OMEGA NAVIGATION SYSTEM

by L. A. Fletcher*

The subject of this paper is precise time and time interval dissemination via the OMEGA Navigation System. Dissemination of time and time interval is an incidental fallout of OMEGA, and this paper will identify the characteristics of the system which give it the ability to disseminate time and time interval.

OMEGA is a very low-frequency navigation system which will, with eight stations, provide worldwide coverage. Figure 1 shows the approximate station locations. The stations located in Norway, New York, Hawaii, and Trinidad are presently in operation (low-power) and the Norway, Hawaii, and Trinidad stations will be upgraded to full-power operation in the final configuration. The New York station will be replaced by a new station presently under construction in North Dakota. These eight stations will be able to provide continuous, all-weather navigation with a one- or two-mile accuracy for user vehicles. At each OMEGA station, the frequency and timing of the transmission are controlled by four cesium beam standards. All eight stations are synchronized to each other so that the epoch for any given station, in comparison to the system's epoch, is generally within 1 μsec. Four stations are currently operating on an interim basis and it has been possible to maintain that synchronization tolerance. Experiments have been performed with the system to see how closely or how easily it can be synchronized to

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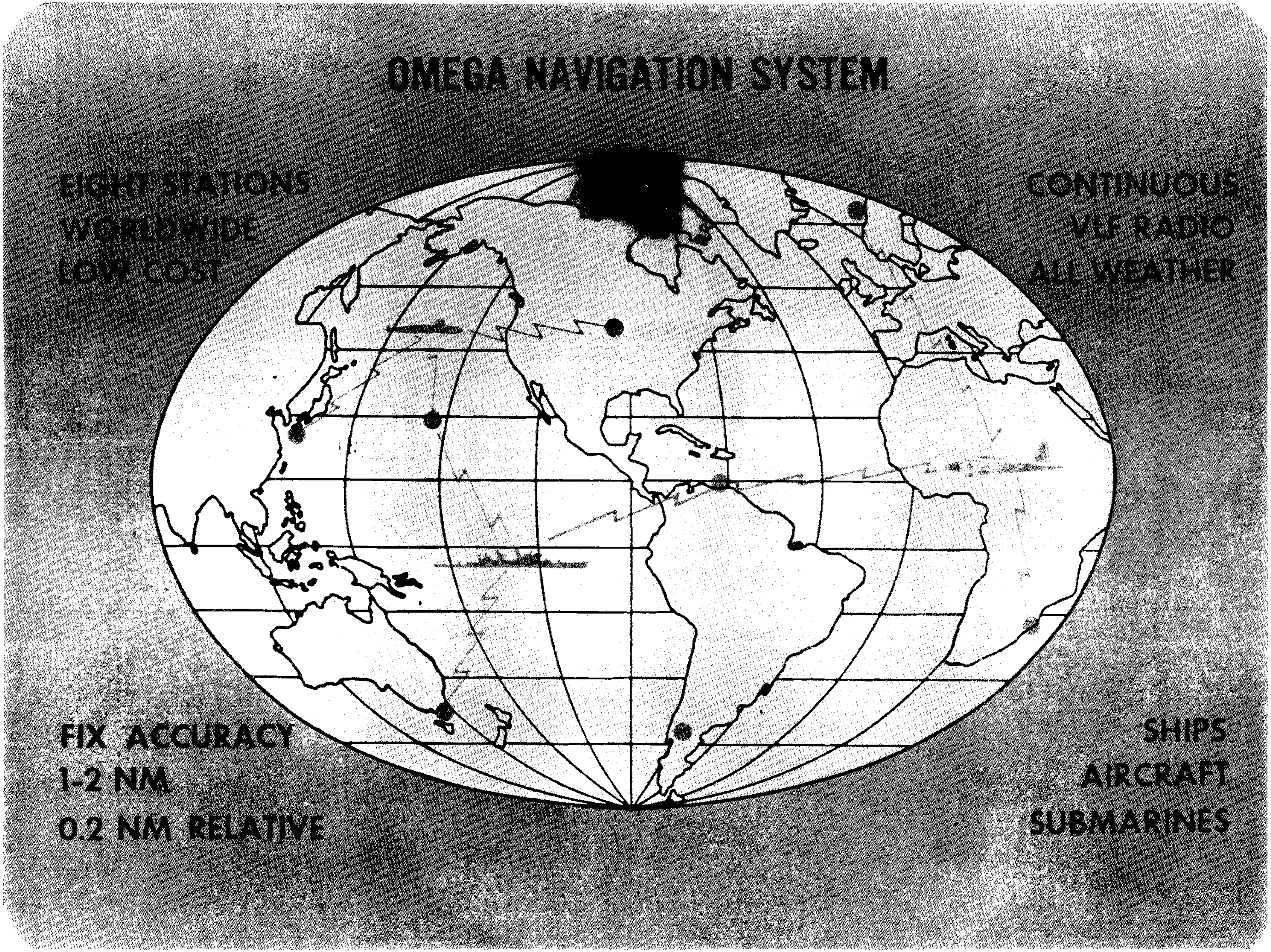
OMEGA NAVIGATION SYSTEM
EIGHT STATIONS
WORLDWIDE
LOW COST
CONTINUOUS
VLF RADIO
ALL WEATHER
FIX ACCURACY
1-2 NM
0.2 NM RELATIVE
SHIPS
AIRCRAFT
SUBMARINES

Observatory time. These experiments indicate that the OMEGA epoch can be held within 5 μsecs of the Observatory epoch without significant effort.

