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This report presents the results of a program directed to the implementation of a time standard system to be used with a PDP-11/45 digital controller for the purpose of directing a ground-based satellite tracking antenna. The function of the time standard system is to present, on command, absolute time-of-day information to the PDP-11/45 which is subsequently used in conjunction with memory-stored, satellite orbital parameter data to generate

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antenna steering signals. To ensure the required antenna pointing accuracy, the absolute time information must be correct to within 100 milliseconds of the primary standard maintained by the National Bureau of Standards (NBS).

The time standard system consists primarily of (1) a WWVB receiver and associated antenna for reception of the time-coded radio transmission from the NBS station at Fort Collins, Colorado and (2) a time code generator which accepts the amplified WWVB signal and then presents the time information in the form of both a front panel numerical readout and in a digital format suitable for use by the PDP-11/45 digital controller.

The time standard system also included the capability of being interfaced with a Georgia Tech owned HP-2100 data acquisition system. This interface capability provided a means for test and evaluation of the time standard system prior to its use with the PDP-11/45 digital controller. The system test also included a determination of the reliability and long-term synchronization pattern of the time code generator to the received WWVB time standard signal.

FOREWORD

This report was prepared by the Engineering Experiment Station at Georgia Tech under Contract No. F33615-75-C-1222. The work described was performed in the Electronics Technology Laboratory and was conducted under the general supervision of Mr. R. W. Moss, Head of the Communications Technology Group, and Mr. C. S. Wilson, Project Director. The report summarizes the objectives, activities and results of a program to develop a time standard system to be used in conjunction with a PDP-11/45 digital controller for use in directing satellite antenna tracking.

In the Communications Technology Group the contributions of Messrs. G. M. Hitchcock and L. A. Jackson are acknowledged. The overall guidance of Mr. David E. Muench and LT Paul F. Humel of the Air Force Avionics Laboratory is also acknowledged.

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SECTION I

INTRODUCTION

Present day technology requires the availability of precision, absolute time information for numerous scientific applications. These applications cover such areas as precision frequency and time measurements, multiple link data communication systems, navigation, and astronomical studies and measurements. One specific need for precision time information is in tracking orbiting satellites with a narrow beam antenna. Even when the satellite is "synchronous", the need still exists unless the inclination of the orbital plane is very small. The term synchronous implies only that the satellite maintains station above a meridian. If the inclination of the orbital plane is other than zero, the satellite will oscillate north and south above the meridian. When the inclination angle is high, the apparent velocity can be high. For an orbital inclination of 45°, north-south velocities in excess of 100 km/min occur.

Since satellites operate with limited power, a reliable communication relay through a satellite repeater calls for a very high gain antenna with its attendant narrow beam width. Ground-based antennas with beam widths of the order of 0.1° are commonly used for this purpose. Such antennas require very precise pointing at any instant; the pointing aspect thus becomes a function of time because of satellite motion. Accurate orbital data describing the position in space are available for each satellite. Successful tracking requires an antenna direction controller which can direct the antenna at any given position along with accurate time information so that the instantaneous position will be known. It is toward design and assembly of a precision time standard system for use as a part of an antenna controller that this program has been directed.

This report describes the assembled instrumentation package for providing absolute time-of-day information to an accuracy of better than 100 milliseconds and maintaining that accuracy by synchronization of a time code generator with the WWVB radio signal transmitted by the National Bureau of Standards, Fort Collins, Colorado.

This report is divided into five sections. Following this introductory section, Section II presents a brief tutorial review of the concept of time with discussions of such specific areas as sidereal, universal, emphemeris, and atomic time. Section III discusses time standards and their expected accuracies and drift specifications; the relationship between drift and accurate timekeeping is also noted. Section IV discusses the various problems associated with time distribution techniques and the techniques and methods available for accurate timekeeping on a local basis. Section V is a discussion of the finalized time standard system for use with the satellite antenna controller. System requirements, system description, and system performance are included as a part of this final section.

Three appendices at the end of the report present (1) a partial listing of time standard radio stations, (2) the time-of-day program for the HP-2100 data acquisition system, and (3) an addendum to the time code generator interface circuitry.

SECTION II

MEASUREMENT OF TIME

1. INTRODUCTION

Man has for many centuries attempted to devise techniques for accurately measuring time. A primary thrust of this effort has been directed to finding an ideal time reference; one which would provide both a uniform time scale and allow for accurate extrapolation to very small intervals or, in the opposite direction, to extended periods of time.

Since man's activities are based on the succession of night and day, it naturally follows that time scales have historically been determined by the apparent movement of the sun with respect to the earth. A number of different time scales have been devised which are based on this earth-sun relationship. The most fundamental time scale is, of course, based on the required interval for the sun to successively reappear at the same point above the earth. This time interval, however, does not account for irregular variations in the period of revolution of the earth around the sun. Other methods for measurement of time were, therefore, required to account for these variations and have resulted in the adoption of a number of successive and co-existent time scales during the past hundred or so years.

Recently, because of the need for increased accuracy in the measurement of time, the atomic second was adopted as a new standard; this is the first standard not based on astronomical observations. The atomic second is based on the precise interval of an atomic transition between different energy levels of a specific element such as cesium. This atomic standard provides the accuracy required for numerous scientific endeavors and is widely used throughout the world today.

2. SOLAR TIME

Apparent Solar Time

Apparent solar time can be defined as the interval required for the sun to successively reappear over a fixed point on the earth. Thus, an apparent solar day is dependent upon the motion and orientation of the earth and the position of the sun. If the earth's orbit were a perfect circle and the plane of the orbit corresponded to the earth's equatorial plane and, further, if the period of rotation were constant, then the length of an apparent solar day would remain essentially constant throughout the year.

Because the earth's orbit is elliptical rather than circular and, in addition, since the orbital plane is at an angle of 27.45 degrees rather than vertical, the length of a day varies during the yearly cycle of the earth's revolution about the sun. The earth, as viewed from the sun, moves faster when the earth is on that portion of its elliptical orbit that brings it closest to the sun. The difference between apparent solar time and mean solar time is the integral of time as the sun crosses a reference meridian throughout the year. This integral is called the equation-of-time and achieves a maximum value of about 16 minutes in November.

Mean Solar Time

Mean solar time is defined as the average length of all solar days in a solar year. This averaging eliminates the effects of incremental time variations that exist because of the orbital eccentricity and axis tilt of the earth. A more fundamental unit of time, the mean solar second, is equal to the mean solar day divided by 86,400. As a fundamental unit of time, the mean solar second is still not adequate because it remains tied to the non-uniform rotation of the earth.

A solar year is the time interval required for the earth to make one complete revolution of the sun and is defined by observing the period from Vernal Equinox-to-Vernal Equinox. Vernal Equinox occurs about March 20 and is the time when apparent motion of the sun causes the sun to move from the southern hemisphere to the northern hemisphere. This apparent path of the sun is called the ecliptic and is inclined at an angle of 27.45 degrees to the equatorial plane of the earth. A solar year is equal to 365.2422 mean solar days.

Since a solar year is not exactly 365 days, corrections must be made to our calendar at regular intervals in order that the Vernal Equinox will continue to occur on about the same calendar day from year to year.

3. UNIVERSAL TIME

There exists several forms of universal time, these being designated as UT_0, UT_1, UT_2, and UTC.

Universal time is based on the rotation of the earth about its axis with the assumption that this rotation is a constant; recall that solar time is based on the earth's orbit about the sun. This time scale was chosen so that on the average local noon would occur when the sun was directly above the local meridian. However, since the earth's rotation is not a constant, the most basic form of universal time, UT_0, is subject to the same variations as mean solar time; and, in fact, if uncorrected, UT_0 units are equivalent to the mean solar second.

The need for a corrected universal time subsequently led to two additional forms of universal time: UT_1 and UT_2. UT_1 provides for a time correction required because of the earth's polar motion. UT_2 carries the correction process an additional step by accounting for seasonal variations that effect the earth's rotation. These seasonal variations are apparently caused by a shift or displacement in matter across the surface of the earth. Most notable is the reduction in the size of the ice pack at one pole that occurs simultaneously with an increase in the mass of the ice pack at the opposite pole.

Coordinated Universal Time (UTC) represents the latest step toward establishing an international time scale. UTC is essentially a step-time adjustment process that has seen two forms of implementation. Prior to 1 January 1972, the frequency of precision oscillators (controlled by atomic standards) in time standard laboratories, such as NBS, were periodically offset to maintain synchronism with UT_2. These periodic offsets or step-time adjustments were typically on the order of 150 to 300 parts in 10^{10}

and occurred at intervals ranging from one to four times a year. By international agreement, worldwide adjustment of these atomic controlled clocks was performed simultaneously; thus, the term Coordinated Universal Time.

Then, beginning on 1 January 1972 the UTC system was improved by allowing UTC time to accumulate at the same rate as International Atomic Time. The improved UTC time is allowed to accumulate until UTC is offset from UT_1 by $\pm$ 0.7 seconds. A leap second is then introduced on the last day of a UTC month, preferably 31 December and/or 30 June. The next leap second is scheduled to occur on 31 December 1975. At that time a positive leap second will be accomplished as follows:

31 December 1975	23 hours, 59 minutes, 59 seconds
31 December 1975	23 hours, 59 minutes, 60 seconds
1 January 1976	0 hours, 0 minutes, 0 seconds

4. ASTRONOMICAL TIME

Because of a need to realize a more accurate time keeping system than is available with solar time, several astronomical time scales have been formulated that are based on the relative motion and position of the stars and other celestial bodies. Sidereal and Emphemeris are the two astronomical time scales that are in present use.

Sidereal time is based on the relative positions of the earth, sun, and a given star. A sidereal year is the interval required for the earth to move from a specific alignment between a given star and the earth, as seen from the sun, to the same position of alignment again.

A sidereal "day" consists of 24 sidereal hours with each divided into 60 minutes and the minutes divided into 60 seconds. However, in mean solar time a sidereal day is about 23 hours, 56 minutes, and 4.03 seconds which accumulates to a difference of about 0.24 days per year. The difference between sidereal time and mean solar time is primarily due to the earth's variable orbital motion about the sun and the motion of the equinox.

Ephemeris time is similar to sidereal in that time measurements are based on orbital movements of other celestial bodies in addition to the earth and sun. An ephemeris is a set of numbers that describes the position of an orbiting body as a function of time and is determined by application of Newtonian Theory. The work of Newcomb, around the turn of the century, in predicting future planetary positions formed the basis for establishment of an Ephemeris time scale.

In practice, Ephemeris Time is based on the orbital motion of the moon by observing its position with respect to the stars. The Ephemeris second has, by international agreement, been defined as "1/31,556,925.9747 of the tropical year, for January 0, 1900 at 12 hours", which is equal to 24 hours, 0 minutes, 0 seconds Universal Time on 31 December 1899.

A salient fact in regard to the Ephemeris Time scale is that celestial bodies are in repeatable astronomical relationships for successive years.

