High-Performance GNSS Antennas with Phase-Reversal Quadrature Feeding Network and Parasitic Circular Array

Ning Yang, *NovAtel Inc.*
Jerry Freestone, N*ovAtel Inc.*

BIOGRAPHIES

Ning Yang is currently the Senior Antenna Engineer at NovAtel. He received a BSc in Electric Engineering and Ph.D. in microwave engineering under a joint-program from Southeast University and National University of Singapore. He was a post-doctoral research fellow with University of Montréal from 2006 to 2010. Since 2003, he has worked as an engineer at Center for Wireless Communications, Associate Scientist with the Institute for Infocomm Research Singapore, Senior Antenna/RF Engineer at Motorola Inc., and Principle Engineer with EMSCAN.

He has authored or coauthored over 60 peer-reviewed technical papers. He was a Technical Program Committee (TPC) member of EuCAP in 2009 and was the recipient of the Young Scientist Award at the International Union of Radio Science (URSI) General Assembly in 2008.

Jerry Freestone is the Chief Engineer for Antennas and Anti-jam products at NovAtel. He received a BSc in electrical engineering from the University of Alberta. Prior to starting at NovAtel in 2010, he worked 15+ years as a senior design engineer for Nortel Networks in their Small Business Communications Systems division.

ABSTRACT

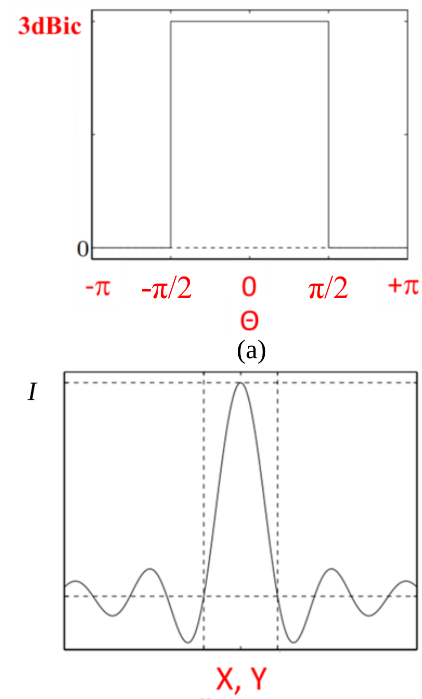
The antenna is the first component in a positioning system, which processes the GNSS and correction signals received from multiple satellites. The precision of a position is strongly related to the performance of the GNSS antenna used. In this paper, several key antenna parameters are discussed with regard to high-precision applications. Two new technologies are proposed to solve the challenges encountered by the GNSS antenna design: ultra-wideband low-loss rotational sequential feed network using phase-reversal, and parasitic circular array loading technology. Based on these technologies, a new generation of high-performance GNSS antennas for ground based applications are proposed and validated by anechoic chamber measurement and live GNSS signal testing. Attributed to the outstanding wideband amplitude and phase balance performance of the antenna feed network, the proposed antenna covers the entire GNSS frequency spectrum with excellent gain and CNo. The antenna features very low axial-ratio and very small phase center variation from zenith to horizon. There is no phase center offset between high band and low band and the radiation patterns are highly symmetrical for which no antenna alignment is required with respect to its mounting direction. In addition, using the parasitic circular array loading (patent pending) technology along the peripheral of the radiation elements, the diffraction of surface waves at the edge of the antenna ground-plane is suppressed or re-radiated which results in further improved axial ratio especially at low-elevation angles. The gain roll-off at these angles is able to be optimized for a balanced low-elevation angle tracking and multipath rejection. Compared to conventional patch antennas, the proposed antenna uses a single PCB to achieve wide dual GNSS bands, maintains the planar and low-profile structure while allows for optimized gain roll-off and multipath performance.

INTRODUCTION

GNSS (Global Navigation Satellite System) is a satellite based navigation system with global coverage, which allows receivers to determine their location (longitude, latitude, and altitude) using signals transmitted by the radio from all the existing satellite constellations, such as US GPS, Russian GLONASS, European Galileo and Chinese Beidou. The antenna is the first front-end component in the positioning system to process the GNSS signals collected from multiple satellites and is one of the key components for positioning accuracy. Depending on the market and application, GNSS antennas can be divided into low-end for mobile devices, and high-end for high-precision such as survey, aerospace, mobile mapping, precision agriculture, timing, UAV and defense. The accuracy of positioning is strongly related to the performance of the GNSS antenna, and its technological challenges are explored and listed as followings:

1) *Wide and multi-band circular polarized.* To increase the positioning speed, reliability and availability, current GNSS systems have to support all satellite constellations. To achieve higher precision positioning (sub-centimeter), the systems need to receive correction signals from argumentation stations (satellite-based or ground-based) to correct the sources of errors such as ionosphere delay and clock errors, through the integration of these additional signals into their calculation process. Therefore the frequency of high-performance GNSS antenna should extend from 1.1GHz to 1.62GHz and even to S band (IRNSS) with good circular polarizations. It is a challenge to design an antenna with consistently circular polarized radiation pattern in such a wide band. Antenna theory [1-2] shows there is a tradeoff among antenna bandwidth, antenna size and radiation efficiency.

