UNCLASSIFIED

APPENDIX

TO THE

FINAL TECHNICAL REPORT

# SHORT RANGE ELECTRONIC POSITIONING EQUIPMENT

PERIOD COVERED: JANUARY, 1962 - OCTOBER, 1962



CONTRACT NO: DA-44-009-ENG 3811

PROJECT NO: 8-35-10-500

PLACED BY: UNITED STATES ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES, FORT BELVOIR, VIRGINIA, U.S.A.

CONTRACTORS NAME: TELLUROMETER (PTY.) LTD.
A DIVISION OF
INSTRUMENT MANUFACTURING
CORPORATION OF SOUTH AFRICA LTD.

CONTRACTORS ADDRESS: IMC HOUSE,
PLUMSTEAD,
CAPE,
SOUTH AFRICA.

ENGTL — Report for Release to OTS, Department of Commerce

USA/ERDL
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The attached report has been cleared by the Department of Defense Directorate for Security Review, for release to the Office of Technical Services, Department of Commerce.

FOR THE CHIEF OF ENGINEERS:

Incl
Short Range Electronic Positioning Equipment, w/Appendix
(8 cys)

STANLEY T. B. JOHNSON
Colonel, Corps of Engineers
Chief, Technical Liaison Office

[redacted]

TELLUROMETER

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# SHORT RANGE ELECTRONIC POSITIONING EQUIPMENT

## 1. Introduction

The main body of this Report covers the period of the Contract up to October, 1961, at which time the Phase-III equipment was delivered to U.S.A. Tests were carried out with the equipment, and as a result it was further modified. The Phase-III equipment was designated Model COR1, and the modified equipment was designated Model COR2. These model numbers are used throughout this Appendix, which deals with the tests on and modifications to Model COR1 and the subsequent tests on Model COR2.

## 2. History

The COR1 equipment was cold-weather tested in the environmental chamber at Fort Belvoir during January, 1962. Various faults brought on by the low-temperature conditions were cleared and the equipment was taken to Fort Greely in Alaska for service tests in February, 1962. From these tests a great deal of useful information was obtained. At a subsequent discussion at Fort Belvoir on the shortcomings of the equipment, it was agreed that re-engineered units would be supplied to GIMRADA (see Paragraph 5).

The progress of the development was such that, with the prior permission of GIMRADA, a demonstration could be given to the British Army at the School of Artillery, Larkhill, England, during July, 1962. Transmitters of Model COR2 with Control Units, Synchronizing Receivers, and Search Receivers, of Model COR1 were used.

Concurrently with the trials in England, Model-COR2 Control Units and Synchronizing Receivers were developed, and during September, 1962, full-scale field trials were carried out in the Malmesbury area of South Africa. After subsequent environmental tests, the equipment was despatched to the U.S.A. and delivered to GIMRADA.

Field trials in northern Virginia and environmental trials at Fort Belvoir were successfully carried out during October 1962.

## 3. Cold-Chamber Tests at Fort Belvoir in January, 1962

During these tests it was found that the timing motors of the transmitters would not start and that it was impossible to centre the pointer on the monitor meter of the Control Unit by adjustment of the BALANCE potentiometer. The first fault was found to be due to the development of an internal resistance by the toggle switches and the deterioration of the by-pass capacitors of the 400-c/s amplifier. The switches and capacitors were replaced by suitable components. The second fault was cleared by inserting some resistance in series with the BALANCE potentiometer. Subsequently, the equipment behaved satisfactorily down to -40$^{o}$C, although the coaxial cables became very stiff.

## 4. Arctic Tests at Fort Greely in February, 1962

Great difficulty was experienced in getting the equipment to work at Fort Greely in Alaska, where, on occasions, the air temperature dropped to -65$^{o}$F. Most of the breakdowns were due to failures of the synchronizing cables and to helicopter vibration. At the low temperatures the synchronizing cables were so stiff that, on almost every occasion on which an attempt was made to straighten the cables, the solid centre conductor pierced the dielectric and was short-circuited to the braid. The coaxial cables used for connecting the output of the test oscillator in the Control Unit to the upper- and lower-channel amplifiers were even more troublesome because of the smaller radius of curvature of the cables when they are in the unit.

