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Electronic Positioning Systems for Surveyors

ANGELO A. FERRARA

Technical Memorandum C&GSTM-3

U.S. DEPARTMENT OF COMMERCE / ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

COAST AND GEODETIC SURVEY TECHNICAL MEMORANDUM

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No. 1 Preliminary Measurements With a Laser Geodimeter. S. E. Smathers, G. B. Lesley, R. Tomlinson and H. W. Boyne, November 1966.

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This Memorandum describes and summarizes the characteristics of various electronic positioning systems that are of interest to the surveyor. Inclusion of the name or description of any product in this Memorandum does not constitute an endorsement by the Environmental Science Services Administration. Use for publicity or advertising purposes of information from this Memorandum concerning proprietary products, or the tests of such products, is not authorized.

PREFACE

Any distinction between a Navigation System and a Positioning System is arbitrary. The primary purpose of a navigation system is usually that of guiding a vessel or plane from one geographic point to another. A positioning system is usually, but not necessarily, more precise to meet the more exacting requirements of surveys or similar projects. In this publication emphasis has been placed on positioning systems, although some systems that are classified as navigational may meet the requirements of a specific application or may be all that is available to meet a given situation.

Descriptions of operating principles and characteristics of the equipment included in this publication are based on Engineering Division experience with the actual systems. Specifications are based on the literature listed in the bibliography following each individual description.

Specifications frequently include claims of accuracy. Such claims can be misleading unless the term "accuracy" is clearly defined. In either a navigation or survey system "accuracy" is an absolute value that locates a position geographically. Determination of such an absolute value is influenced by factors beyond the control of the operator or the equipment. The velocities of light and radio signals, and all navigation and positioning systems depend on one or the other, are affected by atmospheric conditions such as pressure, temperature, and relative humidity. These and other factors along the line of transmission affect the absolute accuracy of any system. Because it usually is not practical to measure these parameters continuously over an entire line, there are always some uncertainties introduced into final calculations. In this publication, the term "accuracy" is not used in the description of individual systems or equipment.

Instead of "accuracy" the terms "resolution" and "repeatability" are used as measures of system performance. The term "resolution" indicates the smallest increment of distance that can be read from the system. The degree to which a system may be expected to give the same reading each time it is used to locate the same fixed point is referred to as "repeatability".

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AUTOTAPE

ABSTRACT

Application:	Precision hydrographic surveying system
Frequency:	3 GHz (10 centimeter radar band
Type of Measurement:	Sequential phase comparison
Range:	Line of sight
Display:	In-line Nixie tube continuous tracking, showing both values to 5 significant digits each.
Resolution:	0.1 meter
Advantages:	Continuously tracking, can be operated unattended, easy to install, battery operated, designed for automatic recording
Limitations:	Intervening land or objects will interfere or cause multi-path signals.

Autotape is an electronic distance measuring system for positioning boats, helicopters and land vehicles from fixed shore points. It is similar in principle to the Geodimeter, Electrotape, or Tellurometer. The Autotape system which consists of an interrogator and two responders(similar to a Master and two Remotes) operates on a carrier frequency of approximately 3 gigahertz. It differs from the other systems mentioned above in that the ranges to the two shore based responders are automatically recorded at the interrogator. Thus Autotape offers a new approach to the problem of recording a large number of positions at a single point for a better averaged value, or, for accurate tracking along a line of position.

This system utilized the phase comparison method of measurement and compares the phases of modulated frequencies in a sequential pattern. The phases of three modulated frequencies are resolved into a single distance which is displayed and recorded if desired at once a second rate. On station, the system works automatically, without the need for adjustments, lane-counting or field calibration. If desired, Autotape can be operated unattented with a printer - making it useful for hydrographic applications.

Since the system operates in the microwave frequencies (radar bands), the ranges are limited to line of sight applications. For shipboard or launch use, the nominal range would be in the order of twentyfive miles, but over 100 miles ranges have been obtained using helicopters. The interrogator is relatively portable, weighing about 55 lbs and having the outside dimensions of 21" by 21" by 11" deep. Two antennas are available and both are equally compact. The horn type weighs about 20 lbs. (which is directional) whereas the four lb. omnidirectional whip is only 18 inches long, making for simple installation on board any vehicle. The two antennas can be used interchangeable at either the Interrogator or at the Remotes. The usual arrangement is to have the whip at the mobile unit and have the horns located at the two shore stations.

The shore based Responders are also quite compact, portable, and lightweight. The responder weights about 15 lbs without the antenna. As in the case of the Interrogator, the Responders can also operate unattended. Both ship and shore units are transistorized for low power consumption and uses a 12 volt storage battery as primary power. The Interrogator will operate for about 8 hours from the typical heavy duty (fully charged) automobile storage battery. The Responders will operate for twice this period since they draw about one half the current from the battery.

As mentioned earlier, the principle of operation is similar to Electrotape or Tellurometer. However, in these latter two, to resolve distance ambiguity different crystals are switched in and the range is read to sequential degree of resolution. The combination of these reading is resolved to the total distance. In the Autotape, the various crystals are switched in automatically, and with the pre-set propagation velocity, the two ranges are displayed to a tenth of a meter at the fine resolution or at one meter resolution at the coarse setting. It can be used on a moving vehicles with speeds up to 200 knots without losing the total range value.

This system is a development of the Cubic Corporation of San Diego, California and was originally designated as AERIS II. With the newer modifications, mostly in the automatic features, it was called AUTOTAPE and is designated as model DM-40. Electrotape, which is made by the same company and is the fore runner of Autotape is called DM-20.

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DECCA

Decca Navigator
Survey Decca
Two-Range Decca

ABSTRACT

Application	Medium range navigation or surveying systems.
Frequency	Approximately 70 to 130 kHz with 4 frequencies per system.
Type of Transmission	Continuous wave.
Type of Measurement	Phase comparision, hyperbolic for Navigator and Survey Decca, circular for Two-Range Decca.
Range	About 300 miles 500km for the Decca Navigator, and much less for the Survey Decca and Two-Range Decca.
Resolution	0.01 lane.
Advantages	Decca Navigator most popular European system for general navigation. Convenient to use on charts marked with Decca lanes or patterns. Has automatic lane identification. Fix can be plotted within a minute. Survey and Two-Range Decca Similar advantages as above. In addition, these two systems are a portable version of the Decca Navigator, and the system is available for purchase or rental.
Limitations	Limited range for all three systems. Also needs special charts with the Decca Lanes imprinted on them. Needs four radio channels or frequencies.

The Decca Company has developed a number of electronic positioning systems both for navigation and for surveying. The following is a list of their systems:

1. Decca Navigator general navigation
2. Survey Decca surveying
3. Two-Range Decca surveying
4. HI-FIX surveying
5. LAMBDA surveying
6. DECTRA special trackline navigation
7. DELRAC long range navigation
8. DIAN airborne Doppler navigation
9. SEA-FIX short range surveying, unattended, can be placed on a bouy
10. MINIFIX miniaturized HI-FIX

Of the above systems, only the Decca Navigator, the Survey Decca and the Two-Range Decca will be described. These three systems are identical in principle and operation. One main difference is that the Decca Navigator system has much higher power transmitters for greater range. The Survey Decca differs only in the positioning of the Master station, in that it is on board ship and is constructed lighter and packaged for simpler installation on board the survey ship. If it is located ashore along with the Slaves (Survey Decca System) then the system is operating in a hyperbolic mode, but permits unlimited users. If the Master is placed on board ship as in Two-Range Decca, then the system is in Two-Range mode in which the patterns or lanes are circular in form instead of hyperbolic. The geometry of the circular system permits greater accuracy over an extended area, but it limits the system to one user because the Master is on board the ship.

All of the Decca systems are phase comparison systems, and the original Decca Navigator was developed during World War II and is now being used for commercial navigation in Europe and many parts of the world. Many Europeans prefer Decca over LORAN because of the higher accuracy and ease of obtaining a fix, as well as continuous tracking. On the other hand, the range of Decca is about one half that of LORAN A, and is much more susceptible to skywave contamination.

Among the various pieces of peripherial equipment manufactured by the Decca Company is the Decca navigator Multipulse Survey Receiver which, when used with the standard Decca Chain or with a special chain set up for the survey, provides greater position accuracy as well as lane identification.

The DECCA hyperbolic radio navigation system was first used in 1944. A DECCA chain consists of a Master station located in the center and the three Slave stations (purple, red, green) located at distances of approximately 75 to 125 miles away. This system operates on the phase comparison principle and without modulation, thus the receivers have very narrow band-pass, which reduces interference from adjacent stations. Each chain uses four radio frequencies in the band from 70 to 130 kHz, and the combination of these frequencies are used to resolve lane ambiguity.

