LEO Satellite Time Synchronization Architecture

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Abstract

A GPS-based time synchronization technique employing a refined HW circuitry and SW algorithm is considered as fine time-management system for Low Earth Orbit (LEO) remote sensing satellites. By synchronizing the On-Board Time (OBT) within satellites to the GPS 1PPS, a very expensive, highly accurate on-board clock is not required to determine the precise on-board time management. Also, the satellite command generation in ground stations and post-processing of earth observation data which a particular image is acquired. This paper analyses on-orbit verification of the existing satellite time sync architecture and presents a new time sync architecture, operation and relation between the OBT and the GPS time.

Keywords: LEO remote sensing satellite, GPS 1PPS, time synchronization, On-Board Time (OBT)

1. Introduction

Generally, the way of time sync architecture used in LEO satellites is that the OBT corresponds with the GPS 1PPS provided by a GPS Receiver using a Digital Phase Lock Loop (DPLL) circuitry. However, this time sync architecture needs too many time, because 3 internal Processors (ECU, OBC, and RDU) perform time synchronization among each other before the synchronized signal is passed to the Payload. During the time sync process, the satellite is in Safe-Hold state for about 208 seconds.

New time sync architecture, following this synthesis, shows the time sync architecture way on the basis of a RTC (Real Time Clock). Considering the efficiency and dilatants of the time sync architecture, the design including the SW Control part were carried out and the operation method and the efficiency analysis were evaluated.

2. Existing Time Sync Architecture

2.1 Existing Time Sync Architecture

The existing time sync is based on a sequential architecture as shown in Figure 1. The ECU processes the 1 Hz time signal supplied by the GPS receiver. Subsequently, OBC and RDU process the time sync signal from the ECU. Finally, the RDU provides the synched 1Hz to Payload for timing reference information.

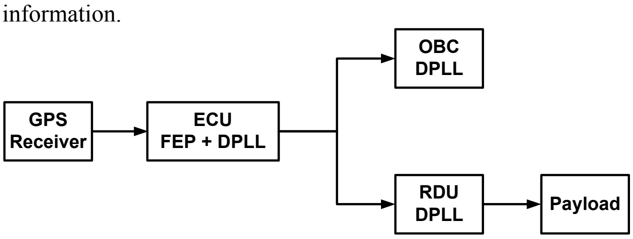

Figure 1. Existing Time Sync Architecture

The adjusted time of ECU's 1Hz synchronized to GPS 1PPS (Pulse Per Seconds) is maximum 104 sec and the OBC and RDU synchronization to ECU 1Hz is also maximum 104 sec. By summing up, the maximum adjust time is 208 sec and in this period the satellite is in Safe-Hold state, i.e. the satellite becomes no execution and no transmission of satellite's control and order. 208 sec in satellite operation is a long time and if the satellite requires urgent actions in this period, the ground station cannot react with the adequate emergency activity.

The FEP (Front End Processor) in the ECU DPLL is designed for anomaly situations of the GPS 1PPS. The PI (Proportional plus Integral) control algorithm is applied for error control between GPS 1PPS and ECU 1Hz and provides pseudo 1Hz for robust control.

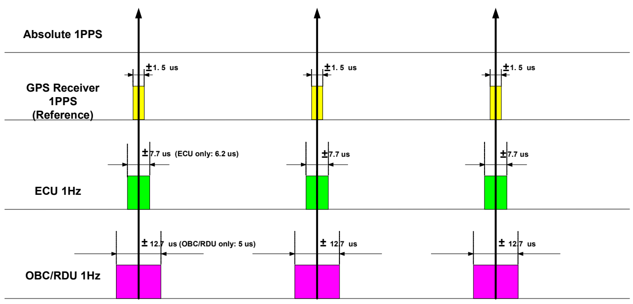

Figure 2. Satellite Time Sync Accuracy Analysis

Furthermore, the analysis explains the 1Hz time sync accuracy in the satellite from GPS 1PPS to OBC/RDU 1Hz which is the last part of 1Hz Output.

