ERIK NISS RAPPORT OM AGA:S OPTIK 1940–1968

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RUBRIK: Optical products 1940–1968. Jobs No. 1 – 3.5

In the following report will be given an account of some interesting and important optical products, constructed and made by AGA during the time 1940–1968. Particular stress will be laid on the optical part, the mechanical will be commented upon only exceptionally. Projects under development will not be mentioned. Finally a summary of the potentialities of the construction-, developing- and manufacturing departments will be given.

Short history

AGA began to make optical products during the First World War, when lenses and components for lighthouses and beacons were produced. These elements required no high precision and were not to be compared with fine precision optics. The manufacture continued until about 1960. After that time the elements were bought. Just before the Second World War AGA started to work with cinefilm-projectors and aerial cameras. For these products the optical components were bought. About 1940 glass works were set up for making fine optics. The first products made were bomb-sights and reflex-sights. Besides there were made cameras with mirror optics and long focal length f = 3,5 m for coast search. They were used for identifying ships passing by far from the coast line.

In the early 40-ies AGA received a large military order of stereoscopic range finders, base 1,25 m, type Wild. AGA manufactured these range finders on license from the firm Wild till about 1947. At this time AGA also received an order of the same instruments for Argentine. In the meantime reflex-sights were made for different customers. A considerable number of binoculars (6 x 30) were produced for the Swedish Army in 1943–1946. A civil product was the microscopes for workshop use (25x, 50x, 75x). In the years 1944–1948 there was developed and manufactured a large stereoscopic range finder base 4 m, objective Ø 90 mm. Around 1943 AGA got an order on submarine periscopes and about 20 periscopes were made.

The military orders decreased during 1948–1950.

About 1950 AGA started to make wind tunnel optics for different Swedish firms and institutes. These optics were made during several years and of different performances. Large mirrors were made, also windows up to 800 mm diameter. To make these large elements AGA had to build special grinding and polishing machines. With the aid of these machines AGA could also make different large size, high-precision optical components for the Swedish astronomical observatories.

When the new cinefilm for wide screen was introduced in 1952, AGA developed projection objectives for this and when shortly after the cinemascope film came AGA started to make anamorphic lenses, in the beginning from Bausch & Lomb, USA: These lenses were made in rather large quantities and during the first years, before competition from other European firms had grown up, AGA sold these lenses to many countries in Europe, Asia and Australia.

This manufacture continued till the end of the 50-ies. During this period AGA also constructed anamorphic objectives for the cameras in the name of AGASCOPE. These lenses were hired out per film. AGASCOPE is still used, above all by the East States in Europe.

In 1952 the development of a new more luminous submarine periscope was started. About 25 such periscopes were made during 1952–1958.

The Swedish Air Force wanted about 1951 a very exclusive camera lens for aerial search (like lenses used by USA in U-2 planes). The demands were very high. AGA succeeded in making one of tele-type with a focal length of f = 1500 mm 1:7 and a resolving power of 1:150 000, e.g. 0.1 m in 15 000 m, image size 24 x 24 cm. For the ray-tracing of this objective AGA for the first time used a data computer, at that time existing BARK, a relay machine (1951-1952). A number of these lenses were then produced with excellent results.

At the same time there were also made some cameras for coast search with lens optics, high resolution, f = 2.5 m Ø 150 mm, film 24 – 18 cm.

In 1958 AGA won an order on periscopes for underground rooms in solid rock, one type (10x, exit pupil 7 mm) for fire control, another type for observation purpose (10x, 2x, 7 mm). The periscopes were of panorama type and about 5,5 m in length. High demands on resolving power and direction precision. The manufacture was completed in 1966.

A collaboration between USA and the Swedish firm Jungner was set up 1960–1966 in order to develop a periscopic range finder (coincidence type, base 40 cm, periscopic height 28 cm). A very large order was completed in 1967.

As sub-contractor to Jungner AGA is now since 1966 manufacturing optics and mechanics for the fire control sight in the Swedish tank S.

During the 60-ies AGA has also produced another series of sub-marine periscopes.

