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ADVANCED MULTI-ENGINE PLATFORM (AMP™) – A WAY TO ROBUST RTK

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ABSTRACT

The paper describes the Advanced Multi-Engine Platform (AMP™) – Topcon's patent pending technique, which is capable to improve RTK performance, based on the idea of running several RTK engines in parallel. The performance of AMP™ is dependent on Topcon receiver board, where it has been implemented, and the best results are achieved with B210 board. The main specifics of B210 is that it has two RF front-ends and a single digital section. Such an architecture allows for calculating heading and tilt within a single receiver board, and providing better RTK performance due to synergy of attitude determination and RTK solutions from two antennas, calculated within a single digital section. The paper describes specifics of B210 board along with mathematical aspects of AMP™ and its logic. The test results demonstrate noticeable improvements in RTK performance for B210 receiver board with AMP™, compared with the classical single-engine RTK approach.

<u>Keywords</u> – RTK, heading, tilt, receiver frontend, receiver digital section

I. INDRUCTION

Real-time kinematics (RTK) is a technique, which allows for cm-level positioning accuracy. The core of RTK is carrier phase ambiguity resolution (AR). In challenging conditions GNSS measurements are often distorted, what reduces the success rate of AR, and leads to outlying solutions due to incorrect AR.

Advanced Multi-Engine Platform (AMP™) is a patent pending technique, which is based on the idea of running several RTK engines in parallel to output a unified solution. The most obvious approach to this idea is to have several RTK engines running simultaneously with different settings. See e.g. [I. di Federico, et al., 2018]. However, when AMP™ is implemented within the B210 board of Topcon, the approach is different, and is described below in the paper.

Topcon's B210 GNSS receiver board is an innovative device capable of tracking and processing all available GNSS open signals: GPS/SBAS/QZSS (L1, L2, L5), GLONASS (L1, L2, L3), GALILEO (E1, E5, E6), Beidou (B1, B2). But, this is not what makes B210 unique. The real value of this board is in its architecture, which is capable to support unique algorithms.

This board has two RF front-ends and a single digital section. Such an architecture makes it possible to fulfill the tasks of calculating attitude parameters (heading and tilt angle) within a single receiver board. And another important feature is that such an architecture facilitates providing better RTK performance due to synergy of attitude determination and RTK solutions, computed within a single digital section for two antennas. More information on B210 hardware can be found in [Averin, et al., 2018].

The B210 board is purposed for a variety of applications where reliable and accurate RTK solutions are of high importance, despite of challenges like canopy or urban canyons. The B210 board can be attractive to integrators working in the area of machine control, because they might face a need to output robust position when GNSS signals are partly blocked or distorted. In conditions like this, RTK fixed solution might be either lost or incorrect due to incorrect AR. Such incorrect solutions, resulting from incorrect AR are called "outliers". With AMP™ implemented within the B210 the success rate of AR is increased and the outlier rate is reduced.

AMP™ implementation within B210 allows for combining RTK solutions, acquired independently for two different antennas, into a single RTK solution with help of attitude determination. Attitude determination within the B210 is made with another Topcon's advanced technique – VHD™.

Detailed description of VHD™ was given in [Averin, et al., 2018]. Also, some general description of AMP™ was presented in [Averin, et al., 2018], along with the first test results, acquired with help of engineering firmware (FW) for B210 receiver board. Now, AMP™ feature is available officially starting with FW5.2.1 for B210.

Further in the paper specifics of AMP™ are explained in more details, and new test results are given.

II. AMP™ IN DETAIL

2.1 The Concept

Performance of RTK is dependent on ambiguity resolution. The ambiguity resolution (AR) process is probabilistic. In order to increase the probability of correct AR different criteria are used. The most widely known and commonly used criteria are the minimum of the quadratic form for ambiguities, and a "contrast ratio" (see e.g. [P. de Jonge, et al., 1996], [Milyutin, et al., 2014]). In practice, it could take one through hundreds of measurement epochs to reach a reliable conclusion on the optimality of a specific candidate integer set. In challenging environments ambiguities might be resolved to incorrect integers, despite these criteria are satisfied. AMP™, in fact, provides an extra criterion to test the solution and make it more reliable.