2) *Mitigation of multipath interference.* The receivers prefer receiving "clean" (noiseless) direct line-of-sight (LOS) signals to obtain accurate timing. However, non-LOS multipath signals may be generated when the satellite signals hit the ground, nearby buildings or waters. Since the satellites transmit Right Hand Circularly Polarized (RHCP) signals, a total reflection (such as on metal) by a surface would transform them into Left Hand Circularly Polarized (LHCP) signals (elliptical polarization for non-metal surfaces). To reject these multipath signals, a RHCP receiving antenna with low axial ratio in all the angles is required. However in real world, the amplitude and polarization of the reflected signals are determined by the reflection coefficient of the reflection surface and by the incident angle. For surface such as moist soil, the reflection coefficient is a complex number and has the highest value below Brewster angle. Therefore, the reflected multipath signal from ground can be any polarization and most problematic at low elevation angle. Furthermore, the near-field scattering from below the GNSS antenna is also a concern if the antenna is not in mounted in a position recommended by the equipment manufacturer. To ensure the rejection of any indirect multipath signals coming from below the horizon, high front-to-back ratio and very low back lobe is always preferred. Ideally, a fixed-station system requires an antenna with uniform radiation amplitude (or 3dBic gain for lossless antenna) in the upper-hemisphere, and with nothing radiated from below, as shown in Fig.1 (a). However from antenna theory [3], antenna radiation pattern in far field is nothing more than the Fourier transformation of antenna current distribution from space domain to spatial spectrum domain. To obtain such ideal radiation pattern with step function in spatial spectrum domain, the antenna current needs to extend to infinite, *i.e*, the antenna has to be infinitely long with *sinc* function current distribution [3], as shown in Fig.1 (b). At the very least, the antenna needs to be very long to be formed by an array of elements to approximate the ideal radiation pattern, which is not practical for GNSS mobile applications. In practice, NovAtel has sought for antennas with slow rolling-off of radiation pattern from the zenith to low elevation angle and a very sharp roll-off close to the horizon after cut-off elevation angle (5~10 degree). Pinwheel^{TM} antennas and the new VEXXIS^{TM} antennas have utilized advanced multi-point sequential feeding (with different implementations) and surface-wave manipulation technologies to reduce the reception of left-handed polarized multipath signals generated at low elevation angles. The back-lobe radiation in general is suppressed, and the antenna's susceptibility to multipath replicas of GNSS signals is reduced.



$$I(x,y) = \frac{1}{4\pi^2}\iint_{-\infty}^{\infty} E(k_x,k_y)e^{-j(k_x+ky)}dk_x dk_y$$

(b)

Fig.1 (a) Ideal radiation pattern of GNSS antennas, 3dBic RHCP gain uniform radiation amplitude in the upper-hemisphere, and with zero in below. (b)Current distribution over the antenna to achieve the ideal radiation pattern. The current has to extend to infinite space.

3) *Moderate gain and beam-width.* The GNSS antenna has to meet the minimum gain requirements to provide certain carrier to noise ratio (C/No) for receivers to acquire and track the GNSS satellites. The gain at low-elevation angles must be above the receiver threshold to cover the entire upper-hemisphere to receive signals from at least four satellites. Since the gain and beam-width are inversely related to each other, both the gain and beam-

width of the optimal GNSS antennas have to be moderate, and the antenna should have a very wide coverage on the upper-hemisphere from zenith down to the low-elevation angle of 5 degree.

4) *Small phase center offset (PCO) and tight phase center variations (PCV).* The GNSS systems use the reference point of the antenna (ARP) and phase or delay of the signal to calculate the delay time and the position information. Therefore, the phase center performance of the GNSS antenna can set the accuracy limitations of differential GPS (DGPS) measurement. The radiation pattern of the GNSS antenna needs to be highly symmetrical to the azimuth angle, both in amplitude and phase. The phase must have minimal variation while incoming satellite signal angle changes from zenith to horizon.

5) *Planar and low-profile.* High-performance GNSS antennas are often three-dimensional, such as crossed drooping-dipole, helix, spirals, etc., since it is easier to satisfy the previously mentioned electrical requirements compared to other two-dimensional solutions. Making the antenna smaller and cheaper is desired by industry, but it is always constrained by available technologies and materials. The low-profile planar antennas make it easier to integrate antennas with GNSS receivers and inertial systems for centimeter-level accuracy. From Pinwheel [4] to VEXXIS antennas, NovAtel has continued to innovate in antenna technologies to keep the antennas planar and low-profile while surpass in performance.

ROLES OF FEEDING NETOWRK IN HIGH-PERFORMANCE GNSS ANTENNAS

Many GPS antennas have historically been designed with single-feed technology. To obtain circular polarization, perturbations or traveling wave type antennas are used [3]. Single-feed antennas typically suffer from asymmetric radiation patterns, large phase center offset and phase center variations due to the inherent asymmetry feeding structure and induced high-order modes. Dual-feeds are widely used to design patch antenna to increase the circular-polarization bandwidth and is relatively easy to implement. However, the radiation pattern asymmetry and phase center offset only improve slightly, and still are not good enough for sub-millimeter accuracy applications. Multiple and push-pull balanced feed is one of the key technologies for antennas to have much more stable phase center and variations.

