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EVA-M8

TCXO-to-crystal migration guide

Application note

Abstract

This document provides options and guidelines for migrating the EVA-M8Q TCXO-based SiP module to EVA-M8M crystal-based SiP module. The application note also explains the potential impact on GNSS performance and other possible hardware/firmware concerns.

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Contents

1. Introduction

This application note describes the migration procedure from EVA-M8Q to EVA-M8M.

The EVA-M8Q uses a TCXO, while the EVA-M8M uses a crystal. This small difference in the internal oscillator leads to some considerations described in this document. For example, the frequency tolerance of the crystal is wider than that of TCXO. This means that the receiver must search over a wider range of frequencies, which will extend the time to first fix especially in weak signal conditions.

In addition, the crystal's frequency is highly sensitive to temperature-variant environments. Therefore, the operating temperature, as well as the heat dissipating systems on the board need to be taken into consideration.

Nevertheless, with proper adjustments and design guidelines, crystal-based GNSS receivers can achieve very similar performance to a TCXO-based solution, and are thus worth considering as an alternative to many applications.

2. Migration guideline

2.1 EVA-M8 (Q/M) comparison

The table below summarizes the specifications to be considered during the migration.

Field	Parameter	EVA-M8Q	EVA-M8M
HW	**Oscillator**	TCXO	Crystal
	RTC derived from osc.	Not possible	Possible
	Interface config.	Same	Same
	Pinout	Same	Same
RF design	**Front-end**	With passive antenna, an external LNA is recommended.	With passive antenna, an external LNA is **mandatory.**
	Out of band immunity	Same	Same
Temp.	**Storage temp. °(C)**	Max +85	Max +105
	Thermal isolation [1]	Optional	Recommended
Power Req.	**Supply (Vcc & Vio) (V)**	[2.7 - 3.6]	[1.65 - 3.6]
	Supply current (mA) [2]	22	23
	SW backup current (mA) [2]	0.02	0.02
	HW backup current (mA) [2]	0.015	0.015
Sensitivity (GPS&GLO)	**Dynamic Tracking (dBm)**	-167	-164
	TTFF (sec) [3]	Same	Same
SW	**Firmware**	ROM SPG 3.01 / Flash FW SPG 3.01	ROM SPG 3.01 / Flash FW SPG 3.01
	OTP config.	VCC_IO monitor HIGH	VCC_IO monitor LOW

Table 1: EVA-M8Q to EVA-M8M migration comparison (default mode: GPS & GLONASS including QZSS, SBAS)

☞ When migrating to crystal-based EVA-M8M module, make sure the receiver is not operated in Galileo-only mode. Crystal variants are not suitable for Galileo-only operation due to worse performance (TTFF, sensitivity).

2.2 RF design

For designs without an external LNA or using a passive antenna, it is mandatory to include an external LNA before the EVA-M8M module during the migration redesign, especially for those applications under difficult GNSS visibility or poor reception. If, in addition, strong out-of-band jammers are close to the GNSS antenna (for example, a cellular antenna), an additional SAW filter in front of the LNA might be needed.

Applications with an active antenna or a present external LNA are exempt of RF front-end redesign.

Refer to the EVA-M8 Hardware Integration Manual [1] for more information about passive antenna designs and recommended LNA/SAW components.

[1] Mainly for applications where the GNSS module is under thermal activity on the board.
[2] Single crystal feature disabled. Voltage supply = 3.0 V.
[3] Cold and hot start under good GNSS visibility and using power levels of -130 dBm.

2.3 Power requirements

Crystal-based EVA-M8M allows a wider voltage supply range. This is due to the lower voltage required by the crystal. Nevertheless, products have overlapping operational voltage ranges and similar current consumption when using the RTC crystal.

The table below shows the expected current drawn of EVA-M8M and EVA-M8Q. More information is available in the EVA-M8 Data Sheet [2].

Parameter	Symbol	Conditions	Module	Typ GPS & GLONASS	Typ GPS / QZSS / SBAS	Max	Units
Max. supply current [4]	Iccp		All			67	mA
Average supply current [5]	Icc Acquisition [6]	VCC_IO = VCC = 3 V	EVA-M8M	25	19		mA
			EVA-M8Q	26	20		mA
	Icc Tracking (Continuous mode)	VCC_IO = VCC = 3 V	EVA-M8M	22	17		mA
			EVA-M8Q	23	18		mA
	Icc Tracking (Power Save mode / 1 Hz)	VCC_IO = VCC = 3 V	EVA-M8M	5.3	4.7		mA
			EVA-M8Q	6.2	5.7		mA
Backup battery current [7]	I_BCKP using the RTC crystal	HW Backup mode, VCC_IO = VCC = 0 V	All	15			µA
	I_BCKP using the 26 MHz XTO in "single crystal" operation	HW Backup mode, VCC_IO = VCC = 0 V	EVA-M8M	100			µA
			EVA-M8Q	N/A [8]			
SW Backup current	I_SWBCKP using the RTC crystal	SW Backup mode, VCC_IO = VCC = 3 V	All	20			µA
	I_SWBCKP using the 26 MHz XTO in "single crystal" operation	SW Backup mode, VCC_IO = VCC = 3 V	EVA-M8M	105			µA
			EVA-M8Q	N/A [9]			

Table 2: EVA-M8Q to EVA-M8M power requirements

2.4 Real-time clock (RTC)

In EVA-M8Q designs without RTC, the TCXO-to-crystal migration offers the option to enable the EVA-M8M's single crystal feature, which uses the crystal as RTC. The single crystal feature will increase the hardware and software backup currents, but will considerably reduce hot and warm start times.

