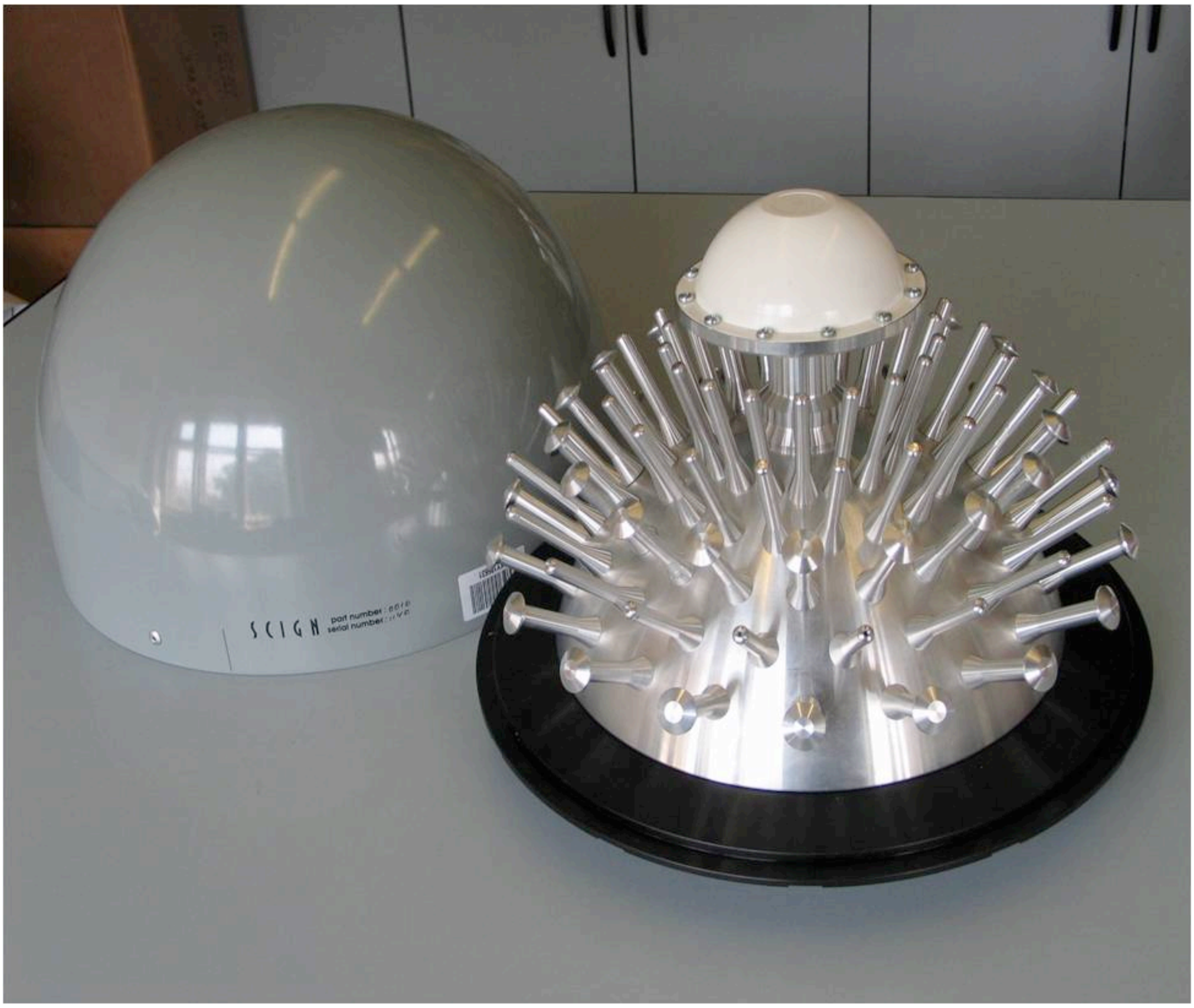
PN-A5

Topcon Full Wave GNSS Reference Station Antenna with Convex Impedance Ground Plane.



Dmitry Tatarnikov

Rev.4

Biography

Dmitry Tatarnikov holds a Master EE degree, PhD degree, and Doctor of Science degree (the highest scientific degree in Russia); all in antenna theory and technique from Moscow Aviation Institute (MAI), Moscow, Russia. He is professor of Radiophysics, Antennas and Microwave Devices Department of MAI. He began his GNSS antenna developments in 1994 with Ashtech Moscow. Since 2000 he is Antenna Design Chief for Topcon Technology Center in Moscow, Russia.

1. INTRODUCTION

The highest accuracy of positioning with the Global Navigation Satellite Systems (GNSS) is achieved with differential modes when the rover receiver uses good quality corrections generated by the reference station. Accuracy in positioning of cm-level or better allows for the broad use of the GNSS signals for geodesy, land survey, construction, and agriculture. Support of differential corrections over large territories requires the installation of a reference antenna for each station within the networks. Presently, networks found globally number thousands of reference stations over the Earth.

An ideal antenna for a reference station receives signals from all satellites in view while fully rejecting signals coming from underneath or indirect. These indirect signals are the result of so-called multipath. They are original satellite signals reflected from the terrain underlying the antenna. These signals mix with the direct signals from the satellites thus providing what is known as multipath error to the positioning. With today's technology, multipath is the largest error source within high precision applications.

Typical antennas used to date for reference networks are of Choke Ring style. This type antenna, originally designed by the Jet Propulsion Laboratory (JPL) of the USA, is shown with Fig.1. This antenna design comprises a special groundplane made of concentric grooves with a total diameter of approximately 40cm. The antenna has typically used a Dorne & Margolin (DM) antenna element mounted in the center. The DM element is a cross-dipole type. The purpose of the choke groove structures used by the antenna is to decrease the antenna gain for the directions below the horizon. This reduces multipath error significantly.

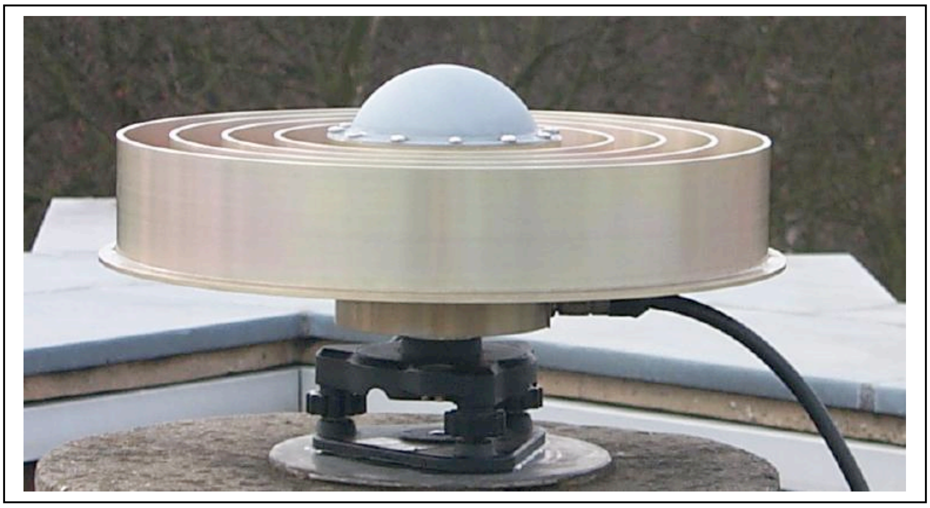


Fig.1 JPL-type Choke Ring antenna with DM antenna element in the center

JPL-designed Choke Ring antennas have been serving satellite positioning applications for over 20 years with a large number of antennas based on this design currently in operation. However, two considerations are to be addressed with new antenna developments.

