THE OMEGA SYSTEM OF GLOBAL NAVIGATION

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ABSTRACT

An overview of the Implementation Status of the Omega Navigation System with information on station construction programs and scheduled milestones is presented. The general descriptions of the stations and their new electronic equipments are discussed. Information is also provided on the program for Omega charts and navigational publications required to support the system expansion. Highlights of the concept of international participation and system management are included in this presentation.

INTRODUCTION

Omega is a very low frequency (VLF) radio navigation system operating in the internationally allocated frequency band between 10 and 14 kHz. It is capable of providing all weather navigational service throughout the world with a transmitting complex of eight stations. The system is useable for navigation purposes by ships, aircraft, and land vehicles. In addition, since the transmissions are controlled by atomic frequency standards, the signals can be useful for precise rating of less accurate frequency standards and possibly for future use in time dissemination.

The characteristics and technical description of the Omega system has been addressed in volumes of papers, reports, and other publications over a period of 15 years. Naturally, changes have taken place in that long period of time. It is the purpose of this paper to present the current status of Omega system implementation and to forecast related events. The discussion will be limited to station construction, system management, charting, and navigation publication support plans.

Readers desiring more technical information on the Omega system are referred to the IHO Special Publication 39, of 1971.

HISTORY

The development of the hyperbolic radio navigation technique, which is basic to the Omega Navigation System, can be traced back to post World War II. In 1947, J.A. PIERCE first proposed a hyperbolic navigation system based on phase difference techniques rather than pulse time differences. At that time, a system operating in the vicinity of 50 kHz with 200 Hz sine wave modulation was suggested. An experimental system of this type was constructed by the U.S. Naval Electronics Laboratory and assigned the name Radux. In 1955, efforts were successful in combining the LF signals of Radux with separate VLF transmission in the vicinity of 10 kHz. This system was called Radux-Omega, and the initial transmissions on 10.2 kHz were made later that year. Subsequent experimentation led to the discontinuance of the LF transmissions. More concentrated research toward extending system range using single frequency Omega system followed. Experimental stations were established in San Diego and Hawaii. A third experimental station began transmitting in 1959 from Forestport, New York. In subsequent years Omega was expanded to a two frequency format; 10.2 kHz and 13.6 kHz. Additional Omega signals were broadcast from experimental stations in the Canal Zone and Wales and finally in Norway and Trinidad.

The need for a worldwide, continuous, passive, radio navigation system began to emerge as early as 1962. In the subsequent 3 years, the Omega system received wider exposure, leading to the U.S. Navy's establishment of the Omega Project Office in June of 1965. The Project Manager was tasked with the overall management responsibility for the multi-faceted development and implementation of the Omega Navigation System. This represented the first major Navy commitment to develop and implement an operational Omega Navigation System that would provide the first continuous, worldwide, all weather radio navigation aid for ships and aircraft.

By 1966, the Omega signals were being transmitted on a regular basis from four stations located in Norway, Trinidad, Hawaii, and New York. However, since these stations utilized existing facilities and developmental equipment, many inherent restrictions prohibited efficient operation. Consequently, none of these stations were capable of transmitting the power required for an operational system, but signals were being transmitted full time from a four station Omega complex providing the vital ingredients necessary to further developmental research.

After 3 years of concentrated management, the Omega Project received authorization to proceed with worldwide system implementation.

During the ensuing years, system concepts were finalized, requirements were defined, and the implementation plan readied. The implementation plan contained a concept unique to Omega in the field of radio navigation, fostered by the requirement to effectively place the minimum number of Omega stations around the world.

In previous U.S. sponsored radio navigation systems, establishment of stations on foreign soil came as a result of base rights agreements and/or host nation contract operation. Since Omega offered a potential worldwide navigation aid, international interest had already been recognized. Numerous countries were conducting cooperative tests with the United States and proceeding independently in receiver development and application research.

