

# Design guide for small, high performance GNSS patch antenna applications

How to find the best balance between size and performance in GNSS patch antenna designs

White paper

## Abstract

This paper discusses the compromises to be made during a GNSS antenna design. It uses SAM-M8Q as an example of good balance between GNSS size and performance, by explaining the choices that have been made during the creation of this product. It is aimed at designers with little to no RF experience who want to integrate a small but good-performing GNSS receiver in their product.

[www.u-blox.com](http://www.u-blox.com)

UBX-16026689 - R01

# Contents

<b>Introduction</b> .....	<b>3</b>
<b>1 Patch antenna theory and influencing factors</b> .....	<b>4</b>
1.1 Intrinsic characteristics .....	4
1.2 External factors .....	6
1.2.1 Antenna tuning .....	6
1.2.2 The effect of EMI on GNSS reception .....	6
<b>2 Antenna design considerations</b> .....	<b>9</b>
2.1 The effect of patch element size .....	9
2.2 The effect of the ground plane .....	10
2.3 Antenna tuning and bandwidth .....	11
<b>3 Validation and testing</b> .....	<b>12</b>
3.1 Ground plane size and antenna placement .....	12
3.2 Radiation pattern and directivity .....	14
3.3 Comparison against other products .....	15
3.4 Use case specific tests and device placement .....	16
<b>4 Design checklist</b> .....	<b>18</b>
<b>5 Conclusion</b> .....	<b>19</b>
<b>About u-blox</b> .....	<b>20</b>

## Introduction

As GNSS receivers shrink in size, the biggest physical component of a complete receiver is the antenna. Markets are in general driven by miniaturization and the designers are often exposed to deliver miracles when it comes to integration.

However, small and medium sized companies can often not afford to have a dedicated RF engineer and may face difficulties designing-in small, yet good-performing products with integrated GNSS. Material, size, ground plane size, and position on the PCB are some of the parameters one needs to take into account when integrating an antenna into a small form factor. Such complexity very often leads to higher development costs and longer Time-to-Market, effectively reducing the profitability and chances of success of the final product. This white paper provides insight into making the best choice when selecting a patch antenna and gives the example of SAM-M8Q, an integrated antenna module with consistent strong performance in an ultra-compact form factor.



SAM-M8Q Antenna Receiver

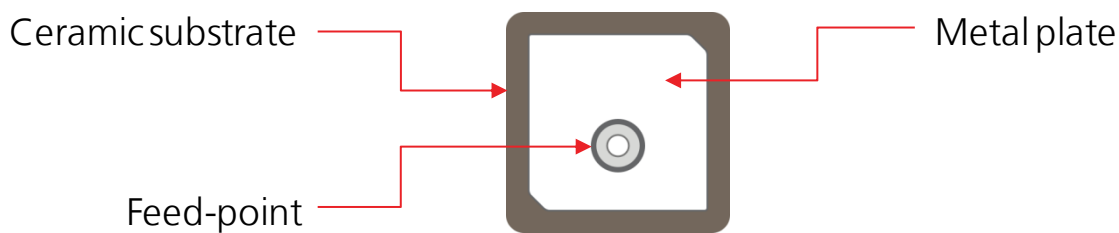
# 1 Patch antenna theory and influencing factors

## 1.1 Intrinsic characteristics

A patch antenna belongs to the family of micro-strip antennas. The most common variant is a rectangular shaped patch with a length of approximately half of the wave length.

The element comprises the following parts:

- A ceramic substrate with a high dielectric constant ( $\epsilon_r$ ) is used to electrically shorten the wavelength and make it possible to have a physically smaller antenna than the wavelength of 19 cm would allow without a high relative permittivity.
- A metal plate on top
- Feed point

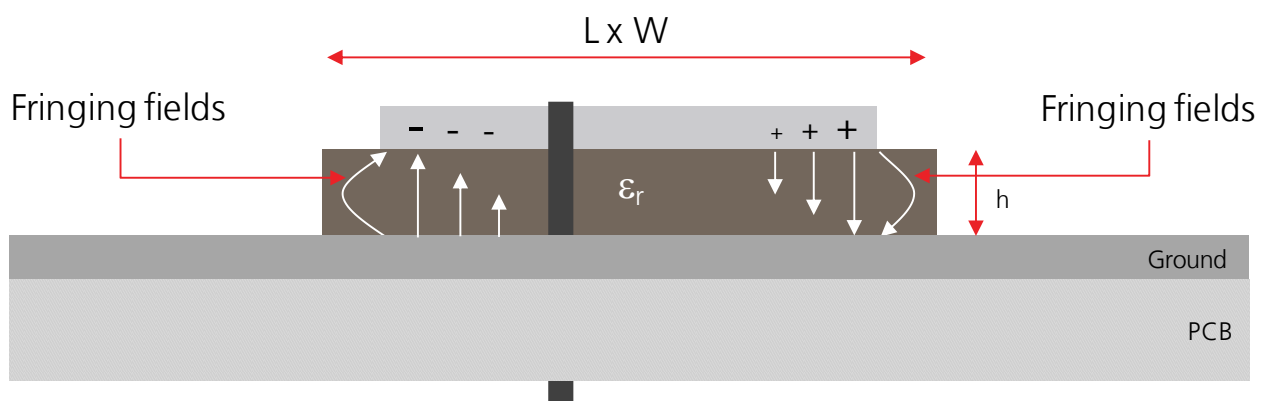


**Figure 1: A patch antenna element**

If the ceramic were replaced by air, the size of the patch would be roughly 9.5 x 9.5 cm at 1.575 GHz. Using a ceramic substrate we can reduce the physical size and have elements the size that we are used to see in GNSS receivers. The higher the  $\epsilon_r$ , the smaller the antenna can be. There is however a drawback in increasing the  $\epsilon_r$  as the radiation efficiency drops.

A patch element radiates thanks to the fringing electrical fields (in phase at the edges). Here the height of the substrate plays an important role as the fringing fields are bigger the higher the element is. That is why most of the commercial patch antennas are 4 mm high. Note also that the smaller the GND underneath the element is, the smaller the fringing fields become and hence lower radiation efficiency. There is also a risk that the polarization becomes linear if the element is placed asymmetrically on the GND plane.

This means that most of the antennas have a dependency to a GND (ground) plane. The GND plane forms a vital part of a patch antenna and size does matter for both the antenna itself and the GND plane. This is true for both plain patch antennas and embedded antenna modules, like SAM-M8Q.



**Figure 2: Patch antenna theory**






The feed-point is asymmetrically located to optimize the input impedance (typically 50  $\Omega$ ) and to achieve proper RHCP (Right Hand Circular Polarization). It is important to achieve RHCP on an antenna since GNSS signals have

a Right Hand Circular Polarization themselves. A good polarization of the antenna is crucial to attenuate reflected signals in e.g. urban environments and achieve best performance in such environments. This is because signal polarization changes (from RHCP to LHCP or from LHCP to RHCP) each time it is reflected from a surface (like a building). A good RHCP antenna attenuates a single reflection as the signal changes polarity from RHCP to LHCP. As a consequence, dipole antennas (like chip antennas), which are by nature linearly polarized, receive equally both RHCP and LHCP signals and are not able to discriminate proper signal from reflections.

On small elements, such as a 9 x 9 mm patch, the resonance cannot be excited properly and thus it becomes more or less linearly polarized regardless of the GND plane size.

Conclusion: an antenna is the entry point to the GNSS receiver. What is lost in the antenna, for instance due to poor radiation efficiency, cannot be recovered later on in the signal processing chain. Since patch antennas are highly affected by their size and the GND plane size, it is therefore imperative to balance size versus performance in the customer application.

