ABSTRACT
The EDM calibration scheme for electro-optical short range distance meters, as adopted in 1983 by the (Australian) National Standards Commission, is discussed. This scheme involves the establishment of EDM calibration baselines around Australia and the measurement of their lengths in terms of National Standards by the Australian States and Territories. Surveyors verify their electro-optical distance meters themselves on these baselines according to a set procedure. However, the respective Surveyor General does the necessary computations and issues a test report. Baselines are presently certified to about ±(0.4 mm + 4.0 ppm) and instrument corrections stated to about ±(1.0 mm + 4.0 ppm) for typical distance meters and baselines. The state of the introduction of the scheme was surveyed in June 1990. Some further work is required in most States/Territories to make the scheme fully operational.

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Introduction
In February 1983, a working party of the National Standards Commission made eight recommendations on how legal traceability to the National Standards of Physical Measurements could be provided for the practising surveyors who use electronic distance measurement (EDM) equipment in day-to-day work. (Further details on the history of the calibration scheme may be found in RÜEGER (1985).) The recommendations were endorsed in the same month by the National Standards Commission. Since that time, the States and Territories have (where required) established new EDM calibration baselines, amended legislations and regulations, published instructions, organized introductory workshops for surveyors and developed processing software. The success of the EDM calibration scheme seems to differ widely between the States/Territories. This paper introduces the scheme and describes the concepts of certified baselines and the calibration of short range distance meters. Some aspects of field procedures and test reports are discussed before focussing on the state of the scheme in June 1990 and on some remaining problems of the scheme's concept and operation.

2. Establishing Traceability
2.1 EDM Calibration Scheme
The calibration scheme is best presented with the aid of a diagram. Figure 1 gives an overview of the scheme as endorsed by the National Standards Commissions, together with some additions by this author. The cali-
TRACEABILITY OF EDM TO THE NATIONAL STANDARD

Commonwealth Standard of Length
  ↓
Commonwealth Working Standard of Length
  ↓
S.G. Reference (Invar) Tape
  ↓
(Common subsidiary standard, certificate)

Commonwealth Standard of Frequency
  ↓
Commonwealth Working Standard of Frequency
  ↓
Prescribed EDM Equipment
  ↓
(Presently: KERN MEKOMETER ME 3000)
  ↓
(Common subsidiary standard, certificate)

Certified EDM Calibration Baseline (Primary)
  ↓
(Subsidiary standard, certificate)

Normal case
  ↓
Surveyor’s EDM Instrument
  ↓
Calibrated by Surveyor
  ↓
(Computations and Test Report by S.G.)

Special case
  ↓
Surveyor General’s EDM Instrument
  ↓
(Subsidiary standard, certificate)

Surveyor’s EDM Instrument
  ↓
Calibrated by Surveyor General
  ↓
(Certificate)

Certified EDM Calibration Baseline (Secondary)
  ↓
(Subsidiary standard, certificate)

Surveyor’s EDM Instrument
  ↓
Calibrated by Surveyor
  ↓
(Computations and Test Report by S.G.)

Figure 1: Traceability of surveyors’ EDM instruments to the National Standard of length (Reger, 1985)

The traceability scheme involves the National Measurement Laboratory (N.M.L.) of CSIRO, the verifying authorities (Surveyors-General) of the States and Territories and all surveyors operating under State/Territory surveyors acts and survey practice regulations. The two former parties are appointed by the National Standards Commission under the National Measurements Act. The activities of the verifying authorities and surveyors are summarized in Tables 1 to 3. The establishment of traceability is now explained in detail.

Typically a “prescribed” EDM instrument is calibrated by the National Measurement Laboratory (N.M.L.), C.S.I.R.O., Sydney, against the national standard of frequency. At the time of writing, only distance meters of the types KERN Mekometer ME 3000 and COM-RAD Geomensor 204 DME are routinely calibrated by the National Measurement Laboratory for certification under the National Standards Act. These two types of instruments have been selected as prescribed distance meters because of their high resolution of 0.1 mm and the presumed absence...
of instrumental errors other than additive constant and frequency errors. In future, superior high precision distance meters (such as the Kern Mekometer ME 5000) are likely to replace the Mekometer ME 3000 and the Geomensor 204 DME.

The National Measurement Laboratory calibrates the modulation frequencies at different ambient temperatures and issues a certificate. The certificate specifies the 99 percent confidence intervals (uncertainty) of the scale corrections at specific temperatures and the date by which reverification is required (typically one year later). The uncertainty of ±10 ppm, as presently stated by the N.M.L. for instruments of the types Mekometer ME 3000 and Geomensor 204 DME, accounts for the frequency measurement errors incurred as well as some residual uncertainties in the principle of frequency measurement (MEIER & RÜGGER 1984), residual frequency instabilities (MAURER 1983), some retrace effects (RÜGGER 1982) and for other instrumental errors which are not removed by frequency calibration and additive constant determination (RÜGGER & CIDDOR 1989).

With the issue of a certificate, the Mekometer or Geomensor becomes a subsidiary standard of length and may then be used by the verifying authorities of the States and Territories, namely the Surveyors-General, to determine the lengths of selected primary baselines in the States and Territories.

All States and Territories follow the measuring and analysis procedures (RÜGGER 1984b) prescribed by the National Standard Commission when determining the true lengths of baselines. Typically, all distance combinations are measured, irrespective of baseline design. This allows the determination of the additive constant of the Mekometer/Geomensor and reflector combination by ‘self-calibration’. Baselines are then declared as subsidiary standards of length by the verifying authorities (Surveyors-General). Having discussed the method recommended by the National Standards Commission, it is mentioned that, at least in principle, an alternative way of measuring baselines is available through the use of another type of subsidiary standard of length, namely invar wires and tapes. In the case of reference tapes being certified at the ±2 ppm level of uncertainty, the resulting baseline uncertainty is likely to be better than in cases where Mekometers or Geomsensors are used. However, one attempt (in Canberra) of using invar wires was quickly abandoned once the temporal instability of the wires became evident.

