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White Paper

Tallysman VeraPhase™ 6000 White Paper

Julien Hautcoeur and Ronald H Johnston

www.tallysman.com

E: info@tallysman.com ▪ **T: +1 613 591-3131**

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Abstract — This paper presents patented GNSS antenna technology, branded by Tallysman as VeraPhase™ technology. This technology has produced a highly efficient antenna that covers all GNSS frequencies and exhibits excellent low axial ratio down to the horizon, over all azimuth angles, and provides extremely tight Phase Centre Variations (PCV), and excellent front-to-back ratios.

1. Introduction

The use of GNSS technology has permeated many aspects of life today. With each advancement in GNSS technology, new applications become possible as a result of lowered costs, smaller size, greater capabilities, and/or higher precision.

The introduction of Tallysman's patented VeraPhase™ technology contributes to the advancement of GNSS applications by providing new levels of precision and capabilities not previously available in a single antenna. Wide bandwidth is important because it allows users to take advantage of more GNSS constellations. This enhances the accuracy, integrity, continuity and availability of GNSS. Using more frequencies improves the ability to eliminate ionospheric errors that otherwise can only be approximated with a single frequency using the Klobuchar model and broadcast GNSS messages. The ability to receive more than one GNSS constellation also improves the ability to receive good quality satellite observables, particularly in challenging environments. The main GNSS frequencies are presented on Fig 1.

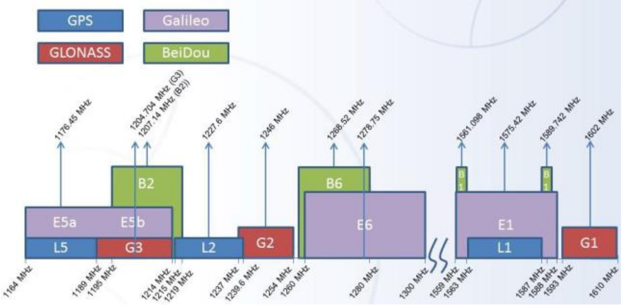


Figure 1 – GNSS Frequencies

The Tallysman VeraPhase™ 6000 antenna (VP6000) covers all GNSS constellation frequencies (1164 – 1300 MHz and 1559 – 1610 MHz) plus L-Band correction services (1525 – 1559 MHz).

The new technology provides a high gain, low loss antenna with excellent axial ratios through all elevations and azimuth angles, across all GNSS frequencies. The high front-back ratios, combined with minimally degraded axial ratio at the horizon combine for good tracking at low elevations. The VP6000 also provides millimetre level PCV through all elevations and azimuth angles across all frequencies. The Phase Centre Offset is virtually identical for all GNSS frequencies. In brief, this antenna rivals any other geodetic and reference antennas available. This antenna can also accommodate a multiband GNSS or RTK receiver PCB or other circuitry within the base of the housing, thereby reducing time to market and minimizing costs for highly integrated precision GNSS instruments.

2. New Innovation

The basic antenna structure employs a wide-band crossed dipole configuration, tuned to the L2 frequency band, combined with a coupled radiating element dimensioned to resonate in the L1 frequency band. The dipoles are driven by balanced wide-band feeds in phase quadrature. These components are positioned in a novel circular waveguide with the back end tapered and shorted, with the upper edge formed as a non-uniform saw tooth shape. The upper part of the waveguide is built of many vertical strap conductors on a fixed radius, with one circumferential strap conductor. This unusual structure allows the equalization of the magnitude and the achievement of quadrature phase of the z directed current and phi directed currents.

Compared with earlier prototypes, the present production implementation has been made more broadband with a coupled radiating resonator, a better axial ratio in the upper hemisphere, and a higher front to back ratio for better suppression of the ground reflections, and is lighter and more compact.

The VP6000 antenna is presented on Fig. 2. It is light and very compact with a diameter of 157mm, a height of 137mm and a weight of <670g.

Figure 2 - VP6000 Antenna

3. Antenna Performances

Anechoic chamber tests were conducted at the Satimo SG 64 facility in Kennesaw, GA to determine the gain pattern, axial ratio, phase center offset and variation in multipath free conditions. Data were collected from 1160 MHz to 1610 MHz to cover all the GNSS frequencies.