The table below compares the performance of a few typical antennas used in embedded applications.

					
	25x25mm patch on 70x70mm GND	15x15mm patch on 50x50mm GND	9x9 mm patch on 50x50mm GND	Helical antenna	Chip antenna on 80x40mm GND
<b>Axial Ratio</b>	1	3	10	1	Linear
<b>Front-to-back ratio</b>	15 dB	6 dB	1 dB	15 dB	-
<b>Radiation efficiency</b>	90%	60%	40%	30%	60%
<b>Antenna gain</b>					
Up	+3.5 dBic	+1.5 dBic	-0.5 dBic	-3 dBic	-0 dBic
Horizon	-3 dBic	-6 dBic	-9 dBic	-7 dBic	-0 dBic
Down	-10 dBic	-5 dBic	-4 dBic	-13 dBic	-10 dBic
<b>GND dependent</b>	Yes	Yes	Yes	No	Yes
<b>Polarization</b>	RHCP	RHCP	Linear	RHCP	Linear
<b>Polarization mismatch</b>	0 dB	0 dB	-3 dB	0 dB	-3 dB
<b>Max C/No (dBHz)</b>	52	48	40	45	45

**Table 1: Comparison of different antenna types**

Here are some details about each of the properties that describe the performance of an antenna:

- **Axial Ratio:** This ratio is a dimensionless number describing how circular the polarization is. Anything below 3 is considered good and RHCP (Right Hand Circular Polarization) is achieved. Note that a patch element smaller than 12 x 12 mm cannot achieve good Axial Ratio even on a fairly large GND plane.
- **Front-to-back ratio:** This ratio describes the directivity of the antenna, i.e. how much of the signal is received from the front side (facing upwards) versus the back side (facing downwards). Here the GND plane size plays a vital role.
- **Radiation efficiency:** This number describes how much of the signal energy is captured by the antenna. To clarify, the smaller the efficiency, the more of the signal is lost in the antenna itself. Note: it is impossible to recover the loss of the signal in the antenna in the processing chain. The efficiency should obviously be as high as possible; more than 50% can be considered acceptable. The factors influencing radiation efficiency are: size of the element and the relative permittivity of the ceramic substrate upon which the antenna is built.
- **Antenna gain:** This is sometimes also referred to as the radiation pattern. Antenna gain also includes the directivity of the antenna. It is usually defined as the gain of the antenna compared to a perfect isotropic antenna in three dimensions (the X, Y and Z axes). The GND plane plays a vital role here. As a consequence, the best gain towards the zenith (and hence best performance) will be achieved when the

antenna is facing upwards. A small GND plane makes the antenna omni-directional, which gives more freedom to the placement of the antenna, but has smaller gain in all directions. Antenna size influences the gain as well. See section 3.2 for a radiation pattern of SAM-M8Q.

- **GND dependency:** All patch elements and chip antennas are dependent on a GND plane. The helical antenna is an exception as it does not require a GND plane to operate. GND plane size plays a vital role which will be explained later in this document. On chip antennas the GND plane forms actually half of the dipole antenna. The chip element itself is the other half of the dipole antenna.
- **Polarization:** RHCP or not. A good polarization of the antenna is crucial to attenuate reflected signals in e.g. urban environments and achieve best performance in such environments.
- **Polarization mismatch:** Loss due to mismatch between transmitting and receiving antenna polarizations. E.g. when GNSS signals are received with a linearly polarized antenna, the loss is 3 dB.
- **Max C/No:** This number shows the expected signal levels of various antennas taking all the parameters described above into account. A C/No value of 40 dBHz and above can be considered good whereas a level of 25-30 dBHz is an absolute minimum for GNSS operation.

In summary, the following factors influence the intrinsic performance of a patch element:

- Element size and width
- GND plane size
- Radiation efficiency of the element
- Polarization

There are also other external factors of influence, which will be discussed in the following section:

- Bandwidth and tuning
- EMI

## 1.2 External factors

### 1.2.1 Antenna tuning

A patch antenna is also to some extent sensitive to close-by materials such as plastic. If the enclosure is very close to the element itself, there will be a few MHz of de-tuning (down-wards) due to the enclosure. I.e. the resonant frequency of the antenna will be lowered. Antenna tuning is typically handled by the element vendor who tunes the resonance frequency for a given element size and ground plane size. No impedance tuning is needed as the feed-point of the element is typically 50  $\Omega$ .

### 1.2.2 The effect of EMI on GNSS reception

All parameters described in the previous section influence the antenna performance. An equally vital part of system level verification is EMI (Electro Magnetic Interference). EMI is present in nearly all modern electronics designs.

There are typically two types of in-band EMI that are harmful to GNSS reception:

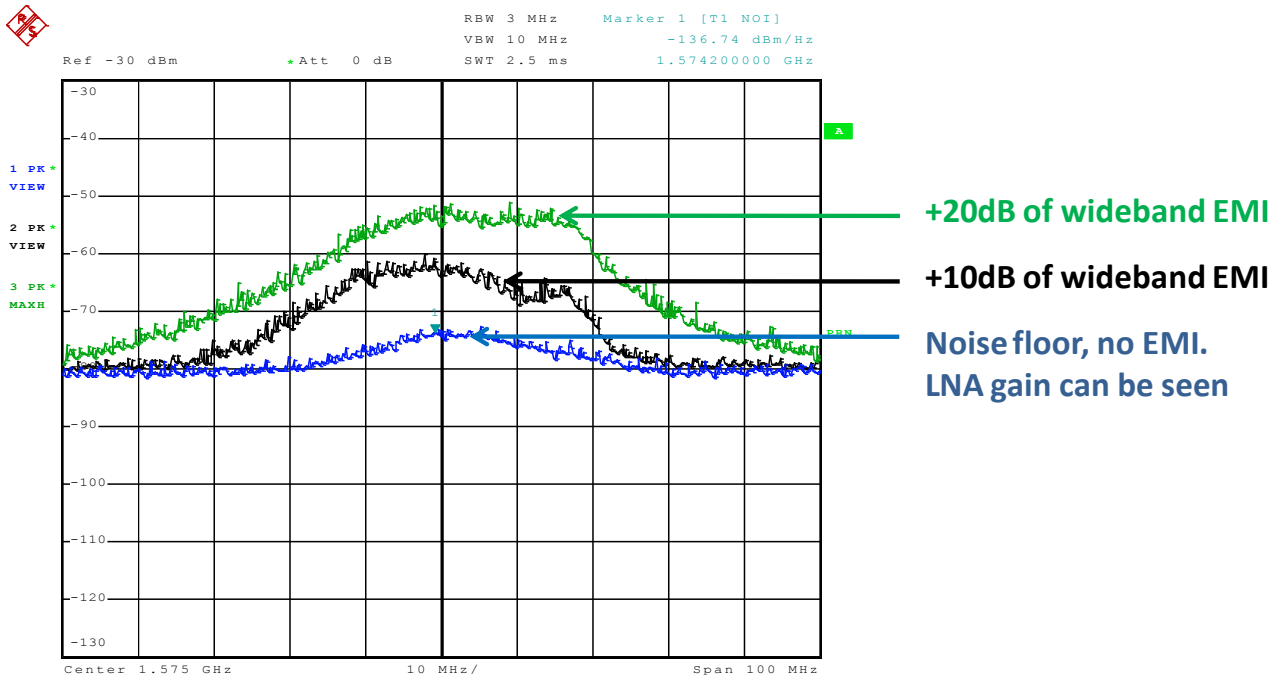
- CW (Continuous Wave), typically generated by clock harmonics. A typical example is the 110<sup>th</sup> harmonic of a laptop oscillator (14.318 MHz) that generates CW interference 420 kHz below the L1 center frequency. u-blox receivers have on-chip CW detection and mitigation circuitry in order to minimize the effect of CW interference. One way to mitigate CW on system level is to choose an oscillator frequency such that there are no harmonics falling into the L1 band.
- Wideband Noise, typically generated by cellular transmitters and high speed electronics located close-by the GNSS antenna. This is a more severe type of EMI as the receiver has no means to suppress the interference. The EMI must be minimized on the customer board with shielding for example.

