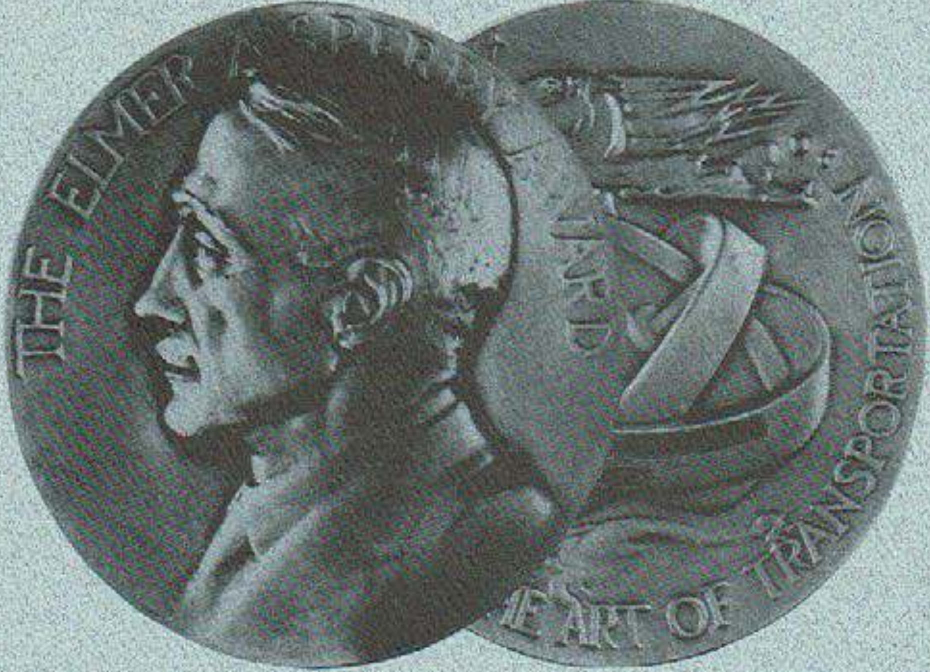


The Elmer A. Sperry Award 1988

for advancing the art of transportation

The Elmer A Sperry Medal

The Elmer A. Sperry Award

The Elmer A. Sperry Award shall be given in recognition of a distinguished engineering contribution which, through application, proved in actual service, has advanced the art of transportation whether by land, sea or air.

In the words of Edmondo Quattrocchi, the sculptor of the Elmer A. Sperry Medal:

"This Sperry medal symbolizes the struggle of man's mind against the forces of nature. The horse represents the primitive state of uncontrolled power. This, as suggested by the clouds and celestial fragments, is essentially the same in all the elements. The Gyroscope, superimposed on these, represents the bringing of this power under control for man's purposes."

Presentation of

The Elmer A. Sperry Award for 1988

to

J. A. PIERCE

by

The Board of Award under the sponsorship of the:

American Society of Mechanical Engineers
Institute of Electrical and Electronics Engineers
Society of Automotive Engineers
Society of Naval Architects and Marine Engineers
American Institute of Aeronautics and Astronautics

At the IEEE Global Telecommunications
Conference & Exhibition, (GLOBECOM '88)
Wednesday, November 30, 1988, Fort Lauderdale, Florida

The Omega Navigation System

Omega is popularly called a world-wide, all-weather, continuous navigation system. It is technically referred to as a very low frequency (VLF) hyperbolic phase-comparison radio-navigation system. A hyperbolic navigation system is one in which electronic lines of position (LOPs) between pairs of transmitting antennae are represented by a series of hyperbolic lines between the antennae. The antennae are at the foci of the family of hyperbolae. The intersection of hyperbolic LOPs from different antenna pairs indicates the position of the receiver with respect to the transmitting antennae, and thus the geographic position is also known.

The Omega Navigation System today is composed of eight transmitting stations, located in Argentina, Australia, Hawaii, Japan, Liberia, North Dakota, Norway and La Réunion. The last station, Australia, became operational in August, 1982. Signals from any suitable combination of station pairs can be used for navigation anywhere in the world. Administration, technical support and operational control are the responsibility of the U.S. Coast Guard Omega Navigation System Center, and synchronization control is performed by the Japanese Maritime Safety Agency.

The Omega system is unique in several respects. It is the only ground-based system which provides global, rather than regional, position fixing. Only eight ground-based stations are required to provide global coverage, which is one reason the system's operating cost is much less than worldwide satellite navigation systems with comparable coverage. It is currently the only continuously available global navigation system. That is, the navigator can fix his position nearly instantaneously at any time of the day or night. Omega has a wide variety of users, including aircraft, ships and subsurface vessels, and is also widely used for scientific applications, such as plotting the drift of weather observation balloons, and as a time reference for remote seismographic monitoring equipment throughout the world. Unlike other major navigation systems, Omega is operated as a cooperative international partnership by seven nations, with all the nations sharing the costs of operation and participating in policy making though the International Omega Technical Commission.

In order to recognize fully the importance of each ground station to the completeness and utility of the Omega system, a portion of this 1988 Award booklet has been dedicated to the ground sites. A world map of the entire system is on pages 9-10.

The Origins of Omega

(Editor's Note: The following is from a memoir by J. A. Pierce on the many technical advances and contributions that resulted ultimately in the development of the world-wide Omega Navigation System. This condensation is used with his permission.)

