Surveying Reflectors
White Paper
Characteristics and Influences

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Surveying Reflectors - Characteristics and Influences

Daniel Nindl and Junyu Mao

Abstract

This paper presents an overview of the different factors regarding surveying reflectors that should be considered by the surveyor in order to ensure the highest quality surveys. First, the properties and differences between round prisms and 360°-reflectors are explained. We will discuss the assembly of the reflectors and why they have different reflector constants. As well, we discuss the typical applications for each of the reflectors. Secondly we'll show which properties have an influence on angle and distance measurements, e.g. the Anti-reflex coating. And last, we will point out what influences remain in the hands of the surveyor, relying on how well setup the survey instrument is and the use of a high-quality tribrach and tripod.
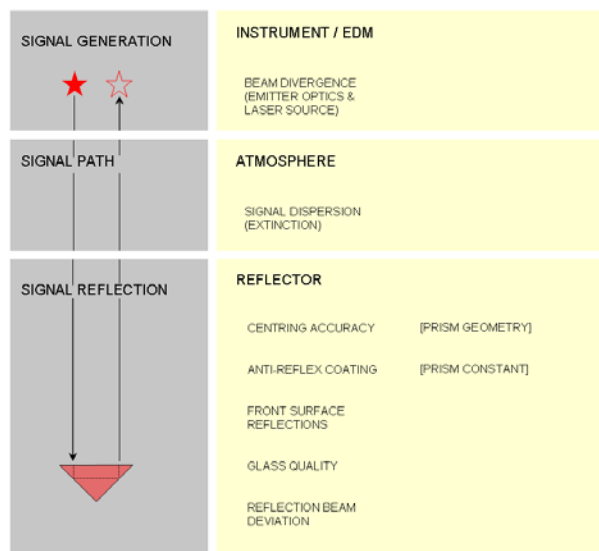
Figure 1 – Different stages of an electronic distance measurement.

Introduction

Surveying targets – surveying reflectors in particular - are important accessories for various applications in surveying. Widely accepted as reliable accessories, surveyors normally do not consider the influence which surveying reflectors have on measurements. However, obtaining a certain level of accuracy and reliability requires the consideration of all possible effects on the measurements. A high emphasis is usually put on specifications and accuracy of the total station. Too often the role of accessories is not given enough thought towards the intended application and the subsequent results. Various applications require 3D coordinate qualities only in the range of centimeters. But other tasks demand much higher accuracies, like machine alignments or deformation measurements of sensitive objects. For such tasks, an in-depth analysis of the influence and treatment of potential error sources is mandatory.

This paper summarizes the key factors relative to surveying reflectors that can influence the measurements - distance as well as angular measurements. Centering accuracy and the geometrical alignment to the instruments line of sight are two examples that may have a crucial effect on the survey results. Ignoring these key factors normally leads to a decrease of the measurement quality. All Leica Geosystems surveying reflectors consider these important factors. Based on sophisticated production techniques, strict assembly and quality control, Leica Geosystems reflectors are of the highest quality.

Figure 1 shows the three main phases of an electronic distance measurement - the generation of the signal, the time of flight towards the reflector through the atmosphere and the signal reflection. It is an important fact that the

emitted EDM signal must be reflected back to the EDM receiver. This is the role of the reflector. Its importance to the measurement path is further discussed below.

This White paper is subdivided in three main sections:
- Reflector Characteristics – focusing on reflector geometry and reflector constants
- Signal Creation and Signal Path – describing the emission and spread of the EDM signal
- Signal Reflection – Influencing Factors include: centering accuracy, beam deviation caused by the reflector, reflex- and anti-reflex-coating for particular wavelength', glass quality and ultimately the alignment to the instruments line of sight
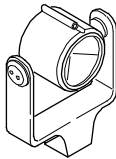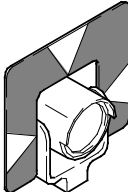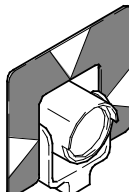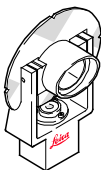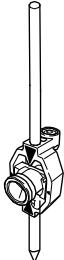
Reflector Characteristics

There are two main reflector properties that are not subjected to a measure of quality. The first is the reflector type and its general geometry (a) – is it a 360°-reflector that reflects measurement signals from all directions or does it require being aligned with the instruments line of sight, such as the round prism. Second main reflector property is the reflector constant. (b) The reflector constant is a given property of the particular model - it defines the relation of the distance measurement to the mechanical reference point of the reflector (holder).

In principal the reflector constant is constant and as long as it is considered correctly no influence on the measurements can be expected. The reflector geometry is purely dependent on which model has been chosen.