Extending the international cooperation to the establishment of the Omega system was a natural recourse, and approval was obtained to solicit the support of geographically suited, prospective nations in this venture. The response was indeed gratifying, and it appeared for the first time a truly international radio navigation system was in the making.

SYSTEM CONFIGURATION

The extensive and accurate measurements of the phase stability of the VLF Omega signals made throughout the past decade show that such signals can provide global position-fixing of good accuracy and high reliability. The viability of this VLF system is further enhanced by the low attenuation experienced in this portion of the spectrum. Long-range propagation of low power transmissions will permit worldwide navigation coverage with a relatively small number of stations. This is a decided fiscal benefit both in initial investment and, over the years, in operation and maintenance costs.

Optimum system geometry would call for six stations. Unfortunately the earth's surface characteristics and properties will not support such a systematic scheme. Therefore an alternate scheme was developed which took into consideration economic factors, properties of VLF propagation and availability of land areas.

This plan called for eight stations to be distributed throughout the world with an average separation of 5 000 - 6 000 nautical miles. The existing Omega stations in Norway, Trinidad, and Hawaii and a new station in North Dakota were included in this plan. Four remaining locations in the vicinity of Australia, Southern South America, Indian Ocean, and Western Pacific were needed. The tentative configuration led to the opening of negotiation with nations situated or having possessions in these regions of the world.

INTERNATIONAL PARTICIPATION

The Navy, acting for the United States, entered into preliminary discussions with other nations, which, within system criteria, could possibly support a station.

These discussions presented the U.S. desire to engage host nation participation in the Omega system. The nations were encouraged to sponsor a station to which they would retain full sovereignty. The U.S. offered to provide the electronics equipment and Omega technology in the interest of international cooperation.

Interest was found high in all countries contacted, and each nation undertook efforts to locate potential sites and assess the degree of participation that might be expected.

As a result, France proposed a French station on the island of La Réunion in the Indian Ocean. Argentina offered a suitable station site on their Atlantic coast. Australia and New Zealand both presented site studies for evaluation. Japan suggested a site on the island of Tsushima. Norway entertained a plan for converting the Navy test station to a permanent facility. Numerous other locations were also considered by those making the evaluations, and in the final analysis Australia, Argentina, France, Japan, Norway, and Trinidad emerged as the prospective partners to join with the United States in implementing the Omega system world-wide. Figure 1 shows the general locations of the stations required for the system.

While negotiations for bi-lateral agreements on Omega have not been finalized with each country, cooperative efforts involving station design and construction planning are proceeding satisfactorily.

STATION CONSTRUCTION PROGRAM

The Omega station at La Moure, North Dakota, replacement for the New York station, is nearing completion. This station features a 1 200 foot tower antenna and the latest in facility design. It represents the first facility specifically designed and constructed as an Omega station. The U.S. Coast Guard personnel who will operate and maintain the station are on the scene. It is anticipated that the station will go on the air for testing by 1 May 1972 and become operational in June, radiating 10 kW of power and replacing New York as the "D" station in the system.

Renovation and new construction associated with the Omega Hawaii station is now underway. Six new valley span antennas will replace the four deteriorated ones and a totally new antenna ground system will be installed. Interior building renovation to accommodate a new electronic