A typical source of EMI is a microprocessor with a memory bus. Such electronics can easily generate wideband noise on GNSS band and is thus considered in-band noise above the noise floor. If the in-band noise raises the noise floor by for example 8 dB, the C/No of the received GNSS signal is lowered by an equal amount. It is thus

imperative to verify the antenna in the actual design and actual installation environment using live GNSS conditions<sup>1</sup>.

There are two different methods to measure wide band EMI on GNSS band:

1. Active GNSS antenna + a spectrum analyzer in frequency domain
2. Active GNSS antenna + a spectrum analyzer in time domain



Date: 27.JAN.2005 13:45:09

**Figure 3: Proof of wideband EMI on GPS L1 band**

Figure 3 shows the EMI test results of a very noisy design. An active GPS antenna is used as an EMI detector to provide selectivity on L1 band for the spectrum analyzer. The blue graph shows the thermal noise floor without any EMI (the active GPS antenna far away from the electronics). The “bump” represents the LNA gain and SAW filter bandwidth of the active GPS antenna. When the EMI detector antenna is moved closer to the electronics the level of increased EMI can be seen clearly. The green graph shows an increase of the noise floor by 20 dB when the active antenna is placed on top of the electronics. The graph in the middle (black) shows the results approximately 10 cm away from the electronics.

The other way to detect EMI is to use a time-domain-analysis. The graph below shows a 1 s sweep with the spectrum analyzer tuned to the GPS L1 band. Here we can see how the EMI varies over time as the memory bus activity of a microprocessor system is random. Nevertheless a general increase of the noise floor of roughly 10 dB can be seen in this case. Time domain analysis is quite useful to detect the exact source of EMI. EMI caused by memory bus activity and EMI caused by USB signaling are quite different and not necessarily distinguishable using the frequency domain analysis.

<sup>1</sup> This should be performed outdoors as using an indoor GNSS signal re-radiator is only indicative in terms of EMI as the net gain from the roof antenna is typically higher than the path loss from the re-radiating antenna to the receiving antenna

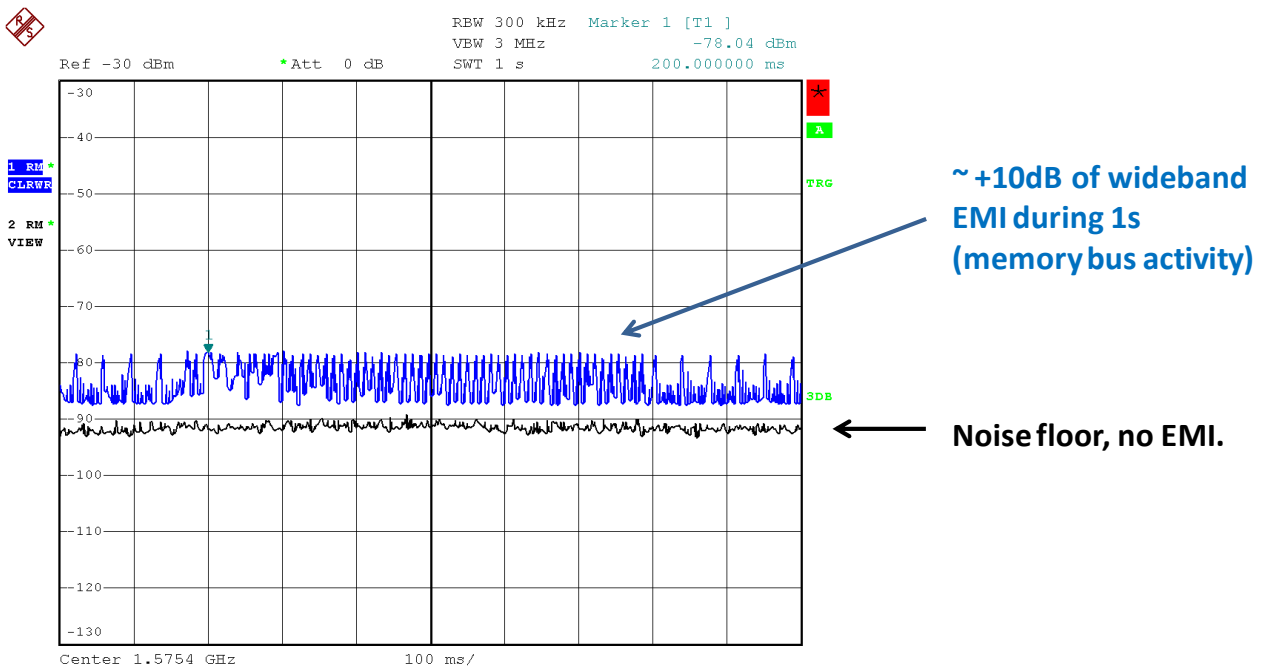


Figure 4: Time domain results on wideband EMI on GPS L1 band

It is important to remember that the level of EMI reduces the effective C/N0 seen by the GNSS antenna by an equal amount. In practice it means that if the GNSS antenna is subject to 10 dB of EMI relative to the noise floor, it reduces the C/N0 by 10 dB. The only way to mitigate is to shield the electronics or move the GNSS antenna further away. Moving the antenna is not often possible as the GNSS antenna is part of the design.

Note also that EMI can also be self-generated. This is most likely the case in one of the existing antenna products that was tested against SAM-M8Q. See section 3 for further details.



## 2 Antenna design considerations

The next sections give step-by-step details about how to make careful and educated decisions during the design-in of a patch antenna. The example of SAM-M8Q, the u-blox surface mounted antenna module, is used. It has the following requirements:

- Excellent signal reception despite its small size
- Easy to design-in with no RF expertise required
- Consistently strong performance regardless of installation
- Concurrent reception of GPS and GLONASS

### 2.1 The effect of patch element size

When designing-in a GNSS antenna, the first step is to select its size and width. Designing SAM-M8Q, the gain achieved by different size patch elements was measured. The following antenna sizes mounted on a 50 x 50 mm GND plane were tested:

- 9 x 9 x 4 mm
- 12 x 12 x 4 mm
- 15 x 15 x 4 mm
- 18 x 18 x 4 mm
- 25 x 25 x 4 mm

In Figure 5 you can see the antenna gain as a function of patch element size.

