Leica AR25
White Paper

- when it has to be **right**

Leica Geosystems

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Biography

Lennon Bedford graduated from the University of Otago in 2003 with a Bachelor of Surveying (Hons). He is currently an Application Engineer for GNSS Networks and Reference Stations for Leica Geosystems based in Heerbrugg, Switzerland.

Neil Brown holds a PhD in satellite geodesy from the University of Melbourne and has been involved with GNSS research since 2000. He is currently Senior Product Manager for GNSS Networks and Reference Stations for Leica Geosystems, based in Heerbrugg, Switzerland.

Justin Walford holds an M.Sc.E in Survey Engineering from the University of New Brunswick, and has been involved in GNSS applications and research since 1990. He is currently Product Manager for GNSS Networks and Reference Station Hardware for Leica Geosystems, based in Heerbrugg, Switzerland.

Abstract

This paper introduces the AR25, a new multi constellation Global Navigation Satellite System (GNSS) choke ring antenna for precise geodetic applications. This revolutionary new '3D' choke ring design allows better low elevation satellite tracking while maintaining the renowned performance characteristics of the traditional choke ring antenna such as smooth amplitude and phase pattern, effective multipath rejections and phase centre stability. The AR25 contains a new ultra wideband Dorne-Margolin element to allow for superior reception of all existing and planned GNSS signals, providing users with improved positioning precision and reliability.

Introduction

The well known Jet Propulsion Laboratory (JPL) designed choke ring antenna with a Dorne-Margolin vertical dipole has been widely accepted within the reference station community. Many choke rings from various manufacturers have been based on this design and used within the IGS and other reference station networks. However, antenna theory has evolved since this antenna was made allowing for innovative choke ring designs that provide better all-round performance. Reference station operators demand the highest performance antennas to allow the most accurate determination of site positions and velocities and high quality Real Time Kinematic (RTK) corrections. The antenna is arguably the most important part of any reference station infrastructure as it defines the measurement reference point. In order to achieve the best performance there are many aspects to the antenna that must be considered, including:

- Low elevation tracking
- Phase centre stability
- Multipath mitigation
- Out of band rejection
- Front to back ratio
- Gain pattern

Reference station operators are generally reluctant to change antennas because they are so important for the site position and accuracy. However, there are many new signals that are now available or planned as part of modernized GPS, modernized GLONASS, Galileo, Compass, QZSS and other satellite navigation or augmentation systems. These space segment improvements include signals transmitted on additional frequencies to the GPS L1 and L2 and GLONASS L1 and L2 that are commonly in use today. Antenna changes will be required to provide "all in view" tracking. Most notable are GPS L5, Galileo E1, E2, E5a, E5b, E6 and Compass B1, B2, B3. Hence it is also important, aside from the factors listed above, that an antenna supports these new signals to avoid the need to change the antenna again in a few years time.

From an antenna design point of view however, widening an antenna to track this range of frequencies creates many challenges to optimize the above characteristics for each frequency. The Galileo E6 and Compass B3 frequencies are the most difficult because of their proximity to frequencies used by air traffic control.

In this paper, the performance of the new wideband AR25 choke ring is compared to the AT504GG, an existing high-end choke ring antenna based on the original design from JPL. The AR25 uses an innovative 3D choke ring design in which the rings are at different heights and contain slots to allow dissipation of unwanted Radio Frequency (RF) energy. This new design helps to improve gain at the horizon while maintaining stable phase centre and pattern symmetry for amplitude, phase and group delay. This allows for better reception and tracking of low elevation satellites, improved multipath mitigation and out of band rejection.

In order to compare the antennas, various real world and laboratory tests were conducted to evaluate key performance criteria for each antenna. Anechoic chambers tests were used to assess the general antenna design and expected performance for the future signals. Empirical tests using the current GPS and GLONASS constellations were used to relate the theoretical characteristics to real world performance.

New Signals

Future proofing the AR25 for the planned GNSS frequencies detailed in Table 1 brings many benefits to reference station and network users. A nominal modernized GPS, modernized GLONASS and Galileo constellation will comprise 78 satellites. This level of coverage will bring new levels of:

- Satellite availability (allowing improved positioning in difficult environments such as urban canyons)
- Geometry (i.e. low GDOP, PDOP etc.)
- Productivity (reduced time to fix)
- Reliability (improved ambiguity resolution, especially in difficult environments)
- Redundancy (better ability of the system to detect problems)
- Precision (more precise signals, better modeling)

Increased satellite availability leads to improved geometry and redundancy of observations. This in turn improves reliability and precision of position, important in a host of applications utilizing GNSS signals. The benefits of combined GNSS technologies for RTK applications are examined in detail by Takac and Walford (2006).