5. INTERNATIONAL ATOMIC TIME

In October 1967 the International Atomic Second (TAI) was formally adopted by the XIII General Convention of Weights and Measures. This formal action based the definition of the atomic second on the invariant transition in the cesium atom.

The agreed upon definition of an atomic second was "the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium atom 133."

The adoption of an atomic standard for the measurement of time resulted in several advantages over the more conventional astronomical methods. First, the absolute accuracy is greater than is realizable by astronomical techniques; and, further, a degree of time measurement accuracy could now be accomplished within a few minutes that formally required an extended averaging period to achieve by conventional means.

The atomic second is closely related to the mean solar second since man's most basic time reference continues to be the period of the earth's orbital path about the sun. The atomic second is as close to agreement to Ephemeris time as is experimentally possible to determine.

Although formally adopted in 1967, International Atomic Time was made retroactive to 1 January 1958 so that it would always correspond to the start of UT_2 time. On that first day of January the epoch of both Atomic Time and UT_2 time was 0 hours, 0 minutes, and 0 seconds.

6. STANDARD TIME

In 1884, by international agreement, a worldwide time reckoning system was established that would, on the average, cause local noon to occur when the sun was directly above the local meridian. Time zones were established at 15 degree longitudinal intervals with "zero time" (midnight) at the Prime Meridian (0 degrees longitude) which passes through Greenwich, England. Time zones in the United States are roughly centered on the longitudes of 75, 90, 105, 120, 135, 150, and 165 degrees. Longitudes 135, 150, and 165 are in the meridians which pass through Alaska.

In the United States, as well as the rest of the world, the meridian time zones are modified for political and geographical considerations.

SECTION III

TIME STANDARDS

1. INTRODUCTION

Because of an ever increasing need for greater accuracy in time and frequency measurements, considerable effort has been directed to attaining precision standards to meet these demands. A time standard must have correlation with a time scale that is based on the yearly cycle of the earth's path around the sun since man's activities are based on this event. This correlation does exist, as noted in Section II.4, in that the atomic second is within as close to agreement to Ephemeris time as is experimentally possible to determine. Basically, Ephemeris time is a large (one year) increment of time; however, the need exists for measurement of much smaller increments, e.g., second and sub-second intervals, and precision time standards fulfill this need.

Prior to the advent of atomic frequency standards, crystal controlled oscillators served as primary standards. Quality crystal oscillators are capable of achieving frequency accuracies of a few parts in 10^{10} per day. Crystal oscillators are subject to long term drift, however, and as a result, this error accumulation must be noted or the frequency must be periodically adjusted to maintain the required agreement with universal time.

Crystal oscillators are now considered as secondary standards with the atomic clocks being primary standards. Crystal oscillators still offer an advantage over atomic standards in improved spectral purity and short term stability.

2. ATOMIC STANDARDS

Since 1964, the basis for timekeeping in the United States and throughout most of the world has been the Atomic Standard. Atomic standards, or clocks, use the transitional energy states that occur in matter with particular emphasis on elements whose energy transitions occur at rates corresponding to microwave frequencies.

Considerable attention has been directed to three devices: the cesium beam tube, the rubidium gas-cell resonator, and the hydrogen maser. Other devices such as the methane stabilized laser, the ammonia maser, and the rubidium gas-cell maser have also been investigated for use as atomic standards. The methane stabilized laser offers the advantage of high spectral purity but a disadvantage of operating in the infrared region. The ammonia maser and the rubidium gas-cell master both exhibit excellent spectral purity characteristics but, at present, are physically large and very costly.

The cesium beam tube and the hydrogen maser atomic standards find considerable use in present day technology with the cesium standard being the most widely used. Both of these devices are considered absolute standards and as such do not require a reference to ensure their accuracy.

Since the energy transitional levels in an atomic clock are invariant, drift or aging rates are, for all practical purposes, non-existent. For a cesium beam standard the manufacturer will typically specify the drift as "negligible". An accuracy specification will be given and refers to the time variance between the atomic clock as supplied by the manufacturer and a primary standard located at one of the international time standard laboratories. A typical accuracy specification is $\pm$ 7 parts in 10^{12}. Two additional important specifications relate to reproducibility and settability with typical values of $\pm$ 3 parts in 10^{12} and $\pm$ 1 part in 10^{13}, respectively. Reproducibility is the degree to which the standard will produce the same frequency from one occasion to another whereas settability describes how closely the clock frequency can be adjusted to a primary standard.

In a cesium standard, the atoms leave a cesium oven and are subsequently formed into a beam by a magnetic field and pass through a microwave cavity where they are subjected to excitation by microwave energy derived by frequency multiplication of a crystal oscillator. The beam, after passing through the cavity, impinges on a mass spectrometer and electron multiplier. The mass spectrometer serves to filter out noise bursts. The electron multiplier converts the ion current to an electronic current and provides signal amplification. This resultant electron current serves to control the frequency of the crystal oscillator in a closed-loop feedback configuration.

Use of a crystal oscillator as an integral part of a cesium standard acts to provide both an output signal with excellent spectral purity and short term stability and to make available a much lower and easier to use frequency than the inherent microwave frequency present within the cavity resonator.

The quartz oscillators used in atomic standards exhibit superior stability characteristics even when not phase-locked to the atomic resonator. Typical drift rate is 5 parts in 10^{10} for 24 hours with short-term stabilities on the order of 5 parts in 10^{12} over a one-second averaging time.

3. CRYSTAL OSCILLATORS

As stated in Section III.1, crystal controlled oscillators served as primary frequency standards prior to the development of atomic standards. Although the crystal controlled oscillator has been relegated to the role of a secondary standard, it still finds very wide use because of low cost (compared with an atomic standard), small size, portability, and good frequency stability.

The state-of-the-art in crystal oscillators has continued to advance even since atomic standards assumed the major role of precision timekeeping. The major emphasis in crystal oscillator technology has been directed to (1) improved cutting, mounting and sealing techniques, (2) improved circuit design to achieve a low and constant crystal drive power, and (3) increased precision in temperature control techniques. Improved techniques in these three areas have not only increased the short-term stability characteristics of quartz crystals but have also improved the long-term drift or aging rate. Aging rate is usually most pronounced during the period immediately following manufacture and tends to decrease toward some small constant value within several weeks. Both manufacturing techniques and subsequent oscillator circuit design are controlling factors in determining the aging rate characteristics.

When a crystal controlled oscillator is used as the time base for a digital clock or time code generator, then long-term drifts in the resonant frequency will introduce error into the time reading. The sources of error in a crystal controlled oscillator are primarily the result of (1) long-term drift and (2) environmental effects, most notably temperature changes. The accumulated time error over a specific period is determined by:

$$E_t = 1/2\ R_d \cdot T^2 \qquad (1)$$

where R_d is the drift rate and T is the time period. As an example, if the drift rate specifications of a crystal oscillator are given as 10 parts in 10^{10} per day, then the accumulated error will be

$$E_t = 1/2 \left\{ \frac{10 \times 10^{-10}}{86,400} \right\} (86,400)^2$$

$$= 43.2 \text{ microseconds per day.}$$

This time error accumulates to 2.12 milliseconds after one week and 38.9 milliseconds if averaged over a one month period.

When a crystal oscillator is used as the time base for a time code generator, an additional source of error is due to the time setting accuracy. This source of error is a result of the base frequency (usually 1 or 5 MHz) not being initially set to the correct value. For this form of offset the accumulated error will increase linearly as a function of time.

The effects of both drift error and setting error as a function of time are presented in the graph of Figure 1.

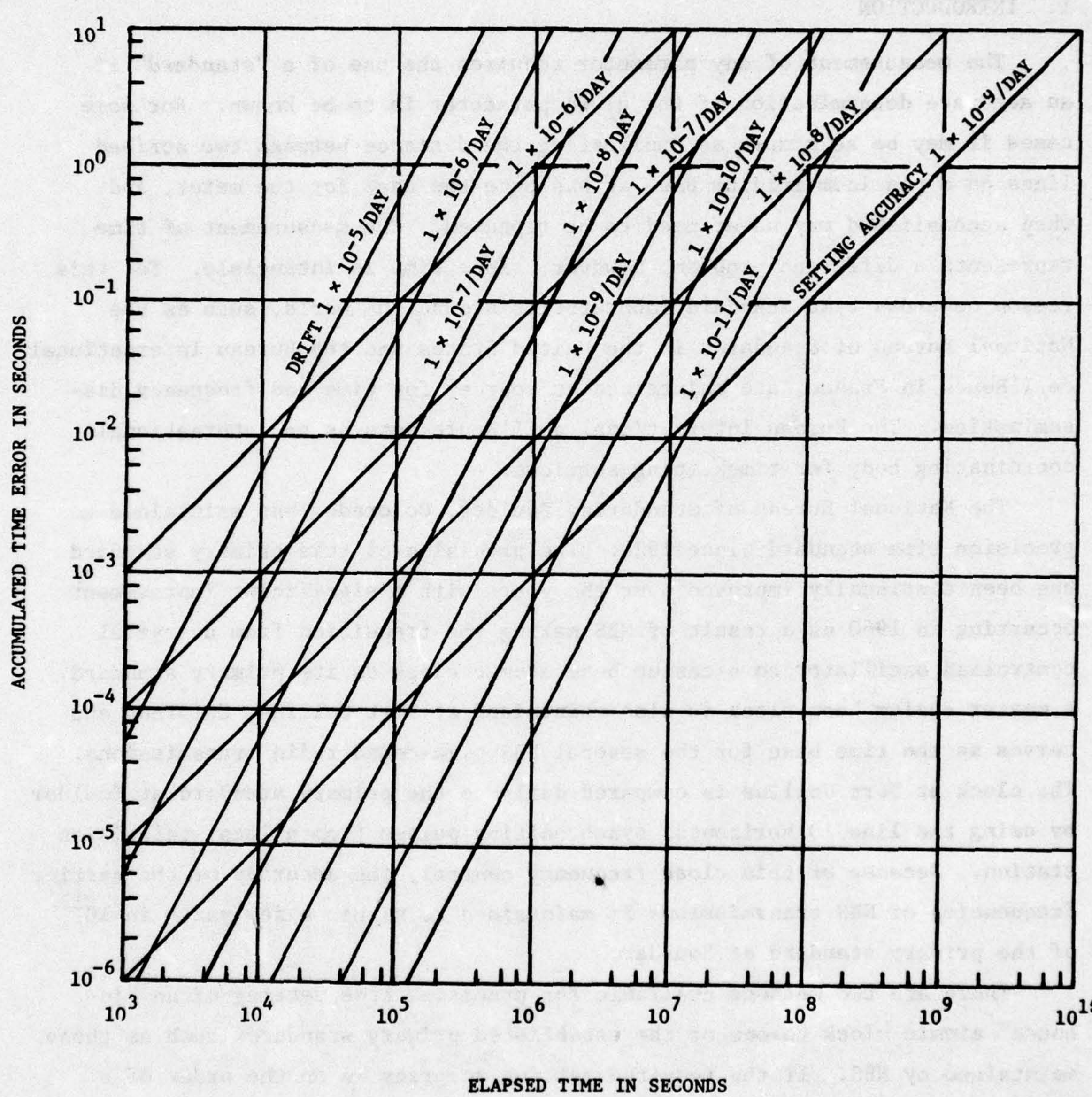

Figure 1. Accumulated Time Error for Various Aging and Time Setting Specifications.

