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SENSORS I SESSION

Location, Location, Location – Antenna Installation

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VERIPOS

ABSTRACT

To ensure optimal performance of the positioning system, a suitable antenna needs to be chosen and installed in an un-obstructed location to provide clear visibility of the sky. By the time the signals arrive at the vessel antenna they are weak which makes them susceptible to interference, whether intentional or un-intentional, so again location of the antenna is important as is the choice of an appropriate antenna.

This paper will examine the factors that should be considered for installing any antenna associated with a positioning system. It not only considers the physical location to prevent blockage or interference but addresses other areas that can often be overlooked but which can have implications on the installation and performance of the system. Examples include cable type and length of cable run, lighting protection and even the selection of the most appropriate antenna.

An overview of antenna design will be presented to highlight some of the issues that are faced when using multi-constellation GNSS or combined GNSS/L-band antennas which can impact system performance through multipath, signal to noise or interference.

Another topic covered is that of GNSS interference which is something that is gaining more press coverage with stories about the availability of low-cost jammers and wireless broadband networks and the impact on GPS. It will consider un-intentional and intentional interference in the offshore environment using real-world case studies to highlight the impact on positioning and how a systematic approach was used to identify the source of interference.

The paper will look at some of the research and development being conducted into the field of antenna and receiver design to help protect GNSS receivers from interference. Finally, consideration of multi-antenna systems and additional sensors may help mitigate any potential issues to provide the user with a reliable position will be examined.

INTRODUCTION

Essential to the optimal operation of any GNSS and augmentation system is the selection and correct installation of antennas used to receive the GNSS and L-band signals. By the time the radio signals broadcast from the satellites reach the antenna, they are very weak, so having the right antenna for reception of these signals is important.

This paper will look at some of the factors that need to be considered in the design and selection of a good GNSS antenna. It will then go on to look at the physical installation onboard a vessel and different aspects that need to be taken into account. The topic of interference will be examined and a real-world example of an issue experienced onboard a vessel along with how the fault was discovered is included. Finally, a brief look at the future of antenna design is examined.

GNSS ANTENNA DESIGN

Crucial to receiving the satellite radio signals is a good antenna, so it is important to consider several factors in the selection of an appropriate antenna. It is worth highlighting that many aspects of antenna design are inter-dependent and by changing one area of the design can directly impact on another area.

Frequency Coverage

The bandwidth of antenna needs to cover the appropriate frequencies for the GNSS signals to be used. It may also need to cover the L-band frequencies used for commercial augmentation services if a combined antenna is used. When an antenna has to cover a wider bandwidth it becomes more complicated to design and to meet all requirements including performance.

Gain Pattern
An important factor that measures the antenna gain change over azimuth and elevation, this is also sometimes referred to as the radiation pattern. This defines the difference in power between the signals for the different satellites.

In the ideal world the gain would be uniform but this is not necessarily the best for GNSS because of multipath which affects low elevation satellites. Therefore, it is common to have high gain towards the zenith with the gain decreasing at lower elevations. An example of a gain pattern for an antenna is shown in Figure 1.

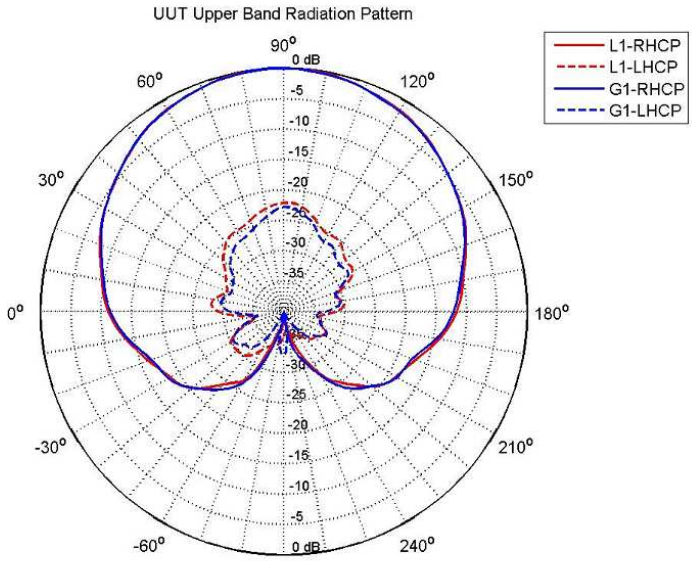

Figure 1 - Gain Pattern for NovAtel 730-GGG Antenna

It is common to use a combined GNSS and L-band antenna for use with commercial augmentation services. While these work well, it can become an issue when working at high latitudes where the elevation angle to the geostationary satellite is low. As the gain pattern has low gain at low elevations it can affect the reception of the L-band signal. This is why a separate antenna with a different gain pattern optimized for L-band reception is used at high latitudes.

