MULTI-PURPOSE TIME ANALYZER AND MONITOR FOR DEEP SPACE NETWORK TIME SYNCHRONIZATION

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Abstract

We report the development of a multi-purpose, automated, and continuously operating Time Analyzer to measure and monitor distributed 1 pps reference signals in the NASA Deep Space Network (DSN). The instrument reports the performance of each 1 pps signal relative to the station master clock and displays time offset and jitter (standard deviation) data for each measurement. The long-term stability of the primary and backup frequency standards are also monitored by measuring time offset data and analyzing over a twenty-four hour period. The instrument output includes alarms that alert the station operator of anomalies or an out of specification condition. All monitor and user displays are developed with Labview and use the LINUX operating system.

INTRODUCTION

NASA/JPL operates the Deep Space Network (DSN), a network of sensitive antennas that support interplanetary spacecraft missions and radio and radar astronomy observations. These antennas are located at three sites near Goldstone, California; Madrid, Spain; and Tidbinbilla, Australia. Time offsets between each station are measured against UTC using traditional GPS common view techniques

Each station operates an independent Frequency and Timing Subsystem (FTS) [1] and distributes timing signals to approximately 100 users. Since time users are scattered over several antennas up to 30 km away from the station master clock, distribution delays due to cable lengths must be accounted for. These delays are typically measured during initial installation but there presently is no monitoring of the residual time offset or stability of the delivered signal. Consequently timing quality can be inadvertently compromised either by human error or equipment anomalies. The Time Analyzer instrument design described here measures time offsets and jitter of the timing output of more than 120 timing users and alerts the DSN operator of any anomalies or out of specification condition. The analyzer also tracks the long term drift of primary and backup frequency standards and provides a generic test capability for any 1 pps signal. The analyzer provides station operators a snapshot view of the entire timing system integrity and performance. The instrument is networked to allow long term data archiving or post processing by DSN time analysts.

DEEP SPACE NETWORK FREQUENCY AND TIMING SUBYSYSTEM

The primary components of the FTS are multiple frequency standards, reference frequency synthesis and distribution, and master clock and time distribution. GPS time transfer is used for time synchronization and frequency syntonization between complexes.

The complement of frequency standards presently consists of four atomic clocks (Fig 1), two Hydrogen Masers, one Mercury Linear Ion Trap Standard (LITS), and one commercial cesium

beam standard. Each standard provides stable output frequencies at 0.1, 1, 5,10, and 100 MHz with 140 dB isolation between channels. The four frequency standards are connected to the Coherent Reference Generator (CRG) for distribution (Fig 2). Relay switches select one of the frequency standard inputs to feed the driver amplifiers in the CRG. The output signals from the driver amplifiers are applied to frequency synthesizers for conversion and to further distribution amplification. There are 256 output ports provided to users with available frequencies at 0.1, 1, 5, 10, 10.1, 45, 50, 55, and 100 MHz. To minimize crosstalk the output signals have a 100 dB reverse isolation between them. One of the 5 MHz output ports from the CRG is sent to the Master Clock and Timing system to provide synchronized and very stable time.

The timing system consists of a triple redundant Master Clock (MCA), Time Insertion and Distribution Assembly (TID), and multiple Time Code Translators (TCTs) (Figure 3). The three time code generators in the master clock are synchronized and driven by the single, online frequency standard. All three generators are voted on by majority vote logic that selects a minimum of two within limits as the correct time of day and pulse timing. The TID is a distribution assembly that generates a modified IRIG-G code for distribution to all the TCT's in the complex. The number of individually addressable TCTs is limited to 100 by the number of output ports. The distribution time code from the TIDS's contains real time (Universal Time Code or UTC) and Simulation (SIM) Time. The SIM time is used primarily for testing, training, or software exercises.

Time Code Translators (TCT) translate the TID time code and provide outputs to users in a variety of formats. The Master Clock provides the 5 MHz distribution which originates from the online frequency standard. The TCT's provide timing pulses at 1 pps, 10 pps, 100 pps, and 1000 pps, time code on an RS-232 format and a 1 pps monitor output. This 1 pps port is used by the time analyzer to measure time offset and jitter performance with respect to the master clock.

