POSITIONING

LEA-M8F

System Integration Guide

Application Note

Abstract

This document provides information and guidance to customers when implementing LEA-M8F based frequency and timing control systems.

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Document status explanation	
Objective Specification	Document contains target values. Revised and supplementary data will be published later.
Advance Information	Document contains data based on early testing. Revised and supplementary data will be published later.
Early Production Information	Document contains data from product verification. Revised and supplementary data may be published later.
Production Information	Document contains the final product specification.

This document applies to the following products:

Product name	Type number	ROM/FLASH version	PCN reference
LEA-M8F	LEA-M8F-0-00	FLASH FW2.20 FTS1.01	N/A

Preface

u-blox Technical Documentation

As part of our commitment to customer support, u-blox maintains an extensive volume of technical documentation for our products. In addition to our product-specific technical data sheets, the following manuals are available to assist u-blox customers in product design and development.

- **GPS Compendium:** This document, also known as the GPS book, provides a wealth of information regarding generic questions about GPS system functionalities and technology.
- **Receiver Description including Protocol Specification:** This document describes messages, configuration and functionalities of the LEA-M8F software releases and receivers.
- **Hardware Integration Manuals:** These manuals provide hardware design instructions and information on how to set up production and final product tests.
- **Application Notes:** These documents provide general design instructions and information that applies to all u-blox GNSS positioning modules.

How to use this Manual

This manual has a modular structure. It is not necessary to read it from beginning to end.

The following symbols highlight important information within the manual:

☞ An index finger points out key information pertaining to module integration and performance.

⚠ **A warning symbol indicates actions that could negatively influence or damage the module.**

Questions

If you have any questions about LEA-M8F integration, please:

- Read this manual carefully.
- Contact our information service on the homepage http://www.u-blox.com.
- Read the questions and answers on our FAQ database on the homepage.

Technical Support

Worldwide Web

Our website (www.u-blox.com) is a rich pool of information. Product information, technical documents and helpful FAQ can be accessed 24h a day.

By E-mail

If you have technical problems or cannot find the required information in the provided documents, contact the closest Technical Support office. To ensure that we process your request as soon as possible, use our service pool email addresses rather than personal staff email addresses. Contact details are at the end of the document.

Helpful Information when Contacting Technical Support

When contacting Technical Support please have the following information ready:

- Receiver type (e.g. NEO-7N-0-000), Datacode (e.g. 172100.0100.000) and firmware version (e.g. ROM1.0)
- Receiver/module configuration
- Clear description of your question or the problem (may include a u-center logfile)
- A short description of the application
- Your complete contact details

Contents

1 Introduction

The LEA-M8F module is a fully self-contained phase and frequency reference based on GNSS which can be part of a timing sub-system, for example for LTE small cells. This application note provides guidance when using a LEA-M8F to implement a timing or frequency control system. This document should be read in conjunction with the *u-blox M8 Receiver Description Including Protocol Specification* [1] and the *u-blox LEA-M8F Hardware Integration Manual* [2].

The LEA-M8F has its own highly accurate disciplined oscillator with a corresponding frequency and time pulse output. For some applications, this is all that is required. It also has many other features, which are introduced in this guide. For example, it can also discipline an external oscillator with control exercised either directly via an externally connected DAC or indirectly via a host. The module can also use one or two additional external frequency or time signals to provide redundancy and signal continuity under difficult GNSS reception conditions. This includes measurements from external sources, such as NTP or sync-E. Ultimately, without any external or GNSS source, the module will continue a time and frequency output in "hold-over" mode.

Normally, the module is expected to be used in a stationary position, which means it can benefit from using a fixed location facility either by setting a known location coordinate or commanding the system to refine its position over time. Once surveyed-in, the system can benefit from operating down to a single satellite and continue supplying a disciplined time and frequency solution. The system employs a sophisticated (T)RAIM algorithm which can exclude satellite signal measurements that fall outside expected values.

The LEA-M8F module firmware also benefits from improvements in signal acquisition techniques, which extends starting performance in difficult signal locations, such as in buildings. Acquiring signals down to -157 dBm is possible with the aid of assistance data that can be downloaded from the u-blox AssistNow service. Periodically assisting the module with SV ephemerides also enables continued running when signal strengths are below the data decoding threshold.

This document outlines configuration and control of the module using the UBX Frequency and Time Synchronization messages and describes the Synchronization Manager (SMGR) which is the main element that handles all the frequency/phase measurements and oscillator control. The module configuration and operation is introduced using typical system cases that illustrate the Frequency Timing and Synchronization (FTS) messages required. An appendix carries some customer related operational issues that users may found useful.

The module has a great many operational possibilities, and hence understanding the necessary configuration aspects is key to successfully designing it into a customer's system. The final section provides a representative use case to illustrate the overall host/module interaction.

In the rest of this document the following terminology will be used:

- **Disciplined oscillator**: an oscillator whose frequency is corrected by a more stable frequency reference, such as a GNSS system.
- **Internal oscillator**: an oscillator which is used in the GNSS receiver subsystem. This oscillator is always disciplined when a more accurate source is available.
- **External oscillator**: an oscillator which is independent of the GNSS receiver frequency. In addition to the internal oscillator, one external oscillator can also be disciplined by the Synchronisation Manager software (SMGR).
- **Source**: a source is a measured signal or an estimation from an external timing sub-system that can be used to determine the error of the internal clock. Sources are handled according to related models, which also provide their estimated uncertainty.

2 Operational Configuration

Implementing a LEA-M8F design requires knowledge of the Frequency and Timing Synchronization (FTS) messages, besides the standard u-blox receiver protocol messages, to implement a viable system. Many of the FTS messages relate to communication and control of the synchronization manager that coordinates all aspects of the time and frequency synchronization operation.

This section provides an overview of UBX message use when implementing frequency control products. While not exhaustive, it highlights those messages and parameters that customers will require when implementing a frequency/timing system. In all cases, the reader is directed to the full specification of any message type, which are given in the *u-blox M8 Receiver Description Including Protocol Specification* [1].

2.1 Start-up

After start-up, the module's default configuration delivers the following NMEA sentences at 1 s intervals:

`NMEA-GNGGA` (Global Positioning Fix Data)
`NMEA-GNGLL` (Geographic Position – Latitude/Longitude)
`NMEA-GNGSA` (GNSS DOP and Active Satellites)
`NMEA-GNGSV` (GNSS satellites in view)
`NMEA-GNRMC` (Recommended Minimum specific GNSS Data)
`NMEA-GNVTG` (Course over Ground and Ground Speed)
`NMEA-GNZDA` (Time and date)

For frequency or timing applications, consider suppressing those NMEA sentences that are not required for an application, and consider applying the following FTS messages to configure and control the system.

Message	Description
`UBX-CFG-SMGR`	Synchronization manager configuration
`UBX-CFG-ESRC`	External source configuration
`UBX-CFG-DOSC`	Disciplined oscillator configuration
`UBX-CFG-TXSLOT`	Message timeslot configuration
`UBX-CFG-TP5`	Configures the output pulse parameters
`UBX-CFG-NAV5`	Configures which variant of UTC is used by the receiver
`UBX-MON-SMGR`	SMGR monitoring message
`UBX-TIM-DOSC`	Message containing disciplining command
`UBX-TIM-HOC`	Host override control of the receivers oscillators
`UBX-TIM-TOS`	Message containing information about the latest pulse output by the receiver
`UBX-TIM-FCHG`	Information about latest frequency change to an oscillator
`UBX-TIM-SMEAS`	Message containing oscillator measurements
`UBX-TIM-VCOCAL`	Oscillator calibration command and result report
`UBX-TIM-VCOOFF`	Sets internal or external oscillator offset

Table 1: u-blox protocol FTS messages

Rather than explaining all the message details at once, the following sections gradually introduce the various UBX FTS message use through typical use-cases. The messages are described in detail and shown with their corresponding u-center window views to aid user familiarization.

2.2 LEA-M8F as stand-alone reference

In the following example (Figure 1), the LEA-M8F provides a stand-alone synchronization source in the context of a femto-cell application. In this use case, the module's internal VCTCXO is disciplined by the GNSS solution providing a frequency reference (30.72 MHz) and a 1PPS signal to synchronize the platform baseband section.

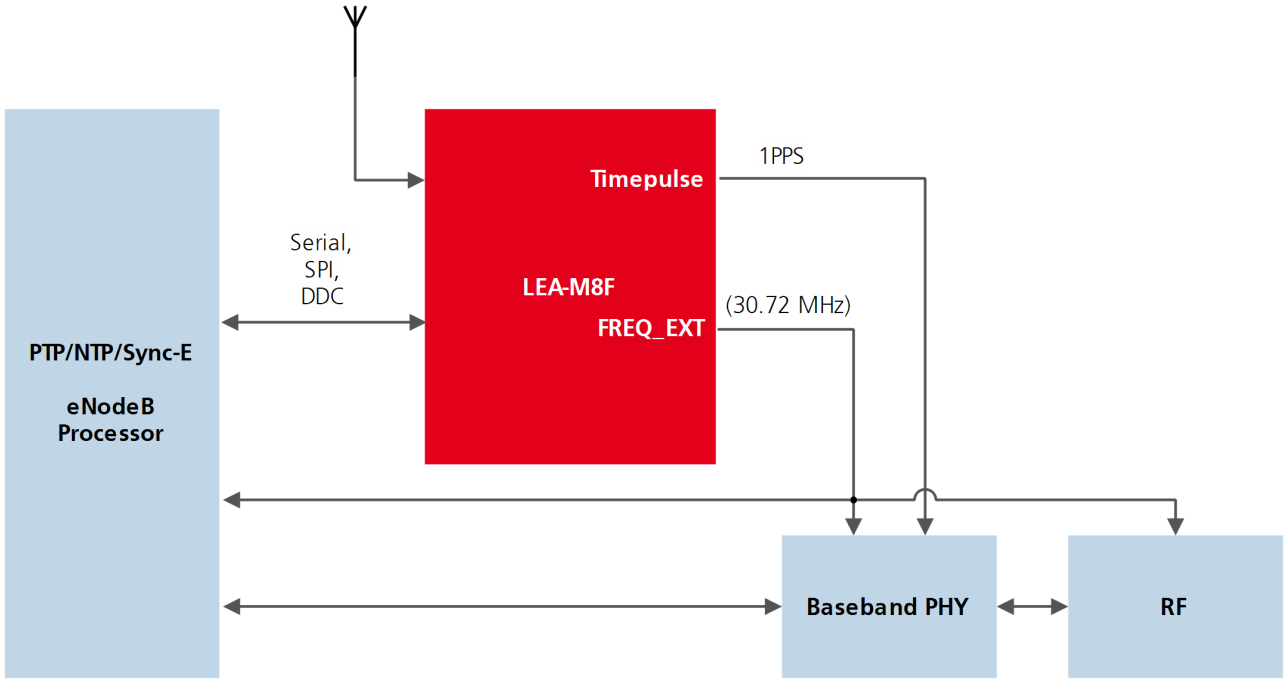


Figure 1: Femto-cell stand-alone reference

The host communicates with the module via any of these standard interfaces: serial RS232, SPI or DDC (I2C). The module provides a 30.72 MHz reference frequency from the FREQ_EXT pin and a coherent 1 PPS signal from the Time pulse output pin.

Normally, the order of setting up any system begins with configuration for the use of any external sources (disciplined or not) prior to setting the Synchronization Manager (SMGR) parameters. However, only the module's internal VCTCXO is required with no other sources. Thus, the SMGR configuration comes next, in the absence of any other frequency or phase inputs.

