# Swift Navigation Binary Protocol

## Protocol Specification 6.2.2-alpha

### Contents



## 1 Overview

The Swift Navigation Binary Protocol (SBP) is a fast, simple, and minimal binary protocol for communicating with Swift devices. It is the native binary protocol used by the Piksi GPS receiver to transmit solutions, observations, status, and debugging messages, as well as receive messages from the host operating system, such as differential corrections and the almanac. As such, it is an important interface with your Piksi receiver and the primary integration method with other systems.

This document provides a specification of SBP framing and the payload structures of the messages currently used with Swift devices. SBP client libraries in a variety of programming languages are available at `https://github.com/swift-nav/libsbp` and support information for sbp is available at `https://support.swiftnav.com/customer/en/portal/articles/2492810-swift-binary-protocol`.

## 2 Message Framing Structure

SBP consists of two pieces:

- an over-the-wire message framing format
- structured payload definitions

As of Version 6.2.2-alpha, the frame consists of a 6-byte binary header section, a variable-sized payload field, and a 16-bit CRC value. All multibyte values are ordered in **little-endian** format. SBP uses the CCITT CRC16 (XMODEM implementation) for error detection[1].

| Offset (bytes) | Size (bytes) | Name | Description |
|---|---|---|---|
| 0 | 1 | Preamble | Denotes the start of frame transmission. Always 0x55. |
| 1 | 2 | Message Type | Identifies the payload contents. |
| 3 | 2 | Sender | A unique identifier of the sender.[2] |
| 5 | 1 | Length | Length (bytes) of the Payload field. |
| 6 | N | Payload | Binary message contents. |
| N + 6 | 2 | CRC | Cyclic Redundancy Check of the frame's binary data from the Message Type up to the end of Payload (does not include the Preamble). |
| | N + 8 | | Total Frame Length |

Table 2.0.1: Swift Binary Protocol message structure. N denotes a variable-length size.

## 3 NMEA-0183

Swift devices, such as the Piksi, also have limited support for the standard NMEA-0183 protocol.

Note that NMEA-0183 doesn't define standardized message string equivalents for many important SBP messages such as observations, baselines and ephemerides. For this reason it is strongly recommended to use SBP for new development. NMEA-0183 output is provided primarily to support legacy devices.

[1] CCITT 16-bit CRC Implementation uses parameters used by XMODEM, i.e. the polynomial: $x^{16} + x^{12} + x^5 + 1$. For more details, please see the implementation at https://github.com/swift-nav/libsbp/blob/master/c/src/edc.c#L59. See also *A Painless Guide to CRC Error Detection Algorithms* at http://www.ross.net/crc/download/crc_v3.txt

[2] By default, clients of 'libsbp' use a sender id value of '0x42' which represents device controllers such as the Piksi Console. On the Piksi, the sender ID is set to the 2 least significant bytes of the device serial number. A stream of SBP messages may also include sender IDs for forwarded messages from other systems. For instance, when using Starling as a hosted software product, Sender 0x1000 (4096) indicates a message originated from the GNSS subsystem, while sender 0x315 (789) indicates a message originated from the sensor fusion subsystem. Sender 0 always indicates the message has been forwarded and contains some form of differential corrections.

# 4 Basic Formats and Payload Structure

The binary payload of an SBP message decodes into structured data based on the message type defined in the header. SBP uses several primitive numerical and collection types for defining payload contents.

| Name | Size (bytes) | Description |
|---|---|---|
| s8 | 1 | Signed 8-bit integer |
| s16 | 2 | Signed 16-bit integer |
| s32 | 4 | Signed 32-bit integer |
| s64 | 8 | Signed 64-bit integer |
| u8 | 1 | Unsigned 8-bit integer |
| u16 | 2 | Unsigned 16-bit integer |
| u32 | 4 | Unsigned 32-bit integer |
| u64 | 8 | Unsigned 64-bit integer |
| float | 4 | Single-precision float (IEEE-754) |
| double | 8 | Double-precision float (IEEE-754) |
| array | — | Fixed or variable length array of any fill type |
| string | — | Fixed or variable length string (NULL padded/terminated) |
| bitfield | — | A primitive type, typically a u8, can encode boolean and enumerated status flags. |

Table 4.0.1: SBP primitive types

**Example Message**

As an example, consider this framed series of bytes read from a serial port:

```
55 0b 02 cc 04 14 70 3d d0 18 cf ef ff ff ef e8 ff ff f0 18 00 00 00 00 05 00 15 dc
```

This byte array decodes into a `MSG_BASELINE_ECEF` (see pg. 26), which reports the baseline position solution of the rover receiver relative to the base station receiver in Earth Centered Earth Fixed (ECEF) coordinates. The segments of this byte array and its contents break down as follows:

| Field Name | Type | Value | Bytestring Segment |
|---|---|---|---|
| Preamble | u8 | 0x55 | `55` |
| Message Type | u16 | `MSG_BASELINE_ECEF` | `0b 02` |
| Sender | u16 | 1228 | `cc 04` |
| Length | u8 | 20 | `14` |
| Payload | | — | `70 3d d0 18 cf ef ff ff ef e8 ff ff f0 18 00 00 00 00 05 00` |
| `MSG_BASELINE_ECEF` | | | |
| .tow | u32 | $416300400$ msec | `70 3d d0 18` |
| .x | s32 | $-4145$ mm | `cf ef ff ff` |
| .y | s32 | $-5905$ mm | `ef e8 ff ff` |
| .z | s32 | $6384$ mm | `f0 18 00 00` |
| .accuracy | u16 | 0 | `00 00` |
| .nsats | u8 | 5 | `05` |
| .flags | u8 | 0 | `00` |
| CRC | u16 | 0x9443 | `15 dc` |

Table 4.0.2: SBP breakdown for `MSG_BASELINE_ECEF`

# 5 GNSS Signals

Code, Constellation, and Band. Signal descriptions are provided in both RINEX and ICD Conventions.

| Value | Rinex Desc. | ICD Desc. | Value | Rinex Desc. | ICD Desc. |
|---|---|---|---|---|---|
| 0 | GPS L1CA | GPS L1 C/A | 30 | GLO L2P | GLONASS L2SF |
| 1 | GPS L2CM | GPS L2C M | 31 | QZS L1CA | QZS L1 C/A |
| 2 | SBAS L1CA | SBAS L1 C/A | 32 | QZS L1CI | QZS L1C D |
| 3 | GLO L1OF | GLONASS L10F | 33 | QZS L1CQ | QZS L1C P |
| 4 | GLO L2OF | GLONASS L20F | 34 | QZS L1CX | QZS L1C D+P |
| 5 | GPS L1P | GPS L1 P(Y) | 35 | QZS L2CM | QZS L2C M |
| 6 | GPS L2P | GPS L2 P(Y) | 36 | QZS L2CL | QZS L2C L |
| 7 | GPS L2CL | GPS L2C L | 37 | QZS L2CX | QZS L2C ML |
| 8 | GPS L2CX | GPS L2C M+L | 38 | QZS L5I | QZS L5 I |
| 9 | GPS L5I | GPS L5 I | 39 | QZS L5Q | QZS L5 Q |
| 10 | GPS L5Q | GPS L5 Q | 40 | QZS L5X | QZS L5 I+Q |
| 11 | GPS L5X | GPS L5 I+Q | 41 | SBAS L5I | SBAS L5 I |
| 12 | BDS2 B1 | BDS B1I | 42 | SBAS L5Q | SBAS L5 Q |
| 13 | BDS2 B2 | BDS B2I | 43 | SBAS L5X | SBAS L5 I+Q |
| 14 | GAL E1B | GAL E1 B | 44 | BDS3 B1CI | BDS B1C D |
| 15 | GAL E1C | GAL E1 C | 45 | BDS3 B1CQ | BDS B1C P |
| 16 | GAL E1X | GAL E1 B+C | 46 | BDS3 B1CX | BDS B1C D+P |
| 17 | GAL E6B | GAL E6 B | 47 | BDS3 B5I | BDS B2a D |
| 18 | GAL E6C | GAL E6 C | 48 | BDS3 B5Q | BDS B2a P |
| 19 | GAL E6X | GAL E6 B+C | 49 | BDS3 B5X | BDS B2a D+P |
| 20 | GAL E7I | GAL E5b I | 50 | BDS3 B7I | BDS B2b D |
| 21 | GAL E7Q | GAL E5b Q | 51 | BDS3 B7Q | BDS B2b P |
| 22 | GAL E7X | GAL E5b I+Q | 52 | BDS3 B7X | BDS B2b D+P |
| 23 | GAL E8I | GAL E5a+b I | 53 | BDS3 B3I | BDS B3I |
| 24 | GAL E8I | GAL E5a+b Q | 54 | BDS3 B3Q | BDS B3Q |
| 25 | GAL E8X | GAL E5a+b I+Q | 55 | BDS3 B3X | BDS B3 I+Q |
| 26 | GAL E5I | GAL E5a I | 56 | GPS L1CI | GPS L1C D |
| 27 | GAL E5Q | GAL E5a Q | 57 | GPS L1CQ | GPS L1C P |
| 28 | GAL E5X | GAL E5a I+Q | 58 | GPS L1CX | GPS L1C D+P |
| 29 | GLO L1P | GLONASS L1SF | | | |

Table 5.0.2: GNSS Signals Table

# 6 Message Types

Packages define a logical collection of SBP messages. The contents and layout of messages in packages marked **stable** are unlikely to change in the future. **Draft** messages *will change with future development* and are detailed purely for *informational purposes only*. Many draft messages are implementation-defined, and some collections, such as the acquisition package, are used for internal development.

| Package | Msg ID | Name | Size (bytes) | Description |
|---|---|---|---|---|
| **Stable** | | | | |
| Ext Events | 257 | MSG_EXT_EVENT | 12 | Reports timestamped external pin event |
| Imu | 2304 | MSG_IMU_RAW | 17 | Raw IMU data |
| | 2305 | MSG_IMU_AUX | 4 | Auxiliary IMU data |
| | 2309 | MSG_IMU_COMP | 34 | Compensated IMU data |
| Logging | 1025 | MSG_LOG | $N+1$ | Plaintext logging messages with levels |
| | 1026 | MSG_FWD | $N+2$ | Wrapper for FWD a separate stream of information over SBP |
| Mag | 2306 | MSG_MAG_RAW | 11 | Raw magnetometer data |
| Navigation | 258 | MSG_GPS_TIME | 11 | GPS Time (GNSS + inertial) |
| | 260 | MSG_GPS_TIME_GNSS | 11 | GNSS-only GPS Time |
| | 259 | MSG_UTC_TIME | 16 | UTC Time |
| | 261 | MSG_UTC_TIME_GNSS | 16 | GNSS-only UTC Time |
| | 520 | MSG_DOPS | 15 | GNSS-only Dilution of Precision |
| | 521 | MSG_POS_ECEF | 32 | Position in ECEF |
| | 532 | MSG_POS_ECEF_COV | 54 | Position in ECEF with Covariances |
| | 522 | MSG_POS_LLH | 34 | Geodetic Position |
| | 529 | MSG_POS_LLH_COV | 54 | Geodetic Position with Covariances |
| | 536 | MSG_POS_LLH_ACC | 67 | Geodetic Position and Accuracy |
| | 523 | MSG_BASELINE_ECEF | 20 | GNSS-only Baseline Position in ECEF |
| | 524 | MSG_BASELINE_NED | 22 | GNSS-only Baseline in NED |
| | 525 | MSG_VEL_ECEF | 20 | Velocity in ECEF |
| | 533 | MSG_VEL_ECEF_COV | 42 | Velocity in ECEF with Covariances |
| | 526 | MSG_VEL_NED | 22 | Velocity in NED |
| | 530 | MSG_VEL_NED_COV | 42 | Velocity in NED with Covariances |
| | 553 | MSG_POS_ECEF_GNSS | 32 | GNSS-only Position in ECEF |
| | 564 | MSG_POS_ECEF_COV_GNSS | 54 | GNSS-only Position in ECEF with Covariances |
| | 554 | MSG_POS_LLH_GNSS | 34 | GNSS-only Geodetic Position |
| | 561 | MSG_POS_LLH_COV_GNSS | 54 | GNSS-only Geodetic Position with Covariances |
| | 557 | MSG_VEL_ECEF_GNSS | 20 | GNSS-only Velocity in ECEF |
| | 565 | MSG_VEL_ECEF_COV_GNSS | 42 | GNSS-only Velocity in ECEF with Covariances |
| | 558 | MSG_VEL_NED_GNSS | 22 | GNSS-only Velocity in NED |
| | 562 | MSG_VEL_NED_COV_GNSS | 42 | GNSS-only Velocity in NED with Covariances |
| | 531 | MSG_VEL_BODY | 42 | Velocity in User Frame |
| | 540 | MSG_VEL_COG | 30 | Velocity expressed as course over ground |
| | 528 | MSG_AGE_CORRECTIONS | 6 | Age of corrections |
| | 570 | MSG_UTC_LEAP_SECOND | 14 | Leap second SBP message. |
| | 580 | MSG_REFERENCE_FRAME_PARAM | 124 | Reference Frame Transformation Parameters |
| | 581 | MSG_POSE_RELATIVE | 90 | Relative Pose |
| Observation | 74 | MSG_OBS | $17N+11$ | GPS satellite observations |
| | 68 | MSG_BASE_POS_LLH | 24 | Base station position |
| | 72 | MSG_BASE_POS_ECEF | 24 | Base station position in ECEF |
| | 138 | MSG_EPHEMERIS_GPS | 139 | Satellite broadcast ephemeris for GPS |
| | 142 | MSG_EPHEMERIS_QZSS | 139 | Satellite broadcast ephemeris for QZSS |
| | 137 | MSG_EPHEMERIS_BDS | 147 | Satellite broadcast ephemeris for BDS |
| | 141 | MSG_EPHEMERIS_GAL | 153 | Satellite broadcast ephemeris for Galileo |
| | 140 | MSG_EPHEMERIS_SBAS | 74 | Satellite broadcast ephemeris for SBAS |
| | 139 | MSG_EPHEMERIS_GLO | 92 | Satellite broadcast ephemeris for GLO |
| | 144 | MSG_IONO | 70 | Iono corrections |
| | 150 | MSG_GNSS_CAPB | 110 | GNSS capabilities masks |
| | 148 | MSG_GROUP_DELAY | 15 | Group Delay |

| | | | | |
|---|---|---|---|---|
| | 114 | MSG_ALMANAC_GPS | 94 | Satellite broadcast almanac for GPS |
| | 115 | MSG_ALMANAC_GLO | 78 | Satellite broadcast almanac for GLO |
| | 117 | MSG_GLO_BIASES | 9 | GLONASS L1/L2 Code-Phase biases |
| | 151 | MSG_SV_AZ_EL | 4N | Satellite azimuths and elevations |
| | 1600 | MSG_OSR | 19N + 11 | OSR corrections |
| Settings | 161 | MSG_SETTINGS_SAVE | 0 | Save settings to flash |
| | 160 | MSG_SETTINGS_WRITE | N | Write device configuration settings |
| | 175 | MSG_SETTINGS_WRITE_RESP | N + 1 | Acknowledgement with status of MSG_SETTINGS_WRITE |
| | 164 | MSG_SETTINGS_READ_REQ | N | Read device configuration settings |
| | 165 | MSG_SETTINGS_READ_RESP | N | Read device configuration settings |
| | 162 | MSG_SETTINGS_READ_BY_INDEX_REQ | 2 | Read setting by direct index |
| | 167 | MSG_SETTINGS_READ_BY_INDEX_RESP | N + 2 | Read setting by direct index |
| | 166 | MSG_SETTINGS_READ_BY_INDEX_DONE | 0 | Finished reading settings |
| Solution Meta | 65294 | MSG_SOLN_META | 2N + 16 | Solution Sensors Metadata |
| System | 65280 | MSG_STARTUP | 4 | System start-up message |
| | 65282 | MSG_DGNSS_STATUS | N + 4 | Status of received corrections |
| | 65535 | MSG_HEARTBEAT | 4 | System heartbeat message |
| | 65534 | MSG_STATUS_REPORT | 4N + 12 | Status report message |
| | 65533 | MSG_STATUS_JOURNAL | 8N + 9 | Status report journal |
| | 65283 | MSG_INS_STATUS | 4 | Inertial Navigation System status message |
| | 65286 | MSG_INS_UPDATES | 10 | Inertial Navigation System update status message |
| | 65287 | MSG_GNSS_TIME_OFFSET | 9 | Offset of the local time with respect to GNSS time |
| | 65288 | MSG_PPS_TIME | 9 | Local time at detection of PPS pulse |
| | 65289 | MSG_SENSOR_AID_EVENT | 15 | Sensor state and update status data |
| | 65290 | MSG_GROUP_META | 2N + 3 | Solution Group Metadata |
| **Draft** | | | | |
| Acquisition | 47 | MSG_ACQ_RESULT | 14 | Satellite acquisition result |
| | 46 | MSG_ACQ_SV_PROFILE | 33N | Acquisition perfomance measurement and debug |
| File IO | 168 | MSG_FILEIO_READ_REQ | N + 9 | Read file from the file system |
| | 163 | MSG_FILEIO_READ_RESP | N + 4 | File read from the file system |
| | 169 | MSG_FILEIO_READ_DIR_REQ | N + 8 | List files in a directory |
| | 170 | MSG_FILEIO_READ_DIR_RESP | N + 4 | Files listed in a directory |
| | 172 | MSG_FILEIO_REMOVE | N | Delete a file from the file system |
| | 173 | MSG_FILEIO_WRITE_REQ | N + 9 | Write to file |
| | 171 | MSG_FILEIO_WRITE_RESP | 4 | File written to |
| | 4097 | MSG_FILEIO_CONFIG_REQ | 4 | Request advice on the optimal configuration for FileIO |
| | 4098 | MSG_FILEIO_CONFIG_RESP | 16 | Response with advice on the optimal configuration for FileIO. |
| Integrity | 3002 | MSG_SSR_FLAG_HIGH_LEVEL | 37 | High level integrity flags |
| | 3005 | MSG_SSR_FLAG_SATELLITES | N + 12 | List of satellites which are faulty, per constellation |
| | 3011 | MSG_SSR_FLAG_TROPO_GRID_POINTS | 2N + 15 | List of grid points which are faulty |
| | 3015 | MSG_SSR_FLAG_IONO_GRID_POINTS | 2N + 15 | List of grid points which are faulty |
| | 3021 | MSG_SSR_FLAG_IONO_TILE_SAT_LOS | 2N + 15 | List of all the LOS which are faulty |
| | 3025 | MSG_SSR_FLAG_IONO_GRID_POINT_SAT_LOS | 2N + 17 | List of all the grid points to satellite which are faulty |
| | 3026 | MSG_ACKNOWLEDGE | 11 | Acknowledgement message in response to a request for corrections |
| Orientation | 527 | MSG_BASELINE_HEADING | 10 | Heading relative to True North |
| | 544 | MSG_ORIENT_QUAT | 37 | Quaternion 4 component vector |
| | 545 | MSG_ORIENT_EULER | 29 | Euler angles |
| | 546 | MSG_ANGULAR_RATE | 17 | Vehicle Body Frame instantaneous angular rates |
| Piksi | 105 | MSG_ALMANAC | 0 | Legacy message to load satellite almanac |
| | 104 | MSG_SET_TIME | 0 | Send GPS time from host |
| | 182 | MSG_RESET | 4 | Reset the device |

| | | | | |
|---|---|---|---|---|
| | 192 | MSG_CW_RESULTS | 0 | Legacy message for CW interference channel (Piksi => host) |
| | 193 | MSG_CW_START | 0 | Legacy message for CW interference channel |
| | 34 | MSG_RESET_FILTERS | 1 | Reset IAR filters |
| | 23 | MSG_THREAD_STATE | 26 | State of an RTOS thread |
| | 29 | MSG_UART_STATE | 74 | State of the UART channels |
| | 25 | MSG_IAR_STATE | 4 | State of the Integer Ambiguity Resolution (IAR) process |
| | 43 | MSG_MASK_SATELLITE | 3 | Mask a satellite from use in Piksi subsystems |
| | 181 | MSG_DEVICE_MONITOR | 10 | Device temperature and voltage levels |
| | 184 | MSG_COMMAND_REQ | $N + 4$ | Execute a command |
| | 185 | MSG_COMMAND_RESP | 8 | Exit code from executed command (device => host) |
| | 188 | MSG_COMMAND_OUTPUT | $N + 4$ | Command output |
| | 186 | MSG_NETWORK_STATE_REQ | 0 | Request state of Piksi network interfaces |
| | 187 | MSG_NETWORK_STATE_RESP | 50 | State of network interface |
| | 189 | MSG_NETWORK_BANDWIDTH_USAGE | 40N | Bandwidth usage reporting message |
| | 190 | MSG_CELL_MODEM_STATUS | $N + 5$ | Cell modem information update message |
| | 81 | MSG_SPECAN | $N + 28$ | Spectrum analyzer |
| | 191 | MSG_FRONT_END_GAIN | 16 | RF AGC status |
| Profiling | 52992 | MSG_MEASUREMENT_POINT | $N + 40$ | Profiling Measurement Point |
| | 52993 | MSG_PROFILING_SYSTEM_INFO | 21 | System Profiling Information |
| | 52994 | MSG_PROFILING_THREAD_INFO | $N + 25$ | Thread Profiling Information |
| | 52995 | MSG_PROFILING_RESOURCE_COUNTER | $41N + 2$ | Information about resource buckets |
| Sbas | 30583 | MSG_SBAS_RAW | 34 | Raw SBAS data |
| Signing | 3076 | MSG_ECDSA_CERTIFICATE | $N + 6$ | An ECDSA certificate split over multiple messages |
| | 3081 | MSG_CERTIFICATE_CHAIN | 144 | The certificate chain |
| | 3088 | MSG_AES_CMAC_SIGNATURE | $N + 23$ | AES-CMAC 128 digital signature |
| | 3080 | MSG_ECDSA_SIGNATURE | $N + 80$ | An ECDSA signature |
| Ssr | 1501 | MSG_SSR_ORBIT_CLOCK | 50 | Precise orbit and clock correction |
| | 1505 | MSG_SSR_CODE_BIASES | $3N + 10$ | Precise code biases correction |
| | 1510 | MSG_SSR_PHASE_BIASES | $8N + 15$ | Precise phase biases correction |
| | 1533 | MSG_SSR_STEC_CORRECTION | $11N + 16$ | STEC correction polynomial coefficients |
| | 1532 | MSG_SSR_GRIDDED_CORRECTION | $5N + 23$ | Gridded troposphere and STEC correction residuals |
| | 1534 | MSG_SSR_GRIDDED_CORRECTION_BOUNDS | $9N + 27$ | Gridded troposhere and STEC correction residuals bounds |
| | 1528 | MSG_SSR_TILE_DEFINITION | 33 | Definition of a SSR atmospheric correction tile. |
| | 1541 | MSG_SSR_SATELLITE_APC | $32N + 9$ | Satellite antenna phase center corrections |
| | 1502 | MSG_SSR_ORBIT_CLOCK_BOUNDS | $9N + 13$ | Combined Orbit and Clock Bound |
| | 1516 | MSG_SSR_CODE_PHASE_BIASES_BOUNDS | $6N + 13$ | Combined Code and Phase Biases Bounds |
| | 1503 | MSG_SSR_ORBIT_CLOCK_BOUNDS_DEGRADATION | 28 | Combined Orbit and Clock Bound Degradation Parameter |
| Telemetry | 288 | MSG_TEL_SV | $12N + 8$ | Per-signal telemetry |
| Tracking | 65 | MSG_TRACKING_STATE | 4N | Signal tracking channel states |
| | 97 | MSG_MEASUREMENT_STATE | 3N | Measurement Engine signal tracking channel states |
| | 45 | MSG_TRACKING_IQ | $4N + 3$ | Tracking channel correlations |
| User | 2048 | MSG_USER_DATA | N | User data |
| Vehicle | 2307 | MSG_ODOMETRY | 9 | Vehicle forward (x-axis) velocity |
| | 2308 | MSG_WHEELTICK | 14 | Accumulated wheeltick count message |

Table 6.0.2: SBP message types

# 7 Stable Message Definitions

## 7.1 Ext Events

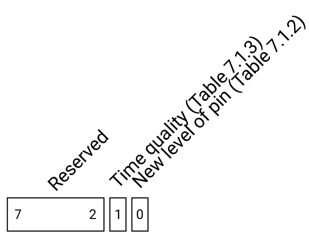
Messages reporting accurately-timestamped external events, e.g. camera shutter time.

#### MSG_EXT_EVENT — 0x0101 — 257

Reports detection of an external event, the GPS time it occurred, which pin it was and whether it was rising or falling.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 2 | u16 | weeks | `wn` | GPS week number |
| 2 | 4 | u32 | ms | `tow` | GPS time of week rounded to the nearest millisecond |
| 6 | 4 | s32 | ns | `ns_residual` | Nanosecond residual of millisecond-rounded TOW (ranges from -500000 to 500000) |
| 10 | 1 | u8 | | `flags` | Flags |
| 11 | 1 | u8 | | `pin` | Pin number. 0..9 = DEBUG0..9. |
| | 12 | | | | Total Payload Length |

Table 7.1.1: MSG_EXT_EVENT 0x0101 message structure




Field 7.1.1: Flags (`flags`)

| Value | Description |
|---|---|
| 0 | Low (falling edge) |
| 1 | High (rising edge) |

Table 7.1.2: New level of pin values (`flags[0]`)

| Value | Description |
|---|---|
| 0 | Unknown - don't have nav solution |
| 1 | Good (< 1 microsecond) |

Table 7.1.3: Time quality values (`flags[1]`)

## 7.2 Imu

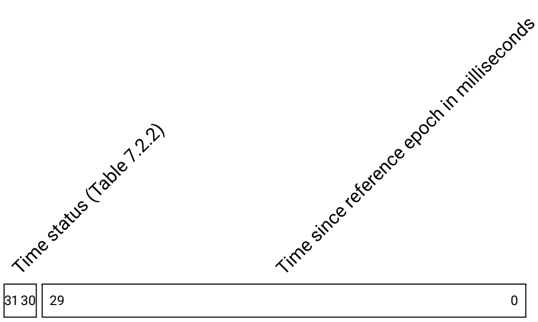
Inertial Measurement Unit (IMU) messages.

#### MSG_IMU_RAW — 0x0900 — 2304

Raw data from the Inertial Measurement Unit, containing accelerometer and gyroscope readings. The sense of the measurements are to be aligned with the indications on the device itself. Measurement units, which are specific to the device hardware and settings, are communicated via the MSG_IMU_AUX message. If using ”time since startup” local time tags, the receiving end will expect either a MSG_GNSS_TIME_OFFSET or MSG_PPS_TIME to establish the relationship between IMU time and GNSS time. Regardless of the timestamping mode, the timestamp is required to roll over to zero when reaching one week (604800 seconds, or 604800000 milliseconds). The time-tagging mode should not change throughout a run.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | `tow` | Milliseconds since reference epoch and time status. |
| 4 | 1 | u8 | ms / 256 | `tow_f` | Milliseconds since reference epoch, fractional part |
| 5 | 2 | s16 | | `acc_x` | Acceleration in the IMU frame X axis |
| 7 | 2 | s16 | | `acc_y` | Acceleration in the IMU frame Y axis |
| 9 | 2 | s16 | | `acc_z` | Acceleration in the IMU frame Z axis |
| 11 | 2 | s16 | | `gyr_x` | Angular rate around IMU frame X axis |
| 13 | 2 | s16 | | `gyr_y` | Angular rate around IMU frame Y axis |
| 15 | 2 | s16 | | `gyr_z` | Angular rate around IMU frame Z axis |
| | 17 | | | | Total Payload Length |

Table 7.2.1: MSG_IMU_RAW 0x0900 message structure




Field 7.2.1: Milliseconds since reference epoch and time status. (`tow`)

| Value | Description |
|---|---|
| 0 | Reference epoch is start of current GPS week |
| 1 | Reference epoch is time of system startup |
| 2 | Reference epoch is unknown |
| 3 | Reference epoch is last PPS |

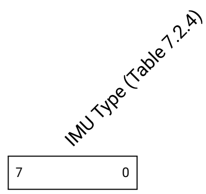
Table 7.2.2: Time status values (`tow[30:31]`)

**MSG_IMU_AUX — 0x0901 — 2305**

Auxiliary data specific to a particular IMU. The ‘imu_type‘ field will always be consistent but the rest of the payload is device specific and depends on the value of ‘imu_type‘.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `imu_type` | IMU type |
| 1 | 2 | s16 | | `temp` | Raw IMU temperature |
| 3 | 1 | u8 | | `imu_conf` | IMU configuration |
| | 4 | | | | Total Payload Length |

Table 7.2.3: MSG_IMU_AUX 0x0901 message structure



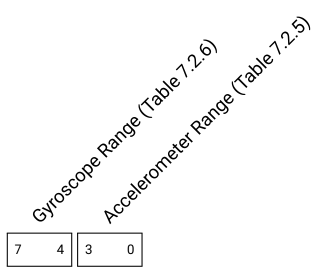

Field 7.2.2: IMU type (`imu_type`)

| Value | Description |
|---|---|
| 0 | Bosch BMI160 |
| 1 | ST Microelectronics ASM330LLH |
| 3 | TDK ICM-42670 |
| 4 | Murata SCHA634-D03 |
| 5 | TDK IAM-20680HP |

Table 7.2.4: IMU Type values (`imu_type[0:7]`)

| Value | Description |
|---|---|
| 0 | +/- 2g |
| 1 | +/- 4g |
| 2 | +/- 8g |
| 3 | +/- 16g |
| 4 | +/- 6g |

Table 7.2.5: Accelerometer Range values (`imu_conf[0:3]`)




Field 7.2.3: IMU configuration (`imu_conf`)

| Value | Description |
|---|---|
| 0 | +/- 2000 deg / s |
| 1 | +/- 1000 deg / s |
| 2 | +/- 500 deg / s |
| 3 | +/- 250 deg / s |
| 4 | +/- 125 deg / s |
| 5 | +/- 300 deg / s |

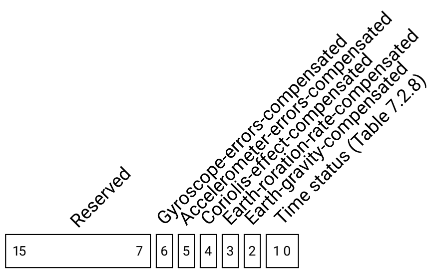
Table 7.2.6: Gyroscope Range values (`imu_conf[4:7]`)

### MSG_IMU_COMP — 0x0905 — 2309

Data from the Inertial Measurement Unit, containing accelerometer and gyroscope readings compensated for estimated errors and constant physical effects. The output is valid for inertially referenced center of navigation (IMU body frame) represented in vehicle body frame.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 8 | u64 | microseconds | `time` | Microseconds since reference epoch |
| 8 | 2 | u16 | | `flags` | Contains the applied compensation parameters and time synchronization mode |
| 10 | 4 | s32 | 1e-6 m/s^2 | `acc_comp_x` | Compensated acceleration X axis |
| 14 | 4 | s32 | 1e-6 m/s^2 | `acc_comp_y` | Compensated acceleration Y axis |
| 18 | 4 | s32 | 1e-6 m/s^2 | `acc_comp_z` | Compensated acceleration Z axis |
| 22 | 4 | s32 | 1e-6 deg/s | `gyr_comp_x` | Compensated angular rate X axis |
| 26 | 4 | s32 | 1e-6 deg/s | `gyr_comp_y` | Compensated angular rate Y axis |
| 30 | 4 | s32 | 1e-6 deg/s | `gyr_comp_z` | Compensated angular rate Z axis |
| | 34 | | | | Total Payload Length |

Table 7.2.7: MSG_IMU_COMP 0x0905 message structure




Field 7.2.4: Contains the applied compensation parameters and time synchronization mode (`flags`)

| Value | Description |
|---|---|
| 0 | Reference epoch is start of current GPS week |
| 1 | Reference epoch is time of system startup |
| 2 | Reference epoch is unknown |
| 3 | Reference epoch is last PPS |

Table 7.2.8: Time status values (`flags[0:1]`)

## 7.3 Logging

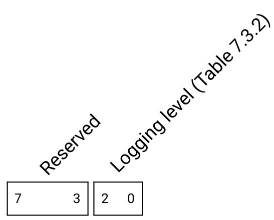
Logging and debugging messages from the device.

#### MSG_LOG — 0x0401 — 1025

This message contains a human-readable payload string from the device containing errors, warnings and informational messages at ERROR, WARNING, DEBUG, INFO logging levels.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `level` | Logging level |
| 1 | N | string | | `text` | Human-readable string |
| | N + 1 | | | | Total Payload Length |

Table 7.3.1: MSG_LOG 0x0401 message structure




Field 7.3.1: Logging level (`level`)

| Value | Description |
|---|---|
| 0 | EMERG |
| 1 | ALERT |
| 2 | CRIT |
| 3 | ERROR |
| 4 | WARN |
| 5 | NOTICE |
| 6 | INFO |
| 7 | DEBUG |

Table 7.3.2: Logging level values (`level[0:2]`)

**MSG_FWD — 0x0402 — 1026**

This message provides the ability to forward messages over SBP. This may take the form of wrapping up SBP messages received by Piksi for logging purposes or wrapping another protocol with SBP.

The source identifier indicates from what interface a forwarded stream derived. The protocol identifier identifies what the expected protocol the forwarded msg contains. Protocol 0 represents SBP and the remaining values are implementation defined.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `source` | source identifier |
| 1 | 1 | u8 | | `protocol` | protocol identifier |
| 2 | N | u8[N] | | `fwd_payload` | variable length wrapped binary message |
| | $N + 2$ | | | | Total Payload Length |

Table 7.3.3: MSG_FWD 0x0402 message structure

## 7.4 Mag

Magnetometer (mag) messages.