METHOD OF MONITORING TIME DISTRIBUTION

Presently, most of the 1 pps TCT monitor signals are routed back to a patch panel near the master clock. The patch panel contains over one hundred 1 pps signals from individual TCTs distributing time from the master clock, plus ten more ports for TCT's free running from distinct 5 MHz inputs from each frequency standard.

A small sample of the TCT's are manually measured daily by a technician who connects one TCT output, along with the Master Clock output, to a HP5370B Universal Time Interval Counter. The counter measures the start and stop time between the sampled TCT and the Master Clock. The samples are measured over a 100 second period to allow sufficient averaging to measure the timing jitter (typically 1- 2 ns level). All frequency standards are sampled in a similar manner providing a single data point to characterize time offset from the master clock.

The current monitoring method leaves most TCT's unmonitored. As a result, performance data is typically not available and the station operations must rely upon the timing user to detect any failure or out of specification condition. The Time Analyzer was developed to address these operational shortcomings.

TIME ANALYZER SYSTEM DESIGN

The Time Analyzer System (Figure 4) was designed for continuous, autonomous, monitoring of TCT performance and does not interfere with timing system functionality. The Time Analyzer

program is written in Labview and is executed on a standard rack mount computer with LINUX operating system.

The instrument interfaces to the existing patch panel and multiplexes the 1 pps signals from individual TCT's to an HP E1420B Time Interval Counter. The second 1 pps signal for the counter comes from the master clock. The counter, switching multiplexers, and the controller to run the measurement process all reside in a standard VXI card cage. The Time Analyzer samples each TCT by switching through the HP E1472/3 multiplexer modules.

Long distance monitoring of remote TCTs is done through an RS-232 interface transmitted through fiber optic line and converted to IEEE 488 standard at the receiver. A second, remotely located VXI card cage and command module controls the multiplexing of the remote TCTs. The multiplexed 1 pps signals at the remote site are routed back to the local time analyzer through a single fiber optic link. To verify switching of the local and remote Multiplexer cards the command module switches to a time delayed reference signal between sampling. The delay signal at the local Time Analyzer is supplied by the master clock and by a custom built time delay circuit at the remote site. The switching is done between TCT sampling and is designed to give the operator confidence in the reliability of the sampled data.

TIME ANALYZER USER INTERFACE AND DISPLAYS

Front Panel

The primary program display "front panel" is shown in Figure 5. When the Time Analyzer Icon in the desk top is clicked the Time Analyzer begins executing using two default files. The two files provide information on TCTs and time standards to the program. The two buttons below the STOP button bring up editing windows. Using these editing windows, a TCT or standard can be removed or added to the program, the time offset can be adjusted, the location of the TCT or standard can be entered or changed, and the name of a time standard can be entered. The time offset in the data compensates for cable delay required to carry the one-pulse-per-second signal to the Time Analyzer Subsystem rack.

Below these buttons on the front panel is the STATUS light. This light will turn from green to orange to indicate a high level time analyzer alarm. There are three sources of errors: a TCT mean or standard deviation value outside the allowable range, an active time standard with no signal, and a mux error. The alarms are reported to station operators by the Status Summary Display Subsystem through an isolated relay switch closure. The switch is closed when one or more errors are active. Removal of all error conditions is required to return the light and the error status to the non-error (green) state.

The MUX STATUS light to the right, below the STATUS light, indicates a multiplexer error. After 100 measurements of the next TCT and after all time standards are measured, the multiplexer is switched to channel 111. There should be no signal on this channel. Data acquisition is then attempted. If the acquisition is successful (a signal is detected on the channel), the multiplexer is not functioning properly and an error will result. If the multiplexer does not switch from this channel, when the next TCT is to be measured, that TCT will flag an error. The two lights below the DATASET and MUX STATUS lights indicate whether a TCT or a standard is being measured at any point in time.

The histogram to the right of the lights and buttons discussed above indicates the time differences between all TCT's and the master clock. Each "bin" is 10 nanoseconds wide. The 21 bins in the center represent time differences from –105 nanoseconds to +105 nanoseconds. The two bins on either side of the center set of bins indicate time differences too large to fit into the center set. For these bins, the indicators are orange rather than blue. The height of each indicator displays the number of TCTs having time differences that fall within that bin's range.

