IALA GUIDELINE

G1193
VDES SIGNAL MEASUREMENT

Edition 1.0

June 2025

urn:mrn:iala:pub:g1193:ed1.0

10, rue des Gaudines - 78100 Saint Germain en Laye, France
Tel. +33 (0)1 34 51 70 01 - contact@iala.int
www.iala.int
International Organization for Marine Aids to Navigation

DOCUMENT REVISION

Revisions to this document are to be noted in the table prior to the issue of a revised document.

Date	Details	Approval
June 2025	First edition	Council 02

Contents

1. SCOPE

This structure provides a detailed framework for preparing and documenting radio signal measurements for a VDES system, using data from real-world campaigns and simulations as a basis for best practices. Each section focuses on crucial elements such as data collection, analysis, and reporting, ensuring that the guideline is comprehensive and aligns with international standards. An integral part of this framework is Annex A, describing best practice and recommendations for VDES measurements and sea trials.

2. INTRODUCTION

Purpose: Define the objectives, such as evaluating the performance of VDES communication (e.g., ship-to-shore, ship-to-ship) in real maritime environments.

Scope: Specify the range of measurements covered (e.g., Bit Error Rate (BER), Signal-to-Noise Ratio (SNR), range, data throughput).

VDES Overview: Briefly introduce the VDES system, its importance for maritime communications, and current research efforts, such as the involved projects.

3. PRE-MEASUREMENT PREPARATIONS

3.1. EQUIPMENT SELECTION

- VDES Transmitter and Receiver: Outline the key specifications of the equipment:
  - Transmitter:
    - Configuration: Include parameters such as modulation types (e.g., π/4-QPSK, 16-QAM), power levels (e.g., 6.3 W for π/4-QPSK, 4 W for 16-QAM), and frequency bands used (e.g., 160 MHz for VDES).
    - Hardware:
      - Amplifier type and data
      - Antennas
      - Cables
      - *tbc*
  - Receiver:
    - Configuration: Discuss receiver sensitivity (e.g., -110 dBm for π/4-QPSK, -96 dBm for 16-QAM) and antenna characteristics. Address the placement of antennas (e.g., different heights on vessels) and cable types and length (e.g., RG214).
    - Hardware:
      - Amplifier type and data
      - SDR
      - Antennas
      - Cables (length, attenuation at measured frequency in [dB] per m and type)

3.2. MEASUREMENT LOCATIONS AND PLANNING

- Site Selection: Describe the setup of shore stations and vessels used for measurement. Add pictures covering the whole site and individual parts.
    - Example: reference example setups like the EfficienSea2 campaign, where shore stations were placed at Gedser and ferries Scandlines M/F Berlin and M/F Copenhagen were equipped with receivers.
- Route Planning: Detail the planned routes for vessel movement and their distances from shore stations.
- Environmental Considerations: Consider the impact of sea conditions, multipath propagation, and weather effects on signal transmission.

4. MEASUREMENT PROCEDURES

4.1. SETUP AND CONFIGURATION

- Transmitter Configuration: Define settings such as frequency, modulation type (e.g., π/4-QPSK, 16-QAM), and bandwidth (e.g., 25 kHz, 50 kHz, 100 kHz).
- Receiver Configuration: Detail how to configure the receivers, ensuring time synchronization using GPS systems, and setting up data acquisition.

4.2. SIGNAL ACQUISITION

- Data Collection: Specify how data will be logged and stored, including raw I/Q data, GPS data, and attenuation markers (e.g., from ATT bits indicating attenuation due to proximity to transmitters).
- Measurement Sequence: Describe the sequence of data transmission across different bandwidths and modulation schemes.
    - Example: such as the predefined sequences like the 20-second transmission structure used in EfficienSea2.

4.3. MEASUREMENT OF KEY PARAMETERS

- Bit Error Rate (BER): Outline the process for measuring BER under different conditions, depending on modulation schemes (MCS-1, MCS-3, MCS-5) and bandwidth (and refer to Link-IDs).
- Packet Error Rate (PER): Outline the process for measuring PER under different conditions, depending on different modulation schemes and bandwidths (and refer to Link-IDs).
- Signal-to-Noise Ratio (SNR): Explain how to calculate SNR using the formulae provided. Ensure accurate measurement through the use of noise reduction techniques.
- Range and Attenuation: Specify how to measure signal attenuation and calculate the theoretical range of transmission based on different modulation schemes and environmental conditions.

4.4. SPECIAL CONSIDERATIONS

- Multipath Effects: Discuss methods for mitigating multipath interference, especially in areas near shore where reflections are common.