After a baseline has been certified, it can be used by surveyors to calibrate (verify) their EDM instruments, in accordance with measuring procedures specified by the Surveyor-General. Typically, a standardised field form is used and then forwarded to the Surveyor-General for processing and issue of a test report. In principle, the field and analysis procedures recommended by the author (RÜGGER 1984a) are followed by most States and Territories. The test reports state the necessary instrument correction and associated uncertainty at different distances. A sample of a test report is given in the Appendix.

Table 1: Involvement of the verifying authorities with the national EDM calibration scheme during the preparation phase.

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meters on a certified baseline for the purpose of measuring other (secondary) baselines with this distance meter. After calibration, a certificate is issued for this selected distance meter, thus declaring it a subsidiary standard of length. When issuing certificates for non-prescribed EDM instruments, the verifying authority has to specify the uncertainty in such a way that all instrumental errors not evaluated in the calibration process are covered. Any electro-optical short range distance meter so issued with a certificate can then be used to measure (secondary) EDM calibration baselines, which, in turn, can then be certified with the issue of certificates. It is obvious, that the accuracy deteriorates with each step of the calibration chain because the stated uncertainty must reflect the measurement errors of all steps, right back to the National Standard.

In special cases, the verifying authorities (Surveyors-General) may be prepared to test a distance meter of a third party and to issue a legal certificate, at a cost. Such an approach may have to be followed in connection with court cases.

- Processing of surveyors’ baseline observations
- Issue of test reports to surveyors
- Maintenance of baselines
- Remeasurement of baselines (at least every two years)
- Renewal of certificates for baselines after remeasurements
- Recertification of certified EDM instruments (initially after 1 year, later every 2 years)

Table 2: Involvement of the verifying authorities with the national EDM calibration scheme during the production phase.

- Measure baseline periodically (typically, once per year) with each EDM instrument following the measurement procedures specified by verifying authority (Surveyor General).
- Forward field forms to verifying authority (Surveyor General) of the State/Territory for processing.
- Repeat baseline measurements if the test report from verifying authority (Surveyor General) states that the instrument does not fulfill the National Standard Commission’s recommendations on the accuracy of the instrument correction (refer to Eq. (2)).
- After receipt of test report from verifying authority (Surveyor General), apply the stated instrument correction to all distances measured in “legal” surveys.

Table 3: Involvement of surveyors with the national EDM calibration scheme.

2.2 Certified Baselines

The National Standards Commission stated clearly that it does not wish to suggest designs for baselines. This applies both to the physical as well as the geometrical design. All that is required is a permanent and durable marking, by either ground marks or survey pillars, and that the baseline is capable of being calibrated with an uncertainty (99 percent confidence interval) of

$$\pm (1.5 \text{ mm } + 20 \text{ ppm})$$  \hspace{1cm} (1)

In terms of standard deviation, standard error and root mean square (r.m.s.) error, this is equivalent to about $\pm (0.6 \text{ mm } + 8 \text{ ppm})$. The relevant recommendation notes that there may be circumstances when calibration to a lower accuracy (higher uncertainty) would be adequate. This statement refers to secondary or tertiary baselines.

The recommended baseline uncertainty was compared against two actual data sets, which were kindly provided by the Melbourne Metropolitan Board of Works, and against another two simulated data sets. In doing so, the uncertainty of the Mekometer ME 3000/Geomensor calibration by the National Measurement Laboratory was taken as $\pm 10 \text{ ppm}$ at the 99 percent confidence level (10 ppm line in Fig. 2), as stated previously. Figure 2 shows the predicted uncertainties of the four baselines. It is evident
that the States and Territories should have no problems to meet the prescribed baseline uncertainty of \( \pm (1.5 \text{ mm} + 20 \text{ ppm}) \) for baselines with eight stations. The four-station baselines in Fig. 2 perform significantly worse. In one of the two cases, the NSC’s recommendation is not met. When considering the baselines with 8 concrete pillars in Fig. 2, it becomes clear that primary EDM baselines can be certified easily to an uncertainty of \( \pm (1.0 \text{ mm} + 10 \text{ ppm}) \). This is significantly better than the requirement of Eq. (1). Better baseline values can only be achieved through an improvement in the scale uncertainty of the “prescribed” distance meters.
According to another recommendation of the National Standards Commission, certified baselines need to be reverified at least every two years. It is generally acknowledged that more frequent remeasurements are required until the stability of a particular baseline has been confirmed and also, on a continuing basis, if a baseline is found to be unstable. Pillared baselines are likely to exhibit some long term movements, particularly if the pillars are not built on bedrock. The worst pillar movements (so far) have been reported from the U.N.S.W. EDM Research Baseline in Regents Park, Sydney, where one pillar showed seasonal changes of 15 mm peak-to-peak over two consecutive years (RÜEGER 1983). The 1989 remeasurement of the baseline of the National Measurement Laboratory in Sydney showed that even pillars set on bedrock can exhibit long term movements (of 6 mm over 7.5 years). Despite the possibility of some long term movements, pillared baselines are now favoured by all States and Territories because of the gain in precision through fixed instrument heights and constrained centring and the greatly reduced field effort.