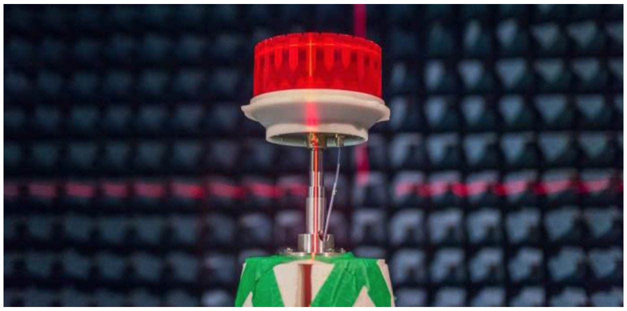


Figure 3 – Prototype of the VP6000 without radome under test in a Stargate 64.

1.1 Antenna Gain, Efficiency and Roll-off

In combination with cross polarization rejection and the back-to-front ratio, the ratio of antenna gain to the system noise temperature (G/T) determines the received signal quality, and is an important indicator of the tracking ability of the antenna. Thus, given a high performance LNA (low system noise temperature), high values of gain translate into higher C/No carrier-to-noise ratios. The VP6000 exhibits a gain at zenith from 4.9dBic at 1164MHz to 7.05dBic at 1610MHz (see Fig. 4). This high gain in combination with a wideband LNA with a noise figure of 1.5dB, provides for high C/No ratios for all GNSS frequencies. Furthermore, the VP6000 exhibits gain at the horizon from -6.8 dBic at 1164MHz to -4.4 dBic at 1610MHz (see Fig. 4). Thus the gain roll-off from zenith to horizon is between 10.1 dB at and 13.6 dB, providing for good tracking at low elevation angles.

The radiation efficiency of the VP6000 is 70% to 80% at zenith, corresponding to an inherent ("hidden") loss of just 1dB to 1.5dB. In contrast, spiral antennas usually exhibit an inherent efficiency loss of close to 4 dB in the lower GNSS frequencies.

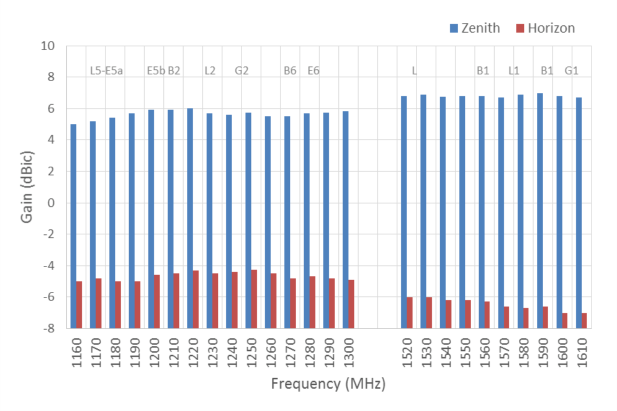


Figure 4 – Gain of the VP6000 at zenith and the horizon.

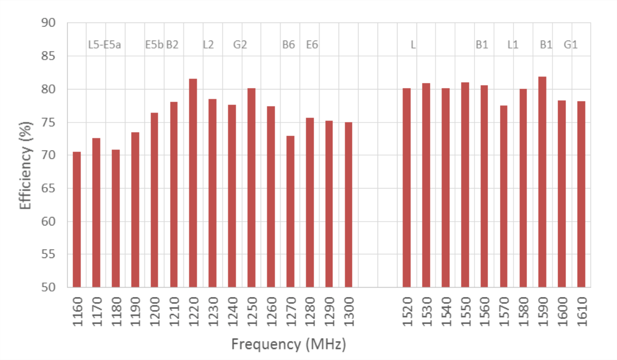


Figure 5 – Efficiency of the VP6000

1.2 Radiation Patterns

The radiation pattern of an idealized antenna would have pure circular polarization and constant high gain from zenith down to the horizon and then roll off rapidly for elevations below the horizon. In a realizable antenna, the gain should be close to constant over the azimuth for each elevation angle, with strong cross polarisation rejection over that frequency range, so as to minimize phase center offset and for tight phase center variation. In the upper hemisphere, the greater the difference between the Right Hand Circular Polarized (RHCP) and Left Hand Circular Polarized (LHCP) antenna gain, the greater the resistance of the antenna to cross polarized signals, usually associated with odd order reflections, and hence improved multi-path signal rejection. The measured radiation patterns shown in Fig. 6 and Fig. 7. The radiation patterns at selected frequencies are normalized to enable direct comparison of the patterns and show the RHCP and LHCP gains on 60 azimuth cuts 3 degrees apart. The radiation patterns show excellent suppression of the LHCP signals in the upper hemisphere.