Circular Polarization
Satellite systems using the L-band frequency (such as GNSS) use circular polarization to prevent signal fading or poor reception. GNSS uses right hand circular polarization (RHCP) but as antennas are not perfect they will pick up left hand circular polarization (LHCP) energy which can be caused by multipath. When a GNSS signal reflects off a nearby object, the first reflection will have its polarization inverted i.e. from RHCP to LHCP.

For GNSS antennas it is important to know how well the antenna suppresses the unwanted left hand circular polarization as this is an indication of how well it will mitigate multipath (Figure 1 also includes the gain pattern for LHCP). The ratio by which a polarization is suppressed vs. another polarization (i.e. RHCP vs LHCP) is referred to as cross-polar suppression or it can be described by the Axial Ratio of an antenna. High quality antennas will have an Axial Ratio of 1dB at the zenith. It is important to have a good Axial Ratio over the entire antenna hemisphere but that affects the antenna design as it will require a lot of physical space in the antenna element(s). Therefore, the Axial Ratio will vary between antennas and it is something that needs to be considered in selecting an appropriate antenna.

Multipath

GNSS receivers use the signals transmitted directly from the satellites but it is possible that some of the signals may be reflected off surfaces close to the antenna. This results in multipath which needs to be avoided as it will degrade the position solution and while some receivers can mitigate multipath, antennas are used as part of mitigation process.

As previous mentioned, the gain pattern (see Figure 1) usually decreases at low elevations so that the multipath signals can be suppressed. Reduction in gain is insufficient to suppress multipath and a good Axial Ratio is also required.

It is possible to quantify the multipath error experienced by logging raw data and analyzing the results. Figure 2 shows the L1 (MP1) and L2 (MP2) code multipath for four different types of antennas which were all connected to the same receiver type. It is another area that is examined when selecting a suitable antenna.

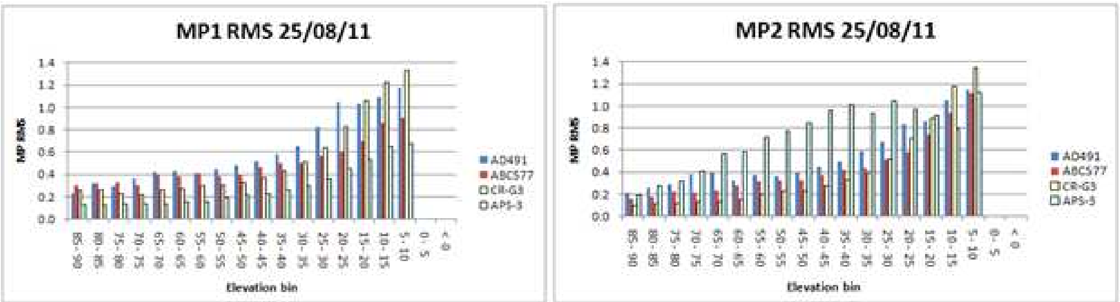

Figure 2 - L1 and L2 Code Multipath for Different Antenna Types

While antennas and receivers can mitigate multipath, installing the antenna in a good location, free of multipath is the best option.

Interference Handling

While receiver technology can help combat interference, the proper design of antennas can help keep out un-wanted signals that can cause interference. The following example is a comparison between two antennas that considers the effect that an Inmarsat Sat-C transmitter would have on them. This is so that a 'theoretical' minimum separation distance could be determined for each antenna. This example is taken from [1] with the GNSS and Sat–C parameters presented in Tables 1 and 2.

	AD491	AD410
Antenna Gain at zenith	5.0 dBi	5.0 dBi
Antenna Gain at 0° elevation	-10dBi	-10dBi
LNA gain at 1575 MHz	45dB	42.7dB
Filter rejection	See Figure 4	
Estimated -1 dB output compression point at 1575MHz	-30dBW	-30dBW

Table 1- GNSS Antenna Parameters

Key performance parameters for an INMARSAT Std-C transmitter are shown in Table 2.