2.3 UBX-CFG-SMGR: Configuring the Synchronization manager

The SMGR is the software entity that controls all aspects of the FTS operation. The `UBX-CFG-SMGR` message is the essential configuration control message for FTS operation. For interested readers, the SMGR organization and operation is explained in detail in section 3.

The `UBX-CFG-SMGR` message is used to set:

- The limiting operational freq/phase adjustment rates for the disciplined oscillator
- Oscillator tolerance limits and alarm enable flags
- A number of over-determined fixes or "any fix" on start-up prior to time o/p
- Selection of the measurements presented via the UBX-TIM-SMEAS message
- Control flags for enabling disciplining of controlled oscillators
- Selection of other sources of synchronization which can be internal or external host based measurements
- The time pulse coherency during reference acquisition

The following u-center messages window illustrates the available parameters and the configuration options that are available with the UBX-CFG-SMGR message.

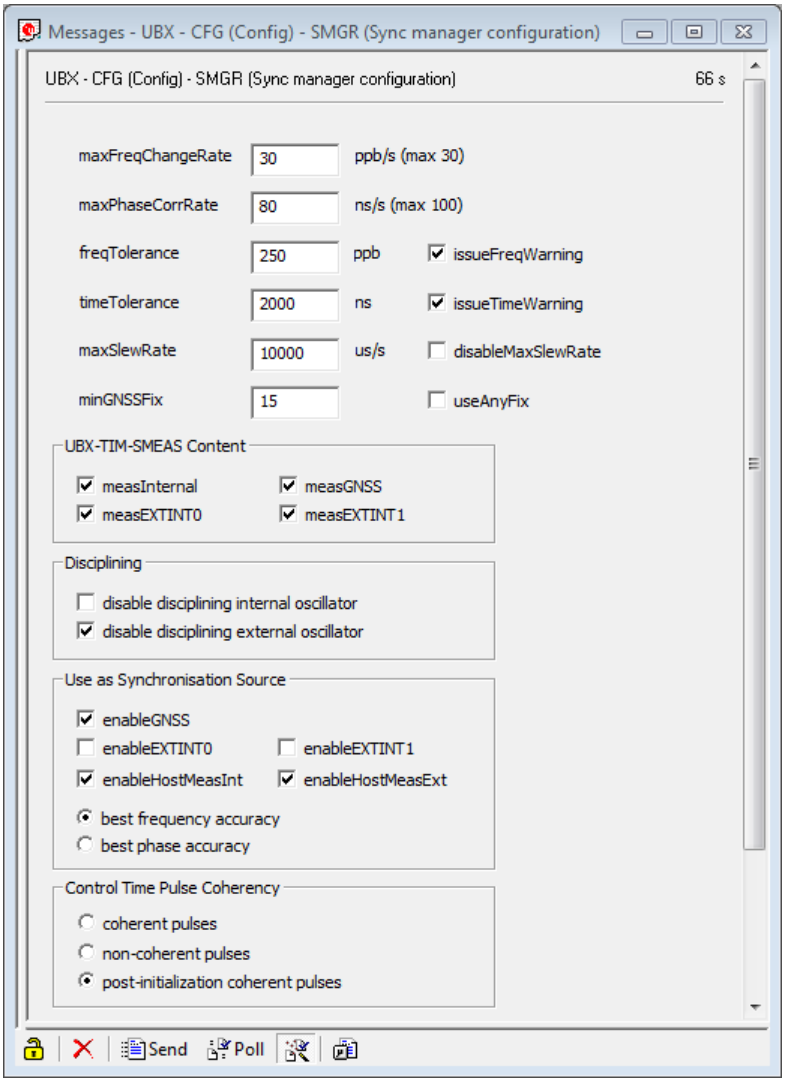


Figure 2: SMGR configuration

In this example, only the internal oscillator disciplining is required by setting the appropriate disable flag under the "Disciplining" heading.

GNSS is set as a synchronization source being the primary reference against which other sources are measured. As no other frequency/phase sources are connected, the external EXTINT1, 2 inputs are disabled under "Use as Synchronization Source". Where applicable, measurements of the internal oscillator by the host can be allowed to provide independent aiding. These measurements can be sent via a UBX-TIM-SMEAS message (see section 2.6.4).

The time pulse coherency setting allows the user to maintain coherent pulses either during frequency acquisition (*coherent pulses*) or after synchronization (*post-initialization etc.*). The latter setting provides a possible quicker acquisition time.

☞ Using the *coherent pulses* setting during acquisition from an arbitrary phase (e.g. stand-alone start-up) will generally result in long convergence times.

In the absence of information from the GNSS solution or any other auxiliary source, the module relies on the VCTCXO for hold-over. That is, if the GNSS signal becomes unusable then the module's frequency and pulse outputs rely on the VCTCXO's excellent temperature compensation until a GNSS signal is restored.

2.4 Attaching Frequency and Time sources

An enhancement to the previous example adds an external 1 PPS input from the host sub-system derived from a phase reference such as NTP, IEEE1588 or a frequency reference such as Sync-E and/or an auxiliary frequency source (with better stability than the module) from an external oscillator. The extra connections are shown below in Figure 3.

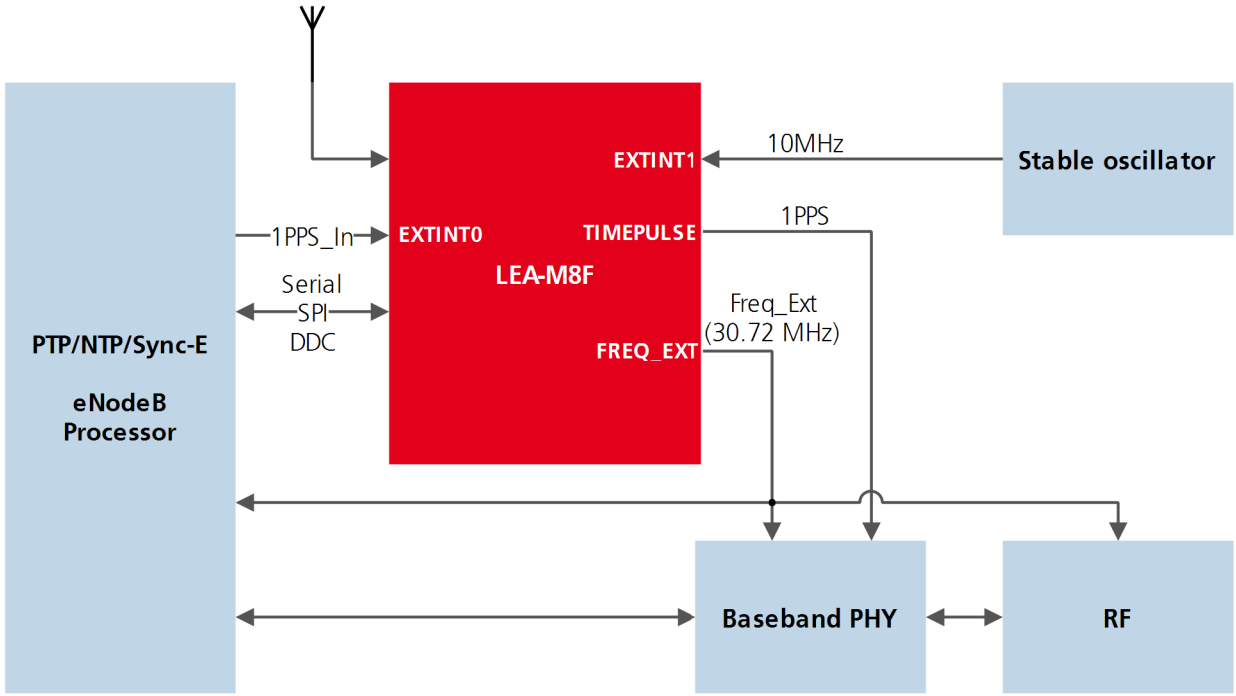


Figure 3: Femto-cell reference with host assistance

External sources are added as auxiliary sources of synchronization that can help to enhance hold-over performance by using an external and stable (but not necessarily accurate) frequency reference (in this case an oscillator and 1 PPS input). Any external frequency or time source is connected to the module using the EXTINT# pins. The external signal parameters are described using the UBX-CFG-ESRC message.

2.4.1 UBX-CFG-ESRC: Configuring Frequency, Time sources

This UBX-CFG-ESRC message sets the characteristics of an external time or frequency source for the SMGR. The particular type of stability parameters used depends upon whether it is a frequency or time signal source. When the user sets a frequency source as feedback from an external oscillator, i.e. a disciplined oscillator then the stability information is not required but given in the disciplined oscillator configuration message: UBX-CFG-DOSC (see section 2.6.3). Otherwise, the message requires that each input port is configured with an appropriate source type as follows:

- None (the default)
- Frequency Source
- Time source
- Feedback from external oscillator (the disciplined source)

After this, the following parameters are required for frequency sources:

- withTemp max. frequency deviation (stability) over operating temperature range (ppb)
- timeToTemp the receiver's model of the oscillator will assume that its frequency moves to the stability limit above in this time (s)
- withAge oscillator aging rate (ppb/year)
- maxDevLifeTime oscillator frequency maximum aging offset over its lifetime

The following parameters are required for time sources:

- offset nominal phase offset of PPS source (ns)
- offsetUncertainty phase offset uncertainty, one std deviation (ns)
- jitter timing uncertainty (1 sigma) phase jitter (ns)

Message control flags allow setting the input port EXTINT0/1 (aka Freq_Phase0/1) polarity and whether the signal time base is GNSS or UTC based. When using GNSS the actual variant of GNSS time is specified by the UBX-CFG-TP5 message - see section 2.5.1 below. When using UTC the particular variant of UTC is defined by the CFG-NAV5 message.

☞ It is easier to use the GNSS based timing. Otherwise the UTC parameters must be in place either by host aiding or via the GNSS signal.

A u-center message window below provides a view of the parameter settings for describing a 1 PPS time source input to EXTINT0 and a 10 MHz frequency source applied to EXTINT1 for the example above.

