I.O.S.

AN EVALUATION OF MARINE MICROWAVE PRECISION SYSTEMS

A J MARKS

Report No 70

1978

NATURAL ENVIRONMENT RESEARCH COUNCIL

INSTITUTE OF OCEANOGRAPHIC SCIENCES

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Institute of Oceanographic Sciences
Crossway
Taunton
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CONTENTS

1. INTRODUCTION

There has always been a need for position-fixing at sea. In the past the need has been mainly one of navigation and hydrographic surveying. The recent increase in scientific interest in the marine environment has led to a greater requirement for positioning.

Accurate positioning forms a basic part of almost all the scientific disciplines being used to study the sea, or commercial development of the sea. The widely differing requirements have resulted in the introduction of many new types of positioning systems, of which no single system can fulfil all the specifications. Hence a range of systems is available,many of which overlap in some way or another.

This report concentrates on the precision systems, but excluding underwater positioning systems which although they may be potentially very accurate, are generally relative, and so require co-ordinating with a surface system if an absolute position is required. Traditional navigation instruments and methods are not mentioned as their characteristics are well known.

Many optical and microwave ranging systems have been developed for land survey use. In general most of these systems are not suitable for marine use; only those systems adapted or developed specifically for use at sea have been considered. A section is devoted to systems other than microwave as a comparison.

2. MICROWAVE POSITIONING SYSTEMS

2.1 Introduction

There are a number of microwave position fixing systems, designed or adapted for marine use. In general they are of the Range/Range type, although at least one system uses Range/Bearing.

In a Range/Range system the distances between the mobile, and at least two shore stations are simultaneously obtained (see Fig 1). Provided the co-ordinates of the shore stations are known to the required accuracy a position may be calculated by trilateration. If the equipment necessary to calculate co-ordinates and to track plot on line are not available, a range circle overlay may be prepared. The overlay can be placed over a chart, and by interpolation between lines the track may be plotted by hand. Range data can also be recorded at the same time for subsequent processing. Although tedious the above method may be adequate for some surveys. When only two shore stations are used an ambiguity exists as to which side of the base line the mobile is located. This ambiguity can either be avoided by consideration of the shore station sites, or it can be

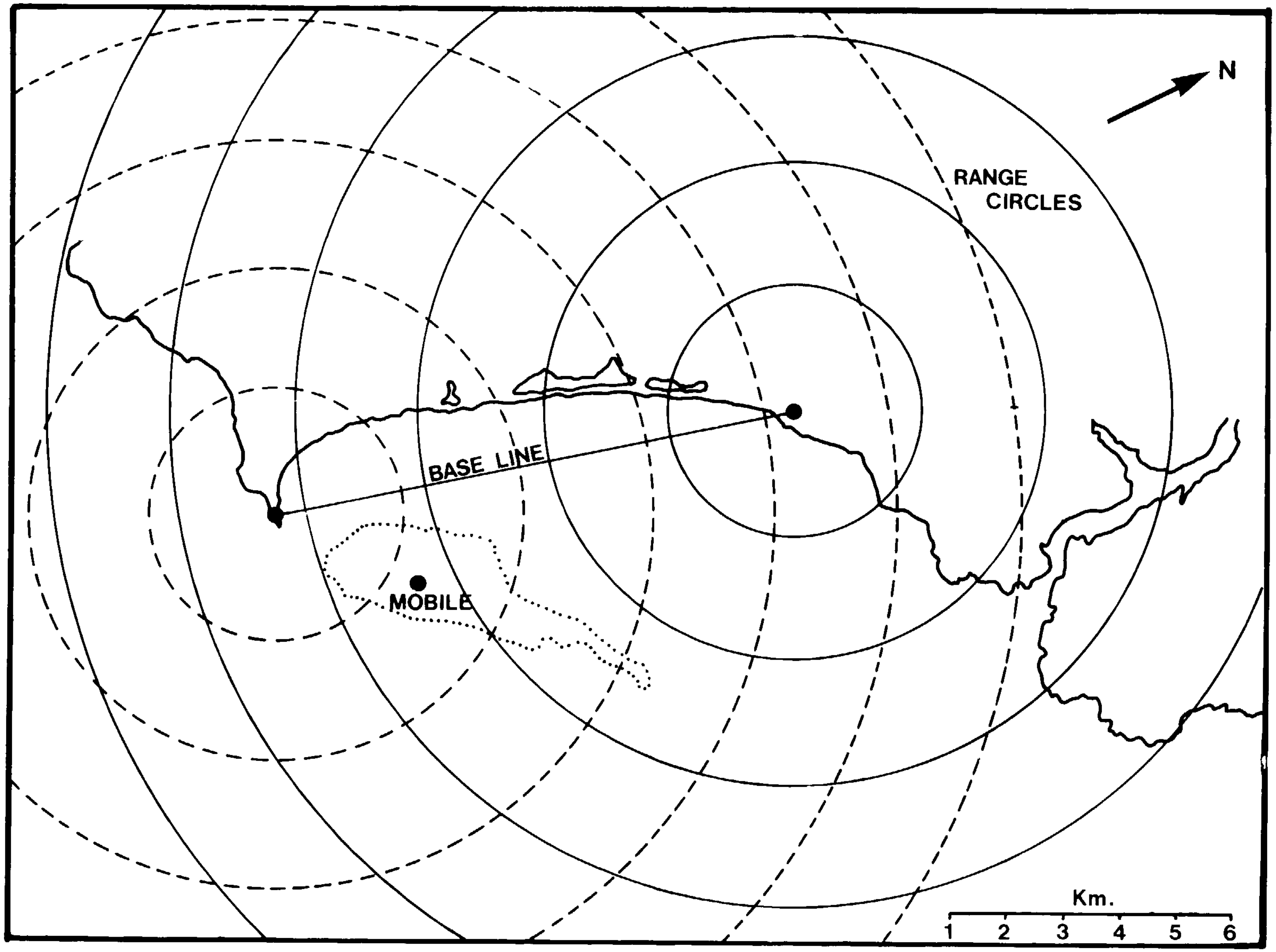

Fig.1 RANGE/RANGE SYSTEM USING TWO STATIONS

resolved by some other navigational technique, whose accuracy need only be sufficient to indicate which side of the base line the mobile is located.

