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MAX modules

TCXO-to-crystal migration guide

Application note

Abstract

This document provides options and guidelines for migrating TCXO-based MAX modules to crystal-based MAX modules. 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 TCXO-based MAX modules to crystal-based MAX variants.

The main difference between TCXO and crystal variants is basically the type of oscillator used. The small difference in the internal oscillator leads to some considerations described in this document. For example, the frequency tolerance of crystals is wider than that of TCXOs. 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 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 for many applications.

This document focuses on TCXO-based MAX-M8Q, MAX-8Q, and MAX-7Q modules.

2. Generic guidelines

Generally, every migration requires different considerations for each dedicated product. However, there are a few parameters that are generic to all MAX modules. One is the presence of a good LNA in the RF front-end, and the second is the effect of the temperature and how to mitigate it. For crystal-based MAX modules, RTC is also one of the generic aspects needing special attention.

2.1 RF design

Performance of crystal-based designs strongly depends on the GNSS signal power levels. Under strong signal reception, crystal-based modules can perform as well as their equivalent TCXO versions. Therefore, for designs without an external LNA or using a passive antenna, it is mandatory to include an external LNA before the crystal-based MAX module, especially in 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 from RF front-end redesign.

Refer to the relevant hardware integration manual for more guidelines on passive antenna designs and recommended LNA/SAW components: MAX-8Q and MAX-M8Q: MAX-8 / MAX-M8 Hardware Integration Manual [1], MAX-7Q: MAX-7, NEO-7 Hardware Integration Manual [2].

2.2 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 Figure 1. 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).

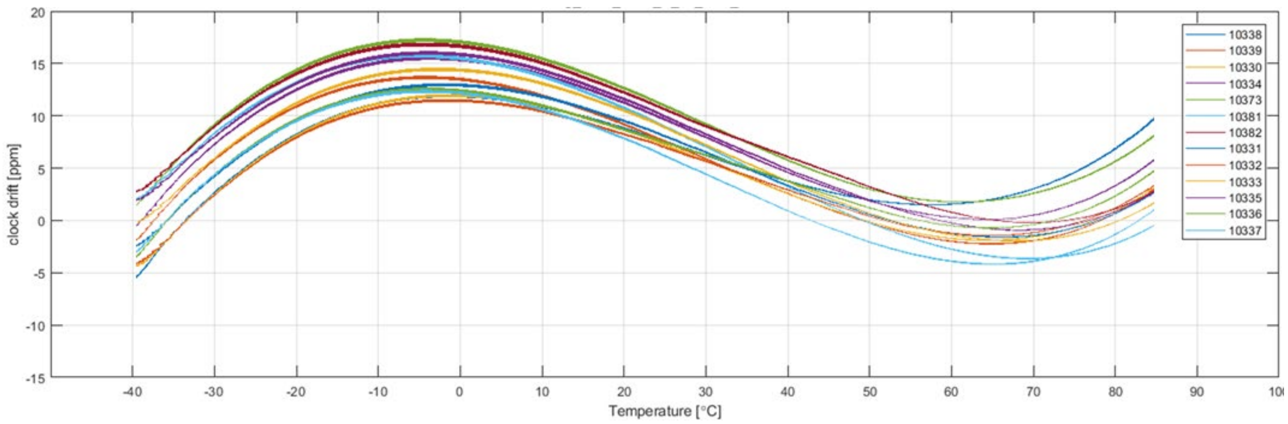


Figure 1: Temperature effect crystal on various crystal-based modules

2.3 Real-time clock (RTC)

The MAX-M8C, MAX-8C, and MAX-7C are optimized variants for cost-sensitive applications. One of the reasons is the absence of the RTC (32 KHz oscillator) compared to the TCXO-based variants. The MAX-M8C and MAX-8C modules compensate for it by using the crystal signal as RTC. For that, the crystal needs to be powered during the hardware and software backup modes, resulting in higher current consumption compared to TCXO versions, which already have an RTC in the module. This backup current difference for each product can be seen in section 3.2, section 4.2, and section 5.2, and it is relevant for battery-powered devices.

Using the crystal as an RTC feature is called “single-crystal”, and by default it is enabled in all MAX crystal modules. For MAX-8C and MAX-M8C, it can be permanently disabled by sending the following command:

B5 62 41 09 00 01 01 92 81 E6 39 93 2B EE 30 31.

☞ Once the disable command is sent, it cannot be reversed.

It is not possible to disable the single-crystal feature in the crystal-based MAX-7C.

For more information about the single-crystal feature, its advantages and how to disable it, see MAX-8M / MAX-M8 Hardware integration manual [1] and MAX-7 / NEO-7 Hardware integration manual [2].

3. MAX-M8Q

This section provides details on the migration from MAX-M8Q to MAX-M8C.

3.1 MAX-M8 (Q/C) comparison

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

Field	Parameter	MAX-M8Q	MAX-M8C
HW	**Oscillator**	TCXO	Crystal
	RTC	Yes	Yes, but with a higher backup current
	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)	Same	Same
	SW backup current (mA)	0.030	0.105 [2]
	HW backup current (mA)	0.015	0.100 [2]
Sensitivity	**Dynamic Tracking (dBm)**	-167	-164
	TTFF (sec) [3]	Same	Same
SW	**Firmware**	ROM SPG 3.01	ROM SPG 3.01
	OTP config.	-	single crystal enabled by default

Table 1: MAX-M8Q to MAX-M8C migration comparison (default mode: GPS & GLONASS including QZSS, SBAS)

☞ When migrating to crystal-based MAX-M8C 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).

3.2 Power requirements

Crystal-based MAX-M8C allows a wider voltage supply range. This is because of the lower voltage required by the crystal. Nevertheless, the products have overlapping operational voltage ranges and the same current consumption in normal operation.

The table below shows the expected current drawn of MAX-M8C and MAX-M8Q. More information is available in the MAX-M8 Data Sheet [3].

Section 2.3 explains why the crystal-based MAX-M8C has higher hardware and software backup current compared to TCXO-based MAX-M8Q.

[1] Mainly for applications where the GNSS module is under thermal activity on the board.
[2] Higher current consumption due to single-crystal feature enabled by default.
[3] Cold and hot start under good GNSS visibility and using power levels of -130 dBm.

Parameter	Symbol	Conditions	Module	Typ. GPS & GLONASS	Typ. GPS / QZSS /SBAS	Units
Average supply current [4]	Icc Acquisition mA [5]	VCC_IO = VCC = 3 V	MAX-M8C	26	20	mA
			MAX-M8Q	26	20	mA
	Icc Tracking (Continuous mode)	VCC_IO = VCC = 3 V	MAX-M8C	23	17	mA
			MAX-M8Q	23	18	mA
	Icc Tracking (Power save mode / 1 Hz)	VCC_IO = VCC = 3 V	MAX-M8C	5.4	4.9	mA
			MAX-M8Q	6.2	5.7	mA
Backup battery current [6]	I_BCKP	HW backup mode, VCC_IO = VCC = 0 V	MAX-M8C using the 26 MHz XTO in single crystal operation	100		µA
			MAX-M8C single crystal operation disabled (No RTC)	15		µA
			MAX-M8Q	15		µA
SW backup current	I_SWBCKP	SW backup mode, VCC_IO = VCC = 3 V	MAX-M8C using the 26 MHz XTO in single crystal operation	105		µA
			MAX-M8C single crystal operation disabled (No RTC)	30		µA
			MAX-M8Q	30		µA

Table 2: MAX-M8Q to MAX-M8C power requirements

3.3 Performance

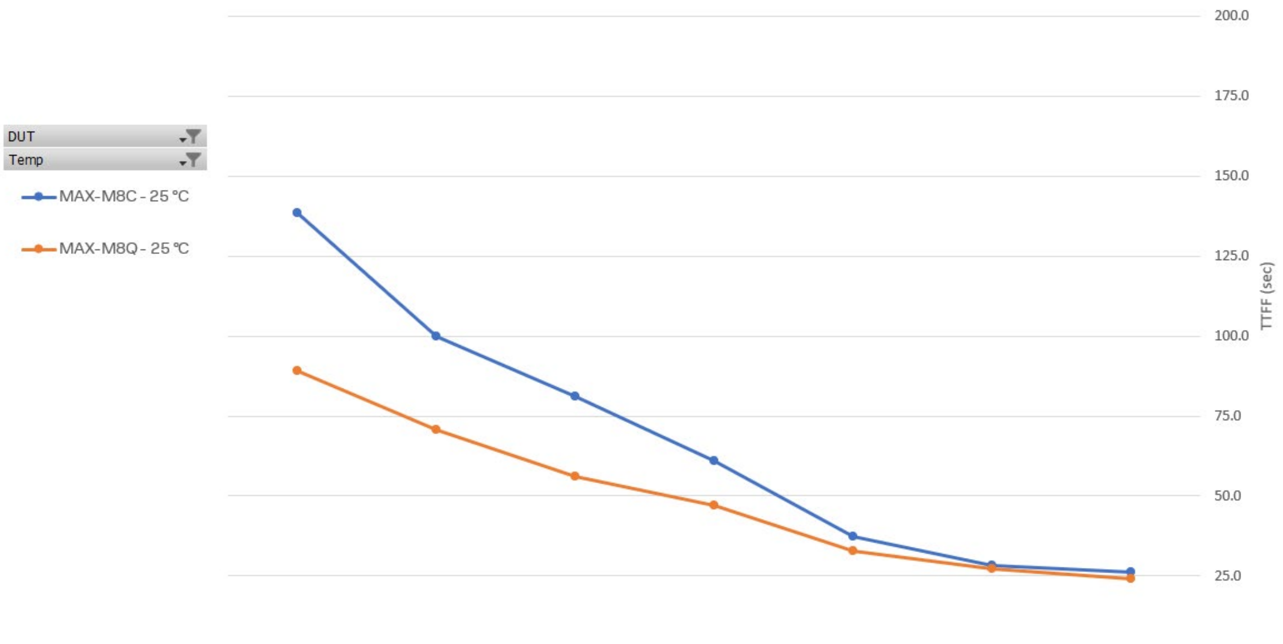
3.3.1 Startup sensitivity and TTFF

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 MAX-M8C become longer than those of TCXO-based MAX-M8Q as the GNSS signal power drops.