During the first five or six years after the war, the Office of Naval Research kept urging me to study very low-frequency wave propagation, although I could think of no satisfactory way to do so. The break-through, the first of the many steps leading to Omega, came about in 1953 with a visit to Harvard by Dr. Louis Essen, a Principal Scientific Officer of the National Physical Laboratory in England, who had devised the first cesium resonator for frequency control, among other accomplishments. Dr. Essen observed our techniques for recording the changes in the times of arrival of pulses received over long distances, which were carried out, like the earliest LORAN observations, by timing with good crystal oscillators at both ends of the circuits. He thought our techniques sensitive enough so that we might detect a standard-frequency signal at 60 khz that was being radiated from the famous Rugby station of the British General Post Office. It was only on the air for one hour per day, and that hour was roughly at noon in the middle of the Atlantic Ocean [9:00 a.m. EST]. After efforts that took a year or more, I succeeded in getting the 16 khz signal from Rugby controlled by the same oscillator as the 60 khz signal. This created a better situation, as the signal was continuous for about 23 hours per day, providing an excellent standard against which to rate my own crystal and let me gradually improve its performance.

At this point, the fact that the United States considered all work toward improved navigation to be classified made itself felt. In my first published paper on this work, in 1955, I referred only casually to any navigational possibilities and did all I could to prove the value of the new technique for frequency and time comparisons over long distances. At the same time, I reported, in a classified letter to the Chief of Naval Research, the idea that a navigational aid of very long range was now possible.

The discoveries in the 1953-1955 era made it clear that a kind of navigational aid that I called Draco could be implemented. This was nothing more than what is now called VLF navigation, or differential phase tracking on the signals of communication stations. In those days, it was next to impossible to carry out, as the concept requires that the frequencies of various stations be commensurate and stable to one part in 10^{10} or 10^{11}. In general, frequencies then were maintained only within a few cycles per second of the assigned values.

The most curious thing about Draco was that the only military branch that showed interest in it was the Polaris Submarine Project Office. This was foolish at the time, because the signals could not penetrate the sea water to the depths at which Polaris wished to spend most of its time, and the problem of simulating phase advances while submerged would be impossible to carry forward for very long with the needed accuracy. Needless to say, this interest faded, after a time, and the Draco technique was not heard of again until there were several stations whose frequencies were controlled by cesium-stabilized oscillators, thus making the method simple for anyone to use.

In 1963 I was appointed to a small group which was called the Omega Implementation Committee. The other members were my old friend Dick Woodward; Winslow Palmer of the Sperry Corporation, who had built the first direct-reading LORAN receiver before the end of World War II and had later devised and tested a VLF pulse system called Cyclan that prepared the way for LORAN C; and Donald Watt, a wave propagation expert formerly with the Bureau of Standards but at that time operating a small research branch later part of the Westinghouse Corporation. We were appointed by the Bureau of Ships and charged with making the complete design for the new aid to navigation.

As far as possible, we cited data to prove that the system would work as expected. Some recommendations, such as low modulation frequencies for world-wide resolution of cyclic ambiguities, and slow-speed inter-station communication by phase-shifting keying, were not adopted by the Navy. Our suggestions for locations for stations were made very tentatively, because we certainly had no authority to implicate other nations to any degree whatever. It should be no surprise that my favorite pattern of stations was ultimately so modified that all six of those outside the United States were "moved" from the countries we recommended to other ones.

It is unnecessary to write of the later development of Omega, largely made possible by the arrival of small and powerful computers. It is also unimportant to discuss here the delays and confusion introduced by hopes for the competing aids to navigation, Satellite and Inertial, or by the determined opposition of forces that tried to discourage Norway, and did discourage New Zealand, from installing Omega stations, on the grounds that they were designed to support Polaris missiles and would, therefore, attract hydrogen bombs! It is enough here to report that the Australian station completed the set of eight and began transmitting 27 1/2 years after my first letter proposal to the Navy in 1955.

I cannot allow this very abbreviated history to come to an end without testifying to my understanding that certainly hundreds, and probably thousands, of others have made crucial contributions to Omega. Whatever I may tell myself about my own work, I know better than anyone else possibly can how little I could have done alone. I thank all these others, perhaps especially the ones whose names I cannot know, for their help in allowing me to see a dream fulfilled.

Using Omega to Determine Position

Omega is configured to permit phase comparisons between synchronized pairs of transmitters. The Omega signals form a family of navigational lanes, which extend as an invisible lattice network worldwide. The orientation of this Omega signal grid is precisely established with respect to its position on the earth's surface, although the individual lanes are unidentified. This is analogous to a city in which streets and avenues are sequentially numbered and carefully laid out in a rectangular pattern, but without any street signs. If you could initially locate yourself at some point within this grid (say the corner of 46th Street and 5th Avenue), maintaining a simple count of street and avenue crossings would provide you with a position (street and avenue) update as you moved across the city. The Omega receiver compares signals from one pair of stations to establish a navigational lane (or, in our example, an avenue). Reception and comparison of Omega signals from a second pair of stations produces a second navigational lane, or street. Since one station can be common to both pairs, only three Omega stations must be received and analyzed to provide a two line-of-position (LOP) fix. En route, the Omega receiver monitors the selected station pairs and keeps track of both the number of lane crossings and the current fraction of lane traversed in order to continously update LOP information. Normally, two or more pairs of stations are used.

