

# Leica GNSS Reference Antennas White Paper



- when it has to be **right**

**Leica**  
Geosystems

# State of The Art , Leading Edge Geodetic Antennas from Leica Geosystems

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## BIOGRAPHY

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 Senior Product Manager for GNSS Networks and Reference Station Hardware for Leica Geosystems, based in Heerbrugg, Switzerland.

## ABSTRACT

This paper introduces the range of state of the art wideband reference antennas from Leica Geosystems with emphasis on the new the Leica AR20 and AR10 antennas.

Leica Geosystems offers three unique and cutting edge geodetic antennas all with leading edge performance within their categories and each with their own individual strengths.

The Leica AR25 choke ring antenna with its revolutionary 3D choke ring design is a high quality; high performance antenna designed for all geodetic applications, including Network RTK and is especially suited for scientific applications requiring extended low elevation tracking. The design of the AR25 3D antenna is well documented in the separate Leica AR25 White Paper, and therefore is not covered here; see Bedford et al (2009). Comparative performance analysis w.r.t. to the AR20 and AR10 is covered within this paper.



Figure 1: Leica AR25 Choke Ring Antenna

The recent Leica AR20 choke ring antenna is a new visionary design taking the strengths of the AR25 3D design in a new; more cost effective way. The AR20 contains a new 3D (inside) choke ring design that brings leading edge multipath performance across all GNSS frequency bands and improved phase centre stability.



Figure 2: Leica AR20 Choke Ring Antenna

The AR10 is a high end performance Geodetic Antenna for a wide range of permanent or semi permanent Reference Station and Monitoring applications that require near choke ring antenna data quality without the size and weight of the traditional choke ring. The AR10 has a unique robust UV resistant integrated conical radome.



Figure 3: Leica AR10 Integrated Antenna

## FUTURE PROOF

The need for future proof geodetic antennas is very clear as the cost of replacing antennas can be a burden for owners and disruptive to end users that use the data. Changing an antenna can also result in a small change of

coordinates due to a variety of reasons, but often relating to the different characteristics of the new antenna versus the old antenna. Quality of calibrations, deterioration of the monumentation over time and near field multipath effects can all contribute to an apparent change in station location which is detrimental to long term tectonic analysis of continuous time series. For these reasons manufactures strive to improve the quality of antenna phase centre information and multipath reduction capability, as well as overall performance.

Future proofing the Leica AR25/20/10 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 degree 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 combining GNSS technologies for RTK applications are examined in detail by Takac and Walford (2006).

<i>System</i>	<i>L1/E1/E2/B1</i>	<i>L2/B2</i>	<i>L5/E5</i>	<i>E6/B3</i>
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
QZSS	1575.42	1227.6	1176.45	1278.75
SBAS	1575.42			
OmniSTAR and CDGPS	1525 - 1560			

**Table 1: Existing and proposed GNSS signals [MHz]**

## STATE OF THE ART TECHNOLOGY

Recently, it has been common for some manufacturers to adapt existing L1/L2 GPS and GLONASS antennas to track newly available or future planned GNSS signals which are outside the existing bandwidths of these antennas. This approach is sub-optimal as, for best results over the entire GNSS spectrum, it is essential to develop each of the interdependent components of the antenna in combination with each other.

The antenna element, low noise amplifier and choke ring/enclosure have been designed together from the ground-up in both the AR20 and AR10 to form a highly compatible wideband system with superior tracking performance.

## LOW PROFILE, WIDEBAND ANTENNA ELEMENT

The classical ‘patch’ antenna is a common type of antenna element contained within many high performance GNSS antennas. In its most basic form, the patch antenna is essentially a flat plate over a ground plane. This low profile element is especially compact, far more so, for example, than classical wideband GNSS antennas which use crossed dipoles or conical spirals. The AR25 uses the latest version of the well established Dorne-Margolin element, which was designed many decades ago and originally optimized for only L1/L2. Later versions were improved to bring in L5/E5 and E6/B3 bands.

At the heart of both the Leica AR20 and AR10 is an all new radiating element which consists of an innovative array of four individual radiating elements. In the AR10, these are suspended over a ground plane with an integrated horizontal choke assembly. This assembly effectively suppresses the undesired effects of diffracted and reflected signals and gives a dramatic improvement in antenna performance. The low profile further helps to avoid scattered multipath energy from reaching the radiating element. In the AR20, an even better performance is achieved through the use of the new ideally spaced 3D-choke rings.