☞ Note that the single crystal mode increases the back-up current consumption 5 times, which is a sensitive factor for battery-powered devices.

For more information about the single crystal feature, see EVA-8M / EVA-M8M Hardware Integration Manual [1].

[4] Use this figure to dimension maximum current capability of power supply. Measurement of this parameter with 1 Hz bandwidth.
[5] Simulated constellation of 8 satellites is used. All signals are at -130 dBm. VCC= 3 V.
[6] Average current from start-up until the first fix.
[7] Use this figure to determine required battery capacity.
[8] Not applicable, feature not supported.
[9] Not applicable, feature not supported.

2.5 VCC_IO monitor

This section applies in case an external SQI flash memory is connected.

The EVA-M8 series has a configurable VCC_IO monitor threshold to ensure that the module will start if the VCC_IO voltage is within the supply range of the SQI flash memory.

By default, this parameter, called "iomonCfg", is set to 1.54 V in EVA-M8M for using a 1.8 V flash memory, which is too low for designs with EVA-M8Q using a 3 V flash memory. Consequently, this needs to be set accordingly in the eFuse (OTP memory).

If VCC_IO voltage 2.7 V to 3.0 V is used, send the following sequence to the module:

- B5 62 06 41 0C 00 00 00 03 1F 04 BA CF 67 FF 7F FF FF E5 95

If VCC_IO voltage 3.0 V to 3.6 V is used, send the following sequence to the module:

- B5 62 06 41 0C 00 00 00 03 1F 4F 22 4C 5C FF 7F 7F FF 8A 7C

☞ The command will permanently set this value and it cannot be reversed.

For more information about the IO monitor configuration, see the EVA-8M / EVA-M8M Hardware Integration Manual [1].

2.6 Temperature

The frequency drift for crystals and TCXO oscillators is very dependent on the ambient temperature. Although the receiver can correct such offset, it is recommended to avoid quick temperature changes. As a brief explanation, a GNSS receiver can track satellite signals up to a certain high dynamic value, which is defined as Delta frequency/ Delta time ($\Delta f/\Delta t$). As a result, a temperature change in a very short time at the crystal will end in a very high dynamic, in the worst scenario losing phase lock.

Although both crystal and TCXO are highly sensitive to any quick temperature changes, due to the wider frequency range of crystals compared to TCXO, special attention is needed for crystal-based designs.

If the receiver is possibly placed under these conditions, it is highly recommended to isolate the module by thermally minimizing the thermal conduction over the PCB and place the module far from fans or other components with quick body temperature changes that can increase the board and ambient temperature. Adding elements for heat dissipation between the receiver and other elements as well as increasing the surface contact area of the board around stabilizes the temperature.

The effect of the temperature on the crystal can be seen in the Figure 1 below. u-blox crystal-based modules can easily re-adjust the frequency drift for normal operation. It is important to mention that all crystal oscillators qualified by u-blox pass extensive tests to ensure such smooth frequency drift over full operation temperature range (-40 to +85 °C).

