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Revision of GNSS modules

In winter 2020/2021, *2D Datarecording* has developed new GNSS (Global Navigation Satellite Systems) modules which containing RTK (Real Time Kinematic) functionality.

The general term for satellite navigation is GNSS but the term GPS (Global Positioning System) has become a synonym for this technology, but GPS is only one of the four GNSS.

Besides GPS, there are the satellites systems called GLONASS (Russian Federation), Galileo (Europe) and BeiDou (China).

The more satellites are used to determine the position, the more accurate and stable the determination of the position and thus the determination of the speed.

By using the RTK functionality, the accuracy of position data derived from GNSS is improved significantly! It uses measurements of the phase of the carrier wave of the signal in addition to the information content of the signal and relies on a single reference station to provide real-time corrections that offer accuracy of up to one centimetre (±1cm)!

The Radio Technical Commission for Maritime Services (RTCM) correction data required for high accuracy can be transmitted to the modules via RF link, Bluetooth, Wi-Fi or 4G.

Of course, the 10 Hz RTK modules can still be used without correction data as a normal GNSS receiver with general GNSS accuracy.

Beside implementing the RTK feature, further modules were developed, and already existing GPS-modules were improved to receiving multiple GNSS whereby the modules are now able use the signals from more than one GNSS. It is now correct to refer to the modules as GNSS modules instead of only GPS modules.

This also applies to already delivered (2019+)**12.5Hz GPS modules! Via a firmware update it is now possible for the GPS2CAN to receive satellites from multiple GNSS.**

For the upgrade, however, the GNSS rate must be reduced from 12.5 to 10 Hz.

Hence, by accessing much more GNSS satellites, the reliability and thus the accuracy of all 2D GNSS modules is highly increased!

However, the reduction in dynamic range due to the reduction of the GNSS rate from 12.5 to 10 Hz for GPS2CAN modules is justified by the improvement in the reliability and accuracy of the signal.

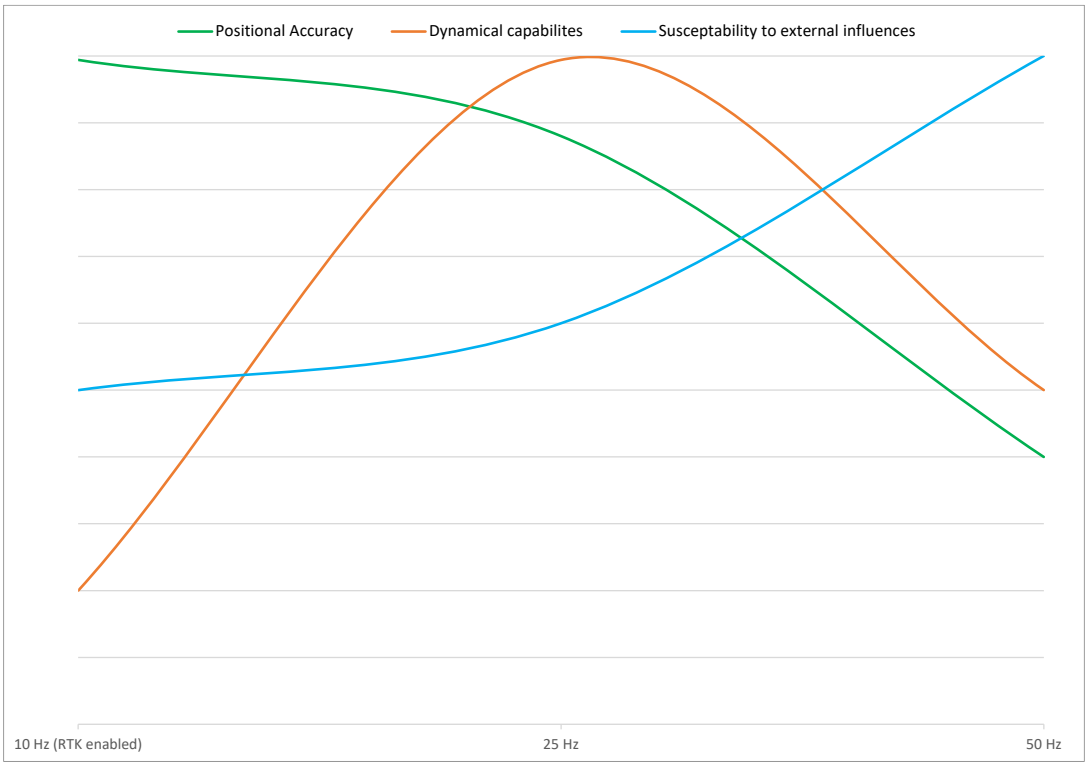
Click here to check how many GNSS satellites are visible at your current location! Also use the filters on the left side of the *Charts* tab to see the improvement by using all GNSS satellites compared to only GPS satellites.

It´s meaningfully to use either GLONASS or BeiDou together with GPS and Galileo, depending on your current location.

Documentation reference
For more information about all new GPS/GNSS modules please see descriptions **New 2D GPS/GNSS CAN Modules 2021** and **Revision of GNSS modules**
http://2d-datarecording.com/downloads/manuals/

Due to the many new features, the following GNSS modules are now available:

10 Hz GNSS module	RTCM ready for high accurate positional tasks (+/- 1 cm) with lower dynamic requirements
25 Hz GNSS module	Very good dynamical capabilities because of 25 Hz rate with good positional accuracy
50 Hz GPS module	Highest dynamic capabilities with general GPS position accuracy. Due to the use of a GNSS rate of 50 Hz, special attention must be paid to the influence of external disturbances such as vibrations, the attachment of the module to the vehicle or signal reflections from buildings or tree, as these strongly influence the measurement result.



The selection of a suitable module depends on the intended use:

For acceleration and braking tests with vehicles we strongly recommend using the 25 Hz module.

In addition, this module is very well suited for all kinds of fast outdoor sports such as skiing, where a combination of high dynamical capabilities and good positioning accuracy are required.

However, as soon as high positioning accuracy is necessary, it is recommended to use the 10 Hz module with RCTM correction data to achieve a positioning accuracy of up to one centimetre!

This module also has a good suitability in the lower dynamic range, as is necessary, for example, for tests of Advanced Driver Assistance Systems (ADAS). Again, the system is also suitable for outdoor sports applications.

The 50 Hz module will also continue to be available, which is suitable for highly dynamical applications.

In general, the correct mounting of GNSS modules must be observed in order to obtain a usable measurement result, but this is particularly important for the 50 Hz module!

External influences such as engine vibrations, road surface, a wobbly mounting or signal reflections from buildings or trees have a particularly strong effect on the quality of the measurement result.

Detailed installation instructions, which are valid for all GNSS modules, were also created during the revision of the GNSS modules.

Improved manual:

Since the GPS/GNSS modules have many important setting options and the assembly of the modules is essential, a separate GPS/GNSS module manual has been prepared.

Documentation reference
For more information about all GPS/GNSS Modules please see the manual **GPS/GNSS General description** on our website:
http://2d-datarecording.com/downloads/manuals/

GNSS accuracy channels

When using 10 and 25 Hz GNSS modules, the GNSS chips are providing accuracy channels which can be used to identify the current, absolute accuracy of horizontal position, vertical position, speed and course. The four channels are updated with the respective rate of the GNSS used.

Improved Post-Processing (Race2020 & Race2021):

Furthermore, the 2D_GPSAuto calculation files responsible for the further processing of the GNSS channel will be further developed so that the user can adjust the filter parameters of the multi-stage IIR filtering according to the dynamics of the used vehicle.