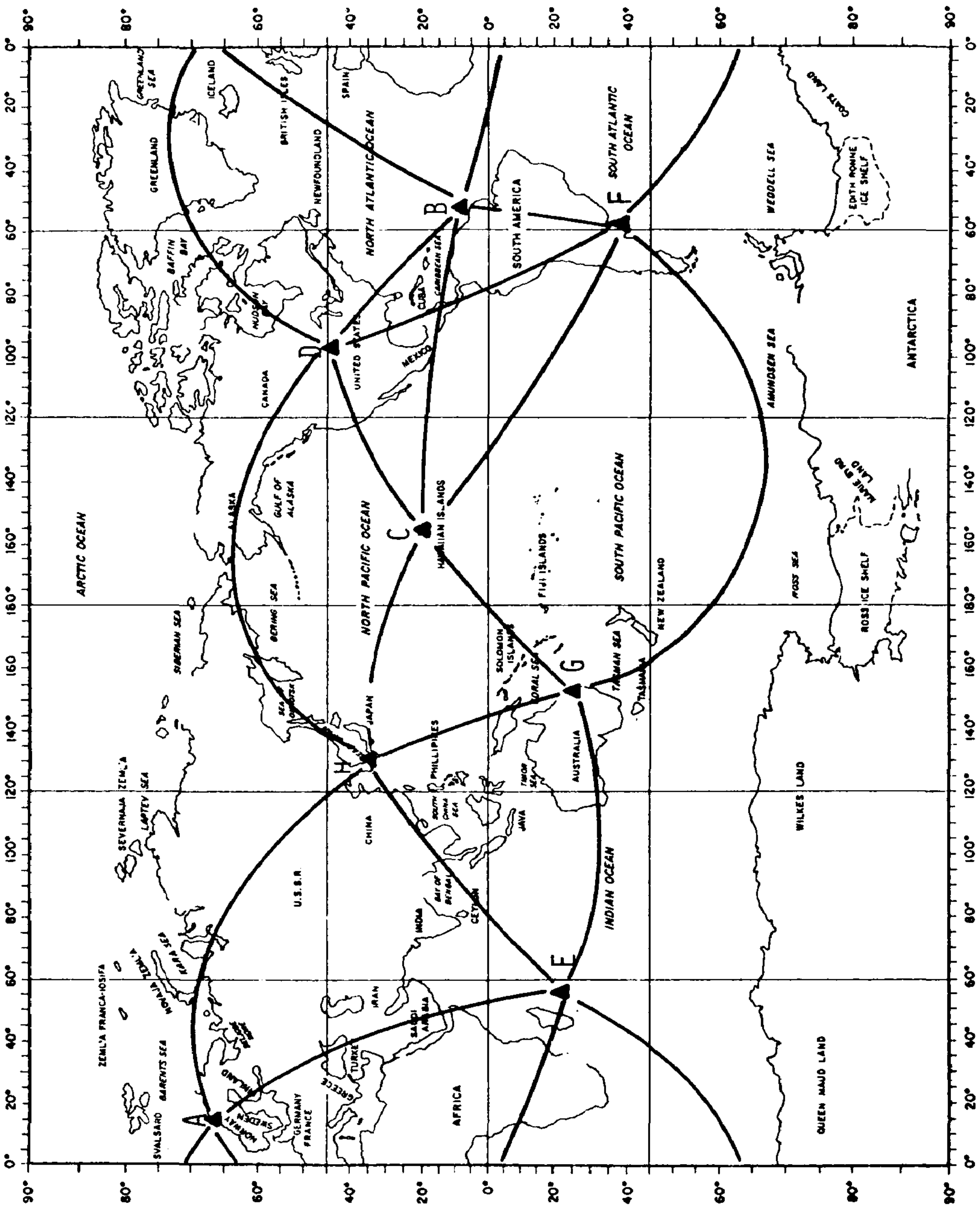

Fig. 1. — Omega System Configuration.

suite and provide administrative offices for the system Directorate are included. Construction schedule sets January 1973 as completion date for the total facility. It is anticipated that the Omega station Hawaii will be operating at full rated power by February 1973 after a four to six month off air period for antenna replacement.

Design is nearing completion for the permanent station in Norway. It will be situated in the immediate vicinity of the existing test station and will utilize some of the present valley span antenna system. New buildings, scheduled for construction in 1972-1973, will be fitted with the new Omega electronic equipment. Omega Norway is scheduled to become operational by the end of 1973. Norway will also have a lengthy off air period during mid 1973 to allow for antenna replacement.