In traditional oceanographic navigation, the navigator plots his dockside position on the Omega chart in port and presets his receiver by entering the selected pairs of Omega transmitting stations. The receiver keeps track of the Omega LOP numbers throughout the voyage. En route, the navigator reads the lane values from his receiver display, applies the corrections to the receiver readings, and plots the numbered LOPs on his Omega chart.

Modern receiver equipment is based on the use of most or all of the Omega signals and frequencies, optimally processed by a computer and read out directly. In both ships and aircraft, computer operated receivers display latitude and longitude, distance to go and course, and other desired values, such as track error. The Omega system was initally designed to provide a fix accuracy of four nautical miles or better, with a 95% confidence level; however, modern receivers do considerably better than that. Based on the Omega transmission format, completely new position information is available once every 10 seconds.

The figure below illustrates the operational procedures used in determining and plotting the positions of a vessel transiting the Pacific Ocean. In the example, stations C (Hawaii), D (North Dakota), and H (Japan) were selected and paired as follows; C-D, C-H, D-H.

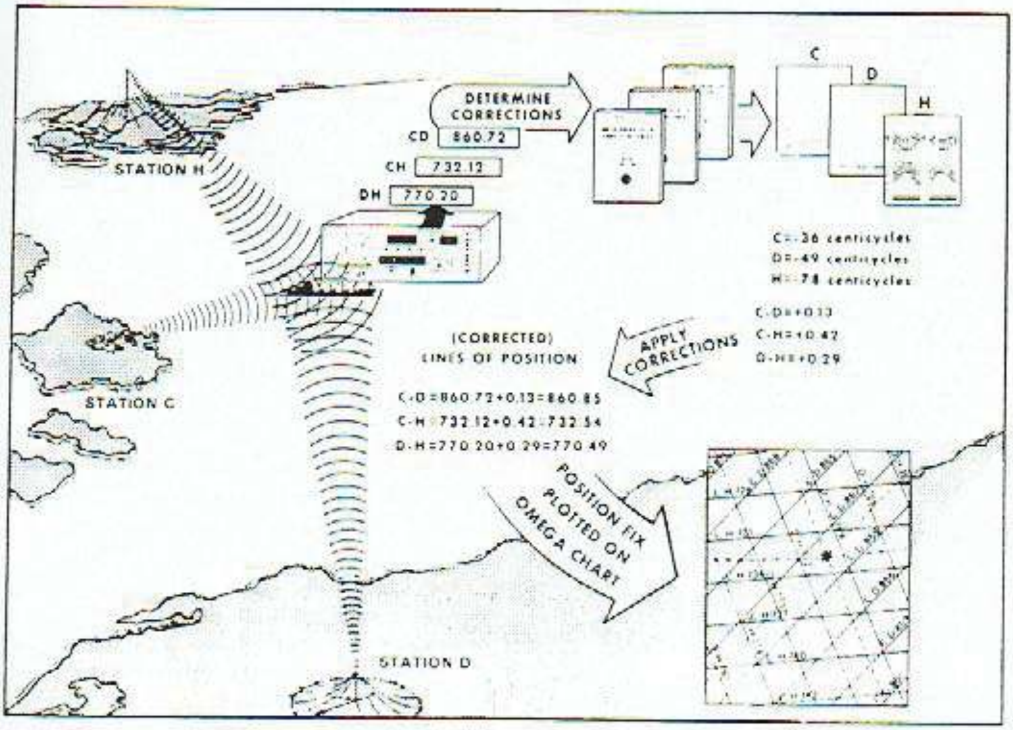


Figure 1 Procedure for Manually Plotting a Position

The Transition to an Operational System

Converting technical achievements and theory into an operating world-wide system was an accomplishment of immense proportions, involving literally hundreds of key individuals and organizations. Although it is not possible to do justice to all, there are several that should be mentioned. As one example, William Scoville was the first to measure accurately the diurnal variations of an LF carrier, in the early 1950s. Another, deserving special attention, is the Navy Electronics Laboratory (NEL), lead laboratory during the critical technical development phase and now a part of the Naval Ocean Systems Center.

NEL provided the lead in technical matters in the early development stage and provided the needed continuity as further implementation stages progressed. Key contributions were made in the areas of transmitting antenna design and tuning, receiver design, predicted propagation corrections, and system installation and calibration. The four stations that were declared "interim operational" in 1968 (Hawaii, New York, Trinidad and Norway) were essentially constructed in-house at NEL and placed in service in early 1966.

The long history of Omega at NEL afforded a continuity of talented personnel, allowing the current Omega system to grow out of the very different Radux system which J.A. Pierce initially proposed in 1947. M. Lowman Tibbals, the Omega project manager, largely maintained the organizational continuity that permitted this to happen. He kept a team of engineers working in the same direction and also managed substantial coordination with hundreds of other organizations, national and international. Although NEL continued to play an important technical role, the overall lead was picked up by the Navy's Omega Program Management Office (PME-119) beginning in about 1968. Besides overseeing the enormous task of constructing the system, a major task was to obtain foreign partner nation cooperation in construction and eventual operation. This began the transition from a U.S. Navy developmental system to an international civil navigation system.

One of the first actions of the Omega Project Office was to establish a U.S. Coast Guard Liaison position. The eventual goal was to transfer all U.S. operational responsibilities to the Coast Guard, the traditional operating agency for civil marine navigation systems.