#### MSG_MAG_RAW — 0x0902 — 2306

Raw data from the magnetometer.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | tow | Milliseconds since start of GPS week. If the high bit is set, the time is unknown or invalid. |
| 4 | 1 | u8 | ms / 256 | tow_f | Milliseconds since start of GPS week, fractional part |
| 5 | 2 | s16 | microteslas | mag_x | Magnetic field in the body frame X axis |
| 7 | 2 | s16 | microteslas | mag_y | Magnetic field in the body frame Y axis |
| 9 | 2 | s16 | microteslas | mag_z | Magnetic field in the body frame Z axis |
| | 11 | | | | Total Payload Length |

Table 7.4.1: MSG_MAG_RAW 0x0902 message structure

## 7.5 Navigation

Geodetic navigation messages reporting GPS time, position, velocity, and baseline position solutions. For position solutions, these messages define several different position solutions: single-point (SPP), RTK, and pseudo-absolute position solutions.

The SPP is the standalone, absolute GPS position solution using only a single receiver. The RTK solution is the differential GPS solution, which can use either a fixed/integer or floating carrier phase ambiguity. The pseudo-absolute position solution uses a user-provided, well-surveyed base station position (if available) and the RTK solution in tandem.

When the inertial navigation mode indicates that the IMU is used, all messages are reported in the vehicle body frame as defined by device settings. By default, the vehicle body frame is configured to be coincident with the antenna phase center. When there is no inertial navigation, the solution will be reported at the phase center of the antenna. There is no inertial navigation capability on Piksi Multi or Duro.

The tow field, when valid, is most often the Time of Measurement. When this is the case, the 5th bit of flags is set to the default value of 0. When this is not the case, the tow may be a time of arrival or a local system timestamp, irrespective of the time reference (GPS Week or else), but not a Time of Measurement.

#### MSG_GPS_TIME — 0x0102 — 258

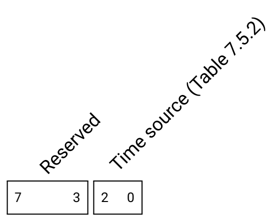
This message reports the GPS time, representing the time since the GPS epoch began on midnight January 6, 1980 UTC. GPS time counts the weeks and seconds of the week. The weeks begin at the Saturday/Sunday transition. GPS week 0 began at the beginning of the GPS time scale.

Within each week number, the GPS time of the week is between between 0 and 604800 seconds (=60*60*24*7). Note that GPS time does not accumulate leap seconds, and as of now, has a small offset from UTC. In a message stream, this message precedes a set of other navigation messages referenced to the same time (but lacking the ns field) and indicates a more precise time of these messages.

The values in this message are from GNSS measurements fused with inertial measurements. To get values from GNSS measurements only use MSG_GPS_TIME_GNSS.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 2 | u16 | weeks | `wn` | GPS week number |
| 2 | 4 | u32 | ms | `tow` | GPS time of week rounded to the nearest millisecond |
| 6 | 4 | s32 | ns | `ns_residual` | Nanosecond residual of millisecond-rounded TOW (ranges from -500000 to 500000) |
| 10 | 1 | u8 | | `flags` | Status flags (reserved) |
| | 11 | | | | Total Payload Length |

Table 7.5.1: MSG_GPS_TIME 0x0102 message structure




Field 7.5.1: Status flags (reserved) (`flags`)

| Value | Description |
|---|---|
| 0 | None (invalid) |
| 1 | GNSS Solution |
| 2 | Propagated |

Table 7.5.2: Time source values (`flags[0:2]`)

#### MSG_GPS_TIME_GNSS — 0x0104 — 260

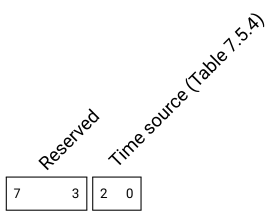
This message reports the GPS time, representing the time since the GPS epoch began on midnight January 6, 1980 UTC. GPS time counts the weeks and seconds of the week. The weeks begin at the Saturday/Sunday transition. GPS week 0 began at the beginning of the GPS time scale.

Within each week number, the GPS time of the week is between between 0 and 604800 seconds (=60*60*24*7). Note that GPS time does not accumulate leap seconds, and as of now, has a small offset from UTC. In a message stream, this message precedes a set of other navigation messages referenced to the same time (but lacking the ns field) and indicates a more precise time of these messages.

The values in this message are from GNSS measurements only. To get values fused with inertial measurements use MSG_GPS_TIME.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 2 | u16 | weeks | `wn` | GPS week number |
| 2 | 4 | u32 | ms | `tow` | GPS time of week rounded to the nearest millisecond |
| 6 | 4 | s32 | ns | `ns_residual` | Nanosecond residual of millisecond-rounded TOW (ranges from -500000 to 500000) |
| 10 | 1 | u8 | | `flags` | Status flags (reserved) |
| | 11 | | | | Total Payload Length |

Table 7.5.3: MSG_GPS_TIME_GNSS 0x0104 message structure




Field 7.5.2: Status flags (reserved) (`flags`)

| Value | Description |
|---|---|
| 0 | None (invalid) |
| 1 | GNSS Solution |
| 2 | Propagated |

Table 7.5.4: Time source values (`flags[0:2]`)

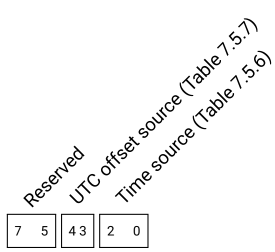
#### MSG_UTC_TIME — 0x0103 — 259

This message reports the Universal Coordinated Time (UTC). Note the flags which indicate the source of the UTC offset value and source of the time fix.

The values in this message are from GNSS measurements fused with inertial measurements. To get values from GNSS measurements only use MSG_UTC_TIME_GNSS.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `flags` | Indicates source and time validity |
| 1 | 4 | u32 | ms | `tow` | GPS time of week rounded to the nearest millisecond |
| 5 | 2 | u16 | year | `year` | Year |
| 7 | 1 | u8 | months | `month` | Month (range 1 .. 12) |
| 8 | 1 | u8 | day | `day` | days in the month (range 1-31) |
| 9 | 1 | u8 | hours | `hours` | hours of day (range 0-23) |
| 10 | 1 | u8 | minutes | `minutes` | minutes of hour (range 0-59) |
| 11 | 1 | u8 | seconds | `seconds` | seconds of minute (range 0-60) rounded down |
| 12 | 4 | u32 | nanoseconds | `ns` | nanoseconds of second (range 0-999999999) |
| | 16 | | | | Total Payload Length |

Table 7.5.5: MSG_UTC_TIME 0x0103 message structure




Field 7.5.3: Indicates source and time validity (`flags`)

| Value | Description |
|---|---|
| 0 | None (invalid) |
| 1 | GNSS Solution |
| 2 | Propagated |

Table 7.5.6: Time source values (`flags[0:2]`)

| Value | Description |
|---|---|
| 0 | Factory Default |
| 1 | Non Volatile Memory |
| 2 | Decoded this Session |

Table 7.5.7: UTC offset source values (`flags[3:4]`)

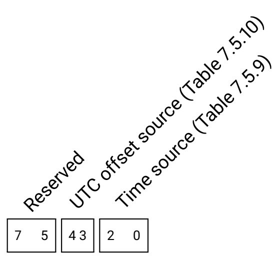
#### MSG_UTC_TIME_GNSS — 0x0105 — 261

This message reports the Universal Coordinated Time (UTC). Note the flags which indicate the source of the UTC offset value and source of the time fix.

The values in this message are from GNSS measurements only. To get values fused with inertial measurements use MSG_UTC_TIME.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `flags` | Indicates source and time validity |
| 1 | 4 | u32 | ms | `tow` | GPS time of week rounded to the nearest millisecond |
| 5 | 2 | u16 | year | `year` | Year |
| 7 | 1 | u8 | months | `month` | Month (range 1 .. 12) |
| 8 | 1 | u8 | day | `day` | days in the month (range 1-31) |
| 9 | 1 | u8 | hours | `hours` | hours of day (range 0-23) |
| 10 | 1 | u8 | minutes | `minutes` | minutes of hour (range 0-59) |
| 11 | 1 | u8 | seconds | `seconds` | seconds of minute (range 0-60) rounded down |
| 12 | 4 | u32 | nanoseconds | `ns` | nanoseconds of second (range 0-999999999) |
| | 16 | | | | Total Payload Length |

Table 7.5.8: MSG_UTC_TIME_GNSS 0x0105 message structure




Field 7.5.4: Indicates source and time validity (`flags`)

| Value | Description |
|---|---|
| 0 | None (invalid) |
| 1 | GNSS Solution |
| 2 | Propagated |

Table 7.5.9: Time source values (`flags[0:2]`)

| Value | Description |
|---|---|
| 0 | Factory Default |
| 1 | Non Volatile Memory |
| 2 | Decoded this Session |

Table 7.5.10: UTC offset source values (`flags[3:4]`)

### MSG_DOPS — 0x0208 — 520

This dilution of precision (DOP) message describes the effect of navigation satellite geometry on positional measurement precision. The flags field indicated whether the DOP reported corresponds to differential or SPP solution.

The values in this message are from GNSS measurements only.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 2 | u16 | 0.01 | `gdop` | Geometric Dilution of Precision |
| 6 | 2 | u16 | 0.01 | `pdop` | Position Dilution of Precision |
| 8 | 2 | u16 | 0.01 | `tdop` | Time Dilution of Precision |
| 10 | 2 | u16 | 0.01 | `hdop` | Horizontal Dilution of Precision |
| 12 | 2 | u16 | 0.01 | `vdop` | Vertical Dilution of Precision |
| 14 | 1 | u8 | | `flags` | Indicates the position solution with which the DOPS message corresponds |
| | 15 | | | | Total Payload Length |

Table 7.5.11: MSG_DOPS 0x0208 message structure


Field 7.5.5: Indicates the position solution with which the DOPS message corresponds (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Single Point Position (SPP) |
| 2 | Differential GNSS (DGNSS) |
| 3 | Float RTK |
| 4 | Fixed RTK |
| 5 | Undefined |
| 6 | SBAS Position |

Table 7.5.12: Fix mode values (`flags[0:2]`)

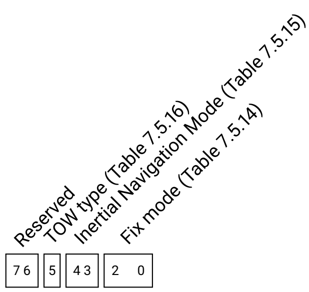
**MSG_POS_ECEF — 0x0209 — 521**

The position solution message reports absolute Earth Centered Earth Fixed (ECEF) coordinates and the status (single point vs pseudo-absolute RTK) of the position solution. If the rover receiver knows the surveyed position of the base station and has an RTK solution, this reports a pseudo-absolute position solution using the base station position and the rover's RTK baseline vector. The full GPS time is given by the preceding MSG_GPS_TIME with the matching time-of-week (tow).

The values in this message are from GNSS measurements fused with inertial measurements. To get values from GNSS measurements only use MSG_POS_ECEF_GNSS.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 8 | double | m | `x` | ECEF X coordinate |
| 12 | 8 | double | m | `y` | ECEF Y coordinate |
| 20 | 8 | double | m | `z` | ECEF Z coordinate |
| 28 | 2 | u16 | mm | `accuracy` | Position estimated standard deviation |
| 30 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 31 | 1 | u8 | | `flags` | Status flags |
| | 32 | | | | Total Payload Length |

Table 7.5.13: MSG_POS_ECEF 0x0209 message structure




Field 7.5.6: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Single Point Position (SPP) |
| 2 | Differential GNSS (DGNSS) |
| 3 | Float RTK |
| 4 | Fixed RTK |
| 5 | Dead Reckoning |
| 6 | SBAS Position |

Table 7.5.14: Fix mode values (`flags[0:2]`)

| Value | Description |
|---|---|
| 0 | None |
| 1 | INS used |

Table 7.5.15: Inertial Navigation Mode values (`flags[3:4]`)

| Value | Description |
|---|---|
| 0 | Time of Measurement |
| 1 | Other |

Table 7.5.16: TOW type values (`flags[5:5]`)

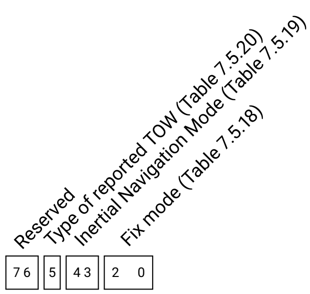
#### MSG_POS_ECEF_COV — 0x0214 — 532

The position solution message reports absolute Earth Centered Earth Fixed (ECEF) coordinates and the status (single point vs pseudo-absolute RTK) of the position solution. The message also reports the upper triangular portion of the 3x3 covariance matrix. If the receiver knows the surveyed position of the base station and has an RTK solution, this reports a pseudo-absolute position solution using the base station position and the rover's RTK baseline vector. The full GPS time is given by the preceding MSG_GPS_TIME with the matching time-of-week (tow).

The values in this message are from GNSS measurements fused with inertial measurements. To get values from GNSS measurements only use MSG_POS_ECEF_COV_GNSS.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 8 | double | m | `x` | ECEF X coordinate |
| 12 | 8 | double | m | `y` | ECEF Y coordinate |
| 20 | 8 | double | m | `z` | ECEF Z coordinate |
| 28 | 4 | float | m^2 | `cov_x_x` | Estimated variance of x |
| 32 | 4 | float | m^2 | `cov_x_y` | Estimated covariance of x and y |
| 36 | 4 | float | m^2 | `cov_x_z` | Estimated covariance of x and z |
| 40 | 4 | float | m^2 | `cov_y_y` | Estimated variance of y |
| 44 | 4 | float | m^2 | `cov_y_z` | Estimated covariance of y and z |
| 48 | 4 | float | m^2 | `cov_z_z` | Estimated variance of z |
| 52 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 53 | 1 | u8 | | `flags` | Status flags |
| | 54 | | | | Total Payload Length |

Table 7.5.17: MSG_POS_ECEF_COV 0x0214 message structure




Field 7.5.7: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Single Point Position (SPP) |
| 2 | Differential GNSS (DGNSS) |
| 3 | Float RTK |
| 4 | Fixed RTK |
| 5 | Dead Reckoning |
| 6 | SBAS Position |

Table 7.5.18: Fix mode values (`flags[0:2]`)

| Value | Description |
|---|---|
| 0 | None |
| 1 | INS used |

Table 7.5.19: Inertial Navigation Mode values (`flags[3:4]`)

| Value | Description |
|---|---|
| 0 | Time of Measurement |
| 1 | Other |

Table 7.5.20: Type of reported TOW values (`flags[5:5]`)

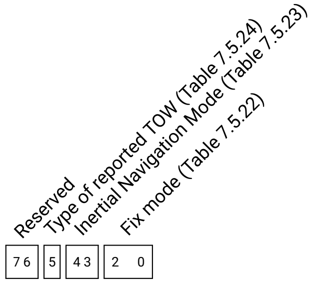
**MSG_POS_LLH — 0x020A — 522**

This position solution message reports the absolute geodetic coordinates and the status (single point vs pseudo-absolute RTK) of the position solution. If the rover receiver knows the surveyed position of the base station and has an RTK solution, this reports a pseudo-absolute position solution using the base station position and the rover's RTK baseline vector. The full GPS time is given by the preceding MSG_GPS_TIME with the matching time-of-week (tow).

The values in this message are from GNSS measurements fused with inertial measurements. To get values from GNSS measurements only use MSG_POS_LLH_GNSS.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 8 | double | deg | `lat` | Latitude |
| 12 | 8 | double | deg | `lon` | Longitude |
| 20 | 8 | double | m | `height` | Height above WGS84 ellipsoid |
| 28 | 2 | u16 | mm | `h_accuracy` | Horizontal position estimated standard deviation |
| 30 | 2 | u16 | mm | `v_accuracy` | Vertical position estimated standard deviation |
| 32 | 1 | u8 | | `n_sats` | Number of satellites used in solution. |
| 33 | 1 | u8 | | `flags` | Status flags |
| | 34 | | | | Total Payload Length |

Table 7.5.21: MSG_POS_LLH 0x020A message structure




Field 7.5.8: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Single Point Position (SPP) |
| 2 | Differential GNSS (DGNSS) |
| 3 | Float RTK |
| 4 | Fixed RTK |
| 5 | Dead Reckoning |
| 6 | SBAS Position |

Table 7.5.22: Fix mode values (`flags[0:2]`)

| Value | Description |
|---|---|
| 0 | None |
| 1 | INS used |

Table 7.5.23: Inertial Navigation Mode values (`flags[3:4]`)

| Value | Description |
|---|---|
| 0 | Time of Measurement |
| 1 | Other |

Table 7.5.24: Type of reported TOW values (`flags[5:5]`)

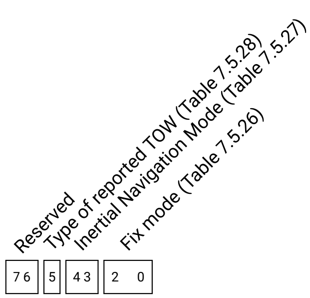
### MSG_POS_LLH_COV — 0x0211 — 529

This position solution message reports the absolute geodetic coordinates and the status (single point vs pseudo-absolute RTK) of the position solution as well as the upper triangle of the 3x3 covariance matrix. The position information and Fix Mode flags follow the MSG_POS_LLH message. Since the covariance matrix is computed in the local-level North, East, Down frame, the covariance terms follow that convention. Thus, covariances are reported against the ”downward” measurement and care should be taken with the sign convention.

The values in this message are from GNSS measurements fused with inertial measurements. To get values from GNSS measurements only use MSG_POS_LLH_COV_GNSS.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 8 | double | deg | `lat` | Latitude |
| 12 | 8 | double | deg | `lon` | Longitude |
| 20 | 8 | double | m | `height` | Height above WGS84 ellipsoid |
| 28 | 4 | float | m^2 | `cov_n_n` | Estimated variance of northing |
| 32 | 4 | float | m^2 | `cov_n_e` | Covariance of northing and easting |
| 36 | 4 | float | m^2 | `cov_n_d` | Covariance of northing and downward measurement |
| 40 | 4 | float | m^2 | `cov_e_e` | Estimated variance of easting |
| 44 | 4 | float | m^2 | `cov_e_d` | Covariance of easting and downward measurement |
| 48 | 4 | float | m^2 | `cov_d_d` | Estimated variance of downward measurement |
| 52 | 1 | u8 | | `n_sats` | Number of satellites used in solution. |
| 53 | 1 | u8 | | `flags` | Status flags |
| | 54 | | | | Total Payload Length |

Table 7.5.25: MSG_POS_LLH_COV 0x0211 message structure




Field 7.5.9: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Single Point Position (SPP) |
| 2 | Differential GNSS (DGNSS) |
| 3 | Float RTK |
| 4 | Fixed RTK |
| 5 | Dead Reckoning |
| 6 | SBAS Position |

Table 7.5.26: Fix mode values (`flags[0:2]`)

| Value | Description |
|---|---|
| 0 | None |
| 1 | INS used |

Table 7.5.27: Inertial Navigation Mode values (`flags[3:4]`)

| Value | Description |
|---|---|
| 0 | Time of Measurement |
| 1 | Other |

Table 7.5.28: Type of reported TOW values (`flags[5:5]`)

#### MSG_POS_LLH_ACC — 0x0218 — 536

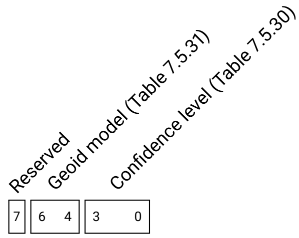
This position solution message reports the absolute geodetic coordinates and the status (single point vs pseudo-absolute RTK) of the position solution as well as the estimated horizontal, vertical, cross-track and along-track errors. The position information and Fix Mode flags follow the MSG_POS_LLH message. Since the covariance matrix is computed in the local-level North, East, Down frame, the estimated error terms follow that convention.

The estimated errors are reported at a user-configurable confidence level. The user-configured percentile is encoded in the percentile field.

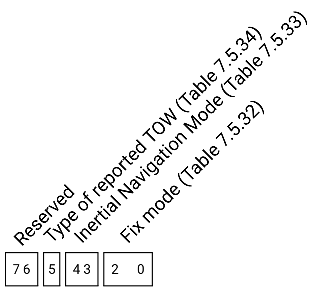
The values in this message are from GNSS measurements fused with inertial measurements.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 8 | double | deg | `lat` | Latitude |
| 12 | 8 | double | deg | `lon` | Longitude |
| 20 | 8 | double | m | `height` | Height above WGS84 ellipsoid |
| 28 | 8 | double | m | `orthometric_height` | Height above the geoid (i.e. height above mean sea level). See confidence_and_geoid for geoid model used. |
| 36 | 4 | float | m | `h_accuracy` | Estimated horizontal error at the user-configured confidence level; zero implies invalid. |
| 40 | 4 | float | m | `v_accuracy` | Estimated vertical error at the user-configured confidence level; zero implies invalid. |
| 44 | 4 | float | m | `ct_accuracy` | Estimated cross-track error at the user-configured confidence level; zero implies invalid. |
| 48 | 4 | float | m | `at_accuracy` | Estimated along-track error at the user-configured confidence level; zero implies invalid. |
| 52 | 4 | float | m | `h_ellipse.semi_major` | The semi major axis of the estimated horizontal error ellipse at the user-configured confidence level; zero implies invalid. |
| 56 | 4 | float | m | `h_ellipse.semi_minor` | The semi minor axis of the estimated horizontal error ellipse at the user-configured confidence level; zero implies invalid. |
| 60 | 4 | float | deg | `h_ellipse.orientation` | The orientation of the semi major axis of the estimated horizontal error ellipse with respect to North. |
| 64 | 1 | u8 | | `confidence_and_geoid` | The lower bits describe the configured confidence level for the estimated position error. The middle bits describe the geoid model used to calculate the orthometric height. |
| 65 | 1 | u8 | | `n_sats` | Number of satellites used in solution. |
| 66 | 1 | u8 | | `flags` | Status flags |
| | 67 | | | | Total Payload Length |

Table 7.5.29: MSG_POS_LLH_ACC 0x0218 message structure




Field 7.5.10: The lower bits describe the configured confidence level for the estimated position error. The middle bits describe the geoid model used to calculate the orthometric height. (`confidence_and_geoid`)




Field 7.5.11: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | reserved |
| 1 | 39.35% |
| 2 | 68.27% |
| 3 | 95.45% |
| 4 | 99.73% |

Table 7.5.30: Confidence level values (`confidence_and_geoid[0:3]`)

| Value | Description |
|---|---|
| 0 | No model |
| 1 | EGM96 |
| 2 | EGM2008 |

Table 7.5.31: Geoid model values (`confidence_and_geoid[4:6]`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Single Point Position (SPP) |
| 2 | Differential GNSS (DGNSS) |
| 3 | Float RTK |
| 4 | Fixed RTK |
| 5 | Dead Reckoning |
| 6 | SBAS Position |

Table 7.5.32: Fix mode values (`flags[0:2]`)

| Value | Description |
|---|---|
| 0 | None |
| 1 | INS used |

Table 7.5.33: Inertial Navigation Mode values (`flags[3:4]`)

| Value | Description |
|---|---|
| 0 | Time of Measurement |
| 1 | Other |

Table 7.5.34: Type of reported TOW values (`flags[5:5]`)

#### MSG_BASELINE_ECEF — 0x020B — 523

This message reports the baseline solution in Earth Centered Earth Fixed (ECEF) coordinates. This baseline is the relative vector distance from the base station to the rover receiver. The full GPS time is given by the preceding MSG_GPS_TIME with the matching time-of-week (tow).

The values in this message are from GNSS measurements only.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | s32 | mm | `x` | Baseline ECEF X coordinate |
| 8 | 4 | s32 | mm | `y` | Baseline ECEF Y coordinate |
| 12 | 4 | s32 | mm | `z` | Baseline ECEF Z coordinate |
| 16 | 2 | u16 | mm | `accuracy` | Position estimated standard deviation |
| 18 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 19 | 1 | u8 | | `flags` | Status flags |
| | 20 | | | | Total Payload Length |

Table 7.5.35: MSG_BASELINE_ECEF 0x020B message structure


Field 7.5.12: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Reserved |
| 2 | Differential GNSS (DGNSS) |
| 3 | Float RTK |
| 4 | Fixed RTK |
| 5 | Reserved |
| 6 | Reserved |

Table 7.5.36: Fix mode values (`flags[0:2]`)

**MSG_BASELINE_NED — 0x020C — 524**

This message reports the baseline solution in North East Down (NED) coordinates. This baseline is the relative vector distance from the base station to the rover receiver, and NED coordinate system is defined at the local WGS84 tangent plane centered at the base station position. The full GPS time is given by the preceding MSG_GPS_TIME with the matching time-of-week (tow).

The values in this message are from GNSS measurements only.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | s32 | mm | `n` | Baseline North coordinate |
| 8 | 4 | s32 | mm | `e` | Baseline East coordinate |
| 12 | 4 | s32 | mm | `d` | Baseline Down coordinate |
| 16 | 2 | u16 | mm | `h_accuracy` | Horizontal position estimated standard deviation |
| 18 | 2 | u16 | mm | `v_accuracy` | Vertical position estimated standard deviation |
| 20 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 21 | 1 | u8 | | `flags` | Status flags |
| | 22 | | | | Total Payload Length |

Table 7.5.37: MSG_BASELINE_NED 0x020C message structure


Field 7.5.13: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Reserved |
| 2 | Differential GNSS (DGNSS) |
| 3 | Float RTK |
| 4 | Fixed RTK |
| 5 | Reserved |
| 6 | Reserved |

Table 7.5.38: Fix mode values (`flags[0:2]`)

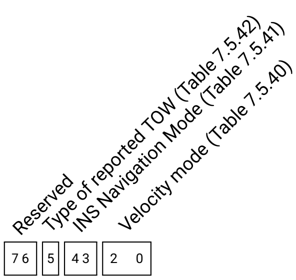
#### MSG_VEL_ECEF — 0x020D — 525

This message reports the velocity in Earth Centered Earth Fixed (ECEF) coordinates. The full GPS time is given by the preceding MSG_GPS_TIME with the matching time-of-week (tow).

The values in this message are from GNSS measurements fused with inertial measurements. To get values from GNSS measurements only use MSG_VEL_ECEF_GNSS.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | s32 | mm/s | `x` | Velocity ECEF X coordinate |
| 8 | 4 | s32 | mm/s | `y` | Velocity ECEF Y coordinate |
| 12 | 4 | s32 | mm/s | `z` | Velocity ECEF Z coordinate |
| 16 | 2 | u16 | mm/s | `accuracy` | Velocity estimated standard deviation |
| 18 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 19 | 1 | u8 | | `flags` | Status flags |
| | 20 | | | | Total Payload Length |

Table 7.5.39: MSG_VEL_ECEF 0x020D message structure




Field 7.5.14: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Measured Doppler derived |
| 2 | Computed Doppler derived |
| 3 | Dead Reckoning |

Table 7.5.40: Velocity mode values (`flags[0:2]`)

| Value | Description |
|---|---|
| 0 | None |
| 1 | INS used |

Table 7.5.41: INS Navigation Mode values (`flags[3:4]`)

| Value | Description |
|---|---|
| 0 | Time of Measurement |
| 1 | Other |

Table 7.5.42: Type of reported TOW values (`flags[5:5]`)

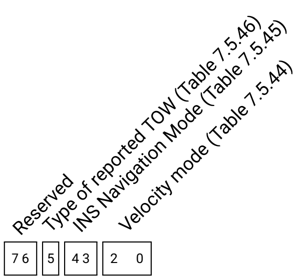
**MSG_VEL_ECEF_COV — 0x0215 — 533**

This message reports the velocity in Earth Centered Earth Fixed (ECEF) coordinates. The full GPS time is given by the preceding MSG_GPS_TIME with the matching time-of-week (tow).

The values in this message are from GNSS measurements fused with inertial measurements. To get values from GNSS measurements only use MSG_VEL_ECEF_COV_GNSS.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | s32 | mm/s | `x` | Velocity ECEF X coordinate |
| 8 | 4 | s32 | mm/s | `y` | Velocity ECEF Y coordinate |
| 12 | 4 | s32 | mm/s | `z` | Velocity ECEF Z coordinate |
| 16 | 4 | float | m^2/s^2 | `cov_x_x` | Estimated variance of x |
| 20 | 4 | float | m^2/s^2 | `cov_x_y` | Estimated covariance of x and y |
| 24 | 4 | float | m^2/s^2 | `cov_x_z` | Estimated covariance of x and z |
| 28 | 4 | float | m^2/s^2 | `cov_y_y` | Estimated variance of y |
| 32 | 4 | float | m^2/s^2 | `cov_y_z` | Estimated covariance of y and z |
| 36 | 4 | float | m^2/s^2 | `cov_z_z` | Estimated variance of z |
| 40 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 41 | 1 | u8 | | `flags` | Status flags |
| | 42 | | | | Total Payload Length |

Table 7.5.43: MSG_VEL_ECEF_COV 0x0215 message structure




Field 7.5.15: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Measured Doppler derived |
| 2 | Computed Doppler derived |
| 3 | Dead Reckoning |

Table 7.5.44: Velocity mode values (`flags[0:2]`)

| Value | Description |
|---|---|
| 0 | None |
| 1 | INS used |

Table 7.5.45: INS Navigation Mode values (`flags[3:4]`)

| Value | Description |
|---|---|
| 0 | Time of Measurement |
| 1 | Other |

Table 7.5.46: Type of reported TOW values (`flags[5:5]`)

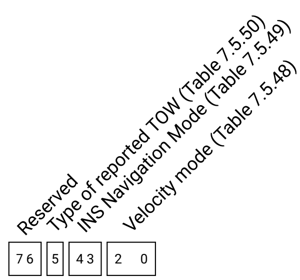
#### MSG_VEL_NED — 0x020E — 526

This message reports the velocity in local North East Down (NED) coordinates. The NED coordinate system is defined as the local WGS84 tangent plane centered at the current position. The full GPS time is given by the preceding MSG_GPS_TIME with the matching time-of-week (tow).

The values in this message are from GNSS measurements fused with inertial measurements. To get values from GNSS measurements only use MSG_VEL_NED_GNSS.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | s32 | mm/s | `n` | Velocity North coordinate |
| 8 | 4 | s32 | mm/s | `e` | Velocity East coordinate |
| 12 | 4 | s32 | mm/s | `d` | Velocity Down coordinate |
| 16 | 2 | u16 | mm/s | `h_accuracy` | Horizontal velocity estimated standard deviation |
| 18 | 2 | u16 | mm/s | `v_accuracy` | Vertical velocity estimated standard deviation |
| 20 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 21 | 1 | u8 | | `flags` | Status flags |
| | 22 | | | | Total Payload Length |

Table 7.5.47: MSG_VEL_NED 0x020E message structure




Field 7.5.16: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Measured Doppler derived |
| 2 | Computed Doppler derived |
| 3 | Dead Reckoning |

Table 7.5.48: Velocity mode values (`flags[0:2]`)

| Value | Description |
|---|---|
| 0 | None |
| 1 | INS used |

Table 7.5.49: INS Navigation Mode values (`flags[3:4]`)

| Value | Description |
|---|---|
| 0 | Time of Measurement |
| 1 | Other |

Table 7.5.50: Type of reported TOW values (`flags[5:5]`)

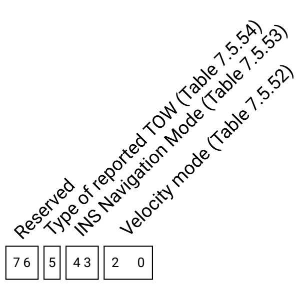
**MSG_VEL_NED_COV — 0x0212 — 530**

This message reports the velocity in local North East Down (NED) coordinates. The NED coordinate system is defined as the local WGS84 tangent plane centered at the current position. The full GPS time is given by the preceding MSG_GPS_TIME with the matching time-of-week (tow). This message is similar to the MSG_VEL_NED, but it includes the upper triangular portion of the 3x3 covariance matrix.

The values in this message are from GNSS measurements fused with inertial measurements. To get values from GNSS measurements only use MSG_VEL_NED_COV_GNSS.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | s32 | mm/s | `n` | Velocity North coordinate |
| 8 | 4 | s32 | mm/s | `e` | Velocity East coordinate |
| 12 | 4 | s32 | mm/s | `d` | Velocity Down coordinate |
| 16 | 4 | float | m^2 | `cov_n_n` | Estimated variance of northward measurement |
| 20 | 4 | float | m^2 | `cov_n_e` | Covariance of northward and eastward measurement |
| 24 | 4 | float | m^2 | `cov_n_d` | Covariance of northward and downward measurement |
| 28 | 4 | float | m^2 | `cov_e_e` | Estimated variance of eastward measurement |
| 32 | 4 | float | m^2 | `cov_e_d` | Covariance of eastward and downward measurement |
| 36 | 4 | float | m^2 | `cov_d_d` | Estimated variance of downward measurement |
| 40 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 41 | 1 | u8 | | `flags` | Status flags |
| | 42 | | | | Total Payload Length |

Table 7.5.51: MSG_VEL_NED_COV 0x0212 message structure




Field 7.5.17: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Measured Doppler derived |
| 2 | Computed Doppler derived |
| 3 | Dead Reckoning |

Table 7.5.52: Velocity mode values (`flags[0:2]`)

| Value | Description |
|---|---|
| 0 | None |
| 1 | INS used |

Table 7.5.53: INS Navigation Mode values (`flags[3:4]`)

| Value | Description |
|---|---|
| 0 | Time of Measurement |
| 1 | Other |

Table 7.5.54: Type of reported TOW values (`flags[5:5]`)

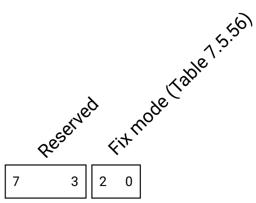
#### MSG_POS_ECEF_GNSS — 0x0229 — 553

The position solution message reports absolute Earth Centered Earth Fixed (ECEF) coordinates and the status (single point vs pseudo-absolute RTK) of the position solution. If the rover receiver knows the surveyed position of the base station and has an RTK solution, this reports a pseudo-absolute position solution using the base station position and the rover's RTK baseline vector. The full GPS time is given by the preceding MSG_GPS_TIME_GNSS with the matching time-of-week (tow).