In addition, the user still has access to the GPS shift time by which all GPS channels are shifted in post-processing.

Beside the GNSS channels already calculated in post-processing, the new version of the 2D_GPSAuto post-processing files also includes channels that represent the curve radius and the curvature as independent channels.

Documentation reference
For more information about all GPS/GNSS Postprocessing please see the manual **GPS/GNSS Postprocessing** on our website:
http://2d-datarecording.com/downloads/manuals/

Tests:

GNSS modules used:

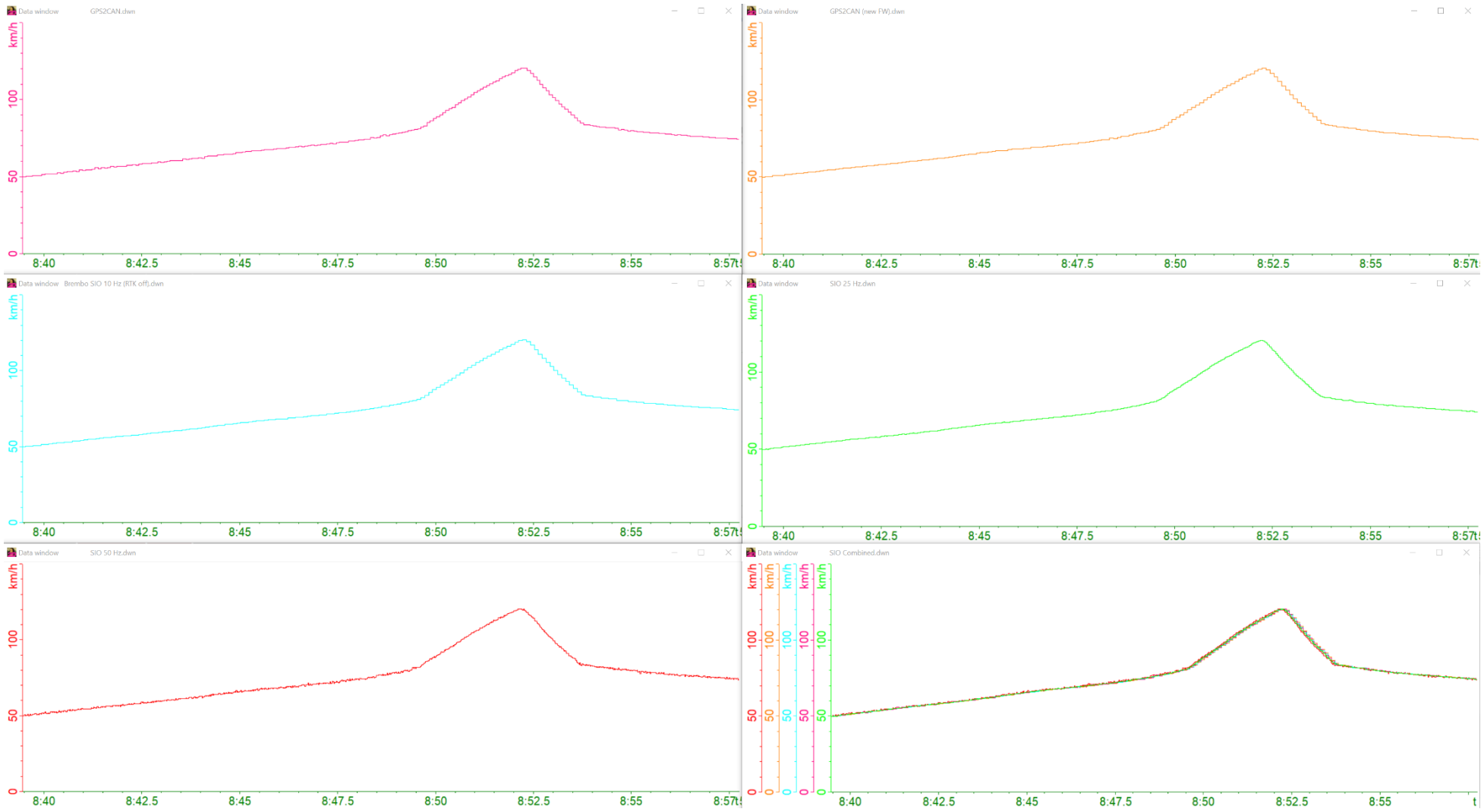
12.5 Hz GPS2CAN (old FW)	Currently delivered GPS2CAN module with rate 12.5 Hz. Due to current firmware, the module is only able to receive signals from GPS satellites. Built-in IMU-Sensor. No RTK feature.
10 Hz GPS2CAN (new FW)	When updating the firmware of a 12.5 Hz GPS2CAN (update only for modules shipped since 2019), the rate of the module is set to 10 Hz, as then the signals of multiple GNSS can be received by the module, which leads to a great improvement in the performance of the GPS2CAN. Build-in IMU-Sensor. No RTK feature.
10 Hz SIO (RTK off)	New serial GNSS module with rate 10 Hz which is able to receive satellites of multiple GNSS. RTK ready: By applying RTK correction data, the positional accuracy is +/- 1 cm! Only at test **6** RTK correction data was applied.
25 Hz SIO	New serial GNSS module with rate 25 Hz which is able to receive satellites of multiple GNSS. No RTK feature. Will be available with build-in IMU-Sensor.
50 Hz SIO	Currently delivered serial GPS module with rate 50 Hz which is only able to receive signals from GPS satellites. No RTK feature.

1. Susceptibility to external influences

a. Urban area

Channels	GNSS Module
V_Sat	12.5 Hz GPS2CAN (old FW)
V_Sat	10 Hz GPS2CAN (new FW)
V_Sat	10 Hz SIO (RTK off)
V_Sat	25 Hz SIO
V_Sat	50 Hz SIO

b. Rural area



Channels	GNSS Module
V_Sat	12.5 Hz GPS2CAN (old FW)
V_Sat	10 Hz GPS2CAN (new FW)
V_Sat	10 Hz SIO (RTK off)
V_Sat	25 Hz SIO
V_Sat	50 Hz SIO

Evaluation a) and b):

The comparison shows that the modules that use more than one GNSS (GPS2CAN 10 Hz (new FW), 10 Hz SIO, 25 Hz) are better suited for inner-city use or in forests, where by nature only a limited number of satellites are visible.

Since the 12.5 Hz and 50 Hz module only use **GPS** satellites, its noise free accuracy inside cities and forests can be problematic.

In open spaces, the differences between the modules are getting smaller.

The 25 Hz module stands out from the other modules with its very good performance in both areas of application!

Results like can be seen here can only be achieved if the modules are mounted correctly!

Further information:

Basically, the output, raw speed of the GPS/GNSS module is a result of the current vehicle speed, the speed of movement of the car due to e.g., pitching movements when braking and the speed caused by inherent movements of the GPS/GNSS module due to poor installation.

The latter can be caused by vibrations of the poorly mounted module or incorrect values caused by the speed of the GNSS module's own movement e.g., due to the tilting movement of the module during heavy braking.

Due to the high dynamics of the 50 Hz module, the movements of an incorrectly mounted 50 Hz module can already superimpose the actual movements of the vehicle.

In general, it is important to know, that the higher the dynamic range of a receiver, the more an modules movement becomes visible as noise. But a slow module will be equally disturbed!

On the other hand, if the antenna is mounted correctly, instead of measuring the wobbly mounting of the antenna the dynamics of a vehicle can be measured highly accurate with this type of antenna. The 10 and 25 Hz modules are also infected by noise from wobbly mounting but due to their lower dynamic range and the higher number of usable satellites, but the effect is not as strong as at 50 Hz modules.