A range and bearing system requires only one co-ordinated shore station. The distance between the mobile and the shore station, and the angle it makes with respect to some reference direction is obtained (Fig 2) and used to calculate a position. In this case any positional error caused by errors in bearing information is a function of range.

Generally in calculating a position, height differences between the shore stations and the mobile are taken into account. The velocity of propagation is usually assumed to be constant. Changes in atmospheric pressure, humidity, and temperature are ignored. At relatively short ranges the curvature of the earth is also neglected.

Frequencies used in microwave positioning systems are in the radar bands 'S', 'C', or 'X', (3GHz, 5GHz and 9GHz respectively). Microwave components at 'X' band are physically smaller than 'S' band components, but attenuation of the signal by rain or snow is more pronounced at the higher frequencies.

Lightness and portability are characteristic of microwave systems. Coupled with simple setting-up procedures, installation may be performed by relatively unskilled personnel. The modern trend towards modular construction reduces fault finding and repair to a minimum. Quite modest power requirements allow systems to be run on car batteries for several days.

Although the Range/Range and Range/Bearing systems are essentially single user, many systems can be provided with an option which enables a limited number of mobiles to utilise the same set of shore stations. A wide range of optional extras exists, to cater for a variety of applications.

All systems have digital outputs which can be readily interfaced to a calculator or computer. Depending upon the user's requirements, the calculator or computer can process the data to produce a position in the appropriate co-ordinate system, and drive ancillary equipment such as a track plotter, data logger, or printer. In some installations it may even be possible for the positioning system to control the mobile vessel.

2.2 Modes of Operation

In order to measure a range with microwave techniques, two basic schemes are used, phase comparison, and the measurement of pulse transit time.

