Report on Electronic Distance Measurements in Australia

G. R. L. RIMINGTON

Division of National Mapping
Department of National Development
Melbourne, Australia

Australia is a large, comparatively undeveloped country, with a small population, as the following statistics show:

Area	2,974,581 square miles
Coastline	12,210 miles
Population	10,000,000

Its present state of development finds only a small amount of geodetic survey completed, and such a small population cannot provide much manpower to cope with the task of establishing a geodetic survey. Consequently, all methods of increasing the effectiveness of available staff must be explored.

The first investigations into the use of electronic distance-measuring equipment were made by the Radiophysics Division of the Commonwealth Scientific and Industrial Research Organization during 1947–1949 [*Warner,* 1950].

At the request of the National Mapping Council, the Division examined the possible application of Shoran to geodetic surveying. The sides and diagonals of a quadrilateral were measured; they varied in length from 158 to 311 miles. The resultant measurements were compared with distances computed from a first-order ground triangulation. The results of more than 100 measurements spread over 6 lines gave an over-all accuracy of about 7 parts in 10^6. The scatter of the individual measurements on any line was about one-third of this. Systematic equipment errors proved the main limiting factor in obtaining higher accuracy. The greatest source of error in the radar equipment was associated with signal strength.

On completion of its experiments the Radiophysics Division advised that by suitable modification to the equipment, in particular the receivers, this error in signal intensity could be reduced to within ±0.002 mile. If this were done it would be likely that the over-all accuracy of the technique would improve to about 2 parts in 10^6. An improvement on this figure would be impossible without extensive improvements in the equipment and a thorough investigation of problems of atmospheric refraction.

At about this time Dr. Bergstrand had demonstrated his first models of the Geodimeter, and it was decided to acquire and test a production model of the instrument before finally deciding on a type of electronic distance-measuring equipment for use in Australia.

A unit of the equipment was obtained in 1953 and thoroughly tested [*Waller,* 1954], with results that have had great significance. The results of these tests, which agreed consistently with those carried out in other countries of the world, established that electronic measurement of the lengths of normal geodetic lines was not only practicable but also had a phenomenal degree of accuracy. It was considered a remarkable advance over Shoran airborne electronic measuring equipment, which relies on extreme length of line (up to 400 miles) to achieve its fractional accuracy.

It was established that the Geodimeter Type NASN.1 could measure distances with a limiting error of ±0.08 ft. Here then was a system that could eliminate the time-consuming base line and its associated network, substituting the direct measurement of a single side of triangulation for all such base lines.

Additional Geodimeters Type NASN.2 were obtained and placed in use in Australia, on the measurement of base lines for first-order triangulation. This equipment for maintenance of scale in classic triangulation proved so successful that its use for making measurements on first-order traverse was inevitable.

Some small schemes of traverse were actually completed, with satisfactory results, leading to the conclusion that, where the topography allowed the use of the Geodimeter, traversing could easily meet first-order accuracy, with considerable saving in manpower and time.

Plans were being prepared for extensive application of Geodimeter traversing when the Tellurometer made its appearance. Preliminary reports on the Tellurometer system of electronic measurement indicated that it was intended to carry out much the same task as the Geodimeter, the basic difference being that the Geodimeter used light waves as the measuring medium and the Tellurometer used radio waves. The specifications of the Tellurometer were such that it offered substantial advantages over the Geodimeter when used on traversing.

Australia was not alone in appreciating the possibilities of the equipment; we in this country were one of the many survey authorities which obtained early production models for investigation.

Our aims in this testing were perhaps slightly different from those of other organizations, in that we had been conditioned by exacting tests of the Geodimeter into accepting the conclusion that first-order traverse carried out by electronic equipment was the most economical solution to our pressing needs in geodetic survey. The testing of the Tellurometer was therefore aimed at determining the relative accuracy and efficiency of the Geodimeter and Tellurometer when both systems were operating at maximum efficiency.