The first consideration is the ongoing GNSS constellation expansion for new satellite systems and new signals. The JPL Choke Ring with DM antenna element was designed at a time when only the United States' GPS constellation was being used for all practical purposes. Later, Russia's GLONASS constellation was supported by the antenna functionality. Both the GPS and GLONASS systems have been radiating two signals known as L1 and L2. Additional to these existing systems, currently under deployment are the GALILEO system of the European Community, the QZSS systems of Japan, and the COMPASS system of China. Several other systems of different countries are being explored. This is in addition to the modernization for the new L5 signal of GPS and the L3 signal of GLONASS.

The GPS L5 signal is already being transmitted by new generation satellites while GLONASS L3 is planned and pending.

Electrical engineers refer to this as GNSS spectrum expansion. One example is the L2 signals of GPS and GLONASS occupying 1217MHz to 1252MHz radio frequencies. Considering all new signals and systems will occupy the range within the spectrum from 1160 MHz to 1300 MHz with a bandwidth of 140MHz, this result in a factor of 4 versus the bandwidth of 35MHz for the L2 band 1253MHz to 1217MHz. This is in addition to the L1 segment from 1560 MHz to 1615MHz. A reference station antenna is desired to serve for many years without replacement and the natural wish of a network administrator is to have the antenna fully compatible with these existing and new signals.

The second consideration comes from the fact the Choke groove structure of the original design contributes to narrowing of the antenna pattern if compared, for instance, to more portable antennas of non-Choke Ring design which are typically used as GNSS rovers. The signals from lower elevated satellites will be suppressed by the Choke Ring antenna at a larger extent than those of a rover antenna. The result is more difficulty with signals from low elevation satellites being tracked by the reference receiver. However, the low elevation satellites are of prime importance for satellite positioning when considering the Dilution of Precision (DOP) factor [1] directly affecting the precision. Antenna pattern narrowing is an unavoidable feature of the plain Choke groove structure.

The new antenna development goals of Topcon are to address both of these before mentioned considerations. Specifically, to obtain robust antenna tracking performance over the expanded GNSS frequency band covering all the existing signals, new signals expected over the next 10-15 year span, and to increase the antenna gain for low elevation satellites making the gain comparable to a typical rover antenna. These goals are to be achieved without decreasing the proven multipath rejection capabilities of the Choke Ring antenna.

It is worth noting any improved antenna performance can be theoretically attained if the antenna design size and weight are unlimited; this fact of electromagnetic technology. One criteria of Topcon's new PN-A5 antenna development was to keep size and weight consistent with the original Choke Ring antenna. This size and weight are already well established by practice. The Topcon PN-A5 antenna is designed to fit the existing Topcon radome and the SCIGN radome that are well known to the GNSS community.

2. DESIGN BASICS.

Design basics of Topcon's PN-A5 antenna have been discussed in detail in the references [2…4] and are briefly summarized in the following sections.

2.1 Straight pins structure versus choke grooves.

Choke grooves of the initial design found in Fig.1 form a so-called impedance structure. The term "impedance" means an imaginary surface exists where the relationship between the electric and magnetic fields is of another type compared to regular conductors or isolators. This impedance surface passes through the choke groove openings. Fig 2 schematically shows a cross-sectional view of the choke grooves structure with the impedance surface shown by a dashed line. Properties of regular conductors or isolators normally do not vary much with changes of the radio frequency of an applied signal. Conversely, the surface impedance of the choke groove structure does exhibit variations over the GNSS frequency band.

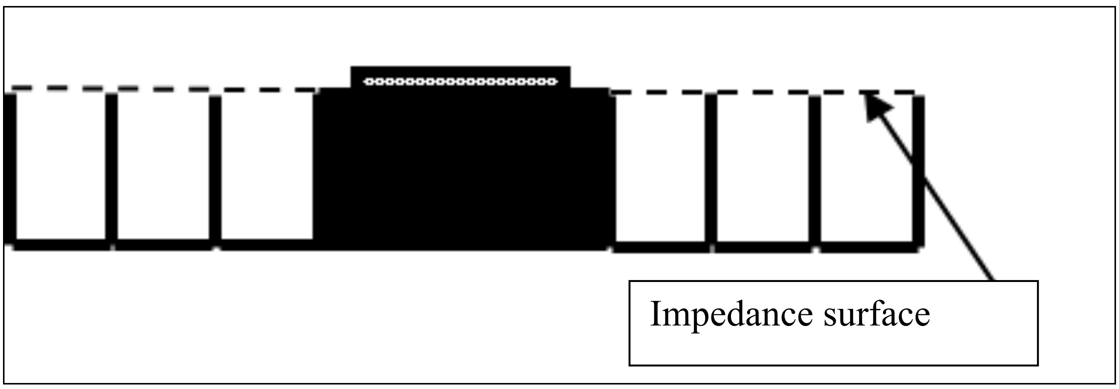


Fig.2 Cross-sectional view of the choke grooves structure of the original Choke Ring antenna with the impedance surface shown by dashed line.

Another design to create an impedance surface is a straight pins structure shown schematically with Fig. 3a. The impedance surface is located at the pins' ends as shown by dashed line with Fig.3b. Within the design process it has been established the desired property of the impedance surface formed by the pins structure demonstrate 30% less frequency derivative compared to a choke groove structure. This allows for more consistent antenna functionality over the expanded GNSS frequency band.