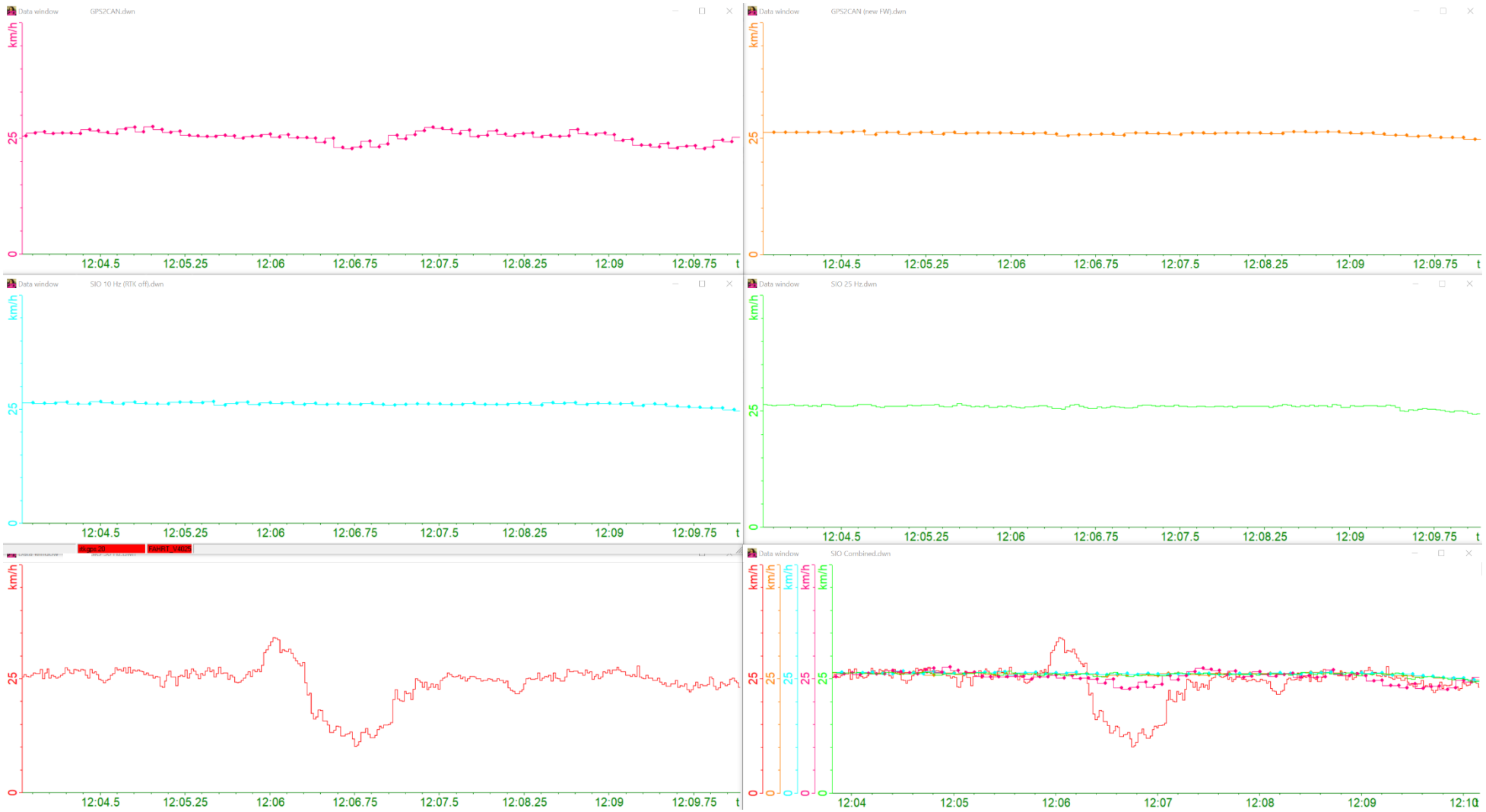
It is important to bear in mind that the 50 Hz antenna is only able to receive signals of GPS satellites. This limits the receivable signals from 32 (all GNSS) to about 10 (GPS only). Of course, it has a greater impact if the connection of 1 out of 10 satellites is lost than if the connection of 1 out of 32 satellites is lost. In urban areas or forests, the negative impact of losing one satellite in an already limited number of satellites is creating noise.

However, in good conditions (correct mounting, sunny weather, clear view of receiver to sky) the module delivers the best values in terms of dynamics.

Due to the noise on the signal, the raw speed of the 50 Hz module is not usable as a trigger channel (e.g., trigger if the speed is less than 100 km/h). Through an online filter the noise can be eliminated, but at same time the signal would be delayed by 100 to 250 ms. So, a comparison to an external trigger (e.g., Brake pedal, …) should not be done (see post-processing/DTS-Dash).

That is why we prefer our post-processing (see below) to determine exact temporal correlations in the case of abrupt changes in driving conditions such as braking.

