PAPER No. 10.

REVIEW OF RECENT DEVELOPMENTS IN ELECTRONIC DISTANCE MEASURING APPARATUS

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SUMMARY. This paper describes some of the sources of error in EDM equipment in order that a proper appraisal may be made of recent developments.

1. INTRODUCTION.

AGA Geodimeter Model 2 was introduced in the early 1950's for the measurement of base-lines and sides of first-order triangulation. This model was soon followed by an improved Model 2A which has been for one and a half decades the most precise equipment for distance measurement. The Model 2A weighs 91 kg; instrument cases, generator etc. bring the total weight to about 150 kg. The range is up to 50 kilometres, but measurements are confined to night-time.

Since that time the trend in electro-optical distance measurement has been to lighten the equipment and to increase the daylight range.

The MRA1 Tellurometer became available towards the end of 1956 and was an immediate success. More portable than the Model 2 Geodimeter, it possessed the further advantage of being able to work in daylight. Range was generally more than adequate. In 1960 the transistorised MRA2 was developed; master and remote stations were made interchangeable, the external power-pack eliminated and the newer model weighed only 13 kg plus battery and tripod.

There were problems however. The refractive index for microwaves can not be determined as accurately as the refractive index for visible light. Secondly the results of measurements were sometimes vitiated by large 'ground swing' errors caused by rays from master or remote reaching the other instrument after reflection from the ground. Thirdly, uncertainty frequently arose in the determination of the zero error of instruments.

Theories of ground swing were developed and, more important, the carrier wavelength was reduced from 10cm to 3cm with a consequent reduction in the ground-swing normally met. A further reduction in ground-swing can now be achieved by reducing the carrier wavelength to 8mm, but unfortunately this reduction in wavelength is only achieved (in 1968) at about 2½ times the cost of the 3cm equipment.

Quite often ground-swing effects are masked; and the whole of the apparent swing-curve is systematically in error. On other occasions it may be more appropriate to vary the height of the instrument than to vary the carrier frequency. In any event, it is very necessary to determine what are the errors actually present in electronic distance measurement in order to fully appreciate the value of new developments in instrumentation.

2. ERRORS IN PHASE MEASUREMENT.

There are a number of reasons why the observed difference in phase between transmitted and received modulations is not equal to the theoretical difference:-

(i) The observed signal is the resultant of the signal which has travelled directly between master and remote instruments and other signals which have undergone reflections. The errors introduced by these reflections will be called Poder errors or ground-swing errors.

(ii) Variation of carrier frequency, in an attempt to eliminate the effect of Poder errors, can of itself produce a change in indicated phase whether ground-swing is occurring or not. This type of error is called antenna or system swing.

(iii) Contamination between the transmitted and received signals inside the master instrument can give rise to errors in the phase comparison. This type of error is referred to as cyclic zero error.

2.1 Poder Errors. Poder has shown that the phase error which results from a single ground reflection with an excess path-length Δ over the direct path is $(X_m + X_r)/2$ (PODER and ANDERSEN, 1965), where

$$\tan X_m = \frac{A_m \sin Z}{1-A_m(1-\cos Z)}$$

$$A_m = \frac{a(\cos z_m + a)}{1+2a \cos z_m + a^2}$$

$z_m = w_Q + r$

= master carrier phase in the excess path Δ = Qc

c = velocity of propagation

Z = WQ

= modulation phase in Δ

w = $2\pi f$

= angular frequency of master carrier

W = angular frequency of modulation

a = ratio of amplitude of the reflected wave to the direct wave

r = phase change of carrier on reflection.

X_r and A_r are similarly defined in terms of the remote carrier phase z_r which differs from z_m because of the carrier frequency offset, usually equal to the intermediate frequency.

It may be readily seen that for $z_m = 2n\pi$ or $(2n+1)\pi$ $(n=0, 1, 2....)$ A_m takes on extreme values of $a/(1+a)$ or $-a/(1-a)$, while $\tan X_m$ becomes

$$\frac{a \sin Z}{1 + a \cos Z} \quad \text{or} \quad \frac{-a \sin Z}{1 - a \cos Z}$$

respectively; $\tan X_r$ behaves similarly. Thus a change in the carrier frequency produces a cyclic change in the phase error $(X_m + X_r)/2$ and hence the well-established practice of plotting a 'swing-curve' of distance indication against 'cavity' (i.e. carrier frequency).

2.2 Amplitude of the Swing Curve. The magnitude of the swing measured on a given line is proportional to a, the ratio of the received amplitudes of the reflected and direct waves, and hence depends on the shape of the polar diagram of the antenna and on the reflection coefficient of the ground.

The half-power beam width of an antenna system is approximately given by

$$\frac{\lambda}{L} . 50^{o}$$

where λ is the carrier wavelength and L is the dimension of the dish. (JORDAN-EGGERT-KNEISSL, 1966, Vol. VI) It follows that decreasing the carrier wave-length from 10cm to 3cm to 8mm reduces the beam width from 17 to 5 to about 1½ degrees for a 30cm dish. Hence surfaces a few degrees from the direct path may produce strong reflections with a 10cm carrier but will be effectively out-side the beam of a 8mm carrier-wave.

Furthermore, if a surface is to produce specular reflection, the size of surface undulations must be small compared with the wavelength of the radiation and hence even if a surface is within the (narrower) beam, the coefficient of reflection will be much smaller for smaller carrier wavelengths.

The effect of both factors acting together is to reduce the average ground swing by a factor of about 10 when the carrier wavelength is reduced from 10cm to 8mm.

2.3 Incomplete Swing Curves. The number of cycles q of the swing curve generated by changing the carrier frequency from f to f+df is given (KUPFER, 1967) by

$$q = \frac{df\,\Delta}{c}$$

It should be noted that q does not depend on the value of the carrier frequency, but merely on the change in frequency. It follows from the formula that for a complete cycle of swing to be developed, the excess path Δ must be greater than

$$\Delta_{min} = \frac{c}{df} .$$

Precise values of df are not readily available in the literature and vary a little from klystron to klystron; generally the range of carrier frequencies is given and this includes the carrier frequency offset between master and remote. Here we are concerned with the range over which the master frequency can be tuned - i.e. the total frequency range less the intermediate frequency IF. In Table I it has been assumed that the frequencies quoted are total ranges and allowance has been made for IF in calculating values of Δ_{min}.

TABLE I.

Minimum excess path for development of full ground swing cycle

Instrument	Carrier frequency MHz	IF MHz	df MHz	Δ_{min} metres
MRA 2	2800 3200	33	367	0.8
MOM	2750 3150			0.8
MRA3	10025 10450	33		0.8
Wild DI50	10197.5 10485	37.5	250	1.2
Electrotape	10000 10500	46.5		0.7
Distameter III	10000 10500	49.5		0.7
OG-2	8800 9700			0.4
MRA4	34500 35100	46.5		0.5
Distameter 8	33400 35000			0.2

The average value of Δ_{min} for most of the instruments is about 3/4 of a metre, and hence the height at which instruments must be set above a level surface if it is desired to develop one full cycle of swing is about 6 metres for a distance of 100 metres, and 19 metres for a distance of 1 kilometre. It is assumed here that the beam width of the instrument is sufficiently large so that enough radiation reaches the reflecting surface to produce a significant ground swing; if the amount of radiation reaching the surface is negligible, then ground swing is, of course, no problem for that line.

The important fact, however, is that the full cycle of the Poder error can <u>not</u> be developed over short distances at normal instrument heights.

Consider a level line of 150 metres, measured with both instruments at a height of 1.5 metres. The excess path is 3cm and assume that the carrier phase changes by 180 degrees on reflection from the surface. If the carrier frequency is 3cm approximately, the Poder errors will cover only about 1/25 of a full swing cycle when the carrier frequency is varied from 10025 to 10417 MHz at the master and 10058 to 10450 at the remote station. If five evenly-spaced readings were taken over the cavity range for a = 0.8 the Poder errors would be -12, -10, -8, -5, and -4cm; all are larger than the excess path, all are of the same sign and any attempt at interpreting a swing curve of this type would be dangerous. If a is reduced to 0.3 the Poder errors remain constant at about -1.2cm over the whole cavity range.

2.4 Height Swing. Cabion has suggested that when the excess path is short, a half-cycle of swing should be developed by changing the height of the instrument (CABION, 1965); Kupfer goes further and recommends that a full cycle of swing be developed by increasing the heights of the instruments in steps, and gives results of a very thorough determination of zero error of a pair of Wild DI50 Distomats by this method (KUPFER, 1967).

It should be noted that if it is desired to develop height swing curves, the separation of the antenna from the control-unit as in the Wild-Albiswerk Distomat and the MOM GET A/Varydist is almost essential. Kupfer has shown that for a given line there are critical heights which should be avoided. These heights are those for which the carrier phase z in the excess path is an odd multiple of 180 degrees. Under these circumstances the Poder error will be negative and perhaps far larger than the excess path for small excess path distances.

2.5 Antenna or System Swing. The phase difference between transmitted and received signals may change systematically as the carrier frequency is altered for reasons other than ground reflections. Yaskowich reports a systematic variation of distance for a pair of MRA3's when one particular instrument was used as master (YASKOWICH, 1965). It does not represent true ground swing but rather a klystron characteristic in which is involved a critical alignment of the tracking between klystron frequency and power output in the cavity tune control.

Cabion states that internal reflections from the antenna and radomes can lead to multiple paths from the local oscillator to the mixer diode (CABION, 1965). The result is antenna swing.

If Poder errors were corrected for, the residual variation would be antenna swing which should thus equal the mean of a large number of ground-swing curves.

2.6 Cyclic Zero Error. Contamination between the received and transmitted (or reference) signals can give rise to a cyclic zero error, not only with microwave instruments but also with electro-optical instruments which do not use a variable light-conductor to measure phase difference. Thus Geodimeter Models 4, 6, 7 and 8 which use an electrical delay-line and a null-setting discriminator to measure phase difference, are provided with calibration curves. Non-linearity in the delay-line itself and eccentricity of rotating components can accentuate the cyclic errors. The delay-line characteristic may change with time and hence the manufacturer's calibration should be checked at intervals. An example of a Geodimeter correction curve is given in (SAASTAMOINEN, 1967). The Carl Zeiss Jena EOS uses a phase resolver incorporating a rotor and a stator similar to those used in MRA3 mark II, MRA 4 and MA100 Tellurometers and the DM20 Electrotape. The manufacturers give a goniometer correction curve for each EOS, but for most precise work a separate calibration is advisable for each of the four frequencies (DELONG, 1968).

In the Model 2A Geodimeter a variable light-path is used to calibrate readings of the delay-line in the field and hence eliminate the effect of any cyclic zero error, while in the Mekometer 'phase measurement' is replaced by the equivalent process of changing the measured light-path until no phase difference exists between received and reference signals and so the question of cyclic zero error can not arise (FROOME and BRADSELL, 1965). With the exception of instruments of this type where cyclic zero error is excluded on theoretical grounds, contamination of signals can be generally expected to cause some form of cyclic error. This error may be reduced to negligible proportions by good design and by attention to multiple screening and decoupling (TELLUROMETER, 1968).