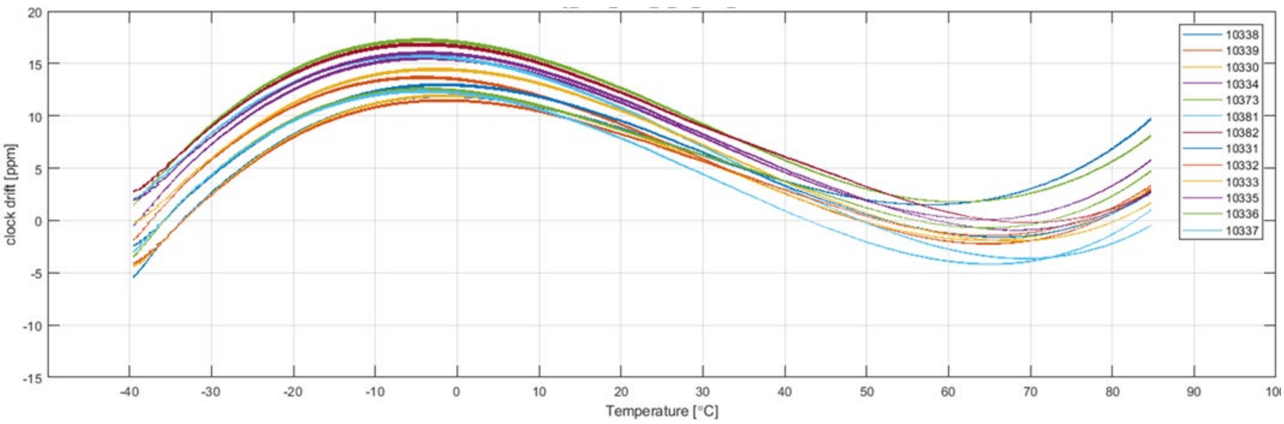


Figure 1: Temperature effect on crystal on various crystal-based modules

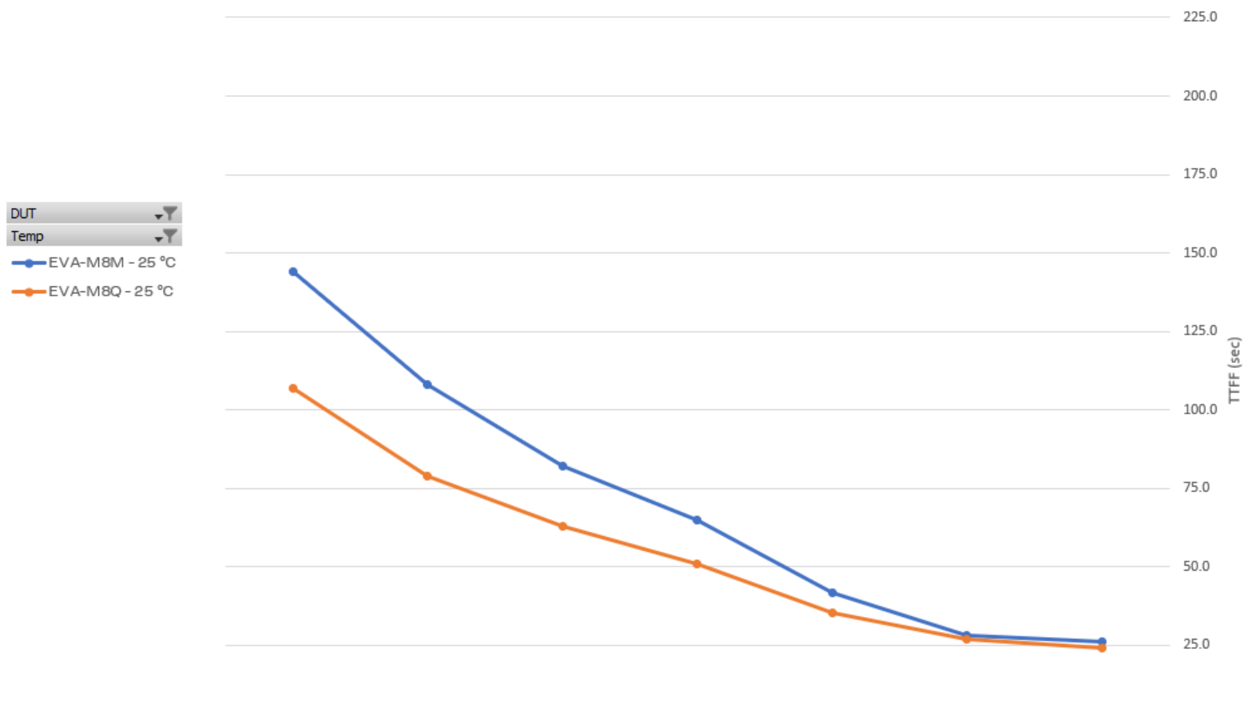
2.7 Performance

2.7.1 Startup sensitivity and TTFF

Crystal-based GNSS receivers are characterized as having a longer time to synchronize with GNSS signals. The effect is more visible when the signals are weak and the GNSS visibility is poor.

Such behavior can be seen in Figure 2, where the times to fix of crystal-based EVA-M8M become longer than those of TCXO-based EVA-M8Q as the GNSS signal power drops. (Note that the scale in the horizontal axis for the signal power is not linear.)

☞ Note that the values in the horizontal axis are not linear. If all levels were present at the horizontal axis, the curve would be plain until -140 dBm, where it would increase exponentially with weaker signals.



	- 148 (25)	- 147 (26)	- 146 (27)	- 144 (29)	- 140 (33)	- 135 (38)	- 130 (43)
EVA-M8M - 25 °C	144.14	108.04	81.87	64.78	41.65	28.07	25.89
EVA-M8Q - 25 °C	106.98	78.67	62.63	50.68	35.20	27.01	24.20

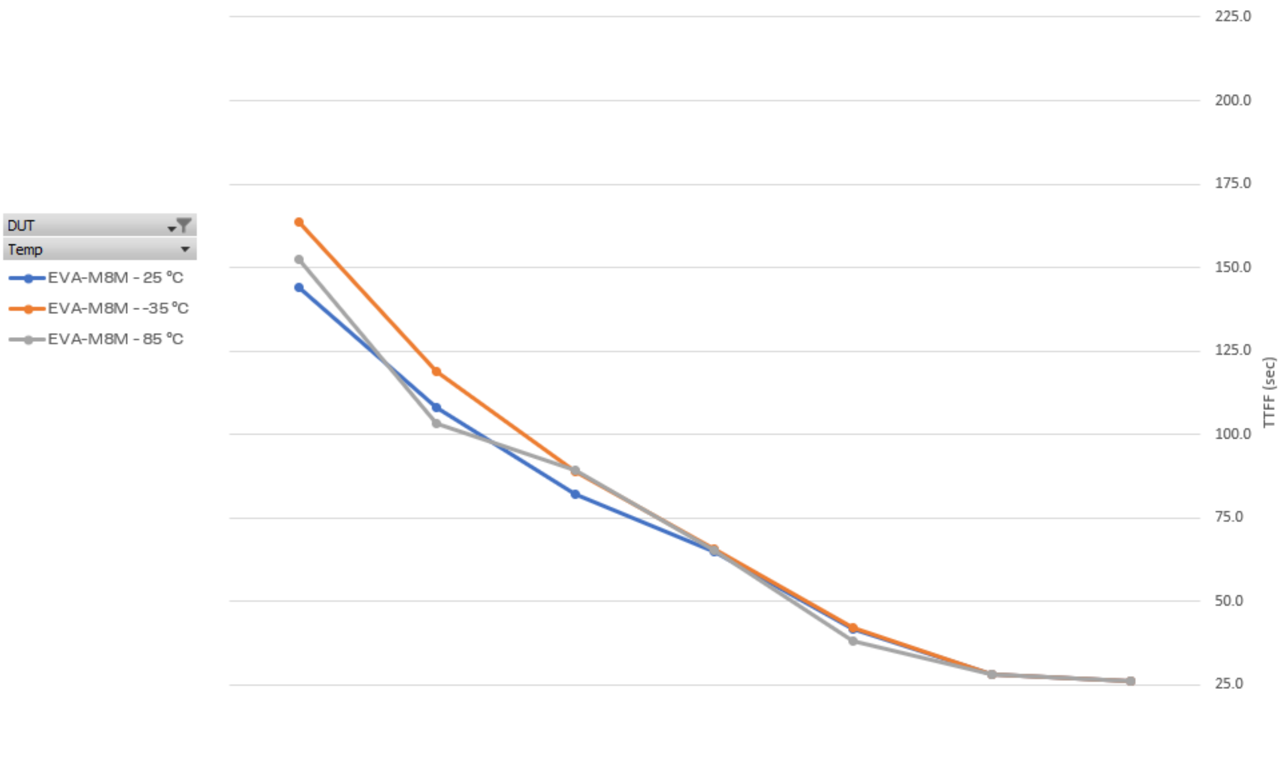
Figure 2: TTFF vs. signal power for EVA-M8Q and EVA-M8M during cold starts[10] (default mode: GPS & GLONASS including QZSS, SBAS)