Different applications require different reflector models – from high accuracy round, omni directional 360° or even the small size targets these properties are deciding factors for the purchase.

Figure 2 – A range of Leica Geosystems surveying reflectors.

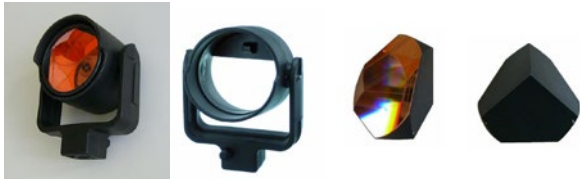| Model:	GPH1P	GPR121	GPR1+GPH1	Mini GMP101	GRZ122	GMP111
Image:						
Material:	Metal	Metal	Plastic	Metal	Metal	Metal
Centering Accuracy:	0,3 mm	1,0 mm	1,0 mm	1,0 mm	2,0 mm	2,0 mm
Leica Constant	0	0	0	+17,5 mm	+23,1 mm	+17,5 mm

Figure 3 - Round Prism consisting of a circular housing and glass insert; shown from different perspectives.

Reflector Geometry – Round Prisms

Typically most surveying tasks are completed using round prisms (cf. Figure 3). High precision measurements that require tight specifications usually are provided by round prisms. 360° reflectors have only been developed in more recent times (specifically for robotic use). Until now, the standard for surveying measurements is still the round prism. Automated instruments are a more recent development. Therefore we can also say many surveyors still do not use motorized instruments and the round prism with its directional reflection fulfills the measurement task. (cf. Figure 10).

A round prism consists of taking a triple-prism glass assembly and grinding down the 3 corners to fit correctly within the circular housing (cf. Figure 3).

In Leica Geosystems' portfolio a model for every particular application is available (cf. Figure 2) – just select what is required for the measuring task.

All Leica Geosystems standard round prisms and holders (GPH1P, GPR121, GPR1, and GPH1) have the same diameter of 62mm. This dimension is used to ensure efficient use of the receiver optics (the prism diameter is adjusted relative to the telescope diameter incl. tolerances). This is referred to as the signal reflection capacity of the prism. Figure 3 shows a round prism (GPR1 + GPH1-holder) disassembled from different perspectives.

Since EDM's have been used, Leica Geosystems offers various round prisms to satisfy the specifications of our customer needs. Fixed installations for precise monitoring purposes to the classical topographic surveys are conducted with Leica Geosystems reflectors. They have become the standard for highly reliable and accurate surveying targets.

Figure 4 – One of Leica Geosystems 360°-reflectors (GRZ122).

Prism Geometry – 360° Reflectors

State of the art total stations like the Leica Geosystems Robotic total stations and the MultiStations utilize automated target recognition (ATR) and automated lock technology. This technology is best used with a prism that works omni directional – to allow a higher level of convenience for the operator at the pole by avoiding the need to constantly align the prism to the instrument. In principal the 360°-prism has the same functionality as a round prism – reflecting the incoming EDM signal towards

the instruments EDM receiver optics. However, it consists of six triple-prism-glass bodies, tightly assembled (patented by Leica Geosystems – U.S. patent number: 6,123,427); each is comparable to a single round prism but with smaller dimensions and with just slightly grounded corners (cf. Figure. 4 and 5).

A continuous and permanent reflection of the EDM signal is important to fully realize the benefits of working with robotics. As in one man mode the operator at the pole is moving around relatively quickly and should concentrate on the points being measured and not permanently aligning the prism to the instrument.

This is accomplished by using one of the following Leica Geosystems 360° reflectors:

- GRZ4   Classical 360°-reflector
- GRZ122   360°-reflector with additional thread
            (for mounting of GNSS Antennas)
- GRZ101   360°-minireflector for close range use
- MPR121   360°-reflector ruggedized for machine control
            applications (reinforced center shaft)

Disadvantages of 360°-reflectors are the relatively high weight and large size. However the higher increase in productivity with robotic surveys (incl. ATR or Lock mode on Leica Geosystems Robotic total stations and MultiStations) when used in one-man mode, together with its capability to support a Leica SmartAntenna, makes it an indispensible accessory for efficient work.

Using Leica Geosystems instruments together with Leica Geosystems 360° reflectors ensures the best measurement performance – the position accuracy is typically 2mm or better - and a high ease of use for the particular surveying task.

Reflector Constants

Whenever measurements to reflectors are made, independent of a distance- or angle-measurement, they need to be referenced between two points – the standing axis of the instrument and the target point). Therefore its important to consider the mechanical design of the reflector body, the housing and the mounting stud, in order to guarantee a well-defined reference of the reflector center (reflector-standing axis) to the designated point (the second point is normally represented through the trunnion or center axis of the instrument).

