Improvements in GBAS VDB Testing

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ABSTRACT

This paper will provide the latest findings in Ground Based Augmentation System (GBAS) testing dealing with the digital datalink (VHF Data Broadcast, VDB). New GBAS options to support category (CAT) III operations and multiple VDB subsystems require improved measurement techniques and success criteria that should be included in the update of ICAO Doc 8071 Vol. II dealing with ground and flight testing/inspection of satellite navigation systems. Extending the GBAS service volume to include autoland and guided take-off causes challenges due to higher level of VDB multipath especially at complex airports. Buildings and other static as well as large mobile objects are causing an increased level of VDB multipath on the runways that can cause signal fluctuations violating the existing VDB field strength criteria for very short periods.

In principle, a single GBAS VDB datalink subsystem can cover all runway ends of an airport. In Frankfurt, the GBAS Approach Service Type (GAST) C with one VDB subsystem supports twelve different approaches for six runway ends. However, due to more challenging requirements for GAST D (CAT III), future GAST D ground station architectures could support up to four VDB subsystems that can be located at different spots of an airport. VDB antenna diversity can cause larger signal variations from slot to slot and from frame to frame. Improved VDB measurement techniques and decision criteria should help in ground and in flight testing/inspection to effectively verify the requirements of GAST C (CAT I/II) and GAST D (CAT II/III) ground stations.

Rohde & Schwarz (R&S) and the German Air Navigation Service Provider Deutsche Flugsicherung GmbH (DFS) are tasked by EUROCAE Working Group 28 (WG-28, writing GBAS ground subsystem MOPS) to develop and test new VDB power measurement techniques that support higher output rates for VDB measurements. The current ICAO-compliant measurement technique is to average field strength (power) over the fixed 48 bits (16 symbols) of the period of the synchronization and ambiguity resolution field of each burst. For a GAST C ground station with a nominal assignment of two (out of eight) VDB slots this procedure results in a sample rate of just four (often un-equidistant) measurements per second. This rate is quite low for high vehicle speeds (aircraft speed during landing and touchdown is typically about 70m/s) and/or if a high level of multipath is expected. In addition, higher VDB power measurement rates could be advantageous when flying though a null or overflying or passing by a VDB transmitter antenna or a VHF interference source (for Desired to Undesired D/U measurements).

The new VDB type 3 fill message introduced for VDB authentication with its constant bit pattern and in-phase and quadrature (IQ) measurement techniques are the two most promising solutions to provide higher sample rates for VDB field strength (power) measurements. This was the outcome of a brainstorming at the EUROCAE WG-28 N44 meeting in Cologne

in September 2019 [14]. The most promising solution was prototyped by Rohde & Schwarz, implemented in a new firmware version of their R&S®EVSG1000 V/UHF AIRNAV/COM analyzer. This analyzer is used by DFS in their GBAS Measurement Tool (GMT, [13]) and its pendent EVSF1000 is installed for special missions in the new Flight Calibration Services (FCS) flight inspection aircraft. These platforms can be used to verify the new ideas in ground and flight testing and to select the best option for final implementation in the EVSG1000 measurement devices so that all GBAS users can profit. The first results of the verification by ground testing will be presented and discussed in this paper.

INTRODUCTION

Current ICAO Standards and Recommended Practices (SARPs, [1]) as well as EUROCAE ground subsystem MOPS [3] and RTCA airborne MOPS [4] already include requirements for GBAS Approach Service Type (GAST) C and D to support GBAS precision approaches based on GPS down to CAT III. Best practice in GBAS testing documented in ICAO Doc 8071 Volume II Chapter 4 published 2007 [2] is still limited to CAT I. Therefore, the GBAS ground and flight testing/inspection chapter 4 in Doc 8071 Volume II is under revision by the ICAO Navigation Systems Panel [14], [15] and reviewed by EUROCAE WG-28 [17]. The updated version of Doc 8071 Vol. II is planned to be finalized by the ICAO Navigation Systems Panel (NSP) end of 2022. Besides multiple service types, GBAS can now support new options like VDB authentication, multiple VDB subsystems (antenna diversity) to improve coverage, and/or Expanded Service Volumes (ESV, [4]). The current ICAO SARPs [1] applicable since November 2020, contain improved and new requirements to better support the co-existence of GBAS and terrestrial navigation aids in the VHF band (namely ILS localizers and VOR) at the same airport. However, NSP work has shown that additional analysis, simulation, or testing are required to ensure safe operation at airports with active ILS and (D)VOR installations [16]. For the time being, the detailed guidance on this topic will find its temporary home in an appendix of ED-114B Change 1 which is planned to be provided for public consultation in July 2022.

The German Air Navigation Service Provider (ANSP) DFS is operating two Honeywell SLS-4000 GAST C ground subsystems for public use at Bremen and Frankfurt airport [10]. The Frankfurt GAST C station is supporting twelve or more different approach paths to six runway ends. In mid-2022 all approaches are planned to get an additional CAT II minimum so that approved aircraft/crews can fly GLS CAT II approaches. An Expanded Service Volume is under preparation to support GBAS precision approaches starting at 66 km slant range (about 35 NM) from the GBAS reference point [13].

In addition to the GAST C station used in daily precision approach operations by several airlines, a GAST D prototype ground station from Indra Navia is installed in Frankfurt since May 2013. This station is used for development and testing activities in frame of the European research program SESAR (Single European Sky ATM Research Program). The NORMARC 8100 GBAS is broadcasting information by two VDB subsystems located at opposite sides of the airport. The GBAS multi VDB option was inspired by SESAR [5], validated by international standardization bodies [6], and will most probably be used for GBAS CAT III implementations at complex airports to fulfill all requirements during aircraft landing and rollout phase. It will help to increase the number of opportunities to successfully receive the required VDB messages in challenging airport environments. This will ensure to meet the reduced time-to-alert (TTA) for GBAS CAT III precision approach operations below 200ft. On the other hand, it will cause new challenges for GBAS ground and flight testing/inspection [6].

Frankfurt airport can be used for ground and flight testing/inspection for GBAS approach service types C and D as well as for testing of the multiple VDB option (antenna diversity). In addition, the airport is complex and shows challenges for testing that are not visible at simpler airports like Bremen.