☞ 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.

[4] Simulated constellation of 8 satellites is used. All signals are at -130 dBm. VCC= 3 V.
[5] Average current from startup until the first fix.
[6] Use this figure to determine the required battery capacity.



	- 148 (25)	- 147 (26)	- 146 (27)	- 144 (29)	- 140 (33)	- 135 (38)	- 130 (43)
MAX-M8C - 25 °C	138.42	99.84	81.09	61.10	37.23	28.36	26.23
MAX-M8Q - 25 °C	89.24	70.82	56.19	47.02	32.82	27.28	24.24

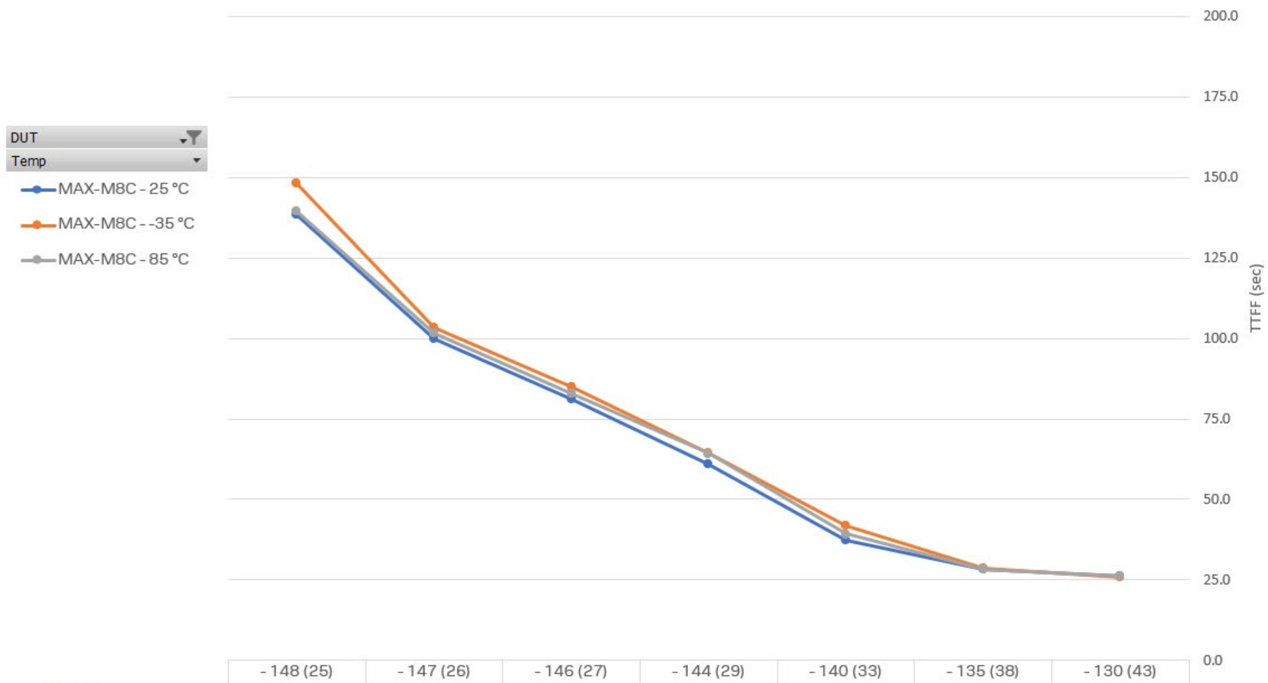
Figure 2: TTFF vs. signal power in dBm and equivalent C/N0 inside parenthesis for MAX-M8Q and MAX-M8C during cold starts[7] (default mode: GPS & GLONASS including QZSS, SBAS)

In general, a strong signal will give the shortest time to first fix. At room temperature (+25 °C), the TTFF differences between the MAX-M8Q (orange line in Figure 2) and the MAX-M8C (blue line) grow as the GNSS signal levels drop. Figure 2 shows that under a strong signal's environment (signals with active antenna), the TTFF is very similar for both TCXO and crystal-based MAX 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 MAX-M8Q and MAX-M8C 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 MAX-M8C, 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.

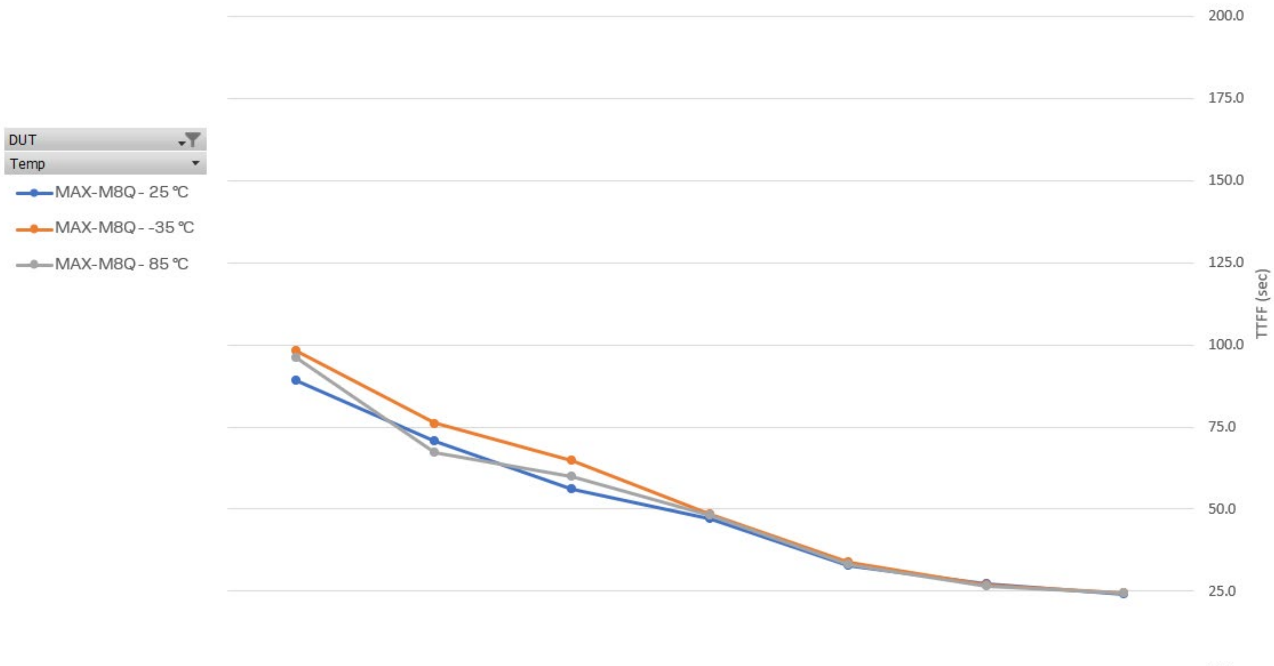
[7] Results obtained on our test sites using a good LNA in front and an attenuator to decrease power level.



	- 148 (25)	- 147 (26)	- 146 (27)	- 144 (29)	- 140 (33)	- 135 (38)	- 130 (43)
MAX-M8C - 25 °C	138.42	99.84	81.09	61.10	37.23	28.36	26.23
MAX-M8C - -35 °C	148.39	103.31	85.01	64.33	41.91	28.55	25.76
MAX-M8C - 85 °C	139.65	101.54	82.76	64.25	39.21	28.19	26.23

Figure 3: TTFF vs. signal power in dBm and equivalent C/N0 inside parenthesis for MAX-M8C during cold starts at +25, -35, and +85 °C (default mode: GPS & GLONASS including QZSS, SBAS)

For TCXO-based MAX-M8Q, the temperature dependency of the TTFF is also visible, as shown in Figure 4. TTFFs of MAX-M8Q stay faster than those of MAX-M8C in all temperature ranges.



	- 148 (25)	- 147 (26)	- 146 (27)	- 144 (29)	- 140 (33)	- 135 (38)	- 130 (43)
MAX-M8Q - 25 °C	89.24	70.82	56.19	47.02	32.82	27.28	24.24
MAX-M8Q - -35 °C	98.06	76.07	64.74	48.30	33.84	26.86	24.56
MAX-M8Q - 85 °C	96.03	67.34	59.81	48.03	33.22	26.61	24.40

Figure 4: TTFF vs. signal power in dBm and equivalent C/N0 inside parenthesis for MAX-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 GNSS 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 2.1, an external LNA is mandatory when using a passive antenna with a crystal-based MAX-M8C.

3.3.2 Road test performance analysis

Road tests show real behavior in dynamic scenarios and allow measuring the position accuracy delivered by the receiver. The accuracy, calculated as an 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.

3.3.2.1 Rural areas with good GNSS visibility

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

Figure 5 shows the error percentiles for both MAX-M8Q and MAX-M8C at two different signal power levels. One is very strong with an average C/N0 of 44.7 dBHz, and the second one with 31.6 dBHz (13 dBHz lower). As shown in Figure 5 and Table 3, the position accuracy is very similar under both scenarios, and the same for the degradation (Δerror/ Δsignal attenuation).