The antenna connection on the Synchronizing Receiver proved unsatisfactory, owing to the effect of vibration on the lead between the antenna and the feed-through insulator. The lug at the end of the lead caused that lead to behave as a cantilever, and the vibration in the helicopters led to partial, and sometimes total, fracture of the lead.

It was found extremely difficult to carry out frequency adjustments and antenna tuning in the field. Because of delays due to the late arrival and breakdown of the equipment, helicopter breakdowns, and the occurrence of non-flying weather, only three days of testing were possible on the site. It was necessary to reduce the base lengths from 9 to 6 km because of very low terrain conductivity. Finally, when calibration and test-point readings were about to be taken, the tests had to be abandoned, for the helicopters were required for military exercises that could not be postponed.

5. Discussions at Fort Belvoir after the Arctic Tests

At a conference, held at Fort Belvoir, between representatives of GIMRADA and of the Contractor it was agreed that, although the equipment had been operated at low (Arctic) temperatures, it would not work at high temperatures (such as those likely to be encountered at Fort Sill in Oklahoma) without considerable modification, that in general it was unsuitable for operation by unskilled military personnel, and that the power output was insufficient to enable a fully unambiguous base line (8.4 km) to be worked under the conditions, prevailing in the Arctic, of poor terrain conductivity.

It was agreed also that the COR1 equipment would be returned to the Contractor and another system (Model COR2), suitably engineered in the light of the experience gained during the February trials, would be delivered to GIMRADA by the end of September, 1962. In return, the requirement for engineering drawings would be waived and shop drawings would be accepted.

6. Modifications to the Transmitters

a. The Main Chassis

The case used was of die-cast, ribbed aluminium with 0.125" wall thickness, and its overall dimensions were 14½" x 9" x 14½". The front panel was of die-cast aluminium with a protective rim and folded carrying handle. The assembled case and front panel formed a watertight unit, for which the ventilation was internal. The U-shaped main chassis, which supported the sub-units, was mounted behind the front panel.

b. The Switching Unit

The James Knight two-crystal ovens were replaced by Perrott BMT-6 crystal ovens each with 4 Outstation and 6 Control-Station crystals. The extra crystals were necessary to provide an extra pattern (the Coarse Coarse pattern).

A separate oscillator was used for each crystal and the collectors were switched by the pattern microswitches. The F1 and F3 crystals of the lower channel of the Control-Station Transmitter were switched directly. The circuits were modified so that none of the switches worked under 'dry-circuit' conditions, a refinement that increased the reliability.

Suitable air-dielectric capacitors for crystal-frequency trimming were used; these had insulated extensions for ease of adjustment from the front panel.

A station selector switch was provided at the Control-Station Transmitter so that separated base lines could be used, if required.

c. The 400-c/s Amplifier

The driver transistor was changed from a germanium type to a silicon type.

d. The Oscillators

The oscillator cards were of the interchangeable plug-in type, and a common-collector coil was used in each channel. In the f.m. oscillator, the switching between frequencies had been carried out by short-circuiting the crystals. Separated buffer amplifiers were later introduced so that the switching could be carried out on them.

e. The Output Stages

The output stages used single-ended 2N1978 transistors in class C, driven by 2N696 transistors. Measurements over various types of ground showed that the effective series resistance of the antenna only varied from about 6 to 9Ω; so it was decided to use fixed antenna coupling. Such coupling was provided by means of inductively coupled, ferrite-cored coils. The difficulty of coupling the two output stages to the antenna was overcome by the use of three devices:-

(1) individual acceptor circuits resonant at the frequencies of the wanted channels and rejector circuits anti-resonant at the frequencies of the unwanted channels,

(2) a common loading coil resonating with the antenna and its tuning capacitance at the midband frequency, and

(3) a common, tapped, parallel tank circuit, which tuned out the reactance of the loading

coil plus the antenna and its tuning capacitance at each of the channel frequencies.

