PRECISE TIME FROM GPS
FOR
DEPARTMENT OF DEFENSE
TEST AND TRAINING RANGES

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ABSTRACT:

The Range Applications Program consists of instrumenting several Department of Defense test and training ranges with NAVSTAR Global Positioning System (GPS) receivers and other equipment to provide Time, Space, Position Information (TSPI) data. TSPI is used to evaluate performance of test vehicles and participants in training exercises for Army, Navy, and Air Force Ranges.

The instrumentation being provided derives time tags and time synchronization signals by tracking GPS satellites. The precision required of time outputs depends upon the application in which a specific equipment is to be used. Precision varies from a few nanoseconds to a few tenths of a microsecond.

This paper outlines the scope of the Range Applications Program, particularly the application of its precise timing capabilities. Derivation of precise timing in the instrumentation being developed is addressed. It describes the various time outputs and their anticipated accuracies. Finally, applications of the time outputs of the RAP instrumentation are delineated. These applications include: precisely controlling Time Division Multiple Access (TDMA) for the data link equipment communicating TSPI data to the range evaluation centers; improving timing accuracy in Range Vernier Tracking Radars; and the precision time tagging of vehicle position and velocity data enabling the range evaluators to determine accurate Space information for TSPI.

INTRODUCTION

The NAVSTAR Global Positioning System (GPS) has been under development and test since the early 1970s. When fully implemented, the Space Segment will consist of 18 satellites in 12-hour (sidereal time) orbits at an altitude of about 10,800 nautical miles above the earth. The monitor and control segment tracks the satellites, predicts their orbits, and uploads the predicted orbits into the satellites. The user segment is composed of various receivers including those of the Department of Defense and others using the satellites for precise radio determination and radio navigation. A fallout from this system is a capability to determine precise time and precise time transfer from one location to another. In the early 1980s a Tri-Services Steering Committee evaluated GPS and determined its applicability to DoD test and training ranges. The purpose of these ranges is to test combatant equipment such as aircraft and to train DoD forces for combat. The Tri-Services Steering Committee recommended that a program be undertaken to evaluate the use of GPS on these ranges. A Range Applications Joint Program Office (RAJPO) was established at Eglin Air Force Base, Florida, to develop GPS equipment and supervise the Range Applications Program (GPS-RAP), including development of prototypes and deployment of early production equipment. Development of the prototype equipment and planning for its integration into five selected ranges started with a contract award to Interstate Electronics Corporation (IEC) in May 1985.

Concurrently IEC has been developing methods to realize the precision time capability of GPS. The purpose of this paper is to outline the GPS Range Applications Program, discuss the derivation of precise GPS time and its implementation in the GPS-RAP context, and to describe specific applications of precise GPS time.

EQUIPMENT AND APPLICATIONS

The equipment developed for this program is designed as a suite of modules suitable for grouping to form a system that meets the requirements of many specified applications. The heart of this family of equipment is the GPS Receiver Assembly. It accepts the GPS downlink signals from an Antenna/Preamplifier assembly and computes the required Time, Space, Position Information (TSPI) data in addition to the pseudorange correction data and other parameters, including satellite status, which are required for differential correction. A Receiver Power Supply provides the necessary receiver operating voltages. An optional Inertial Reference Unit provides inertial inputs to the receiver to assist in maintaining accuracy during periods of very high dynamics maneuvers including conditions in which the satellite view is occluded by the aircraft wing or fuselage. A Data Link System is provided for use on ranges that do not have a data link available for this application.

The items described above are designed to attach to a rail and to be contained within an AIM-9 type Missile pod. Adding a nose cone assembly containing GPS and Data Link antennas and GPS preamplifiers completes the configuration of a GPS instrumentation pod, which can be mounted to any aircraft capable of supporting an AIM-9 type pod. This suite of equipment, excluding the pod, is identified as a High Dynamics Instrumentation Set (HDIS).