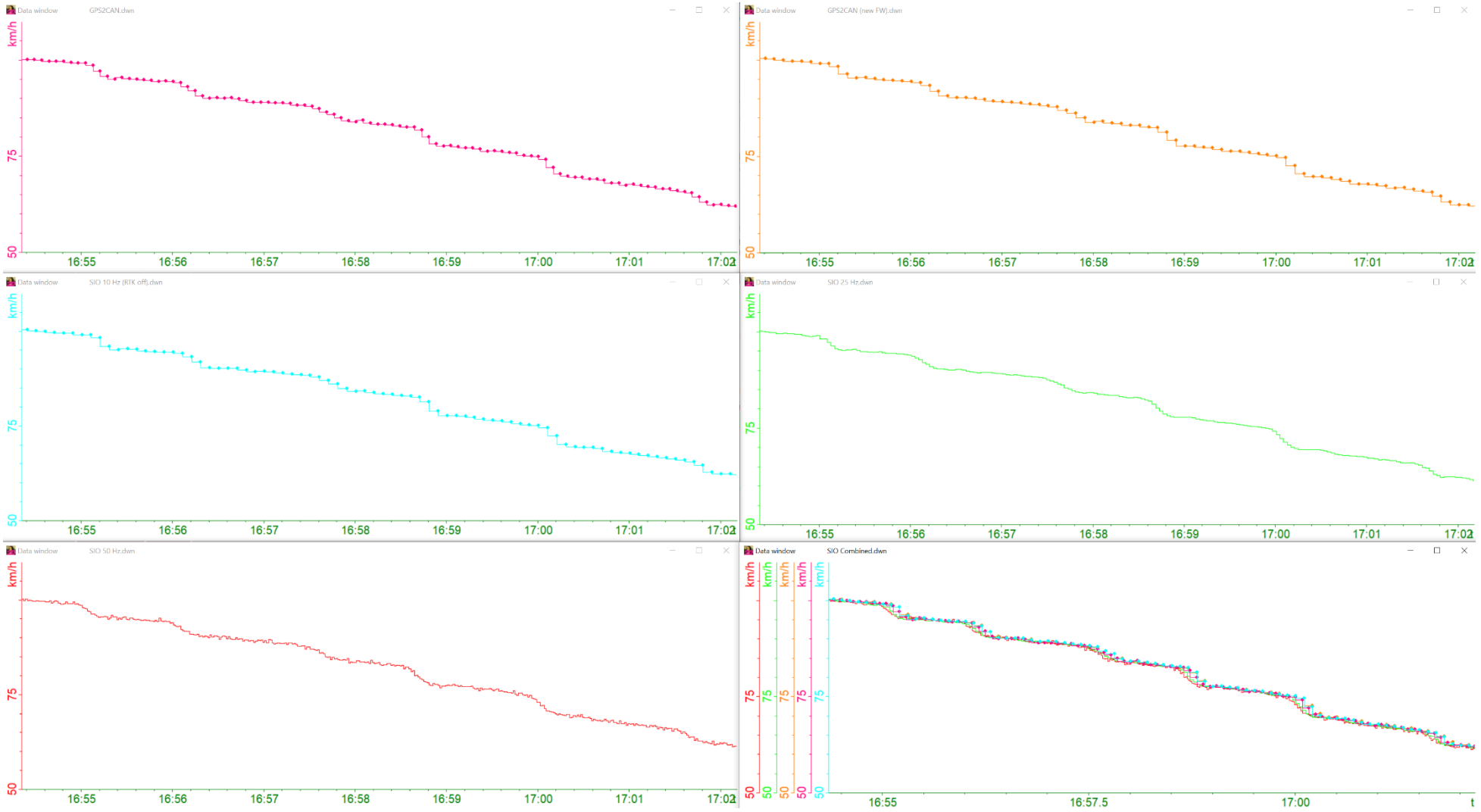
c. Bridge



The behaviour of the different GNSS modules in this test strongly depends on how many GNSS satellites are used. Since the 12.5 Hz and 50 Hz GNSS module only uses approx. 8 **GPS** satellites, its behaviour is worst with bridges or trees!

Channels	GNSS Module
V_Sat	12.5 Hz GPS2CAN (old FW)
V_Sat	10 Hz GPS2CAN (new FW)
V_Sat	10 Hz SIO (RTK off)
V_Sat	25 Hz SIO
V_Sat	50 Hz SIO

2. Intermitted Braking-test for reaction time



In this test, the driver briefly steps on the brake pedal to brake only briefly at a time in order to make the respective braking processes visible on the unfiltered speed signals shown below.

The examples shown here clearly show that the modules with the **higher** GNSS rates (25 and 50 Hz) are much better suited for tests with abrupt changes in driving conditions due to their accuracy!

Channels	GNSS Module
V_Sat	12.5 Hz GPS2CAN (old FW)
V_Sat	10 Hz GPS2CAN (new FW)
V_Sat	10 Hz SIO (RTK off)
V_Sat	25 Hz SIO
V_Sat	50 Hz SIO

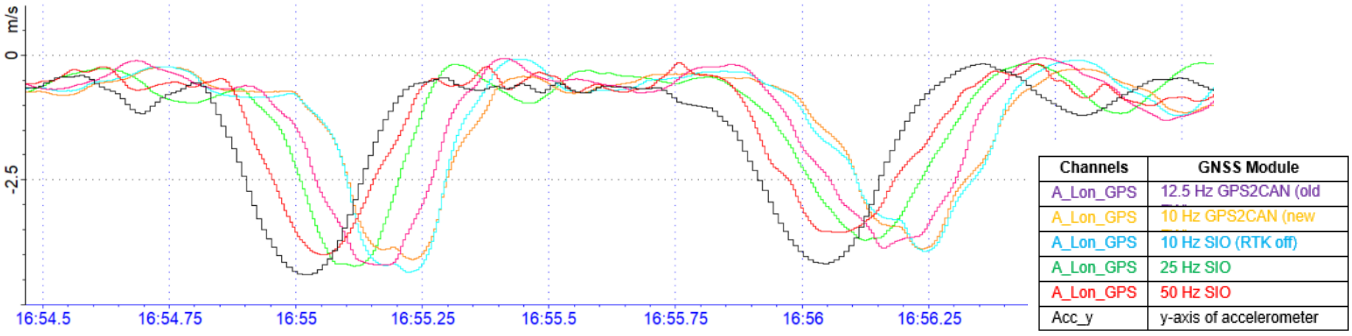
3. Post-Processing

The big advantages of the 2D system are the advanced post-processing of the channels received by GNSS modules whereby to user can take influence on the following parameters:

- Time delay correction
- Filter adjustment
- Post-processing channels

Time delay correction:

One of the greatest advantages of 2D post-processing is that the time delay, which inevitably occurs due to the reception of the GNSS data, can be corrected by the user as desired.



To visualize the time delay and show the differences at modules with various GNSS rates a test was executed where an accelerometer (black channel) was used to compare the actual deceleration of the car by accelerometer with the derivation of the speed signals (longitudinal acceleration) at the braking tests from previous chapter.

The displayed colored longitudinal acceleration channels are <u>not</u> derived from raw V_Sat channels because without processing the raw channels it is not meaningful to compare channels from modules with different GNSS rates!

Hence, the post-processing was first used to upsampling the raw GNSS speed signals to a higher, common frequency without interpolating (e.g., 200 Hz).

Afterwards a moving average filter was applied to all speed signals. The parameters of the filters differ according to the respective GNSS rate of the modules, so that the high-sampled signals are filtered in such a way that the raw speed signals of the different GNSS modules would always correspond to the same filter time.

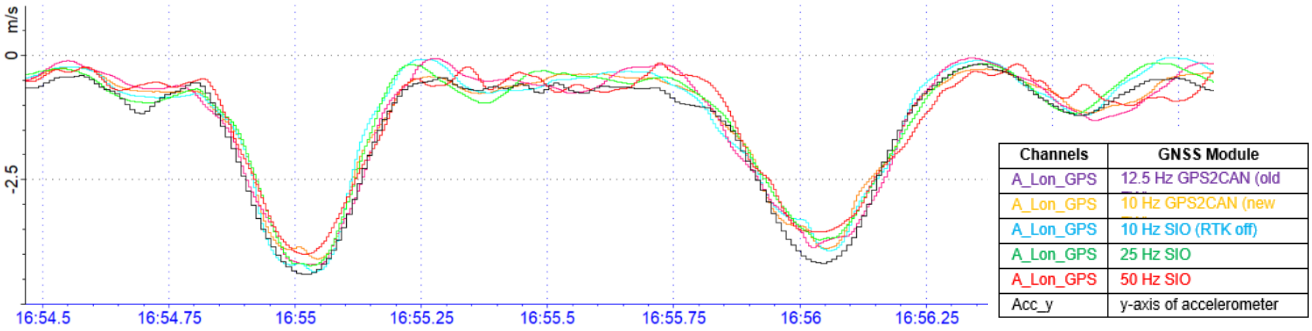
At the end, an IIR (infinite impulse response) -filter is used to finally remove the noise of the speed signals.

Only after this processing is it possible to derive the longitudinal acceleration correctly, which now clearly shows the different time delays, and compare the GNSS modules to the black acceleration signal.

The time delay of the different modules is indirectly proportional to the GNSS rate of the modules, because the higher the GNSS rate of the module, the lower the time delay.

Furthermore, the remarkably similar time delay of the two 10 Hz modules (light blue and orange) becomes clear.