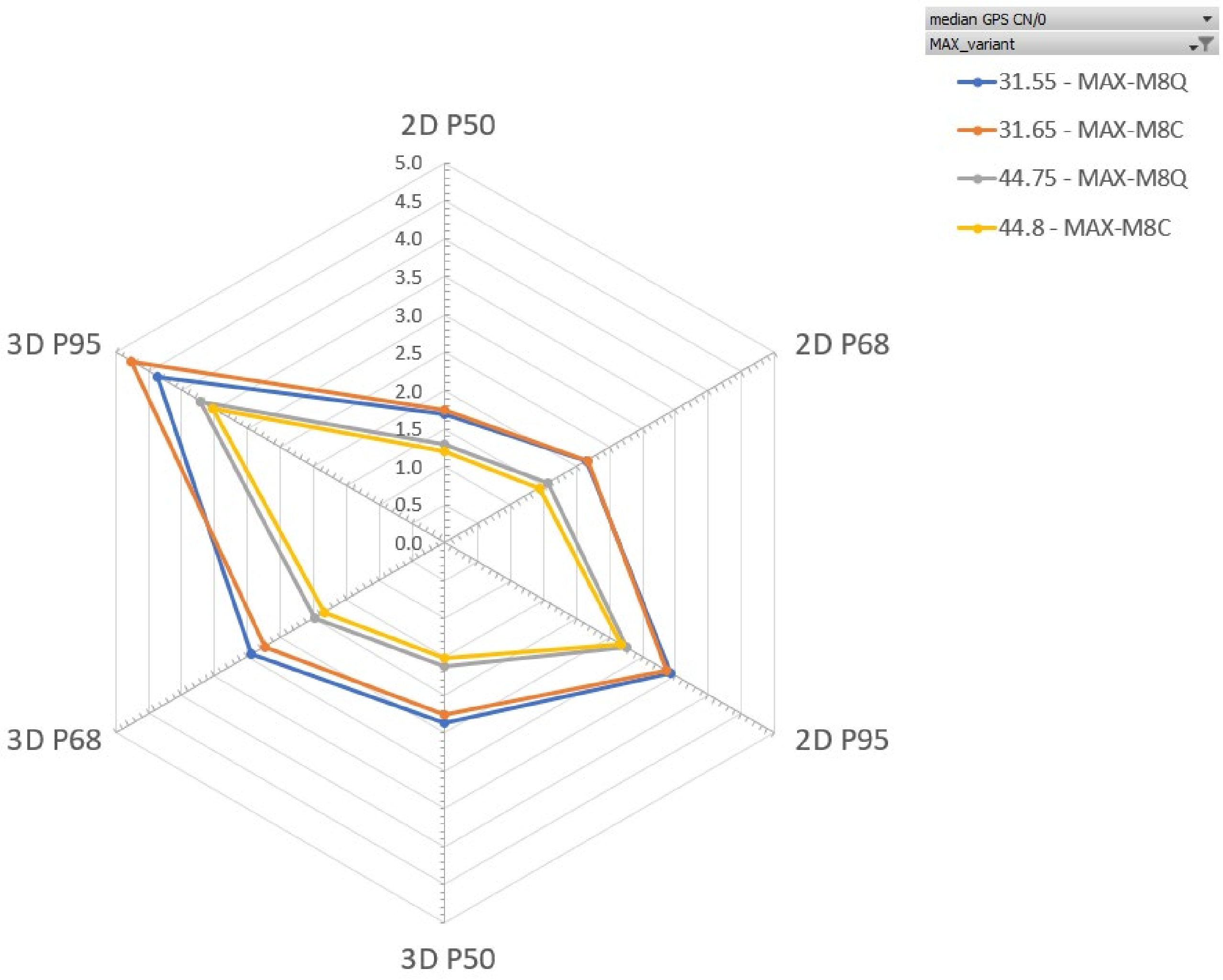


Figure 5: Position error in meters for MAX-M8C and MAX-M8Q in percentiles at 31.6 and 44.7 dBHz in rural areas (default mode: GPS and GLONASS including QZSS, SBAS)

Values	Weak signals 31.55 dBHz MAX-M8Q	 31.65 dBHz MAX-M8C	Strong signals 44.75 dBHz MAX-M8Q	 44.8 dBHz MAX-M8C
2D P50 (m)	1.70	1.75	1.30	1.20
2D P68 (m)	2.14	2.17	1.57	1.44
2D P95 (m)	3.43	3.37	2.77	2.68
3D P50 (m)	2.37	2.27	1.63	1.52
3D P68 (m)	2.95	2.73	1.98	1.84
3D P95 (m)	4.37	4.77	3.72	3.53

Table 3: Position error in percentiles for MAX-M8C and MAX-M8Q variants at different signal power levels in rural areas (default mode: GPS and GLONASS including QZSS, SBAS)

Note that GNSS signals around 32 dBHz are in line with the threshold defined in section 3.3.1, where TTFF numbers of both TCXO-based MAX-M8Q and crystal-based MAX-M8C are still very close to each other even at the weaker signal condition of 33 dBHz (-140 dBm).

The rural road test results further confirmed that crystal-based MAX-M8C module can achieve very good position accuracy under strong/good signal condition. In most cases it even reaches a similar accuracy level compared to the TCXO-based MAX-M8Q under weak signal scenario.

3.3.2.1 Urban canyon areas

An urban canyon environment with low signal powers (average at 29.6 dBHz) was chosen as the second road test scenario. The goal was to simulate one of the worst signal conditions that a GNSS receiver may face.

As expected, the position accuracy errors are very high in the urban canyon, however, both TCXO and crystal-based MAX modules show very similar accuracy levels, as shown in Figure 6 below.

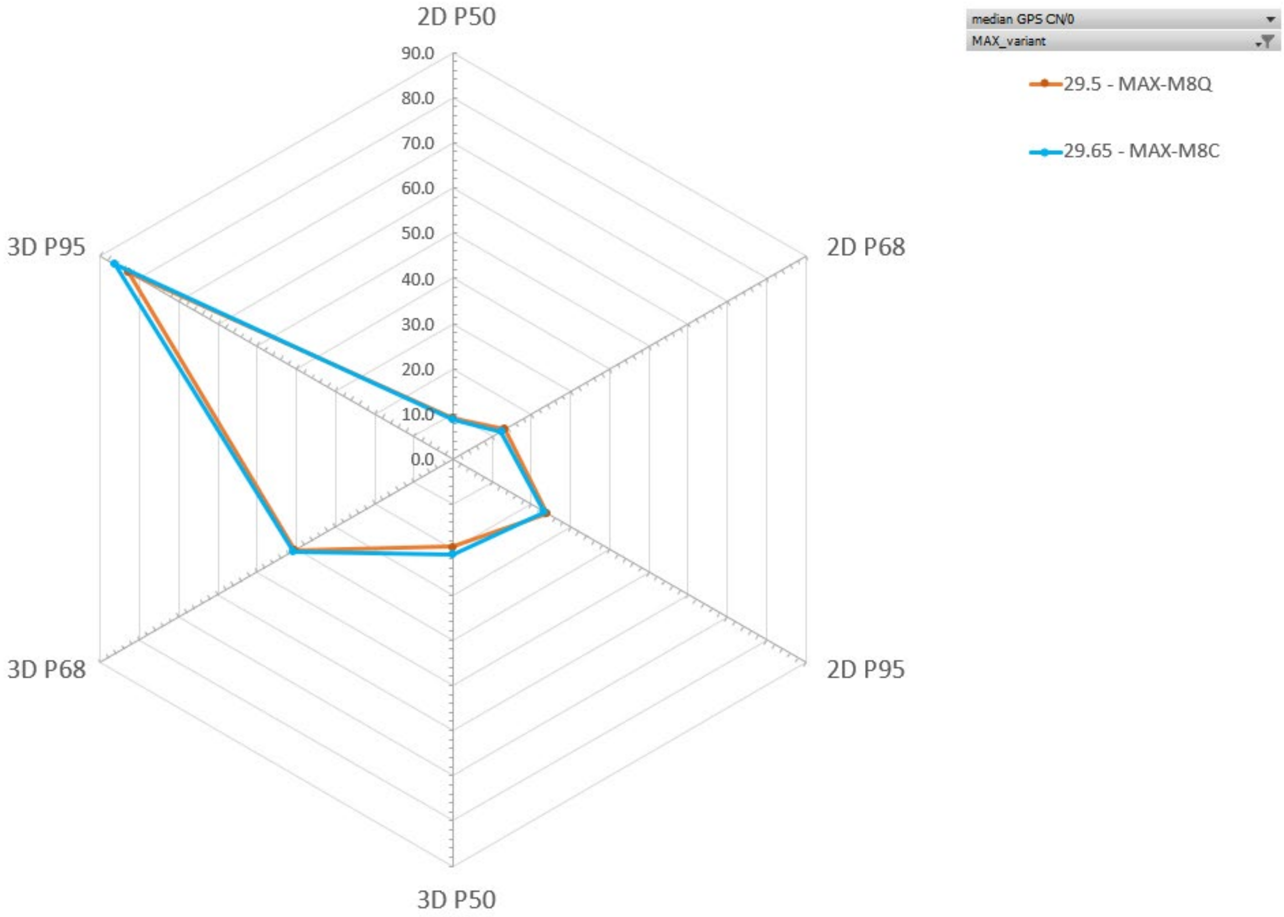


Figure 6: Position error in meters for MAX-M8C and MAX-M8Q in percentiles at 29.5 dBHz in urban canyon (default mode: GPS and GLONASS including QZSS, SBAS)

Values	Weak signals 29.5 dBHz MAX-M8Q	 29.65 dBHz MAX-M8C
2D P50 (m)	9.00	8.75
2D P68 (m)	13.13	12.37
2D P95 (m)	24.09	23.22
3D P50 (m)	19.43	21.08
3D P68 (m)	40.37	40.69
3D P95 (m)	82.92	86.35

Table 4: Position error in percentiles for MAX-M8C and MAX-M8Q variants at different signal power levels in an urban canyon (default mode: GPS and GLONASS including QZSS, SBAS)

Note that although the position errors of MAX-M8Q and MAX-M8C are high, such performance is normal and expected for all standard precision receivers in such a particularly challenging environment. The real track used in urban canyon test is shown in Figure 7 below.

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

3.3.2.2 Highway road test

Finally, a highway scenario was 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 GNSS 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 stronger influence on the position accuracy as shown in Figure 9 and Table 5.

