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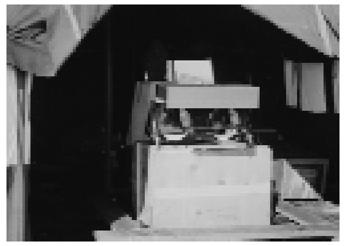
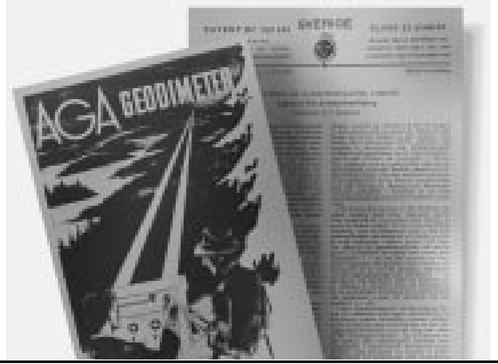


The History of Geodimeter®

J.R. Smith



Geodimeter®

Geodimeter®

1947-1997

J.R.Smith

CONTENTS:

AGA (=Svenska Aktiebolaget Gasaccumulator, Stockholm-Lidingö) was founded in 1904 by Gustaf Dahlén, who, in 1912, was awarded the Nobel Prize in physics for his invention of the flashlight apparatus and the sun-valve which enabled lighthouses to operate unattended for long periods through a more economical gas consumption.

With his foundation AGA began to expand its development of signal aids to communications on land, at sea and in the air. Such equipment as radio beacons, VHF direction finders, soundfilm equipment and even radio and television sets.

This developed into the production of precision optical instruments such as submarine periscopes and film projectors.

In 1947 AGA purchased the patent for the first ever light based distance measurement system and so may fairly claim to be the originator of electromagnetic surveying instrumentation as we know it today.

When AGA purchased Bergstrand's patent they further refined the instrument for commercial use and the first Geodimeter revolutionised surveying practice when it was launched with the Model 1 in 1953. In 1973 Geotronics became an independent company within the AGA-group with the motto "measurement is our profession."

The Dynamic Positioning group has close product links with Geodimeter in its Total Control System (TCS) for exact positioning of moving objects in materials handling.

Industrial Measuring Systems (IMS) became a separate product group in 1975 and similarly used the Geodimeter principle in their instruments. In 1997, the IMS was incorporated into Spectra-Physics Vision Systems group.

Dataliner (originally Nicator) was acquired in 1981. Its systems were mainly workshop oriented. Dataliner was sold a few years later.

In 1989 C E Johansson was acquired. This firm made the first combination gauge in 1892 and this became the world's first engineering standard and was used by Henry Ford for setting up his quality system. C E Johansson was similarly sold a few years later.

In 1981, a new company was formed of AGA's electro-optical manufacturing companies and introduced at the Stockholm stock market under the name Pharos. In 1986, Pharos bought the US company Spectra-Physics, and also adopted the name.

After the acquisition of Plus 3 Software Inc, USA, and Quadriga GmbH in Germany in 1997, Spectra Physics formed a new company, Spectra Precision, consisting of Geotronics, Spectra Physics Laserplane Inc. and the two new companies Plus 3 Software Inc. and Quadriga GmbH.

Spectra Precision AB (The Swedish part of Spectra Precision) will continue to develop the Geodimeter instruments - now with even greater resources than before.

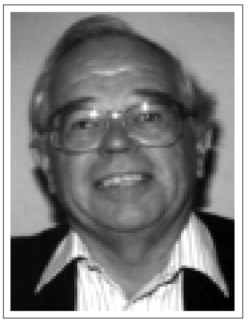
Thanks are expressed to the following for their assistance and helpful comments:-

Mr. B McGuigan and Dr. R Schöldström for the first edition.

Mr. B McGuigan also for the second edition.

Staff at both the United Kingdom and Swedish Offices of Spectra Precision (former Geotronics) particularly Mrs. Vappu Hämeenaho, for this third edition.

First edition	*1978*
Second edition	*1983*
Third edition	*1997*



J.R. Smith

GEODIMETER® 1947-1997

”It is difficult at present, in the absence of extensive tests by different experimenters in different parts of the world, to assess the extent to which this apparatus will be used in the future, but it appears from the tests already made in Sweden that it possesses considerable potentialities.”

J Clendinning. Plane & Geodetic Surveying
Vol. 2 Page 540, 4th Edition 1951.

The widely experienced Mr. Clendinning was obviously not willing to commit himself fully so early in the life of a completely new surveying tool but this publication marks 50 successful years of worldwide application of the “potentialities” of Geodimeter.

If either light or radio waves are to be used in the measurement of distances, the basic relationship is that

distance = time x velocity

Before such an approach can be used at survey accuracies the velocity must be known to better than ±1 km/sec.

Until the early 20th century such accuracies were impossible to achieve. Thus before any serious attempt could be made to use the relation as it stands it had first to be turned around as

velocity = distance/time

and extensive experiments carried out to obtain a reliable velocity value for light waves in vacuo. As chronicled below, the route to an acceptable value was a long one. However as far as the surveyor is concerned, the key personality was Dr E Bergstrand who began by developing an apparatus for determining the velocity and having achieved that, then reversed the procedure to get a very successful distance measuring unit.

Unfortunately both Dr Bergstrand and his close colleague, Dr Schöldström, died in 1987 and brief mention of their respective careers are given later.

Measurement of the velocity of light

The fact that light waves travel at a finite velocity was appreciated some three centuries ago. The problem was how to determine that velocity with any degree of certainty, in particular, its value in vacuo.

During 1676 Olaüs Roemer (1644-1710), who later became the Danish Astronomer Royal, was observing eclipses of Jupiter’s satellites and determined that the 22 minutes taken for light to travel a distance equal to the diameter of the earth’s annual orbit equated to a velocity of light of

214 000 km/sec. (48 203 leagues/sec.)

Fifty years later in 1728, the Rev. James Bradley (1693-1762), who became the Third Astronomer Royal, working at Kew Observatory discovered the aberration of light or apparent motion of the stars due to the earth’s orbital velocity. This apparent displacement of a heavenly body had both an annual and a diurnal component with the former constant at 20.445" and the latter varying up to 0.32".

From his results the deduced velocity of light was **301 000 km/sec.**

Modern calculations using the same method give **299 714 km/sec.**

Optical mechanical methods for determining the velocity were developing around 1820 when D F Arago (1786-1853), Director of the Paris Observatory, experimented with a rotating mirror. A ray of light was reflected from one face of the mirror to a distant reflector and hence back to an adjacent face of the rotating mirror.

This approach was modified in 1849 by A-H-L Fizeau (1819-1896), a French physicist, who used a rotating cogwheel - equivalent to both the light modulator and the phase meter or synchronised shutter of modern equipment. A pulse of light was transmitted to a distant mirror and on its return was interrupted by the rotating cogwheel. At a particular velocity of the wheel the returning ray would be intercepted by the cogs and not be visible to an observer near the source. In effect the ray was modulated with the required frequency as it passed back through the cogs.

From the known parameters of the system it was possible to calculate the velocity of light. Using a cogwheel with 720 teeth the first interception or eclipse by the cogs occurred at an angular velocity of 12.6 revolutions a second, which was equivalent to the light travelling 17.266 km and from this the velocity becomes

313 300 km/sec.

Rotations of up to 200 revs/sec. are said to have been tried.

Developments of this by Cornu, Young, Forbes and others gave a mean value of

301 400 km/sec.

In 1862 J-B-L Foucault (1819-1868), used a mirror rotating at 500 revs/sec. to obtain

298 000 ±500 km/sec.

but his baseline was only 20 m long.

The Polish professor, Albert A Michelson (1852-1931), made many experimental measures spread over some 40 years. In 1879 a baseline of 600 m was used to give a value of

299 910 ±50 km/sec.

using a rotating mirror system.

In 1882 further measures gave

299 853±60 km/sec.

In 1926 he experimented over a 35 km baseline from Mount Wilson to San Antonio Peak measured in the traditional manner by the U.S.Coast and Geodetic Survey. Whilst it was seen at that time that it might be possible to do the reverse operation of using a calculated velocity of light to determine distance the method of Michelson was never directly used for that purpose. Michelson's value was

299 798 ± 4 km/sec.

Other experiments of his gave

299 774 ±11 km/sec.

using a 1.6 km evacuated pipe 1 m in diameter. Multiple reflections of this path gave a total path length of up to 16 km.

The Väisälä comparator for measuring distances with light interference was introduced in 1923 and fully developed by 1929. It was used up to 864 m and accuracies of 0.1 ppm were achieved on distances up to 200 m.

Electro-optical methods were first developed around 1925 by Karolus and Mittelstaedt at Harvard University [87]. They replaced the cog-wheel by electro-optical light modulation consisting of a Kerr cell positioned between two crossed Nicol prisms acting as polarisers. (John Kerr (1824-1907) was a Scottish physicist and associate of Lord Kelvin). The Kerr cell consisted of a glass container fitted with sealed-in metal electrodes and filled with nitro-benzene. They used a 40 m passageway for multiple reflections. The result was

299 778 ±20 km/sec.

In 1937 W C Anderson developed the system using two sets of light pulses for phase comparison and incorporated use of a multiplying phototube. From several thousand observations he found the velocity of light as

299 776 ±14 km/sec.

The first patent for an electro-optical distance measuring device was applied for by Wolff in 1939. [34]

In 1941 Birge used a statistical collation of all measures made up to that time to arrive at

299 776 ±4 km/sec.,

and Essen in 1947, using short radio waves in resonance in a short cavity tube gave

299 792.5 ±3 km/sec.

During 1949-1951 Aslakson used radar (Shoran) over six geodetic distances in the USA to arrive at

299 792.4 ±2.4 km/sec.

and further measures over 15 lines gave

299 794.2 ±1.4 km/sec.

In 1958 K.D.Froome of the National Physical Laboratory (NPL), using microwave interferometry found the velocity as

299 792.5±0.1 km/sec.

The International Scientific Radio Union at their XII General Assembly in 1957 adopted a value of

299 792.5± 0.4 km/sec.

for vacuo and this was similarly accepted by the International Union of Geodesy and Geophysics (IUGG) although the reliability was later thought to be more like ±0.2 km/sec.

1972 saw two determinations at the National Bureau of Standards in Washington - using a HeNe laser of 0.63 µm gave

299 792.462 ± 0.018 km/sec.

and with a HeNe laser of 3.39 µm gave

299 792.4574 ±0.0011 km/sec. [91]

In 1973 the recommended value for practical use was

299 792.458± 0.0012 km/sec.

The following year at the NPL using a CO_2 laser of 9.3µm gave

299 792.4590± 0.0006 km/sec.

and in 1976, again at NPL with a similar laser

299 792.4588 ±0.0002 km/sec.

Dr Erik Bergstrand

One name of particular note has been omitted from the above list and that is Dr Erik Bergstrand, of the Geographical Survey of Sweden. He had been experimenting on the velocity of light for some years when, in 1941, he conceived a 'blinking' light system. His apparatus replaced the toothed wheel and manual observation of the ray as used by Fizeau with light pulses of known frequency and variable intensity projected over the line and returned to a receiving unit near the transmitter. The distance from the instrument to the reflector and back could then be expressed as a number of whole cycles and a fraction of a cycle.

Dr. Erik Bergstrand

His original prototype included some radio parts and other unlikely components but was still capable of transmitting 10 million light pulses a second to a mirror 30 km away and calculating the time it took for the light pulses to travel the distance out and back and get a result to the nearest mm.

In 1947 he carried out field tests with a laboratory instrument over a 7734 m line from the island of Lovö to Vårby near Stockholm. These gave the velocity of light as

299 793.9 ±2.7 km/sec.

The results were so promising that AGA (=Svenska Aktiebolaget Gasaccumulator, Stockholm-Lidingö) in conjunction with the Geographical Survey paid for a sturdier, improved apparatus. This was built by AGA and included many of the actual parts of the first instrument. In the autumn of 1948 a ’preliminary determination of the velocity of light was made with this, as yet incomplete, first Geodimeter® (**GEO**detic **DI**stance **METER**). The completed instrument, model 0, was used during the winter of 1948-1949 at Enköping over a 7 km baseline and resulted in a determination for the velocity of light as

299 793.1 ±0.26 km/sec.

Further measurements over two parts of the line during 1949 gave

299 794.0 over 5144 m

and

299 792.3 over 1762 m.

These were later corrected and combined as

299 793.1±2.0 km/sec.

In 1957 Bergstrand published an evaluation of all his determinations and gave a weighted mean value of **299 792.85 ± 0.16 km/sec.**

By the late 1940s the value for the velocity was obviously getting to the stage where it was sufficiently well defined to be used for the measurement of distance. As a practical test of this new technique Bergstrand measured two triangle sides in Norrland during August - September 1949.

a. between the islands of Prästgrundet and Storjungfrun near Söderhamn.
Measured 20 203.59 ± 0.04 m From coordinates 20 203.25 m

b. between Ounistunturi and Sautusvaara near Kiruna in Lappland.
Measured 30 921.50 ± 0.07 m. From coordinates 30 921.42 m.

In August 1950 the most accurate Swedish baseline of 5413 m ±1mm on the island of Öland was used and gave a result of

299 793.15 ±0.42 km/sec.

Dr Bergstrand died 28 April 1987 aged 82. He was born in Uppsala 3 July 1904 where his father, Östen Bergstrand, was Professor of Astronomy at the University. After obtaining a BA degree in 1939 he went to the Geodetic Bureau of the Swedish Geographical Survey.

As part of his work there, and with the assistance of the Swedish Nobel Institute for Physics, he started his research into the velocity of light at the end of the 1930s. The Second World War intervened and it was 1947 before his invention was patented.

In 1947 numerous scientists used the total solar eclipse to determine the distances between the continents of Africa and South America. Bergstrand led an expedition under the auspices of Swedish universities that went to Lomé in West Africa while the companion group went to Araxa in Brazil.

In 1948 he approached AGA for the financial and technical resources necessary to improve his apparatus and to establish its commercial value. AGA took up this challenge and development of Geodimeter instruments started.

In 1949 his doctorate thesis *A determination of the velocity of light*, complemented his invention of the **Geodimeter** and gave him a worldwide reputation. The thesis was based on measurements taken using the first Geodimeter prototype on various known baselines of the Swedish triangulation network.

His contribution to modern surveying techniques was of the greatest importance worldwide and is still having its effect 50 years after the introduction of the first Geodimeter instrument.

Tabulating all the early values of Bergstrand gives:

Year	Distance	Velocity km/sec.	Location	Instrument
1947	11 025 ± 0.08 m	299 793.9 ± 2.7	Lovö	Prototype
1948a	9 064 ± 0.01	299 794.1 ± 1.3	“	1st incomplete Geodimeter
1948b	4 208 ± 0.01	299 789.3 ± 2.5	“	“ “ “
1949a	6 906 ± 0.0035	299 793.0 ± 0.27	Enköping	1st complete Geodimeter
1949b	6 906 ± 0.0035	299 793.1 ± 0.28	“	“ “ “
1949c	5 144 ± 0.01	299 794.0 ± 0.75	“	“ “ “
1949d	1 762 ± 0.01	299 792.3 ± 1.50	“	
Weighted mean		299 793.1 ± 0.25 km/sec.		

Dr Ragnar Schöldström

After Bergstrand, the development of **Geodimeter** was very much synonymous with Dr Schöldström. Born in Helsinki 22 December 1913, his family moved to Sweden while he was a child.
Dr Schöldström died in Vence, France aged 73 on 8 May 1987.