SECTION IV

TIME DISTRIBUTION TECHNIQUES

1. INTRODUCTION

The measurement of any parameter requires the use of a "standard" if an accurate determination of the given parameter is to be known. For some cases it may be as simple as duplicating the distance between two scribed lines on a platinum-iridium bar, as was once the case for the meter, and when accomplished may never need to be repeated. The measurement of time represents a different problem, however, since time is intangible. For this reason numerous time standard laboratories around the world, such as the National Bureau of Standards in the United States and the Bureau International de I'Heure in France, are maintained as sources for time and frequency dissemination. The Bureau International de I'Heure acts as an international coordinating body for timekeeping services.

The National Bureau of Standards, Boulder, Colorado, has maintained a precision time standard since 1920. The precision of this primary standard has been continually improved over the years with a significant improvement occurring in 1960 as a result of NBS making the transition from a crystal controlled oscillator to a cesium beam atomic clock as its primary standard. A master cesium beam clock is also maintained at Fort Collins, Colorado and serves as the time base for the several NBS time-coded radio transmissions. The clock at Fort Collins is compared daily to the primary standard at Boulder by using the line-10 horizontal synchronizing pulses from a local television station. Because of this close frequency control, the accuracy of the carrier frequencies of NBS transmissions is maintained to within a few parts in 10^{11} of the primary standard at Boulder.

There are two methods available for precision time setting of an "in-house" atomic clock to one of the established primary standards such as those maintained by NBS. If the required setting accuracy is on the order of a microsecond or better, it is necessary to physically transport the in-house clock to a primary standard for direct comparison. When the permissible tolerance on accuracy is on the order of milliseconds, however, the simpler technique is to make use of one of the several radio broadcasts that carry precise time information. Among the broadcasts in this category are those from the National Bureau of Standards stations and transmissions on LORAN and OMEGA navigation systems.

Thus, the method selected for precision time setting of the in-house standard will be determined simply by the required accuracy.

2. HIGH PRECISION TIME DISTRIBUTION

For timing accuracies greater than a few milliseconds reception of radio propagated time signals will not suffice. For high precision time setting requirements it becomes necessary to physically transport the local clock to a primary time standard. Such a task is done on a fairly widespread basis and is generally referred to as "flying the clock".

In one particular flying clock experiment [1] two cesium beam standards were flown to 53 locations in 18 countries for the purpose of time correlating all clocks at these locations. Prior to the trip the two cesium beam clocks were phase-compared to an in-house primary standard. One clock was determined to have no offset while the other clock was within one-to-two parts in 10^{13} of the primary standard. On completion of the 41-day trip the two flying clocks were found to be within 5 parts in 10^{13} of each other and within 10 parts in 10^{13} of the primary standard.

This experiment clearly demonstrates the capability for time correlating a local clock to within sub-microsecond accuracies of a primary standard when a high degree of precision is required.

3. TIME-CODED RADIO TRANSMISSIONS

The most convenient method of local clock synchronization is to make use of one of the several VLF, LF and HF time-coded radio transmissions that are broadcast from various locations around the world. These time-coded signals, as transmitted, are highly accurate; but the information as received is subject to two errors: (1) the propagation delay between the transmitter and receiver

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[1] L. N. Bodily and R. C. Hyatt, "Flying Clock Comparisons Extended to East Europe, Africa and Australia," Hewlett-Packard Journal, Vol. 19, No. 4, December 1967, pp. 12-20.

and (2) the delay time through the receiver. Compensation for these delays can be introduced into the clock provided the delays are known and constant. If radio signals propagated at a constant velocity and if the propagation paths remained constant and noise-free, then the signals as received would be essentially as accurate as when transmitted. Unfortunately, this is not the case so systems must be designed to overcome or minimize these effects.

In addition to absolute time-of-day information, time-coded radio transmissions are also used as precision frequency references with which to set a local frequency standard. For this application only the carrier portion of the received signal is required, and thus the effective bandwidth of the received signal can be significantly reduced to minimize the effects of both noise and variations in propagation delays. With sufficient averaging time the frequency of the local standard can be made to coincide very closely with the frequency of the transmitter carrier, particularly when VLF and LF transmissions are used; HF transmissions require a much longer averaging time to achieve the same results and, therefore, are generally not used for frequency comparison purposes.

It is primarily the propagation characteristics of HF transmissions that make it difficult to use these signals for setting a local standard. The height of the ionosphere and the ionic-profile exhibit continuously changing characteristics which, in turn, are responsible for variations in the propagation time. As a result, many days of phase averaging are required to achieve an accuracy approaching 1 part in 10^8; whereas the accuracy of the transmitted carrier may be, as is the case for WWV, a few parts in 10^{11}.

Transmission paths of VLF and LF signals are much more stable than the HF propagated signals. These lower frequency signals follow the earth's curvature because of a ducting effect between the surface of the earth and the ionosphere. The ionosphere thus acts as a boundary rather than a reflector and, therefore, provides for a more constant propagation medium. The resultant high phase-stability and long range coverage of the VLF and LF signals makes them valuable for standard frequency transmission.

When transmissions are to contain absolute time-of-day information, it is necessary that some form of carrier encoding be implemented. The coding techniques used generally take the form of amplitude modulation (AM) of the carrier with markers or time ticks at one second intervals. For accurate timekeeping the leading edge, or rise time, of these markers must be precisely determined, and the actual time of occurrence of that leading edge must be known. The actual occurrence of the leading edge is the time of transmission minus the propagation time and receiver delay time. The ability to accurately resolve the leading edge of the time-mark is primarily determined by the transmitter and receiver bandwidths. Reducing the bandwidth will improve the signal-to-noise ratio but has the adverse effect of producing a slower rise time pulse, thus making it more difficult to determine what portion of the leading edge corresponds to the original time-mark.

Because the HF bandwidths are greater, the quality of the time ticks on signal transmissions such as WWV or WWVH will usually permit synchronization to within 100 microseconds. For VLF and LF, however, the characteristics of the antennas produce inherently slow rise-time pulses, and a synchronizing accuracy of 10 to 15 milliseconds is about the best that can be expected.

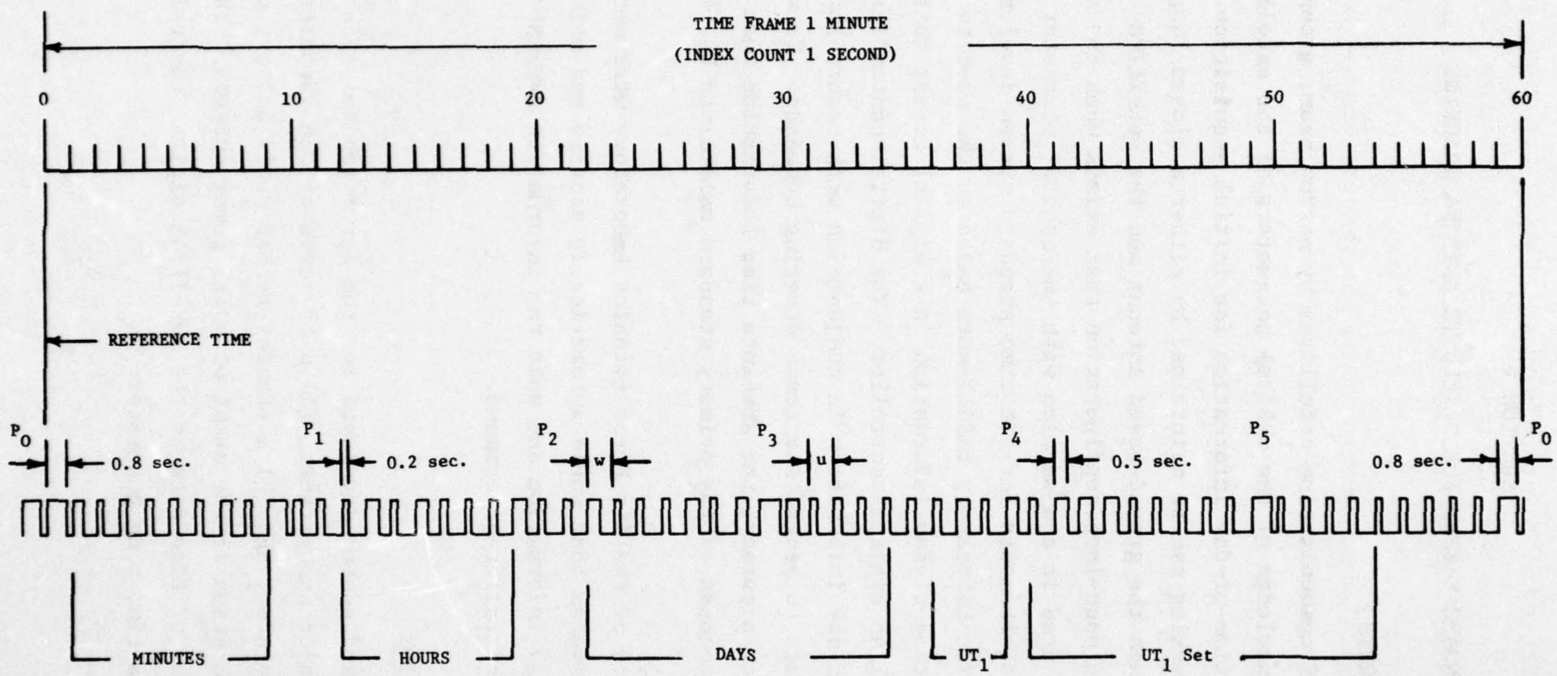
A desirable feature is the ability to have a time code generator that remains synchronized or will re-synchronize with a minimum of operator assistance. This form of automatic operation is possible when using specific VLF or LF time signals such as WWVB because the time-of-day information is encoded in the form of a modulated carrier. In contrast WWV and WWVH consists of one-second time ticks in conjunction with voice transmissions to provide exact time information. The use of WWV, therefore, requires manually setting the time code generator to the approximate correct time and then switching to automatic operation for a final precision adjustment.

The time standard system described in this report makes use of the time-coded LF signal of WWVB to achieve accurate synchronization of a time code generator. WWVB is operated and maintained by the National Bureau of Standards and transmits on a frequency of 60 kHz with the carrier being maintained to within 1 part in 10^{11} of the primary standard at Boulder, Colorado. The time code is in an IRIG H format and serves as the amplitude modulating signal for the 60 kHz carrier.