This newly designed radiating element is optimized to cover all GNSS bands while suppressing unwanted out-of-band signals. Custom designed filters further add to the rejection of potential interferers. This structure achieves less gain roll-off versus frequency than classic dual band antennas while yielding very stable radiation patterns over frequency at all elevations and azimuths and exceptional phase centre variation versus frequency.

## ANTENNA ELEMENT FEED POINTS

The number of feed points used to connect to the antenna element has a significant influence on the characteristics of the antenna. A traditional single feed point antenna is not able to generate usable circular polarization which is necessary for the antenna to track the entire range of the GNSS bandwidth. Also, due to their asymmetrical nature, single feed antennas suffer from inherent phase centre tilt. At the other end of the scale, antennas with numerous feed points require complex splitters which result in unwanted losses in signal strength and signal delays which affect the phase centre.

The Leica AR20/AR10 designs use four feed points to connect the antenna element. This four point configuration provides superior circular polarization over the entire GNSS bandwidth and spreads the energy symmetrically resulting in sub-millimetre phase centre stability.

## ALL NEW LOW NOISE AMPLIFIER

The AR20 incorporates a new low noise amplifier that was designed for exceptionally low noise temperature yielding superior measurement quality. The use of custom filtering technology guarantees excellent out of band rejection, helping to significantly reduce potential signal degradation due to interference. The Leica AR20/AR10 antennas are suitable for use with antenna cable lengths of up to 70 m without the need for an in-line amplifier. The AR25 can be used with even longer cables depending on the cable type.

## AR10 : INTEGRATED CONICAL RADOME

The non-spherical radome was designed in combination with the antenna element for optimal signal quality. The conical shape of the Leica AR10's enclosure prevents the build-up of snow which could otherwise degrade signal quality. It also has the added benefit of discouraging birds from perching on the antenna, a common source of signal attenuation with flat topped antennas or rounded radomes. The aerodynamic shape of the antenna reduces wind loading and together with the light weight ensures that the Leica AR10 can be installed on a variety of antenna masts or as a field or campaign base on a tripod. Constructed using a robust and UV resistant enclosure the Leica AR10 is made to withstand extreme temperature, humidity, dust, salt, solar radiation, pollution, shock and vibration for extended periods making it ideally suited to permanent and semi-permanent reference station installations.



**Figure 4: The innovative Leica AR10 with integrated conical radome**

## AR20 : UNIQUE 3D CHOKE RING DESIGN

The Leica AR20 is a new visionary choke ring design that brings the benefits of having multiple sized choke rings, such as was first introduced with the AR25, but in a new more cost effective and compact manner. The AR20 has both variable depth and widths for the ultimate multipath mitigation performance across all GNSS frequency bands.



**Figure 5: The Leica AR20 variable choke ring design**

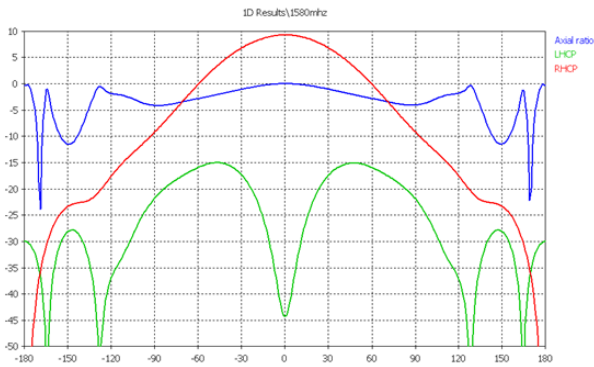
The AR20 choke ring is produced using a newer and more robust double treatment for even longer lasting durability in all environments. The AR20 also has an optional conical radome for added protection.



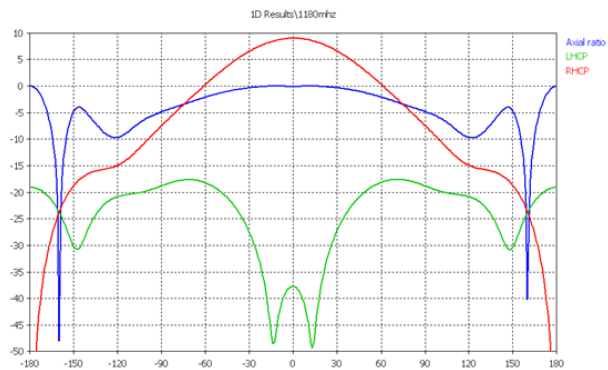
**Figure 6: The Leica AR20 with conical radome**