As shown in figure 2, the 1PPS accuracy of GPS receiver used in LEO Satellite is ±1.5 us. Together with the ECU it adds up to totally ±7.7 us. OBC and RDU contribute this value with an accuracy of ±5 us. Accordingly, the overall 1Hz uncertainty amounts to ±12.7 us.

2.2 On-Orbit Time Sync Performance

The real On-Orbit Time sync performance is provided as shown in Figure 3 & 4. The time difference between GPS 1PPS and EUC 1Hz is internally 1.5us which is lower than the analysis result in section 2.1 and this value of error is stable without the GPS receiver tracked satellite and Satellite temperature variation. The GPS 1PPS interval measured in ECU DPLL is about 0.9998999 sec (49945003 or 49945004 counter) and the counter variance is internally 1 counter. The real satellite operation reveals that the GPS 1PPS is very accurate and stable.

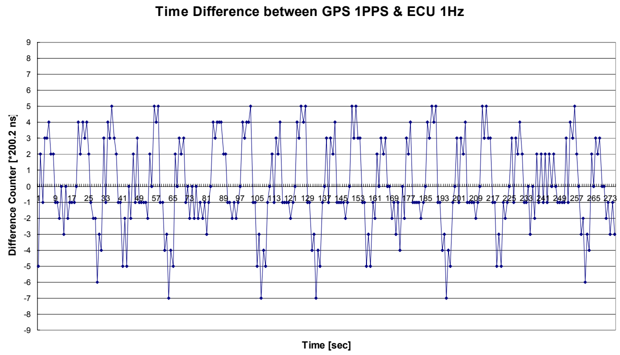

Figure 3. Time Difference GPS 1PPS and ECU 1Hz

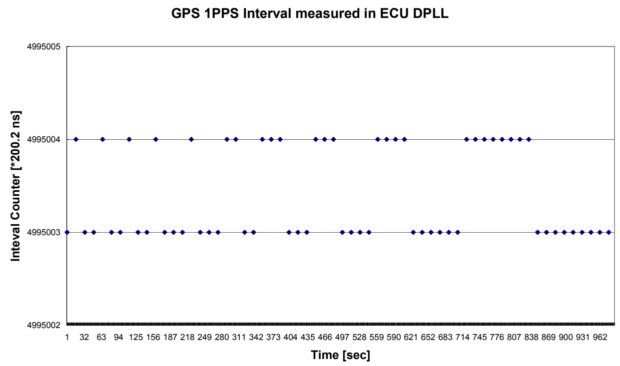

Figure 4. GPS 1PPS Interval measured in ECU DPLL

2.3 GPS 1sec epoch & GPS 1PPS

In LEO Satellite, GPS Receiver is running in 1PPS free running Mode which means that GPS 1PPS is provided on the GPS receiver local time and it is not synchronized the GPS time 1 sec epoch which is absolute time as shown in Figure 5.

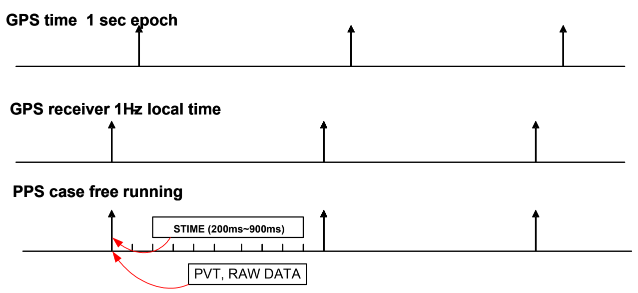

Figure 5. GPS 1sec epoch & GPS 1PPS

Because internally, the time and GPS telemetry information is processed on GPS receiver local time and if GPS 1PPS is synchronized the GPS time 1 sec epoch, some telemetry parameters have a delay up to 1 second and indicate 2 times the same value.