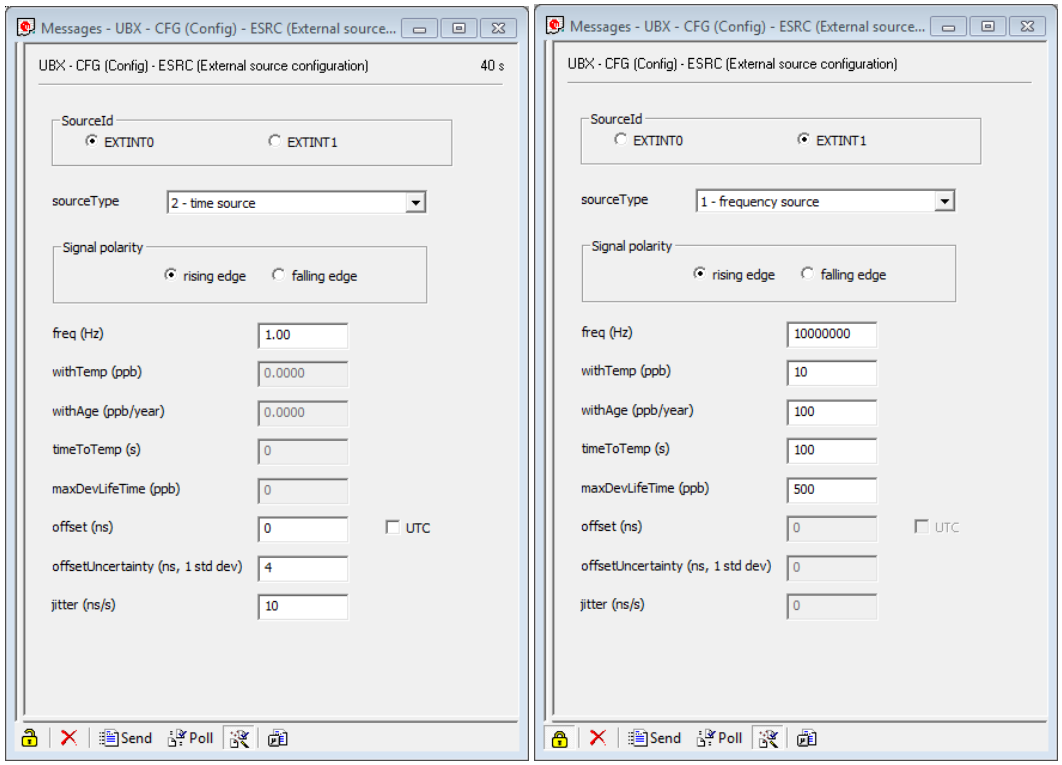


Figure 4: Parameter setting for EXTINT0/1

2.4.2 Starting up with an external time source

If the module is configured for use with a PPS time source without GNSS signal reception, then the time pulse must be accompanied by time of day information, UTC offset, etc. to enable it to produce a time pulse output. This information can be provided using the MGA assistance methods described below in section 2.7.2.

The time pulse settings can now be explained, introducing the time pulse output configuration (UBX-CFG-TP5) and the top of second (UBX-TIM-TOS) messages.

2.5 The Time pulse output

The period, offset, and duty cycle properties of the time pulse output are set using the UBX-CFG-TP5 message. For FTS products the time pulse can be used over a frequency range of 0.5 to 2 Hz with an accompanying Top-of-Second message in a reserved time-slot synchronized to each pulse. The time pulse becomes active when the frequency and phase solution has a stabilized within the SMGR pre-set tolerances. Plus, when using GNSS the time pulse is contingent on a minimum number of consecutive fixes (with a minimum number of non-RAIMed SVs) have been processed. The default value for consecutive fixes is 15, which normally allows sufficient confidence in the signal quality. Hence, the time to pulse output will be longer by 15 seconds compared to a "normal" TTFF value. This number of fixes is programmable using the UBX-CFG-SMGR minGNSSFix parameter.

Normally, the output time pulse is maintained with a fixed number of cycles of the module reference frequency, i.e. for a 1 Hz rate there is a pulse output every 30720000 reference cycles. The output is aligned with the selected time grid (typically to a second or even second) when phase locked. If an external oscillator is controlled in phase locked mode it will also have the same number of cycles between two time pulses.

The time pulse output can be configured for rates up to 10 MHz with the Top-of-Second message and interface time-slot reservation mechanism disabled. Contact u-blox support if you require this facility.

2.5.1 UBX-CFG-TP5: Time pulse Programming

The UBX-CFG-TP5 message sets the time pulse nominal phase offset and time delay corrections with respect to the time base in use.

☞ The LEA-M8F module time pulse output is designated "Timepulse 2" in documentation and messages. All settings should be made with Timepulse 2 selected in messages.

☞ Timepulse 1 is not implemented in the LEA-M8F product.

The two pulse length/duty cycle combinations which are used depend on whether the SMGR has determined an accurate time within the set tolerances and vice versa. Within the u-center window shown in Figure 5 the topmost combination ("standard setting") is used during start-up or whenever the time accuracy estimate is out of tolerance. The lower combination ("locked setting") is used when the time is within the SMGR tolerance band and the pulse is locked to the time base in use. In the message payload, these combinations are set by choosing appropriate values for the *freqperiod/pulsLenRatio* and *freqPeriodLock/pulseLenRatioLock*. The *syncMode* control flag allows choosing if the time pulse output reverts to the out-of-tolerance configuration or simply continues with the accurate parameter setting if the time falls out of tolerance.

☞ The *lockedOtherSet* control flag is set by default to enable use of the *freqPeriodLock/pulseLenRatioLock* parameters. The default parameter settings are:

- Static, (no pulse, digital low) – "standard setting" outside tolerance
- 1 Hz, 10% duty cycle – "locked setting" within tolerance

When operating under FLL control, if the reference source provides time information, then the time pulse is aligned to the specified time grid; this may not necessarily be a GNSS solution but a signal from an external source. Instead of GNSS lock, the switching condition between the alternative pulse configurations (if the *lockedOtherSet* flag is set) is dependent on the SMGR meeting the configured frequency tolerance conditions (see section 2.3).

During host-driven steering and in calibration mode the "standard setting" is used.

The message flags bitfield provide for:

- Is Freq,is Length - Selecting frequency/period or time pulse length duty cycle

- gridUtcGps - Selecting the GNSS time base grid i.e. UTC,GPS,GLONASS or BeiDou
- syncMode - Selecting the SMGR lock mode for signaling in/out of time tolerance
- polarity - Setting the time pulse polarity; when set gives a rising edge at top of second

The message *lockGnssFreq* control flag is ignored by the LEA-M8F module as it locks to the best available time/frequency reference which may not be a GNSS source.

The TP5 default values are shown in the u-center message view below.

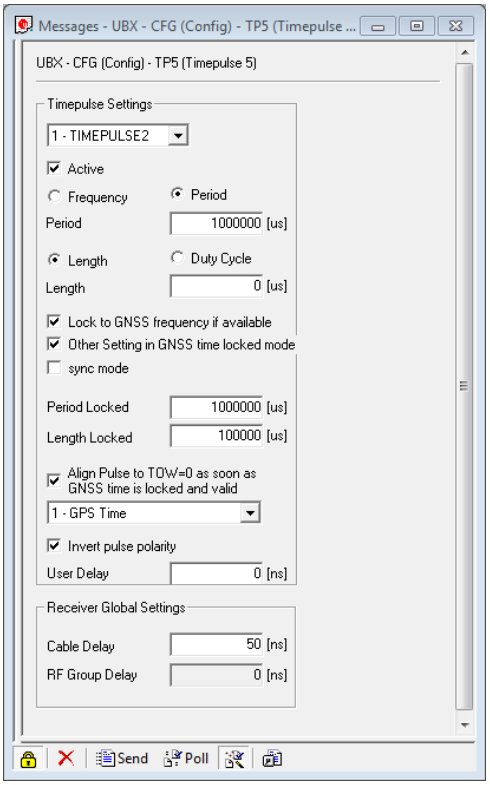


Figure 5: Time pulse configuration

2.5.2 The Top of Second message: UBX-TIM-TOS

The top-of-second message, enabled using `UBX-CFG-MSG`, is a single message containing essential time information for the system host that directly follows each time-pulse.

The `UBX-TIM-TOS` message provides information about the preceding time pulse event and the state of the disciplined oscillators. It provides the time solution value, the disciplining source, the UTC standard in use and the oscillator's frequency offset and uncertainty ppb values. The message's *Flags* bit-field identifies leap second status, SMGR tolerance bounds, time validity, the disciplining source used besides the receiver (T)RAIM status and pulse coherency and locked status. To guarantee that this message is output after the time pulse, it is transmitted during message slot 1, as described in section 2.5.3.

The u-center window in Figure 6 shows the output parameters and information flags.

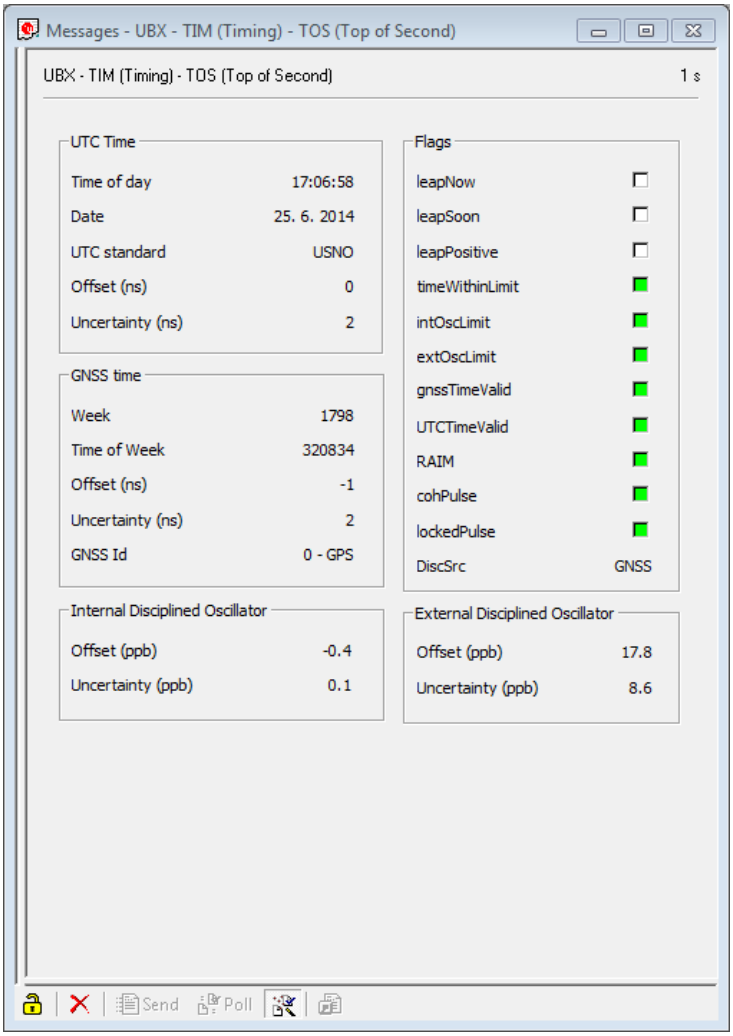


Figure 6: The UBX-TIM-TOS output parameters from u-center

2.5.3 Message Transmission slots

The receiver provides three message transmission time slots, which are synchronized to the leading edge of the time pulse. The `UBX-CFG-TXSLOT` message configures how the time slots are defined for each of the module interfaces: SPI, UART1 and DDC(I2C).

☞ The USB interface is not intended for this use as its timing cannot be guaranteed.

The end of each slot can be specified using this message. The slot beginning starts where the circularly previous slot ends (i.e. slot 0 starts when slot 2 finishes). The module starts with the following default configuration for all interfaces.

- Slot 0 (to +10ms) is empty
- Slot 1 (to +50ms) is for UBX-TIM-TOS only
- Slot 2 (to +900ms) is for all other messages

The time pulses follow each other and their associated priorities decrease in this order. Figure 7 below shows the relationship between successive time slots.

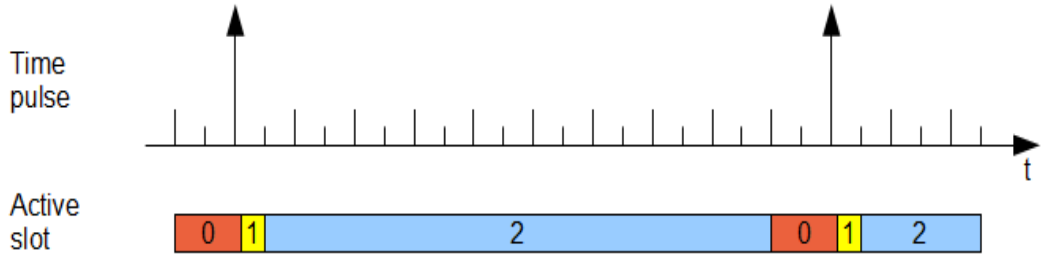


Figure 7: Message Transmission Slot Organization

For more information, see the *u-blox M8 Receiver Description Including Protocol Specification* [1].