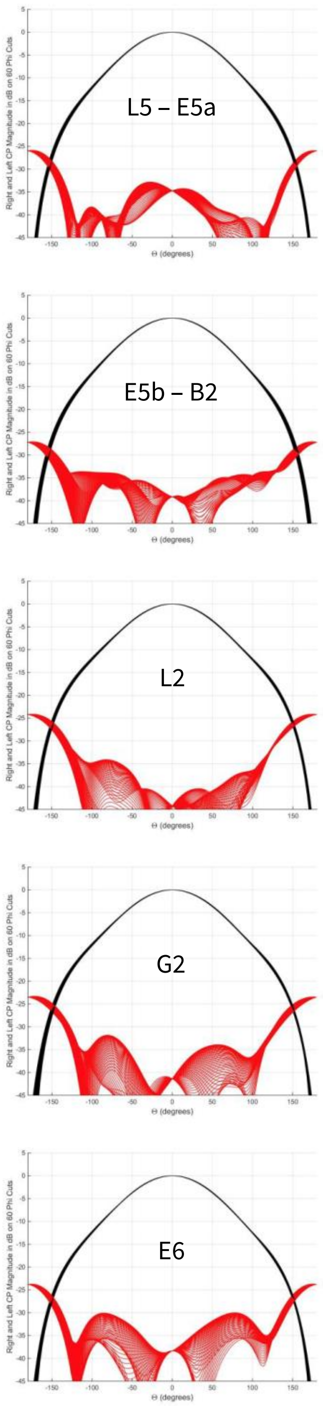


Figure 6 – Normalized radiation patterns at lower GNSS frequencies.

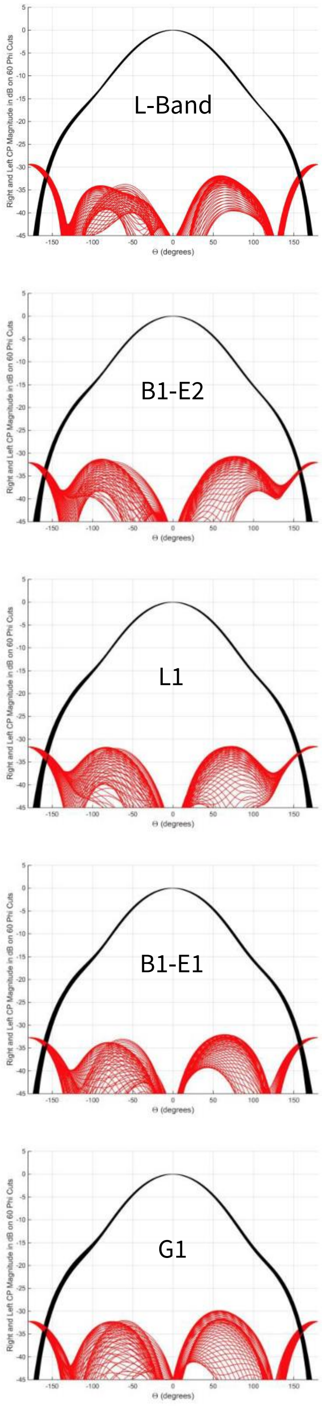


Figure 7 – Normalized radiation patterns at higher GNSS frequencies.

The difference between the RHCP gain and the LHCP gain at zenith is plotted in Fig.8. It can be seen that there is excellent discrimination ranging from 31dB to 53dB. Also for the other elevation angles, the LHCP signals usually stay 25dB below the maximum RHCP gain and even 30 dB from 1200MHz to 1580MHz. The antenna shows a very constant amplitude response to signals coming on a constant elevation angle regardless of the azimuth or bearing angle. This illustrates the excellent multipath mitigation characteristics of the VP6000 at every elevation and every GNSS frequency.