IRIG H, one of a number of IRIG time codes, consists of successive one-minute time frames with each frame encoded to provide (1) minutes, (2) hours, (3) day-of-year, and (4) correction to UT_1 time. This information is encoded in a binary-coded-decimal (BCD) format. A sample frame of the IRIG H time code is shown in Figure 2. From the figure it can be seen that the code consists of a mark-space configuration with the leading edge of consecutive marks occurring at one-second intervals. A binary "0" is represented by a mark with a 0.2 second duration while a binary "1" is represented by a mark duration of 0.5 seconds. 0.8 second marks are used as reference indicators to separate the minutes from the hours, hours from the days, and so on.

In the sample IRIG H frame shown in Figure 2, the time indicated is 258 days, 18 hours, 42 minutes, and 34 seconds.

A compilation of the more widely used standard frequency broadcast stations and some of their pertinent characteristics is given in Appendix A.



IRIG H CHARACTERISTICS

1) 1 PPM FRAME REFERENCE MARKERS
2) BINARY CODED DECIMAL TIME-OF-YEAR CODE WORD (23 DIGITS)
3) CONTROL FUNCTIONS USED FOR UT_1 CORRECTIONS (15 DIGITS)
4) 6 PPM POSITION IDENTIFIER MARKERS AND PULSES (P_0 THRU P_5)
(REDUCED CARRIER 0.8 SECOND DURATION PLUS 0.2 SECOND DURATION PULSE)
5) W-WEIGHTED CODE DIGIT (CARRIER RESTORED IN 0.5 SECOND - BINARY ONE)
6) U-UNWEIGHTED CODE DIGIT (CARRIER RESTORED IN 0.2 SECOND - BINARY ZERO)

SECTION V

TIME STANDARD SYSTEM FOR SATELLITE ANTENNA TRACKING

1. SYSTEM REQUIREMENTS

The tracking of communication satellites by narrow beam, ground-based antennas requires knowledge of the orbital parameters of the satellite and precision absolute time-of-day information for initial acquisition. Following acquisition, tracking can be maintained by either a closed loop communications link between the ground-based antenna and the satellite or by continued use of the open-loop configuration that exists when the absolute time information is used in conjunction with the orbital parameter data.

The specific requirements for the time standard system developed for the Air Force Avionics Laboratory (AFAL) were based on the need to have available absolute time-of-day information in a digital format that could be accessed by a PDP-11/45 digital controller. The digital controller would then use the time-of-day information in conjunction with memory-stored, satellite orbital data to generate antenna steering commands. To assure the required pointing accuracy, the absolute time information must be known to within 100 milliseconds of the primary standard maintained by the National Bureau of Standards.

The requirements of the Air Force Avionics Laboratory were met by design of a time standard system that would automatically acquire and maintain precision time-of-day information and make the information available to the PDP-11/45 digital controller on command.

2. SYSTEM DESCRIPTION

The time standard system developed for the Air Force Avionics Laboratory consists of three major subsystems: (1) a LF receiver and associated antenna, (2) a time code generator, and (3) a standby rechargeable battery pack to ensure continued system operation in the event of brief power outages. The interface that permits transfer of time data to the PDP-11/45 digital controller is an integral part of the time code generator.

a. WWVB Receiver

The LF receiver used in the time standard system is fixed tuned for reception of the 60 kHz time-coded signal transmitted by NBS from Boulder, Colorado. The receiver is Model 60TR manufactured by True Time Instrument Company. A ferrite rod antenna is included as a part of the receiver package; a low noise preamplifier is housed within the antenna assembly. The DC power required by the preamplifier is obtained from the main receiver via the coaxial cable used to interconnect the antenna and receiver. A long wire antenna is also available for use in locations where the field strengths are insufficient for reliable reception using the ferrite rod antenna. The ferrite antenna is recommended for areas where the field strengths are 125 uV/meter or greater, and the long wire antenna is for use in areas with lower field strengths. Based on a WWVB field strength contour map, the field strength in Atlanta, Georgia is on the order of 150 to 200 uV/meter. The field strength at Dayton, Ohio is essentially the same since Dayton is closer to the NBS transmitter than Atlanta by only about 15 percent.

The WWVB receiver consists of a tuned-radio-frequency (TRF) section, followed by a precision envelope detector (using an active device) and a limited amount of post detection signal conditioning. The recovered IRIG H time code signal is converted to standard digital logic levels (0, +5 volts) and fed parallel to both a front panel and a rear panel coaxial connector. The amplified RF signal (prior to envelope detection) is made available at a rear panel test point. Since the time code generator accepts the RF signal rather than the demodulated signal, a coaxial connector (BNC) was added to the rear panel in parallel with the existing RF test point so a suitable cable could be used to interconnect the receiver and time code generator.

The bandwidth of the WWVB receiver is $\pm$ 150 Hertz centered at 60 kHz with a sensitivity specification of 0.5 microvolts. The receiver delay is given as 14 $\pm$ 5 milliseconds.

b. Time Code Generator

The time code generator (Systron-Donner Model 8155) is the most complex element of the time standard system. The major functions of the time code generator are to (1) accept the amplified time-coded signal from the WWVB receiver, (2) demodulate and decode the signal for front panel numeric display, and (3) on command provide to the PDP-11/45 digital controller the requested time-of-day information.

The time code generator has no provisions for setting the time manually; the initial time information can come only from the decoded WWVB signal. However, once set, the time code generator will maintain time to an accuracy determined by its internal crystal controlled time base without further use of the WWVB signal. Re-synchronization with WWVB will correct any time error that may occur due to drift of the internal time base. In practice, synchronization will generally be maintained for a good portion of each day.

The frequency stability of the crystal controlled time base is specified at $\pm$ 4 parts in 10^9 for a 20 degree temperature change within -20 to +55 degrees Celsius and an aging rate of $\pm$ 1 part in 10^9 per day. The long term effect of this aging rate on uncorrected time accuracy can be determined by referring to Figure 1. External controls are available on the rear panel of the time code generator for both fine and course adjustment of the crystal oscillator frequency. If available, an "in-house" standard should be used periodically to check the frequency of the crystal oscillator to ensure that the time base is maintained to exactly 1 MHz. A convenient procedure for checking the accuracy of the time base is by use of an oscilloscope in conjunction with the in-house standard. If a 1 MHz signal from the in-house standard is applied to the vertical input of the scope and the 1 MHz signal from the time code generator (available on a rear panel coaxial connector) is used to trigger the oscilloscope, then the rate at which the trace moves across the face of the scope can be used to determine the accuracy of the crystal oscillator. If the trace moves to the right, the oscillator frequency is less than the standard frequency; and, conversely, a trace movement to the left means the oscillator frequency is greater than the standard frequency. The amount of frequency offset can be determined or extrapolated from the following table.

Trace Drift	Accuracy
1 cm/0.1 sec.	1 part in 10^6
1 cm/sec.	1 part in 10^7
1 cm/10 sec.	1 part in 10^8

Synchronization of the time code generator to the received WWVB signal is indicated by a front panel lamp. During abnormal conditions when there are bit errors in the time code, because of extraneous noise, the "Sync" indicator lamp is turned off and the time code generator reverts to its internal time base. Upon restoration of the input code and after three consecutive "good" time frames, the time code generator will again synchronize to the WWVB signal.

In addition to the crystal oscillator time base other elements of the time code generator are (1) the WWVB decoder/signal processor, (2) a minor counter, (3) a time-of-day (TOD) accumulator, (3) a time-of-day display, and (4) a time code generator/digital controller interface.

Following is a brief operating description of the time code generator; reference to the instruction manual is suggested for detailed information.

The amplified 60 kHz signal from the WWVB receiver is fed to the decoder/signal processor portion of the time code generator. An AGC amplifier establishes a standard level signal prior to processing by the "cycle detectors". The function of the cycle detectors is to extract the modulated time code. The particular demodulation process provides a degree of noise immunity not attainable with a conventional envelope detector. The demodulated time code signal is subsequently examined by a time-data-error-detector which compares sequential one-minute time frames to determine on a frame-by-frame basis if a legitimate time-code signal has been recovered. "Good" time frames are then compared with the internally generated time frames for the purpose of developing an error signal to force agreement between the internal time signal and the received WWVB signal. Synchronization is accomplished within the minor counter.

The 1 MHz time base signal is divided by a fixed 10^3 and delivered to the minor counter. The minor counter is a 3-decade, parallel presetable counter which further divides the time base signal down to 1 pps which serves as the update signal for the TOD accumulator. The parallel presetable feature allows the minor counter to be synchronized with the decoded WWVB time signal.

Briefly stated, time synchronization is accomplished by comparing the phase of the 1 pps divided-down time base signal with a 1 pps signal derived from the WWVB time code signal. If the phase error is greater than a preset amount, the time base is advanced or retarded at the rate of 1 microsecond per millisecond by adding or deleting one pulse out of each 1000 at the 1 Mpps level of the time base. This pulse deletion process continues until the phase error falls within the acceptable limit.

The TOD accumulator accepts the 1 pps signal from the minor counter and divides this signal into units and tens of minutes and hours. The digital signals are further processed to provide a resultant parallel data output that contains the time-of-day information in a 8-4-2-1 binary-coded-decimal (BCD) format.

The BCD time information is also fed to display decoders to provide appropriate drive signals for the 6-digit front panel readout. The time display is presented in hours, minutes, and seconds.

The time code generator is internally provided with the interface necessary to supply time-of-day information to either a HP-2100 data acquisition system or a PDP-11/45 digital controller. The HP-2100 system must be provided with a HP-12566B interface, and the PDP-11/45 digital controller must be provided with a PDP11/DR11C interface card. Portions of the time code generator interface circuitry share common usage with either the HP-2100 or the PDP-11/45 so that a single multi-terminal connector (rear panel mounted) serves for interconnecting to either system.

Two 20-bit latches within the time code generator are used exclusively to store the time-of-day information, in two bytes, for acquisition on-command by either the HP-2100 or the PDP-11/45.

The time code generator interface logic is shown in the schematic diagram of Figure 3. The universal logic portion of the interface is shown in detail whereas the 20-bit latches are presented in block diagram form. Specifics of the 20-bit latch circuitry can be obtained by referring to the instruction manual.