It is possible that the cyclic zero error will vary somewhat with the intensity of received signals.

A number of investigations have been made into Tellurometer zero errors (YASKOWICH, 1965; BOSSLER and LAURILA, 1965). (See also Robinson, Paper No. 14)

3. INSTRUMENTS FOR SHORT RANGE MEASUREMENTS.

It has been shown that account must be taken of a number of possible errors before microwave equipment with 3 cm carrier-wave can be seriously considered for measurement of short distances. There is no doubt that available equipment can be used successfully if due account is taken of the error theory, but generally the care required is too great for economical work.

The high cost of the MRA4 Tellurometer would preclude its use for normal short range work.

The current electro-optical systems (Model 4 and Model 6 Geodimeter, Zeiss EOS) are sufficiently precise for measurement of short distances of the order of 100 to 200 metres, but the observation and reduction time required is perhaps rather high and, in the case of the EOS, the instrument is too cumbersome to be considered for such a short length. The Mekometer has more than sufficient precision and can be operated quickly but unfortunately is not commercially available.

To fill this short-range field AGA has developed a Model 7T Geodimeter which combines the tasks of angle measurement with distance measurements of up to 500 metres with a precision of ±1cm.

A rather different approach has been the development of EDM equipment based on the use of a gallium arsenide diode as a source of modulated infra-red light. Four different instruments are available (HOLSCHER, 1965; LEITZ and BORNEFELD, 1968): while all use the same principle, the designs are refreshingly different as regards range, precision, method of reading and cost. The Tellurometer MA100 uses the highest modulation frequency of 75 MHz; at this frequency a phase resolver allows reading to 1 mm and a precision of a few mm. It should be noted that fluctuations in phase between the voltage across the diode and the emitted signal made it necessary to introduce a reference light-path between diode and photo multiplier to give an accurate phase reference.

The modulation frequencies used by Wild-Sercel in their Distomat DI10 and by Carl Zeiss (West Germany) in their SM11 are about 15 MHz and both designs incorporate automatic systems which average a large number of phase measurements and give a digital reading of distance in about 20 seconds. This averaging process takes account of the fluctuations in phase between the diode voltage and the emitted radiation. Wild have separated the aiming and the control units, while Zeiss allow for the use of a punched tape output if desired. The performance of the Zeiss frequency is 3cm approximately, the Poder errors will cover only about 1/25 of a full swing cycle when the carrier frequency is varied from 10025 to 10417 MHz at the master and 10058 to 10450 at the remote station. If five evenly-spaced readings were taken over the cavity range for a = 0.8 the Poder errors would be -12, -10, -8, -5, and -4cm; all are larger than the excess path, all are of the same sign and any attempt at interpreting a swing curve of this type would be dangerous. If a is reduced to 0.3 the Poder errors remain constant at about -1.2cm over the whole cavity range.

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Carl Zeiss Jena (East Germany) have produced an EOK 2000 with a frequency of 30 MHz. Readings are digital and partly automatic; range is 2000 metres and precision is ±1cm. The transmitter/receiver optics are used as a 'search light' projector and telescope for visible light when searching for the reflector. Details of design are not available at present.

It should be noted that the infra-red radiation has a wavelength of less than 1 micron; ground swing effects do not occur, nor is the refractive index of the atmosphere strongly affected by humidity for infra-red waves.

TABLE II.

Characteristics of short range instruments.

	Tellurometer MA100	Wild DI10	Zeiss SM11	Zeiss EOK
Daylight range metres	3000	1000	2000	2000
Resolution mm	1	10	1	
Precision	±5mm ±2ppm	±1 to 2cm	±1cm	±1cm
Power Consumption W	14 peak	10	18	8
Radiated Power mW	6	1.2	10	
Modulation frequency MHz	75	15	15	30
Weight Kg	16	7 & 13	12	12
Dimensions cm	33x33x51	17x26x29 33x19x36		30x35x29
Tilt range		±40°	±45°	±40°
Temperature Range °C	-20 to +55	-25 to +50		-30 to +45

4. INSTRUMENTS FOR PRECISE MEASUREMENTS.

Instruments for precise measurements would include the 8mm microwave equipment MRA4 and the Ertel-Grundig Distameter 8 provided that due account was taken of possible unresolved ground swing and provided that the refractive index of the air could be adequately assessed.

Amongst the electro optical equipment suitable for medium to long range applications is the AGA Model 8 laser Geodimeter. This instrument was developed by AGA after experiments in the U.S. had shown that a Model 4 could be successfully converted for use with a laser source (C.S.M., 1965; SMATHERS et al, 1965). An 8 mile line was successfully measured using a 0.5 mW laser. In the commercial model, the Kerr cell has been replaced by a crystal modulator, presumably KDP, with far less light loss than the Kerr cell, and the laser power has been increased to 5mW. The very narrow bandwidth of the laser allows the use of very narrow band filters to remove unwanted stray light and hence the daylight range approaches that obtainable at night. Instrument weight is reasonable at 20Kg, for a range of 50 to 60 Km.

Spectra Physics have also produced a laser distance measuring instrument, the Geodolite. Ranges of greater than 50 miles at night or 20 miles in full sunlight are obtained from a 25mW CW laser source which is modulated by means of a KDP crystal. A terrain-profiling variant can be used up to altitudes of 15,000 feet in full sunlight. Output can be varied to suit requirements and ranges from determination of velocity or acceleration of moving bodies to a digital output of distance. Weight is high at 45 Kg for the telescope assembly, 18 Kg for the control unit and 15 Kg for digital read out, but it should be rembered that for distances of up to a few miles it is not necessary to have a reflector at the remote station. The Geodolite is a very expensive instrument.

The Zeiss EOS also seems very promising for precise measurements. At present the daylight range with an incandescant lamp is 10 km in daylight, but reports of measurements with a prototype mercury vapour lamp indicate that the range can be increased significantly. The instrument is large and heavy, mainly because large astronomical systems have been used for the transmitter and receiver optics. An ultra-sonic cell is used as modulator; while the transmission factor of the modulator is very high, the phase of the applied voltage is not closely related to the phase of the transmitted light and hence a reference light path and a second photomultiplier is required to give a reference phase-position. These requirements increase the weight of the system, but probably contribute to the steadiness of reading the instrument.

5. ASSESSMENTS OF ACCURACY.

It is very difficult to assess reliably the accuracy of EDM equipment. The best method is, of course, to measure base-lines whose lengths are known very precisely. Such lines are however generally short and there are not enough of them to obtain a reliable estimate of accuracy, nor do they offer sufficiently varied terrain. Hence it has become the practice to measure a network of lines and then to adjust this net by least squares. A very elaborate set of measurements, including angle measurements, were made on the Graz test net (JORDAN-EGGERT-KNEISSL, 1966, VOL. VI; RINNER, 1968). One of the problems involved was to assess weights of distances and angle in the adjustment. Many different combinations of weights were tried and that set which gave the highest precision of point coordinates etc. was adjudged the best. In another analysis the most probable value of the apparent zero errors and frequency differences between the results of a NASM 4D Geodimeter and other EDM instruments were computed.

For present purposes it is more useful to calculate the variance of the observed difference between the Model 4D Geodimeter measurements and measurements with other equipment, after allowing for zero error and frequency difference. Measurements were also available for a Model 4B Geodimeter, and assuming these to be as precise as those of the Model 4D, it was possible to finally deduce variance estimates for each of the instruments used on the test net as tabulated below. Sides of the net varied from 1.3 to 18 km with an average value of about 10 km. Degrees of freedom were generally 25.

TABLE III.

Comparison of Variances for E.D.M. Instruments.

Instrument	Mean Error (mm)
Geodimeter NASM4	15
Tellurometer MRA4	33
Tellurometer MRA3	52
Wild Distomat DI50	46
Ertel Distameter	48
Electrotape (1962)	27
Electrotape (1963)	55
Tellurometer MRA2	42
Tellurometer MRA1 (1962)	48
Tellurometer MRA1 (1963)	52

A matter of some concern is the fact that some writers wrongly assess the degrees of freedom in a free net adjustment. Thus Hall assesses the MRA4 as having a standard deviation of ±1.4mm from a net with 9 lines and 5 points (HALL, 1967). The degrees of freedom are obviously 2, not 8, and this gives a mean error of ± 2.7mm - with ±5% limits of 1.5 to 11.9! For distances of 2 to 9km even the upper limit is excellent but one loses faith in claims that are not soundly based.

In a slightly different fashion Webley merely tabulates errors obtained from a free adjustment of 10 lines on 5 stations - thus giving 3 degrees of freedom (WEBLEY, 1965). The standard deviation estimate - for a MRA101 over lines of 3½ to 8km - may be calculated as ±6cm. This is larger than any of the 10 'errors', and very much larger than the value claimed of ±2.5cm ±4ppm two pages on. The test does not disprove the claimed accuracy - because with 3 degrees of freedom little can be either proved or disproved.

It is unfortunate that little information is available at this stage on the precision of the Zeiss Jena EOS. Tests on a Munich net gave a mean error of ±1.5 cm for sides of 3 to 15km as a result of a free adjustment with 7 degrees of freedom. (SIGL and DEICHL, 1967) Allowing for the fact that heights were uncertain and that some lines were steep, these results are very good. On the same net a MRA101 Tellurometer used in conjunction with a MRA3 gave a mean error of ±6.6cm.

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PAPER No. 11.

N. P. L. MEKOMETER III.

K.D. Froome and R.H. Bradsell.

1. INTRODUCTION.

The N.P.L. Mekometer III is basically very similar in method of operation to the Mekometer II already described elsewhere. (FROOME and BRADSELL, 1966) The measuring process consists of determining the phase of modulated light returned from a reflector (placed at one end of the line to be measured) back to the instrument. Elliptical polarisation modulation is used so that linear electro-optic crystals of the ADP or KDP type may be used for both modulation and de-modulation. In order to be suitable for the measurement of large nuclear machines, the resolution has been improved to be approximately 0.0003 ft. (0.1 mm) under good conditions at distances up to 3 000 ft. (1 km). The maximum expected range is 10000 ft. (3 km). Nevertheless, the principal objective remains to produce a very simple measuring instrument for commercial exploitation. The volume and weight of Mekometer III is one-half that of the predecessor. The instrument and power unit each weigh 5.5 kg (12 lbs.)

Other significant changes include the use of two (or possibly four) potassium dihydrogen phosphate (KDP) crystals. This dual system eliminates scattering from the transmitted light beam into the receiving photodetector. The distance required is obtained on a simple decimal read-out system requiring no computations.

2. THE APPARATUS.

Fig. 11.1 shows a diagram of the new arrangement. The KDP crystals are arranged at the high impedance end of a quarter-wave coaxial cavity resonator. The optic axes (Z axes) of the crystals are parallel to the electric field in the cavity. This modulating cavity is excited into strong oscillations at frequencies near to 500 MHz for a duration of 40 μs by pulsing the ceramic discseal triode valve shown. It develops several thousand volts of modulating field across each crystal.