The number matrix to the right of the histogram indicates the status of all local TCTs. The background color behind each TCT number is light blue when the TCT is not active. Green indicates that the TCT is present and no error has been detected. The background turns to orange when the TCT's time difference mean or standard deviation falls outside the acceptable range. Clicking directly on a TCT number will cause a detailed status window for that TCT to open. The window displays a histogram representing 100 one second measurements to determine the mean offset and standard deviation (jitter) for that individual TCT. This feature allows the time analyzer user to override the default chronological TCT measurement sequence.

To the left of the main TCT status matrix, at the bottom of the front panel, is a second TCT matrix. This matrix provides the same functions as the local TCT matrix, for the remote TCTs. The location of the TCTs have no effect on the behavior of the program other than the size of the time offset required in the TCT data file.

Between the remote TCT status matrix and the histogram are a set of indicators that display information on the TCT currently being measured. Data displayed include the location (local or remote) and number of the TCT, the subsystem and rack where the TCT is located, the active measurement number (0 to 99), and the value of the previous measurement. When the last measurement is made, this set of measurements is used to calculate the mean and standard deviation for that TCT. Those values are then checked against the limits to determine whether or not an error has occurred.

The frequency standard display is in the lower left corner. At the far left is a set of lights that display the time standard status. When the time signal is present and the channel is active, the light is green. The light is light blue when the channel is not active (the time standard name field is blank). The light is orange when the one-pulse-per-second signal is not present on an active channel. Standard names are shown in the next column. If the standard name is blank, the channel is not active. The next column shows the mean of the previous 100 measurements. Since 100 TCT measurements are made between frequency standard measurements, the mean value will remain at zero for the first 4 hours and 10 minutes after the program is started. The mean is not recorded in the log but the individual measurements of the dataset used to calculate the mean are saved in the log. The next column shows the measured drift per day of the frequency standards. The values in this column represent the difference between the current mean time offset reading and the mean time offset reading acquired 24 hours previous. This value is updated every 3 hours and is not recorded in the log. The final column in this area is a column of buttons. Clicking on a button will bring up the frequency standard detail window showing a histogram of the measurements that were used to calculate the mean value. The window functions in the same way as the TCT detailed window described above.

TCT Assignment List Window

The first column of the TCT Assignment List Window (Figure 6a) begins with an "L" or an "R" indicating whether the TCT is local or remote respectively. The location letter is followed by the TCT number. The next column is used to identify the subsystem to which the TCT is attached. If this parameter is blank, the TCT will be inactive and the background color for the status matrix in the front panel will be light blue. The next column is used to indicate the TCT location. The final column sets the time offset required for that TCT. This value should be the time required for the one-pulse-per-second signal to travel from the TCT to the Time Analyzer subsystem. Once set, this parameter should only require change when the TCT is moved.

Standard Assignment List Window

The Standard Assignment List Window is shown in Figure 6b. This window is similar to the TCT Assignment List Window except that there is no index. Here, the first column is the standard name. If the name is blank, the channel is skipped during the measurement process. The second and third columns identify the location of each standard. As in the TCT Assignment List Window, the final column holds a time offset which should correspond to the time required for the one-pulse-per-second signal to travel to the Time Analyzer Subsystem.

TCT Detail Window

The TCT Detail Window (Figure 7a) appears when the user clicks on one of the TCT numbers in the local or remote TCT matrix on the front panel. The window overlays part of the front panel but does not affect measurements being made by the Time Analyzer Subsystem except as described below.

Indicators at the top of the window show the TCT number, Subsystem, and Rack for the selected TCT. The histogram in the center of the window functions in the same way as the histogram on the front panel. Here, however, the values being displayed represent the measurement to measurement jitter. Two indicators below the histogram display the precise mean and standard deviation values for the TCT.

Two buttons are displayed at the bottom of the window. Clicking the CONTINUE button will close the window. Clicking on the NEW ACQUIRE button forces the Time Analyzer Subsystem to sample the selected TCT as the next TCT in sequence. If a TCT is being sampled when the button is clicked, that set of samples is finished, the time standards are measured, then the selected TCT is sampled. When the sampling of the selected TCT starts, two more indicators appear in the TCT Detail Window as shown in Figure 7b. The upper of the two new indicators displays the measurement count (from 0 to 99). The lower indicator displays the measurement values as measurements are made. In addition, the histogram registers each measurement in real time as it is made. When the measurement set is complete, the mean and standard deviation are re-calculated and the new values are displayed in the window. The TCT number and values are stored in the log, indicating out of sequence measurements. The time standards are read again before returning to the normal TCT sequence.

