A TIME TRANSFER UNIT FOR GPS

Jackson T. Witherspoon, Leonard Schuchman
Stanford Telecommunications, Inc., Sunnyvale, CA & McLean, VA

ABSTRACT

A Time Transfer Unit (TTU) for use with NAVSTAR satellites of the Global Positioning System (GPS) is described. The unit can provide world-wide time transfer with an accuracy of better than 100 nanoseconds relative to GPS system time. Techniques used for GPS signal processing and data reduction are summarized, and potential applications discussed.

INTRODUCTION

Satellites have been used for a number of years for transfer of time and frequency between primary standards and users of precise time [1]. NAVSTAR satellites of the Global Positioning System (GPS) will soon provide world-wide access to precise timing signals which will permit a properly equipped user to calibrate a local time source relative to a primary standard to within fractions of a microsecond. The minimum user configuration consists of an omni-directional antenna and preamp, a Time Transfer Receiver, a teletype or equivalent alphanumeric printer, and a scientific hand calculator. Users with existing computers can eliminate the manual computation by connecting the receiver directly to a host processor.

For users without existing processing capability, an integrated receiver/processor or Time Transfer Unit (TTU) is available which is completely self-contained and fully automated. For users who do not have atomic frequency standards but who wish to improve the accuracy of their local time reference to better than 1 microsecond, the TTU can be operated in an automatic time correction mode in which the local time reference is periodically corrected.

This paper describes the operation and design of a prototype unit now under development.

OPERATION

The basic configuration of the TTU is shown in Figure 1. The unit accepts stable reference time (1 pps) and frequency (5 MHz) signals from the local time standard or unit to be calibrated, and the L1 signal at 1575 MHz from any GPS NAVSTAR satellite. Ephemeris data from the NAVSTAR satellite is detected and processed to determine satellite position and to estimate the time of arrival of the satellite signal epoch. The actual time of arrival is recorded and compared with the expected value after correction for ionospheric, tropospheric, and relativistic errors, and the difference is displayed as the local time error. Sequential time error measurements are filtered to provide minimum variance time and frequency error data for display to the user or for logging with other user applications data. Time error is displayed as a nine digit plus sign decimal number in units of seconds with a range of ± six seconds and a resolution of 10 nanoseconds. Frequency error is computed from the rate of change of the filtered time error and displayed as a six digit plus sign decimal number in parts per 10^9 with a range of ± one part 10^6 and a resolution of one part in 10^{12}. The output data is updated every six seconds; the normal smoothing interval is two minutes but can be adjusted to a particular user's requirements. The smoothing filter also generates an estimate of the variance of the output data.

Several optional modes of operation are available to match different user requirements. For the user who needs a corrected 1 pps time reference, a time synthesizer can be added to the basic configuration which generates a 1 pps which is advanced or retarded relative to the reference 1 pps by an amount equal to the computed time error.

Time Transfer Technique

The time transfer technique used is illustrated in Figure 2 which shows typical satellite, user and received time epochs relative to system (GPS) time. GPS satellites transmit continuous navigation signals with readily identified epochs every 6 seconds. The satellite transmission is determined by an atomic standard which will in general differ by some amount (Parameter A in Figure 2) from system time. An estimate of A is contained in the navigation data and is available to the TTU. The satellite epoch arrives at the TTU and is detected by the receiver at some later time and is measured by reference to the local station time reference (Parameter C in Figure 2). The transit time (sum of A + B + C in Figure 2) can be estimated from satellite ephemeris and ionospheric error available in the navigation data, and from known user location and equipment bias calibrations. The station time error is taken as the difference between expected and measured time of arrival. Table 1 summarizes the major sources of error in the technique described. Note that these errors are associated with a single measurement and do not include potential improvement from smoothing over multiple samples or combining measurements from multiple satellites. The reader is referred to [2] for a more complete discussion of the GPS Navigation Data Message and its contents.

TABLE 1

TTU ERROR BUDGET

Satellite Ephemeris	10 ns
Satellite Clock Drift	10 ns
Ionosphere/Troposphere	30 ns
User Location/Calibration	15 ns
Receiver Noise	20 ns
RSS Error	41 ns

Satellite Availability

NTS-2, the first of six NAVSTAR satellites planned for Phase I system deployment was launched in 1977 and is undergoing test and evaluation. This satellite can be seen for an average of six hours per day anywhere in the world. Figure 3 illustrates expected times in view for the six satellite constellation from San Francisco. Note that at least one satellite is in view about 18 out of 24 hours each day.

