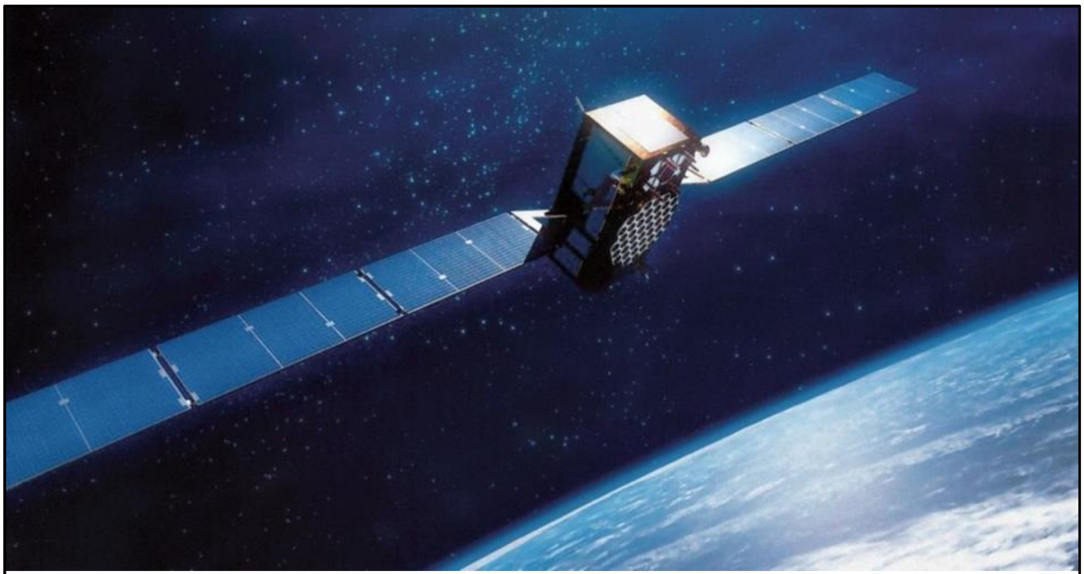

NovAtel OEM7 Interference Toolkit

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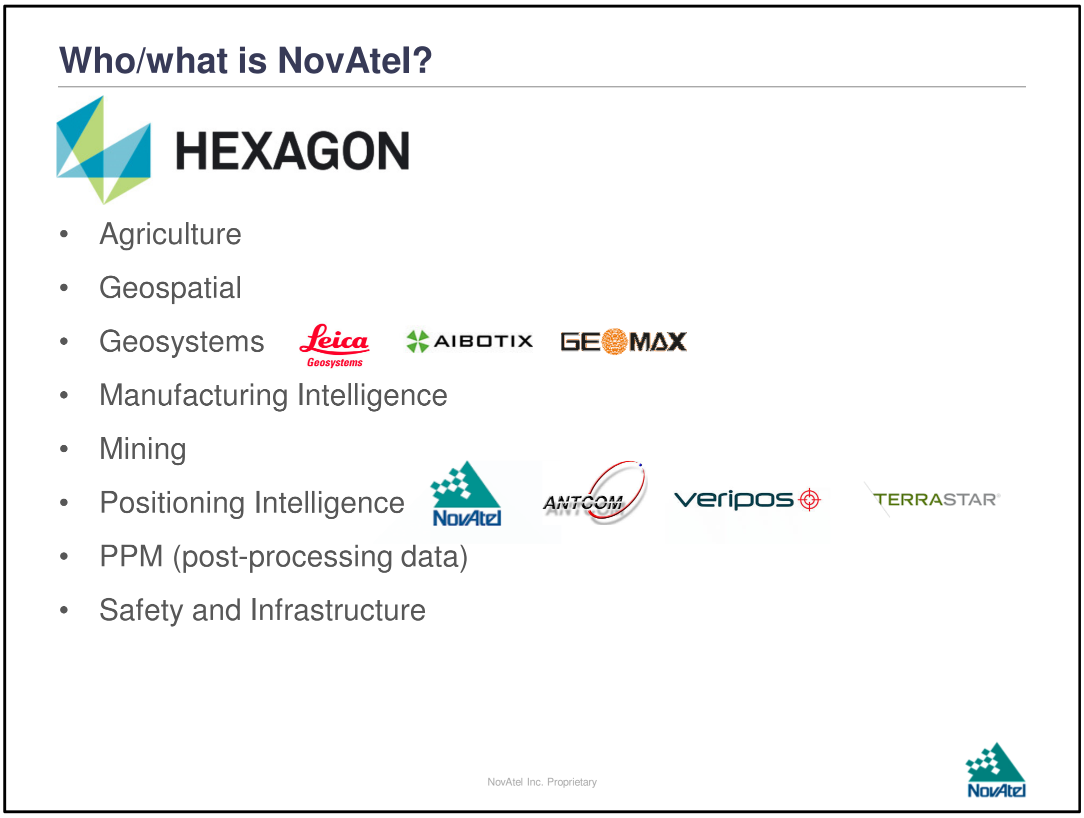