The AMP™ implementation within the B210 is based on assumption that two antennas are connected to this board, being installed in different locations on a vehicle. When a vehicle is driven through challenging environment like urban canyon, or open pit mine, these two antennas face different multipath and signal distortions. So, it looks rational to combine solutions computed for these two antennas in order to obtain a single solution of better quality. And this combined solution of better quality can be referenced (i.e. recalculated) to one of the antennas, provided the orientation parameters are known for the vector between these two antennas.

The general logic of AMP™ operation within the B210 can be understood better, if to look at fig. 1. In the figure, two antennas are connected to the same B210 board. One antenna is considered main, another – auxiliary. Let us assume antenna 1 is the main, which means that the target is to determine position of antenna 1 namely.

The radio-signals are passed from these antennas to two different radio-frequency (RF) receiver front-ends, denoted as RF1 and RF2 in the figure. From two RF front-ends the signals arrive to a common digital section, where the standard manipulations with incoming RF signals are made: down-conversion, filtering, amplification, digitization, generating raw measurements and digital data.

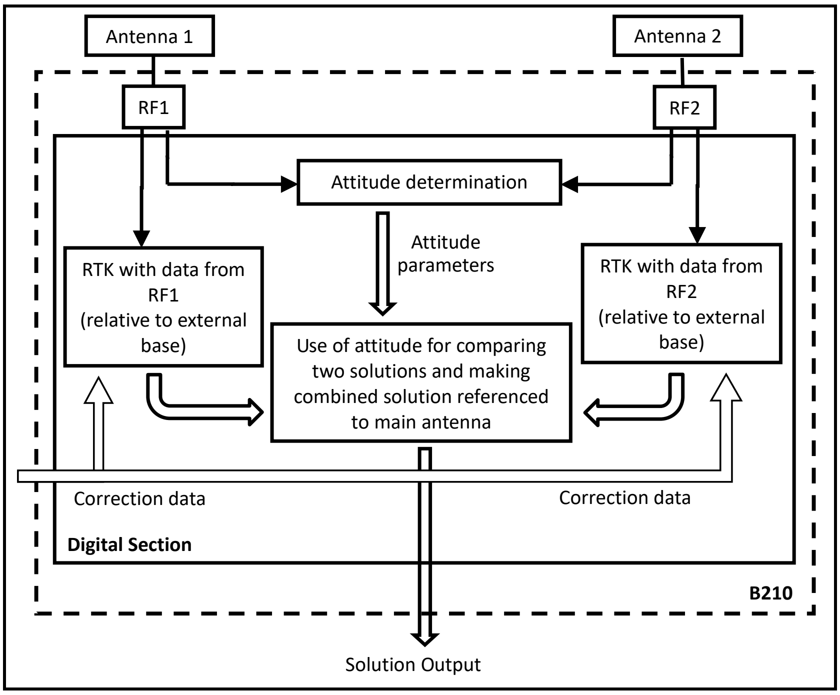

Fig. 1. The generalized logic of AMP™

Let us assume, there is an external source of RTK corrections, coming from a distant base, which arrive to the receiver board, namely, to its digital section. Then, the logic, illustrated in fig. 1 works as follows:

1) RTK engine determines position of antenna 1 with respect to a distant base;

2) RTK engine determines position of antenna 2 with respect to the same distant base with the same correction data;

3) VHD™ algorithm computes the orientation parameters of the vector between antenna 1 and antenna 2;

4) Alternative position of antenna 1 is calculated, based on determined position of antenna 2 and computed orientation parameters;

5) Initially derived position of antenna 1, and the alternative position of antenna 1 are compared to each other, and a combined RTK solution for antenna 1 is generated and output.

2.2 The Logic for Combining Solutions

As is explained in [Averin, et al., 2018], VHD™ is a technique, which is capable of computing orientation parameters for the vector between two antennas. As was also stated in [Averin, et al., 2018], B210 architecture makes it possible to compute highly robust orientation. In many cases, VHD™ is capable to deliver reliable orientation results when RTK fix is unavailable for antenna 1, or 2, due to signal obstructions, or distortions. This advantage of VHD™ serves as a basis for building several ideas, which make AMP™ advantageous.