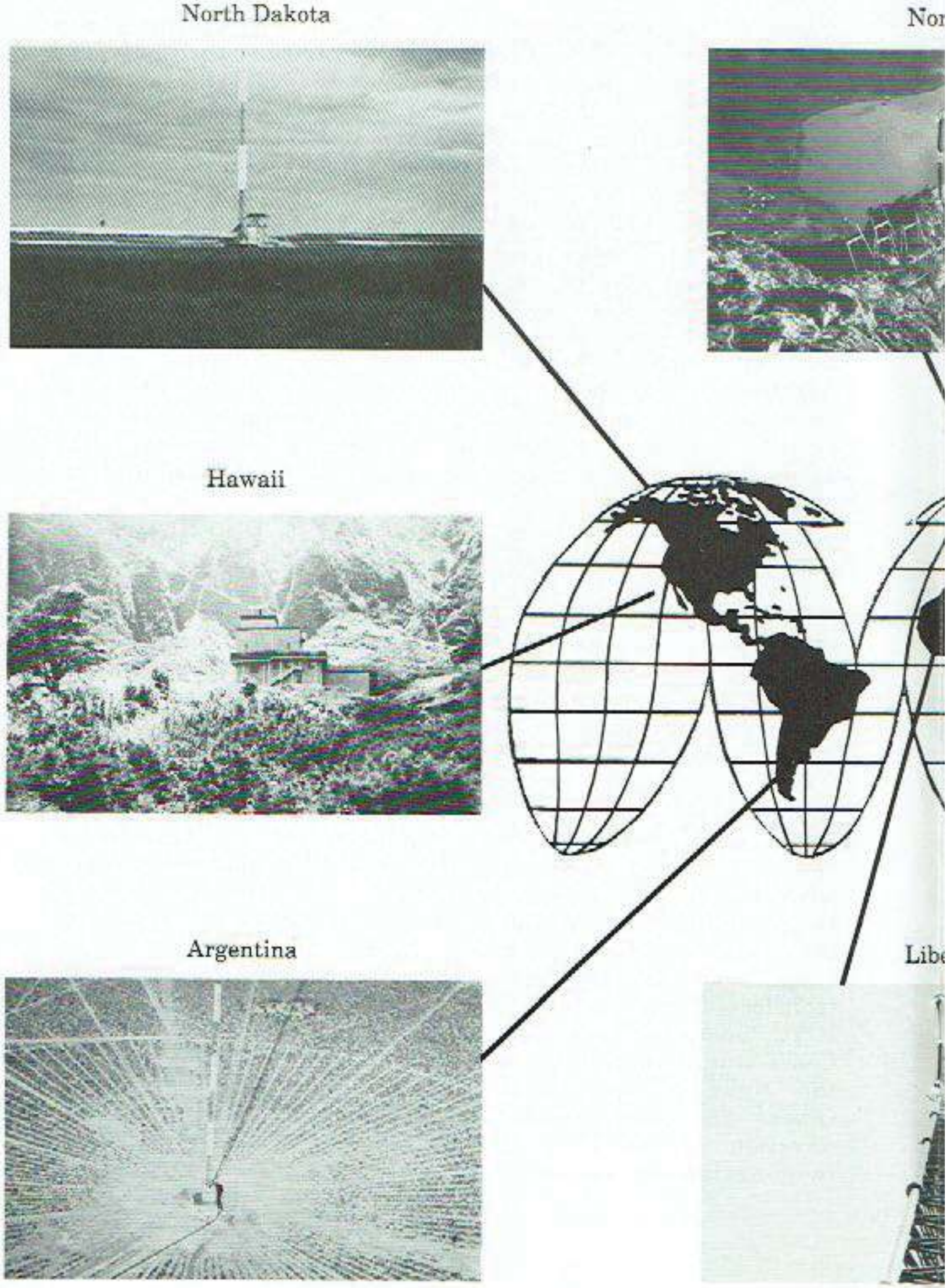
As partner nation negotiations and construction plans proceeded, the Navy initiated action to create the next organization which played a key role in the system's history. In 1971, the Omega Navigation System Operations Detail (ONSOD) was created as a Coast Guard command operating under the control of the Omega Program Management Office. It was made responsible for creating and eventually directing all operational procedures for the infant system. Additionally, it began a transition period in which it eventually assumed all technical responsibilities for the system. These included all electronics equipment, the development of propagation corrections, and responsibility for system calibration.

As one of its first major accomplishments, ONSOD took the lead in the formation of the final key Omega organization, the International Omega Technical Commission (IOTC). The IOTC is, in effect, the governing body of the cooperating international Omega operating network. It is comprised of operating agency representatives from each of the partner nations and provides direction to ONSOD, which coordinates day-to-day operation of the system. The IOTC first met in Washington, D.C. in 1973. It has met 10 times since, at formal conferences, and carries out an active exchange of technical information on a routine basis.

The IOTC has been the mechanism for the transfer of needed technical information from the NEL pioneers through ONSOD. A major accomplishment was the transfer of responsibility for day-to-day synchronization of the system to the Japanese Maritime Safety Agency in 1977.

As each transmitting station came on-line, ONSOD transferred the maintenance responsibility to each of the IOTC operating agencies. ONSOD was moved under full Coast Guard control in 1978 and, in 1979, formally relieved the Navy of operational responsibilities for the system. Omega has been operated throughout the 1980's under the direction of the IOTC as an effective international civil radio-navigation system.