- Dynamic Adjustments: Include procedures for adapting modulation schemes and transmission power in response to real-time conditions using feedback mechanisms like MER (Modulation Error Ratio).

5. ANALYSIS OF RESULTS

5.1. KEY METRICS

- Signal Strength and Propagation Analysis:
  - Use models like ITU-R P.1546-5 to estimate signal strength and coverage range based on the height of antennas, transmitter power, and distance.
  - Compare measured signal strength to theoretical predictions for different modulation schemes (e.g., π/4-QPSK and 16-QAM) under various bandwidths.
- Bit Error Rate (BER):
  - Calculate BER as a function of SNR for different modulation and coding schemes (MCS). For instance, BER results for link-ID 11 or 17 are provided in the documents, illustrating performance at various bandwidths.
  - Analyze the relationship between signal quality (Es/N0) and BER using tools such as post-processing software. Present the results graphically for clarity.
- Signal-to-Noise Ratio (SNR):
  - SNR calculations help in assessing transmission quality. The method for calculating SNR involves comparing signal power to noise power across the received bandwidth.
  - Use noise floors and attenuation indicators from the recorded data to ensure accuracy in SNR measurements.

5.2. RANGE AND COVERAGE

- Range Calculations:
  - Based on signal attenuation and environmental factors, calculate the maximum useful range for each modulation scheme (e.g., up to 62.9 km for π/4-QPSK and 33.3 km for 16-QAM).
  - Use the EfficienSea2 test route as an example, demonstrating how different antenna heights and propagation conditions (significant wave height, weather conditions, ship details, other vessels nearby) affect the range of the VDES system.
- Coverage Maps:
  - Create coverage maps showing the predicted and measured ranges for different configurations (antenna heights, power levels, etc.). These maps can provide visual representations of signal strength over different distances and locations.

5.3. MULTIPATH EFFECTS AND MITIGATION

- Multipath Analysis:
  - Evaluate the impact of multipath propagation, especially near harbours or landmasses, where reflections from water or nearby objects may degrade the signal.

- Include results from simulations that model maritime radio channels, such as AWGN, Rayleigh fading, or two-path maritime channels, to estimate how multipath affects signal quality.

- Mitigation Techniques:
  - Implement methods like Zero-Forcing Equalizers (ZF) to mitigate the effects of multipath and fading. Analyze the effectiveness of these techniques using real-world measurement data.

6. DOCUMENTATION AND REPORTING

6.1. DATA DOCUMENTATION

- Raw Data Logging:
  - Ensure that all relevant data points are recorded and stored during the measurement process. This includes raw signal data such as I/Q samples, GPS coordinates, and any attenuation indicators. The files should be saved in a standardized format, e.g. data is logged in a 64-bit I/Q format with time-stamped records.
  - Each measurement file should, e.g. contain one minute of data, ensuring consistency across the dataset and making it easier to handle large data volumes during post-processing.
- Measurement Parameters:
  - Ensure that key parameters are systematically logged alongside the signal data, including:
    - Transmitter power levels.
    - Modulation schemes used (e.g., π/4-QPSK, 16-QAM).
    - Antenna height and location details.
    - Receiver sensitivity settings.
    - Environmental conditions (sea state, weather, vessel speed).

6.2. DATA ANALYSIS REPORTING

- Key Metrics Reporting:
  - Present the core performance metrics for each test in well-structured tables and graphs. These should include:
    - SNR: Calculated across different segments of the route or test areas, with reference to the method used to derive SNR from raw data.
    - Interference: Consider local interference sources, such as voice or AIS transmitters. Silence them or document the time of these sources during the measurement periods.
    - Bit Error Rate (BER): Provide detailed tables and charts showing BER vs. SNR or PER vs. SNR for various modulation schemes and bandwidth settings (e.g., 25 kHz, 50 kHz, 100 kHz).
    - Transmission Range: Report the maximum and minimum transmission ranges observed, comparing measured values against theoretical estimates (e.g., based on ITU-R P.1546-5).
    - Multipath Effects: Present the impact of multipath interference and how the system mitigated these effects using methods such as Zero-Forcing Equalization (ZF).
- Performance Comparisons:

- Compare the measured data to in-lab measurements and simulation results and theoretical models. This will help highlight any discrepancies and potential areas for improvement in the measurement setup or system performance.
- Use real-world data from field tests as benchmarks to evaluate the performance of the system under various environmental conditions.