In general, a strong signal will give the shortest time to first fix. At room temperature (+25 °C), the TTFF differences between the EVA-M8Q (orange line in Figure 2) and the EVA-M8M (blue line) grow as the GNSS signal levels drop. Figure 2 shows that under a strong signals environment (signals with active antenna), the TTFF is very similar for both TCXO and crystal-based EVA products.

The GNSS signal power levels above 43 dBHz (-130 dBm) are considered as strong signals. The cold start results in Figure 2 show that the TTFF numbers of EVA-M8Q and EVA-M8M are still very close to each other even at weaker signal condition of 33 dBHz (-140 dBm). Such Carrier-to-Noise ratio (C/N0) levels should be achievable with good open-sky visibility (best to have the satellite at the Zenith) using an active antenna.

If we compare TTFF at different operating temperatures, a small degradation is visible under very cold environments for crystal-based EVA-M8M, as shown in Figure 3. As an example, a receiver which starts at -35 °C will gradually increase the crystal temperature due to both components' proximity (self-heating), which results in an increase of the clock drift during the acquisition of the GNSS signals. Again, the consequences associated are not relevant when GNSS signals are strong enough, as can be seen in the figure below.

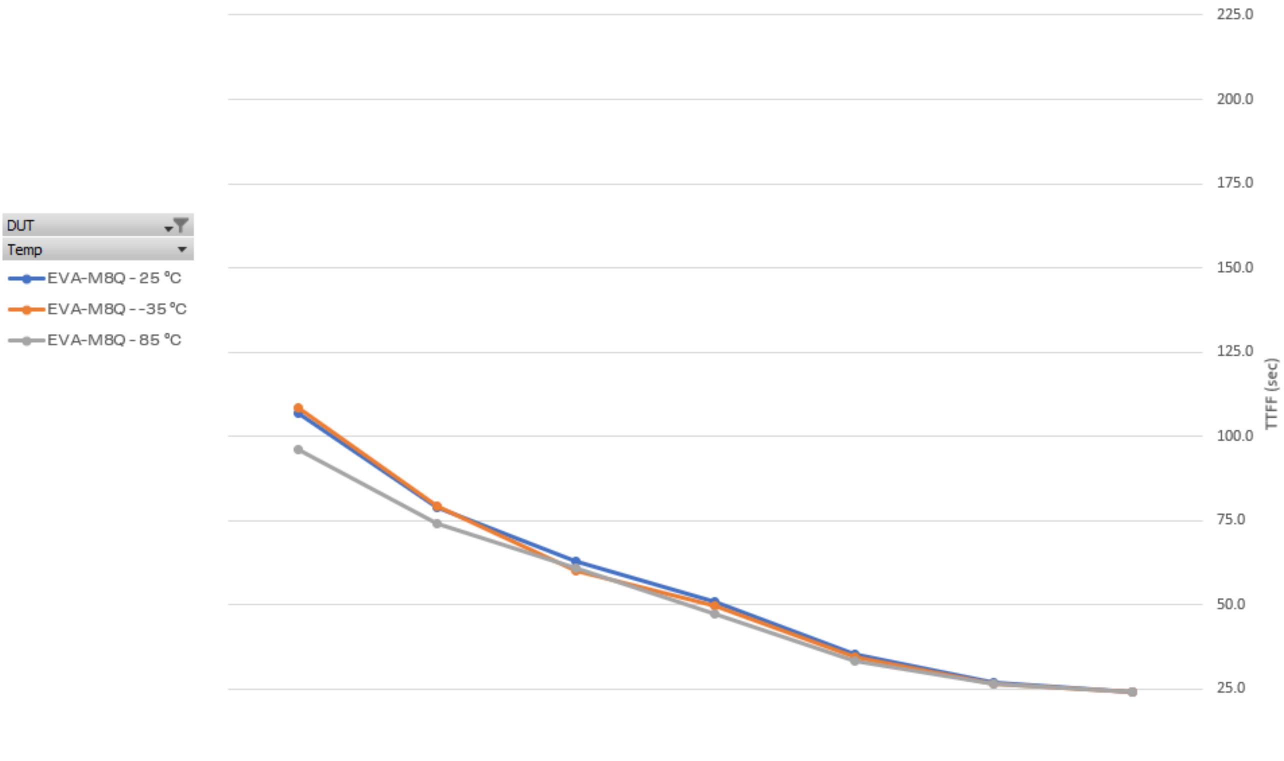
[10] Results obtained in our test sites using a good LNA in front.