Japan has undertaken to construct an Omega station on the island of Tsushima in the Korea Strait. This venture represents the first major Omega construction program to be totally directed by a partner nation. Design has been completed and construction is in progress. This station will feature a 1 500 foot cylindrical tower antenna structure unique to this station and the system. This antenna may well be the first of its kind in the world. It is understood that the station may be operational by mid 1973. It will provide the first expansion to system coverage since 1966.

The site investigation work leading to construction of the French station on the island of La Réunion in the Indian Ocean has been completed. The French Government has employed an architectural and engineering firm to perform their design and supervise the construction phase of the program. Barring any unforeseen delays, signals should be broadcast from La Réunion by the end of 1974.

Omega Trinidad, in existence since 1966, is situated in a relatively shallow valley on the northern coast of Trinidad. It occupies what once was an active VLF communication station of the U.S. Navy. Since the Omega operation began at this facility, interim repairs were made which included replacement antenna spans. Trinidad, much like Hawaii, is planned to receive building renovation and major antenna system rework. However, since Omega Trinidad is on the air, emphasis is being directed toward the completion of new stations; and consequently, Trinidad is scheduled for renovation commencing in 1974 and to become capable of transmitting rated power by mid 1975.

Trelew, located in the coastal area of central Argentina, is approximately 600 miles south of Buenos Aires. This region of the country is comparable to the Southwestern United States, and its flat terrain provides an excellent platform for a tower antenna system. The tower for Omega Argentina is fabricated and awaiting shipment to the site. The Argentine Navy is currently in the process of selecting an architectural and engineering firm to design the station complex. Scheduled completion date for that station is late 1974.

The Australian Department of Shipping and Transport is actively engaged in making a final site selection for the station in Southeastern Australia. In all likelihood, it too will utilize a tower antenna system. With the close cooperation of the Department of Shipping and Transport, a station in Australia should be active by mid 1975.

STATION ELECTRONIC EQUIPMENTS

Omega ground stations correspond very closely to the concepts of their higher frequency counterparts, Loran A and Loran C. The station fundamentally consists of an atomic frequency source, timing and signal format generating equipment, signal transmitter, antenna and associated tuning equipment.

The Timing and Control Set, receiving its input from cesium beam frequency standards, generates the Omega frequencies and signal format for transmission.

The Transmitting Set amplifies the CW signals provided by the Timing and Control Set and applies the higher powered signals to the antenna system. Transmitting in the 10 - 14 kHz band from an antenna with a bandwidth of 10 Hz not only requires immense components in the tuning network, but also requires special attention to insure that the antenna remains tuned to the frequency being transmitted. This is accomplished through the use of separate tuning networks for each frequency and servo controlled tuning adjustments.

Equipment redundancy has been designed into nearly all functions of the Omega signal transmission process, from signal generation to the antenna, which will contribute to maximum station reliability. To insure equipment standardization and minimize the scope of logistics support required, the United States Navy has procured eight complete sets of station electronics equipments for use throughout the system.

OPERATING CHARACTERISTICS

Certain advantages postulated for the Omega system can immediately be seen by examination of the operating characteristics shown in table 1. With an arrangement of stations as illustrated in figure 1, a complete electro-magnetic environment can be established around the globe. In addition, in view of the extreme long range of the signals in this frequency range, there will be a high order of redundancy of lines-of-position. It is predicted that at any point on the surface of the earth at least five lines of position will be available, allowing the navigator to take advantage of LOP redundancy and of optimum geometry and crossing angles by properly choosing station pairs.

The accuracy of the VLF navigation concept is a point of controversy. The practicality of the system is based on the fact, verified over many years of measurement, that RF signals in the VLF band demonstrate remarkable phase stability over extremely long distances. The degree of accuracy claimed includes the limitations of the inherent stability and predictability of variations of phase along the transmission path. Measurements, primarily by the U.S. Navy Electronics Laboratory, over a period of years have led to fairly general acceptance of the figures in table 1.