Definition of reflector constant:

Prisms are still mainly made of glass. Glass has a different refraction index compared to air – the medium wherein

Figure 5 – Six triple-prism glass assembly**.**

5

measurement signals normally spread out. The propagation velocity of an electromagnetic wave as it enters a glass body is decelerated thereby the actual measured distance is extended. For all light beams perpendicular to the prism front, the length of the optical path (cf. Figure 6) accumulates to:

$$W = n \cdot d \qquad\qquad\qquad (1)$$

where

d distance from the front surface of the prism to the corner point of the triple prism (cf. Figure 6)

n index of refraction of the glass body

W is the distance from the prism front surface to the theoretical reversal point S_0

d is equal to the geometrical distance from the front surface to the corner point of the prism. **W** is defined by the distance between the theoretical reversal point **S_0** to the prism front (cf. Figure 6

The reflector standing axis is located in front of the theoretical reversal point **S_0**. To relate the measurements to the standing axis (with distance e to the front face) the particular prism constant **K_R** is applied. Other manufactures are normally using the following definition:

$$K_R = e - n \cdot d \qquad\qquad\qquad (2)$$

where

K_R prism constant definition of other manufacturers (not used by Leica Geosystems)

e   distance from center-symmetric point to the front face

Based on the definition mentioned above, the prism constant for a Leica Geosystems standard prism is **K_R** = -34,4 mm. Leica Geosystems defines the Leica constant for the standard prim as **K_{Leica}**= 0 mm. It is important to distinguish the difference between these two definitions. Distance meters in Leica Geosystems total stations consider this offset.

Location of the prism standing axis:
EDM-measurements must be referenced to the reflector standing axis. Leica Geosystems mounts the reflectors in such a way to ensure a minimal effect to the angle- and distance measurement, in case the reflectors are not aligned perpendicular to the line of sight of the instrument. The reflector standing axis coincidences with the central-symmetric point (or virtual prism center) of the prism glass (cf. Figure 6).
Referring to Leica standard reflectors, e.g. GPH1P and GPR121, the reflectors standing axis lies in front of the geometrical prism center (the back corner of the glass cube) – but is put into the apparent prism center. Thereby the emerging distance between the true center and the apparent center (if the aiming direction is not perpendicular

to the front surface) is minimized. This design has been especially chosen in order to provide an angle-independent definition of K_R for Leica Geosystems reflectors. Consequently a misaligned prism has a minimized influence on the angular and distance measurements.

In case that the light (wave) does not hit the front surface perpendicular but under the angle α the beam path is further extended and thereby a distance measurement error Δd ($\equiv \Delta AC$) is created. It is possible to describe this effect with the following formula:

$$\Delta d = e \cdot (1 - \cos\alpha) - d \cdot \left(n - \sqrt{n^2 - \sin^2\alpha}\right) \quad (3)$$

where

α incident angle of the line of sight referring to front surface of the prism

E.g. the outcome of a reflector with the dimensions e = 40 mm, d = 60 mm and n = 1.5 is a prism constant of K_R = -50 mm. Based on this number adding an angle of 30° (deviation of the collimation axis) a distance error of Δd = 0.1 mm can be realized [cf. Joeckel/Stober, 1999].

A distance error from an inaccurate alignment of the prism reflector is normally negligible. However, a proper (accurate) alignment is still highly recommended in order to achieve a maximum degree of efficiency of the reflector surface reflecting the incoming EDM-signal.

Furthermore prism constants are dependent on the wavelength of the EDM-signal because of varying refraction indices of the prism glass according to different wavelengths.

By employing high quality glass and precise assembly of the prism, along with an accurate determination of the refractive index n Leica Geosystems ensures highly reliable prism constants and negligible variations over time for all prism models.

Signal Creation and Signal Path

At the start of a distance measurement the instrument emits a laser beam that's performance is, due to the general electronic design, exposed to the environmental conditions during the distance measurement. However, any limitations caused during the signal creation or during the travel time of the signal influence the amount (intensity) of light arriving at the prism and are not factors influenced from the particular surveying prism used. Based on that information, we now explain this in more detail to have an understanding of how much signal is actually available for retro-reflection at the prism.
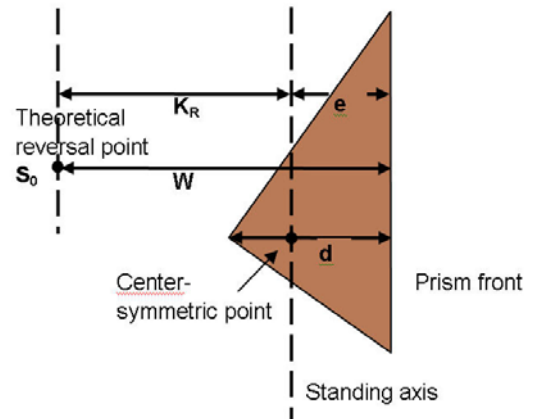

