CHAPTER 18

TIME

TIME IN NAVIGATION

1800. Solar Time

The Earth's rotation on its axis causes the Sun and other celestial bodies to appear to move across the sky from east to west each day. If a person located on the Earth's equator measured the time interval between two successive transits overhead of a very distant star, he would be measuring the period of the Earth's rotation. If he then made a similar measurement of the Sun, the resulting time would be about 4 minutes longer. This is due to the Earth's motion around the Sun, which continuously changes the apparent place of the Sun among the stars. Thus, during the course of a day the Sun appears to move a little to the east among the stars, so that the Earth must rotate on its axis through more than 360° in order to bring the Sun overhead again.

See Figure 1800. If the Sun is on the observer's meridian when the Earth is at point A in its orbit around the Sun, it will not be on the observer's meridian after the Earth has rotated through 360° because the Earth will have moved along its orbit to point B. Before the Sun is again on the observer's meridian, the Earth must turn a little more on its axis. The Sun will be on the observer's meridian again when the Earth has moved to point C in its orbit. Thus, during the course of a day the Sun appears to move eastward with respect to the stars.

The apparent positions of the stars are commonly reckoned with reference to an imaginary point called the **vernal equinox**, the intersection of the celestial equator and the ecliptic. The period of the Earth's rotation measured with respect to the vernal equinox is called a **sidereal day**. The period with respect to the Sun is called an **apparent solar day**.

When measuring time by the Earth's rotation, using the actual position of the Sun, or the apparent Sun, results in **apparent solar time**. Use of the apparent Sun as a time reference results in time of non-constant rate for at least three reasons. First, revolution of the Earth in its orbit is not constant. Second, time is measured along the celestial equator and the path of the real Sun is not along the celestial equator. Rather, its path is along the ecliptic, which is tilted at an angle of 23° 27' with respect to the celestial equator. Third, rotation of the Earth on its axis is not constant.

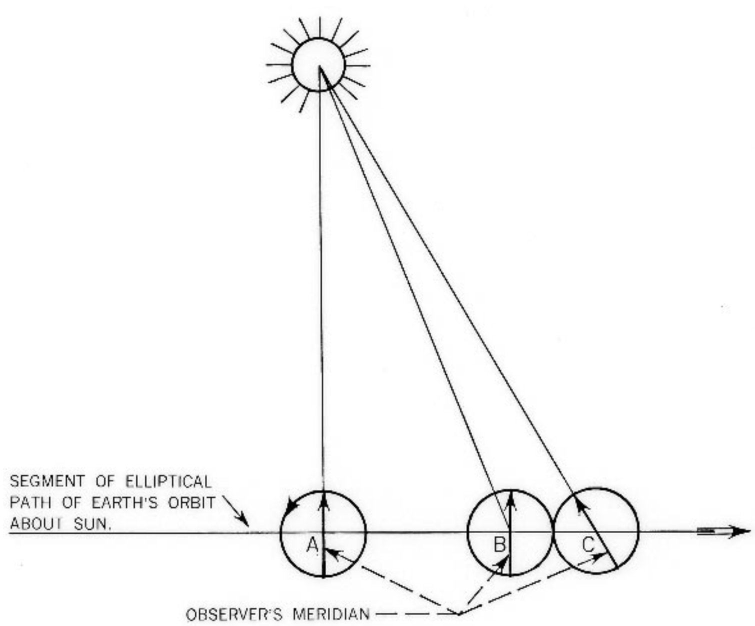

Figure 1800. Apparent eastward movement of the Sun with respect to the stars.

To obtain a constant rate of time, we replace the apparent Sun with a fictitious **mean Sun**. This mean Sun moves eastward along the celestial equator at a uniform speed equal to the average speed of the apparent Sun along the ecliptic. This mean Sun, therefore, provides a uniform measure of time which approximates the average apparent time. The speed of the mean Sun along the celestial equator is 15° per hour of mean solar time.

1801. Equation of Time

Mean solar time, or **mean time** as it is commonly called, is sometimes ahead of and sometimes behind apparent solar time. This difference, which never exceeds about 16.4 minutes, is called the **equation of time**.

The navigator most often deals with the equation of time when determining the time of **upper meridian passage** of the Sun. The Sun transits the observer's upper meridian at **local apparent noon**. Were it not for the difference in rate between the mean and apparent Sun, the Sun would be on the observer's meridian when the mean Sun indicated 1200 local time. The apparent solar time of upper meridian passage, however, is offset from exactly 1200 mean solar time. This time difference, the equation of time at meridian transit, is listed on the right hand daily pages of the *Nautical Almanac*.

The sign of the equation of time is negative if the time of Sun's meridian passage is earlier than 1200 and positive if later than 1200. Therefore: Apparent Time = Mean Time + (equation of time).

Example 1: *Determine the time of the Sun's meridian passage (Local Apparent Noon) on June 16, 1994.*

Solution: *See Figure 2008 in Chapter 20, the Nautical Almanac's right hand daily page for June 16, 1994. The equation of time is listed in the bottom right hand corner of the page. There are two ways to solve the problem, depending on the accuracy required for the value of meridian passage. The time of the Sun at meridian passage is given to the nearest minute in the "Mer. Pass."column. For June 16, 1994, this value is 1201.*

To determine the exact time of meridian passage, use the value given for the equation of time. This value is listed immediately to the left of the "Mer. Pass." column on the daily pages. For June 16, 1994, the value is given as 00^m37^s. Use the "12^h" column because the problem asked for meridian passage at LAN. The value of meridian passage from the "Mer. Pass." column indicates that meridian passage occurs <u>after</u> 1200; therefore, add the 37 second correction to 1200 to obtain the exact time of meridian passage. The exact time of meridian passage for June 16, 1994, is $12^h00^m37^s$.