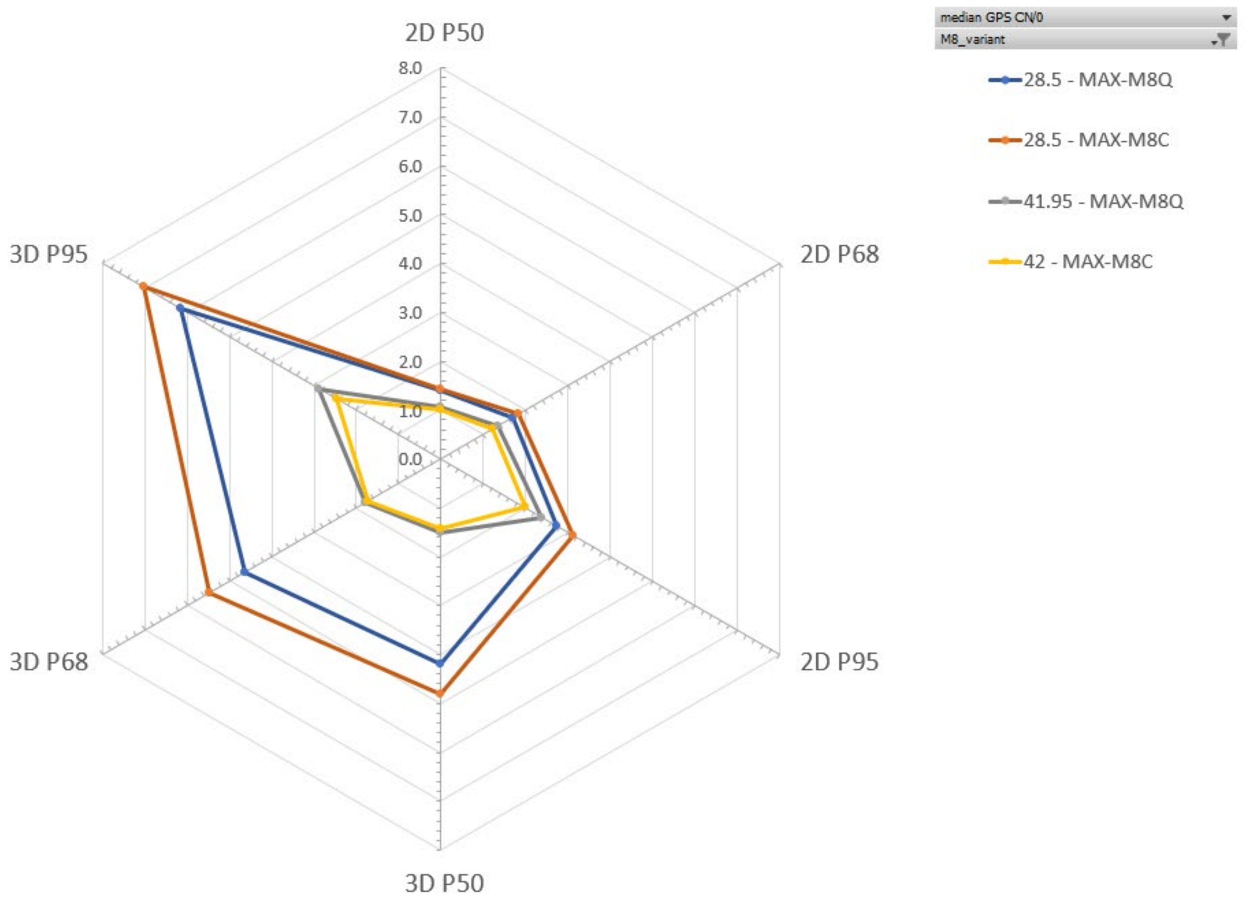


Figure 9: Position error in meters for MAX-M8C and MAX-M8Q in percentiles at 28.5 and 42 dBHz in a highway test (default mode: GPS and GLONASS including QZSS, SBAS)

Values	Weak signals 28.5 dBHz MAX-M8Q	28.5 dBHz MAX-M8C	Good signals 41.95 dBHz MAX-M8Q	42 dBHz MAX-M8C
2D P50 (m)	1.40	1.43	1.06	1.00
2D P68 (m)	1.70	1.84	1.33	1.21
2D P95 (m)	2.74	3.11	2.38	1.98
3D P50 (m)	4.21	4.81	1.52	1.42
3D P68 (m)	4.64	5.47	1.80	1.72
3D P95 (m)	6.16	7.04	2.88	2.46

Table 5: Position error in percentiles for MAX-M8C and MAX-M8Q at different signal power levels in highway scenario (default mode: GPS and GLONASS including QZSS, SBAS)

Highway test results demonstrate once again that crystal-based MAX-M8C receivers have very similar position accuracy compared to the TCXO-based variant under both weak and good GNSS signal condition on highway. It is also clear that the highway weak signal scenarios cause worse position accuracy of the GNSS receiver, independent of the TCXO or crystal oscillator.

4. MAX-8Q

This section provides details on the migration from MAX-8Q to MAX-8C.

4.1 MAX-8 (Q/C) comparison

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

Field	Parameter	MAX-8Q	MAX-8C
HW	**Oscillator**	TCXO	Crystal
	RTC	Yes	Yes, but with a higher backup current
	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[8]	Optional	Recommended
Power Req.	**Supply (Vcc & Vio) (V)**	[2.7 - 3.6]	[1.65 - 3.6]
	Supply current (mA)	17	16
	SW backup current (mA)	0.020	0.105
	HW backup current (mA)	0.015	0.100
Sensitivity	**Dynamic tracking (dBm)**	-166	-164
	TTFF (sec)[9]	29	30
	Cold start sensitivity (dBm)	-148	-147
	Hot start sensitivity (dBm)	-157	-156
SW	**Firmware**	ROM SPG 3.01	ROM SPG 3.01
	OTP config.	-	single crystal enabled by default

Table 6: MAX-8Q to MAX-8C migration comparison (default mode: GPS, QZSS and SBAS)

4.2 Power requirements

Table 7 shows the expected current drawn of MAX-8C and MAX-8Q. More information is available in the MAX-8 Data Sheet [4].

Section 2.3 explains why the crystal-based MAX-8C has a higher hardware and software backup current compared to TCXO-based MAX-8Q.

[8] Mainly for applications where the GNSS module is under thermal activity on the board.
[9] Cold and hot start under good GNSS visibility and using power levels of -130 dBm.

Parameter	Symbol	Conditions	Module	Typ. GPS / QZSS /SBAS	Typ. GLONASS	Units
Average supply current [10]	Icc Acquisition [11]	VCC_IO = VCC = 3 V	MAX-8C	18	17	mA
			MAX-8Q	19	18	mA
	Icc Tracking (Continuous mode)	VCC_IO = VCC = 3 V	MAX-8C	16	16	mA
			MAX-8Q	17	17	mA
	Icc Tracking (Power Save mode / 1 Hz)	VCC_IO = VCC = 3 V	MAX-8C	5.4	4.9	mA
			MAX-8Q	6.2	5.7	mA
Backup battery current [12]	I_BCKP	HW backup mode, VCC_IO = VCC = 0 V	MAX-8C using the 26 MHz XTO in single crystal operation	100		µA
			MAX-8C single crystal operation disabled (No RTC)	15		µA
			MAX-8Q	15		µA
SW Backup current	I_SWBCKP	SW backup mode, VCC_IO = VCC = 3 V	MAX-8C using the 26 MHz XTO in single crystal operation	105		µA
			MAX-8C single crystal operation disabled (No RTC)	30		µA
			MAX-8Q	30		µA

Table 7: MAX-8Q to MAX-8C power requirements

MAX-8C (GPS or GLONASS only) uses the same crystal as multi-GNSS MAX-M8C variant, thus has similar behavior in terms of cold start TTFF at different temperatures. For performance of crystal-based MAX-8C, refer to MAX-M8Q and MAX-M8C test results presented in section 3.3.

[10] Simulated GNSS constellation is used. All signals are at -130 dBm. VCC= 3 V.

[11] Average current from startup until the first fix.

[12] Use this figure to determine the required battery capacity.

5. MAX-7Q

This section provides details on the migration from MAX-7Q to MAX-7C, or on upgrading MAX-7Q to MAX-8C or MAX-M8C for an improved GNSS performance of u-blox 8 and M8 platforms.

5.1 MAX-7(Q/C) comparison

Field	Parameter	MAX-7Q	MAX-7C
HW	**Oscillator**	TCXO	Crystal
	RTC	Yes	Yes, but with a higher backup current
	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 [13]	Optional	Recommended
Power Req.	**Supply (Vcc & Vio) (V)**	[2.7 - 3.6]	[1.65 - 3.6]
	Supply current (mA)	17.5	16.5
	SW backup current (mA)	0.020	0.305
	HW backup current (mA)	0.015	0.300
Sensitivity	**Dynamic Tracking (dBm)**	-161	-160
	TTFF (sec) [14]	29	30
	Cold start sensitivity (dBm)	-148	-147
	Hot start sensitivity (dBm)	-156	-155
SW	**Firmware**	ROM 1.00	ROM 1.00
	OTP config.	-	-

Table 8: MAX-7Q to MAX-7C migration comparison (default mode: GPS, QZSS and SBAS)

5.2 Power requirements

In terms of power consumption, the migration to the crystal version MAX-7C would imply around 1 mA less current in all modes and a very significant increase in the hardware and software backup modes as shown in Table 9. More information is available in the MAX-7 Data Sheet [5].