As shown in Fig.2, for RHCP signals, many linear antenna radiation elements must be arranged in a sequentially rotational configuration, and a synchronized phase should be applied to each element so that circular polarized electric field spinning in right hand rule could be observed in far field:

$$\text{Phase}_n = \emptyset_n = \frac{2\pi(n-1)}{N} \quad . \tag{1}$$

For such feeding scheme, the operation bandwidth of the feeding network determines the maximum obtainable axial ratio bandwidth of the antenna.

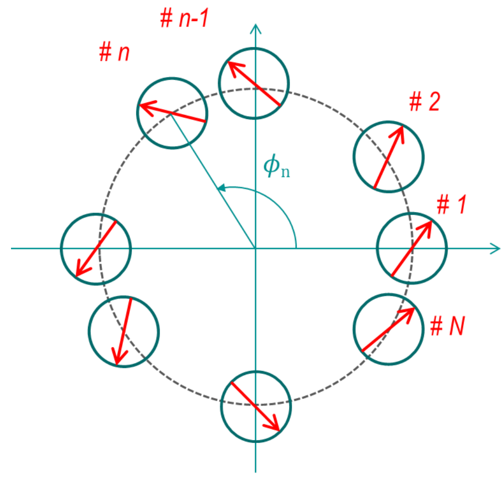


Fig.2 Sequential rotating antenna feed to generate circular polarization from multiple linear radiation components.

To evaluate how good a feeding network is, several figure-of-merits are considered. First is the insertion loss. Insertion loss of the feeding network decreases the C/No at the GNSS receiver and is one of the key indicators of antenna performance. Second is the amplitude and phase balance. The amplitude and phase imbalances among the N coupled output of the feeding network are contributors of bad axial ratio and asymmetry of radiation pattern. Third is the operation bandwidth. For multi-constellation GNSS applications, the bandwidth of the feed network should be wide enough to track all frequencies in all constellations.

NovAtel's Pinwheel™ antenna [4] is a multiple-point fed antenna with outstanding wideband circular polarization performance. It uses spiral shaped traveling wave microstrip line to feed power to each slot radiator through aperture coupling. These couplings have to satisfy the phase equation in Eq. (1).

For patch antennas, the multiple or balanced feed suppresses some of the high-order radiation modes (for example, TM^{21} mode for circular patch antenna) so that the source for cross-polarization is significantly reduced. Cross-polarization is one of the main causes of bad axial ratios, strong multipath noise and low radiation efficiency. The push-pull balanced feed also improves the radiation pattern symmetry in the elevation cuts [6-7], so that the phase center stability of the antenna is improved. However, most of the quadrature feed components for antennas in the commercial market are still single band. Although some researchers have endeavored to design dual-band/wideband quadrature feed network for GNSS applications, the challenges are high cost, higher insertion loss and enormous phase imbalance. Some designs separate the high-band and low-band into two sets of feeding networks to feed two antenna elements independently. This approach sacrifices antenna radiation efficiency and the gains due to unavoidable mutual couplings.

NEW ULTRAWIDEBAND ANTENNA FEEDING NETWORK USING PHASE REVESALS

Recently, a novel ultra-wideband quadrature antenna feeding technology has been developed at NovAtel [10-11], which features very low insertion loss and frequency independent amplitude/phase balance. The concept is explained as follows: phase difference of 180-degree represents two opposite phase values, therefore such device can be regarded as phase reversals. In two-wire based DC transmission lines, the phase of transmitted signals can be reversed by simply exchanging the positions of the two wires ("+" and "−"). Applying the same concept in microwave transmission line systems, frequency-independent phase reversals can be obtained.

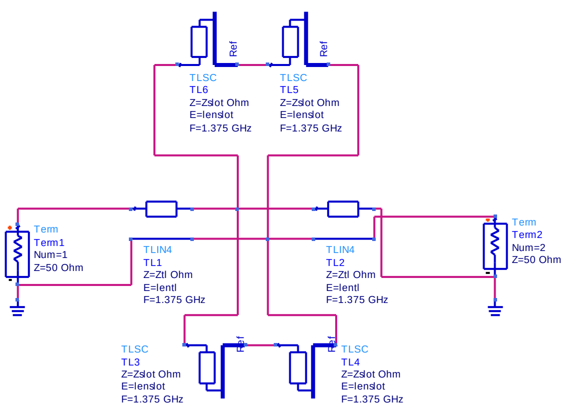
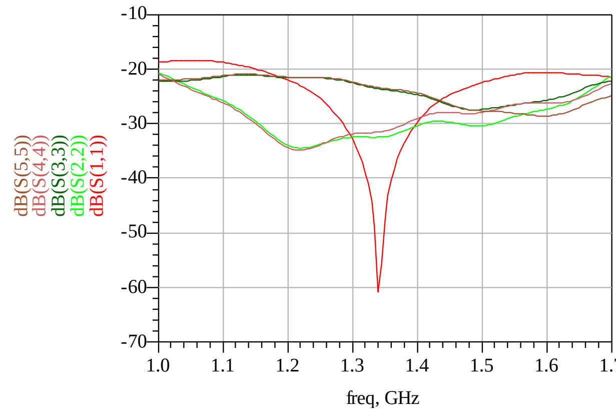
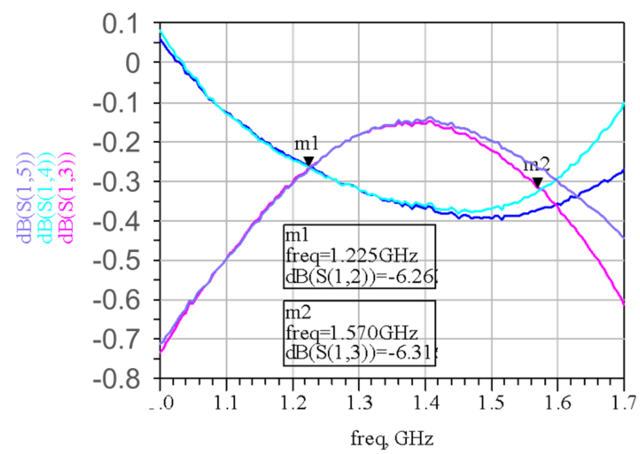