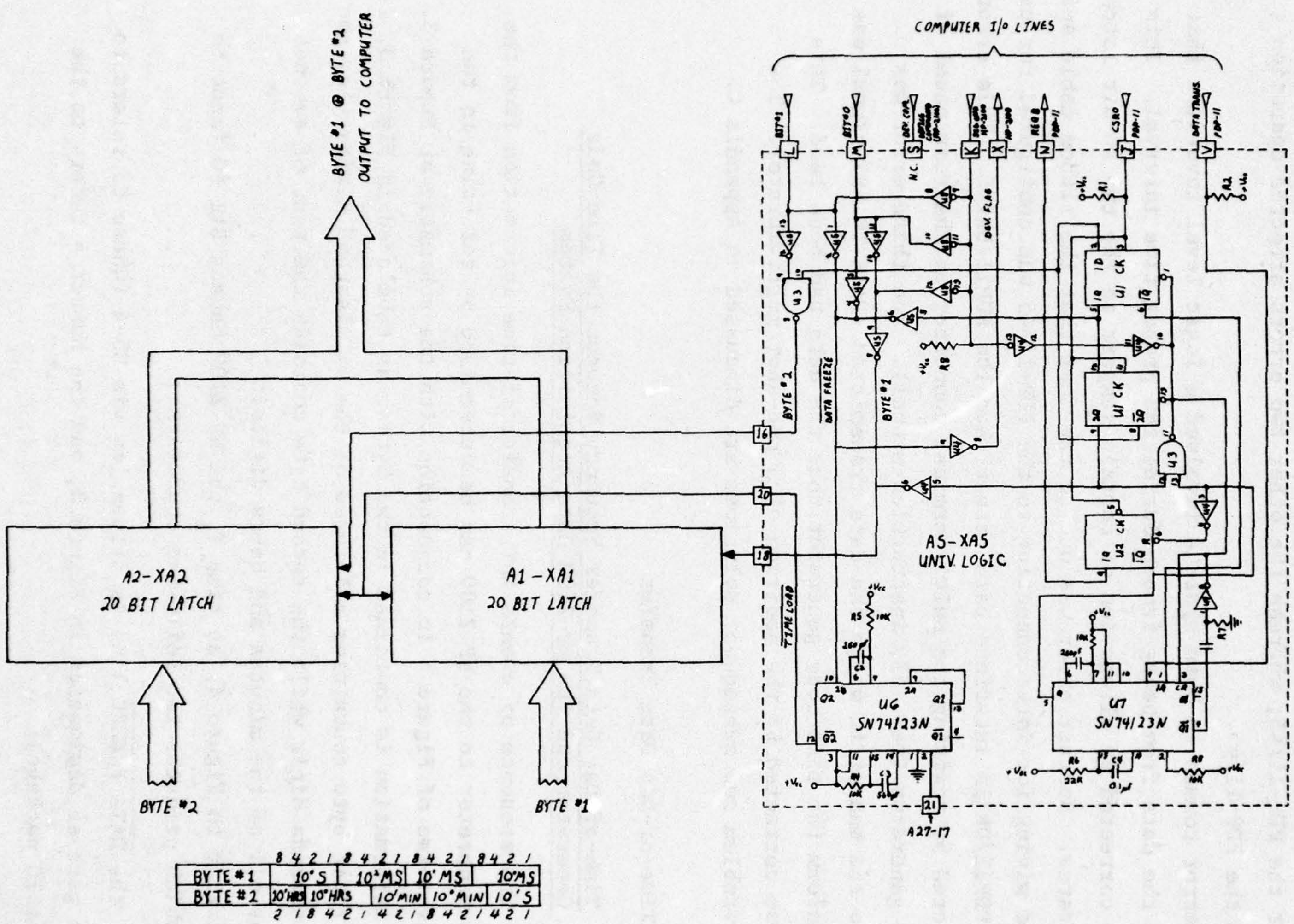


Figure 3. Schematic Diagram of Time Code Generator Interface.

There are three errors relative to the time code generator interface that existed in the original system. These errors have been corrected and the addendum of Appendix C should be used in conjunction with the time code generator instruction manual. One error was common to use of either the HP-2100 or the PDP-11/45; whereas the other two errors affected operation only with the PDP-11/45.

The error common to both systems involved a logic level inversion that prevented the data from being frozen during the proper time interval. This error was corrected by alteration of certain jumpers on the two 20-bit latch circuit boards. Another error was due to the fact that the ribbon cable and associated wiring for interconnecting to the PDP-11/45 was configured for use with the PDP11/DR11A interface card rather than the PDP11/DR11C. This error was corrected by rewiring the multi-terminal connector on the rear panel of the time code generator (ref. J3, instruction manual). The third error was related to the manner in which the data transmitted (DATA TRANS) signal was used to inform the time code generator that the data had been read. This problem was corrected by the addition of a one-shot multivibrator. The complete problem and subsequent solutions are discussed in Appendix C.

c. Time-of-Day Data Transfer

Time-of-Day Data Transfer Sequency Between the Time Code Generator and the HP-2100 Data Acquisition System

The sequence of events for transfer of time information from the time code generator to the HP-2100 can be determined by referring to the timing waveforms of Figure 4 in conjunction with the schematic of Figure 3. The time information is contained in two bytes, as tabulated in Figure 3, with the first byte containing all three of the millisecond digits plus the units of seconds digit while the second byte contains the tens of seconds digit plus all of the minutes and hours digits.

Referring to Figure 4, at time T_1 the HP-2100 causes BIT #0 input to go high which produces the following conditions:

(1) the $\overline{\text{DATA FREEZE}}$ line is driven low via U5-4 (where U5 refers to the logic gate so designated in Figure 3, and the number 4 refers to the pin on the IC package);

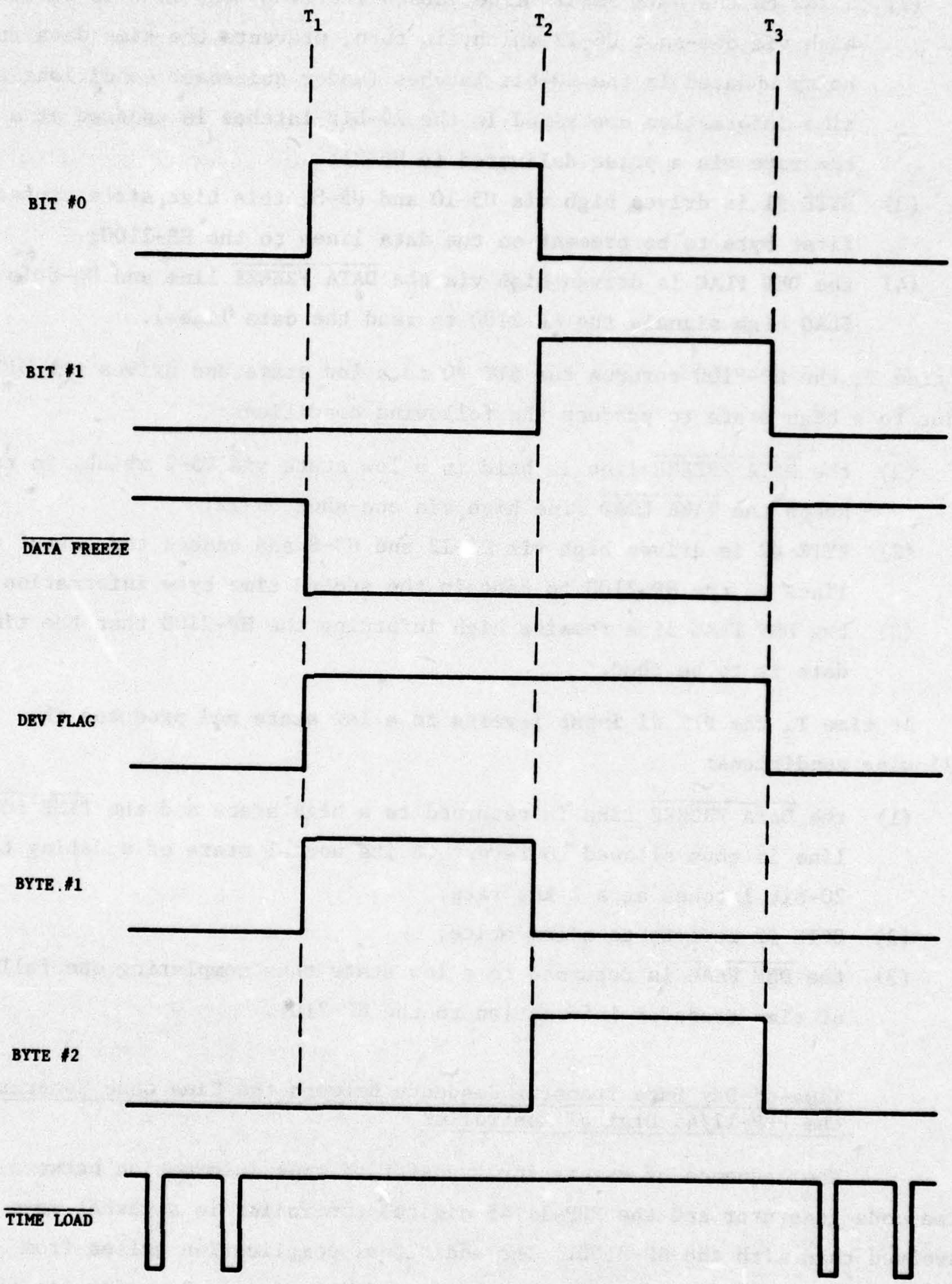


Figure 4. Timing Waveforms with the HP-2100.

(2) a low on the $\overline{\text{DATA FREEZE}}$ line causes the $\overline{\text{TIME LOAD}}$ line to be held high via one-shot U6-12 which, in turn, prevents the time data from being updated in the 20-bit latches (under quiescent conditions the time information contained in the 20-bit latches is updated at a 1 kHz rate via a pulse delivered to U6-2);

(3) BYTE #1 is driven high via U5-10 and U5-8; this high state causes the first byte to be present on the data lines to the HP-2100;

(4) the DEV FLAG is driven high via the $\overline{\text{DATA FREEZE}}$ line and U4-8 (a DEV FLAG high signals the HP-2100 to read the data lines).

At time T_2 the HP-2100 returns the BIT #0 to a low state and drives the BIT #1 input to a high state to produce the following conditions:

(1) the $\overline{\text{DATA FREEZE}}$ line is held in a low state via U5-2 which, in turn, keeps the $\overline{\text{TIME LOAD}}$ line high via one-shot U6-12;

(2) BYTE #2 is driven high via U5-12 and U3-8 and causes the output data lines to the HP-2100 to contain the second time byte information;

(3) the DEV FLAG line remains high informing the HP-2100 that the time data is to be read.

At time T_3 the BIT #1 input reverts to a low state and produces the following conditions:

(1) the $\overline{\text{DATA FREEZE}}$ line is returned to a high state and the $\overline{\text{TIME LOAD}}$ line is thus allowed to revert to its normal state of updating the 20-bit latches at a 1 kHz rate;

(2) BYTE #2 reverts to a low state;

(3) the $\overline{\text{DEV FLAG}}$ is returned to a low state thus completing one full cycle of time transfer information to the HP-2100.

Time-of-Day Data Transfer Sequence Between the Time Code Generator and the PDP-11/45 Digital Controller

The sequence of events for transfer of time information between the time code generator and the PDP-11/45 digital controller is somewhat more involved than with the HP-2100. The additional complication arises from operational variances between the two modes of interface. By referring to the timing waveforms of Figure 5 and the schematic diagram of Figure 3 the sequence of events can be explained.