CHALLENGS OF VDB FLIED STRENGTH MEASUREMENTS IN COMPLEX AIRPORT ENVIRONMENTS

Paper [10] presented at the IFIS 2018 describes several of the challenges that VDB Flight inspection is facing. Complementary ground testing in 12ft height above runways and at pre-defined checkpoints at each airport [20] help to detect and eliminate possible issues. Additional analysis is necessary to cover VDB field strength requirements at 36ft height above runways as well as to avoid impact by undesired signals (from active localizer and/or VOR antennas). All this is planned to be addressed in the new revision of Doc 8071 Vol. II chapter 4 GBAS [17], [18].

NEW VDB MEASUREMENT METHOD

The new VDB power measurement method in the digital plane provides up to 633 level measurement per burst (instead of 1 measurement per bust with the currently recommended method) and helps for example to measure power variation within each burst. Thereby the new method better supports high vehicle speeds and measurements in regions where VDB power is changing with high gradients (nulls, antenna overflights, pass-by). For runway measurements it enables to record a detailed footprint of the VDB multipath environment for each runway.

THE R&S®EVSG1000 VHF/UHF AIRNAV/COM ANALYZER

The EVSG1000 (see Figure 1 and [23] for more information) is a portable signal level and modulation analyzer. It is designed for commissioning and servicing ILS, GBAS, VOR, NDB and marker beacon ground stations and for analyzing air traffic control communications (ATC COM) signals in a single instrument. It performs efficient analyses in the frequency range from 70 MHz to 410 MHz with a dynamic range of more than 130 dB. These features enable the EVSG1000 to carry out fast, accurate, ICAO-compliant measurements. By using digital signal processing, the EVSG1000 offers outstanding accuracy during modulation analysis. The input signal is sampled at the intermediate frequency (IF) using a high-precision analog-to-digital converter. FPGA technology is used to process results in real-time with the highest degree of reproducibility. The EVSG1000 has a modular design and comes with numerous options, allowing it to be tailored to the specific application.

The EVSF1000 measurement hardware and software are identical to that of the EVSG1000, which was designed to perform ground measurements. The identical performance of the two instruments ensures that results obtained in flight and from the ground are comparable, as stipulated by the ICAO standards.

Figure 1. R&S®EVSG1000 (left) and R&S®EVSF1000 (right).

The EVSG-K4 software option makes it possible to test the VHF Data Broadcast (VDB) of GBAS ground subsystems. The content of all GBAS timeslots (A to H) is analyzed and synchronized using an external PPS signal. The user is able to visualize the sequence of GBAS messages over time, analyze a complete GBAS frame (time domain overview plus measurement results for each timeslot), perform detailed time domain measurements on a single burst, analyze the signal via a constellation diagram and last not least look at the data content in the message view (see Table 1 and Figure 2).

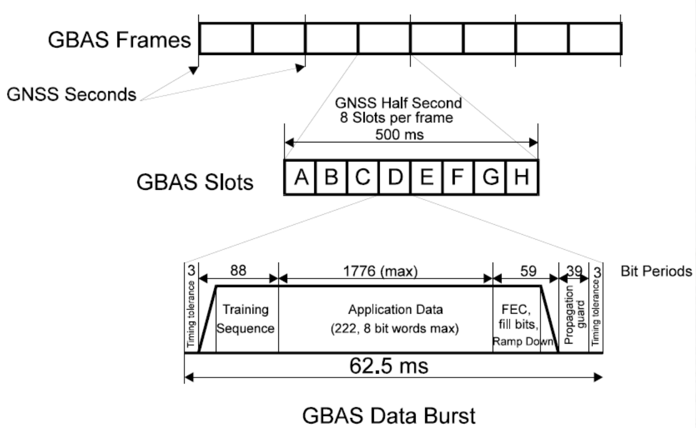
Measurement value	Description
Burst level average in dBm	Arithmetic average measured over the period of the synchronization and ambiguity resolution field of the burst
Slot peak level in dBm	Highest measured power level in the slot
Carrier frequency offset in kHz	Offset of the measured carrier frequency from the tuned center frequency
Error vector magnitude (EVM) RMS in %	Indicates the quality of the transmitted symbols in relation to the ideal constellation point
GBAS identifier	Identification of the ground station broadcasting the message

Table 1. Few examples for GBAS measurements of the EVSG-K4 option.

Figure 2. Two bursts of the GAST C VDB displayed by the EVSG1000 (frame view and constellation diagram).

CURRENT VDB MEASUREMENT METHOD

The standardized method for VDB field strength (level) measurements is to average over the 48 synchronization and ambiguity resolution bits of the training sequence on all available samples (16 symbols = 48 bit = 1.5238 ms, see Figure 3 yellow frame). In former times, this 48 bit sequence at the beginning of each burst was the only part with a fixed content ([3], 3.6.2.3.8.2) and 100% nominal percentage of the steady-state power (see Figure 3 ED-114B table on the right side). Remark: With addition of the VDB authentication protocol, type 3 message was introduced in the GBAS standards that has a fixed content as well but a variable length).



Event	Number of symbols	Number of bits	Nominal event duration:	Nominal percentage of steady-state power	Bits
Ramp-up	2	6	190.5 µs	0% to 90%	88 bits Training Sequence
Power stabilisation	3	9	285.7 µs	90% to 100%	
Synchronisation & ambiguity resolution	16	48	1523.8 µs	100%	
Station Slot Identifier (SSID)		3	Transmission of scrambled data: 58 761.9 µs (see NOTE1)	100%	
Transmission Length		17			
Training Sequence FEC		5			
Application Data		Up to 1776			≤1776 bits Application Data
Application FEC		48			59 bits: FEC, Fill bits, Ramp Down
Fill Bits		0 to 2			
Ramp-down	3	9	285.7 µs	100% to 0%	

Figure 3. VDB TDMA Timing Structure [3].

The level measurement in an EVSG1000 is implemented as defined in the standards over the 16 symbols of the synchronization & ambiguity section of a GBAS burst. Thus, the time for the level measurement is 1.5238 ms or just 2.5% of an occupied slot (Figure 3 yellow frame) with a slot duration of 62.5 ms (Figure 3 left side).

The measurement of the GBAS VDB level as described in the standards can be done by measuring the analogue signal level during the synchronization & ambiguity resolution field or by sampling the signal and averaging all samples. This is what the EVSG1000 does. Figure 4 shows ramp up, power stabilization and synchronization & ambiguity resolution field of a GBAS VDB bust. Red dots mark the samples, orange arrows the symbol times of the trainings sequence. Due to the nature of a digitally modulated signal this will include also times when the signal pointer is not in its maximum (between the symbols) and lead to slightly lower level measurements than a measurement that is done *only* at the symbol times (marked by arrows).