6.3. REPORT STRUCTURE

- Executive Summary: Summarise key insights, such as the overall performance of the VDES system, key findings related to transmission range, signal strength, and any unexpected challenges (e.g., interference or multipath effects).
- Technical Report Sections:
  - Measurement Setup: Detail the equipment and configurations used, including antenna heights, transmission power, and modulation schemes.
  - Environmental Conditions: Note any significant environmental factors that could have impacted the measurements, such as sea conditions, weather, and geographic obstacles.
  - Results and Analysis: Present all core findings, such as BER, SNR, and achievable range, with appropriate visual representations (e.g., graphs, maps, and charts).
  - Conclusions and Recommendations: Highlight the strengths and weaknesses of the system based on the measurement results and suggest areas for future improvement or further research.
- Appendices: Include supplementary data, such as raw data files, detailed equipment specifications, and additional graphs or charts that support the findings presented in the report.

7. CONCLUSION

- Summary of Findings: Recap the core outcomes of the measurement campaign, emphasizing how the VDES system performed in terms of range, data transmission quality, and its resilience to environmental challenges (e.g., multipath effects or fading).
- Assessment of System Performance: Discuss the system’s compliance with expected performance levels based on VDES specifications, including signal strength, bit error rates, and overall data integrity.
- Recommendations for Improvement: Suggest potential areas for enhancing measurement accuracy, such as more advanced signal processing techniques, improved calibration procedures, or enhanced equipment setup (e.g., optimising antenna heights or receiver sensitivity).

8. APPENDICES

8.1. MEASUREMENT EQUIPMENT SPECIFICATIONS

- Include detailed technical specifications for the VDES transmitters, receivers, antennas, and other relevant equipment used during the measurement campaign.

8.2. MEASUREMENT LOCATIONS AND ROUTES

- Provide detailed maps and diagrams showing the locations of shore stations, vessels, and the routes followed during the measurements. Include GPS data where applicable.

8.3. RAW DATA AND CALCULATION EXAMPLES

- Include raw data samples, such as I/Q data, GPS coordinates, and attenuation logs, along with examples of how calculations (e.g., SNR, BER) were performed.

8.4. CHECKLIST

The following checklist ensures that every step of the process is properly executed and documented, from the initial setup of equipment to the final reporting of results. It can be used as a reference to make sure nothing is missed during the VDES radio signal measurement process.

8.4.1. CHECKLIST FOR VDES RADIO SIGNAL MEASUREMENT PREPARATION AND DOCUMENTATION

8.4.1.1. Pre-Measurement Preparations

- Define the objectives of the measurement campaign (e.g., range assessment, BER or PER analysis).
- Identify the scope (e.g., ship-to-shore, ship-to-ship, or shore-to-shore communication).
- Determine the equipment to be used:
  - VDES transmitter (confirm power levels, modulation schemes, bandwidths).
  - VDES receiver (check sensitivity levels for different modulation schemes).
  - Antennas (verify gain, type, and height on vessels and shore).
  - GPS system for precise time synchronization.
  - Measurement tools (e.g., signal analysers, spectrum analysers).
- Calibrate all equipment before use.
- Plan the measurement route:
  - Ensure vessel routes and distances are predefined.
  - Consider environmental factors (sea state, weather conditions).
  - Verify shore station and vessel antenna configurations (different heights, positions).

8.4.1.2. Signal Acquisition Setup

- Configure transmitter settings:
  - Set correct power levels for modulation schemes (e.g., π/4-QPSK, 16-QAM).
  - Choose bandwidth (25 kHz, 50 kHz, 100 kHz).
- Set up receivers on vessels and shore:
  - Verify receiver sensitivity settings.
  - Ensure proper antenna placement on vessels and shore (height, clearance).
- Set GPS synchronization:
  - Verify that all measurement tools are synced with GPS for timestamping.
- Log technical parameters:
  - Record power levels, bandwidths, modulation schemes, and antenna heights.

8.4.1.3. Measurement Execution

- Conduct initial signal testing:
  - Ensure communication between vessels and shore stations.

    - Verify that signal strength, BER, and SNR are within expected ranges.
- Start data acquisition:
    - Log raw I/Q data and GPS coordinates.
    - Collect data for a minimum of one minute per file segment.
    - Monitor for noise or interference (use SNR and attenuation indicators).
- Monitor transmission parameters:
    - Verify that data is being transmitted correctly in different bandwidths and modulation schemes.
    - Ensure noise and attenuation are being tracked.