The main production at AGAs glass works since about 1950 has been the production of optical elements for the Geodimeters as well as cube corner prisms. The models 1 and 2 were introduced in 1953. They had an aperture of 300 mm diameter. In 1957 model 3 (Ø 200 mm) and in 1958 model 4 with an aperture of 100 mm diameter were introduced. The first instrument of model 6 with concentrical projector and receiver was sold in 1964. Today, there are also model 7 for both distance and angular measurements, and model 8 with a He-Ne laser as projection lamp for long distances (40 miles).

The development of the AGA infrared camera, Thermovision, started in 1958, then in military performance. The civilian model was introduced in 1965. Several models have been developed since then.

Parallel to the above mentioned products AGA has developed and produced different optical elements and instruments in small quantities or in solitary specimens for different customers. To be mentioned are the AGA polar coordinatograph and the tachymeter. The coordinatograph was used for plotting charts after surveying data or also for measuring the coordinates from ready charts; in both cases in polar coordinates. Scale length 160 mm, angles 0–360° (1959). Total accuracy 0,05 mm.

Some prototypes of the tachymeter were produced. The instrument reduced automatically the distance to the horizontal plane. Accuracy: distance ± 1 cm, angles ± 20″ (1950). Measuring range 8–80 m. Both instruments were used by surveyors.

In collaboration with the American firm Hazeltine AGA developed (1958–1960) an expensive electro-optical instrument, Color Analyzer, with which one could automatically adjust color faults in exposed color film. This instrument was sold to some countries in Europe and USA.

AGA has also manufactured (1948–1952) spectacle glasses. These spectacles were generally of torical (cylindrical) type and were made according to prescription by eye-doctors. The manufacture was later taken over by the daughter company AGA-Bausch & Lomb.

About 1945 AGA started anti-reflexion coating and aluminizing of glass elements. At that time vacuum-equipment was not to be bought, why this equipment had to be built. The development continued and good vacuum equipments have been bought gradually.

Products

The following products will be described very briefly, particular stress will be laid on specific characters, special features and special construction or/and manufacturing difficulties. The number of products will be restricted to important and interesting ones. The list will be numbered (job nr …) and thus it can be continued.

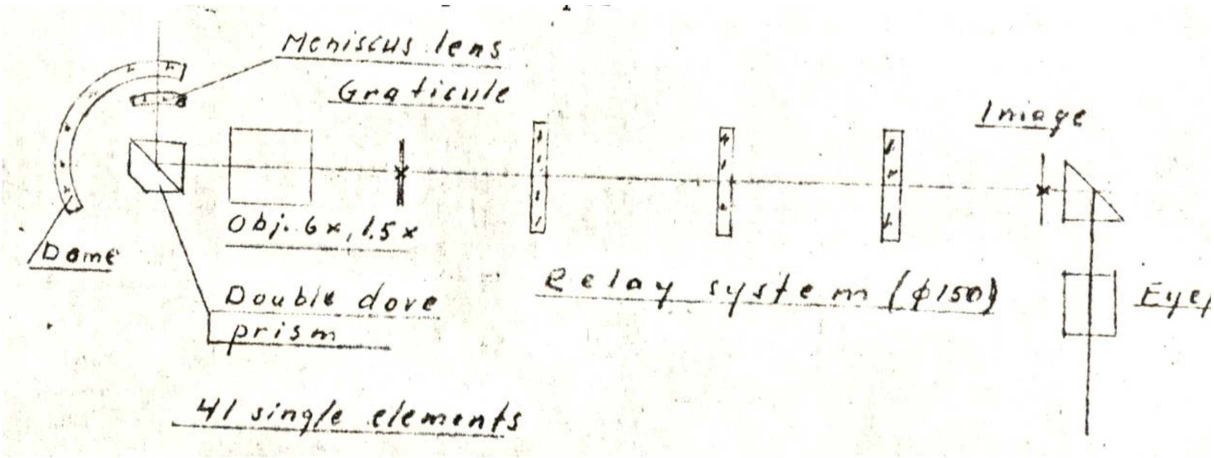
1.0 Periscopes
2.0 Range finders
3.0 Geodimeters
4.0 Wind tunnel optics
5.0 Collimators
6.0 Special objectives
7.0 Cylindrical lenses
8.0 Laser optics
..9.0 Interferometers
10.0 Special elements

Job nr 1.0 (1944–1968)

1. Periscopes

AGA has hitherto mainly made two types of periscopes: submarine periscopes and periscopes for underground rooms in solid rock.