The equation of time's maximum value approaches 16^m22^s in November.

If the *Almanac* lists the time of meridian passage as 1200, proceed as follows. Examine the equations of time listed in the *Almanac* to find the dividing line marking where the equation of time changes between positive and negative values. Examine the trend of the values near this dividing line to determine the correct sign for the equation of time.

Example 2: *See Figure 1801. Determine the time of the upper meridian passage of the Sun on April 16, 1995.*

Solution: *From Figure 1801, upper meridian passage of the Sun on April 16, 1995, is given as 1200. The dividing line between the values for upper and lower meridian passage on April 16th indicates that the sign of the equation of time changes between lower meridian passage and upper meridian passage on this date; the question, therefore, becomes: does it become positive or negative? Note that on April 18, 1995, upper meridian passage is given as 1159, indicating that on April 18, 1995, the equation of time is positive. All values for the equation of time on the same side of the dividing line as April 18th are positive. Therefore, the equation of time for upper meridian passage of the Sun on April 16, 1995 is (+) 00^m05^s. Upper meridian passage, therefore, takes place at $11^h59^m55^s$.*

Day	SUN						MOON					
	Eqn. of Time				Mer. Pass.		Mer. Pass.				Age	Phase
	00^h		12^h				Upper		Lower			
	m	s	m	s	h	m	h	m	h	m	d	
16	00	02	00	05	12	00	00	26	12	55	16	○
17	00	13	00	20	12	00	01	25	13	54	17	
18	00	27	00	33	11	59	02	25	14	55	18	

Figure 1801. The equation of time for April 16, 17, 18, 1995.

To calculate latitude and longitude at LAN, the navigator seldom requires the time of meridian passage to accuracies greater than one minute. Therefore, use the time listed under the "Mer. Pass." column to estimate LAN unless extraordinary accuracy is required.

1802. Fundamental Systems of Time

Atomic time is defined by the Systeme International (SI) second, with a duration of 9,192,631,770 cycles of radiation corresponding to the transition between two hyperfine levels of the ground state of cesium 133. **International Atomic Time** (**TAI**) is an international time scale based on the average of a number of atomic clocks.

Universal time (**UT**) is counted from 0 hours at midnight, with a duration of one mean solar day, averaging out minor variations in the rotation of the Earth.

UT0 is the rotational time of a particular place of observation, observed as the diurnal motion of stars or extraterrestrial radio sources.

UT1 is computed by correcting UT0 for the effect of polar motion on the longitude of the observer, and varies because of irregularities in the Earth's rotation.

Coordinated Universal Time, or **UTC**, used as a standard reference worldwide for certain purposes, is kept within one second of TAI by the introduction of leap seconds. It differs from TAI by an integral number of seconds, but is always kept within 0.9 seconds of TAI.

Dynamical time has replaced ephemeris time in theoretical usage, and is based on the orbital motions of the Earth, Moon, and planets.

Terrestrial time (**TT**), also known as **Terrestrial Dynamical Time** (**TDT**), is defined as 86,400 seconds on the geoid.

Sidereal time is the hour angle of the vernal equinox, and has a unit of duration related to the period of the Earth's rotation with respect to the stars.

Delta T is the difference between UT1 and TDT.

Dissemination of time is an inherent part of various electronic navigation systems. The U.S. Naval Observatory Master Clock is used to coordinate Loran signals, and GPS signals have a time reference encoded in the data message. GPS time is normally within 15 nanoseconds with SA off, about 70 nanoseconds with SA on. One nanosecond (one one-billionth of a second) of time is roughly equivalent to one foot on the Earth for the GPS system.

1803. Time and Arc

One day represents one complete rotation of the Earth. Each day is divided into 24 hours of 60 minutes; each minute has 60 seconds.

Time of day is an indication of the phase of rotation of the Earth. That is, it indicates how much of a day has elapsed, or what part of a rotation has been completed. Thus, at zero hours the day begins. One hour later, the Earth has turned through 1/24 of a day, or 1/24 of 360°, or 360° ÷ 24 = 15°

Smaller intervals can also be stated in angular units; since 1 hour or 60 minutes is equivalent to 15° of arc, 1 minute of time is equivalent to 15° ÷ 60 = 0.25° = 15' of arc, and 1 second of time is equivalent to 15' ÷ 60 = 0.25' = 15" of arc.

Summarizing in table form:

1^d	$=24^h$	$=360°$
60^m	$=1^h$	$=15°$
4^m	$= 1°$	$=60'$
60^s	$= 1^m$	$= 15'$
4^s	$= 1'$	$= 60''$
1^s	$= 15''$	$= 0.25'$

Therefore any time interval can be expressed as an equivalent amount of rotation, and vice versa. Interconversion of these units can be made by the relationships indicated above.

To convert time to arc:

1. Multiply the hours by 15 to obtain degrees of arc.
2. Divide the minutes of time by four to obtain degrees.
3. Multiply the remainder of step 2 by 15 to obtain minutes of arc.
4. Divide the seconds of time by four to obtain minutes of arc
5. Multiply the remainder by 15 to obtain seconds of arc.
6. Add the resulting degrees, minutes, and seconds.

Example 1: *Convert $14^h21^m39^s$ to arc.*

Solution:

(1)	$14^h \times 15$	=	*210° 00' 00"*
(2)	$21^m \div 4$	=	*005° 00' 00" (remainder 1)*
(3)	1×15	=	*000° 15' 00"*
(4)	$39^s \div 4$	=	*000° 09' 00" (remainder 3)*
(5)	3×15	=	*000° 00' 45"*
(6)	$14^h21^m39^s$	=	*215° 24' 45"*

To convert arc to time:

1. Divide the degrees by 15 to obtain hours.
2. Multiply the remainder from step 1 by four to obtain minutes of time.
3. Divide the minutes of arc by 15 to obtain minutes of time.
4. Multiply the remainder from step 3 by four to obtain seconds of time.
5. Divide the seconds of arc by 15 to obtain seconds of time.
6. Add the resulting hours, minutes, and seconds.