Dr. Ragnar Schöldström

Even during his student days at Stockholm Royal Technical University he had worked part time for AGA.

Graduating in electrical engineering he spent 42 years with the company before retiring in early 1979. It was very much because of Schöldström's enthusiasm that **Geodimeter** became a commercial enterprise.

In November 1950 he used the new Geodimeter prototype Geodimeter (No 1) which had a fixed frequency. In 1955 he used the Geodimeter Model 2 to obtain a value for the velocity of

299 792.4 ±0.4 km/sec.

In 1977 he was awarded an honorary doctorate of the Royal University of Technology, Stockholm as a pioneer in the development of electro optical techniques for geodetic purposes. However he was always quick to point out that the success of the instrument was very much the result of good teamwork. [40] The joint work completely changed survey measurement techniques to the benefit of surveyors throughout the world. Ragnar was in charge of development of the Geodimeter instruments for several decades and his interdisciplinary knowledge was of particular importance. Over the years he acquired a large circle of contacts in the survey profession and these had considerable influence on the developments of the Geodimeter instruments. New ideas were tried out on these practising surveyors and their suggestions accommodated wherever possible.

As electronics developed so he and his team kept in step and moved from long range equipment into the, now more familiar, shorter range models. Even after retirement he visited the factory twice a year.

Geodimeter®

Professor Bjerhammar [34] in 1945 gave the legal inventor of the electro-optical distance measuring device as Irving Wolff who effectively replaced the mechanical cogwheel with an electronic cogwheel. However, as far as the surveyor is concerned, all relevant developments spring from the work of Dr Bergstrand. Basically his equipment projected a pulsating beam of light to a reflector which returned the light back to the instrument. A comparison was made between the transmitted and received light to measure the time for the light pulses to make the round trip.

From a 6V, 5 amp projection lamp as light source rays were passed through the lenses of a condenser to a *Nicol prism* where they were plane polarised. (Nicol prism is made from a long crystal of Iceland spar cut in halves along a particular plane in the crystal and then cemented together by a thin film of Canada balsam after the cut surfaces have been ground and polished). Thence through a *Kerr cell* (fast electronic shutter of 10 million pulses/sec. equivalent to Fizeau's toothed wheel) between the plates of which is a crystal controlled high frequency voltage, and then to another Nicol prism. On emergence the rays of light vary in intensity with the same frequency as the electrical high frequency oscillations imposed by the oscillator on the Kerr cell. Passing through more lenses the rays were projected by a concave (or parabolic) mirror to a plane mirror at the distant end of the line. On return, the rays passed through a similar mirror system and were focused on the cathode of a photomultiplier tube, whose sensitivity was changed by applying a voltage of the same frequency to the cathode. Maximum output current appeared when maximum light coincided with maximum sensitivity. This replaced the eye as a receiver in Fizeau's experiments. The signal was then amplified and fed to a galvanometer.

As the pulses took a finite time to cover the double distance so the current repeated at specific distances which were multiples of a factor dependent on the modulating frequency. Such current maxima could represent divisions on a scale for measuring distance. Unfortunately the maxima were not sharply defined and it would have been preferable to have two units arranged so that one had a maximum sensitivity when the other had a minimum. If these could have been connected so that the differences between them could be measured then a null or zero position would have occurred halfway between the two extremes.

Such an arrangement would have been cumbersome and expensive but instead it was possible to achieve the same result by switching a low frequency to a Kerr cell so that the phase of the outgoing light pulses was changed 180° during each half cycle of the low frequency. Zero readings on the galvanometer thus occur halfway between alternating maxima, and where the slope is highest which means that the sensitivity will be maximum.

Geodimeter is thus a phase intensity comparator and the intensity comparison is made at the point of maximum rate of change (Fizeau measured where the intensity was small).

Such is the basis of the Geodimeter instruments.

Operation

When used in anger, if the distant mirror were moved backwards or forwards a position would be found where the currents balanced out and gave a null reading. Obviously it would be very inconvenient to have to move the mirror for each line. One alternative was to vary the frequency of light modulation until a null reading was obtained since the distance between the zeros is a function of the frequency. In conjunction with such a system the instrument had to be calibrated to allow for time lag within its electrical circuits. The Bergstrand-built prototype of the Geodimeter was built according to this arrangement using a frequency of 8.332 230 MHz

For the first AGA production model instead of varying the frequency the phase of the voltage was varied by use of a variable time delay in the circuit joining the plates of the Kerr cell to the anode of the phototube.

The advantage with fixed frequencies was that even short distances could be measured, which at that time would have been very difficult using variable frequencies. This would have necessitated a large frequency range combined with high accuracy, impossible to achieve for portable equipment before the advent of transistor technology.

The basis of the distance computation when the galvanometer read zero was that

$$\mathbf{D = K + (2N-1)\lambda/8} \qquad (1)$$

where

D = distance to be measured
K = constant dependent on electrical delay factors
N = positive whole number
λ = wavelength of the light pulses leaving the Nicol prism

The oscillations from the crystal controlled high frequency oscillator in models 1, 2 and 2A had a frequency of about 10^7 cycles per sec. and amplitude of about 2000 volts and they were superimposed on oscillations of 50 cycles per sec. and 5000 volts which formed a carrier wave. These were rectangular waves which means that positive and negative voltages occurred over successive half oscillations and these deflected the galvanometer in opposite directions. Thus when voltages were equal there was a null deflection. Since the velocity of light was about $3x10^8$ m/sec. with a frequency of 10^7 cycles/sec. this gave a wavelength of about 30 m.

Wavelengths

Among the wavelengths used in various models of Geodimeter are:

Mercury vapour lamp	5500 Å
Standard lamp	5650
Red laser light	6328
Infra-red	9200
Infra-red	9300

Observing with Geodimeter Model 1
(Photo: Ordnance Survey, U.K.)

Reflector systems

In the early days of his investigations Bergstrand used a plane mirror as the reflector system but this quickly gave way to firstly a spherical mirror and then to a prism system. During early Geodimeter tests in the USA eight forms of reflector were tested. These ranged from plane mirror, silver coated mirrors and a corner cube system to various shapes and combinations of prisms - up to 162 in three banks of 54.

Plane mirror

A 30 cm diameter mirror with telescope attachment allowed very sensitive alignment through fine adjustment screws but even so a very stable base was necessary for the observer to get the unit sufficiently aligned.

Refraction changes caused by temperature changes could necessitate frequent re-alignment and hence it needed to be reliably supervised. The reflecting surface was obtained by aluminium vapourisation and the radius of curvature of the 'plane' surface was approximately 20 km.

McVilly [100] mounted a plane mirror in a box as a simple and cheap device for short lines. He used a thin glass 'sandwich' with silvered interface and central aperture of an inch diameter only faintly silvered.

Spherical mirror system

This had a slightly lower optical efficiency than the plane mirror. Once aligned to ±1° it could be left unattended. Slightly greater efficiency was obtained from this spherical reflex system than from the prismatic reflex system although the former, at 10 kg. was over three times as heavy and required much better alignment.

Prismatic system

Initially designed as seven high-precision corner cube (tetrahedron) prisms in a rigid mounting weighing 3 kg. and called the automatic prismatic reflex system. Three such groups of prisms together gave an efficiency comparable to the plane mirror. Pointing was only needed to ±20° so no attendant was required. Because of its much coarser alignment requirements the prism system was preferred for general use. The angular tolerance of the prisms was approximately 0.5 sec between faces and this had the property of reflecting a beam parallel to itself.

Modern prisms

At least seven types of prism have been produced although for some years until recently only type (a) was marketed for Geodimeter instruments. The newest technology is the active reflector introduced in 1996. Most modern prisms are so mounted that they will give a zero constant.

a) Super - for ranges over 10 km; divergence less than 2 sec of arc

b) Standard - for lines up to 10 km; divergence less than 8 sec of arc

c) Short - for lines up to 4 km; divergence less than 20 sec of arc

d) Zero index - for lines up to 4 km; divergence less than 12 sec of arc

e) Acrylic - up to 400 m

f) Tiltable - particularly for attaching to ranging rods for setting-out.

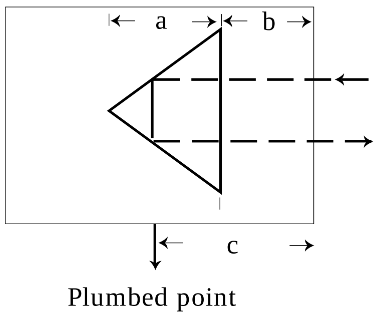
g) Active reflectors

Zero index reflectors

The zero index type can be mounted on a ranging rod. The error of each 90° angle should be less than approximately 1/6 of the required divergence of the prism.

Because the velocity of light within the glass is not the same as that in air the effective (optical) centre of the prism is not the same as the physical centre and constant corrections are necessary since the units are not plumbed below the effective centre.

Constant = - (RI of glass x a) - b + c
= - 1.32a - b + c



This is normally approximately - 0.030 m (negative as the optical centre is behind the physical centre)

A value of 1.32 is used above for the RI (refractive index) of glass but other makes of prism with different glass will be found with RI values of 1.57 and 1.64

Acrylic reflectors

Compared with standard corner cube reflectors the acrylic (plastic) reflector is far cheaper, more portable and in some tasks, expendable. Close-up they have a honeycomb appearance of numerous hexagonal prisms each with sides of about 1 mm.

Tests carried out [52] indicate that reliable results can be obtained over ranges up to about 400 m. A pattern of 14 would seem to give about half the return signal strength of a single prism over such distances.

Introduced around 1988, this range of reflector is suitable for most shorter range EDMs. They can be mounted on purpose designed targets. The advantage is that they are unlikely to break under harsh usage and as they are inexpensive, can be left in situ if necessary.

Such reflectors have a zero constant when the back of the reflectors is over the plumb point.

Tiltable reflectors

For setting out purposes tiltable reflectors are available for attaching to ranging rods. These reflectors have a range of ±30° and some are so constructed that there are no eccentricity errors. A Geodimeter mounted on a theodolite, will move off-centre as the unit is tilted. With a non-tiltable reflector system, an elevation of 20° would move the centre of the Geodimeter by about 63 mm, together with a small amount that is proportional to the distance (3 mm at 2 m and 1.0 mm at 6 m) but negligible for ranges greater than 10 m.

Tiltable targets have built-in collimator sights for accurate aiming to eliminate these eccentricities when measuring slopes. Their range of tilt is about ±35°.

Geodimeter instruments fitted with a vertical angle sensor also have a switch to select so that eccentricity error is eliminated when using reflector systems which are not tiltable over the plumbing axis.

Active reflectors

The newest type of reflector is the omnidirectional RMT Super version. This has a ring of luminous diodes reflected in a glass cone. In particular it is designed to ensure that the signal is being reflected from a particular prism and not from any other reflective surface. It is so arranged that the instrument will not accept the reflected light unless it is accompanied by a signal from the diodes. It is essentially an active reflector with communication between it and the instrument. It operates in three modes- searching, following and measuring.

It is particularly necessary for the robotic surveying systems where the instrument scans the area until it detects light from the diodes and then locks on to the reflector. The same technology is used with the AUTOLOCK. (see page 36)

Light sources

a. Tungsten filament lamp. A visible light source with wavelength near that of daylight. Hence better ranges achieved at night. Although cheap, a few pence per bulb, they were over-driven and as such the life could be as short as a week or run to many months. It had a comparatively short range which was about the same for the Model 6 as the GaAs diode in the later instruments.

b. Mercury vapour lamp. Much higher powered but required a generator to ignite it. It could achieve about twice the tungsten range with an upper limit of about 30 km as opposed to laser sources where 60 km are possible.

c. Gallium Arsenide (GaAs) light emitting diode (LED). This allows direct modulation without the aid of a Kerr cell. Such a cell was a complex component, difficult to make, fragile, needed highly purified nitro-benzine and had a limited life. Being able to do without it allowed the GaAs to form the basis of a low power, portable, reliable and robust instrument. It has been used in many short range instruments.

d. Helium Neon (HeNe) laser. Is a coherent source giving an extended range of up to 50 or 60 km. Being a plasma tube requiring a high ignition voltage it is more expensive and more vulnerable than the GaAs.

Optics

a. Dual optics. The outgoing and return signals travel through different optical systems. The units are fairly bulky. To make the beam diverge on its reflection so as to enter the other optical system, early Geodimeter models required wedges in front of the prisms. So many seconds of wedge was required according to the approximate length of the line. Some prisms had a built-in compensation but could only be used with particular ranges.

b. Coaxial optics. Smaller in size, no wedge deflectors required. Less optical parts but they were more complicated. This form is necessary if there is a need to transit the telescope, except for the Model 140, which, although it has dual optics, it is possible to transit.

Mounting

a. Separate. A distance measuring unit on its own. Normally used for geodetic applications where angles and distances are measured as separate operations.

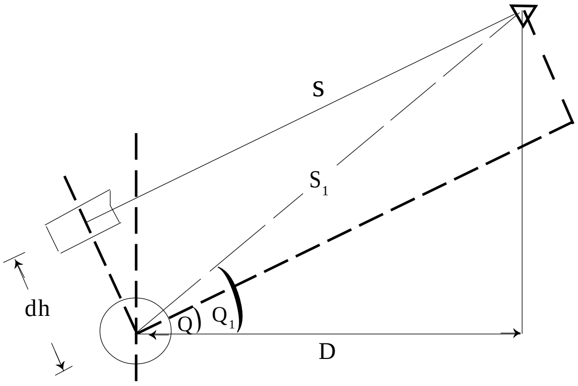
b. As theodolite attachment. Is an economic approach when both angles and distances are required. About 1/4 to 1/3 of the cost of a combined unit. If the EDM unit fails it is still possible to use the theodolite while the EDM is sent for repair. Usually mounted on the telescope so as to rotate with it. It has been suggested that the telescope bearings are not normally designed to take such extra weight but no particular distortions have been reported.

c. Combined. Total station instruments. The most recent developments in EDM equipment combine in one unit the angle and distance measuring components and incorporate data acquisition facilities as well. If either part fails then the whole instrument has to go for repair.

Eccentricity errors

When a theodolite mounted Geodimeter is tilted and the reflector system in use is one that does not compensate for this tilt then eccentricity errors arise. It has to be assumed that the Geodimeter axis lies parallel to that of the theodolite telescope. Let these axes be separated by dh (m) - usually 0.110 m.

The situation in the figure then applies:



where s = recorded distance

Q_1 = vertical angle from instrument to reflector. Note that this is slightly different to Q, the angle through which the unit is tilted.

Then the required horizontal distance is:

$$D = s_1 \cos Q_1$$

$$= (s^2 + dh^2)^{1/2}. \cos Q_1$$

$$\rightarrow s\left(1 + \frac{dh^2}{s^2}\right)^{1/2}. \cos Q_1$$

$$\rightarrow \left(s + \frac{dh^2}{2s}\right). \cos Q_1$$

For dh = 0.110 m the value of the term $dh^2/2s$ is 0.006/s m which becomes negligible when s>10m.