The values in this message are from GNSS measurements only. To get values fused with inertial measurements use MSG_POS_ECEF.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 8 | double | m | `x` | ECEF X coordinate |
| 12 | 8 | double | m | `y` | ECEF Y coordinate |
| 20 | 8 | double | m | `z` | ECEF Z coordinate |
| 28 | 2 | u16 | mm | `accuracy` | Position estimated standard deviation |
| 30 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 31 | 1 | u8 | | `flags` | Status flags |
| | 32 | | | | Total Payload Length |

Table 7.5.55: MSG_POS_ECEF_GNSS 0x0229 message structure




Field 7.5.18: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Single Point Position (SPP) |
| 2 | Differential GNSS (DGNSS) |
| 3 | Float RTK |
| 4 | Fixed RTK |
| 5 | Reserved |
| 6 | SBAS Position |

Table 7.5.56: Fix mode values (`flags[0:2]`)

#### MSG_POS_ECEF_COV_GNSS — 0x0234 — 564

The position solution message reports absolute Earth Centered Earth Fixed (ECEF) coordinates and the status (single point vs pseudo-absolute RTK) of the position solution. The message also reports the upper triangular portion of the 3x3 covariance matrix. If the receiver knows the surveyed position of the base station and has an RTK solution, this reports a pseudo-absolute position solution using the base station position and the rover's RTK baseline vector. The full GPS time is given by the preceding MSG_GPS_TIME_GNSS with the matching time-of-week (tow).

The values in this message are from GNSS measurements only. To get values fused with inertial measurements use MSG_POS_ECEF_COV.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 8 | double | m | `x` | ECEF X coordinate |
| 12 | 8 | double | m | `y` | ECEF Y coordinate |
| 20 | 8 | double | m | `z` | ECEF Z coordinate |
| 28 | 4 | float | m^2 | `cov_x_x` | Estimated variance of x |
| 32 | 4 | float | m^2 | `cov_x_y` | Estimated covariance of x and y |
| 36 | 4 | float | m^2 | `cov_x_z` | Estimated covariance of x and z |
| 40 | 4 | float | m^2 | `cov_y_y` | Estimated variance of y |
| 44 | 4 | float | m^2 | `cov_y_z` | Estimated covariance of y and z |
| 48 | 4 | float | m^2 | `cov_z_z` | Estimated variance of z |
| 52 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 53 | 1 | u8 | | `flags` | Status flags |
| | 54 | | | | Total Payload Length |

Table 7.5.57: MSG_POS_ECEF_COV_GNSS 0x0234 message structure


Field 7.5.19: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Single Point Position (SPP) |
| 2 | Differential GNSS (DGNSS) |
| 3 | Float RTK |
| 4 | Fixed RTK |
| 5 | Reserved |
| 6 | SBAS Position |

Table 7.5.58: Fix mode values (`flags[0:2]`)

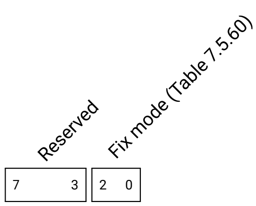
### MSG_POS_LLH_GNSS — 0x022A — 554

This position solution message reports the absolute geodetic coordinates and the status (single point vs pseudo-absolute RTK) of the position solution. If the rover receiver knows the surveyed position of the base station and has an RTK solution, this reports a pseudo-absolute position solution using the base station position and the rover's RTK baseline vector. The full GPS time is given by the preceding MSG_GPS_TIME_GNSS with the matching time-of-week (tow).

The values in this message are from GNSS measurements only. To get values fused with inertial measurements use MSG_POS_LLH.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 8 | double | deg | `lat` | Latitude |
| 12 | 8 | double | deg | `lon` | Longitude |
| 20 | 8 | double | m | `height` | Height above WGS84 ellipsoid |
| 28 | 2 | u16 | mm | `h_accuracy` | Horizontal position estimated standard deviation |
| 30 | 2 | u16 | mm | `v_accuracy` | Vertical position estimated standard deviation |
| 32 | 1 | u8 | | `n_sats` | Number of satellites used in solution. |
| 33 | 1 | u8 | | `flags` | Status flags |
| | 34 | | | | Total Payload Length |

Table 7.5.59: MSG_POS_LLH_GNSS 0x022A message structure




Field 7.5.20: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Single Point Position (SPP) |
| 2 | Differential GNSS (DGNSS) |
| 3 | Float RTK |
| 4 | Fixed RTK |
| 5 | Reserved |
| 6 | SBAS Position |

Table 7.5.60: Fix mode values (`flags[0:2]`)

#### MSG_POS_LLH_COV_GNSS — 0x0231 — 561

This position solution message reports the absolute geodetic coordinates and the status (single point vs pseudo-absolute RTK) of the position solution as well as the upper triangle of the 3x3 covariance matrix. The position information and Fix Mode flags should follow the MSG_POS_LLH_GNSS message. Since the covariance matrix is computed in the local-level North, East, Down frame, the covariance terms follow with that convention. Thus, covariances are reported against the ”downward” measurement and care should be taken with the sign convention.

The values in this message are from GNSS measurements only. To get values fused with inertial measurements use MSG_POS_LLH_COV.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 8 | double | deg | `lat` | Latitude |
| 12 | 8 | double | deg | `lon` | Longitude |
| 20 | 8 | double | m | `height` | Height above WGS84 ellipsoid |
| 28 | 4 | float | m^2 | `cov_n_n` | Estimated variance of northing |
| 32 | 4 | float | m^2 | `cov_n_e` | Covariance of northing and easting |
| 36 | 4 | float | m^2 | `cov_n_d` | Covariance of northing and downward measurement |
| 40 | 4 | float | m^2 | `cov_e_e` | Estimated variance of easting |
| 44 | 4 | float | m^2 | `cov_e_d` | Covariance of easting and downward measurement |
| 48 | 4 | float | m^2 | `cov_d_d` | Estimated variance of downward measurement |
| 52 | 1 | u8 | | `n_sats` | Number of satellites used in solution. |
| 53 | 1 | u8 | | `flags` | Status flags |
| | 54 | | | | Total Payload Length |

Table 7.5.61: MSG_POS_LLH_COV_GNSS 0x0231 message structure


Field 7.5.21: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Single Point Position (SPP) |
| 2 | Differential GNSS (DGNSS) |
| 3 | Float RTK |
| 4 | Fixed RTK |
| 5 | Dead Reckoning |
| 6 | SBAS Position |

Table 7.5.62: Fix mode values (`flags[0:2]`)

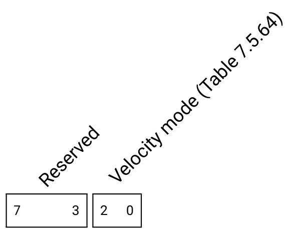
#### MSG_VEL_ECEF_GNSS — 0x022D — 557

This message reports the velocity in Earth Centered Earth Fixed (ECEF) coordinates. The full GPS time is given by the preceding MSG_GPS_TIME_GNSS with the matching time-of-week (tow).

The values in this message are from GNSS measurements only. To get values fused with inertial measurements use MSG_VEL_ECEF.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | s32 | mm/s | `x` | Velocity ECEF X coordinate |
| 8 | 4 | s32 | mm/s | `y` | Velocity ECEF Y coordinate |
| 12 | 4 | s32 | mm/s | `z` | Velocity ECEF Z coordinate |
| 16 | 2 | u16 | mm/s | `accuracy` | Velocity estimated standard deviation |
| 18 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 19 | 1 | u8 | | `flags` | Status flags |
| | 20 | | | | Total Payload Length |

Table 7.5.63: MSG_VEL_ECEF_GNSS 0x022D message structure




Field 7.5.22: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Measured Doppler derived |
| 2 | Computed Doppler derived |
| 3 | Reserved |

Table 7.5.64: Velocity mode values (`flags[0:2]`)

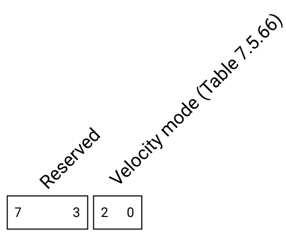
#### MSG_VEL_ECEF_COV_GNSS — 0x0235 — 565

This message reports the velocity in Earth Centered Earth Fixed (ECEF) coordinates. The full GPS time is given by the preceding MSG_GPS_TIME_GNSS with the matching time-of-week (tow).

The values in this message are from GNSS measurements only. To get values fused with inertial measurements use MSG_VEL_ECEF_COV.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | s32 | mm/s | `x` | Velocity ECEF X coordinate |
| 8 | 4 | s32 | mm/s | `y` | Velocity ECEF Y coordinate |
| 12 | 4 | s32 | mm/s | `z` | Velocity ECEF Z coordinate |
| 16 | 4 | float | m^2/s^2 | `cov_x_x` | Estimated variance of x |
| 20 | 4 | float | m^2/s^2 | `cov_x_y` | Estimated covariance of x and y |
| 24 | 4 | float | m^2/s^2 | `cov_x_z` | Estimated covariance of x and z |
| 28 | 4 | float | m^2/s^2 | `cov_y_y` | Estimated variance of y |
| 32 | 4 | float | m^2/s^2 | `cov_y_z` | Estimated covariance of y and z |
| 36 | 4 | float | m^2/s^2 | `cov_z_z` | Estimated variance of z |
| 40 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 41 | 1 | u8 | | `flags` | Status flags |
| | 42 | | | | Total Payload Length |

Table 7.5.65: MSG_VEL_ECEF_COV_GNSS 0x0235 message structure




Field 7.5.23: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Measured Doppler derived |
| 2 | Computed Doppler derived |
| 3 | Reserved |

Table 7.5.66: Velocity mode values (`flags[0:2]`)

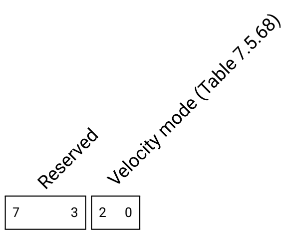
### MSG_VEL_NED_GNSS — 0x022E — 558

This message reports the velocity in local North East Down (NED) coordinates. The NED coordinate system is defined as the local WGS84 tangent plane centered at the current position. The full GPS time is given by the preceding MSG_GPS_TIME_GNSS with the matching time-of-week (tow).

The values in this message are from GNSS measurements only. To get values fused with inertial measurements use MSG_VEL_NED.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | s32 | mm/s | `n` | Velocity North coordinate |
| 8 | 4 | s32 | mm/s | `e` | Velocity East coordinate |
| 12 | 4 | s32 | mm/s | `d` | Velocity Down coordinate |
| 16 | 2 | u16 | mm/s | `h_accuracy` | Horizontal velocity estimated standard deviation |
| 18 | 2 | u16 | mm/s | `v_accuracy` | Vertical velocity estimated standard deviation |
| 20 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 21 | 1 | u8 | | `flags` | Status flags |
| | 22 | | | | Total Payload Length |

Table 7.5.67: MSG_VEL_NED_GNSS 0x022E message structure




Field 7.5.24: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Measured Doppler derived |
| 2 | Computed Doppler derived |
| 3 | Reserved |

Table 7.5.68: Velocity mode values (`flags[0:2]`)

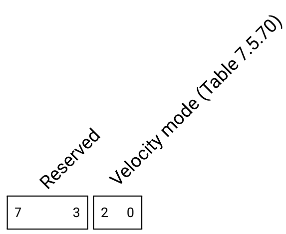
### MSG_VEL_NED_COV_GNSS — 0x0232 — 562

This message reports the velocity in local North East Down (NED) coordinates. The NED coordinate system is defined as the local WGS84 tangent plane centered at the current position. The full GPS time is given by the preceding MSG_GPS_TIME_GNSS with the matching time-of-week (tow). This message is similar to the MSG_VEL_NED_GNSS, but it includes the upper triangular portion of the 3x3 covariance matrix.

The values in this message are from GNSS measurements only. To get values fused with inertial measurements use MSG_VEL_NED_COV.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | s32 | mm/s | `n` | Velocity North coordinate |
| 8 | 4 | s32 | mm/s | `e` | Velocity East coordinate |
| 12 | 4 | s32 | mm/s | `d` | Velocity Down coordinate |
| 16 | 4 | float | m^2 | `cov_n_n` | Estimated variance of northward measurement |
| 20 | 4 | float | m^2 | `cov_n_e` | Covariance of northward and eastward measurement |
| 24 | 4 | float | m^2 | `cov_n_d` | Covariance of northward and downward measurement |
| 28 | 4 | float | m^2 | `cov_e_e` | Estimated variance of eastward measurement |
| 32 | 4 | float | m^2 | `cov_e_d` | Covariance of eastward and downward measurement |
| 36 | 4 | float | m^2 | `cov_d_d` | Estimated variance of downward measurement |
| 40 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 41 | 1 | u8 | | `flags` | Status flags |
| | 42 | | | | Total Payload Length |

Table 7.5.69: MSG_VEL_NED_COV_GNSS 0x0232 message structure




Field 7.5.25: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Measured Doppler derived |
| 2 | Computed Doppler derived |
| 3 | Reserved |

Table 7.5.70: Velocity mode values (`flags[0:2]`)

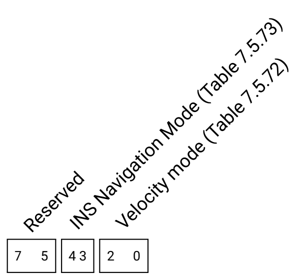
### MSG_VEL_BODY — 0x0213 — 531

This message reports the velocity in the Vehicle Body Frame. By convention, the x-axis should point out the nose of the vehicle and represent the forward direction, while as the y-axis should point out the right hand side of the vehicle. Since this is a right handed system, z should point out the bottom of the vehicle. The orientation and origin of the Vehicle Body Frame are specified via the device settings. The full GPS time is given by the preceding MSG_GPS_TIME with the matching time-of-week (tow). This message is only produced by inertial versions of Swift products and is not available from Piksi Multi or Duro.

The values in this message are from GNSS measurements fused with inertial measurements.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | s32 | mm/s | `x` | Velocity in x direction |
| 8 | 4 | s32 | mm/s | `y` | Velocity in y direction |
| 12 | 4 | s32 | mm/s | `z` | Velocity in z direction |
| 16 | 4 | float | m^2 | `cov_x_x` | Estimated variance of x |
| 20 | 4 | float | m^2 | `cov_x_y` | Covariance of x and y |
| 24 | 4 | float | m^2 | `cov_x_z` | Covariance of x and z |
| 28 | 4 | float | m^2 | `cov_y_y` | Estimated variance of y |
| 32 | 4 | float | m^2 | `cov_y_z` | Covariance of y and z |
| 36 | 4 | float | m^2 | `cov_z_z` | Estimated variance of z |
| 40 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 41 | 1 | u8 | | `flags` | Status flags |
| | 42 | | | | Total Payload Length |

Table 7.5.71: MSG_VEL_BODY 0x0213 message structure




Field 7.5.26: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Measured Doppler derived |
| 2 | Computed Doppler derived |
| 3 | Dead Reckoning |

Table 7.5.72: Velocity mode values (`flags[0:2]`)

| Value | Description |
|---|---|
| 0 | None |
| 1 | INS used |

Table 7.5.73: INS Navigation Mode values (`flags[3:4]`)

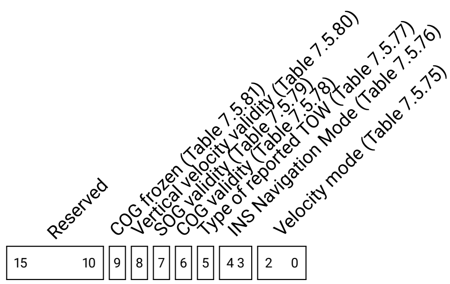
**MSG_VEL_COG — 0x021C — 540**

This message reports the receiver course over ground (COG) and speed over ground (SOG) based on the horizontal (N-E) components of the NED velocity vector. It also includes the vertical velocity coordinate. A flag is provided to indicate whether the COG value has been frozen. When the flag is set to true, the COG field is set to its last valid value until the system exceeds a minimum velocity threshold. No other fields are affected by this flag. The NED coordinate system is defined as the local WGS84 tangent plane centered at the current position. The full GPS time is given by the preceding MSG_GPS_TIME with the matching time-of-week (tow). Note: course over ground represents the receiver's direction of travel, but not necessarily the device heading.

The values in this message are from GNSS measurements fused with inertial measurements.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | u32 | microdegrees | `cog` | Course over ground relative to north direction |
| 8 | 4 | u32 | mm/s | `sog` | Speed over ground (based on horizontal velocity) |
| 12 | 4 | s32 | mm/s | `v_up` | Vertical velocity component (positive up) |
| 16 | 4 | u32 | microdegrees | `cog_accuracy` | Course over ground estimated standard deviation |
| 20 | 4 | u32 | mm/s | `sog_accuracy` | Speed over ground estimated standard deviation |
| 24 | 4 | u32 | mm/s | `v_up_accuracy` | Vertical velocity estimated standard deviation |
| 28 | 2 | u16 | | `flags` | Status flags |
| | 30 | | | | Total Payload Length |

Table 7.5.74: MSG_VEL_COG 0x021C message structure




Field 7.5.27: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Measured Doppler derived |
| 2 | Computed Doppler derived |
| 3 | Dead Reckoning |

Table 7.5.75: Velocity mode values (`flags[0:2]`)

| Value | Description |
|---|---|
| 0 | None |
| 1 | INS used |

Table 7.5.76: INS Navigation Mode values (`flags[3:4]`)

| Value | Description |
|---|---|
| 0 | Time of Measurement |
| 1 | Other |

Table 7.5.77: Type of reported TOW values (`flags[5]`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | COG valid |

Table 7.5.78: COG validity values (`flags[6]`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | SOG valid |

Table 7.5.79: SOG validity values (`flags[7]`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Vertical velocity valid |

Table 7.5.80: Vertical velocity validity values (`flags[8]`)

| Value | Description |
|---|---|
| 0 | Not frozen |
| 1 | Frozen |

Table 7.5.81: COG frozen values (`flags[9]`)

#### MSG_AGE_CORRECTIONS — 0x0210 — 528

This message reports the Age of the corrections used for the current Differential solution.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | tow | GPS Time of Week |
| 4 | 2 | u16 | deciseconds | age | Age of the corrections (0xFFFF indicates invalid) |
| | 6 | | | | Total Payload Length |

Table 7.5.82: MSG_AGE_CORRECTIONS 0x0210 message structure

#### MSG_UTC_LEAP_SECOND — 0x023A — 570

UTC-GPST leap seconds before and after the most recent (past, or future, for announced insertions) UTC leap second insertion.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 2 | s16 | | reserved_0 | Reserved. |
| 2 | 2 | s16 | | reserved_1 | Reserved. |
| 4 | 1 | s8 | | reserved_2 | Reserved. |
| 5 | 1 | s8 | s | count_before | Leap second count before insertion. |
| 6 | 2 | u16 | | reserved_3 | Reserved. |
| 8 | 2 | u16 | | reserved_4 | Reserved. |
| 10 | 2 | u16 | weeks | ref_wn | Leap second reference GPS week number. |
| 12 | 1 | u8 | days | ref_dn | Leap second reference day number. |
| 13 | 1 | s8 | s | count_after | Leap second count after insertion. |
| | 14 | | | | Total Payload Length |

Table 7.5.83: MSG_UTC_LEAP_SECOND 0x023A message structure

**MSG_REFERENCE_FRAME_PARAM — 0x0244 — 580**

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | ssr_iod | SSR IOD parameter. |
| 1 | 32 | string | | sn | Name of source coordinate-system. |
| 33 | 32 | string | | tn | Name of target coordinate-system. |
| 65 | 1 | u8 | | sin | System Identification Number. |
| 66 | 2 | u16 | | utn | Utilized Transformation Message. |
| 68 | 2 | u16 | 1 day | re_t0 | Reference Epoch t0 for transformation parameter set given as Modified Julian Day (MJD) Number minus 44244 days. |
| 70 | 4 | s32 | 0.001 m | delta_X0 | Translation in X for Reference Epoch t0. |
| 74 | 4 | s32 | 0.001 m | delta_Y0 | Translation in Y for Reference Epoch t0. |
| 78 | 4 | s32 | 0.001 m | delta_Z0 | Translation in Z for Reference Epoch t0. |
| 82 | 4 | s32 | 0.00002 ” | theta_01 | Rotation around the X-axis for Reference Epoch t0. |
| 86 | 4 | s32 | 0.00002 ” | theta_02 | Rotation around the Y-axis for Reference Epoch t0. |
| 90 | 4 | s32 | 0.00002 ” | theta_03 | Rotation around the Z-axis for Reference Epoch t0. |
| 94 | 4 | s32 | 0.00001 ppm | scale | Scale correction for Reference Epoch t0. |
| 98 | 4 | s32 | 0.00002 m/yr | dot_delta_X0 | Rate of change of translation in X. |
| 102 | 4 | s32 | 0.00002 m/yr | dot_delta_Y0 | Rate of change of translation in Y. |
| 106 | 4 | s32 | 0.00002 m/yr | dot_delta_Z0 | Rate of change of translation in Z. |
| 110 | 4 | s32 | 0.0000004 ”/yr | dot_theta_01 | Rate of change of rotation around the X-axis. |
| 114 | 4 | s32 | 0.0000004 ”/yr | dot_theta_02 | Rate of change of rotation around the Y-axis. |
| 118 | 4 | s32 | 0.0000004 ”/yr | dot_theta_03 | Rate of change of rotation around the Z-axis. |
| 122 | 2 | s16 | 0.0000002 ppm/yr | dot_scale | Rate of change of scale correction. |
| | 124 | | | | Total Payload Length |

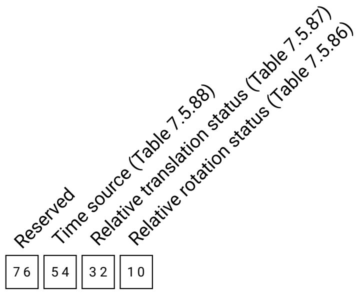
Table 7.5.84: MSG_REFERENCE_FRAME_PARAM 0x0244 message structure

#### MSG_POSE_RELATIVE — 0x0245 — 581

This solution message reports the relative pose of a sensor between two time instances. The relative pose comprises of a rotation and a translation which relates the sensor (e.g. camera) frame at a given time (first keyframe) to the sensor frame at another time (second keyframe). The relative translations is a 3x1 vector described in the first keyframe. Relative rotation is described by a quaternion from second keyframe to the first keyframe.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 1 | u8 | | `sensor_id` | ID of the sensor producing this message |
| 5 | 4 | u32 | ms | `timestamp_1` | Timestamp of first keyframe |
| 9 | 4 | u32 | ms | `timestamp_2` | Timestamp of second keyframe |
| 13 | 12 | s32[3] | mm | `trans` | Relative translation [x,y,z] described in first keyframe |
| 25 | 4 | s32 | 2ˆ-31 | `w` | Real component of quaternion to describe relative rotation (second to first keyframe) |
| 29 | 4 | s32 | 2ˆ-31 | `x` | 1st imaginary component of quaternion to describe relative rotation (second to first keyframe) |
| 33 | 4 | s32 | 2ˆ-31 | `y` | 2nd imaginary component of quaternion to describe relative rotation (second to first keyframe) |
| 37 | 4 | s32 | 2ˆ-31 | `z` | 3rd imaginary component of quaternion to describe relative rotation (second to first keyframe) |
| 41 | 4 | float | mˆ2 | `cov_r_x_x` | Estimated variance of x (relative translation) |
| 45 | 4 | float | mˆ2 | `cov_r_x_y` | Covariance of x and y (relative translation) |
| 49 | 4 | float | mˆ2 | `cov_r_x_z` | Covariance of x and z (relative translation) |
| 53 | 4 | float | mˆ2 | `cov_r_y_y` | Estimated variance of y (relative translation) |
| 57 | 4 | float | mˆ2 | `cov_r_y_z` | Covariance of y and z (relative translation) |
| 61 | 4 | float | mˆ2 | `cov_r_z_z` | Estimated variance of z (relative translation) |
| 65 | 4 | float | radˆ2 | `cov_c_x_x` | Estimated variance of x (relative rotation) |
| 69 | 4 | float | radˆ2 | `cov_c_x_y` | Covariance of x and y (relative rotation) |
| 73 | 4 | float | radˆ2 | `cov_c_x_z` | Covariance of x and z (relative rotation) |
| 77 | 4 | float | radˆ2 | `cov_c_y_y` | Estimated variance of y (relative rotation) |
| 81 | 4 | float | radˆ2 | `cov_c_y_z` | Covariance of y and z (relative rotation) |
| 85 | 4 | float | radˆ2 | `cov_c_z_z` | Estimated variance of z (relative rotation) |
| 89 | 1 | u8 | | `flags` | Status flags of relative translation and rotation |
| | 90 | | | | Total Payload Length |

Table 7.5.85: MSG_POSE_RELATIVE 0x0245 message structure




Field 7.5.28: Status flags of relative translation and rotation (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Valid |

Table 7.5.86: Relative rotation status values (`flags[0:1]`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Valid |

Table 7.5.87: Relative translation status values (`flags[2:3]`)

| Value | Description |
|---|---|
| 0 | None (invalid) |
| 1 | GNSS Solution (ms in week) |
| 2 | Local CPU Time (ms) |

Table 7.5.88: Time source values (`flags[4:5]`)

## 7.6 Observation

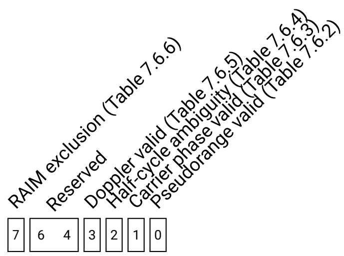
Satellite observation messages from the device. The SBP sender ID of 0 indicates remote observations from a GNSS base station, correction network, or Skylark, Swift's cloud GNSS correction product.

#### MSG_OBS — 0x004A — 74

The GPS observations message reports all the raw pseudorange and carrier phase observations for the satellites being tracked by the device. Carrier phase observation here is represented as a 40-bit fixed point number with Q32.8 layout (i.e. 32-bits of whole cycles and 8-bits of fractional cycles). The observations are be interoperable with 3rd party receivers and conform with typical RTCMv3 GNSS observations.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `header.t.tow` | Milliseconds since start of GPS week |
| 4 | 4 | s32 | ns | `header.t.ns_residual` | Nanosecond residual of millisecond-rounded TOW (ranges from -500000 to 500000) |
| 8 | 2 | u16 | week | `header.t.wn` | GPS week number |
| 10 | 1 | u8 | | `header.n_obs` | Total number of observations. First nibble is the size of the sequence (n), second nibble is the zero-indexed counter (ith packet of n) |
| $17N + 11$ | 4 | u32 | 2 cm | `obs[N].P` | Pseudorange observation |
| $17N + 15$ | 4 | s32 | cycles | `obs[N].L.i` | Carrier phase whole cycles |
| $17N + 19$ | 1 | u8 | cycles / 256 | `obs[N].L.f` | Carrier phase fractional part |
| $17N + 20$ | 2 | s16 | Hz | `obs[N].D.i` | Doppler whole Hz |
| $17N + 22$ | 1 | u8 | Hz / 256 | `obs[N].D.f` | Doppler fractional part |
| $17N + 23$ | 1 | u8 | dB Hz / 4 | `obs[N].cn0` | Carrier-to-Noise density. Zero implies invalid cn0. |
| $17N + 24$ | 1 | u8 | | `obs[N].lock` | Lock timer. This value gives an indication of the time for which a signal has maintained continuous phase lock. Whenever a signal has lost and regained lock, this value is reset to zero. It is encoded according to DF402 from the RTCM 10403.2 Amendment 2 specification. Valid values range from 0 to 15 and the most significant nibble is reserved for future use. |
| $17N + 25$ | 1 | u8 | | `obs[N].flags` | Measurement status flags. A bit field of flags providing the status of this observation. If this field is 0 it means only the Cn0 estimate for the signal is valid. |
| $17N + 26$ | 1 | u8 | | `obs[N].sid.sat` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| $17N + 27$ | 1 | u8 | | `obs[N].sid.code` | Signal constellation, band and code (see pg. 4) |
| | $17N + 11$ | | | | Total Payload Length |

Table 7.6.1: MSG_OBS 0x004A message structure




Field 7.6.1: Measurement status flags. A bit field of flags providing the status of this observation. If this field is 0 it means only the Cn0 estimate for the signal is valid. (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid pseudorange measurement |
| 1 | Valid pseudorange measurement and coarse TOW decoded |

Table 7.6.2: Pseudorange valid values (`flags[0]`)

| Value | Description |
|---|---|
| 0 | Invalid carrier phase measurement |
| 1 | Valid carrier phase measurement |

Table 7.6.3: Carrier phase valid values (`flags[1]`)

| Value | Description |
|---|---|
| 0 | Half cycle phase ambiguity unresolved |
| 1 | Half cycle phase ambiguity resolved |

Table 7.6.4: Half-cycle ambiguity values (`flags[2]`)

| Value | Description |
|---|---|
| 0 | Invalid doppler measurement |
| 1 | Valid doppler measurement |

Table 7.6.5: Doppler valid values (`flags[3]`)

| Value | Description |
|---|---|
| 0 | No exclusion |
| 1 | Measurement was excluded by SPP RAIM, use with care |

Table 7.6.6: RAIM exclusion values (`flags[7]`)

#### MSG_BASE_POS_LLH — 0x0044 — 68

The base station position message is the position reported by the base station itself. It is used for pseudo-absolute RTK positioning, and is required to be a high-accuracy surveyed location of the base station. Any error here will result in an error in the pseudo-absolute position output.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 8 | double | deg | `lat` | Latitude |
| 8 | 8 | double | deg | `lon` | Longitude |
| 16 | 8 | double | m | `height` | Height |
| | 24 | | | | Total Payload Length |

Table 7.6.7: MSG_BASE_POS_LLH 0x0044 message structure

#### MSG_BASE_POS_ECEF — 0x0048 — 72

The base station position message is the position reported by the base station itself in absolute Earth Centered Earth Fixed coordinates. It is used for pseudo-absolute RTK positioning, and is required to be a high-accuracy surveyed location of the base station. Any error here will result in an error in the pseudo-absolute position output.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 8 | double | m | x | ECEF X coordinate |
| 8 | 8 | double | m | y | ECEF Y coordinate |
| 16 | 8 | double | m | z | ECEF Z coordinate |
| | 24 | | | | Total Payload Length |

Table 7.6.8: MSG_BASE_POS_ECEF 0x0048 message structure

### MSG_EPHEMERIS_GPS — 0x008A — 138

The ephemeris message returns a set of satellite orbit parameters that is used to calculate GPS satellite position, velocity, and clock offset. Please see the Navstar GPS Space Segment/Navigation user interfaces (ICD-GPS-200, Table 20-III) for more details.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `common.sid.sat` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 1 | 1 | u8 | | `common.sid.code` | Signal constellation, band and code (see pg. 4) |
| 2 | 4 | u32 | s | `common.toe.tow` | Seconds since start of GPS week |
| 6 | 2 | u16 | week | `common.toe.wn` | GPS week number |
| 8 | 4 | float | m | `common.ura` | User Range Accuracy |
| 12 | 4 | u32 | s | `common.fit_interval` | Curve fit interval |
| 16 | 1 | u8 | | `common.valid` | Status of ephemeris, 1 = valid, 0 = invalid |
| 17 | 1 | u8 | | `common.health_bits` | Satellite health status. GPS: ICD-GPS-200, chapter 20.3.3.3.1.4 SBAS: 0 = valid, non-zero = invalid GLO: 0 = valid, non-zero = invalid |
| 18 | 4 | float | s | `tgd` | Group delay differential between L1 and L2 |
| 22 | 4 | float | m | `c_rs` | Amplitude of the sine harmonic correction term to the orbit radius |
| 26 | 4 | float | m | `c_rc` | Amplitude of the cosine harmonic correction term to the orbit radius |
| 30 | 4 | float | rad | `c_uc` | Amplitude of the cosine harmonic correction term to the argument of latitude |
| 34 | 4 | float | rad | `c_us` | Amplitude of the sine harmonic correction term to the argument of latitude |
| 38 | 4 | float | rad | `c_ic` | Amplitude of the cosine harmonic correction term to the angle of inclination |
| 42 | 4 | float | rad | `c_is` | Amplitude of the sine harmonic correction term to the angle of inclination |
| 46 | 8 | double | rad/s | `dn` | Mean motion difference |
| 54 | 8 | double | rad | `m0` | Mean anomaly at reference time |
| 62 | 8 | double | | `ecc` | Eccentricity of satellite orbit |
| 70 | 8 | double | m^(1/2) | `sqrta` | Square root of the semi-major axis of orbit |
| 78 | 8 | double | rad | `omega0` | Longitude of ascending node of orbit plane at weekly epoch |
| 86 | 8 | double | rad/s | `omegadot` | Rate of right ascension |
| 94 | 8 | double | rad | `w` | Argument of perigee |
| 102 | 8 | double | rad | `inc` | Inclination |
| 110 | 8 | double | rad/s | `inc_dot` | Inclination first derivative |
| 118 | 4 | float | s | `af0` | Polynomial clock correction coefficient (clock bias) |
| 122 | 4 | float | s/s | `af1` | Polynomial clock correction coefficient (clock drift) |
| 126 | 4 | float | s/s^2 | `af2` | Polynomial clock correction coefficient (rate of clock drift) |
| 130 | 4 | u32 | s | `toc.tow` | Seconds since start of GPS week |
| 134 | 2 | u16 | week | `toc.wn` | GPS week number |
| 136 | 1 | u8 | | `iode` | Issue of ephemeris data |
| 137 | 2 | u16 | | `iodc` | Issue of clock data |
| | 139 | | | | Total Payload Length |