Parameter	Symbol	Module	Typ.	Units	Condition
Average supply current [15, 16]	Icc Acquisition [17]	MAX-7C	21	mA	Estimated at 3 V
		MAX-7Q	22	mA	
	Icc Tracking (Continuous mode)	MAX-7C	16.5	mA	
		MAX-7Q	17.5	mA	
	Icc Tracking (Power Save mode / 1 Hz)	MAX-7C	4.5	mA	
		MAX-7Q	5.0	mA	
Backup battery current	I_BCKP	MAX-7C	300	µA	V_BCKP = 3.0 V, VCC = 0 V
		MAX-7Q	15	µA	
SW backup current	I_SWBCKP	MAX-7C	305	µA	VCC = 3.0 V
		MAX-7Q	20	µA	

Table 9: MAX-7Q to MAX-7C power requirements

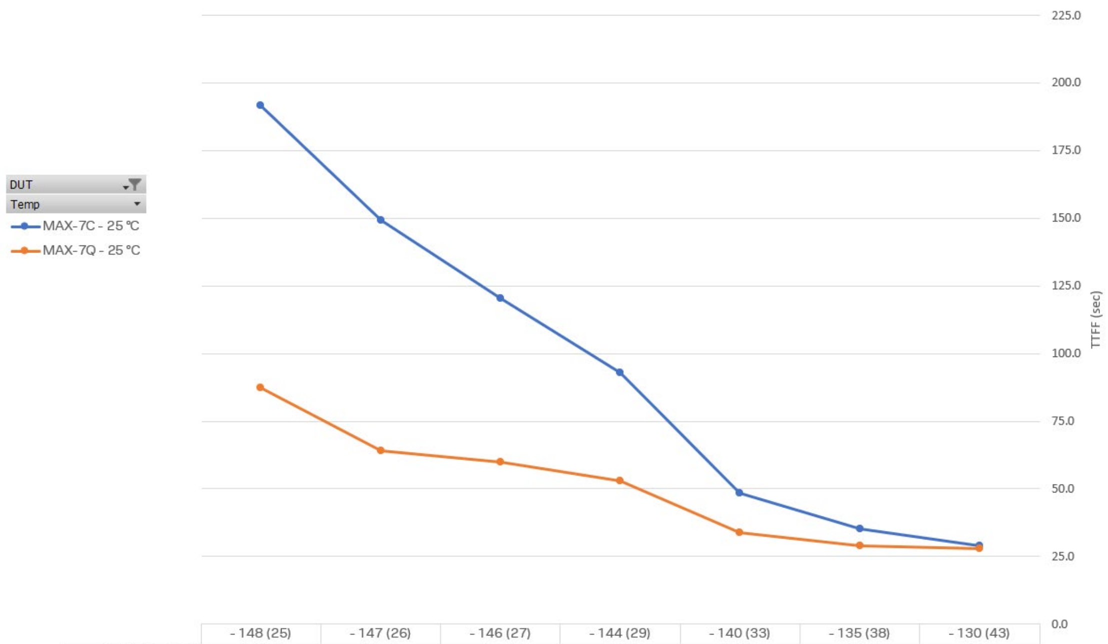
[13] Mainly for applications where the GNSS module is under thermal activity on the board.
[14] Cold and hot start under good GNSS visibility and using power levels of -130 dBm.
[15] Use this figure to determine required battery capacity.
[16] Simulated GNSS constellation using power levels of -130 dBm. Voltage supply= 3.0 V.
[17] Average current from startup until the first fix.

The higher current values in the backup modes seen in the MAX-7C are caused by keeping the crystal alive during off times, with the aim of providing faster warm and hot starts. This single-crystal feature cannot be disabled in u-blox 7 generation. Refer to section 2.3 for more information about the single-crystal feature.

☞ The new generation MAX-8C and MAX-M8C crystal modules have three times lower hardware and software backup current in the single-crystal mode, and have the option of disabling the single-crystal feature. If the application has other means of providing a time reference and/or the low current consumption is a key factor, refer to the section 5.4 for information on upgrading MAX-7 design to the u-blox 8 and M8-based MAX-8C or MAX-M8C solution.

5.3 Performance

5.3.1 Startup sensitivity and TTFF



	- 148 (25)	- 147 (26)	- 146 (27)	- 144 (29)	- 140 (33)	- 135 (38)	- 130 (43)
MAX-7C - 25 °C	191.76	149.18	120.49	92.87	48.30	35.30	28.96
MAX-7Q - 25 °C	87.27	64.06	59.87	52.89	33.91	28.85	27.90

Figure 10: TTFF vs. signal power in dBm and equivalent C/N0 inside parenthesis for MAX-7Q and MAX-7C during cold starts[18]

The MAX-7Q and MAX-7C show a significant difference in TTFF at weak signals. Even at very strong signals, there is a minor difference between TCXO and crystal-based variants. The single GNSS operation (fewer satellites) may contribute to the longer TTFF times of MAX-7C.

Overall, when switching from the MAX-7Q to the MAX-7C, an active antenna or an LNA can limit the degradation of the TTFF performance somewhat.

5.3.2 Road test performance analysis

Three road tests at different scenarios and signal power levels were carried out for performance comparison between TCXO and crystal-based modules. The results of the road tests are presented in section 5.4.3.2. To show the advantages of migrating from u-blox 7 (single GNSS) TCXO solution to u-blox M8 (multi-GNSS) generation modules, the road test results also include MAX-M8C.

[18] Results obtained on our test sites using a good LNA in front and an attenuator to decrease power level.

5.4 Upgrading MAX-7Q to MAX-8C/M8C

Before taking the decision to migrate from MAX-7Q to the crystal-based MAX-7C version, u-blox recommends considering an upgrade to the newer generation MAX-8C or MAX-M8C.

☞ Similar to MAX-7Q, MAX-8C is also a single-GNSS module supporting GPS only or GLONASS-only operation. MAX-M8C supports multi-GNSS operation.

Refer to MAX-8 / MAX-M8 Hardware Integration Manual [1] and GNSS FW3.01 Release notes [6] for more hardware (including antenna) and software-related guidelines during the migration of MAX-7Q to MAX-8C or MAX-M8C.

The upgrade to MAX-8C allows the customer to take advantage of the improved SPG 3.01 firmware (better tracking sensitivity) compared to ROM 1.00 used in the MAX-7 modules. More performance improvements can be achieved by migrating from MAX-7Q to multi-GNSS MAX-M8C, thanks to the higher numbers of available satellites, which will significantly improve the TTFFs, sensitivity, and performance, especially in dynamic and difficult environments. The performance benefits of MAX-8C and MAX-M8C are shown in Table 10.

It is highly advisable that customers consider a migration design review with the u-blox technical support team to ensure the compatibility of key functionalities.

5.4.1 MAX-7Q vs. MAX-8C/M8C comparison

Field	Parameter	MAX-7Q	MAX-8C	MAX-M8C
HW	**Oscillator**	TCXO	Crystal	Crystal
	RTC	Yes	Yes, but with a higher backup current	Yes, but with a higher backup current
	Interface config.	Same	Same	Same
	Pinout	Same	Same	Same
	GNSS	Single GNSS (GPS or GLO)	Single GNSS (GPS or GLO)	Multi-GNSS (up to 3 concurrent GNSS)
RF design	**Front-end**	With passive antenna, an external LNA is recommended.	With passive antenna, an external LNA is **mandatory.**	With passive antenna, an external LNA is **mandatory.**
	Out of band immunity	Same	Same	Same
Temp.	**Storage temp. °(C)**	Max +85	Max +105	Max +105
	Thermal isolation [19]	Optional	Recommended	Recommended
Power req.	**Supply (Vcc & Vio) (V)**	[2.7 - 3.6]	[1.65 - 3.6]	[1.65 - 3.6]
	Supply current (mA)	17.5	18	23
	SW backup current (mA)	0.020	0.105	0.105
	HW backup current (mA)	0.015	0.100	0.100
Sensitivity	**Dynamic Tracking (dBm)**	-161	-164	-164
	TTFF (sec) [20]	29	30	26
	Coldstarts sensitivity (dBm)	-148	-147	-148
	Hotstarts sensitivity (dBm)	-156	-156	-157
SW	**Firmware**	ROM 1.00	ROM SPG 3.01	ROM SPG 3.01
	OTP config.	-	single crystal enabled by default	single crystal enabled by default

Table 10: MAX-7Q to MAX-8C, MAX-M8C migration comparison (default configuration)

☞ When migrating to crystal-based MAX-M8C 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).

[19] Mainly for applications where the GNSS module is under thermal activity on the board.
[20] Cold and hot start under good GNSS visibility and using power levels of -130 dBm.

5.4.2 Power requirements

The table below shows that the MAX-8C and MAX-M8C modules have very similar power requirements as the MAX-7Q module.

Parameter	Symbol	Module	Min	Typ.	Max	Units	Condition
Power supply voltage	VCC, VCC_IO	MAX-7Q	2.7	3.0	3.6	V	
		MAX-8C	1.65	3.0	3.6	V	
		MAX-M8C	1.65	3.0	3.6	V	
Backup battery voltage	V_BCKP	All	1.4		3.6	V	
Average supply current [21, 22]	Icc Acquisition[23]	MAX-7Q		22		mA	Estimated at 3 V
		MAX-8C		18		mA	
		MAX-M8C		19		mA	
	Icc Tracking (Continuous mode)	MAX-7Q		17.5		mA	
		MAX-8C		16		mA	
		MAX-M8C		17		mA	
	Icc Tracking (Power Save mode / 1 Hz)	MAX-7Q		5.0		mA	
		MAX-8C		5.4		mA	
		MAX-M8C		6.2		mA	
Backup battery current	I_BCKP	MAX-7Q		15		µA	V_BCKP = 3.0 V, VCC = 0 V
		MAX-8C/M8C using the 26 MHz XTO in single crystal operation		100		µA	
		MAX-8C/M8C single crystal operation disabled (No RTC)		15		µA	
SW backup current	I_SWBCKP	MAX-7Q		20		µA	VCC = 3.0 V
		MAX-8C/M8C using the 26 MHz XTO in single crystal operation		105		µA	
		MAX-8C/M8C single crystal operation disabled (No RTC)		30		µA	

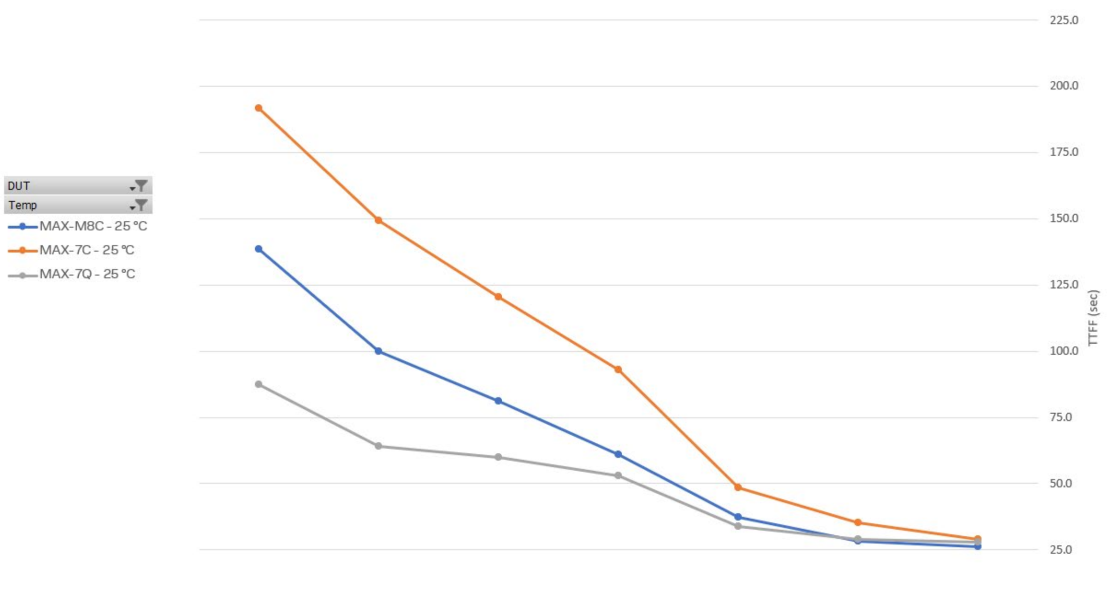
Table 11: MAX-7Q to MAX-8C and MAX-M8C power requirements