Fig.3 Equivalent circuit for the proposed phase reversal structure.

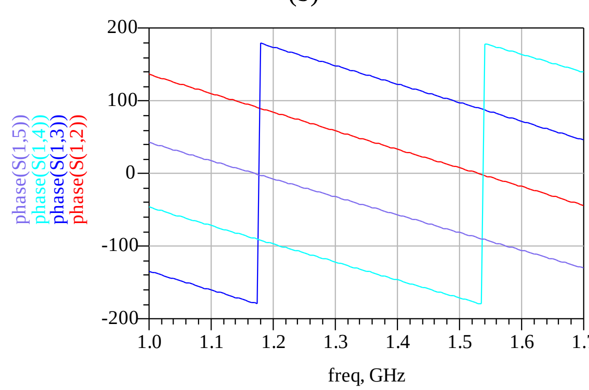
The novel microstrip line phase reversal structure consists of two sections of microstrip lines and two slots etched into the ground. A transition structure is first used to transit single-ended microstrip line to parallel-striplines. Then the two vias make the position exchange of the strip pairs, which is the key to obtain the phase reversal. The parallel-stripline subsequently transitions back into microstrip line again. The corresponding equivalent circuit of such phase reversal structure is shown in Fig.3, taking into consideration all the affiliated EM elements and their parasitic effects. The slot lines etched on the ground plane act as the shunted series short-ended stubs for the main microstrip lines. For best matching and insertion loss, the length of the slot line should be close to quarter-wavelength at the center frequency of interest. The microstrip line transition in such structure is ultra-wideband in amplitude and phase response. The only bandwidth limiting part is the slot-loading, but it is wide enough to cover whole GNSS frequencies. The length and width of the slotline is used to tune the bandwidth and impedance matching.



(a)



(b)



(c)

Fig.4. Measured performance of the quadrature feed network. (a) Return loss. (b) Insertion loss. (c) Phase.

A quadrature antenna feed network is designed and tested, and the measured return loss, insertion loss and phase from input port to four of the individual output port are shown in Fig.4. The feed network designed with this technology offers ultra-wideband impedance matching, has amplitude imbalance of below 0.2dB and almost zero phase imbalances (seen from equal phase distances among the output phases with frequency in Fig.4(c)). The ultra-wideband balanced phase and amplitude response guarantees an outstanding circular-polarization radiation. NovAtel's quad-feed network has superior performance compared to most other feed network technology, and is useful for all the multi-fed antennas that desire good performance.

ANTENNA RADAITION PATTERN OPTIMIZATION WITH PARASITIC CIRCULAR ARRAY LOADING TECHNOLOGY

The gain roll-off for most low-profile and planar GNSS antennas, such as patch and Pinwheel antenna, are at 12~14 dB range from zenith to horizon and the C/No at low-elevation angle typically drops by a large amount. In some regions, such as those at high latitude, receiving L-band correction signals from geostationary satellites could become difficult. To improve the low-elevation angle coverage, much taller antennas (for example helixes, need at least 8cm) have been used in practice to meet such requirement. However, they suffer from their intrinsic high-profile, enormous backlobes and receive more multipath signals from below the antenna which prevent them from being used in high accuracy systems. As stated in the introduction, high performance GNSS antenna often requires both balanced gain roll-off and multipath rejection at low-elevation angles. NovAtel has endeavored to develop new technologies to achieve a low profile, and gradual radiation pattern roll-off, in one antenna.