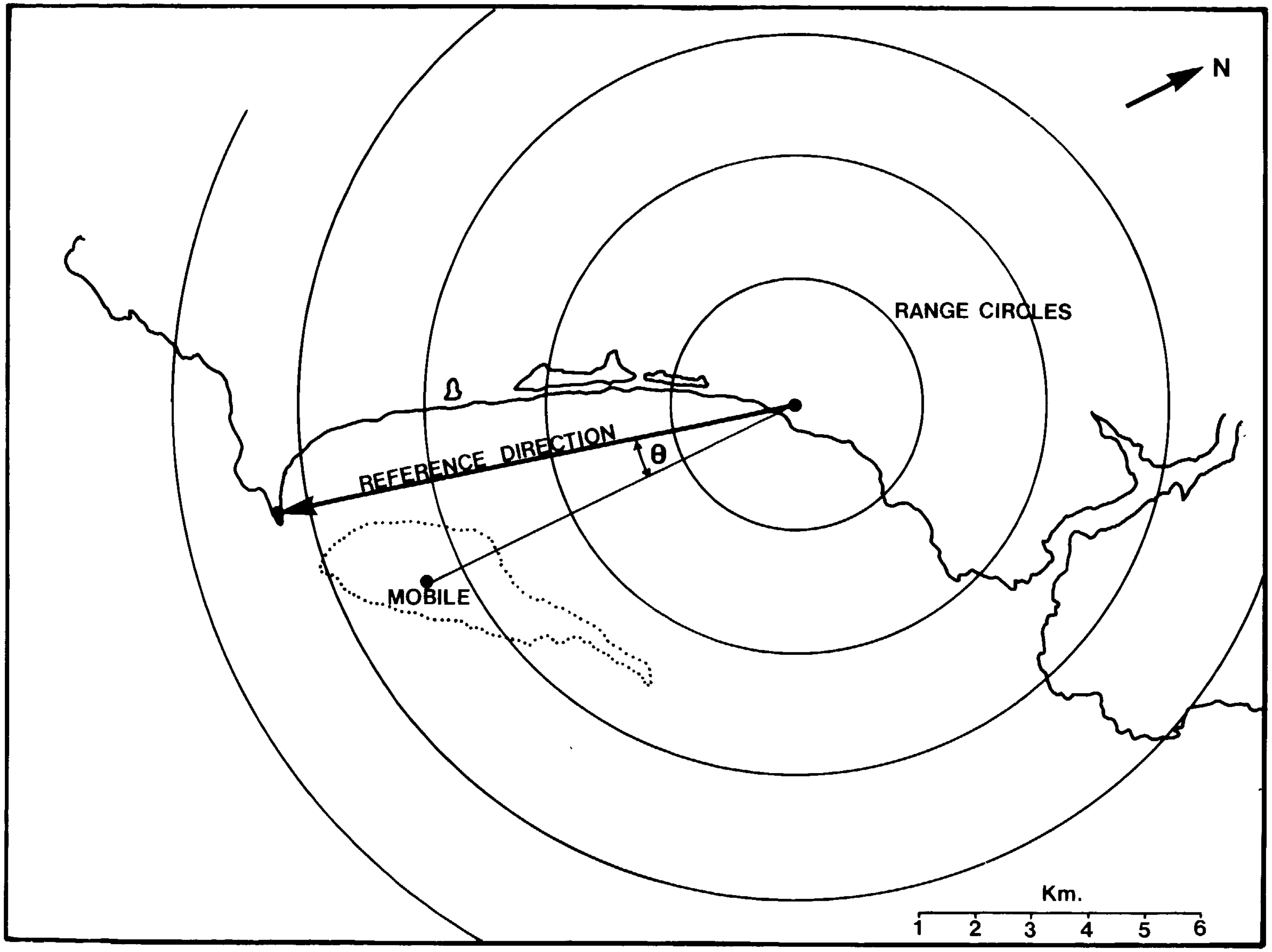

Fig. 2 A RANGE AND BEARING SYSTEM USING ONE STATION AND A REFERENCE DIRECTION

2.3 Phase comparison system

The usual arrangement for a phase comparison system is to have a mobile master station, and two remote stations, all transmitting continuous waves. The ranges are obtained by comparing the phase of modulation frequencies on the master and reference station waves. The multiple ambiguities are resolved by sweeping through a range of modulating frequencies or using a discrete series of modulating frequencies.

Another advantage with continuous wave systems is the useful bonus of having the possibility of a built-in two way voice, or even data link, between the mobile and reference stations. This facility can usually only be used when not ranging.

Phase comparison systems are more complex than pulse systems, and inevitably more expensive. They are however inherently more accurate: $\pm$ 1m is quoted as the probable accuracy for some systems. Once calibrated the calibration should hold good for all ranges, and remain accurate provided the system frequencies are periodically checked for drift.

2.4 Pulse Transit System

Unlike phase comparison systems, there are no inherent Range ambiguities. Pulse systems have a mobile station which transmits a pulse or coded sequence of pulses to two or more reference stations. The reference stations have a transponder which, when interrogated by the pulse from the master, re-transmits a coded reply. The time interval between the interrogate pulse leaving and the reply pulse being received, is measured by means of a very accurate counter. With a knowledge of the propagation velocity a range can be obtained. The coding identifies the reference stations to the mobile and gives a high immunity from spurious signals in the same frequency band. As in pulse radar high peak power is used, but average power is low. The higher frequency 'X' band is usually favoured, but at least one system uses the 'C' band which is the least used of the marine radar bands and would be freer from interference. The probable accuracy of a pulse system is $\pm$ 3m.

3. USE OF MICROWAVE SYSTEMS

3.1 Reflections

Signal paths other than the direct one can be conveniently divided into two types. Over the sea there is nearly always a path via a sea-surface reflection which differs only slightly in path-length from the direct path. The reflection also involves a change in phase. Other reflection paths may involve much greater path differences: for example, reflections from cliffs, other vessels, or even from other parts of the same vessel.

Signals via the sea-surface reflection can be exactly out-of-phase with and of almost equal strength to those via the direct path, causing cancellation. In these circumstances signals via other paths become potentially more important. The result on the measuring system can be very different for timed pulse-delay systems and for systems depending on the phase of a modulation of a continuous wave.

In timed pulse-delay systems, so long as the correct pulse is present and the system locks on it, the presence of other pulses at different delays does not affect accuracy. Most pulse systems have arrangements for staying locked-on to the correct pulse even in conditions of severe fading. However, where the phase of a modulation on a CW is being used, this cannot be achieved, and CW systems are therefore inherently more subject to errors than pulsed systems.

3.2 Signal Strength

In general the antennae should have as narrow a vertical aperture as is consistent with ship motion (15° is usually a fair compromise). Ideally the heights of the antennae should be kept to the minimum required for the given range. Diversity receiving could be used with two mobile receiver units operated at different heights and only the strongest signal used.

One error found in pulsed systems is caused by the degradation of the pulses with signal strength. The effect is that the ranges will vary slightly with signal strength. As the main cause of signal strength reduction is range, a system calibrated at one range will be in error at other ranges. For example, if calibrated at mid-range then the measured short ranges will be too short, and the measured long ranges will be too long, but the mid-ranges will be correct.

To minimise this error, calibration over several ranges may be performed, and a correction curve used for the range at which it is intended to be next used. However, range is not the only factor affecting signal strength. Antenna alignment due to poor setting up or excessive ship motion, cancellation, or partial obstruction, weather conditions, and mis-tuning of transmitters or receivers can all cause variations. A direct measurement and recording of signal strength at the master can be used to apply a correction.

3.3 Geometry

The geometric plan layout of a system can affect the accuracy. An ideal layout is one in which the angle between the two ranges is 90°. In practice this is not always possible to achieve. A generally accepted compromise is to allow angles of 30° to 150° unless optimum performance is required (see Fig 3). However, the effect of any deviation from the ideal will accentuate errors already present in the system. Consequently if the survey area is large the angle and the errors will vary from point to point. Assuming a possible error of ± 3 metres in each range at an angle of 90° the maximum positional error will be about ± 4m. At 30° or 150° the maximum positional error will be about ± 12m. Calculation or graphical analysis of an area will indicate this geometric effect on the system errors, and an estimate of the maximum error can be made.

3.4 Range

Assuming that the range is not being limited by power output, the factors controlling the range that may be obtained are:

(a) Line of sight operation - this is a function of the height of obstructions and of the instruments;

(b) The length of the base line - this affects the geometry of the system, and precludes operation at long ranges due to excessive errors (see Section 3.3).