By using the 2D post-processing, the different time delays between the actual deceleration (given by the accelerometer) and the deceleration visible on the signal of the GNSS module can be determined and corrected:

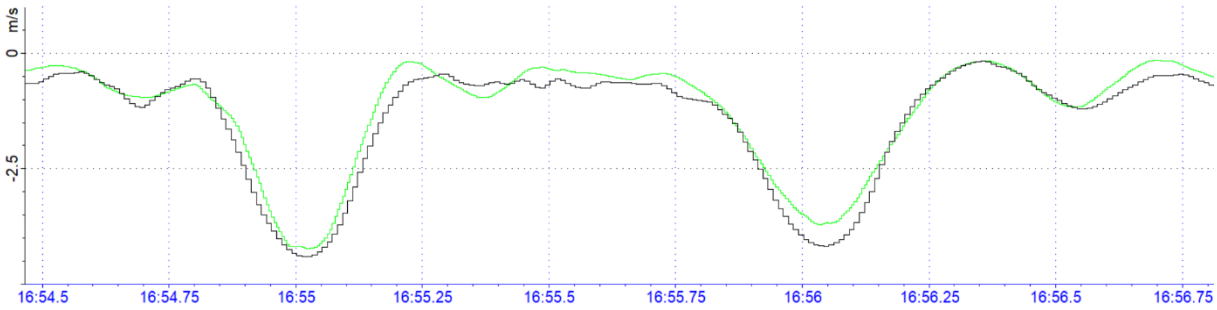


GNSS Module	Time delay correction [sec]
12.5 Hz GPS2CAN (old FW)	-0.140
10 Hz GPS2CAN (new FW)	-0.210
10 Hz SIO (RTK off)	-0.210
25 Hz SIO	-0.075
50 Hz SIO	-0.065

The 2D post-processing allows the user to freely select a time correction value with a resolution of 1/1000 sec (internal post-processing is done with 1000 Hz), which corrects exactly this time delay for all channels received from the GNSS modules!

More information how to adjust the time delay can be found in the respective manual.
The manual will be available soon!

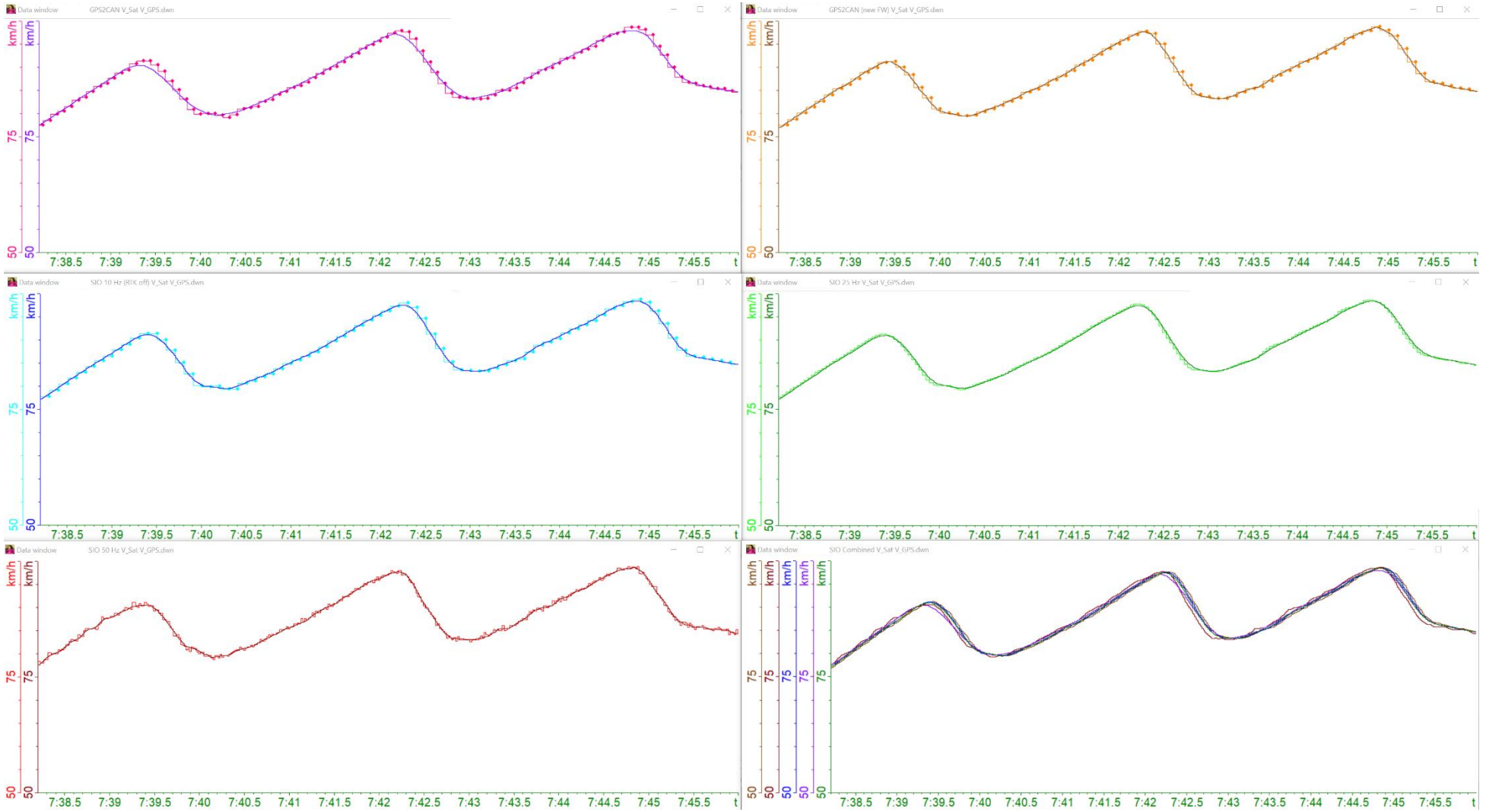
If only the 25 Hz is compared to the accelerometer signal the incredibly good dynamic performance of this module becomes obvious:



Filter adjustment:

By adjusting the filter parameters of the 2D_AutoGPS calculation files, the user can freely adapt the filtering to his respective application, as the multi-level IIR filtering can be set by the user and thus adapted to the dynamics of the vehicle used.
Different applications such as vehicle development or ski tests require different filter parameters.
The default setting is basically aligned to car dynamics.

Documentation reference
For more information about all GPS/GNSS Postprocessing please see the manual **GPS/GNSS Postprocessing** on our website:
http://2d-datarecording.com/downloads/manuals/

