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Technical Domain / Task Number 2 …………………………………

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VDE-SAT R-Mode Signal Design Considerations

# Summary

This paper introduces the ANGELOS (Augmenting GNSS to Prevent Loss of Service) project, which investigates the feasibility of a satellite-based component to VDES R-Mode. It presents some technical considerations that emerged during the initial stages of the project, related to the ranging signal definition and generation, and invites Committee members to comment on a number of questions summarised at the end of the document.

## Purpose of the document

To inform the Committee of on-going work related to VDES R-Mode development and solicit feedback.

## Related documents

IALA Guideline 1158: VDES R-Mode.

IALA Guideline 1139: The Technical Specification of VDES.

# Background

The General Lighthouse Authorities of the UK & Ireland (GLA) are working alongside GMV NSL to deliver the European Space Agency-funded ANGELOS project [1]. ANGELOS is a preliminary concept study investigating the feasibility of a satellite-based component to VDES R-Mode, designed to work together with the terrestrial R-Mode component currently being developed by the international maritime community.

Recent work of the project has focused on defining the ranging signal structure and estimating the achievable ranging performance. A number of questions have emerged in the course of the research that would benefit from discussion with the Committee members.

# Discussion

## Meta-signals

Noting that the VDE‐SAT spectrum includes lower and upper VDES bands separated from each other by 4.6 MHz [2], there is potential to provide ranging signals in both. This approach is novel and brings a number of open questions; however, the potential for such ‘meta‐signals’ has been demonstrated for GNSS [3] and the technique could potentially be applied to VDE‐SAT as well.

Estimation theory suggests that there are substantial performance improvements to be gained from combining the lower and upper VDE‐SAT bands for the purpose of ranging. The Cramér–Rao bound for pseudorange estimation shows that the variance of the ranging error is inversely proportional to the mean square bandwidth of the ranging signal; furthermore, the mean square bandwidth increases when the signal's energy is concentrated near the edges of the frequency band of interest. As such, it is anticipated that considerable ranging performance improvements can be achieved when two (relatively narrow‐band) ranging signals in the lower and upper VDE‑SAT bands are combined to form a single wide‐band meta‐signal. The wider signal bandwidth is also expected to improve multipath resolvability, potentially reducing the ranging error due to multipath propagation.

