TIME DISSEMINATION CAPABILITIES OF THE OMEGA SYSTEM *

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Summary

The Omega VLF navigation system affords an opportunity to disseminate time synchronization signals which could serve two classes of users: those who need precise timing and those who need time-of-day information in the form of a time code. This paper discusses precise timing use in terms of carrier pulse timing, multiple frequency techniques for carrier cycle ambiguity resolution, and Omega system capabilities in the microsecond region. For use where unattended automatic timing is needed, a time code giving second, minute, hour, and day number information could serve a variety of needs. These are described along with characteristics and constraints of such a code imposed by the existing navigation format. The paper concludes with desirable receiver characteristics and development requirements for these two timing uses.

Key Words: Multiple frequency timing; Omega time code; precise time receiver; precise timing; time code receivers; VLF timing.

It is always difficult to find out who timing customers are and what they really need. But, if they need precise timing, this implies that they are already working in a rather sophisticated technological area. They probably have some high quality equipment or money to buy it; they have made some effort to learn about possible solutions to their problems; and they tend to know when to ask help of either or both of the time dissemination agencies in this country: The U. S. Naval Observatory or the National Bureau of Standards. No present system, WWV-WWVH, WWVB included, has the worldwide, continuous availability time code potential of the Omega system. Some problems exist in adapting a time code to Omega's existing format, but these can be overcome.

An Omega Time Code

On the other hand, we know of the existence of a number of requirements for low accuracy timing which needs not only seconds but also minutes, hours, days, and perhaps years, and which is available continuously and automatically.[1] The users for this service are harder to identify because timing, though essential, is not such a central part of their problem. This type of use generally is to time the occurrence of events which are recorded on permanent media such as strip charts or magnetic tape. Often the events occur at random times--for instance, seismic activity and other geophysical phenomena. Sometimes communication centers need to record and time all of their communication traffic. Another use is when large amounts of test data are recorded and later the results correlated in time among a number of locations. Sometimes this requires both coarse and fine timing such as for missile and satellite tracking.

For these uses it is not sufficient just to have special timing marks to identify the beginning of longer time subdivisions such as WWV's double seconds ticks which identify occurrence of the beginning of a minute. It is necessary to provide additional information to tell which minute is beginning.

Serial Time Code

A special time code which can meet this need and is applicable to Omega is the serial time code. Such a code can give the necessary timing information, repeating and updating it at a fixed rate appropriate to the timing requirements. The most well-known examples of such codes are the so-called IRIG codes. IRIG stands for Inter-Range Instrumentation Group, consisting of representatives from various missile ranges and tracking stations. This group has developed and standardized a number of codes suitable for different timing purposes.[2] All IRIG codes use pulse width encoding in binary form to convey timing information. They are transmitted either as a d-c signal level shift or as amplitude modulation of a carrier. The most well-known examples use binary coded decimal form and are not difficult to ready by eye. An example, IRIG H, is shown in Fig. 1. It has a frame length of 1 minute with 1 pulse per second index markers. Wide index pulses represent a binary one and narrow pulses a binary zero. In addition, extra wide pulses are used as position identifiers to help identify the elements of the code within the code frame. Since the frame is 1 minute long the code only gives time to the nearest minute. The time to which the code refers is the beginning of the code frame.

When such a time code is recorded on a separate track along with data on magnetic tape it greatly simplifies the recovery of data. If one wishes to examine data for a specific time it is possible to locate this time with a device called a tape search unit. If a particular type of phenomenon needs to be examined, a computer unit, in conjunction with a tape search unit, can identify all events of a given class on a tape. Then these events can be reexamined in detail at low speed if desired.

If the time code is recorded directly on a strip chart recording along with other phenomena, the code can be decoded by eye with a little practice. An example might be a recording of phase difference between two oscillators. A time code could be added at the edge of the recording using an event marker giving time reference.

It is also possible to use time code decoders, or readers, to convert the code to an on-line digital time display when desired. Such a display will update the time reading once for each received time code frame--that is, once per minute in the examples cited of IRIG. Or, it can be provided with its own time base which is synchronized by means of the time code, but may be updated more often according to requirements.

The type of time code just discussed is the result of designing the code around a given kind of timing need. It may be generated and decoded using conventional digital logic circuit techniques. It is well suited for transmission over hard wire or high signal-to-noise radio circuits. These codes are now generally available on missile ranges and other extensive operations requiring timing. IRIG H will also become available on a 100 Hz AM subcarrier of the NBS HF stations, WWV and WWVH, starting July 1, 1971.[3] A somewhat similar though non-standard type of time code has been available from the NBS 60 kHz station, WWVB. Coverage of all these services is limited to small regions of the world and is interrupted due to changing radio propagation conditions.