8.4.1.4. Post-Measurement Data Processing

- Process raw data:
    - Use processing tools to convert raw I/Q data into usable metrics (e.g., SNR, BER).
    - Calculate signal-to-noise ratio (SNR) and bit error rate (BER) using standardized methods.
    - Generate transmission range estimates using models (e.g., ITU-R P.1546-5).
- Analyse the impact of multipath:
    - Identify potential multipath interference using multipath-resistant algorithms.
    - Apply filtering and equalisation (e.g., Zero-Forcing Equaliser) to reduce errors.
- Compare results:
    - Match measured data against simulation results and theoretical models.
    - Create charts showing BER vs. SNR and signal strength vs. range.

8.4.1.5. Documentation and Reporting

- Document all raw data:
    - Ensure data is stored in standardized formats (e.g., 64-bit I/Q data).
    - Attach metadata (e.g., power settings, modulation schemes, GPS coordinates).
- Prepare performance reports:
    - Include tables and graphs detailing SNR, BER, and range.
    - Highlight key findings related to system performance and potential issues (e.g., noise, interference).
- Include visual aids:
    - Provide range maps showing maximum and minimum useful ranges.
    - Generate BER vs. SNR graphs for each modulation and bandwidth setting.
- Write a comprehensive report:
    - Executive summary of key findings.
    - Detailed descriptions of the measurement setup, conditions, and results.
    - Comparisons with theoretical models and simulation data.

8.4.1.6. Final Review and Submission

- Review the data for completeness:
    - Ensure all raw data and processed results are included.
    - Cross-check the report for consistency and accuracy.
- Submit the report with all supporting data (raw I/Q files, processed data, metadata, charts).

9. REFERENCES

- Include all relevant sources and technical documents referenced during the creation of the guideline, such as the EfficienSea2 project reports, USCG VDES performance assessments, and ITU recommendations.

ANNEX A VDES MEASUREMENTS AND SEA TRIALS –

BEST PRACTICES AND RECOMMENDATIONS FOR VDE-TER TEST SCENARIOS

The following description is intended to provide some advice and recommendations for the purpose of the VDES measurement campaigns and sea trials, their design, conducting and reporting. This appendix content is based on the best practice, RF engineering knowledge and experience gathered during numerous measurement campaigns and sea trials, including those directly dedicated and covering assessment of the VDES system during its main phase of standardisation in IALA and ITU. It is also based on internationally accepted standards as well as scientific methods of system performance evaluation.

The appendix is divided into four sections, each covering a separate aspect of recommendations for VDES measurement campaigns and their execution:

1. Campaign design and preparations – measurements methodology and theoretical analysis.
2. Equipment parameters and configuration.
3. Environmental impact.
4. General recommendations and conclusions.

1. CAMPAIGN DESIGN AND PREPARATIONS – MEASUREMENTS METHODOLOGY AND THEORETICAL ANALYSIS

Before conducting the measurement campaign itself and even before designing a dedicated methodology, one must analyse the theoretical conditions regarding future measurements and tests.

The minimum would be to calculate the link budget of the VDES radio link and to conduct propagation attenuation calculations.

For the link budget, the following aspects should be considered:

- EIRP power of the VDES base station and terminal.
- Sensitivity of ship and shore receivers.
- Amplifiers used and their gains.
- Antennas gain.
- RF cables lengths and types.

The outcome of the radio link calculations should provide at least the maximum acceptable propagation attenuation for each analysed transmission case, for each power value and Link ID.

The next step is to conduct preliminary radio planning – at least coverage analysis is needed. For coverage analysis, one needs to additionally take into account:

- Shore stations' exact geographical coordinates.
- Shore stations and ship terminals' antenna heights above mean sea level, as well as heights above mean terrain height if the shore station is not directly adjacent to the sea.
- Antennas directivity.
- Applicable propagation model (e.g. one of the following ITU-R P.1546, ITU-R P.1812 or ITU-R P.2001),
- Appropriate time percentile for propagation attenuation analysis:
  - 50% recommended for useful range calculations, and,
  - 10% or even 1% for interference range calculations.

Coverage analysis should be used to support the selection of ship routes and device configurations. The latter aspect is discussed in the next section of this appendix.

