Leica GS05

The lightest GNSS smart antenna to trust

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Abstract

The ongoing miniaturization of surveying equipment offers immense potential in terms of usability and cost savings. In recent years, the reduction in size of GNSS devices in the surveying sector has gained significant importance and improvements. However, it remains a challenging task to find a balanced trade-off between compactness and performance. The new Leica GS05 GNSS smart antenna belongs to this category, and this paper examines its advanced usability and reliability despite the compact design. It also explains the key components of this new GNSS RTK rover from Leica Geosystems and highlights the main differences between premium and mid-range GNSS receivers.

1. Introduction

A well-known principle, the Pareto Principle, states that 80% of the results can be achieved with 20% of the total effort. For high-precision RTK surveys with centimeter accuracy, GNSS devices have been developed over decades to optimally receive GNSS signals and minimize the influence of multipath effects and signal interference. High-end devices like the Leica GS18 I rely on industrial technologies for optimal user experience and performance (SCHAUFLER et al. 2020), even under challenging measurement conditions. A new trend in the GNSS surveying sector, which has become evident in recent years, is the continuous miniaturization of GNSS devices using components also found in consumer goods such as mobile phones, car navigation systems, and even e-scooters.

In the past, such compact and lightweight GNSS receivers have primarily been developed for GIS applications such as utility and infrastructure surveying, where decimeter-level accuracy is sufficient. In recent years, however, GNSS module manufacturers like u-blox and Unicore have introduced compact and low-cost GNSS chips that approach the performance level of premium products from NovAtel (part of Hexagon), Trimble, Topcon, and Septentrio (part of Hexagon). As a result, more and more little-known manufacturers are bringing compact GNSS receivers with aggressive specifications in terms of accuracy and functionality to the market. These compact models are often positioned as cost-effective alternatives for users who need precise positioning but do not require the full functionality or reliability of high-end devices. One aspect, for instance, is the growing demand on jamming robustness, which protects GNSS receivers from intentional and unintentional interference. Jamming can be caused by various types of jammers specifically designed to disrupt the weak satellite signals. High-end models, such as the GS18 products, have anti-jamming functions that enhance the reception of GNSS signals while simultaneously detecting and suppressing interference signals (GONZÁLEZ-CALVO et al. 2022). Such advanced feature is often not available in entry-level or mid-range devices that rely on consumer technologies. This illustrates the Pareto Principle: achieving the last 20% of performance requires a disproportionately high investment.

Compact GNSS devices are often used in conjunction with smartphones as control units to directly process precise positioning results in data collection apps like ArcGIS Field Maps. These devices are designed to be lightweight and handy while still meeting the essential requirements of many surveying tasks. However, the question arises, whether they could fulfill the stringent requirements of high-precision RTK positioning in terms of availability, accuracy, and reliability despite their compact design and integrated consumer parts. In October 2024, Leica Geosystems introduced the Leica GS05, a new GNSS smart antenna in this compact category, which aims to provide a lightweight, powerful, and reliable GNSS RTK solution. Together with the Leica Captivate software, the GS05 offers a variety of functionalities for versatile applications.

2. Leica GS05 – Lightweight and Powerful

The Leica GS05 was introduced to address several key trends and requirements in the GNSS surveying sector. One of the primary motivations is the ongoing trend of miniaturization, which aims to reduce the weight of surveying equipment. This trend not only enhances instrument portability, but also reduces the physical strain on users during field operations. The GS05 is positioned as a mid-range GNSS RTK rover that combines compact design with powerful performance. It supports multiple communication options, including LTE, UHF, WLAN, and Bluetooth. This versatility makes the GS05 suitable for a wide range of applications, from utility and infrastructure surveying to more demanding high-precision tasks. Fig. 1 gives a product overview of the Leica GS05, showing its flexible connectivity options for RTK link and data sharing.