5.4.3 Performance

5.4.3.1 Startup sensitivity and TTFF

Because of the higher number of tracking satellites in multi-GNSS MAX-M8C, TTFF values with strong signals at room temperature are even lower than the TCXO-based single-GNSS MAX-7Q, as shown in Figure 11. By comparing the MAX-M8C (blue line) and the MAX-7C (orange line), it is clearly visible that the MAX-M8C brings the TTFF of crystal version closer to that of the TTFF of TCXO-based MAX-7Q (grey line). The cold start performance of the MAX-M8C clearly shows better performance than the MAX-7C, even at strong signals. Due to the limitation to the single-GNSS operation mode, MAX-8C would not achieve the same performance as the MAX-M8C, but would be closer to the blue curve of MAX-M8C than to the orange curve of MAX-7C.

[21] Use this figure to determine the required battery capacity.
[22] Simulated GNSS constellation using power levels of -130 dBm. Voltage supply= 3.0 V.
[23] Average current from startup until the first fix.



	- 148 (25)	- 147 (26)	- 146 (27)	- 144 (29)	- 140 (33)	- 135 (38)	- 130 (43)
MAX-M8C - 25 °C	138.42	99.84	81.09	61.10	37.23	28.36	26.23
MAX-7C - 25 °C	191.76	149.18	120.49	92.87	48.30	35.30	28.96
MAX-7Q - 25 °C	87.27	64.06	59.87	52.89	33.91	28.85	27.90

Figure 11: TTFF vs. signal power in dBm and equivalent C/N0 inside parenthesis for MAX-M8C, MAX-7Q and MAX-7C during cold starts[24] (default configuration)

The cold startup behavior of MAX-M8C at different temperatures (-35, +25 and +85 °C) presented in Figure 3 shows that the crystal-based MAX-M8C has only a small dependency on the temperature.

Migration from MAX-7Q to MAX-M8C provides improved startup performance at strong signals. MAX-8C and MAX-M8C are good migration alternatives for the TCXO-based MAX-7Q module.

5.4.3.2 Road test performance analysis

Road tests show real behavior in dynamic scenarios, and 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. 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.

5.4.3.2.1 Rural areas with good GNSS visibility

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

Figure 12 and Figure 13 show the error percentiles for two different power signals levels (average of 31.6 dBHz and 27.2 dBHz). Note that these GNSS signal levels are quite low, especially the second one with 27.2 dBHz.

[24] Results obtained on our test sites using a good LNA in front and an attenuator to decrease power level.

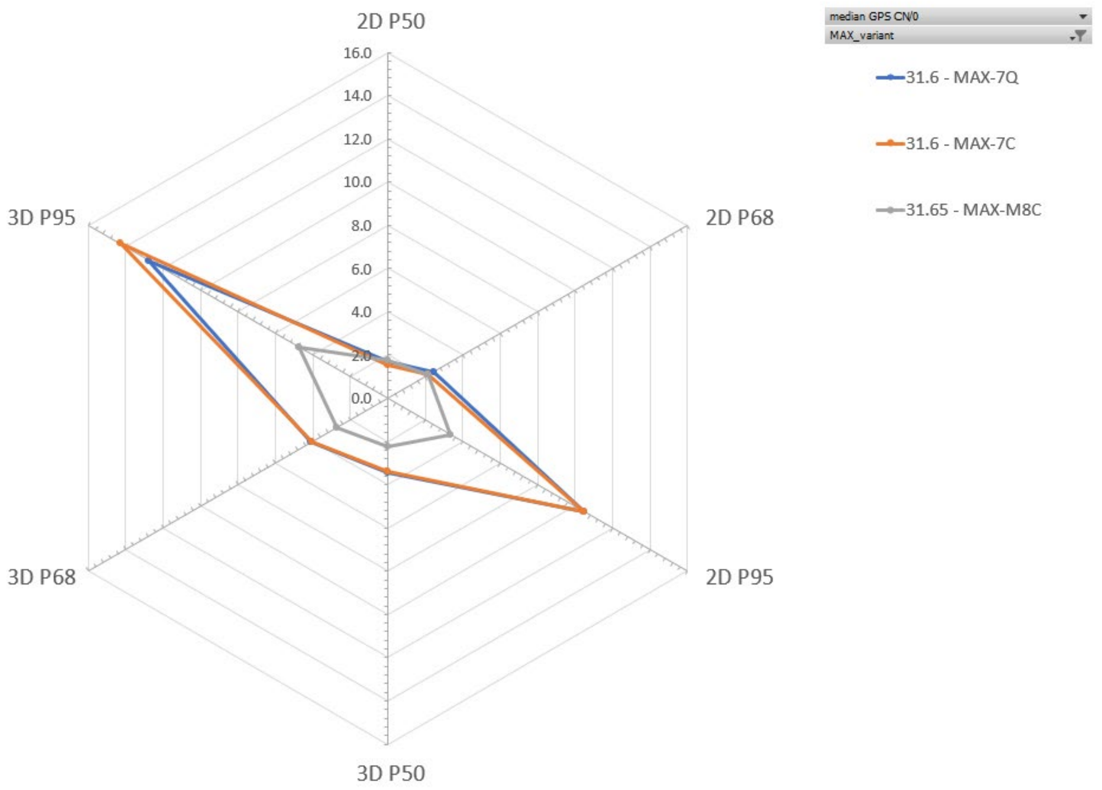


Figure 12: Position error in meters for MAX-M8C, MAX-7Q and MAX-7C in percentiles at 31.6 dBHz in a rural area

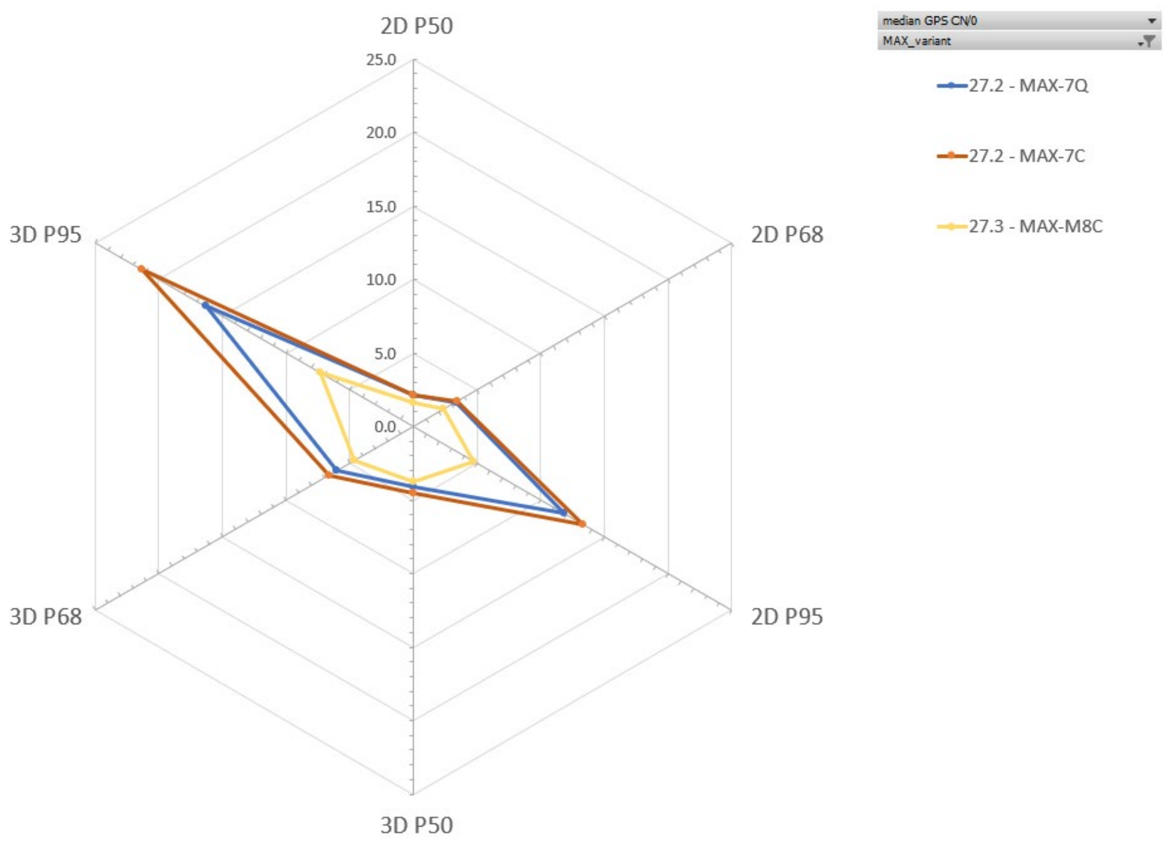


Figure 13: Position error in meters for MAX-M8C, MAX-7Q and MAX-7C in percentiles at 27.2 dBHz in a rural area

☞ Default mode for rural road test: GPS and GLONASS including QZSS, SBAS for MAX-M8C, and GPS plus QZSS and SBAS for MAX-7Q and MAX-7C.

From Figure 12 and Figure 13, we can see that the 95 percentiles of the position errors of MAX-7Q and MAX-7C modules are extremely high compared to that of crystal-based MAX-M8C. Looking at the positioning tracks for each MAX module in detail, we can see that in some locations the crystal-based MAX-M8C's multi-GNSS feature plays a very important role on achieving a better position accuracy compared to the single-GNSS MAX-7Q and MAX-7C modules.