## ANTENNA RADIATION PATTERNS

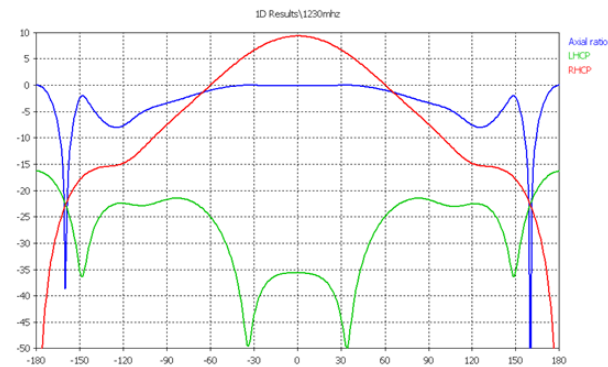
The radiation pattern for an ideal antenna would show consistently high gain from the zenith down to the horizon and would then roll off rapidly for elevations below the horizon. A consistent radiation pattern across all frequencies translates to similar phase center offset and tracking ability. The 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. Figures 7 to 10 show the RHCP gain, LHCP gain and axial ratio of the AR20 for the 4 main frequency bands.



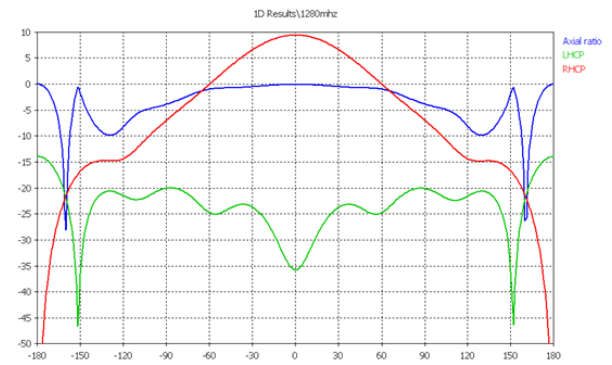
**Figure 7: The AR20 RHCP gain, LHCP gain and axial ratio versus elevation near GPS L1 (1575 MHz)**



**Figure 8: The AR20 RHCP gain, LHCP gain and axial ratio versus elevation near GPS L5 (1180 MHz)**



**Figure 9: The AR20 RHCP gain, LHCP gain and axial ratio versus elevation near GPS L2 (1230 MHz)**



**Figure 10: The AR20 RHCP gain, LHCP gain and axial ratio versus elevation near GAL E6 (1280 MHz)**

## TRACKING PERFORMANCE

The following analysis shows the tracking performance and highlights the key strengths of each antenna.

## DATA COMPLETENESS

The tracking performance of an antenna can be evaluated simply and clearly by calculating the ratio of the recorded observations to the number of observations which are theoretically possible in a perfect open sky environment. A near complete dataset indicates that an antenna is highly effective in obtaining and maintaining lock on all the available satellites.

The test location used here has good sky visibility however there are a number of obstructions (even above 15 degrees) which prevent 100% data completeness. The tables 2 and 3 below show the total number of observations above and below 15 degrees elevation, as a percentage of the theoretically possible number.



**Figure 11: The test setup environment**

Whilst the number of observations is important, data completeness (for all signals) is more important for many applications including Network RTK. The below tables also show the percentage of complete observations, where

all signals (L1/L2/L5) are tracked in each epoch. The test setup consisted of collecting 24 hours of 1Hz data.

	Total Possible (>15deg)			Number of Complete obs			% Complete Obs		
	Total	GPS	GLO	Total	GPS	GLO	Total	GPS	GLO
	1187974	649937	538037						
AR10	1178839	646868	531971	1177479	646864	530615	99.12%	99.53%	98.62%
AR20	1178467	646891	531576	1178372	646818	531554	99.19%	99.52%	98.80%
AR25	1180025	647500	532525	1179566	647426	532140	99.29%	99.61%	98.90%

**Table 2: Antenna data completeness above 15 degrees**

Elevation	Total	AR10 GPS	GLO	Total	AR20 GPS	GLO	Total	AR25 GPS	GLO
0 - 5	16.0%	13.5%	23.5%	15.2%	11.8%	25.9%	17.6%	14.3%	27.9%
5 - 10	36.9%	32.6%	46.8%	36.4%	30.8%	49.0%	36.7%	33.3%	50.9%
10 - 15	50.8%	46.1%	60.3%	50.4%	44.6%	62.3%	52.6%	47.0%	64.2%