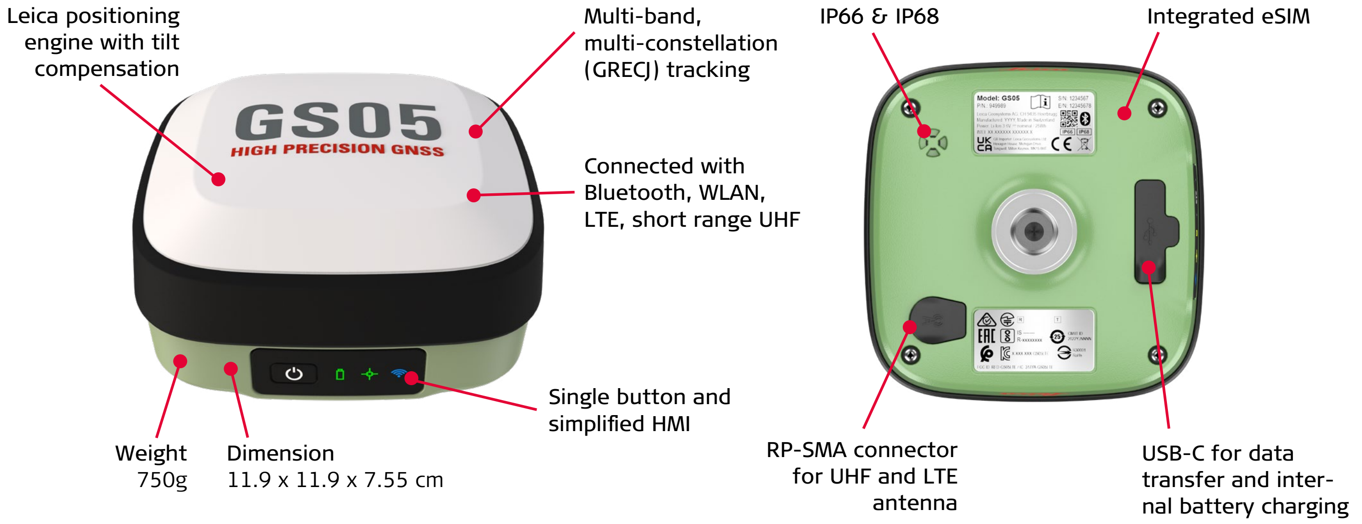


Figure 1: Product summary of the Leica GS05 GNSS smart antenna.

For field use, the portability of GNSS measurement systems plays an important role. GNSS RTK rovers are almost exclusively mounted on a pole, where low weight is a favorable factor for transportation and field operation. The GS05, weighing 0.75 kg and having a housing size smaller than 12 cm, falls within the typical range for compact devices and thus offers higher portability compared to heavier high-end models (e.g., GS18 I with 1.25 kg). Even lighter alternatives in the range of 0.3 kg are also available, such as the Leica Zeno FLX100 plus with 0.32 kg (LEICA GEOSYSTEMS 2020). These ultra-light devices use cost-effective helix GNSS antennas, which however, bring significant limitations in terms of antenna characteristics, as detailed in section 4.1.

The miniaturization is achieved almost without compromising the positioning performance. Looking at the accuracy values specified in the data sheet (LEICA GEOSYSTEMS 2024), the GS05 claims a horizontal RTK accuracy of 10 mm (25 mm with tilt compensation) and a vertical accuracy of 20 mm under ideal measurement conditions. These values suggest that the GS05 should be suitable for a variety of surveying tasks and would only slightly deviate from premium high-precision models (e.g., GS18 I with Hz: 8 mm and V: 15 mm; LEICA GEOSYSTEMS 2022) at first glance. However, a detailed examination reveals that the GS05 relies on multi-band signal tracking with only dual-frequency positioning for each constellation, while the GS18 I supports multi-frequency positioning. A third frequency in GNSS positioning offers significant advantages for phase ambiguity resolution, as it increases accuracy and reliability under challenging conditions (LI 2018). Particularly under increased ionospheric activity (e.g., due to solar storms), more stable RTK solutions could be achieved with multi-frequency receivers (VAN HEES et al. 2014). However, dual-frequency remains competitive in terms of cost-benefit ratio, as in some cases, the transition of GNSS satellites to the third frequency and the adaptation of RTK reference networks are not yet fully completed.

3 Usability – Versatile Applications

Many lightweight GNSS devices are designed to require minimal computing power to transmit precise position information directly to a smartphone. An application on the smartphone then uses this precise position (known as "mocking"), along with other connectivity options provided by the smartphone. This concept offers the advantage that the GNSS device itself only needs a connection to the smartphone, while all other data transmission processes take place using the internet connection on the smartphone. However, such solutions also have limitations and cannot serve the following GNSS applications, for example, 1) in areas without network coverage where RTK surveying with a direct UHF radio link is required; 2) operation as a base; 3) GNSS data logging for post-processing. Therefore, the new Leica GS05 has been designed as a smart antenna to offer high flexibility to operate independently of RTK network availability and coverage. It is equipped with LTE, UHF, WLAN and Bluetooth, providing versatile data connectivity options to serve a wide range of GNSS surveying tasks.