2.6 Disciplining External Oscillator Sources

Apart from the module's internal VCTCXO, the LEA-M8F can discipline one other external frequency/time source. This gives the system designer an option to provide an alternative disciplined reference frequency or time base besides the module's 30.72 MHz output.

An external oscillator is controlled by the following methods:

- via a DAC connected to the dedicated DDC (I2C) interface pins (SDA_DAC,SCL_DAC)
- via messages sent to the host which controls the oscillator

☞ The dedicated DDC interface is a bus master designed to support a single controlled DAC only. The LEA-M8F internal frequency control mechanism is organised separately to these methods.

The use-case example shown earlier has been modified with the addition of an external oscillator using the dedicated DAC control option. This is shown below with an explanation of the UBX messages required to configure the module for external oscillator control.

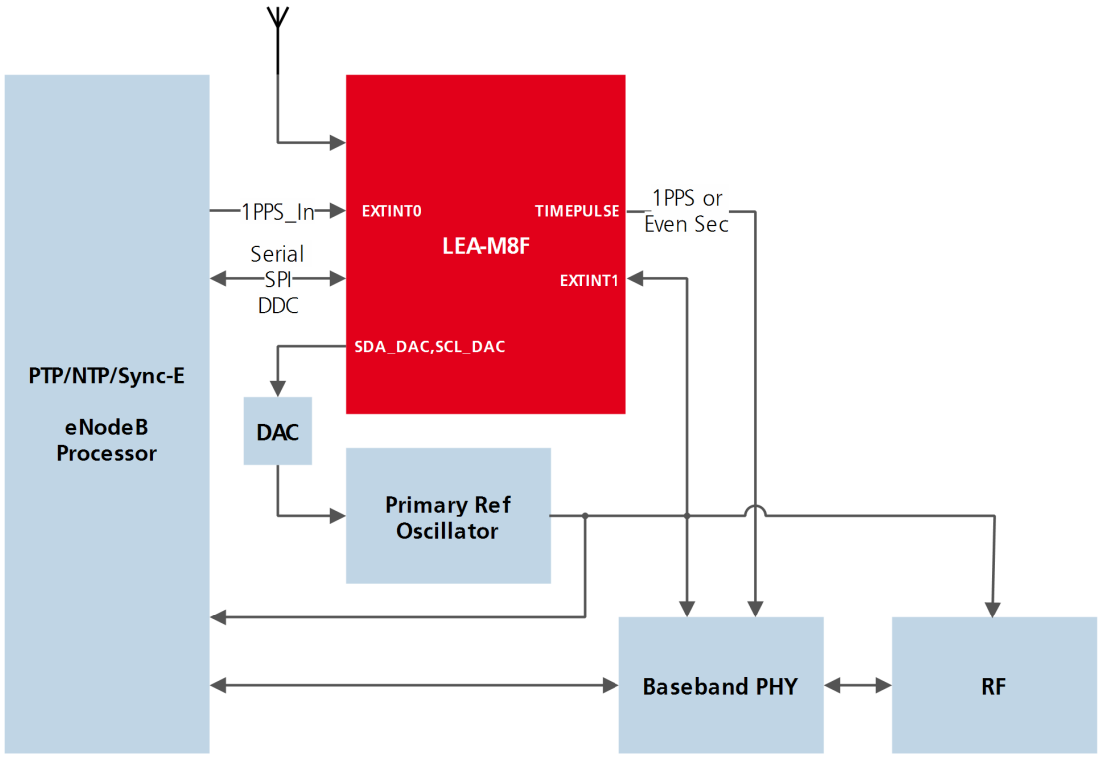


Figure 8: Adding a disciplined frequency source

2.6.1 UBX-CFG-DOSC: Configuring disciplined oscillators

The UBX-CFG-DOSC message describes the disciplined oscillator parameters and the method used for frequency adjustment.

☞ The LEA-M8F internal oscillator parameters are set during production and should not need to be changed.

When configuring an external oscillator, control is provided directly by the dedicated DDC interface or via a connected host. The module supports two industry-standard DACs using the dedicated DDC interface: a Microchip MCP4726 or Texas Instruments DAC8571; refer to u-blox Support for use of other DACs. When the host controls the oscillator, it must interpret UBX-TIM-DOSC messages from the receiver to pass on the desired DAC value. Here, 12, 14 and 16 bit DAC values can be configured in the UBX-CFG_DOSC message to suit the DAC word size.

☞ Phase locked performance using host control may be poor owing to the variation of transmission delay.

When configuring for use with an external disciplined oscillator the following message parameters are required:

- Nominal Oscillator frequency (Hz)
- Phase offset with respect to time pulse (ps) — For setup and hold trimming between clock and PPS
- Stability over temperature range (ppb) — Stability limit
- Stability with age (ppb/year) — Term aging rate
- Time to operating temperature (s) — Time for oscillator model to grow to limit above
- Oscillator control gain (ppb/lsb)
- Oscillator gain uncertainty, 1 sigma — Including measurement uncertainty, linearity etc.

The message flags control:

- Settings for the internal and/or external oscillator
- The calibration status (isCalibrated)
- The means for control interface for an external oscillator (controlIf)
    - Either preferred DACs (TI DAC8571 or MicroChip MCP4726)
    - 12, 14 or 16 bit DAC values sent via UBX-TIM-DOSC to the attached host

The following settings are an example for an external 20 MHz VCOCXO taken from a u-center message view with its associated external source configuration message.

☞ The UBX-CFG-ESRC message shows this external oscillator source as type 3 (feedback ext osc) which means that it will be disciplined if the *disableExtern* flag in the CFG-SMGR message flag is reset.

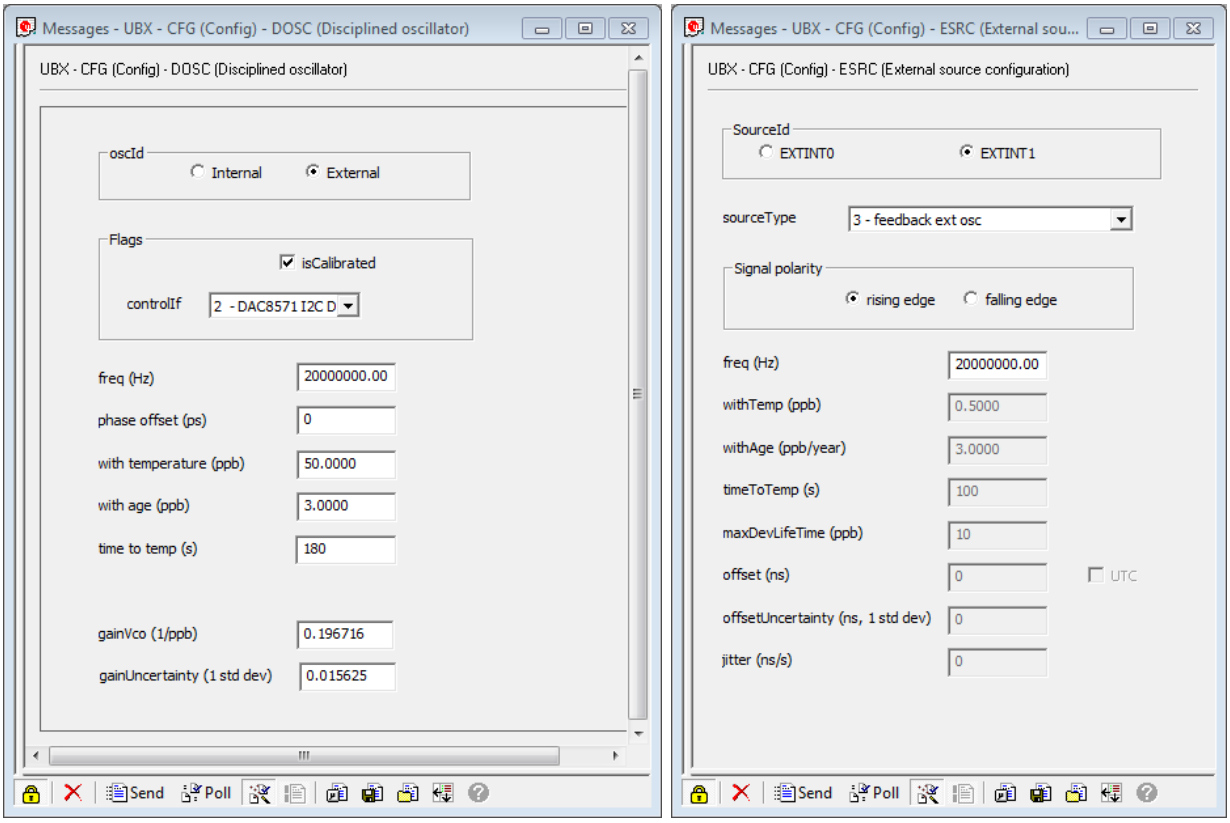


Figure 9: Disciplined Oscillator Settings

If known, the calibration values can be applied directly in the message. However, the oscillator control gain can also be determined using the built-in calibration facility described below (section 2.6.2). When run, the resultant calibration values will be available when the UBX-TIM-VCOCAL message is polled.

In use, the oscillator gain is assumed to be quite stable over time, however the frequency offset of the oscillator is assumed to change with aging. Due to the oscillator's offset changing with time (albeit slowly), the frequency offset is updated (approximately every 30 mins) and held in flash memory. The gain is updated only on request or after a successful calibration operation.

Similar parameters to those for UBX-CFG-ESRC (fast and slow aging, frequency noise) are used to specify the stability of the oscillator.

2.6.2 UBX-TIM-VCOCAL: calibrating a disciplined oscillator source

Any controlled oscillator is characterized by two metrics: an *offset* (control voltage for nominal frequency) and a *gain* (relative frequency change for unit control voltage change)[1]. It is assumed that any temperature compensated or ovenized voltage controlled oscillator used has a constant ratio of *relative* frequency change to control voltage change.

The UBX-TIM-VCOCAL calibration message initiates a utility function to establish the gain of a disciplined oscillator for subsequent use by the SMGR. It takes place in response to a specific UBX-TIM-VCOCAL message from the host to calibrate a single source. During this phase, the SMGR forces oscillator frequency variations by changing the input of the digital to analogue conversion device whose output is driving the oscillator. The oscillator gain is estimated after several frequency measurements have been performed.

An ongoing calibration process can be aborted using the same UBX-TIM-VCOCAL message with appropriate flag settings. Upon completion of the process, a UBX-TIM-VCOCAL message is sent to the host with the estimated gain and gain uncertainty parameters. Otherwise if unsuccessful, these values are set to zero.

[1] Relative frequency change is relative to nominal frequency; the gain might be e.g. 6 ppm/V

The message is used mainly for estimating an external oscillator gain when configuring it as a feedback source within an external source configuration message – see section 2.6.1 above.

☞ The internal disciplined oscillator is calibrated in production and should not need to be re-calibrated in normal use. For an external oscillator the oscillator designated by sourceType 3 "feedback from ext. osc." in the UBX-CFG-ESRC message is the one subject to the procedure.

☞ The customer must ensure that calibration of an external oscillator takes place during the end product production

In order to enter the calibration mode it is required that:

- A stable frequency source is available for the duration of the calibration. This source may be a GNSS solution or a frequency signal on a FREQ_PHASE_IN pin.
- The oscillator subject to calibration is configured via the UBX-CFG-DOSC message and available for the duration of the process.