Leica – Optical instruments, Survey-grade GNSS + base stations (SmartNet)
Aibotix – UAVs
Geomax – Total Stations, Laser scanners, Survey-grade GNSS
NovAtel – GNSS receiver boards (also used in Leica GNSS equipment)
Antcom – GNSS antennae
Veripos – PPP DGNSS provider, mainly for the offshore industry. Correction signals are broadcast in the L-band frequency range using 7 geostationary satellites
Terrastar – PPP DGNSS provider, aimed at land-based non-oil and gas markets. Uses the Veripos signals and satellites.

Contents

- What exactly is the NovAtel Interference Toolkit (ITK)?
- Features of the ITK
- Limitations of the ITK
- Under which conditions can the ITK best be used?

OEM7 Multi-GNSS Receivers

NovAtel Interference Toolkit

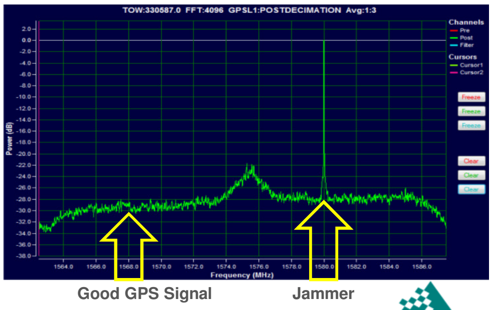
Built-in feature of every OEM7® based GNSS receiver

Spectrum-analyzer functionality

- Check the presence of interference signals and determine whether these signals are a threat to your operations
- Use digital notch filters and bandpass filters
- Using data of multiple receivers, jammers can be geolocated

High Dynamic Range (HDR) mode (to be selected manually)

- Modified settings of the Automatic Gain Control (AGC), for improved performance in the presence of a strong interference signal



The NovAtel Interference Toolkit is a default (built-in) part of the OEM7 firmware. It is enabled by default, so you don't have to buy extra option codes to enable it.
HDR mode changes the way the Automatic Gain Control (AGC) of the receiver handles incoming signals. When HDR is not selected, the AGC will do a linear scaling of the incoming signals so the strongest incoming signal can be correctly digitized. With HDR mode enabled, the AGC will use non-linear scaling of the incoming signals, which favours the weaker incoming signals. As a result, the stronger signals will be "compressed" and the weaker signals will be boosted.