	Sat-C
Nominal EIRP at 5° elevation	14dBW
Gain at 0° elevation relative to 5°	-0.5dB

Table 2 - Inmarsat Sat-C Parameters

INMARSAT typically assigns transmit frequencies for Sat-C in the range 1626.5 to 1628.5MHz.

It was also assumed that the minimum separation distance is calculated such that the interfering signal level at the LNA's input is equal to the GNSS antenna's LNA -1 dB input compression point.

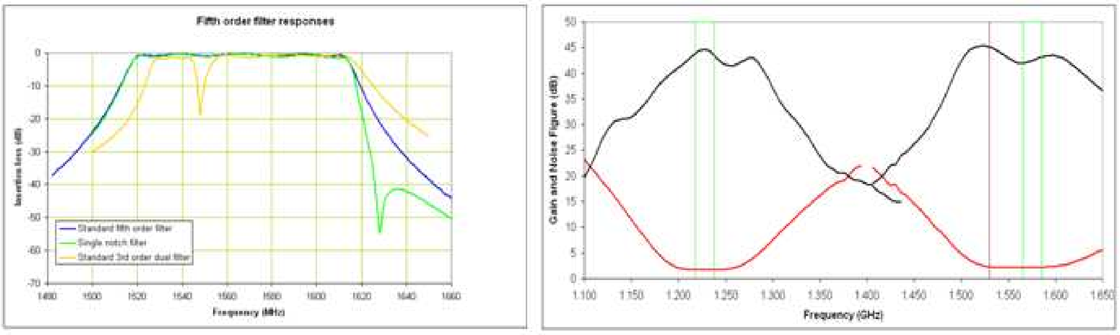

Figure 3 - Filter Response for AD491 (left) and AD410 (right)

Figure 3 shows the filter response for the two GNSS antennas. It is worth pointing out that the AD491 has a notch filter at the Inmarsat Sat-C frequency band whereas the AD410 does not.

Estimating the minimum separation distance using the previous assumptions gives the following values for the AD491 and AD410 antennas.

	Units	Frequency of Interferer				
	MHz	1626.5	1627.5	1628.5	1629.5	1630.5
Wavelength of Interferer	m	0.1844	0.1843	0.1842	0.1841	0.1840
Capsat ERIP (nom 5°elevation)	dBW	14.0	14.0	14.0	14.0	14.0
Est. Gain of Capsat Antntenna relative to 5° elevation in the direction of the GNSS antenna	dB	-0.5	-0.5	-0.5	-0.5	-0.5
Est. Gain of GNSS Ant. in direction of Capsat Ant	dBi	-10.0	-10.0	-10.0	-10.0	-10.0
-1dB input compression point of AD491 at 1575MHz	dBW	-75.0	-75.0	-75.0	-75.0	-75.0
Filter rejection	dB	45.0	49.0	53.0	49.0	46.0
Est input compression point of AD491 at freq of interferer	dBW	-30.0	-26.0	-22.0	-26.0	-29.0
Minimum loss to operate at -1dB compression	dB	44.0	40.0	36.0	40.0	43.0
Minimum free space loss between antennas	dB	33.5	29.5	25.5	29.5	32.5
Minimum separation distance to operate AD491 at -1dB compression	m	0.69	0.44	0.28	0.44	0.62

Table 3 - AD491 Antenna Characteristics

	Units	Frequency of Interferer				
	MHz	1626.5	1627.5	1628.5	1629.5	1630.5
Wavelength of Interferer	m	0.1844	0.1843	0.1842	0.1841	0.1840
Capsat ERIP (nom 5°elevation)	dBW	14.0	14.0	14.0	14.0	14.0
Est. Gain of Capsat Antntenna relative to 5° elevation in the direction of the GNSS antenna	dB	-0.5	-0.5	-0.5	-0.5	-0.5
Est. Gain of GNSS Ant. in direction of Capsat Ant	dBi	-10.0	-10.0	-10.0	-10.0	-10.0
-1dB input compression point of AD410 at 1575MHz	dBW	-73.0	-73.0	-73.0	-73.0	-73.0
Filter rejection	dB	2.50	2.65	2.80	2.95	3.10
Est input compression point of AD491 at freq of interferer	dBW	-70.5	-70.4	-70.2	-70.1	-69.9
Minimum loss to operate at -1dB compression	dB	84.5	84.4	84.2	84.1	83.9
Minimum free space loss between antennas	dB	74.0	73.9	73.7	73.6	73.4
Minimum separation distance to operate AD410 at -1dB compression	m	73.56	72.26	70.98	69.72	68.48

Table 4 - AD410 Antenna Characteristics

The estimates above are based on assumptions of the antenna performance and do not take into consideration the performance of the GNSS receiver. The figure does provide a useful insight into how Sat-C transmissions can affect system performance. The AD491 antenna has a notch filter which helps mitigate any interference from Sat-C transmission whereas the AD410 does not and is thus more susceptible to interference which is why it has to be a greater distance away from any Sat-C transmit antenna. This analysis helps select the appropriate antenna for the use in offshore operations.