Power sources

a. Generator. Was required for mercury light sources to obtain the initial ignition.

b. Lead acid. Bulky and prone to spillage. Good capacity for high consumption. The Geodimeter Model 12 had an adaptor so that when necessary it could be run off a land rover battery. Life normally around two years or about 200 cycles of charge/discharge.

c. Nickel cadmium (NiCd) cells. Compact units of light weight. Can be temperamental and should be fully discharged before recharge. Care should be taken not to overcharge. Life normally 3-4 years. Expensive initially but life length reduces pro-rata cost.

d. Lead acid gel cells. Similar in weight to NiCd but with lower cycle of charge/ discharge. Unlikely to be overcharged.

e. 'Throw-away' batteries. Cheap but short life. Requirement to carry stock of spares.

f. Metal-Hydride batteries. Because of the poisonous elements within the common NiCd batteries, Geotronics are moving gradually from their use to the more environmentally friendly Metal-Hydride (NiMH) versions. These require a special charger system, PowerPack. In addition to their environmental advantage they also have a 50% greater capacity than the NiCad versions.

Measurement

There are three main steps in the measurement process:

1. Determination of the unit length that gives successive null readings
2. Determination of the fractional part of the unit = D_1
3. Determination of N

1. Substituting in (1) - page 9 - for
N, with λ= 30 m,
null points will be obtained every 7.5 m since
For N = 1
$D_1 = K + \lambda/8$
N = 2
$D_2 = K + 3\lambda/8$
....

or $D_n = D_1 + (N-1)\lambda/4$

and $D_2 - D_1 = \lambda/4 = 7.5$ m

2. As it is highly unlikely that the distant mirror will be at an integer multiple of $\lambda/4$ there will be a resulting deflection on the galvanometer. In early models this difficulty was overcome by the introduction of a variable condenser in the oscillator circuit. By varying the capacity of the condenser the distance from the transmitter to the first null point could be obtained.

In later models this system was replaced by a variable time delay circuit between the Kerr cell and the photo electric cell. This allowed the value of K in (1) to be varied by the block movement of all the zero points over a $\lambda/4$ range until a zero deflection was found. This time delay circuit consisted of ten inductance coils connected to the photoelectric tube. This allowed the delay to be altered in ten steps and a variable condenser gave the subdivisions. The coarse and fine delays were calibrated directly in terms of distance to give D_1.

Since the oscillator frequency altered with the temperature of the crystal, thermostatic control was required. The variable condenser or variable time delay circuits required initial calibration and this was done using a series of mirrors and a 70 cm calibrated scale.

3. If the distance to be measured is known to within half a wavelength only one crystal is theoretically required. However since half a wavelength is likely to be of the order of 15 m such prior knowledge is unlikely and a second crystal frequency is required to resolve the ambiguity. In some models 3 and 4 crystals have been used to allow unambiguous measurements to many kilometres.

   A second crystal of frequency 1.01 x 10^7 Hz allows a frequency overlap of 1% or

$$\lambda_2 = 100\lambda_1/101$$

Then $D_1 = K_1 + \lambda_1/8$ and $D'_1 = K_1 + \lambda_2/8$

Or $\Delta_1 = D_1 - D'_1 = (\lambda_1 - \lambda_2)/8$

and for other values of N

$$\Delta_N - \Delta_{N-1} = (\lambda_1 - \lambda_2)/4$$

Thus when N <101 successive Δs are equal; after which the values repeat.

N can now be calculated from

$$\Delta_N = (2N - 1)(\lambda_1 - \lambda_2)/8$$

$$\Delta_1 = (\lambda_1 - \lambda_2)/8$$

Thus $N = 4(\Delta_N + \Delta_1)/(\lambda_1 - \lambda_2)$

Δ_N can be measured, Δ_1 and $(\lambda_1 - \lambda_2)$ are known, so N can be determined.

For the range 101<N<202 the pointer records in reverse direction so that distances up to 1500 m can be read directly.

The total length of a line is then given as

$$D = D_1 + p \times 1500 + N.\lambda/4$$

where p = multiples of 1500 m in the total length.

Using three frequencies (as in the Model 4) the relations can be:

$\lambda_1 = 10.000$ m

$\lambda_2 = 400.\lambda_1/401 = 9.975\ 06$ m

$\lambda_3 = 20.\lambda_1/21 = 9.523\ 81$ m

$D = n.\lambda_1 + D_1$

$\quad = n.\lambda_2 + D_2$

$\quad = n.\lambda_3 + D_3$

Whence D_1 gives the 0 - 5 m element of the total distance

$D_3 - D_1$ the 5 - 100 m element

and $D_2 - D_1$ the 100 - 2000 m element

The choice of a basic frequency of 29 700 000 Hz for Model 4 was such that the wavelength was exactly 10 m at an assumed refractive index of 1.000 3104.

Further details can be found in [41] edn 2 pp 144-152 and edn 3 pp 185-196.

Velocity of light in air

The velocity of light in any medium is given as

$$V = V_0/\mu$$

Where V_0 = the velocity of light in vacuo

μ = refractive index of the medium

but μ varies with the wavelength λ as

$$\mu = A + B/\lambda^2 + C/\lambda^4$$

but the emergent light consists of a bundle of waves of slightly varying length rather than a single wavelength. For such a group of waves a group refractive index is given as

$$\mu_g = A + 3B/\lambda^2 + 5C/\lambda^4$$

For dry air at 0°C, 760 mm Hg and 0.03% CO_2, Barrel and Sears gave the wave refractive index as

$$\mu_0 = 1 + 2876.04 + 16.288/\lambda^2 + 0.136/\lambda^4)10^{-7}$$

where λ is in thousandths of mm or microns.

Putting λ= 0.000 5600 mm (5600Å) and transforming to group refractive index gives

$$\mu_g = 1.000\ 303\ 88$$

After comparing this with the results obtained from formulae by Perard in 1934 and Koster and Lampe, Bergstrand accepted

$$\mu_g = 1.000\ 3039 \pm 0.000\ 0002$$

For field use this had to be converted to its wet air equivalent which was done according to Kohlrausch as

$$\mu = 1 + \frac{(\mu_g - 1).p}{(1+\alpha.t)\ 760} - \frac{0.000\ 000\ 55e}{(1+\alpha.t)}$$

where t is in °C

p and e in mm Hg

α as 0.003 67 for the coefficient of expansion of a gas.

Correction to built-in refractive index values

Modern EDM instruments often have a built-in value for refractive index e.g. 1.000 273 in the Model 10 and others and 1.000 30864 for laser light.

At the time of observation a correction, found from a graduated disc, can be dialled into the Geodimeter instrument to correct for the variation of prevailing conditions from those relating to the built-in factor. This correction is derived from the expressions

$N = V_0/4.u.F = 308.64 \times 10^{-6}$ for laser light

or $= 280.9 \times 10^{-6}$ for Model 76

where N = assumed, preset or group refractive index

V_0 = velocity of light in vacuo = 299 792.5 km/s

u = unit length = 2.5 m for Models 700, 710, 6BL, 8 etc

F = measuring frequency = 29 970 000 Hz
and C (ppm) = N + (15e -K.p)/(273.2 + t)
Where K = constant for given value of λ = 0.359 474 (μ_g - 1)
p = atmospheric pressure in mm Hg
t = dry bulb temperature in °C
t´ = wet bulb temperature in °C (required for e)
e = vapour pressure in mm Hg

Example
N = 273
K = 105.496 (For infra-red of λ = 9200 Å)
p = 740 mm
t = 25°C
t´ = 20°C
Then C = + 12 ppm

Generally corrections in the range ±50 ppm can be dialled in. The temperature (°C or °F) and pressure (mm Hg; inch Hg or Pa/mbar) are set on the disc and the appropriate factor read off and set on the correction dial. The measured distance is then automatically corrected for the prevailing atmospheric conditions.

Angle reading system

With the Model 140 a new revolutionary angle reading was introduced that warrants some details. The devices for both horizontal and vertical circles each measure an electrodynamic, high frequency field which is integrated over the complete circle. This gives a surface average reading around the relevant axis of rotation and therefore eliminates circle eccentricity. There are no graduations and no micrometer and so there are no graduation or micrometer errors.

Geodimeter circles have no glass and so are not subject to fungus, damp or dust, have no moving parts and by design have eliminated all traditional errors.

In addition to the circle itself, the horizontal angle accuracy depends on: horizontal collimation error, levelling error in the direction perpendicular to the telescope and trunnion axis error. The collimation and trunnion axis errors are stored in the Geodimeter instrument´s continuous memory and are applied to each circle reading at time intervals of 0.3 sec. The levelling error is also measured and applied to each circle reading. Thus the angle displayed is calculated as:

$Hz_a = Hz_s + \Delta_c + \Delta_L + \Delta_t$ where:
Hz_a = the correct angle reading
Hz_s = the reading from the Geodimeter circle
Δ_c = horizontal collimation error
Δ_L = levelling error perpendicular to the telescope. Particularly significant on steep sights.
Geodimeter levels itself to ± 0.5"
Δ_t = trunnion axis error. This also increases with increased vertical angle.

Because of this arrangement, Geodimeter is not only as accurate on one face as a conventional instrument is on two faces but also is more accurate when steep sights are involved.

The vertical angle accuracy depends on: position of the vertical axis, vertical collimation error and parallax error.

In the Geodimeter instrument the vertical collimation error is stored in the continuous memory and applied to each reading. Deviations in the horizontal axis are compensated by dual axis compensators. The vertical index error is measured and also stored. A parallax correction is applied to the vertical angle each time it is taken.

Thus

$$V = V_s + \Delta_c + \Delta_L + P$$

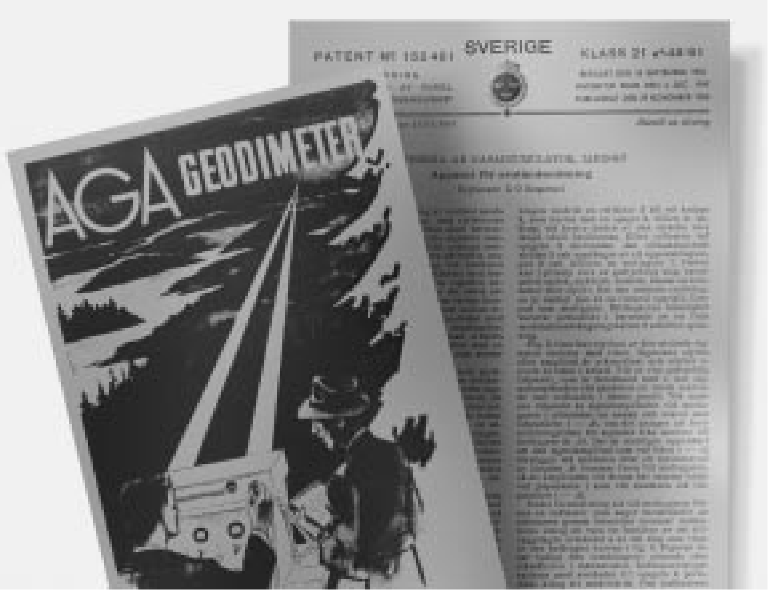
where

V = correct vertical angle
V_s = vertical circle reading
Δ_c = collimation error
Δ_L = levelling error
P = parallax effect = $200D/\pi L$
D = slope distance
L = base of the parallax = 60 mm

The different Geodimeter Models from 1947 to 1997

Prototype (1947)

Light from an incandescent 6V, 30W Luma projection lamp, where the spiral filament had a projected area of about 2 x 2 mm, was directed towards a 33 cm diameter plane mirror with the aid of a 46 cm diameter concave mirror. This mirror and the similar receiving one were front silvered by a vapourisation process. The receiving mirror had yellow and green filters so that there was no need for the basic light to be monochromatic. The distant mirror was surfaced by aluminium vapourisation and a field glass with cross hair provided for alignment. It was adjustable both horizontally and vertically. The curvature of this mirror was said to be probably about 20 km.



Geodimeter was patended in 1997

The effective wavelength was about 5600 Å, dependent on the filter, transmission in the nitrobenzene and sensitivity of the phototube. In front of the phototube colour filters could be inserted for a more precise definition of the effective wavelength of the light. The change in frequency due to the small changes in wavelength to resolve the fine reading could be recorded to 2 cycles or a difference of 4 mm over a 18 km line. Because of the crystal frequency the strength of the current repeated every 18th metre, or changed sign every 9th metre which was the distance between successive zeros. A 90 m line and 50 cm scale was used to calibrate the 70 cm scale of the variable loop that measured the fine reading.

The experimental equipment required a 400 W generator and the whole set of apparatus weighed some 200 lbs.

For the Öland base the yellow filter was removed and with a lower lamp voltage the effective wavelength was 5150Å. Lines of up to 30 km were possible with the equipment, although it was primarily used for the determination of the velocity of light and only later used in reverse for distance measurement.

Geodimeter Model 1 (1953)

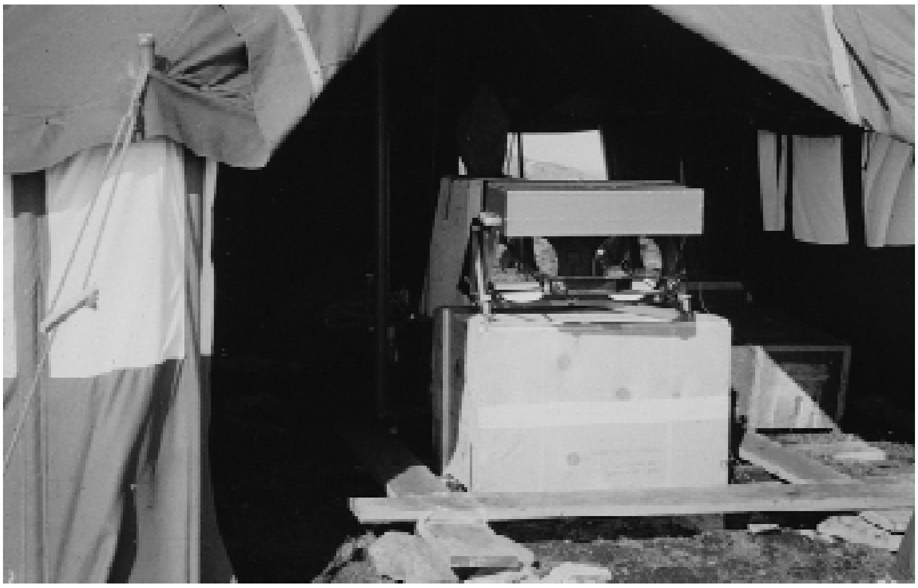
To increase the accuracy of the Bergstrand prototype instrument instead of varying the frequency of the high frequency phototube voltage to obtain a zero reading the phase of the voltage was varied by means of an electric delay network to obtain a zero reading. The setting of the delay line could be calibrated by use of an internal light path whose length could be varied up to 18 m, i.e. corresponding to a distance of up to 9 m. The range of this model was 30 km. and it was of similar dimensions to the prototype and could be operated from a portable gasoline generator. The concave mirrors were reduced to 30 cm diameter.

With the introduction of two frequencies the distance reading needed to be known to ±750 m. These frequencies differed by 1 per cent. Tests in Australia showed that there was a limiting error of ±0.08 ft (0.024 m). In 1953 the US Army Engineering Research Corp. obtained four Model 1 instruments and put them through extensive tests ranging from use in desert conditions at 96°F to Arctic tests at lower than -30°F; tests in the laboratory and from 103 ft (31.4 m) towers. In addition, experiments were carried out with several different forms of reflector unit. While testing the Model 1 (and subsequently some Models 2s) some 750 lines were measured at ranges from 35 m to 30 km. Various modifications suggested as a result of these tests were incorporated in the Model 2.