Charts can be purchased with the hyperbolic lines of position over-printed on normal marine charts, thus aiding the navigator in plotting his position.

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DISTOMAT

ABSTRACT

Application:	Precise distance measurement
Frequency:	About 2.9 centimeters (10 GHz)
Type of transmission:	Modulated radio waves
Resolution:	One centimeter
Advantages:	Distance readings are read directly from an in-line numerical display. Can be used either as a Master or Remote. Control unit can be separated from transmitter unit by 100 ft. cable.
Limitations:	Fairly complex equipment. Internal crystals are at specified odd frequencies instead of being at 10 MHz thus requiring a specialized counter for setting crystals.

The Distomat is a trade name for the Wild Instrument Company distant measuring equipment and is officially designated as the Wild 50 Distomat. It is a combined product of the Wild Heerbrugg Company and Albiswerk Zurich, Ltd., the latter firm being responsible for the electronic parts. It is used for geodetic line measurements in a similar fashion to Tellurometer and Electrotape - DM-20. This equipment operates on the same 3-centimeter radar band as the above two mentioned equipment. There is two-way radio communication between the two instruments, and also either instrument can be used as a Master or a Remote set. The observed distance is read to the nearest centimeter, just as is true with the other two equipment, except that the Distomat is the first distance measuring instrument in which the measured distance is displayed as a fully-digitalized read-out in a single continuous number.

Each instrument consist of two pieces of equipment, the transmitter, which is placed on the tripod and the control console which can be placed on any convenient box or support and is connected to the transmitter by a cable, that can be up to 100 feet long without affecting the accuracy or range. Since the two pieces of equipment can be separated, the observer can take a series of measurements from a sheltered area. Also, the observer can use the cover of the control unit as a writing desk, and eliminate the need for a another person for a recorder. Another convenience is a loud speaker so that the observer can monitor the system without the need for wearing a headset. If communication is desired, a handset can be used.

To use, the observer turns a large knob on the control unit through a series of positions and then observes the slope distance on an in-line display of numbers. To simplify the calculations, there is a built-in atmospheric refractive index ($n = 1.000320$) which indicates the slope distance where the higher accuracy is not required. For better accuracies, the meteorological conditions at each end of the line must be taken, and also along the line if possible.

The DISTOMAT has an indicated maximum range of 20,000 meters. For greater distances, the approximate distance to within 20 km must be known and the multiple of 20 km is recorded separated.

This equipment is fairly light weight. Each of the two pieces of equipment in their transport box weights about 50 lbs. The equipment operates from a separate storage battery of 12 volts. A complete system cost about $30,000 for two sets which is needed to make line measurements.

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ELECTROTAPE

ABSTRACT

Application:	Precise Distance Measurement
Frequency:	3 centimeter radar band (9 GHz)
Type of Transmission:	Modulated radio waves
Resolution:	1 centimeter
Advantages:	Distance readings are read directly from a counter dial No cathode ray display. Higher frequency produces sharper beam with less reflections from adjacent objects. Either unit can be used as Master or Remote.
Limitations:	Fairly complex equipment. Internal crystals are at specified odd frequencies instead of being at 10 MHz and harmonics thus requiring a specialized counter for setting crystals.

ELECTROTAPE is a phase comparison distance measuring system developed by the Cubic Corporation under contract from the U.S. Army Corps of Engineers. It initially was called MICRODIST, but because of conflict with MICRODISTANCER (name patented by the TELLUROMETER Co.), the name was changed to ELECTROTAPE and now has the designation of Model DM-20. It is a phase comparison, base line measuring system similar to TELLUROMETER and GEODIMETER. The distance information is carried on a 3-centimeter radar beam (9-GHz). It is unique in one manner in that the crystal frequencies are so selected that the width of the finest lane pattern is 10 meters wide. Since the display consists of a 3-digit figure, the least significant figure is in centimeters, thus the equipment can be read directly in centimeters when the average value of the index of refraction is used (1/1,000,320). Other equipment shows the distance in fractional parts of a lane and then this value has to be converted into distance. The system has 5 different modulation frequencies so that the widest is 100 km., which means that one must know the distance between the "Interrogator" and the "Responder" to within 100 km. The one problem with such a system is that the frequencies are in odd values (for example, the channel 1 crystal in the Interrogator is 7.492427 MHz) and therefore a special high quality frequency counter is needed to calibrate the crystals. Other systems use 10 MHz crystals for the fundamental or finest lane width. To adjust these latter crystals to the correct frequency, all one needs is a shortwave receiver and then zero-beat the internal crystal against the 10 MHz frequency of station WWV.

The ELECTROTAPE uses all solid-state circuitry except for the magnetron transmitting tube, and its history of reliability is fairly good. As is true with other systems, there is provision to maintain two-way voice communication with the system. The voice circuit is a FM system and is quite intelligible.

The ELECTROTAPE is relatively easy to use. The two units are set up at each end of the line and voice communication is first established. To make the measurement, a digital phase dial is rotated until a null meter indicates balance and then the distance is read directly from the dials. The distance is adequate for third order accuracy; for higher degrees of accuracy, the corrections for the effects of the meteorological parameters should be applied. The system can operate from an internal nickel-cadium 12 volt battery for several hours, or from an external 12 volt battery for operations over longer periods.

The original system was funded by the U.S. Army, who have since let out contracts for more of the same equipment. Lockheed-Fairchild won the contract and they call their version MICROCHAIN. It is identical in principle and similar in appearance to ELECTROTAPE.

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ELECTROTRANSIT

ABSTRACT

Application:	Precise Angle Measurement
Frequency:	34.0 to 35.6 GHz
Type of Transmission:	Continuous wave
Type of measurement:	Interferometer
Accuracy:	Not to exceed plus/minus 10 arc-seconds, three sigma.
Range:	50 meters to 50 kms
Advantages:	This new portable, light weight system, when completed, will broaden the capabilities of survey parties to extend geodetic control quickly under adverse weather conditions over large areas.
Limitations:	Not known at this time.

The U.S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency, Fort Belvoir, Virginia has a contract with Cubic Corporation for the development of a microwave azithmuth measuring system, which is called ElectroTransit or Microwave Pointing Device. The proposed system, which has been built experimentally, is a microwave receiver operating in the 35 GHz band and having two parabolic antennas for picking up the signal from two or more tripod-mounted microwave sources. The measurement circuit is a microwave interferometer (essentially a phase comparison system) and is capable of being read to 0.1 arc-second.

The performance requirements as called for under the Army contract are as follows:

Operating Range:	50 meters to 50 kms.
Acquisition:	Sufficient information must be presented to the equipment operator to enable rapid acquisition of the transmitted signal at maximum range when a priori knowledge of the transmitter location is of limited angular accuracy.
Angular Accuracy:	The system must be capable of determining the alignment between a sensor unit and a transmitting target within plus

	or minus 10 arc-seconds, three sigma, when operating within other stated conditions.
Environmental Conditions:	The system must be operable whenever radio frequency line-of-sight exists, and under adverse meteorological conditions such as haze, fog and clouds, rainfall and snow, or hail along the propagation path.

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E.O.S.

ABSTRACT

Application:	Precision base line measurement
Frequency:	Light waves
Type of measurement:	Phase comparison
Range:	Line of sight
Advantages:	Greater daylight distance operation claimed
Limitations:	Not determined or stated

The "EOS" distance measuring system is an optical-electronic system similar to the Geodimeter Model 4, and of similar size and weight. The principal difference between the EOS and the Geodimeter is the modulation system and modulating frequency.

The Geodimeter uses a Kerr Cell for the modulation of the light waves, while the EOS uses a quartz crystal. The modulation frequency of the Geodimeter is approximately 30 MHz and the modulation frequency of the EOS is about 60 MHz.

An incandescent lamp is used as the light source of the EOS and the daylight measuring range is 15 km. The night time range is claimed to be better than 25 km. The light intensity is claimed to be much higher than that of the Geodimeter with the incandescent lamp, since it is claimed that 95% of the light is lost when transmitted through the Kerr Cell.

The manufacturers claim an accuracy of 5 mm plus two parts in a million times the distance for distances above 200 meters.

The instrument is manufactured by Carl Zeiss of Jena, Germany. No information is available about the cost of the equpment.

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GEODIMETER

ABSTRACT

Application:	Precision base line measurements
Frequency:	Light waves
Type of measurement:	Phase comparison of a 10 or 30 MHz signal
Range:	Line of sight
Display:	Dial presentation, null meter
Resolution:	Approximately 1 centimeter
Advantages:	Most accurate field method of electronic distance measurement available today
Limitations:	Used mostly at night. Line of sight must be clear of all foliage or other light-obstructing objects, such as fog or rain

GEODIMETER (Models I, II, III, IV and VI)

The Geodimeter is an electronic method of measuring distance by measuring the time it takes a modulated light wave to travel from the master unit to a mirror and return.