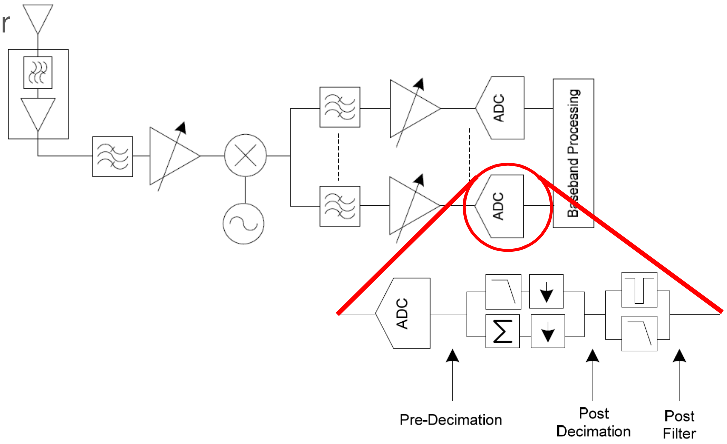
Features of the Interference Toolkit

- Signal analysis and filtering of the digitized signals, prior to the actual signal processing
- Automatic detection of interference signals in all GNSS frequency bands
- Identification and characterization of the interference signals
- The spectrum analyser function provides a quick (visual) overview of the presence of interference signals in a GNSS frequency band
- Applying bandpass and/or notch filters to (partially) filter out interference signals (receiver model dependent).
- Spectrum analyser data are output and can be logged in real-time. These data can be used for a visual presentation of the selected GNSS frequency band using either a NovAtel PC application or an application written by the user.

The automatic spectrum analysis function is running continuously on any OEM7 receiver to monitor the environment, even when the specific spectrum analysis logs are not being requested by the user. When an interference signal is detected, the receiver will toggle a status flag. For now, the receiver will not automatically apply filtering to mitigate an interference source.
The spectrum analysis output of the receiver allows the user to identify certain characteristics of the interference signal, such as frequency, bandwidth and whether the interfering signal is a CW signal or hopping through the GNSS bands. Narrow-band CW signals can best be filtered out using a notch filter, wide-band signals or frequency-hopping interferers can best be filtered out using a bandpass filter.

Features of the Interference Toolkit

- The spectrum analyzer data provides the output of different stages of the signal processing chain:
  - Pre-decimation (“raw” output of the A/D converter)
  - Post Decimation (“raw” output of the FFT process)
  - Post Filter



The Interference Toolkit, or ITK for short, is a digital filter that sits in-between the digitization of the RF/IF signals and the baseband processing of the digitized signals. The functionality is included in every OEM7-based receiver board, but the active filtering needs to be enabled using an authorization code. The spectrum analysis logs provide the outputs of different stages of the signal processing chain: pre-decimation - the signals coming directly from the ADC -, post-decimation and lastly post-filter. When a filter is not applied, post-decimation and post-filter will show the same results. Comparing the outputs of the different stages allows the user to see the effectiveness of the filtering applied to the signals.

Limitations of the Interference Toolkit

- No protection agains spoofing attacks
- Interference can be detected all across a specific frequency band, but it is not possible to configure a filter in such a way that it will (also) filter out the actual GNSS frequency
- Filtering is symmetrical around the center frequency of a GNSS band, so a filter set to a frequency $f_c + \omega$ will also filter at frequency $f_c - \omega$ (result of the FFT process)
- Filters cannot be cascaded in one frequency band, but it is possible to apply one filter in one frequency band and a different filter in another frequency band
- Fully automatic detection and filtering of interference signals is not yet possible, but it is expected in the near future

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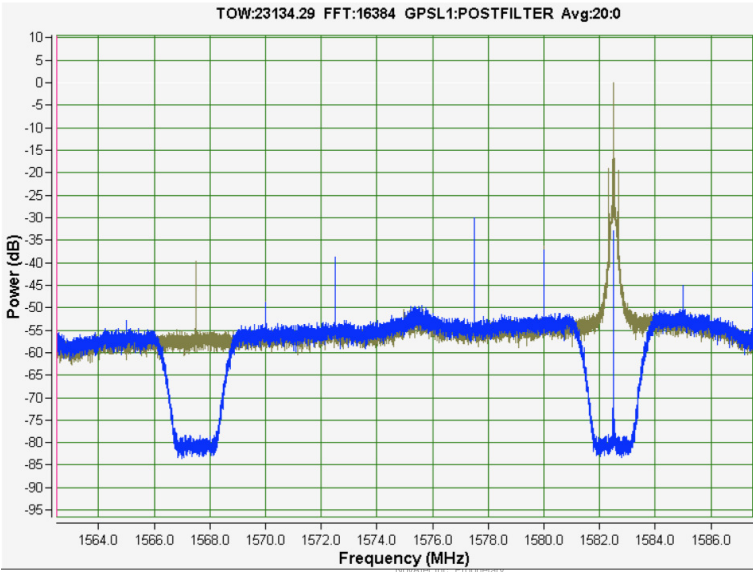
The spectrum analysis data are covering all of the GNSS bands “allowed” by the receiver model. When a filter is applied, the frequencies of the actual GNSS signals are protected by not allowing the filter settings to filter out any of the actual GNSS frequencies. If this protection had not been implemented, it would have been possible to (accidentally) filter out the signals needed for the actual positioning.