Flexibility in communication directly increases the required device volume and affects the energy budget. In general, an LTE or UHF modem requires significant amounts of energy during continuous operation, which impacts upon the battery design. To cope with this, the Leica GS05 utilizes a low-power UHF module that has a minimum effect on the battery runtime. The GS05 is equipped with an internal 6000 mAh battery which powers the device over a whole working day. It enables charging via a standard USB-C connector, making the device flexible and convenient to charge, for example, with a portable power bank. Fig. 2 illustrates the battery runtime of the GS05 in various application scenarios. A typical operating time of about 10 hours can be expected in most use cases, with a slight decrease to 8 hours when the LTE modem is in use. The presented battery runtimes were measured at 20°C temperature and only degrade by about 10% when operating at -20°C temperature.

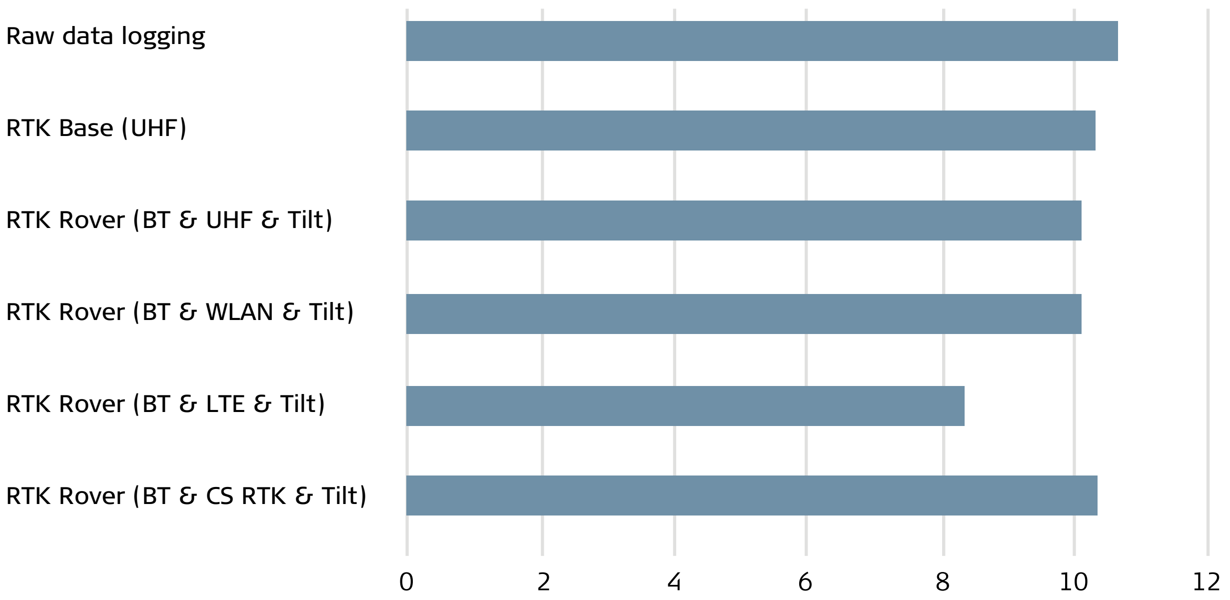


Figure 2: Battery runtime of the Leica GS05 in hours for different use cases.

The integration of IMU (inertial measurement unit) measurements from micro-electro-mechanical systems (MEMS) is now standard in modern premium and mid-range GNSS RTK rover products. The IMU-based tilt compensation allows high-precision determination of the pole tip position even when the surveying pole is tilted (LUO et al. 2018a). This approach significantly increases productivity, extends RTK applicability and improves positioning performance in difficult environments. However, integrating MEMS IMUs places high demands on the precision of the internal device architecture. For accurate tilt compensation results, knowledge about the exact position and orientation of the IMU in the GNSS receiver housing is crucial. These are usually determined during production through factory calibration. However, extreme mechanical stresses, such as physical shocks, can change the calibration values and thus impair the quality of tilt compensation. Therefore, a stable housing structure plays an important role in ensuring that the IMU calibration remains valid throughout the entire life cycle. Instead of lightweight plastic, both the GS05 and GS18 products use an aluminum housing, which guarantees long-term stability of tilt compensation without requiring any field calibrations by the user. In addition, the GS05 utilizes the same proven IMU-based tilt compensation algorithm as the GS18 T (LUO et al. 2018b). The only difference on the GS05 is that the tilt compensation is supported up to a tilt angle of 30°, which is sufficient for the great majority of application scenarios. In section 4.2.2 the reliable tilt compensation performance of the GS05 is demonstrated and compared against a competitor device.