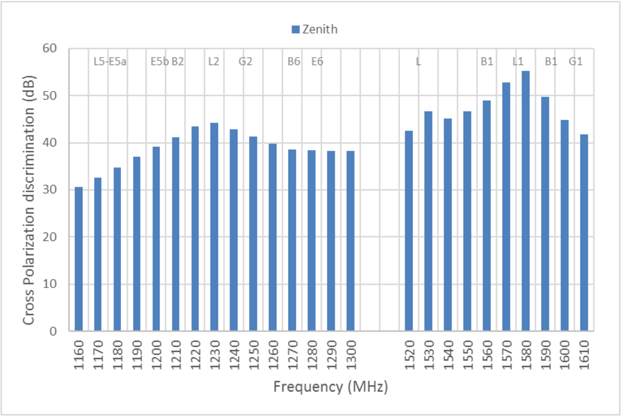


Figure 8 – Cross polarization discrimination at zenith.

1.2.1 Down-Up Ratio

When a direct satellite signal is reflected from the ground, the reflected signal polarization tends to convert, at least partially, from RHCP to LHCP for most soil types. If the terrain underneath the antenna is homogeneous, then the ground surface acts as a mirror thus providing a reflected signal coming from below the horizon at the negative of the angle of the direct signal above the horizon. Depending upon the angle, in part, the field of the inverted, reflected wave adds to the direct wave, which is very undesirable. This is the reason, when characterizing the multipath reflection capabilities of the antenna, it is common to use a down-up ratio between antenna gain for LHCP signals for a given angle below horizon as that for the RHCP signals at the same angle above the horizon. The down-up ratios at L2 and L1 on 60 azimuth cuts are plotted in Fig. 9. The graphs show that the down-up ratio is -25 dB at L2 and 32 dB at L1at zenith and it stays close to -25 dB at L2 and under -25 dB for the upper hemisphere which is usually not the case for standard GNSS antennas. Similar results have been measured over the whole GNSS frequencies and confirm the excellent multipath rejection capabilities of the VP6000. The down-up Ratio at zenith is plotted in Fig.10. It can be seen that the down-up ratio is around 25 dB in the lower GNSS frequency band and over 30 dB in the higher GNSS frequency band.

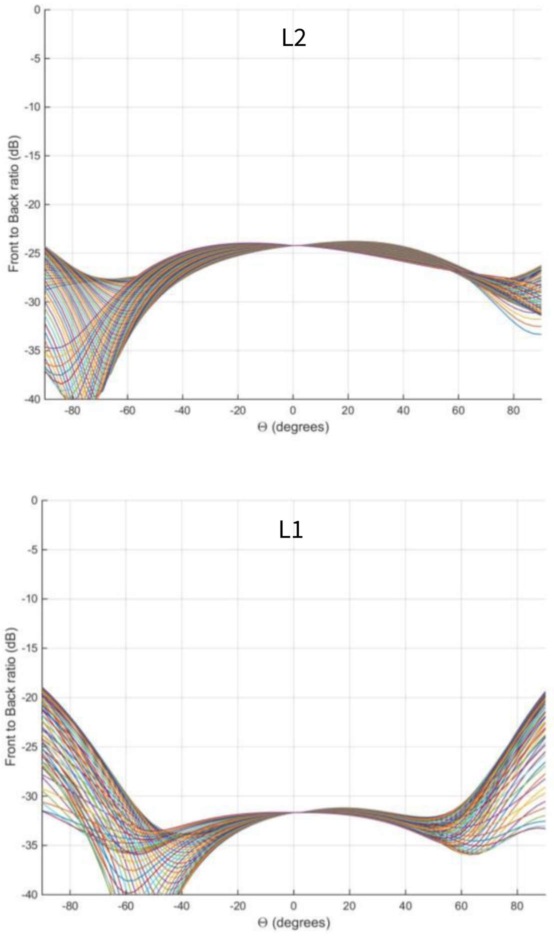


Figure 9 – Down-Up Ratio of the VP6000 at L2 and L1 on 60 azimuth cuts.