Planar antennas may unavoidably excite surface waves that bounce along the interface between the air and the ground plane until it diffracts at the edge of the ground, which generally causes more left-handed cross polarization. For example, a patch antenna equivalently radiates at the resonant slot ring formed between the metallic patches and the ground plane. Since the dielectric substrate for most of our designed antennas has a truncated edge, it does not support the propagation of dielectric/metal interface bounded surface waves. However, the fringe field in the patch edge does launch TM surface waves propagating along the air-metal (ground plane) surface [12]. Such surface waves are also called surface plasmons in optics, and at microwave frequencies they extend a great distance into the surrounding space with very low decaying factor. The H-fields of such wave are transverse to the direction of the propagation, wherein corresponding longitudinal surface current flows on the metal conductor. While the E-fields are linked to oscillating (at the frequency of the radiating waves) charges distributed on top of the metal and therefore forming loops vertically jumping in and out of the surface along the longitude direction. It propagates at nearly the freespace speed of the light. It is often described as surface currents, rather than surface waves in microwave. In fact, they are not so different from the normal alternating currents on any conductor. The surface wave travels from the formed patch-slot ring all the way to the edge of the truncated ground plane, where it would be diffracted and re-radiates to the space as if the metal edge were point sources. These radiations contribute to the far-field of the antenna in all direction, the upper-hemisphere, lower-hemisphere and the horizon. For GNSS applications, these unexpected radiations generally increase the reception of noise signal from multipath or nearby interferences. Several technologies have been used to suppress or attenuate the TM surface current from propagating, such as chock ring and resistive stealth ground plane. The surface impedance for the wave on a flat metal sheet is derived as

$$Z_s = \frac{E_z}{H_x} = \frac{1+j}{\sigma\delta}\ [\Omega/\square]. \tag{2}$$

where σ is the metal conductivity, δ is the skin depth. From this equation, a conductor surface typically shows low surface impedance.

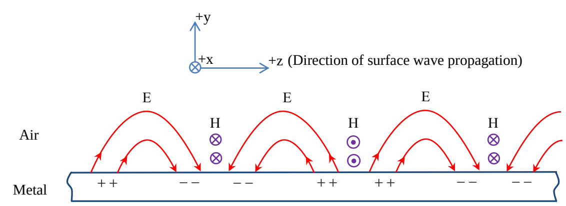


Fig.5. Propagation of TM+z surface wave along the metal/air surface.

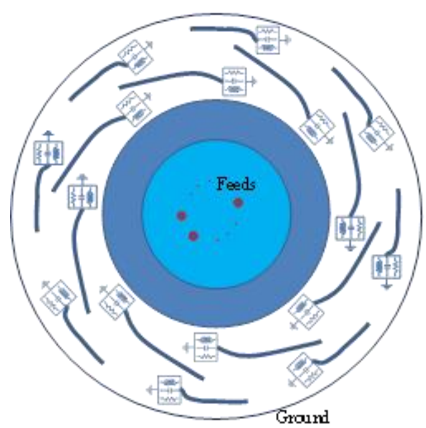


Fig.6. Proposed antenna concept with spiral shaped peripheral parasitic circular array loadings.

A new planar antenna technology (Fig.6) is proposed [13] by using peripheral spiral shaped reactive/resistive-loaded (could also be connected with certain phase-delay lines) monopoles circularly arrayed around the main antenna element to interact with and manipulate the aroused surface wave and re-radiate to the freespace. The reradiation of the electromagnetic field contributes to the antenna's total far field and is used in the design to reshape the radiation pattern and reduce the cross-polarization.

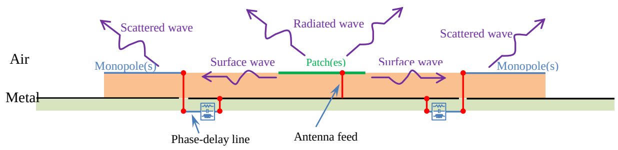


Fig.7. Illustration of the interactions of microstrip antenna excited surface wave with the proposed structure. The surface wave becomes scattered wave after hitting the surrounding parasitic monopoles.

Depending on the loading impedance of the RLC tank (resistor, inductor and capacitor, $Z_L=R//L//C=R_L+jX_L$, it is a combination of R, L and C, which can be designed to control its matching to the input impedance of the monopole), some portion of the surface wave signals induced in the parasitic monopoles are first guided through the phase-delay lines and then are reflected (scattered) and re-radiated at certain phase as illustrated in Fig.7. The reflection coefficient at the monopole is a function of the load impedance and the magnitude of the re-radiated power depends on the design of the monopoles. For instance, the position, height and shape of the monopole define how much power is induced and the radiation efficiency. Typically, the parasitic elements are near resonance to re-radiate the surface wave more efficiently, i.e. when the total electric length of the monopole is close to multiple-quarter of guided wavelength, it reaches highest efficiency.

This new design has the following benefits: 1) The surrounding parasitic monopoles act as the loads to the main radiator which reduces the quality (Q) factor, increasing the bandwidth of the antenna; 2) the near field and far field of the antenna is changed, allowing the radiation pattern of the antenna to be varied, eg., the roll-off may be decreased or increased, sometimes desirable for GNSS applications; 3) the axial ratio at the low-elevation angle is improved since the unwanted surface wave diffraction at the ground edge is manipulated by the purposely added peripheral parasitic radiators. Together with the frequency-independent quadrature feed network technology, the immunity to left-handed polarized multipath signals reflected from objects beside or below the antenna is enhanced; 4) the phase center is tightened still due to suppressed surface current.