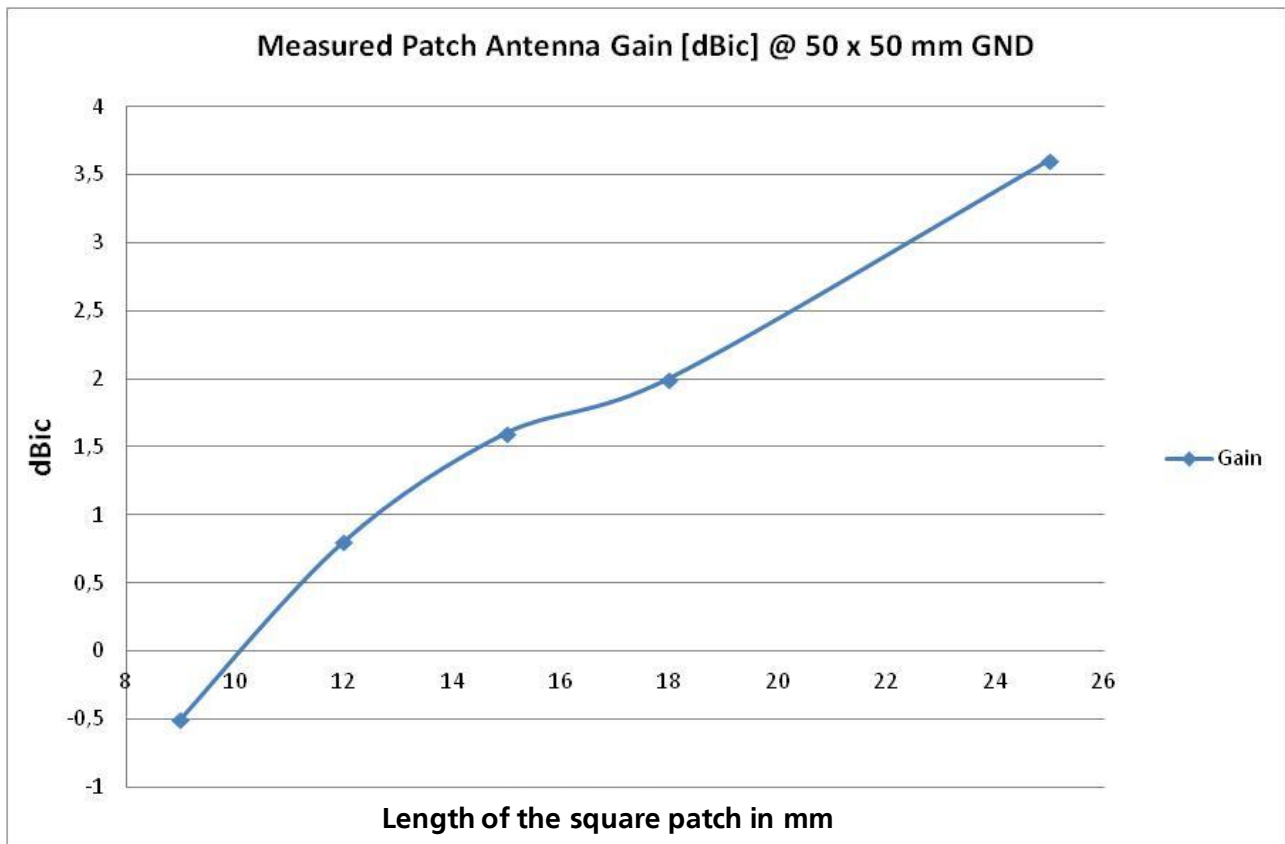


Figure 5: Antenna gain of different element sizes mounted on a 50 x 50 mm GND plane

The results show that a 15 x 15 x 4 mm element has roughly the same gain as an 18 x 18 x 4 mm element. There is a 2 dB penalty compared to a 25 x 25 x 4 mm element, but such a big element is impractical for most use cases. A 15 x 15 x 4 mm antenna is a good balance between size and performance. Note also that small antennas like 9 x 9 mm are effectively linearly polarized and another 3 dB is lost compared to the chart. This would effectively lead to 5.5 dB loss and impede performance by a large factor.

## 2.2 The effect of the ground plane

As discussed in previous sections, the second influencer is the GND plane size. Since a 15 x 15 mm element seems to be a good balance between size and performance. The effect of the GND plane size was also studied on this patch element size, by measuring the gain against the GND plane size.

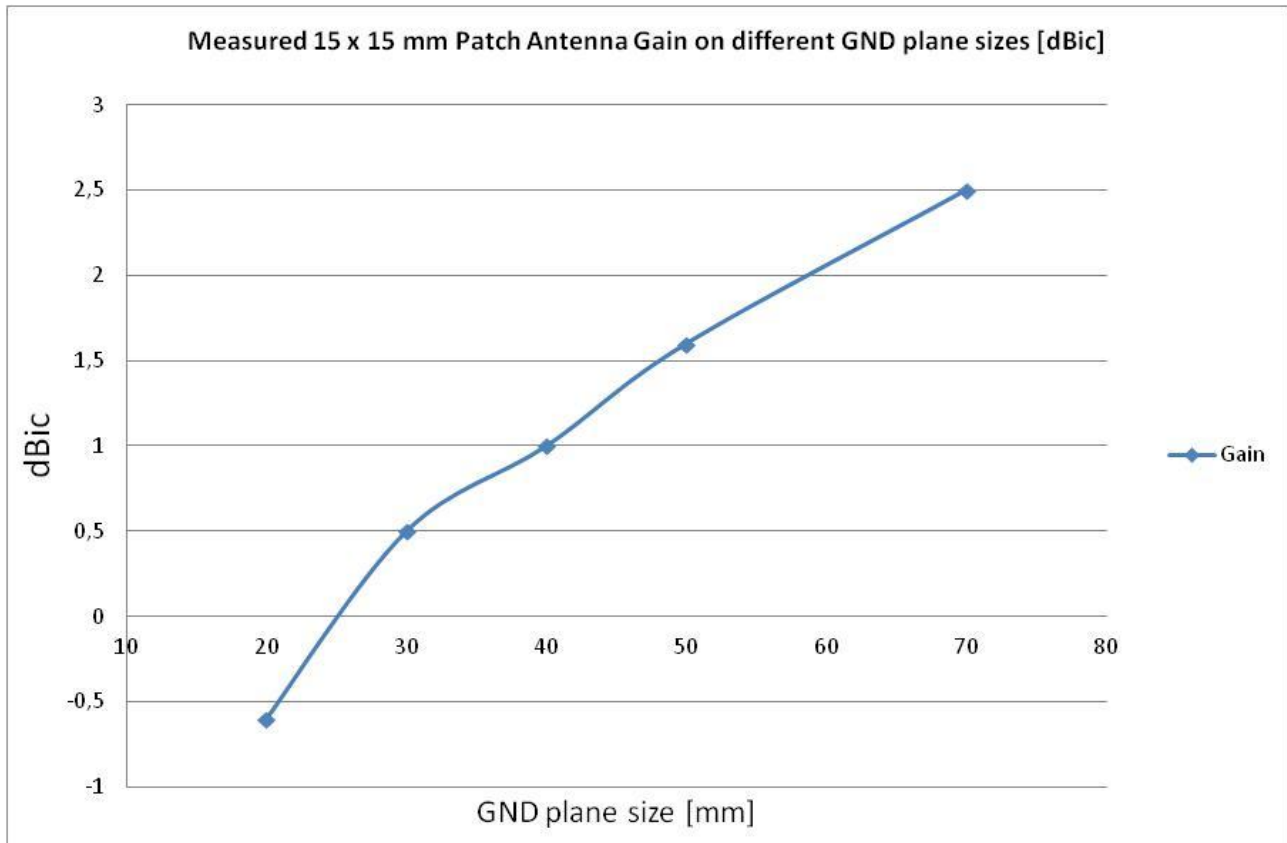


Figure 6: Patch element gain on different GND plane sizes

The gain drops as the GND plane gets smaller. There is however, only about a 1.1 dB drop in reducing the size from a 50 x 50 mm GND plane to a 30 x 30 mm GND plane.