The geometric design of certified baselines differs between the States and Territories. Here, the author's new terminology (RÜEGER 1990) is used to classify the different types of EDM calibration baselines. (The original publications are also given for easier reference.) Since the 1980 survey of EDM calibration facilities (RÜEGER 1981), new baselines have been established and old ones lost or abandoned. At the time of the adoption of the new scheme, Queensland and the Northern Territory had already a large number of Heerbrugg-type baselines, either in original (SCHWENDENER 1972) or generalised form (RÜEGER 1978). A number of additional baselines were built in Queensland since that time. The Surveyor-General of New South Wales constructed 18 Heerbrugg-type baselines with four pillars each across the State. The baseline in the Australian Capital Territory is of Hobart-type (SPRENT & ZWART 1978, SPRENT 1980) and features 10 concrete pillars. The state of Victoria has presently four certified Hobart-type baselines in the Melbourne Metropolitan Area and two in country areas. Tasmania has a network of three Hobart-type baselines with 7 pillars each. South Australia established one Aarau-type (AESCHLIMANN & STOCKER 1974; RÜEGER 1976, 1977) baseline (with cyclic error rail) in Adelaide (LARDEN et al 1983). Western Australia relies on a certified eight pillar baseline in Perth of non-standard design. A shorter seven pillar baseline of Heerbrugg-type is operated by the Water Authority of W.A. in a disused railway tunnel. The latter is likely to be the sole underground EDM calibration facility in Australia.

Figure 3 shows the geographical distribution of Australian EDM calibration baselines, which were reported by the verifying authorities in a survey in June 1990. The figure does not depict all existing baselines. Also, it is unlikely, that the verifying authorities intend to establish and maintain certification of all baselines shown. The distribution of the baselines exhibits similar patterns as the population distribution. It should be noted that a large number of Queensland's baselines are operated by mining companies. Considering this, the lack of baselines in the NW of Western Australia and New South Wales is noticable.

2.3 Calibration of Short-Range Distance Meters

The National Standards Commission states that the minimum standard for the uncertainty of calibration of an EDM instrument should be

\[ \pm (5.0 \text{ mm} + 30 \text{ ppm} ) \]

(2)

at the 99 percent confidence level*. This recommendation means that an instrument correction is derived for a distance meter/ reflector pair from measurements on a certified EDM baseline and that the uncertainty (against the National Standard) of this instrument correction (i.c.) does not exceed \( \pm (5 \text{ mm} + 30 \text{ ppm}) \). After a calibration, the derived instrument correction is applied to
distance measurements, which brings the distance meter readings in line with the National Standard of length. In terms of standard deviation, the instrument correction must be accurate to at least

$$\pm (2.0 \text{ mm} + 12 \text{ ppm})$$  \hspace{1cm} (3)

It is important to realise that the uncertainty and standard deviations listed above refer to the accuracy of the instrument correction and not to the precision of a distance measurement. In particular, Eq. (3) does not relate in any way to the accuracy specifications quoted by manufacturers for their instruments.

The minimum standard for the uncertainty of the instrument correction (Eq. (2)) takes into account that the surveying tolerances set by the Surveyors-General must accommodate the uncertainty (or precision) of the field measurements of cadastral surveys as well as the uncertainty of the instrument correction. The precision of the instrument correction must be considered because the instrument correction is added to each single distance. The chosen uncertainty of the instrument correction corresponds to 50 percent and 43 percent of the most stringent cadastral requirements of $\pm 83$ ppm (1 part

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in 12 000) at distances of 500 m and 1000 m, respectively. At 94 m, the uncertainty of the instrument correction after Eq. (2) fully consumes the most stringent tolerance of cadastral surveys of 1 part in 12 000. This means, in principle, that instruments, which just fulfill the conditions of Eq. (2), cannot be used for cadastral surveys in States and Territories where the ‘1 part in 12 000’ rule applies, unless the actual uncertainty of the instrument correction is better than specified by the National Standards Commission (Eq. (2)). Some Australian States and Territories have relaxed their cadastral tolerances (by introducing a millimetre term of typically 10 mm) to remove this anomaly.

In the context of routine legal calibration of EDM instruments, the following maximum number of parameters of the instrument correction are determined:

\[
\text{I.C.} = a_0 + a_1 (D/1000)^1 + a_2 (D/1000)^2 + a_3 (D/1000)^3 + a_4 (D/1000)^4 + a_5 (D/1000)^5
\]

\[
+ b_{11} \sin B_1 + b_{12} \cos B_1 + b_{21} \sin B_2 + b_{22} \cos B_2 + b_{31} \sin B_3 + b_{32} \cos B_3 + b_{41} \sin B_4 + b_{42} \cos B_4
\]

where \( B_i = 2\pi(D/U) \), \( B_2 = 4\pi(D/U) \), \( B_3 = 6\pi(D/U) \) and \( B_4 = 8\pi(D/10) \).

The instrument correction (I.C.) is obtained in millimetres. The distance (D) and the unit length (U) are entered in units of metres. The parameters \( a_0 \) to \( a_5 \) are the coefficients of a fifth degree polynomial, with \( a_0 \) and \( a_{11} \) being the additive constant (in mm) and the scale correction (in ppm), respectively. The parameters \( b_{ij} \) are the coefficients and \( B_i \) the arguments of the short periodic errors of first to fourth order, respectively.