Fig. 11.2 illustrates the optical layout in greater detail. Light from a xenon flash-tube is first plane-polarized and then passed through a KDP crystal from which it emerges elliptically polarized at the modulation frequency. This beam is imaged down by a short focal length lens at the focus of the main 60 mm

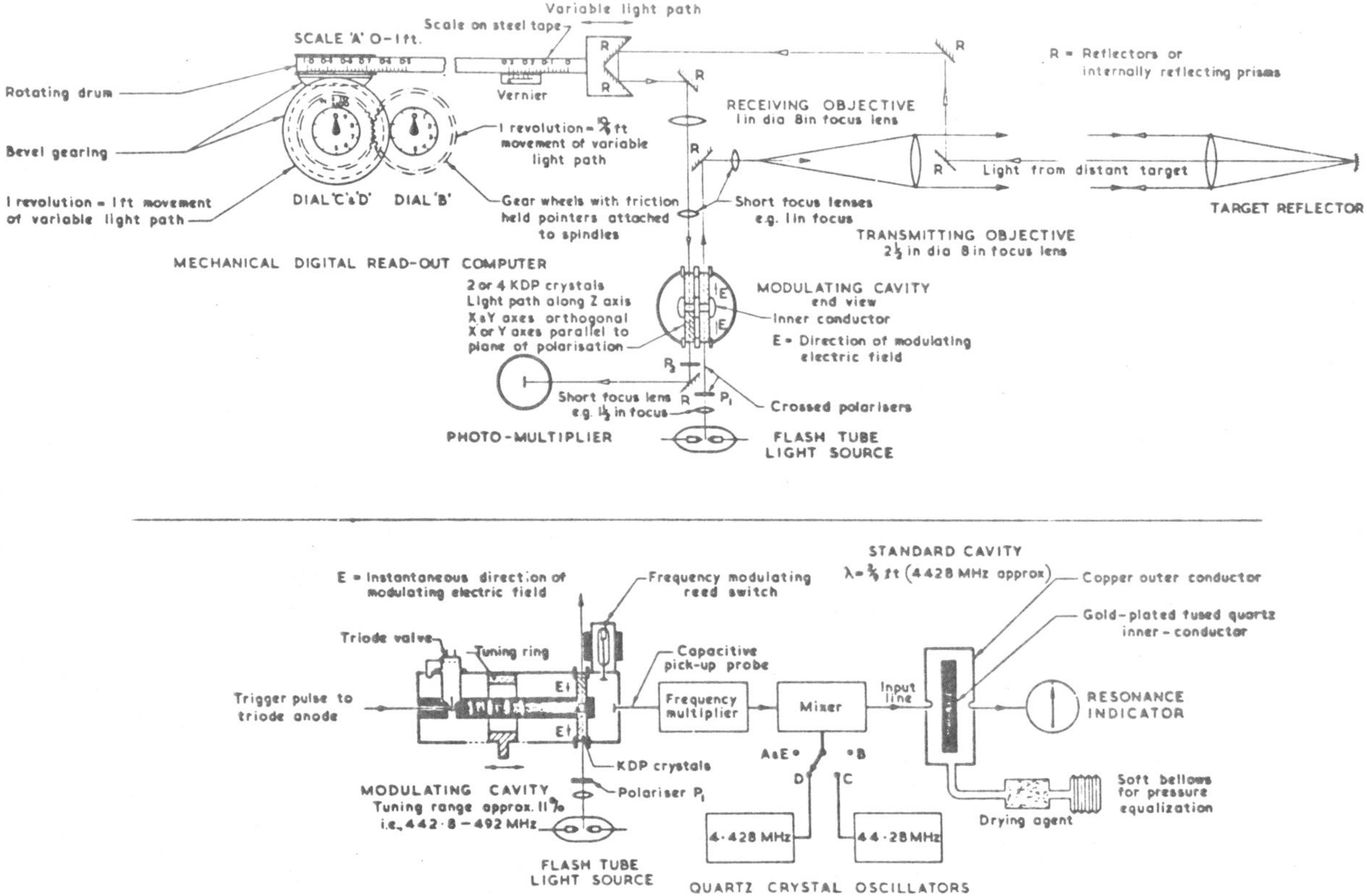

FIG. 11.1

NPL MEKOMETER III

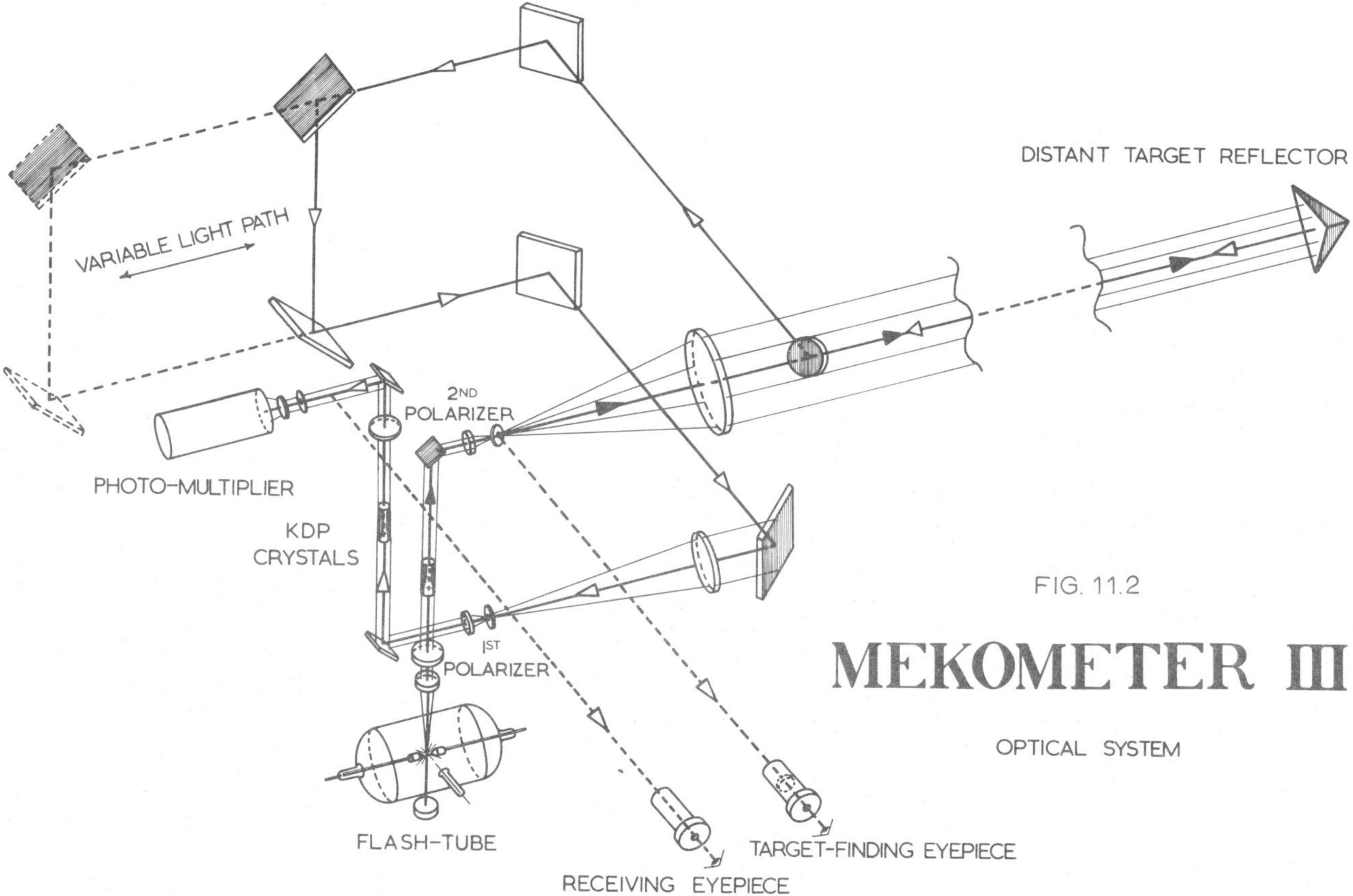

FIG. 11.2

MEKOMETER III

OPTICAL SYSTEM

diameter objective, thereby transmitting a beam about 1 milliradian (3½ minutes) in divergence.

The reflector, placed at the far end of the line to be measured, may be of either the "cat's eye" or cube-corner type. At the instrument returned light is deflected sideways by a plane mirror placed in front of the main objective, into the variable light-path shown. After traversing this phase-shifter, the returned light is passed through the second KDP crystal and thence to the photomultiplier. Between this second KDP crystal and the photodetector is a second polarizer crossed relative to the first. Thus the intensity of light reaching the photomultiplier is a measure of the degree of ellipticity of polarization left after passage through the KDP crystal and this, in turn, depends upon the modulation phase of the light from the distant reflector.

The position of the movable element of the variable light path is accurately and directly measured by a graduated steel tape running over a drum geared to the read-out dials. These dials are used only for obtaining the integer number of modulation half-waves in the required distance, the excess fraction being obtained from the tape. For a measurement, the variable path is first adjusted to a minimum of the photodetector output as indicated on the phase-meter. Once this position has been approximately located, accurate positioning is achieved by an FM switch which introduces a small symmetrical deviation of the modulating frequency between alternate pulses of light and operates the detector synchronously so that the minimum now appears on the phasemeter as a centre-zero null.

The effect of atmospheric refractive index is eliminated* in substantially the same manner as for the Mekometer II. The modulation wavelength is determined from the resonance of a cavity resonator filled with dry air at the ambient atmospheric pressure and aspirated externally so as to acquire quickly the prevailing temperature. A single small fixed resonator is used,operating at nine times the fundamental modulating frequency (4.4GHz). This is a coaxial-line resonator entirely constructed of plated fused quartz.

The nine-times multiplier can also be arranged to multiply by ten times, so that in this case the modulating frequency has a value of nine-tenths the fundamental value and this value is used to obtain the 0-10 ft. intervals. The 0-100 ft. and 0-1000 ft. intervals are obtained by amplitude-modulating the multiplier (when in the x9 position) by quartz crystal derived frequencies which are 1% and 0.1% respectively of the fundamental. The modulating frequency is adjusted lower first by one and then by the other of these fractions so that the fixed standard cavity sees the upper sidebands caused by this amplitude modulation of the multiplier. Quartz crystal oscillators without temperature control are adequate for the production of these sidebands. Resonance of the standard cavity is displayed on the cavity meter in the same manner as the phase-meter. The modulating cavity has a coarse and fine tuner consisting of an inner sliding cylinder producing up to 11% frequency shift.

The instrument can be mounted either on a standard theodolite tripod fitted with a centering base and optical plummet or removed from this for use on concrete survey pillars. Two eyepieces are provided for ease of setting-up. One views the area surrounding the target, the other shows the target illuminated by light from the transmitter. An elevation scale is provided which reads directly the slope to horizontal correction in parts per million, for deviations up to $\pm 3^{\circ}$. A general view of the instrument is given in Fig. 11.3.