One product variant of the GS05 is equipped with an internal UHF radio that allows to transmit and receive RTK corrections independently from any RTK network coverage. This is ideal for high-precision surveys at small to medium construction sites with a typical line-of-sight range of up to 1.5 km (approx. 1 mile). As is well known for RTK radio communication, the signal is susceptible to local interferences, and thus in built-up areas, the effective radio operation range may reduce to a few hundred meters. Fig. 3 illustrates the results from a radio range test with a single baseline setup, where an RTK survey using the GS05 internal UHF could be successfully conducted at a range exceeding 2 km. Although reduced amounts of RTK packages were received at longer distances, RTK fixed solutions remained available thanks to the robust positioning engine in the GS05. This demonstrates that the specified radio operation range of 1.5 km is achievable under normal conditions. Premium GNSS receivers like the GS18 family offer long-range UHF link support and are superior in such scenarios. Nonetheless, this low-power radio solution on the GS05 can already support various use cases effectively.

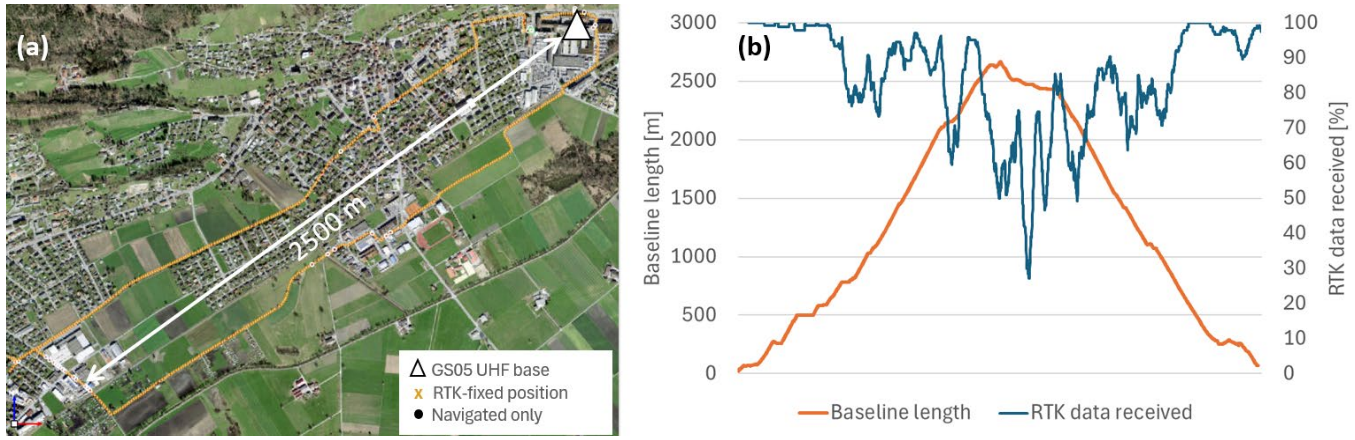


Figure 3: GS05 UHF single baseline range test in Heerbrugg (a) Location and position type overview, (b) Percentage of received RTK data compared to baseline length.

4. Reliable Positioning Performance

The previous sections presented a brief overview of the compact Leica GS05 smart antenna. In practice, the actual RTK positioning performance is of primary importance, which needs to be analyzed considering representative measurement conditions and different performance characteristics such as availability, accuracy, and reliability. This section provides an insight into the GNSS antenna selection for the GS05 and presents some benchmark results from RTK positioning with tilt compensation.

4.1 GNSS signal tracking – Patch vs. Helix antenna

GNSS satellites transmit signals over various frequency bands. For example, the GPS system transmits three frequencies for civilian use: L1 at 1575.42 MHz, L2 at 1227.60 MHz, and L5 at 1176.45 MHz. The usage of multiple frequencies allows forming ionosphere-free linear combinations to reduce ionospheric effects, which could otherwise cause horizontal errors in the meter range (HOFMANN-WELLENHOF et al. 2008). Other GNSS constellations like Galileo, GLONASS, and BeiDou also use multiple frequencies distributed across the upper and lower L-band. A key advantage of this structure is the ability to receive all GNSS signals simultaneously with a broadband antenna.