Frequency Standard Detail Window

Clicking on one of the buttons on the right of the frequency standard data display on the front panel will bring up a frequency standard detail window as shown in Figure 7c. This window functions in the same way as the TCT detail window described above. The only difference, besides the source of the measurements, is that the frequency standard name appears in an indicator at the top of the window.

The histogram in the detail window reflects the previous 100 time difference measurements of the selected frequency standard. The range of time differences covered by the time standard histogram is –10.5 microseconds to +10.5 microseconds. Each bin covers 1 microsecond. This dataset displayed in the histogram represents a time history of 4 hours and 10 minutes. Clicking on the NEW ACQUIRE button will cause the Time Analyzer VI to acquire a set of time measurements of the selected standard in the same way that TCT datasets are acquired, in 100 seconds. As with the TCT Detail Window, two new indicators appear when the measurement process begins. These new indicators show the measurement number and the previous measurement value. The mean and standard deviation are recalculated and the new values are displayed when the new dataset is complete. Data from the acquisition are stored in the log in the same way as TCT data.

CONCLUSION

We described the development of a multi-purpose, automated, and continuously operating time analyzer to measure and monitor distributed 1 pps signals in the NASA Deep Space Network. The instrument consists of a Labview based user interface on a LINUX OS and performs three major functions needed for operation of the DSN Frequency and Timing Subsystem.

1) Performance tests and monitor of timing offsets and jitter of 1 pps timing outputs of 120 TCT's relative to the station master clock. Time offset data from each TCT is summarized in histogram form. Additional test channels to monitor 1 pps from any other source (e.g. the GPS time sync receivers) against the master clock are also provided
2) Captures any anomalies and alerts station operators in event of performance or operational failure and archives timing configuration, station performance, and status.
3) Provides monitor of frequency offsets and long term stability of backup frequency standards with respect to the online frequency standard (which drives the master clock). Time and frequency offset data between online and backup frequency standards are analyzed over a twenty-four hour period and displayed numerically.

The user interface is designed to provide a high level summary of the entire timing system performance and to alert station operations in the event of an anomaly. Raw data is fully archived and network accessible if detailed analysis is warranted.

ACKNOWLEDEMENTS

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

REFERENCES

[1] P.F. Kuhnle, "NASA/JPL Deep Space Network Frequency and Timing", Proceedings of the 21th Annual Precise Time and Time Interval and Applications Meeting (PTTI) , December 1989.