Table 7.6.9: MSG_EPHEMERIS_GPS 0x008A message structure

**MSG_EPHEMERIS_QZSS — 0x008E — 142**

The ephemeris message returns a set of satellite orbit parameters that is used to calculate QZSS satellite position, velocity, and clock offset.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `common.sid.sat` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 1 | 1 | u8 | | `common.sid.code` | Signal constellation, band and code (see pg. 4) |
| 2 | 4 | u32 | s | `common.toe.tow` | Seconds since start of GPS week |
| 6 | 2 | u16 | week | `common.toe.wn` | GPS week number |
| 8 | 4 | float | m | `common.ura` | User Range Accuracy |
| 12 | 4 | u32 | s | `common.fit_interval` | Curve fit interval |
| 16 | 1 | u8 | | `common.valid` | Status of ephemeris, 1 = valid, 0 = invalid |
| 17 | 1 | u8 | | `common.health_bits` | Satellite health status. GPS: ICD-GPS-200, chapter 20.3.3.3.1.4 SBAS: 0 = valid, non-zero = invalid GLO: 0 = valid, non-zero = invalid |
| 18 | 4 | float | s | `tgd` | Group delay differential between L1 and L2 |
| 22 | 4 | float | m | `c_rs` | Amplitude of the sine harmonic correction term to the orbit radius |
| 26 | 4 | float | m | `c_rc` | Amplitude of the cosine harmonic correction term to the orbit radius |
| 30 | 4 | float | rad | `c_uc` | Amplitude of the cosine harmonic correction term to the argument of latitude |
| 34 | 4 | float | rad | `c_us` | Amplitude of the sine harmonic correction term to the argument of latitude |
| 38 | 4 | float | rad | `c_ic` | Amplitude of the cosine harmonic correction term to the angle of inclination |
| 42 | 4 | float | rad | `c_is` | Amplitude of the sine harmonic correction term to the angle of inclination |
| 46 | 8 | double | rad/s | `dn` | Mean motion difference |
| 54 | 8 | double | rad | `m0` | Mean anomaly at reference time |
| 62 | 8 | double | | `ecc` | Eccentricity of satellite orbit |
| 70 | 8 | double | mˆ(1/2) | `sqrta` | Square root of the semi-major axis of orbit |
| 78 | 8 | double | rad | `omega0` | Longitude of ascending node of orbit plane at weekly epoch |
| 86 | 8 | double | rad/s | `omegadot` | Rate of right ascension |
| 94 | 8 | double | rad | `w` | Argument of perigee |
| 102 | 8 | double | rad | `inc` | Inclination |
| 110 | 8 | double | rad/s | `inc_dot` | Inclination first derivative |
| 118 | 4 | float | s | `af0` | Polynomial clock correction coefficient (clock bias) |
| 122 | 4 | float | s/s | `af1` | Polynomial clock correction coefficient (clock drift) |
| 126 | 4 | float | s/sˆ2 | `af2` | Polynomial clock correction coefficient (rate of clock drift) |
| 130 | 4 | u32 | s | `toc.tow` | Seconds since start of GPS week |
| 134 | 2 | u16 | week | `toc.wn` | GPS week number |
| 136 | 1 | u8 | | `iode` | Issue of ephemeris data |
| 137 | 2 | u16 | | `iodc` | Issue of clock data |
| | 139 | | | | Total Payload Length |

Table 7.6.10: MSG_EPHEMERIS_QZSS 0x008E message structure

#### MSG_EPHEMERIS_BDS — 0x0089 — 137

The ephemeris message returns a set of satellite orbit parameters that is used to calculate BDS satellite position, velocity, and clock offset. Please see the BeiDou Navigation Satellite System SIS-ICD Version 2.1, Table 5-9 for more details.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | common.sid.sat | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 1 | 1 | u8 | | common.sid.code | Signal constellation, band and code (see pg. 4) |
| 2 | 4 | u32 | s | common.toe.tow | Seconds since start of GPS week |
| 6 | 2 | u16 | week | common.toe.wn | GPS week number |
| 8 | 4 | float | m | common.ura | User Range Accuracy |
| 12 | 4 | u32 | s | common.fit_interval | Curve fit interval |
| 16 | 1 | u8 | | common.valid | Status of ephemeris, 1 = valid, 0 = invalid |
| 17 | 1 | u8 | | common.health_bits | Satellite health status. GPS: ICD-GPS-200, chapter 20.3.3.3.1.4 SBAS: 0 = valid, non-zero = invalid GLO: 0 = valid, non-zero = invalid |
| 18 | 4 | float | s | tgd1 | Group delay differential for B1 |
| 22 | 4 | float | s | tgd2 | Group delay differential for B2 |
| 26 | 4 | float | m | c_rs | Amplitude of the sine harmonic correction term to the orbit radius |
| 30 | 4 | float | m | c_rc | Amplitude of the cosine harmonic correction term to the orbit radius |
| 34 | 4 | float | rad | c_uc | Amplitude of the cosine harmonic correction term to the argument of latitude |
| 38 | 4 | float | rad | c_us | Amplitude of the sine harmonic correction term to the argument of latitude |
| 42 | 4 | float | rad | c_ic | Amplitude of the cosine harmonic correction term to the angle of inclination |
| 46 | 4 | float | rad | c_is | Amplitude of the sine harmonic correction term to the angle of inclination |
| 50 | 8 | double | rad/s | dn | Mean motion difference |
| 58 | 8 | double | rad | m0 | Mean anomaly at reference time |
| 66 | 8 | double | | ecc | Eccentricity of satellite orbit |
| 74 | 8 | double | m^(1/2) | sqrta | Square root of the semi-major axis of orbit |
| 82 | 8 | double | rad | omega0 | Longitude of ascending node of orbit plane at weekly epoch |
| 90 | 8 | double | rad/s | omegadot | Rate of right ascension |
| 98 | 8 | double | rad | w | Argument of perigee |
| 106 | 8 | double | rad | inc | Inclination |
| 114 | 8 | double | rad/s | inc_dot | Inclination first derivative |
| 122 | 8 | double | s | af0 | Polynomial clock correction coefficient (clock bias) |
| 130 | 4 | float | s/s | af1 | Polynomial clock correction coefficient (clock drift) |
| 134 | 4 | float | s/s^2 | af2 | Polynomial clock correction coefficient (rate of clock drift) |
| 138 | 4 | u32 | s | toc.tow | Seconds since start of GPS week |
| 142 | 2 | u16 | week | toc.wn | GPS week number |
| 144 | 1 | u8 | | iode | Issue of ephemeris data Calculated from the navigation data parameter t_oe per RTCM/CSNO recommendation: IODE = mod (t_oe / 720, 240) |
| 145 | 2 | u16 | | iodc | Issue of clock data Calculated from the navigation data parameter t_oe per RTCM/CSNO recommendation: IODE = mod (t_oc / 720, 240) |
| | 147 | | | | Total Payload Length |

Table 7.6.11: MSG_EPHEMERIS_BDS 0x0089 message structure

### MSG_EPHEMERIS_GAL — 0x008D — 141

The ephemeris message returns a set of satellite orbit parameters that is used to calculate Galileo satellite position, velocity, and clock offset. Please see the Signal In Space ICD OS SIS ICD, Issue 1.3, December 2016 for more details.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | common.sid.sat | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 1 | 1 | u8 | | common.sid.code | Signal constellation, band and code (see pg. 4) |
| 2 | 4 | u32 | s | common.toe.tow | Seconds since start of GPS week |
| 6 | 2 | u16 | week | common.toe.wn | GPS week number |
| 8 | 4 | float | m | common.ura | User Range Accuracy |
| 12 | 4 | u32 | s | common.fit_interval | Curve fit interval |
| 16 | 1 | u8 | | common.valid | Status of ephemeris, 1 = valid, 0 = invalid |
| 17 | 1 | u8 | | common.health_bits | Satellite health status. GPS: ICD-GPS-200, chapter 20.3.3.3.1.4 SBAS: 0 = valid, non-zero = invalid GLO: 0 = valid, non-zero = invalid |
| 18 | 4 | float | s | bgd_e1e5a | E1-E5a Broadcast Group Delay |
| 22 | 4 | float | s | bgd_e1e5b | E1-E5b Broadcast Group Delay |
| 26 | 4 | float | m | c_rs | Amplitude of the sine harmonic correction term to the orbit radius |
| 30 | 4 | float | m | c_rc | Amplitude of the cosine harmonic correction term to the orbit radius |
| 34 | 4 | float | rad | c_uc | Amplitude of the cosine harmonic correction term to the argument of latitude |
| 38 | 4 | float | rad | c_us | Amplitude of the sine harmonic correction term to the argument of latitude |
| 42 | 4 | float | rad | c_ic | Amplitude of the cosine harmonic correction term to the angle of inclination |
| 46 | 4 | float | rad | c_is | Amplitude of the sine harmonic correction term to the angle of inclination |
| 50 | 8 | double | rad/s | dn | Mean motion difference |
| 58 | 8 | double | rad | m0 | Mean anomaly at reference time |
| 66 | 8 | double | | ecc | Eccentricity of satellite orbit |
| 74 | 8 | double | m^(1/2) | sqrta | Square root of the semi-major axis of orbit |
| 82 | 8 | double | rad | omega0 | Longitude of ascending node of orbit plane at weekly epoch |
| 90 | 8 | double | rad/s | omegadot | Rate of right ascension |
| 98 | 8 | double | rad | w | Argument of perigee |
| 106 | 8 | double | rad | inc | Inclination |
| 114 | 8 | double | rad/s | inc_dot | Inclination first derivative |
| 122 | 8 | double | s | af0 | Polynomial clock correction coefficient (clock bias) |
| 130 | 8 | double | s/s | af1 | Polynomial clock correction coefficient (clock drift) |
| 138 | 4 | float | s/s^2 | af2 | Polynomial clock correction coefficient (rate of clock drift) |
| 142 | 4 | u32 | s | toc.tow | Seconds since start of GPS week |
| 146 | 2 | u16 | week | toc.wn | GPS week number |
| 148 | 2 | u16 | | iode | Issue of data (IODnav) |
| 150 | 2 | u16 | | iodc | Issue of data (IODnav). Always equal to iode |
| 152 | 1 | u8 | | source | 0=I/NAV, 1=F/NAV |
| | 153 | | | | Total Payload Length |

Table 7.6.12: MSG_EPHEMERIS_GAL 0x008D message structure

### MSG_EPHEMERIS_SBAS — 0x008C — 140

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | common.sid.sat | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 1 | 1 | u8 | | common.sid.code | Signal constellation, band and code (see pg. 4) |
| 2 | 4 | u32 | s | common.toe.tow | Seconds since start of GPS week |
| 6 | 2 | u16 | week | common.toe.wn | GPS week number |
| 8 | 4 | float | m | common.ura | User Range Accuracy |
| 12 | 4 | u32 | s | common.fit_interval | Curve fit interval |
| 16 | 1 | u8 | | common.valid | Status of ephemeris, 1 = valid, 0 = invalid |
| 17 | 1 | u8 | | common.health_bits | Satellite health status. GPS: ICD-GPS-200, chapter 20.3.3.3.1.4 SBAS: 0 = valid, non-zero = invalid GLO: 0 = valid, non-zero = invalid |
| 18 | 24 | double[3] | m | pos | Position of the GEO at time toe |
| 42 | 12 | float[3] | m/s | vel | Velocity of the GEO at time toe |
| 54 | 12 | float[3] | m/s^2 | acc | Acceleration of the GEO at time toe |
| 66 | 4 | float | s | a_gf0 | Time offset of the GEO clock w.r.t. SBAS Network Time |
| 70 | 4 | float | s/s | a_gf1 | Drift of the GEO clock w.r.t. SBAS Network Time |
| | 74 | | | | Total Payload Length |

Table 7.6.13: MSG_EPHEMERIS_SBAS 0x008C message structure

#### MSG_EPHEMERIS_GLO — 0x008B — 139

The ephemeris message returns a set of satellite orbit parameters that is used to calculate GLO satellite position, velocity, and clock offset. Please see the GLO ICD 5.1 ”Table 4.5 Characteristics of words of immediate information (ephemeris parameters)” for more details.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `common.sid.sat` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 1 | 1 | u8 | | `common.sid.code` | Signal constellation, band and code (see pg. 4) |
| 2 | 4 | u32 | s | `common.toe.tow` | Seconds since start of GPS week |
| 6 | 2 | u16 | week | `common.toe.wn` | GPS week number |
| 8 | 4 | float | m | `common.ura` | User Range Accuracy |
| 12 | 4 | u32 | s | `common.fit_interval` | Curve fit interval |
| 16 | 1 | u8 | | `common.valid` | Status of ephemeris, 1 = valid, 0 = invalid |
| 17 | 1 | u8 | | `common.health_bits` | Satellite health status. GPS: ICD-GPS-200, chapter 20.3.3.3.1.4 SBAS: 0 = valid, non-zero = invalid GLO: 0 = valid, non-zero = invalid |
| 18 | 4 | float | | `gamma` | Relative deviation of predicted carrier frequency from nominal |
| 22 | 4 | float | s | `tau` | Correction to the SV time |
| 26 | 4 | float | s | `d_tau` | Equipment delay between L1 and L2 |
| 30 | 24 | double[3] | m | `pos` | Position of the SV at tb in PZ-90.02 coordinates system |
| 54 | 24 | double[3] | m/s | `vel` | Velocity vector of the SV at tb in PZ-90.02 coordinates system |
| 78 | 12 | float[3] | m/sˆ2 | `acc` | Acceleration vector of the SV at tb in PZ-90.02 coordinates sys |
| 90 | 1 | u8 | | `fcn` | Frequency slot. FCN+8 (that is [1..14]). 0 or 0xFF for invalid |
| 91 | 1 | u8 | | `iod` | Issue of data. Equal to the 7 bits of the immediate data word t_b |
| | 92 | | | | Total Payload Length |

Table 7.6.14: MSG_EPHEMERIS_GLO 0x008B message structure

**MSG_IONO — 0x0090 — 144**

The ionospheric parameters which allow the ”L1 only” or ”L2 only” user to utilize the ionospheric model for computation of the ionospheric delay. Please see ICD-GPS-200 (Chapter 20.3.3.5.1.7) for more details.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | `t_nmct.tow` | Seconds since start of GPS week |
| 4 | 2 | u16 | week | `t_nmct.wn` | GPS week number |
| 6 | 8 | double | s | `a0` | |
| 14 | 8 | double | s/semi-circle | `a1` | |
| 22 | 8 | double | s/(semi-circle)ˆ2 | `a2` | |
| 30 | 8 | double | s/(semi-circle)ˆ3 | `a3` | |
| 38 | 8 | double | s | `b0` | |
| 46 | 8 | double | s/semi-circle | `b1` | |
| 54 | 8 | double | s/(semi-circle)ˆ2 | `b2` | |
| 62 | 8 | double | s/(semi-circle)ˆ3 | `b3` | |
| | 70 | | | | Total Payload Length |

Table 7.6.15: MSG_IONO 0x0090 message structure

**MSG_GNSS_CAPB — 0x0096 — 150**

Bit masks of signal capabilities for each GNSS satellite PRN. Please see ICD-GPS-200 (Chapter 20.3.3.5.1.4) for more details.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | t_nmct.tow | Seconds since start of GPS week |
| 4 | 2 | u16 | week | t_nmct.wn | GPS week number |
| 6 | 8 | u64 | | gc.gps_active | GPS SV active mask |
| 14 | 8 | u64 | | gc.gps_l2c | GPS L2C active mask |
| 22 | 8 | u64 | | gc.gps_l5 | GPS L5 active mask |
| 30 | 4 | u32 | | gc.glo_active | GLO active mask |
| 34 | 4 | u32 | | gc.glo_l2of | GLO L2OF active mask |
| 38 | 4 | u32 | | gc.glo_l3 | GLO L3 active mask |
| 42 | 8 | u64 | | gc.sbas_active | SBAS active mask (PRNs 120..158, AN 7/62.2.2-18/18 Table B-23, https://www.caat.or.th/wp-content/uploads/2018/03/SL-2018.18.E-1.pdf) |
| 50 | 8 | u64 | | gc.sbas_l5 | SBAS L5 active mask (PRNs 120..158, AN 7/62.2.2-18/18 Table B-23, https://www.caat.or.th/wp-content/uploads/2018/03/SL-2018.18.E-1.pdf) |
| 58 | 8 | u64 | | gc.bds_active | BDS active mask |
| 66 | 8 | u64 | | gc.bds_d2nav | BDS D2NAV active mask |
| 74 | 8 | u64 | | gc.bds_b2 | BDS B2 active mask |
| 82 | 8 | u64 | | gc.bds_b2a | BDS B2A active mask |
| 90 | 4 | u32 | | gc.qzss_active | QZSS active mask |
| 94 | 8 | u64 | | gc.gal_active | GAL active mask |
| 102 | 8 | u64 | | gc.gal_e5 | GAL E5 active mask |
| | 110 | | | | Total Payload Length |

Table 7.6.16: MSG_GNSS_CAPB 0x0096 message structure

### MSG_GROUP_DELAY — 0x0094 — 148

Please see ICD-GPS-200 (30.3.3.3.1.1) for more details.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | t_op.tow | Seconds since start of GPS week |
| 4 | 2 | u16 | week | t_op.wn | GPS week number |
| 6 | 1 | u8 | | sid.sat | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 7 | 1 | u8 | | sid.code | Signal constellation, band and code (see pg. 4) |
| 8 | 1 | u8 | | valid | bit-field indicating validity of the values, LSB indicating tgd validity etc. 1 = value is valid, 0 = value is not valid. |
| 9 | 2 | s16 | s * 2^-35 | tgd | |
| 11 | 2 | s16 | s * 2^-35 | isc_l1ca | |
| 13 | 2 | s16 | s * 2^-35 | isc_l2c | |
| | 15 | | | | Total Payload Length |

Table 7.6.17: MSG_GROUP_DELAY 0x0094 message structure

**MSG_ALMANAC_GPS — 0x0072 — 114**

The almanac message returns a set of satellite orbit parameters. Almanac data is not very precise and is considered valid for up to several months. Please see the Navstar GPS Space Segment/Navigation user interfaces (ICD-GPS-200, Chapter 20.3.3.5.1.2 Almanac Data) for more details.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `common.sid.sat` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 1 | 1 | u8 | | `common.sid.code` | Signal constellation, band and code (see pg. 4) |
| 2 | 4 | u32 | s | `common.toa.tow` | Seconds since start of GPS week |
| 6 | 2 | u16 | week | `common.toa.wn` | GPS week number |
| 8 | 8 | double | m | `common.ura` | User Range Accuracy |
| 16 | 4 | u32 | s | `common.fit_interval` | Curve fit interval |
| 20 | 1 | u8 | | `common.valid` | Status of almanac, 1 = valid, 0 = invalid |
| 21 | 1 | u8 | | `common.health_bits` | Satellite health status for GPS: - bits 5-7: NAV data health status. See IS-GPS-200H Table 20-VII: NAV Data Health Indications. - bits 0-4: Signal health status. See IS-GPS-200H Table 20-VIII. Codes for Health of SV Signal Components.<br>Satellite health status for GLO (see GLO ICD 5.1 table 5.1 for details): - bit 0: C(n), ”unhealthy” flag that is transmitted within non-immediate data and indicates overall constellation status at the moment of almanac uploading. ’0’ indicates malfunction of n-satellite. ’1’ indicates that n-satellite is operational. - bit 1: Bn(ln), ’0’ indicates the satellite is operational and suitable for navigation. |
| 22 | 8 | double | rad | `m0` | Mean anomaly at reference time |
| 30 | 8 | double | | `ecc` | Eccentricity of satellite orbit |
| 38 | 8 | double | m^(1/2) | `sqrta` | Square root of the semi-major axis of orbit |
| 46 | 8 | double | rad | `omega0` | Longitude of ascending node of orbit plane at weekly epoch |
| 54 | 8 | double | rad/s | `omegadot` | Rate of right ascension |
| 62 | 8 | double | rad | `w` | Argument of perigee |
| 70 | 8 | double | rad | `inc` | Inclination |
| 78 | 8 | double | s | `af0` | Polynomial clock correction coefficient (clock bias) |
| 86 | 8 | double | s/s | `af1` | Polynomial clock correction coefficient (clock drift) |
| | 94 | | | | Total Payload Length |

Table 7.6.18: MSG_ALMANAC_GPS 0x0072 message structure

**MSG_ALMANAC_GLO — 0x0073 — 115**

The almanac message returns a set of satellite orbit parameters. Almanac data is not very precise and is considered valid for up to several months. Please see the GLO ICD 5.1 ”Chapter 4.5 Non-immediate information and almanac” for details.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `common.sid.sat` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 1 | 1 | u8 | | `common.sid.code` | Signal constellation, band and code (see pg. 4) |
| 2 | 4 | u32 | s | `common.toa.tow` | Seconds since start of GPS week |
| 6 | 2 | u16 | week | `common.toa.wn` | GPS week number |
| 8 | 8 | double | m | `common.ura` | User Range Accuracy |
| 16 | 4 | u32 | s | `common.fit_interval` | Curve fit interval |
| 20 | 1 | u8 | | `common.valid` | Status of almanac, 1 = valid, 0 = invalid |
| 21 | 1 | u8 | | `common.health_bits` | Satellite health status for GPS: - bits 5-7: NAV data health status. See IS-GPS-200H Table 20-VII: NAV Data Health Indications. - bits 0-4: Signal health status. See IS-GPS-200H Table 20-VIII. Codes for Health of SV Signal Components.<br>Satellite health status for GLO (see GLO ICD 5.1 table 5.1 for details): - bit 0: C(n), ”unhealthy” flag that is transmitted within non-immediate data and indicates overall constellation status at the moment of almanac uploading. ’0’ indicates malfunction of n-satellite. ’1’ indicates that n-satellite is operational. - bit 1: Bn(ln), ’0’ indicates the satellite is operational and suitable for navigation. |
| 22 | 8 | double | rad | `lambda_na` | Longitude of the first ascending node of the orbit in PZ-90.02 coordinate system |
| 30 | 8 | double | s | `t_lambda_na` | Time of the first ascending node passage |
| 38 | 8 | double | rad | `i` | Value of inclination at instant of t_lambda |
| 46 | 8 | double | s/orbital period | `t` | Value of Draconian period at instant of t_lambda |
| 54 | 8 | double | s/(orbital period^2) | `t_dot` | Rate of change of the Draconian period |
| 62 | 8 | double | | `epsilon` | Eccentricity at instant of t_lambda |
| 70 | 8 | double | rad | `omega` | Argument of perigee at instant of t_lambda |
| | 78 | | | | Total Payload Length |

Table 7.6.19: MSG_ALMANAC_GLO 0x0073 message structure

#### MSG_GLO_BIASES — 0x0075 — 117

The GLONASS L1/L2 Code-Phase biases allows to perform GPS+GLONASS integer ambiguity resolution for baselines with mixed receiver types (e.g. receiver of different manufacturers).

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | boolean | mask | GLONASS FDMA signals mask |
| 1 | 2 | s16 | m * 0.02 | l1ca_bias | GLONASS L1 C/A Code-Phase Bias |
| 3 | 2 | s16 | m * 0.02 | l1p_bias | GLONASS L1 P Code-Phase Bias |
| 5 | 2 | s16 | m * 0.02 | l2ca_bias | GLONASS L2 C/A Code-Phase Bias |
| 7 | 2 | s16 | m * 0.02 | l2p_bias | GLONASS L2 P Code-Phase Bias |
| | 9 | | | | Total Payload Length |

Table 7.6.20: MSG_GLO_BIASES 0x0075 message structure

### MSG_SV_AZ_EL — 0x0097 — 151

Azimuth and elevation angles of all the visible satellites that the device does have ephemeris or almanac for.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| $4N + 0$ | 1 | u8 | | azel[N].sid.sat | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| $4N + 1$ | 1 | u8 | | azel[N].sid.code | Signal constellation, band and code (see pg. 4) |
| $4N + 2$ | 1 | u8 | deg * 2 | azel[N].az | Azimuth angle (range 0..179) |
| $4N + 3$ | 1 | s8 | deg | azel[N].el | Elevation angle (range -90..90) |
| | 4N | | | | Total Payload Length |

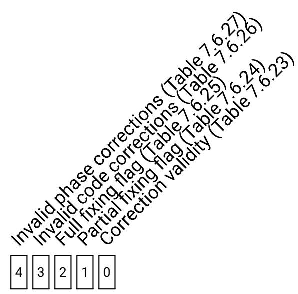
Table 7.6.21: MSG_SV_AZ_EL 0x0097 message structure

**MSG_OSR — 0x0640 — 1600**

The OSR message contains network corrections in an observation-like format.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | header.t.tow | Milliseconds since start of GPS week |
| 4 | 4 | s32 | ns | header.t.ns_residual | Nanosecond residual of millisecond-rounded TOW (ranges from -500000 to 500000) |
| 8 | 2 | u16 | week | header.t.wn | GPS week number |
| 10 | 1 | u8 | | header.n_obs | Total number of observations. First nibble is the size of the sequence (n), second nibble is the zero-indexed counter (ith packet of n) |
| $19N + 11$ | 4 | u32 | 2 cm | obs[N].P | Pseudorange observation |
| $19N + 15$ | 4 | s32 | cycles | obs[N].L.i | Carrier phase whole cycles |
| $19N + 19$ | 1 | u8 | cycles / 256 | obs[N].L.f | Carrier phase fractional part |
| $19N + 20$ | 1 | u8 | | obs[N].lock | Lock timer. This value gives an indication of the time for which a signal has maintained continuous phase lock. Whenever a signal has lost and regained lock, this value is reset to zero. It is encoded according to DF402 from the RTCM 10403.2 Amendment 2 specification. Valid values range from 0 to 15 and the most significant nibble is reserved for future use. |
| $19N + 21$ | 1 | u8 | | obs[N].flags | Correction flags. |
| $19N + 22$ | 1 | u8 | | obs[N].sid.sat | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| $19N + 23$ | 1 | u8 | | obs[N].sid.code | Signal constellation, band and code (see pg. 4) |
| $19N + 24$ | 2 | u16 | 5 mm | obs[N].iono_std | Slant ionospheric correction standard deviation |
| $19N + 26$ | 2 | u16 | 5 mm | obs[N].tropo_std | Slant tropospheric correction standard deviation |
| $19N + 28$ | 2 | u16 | 5 mm | obs[N].range_std | Orbit/clock/bias correction projected on range standard deviation |
| | $19N + 11$ | | | | Total Payload Length |

Table 7.6.22: MSG_OSR 0x0640 message structure




Field 7.6.2: Correction flags. (`flags`)

| Value | Description |
|---|---|
| 0 | Do not use signal |
| 1 | Valid signal |

Table 7.6.23: Correction validity values (`flags[0]`)

| Value | Description |
|---|---|
| 0 | Partial fixing unavailable |
| 1 | Partial fixing available |

Table 7.6.24: Partial fixing flag values (`flags[1]`)

| Value | Description |
|---|---|
| 0 | Full fixing unavailable |
| 1 | Full fixing available |

Table 7.6.25: Full fixing flag values (`flags[2]`)

| Value | Description |
|---|---|
| 0 | Valid code corrections |
| 1 | Do not use code corrections |

Table 7.6.26: Invalid code corrections values (`flags[3]`)

| Value | Description |
|---|---|
| 0 | Valid phase corrections |
| 1 | Do not use phase corrections |

Table 7.6.27: Invalid phase corrections values (`flags[4]`)

## 7.7 Settings

Messages for reading, writing, and discovering device settings. Settings with a "string" field have multiple values in this field delimited with a null character (the c style null terminator). For instance, when querying the 'firmware_version' setting in the 'system_info' section, the following array of characters needs to be sent for the string field in MSG_SETTINGS_READ: "system_info\0firmware_version\0", where the delimiting null characters are specified with the escape sequence '\0' and all quotation marks should be omitted.

In the message descriptions below, the generic strings SECTION_SETTING and SETTING are used to refer to the two strings that comprise the identifier of an individual setting.In firmware_version example above, SECTION_SETTING is the 'system_info', and the SETTING portion is 'firmware_version'. See the "Software Settings Manual" on support.swiftnav.com for detailed documentation about all settings and sections available for each Swift firmware version. Settings manuals are available for each firmware version at the following link: Piksi Multi Specifications. The latest settings document is also available at the following link: Latest settings document . See lastly settings.py , the open source python command line utility for reading, writing, and saving settings in the piksi_tools repository on github as a helpful reference and example.

#### MSG_SETTINGS_SAVE — 0x00A1 — 161

The save settings message persists the device's current settings configuration to its onboard flash memory file system.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| | 0 | | | | Total Payload Length |

Table 7.7.1: MSG_SETTINGS_SAVE 0x00A1 message structure

**MSG_SETTINGS_WRITE — 0x00A0 — 160**

The setting message writes the device configuration for a particular setting via A NULL-terminated and NULL-delimited string with contents ”SECTION_SETTING\0SETTING\0VALUE\0” where the ’\0’ escape sequence denotes the NULL character and where quotation marks are omitted. A device will only process to this message when it is received from sender ID 0x42. An example string that could be sent to a device is ”solution\0soln_freq\010\0”.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | N | string | | `setting` | A NULL-terminated and NULL-delimited string with contents ”SECTION_SETTING\0SETTING\0VALUE\0” |
| | N | | | | Total Payload Length |

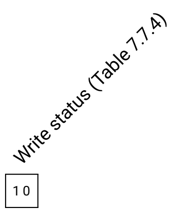
Table 7.7.2: MSG_SETTINGS_WRITE 0x00A0 message structure

#### MSG_SETTINGS_WRITE_RESP — 0x00AF — 175

Return the status of a write request with the new value of the setting. If the requested value is rejected, the current value will be returned. The string field is a NULL-terminated and NULL-delimited string with contents ”SECTION_SETTING\0SETTING\0VALUE\ where the ’\0’ escape sequence denotes the NULL character and where quotation marks are omitted. An example string that could be sent from device is ”solution\0soln_freq\010\0”.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `status` | Write status |
| 1 | N | string | | `setting` | A NULL-terminated and delimited string with contents ”SECTION_SETTING\0SETTING\0VALUE\0” |
| | N + 1 | | | | Total Payload Length |

Table 7.7.3: MSG_SETTINGS_WRITE_RESP 0x00AF message structure




Field 7.7.1: Write status (`status`)

| Value | Description |
|---|---|
| 0 | Accepted; value updated |
| 1 | Rejected; value unparsable or out-of-range |
| 2 | Rejected; requested setting does not exist |
| 3 | Rejected; setting name could not be parsed |
| 4 | Rejected; setting is read only |
| 5 | Rejected; modification is temporarily disabled |
| 6 | Rejected; unspecified error |

Table 7.7.4: Write status values (`status[0:1]`)

#### MSG_SETTINGS_READ_REQ — 0x00A4 — 164

The setting message that reads the device configuration. The string field is a NULL-terminated and NULL-delimited string with contents ”SECTION_SETTING\0SETTING\0” where the ’\0’ escape sequence denotes the NULL character and where quotation marks are omitted. An example string that could be sent to a device is ”solution\0soln_freq\0”. A device will only respond to this message when it is received from sender ID 0x42. A device should respond with a MSG_SETTINGS_READ_RESP message (msg_id 0x00A5).

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | N | string | | `setting` | A NULL-terminated and NULL-delimited string with contents ”SECTION_SETTING\0SETTING\0” |
| | N | | | | Total Payload Length |

Table 7.7.5: MSG_SETTINGS_READ_REQ 0x00A4 message structure

#### MSG_SETTINGS_READ_RESP — 0x00A5 — 165

The setting message with which the device responds after a MSG_SETTING_READ_REQ is sent to device. The string field is a NULL-terminated and NULL-delimited string with contents ”SECTION_SETTING\0SETTING\0VALUE\0” where the ’\0’ escape sequence denotes the NULL character and where quotation marks are omitted. An example string that could be sent from device is ”solution\0soln_freq\010\0”.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | N | string | | setting | A NULL-terminated and NULL-delimited string with contents ”SECTION_SETTING\0SETTING\0VALUE\0” |
| | N | | | | Total Payload Length |

Table 7.7.6: MSG_SETTINGS_READ_RESP 0x00A5 message structure

#### MSG_SETTINGS_READ_BY_INDEX_REQ — 0x00A2 — 162

The settings message for iterating through the settings values. A device will respond to this message with a ”MSG_SETTINGS_READ_

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 2 | u16 | | `index` | An index into the device settings, with values ranging from 0 to length(settings). |
| | 2 | | | | Total Payload Length |

Table 7.7.7: MSG_SETTINGS_READ_BY_INDEX_REQ 0x00A2 message structure

#### MSG_SETTINGS_READ_BY_INDEX_RESP — 0x00A7 — 167

The settings message that reports the value of a setting at an index.

In the string field, it reports NULL-terminated and delimited string with contents "SECTION_SETTING\0SETTING\0VALUE\0FORM where the '\0' escape sequence denotes the NULL character and where quotation marks are omitted. The FORMAT_TYPE field is optional and denotes possible string values of the setting as a hint to the user. If included, the format type portion of the string has the format "enum:value1,value2,value3". An example string that could be sent from the device is "simulator\0enabled\0True\0enum:True,False\0".