Output-transistor currents were indicated on individual panel meters, and the antenna current on an r.f.-thermocouple meter. An antenna tuning capacitor with a higher voltage rating and capable of operation down to $-65^{o}F$ was used. The power output was about 13W per channel.

7. Initial Field Tests of the Transmitters

During initial field tests it was found that frequency pulling occurred as the antenna was tuned. This pulling was reduced to a variation of about 1 c/s for any antenna tuning by totally enclosing the crystal circuits (trimmers, microswitches, leads, etc.) in a screening box and decoupling the oscillators and buffer amplifiers by means of a $\pi$ filter. It was also found that, with incorrect phasing of the transformer between the driver and the output stage, the lower channel of the Outstation Transmitter could produce power on Pattern 4.

8. Modifications to the Control Unit

The Control Unit was rebuilt in a military-style case, of dimensions $8\frac{1}{2}$" x 14" x 9", with far fewer external controls. The f.m. cable lead had been included in the multi-core cable, an arrangement that had had the effect of injecting the upper-channel square wave into the control voltage on the lower channel. This effect was eliminated by inserting in series with the lead a diode that was rendered conducting on Pattern 4 and non-conducting on all the other patterns. The oscillator amplitude control and test cables were eliminated; the switching of the oscillator to either amplifier channel or both was achieved by the use of a selector switch. The REFERENCE, BALANCE, and STABILITY controls were of the screwdriver type, as also were the controls for the 1" diameter c.r.t. tube that was used. The a.g.c. system was replaced by a limiter system, which permitted two gain controls to be eliminated. A smaller monitor meter was used.

9. Modifications to the Synchronizing Receiver

The Synchronizing Receiver was rebuilt into an aluminium case of 0.125" wall thickness, and it had a single feedthrough insulator capable of supporting the whip antenna. Individual plugs and sockets for flying leads, and a front panel grip, were incorporated for facilitating the removal of the panel from the case. The synchronizing cables were made up from RG-58C/U cable, with a special low-temperature jacket, and fitted with UG-88C/U connectors. The smaller-sized cable permitted the use of much smaller cable drums.

10. Modifications to the Search Receiver

In order to facilitate reading at night, the red line on the cursor drum assembly was thickened and the engraving on the plastic panel was reversed to black graduations and numbers on a white background. The original telescopic antenna was modified so that it could be screwed into its mounting for operation or unscrewed and clamped to the front panel when not in use. Subsequently it was modified to the multiple-tape variety.

11. British Army Trials

During July, 1962, trials were carried out in conjunction with the British Army at Larkhill in England. Model-COR2 transmitters and Model-COR1 Control Units, Synchronizing Receivers, and Search Receivers, were used. The test area was criss-crossed by power lines at voltages of 6.6, 11, 33, 132, and 275 kV, and the ground was of poor conductivity (4 to 8 x $10^{-14}$ e.m.u.). The combination of high power-line density and poor conductivity led to frequent bad breaks between the MEDIUM and FINE patterns and occasional bad breaks between the COARSE and MEDIUM patterns.

A high percentage of ambiguous and incorrect breaks was obtained on 8-km joined base lines. On separated short base lines of fixed length these effects were reduced progressively as the base lengths were shortened.

The use of separated short base lines of fixed length has much to be commended. Shorter base lines can be more quickly put into operation by the same crew than longer base lines can, path anomalies are smaller, the effect of power lines is less, and range corrections may be neglected; but they have the disadvantage of greater lane expansion. Separated base lines can be selected for orientation for good position-line cuts in the area of coverage. Using base lines of fixed length makes possible the use of hyperbolic position-line protractors. These protractors however, can be used with any length of base line, provided that the hyperbolic readings are rationalized by being expressed as fractions of the electrical base length in base units.

Owing to the onset of the Summer holidays, it was impossible to continue the tests. The limitation of ambiguity breakdown due to the density of power lines precludes the use of the system in highly built-up areas. In any case, the system is not likely to be operated in such areas.