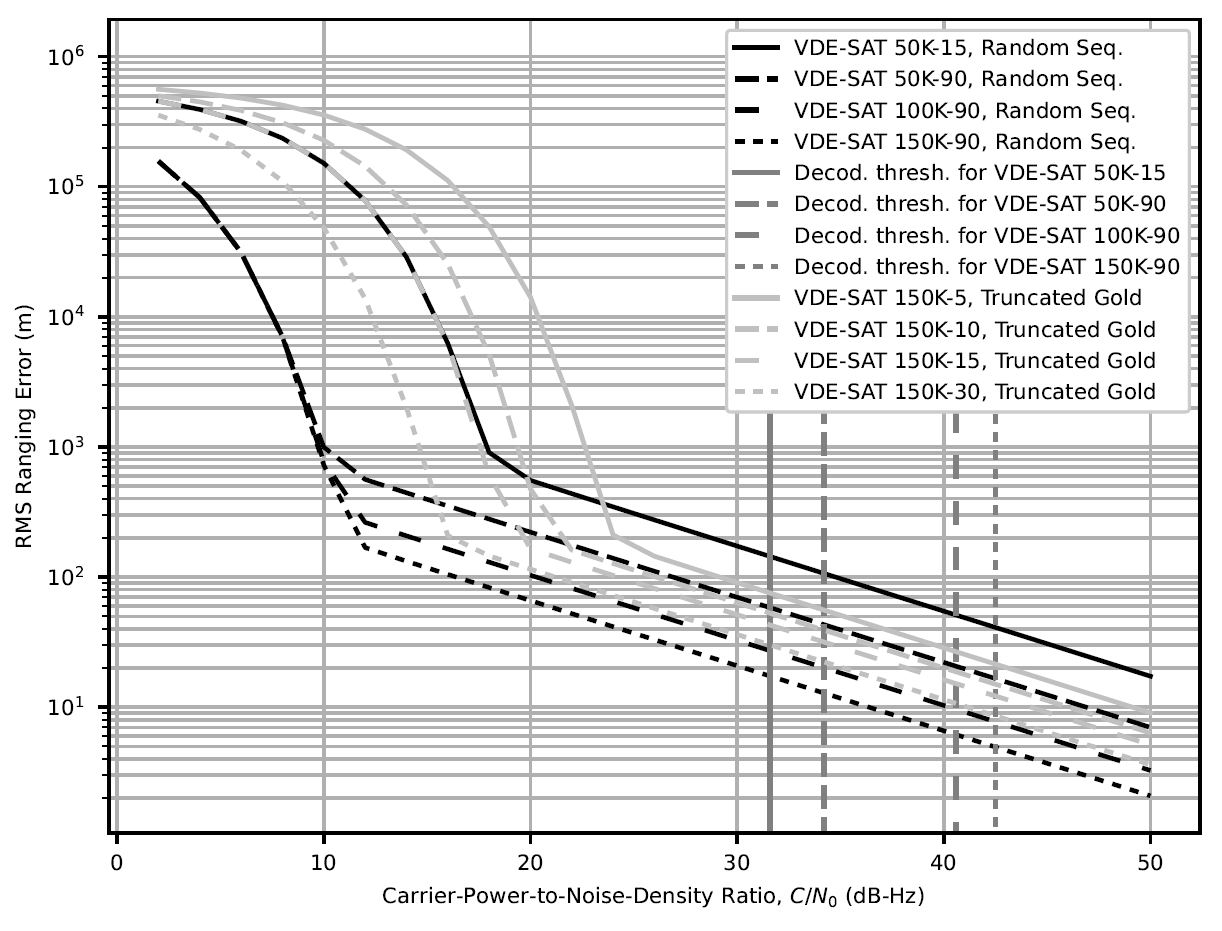
Such an approach brings its own challenges, primarily related to whether it is possible to provide simultaneous, synchronised, VDE‐SAT transmissions on multiple frequency channels. It is assumed that there may be limitations or concerns due to power amplifier non‐linearity, potential intermodulation issues and the need to design for a higher total RF power (if the power per channel is to be preserved). However, it should be noted that the transmissions in the lower and upper bands may not need to be simultaneous; it seems sufficient to require that the transmission waveforms be accurately synchronised with each other, so that they can be treated by the receiver as a single, known waveform (although this remains to be verified). Similarly, there are open questions related to the receiver design; however, modern VDES receivers are likely to be capable of digitising the entire maritime VHF band at once and therefore the receiving side is expected to present less of a challenge.

The current work focuses on VDE-SAT R-Mode; however, it should be noted that the meta-signals approach could equally be used to enhance the ranging accuracy of VDE-TER R-Mode.

## Ranging Using Existing VDE-SAT Waveforms and Protocols

The ANGELOS project has so far considered two potential approaches to satellite-based VDES ranging: (i) using the existing VDE‑SAT downlink waveforms modulated by random (user‐generated) data; and (ii) using custom‐designed VDE‐SAT R‐Mode waveforms modulated with a known symbol sequence, optimised for ranging. The first approach requires no or minimal modifications to the VDES specification and would have little impact on the VDE‐SAT datalink loading but necessitates a more complex receiver architecture and cannot be used below the *C*/*N*0 thresholds required for data demodulation. The second approach would enable (some degree of) operation at considerably lower *C*/*N*0 than the first method and would allow ranging performance to be traded for datalink loading (by controlling the duration and frequency of the ranging signal transmissions). However, it would likely require significant changes to be made to the VDES specification.

For illustration, Figure 1 shows a comparison of the achievable ranging performance for the existing (shown in black) and custom (light grey) waveforms. The traces labelled with ‘50K’, ‘100K’ and ‘150K’ represent VDE-SAT downlink waveforms designed for a 50, 100 and 150 kHz bandwidth channels, respectively. The second number in the label (5, 10, 15, 30, 90) indicates the transmission duration in VDES time slots. For more details see reference [4].