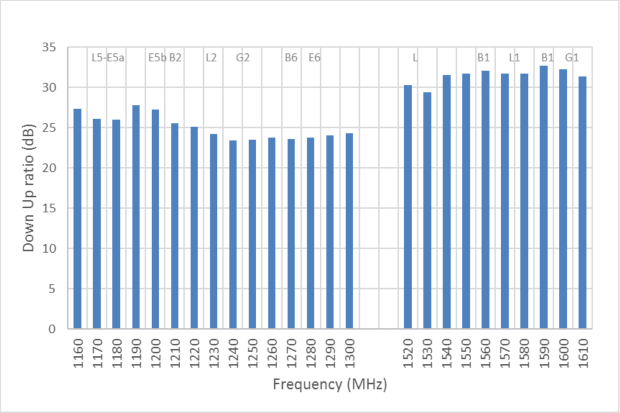


Figure 10 – Down Up at zenith.

1.3 Axial Ratio

The axial ratio is a measure of an antenna's ability to reject the cross polarized portion of a composite signal with both RHCP and LHCP components. Physically this is an elliptical wave, typically being the combination of the direct and reflected signals from the satellite. The lower the ratio of the major axis to the minor axis of the polarization ellipse, the better the multipath rejection capability of the antenna. To meet operational standards for a multi-band antenna, the axial ratio should meet these requirements at the following elevation angles:

- At 45^{o} : not to exceed 3 dB
- At 15^{o} : not to exceed 6 dB
- At 5^{o} : not to exceed 8 dB

The worst case axial ratio values of the VP6000 at different elevations have been plotted on Fig. 11. The graph shows an axial ratio of less than 0.5dB at zenith typically, over the whole GNSS frequencies, and which stays low at all elevations down to the horizon. A maximum value of 1.5 dB has been measured for the elevations above 30 degrees, increasing to just 2 dB at the horizon (0 degrees elevation). This performance provides for excellent multipath rejection capability of the VP6000 and to the best of our knowledge, there is no other GNSS antenna which can match this performance.

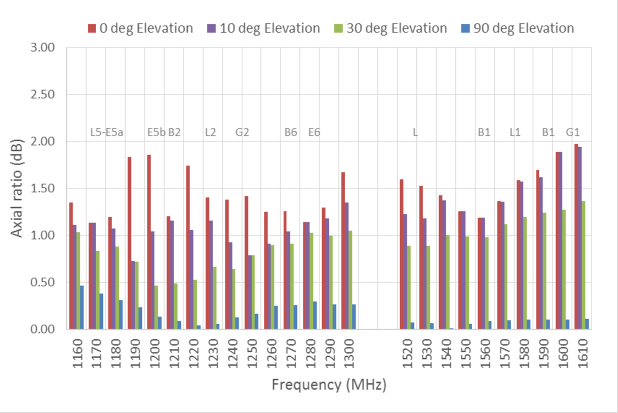


Figure 11 – Worst case of axial ratios of the VP6000 at different elevations: 90 degrees (zenith), 30 degrees, 10 degrees and 0 degree (horizon).

1.4 Phase Center Offset / Phase Center Variation and absolute calibration

For use as a measurement instrument, the antenna must have a precise origin, equivalent to a tape measure zero mark. Thus it is important that the phase of the waves received by the antenna "appear" to arrive at a single point that is independent of the elevation and azimuth of the incoming wave. This point is known as the phase center of the antenna which should remain fixed for all operational frequencies, and for all azimuth and elevation angles of incoming waves, otherwise dimensional measurement is compromised.