1.0 Submarine periscopes



Data

Magnification	1,5 and 6x	
Field of view	38° 9°	
Elevation	-10° – +98°	
Exit pupil	4 or 7 mm	(two types of periscopes)
Diameter	150 0r 180 mm	– " –
Optical length	9 m	

The dome in the periscope has three tasks, sealing pressure absorbing (> 25 kp) and to make maximum elevation angle possible. The dome has concentric surfaces, their centers coinciding with the turning center of the prism. In that way, the conditions will be equal for different elevations. The double doveprism requires parallel light, the refractive power of the dome must therefore be compensated by the meniscus lens. This lens has to be moved in coincidence with the elevations direction.

The prism rotates with half the angular speed. The prism is double in order to keep the same light intensity at larger elevation angles.

The task of the relay system is mainly to transport the light from the graticule to the eyepiece.

For horizontal pointing the whole periscope is turned.

The main difficulties in making the optical components are three:

angular accuracy of the dove prism (max. deviation difference between the two prisms 5"),
centering and “concentricity” of the dome and the meniscus lens (as a unit),

centering and form of the relay system (Ø 150 mm). The long focal length of the lenses (f up to 3,5 m) requires a deviation less than 1 mm in the focal plane.

The mechanical building must be very robust in order to stand chocks (up to 600 g). The external tube must be made of high quality stainless steel and has to be very straight (< 0,05 mm in 1 000 mm) in order to facilitate the turning of the periscope.

The relay system contains lenses with long focal lengths and the distances between the lenses are also very long. Owing to this it is impossible to avoid large vignetting of the light, i.e. the light loss in the outer parts of the image field is very large. This is very obvious on photographs exposed through the periscope. In order to avoid these light losses it is necessary to introduce intermediate images (see “underground” periscopes).

The attachments of the periscopes are:

1. attachment for binocular observing (50 % of the light to each eye)
2. Camera
3. Range finder

Job nr 1.1 (1958–1966)

<u>Underground room periscope</u>

These periscopes are rigidly mounted in solid rock and are of two types

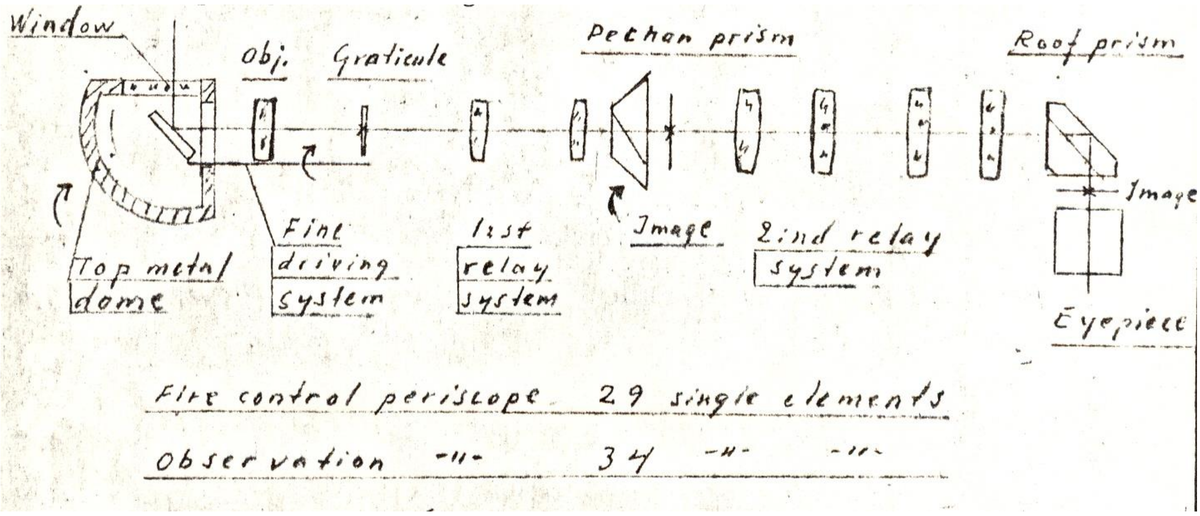
fire control sight periscopes
observations periscopes

They are used by the Coast Artillery. Both are panoramic periscopes with the observer sitting stationary and the outer top part turning.

