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A case study for potential implications on the reception of Galileo E6 by amateur radio interference on German highways considering various transmitter-receiver and signal combinations

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Modern GNSS offer various services over multiple frequency bands and allow the user receiver to determine its position with high precision and accuracy. Especially with regard to safety critical applications in land-based navigation, such as autonomous driving, precise, accurate and reliable GNSS poses as the key technology for absolute navigation as well as a welcome solution for independent and continuous on-board sensor calibration during operation. Highest quality positioning is enabled by obtaining an unobstructed GNSS signal, among other aspects, to perform ranging and decode navigation bits properly. Interference – whether intentional or not – upholds the potential to deny the user device exactly that.

Considering Galileo's own "High Accuracy Service", a PPP service to be broadcast in the near future on E6B by the MEO standard constellation itself, and one of its most prominent use cases, i.e. autonomous driving, we take a closer look at potential interference on this upcoming enhancement of the European GNSS. Since autonomous driving most probably will not be deployed everywhere at once and at the same time, we assume a gradual rollout of the technology starting on highways only (which is already happening to some extent). Therefore, the areas of impact in this investigation were chosen to be the highways in Germany (as displayed in figures 1 and 2). Assuming, when it comes to accurate absolute navigation, the vehicle navigation unit relies on the PPP correction data broadcast on E6B to a certain extent, flawless signal reception must be guaranteed on the autonomous driving enabled corridors. If we draw the comparison to aviation, any RF transmission within safety critical frequencies around an airport by third parties is strictly prohibited. Yet on the other hand, a GNSS receiver used in aviation must be robust to specific threats. This suggests that receiver hardening, or rather receiver signal processing and interference handling, must be taken into account. Additionally, the E6 band is already considerably populated, due to a very enthusiastic amateur radio community in this country. This gives us a potentially highly challenging environment for the Galileo E6B reception, as amateur radio services are not regulated very stringently with respect to transmission power and frequency within E6.

Now, for the core message of the study, we want to determine the possible level of coexistence between Galileo E6B and amateur radio transmissions. Amateur radio signals in this case serve as a concrete example for any narrow-band interference. To display this, we pinpoint areas within Germany, more precisely: areas around German highways, that are possibly affected severely by interference and vice versa. Our measure to derive such areas is the delta in signal to noise ratio $\Delta CN0 = CN0 - CN0_{eff}$ , $CN0$ being the SNR without the presence of interference, opposed to $CN0_{eff}$ being the SNR in presence of interference. The $CN0_{eff}$ depends on the characteristics of numerous variables, such as transmitter antenna, interference signal type, power and design of the desired signal, receiver signal processing, distance between receiver and transmitter, etc. Due to the sheer complexity of combination possibilities, we opt for two fixed representative signal types and three receiver categories. To restrict the perimeter of the experiment further, we only assume one transmitter at the same time.

The amateur radio signals used for the simulations are worst case considerations, as already applied in a German study [1]. For this paper, two types of signals are used: a) a continuous wave and frequency modulated signal, which transmits a voice signal (FM voice) and b) a frequency-shift keying signal (FSK) with a fixed sequence of typical data traffic. Both signals have a frequency closest possible to the Galileo center frequency, with the constraint to be still within the Region 1 of IARU frequency band plan [2]. Amateur TV signals are not considered, because previous studies already demonstrated, that there is no coexistence possible for wide band signals within the RNSS band [1] [3].

Similarly, we assume three different receiver categories, distinguished by a unique Q-factor, expressing their grade of vulnerability to the specific interference signal: a) a Galileo ICD receiver, b) a geodetic receiver and c) a mass market automotive grade receiver. The Galileo ICD receiver applies the entire defined signal bandwidth, as suggested by the official service description, with no further radio frequency filtering. The geodetic receiver is the same as was used for the German study [1]. The mass market grade receiver will be discussed in this paper, evaluating options to achieve a RF hardened receiver with additional emphasis on cost-effectiveness. The Q-factors suggested in this paper are obtained by measurements or theoretical considerations.

Since also the locations of both stations, respective the distances between receiver and transmitter play an important role, we conduct our experiment as following: In the beginning, we lay a narrowly meshed grid over Germany. We then place our interfering transmitter right on the very first grid point, compute the distance to the nearest highway intersection point, and determine the $CN0_{eff}$. Afterwards we store the $\Delta CN0$ value for the current grid point. The imaginary transmitter is then moved to the second grid point and the procedure is repeated. Upon complete iteration over the whole grid, what we get is the $\Delta CN0$ at the nearest highway intersection depending on the location of the transmitter (and the used signal/receiver combination), displayed at the transmitter position. In other words, we derive a map which shows, valid only for the respective signal/receiver setup, where it is safe and where it is not safe to operate a radio transmitter with respect to the potential interference caused on the nearest highway.

The study visually shows by heatmap plots such as figures 1 and 2, that for a receiver with a low Q-factor (similar to figure 1), which means using the full E6 bandwidth with no RFI protection, a coexistence between neither the low power nor the high-power signal is possible. For the geodetic receiver, only a narrow area around the highways would not allow a coexistence between both, due to its superior signal processing and filtering. This is of course the case for any receiver with a high Q-factor with respect to the scenario (similar to figure 2). It must be stressed though, that this study shows an absolute worst case with respect to the affected areas within our regions of interest. Since no topographic information was considered, and for the computation of the link budget respective the $CN0_{eff}$ only the pure 2D geometric distance was assumed, the visualizations show a far too pessimistic scenario compared the real circumstances, at least in certain areas.