Adverse weather conditions can also limit the range by introducing attenuation, for example heavy rain at X band may reduce the signal strength by 30%, while at S band it would be 7%. Abnormal meteorological conditions cause refraction effects which can result in maximum ranges being shorter or longer than expected.

Provision of good shore stations can be a problem. Ideal positions may be inaccessible or unusable for one reason or another and range suffer as a consequence. The investigation of suitable sites should be a high priority and not left as a last-minute compromise. Shore stations are generally on private property and permission to use the site must be obtained from the owner.

3.5 Drift

With all microwave components there is a tendency to age, especially in the first year of operation, so a wise precaution is to periodically check frequencies and calibrations until the age and drift characteristics of the equipment have been established. For maximum accuracy calibrations may need to be performed before each period of use.

3.6 Simultaneous Range Measurement

If both ranges are not measured simultaneously, and the vessel is moving for

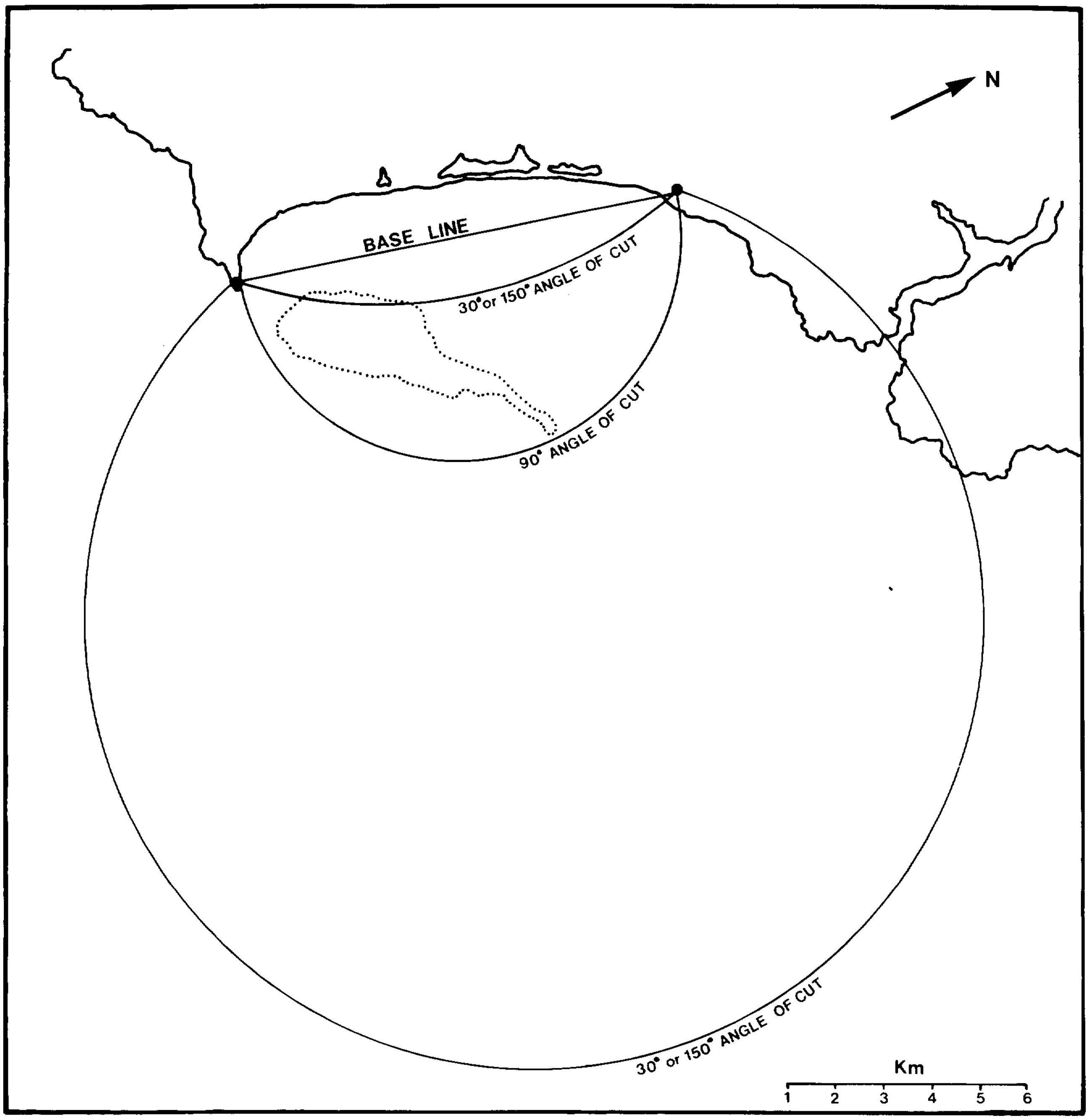

Fig. 3 ANGLE OF CUT CONTOURS FOR 90° AND 30° OR 150°

example at 10 knots, a difference between measurements of 0.1 sec would give at least a 0.5m error.

3.7 Microwave Radiation Hazard

The recommended maximum level of exposure to microwave radiation (10 watt/cm^2) may be exceeded by some systems. Efforts should be made to keep personnel outside the 10m watt/cm^2 envelope. Factors influencing the size and shape of this envelope are: peak power; pulse width; pulse repetition rate; and the radiated beam pattern. Advice may be obtained from the National Radiological Protection Board, Harwell.