Whilst the results of the measurements are available, [133] it is not easy to comment directly on the accuracies achieved since no indication is given of the reliability of the measurements against which the instrument values were compared. The report concludes however that both models 1 and 2 were capable of 1:300 000 for lines greater than 3 miles (4.8 km) and of 1:150 000 for ranges from 1 to 3 miles (1.6 to 4.8 km)

In order to test one of the instruments over reliable baselines it was brought to the UK and used on the Ridgeway and Caithness baselines of the Ordnance Survey. Some 72 measures were made on the Ridgeway, of which 28 were thought acceptable, and 104 at Caithness, of which 32 were accepted. The mean values for spheroidal lengths at mean sea level were:

	Geodimeter	Catenary	Difference
Ridgeway	11 260.215 m	11 260.189 m	+ 0.026 m
Caithness	24 828.071	24 828.000	+ 0.071



Geodimeter 1, front view & platform
Photo: Ordnance Survey, U.K.

Considering the close agreement of these results the catenary values were taken as ’correct’ and the formulae inverted to give equivalent velocities for the speed of light. These were:

From the Ridgeway results 299 792.4 ± 0.5 km/sec
From the Caithness results 299 792.2 ± 0.4 km/sec

One measurement of each of the two frequencies required from 2 to 3 hours with 3 persons.

Geodimeter Model 2 (1955)

In addition to the four Geodimeter 1s, the US Army also tested three Model 2s. The voltage modulating the phototube was now applied to the cathode rather than the plate. This made centering of the receiver optics less critical and reduced the spread of the observations. As in the Model 1 a built-in light path was used for calibrating the electronic circuits. One of the three modulating frequencies was 10 000 000 MHz in order to allow field check against standard 10 MHz transmission. As the crystal frequencies could vary by as much as 15 Hz per 1°C, thermostats were designed to control the temperature to 0.05°C.

The US Coast and Geodetic Survey [124] are reported to have used a Model 2 for checking 43 lines in the triangulation network, including use from a Bilby tower. For this operation 6 men were required, principally to ensure that the boxed instrument was raised safely to the top of the tower.

During 1960-1962, five taped distances from 10-18 km long, were measured in the US [56] with agreement to better than 5.5 ppm.

The introduction of the newly developed prism reflectors required alignment to no better than ±20°C. A bank of seven prisms weighed 3 kg.

With the introduction of a mercury lamp Bergstrand measured a 50 km line over the sea between Öland and Stora Karlsö.

In the late 1950s and early 1960s a small number of Model 2s were equipped with mercury lamps in order to increase the range and also to better define the effective wavelength.

Training for personnel was quoted as ’less than 5 days’ and measuring time was 45 minutes for accuracies of:

1 000 m	1: 90 000
10 000	1: 500 000
50 000	1: 850 000

Geodimeter Model 3 (1956)

The second frequency in this model differed from the first of 1.5 MHz by 2.5% with a basic measuring unit of 50 m. giving an ambiguity range of 20 km. In this model all parts were made of lightweight material to give a total weight of 55 lbs. (25 kg).

Although designed to be of lower accuracy it was possible with the use of special observing techniques to improve on the quoted figures of (±10 cm + 2 ppm). In the USA time reductions of 30% were found in areas suitable for tape traversing and considerably more in mountain areas.

A measuring time of 20 minutes was required for accuracies of

1 000 m	1 : 10 000
10 000	1 : 85 000
30 000	1 : 190 000

Geodimeter Model 2A (1958)

The Model 2 and 2A differed only in the material of the housings. The 2 had ’silumin’ castings and the 2A ’electron’ castings. The former is a silicon-aluminium alloy, and the latter a magnesium- aluminium alloy which is considerably lighter.

Following a Resolution in 1954 by the International Union of Geodesy and Geophysics (IUGG), four baselines in Germany and Switzerland were measured with the Model 2A during 1958-1961. [69] The lines were measured first by invar and then by Geodimeter with the following results:

	Year	Invar	Geodimeter 2A
Munich	1959	8 231.847 m	8 231.870 m
Heerbrugg	1960	7 253.514	7 253.513
Meppen	1961/2	7 039.455	7 039.456
Göttingen	1961	5 192.901	5 192.929

Over periods of several hours during measurements the frequency varied by no more than 0.2 Hz. Experiments indicated that the constants (additive and light conductor) needed frequent calibration.

With the standard lamp only up to 20 km were possible in good visibility but changing to a super-pressure mercury lamp almost doubled the range.

10 Model 1s and close to 50 Model 2 and 2A were delivered in the period 1953 - 1967.

Geodimeter Model 4 (1958)

This instrument used modulation frequencies around 30 MHz and thereby the measuring time could be reduced to about 10 minutes compared to 45 for the Models 1 and 2. The optical system had apertures of 90 mm which reduced the range to about 10 km at night.

Designed more as a scientific than a practical field instrument this model was considered heavy and bulky although its weight compared favourably with that of the Model 3. It was especially used for distances up to 4 km. It had coarse and fine movements in both the horizontal and vertical of ±15°.

The Ordnance Survey used this model with a mercury lamp for refractive index studies on the 24 828 m Caithness base.

Measurements in two groups gave results of

40 measures	Mean	24 828.097 ± 0.004 m
17 measures	Mean	24 828.029 ± 0.009 m

Compared with the mean of 24 828.071 m with the Model 1.

Observations included pressure and wet and dry bulbs at various altitudes made at points along the line and all the data was made available to researchers. Three modulating frequencies around 30 MHz gave wavelengths that were in the ratio

λ, $400\lambda/401$ and $20\lambda/21$

Electronically the Model 4 was similar to previous models and the range of uncertainty 4000 m. The instrument had a continuously variable electric delay line of approximately 3 m, readable to the nearest cm, by the aid of calibration curves. It was mounted on a head providing coarse and fine movements both horizontal and vertical to ±15°.

Training for personnel took about one day.

A measuring time of 10 minutes was required for accuracies of

250 m	1 : 25 000
1 000 m	1 : 70 000
10 000 m	1 : 170 000

A normal slide rule and precomputed tables gave the distance after some 10 - 15 minutes of computing time. [6]

Geodimeter Model 4B (1960)

This was optically and electronically almost identical to the Model 4 but had a different type of housing. Produced during 1960-1964.

The National Research Council of Canada [118] carried out tests over a 9 km line near Ottawa where the difference of height of the terminals was 300 m. The aim was to not only use a long line but also adverse terrain. One of the major factors contributing to errors in the results of EDM measures was (and still is) the variable nature of the atmosphere between the terminals. The effect of this is most noticeable on long lines. Detailed measurements during three nights gave a mean result for the line of 9 316.763 ± 0.010 m.

From the observations it became apparent that if the meteorological parameters had been made at the instrument station only and not at the reflector as well, there would have been discrepancies of up to 38 mm for the whole line.

Saastamoinen [118] developed a formula to allow for the determination of the meteorological correction without the need to take observations at the reflector. The approximate relation was given as

Mean corr. (ppm) = observed corr. (ppm) + 0.012 (h_r - h_i)

where h is expressed in metres.

Geodimeter Model 4D (1963)

This model was identical with the 4B except for a high-pressure mercury lamp instead of a tungsten one. Whence the D in the model number stands for daylight.

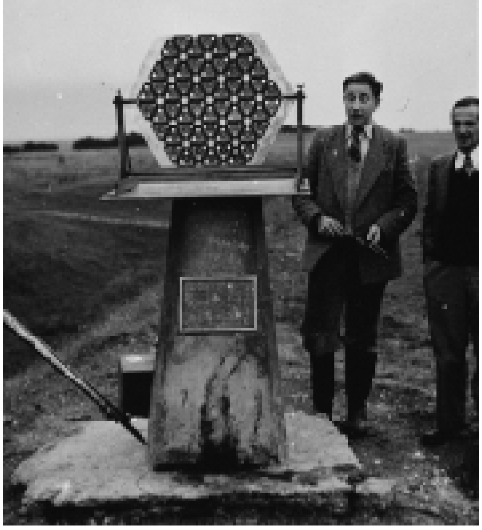
In 1963 the Geodetic Survey of Canada developed a technique for using the Model 4D that eliminated most of the delay line error and reduced the standard deviation by almost half to around 10 mm [85]. Some 469 measures were taken during tests over ranges from 5 to 36 km. The largest source of error was found to be the frequency instability which could be contained by checking the frequency while the instrument was in use. The range of frequency drift was found to be reduced when a higher thermostat temperature was used.

With an arc lamp the mean colour that reaches the phototube is dependent on the signal strength and if this is not allowed for could contribute errors of 1 ppm. The tests concluded that accuracies of 1 ppm were readily obtainable.

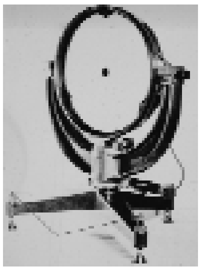
The problems of refractive index were further investigated around this time [131] using atmospheric dispersion techniques. For the yellow and violet mercury arc lines the difference in wavelength was 1744Å and with a resolution of 0.6 mm/10 km the distances recorded by each wavelength would give the average path refractive index to 1 ppm. In order to approach such accuracy the frequency standard of the Model 4D was replaced by a much more accurate one and in addition the optics required modification to accept wavelengths in the blue and violet regions. [131] fully describes these modifications.

Geodimeter Model 2 ....

.... being transported through the forest.

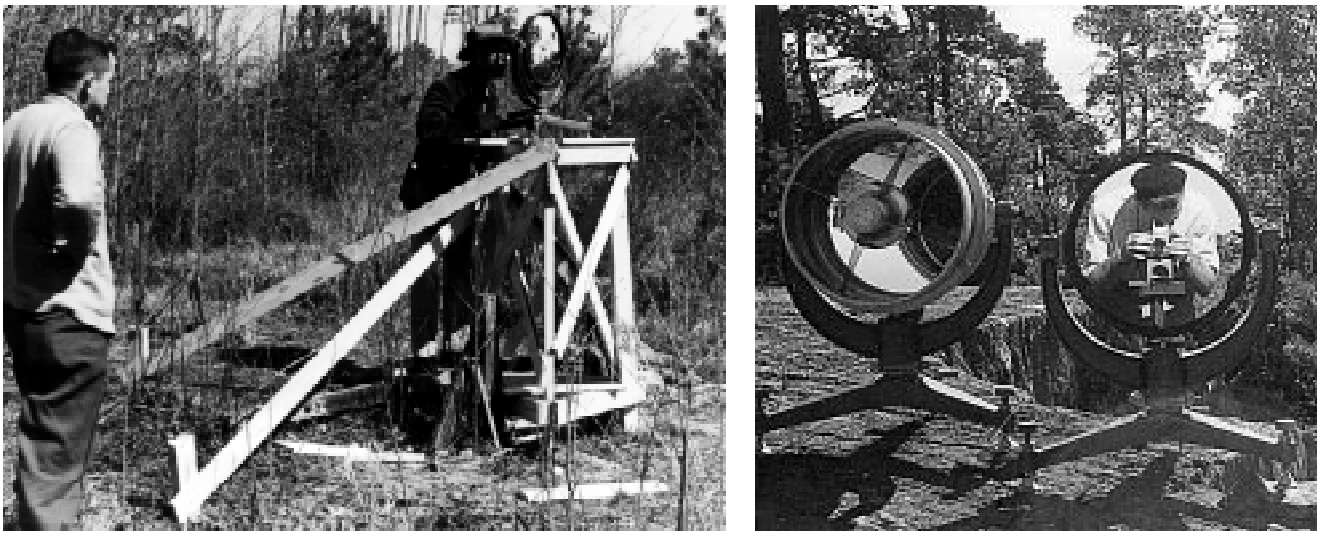


A cluster of cube corner prisms
(Photo: Ordnance Survey, UK)



Plane mirror (Photo: Ordnance Survey, UK)

Geodimeter Model 4



The plane mirror reflectors being adjusted.

Geodimeter Model 3

An early power source
- the motor generator ”Elsa”.....

.....and Geodimeter ”Power pack” -50 years later.

Ragnar Schöldström and Erik Bergstrand testing one of the first prototypes.

Geodimeter Model 6 in front of the Pyramids in Giza.
A control measurement of the 4700-year old Cheops pyramid showed that the north side measured 231.434 m and the east side 231.379 m - a difference of only 5.5 cm from a perfect square!

Geodimeter Model 8 in Nepal

In late 1965 the US Coast and Geodetic Survey experimented with modifying a Model 4D to use a laser light source and by mid 1966 were making test measures over ranges from 2 to 16 km. In addition a KDP cell was used instead of a Kerr cell and a different form of phototube. The laser was a 2 mW HeNe type and the beam exit width was 20 mm. Three frequencies were used - 29 970 000 Hz ; 30 044 920 Hz and 31 468 500 Hz as in all Model 4 series.

In tests over a 10.2 mile (16.3 km) line [94] the laser return signal proved to be 50% better than the mercury lamp. Changing from a mercury to laser light source gave a change in atmospheric correction amounting to around 4.2 ppm since the laser wavelength was 6328Å compared with the mercury value of 5500Å.

The Model 4D had a built-in refractive index value of 1.000 3100 to which corrections were applied for existing atmospheric conditions. The tests gave accuracies similar to the Model 2A and normal 4D but the range was improved to about 40 km. During 1967 AGA modified 16 Model 4Ds to use a laser.

Geodimeter Model 5

A Model 5 was designed but not produced commercially

Geodimeter Model 6 (1964)

Described by Bjerhammar [35] as the last of the first generation of Geodimeters. Nevertheless there were notable differences between this Model and the Model 4s. Fully transistorised, it used coaxial optics for the first time. The optics were arranged so that transiting was possible and measurements could be taken in the range -55° to 90°.

Lightweight rechargeable batteries allowed operation for 2 -3 hours compared with the 12V car battery of 7 -10 hours.

The coaxial optics did away with the requirement for deviation wedges in front of the prisms that were previously needed for short lines. Transmission was from the outer part of the tube and the received signal at the inner part.

In general terms the aim with the Model 6 was to make the following improvements as compared to the Model 4.

- Lower weight and power consumption
- Increased daylight range
- Simpler pointing to the prisms

The three thermostatically controlled crystal frequencies were the same as for the Model 4D. The delay line was given as a three figure digital readout. Conversion to length units still required a calibration table. Such tables were found from measures of known distances at increments of 0.1 m from, say, 20 to 23 m. Plotted on a graph, a smooth curve was fitted and the tables derived by computer. A horizontal circle, graduated in both degrees and gons (grads), assisted telescopic alignment.

Compared to the Model 4 the daylight range was improved 2-3 times and both power and weight reduced by half. With adequate visibility it would consistently measure in daylight up to 10 km with a mercury vapour lamp. New coated reflectors improved the reflected signal and were particularly useful at ranges greater than 15 km.

Checks over a 240 m catenary base at Chessington gave mean variations of 2 mm. Tests at Nottingham [78] illustrated the high consistency of the results since 20 measures of a 3172 m line under different conditions gave a standard error of 2 mm.

Geodimeter Model 6A (1967)

The prototype Geodimeter varied the modulation frequency until the distance was an integer number of quarter wavelengths. The early commercial models used several fixed frequencies.

The new generation, of which the 6A was the first Model, had the phase difference between outgoing and return signals measured indirectly by use of a twin heterodyne technique similar to that developed by Arne Bjerhammar [35] at the Royal Institute of Technology in Stockholm.

1967 saw the production of the 6A, where a modulated light signal f_1 was emitted and after reflection received back mixed in a multiplicative way with an auxiliary signal f_2 of slightly different frequency. Phase measurements were made on the beat frequency $(f_1 - f_2)$ where, for the Model 6A, f_1 was 29.970 MHz and $(f_1 - f_2)$ 1500 Hz.
The delay line of previous models was replaced by an electro-mechanical resolver and a different form of null point reading.