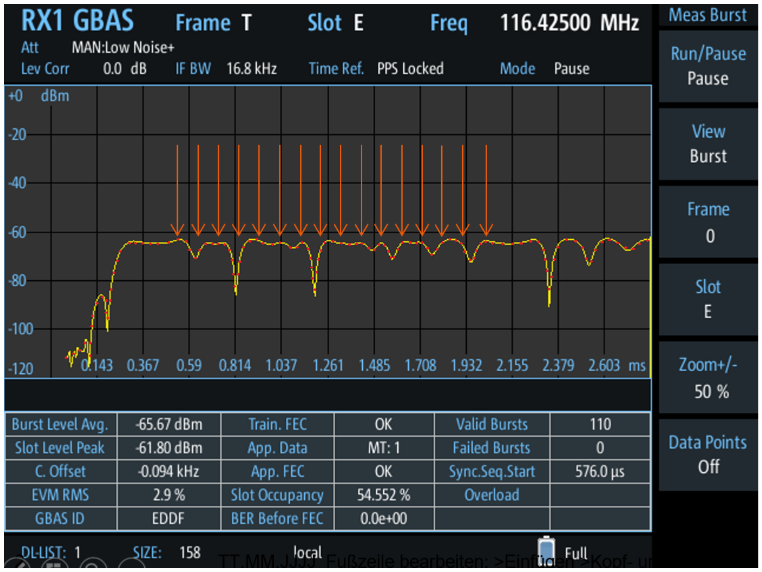


Figure 4. Zoomed burst view of the EVSG1000.

Remark: As the trainings sequence always contains the same information the shape of this part of the GBAS signal is not changing from one burst to the other and the reduced power level can be easily corrected by a fixed factor.

The digital signal processing of the EVSG1000 guarantees that the symbol sampling time is exactly in the middle of the symbol. Due to the raised cosine filter in the TX path of the EVSG1000 the level reaches here it's maximum.

MODIFIED VDB BURST POWER MEASUREMENT

The disadvantages of the level measurement method described above are:

- The trainings sequence is short and a disturbance or a wrong antenna correction factor at a certain antenna angle can lead to wrong GBAS level indications.
- Dynamic GBAS measurements (ground measurement vehicle or flight inspection aircraft) require a very accurate knowledge of the antenna characteristics at the time of the measurement (about 1.5 ms).
- Changes of the GBAS power during a burst are (more or less) not taken into account (see Figure 2 with an example screenshot of an EVSG1000 taken at Frankfurt airport and mor examples later in this paper). In that case the burst power differs significantly from the indicated value.

Paper [14] describes a different method to measure the burst level. The basic idea behind that method is that the measurements are performed over the complete burst – but only at the symbol times when the length of the pointer is always one. This eliminates the signal values when the signal pointer moves in the signal plane from one point of the constellation diagram to the other (these transition times between the symbols are normally not displayed in the constellation diagram). Doing so one gets simply more measurement values than standard (max. 633 symbols in contradiction to 16 symbols) plus the measurement is spread over a longer time period - but still not dependent on message content.

Such a method can be used in two different ways:

1. It is possible to use the up to 633 level values of a burst to see level variations (e.g., due to multipath effects) along the runway e.g., during a runway measurement with a vehicle. This was practically tried out in Frankfurt and results are described in the following chapters.

2. It is also possible to average these level values over one burst to get a more stable burst level measurement that minimizes the effects of multipath or antenna notches. This second possibility was evaluated in lab tests that are described in [16]. The next chapter gives a rough overview of the R&S lab test results.

LAB TESTS WITH SYNTHETIC BUSTS

With the help of synthetic signals, four different GBAS VDB scenarios were created. The results show the differences of the two VDB level measurement methods. The basic settings are:

- Burst length 1824 bits (608 symbols)
- All slots are used. Slots A, C, E and G are attenuated (-3 dB, -6 dB, -9 dB, -12 dB)
- Slots A, C, E and G get additionally a ramp, cosine or a rectangular burst shape to simulate level changes within one burst. The level changes are always between 50% of the amplitude (- 6 dB) and full scale (Figure 5).

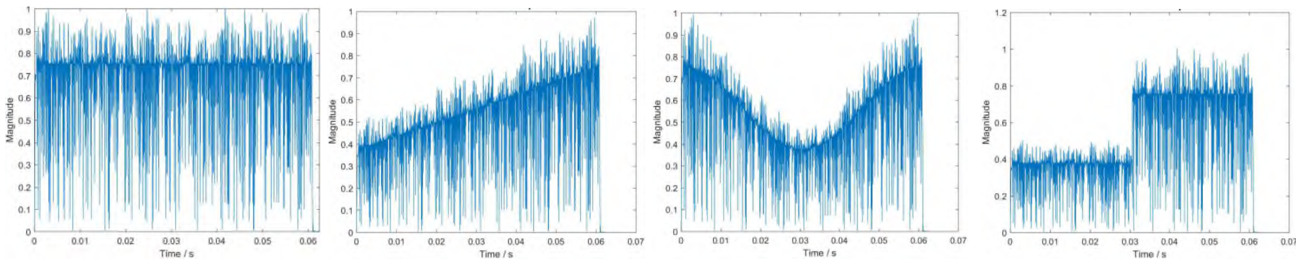


Figure 5. Different VDB burst pulse shapes.

The expectation was that all burst level measurements of the unchanged slots B, D, F and H would show identical burst level results independent of the method (measurement over the trainings sequence (Av) or average over all burst symbols (Pk)). This was validated in a first test (Table 2).

	Slot A	Slot B	Slot C	Slot D	Slot E	Slot F	Slot G	Slot H
Av [dBm]	-81.16	-78.16	-84.17	-78.16	-87.18	-78.17	-90.15	-78.19
Pk [dBm]	-81.17	-78.17	-84.16	-78.17	-87.16	-78.17	-90.15	-78.17
Delta [dB]	0.01	0.01	0.01	0.01	0.02	0.0	0.0	0.02

Table 2. Av and Pk measurement results of unmodulated busts (Figure 4 left example).

For the different burst pulse shapes a difference between the two level measurement methods was expected. The expectations are listed in Table 3.

Burst shape / expected level difference (compared to full scale)	Ramp	Cosine	Rectangular
Av	-6 dB	0 dB	-6 dB
Pk	-2.5 dB	-2.5 dB	-2.5 dB
Difference (|Av – Pk|)	3.5 dB	2.5 dB	3.5 dB

Table 3. Expected level difference for different modulation schemes in a single bust**.**

All results and more details are containted in [16]. Here we will only show one example and look at the results of a cosine shaped burst (Figure 6 and Table 4):

- Identical Av level measurements in all slots (same bust levels on all slots in trainings sequence of bursts in slots B, D, F, H)
- ~ 2.5 dB less level of the Pk level measurements in slots B, D, F, and H than the Av level measurements in slots B, D, F, and H.