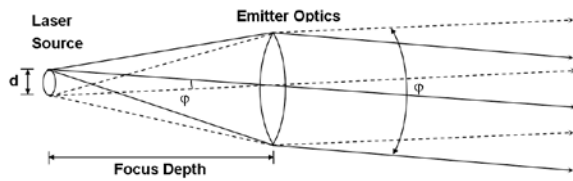**Figure 6** - Cross section through a triple prism.

Figure 7: Example of beam divergence after emission from the telescope.

The range of distance measurements is highly dependent on the energy available from the laser source. Through the EDM sensor, the emitted laser beam is subjected to several other effects: principally the atmosphere. As an adequate media for the emission of infrared (or visible) signals, however the transmissibility is reduced through the absorption from dust, air molecules and water drops – the so called extinction. Secondly, the EDM-signal must be precisely collimated – to minimize the remaining divergence angle (cf. Figure 7):

E.g. an angle φ = 5′ (average for a modern instrument) produces a footprint of 41,5 m^2 in a distance at 5 km.

A given prism (e.g. $\varnothing$ 5 cm) provides a reflection surface of 0,002 m^2 – that represents 1/20000 of the signal emitted. In turn just a fraction of this amount is received by the EDM-optics. But it is important to understand that this reflection surface is the optimum to reflecting the EDM signal. A bigger prism would not increase the distance measurement range. Why? The receiver optics can only process the reflected signal within a given diameter – a bigger prism would certainly contribute to the amount of signal returned but most of the EDM signal would just pass by the instrument. But using several reflectors (preferably of the same size/model) would increase the amount of usable signal returned and subsequently the distance measurement range would increase as well.

Using a measurement setup consisting of Leica Geosystems components ensures that signal power, emitter optics and prism design match each other and provide the highest performance. Thus the measurement specifications are easily met.

Signal Reflection – Influencing Factors

After the signal creation (by the EDM) and the travel time of the signal (through the atmosphere) the measurement signal arrives at the surveying prism. Now the signal should be reflected towards the instrument. The factors relating to influencing reflections from surveying reflectors are further described here.
A measurement setup is as accurate as the surveyors care to properly set the instrument over a point, but other parameters described below are product-dependent.

Within a measurement setup consisting of Leica Geosystems instruments and accessories, it is ensured that signal power, emitter optics and prism design match each other and yield the highest performance.

Centring Accuracy

This is the measurement for the precision relating the optical center point of the prism coinciding with the vertical axis of the prism holder. It is described by the following formula:

$$\sigma_{3D} = \left(\sqrt{\sigma_{cross}^2 + \sigma_{vertical}^2 + \sigma_{along}^2} \right) \qquad (4)$$

where

σ_{cross} Stndev. across the instrument's line of sight

$\sigma_{vertical}$ Stndev. vertically relating to the instrument's line of sight

σ_{along} Stndev. along the instrument's line of sight

It is important to know that this is not yet the measurement that defines the general centring accuracy over a given control point. Therefore the tribrach together with the tripod play an important role. Also to be considered are the centering accuracies of the selected prism, as example Leica Geosystems GPH1P model with 0.3 mm or the 360°-prism GRZ122 with 2.0 mm.

The mechanical design of Leica Geosystems' reflectors also considers the minimizing of mechanical wear in order to provide a long lifecycle, meeting customer's expectations of quality products.

Beam Deviation

The grinding of a prism glass plays a major role when reflecting signals. The more accurate the glass is ground (corner angles and surfaces), the better the signal will be returned in the same direction and the better its intensity.

The deviation between incoming and outgoing beams has a critical influence on the measurement range (cf. Figure 8). The signal returned goes along a deviant angle φ'. Figure 9 shows a test measurement of the beam deviation for a round prism taken with an interferometer.