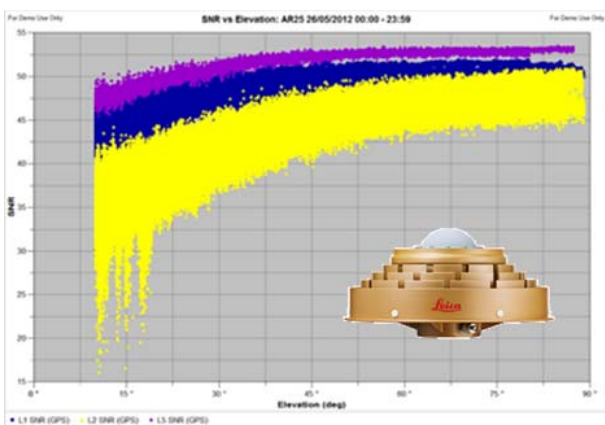
**Table 3: Antenna data completeness below 15 degrees**

All three antennas show a very high percentage of observations and complete observations above 15 degrees. The AR10 provides near choke ring level performance in this respect, compared to the AR20 and AR25 antennas. But the choke ring antennas show better data completeness and the AR25 shows the best low elevation tracking.

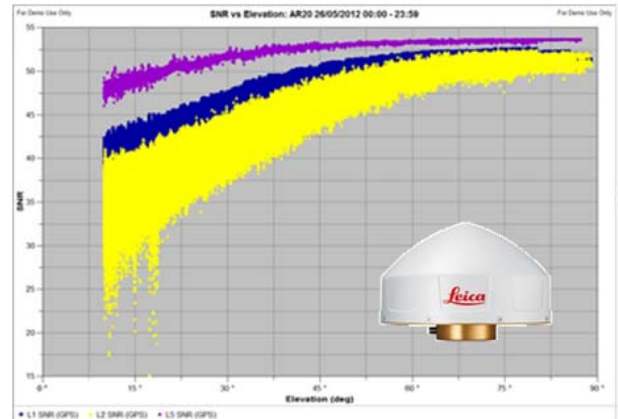
### SIGNAL TO NOISE RATIO

The following plots show the GPS signal to noise ratio versus elevation for all antennas. Good signal to noise characteristics are important for high quality tracking and positioning.

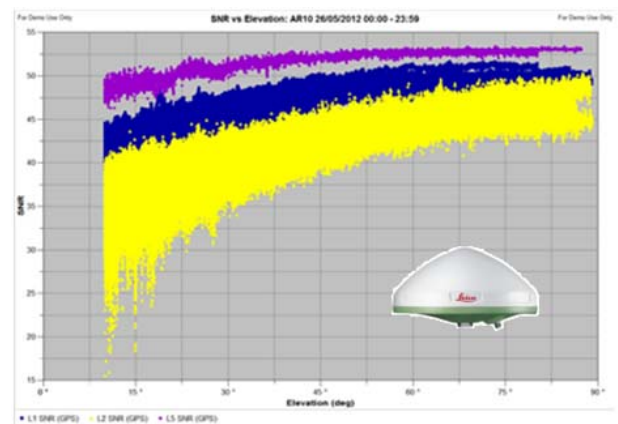
The previous plots clearly show the future benefit of the GPS L5 signal with very high SNRs even at low elevations, with the AR20 showing very low noise compared to the AR10 and AR25.



**Figure 12: AR25 GPS SNR versus Elevation**

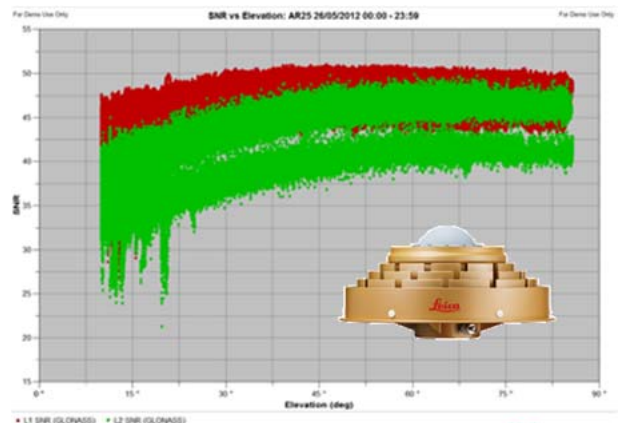


**Figure 13: AR20 GPS SNR versus Elevation**



**Figure 14: AR10 GPS SNR versus Elevation**

The following plots show the GLONASS signal to noise versus elevation for all antennas.