The new AR25 3D choke ring design has been optimized for maximum compatibility with the antenna element, for the highest tracking performance.

Table 1: Existing and proposed GNSS signals [MHz]

System	L1/E1/E2/B1	L2/B2	L5/E5	E6/B3
GPS	1575.42	1227.6	1176.45	
GLONASS	1598.063 - 1605.375 *	1242.938 - 1248.625 *		
Galileo	1575.42		1176.45, 1207.14, 1191.795	1278.75
Compass	1561.098, 1575.42, 1589.742	1207.14	1176.45	1268.52
SBAS	1575.42			
OmniSTAR and CDGPS	1525 - 1560			

k = -7,6

New Innovative 3D Choke Ring Design

A typical choke ring antenna consists of several concentric ring structures that surround the central antenna element (Figure 1). The choke rings, which are usually slightly more than one quarter of a GPS L2 wavelength deep, are designed to eliminate reflected signals and prevent the propagation of surface waves near the antenna (Kunysz, 2001).

Figure 1: The AT504GG – A traditional '2D' choke ring antenna

The choke ring antenna has become the industry 'standard' for high end permanent reference stations due to its proven phase center stability, smooth amplitude and phase pattern and low susceptibility to multipath. The choke ring antenna is used as a benchmark for antenna qualification as an IGS station (IGS, 2007).

A significant weakness of the traditional choke ring antenna is its poor reception and tracking of satellites near the horizon. Signals from low elevation satellites are very important for many applications of GNSS because they help to de-correlate station height and troposphere parameters. One of the main design features of the 3D design of the AR25 choke ring antenna (Figure 2) is the improved low elevation tracking.

Figure 2: New "3D" Leica AR25 wideband choke ring antenna

The rings of the AR25's ground plane are arranged with each ring sitting lower than the previous ring so that the choke ring forms a conical shape. The steps between the rings are configured in such a way that their length on the longer side is approximately equal to a quarter wavelength of the lowest frequency used, in this case L5-L2, and the shorter side is approximately a quarter wavelength of the highest frequency used, in this case L1-G1 (Figure 3). The net effect of this configuration is a high impedance surface, which attenuates any surface currents excited by the antenna, and eliminates distortion of the amplitude and phase pattern. The 3D design improves low elevation antenna gain while maintaining the renowned characteristics of the original choke ring antenna such as stable phase center, pattern symmetry for amplitude, phase and group delay.

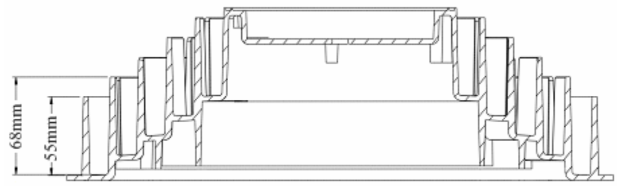

Figure 3: Cross-section of AR25 showing the groove depths

Additionally the AR25 uses a new ultra wideband Dorne-Margolin element. The new element is specially constructed and tested to ensure consistent performance across all bands.

Choke ring antennas are the preferred choice for reference station installations partly because of their durable construction. The AR25's robust construction ensures that the antenna will pass the test of time in the harshest of environments. An optional weather proof radome is also available.

Testing

The Anechoic chamber tests were conducted at the David Florida Labs of Canadian Space Agency located in Ottawa (Kanata) to determine the radiation pattern and phase center offset and variation in benign conditions (free of multipath). Data was collected at 23 GNSS discrete frequencies from 1175.3MHz to 1610 MHz. Spatially, data was sampled at 3 deg. intervals in both azimuth and elevation planes. The wideband antenna was tested using a carrier wave RF frequency.

The AR25 3D choke ring with its new Dorne-Margolin element was compared with an existing high-end 2D choke ring antenna with a standard Dorne-Margolin element. During the test the Low Noise Amplifier (LNA) circuits were bypassed to determine the net gain of the antenna element.

In order to assess the performance of the antenna outside of an anechoic chamber, testing was carried out in a 'real world' environment by Leica Geosystems in Switzerland. The antennas tested were production models including the filter and LNA.