The distance measurement is based on the detection of the phase difference (or time of flight) between incoming and outgoing signals. Normally surveying reflectors have a beam deviation of a few arc seconds. The check whether the beam deviation falls below the threshold of one arc second is done after its assembly. Every single prism is certified. Referring to the example shown in figure 9 the star-shaped pattern representing a slightly higher deviation than the average is caused by the prism edges. The round prism tested above has a maximum deviation of 0,8 arc seconds. That means, in every sixth of the prism glass body the direction of the incoming beam differs less than 0,8 arc seconds compared to the outgoing beam. However,
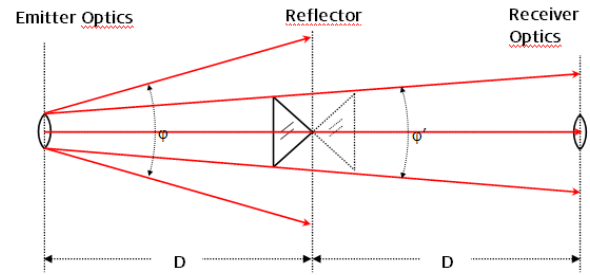

Figure 8 – Deviation of the reflected signal after leaving the prism towards the instrument (deviation angle φ' compared to the direction of the incoming signal).
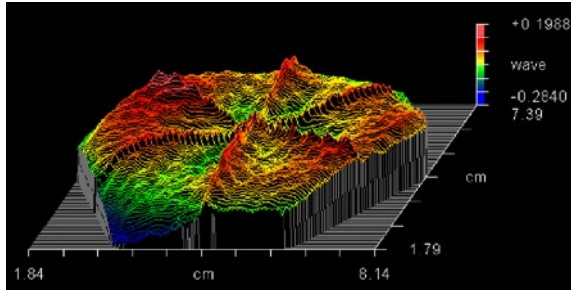
Figure 9 - Interferometer measurement to determine phase in homogeneity (how well polished is the particular prism) of reflected beams.
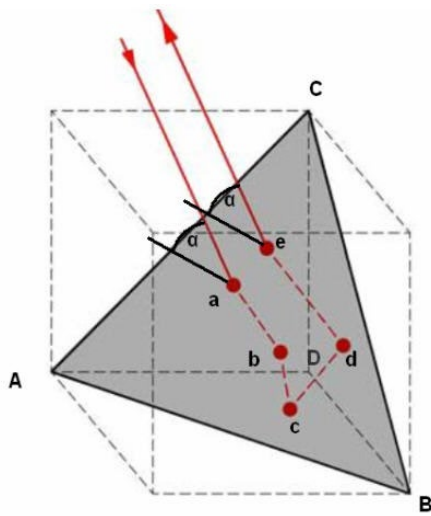

Figure 10 - Beam path in a triple prism showing the incoming and outgoing beam.
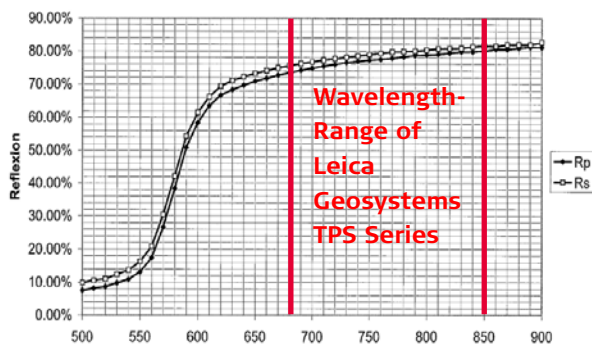

Figure 11 – Reflectivity of copper reflex coating dependent on the signal (EDM) wavelength.

if the glass edges are excluded then the average values are far below one arc second.

Reflex Coating

The degree of reflection is defined as the ability of a material – in this particular case - to reflect visible & infrared radiation (EDM wavelength` may vary between different manufacturers). This depends on the material itself as well as on the surface quality. Figure 9 shows actually a well polished example. Leica Geosystems' reflectors are coated with copper (cf. Figure 11). Its degree of reflection is higher than 75%, it is highly robust and not corroding (encapsulated with black epoxy).