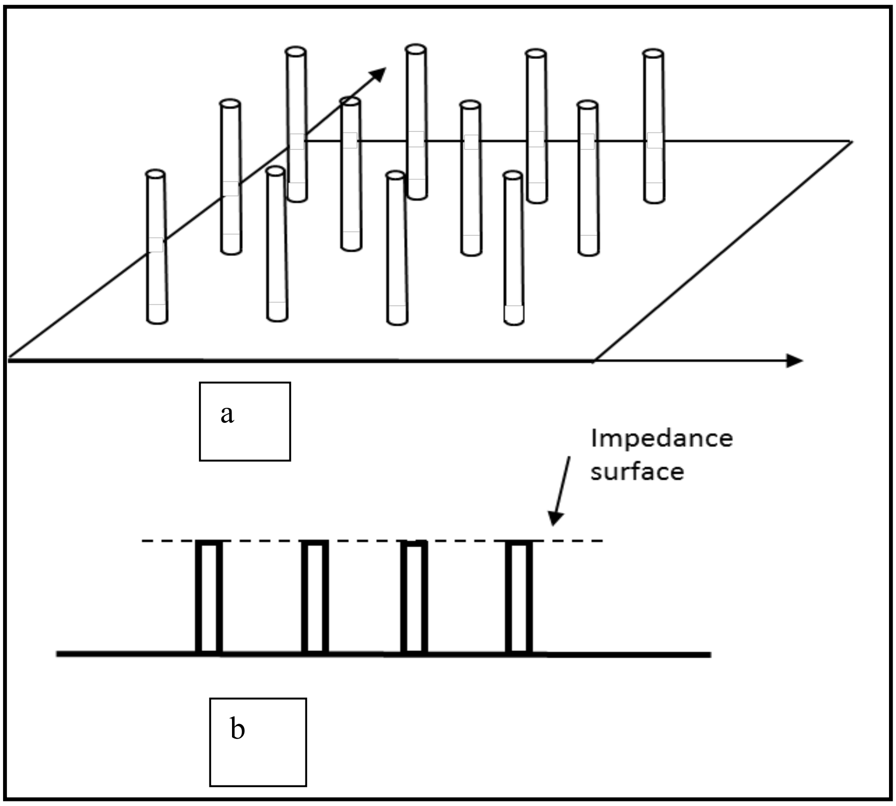


Fig.3 Straight pins structure (a) and cross-sectional view (b) with the imaginary impedance surface shown by dashed line.

2.2 Convex impedance ground plane versus flat ground plane.

Antennae used with satellite positioning are essentially of the receiving type. However, as with most cases related to the antenna technology, it is easier to consider transmitting mode of the antenna rather than receiving. Equality of antenna properties for both modes of operation is established by basic theorems of the antenna area. We will consider this approach now.

With transmitting mode, the DM antenna element placed in the center of the structure of Fig.1 would be the source of excitation. If the impedance surface of the choke groove openings is properly tuned then it generally forces the wave travelling from the source to leave the surface faster than it would if the surface was made of a plain conductor such as metal. This is schematically shown with Fig.4. This is why, with the impedance surface, the field along the surface decays faster, resulting in a small portion of the radiated power reaching the ends of the impedance surface. Thus only a small portion of the power will diffract over the structure's ends and propagate in directions underneath the antenna. This explains why with the impedance structure, an antenna gain for the directions underneath the antenna is small. Considering now receiving mode, one can say the impedance structure does provide suppression of multipath signals coming from underneath. However, by "forcing" the wave travelling from the source to leave the impedance surface also results in antenna gain degradation for directions close to grazing. These grazing directions coincide with low elevation angles.

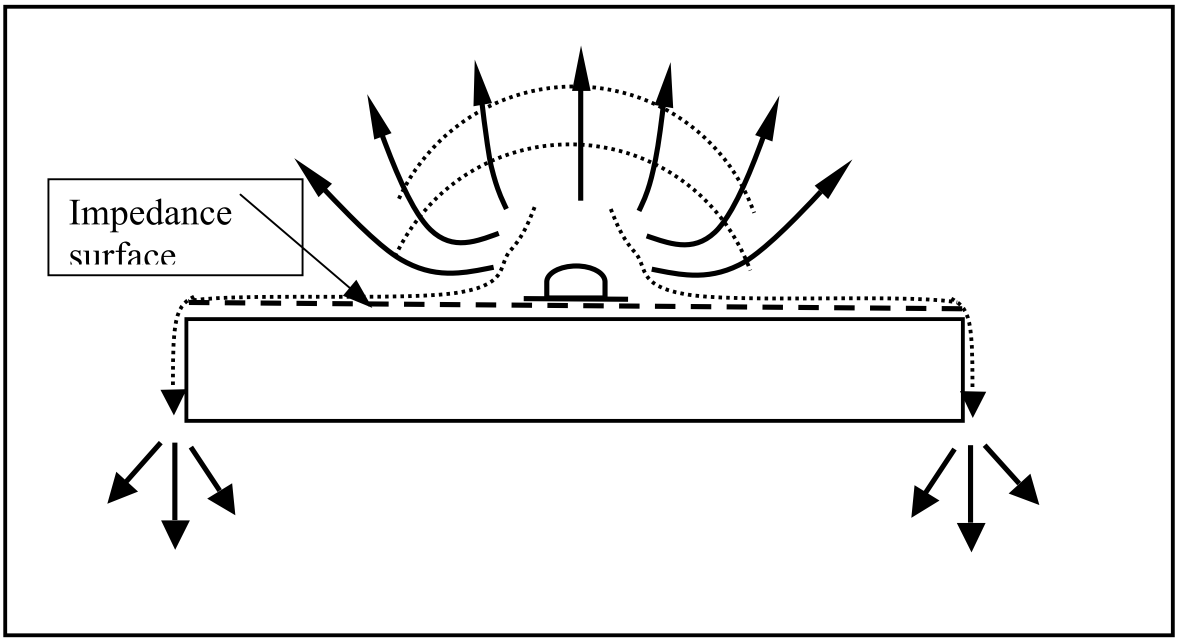


Fig.4 To mechanism of multipath rejection and antenna pattern narrowing with flat impedance structure.

If the surface is made convex rather than flat then the same scenario just discussed holds true (Fig.5). Only the grazing directions are now below the horizon. This improves sensitivity to low elevation satellites. An important consideration is the radius of the curvature of the surface be properly chosen as not to increase the antenna sensitivity for signals coming from underneath. These signals from underneath are multipath. A detailed discussion on this topic is found in the references [3].

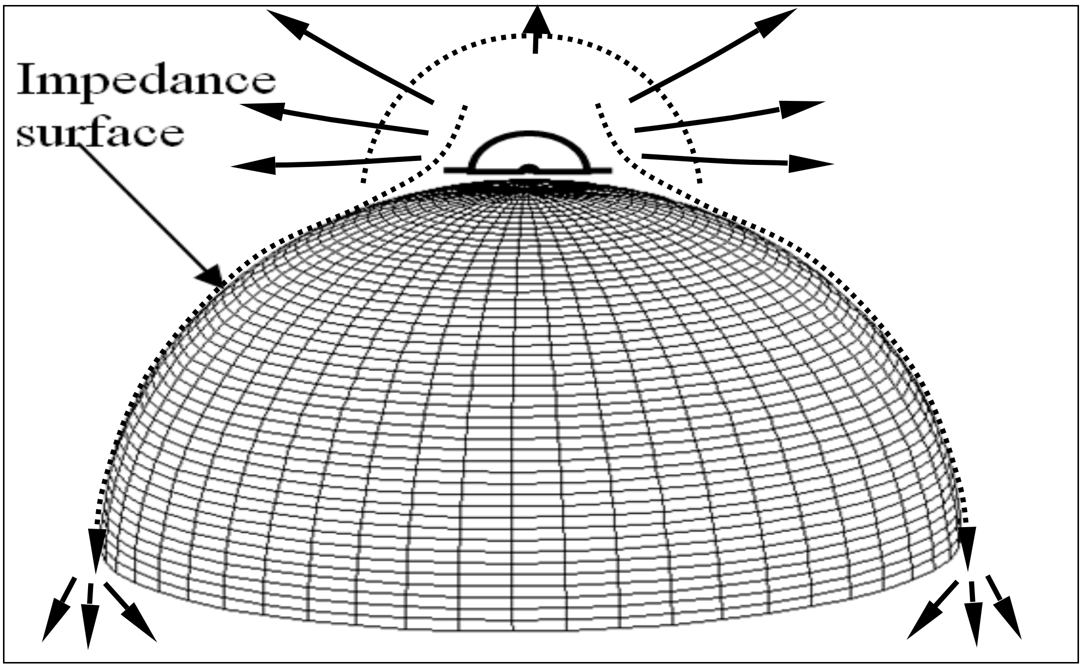


Fig.5 To mechanism of multipath rejection by convex impedance structure.