OMEGA GROU



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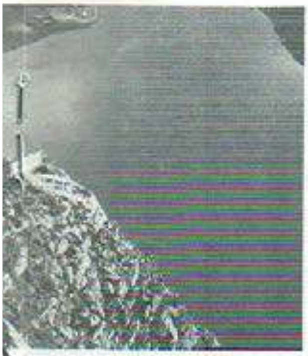

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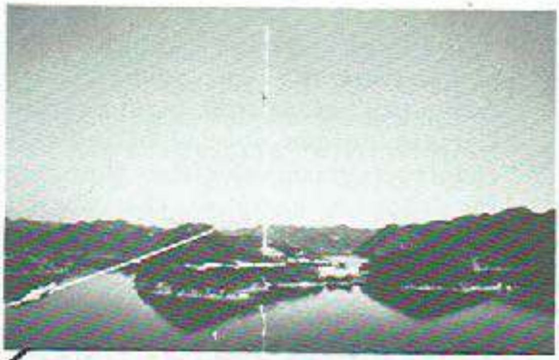

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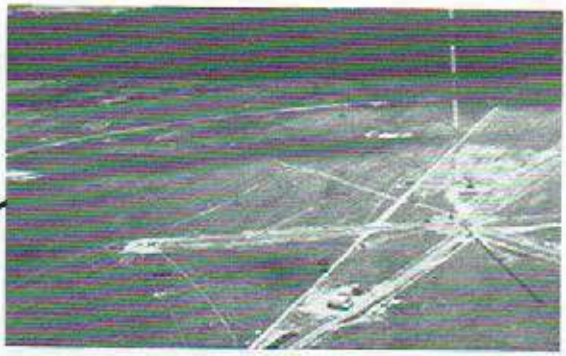


beria

La Réunion

Omega Ground Stations

The eight Omega stations have in common the challenge of engineering in remote locations. All have identical frequency standards, transmitter timers, and transmitters. Certain unique aspects of individual stations demonstrate the construction complexities that were overcome in various ways in different parts of the world.

Omega Station Argentina

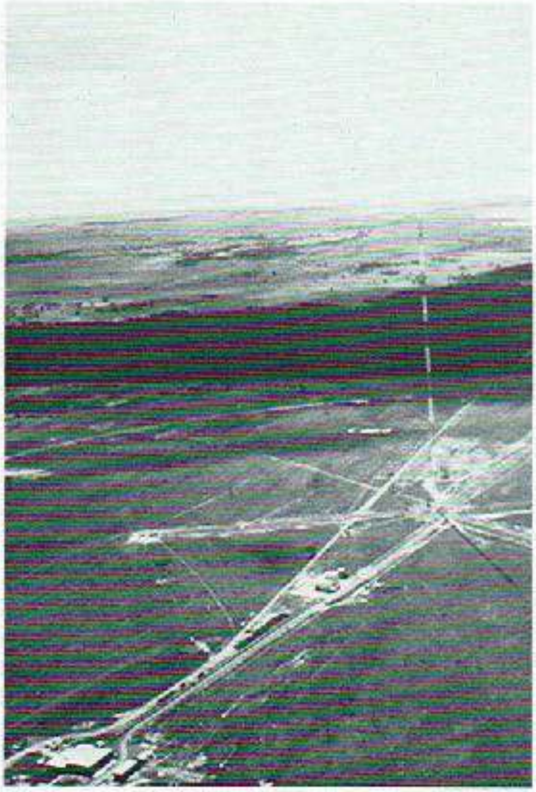
This station is located near the city of Trelew, on the east coast of Argentina, 700 miles southwest of Buenos Aires. It is operated by the Argentine Navy. Its antenna is insulated-based and 1,200 feet tall. A bilateral agreement was signed for the station in December, 1970, and it became operational in July, 1976.

Omega Station Australia

The Australian Omega facility was the last of the eight stations to be built and thus drew heavily on the design of the others. The tower is of the open lattice design and, at 427 meters, the largest man-made structure in Australia. Its design is basically the same as the one in Liberia, but with increased strength to withstand the higher wind speeds encountered at the Australian site.

The antenna system employs the same "grounded tower" concept as in La Réunion and Liberia. In this approach, one of the sixteen radials is energized, and the remaining fifteen radials form the conventional antenna loading elements. The radials are insulated from the tower at the top and at their lower ends. The tower has been designed to accommodate meteorological equipment on booms at five levels to collect data on wind speed and temperature. The booms also have fitted equipment for monitoring air pollution.

A bilateral agreement was signed in September, 1977, and Omega Station Australia became operational in August, 1982.



Omega Station Hawaii

The Hawaii station is located in Kaneohe, on the east coast of Oahu. Built in WW II, the site was originally a communications station. The station is built entirely of reinforced concrete, with a five foot thick bomb-proof roof. The antenna is a valley span configuration, similar to Norway's, but with six spans instead of two. The spans, which range from 4,000 to 7,000 feet long, are suspended between Pali Ridge on the south and Kahuku Ridge on the north. The station is operated by the fourteenth Coast Guard District, Honolulu. It became operational in January, 1975.