This guarantees a long lifecycle of the prism glass body itself. Various other reflectors on the market have no such coating. This could affect EDM performance by up to 30%. The Leica Geosystems TPS Series distance measurement signal varies between 658 nm and 850 nm (e.g. the TCA2003 IR EDM module operates on a frequency basis of 850 nm whereas TPS1200+ operates with 660 nm).
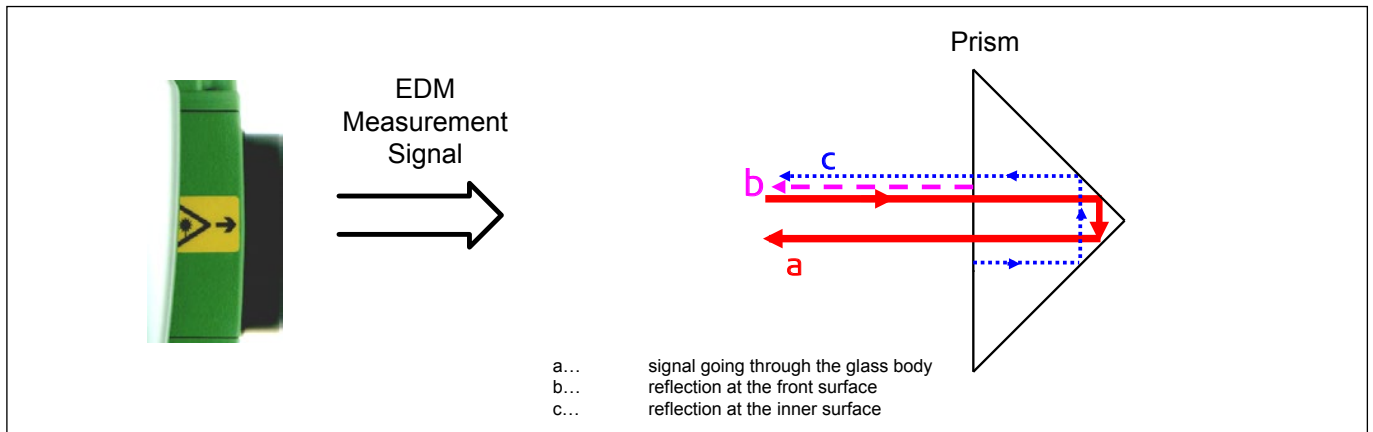
According to the reflectivity chart shown in figure 11 it can be seen for the wavelengths of Leica Geosystems' EDM, the reflectivity values are within the entire range (660 nm - 850 nm) providing the highest reflectivity.

This is one aspect that guarantees that all Leica Geosystems reflector models are verified to fit with our total stations.

Anti-Reflex Coating

During a distance measurement a large percentage of the signal is returned through the prism as shown in figure 10 and 12, but beside the desired reflection through the prism body the emitted EDM signal will also be reflected (typically 4%) by the front surface. This part of the returned signal will disturb the desired signal because its travel time is shorter as it does not penetrate into the glass body of the prism.

This phenomenon can happen in close ranges assuming a very accurate alignment (the instruments line of sight must perpendicularly intersect the prism front surface). In such a case, shorter distances are determined. To avoid this phenomenon a special layer is coated to the front surface of the particular prism glass. Figure 12 shows the beam path of the incoming signal. The expected signal is shown as red line (a). It has the strongest intensity of about 70%.
The signal reflected at the inner surface is indicated in magenta (b) (less than 2%). The reflection caused at the front surface is shown in blue (c) (about 4%).

EDM
Measurement
Signal

Prism

c
b
a

a…   signal going through the glass body
b…   reflection at the front surface
c…   reflection at the inner surface

– Different reflections at the prism caused by the front surface, the inner (front) surface or the 'normal' way through the back surfaces.

When using a prism without anti-reflex coating (or a coating adjusted to the wrong wavelength) distance measurement errors up to 3mm can occur.

Reflectors manufactured other than by Leica Geosystems normally have no coating. But it should also be considered that coated reflectors sold by different manufacturers also may reduce the accuracy of the measurements – this depends on the basis of the EDM wavelength considered in the design because anti-reflective coatings must match wavelength' of used EDM sensors. Figure 14 shows this influence on a distance measurement at 20 m. To observe this effect, the prism's front surface must be aligned perpendicular to the instrument's line of sight.
The design of the anti-reflex coating for certain Leica Geosystems round prisms is shown in figure 13.
The reflection lies below 0.5% for the overall signal bandwidth (660 nm-850 nm) used by Leica Geosystems.

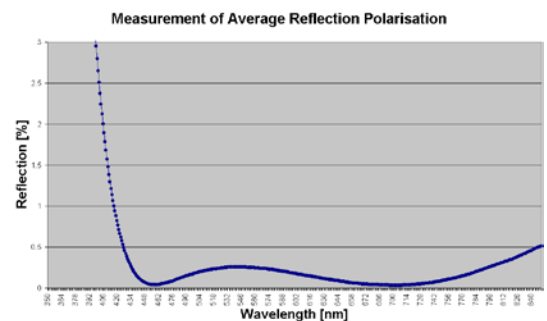With Leica Geosystems coated reflectors the detection of the right EDM signal is 100% ensured.

Figure 13 – Reflectivity of Anti-Reflex coating dependent on the signal (EDM) wavelength.