	- 148 (25)	- 147 (26)	- 146 (27)	- 144 (29)	- 140 (33)	- 135 (38)	- 130 (43)
EVA-M8M - 25 °C	144.14	108.04	81.87	64.78	41.65	28.07	25.89
EVA-M8M - -35 °C	163.69	118.72	88.68	65.46	41.84	28.19	25.98
EVA-M8M - 85 °C	152.55	103.27	89.24	65.10	38.15	27.94	26.12

Figure 3: TTFF vs. signal power for EVA-M8M during cold starts at +25, -35, and +85 °C (default mode: GPS & GLONASS including QZSS, SBAS)

For TCXO-based EVA-M8Q, the temperature dependency of the TTFF is quite small, as shown in Figure 4. This result is expected as the TCXO frequency variation due to temperature is significantly smaller than the frequency variation of the crystal.



	- 148 (25)	- 147 (26)	- 146 (27)	- 144 (29)	- 140 (33)	- 135 (38)	- 130 (43)
EVA-M8Q - 25 °C	106.98	78.67	62.63	50.68	35.20	27.01	24.20
EVA-M8Q - -35 °C	108.40	79.04	60.03	49.60	34.48	26.44	24.18
EVA-M8Q - 85 °C	95.82	74.21	60.89	47.28	33.20	26.58	24.18

Figure 4: TTFF vs. signal power for EVA-M8Q during cold starts at +25, -35, and +85 °C (default mode: GPS & GLONASS including QZSS, SBAS)

As a summary, the longer TTFFs due to the crystal's wider drift and extreme operating temperature can be easily mitigated by using a good antenna or LNA. Under such good GNSS signal conditions, we can predict a signal power level above -144 dBm, where both TCXO and crystal variants show similar TTFF values. As mentioned in section 2.2, an external LNA is mandatory when using a passive antenna with a crystal-based EVA-M8M.

Note that the following results have been obtained using GPS and GLO signals and using the default configuration.

2.7.2 Road test performance analysis

Road tests show real behavior in dynamic scenarios. The road tests allow measuring the position accuracy delivered by the receiver. The accuracy, calculated as the offset to the real position, is showed in error percentiles for 2D and 3D coordinates.

Three different road tests have been carried out for both crystal and TCXO variants. The goal of these tests is to assess the impact of different signal power levels and to see if the degradation is similar.

☞ The C/N0 value in the following figures and tables is the median of all GPS signals used for tracking along the test.

☞ The test results are based on limited samples and should be considered as a reference.

2.7.2.1 Rural areas with good GNSS visibility

The test in a rural area is characterized as having excellent GNSS visibility most of the time, alternating with weak signal areas where there are trees and small houses along the road.

The figure below shows position accuracy for the EVA-M8Q and EVA-M8M on a radar plot under three different signal power levels. The first one of these three represents designs with good signal reception, where average C/N0 values for all GNSS signals tracked are around 40 dBHz, suitable for designs using active or external LNA. The second one is with 8-9 dBHz weaker signal power, average C/N0 around 31.5 dBHz. The last scenario with a signal around 27 dBHz represents applications with very poor signal reception.

The goal is to compare the accuracy degradation of both TCXO and crystal-based EVA modules in these three situations.