For an external oscillator, it is also assumed that the useful range of the input is covered by the output of the DAC and that there is a broadly linear relationship of frequency versus DAC input.

It is recommended to supply an initial estimate of the external oscillator's gain parameter through the UBX-CFG-DOSC message. Otherwise, the calibration process can fail or take a prohibitive amount of time.

To initiate a calibration operation the message requires the following parameters:

a) Identity of the oscillator to calibrate; Internal (module) or External
b) Source of reference frequency (GNSS, Freq_Phase/EXTINT)
c) Start, End and step values (DAC) for the calibration run

At the end of a calibration procedure, the message reports the following parameters:

a) Gain value of oscillator (or 0 to indicate calibration failed)
b) Relative gain uncertainty after calibration (0 if calibration failed)

The u-center view of this message is shown in Figure 10. It shows the calibration range parameters plus the resultant gain and uncertainty values from a previous run.

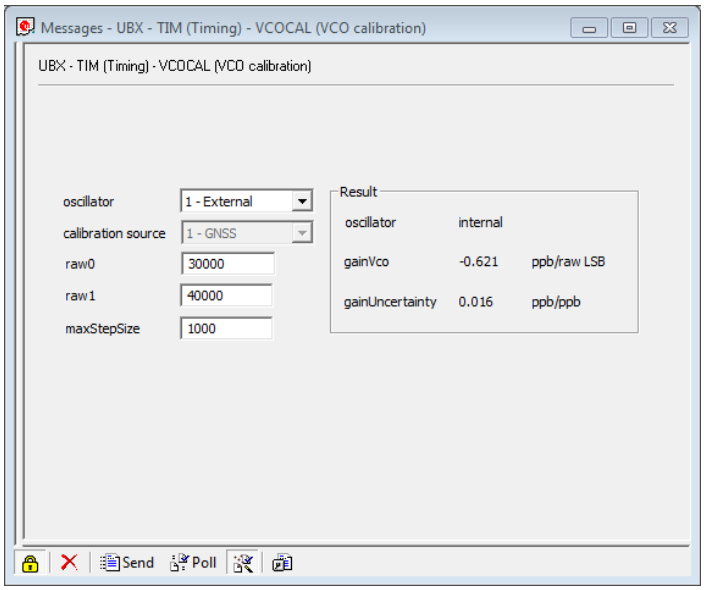


Figure 10: TIM-VCOCAL message

2.6.3 UBX-TIM-DOSC

If the user has configured the external oscillator control as a 12, 14 or 16 bit DAC value, then an oscillator disciplining (frequency adjustment) request message is sent from the module to the host. Essentially, UBX-TIM-DOSC provides a raw value for the host system to be written to a DAC controlling the voltage controlled oscillator. The word width used is determined by the *controlIf* flag setting when the disciplined oscillator method is configured via UBX-CFG-DOSC.

Once a frequency or timing control system is configured, the user can monitor the frequency and time parameters using the following UBX message.

2.6.4 UBX-TIM-SMEAS: observing the source measurements

This measurement message provides a view of the SMGR output estimates of phase and frequency offsets from all sources enabled via the CFG-SMGR message. This can include the following sources:

- The GNSS solution,
- The module internal oscillator
- Both Freq_Phase /(EXTINT) inputs

Flags provide an indication of the phase and frequency measurement validity for all sources.

Apart from measurement information, the message is also used to communicate measurements made by the host of either the internal or external oscillator the systems oscillators.

☞ This facility must be enabled via the UBX-CFG-SMGR message flag word by setting the appropriate flag bits (*enableHostMeasExt,enableHostMeasInt*). Otherwise, any measurement feedback from the host will be ignored. The following u-center view shows the message measurement output with all four receiver derived measurements active.

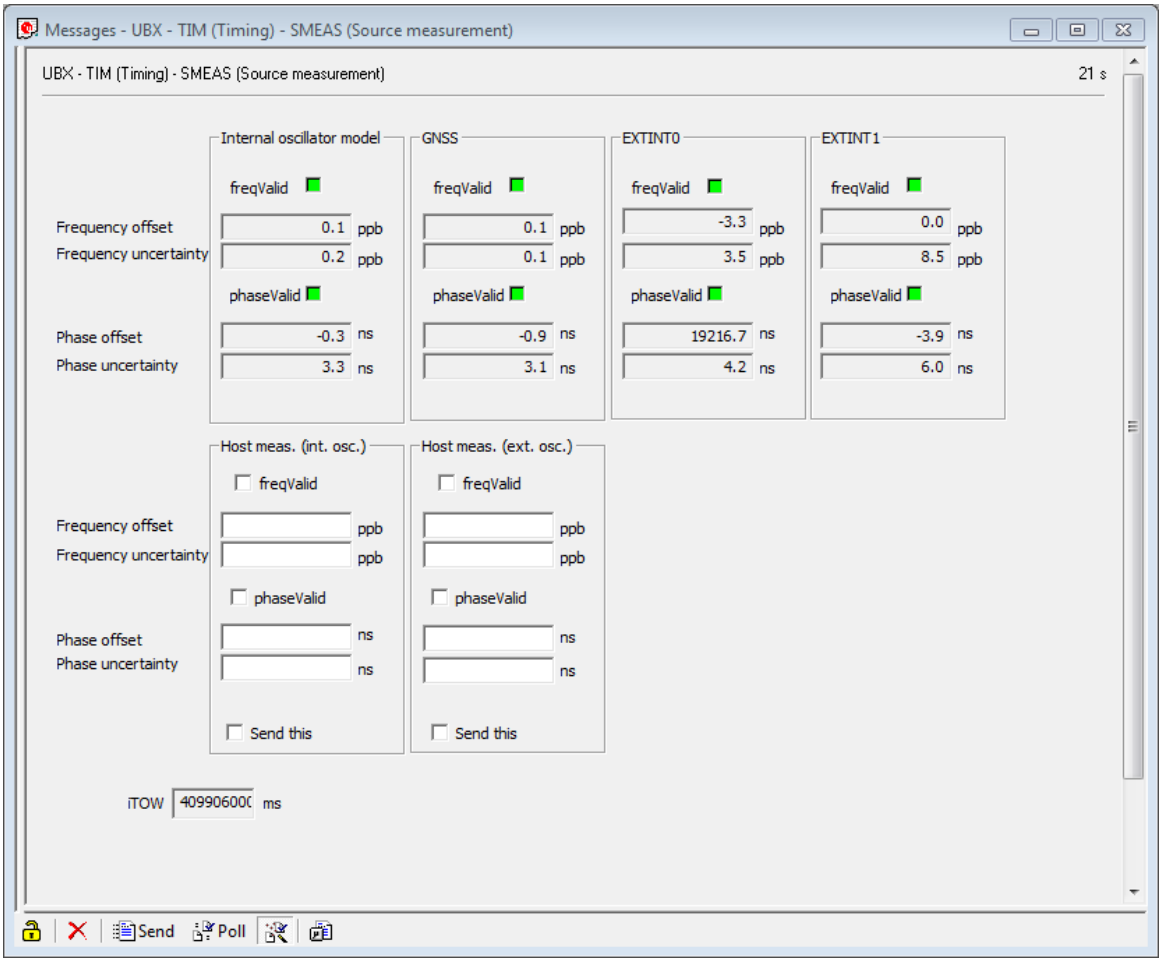


Figure 11: SMGR Measurement outputs

2.6.5 UBX-TIM-FCHG

This is a frequency change message sent by the receiver indicating the adjustments made to the internal or external oscillator and enables a host to monitor the system operation as it progresses. The u-center message view (shown below in Figure 12) is a useful facility to monitor these oscillator control values.

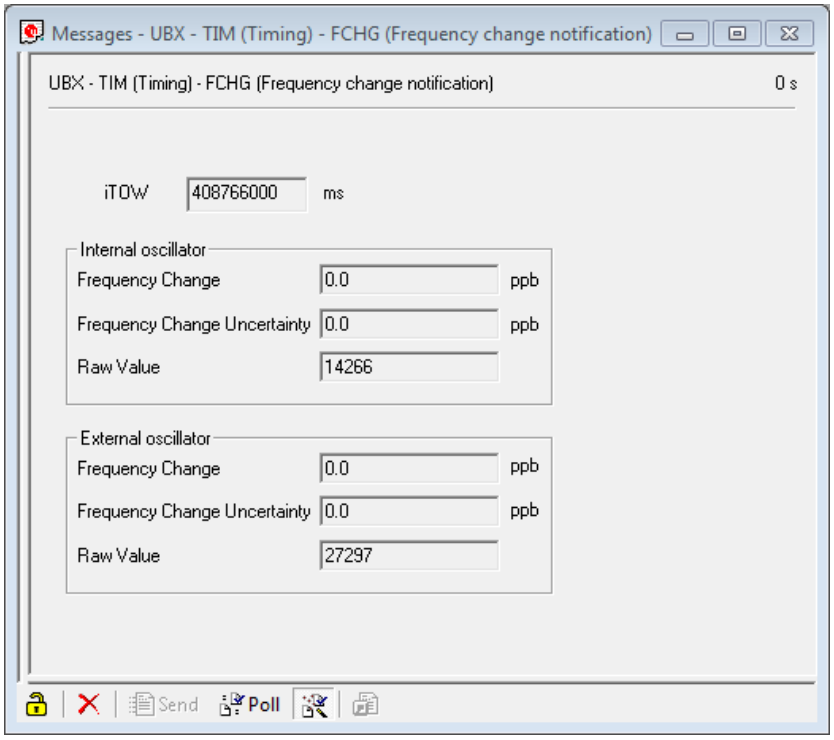


Figure 12: FCHG message output

2.6.6 UBX-TIM-HOC

This message enables a host system to force the receiver to bypass the internal control and update either the internal (module) or external oscillator's frequency. This can be particularly useful when a large step change is required to bring an oscillator close to its tuned condition faster than the normal pull-in rate. It is advisable to disable disciplining the oscillator to prevent the SMGR cancelling any of the frequency change, and then re-enable once the step has been accomplished. This can be done by resetting the *disableIntern* flag in the `UBX-CFG-SMGR` message. Be aware that large changes to the internal oscillator frequency can have a detrimental effect on the receiver satellite signal tracking and may cause it to lose track.

2.6.7 UBX-MON-SMGR

This message provides the current SMGR status plus the state of the internal (module) and any optional external oscillator operation modes. The current disciplining source is identified, which can be the GNSS solution, internal or external sources or host measurements. The particular state of the oscillators is shown, i.e. whether idle, running (autonomous), undergoing calibration or being steered by a host. The user can also ascertain whether it is disciplined and calibrated. The u-center view in Figure 12 shows these messages parameters.