Example 2: *Convert 215° 24' 45" to time units.*

Solution:

(1)	$215° \div 15$	=	$14^h00^m00^s$	*remainder 5*
(2)	5×4	=	$00^h20^m00^s$	
(3)	$24' \div 15$	=	$00^h01^m00^s$	*remainder 9*
(4)	9×4	=	$00^h00^m36^s$	
(5)	$45'' \div 15$	=	$00^h00^m03^s$	
(6)	*215° 24' 45"*	=	$14^h21^m39^s$	

Solutions can also be made using arc to time conversion tables in the almanacs. In the *Nautical Almanac*, the table given near the back of the volume is in two parts, permitting separate entries with degrees, minutes, and quarter minutes of arc. This table is arranged in this manner because the navigator converts arc to time more often than the reverse.

Example 3: *Convert 334°18'22" to time units, using the Nautical Almanac arc to time conversion table.*

Solution:

Convert the 22" to the nearest quarter minute of arc for solution to the nearest second of time. Interpolate if more precise results are required.

334° 00.00^m	=	*22^{h}16^{m}00^s*
000° 18.25^m	=	*00^{h}01^{m}13^s*
334° 18' 22"	=	*22^{h}17^{m}13^s*

1804. Time and Longitude

Suppose the Sun were directly over a certain point on the Earth at a given time. An hour later the Earth would have turned through 15°, and the Sun would then be directly over a meridian 15° farther west. Thus, any difference of longitude between two points is a measure of the angle through which the Earth must rotate to separate them. Therefore, places east of an observer have later time, and those west have earlier time, and the difference is exactly equal to the difference in longitude, expressed in *time* units. The difference in time between two places is equal to the difference of longitude between their meridians, expressed in units of time instead of arc.

1805. The Date Line

Since time grows later toward the east and earlier toward the west of an observer, time at the lower branch of one's meridian is 12 hours earlier or later, depending upon the direction of reckoning. A traveler circling the Earth gains or loses an entire day depending on the direction of travel, and only for a single instant of time, at precisely Greenwich noon, is it the same date around the earth. To prevent the date from being in error and to provide a starting place for each new day, a **date line** is fixed by informal agreement. This line coincides with the 180th meridian over most of its length. In crossing this line, the date is altered by one day. If a person is traveling eastward from east longitude to west longitude, time is becoming later, and when the date line is crossed the date becomes 1 day earlier. At any instant the date immediately to the west of the date line (east longitude) is 1 day later than the date immediately to the east of the line. When solving celestial problems, we convert local time to Greenwich time and then convert this to local time on the opposite side of the date line.

1806. Zone Time

At sea, as well as ashore, watches and clocks are normally set to some form of **zone time (ZT)**. At sea the nearest meridian exactly divisible by 15° is usually used as the **time meridian** or **zone meridian**. Thus, within a time zone extending 7.5° on each side of the time meridian the time is the same, and time in consecutive zones differs by exactly one hour. The time is changed as convenient, usually at a whole hour, when crossing the boundary between zones. Each time zone is identified by the number of times the longitude of its zone meridian is divisible by 15°, *positive in west longitude* and *negative in east longitude*. This number and its sign, called the **zone description (ZD)**, is the number of whole hours that are added to or subtracted from the zone time to obtain Greenwich Mean Time (GMT). The mean Sun is the celestial reference point for zone time. See Figure 1806.

Converting ZT to GMT, a positive ZT is added and a negative one subtracted; converting GMT to ZT, a positive ZD is subtracted, and a negative one added.

Example: *The GMT is 15^{h}27^{m}09^s.*

Required: *(1) ZT at long. 156°24.4' W.*
(2) ZT at long. 039°04.8' E.

Solutions:

(1)	*GMT*	*15^{h}27^{m}09^s*
	ZD	*+10^h (rev.)*
	ZT	*05^{h}27^{m}09^s*
(2)	*GMT*	*15^{h}27^{m}09^s*
	ZD	*–03^h (rev.)*
	ZT	*18^{h}27^{m}09^s*

1807. Chronometer Time

Chronometer time (C) is time indicated by a chronometer. Since a chronometer is set approximately to GMT and not reset until it is overhauled and cleaned about every 3 years, there is nearly always a **chronometer error (CE)**, either fast (F) or slow (S). The change in chronometer error in 24 hours is called **chronometer rate**, or **daily rate**, and designated gaining or losing. With a consistent rate of 1^s per day for three years, the chronometer error would total approximately 18^m. Since chronometer error is subject to change, it should be determined from time to time, preferably daily at sea. Chronometer error is found by radio time signal, by comparison with another timepiece of known error, or by applying chronometer rate to previous readings of the same instrument. It is recorded to the nearest whole or half second. Chronometer rate is recorded to the nearest 0.1 second.

Example: *At GMT 1200 on May 12 the chronometer reads 12^{h}04^{m}21^s. At GMT 1600 on May 18 it reads 4^{h}04^{m}25^s.*

Required: . *1. Chronometer error at 1200 GMT May 12.*
2. Chronometer error at 1600 GMT May 18.
3. Chronometer rate.
4. Chronometer error at GMT 0530, May 27.

