

3G+C antenna in the Galileo Monitoring network

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Key words: GNSS Antennas, Calibration, Monitoring Stations

SUMMARY

The global navigation satellite system Galileo takes big steps to its target. The IOV (In Orbit Validation) phase is working now. The financing is sure, the satellites are ordered and the rockets are in mission. In between the control centers, the TTC and the sensor stations are also building up monitoring stations. This paper informs you about the selection procedure of the antennas and how important the antenna parameters like multipath reduction and phase center variation are in the reality.

ZUSAMMENFASSUNG

Das Satellitennavigationssystem Galileo kommt jetzt endlich mit großen Schritten voran. Die IOV (In Orbit Validation) Phase ist im vollen Gange, die Finanzierung ist gesichert, die Satelliten sind bestellt und die Raketen sind auch in Auftrag gegeben. Neben den Kontrollcentern, den TTC und Sensor Stationen werden auch Monitoring Stationen aufgebaut. Es wird hier auf das Auswahlverfahren und die Wichtigkeit von Antenneneigenschaften wie gute Multipathunterdrückung und sehr geringe Phasenzentrumsvariationen hingewiesen.

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1. STATUS OF GALILEO

Galileo, the European Navigation System, has a long history. The first plan of the European Union was to have an operable system since 2008. The miscarrying of the public private partnership between the EU and a part of the industrial magnate took a lot of time. The fact that 27 EU countries discussed about the financing of Galileo didn't really helped for fast decisions. But now everything is fixed, the financial budget is concluded and Galileo is on a good way. The first satellite GIOVE-A started in 2007 and the second test satellite GIOVE-B followed in 2008. One important payload of GIOVE-B was the hydrogen passive maser clock. This clock has a significant higher accuracy than the atomic clocks from the GPS or GLONASS satellite navigation systems. Another big step for Galileo is the signal structure. It helps to track the signals faster.

1.1 In Orbit Validation (IOV)

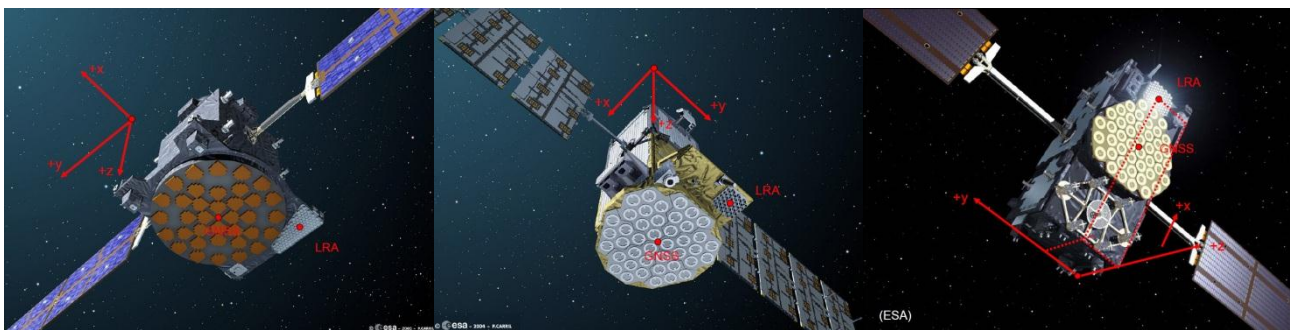
The IOV phase is a very important milestone for the Galileo navigation system. In IOV we have four operable Galileo satellites in the Orbit. Two satellites launched on the 21 October 2011 and the next two on the 12 October 2012. Both Soyuz rockets (Russia) started from the Guiana Space Centre (CSG) in Kourou in French Guiana. This was the first time that a Russian missile launched in CSG. Four navigation satellites the absolutely minimum requirement for a positioning by means of trilateration calculation, as well longitude and latitude as the altitude and point in time can exactly be captured. Assist by this Satellite quartet starts the construction of the new worldwide navigation system Galileo. The development and the manufacturing occur in Ottobrunn, Germany. The main contractor was EADS Astrium and OHB. The IOV says, that the satellites are fully operable, all Galileosignals can be received and the monitoring system from two Ground Control Centers (GCC) works also. One is in Fucino, Italy. They host and operate the Ground Mission Segment (GMS). The second one is in Oberpfaffenhofen, Germany. They will host and operate the Ground Control Segment (GCS). A network of sensor stations is providing the coverage for orbitography and synchronization of the measurements.