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* It will not be eliminated entirely unless atmospheric conditions along the measured line correspond exactly to conditions within the cavity resonator. Ed.

3. EXPERIMENTAL PROCEDURE.

The observer makes the measurement as follows:-

After having positioned the instrument and reflector, he sets the modulating cavity to produce the fundamental standard modulation wavelength, (i.e. with the standard cavity frequency nine times this modulation frequency) and sets the variable light path for a detector minimum in the manner already described. The fraction of a foot in the required distance is then read off from the steel tape measure estimating (if required) to 0.0001 ft. The pointers of the two read-out dials are then set to zero and the modulation frequency reduced to be one-tenth that of the standard cavity. The variable light path is again adjusted and the 0-10 ft. rounding dial (B on Fig. 11.1) read to the nearest whole number and entered on the "unit" box on the data reduction sheet, Fig. 11.4 With the modulation wavelength set respectively 1% and 0.1% longer than the fundamental value (2 ft.) two more settings of the variable light path are made and the corresponding readings of the other read-out (C and D) dial drawn in as radial lines in the "tens" and "hundreds" boxes respectively.

If the required distance is not known to the nearest thousand feet, this rough measure is obtained from the unity count dial. This is operated manually and is used to change the modulation frequency a small amount in order to go from the photo-detector minimum to an adjacent one, after the initial variable light path setting has been made. The reading of this dial is drawn in on the "thousands" box in Fig. 11.4. The distance is then obtained directly in the manner of reading a dial gas or electricity meter. For metric use the fundamental modulation length unit is 60 cms., the steel tape, of course, being divided in millimetres.

4. RESULTS.

For the short and medium distance ranges the sensitivity of phase measurement is very high, at least as good as 0.1 mm. From measurements on the 300 m and 700 m bases at the NPL it has been possible to make preliminary assessment of the accuracy as: ± 0.1 mm ± 3 parts per million of the distance. Thus it is seen that the phase resolution at, for example, 700 m is greater than the accuracy obtainable from the standard cavity resonator. For those specialist users who require the maximum precision, it is possible to calibrate this cavity from a frequency standard related to a radio transmission.

An extensive series of field trials have been made including external and internal measurements on dams, airport measurements and geophysical surveys in Iceland.

A search for cyclical errors in the phase measuring process represented by the variable light path has shown the system to be substantially free from such errors. Fig. 11.5 is a diagram of the results. To obtain these curves, the Mekometer instrument has moved in measured steps through one foot (30 cm), the variable light path being re-set each time. The difference between the accurately moved step and the light path movement is plotted on the vertical axis, the step position being indicated horizontally. Since the smallest interval on the light path tape scale is 0.001 ft., estimation had to be made to obtain 0.0001 ft. Even so it was concluded that any cyclical phase error present was less than ± 0.05 mm in magnitude. Furthermore, by making the observations with the cube-corner reflector stopped down to reduce the reflected light by a factor of one-thousand times, the overall effect of this reduction was to change the setting of the light-path by less than 0.03 mm. The results obtained with a "cat's-eye" reflector (a concave mirror situated at the focus of a convex lens) show slightly less scatter than those from a cube-corner reflector. This is because the latter introduces a small degree of permanent ellipticity into the reflected polarization so that effective sensitivity is very slightly poorer in this case.

Fig. 11.3. General view of Mekometer III.
(Photo by courtesy of NPL, Teddington)

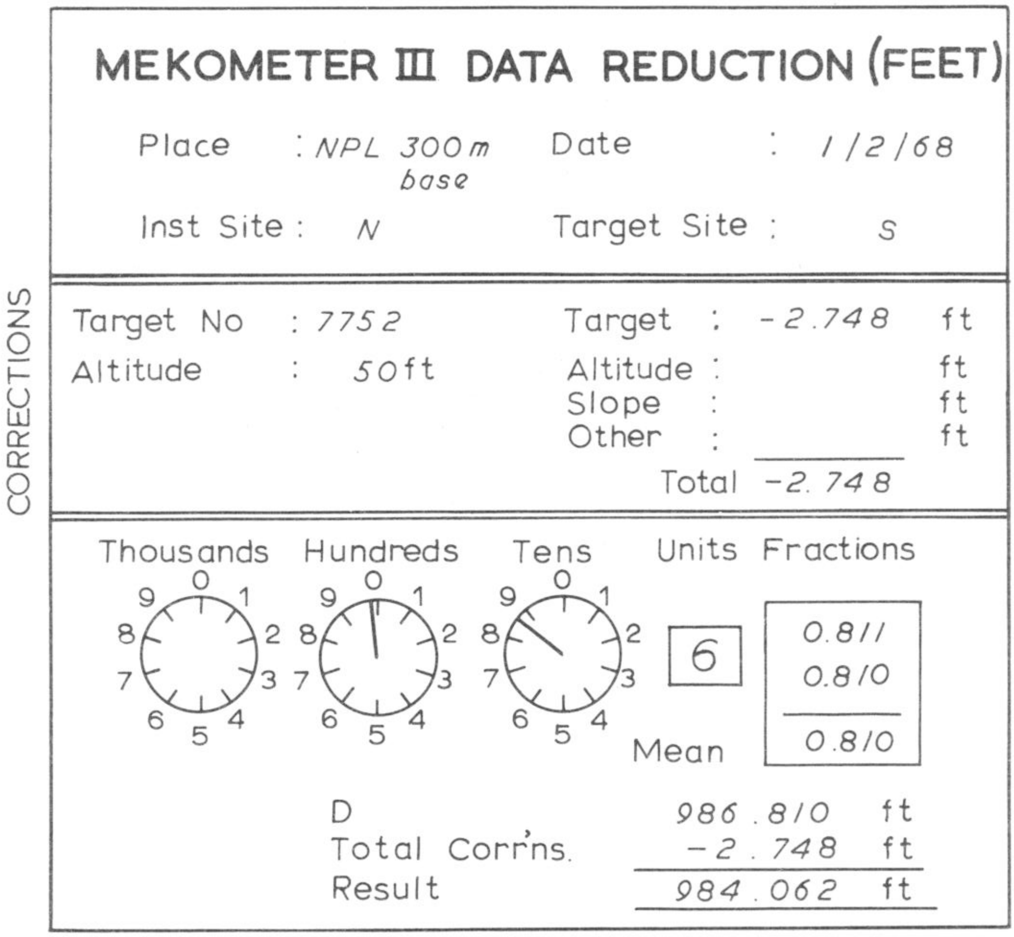


FIG. 11.4 OBSERVATION & REDUCTION SHEET

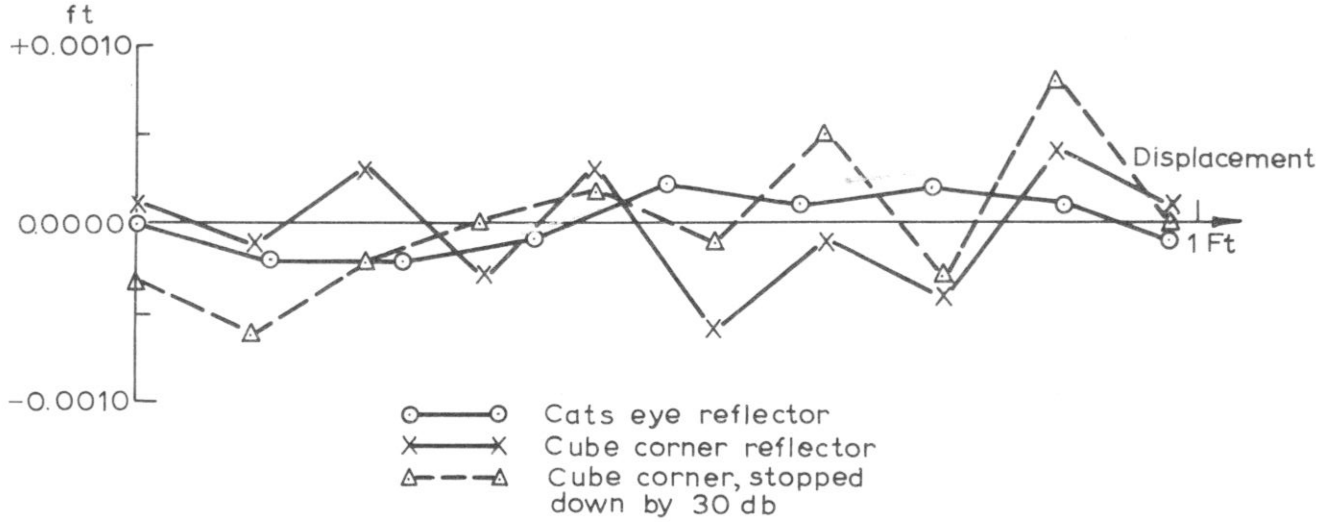


FIG. 11.5 MEKOMETER III. TEST FOR CYCLICAL PHASE ERRORS

NOTES:-
1. Mekometer reflector separation = 130ft (40m)
2. Each point is mean of only two settings
3. Conclusions: Cyclical phase error is less than ±0.0002 ft (±0.05mm) and a thousand fold change of intensity changes the measured phase by less than 0.00015ft (0.03 mm)

REFERENCE:

FROOME, K.D. and BRADSELL, R.H. 1966 — J. Sci. Instrum, Vol. 43, 129-33.

PAPER NO. 12.

THE MODEL 8 LASER GEODIMETER.

H. Edvardsson.

SUMMARY. Following a successful conversion by the U.S. Coast and Geodetic Survey of a Model 4 Geodimeter, a new instrument has been designed by AGA. It uses a 5 mW Helium-Neon laser with wavelength 6328A, and KDP light modulator. Brief details of the optics, circuitry, power supply and field performance are given.

