TECHNICAL NOTE

TIME SYNCHRONIZATION

Timing, Latency, and Synchronization Signals

VECTORNAV

1 INTRODUCTION

This technical note provides the information necessary to synchronize a VectorNav sensor to an external system. Additionally, information on system latencies, synchronization signal inputs and outputs, and timestamping capabilities are also included. Section 2 provides an overview of the various timing events and processing steps. Section 3 provides an overview of the various timestamps and signal lines available for time synchronization purposes. Finally, Section 4 provides a review of the most common methods for time synchronization using VectorNav products.

2 SYSTEM TIMING

Figure 1 illustrates the major events that occur on a VectorNav sensor starting sequentially from a real-world event (A) until data is transmitted to the user (F). Table 2 provides a detailed breakdown of the latencies involved with each of the various steps that directly impact time synchronization. The timing provided here results from testing performed using firmware versions listed in Table 1. Timing may vary from the values listed depending on the firmware version and user settings.

Hardware and Firmware Versions Tested

SERIES	PART NUMBER	HARDWARE	FIRMWARE
Industrial	VN-100	7	3.1.0.0
	VN-200	3	2.1.0.0
	VN-300	3	1.1.0.0
Tactical	VN-110	3	2.4.1.0
	VN-210	3	1.4.1.0
	VN-310	3	0.8.1.0

TABLE 1

Timing Diagram

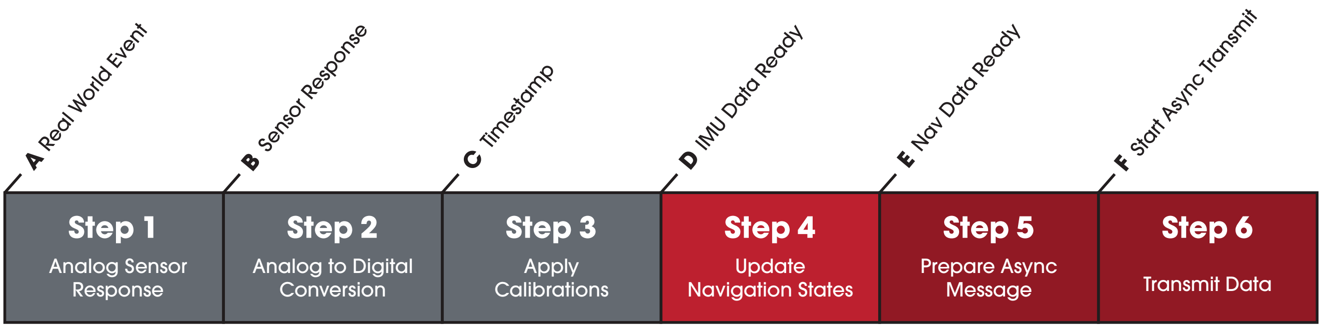

FIGURE 1

Step 1: Analog Sensor Response

The analog sensor response is based on the sensor bandwidth of 200–265 Hz as well as the frequency content of the input signal. The user-defined, low-pass filter specified by Register 85, IMU Filtering Configuration, effectively increases this delay by a fixed amount given by:

$$\delta = \frac{\text{WindowSize} - 1}{2 \times \text{ImuRate}}$$

Register 85 does not affect the IMU data used in the filter—it only affects the IMU measurements output to the user. Refer to the sensor's Interface Control Document for the definition of *ImuRate* and *WindowSize*.

Step 2: Analog to Digital Conversion

Because VectorNav sensors provide a digital output, the analog sensor response must be converted into a digital output. This conversion is a standard half-cycle delay, though the accelerometer sampling takes an additional 0.875 ms. The accelerometer and gyroscope conversions complete at the same time and are given the same timestamp.

Step 3: Apply Calibrations

During this step, the factory calibration as well as any user-defined calibrations are applied to the sensor data. For the VN-300, an additional 0.5 ms is required. Additional information on the factory calibration and the user-defined calibration stage can be found in the sensor's respective user manual.

Step 4: Update Navigation States

Every VectorNav sensor includes a NavState subsystem onboard that is used to update the navigation outputs, such as attitude. This subsystem runs at 400 Hz by default and does not necessarily occur every IMU sampling cycle. During cycles in which the NavState subsystem is run, there will be an added delay due to the additional algorithms that must be processed before the data can be packetized and transmitted. This will cause the message to message timing of an 800 Hz signal to range from 1.05–1.45 ms rather than a fixed 1.25 ms despite the fact that the sampling is occurring on the sensor at a fixed 800 Hz rate.