This is a phase comparison method similar to those used in Electrotape or Tellurometer, etc. The comparison is of a modulated light wave instead of a radio wave. The basic measuring unit is a 10 or 30 megacycle crystal. In the Tellurometer, the phase of the reflected 10 megacycle signal is compared directly with the phase of the outgoing signal by measuring the phase of the beat notes. One phase relationship of 360 degrees is equal to one full cycle of the 10 megacycle signal. The wavelength of the cycle at 10 megacycles is approximately 30 meters. Because it is a round-trip path, the actual range measured is one-half the wave length, or 15 meters.

In the Geodimeter, the 10 or 30 megaHertz signal (depending on which model is used) operates a Kerr Cell which interrupts the light beam at this frequency. A Kerr Cell has the property of rotating the plane of the polarized light beam when under the influence of a strong electrical field. A second polarized lens on the output of the Kerr Cell is so adjusted as to pass the light beam after its plane has been rotated. Thus, the Kerr Cell has the effect of pulsing (or modulating) the light beam at a rate dependent upon the frequency of the applied voltage. Since the applied frequency is 10 or 30 MHz, the Kerr Cell will permit the light to pass on the positive alternation of the 10 or 30 MHz signal and also on the negative alternation. Thus, the light is pulsed at twice the applied frequency, or at a 20 or 60 MHz rate, depending on whether the model II or the model IV is used.

The modulated (or pulsed) light beam is directed towards a distant mirror and reflected back to the GEODIMETER, which is focused on a phototube (a tube sensitive to light variations). Also, a portion of the outgoing light is passed to a variable delay line, which can delay the light beam over the distance of one phase at 20 or 60 megacycle. This distance is 7.5 or 2.5 meters instead of 15 meters as in Tellurometer. Thus, the Geodimeter is capable of being read more closely, since the lane widths are less than the width of the Tellurometer lanes. Also, the light waves of the Geodimeter are less sensitive to meteorological phenomena than radio waves so a higher accuracy can be obtained with the Geodimeter.

The reading accuracy of the Geodimeter is plus or minus 3 millimeters. However, the ultimate accuracy of the position is determined by the temperature, pressure, humidity, and color (or atmospheric dispersion).

With the 10 megacycle modulation, the surveyor must know the true distance to within 3000 meters; with the 30 megacycle modulation, 2000 meters.

Geodimeters Nos. 1 and 2 are quite heavy (over 200 lbs.) and are well calibrated and thus can be used for very accurate base line measurements. Model No. 3 was an attempt to reduce the bulk of the instrument, but it was not successful. The Geodimeters Nos. 4 and 6 are more successful versions. They are quite compact and light weight (45 lbs.) and almost as accurate as the models 1 and 2. However, because of the smaller mirrors, the range is much less. Actually, the models 4 and 6 can measure as accurately as the models 1 or 2, but the crystals in the former are not as stable as the latter. If some external means of measuring the frequency is available, such as a frequency standard, then the accuracy can be quite high, and the models 4 and 6 have measured lines to an accuracy of better than one part in a million afer the crystals have been set and checked by some external accurate standard.

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HI-FIX

ABSTRACT

Application:	Medium range hydrographic surveying system
Frequency:	1.7 to 2.0 MHz band
Type of measurement:	Pulsed, phase comparison
Range:	About 150 miles maximum for the 100-watt transmitters.
Mode of operation:	Hyperbolic or two-range
Resolution:	0.01 lane
Advantages:	Uses only one frequency. If lane identification is desired a second system with a nearby frequency is used. Relatively lightweight, and battery operated. Designed for rugged use.
Limitations:	As with any phase comparison system, Hi-Fix is affected by sky waves interference. Also parts are manufactured in Great Britain and at times are not readily available in the U.S. thus there are long delays in obtaining components.

HI-FIX is a medium range surveying system which uses the radio-navigation band of 1.7 to 2.0 MHz, although if the need exists, higher frequencies could be used with correspondingly smaller lane widths. The problem with using frequencies other than those in the radio-navigational band is the interferences from other services in the short-wave radio bands.

Some of the features of the HI-FIX system are:

1. It uses only one radio frequency. Other systems use several radio channels, some of which have to be harmonically related (which is a problem in these days of crowded radio bands.)

2. The signals from the ship or the shore stations are not modulated. Therefore, the receivers can be tuned more selectively to eliminate noise and interference to nearby radio systems.

3. This system can be arranged to operate either as a two-range mode (for single party user) or in hyperbolic mode (for unlimited users.)

4. There are two systems, the HI-FIX Type A and the Type B system. The Type B system is essentially two Type A systems, each operating on separate frequencies. If the two systems are operating simultaneously, then fixes can be taken from both systems to check one against the other and to minimize stoppages due to breakdowns. But more important, the B system provides lane identification. While

operating on the first system, if the second system is tuned in, coarse lane pattern values are obtained, the lane width being equal to the half-wavelength of the difference frequency between the two systems. For instance, if the difference frequency is one-tenth of the original frequency, then the lane-widths will be 10 times as wide as previously.

5. This equipment can be leased or purchased outright. The Decca Company is a world-wide organization and can provide services anywhere.

6. A number of peripherial equipment is available as part of the system. This includes track plotters, Helmsman left-right indicator, remote displays, automatic recorders and printers, automatic battery chargers, light-weight and compact airborne equipment, and navigation computers to convert the HI-FIX values, both hyperbolic and two-range mode, into latitude and longitude values.

The HI-FIX system (Type A) is able to operate on one frequency by virtue of time-sharing the frequency channel between the Master and the two Slave stations. A cycle of events takes place each second. After the initial timing signal, the Master transmits for 0.3 second, and then the first Slave transmits for 0.3 second. The Master unit has three oscillators, two of which are phase-locked to the two Slave stations.

The frequency of the Master oscillator is transmitted to both Slave stations each of which also have phase-lock oscillators. As the Master signal is received at each station, the Slave oscillator is shifted in phase to lock into the received signal. Then as explained above, the two Slaves transmit back to the Master sequentially. They transmit the frequency of the internal phase-lock oscillators, which have the phase of the received signals from the ship. So the signal, as received by the ship, contains only the phase-shift caused by the transmission time from the Master to the Slave and return. On the Master unit, the two internal phase-lock oscillators adjust their oscillations to the incoming signals from the respective Slave stations. The phase relationship between the Master oscillator and the two Slave phase-lock oscillators are shown on two numerical registers which indicate this value to within one-hundredth part. One complete cycle of phase relationship is called a lane and the entire configuration of lanes from a Master and one Slave station is called a pattern.

As a result of the above internal oscillators, the pattern values are shown continuously even though the information is being updated only once a second.

The HI-FIX system (and other similar systems) can be operated either in range-range mode or hyperbolic mode by the placement of the Master station. If it is on board the ship, then the system is in two-range mode. In this mode, only one ship can operate on a system. If the Master is ashore, then a hyperbolic pattern is set up which permits unlimited number of users.

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LAMBDA

ABSTRACT

Application:	Long range surveying
Frequency:	100 to 200 kHz band
Type of measurement:	Phase comparison, 2-range
Range:	300 to 500 miles maximum, depending on regional noise level and transmitter power
Display:	Dial presentation, showing both fine and coarse lane values
Advantages:	Has continuous lane identification. Has the greatest range consistent with good accuracy of any present day system
Limitations:	Requires four frequencies, not as accurate as Hi-Fix or similar systems at closer ranges, so it is not a good dual purpose system

Lambda is a low-ambiguity, accurate position-fixing system for oceanography and hydrography. It is quite similar to two-range Decca, with two additional features. The first feature is Lane Identification and the second is the use of Phase Locked Oscillators at both ship and ground stations.

The technique of lane identification is entirely new. It does not require an extra ground station. Also, it only requires one additional radio frequency, which is used for a fraction of a second during lane identification. When the lane identification button is pressed, the ship's transmitter shifts to a new frequency. This operates relays at the ground station which shifts their frequency by about 14 kHz. On the ship is a phase-locked oscillator which was locked to the ground station transmitter. Since it continues on the same frequency during lane identification, it now differs from ground station transmitter by 14 kHz. Special phase meters read the ship's position within lanes of 14 kHz, each lane being about 10km.