1. INTRODUCTION.

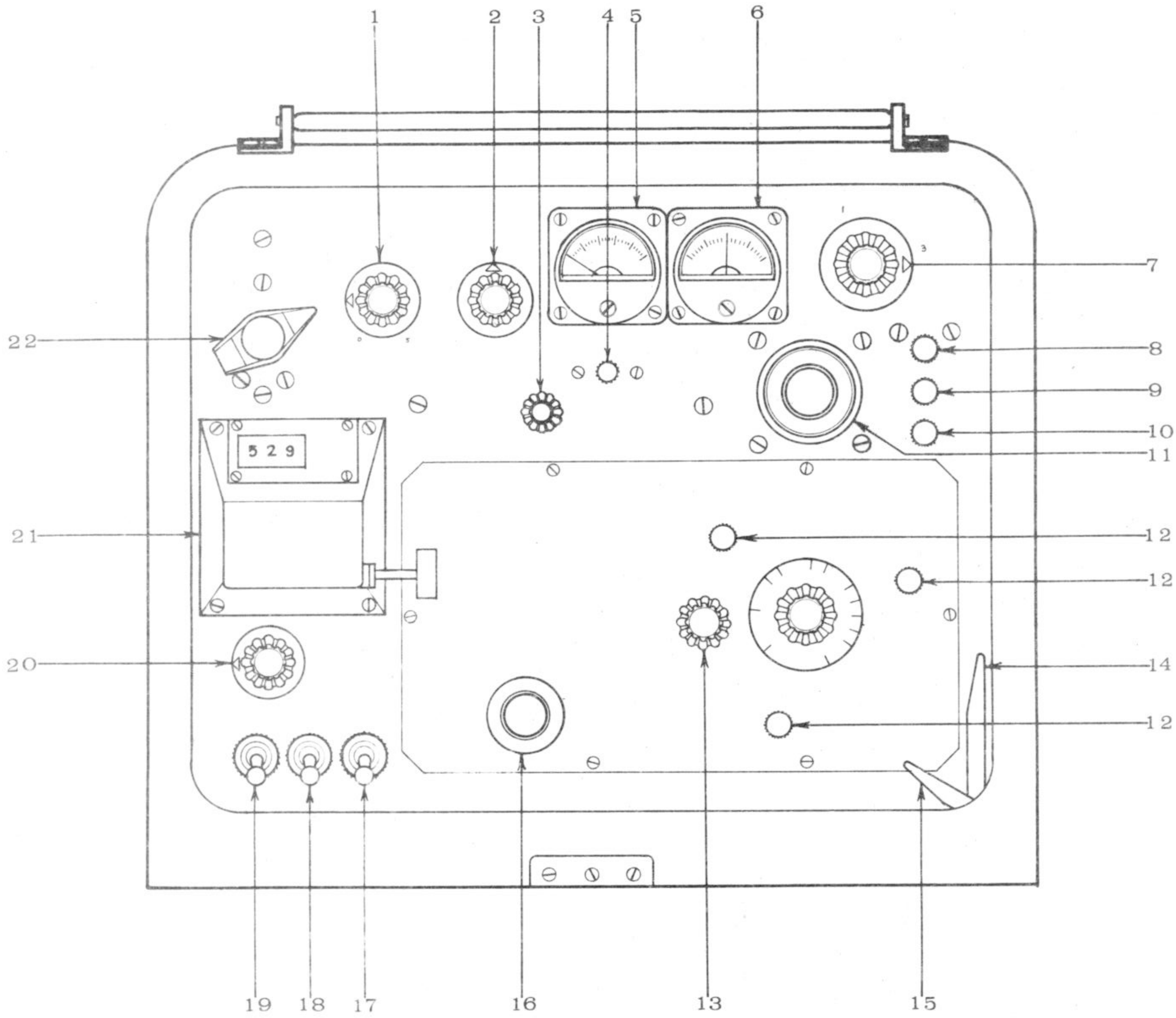
In 1967, the Coast and Geodetic Survey in USA started converting Model 4 Geodimeters in order to obtain longer ranges of the order of 15 - 25 miles. For this purpose a 2 mW laser with a crystal modulator was built into the instrument. The receiver was equipped with a more sensitive phototube and a narrow band optical transmission filter. These changes made it possible to obtain ranges of the order of 25 miles with a daylight range approaching the range in darkness. Improved crystal oscillators made it possible to increase the long range accuracy to such a degree that using precise determination of meteorological data, the observed errors were claimed to be about 1 ppm. Experiences gained during field tests and progress in the laser industry have now made it possible to design a new instrument, the Model 8, which in many respects is a considerable improvement over the laser-modified Model 4 used by U.S. Coast and Geodetic Survey.

2. LASER AND LIGHT MODULATOR.

The instrument is fitted with a 5 mW Helium-Neon gas laser with a wavelength of 6328A. The average life of this laser is no less than 5000 hours, and the laser tube is covered by a one year unconditional warranty.

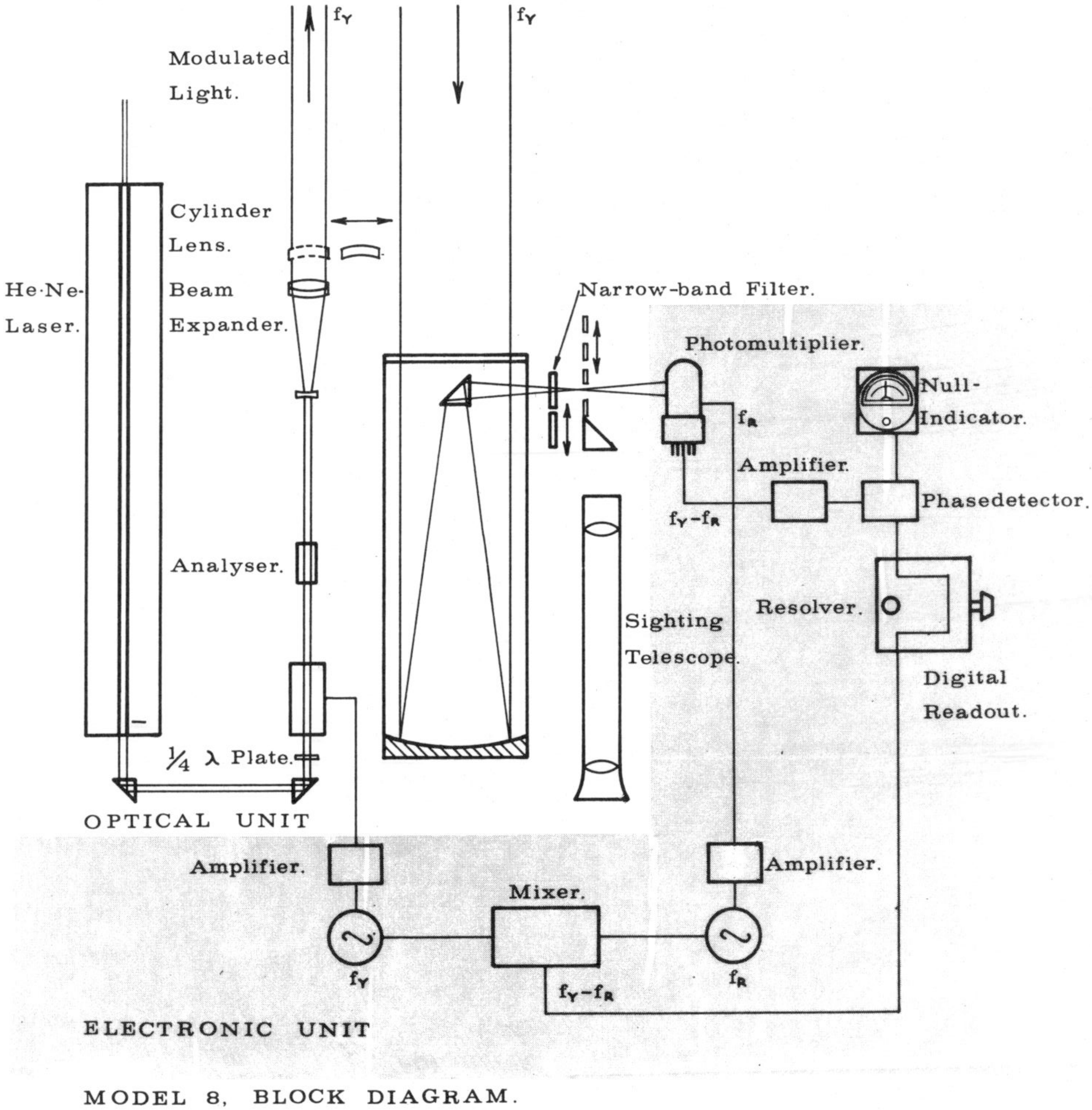
The instrument is mounted on a tilting head allowing a vertical angle of ±12 degrees. A horizontal circle is mounted on the head to facilitate pointing.

The light modulator is of KDP-Type (Potassium Dideuterium Phosphate) with temperature control. The modulated light is projected to the reflector by means of an expander with a 20 mm aperture, transmitting a light-beam with a minimum divergence of 0.1 milliradian or 1 meter in 10 kilometres. In order to simplify the location of the reflector, a cylinder lens can be introduced which will spread the light vertically 0.5°. This makes the Model 8 a very easy instrument to point. The entire laser and modulator assembly is rigidly mounted directly on the instrument base.



1	Amplification control	12	Mirror adjustment knobs
2	Phase selector	13	Focussing adjustment
3	Tuning control	14	Lightpath selector
4	Zero adjustment	15	Cylinder lens level
5	Null indicator	16	Sighting telescope
6	Control instrument	17	Panel lights
7	Instrument selector	18	Laser switch
8	Grey wedge	19	Power switch
9	Eyepiece-aperture selector	20	Reticle illumination
10	Narrow-band filter	21	Resolver read out
11	Eyepiece	22	Frequency selector

Fig. 12.1.



MODEL 8, BLOCK DIAGRAM.

FIG. 12.2.

3. THE RECEIVER OPTICS.

The receiver optics have an aperture of 90 mm and can be focussed from infinity down to 15 meters. The eye-piece can be switched into a reticule,making the receiver optics a powerful telescope when pointing the instrument. Variable aperture stops, a variable grey wedge and a "spike" filter make it possible to optimize the characteristics of the optics to existing light conditions.

The so-called "spike" filter is an optical filter allowing only light in the 6328A range to enter the receiver. As a result the daylight and after dark ranges are very nearly the same.

Fine adjustments of the optical axis of the receiver system as on the Model 6 Geodimeter, permit precise collimation of the transmitter and receiver systems. This collimation can be made in less than one minute in connection with pointing the instrument for maximum return signal.

4. THE ELECTRONIC CIRCUITRY AND POWER SUPPLY.

The electronic circuitry is fully transistorized. The four frequencies used, (which is one more than on the Model 4, thereby limiting the ambiguity to 40 KM) are controlled by pre-aged quartz crystals in ovens with proportional temperature control, and a stability of better than 1 ppm.

The receiver electronics employs a system for phase determination developed by Prof. A. Bjerhammar, Royal Institute of Technology, Stockholm, and which eliminates the need for calibration tables.

The Model 8 can be operated from a 12 volt battery. The total current drain is less than 6 amps with the laser light on. The electronic circuits consume less than 3 amps alone.

Since measurements can be made in 10-12 minutes, a comparatively small battery may be used, a great advantage when operating from high towers. The power unit is integrated with the instrument and the only connection to the instrument is the cable from the battery.

5. ACCURACY AND RANGE.

The Model 8 uses the same basic system as previous geodimeters. This system is well known and proven by 20 years of experience in the design and manufacture of electro optical instruments for distance measurement. The measurements with the Model 8 indicate that whenever distances of more than 10 kilometers are measured the limiting factor will be the meteorological uncertainty, i.e. for longer distances, an uncertainty of 1 - 2 ppm. For shorter distances, the error will be less than 1 cm. Testing has shown that distances in the range of 25-30 miles are measured with little difficulty. To obtain the maximum range of 40 miles the atmospheric conditions should be favourable.

The Model 8 Laser Geodimeter offers the geodesist an instrument for precise determination of long distances with the advantage of using light instead of microwaves thus being able to minimize the error caused by insufficient meteorological data.