2.3 Broadband antenna element design

The PN-A5 antenna comprises a newly designed full spectrum GNSS antenna element. This antenna element utilizes an array of vertical convex dipoles. Fig.6 shows the main components of the antenna element. It has an antenna radome (1), a cup with dipoles (2) and power summarizing unit (3). The latter is capacitively coupled with the dipoles. It has been found within the design process that such an array of dipoles possesses a property which could be called an inverse reactance behavior [4]. With such a property, an input reactance of the array structure has a null of the derivative with respect to frequency inside the desired frequency band. The result is a very smooth behavior of the reactance versus frequency and, in turn, broadband functionality. This antenna element possesses a relative bandwidth of more than 40% which is larger than the entire GNSS band from 1160 up to 1615 MHz.

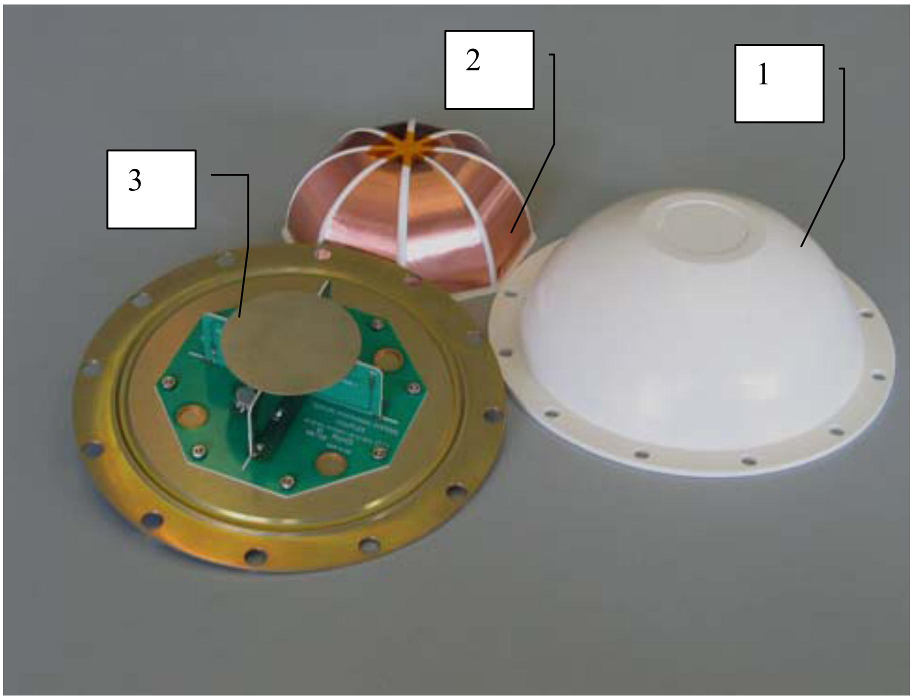


Fig.6 Antenna element of PN-A5 antenna.

3. ANTENNA PERFORMANCE CHARACTERIZATION.

The following section compares the performance of the PN-A5 antenna with a CR4 antenna, which is a Topcon version of the original JPL Choke Ring design.

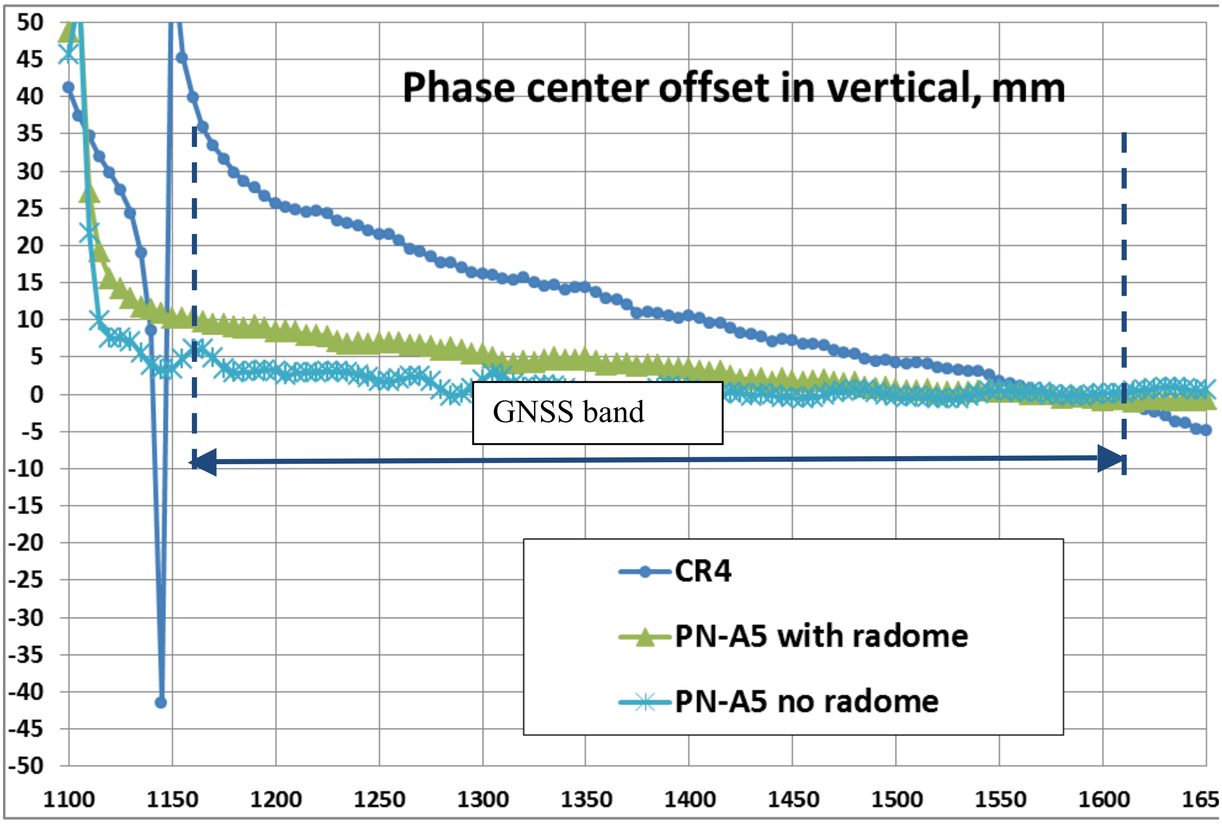


Fig.7 Phase center offset in vertical versus frequency of radiosignal.