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 2 | u16 | | `index` | An index into the device settings, with values ranging from 0 to length(settings) |
| 2 | N | string | | `setting` | A NULL-terminated and delimited string with contents "SECTION_SETTING\0SETTING\0VALUE\0FORMAT_TYPE\0 |
| | $N + 2$ | | | | Total Payload Length |

Table 7.7.8: MSG_SETTINGS_READ_BY_INDEX_RESP 0x00A7 message structure

#### MSG_SETTINGS_READ_BY_INDEX_DONE — 0x00A6 — 166

The settings message for indicating end of the settings values.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| | 0 | | | | Total Payload Length |

Table 7.7.9: MSG_SETTINGS_READ_BY_INDEX_DONE 0x00A6 message structure

## 7.8 Solution Meta

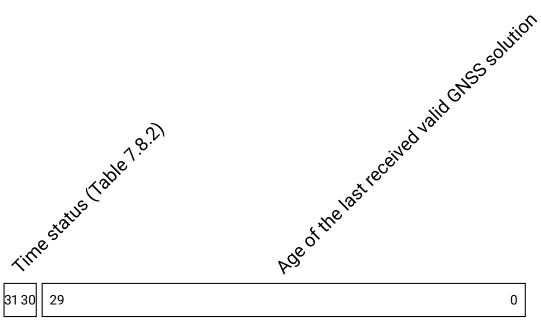
Standardized Metadata messages for Fuzed Solution from Swift Navigation devices.

#### MSG_SOLN_META — 0xFF0E — 65294

This message contains all metadata about the sensors received and/or used in computing the sensorfusion solution. It focuses primarily, but not only, on GNSS metadata. Regarding the age of the last received valid GNSS solution, the highest two bits are time status, indicating whether age gnss can or can not be used to retrieve time of measurement (noted TOM, also known as time of validity) If it can, subtract 'age gnss' from 'tow' in navigation messages to get TOM. Can be used before alignment is complete in the Fusion Engine, when output solution is the last received valid GNSS solution and its tow is not a TOM.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS time of week rounded to the nearest millisecond |
| 4 | 2 | u16 | 0.01 | `pdop` | Position Dilution of Precision as per last available DOPS from PVT engine (0xFFFF indicates invalid) |
| 6 | 2 | u16 | 0.01 | `hdop` | Horizontal Dilution of Precision as per last available DOPS from PVT engine (0xFFFF indicates invalid) |
| 8 | 2 | u16 | 0.01 | `vdop` | Vertical Dilution of Precision as per last available DOPS from PVT engine (0xFFFF indicates invalid) |
| 10 | 2 | u16 | deciseconds | `age_corrections` | Age of corrections as per last available AGE_CORRECTIONS from PVT engine (0xFFFF indicates invalid) |
| 12 | 4 | u32 | ms | `age_gnss` | Age and Time Status of the last received valid GNSS solution. |
| $2N+16$ | 1 | u8 | | `sol_in[N].sensor_type` | The type of sensor |
| $2N+17$ | 1 | u8 | (XX)InputType | `sol_in[N].flags` | Refer to each InputType description |
| | $2N+16$ | | | | Total Payload Length |

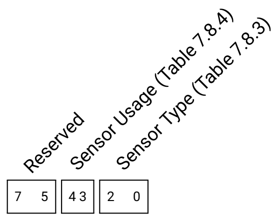
Table 7.8.1: MSG_SOLN_META 0xFF0E message structure




Field 7.8.1: Age and Time Status of the last received valid GNSS solution. (`age_gnss`)

| Value | Description |
|---|---|
| 0 | Age can not be used to retrieve TOM |
| 1 | Age can be used to retrieve TOM |
| 2 | Reserved |
| 3 | Reserved |

Table 7.8.2: Time status values (`age_gnss[30:31]`)




Field 7.8.2: The type of sensor (`sol_in[N].sensor_type`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | GNSS Position (see GNSSInputType) |
| 2 | GNSS Velocity Displacement (see GNSSInputType) |
| 3 | GNSS Velocity Doppler (see GNSSInputType) |
| 4 | Odometry Ticks (see OdoInputType) |
| 5 | Odometry Speed (see OdoInputType) |
| 6 | IMU Sensor (see IMUInputType) |
| 7 | Reserved |

Table 7.8.3: Sensor Type values (`sol_in[N].sensor_type[0:2]`)

| Value | Description |
|---|---|
| 0 | Unknown |
| 1 | Received and used |
| 2 | Received but not used |

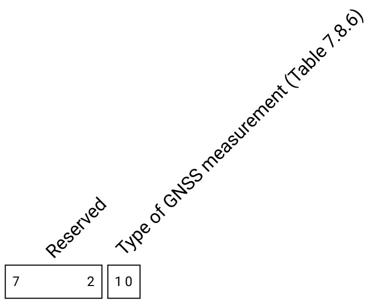
Table 7.8.4: Sensor Usage values (`sol_in[N].sensor_type[3:4]`)

#### GNSSInputType

Metadata around the GNSS sensors involved in the fuzed solution. Accessible through sol_in[N].flags in a MSG_SOLN_META.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `flags` | flags that store all relevant info specific to this sensor type. |
| | 1 | | | | Total Payload Length |

Table 7.8.5: GNSSInputType message structure




Field 7.8.3: flags that store all relevant info specific to this sensor type. (`flags`)

| Value | Description |
|---|---|
| 0 | GNSS Position |
| 1 | GNSS Velocity Doppler |
| 2 | GNSS Velocity Displacement |

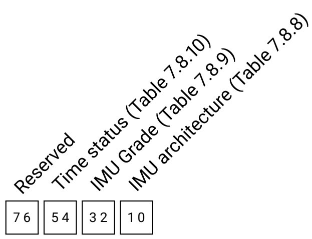
Table 7.8.6: Type of GNSS measurement values (`flags[0:1]`)

### IMUInputType

Metadata around the IMU sensors involved in the fuzed solution. Accessible through sol_in[N].flags in a MSG_SOLN_META.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `flags` | Instrument time, grade, and architecture for a sensor. |
| | 1 | | | | Total Payload Length |

Table 7.8.7: IMUInputType message structure




Field 7.8.4: Instrument time, grade, and architecture for a sensor. (`flags`)

| Value | Description |
|---|---|
| 0 | 6-axis MEMS |
| 1 | Other type |

Table 7.8.8: IMU architecture values (`flags[0:1]`)

| Value | Description |
|---|---|
| 0 | Consumer Grade |
| 1 | Tactical grade |
| 2 | Intermediate Grade |
| 3 | Superior (Marine / Aviation) Grade |

Table 7.8.9: IMU Grade values (`flags[2:3]`)

| Value | Description |
|---|---|
| 0 | Reference epoch is start of current GPS week |
| 1 | Reference epoch is time of system startup |
| 2 | Reference epoch is unknown |
| 3 | Reference epoch is last PPS |

Table 7.8.10: Time status values (`flags[4:5]`)

#### OdoInputType

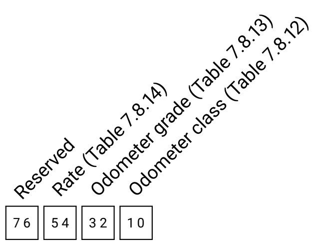
Metadata around the Odometry sensors involved in the fuzed solution. Accessible through sol_in[N].flags in a MSG_SOLN_META.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `flags` | Instrument ODO rate, grade, and quality. |
| | 1 | | | | Total Payload Length |

Table 7.8.11: OdoInputType message structure

| Value | Description |
|---|---|
| 0 | Single or averaged ticks |
| 1 | Single or averaged speed |
| 2 | Multi-dimensional ticks |
| 3 | Multi-dimensional speed |

Table 7.8.12: Odometer class values (`flags[0:1]`)




Field 7.8.5: Instrument ODO rate, grade, and quality. (`flags`)

| Value | Description |
|---|---|
| 0 | Low Grade (e.g. quantized CAN) |
| 1 | Medium Grade |
| 2 | Superior Grade |
| 3 | Reserved |

Table 7.8.13: Odometer grade values (`flags[2:3]`)

| Value | Description |
|---|---|
| 0 | Fixed incoming rate |
| 1 | Triggered by minimum distance or speed |
| 2 | Reserved |
| 3 | Reserved |

Table 7.8.14: Rate values (`flags[4:5]`)

## 7.9 System

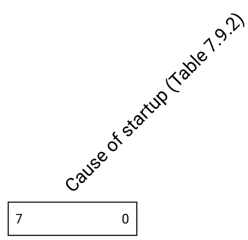
Standardized system messages from Swift Navigation devices.

### MSG_STARTUP — 0xFF00 — 65280

The system start-up message is sent once on system start-up. It notifies the host or other attached devices that the system has started and is now ready to respond to commands or configuration requests.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `cause` | Cause of startup |
| 1 | 1 | u8 | | `startup_type` | Startup type |
| 2 | 2 | u16 | | `reserved` | Reserved |
| | 4 | | | | Total Payload Length |

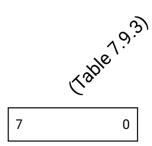
Table 7.9.1: MSG_STARTUP 0xFF00 message structure




Field 7.9.1: Cause of startup (`cause`)

| Value | Description |
|---|---|
| 0 | Power on |
| 1 | Software reset |
| 2 | Watchdog reset |

Table 7.9.2: Cause of startup values (`cause[0:7]`)




Field 7.9.2: Startup type (`startup_type`)

| Value | Description |
|---|---|
| 0 | Cold start |
| 1 | Warm start |
| 2 | Hot start |

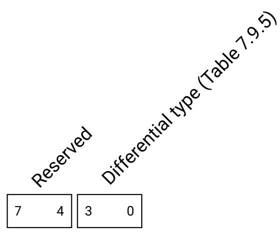
Table 7.9.3: values (`startup_type[0:7]`)

#### MSG_DGNSS_STATUS — 0xFF02 — 65282

This message provides information about the receipt of Differential corrections. It is expected to be sent with each receipt of a complete corrections packet.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | flags | Status flags |
| 1 | 2 | u16 | deci-seconds | latency | Latency of observation receipt |
| 3 | 1 | u8 | | num_signals | Number of signals from base station |
| 4 | N | string | | source | Corrections source string |
| | N + 4 | | | | Total Payload Length |

Table 7.9.4: MSG_DGNSS_STATUS 0xFF02 message structure




Field 7.9.3: Status flags (flags)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Code Difference |
| 2 | RTK |

Table 7.9.5: Differential type values (flags[0:3])

### MSG_HEARTBEAT — 0xFFFF — 65535

The heartbeat message is sent periodically to inform the host or other attached devices that the system is running. It is used to monitor system malfunctions. It also contains status flags that indicate to the host the status of the system and whether it is operating correctly. Currently, the expected heartbeat interval is 1 sec.

The system error flag is used to indicate that an error has occurred in the system. To determine the source of the error, the remaining error flags should be inspected.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | `flags` | Status flags |
| | 4 | | | | Total Payload Length |

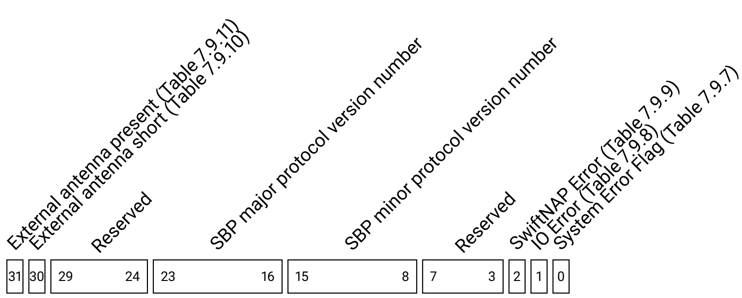
Table 7.9.6: MSG_HEARTBEAT 0xFFFF message structure

| Value | Description |
|---|---|
| 0 | System Healthy |
| 1 | An error has occurred |

Table 7.9.7: System Error Flag values (`flags[0]`)

| Value | Description |
|---|---|
| 0 | System Healthy |
| 1 | An IO error has occurred |

Table 7.9.8: IO Error values (`flags[1]`)




Field 7.9.4: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | System Healthy |
| 1 | An error has occurred in the SwiftNAP |

Table 7.9.9: SwiftNAP Error values (`flags[2]`)

| Value | Description |
|---|---|
| 0 | No short detected |
| 1 | Short detected |

Table 7.9.10: External antenna short values (`flags[30]`)

| Value | Description |
|---|---|
| 0 | No external antenna detected |
| 1 | External antenna is present |

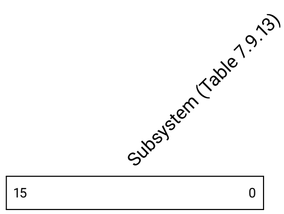
Table 7.9.11: External antenna present values (`flags[31]`)

#### SubSystemReport

Report the general and specific state of a subsystem. If the generic state is reported as initializing, the specific state should be ignored.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 2 | u16 | | `component` | Identity of reporting subsystem |
| 2 | 1 | u8 | | `generic` | Generic form status report |
| 3 | 1 | u8 | | `specific` | Subsystem specific status code |
| | 4 | | | | Total Payload Length |

Table 7.9.12: SubSystemReport message structure




Field 7.9.5: Identity of reporting subsystem (`component`)

| Value | Description |
|---|---|
| 0 | Primary GNSS Antenna |
| 1 | Measurement Engine |
| 2 | Corrections Client |
| 3 | Differential GNSS Engine |
| 4 | CAN |
| 5 | Wheel Odometry |
| 6 | Sensor Fusion Engine |

Table 7.9.13: Subsystem values (`component[0:15]`)


Field 7.9.6: Generic form status report (`generic`)

| Value | Description |
|---|---|
| 0 | OK/Nominal |
| 1 | Initializing |
| 2 | Unknown |
| 3 | Degraded |
| 4 | Unusable |

Table 7.9.14: Generic values (`generic[0:7]`)

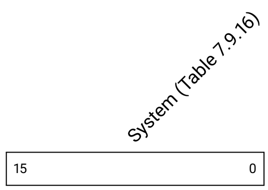
### MSG_STATUS_REPORT — 0xFFFE — 65534

The status report is sent periodically to inform the host or other attached devices that the system is running. It is used to monitor system malfunctions. It contains status reports that indicate to the host the status of each subsystem and whether it is operating correctly.

Interpretation of the subsystem specific status code is product dependent, but if the generic status code is initializing, it should be ignored. Refer to product documentation for details.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 2 | u16 | | `reporting_system` | Identity of reporting system |
| 2 | 2 | u16 | | `sbp_version` | SBP protocol version |
| 4 | 4 | u32 | | `sequence` | Increments on each status report sent |
| 8 | 4 | u32 | | `uptime` | Number of seconds since system start-up |
| $4N + 12$ | 2 | u16 | | `status[N].component` | Identity of reporting subsystem |
| $4N + 14$ | 1 | u8 | | `status[N].generic` | Generic form status report |
| $4N + 15$ | 1 | u8 | | `status[N].specific` | Subsystem specific status code |
| | $4N + 12$ | | | | Total Payload Length |

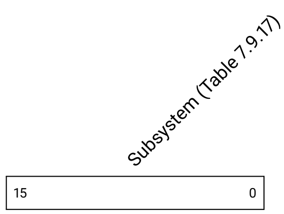
Table 7.9.15: MSG_STATUS_REPORT 0xFFFE message structure




Field 7.9.7: Identity of reporting system (`reporting_system`)

| Value | Description |
|---|---|
| 0 | Starling |
| 1 | Precision GNSS Module (PGM) |

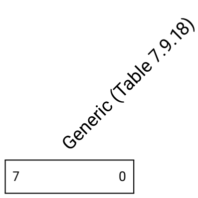
Table 7.9.16: System values (`reporting_system[0:15]`)




Field 7.9.8: Identity of reporting subsystem (`component`)

| Value | Description |
|---|---|
| 0 | Primary GNSS Antenna |
| 1 | Measurement Engine |
| 2 | Corrections Client |
| 3 | Differential GNSS Engine |
| 4 | CAN |
| 5 | Wheel Odometry |
| 6 | Sensor Fusion Engine |

Table 7.9.17: Subsystem values (`component[0:15]`)




Field 7.9.9: Generic form status report (`generic`)

| Value | Description |
|---|---|
| 0 | OK/Nominal |
| 1 | Initializing |
| 2 | Unknown |
| 3 | Degraded |
| 4 | Unusable |

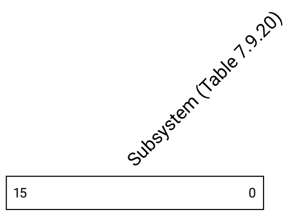
Table 7.9.18: Generic values (`generic[0:7]`)

### StatusJournalItem

Reports the uptime and the state of a subsystem via generic and specific status codes. If the generic state is reported as initializing, the specific state should be ignored.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | `uptime` | Milliseconds since system startup |
| 4 | 2 | u16 | | `report.component` | Identity of reporting subsystem |
| 6 | 1 | u8 | | `report.generic` | Generic form status report |
| 7 | 1 | u8 | | `report.specific` | Subsystem specific status code |
| | 8 | | | | Total Payload Length |

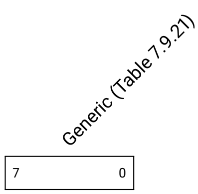
Table 7.9.19: StatusJournalItem message structure




Field 7.9.10: Identity of reporting subsystem (`report.component`)

| Value | Description |
|---|---|
| 0 | Primary GNSS Antenna |
| 1 | Measurement Engine |
| 2 | Corrections Client |
| 3 | Differential GNSS Engine |
| 4 | CAN |
| 5 | Wheel Odometry |
| 6 | Sensor Fusion Engine |

Table 7.9.20: Subsystem values (`report.component[0:15]`)




Field 7.9.11: Generic form status report (`report.generic`)

| Value | Description |
|---|---|
| 0 | OK/Nominal |
| 1 | Initializing |
| 2 | Unknown |
| 3 | Degraded |
| 4 | Unusable |

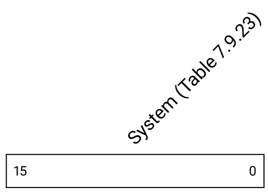
Table 7.9.21: Generic values (`report.generic[0:7]`)

#### MSG_STATUS_JOURNAL — 0xFFFD — 65533

The status journal message contains past status reports (see MSG_STATUS_REPORT) and functions as a error/event storage for telemetry purposes.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 2 | u16 | | `reporting_system` | Identity of reporting system |
| 2 | 2 | u16 | | `sbp_version` | SBP protocol version |
| 4 | 4 | u32 | | `total_status_reports` | Total number of status reports sent since system startup |
| 8 | 1 | u8 | | `sequence_descriptor` | Index and number of messages in this sequence. First nibble is the size of the sequence (n), second nibble is the zero-indexed counter (ith packet of n) |
| $8N + 9$ | 4 | u32 | | `journal[N].uptime` | Milliseconds since system startup |
| $8N + 13$ | 2 | u16 | | `journal[N].report.component` | Identity of reporting subsystem |
| $8N + 15$ | 1 | u8 | | `journal[N].report.generic` | Generic form status report |
| $8N + 16$ | 1 | u8 | | `journal[N].report.specific` | Subsystem specific status code |
| | $8N + 9$ | | | | Total Payload Length |

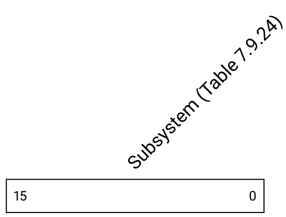
Table 7.9.22: MSG_STATUS_JOURNAL 0xFFFD message structure




Field 7.9.12: Identity of reporting system (`reporting_system`)

| Value | Description |
|---|---|
| 0 | Starling |
| 1 | Precision GNSS Module (PGM) |

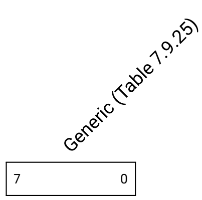
Table 7.9.23: System values (`reporting_system[0:15]`)




Field 7.9.13: Identity of reporting subsystem (`report.component`)

| Value | Description |
|---|---|
| 0 | Primary GNSS Antenna |
| 1 | Measurement Engine |
| 2 | Corrections Client |
| 3 | Differential GNSS Engine |
| 4 | CAN |
| 5 | Wheel Odometry |
| 6 | Sensor Fusion Engine |

Table 7.9.24: Subsystem values (`report.component[0:15]`)




Field 7.9.14: Generic form status report (`report.generic`)

| Value | Description |
|---|---|
| 0 | OK/Nominal |
| 1 | Initializing |
| 2 | Unknown |
| 3 | Degraded |
| 4 | Unusable |

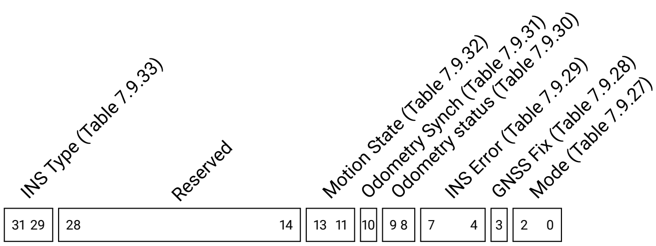
Table 7.9.25: Generic values (`report.generic[0:7]`)

#### MSG_INS_STATUS — 0xFF03 — 65283

The INS status message describes the state of the operation and initialization of the inertial navigation system.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | `flags` | Status flags |
| | 4 | | | | Total Payload Length |

Table 7.9.26: MSG_INS_STATUS 0xFF03 message structure




Field 7.9.15: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Awaiting initialization |
| 1 | Dynamically aligning |
| 2 | Ready |
| 3 | GNSS Outage exceeds max duration |
| 4 | FastStart seeding |
| 5 | FastStart validating |
| 6 | Validating unsafe fast start seed |

Table 7.9.27: Mode values (`flags[0:2]`)

| Value | Description |
|---|---|
| 0 | No GNSS fix available |
| 1 | GNSS fix |

Table 7.9.28: GNSS Fix values (`flags[3]`)

| Value | Description |
|---|---|
| 0 | Reserved |
| 1 | IMU Data Error |
| 2 | INS License Error |
| 3 | IMU Calibration Data Error |

Table 7.9.29: INS Error values (`flags[4:7]`)

| Value | Description |
|---|---|
| 0 | No Odometry |
| 1 | Odometry received within last second |
| 2 | Odometry not received within last second |

Table 7.9.30: Odometry status values (`flags[8:9]`)

| Value | Description |
|---|---|
| 0 | Odometry timestamp nominal |
| 1 | Odometry timestamp out of bounds |

Table 7.9.31: Odometry Synch values (`flags[10]`)

| Value | Description |
|---|---|
| 0 | Unknown or Init |
| 1 | Arbitrary Motion |
| 2 | Straight Motion |
| 3 | Stationary |

Table 7.9.32: Motion State values (`flags[11:13]`)

| Value | Description |
|---|---|
| 0 | Smoothpose Loosely Coupled |
| 1 | Starling |

Table 7.9.33: INS Type values (`flags[29:31]`)

**MSG_INS_UPDATES — 0xFF06 — 65286**

The INS update status message contains information about executed and rejected INS updates. This message is expected to be extended in the future as new types of measurements are being added.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | tow | GPS Time of Week |
| 4 | 1 | u8 | | gnsspos | GNSS position update status flags |
| 5 | 1 | u8 | | gnssvel | GNSS velocity update status flags |
| 6 | 1 | u8 | | wheelticks | Wheelticks update status flags |
| 7 | 1 | u8 | | speed | Wheelticks update status flags |
| 8 | 1 | u8 | | nhc | NHC update status flags |
| 9 | 1 | u8 | | zerovel | Zero velocity update status flags |
| | 10 | | | | Total Payload Length |

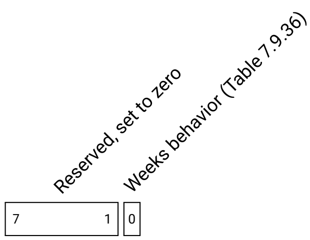
Table 7.9.34: MSG_INS_UPDATES 0xFF06 message structure

### MSG_GNSS_TIME_OFFSET — 0xFF07 — 65287

The GNSS time offset message contains the information that is needed to translate messages tagged with a local timestamp (e.g. IMU or wheeltick messages) to GNSS time for the sender producing this message.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 2 | s16 | weeks | `weeks` | Weeks portion of the time offset |
| 2 | 4 | s32 | ms | `milliseconds` | Milliseconds portion of the time offset |
| 6 | 2 | s16 | microseconds | `microseconds` | Microseconds portion of the time offset |
| 8 | 1 | u8 | | `flags` | Status flags |
| | 9 | | | | Total Payload Length |

Table 7.9.35: MSG_GNSS_TIME_OFFSET 0xFF07 message structure




Field 7.9.16: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Not affected on local timestamp rollover |
| 1 | Incremented on local timestamp rollover |

Table 7.9.36: Weeks behavior values (`flags[0]`)

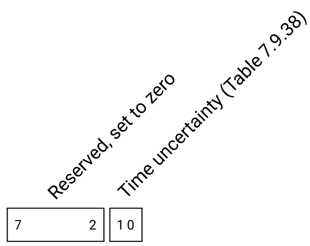
#### MSG_PPS_TIME — 0xFF08 — 65288

The PPS time message contains the value of the sender's local time in microseconds at the moment a pulse is detected on the PPS input. This is to be used for synchronisation of sensor data sampled with a local timestamp (e.g. IMU or wheeltick messages) where GNSS time is unknown to the sender.

The local time used to timestamp the PPS pulse must be generated by the same clock which is used to timestamp the IMU/wheel sensor data and should follow the same roll-over rules (i.e. it should roll over to zero after 604800 seconds). A separate MSG_PPS_TIME message should be sent for each source of sensor data which uses local timestamping. The sender ID for each of these MSG_PPS_TIME messages should match the sender ID of the respective sensor data.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 8 | u64 | microseconds | `time` | Local time in microseconds |
| 8 | 1 | u8 | | `flags` | Status flags |
| | 9 | | | | Total Payload Length |

Table 7.9.37: MSG_PPS_TIME 0xFF08 message structure




Field 7.9.17: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Unknown |
| 1 | +/- 10 milliseconds |
| 2 | +/- 10 microseconds |
| 3 | < 1 microseconds |

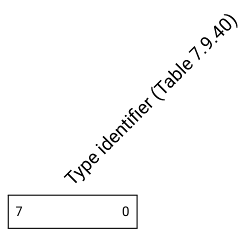
Table 7.9.38: Time uncertainty values (`flags[0:1]`)

#### MSG_SENSOR_AID_EVENT — 0xFF09 — 65289

This diagnostic message contains state and update status information for all sensors that are being used by the fusion engine. This message will be generated asynchronously to the solution messages and will be emitted anytime a sensor update is being processed.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | milliseconds | time | Update timestamp in milliseconds. |
| 4 | 1 | u8 | | sensor_type | Sensor type |
| 5 | 2 | u16 | | sensor_id | Sensor identifier |
| 7 | 1 | u8 | | sensor_state | Reserved for future use |
| 8 | 1 | u8 | | n_available_meas | Number of available measurements in this epoch |
| 9 | 1 | u8 | | n_attempted_meas | Number of attempted measurements in this epoch |
| 10 | 1 | u8 | | n_accepted_meas | Number of accepted measurements in this epoch |
| 11 | 4 | u32 | | flags | Reserved for future use |
| | 15 | | | | Total Payload Length |

Table 7.9.39: MSG_SENSOR_AID_EVENT 0xFF09 message structure




Field 7.9.18: Sensor type (sensor_type)

| Value | Description |
|---|---|
| 0 | GNSS position |
| 1 | GNSS average velocity |
| 2 | GNSS instantaneous velocity |
| 3 | Wheel ticks |
| 4 | Wheel speed |
| 5 | IMU |
| 6 | Time differences of carrier phase |

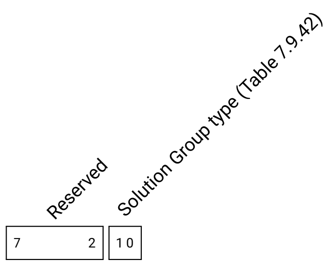
Table 7.9.40: Type identifier values (sensor_type[0:7])

#### MSG_GROUP_META — 0xFF0A — 65290

This leading message lists the time metadata of the Solution Group. It also lists the atomic contents (i.e. types of messages included) of the Solution Group.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | group_id | Id of the Msgs Group, 0 is Unknown, 1 is Bestpos, 2 is Gnss |
| 1 | 1 | u8 | | flags | Status flags (reserved) |
| 2 | 1 | u8 | | n_group_msgs | Size of list group_msgs |
| 3 | N | u16[N] | | group_msgs | An in-order list of message types included in the Solution Group, including GROUP_META itself |
| | $2N + 3$ | | | | Total Payload Length |

Table 7.9.41: MSG_GROUP_META 0xFF0A message structure




Field 7.9.19: Status flags (reserved) (flags)

| Value | Description |
|---|---|
| 0 | None (invalid) |
| 1 | GNSS only |
| 2 | GNSS+INS (Fuzed) |
| 3 | Reserved |

Table 7.9.42: Solution Group type values (flags[0:1])

# 8 Draft Message Definitions

## 8.1 Acquisition

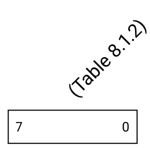
Satellite acquisition messages from the device.

**MSG ACQ RESULT — 0x002F — 47**

This message describes the results from an attempted GPS signal acquisition search for a satellite PRN over a code phase/carrier frequency range. It contains the parameters of the point in the acquisition search space with the best carrier-to-noise (CN/0) ratio.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | float | dB Hz | `cn0` | CN/0 of best point |
| 4 | 4 | float | chips | `cp` | Code phase of best point |
| 8 | 4 | float | hz | `cf` | Carrier frequency of best point |
| 12 | 1 | u8 | | `sid.sat` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 13 | 1 | u8 | | `sid.code` | Signal constellation, band and code |
| | 14 | | | | Total Payload Length |

Table 8.1.1: MSG_ACQ_RESULT 0x002F message structure




Field 8.1.1: Signal constellation, band and code (`sid.code`)

| Value | Description |
|---|---|
| 0 | GPS L1CA |
| 1 | GPS L2CM |
| 2 | SBAS L1CA |
| 3 | GLO L1CA |
| 4 | GLO L2CA |
| 5 | GPS L1P |
| 6 | GPS L2P |
| 12 | BDS2 B1 |
| 13 | BDS2 B2 |
| 14 | GAL E1B |
| 20 | GAL E7I |
| 31 | QZS L1CA |
| 36 | QZS L2CL |
| 39 | QZS L5Q |
| 47 | BDS3 B2a |

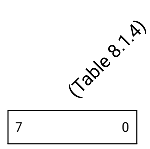
Table 8.1.2: values (`sid.code[0:7]`)

**MSG ACQ SV PROFILE — 0x002E — 46**

The message describes all SV profiles during acquisition time. The message is used to debug and measure the performance.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| $33N + 0$ | 1 | u8 | | acq_sv_profile[N].job_type | SV search job type (deep, fallback, etc) |
| $33N + 1$ | 1 | u8 | | acq_sv_profile[N].status | Acquisition status 1 is Success, 0 is Failure |
| $33N + 2$ | 2 | u16 | dB-Hz*10 | acq_sv_profile[N].cn0 | CN0 value. Only valid if status is '1' |
| $33N + 4$ | 1 | u8 | ms | acq_sv_profile[N].int_time | Acquisition integration time |
| $33N + 5$ | 1 | u8 | | acq_sv_profile[N].sid.sat | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| $33N + 6$ | 1 | u8 | | acq_sv_profile[N].sid.code | Signal constellation, band and code |
| $33N + 7$ | 2 | u16 | Hz | acq_sv_profile[N].bin_width | Acq frequency bin width |
| $33N + 9$ | 4 | u32 | ms | acq_sv_profile[N].timestamp | Timestamp of the job complete event |
| $33N + 13$ | 4 | u32 | us | acq_sv_profile[N].time_spent | Time spent to search for sid.code |
| $33N + 17$ | 4 | s32 | Hz | acq_sv_profile[N].cf_min | Doppler range lowest frequency |
| $33N + 21$ | 4 | s32 | Hz | acq_sv_profile[N].cf_max | Doppler range highest frequency |
| $33N + 25$ | 4 | s32 | Hz | acq_sv_profile[N].cf | Doppler value of detected peak. Only valid if status is '1' |
| $33N + 29$ | 4 | u32 | chips*10 | acq_sv_profile[N].cp | Codephase of detected peak. Only valid if status is '1' |
| | 33N | | | | Total Payload Length |

Table 8.1.3: MSG_ACQ_SV_PROFILE 0x002E message structure




Field 8.1.2: Signal constellation, band and code (acq_sv_profile[N].sid.code)

| Value | Description |
|---|---|
| 0 | GPS L1CA |
| 1 | GPS L2CM |
| 2 | SBAS L1CA |
| 3 | GLO L1CA |
| 4 | GLO L2CA |
| 5 | GPS L1P |
| 6 | GPS L2P |
| 12 | BDS2 B1 |
| 13 | BDS2 B2 |
| 14 | GAL E1B |
| 20 | GAL E7I |
| 31 | QZS L1CA |
| 36 | QZS L2CL |
| 39 | QZS L5Q |
| 47 | BDS3 B2a |

Table 8.1.4: values (acq_sv_profile[N].sid.code[0:7])

## 8.2 File IO

Messages for using device's onboard flash filesystem functionality. This allows data to be stored persistently in the device's program flash with wear-levelling using a simple filesystem interface. The file system interface (CFS) defines an abstract API for reading directories and for reading and writing files.

Note that some of these messages share the same message type ID for both the host request and the device response.

