Utilization of the Global Positioning System (GPS) for Timing Systems Under Range Standardization & Automation Phase-IIA Program

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Abstract

Lockheed Martin was awarded a contract at the end of 1995 by the US Air Force to upgrade the space lift range infrastructure at Cape Canaveral Air Force Station in Florida and Vandenberg Air Force Base in California. The goal of the RSA Program is to reduce the total cost per launch while meeting the Range safety requirements. This will be accomplished on both coasts by adopting industry standards and replacing antiquated instruments with Commercial-off-the-Shelf (COTS) equipment. Furthermore, common operation and maintenance procedures will be developed for both ranges in order to reduce the total life cycle cost and subsequent operation and maintenance expenses at both ranges. The purpose of this paper is to present the overall system requirements and system architecture for the three timing product subsystems.

INTRODUCTION

Our Timing System consists of three product subsystems: GPS Timing, Range Countdown, and generation of Time of Vehicle First Motion (TVFM). These three product subsystems will directly or indirectly utilize the precise timing information broadcasted by the GPS satellites to generate accurate time, stable reference frequencies, countdown clock, and first motion time to support launch and launch related activities in both ranges.

GPS Timing Subsystem

Lockheed Martin proposed a GPS-based timing system to provide accurate time-of-day information, precise & stable reference frequencies, and clocks to synchronize communication network, computer workstations, and radar & telemetry instruments. The decision of implementing a GPS-based timing system is based on three significant factors. (1) The GPS Timing System has a significant lower initial procurement cost and subsequent operation and maintenance expenses compared against a primary timing source, (2) The timing information broadcasted by the GPS satellites is available on a 24-hour basis, and (3) the accuracy of the GPS time is directly traceable to the DoD Master Clock (UTC-USNO) located at the U.S. Naval Observatory.

Requirements

Currently the stringent requirements imposed upon the GPS Timing Subsystem are that each timing station must have an accuracy within +/- one microsecond of UTC-USNO, the station-to-station accuracy must also be within +/- one microsecond, and all of the time codes generated by the GPS timing receivers must conform to Inter Range Instrumentation Group (IRIG) Standard 200-95, "IRIG Serial Time Code Formats". The accuracy and stability of timing product data are based on one sigma confidence level (68%).

The subsequent derived requirement requires that each timing station must be within +/- 500 nanoseconds of UTC-USNO, and the reference frequencies generated by each timing station shall be maintained at a Stratum Two level stability (1.6×10^{-8}). Based on a recent survey of commercial market, a typical Standard Positioning Service (SPS) GPS timing receiver will meet all of the timing requirements by maintaining an average of +/- 150 nanoseconds accuracy with respect to the DoD Master Clock. Furthermore, the reference frequencies generated by the GPS receivers will maintain a long-term Stratum One level (1×10^{-11}) of precision and stability. It has been determined that SPS receivers will meet and satisfy all of the requirements imposed by the Air Force.

Implementation

Each GPS timing station will either be a single receiver station or a redundant station. The GPS timing stations will be located throughout each range, including remote instrumentation sites. Refer to Figure 1, RSA-IIA GPS Timing System Overview.

Single Receiver Station

Each single GPS timing station will consist of a GPS-synchronized time and frequency receiver in a 3.5 inch chassis plus an antenna and pre-amplifier. Each timing receiver will have a basic IRIG-B and a One Pulse Per Second (1pps) output. In addition to the two basic outputs, each single station will have outputs for 1, 5, and 10 MHz reference frequencies and a multiple time code output module. The single receiver station will be strategically implemented throughout each range to allow timing users to receive time codes and reference frequencies from the nearest GPS timing station.

Redundant Receivers Station

Each redundant GPS timing station will consist of a redundant GPS synchronized time and frequency receiver in a distributed amplifier chassis with a fault-sensing switch unit (FSSU) embedded in the chassis. One of the GPS receivers will be designated as the Primary and the other one designated as Secondary (backup). Both the Primary and the Secondary receivers will generate the same seven time codes and reference frequencies (1 PPS, IRIG-B, 1, 5, and 10 MHz reference frequencies, plus two optional outputs). The same outputs from both receivers will be fed into the FSSU. Each FSSU module will receive and monitor the time codes or reference frequencies from both GPS receivers. In the event of an anomaly in the time code or frequency module in the primary GPS receiver, the FSSU will automatically detect the interrupt of time code or reference frequency and switch the output from the Primary GPS receiver to the Secondary GPS receiver. The redundant receivers stations will be implemented at all Consolidated Instrumentation Facilities (CIF), because the CIF provides a significant role in tracking the vehicle flight and ensures safety of the civilian community surrounding the range. The redundant system will provide enhanced reliability in support of the operation of CIF.

Concept of Operation

Initialization & Cold Start

Each GPS receiver is designed to operate on a 24-hour basis. In the initiation stage, the geodetic information of each GPS receiver location will be programmed into the GPS receiver. In the case where the geodetic information is not available or the receiver is being used as a mobile unit, the GPS receiver will be initialized in the "AUTO" mode to allow the receiver to perform the long-term position averaging after it is stationary. It should take approximately 10 minutes to have the receiver lock on to the GPS constellation and download the new almanac data prior to performing a timing solution. Once the GPS receiver has been initialized, it will receive the GPS almanac information and determine the health of each GPS satellite. This will allow the receiver to only track the satellites that are healthy based on the almanac information provided by the GPS.