Considering the requirements of achieving minimal size with yet solid overall performance in most of the situations, it was decided to select a 15 x 15 mm antenna. Indeed, measurements showed that a 15 x 15 mm element, as long as used with a 30 x 30 mm or bigger PCB, will maintain a high gain and will ensure great GNSS performance. It is a good compromise as using a smaller antenna would make performance too dependent on GND plane and using a bigger antenna would improve the gain but only marginally and is not worth the size penalty for space conscious applications.

Note that using a really small GND plane, like 20 x 20 mm, makes the antenna effectively linearly polarized so that it is no longer circularly polarized, and hence loses an additional 3 dB in signal level.

## 2.3 Antenna tuning and bandwidth

Now that the size of the antenna has been selected, the next step is to verify the other requirements of SAM-M8Q: simplicity of use and support for GPS and GLONASS. This is done by measuring the bandwidth as well as the antenna tuning.

The following figure shows the antenna tuning (S11 parameter) and bandwidth (S21 parameter) of the 15 x 15 x 4 mm element used in SAM-M8Q. S21 shows that the 3 dB bandwidth is roughly 43 MHz covering both GPS and GLONASS frequencies. The large bandwidth makes the receiver also less vulnerable to frequency de-tuning caused by plastic material (casing) close to the antenna.

An S11 of -10dB is considered good for achieving a good axial ratio. In the figure below we can see two resonance frequencies; one for GPS and one for GLONASS.

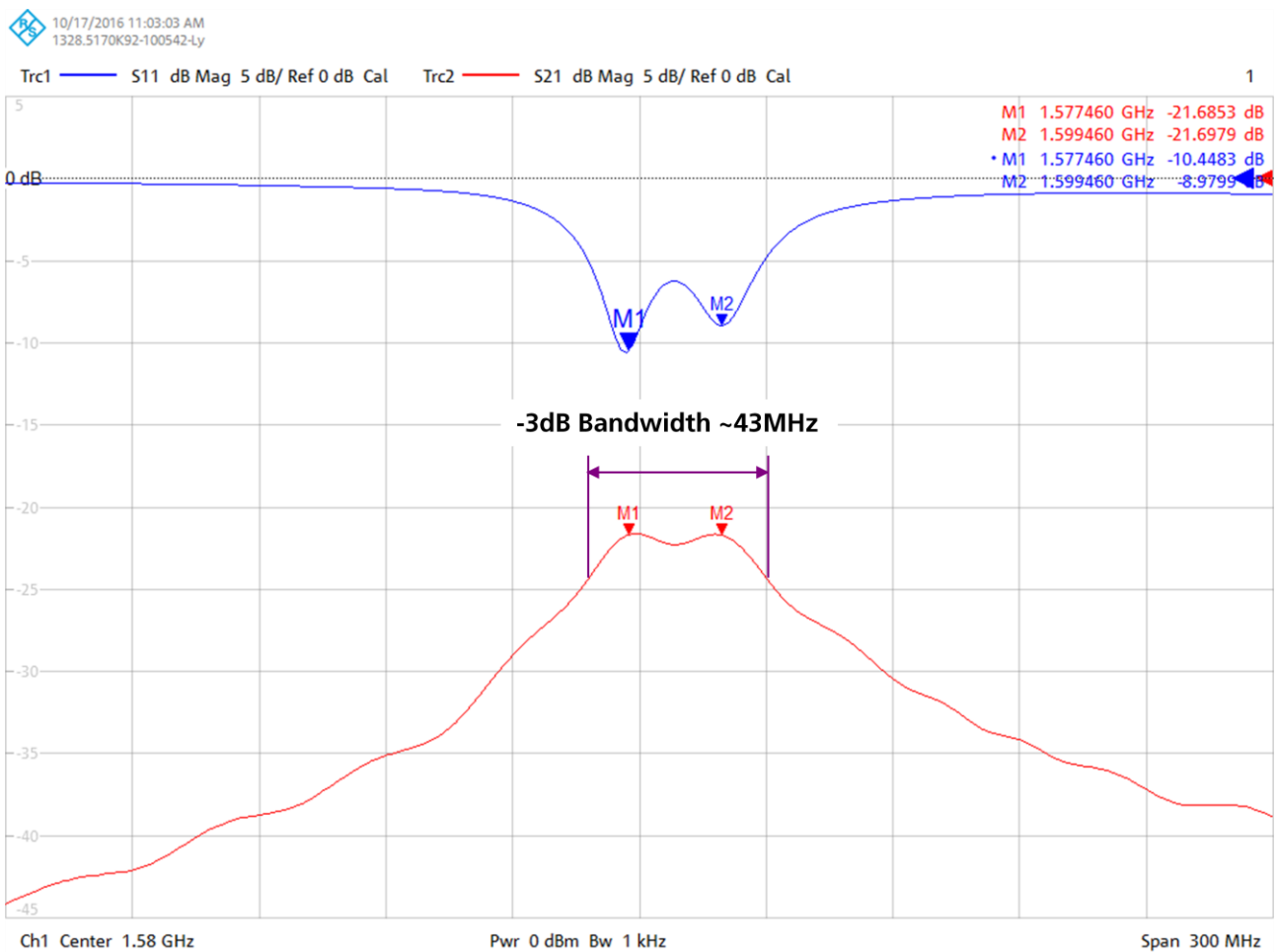


Figure 7: Antenna tuning of a 15 x 15 x 4 mm patch antenna on 50 x 50 mm GND plane.

This measurement shows that SAM-M8Q will indeed support GPS and GLONASS and can be used with close proximity of detuning material without major performance degradation (i.e. detuning).

Antenna tuning and bandwidth maximization is already optimized in the SAM-M8Q so no additional efforts are needed. In case it is decided to use a plain patch element, the tuning will become a crucial part of the design process.

### 3 Validation and testing

Validation is a very important part of the process as it makes sure that the product can be used in real conditions and all considerations mentioned in the previous sections have been taken into account.

#### 3.1 Ground plane size and antenna placement

In order to validate the final design and make sure SAM-M8Q has consistent performance regardless of installation, u-blox developed a “cuttable” PCB.

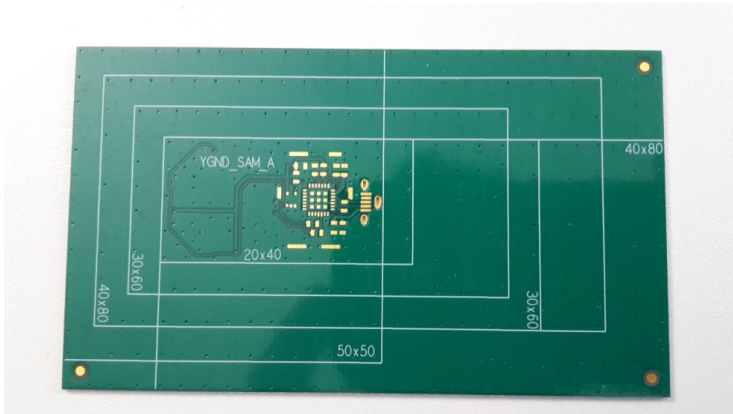


Figure 8: Cuttable test PCB

The following PCB sizes were tested:

- 55 x 95 mm with SAM in the middle (#1)
- 50 x 50 mm with SAM in the middle (#2)
- 40 x 80 mm with SAM in middle of one side (#3)
- 40 x 80 mm with SAM in corner (#4)
- 30 x 60 mm with SAM in corner (#5)
- 30 x 60 mm with SAM in middle of one side (#6)
- 20 x 40 mm with SAM on one edge (#7)



Figure 9: SAM-M8Q on different GND planes

The following graphs show the average C/No values as a function of elevation angle on SAM mounted on different GND plane sizes.