ANECHOIC CHAMBER AND GNSS LIVE SIGNAL MEASUREMENTS

The antenna design is optimized to cover all GNSS bands while suppressing unwanted out-of-band signals by adding to the rejection of potential interferers with designed filters. Antenna efficiency is an important parameter quantifying how efficient it is for an antenna to radiate power away to freespace. It is defined as the ratio of the power radiated from the antenna relative to the power delivered to the antenna. A low efficiency antenna has most of the power absorbed as losses within the antenna structure and material, or reflected due to impedance mismatch. Typically higher efficiency gives higher antenna gain. Due to the losses to heat in dielectric, metal conductor and other materials such as plastics, 60% efficiency is regarded as good in GNSS antennas, accounting for 2.2dB loss. Fig. 8 shows the total efficiency of the proposed antenna at GNSS high band and low band with the proposed new circular array loading technology compared to the original antenna without any loading. It demonstrates that the proposed technology in general increases the efficiency and enhances the operation bandwidth.

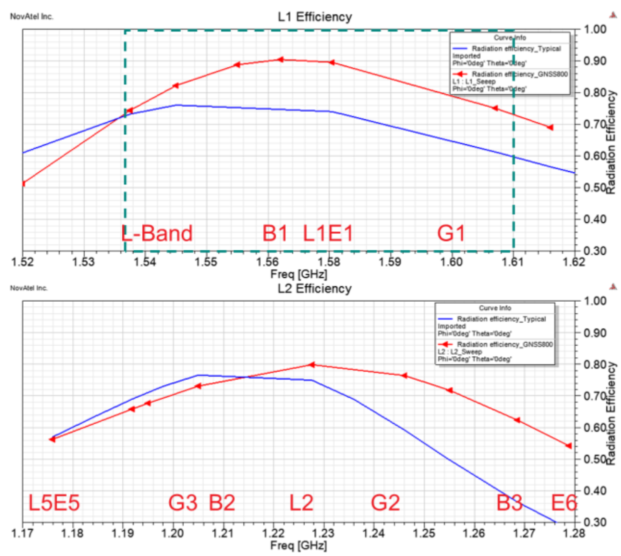


Fig.8. Comparison of total efficiency of the antenna with circular array parasitic loadings (red marked curve) and without (blue solid line) in high and low band respectively.

The radiation performance of the antenna is validated by performing detailed measurements both in NovAtel's in-house anechoic chamber and by various GNSS live signals. The anechoic chamber is used to measure the actual 3D amplitude/phase radiation patterns for right-hand and left-hand signals and determine the phase center location and variations with satellite signal incident angles. The mean PCOs in the horizontal plane, relative to the antenna physical center, or antenna reference point (ARP), are within millimeter range throughout the operation bandwidth, almost frequency-independent. The PCVs across all elevation angles are below half millimeter. This is beneficial for geodetic or rover applications, since the orientation of the antenna is unknown and cannot be corrected for on the receiver. It is normal for directive antenna that the phase center moves in Z-axis. The results are not shown here since this offset can be corrected in receiver with software.

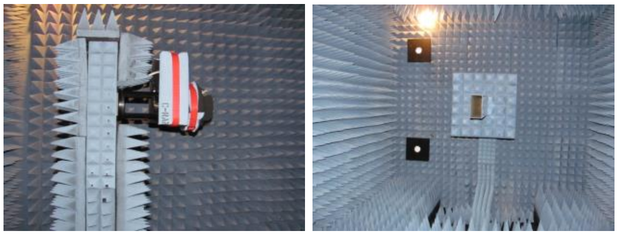


Fig.9. Photos of anechoic chamber used for testing the GNSS antennas at NovAtel.

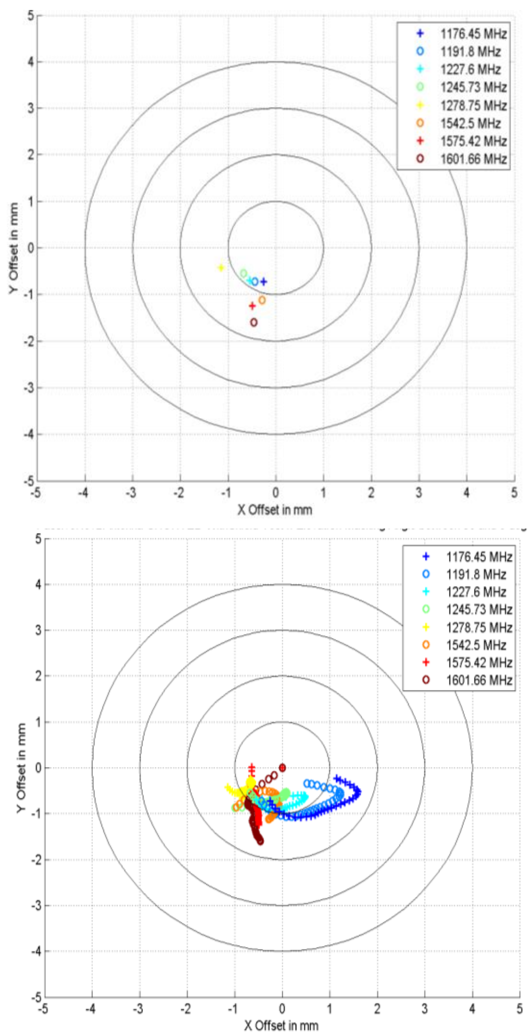


Fig.10. Azimuth XY-plane mean phase center offset (PCO) from antenna reference point (ARP) and phase center variations (PCV) with elevation angles measured at different GNSS center frequencies for GNSS800 antenna.