The figures quoted include any geometrical effects such as hyperbolic divergence and lines of position (LOP) crossing angles and, while admittedly conservative, compare quite nicely with the established accuracies of Loran A. What is remarkable about the Omega system is not its potential accuracy but that this accuracy is obtainable anywhere on the globe with only eight ground stations.

Since the Omega signal varies diurnally as a function of the ionospheric activity along the signal transmission paths, propagation corrections at a given location are required. Use of published propagation correction tables will enable the user to achieve accuracies of 1 - 2 nautical miles.

Differential Omega employs real-time propagation information provided to the navigator to reduce errors caused by vagaries in the velocity of the transmitted signal. Simply stated a monitor at a fixed, known location transmits real-time propagation corrections to moving vehicles operating in the local area. Studies and tests using the Differential Omega mode support the accuracies shown in table 1.

TABLE 1

Omega Operating Characteristics

Geometry	Hyperbolic(*)
Baseline length	5 000 – 6 000 nautical miles
Frequency band	10 – 14 kHz
Type of emission	CW (Time sequenced)
Radiated power	10 kW at 10.2 kHz
Coverage	Worldwide
Number of stations	8
Time coverage	Full time/All weather
Accuracy :	
Conventional mode	1 – 2 nautical miles RMS
Differential or Relative mode	0.1 – 0.3 nautical mile RMS

(*) With transportable stable frequency standards the Omega transmissions may also be used in a circular geometry to direct distance measurement.

OMEGA RECEIVERS

In the complete Omega system, the design complexity of a receiver can, at the option of the manufacturer or customer, reflect a large range of user philosophies. Since the basic system depends on the measurement at 10.2 kHz regardless of the degrees of automatic lane resolution desired, cost and complexity normally can depend on the narrowest unambiguous lane that a user considers practical. For example, a relatively slow speed surface craft might operate very satisfactorily on a single frequency, depending on a strip chart recording, automatic lane counters, or ships dead reckoning to identify the lane. However, an aircraft will probably need a fully automatic computerized receiver with a latitude and longitude readout. In any event, the basic system accuracy of the 10.2 kHz lane is available at all levels of complexity.

Numerous receivers have been developed and are currently in use in both the military and civilian community. Militarized receivers of various degrees of complexity are expected to be priced from \$4 000 - \$60 000. Non-militarized receivers may also be purchased in this price range, but it is expected that a quite adequate, simple receiver may be purchased for as little as \$2 000.

The U.S. Navy is using two general types of receivers; (a) a relatively simple, single-frequency receiver for use aboard small and medium size surface ships, and (b) a computerized, fully-automatic receiver for use aboard high performance ships and aircraft.

The U.S. Coast Guard is evaluating several commercially available receivers for use aboard Coast Guard ships and by U.S. civil users.

Several U.S. and other manufacturers of Omega receivers have entered the international receiver market. They are currently selling receivers in Europe and Japan.

CHARTS AND PUBLICATIONS

Since most naval and civilian vessels equipped with Omega receivers will not be equipped with coordinate converters or automatic computing systems, it is extremely important that useful charts and publications be provided for the Omega Navigation System. Two significant problems exist in this area. The first requires addressing a navigation system that provides coverage throughout the world and the second is obtaining and updating information that supports a perishable product; e.g. propagation correction tables.

Charting for the Omega Navigation System will be especially dynamic in the next few years as new transmitters are added to the system. Fortunately, a standard propagation velocity is used for each chart (changes in propagation velocity are accounted for in the propagation prediction corrections) and LOP's for other frequencies can be extrapolated from the basic 10.2 kHz frequency portrayed on each chart. To avoid reworking large numbers of charts for the purpose of adding new LOP's, some LOP's will probably be included on the charts in advance of transmitting stations becoming operational, such as Japan and Argentina.