<u>Data</u>	Fire control periscope	Observation periscope
Magnification	10 x	10 x 2 x
Field of view	5°	5° 25°
Exit pupil	7 mm	7 mm
Elevation	fixed	fixed
Length	5.1 m	5.4 m
Resolving power	5"	6" within 2/3 of the field of view 30"
Max. direction error	0.5 mr	1 mr

As seen from the above table, the demands with respect to resolving power and precision in pointing are extremely high. In the first place this required very carefully planned and computed optics. Three lens aplanats were used instead of two lens ones, a special triplet lens was used in the magnification system to reduce field curvature, some reflecting surfaces were placed near the focal planes to reduce the demands of flatness and so on. There was specified a certain distance between the eye and the axis of the periscope tube and therefore a special eyepiece with an extended building length had to be designed. The manufacturing tolerances were extremely small, but could be carried out.

The mechanical tolerances were also very small, above all in the gearing system. The fire control periscope was directly connected to the central artillery directing instrument. In the observation periscope the direction was read on a scale. The sealing top dome with the window was driven by a separate motor controlled by the inner fine driving system that contained the top mirror, main objective and the graticule. As these three parts were built together as a unit, the optical deviation errors could be adjusted to zero. The inner driving system required very low torque and high precision. At the beginning there was a rather large rejection of the gear wheels.



When the top unit rotates to point round the horizon, the image rotates. This is compensated by a special prism, rotating with half the speed. In this case a Pechan prism was chosen which can be located in convergent light and requires small room.

As seen from the figures, there are intermediate images in the optical system. In that way vignetting will be less than in the submarine periscope. Pictures exposed through the periscope show a good exposure out at the margin of the image field.

Job nr 2.0

Optical range finders

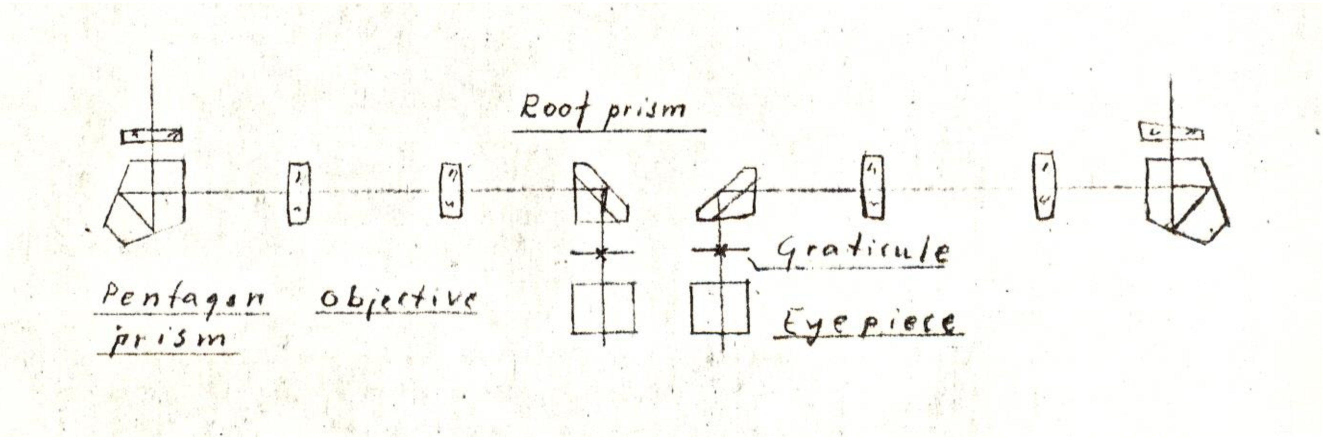
AGA has developed and produced the following types of optical range finders.

1. Stereoscopic with fixed measuring marks (base 1.25 m)
2. Stereoscopic with moving measuring marks (base 4 m)
3. Coincident, periscopic, base 0.4 m, periscopic height 0.28 m
4. Range finder where the object is the base (for periscopes)

Job nr 2.1 (1943–1949)

Range finder with fixed measuring marks

The first range finder made by AGA was of a stereoscopic type with fixed measuring marks located in a zigzag line in the image field. It was made on license from the Swiss firm Wild.