**Figure 15: AR25 GLONASS SNR versus Elevation**

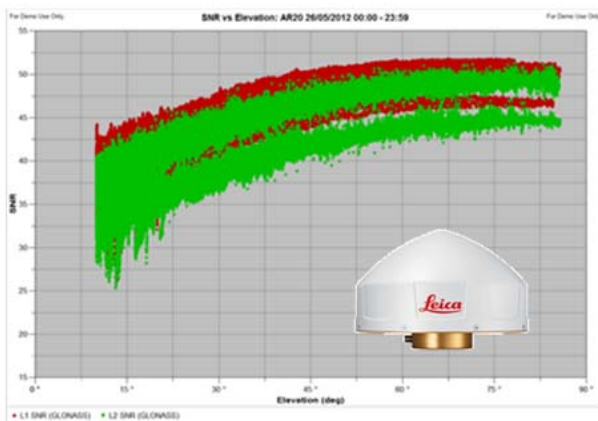


Figure 16: AR20 GLONASS SNR versus Elevation

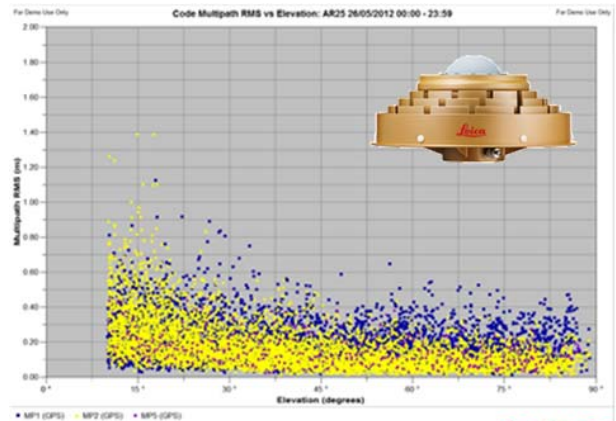


Figure 18: AR25 GPS Multipath versus Elevation

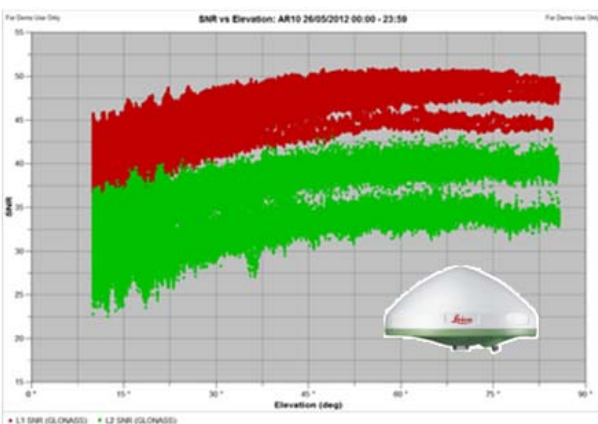


Figure 17: AR10 GLONASS SNR versus Elevation

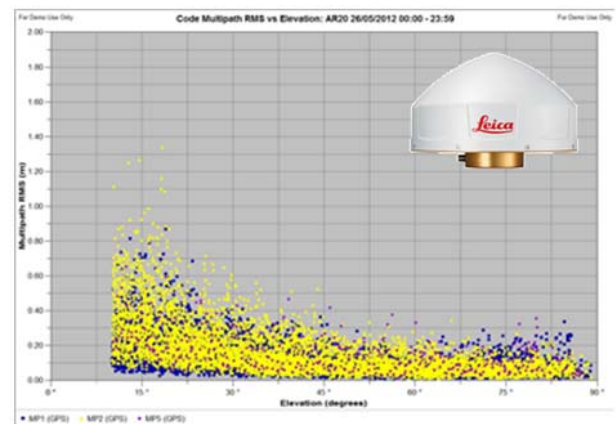


Figure 19: AR20 GPS Multipath versus Elevation

The benefit of the choke ring design can be seen in the SNR comparison, with the AR20 showing the lowest noise for all the three signal bands. Strong SNRs and low noise will help in achieving high precision positioning shown later in the paper.

### MULTIPATH MITIGATION

Antenna multipath performance is also very important in achieving high precision positioning. The following plots show the GPS Code Multipath RMS versus elevation for all antennas, for L1/L2/L5. Note receivers settings were set to unsmoothed data.

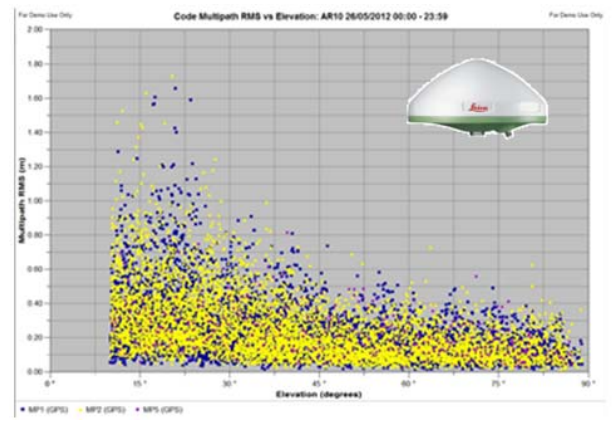


Figure 20: AR10 GPS Multipath versus Elevation

The following plots show the GLONASS Code Multipath RMS versus elevation for all antennas, for L1/L2.