In an ideal GNSS antenna, the phase center would correspond exactly with the physical center of the antenna housing. In practice the electrical phase center, moves around in three dimensions with the changing azimuth and elevation of the satellite signal. The difference between the electrical phase center and an accessible location amenable to measurement on the antenna is described by Phase Center Offset (PCO) and Phase Center Variation (PCV) parameters and data, calculated through antenna calibration. These corrections are only effective if the predicted phase center movement is repeatable for all antennas of the same model. The PCO is calculated for each measured elevation angle by considering the signal phase output for all phi (azimuth) values at a specific theta (elevation) angle, and mathematical removal of the normal phase windup effect in this type of antenna. A Fourier analysis is then conducted on this resulting data. The fundamental output gives the variation of the horizontal position of the antenna as it is rotated on the z axis. The apparent position normally varies somewhat as the antenna is viewed from various theta angles. The PCV of the VP6000 is plotted in Fig.12 and Fig.13. The graphs show the variation of the phase center in the horizontal plane for elevation angles of 18 to 90 degrees in 3 degree steps at different frequencies. The graphs show a tight grouping for all frequencies and all values of theta. The variations for specified signals are typically less than ±1mm from the x and y axis.

Five copies of the antenna were sent for absolute calibration by Geo++ in Germany where the VP6000 has been calibrated at the frequencies L1/L2 and G1/G2. The PCV for the upper hemisphere of the VP6000 at L1 and L2 are plotted in Fig.14 and Fig.15. These results confirm a 1mm PCV at L1 and a ±1mm PCV at L2. Also the standard deviation of the PCV over the five measured antenna stays under 0.2mm which represents excellent repeatability. Same results have been observed at G1 and G2.

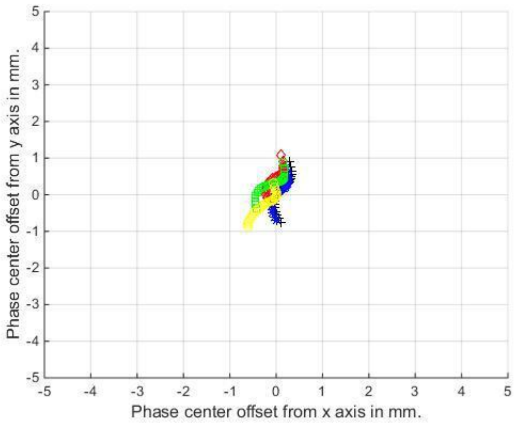


Figure 12 – Phase center variation from 1520 MHz to 1610 MHz in10 MHz increments.

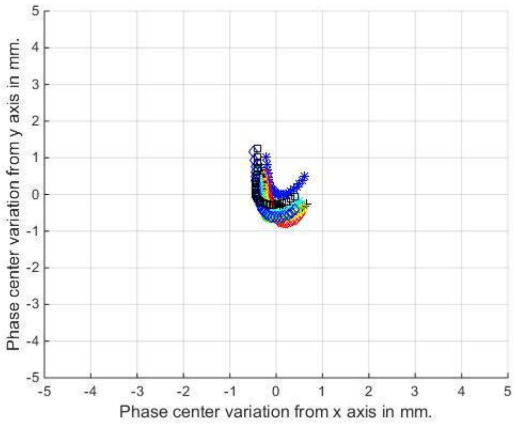


Figure 13 – Phase center variation from 1160 MHz to 1300 MHz in 20 MHz increments.

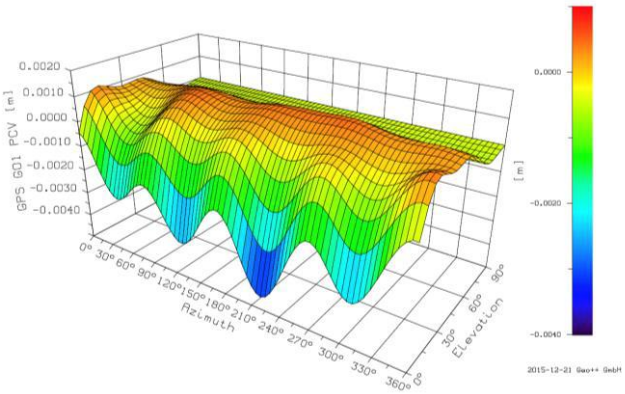


Figure 14 – Phase center variation at L1. Same results have been observed at G1.