Calibration tables were no longer needed since the setting of the resolver was linear in relation to the distance to be measured. Three frequencies were used to give the total distance directly. Improved crystal ovens led to improved accuracy.

Fuller details of this system can be found at pp 193-195 of [41] 3rd edition.

Geodimeter Model 8 (1968)

The main difference compared with the Model 6 was the use of a continuous wave, 5mW He-Ne laser light source and a 25 mm collimator resulting in a beam divergence of 0.1 m per km.

Modulation was by a Pockels (KDP) cell instead of a Kerr cell. Four crystals were used and there was a built-in refractive index value of 1.000 3086.

The laser gave ranges of up to 60 km by both day and night. 20Å filters excluded most of the light at wavelengths other than that of the transmitted signal. The photocell was varied in sensitivity in phase with another frequency 1500 Hz lower than the relevant modulator frequency.
A crystal controlled oscillator mounted in an oven assured stability of the transmitting frequency to better than 1 ppm.

Geodimeter 7T (1969)

A short range instrument (up to 500 m) that used the two lower frequencies of the Model 6A. The distance was given directly as a digital readout to 0.01 m. The instrument also incorporated horizontal and vertical circles with the possibility of using both faces on the reversal of a plane mirror. The angles could be read directly to 0.01^g.

The optics were coaxial. Both transmitted and received signals followed the same optical axis separated by a light proof wall. This instrument only reached the pre-production stage.

Geodimeter Model 6B (1969)

Similar in most ways to the Model 6A except that the electronic system was completely redesigned so that readings were obtained more quickly and reduction of the observations was faster. The operator had the choice of either direct read-out with a 200 m range to ± 10 mm or by taking extra time an accuracy of ± (5 mm + 1 ppm) was possible.

Geodimeter 700 Total Station (1971)

This was one of the first of what are now termed Total Stations. It measured slope distance, horizontal angle and vertical angle and computed the horizontal distance- each selected by the appropriate switch. A tape punch could be attached to the read out unit which stood apart from the measurement unit. The light source was a 1 mW He-Ne laser of effective wavelength 632.8 nm.

It was particularly useful for setting out, traversing and detailing with the automatic tracking of a prism up to 500 m. The angle readings had an accuracy comparable to that of a 1 second theodolite although obtained from coded circles, with automatic compensation on the vertical circle. The circles read to ±2" horizontal and ±3" vertical. One measure took 10 - 15 seconds. The coded circle was produced by the photolithographic process and used together with the moiré fringe effect. A radial grating (lines) was ruled at approximately 100 to the mm to give 20 000 divisions on the 7 cm diameter circle. A second grating was obtained by optical superimposition of one side of the circle on the other. Full details of the circle reading system can be found in [107]. The instrument only needed to be calibrated at the beginning of a set up or after the power had been turned off. The theodolite and EDM unit had coaxial optics and automatic dislevelment compensation up to 90°.

In one motorway scheme 100 points an hour were surveyed by the polar method.

Geodimeter 76 (1972)

Developed in America for the North American market. It had a digital readout to 1 mm over ranges up to 3 km. It used a 2mW laser light source. Atmospheric corrections could be dialled in, and measuring time was only a few seconds.

Geodimeter 6BL (1973)

In this Model the previous tungsten or mercury light sources were replaced by a 1 mW He-Ne laser. The introduction of a laser greatly improved the daylight range so that it was practically the same as after dark and there were improved capabilities with poor visibility. Accuracies obtainable remained similar to the Model 6B. The circuitry was redesigned as plug-in units.

Geodimeter 710 (1974)

This was a development of the Model 700. It gave a continuous indication of height difference, horizontal and slope distance up to 4.7 km. It was a combined digital electronic theodolite and distance meter with calculator. The readings were automatically adjusted for atmospheric changes by setting a dial to the actual refractive index as in the Model 700.

It used a 1 mW He-Ne laser visible light source. A punch tape output could be fed through a tape reader to a desk calculator and plotter.

It was simpler and quicker to calibrate than the Model 700. The circles could be read to ±2" in the horizontal and ±3" in the vertical. There was an automatic vertical circle index.

Possible to use with the Geodat 700 for automatic data collection either on punched tape or coded for telex transmission.

Geodimeter 12 Mount-On (1975)

A theodolite-mounted instrument with digital readout to mm. Its range was 3000 m. No calibrations or tuning required. It could track a moving reflector at ranges up to 700 m. Very suitable for large numbers of detail points. Corrections could be dialled in to allow for changes of pressure and temperature. It had a similar audio alignment signal to the Model 10. Used with prisms of zero constant to simplify the measuring procedure.

Geodimeter 78 (1976)

Similar to the Model 76 except for improved electronic circuitry increasing the range to 10 km.

Geodimeter 12A (1977)

Very similar to the Model 12 but incorporating a switch for long and short range measurements. This switch reduces the signal to noise ratio on short distances and accordingly improves the proportional accuracy. Allows tracking of a moving target. Atmospheric corrections can be dialled in.

Geodimeter 10 (1977)

A theodolite mounted instrument designed to meet the needs of those requiring a short range traverse instrument. It does not have the tracking facility of the Model 12. Its range is about 1 400 m with three prisms.

After aiming at the reflector, a press button produces a reading in 10 seconds. To locate the target speedily the instrument emits an audible signal as well as having a signal strength meter for maximising. This makes pointing easier since the light source is a light emitting diode emitting invisible radiation at 900 nm (9000Å). Almost any make of theodolite can be used as the carrier to provide simultaneous angle and distance values. Built-in refractive index for this and the 12, 12A and 14 is 1.000 273 and changes from this can be dialled in.

Geodimeter 14 (1977)

Of the same family as the Model 12 but with a range up to 10 km. It will measure to 4 km on a single corner cube and 6 km on three. On the longer ranges the instrument samples a large number of measurements on both phase 1 and phase 2 and averages these before presenting it on display. Meaning the phase 1 and phase 2 readings reduces the proportional error to ±3 ppm. A control on the front panel provided the operator with an indication of the accuracy of a measurement under the prevailing signal conditions. The same control showed the number of measures required to achieve that accuracy and indicated how many times both phases should be read to achieve that value. There was no tracking mode, but there was an audio aiming signal.

Geodimeter 600 (1977)

On the 30th anniversary of Geodimeter, a new model - 600 - was launched. To look at it was styled on the Model 6B with maximum range of 40 km, with a 1 mW He-Ne laser light source. For ranges up to 200 m it was possible to reflect directly off walls or other surfaces of similar reflective quality. Up to 1.5 km could be measured to a plastic reflector. Special measuring techniques, taking up to half an hour, could give mean square errors of less than (1 mm + 1 ppm). Because of the narrow beam divergence the instrument required a solidly placed tripod or pillar.

Geodimeter 120 Semi-Total Station (1978)

This was referred to as a semi-total station. It automatically presented the horizontal distance and also gave the slope distance and difference of height. Various settings allowed different combinations of results.

It could be telescope mounted as the Models 10, 12, 12A and 14 and the mounting allowed ±31.5° movement in the vertical plane. The vertical angle readout could be readily adjusted to agree with the vertical angle on the theodolite. The vertical circle index was automatic.

There were three modes of operation:

- automatic
- automatic mean
- tracking

The tracking mode gave distances to ±10 mm every 0.4 seconds. The wide beam width (250 mm at 100 m or 2.5 mrad) facilitated setting out.

The mean value of a distance could be updated every 0.4 seconds as the values were repeated. The reflector man could leave or enter the beam at any point without introducing any error to the distance.

It could be interfaced with most modern makes of theodolite. Pressure and temperature changes could be allowed for by dialling in the relevant correction factor. This correction was applied to the wavelength used and not to the difference in phase measurement. The vertical circle pendulum required adjustment if the instrument was transported more than 1000 km in latitude or 500 m in altitude. Constants of 6372 km for the mean radius of the earth and 0.071 for the mean coefficient of refraction were built into the automatic vertical angle correction. (Later investigations into the coefficient of refraction indicated that some modification of such a facility might be required for different conditions).

Care needed to be taken over reflector eccentricity corrections as the Model 120 had a built in correction for the tiltable reflector which was not applicable to the tiltable target.

The true potential of this Model was achieved by use of the Geodat (see page 37) to automatically record and store the observations.

Tests detailed in [62] gave levels of points on hard detail good to ±5 mm. Other tests [75] showed that the instrument was capable of high accuracy even at extremely short (3 m) distances.

Geodimeter 14A (1979)

Can be mounted on most modern theodolite telescopes or on a yoke. It has a numitron display, audio visual aiming and push button or remote control operation. A range up to 6 km on 1 prism and maximum of 15 km.

Two modes of operation- auto and phase measurement. For speed or short range work auto takes only 10 - 15 seconds for each measure with an accuracy of ±5 mm + 5 ppm. For maximum accuracy, phase measurement improves the results to ±5 mm + 3 ppm.

Geodimeter 110 (1979)

Described as a low cost, no frills, instrument for routine survey. Compared with its predecessor, the Model 10, it has longer range, smaller battery and 'repeat measure' function. It is telescope mounted and has a range of 2 km on 3 prisms. There is an acoustic signal, LED display and a low battery warning. Auto measure takes 10 seconds but the repeat mode for setting out gives a new indication every 2 seconds.

Geodimeter 112 (1979)

This was the successor to the Model 12A. Designed for traversing, setting out and data collection, it had a longer range, smaller battery, arithmetic mean of repeated measures and data output facility. It could be either telescope or yoke mounted. There was a range of 5.5 km with 8 prisms. The data outlet allowed automatic registration of measurements via the Geodat (see page 37). Continuous arithmetic mean of measurements had an accuracy of ±5 mm + 3 ppm. A fast tracking mode with a complete measure every 0.4 seconds, added inshore hydrographic measurements to the range of applications for this model.

Geodimeter 114 (1979)

Range 1000 m to a single prism and accuracy of ±(5 mm + 1 ppm).

Geodimeter 116 (1979)

Designed for the construction market with instantaneous read-out of horizontal distance, difference in height and slope distance. It did not have a data transfer facility but had a ROE option (see page 36). A variable pitch, audio signal aided alignment. The tracking at 4 m per second was not affected by traffic interruption or by the reflector occasionally wandering from the beam. Increased accuracy was obtainable by meaning on repeated values.

Geodimeter Model 122 (1981)

This was an up dated version of the Geodimeter 120 with two novel features for setting out. Tracklight, a visible guide light to enable a reflector man to set himself on the correct bearing, and Unicom, a one way voice link along the measuring beam which allowed the operator to instruct the reflector holder to move forward or backward until the correct distance was obtained. (See page 36)

The Geodimeter 122 also had enhanced range capability and an improvement in the vertical angle sensor which meant more accurate ΔH measurements.

Geodimeter 140 (1981)

This was a total station instrument with digital measurement of distance, horizontal and vertical angle. The Geodimeter 140 saw the introduction of the first electronic angle measuring device with no optical parts. The angle measuring devices in both the horizontal and vertical circles each measure an electrodynamic, high frequency field which is integrated over the complete circle. This gives a surface average reading around the relevant axis of rotation and thus eliminates circle eccentricity. There are no graduations and no micrometer and so there are no graduation or micrometer errors. These circles have no glass and so are not subject to fungus, damp or dust, have no moving parts and by design have eliminated all traditional errors. Full accuracy of ±2" was obtained from a single face measurement.

For horizontal angles the collimation and trunnion axis errors are stored in the continuous memory and applied to each circle reading at time intervals of 0.3 sec. The levelling error is measured and applied to each circle reading. For vertical angles the collimation error is stored in a continuous memory and applied to each circle reading. The deviations in the horizontal axis are compensated by the dual axes compensator and the vertical index error is measured and stored within the Geodimeter.

All survey measurements could be automatically recorded in a Geodat (see page 37) together with details of coding in either numeric or alpha numeric format. The Geodimeter 140 also incorporated the transmitter end of the Unicom system. An adaptation of the Geodimeter 140 was called Geodimeter 136.

Geodimeter 136 (1983)

Similar in many ways to the model 140. The most noticeable exception, at the time of production, was that it was some 30% cheaper. Principal among the differences are that the range to a single prism is 1000 m whereas the 140 had a range of 2500 m, single axis instead of two axis level compensation, and one way instead of two way Geodat communication. It is particularly applicable for control traversing, open cast mining, earthwork quantities and digital ground models.

Options include increased range of 2500 m to a single prism, dual axis compensation, two way data communication, one way speech and ROE. Thus it is in effect upgradeable to the equivalent of a model 140.

Geodimeter 142 (1984)

Similar in most respects to the Model 140. Accuracy ±(2 mm + 3 ppm) up to 1000 m.

Compensates automatically for all instrument errors. 2500 m on one prism and 5500 m on 8 prisms. Automatic meaning of angles. Uses an Instrument Centre Correction (ICC) with 2 axis compensator. Among options is use with a Tracklight®.

Geodimeter 220 (1984)

This model has a built-in tilt sensor, microprocessor, on-board battery and maximum range of 7 km. A one way speech channel has a range of 1600 m. which reduces during measurement to about 800 m. Fully automatic display of horizontal, slope and vertical distances. Alignment is possible via a Tracklight. Selector control for prism constant and atmospheric correction. High speed tracking to a mobile reflector with read out 2.5 times per second. Arithmetic mean value of repeated measurements. It can accept the options such as Tracklight® and Unicom®. Weighing only 1.3 kg it is one of the smallest EDMs. It is designed to be theodolite mounted.

Geodimeter 210 (1985)

Range of 2300 m to one prism. Accuracy of ±(5 mm + 3 ppm).

Geodimeter 216 (1985)

Range of 1000 m to one prism. Accuracy ±(5 mm + 5 ppm).

Geodimeter 600 (1985)

This laser EDM is capable of up to 50 km to an accuracy of a few centimetres. One of its uses has been to establish new reference baselines for infra red and microwave EDM in countries such as Nepal and the Falkland Islands. It is used also to assist GPS in areas where the satellite coverage is poor.

Geodimeter 140H (1985)

Specifically designed for inshore hydrographic work where position and depth are required in real time. With a range of 3 km it is ideal for harbour, river and estuary work. The hardware requirements are a Hewlett-Packard HP9816S or other HP 200 series computer, with twin disc drives. A plotter and printer are optional. The Geodimeter-Hydropac software is arranged in three modules for setting-up the system, data collection and survey processing. The data collection module has four main operating modes - a test mode checking data reception, a navigation mode for position, speed and course information, a line or grid system of survey and a general mapping mode. Any echo-sounder with either BCD or RS232 based output may be interfaced directly with the system.

Geodimeter System 400 (1986)

Is a fully integrated system since it is a combination of electronic theodolite, EDM and menu driven computing facility. A dual axis compensation system allows single face observations with full instrument accuracy. Two face measurements can give an automatic mean value. The EDM can provide single observations to stationary targets or in tracking mode will give measurements every 0.4 seconds.

For setting out the horizontal distance is up-dated 2.5 times every second. This can be used in conjunction with ROE for combined setting out of distance and height. If needed, the output can be as easting, northing and elevation of the set out point.

For data collection either horizontal angle, vertical angle and slope distance or horizontal angle, horizontal distance and vertical distance are displayed in 0.4 seconds.

As from 1988 the System incorporated three total stations with different capacities, software and options. These are the 410, 420 and 440.