For aircraft on which adequate internal volume is available or an AIM-9 pod is not supported, the components described above are packaged on a plate or in an ATR chassis and located appropriately within the aircraft. The GPS antennas, preamplifiers, and data link antenna are installed in each aircraft type according to the constraints of view and aircraft status, i.e., dedicated or operational (tactical). The Inertial Reference Unit is not required for lower dynamics aircraft such as a P3 or DASH 8.

A subset of the HDIS is provided for platforms on which the dynamics environment is less stringent, e.g., ships and land vehicles. In these applications, the length of the GPS Receiver Assembly is reduced by about half by deleting four of the five satellite tracking cards. The remaining tracker card is time multiplexed to track the required number of GPS satellites. The reduced length GPS Receiver Assembly with a Receiver Power Supply, GPS Antenna and Preamplifier, and Data Link equipment constitute a Low Dynamics Instrumentation Set (LDIS).

A Reference Receiver is required to implement the Differential Mode of GPS. It is essentially an HDIS without an Inertial Reference Unit. In one mode of differential operation, a stationary GPS receiver located at a surveyed site computes the pseudorange error between itself and all satellites in view and uplinks pseudorange correction values to all participants to compensate for GPS satellite ephemeris and clock prediction errors as well as ionospheric and tropospheric effects. The participants then apply these corrections to their pseudorange measurements for improved accuracy in position determination. For other methods of differential correction, additional processing capability is required. A separate computer, the DEC MicroVAX is provided for this purpose. The satellites broadcast on two frequencies; L_1 at 1575 MHz and L_2 at 1227 MHz. Ionospheric correction can be computed by model or by $L_1 - L_2$ differential delay measurement. Tropospheric correction is computed by model using either manually entered meterological data or by using a Meteorological Sensor Subsystem (MSS). The MSS is a commercially available weather station with temperature, relative humidity, and barometric pressure sensors and a processor to format the data for automatic input to the Reference Receiver. The Reference Receiver with its associated equipment is identified as the Reference Receiver/Processor (RR/P).

For applications in which weight, volume, power, and cost are at a special premium, a Position Location Mode (PLM) is provided. It provides TSPI data and supports differential GPS operation, but tracks the L_1 frequency and C/A code only.

RANGES TO BE EQUIPPED

Five DoD Test and Training ranges are presently scheduled for incorporation of GPS capability. They are:

- Gulf Range Drone Control Upgrade System (GRDCUS)
      Eglin AFB, Florida

- Mobile Automated Field Instrumentation System (MAFIS)
      Ft. Hood, Texas

- Extended Area Test System (EATS)
  Pt. Mugu, California

- Advanced Range Data System (ARDS)
  Edwards AFB, California

- Tactical Aircrew Combat Training System/
  Air Combat Maneuvering Instrumentation (TACTS/ACMI)
  Nellis AFB, Nevada

RANGE INTEGRATION

The Range Integration activity is a major feature of the program. Its function is to ensure that the equipment will integrate properly into the intended application. It provides a mechanism for coordinating interface design for both hardware and software, as well as a forum for identifying relevant issues of design, test, training, and logistics.

Interface Control Working Group (ICWG) meetings for each range are convened as specified by the contract. The working group consists of representatives from the GPS contractor (IEC), the range, range support contractors, and the RAJPO. Through the ICWG process, detailed equipment interface definitions are developed and specific responsibilities are defined. For interface issues requiring further study or analysis before resolution, action items are taken and completion dates are established. Action item status is reported periodically to the range and to the RAJPO.

The Interface Control Drawing (ICD) is the primary product of the range integration activity. It is prepared by the GPS contractor and incorporates the data coordinated through the ICWG process. The range integration activity continues through the interface definition phase to Site Acceptance Test (SAT) at which time a Range Integration Engineer coordinates the integration and test activities.