Synchronization of the OMEGA system is presently accomplished as follows. Each station monitors every other station's transmissions and communicates the results back to the control station. The control station then takes these results (numbers) and issues a control message of adjustment to each station. The control communications are presently handled via existing military commercial communication systems; whereas in the implemented system, communication is direct, not via OMEGA frequencies, but by using two additional frequencies in the OMEGA format. This approach will relieve normal communication channels and enhance the reliability and efficiency of OMEGA synchronization control.

Figure 2 shows the anticipated frequency assignment. The Trinidad station, the Hawaii station, and the North Dakota station are the U.S.-owned and operated stations. Frequency assignments have been requested for each of these three stations as shown in the figure. The 10.2, 13.6, and 11.33 KHz are the basic OMEGA frequencies and, as shown for the Trinidad station, the 12.0 and 12.25 KHz will be used to transmit synchronization information between Trinidad and the control station when the system is fully implemented. Some relaying between stations will be required. For example, La Reunion will need to relay its communications data through some other station in order to get to the control station. The planned method of communication is a form of Frequency Shift Keying (FSK) implemented by keying different segment/frequency combinations for each ten-second OMEGA "frame."

It should be reemphasized that Figure 2 depicts a proposed frequency assignment. OMEGA is an international system, and stations that are non-U.S. owned are fully owned and operated by the partner nations and as such, they must request their own frequency assignment. The U.S.

PROPOSED SEGMENT - FREQUENCY ASSIGNMENT (KHz)

STATION / SEGMENT	A	B	C	D	E	F	G	H
A. NORWAY	10.2	13.6	11.33	12.10	12.10	12.10	12.35	12.35
B. TRINIDAD	12.25	10.2	13.6	11.33	12.0	12.0	12.0	12.25
C. HAWAII	11.80	11.80	10.2	13.6	11.33	11.55	11.55	11.55
D. NORTH DAKOTA	12.85	13.10	13.10	10.2	13.6	11.33	12.85	12.85
E. La REUNION	12.05	12.05	12.30	12.30	10.2	13.6	11.33	12.05
F. S. AMERICA	12.90	12.90	12.90	13.15	13.15	10.2	13.6	11.33
G. S. AUSTRALIA	11.33	12.75	12.75	12.75	13.00	13.00	10.2	13.6
H. JAPAN	13.6	11.33	12.80	12.80	12.80	13.05	13.05	10.2

FIGURE 2

position regarding foreign OMEGA frequency assignments is that of coordinator, and changes may be necessary in the frequencies shown in Figure 2.

With regard to the subject of time and time interval, time interval dissemination is a very obvious fallout from OMEGA. The OMEGA signal is cesium-controlled and can provide a rather excellent method of time interval dissemination worldwide because the system is internally synchronized to within 1 μsec. It can be synchronized without great difficulty to within 5 μsecs of Observatory time. The side frequencies are controlled by the same four cesium standards as the three OMEGA frequencies, and they are unique in that an OMEGA switch or commutator is not required for their use. Precise time can be disseminated by the system, and has been investigated by the U. S. Naval Observatory, NASA, and NBS. The technique involves the use of the two unique frequencies from each station and will be left to other papers presented at this symposium for details.

OMEGA station epoch is defined as the rise time of the 10.2 KHz signal; the 11.33 KHz and the 13.6 KHz signals will be controlled to within $\pm$10 nsecs of the epoch. The side or unique frequencies will be controlled to within $\pm$100 nsec of the epoch and, further, will be controlled to within $\pm$20 nsecs of each other.

As pointed out earlier, OMEGA will use the unique frequencies to communicate the system synchronization data. It is presently anticipated that system synchronization will not require full-time use of the unique frequencies, so there is a possibility that any remaining time may become available at some later date to transmit a time code. With regard to that aspect, the present Navy policy regarding OMEGA is discussed in the following paragraphs.

The Navy is charged with developing OMEGA as a navigation system. The Coast Guard will operate the system and will be the U.S. agent involved in any additional requirement placed on the system. The Navy has no money and no requirement to do more than implement a navigation system. The selection of the unique frequencies has been coordinated with the Observatory, NASA, and NBS to assure, where possible, that OMEGA offers a time disseminating capability. Also, the foreign stations will obviously develop their own policy toward whatever other use besides navigation is made of OMEGA.

Figure 3 shows the present schedule for the OMEGA system. The North Dakota station is now under construction, with about 35 percent of the funds expended on the construction. Buildings are up and the tower will be erected next year. All equipment for all eight stations has been placed under contract, with deliveries to start about January or February of 1971.

