TIME AND TIME FREQUENCY STANDARDS[1]

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ABSTRACT

In astronomical surveying time is an important element that is considered in the determination of longitude, latitude and azimuth. The various time scales may cause confusion, thus, the relationship of these different time scales is explored. These include solar and universal time, sidereal time, and ephemeris time. Another important scale is atomic time and its use as the standard is reviewed.

INTRODUCTION

In astronomical surveying, time is a very important element. If we recall the celestial coordinates, we know that they are subject to change over time. Mueller (1969) separates different time systems into three classifications based upon the natural phenomenon that generates time. The rotational time system includes sidereal and solar time and is based on the rotation of the earth. Ephemeris time is dependent upon the revolution of' the planets about the sun. Finally, atomic time is generated by the oscillation of an atom, for example the cesium atom.

When the position of objects are referenced to some coordinate system, its normal practice to define their position by some prefix i.e. observed place, apparent place, true place, and mean place. When reference is made to the true place, it is referred to the true equator and equinox. The mean place is referenced to a specified mean equator and equinox. Both positions refer to the barycentric position, which is the center of mass of the solar system. The difference between true and mean place is due to nutation. Both are affected by precession

SIDEREAL TIME

Sidereal time is related directly to the rotation of the earth by referencing this scale to the relative position of the stars as they relate to the rotation of the earth. The sidereal day is the interval between two successive upper transits of the vernal equinox over the

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meridian. Roelofs (1950) outlines the motions that affect the mean vernal equinox. These motions are due to diurnal rotation, luni-solar precession and planetary precession. The mean sidereal day would be the same as the earth's rotation if only diurnal rotation is considered The effect of precession is to speed up the motion thus sidereal time is shorter than the rotational period of the earth.

Apparent Sidereal Time (AST) is the local hour angle of the true vernal equinox. Greenwich Apparent Sidereal Time (GAST) is the local hour angle of the true vernal equinox that is referenced to the Greenwich Mean Astronomic Meridian (Figure 1). The mean positions are similar except that they are referenced to the mean vernal equinox. Hence, the local hour angle of the mean vernal equinox is called Mean Sidereal Time (MST) and when this hour angle is referenced to the Greenwich Mean Astronomic Meridian we have Greenwich Mean Sidereal Time (Figure 1).

From Figure 1, it is evident that we can write the following relationships:

$$\left.\begin{aligned} \mathrm{MST} &= \mathrm{GMST} + \Lambda \\ \mathrm{AST} &= \mathrm{GAST} + \Lambda \end{aligned}\right\} \qquad (1)$$

or

$$\Lambda = \mathrm{MST} - \mathrm{GMST} = \mathrm{AST} - \mathrm{GAST} \qquad (2)$$

where Λ is the longitude of the observer.

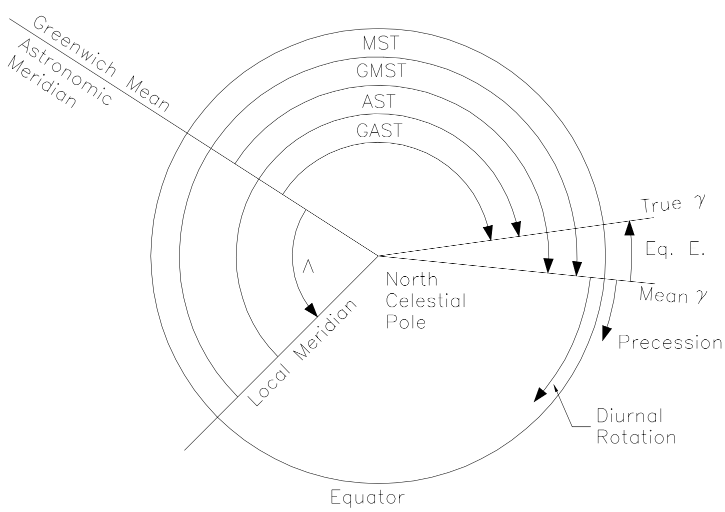

Figure 1. Sidereal Time Relationships

The difference between mean and true sidereal time is the equation of the equinox (referred to as the nutation in right ascension by Roelofs). This is given by the following