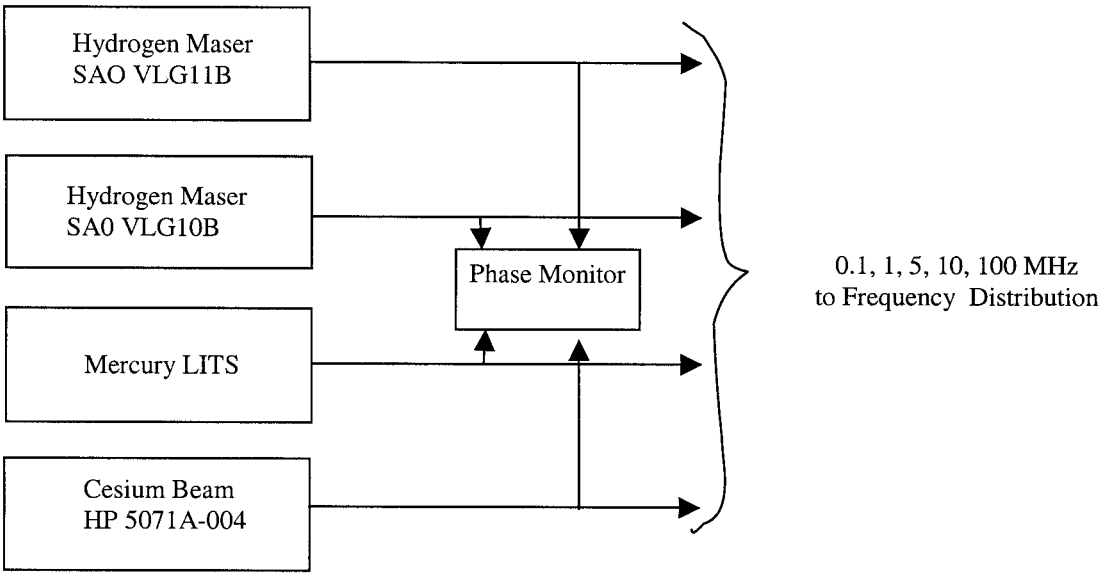


Figure 1. DSN Frequency Standards

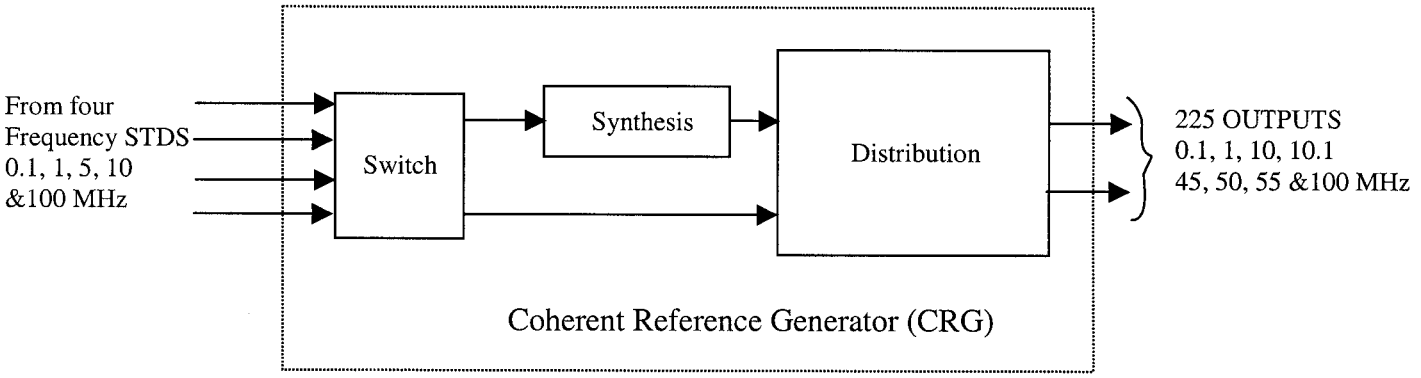


Figure 2. Reference Frequency