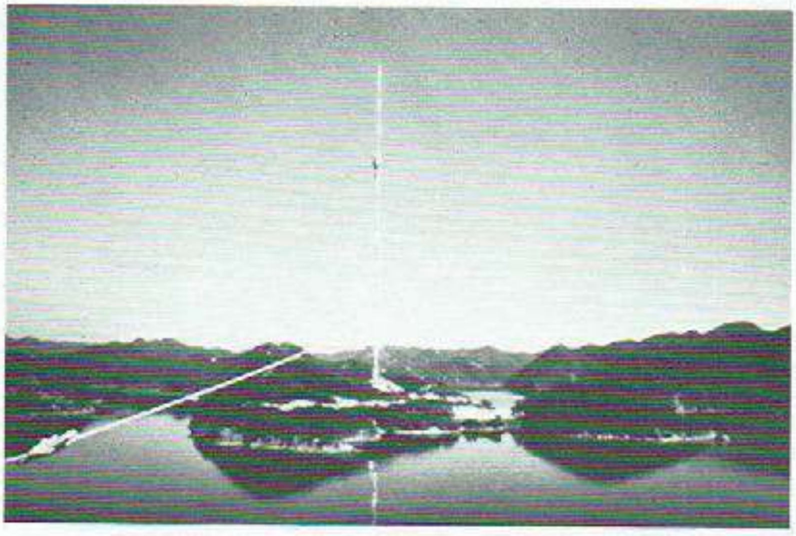
Omega Station Japan

Omega station Japan is located at the head of a small peninsula stretching out into a little bay on the east coast of an island called "Isushima", which lies between the southern part of Japan and the Korean peninsula. Because of its geographical features, the island has repeatedly appeared in history as a crossroad for culture and immigration and, at one time, a stage for international conflicts. Natural forests cover the mountainous land area, and typical coastal features along the shore line and ancient remains here and there confirm a beautiful and mysterious history.

The Omega tower stands 455 meters tall, the highest in the Orient, with 16 top radials extending uniformly in all directions to the anchors, placed about one kilometer away, across the water. The ground system utilizes the benefit of sea water to improve the antenna efficiency.

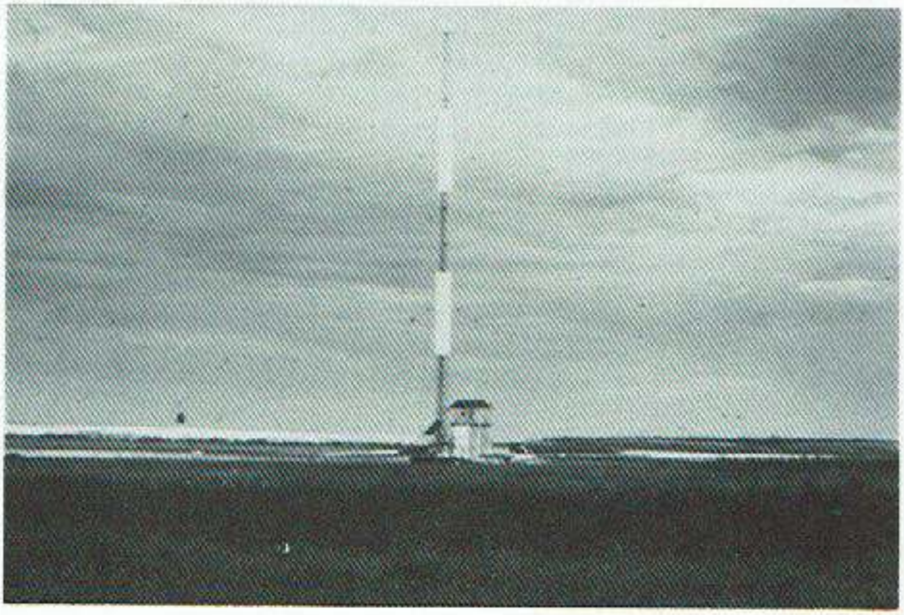
The tower is top-loaded, base-insulated, three-directional, six level, guyed and cylindrical. It consists of 63 units of flange-jointed tubulars, each three meters in diameter. Each unit is 7.45 meters long, has a 22 to 25 mm thick wall and weighs about 20 tons. Double-stacked, 6-paired insulators in a hexagonal shape support the base of the tower, and locked-coil guy wires 70 to 100 mm. in diameter fasten the tower to the anchors.

The tower construction, applying every modern technique of guyed towers in Japan, began in 1971 and was finished in 1975.



Omega Station La Moure, North Dakota

The La Moure station is located 75 miles southwest of Fargo, North Dakota. It is situated farther from the sea than any other Omega station, being over 1,000 miles from both the Atlantic and Pacific coasts. The antenna has an insulated base and is over 1,200 feet tall. The station is operated by the Second Coast Guard District in St. Louis, Missouri. It became operational in October, 1972.



Omega Station Liberia

Omega Station Liberia is located 10 miles east of the capital city of Monrovia. Negotiations for the establishment of the station and selection of the 700-acre site were finalized through an exchange of notes between the Republic of Liberia and the United States of America in April, 1973. Surveying and land clearing operations commenced, and construction was begun in early March, 1974. The 1,400 foot tower, the tallest structure in Africa, was completed in April, 1975. In all, 1,670 cubic yards of concrete were poured in the foundation and guy anchors which support the 430 tons of structural steel used to build the tower. Continuous, full power operation commenced in February, 1976, after three months of testing. The station is operated by the Liberian Ministry of Transport.