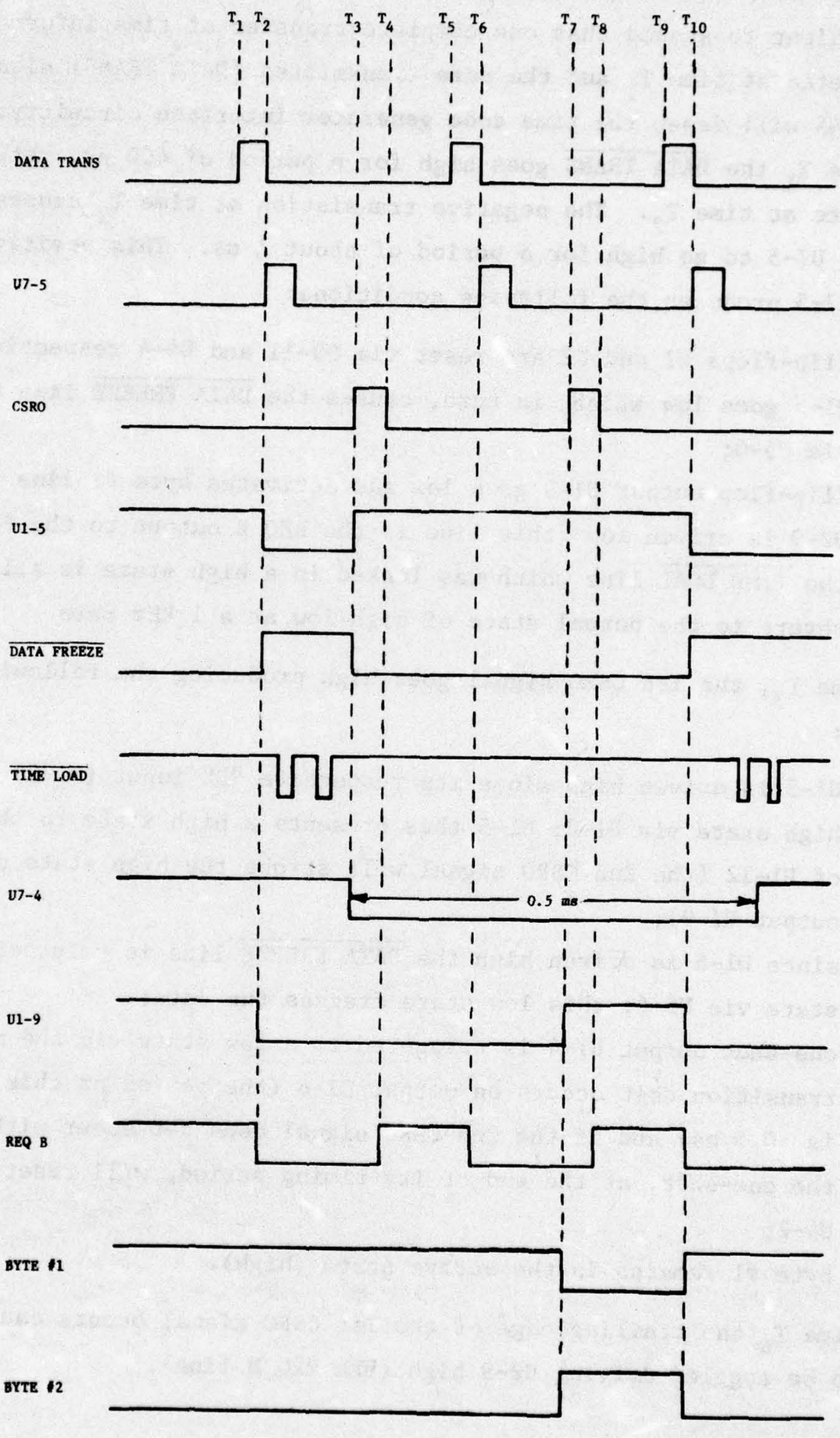


Figure 5. Timing Waveforms with the PDP-11/45.

In order to present the sequence of events in a straightforward manner it is convenient to assume that one complete transfer of time information is being completed at time T_1 and the data transmitted (DATA TRANS) signal from the PDP-11/45 will reset the time code generator interface circuitry.

At time T_1 the $\overline{\text{DATA TRANS}}$ goes high for a period of 400 ns, returning to the low state at time T_2. The negative transistion at time T_2 causes one-shot output U7-5 to go high for a period of about 1 us. This positive transition on U7-5 produces the following conditions:

(1) flip-flops U1 and U2 are reset via U3-11 and U4-4 respectively;

(2) U1-5 goes low which, in turn, causes the $\overline{\text{DATA FREEZE}}$ line to go high via U5-6;

(3) flip-flop output U1-9 goes low and activates byte #1 line via U4-6;

(4) U2-9 is driven low (this line is the REQ B output to the PDP-11/45);

(5) the $\overline{\text{TIME LOAD}}$ line which was locked in a high state is allowed to revert to the normal state of high/low at a 1 kHz rate.

At time T_3, the 1st CSRO signal goes high producing the following conditions:

(1) U1-5 is driven high since its respective "D" input (U1-2) is in a high state via U1-8; U1-5 thus presents a high state to the 2D input of U1-12 (the 2nd CSRO signal will strobe the high state of 2D to output U1-9);

(2) since U1-5 is driven high the $\overline{\text{DATA FREEZE}}$ line is returned to a low state via U5-6; this low state freezes the data;

(3) one-shot output U7-4 is triggered to a low state via the negative transition that occurs on output U1-6 (the period of this one-shot is ~0.5 ms) and if the 2nd CSRO signal does not occur within 0.5 ms the one-shot, at the end of its timing period, will reset U1 via U4-2;

(4) byte #1 remains in the active state (high).

At time T_4 the trailing edge of the 1st CSRO signal occurs causing flip-flop U2 to be toggled driving U2-9 high (the REQ B line).

At time T_5 the DATA TRANS line from the PDP-11/45 goes high indicating that the data is being read. At time T_6 the trailing edge of the DATA TRANS signal causes one-shot output U7-5 to go high. This positive transition on U7-5 produces the following conditions:

(1) flip-flop output U2-9 (the REQ B line) is returned to a low state via U4-4 (U1 is not reset because U3-12 is held in a low state via U1-9 causing output U3-11 to remain high);

(2) all other lines remain unchanged, thus a data freeze condition still exists.

At time T_7 the CSRO signal goes high for a second time and the following conditions are produced:

(1) the high state present at U1-12 is strobed to U1-9 which causes byte #1 to go low and simultaneously causing byte #2 to go high (the active state);

(2) the high state at U1-9 "arms" U3 for reset of U1 at the next DATA TRANS signal.

At time T_8 the CSRO signal returns to a low state and the trailing edge causes flip-flop U2 to be toggled with U2-9 going high (the REQ B output line).

At time T_9 the DATA TRANS again goes high for a period of 400 ns. At time T_{10} when the DATA TRANS returns to a low state one-shot output U7-5 goes high and the positive transition results in the following conditions:

(1) U1 is reset via U3-11 causing U1-5 to revert to a low state which, in turn, causes the $\overline{\text{DATA FREEZE}}$ line to go high via U5-6, the $\overline{\text{TIME LOAD}}$ line is returned to a high state via U1-9 and U4-6 and simultaneously byte #2 line is returned to a low state via U1-8 and U3-8.

This completes one full cycle of a time transfer sequence.

Briefly summarized, the time-of-day transfer sequence between the time code generator and the PDP-11/45 is as follows:

(1) the DATA TRANS signal goes high as a result of reading the previous time data information and then on the trailing edge of this signal,

(a) both F/F's are reset,

(b) BYTE #1 is active,

(c) the data freeze condition is released, and

(d) REQ B goes low;

(2) the first CSRO signal goes high and

(a) BYTE #1 remains active,

(b) the data is frozen,

(c) the 0.5 ms O/S is triggered,

(d) computer reads in BYTE #1, and

(e) REQ B goes high on the trailing edge of the CSRO;

(3) the DATA TRANS signal goes high and then on the trailing edge

(a) REQ B goes low;

(4) the second CSRO signal goes high and

(a) BYTE #2 becomes active,

(b) BYTE #1 reverts to an inactive state,

(c) computer reads in BYTE #2, and

(d) REQ B goes high on the trailing edge of the CSRO;

(5) the DATA TRANS signal again goes high and on the trailing edge

(a) both F/F's are reset,

(b) BYTE #1 again becomes active,

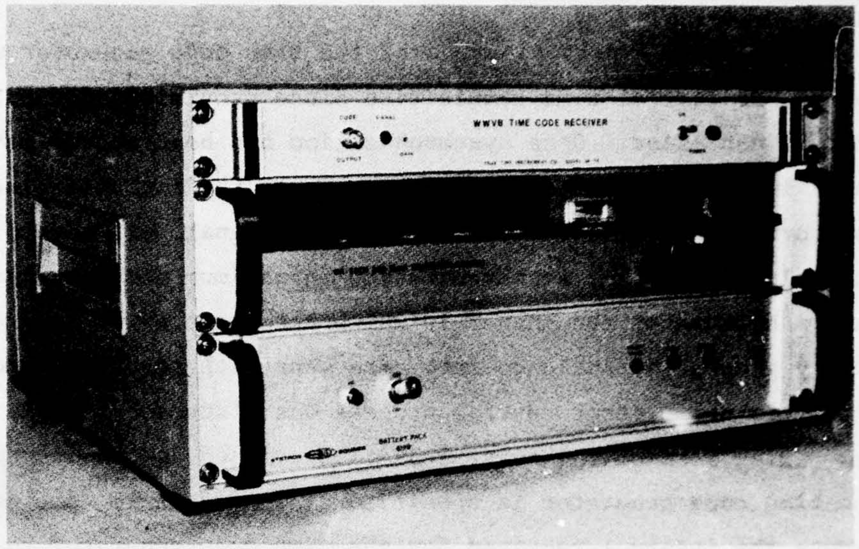
(c) the data freeze line is released,

(d) REQ B goes low, and

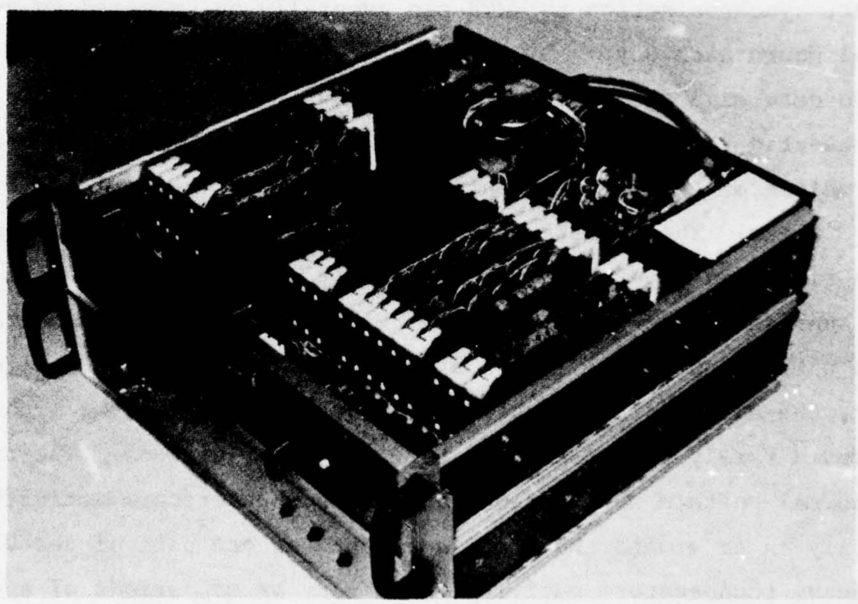
and a complete time transfer sequence has been accomplished.

d. Configuration of the Time Standard System

The time standard system which consists of the WWVB receiver, the time code generator and the battery pack are each configured as rack mountable units. The three units have been housed in a single instrument case having a total panel height of 8.75 inches. A photograph of the time standard system is given in Figure 6. If desired, the system can be removed from the instrument case and installed in a standard 19 inch equipment rack.