The phase meters do not read the phase of the signals directly, but the phase of the phase-locked oscillators, which are in turn controlled by the phase of the incoming signals. Phase-locked oscillators are very stable oscillators which operate at the same frequency as a distant transmitter with phase and frequency of this oscillator being held to that of the distant transmitter.

Thus, at the ground station, if there is a loss of the ship's transmitted signal due to failure, noise, or skywaves for a short period, the oscillator continues to run and the ground station sends out its transmitted signal free of noise.

At the ship are similar phase-locked oscillators, and since the phasemeters are connected to these oscillators, the phase meters will remain steady and show the distances even in the presence of a short burst of static or noise. There isn't any tendency for the phase to run erratically.

Phase-locked oscillators act as storage devices similar to a flywheel, thus, they keep the system going while the noise level is excessive. It is, therefore, possible to receive weaker signals for a given noise level. The effect then is the same as a power increase of the transmitters, making greater range possible.

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LORAC

ABSTRACT

Application:	Medium range hydrographic surveying system
Frequency:	1.7 to 2.0 MHz band.
Type of measurement:	Pulsed, phase comparison
Range:	About 250 miles maximum
Resolution:	0.01 lane
Advantages:	Well established firm. Has many permanent commercial chains along the Gulf Coast. Can provide additional equipment for lane identification. System can be leased or purchased. Engineering services and charts are also available.
Limitations:	As with any other phase comparison system, LORAC is affected by sky waves which causes lane jumps. System is high powered and is not easily adapted for portable operation. Only available in the hyperbolic mode of operation.

LORAC (Long Range Accuracy) electronic positioning system was developed by the Seismograph Service Corporation of Oklahoma for surveying and positioning of oil equipment along the shelf area of the Gulf of Mexico, to an approximate maximum distance of 300 miles. This company has set up a chain of LORAC stations, available for leasing along the Gulf Coast to provide electronic control throughout the area.

LORAC is a hyperbolic continuous-wave phase comparison system using frequencies in the 1700 to 2500 kHz band. In this manner, it is similar to other systems such as Decca, HI-FIX, RAYDIST, and RANA, that is; they all are phase-comparison, hyperbolic systems, operating in the 2 MHz band.

There are basically two LORAC positioning systems, the Type A and Type B. The Type A has a center station and two end stations. The difference in phase relationship between the center station and any one of the two end stations produces a hyperbolic pattern. In order to obtain a stationary pattern, the end station must either be synchronized to the center station (so that some definite relationship exists) or there must be some other means of determining this relationship and forwarding that information to the user. In the type A systems, the stations are not synchronized to each other, but are all operating independently. Thus, for the first half of the cycle, the center station and left end station would be radiating two radio frequencies, one separated from the other by a low frequency of 135 Hertz. The ship receives the two radio signals and detects the 135 Hertz difference, which is fed to one side of a phase indicator meter. In the meantime, the right-end station would also receive the two signals from the center and left stations. The 135 Hertz frequency difference would then modulate the right end station transmitter which would be picked up by the ship and fed into the other side of the phase meter. Since the right end station is permanently fixed in position, the only phase relationship it would indicate would be that of the center and left stations. Thus as the ship moves, the phase relationship of the two signals coming directly from the center and left stations would change with reference to the signal coming from the right station. Therefore, this changing phase relationship would indicate ship's position.

On the second half of the cycle, the center station transmitter would change frequency slightly, so that the difference between this new frequency and that of the right hand station is now 315 Hertz. The ship detects this frequency difference and again places it on one side of another phase meter. In the meantime, the left hand station now picks up the signals from the center and right stations and sends this reference information as a modulated signal to the ship. The ship's equipment has filters in it to separate the 135 and 315 Hertz information and present this information to the respective phase meters.

The main disadvantage with the type A system is that the end stations must receive the signals from each other, and aside from the attenuation of the signals over land between the two end stations, there is also the additional problem of phase shift caused by the changing conductivity of the earth between the stations. These two effects would cause undeterminable errors in the system.

The system presently furnished by LORAC is the type B system. In this case, a fourth station is located near the center station. This fourth station's receiver picks up the phase relationship from both end stations with respect to the center and transmits both the 135 and 315 Hertz frequency reference signals to the ship on a modulated radio carrier. Since the path-length between the end stations and the reference station is much shorter, the effects mentioned in the previous paragraph are reduced and consequently the errors are smaller.

In addition to the Gulf of Mexico area, the Seismograph Service Corporation will provide equipment and personnel for other areas of the world. Also they can provide preplotted charts, automatic course plotters, automatic data recording systems, helmsman steering indicator, antennas, power system and instrumentation trailers.

As in any hyperbolic mode of operation, the accuracy of the position decreases proportional with the distance away from the baseline. The engineers of the Seismograph Service Corporation have made extensive studies to improve the overall accuracy of their system, and for a detailed discussion of a particular problem regarding the accuracy of LORAC, the officials of the company should be contacted. In general terms, the overall positional accuracy would be in the same order as other hyperbolic systems operating in the same frequency band.

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LORAN A

ABSTRACT

Application	Long range navigation.
Frequency	1850, 1900, and 1950 kHz.
Type of Transmission	Pulse.
Type of Measurement	Hyperbolic, time difference, pulse match.
Resolution	One microsecond.
Advantages	Nominal long range navigation with a good degree of accuracy. Mobile equipment relatively inexpensive and standardized. Equipment fairly easy to use and service.
Limitations	With present equipment, two separate readings are required. The pulse matching technique gives only fair accuracy when compared to phase matching. Not considered sufficiently accurate for surveying.

LORAN A (formerly designated as STANDARD LORAN) was developed in the United States in 1940 and put into use in 1943. The shipboard receiver determines the position of the ship by measuring the differentce in the time of arrival of two radio pulsed signals transmitted from a pair of stations ashore. On the surface of the earth, the difference of time creates a hyperbolic pattern (actually a spherical hyperbolae) with the transmitting stations located at the forcal points.

A LORAN chain consist of three transmitting stations with the center one designated as the Master and the two end stations called Slaves. The center station performs a double duty in that it serves as a Master for one Slave and then for the other Slave. To separate pairs of stations from each other, a specific pulse rate is used for identifying the pair. By adjusting the shipboard equipment to the specifiied rate desired, the signals from this pair will remain stationary on the face of the cathode ray tube display while all other signals will move.

The operator selects the proper pair of stations and aligns the Master and Slave signals until they are superimposed. The dials that are turned to make the alignment have time values on them and this time value is the hyperbolic lines of constant time difference of arrival at the ship between the Master and the Slave. By first reading the time difference of a Master station and one Slave, and then the same Master (which pulses at both rates) and the second Slave, the navigator can determine the ship's position from the intersection of the two values of time differences.

LORAN A operates in channels within the radio-navigation band from 1.75 to 2.0 MHz. The average range of the ground wave (and therefore the most direct signal) is about 400 miles over land and about 700 miles over water, although this range may vary widely in specific locations. The overall accuracy of LORAN A (as well as any other system) is determined by the geometry of the radiation pattern, the position of the observer within the service area of the system and by the accuracy of the time measurement. This last factor (time measurement) is affected by the receiver calibration and the propagation velocity of the radio waves. In general, the accuracy of a LORAN A position can be said to be about 1% of the distance between the ship and the LORAN stations.

LORAN A has one advantage over many other systems in that the signals are shown on the face of a cathode ray tube. Thus the signals can be observed in the presence of heavy atmospherics static or other noises. This is also true for the other LORAN systems (B, C, and D.) since the operator is initially required to select the proper group of stations.

A disadvantage of LORAN as far as frequency economy is concerned, is the large frequency spectrum inherent in pulse modulation and the consequently large receiver bandwidth required. This disadvantage is compensated for by the fact that LORAN is the only radio navigation system that by virtue of the pulse modulation and the cathode ray tube display allows separation of ground wave and sky wave components and, at the same time, indicates the reliability of the signal received.

Although LORAN A was originally designed for maritime use, it since has proven useful for aircraft and has been used by planes since 1944.

To extend the range of LORAN A and make use of the skywaves which at a great distance are much stronger in signal strength than the direct waves, an attempt was made during World War II to make use of the skywaves. The Slave stations would synchronize to the Master station skywave, and thus as the ionized layer above the surface of the earth would vary in height, the Slave stations would automatically compensate for this change. This system was called SS LORAN (Skywave Synchronized LORAN). While the system was feasible, it was not used to any extend and was discontinued. The navigators had charts which would give corrections for skywaves received from regular LORAN A stations and this served in much the same manner as SS LORAN.

Despite the advantages of LORAN A, it did not fulfill the accuracy and range requirements for many users, and several other systems were proposed, among which were LF LORAN (Low Frequency LORAN), Cycle-Matching LORAN, and CYTAC (the name given by Sperry Company for LORAN C). These systems were finally incorporated into what is known today as LORAN C.