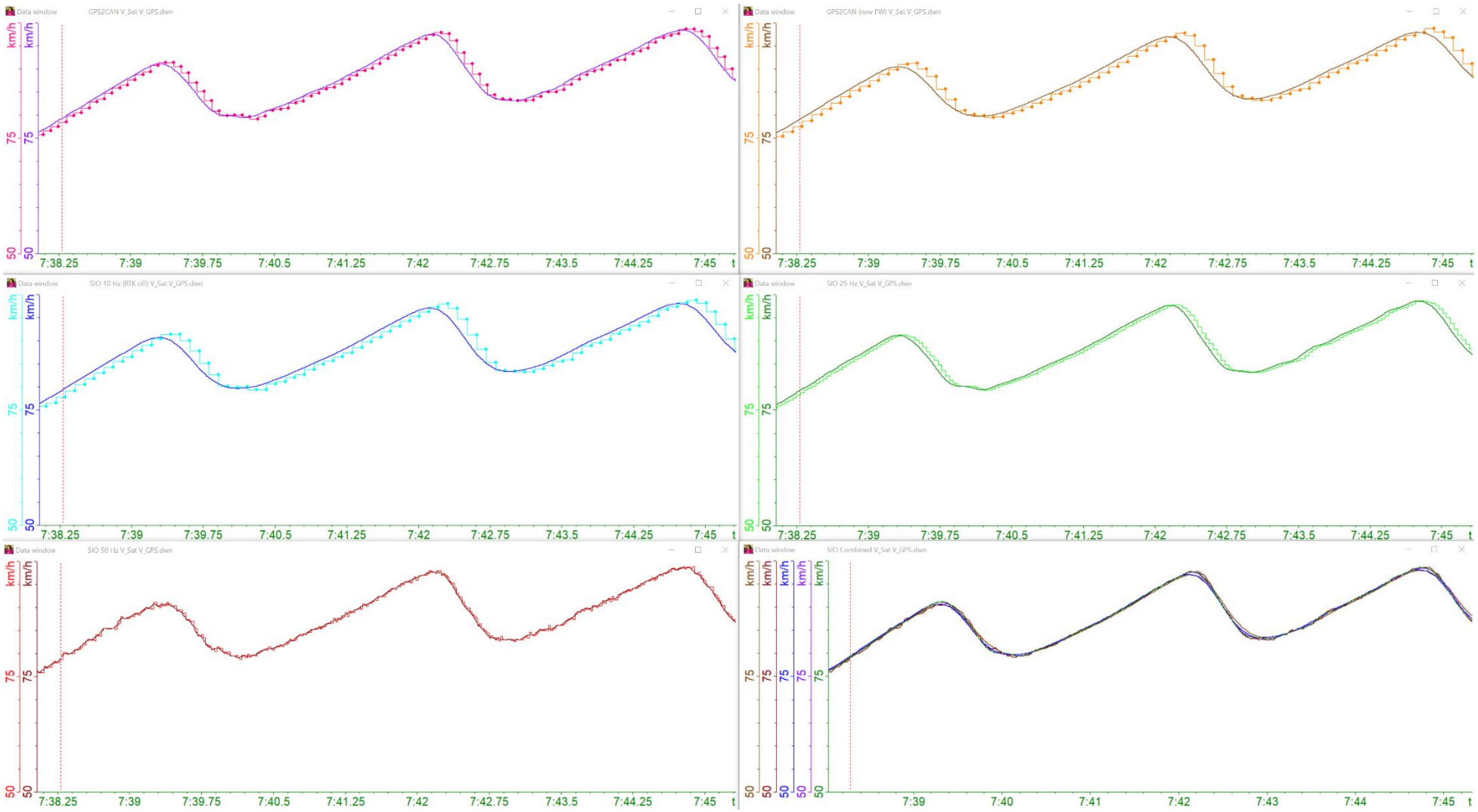


In addition to compensating for the time delay of GNSS channels, further options are available in 2D post-processing, for example for filtering the GNSS channels. The raw speed channel *V_Sat* is filtered by a freely adjustable moving average filter and results in the channel V_GPS (darker colour in each case). By default the filtering frequency is aligned to the GNSS frequency of the module used! Due to the freely adjustable parameters, the post-processing can be adapted to any application and the user can determine whether and how much filtering should be applied to the raw values.

For better comparison, shifting was disabled here by using ShiftTime 0 sec for all modules!

Channels	Channels	GNSS Module
V_Sat	V_GPS	12.5 Hz GPS2CAN (old FW)
V_Sat	V_GPS	10 Hz GPS2CAN (new FW)
V_Sat	V_GPS	10 Hz SIO (RTK off)
V_Sat	V_GPS	25 Hz SIO
V_Sat	V_GPS	50 Hz SIO

Filtering and Time correction



After filtering the raw values in the previous step, the time delay correction mentioned above is now applied. In post-processing, all GNSS channels are shifted to 1/1000 sec with the respective values entered and thus aligned with each other and the actual car movements.

Channels	Channels	GNSS Module
V_Sat	V_GPS	12.5 Hz GPS2CAN (old FW)
V_Sat	V_GPS	10 Hz GPS2CAN (new FW)
V_Sat	V_GPS	10 Hz SIO (RTK off)
V_Sat	V_GPS	25 Hz SIO
V_Sat	V_GPS	50 Hz SIO

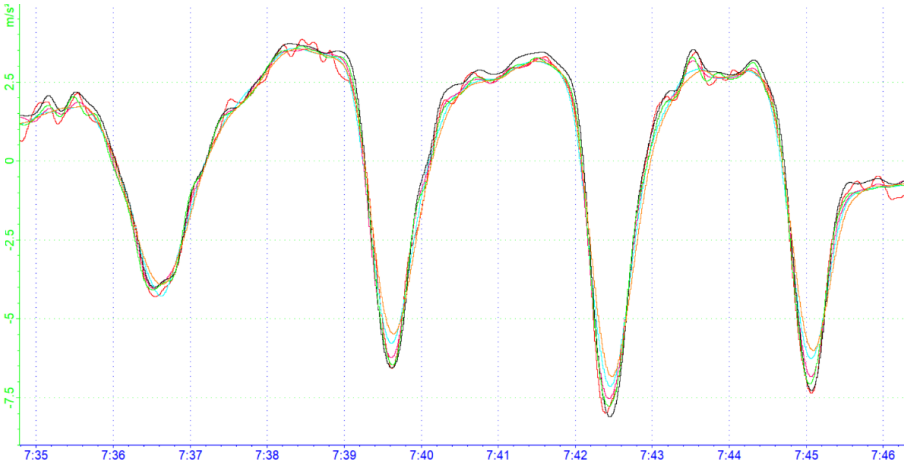
Post-Processing channels:
Beside the time delay correction and filtering of the GNSS channels, additional channels are created from the recorded GNSS channels. Therefore, the different channels like speed and course are combined to calculate the lateral or longitudinal acceleration.
The processing and alignment of the channels of non-2D GNSS modules is also carried out in post-processing.

Documentation reference
For more information about all GPS/GNSS Postprocessing please see the manual **GPS/GNSS Postprocessing** on our website:
http://2d-datarecording.com/downloads/manuals/

Longitudinal acceleration:

Like seen before, the post-processing creates various channels from recorded GNSS channels. For example, by using the GNSS speed, **longitudinal acceleration** is created which is compared with a signal of an accelerometer (**black**) as reference signal in the following figure. The accelerometer was sampled with 1000 Hz.

Channels	GNSS Module
A_Lon_GPS	12.5 Hz GPS2CAN (old
A_Lon_GPS	10 Hz GPS2CAN (new
A_Lon_GPS	10 Hz SIO (RTK off)
A_Lon_GPS	25 Hz SIO
A_Lon_GPS	50 Hz SIO
Acc_y	y-axis of accelerometer

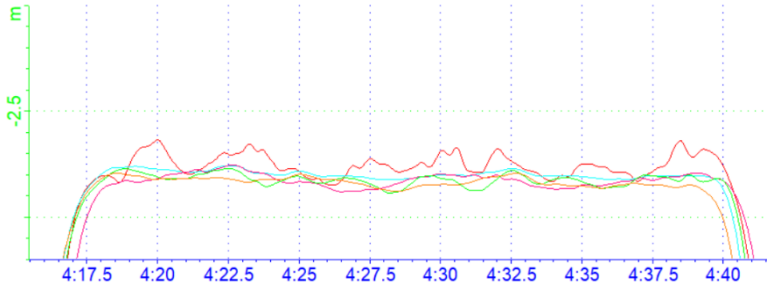


By eliminating the time delay and filtering the coloured longitudinal acceleration channels are compared to the black acceleration signal which shows the actual acceleration of the car at braking and accelerating tests.

Here again, the differences in the dynamics of the various modules become clear. While the 10 and 12.5 Hz modules are only conditionally suitable for dynamic tests, the 25 Hz and 50 Hz modules are well suited for these tests. The 25 Hz module in particular stands out with its very good suitability for dynamic tests.