ANTENNA INSTALLATION

Once the appropriate antenna(s) have been selected for the system the next step is the physical installation onboard a vessel. A badly installed antenna system will degrade the performance of any positioning system and thus it must be installed correctly and there are several aspects that need to be considered. Detailed information on the installation and maintenance of GNSS positioning system is available in [2].

Firstly, the location of the antenna on the mast must provide clear line-of-site to sky in order to receive the GNSS signals. The antennas should also be installed away from any systems that may cause interference and degradation of the GNSS system or introduce multipath into the system.

If there is any blockage or masking the antenna will be unable to receive the satellite signals as illustrated in Figure 4. In this example, antenna is installed incorrectly on the bracket and is also located next to the pole containing the anemometer. This caused severe degradation in the performance of the positioning system. Near-field issues can occur when antennas are installed close to metal or even two antennas close together which can change the gain pattern of an antenna thus affect signal reception.

Figure 4 - Antenna Masking/Blockage

The antennas were installed by a third party during the vessel build but when the vessel went operational problems were reported to VERIPOS about the performance of the positioning system. After visiting the vessel, it was decided to re-configure the installation to try and improve the antenna location which involved extended the arms of the mast to provide better visibility of the sky (Figure 5).

Figure 5 – New Configuration of Antennas

Once a suitable antenna location has been sourced free of masking and also minimizing multipath the next step is to figure out the cable run from the antenna to the receiver. Cable and connectors will attenuate the

GNSS signal so it is important to work out the total loss in order to select the most appropriate cable type. Table 5 shows the different properties of a selection of coaxial cable types with the attenuation being the value of most significance. For long cable runs, RF over fibre should be considered as an option in order to prevent significant signal attenuation which may affect positioning performance. It must also be remembered that the signal attenuation varies between different frequencies and must be accounted for.

	RG213	RG223	LMR400	LDF4-50 Heliax
Impedance	50Ω	50Ω	50Ω	50Ω
Attenuation dB/100ft @ 1500MHZ	9.6	16.8	5.1	2.8
Attenuation dB/100m @ 1500MHZ	31.5	54.9	16.8	9.2
Minimum Bend Radius	5.0” / 127mm	1.0” / 25mm	1.0” / 25mm	5.0” / 127mm

Table 5 - RF Coaxial Cable Parameters

The number of connectors will also impact on the attenuation of the GNSS signals. The more connections there are, the more the signal will be attenuated and some installations may require an in-line amplifier to help boost the signal to ensure reception at the receiver.

For all connectors that are exposed to the elements, it is important that they are properly sealed and waterproofed to maximize the longevity of the installation and prevent water ingress.

INTERFERENCE

The radio frequency spectrum is very crowded and as the GNSS satellite signals are very weak they are susceptible to both in-band and out-band interference. The radio spectrum allocation for the US is shown in Figure 6 with the spectrum specific to GNSS positioning shown in Figure 7.