PRECISE TIME IN RAP EQUIPMENT

The derivation of precise time in a GPS receiver is a fallout of position determination. The standard solution uses four propagation time measurements to determine pseudoranges to four satellites, sets up the equivalent of four equations in four unknowns, and solves for a position in three dimensions and a time correction for the receiver clock. This procedure is described in GPS literature, for example, Reference 1. Applying the time correction to the receiver clock corrects it to "system time" or "GPS time". GPS time is an atomic standard time and is maintained by the GPS control segment using a bank of cesium beam time standards. Each satellite also uses a bank of cesium beam and/or rubidium standards. The satellites are monitored by the control segment and each satellite master clock is corrected by uplink messages from the control segment. Satellite master clock offset errors and rate of change of master clock are also uplinked to each satellite and are included in the satellite's downlinked navigation (NAV) message. Applying the downlinked corrections to the pseudorange measurements and then applying the position solution generated time correction to the GPS receiver clock synchronizes the receiver clock to GPS time. Also

contained in the NAV message are the parameters necessary to convert GPS time to Coordinated Universal Time (UTC). The U.S. Naval Observatory monitors to check and feed back corrections to the control segment in order to ensure that GPS time and UTC are maintained accurately (Reference 2). UTC from GPS satellites is maintained within 100 nanoseconds (ns) 3 sigma when compared to the UTC as maintained by the Naval Observatory. This is a brief description of time synchronization in GPS receivers. The instrumentation that IEC is providing for the Range Applications Program is a refinement of this approach.

The architecture of the IEC developed receivers differs from the classical design in that it uses digital methods for correlating the pseudo-random noise (PRN) codes to measure pseudoranges as well as digital methods for tracking the carrier transmitted by each satellite. To briefly summarize the digital receiver architecture, a radio frequency downconverter converts the received satellite signals to baseband frequencies where they are digitized and fed to tracking processors. The matched filter function is performed in the tracking processors, and the pseudorange and delta range measurements made there are fed to the Control Navigation Processor (CNP), which uses them to solve for position and time. Reference 3 describes the basic implementation of the IEC receivers.

The HDIS contains a downconverter, five tracking processors, and a CNP. This receiver tracks both the Precision (P) Code, 10.23 megachips per second, and the Coarse/Acquisition (C/A) Code, 1.023 megachips per second. It is a dual frequency receiver and will track either L_1 or L_2. It interfaces to an IRU. The LDIS contains one tracking processor and the same CNP. The single tracking processor is fast multiplexed to make measurements on four satellite signals. Typical dwell time on each satellite is four milliseconds. This receiver tracks P and C/A-codes on the L_1 frequency only. The PLM employs a design similar to the LDIS but without the capability to track the P-code. As indicated earlier, the Reference Receiver is used at a fixed position to generate corrections for use by the other receivers to improve position accuracy when operating in a differential mode. The Reference Receiver is also used to provide a precision time output.

A variation of the HDIS with one tracking processor is planned for the Ground Transmitter (GT) development. In the case of the GT, the HDIS is used to maintain the capability to track both GPS satellite L-band frequencies. GTs are an interim implementation to be used in the period preceding the full 18 satellite deployment. GTs broadcast signals on one frequency (L_1) with modulation almost identical to that of the satellites. With each GT at a surveyed position and its timing receiver providing accurate time, the HDIS/LDIS/PLM equipment tracks the GT signals and uses them in conjunction with the satellite signals to determine position, velocity, and time. The final member of the GPS-RAP family is the translator/Vehicle Tracking System (VTS). The VTS is composed of a link converter, a translator receiver and a reference receiver/processor. A translator is carried by a missile or other vehicle. It receives GPS signals and translates them from L-band to S-band for downlinking to the VTS. The VTS translator receiver, with its link converter, converts these signals to baseband and processes them to determine the translator's position and velocity. The translator receiver is a user of GPS time. It receives timing pulses and time tags for the pulses from a reference receiver to synchronize its operation to GPS time. The pulses are input to the translator receiver at a 1 Hz rate.