Step 5: Prepare Async Message

In this step, the configured asynchronous output messages are packetized and prepared. The length of this step depends on the user setup, including the configured messages on each port, SPI, etc. Note that asynchronous messages will be prepared and sent out in the following order: binary output messages on UART-1, binary output messages on UART-2, ASCII output message on UART-1, ASCII output message on UART-2.

Step 6: Transmit Data

The duration required to transmit the desired data from the sensor to an external system or sensor depends on the baud rate configured as well as the message length. Tables 3–6 in Appendix A provide a comparison of the data transmit time for some of the more common messages in both standard ASCII form and their binary equivalent at various baud rates.

Detailed Timing Breakdown

STEP	NAME	DURATION
1	Analog Sensor Response	0.8–1.2 ms
2	Analog to Digital Conversion	$\frac{1}{2 \times \text{ImuRate}}{}^{+0.125\,\text{ms}*}_{-0.000\,\text{ms}}$
3	Apply Calibrations	*Industrial* 0.8–1.0 ms** *Tactical* 0.6–1.0 ms
4	Update Navigation States	*Industrial* 0.2 ms *Tactical* 0.1 ms
5	Prepare Async Message	*Industrial* 0.1–0.6 ms *Tactical* 0.1–0.4 ms
6	Transmit Data	See Appendix A

** See Step 2 description*
*** See Step 3 description*

TABLE 2

3 TIMESTAMPS & SYNCHRONIZATION SIGNALS

All VectorNav products provide two synchronization lines, SyncIn and SyncOut, and a variety of timestamps that can be used for time synchronization across devices. This section provides an overview of the functionality of each signal line, which can be configured in the Synchronization Control register (Register 32) as shown in Figure 2. For specific configuration commands, refer to the sensor's Interface Control Document. The following discussion references the events diagrammed in Figure 1.

Synchronization Control Register

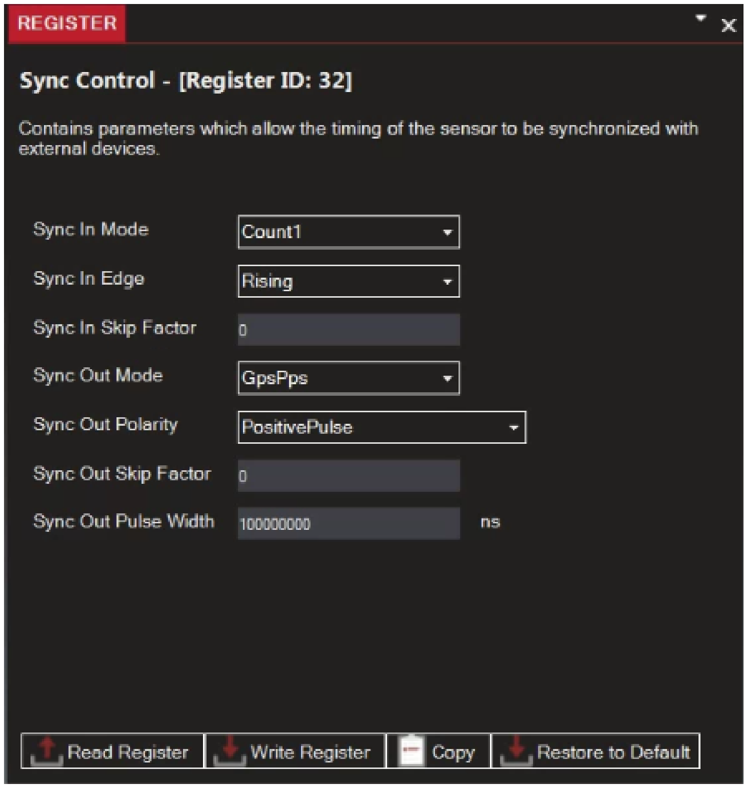

FIGURE 2

3.1 SyncIn

The SyncIn line is a 5 V tolerant input that drives SyncIn Events and can be configured for either rising or falling edge detection. A SyncIn Event occurs when an internal counter exceeds a user defined *SyncInSkipFactor*. This allows SyncIn Events to occur at a multiple of the input signal such that a high-frequency input signal can be provided that is divided to the desired rate (e.g. providing a 10 kHz signal that the sensor responds to only every 100 triggers will yield a 100 Hz response). At every SyncIn Event, *TimeSyncIn* is reset and *SyncInCount* is incremented. In addition, VectorNav sensors can also be configured for the following behavior in response to a SyncIn Event:

- *Event (C) Timestamp*: Initiate the processing of an IMU sample
- *Event (F) Start Async Transmit*: Output the most recently available asynchronous message

3.2 SyncOut

The SyncOut line is an output line with configurable output polarity and pulse-width duration. A SyncOut Event occurs when an internal counter exceeds the user configurable *SyncOutSkipFactor*. The internal counter is incremented at a configurable rate defined by the *SyncOutMode*. The skip factor allows a SyncOut Event to occur at some multiple of the sensor event (e.g. a 400 Hz NavReady signal with a *SyncOutSkipFactor* of 2 will yield a 200 Hz SyncOut pulse aligned with the NavFilter outputs). Upon each SyncOut Event, a SyncOut signal pulse will occur and the *SyncOutCount* is incremented, which can be appended to asynchronous messages or read directly from the Synchronization Status register (Register 33). There are three different events that can be defined for the SyncOut:

- *Event (C) Timestamp*: Start of processing an IMU sample
- *Event (D) IMU Data Ready*: IMU measurements calibrated and available
- *Event (E) Navigation Data Ready*: Navigation state processing complete and navigation measurements are available

> Typically the two data-ready events are only of interest for initiating a SPI transaction to request the data and are not used when communicating over the sensor's serial ports.

On GNSS-enabled products, the SyncOut line can also be configured to relay the PPS signal from the GPS, though the PPS signal is also available via the dedicated PPS pin. There are three critical differences between these two PPS signal methods:

- The dedicated PPS output is fixed to positive polarity and 1 Hz output whereas the SyncOut signal can have polarity flipped and can output at a lower rate.
- The SyncOut signal is delayed 10–20 μs whereas the dedicated PPS line has a time uncertainty of 90 ns.
- The dedicated PPS output provides a signal regardless of GNSS fix whereas the SyncOut signal will only trigger if a valid GNSS fix is present.

> On VN-200 firmware version v2.1.0.0 and later as well as VN-300 firmware version v1.1.0.0 and later, the dedicated PPS no longer triggers prior to a valid GNSS fix.

3.3 Timestamps

All VectorNav sensors are equipped with an internal temperature-compensated crystal oscillator (TCXO) that has an accuracy of $\pm$20 ppm over the sensor's operating temperature range. This internal clock is used as the basis of the *TimeStartup* timestamp, upon which everything on board the sensor is based—from handling the IMU sampling to the transmission of the desired output data. All measurements on board the sensor can be timestamped relative to *TimeStartup* as well as realtive to the last SyncIn event:

- *TimeStartup*: Time since system start-up
- *TimeSyncIn*: Time since the last SyncIn pulse

On GNSS-enabled products, all measurements can also be timestamped relative to the last GPS PPS pulse, allowing for the following additional timestamps:

- *TimeGps*: Absolute GPS time since January 6, 1980
- *GpsTow & GpsWeek*: Week number since January 6, 1980 and number of seconds into the current week
- *TimeGpsPps*: Time since last GPS PPS pulse
- *TimeUtc*: Coordinated Universal Time, which is a standard date time (Month, Day, Year, Hour, Minute, Second) that differs from TimeGPS by the current number of leap seconds and requires the full almanac to be downloaded by the GNSS receiver before it is valid

These timestamps are recorded with nanosecond resolution and approximately 20 μs accuracy. If timing errors on the order of microseconds are critical in your application, reach out to VectorNav Support to discuss the best synchronization approach for your system.

While everything on board the sensor is based on the *TimeStartup* timestamp, the one exception to this includes the GPS timestamps found in the GNSS binary output groups (e.g. *Gnss*, *Gnss2*, and *Gnss3*) as well as in the ASCII GPS output messages, which come directly from the GNSS receiver(s) and are in no way affected by the local clock onboard the sensor. Due to the differences in timing, if outputs from the GNSS binary output groups are needed, it is recommended that these outputs be configured in a separate binary output message at the update rate of the GNSS receiver (nominally 5 Hz).