We feel that a uniform world-wide 24-hour a day time code service could be provided which would benefit a much larger group of users than now can receive time codes broadcast by NBS. The Omega VLF navigation system, presently being made operational by the U. S. Navy and which will ultimately have eight transmitters located throughout the world, has the potential to meet these requirements. Therefore, we are exploring the possibilities for sharing a time code broadcast from Omega along with its navigation service broadcast. Such a code cannot be one of some six IRIG codes because of the constraints imposed by the existing Omega format, which is shown in Fig. 2. To be noted here is that the navigation frequencies, 10.2, 13.6, and 11.3 kHz are broadcast on three consecutive time segments in turn from each Omega transmitter. This is shown by dotted crosshatching in Fig. 2. (The vertical crosshatching in this figure indicates the basic unique frequency transmission slot for each station.) Each Omega time frame is 10 seconds long and contains 8 segments, thus each segment occupies 1.25 seconds on the average. In practice the segments are of slightly unequal length and are separated by 0.2 second when transmission occurs. We see that there are 5 unused segments (including unique frequency slots) which are available in turn from each transmitter. These segments have been reserved for interstation data exchange. The method used will be Frequency Shift Keying (FSK) using a different pair of unique frequencies at each station. Since there are 8 stations this makes 16 unique frequencies in all. A pair from a given station will be separated by 250 Hz. Most of these frequencies will be between 12 and 13 kHz. The required data exchange rate is sufficiently low that the Omega Planning Office and NBS have tentatively agreed that 2 minutes out of every 5 will be made available for a time code broadcast. Now we see that as a starting point in designing such a code, we have twelve 10-second Omega frames to construct a time code frame 2 minutes long. Each 10-second frame has 5 out of 8 consecutive approximately 1-second segments available. The first of these has been reserved for receiver synchronization purposes and will therefore transmit this same frequency every frame. This leaves 4 segments, appropriately the right number to transmit one decimal digit in binary form. Of the 12 time code 10-second frames in the 2 minute time code frame, the first needs to be used to identify the beginning of the time code frame and distinguish it from the 3-minute communication frame. The remaining 11 frames are available to provide a time code. A straightforward form of this code then is: minutes, 2 frames; hours, 2 frames; days, 3 frames; and years, 2 frames; leaving 2 frames unspecified. This format is shown in Fig. 3. This time code format would seem to provide the information needed by the anticipated users.

It would not be necessary for all 8 Omega transmitters to transmit a time code for worldwide reception. Eight Omega stations are planned because a navigator must be able to receive at least 3 stations simultaneously to determine his position. A time user need only receive one station to determine time. The number and location of transmitters needed to provide sufficient coverage for a time code are uncertain, but perhaps 3 would be adequate. If only 1 station is so equipped the North Dakota station would provide very good coverage of the United States.

Before discussing receiving techniques, the subject of time scales and the relation of an Omega time scale to existing time scales should be mentioned. Beginning January 1, 1972 all time and frequency broadcasts in countries supporting the International Telecommunications Union will change from the present offset frequency to exact atomic frequency and the resulting atomic time scale will be coordinated internationally by the International Bureau of Time located in Paris.[4] It will get out of step with earth time (UTC) at the rate of about 1 second per year. To prevent this, 1-second "steps" will be made in the new atomic time scale so that this scale will never depart from UTC by more than about 0.7 second. Since the steps are 1 second and the usual time signals are 1-second ticks, these steps merely amount to relabeling the ticks which are broadcast. This relabeling of seconds would not interfere with systems requiring timing which operate with a 1-second basic period. The Omega transmission format, however, has a 10-second basic period; to remain in step with the UTC system, its format would have to shift by 1/10 the basic period every time a 1-second step took place. This would contribute nothing to the navigation use; on the other hand it would most certainly jeopardize its performance. Therefore, the Omega navigation format will operate on a pure atomic scale with no steps and this will necessarily be true of any time scale it disseminates. The Omega Navigation System is already in limited operation and therefore has its own time scale now operating on the offset frequency. Changing to atomic frequency on January 1, 1972 will be disruptive enough for the system without also resetting signal phases to conform to the new international time scale. Thus, the ticks from this scale and those of the Omega atomic time scale will not coincide. This fact will not particularly affect the usefulness of an Omega time code broadcast since users will not be concerned with differences of less than a second anyway. Precise timing users, however, will need to know the constant difference between the two scales.