Compact GNSS receivers integrate two main types of antennas: the patch antenna and the helix antenna. Patch antennas consist of a metallic layer on a dielectric material, which is mounted on a larger conductive plate, known as the antenna ground plane. The flat design of patch antennas allows for flexible adaptation in shape and size, making them versatile and cost-effective to manufacture. Although a single patch can only receive one frequency, stacking patches can cover multiple frequencies, offering flexible application possibilities (RAO et al. 2013).

In contrast, a helix antenna consists of multiple wound elements that enable signal tracking. To receive multiple frequencies, additional helices are wound in parallel, where the length of the helices determines the frequency band that can be received (MAQSOOD et al. 2017). Helix antennas are very sensitive to orientation, and thus for maximum antenna performance, the main lobe of the antenna should point towards the sky. This leads to limitations in the tilt range of the antenna and IMU integration to offer tilt-compensated point measurements. As the tilt angle of the pole increases, the main lobe deviates more from the local zenith, resulting in degraded signal reception and greater phase center deviation. Furthermore, helix antennas do not require a ground plate, making them compact and lightweight, but also more vulnerable to multipath effects (RAO et al. 2013; WANNINGER et al. 2022).

To illustrate the differences between patch and helix antennas, Fig. 4 compares the phase center offset (PCO) characteristics of the GS05 and FLX100 plus, where the antenna corrections were determined using absolute robot calibration (WÜBBENA et al. 1996, 2000). For the supported frequency bands, Fig. 4a shows the horizontal distance between the antenna reference point (ARP) and the antenna phase center (APC), calculated based on the North and East components of the PCO. In comparison to the FLX100 plus with a helix antenna, the GS05 with a patch antenna shows significantly smaller distances, mostly less than 2 mm. The smaller this distance, the lower the horizontal error due to the unknown orientation of a GNSS antenna. When comparing the UP component of the PCO in terms of spatial distribution (Fig. 4b), the GS05 antenna also shows smaller dispersion across the entire frequency bands.

In summary, to achieve real-time cm-level accuracy with compact GNSS receivers, it is necessary to consider the antenna calibration values. Nevertheless, the horizontal PCO components and rotation-dependent influences cannot be fully modeled mathematically despite the orientation information provided by the IMU. This results in greater position errors for helix antennas. To ensure high performance also for tilt compensated measurements, the GS05 is equipped with a survey-grade patch antenna rather than a helix antenna.

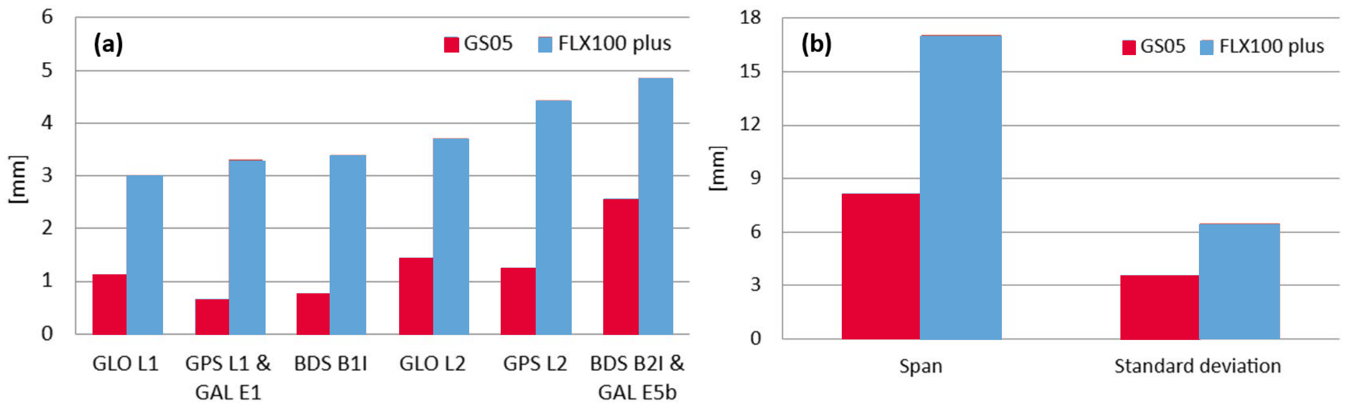
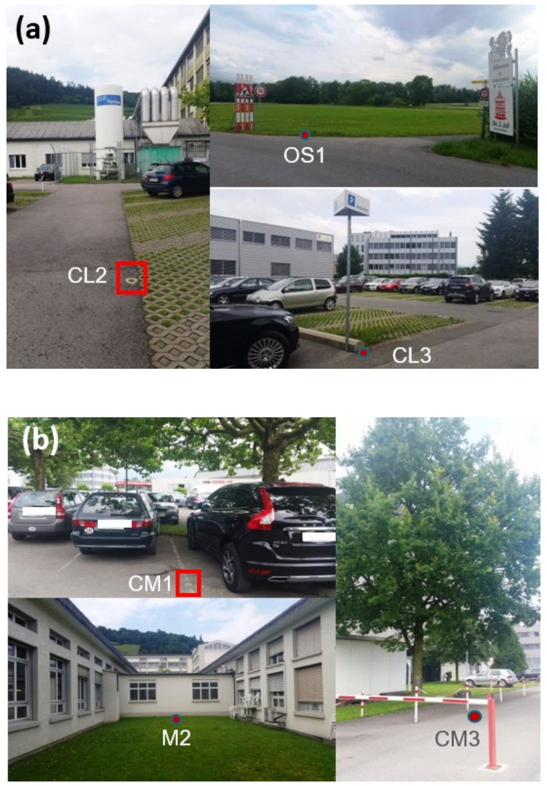