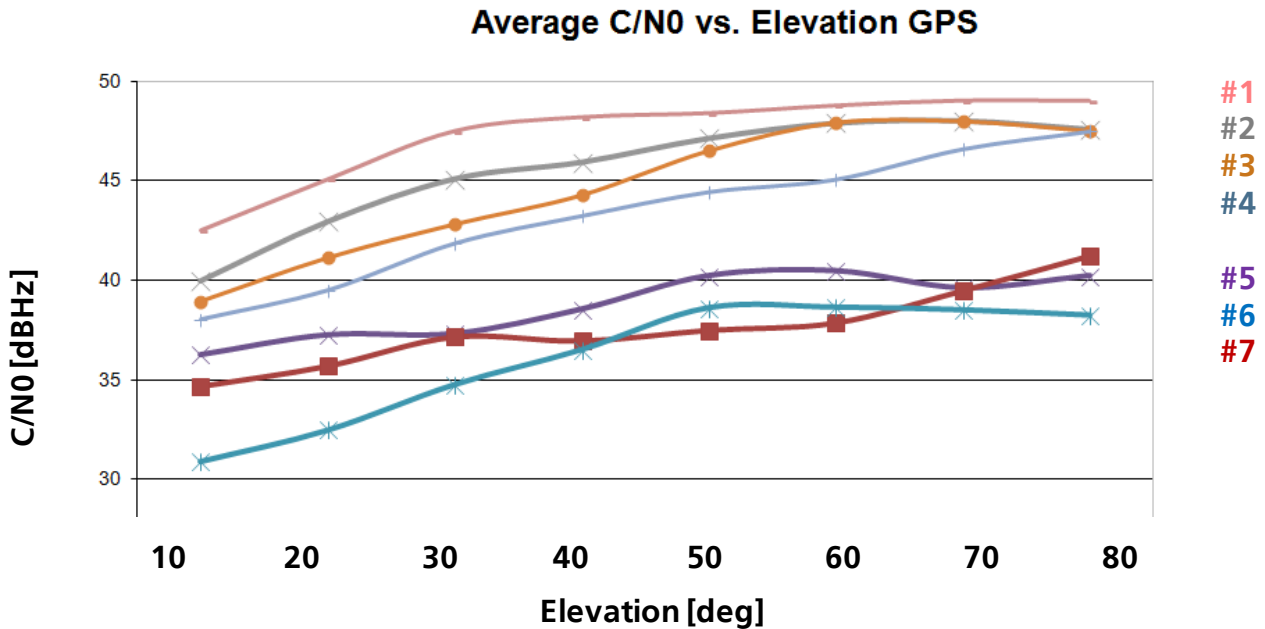


Figure 10: Average signal level C/No versus GNSS elevation of visible GNSS satellites for the 7 PCB variants

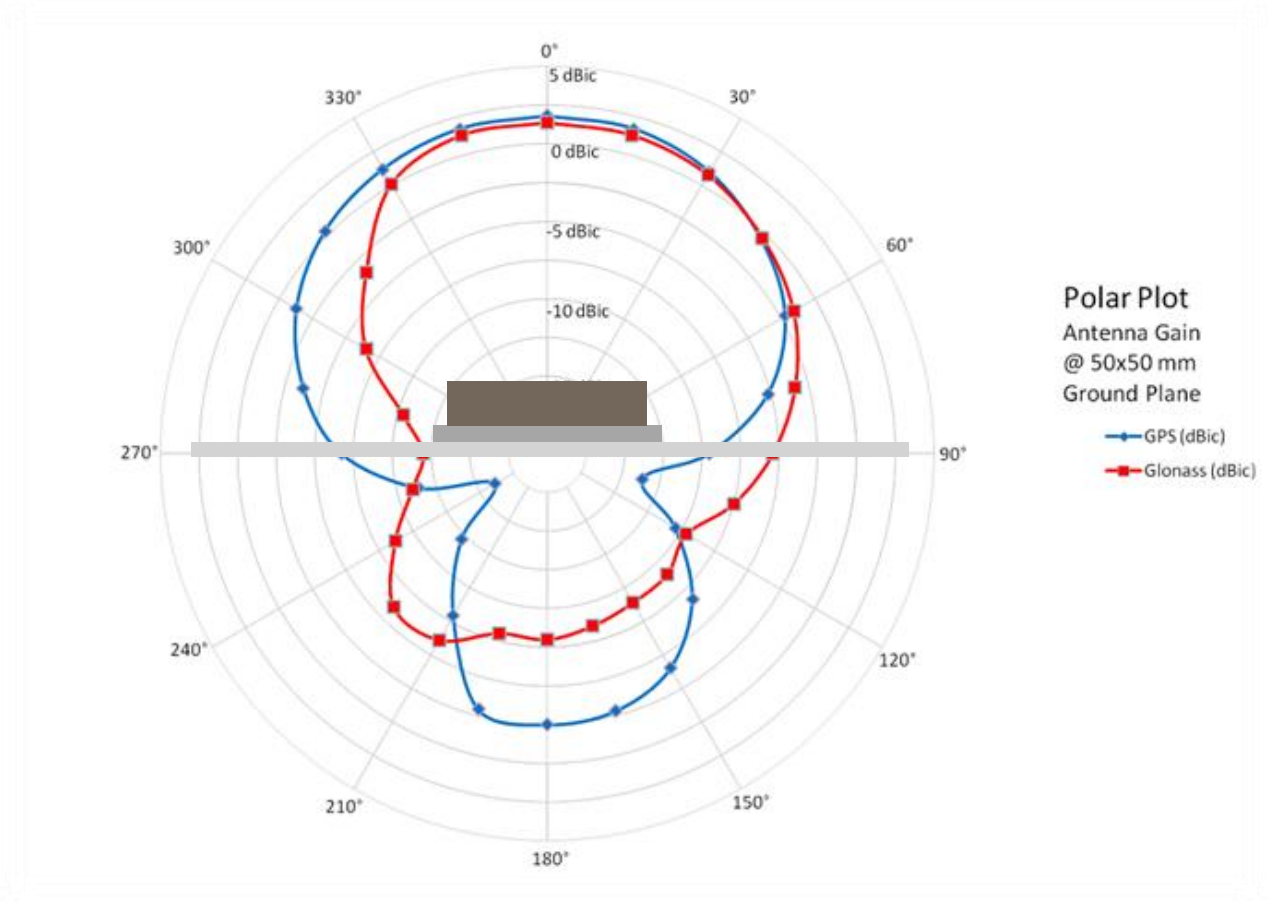
Note that those values are averaged over all satellites in view (the peak values are typically about 3 dB higher than average C/No values shown in the plot).

As discussed previously, C/No > 40 dBHz will lead to optimal performance and C/No > 30 dBHz is required to ensure minimal performance.

The graph above shows that when using a 15 x 15 mm element for SAM-M8Q, this product will be able to deliver solid performance, even if the antenna is placed on a small PCB and on its side. If placed on a large PCB, it will even be able to deliver optimal performance with C/No close to 50 dBHz.

### 3.2 Radiation pattern and directivity

The radiation pattern (often referred to as a polar plot) of SAM-M8Q mounted on a 50 x 50 mm GND plane is shown below.



**Figure 11: Radiation pattern of SAM-M8Q mounted on a 50 x 50 mm GND plane**

Reducing the GND plane size makes the pattern more omni-directional but it comes also with a penalty of lower gain achievable compared to an isotropic antenna (dBic). Highest gain is achieved when the antenna module is facing upwards. It is thus recommended that a patch antenna or a module with integrated patch antenna is facing upwards in customers application.