1.2 The next steps of the Galileo navigations system

The EU Commission give the order to OHB Technology to build further 22 Galileo navigation satellites and EADS Astrium has the order to build also 4 Galileo navigation satellites. With the 4 IOV satellites the Galileo system will have 30 Satellites in orbit. Arianespace will send with 6 Sojuz rockets 12 satellites and with three Ariane 5 rockets 12 satellites in the orbit. The target is to have in 2015 a fully operable Galileo navigation system. In my opinion the chance is very good to have the system in time.

1.3 Technical sheets from the Galileo Satellites

Parameter	GIOVE-A	GIOVE-B	IOV	OHC
Launch mass	602 kg	530 kg	700 kg	733 kg
Dry mass	550 kg	502 kg	640 kg	680 kg
Body size	1.3 m x 1.8 m x 1.65 m	0.95 m x 0.95 m x 2.4 m	2.74 m x 1.58 m x 1.59 m	2.5 m x 1.2 m x 1.1 m
Solar array size	2 x 2 x 1.74 m x 0.98 m	2 x 4 x 1.5 m x 0.8 m	2 x 2 x ~3 m x ~1 m	2 x 2 x 2.5 m x 1.1 m
Span width	~10 m	~10 m	14.5 m	14.8 m
Cross section	9 m ²	12 m ²	n/a	n/a
SRP acceleration	99 nm/s ²	151 nm/s ²	113 nm/s ²	n/a



GIOVE-A

GIOVE-B

Galileo-IOV

2. GALILEO GROUND SEGMENT

The whole Galileo constellation will be monitored from the Galileo ground segment. The task of the ground segment is to control the Galileo constellation, monitoring satellite health and uploading data to the satellites. The most important task is the clock synchronization and the orbit ephemeris. For this job Galileo needs a worldwide network of stations. Forty Galileo sensor stations (GSS) for orbit determination and time synchronization. Five Galileo TTC Station with a 13 m antenna dish for telematics and remote control and nine Galileo Mission Uplink Stations (ULS) to send navigation and integrity signals to the satellites. The following sheet compares the ground segment infrastructure of GPS and Galileo.

	GPS	Galileo
Sensor Station	6	40 (GSS)
Uplink Station	3	9 (ULS)
TTC Stations	-	5 (TTC)
Control Center	1	2 (GCC)

3. GALILEO MONITORING STATIONS

Further the ESA builds up monitoring stations. The plan is that every country in the EU shall build up minimum one station. Every monitoring station must have 3 reference stations and two rovers. The special task is at now not defined, but everybody knows that they have to control the accuracy and the time shift of the system. For this task they need special GNSS receivers and also very good GNSS antennas. The following subsection describes the selection procedure of the GNSS antennas.

4. SELECTION OF GNSS ANTENNAS

In the shortlist came three antennas. The Trimble Zephyr Geodetic II, the Leica AR10 and the navXperience 3G+C.

4.1 Trimble Zephyr Geodetic II

The brochure of the Trimble Zephyr antenna promises a lot of good parameters, minimum tracking elevation 0° . But in the leaflet is written in practice more than 3° . An important feature is the phase center accuracy of 2 mm or better and the phase center repeatability of less than 1 mm. Furthermore the brochure promises to receive all existing and prospectively GNSS signals. The Zephyr technology promises a good multipath reduction and the stealth ground plane cuts reflected signals. The antenna is developed in 2006 and a big quantity of Zephyr Geodetic II is in the market.



4.2 Leica AR10

The brochure also promises the tracking of all signals from GPS, Glonass Galileo and Compass (BeiDou), sup-millimeter phase center repeatability and an optimal signal quality. If you trust the brochure the antenna has nearly a choking performance and a high multipath

suppression. The development is from 2010.



4.3 navXperience 3G+C

The brochure from the 3G+C antenna promises nearly the same as the two models before, tracking all GNSS signals, a very low phase center variation and a really good multipath reduction. But by the new technology this antenna is constructed for all applications, as reference stations, for mobile surveying, machine control, etc. This is really interesting for the Galileo monitoring stations, because they use the same antenna as reference station and rover. This gives a lot of advantages. The antenna reference point is the same for reference station and rover, they have the same quality of the GNSS signals.