RECEIVER DESCRIPTION

The Time Transfer Receiver is contained in a standard 19" wide rack mounted chassis. A remotable L-band preamp and omni-directional antenna are provided for external or roof top mounting.

RF Antenna/Preamp

The RF antenna/preamp assembly is designed to ensure a carrier-to-noise-density ratio for the L1 signal under worst case conditions of 37 dB/Hz. The antenna is a narrowband, circularly polarized unit providing unity gain over the L1 frequency band everywhere above 20 degrees elevation. The preamplifier is of conventional design, preceded by a narrowband preselector, providing a noise figure of better than 5 dB and a gain of more than 40 dB. The entire assembly is designed for operation in an unprotected environment over a temperature range of $-25^{\circ}C$ to $+65^{\circ}C$.

Time Transfer Receiver

The heart of the TTU is the Time Transfer Receiver (TTR). The TTR receives and tracks the PRN coded GPS signal at 1575 MHz, demodulates the carrier and detects the 50 bps Navigation data which bi-phase modulates the carrier. Navigation data, code epochs, and receiver status are provided as outputs for processing or printing via an IEEE-488-1975 compatible interface bus every six seconds. Figure 4 illustrates the TTR front panel controls. The receiver may be operated manually from this panel or remotely via the processor interface. GPS time-of-week is continuously displayed in the center display. Figure 5 illustrates the major functional elements of the receiver.

Downconverter

The downconverter preselects, downconverts, amplifies, filters, and levels the input L-band signal. Single downconversion is used to an IF of 81.84 MHz where signal distribution and correlation is performed. All conversion signals are synthesized from the local frequency standard. Provisions are included for injection of test RF or IF signals from a NAVSTAR test transmitter such as STI Model 5001.

Code Tracking Loop

The code tracking loop is a conventional early-late delay-locked loop employing a single code channel which is switched between early and late code references. An early-late discriminator accepts the early and late codes, correlates the received and reference codes, and demultiplexes the switched error signals to produce a digital error signal proportional to the received code offset. The code loop filter and number-controlled-oscillator circuits which generate the corrected code clock are all digital designs which retain the phase noise purity of the reference oscillator so as to achieve a very narrow band tracking loop. The code generator generates any one of 37 Gold codes used for the GPS C/A signals, the proper code selectable by satellite ID.

Navigation Data Detection

This module accepts video 50 Hz navigation data from the carrier loop, synchronizes and detects the data and subframe synchronization, and generates data, timing and synchronization signals for the external processor. The received HOW word is also extracted for panel display.

Frequency Synthesizer

This module plus an internal 10 MHz frequency reference provides for generation of all internally used frequencies from an internal or external frequency standard.

Interface and Control

This module provides control of receiver operating modes, front panel controls, local HOW generation and external control and status interfaces with the processor via the IEEE Interface Bus.

Data Processing Configuration

As indicated earlier, the data processing configuration required for the TTU will depend on the particular host user's application. For the development model of the TTU, a time-shared 16-bit mini-processor/CRT keyboard will be used. This configuration was selected to provide flexibility of test and evaluation, particularly with respect to evaluation of time-transfer algorithms. An extended precision time interval counter is included in the processor configuration to process the receiver generated code epochs measurements with 10 nanosecond resolution.

The software provided with the TTC includes, in addition to standard vendor operating systems and library routines, nine applications peculiar modules which provide operator initiation, control, data acquisition, data reduction, display, and diagnostic capability, all at the CRT/keyboard which acts as the control station for the system. Figure 6 illustrates the processing sequence.

Upon initialization, the system verifies proper program loading, checks all Input/Output operations, and requests operator inputs for satellite ID, initial doppler offset and verification of proper system time. The receiver is then interrogated, and if status is valid, a navigation data frame is read in and checked for validity. When a valid frame of data is available, navigation data processing begins. This process produces an estimate of transit-time once every six seconds which is then compared to the measured time-of-arrival as determined from the time interval between received and local code epochs. Consecutive differences are then smoothed over a two minute interval to produce refined estimates of both time and frequency error in the local user's clock. These data are displayed to the operator as illustrated in Figure 7.

SUMMARY

A Time Transfer Unit capable of providing 100 nanosecond world-wide time synchronization via RF signals transmitted by GPS NAVSTAR satellites has been described. Such units can provide more frequent and improved calibration of existing atomic clocks at remote locations, and upgrading of time and frequency accuracy available from conventional crystal frequency standards.