1. Comparison of the achievable ranging performance for the existing (black) and custom (light grey) waveforms; data decoding thresholds for the existing waveforms are indicated by vertical grey lines.

A new revision of the ITU‐R Recommendation on VDES [5] is expected to be approved in November 2021. While this (de facto) standard is not yet finalised, it is anticipated that it is too late to introduce significant changes at this stage. Therefore, prior to any update to this standard, it may be desirable to explore a third approach to VDE‐SAT ranging — one that would not require any changes to the VDES specification but would allow dedicated (known) ranging sequences to be used. It would also seem reasonable in the short term to focus on a scenario where a small constellation of VDE‐SAT satellites (offering, perhaps, continuous but not overlapping satellite coverage) is used to support VDE‐TER R‐Mode in coastal areas, as the likelihood of a large VDE‐SAT constellation being deployed in the next few years is considered low. One possible approach to implementing a ranging signal consistent with the above constraints and assumptions is outlined below.

The proposed approach would transmit a known symbol sequence using the ‘Satellite to Ship Short Data without Acknowledgement’ protocol and Link ID 32, either in a single 50‐kHz bandwidth channel, or in both the lower and upper frequency bands (using the meta‐signal approach discussed previously). Recall that the Satellite to Ship Short Data without Acknowledgement protocol is only allowed to be used on the Announcement Signalling Channel (ASC), which currently only allows Link ID 32 to be used. It is assumed that the default satellite Bulletin Board would be used.

The ranging performance when the single‐channel approach is used would be expected to be close to the performance bounds for the VDE‐SAT 50K‐15 transmission configuration (i.e., the worst of all options considered in the ANGELOS analyses to this point; see Figure 1). Considerable performance improvements can be expected if the meta‐signal approach is used; however, quantifying these would require significant further work to be carried out. The transmission repetition interval would be longer than the 15‑second position update rate required for R‑Mode [6]; however, more frequent updates may be made possible by using a custom Bulletin Board. The proposed approach would present only a mild channel load of 2% (assuming only one R‐Mode satellite in view at any given time).

An outstanding question is how the receiver would distinguish between a ranging signal transmission and an ordinary data transmission on the ASC (in VDE‐TER, a dedicated logical channel and Link IDs were introduced for this purpose). Perhaps the (known) ranging sequence could be used as a signature identifying the ranging signal, noting that this would require the receiver to search for the signature in each ASC time slot. Or the time slots used for ranging could be identified within the R-Mode navigation message.

1. VDE-SAT ranging signal elements and constraints for an approach using existing waveforms in conjunction with a fixed (known) symbol sequence.

|  |  |  |
| --- | --- | --- |
|  | Rec. ITU-R M.2092 Reference | Notes |
| Protocol | Satellite to Ship Short Data w/o ACK | To minimise transmission overheads.  Currently allowed only on the ASC. |
| Message Type | #16 (Short Message) | It is unclear whether #16 can be used for broadcast or only for addressed communication. |
| Logical Channel | ASC | Only Link ID 32 is currently allowed on the VDE-SAT ASC. |
| Link ID | 32 (SAT-MCS-0.50-2) | Modulation: BPSK/CDMA  CDMA Chip rate: 33.6 kcps  Spreading factor: 8  Signal bandwidth: 42 kHz  Transmission duration: 15 time slots  Repeated syncword: yes  Pilot symbols: yes  FEC encoder input bits: 312  Bit-scrambler: yes  Channel interleaver: yes |
| Bulletin Board | Default VDE-SAT bulletin board | The default VDE-SAT bulletin board allocates 90 slots for ASC transmission approximately every 20 seconds. |

1. Key characteristics of a VDE-SAT ranging signal consistent with the assumptions and constraints listed in Table 1.

|  |  |
| --- | --- |
| Data Symbols | Known symbol sequence, e.g. pseudorandom or an optimised sequence determined through simulations or analysis of the error correcting and synchronisation algorithms applied in VDE‑SAT. |
| Signal Bandwidth | 1x 42 kHz; or  2x 42 kHz, 4.6 MHz separation (meta-signal approach) |
| Transmission Duration | 15 VDES time slots (0.4 second);  Constrained by the existing VDE-SAT waveforms and rules |
| Repetition Interval | Approximately 20 seconds;  Longer than the 15 second position update interval required for coastal navigation by IALA R‑129 |
| Channel Loading | 2% |