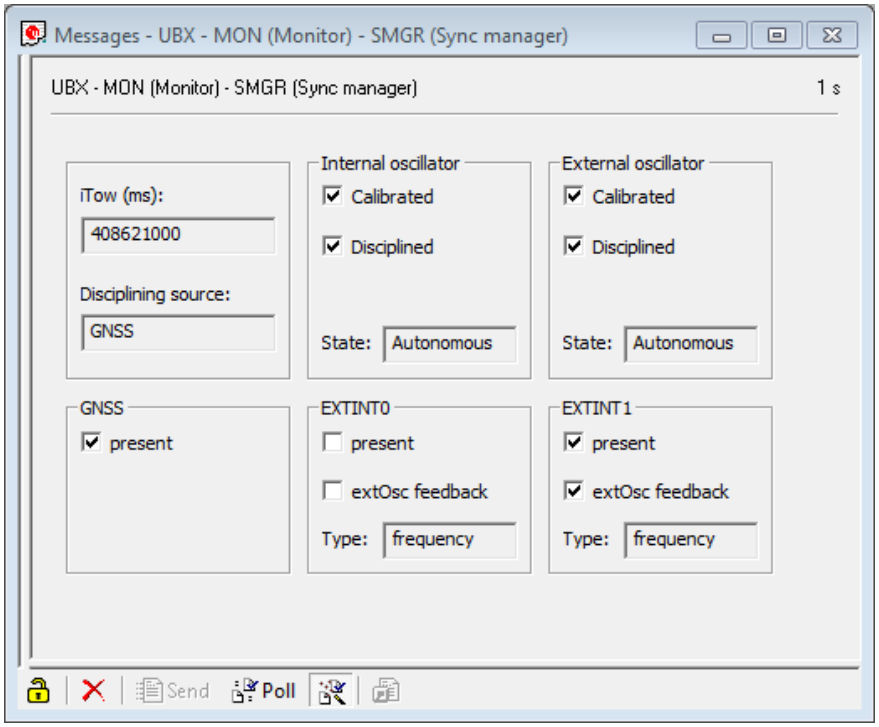


Figure 13: SMGR monitor message output

2.6.8 UBX-CFG-TMODE2

This message enables the receiver to work in a stationary mode typical of a timing receiver in which only time is calculated. The user can optionally set the antenna coordinates if known or begin a survey-in procedure to find and fix the antenna location. After this, the receiver will only calculate time, as the position will be fixed. Knowing the fixed location provides a timing estimate with typically lower jitter, plus allows the receiver to continue operation in single satellite mode and work using (T)RAIM analysis.

2.6.9 UBX-TIM-SVIN

The survey-in message indicates the progress and validity of timing improvement through location averaging and availability of single-SV timing. This message allows the current state of the survey-in mode to be queried as to whether it has fulfilled the required accuracy requirements or exceeded the observation time.

2.7 Additional Operational Messages

In addition to the general FTS related messages discussed above, the following set of messages will be of interest to customers designing for assisted operation, setting particular GNSS constellation. As before, these descriptions give an overview of the likely message usage; the specific requirements and specification of each message is given in the *u-blox M8 Receiver Description Including Protocol Specification* [1].

2.7.1 UBX-CFG-GNSS

This selects the GNSS constellation that the receiver should use if the user wishes to restrict the GNSS constellations in use. The receiver default is to enable GPS, GLONASS and QZSS.

If a change in the combination of GNSS constellation requested needs a different combination of frequencies then the receiver has to restart (e.g. a change from GPS+GLO to GPS+BDS will always need a restart). However, it is possible to enable or disable different GNSS constellations without a restart by changing the number of channels assigned to the GNSS. To do this only the Channels Min and Max values should be altered in the UBX-CFG-GNSS message, not the Enable flags.

☞ Use of SBAS is disabled by default, which is the recommended setting as the SBAS constellation time-base is not modeled separately and if enabled can degrade the wanted timing accuracy.

2.7.2 Assistance Messages and High Sensitivity Operation

The module offers an enhanced sensitivity acquisition algorithm which when coupled with external assistance data allows GNSS signal acquisition down to -157 dBm.

The multi-GNSS assistance (MGA) messages provide this facility by pre-setting the receiver with broadcast GNSS data, accurate time and approximate position to enable starting. Once aided, the receivers' sensitivity is effectively extended, enabling operation under poor signal conditions, e.g. inside buildings. Moreover, periodically uploading assistance data in these circumstances enables the receiver to continue operation with GNSS signals below the data demodulation threshold providing continued operation as the satellite constellation changes.

The following UBX messages supply the following particular assistance data sets:

- UBX-MGA-GLO GLONASS orbit and clock assistance data to the receiver.
- UBX-MGA-GPS GPS Ephemeris and Clock data plus ionospheric assistance data to the receiver.
- UBX-MGA-QZSS QZSS Ephemeris aiding data to the receiver.
- UBX-MGA-INI location, fine and coarse time, time-drift, leap-second and frequency aiding data to the receiver

Assistance data can be downloaded from the u-blox AssistNow Online internet service. Otherwise, customers can obtain assistance data from alternate sources (eg. SUPL/RRLP) and generate the appropriate UBX-MGA message themselves. More information is provided in the *u-blox M8 Receiver Description Including Protocol Specification* [1] and the *MultiGNSS -Assistance User Guide* [3].

☞ FTS products do not support AssistNow Offline and autonomous operation.

To provide the best outcome, be sure to provide information only on the satellites in view. When calling the AssistNow service a reference position parameter can be provided so that the assistance server will provide only those SVs in view at the reference location. This is invoked when the *filteronpos* option is set within the service HTML request and by setting the position flag under "Filter Ephemeris On:" in u-center. This will ensure the receiver makes best use of the memory holding the satellite broadcast data for high sensitivity processing. Providing a good estimate of time within 1-2 seconds will also help. Remember to invoke the *pos* calling option to provide an MGA-INI-POS-LLH message to initialize at the reference location. This is done within u-center by setting the "position" flag under Data Type.

The u-center MGA AssistNow Online window is shown below in Figure 14. The particular parameter setting is shown for cold starting the receiver in which Ephemeris, Time and UTC time offsets plus position assistance data are provided. All the basic variation of MGA messages can be enabled by selecting the appropriate "GNNS", "Data Type" and "Time Aiding" options. The desired reference position can be sent to enable the service to provide the relevant satellite data. The HTML server request string to the AssistNow server is also shown for information, a useful feature that shows how a server request can be built up.

☞ The u-center AssistNow settings provide a periodic up-load feature which operates when the "Run in background" flag is set; a useful feature when testing a receiver or evaluation kit for long term operation. The upload period should be set according to the nominal constelations ephemeris up-load frequency, i.e. 30mins for GLONASS and 2Hours for GPS/QZSS

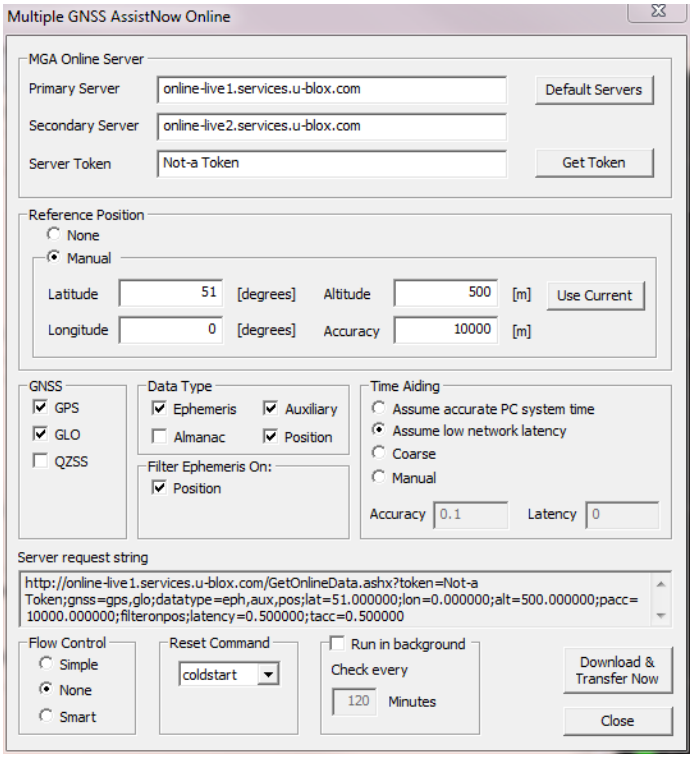


Figure 14: u-center AssistNow Online window

2.7.3 UBX-NAV-SAT

The u-blox M8 allows use of up to 20 navigation channels. Therefore, the navigation solution will only include up to 20 measurements from different satellites, even if more signals are being tracked. The receiver selects the set of measurements for concurrent GNSS operation. The UBX-NAV-SAT message provides information about satellites that are either known to be visible or currently tracked. It gives a description of each signal candidate, its quality and whether being used in the current fix plus health, almanac and ephemeris status. Since the change to M8 firmware, users are recommended to use this instead of the now deprecated NAV-SVINFO message, which they may have been familiar with.

3 The Synchronization Manager

3.1.1 Overview

The following section provides more information concerning the Synchronization Manager (SMGR) operation and is included to help put the initial sections into context. The SMGR is the major software entity, which makes internal and external phase and frequency measurements, derives the disciplining commands (necessary frequency change) and assesses the quality (uncertainty) of input time and frequency signals.

The SMGR can make use the following synchronization sources:

- The GNSS time and frequency solution
- The module internal VCTCXO oscillator (30.72 MHz)
- Up to two external signals: frequency and/or time pulse reference signals on Freq_Phase/INT input pins
- Externally conducted measurements sent from a host via UBX messages

The SMGR evaluates each source of frequency or phase to select the best one for control given their characteristics (phase noise and stability) and uncertainty of their measurements. These can be the GNSS receiver solution or external sources of phase or frequency. Depending on the choice of disciplined oscillator, corrections will be made to the internal VCTCXO and/or externally via a dedicated DDC(I2C) interface which controls a DAC for setting an external oscillator control voltage. Corrections can also be made indirectly as the SMGR provides output frequency change UBX messages that enable a connected host to adjust the external oscillator frequency.

A diagram identifying the main elements associated with the SMGR is shown in Figure 15.

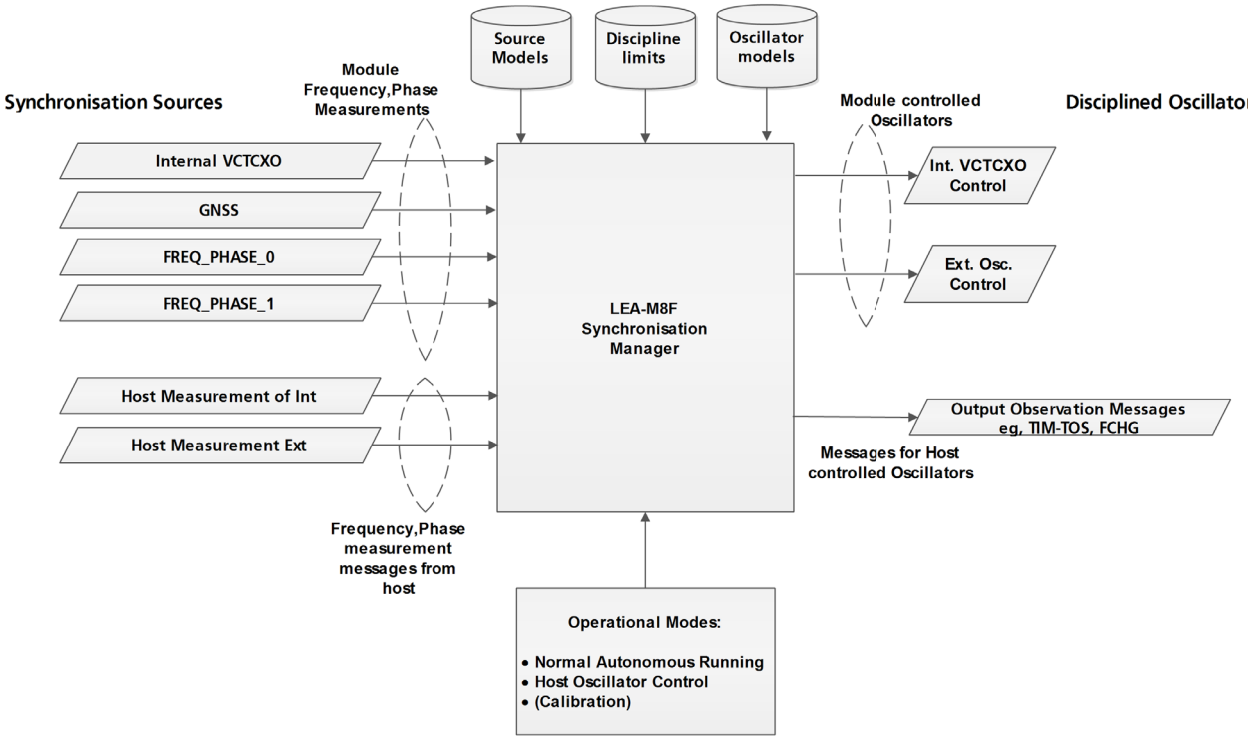


Figure 15: Logical representation of the Synchronization Manager

3.2 Sync Manager Operation

The SMGR operates in either a frequency locked or phase locked mode dependant on the reference source type and configuration setting. The SMGR runs under one of these specific modes:

- Normal (autonomous) operation
- Host driven steering
- Calibration

3.2.1 Normal Operation

In normal running also described as *autonomous mode* the sync manager uses the best available reference source to discipline either the module VCTCXO and/or an external oscillator.