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LORAN B

ABSTRACT

Application	Medium range precise navigation (experimental)
Frequency	1850, 1900, and 1950 kHz.
Type of Transmission	Pulse.
Type of Measurement	Hyperbolic, time difference, both pulse and cycle matching.
Resolution	0.01 microsecond.
Advantages	Has the high precision of a 2 MHz phase comparison system and yet retains the sky wave and ambiguity-free features of LORAN.
Limitations	Requires very strong signal to noise ratio for satisfactory matching, thus limiting the useful range.

LORAN B is similar to standard LORAN (Loran A) in that it is a pulse and hyperbolic system. The envelopes are matched as in standard Loran to determine proper lane identification.

For greater accuracy, the cycles of the radio frequency signal inside the envelopes (or pulses) are compared in phase; the same as in any phase comparison system. The only difference being that the information presented on the dials is given in nanoseconds (one billionth of a second) instead of fractional parts of a lane. It should be noted that the above applies also to Loran C, and actually Loran B can be considered as being Loran C except that now the carrier frequency is near 2 megahertz instead of one twentieth of that frequency or 100 kilohertz. The higher frequency results in better resolution by a factor of 20 over Loran C. However, with the higher frequency comes additional problems, one of which is decreased range. In fact, the range is less than with Loran A despite the fact that they are both on the same frequency. It seemed that a higher signal to noise ratio was required for proper phase comparison, with the result that the useful range of Loran B was about one third that of Loran A.

Although many of the techniques of Loran C could be successfully applied to Loran B, further experimentation of Loran B had been shelved since the present day need is for long range navigation for which Loran C and Omega are better suited.

LORAN C

	ABSTRACT
Application	Extra long range nagivation.
Frequency	100 kHz band.
Type of transmission	Pulse.
Type of measurement	Hyperbolic, time difference, both pulse and phase match.
Resolution	0.01 microsecond.
Advantages	It is the longest range system with the highest degree of accuracy available in 1965 among shore-based navigation equipment. It is not affected by sky wave contamination as conventional phase measuring systems. Receivers can be purchased which will continuously track LORAN C stations. It can be connected into an automatic data acquisition system and plotter.

LORAN C is similar to Standard LORAN (LORAN A) in that it is a pulse and hyperbolic system. LORAN C differs from Standard LORAN in three major characteristics:

1. It is possible to measure the "coarse" time difference by matching the leading edge of the pulses (as is done in LORAN A) and the "fine" time difference by matching the cycles of the radio frequency waves inside the envelope, thereby permitting accurate reading without sky wave contamination.

2. Because of the lower frequency (100 kHz as compared to approximately 1800 kHz of LORAN A), a greater range of the ground wave, particularly over land, is obtained.

3. Automatic tracking of signals is available because of the special design of the equipment.

The LORAN C receiver can detect very much weaker signals in the presence of noise than is now possible with LORAN A receivers, because of correlation techniques, namely, by transmitting 8 pulses closely spaced. These 8 pulses, therefore, give the time difference information 8 times to the receiver during one transmission cycle, thus boosting the ability to detect weak signals. Also, these 8 pulses are coded (the pulses start in a positive or negative direction in a certain order) for each LORAN C station. The receiver has this same code set up internally thereby being able to track a given station and ignoring all other LORAN C stations and noise.

As is the procedure with LORAN A, the operator selects the proper station rate and places the Master and Slave signals on the proper respective pedestals, as viewed on a cathode ray display tube. The pulses are then matched visually and the time difference is read from the dials. However in LORAN C, there is a further step, in that, both Slave signals (as well as the Master) are placed on their respective pedestals. Once they are set, the receiver is switched to automatic tracking and the internal servo system will continue to keep the signals matched and display the correct time difference continuously.

The overall system accuracy of LORAN C is claimed to be plus or minus 0.25 microseconds at 95% of the time, with the baseline between the stations being approximately 900 miles. This figure does not take into consideration the errors caused by irregularities in the propagation velocity of radio waves. However, it is considered to be at least one order of magnitude better than LORAN A, all other considerations being equal. That is, the general figure of accuracy for LORAN A is about 1% of the distance from the ship to the stations, whereas for LORAN C, it is 0.1% of the same distance.

LORAN C transmissions are at 100 kHz, which are synchronized to WWV time transmissions. Therefore, receivers at fixed locations can use this constant frequency (good to one part in a billion) to set their electronic clocks and maintain absolute time to approximately within one microsecond. This system is being used along the Atlantic Missile Range.

One of the serious disadvantages of LORAN C receivers is their complexity and resulting high cost of maintenance. Many receivers are critical in operation and requires frequent servicing to maintain satisfactory performance.

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LORAN D

This is an experimental system being developed by Sperry Gyroscope Company under contract for the Defense Department. The principle of operation is similar to LORAN C and the receiving equipment can obtain a position on existing LORAN C networks or chains. However, the main emphasis is on making a portable, tactical navigation system, taking advantage of the latest developments in electronics in reducing the size and increasing the reliability. Also proposed as part of the system is a data link for communication between the ship and the shore stations. This equipment is being packaged to be portable and easily assembled as shore stations. The shore stations can be quickly erected with a minimum of personnel even within range of enemy guns.

The range will be a function of the power of the shore stations, but the design plan calls for a range of 500 miles with baselines of 300 to 400 miles.

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MAP

Marine Autotraverse Positioner

(Rayflex)

ABSTRACT

Application	Short range surveying.
Frequency	Radar frequencies.
Type of measurement	Pulse - time
Range	Line of sight, or about 30 miles from shore stations.
Display	Visually on radar screen, digitally by automatic readout, and graphically by automatic plotter.
Advantages	Uses regular radar frequencies and therefore does not need special authorization for this frequency. Targets for the most part are passive or just reflectors. Any number of ships can operate without interference. No ambiguity. Accuracy does not depend upon operator's skill.
Disadvantages	Not quite as accurate as phase comparison systems.

MAP is an inshore navigation system with a range of about 30 miles or line of sight. It is essential that a good quality radar be provided as part of the MAP system. The radar is modified to give a high precision range accuracy and a selective azimuth control so that only the desired shore targets are indicated and shown.

The shore targets are mutually perpendicular screens mounted on top of a tower or support. Two or more targets may be located ashore to cover the survey area.

An automatic plotter fastened over the boat sheet automatically follows the course of the vessel on the sheet. The ship's position can be pricked into the boat sheet or observed through cross-hairs. The ship's distance from both targets is also printed on a tape at any time or command.

In the survey operation, the operator at the radar keeps a range gate and an azimuth gate on each of the two targets as seen on the radar. This is a simple operation which requires little skill. The purpose of this operation is to exclude all unwanted targets.

MAP has the following features:

(a) In many areas it does not require an active (powered) target. These targets are as easy to establish as visual hydrographic signals. There is no need to establish camps for personnel ashore. These targets are reflectors placed at selected points.

(b) In areas where the target is indistinguishable, a noise-maker is attached to target. This is a low-powered transmitter which will run a month on a battery. Its purpose is to make its target as seen on the radar different from other targets or signals.

(c) MAP is useful for both large and small vessels. One radio technician is needed to service the system and the storage of ground station equipment on board the vessel is of minor consequences since the targets and noise-makers are quite small.

(d) Targets may be used on buoys or may be attached to navigational aids.

(e) The radar does not lose its value as a navigational aid or warning system during the survey operations. That is, the radar will continue to function as a regular radar during survey operations. The radar that has been used is the Raytheon Model 1500 Radar.

(f) MAP has an advantage over many other short range systems in that the shore equipment is neither expensive nor complicated.

The Alpine Company has a similar system called PRS (Precision Ranging System) which uses a Decca radar and an active transponder for the shore station.

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MORAN

ABSTRACT

Application:	Short range surveying
Frequency:	400 MHz for original equipment, 3-centimeter radar band for new equipment
Type of transmission:	Pulse
Type of measurement:	Round-trip time values, pulse matching, automatic
Resolution:	One thousandth of a mile
Display:	Counters, also servo track plotter
Advantages:	Portable, rugged, low-powered drain, low-cost, relatively easy to operate, no ambiguity
Limitations:	Not as accurate as phase comparison systems

MORAN, a development of the Moran Instrument Corporation, is quite similar in many respects to SHORAN, that is; an UHF distance measuring system utilizing time measurement of pulses in an interrogator - transponder system. The main emphasis here was to develop a light-weight, low power drain, rugged instrument with a minimum of automatic features to increase reliability and reduce overall cost. Also, SHORAN is no longer available except as surplus equipment so MORAN and a few other systems such as SHIRAN, AUTOTAPE, etc. are the only systems that can be purchased. While MORAN does not have the automatic recording features of SHIRAN, it is much lower in price. In 1959, the cost of one system to the U.S. Navy was about $35,000.