Glass Quality

Leica Geosystems reflectors are made from the highest quality glass. The following characteristics ensure best performance for distance measurements and target recognition:

- High homogeneity of refraction index within entire glass bodies
- Minimized tolerances for the determination of refraction index and Abbe coefficient
- Minimized number of streaks
- High acid resistivity
- Minimized number of air bubbles
- High robustness against different climate conditions

These characteristics guarantee superior durability and resistance against environmental influences.
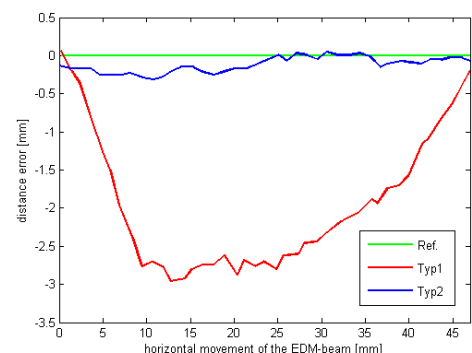

Figure 14 - Anti-Reflex coating influence on distance measurement.
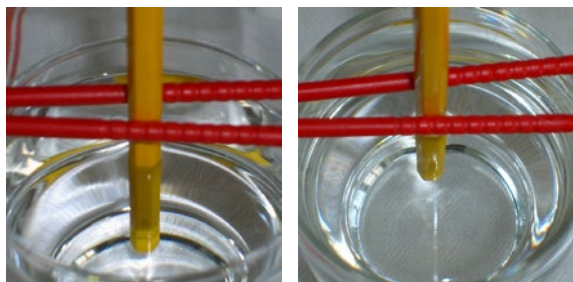
Figure 15 – Example for refraction in daily life – the same effect appears when doing tilted measurements to reflectors – a pencil in a water glass observed in different viewing angles
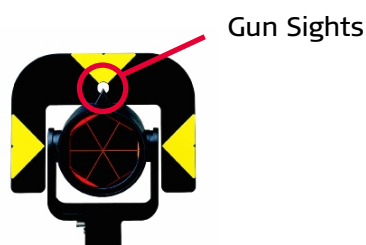

Gun Sights

Figure 16 - Leica Geosystems GPR1 round prism with gun sights for alignment

(Geom.) Prism Center

Standing Axis

Prism Body

Apparent and true direction of the prism center

View from above

(Geom.) Prism Center

Standing Axis

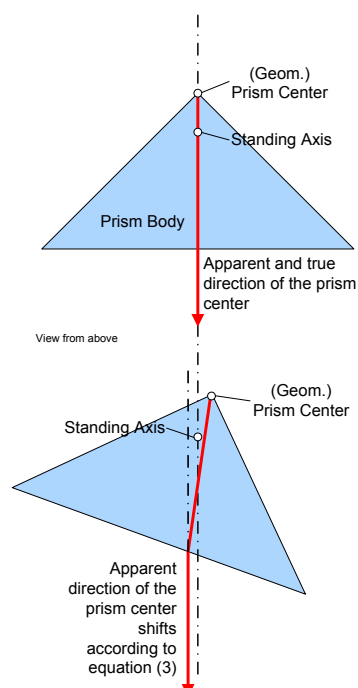Apparent direction of the prism center shifts according to equation (3)

Figure 17 - True and apparent recognition of prism centers.

Alignment/Setup

Round prisms require being aligned with the line of sight of the instrument within a certain tolerance. For high precision measurements this dependency is clearly shown with figure 18. An acceptable deviation would be ±10°.

When pointing to a prism that is not perpendicular to the line of sight of the instrument, it is not easily possible to point to the actual prism center. This is a result of the refractive index between air and glass being different, thus adding possible further error in the measurement of the horizontal direction.

Looking at the pencil in figure 15 demonstrates the effect described – the recognition of the pencil in the left image is different because the refractive index differs from air to water. But observing the prism perpendicular to its front surface allows the true recognition of its position – this effect should be shown in the right image of figure 15.

However, Leica Geosystems offers gun sights to ensure an accurate alignment with the instruments line of sight (cf. Figure 16). The operator can do a quick and easy alignment within seconds, by aiming the prism to the instrument.

If the prism is not aligned with the instruments collimation axis the standing axis of the prism pole does not coincide with the apparent prism center (cf. Figure 17). Subsequently the operator would aim to the apparent prism center.

This deficiency is minimized with the special design of Leica Geosystems reflectors. Below 40°, the aiming error would be less than 0,5 mm, however, over 50° it is already higher than 1mm. At 60° it is already above 2,5 mm. (cf. Figure 18).

Because the prism body is symmetrical the effect of vertical misalignment is the same as for the horizontal misalignment.