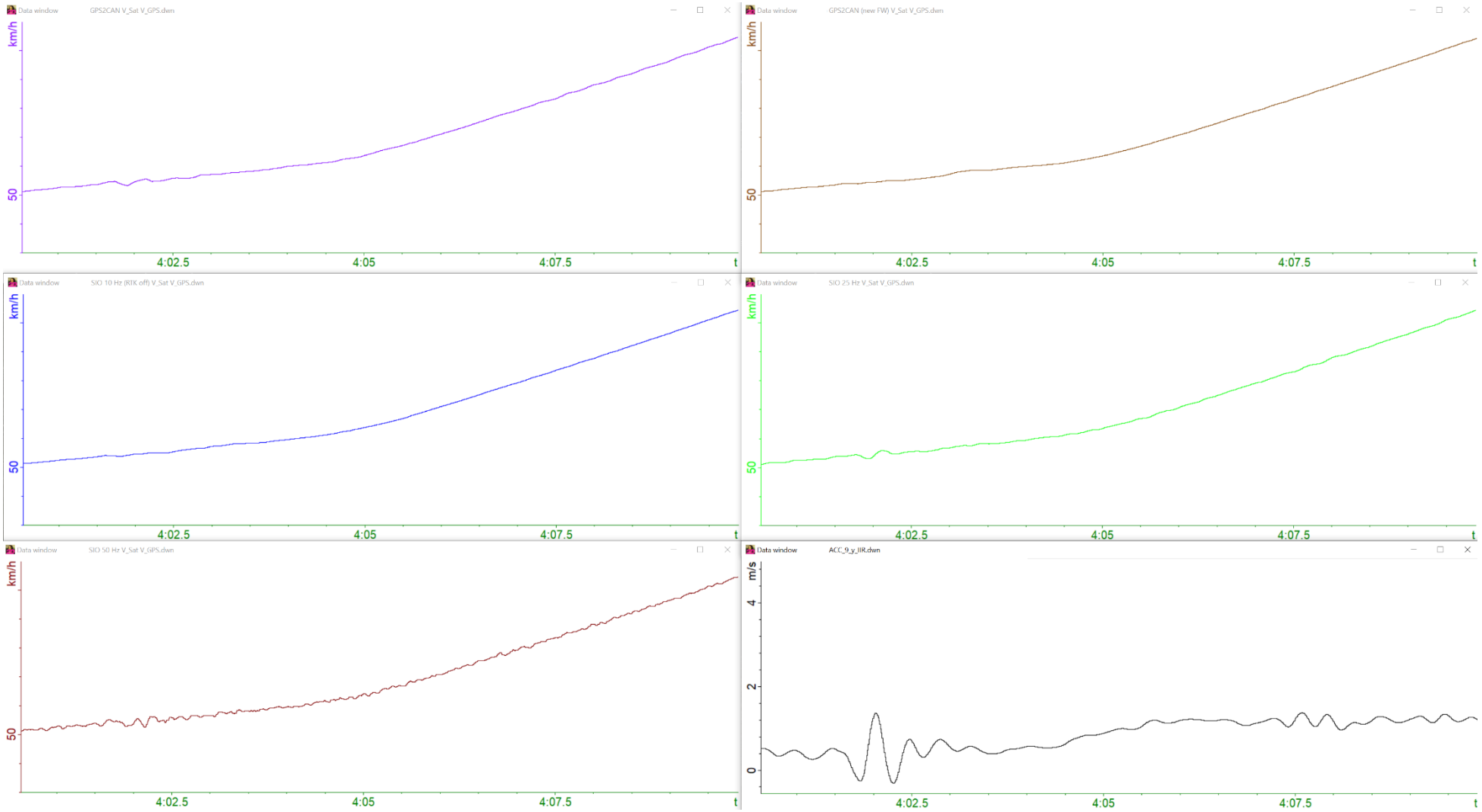
Radius/Curvature
Furthermore, the curve radius and the curvature are also calculated via the GNSS during post-processing. The following example shows the curvature channels of all modules when driving around a roundabout:

Channels	GNSS Module
Radius	12.5 Hz GPS2CAN (old FW)
Radius	10 Hz GPS2CAN (new FW)
Radius	10 Hz SIO (RTK off)
Radius	25 Hz SIO
Radius	50 Hz SIO



Accuracy channels
All GNSS modules, except the 50 Hz module, directly provide accuracy channels that represent the **absolute** accuracy of the horizontal and vertical position, as well as the speed and direction of heading. these channels are available to the user as channels in 2D post-processing.
These channels are suitable for validating the GNSS speed, e.g., during brake tests.

4. Susceptibility of post-processing speed to car movements

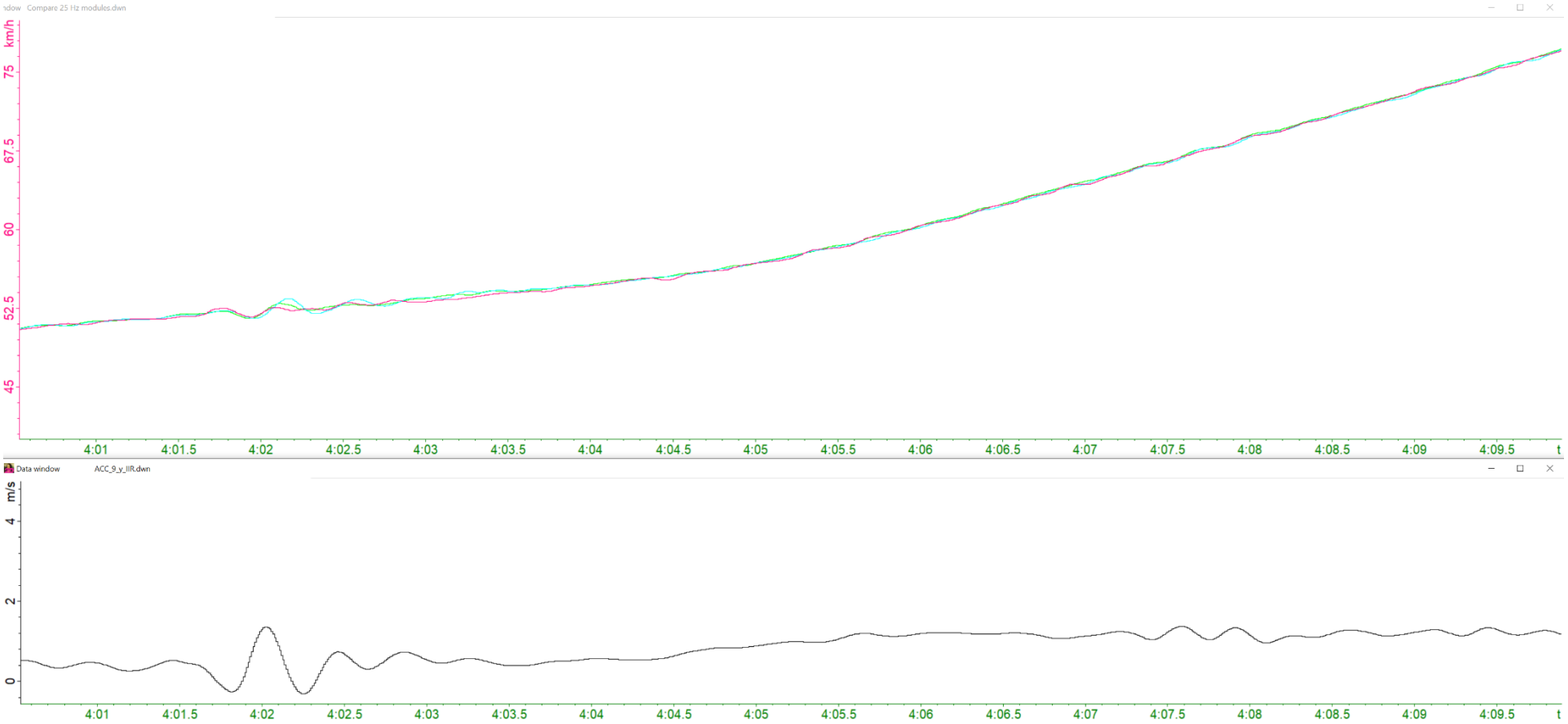


The lower right corner shows the acceleration signal, which represents the actual movements of the vehicle. The other windows show the respective speed channels processed by post-processing. It can be clearly seen that the modules with the higher rates react much more strongly to the actual movements of the vehicle. The best performance is once again delivered by the 25 Hz module, as the movements of the car are clearly displayed there, but the signal itself is not as noisy as the signal of the 50 Hz module.