Measuring the radiation pattern requires an antenna chamber. This is a service that the antenna vendors can provide.

### 3.3 Comparison against other products

To emphasize the importance of the implementation (tuning, EMI) SAM-M8Q has been tested against comparative products with different implementations available on the market. The table below shows the different antenna modules sizes and antenna sizes.

	SAM-M8Q	Product A	Product B	Product C	Product D
<b>Size</b>	15.5 x 15.5 x 6.2 mm	15.5 x 15.5 x 6.6 mm	16 x 16 x 6.45 mm	16 x 16 x 6.8 mm	11 x 11 x 6.1 mm
<b>Antenna size</b>	15 x 15 x 4 mm	15 x 15 x 4 mm	15 x 15 x 4 mm	15 x 15 x 4 mm	9 x 9 x 4mm
<b>Average C/N0</b>	45	45	42	36	35
<b>Max C/No</b>	48	46	44	37	37

Table 2: SAM-M8Q versus similar products available in the market

The C/No plots as a function of elevation angle are shown below. All modules were measured on a 50 x 50 mm GND plane.

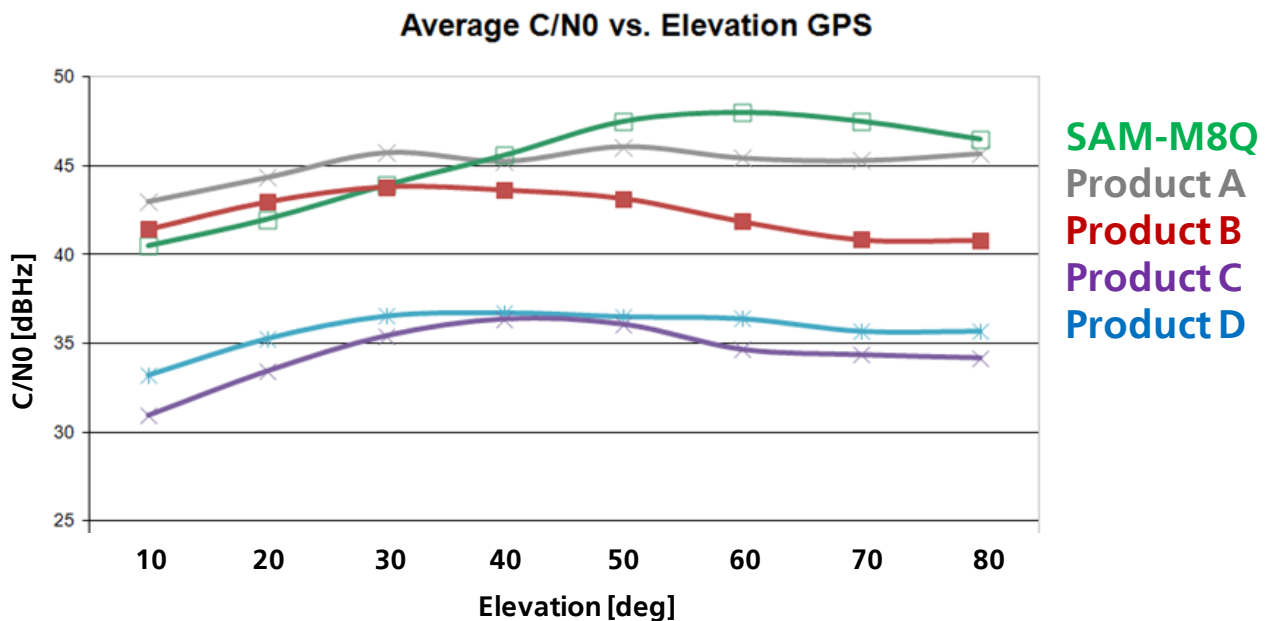


Figure 12: Average C/No of SAM-M8Q versus competition

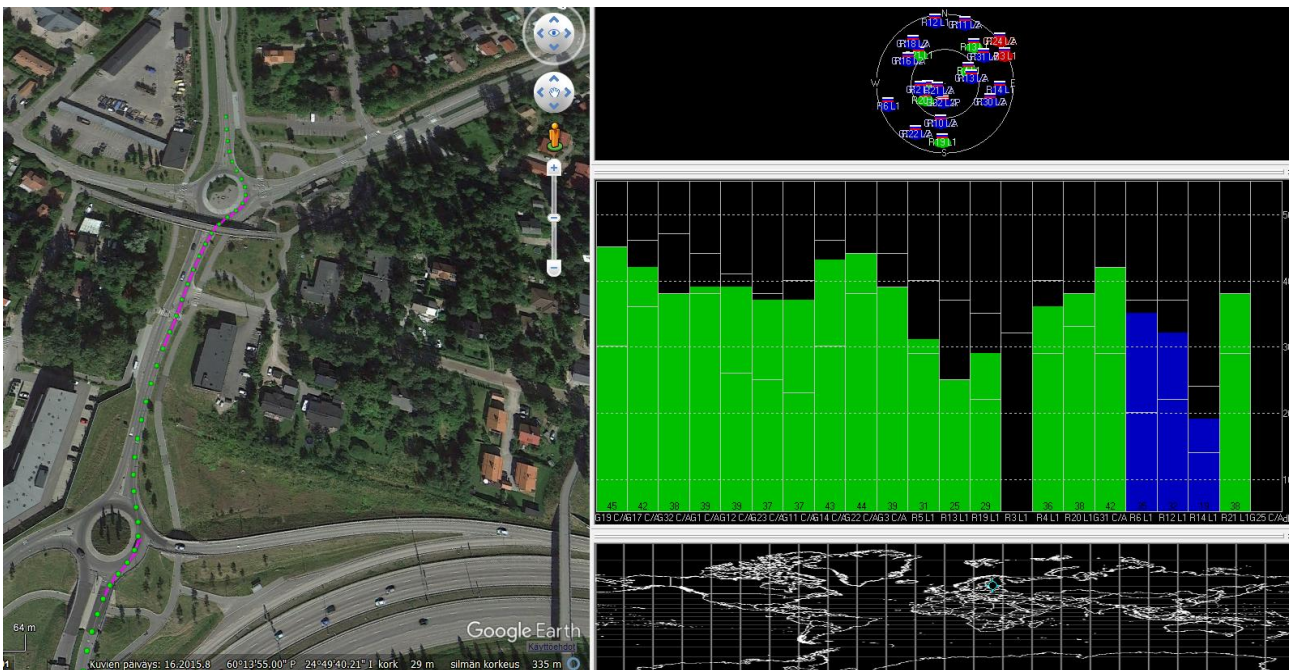
SAM-M8Q shows the best maximum signal levels and average signal levels against other products. Product C clearly has some issues in the design, as it shows <40 dBHz signal levels despite having a 15 x 15 mm antenna. This could potentially be due to an internal EMI issue in Product C.

Note also the low signal levels that the small 9 x 9 mm antenna of Product D can deliver regardless of how well the module is designed or how big the GND plane is. This has to do with physical properties of such small antennas.