6. TECHNICAL DATA.

Range, maximum	60 km	40 miles
Range, minimum	15 meter	50 feet
Accuracy	6 mm + 1 ppm	0.018 ft + 1 ppm
Laser power output	5 mW	
Power consumption	75 W, 12 V DC	
Instrument weight	23 kg	51 lb
Instrument dimensions	555 X 310 X 260mm	22 X 12 X 10 in

REFERENCES:

SCHOLDSTROM, R. 1968 — Technical Information: The Geodimeter Model 8. AGA Aktiebolog, Sweden.

PAPER No. 13.

MODERN DISTANCER FOR SHORT LINES

G. Strasser.

English translation of an article originally published in German in the "Zeitschrift fur Vermessungswesen" 1968, No.9 with the kind permission of the Editor.

SUMMARY. After a short historical review of EDM equipment especially for short distances, the considerations leading to the design of the WILD-SERCEL Distomat DI10 are discussed. The functional principles, the equipment and the technical data of this infra-red Distancer for distances up to 1000 metres with an accuracy of 1 to 2 cm are given.

1. HISTORICAL REVIEW.

In 1948, E. Bergstrand published the principle of his electro-optical distancer "Geodimeter" using visible light as carrier wave (BERGSTRAND, 1948). The way was now open to measure distances as easily and quickly as angles. The tiring method of measuring distances by rods, tapes or wires, placed one after the other over a terrain which by its very nature is never flat should, in the very near future, belong only to the past. In this respect, it became already a little easier in the twenties, with the introduction of optical distance measurement but this was restricted, for reasons of accuracy, to distances of 100 metres to 150 metres utmost. Therefore, measuring techniques had to be adapted to this method of measurement. Some ten years later, at the Royal Geographical Society in London, 1957, Wadley introduced his Tellurometer which realised another dream of those surveyors who had operated in World War II with RADAR, namely, measuring distances with the help of micro-waves. One could now measure through fog and rain. The enthusiasm over these two new measuring techniques was, however, only spread amongst some colleagues, indeed only a small group of them, because working with these instruments was economical only for medium and long distances. In daily work, the shortcomings of the classical measuring methods were still there and it was not easy to understand that electronics had nothing to offer for the numerous measurements of the short distance.

In the beginning of the fifties, E. Gigas was the first who tried, together with K. Nottarp, to develop an electro-optical distancer for measuring traverse legs, based on Bergstrand's principle. Unfortunately, the models EM_C and EM_E did not go beyond the experimental stage. In the beginning of the sixties the engineers in the various laboratories of the well-known instrument makers started to take up the urgent problem of developing electronic instruments for measuring short distances. In Autumn 1965, at the IAG Symposium on EDM in Oxford, the first pre-production models of such instruments were shown. Tellurometer reported on the use of Gallium-Arsenid-Luminescent-diodes in electronic distances and exhibited a laboratory model. (HOLSCHER, 1967) K.D. Froome explained his Mekometer II giving, at distances of up to 3 km, an accuracy of 0.0005 ft. (FROOME and BRADSELL, 1967). Hilger and Watts showed the prototype of a Mekometer I (after Froome), which was similar in form to a theodolite with vertical circle (CONNEL, 1967). The production of these instruments was never started and also the latest Mekometer, which Froome introduced at Cambridge in 1967 as model III, has still not been produced commercially. In the same year, in the Summer of 1965, Soviet Russia developed a distancer GD-314 with gallium-arsenide-diode radiation as carrier wave which was widely used in the field for distances up to a range of 2 to 3 km (POPOV, 1967). In Autumn 1967, Zeiss-Oberkochen showed, during the Photogrammetric Weeks in Karlsruhe, the electro-optical distancer SM11 (up to 500 m). Zeiss uses as carrier also the infra-red radiation of a GaAs-diode (LEITZ and BORNEFELD, 1968). In March, 1968, at the annual convention of the ASP and ACSM in Washington, AGA of Sweden demonstrated its newest Geodimeter Model 7T in which the Bergstrand principle of the Kerr cell modulation of visible light was combined with a tacheometer theodolite.

2. WILD-SERCEL INVESTIGATIONS.

Wild Heerbrugg started to experiment in 1963, with GaAs-diodes for the purpose of measuring short distances. Towards the end of 1965, the Societe d'Etudes, Recherches et Constructions Electroniques (SERCEL) in Nantes, which was working on the same problem, started to co-operate with Wild. By the end of the following year, a measurement of 912 metres was accomplished with a laboratory model in misty weather. In the development which followed, particular weight was given to the following points. As the instrument was intended, in the first instance, for the bread and butter work of the surveyor, an important factor was price. Therefore, all the electronic gadgets which could be built into such an instrument were first examined for their value to the user. Another point was that the instrument which was to be used in detachable Wild tribrachs for forced centring, should not become too heavy so that it could be easily interchanged against theodolite, reflector or targets. The ease and comfort of manipulating such an instrument should be in line with an instrument of this class. As the range also influences weight and price an attempt was made to estimate where the maximum lies of measured distances used in daily practice and also to what maximum range the instrument should be used occasionally, with additional effort and equipment (Fig. 13.1b). It does not seem wrong to assume, for the first case, distances of 300 to 400 metres because at this range the terrain can still be overlooked and the chainman can be supervised. For the second case, about 1,000 metres can be taken, because at this range it is just possible to work without time-consuming reconnaissance and expensive beaconing. Beyond this distance the application of available electro-optical and micro-wave instruments becomes economical.

It is certainly correct to apply the same economical principles for distance measuring instruments as hitherto for angle measuring instruments and to design instruments here also for the different orders of survey, otherwise the result will only be expensive hybrids. Unfortunately too little attention is often paid to this fact because again and again different contradicting specifications are put forward for such an instrument. All in all, it is most important to find a good compromise in every design.

3. DISTOMAT DI10.

The Wild solution, the Distomat Wild DI10 has the following features. It consists of an aiming unit with detachable tribrach with optical plummet and a separate control unit so that the instrument on the tripod is not too heavy and above all not top heavy. In order to keep the diameter of the optics as small as possible without losing range (see also Fig. 13.1), separate optical systems were chosen for the transmitter, receiver and sighting telescope (Fig. 13.2a). This ensures an optimum in

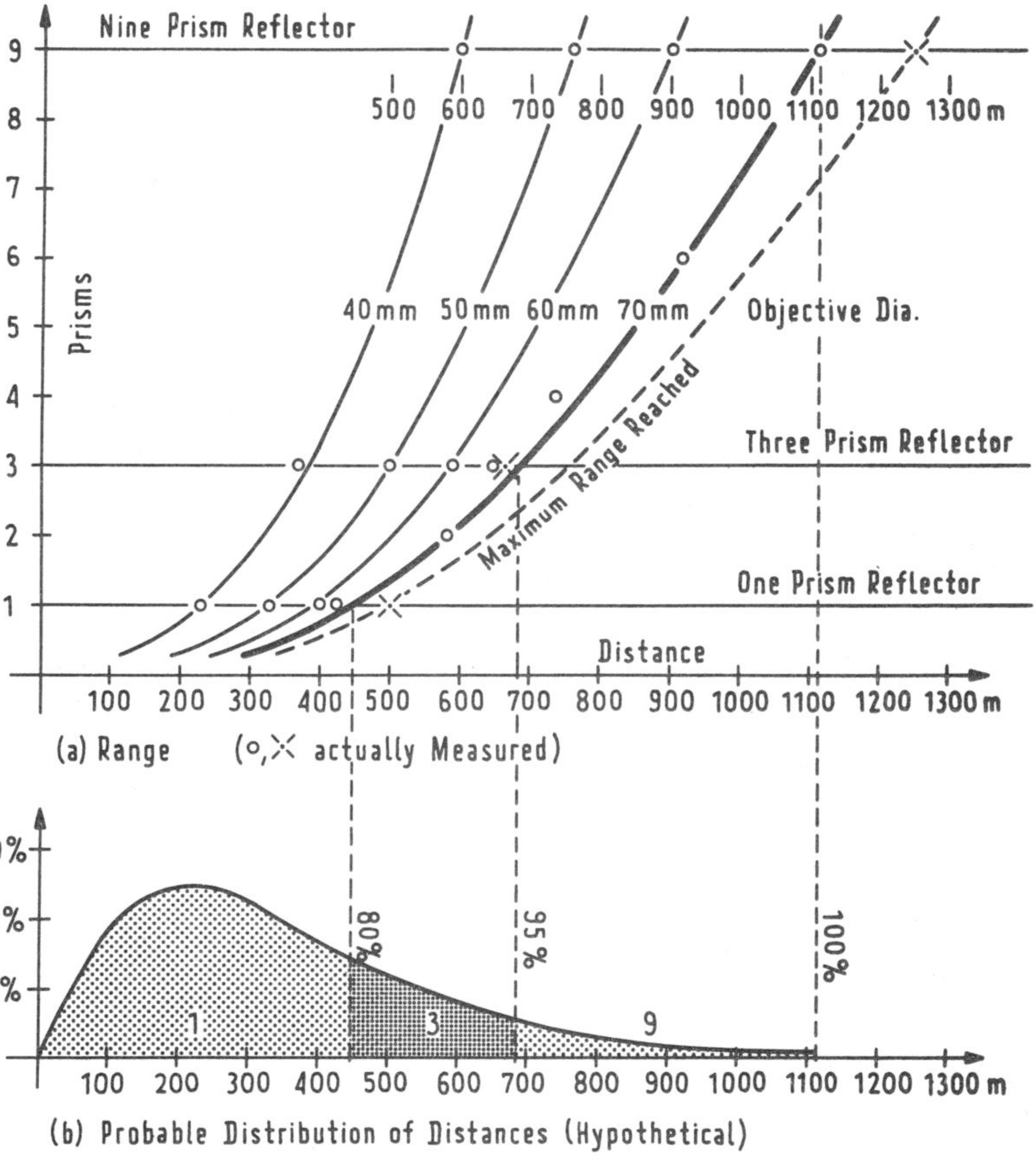
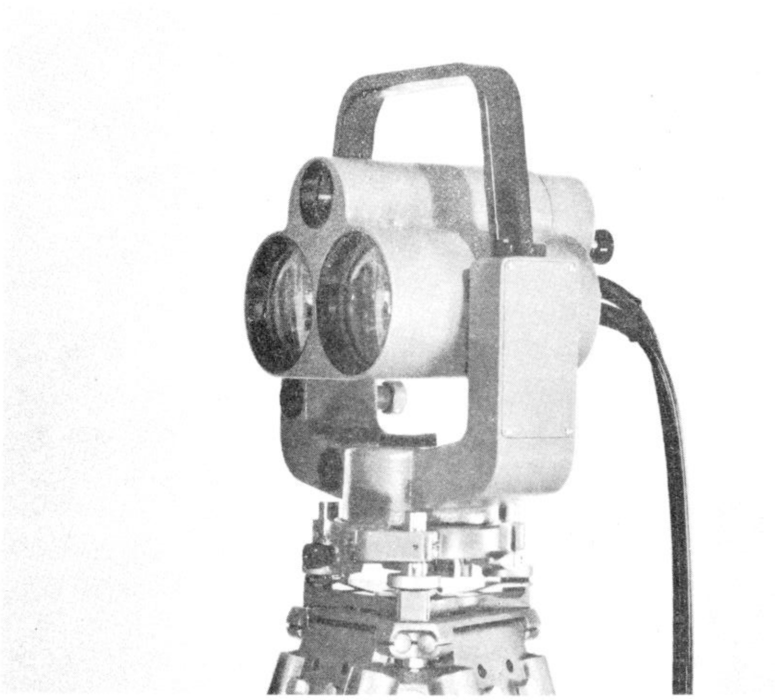


FIG. 13.1.