In GPS 1PPS free running mode, 1PPS time information of GPS receiver is supplied in the range 200 ms ~ 900 ms after occurring of the 1PPS, the position of satellite, and other GPS information are supplied corresponding with GPS local time.

On the basis of this information, the 1PPS operation mode of present satellite is the Free-Running Mode. But when the GPS Receiver local time is used, the GPS time telemetry has a drift which is a known factor and can be corrected after Ground Station post-processing.

The GPS 1PPS generated by GPS Receiver local time has a long-term drift caused by the crystal oscillator used in GPS Receiver.

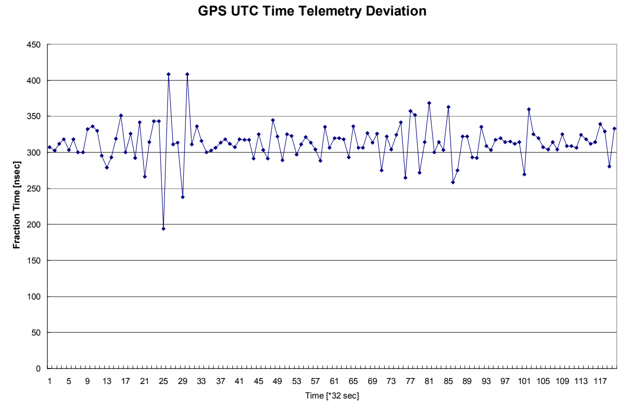

Figure 6. GPS UTC Time Telemetry Deviation

As shown in Figure 6, the GPS receiver local time drift and GPS 1PPS accuracy is analyzed using the UTC Time telemetry of GPS 1PPS generated by GPS receiver local time. The drift is about 300 ns/32sec i.e. 9.4 ns/sec which is lower than the analysis result in section 2.1.

This drift does not provide a problem because there is no need to adjust OBT setting within the satellite life time of 3 years.

2.4 GPS Time & OBT telemetry Processing

As mentioned before, we designed and analyzed the time synchronization architecture corresponding to the OBT with GPS 1PPS from a HW point of view. But, the satellite time information is provided to the Ground Station as a telemetry formatting where also software is involved.

In this section, we present the analysis about the relation between time information of GPS 1PPS and OBT. The following picture shows the relation between GPS 1PPS time information and OBT.

When the satellite begins with its initial operation, the OBT time is set up by ground command. Additionally the set-up of GPS Receiver is completed and the GPS 1PPS is synchronized to the OBT. After this synchronization the relation between OBT and GPS Time was observed.

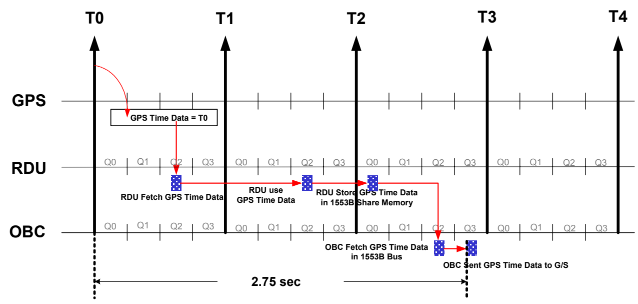

Figure 7. GPS Time and OBT Telemetry Processing

The time information of GPS 1PPS taken by GPS receiver is transmitted by a MIL-STD-1553B to the OBC and the OBC SW transmits the data to ground after OBT time-stamping and forming telemetry packets.

Figure 7 shows the difference between the GPS 1PPS time data and the OBT which amounts to 2.75 sec when received by the ground. Therefore, the OBT is set-up 2.75 sec later than GPS time data and the Ground Station has to consider this time difference in adjusting OBT with respect to GPS time.

After the adjustment of the OBT the satellite operation by ground can be easily be performed.