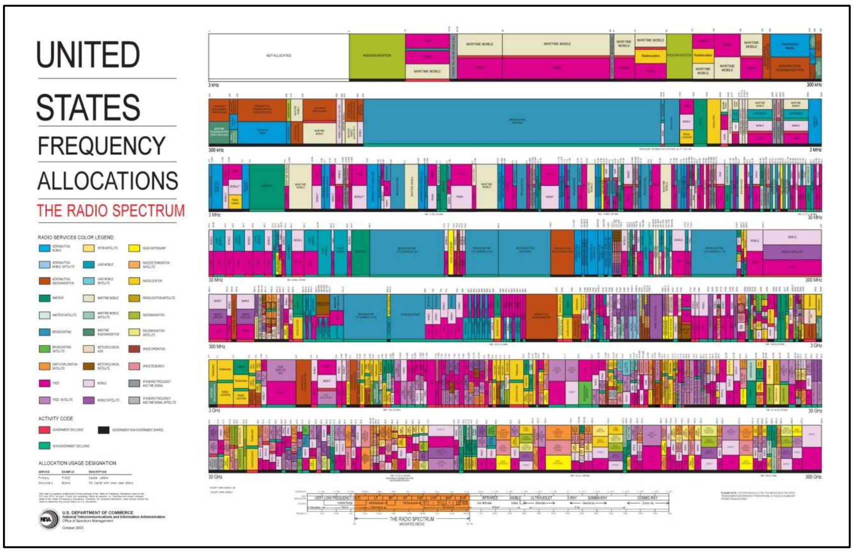

Figure 6 - US Radio Spectrum Frequency Allocations

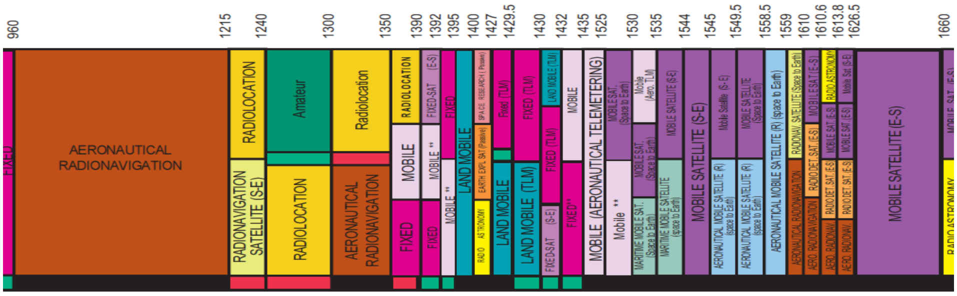

Figure 7 - Radio Spectrum for Satellite Navigation

In-band interference
Typically, unintentional in-band interference is caused by GNSS receivers themselves. GNSS receivers are passive devices and we don't expect them to radiate RF. However, it is possible for a receiver to reradiate the local oscillator due to either a faulty antenna or more often the breakdown of shielding in the coaxial cable to the antenna, or an antenna going into oscillation due to similar issues.

All receive equipment has a local oscillator used at the first and subsequent stages to mix with the incoming received signal to derive an intermediate frequency (IF) that can be better handled in electronics to extract the received data or audio.

This local oscillator is of a very low background RF level but it is radiated back via the RF section of the receiver and normally blocked by the antenna. This principle is used in detector equipment for checking that people have paid their TV license. The detector identifies the local oscillator radiated from the TV which can be pinpointed to a specific antenna and even the channel that is being watched as the local oscillator frequency will vary depending on channel frequency.

As stated above the issue is normally with the coaxial cable where the earth braid/shield has either detached from a connector or broken somewhere in the cable causing continuity to be lost between antenna and receiver. The coaxial cable then acts as an antenna for the local oscillator which is picked up by other GNSS receivers in the vicinity.

This has a severe impact on reception of GNSS signals and will cause receivers within a 100m radius (all receivers on a specific vessel) to lose lock and to be affected to some extent over a much longer range.

If the coaxial cable has been subject to water ingress then corrosion to the braid may have taken place and the braid will suffer from high resistance between receiver and antenna. This causes a similar effect, but to a much lower level which is likely to show symptoms in adjacent GNSS receivers not being able to pick up low elevation satellites and other satellites with lower signal strength than expected.

The symptoms as described can also be intermittent when a cable is subject to movement or when there is poor continuity to a coaxial connector.

On vessels, there is a myriad of equipment that contains GNSS receivers including equipment that traditionally associated with having GNSS technology. The following is an example list of equipment where GNSS receivers.

- General navigation receivers which form part of the ships GMDSS equipment from manufacturers such as Furuno, Thrane & Thrane, Leica, JRC etc.
- Communications domes where the GNSS receivers are integrated for orientation and will not be obvious such as Inmarsat, (B, C and BGAN) from Thrane & Thrane, NERA and Furuno etc., KU and C Band V-Sat, and TV systems from Caprock, Schlumberger-DMS etc.

- Doppler speed logs such as SatLog etc.
- Automatic Identification Systems (AIS)
- GPS Heading Sensor such as Furuno SC 110, Hemisphere Vector etc.
- Plotter systems or ECDIS with integral GNSS
- High Accuracy commercial augmentation services (Fugro, VERIPOS or C-Nav)
- GNSS receivers integrated into a vessel DP system
- Survey and seismic GNSS receivers inc Heading Sensors and Tailbuoy Tracking etc.
- Precision timing equipment used to time survey systems

Other forms of in-band interference is caused by intentional jamming, a topic which is gaining wider coverage in the popular press. Intentional jamming was typically used by governments but now there are websites selling GNSS jammers for several hundred dollars which can be bought by anyone (see Figure 8).