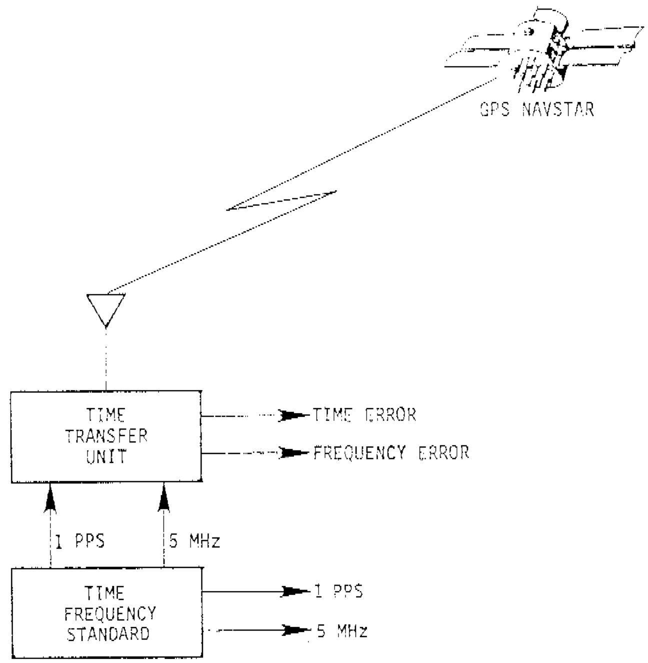

FIGURE 1 GPS TIME TRANSFER UNIT

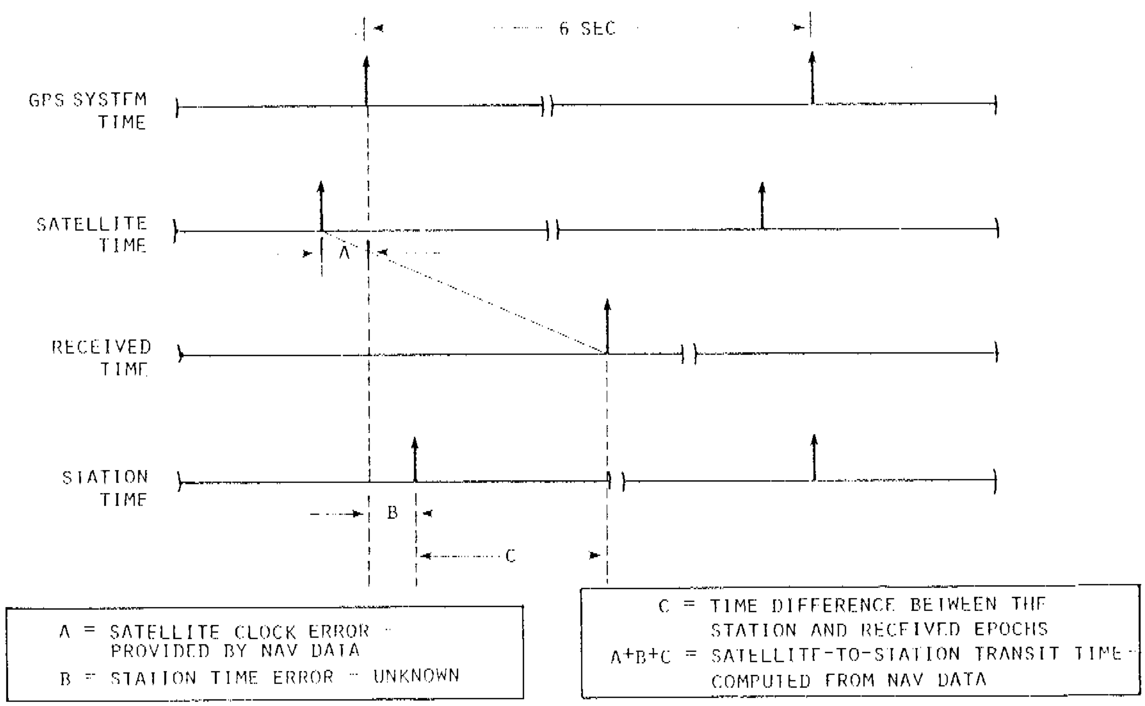

FIGURE 2 SYSTEM TIME RELATIONSHIPS

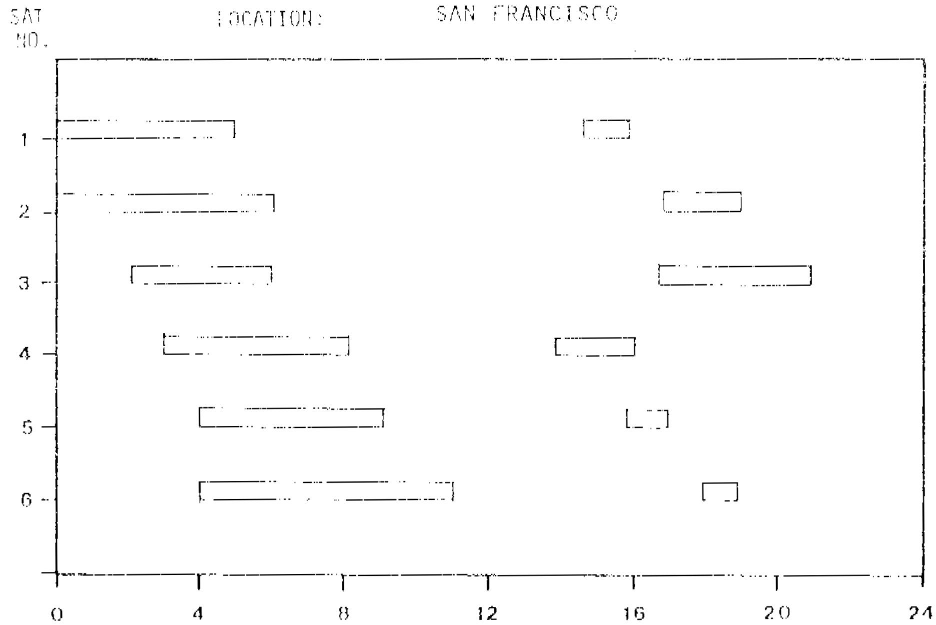

FIGURE 3 GPS PHASE I SATELLITE IN VIEW TIME

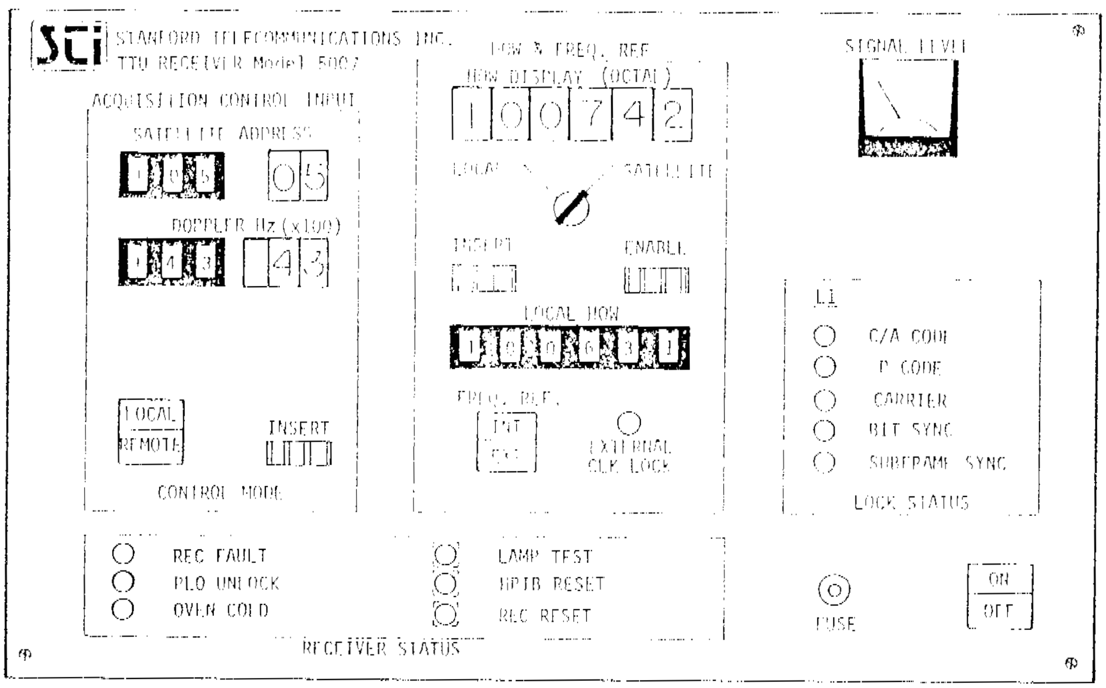

FIGURE 4 FRONT PANEL FROM PROPOSAL

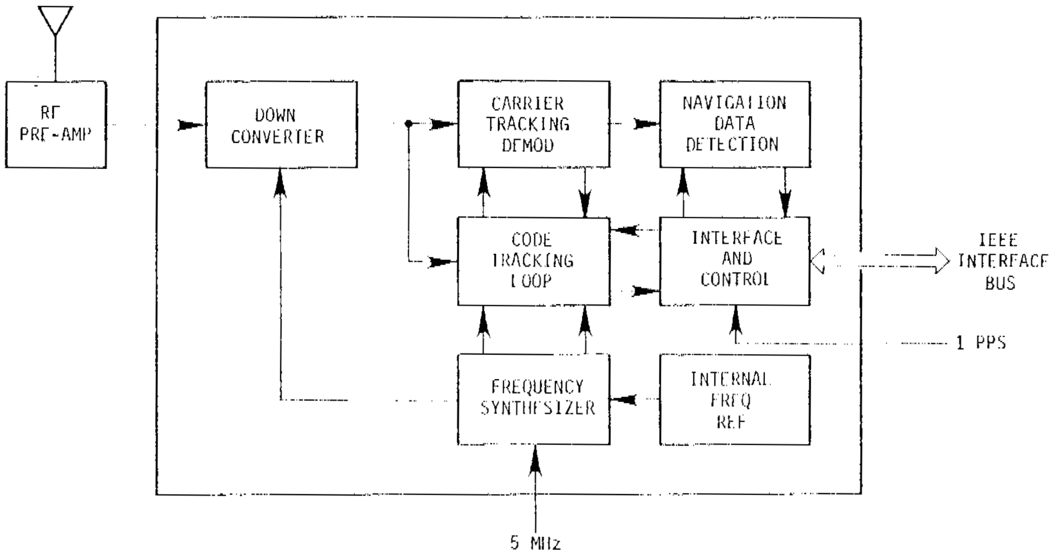

FIGURE 5 TIME TRANSFER RECEIVER

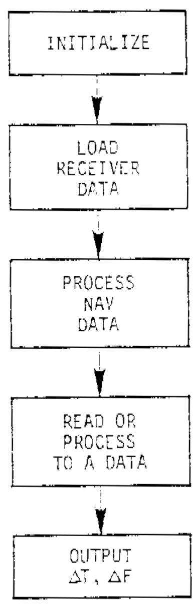

FIGURE 6 TTU PROCESSING SEQUENCE

GMT TIME DAY:HR:MI:SE	GPS TIME OF WEEK	TIME ERROR SECONDS	FREQ ERROR PARTS
123:12:23:40	12394	+5.11891E-07	+4.35179E-09
123:12:23:46	12395	+5.12510E-07	+4.26892E-09
123:12:23:52	12396	+5.16636E-07	+4.16312E-09
123:12:23:58	12397	+5.19073E-07	+4.06891E-09