Part of the Master (interrogator) system is an automatic tracker and plotter for plotting tracklines. This plotter can be used by inexperienced personnel instead of civil engineers in plotting the position. The operation of the system is also straight-forward. Just as in SHORAN, the operator aligns up two pulses with a marker and reads off the distances on a numerical range counter.

Since the system operates in the UHF band, on about 400 MHz, the range is limited to line-of-sight operations, which means about 25 miles with the typical shipboard antenna installation. Of course, the range is extended if the equipment is on an aircraft. The accuracy is also in the same order as SHORAN since the principles are the same.

A modification of this basic equipment was made in 1963 which increased the peak output of the transmitters by 10-fold and thus greatly increased the maximum range of the system.

The Moran Instrument Corporation is now developing a more advanced system which utilized the same basic principles but which would include a new completely automatic-tracking plotting system. This system, which is called AUTONAVIGATOR, continuously plots the ship's position on a chart without the presence of an operator. AUTONAVIGATOR is available for either purchase or lease. One feature of AUTONAVIGATOR is that it can be connected into the ship's autopilot to control the course of the ship. Microwave bands (radar bands) are used so interference problems with other services are minimized. Generally, the UHF systems interfere with satellite communications and telemetering circuits.

Moran AUTONAVIGATOR operates in X band (3 cm.) radar band and utilized a 40-KW peak power transmitter and two separate receivers in the ship's master station. The transmitter and two receivers are housed in a compact, omnidirectional, watertight antenna package which is mounted on the ship's mast. This is connected to the control unit and range computer by a flexible cable instead of a rigid waveguide which is expensive and difficult to install. The computer unit contains two separate automatic tracking range computers for each of the two receiver channels. This equipment drives two servo plotting heads which are mounted on a chart and arranged to pivot about the map positions of the two beacon stations. These two servo plotting heads drive a plotting bug by means of two lead screws so that the plotting bug automatically and continuously follows the ship's position on the chart while the survey is in progress.

Some extremely reliable, very compact, low power beacon stations are now available which can be operated from batteries at unattended shore stations. These low power beacons are suitable for ranges up to 35 miles where line-of-sight conditions exist.

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OMEGA

ABSTRACT

Application	Extra long range navigation
Frequency	10 to 14 kHz.
Type of measurement	Phase comparison - pulsed.
Range	Over 5000 miles.
Usage	Experimental
Display	Dial presentation, automatic tracking.
Advantages	Complete world coverage with seven stations. Good long period stability. Reception in air, on the surface, and under water (for submarines) Similar in operation to LORAN C but with greater coverage. Other than satellites this is the only world wide system planned.
Disadvantages	Data output rate too slow for jet planes with special computer to advance the OMEGA position. It is a hyperbolic system similar to LORAN and therefore the accuracy is a function of the distance. Accuracy is also affected if there is darkness between the ships and the shore stations.

OMEGA is an experimental long distance navigation system now being developed by the Department of Defense for use with surface and underwater ships. It is outgrowth of the RADUX system which was initially developed to operate on 40 kHz but since greater range and better phase stability was possible at 10 kHz, RADUX as such was discontinued and OMEGA is now the system under development. The DECCA Company has developed a similar system called DELRAC but it is not being used as system since the Decca Company is awaiting the outcome of the OMEGA system.

OMEGA is a pulsed, phase comparison, hyperbolic, long range navigation system. In a regular phase comparison system, the signals from a pair of stations are radiating continuously and the ship determines the phase relationship between the two signals. In a pulsed system, the signals only appear intermittently and thus the phase meters would fluctuate. To overcome this problem, phase-locked oscillators are used which serve as storage units for the signals from the shore stations. These oscillators are quite stabile and they retain the phase information being radiated from the shore stations. As the pulses come in, they phase-lock, or adjust the oscillators to the new phase value. The output of the oscillators are compared and the phase relationship between two oscillators are shown on a dial or some other similar type of presentation. Since the oscillators are running continuously, the phase meters indicate a steady value, that is, they do not fluctuate. As the pulses come in, the oscillators move to the new values and the phase meters adjust accordingly.

As with any other phase comparison system, there is a problem of lane ambiguity or identification. At 10 kHz, the lane width at the base line is about 8 miles, and the OMEGA equipment can be read to one thousandth part of a lane. Thus if the navigator is near the base line, he has to know his position by some other means to within the 8 miles, to be certain which lane he is in. Further away from the base line, the lane width (proportional to the cosecant of one-half the angle between the two stations as seen from the navigator's position) but still there is need for some other means of knowing one's position. To overcome this problem, additional frequencies are used which, when compared to the 10 kHz frequency, indicate lanes of much greater width than formerly. Since lane widths are inversely proportional to the frequency, if 13 kHz is compared to a 10 kHz frequency, the difference being 3 kHz, or about 1/3 of 10 kHz, the apparent lane widths will be about 3 times wider, or about 24 miles wide at the base line. By using other frequencies whose differences are even smaller, much greater lane widths are then obtained. It has been proposed that the coarse lanes should be in the order of 75 miles wide at the base line in order that a navigator can resolve his position under any conditions.

Instead of using separate radio frequency channels for each chain of OMEGA stations, a chain usually consist of a Master and two Slaves; all OMEGA stations will be on the same frequencies, but will time-share these frequencies at one second per station. The time-relationship of when the Master and Slave pulses are transmitted will serve as the identification for each chain.

This system appears to be the most suitable for long range navigation (other than satellites). It will provide navigational control for submarines, surface ships, and aircrafts simultaneously. In fact, this is the only system that is suitable for submarines. Successful reception of signals have been made by submarines operating under the ice. Aircraft have another problem, however, in that of speed. At sea level and at Mach 1 speed, a jet aircraft can pass through one OMEGA lane (8 miles wide) in about 45 seconds. Thus a loss of signal for about 20 seconds could result in an improper lane count. A special computer has been design which will advance the OMEGA position, and also keep track of the plane's position, using the coarse lane widths.

In 1965, the OMEGA system was still in the experimental stage, but a chain has been set up for detailed testing. This chain consist of a Master station at Panama, Canal Zone, and Slave stations at England, New York, and Hawaii. Through the use of atomic frequency standards, this system will then provide a world-wide frequency and time standard as well as navigational control.

It has been proposed that seven or eight OMEGA stations will have sufficient coverage to permit navigation over most of the earth's surface. With minor exceptions, caused by high attenuation in transmission over the polar ice-cap and permafrost, all eight stations will be observable at any receiving point; five or six of the stations will ordinarily supply signals fully satisfying the system standards of fix accuracy and reliability. Based on a number of tests, the OMEGA fix accuracies are estimated to be within a half mile during the day and one mile at night. There is a change in the velocity of radio waves from day to night which causes a phase shift in the signals being received on the ship. This variation causes the accuracies of the OMEGA fix to diminish, although some corrections can be applied which will improve the fix.

Over any more or less restricted area, the accuracy of OMEGA can be improved by perhaps an order of magnitude by a technique called "Differential OMEGA" in which the separation of two or more receivers is determined by the differences of their indications, with all propagation disturbances cancelled to the extent they are correlated at the receivers. One receiver might be a fixed monitor broadcasting or telemetering its readings to vehicles navigating in the vicinity, as in a terminal area or tactical theatre; or two or more vehicles may converge to previously agreed upon OMEGA coordinates in a rendezvous.

In a rendezvous, where the receivers are brought to the same coordinates, the correlation would be perfect, and the final accuracy would be determined purely by the resolution and accuracy of the receivers under the existing signal and noise environment. In a terminal area, the accuracy would be determined by the extent propagation fluctuations correlate over the area. Correlation would be substantially perfect at distances of a few miles, and useful out to at least several hundred miles.

Another form of Differential OMEGA is the use of a monitor indication to adjust the diurnal compensation for the fluctuation of the particular moment.

In intercontinental air navigation, for example, it may be feasible to interpolate deviation from the daytime value observed at each end of the path for the diurnal compensation at the immediate position. The diurnal effect is the daily change in propagation velocity which occurs between day and night. It is expected that there will be automatic compensation for this effect. Other procedures can use the difference between the actual reading of the monitor and its predicted value to correct diurnal compensation at the position of the ship.