12. Hyperbolic Position-Line Protractor

For fixed-length base lines it is possible to use a protractor on which the radials represent hyperbolic asymptotes. For a given ordinate the difference between the abscissa values of the hyperbola and the asymptote is less than 4% of the abscissa value of the asymptote at ranges greater than $1\,^3/_4$ times the base length. The error is less than 2% for ranges greater than $2\frac{1}{2}$ times the base length and less than $\frac{1}{2}$% for ranges greater than 5 times the base length. (See Appendix.)

13. Final Local Field Tests

Local tests were carried out in the Malmesbury area (conductivity = 10 to 17 x $10^{-14}$ e.m.u.). Day-time ranges of over 60 miles and night-time ranges of 40 miles were achieved. This night-time range, which is about twice that of the COR1 equipment, shows that range by night is limited by general skywave noise and not by the skywave of the desired transmission. Satisfactory results were obtained on both 8-km and 16-km base lines.

14. Final Delivery

After the local field trials at Malmesbury the equipment was successfully tested at $-15^{o}$F and at $+125^{o}$F with incident radiation of 360 Btu/$ft^2$/hour for 4 hours. Then the equipment was despatched to the U.S.A. checked at the Rockville factory of Tellurometer Incorporated, and delivered to GIMRADA on 1st October, 1962.

15. Field Tests

Field tests were carried out during October in northern Virginia on 8-km and 16-km base lines. Trouble was experienced with the transmitter timing-motor clutches. These were modified to have straight-through drives, the direction of rotation of the motor was reversed, and the slipping clutch in the gear train of the motor was used. Thereafter the equipment performed very reliably.

The results of the tests are shown in Tables 1 and 2. On the 8-km base lines all the points inside the 10 x 10-mile area are within 15 metres of their true positions, except for Meadow, Meadow offset, and Meetz, which are within 20 metres. On the 16-km base line all test points inside the 20 x 20-mile area are within 15 metres of their true positions, except for Steiner and Opal, although corrections of 50 base units had to be applied to the Tapp readings on Woodbourne, Meetz, and Opal.

16. Environmental Test

After the field tests the equipment was taken to Fort Belvoir and tested in the environmental chamber at $-65^{o}$F and at $+125^{o}$F with incident radiation of 360 Btu/$ft^2$/hour for 4 hours. These tests were satisfactorily completed.

17. Conclusion of Contract

It is now considered that all requirements of the Contract have been satisfied.