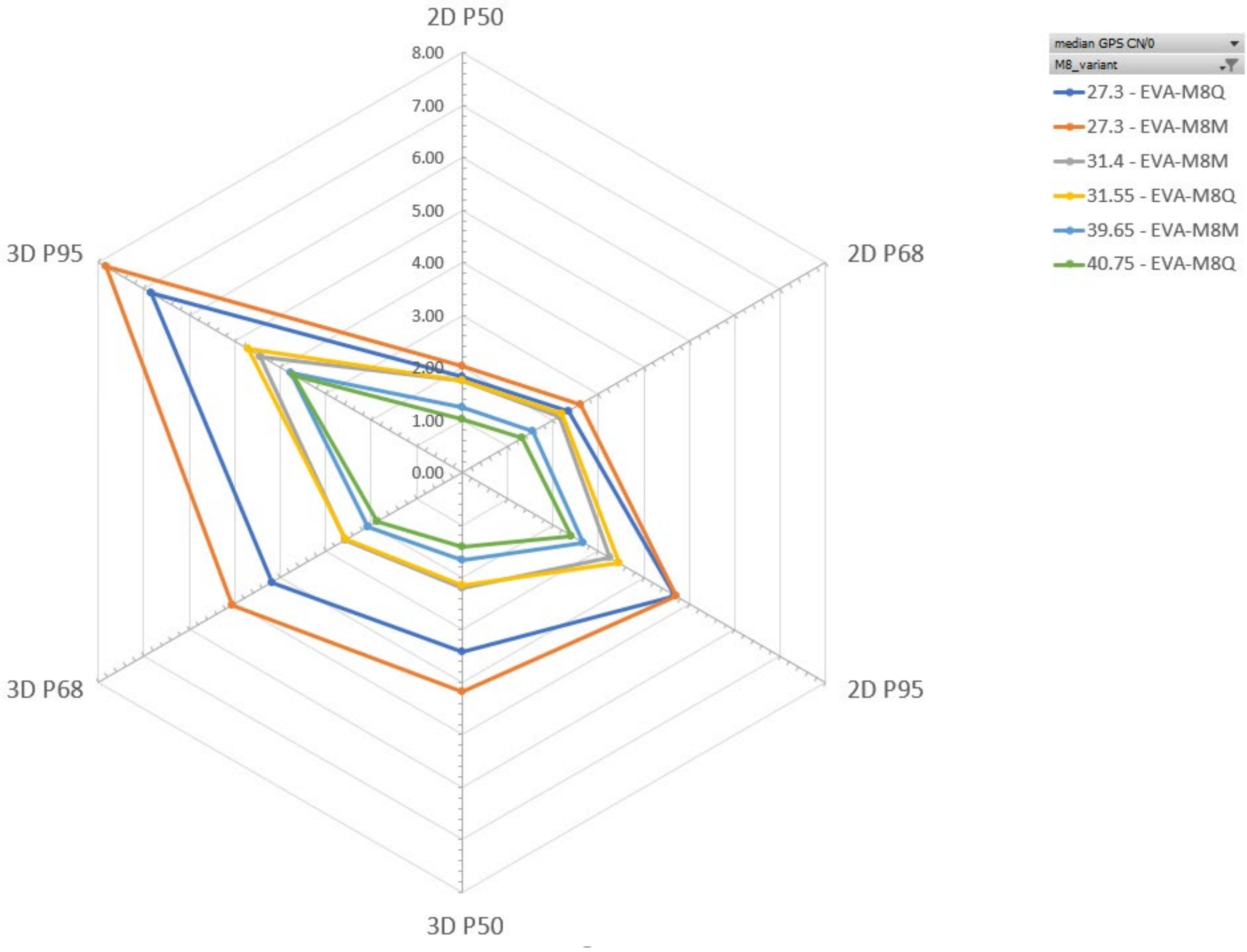


Figure 5: Position error in meters for EVA-M8Q and EVA-M8M in percentiles at 27.3, 31.5 and 40 dBHz in rural areas (default mode: GPS and GLONASS including QZSS, SBAS)

The test results presented in Figure 5 show 6 curves that can be grouped into three. The two inner ones represent accuracy under good signals, the two in the middle under weaker signals, and the outer ones for the weakest scenario. The worst performance degradation of the crystal-based EVA-M8M appears when the average signal levels are dropped to below 30 dBHz. For signals above that "threshold", the position accuracy and the degradation relation (Δerror/ Δsignal attenuation) are very similar for both the TCXO-based EVA-M8Q and the crystal-based EVA-M8M. The accuracy values for all three test scenarios are also represented in Table 3 below.

Values	Weakest signal 27.3 dBHz EVA-M8Q	27.3 dBHz EVA-M8M	Weak signal 31.55 dBHz EVA-M8Q	31.4 dBHz EVA-M8M	Good signal 40.75 dBHz EVA-M8Q	40.7 dBHz EVA-M8M
2D P50 (m)	1.82	2.03	1.75	1.74	1.02	1.27
2D P68 (m)	2.36	2.60	2.21	2.13	1.33	1.61
2D P95 (m)	4.70	4.70	3.45	3.24	2.42	2.64
3D P50 (m)	3.42	4.19	2.14	2.20	1.43	1.67
3D P68 (m)	4.19	5.06	2.56	2.58	1.86	2.02
3D P95 (m)	6.83	7.83	4.71	4.43	3.72	3.74

Table 3: Position error in percentiles for EVA-M8(Q/M) at different signal power levels in rural areas (default mode: GPS and GLONASS including QZSS, SBAS)

2.7.2.2 Urban canyon with weak signal levels and multipath

Figure 6 shows the position accuracy percentiles for EVA-M8Q and EVA-M8M modules in the urban canyon environment. The test results in Figure 6 and Table 4 show that the position accuracy of the TCXO-based EVA-M8Q and the crystal-based EVA-M8M is very similar in urban canyon with extremely weak GNSS signal level (average C/N0 at 29.6 dBHz).