4.4 Compare the technical data

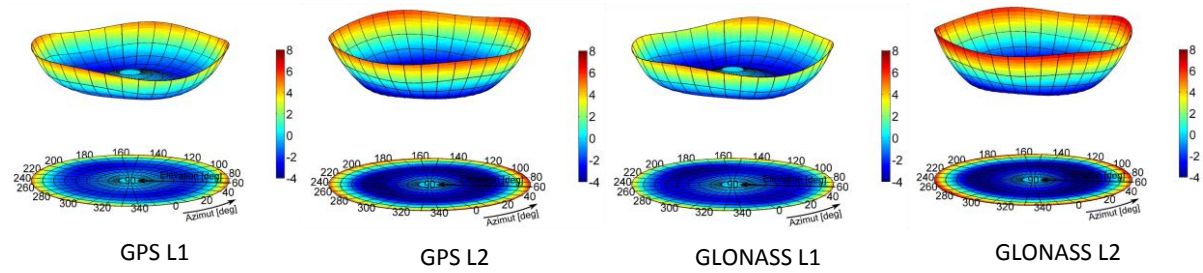
	Zephyr Geod. II	AR10	3G+C
Tracking all signals	Yes	Yes	Yes
Minimum phase v.	Yes	Yes	Yes
Polarization	RHCP	RHCP	RHCP
Power	3.5 to 20 V	3.3 to 12 V	3.3 to 20 V
Antenna gain	50 dB	29 dB	29 dB the 3G+C 42 dB the 3G+C marine 48 dB the 3G+C reference
Axial Ratio (Zenit)	2 dB	1.4 dB	3 dB
Vibration rating	MIL-STD 810f	ISO9022-3	MIL-STD 810f
Weight	1.36 kg	1.12 kg	0.38 kg

5. MEASUREMENTS

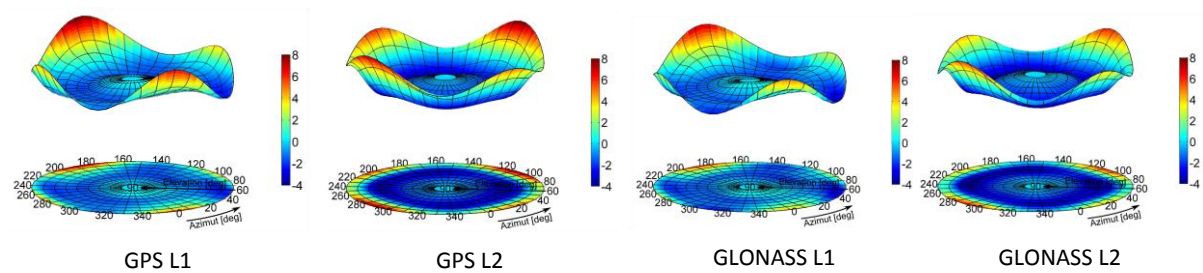
5.1 Phase Center Variations (PCV)

The phase center of a GNSS antenna is in an ideal case stabile, punctual and constant. It is not possible to build an antenna without a phase center variation. Each antenna phase center is flitting according to the azimuth and elevation angle of the satellites. GNSS antennas with azimuth dependence are not so good antennas. The Trimble and the Leica GNSS antenna promise a good phase center repeatability, but the brochures doesn't mention anything about the phase center variation. The phase center variations are very important for precise measurements. Nearly each manufacture of GNSS antennas let them calibrate from independent companies or Institutes. It needs minimum 5 antennas for a typical calibration file. The following chapters show the results of calibrations. Everybody can download the typical calibration files from the following website: <http://www.ngs.noaa.gov/ANTCAL/>. Here are the results absolute comparable, because all calibration has been done from the same company, Geo++. They made the typical calibration for these three antennas. Geo++ calibrated five antennas from AR10, six antennas from the Zephyr und eight antennas from the 3G+C.