Fig.7 shows phase center offset in vertical versus frequency of the radio signal. The results represented in the figure were obtained from anechoic chamber measurements. An offset for GPS L1 (1575MHz) is used as reference. As demonstrated by the graph, the Choke groove structure of the CR4 has resonance at approximately 1150MHz with rapid phase center variation near resonance. This opposed to a phase center offset for the PN-A5 which is smooth versus frequency, with variations not exceeding 1cm over the entire GNSS band. This provides with consistent response for the different GNSS signals.

Fig.8,9 shows normalized antenna gain patterns. GPS L1 and L2 frequencies are chosen as examples. The data plotted is from anechoic chamber measurements. Right-hand circular polarization (RHCP), which coincides with those transmitted by GNSS satellites, is shown as solid lines. Left-hand circular (LHCP) is shown as dotted lines. It is demonstrated the antenna gain pattern roll-off from zenith to horizon for PNA5 antenna is 10-12dB, this being approximately 5dB less than the CR4.

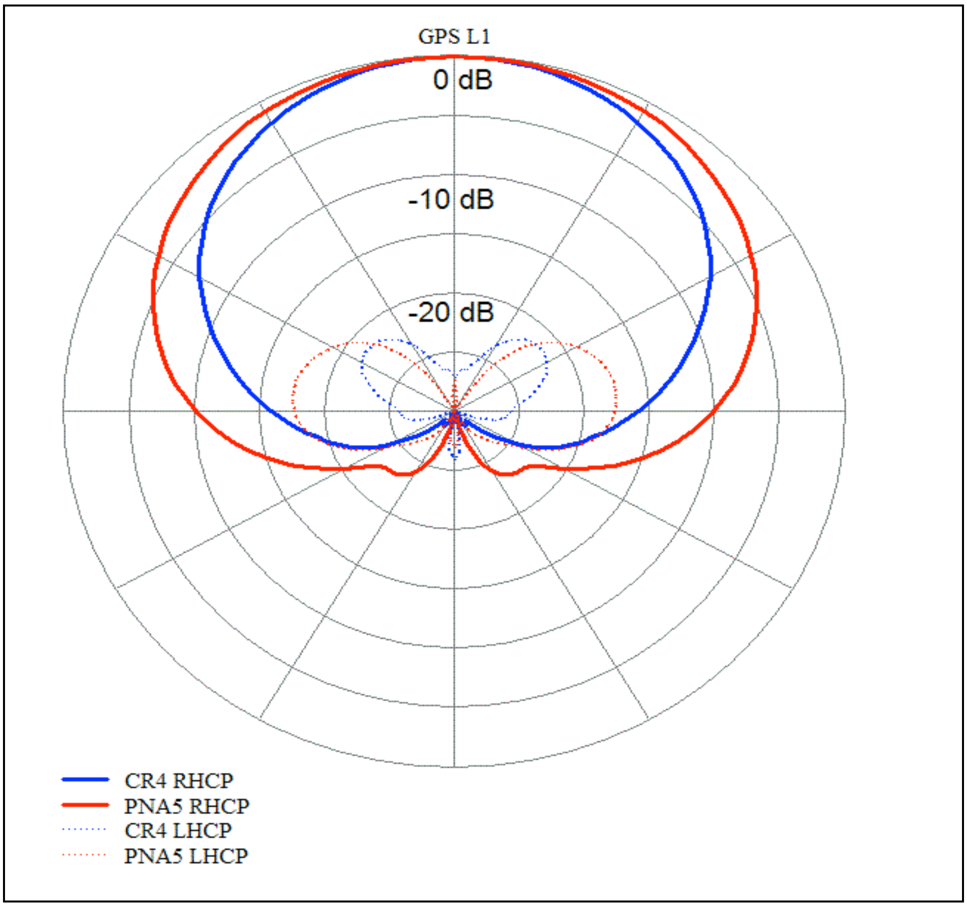


Fig8. Normalized antenna gain pattern for L1 frequency

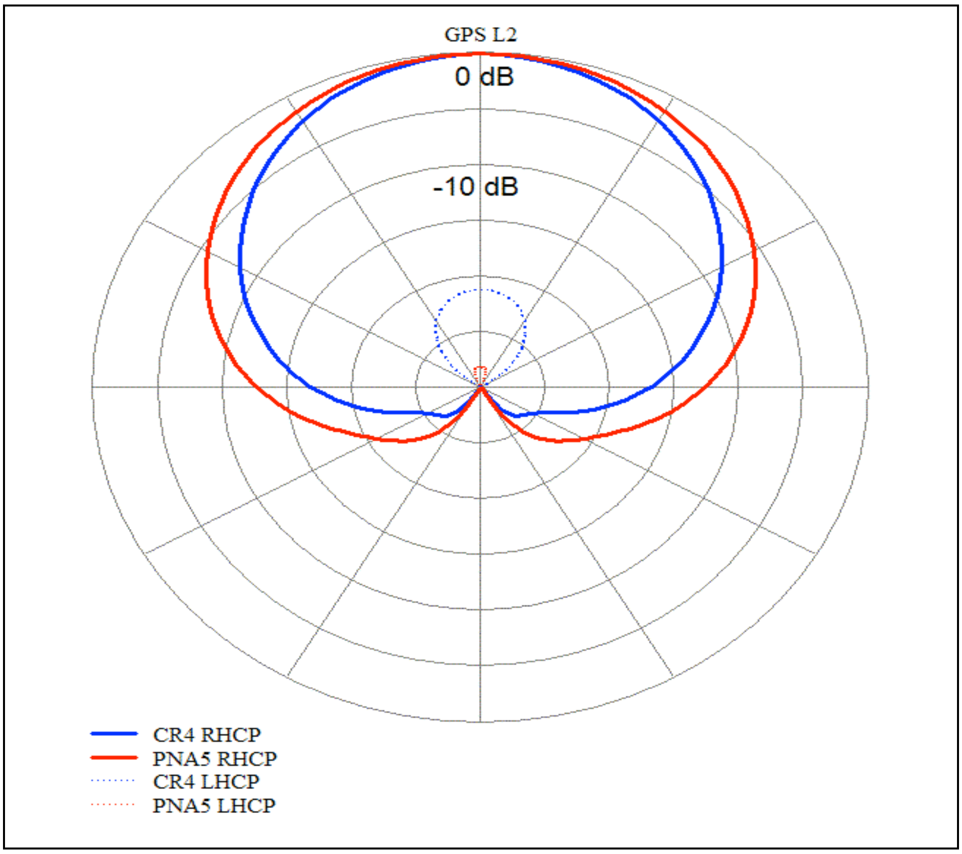


Fig9. Normalized antenna gain pattern for L2 frequency

The 5dB of antenna gain improvement is extremely important for low elevation satellites being tracked by a receiver. With the receiver signal processing algorithms, 5 dB gain improvement of low elevation gain provides up to 10dB improvement in signal-to-noise ratio (SNR) for the P code of GPS. This is illustrated by Fig.10a,b. with the plots representing SNR versus elevation. The receiver used for data collection is the Topcon GB500 receiver.