Idea 1 – If RTK fixed solution is lost for antenna 1 but is available for antenna 2, position of antenna 1 is computed based on fixed RTK solution for antenna 2 and orientation parameters of the vector between antenna 1 and 2.

Idea 2 – If fixed RTK solutions are available for both antenna 1, and antenna 2, they are compared to each other with help of computed orientation. If positions match, a combined solution is generated as a weighted average between solution for antenna 1 and solution for antenna 2 recomputed to the position of antenna 1.

Weights are assigned based on solution statistics like RMS error, solution residuals, number of degrees of freedom, etc.

Idea 3 – If fixed RTK solutions are available for both antenna 1, and antenna 2, and they do not match, the one selected which provides better solution statistics mentioned above.

Idea 4 – If fixed RTK solution was lost for one of the antennas, but is available for another antenna, the available position, recomputed with help of orientation is used to "seed" the AR process for data coming from the antenna where RTK fix was lost.

It should be noted, that the algorithm of VHD™ evaluates the quality of processed raw data based on internal consistency checks, and if some data were detected as being "possibly erroneous", the relevant indications arrive to AMP™, and these data are treated accordingly, what further improves the solution robustness.

2.3 Alternative Concept

A concept described above in paragraphs 2.1 and 2.2, is implemented within the latest B210 board firmware, available to customers. However, this is possible to use raw data coming from two antennas in a different way. This alternative logic is presented in fig. 2. This alternative approach is yet to be researched and its benefits are yet to be understood from the practical point of view.

In fig. 2, similarly to fig. 1 two antennas are connected to the same B210 board, and one antenna is considered main, while another – auxiliary. Let us assume, antenna 1 is the main.

The radio-signals are passed from these antennas to two different RF front-ends, denoted as RF1 and RF2. From two RF front-ends the signals arrive to a common digital section, where the standard manipulations with incoming RF signals are made.

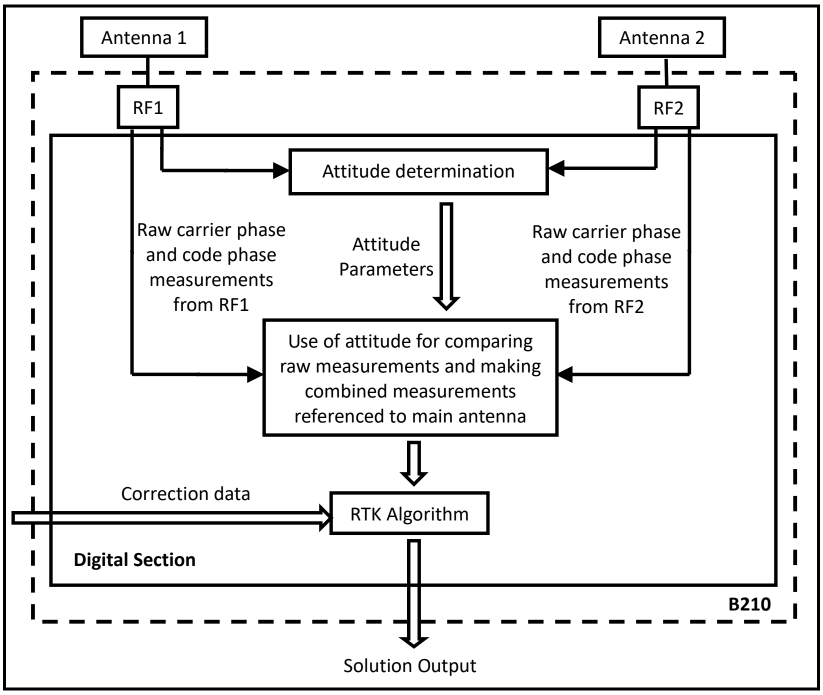

Fig. 2. Alternative logic of data processing

When data are ready, then, according to fig.2:

1) VHD™ algorithm determines the orientation parameters of the vector between antenna 1 and antenna 2;

2) Every measurement of antenna 2 is recomputed with help of known orientation so as to appear be originating from antenna 1;

3) Real and recomputed measurements, related to the same satellite, frequency, type are checked for consistency by means of comparing to each other, and if consistency check is fine, combined measurements are generated;

4) Combined measurements are sent to RTK engine, along with incoming correction data, and finally, RTK solution for antenna 1 is generated.