The verifying authorities will compute instrument corrections which have the smallest number of parameters and still fulfill the recommendation of the NSC given in Eq. (2). In practice it is suggested that all parameters shown in plain face in Eq. (4) are determined in a first least squares adjustment and that the resulting parameters are statistically tested for the significance of their differences from zero. If the instrument correction fulfills the accuracy recommendation of the NSC, a second adjustment is carried out with solution for \( a_0 \) and \( a_{11} \) and other significant parameters, after which the accuracy of the final instrument correction is again checked against the NSC recommendation. It should be noted that the additive constant \( a_0 \) and the scale correction \( a_{11} \) are always solved for, even if they do not statistically differ from zero. This is necessary, because the NSC recommendations of Eq. (2) refers to the accuracy of the instrument correction. It is well known that the accuracy of the instrument correction cannot be computed unless such an instrument correction is first determined. As the latter must include the absolute scale uncertainty (against National Standards) of the baseline lengths, it is of advantage to always determine a scale correction in addition to the additive constant.

Should the instrument correction not fulfill the accuracy recommendation specified by the NSC after an initial adjustment, the parameters shown in italics in Eq. (4) are included in a second adjustment. If the new solution for a 14-parameter instrument correction fulfills the NSC recommendation, a third adjustment follows, which solves for \( a_0 \) and \( a_{11} \) and all statistically significant parameters. Should even a full 14-parameter solution for the I.C. fail to satisfy the NSC's accuracy recommendation, the instrument must be recalibrated, possibly on a more sophisticated EDM calibration baseline.

According to WITTE & SCHWARZ (1984), about 80% of instruments will require only the first two terms of the polynomial expression. In their sample of 133 instruments, 20% required a full polynomial solution. A large number of instruments will also require a further two parameters to model one cyclic error.

Based on the 'error allowance' between the specified surveying tolerance and the actual uncertainty of the instrument correction, a surveyor has to decide on:

- how accurately to centre EDM instrument and reflector,
- how accurately to measure temperature (or to take a guess),

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• how accurately to measure the pressure (or to operate on 'normal' pressures based on elevation),
• the necessity of shading the EDM instrument,
• how accurately to measure zenith angles and so forth.

For example, the specified tolerance of ± 83 ppm (1 part in 12,000) amounts to ± 21 mm at a distance of 250 m. At the same distance, the instrument correction will have an uncertainty of ± 12.5 mm or better according to Eq. (2). With the use of the propagation law of variances, the error allowance for the field operation can be calculated as:

$$(21^2 - 12.5^2)^{0.5} = ± 17 \text{ mm}$$

(5)

In order to find out how actual uncertainties of instrument corrections compare to specified uncertainties, computer simulations were carried out using five different geometrical baseline designs. Some aspects of the baselines considered are listed in Table 4. It is assumed that all five baselines were measured with the same Mekometer ME 3000, each measurement having a precision of ± (0.3 mm + 0.5 ppm). The scale uncertainty (at 99 percent confidence level) was again taken as ± 10 ppm. It is also assumed that the same ordinary distance meter was calibrated on all baselines, that each distance measured had a precision of ± (1.5 mm + 1.0 ppm) and that an additive constant, a scale correction and “one” cyclic error (of 10 m wavelength) was solved for each time.

The results of these computations are given in Fig. 4 in graphical form. The curves confirm that the quality of the instrument correction increases (the uncertainty decreases) with an increase in the number of measurements, in the number of pillars and the overall length of lines. Considering that curves 1 and 5 refer to very similar baselines, their difference is quite striking. As Table 4 shows, the main difference between the two baselines is not the maximum but rather the minimum measurable distance. The shortest line on baseline 5 is rather long (183 m), which seriously degrades the scale accuracy of the derived instrument correction. A distinct improvement can also be seen between curves 1 and 2; this is particularly interesting when considering that a surveyor spends less time measuring the Mitcham baseline than the Newcastle baseline. A less significant improvement is evident between curves 2 and 3/4, despite the large increase in measuring time for the latter two. (This would look quite different, if the scale uncertainty of the prescribed distance meter (here Mekometer ME 3000) were better than the assumed ± 10.0 ppm). The reason why Eagle Farm performs (unexpectedly) better than Regents Park (at least above 500 m) stems from its greater length, its shorter minimum distance and the fact, that all combinations were measured with the Mekometer. (In practice, distances longer than 900 m should not be measured in the low-range setting of the Mekometer ME 3000).

<table>
<thead>
<tr>
<th>Locality</th>
<th>State</th>
<th>Number of Pillars</th>
<th>Distance Min./Max. (m)</th>
<th>Number of Measurements ME 3000</th>
<th>Other</th>
<th>Baseline Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newcastle</td>
<td>NSW</td>
<td>4</td>
<td>42/611</td>
<td>6</td>
<td>6</td>
<td>Heerbrugg</td>
</tr>
<tr>
<td>Mitcham</td>
<td>VIC</td>
<td>6 + 2</td>
<td>70/600</td>
<td>25</td>
<td>10</td>
<td>Hobart</td>
</tr>
<tr>
<td>Regents Park</td>
<td>NSW</td>
<td>8</td>
<td>60/980</td>
<td>21</td>
<td>28( + 20)</td>
<td>Aarau</td>
</tr>
<tr>
<td>Eagle Farm</td>
<td>QLD</td>
<td>7</td>
<td>20/1021</td>
<td>21</td>
<td>21</td>
<td>Heerbrugg</td>
</tr>
<tr>
<td>Wollongong</td>
<td>NSW</td>
<td>4</td>
<td>183/600</td>
<td>6</td>
<td>6</td>
<td>Heerbrugg</td>
</tr>
</tbody>
</table>