Figure 1 shows the relationship of the various GPS-RAP equipment, except the GT and the VTS. It also shows the data link equipment used to downlink the GPS derived TSPI data.

In lieu of performing an algebraic solution of four simultaneous equations to determine position and receiver time offset, the GPS-RAP equipments use a Kalman filter for optimal estimation of these quantities. Table 1 shows how these filters vary from equipment to equipment depending on the dynamic conditions in which each is designed to perform.

As indicated in Table I, Kalman filters in all configurations have two clock (time) filter states continually estimating receiver clock offset and the rate of change of each receiver's clock offset. The Reference Receiver constrains all but the position and clock states since it is stationary at a surveyed position. The Reference Receiver with the precise timing option is also stationary. In this configuration the position states are constrained so that all the pseudorange measurements are used to produce a better estimate of the clock states.

The timing outputs of the GPS-RAP receivers are pulses and time tags. The pulses are output at a 1 pulse-per-second (pps) rate synchronized to GPS time (or UTC in the case of the Reference Receiver with the timing option). The time tags may be applied to the 1-pps output, as is the case with the PLM, and are always applied to outputs of position, velocity, acceleration, and measurement data. Pulse outputs from the receiver occur as GPS time changes from one second
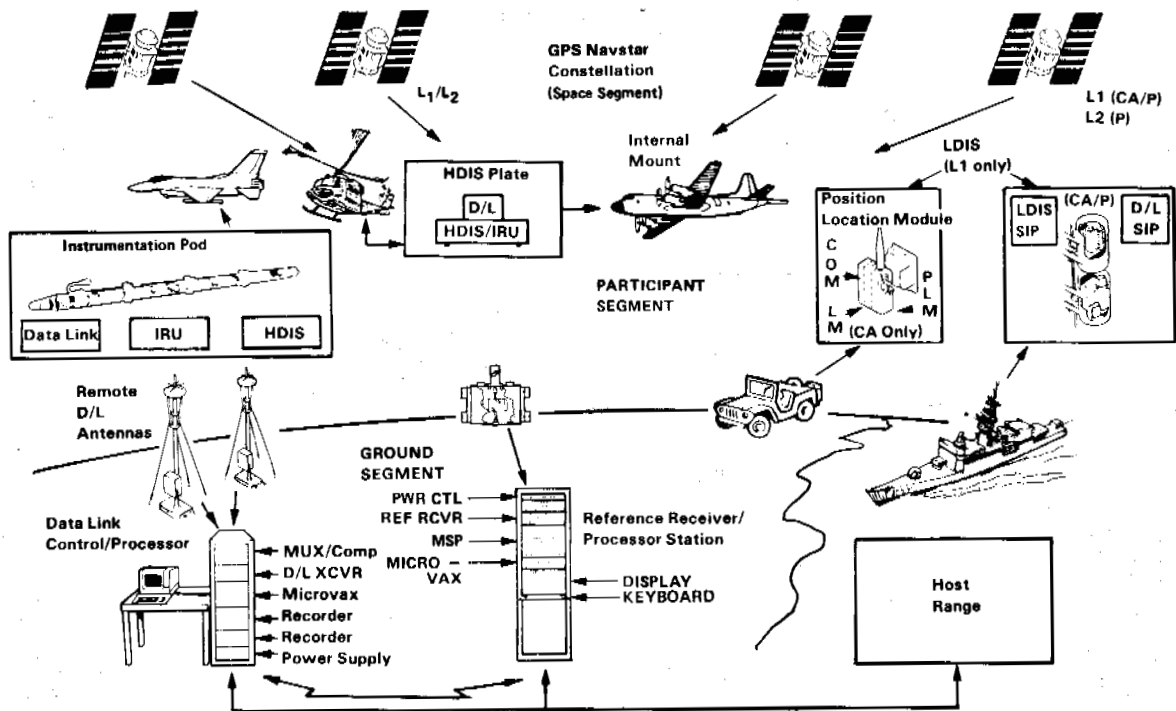