Data

Base 1.25 m = B
Magnification 12x = M
Exit pupil 2 mm
Field of view 3°
Measuring range 400–8000 m = R
Accuracy 3 unit errors where

$$\text{one unit error} = dE = \frac{R^2}{B \cdot M \cdot 20\,000}$$

The instrument was of conventional design at that time (1942). It was used for range measuring to aircrafts.

The young optical department met great difficulties in almost every respect. Thus, the glass works had troubles with the flatness of pentagon prisms, the 90°-angle of the prisms, dimensions of the rhomb prisms, beauty defects, etc. The graticule glass carried the measuring marks which had to be located within less than 0.001 mm and of which the largest was 0.08 mm. The marks had to be absolutely unbroken, black and must light when illuminated from the edge of the glass. A special fine grain silver emulsion was used. A rejection of 95–100 % was not unusual.

Assembly and adjusting took 100–200 hours per instrument the first time thanks to untrained men. After 1.5-2 years the assembly time could be reduced to about 30–35 hours.

The measuring accuracy was 3 unit error, at –20° C 5 errors. One unit error is the defined as an angular coincident resolving power of 10" (in USA 12") of the eye and the instrument itself must then have a resolving power of 10" divided by the magnification per unit error. Valid also by stereoscopic measuring.

The manufacturing of the Argentine order (1947-1948) run on rather good.

Job nr 2.2 (1944–1948)

Stereoscopic range finder with moving measuring marks

This instrument was a heavy naval range finder with a base of 4 m.

Data

Base	4 m
Magnification	17 and 32 x
Exit pupil	4.2 and 2.2 mm
Field of view	2°.25 and 1°.2
Measuring range	1 500 – 22 500 m
Measuring accuracy	2 unit errors

A project like this is considered to be one of the most difficult in optical engineering and manufacturing. AGA's instrument was severely tested in competition with the Zeiss instruments Disuni and Somet, the later with quartz pentagon mirrors. The test was made by a special commission of specialists from the Swedish Army and Navy. The tests were made during July 1947 – March 1948. It included indoor tests in collimators, tests on ships and outdoor tests under different weather circumstances.

The commission said in its final report that the AGA instrument was at least of the same class as the others, in some respects superior (e.g. better luminosity, objective aperture Ø 70 mm on AGA instrument, Ø 50 mm on the Somet).

However, the Navy bought the Somet instruments because of the lower price.

Job nr 2.3 (1961–1967)

This is a range finder of coincident and periscopic type. It is described in the AGA folder "Optical Periscopic Range Finder A40P".

Some features will be mentioned. The instrument has a common objective for the two entrance pupils. Due to this, the instrument will be "self-stable" and needs no distance adjustment. The building up of the instrument gives a target distance d for the lower entrance pupil and d+b, where b is the base (0.4 m) of the instrument, for the upper one. This resulted in very small tolerances of the optical components in the lower and upper systems; the tolerances are very small not only concerning astigmatism but also refracting power. For the reserve sets the upper and lower systems had to be delivered in pairs.

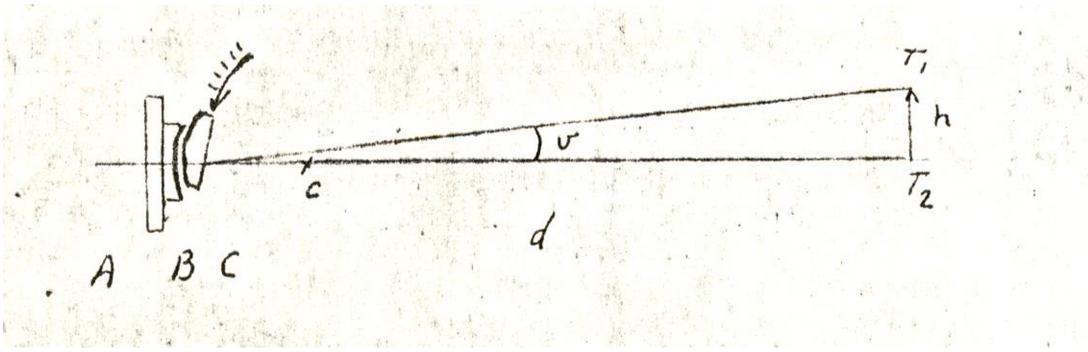
In order to meet competition from foreign firms AGA and the other Swedish optical firm Jungner collaborated in this large order of range finders. Besides, none of the firms alone could have delivered the instruments within the time required.