The logic for combining the raw measurements is based on ideas similar to those presented in paragraph B, with the difference that these ideas relate to measurement domain, rather than to position domain. So, in general:

1) If a specific measurement is lost for antenna 1, but is available for antenna 2, the lost measurement is restored with help of orientation parameters of the vector between antenna 1 and 2.

2) If a specific measurement is available for both antenna 1 and 2, the measurement from antenna 2 is recomputed so as to appear be originating from antenna 1 with help of orientation parameters, then, original and recomputed measurements are checked for consistency, and if consistency check is fine, a combined measurement is generated as a weighted average. Weights are assigned based on assumptions on measurement quality, dependent on factors like SNR, elevation, GNSS signal type, etc.

3) If the above consistency check fails, the measurement with better weight is chosen.

As result, a single RTK engine is fed with more consistent raw data related to antenna 1, what improves the robustness of positioning results.

Moreover, two concepts can be combined – the one, which is implemented (fig. 1), and another one – alternative (fig. 2). Fig. 3 describes the details.

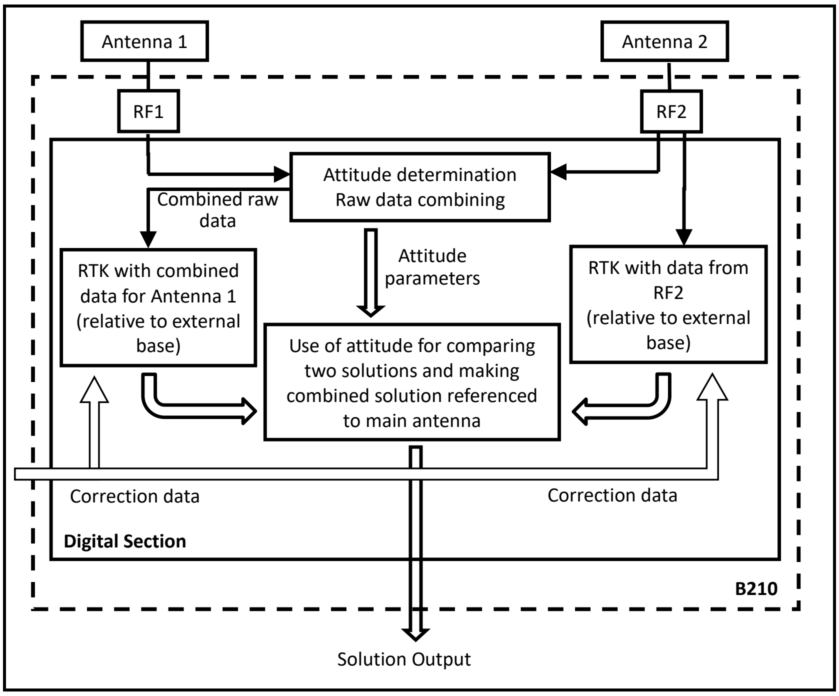

Fig. 3. Combination of two logics in a single thread

The advantages of such a combination as in fig. 3 are expected in case if RTK, supplied with combined measurements related to antenna 1 fails to output fixed solution because of whatever reason, but RTK supplied with the original data from antenna 2 works fine, as such, the solution for antenna 1 can be generated. A logic presented in fig. 3 is capable to provide the most robust RTK solution related to main antenna.

However, this logic is yet awaits implementation.

III. TEST RESULTS

3.1 Test Objectives

Some tests results for AMP™ were reported in [Averin, et al., 2018]. Those results have proven the efficacy of AMP™ while testing in urban canyon. The objectives of test results presented in this paper are the following:

1) to confirm the positive effect of AMP™, implemented within the latest official FW release for B210;

2) to verify the impact, which mutual geometry of main and auxiliary antenna could make to positioning performance.