Figure 1. GPS Range Applications System

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TABLE I. KALMAN FILTER CONFIGURATIONS

Filter States	HDIS Inertially Aided	HDIS Unaided	LDIS	PLM	Reference Receiver (Differential)	Reference Receiver (Precise Timing)
Clock Offset	1	1	1	1	1	1
Clock Rate	1	1	1	1	1	1
Position	3	3	3	3	3	--
Velocity	3	3	3	3	--	--
Acceleration	3	3	3	3	--	--
Inertial Gyro Biases	3	--	--	--	--	--
Inertial Accelerometer Biases	3	--	--	--	--	--
Total States	17	11	11	11	5	2

to the next with varying degrees of accuracy. In the standard HDIS/LDIS and Reference Receiver implementation, the 1-pps output is derived as shown in Figure 2. The local oscillator frequency generated in the synthesizer portion of the RF downconverter is divided down to 1 Hz and shaped into a pulse the rising edge (nominally 0 to 5 volts) of which is synchronized to the change from the nth second to the $n+1^{th}$ second, GPS time. The resettable counter operates from a 10.23 MHz source. Hence the smallest incremental time change in the 1-pps output is about 98 ns. The actual error in the 1-pps output due to this incremental time change depends on the phase angle of the 10.23 MHz zero-crossing relative to GPS time. The receiver's overall accuracy depends on several other factors, including signal delay through the receiver, measurement accuracy, and the ability to compensate for receiver and cable delays.

As shown in Figure 2, the accuracy of the 1-pps is partially dependent upon the phase of the 143.22 MHz input to the first divider. To obtain better accuracy, it is necessary to control the phase of the local oscillator. In the Reference Receiver timing option, an external frequency standard (cesium beam or rubidium) and a Precision Time Module (PTM) are substituted for the internal local oscillator. The PTM controls the phase of the 143.22 MHz signal input to the divider chain. Its connection is the other pole of the switch shown in Figure 2. Figure 3 shows the means of controlling the phase of the 143.22 MHz signal generated from the external frequency standard. The phase shift of this signal is controlled by the receiver software based on the receiver clock offset error as determined in the Kalman filter. The receiver software resets the numerically controlled synthesizer to advance or retard the phase angle of its output in

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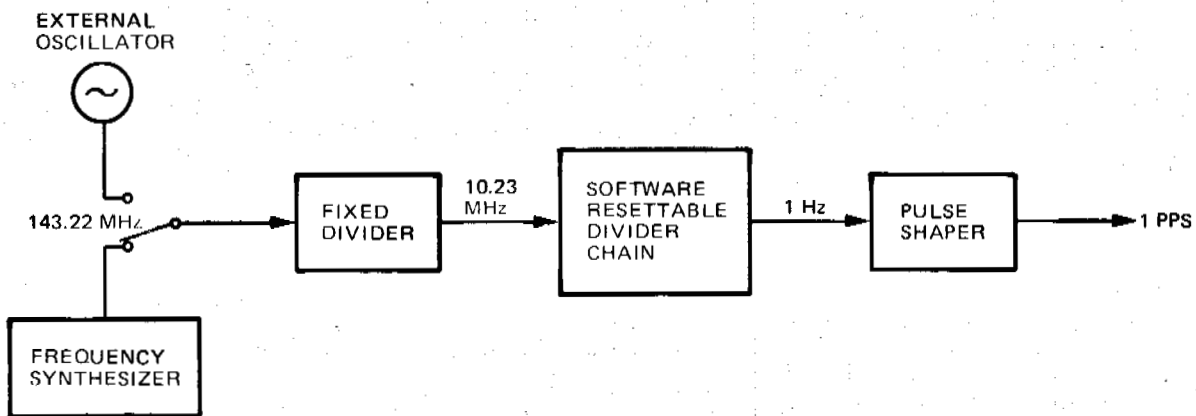63734