Both firms had many troubles with the army inspectors regarding the beauty defects. Only vague, "floating" and subjective norms were applied. There is a need of norms for beauty defects.

Job nr 2.4 (1954–1968)

This job is mentioned only as an example of a range finder which measures the angle of the object. Thus, the distance can be computed when the height of the object is known.

The principle



The instrument consists of three optical parts, a window A, carrying a cylindrical lens B with the power B and a moving cylindrical lens C with power C = –B. When C rotates around its curvature center C, B+C will produce a variable wedge and the deviation angle v will be changed. If the instrument for instance is located at the exit pupil of a periscope in such a way that half of the pupil of the eye looks through the wedge and the other half directly through the periscope, the eye will see two images above each other. When varying v so that T_1 co-incides with T_2, the right angle is measured. On a nomogram it is easy to determine the distance d, when h is known. The submarine people have catalogues with data on all known warships and after identifying the ship (height h) the distance can be measured. Of course there can be large errors depending on h.

Job 3.0

<u>Geodimeters</u>

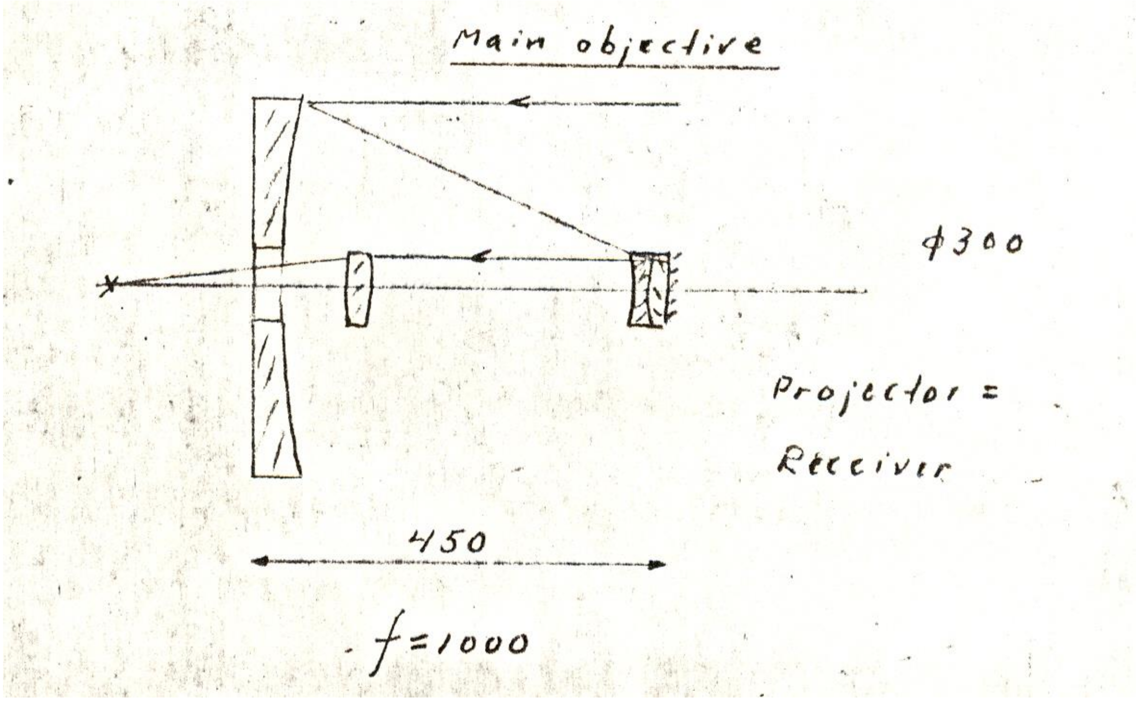
The electro-optical instrument “Geodimeter” was introduced by AGA about 1953. The development has continued since that time and many models have been built. Some firms have tried to compete, but until now none has been successful. Many of the firms surely can make optics and mechanics as good as AGA, but the combination electronics, optics and mechanics to a complete Geodimeter is difficult and AGAs total know-how in the Geodimeter field is still outstanding.