Synthesis and Distribution

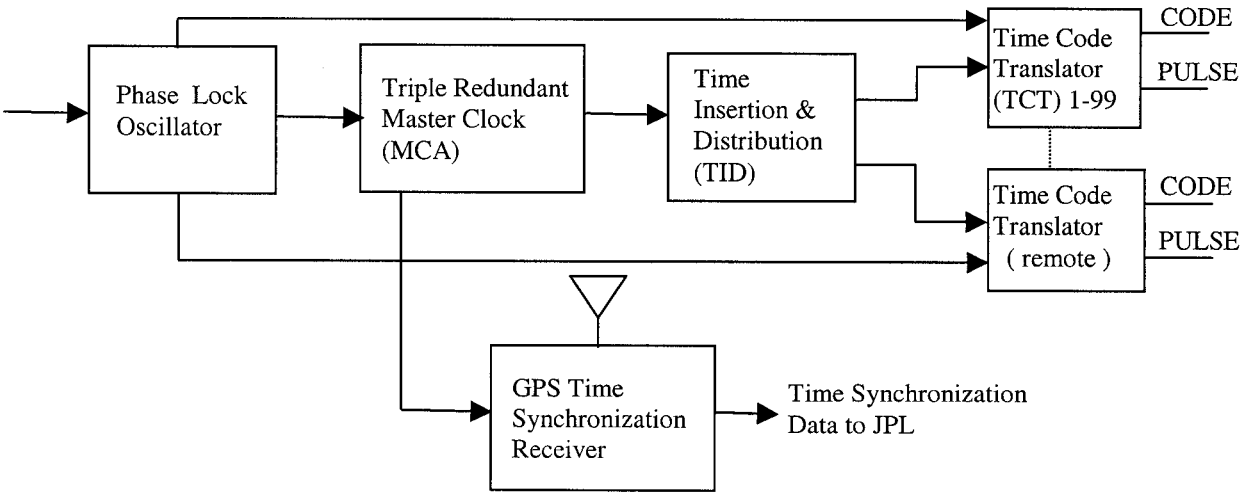


Figure 3. DSN Timing System

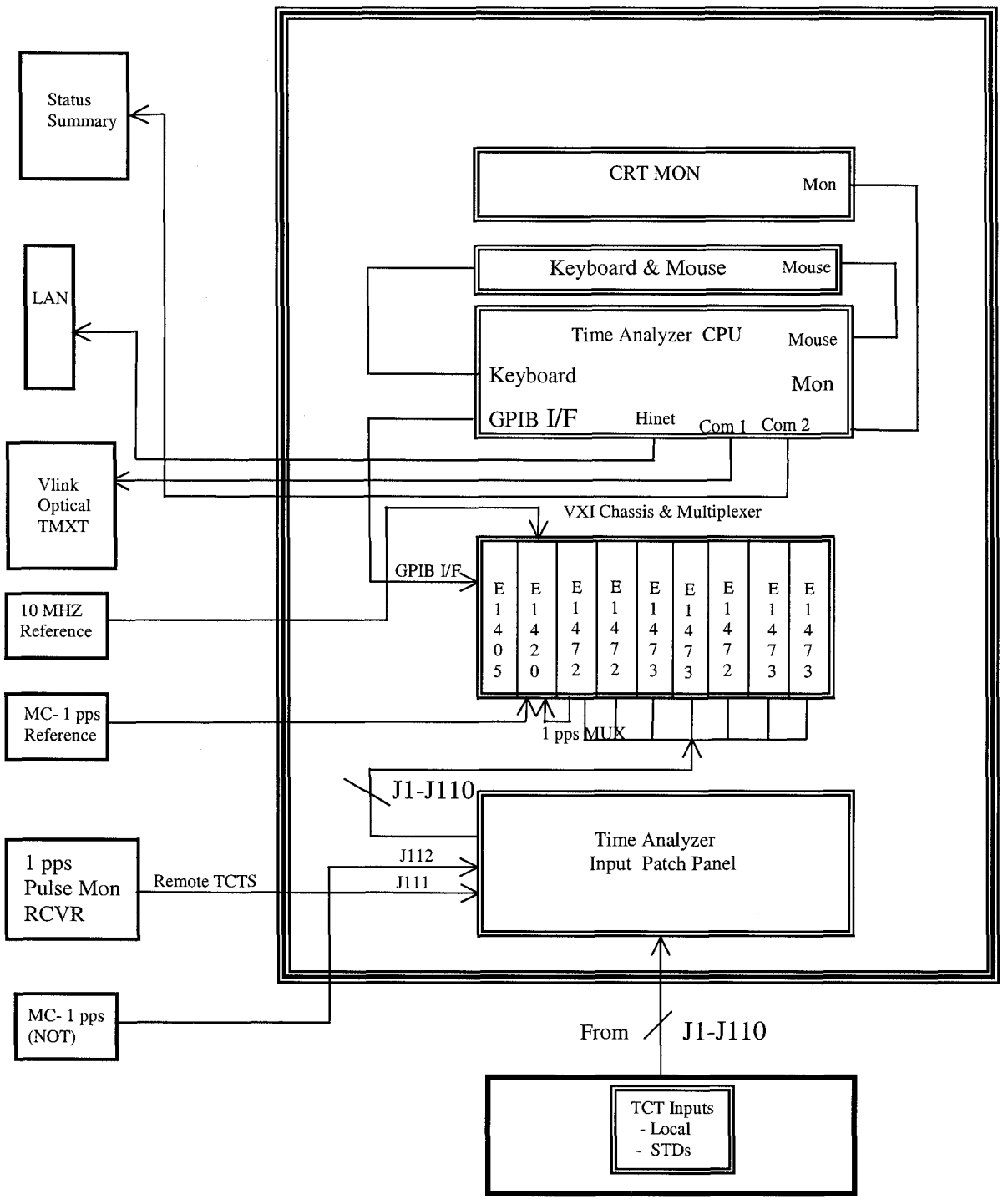