4 SYNCHRONIZATION APPROACHES

This section describes the three most common approaches for synchronizing a VectorNav sensor with an external system. Each has its own advantages and drawbacks and the choice typically depends on the capability of the external system to timestamp data and generate or receive synchronization signals. A couple of examples are also provided to further illustrate the different synchronization approaches. Please contact VectorNav for additional support if the proper synchronization approach for your particular application is unclear.

4.1 SyncIn Timestamps

When synchronizing multiple systems, it is often useful to have a single device providing a synchronization signal that all other devices use for timestamping. In this setup, that signal is sent into the SyncIn line and the *TimeSyncIn* timestamp is appended to any measurements output from the sensor. Similar timestamping on the other sensing or control systems allows for interpolation to a common time basis. On GNSS-enabled units, appending the GPS timestamp allows for easy synchronization to other GPS-enabled systems without the need for a separate synchronization signal on SyncIn.

4.2 SyncOut Trigger

In some cases, it is desirable to have the VectorNav sensor provide the synchronization signal, allowing an external system to be triggered by the sensor (either for timestamping or to trigger a measurement). Typically, this is done by configuring SyncOut to trigger on the start of processing an IMU sample, which corresponds to the timestamp event on the sensor. Care must be taken to associate the correct output from the sensor with the correct SyncOut trigger, something that can be aided by appending the *SyncOutCount* to the output message. On GNSS-enabled products, this synchronization signal can be generated by the GPS PPS, either on the SyncOut line or the dedicated PPS pin as discussed previously.

4.3 SyncIn Trigger

Finally, it is possible to configure the VectorNav sensor to initiate the IMU sample processing by triggering the SyncIn line directly. While this can be effective, great care must be taken in such a setup as the sensor's entire system will operate off the SyncIn triggers, so signals that are too fast, too slow, or unreliable can cause the unit to operate inconsistently and sometimes lock up altogether. The minimum SyncIn event rate is 200 Hz, with a maximum of the default IMU Rate (see the sensor's user manual for default specification).

4.4 Synchronization Examples

Consider a LiDAR sensor needing accurate timing information from a GNSS-enabled VectorNav sensor. The simplest approach for synchronization is to connect the synchronization pin on the LiDAR sensor to the SyncOut pin on the VectorNav sensor. The SyncOut signal on the VectorNav sensor will need to be generated by the PPS, which can be configured by setting the *SyncOutMode* in the Synchronization Control register (Register 32) to *GpsPps*. The TX communication pin on the VectorNav sensor can then be configured to output the NMEA GPRMC message and connected to the RX communication pin on the LiDAR sensor. The PPS pulse will supply the top of the GPS second while the GPRMC output message provides the associated GPS time.

Alternatively, an external system can instead be used to provide the timing synchronization signal. For example, a surveying camera system needing georeferenced data from a VectorNav sensor may be driven off of a master shutter trigger signal. The SyncIn pin on the VectorNav sensor can be connected to the master shutter trigger signal and used in the default *SyncInMode* of *Count* found in the Synchronization Control register (Register 32). The *TimeSyncIn* output can be added or appended to an asynchronous output message and used to determine the time since the last trigger event. Once the survey is complete, the data from the VectorNav sensor can then be interpolated to obtain the points of interest.

A DATA TRANSMIT TIMES

Yaw-Pitch-Roll (VNYPR) Transmission Times

Format	9600 baud	115200 baud	921600 baud
ASCII	39.6 ms	3.3 ms	0.41 ms
Binary	18.8 ms	1.6 ms	0.20 ms

TABLE 3

Yaw-Pitch-Roll, Magnetic, Acceleration, and Angular Rates (VNYMR) Transmission Times

Format	9600 baud	115200 baud	921600 baud
ASCII	127.1 ms	10.6 ms	1.3 ms
Binary	58.3 ms	4.9 ms	0.61 ms

TABLE 4

IMU Measurements (VNIMU) Transmission Times

Format	9600 baud	115200 baud	921600 baud
ASCII	114.6 ms	9.5 ms	1.2 ms
Binary	52.1 ms	4.3 ms	0.54 ms

TABLE 5

INS Solution - LLA (VNINS) Transmission Times

Format	9600 baud	115200 baud	921600 baud
ASCII	148.0 ms	12.3 ms	1.5 ms
Binary	93.8 ms	7.8 ms	0.98 ms

TABLE 6

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