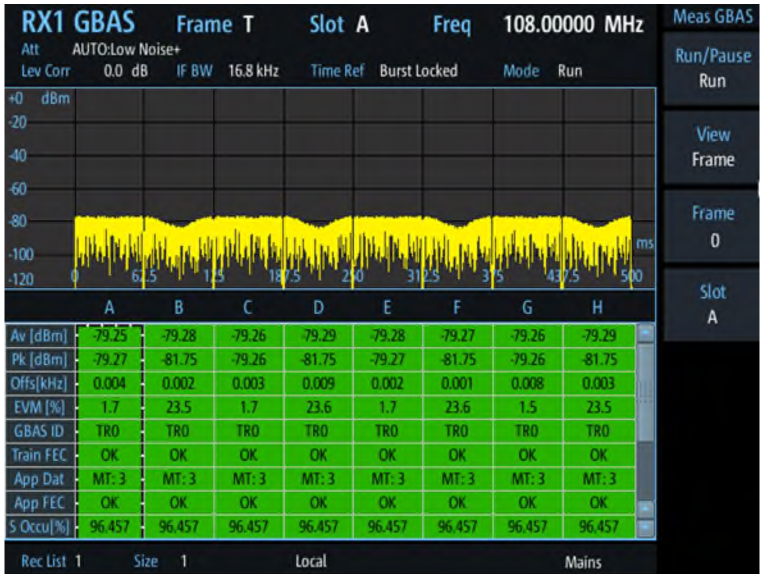


Figure 6. EVSG1000 display showing Av and Pk measurement results of a cosine shaped burst in slots B, D, F, H.

	Slot A	Slot B	Slot C	Slot D	Slot E	Slot F	Slot G	Slot H
Av [dBm]	-79.25	-79.28	-79.26	-79.29	-79.28	-79.27	-79.26	-79.29
Pk [dBm]	-79.27	-81.75	-79.26	-81.75	-79.27	-81.75	-79.26	-81.75
Delta [dB]	0.02	2.47	0.0	2.46	0.01	2.48	0.0	2.46

Table 4. Av and Pk measurement results of a cosine shaped burst in slots B, D, F, H.

It could be shown that a level measurement over the complete burst helps to avoid level errors due fluctuations of the GBAS power (e.g., reduce influence of receiving antenna diagram – notches) and as the result is averaged over a complete burst lead to more stable results. Additionally, a GBAS level measurement only at the symbol times (DPSK) avoids any dependency of the level measurement of the content of the GBAS message.

Draft EVSG1000 Firmware Implementations

To be able to analyze level variations during the GBAS bursts R&S implemented an additional export of all burst symbol level values. These level values of the GBAS symbol times are stored in one single list (max. number of 633 symbols for a GBAS burst).

STATIC TESTING

The Germany air navigation service provider DFS started the testing of the draft EVSG1000 firmware with static tests in the DFS lab in Langen with live signals from Frankfurt airport in autumn 2021.

Measurement Setup

The roof of the DFS lab in Langen is located 5-10 km from the airport and is equipped with a Trimble GNSS antenna and a Polar Electronics 3-bay crossed dipole VDB antenna. Different GNSS receivers can be connected and provide GPS time-synchronized Pulse per Second (PPS) as well as a National Marine Electronics Association (NMEA) 0183 data stream containing GNSS Position, Velocity, and Time (PVT) per serial interface to the EVSG1000 (similar to Figure 11). The decoded VDB messages and the VDB measurement data of the EVSG1000 can be recorded in the internal memory of this measurement device or by a laptop connected via an Ethernet cable. The Windows laptop is running the GMT software coded by DFS [13]. In addition to the EVSG1000 data output, the GMT can record the GNSS raw data and its PVT data. For the first static testing the GNSS receiver was operating with 1 Hz.

Results

After some iterations the EVSG1000 prototype firmware was operating stable and the output format of the additional level measurement values for each symbol was improved. Challenges in the time stamping of the data output needed to be fixed. Due to the distance of the DFS lab to the airport the VDB signal reception is quite weak, typically at or below the minimum VDB power (72 dBm). The recorded power variations were in the order of 1.0 dB during opening hours of the airport and lower values at night when the airport is closed.

DYNAMIC GROUND TESTING

With a stable operating draft firmware for the EVSG1000 and the GMT software the dynamic ground testing at Frankfurt airport started.

GBAS Ground Subsystems at Frankfurt Airport

As mentioned above, Frankfurt airport consists of two GBAS ground subsystems, an operational GAST C GS and a prototype GAST D GS. For the following tests mainly the GAST D station was used because it could be operated in different VDB configurations optimized for VDB measurements. As GAST D GS it is supporting VDB authentication with a slot occupancy rate of more than 89% [1], [3]. The two VDB subsystems are connected via optical fiber lines. Beyond others, each of them consists of the VDB transmitter and a 2-bay crossed dipole VDB transmitter antenna (Figure 7). VDB TX1 is providing the signal to a ground antenna in about 12 m height while VDB TX2 is broadcasting its signal via a roof-top antenna in about 30 m height on the other side of the airport (Figure 9).