The overall philosophy behind the 400 System is to allow the user to select the options best suited to his/her requirements and effectively have a customer designed System. The options are:

- Three different memory units - Geodat 126, Geodat 400 and an Internal Memory 400
- Four software data collection packages - UDS 400,View 400, Edit 400 and Pcod 400
- Software for field computation - Set-Out 400.
- In addition there are three different modes of distance measuring - Normal, D (or precision) mode and Tracking mode. Aiming is simplified by the wide beam, 25 cm/100 m (2.5 mrad), and it is possible to set out or do hydrographic survey to a moving target at speeds up to 4 m/s (14.4 km/h).

The display panel consists of four lines of LED with 16 characters per line and this is automatically lit as the prevailing light around deteriorates and similarly when the air temperature falls to 0°C or below so automatic heating comes on.

Geodimeter 440 (1986)

The options available with this model are:

- Geodat 126 and 400
- Internal memory 400
- UDS 400, View 400, Edit 400 and Pcod 400 software for data collection
- Set-Out 400 software for field computation.

Geodimeter 140S (1986)

A servo controlled total station with 'raster memory' that can be used for both land and hydrographic surveying. It can be transformed with a small video camera, monitor and joystick into a system for marine surveying and other tracking of objects that move at a relatively constant speed.

Geodimeter 420 (1987)

The options available with this model are:
Geodat 126 and 400 UDS 400, View 400, Edit 400 and Pcod 400 software for data collection. Set-Out 400 software for field computation.

The dual axis compensator provides a continuous and automatic correction of instrument levelling errors and it has the facility to use all the other available options.

Geodimeter 140T (1987)

T = Automatic Tracking. This is a servo driven total station for both hydrographic and topographic work. It is based on the Geodimeter 140 and can automatically track a moving prism at speeds of up to 34 km/h.

A modification to the standard model is the positioning of a small video camera on top of the telescope, enabling the operator to control initial aiming, after which tracking the target is automatic. It is good to 0.4 m up to 2.2 km on a single prism with position fixes once every second.

Geodimeter 6000 (1987)

This model had a range of 21 km in standard clear conditions so that in fairly poor visibility it could still measure reasonably long distances. The range on one prism was 14 km or even 22 km in very good visibility. Measurements were automatically presented on the display as the arithmetic mean to ±(5 mm + 1 ppm). It had a tracking facility that allowed up-dates every 2 seconds and a data outlet for the Geodat.

Geodimeter 140 Slope Monitoring System (SMS) (1987)

This is a system designed for use on open cast mines,

dams and embankments where continuous monitoring of slope movement is essential. It is computer controlled to measure distances, horizontal and vertical angles and predetermined intervals to prism targets anchored to points on the slope. It incorporates a servo driven total station, an IBM XT computer and a sensor for air temperature and pressure. Automatic 3D measurements for slope monitoring. 1000 m to a single prism.
Accuracy ±(5 mm + 3 ppm)

Geodimeter 140SR (1988)

Automatic 3D measurements with computer control for slope monitoring. 1000 m to a single prism. Angles to 3" and distance accuracy of ± (5 mm + 3 ppm)

Geodimeter 410 (1988)

Identical in appearance to the 420 and 440. Its specifications are aimed at suiting the needs of the smaller land and engineering survey firms. It has an accuracy of 3 sec and ±(5 mm + 3 ppm) for distances with a single prism to 1000 m. It is designed to accept the Geodat 126 and 400 external memory, UDS 400 and View 400 software. and has a range up to 2200 m.

Geodimeter 400CD (1989)

CD = Custom Designed. This Model is more of a total station than most of its predecessors and incorporates features particularly suited to construction work and topographical surveys. It has full coordinate display, tracking with distance measures every 0. 4 sec. to ±(3 mm + 3 ppm) at ranges up to 1000 m with a single prism.

For setting out there is an automatic countdown to zero.

The instrument can be used with the Geodat 400 memory pack and operate with the software FS-Setout 400 and DistOb 400 for setting out, and UDS 400 and Edit 400 for survey.

Geodimeter 400 CDS (1989)

This model is aimed particularly at the construction and civil engineering market. It has a range of 1600 m to a single prism and accuracies of ±3 mm and 3 seconds. Once a bearing or coordinate is keyed in the instrument automatically points itself. On-board software and internal memory allow the instrument to be loaded with setting out data.

Geodimeter 408 (1989)

This Model has a range of 2 200 m and ability for fast tracking, wide beam, automatic ROE and use of the Unicom receiver. It can be connected to Geodat 122, 124, 126 or 400 data loggers. It is aimed at the construction market with a range of 1000 m to a single prism. It has a single axis level compensator.

Geodimeter 412 (1989)

This Model replaces the Model 410 and has a range of 3100 m, fast tracking, wide beam, automatic ROE and use of Unicom receiver. It can be connected to Geodats 122, 124, 126 or 400 data loggers and has the facility for the System software UDS 400, View 400 and Edit 400. The range to a single prism is 1600 m and it has a dual axis level compensator. Accuracies are 3” and ±(5 mm + 3 ppm).

Geodimeter 420 LR (1989)

(LR = Long Range) Range of 7 km to sixteen prisms and 6 km to eight prisms with high performance optics to give a brighter image over longer distances or in poor light conditions.

Geodimeter 422 (1989)

This Model succeeded the Model 420 and has a built-in memory option for storage of both data bases and raw data, and can hold all existing System 400 software.

The menu driven operation has all the options of Geodat units and software. The range is 2300 m to a single prism, 4300 m with 8 prisms and Unicom transmission up to 1600 m. Its accuracy is 2" and ±(3 mm + 3 ppm).

Geodimeter 422 LR (1989)

This Model has a range of 3300 m to a single prism and 7 km with 16 prisms and accuracy of ±(3 mm + 3 ppm). It has all the options of the System 400.

Geodimeter 440 LR (1989)

LR = Long Range. This model has an internal memory option and the accuracy capabilities required for precise traversing and monitoring. A range of 7 km to ±(3 mm + 3 ppm).

The display presents three possibilities:

Horizontal angle	**Horizontal angle**	**X coordinate**
Vertical angle	**Horizontal distance**	**Y coordinate**
Slope distance	**Vertical distance**	**Z coordinate**

It has all the options of the System 400.

Geodimeter 424 (1990)

Full angular accuracy on a single reading with all angles corrected for collimation and trunnion axis errors. Ability to use tracking mode, Unicom and Tracklight and an alphanumeric keyboard for use in coding or programming through the UDS. It also has the option of an internal memory to store both co-ordinates and measuring data.

It has the same alpha numeric keypad as the model 444. This is a 20 character, four line display to allow entry of feature coding. With an accuracy of ±(3 mm + 3 ppm) and 2" it has a range of 2300 m to a single prism. It has a stand by mode which avoids the need to re-initialise the automatic level compensator when setting up at a new station or when returning to the instrument after a break.

Geodimeter System 4000 (1990)

The prime features of the System 4000 are threefold

- Servo-assisted surveying
- Remote surveying and
- Robotic surveying.

In essence it is similar to any other total station except for its servo drive.

With a servo drive all that needs to be manually input is the point number. With the measurement of angles, once a point has been sighted the instrument 'remembers' it and will relocate on it automatically for repeat observations. Circle clamps are no longer required.

Remote surveying allows the experienced person to be at the target end and hence the important position for recording coding, registration etc. The instrument end needs only to have an assistant directing the telescope on to the reflector.

The robotic arrangement takes the remote system a stage further in that even the aiming can be done from the target end via a Remote Processing Unit. The RPU 4002 mounts on the ranging pole and has a storage capacity up to 10 000 points. The internal memory unit holds 2 700 points. The prism station's Remote Rositioning Unit (RPU) sends a signal to the measuring instrument which starts a search procedure to find the prism station and aim itself towards it. All operations that were previously done at the instrument station can then be done at the RPU.

The system has a dual axis compensator to eliminate level errors, and the automatic compensation of any collimation error or trunnion axis tilt.

Initial tests on setting out work indicated an improvement of some 40% compared with traditional methods.

The keyboard of the RPU can be detached and taken wherever necessary for editing and processing the data.

With the Systems 600 and 4000 both current, the principal difference between them is available range. The System 4000 can be controlled from up to 1800 m whereas the System 600 initially only had robotic control up to 250 m. In addition the 4000 will be supplemented with a Surveying Robot or SR option. This will combine all functions of the conventional surveying system with the capability to be linked using either hard-wired RS 232 or RS 232 telemetry to a remote computer or field data collector.

This development allows the control of machine position on site and a means of monitoring slope stability. It can also be coupled to a Husky Hunter or Psion Organiser for conventional surveying.

Geodimeter 4400 (1990)

This is the station unit of the System 4000. It can serve either as a robotic unit or as a conventional servo controlled total station. It has an automatic search/ aim function and a telemetric link for communications between the instrument and the RPU. The servo motors provide automatic aiming in both the horizontal and vertical planes. Once locked onto the RPU the unit will automatically follow the movement of the RPU. In this mode it can cover an area of 785 000 m^2.

Conversion from conventional operation to robotic requires just one key stroke. By using special User definable sequences (UDS) the operator can create customised measuring sequences.

The range with a single prism is 2300 m, 8 prisms is 4300 m with a least count of 1 mm or 10 mm with fast tracking. Angle measure is to 1" or 0.1 mgon. with an accuracy of ±(3 mm + 3 ppm).

One particular plus point when using a roboting arrangement is that measurements can be taken in the dark since the instrument, rather than a human, does the sighting.

It supersedes the Geodimeter 460.

Geodimeter 444 (1990)

A range of 7 km to 16 prisms and accuracy of ±(2 mm + 3 ppm). In clear weather the range is 3 300 m to a single prism. Angle measures are presented to 0.1 mgon (= 0.3")

A precise electronic level allows the operator to level in x and y without moving the instrument. The built in hard disc can accommodate the coordinates and measuring data equivalent to 900 points.

Geodimeter 460 (1990)

Operated by servo motors, this is a major step in the evolution of the Geodimeter. It overcomes one of the main sources of error associated with operator alignment of the instrument and at the same time can keep two staffmen busy. Two face measurement and positioning horizontally and vertically are done quickly and accurately. A dual axis compensator is automatically calibrated and any collimation or trunnion axis errors measured and stored.

There is a range of 2300 m to a single prism and accuracy of ±(3 mm + 3 ppm) and a 1 second resolution.

The built-in hard disc has a capacity of 128K - equivalent to data for about 3600 points which, supplemented with a Geodat 400 will give a capacity of 5100 points.

Users are able to create their own programs for collecting detail and for tacheometry.

For setting out the optimum is achieved through use of the software FS/SetOut 400 or Roadline 400. The entry of one point or section number will retrieve coordinates from the memory and calculate the setting out data. After calculation the instrument then aims in the correct direction.

For angle measurement, once the points have been sighted the servo system can then repeat the observations as many times as required to achieve the accuracy needed.

Geodimeter 464 (1991)

This model has a range of 7 km with accuracy of ±(2 mm + 3 ppm) and angles to 1". Servo driven, it has an internal memory capacity of 2700 points. An alpha numeric keyboard provides logical, easy to follow commands, and the ability for it to be tailored to suit various surveying tasks is achieved through software for both data collection and field calculations.

Geodimeter 468 DR (1992)

(DR = Direct Reflex) This is essentially a tunnel surveying system. A servo driven total station for 3D direct reflex measurement in tunnels. Its diffuse reflex module allows measurement from surfaces such as concrete, rock and steel as well as the normal prism or plastic reflector. A built in red laser aids aiming.

Range up to 200 m in DR mode. In normal mode 2000 m to ±5 mm. Angular accuracy 2" (6^{cc}). Special Geo Tunnel Software module gives an integrated Windows™ solution for the automatic measurement and analysis of tunnels. Works with Windows 3.11 or 95 with 468 or pentium processor. It provides a tunnel terrain model with opportunities to calculate volumes, overbreak and underbreak, clearance tolerances, cross sections and long sections compared with any design or redesign. Points inside or outside defined tolerances are flagged.

Operating speeds of 10-15 points a minute are possible. Most of the options available in the System 400 can be used with this instrument.

Geodimeter System 500 (1992)

This System allows customers to create their own configurations. There is a choice of accuracy class, of either numeric or alphanumeric keyboard and software. The memory options allow a capacity up to 10 000 points. An external Geodat can store up to 3 000 points for transfer from the Geodimeter to a computer and vice versa.

With the RPU (Remote Positioning Unit) control of the operations can be at the target rather than at the instrument end. This unit also speeds up data collection, setting out and detailing.

Available in three accuracy classes from 1 sec to 5 sec in angle measurement and distance accuracy of ±(2 mm + 2 ppm) with a resolution of 0.1 mm on the top model to ±(3 mm + 3 ppm) on the other two. Servo driven, the instrument points itself once the relevant data has been keyed in. Multiple readings to the same points are achieved automatically after the first pointing to each.

Geodimeter 510 (1992)

A system with three options for range where one prism may give 1200 m, 1800 m or 2500 m. Angular accuracy is to 3" (10^{cc}) and arithmetic mean value to ±(3 mm + 2 ppm). For distances the arithmetic mean value of the least count is 1 mm.

This system will operate with the RPU 502 to allow control of operations from the measuring point. It has a range up to 2000 m depending on which System 500 total station is being used.

Geodimeter 520 (1992)

Similar to the Model 510 except that the angular accuracy is to 2" (5^{cc}).

Geodimeter 540 (1992)

Similar to the Models 510 and 520 except that the angular accuracy is 1" (3^{cc}) and arithmetic mean value to ± (2 mm + 2 ppm). For distances the arithmetic mean value is 0.1 mm.

Geodimeter® System 600 (1994)

The System covers three range and accuracy classes:

Class 1	Geodimeter 640
Class 2	Geodimeter 620
Class 3	Geodimeter 610

The System 600 can be upgraded by adding different modules so that it is possible to tailor a total station to match ones needs. The range of options is considerable:

- three range options, 1 200 m, 1 800 m and 2 500 m to one prism. (max. range 4.500 m)
- automatic compensation for mislevelment up to 10^{cc} (30") and a warning if greater than this
- storage of corrections for collimation and trunnion axis errors
- automatic calculation of arithmetic mean of a series of readings
- tracking of objects moving up to 4 m/s (14.4 km/h)
- setting out elevations by ROE
- use of Tracklight system for communication between instrument and reflector operators
- choice of 11 programs that can be added as and when required
- the option of additional external battery power
- up to 10 000 point capacity depending on the chosen memory
- removable keyboards so that each crew can have its own
- the ability to control all operations from the target end while an assistant aims the instrument
- the previous option can be extended to robotic surveying using a Tracker and Remote Positioning Unit to make a ”one person system”.

For remote/robotic control the modular keyboard is transferred from the instrument to the target end and interfaced to the instrument via a radio telemetry system on the rod.

In radio-only remote control mode, data communication between target and instrument allows the survey or setting out operation to be controlled from the target end with servo-assisted instrument aiming.

The combination of the Tracker/Autolock and the RPU developed for System 600 gives the Geodimeter System 600 ”Robotic”, where the rod

Geodimeter Model 6 was used for surveying the Essingeleden highway bridges in Stockholm.

A surveying team with Geodimeter 700 in the Stockholm archipelago.

The control unit of Geodimeter 700 mounted on Geodat 700 data collector

Left:
Geodimeter 120
"mount-on" with
Geodat 120.

Right:
Geodimeter 143
with Geodat 126.

man is in full charge including instrument aiming. The automatic tracking operates up to 250 m. With this system accurate night time working is perfectly feasible.