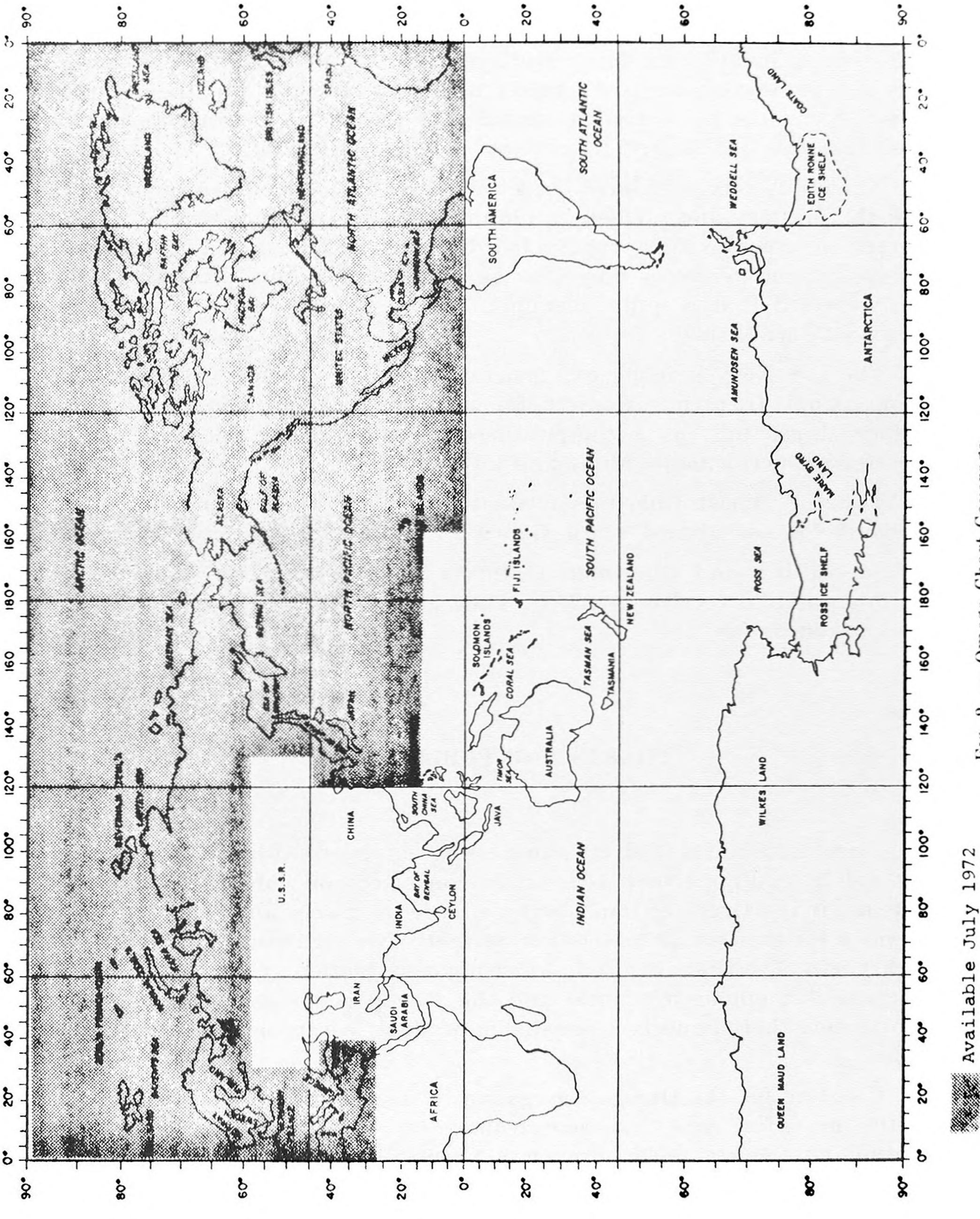

FIG. 2. — Omega Chart Coverage.