Figure 2. Generation of 1–pps Output in Less Precise GPS–RAP Receivers.
Software Resets the Counter Chain To Correct for Clock Bias as
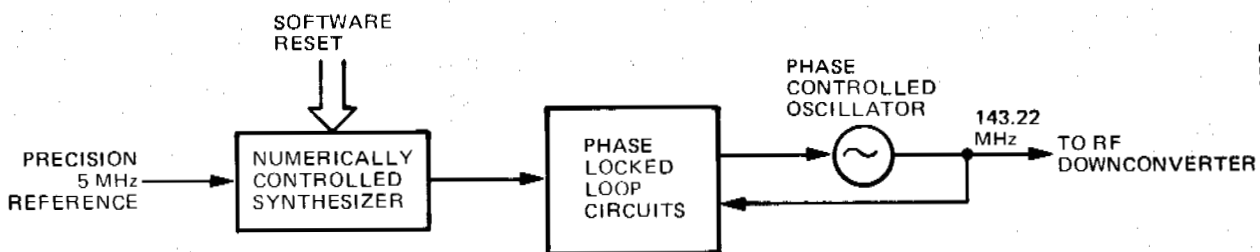Determined in the Kalman Filter.

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Figure 3. Functional Representation of the Precision Time Module (PTM).
Software Resets the Numerically Controlled Synthesizer To Control
the Phase of the 143.22 MHz Signal Input to the RF Downconverter

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increments of 0.36 degrees. The phase-locked-loop circuits detect any phase difference in the output of the phase controlled oscillator and advances or retards the phase of its output in increments of 0.36 degrees to match the instantaneous phase angle of the synthesizer. The stability of the 143.22 MHz output is controlled by the 5 MHz reference frequency standard and the phase angle of the 143.22 MHz output is controlled by the software reset. When the phase controlled oscillator output is divided to 10.23 MHz and counted down as shown in Figure 2, the incremental phase shift of 0.36 degrees in the numerically controlled synthesizer results in an incremental shift of about 0.2 ns in the 1-pps output. The 1-pps output is thus adjustable to ± 0.1 ns by resetting the counter chain and adjusting the local oscillator phase output of the PTM.

ERROR BUDGETS

Total expected error in time outputs of a RAP receiver is a function of the application. The applications are time tags for events such as position determination or weapons firing, time tags reduced to UTC, 1-pps outputs for GPS time or UTC time and the relative errors in time outputs for several receivers operating in the same mission. The sources of error in time determination affect the application accuracy in different ways depending upon which are common mode bias errors. As with the position errors, time error depends upon the errors shown in Table II, the User Equivalent Range Error (UERE) budget. This is the expected error in the range measurement for each satellite. In the general case as shown in reference 1, UERE multiplied by Time Dilution of Precision (TDOP), a function of satellite geometry, gives the expected error in time (in a statistical sense).

Table II is the RAP error budget as given in reference 4, the system level specification for the HDIS. It applies to the reference receiver and to the LDIS (See Table 4 note). This error budget is similar to the error summary given in reference 5. Martin characterizes these error sources as to their randomness and bias types in this paper. A typical TDOP is 1.2. Converting the above UEREs to nanosecond delays and multiplying them by 1.2 gives the expected GPS time errors for the conditions and codes tracked in Table II. Table III shows these errors.

These errors are for time and position solutions at the receiver antenna, which is suitable for time tags. To output the 1-pps on time, the system must compensate for the delay through the receiver. This delay is determined in the factory and entered into the data base. It remains relatively constant. The Reference Receiver with the precise timing option uses a Test Signal Synthesizer to measure the time delay through the receiver during periodic calibrations.