TIME ZONE CHART

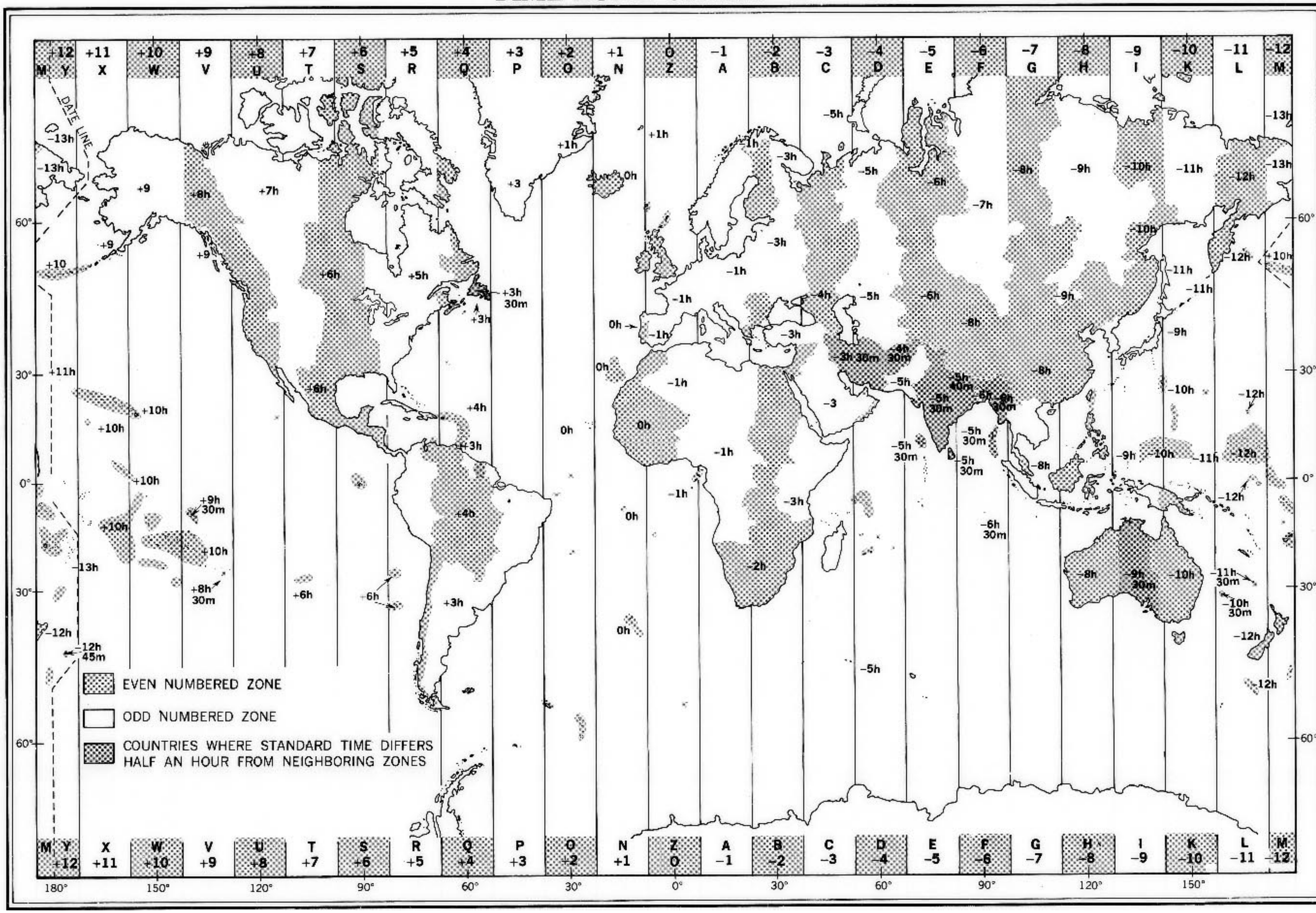

Figure 1806. Time Zone Chart.

Solutions:

1.	*GMT*	$12^h00^m00^s$	*May 12*
	C	$12^h04^m21^s$	
	CE	*(F)*4^m21^s	
2.	*GMT*	$16^h00^m00^s$	*May 18*
	C	*04 04 25*	
	CE	*(F)*4^m25^s	
3.	*GMT*	18^d16^h	
	GMT	12^d12h	
	diff.	$06^d04^h = 6.2^d$	
	CE	*(F)*4^m21^s	*1200 May 12*
	CE	*(F)*4^m25^s	*1600 May 18*
	diff.	4^s *(gained)*	
	daily rate	0.6^s *(gain)*	
4.	*GMT*	$27^d05^h30^m$	
	GMT	$18^d16^h00^m$	
	diff.	$08^d13^h30^m$ *(*8.5^d*)*	
	CE	*(F)*4^m25^s	*1600 May 18*
	corr.	*(+)*0^m05^s	*diff.* × *rate*
	CE	*(F)*4^m30^s	*0530 May 27*

Because GMT is on a 24-hour basis and chronometer time on a 12-hour basis, a 12-hour ambiguity exists. This is ignored in finding chronometer error. However, if chronometer error is applied to chronometer time to find GMT, a 12-hour error can result. This can be resolved by mentally applying the zone description to local time to obtain approximate GMT. A time diagram can be used for resolving doubt as to approximate GMT and Greenwich date. If the Sun for the kind of time used (mean or apparent) is between the lower branches of two time meridians (as the standard meridian for local time, and the Greenwich meridian for GMT), the date at the place farther east is one day later than at the place farther west.

1808. Watch Time

Watch time (WT) is usually an approximation of zone time, except that for timing celestial observations it is easiest to set a comparing watch to GMT. If the watch has a second-setting hand, the watch can be set exactly to ZT or GMT, and the time is so designated. If the watch is not set exactly to one of these times, the difference is known as **watch error (WE)**, labeled fast (F) or slow (S) to indicate whether the watch is ahead of or behind the correct time.