Channels	GNSS Module
V_GPS	12.5 Hz GPS2CAN (old FW)
V_GPS	10 Hz GPS2CAN (new FW)
V_GPS	10 Hz SIO (RTK off)
V_GPS	25 Hz SIO
V_GPS	50 Hz SIO
Acc_y	y-axis of accelerometer

5. Comparison of three different 25 Hz modules

In this drive test, three 25 Hz modules were compared with each other, which differ in their design and chip configuration, in order to identify any differences.



The colours used in this figure do not relate to the other tests with modules with different GNSS modules!

Channels	GNSS Module
V_Sat	25 Hz SIO
V_Sat	25 Hz SIO
V_Sat	25 Hz SIO
Acc_y	y-axis of accelerometer

Evaluation:

The evaluation of this test showed that all three modules perform at the same, very high level, which can be seen from the fact that the curves of the speed signals hardly differ.

Since a three-axis accelerometer (black). Lower right plot) was used in this test, it is possible to draw very good conclusions from road changes and general vehicle movements.

Here, the road irregularities reproduce themselves very clearly in car movements, and also with the same behaviour in each case, on the speed signal of the 25 Hz GNSS module.

Theoretically, a 50 Hz GNSS would be better for such an evaluation because of its dynamical range, but the disadvantages of this module due to the strong influence of signal reflections or other external influences outweigh this and argue for the use of a 25 Hz module!

However, such an accurate type of evaluation is only possible if the respective GNSS module has been correctly mounted on the vehicle!

6. Positional accuracy tests

All GNSS modules, except the 50 Hz module, directly provide accuracy channels that represent the absolute accuracy of the horizontal and vertical position, as well as the speed and heading.

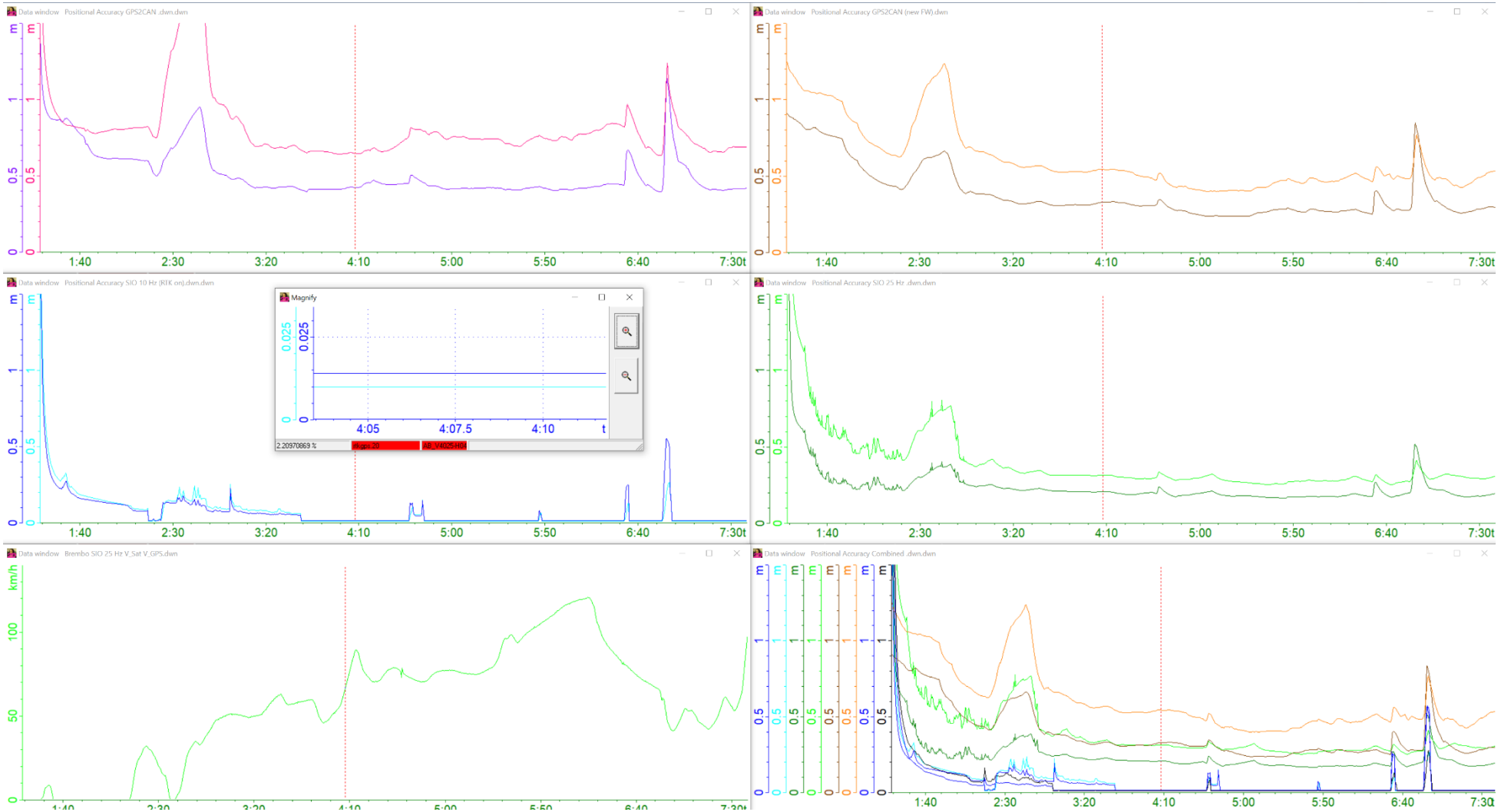
These channels are available to the user as channels in 2D post-processing.

As already mentioned, these channels are suitable for the validation of tests, as the accuracy channels provide a decision criterion for the validation of tests, e.g. that the speed accuracy must be permanently below a freely definable speed level during the test so that a braking test is recognised as valid.

The accuracy channels naturally have the same units as the associated channels and are sampled at the same frequency.

In the following, the horizontal and vertical accuracy channels are used to show the influence of Real Time Kinematic.

The 50 Hz module is the only module that does not provide any accuracy channels, which is why the display area is used to provide the speed of the 25 Hz module!



In this test, the SIO 10 Hz module (blue channels) received the RealTimeKinematic correction data, which improved the accuracy to +/- 1 cm!

The 50 Hz module is the only module that does not provide any accuracy channels! The remaining modules are not capable of processing RTK correction data. However, the 25 Hz module is superior to the 10 and 12.5 Hz modules in terms of positional accuracy.

Channels	Channels	GNSS Module
VerAccu	HorAccu	12.5 Hz GPS2CAN (old FW)
VerAccu	HorAccu	10 Hz GPS2CAN (new FW)
VerAccu	HorAccu	10 Hz SIO (RTK off)
VerAccu	HorAccu	25 Hz SIO
V_Sat		25 Hz SIO