The results of the tests of the Tellurometer were published in Australia [*Rimington*, 1957], and limited copies of the report were distributed to interested overseas organizations; the report concluded that the results of Tellurometer measurements were very little inferior to those obtained with the Geodimeter.

It is conceded that in some extreme circumstances the Tellurometer will fail to measure accurately between two fixed points, and that the use of short eccentric observing points may be necessary to avoid the effect of 'ground swings.' Experience has indicated that wide swings which *may* cause inaccuracy can be minimized by a small change in the instrument standpoint. In support of this belief, it is on record that in some 9000 miles of accurate measurements it has always been possible to measure satisfactorily all previously selected lines.

EFFICIENCY

The physical characteristics of the Geodimeter and Tellurometer are such that it is very easy to decide which of the two instruments is preferable for extensive field work. Weight, cost, and susceptibility to weather conditions all weigh so heavily against the Geodimeter that all authorities engaged in geodetic survey in Australia are using Tellurometers in the field. The few Geodimeters are held in reserve for occasions when extreme accuracy of the order of ±2 parts in 10^6 is required, or when the line is so short that the limiting accuracy of the Tellurometer (±0.20 ft) cannot be tolerated. Such occasions are very rare.

FUTURE PLANNING

On present planning the initial stage of the Geodetic Survey of Australia will take the form of extensive loops of Tellurometer traverse encircling and subdividing the continent.

It is realized that there may still be a considerable difference of opinion as to the accuracy and dependability of the Tellurometer, and it is the purpose of this report to set out some of the results of the testing and work carried out in Australia during the past two years. These results have bred confidence in electronic measurements to such an extent that a major change in methods of geodetic survey is accepted in Australia.

USE OF TELLUROMETER FOR GEODETIC MEASUREMENTS

General considerations. Measurements made with this instrument are subject to: (*a*) index error; (*b*) systematic error in the accepted velocity for electromagnetic waves in vacuo; (*c*) variation of frequency of the crystals in the equipment; (*d*) inaccuracy in the accepted meteorological corrections; (*e*) errors in measurement due to reflected waves (swing).

Index error. This type of error undoubtedly exists in every measurement made with the equipment. The designer informs us that it will always be of the same sign (distance measured too long) and can vary between 0.00 and 0.25 ft.

TABLE 1. Tellurometer calibrations, Balcombe, Victoria
Measurements are in feet.

Tellurometer and Index Correction Used		MA.11, −0.23		MA.40, −0.19		MA.74, −0.25		MA.318, −0.05	
Line	Taped Feet	Measured	Residual	Measured	Residual	Measured	Residual	Measured	Residual
W. base–E. base	5899.45	5899.50	+0.05	5899.50	+0.05	5899.52	+0.07	5899.56	+0.11
Peg 18–E. base	2951.37*			2951.31	−0.06	2951.33	−0.04	2951.36	−0.01
Peg 18–W. base	2948.08*			2948.18	+0.10	2948.01	−0.07	2948.10	+0.02
Sum (E.–W.)	5899.45			5899.49	+0.04	5899.34	−0.11	5899.46	+0.01
Peg 19–E. base	3115.44	3115.48	+0.04						
Peg 19–W. base	2784.01	2784.05	+0.04	Note: Peg 19 was destroyed after first calibration.					
Sum (E.–W.)	5899.45	5899.53	+0.08						
Peg 20–E. base	3279.34	3279.31	−0.03	3279.30	−0.04	3279.21	−0.13	3279.12	−0.22
Peg 20–W. base	2620.11	2620.10	−0.01	2620.06	−0.05	2620.28	+0.17	2620.25	+0.14
Sum (E.–W.)	5899.45	5899.41	−0.04	5899.36	−0.09	5899.49	+0.04	5899.37	−0.08
Total of E.–W. residuals			+0.09		0.00		−0.00		+0.04
Mean of E.–W. residuals			+0.03		0.00		−0.00		+0.01

* Provisional, may be ±0.02 ft in error.