If a watch is to be set exactly to ZT or GMT, set it to some whole minute slightly ahead of the correct time and stopped. When the set time arrives, start the watch and check it for accuracy.

The GMT may be in error by 12^h, but if the watch is graduated to 12 hours, this will not be reflected. If a watch with a 24-hour dial is used, the actual GMT should be determined.

To determine watch error compare the reading of the watch with that of the chronometer at a selected moment. This may also be at some selected GMT. Unless a watch is graduated to 24 hours, its time is designated am before noon and pm after noon.

Even though a watch is set to zone time approximately, its error on GMT can be determined and used for timing observations. In this case the 12-hour ambiguity in GMT should be resolved, and a time diagram used to avoid error. This method requires additional work, and presents a greater probability of error, without compensating advantages.

If a stopwatch is used for timing observations, it should be started at some convenient GMT, such as a whole 5^m or 10^m. The time of each observation is then the GMT plus the watch time. Digital stopwatches and wristwatches are ideal for this purpose, as they can be set from a convenient GMT and read immediately after the altitude is taken.

1809. Local Mean Time

Local mean time (LMT), like zone time, uses the mean Sun as the celestial reference point. It differs from zone time in that the local meridian is used as the terrestrial reference, rather than a zone meridian. Thus, the local mean time at each meridian differs from every other meridian, the difference being equal to the difference of longitude expressed in time units. At each zone meridian, including 0°, LMT and ZT are identical.

In navigation the principal use of LMT is in rising, setting, and twilight tables. The problem is usually one of converting the LMT taken from the table to ZT. At sea, the difference between the times is normally not more than 30^m, and the conversion is made directly, without finding GMT as an intermediate step. This is done by applying a correction equal to the difference of longitude. If the observer is west of the time meridian, the correction is added, and if east of it, the correction is subtracted. If Greenwich time is desired, it is found from ZT.

Where there is an irregular zone boundary, the longitude may differ by more than 7.5° (30^m) from the time meridian.

If LMT is to be corrected to daylight saving time, the difference in longitude between the local and time meridian can be used, or the ZT can first be found and then increased by one hour.

Conversion of ZT (including GMT) to LMT is the same as conversion in the opposite direction, except that the sign of difference of longitude is reversed. This problem is not normally encountered in navigation.

1810. Sidereal Time

Sidereal time uses the first point of Aries (vernal equinox) as the celestial reference point. Since the Earth revolves around the Sun, and since the direction of the Earth's rotation and revolution are the same, it completes a rotation with respect to the stars in less time (about $3^m56.6^s$ of mean solar units) than with respect to the Sun, and during one revolution about the Sun (1 year) it makes one complete rotation more with respect to the stars than with the Sun. This accounts for the daily shift of the stars nearly 1° westward each night. Hence, sidereal days are shorter than solar days, and its hours, minutes, and seconds are correspondingly shorter. Because of nutation, sidereal time is not quite constant in rate. Time based upon the average rate is called **mean sidereal time**, when it is to be distinguished from the slightly irregular sidereal time. The ratio of mean solar time units to mean sidereal time units is 1:1.00273791.

A navigator very seldom uses sidereal time. Astronomers use it to regulate mean time because its celestial reference point remains almost fixed in relation to the stars.

1811. Time And Hour Angle

Both time and hour angle are a measure of the phase of rotation of the Earth, since both indicate the angular distance of a celestial reference point west of a terrestrial reference meridian. Hour angle, however, applies to any point on the celestial sphere. Time might be used in this respect, but only the apparent Sun, mean Sun, the first point of Aries, and occasionally the Moon, are commonly used.

Hour angles are usually expressed in arc units, and are measured from the upper branch of the celestial meridian. Time is customarily expressed in time units. Sidereal time is measured from the upper branch of the celestial meridian, like hour angle, but solar time is measured from the lower branch. Thus, LMT = LHA mean Sun plus or minus 180°, LAT = LHA apparent Sun plus or minus 180°, and LST = LHA Aries.

As with time, local hour angle (LHA) at two places differs by their difference in longitude, and LHA at longitude 0° is called Greenwich hour angle (GHA). In addition, it is often convenient to express hour angle in terms of the shorter arc between the local meridian and the body. This is similar to measurement of longitude from the Greenwich meridian. Local hour angle measured in this way is called meridian angle (t), which is labeled east or west, like longitude, to indicate the direction of measurement. A westerly meridian angle is numerically equal to LHA, while an easterly meridian angle is equal to 360° – LHA. LHA = t (W), and LHA = 360° – t (E). Meridian angle is used in the solution of the navigational triangle.

Example: *Find LHA and t of the Sun at GMT $3^h24^m16^s$ on June 1, 1975, for long. 118°48.2' W.*

Solution:

GMT	$3^h24^m16^s$	*June 1*
3^h	*225°35.7'*	
24^m16^s	*6°04.0'*	
GHA	*231°39.7'*	
λ	*118°48.2'* W	
LHA	*112°51.5'*	
t	*112°51.5' W*	

RADIO DISSEMINATION OF TIME SIGNALS

1812. Dissemination Systems

Of the many systems for time and frequency dissemination, the majority employ some type of radio transmission, either in dedicated time and frequency emissions or established systems such as radionavigation systems. The most accurate means of time and frequency dissemination today is by the mutual exchange of time signals through communication (commonly called Two-Way) and by the mutual observation of navigation satellites (commonly called Common View).

Radio time signals can be used either to perform a clock's function or to set clocks. When using a radio wave instead of a clock, however, new considerations evolve. One is the delay time of approximately 3 microseconds per kilometer it takes the radio wave to propagate and arrive at the reception point. Thus, a user 1,000 kilometers from a transmitter receives the time signal about 3 milliseconds later than the on-time transmitter signal. If time is needed to better than 3 milliseconds, a correction must be made for the time it takes the signal to pass through the receiver.