Figure 4: Comparison of the PCO characteristics between GS05 (patch) and FLX100 plus (helix) (a) Horizontal distance between the ARP and APC, (b) Dispersion of the PCO UP component across different frequency bands.

4.2 RTK Positioning Performance

This section presents benchmark results comparing the compact Leica GS05, the premium model Leica GS18 T, and another mid-range competitor GNSS smart antenna, denoted as Rover A. Since all these GNSS receivers are equipped with a MEMS IMU, the test measurements were conducted using tilt compensation. The GNSS and RTK configurations on the GS05, GS18 T and Rover A were largely consistent, where 4GNSS-VRS corrections were generated in the RTCM v3 MSM format using the Leica GNSS Spider software 7.10.0.



To reflect various working environments of surveyors, representative measuring conditions in the Heerbrugg testbed were considered, which can be divided into three categories: normal, medium, and difficult. Fig. 5 shows examples of the testbed points from different categories. For points under normal conditions, which are located in relatively open areas without significant obstructions and multipath effects, it is expected that a large number of high-quality observations will be available for multi-GNSS RTK. More interesting is the performance comparison under medium and difficult conditions, where degraded GNSS signal quality, variable satellite geometry, and increased multipath effects have larger impact upon the positioning results.

Figure 5: Examples of the different measuring environments in the Heerbrugg testbed
(a) Normal conditions,
(b) Medium conditions,
(c) Difficult conditions.

4.2.1 RTK Performance Characteristics

Multi-GNSS RTK with tilt compensation is a highly complex real-time process, aiming to achieve cm-level accuracy through sensor fusion of GNSS and IMU in the least amount of time possible and even under challenging conditions. To evaluate the system as a whole and to reflect users' requirements in their applications, the following performance characteristics are considered in this analysis:

- **AVAILABILITY:** The percentage of RTK fixed positions relative to all measured positions.

- **ACCURACY:** The deviation of RTK fixed positions from ground truth coordinates with a higher degree of accuracy, determined using a total station or by post-processing long-term static GNSS data.

- **RELIABILITY:** Percentage that the position error (with respect to ground truth) is less than three times the coordinate quality (CQ) indicator.

4.2.2 Tilt Compensation Performance

Firstly, to verify the tilt compensation performance, the GS05 was benchmarked against the high-end model GS18 T and another mid-range GNSS smart antenna (Rover A). The test was carried out in an open-sky environment to minimize the effect of obstructions and to focus on the tilt accuracy. A total of 64 instantaneous RTK measurements were taken considering variations in GNSS satellite geometry as well as different tilt angles and tilt directions. Since it is well known that enabling tilt compensation primarily affects the horizontal components, Fig. 6 compares the 2D root mean square (RMS) errors for tilt angles up to 30°. As can be seen, the GS18 T provides constantly the best horizontal accuracy across all evaluated tilt angles, with an overall 2D RMS error of 1.1 cm. When compared to the GS18 T, the GS05 shows slightly larger horizontal errors by up to 6 mm at 0° tilt, where the direction of tilt is poorly defined and is determined with low quality. Overall, the GS05 delivers a similar tilt accuracy level as the GS18 T. Using Rover A, the tilt compensation performance is highly variable and unreliable, with the maximum 2D RMS error of 8.4 cm at 10° tilt. On average, the GS05 is more than twice as accurate as Rover A, offering a tilt compensation solution that can be trusted.