#### MSG FILEIO READ REQ — 0x00A8 — 168

The file read message reads a certain length (up to 255 bytes) from a given offset into a file, and returns the data in a MSG_FILEIO_READ_RESP message where the message length field indicates how many bytes were successfully read. The sequence number in the request will be returned in the response. If the message is invalid, a followup MSG_PRINT message will print ”Invalid fileio read message”. A device will only respond to this message when it is received from sender ID 0x42.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | sequence | Read sequence number |
| 4 | 4 | u32 | bytes | offset | File offset |
| 8 | 1 | u8 | bytes | chunk_size | Chunk size to read |
| 9 | N | string | | filename | Name of the file to read from |
| | N + 9 | | | | Total Payload Length |

Table 8.2.1: MSG_FILEIO_READ_REQ 0x00A8 message structure

**MSG FILEIO READ RESP — 0x00A3 — 163**

The file read message reads a certain length (up to 255 bytes) from a given offset into a file, and returns the data in a message where the message length field indicates how many bytes were successfully read. The sequence number in the response is preserved from the request.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | `sequence` | Read sequence number |
| 4 | N | u8[N] | | `contents` | Contents of read file |
| | $N + 4$ | | | | Total Payload Length |

Table 8.2.2: MSG_FILEIO_READ_RESP 0x00A3 message structure

**MSG FILEIO READ DIR REQ — 0x00A9 — 169**

The read directory message lists the files in a directory on the device's onboard flash file system. The offset parameter can be used to skip the first n elements of the file list. Returns a MSG_FILEIO_READ_DIR_RESP message containing the directory listings as a NULL delimited list. The listing is chunked over multiple SBP packets. The sequence number in the request will be returned in the response. If message is invalid, a followup MSG_PRINT message will print "Invalid fileio read message". A device will only respond to this message when it is received from sender ID 0x42.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | `sequence` | Read sequence number |
| 4 | 4 | u32 | | `offset` | The offset to skip the first n elements of the file list |
| 8 | N | string | | `dirname` | Name of the directory to list |
| | $N + 8$ | | | | Total Payload Length |

Table 8.2.3: MSG_FILEIO_READ_DIR_REQ 0x00A9 message structure

**MSG FILEIO READ DIR RESP — 0x00AA — 170**

The read directory message lists the files in a directory on the device's onboard flash file system. Message contains the directory listings as a NULL delimited list. The listing is chunked over multiple SBP packets and the end of the list is identified by an packet with no entries. The sequence number in the response is preserved from the request.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | sequence | Read sequence number |
| 4 | N | string | | contents | Contents of read directory |
| | N + 4 | | | | Total Payload Length |

Table 8.2.4: MSG_FILEIO_READ_DIR_RESP 0x00AA message structure

**MSG FILEIO REMOVE — 0x00AC — 172**

The file remove message deletes a file from the file system. If the message is invalid, a followup MSG_PRINT message will print ”Invalid fileio remove message”. A device will only process this message when it is received from sender ID 0x42.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | N | string | | filename | Name of the file to delete |
| | N | | | | Total Payload Length |

Table 8.2.5: MSG_FILEIO_REMOVE 0x00AC message structure

**MSG FILEIO WRITE REQ — 0x00AD — 173**

The file write message writes a certain length (up to 255 bytes) of data to a file at a given offset. Returns a copy of the original MSG_FILEIO_WRITE_RESP message to check integrity of the write. The sequence number in the request will be returned in the response. If message is invalid, a followup MSG_PRINT message will print ”Invalid fileio write message”. A device will only process this message when it is received from sender ID 0x42.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | `sequence` | Write sequence number |
| 4 | 4 | u32 | bytes | `offset` | Offset into the file at which to start writing in bytes |
| 8 | N | string | | `filename` | Name of the file to write to |
| 9 | N | u8[N] | | `data` | Variable-length array of data to write |
| | N + 9 | | | | Total Payload Length |

Table 8.2.6: MSG_FILEIO_WRITE_REQ 0x00AD message structure

**MSG FILEIO WRITE RESP — 0x00AB — 171**

The file write message writes a certain length (up to 255 bytes) of data to a file at a given offset. The message is a copy of the original MSG_FILEIO_WRITE_REQ message to check integrity of the write. The sequence number in the response is preserved from the request.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | sequence | Write sequence number |
| | 4 | | | | Total Payload Length |

Table 8.2.7: MSG_FILEIO_WRITE_RESP 0x00AB message structure

#### MSG FILEIO CONFIG REQ — 0x1001 — 4097

Requests advice on the optimal configuration for a FileIO transfer. Newer version of FileIO can support greater throughput by supporting a large window of FileIO data that can be in-flight during read or write operations.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | sequence | Advice sequence number |
| | 4 | | | | Total Payload Length |

Table 8.2.8: MSG_FILEIO_CONFIG_REQ 0x1001 message structure

#### MSG FILEIO CONFIG RESP — 0x1002 — 4098

The advice on the optimal configuration for a FileIO transfer. Newer version of FileIO can support greater throughput by supporting a large window of FileIO data that can be in-flight during read or write operations.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | sequence | Advice sequence number |
| 4 | 4 | u32 | | window_size | The number of SBP packets in the data in-flight window |
| 8 | 4 | u32 | | batch_size | The number of SBP packets sent in one PDU |
| 12 | 4 | u32 | | fileio_version | The version of FileIO that is supported |
| | 16 | | | | Total Payload Length |

Table 8.2.9: MSG_FILEIO_CONFIG_RESP 0x1002 message structure

## 8.3 Integrity

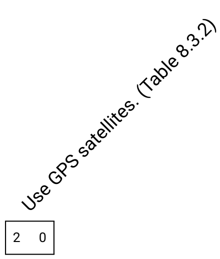
Integrity flag messages

#### MSG SSR FLAG HIGH LEVEL — 0x0BBA — 3002

Integrity monitoring flags for multiple aggregated elements. An element could be a satellite, SSR grid point, or SSR tile. A group of aggregated elements being monitored for integrity could refer to:
- Satellites in a particular {GPS, GAL, BDS, QZSS} constellation.
- Satellites in the line-of-sight of a particular SSR tile.
- Satellites in the line-of-sight of a particular SSR grid point.
The integrity usage for a group of aggregated elements varies according to the integrity flag of the satellites comprising that group.
SSR_INTEGRITY_USAGE_NOMINAL: All satellites received passed the integrity check and have flag INTEGRITY_FLAG_OK.
SSR_INTEGRITY_USAGE_WARNING: A limited number of elements in the group failed the integrity check. Refer to more granular integrity messages for details on the specific failing elements.
SSR_INTEGRITY_USAGE_ALERT: Most elements in the group failed the integrity check, do not use for positioning.
SSR_INTEGRITY_USAGE_NOT_MONITORED: Unable to verify the integrity flag of elements in the group.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | obs_time.tow | Seconds since start of GPS week |
| 4 | 2 | u16 | week | obs_time.wn | GPS week number |
| 6 | 4 | u32 | s | iono_corr_time.tow | Seconds since start of GPS week |
| 10 | 2 | u16 | week | iono_corr_time.wn | GPS week number |
| 12 | 4 | u32 | s | sat_corr_time.tow | Seconds since start of GPS week |
| 16 | 2 | u16 | week | sat_corr_time.wn | GPS week number |
| 18 | 1 | u8 | | ssr_sol_id | SSR Solution ID. |
| 19 | 2 | u16 | | tile_set_id | Unique identifier of the set this tile belongs to. |
| 21 | 2 | u16 | | tile_id | Unique identifier of this tile in the tile set. |
| 23 | 1 | u8 | | chain_id | Chain and type of flag. |
| 24 | 1 | u8 | | use_gps_sat | Use GPS satellites. |
| 25 | 1 | u8 | | use_gal_sat | Use GAL satellites. |
| 26 | 1 | u8 | | use_bds_sat | Use BDS satellites. |
| 27 | 1 | u8 | | use_qzss_sat | Use QZSS satellites. |
| 28 | 5 | u8[5] | | reserved | Reserved |
| 33 | 1 | u8 | | use_tropo_grid_points | Use tropo grid points. |
| 34 | 1 | u8 | | use_iono_grid_points | Use iono grid points. |
| 35 | 1 | u8 | | use_iono_tile_sat_los | Use iono tile satellite LoS. |
| 36 | 1 | u8 | | use_iono_grid_point_sat_los | Use iono grid point satellite LoS. |
| | 37 | | | | Total Payload Length |

Table 8.3.1: MSG_SSR_FLAG_HIGH_LEVEL 0x0BBA message structure




Field 8.3.1: Use GPS satellites. (use_gps_sat)

| Value | Description |
|---|---|
| 0 | Nominal |
| 1 | Warning |
| 2 | Alert |
| 3 | Not monitored |

Table 8.3.2: Use GPS satellites. values (use_gps_sat[0:2])

Use GAL satellites. (Table 8.3.3)

| 2 | 0 |
|---|---|

Field 8.3.2: Use GAL satellites. (`use_gal_sat`)

| Value | Description |
|---|---|
| 0 | Nominal |
| 1 | Warning |
| 2 | Alert |
| 3 | Not monitored |

Table 8.3.3: Use GAL satellites. values (`use_gal_sat[0:2]`)

Use BDS satellites. (Table 8.3.4)

| 2 | 0 |
|---|---|

Field 8.3.3: Use BDS satellites. (`use_bds_sat`)

| Value | Description |
|---|---|
| 0 | Nominal |
| 1 | Warning |
| 2 | Alert |
| 3 | Not monitored |

Table 8.3.4: Use BDS satellites. values (`use_bds_sat[0:2]`)

Use QZSS satellites. (Table 8.3.5)

| 2 | 0 |
|---|---|

Field 8.3.4: Use QZSS satellites. (`use_qzss_sat`)

| Value | Description |
|---|---|
| 0 | Nominal |
| 1 | Warning |
| 2 | Alert |
| 3 | Not monitored |

Table 8.3.5: Use QZSS satellites. values (`use_qzss_sat[0:2]`)

Use tropo grid points. (Table 8.3.6)

| 2 | 0 |
|---|---|

Field 8.3.5: Use tropo grid points. (`use_tropo_grid_points`)

| Value | Description |
|---|---|
| 0 | Nominal |
| 1 | Warning |
| 2 | Alert |
| 3 | Not monitored |

Table 8.3.6: Use tropo grid points. values (`use_tropo_grid_points[0:2]`)

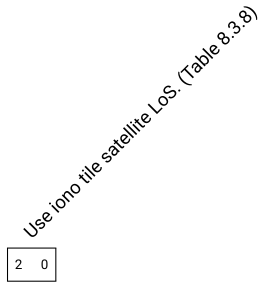
Use iono grid points. (Table 8.3.7)

| 2 | 0 |
|---|---|

Field 8.3.6: Use iono grid points. (`use_iono_grid_points`)

| Value | Description |
|---|---|
| 0 | Nominal |
| 1 | Warning |
| 2 | Alert |
| 3 | Not monitored |

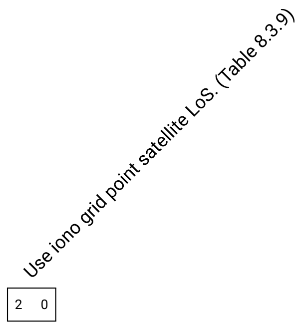
Table 8.3.7: Use iono grid points. values (`use_iono_grid_points[0:2]`)




Field 8.3.7: Use iono tile satellite LoS. (use_iono_tile_sat_los)

| Value | Description |
|---|---|
| 0 | Nominal |
| 1 | Warning |
| 2 | Alert |
| 3 | Not monitored |

Table 8.3.8: Use iono tile satellite LoS. values (use_iono_tile_sat_los[0:2])




Field 8.3.8: Use iono grid point satellite LoS. (use_iono_grid_point_sat_los)

| Value | Description |
|---|---|
| 0 | Nominal |
| 1 | Warning |
| 2 | Alert |
| 3 | Not monitored |

Table 8.3.9: Use iono grid point satellite LoS. values (use_iono_grid_point_sat_los[0:2])

### MSG SSR FLAG SATELLITES — 0x0BBD — 3005

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | obs_time.tow | Seconds since start of GPS week |
| 4 | 2 | u16 | week | obs_time.wn | GPS week number |
| 6 | 1 | u8 | | num_msgs | Number of messages in the dataset |
| 7 | 1 | u8 | | seq_num | Position of this message in the dataset |
| 8 | 1 | u8 | | ssr_sol_id | SSR Solution ID. |
| 9 | 1 | u8 | | chain_id | Chain and type of flag. |
| 10 | 1 | u8 | | const_id | Constellation ID. |
| 11 | 1 | u8 | | n_faulty_sats | Number of faulty satellites. |
| 12 | N | u8[N] | | faulty_sats | List of faulty satellites. |
| | N + 12 | | | | Total Payload Length |

Table 8.3.10: MSG_SSR_FLAG_SATELLITES 0x0BBD message structure

#### MSG SSR FLAG TROPO GRID POINTS — 0x0BC3 — 3011

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | header.obs_time.tow | Seconds since start of GPS week |
| 4 | 2 | u16 | week | header.obs_time.wn | GPS week number |
| 6 | 1 | u8 | | header.num_msgs | Number of messages in the dataset |
| 7 | 1 | u8 | | header.seq_num | Position of this message in the dataset |
| 8 | 1 | u8 | | header.ssr_sol_id | SSR Solution ID. |
| 9 | 2 | u16 | | header.tile_set_id | Unique identifier of the set this tile belongs to. |
| 11 | 2 | u16 | | header.tile_id | Unique identifier of this tile in the tile set. |
| 13 | 1 | u8 | | header.chain_id | Chain and type of flag. |
| 14 | 1 | u8 | | n_faulty_points | Number of faulty grid points. |
| 15 | N | u16[N] | | faulty_points | List of faulty grid points. |
| | $2N + 15$ | | | | Total Payload Length |

Table 8.3.11: MSG_SSR_FLAG_TROPO_GRID_POINTS 0x0BC3 message structure

#### MSG SSR FLAG IONO GRID POINTS — 0x0BC7 — 3015

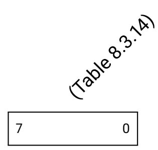
| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | header.obs_time.tow | Seconds since start of GPS week |
| 4 | 2 | u16 | week | header.obs_time.wn | GPS week number |
| 6 | 1 | u8 | | header.num_msgs | Number of messages in the dataset |
| 7 | 1 | u8 | | header.seq_num | Position of this message in the dataset |
| 8 | 1 | u8 | | header.ssr_sol_id | SSR Solution ID. |
| 9 | 2 | u16 | | header.tile_set_id | Unique identifier of the set this tile belongs to. |
| 11 | 2 | u16 | | header.tile_id | Unique identifier of this tile in the tile set. |
| 13 | 1 | u8 | | header.chain_id | Chain and type of flag. |
| 14 | 1 | u8 | | n_faulty_points | Number of faulty grid points. |
| 15 | N | u16[N] | | faulty_points | List of faulty grid points. |
| | $2N + 15$ | | | | Total Payload Length |

Table 8.3.12: MSG_SSR_FLAG_IONO_GRID_POINTS 0x0BC7 message structure

**MSG SSR FLAG IONO TILE SAT LOS — 0x0BCD — 3021**

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | `header.obs_time.tow` | Seconds since start of GPS week |
| 4 | 2 | u16 | week | `header.obs_time.wn` | GPS week number |
| 6 | 1 | u8 | | `header.num_msgs` | Number of messages in the dataset |
| 7 | 1 | u8 | | `header.seq_num` | Position of this message in the dataset |
| 8 | 1 | u8 | | `header.ssr_sol_id` | SSR Solution ID. |
| 9 | 2 | u16 | | `header.tile_set_id` | Unique identifier of the set this tile belongs to. |
| 11 | 2 | u16 | | `header.tile_id` | Unique identifier of this tile in the tile set. |
| 13 | 1 | u8 | | `header.chain_id` | Chain and type of flag. |
| 14 | 1 | u8 | | `n_faulty_los` | Number of faulty LOS. |
| $2N + 15$ | 1 | u8 | | `faulty_los[N].satId` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| $2N + 16$ | 1 | u8 | | `faulty_los[N].constellation` | Constellation ID to which the SV belongs |
| | $2N + 15$ | | | | Total Payload Length |

Table 8.3.13: MSG_SSR_FLAG_IONO_TILE_SAT_LOS 0x0BCD message structure




Field 8.3.9: Constellation ID to which the SV belongs (`faulty_los[N].constellation`)

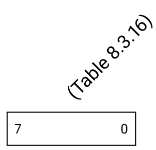
| Value | Description |
|---|---|
| 0 | GPS |
| 3 | BDS |
| 4 | QZS |
| 5 | GAL |

Table 8.3.14: values (`faulty_los[N].constellation[0:7]`)

#### MSG SSR FLAG IONO GRID POINT SAT LOS — 0x0BD1 — 3025

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | `header.obs_time.tow` | Seconds since start of GPS week |
| 4 | 2 | u16 | week | `header.obs_time.wn` | GPS week number |
| 6 | 1 | u8 | | `header.num_msgs` | Number of messages in the dataset |
| 7 | 1 | u8 | | `header.seq_num` | Position of this message in the dataset |
| 8 | 1 | u8 | | `header.ssr_sol_id` | SSR Solution ID. |
| 9 | 2 | u16 | | `header.tile_set_id` | Unique identifier of the set this tile belongs to. |
| 11 | 2 | u16 | | `header.tile_id` | Unique identifier of this tile in the tile set. |
| 13 | 1 | u8 | | `header.chain_id` | Chain and type of flag. |
| 14 | 2 | u16 | | `grid_point_id` | Index of the grid point. |
| 16 | 1 | u8 | | `n_faulty_los` | Number of faulty LOS. |
| $2N + 17$ | 1 | u8 | | `faulty_los[N].satId` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| $2N + 18$ | 1 | u8 | | `faulty_los[N].constellation` | Constellation ID to which the SV belongs |
| | $2N + 17$ | | | | Total Payload Length |

Table 8.3.15: MSG_SSR_FLAG_IONO_GRID_POINT_SAT_LOS 0x0BD1 message structure




Field 8.3.10: Constellation ID to which the SV belongs (`faulty_los[N].constellation`)

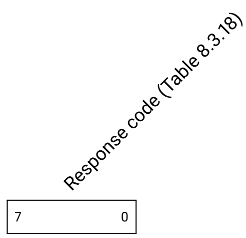
| Value | Description |
|---|---|
| 0 | GPS |
| 3 | BDS |
| 4 | QZS |
| 5 | GAL |

Table 8.3.16: values (`faulty_los[N].constellation[0:7]`)

**MSG ACKNOWLEDGE — 0x0BD2 — 3026**

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | request_id | Echo of the request ID field from the corresponding CRA message, or 255 if no request ID was provided. |
| 1 | 4 | u32 | | area_id | Echo of the Area ID field from the corresponding CRA message. |
| 5 | 1 | u8 | | response_code | Reported status of the request. |
| 6 | 2 | u16 | | correction_mask_on_demand | Contains the message group(s) that will be sent in response from the corresponding CRA correction mask. An echo of the correction mask field from the corresponding CRA message. |
| 8 | 2 | u16 | | correction_mask_stream | For future expansion. Always set to 0. |
| 10 | 1 | u8 | | solution_id | The solution ID of the instance providing the corrections. |
| | 11 | | | | Total Payload Length |

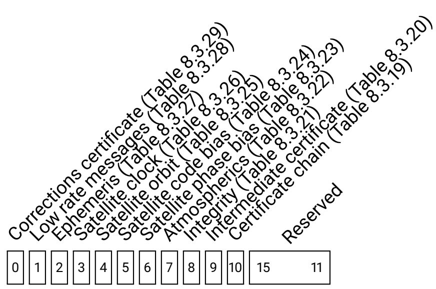
Table 8.3.17: MSG_ACKNOWLEDGE 0x0BD2 message structure




Field 8.3.11: Reported status of the request. (response_code)

| Value | Description |
|---|---|
| 0 | Ok |
| 1 | Out of coverage |
| 2 | Forbidden |
| 3 | Invalid request |
| 4 | Invalid area id |

Table 8.3.18: Response code values (response_code[0:7])




Field 8.3.12: Contains the message group(s) that will be sent in response from the corresponding CRA correction mask. An echo of the correction mask field from the corresponding CRA message. (`correction_mask_on_demand`)

| Value | Description |
|---|---|
| 0 | Not requested |
| 1 | Requested |

Table 8.3.19: Certificate chain values (`correction_mask_on_demand[10]`)

| Value | Description |
|---|---|
| 0 | Not requested |
| 1 | Requested |

Table 8.3.20: Intermediate certificate values (`correction_mask_on_demand[9]`)

| Value | Description |
|---|---|
| 0 | Not requested |
| 1 | Requested |

Table 8.3.21: Integrity values (`correction_mask_on_demand[8]`)

| Value | Description |
|---|---|
| 0 | Not requested |
| 1 | Requested |

Table 8.3.22: Atmospherics values (`correction_mask_on_demand[7]`)

| Value | Description |
|---|---|
| 0 | Not requested |
| 1 | Requested |

Table 8.3.23: Satellite phase bias values (`correction_mask_on_demand[6]`)

| Value | Description |
|---|---|
| 0 | Not requested |
| 1 | Requested |

Table 8.3.24: Satellite code bias values (`correction_mask_on_demand[5]`)

| Value | Description |
|---|---|
| 0 | Not requested |
| 1 | Requested |

Table 8.3.25: Satellite orbit values (`correction_mask_on_demand[4]`)

| Value | Description |
|---|---|
| 0 | Not requested |
| 1 | Requested |

Table 8.3.26: Satellite clock values (`correction_mask_on_demand[3]`)

## 8.4 Orientation

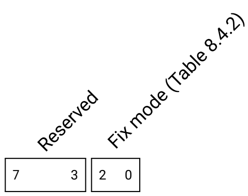
Orientation Messages

**MSG BASELINE HEADING — 0x020F — 527**

This message reports the baseline heading pointing from the base station to the rover relative to True North. The full GPS time is given by the preceding MSG_GPS_TIME with the matching time-of-week (tow). It is intended that time-matched RTK mode is used when the base station is moving.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | u32 | mdeg | `heading` | Heading |
| 8 | 1 | u8 | | `n_sats` | Number of satellites used in solution |
| 9 | 1 | u8 | | `flags` | Status flags |
| | 10 | | | | Total Payload Length |

Table 8.4.1: MSG_BASELINE_HEADING 0x020F message structure




Field 8.4.1: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Reserved |
| 2 | Differential GNSS (DGNSS) |
| 3 | Float RTK |
| 4 | Fixed RTK |

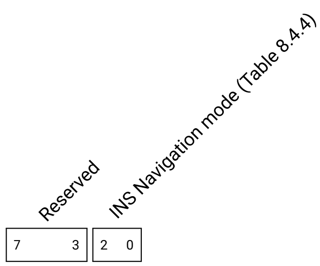
Table 8.4.2: Fix mode values (`flags[0:2]`)

**MSG ORIENT QUAT — 0x0220 — 544**

This message reports the quaternion vector describing the vehicle body frame's orientation with respect to a local-level NED frame. The components of the vector should sum to a unit vector assuming that the LSB of each component as a value of 2ˆ-31. This message will only be available in future INS versions of Swift Products and is not produced by Piksi Multi or Duro.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | s32 | 2ˆ-31 | `w` | Real component |
| 8 | 4 | s32 | 2ˆ-31 | `x` | 1st imaginary component |
| 12 | 4 | s32 | 2ˆ-31 | `y` | 2nd imaginary component |
| 16 | 4 | s32 | 2ˆ-31 | `z` | 3rd imaginary component |
| 20 | 4 | float | N/A | `w_accuracy` | Estimated standard deviation of w |
| 24 | 4 | float | N/A | `x_accuracy` | Estimated standard deviation of x |
| 28 | 4 | float | N/A | `y_accuracy` | Estimated standard deviation of y |
| 32 | 4 | float | N/A | `z_accuracy` | Estimated standard deviation of z |
| 36 | 1 | u8 | | `flags` | Status flags |
| | 37 | | | | Total Payload Length |

Table 8.4.3: MSG_ORIENT_QUAT 0x0220 message structure




Field 8.4.2: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Valid |

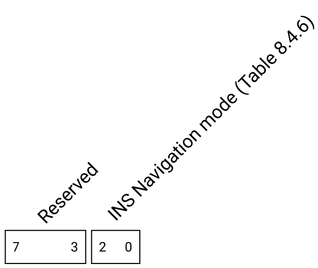
Table 8.4.4: INS Navigation mode values (`flags[0:2]`)

**MSG ORIENT EULER — 0x0221 — 545**

This message reports the yaw, pitch, and roll angles of the vehicle body frame. The rotations should applied intrinsically in the order yaw, pitch, and roll in order to rotate the from a frame aligned with the local-level NED frame to the vehicle body frame. This message will only be available in future INS versions of Swift Products and is not produced by Piksi Multi or Duro.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | s32 | microdegrees | `roll` | rotation about the forward axis of the vehicle |
| 8 | 4 | s32 | microdegrees | `pitch` | rotation about the rightward axis of the vehicle |
| 12 | 4 | s32 | microdegrees | `yaw` | rotation about the downward axis of the vehicle |
| 16 | 4 | float | degrees | `roll_accuracy` | Estimated standard deviation of roll |
| 20 | 4 | float | degrees | `pitch_accuracy` | Estimated standard deviation of pitch |
| 24 | 4 | float | degrees | `yaw_accuracy` | Estimated standard deviation of yaw |
| 28 | 1 | u8 | | `flags` | Status flags |
| | 29 | | | | Total Payload Length |

Table 8.4.5: MSG_ORIENT_EULER 0x0221 message structure




Field 8.4.3: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Valid |

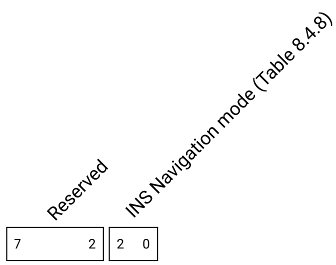
Table 8.4.6: INS Navigation mode values (`flags[0:2]`)

**MSG ANGULAR RATE — 0x0222 — 546**

This message reports the orientation rates in the vehicle body frame. The values represent the measurements a strapped down gyroscope would make and are not equivalent to the time derivative of the Euler angles. The orientation and origin of the user frame is specified via device settings. By convention, the vehicle x-axis is expected to be aligned with the forward direction, while the vehicle y-axis is expected to be aligned with the right direction, and the vehicle z-axis should be aligned with the down direction. This message will only be available in future INS versions of Swift Products and is not produced by Piksi Multi or Duro.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | GPS Time of Week |
| 4 | 4 | s32 | microdegrees, | `x` | angular rate about x axis |
| 8 | 4 | s32 | microdegrees, | `y` | angular rate about y axis |
| 12 | 4 | s32 | microdegrees, | `z` | angular rate about z axis |
| 16 | 1 | u8 | | `flags` | Status flags |
| | 17 | | | | Total Payload Length |

Table 8.4.7: MSG_ANGULAR_RATE 0x0222 message structure




Field 8.4.4: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Invalid |
| 1 | Valid |

Table 8.4.8: INS Navigation mode values (`flags[0:2]`)

## 8.5 Piksi

System health, configuration, and diagnostic messages specific to the Piksi L1 receiver, including a variety of legacy messages that may no longer be used.

**MSG ALMANAC — 0x0069 — 105**

This is a legacy message for sending and loading a satellite alamanac onto the Piksi's flash memory from the host.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| | 0 | | | | Total Payload Length |

Table 8.5.1: MSG_ALMANAC 0x0069 message structure

**MSG SET TIME — 0x0068 — 104**

This message sets up timing functionality using a coarse GPS time estimate sent by the host.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| | 0 | | | | Total Payload Length |

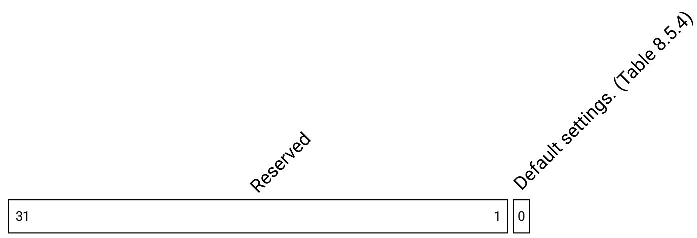
Table 8.5.2: MSG_SET_TIME 0x0068 message structure

**MSG RESET — 0x00B6 — 182**

This message from the host resets the Piksi back into the bootloader.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | `flags` | Reset flags |
| | 4 | | | | Total Payload Length |

Table 8.5.3: MSG_RESET 0x00B6 message structure




Field 8.5.1: Reset flags (`flags`)

| Value | Description |
|---|---|
| 0 | Preserve existing settings. |
| 1 | Resore default settings. |

Table 8.5.4: Default settings. values (`flags[0]`)

**MSG CW RESULTS — 0x00C0 — 192**

This is an unused legacy message for result reporting from the CW interference channel on the SwiftNAP. This message will be removed in a future release.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| | 0 | | | | Total Payload Length |

Table 8.5.5: MSG_CW_RESULTS 0x00C0 message structure

**MSG CW START — 0x00C1 — 193**

This is an unused legacy message from the host for starting the CW interference channel on the SwiftNAP. This message will be removed in a future release.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| | 0 | | | | Total Payload Length |

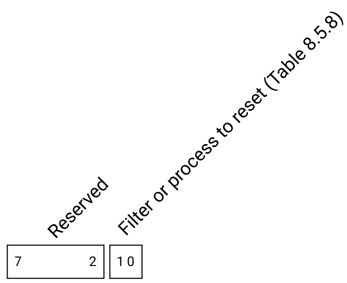
Table 8.5.6: MSG_CW_START 0x00C1 message structure

**MSG RESET FILTERS — 0x0022 — 34**

This message resets either the DGNSS Kalman filters or Integer Ambiguity Resolution (IAR) process.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `filter` | Filter flags |
| | 1 | | | | Total Payload Length |

Table 8.5.7: MSG_RESET_FILTERS 0x0022 message structure




Field 8.5.2: Filter flags (`filter`)

| Value | Description |
|---|---|
| 0 | DGNSS filter |
| 1 | IAR process |
| 2 | Inertial filter |

Table 8.5.8: Filter or process to reset values (`filter[0:1]`)

**MSG THREAD STATE — 0x0017 — 23**

The thread usage message from the device reports real-time operating system (RTOS) thread usage statistics for the named thread. The reported percentage values must be normalized.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 20 | string | | `name` | Thread name (NULL terminated) |
| 20 | 2 | u16 | | `cpu` | Percentage cpu use for this thread. Values range from 0 - 1000 and needs to be renormalized to 100 |
| 22 | 4 | u32 | bytes | `stack_free` | Free stack space for this thread |
| | 26 | | | | Total Payload Length |

Table 8.5.9: MSG_THREAD_STATE 0x0017 message structure

**MSG UART STATE — 0x001D — 29**

The UART message reports data latency and throughput of the UART channels providing SBP I/O. On the default Piksi configuration, UARTs A and B are used for telemetry radios, but can also be host access ports for embedded hosts, or other interfaces in future. The reported percentage values must be normalized. Observations latency and period can be used to assess the health of the differential corrections link. Latency provides the timeliness of received base observations while the period indicates their likelihood of transmission.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | float | kB/s | uart_a.tx_throughput | UART transmit throughput |
| 4 | 4 | float | kB/s | uart_a.rx_throughput | UART receive throughput |
| 8 | 2 | u16 | | uart_a.crc_error_count | UART CRC error count |
| 10 | 2 | u16 | | uart_a.io_error_count | UART IO error count |
| 12 | 1 | u8 | | uart_a.tx_buffer_level | UART transmit buffer percentage utilization (ranges from 0 to 255) |
| 13 | 1 | u8 | | uart_a.rx_buffer_level | UART receive buffer percentage utilization (ranges from 0 to 255) |
| 14 | 4 | float | kB/s | uart_b.tx_throughput | UART transmit throughput |
| 18 | 4 | float | kB/s | uart_b.rx_throughput | UART receive throughput |
| 22 | 2 | u16 | | uart_b.crc_error_count | UART CRC error count |
| 24 | 2 | u16 | | uart_b.io_error_count | UART IO error count |
| 26 | 1 | u8 | | uart_b.tx_buffer_level | UART transmit buffer percentage utilization (ranges from 0 to 255) |
| 27 | 1 | u8 | | uart_b.rx_buffer_level | UART receive buffer percentage utilization (ranges from 0 to 255) |
| 28 | 4 | float | kB/s | uart_ftdi.tx_throughput | UART transmit throughput |
| 32 | 4 | float | kB/s | uart_ftdi.rx_throughput | UART receive throughput |
| 36 | 2 | u16 | | uart_ftdi.crc_error_count | UART CRC error count |
| 38 | 2 | u16 | | uart_ftdi.io_error_count | UART IO error count |
| 40 | 1 | u8 | | uart_ftdi.tx_buffer_level | UART transmit buffer percentage utilization (ranges from 0 to 255) |
| 41 | 1 | u8 | | uart_ftdi.rx_buffer_level | UART receive buffer percentage utilization (ranges from 0 to 255) |
| 42 | 4 | s32 | ms | latency.avg | Average latency |
| 46 | 4 | s32 | ms | latency.lmin | Minimum latency |
| 50 | 4 | s32 | ms | latency.lmax | Maximum latency |
| 54 | 4 | s32 | ms | latency.current | Smoothed estimate of the current latency |
| 58 | 4 | s32 | ms | obs_period.avg | Average period |
| 62 | 4 | s32 | ms | obs_period.pmin | Minimum period |
| 66 | 4 | s32 | ms | obs_period.pmax | Maximum period |
| 70 | 4 | s32 | ms | obs_period.current | Smoothed estimate of the current period |
| | 74 | | | | Total Payload Length |

Table 8.5.10: MSG_UART_STATE 0x001D message structure

**MSG IAR STATE — 0x0019 — 25**

This message reports the state of the Integer Ambiguity Resolution (IAR) process, which resolves unknown integer ambiguities from double-differenced carrier-phase measurements from satellite observations.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | num_hyps | Number of integer ambiguity hypotheses remaining |
| | 4 | | | | Total Payload Length |

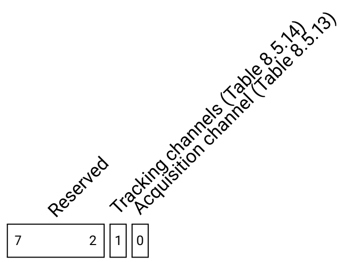
Table 8.5.11: MSG_IAR_STATE 0x0019 message structure

**MSG MASK SATELLITE — 0x002B — 43**

This message allows setting a mask to prevent a particular satellite from being used in various Piksi subsystems.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `mask` | Mask of systems that should ignore this satellite. |
| 1 | 1 | u8 | | `sid.sat` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 2 | 1 | u8 | | `sid.code` | Signal constellation, band and code |
| | 3 | | | | Total Payload Length |