Being always of the one sign, the error will be cumulative in traverse work, and some effort should be made to ascertain and apply a correction. It is difficult to determine a correction of this order of magnitude when: (*a*) the smallest scale division is 0.50 ft; (*b*) the presence of swing may cause errors of the order of ±0.20 ft; (*c*) completely reliable reference lengths are required; (*d*) overloading of the equipment must be avoided.

The Division of National Mapping has been using a test site at Balcomb, Victoria, which has fairly satisfactory characteristics. It is a former training base line of the Royal Australian Army Survey School. The line is 5899.45 ft long, over slightly undulating country, which at certain times of the year has a covering of long grass. When long grass covers the site, ground swings are at a minimum; when the grass is dry and short, only moderate swings are developed. Intermediate pegs are available along the length of the line, and it is possible to measure the line in whole and in parts.

It is of particular importance that all measurements with the original model of the Tellurometer were carried out with the crystals at 'turn-over' temperature (see under 'Frequency,' below). The crystals were calibrated in such a manner that the turn-over temperature was accurately determined.

Table 1 shows the results of the tests for index error for equipment numbers MA11, MA40, MA74, and MA318. It will be observed that the results of the MA11 and MA40 tests are noticeably more consistent than those of MA74 and MA318. The former two tests were made with long grass covering the line, and the latter two with short grass cover.

These results clearly show both the existence of an index error and its probable amount. They also give some idea of the consistency of the instrument at short range under favorable conditions. Tests such as these confirm the conclusion arrived at after our early tests, that the manufacturers' specification of accuracy is substantially correct at distances of this order.

Velocity of electromagnetic waves. The present accepted velocity of 299792.5 km/sec is the result of experimental work carried out by different methods, and has been endorsed by the I. U. G. G. The use of this value should not introduce a systematic error in excess of 1 part in 600,000. An error of this magnitude is insignificant in normal geodetic work. It is notable that the velocity deduced in various countries of the world from the use of the Tellurometer over accurately measured lines shows an amazing agreement with this figure. It is very strong contributory evidence that the equipment is capable of a high order of accuracy.

Frequency. The initial models of the Tellurometer relied on crystal monitoring to determine the actual frequency used during a measurement. To obtain a high order of accuracy in frequency it was necessary to operate the equipment at the 'turn-over' temperature of the crystal, at which temperature errors in the monitoring circuit were at a minimum. By means of such a technique, combined with frequent reference to standard frequency, it has been possible to preserve frequency stability to within 1 part in 10^6.

A modification is available in which the crystals are maintained in a controlled oven. Frequency is maintained within 1 part in 10^6 without special routines. All equipment being used in Australia on geodetic survey is being fitted with this modification.

Meteorological corrections. This is perhaps the most controversial issue in any discussion on the Tellurometer. The formulas on which the corrections are based appear to be acceptable for the order of accuracy envisaged in geodetic survey, and it is not anticipated that they will be seriously challenged for validity.

Debate generally centers around the accuracy of the conventional meteorological measurements, and the propriety of using readings made at both ends of a line as representative of conditions over the whole line. Bearing in mind the vagaries of atmospheric conditions it is understandable that this aspect of the measurement should be viewed with suspicion. Perhaps this skepticism about the meteorological corrections is felt by all who come into contact with electronic distance measurements. In the initial tests of the Geodimeter and Shoran much the same uncertainty prevailed, but as further work progressed it was replaced by confidence.

The Tellurometer is more sensitive to vapor content of the atmosphere than the Geodimeter, but, as the results of many measurements show agreement under widely varying conditions, confidence in these corrections will be established.

In work of geodetic quality it is proper that due regard should be paid to the chance that freak atmospheric conditions may lower the quality of the measurement; to guard against this possibility, geodetic lines are measured twice, once on each of two different days. This procedure is an insurance both against freak meteorological conditions and against the possibility of gross errors.