Figure 8 - Website Selling GPS Jammers

These inexpensive jammers were reportedly the reason for interference issues experienced at Newark Liberty international airport in 2010 [3] and are also being used by criminals to defeat GNSS tracking devices fitted to vehicles [4]. The effective range over which these devices can jam GNSS depends on their power but can range anywhere from meters to kilometers.

Out-band interference

This is when an interferer (RF source) from outside the GNSS band causes interference which saturates the antenna which drives the amplifier (LNA) into saturation and effectively blocks the GNSS signals. Various devices can cause out-band interference including following:

- Microwave data links
- Radar systems
- TV antenna amplifiers or transmitters

- Communication systems
- Telemetry systems (data and video)

If these out-band interferers exist on the vessel then systematic testing can be conducted to determine the source and subsequently the GNSS antenna can be relocated to a better location where the interference does not cause a problem. For other sources not located on the vessel, for example microwave data links between platforms, it may require the vessel to change heading or change position to solve the issue.

Interference is just not caused by RF but can be caused by the animal kind as illustrated in Figure 9.

Figure 9- Interference caused by Birds Sitting on Antenna

Example of Interference on Offshore Vessel

Offshore construction vessel reported issues with loss of VERIPOS GNSS positioning which was happening at random times. Some logged data from the vessel was analyzed and showed that the signals levels dropped during these periods. An engineer was sent to the vessel to inspect the system and during this visit the engineer re-terminated the antenna cables and tested everything which checked out ok.

A few weeks later, the vessel reported the same issues with further data analyzed showing the same symptoms as before. It was also ascertained that all GNSS systems were being affected and it was concluded that there must be a GNSS re-radiating onboard. An engineer was sent to the vessel to identify the system causing the issue.

In order to identify the source interference, the following systematic approach was adopted:

- Identify all equipment likely to contain GNSS receivers on the vessel.
- Switch on all equipment containing or likely to contain GNSS receivers.
- Systematically switch off one system at a time and check if all other systems are operating correctly, if so then switch the system back on.
- When a system is switched off and all other systems recover, ensure the problem is repeatable by switching the interfering system off and on several times over a period of time.
- To verify that the interfering system has been correctly identified it should be confirmed by disconnection of the antenna at the receiver and all other systems should operate as normal.

It transpired that the issue was with a Doppler Log which had a GNSS receiver and re-radiating causing interference with all other GNSS positioning sensors on the vessel. Re-termination of the antenna cable solved the issue. The random nature of the fault was down to the fact that the Doppler Log was only used by certain DPO’s when the vessel was conducting certain operations.

THE FUTURE

Technology always develops and evolves to improve and while certain people call for an alternative to GNSS there is ongoing work into protecting the performance of GNSS not only through receiver design but also through antenna technology.

There have been advances in antenna solutions through adaptive antennas with digital jammer cancellation or adaptive beamforming [5]. This technology was once only available to the military but is beginning to find its way into the commercial world. NovAtel have recently released an anti-jam antenna called GAJT-700ML (Figure 10), which was developed in conjunction with defense contractor QinetiQ. While it is commercially available, it does require Canadian and UK export approval.

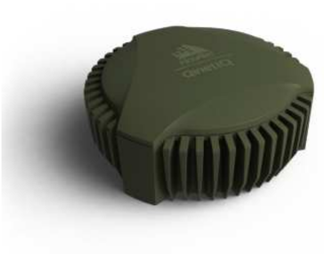

Figure 10 - NovAtel GAJT GPS Antenna

The GAJT antenna essentially alters the gain pattern of the antenna in order to create nulls (blind-spots) in the direction of jammers, allowing the satellite signals to be received by the receiver – essentially the antenna uses a similar concept to that found in noise-cancelling headphones [6]. However, it is not clear how the antenna would handle interference (jamming) which was caused by re-radiation of the local oscillator or a Sat-C system – would it create a blind spot which would prevent the tracking of GNSS satellites?

There is also the possibility of integrating other sensors such as INS to help overcome issues with GNSS but there has been little work done into looking at how these sensors can aid the GNSS to help protect the signals. Most work has been done looking at how GNSS can aid INS to maintain accuracy.

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