Table 4: Some important parameters used in the computer simulations for the uncertainty of instrument corrections determined with the same distance meter on different baselines. All baselines are assumed to be pillared and to have been measured with the same Kern Mekometer ME 3000 for certification. The ‘(+ 20) ’ refers to 20 cyclic error testline observations (RÜGER 1985). The Mitcham baseline has six main pillars. Of the two additional pillars at 5 m and 10 m from the origin, only one is used for routine calibrations.
Figure 4: Uncertainty of instrument corrections as specified by the National Standards Commission and as predicted for some typical EDM calibration baselines. The predictions are based on Mekometer ME 3000 measurements (in all combinations) of a precision of $\pm (0.3 \text{ mm} + 0.5 \text{ ppm})$ and on measurements with a distance meter to be tested, assuming a precision of $\pm (1.5 \text{ mm} + 1.0 \text{ ppm})$. The curves 1, 2, 3, 4 and 5 refer to uncertainties (at 99 percent level of confidence) of the instrument correction as derived from fictitious measurements on the Newcastle (NSW, 4 pillars), Mitcham (VIC, 8 pillars), Regents Park (NSW, 8 pillars), Eagle Farm (QLD, 7 stations) and Wollongong (NSW, 4 pillars) baselines, respectively. The five baselines are further described in Table 4. The uncertainty of the Mekometer's scale was again taken as $\pm 10.0 \text{ ppm at the 99 percent level. It is the largest contribution to curves 3 and 4 at longer distances. A four-parameter instrument correction (one constant, one linear and two periodic terms) was determined in all five cases.}

Figure 4 also demonstrates that the curve 5 does not comply with the National Standards Commission's recommendation of $\pm (5 \text{ mm} + 30 \text{ ppm})$ between zero and about 80 m and again beyond about 1200 m. Curve 1 does not comply between zero and about 45 m. Curves 2, 3 and 4 are better than recommended at all distances. The computer simulations indicate that all Australian baselines with more than four pillars permit the determination of four-parameter instrument corrections to better than recommended uncertainties. (Four-parameter corrections will be sufficient for about 80 percent of instruments.) Even better results can be expected in cases where a two-parameter instrument correction (additive constant, scale correction) is sufficient.
3. Field Procedures and Test Reports

Field procedures for the verification of electro-optical short-range distance meters on certified baselines are prescribed by the Surveyors-General of the States and Territories. The prescribed field procedures are minimal requirements thought necessary to meet the uncertainty requirements for the instrument correction as recommended by the National Standards Commission.

Surveyors may find for example that:

- the EDM instrument (station) needs to be shaded by an umbrella in order to protect EDM instrument, thermometer and barometer from direct sunlight.
- the pressure has to be measured (rather than derived from height above sea level). A ±10 ppm uncertainty (at 99 percent confidence level) of scale is so avoided.
- the ‘ppm-knob’ is set to the neutral position, usually 0 ppm, in order to avoid round-off errors in the dial (worst case ±15 ppm).
- the (mercury-in-glass) thermometer used must be calibrated (at least once in its lifetime) against Bureau of Meteorology or National Standards equipment.
- the barometer used must be calibrated prior to the baseline measurements against Bureau of Meteorology or National Standards equipment.

A complete list of recommended practices may be found elsewhere (RUEGER 1984a, 1990).

The Surveyors-General as verifying authorities provide standard field forms for the baselines under their control. Because of different baseline designs, the forms differ between the States/Territories and, possibly, between baselines within States/Territories. These forms ensure that the verifying authorities receive all data necessary for the computation of the instrument correction and for the issue of a test report. Because of the statistical aspects, the computations are quite demanding. They are best executed by the verifying authority, which already holds all data in relation to the certification measurements of the baselines. Details on the recommended analysis procedures may be found in RUEGER (1984a). Centralised processing also permits the monitoring of the stability of the baselines on a continuing basis, using the data supplied by the surveyors.

It is anticipated that, eventually, all Surveyors-General will issue test reports to surveyors on the basis of submitted field forms. A fictitious sample of such a report is given in the Appendix. These reports need to establish what equipment was tested and under what conditions. This ensures the repeatability of calibrations. The first paragraph in the Appendix lists the relevant equipment. The second defines the baseline and its ‘true value’ datum. The third paragraph lists the first velocity correction equation used in the analysis procedure, because the correction directly affects the listed scale correction. Rather than measured humidities, yearly average values are used. This simplification causes scale errors of less than one part per million.

Paragraph 6 in the Appendix describes the thermometer and barometer employed and how, where and when these were calibrated. The resulting instrument correction, comprising only two parameters in this case, is stated in paragraph 7. The same paragraph states also the validity of the correction in terms of distance and temperature. The uncertainty of the instrument correction is given at selected distances, which allows the production of diagrams similar to Fig. 4.

The question arises how a surveyor should deal with the restriction of the instrument correction to one particular temperature and a specific range of distances. In particular, what should be done if the field temperature does not correspond to the 19°C listed in the report? Initially, the surveyor would have to rely on the manufacturer’s specification of, say, ±(3 mm + 3 ppm) and assume that the second (ppm–) term reflects the oscillator specifications between −10°C and +50°C. This additional uncertainty of ±3 ppm does not matter considering the most stringent cadastral requirements in Australia of
±83 ppm (or 1 part in 12,000). Eventually the surveyor should be able to plot the scale corrections of repeat calibrations against temperature and, thus, to find out how the scale of the EDM instrument is varying with temperature. (If necessary, this scale versus temperature characteristic can be obtained faster and with better accuracy by frequency measurement (RÜEGER 1982, 1990).) To avoid erroneous conclusions, the scale corrections should also be plotted against time to monitor the ageing effect. Maximum drift rates of scale measured by this author do not exceed 0.3 ppm/°C (RÜEGER 1987) and 0.82 ppm/year (RÜEGER 1982).