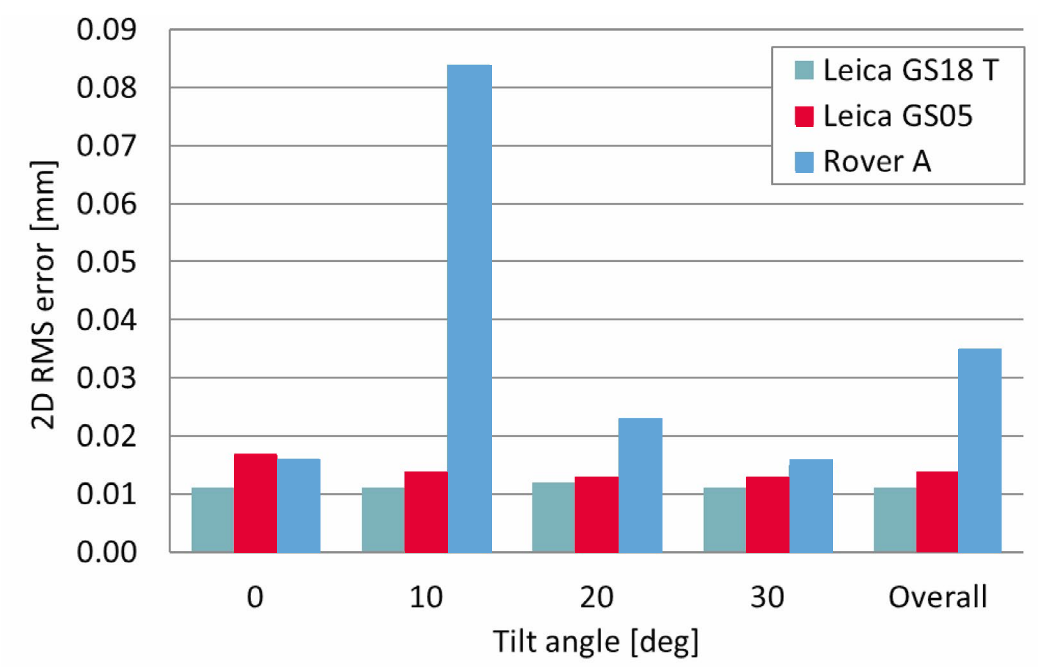


Figure 6: Comparison of the 2D RMS errors for different tilt angles (open sky, pole length: 1.800 m, 64 instantaneous RTK measurements).

4.2.3 RTK Positioning: Leica GS05 vs. Leica GS18 T

To evaluate the achievable accuracy in a working scenario, Table 1 compares the RMS errors of the RTK fixed positions under normal conditions (Fig. 5a). The GS05 shows a horizontal RMS error of 2.2 cm and a vertical of 1.5 cm, demonstrating that the accuracy specifications for RTK with tilt compensation (Hz: 2.5 cm, V: 2 cm; LEICA GEOSYSTEMS 2024) are reachable in normal surveying environments. In addition, the premium model GS18 T delivers a better horizontal accuracy by 9 mm, while the vertical accuracy differs only insignificantly. This can be explained by the fact that the GS18 T is equipped with an industrial grade IMU for optimum accuracy (LUO et al. 2018b), whereas the GS05 utilizes a commercial grade IMU for better compactness and lower cost. Moreover, enabling tilt compensation introduces additional uncertainty in position estimation, primarily affecting the horizontal components.

Table 1: Comparison of the RMS errors [m] of the tilt-compensated positions between the GS05 and GS18 T under normal conditions (pole length: 1.800 m, 30 RTK fixed solutions for each device).

	Total (3D)	Horizontal (2D)	Height (1D)
GS05	0.027	0.022	0.015
GS18 T	0.019	0.013	0.014
Difference	-0.008	-0.009	-0.001

Table 2 compares the availability of RTK fixed solutions between the GS05 and GS18 T under various measuring conditions. As expected, under normal conditions, both receivers deliver the maximum availability of 100%. Under medium conditions, the GS05 failed only one time (out of 40 measurements) to produce an RTK fix at the point CM3 (Fig. 5b), resulting in a slightly lower availability by 2.5% compared to the GS18 T. Under difficult conditions, the GS18 T provides a significantly higher availability by 20.3% than the GS05. This is due to the advantages of the GS18 T in terms of better GNSS signal reception using a more sensitive antenna element (LUO et al. 2018a), multi-frequency positioning support, and advanced multipath reduction (GONZÁLEZ-CALVO et al. 2022). Despite the improved availability under difficult conditions, the GS18 T shows a similar horizontal RMS error of 6.4 cm as the GS05 (6.2 cm).