Precise Timing Uses

The Omega system can be used simultaneously for precise time dissemination and time code dissemination. The multiple frequency technique for precise time recovery, essentially the same as that for navigational use, has been discussed extensively[5, 6], but will be mentioned again briefly.

For this use, it is necessary to determine the phases of two or more received frequencies. The frequencies have been arranged so that by taking differences between them, lower and lower derived frequencies can be obtained and their phases also determined. These lower frequencies then constitute timing signals with wider and wider ambiguity spacing. If time fluctuation of the phase of a given (lower) frequency is smaller than half the period of a higher frequency, a given cycle of the higher frequency can be identified with a zero crossover of the lower frequency. This method can be employed to proceed step by step from an easily identified lower frequency such as the Omega approximately 1-second segments all the way to the carrier frequency. In this way a time dissemination system with timing stability corresponding to the phase stability of the carrier may be obtained, typically a few microseconds from day to day for Omega. If propagation delay can also be determined, then the system could have an accuracy as well as a stability of a few microseconds. Portable clocks provide this possibility for such propagation delay measurement. Theoretical delay predictions may also be used, with lower timing accuracy.[7]

The number of cycle identification steps necessary to identify a carrier cycle in such a system is to first order, determined by the magnitude of the carrier phase fluctuations. As frequency differences are taken to get lower frequencies, the magnitude of the phase fluctuations, expressed in fractions of a period, are preserved.

We saw that the difference frequency fluctuations must be less than half the period of the higher frequency for cycle identification. Thus, if day-to-day averages for carrier fluctuations are 1/20 of a half period, (about 2.5 microseconds is typical of Omega) a step with a ratio of a lower to higher frequency of 20 may be used.

Since the Omega format is already fixed, only certain frequency ratios are possible. The 250 Hz separation of the unique frequencies is the lowest direct difference obtainable. With this frequency a ratio of 40.8 is required to get to the carrier frequency of 10.2 kHz in one step. This single step would probably suffice for carrier cycle identification over low fluctuation paths such as Hawaii to Boulder. Where two steps are required, the Omega format permits the ratios of 13.6 and 3, or 5.33 and 7.75, to identify carrier cycles of 10.2 kHz. The additional navigation frequencies of 13.6 kHz or 11 1/3 kHz would be used in this case.

After relating a zero crossover of the 250 Hz to a carrier cycle by the procedure just described, the next step in reducing ambiguities would be to relate the approximately 1-second Omega segment time markers to a cycle of the 250 Hz. This must be done by determining the time of arrival of these segment pulses to better than half the period of 250 Hz, that is 2 ms. Work at NBS and NELC indicates that this may be done.

Identification of the time of occurrence in seconds and minutes, etc., of Omega segment pulses may be made with the aid of some other source of coarse timing such as WWV time announcements, or it could be made from an Omega time code. In that case Omega would provide a self-contained worldwide timing capability offering a range of timing from coarse to precise.

Receivers

To make such a timing system usable, much development of a Omega time code receiver must take place. A receiver capable of giving both precise timing and of decoding the time code could consist of a number of modules. The precise timing portion must be capable of phase locking to the several carrier frequencies which are employed. Its circuits must be phase stable and a method must be provided to relate the phases of the incoming signals to the local time scale. Probably the most promising way of doing this is by a calibration technique whereby replicas of the incoming signals are generated from the local clock and then injected into the receiver front end or antenna. The receiver then becomes a comparison or null detecting device and precise knowledge of its phase shifts are unnecessary.

For determining the time of arrival of the carrier pulses with sufficient accuracy to identify a period of 250 Hz, some pulse averaging is necessary if conditions are noisy. This could be done by photographic integration or signal processing. Another way of solving this problem, described by Baltzer,[8] consists of first lowering the difference frequency from 250 Hz to 50 Hz by looking for simultaneous zero crossing of the two unique frequencies and one of the navigation frequencies. This reduction in ambiguity by a factor of five relaxes the pulse timing accuracy requirement from 2 microseconds to 10 microseconds.