Antenna Gain

The level of antenna gain is an important indicator of the antenna's tracking ability. High gain values over the elevation range translate into more complete data and a higher signal to noise ratio.

While the bandwidth of the AR25 has been significantly widened and the low elevation performance optimized, it is clear from Table 2 that the peak antenna gain at the zenith has not been compromised.

Table 2: Comparison of the antenna peak gain of the AR25 and AT504GG measured at the zenith (90°El) for the three frequency bands

	AR25	AT504GG
High-Band Frequencies (L1,C1,C2,G1,E1,E2)	+4.9dBic	+5.5dBic
Mid-Band Frequencies (L2,G2,E6,C6)	+7.0dBic	+7.7dBic
Low-Band Frequencies (L5,E5a, E5b)	+5.3dBic	+5.9dBic

Table 3 shows that the peak gain on the horizon is better for the AR25 than for the AT504GG across all frequency bands, especially the high-band where significant improvement is seen. This indicates that the AR25 has superior low elevation tracking ability.

Table 3: Comparison of the antenna peak gain of the AR25 and AT504GG measured on the horizon (0°El) for the three frequency bands

	AR25	AT504GG
High-Band Frequencies (L1,C1,C2,G1,E1,E2)	-4.3dBic	-11.1dBic
Mid-Band Frequencies (L2,G2,E6,C6)	-7.3dBic	-9.8dBic
Low-Band Frequencies (L5,E5a, E5b)	-9.0dBic	-10.2Bic

Front-Back Ratio

The front-back ratio indicates an antenna's directivity and resistance to multipath (Hekmat et al., 2005). The higher the ratio of gain from the front (90° elevation) compared to the back (-90° elevation), the better the antenna's theoretical ability to reject reflected signals. The front-back ratio is influenced by a combination of the antenna's backside shielding and sensitivity to Left Hand Circular Polarized (LHCP) signals.

Table 4 shows the back-front ratios for the antennas for each of the 3 frequency bands. While the ratios are lower than those for the AT504GG, the values are still very good and exceed the values from a non-choke ring antenna. Some trade off is to be expected due to the significantly improved low elevation tracking.

Table 4: Comparison of the front back ratio for the AR25 and AT504GG tested at +/-90° elevation

	AR25	AT504GG
High-Band Frequencies (L1,C1,C2,G1,E1,E2)	28.9dB	36.4dB
Mid-Band Frequencies (L2,G2,E6,C6)	35.5dB	35.8dB
Low-Band Frequencies (L5,E5a, E5b)	24.9dB	35.6dB

Antenna Radiation Patterns

The radiation pattern for an ideal antenna would show consistently high gain from the zenith down to the horizon and would then roll off rapidly for elevations below the horizon. A consistent radiation pattern across all frequencies translates to similar phase center offset and tracking ability. The greater the difference between the Right Hand Circular Polarized (RHCP) and Left Hand Circular Polarized (LHCP) antenna gain, the greater the antenna's resistance to reflected signals. The high frequency band antenna radiation patterns for the AR25 and the AT504GG are shown in Figures 4 and 5. The antenna gain values have been normalized to enable direct comparison of the patterns. The peak antenna gain is 0dBic in each case.

Figures 4 and 5 show that while the antenna gain of the AT504GG falls away sharply as the high band signals elevation decreases, the AR25 maintains superior antenna gain over a greater elevation range. This translates into superior tracking ability of high band signals. The peak gain of the AR25 is +5dBic at the zenith and -5dBic on the horizon, enabling the antenna to track satellites at all elevation angles. It is also clear that, while the difference between the RHCP and LHCP signals is more or less the same for both antennas for the low elevations, the separation between the oppositely polarized signals is much greater for the AR25 for the high elevations, in comparison to the AT504GG. This indicates that, not only has the AR25 retained the renowned multipath mitigation characteristics of the AT504GG at low elevations, but has even improved the resistance reflected signals at high elevations for the high band frequencies.