Whenever a filter is applied, its filter characteristics will be symmetrical around the center frequency, a result of the digital processing of the signals. This will be clearly visible when a notch filter is applied to filter out interference at a specific frequency fc + ω. This will also apply a notch filter on the frequency fc - ω. Bandpass filters will show a passband between fc-ω and fc+ω.

It is not possible to cascade a bandpass filter and a notch filter in one single frequency band. It is possible to apply a bandpass filter to one frequency band and a notch filter to a different frequency band. It is not possible to have more than one bandpass filter or more than one notch filter active at a time.

Examples (Notch filter)

- GPS L1 (fc = 1575.42 MHz), interference signal at 1582.5 MHz
- Notch filter at 1582.500 MHz, 0.5 MHz bandwidth



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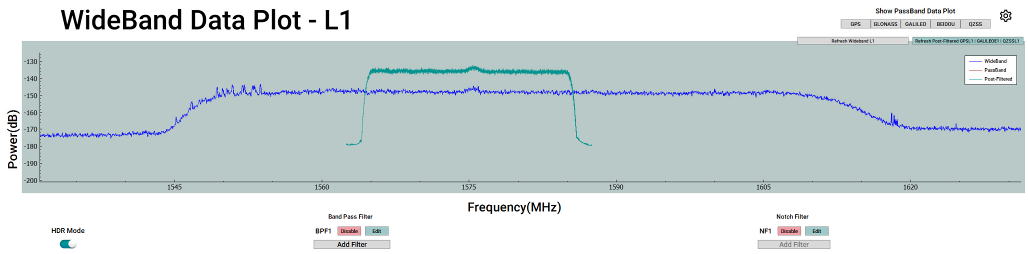
The green line shows the post-decimation signal, in which an in-band interference signal 50 dB stronger than the GPS L1 signal is clearly visible. The blue line shows the resulting spectrum after applying a notch filter at the frequency of the interferer. The interferer is still visible in the resulting plot, but it is now only 15 dB stronger than the GPS L1 signal. Since this is a relatively narrow interference signal sufficiently far away from the GPS L1 frequency, the GNSS receiver will be able to process the incoming signals without suffering from the mitigated interference signal.

Examples (Bandpass filter)

- GPS L1 (f_c = 1575.420 MHz), 16k FFT, 2 seconds time averaging
- Banddpass filter configured with a high cut-off frequency of 1586 MHz = f_c + 10.58 MHz. The low cut-off frequency will automatically be set to f_c - 10.58 MHz = 1564.84 MHz



Applications and expected results

The Interference Toolkit can be used to filter out or mitigate the effects of the following types of interference signals:

- Small bandwidth in-band interference signals
  examples: processor clock, VHF/3GPP [LTE 5G] harmonic signals

		In-band CW	
		Before	**After**
SV tracked	**Avg.**	6.3	11.5
C/No (Db-Hz)	**Avg.**	32.8	44.7
	Std. Dev.	0.8	0.4
RTK	**Avg.**	0.029	0.008
3D Position Error	**Std. Dev.**	0.028	0.003
(m)	**Max.**	0.235	0.017
Pseudorange	**Avg.**	2.52	1.16
3D Position Error	**Std. Dev.**	1.35	0.27
(m)	**Max.**	20.46	2.19

As long as the interfering signal is not covering the center frequency of a specific GNSS band, the Interference Toolkit can be used to filter out or at least mitigate the effects of the interfering signal.