3.8 Licensing for use of the radio frequencies

Licensing in the UK depends on type of system and options employed, the area where the equipment is to be used, the particular application of the equipment, and the amount of use. All manufacturers are confident that their equipment would be granted a Home Office radio licence. As a condition of licensing the Home Office require notice in writing of each usage of the equipment, stating area, reason for use, and period of use.

4. A BRIEF DESCRIPTION OF SOME MICROWAVE POSITIONING SYSTEMS

Characteristics of the systems described below are tabulated in Table 1.

4.1 Tellurometer MRD 1

The MRD 1 is a Range/Range phase comparison system operating at about 3 GHz. Although it is an improved and simplified version of the MRB 201 it is still compatible with the MRB 201 system. A wide range of ancillary equipment may be interfaced to the MRD 1 to enable recording, data processing, track plotting etc to be performed. Power consumption at a nominal 12 volts dc is 90 watts for the mobile unit, and 40 watts for the remote units which have a standby mode requirement of 6 watts.

4.2 Cubic Autotape DM40A

The DM40A again is a range/range phase comparison system operating at about 3 GHz. A variety of peripheral equipment is available for this system. The DM43 mobel has identical characteristics to the DM40A except that three ranges may be measured simultaneously, thus allowing an estimate of the positional error to be made.

Power requirements are 95 watts for the mobile unit and 60 watts for the

4.6

TABLE 1

	Tellurometer MRD 1	Cubic Autotape DM40A	Decca Trisponder	Motorola Miniranger III	Artemis III
Type of System	Phase Comparison Range/Range	Phase Comparison Range/Range	Microwave Pulse Range/Range	Microwave Pulse Range/Range	Phase Comparison Range/Bearing
Frequency	'S' Band	'S' Band	'X' Band	'C' Band	'X' Band
Probable Accuracy	± 1m	± 0.5m	± 3m	± 3m	2' of ARC ± 1.5m
Resolution	0.1m	0.1m	1m	1m	30" of ARC 0.1m
Maximum Range Line of sight	100 km	100 km	80 km	37 m	30 km

Brief operating characteristics of some microwave positioning systems.

remotes at 12 or 24 volts dc.

4.3 Decca Trisponder

The Trisponder is a range/range pulse system operating at about 9 GHz. There are three variants: a multichannel version which can use a chain of up to eight remote stations; a short range (5km) high resolution model; and a standard system which can use any two of up to four remotes. Various data recording and track plotting facilities are available. Power requirements at 24v dc are 65 watts for the mobile unit and 17 watts for the remote units which have a standby requirement of 9 watts.

4.4 Motorola Miniranger III

The Miniranger is a range/range pulse system operating at about 5 GHz. Recording and track plotting facilities are available together with many optional extras, such as operation with up to 16 remotes, a built-in test system, diversity reception and increased range.

Power requirements are 150 watts for the mobile unit and 13 watts for the remotes at nominal 24 volts dc.

4.5 Artemis III

The artemis III is a range/bearing phase comparison type of system operating at about 9 GHz. As it is a range/bearing system only one remote station is required. Voice communication does not affect the range measurements. Track plotting and recording facilities are available. Power requirements are about 90 watts at 24 volts dc.

5. UHF POSITIONING SYSTEMS

5.1 Introduction

UHF systems are not affected to any great extent by atmospheric conditions such as refraction or attenuation. Range is limited to perhaps twice the line of sight with some degree of deterioration beyond the line of sight. A disadvantage with UHF systems is that a Home Office licence to operate in UK waters may be difficult to obtain. The examples below are of the Pulse transit time and Doppler shift types but phase comparison systems are quite feasible.

5.2 Decca Maxiran

Maxiran which has been derived from the Shoran and Hiran systems operates at about 430 or 440 MHz. It is a pulse coded system employing up to six shore stations, and obtaining a fix from any three of them in a Range/Range mode. Sophisticated coding techniques give a resolution comparable with microwave systems.

5.3 Syledis

Syledis uses a single frequency in the 420 MHz to 450 MHz band. Peak output power is 20 watts, or with an optional booster amplifier 400 watts. The standard 20 watt system has a quoted range of 2.5 times line of sight. Resolution is 0.1m, with a probable range accuracy of ± 1m deteriorating to a few metres at maximum range. The system is insensitive to diurnal and meteorological influences. Time discrimination techniques are employed to reduce multipath errors.

A mobile transceiver, and a display unit, are carried by the ship. On shore two or three transceiver stations are required. (Three shore stations allow some redundancy of data). One of the shore stations is designated 'master' and is connected to a computing centre supervised by an operator. In a harbour type of installation the operator enters administration information, and constants, into the computer. He also supervises the storage and distribution of the processed data.

Positional data is obtained by a sequence of propagation time measurements between the mobile and shore stations, and between shore stations. The measurement is made by means of a coded pulse. Between sequences, information is transferred from the master shore station to the ship for display.

Syledis is a portable and flexible system; combinations of up to eight shore stations and seven mobiles may be used. Two mobiles may be carried by a ship to give rate of turn information. It is also possible to use the system in a Hyperbolic mode with any number of users, or a combination of hyperbolic and range/range.

5.4 Satellite Navigation

Satellite navigation is performed by receiving signals from an orbiting satellite, and by measuring the doppler shift of the signal frequencies, its closest approach and its rate of closure may be determined. The frequencies used are in the order 400 MHz and 150 MHz. If two frequencies are used corrections for refraction can be applied and a more accurate fix obtained.

A computer is required to handle the complex calculations including the predicted satellite position and an accuracy of about 300m for a single frequency or 100m for a dual frequency system may be obtained.