TABLE II. GPS STATIC RANGE ERROR BUDGET

Source	Error Budget (ft)			
Space Segment				
— Clock Error	10			
Control Segment				
— Ephemeris Error	8.6			
User Segment	P-Code		C/A-code	
	$C/N_O =$ 38 dB–Hz	At loss– of–lock	$C/N_O =$ 38 dB–Hz	At loss– of–lock
Ionospheric Delay	1.3	5.3	21.0	21.0
Tropospheric Delay	1.3	1.3	1.3	1.3
Receiver Noise, Quantization and Channel Bias	0.8	3.2	8.0	32.0
Multipath	4.0	4.0	10.0	10.0
UERE (RSS)	13.9	15.2	27.9	42.5

TABLE III. GPS TIME ACCURACY FOR TDOP = 1.2

Parameter	P-Code		C/A-code	
	$C/N_O =$ 38 dB–Hz	At Loss– of–Lock	$C/N_O =$ 38 dB–Hz	At Loss– of–Lock
UERE (ns)	14.1	15.4	28.3	43.5
Expected Time Error (ns)	16.9	18.4	34.0	52.2

A further error source is the conversion to UTC. In addition to the four leap seconds inserted into UTC since the GPS system became operational for test purposes, a polynominal conversion is used for a more precise correction. Each satellite NAV message includes the coefficients for this polynomial. The U.S. Naval Observatory steers these coefficients to maintain satellite conversion to UTC within 100 ns, 3 sigma. Table IV summarizes these errors and shows the expected error in the 1-pps output.

TABLE IV. EXPECTED ERROR IN 1-PPS OUTPUT, NANOSECONDS
(P-CODE, C/N_o = 38 dB-Hz)

Parameter	LDIS	HDIS and Reference Receiver	Reference Receiver With Timing Option
Expected Time Error (from Table III)	30.2[1]	16.9	16.9
Expected Receiver Delay Error	4.0	4.0	4.0
Expected 10.23 MHz Counter Error	28.3[2]	28.3[2]	0.06[2]
Expected GPS Time Error (RSS)	41.6	33.2	17.4
GPS to UTC Error (1 sigma)	33.3	33.3	33.3
Expected UTC Error	53.2	47.0	37.6

NOTES

(1) The LDIS uses a model to correct for ionospheric delay rather than L_1/L_2 measurements; hence its expected time error is larger.

(2) Resetting the 10.23 counter chain moves the 1-pps output in increments of about 98 ns. The true GPS second mark will thus be up to 49 ns earlier or later than the pulse. This is a uniform distribution with an expected error of 28.3 ns. The same applies to the 0.2 ns increment in the timing option.

The expected errors shown in Table IV are for an individual receiver compared to an absolute standard. On a range, for some applications such as Time Division Multiple Access (TDMA) data links, the test or training participants will be in the same area and may be tracking the same satellites. If they are, the difference in time marks between the participants will be less than the budgets shown. The relative time errors decrease because some of the error sources are common mode or correlated and hence cancel out. For example, in Table II, the satellite clock and ephemeris errors are common. The ionospheric errors are correlated over distances of 300 nautical miles or more and troposheric errors are also correlated in local areas. Counting error residuals in these sources as one foot, UERE reduces to 4.2 ns for P-code. The 1-pps output error for one HDIS relative to another HDIS will be 29 x $\sqrt{2}$ or 41.0 ns, and will be dominated by the counter errors of the two receivers. Time tags for positions will show a similar benefit.

APPLICATIONS

The precise timing available with the GPS-RAP equipment makes several applications practical. Among them are:

- A true data link TDMA with minimum guard bands.

- Greater accuracy for Range Vernier Radars.

- Time tagging of position, velocity, and acceleration outputs to produce better TSPI.

The Range System under development in the GPS-Range Applications Program includes a TDMA Data Link Subsystem. The TDMA implementation provides that each participant transmits TSPI data in an assigned time slot up to ten times per second. Guard bands between time slots are required to prevent collisions of messages transmitted by different participants. These guard bands must include an allowance for propagation time between the transmitter and receiver as well as an allowance for timing errors. With all participants equipped with HDISs using GPS timed pulses, a timing error guard band of four times the expected error (133 ns) will prevent collisions better than 99.9 percent of the time even with all participants at the maximum range from the ground stations. With all participants using the same constellation of satellites, collisions will be even less frequent. The use of GPS time for controlling the TDMA will make the Range System Data Link Subsystem very robust.