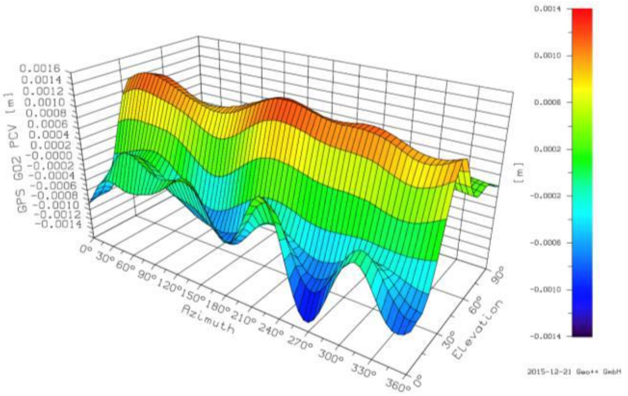


Figure 15 – Phase center variation at L2. Same results have been observed at G2.

4. LNA and Optional Circuitry

The best achievable carrier to noise ratio (usually expressed as C/No) for signals with marginal power flux density (PFD) is limited by each of the antenna element efficiency, gain and the overall receiver noise figure. This can be quantified by a ratio parameter, usually referred to as "G/T", where G is the antenna gain (in a specific direction) and "T" is the effective noise temperature of the receiver; usually dominated by the noise figure of the input amplifier (LNA).

That being said, GNSS receivers must accommodate a crowded RF spectrum, and there are a number of high-level, potentially interfering signals that can saturate and desensitize GNSS receivers. These include, for example, ISM band signals, mobile phone signals, particularly LTE signals in the newer 700MHz band, which are a hazard because of the potential for harmonic generation in the GNSS LNA. Other potentially interfering signals include Globalstar (1610MHz –to 1618.25MHz) and Iridium (1616MHz -1626MHz) because they are high power up-link signals and particularly close in frequency to GLONASS signals.

A first defensive measure in the VP6000 LNA is the addition of multi-element band pass filters at the antenna element terminals, (ahead of the LNA). These have a typical insertion loss of 1dB because of their tight pass band and steep rejection characteristics. Sadly, there is no free lunch, and the LNA noise figure is increased approximately by the additional filter insertion loss.

The second defensive measure in the VP6000 LNA is the use of a highly linear LNA that is achieved without any significantly increase in LNA power consumption, by use of LNA chips that employ negative feedback to provide well-controlled impedance and gain over a very wide bandwidth with considerably improved linearity.

It should also be borne in mind that while an installation might initially be determined to have an "uncluttered" environment, subsequent introduction of new services may change this, so interference defenses are prudent even in a "clean" environment.

A potentially undesirable side effect of tight pre-filters is possible dispersion that can result from variable group delay across the filter pass band. Thus it is important to include these criteria in selection of suitable pre-filters. The filters in the VP60000 LNA give rise to a maximum variation of 2nS in group delay over the lower GNSS frequencies (from 1160MHz to 1300MHz) and 2.5 nS over the higher GNSS frequencies (from 1525MHz to 1610MHz). Also, the difference between the lower GNSS frequencies and the higher GNSS frequencies stays less than 5 nS.

Thus the VP6000 series LNAs are a best compromise between ultimate sensitivity and ultimate interference rejection. The received signal is split into L2 and (L/L1) bands in a diplexer connected directly to the antenna terminals and then pre-filtered in each band. This is where the high gain and high efficiency of the basic VP6000 antenna element provides a starting advantage, since the losses introduced by the diplexer and filters are offset by the higher antenna gain, thereby preserving the all-important G/T ratio. After initial amplification, the signals in each frequency band are again filtered and further amplified prior to recombination of both bands at the output.

The VP6000 series antennas are available with either a 35dB gain LNA or with a 50dB gain LNA for installations with long coaxial runs. The VP6000 is internally regulated to allow a supply voltage from 2.7V to 26V

An interesting feature of the VP6000 is that the physical housing includes a secondary shielded PCB that is available for integration of custom circuits/systems within the antenna. The purpose of this to allow addition of L1/L2 receivers for RTK receivers etc. A pre-filtered, 15dB pre-amp version of the LNA is also available to provide RF input for OEM systems embedded within the antenna housing.

The VP6000 is also available with a variety with N or TNC connectors and with a conical radome to shed ice, snow and birds for reference antenna installations. A precise and robust monument mount is also available.