Table 8.5.12: MSG_MASK_SATELLITE 0x002B message structure



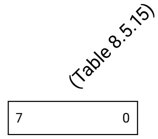

Field 8.5.3: Mask of systems that should ignore this satellite. (`mask`)

| Value | Description |
|---|---|
| 0 | Enabled |
| 1 | Skip this satellite on future acquisitions |

Table 8.5.13: Acquisition channel values (`mask[0]`)

| Value | Description |
|---|---|
| 0 | Enabled |
| 1 | Drop this PRN if currently tracking |

Table 8.5.14: Tracking channels values (`mask[1]`)




Field 8.5.4: Signal constellation, band and code (`sid.code`)

| Value | Description |
|---|---|
| 0 | GPS L1CA |
| 1 | GPS L2CM |
| 2 | SBAS L1CA |
| 3 | GLO L1CA |
| 4 | GLO L2CA |
| 5 | GPS L1P |
| 6 | GPS L2P |
| 12 | BDS2 B1 |
| 13 | BDS2 B2 |
| 14 | GAL E1B |
| 20 | GAL E7I |
| 31 | QZS L1CA |
| 36 | QZS L2CL |
| 39 | QZS L5Q |
| 47 | BDS3 B2a |

Table 8.5.15: values (`sid.code[0:7]`)

**MSG DEVICE MONITOR — 0x00B5 — 181**

This message contains temperature and voltage level measurements from the processor's monitoring system and the RF frontend die temperature if available.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 2 | s16 | V / 1000 | dev_vin | Device V_in |
| 2 | 2 | s16 | V / 1000 | cpu_vint | Processor V_int |
| 4 | 2 | s16 | V / 1000 | cpu_vaux | Processor V_aux |
| 6 | 2 | s16 | degrees C / 100 | cpu_temperature | Processor temperature |
| 8 | 2 | s16 | degrees C / 100 | fe_temperature | Frontend temperature (if available) |
| | 10 | | | | Total Payload Length |

Table 8.5.16: MSG_DEVICE_MONITOR 0x00B5 message structure

#### MSG COMMAND REQ — 0x00B8 — 184

Request the recipient to execute an command. Output will be sent in MSG_LOG messages, and the exit code will be returned with MSG_COMMAND_RESP.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | sequence | Sequence number |
| 4 | N | string | | command | Command line to execute |
| | N + 4 | | | | Total Payload Length |

Table 8.5.17: MSG_COMMAND_REQ 0x00B8 message structure

**MSG COMMAND RESP — 0x00B9 — 185**

The response to MSG_COMMAND_REQ with the return code of the command. A return code of zero indicates success.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | `sequence` | Sequence number |
| 4 | 4 | s32 | | `code` | Exit code |
| | 8 | | | | Total Payload Length |

Table 8.5.18: MSG_COMMAND_RESP 0x00B9 message structure

#### MSG COMMAND OUTPUT — 0x00BC — 188

Returns the standard output and standard error of the command requested by MSG_COMMAND_REQ. The sequence number can be used to filter for filtering the correct command.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | sequence | Sequence number |
| 4 | N | string | | line | Line of standard output or standard error |
| | N + 4 | | | | Total Payload Length |

Table 8.5.19: MSG_COMMAND_OUTPUT 0x00BC message structure

#### MSG NETWORK STATE REQ — 0x00BA — 186

Request state of Piksi network interfaces. Output will be sent in MSG_NETWORK_STATE_RESP messages.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| | 0 | | | | Total Payload Length |

Table 8.5.20: MSG_NETWORK_STATE_REQ 0x00BA message structure

#### MSG NETWORK STATE RESP — 0x00BB — 187

The state of a network interface on the Piksi. Data is made to reflect output of ifaddrs struct returned by getifaddrs in c.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u8[4] | | `ipv4_address` | IPv4 address (all zero when unavailable) |
| 4 | 1 | u8 | | `ipv4_mask_size` | IPv4 netmask CIDR notation |
| 5 | 16 | u8[16] | | `ipv6_address` | IPv6 address (all zero when unavailable) |
| 21 | 1 | u8 | | `ipv6_mask_size` | IPv6 netmask CIDR notation |
| 22 | 4 | u32 | | `rx_bytes` | Number of Rx bytes |
| 26 | 4 | u32 | | `tx_bytes` | Number of Tx bytes |
| 30 | 16 | string | | `interface_name` | Interface Name |
| 46 | 4 | u32 | | `flags` | Interface flags from SIOCGIFFLAGS |
| | 50 | | | | Total Payload Length |

Table 8.5.21: MSG_NETWORK_STATE_RESP 0x00BB message structure

#### MSG NETWORK BANDWIDTH USAGE — 0x00BD — 189

The bandwidth usage, a list of usage by interface.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| $40N + 0$ | 8 | u64 | ms | interfaces[N].duration | Duration over which the measurement was collected |
| $40N + 8$ | 8 | u64 | | interfaces[N].total_bytes | Number of bytes handled in total within period |
| $40N + 16$ | 4 | u32 | | interfaces[N].rx_bytes | Number of bytes transmitted within period |
| $40N + 20$ | 4 | u32 | | interfaces[N].tx_bytes | Number of bytes received within period |
| $40N + 24$ | 16 | string | | interfaces[N].interface_name | Interface Name |
| | 40N | | | | Total Payload Length |

Table 8.5.22: MSG_NETWORK_BANDWIDTH_USAGE 0x00BD message structure

#### MSG CELL MODEM STATUS — 0x00BE — 190

If a cell modem is present on a piksi device, this message will be send periodically to update the host on the status of the modem and its various parameters.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | s8 | dBm | signal_strength | Received cell signal strength in dBm, zero translates to unknown |
| 1 | 4 | float | | signal_error_rate | BER as reported by the modem, zero translates to unknown |
| 5 | N | u8[N] | | reserved | Unspecified data TBD for this schema |
| | $N + 5$ | | | | Total Payload Length |

Table 8.5.23: MSG_CELL_MODEM_STATUS 0x00BE message structure

**MSG SPECAN — 0x0051 — 81**

Spectrum analyzer packet.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 2 | u16 | | channel_tag | Channel ID |
| 2 | 4 | u32 | ms | t.tow | Milliseconds since start of GPS week |
| 6 | 4 | s32 | ns | t.ns_residual | Nanosecond residual of millisecond-rounded TOW (ranges from -500000 to 500000) |
| 10 | 2 | u16 | week | t.wn | GPS week number |
| 12 | 4 | float | MHz | freq_ref | Reference frequency of this packet |
| 16 | 4 | float | MHz | freq_step | Frequency step of points in this packet |
| 20 | 4 | float | dB | amplitude_ref | Reference amplitude of this packet |
| 24 | 4 | float | dB | amplitude_unit | Amplitude unit value of points in this packet |
| 28 | N | u8[N] | | amplitude_value | Amplitude values (in the above units) of points in this packet |
| | $N + 28$ | | | | Total Payload Length |

Table 8.5.24: MSG_SPECAN 0x0051 message structure

#### MSG FRONT END GAIN — 0x00BF — 191

This message describes the gain of each channel in the receiver frontend. Each gain is encoded as a non-dimensional percentage relative to the maximum range possible for the gain stage of the frontend. By convention, each gain array has 8 entries and the index of the array corresponding to the index of the rf channel in the frontend. A gain of 127 percent encodes that rf channel is not present in the hardware. A negative value implies an error for the particular gain stage as reported by the frontend.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 8 | s8[8] | percent | rf_gain | RF gain for each frontend channel |
| 8 | 8 | s8[8] | percent | if_gain | Intermediate frequency gain for each frontend channel |
| | 16 | | | | Total Payload Length |

Table 8.5.25: MSG_FRONT_END_GAIN 0x00BF message structure

## 8.6 Profiling

Standardized profiling messages from Swift Navigation devices.

#### MSG MEASUREMENT POINT — 0xCF00 — 52992

Tracks execution time of certain code paths in specially built products. This message should only be expected and processed on the direction of Swift's engineering teams.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | | `total_time` | Total time spent in measurement point (microseconds) |
| 4 | 2 | u16 | | `num_executions` | Number of times measurement point has executed |
| 6 | 4 | u32 | | `min` | Minimum execution time (microseconds) |
| 10 | 4 | u32 | | `max` | Maximum execution time (microseconds) |
| 14 | 8 | u64 | | `return_addr` | Return address |
| 22 | 8 | u64 | | `id` | Unique ID |
| 30 | 8 | u64 | | `slice_time` | CPU slice time (milliseconds) |
| 38 | 2 | u16 | | `line` | Line number |
| 40 | N | string | | `func` | Function name |
| | N + 40 | | | | Total Payload Length |

Table 8.6.1: MSG_MEASUREMENT_POINT 0xCF00 message structure

#### MSG PROFILING SYSTEM INFO — 0xCF01 — 52993

Contains basic information about system resource usage. System is defined in terms of the source of this message and may vary from sender to sender. Refer to product documentation to understand the exact scope and meaning of this message.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 8 | u64 | | total_cpu_time | Total cpu time in microseconds consumed by this system |
| 8 | 8 | u64 | | age | Age of the producing system in microseconds |
| 16 | 1 | u8 | | n_threads | Number of threads being tracked by this system |
| 17 | 4 | u32 | | heap_usage | Number of bytes allocated on the heap |
| | 21 | | | | Total Payload Length |

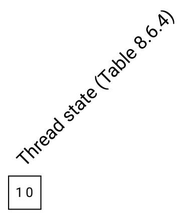
Table 8.6.2: MSG_PROFILING_SYSTEM_INFO 0xCF01 message structure

#### MSG PROFILING THREAD INFO — 0xCF02 — 52994

Contains profiling information related to a single thread being tracked by the producing system. Refer to product documentation to understand the exact scope and meaning of this message.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 8 | u64 | | total_cpu_time | Total cpu time in microseconds consumed by this thread |
| 8 | 8 | u64 | | age | Age of the thread in microseconds |
| 16 | 1 | u8 | | state | Thread state |
| 17 | 4 | u32 | | stack_size | Stack size in bytes |
| 21 | 4 | u32 | | stack_usage | Stack high water usage in bytes |
| 25 | N | string | | name | Thread name |
| | N + 25 | | | | Total Payload Length |

Table 8.6.3: MSG_PROFILING_THREAD_INFO 0xCF02 message structure




Field 8.6.1: Thread state (state)

| Value | Description |
|---|---|
| 0 | External |
| 1 | Running |
| 2 | Stopped |
| 3 | Reserved |

Table 8.6.4: Thread state values (state[0:1])

**MSG PROFILING RESOURCE COUNTER — 0xCF03 — 52995**

Information about resource buckets. Refer to product documentation to understand the meaning and values in this message.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | seq_no | Message number in complete sequence |
| 1 | 1 | u8 | | seq_len | Length of message sequence |
| $41N + 2$ | 21 | string | | buckets[N].name | Bucket name |
| $41N + 23$ | 1 | u8 | | buckets[N].thread | Number of threads |
| $41N + 24$ | 1 | u8 | | buckets[N].mutex | Number of mutexes |
| $41N + 25$ | 1 | u8 | | buckets[N].cv | Number of condition variables |
| $41N + 26$ | 1 | u8 | | buckets[N].io | Number of IO handles |
| $41N + 27$ | 4 | u32 | | buckets[N].heap_bytes_alloc | Number of bytes allocated on the heap |
| $41N + 31$ | 4 | u32 | | buckets[N].heap_bytes_free | Number of bytes freed on the heap |
| $41N + 35$ | 4 | u32 | | buckets[N].io_write | Number of bytes written to IO handles |
| $41N + 39$ | 4 | u32 | | buckets[N].io_read | Number of bytes read from IO handles |
| | $41N + 2$ | | | | Total Payload Length |

Table 8.6.5: MSG_PROFILING_RESOURCE_COUNTER 0xCF03 message structure

## 8.7 Sbas

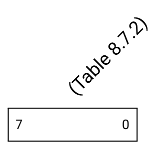
SBAS data

**MSG SBAS RAW — 0x7777 — 30583**

This message is sent once per second per SBAS satellite. ME checks the parity of the data block and sends only blocks that pass the check.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `sid.sat` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 1 | 1 | u8 | | `sid.code` | Signal constellation, band and code |
| 2 | 4 | u32 | ms | `tow` | GPS time-of-week at the start of the data block. |
| 6 | 1 | u8 | | `message_type` | SBAS message type (0-63) |
| 7 | 27 | u8[27] | | `data` | Raw SBAS data field of 212 bits (last byte padded with zeros). |
| | 34 | | | | Total Payload Length |

Table 8.7.1: MSG_SBAS_RAW 0x7777 message structure




Field 8.7.1: Signal constellation, band and code (`sid.code`)

| Value | Description |
|---|---|
| 0 | GPS L1CA |
| 1 | GPS L2CM |
| 2 | SBAS L1CA |
| 3 | GLO L1CA |
| 4 | GLO L2CA |
| 5 | GPS L1P |
| 6 | GPS L2P |
| 12 | BDS2 B1 |
| 13 | BDS2 B2 |
| 14 | GAL E1B |
| 20 | GAL E7I |
| 31 | QZS L1CA |
| 36 | QZS L2CL |
| 39 | QZS L5Q |
| 47 | BDS3 B2a |

Table 8.7.2: values (`sid.code[0:7]`)

## 8.8 Signing

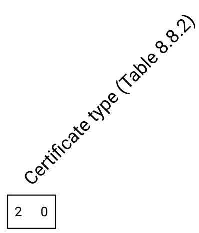
Messages relating to signatures

### MSG ECDSA CERTIFICATE — 0x0C04 — 3076

A DER encoded x.509 ECDSA-256 certificate (using curve secp256r1).

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `n_msg` | Total number messages that make up the certificate. The first nibble (mask 0xF0 or left shifted by 4 bits) is the size of the sequence (n), second nibble (mask 0x0F) is the zero-indexed counter (ith packet of n). |
| 1 | 4 | u8[4] | | `certificate_id` | The last 4 bytes of the certificate's SHA-1 fingerprint |
| 5 | 1 | u8 | | `flags` | |
| 6 | N | u8[N] | | `certificate_bytes` | DER encoded x.509 ECDSA certificate bytes |
| | $N+6$ | | | | Total Payload Length |

Table 8.8.1: MSG_ECDSA_CERTIFICATE 0x0C04 message structure




Field 8.8.1: (`flags`)

| Value | Description |
|---|---|
| 0 | Corrections certificate |
| 1 | Root certificate |
| 2 | Intermediate certificate |

Table 8.8.2: Certificate type values (`flags[0:2]`)

### MSG CERTIFICATE CHAIN — 0x0C09 — 3081

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 20 | u8[20] | | `root_certificate` | SHA-1 fingerprint of the root certificate |
| 20 | 20 | u8[20] | | `intermediate_certificate` | SHA-1 fingerprint of the intermediate certificate |
| 40 | 20 | u8[20] | | `corrections_certificate` | SHA-1 fingerprint of the corrections certificate |
| 60 | 2 | u16 | year | `expiration.year` | Year |
| 62 | 1 | u8 | months | `expiration.month` | Month (range 1 .. 12) |
| 63 | 1 | u8 | day | `expiration.day` | days in the month (range 1-31) |
| 64 | 1 | u8 | hours | `expiration.hours` | hours of day (range 0-23) |
| 65 | 1 | u8 | minutes | `expiration.minutes` | minutes of hour (range 0-59) |
| 66 | 1 | u8 | seconds | `expiration.seconds` | seconds of minute (range 0-60) rounded down |
| 67 | 4 | u32 | nanoseconds | `expiration.ns` | nanoseconds of second (range 0-999999999) |
| 71 | 1 | u8 | | `signature.len` | Number of bytes to use of the signature field. The DER encoded signature has a maximum size of 72 bytes but can vary between 70 and 72 bytes in length. |
| 72 | 72 | u8[72] | | `signature.data` | DER encoded ECDSA signature for the messages using SHA-256 as the digest algorithm. |
| | 144 | | | | Total Payload Length |

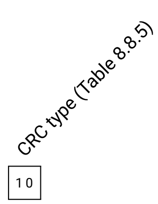
Table 8.8.3: MSG_CERTIFICATE_CHAIN 0x0C09 message structure

#### MSG AES CMAC SIGNATURE — 0x0C10 — 3088

Digital signature using AES-CMAC 128 algorithm used for data integrity.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | stream_counter | Signature message counter. Zero indexed and incremented with each signature message. The counter will not increment if this message was in response to an on demand request. The counter will roll over after 256 messages. Upon connection, the value of the counter may not initially be zero. |
| 1 | 1 | u8 | | on_demand_counter | On demand message counter. Zero indexed and incremented with each signature message sent in response to an on demand message. The counter will roll over after 256 messages. Upon connection, the value of the counter may not initially be zero. |
| 2 | 4 | u8[4] | | certificate_id | The last 4 bytes of the certificate's SHA-1 fingerprint |
| 6 | 16 | u8[16] | | signature | Signature (CMAC tag value) |
| 22 | 1 | u8 | | flags | Describes the format of the 'signed messages' field below. |
| 23 | N | u8[N] | | signed_messages | CRCs of the messages covered by this signature. For Skylark, which delivers SBP messages wrapped in Swift's proprietary RTCM message, these are the 24-bit CRCs from the RTCM message framing. For SBP only streams, this will be 16-bit CRCs from the SBP framing. See the 'flags' field to determine the type of CRCs covered. |
| | $N + 23$ | | | | Total Payload Length |

Table 8.8.4: MSG_AES_CMAC_SIGNATURE 0x0C10 message structure




Field 8.8.2: Describes the format of the 'signed messages' field below. (flags)

| Value | Description |
|---|---|
| 0 | 24-bit CRCs from RTCM framing |
| 1 | 16-bit CRCs from SBP framing |

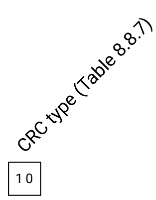
Table 8.8.5: CRC type values (flags[0:1])

#### MSG ECDSA SIGNATURE — 0x0C08 — 3080

An ECDSA-256 signature using SHA-256 as the message digest algorithm.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `flags` | Describes the format of the ‘signed_messages‘ field below. |
| 1 | 1 | u8 | | `stream_counter` | Signature message counter. Zero indexed and incremented with each signature message. The counter will not increment if this message was in response to an on demand request. The counter will roll over after 256 messages. Upon connection, the value of the counter may not initially be zero. |
| 2 | 1 | u8 | | `on_demand_counter` | On demand message counter. Zero indexed and incremented with each signature message sent in response to an on demand message. The counter will roll over after 256 messages. Upon connection, the value of the counter may not initially be zero. |
| 3 | 4 | u8[4] | | `certificate_id` | The last 4 bytes of the certificate’s SHA-1 fingerprint |
| 7 | 1 | u8 | | `signature.len` | Number of bytes to use of the signature field. The DER encoded signature has a maximum size of 72 bytes but can vary between 70 and 72 bytes in length. |
| 8 | 72 | u8[72] | | `signature.data` | DER encoded ECDSA signature for the messages using SHA-256 as the digest algorithm. |
| 80 | N | u8[N] | | `signed_messages` | CRCs of the messages covered by this signature. For Skylark, which delivers SBP messages wrapped in Swift’s proprietary RTCM message, these are the 24-bit CRCs from the RTCM message framing. For SBP only streams, this will be 16-bit CRCs from the SBP framing. See the ‘flags‘ field to determine the type of CRCs covered. |
| | $N + 80$ | | | | Total Payload Length |

Table 8.8.6: MSG_ECDSA_SIGNATURE 0x0C08 message structure




Field 8.8.3: Describes the format of the ‘signed_messages‘ field below. (`flags`)

| Value | Description |
|---|---|
| 0 | 24-bit CRCs from RTCM framing |
| 1 | 16-bit CRCs from SBP framing |

Table 8.8.7: CRC type values (`flags[0:1]`)

## 8.9 Ssr

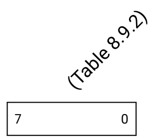
Precise State Space Representation (SSR) corrections format

#### MSG SSR ORBIT CLOCK — 0x05DD — 1501

The precise orbit and clock correction message is to be applied as a delta correction to broadcast ephemeris and is an equivalent to the 1060 /1066 RTCM message types.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | time.tow | Seconds since start of GPS week |
| 4 | 2 | u16 | week | time.wn | GPS week number |
| 6 | 1 | u8 | | sid.sat | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 7 | 1 | u8 | | sid.code | Signal constellation, band and code |
| 8 | 1 | u8 | | update_interval | Update interval between consecutive corrections. Encoded following RTCM DF391 specification. |
| 9 | 1 | u8 | | iod_ssr | IOD of the SSR correction. A change of Issue Of Data SSR is used to indicate a change in the SSR generating configuration |
| 10 | 4 | u32 | | iod | Issue of broadcast ephemeris data or IOD-CRC (Beidou) |
| 14 | 4 | s32 | 0.1 mm | radial | Orbit radial delta correction |
| 18 | 4 | s32 | 0.4 mm | along | Orbit along delta correction |
| 22 | 4 | s32 | 0.4 mm | cross | Orbit along delta correction |
| 26 | 4 | s32 | 0.001 mm/s | dot_radial | Velocity of orbit radial delta correction |
| 30 | 4 | s32 | 0.004 mm/s | dot_along | Velocity of orbit along delta correction |
| 34 | 4 | s32 | 0.004 mm/s | dot_cross | Velocity of orbit cross delta correction |
| 38 | 4 | s32 | 0.1 mm | c0 | C0 polynomial coefficient for correction of broadcast satellite clock |
| 42 | 4 | s32 | 0.001 mm/s | c1 | C1 polynomial coefficient for correction of broadcast satellite clock |
| 46 | 4 | s32 | 0.00002 mm/s^-2 | c2 | C2 polynomial coefficient for correction of broadcast satellite clock |
| | 50 | | | | Total Payload Length |

Table 8.9.1: MSG_SSR_ORBIT_CLOCK 0x05DD message structure




Field 8.9.1: Signal constellation, band and code (`sid.code`)

| Value | Description |
|---|---|
| 0 | GPS L1CA |
| 1 | GPS L2CM |
| 2 | SBAS L1CA |
| 3 | GLO L1CA |
| 4 | GLO L2CA |
| 5 | GPS L1P |
| 6 | GPS L2P |
| 12 | BDS2 B1 |
| 13 | BDS2 B2 |
| 14 | GAL E1B |
| 20 | GAL E7I |
| 31 | QZS L1CA |
| 36 | QZS L2CL |
| 39 | QZS L5Q |
| 47 | BDS3 B2a |

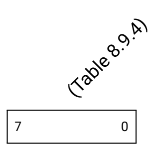
Table 8.9.2: values (`sid.code[0:7]`)

#### MSG SSR CODE BIASES — 0x05E1 — 1505

The precise code biases message is to be added to the pseudorange of the corresponding signal to get corrected pseudorange. It is an equivalent to the 1059 / 1065 RTCM message types.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | `time.tow` | Seconds since start of GPS week |
| 4 | 2 | u16 | week | `time.wn` | GPS week number |
| 6 | 1 | u8 | | `sid.sat` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 7 | 1 | u8 | | `sid.code` | Signal constellation, band and code |
| 8 | 1 | u8 | | `update_interval` | Update interval between consecutive corrections. Encoded following RTCM DF391 specification. |
| 9 | 1 | u8 | | `iod_ssr` | IOD of the SSR correction. A change of Issue Of Data SSR is used to indicate a change in the SSR generating configuration |
| $3N + 10$ | 1 | u8 | | `biases[N].code` | Signal encoded following RTCM specifications (DF380, DF381, DF382 and DF467). |
| $3N + 11$ | 2 | s16 | 0.01 m | `biases[N].value` | Code bias value |
| | $3N + 10$ | | | | Total Payload Length |

Table 8.9.3: MSG_SSR_CODE_BIASES 0x05E1 message structure




Field 8.9.2: Signal constellation, band and code (`sid.code`)

| Value | Description |
|---|---|
| 0 | GPS L1CA |
| 1 | GPS L2CM |
| 2 | SBAS L1CA |
| 3 | GLO L1CA |
| 4 | GLO L2CA |
| 5 | GPS L1P |
| 6 | GPS L2P |
| 12 | BDS2 B1 |
| 13 | BDS2 B2 |
| 14 | GAL E1B |
| 20 | GAL E7I |
| 31 | QZS L1CA |
| 36 | QZS L2CL |
| 39 | QZS L5Q |
| 47 | BDS3 B2a |

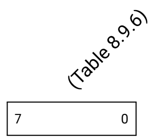
Table 8.9.4: values (`sid.code[0:7]`)

#### MSG SSR PHASE BIASES — 0x05E6 — 1510

The precise phase biases message contains the biases to be added to the carrier phase of the corresponding signal to get corrected carrier phase measurement, as well as the satellite yaw angle to be applied to compute the phase wind-up correction. It is typically an equivalent to the 1265 RTCM message types.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | `time.tow` | Seconds since start of GPS week |
| 4 | 2 | u16 | week | `time.wn` | GPS week number |
| 6 | 1 | u8 | | `sid.sat` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 7 | 1 | u8 | | `sid.code` | Signal constellation, band and code |
| 8 | 1 | u8 | | `update_interval` | Update interval between consecutive corrections. Encoded following RTCM DF391 specification. |
| 9 | 1 | u8 | | `iod_ssr` | IOD of the SSR correction. A change of Issue Of Data SSR is used to indicate a change in the SSR generating configuration |
| 10 | 1 | u8 | | `dispersive_bias` | Indicator for the dispersive phase biases property. |
| 11 | 1 | u8 | | `mw_consistency` | Consistency indicator for Melbourne-Wubbena linear combinations |
| 12 | 2 | u16 | 1 / 256 semi-circle | `yaw` | Satellite yaw angle |
| 14 | 1 | s8 | 1 / 8192 semi-circle / s | `yaw_rate` | Satellite yaw angle rate |
| $8N + 15$ | 1 | u8 | | `biases[N].code` | Signal encoded following RTCM specifications (DF380, DF381, DF382 and DF467) |
| $8N + 16$ | 1 | u8 | | `biases[N].integer_indicator` | Indicator for integer property |
| $8N + 17$ | 1 | u8 | | `biases[N].widelane_integer_indicator` | Indicator for two groups of Wide-Lane(s) integer property |
| $8N + 18$ | 1 | u8 | | `biases[N].discontinuity_counter` | Signal phase discontinuity counter. Increased for every discontinuity in phase. |
| $8N + 19$ | 4 | s32 | 0.1 mm | `biases[N].bias` | Phase bias for specified signal |
| | $8N + 15$ | | | | Total Payload Length |

Table 8.9.5: MSG_SSR_PHASE_BIASES 0x05E6 message structure




Field 8.9.3: Signal constellation, band and code (`sid.code`)

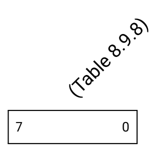
| Value | Description |
|---|---|
| 0 | GPS L1CA |
| 1 | GPS L2CM |
| 2 | SBAS L1CA |
| 3 | GLO L1CA |
| 4 | GLO L2CA |
| 5 | GPS L1P |
| 6 | GPS L2P |
| 12 | BDS2 B1 |
| 13 | BDS2 B2 |
| 14 | GAL E1B |
| 20 | GAL E7I |
| 31 | QZS L1CA |
| 36 | QZS L2CL |
| 39 | QZS L5Q |
| 47 | BDS3 B2a |

Table 8.9.6: values (`sid.code[0:7]`)

**MSG SSR STEC CORRECTION — 0x05FD — 1533**

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | `header.time.tow` | Seconds since start of GPS week |
| 4 | 2 | u16 | week | `header.time.wn` | GPS week number |
| 6 | 1 | u8 | | `header.num_msgs` | Number of messages in the dataset |
| 7 | 1 | u8 | | `header.seq_num` | Position of this message in the dataset |
| 8 | 1 | u8 | | `header.update_interval` | Update interval between consecutive bounds. Similar to RTCM DF391. |
| 9 | 1 | u8 | | `header.sol_id` | SSR Solution ID. |
| 10 | 1 | u8 | | `ssr_iod_atmo` | IOD of the SSR atmospheric correction |
| 11 | 2 | u16 | | `tile_set_id` | Tile set ID |
| 13 | 2 | u16 | | `tile_id` | Tile ID |
| 15 | 1 | u8 | | `n_sats` | Number of satellites. |
| $11N + 16$ | 1 | u8 | | `stec_sat_list[N].sv_id.satId` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| $11N + 17$ | 1 | u8 | | `stec_sat_list[N].sv_id.constellation` | Constellation ID to which the SV belongs |
| $11N + 18$ | 1 | u8 | | `stec_sat_list[N].stec_quality_indicator` | Quality of the STEC data. Encoded following RTCM DF389 specification but in units of TECU instead of m. |
| $11N + 19$ | 8 | s16[4] | | `stec_sat_list[N].stec_coeff` | Coefficients of the STEC polynomial in the order of C00, C01, C10, C11. C00 = 0.05 TECU, C01/C10 = 0.02 TECU/deg, C11 0.02 TECU/deg^2 |
| | $11N + 16$ | | | | Total Payload Length |

Table 8.9.7: MSG_SSR_STEC_CORRECTION 0x05FD message structure




Field 8.9.4: Constellation ID to which the SV belongs (`stec_sat_list[N].sv_id.constellation`)

| Value | Description |
|---|---|
| 0 | GPS |
| 3 | BDS |
| 4 | QZS |
| 5 | GAL |

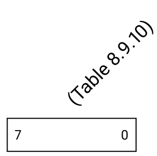
Table 8.9.8: values (`stec_sat_list[N].sv_id.constellation[0:7]`)

#### MSG SSR GRIDDED CORRECTION — 0x05FC — 1532

STEC residuals are per space vehicle, troposphere is not.
It is typically equivalent to the QZSS CLAS Sub Type 9 messages.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 2 | u16 | | header.tile_set_id | Unique identifier of the tile set this tile belongs to. |
| 2 | 2 | u16 | | header.tile_id | Unique identifier of this tile in the tile set. |
| 4 | 4 | u32 | s | header.time.tow | Seconds since start of GPS week |
| 8 | 2 | u16 | week | header.time.wn | GPS week number |
| 10 | 2 | u16 | | header.num_msgs | Number of messages in the dataset |
| 12 | 2 | u16 | | header.seq_num | Position of this message in the dataset |
| 14 | 1 | u8 | | header.update_interval | Update interval between consecutive corrections. Encoded following RTCM DF391 specification. |
| 15 | 1 | u8 | | header.iod_atmo | IOD of the SSR atmospheric correction |
| 16 | 1 | u8 | | header.tropo_quality_indicator | Quality of the troposphere data. Encoded following RTCM DF389 specification in units of m. |
| 17 | 2 | u16 | | index | Index of the grid point. |
| 19 | 2 | s16 | 4 mm | tropo_delay_correction.hydro | Hydrostatic vertical delay. Add 2.3 m to get actual value. |
| 21 | 1 | s8 | 4 mm | tropo_delay_correction.wet | Wet vertical delay. Add 0.252 m to get actual value. |
| 22 | 1 | u8 | mm | tropo_delay_correction.stddev | Standard deviation encoded using a similar method as RTCM DF389. The upper 3 bit are the class, the lower 5 bits are the value. Standard deviation [mm] = (3ˆclass * (1 + value/16) - 1) |
| $5N + 23$ | 1 | u8 | | stec_residuals[N].sv_id.satId | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| $5N + 24$ | 1 | u8 | | stec_residuals[N].sv_id.constellation | Constellation ID to which the SV belongs |
| $5N + 25$ | 2 | s16 | 0.04 TECU | stec_residuals[N].residual | STEC residual |
| $5N + 27$ | 1 | u8 | TECU | stec_residuals[N].stddev | Standard deviation encoded using a similar method as RTCM DF389. The upper 3 bit are the class, the lower 5 bits are the value. Standard deviation [TECU] = (3ˆclass * (1 + value/16) - 1) * 0.1 |
| | $5N + 23$ | | | | Total Payload Length |

Table 8.9.9: MSG_SSR_GRIDDED_CORRECTION 0x05FC message structure



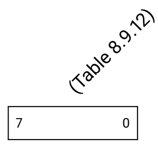

Field 8.9.5: Constellation ID to which the SV belongs (stec_residuals[N].sv_id.constellation)

| Value | Description |
|---|---|
| 0 | GPS |
| 3 | BDS |
| 4 | QZS |
| 5 | GAL |

Table 8.9.10: values (stec_residuals[N].sv_id.constellation[0:7])

**MSG SSR GRIDDED CORRECTION BOUNDS — 0x05FE — 1534**

Note 1: Range: 0-17.5 m. i<= 200, mean = 0.01i; 200<i<=230, mean=2+0.1(i-200); i>230, mean=5+0.5(i-230).