Diameter of objective, number of prisms and range
Probable Distribution curve of distances (hypothetical)



2a Wild Sercel Distomat DI10 Aiming Unit

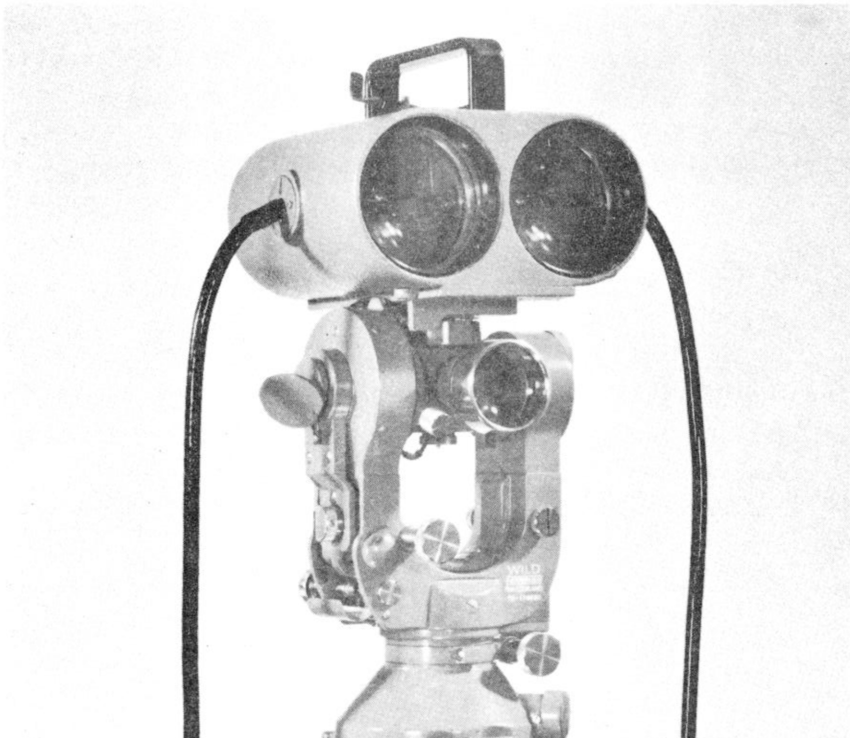


FIG. 13.2.

2b Infra-red Measuring head DI10T attached to a Wild T2 return of the transmitted energy. The whole optical system, as a complete unit, sits like a telescope orientable in a standing and vertical axis. At the ISP-Congress in Lausanne in July 1968 the model DI10T, a detachable infra-red measuring head to the telescope of the Wild T2 one second reading theodolite was shown (Fig. 13.2b). The control unit contains the electronics, the digital display system and the battery. At the other terminal of the line to be measured there is a retro-reflector in an identical detachable tribrach (forced centring). Depending on the distance to be measured the reflector consists of one prism (up to 400m) or three (up to 600 m) or of nine prisms(up to 1000 m). The prisms are of special design taking into account the horizontal displacement between the transmitting and receiving optics (Fig. 13.3)

As carrier wave the invisible radiation in the near infra-red between 0.72 to 0.94 µm, a so called window (i.e. with favourable propagation properties) in the infra-red spectrum is used. In this region no strong absorption bands exist and any attenuation along the measuring path depends only on the scattering, with the exception of high relative humidity and high temperature where water vapor absorbs the rays more strongly. The GaAs-diode used in the DI10 emits about 1.2 mW incoherent radiation of 0.875 µm wave length which is monochromatic within 0.04 µm. The radiation is focussed to a beam with a 15' spread by the three-lens transmitting objective of 70 mm diameter and 80 mm focal length, especially corrected for this wave length. The reflected beam is focussed by an identical receiving objective to a silicon photo diode.

The radiation of the GaAs-diode is directly amplitude modulated, by varying only the power which controls the intensity of the radiation. The modulation frequency of 14.98540 MHz chosen corresponds, at the refractive index of the atmosphere of 1.000282, to a wave length of 20 metres, i.e. a measuring unit of 10 metres as the beam passes twice over the measured distance. If the realistic centimetre reading is accepted it is possible to measure up to 1,000 metres, with a few exceptions of extreme atmospheric conditions, without applying any correction for refractive index. This is an advantage for those measurements cropping up in daily practice. When measuring a distance using a 15 MHz frequency pattern, the problem is to find the multiple of the 10 m unit within the distance to be measured. The problem was solved by Sercel by sweeping-up automatically the modulation frequency by 10% from 13.48686 MHz to 14.98540 MHz. The modulation frequency is generated by a variable HF oscillator and automatically synchronised with two quartz crystals of corresponding frequencies before and after the measurement. Changing the frequency by 10% causes a change of 10% in the resulting phase shift when measuring a distance of certain length. This phase shift is continuously measured during the sweeping-up. A measured distance of 100 metres results in a phase shift of 2π (full rotation). The phase meter is so designed that, during sweeping-up of the frequency, it can integrate without ambiguity up to $10 \times 2\pi$, i.e. 1000 metres. The multiple and partial measurement of the phase rotation is possible in one continuous measuring procedure. The phase shift is measured in a phase meter which is a follow-up servo consisting of a resolver, a phase detector and a DC-motor. Fig. 13.4 shows a simplified block diagram. The resolver axis carries a glass circle with three figure numbers (metre, decimetre and centimetre) in steps of 2 cm. A second glass circle with two figure numbers (hundreds and tens of metres) is mounted on an axis geared down ten times. The readings of the two circles are projected on to a ground glass screen giving a five figure display (Fig. 13.5).

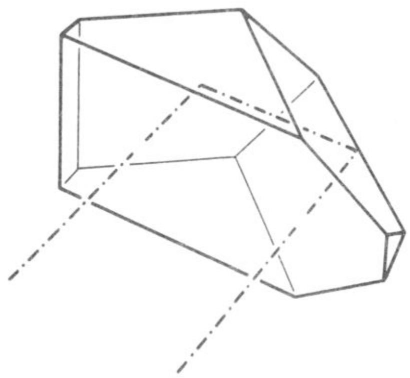
The aiming unit contains an internal calibration line. By switching a knob the beam of the transmitting diode is directly reflected on to the receiving diode. With the aid of a drive screw on the control unit the stator of the resolver is turned until the last three digits of the display are set to zero or to an additive constant, caused by the internal path within the instrument and reflector prism. Apart from this "zero calibration" and the setting of a starting value, the display of the measured distance runs up automatically in 10 secs. The chosen measuring principle has, furthermore, the advantage that the metre-, decimetre- and centimetre reading follows up as soon as the reflector is moved along the measured line so that when setting out points the distances to them can be read immediately. For a survey of this kind a pole reflector was developed which is made up of an extendable centring rod with metric divisions and fitted with a detachable reflector prism. This allows measurements up to 400 metres in flat terrain. With a gradient of 19° (i.e. 35%) it can still measure up to 250 metres.

The invisible infra-red radiation makes it possible to measure by day and by night. During the test measurements slight rain had no significant influence on the range. The following maximum ranges were reached under favourable conditions. With the single prism reflector 500 m, with the standard reflector of three prisms 650 m, and with the attachable supplementary reflector (a total of 9 prisms) 1250 m. The mean square error (standard deviation) for a single measurement derived from all measurements made up to now was ±0.8 cm (inner accuracy). The outer accuracy was determined by comparison with known sections of the international base Heerbrugg as between ± 1.0 cm and 1.5 cm independent of the distance.

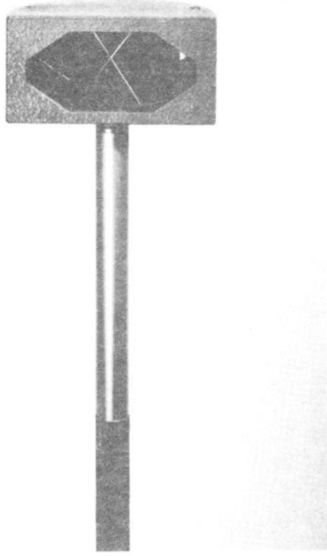
4. TECHNICAL DETAILS.

Listed below are the important technical data of the Wild Distomat DI10.

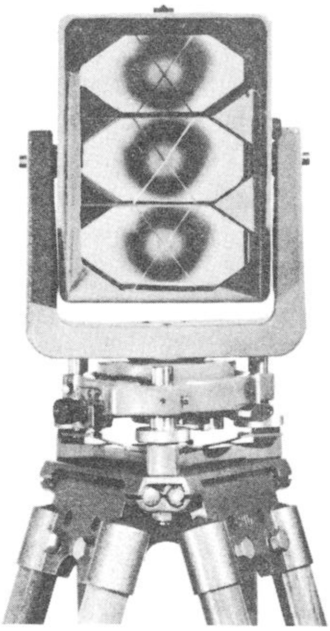
Measuring range		
with single prism reflector	up to 400 m	
three " "	up to 600 m	
nine " "	up to 1000 m	
Distance reading (digital)	000.00 to 999.98 m	
Mean square error (standard deviation), independent of the distance	± 1 to 2 cm	
Carrier wave length	0.875 μm	
Measuring frequency, automatically swept-up	13.48686 to 14.98540 MHz	
Transmitted power	1.2 mW	
Power consumption during measurement	about 10 W	
Time required for one measurement including pointing	60 s max.	
Internal NiCd battery, rechargeable	12 W/6 A	
Number of measurements with fully charged battery (at 20°C = 68°F)	about 200	
Temperature range	-25°C up to +50°C (-13°F up to +122°F)	
Sighting telescope (upright image, fixed focus)	15 x	
Tilting range of the aiming unit	± 40°	
Dimensions and weights		
Aiming Unit with tribrach (optical plummet)	17 x 26 x 29 cm 6.7 x 10.2 x 11.4 in.	7.2 kg 15.6 lb



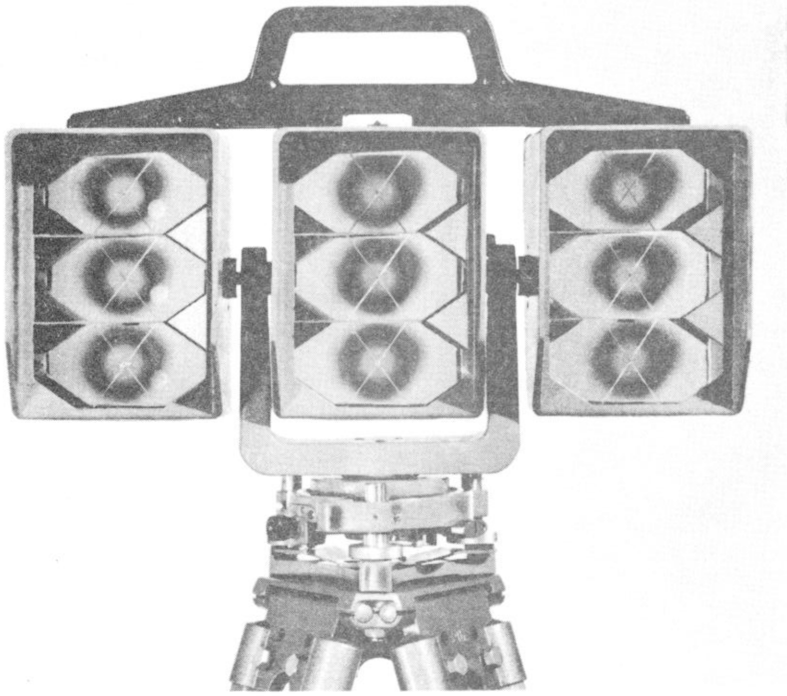
3 a. Retro-reflecting Prism



b. Reflector Pole



c. Three Prism Reflector GDR1



d. Six Prism Reflector attached to GDR1

FIG. 13.3.