For using the time code, the receiver must be capable of recognizing the presence or absence of signals during each of the 4 time code segments which occur during an Omega 10-second frame. Since signals from different Omega stations can be separated by as little as 50 Hz, the filtering problem may be severe. Once the signals are obtained from the two unique frequencies they may be recorded directly on tape or strip chart along with data from phenomena being studied. Or, if a time display is desired the logic problem of decoding them is as straightforward as with any conventional time code decoder. We believe these various developments are needed; moreover, they are well within the present state of technology and could lead to the most nearly universal timing receiver yet produced.

Conclusions

In summary, this paper proposes an opportunity for using the Omega VLF navigation system for both low and high accuracy time users. Implementation for time of day needs is suggested by means of an NBS-Omega time code (minutes, hours, days, and years) compatible with the existing Omega format. Precise timing is available through the multiple frequency technique for carrier cycle ambiguity resolution. The advantages of Omega timing are attractive, and if receiver and developmental techniques can be resolved, many timing requirements can be met throughout the world.

References

1. Richter, Henry L., Private communication, 1970.

2. IRIG, "IRIG standard time formats," Inter-Range Instrumentation Group Doc. No. 104-70, (Secretariat, Range Commanders Council, White Sands Missile Range, New Mexico 88002) August 1970.

3. Viezbicke, P. (ed.), "NBS frequency and time broadcast services--radio stations WWV, WWVH, WWVB, WWVL," Nat. Bur. Stds. (U.S.) Spec. Publ. 236, 1971 Edition (in press).

4. NBS, "UTC time scale to change in 1972," Nat. Bur. Stds. (U.S.) Tech. News Bull. CODEN:NBSTA 55(3), pp. 79, 82, March 1971.

5. Fey, L., and C. H. Looney, "A dual frequency VLF timing system," IEEE Trans. Instrumentation & Measurement, Vol. IM-15, No. 4, p. 190, December, 1966.

6. Swanson, E. R., and C. P. Kugel, "Omega VLF-timing," Naval Electronics Laboratory Center Report No. 1740, November 5, 1970.

7. Hamilton, W. and J. Jesperson, "Application of VLF theory to time dissemination," Private Communication, May 1971.

8. Baltzer, O. J., "Microsecond timekeeping by means of multiple-frequency VLF reception," Electronic Instrument Digest, Vol. 6, No. 12, p. 75, December 1970.

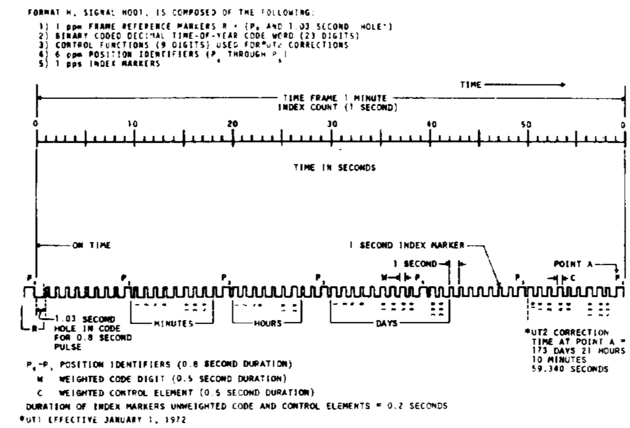

Fig. 1 - Composition of the IRIG H Format, signal H001.

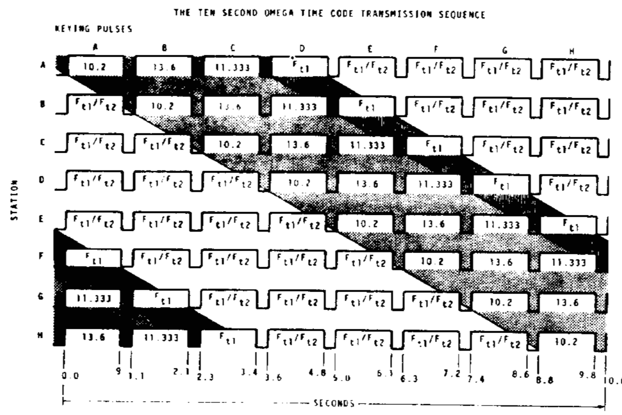

Fig. 2 - The 10 second Omega signal format.

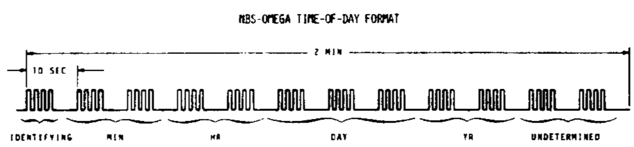

Fig. 3 - Proposed NBS-Omega time code format.