In most cases standard time and frequency emissions as received are more than adequate for ordinary needs. However, many systems exist for the more exacting scientific requirements.

1813. Characteristic Elements of Dissemination Systems

A number of common elements characterize most time and frequency dissemination systems. Among the more important elements are accuracy, ambiguity, repeatability, coverage, availability of time signal, reliability, ease of use, cost to the user, and the number of users served. No single system incorporates all desired characteristics. The relative importance of these characteristics will vary from one user to the next, and the solution for one user may not be satisfactory to another. These common elements are discussed in the following examination of a hypothetical radio signal.

Consider a very simple system consisting of an unmodulated 10-kHz signal as shown in Figure 1813. This signal, leaving the transmitter at 0000 UTC, will reach the receiver at a later time equivalent to the propagation delay. The user must know this delay because the accuracy of his knowledge of time can be no better than the degree to which the delay is known. Since all cycles of the signal are identical, the signal is ambiguous and the user must somehow decide which cycle is the "on time" cycle. This means, in the case of the hypothetical 10-kHz signal, that the user must know the time to ± 50 microseconds (half the period of the signal). Further, the user may desire to use this system, say once a day, for an extended period of time to check his clock or frequency standard. However, if the delay varies from one day to the next without the user knowing, accuracy will be limited by the lack of repeatability.

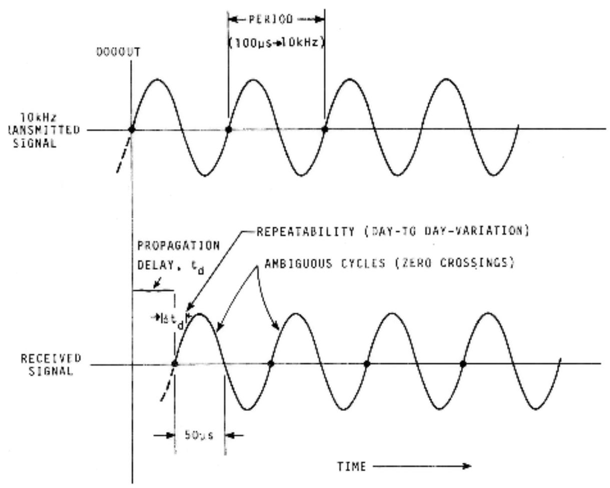

Figure 1813. Single tone time dissemination.

Many users are interested in making time coordinated measurements over large geographic areas. They would like all measurements to be referenced to one time system to eliminate corrections for different time systems used at scattered or remote locations. This is a very important practical consideration when measurements are undertaken in the field. In addition, a one-reference system, such as a single time broadcast, increases confidence that all measurements can be related to each other in some known way. Thus, the coverage of a system is an important concept. Another important characteristic of a timing system is the percent of time available. The man on the street who has to keep an appointment needs to know the time perhaps to a minute or so. Although requiring only coarse time information, he wants it on demand, so he carries a wristwatch that gives the time 24 hours a day. On the other hand, a user who needs time to a few microseconds employs a very good clock which only needs an occasional update, perhaps only once or twice a day. An additional characteristic of time and frequency dissemination is reliability, i.e., the likelihood that a time signal will be available when scheduled. Propagation fade-out can sometimes prevent reception of HF signals.

1814. Radio Wave Propagation Factors

Radio has been used to transmit standard time and frequency signals since the early 1900's. As opposed to the physical transfer of time via portable clocks, the transfer of information by radio entails propagation of electromagnetic energy from a transmitter to a distant receiver.

In a typical standard frequency and time broadcast, the signals are directly related to some master clock and are transmitted with little or no degradation in accuracy. In a vacuum and with a noise-free background, the signals should be received at a distant point essentially as transmitted, except for a constant path delay with the radio wave propagating near the speed of light (299,773 kilometers per second). The propagation media, including the Earth, atmosphere, and ionosphere, as well as physical and electrical characteristics of transmitters and receivers, influence the stability and accuracy of received radio signals, dependent upon the frequency of the transmission and length of signal path. Propagation delays are affected in varying degrees by extraneous radiations in the propagation media, solar disturbances, diurnal effects, and weather conditions, among others.

Radio dissemination systems can be classified in a number of different ways. One way is to divide those carrier frequencies low enough to be reflected by the ionosphere (below 30 MHz) from those sufficiently high to penetrate the ionosphere (above 30 MHz). The former can be observed at great distances from the transmitter but suffer from ionospheric propagation anomalies that limit accuracy; the latter are restricted to line-of-sight applications but show little or no signal deterioration caused by propagation anomalies. The most accurate systems tend to be those which use the higher, line-of-sight frequencies, while broadcasts of the lower carrier frequencies show the greatest number of users.

1815. Standard Time Broadcasts

The World Administrative Radio Council (WARC) has allocated certain frequencies in five bands for standard frequency and time signal emission. For such dedicated standard frequency transmissions, the International Radio Consultative Committee (CCIR) recommends that carrier frequencies be maintained so that the average daily fractional frequency deviations from the internationally designated standard for measurement of time interval should not exceed 1×10^{-10}. The U.S. Naval Observatory Time Service Announcement Series 1, No. 2, gives characteristics of standard time signals assigned to allocated bands, as reported by the CCIR.

1816. Time Signals

The usual method of determining chronometer error and daily rate is by radio time signals, popularly called **time ticks**. Most maritime nations broadcast time signals several times daily from one or more stations, and a vessel equipped with radio receiving equipment normally has no difficulty in obtaining a time tick anywhere in the world. Normally, the time transmitted is maintained virtually uniform with respect to atomic clocks. The Coordinated Universal Time (UTC) as received by a vessel may differ from (GMT) by as much as 0.9 second.