Fig.11 shows a typical radiation pattern of the antenna. Over all GNSS frequencies and azimuth angles, it obtained very stable/symmetric radiation patterns over elevation. The gain roll-off from antenna boresight to horizon can be varied in a wide range from 9dB to 13 dB by the loaded circular-array design. For better low-elevation angle tracking, the roll-off should be low; however to increase the up/down ratio or multipath rejection, the roll-off should be high. The obtained radiation pattern is a result of performance optimization and best compromise, with moderate roll-off from zenith to 10 degree elevation, and then decrease sharply to very low in the backside of the antenna.

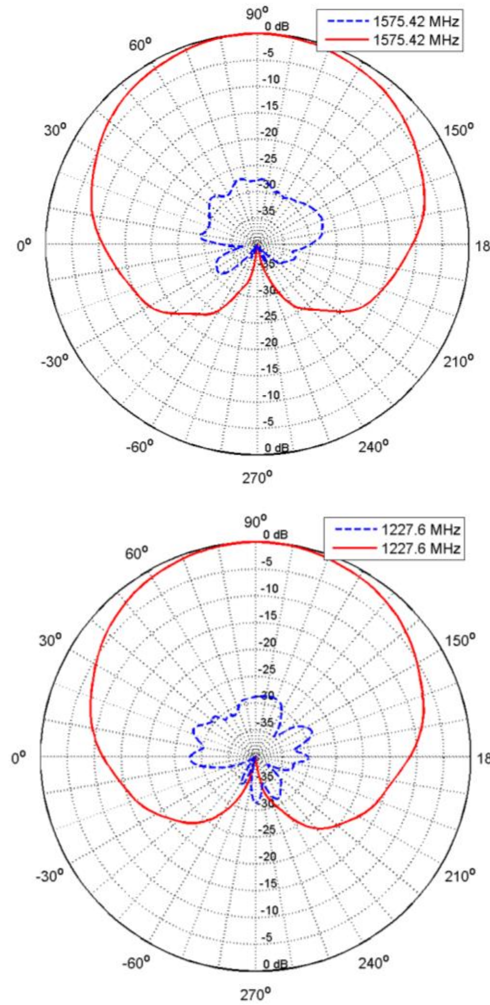


Fig.11. Measured RHCP and LHCP amplitude radiation patterns at L1 and L2 channels.

The axial ratio with elevation angle is plotted in Fig.12 for all the GNSS channels. For satellite elevation angle from zenith to horizon, the axial ratios at all the GNSS frequencies are below 3dB, which provides pleasant suppressions of unwanted left-hand polarized signals.

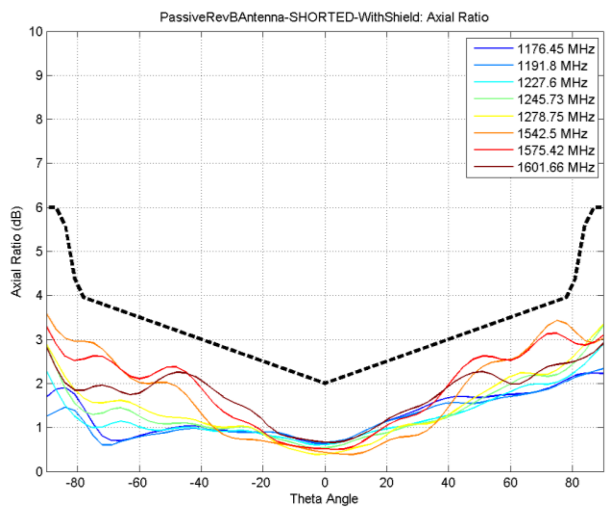


Fig. 12. Measured axial ratio with elevation angle at all GNSS frequency.

The proposed antenna was also validated by live GNSS signal measurement by mounting the antenna on the roof of NovAtel building. The data was collected using NovAtel's OEM719 GNSS receiver. By collecting data for all the satellites trackable over a 24-hour period, the mean C/No with elevation angle of tracked satellite at GPS L1, L2 and L5 are shown in Fig.13. In comparison with another commercial survey grade antenna, the low elevation angle C/No is improved while the zenith C/No is the same or better. The drop of C/No at about 22 degree at L1 is mostly due to scattering and reflection off a nearby building structure, similarly seen for the comparison antenna mounted at same position.