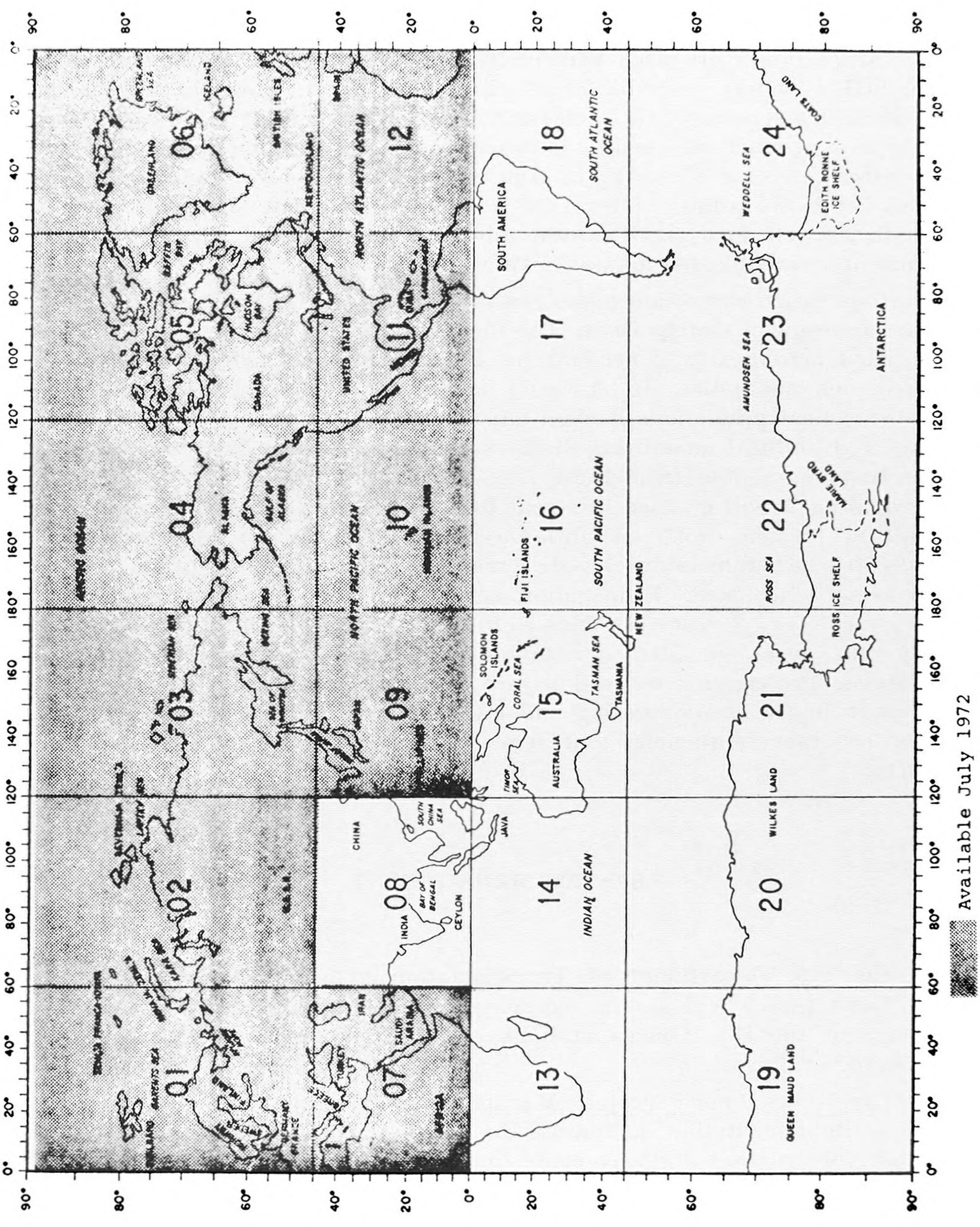

Fig. 3. — Omega Lattice and Propagation Correction Table Coverage.