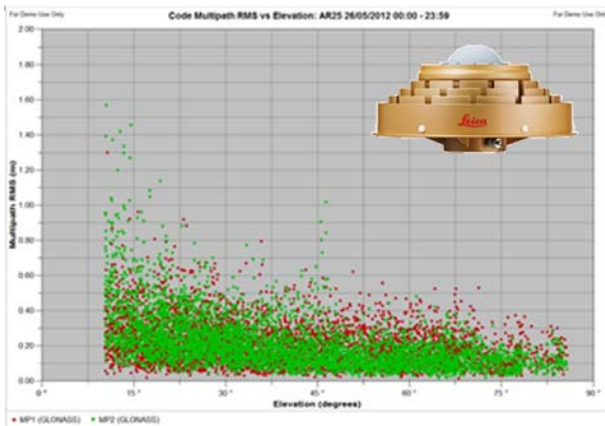


Figure 21: AR25 GLONASS Multipath versus Elevation

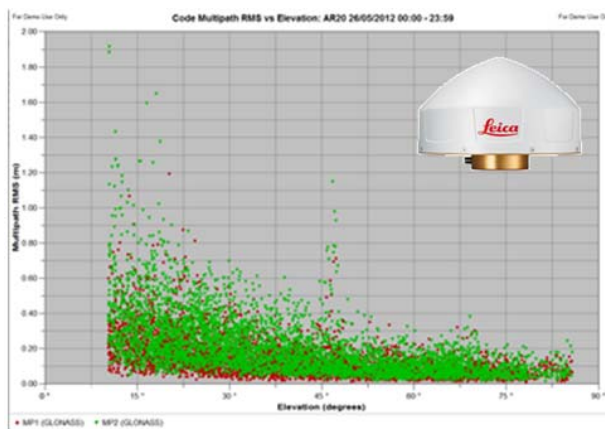


Figure 22: AR20 GLONASS Multipath versus Elevation

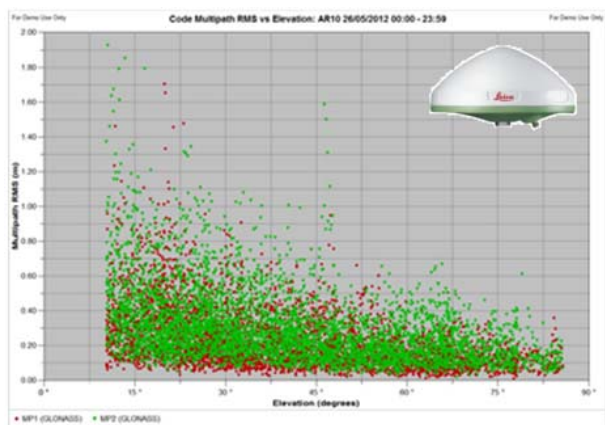


Figure 23: AR10 GLONASS Multipath versus Elevation

The advantage of a choke ring design can easily be seen in this respect, with generally much lower MP values across all elevations. The benefit of the new 3D (inside) choke ring design of the AR20 is clearly shown with very low MP values across all frequency bands. The AR20 also

brings new levels of L1 multipath rejection. This can be seen by averaging the MP values per 5 degree elevation band. This is shown in figures 24 to 26.