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RAYDIST

ABSTRACT

Application:	Medium range hydrographic surveying system
Frequency:	1.6 to 3.3 MHz (Measurement frequency). Relay frequencies can be any radio channel upon which modulated signals are permitted
Type of measurement:	Continuous-wave, phase comparison
Range:	About 150 miles maximum for the 100 watt transmitters, Correspondingly less for the 15 watt transmitters
Mode of operation:	Hyperbolic or two-range depending upon the system
Resolution:	0.01 lane
Advantages:	Very accurate control, system relatively easy to use. Some systems suitable for aerial photogrammetric surveys
Limitations:	Requires a number of frequencies, usually 4; no lane identification available

RAYDIST (Types E, R, ER, N, & DM)

Raydist is a radio system in which the phases of two continuous-wave signals are compared. It is based on the heterodyne principle and uses low or medium frequencies. It requires a minimum number of frequencies and these frequencies usually need bear no fixed relationship with each other.

A number of designs of the Raydist system enable position lines of various configurations, such as circular, hyperbolic and elliptic. The mobile portion of the apparatus can be made very light and the ground equipment both highly transportable and free from complex or bulky antenna structures. It operates automatically and requires no specially trained personnel. Its range, due to the frequency used, is not limited to line-of-sight operation. The range varies for each type, depending upon the power of the transmitters.

In the Decca system, the phase of two radio waves are compared. However, in the Raydist system, the phase of the beat note (which is about 400 cycles) is compared. Since this is an audio frequency, the phase meters are simpler and not so critical in construction.

The type R system is an one-dimensional circular configuration. That is, it measures one distance. The type R is not sufficient for obtaining a position, but merely a line of position.

The type E system is a hyperbolic configuration using three ground stations. In this system, the indicating phase meters can either be placed on the mobile craft or on any fixed shore installation. At that position, it will continuously track the mobile craft. In this case, all that is required on the mobile craft is a single frequency unmodulated transmitter. This system is often used in aerial surveys. The plane can use any of its regular communication transmitters, by merely leaving it on without modulation. This signal is picked up by the shore stations and relayed to the indicator which can be at any shore point or on the plane. Quite often it is more convenient not to have any special equipment on the plane so that any plane can be sent on a mission, and its flight would then be accurately logged.

The type N system is a hyperbolic system like Decca but it provides lane identification by providing a coarse lane which is about 30 times as wide as the fine lanes. It does this by having six transmitters, five of which are all on the same frequency, but having different tones near 400 cycles, and the sixth one on a second separate unrelated frequency.

The type ER system is a combination of the E and the R system in that it will supply a two-range information. The actual configuration is circular-hyperbolic, but by relatively simple computation, the hyperbolic information together with the range information will give a second range value for the mobile craft.

The type DM system is a range-elliptical system that requires four radio frequencies. This distance to one station is read directly on one phase meter dial, but the distance to the other shore station is automatically and continuously computed and the second meter dial indicates the range to the second shore station.

In all systems, the phasemeter dials indicate fractional part of a lane to the nearest 0.01 lane. It was found, however, that readings to the nearest 0.1 lane were sufficiently accurate for purposes of surveying or hydrography.

Attached to the phasemeter dial is a counter which registers the number of revolutions made by the pointer hand of the dial. Since one revolution of the hand is a lane, then these counters registers the total number of lanes. On the portable transistorized Raydist, instead of the dials mentioned above, a 7-place counter, similar in appearance to the odmeter on a car, indicates the value with the last two digits indicating the fractional one-hundredth part of the lanes.

The most popular of the Raydist systems is the DM (distance measuring) system since it results in a circular plot. In this manner, it is similar to the 2-range Decca, or Lambda. Circular plotting sheets are easy to construct since they consist of a series of equally spaced concentric circles from each of the two shore stations. Another advantage is that since the lane widths are constant throughout the sheet, the error remains constant, whereas in the hyperbolic plot, the error increases with increased distance from the shore stations because the lane widths are increasing correspondingly.

Raydist is often compared to Decca Hi-Fix since the latter can be used in the two-range mode also. They both have the same general order of accuracy as both use the same general frequency band. However, Raydist doubles its frequency so its lane-widths are one-half that of Hi-Fix and thus its resolution is twice as fine. Raydist is a continuous wave system where Hi-Fix is a pulsed system. Because of this fact, Raydist is more sensitive to small motions, and the rolling of the ship can be seen on the indicators. However currently, Raydist requires four radio channels of which two must be harmonically related. A new system under development by Raydist will require five radio channels. This will permit true two-range operation instead of range-elliptical. This will eliminate the need for signals to travel from one shore station to the other with the corresponding problems of noise and attenuation.

At this time Raydist does not have lane identification, but they have developed a multi-party system using the two-range mode. By using different tones for each user, they are able to accommodate up to three users or ships with a single pair of shore stations. The only limitation is that the users can not be too far separated, that is; there should not be too great in difference between the signals from the various users.

The regular DM system consisted of vacuum tubes receivers with 100-watt transmitters. Presently only the transistorized receivers are manufactured and these are available with either 15 or 100 watt transmitters.

The Hasting-Raydist Company provides services as well as equipment, and they have stations for commercial use both on the Gulf and Atlantic Coasts.

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SHIRAN

ABSTRACT

Application:	Precision short range surveying system
Frequency:	3 GHz (10 centimeter radar band)
Type of measurement:	Sequential phase comparison
Range:	Line of sight
Display:	Four in-line digital readout
Resolution:	0.2 meter
Advantages:	Automatic continuous tracking up to four shore based stations for high accuracy. Recorded on magnetic tape for computer processing.
Limitations:	Shipboard Interrogator system is quite large and complex. Most applicable for aircraft photogrammetric operations.

SHIRAN is an automatic distance measuring system, capable of simultaneously reading and recording the ranges to four transponders on the ground with a high degree of accuracy; suitable for geodetic measurements and photogrammetric control. SHIRAN (S-band frequency HIRAN - see SHORAN) is manufactured by the Cubic Corporation of San Diego, California and was developed for the U. S. Air Force program on worldwide geodetic survey. SHIRAN has improved accuracy, more efficient operation and data handling characteristics than HIRAN. The greater accuracy is mostly due to the fact that ranging or distance measurements are made to 4 stations simultaneously instead of two, which results in a stronger position. Of course there is still the problem of the uncertainty of the propagation velocity of the radio waves, caused by meteorological variations, but a number of tests have indicated that the positional accuracy of the fix can be less than plus or minus 25 feet.

SHIRAN is similar to HIRAN or SHORAN in that it is a distance measuring system, but differs in that it is a phase comparison system. It is also capable of recording on magnetic tape, the range measurements at the rate of 5 times per second; whereas with SHORAN, the time is limited to the ability of the operator to make the alignment and read the position -- usually 30 seconds for a fix involving two stations.

The airborne unit, called Interrogator, transmits four modulation frequencies which are superimposed on the carrier frequency of about 3 GHz. The ground unit, called Transponder, receives the signals and retransmits them on another nearby frequency. Then the airborne unit compares the phase relationship of each outgoing modulation frequency with the phase of the returning modulation frequency, and the phase differences are converted into distance measurements which are recorded automatically. The four modulation frequencies are used to give both accuracy and non-ambiguity, which tend to be incompatible objectives. The highest frequencies give the smallest lane widths and the smallest increment that can be read is 0.725 feet, or 0.2 meters; while the width of the widest lane that can be determined is 500 nautical miles. To provide stability and reduce erratic operation because of noise, the four modulation frequencies phase-lock four internal oscillators in the Interrogator Set and these phase-lock oscillators serve as storage and memory units for the range information. If a "wild" reading comes in, because of interference or noise, the phase-lock oscillators will ignore it.

Four selective tones are used to turn on each of the four transponders, the system reading the range to each transponder in sequence, all within a fifth of a second. The phase information from the four transponders are stored in sixteen phase-lock oscillators and then it is displayed for the convenience of the operator and also recorded on magnetic tape in IBM format for later processing.

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SHORAN

ABSTRACT

Application:	Short range surveying
Frequency:	200 to 300 megahertz
Type of measurement:	Pulse matching, time values
Range:	Line of sight, usually about 40 miles
Resolution:	One thousand of a statute mile
Display:	Counters
Advantages:	Provides distance information without ambiguity. Relatively easy to operate
Limitations:	Not as accurate as phase comparison systems. Now is an obsolete system and also not permitted in many areas because of interference with signals to satellites.

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Advantages:	Provides distance information without ambiguity. Relatively easy to operate
Limitations:	Not as accurate as phase comparison systems. Now is an obsolete system and also not permitted in many areas because of interference with signals to satellites.

SHORAN (SHOrt RAnge Navigation) is a pulse, distance measuring system resulting in a circular plotting system instead of a hyperbolic plotting system. It was developed during World War II for the U. S. Air Force for pin-point bombing and was used during the latter part of that war over Germany. It operates in the UHF band from 200 to 300 MHz.