3. Proposed Time Sync Architecture

The existing Time Sync architecture which has the error factor in many stages provides disadvantages for satellite attitude control and high resolution Earth Image processing. Since a reduction of the error is required simpler and more efficient time sync architecture is proposed.

The newly proposed time sync is a simple architecture that diminishes the propagation delay as the time sync circuit is limited to only 1-Processor as shown in figure 8.

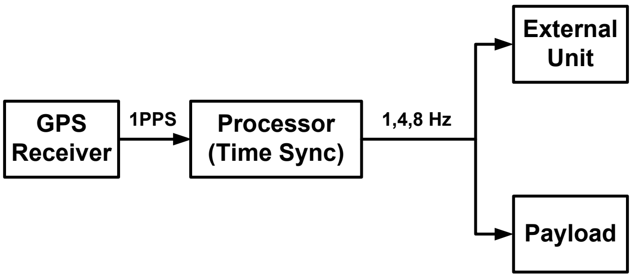

Figure 8. Newly proposed time sync architecture

The difference to the existing architecture is the replacement of the 3-processor time sync configuration by a single processor synch configuration. The transfer of the synch signal to External Unit and Payload is again the same.

3.1 RTC based Time Sync Architecture

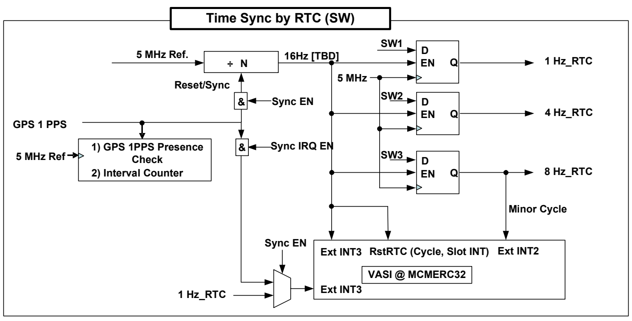

Figure 9. RTC based Time Sync architecture

Figure 9 shows the proposed time sync internal architecture which is a RTC based time control scheme.

The required time sync output in the satellite is 1Hz, 4Hz or 8Hz.

It is composed of GPS 1PPS Presence Checker and Interval Counter, N-counter and Distribution logic.

The purpose of the GPS 1PPS Presence Checker is to verify that the 1PPS is available, the purpose of the Interval Counter is to check the 1PPS accuracy with respect to processor internal counter.

The N-counter is provides the reference clock to the divide and distribution logic which is itself responsible for distribution of the sync signal to external unit and payload.

Furthermore, there is a 16Hz clock signal received by CPU used to SW controlling the N-Counter and the Distribution logic.

When the GPS 1PPS is provided, the RTC performs the s ync with inner time and transmits the sync output to external unit and payload at the same time.

The proposed architecture can be easily modified, because a SW control is implemented for the N-Counter and for the Distribution logic output formation part.

3.2 Time Sync Operation

As already explained above, the GPS 1PPS is checked by the Presence Checker and the accuracy of GPS 1PPS is verified by the Interval Counter.

If the GPS 1PPS is nominal, then the N-counter is initialized and Sync EN and Sync IRQ are enabled by the SW and time sync is started. If the time synchronization shall be stopped, the Sync EN has to be disabled.

Generally, when the GPS 1PPS is triggered, the N-Counter is initialized and the Distribution logic output keep signal are set to high state.

Figure 10 explains the 1 Hz generation timing diagram by RTC.

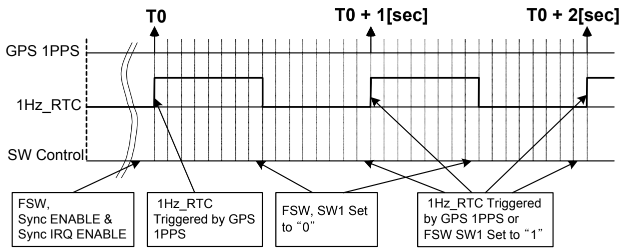

Figure 10. 1Hz Generation Timing Diagram by RTC

Generally, the design is progressed on the assumption that accuracy of GPS 1PPS is better than 1.5 usec.