Based on common sense, it might be clear that the bigger the separation between main and auxiliary antennas, the better the positioning performance. This conclusion might originate from the following facts:

1) the bigger the separation, the better the accuracy of attitude determination;

2) the bigger the separation, the more the difference in conditions for signal reception, and the bigger the effect of combining different RTK solutions.

Fig. 3 shows schematic composition of different antennas on minivan's roof, used in test campaign.

Three B210 boards were totally used. They were connected to the same main antenna (denoted as "Main" in fig. 3), and to three different auxiliary antennas (denoted as "Aux1", "Aux2", "Aux3" in fig. 3). Antenna separations were 0.8 m, 1.0 m, 2.5 m as is shown in fig. 3. The idea standing behind the antenna geometry shown in fig. 3 was to see if there is a difference in RTK performance for Aux1 and Aux2, as Aux1 was located more close to the potential signal obstructions when driving through urban canyon.

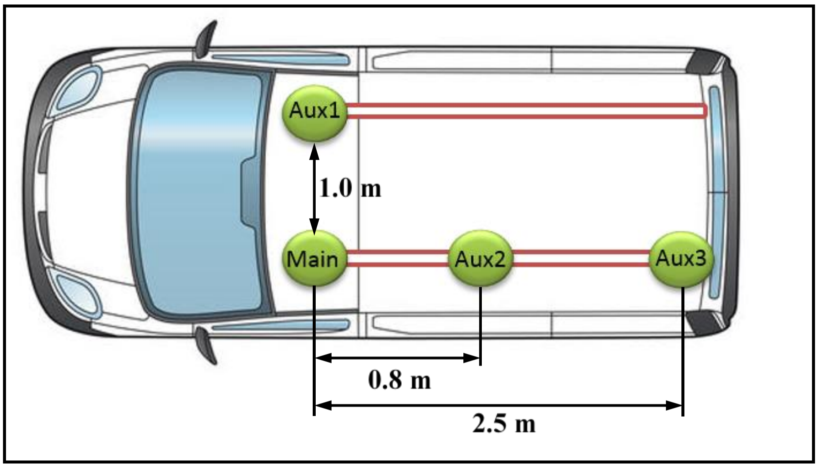

Fig. 3. Antenna composition while testing

Fig.4 shows the trajectory which was made by a car while data collection. As it follows from fig. 4, the route was laid through different conditions – from weak through moderate and strong signal obstructions.

In the process of data collection, every B210 board was commanded to store RTK solutions obtained with data from main antenna, auxiliary antenna, and a combined solution. These three solutions for one board will help to illustrate the difference in performance, which AMP™ could bring, compared with a classical single-engine approach.

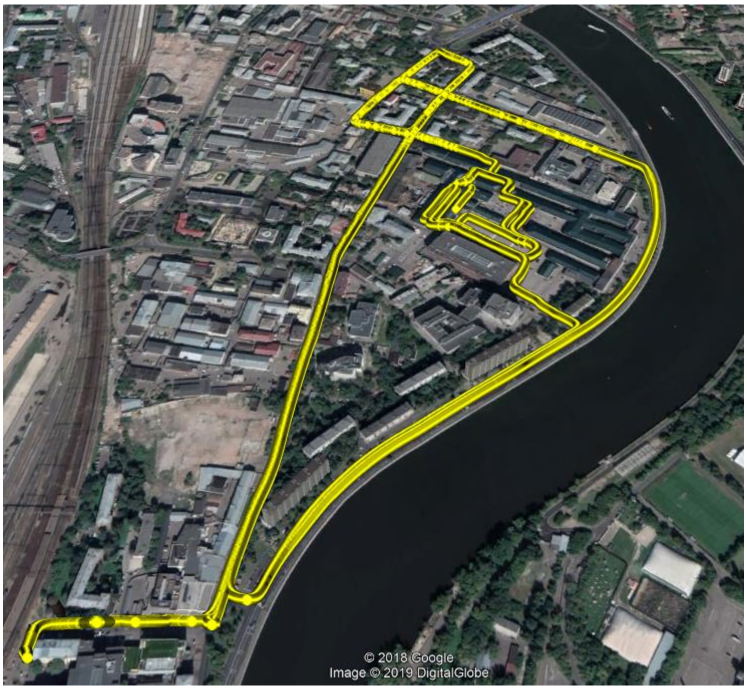

Fig. 4. The route made while testing

Multiple runs along the trajectory shown in fig. 4 were made. The section below describes the typical results.