Field 8.9.6: Constellation ID to which the SV belongs (`stec_sat_list[N].stec_residual.sv_id.constellation`)

| Value | Description |
|---|---|
| 0 | GPS |
| 3 | BDS |
| 4 | QZS |
| 5 | GAL |

Table 8.9.12: values (`stec_sat_list[N].stec_residual.sv_id.constella`

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | header.time.tow | Seconds since start of GPS week |
| 4 | 2 | u16 | week | header.time.wn | GPS week number |
| 6 | 1 | u8 | | header.num_msgs | Number of messages in the dataset |
| 7 | 1 | u8 | | header.seq_num | Position of this message in the dataset |
| 8 | 1 | u8 | | header.update_interval | Update interval between consecutive bounds. Similar to RTCM DF391. |
| 9 | 1 | u8 | | header.sol_id | SSR Solution ID. |
| 10 | 1 | u8 | | ssr_iod_atmo | IOD of the correction. |
| 11 | 2 | u16 | | tile_set_id | Set this tile belongs to. |
| 13 | 2 | u16 | | tile_id | Unique identifier of this tile in the tile set. |
| 15 | 1 | u8 | | tropo_qi | Tropo Quality Indicator. Similar to RTCM DF389. |
| 16 | 2 | u16 | | grid_point_id | Index of the Grid Point. |
| 18 | 2 | s16 | 4 mm | tropo_delay_correction.hydro | Hydrostatic vertical delay. Add 2.3 m to get actual value. |
| 20 | 1 | s8 | 4 mm | tropo_delay_correction.wet | Wet vertical delay. Add 0.252 m to get actual value. |
| 21 | 1 | u8 | mm | tropo_delay_correction.stddev | Standard deviation encoded using a similar method as RTCM DF389. The upper 3 bit are the class, the lower 5 bits are the value. Standard deviation [mm] = (3ˆclass * (1 + value/16) - 1) |
| 22 | 1 | u8 | 0.005 m | tropo_v_hydro_bound_mu | Vertical Hydrostatic Error Bound Mean. |
| 23 | 1 | u8 | 0.005 m | tropo_v_hydro_bound_sig | Vertical Hydrostatic Error Bound StDev. |
| 24 | 1 | u8 | 0.005 m | tropo_v_wet_bound_mu | Vertical Wet Error Bound Mean. |
| 25 | 1 | u8 | 0.005 m | tropo_v_wet_bound_sig | Vertical Wet Error Bound StDev. |
| 26 | 1 | u8 | | n_sats | Number of satellites. |
| 9N + 27 | 1 | u8 | | stec_sat_list[N].stec_residual.sv_id.satId | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 9N + 28 | 1 | u8 | | stec_sat_list[N].stec_residual.sv_id.constellation | Constellation ID to which the SV belongs |
| 9N + 29 | 2 | s16 | 0.04 TECU | stec_sat_list[N].stec_residual.residual | STEC residual |
| 9N + 31 | 1 | u8 | TECU | stec_sat_list[N].stec_residual.stddev | Standard deviation encoded using a similar method as RTCM DF389. The upper 3 bit are the class, the lower 5 bits are the value. Standard deviation [TECU] = (3ˆclass * (1 + value/16) - 1) * 0.1 |
| 9N + 32 | 1 | u8 | m | stec_sat_list[N].stec_bound_mu | Error Bound Mean. See Note 1. |
| 9N + 33 | 1 | u8 | m | stec_sat_list[N].stec_bound_sig | Error Bound StDev. See Note 1. |
| 9N + 34 | 1 | u8 | 0.00005 m/s | stec_sat_list[N].stec_bound_mu_dot | Error Bound Mean First derivative. |
| 9N + 35 | 1 | u8 | 0.00005 m/s | stec_sat_list[N].stec_bound_sig_dot | Error Bound StDev First derivative. |
| | 9N + 27 | | | | Total Payload Length |

Table 8.9.11: MSG_SSR_GRIDDED_CORRECTION_BOUNDS 0x05FE message structure

**MSG SSR TILE DEFINITION — 0x05F8 — 1528**

Provides the correction point coordinates for the atmospheric correction values in the MSG_SSR_STEC_CORRECTION and MSG_SSR_GRIDDED_CORRECTION messages.
Based on ETSI TS 137 355 V16.1.0 (LTE Positioning Protocol) information element GNSS-SSR-CorrectionPoints. SBP only supports gridded arrays of correction points, not lists of points.

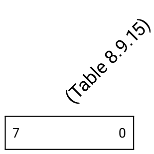
| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | `time.tow` | Seconds since start of GPS week |
| 4 | 2 | u16 | week | `time.wn` | GPS week number |
| 6 | 1 | u8 | | `update_interval` | Update interval between consecutive corrections. Encoded following RTCM DF391 specification. |
| 7 | 1 | u8 | | `sol_id` | SSR Solution ID. Similar to RTCM DF415. |
| 8 | 1 | u8 | | `iod_atmo` | IOD of the SSR atmospheric correction. |
| 9 | 2 | u16 | | `tile_set_id` | Unique identifier of the tile set this tile belongs to. |
| 11 | 2 | u16 | | `tile_id` | Unique identifier of this tile in the tile set. See GNSS-SSR-ArrayOfCorrectionPoints field correctionPointSetID. |
| 13 | 2 | s16 | encoded degrees | `corner_nw_lat` | North-West corner correction point latitude.<br>The relation between the latitude X in the range [-90, 90] and the coded number N is: N = floor((X / 90) * 2^14)<br>See GNSS-SSR-ArrayOfCorrectionPoints field referencePointLatitude. |
| 15 | 2 | s16 | encoded degrees | `corner_nw_lon` | North-West corner correction point longitude.<br>The relation between the longitude X in the range [-180, 180] and the coded number N is: N = floor((X / 180) * 2^15)<br>See GNSS-SSR-ArrayOfCorrectionPoints field referencePointLongitude. |
| 17 | 2 | u16 | 0.01 degrees | `spacing_lat` | Spacing of the correction points in the latitude direction.<br>See GNSS-SSR-ArrayOfCorrectionPoints field stepOfLatitude. |
| 19 | 2 | u16 | 0.01 degrees | `spacing_lon` | Spacing of the correction points in the longitude direction.<br>See GNSS-SSR-ArrayOfCorrectionPoints field stepOfLongitude. |
| 21 | 2 | u16 | | `rows` | Number of steps in the latitude direction.<br>See GNSS-SSR-ArrayOfCorrectionPoints field numberOfStepsLatitude. |
| 23 | 2 | u16 | | `cols` | Number of steps in the longitude direction.<br>See GNSS-SSR-ArrayOfCorrectionPoints field numberOfStepsLongitude. |
| 25 | 8 | u64 | | `bitmask` | Specifies the absence of correction data at the correction points in the array (grid).<br>Only the first rows * cols bits are used, and if a specific bit is enabled (set to 1), the correction is not available. If there are more than 64 correction points the remaining corrections are always available.<br>The correction points are packed by rows, starting with the northwest corner of the array (top-left on a north oriented map), with each row spanning west to east, ending with the southeast corner of the array.<br>See GNSS-SSR-ArrayOfCorrectionPoints field bitmaskOfGrids but note the definition of the bits is inverted. |
| | 33 | | | | Total Payload Length |

Table 8.9.13: MSG_SSR_TILE_DEFINITION 0x05F8 message structure

**MSG SSR SATELLITE APC — 0x0605 — 1541**

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | `time.tow` | Seconds since start of GPS week |
| 4 | 2 | u16 | week | `time.wn` | GPS week number |
| 6 | 1 | u8 | | `update_interval` | Update interval between consecutive corrections. Encoded following RTCM DF391 specification. |
| 7 | 1 | u8 | | `sol_id` | SSR Solution ID. Similar to RTCM DF415. |
| 8 | 1 | u8 | | `iod_ssr` | IOD of the SSR correction. A change of Issue Of Data SSR is used to indicate a change in the SSR generating configuration |
| $32N + 9$ | 1 | u8 | | `apc[N].sid.sat` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| $32N + 10$ | 1 | u8 | | `apc[N].sid.code` | Signal constellation, band and code |
| $32N + 11$ | 1 | u8 | | `apc[N].sat_info` | Additional satellite information |
| $32N + 12$ | 2 | u16 | | `apc[N].svn` | Satellite Code, as defined by IGS. Typically the space vehicle number. |
| $32N + 14$ | 6 | s16[3] | 1 mm | `apc[N].pco` | Mean phase center offset, X Y and Z axes. See IGS ANTEX file format description for coordinate system definition. |
| $32N + 20$ | 21 | s8[21] | 1 mm | `apc[N].pcv` | Elevation dependent phase center variations. First element is 0 degrees separation from the Z axis, subsequent elements represent elevation variations in 1 degree increments. |
| | $32N + 9$ | | | | Total Payload Length |

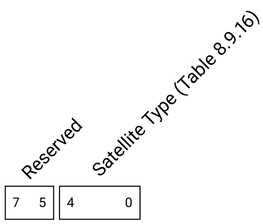
Table 8.9.14: MSG_SSR_SATELLITE_APC 0x0605 message structure




Field 8.9.7: Signal constellation, band and code (`sid.code`)

| Value | Description |
|---|---|
| 0 | GPS L1CA |
| 1 | GPS L2CM |
| 2 | SBAS L1CA |
| 3 | GLO L1CA |
| 4 | GLO L2CA |
| 5 | GPS L1P |
| 6 | GPS L2P |
| 12 | BDS2 B1 |
| 13 | BDS2 B2 |
| 14 | GAL E1B |
| 20 | GAL E7I |
| 31 | QZS L1CA |
| 36 | QZS L2CL |
| 39 | QZS L5Q |
| 47 | BDS3 B2a |

Table 8.9.15: values (`sid.code[0:7]`)




Field 8.9.8: Additional satellite information (`sat_info`)

| Value | Description |
|---|---|
| 0 | Unknown Type |
| 1 | GPS I |
| 2 | GPS II |
| 3 | GPS IIA |
| 4 | GPS IIR |
| 5 | GPS IIF |
| 6 | GPS III |
| 7 | GLONASS |
| 8 | GLONASS M |
| 9 | GLONASS K1 |
| 10 | GALILEO |
| 11 | BEIDOU 2G |
| 12 | BEIDOU 2I |
| 13 | BEIDOU 2M |
| 14 | BEIDOU 3M, SECM |
| 15 | BEIDOU 3G, SECM |
| 16 | BEIDOU 3M, CAST |
| 17 | BEIDOU 3G, CAST |
| 18 | BEIDOU 3I, CAST |
| 19 | QZSS |
| 20 | BEIDOU 3I |
| 21 | BEIDOU 3SM, CAST |
| 22 | BEIDOU 3SI, CAST |
| 23 | BEIDOU 3SM, SECM |
| 24 | BEIDOU 3SI, SECM |

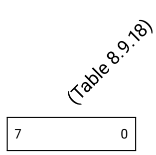
Table 8.9.16: Satellite Type values (`sat_info[0:4]`)

#### MSG SSR ORBIT CLOCK BOUNDS — 0x05DE — 1502

Note 1: Range: 0-17.5 m. i<=200, mean=0.01i; 200<i<=230, mean=2+0.1(i-200); i>230, mean=5+0.5(i-230).
Note 2: Range: 0-17.5 m. i<=200, std=0.01i; 200<i<=230, std=2+0.1(i-200) i>230, std=5+0.5(i-230).

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | header.time.tow | Seconds since start of GPS week |
| 4 | 2 | u16 | week | header.time.wn | GPS week number |
| 6 | 1 | u8 | | header.num_msgs | Number of messages in the dataset |
| 7 | 1 | u8 | | header.seq_num | Position of this message in the dataset |
| 8 | 1 | u8 | | header.update_interval | Update interval between consecutive bounds. Similar to RTCM DF391. |
| 9 | 1 | u8 | | header.sol_id | SSR Solution ID. |
| 10 | 1 | u8 | | ssr_iod | IOD of the SSR bound. |
| 11 | 1 | u8 | | const_id | Constellation ID to which the SVs belong. |
| 12 | 1 | u8 | | n_sats | Number of satellites. |
| $9N + 13$ | 1 | u8 | | orbit_clock_bounds[N].sat_id | Satellite ID. Similar to either RTCM DF068 (GPS), DF252 (Galileo), or DF488 (BDS) depending on the constellation. |
| $9N + 14$ | 1 | u8 | m | orbit_clock_bounds[N].orb_radial_bound_mu | Mean Radial. See Note 1. |
| $9N + 15$ | 1 | u8 | m | orbit_clock_bounds[N].orb_along_bound_mu | Mean Along-Track. See Note 1. |
| $9N + 16$ | 1 | u8 | m | orbit_clock_bounds[N].orb_cross_bound_mu | Mean Cross-Track. See Note 1. |
| $9N + 17$ | 1 | u8 | m | orbit_clock_bounds[N].orb_radial_bound_sig | Standard Deviation Radial. See Note 2. |
| $9N + 18$ | 1 | u8 | m | orbit_clock_bounds[N].orb_along_bound_sig | Standard Deviation Along-Track. See Note 2. |
| $9N + 19$ | 1 | u8 | m | orbit_clock_bounds[N].orb_cross_bound_sig | Standard Deviation Cross-Track. See Note 2. |
| $9N + 20$ | 1 | u8 | m | orbit_clock_bounds[N].clock_bound_mu | Clock Bound Mean. See Note 1. |
| $9N + 21$ | 1 | u8 | m | orbit_clock_bounds[N].clock_bound_sig | Clock Bound Standard Deviation. See Note 2. |
| | $9N + 13$ | | | | Total Payload Length |

Table 8.9.17: MSG_SSR_ORBIT_CLOCK_BOUNDS 0x05DE message structure




Field 8.9.9: Constellation ID to which the SVs belong. (const_id)

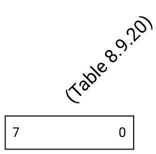
| Value | Description |
|---|---|
| 0 | GPS |
| 3 | BDS |
| 4 | QZS |
| 5 | GAL |

Table 8.9.18: values (const_id[0:7])

### MSG SSR CODE PHASE BIASES BOUNDS — 0x05EC — 1516

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | `header.time.tow` | Seconds since start of GPS week |
| 4 | 2 | u16 | week | `header.time.wn` | GPS week number |
| 6 | 1 | u8 | | `header.num_msgs` | Number of messages in the dataset |
| 7 | 1 | u8 | | `header.seq_num` | Position of this message in the dataset |
| 8 | 1 | u8 | | `header.update_interval` | Update interval between consecutive bounds. Similar to RTCM DF391. |
| 9 | 1 | u8 | | `header.sol_id` | SSR Solution ID. |
| 10 | 1 | u8 | | `ssr_iod` | IOD of the SSR bound. |
| 11 | 1 | u8 | | `const_id` | Constellation ID to which the SVs belong. |
| 12 | 1 | u8 | | `n_sats_signals` | Number of satellite-signal couples. |
| $6N + 13$ | 1 | u8 | | `satellites_signals[N].sat_id` | Satellite ID. Similar to either RTCM DF068 (GPS), DF252 (Galileo), or DF488 (BDS) depending on the constellation. |
| $6N + 14$ | 1 | u8 | | `satellites_signals[N].signal_id` | Signal and Tracking Mode Identifier. Similar to either RTCM DF380 (GPS), DF382 (Galileo) or DF467 (BDS) depending on the constellation. |
| $6N + 15$ | 1 | u8 | 0.005 m | `satellites_signals[N].code_bias_bound_mu` | Code Bias Mean. Range: 0-1.275 m |
| $6N + 16$ | 1 | u8 | 0.005 m | `satellites_signals[N].code_bias_bound_sig` | Code Bias Standard Deviation. Range: 0-1.275 m |
| $6N + 17$ | 1 | u8 | 0.005 m | `satellites_signals[N].phase_bias_bound_mu` | Phase Bias Mean. Range: 0-1.275 m |
| $6N + 18$ | 1 | u8 | 0.005 m | `satellites_signals[N].phase_bias_bound_sig` | Phase Bias Standard Deviation. Range: 0-1.275 m |
| | $6N + 13$ | | | | Total Payload Length |

Table 8.9.19: MSG_SSR_CODE_PHASE_BIASES_BOUNDS 0x05EC message structure




Field 8.9.10: Constellation ID to which the SVs belong. (`const_id`)

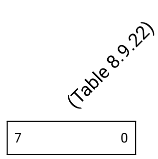
| Value | Description |
|---|---|
| 0 | GPS |
| 3 | BDS |
| 4 | QZS |
| 5 | GAL |

Table 8.9.20: values (`const_id[0:7]`)

### MSG SSR ORBIT CLOCK BOUNDS DEGRADATION — 0x05DF — 1503

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | s | `header.time.tow` | Seconds since start of GPS week |
| 4 | 2 | u16 | week | `header.time.wn` | GPS week number |
| 6 | 1 | u8 | | `header.num_msgs` | Number of messages in the dataset |
| 7 | 1 | u8 | | `header.seq_num` | Position of this message in the dataset |
| 8 | 1 | u8 | | `header.update_interval` | Update interval between consecutive bounds. Similar to RTCM DF391. |
| 9 | 1 | u8 | | `header.sol_id` | SSR Solution ID. |
| 10 | 1 | u8 | | `ssr_iod` | IOD of the SSR bound degradation parameter. |
| 11 | 1 | u8 | | `const_id` | Constellation ID to which the SVs belong. |
| 12 | 8 | u64 | | `sat_bitmask` | Satellite Bit Mask. Put 1 for each satellite where the following degradation parameters are applicable, 0 otherwise. Encoded following RTCM DF394 specification. |
| 20 | 1 | u8 | 0.001 m/s | `orbit_clock_bounds_degradation.orb_radial_bound_mu_dot` | Orbit Bound Mean Radial First derivative. Range: 0-0.255 m/s |
| 21 | 1 | u8 | 0.001 m/s | `orbit_clock_bounds_degradation.orb_along_bound_mu_dot` | Orbit Bound Mean Along-Track First derivative. Range: 0-0.255 m/s |
| 22 | 1 | u8 | 0.001 m/s | `orbit_clock_bounds_degradation.orb_cross_bound_mu_dot` | Orbit Bound Mean Cross-Track First derivative. Range: 0-0.255 m/s |
| 23 | 1 | u8 | 0.001 m/s | `orbit_clock_bounds_degradation.orb_radial_bound_sig_dot` | Orbit Bound Standard Deviation Radial First derivative. Range: 0-0.255 m/s |
| 24 | 1 | u8 | 0.001 m/s | `orbit_clock_bounds_degradation.orb_along_bound_sig_dot` | Orbit Bound Standard Deviation Along-Track First derivative. Range: 0-0.255 m/s |
| 25 | 1 | u8 | 0.001 m/s | `orbit_clock_bounds_degradation.orb_cross_bound_sig_dot` | Orbit Bound Standard Deviation Cross-Track First derivative. Range: 0-0.255 m/s |
| 26 | 1 | u8 | 0.001 m/s | `orbit_clock_bounds_degradation.clock_bound_mu_dot` | Clock Bound Mean First derivative. Range: 0-0.255 m/s |
| 27 | 1 | u8 | 0.001 m/s | `orbit_clock_bounds_degradation.clock_bound_sig_dot` | Clock Bound Standard Deviation First derivative. Range: 0-0.255 m/s |
| | 28 | | | | Total Payload Length |

Table 8.9.21: MSG_SSR_ORBIT_CLOCK_BOUNDS_DEGRADATION 0x05DF message structure




Field 8.9.11: Constellation ID to which the SVs belong. (`const_id`)

| Value | Description |
|---|---|
| 0 | GPS |
| 3 | BDS |
| 4 | QZS |
| 5 | GAL |

Table 8.9.22: values (`const_id[0:7]`)

## 8.10 Telemetry

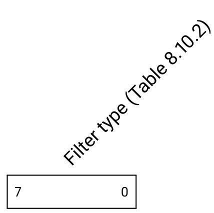
Telemetry messages reported by Starling engine. The messages include various byproducts of state estimation and other logic across Starling and are aimed at efficient issue diagnostics.

#### MSG TEL SV — 0x0120 — 288

This message includes telemetry pertinent to satellite signals available to Starling.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 2 | u16 | weeks | wn | GPS week number |
| 2 | 4 | u32 | ms | tow | GPS Time of Week |
| 6 | 1 | u8 | | n_obs | Total number of observations. First nibble is the size of the sequence (n), second nibble is the zero-indexed counter (ith packet of n) |
| 7 | 1 | u8 | | origin_flags | Flags to identify the filter type from which the telemetry is reported from |
| 12N + 8 | 1 | u8 | deg * 2 | sv_tel[N].az | Azimuth angle (range 0..179) |
| 12N + 9 | 1 | s8 | deg | sv_tel[N].el | Elevation angle (range -90..90) |
| 12N + 10 | 1 | u8 | | sv_tel[N].availability_flags | Observation availability at filter update |
| 12N + 11 | 2 | s16 | 1 dm | sv_tel[N].pseudorange_residual | Pseudorange observation residual |
| 12N + 13 | 2 | s16 | 5 mm | sv_tel[N].phase_residual | Carrier-phase or carrier-phase-derived observation residual |
| 12N + 15 | 1 | u8 | | sv_tel[N].outlier_flags | Reports if observation is marked as an outlier and is excluded from the update |
| 12N + 16 | 1 | u8 | | sv_tel[N].ephemeris_flags | Ephemeris metadata |
| 12N + 17 | 1 | u8 | | sv_tel[N].correction_flags | Reserved |
| 12N + 18 | 1 | u8 | | sv_tel[N].sid.sat | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 12N + 19 | 1 | u8 | | sv_tel[N].sid.code | Signal constellation, band and code |
| | 12N + 8 | | | | Total Payload Length |

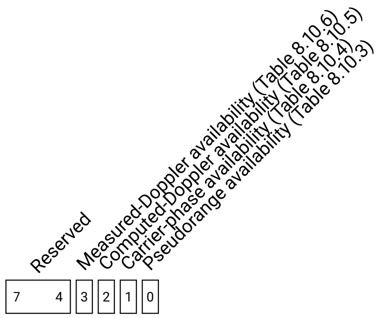
Table 8.10.1: MSG_TEL_SV 0x0120 message structure




Field 8.10.1: Flags to identify the filter type from which the telemetry is reported from (origin_flags)

| Value | Description |
|---|---|
| 0 | Standalone |
| 1 | Differential |

Table 8.10.2: Filter type values (origin_flags[0:7])




Field 8.10.2: Observation availability at filter update (`sv_tel[N].availability_flags`)

| Value | Description |
|---|---|
| 0 | Pseudorange unavailable |
| 1 | Pseudorange available |

Table 8.10.3: Pseudorange availability values (`sv_tel[N].availability_flags[0]`)

| Value | Description |
|---|---|
| 0 | Carrier-phase unavailable |
| 1 | Carrier-phase available |

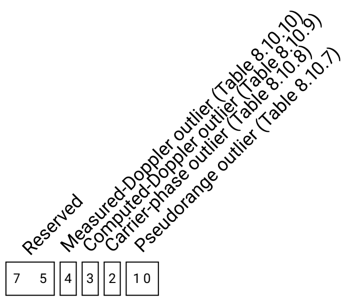
Table 8.10.4: Carrier-phase availability values (`sv_tel[N].availability_flags[1]`)

| Value | Description |
|---|---|
| 0 | Computed-Doppler unavailable |
| 1 | Computed-Doppler available |

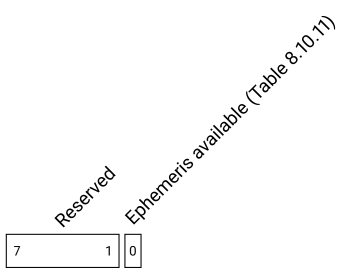
Table 8.10.5: Computed-Doppler availability values (`sv_tel[N].availability_flags[2]`)

| Value | Description |
|---|---|
| 0 | Measured-Doppler unavailable |
| 1 | Measured-Doppler available |

Table 8.10.6: Measured-Doppler availability values (`sv_tel[N].availability_flags[3]`)




Field 8.10.3: Reports if observation is marked as an outlier and is excluded from the update (sv_tel[N].outlier_flags)




Field 8.10.4: Ephemeris metadata (sv_tel[N].ephemeris_flags)

| Value | Description |
|---|---|
| 0 | Pseudorange accepted |
| 1 | Pseudorange marked as outlier |
| 2 | Pseudorange marked as major outlier |

Table 8.10.7: Pseudorange outlier values (sv_tel[N].outlier_flags[0:1])

| Value | Description |
|---|---|
| 0 | Carrier-phase accepted |
| 1 | Carrier-phase marked as outlier |

Table 8.10.8: Carrier-phase outlier values (sv_tel[N].outlier_flags[2])

| Value | Description |
|---|---|
| 0 | Computed-Doppler accepted |
| 1 | Computed-Doppler marked as outlier |

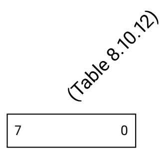
Table 8.10.9: Computed-Doppler outlier values (sv_tel[N].outlier_flags[3])

| Value | Description |
|---|---|
| 0 | Measured-Doppler accepted |
| 1 | Measured-Doppler marked as outlier |

Table 8.10.10: Measured-Doppler outlier values (sv_tel[N].outlier_flags[4])

| Value | Description |
|---|---|
| 0 | Valid ephemeris available |
| 1 | No valid ephemeris available (general status) |

Table 8.10.11: Ephemeris available values (sv_tel[N].ephemeris_flags[0])




Field 8.10.5: Signal constellation, band and code (`sv_tel[N].sid.code`)

| Value | Description |
|---|---|
| 0 | GPS L1CA |
| 1 | GPS L2CM |
| 2 | SBAS L1CA |
| 3 | GLO L1CA |
| 4 | GLO L2CA |
| 5 | GPS L1P |
| 6 | GPS L2P |
| 12 | BDS2 B1 |
| 13 | BDS2 B2 |
| 14 | GAL E1B |
| 20 | GAL E7I |
| 31 | QZS L1CA |
| 36 | QZS L2CL |
| 39 | QZS L5Q |
| 47 | BDS3 B2a |

Table 8.10.12: values (`sv_tel[N].sid.code[0:7]`)

## 8.11 Tracking

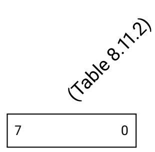
Satellite code and carrier-phase tracking messages from the device.

**MSG TRACKING STATE — 0x0041 — 65**

The tracking message returns a variable-length array of tracking channel states. It reports status and carrier-to-noise density measurements for all tracked satellites.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| $4N + 0$ | 1 | u8 | | `states[N].sid.sat` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| $4N + 1$ | 1 | u8 | | `states[N].sid.code` | Signal constellation, band and code |
| $4N + 2$ | 1 | u8 | | `states[N].fcn` | Frequency channel number (GLONASS only) |
| $4N + 3$ | 1 | u8 | dB Hz / 4 | `states[N].cn0` | Carrier-to-Noise density. Zero implies invalid cn0. |
| | 4N | | | | Total Payload Length |

Table 8.11.1: MSG_TRACKING_STATE 0x0041 message structure




Field 8.11.1: Signal constellation, band and code (`sid.code`)

| Value | Description |
|---|---|
| 0 | GPS L1CA |
| 1 | GPS L2CM |
| 2 | SBAS L1CA |
| 3 | GLO L1CA |
| 4 | GLO L2CA |
| 5 | GPS L1P |
| 6 | GPS L2P |
| 12 | BDS2 B1 |
| 13 | BDS2 B2 |
| 14 | GAL E1B |
| 20 | GAL E7I |
| 31 | QZS L1CA |
| 36 | QZS L2CL |
| 39 | QZS L5Q |
| 47 | BDS3 B2a |

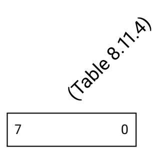
Table 8.11.2: values (`sid.code[0:7]`)

**MSG MEASUREMENT STATE — 0x0061 — 97**

The tracking message returns a variable-length array of tracking channel states. It reports status and carrier-to-noise density measurements for all tracked satellites.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| $3N + 0$ | 1 | u8 | | `states[N].mesid.sat` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| $3N + 1$ | 1 | u8 | | `states[N].mesid.code` | Signal constellation, band and code |
| $3N + 2$ | 1 | u8 | dB Hz / 4 | `states[N].cn0` | Carrier-to-Noise density. Zero implies invalid cn0. |
| | 3N | | | | Total Payload Length |

Table 8.11.3: MSG_MEASUREMENT_STATE 0x0061 message structure




Field 8.11.2: Signal constellation, band and code (`mesid.code`)

| Value | Description |
|---|---|
| 0 | GPS L1CA |
| 1 | GPS L2CM |
| 2 | SBAS L1CA |
| 3 | GLO L1CA |
| 4 | GLO L2CA |
| 5 | GPS L1P |
| 6 | GPS L2P |
| 12 | BDS2 B1 |
| 13 | BDS2 B2 |
| 14 | GAL E1B |
| 20 | GAL E7I |
| 31 | QZS L1CA |
| 36 | QZS L2CL |
| 39 | QZS L5Q |
| 47 | BDS3 B2a |

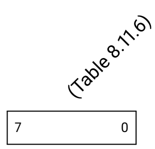
Table 8.11.4: values (`mesid.code[0:7]`)

### MSG TRACKING IQ — 0x002D — 45

When enabled, a tracking channel can output the correlations at each update interval.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 1 | u8 | | `channel` | Tracking channel of origin |
| 1 | 1 | u8 | | `sid.sat` | Constellation-specific satellite id. For GLO can either be (100+FCN) where FCN is in [-7,+6] or the Slot ID in [1,28]. |
| 2 | 1 | u8 | | `sid.code` | Signal constellation, band and code |
| $4N+3$ | 2 | s16 | | `corrs[N].I` | In-phase correlation |
| $4N+5$ | 2 | s16 | | `corrs[N].Q` | Quadrature correlation |
| | $4N+3$ | | | | Total Payload Length |

Table 8.11.5: MSG_TRACKING_IQ 0x002D message structure




Field 8.11.3: Signal constellation, band and code (`sid.code`)

| Value | Description |
|---|---|
| 0 | GPS L1CA |
| 1 | GPS L2CM |
| 2 | SBAS L1CA |
| 3 | GLO L1CA |
| 4 | GLO L2CA |
| 5 | GPS L1P |
| 6 | GPS L2P |
| 12 | BDS2 B1 |
| 13 | BDS2 B2 |
| 14 | GAL E1B |
| 20 | GAL E7I |
| 31 | QZS L1CA |
| 36 | QZS L2CL |
| 39 | QZS L5Q |
| 47 | BDS3 B2a |

Table 8.11.6: values (`sid.code[0:7]`)

## 8.12 User

Messages reserved for use by the user.

**MSG USER DATA — 0x0800 — 2048**

This message can contain any application specific user data up to a maximum length of 255 bytes per message.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | N | u8[N] | | contents | User data payload |
| | N | | | | Total Payload Length |

Table 8.12.1: MSG_USER_DATA 0x0800 message structure

## 8.13 Vehicle

Messages from a vehicle.

**MSG ODOMETRY — 0x0903 — 2307**

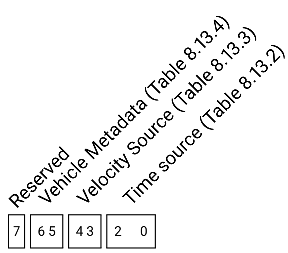
Message representing the x component of vehicle velocity in the user frame at the odometry reference point(s) specified by the user. The offset for the odometry reference point and the definition and origin of the user frame are defined through the device settings interface. There are 4 possible user-defined sources of this message which are labeled arbitrarily source 0 through 3. If using "processor time" time tags, the receiving end will expect either 'MSG_GNSS_TIME_OFFSET' or 'MSG_PPS_TIME' to sync incoming odometry data to GNSS time. Processor time shall roll over to zero after one week.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 4 | u32 | ms | `tow` | Time field representing either milliseconds in the GPS Week or local CPU time from the producing system in milliseconds. See the tow_source flag for the exact source of this timestamp. |
| 4 | 4 | s32 | mm/s | `velocity` | The signed forward component of vehicle velocity. |
| 8 | 1 | u8 | | `flags` | Status flags |
| | 9 | | | | Total Payload Length |

Table 8.13.1: MSG_ODOMETRY 0x0903 message structure

| Value | Description |
|---|---|
| 0 | None (invalid) |
| 1 | GPS Solution (ms in week) |
| 2 | Processor Time |

Table 8.13.2: Time source values (`flags[0:2]`)




Field 8.13.1: Status flags (`flags`)

| Value | Description |
|---|---|
| 0 | Source 0 |
| 1 | Source 1 |
| 2 | Source 2 |
| 3 | Source 3 |

Table 8.13.3: Velocity Source values (`flags[3:4]`)

| Value | Description |
|---|---|
| 0 | Unavailable |
| 1 | Forward |
| 2 | Reverse |
| 3 | Park |

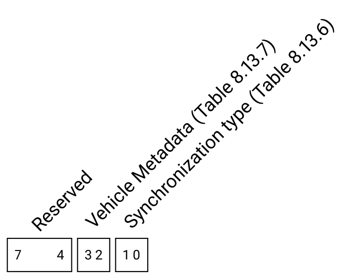
Table 8.13.4: Vehicle Metadata values (`flags[5:6]`)

**MSG WHEELTICK — 0x0904 — 2308**

Message containing the accumulated distance travelled by a wheel located at an odometry reference point defined by the user. The offset for the odometry reference point and the definition and origin of the user frame are defined through the device settings interface. The source of this message is identified by the source field, which is an integer ranging from 0 to 255. The timestamp associated with this message should represent the time when the accumulated tick count reached the value given by the contents of this message as accurately as possible. If using ”local CPU time” time tags, the receiving end will also expect either ‘MSG_GNSS_TIME_OFFSET‘ or ‘MSG_PPS_TIME‘ to sync incoming wheeltick data to GNSS time. Local CPU time shall roll over to zero after one week.

| Offset (bytes) | Size (bytes) | Format | Units | Name | Description |
|---|---|---|---|---|---|
| 0 | 8 | u64 | us | `time` | Time field representing either microseconds since the last PPS, microseconds in the GPS Week or local CPU time from the producing system in microseconds. See the synch_type field for the exact meaning of this timestamp. |
| 8 | 1 | u8 | | `flags` | Field indicating the type of timestamp contained in the time field. |
| 9 | 1 | u8 | | `source` | ID of the sensor producing this message |
| 10 | 4 | s32 | arbitrary distance units | `ticks` | Free-running counter of the accumulated distance for this sensor. The counter should be incrementing if travelling into one direction and decrementing when travelling in the opposite direction. |
| | 14 | | | | Total Payload Length |

Table 8.13.5: MSG_WHEELTICK 0x0904 message structure




Field 8.13.2: Field indicating the type of timestamp contained in the time field. (`flags`)

| Value | Description |
|---|---|
| 0 | microseconds since last PPS |
| 1 | microseconds in GPS week |
| 2 | local CPU time in nominal microseconds |

Table 8.13.6: Synchronization type values (`flags[0:1]`)

| Value | Description |
|---|---|
| 0 | Unavailable |
| 1 | Forward |
| 2 | Reverse |
| 3 | Park |

Table 8.13.7: Vehicle Metadata values (`flags[2:3]`)