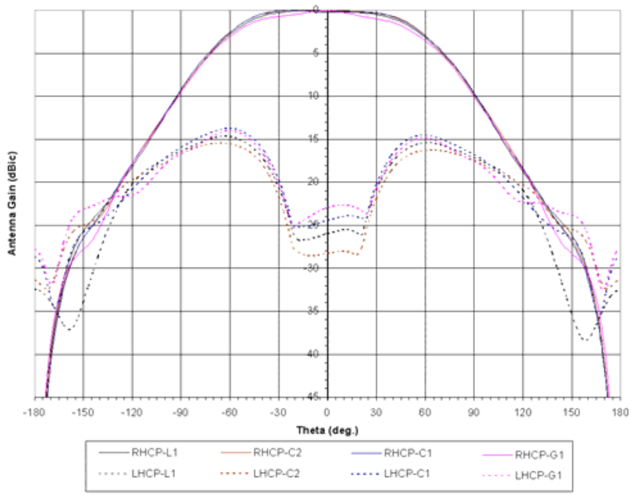

Figure 4: High-band antenna radiation pattern for AR25

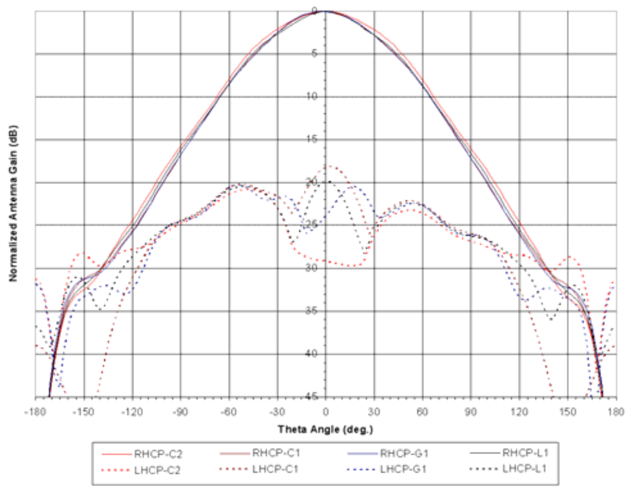

Figure 5: High-band antenna radiation pattern for AT504GG

Low Elevation Tracking

The anechoic chamber test results for the AR25 showed significant improvements in peak antenna gain on the horizon in comparison to the AT504GG. In theory, this improvement in antenna gain should result in superior low elevation satellite tracking. In order to confirm this theory, 'real world' testing was carried out. Data was recorded down to zero degrees elevation for both the AT504GG and AR25 antennas at 1Hz over a 24 hour period.

Figure 6 clearly reveals the AR25's exceptional reception of signals from low elevation satellites. For example, at 4° elevation the AR25 receives 99.14% of the expected GPS L1 observations, while the AT504GG receives just 3.95%. The AR25 displays a clear superiority in tracking ability from the horizon up to 10° elevation making it a powerful tool for a wide range of applications such as such as atmospheric modeling.

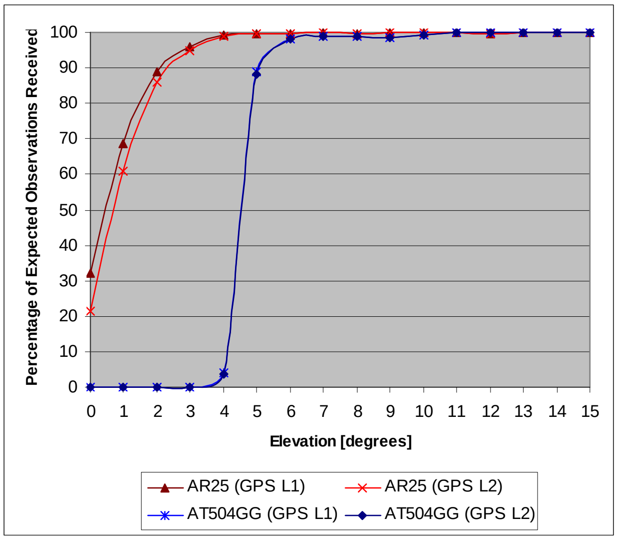

Figure 6: Completeness of observations by elevation for the AR25 and the AT504GG

Carrier Phase Multipath Mitigation

The antenna radiation patterns and front-back ratios calculated using observations performed in the anechoic chamber give us some indication of the antennas ability to mitigate multipath. However, testing the antenna in a 'real world' environment with low elevation obstructions and nearby reflective surfaces can show different characteristics.

GPS and GLONASS data was recorded for both the AT504GG and AR25 antennas every 10 seconds over a 24 hour period. The reference antenna was set up 3m away from the subject antenna. This short baseline length means that, following double difference processing, the remaining error will show the residual measurement noise. Each epoch of data was processed independently resulting in 8640 position solutions. Figure 7 shows the horizontal coordinate scatter plots for the two antennas while Figure 8 shows the height times series. Table 5 shows the standard deviations of the both antenna's.