The sync manager runs once every second and retrieves the most recent measurements for each source along with the estimates about their respective uncertainty. The source with the smallest estimated uncertainty is selected as the reference for oscillator steering. SMGR configuration parameters can set the frequency adjustment rates to prevent large frequency errors so that FLLs in the user's system can maintain lock. Once within a nominated frequency error the system can begin PLL operation. Then any measured phase error is corrected by a controlled frequency shift. The rate of correction applied is dependent on the uncertainty of the incoming phase information and the phase correction rate can be limited to avoid large intentional frequency offsets.

The uncertainty of external sources fed into the module is determined with respect to the GNSS reference by an estimation filter. The filter output provides a measure of the accuracy of the estimated phase and frequency. If the use of a source is disabled and re-enabled, the filter state is reset and will take approximately 10 s to build up a working uncertainty estimate for the applied source(s).

The SMGR uses only one reference source at a time and does not combine measurements from different sources in any way; it especially does not use time information from one input signal if another one is chosen as reference due to more reliable frequency measurements. The timing output may therefore accumulate a significantly larger time error than the accuracy of a time reference input.

If the selected reference provides a time error measurement then a phase locked loop is possible, otherwise the receiver automatically enters frequency lock even if configured to maintain phase lock.

3.2.2 Host-driven oscillator steering

In some applications, the host software may drive an oscillator directly using the `UBX-TIM-HOC` message. This may be useful after a hold-over period where the reported timing error is too large for normal operation and the host chooses to steer the oscillator towards the correct timing in large steps. In this case the maximum phase correction limit is ignored by the SMGR. To prevent the system offsetting the required frequency change, it is recommended to temporarily disable oscillator disciplining by using `UBX-CFG-SMGR` control flags prior to sending host commands. Another use of the direct host-driven steering can be the calibration of other parts of the system.

3.2.3 Oscillator Calibration

The oscillator calibration facility, described in section 2.6.2, is a utility function in which all disciplining operations are suspended and therefore all oscillators, whether the module (internal) or an external oscillator, cease to produce usable outputs.

Systems that involve the host controlling an external oscillator are excluded from the calibration process. It is assumed that the host will carry out any necessary calibration and set the appropriate parameters in `UBX-CFG-DOSC` with `the calibStatus` flag set. The receiver can report frequency measurements of the external oscillator to facilitate this, and such behavior is covered within the normal operation of the receiver.

3.3 Measurements by the host

The host system may measure the output of one or both disciplined oscillators and send the results to the LEA-M8F via a `UBX-TIM-SMEAS` message. The SMGR must be configured via the `UBX-CFG-SMGR` message flag *enableHostMeasExt* to enable this, otherwise any host measurement messages will be ignored.

After reception, the SMGR considers these recent measurements together with measurements on other sources. This means that the SMGR assumes that the delivered measurements and their respective uncertainties take into account frequency changes during measurement ie. the SMGR expects the measurements to have been made after the disciplining has taken place. The host has two options to deal with frequency changes due to disciplining:

- Account for the changes in the measurement algorithm
- Increase the uncertainty for the measurement depending on the changes done

3.4 Fixing the reference source

If for some time the user wants to fix which source to use as reference, then the other sources must be disabled through the *enable* source flags within the `UBX-CFG-SMGR` message.

☞ The module internal oscillator cannot be disabled separately because all other sources are measured against it. When all other sources are disabled the sync manager will not make any corrections on any disciplined oscillator.

3.5 Hold-Over Operation

When the reference source (normally GNSS) is not present for any reason, the disciplined oscillators are maintained to produce the best estimate of output frequency. The stability of the resultant output is then dependant on the inherent stability of these oscillators.

The system will essentially degrade the stability parameters of the connected sources with time and decide which one to use. Stand-alone, the hold-over performance is governed by the internal oscillator's performance over temperature. However, when an external source is used with better stability the SMGR will use this oscillator to maintain its time base. Hence, even though an external oscillator is not disciplined, the fact that it has greater stability is used to maintain the same frequency difference with respect to the internal oscillator, effectively transferring the greater stability to the internal oscillator.

4 Example Design Use Case

The following example examines more closely the logical interconnection and typical signaling required for a particular timing scenario. Essentially, this expands upon the information and examples given earlier together with typical receiver-host interaction messages.

4.1 External (coherent) PPS

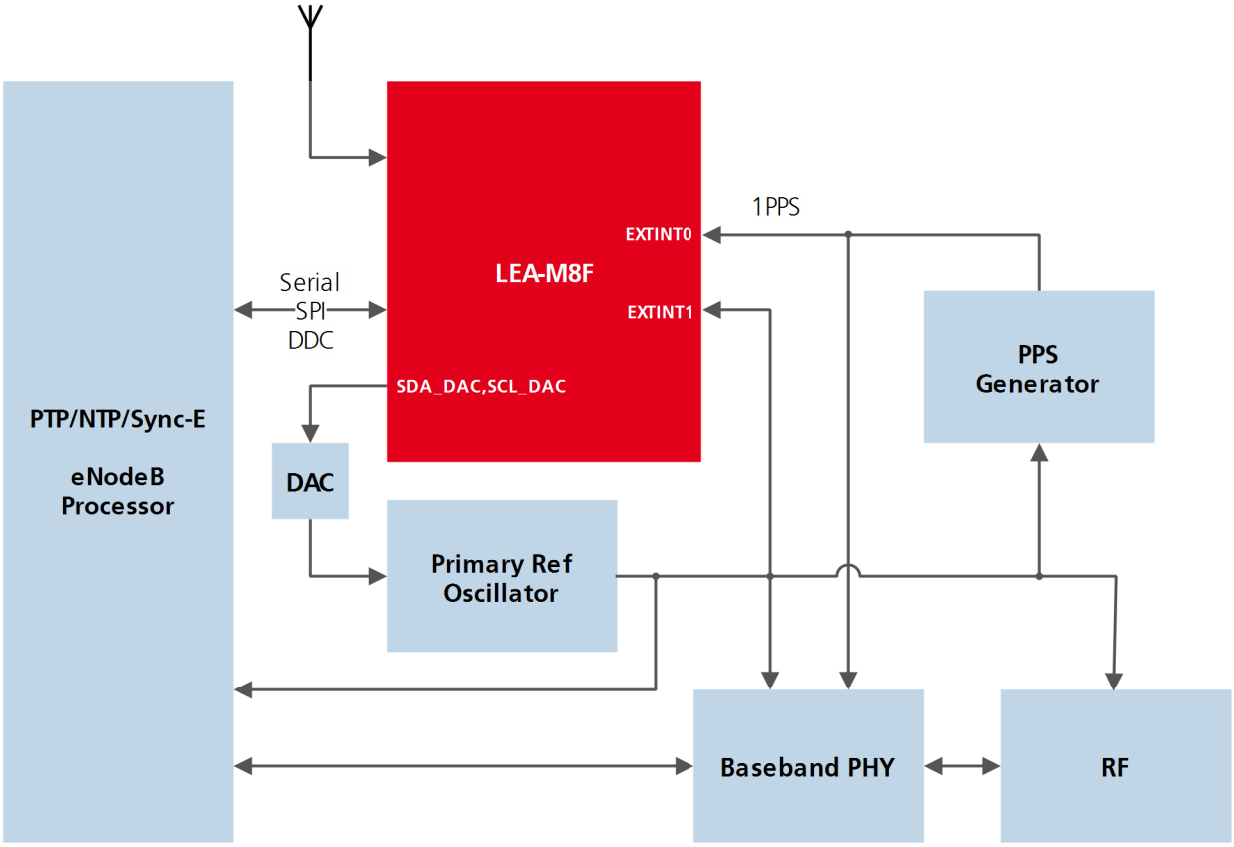


Figure 16 System with external frequency reference and PPS generation

In this example, the system PPS is generated outside the module and the LEA-M8F can measure this PPS phase against GNSS time. The platform may support step changes in the phase of PPS to accelerate acquisition, may require phase to be adjusted by a small reference frequency change, and may require phase offsets to be simply reported with no adjustments made to phase or frequency for this purpose. (The oscillator may be controlled either via a directly connected DAC or via the host.)

4.2 Observations

4.2.1 Self-Calibration

The receiver may need to run the self-calibration utility (`UBX-TIM-VCOCAL`) prior to operation, dependant on knowledge of the oscillator parameters.

4.2.2 Startup

GNSS acquisition can be aided by:

- Primary reference oscillator to help estimate the frequency error of the GNSS oscillator (if inherently of better quality than GNSS oscillator).
- Optional assistance messages when time/position assistance is available and/or when data demodulation is expected to be difficult.

4.2.3 Operation

The Phase of the external PPS signal generated is measured against the GNSS solution and reported to the host.

The frequency of the primary reference oscillator is measured and controlled to be as close to the target frequency as possible.

☞ The module 1 PPS output is not used in this example.

4.2.4 Holdover

The receiver should hold the current DAC value; the hold over performance is then governed by the inherent quality of the Primary Reference oscillator.

4.2.5 Message Interaction with Host

The following message interaction diagram shows a typical exchange between the host controller and the module. Some explanatory notes are given adjacent to the message interaction chart. In this exchange, the module is assumed to be initially powered up and then configured. Firstly, with information relating to the external 1 PPS and external oscillator parameters and secondly, setting the primary reference oscillator as a disciplined source. Initially, all oscillator disciplining is turned off. If there are no calibration parameters available for the external oscillator (primary reference oscillator) then a calibration step is performed to provide a reasonable gain value. The external oscillator is assumed to possess a higher frequency accuracy than the module and the SMGR should then use this as the reference prior to GNSS acquisition. After this, the GNSS operation will start, disciplining of the oscillators can be enabled, and the reference will revert to a GNSS source. Note that the external oscillator can be disciplined either via the frequency feedback into EXTINT1 or via the 1 Hz PPS signal at EXTINT0 depending on whether the external 1 PPS source is synchronized or not. The top of second message is monitored providing current time information and the states of frequency offset and uncertainty of the internal and external disciplined oscillators.