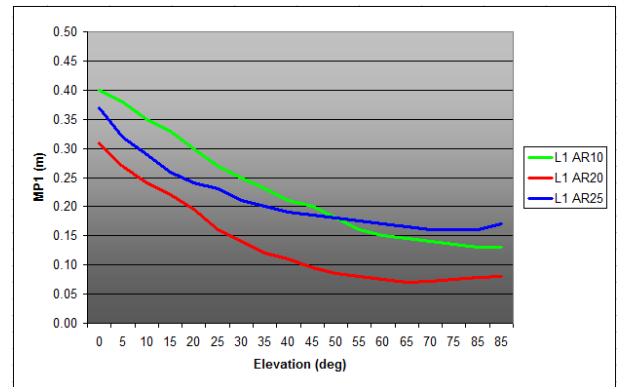


Figure 24: L1 Average Multipath versus Elevation

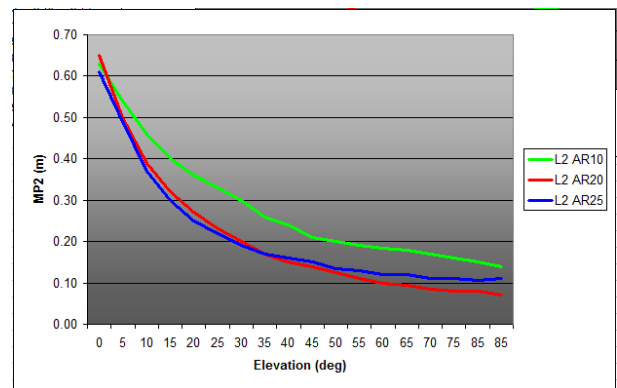


Figure 25: L2 Average Multipath versus Elevation

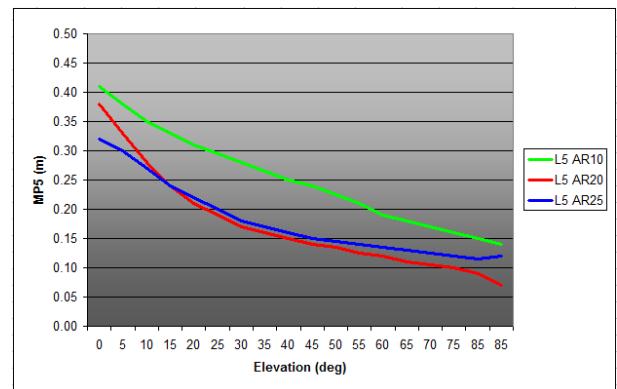


Figure 26: L5 Average Multipath versus Elevation

The following table shows the overall average MP values for each antenna, using a 15 degree elevation cut off.

Antenna	L1/E1			L2			L5/E5a			
	GPS	GLO	GAL	Average	GPS	GLO	Average	GPS	GAL	Average
AR10	0.221	0.225	-	0.223	0.234	0.280	0.254	0.223	-	0.223
AR20	0.111	0.138	-	0.123	0.149	0.186	0.165	0.146	-	0.146
AR25	0.180	0.199	-	0.188	0.155	0.194	0.172	0.149	-	0.149

Table 4: Average MP values (L1/L2/L5)



Overall whilst the AR25 and AR20 show fairly similar L2 and L5 values, the AR20 shows unmatched L1 multipath mitigation performance.

The impact of good SNRs and multipath rejection can be easily seen in the horizontal and vertical scatter plot of the 24 hour data sets for each antenna, by computing the single position for each epoch over 24 hours and plotting the scatter and computing the dispersion. The table below shows the standard deviation for all 86400 epochs for each antenna.

	Std (m) - some obs removed		
	Easting	Northing	Height
AR10	0.0018	0.0028	0.0038
AR20	0.0012	0.0016	0.0033
AR25	0.0016	0.0017	0.0037

**Table 5: Antenna position dispersion**

Both the AR25 and the AR20 show exceptional tightness of both the horizontal and vertical position scatter, with the AR20 showing the highest precision.

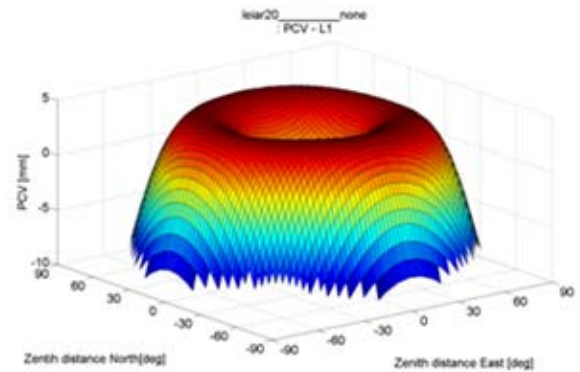
**PHASE CENTRE OFFSETS/VARIATIONS (PCO/V)**

Very low phase centre offsets and variations are also important for high precision positioning. All the antennas show very low phase centre offsets. Both the AR25 and AR20 antennas have type-mean phase centre offsets below 1mm, whilst the AR10 is within 2mm. AR25 and AR20 values are the without radome.