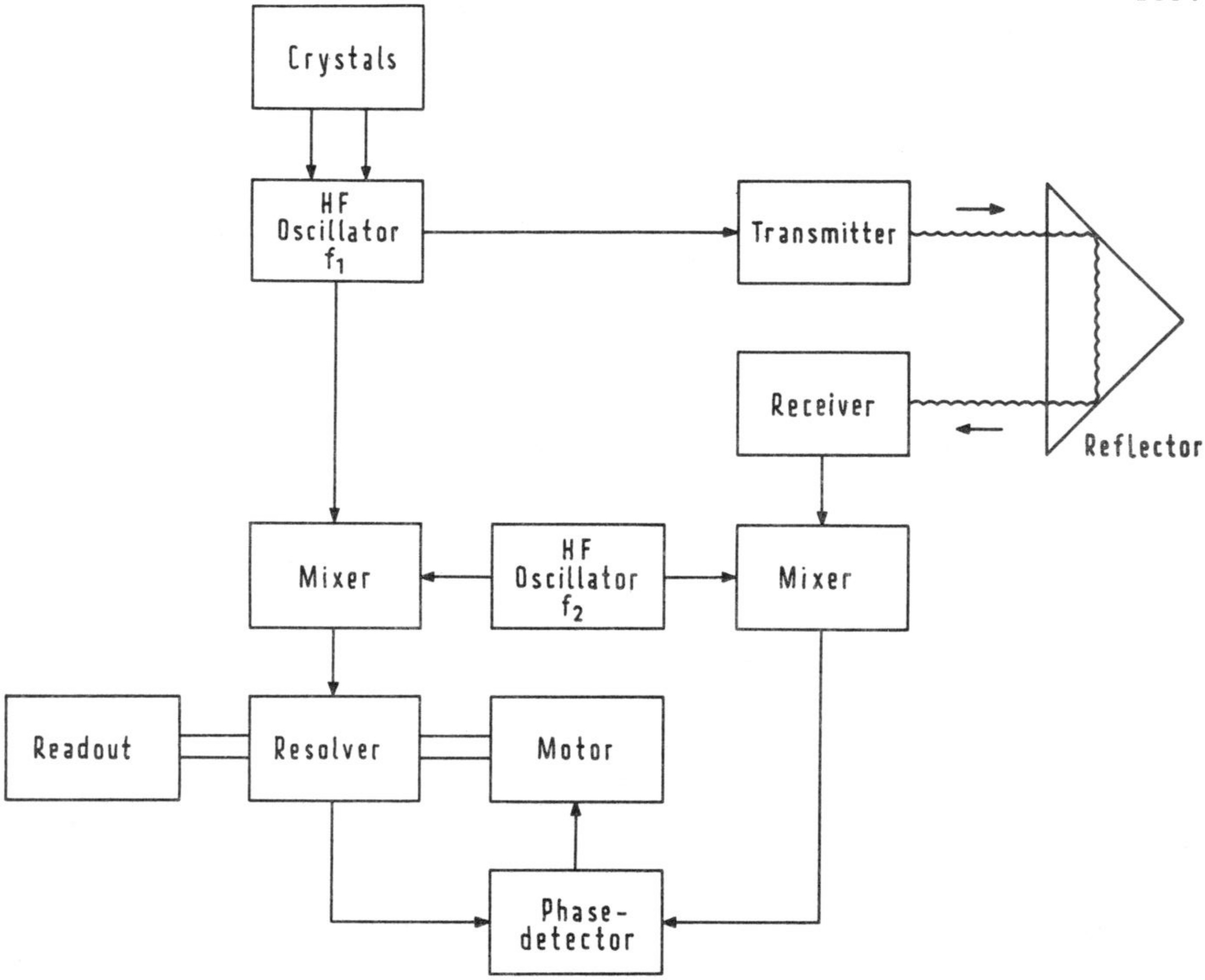


Fig. 13.4. Block diagram DI10

Fig. 13.5. Readings: 570.69 m
629.98 m

Control Unit with internal battery	33 x 19 x 39 cm	13.8 kg
	13.0 x 7.5 x 14.1 in	30.4 lb
Three Prism Reflector with tribrach	16 x 13 x 26 cm	3.5 kg
	6.3 x 5.1 x 10.2 in	7.7 lb

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DISCUSSION: PAPERS 10 - 13.

Chairman: Dr. James C. Owens

JONES:	EDM Apparatus
EDVARDSSON:	Laser Geodimeter
BENNETT:	Mekometer III (Froome and Bradsell)
CAMERON:	Wild D 10 (Strasser)

MACKIE: What is a 'resolver'?

EDVARDSSON: It is similar to the unit used in microwave systems to make a phase shift.

JONES: It is fully described in the text by Saastamoinen.

MACKIE: Can this DI 10 attachment be fitted on to the Wild T2 theodolite?

CAMERON: No this particular unit cannot. It weighs 16 lbs, including tribrach. However there is a unit, the DI 10 T, weighing less than half this amount, which clamps on to the T2 telescope.

BOBROFF: What instrument calibrations are necessary?

CAMERON: The DI 10 is self-calibrating and the only calibration necessary forms part of the normal observing procedure.

BENNETT: The instrument was tested at the University. In one test the aiming unit was placed on a 10 cm. slide and the effect of small random changes measured. In the second the reflector was moved over a 10m. length in 1m. steps. (10 m. corresponds to one cycle of the measuring wave). Readings were estimated to one millimeter. Cyclic error was present though the amplitude was well under 1 cm. We concluded that the makers' claim of 1-2 cm accuracy was very conservative and that a means of reading to millimeters would be justified.

FREISLICH: Can you give some details of the hand held reflector. If it is moved during measurement does this give the electronic unit indigestion?

CAMERON: No. The reading will be an average over the observing period. Interruption of the measuring beam can change the coarse reading but the fine readings are retained.

KIRSCH: Can a system of voice communication between power pack and reflector be arranged on the DI 10?

CAMERON: On lines only 1000 m. long visual communication is always possible.

EDVARDSSON: Since there is no power or receiving unit at the remote end, only a prism, voice communication systems would be an unnecessary extra. Efficient and cheap voice communications are available separately in the form of two-way radios.

MILLER: What is the significance of the term 'mean error' in Jones' paper, Table III?

JONES: This indicates internal consistency of readings taken with any one instrument.

LYONS: Over a line of 40 miles how critical is the alignment of the prisms for Geodimeter 8 measurement.

EDVARDSSON: Alignment is in fact more critical on shorter lines. The corner cube prisms accept a light beam over a range of 20° of alignment, although at the edge of this range there is some light loss.

LYONS: Is the Model 8 laser safe in built up areas?

EDVARDSSON: Yes. It is in fact safer than the mercury lamp.

LYONS: Is this danger to the eye common to all lasers used in survey work?

EDVARDSSON: It is not a real danger. It is comparable to looking at a welding arc. Because of the discomfort you would not look at it long enough to cause damage.

McQUISTAN: The safety limit for lasers at WRE is based on the safety limit expressed by the British Department of Civil Aviation and is below the level of the Model 8 geodimeter. It is 1 mwatt in a 6 cm. diameter.

JONES: I have looked into stronger beams than that and experienced only temporary discomfort.

EDVARDSSON: The output of the geodimeter 8 laser is only 2 mwatts.*

OWENS: Safety limits are still the subject of discussion, and have not been firmly established. The power concentrated on the retina depends on the aperture of the eye at that moment, and whether the eye is focussed on the beam.

TURNER: Is there any alternative power-source with improved capacity, weight or rechargability?

EDVARDSSON: The power drain of the geodimeter 8 is far higher than that of the 6, which can have a cadmium battery - light and convenient, but more expensive.

TURNER: It is also critical in its requirements for charging. Are there any alternatives, for example, fuel cells.

EDVARDSSON: There is research on fuel cells, but nothing which could be used for such practical applications has been produced yet.

KING: The KDP cell seems to be the normal modulator. Owens spoke of barium cells. Would these be advantageous.

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* He is mistaken. The early modifications of the geodimeter 4 had 2 mw. lasers but the geodimeter 8 has a 5 mw. laser. - Ed.

OWENS: The barium cell requires very precise temperature control. The KDP cell is reliable and relatively simple to use compared with the barium cell.

McMAHON: Is it practicable to convert the geodimeter 4 to laser use?

EDVARDSSON: The U.S. Coast and Geodetic Survey converted their geodimeter 4 but it turned out to be a highly complex operation and much of the circuitry had to be redesigned and rebuilt. The cost was high. At that time AGA was not manufacturing the Laser Geodimeter. They had reviewed the market and concluded that there was only a small market. Since then costs have come down and AGA considers it worthwhile.* The USCGS version was very unstable in optical alignment and modification is not recommended.

WALKER: Has the position of the power pack any effect on the readings of the DI 10?

CAMERON: No. It is convenient to have it in a position where the meter deflection is visible from the aiming unit, for lining in. Lying the pack down may upset the balance of the reading drums. Once it has been set up it is best not to move it. Also in heavy wind it is best to tie the leads to the tripod legs to prevent movement which seems to change the reading.

BROUGHTON: How does this occur?

CAMERON: The effect is small, but evidently movement of the leads changes the capacitance of the total circuits.

SEARLE: How long does it take to make a reading on the Mekometer? If it is so good why is it not being manufactured commercially?

JONES: I have seen the Mekometer I in action. It took only a few minutes to set up and about 20 seconds to read.

OWENS: After completion of the Mekometer I prototype at National Physical Laboratories, Hilger and Watts held a contract to manufacture the instrument but this apparently fell through. The N.P.L. holds the patents and is reported to be negotiating with other companies for its manufacture.

SEARLE: What is the minimum range of the instrument?

OWENS: The optical light path inside the instrument.

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* Particularly since its feasibility had been proved by another organisation - Ed.