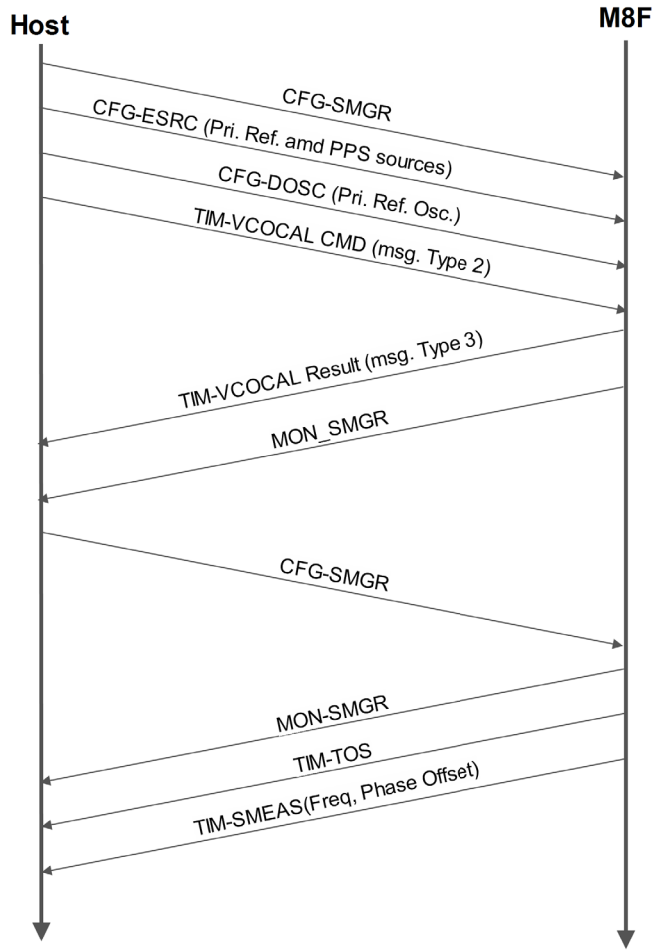


Figure 17 Host Module interaction

Notes on Host-Module message interaction:

- CFG-SMGR: Configure SMGR operation
  - Disable all source disciplining
  - (Enable MON-SMGR for SMGR status reporting)
- CFG-ESRC: Configure the external sources
  - PPS source at EXTINT0 as time source
  - Primary Ref. Osc. at EXTINT1 as frequency source
- CFG-DOSC: Configure the disciplined source
  - Set the primary ref. osc. as "feedback ext osc"
  - Provide approximate params, ControlIF = DAC
- TIM-VCOCAL: Calibrate external oscillator with respect to internal oscillator (send msg type 2; provide range for a cal run)

  Wait for TIM-VCOCAL (type 3 msg; with return value, status)
- MON-SMGR: RX should be using the external oscillator as disciplining source
- CFG-SMGR: Configure SMGR to discipline both oscillators:

  Setting for Freq or Phase lock, i.e. whether the external PPS is required to be used as timing source.
- TIM-TOS: Host monitors the Top of Second message data (use CFG-MSG to enable Top of Second message for appropriate interface)
- TIM-SMEAS: Monitor current measurements

Appendix

A Operational Issues

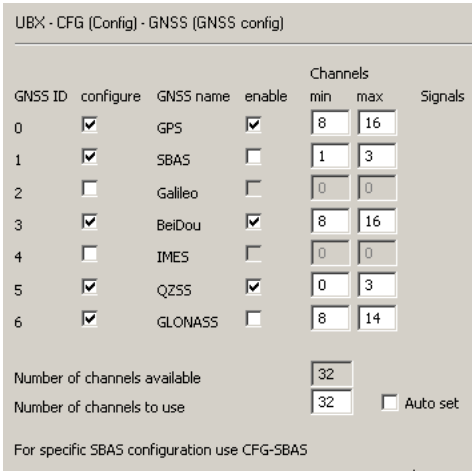
This section examines some less typical operational issues prompted from customer feedback.

A.1 Changing between GNSS constellations – without restarting.

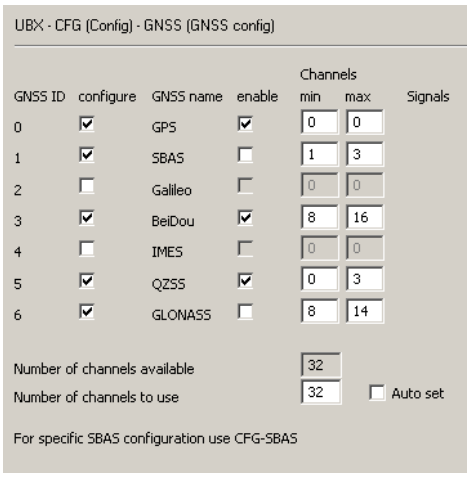
If the CFG-GNSS message enables a different GNSS constellation, this action provokes a system reset which will interrupt the PPS generation. The following procedure ensures that the time pulse continues during constellation changes between two GNSS systems.

The following shows an example, starting with GPS+BeiDou operation and turning on and off each constellation in sequence.

Start with GPS and Beidou:

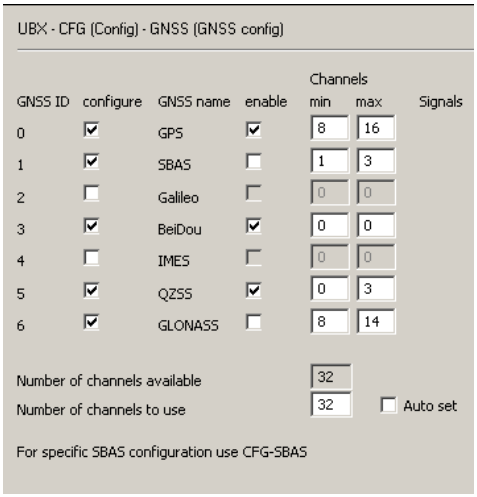


Then change to BeiDou only:

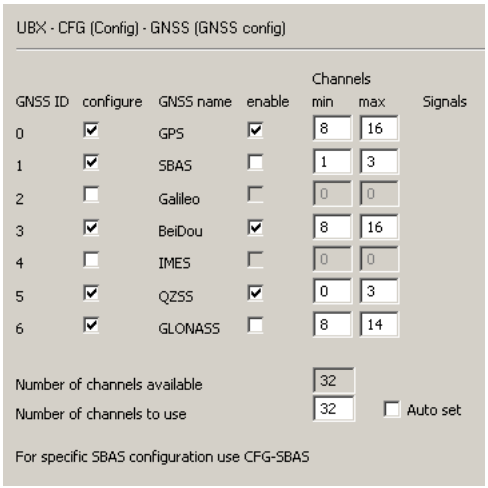


Note: only change the channel min and max numbers.

Then change back to GPS only:

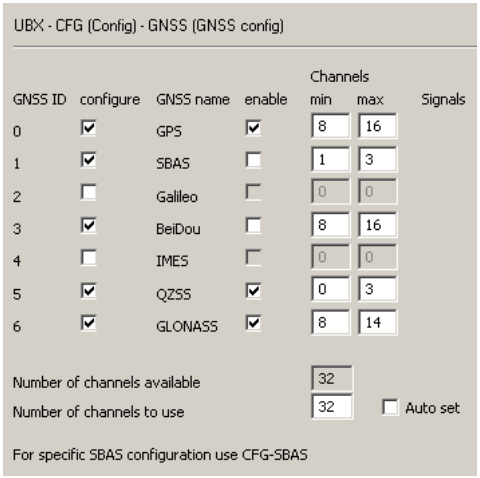


Then back to GPS+BeiDou:

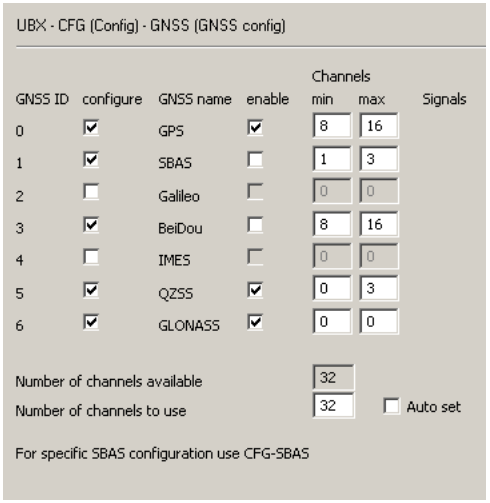


Each of these changes will not provoke a reset.

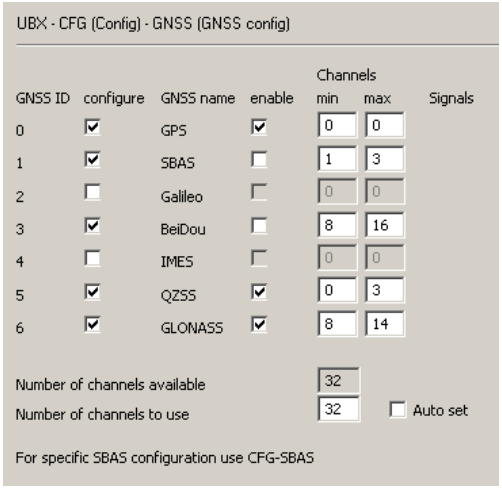
If changing to GPS+GLONASS, it will require one reset to reconfigure the receiver RF front-end.



Then to GPS only:



and GLONASS only with no reset:



A.2 Use of a time source only

Some LEA-M8F implementations may be designed to work with a time reference input only and not rely on GNSS to provide phase information. This can occur for applications which are designed for deep indoors and use network timing (NTP,PTP).

In these cases, the time pulse output will not be enabled, as the "locked" status for CFG-TP5 will not be met because the system has no information about absolute time, which is normally taken from the GNSS fixes. To produce a time pulse, the user can initialize time in the receiver by issuing an MGA message containing time information. The time assistance message needs to specify an accuracy of 0.1 s or better.

B Glossary

Abbreviation	Definition
BeiDou	Chinese Navigation System (BDS)
DAC	Digital to Analog Convertor
DOP	Dilution Of Precision
FLL	Frequency Locked Loop
FTS	Frequency and Time Synchronization
GLONASS	Russian satellite system
GND	Ground
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
NTP	Network Time Protocol
PCB	Printed circuit board
PLL	Phase Locked Loop
PPS	Pulse Per Second
PTP	Precision Time Protocol (IEEE 1588)
QZSS	Quasi-Zenith Satellite System
RAIM	Receiver Autonomous Integrity Monitoring
SYNC E	Synchronous Ethernet (standard for transference of clock signals over Ethernet)
T(RAIM)	Time Receiver Autonomous Integrity Monitoring
TTFF	Time To First Fix
UTC	Universal Coordinated Time
VCOCXO	Voltage Controlled Oven-Controlled Crystal Oscillator
VCTCXO	Voltage Controlled Temperature Compensated Crystal Oscillator

Table 2: Explanation of abbreviations used

Related documents

[1] u-blox M8 Receiver Description Including Protocol Specification (Public version), Docu. No. UBX-13003221

[2] LEA-M8F Hardware Integration Manual, Docu. No. UBX-14000034

[3] Multi GNSS Assistance User Guide, Docu. No. UBX-13004360

☞ For regular updates to u-blox documentation and to receive product change notifications, register on our homepage (http://www.u-blox.com)

Revision history

Revision	Date	Name	Status / Comments
R01	24-Sep-2014	byou	Objective Specification
R02	22-Dec-2014	byou	Updated ROM/FLASH information on page 2; Added appendix A with remedies for customer related operational issues.

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