The N-Counter data load and Distribution logic data control are operated by SW. In other words, every 16Hz tick is generated, SW load the counter number of N-counter and data control of Distribution logic. The N-Counter changed every 16Hz and last tick, inputting clock of N-Counter set up 62.5 msec + 0.5 msec. Such a setting up reason is that error of internal reference clock exists, even though GPS 1PPS is more correct.

In other words, GPS 1PPS is entered to 937.5 msec ~ 1000.5 msec on the internal clock standard. If GPS 1PPS isn't entered in this term, Sync EN is to be in disable state with understanding that GPS 1PPS has a problem. And GPS 1PPS isn't entered, but 1Hz_RTC divided by internal clock is entered and doing in CPU.

After 1Hz_RTC in high state write (Q7) SW to "0" in data by GPS 1PPS and 1Hz_RTC is in low state when 16Hz tick signal is started. And when Task of Q15 is ended, GPS 1PPS is entered and become to be in high state again and carried out repeating the movement. Corresponded signal is generated like purse form. Clock source of Distribution logic formation part is used to 16Hz and SW is supposed to control data of sync output formation part in this cycle.

The Advantage of RTC based time sync architecture is that a variable design of frequency of sync output is possible and the SW can at any time monitor the synchronization process and in case of an anomaly it is possible to react, The SW tasks are not considered complicated since it is mainly limited to providing input of n-division counter change and writing data "1" or "0" to the clock output formation part.

3.3 Operation in anomaly

The anomaly situations generated in working satellite are twofold, firstly the GPS 1PPS is not transmitted and secondly the accuracy of the GPS 1PPS is not as expected.

Both anomalies are detected by Interval Counter and GPS 1PPS Presence Check and in this case, the Sync EN has to be disabled, the Sync Clock Output is generated by the internal clock and the 1Hz_RTC not GPS 1PPS is entered into the CPU. If the accuracy of GPS 1PPS is worse than a set point of 500 usec, the Sync EN is also disabled by the SW. From this point in time onwards, the sync output is again generated by the Internal Clock.

3.4 1Hz Time Sync Performance

The sync output provides several kinds of output frequencies like 1, 4, or 8Hz, but the most important one is the 1Hz time sync performance. The 1PPS capability of commonly used GPS receiver is within 1usec as mentioned above and this is based on the capability of time sync circuit. The internal clock uses TCXO or OCXO because of the accuracy and the operating temperature of satellite and the accuracy of 1~2 us per second.

Although RTC based time sync architecture generates an error of the internal clock, the error can be disregarded by n-division counter charge being reset by GPS 1PPS.

In order to improve the accuracy a high speed reference clock is used for each control logics. However, if this high speed reference clock is used, the counter bit size may get large and the FPGA size may be increased.

After making a trade-off it was decided to use a 5MHz reference clock. When using this clock the error contributions are as follows:

- GPS 1PPS (1.5 usec)
- RTC logic error (1 counter = 200 ns)
- Propagation delay (1 us)

This means, the total error amounts to 2.7 us. If the GPS 1PPS contribution is not considered, the total error is only 1.2 us.

4. Conclusion

This thesis presented the design of time sync circuits as used in LEO satellite time sync architecture, and explained their working architecture and capability. As mentioned above, the time sync of satellite in this thesis is based on using the internal reference clock, and quick-track propagation of GPS 1PPS under SW control. This architecture considers flexibility and allows design changes

According to the variation of GPS 1PPS, the working situation of time sync architecture and 1Hz performance is analyzed.

I hope this thesis does not only improve satellite design in future, but also supports the time sync using GPS receiver on ground.

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