One of such examples is marked as the circled area shown in Figure 14, where the satellite visibility is poor due to the forest on one side of the street, and discontinuity on the track caused by the building on the other side. Figure 14 show the real track (in green), the position calculated by the multi-GNSS crystal-based MAX-M8C (in blue), the single-GNSS TCXO-based MAX-7Q (in yellow), and the single-GNSS crystal-based MAX-7C (in red).

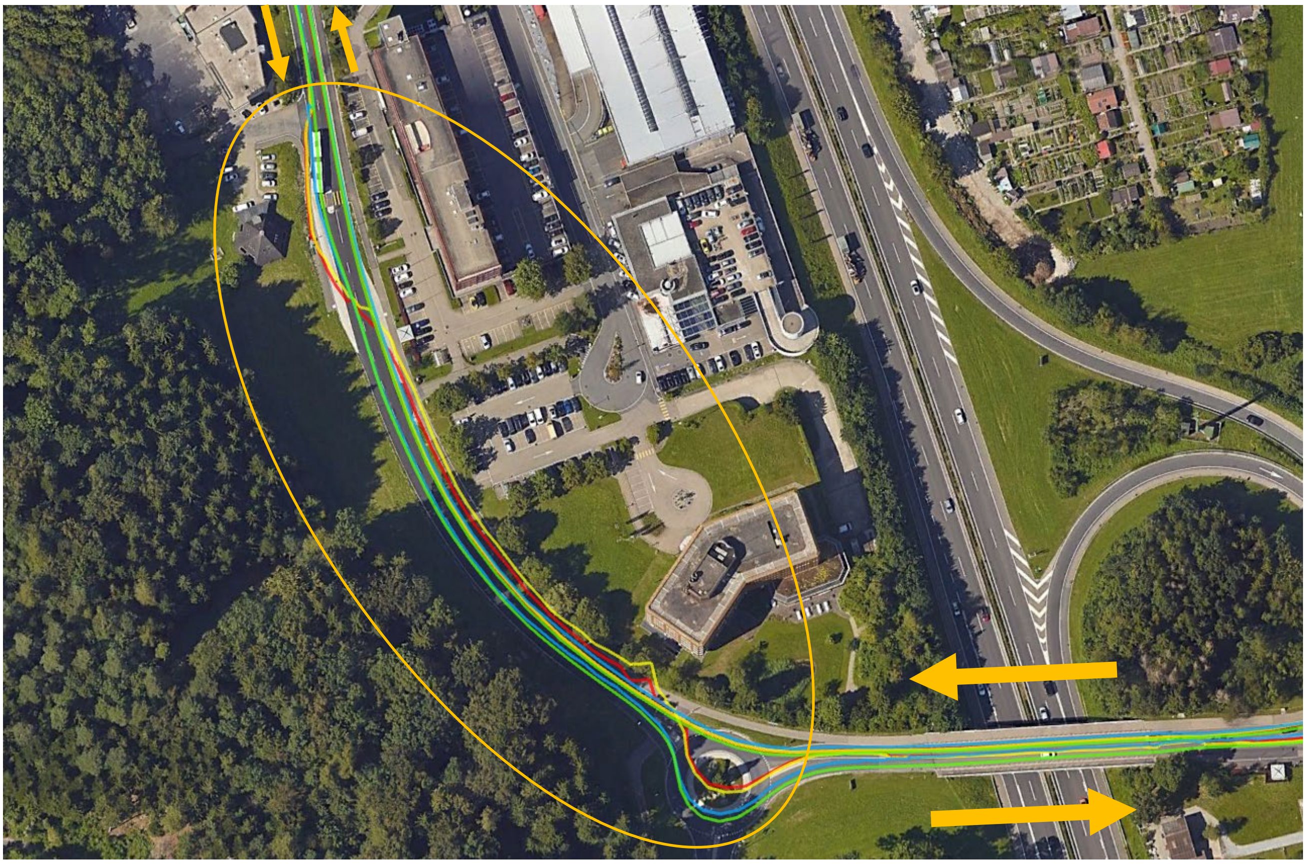


Figure 14: Tracks for MAX-M8C (in blue), MAX-7Q (in yellow), and MAX-7C (in red), and reference position (in green) in an area with lower GNSS visibility

A second example is shown in Figure 15 below, where the car goes through a narrow street with a building on each side of the track.

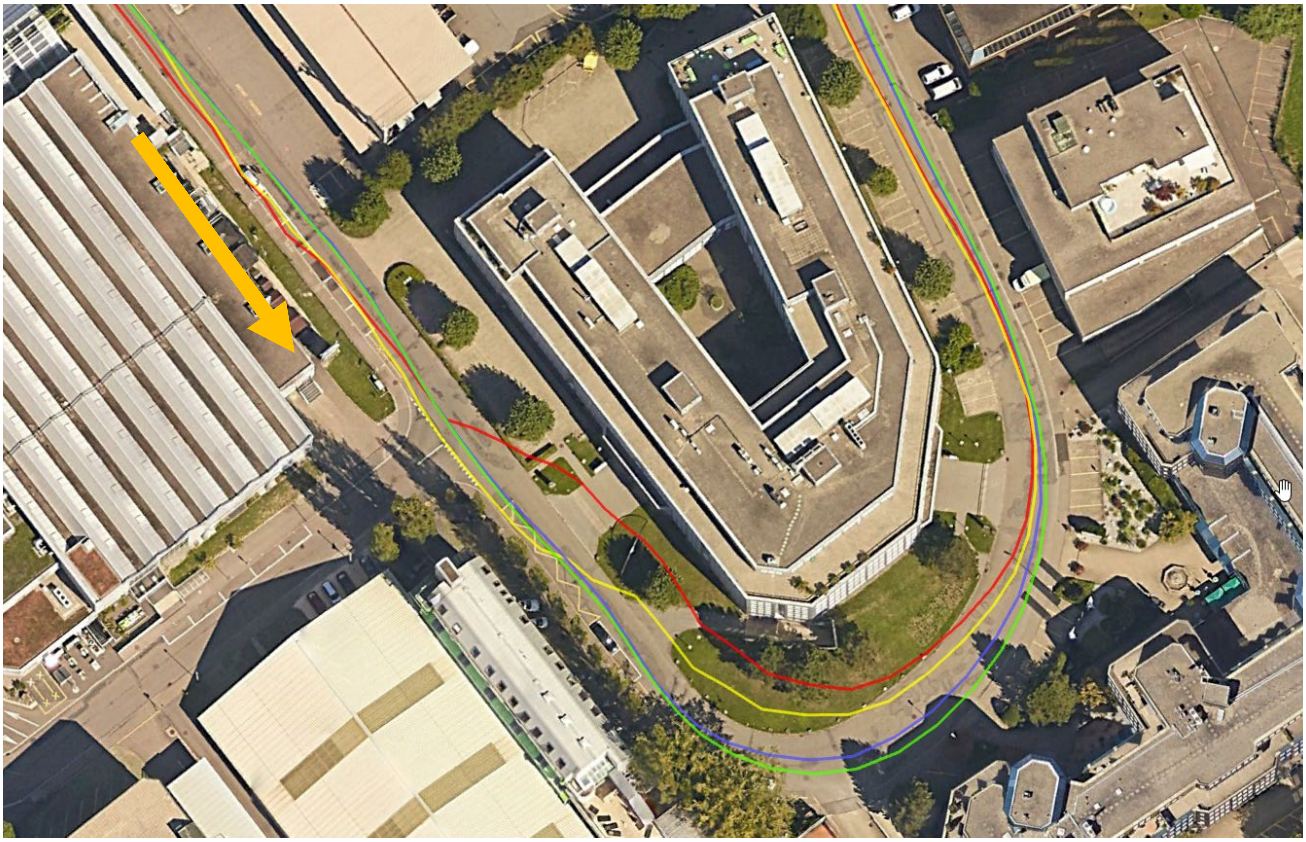


Figure 15: Tracks for MAX-M8C (in blue), MAX-7Q (in yellow), and MAX-7C (in red), and reference position (in green) in a narrow street

Values	Weakest signals 27.2 dBHz MAX-7Q	MAX-7C	MAX-M8C	Weak signals 31.6 dBHz MAX-7Q	MAX-7C	MAX-M8C
2D P50 (m)	2.14	2.15	1.64	1.71	1.52	1.75
2D P68 (m)	3.32	3.45	2.33	2.47	2.17	2.17
2D P95 (m)	11.81	13.36	4.74	10.47	10.47	3.37
3D P50 (m)	4.10	4.49	3.78	3.42	3.40	2.27
3D P68 (m)	6.02	6.63	4.62	4.09	4.05	2.73
3D P95 (m)	16.35	21.36	7.37	12.75	14.30	4.77

Table 12: Position error in percentiles for MAX-M8C, MAX-7Q, and MAX-7C at 27.2 and 31.6 dBHz signal power levels in rural areas

The results listed in the Table 12 highlight again the overall better position accuracy of the crystal-based multi-GNSS MAX-M8C module compared to the single-GNSS platform based MAX-7Q and MAX-7C modules, even under weak signal scenarios.

5.4.3.2.2 Urban canyon areas

In urban canyon (weak signal level and multipath) scenarios, the position accuracy percentiles of MAX-7Q, MAX-7C and MAX-M8C are presented in Figure 16.