Table 2: Comparison of the availability of RTK fixed positions between the GS05 and GS18 T under different measuring conditions (pole length: 1.800 m).

Environment	Number of measurements	GNSS sensor	RTK fixed solution	Availability (%)
Normal conditions	30	GS05 GS18 T Difference	30 30 0	100.0 100.0 0.0
Medium conditions	40	GS05 GS18 T Difference	39 40 1	97.5 100.0 2.5
Difficult conditions	84	GS05 GS18 T Difference	40 57 17	47.6 67.9 20.3

Apart from availability and accuracy, another important performance characteristic is reliability. It reflects the consistency between the actual position error with respect to ground truth and the CQ indicator estimated based on mathematical models in positioning algorithms. In this benchmark test, it was observed that the 3D reliability of the GS18 T and GS05 reaches a similar level under all measurement conditions, consistently delivering a large value of more than 95%.

4.2.4 RTK Positioning: Leica GS05 vs. Rover A

The same RTK positioning test as presented in section 4.2.3 was performed using the GS05 and the mid-range competitor device Rover A. The total numbers of measurements are 12, 16 and 64 for normal, medium and difficult conditions, respectively, with more focus on challenging environments. Table 3 summarizes the test results with respect to availability, 3D accuracy and 3D reliability. Under normal and medium conditions, both compact GNSS receivers provide the maximum availability of 100%. Under difficult conditions, the GS05 outperforms Rover A, with a higher availability by 7.8%. In terms of accuracy, under normal conditions Rover A delivers a significantly large 3D RMS error of 10.1 cm, which is 8 cm higher than the GS05. This is mainly attributed to the large 2D RMS error of 9.9 cm of Rover A, indicating an unreliable tilt compensation solution (cf. Fig. 6). Under medium and difficult conditions, the GS05 also performs more accurately than Rover A, with smaller 3D RMS errors by 6 mm (11.1%) and 12 mm (13.3%), respectively. Regarding the 3D reliability, the GS05 achieves the maximum value of 100% under normal and medium conditions, which is 33.3% and 12.5% higher than Rover A, respectively. Under difficult conditions, the GS05 shows 14.5% higher reliability than Rover A. Overall, the GS05 outperforms Rover A in all aspects and under all conditions, offering an excellent balance between reliable performance and compact design.

Table 3: Comparison of the RTK performance with tilt compensation between the GS05 and Rover A under different measuring conditions (pole length: 1.800 m).

Environment	Number of measurements	GNSS sensor	Availability (%)	3D accuracy (m)	3D reliability (%)
Normal conditions	12	Rover A GS05 Difference	100.0 100.0 0.0	0.101 0.021 -0.080	66.7 100.0 33.3
Medium conditions	16	Rover A GS05 Difference	100.0 100.0 0.0	0.054 0.048 -0.006	87.5 100.0 12.5
Difficult conditions	64	Rover A GS05 Difference	46.9 54.7 7.8	0.090 0.078 -0.012	73.0 87.5 14.5

5. Conclusions

The trend towards compact and lightweight GNSS receivers is steadily increasing. They have rapidly evolved into sophisticated surveying instruments through a thorough selection of hardware components as well as intelligent design and integration. The main challenge is finding a balance between functional versatility, reliable performance, and compact design. The Leica GS05 aims to find this "sweet spot" between performance and miniaturization, which is crucial for a powerful and user-friendly mid-range GNSS receiver that still meets most requirements of high-precision RTK positioning under various measuring conditions. The novel GS05 will particularly appeal to users for whom compactness plays an important role. However, experienced and demanding users in the GNSS sector will continue to rely on high-end solutions to ensure that all requirements of high-precision RTK are fulfilled. Table 4 highlights the main differences between the Leica GS05 and the premium model GS18 T.

Table 4: Main differences between the mid-range Leica GS05 and the high-end GS18 T.

	Max. accuracy	GNSS & IMU module type	Tilt compensation	SmartNet RTK Bridging / PPP	Cellular / UHF	GNSS channels / Frequencies	Advanced multipath and iono mitigation	Anti-jamming functionality
GS05	10mm H / 20 mm V	Commercial	Up to 30º	✗ / ✗	✔ / (✔)*	184 / dual	✗	✗
GS18 T	8mm H / 15mm V	Industrial	Unlimited	✔ / ✔	✔ / ✔	555 / all	✔	✔

* Short range only

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Leica Geosystems – when it has to be right

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