Applications and expected results

The Interference Toolkit can be used to filter out or mitigate the effects of the following types of interference signals:

- Near-band (small bandwidth) interference signals
  example: Globalstar CDMA2000 satellite-telephony handsets

		Near-band	
		Before	**After**
SV tracked	**Avg.**	5.7	9.7
C/No (Db-Hz)	**Avg.**	33.7	37.4
	Std. Dev.	0.8	0.3
RTK	**Avg.**	0.221	0.008
3D Position Error	**Std. Dev.**	0.171	0.004
(m)	**Max.**	0.508	0.025
Pseudorange	**Avg.**	2.24	1.62
3D Position Error	**Std. Dev.**	2.92	0.24
(m)	**Max.**	60.93	2.19

As long as the interfering signal is not covering the center frequency of a specific GNSS band, the Interference Toolkit can be used to filter out or at least mitigate the effects of the interfering signal.

Applications and expected results

The Interference Toolkit can be used to filter out or mitigate the effects of the following types of interference signals:

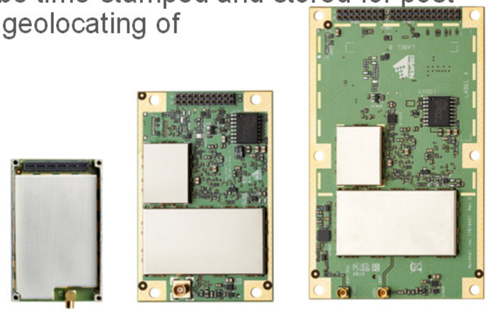
- Wide-band out-of-band interference signals
  example: 4G/4G+ transmitters

		Out-of-band (wide)	
		Before	After
SV tracked	**Avg.**	3.0	9.8
C/No (Db-Hz)	**Avg.**	32.0	43.3
	Std. Dev.	0.8	0.4
RTK	**Avg.**	N/A	0.007
3D Position Error	**Std. Dev.**	N/A	0.002
(m)	**Max.**	N/A	0.025
Pseudorange	**Avg.**	N/A	0.89
3D Position Error	**Std. Dev.**	N/A	0.20
(m)	**Max.**	N/A	1.56

As long as the interfering signal is not covering the center frequency of a specific GNSS band, the Interference Toolkit can be used to filter out or at least mitigate the effects of the interfering signal.

Interference will always be a problem for GNSS users

- NovAtel OEM7® receivers provide the means to detect and filter/mitigate interference signals
- Raw spectrum analysis data can be time-stamped and stored for post-processing, which will enable the geolocating of jammers/interferers



- Wide-band in-band interferers or interferers/jammers (also) covering the central frequency of a GNSS frequency band can not be fully filtered out or mitigated using the Interference Toolkit.
- In cases like this, the **GAJT anti-jam antenna** may be a better option to filter out the interference signals.

GAJT anti-jam antenna

- 4-elements or 7-elements CRPA
  (Controlled Radiation Pattern Antenna)
- Antenna with built-in signal processor
- Null-steering antenna: 3 to 6 interference sources can be filtered out simultaneously through dynamical adjustment of the reception pattern characteristics of the antenne
- Fully automatic detection and filtering
- Only GPS L1/L2, no other GNSS systems, no other frequency bands
- 50-150 ns time delay caused by the signal processing

The GAJT (pronounced: gadget) anti-jam antenna will automatically detect and filter out 3 to 6 simultaneous interference sources, depending on the exact GAJT model.
The GAJT is designed for only the GPS L1+L2 bands, so even if the connected receiver is capable of handling other systems/frequency bands, it will only get the GPS L1+L2 signals from the GAJT antenna.
The time delay caused by the signal processing of the GAJT makes the GAJT less suitable for precise timing solutions.