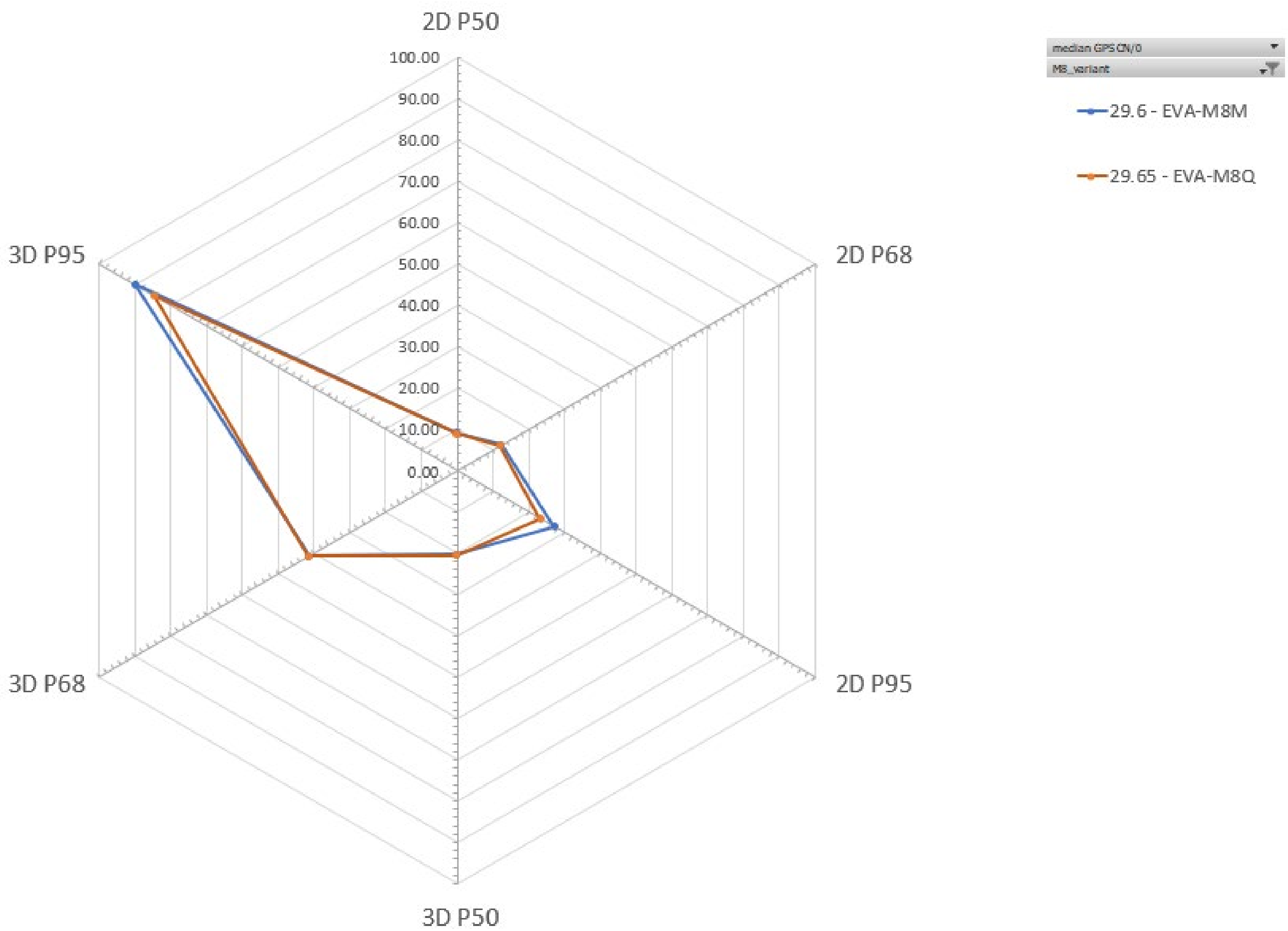


Figure 6: Position error in meters for EVA-M8Q and EVA-M8M in percentiles. Urban canyon with good and bad signal reception conditions (default mode: GPS and GLONASS including QZSS, SBAS)

Values	Weak signal 29.6 dBHz EVA-M8Q	 29.65 dBHz EVA-M8M
2D P50 (m)	9.07	8.89
2D P68 (m)	12.34	12.07
2D P95 (m)	27.19	23.20
3D P50 (m)	20.41	20.46
3D P68 (m)	41.45	41.56
3D P95 (m)	90.06	84.70

Table 4: Position error in percentiles for EVA-M8Q and EVA-M8M at weak signal power levels in urban canyon scenario (default mode: GPS and GLONASS including QZSS, SBAS)

Note that although the position errors are very big for all EVA modules, such performance is expected for all standard precision receivers under such a particularly challenging environment (poor GNSS visibility and high multipath effect). The real track followed is seen in the Figure 7 **Error! Reference source not found.**.

Figure 7: Scenario used for "Urban canyon" to compare performance between TCXO and crystal variants

2.7.2.3 Highway road test

Finally, a highway scenario has been used in the road test, under good GNSS signal and weak signal conditions. In this case, the receiver calculates a position where conditions change rapidly on a highway due to the car speed. Figure 8 captures a part of the drive and gives a good representation of the test conditions.

Figure 8: Part of the "Highway" scenario used and track of the receivers

The higher speed is more challenging for GNSS receivers due to the tracking loops. The highway scenario means the tracking is more difficult. Thus, the degradation of the signal levels has a larger influence on the position accuracy. The active antennas will significantly help the GNSS receiver performance here.