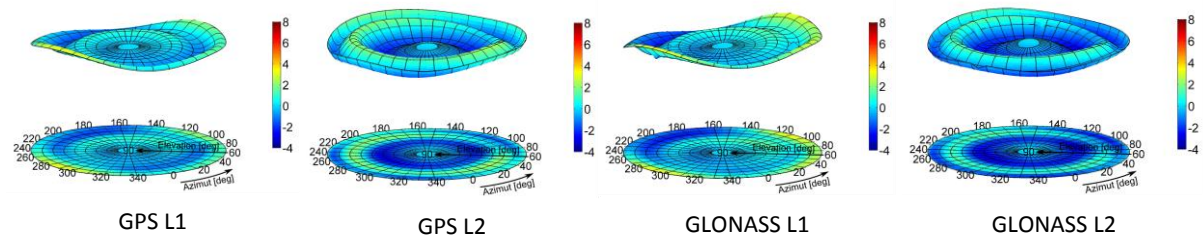
5.1.1 Zephyr Geodetic II: results of the typical calibration



5.1.2 Leica AR10: results of the typical calibration



5.1.3 navXperience 3G+C: results of the typical calibration



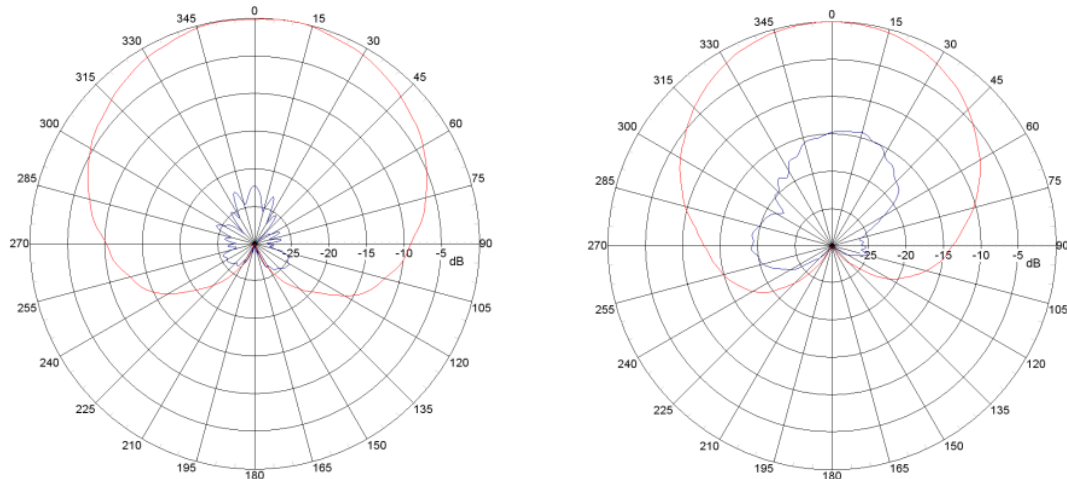
5.1.4 Assessment of the results

The Trimble Zephyr Geodetic II has a phase center variation from -4 to +8 mm and the antenna has only the variation in the height. This is a really good result. The Leica AR10 has a phase center variation of 12 mm, but the wings are not good for the accuracy when you work without a calibration or if you use this antenna for a mobile (rover) application. This antenna was canceled for the next step. The navXperience 3G+C has only a maximum of 4 mm phase center variation and also only variations in the height. In this comparison the 3G+C is better. The next step was to elaborate the navXperience 3G+C antenna for the qualification

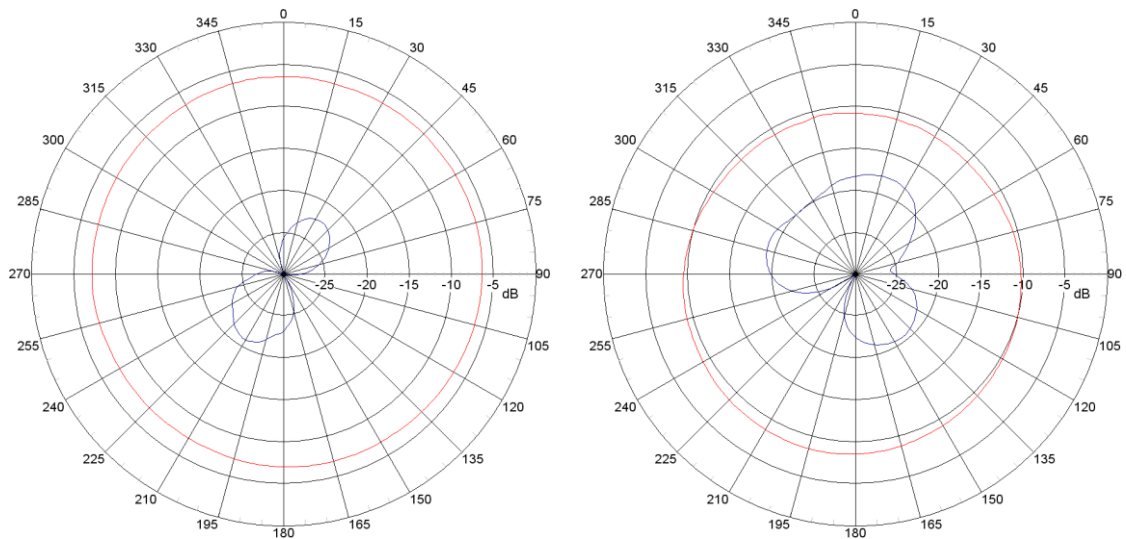
as a reference and mobile GNSS antenna.