Such improvement of PN-A5 antenna SNR for low elevation satellites allows a receiver to reliably track satellites to the horizon. It should be noted the antenna gain for zenith for the PN-A5 antenna is 2dB less compared to CR4. This is in agreement with the main antenna directivity theorems based on energy conservation law. Namely, an antenna with a wider pattern is to have less maximal gain. Demonstrated in Fig. 10a,b, this maximal gain lessening of 2dB in SNR decreases for directions close to zenith when compared to the CR4. This does not lead to signal tracking difficulties due to the already high SNR values for these directions.

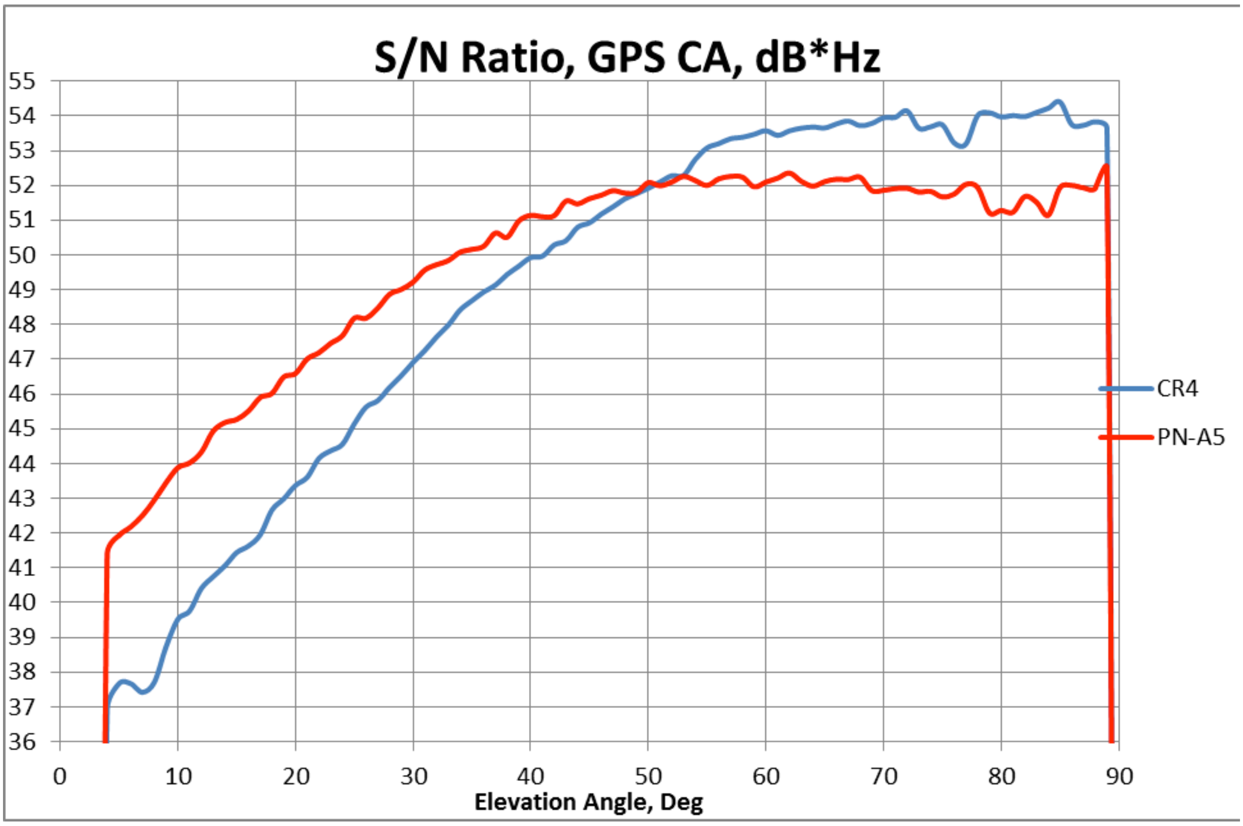


Fig.10a Signal-to-noise ratio versus satellite elevation for GPS CA code.

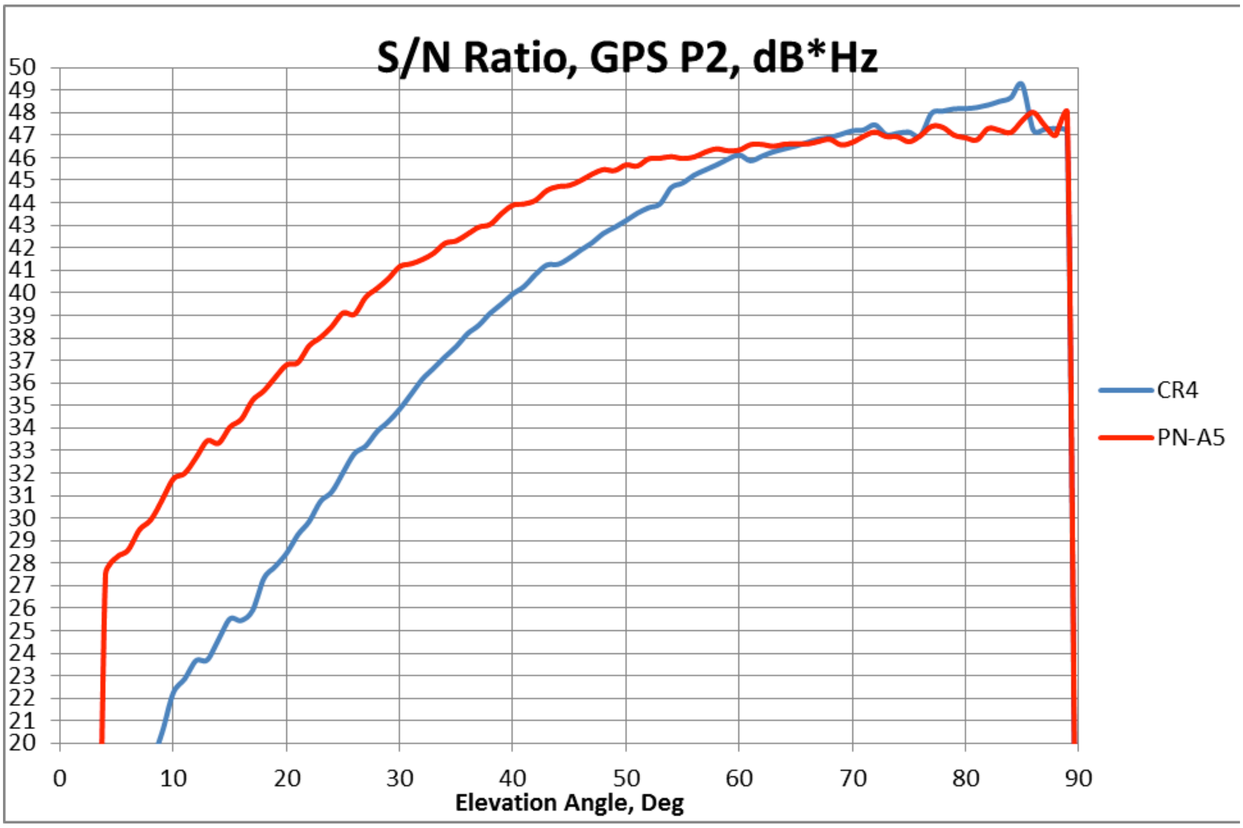


Fig.10b Signal-to-noise ratio versus satellite elevation for GPS P code.