The majority of radio time signals are transmitted automatically, being controlled by the standard clock of an astronomical observatory or a national measurement standards laboratory. Absolute reliance may be placed on these signals because they are required to be accurate to at least 0.001^s as transmitted.

Other radio stations, however, have no automatic transmission system installed, and the signals are given by hand. In this instance the operator is guided by the standard clock at the station. The clock is checked by astronomical observations or radio time signals and is normally correct to 0.25 second.

At sea, a spring-driven chronometer should be checked daily by radio time signal, and in port daily checks should be maintained, or begun at least three days prior to departure, if conditions permit. Error and rate are entered in the chronometer record book (or record sheet) each time they are determined.

The various time signal systems used throughout the world are discussed in NIMA *Pub. 117, Radio Navigational Aids*, and volume 5 of *Admiralty List of Radio Signals*. Only the United States signals are discussed here.

The National Institute of Standards and Technology (NIST) broadcasts continuous time and frequency reference signals from WWV, WWVH, WWVB, and the GOES satellite system. Because of their wide coverage and relative simplicity, the HF services from WWV and WWVH are used extensively for navigation.

Station WWV broadcasts from Fort Collins, Colorado at the internationally allocated frequencies of 2.5, 5.0, 10.0, 15.0, and 20.0 MHz; station WWVH transmits from Kauai, Hawaii on the same frequencies with the exception of 20.0 MHz. The broadcast signals include standard time and frequencies, and various voice announcements. Details of these broadcasts are given in NIST *Special Publication 432, NIST Frequency and Time Dissemination Services*. Both HF emissions are directly controlled by cesium beam frequency standards with periodic reference to the NIST atomic frequency and time standards.

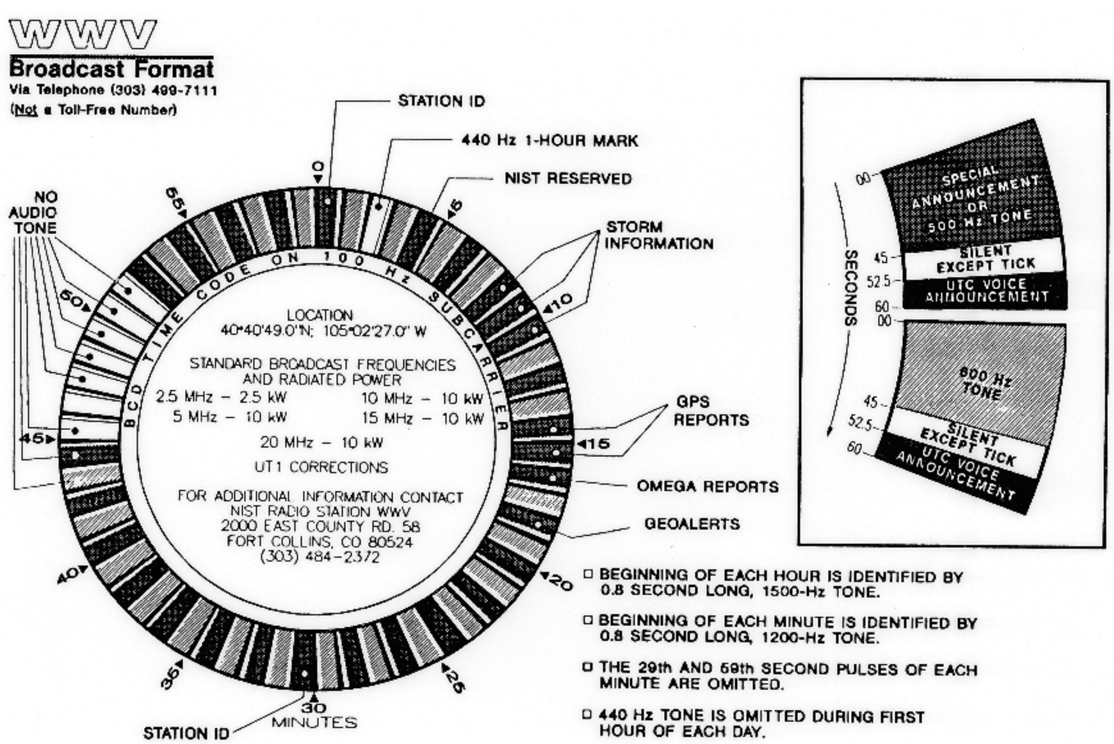

Figure 1816a. Broadcast format of station WWV.