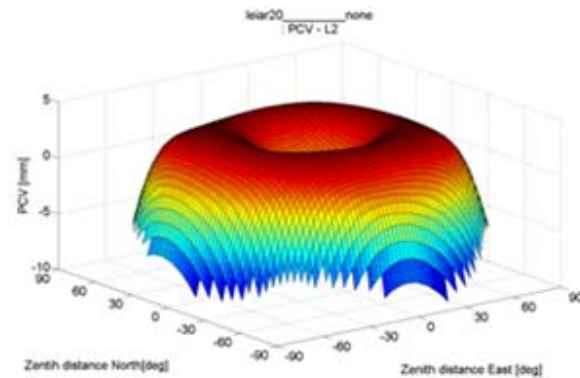
Antenna	GPS freq.	North (mm)	East (mm)	Up (mm)
AR25	L1	0.88	0.87	159.36
	L2	0.12	0.02	153.58
AR20	L1	0.14	-0.77	124.24
	L2	-0.01	-0.79	133.67
AR10	L1	1.29	-0.70	88.84
	L2	0.52	0.15	81.79
		Std (mm)	Std (mm)	Std (mm)
AR25	L1	0.42	0.38	0.55
	L2	0.64	0.32	0.77
AR20	L1	0.37	0.25	0.53
	L2	0.13	0.19	0.41
AR10	L1	0.67	0.39	0.30
	L2	0.58	0.17	0.27

**Table 6: GPS Phase centre offsets and dispersion**

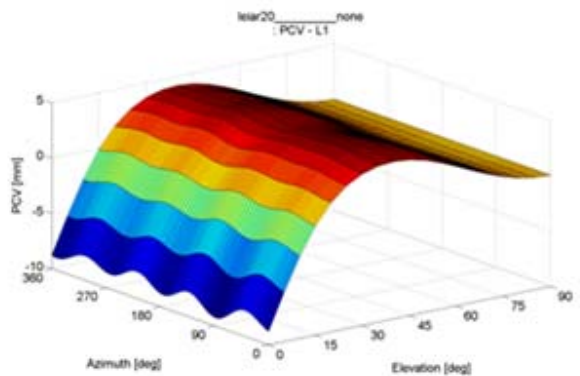
Whilst all antennas have very low phase centre offsets, the strength of the AR20 unit to unit repeatability can be seen in the PCO standard deviations from the individual absolute calibrations. The AR20 also has very smooth phase centre variations with respect to the antenna and also versus elevation and azimuth, as shown below.



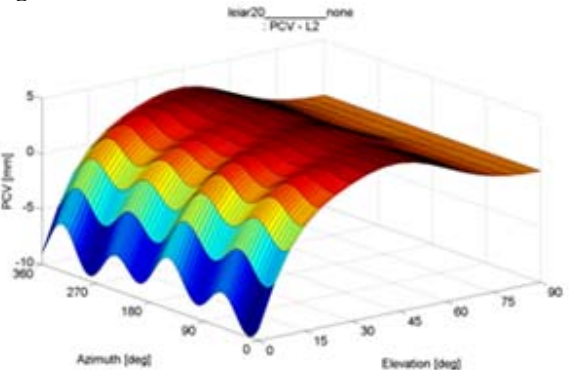
**Figure 27: AR20 PCV for L1 w.r.t. to the antenna**



**Figure 28: AR20 PCV for L2 w.r.t. to the antenna**



**Figure 29: AR20 PCV for L1 w.r.t. elevation / azimuth**



**Figure 30: AR20 PCV for L2 w.r.t. elevation / azimuth**

## CONCLUSION

This paper presents the range of new wideband geodetic antennas from Leica Geosystems. With emerging satellites systems and new signals on the horizon, new high performance antennas are needed to encompass all GNSS signals now and in the future. The AR25, AR20 and AR10 have all been designed and built for durability and will stand the test of time, even in the harshest of environments.

The **AR25** offers a unique 3D design that allows excellent low elevation tracking and data completeness, whilst at the same time maintaining very good multipath rejection and high precision positioning; making it suitable for all Network RTK and scientific applications demanding the highest tracking performance.

The **AR20** with its visionary 3D (inside) design offers the highest overall performance with excellent data completeness and the very best in multipath rejection across all GNSS frequency bands. Its new design also offers the highest standard in phase centre stability. The combined effect of all these strengths result in an antenna with the best positioning precision. As such it is the ultimate choice for the majority of applications, including Network RTK and Monitoring.

The **AR10** brings near choke ring level performance in a light weight and very robust plastic antenna with integrated conical radome, making it suitable for all Reference Station and Monitoring applications that do not require a choke ring and can take advantage of its light weight design.

## ACKNOWLEDGEMENTS

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Whether providing corrections from just a single reference station, or an extensive range of services from a nationwide RTK network – innovative reference station solutions from Leica Geosystems offer tailor-made yet scalable systems, designed for minimum operator interaction whilst providing maximum user benefit. In full compliance with international standards, Leica Geosystems' proven and reliable solutions are based on the latest technology.

Precision, value, and service from Leica Geosystems.

**When it has to be right.**

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