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TECHNICAL BULLETIN

NOVATEL OEM SERIES
Receiver Time, GPS Time, Clock Steering and the 1 PPS Strobe

NovAtel OEM Series and GPS Card receivers offer a 1PPS output that yields a one-pulse-per-second time synchronized output. This is a normally high, active low pulse where the falling edge is the reference. Before the 1PPS strobe can be fully understood, however, it will be necessary to study receiver time, GPS time and clock steering; these topics will be examined before the 1PPS output is explained.

1. How Receiver Time is Generated

The clock on NovAtel's GPSCard receiver is derived from a local oscillator. In most cases the oscillator is a Temperature Compensated Crystal Oscillator (TCXO). Other applications may require an Ovenized Crystal Oscillator (OCXO). The oscillator on the NovAtel OEM2 card (e.g. the 3151R) operates at a nominal frequency of 20.473 MHz. The receiver time is determined by keeping a running count of how many cycles are generated by the oscillator. This function is performed by hardware using NovAtel's custom Application Specific Integrated Circuit (ASIC). Approximately every 20,473,000 cycles the "seconds counter" is incremented. TCXO clocks are rated at ~ +/-6ppm or ~ +/-120 Hz. Thus the receiver constantly performs dithering to compensate for this less than perfect clock which serves to dilute the absolute precision of the 1PPS output.

Prior to the receiver locking onto satellites, the seconds counter represents the number of seconds that have elapsed since the receiver was powered on. It does not relate to any standard time reference such as GPS or UTC. The NovAtel MiLLennium card (i.e. L1/L2, OEM3) operates in the same way except its oscillator nominal frequency is 20.000 MHz.

2. How Receiver Time is Synchronized with GPS Time

Synchronization of receiver time with GPS time does not occur until the receiver locks onto its first satellite. The GPS L1 signal has two main streams of data modulated on the carrier. These data streams are the C/A code (1.023 MHz rate) and the encrypted or unencrypted P (or "Y") code (10.23 MHz rate). Additionally, a navigation message (at a 50 Hz rate) contains GPS satellite data including the ephemeris, clock corrections and constellation status. This navigation message is encoded on both the C/A and P (or "Y") codes. The navigation message is transmitted via individual subframes and each subframe is 300 bits in length. With the 50 Hz data bit rate there is a new subframe transmitted every 6 seconds.

Each subframe contains the transmit time of the next subframe in seconds of GPS time of week. After the first subframe is collected and decoded by the receiver, an approximate calculation of the "receiver clock offset" can be made. The receiver clock offset is the difference between GPS time and internal receiver time. The calculation is based on subframe transmit time and the approximate propagation time from the satellite signal to the receiver. The position of the satellite and receiver clock offset are used to reinitialize the seconds counter on the receiver, resulting in receiver/GPS time synchronization. The accuracy of the receiver time is expected to be within 30 milliseconds (ms) of GPS time. This initial synchronization is referred to as "coarse time set" and is indicated by bit number 9 in the receiver status word.

Once enough satellites have been acquired to calculate the antenna position, a more accurate estimate of the receiver clock offset is calculated. The new receiver clock offset is used to synchronize the receiver clock even closer to GPS time. This is referred to as "fine time set" and is indicated by bit number 10 in the receiver status word. Fine time accuracy is a function of the GPS constellation status. For the Standard Position Service (SPS) the time accuracy is specified as 250 nanoseconds (ns) with Selective Availability (SA) on and 50 ns with SA off assuming clock steering is enabled.

NOTE: Bits 9 and 10 of the receiver status word are only set initially; if clock adjust is disabled or there is a prolonged outage of satellites the receiver time will diverge from GPS time and the accuracy will not be correct even though bits 9 and 10 were previously set.

3. Clock Steering

The local oscillator on the receiver is not perfectly stable with respect to the GPS time standard. This drifting effect will cause receiver time and GPS time to slowly diverge. The receiver can compensate for this drift by periodically re-synchronizing the receiver time with GPS time using the estimated receiver clock offset. This periodic re-synchronization is referred to as clock steering, and can be enabled or disabled using the CLOCKADJUST command.

On most NovAtel products clock steering is enabled by default. (an exception to this default is the WAAS Receiver Subsystem the operation of which is beyond the scope of this application note.)

4. The 1PPS Strobe

The 1PPS strobe output produces a "pulse" of varying duration depending on the version of hardware utilized:

OEM1/PC1 ~ 50 ns
OEM2/PC2 ~ 200 µs
OEM3 ~ 1 ms

The 1PPS strobe timing is directly tied by hardware to the receiver time. Its output is as close as possible to every integer second of receiver time; for example, within 1 TCXO clock cycle. The TM1 log message outputs the time of the 1PPS strobe and its offset to GPS time. The 1PPS will drift synchronously with the receiver time. Thus, if the receiver's oscillator has a high drift rate and the clock steering is disabled, the clock offset between GPS time and receiver time (to which 1PPS is synched) reported in the TM1A log will increase. In this case there will be no jitter on the 1PPS because clock steering is not constantly adjusting the 1PPS output.

With clock steering enabled, the receiver's clock is continuously re-synchronized to GPS time. Since the system is digital, the resolution of the 1PPS is to one clock cycle of the receiver's nominal TCXO frequency. The receiver attempts to keep the 1PPS aligned as closely as possible to GPS time which in turn causes the 1PPS strobe to jitter by approximately 50 ns.

After the receiver clock correction has been made and the 1PPS output strobe has jumped once to compensate, operation reverts to normal where the 1PPS output is synched to the receiver clock and yields a single pulse once every 1.0 s ~ 20,473,000 or 20,000,000 cycles depending on OEM hardware used.

In conclusion: 1PPS is directly tied via hardware to the receiver clock. If the receiver clock is constant then the 1PPS output will render a one pulse every second. If the receiver clock drifts and is corrected to GPS time, the 1PPS output will follow the receiver time because of its hardware connection to the receiver clock. The time between 1PPS output pulses when the receiver clock correction takes place will be increased or decreased approximately 50.00 ns depending on the OEM hardware used.

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