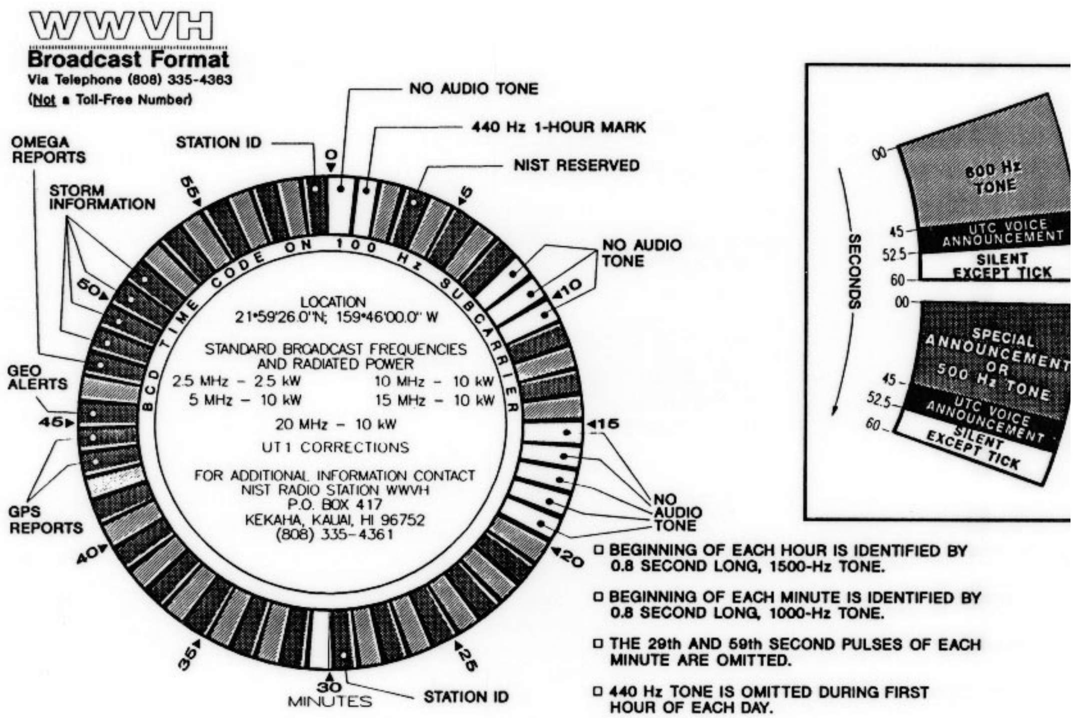

Figure 1816b. Broadcast format of station WWVH.

The time ticks in the WWV and WWVH emissions are shown in Figure 1816a and Figure 1816b. The 1-second UTC markers are transmitted continuously by WWV and WWVH, except for omission of the 29th and 59th marker each minute. With the exception of the beginning tone at each minute (800 milliseconds) all 1-second markers are of 5 milliseconds duration. Each pulse is preceded by 10 milliseconds of silence and followed by 25 milliseconds of silence. Time voice announcements are given also at 1-minute intervals. All time announcements are UTC.

Pub. No. 117, *Radio Navigational Aids*, should be referred to for further information on time signals.

1817. Leap-Second Adjustments

By international agreement, UTC is maintained within about 0.9 seconds of the celestial navigator's time scale, UT1. The introduction of **leap seconds** allows a clock to keep approximately in step with the Sun. Because of the variations in the rate of rotation of the Earth, however, the occurrences of the leap seconds are not predictable in detail.

The Central Bureau of the International Earth Rotation Service (IERS) decides upon and announces the introduction of a leap second. The IERS announces the new leap second at least several weeks in advance. A positive or negative leap

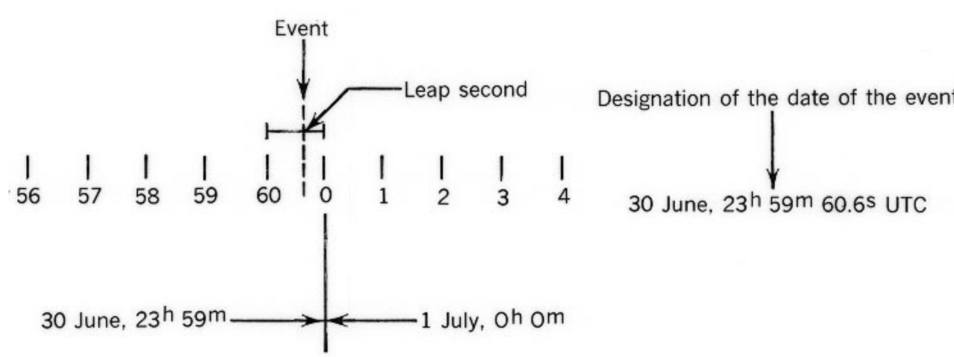

Figure 1817a. Dating of event in the vicinity of a positive leap second.

second is introduced the last second of a UTC month, but first preference is given to the end of December and June, and second preference is given to the end of March and September. A positive leap second begins at $23^h59^m60^s$ and ends at $00^h00^m00^s$ of the first day of the following month. In the case of a negative leap second, $23^h59^m58^s$ is followed one second later by $00^h00^m00^s$ of the first day of the following month.

The dating of events in the vicinity of a leap second is effected in the manner indicated in Figure 1817a and Figure 1817b.

Whenever leap second adjustments are to be made to UTC, mariners are advised by messages from NIMA.

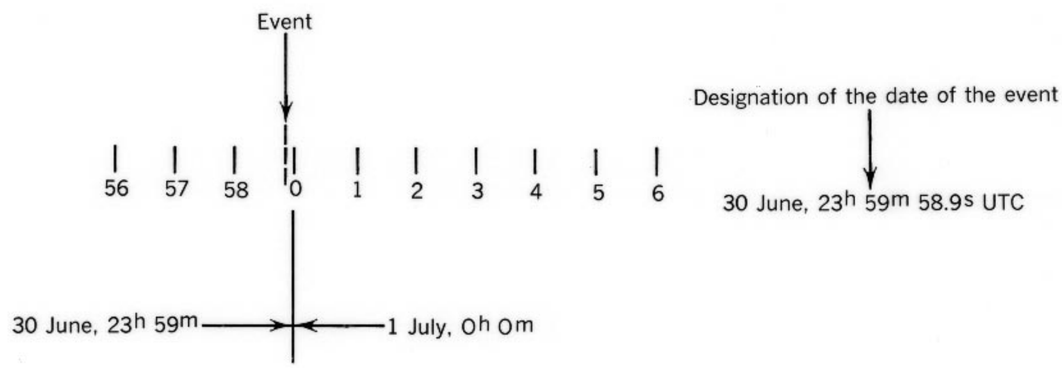

Figure 1817b. Dating of event in the vicinity of a negative leap second.