1.	Model 1	Mirror-lens optics	Ø 300
2.	Model 2	Mirror-lens optics	Ø 300
3.	Model 3	Mirror-lens optics	Ø 200
4.	Model 4	Mirror-lens optics	Ø 100
5.	Model 6	Concentric optics	
6.	Model 6A	Concentric optics	
7.	Model 7	Lens optics, also angular measuring	
8.	Model 8	Mirror-lens optics, laser for long range	

Job 3.1, 3.2, 3.3 (1953–1967)

Model 1 was a development of Bergstrand's prototype of Geodimeter. Bergstrand's first intension was to measure the speed of the light.

Models 1 and 2 were optically the same, both had an internal variable calibration. Later models have, thanks to better electronics, only a fixed internal light path, and calibration is made to one position. The projection and receiving systems consisted of mirror + lens optics (f = 1 m) with an aperture of Ø 300 mm.



Principally the same optics for projection and receiver.

Models 1 and 2 were heavy instruments.

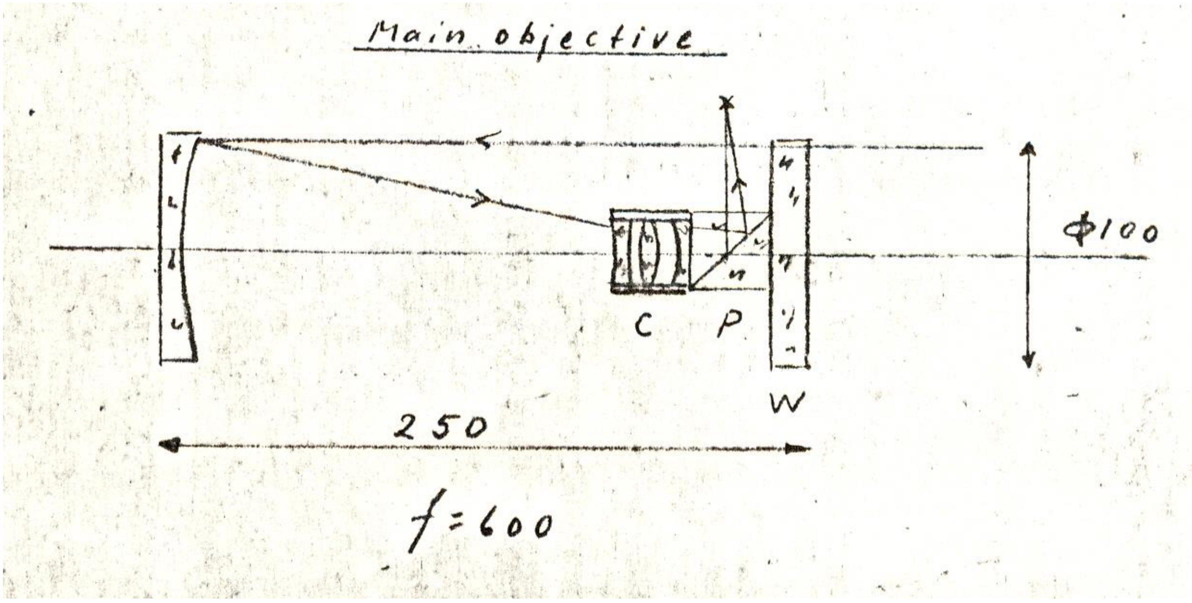
Thanks to simplified electronics the optics of model 3 could be scaled down from Ø 300 mm to Ø 200 mm (in 1957).

All these three models were to be used for measuring long distances by night. The lamps used were 5–6 W ordinary lamps. A gasoline motor generator supplied electric power for the instruments.

Job 3.4 (1958–1964)

A great step forward in the Geodimeter development was the model 4. Thus, the weight could be reduced totally c:a 90 kg for M2 to about 25 kg for M4. With a special Hg-lamp attachment measurements could be done in daylight for distances up to 7 km. The optics, mechanics and electronics were all new. The instrument was an easily handled field instrument.