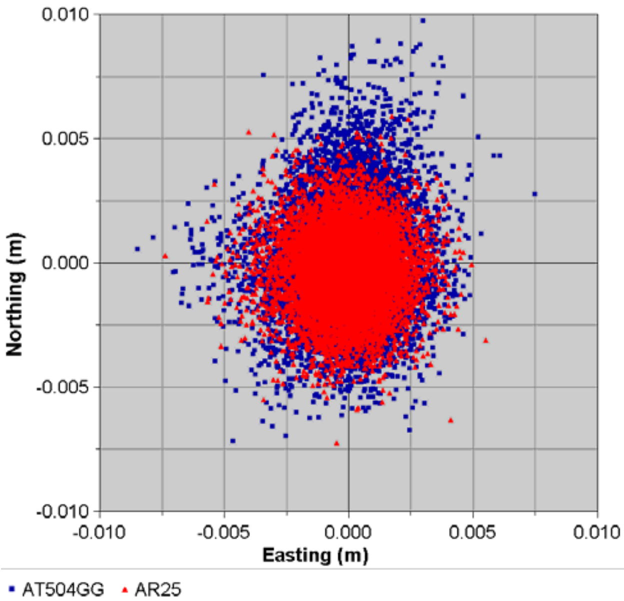

Figure 7: Horizontal coordinate variation for AR25 (red) and AT504GG (blue)

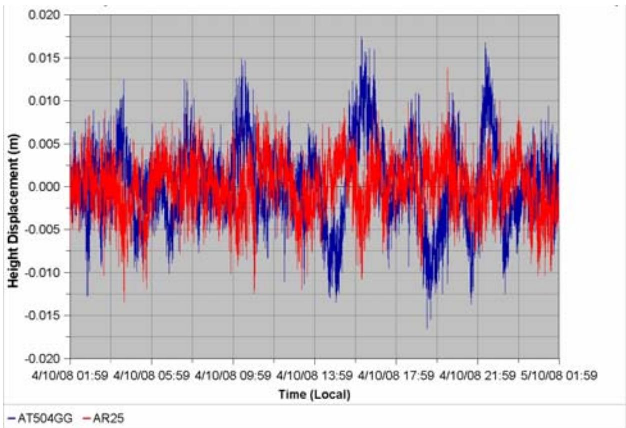

Figure 8: Height displacement over time for AR25 (red) and AT504GG (blue)

The horizontal scatter for the AR25 is noticeably less variable (Figure 7), and vertical variations are also significantly smaller (Figure 8), than for the AT504GG. This superiority is confirmed by the smaller standard deviations (STDV) in Table 5.

Table 5: Dispersion of the calculated coordinates

	STDV (E)	STDV (N)	STDV (H)
AR25	1.1mm	1.3mm	2.5mm
AT504GG	1.3mm	1.8mm	3.8mm

Phase Center Variation

In an ideal GNSS antenna, the observation point would correspond exactly with the physical center of the antenna housing. In practice the observation point, or 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 the physical center of the antenna can be removed through Phase Center Offsets (PCO) and Phase Center Variations (PCV) 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 horizontal phase center offsets (HPCO) for the GPS L1 and L2 frequencies were calculated for 20 production model AR25 antennas in order to asses the repeatability. Table 6 shows the mean HPCO values for the L1 and L2 frequencies along with the respective standard deviations.

Table 6: Horizontal Phase Center Offsets of a sample of 20 production model AR25 antennas

	L1 E	L1 N	L2E	L2N
Mean	0.6	1.0	0.0	0.2
Std. Dev.	0.6	0.4	0.6	0.5

The average HPCO's are all 1mm or less (Table 6). However, since the constant offset is removed via the antenna calibration, the most important factor for insuring repeatable measurements is the unit to unit variation. The sub-millimeter standard deviations show that repeatability of the phase center is very good.

Conclusion

This paper presents the new AR25 3D wideband choke ring antenna from Leica Geosystems. With emerging satellites systems on the horizon, a new high performance antenna is needed to encompass all GNSS signals. The AR25 has sufficient bandwidth to receive all existing and currently planned GNSS signals, while maintaining the highest performance standards. A detailed comparison with the renowned AT504GG choke ring antenna has shown that the revolutionary new 3D choke ring design, combined with a new ultra wideband Dorne-Margolin element and high performance LNA, has revealed impressive performance improvements, especially with respect to 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. The AR25 has been designed and built for durability and will stand the test of time, even in the harshest of environments.

References

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