A second question refers to the use of an instrument correction outside its specified distance range (70 to 600 m for the example in the Appendix). In the absence of other calibrations, the same instrument correction would have to be used outside this range. As the instrument correction would be based on extrapolation below 70 m and beyond 600 m extra allowance should be made for the additional uncertainty. Extrapolations below the minimal distance measured on a baseline are particularly dangerous, as many distance meters exhibit unusual error patterns on close range. It is suggested that the distance range below the minimal baseline distance be tested separately, if required. Paragraph 8 of the Appendix refers to short periodic errors, commonly known as cyclic errors. It should be remembered that the cyclic error at distances shorter than 70 m or longer than 600 m could be different from the one stated in the instrument correction. In this particular case, the short periodic errors were found to be insignificant. The last paragraph of the sample test report specifies the date, by which the distance meter needs to be reverified. The Surveyors-General will specify the reverification schedule. Outside the normal reverification schedule, distance meters need to be recalibrated whenever they return from repairs and service and after ‘accidents’ in handling the equipment.

As mentioned before, the surveyor is likely to be asked to repeat the baseline test in cases where the instrument correction of a particular distance meter does not meet the requirements of the National Standards Commission (Eq. (2)). Should the second instrument correction, comprising the maximum number of parameters, again fail to meet the requirements, a third calibration on a more sophisticated certified EDM baseline may be required, where either an instrument correction with more parameters or a more precise correction can be resolved. It is clear that the maximum number of fourteen terms in the instrument correction (six polynomial terms, eight cyclic error terms; RÜEGER 1987, 1990) can only be obtained if more than fourteen different distances can be measured on a baseline. This implies a minimum number of 6 stations for Hecbrugg-type baselines, 7+1 stations for Hobart-type baselines and 5 stations (+ cyclic error testline) for Aarau-type baselines. Most (but not all) certified Australian EDM calibration baselines meet this requirement.

4. Present Operation of Scheme

The computer simulations show that it is possible to certify primary EDM baselines with an uncertainty of ±(1.0 mm + 10.0 ppm) or better at the 99 percent confidence level and with respect to National Standards when using the KERN Mekometer ME 3000 or the COM-RAD Geomensor 204 DME as a transfer standard. Improved results can be expected as soon as the scale uncertainty of the transfer standard is reduced, most likely after the introduction of alternative prescribed distance meters such as the KERN Mekometer ME 5000. The computer simulations also indicate that instrument corrections based on a four parameter model are likely to fulfill the uncertainty specified by the National Standards Commission irrespective of what type of certified baseline is used for its determination. The only certified baselines not to fulfill the recommendation are those in New South Wales at short and, in some cases, long distances.

On the four-pillar baselines established recently by the Department of Lands in NSW, it is not possible to determine instrument corrections with more than six parameters.
Also, solutions for five and six parameters are unlikely to meet the recommended uncertainty for the corrections. The Tasmanian baselines do not allow the determination of 14-parameter instrument corrections at the recommended uncertainty. In all other States and Territories, one, some or all certified baselines allow successful determinations of instrument corrections with 14 parameters.

The calibration scheme endorsed by the National Standards Commission has been designed for electro-optical short-range distance meters and their use in cadastral surveys. Even so, distance meters calibrated to National Standards Commission’s specifications will not meet the 83 ppm tolerance of cadastral surveys in New South Wales and in the Australian Capital Territory at distances below 94 m. The more common tolerance of 1 part in 10 000 (100 ppm) is not met for distances below 71 m.

A successful calibration scheme must address the following operational aspects: EDM calibration baselines, certification of these baselines, written instructions and field forms for users, software packages for the analysis of data and the preparation of test reports, issue of test reports by verifying authorities, appropriate changes to legislation/regulations, information/training meetings for the profession and enforcement of legislation/regulations. To evaluate the state of introduction of the seven year old legal EDM calibration scheme in Australia, the verifying authorities were asked to respond to a short questionnaire in June 1990. Table 5 summarizes the replies received and Figure 3 depicts the geographical distribution of the baselines reported on this occasion.

<table>
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<th>Inform</th>
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Table 5: Summary of the state of introduction of the Australian legal EDM calibration scheme based on information supplied by verifying authorities in June 1990. The ‘Baselines’ referred to are reported by the Surveyors-General. A “Y” in columns “Form” and “Instr.” indicates that field forms and baseline measurement instructions are available. For software used in processing, their availability and the maximum number of generated “polynomial” and “periodic” terms of the instrument correction are listed. A “Y” in the “Process.” and “Report” columns means that surveyors data are processed and that test reports are issued to surveyors. (Some States/Territories have delegated some or all processing and issuing of reports to other organisations.) Also, it is reported that not all measurements carried out on certified EDM baselines are supplied to verifying authorities. A yes (“Y”) in the column “Legist.” indicates that legislation (acts, regulations, instructions) have been changed to include an explicit requirement for periodic baseline calibrations. The importance of changes in legal requirements for EDM calibration varies greatly between States/Territories. The column “Training-Information” lists the means by which practising surveyors have been informed (and are being kept up-to-date) with the scheme H = handbooks, B = bulletins (e.g. in surveyors’ newsletters), S = seminars.
It is evident that few States/Territories have introduced the complete EDM calibration scheme as defined above. For example, Tasmania has implemented all aspects minus the certification of the baselines. New South Wales has built and certified a large number of baselines but has not yet considered most other aspects of the scheme. Dedicated computer programs were written by the verifying authorities of Victoria (NORTON 1986) and South Australia. The former software package is also used in Western Australia and in the Australian Capital Territory. The other States/Territories do not use appropriate programs and do not yet conduct the required statistical analyses. For various reasons, the operation of the scheme necessarily varies between States/Territories. For example, calibrated thermometers and barometers are supplied to baseline users in Victoria. This is a valuable service as long as the surveyors test their own thermometers and barometers against the calibrated equipment on such occasions. In line with the recent moves towards “cost recovery” of government departments, some States report the likely introduction of the “user-pays” principle for baseline use, data processing and preparation of a test report. Experience has shown that surveyors will support the scheme once they see how easy it is to keep track of the performance of electronic distance meters and once they accept that checking one’s instrument is an important aspect of quality assurance in professional practice. A small fee for the yearly calibration is unlikely to change this. Early results showed clearly the need for legal EDM calibration (BENWELL, MURNANE & SPRENT 1985). Based on the past and present experience with the legal requirements for the calibration of surveyor’s tapes and bands, it is predictable that the Surveyors-General as verifying authorities are unlikely to enforce legal requirements for EDM instrument calibration. If true, this would be unfortunate.