The main optical system consisted of a projector and an identical receiver, the center distance of which was 135 mm. Mirror-lens optics Ø 100.



The focal length of the objective was 600 mm, but the building length only 250. The correction system C had two tasks

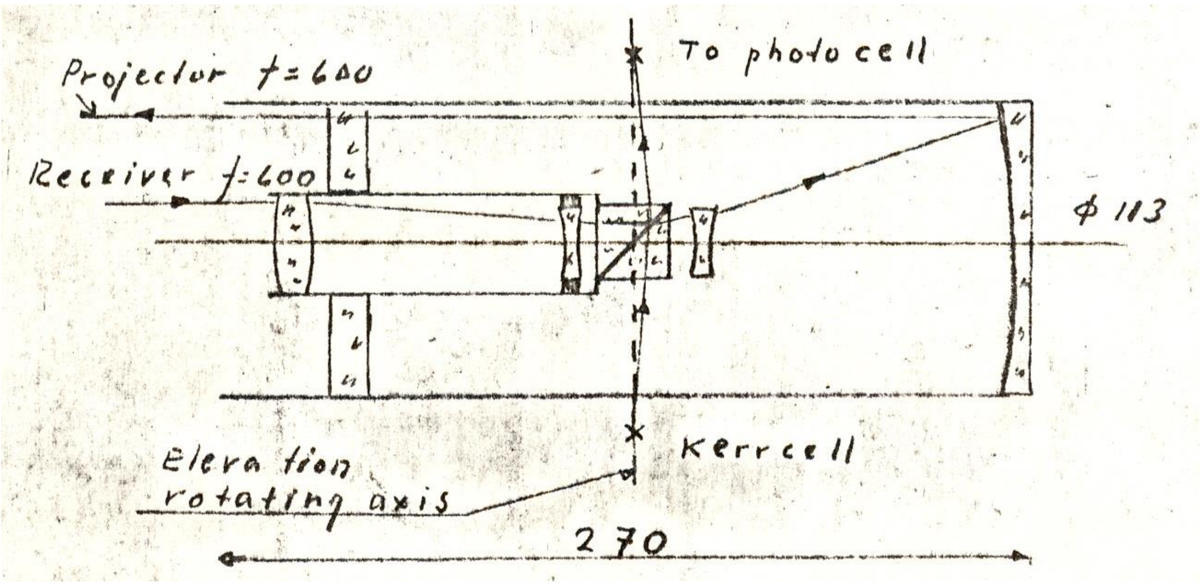
1) correcting the image errors from the main spherical mirror,
2) making the focal length of the whole system possible within short building length.

C was cemented and centered on the prism P and the whole package (P+C) also cemented and centered on the window W. In that way no spokes were used for carrying C+P. The principle worked excellent.

The image quality was very good, better than lens optics with respect to colour errors and spherical aberration.

Job 3.5 (1964 –   )

Model 6 was introduced in 1964. This instrument has two main advantages compared to model 4. Model 4 has a center distance between the receiver and the projector of 135 mm. Thanks to this distance the light will, after reflexion in the cube corner prisms, go back into the projector when measuring short distances. Therefore one had to put on special, for different ranges suitable wedges covering half the front surface of the prisms. These wedges deviated the light so that it could enter the receiver. Model 6 has concentric projector and receiver and thus every distance can be measured without any arrangements on the prisms. The other advantage is that the tube containing the projector and receiver is set up in a fork mounting, constituted of two boxes containing the electronics. With this fork mounting elevation up to 90° and down to –70° is possible.



The principal optical building is seen from the figure. One design feature will be mentioned. The front glass has three tasks

1) carrying the receiver optics,
2) centering it and
3) sealing the whole tube.

The glass is Ø 113 mm, thickness 10 mm, center hole Ø 50 mm (same as the diameter of the receiver). A very large number of instruments of model 6 have been sold and used under different circumstances by the customers, but until now no instrument has been returned with broken front glass.

The model 6 instrument consists of 45 single optical elements. A Hg-lamp attachment can be used for long distance measurements in daylight.

Model 6A is almost identical with model 6 optically and mechanically, but with improved electronics.