Geodimeter 610 (1994)

The basic model in the System 600, this has various distance accuracies, according to mode of operation, up to ±(3 mm + 3 ppm), dual axis compensator range of 100 mgon (6') and angular least count of 1" or 1^{cc} to an accuracy of 3" or 10^{cc}.

Also this ’entry’ level instrument in the System 600 range can be upgraded to fully robotic operation by fitment of the Tracker and Radio modules. All models can also be upgraded to Autolock aiming, remote reading or fully robotic operation.

Instrument specification options include range up to 2500 m with a single prism, accuracy in three classes up to ± (5 mm + 2 ppm) and 1 second of arc. Memory systems can be up to 10 000 points. Autolock assisted aiming allows manual instruments to lock on to the target automatically when aimed within 2.3 m at 100 m range (around 1.5°). Autolock™ allows operation in poor visibility provided the target is pointed towards the instrument while moving from point to point. The Tracker and Radio modules enable the instrument to track the pole target automatically with the data acquisition controlled from the prism end.

Geodimeter 620 (1994)

As the 610 except for angular accuracy of 2" or 5^{cc}. Distance accuracy ±(3mm + 3 ppm).

Geodimeter 640 (1994)

As the 610 and 620 except for distance accuracy of ±(3mm + 3 ppm) which is improved to ±(2mm + 3 ppm) in temperatures between -5°C and +40°C. Angular least count of 0.1" or 0.1^{cc} and accuracy of 1"or 3^{cc}.

Geodimeter 600 M & S (1996)
M = Mechanical, S = Servo

In 1996 the Geodimeter 600 family was divided into mechanical and servo driven series of instruments. They have similar functions as 610, 620 and 640 described before, but with improved range and accuracy figures.

Geodimeter 610M and S range up to 2 900 to one prism, max. 5 800 m. Distance accuracy ±(2mm + 2ppm) and angular accuracy $10^{cc,}$ 3"

Geodimeter 620M and S has same range options and distance accuracy as 610M, but angular accuracy is $5^{cc,}$ 2"

Geodimeter 640M and S range and distance as 610M and angular accuracy $3^{cc,}$ 1".

Geodimeter 608M (1997)

(M = Mechanical). A member of the 600 family, this has a detachable keyboard to take to your computer for either up or down loading of data. There is a choice of either alphanumeric or numeric keyboard. An internal memory or PCMCIA card memory can accommodate up to 5000 points. An option is 15 embedded programs covering all applications.

Geodimeter 608S (1997)

(S = Servo). As the 608M, this has a detachable keyboard, optional embedded software and similar memory capacity. As other servo instruments in the 600 series it is upgradeable to Autolock and Robotic.

Geodimeter Bergstrand (1997)

”The World’s Best Total Station” introduced to celebrate the 50th aniversary of Geodimeter. The Model Bergstrand features 10 years warranty, range of 3 500 m to one prism, distance accuracy of ±(1mm+1ppm), angular accuracy of 1" (3^{cc}), internal memory for 10 000 measured points, 15 internal software programs, 4-speed servo drive, Autolock and Robotic functions as standard, 33-key detachable alpha numeric keyboard as standard.

DYNAMIC POSITIONING SYSTEMS

Particularly designed to position and control such items as cranes and other similar objects in linear motion, by use of infrared light beams. This system gives a repeatability of ± 2 mm and has a range of 5500 m. The laser beam is bounced off a reflector usually mounted on the moving object. The phase difference of the reflected wave is measured and converted into a distance. As with the TCS 4000, it has its own PID control system.

Total Control System (TCS) 4000 (1990)

TCS = Total Control System. One of a new series of instruments for use in industrial applications such as surface finishing, and a range of non-contact measuring functions. Positioning is achieved by use of a non-laser infra-red light and measurement by an eye-safe infra-red EDM at a rate of 30 times a second to a resolution of 1 mm. A Proportional Integral Differential (PID) Controller processes all required detection systems, data collection and manipulation. Once the system has ’learnt’ the station locations then all positioning becomes automatic.

AUTO TRACKING SYSTEMS (1996)

Automatic systems for position monitoring, position tracking and machine guidance, based on Geodimeter System 4000 total station concept.

Geodimeter ATS-PM (1996)

(PM = Position monitoring). This is a computer-controlled system for real-time automatic position monitoring, particularly designed for non-contact safety control situations. It is particularly applicable for land slides, dams, open pit mines, oil rigs and bridge monitoring. It has a resolution of 0.1 mm, accuracy of ± (1 mm + 3 ppm) and range of 3200 m.

Geodimeter ATS-PT (1996)

(PT = Position tracking). This total station configuration is designed specifically for automatic, real-time tracking of moving vehicles whether on land or water. As such it is applicable in situations such as dredging, sea bed mapping and construction machinery movement. With a range of 2300 m it tracks a target moving at 4 m/s axially and 27° (30^{g})/s radially.

Geodimeter ATS-MC (1996)

MC = Machine control. This total station is designed for automatic, real-time machine guidance in applications such as: guidance of road construction machinery, pavers, motor grades, bulldozers, etc. Range up to 700 m.

GEODOLITE (1993)

The Geodolite series of instruments were designed to be low cost yet high quality instruments. This was in response to a market requirement for such instruments. The first two models were the 404 and 406 leading to a growing family.

Geodolite 404 (1993)

The angular accuracy is 6" and range 1200 m to a single prism with accuracy of ±(5 mm + 5 ppm). It has the standard Geodimeter options of automatic vertical compensation, zero count down, Tracklight, automatic height location and a wide measuring beam.

Geodolite 406 (1993)

In addition to the features of the Geodolite 404 this model is compatible with the Geodat 500.

Geodolite 504 (1994)

Like some of the Geodimeters, this model has the ability to 'turn' the instrument to zero which is particularly useful in setting out. A vertical axis compensator has a working range of 6´ (10^{c}) to automatically correct all vertical angles before they are displayed. An audible and visual warning indicates if the working range is exceeded. It is compatible with Tracklight and in tracking mode can record 2.5 times per second.

Geodolite 506 (1994)

This model has special applications programs for a range of tasks. To set out, all that is needed is entry of the point number and the Geodolite calculates the necessary data.

Geodolite 506B (1995)

The specifications for this instrument relate closely to the System 500 Geodimeter. It has a range of 2 500 m with 8 prisms with an accuracy of ±(5 mm + 5 ppm). Angular readings have an accuracy of 5" (15^{cc}).

Various System 500 options such as Tracklight, Geodat 500 and a range of software are available.

CONSTRUCTOR

In 1997, the Geodolite range was replaced by a new range of construction total stations called Constructor. Constructor 100 features many of Geodimter System 600 capabilities, such as upgradability, a package of software options, detachable keyboard/memory unit, range 1.500 m with a triple prism and Tracklight option.

GEOTRACER® GPS RECEIVERS

THREE STAGES OF DEVELOPMENT

The Geodimeter grew up using the concept of measuring between various points on or near to the ground surface. Essentially it was solely a distance measuring instrument based on knowledge of the value for velocity of light and measured atmospheric variations. No angle measuring device was incorporated in the early models. So the surveyor, whose business was very much the measurement of both angles and distances had to use two different instruments - the geodimeter and a theodolite. This was essentially the first of the three major steps in the development of the geodimeter although there were also some intermediate, smaller, steps.

1964 saw, in the Model 6, the first transistorised instrument. Then in 1968 the Model 8 was the first laser instrument with a range of some 120 km.

The first total station came in 1971 with the Model 700 and 1972 saw the first equipment for recording measuring data in the field - the Geodat.

Then around 1977 models of Geodimeter, starting with the Model 10, were produced that could be mounted directly on to a theodolite. With this arrangement both the distance measuring part and the theodolite could still be used as separate instruments if so required.

In 1986 Geotronics introduced the first computerised intelligent total station.

The total station concept was a major step in the progression towards the wholly integrated system. This in itself developed from the manual operation of the instrument into servo driven models, starting with the Model 460 in 1990, and the possibility of operation from the target end as a remote system with the 600 Series in 1994, but they were still essentially total stations.

By 1989 the development of accurate units to allow positioning from observations involving orbiting satellites moved the firm into the third phase of its life and into the field of distance measurement and positioning by GPS and introduction of the Geotracer. GPS in itself was not new at this period but Geotronics chose an appropriate time to come into the market when the achievable accuracies were approaching comparability with that of EDM and total station instruments.

GPS eliminates the need for intervisibility between receivers and hence decreases the number of stations required. Not only does this reduce the time required for a task but there is little delay for weather conditions and not even darkness need stop operations. A whole new field of possibilities are opened up as GPS becomes a very powerful tool in the surveyors equipment range.

The most recent development has been the Integrated Surveying system where the total station and GPS speak the same language and hence complement one another.

GPS units require the wherewithal to compute the results and for this there is a **PostProcessing Software** package. This operates in a full graphical environment where the functions are all controlled with a mouse. It is designed to work with data from the various models of Geotracer receivers as well as with data from other makes of receiver. It supports all modes of field operation and has separate modules for Planning, Processing, Adjustment and Transformations.

- The planning module has been designed to minimise the time spent in the field by instantly indicating graphically the best time to observe.
- The Processing module is fully interactive where all data including antenna heights and station names can be checked and edited. Each result is displayed together with its error ellipse and other analyses.
- The Network module applies a least squares adjustment and transforms the coordinates to State Plane, Local or National Grid as required. For 50 stations the adjustment time is about 5 seconds. A range of tests can be applied to the results.

The Transformation module is of seven parameters. A long list of datums and projections is available. One or more points can be held fixed and various weighting options used.

The automatic reduction of geodetic baseline can achieve relative accuracies of ± (5mm + 1 ppm) or better depending on the ephemeris accuracy.

For use at base stations (locations where a GPS unit is set up permanently at a known position) a software package **”GPS Base”** incorporates all requirements. It is Windows™ based.

A later vesion of the Postprocessing Software – **GeoGenius™ –** was introduced 1997. It is Windows™ based software containing all the features of the previous program, but can also be used for processing of GLONASS data.

GPS receiver Geotracer® 100 (1989)

The first GPS system by Geotronics, it is designed primarily for baseline measurement, particularly over longer ranges. It can be used to connect a local grid to the national grid and supply control over large areas.

Geotracer® System 2000 (1995)

As with the Geodimeter instruments, so Geotracer is modular in that it allows upgrading as the need arises and thus provides a tailor made system. It allows setting out, data collection, control mapping and related activities. It can be used in any of the common modes of GPS static, kinematic, Stop & Go, Real time kinematic (RTK) and others. It has the choice of receivers from L1 to L1/L2. All receivers have automatic recording of measurements on a removable PCMCIA card. Besides allowing the transfer of data to a PC this gives the possibility of transfer to a Geodimeter total station, or vice versa - when conditions warrant it. Thus the two totally different approaches to surveying are integrated.

Within the Geotracer System 2000 there are four GPS receivers. To fill the requirement for a powerful Automatic Control Unit (ACU) the Geotracer System 2000 has a hand held MS-DOS based computer with GEOGPS software. The storage capacity in the ACU is equivalent to 100 000 points. The results are displayed both graphically and numerically for efficient setting out and collecting detail.

The software allows working with a number of carrier frequencies and frequency combinations. The fully automatic reduction of base lines make a relative accuracy of ±(5mm+1ppm) or better possible.

Included in the software are programs for network adjustment, variance/covariance matrix analysis and transformations between most datums and projections.

Geotracer 2100 (1994)

An L1 receiver with integral antenna. Its accuracy in the horizontal is
5 mm + 1-2 ppm x baseline length (<10 km) or
5 mm + 1-3 ppm x baseline length (> 10 km)
In the vertical this becomes 10 mm + 2-3 ppm x baseline length. For azimuth it is given as 1 arc second + 5/baseline length in km.

Geotracer 2102 (1995)

Similar specifications to the Model 2100.

Geotracer 2104/Geotracer 2104RTK 8(1996)

Is an L1 receiver which can be upgraded from static to RTK. Similar in specifications to the Model 2100.

Geotracer 2200/Geotracer 2200RTK (1996)

Is a very flexible L1/L2 receiver which can be upgraded from Static to RTK. Its accuracy in the horizontal is given as 5 mm + 1ppm x baseline length. In the vertical it is 10 mm + 1 ppm x baseline length and in azimuth 1 arc second + 5/baseline length in km.

Geotracer 2204 (1997)

It has much better capabilities for performance, interfacing and future upgrading compared to the Geotracer 2200. These include RTCM 2.0 and 2.1 input/output as standard, support of NMEA and other serial outputs which means that the receiver will instantly interface to many third party devices used in navigation. A 5 Hz option for output is also available The 2204 receiver has four serial ports instead of two. Two of the serial ports are 12 pin Hirose which support a hardware handshake at data transfer speeds up to 1152 baud rate. Two are 4 pin Hirose which support standard serial communications similar to the Geotracer 2200.

There are two PCMCIA ports which can be used for two type 2 or one type 3 PCMCIA-ATA cards.

The Geotracer 2204 can be used with an Advanced Control Unit or other PCs which have good quality serial ports. However RTK calculations can be made on the receiver and serially outputted in the standard Geotronics formats RG,RGD,RGV and RGH.

GeoGIS

This system combines the performance of Geotracer 2000 L1 receiver with post processing software. This results in a sub metre DGPS accuracy suitable for GIS, boundary mapping, oil exploration and similar projects. It can be upgraded to a static or kinematic survey system with millimetre accuracy by installing a software upgrade.

The data output can be readily converted to formats such as DXF for CAD applications.

IMS (INDUSTRIAL MEASURING SYSTEMS) (1975)

This is basically a Model 710 interface to a Geodat, and hence a mini-computer, that has been developed for specific use in the steel industry. It enables measures to be taken of the internal profiles of furnaces without shutting down the manufacture.

Of particular importance in furnaces is the fact that the beam diameter at 30 m is only a few mm. Accuracy is ±5 mm radially from the axis of symmetry of the converter. As a result of its use a 10% increase can be expected in the life of furnace linings.

Aside from the uses for which it was specifically designed alternative programs can be supplied for other purposes if the customer requires.

By means of sophisticated optical filtering (very small focal stops reducing the disturbing 'noise' from the hot - 1500°C - walls of the furnace and optical filters with bandwidths of a few tenths of an Å it was possible to get sufficiently strong signals back from the rough surface of the oven walls for measurements to an accuracy of ± 5 mm.

Measurements are normally made from points 10 - 15 m in front of the oven. The position of the instrument relative to the oven is determined by measuring three known points around the circular aperture of the oven. Thereafter points inside the oven are measured and plotted automatically resulting in a profile of the lining.

IMS 1600 (1976)

As with the IMS 1100, this was developed to give an accurate record of the lining wear of furnaces. It utilises natural interruptions to the production stoppages for measurement. The unit is positioned about 10 - 20 m from the mouth of the furnace. The laser beam is aimed by means of a telescope at the area to be studied. The beam is reflected from the furnace lining back to the instrument. The record consists of slope distance, horizontal and vertical angle to the point. Results appear 3 - 10 seconds after start of the measure. Final output can be numeric or graphical.

With this type of unit the working environment is particularly hostile and precautions have to be taken against extreme heat and dust.

IMS 1100 (1983)

This is a unique laser based system for high accuracy measuring and recording of the wear of linings in steel ladle vessels. It was developed from the earlier AGA system for furnace lining control in steel converters and is based on the Geodimeter 700 Total Station. Visual inspection of the amount of lining left is uncertain and often leads to the ladles being taken out of production earlier than necessary. The IMS 1100 can measure exactly how much lining is left after each charge. This it does during the natural pauses in operation.