## TABLE 1

## TEST RESULTS 8-km BASE LINE

| Station | Calc. Hyp. Coord. | | Corr. S.R. Coord. | | Error | | $Error^2$ | | Radial Error (Metres) |
|---|---|---|---|---|---|---|---|---|---|
| | Riverland | Lee | Riverland | Lee | Riv. | Lee | Riv. | Lee | |
| Meadow | 1650.8 | 7049.3 | 1651 | 7641.7 | +0.2 | -7.6 | 0.04 | 57.76 | 17.17 |
| Meadow offset | 1654.2 | 7600.8 | 1652.2 | 7594.4 | -2.0 | -5.4 | 4.00 | 29.16 | 19.70 |
| Woodbourne | 7640.4 | 1918.6 | 7641 | 1914.7 | +0.6 | -3.9 | 0.36 | 15.21 | 14.48 |
| Dakota | 6603 | 3372.9 | 6601.2 | 3373.2 | -1.8 | +0.3 | 3.24 | 0.09 | 6.12 |
| Dakota offset | 6591.2 | 3403.2 | 6592.2 | 3406.2 | +1.0 | +3.0 | 1.00 | 9.00 | 15.10 |
| Meetz | 4983.3 | 5020.2 | 4984 | 5023.4 | +0.7 | +3.2 | 0.49 | 10.24 | 15.76 |
| Williams | 3328.6 | 6734.6 | 3327.2 | 6736 | -1.4 | +1.4 | 1.96 | 1.96 | 4.00 |
| Routs Hill | 611.5 | 897.1 | 607.2 | 908.9 | -4.3 | +11.8 | 18.49 | 139.20 | 14.25 |
| Routs Hill offset | 794.2 | 1110.5 | 973.5 | 1119.3 | -0.7 | +8.8 | 0.49 | 77.44 | 9.04 |
| TVS A1 | 1453.5 | 1276.5 | 1444.7 | 1273 | -8.5 | -3.5 | 72.25 | 12.25 | 8.83 |
| Steiner | 4305.5 | 563.0 | 4312.4 | 559.3 | +6.9 | -3.7 | 47.61 | 13.69 | 10.94 |
| TVS B1 | 2483.4 | 3020.8 | 2482.8 | 3021.4 | -0.6 | +0.6 | 0.36 | 0.36 | 1.15 |
| Opal | 1217.2 | 5103.0 | 1215.1 | 5103.8 | -2.0 | +0.8 | 4.00 | 0.64 | 3.95 |
| Sand | 3266.6 | 3551.4 | 3266.4 | 3550 | -0.2 | -1.4 | 0.04 | 1.96 | 2.16 |
| Aldie | 7336.3 | 4920.3 | 7329.8 | 4917.7 | -6.5 | -2.6 | 42.25 | 6.76 | 571.64 x |
| Fairview | 5955.8 | 6146.4 | 5952.3 | 6146 | -3.5 | -0.4 | 12.25 | 0.16 | 204.69 x |
| Hume | 9725.6 | 1001.5 | 9724.8 | 998.1 | -0.8 | -3.4 | 0.64 | 11.56 | 1254.88 x |
| Hurley | 2272.2 | 6445.6 | 2270.3 | 6443.5 | -1.9 | -2.1 | 3.61 | 4.41 | 8.50 |
| Paradise | 3505.9 | 1923.1 | 3504.6 | 1924.8 | -1.3 | +1.7 | 1.69 | 2.89 | 2.82 |
| | | | TOTAL | | -26.1 | -2.4 | 214.77 | 394.74 | |
| | | | AVERAGE | | -1.37 | -0.13 | 11.3 | 20.8 | |
| | | | PEAK | | 8.5 | 11.8 | | | |
| | | | S.D. | | | | 3.36 | 4.56 | |

x Outside 10 x 10-mile area

## TABLE 2

## TEST RESULTS 16-km BASE LINE

| Station | Calc. Hyp. Coord. | | Corr. S.R. Coord. | | Error | | $Error^2$ | | Radial Error (Metres) |
|---|---|---|---|---|---|---|---|---|---|
| | Williams | Tapp | Williams | Tapp | Will. | Tapp | Will. | Tapp | |
| Meadow | 9137.2 | 769.4 | 9128.0 | 771.6 | -9.2 | +2.2 | 84.64 | 4.84 | 8.65 |
| Meadow offset | 9069.5 | 773.8 | 9064.9 | 777.3 | -5.4 | +3.5 | 29.16 | 12.25 | 5.74 |
| | | | | (6936.2) | | | | | (5.06) |
| Woodbourne | 5700.9 | 6931.1 | 5704.2 | 6886.2 | +3.3 | +5.1 | 10.89 | 26.01 | 55.9 |
| Dakota | 8886.2 | 6142.0 | 8890.2 | 6146.1 | +4.0 | +4.1 | 16.00 | 16.81 | 5.94 |
| Dakota offset | 8960.3 | 6137.5 | 8966.0 | 6137.5 | +5.7 | 0 | 32.49 | 0 | 8.21 |
| | | | | (4224.4) | | | | | (12.50) |
| Meetz | 11935.0 | 4215.3 | 11935.3 | 4174.4 | +0.3 | +9.1 | 0.09 | 82.81 | 94.4 |
| Routs Hill | 1127.5 | 354.5 | 1129.7 | 364.0 | +2.2 | +9.5 | 4.84 | 90.25 | 9.49 |
| Routs Hill offset | 1431.1 | 472.2 | 1433.8 | 475.9 | +2.7 | +3.7 | 7.29 | 13.69 | 2.47 |
| TVS A1 | 1966.7 | 995.7 | 1971.0 | 1000.5 | +4.3 | +4.8 | 18.49 | 23.04 | 3.75 |
| Steiner | 1980.7 | 3896.4 | 1968.3 | 3892.5 | 12.4 | -3.9 | 153.80 | 15.21 | 16.86 |
| TVS B1 | 4677.5 | 1649.5 | 4676.3 | 1658.1 | -1.2 | +8.6 | 1.44 | 73.96 | 8.89 |
| | | | | (538.7) | | | | | (25.64) |
| Opal | 5311.3 | 528.5 | 5308.5 | 488.7 | -2.8 | +10.2 | 7.84 | 104.00 | 158.05 |
| Sand | 6188.2 | 2300.9 | 6187.9 | 2307.1 | -0.3 | +6.2 | 0.09 | 38.44 | 4.55 |
| | | | (12941.5) | | | | | | (512.10) |
| Aldie | 12945.3 | 9365.1 | 13041.5 | 9342.0 | -3.8 | -23.1 | 14.44 | 533.60 | 2414.68 ⁎ |
| | | | | (17271.9) | | | | | (51.37) |
| Hume | 5265.4 | 17273.8 | 5260.7 | 17221.9 | -4.7 | -1.9 | 22.09 | 3.61 | 257.90 ⁎ |
| Hurley | 9316.2 | 1314.6 | 9315.5 | 1319.8 | -0.7 | +5.2 | 0.49 | 27.04 | 6.60 |
| Paradise | 3847.5 | 2668.2 | 3847.5 | 2669.3 | 0 | +1.1 | 0 | 1.21 | 6.09 |
| | | | TOTAL | | -18.0 | +44.4 | 404.08 | 966.77 | |
| | | | AVERAGE | | -1.06 | +2.62 | 26.0 | 56.9 | |
| | | | PEAK | | 12.4 | 23.1 | | | |
| | | | S.D. | | | | 5.1 | 7.55 | |