Figure 4: Time Analyzer Block Diagram

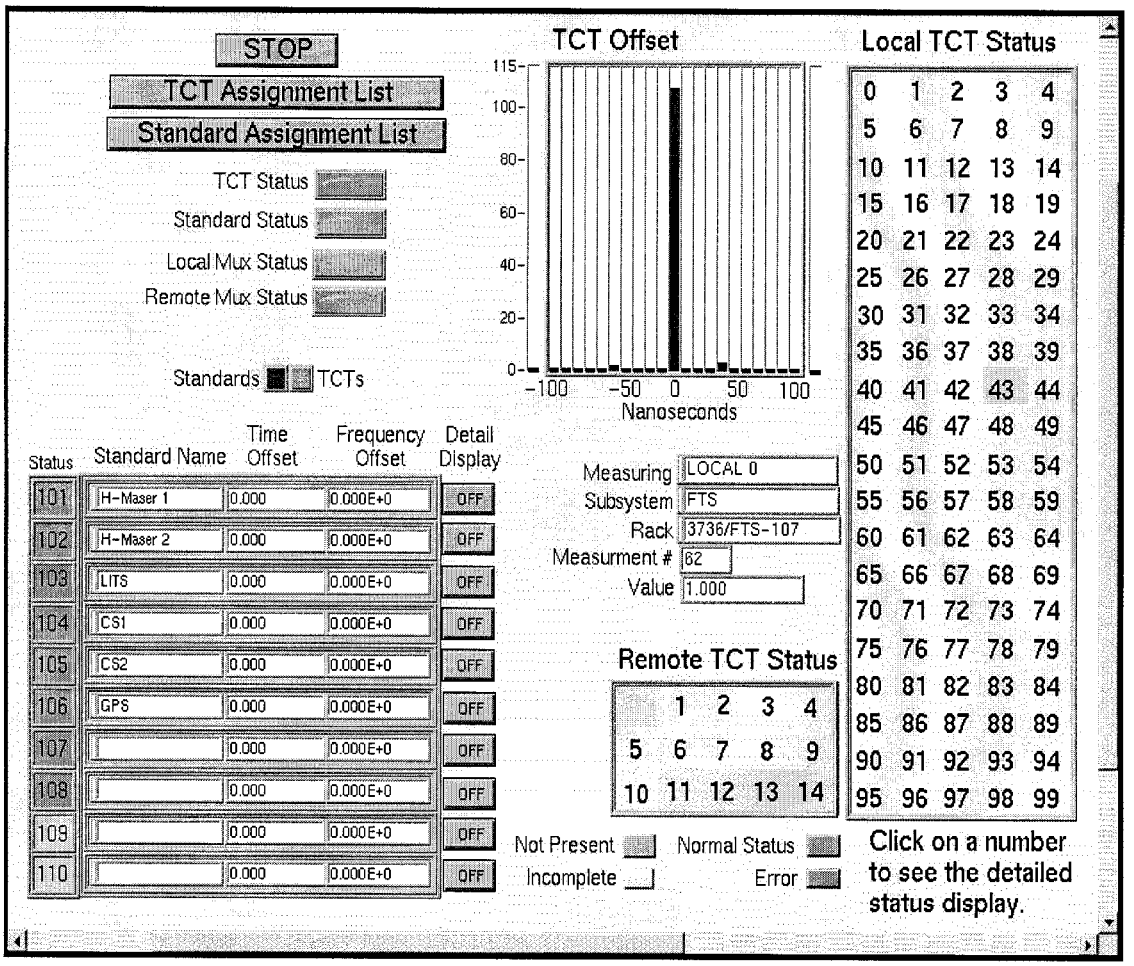
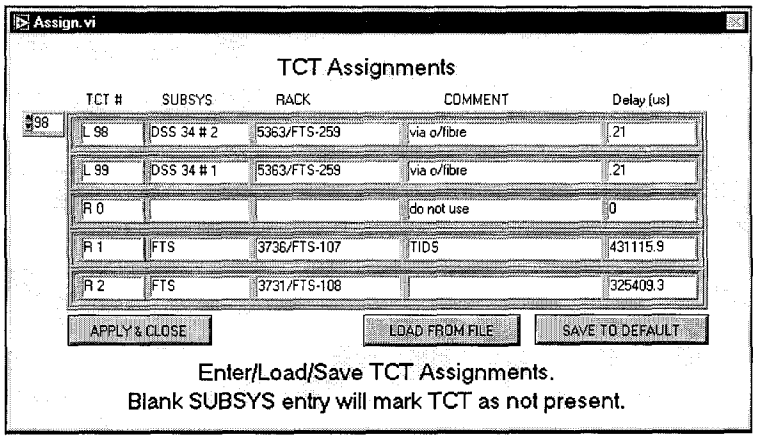
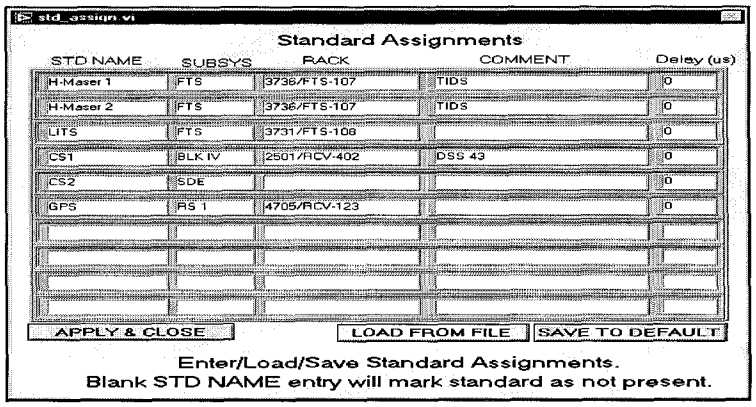