Omega Station Norway

This station is located in Aldersundet, a mile north of Bratland, in the community of Luroy, very close to the Arctic Circle. Its approximate position is 66 23° N by 13 09° E. It is located near the interim station, which was in operation from 1966 to 1971. The terrain is very rugged and, being close to the North Atlantic, presents a significant challenge to those who must operate and maintain the station.

The aerials for the antenna system are strung between the mountain ridge called Aldertind on the island Alberen and the mountain summit called Liatind on the mainland Bratland. These aerials cross the Aldersund at a width of approximately 1600 meters. On Aldertind, the two aerials are suspended from steel towers approximately 10 meters high, placed 1289 meters apart.

On Liatind, the spans are connected to haulage ropes directed downward along the slope of Liatind and suspended upon sheaves with roller bearings. The haulage ropes are tensioned by hoisting machinery in a building approximately 350 meters south of the Helix building at the main road. The tension upon the haulage rope and tail rope is recorded continuously by instruments in the winch-building.

The Omega Norway Helix Assembly is a fixed vertical coil 14 feet in diameter and 30 feet high. The coil is placed on a dielectric coil support frame eight feet above the floor. Six variometer assemblies are provided as part of the antenna network tuning equipment. Only one variometer is in operation at a time.

A bilateral agreement was signed in November, 1971, and Omega Station Norway became operational in December, 1973.

Omega Station La Réunion

La Réunion is a French territory, located in the Indian Ocean 500 miles east of Madagascar. The antenna is ground based, 1,400 feet tall, and designed to withstand typhoon force winds.

Omega Station La Réunion became operational in March, 1976, and a bilateral agreement was signed in June, 1981. It is operated by the French Navy.

Omega Synchronization

To keep transmitted signals in-phase among all Omega transmitting stations, and to have Omega Mean Time follow Universal Coordinated Time, each station must adjust the phase of its transmission signals. The adjustment values are provided weekly from the Tokyo office of the Japanese Maritime Safety Agency.

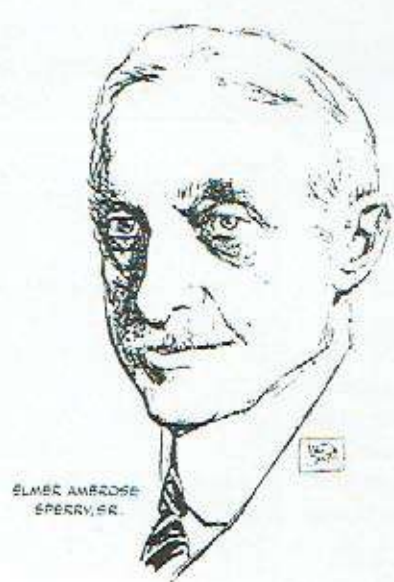
To accomplish this objective, each Omega station provides Omega Japan with Omega phase difference data obtained from readings of coordinated stations and frequencies at predetermined times. Using these data, the Analysis Office calculates a weekly adjustment, called CORRECTIONS, and a 4-hourly adjustment, ACCUMS. The former corrects offsets between Omega Mean Time and the Station epoch time at the moment of the computation. The latter is an estimated time adjustment value which correlates to the phase drift rate of the cesium standard and is computed with regard to Omege Mean Time. The two adjustments are distributed by message to each station, where the Phase Shifter of the Timing Control equipment is directed to correct the phase of the transmitted signal.

Dedication

The Sperry Board of Award gratefully acknowledges the contributions to this Award booklet made by the (U.S.) Institute of Navigation, the U.S. Coast Guard, and the International Omega Association.

Elmer A. Sperry, 1860-1930

After attending Cornell University in 1879-80, Sperry invented an improved electric generator and arc light and opened an electric company in Chicago. He invented electric mining equipment, locomotives, streetcars and an electric automobile. He developed gyroscopic stabilizers for ships and aircraft, a successful marine gyro-compass, and gyro controlled steering and fire control systems used on Allied warships during World War I. Sperry also developed an aircraft searchlight and the world's first guided missile. His gyroscopic work resulted in the automatic pilot in 1930.



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Previous Elmer A. Sperry Awards

1955 to *William Francis Gibbs* and his Associates for development of the S.S. United States.

1956 to *Donald W. Douglas* and his Associates for the DC series of air transport planes.

1957 to *Harold L. Hamilton, Richard M. Dilworth and Eugene W. Kettering* and Citation to their Associates for the diesel-electric locomotive.

1958 to *Ferdinand Porsche* (in memoriam) and *Heinz Nordhoff* and Citation to their Associates for development of the Volkswagen automobile.

1959 to *Sir Geoffry De Havilland, Major Frank B. Halford* (in memoriam) and *Charles C. Walker* and Citation to their Associates for the first jet-powered aircraft and engines.

1960 to *Frederick Darcy Braddon* and Citation to the Engineering Department of the Marine Division, *Sperry Gyroscope Company*, for the three-axis gyroscopic navigational reference.

1961 to *Robert Gilmore Letourneau* and Citation to the Research and Development Division, *Firestone Tire and Rubber Company*, for high speed, large capacity, earth moving equipment and giant size tires.

1962 to *Lloyd J. Hibbard* for application of the ignitron rectifier to railroad motive power.

1963 To *Earl A. Thompson* and Citation to his Associates for design and development of the first notably successful automobile transmission.