A new global series of Naval Oceanographic Office Charts is currently in production. The scale of these charts will be the same as the present VO30 series, 1/2 188 000, but the base will be changed to improve its use for shipboard navigation. Figure 2 indicates the 1972 planned coverage area of these charts.

Lattice tables are used principally by the navigator to construct his own LOP's on any desirable chart or plotting sheet. Since lattice tables are published separately for each LOP, they are independent of other LOP's as far as a production schedule is concerned. A lattice table would require correction only for a change in transmitting station coordinates. Lattice tables are being produced for LOP's including the new station at North Dakota as well as a significant number including Japan and Argentina. Tables are available for areas shown in figure 3.

Propagation correction tables are essential to the system and contribute to the accuracy of Omega fixes. The theoretical model for these predictions is revised periodically to account for changes in solar activity and other propagation anomalies. It has been known for a considerable time that the theoretical predictions can be improved by force fitting them to data monitored at the transmitting stations and other sites. The U.S. Navy is collecting phase data from these sites and storing them in a data bank. The data bank will be used this year to adjust computed correction values tabulated for the North Atlantic area. In time, as an internationally cooperative program is developed, corrections for other parts of the world will also be adjusted. Propagation correction tables are updated on an average of every 2 years. Besides adding new tables for the North Dakota station this year, all correction tables requiring the periodic update will be issued. Propagation corrections are available for the geographical area shown in figure 3. As funding and international support permits, corrections for other frequencies and areas of the world will be added to the system.

SYSTEM MANAGEMENT

The U.S. Department of Transportation and more specifically the U.S. Coast Guard will assume responsibility for the operation and maintenance of the U.S. Omega stations and U.S. management commitment for the overall system.

The Navy Omega Project Manager will be given responsibility for system implementation including the required U.S. support of foreign station construction and electronic installation.

As the remaining stations are completed, it is envisioned that an International Omega Policy Committee, consisting of representatives from each of the participating nations will be formed to set forth overall policy governing the international aspects of the Omega system.

In the interim, the Coast Guard Operations Detail will provide the essential management and operational coordination for the system. With the addition of each new station, the system management will take on added international complexion and ultimately evolve into a Directorate for the International Omega Navigation System. The Director will be guided by a charter developed by an International Omega Policy Committee. Under this charter, the Director will be responsible for the coordination of station operations, including system synchronization, and for technical and logistic support. The Director shall coordinate with all nations producing Omega navigation documents to identify requirements and insure exchange of information between partner nations in accordance with the provisions of the charter.

The Coast Guard Omega Station in Hawaii when completed, will house the activities of the Directorate, International Omega Navigation System and the staff of Coast Guard and cosponsoring international representatives.

SUMMARY

Overall system implementation is continuing under the direction of the U.S. Navy Omega Project Manager. Agencies of the other participating nations are coordinating their programs with the United States. The U.S. Coast Guard will operate the U.S. stations and provide system management and support to the participating nations in response to the U.S. commitment. The system will be declared operational when a sufficient number of stations are operating in the final configuration.

International cooperation is also required for the development of the charting, navigational publications and notices required to implement and provide continued support to the users of the Omega Navigation System.

Renovation of existing stations and the construction of new stations is underway. The information shown in figure 4 represents the latest schedule of station completion dates. Worldwide Omega navigation coverage should be realized by 1975.

Station	Date	Station	Date
(A) NORWAY(*)	Late 1973	(E) REUNION	Late 1974
(B) TRINIDAD(*)	Mid 1975	(F) ARGENTINA	Late 1974
(C) HAWAII(*)	Early 1973	(G) AUSTRALIA	Mid 1975
(D) NORTH DAKOTA	Mid 1972	(H) JAPAN	Mid 1973
(*) Interim Stations on air at reduced power			

FIG. 4.

The Omega system is destined to become an international worldwide general purpose navigation aid, available to an unlimited community of users, through the joint efforts of many nations.