(a) TIME STANDARD SYSTEM



(b) INTERIOR VIEW OF THE TIME CODE GENERATOR

Figure 6. Photograph of Time Standard Systems.

3. SYSTEM PERFORMANCE

a. WWVB Synchronization

Automatic synchronization of the time code generator with WWVB is mandantory for initial time acquisition since provisions for setting the time manually do not exist. Once synchronization has been accomplished the time accuracy will be maintained to the accuracy of the internal time base without further correction, or updating, by the WWVB signal. It should be noted that from a "cold start" time synchronization to maximum accuracy can take close to 2 hours because of the manner in which the phase error loop servos the internally generated time code into agreement with the WWVB demodulated signal. This phase error control process was discussed briefly in Section V.2.

The aging rate of the crystal oscillator used as the internal time base for the time code generator is specified at 1 part in 10^9 per day. With this aging rate the interval required for the time code generator to accumulate an error of 100 milliseconds is, from equation (1), 48.1 days. Therefore, if the time code generator should synchronize to the WWVB signal only once a month, absolute time-of-day information would be maintained to the accuracy required for correct pointing of the satellite tracking antenna. In practice, however, synchronization to WWVB can generally be expected to occur for several hours each day.

To determine the expected synchronization pattern, a strip chart recorder was connected to the time code generator in such a way as to monitor the on-off synchronization to WWVB. A continuous record was accumulated over a period of about 3 weeks. The results of this test showed that initial synchronization of the time code generator would generally occur each day about 2 hours after local sunrise and, except for a few brief dropouts, would maintain synchronization until about 1 to 2 hours prior to local sunset. As the day approached sunset, the number of dropouts would increase. During the night, synchronization would rarely occur and then for only brief periods. The exception to this normal pattern would occur when heavy thunderstorm activity existed primarily in or around the immediate southeastern part of the United States. With heavy thunderstorm activity, only very brief periods of synchronization would occur because of the large electromagnetic signals emanating from this severe weather activity. At Wright-Patterson Air Force Base the same general synchronization pattern can be expected since the distance from the WWVB transmitter to Atlanta and to WPAFB is about the same.

b. Absolute Time-of-Day Accuracy

The accuracy of the time-of-day information is determined by (1) the ability to resolve the "on-time" marks of the WWVB code which, as was discussed earlier, is a function of the pulse rise time and (2) any uncertainty in propagation delay and receiver delay. The absolute time-of-day information is the measured time minus the known and fixed delays.

A summary of the known delays and the equipment specified delays yields:

(1) a propagation delay from Fort Collins, Colorado to WPAFB of 5.9 milliseconds;

(2) a specified receiver delay of 14±5 milliseconds;

(3) a specified time code generator synchronization accuracy of ±5 milliseconds.

Since variations in propagation delay have a second order effect the accuracy of the time-of-day will be the uncertainty in receiver delay plus the resolving power of the time code generator or a total of ±10 milliseconds. The absolute time-of-day will then be the sum of the propagation delay and the known receiver delay or 19.9 milliseconds. This delay of approximately 20 milliseconds can be removed by the PDP-11/45 digital controller by including this constant as a part of the computation program.

APPENDIX A

PARTIAL LISTING OF TIME STANDARD TRANSMITTING STATIONS

APPENDIX A

PARTIAL LISTING OF TIME STANDARD TRANSMITTING STATIONS

Station	Accuracy of the carrier frequency in 10^{-10}	Location Latitude Longitude	Frequency (kHz)
CHU	0.2	Ottawa Canada +45°18' +75°45'	3330 7335 14670
DCF77	0.02	Mainflingen German, F.R. +50°1' -9°0'	77.5
FFH	0.2	Chevannes France +48°32' -2°27'	2500
GBR	0.2	Rugby United Kingdom +52°22' +1°11'	16
HBG	0.02	Prangins Switzerland +46°24' -6°15'	75
IAM	0.5	Rome Italy +41°52' -12°27'	5000
IBF	0.1	Torino Italy +45°2' -7°42'	5000

APPENDIX A

PARTIAL LISTING OF TIME STANDARD TRANSMITTING STATIONS
(continued)

Station	Accuracy of the carrier frequency in 10-10	Location Latitude Longitude	Frequency (kHz)
JJY, JG2AE, JG2AS	0.5	Koganei Japan +35°42' -139°31'	2500 5000 10000 10000
LOLI	0.2	Buenos-Aires Argentina -34°37' +58°21'	5000 10000 10000
MSF (60 kHz)	0.2	Rugby United Kingdom +52°22' +1°11'	60
MSF (h.f.)	1.0	Rugby United Kingdom +52°22' +1°11'	2500 5000 10000
NBA (V.L.F.) NDT	0.1	Balboa USA +9°3' +79°39'	24 147.85 5448.5 11080 17697.5
NSS (V.L.F.) NWC	0.1	Annapolis USA +38°59' +76°27'	21.4 88 5870 8090 12135 16180 20225 22590

APPENDIX A

PARTIAL LISTING OF TIME STANDARD TRANSMITTING STATIONS
(continued)

Station	Accuracy of the carrier frequency in 10^{-10}	Location Latitude Longitude	Frequency (kHz)
OMA (all frequencies)	0.5	Liblice Czechoslovakia +50°4' -14°53'	50 2500
VNG	1.0	Lyndhurst Australia -38°3' -145°16'	4500 7500 12000
WWV	0.1	Fort-Collins USA +40°41' +105°2'	2500 5000 10000 15000 20000 25000
WWVB	0.1	Fort-Collins USA +40°40' +105°3'	60
WWVH	0.1	Kauai USA +21°59' +159°46'	2500 5000 10000 20000
ZUO	0.5	Olifants- fontein South Africa -25°58' -28°14'	2500 5000 100000

APPENDIX B

TIME-OF-DAY PROGRAM FOR THE HP-2100 DATA ACQUISITION SYSTEM

APPENDIX B

TIME-OF-DAY PROGRAM FOR THE HP-2100 DATA ACQUISITION SYSTEM

The program begins execution at line number 46 (Figure B-2) by clearing the interface lines associated with I/O slot number 13 (octal), and jumping to subroutine "input". The calling program is suspended until a carriage return is entered from the teletype signaling the request for time sample; control then moves to the time code generator driver routine.

In order to request data from the time code generator, one, and only one, of two input lines is held high, when this condition is satisfied a device flag and the respective time byte is made available to the requesting data acquisition system. It is the interface driver which provides this function by performing the following operations. First the low order byte request code (A) is sent to the time code generator which returns the low order time byte information. The "Load Into A-register" (LIA) instruction strobes the data into the machine where it is stored in temporary location CODEA. After the interface lines are cleared a high order byte request code (B) is sent and the resulting data is placed in temporary location CODEB.

Now with both time code generator bytes internal to the machine the next section converts the bytes into ASCII form suitable for display on a teletype device. In order to illustrate the method employed to achieve this conversion, the section of code in lines 100 through 107 is described more fully below. All of the displayed characters are generated in the same manner, but the following example is more representative of the operations involved.

Example of Conversion to ASCII Format

By the time line 100 is reached six characters have been processed and the first three words of the output buffer are filled. Contained in bits 13 through 15 of the B-register are the "tens of seconds" (10^1 sec.) field from the high order time byte coded in binary-coded-decimal (BCD) format. The first step in the conversion is to clear the A-register and left shift the AB-registers three positions, entering the "tens of seconds" field into bits 0 through 2 of the A-register. Since this accessed the last of the information contained in the high order byte, the low order byte is now loaded into the

B-register so it can be decoded. Next the information in the A-register is shifted to the left to allow room for intercharacter spacing and the ASCII control bits. At this point the combined AB-register is again shifted to the left, this time four positions, entering the BCD equivalent of "unit seconds" (10^0 sec.) into bits 0 through 3 of the A-register. The A register now has the appearance of line a in Figure B-1.

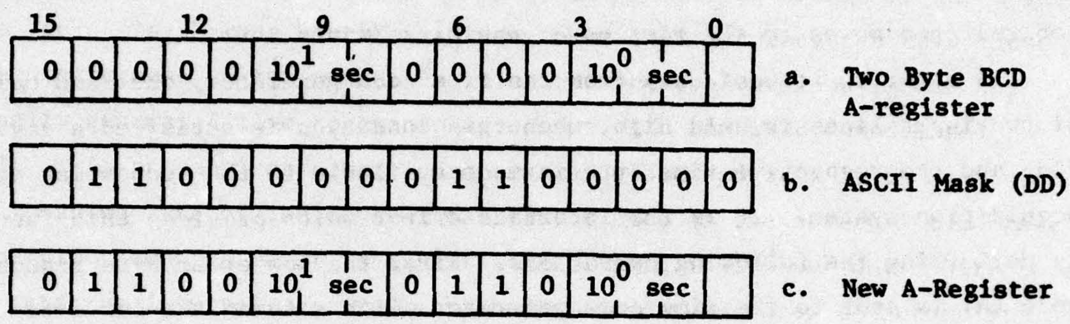


Figure B-1. Sample BCD to ASCII Conversion

The A-register contains two bytes of BCD information representing the seconds field of the time code generator sample. These two bytes are right justified at bit positions 0 and 8 respectively, as ASCII characters should be for output operations performed by a HP2100S device interface. To convert this data into the desired ASCII code, bits 6 and 7 of each byte must be set, these correspond to bits 5, 6, 13 and 14 of the A-register. Line b of Figure B-1 represents a word with these properties which is referenced as data in location MASK1. The Exclusive-OR of this data with the A-register results in the new state of the A-register given in line c.

The new contents of the A-register represents the ASCII equivalent of the seconds field of the data received from the time code generator, this information is placed in the output buffer at location Buff+3.

Once the output buffer is filled it is outputed to the teletype, a linefeed is also outputed to avoid overwriting the previous output. A control command returns to the instruction in the starting location, thus completing one full cycle.