Route selection recommendations:

- Routes with different attenuation values expected:

  - Both low and high attenuations were represented during measurements.
  - Routes with attenuations adequate for different devices, antenna heights and link IDs selected for sea trials – achievable both high and low signal values for the particular configuration.
- Different or dedicated (if specific conditions are in the scope of sea trials) propagation conditions expected (see also the section concerning the environment):
  - Segments of the route preassigned to particular conditions (e.g. Segment 1: LOS and open sea with light-multipath conditions, Segment 2: Heavy-multipath port area, Segment 3: over-the-horizon NLOS).
  - Dynamic, static or both types of tests – static location detailed description and dynamic characteristic (e.g. speed of the vessel) provided.
  - Hydro-meteorological conditions – available weather forecasts and measurements are assessed before initiating sea trials.
- Statistical representativeness of the data collected samples:
  - Measured data confidence intervals and measurement error analysis are both important to calculate, especially in multipath and high-noise conditions. The time length (i.e. averaging time and number of single measurements) of the measurement needs to be carefully chosen.
  - Speed of the vessel should be considered – there is a limited time responsiveness of the receivers.
  - Measurements for the same routes, weather conditions and locations need to be repeated to achieve the desired confidence.

2. EQUIPMENT PARAMETERS AND CONFIGURATION

Equipment parameters are crucial for a proper design end execution of measurements, that is a fact beyond any dispute. There are, however, some characteristics and values which are considerably more important than others. Given below list describes notably the most important ones as well as some more tricky to be set and defined correctly:

- **Transmitter output power.** This parameter is extremely crucial, and both its unambiguous understanding and proper setting might decide the final correctness of the trials. It is vital to understand that most VDES devices use amplifiers optimized for AIS transmissions (i.e. optimized for the constant envelope modulation with up to 3dB of RF PAPR – sample output power: 12.5W RMS and 25W peak) but not entirely optimized for e.g. 16QAM modulation. The fact must result in the amplifier back-off of at least 6-7 dB compared to GMSK transmissions, resulting in average transmitted power being reduced by that value. Obviously, this might not be a necessary and ultimate limitation. For instance, one might use a different amplifier, with much better PAPR tolerance and allowing average transmitter power on an AIS-like levels.
  It is therefore important that both peak and average power values need to be considered and described for the sea trials preparation purposes. The fact that lower average power affects the range of the radiocommunication system cannot be neglected and this is even more vital when considering VDES technical specification. Detailed analysis of the standard reveals that there are different average power levels defined for different Link IDs. Conducting sea trials using devices built according to the standard must result in different power levels for different Link IDs used during measurements. Obviously that fact does not just mean that different VDE-TER link IDs use different power levels, but that there are different average power requirements for VDE, ASM and AIS. Thus, in order to compare ranges achieved by different physical links, one must take into account their respective link budgets, most notably the average power.
- **Receiver sensitivity.** VDES receiver is a quite complex device which may exploit different modulations and coding schemes, not just within the VDE but, what is even more important, between different components, i.e.: VDE, ASM and AIS. It needs to be considered that the sensitivity difference between AIS/ASM and VDE-TER 16QAM 100kHz is about 10 dB! This is a huge difference and unequivocally disadvantageous to the VDE-TER. A direct comparison of AIS or ASM with 16QAM VDE-TER in 100 kHz

would then be entirely unfair and should not be made without at least considering the much higher throughput in case of that VDE-TER configuration. Particularly sensitivity values for different links can obviously be checked in both systems' standards and technical documentation of specific devices.

- Other important technical parameters of the equipment to be considered:
  - Noise figure of both the LNA and the whole receiver system – the standard defines the minimum sensitivities, however LNAs used within VDES terminals may provide a better performance in this regard. Additionally, RF system design may introduce some NF degradations that needs to be taken into account.
  - Automatic gain control mechanism of the receiver – which is not defined in the VDES standard, but may potentially cause receiver/ADC saturation and signal clipping for higher gains (or for stations close to the shore and for other strong signal sources). It may also result in the receiver's NF degradation for lower gains.
  - Antenna characteristic and gain of the shore station – for the measurement purpose, the average EIRP is the most important power parameter that should be both considered and verified in the link budget calculations and radio planning processes.
  - Antenna height and proper installation location onboard the vessel – height of the terminal antenna above mean sea level is crucial and may substantially influence ranges achieved by a radio system. Location of the antenna may influence:
    - Noise levels received onboard the vessel (vessel-originated noise),
    - Interference received from other radio equipment not used for the measurements and/or not coordinated for the purpose of the measurements,
    - Vessel antenna facing the shore station – side of the vessel pointed at shore station matters and may affect the measurements depending on the vessel location and course.
  - Antenna path matching - VSWR/RL characteristic in the frequency band used for measurements may influence both radiated power as well as sensitivity. One needs to consider proper antenna installation verification and measurements.
  - Antenna separation distances and types (i.e. horizontal and/or vertical) between radio systems on board the vessel as well as at the base station – one of the solutions allowing collocation of radio systems that minimizes introduced interference and limits receiver blocking situations.
  - Physical filters and their parameters used – filters may help reducing noise and interference introduced to the radio system as well as minimize the interference produced by the measured solution. Filters will however reduce both power and sensitivity of radio system, so they must be considered within link budget.
  - Channel equalizer used at the receiver and its characteristic as well as configuration – if available, may substantially influence the radio system performance especially when used within the multipath conditions.