### 3.4 Use case specific tests and device placement

Final step in the design process is to validate the design under real conditions of use. In that respect, a few typical installation scenarios were tested using the SAM-M8Q EVK: The EVK-M8QSAM has a 50 x 80 mm GND plane

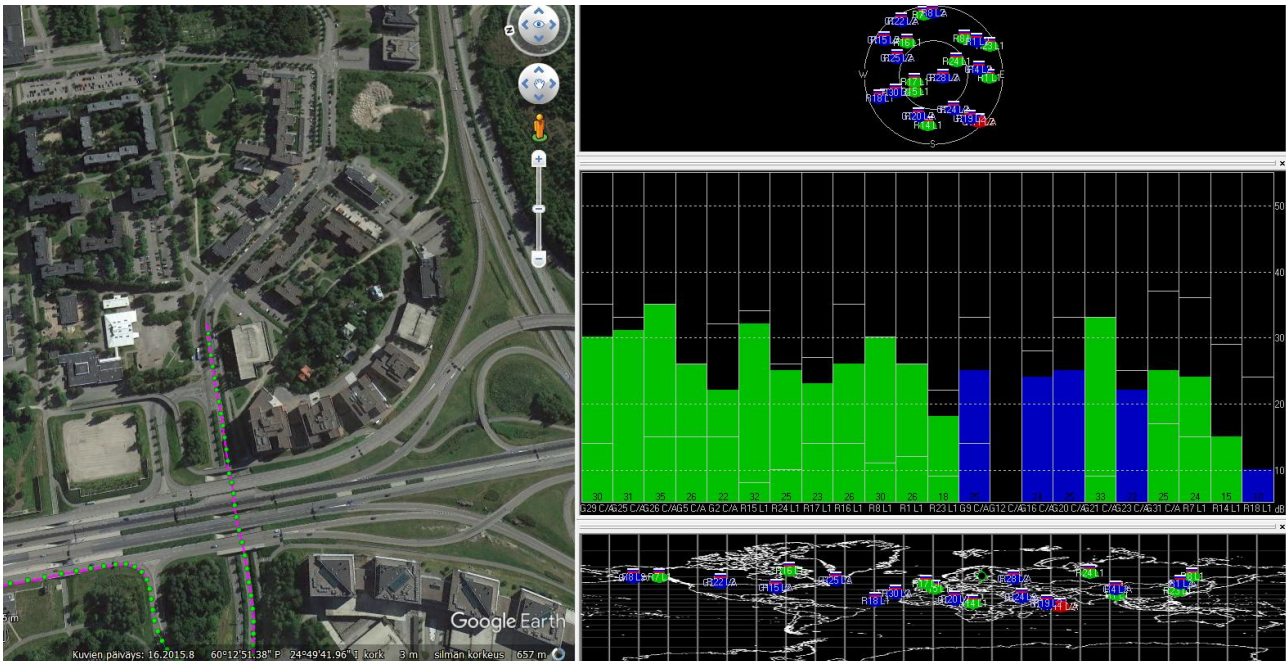
- On the dash-board, representing an installation inside a car, such as on a rear-view mirror. The test vehicle has a heated windshield (integrated heating resistors) which attenuates the GNSS signal about 6-10 dB
- Under the driver's seat, representing an installation inside a car, like an OBD (on-board diagnostics) dongle with a lot of attenuation. Here the car has a heated windshield as well.



**Figure 13: SAM-M8Q on dashboard of a car. Heated windshield attenuates the signal with 6-10 dB**

In the dash-board test we can see good signal levels across the board even though the signal is attenuated due to integrated heating resistors in the windshield. This set-up can be considered optimal from the GNSS device installation point-of-view. Also note that the antenna is facing upwards, which provides good sky visibility.





**Figure 14: SAM-M8Q under the driver's seat (in a car with again the heated windshield)**

In the next test the EVK was placed under the driver's seat. This scenario represents a typical covert installation in a vehicle. The placement is chosen to visualize the effect of the attenuation caused by the human body and the seat itself. Note that the heated windshield also attenuates the signal as in the previous scenario.

The installation will impact signal levels to the point where they can be considered the minimum for proper GNSS operation. Such signal levels may have an impact on Cold Start Time-To-First-Fixes. One way to improve performance in such installations is to use assisted GNSS and to keep the battery backup supply active for the GNSS receiver when the vehicle is stopped.

It is also important to note that the evaluation kit for SAM-M8Q is "EMI-free". In a design which has in-band EMI of, for instance, 10 dB, the signal levels shown above will be further attenuated by 10 dB. For the dashboard installation it will still be acceptable, but for the covert installation the signal levels will simply be too weak for GNSS operation.

As a conclusion, it is an absolute must to perform trials of prototypes in the real environment as early as possible in the design process. This will allow validation of the design choices and moving on to less critical steps.

## 4 Design checklist

Based on this paper, below is a checklist with a step-by-step approach for any designer who wants to integrate a GNSS patch antenna to his design:

- a. Carefully choose the antenna size for the application
- b. Produce and compare different prototypes with different antenna placement and if possible different GND plane sizes
- c. Tune them at the right frequency and make the appropriate laboratory measurements (S11, C/No, etc.)
- d. Measure the EMI levels at the antenna location
- e. Perform live signal tests outdoors to verify the signal levels
- f. Monitor the C/N0 values with the unit installed in the envisioned installation

An average signal level of 40 dBHz can be considered good; an average signal level of 25 dBHz and below will cause major performance issues.

It is also important that the link budget is considered from the beginning of the project. Early prototypes should be tested in the envisioned installation using live GNSS signals. A device tested in a laboratory environment using a GNSS re-radiator will only provide a relative indication of performance.

## 5 Conclusion

Each application has different requirements, and as shown in this paper, many trade-offs can be made with antenna size, material, placement, GND plane size, etc. It is important to make educated choices based on requirements and measurements.

As an example of a step-by-step approach, this paper shows how to design the SAM-M8Q antenna module with the following requirements:

- Excellent signal reception despite its small size
- Ready to use product even for non RF experts
- Consistently delivering strong performance regardless of where the unit is installed
- Concurrent reception GPS and GLONASS

The best balance between size and performance has been found thanks to gain measurements in various conditions; the product has been tuned to achieve the required performance and support both GPS and GLONASS. Finally, it has been tested in envisioned use cases to ensure its performance in a majority of environments. This can be reproduced to design-in a GNSS patch antenna in any application.

## About u-blox

Swiss u-blox (SIX:UBXN) is a global leader in positioning and wireless semiconductors and modules for the automotive, industrial and consumer markets. Our solutions enable people, vehicles and machines to locate their exact position and communicate wirelessly over cellular and short range networks. With a broad portfolio of chips, modules and software solutions, u-blox is uniquely positioned to empower OEMs to develop innovative solutions for the Internet of Things, quickly and cost-effectively. With headquarters in Thalwil, Switzerland, u-blox is globally present with offices in Europe, Asia and the USA. [www.u-blox.com](http://www.u-blox.com)

### Document Information

<b>Title</b>	<b>Design guide for small, high performance GNSS patch antenna applications</b>	
<b>Subtitle</b>	How to find the best balance between size and performance in GNSS patch antenna designs	
<b>Document type</b>	White paper	
<b>Document number</b>	UBX-16026689	
<b>Revision and date</b>	R01	22-May-2017

u-blox reserves all rights to this document and the information contained herein. Products, names, logos and designs described herein may in whole or in part be subject to intellectual property rights. Reproduction, use, modification or disclosure to third parties of this document or any part thereof without the express permission of u-blox is strictly prohibited.

The information contained herein is provided "as is" and u-blox assumes no liability for the use of the information. No warranty, either express or implied, is given with respect to, including but not limited to, the accuracy, correctness, reliability and fitness for a particular purpose of the information. This document may be revised by u-blox at any time. For most recent documents, visit [www.u-blox.com](http://www.u-blox.com).

Copyright © 2017, u-blox AG