Figure 5. Time Analyzer Front Panel. The upper left shows summary alarm conditions to station operators. The right half displays individual TCT status and a summary histogram capturing synchronization of all TCT's to the master clock. The lower left provides a user configurable window for monitoring frequency standards and other 1 pps tests.

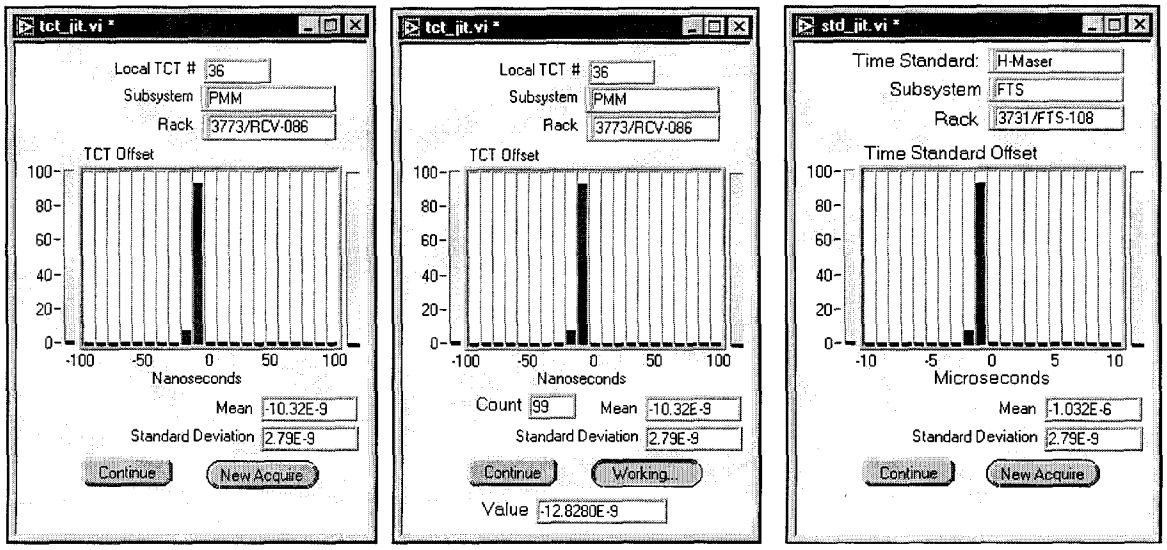


(a)



(b)

Figure 6: Assignment List Windows for a) TCT assignments and b) frequency standard and test input assignments.



(a) **(b)** **(c)**

Figure 7: Time offset and jitter detail display windows.
a) b) for individual TCT, c) for frequency standards or 1 pps test input..