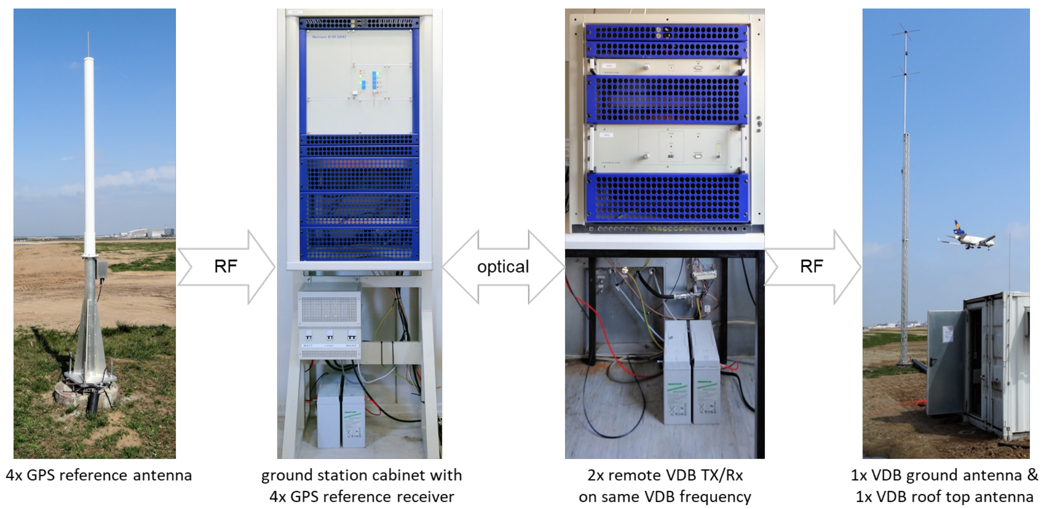
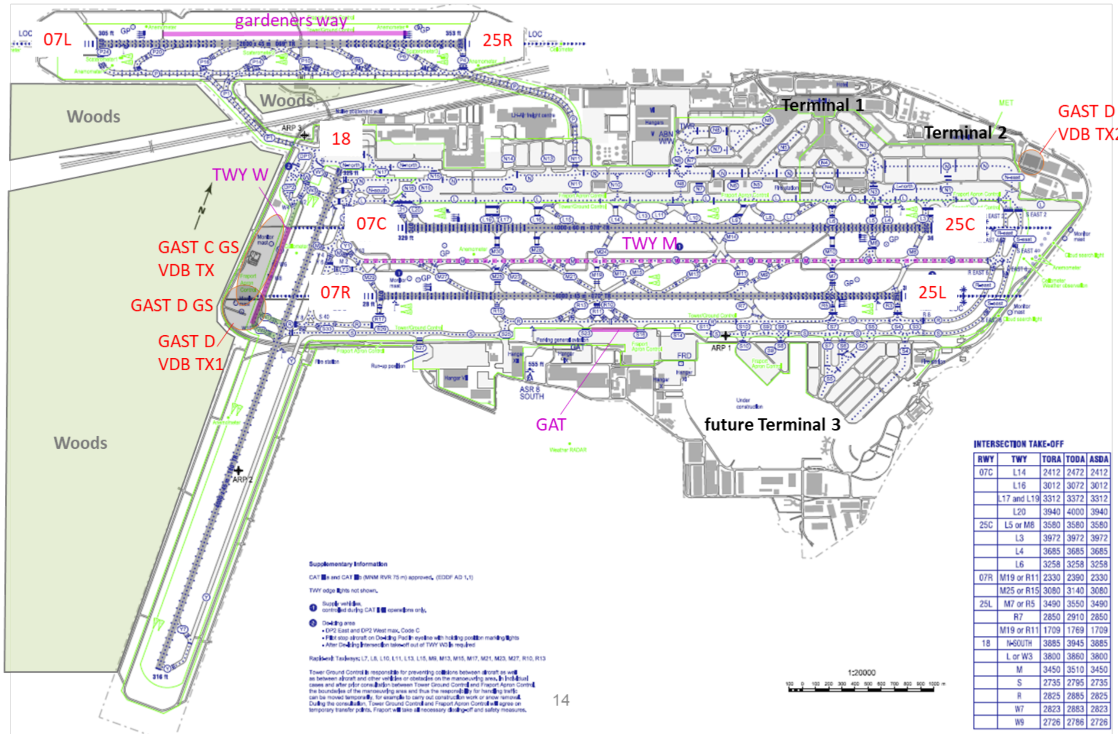


Figure 7. Indra Navia prototype GAST D ground subsystem with 2 VDB subsystems.

Most of the time the GAST D GS was broadcasting in all 8 slots with both VDB transmitters broadcasting on the same frequency (116.550 MHz) but in different slots. The VDB time slot scheme used is depicted in Figure 8. This is not a normal GAST D VDB time slot allocation scheme. All 8 slots are occupied to get a maximum of measurement information. Each of the two VDB transmitters (TX1 and TX2) are broadcasting in every second slot, with TX1 starting in slot A.

Frames	N								N+1							
Transmitter #	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Message types	2, 3	2, 3	4, 3	4, 3	1, 3	1, 3	11, 3	11, 3	2, 3	2, 3	4, 3	4, 3	1, 3	1, 3	11, 3	11,3
Slots	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H

Figure 8. GAST D VDB time slot allocation scheme used for first measurements.



RWY	TWY	TORA	TODA	ASDA
07C	L14	2412	2472	2412
	L16	3012	3072	3012
	L17 and L19	3312	3372	3312
	L20	3940	4000	3940
25C	L5 or M8	3580	3580	3580
	L3	3972	3972	3972
	L4	3685	3685	3685
	L6	3258	3258	3258
07R	M19 or R11	2330	2390	2330
	M25 or R15	3080	3140	3080
25L	M7 or R5	3490	3550	3490
	R7	2850	2910	2850
	M19 or R11	1709	1769	1709
18	N-SOUTH	3885	3945	3885
	L or W3	3800	3860	3800
	M	3450	3510	3450
	S	2735	2795	2735
	R	2825	2885	2825
	W7	2823	2883	2823
	W9	2726	2786	2726

Figure 9. Frankfurt Airport map.

Frankfurt Airport Scenario

To avoid unnecessary traffic obstructions, the measurement campaigns in December 2021, February 2022 and April 2022 were performed on the closed taxiway (TWY) W, the airport support street close to the General Aviation Terminal (GAT), and/or on a gardener's ways close to the northern runway (see Figure 9). These test scenarios were selected because they are flat and straight. The necessary coordination with ATC and airport operator is limited.

The taxiway W is close to both GBAS ground subsystems (GS) and two VDB transmitter antennas (GAST C VDB TX and GAST D VDB TX1 antenna, distance > min. distance of 80 m). For the GAST D ground subsystem there is a high slot-to-slot dynamic because the first of the two VDB subsystems (GAST D VDB TX1 antenna) is located near-by while the second VDB subsystem (GAST D VDB TX2) is located on the other side of the airport in about 6 km distance (see Figure 9). The multipath environment on TWY W is moderate. The two-floor high weather observation building west of the runway is expected to cause some multipath in the northern section. Because of blocking obstacles, test drives were only possible on the side stripes of TWY W not in the middle of the taxiway.

The short section in front of the GAT was selected as an example for a high multipath environment. All VDB signals are well inside the defined limits and all VDB signals are in about the same order of magnitude (no high slot-to-slot dynamics). On the airport support street, the driving speed is limited to about 30 km/h.