Now we address the multipath rejection capabilities of the PN-A5 antenna. As is well known [1], multipath error is proportional to the ratio between the reflected signal and the direct satellite signal magnitudes. While reflecting from the ground, the original satellite signal changes its polarization properties. For most soil types, the reflected signal is generally left-hand circular polarized (LHCP) rather than RHCP. If the terrain underneath the antenna is homogeneous, then the ground surface acts as a mirror thus providing a reflected signal coming from below horizon at an angle equal to a direct signal above horizon. This is schematically shown with Fig.11. This the reason when characterizing the multipath reflection capabilities of the antenna it is common to use the Down-Up ratio (DU) as a proportion between antenna gain patterns for LHCP signals for the same certain angle below horizon as that for the RHCP signals above horizon at the same angle.

The DU ratio is plotted below. Fig 12,13 demonstrates the DU versus elevation angle for GPS L1 and L2 frequencies. Fig. 14 shows the DU for the zenith direction versus frequency of the radio signal. The data represented is from anechoic chamber measurements. As seen by these plots, multipath rejection capabilities of the PNA5 antenna is competitive to that of CR4 antenna. Fig.14 illustrates the slight advantage of the PNA5 antenna multipath rejection for zenith direction over the entire GNSS frequency band.

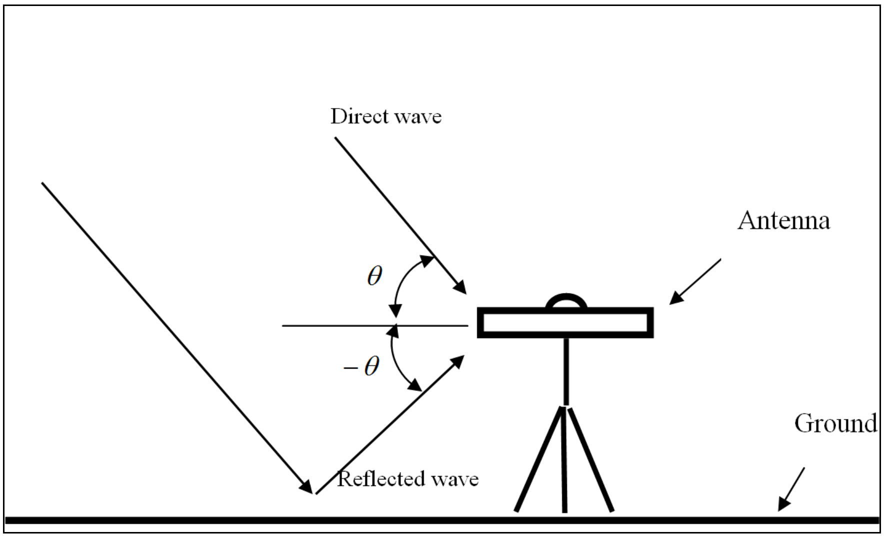


Fig.11 Direct and reflected signals orientation with respect to the antenna.

The undesired resonance at the lowest GNSS band demonstrated by this plot has been discussed previously in regards to phase center offset in vertical. For the PNA5 antenna, this resonance is shifted far below GNSS band.