A tabulation of the dual readings reveals interesting information, particularly when the meteorological corrections are compared. A small sample appears as Table 2, listing the lines of a traverse running from Alice Springs (vicinity) to Halls Creek in Central Australia. The temperatures experienced on this particular survey varied from 64°F to 99°F, and the results indicate that, despite violent changes of temperature, the agreement between the two measurements of the lines is satisfactory. The line Gardiner-Finniss (last measurement) failed in this respect and will be remeasured. This tabulation is typical of the agreement obtained over lines measured in Australia; it has been a rare occurrence for two measurements to fail to agree within 1 part in 10^5. In the event of such disagreement the line is remeasured.

Ground swings. Much has been written about 'ground swings,' the term applied to the measured effect of reflected waves on the direct wave. That such ground swings exist is obvious, and their presence on very short lines is pronounced.

Almost without exception, the new user of Tellurometer equipment will first test it over very short lines, with the inevitable result that quite large ground swings are encountered, which have a catastrophic effect on the proportional accuracy obtained.

The situation changes completely when the equipment is placed in field use, measuring lines of main-scheme geodetic control. With the ruling length of line in the vicinity of 20 miles and over, it becomes quickly apparent that ground swings exceeding 6 μsec (or 3 ft) are few and far between. Referring to Table 2 again, it is seen that the normal amount of ground swing is of the order of 2 or 3 μsec. In a line of length 20 miles the whole extent of the ground swing represents approximately 1 part in 60,000; when the ground swings have been plotted and analyzed in the usual fashion, their effect on the measurement is not considered significant.

Recommendations. Earlier this year, the National Mapping Council of Australia, after reviewing the development work on the Tellurometer and the uniformity of results obtained by various agencies, endorsed the following advice

TABLE 2. Tellurometer Traverse, Alice Springs to Halls Creek

Backward and forward measurements made by the Division of National Mapping during the 1958 field season are compared.

Slope Distance Ecce to Ecce	Forward, ft	Meteorological Correction	Range of Swings, ft	Backward, ft	Meteorological Correction	Range of Swings, ft	Difference, Forward − Backward, ft	Measurement 1 : Fractional	Difference in Meteor. Corr. Forward − Backward, ft
Gardiner–Treachery	127,420.55	32.02	3.37	127,421.04	35.26	2.87	−0.49	262,000	−3.24
Treachery–Matthews	57,846.50	15.28	3.4	57,846.61	14.66	3.5	−0.11	527,000	+0.62
Campbell–Matthews	121,714.77	31.39	1.4	121,714.91	32.07	1.1	−0.14	860,000	−0.68
Campbell–Patricia	162,618.46	42.08	1.4	162,617.88	43.01	0.9	+0.58	279,000	−0.93
Theo–Patricia	78,201.35	21.31	4.5	78,200.82	21.05	3.7	+0.53	148,000	+0.26
Theo–Bennett	166,821.84	42.75	1.2	166,822.76	43.25	0.6	−0.92	181,000	−0.50
Bennett–Solitaire	137,222.70	36.19	1.0	137,223.55	37.12	0.9	−0.85	161,000	−0.93
Solitaire–Davidson	113,178.28	29.39	2.0	113,178.06	30.56	2.3	+0.22	513,000	+1.17
Davidson–Approach	151,909.91	40.12	0.9	151,910.38	40.55	1.2	−0.47	321,000	−0.43
Approach–Granites	48,406.03	12.85	1.2	48,405.90	13.11	1.2	+0.13	371,000	−0.26
Granites–Ptilotus	117,050.59	31.54	2.5	117,050.75	31.55	3.2	−0.16	728,000	−0.01
Ptilotus–Frankenia	112,973.30	30.10	1.5	112,973.43	32.19	1.4	−0.13	677,000	−2.09
Frankenia–Tanami	103,627.96	29.32	1.5	103,627.90	27.75	1.4	+0.21	490,000	+1.57
Tanami–Frederick	184,945.47	49.76	1.7	184,946.78	49.93	1.6	−1.31	141,000	−0.17
Frederick–Junction	179,210.58	46.92	1.0	179,211.31	47.01	0.6	−0.73	245,000	−0.09
Junction–Westwall	180,962.08	48.77	2.1	180,962.33	48.90	1.8	−0.25	722,000	−0.13
Westwall–Browns	45,274.58	12.33	0.9	45,274.41	12.15	0.7	+0.17	267,000	−0.08
Browns–Windoo	127,126.74	36.71	1.3	127,126.61	34.94	1.0	+0.13	975,000	+1.77
Oaks–Windoo	128,598.21	41.69	1.5	128,590.47	33.46	0.5	−0.26	495,000	+8.23
Gardiner–Finniss	146,352.07	35.81	3.1	146,354.44	38.78	2.7	−2.37	62,000*	+2.97