123:12:24: 0	12398	+5.17294E-07	+4.00627E-09
123:12:24: 6	12399	+5.13459E-07	+3.93368E-09
123:12:24:12	12400	+5.14403E-07	+3.83309E-09
123:12:24:18	12401	+5.14099E-07	+3.72197E-09
123:12:24:24	12402	+5.15022E-07	+3.64947E-09
123:12:24:30	12403	+5.13194E-07	+3.57126E-09
123:12:24:36	12404	+5.18841E-07	+3.50480E-09
123:12:24:42	12405	+5.19879E-07	+3.42245E-09
123:12:24:48	12406	+5.20146E-07	+3.39225E-09
123:12:24:54	12407	+5.23184E-07	+3.33367E-09
123:12:25: 0	12408	+5.25976E-07	+3.27245E-09
123:12:25: 6	12409	+5.21148E-07	+3.23060E-09
123:12:25:12	12410	+5.20144E-07	+3.18878E-09
123:12:25:18	12411	+5.23869E-07	+3.10310E-09
123:12:25:24	12412	+5.23300E-07	+3.04279E-09
123:12:25:30	12413	+5.20562E-07	+3.01173E-09
123:12:25:36	12414	+5.21002E-07	+2.95748E-09
123:12:25:42	12415	+5.22653E-07	+2.89300E-09
123:12:25:48	12416	+5.19774E-07	+2.84795E-09
123:12:25:54	12417	+5.18780E-07	+2.81059E-09
123:12:26: 0	12418	+5.21168E-07	+2.75104E-09
123:12:26: 6	12419	+5.23914E-07	+2.70288E-09
123:12:26:12	12420	+5.19829E-07	+2.67354E-09
123:12:26:18	12421	+5.20344E-07	+2.64690E-09

FIGURE 7 TYPICAL TTU DISPLAY

REFERENCES

[1] Easton, R.L., Fisher, L. C., Hanson, D. W., Hellwig, H. W., Rueger, L. J., "Dissemination of Time and Frequency by Satellite," Proc. IEEE, Oct. 1976, Vol. 64, pp. 1482.

[2] Van Dierendonck, A. J., Russell, S. S., Kopitske, E. R., Birnbaum, M., "The GPS Navigation Message," AIAA Guidance and Control Conference, San Diego, CA, August 1976.