3.2 Statistic Results

Multiple runs along the trajectory shown in fig. 4 were made. In order to obtain the reference trajectory, real-time results were post-processed in forward/backward RTK-like mode. As result, the reference trajectory was computed, which had much better availability of fixed solutions, and less outlier rate than real-time results.

Real-time trajectories were benchmarked against the reference one, and the statistics shown in Table 1 were evaluated. When treating these statistics, the following considerations should be taken into account:

a solution was considered an outlier if it was offset by more than 20 cm from the reference trajectory (in 3D space);

3D RMS error estimations include the joint effect of remnant noise of the reference trajectory and the noise of real-time results;

3D RMS errors and outlier rate were estimated using only those positioning results, which were available simultaneously for both the reference and real time trajectories, as it was impossible to compute the reference trajectory covering the whole route.

Table 1 contains statistics evaluated separately for RTK solutions obtained with data from main antenna, from all the auxiliary antennas and for combined solutions, based on solutions from main and auxiliary antennas.

Table 1. Test statistics

RCVR Board	**Solution**	**Fix Rate [%]**	**3D RMS Error [m]**	**Outlier Rate [%]**
B210 with Aux 1 (Distance: 1 m)	Aux	77.35	0.022	0.76
	Main	75.59	0.033	2.10
	Main: Combined	80.52	0.026	1.89
B210 with Aux 2 (Distance: 0.8 m)	Aux	76.88	0.018	1.21
	Main	76.67	0.033	6.63
	Main: Combined	81.37	0.034	5.08
B210 with Aux 3 (Distance: 2.5 m)	Aux	75.89	0.015	0.00
	Main	74.63	0.029	1.86
	Main: Combined	79.72	0.030	0.88

3.3 Result Analysis

As it follows from the statistics presented in table 1, the following conclusions can be drawn:

1) AMP™ provides noticeably more fixed solutions compared with a classical single engine approach;

2) AMP™ solution provides the number of outliers, which is the average between numbers provided by Main and Aux alone;

3) No positive effect was observed for Aux2 compared with Aux1, as in typical urban canyon being farther by ~1 m from the obstruction seems to play no role;

4) The distance between Main and Aux seems to really play a role, and as expected, the bigger the distance the better, as the number of outliers is reduced with growing distance.

The most discouraging conclusion is conclusion 2 that outliers are not completely removed in combined solution provided by AMP™. But as it turns out, the most of outliers in combined solution occur when only either Main, or Aux solution is available and there is no mean to check such a solution for consistency. So, in summary, the number of outliers in combined solution is steadily smaller than the maximum number of outliers in solutions of either Main, or Aux, and this proves the efficacy of AMP™.

IV. CONCLUSIONS

Topcon's B210 GNSS receiver board is an innovative product capable of tracking and processing all available GNSS open signals: GPS/SBAS/QZSS (L1, L2, L5), GLONASS (L1, L2, L3), GALILEO (E1, E5, E6), Beidou (B1, B2). This board has two RF front-ends and a single digital section, what makes it capable to support VHD™ and AMP™ technologies. Because of VHD™ technology, precise heading and tilt angles are available. AMP™ technology coupled with VHD™ is capable to provide robust RTK results.

As test results show, B210 board with VHD™ and AMP™ functionalities is advantageous in environments like urban canyons, open pit mines, tree canopy, etc., where achieving good quality RTK fix is a challenge. As such, this board is of value for those developers who aim at applications like controlling vehicles of different types while the sky view is partly obstructed.

In future, addition of extra functionalities is planned to AMP™ which should further improve the solution availability and robustness.

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