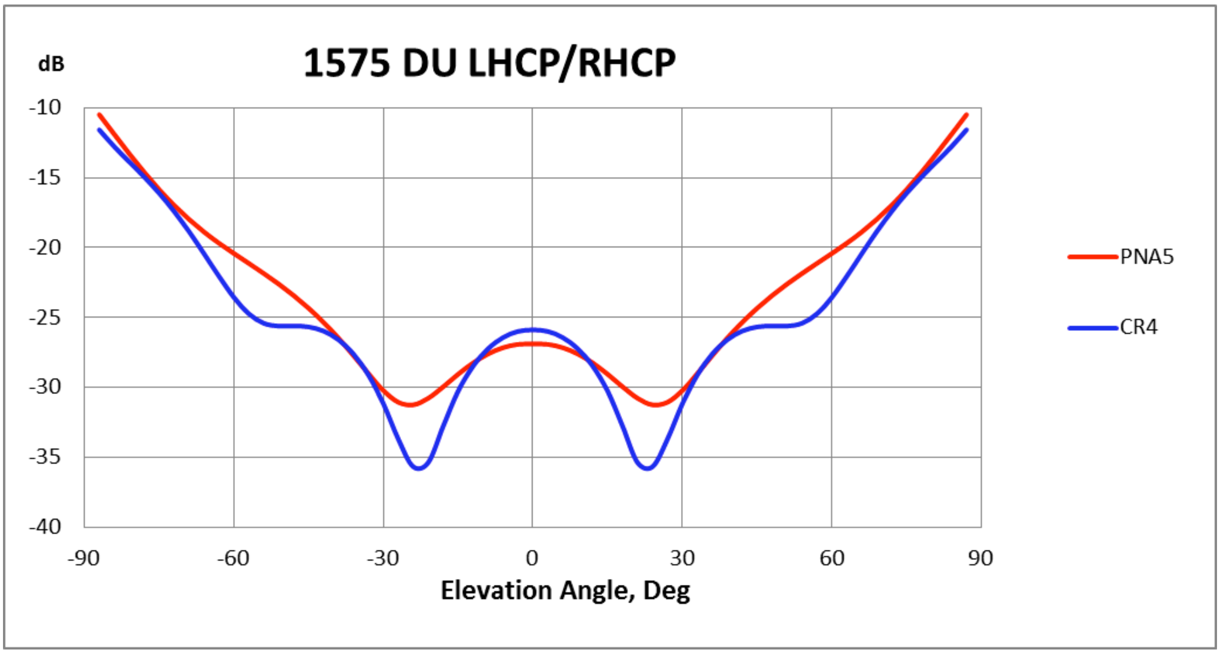


Fig.12 DU plot versus elevation angle for GPS L1 frequency

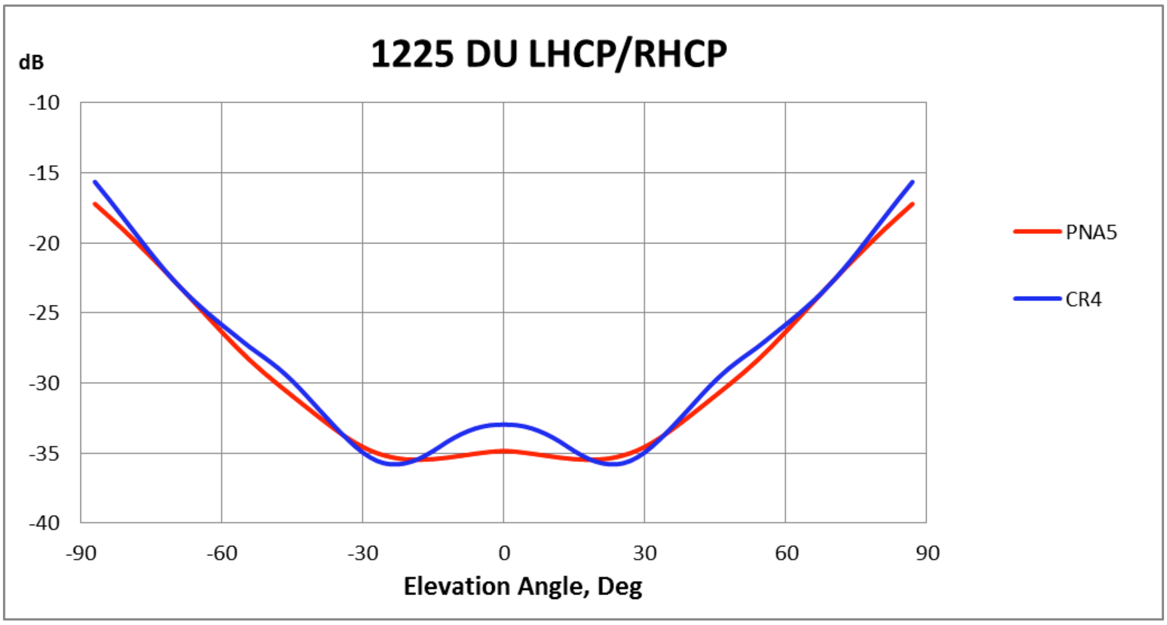


Fig.13 DU plot versus elevation angle for GPS L2 frequency

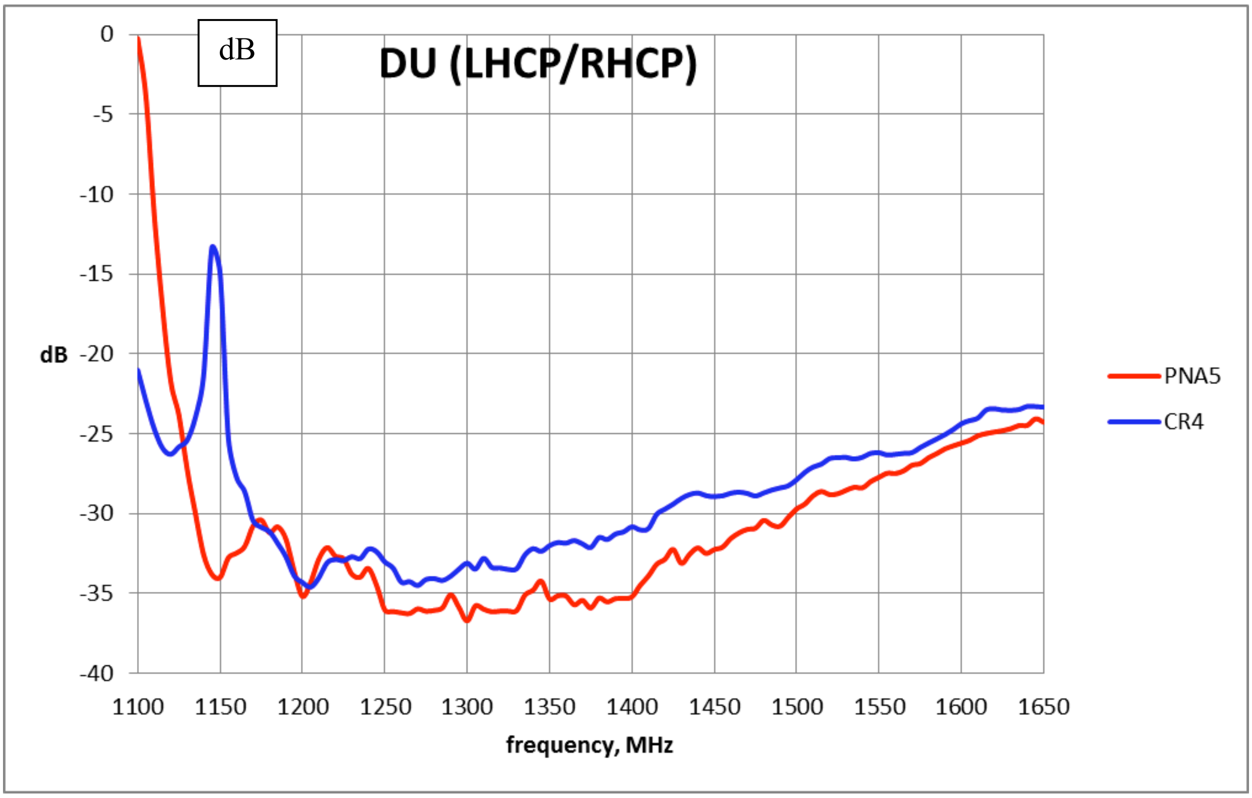


Fig.14 DU plot for zenith direction versus frequency.

Finally, it should be noted the PNA5 antenna is equipped with a state-of –the –art low noise amplifier (LNA). The LNA provides a 1.0dB noise figure, 48dB gain, and 50dB or better of out-of-band signals rejection; starting from 100MHz offset from the GNSS bands. The antenna has a robust and environmentally protected design. It is housed within the exisiting Topcon and SCIGN radomes as previously mentioned with a total weight of 9kg.

4. CONCLUSION

The PNA5 is a new Topcon full wave GNSS reference station antenna. It comprises a convex impedance ground plane and original broadband multi-dipole antenna element. The antenna is suitable for all GNSS signals existing and those planned for the coming 10-15 years. When compared to the common Choke Ring antenna, the PNA5 provides more consistent frequency response over the entire GNSS band. It offers 5dB gain with up to 10dB signal-to-noise (SNR) improvements for low elevation satellites allowing with reliable signal tracking from the local horizon to zenith. Multipath rejection capabilities of the PNA5 antenna are comparable or exceeding those of the the common Choke Ring antenna. The PNA5 antenna is equipped with a state-of-the-art low noise amplifier with a 1dB noise figure, 48dB gain, and improved out-of-band signals rejection. The antenna has a robust, environmentally protected design with size and weight typical for today reference station applications.

5. REFERENCES

1. A. Leick GPS Satellite Surveying. Second ed. John Wiley & Sons, Inc, New York, 1995
2. D.Tatarnikov, A.Astakhov, A.Stepanenko Broadband Convex Impedance Ground Planes for Multi-System GNSS Reference Station Antennas, GPS Solutions, v15, N2, 2011, pp. 101-108
3. D.Tatarnikov, A.Astakhov, A.Stepanenko GNSS Reference Station Antenna with Convex Impedance Ground Plane: Basics of Design and Performance Characterization, Institute of Navigation, International Technical Meeting (ION ITM), 2011, San Diego, CA, USA, January 24-26
4. D.Tatarnikov, A.Stepanenko, A.Astakhov, V.Filippov Compact circular-polarized antenna with expanded frequency bandwidth, Patent of Russian Federation, №2380799, 2010