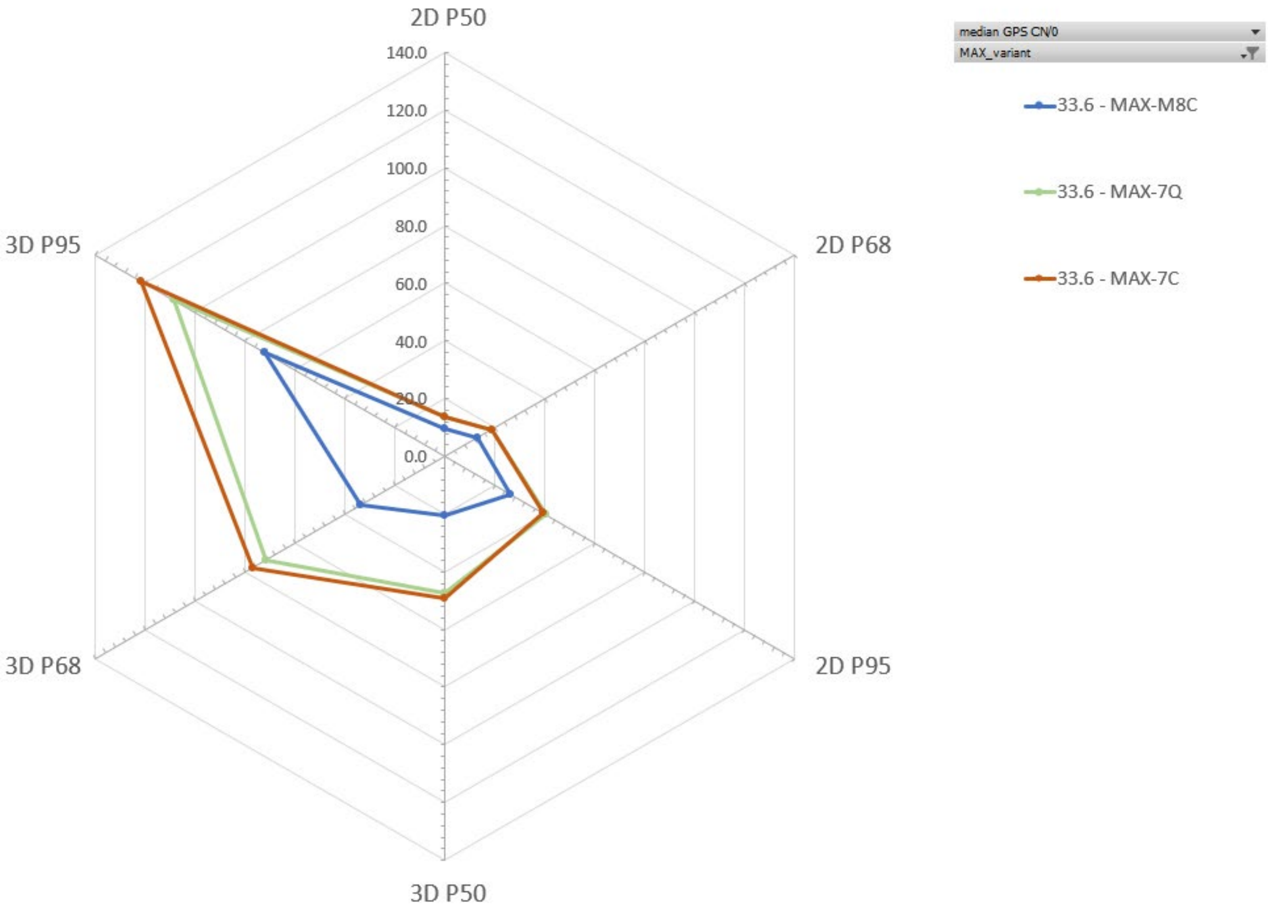


Figure 16: Position error in meters for MAX-M8C, MAX-7Q and MAX-7C in percentiles at 33.6 dBHz in an urban canyon

☞ Default mode: GPS and GLONASS including QZSS, SBAS for MAX-M8C, and GPS plus QZSS and SBAS for MAX-7Q and MAX-7C.

As shown in Figure 16, under weak signal scenarios, the crystal-based multi-GNSS MAX-M8C once again shows much better accuracy compared to single-GNSS MAX-7Q and MAX-7C solutions.

Refer to Figure 7 and section 3.3.2.1 for the real track used in an urban canyon road test and the expected high position errors for all standard precision GNSS receivers under such challenging environment.

5.4.3.2.3 Highway road test

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

The position accuracy errors for MAX-7Q, MAX-7C and MAX-M8C are shown in Figure 17. The highway test starts statically with low GNSS visibility, where it stays for 3-4 minutes. During that time, and until the car starts moving to acquire better visibility, the position is completely shifted. The big accuracy error during that time is the consequence of above-mentioned highway test setup.

Note that the P95 values in Figure 17 do not really represent the behavior of the MAX-7Q and MAX-7C modules in the real highway scenario. Under the highway test condition, the error percentile 95 is extremely high for both TCXO-based MAX-7Q and crystal-based MAX-7C modules, while accuracy is much better for crystal-based MAX-M8C, thanks to the u-blox M8 multi-GNSS feature.

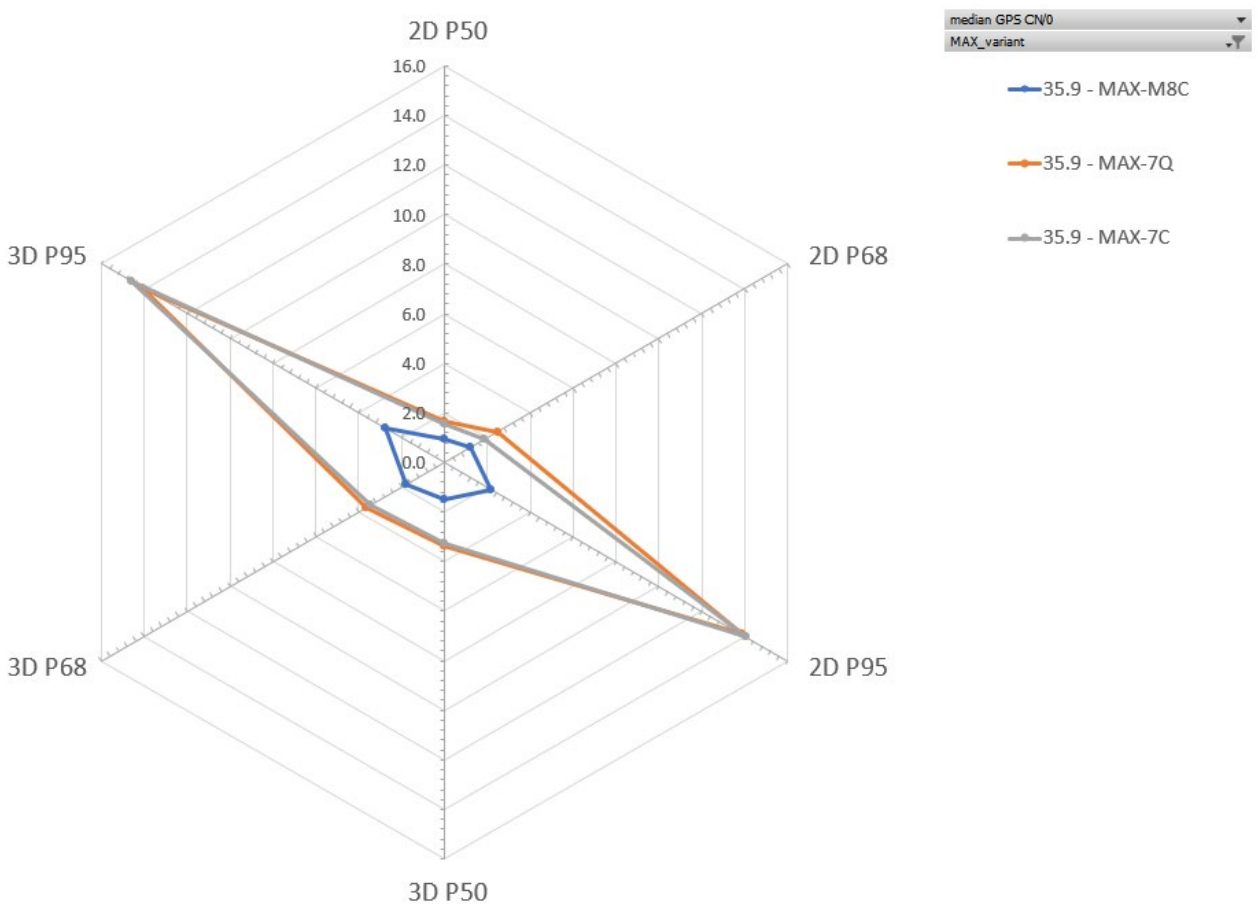


Figure 17: Position error in meters for MAX-M8C, MAX-7Q and MAX-7C in percentiles at 35.9 dBHz in a highway

☞ Default mode: GPS and GLONASS including QZSS, SBAS for MAX-M8C, and GPS plus QZSS and SBAS for MAX-7Q and MAX-7C.

Highway test results again demonstrate that the crystal-based MAX-7C has very similar position accuracy compared to the TCXO-based variant MAX-7Q under weak GNSS signal conditions. In addition, the accuracy improvement of the multi-GNSS MAX-M8C module is very significant in such a dynamic scenario, thus upgrading the TCXO-based MAX-7Q design to crystal-based MAX-M8C is highly recommended for utilizing the benefits from the multi-GNSS feature, and to ensure the best GNSS performance.

6. Conclusion

For customers with active antennas or an external LNA in their current designs, there should be no issue when switching from TCXO-based MAX-M8Q to crystal-based MAX-M8C, or from TCXO-based MAX-8Q to crystal-based MAX-8C.

For migration from TCXO-based MAX-7Q to crystal-based MAX-7C, MAX-8C or MAX-M8C, refer to section 5 for detailed comparison of the different options. Contact u-blox technical support team for guidelines for finding the best suitable crystal-based solution for your MAX-7Q design.

Large and well-designed passive patch antennas, external LNA or active antennas can work perfectly well with u-blox crystal-based MAX receivers despite the minimal performance differences between the crystal and the TCXO variants. MAX-M8C, MAX-8C and MAX-7C solutions are good for applications where operation with a weak signal is not necessary.

Related documents

[1] MAX-8 / MAX-M8 Hardware integration manual, UBX-15030059
[2] MAX-7, NEO-7 Hardware integration manual, UBX-13003704
[3] MAX-M8 Data sheet, UBX-15031506
[4] MAX-8 Data sheet, UBX-16000093
[5] MAX-7 Data sheet, UBX-13004068
[6] GNSS FW3.01 Release notes, UBX-16000319

Revision history

Revision	Date	Name	Comments
R01	21-Dec-2020	imar, cbib	Initial draft
R02	15-Feb-2021	imar	Added road data results (section 3.3.2, section 5.3.2 and section 5.4.3.2)

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