1964 to *Igor Sikorsky* and *Michael E. Gluhareff* and Citation to the Engineering Department of the Sikorsky Aircraft Division, *United Aircraft Corporation*, for the invention and development of the high-lift helicopter leading to the Skycrane.

1965 to *Maynard L. Pennell, Richard L. Rouzie, John E. Steiner, William H. Cook* and *Richard L. Loesch, Jr.* and Citation to the Commerical Airplane Division, *The Boeing Company*, for the concept, design, development, production and practical application of the family of jet transports exemplified by the 707, 720, and 727.

1966 to *Hideo Shima, Matsutaro Fuji* and *Shigenari Oishi* and Citation to the *Japanese National Railways* for the design, development and construction of the New Tokaido Line with its many important advances in railroad transportation.

1967 to *Edward R. Dye* (in memoriam), *Hugh DeHaven and Robert A. Wolf* and Citation to the research engineers of *Cornell Aeronautical Laboratory* and the staff of the Crash Injury Research projects of the *Cornell University Medical College*.

1968 to *Christopher S. Cockerell* and *Richard Stanton-Jones* and Citation to the men and women of the *British Hovercraft Corporation* for the design, construction and application of a family of commerically useful Hovercraft.

1969 to *Douglas C. MacMillan, M. Neilsen* and *Edward L. Teale, Jr.* and Citations to Wilbert C. Gumprich and the organizations of *George G. Sharp, Inc., Babcock and Wilcox Company*, and the *New York Shipbuilding Corporation*, for the design and construction of the N.S. Savannah, the first nuclear ship with reactor, to be operated for commercial purposes.

1970 to *Charles Stark Draper* and Citations to the personnel of the *MIT Instrumentation Laboratories:* Delco Electronics Division, *General Motors Corporation*, and Aero Products Division, *Litton Systems*, for the successful application of inertial guidance systems to commercial air navigation.

1971 to *Sedgwick N. Wight* (in memoriam), and *George W. Baughman* and Citations to William D. Hailes, Lloyd V. Lewis, Clarence S. Snavely, Herbert A. Wallace, and the employees of *General Railway Signal Company*, and the Signal & Communications Division, *Westinghouse Air Brake Company*, for development of Centralized Traffic Control on railways.

1972 to *Leonard S. Hobbs* and *Perry W. Pratt* and the dedicated engineers of the Pratt & Whitney Aircraft Division of *United Aircraft Corporation* for the design and development of the JT-3 turbo jet engine.

1975 to *Jerome L. Goldman, Frank A. Nemec* and *James J. Henry* and Citations to the naval architects and marine engineers of *Friede and Goldman, Inc.* and *Alfred W. Schwendtner* for revolutionizing marine cargo transport through the design and development of barge carrying general cargo vessels.

1977 to *Clifford L. Eastburg* and *Harley J. Urbach* and Citations to the Railroad Engineering Department of *The Timken Company* for the development, subsequent improvement, manufacture and application of tapered roller bearings for railroad and industrial uses.

1978 to *Robert Puiseux* and Citations to the employees of the *Manufacture Francais des Pneumatiques Michelin* for the design, development and application of the radial tire.

1979 to *Leslie J. Clark* for his contributions to the conceptualization and initial development of the sea transport of liquefied natural gas.

1980 to *William M. Allen, Malcolm T. Stamper, Joseph F. Sutter* and *Everette L. Webb* and Citations to the employees of *Boeing Commercial Airplane Company* for their leadership in the development, successful introduction and acceptance of wide-body jet aircraft for commercial service.

1981 to *Edward J. Wasp* for his contributions toward the development and application of long distance pipeline slurry transport of coal and other finely divided solid materials.

1982 to *Jorg Brenneisen, Ehrhard Futterlieb, Joachim Korber, Edmund Muller, G. Reiner Nill, Manfred Schulz, Herbert Stemmler* and *Werner Teich* for their contributions to the development and application of solid state adjustable frequency induction motor transmission to diesel and electric motor locomotives in heavy freight and passenger service.

1983 to *Sir George Edwards, OM, CBE, FRS; General Henri Ziegler, CBE, CVO, LM, CG; Sir Stanley Hooker, CBE, FRS* (in memoriam); *Sir Archibald Russell, CBE, FRS;* and M. Andre Turcat, Ld'H, GG; commemorating their outstanding international contributions to the successful introduction and subsequent safe service of commerical supersonic aircraft exemplified by the Concorde.

1984 to *Frederick Aronowitz, Joseph E. Killpatrick, Warren M. Macek* and *Theodore J. Podgorski* for the conception of the principles and development of a ring laser gyroscopic system incorporated in a new series of commerical jet liners and other vehicles.

1985 to *Richard K. Quinn, Carlton E. Tripp,* and *George H. Plude* for the inclusion of numerous innovative design concepts and an unusual method of construction of the first, 1,000-foot self-unloading Great Lakes vessel, the M/V Stewart J. Cort, which revolutionized the economics of Great Lakes transportation.

1986 to *George W. Jeffs, Dr. William R. Lucas, Dr George E. Mueller, George F. Page, Robert F. Thompson* and *John F. Yardley* for significant personal and technical contributions to the concept and achievement of a reusable Space Transportation System.

1987 to *Harry R. Wetenkamp* for his contributions toward the development and application of curved plate railroad wheel designs.

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