It operates with a laser beam of two modulated frequencies transmitted to the point being measured. The beam is reflected from that point back to the measuring head where it is demodulated and the position of the point defined as a distance together with horizontal and vertical angle. This can then be converted into the coordinate system of the ladle for comparison with the predetermined safety limit coordinates at each point. Final output can be numeric or as a plot.

IMS 500 Autotracker (1984)

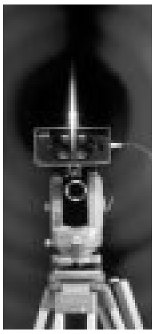
This laser beam instrument automatically measured distance, elevation and bearing of objects up to 5 km distant. To do so only required one shore based station. Had many applications in offshore

IMS 1700 (1988)

This replaces its manually operated predecessor, the Model 1600. Automatic measurement of refractory thickness in steel making to ±5 mm. Automatic in operation, faster measures, a vessel mounted goniometer, and instant presentation of results. It centres around a servo driven laser based instrument which orients itself with the vessel's axis and

Geodimeter 220

Unicom®

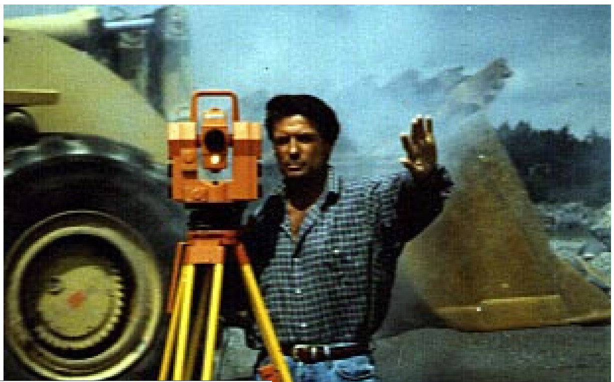


Tracklight®

Geodimeter 220 with Tracklight and a battery

Geodimeter System 400

Geodimeter System 4000 with RPU (Remote Positioning Unit)



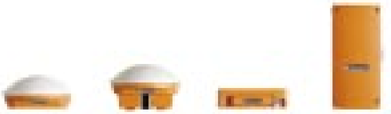
Geodimeter System 500

Geodat 500

Geodimeter System 600, the Card Memory unit and the PCMCIA card for data storage.

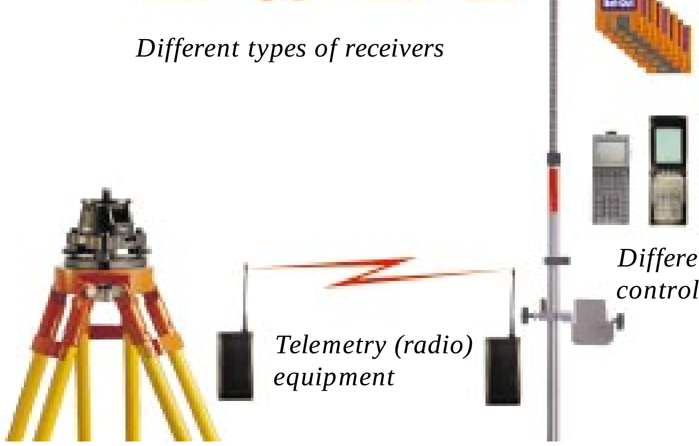
Geotracer® GPS / GLONASS Surveying System

Different types of antennas



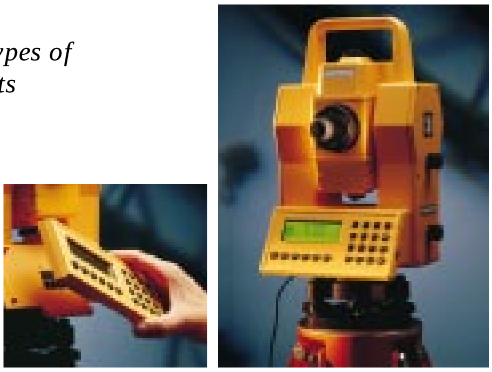
Different types of receivers

Geotracer 2204/2404 receiver



Telemetry (radio) equipment

Different types of control units



Constructor 100 features a detachable keyboard/memory unit.

IS, Integrated Surveying™ – Integration of the two different surveying techniques – the conventional electronic total stations and the new GPS satellite surveying techniques.

then follows a predetermined measurement pattern. Protection against heat is required.

IMS 1700 Turbo (1990)

Improved model of IMS 1700. Built-in computer for data processing.situations tracking the course of shipping, locating underwater pipes and monitoring changes in river deltas.

Accessories / upgrades

Remote Object Elevation (ROE) (1980)

This has been an option from the time of the Models 116, 120 and 122. It is used for setting out or determining heights. From measurement of the instrument height and distance it is possible to calculate the required dH. The theodolite telescope is tilted until the required dH appears on the Geodimeter display. The cross hairs are then at the correct height for the sight rod setting. For heights of existing features, measure the distance to the reflector, point the cross hairs first at the ground level at the object position, then at the top of the object. The sum of the recorded dHs is the required height. Accuracy is dependent on the theodolite but can be ±3 mm at 100 m.

Tracklight® (1981)

From the time of the Model 122 it has been possible to have a visible flashing guidelight built into the carrying handle of the instrument. This makes it easy for the reflector man to position himself. When correctly on line he sees a white light, when he moves off line the colour changes to red or green indicating that he is too far to the right or left.

Unicom® (1981)

Starting with the Geodimeter Models 122 and 140 there has been a built-in one or two way communication system between the instrument and target. Unicom, which superimposes speech on the infra-red measuring beam, allows the instrument operator to give direct instructions to the staffman when setting out a distance or level.

Autolock (1994)

This automatic instrument aiming system unit takes over once the measuring instrument has been roughly aligned and locks on to the reflector and then follows it whether moving or stationary. If contact is lost with the reflector it locks on again by aiming roughly or by activating the integral automatic aiming function. One particular benefit is the time saved in aiming, fine adjustment and focusing. The whole sequence of aiming, measuring and recording takes less than 3 seconds per point. When setting out it works in conjunction with Tracklight and the display at the reflector indicates by how much it needs to be moved to get to the required position.

Tracker Unit (1994)

A system developed initially for the Geodimeter System 600. When aiming within 2.3 m of a target at 100 m range this unit takes over the instrument aiming by utilising the integral servo driven pointing system of the Model 600. An integral part of the Tracker is the Tracklight system.

Remote Processing Unit (RPU) (1992)

This device allows all operations to be carried out at the target end of a line via a unit that attaches to a pole. Access is possible to the menu options that are at the instrument end and the RPU also has an internal memory for some 10 000 points and a built- in telemetry system to provide data communication to the instrument.

Designed initially to go with the Geodimeter System 500, it not only improves the rate at which data can be collected but also with all the control at the RPU the surveyor is in the most advantageous position. The control unit of the RPU can be easily disconnected and taken to the office or elsewhere for processing or editing.

With an internal rechargeable NiCd battery, two way communication and built-in software it weighs only 3.5 kg

RPU 4000 (1990)

Robotic measuring and instrument control for the Geodimeter System 4000.

RPU 4002 (1993)

Designed for use with the Geodimeter System 4000. Instead of the entire system attached to a pole this is now in three modules- the target, control panel and telemetry link. Besides the possibility of attaching these to the pole it is also possible to ’wear ’ the control panel and telemetry link.

RPU 502 (1993)

This version of the RPU allows the telemetry and control unit to be either fastened to a rod or hung around the neck. The prism unit holder is much smaller than in the RPU 500. All survey operations except aiming to the measuring point can be controlled from the RPU. It has a range of up to 2000 m depending on which System 500 Total Station is used.

RPU 600 (1994)

RPU developed for Robotic measuring and instrument control for the Geodimeter System 600.

RMT (Remote Measuremet Target) (1996)

RMT works in a similar way as the RPU, i.e. the instrument, working in Robotic mode, locates the target automatically. RMT ”Super” introduced late 1996, is equipped with an omnidirectional reflector, so it is no longer necessary to keep the RMT reflector directed towards the instrument while moving from point to point during measurements.

The instrument receives the signal from the reflector irrespective of the angle at which it is facing.

Telemetric link (radio) for Geodimeter 600 (1994)

The operational commands and the data communication between the instrument and the RPU/RMT are carried out via a radio (telemetry) equipment. The radio is built into the instrument side cover. An external radio equipment is used at the RPU/RMT unit. The range of this telemetric link is approx. 1 600 m, depending on site conditions.

Internal Memory (Imem) 400 (1987)

Imem 400 provides the same facilities as the Geodat 400 but with a memory capacity around 900 points, which is suitable for most daily detailing tasks. It can be fitted to any System 400 instruments. It can even be used in conjunction with the Geodat 400 to give an extended memory of about 2400 points.

User Definable Sequences (UDS) 400 (1987)

This allows the user to program up to 20 measurement and recording sequences. With all operations controlled from the instrument keyboard it allows ready use of the external data loggers such as Geodat 126 and 400. It can be used with all System 400 instruments.

Other software packages

Numerous software packages are available for use with the Geodimeter instruments. These include:

- **Area/Vol/Calc-C**alculation of areas and volumes.
- **AngleMeas -** for measuring multiple rounds of angles and automatic calculation of corrected angle measurement values
- **AngleMeasPlus** - an improved version of AngleMeas
- **AreaVolCalc** - calculates area and volume between points that have been measured
- **COGO** - a program package for field calculations of all common surveying tasks
- **DistOb** - for the distance between two objects
- **Edit** - combines with View 400 to enable users to search for, retrieve, check and edit stored data.
- **FS-Set Out** - 3 D setting out and automatic checking plus two point resection.
- **Geodos** - caters for all aspects of setting out, checking and computations.
- **GeoGenius -** a GPS data processing package
- **GeoTool** - a Windows™ based software package that simplifies communication between Geodimeter or Geotracer instruments and a third party PC-software
- **GeoTool Plus -** an improved version of GeoTool
- **MCF** - Moving Coordinates Forward.
- **Obstructed point** - measurement of obscured points
- **Pcode** - allows the unambiguous definition of point codes.
- **RefLine** - helps in the setting out of baseline related detail.
- **RoadLine** - allows the storage, checking and setting out of roadlines without the need for complicated calculations.
- **RoadLine 3D** - an improved version of RoadLine with possibility of 3D-setting out of road lines
- **SetOut** - offers a rapid and sophisticated system for setting out in three dimensions.
- **View** - enhances the security in measurement and recording of data.
- **Z/Ih** - gives either the reduced level of the instrument station or height of collimation.
- **Z/IZ** - gives the absolute elevation of the instrument

Some Geotronics´ subsidiaries produce their own software packages. For example, the following items are from the UK.

- **Geosite 500** - calculation, communication, plotting and print out.
- **Landscape** - Fully integrated modular land survey and engineering package.
- **Laser 3D** - non-contact measurement
- **Map 400** - Calculation, listing and plotting of coordinates

DATA STORING / RECORDING UNITS

Geodat®

This electronic data recording device enhancing the potential of the Geodimeter range of instruments was introduced in 1980. It can be used manually as a hand held field book or automatically to accept data directly from Models 112, 120, 122, 140, 710 and successive versions

Early models had only a 17 hour retention time for the data but the later models can retain the information for 2000 hours. The capacity is up to 1000 measured points or 32K characters.

The operator is guided through the entry routine with a series of prompts which appear in sequence in the display. The sequence can be varied to suit specific field applications. Full search and editing facilities are available.

Early versions of the Geodat were equipped with LED display, later models with liquid crystal.

The data can be off loaded:

- directly to a printer
- to computer or desk top calculator
- by use of modem to access a remote computer
- to cassette recorder ready for mailing
- to a separate memory unit

These have the advantage of error free transfer and in addition using programmable sequences within the Geodat it is possible to tailor its operation to your own requirements.

Geodat® 122, Geodat® 124, Geodat® 126

The facilities of the Model 124 are enhanced by the computing power of a Hewlett Packard HP41 series programmable calculator. This effectively gives the surveyor a field computer. Customised software allow the transfer of information to and from the Geodimeter or storing the data in a built-in memory module.

With the Roadline program the Geodat 126 can not only collect data but also provide setting out values in relation to pre-determined coordinates.

Geodat® 400, Geodat® 402

This third generation of recording unit has a capacity of about 1500 points. It has no keyboard or display. All recording is via the Geodimeter keyboard. Its memory is structured so that data can be stored in a virtually unlimited number of files that are automatically adjusted in size.

Geodat® 500

This external memory unit connects by cable to the Geodimeter instrument. It has neither keyboard nor display as all commands are entered via the keyboard on the measuring unit. When disconnected, data can be stored for up to 2000 hours (3 months). Its storage capacity is the data for 3000 points and transfer to a computer is via an RS 232C interface. There is two way data communication with the Geodimeters Model 400, 500 and 4000.

Geodimeter Card Memory

This external memory unit has been designed specifically for the Geodimeter System 600. It records and stores measurement results and coordinates on a PCMCIA card. It can be either attached to the keyboard of the instrument or placed on a tripod leg. With a 6.0 Mb memory capacity it can store approximately 250 000 surveyed points. A standard cable allows connection to any external computer for data transfer. The Card Memory unit weighs only 0.325 kg.

Chronology

1947	Prototype
1953	Model 1
1955	Model 2
1956	Model 3
1958	Model 2A, Model 4
1960	Model 4B
1963	Model 4D
1964	Model 6
1967	Model 6A
1968	Model 8
1969	Model 7T, Model 6B
1971	Model 700
1972	Model 76
1973	Model 6BL
1974	Model 710
1975	Model 12, Industrial Measuring System (IMS)
1976	Model 78, IMS 1600
1977	Model 10, Model 12A, Model 14, Model 600
1978	Model 120
1979	Model 14A, Model 110, Model 112, Model 114, Model 116, IMS 1000
1980	Remote Object Elevation (ROE), Geodat
1981	Model 122, Model 140, Tracklight, Unicom
1983	Model 136, IMS 1100
1984	Model 134, Model 142, Model 220, IMS 500
1985	Model 140H, Model 210, Model 216, Model 600
1986	Model 140S, System 400, Model 440
1987	Model 140SMS, Model 140T, Model 420, Model 6000, Internal Memory 400, User Definable Sequences (UDS) 400
1988	Model 140SR, Model 410, IMS 1700
1989	Model 400CD, Model 400CDS, Model 408, Model 412, Model 420LR, Model 422, Model 422LR, Model 440LR, Geotracer 100
1990	Model 424, Model 444, Model 460, System 4000, Model 4400, IMS 1700 Turbo, Dynamic Positioning System, Remote Processing Unit (RPU) 4000, TCS 4000
1991	Model 464
1992	Model 468DR, System 500, Model 510, Model 520, Model 540, RPU 500
1993	Geodolite 404, Geodolite 406, RPU 502, RPU 4002
1994	Geodimeter System 600, Model 610, Model 620, Model 640, Autolock, Tracker Geodolite 504, Geodolite 506, Geotracer 2100, RPU 600, Telemetric link
1995	Geodolite 506B, Geotracer System 2102,
1996	Geotracer 2104/2104 RTK, Geotracer 2200/2200 RTK, ATS-PM, ATS-PT, ATS-MC, RMT
1997	Model 608M&S, Model 610M&S, Model 620M&S, Model 640M&S Model Bergstrand, Geotracer 2204/2404, Constructor