The gardener's way is parallel to the northern runway and quite close to this landing runway (about 90 m distance to the centerline). Due to its unpaved surface, it does not allow very high driving speeds. However, the VDB measurement results should be very similar to runway measurements on the northern runway.

Measurement Setup

At the moment, DFS is testing a new horizontally polarized VHF measurement antenna in 12 ft height on a VW van. Recently both measurement antennas were in a measuring chamber to determine better measurement antenna corrections for VDB frequencies in the 108 to 118 MHz frequency range, for azimuth angles from 0 to 360°, and for several elevation angles. An Electromagnetic (EM) simulation scenario is available to determine corrections for measuring in the near field at a distance of 10 m (in the measuring chamber). The technical validation of this setup is part of a SESAR project for GAST D.

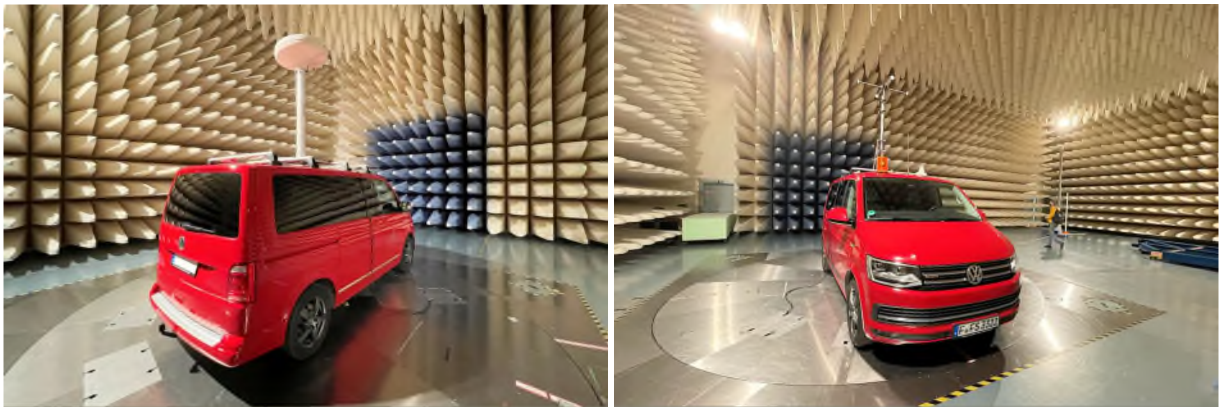


Figure 10. Measurement van with old (left) and new (right) VDB measurement antenna in the measuring chamber.

Other than in the static measurements (see section above) the precise VDB measurement antenna position at any point in time is unknown. For the results presented in this paper a GNSS receiver Septentrio AsteRX with a Real-Time Kinematic (RTK) PVT solution was used as PPS source and as reference system. A mobile phone provided GNSS corrections of the Satellitenpositionierungsdienst (SAPOS) high precision real-time positioning service (HEPS) in RTCM format to the GNSS receiver (Figure 11). SAPOS provides satellite corrections for GPS, GLONASS, Galileo and BeiDou with 1 Hz. The achievable position accuracy should be in the order of 1-2 cm.

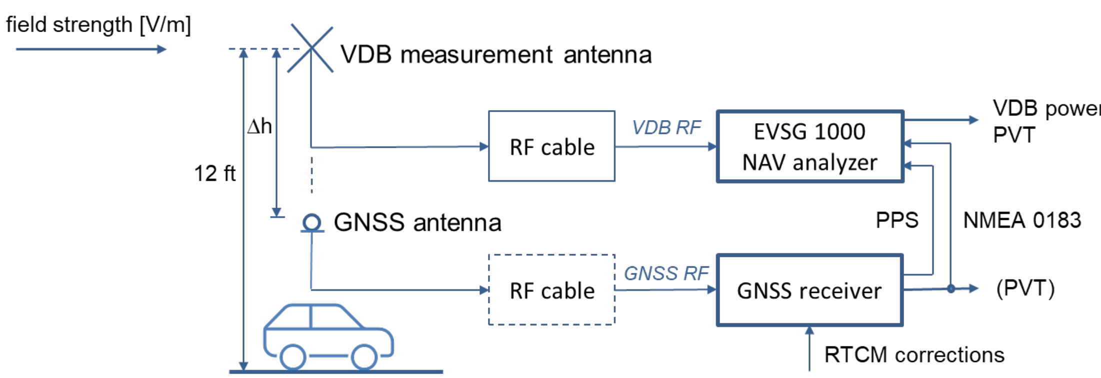


Figure 11. Measurement setup.

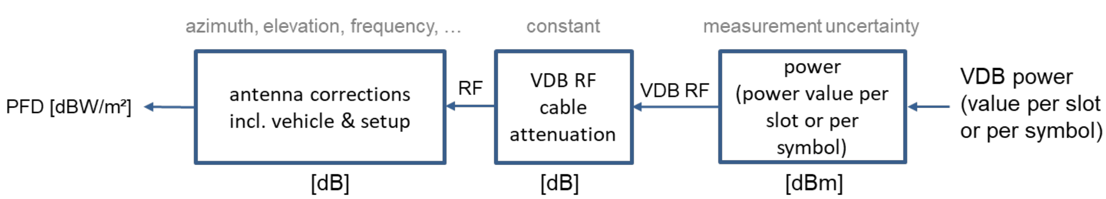


Figure 12. Calculation of the Power Flux Density (PFD).

Data Evaluation

In the current draft firmware of the EVSG1000 linearly interpolated PVT information for each VDB slot based on the incoming NMEA data stream from the GNSS receiver is provided. At the beginning of the testing the GNSS receiver operated with 2 Hz which results in quite limited accuracy in curves. Therefore, the message rate in the NMEA data stream was increased to 5 Hz in a first step. Perfect would be a data rate in sync with the VDB slots of 8 Hz or 16 Hz. But most GNSSs receivers are not supporting these data rates. Instead, 10 Hz or 20 Hz are typically supported but did not result in stable operations with the draft firmware. Further improvements by configuring the NMEA data stream in more details may be possible.

From the PVT information received from the EVSG1000 the GPS time of week (TOW) and the position coordinates (distance to a reference point) for each level measurement at symbol time are calculated [22] taking into account the knowledge about the Time Division Multiple Access (TDMA) timing in the standards (see Figure 3) and the provided information about the message length in the header of each message.

First Results

The above-mentioned airport scenarios (see Figure 9) selected for ground testing were used for reproducible test drives with the above-mentioned measurement van and the 12ft high VHF measurement antenna (Figure 10 right side). Different speeds (10, 30, 50, 70 km/h) and both driving directions were used. The following results are showing raw VDB power values recorded by the EVSG1000. The first figure (Figure 13) shows an overview of a test drive on TWY W with a color coding of the vehicle speed (blue color corresponds to 0 km/h speed, pink corresponds to 70 km/h).