Fixes are obtained about once every $1\frac{1}{2}$ hours between which dead reckoning or some other system has to be used.

The satellites are continuously tracked and orbital information is transmitted about twice a day.

6. LOW AND MEDIUM FREQUENCY POSITIONING SYSTEMS

6.1 Introduction

Almost all low and medium frequency systems use hyperbolic patterns generated by a number of shore stations to obtain a position fix. A master and two slave stations form a basic grid (see Fig 4) but some systems use three slaves to give a choice of grids and enable a better angle of cut to be obtained. Frequencies commonly in use are 120 KHz to about 5 MHz. Any number of vessels may use a hyperbolic system simultaneously, which is a necessary requirement when the system is used as a general navigation aid. Range/range operation is possible, and has been used with many of the low and medium frequency systems. However, a range/range mode of working usually implies only a single or very limited number of users.

Low and medium frequency systems rely on ground wave propagation. Errors can be introduced by variations in the mean velocity of propagation due either to variations in atmospheric conditions, or by changes in conductivity along the propagation path, (varying amounts of land and sea path). Reflected or refracted waves from layers in the ionosphere ("skywave") can cause errors and this effect is particularly troublesome about dawn, also causing reduced accuracy during the hours of darkness. Some systems such as Loran may make use of skywave to extend their service area. When using skywave propagation, corrections have to be applied and reduced accuracy accepted. Many systems provide correction sheets for "skywave" and velocity of propagation errors, for various areas and conditions. Higher accuracy may be achieved in some cases in a differential mode, in which corrections are supplied from fixed monitor stations.

As with Microwave systems two basic schemes are used. The transit time of a pulse or pulses, and the comparison of the phase of various transmitted frequencies.

6.2 Timed Pulse Systems

The usual arrangement is to have a series of stations synchronised together by an extremely accurate master clock. Time differences between pulses transmitted from these stations are measured on board the user vessel. From consideration of the shore station positions and their relative timings a position can

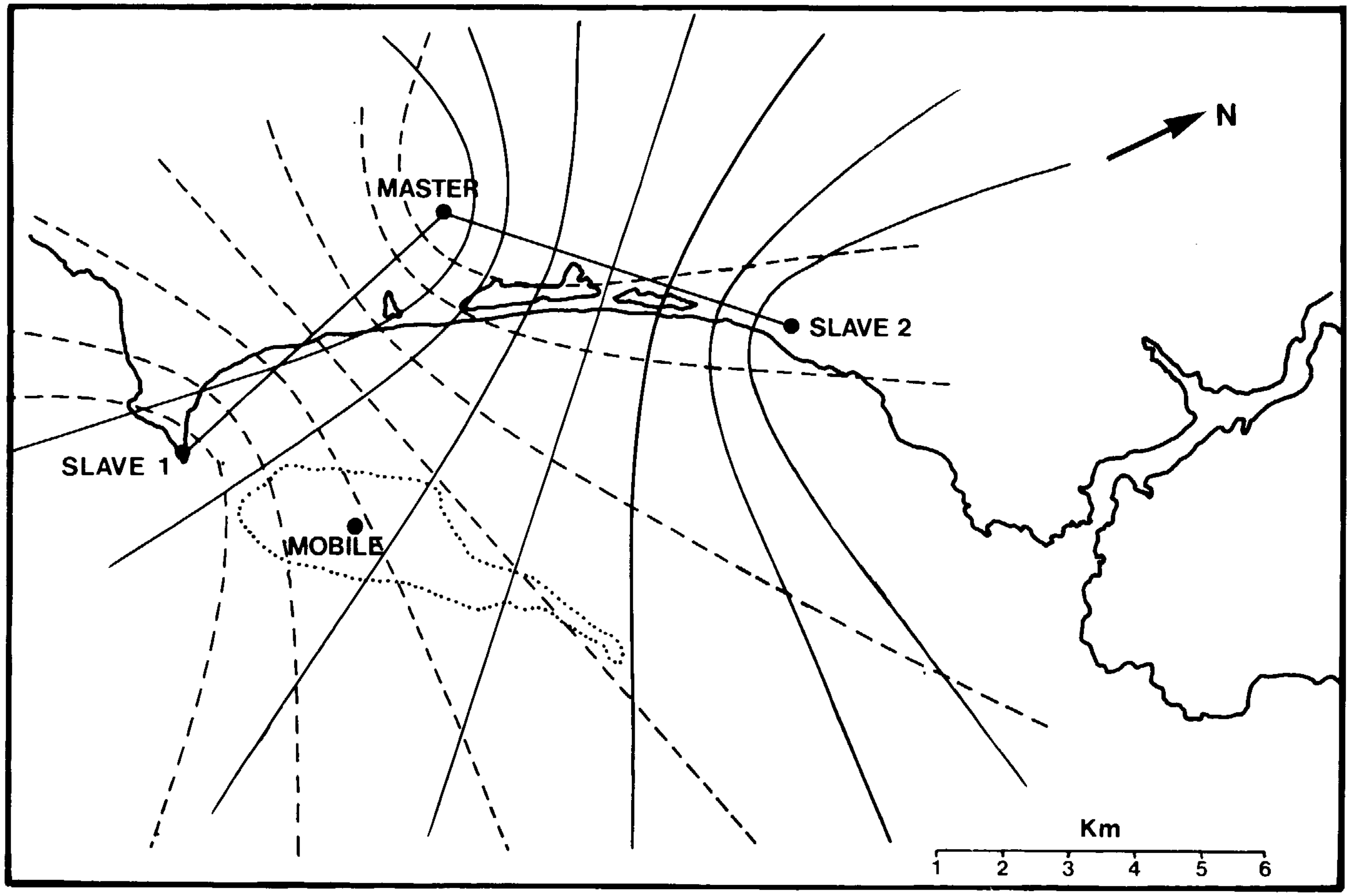

Fig. 4 THE GENERATION OF A HYPERBOLIC LATTICE BY A MASTER AND TWO SLAVE STATIONS

be calculated. Examples of this type of system are Loran and Pulse 8.