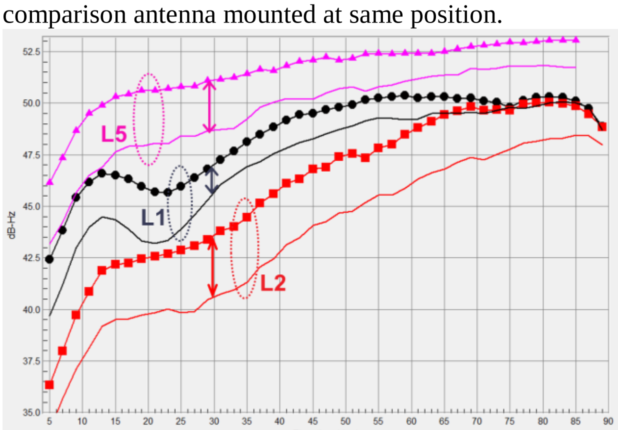
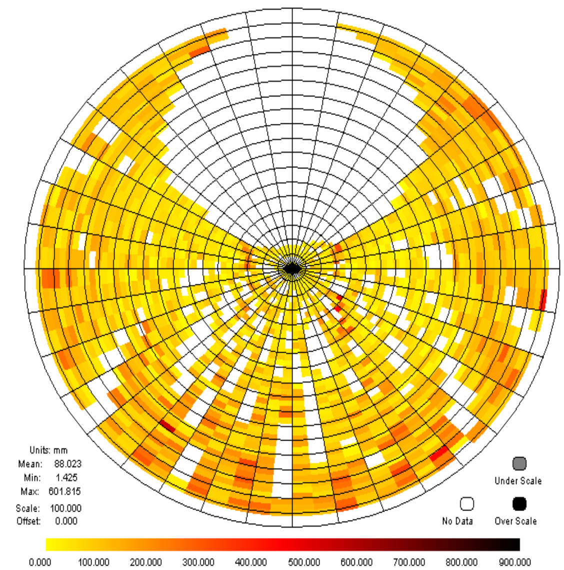
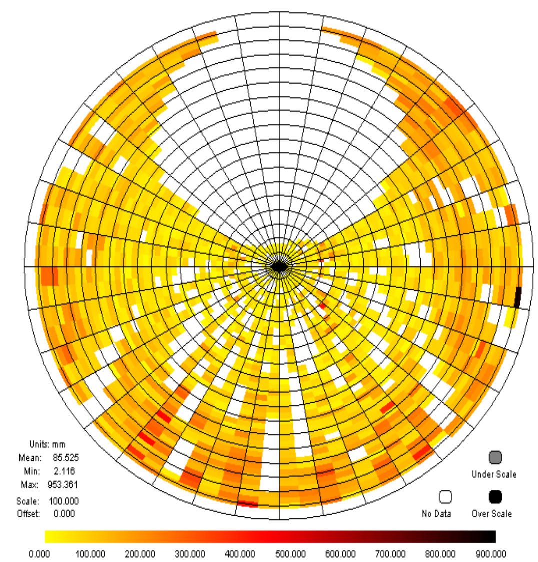


Fig.13. Roof-top live GNSS signal measured mean CNo with elevation angle, in comparison with another commercial survey grade antenna.

An antenna's multipath susceptibility level could be affected by many factors: the terrain profile and material property of ground surface where the antenna is mounted; sky obstruction surrounding the antenna; receiver's multipath mitigation technique, such as Narrow Correlator™[14], MEDLL™[15], PAC™[16], etc.; and the antenna's axial ratio and radiation pattern roll-off and up-down ratio. Figure 14 below shows the multipath level plotted using NovAtel's proprietary Sky Plot processing program by calculating the standard deviation of code minus carrier (CMC in meter). Statistically, the standard deviation of the code minus carrier (CMC) can be used to create a picture of the pseudorange distortion, usually multipath, from a single receiver [17].



(a) GNSS-850 antenna



(b) GPS-703-GGG

Fig. 14. GPS L1 CA Code minus Carrier Standard Deviation plot for (a) GNSS800 antenna and (B) GNSS703 antenna.

The above sky plots show the CMC standard deviation, for NovAtel's VEXXIS GNSS-850 and Pinwheel GPS-703-GGG antenna respectively, using a 24-hour data set, where North is at the top of the polar plot. The zenith (90 degree elevation angle) represents the phase center of the antenna and the horizon (0 degree elevation) is around the rim of the sky projection. White is for the sky angle where no satellites appear, and the prominent hole in the upper center is due to the fact that satellites never go over the North Pole area. This multipath rejection performance of the new antenna compares very well to 703-GGG antennas and some improvements are seen over low elevation angles.

CONCLUSION

The patented ultra-wideband antenna feeding technology has been utilized to design NovAtel's low-profile high performance VEXXIS family of antennas with reduced size. This feeding network contributes to the outstanding wideband amplitude and phase balance performance. The new generation of antennas offers superior circular polarization and antenna gains over the entire GNSS bandwidth, and symmetric radiation pattern in an extended elevation angle range, resulting in sub-millimeter phase center. In addition, by using the parasitic circular array loading technology along the peripheral of the radiation elements, axial ratio is further improved especially at low-elevation angles, and the gain roll-off at these angles is able to be optimized for balanced low-elevation angle tracking and multipath rejection. Compared to conventional patch antennas, the VEXXIS antennas uses a single PCB to achieve wide dual GNSS bands, keeping a planar and low-profile form factor while allowing for optimized gain roll-off and multipath performance without resorting to 3D structures.

Its performance meets the stringent requirements that GNSS systems require from a front-end antenna. The features of this new series of antennas are very attractive for high-precision positioning applications when more satellite constellations, wider angle coverage, and "anywhere/anytime" correction service is required. It is low profile and meets harsh environment requirements, making it desirable for any applications that require a highly accurate positioning solution.

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