* This line will be remeasured.

as tendered by its Technical Subcommittee, and recommended that it be taken into account in future Geodimeter and Tellurometer operations:

> The Subcommittee believes that, after consideration of the work carried out during the past two years, an average accuracy can be obtained with electronic distance-measuring equipment as follows:
>
> (*a*) Geodimeter, 2 parts in 10^6
> (*b*) Tellurometer, between 5 and 10 parts in 10^6
>
> *Recommended distances* for use of various instruments for geodetic purposes:
>
> Geodimeters, from 1 to 20 miles
> Tellurometers, from 10 to 50 miles
>
> *Frequency.* Recommended that error in frequency of the crystal should not exceed 1 part in 10^6.
>
> The Subcommittee is keenly aware of the danger of possible changes of frequency in the field and is of the opinion that simple and economical equipment can be designed to carry out field checks of the frequency of the 'A' crystal. It recommends that action be taken to have such equipment designed and tested.
>
> *Ground swing with Tellurometer.* The Subcommittee has considered the effects of ground swing on measurements, and believes that the treatment suggested by Mr. Wadley in the handbook of the equipment will provide a satisfactory interpretation of such swings.
>
> *Meteorological corrections.* The Subcommittee is of the opinion that the formulas for meteorological corrections, as laid down in the operating handbook, will give results which are acceptable for the order of accuracy envisaged in paragraph 1 of this recommendation.
>
> *Recommended practices in operation of the Tellurometer. Amplitude of ground swings.* The Subcommittee is of the opinion that the recommended accuracy can be obtained from measurements in which the regular ground swing does not exceed 6 μsec in total transit time.
>
> Where an initial measurement discloses ground swing of greater than 4 μsec it is desirable to change the standpoint of the instrument in an endeavor to reduce this ground swing.
>
> A ground swing of 10 μsec or more is considered to be a breakdown in measuring technique for *geodetic* purposes, and in such cases relocation or division of the line should be considered.
>
> In continuation of conventional survey practice it is recommended that all first-order control measurements be carried out twice, each measurement covering the whole range of cavities.

PROGRESS TO DATE

During the past 1½ years approximately 40 Tellurometer systems have been, or are in the course of being, placed in service in Australia by Commonwealth and State Survey authorities.

In addition to geodetic survey, a large amount of work is being carried out as control for topographic mapping.

With the geodetic survey in its skeleton form, many of the topographic measurements are made over lines that may at some future time be incorporated in the main geodetic scheme.

In view of the comparative ease with which first-order measurements can be made with the Tellurometer, it is standard practice to read all long lines to the recommended standard of accuracy of 1 part in 10^6.

The approximate total length of lines measured to this order of accuracy to date is 9000 miles, and it is apparent that within 5 years the Geodetic Survey of Australia will be well on the way to completion.

REFERENCES

Rimington, G. R. L., Report on Tellurometer tests, *Australian Surveyor, 16,* 494, 1957.

Waller, C. K., Field use of the Geodimeter, *Cartography, 1* (3), 1954.

Warner, J., The application of radar to geodetic surveying, *Australian J. Appl. Sci., 1* (2), 1950.