The complete program for transfer of time-of-day information between the HP-2100 and the time code generator is listed in Figure B-2.

```
PAGE 0002 #01

                        ASMB,L,A
      02000                     ORG 2000B
*
*
*
*****************************************************************************
*****************************************************************************
*******                                                               *******
*******          THIS SECTION CONTAINS ALL OF THE DATA                *******
*******                                                               *******
*****************************************************************************
*
*
      02000 017172    INPUT OCT 17172          ENTRY POINTS TO
      02001 017142    OUTPT OCT 17142          INPUT/OUTPUT ROUTINE
*
      02002 000000    CODEA BSS 1              LO BYTE STORAGE AREA
      02003 000000    CODEB BSS 1              HI BYTE STORAGE AREA
*
      02004 000001    A     OCT 1              LO BYTE REQUEST CODE
      02005 000002    B     OCT 2              HI BYTE REQUEST CODE
*
      02006 000000    ZER   OCT 0              CONSTANT ZERO
      02007 000006    SIX   OCT 6              CONSTANT SIX
      02010 000007    SEV   OCT 7              CONSTANT SEVEN
*
      02011 000000    BUFF  BSS 6              OUTPUT BUFFER AREA
      02017 000012          OCT 12             ASCII LF (CR/LF)
      02020 002011    CBUF  DEF BUFF           POINTER TO BUFF
*
      02021 030060    MASK1 OCT 30060          2-DIG  MASK (DD)
      02022 035060    MASK2 OCT 35060          1-DIG  MASK (:D)
      02023 030072    MASK3 OCT 30072          1-DIG  MASK (D:)
      02024 027060    MASK4 OCT 27060          1-DIG  MASK (.D)
*
*
*
*****************************************************************************
*****************************************************************************
*******                                                              ********
*******             THIS IS THE MAIN DRIVER ROUTINE                  ********
*******                                                              ********
*****************************************************************************
*
*
      02025 000000    START NOP                START OF ROUTINE
      02026 102113          STF 13B            SET I/O FLAG
      02027 062006          LDA ZER            CLEAR A-REG
      02030 102613          OTA 13B            CLEAR INTERFACE LINES
      02031 066020          LDB CBUF           WAIT HERE FOR A
      02032 116000          JSB INPUT,I        KEYBOARD INPUT
*
*
*
*
*
```

Figure B-2 (a) Time-of-Day Program for the HP-2100

```
*
********************************************************************
********************************************************************
*******                                                      *******
*******        THIS BEGINS THE TIME CODE GENERATOR           *******
*******        INTERFACE DRIVER ROUTINE                      *******
*******                                                      *******
********************************************************************
*
*
02033 103100          CLF 00          TURN THE INTERRUPT SYSTEM
02034 062004          LDA A           OFF AND REQUEST THE HI ORDER
02035 102613          OTA 13B         BYTE FROM THE T-C GENERATOR.
*                                     READ IT IN THROUGH THE
02036 102513          LIA 13B         A-REG, THEN STORE IT IN
02037 072002          STA CODEA       LOCATION CODEA
*
02040 102113          STF 13B         SET THE I/O FLAG
02041 062006          LDA ZER         AND CLEAR THE
02042 102613          OTA 13B         INTERFACE LINES
*
02043 102113          STF 13B         SET THE I/O FLAG AND
02044 062005          LDA B           REQUEST THE LO ORDER BYTE
02045 102613          OTA 13B         FROM THE T-C GENERATOR.
02046 102513          LIA 13B         READ IT IN THROUGH THE
02047 072003          STA CODEB       A-REG AND STORE IN CODEB
*
*
*
*
********************************************************************
********************************************************************
*******                                                      *******
*******     AT THIS POINT THE TIME OF THE KEYBOARD           *******
*******     INPUT IS STORED IN LOCATIONS CODEA AND           *******
*******     CODEB, THE NEXT SECTION CONVERTS THE             *******
*******     DATA INTO THE ASCII FORMAT BELOW                 *******
*******                                                      *******
*******                 HH:MM:SS.SSS                         *******
*******                                                      *******
********************************************************************
*
*
02050 002400          CLA             CLEAR THE A-REG AND LOAD
02051 066002          LDB CODEA       THE HI ORDER BYTE INTO THE
02052 100102          RRL 2           B-REG, SHIFT THE HOURS INTO
02053 001222          RAL,RAL         A-REG WITH BLANK CONTROL BIT
02054 001222          RAL,RAL         MASK WITH (DD) AND PLACE
02055 100104          RRL 4           THE FIRST TWO ASCII CHARS
02056 022021          XOR MASK1       IN THE FIRST LOCATION OF
02057 072011          STA BUFF        THE OUTPUT BUFFER
*
02060 002400          CLA             CLEAR THE A-REG AND SHIFT
02061 100103          RRL 3           IN THE TENS OF MINS.,
02062 022022          XOR MASK2       MASK IT WITH (:D) AND PLACE
02063 072012          STA BUFF+1      IT IN THE NEXT BUFFER WORD
```

Figure B-2 (b) Time-of-Day Program for the HP-2100

```
*
      02064 002400        CLA                  CLEAR THE A-REG AND SHIFT
      02065 100104        RRL 4                THE MIN. UNITS ALL THE WAY
      02066 001222        RAL,RAL              OVER TO THE UPPER BYTE OF
      02067 001222        RAL,RAL              THE A-REG, LEAVING THE LOWER
      02070 001222        RAL,RAL              BYTE CLEAR SO THAT A COLON
      02071 001222        RAL,RAL              CAN BE INSERTED, MASK WITH
      02072 022023        XOR MASK3            (D:) AND PLACE IT INTO THE
      02073 072013        STA BUFF+2           NEXT BUFFER LOCATION
*
      02074 002400        CLA                  CLEAR THE A-REG AND SHIFT IN
      02075 100103        RRL 3                THE TENS OF SECS., LOAD THE
      02076 066003        LDB CODEB            B-REG WITH THE LO ORDER BYTE
      02077 001222        RAL,RAL              AND SHIFT IN THE SEC. UNITS.
      02100 001222        RAL,RAL              MASK THE A-REG WITH (DD) AND
      02101 100104        RRL 4                STORE THE TWO CHARACTERS
      02102 022021        XOR MASK1            INTO BUFFER LOCATION BUFF+3
      02103 072014        STA BUFF+3
*
      02104 002400        CLA                  CLEAR THE A-REG AND SHIFT
      02105 100104        RRL 4                INTO IT THE 100-MS, MASK
      02106 022024        XOR MASK4            IT WITH (.D) AND STORE THE
      02107 072015        STA BUFF+4           RESULT IN THE BUFFER AREA
*
      02110 002400        CLA                  CLEAR THE A-REG AND SHIFT
      02111 100104        RRL 4                IN THE TENS AND UNIT MS
      02112 001222        RAL,RAL              MASK THE A-REG WITH (DD)
      02113 001222        RAL,RAL              AND PLACE THESE LAST TWO
      02114 100104        RRL 4                ASCII CHARACTERS INTO THE
      02115 022021        XOR MASK1            NEXT LOCATION IN THE
      02116 072016        STA BUFF+5           OUTPUT BUFFER
*
*
*
**********************************************************************
**********************************************************************
*******                                                        *******
*******       THE FOLLOWING SECTION SENDS THE ASCII            *******
*******       BUFFER (WITH CR/LF) TO THE OUTPUT DEVICE         *******
*******                                                        *******
**********************************************************************
*
*
      02117 062010        LDA SEV              A SIX WORD BUFFER FOLLOWED
      02120 066020        LDB CBUF             BY A CR/LF IS SENT WITH THE
      02121 116001        JSB OUTPT,I          AID OF AN EXTERNAL ROUTINE
*
*
**********************************************************************
**********************************************************************
*
*
      02122 026025        JMP START            CONTROL NOW RETURNS TO THE
                          END                  MAIN ROUTINE WHICH WAITS
**  NO ERRORS*
```

Figure B-2 (c) Time-of-Day Program for the HP-2100

APPENDIX C

ADDENDUM TO THE TIME CODE GENERATOR INTERFACE

APPENDIX C

ADDENDUM TO THE TIME CODE GENERATOR INTERFACE

C.1 Correction for Proper Data Freeze Operation

In the original configuration when the DATA FREEZE line was driven low (Figure 3) the data lines were released rather than held as required. As a result the time data would be changing during the data read interval for either the HP-2100 or the PDP-11/45. This problem was corrected by removing jumper W4 and installing jumper W3 on both 20-bit latch circuit cards. The schematic, in its original form, is given on drawing number 21587-7-26 of the time code generator instruction manual.

C.2 Wiring Changes Relative to Interconnection of the PDP-11/45

The interconnecting wiring between the time code generator and the PDP-11/45 was originally wired for the DR11-A interface rather than the DR11-C. A ribbon cable is used to interconnect the time code generator with the PDP-11/45 and because of physical constraints with this type cable it was not practical to rewire the cable and its respective connectors. As a result, a decision was made to rewire the Amphenol connector (J3) on the rear panel of the time code generator. The original wiring configuration is included as a part of drawing number 07123801 of the time code generator instruction manual. Table C-1 shows the wiring changes that were required to achieve proper operation.

C.3 Logic Circuit Correction to Time Code Generator Interface

The logic error that existed on the time code generator interface circuitry was related to the process whereby the PDP-11/45 acquired data from the time code generator. The first data byte would be read into the PDP-11/45, after which the PDP-11/45 would signal the time code generator with a DATA TRANSMITTED (DATA TRANS) pulse that the data had been read. The time code generator would respond by signaling with a REQUEST B (REQ B) status change. The logic error resulted from the fact that the REQ B status change occurred on the leading edge of the DATA TRANS rather than the trailing edge as

CONNECTOR J3 PIN NUMBERS		FUNCTION
Wire Moved From	To	
23	27	D. TRANS
19	31	CSRO
16	34	REQ B
27	23	BIT 0
31	19	BIT 1
21,22*	29,28*	BIT 2
36	14	BIT 3
6	44	BIT 4
7	43	BIT 5
8	42	BIT 6
9	41	BIT 7
37	13	BIT 8
12	38	BIT 9
13	37	BIT 10
39	11	BIT 11
14	36	BIT 12
17	33	BIT 13
43	7	BIT 14
18	32	BIT 15
1	49	GND
2	48	GND

*Shorted Pins

Table C-1. Connector J3 Wiring Modifications

required. Quoting from the PDP-11/45 instruction manual: "The signal is true (+3v) as soon as the DRINBUF has been addressed for reading and remains true for approximately 400 ns; therefore, the lines should be held until the trailing edge of this signal."

The timing problem was resolved by the addition of a one-shot between the DATA TRANS input line and the gates and flip-flops normally driven by the DATA TRANS signal. The one-shot output is, in effect, a time delayed DATA TRANS signal. The use of a one-shot was selected since the circuit board already contained an unused portion of a dual one-shot integrated circuit.

The manner in which the one-shot is used can be determined by comparing the corrected circuit of Figure 3 with the original drawing (number 07123801) in the time code generator instruction manual.

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