Although the present certification at \( \pm 10 \) ppm (99 percent confidence level) of the Mekometer ME 3000 and the COM-RAD Geomensor 204 DME may be somewhat conservative, it is warranted considering the large number of systematic errors in these distance meters. Some of these systematic errors have not been investigated and some others are unpredictable (CIDDOR 1989, MAURER 1983, MEIER & RUEGER 1984, RUEGER 1984c, RUEGER & CIDDOR 1989). The measuring process with both types of instruments was found to be cumbersome. Lengthy down periods for repairs and problems when measuring under high voltage power lines were reported for the Geomensor. Certification measurements are also hampered by the fact that both instruments exhibit poor resolution (\( \pm 0.5 \) to \( \pm 1.0 \) mm) on close range (RUEGER & CIDDOR 1989).

Some verifying authorities intend to replace the above two instruments with less cumbersome instruments such as precise infrared distance meters, at least for the verification of secondary EDM calibration baselines. For infrared distance meters, it is insufficient to calibrate solely an additive constant and a scale correction. Short periodic errors and other non-linear distance-dependent errors would have to be carefully calibrated (RUEGER 1990). One aspect, which clearly restricts the use of infrared distance meters as transfer standards, is the temperature dependence of the transmitted infrared radiation and, thus, of the scale of the measured distances (RUEGER 1990).

The Australian scheme for the legal calibration of distance meters does not yet address the question how high-precision, long-range and microwave distance meters should be calibrated against National Standards. To permit the calibration of precision distance meters, the accuracy of the certified baselines must be greatly improved. This is only possible through the use of better certified distance meters (transfer standards). At the present time, the KERN Mekometer ME 5000 is the only commercial high precision instrument with quasi-absolute length standard qualities. Development work in Australia and Japan on absolute CO2 (and other) interferometers may eventually lead to alternative measuring systems for primary EDM calibration baselines (MATSUMOTO 1986, WALSH 1987). Considering the gradual re-
placement of long range EDM by GPS, it is not felt necessary to set up a legal calibration system for optical long-range and microwave distance meters. As in the past, the scale of these instruments continues to be verified by frequency measurement and the additive/reflector constant on baselines.

Recommendations

A final effort must be made to fully implement the legal calibration scheme for electro-optical short range distance meters. Most States/Territories have a reasonable distribution of EDM calibration baselines. Victoria and Western Australia could benefit from some additional baselines in country areas. In New South Wales, the baselines established by the Lands Department should be upgraded to six pillars as soon as possible. The present four-pillar baselines cannot satisfy the requirements of the national scheme (Figs. 2 and 4).

All baselines in Tasmania, Victoria, Western Australia and Northern Territory were not certified on 1 July 1990. Considering that all Surveyors-General are legally appointed (under the National Measurements Act) as verifying authorities for length and that certified baselines must be reverified at least every two years, this seems to indicate a serious lack of attention. It is hoped that this lack of certification will be remedied soon and measures are taken to maintain certification in future.

A number of States/Territories need to upgrade their analysis software, both in terms of the number of parameters of the instrument correction solved for and in terms of a rigorous computation of the statistical uncertainty of the I.C. relative to National Standards. As far as the first aspect is concerned, all States/Territories should be able to compute at least the six basic parameters (shown in plain type in Eq.(4)) of the I.C. The full set of 14 parameters would be desirable. Some States/Territories might consider using the Victorian analysis program (NORTON 1986), which is now running on personal computers under MS-DOS. It is often forgotten that the second aspect, namely the rigorous determination of the statistical un-

certainty of the I.C. against National Standards, is equally important. This information is required to determine if a tested instrument fulfils the NSC requirement of Eq. (2). As the computation of the I.C.’s uncertainty requires access to the original certification measurements of a baseline, the processing of surveyors baseline data are best carried out by the organisation, which also processes the certification measurements. Individual surveyors are unable to do their own baseline processing because they usually lack the necessary software and do not have access to the certification measurements. With the recent introduction of facsimile transmission, centralised processing within States/Territories seems the most efficient approach. Regional processing is feasible as long as only one centre deals with one particular baseline (or a number of baselines). Regionalised processing requires naturally more skilled computer operators than a centralised one. These operators must not only process the certification measurements and the data supplied by surveyors; they must also monitor the stability of each baseline between reverifications.

After implementation of the above recommendations and the rectification of some smaller deficiencies (outlined in Table 5 and in the previous section), Australia will have a very efficient scheme for the legal calibration of electro-optical distance meters. In future, it may be possible to improve the accuracy of the certified baselines by using better prescribed distance meters. The scheme would then be able to cater for the more stringent calibration requirements of distance meters used in engineering and industrial surveys. This could be easily achieved if the Surveyors-General of the States and Territories would pool their resources for the purchase of a high precision distance meter.