5. Conclusion

This paper presents the new VP6000 GNSS wideband antenna from Tallysman Wireless Inc. With emerging satellites systems on the horizon, a new high performance antenna is needed to encompass all GNSS signals. The VP6000 has sufficient bandwidth to receive all existing and currently planned GNSS signals, while providing the highest performance standards. A detailed report of the performances has shown that the new innovative design: crossed driven dipoles associated with a coupled radiating element combined with a high performance LNA, has revealed unmatched performances, especially with respect to axial ratios, cross polarization discrimination and phase center variation. These improvements make the VP6000 the best candidate for low elevation tracking. The reception of the proposed new signals along with additional low elevation satellites will bring new levels of positional accuracy to reference networks, and benefits the end users of the data. With its compact size and light weight, the VP6000 has been designed and built for durability and will stand the test of time, even in the harshest of environments.

6. Acknowledgement

Earlier research on this antenna have been carried out with an NSERC Discovery Grant and a NSERC Industrial R&D Fellowship.

7. Calibration Files

Calibration files can be found on the NGS website:

VP6000 35dB Flat Radome

VP6000 50dB Conical Radome

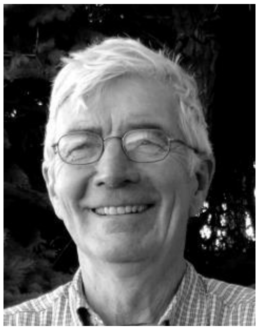
8. References

GPS-704X White Paper - Antenna Design and Performance, NovAtel Inc.R.H.Johnston, “Dual Circularly Polarized Antenna”, Pat.No. US9,070,971 June 30, 2015

Julien Hautcoeur was born in Nantes, France in 1983. He graduated in electronics systems engineering and industrial informatics from the Ecole Polytechnique de l'Université de Nantes, Nantes, France, and received the Master's degree radio communications systems and electronics in 2007 and the Ph.D. degree in signal processing and telecommunications from the Institute of Electronics and Telecommunications of Rennes 1, Rennes, France, in 2011.

From 2011 to 2013, he accomplished a Postdoctoral training with the University of Québec in Outaouais. His research field was optically transparent antenna systems for telecommunications (transparent and conductive materials, thin films, meshed antenna).

In 2014 he joined Tallysman Wireless Inc. in Ottawa, Canada as an antenna and RF engineer for the development of very accurate GNSS antennas with precise phase center and low axial ratio for GNSS applications and associated electronics.



Ronald H. Johnston was born in Drumheller Alberta Canada. He received a BSc from the University of Alberta in 1961 and the PhD and DIC from the University of London (UK) and Imperial College, respectively, in 1967.

In 1970 he joined the University of Calgary and held Assistant to Full Professor positions and was the Head of the Department of Electrical and Computer Engineering from July 1997 to June 2002. He became Professor Emeritus in the Schulich School of Engineering, University of Calgary in 2006. Other professional experience includes work at Canadian General Electric (Toronto), Nortel (Ottawa), Communications Research Centre (Ottawa), Carleton University(Ottawa), University of Sydney (Australia), TRLabs (Calgary) and Nortel (Harlow UK).

He has authored or co-authored about 160 journal and conference papers mostly in the areas of RF circuits, diversity antennas, small antennas, slot antennas, radiation efficiency, MIMO systems and subsurface EM wave propagation. Present research is mostly concerned with small antenna efficiency measurements, compact low Q antennas, slot array antennas and high purity circularly polarized antennas. A number of patents have been published. He has supervised (or co-supervised) over 45 postgraduate students in programs for PhD, MSc or MEngg degrees.

About Tallysman

Tallysman® is a developer, provider, and manufacturer of global positioning components and intelligent location based wireless infrastructure solutions for tracking systems.

Based in Ottawa, Canada, Tallysman is focused on high function, high performance technology and solutions. Our core competencies include digital wireless networks, RF and Global Navigation Satellite Systems (GNSS) component design.

Tallysman is known for its brands of Accutenna® and VeraPhase®. These technologies have proven themselves to provide the highest performance antennas (low axial ratios, high multi-path signal rejection, tight PCV) in their size and weight, while setting lower economical price points. Tallysman's antennas are the antennas of choice for a wide variety of applications.

Learn more at www.tallysman.com.