The aircraft transmits first on 230 MHz which is picked up by one of the two ground stations whose receiver is tuned to that frequency. This station in turn transmits a pulse back on 310 MHz for each pulse received, and thus the plane is able to determine the distance by measuring the round trip time of the signals or pulses. Then the plane transmits pulses on 250 MHz which is picked up by the other ground station which is tuned to this frequency. This station in turn transmits back to the plane also on 310 MHz; and the second distance or range is measured by the aircraft. The aircraft operator measure the distances by aligning the transmitted signals with the corresponding received signals from the ground stations. To make the alignment, the operator turns two range dials, and he can read from these dials the ranges to the two ground stations. The aircraft SHORAN equipment is switching from 230 to 250 MHz at the rate of 10 times per second, so the signals from the two stations appear continuously on the cathode ray tube because of the persistence of the material in the tube.

The original aircraft SHORAN equipment had the military designation of AN/APN-3, and the ground stations were called AN/CPN-2. Then several years later, on another Air Force contract, RCA company redesigned the SHORAN system and it was given the name of HIRAN (HIgh accuracy shoRAN). The designation for the airborne equipment (HIRAN) is AN/APN-84 and the ground stations are called AN/CPN-2A. One of the improvements with HIRAN over SHORAN is an expanded time base, so that the circumference of the circle on the cathode ray tube now represents 0.2 mile instead of 1 mile.

There are still a few government agencies and oil companies using SHORAN or HIRAN for surveying but, for the most part, the equipment is obsolete and has been superceded by other systems, mainly the phase comparison systems which have a higher resolution and automatic tracking systems. The advantage of SHORAN and any time-measuring (pulsed) systems over phase comparison systems is that there is no lane ambiguity problem. With any phase comparison system without lane identification one must know their approximate location and then the phase system can resolve this to a fine degree.

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TELLUROMETER

ABSTRACT

Application:	Precise distance measurement
Frequency:	From 3 to 35 GHz depending upon which model is used
Type of measurement:	Phase comparison
Range:	Line of sight
Resolution:	From 3 inches to 1 millimeter depending upon model used
Advantages:	This company has produced more instruments of this type than any other company, thus they have built up considerable experience.
Limitations:	Although many of the sets are assembled in the U. S. yet many of the parts are manufactured in South Africa and at times there may be considerable delay in the delivery of spare parts.

Tellurometer is a phase comparison base-line measuring system similar to Electrotape and Geodimeter. It is more similar to Electrotape in that radar frequencies are used to carry the distance information while in the Geodimeter, light waves are used. All three systems uses crystal oscillators, which modulates the radio or light carrier waves; to produce the basic measuring frequencies. Therefore, the stability of the measurement circuitry depends upon the stability of the crystals.

Tellurometer was developed in the Union of South Africa and is the first and the most widely used geodetic system available today. All these electronic systems have a distinct advantage over the invar steel tape method of measurement in that long lines can be spanned at one time over difficult terrain or water. Tellurometer (and Electrotape) has the advantage over the Geodimeter in that it can be used during the daytime and in sunlight as well as in smog over relatively great distances.

The original Tellurometer was called the Model MRA-1. The phase information was projected on the face of a cathode-ray tube as a break on a circle as seen behind radial graduations which were indicative of the distance value. A viewing mask had to be placed over the tube in order to see the circle on the screen of the cathode-ray tube. As can well be imagined, at times and in bright daylight there was some difficulty in viewing the circle.

Model MRA-2 was an improved version of the model MRA-1, but essentially it was the same instrument and the two could be used interchangeably. Model MRA-3 used a null meter and a digital dial similar to the Electrotape. This was a considerable improvement in that no viewing mask was required and the instrument could be operated easily in daylight.

Model MRA-4 is the latest development (1966) of the Tellurometers and is quite drastically changed from the older models. Its operating frequency is about 35 gigaHertz whereas the models 1 and 2 were 3 GHz and the model 3 operated at 10 GHz. This higher carrier frequency projected a narrower beam width (2 degrees) and a higher internal measurement frequency resulted in a resolution of plus or minus 1 millimeter. The instrument is built to meet military specifications and contain silicon solid-state circuitry for operation over a wider temperature range.

The Tellurometer company also produces the model MRA 101 instrument which is their most lightest, and lowest cost system available. eEach instrument weighs 16 lbs, and a pair of instruments, complete with tripods and other accessories cost less than $9,000.00. This model is compatible and can be used with the MRA-3 units.

In addition to the systems mentioned above for geodetic measurements, this company also manufactures the HYDRODIST which is two separate Tellurometer systems mounted on a ship. Each of the two masters are mounted side by side and aimed to their respective remote units. Obviously this system is used for precise hydrographic control and of course it would not be suitable in choppy seas or on rolling ships because of the narrow width of the radio beam. The Tellurometers are modified so that the finest or least significant digit is in meters instead of centimeters. To resolve ambiguity, the Master operators can electronically switch crystals in the Remotes without calling the Remote operator.

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TRANSIT

ABSTRACT

Application:	Precise long range navigation
Frequency:	150 and 400 MHz
Type of transmission:	Phase modulated signals
Type of measurement:	Doppler shift
Resolution:	1/100th of a minute of Lat. or Long.
Range:	Ship has to be within receiving range of the satellite
Advantages:	Promises to be useful system for worldwide navigation
Limitations:	Position can be obtained when within range of the satellite, thus continuous tracking is not possible. Shipboard system complex and expensive

This navigation system, officially called "The Navy Satellite Navigation System", but popularly called TRANSIT is a low-altitude (about 150 miles) radiating continuously, orbiting satellite which provides geographical position information by the doppler shift principle. The shipboard equipment requires both the receiver and a computer for determining the position or "fix" of the ship. The satellite transmits not only the radio signal for the doppler measurement but also its position or ephemeris data. By taking a number of readings on the satellite as it passes over the ship, a number of lines of position are obtained and the intersection of these lines is the position of the ship.

The problem of determining the propagation velocity of the radio waves was solved in the satellite system by using two frequencies. The doppler shift is measured on the 400 MHz frequency. The satellite also transmits a 150 MHz signal, and the phase difference between the 150 and 400 MHz signals are indicative of the meteorological conditions in the atmosphere, factors which affect the velocity of radio waves.

This satellite system is a part of the Navy and much of the data concerning it has been classified. But in general, the positional accuracy of a fix as determined by the satellite has been in the order of a half mile. Many proponents of satellites feel that the ultimate accuracy of these systems should be within 50 feet. However, since this system is still in the development stage, it would be difficult to make any accurate statements at this time.

Two factors should be considered when using satellites for navigational control, namely; fixes are available only for about 15 minutes out of each 90 minute period for any particular low-altitude orbitting satellite, and secondly, data on the position of the satellite (ephemeris data) has to be provided in order to obtain a fix.

Although it was mentioned earlier that the satellites will give a positional accuracy of about one-half mile, one should not consider this figure of accuracy as being a definite or positive value. The difficulty in making a positive statement regarding the accuracy of a fix as obtained from satellites is that the motion of the ship contributes to the positional error. It has been determined that an error of one or two knots in the value of the ship's speed can cause a positional error of about a half mile. Therefore, the more accurate the shipboard navigational equipment is (ship's compass and log) the higher will the figure of positional accuracy be.

Besides the TRANSIT satellite mentioned above which is designed for navigational control, there is another satellite in use which is called ANNA, an acronym for Army, Navy, NASA, and Air Force. This is a geodetic satellite designed specifically to provide a triangulation point in space. It will provide optical, radio ranging and Doppler methods of geodetic measurement. In 1965, the second satellite of this series, ANNA 1B was in operation. Also, a number of satellites under the name of GEOS (Geodetic Earth Orbitting Satellite) are being proposed for geodetic measurements, both optically and electronically. These satellites and their systems are quite complex and are under the supervision of National Aeronautics and Space Agency (NASA). Interested persons should contact NASA for further details regarding satellites.

The electronic positioning systems of these satellites are similar to existing systems used with shore based equipment. The radio ranging system is a transponder inside the satellite which receives on one radio frequency and retransmits on another frequency. The ground or control station can then determine the distance (or range) to the satellite by determining the time it takes for a signal to make the round trip. The doppler system is quite similar to the system used in TRANSIT, the only difference being that other radio frequencies are used and the methods of determining the doppler value may be different. It should be noted here that TRANET is a network of doppler receiving stations and not a different electronic positioning system. Similarly, STADAN is a network of receiving stations using the SECOR system developed by Cubic Corporation of San Diego, California for the military.

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