6.3 Phase Comparison Systems

Phase comparison systems are more complex than pulse systems, but have a higher accuracy. A number of stations are used to generate the hyperbolic patterns. A master and two slaves is the minimum requirement but some systems use a master and three slaves to give a larger area and a choice of angle of cut. On board the user vessel a receiver compares the phase of two of the patterns received, and position is usually given in terms of 'lanes' from each station. One 'lane' is a complete cycle of phase. The multiple ambiguities are resolved by counting lanes from a known starting point, or by the use of auxiliary frequencies. The width of the lanes which is a function of the frequencies used is not constant and increases with the acuteness of the 'angle of cut' (the angle formed between the vessel and the shore stations). This Range Expansion Factor, as it is called, is given by the expression cosec $\frac{\theta}{2}$ multiplied by the width of a lane on the base line, where θ is the angle of cut. Track plotting facilities and pre-laned charts are usually available for systems where fixed chains are in use. The following are two examples of the many systems available at these frequencies.

6.4 Decca Navigator

Decca Navigator operates at a frequency of about 120 KHz. A resolution of about 0.01 of a lane may be achieved in practice, corresponding to approximately 5m on the base line. The absolute accuracy depends upon the condition and geometric layout. A series of hyperbolic Decca chains cover UK waters, large areas of the Continent, the Persian Gulf, and Newfoundland areas. Chains usually consist of a master the three slave stations, two of which are selected to give the best angle of cut. Lane identification signals are transmitted at intervals. The average width of lane is about 500m.

6.5 HiFix and HiFix 6

HiFix operates at about 1.6 to 2 MHz. It utilises a single frequency with sequential transmissions from each station, unless lane identification is required, when an auxiliary frequency is transmitted. The usual configuration is to have a master and three slave stations generating hyperbolic patterns, two of which are selected to give the best angle of cut. A more portable and compact variant called SeaFix is also produced, it has similar characteristics but lower power and shorter range. A resolution of 0.01 of a lane on the basline is possible, with an average lane width of about 90m, this gives a baseline resolution of about 1m. Absolute accuracy is variable with conditions, geometry, etc. A number of fixed HiFix chains have been in use in UK for which there are pre-laned charts. These chains are now being replaced by HiFix 6, which has a similar basic specification. Up to 6 slave stations can form a chain to enable good coverage of awkward coastlines. Hyperbolic and three user range/range operation is possible.

7. SUMMARY

Microwave position fixing systems are portable, and relatively simple to install and use. Suitable shore sites in the survey area have to be provided. The accuracy and range (slightly more than line of sight) is generally adequate for inshore precision survey work. Power requirements are small, and can be provided by car batteries. Such a system may accommodate only a single or very limited number of ships. Microwave signals are insensitive to the 'skywave' effect, although they suffer attenuation by certain meteorological conditions, and can be reflected from large surfaces.

For 'on line' position fixing a moderately fast calculating or computing unit is required to convert ranges into an acceptable co-ordinate system, and to perform data logging and track plotting as required.

UHF systems have ranges slightly longer than the equivalent microwave system, but with some deterioration beyond line of sight. By means of complex signal processing, and computer analysis of the data, an accuracy comparable with microwave systems can be achieved. UHF transmissions are not susceptible to 'skywave' effects and are insensitive to meteorological conditions.

The low and medium frequency systems are generally multi-user hyperbolic systems. Special charts may be used on which a position may be plotted in terms of hyperbolic 'lanes'. Track plotters are usually available for use with these systems. There may be no or poor coverage from existing chains in some areas of interest. (Low and Medium frequency shore stations are less portable, and more expensive to install and maintain than UHF or microwave stations). The accuracy is variable for geometrical and propagational reasons.

The 'skywave' effect can cause difficulties during the hours of darkness. Multiple ambiguities generally have to be resolved by referencing to some known location.

8. GENERAL REFERENCES

APPLEYARD, S.F. 1975. Marine navigational aids. Electrotechnology,3(2),7-10.

BROADWOOD, W.F. 1976. High accuracy positioning for submarine pipelines. Journal of Navigation, 29(2), 182 - 193.

GILB, T.P. and WEEDON, G.F.C. 'Range Holes' and what to do about them (personal communication).

HAIGH, J.D. 1975. Precision position-finding under dynamic conditions. Systems Technology (Plessey Radar and Telecommunications Divisions)(22), 32-35.

HOOPER, D.J. and MILLIGAN, S.E. 1974. A static trial of the Decca Trisponder system. Hydrographic Journal, 1 (3), 56 - 58.

INTERNATIONAL HYDROGRAPHIC BUREAU 1972. Swedish Hydrographic Office tests of Artemis. International Hydrographic Bulletin, Circular Letter No 43.

LAUTENT, P. 1975. New radioelectric pilot aid for harbor entrance. Paper No OTC 2175, pp 289 - 296 in Proceedings of the Seventh Annual Offshore Technology Conference, Houston, Texas 1975. Volume 1. Dallas, Texas: OTC.