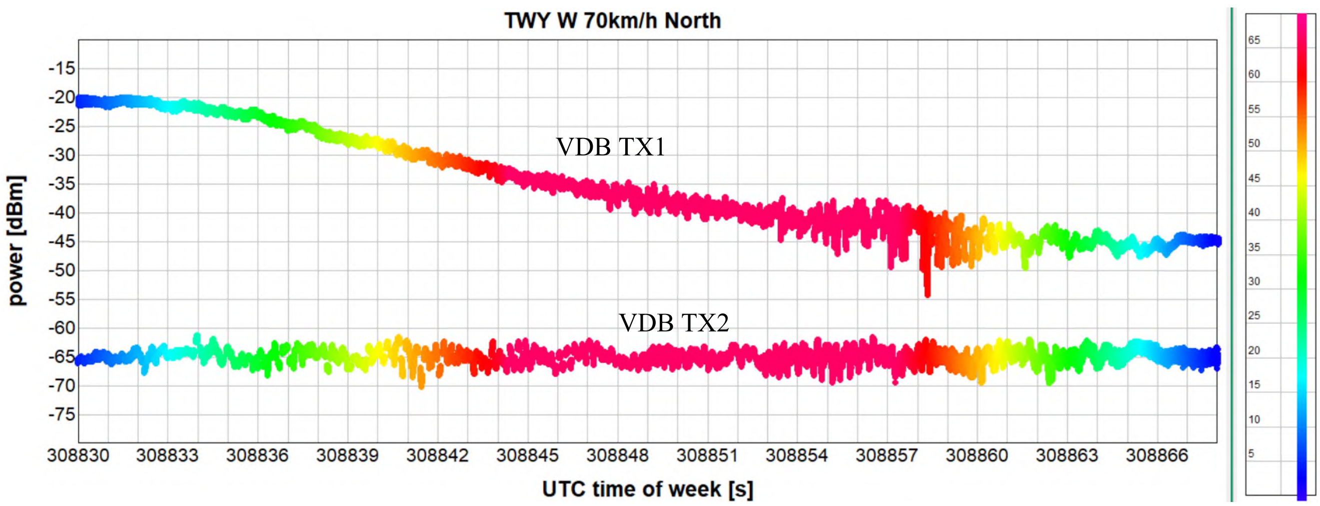


Figure 13. Results new VDB level measurement method driving on TWY W in northern direction with up to 70 km/h.

The next two figures show the same data as before but for just a section of 1 second in an area with elevated VDB multipath. This enables a direct comparison of the old measurement method (Figure 14) and the new measurement method (Figure 15) for the same time period. Color coded are the different VDB slots (A=0 in blue to H=7 in red). Due to a software error, there is an offset of 18s (current number of GPS leap seconds) between both files.

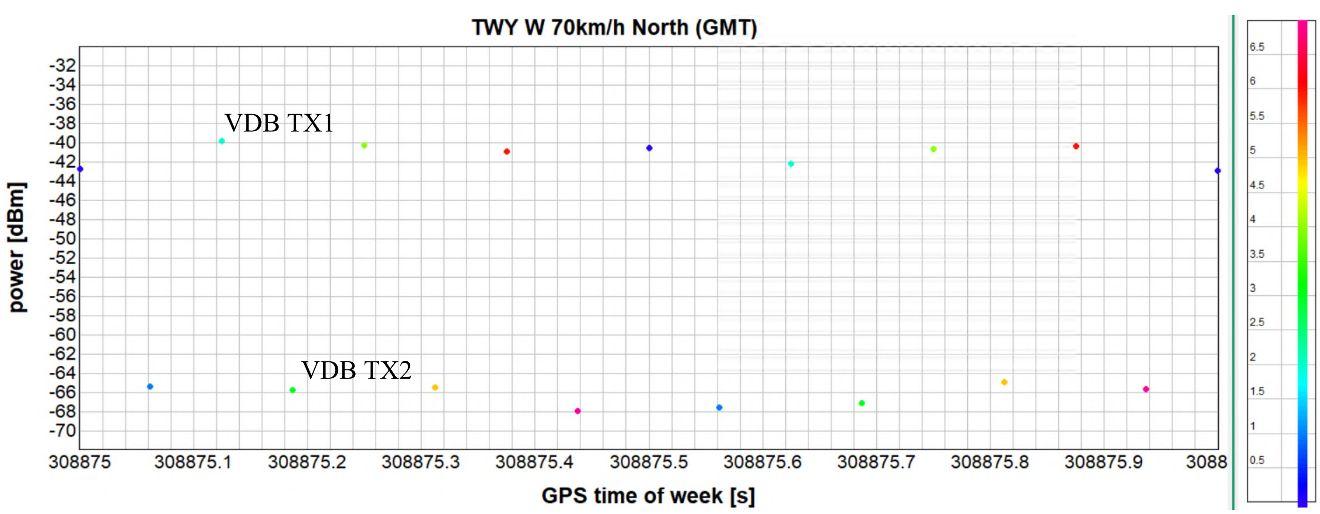


Figure 14. Results old VDB level measurement method driving on TWY W in northern direction with about 70 km/h.