5.2 Antenna Pattern

The GNSS satellites send right hand circular pattern. That means: It is a polarized signal which plane rotates right handed. If this signal is reflected its plane rotates left handed (RHCP). The antennas try to use the right handed rotating signals and avoid the left handed rotating signals (LHCP). The pattern displays the amount of the receiving signals.



Vertical slice @ PHI=90°: RHCP and LHCP
@ 1,16 GHz (left) @ 1,61 GHz (right)

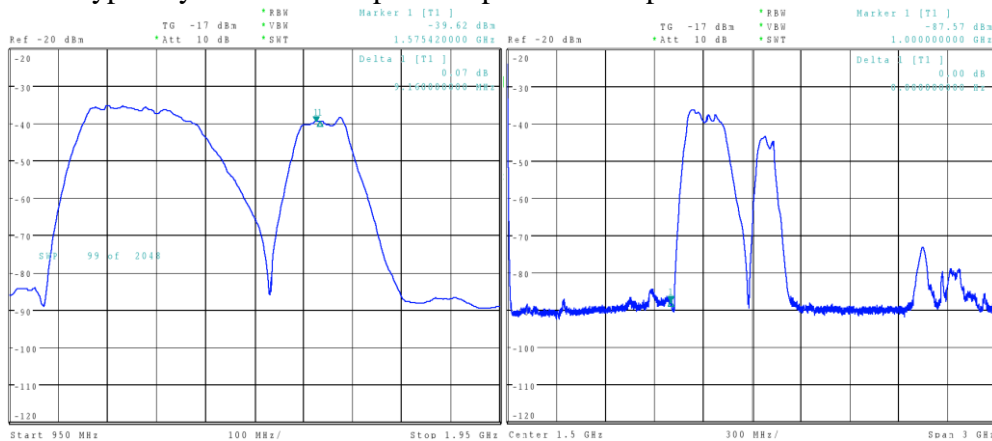


Horizontal slice @ THETA=75°: RHCP and LHCP
@ 1,16 GHz (left) @ 1,61 GHz (right)

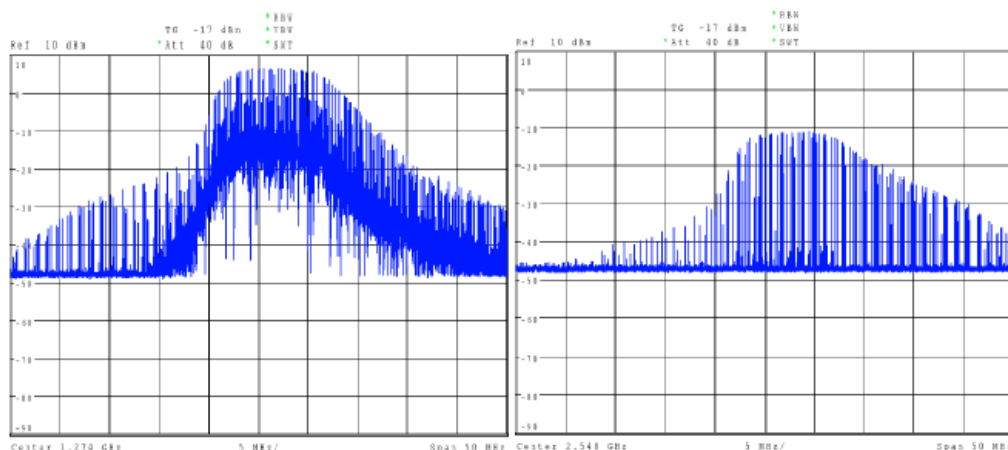
The red line shows the received quality of the RHCP signals and the blue line shows the LHCP signals. The measurement told us that the 3G+C antenna has a very good multipath reduction (blue line) and enough gain to receive the signals from the satellites with low elevation (0°).