Other approaches, or variations of the above approach, may be possible which could provide improved performance. For example, multiple VDES Link ID 32 transmissions could be concatenated to increase the signal energy (this may require allocating additional slots to the ASC in a custom Bulletin Board). Use of the ‘Satellite Originated Broadcast’ protocol could also be considered, which would enable the use of the wider‐bandwidth, longer‐duration VDE‐SAT waveforms; however, this protocol requires resource allocations to be made before any ‘useful’ data can be transmitted, and may therefore introduce substantial additional overhead to the datalink. If a 90‐slot waveform is used for ranging and the datalink loading becomes excessive, it may be possible to reduce the length of the known data sequence so that not all the data capacity within a transmission is used (multiple messages could be packed in a single transmission packet, one message carrying the shortened ranging sequence and the rest carrying user‐generated data); however, the effects of the VDE‐SAT channel interleaver, which would interleave the known symbols with the user‐generated (unknown) ones, would have to be taken into account.

## Summary of Questions

1. Is it possible for a state-of-the-art VDES transmitter to provide synchronised (not necessarily simultaneous) VDE transmissions in the lower and upper VDES bands? ‘Synchronised’ in this context means having defined time offsets with respect to a common time base as well as defined initial carrier phase and carrier frequency offsets with respect to a common carrier signal.
2. Is it possible for a state-of-the-art VDES transmitter to provide simultaneous, synchronised VDE transmissions in the lower and upper VDES bands?
3. Is it possible for a state-of-the-art VDES receiver to simultaneously receive VDE transmissions in the lower and upper VDES bands? Note that in order to support meta-signal processing the time offsets of the captured signals in both frequency bands should be defined with respect to a common time base and the initial carrier phase and carrier frequency offsets should be defined with respect to a common carrier signal.
4. Do you consider the approach to VDE-SAT ranging signal transmission described in Section 3.2 feasible?
5. Can VDE-SAT Message #16 (Short Message) be used for broadcast or only addressed communication?
6. How can a VDES receiver identify a VDE-SAT ranging signal transmission (as opposed to an ordinary data transmission)?
7. Is it possible (within the existing constraints of the VDE-SAT specification) to use a wider-bandwidth (100 kHz or 150 kHz) waveform for repetitive, short message transmissions?

# References

[1] GMV NSL, ‘ANGELOS Press Release’, *GMV NSL website*, Nov. 2020. http://gmvnsl.com/pressrelease/ANGELOS\_Press\_Release\_v1.0\_Final.pdf

[2] ITU, ‘World Radiocommunication Conference 2019 (WRC-19) - Final Acts’, 2020.

[3] M. Paonni, J. T. Curran, M. Bavaro, and J. Fortuny-Guasch, ‘GNSS Meta Signals: Coherently Composite Processing of Multiple GNSS Signals’, in *Proceedings of the 27th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2014)*, Sep. 2014, pp. 2592–2601. Accessed: Jun. 07, 2021. [Online]. Available: http://www.ion.org/publications/abstract.cfm?jp=p&articleID=12322

[4] J. Šafář, A. Grant, and M. Bransby, ‘Performance Bounds for VDE-SAT R-Mode’, *Int J Satell Commun Network*, To be published, doi: https://doi.org/10.1002/sat.1429.

[5] ITU, ‘Technical Characteristics for a VHF Data Exchange System in the VHF Maritime Mobile Band’, Geneva, Switzerland, Recommendation ITU-R M.2092-0, Oct. 2015.

[6] IALA, ‘Stakeholder Requirements for R-Mode, Edition 0.2, draft’, St-Germain-en-Laye, France, Guideline, Sep. 2019.

# Action requested of the Committee

The Committee is requested to:

1. Note the contents of this paper; and
2. Provide the authors with answers to / comments on the questions raised herein.

1. Input document number, to be assigned by the Committee Secretary [↑](#footnote-ref-1)
2. Leave open if uncertain [↑](#footnote-ref-2)