Generation of Time Codes and Reference Frequencies

In order to allow the GPS receiver to achieve its optimal performance, the receiver will be allowed to track as many healthy satellites as possible. Multiple satellites offer the strength of averaging and minimizing errors. The effect of Selective Availability (S/A, intentional degrading of accuracy) can be reduced by increasing the number of satellites being tracked. The antenna of the GPS receiver will be placed where an unobstructed and full view of the sky is available. Once the receiver has been initially setup, it will track the satellites that are available over the horizon. The propagation delay induced between the antenna and receiver will be compensated for by programming the cable delay at a rate of one nanosecond per foot based on the length of the cable from the antenna to the GPS receiver. All of the COTS GPS receivers we have looked at have modular design and are capable of generating accurate time codes and precise reference frequencies by implementing a time code module or a reference frequency module in the timing receiver hardware chassis.

Monitoring Health and Status of GPS Timing Receiver

This section describes some of the features in the GPS receiver that can be monitored by a Network Manager via the RS-232 interface of the GPS timing receiver. The following bullets describe the capabilities in some of the COTS GPS receivers that are currently available:

- **Acquire and Lock onto the GPS Satellites:** The GPS receiver will provide an indication whether the receiver has locked onto the GPS constellation.

- **Time Quality Check:** In a case of an anomaly in the GPS constellation or defective antenna, the GPS receiver will be unable to track the satellites. When an anomaly occurs, the internal oscillator will drive the time codes and reference frequency outputs. Since the oscillator is not perfect, each GPS receiver will have an average oscillator error rate programmed and will calculate the error that is being induced by the oscillator. There are different levels of error indication that can be obtained based on the rate of drift of the internal oscillator. Each level can be set up to provide an alarm and report the status to the Network Manager.

- **Satellite List:** A Network Manager will be able to retrieve information from the receiver via the RS-232 interface to see which satellite is currently being tracked.

- **Alarm Notification:** Health and status of the receiver will be provided to the Network Manager via the RS-232 interface. In case of an anomaly, an alarm notification will be generated for the Network Manager to initiate repair or maintenance action.

Reliability, Maintainability, and Availability (RMA) of GPS Timing Receiver

Based on the performance values supplied by some COTS GPS receiver manufacturers, a typical GPS receiver will have a Mean Time Between Failure (MTBF) of 78,000 hours, and Mean Time To Restore (MTTR) of 1 hour.

Distribution of Time Codes and Reference Frequencies

Since the proposed Timing System has a distributed architecture, instead of a centralized system, it is the intent that time codes and reference frequencies from each GPS timing station will only be distributed to local users. Conversely, each user shall obtain time codes and reference frequencies from the nearest GPS timing station. In order to maintain the required accuracy and precision of time codes and reference frequencies, time codes and reference frequencies will be transmitted using dedicated copper or coaxial cables. The error induced in the cable delay will be compensated for by the individual user.

Test & Evaluation

Accuracy of the GPS Timing Receiver

Each GPS timing receiver will be factory-certified and tested to guarantee its accuracy and confidence level. It is intended that the accuracy of each receiver will be re-evaluated during a scheduled or unscheduled maintenance by measuring the 1pps output against another 1pps generated by a primary time source or from another GPS receiver that has been calibrated by a standard laboratory.

The Stability of the Reference Frequency

The reference frequencies, generated by the GPS timing receiver, will be measured against a calibrated frequency counter or reference oscillator. The reference oscillator must be either a primary standard, if available, or another GPS disciplined frequency standard at least of equal stability to the unit under test. The stability of the reference frequency will be measured by an oscilloscope. All clocks and reference frequencies will be verified to ensure that the stability is maintained at a Stratum Two level ($1.6x10^{-8}$).

Maintenance Concept

All of the GPS timing receivers and associated equipment will have modular design using solid-state electronic components. All of the repair and scheduled and unscheduled maintenance will follow the prescribed maintenance procedures mandated by the manufacturer.

Summary of GPS Timing System

The overall system architecture is defined based on the requirements specified in the Space Lift Range System (SLRS) Specification. The goal of a modernized GPS-based timing system is to reduce the cost of operation and maintenance. We believe the employment of a GPS-based timing system will enable both ranges to achieve this goal.

Range Countdown Subsystem

The Countdown Subsystem provides a timeline for coordinating a multitude of tests and system validations between the Range and space vehicle operator in preparation for the launch of space vehicles. This is to ensure that the range and vehicle operator are operating on the same time scale with a common lift-off time.

Countdown System Requirements

The current requirements, specified in the Space Lift Range System Specification, indicate that the Countdown Subsystem shall provide eight simultaneous countdown signals. The accuracy of the countdown signal shall be within +/- 100 milliseconds against the DoD Master Clock with a reference to a countdown script. The countdown format shall conform to the Inter Range Instrumentation Group (IRIG) 215-96 Standard. The Countdown Subsystem shall also provide the capability to allow authorized personnel to initiate, synchronize, suspend, resume, and terminate the countdown operation.