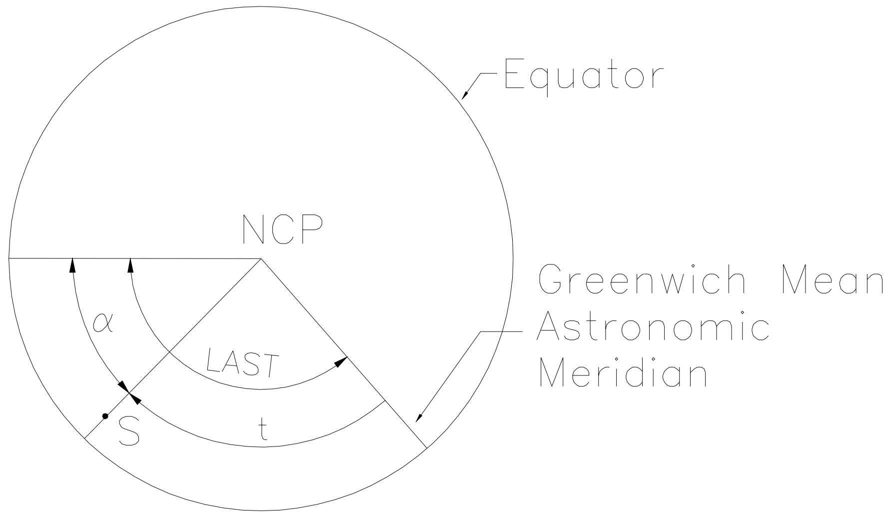

Figure 2. Relationship between LAST and right ascension.

$$\text{Eq. E.} = AST - MST = GAST - GMST \tag{3}$$

Some authors also refer to Local Sidereal Time (Roelofs, 1950). .This is the same as the Greenwich Sidereal time scale except that the hour angle is referenced to the observer's meridian. Another important relationship is shown in figure 2 which is based on the property that the vernal equinox's hour angle is equal to the right ascension (α) of the object. Hence,

$$LAST = \alpha + t \tag{4}$$

SOLAR TIME

Solar time is related to the motion of the **s**un. True Solar Time (TT), also known as Local Apparent Time or Apparent Solar Time (Nassau, 1948) is related to the local hour angles of the true sun (figure 3). Thus**,**

$$TT = h_S + 12^h \tag{5}$$

where h_S is the hour angle of the true sun and 12 hours is added to make solar time coincident with civil time. Therefore, the interval is two successive lower transits of the sun over the meridian. If the hour angle is referenced to the Greenwich Mean Astronomic Meridian then we have Greenwich Apparent or True Time (GTT).

$$GTT = h + 12 \tag{6}$$

Unlike the motions that affect the vernal equinox, the motion of the sun is affected by an annual motion along the ecliptic. This is implied in Kepler's second law Mueller 1969). The motion is non-uniform and it takes place near the ecliptic and not parallel to the equator. This makes the use of the true sun as a timekeeper unsuitable. It is replaced by a "fictitious" or mean sun.

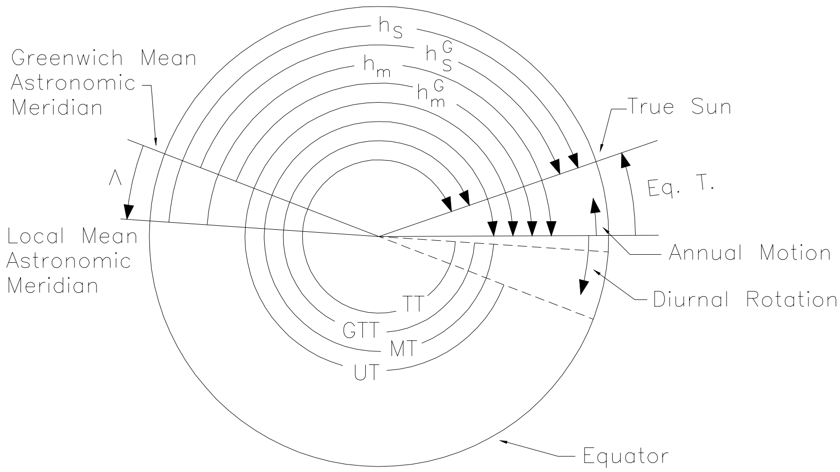

Figure 3. Solar time relationships. (Annual motion refers to the annual motion which is in the ecliptic)

The mean sun consists of a uniform motion along the equator which is nearly the same as the mean rate of the annual motion of the sun along the ecliptic. The time system based on This mean sun is called Mean Solar Time (MT) or Local Civil Time (Nassau, 1948) or Local Mean Time (Mackie, 1978) and is defined as

$$MT = h + 12 \tag{7}$$

where the hour angle is that of the mean sun. If the hour angle is referenced to the Greenwich Mean Astronomic Meridian the time is referred to as Greenwich Mean (Solar) Time or more commonly as Universal Time (UT),(figure 3). UT is defined as

$$UT = h_m^G + 12^h \tag{8}$$

The difference between the mean and true sun is called the equation of time and is shown by

$$\left.\begin{aligned} Eq.\,T. &= TT - MT = GTT - UT \\ &= h_S - h_m = h_S^G - h_m^G \end{aligned}\right\} \quad (9)$$

The relationship between sidereal time and solar time is shown in figure 4.