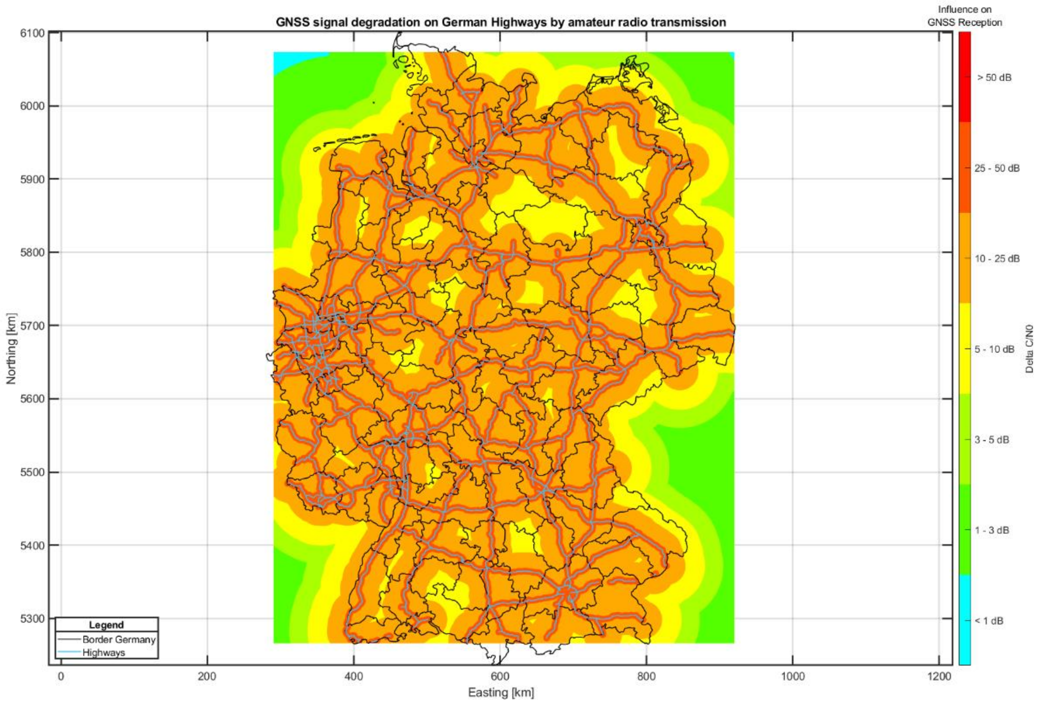


*Figure 1: Exemplary visualization scenario with low Q-Factor*

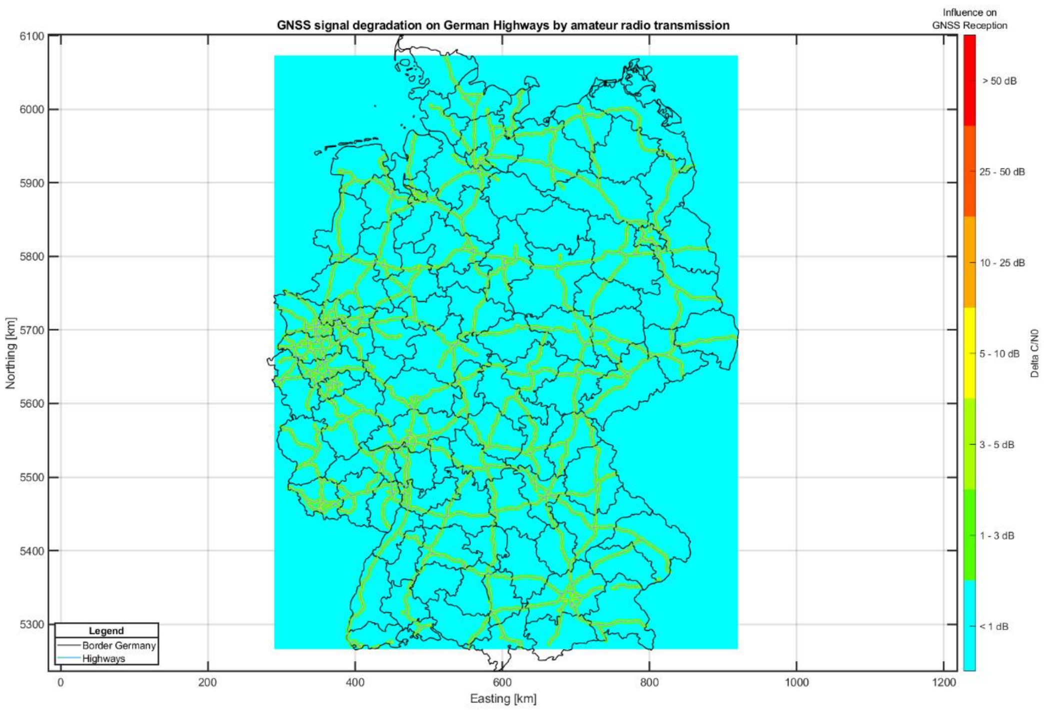


*Figure 2: Exemplary visualization scenario with high Q-Factor*

# References

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[3] EC, "Compatibility between Amateur Radio Services and Galileo in the 1260-1300 MHz, no. SE40(19)52," 2015. [Online]. Available: https://www.cept.org/Documents/se-40/56613/se40-19-52_compatibility-between-amateur-radio-services-and-galileo-in-the-1260-1.