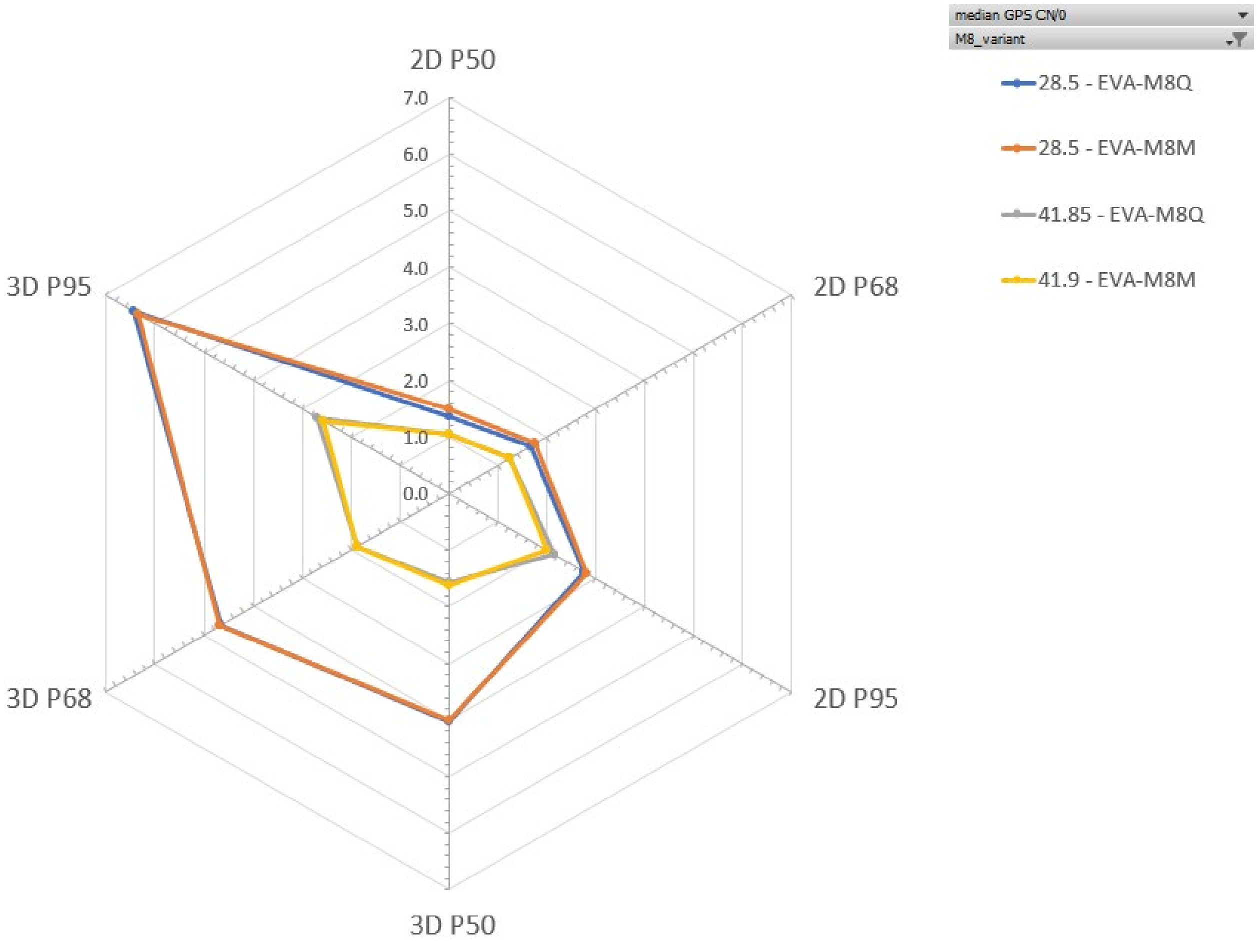


Figure 9: Position error in meters for EVA-M8Q and EVA-M8M in percentiles. Highway with strong and weak signal reception conditions (default mode: GPS and GLONASS including QZSS, SBAS)

Values	Weak signal 28.5 dBHz EVA-M8Q	 28.5 dBHz EVA-M8M	Good signal 41.85 dBHz EVA-M8Q	 41.9 dBHz EVA-M8M
2D P50 (m)	1.37	1.49	1.05	1.06
2D P68 (m)	1.67	1.77	1.25	1.24
2D P95 (m)	2.77	2.80	2.15	2.00
3D P50 (m)	4.03	4.01	1.58	1.61
3D P68 (m)	4.66	4.68	1.88	1.86
3D P95 (m)	6.44	6.36	2.68	2.57

Table 5: Position error in percentiles for EVA-M8Q and EVA-M8M at different signal power levels in highway scenario (default mode: GPS and GLONASS including QZSS, SBAS)

Highway test results shown in Figure 9 and Table 5 demonstrate once again that the crystal-based EVA-M8M has very similar position accuracy compared to the TCXO-based EVA-M8Q under both weak and good GNSS signal conditions on highway.

3. Conclusion

From startup sensitivity and TTFF test (section 2.7.1) and road tests (section 2.7.2), we can see that for customers using an external LNA or an active antenna in current designs, there should be no issue when switching from TCXO-based EVA-M8Q to crystal-based EVA-M8M.

Large and well-designed passive patch antennas, external LNA or active antennas can work perfectly well with u-blox EVA-M8M receivers despite the minimal performance differences between the crystal and the TCXO variant. EVA-M8M is a good crystal-based solution for applications where operation with a weak signal is not necessary.

Related documentation

[1] EVA-8M / EVA-M8 Hardware integration manual, UBX-16010593
[2] EVA-M8 Data sheet, UBX-16014189

Revision history

Revision	Date	Name	Comments
R01	14-Dec-2020	cbib, imar	Initial release
R02	11-Feb-2021	imar	Minor updates in Figure 2, Figure 3 and Figure 4 (Startup sensitivity and TTFF plots). Added section 2.7.2 (road test data).

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