⁎ Outside 20 x 20-mile area

## ACCURACY OF A STRAIGHT-LINE APPROXIMATION TO A HYPERBOLA

1. Equation of hyperbola is $\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$ where $b^2 = a^2(e^2 - 1)$

$$\text{or} \quad \frac{x^2}{a^2} = \frac{y^2}{a^2(e^2 - 1)} + 1$$

$$\therefore \quad x^2 = \frac{y^2}{e^2 - 1} + a^2$$

$$= \frac{y^2}{e^2 - 1}\left[1 + \frac{a^2(e^2 - 1)}{y^2}\right]$$

$$\therefore \quad x = \frac{y}{\sqrt{e^2 - 1}}\left[1 + \tfrac{1}{2}\,\frac{a^2(e^2 - 1)}{y^2} - \frac{1}{8}\,\frac{a^4(e^2 - 1)^2}{y^4} + \ldots\ldots\right]$$

2. Hyperbolae can be considered as approximately straight lines at a minimum value of y given by

$$y = 3.5a\sqrt{e^2 - 1} \quad \text{for which} \quad \frac{a^2(e^2 - 1)}{y^2} = \left(\frac{1}{3.5}\right)^2 = \frac{1}{12.25}$$

$$\text{Then} \quad x = \frac{y}{\sqrt{e^2 - 1}}\left[\;1 + \frac{1}{25} - \;\ldots\ldots\;\right]$$

Thus the error in the value of x produced by replacing the hyperbola by its straight-line asymptote is about 4%.

3. The radius vector for the limit of straight-line approximation is

$$r = \sqrt{x^2 + y^2} \quad \text{where} \quad y = 3.5a\sqrt{e^2 - 1} \quad \text{and} \quad x = \frac{y}{\sqrt{e^2 - 1}} = 3.5a$$

$$= \sqrt{(3.5a)^2 + (3.5a)^2\,(e^2 - 1)}$$

$= \quad 3.5ae$

$= \quad 3.5$ x half the base length

$= \quad 1.75$ x the base length.

4. If $y = 5a\sqrt{e^2 - 1}$ then $\frac{a^2(e^2 - 1)}{y^2} = \frac{1}{25}$

The error is $\frac{1}{50} = 2\%$

Limiting range = 2.5 x the base length.

5. If $y = 10a\sqrt{e^2 - 1}$ then $\frac{a^2(e^2 - 1)}{y^2} = \frac{1}{100}$

The error is $\frac{1}{200} = \frac{1}{2}\%$

Limiting range = 5 x the base length.