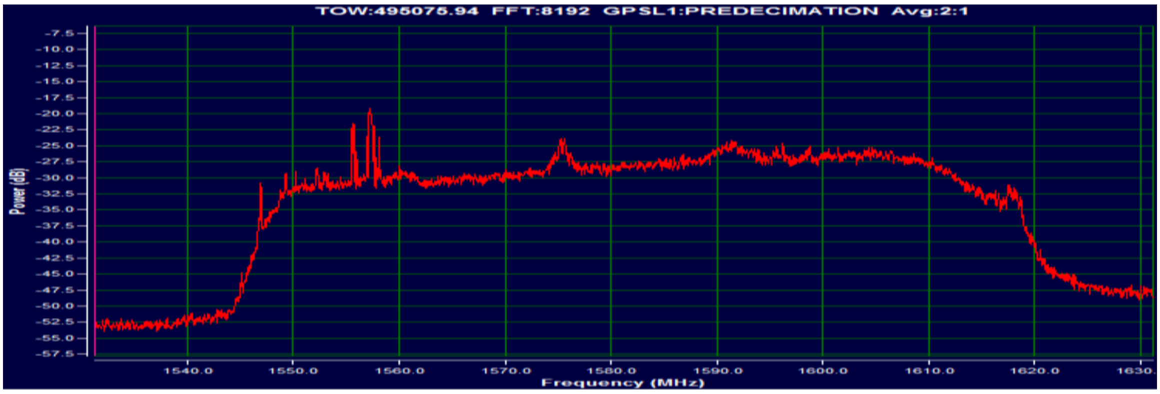

Figure 16. OEM719 Interference Toolkit L1 predecimation spectrum – Globalstar interferer with mitigation

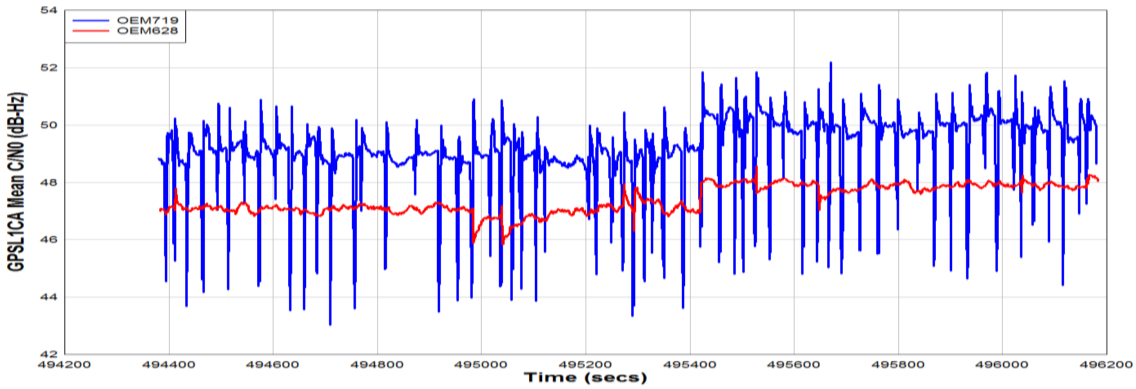

Figure 17. GPSL1 average C/N_0 for test receivers – Globalstar interferer with mitigation

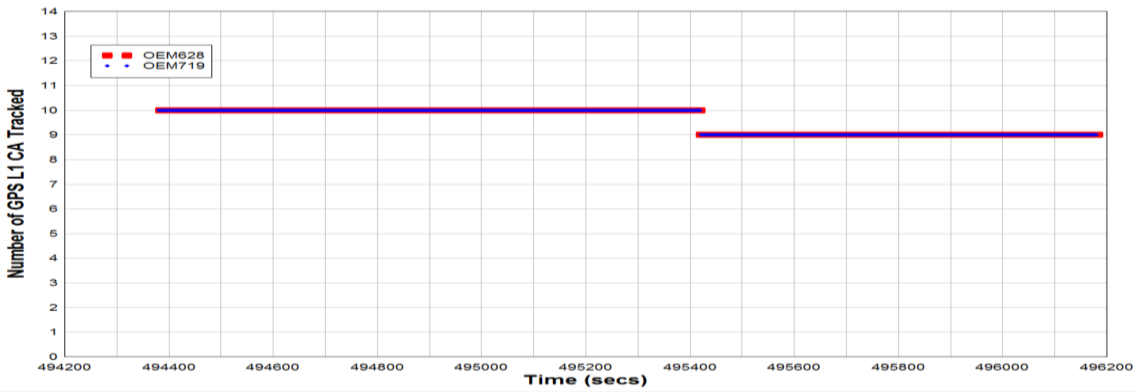

Figure 18. Number of GPSL1 satellites tracked – Globalstar interferer with mitigation