Leica Geosystems' latest instruments provides a high accurate angular and distance measurement system. To tap its full potential the reflector setup is certainly worth being well aligned with the instruments line of sight.

When using Leica Geosystems' reflectors it is made as easy as possible to achieve a proper alignment but ultimately the responsibility is still in the hands of the surveyor.

Genuine Leica vs. Leica Copies

The sections above described several factors contributing to the high quality of original Leica Geosystems' surveying reflectors. Because of their well known quality these Leica Geosystems products are often perceived as quality-defining references on the market.

Hence Leica reflectors are often used as a model for copying. Subsequently several manufacturers have started to make business by flooding the market with cheap prism copies without having a warranted quality standard ensured. The right column in figure 19 shows the necessary steps to make a genuine Leica Geosystems prism. Most of the steps are invisible to the customer, but in compliance with our strong quality management, we guarantee to supply the best products for our customers.

Recommendations

The goal of this paper is to provide surveyors with basic knowledge of the less thought about details which a measurement consists of. And for the surveyors who strive for the most precise distance measurement, this paper provides a summary for both the magnitude and effects of the chosen target components that influence the accuracy of the measurement.
To achieve highest measurement accuracy
- Use the same prism types to avoid different centering errors because of different reflectors
- If performing measurements exclusively in close ranges make sure that you use a coated (anti-reflex-coating) model
- Use a prism that fits to your instrument
- Keep the surfaces of your reflector dust free to avoid any reduction of the signal returned

The benefits when using Leica Geosystems surveying reflectors are long lifetime, highest accuracy and highest reliability. Leica Geosystems accessories are adjusted together with Leica Geosystems instruments. Thus we can guarantee best performance and quality of your measurements.
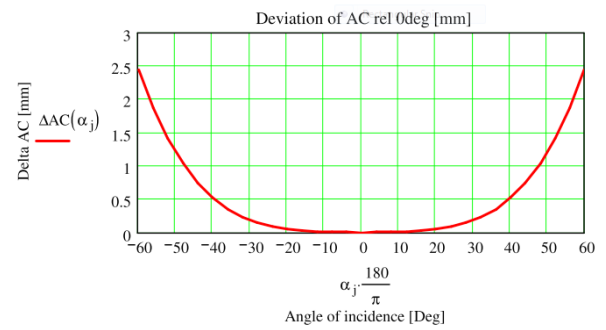

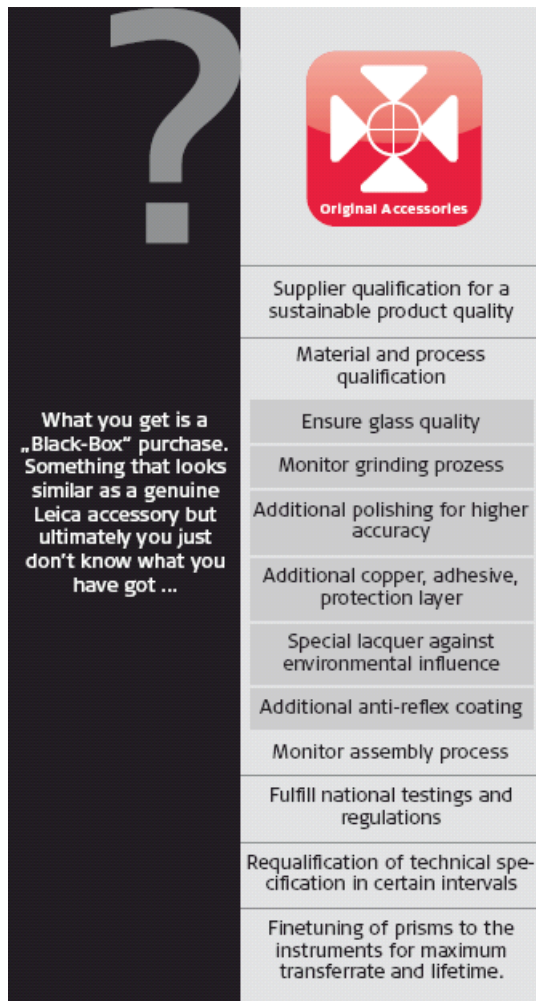**Figure 18** - Deviation of the axis in dependence of the misalignment for a Leica GPR1 reflector

Figure 19 – Manufacturing process of
Leica Geosystems' Originals cs. Leica copies

Source

This document is based on the diploma thesis named
"Analyse und Vergleich von Vermessungsreflektoren"
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of Daniel Nindl (Leica Geosystems AG Heerbrugg) and Volker
Schwieger from the Institute for Applications of Geodesy and
Engineering (IAGB), University of Stuttgart.

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