The requirements and planned use of Reference Receivers with missile and satellite tracking radars is the subject of a companion paper at this meeting (Reference 6). It is the plan of the Western Space and Missile Center to locate Reference Receivers with timing options at various sites on the Western Test Range to improve timing for the Range Vernier Radar System. Providing that the ionosphere is correlated at the various sites, each Reference Receiver performs its own tropospheric corrections and that the Reference Receivers track the same constellation of satellites (up to eight), the expected relative timing error between these sites is 9.1 ns. Correlation of the ionospheric delays between Hawaii and California is probable providing that the day-night terminator is not between them.

The RAP family of GPS receivers outputs time, position, velocity, and acceleration data of the vehicles on which they are mounted. They do not output complete TSPI (Time, Space, Position Information) which the ranges need for the safety of any given exercise and for evaluation of participant performance. The TSPI element that RAP receivers do not provide is Space. Space information is defined as relative position and velocity vectors from one participant to another.

The expected time errors in Table III apply to the time tags generated for participant position, velocity, and acceleration data as downlinked via a data link. The participant time tags will show different times. With the precision attainable with RAP receivers, interpolation of participant positions, etc., to a common time can be accurately done in the host range computers. Accurate relative position/velocity vectors can then be generated under the dynamic conditions expected for the various vehicles thus providing the ranges´ evaluators with accurate TSPI including Space.

CONCLUSIONS

Development of the equipment discussed in this paper has occurred and is continuing in three areas; Internally funded Research and Development (IR&D), the Range Applications Program, and other existing programs. The High Dynamics Instrumentation Set, the Low Dynamics Instrumentation Set, the Position Location Module, and the conventional Reference Receiver/Processor presently on contract under the Range Applications Program will provide solid sub-microsecond timing precision to DoD Test and Training Ranges. With the precise timing option included, the Reference Receiver/Processor provides precision time output pulses accurate to a few tens of nanoseconds. The applications identified to date for these timing precisions include improved Time, Space, Position Information (TSPI) data, improved Time Division Multiple Access (TDMA) data link operation, and improved accuracy for Range Vernier Radar Systems.

REFERENCES

1. R.J. Milliken and C.J. Zeller; "Principle of Operation of NAVSTAR and System Characteristics" The Institute of Navigation GPS Monograph Volume I, 1980.

2. F.N. Withington and W.V. Klepczynski "Operational Results of GPS in Time-keeping" Institute of Navigation National Technical Meeting, January, 1986.

3. P.C. Ould and R.J. Van Wechel; "All-Digital GPS Receiver Mechanization" The Institute of Navigation GPS Monograph, Volume II, 1984.

4. Specification Number 7328226, Code Ident. 07421 dated 16 June 1986, "System Specification for Global Positioning System (GPS) High-Dynamics Instrumentation Set (HDIS), Type A".

5. E.H. Martin; "GPS User Equipment Error Models" The Institute of Navigation GPS Monograph, Volume I, 1980.

6. J.B. McConnell and R.L. Baker; "WSMC Approach for Using GPS to Synchronize Remote Site Timing" PTTI Meeting, December, 1986.

QUESTIONS AND ANSWERS

GERNOT WINKLER, UNITED STATES NAVAL OBSERVATORY: You indicate two states for your time reference receiver. What is the intended purpose of the second state?

MR. LUSE: The two states would be clock offset and clock rate bias.

MR. WINKLER: What are you going to do with your rate bias?

MR. LUSE: We will factor it in and account for it as closely as we can.

MR. WINKLER: I am worried about the resolution that you can expect in the Kalman filter. Unless you are filtering for a day or so, with the expected errors in time, the resolution would not be much better than a part in ten to the twelfth.

MR. LUSE: I understand.