OMEGA TRANSMITTER STATION ON-AIR SCHEDULE

NORTH DAKOTA	DECEMBER 1971
NORWAY	JANUARY 1973
JAPAN	APRIL 1973
HAWAII	MAY 1972
LA REUNION	OCTOBER 1973
ARGENTINA	MARCH 1973
AUSTRALIA	MAY 1973
TRINIDAD	NOVEMBER 1973

FIGURE 3

DISCUSSION

Dr. G.M.R. Winkler

I would like to make some supplementary remarks. The Observatory is, of course, interested in assuring that these capabilities which have been explained will be fully utilized and available for dissemination of time. There are a number of problems which have to be solved, the most urgent problem of which is to develop a clear picture of the requirements for the use of the OMEGA system for precise time and time interval dissemination. Another point of uncertainty is the need for a time code. As Mr. Fletcher explained, each station will have five segments which are reserved for unique frequencies, spaced 250 cycles apart. These 250-cycle spacings, and the availability of three additional navigational frequencies which are time-shared, will make it possible to identify a cycle unambiguously at each location with respect to your own clock time. Very simply stated, this is being done by taking advantage of the different durations of one cycle of the two frequencies. If you just consider the two unique frequencies spaced 250 cycles apart, at the moment of emission at the transmitter, they are in phase every 20 msecs because they are multiples of 50 cycles per second. However, as you go out for each cycle, for each wave length you go out away from the transmitter in time and/or space, the difference in periods between these two frequencies is almost one and one-half μsecs -- the exact difference depends upon the frequency. In any event, as you go away in wave lengths from the transmitter, your phase difference increases by about one and one-half μsecs per wave length. This magnitude is large enough to be recognized, and by simply looking at the accumulated phase difference, the knowledge of your distance, and the "electrical" distance from the transmitter (propagation delay is still another problem) you can identify the cycle; you know which cycle you are on. Once the approximate time is known from the segments timing to within a few milliseconds, you can then, presumably, identify a cycle. As you can imagine, that is not a very simple method, although it can be done. Laboratories have done it successfully, as mentioned by Mr. Fletcher. The laboratories most interested in this kind of cycle identification have been NELC (San Diego); NBS in Boulder, Colorado; and NASA at Goddard. There is a question of how it should be done in practice because it is not a very simple procedure. Any systems used would have to, in my opinion, do that automatically. It would also require a much more extensive prediction of electrical delay, depending upon the solar conditions and the atmospheric conditions between the transmitter and the receiver, than we have available today in order to fully exploit the capabilities in the microsecond range.

Now, again, it can be done and it will be available also to support the primary navigation function of the system by increasing the precision of the fix. The question is: What else would be required to assure the greatest utility of the system? Would there be a need to transmit any time information over and beyond the segment's timing which enables you to identify your clock position within the 10-second interval? Would it be necessary, then, to transmit a time code which would be very slow? Necessarily, the time code could only use the slow segment bit timing or communications capability mentioned by Mr. Fletcher. A complete code cycle, as has been proposed by NBS, would require approximately two minutes. So you would require at least a two-minute sequence; that is, two minutes recording or correlating with an automatic equipment, before you could identify a particular part in your OMEGA sequence, if you did not want to simply listen to a standard time signal.

The code (even if it were on the air) could not possibly be continued 24-hours a day, because in between there is a communication requirement of the system to support the navigation function. The question which we want to solve, relative to requirement is: Do we need such a time code which would identify not only seconds, but also minutes, hours, and possibly days? The second question is: If any system feels that such a time code would be useful and would be required, what is the minimum amount of time the time code has to be on the air? For instance, would a two-minute period every 30 minutes be sufficient? These are two important questions which we have discussed and which will require a clear definition of requirement. We are very much looking forward to hearing from each one of you who is interested or who foresees a future use of that system for timing purposes.

There are additional questions which have been studied or are being studied by timing advisory group members from each of the agencies previously mentioned as well as from others. These questions concern various antenna and receiver techniques to be used for the extraction of timing information. As you can see, it is possible that for applications on a moving vessel; ship or aircraft, for instance, you would want to have precise time from the same system that provides position. The OMEGA system and the navigation systems generally make it very easy to provide time in a silent one-way mode because they provide proper position and electrical delay from the same system, which also makes the time available. The reason you get both of them is that the signals are redundant. For navigation you receive relative or difference signals simultaneously from several stations which define your geometry. For timing, then, you use one of these signals, but in an absolute way on all frequencies to possibly arrive at your time. At any rate, since it is such a system, it is also possible to obtain time continuously. If that is required, it would mean that navigational receivers, which are under development or testing, would have to be equipped with an additional timing capability to put out a time tick for the vessel's master timing center.

Finally, of greatest concern to us is the actual usefulness of such a system for the dissemination of time. It would be necessary to know much more, as I mentioned before, about the exact propagation characteristics. One would have to be able with either the help of tables or of mathematical models to compute a momentary electromagnetic distance in terms of wave length from the transmitter to your receiver in order to make fast-timing information available to you with the precision approaching 1 μsec.

I would like to close by asking you again to make your ideas or requirements known to the Observatory.