MEETKUNDIGE DIENST. CHRISTIAAN HUGENSLABORATORIUM NOORDWIJK AAN SEE 1972. Experimental measurements of the Artemis in the Waddenzee. 8 pp.

POWELL, C. 1974. The Decca HiFix 6 position fixing system. International Hydrographic Review, 51 (1), 81 - 93.

INTERNATIONAL HYDROGRAPHIC BUREAU. Radio Aids to maritime havigation and Hydrography. Special publication No 39. 2nd edition.

APPENDIX I

Experience with a Trisponder system

IOS (Taunton) has always had a requirement for surface positioning in its work. The increasing scientific need for higher accuracies, and coverage of areas not provided for by existing systems led to the proposal that new system should be purchased by IOS(T). A brief specification was drawn up.

A range of about 50 Km with a range accuracy of better than ± 5m was the first requirement. Portable and unattended remote stations that could be set up rapidly by unskilled personnel, and be powered for several days by batteries were also necessary.

Following the survey of the available techniques, summarised in the main body of this report, a microwave system appeared to most easily meet the above requirements. The choice of a Trisponder system was made on the basis of fulfilling the specifications, cost and compatibility with existing IOS(T) data logging and plotting facilities.

With a Range/Range positioning system a co-ordinate system is required to specify particular points. The system IOS has adopted is the National Grid. The ranges as measured have to be corrected for height differences and for scale factor (a factor used to correct the errors introduced when an area is reduced to a flat plane). The data is reprocessed on a computer to take account of these errors and also to remove any anomalous data, usually caused by reflections, radar interference, ship motion, etc.

In Start Bay repeat surveys of an area have been performed and the track plotted manually with 30 sec fixes on a pre-drawn chart. This was found to be adequate to maintain a line, and to later fill in gaps in the area, although rather tedious.

Calibration was carried out between two Ordnance Survey triangulation points, the range between the two being calculated from their co-ordinates, and corrections made for slant range and scale factor. Attempts have been made to obtain ranges from three shore stations while at anchor. The ship's position was calculated using the ranges in pairs. Agreement was in the order of 3 to 5 metres.

When not at anchor or in conditions where ship motion was apparent this procedure could be used as a check for gross errors in position, ie to check that correct information had been put into the data processing or plotting system. For checking position and performing the initial setting up for a track plotter a small hand-held programmable calculator has proved very useful.

An analysis of the variation of calibration when a number of unrelated ranges were used, has shown discrepancies. It became apparent that to resolve the factors involved, a well-established range with a series of accurately known points would have to be used. Consequently, a calibration was performed on the Ordnance Survey range. The results of this trial are reproduced in Table 2.

After discussion with the Ordnance Survey on the problems of the calibration of microwave systems, it was decided to adopt their technique of performing a major calibration on an established range once a year, and a single check calibration before each usage of the equipment. Any discrepancy between calibration checks should be noted and a correction applied to the survey data (up to some maximum allowable error). Adjustment of the equipment should only be performed on the yearly main calibration, in this way confusion can be reduced.

9 RESULTS OF ORDNANCE SURVEY RANGE CALIBRATION

REMOTE UNIT NO	76	72	74
Additive Constant	- 1.8m	+ 0.4m	- 0.5m
Scale correction factor	0.999948	1.000056	1.000085
Standard error of a measure	± 0.5m	± 0.8m	± 0.4m

To obtain a corrected distance the additive constant should be added to the distance and the result multiplied by the scale factor.

TABLE 2

Over about a 12-month period the Trisponder system has proved to be very reliable apart from minor teething troubles. It has virtually replaced usage of a HiFix system and has provided accurate positioning in many areas that previously had none or poor quality coverage.

Survey operations have been performed from a small survey launch and chartered fishing boats as well as from larger research vessels. With larger vessels which use radar, it is generally possible to mount the mobile antenna unit directly above or below the radar scanner in order to avoid the radar beam. An increase in range scatter has been noted when the unit has been mounted in a main lobe of the radar beam. In order to maintain accuracy and reliability, power supplies, whether mains or battery, should not be neglected.

Also careful consideration should be given to shore sites from the point of view of geometry, optimum elevation for a given range, and obstructions or reflection problems.

APPENDIX II

LIST OF UK OR EUROPEAN AGENTS WHERE INFORMATION OR SERVICE MAY BE OBTAINED

1. TELLUROMETER MRB 201
   Tellurometer (UK) Ltd, Roebuck Road, Chessington, Surrey, KT9 1RQ.
   Telephone: 01 397 8244
2. CUBIC CORPORATION AUTOTAPE CM-41A
   Radio-Holland NV, 20 Jan Rebelstraat, PO Box 9094, Amsterdam 1018.
   Telephone: 020 101972
3. MINI RANGER III and RPS
   Motorola Military and Aerospace Electronics Ins, Taylors Road, Stofold, Hitchin, Herts, SG5 4AY.
   Telephone: 0462 730661.
4. TRISPONDER
   Decca Survey Ltd, Kingston Road, Leatherhead, Surrey
   Telephone: 03723 76971
5. ARTEMIS
   Osiris Survey Projects Ltd, Port Causeway, Bromborough, Wirral, Merseyside, L62 4SY. Telephone: 051 645 2293.
6. SYLEDIS
   Kelvin Hughes Ltd
   Telephone: 01 500 1020
7. DECCA NAVIGATOR, HIFIX, SEAFIX, HIFIX 6, MAXIRAN, PULSE 8
   Decca Survey Ltd, Kingston Road, Leatherhead, Surrey
   Telephone: 037 23 76971