Since the rotation of the earth is subject to variations which are periodic, seculr, and irregular, UT is also subject to these variations. When left uncorrected, then UT is designated as UT0 and is equavalent to mean solar time at Greenwich. Hence, UT0 is found directly through observations. Barnes (in Blair, 1974) explains that as clocks become better timekeepers, a discrepancy developed in the measurement of UT at various locations. It was found that the cause of this difference was due to the phenomenon that the earth wobbles on its axis which is referred to as polar motion. Thus, UT1 is corrected for polar motion and yields the true angular rotation of the earth about its axis. The effect of this wobble is shown in figure 5. As clocks improved, periodic fluctuations in UT1 were discovered. Periods of one-half year and one year for these fluctuations were observed One possible explanation (Hewlett Packard, 1974) is the seasonal displacement of matter on the earth's surface Due to movement of the sun from the southern hemisphere to the northern hemisphere, changes in the amount of ice in the polar regions occurs. This may be significant enough to affect the earth's rotation. Therefore, UT2 removes these fluctuations and it is at present the most uniform system for universal time that we have.

EPHEMERIS TIME

Observations of objects using Universal Time are subject to deviations that affect the rotation of the earth. Thus, for an absolute time scale, it is inappropriate. While atomic clocks provide a very precise uniform scale, their use over a long time period is not possible due to variation in the frequency rate and due to the possibility of stoppage. Simon Newcomb expressed the function of time through the variation in the celestial mean longitude of the sun. The Ephemeris second therefore is reflected in the changes of the longitude of the sun and, if the solar theory is correct, then, the Ephemeris Time scale is uniform. The second is defined as "the fraction 1/31,556,925.9747 of the tropical year for 12 hours E.T. of January 0, 1900" (Rice, 1959). This is in reference to the fictitious mean sun. Hence, the tropical year is that in which the sun maintained its apparent instantaneous rate. It is corrected for eccentricity of the orbit and nutation.

In 1967, the General Conference on Weights and Measures adopted as a value for the Ephemeris second the transition between two energy levels of the atom Cesium 133 (Hewlett Packard, 1974). Thus, a relationship between Ephemeris and Atomic times are possible. Mueller gives this relation as:

$$\mathrm{AT} - \mathrm{ET} = a + bt + ct^2 \tag{10}$$

where t cis the time epoch when

$$\mathrm{AT} = \mathrm{ET} + \alpha \tag{11}$$

The coefficients are defined as;

a = atomic time epoch as related to Ephemeris Time,
b = adopted ratio for the atomic resonator, and
c = a constant.

In practice, it is the moon upon which we make our Ephermeris time determination. Because the earth/moon distance is relatively small, and because the motio is not Newtonian, Ephemeris Time is not often employed in surveying.

ATOMIC TIME

The third calss fo time system is based on some baic proerties of the atom. The XII General Conference of Weights and Measures defined the second as “the duration of 9,192,631,770periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of thecesium atom 133” (Hewlett Packaard, 1974). It is emperically related to Universal Time sicne the Atomic Time epoch of $0^h\ 0^m\ 0^s$ was fixed when UT2 was $0^h\ 0^m\ 0^s$ on January 1, 1958. This was the initail epoch adopted for the atomic time system of the U.S. Naval Observatory in Washington. This system, designated as A.1, consists of comparing porable cesium beam oscillators to a number of laboratory systems throughout the world. Since there are other atomic time systems, their initial adopted epoch can vary from the initial epoch given above.

Many broadcast signals are given in a time scale called Coordinated Universal Time (UTC). Initially, this scale was offset from the atomic time rate. In 1972, the new UTC system was adoted by the international community so that its rate coincided with that of the atomic standards. This agreement stipulated that UTC was to be maintained with UT1 (thetrue angualr rotation of the earth)to within 0.9 seconds (Howe, 1976). Since the atomic clock will have a constant rate trhroughout the year while the rotation of the earth varies, it is necessary to occasionally advance or retard UTC to keep it in line with UT1. This change is called a “leap second”. This can only be done at two different times during the year. Therefore, the “last minute” on June 30 or December 31 may contain 59, 60, or 61 seconds depending on whether the UTC scale is to be changed or maintained at its present rate.

Some users may require knowledge of UT1 to a greater accuracy than 0.9 seconds. This information is readily available through WWV broadcasts. Corrections are given in 0.1 sedond icrements by emitting double ticks at the beginning of each minute. If the 1^{st} through 8^{th} second ticks employ double ticks then the number of double ticks beginnin with the first second tick indicates a plus correction to the nearest 0.1 second. If the double ticks occur from the 9^{th} to the 16^{th} second then it is a negative correction.

CONCLUSION

The relationship between the three classifications of time scales shows that no exact formula can be derived from which conversion form one system to another can be performed. This is due to the different phenomenon upon which they are defined. The relationships are strictly emperical, set by agreement. On the otherhand, conversion from solar to sidereal time is based on formulae that can be derived from the relationships that exist. For examples on converions see Mueler (1965) or Makcie (1978).

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