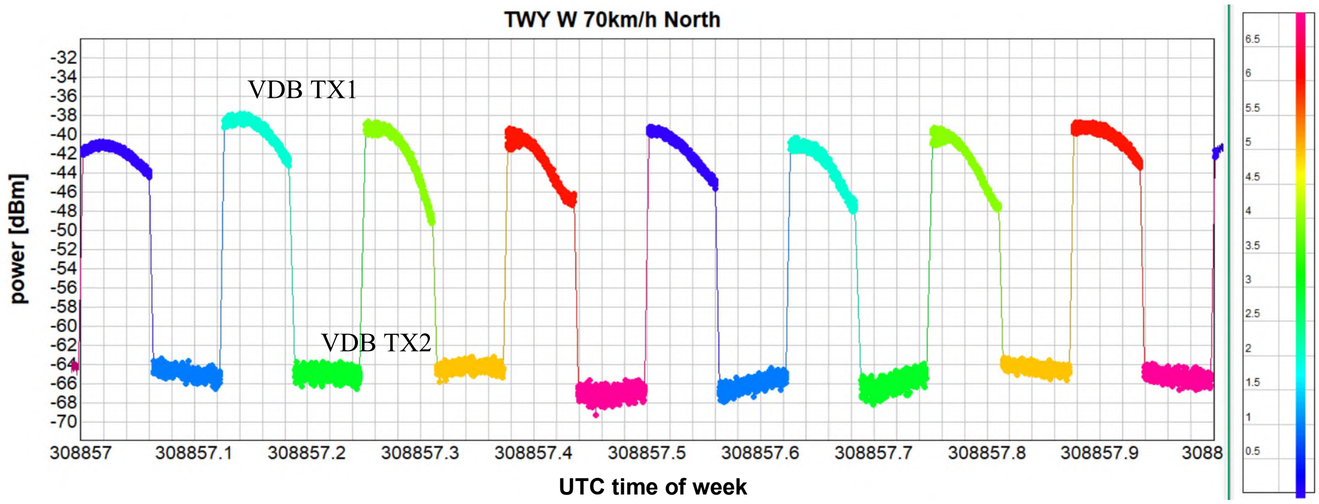


Figure 15. Results new VDB level measurement method driving on TWY W in northern direction with about 70 km/h.

The significant increase in information that the new method is providing (Figure 15) compared to the currently recommended method (Figure 14) is obvious. Power variations of up to 12 dB within one slot are only visible when using the new method. One can see a small differences in the recorded values at the beginning of each burst (<1 dB) between old and new method due to the missing calibration for the new method (see Figure 4).

The last Figure 16 shows level measurements recorded over a distance of 30 m in an area with elevated multipath this time recorded with a lower speed of up to 50 km/h. The distance is calculated to a fixed start point and uses the RTK position coordinates. This is expected to allow to record multipath footprints of runways in the next step.

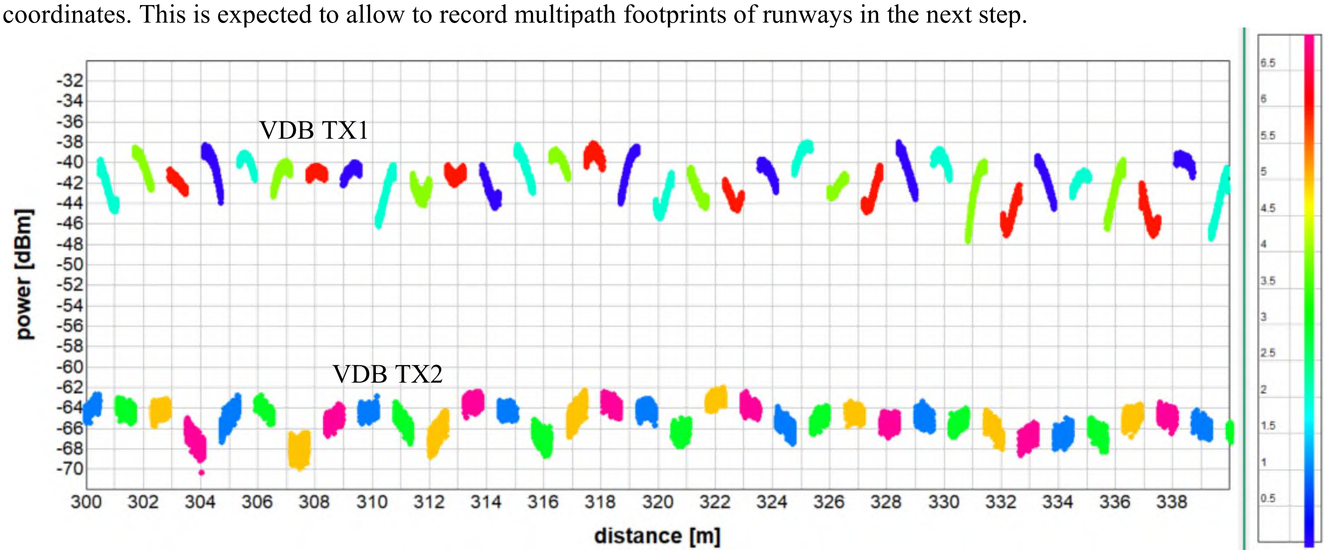


Figure 16. Results new VDB level measurement method driving on TWY W in northern direction with about 50 km/h.

One can clearly see the multipath impact and the noise levels of both measured VDB signals, the near-by VDB TX1 antenna in about 400 m distance and the VDB TX2 antenna in about 6 km distance. Both VDB signals are well within the defined limit (VDB power ≥ -72 dBm).

CONCLUSIONS

a. The new VDB level measurement method can provide up to 633 measurements per bust instead of one measurement value averaged over 1.5238 ms of the VDB training sequence (with fixed bit values).

b. The results of the level measurements for each symbol with 100% VDB power setting are less noisy than expected. For static measurements the typical variation is in the order of 1.0 dB. During nighttime, when the airport is closed the typical variations are even lower.

c. The difference in results of the old and the new measurement method are typically less than 1 dB and can be calibrated.

d. The first results of mobile ground measurements in environments with an elevated level of multipath show that VDB power can vary more than 12 dB within one bust. Close to the VDB antenna and in flight measurements the variations could be even higher.

e. These variations are expected to be caused by multipath and should be taken into account when performing VDB ground and flight measurements.

RECOMMENDATIONS

The following recommendations are made for the benefit of GBAS VDB ground (runway) and flight measurements especially at complex airports. The new VDB measurement method in the digital plane provides more information at the same time and without additional expenses.

It is recommended to be used for dynamic ground and flight measurements especially at airports with an increased level of VDB multipath or in areas with fast changing VDB signal power at the receiver input.

It has the potential to become the standard VDB measurement method in future. For the time being it should be added as alternative measurement method in the standards (SARPs, MOPS, Doc 8071 Vol. II).

FUTURE WORK

The restrictions during the COVID 19 pandemic caused a two-year delay of this work because lab testing, and airport measurements were not allowed for long time periods. Therefore, time is running out to work out and include all details of the new VDB measurement method in the upcoming updates of the standards.

To reduce the amount of data that needs to be recorded, some kind of averaging or filtering could be added. For this it could be interesting to take the characteristics of VDB airborne receivers into account and to come to results that are largely independent from vehicle speed.

Although an EVSF1000 is integrated in the new FIS of the FCS flight inspection aircraft, aircraft approval issues must be solved before flight testing of the new VDB measurement method can be performed.

However, work will continue to make suggestions for an implementation in the Rohde & Schwarz EVSG1000 series later this year. The new method should become available to interested users of the GBAS option of the beforementioned measurement device.

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