	OEM628				OEM719			
	Lock Breaks	Loss of Lock	Avg C/N_0 (dB-Hz)	# GPS SVs	Lock Breaks	Loss of Lock	Avg C/N_0 (dB-Hz)	# GPS SVs
Count	0	1			0	1		
Min			45.83	9			43.03	9
Max			48.57	10			52.20	10
Mean			47.39	9.58			49.16	9.58
StDev			0.48	0.49			1.31	0.49
Range			2.74	1			9.17	1

Table 5. Tracking statistics – Globalstar interferer with mitigation

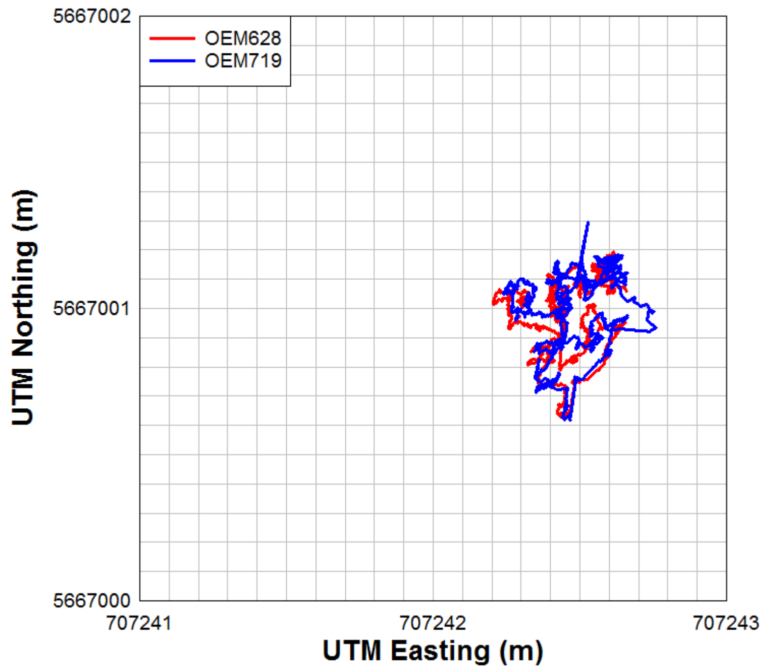

Figure 19. Test receivers UTM positions – Globalstar interferer with mitigation

	OEM628			OEM719		
	Northing (m)	Easting (m)	Height (m)	Northing (m)	Easting (m)	Height (m)
Count	1800	1800	1800	1800	1800	1800
Min	5667000.628	707242.205	1062.359	5667000.616	707242.239	1062.262
Max	5667001.193	707242.665	1063.642	5667001.296	707242.761	1063.493
Mean	5667000.977	707242.459	1062.910	5667000.989	707242.477	1062.890
StDev	0.122	0.113	0.291	0.129	0.114	0.260
Range	0.566	0.460	1.283	0.679	0.522	1.231

Table 6. Positioning statistics – Globalstar interferer with mitigation

The tracking statistics are shown in Table 5, and graphically in Figure 17 and Figure 18. During the 1800 second test, both the OEM628 and OEM719 only experienced one loss of lock. This occurred when GPS PRN8 dropped below the tracking elevation cut-off. The C/N_0 values reflect the different nature of the mitigation methods, with the cavity filter working before the RF reaches the receiver, while the HDR mode works after the initial RF filtering on the receiver during and after the analogue to digital converter. Larger min-max range values in C/N_0 are seen in the OEM719 over those in the OEM628.

The horizontal position results are shown in Figure 19 and the statistics are given in Table 6. The positioning results for the OEM628 with the cavity filter and the OEM719 in HDR mode are very similar, with the average positions and heights with 2 cm of each other. Range values and standard deviations are also very close. Overall the HDR mode on the OEM719 did provide satisfactory single-point position results, and if the receivers were using phase observations in RTK, both would have performed well.

6. CONCLUSIONS

The series of tests confirm the OEM628 and OEM719 have very similar performance when no interference is present, as well as when the Globalstar interferer was present and they had no mitigation in place. The testing presented shows that HDR mode is as effective as a cavity filter at mitigating the effects of a large out of band interference source such as the Globalstar interferer. Although the testing was conducted using an OEM719 receiver, the same performance is expected on the OEM729 and OEM7700 receivers as this capability lies in the architecture of the OEM7 product family.

For applications that are size and weight constrained, HDR mode is the superior mitigation solution because it adds no additional components to the system. It also has the added benefit of preserving access to all GNSS frequencies and constellations. If a cavity filter is used, the user is restricted to only GNSS signals within the narrow pass band of that cavity filter, which does protect against interference but will also prevent use of other signals like BeiDou B1 and GLONASS L1.

The mitigation features of OEM7 allow the user to maintain the solution availability advantages provided by multi-constellation and multi-frequency support, while also protecting themselves from interference threats.

ACKNOWLEDGEMENTS

The authors would like to thank Neil Gerein, Sandy Kennedy, and Tina Mosstajiri of NovAtel for their contribution to this paper.

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