Surveyors, who wish to get information on the operation of the legal EDM calibration scheme in their State/Territory, should contact their Surveyor-General. A full report on the 1990 survey of Australian EDM instrument calibration facilities will be published separately.
Acknowledgements
The author is greatly indebted to the verifying authorities for their response to the questionnaire in June 1990. In particular, the author wishes to thank Messrs. K. Freund, G. Helsham, P. Ronaldson, C. Lutz, A.G. Poznanski, K. Alexander, J. Veal and P. Bakes for collating the necessary information, and Mr. C. Rusu, for the preparation of the diagrams.

References


Appendix: Sample of a Test Report

This report (RÜEGER 1985) is fictitious in most parts. However, distance measurements and baseline are real.

Surveyor-General of Victoria

Test No.: 1248 Date: 15 October 1983

Statement of Test

ELECTRONIC DISTANCE METER

(1) The electronic distance meter AGA Geodimeter 112, serial number 23620, as mounted on the telescope of the theodolite Wild T2, serial number 234618, together with an AGA prism (AGA Part No. 571 125 021), as mounted in the centre hole of a tiltable AGA target (AGA Part No. 571 125 026), was calibrated on the ‘Mitcham’ Baseline in Melbourne on 10 October 1983 between 11.00 h and 12.00 h. The prism and the tiltable target carry the engraved marks ‘M.M.B.W. 427’ and ‘M.M.B.W. 286’, respectively.

(2) The ‘Mitcham’ Baseline was last measured and certified under Regulation 80 of the National Standards Regulations on 5 October 1983. A full description of this baseline may be found in the publication ‘The Mitcham Baseline’, as published by this Department (Publ. No. 247, February 1983). The EDM instrument as well as the target-reflector are owned by the Melbourne Metropolitan Board of Works, Mitcham Area Office.

(3) The measurements were executed in daylight and as specified in ‘Recommended Field Procedures for . . .’ (Published by this Department, Publ. No. 286, March 1983). The reflector/target assembly was
always pointed to the telescopic of the theodolite using the gun sight in the centre of the target, both, horizontally and vertically. All observations were made on a sunny day with light NW winds. The temperatures varied from +17 degrees Celsius to +21 degrees Celsius, with a mean temperature of +19 degrees Celsius.

(4) The following first velocity correction $K'$ was applied to all measurements $D$ by computation:

$$K' = \left( \frac{275.0 - \frac{79.6}{273.15 + t} + \frac{11.27e}{273.15 + t}}{10^6} \right) D$$

where $t$ in degree Celsius, $p$ and $e$ in millibar. The yearly average partial water vapour pressure of 12.8 mb was used, as specified for the Mitcham Baseline.

(5) No additive constant was applied to the measurements. Any built-in additive constants are unknown and inaccessible to the user. The observations were executed by Messrs. B. Green, P. Brown and G. Blue of the Melbourne Metropolitan Board of Works.

(6) For the temperature measurements a Zeal mercury pocket thermometer graduated from 0 degrees Celsius to 60 degrees Celsius at 1 degree Celsius intervals was used. The calibration constant of this thermometer was determined by comparison with the weather station dry bulb thermometer at Mitcham Post Office on 9 October 1983 and yielded +0.4 degree Celsius with an uncertainty of one part in one hundred of ±0.5 degrees Celsius. This thermometer carries the engraved mark 'M.M.B.W. 846'. A Thommen pocket barometer 'Everest 6000 m' with the serial number 416452 was used for the measurement of atmospheric pressure. Its calibration constant of −16.4 mb was derived by comparison with the mercury column barometer at the Mitcham Post Office on 9 October 1983 and with an uncertainty of one part in one hundred of ±0.5 mb. Both calibrations were executed as specified by the

‘Recommended Field Procedures for . . . ’ (published by this Department, Publ. No. 286, March 1983).

(7) The instrument correction I.C. (in millimetre) was determined according to the ‘Recommended Analysis Procedures for . . . ’ (Published by this Department, Publ. No. 287, March 1983) as follows:

$$I.C. = -0.7 - 1.8 \cdot \left( \frac{D}{1000} \right)$$

where $D$ is the distance in metre. This instrument correction is valid in the distance range from 70 m to 600 m and for an ambient temperature of +19 degrees Celsius. The second term of the instrument correction refers to a setting of the PPM-Dial to 0 ppm. The uncertainty of one part in one hundred of the above instrument correction I.C. is ±2.51 mm, ±3.29 mm, ±6.56 mm at 70 m, 260 m and 600 m, respectively. As a guide only, the uncertainties of the instrument correction are also given for longer distances as ±13.0 mm, ±19.7 mm and ±26.4 mm for distances of 1200 m, 1800 m, and 2400 m, respectively. When considering these values, due allowance should be made for the fact that they are based on extrapolation.

(8) This instrument/reflector set fulfils the requirements of Recommendation No. 8 of the NSC's working party on the 'Calibration of EDM Equipment'. The periodical error was tested over a wavelength of 10 m at distances ranging from 70 m to 600 m; it was found to be insignificant. The measured mean distances were found to have a precision of ±(0.6 mm + 0.4 ppm).

(9) The original measurements and computations may be found in file 'Test 1248' of this Department. The instrument should be reverified on or before the fifth October 1984.

CERTIFIED ON THE FIFTEENTH DAY OF OCTOBER 1983
FOR THE SURVEYOR-GENERAL OF VICTORIA
A.B.C. Miller