5.3 Filtering

The antenna filter was measured with a network analyzer. The input of the antenna is not accessible. A wideband log-periodic antenna was used to radiate into the 3G+C. This implies that the measurements are only relative and of limited accuracy. Nevertheless, we can conclude the antenna is nicely tuned to all GNSS frequency, with rather good suppression by 50dB typically with the exception of parts of the spectrum around 2.5GHz.

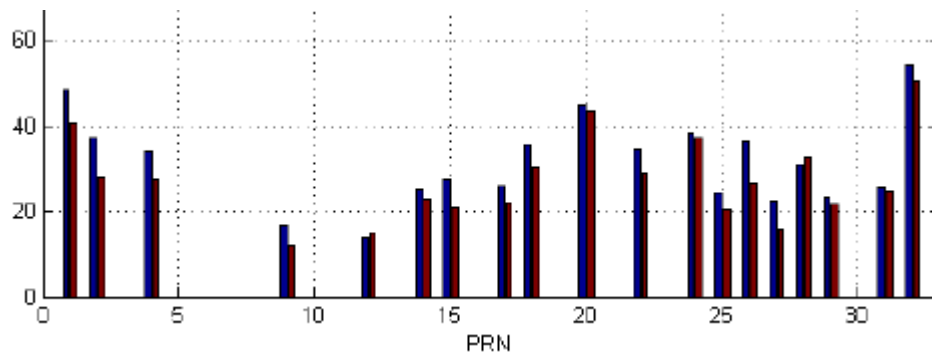


In spite of this filter, really strong signals, such as the air traffic radar at Bertem, which has a line of sight with the installation on the roof, can still leak through and saturate the amplifier. The radar in our vicinity has a frequency of 1.274GHz and the first and second harmonic are clearly leaking through. Following measurements show the peak power recorded with a spectrum analyzer.



5.4 The passive gain

The value of the passive gain is in dbic. For simplifying you can determine: If the value is higher the antenna is able to hear better the signals from the satellites. Normally the receiver hears nothing under a value of 2 dbic. The 3G+C antenna has a really good passive gain. Here the s/n ratio between 3G+C (blue) and the Zephyr (red).



The 3G+C has a better s/n ratio with every GPS satellite independent of the elevation angle. This is the reason to do the next step only with the 3G+C antenna from navXperience.

5.5 The group delay phase variation

The phase delay variation in depend of the elevation angle is very important for the time synchronization and for the accuracy. In March 2013 the Geo++ Company got the order to make the measurement with three 3G+C antennas. Unfortunately for this paper the information about the results comes too late. More information about the group delays in the presentation. In simulation we expect a group delay phase variation under 1 ns.

6. CONCLUSION

A disappointment in the comparisons was the Leica AR10. The brochure promised a new good antenna design with a high accuracy. But the ANTEX data showed a four wings result when the elevation angle goes down. We don't expect these results from a new precise GNSS antenna. The Zephyr and the 3G+C antenna deliver here much better results. Surprisingly were the PCV results from the navXperience 3G+C antenna. Also in the other disciplines surprised the 3G+C antenna: A very good tracking of GNSS satellites with low elevation, good filters and perfect multipath reduction. If ESA has no negative surprise with the group delay phase variation the 3G+C antenna is fixed for rover and for reference station in the Galileo monitoring network.

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BIOGRAPHICAL NOTES

1987 – 1991 Technische Fachhochschule Berlin Dipl.-Ing. Geodesy

From 2001 Founder and director of the Geo.IT Systeme GmbH

From 2009 Founder and director of the navXperience GmbH

2009 – 2012 Research projects: MoDeSh with GL and HSVA: Motion and Deformation of Ships

From 2010 Developing precise GNSS antennas

From 2012 Member of the working group AK 3 "Measurement method and Systems" DVW Germany

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