While preparing for the VDES measurements at sea one needs to consider some additional and general technical parameters:

- VDES standard revision and Link ID used – newer revisions of VDES standard introduced substantial enhancements and modifications. On the other hand, specific Link IDs are optimized to serve different purposes in the VDES system – some of them are designed to provide very robust and long-range communications and some are focused on delivering the highest possible throughput.
- Time sources and/or time transfer solutions and their parameters – to be considered especially for any VDES R-mode tests and measurements.
- GNSS equipment used – precise and reliable PNT data is crucial for the measurements of the radio system especially at sea. GNSS equipment should be capable of providing accurate and somehow authenticated PNT data (e.g. via Galileo OSNMA) – nowadays, the ubiquitous phenomenon of radio interference puts extra emphasis on this aspect.

- Higher level protocols used – their characteristic and measurement impact description (including overhead) may be important since many different protocols are currently being discussed and proposed. Their utilization introduces an important impact on data net throughput available to single user.
- Successful communication criteria and thresholds (KPIs) – detailed and clear definitions and descriptions are crucial for the proper results analysis and comparison. Possible parameters to be used: signal level, BER, FER, SNR, EVM, MER, raw and net data throughput, delay.

3. ENVIRONMENTAL IMPACT

For the successful execution of any VDES sea trial, at least the following aspects of environmental impact should be considered:

3.1 Noise

Two different source types of noise need to be discussed:

- White thermal noise within the bandwidth of the radio signal being received by VDES capable equipment. This might sound obvious but in order to properly analyse and characterize the noise impact one needs to know the total NF of the whole radio receiving system. This needs to be carefully verified and assessed – each element of the reception chain should be analysed, and the total NF of the device cascade needs to be calculated if needed.
- External: ship, shore, propagation environment and man-made noise need to be considered. Preferably noise level measurements should be conducted whenever possible. The minimum approach would be to consider ITU-R Recommendation P.372 Radio Noise. External noise sources will in general increase the value of NF calculated for reception chain.

3.2 Multipath

The multipath analysis for the maritime environment may sometimes be omitted. However, even at sea, there are numerous measurement and test scenarios when full or at least partial multipath analysis is required. That is particularly true for the following cases:

- Propagation near the coastline and especially close to the harbours, within bays, straits and near mountainous coastline in general.
- Whenever base station is not adjacent to sea but located deeper inland, at more difficult terrestrial locations – especially in urban or mountainous environment.
- Measurements at the vessel operating in dense maritime traffic conditions.
- For over-the-horizon and other NLOS propagation scenarios.
- For even partial over the land propagation conditions in general.

For the given above scenarios, one needs to consider that both 50 and particularly 100 kHz bandwidths used for VDE-TER may become clearly selective. Severe multipath conditions will very often cause the non-equalized single carrier and broadband transmissions to become highly erroneous, especially under NLOS conditions, close to the shore infrastructure and for overland propagation paths. In those situations, at least some channel equalization needs to be ensured to reduce the impact of multipath. Such scenarios should then be avoided whenever using VDES devices not equipped with equalization solutions, alternatively narrower bandwidth needs to be used (i.e. 25 kHz). Conducting measurements and trials within severe multipath conditions with broader bandwidths and without equalisation can highly degrade reception performance. Such a quality reduction may cause radio system to become unusable and, importantly, that situation cannot be precisely predicted before measurements. Moreover, outcome of these measurements can neither be thoroughly explained nor fairly compared with results obtained for narrowband systems, and to emphasise even more, such measures are definitely not possible without detailed knowledge of channel characteristic, i.e. without a proper VHF radio channel model.

3.2.1 INTERFERENCE

VDE-TER sea trials are generally all about mutual interference. It is not just about VDE-TER interfering with AIS, as it might seem initially. There is interference from AIS and VHF voice introduced to VDE-TER transmissions as well. The latter can be much worse than the former. There are many AIS and voice communication links currently operational. It is therefore necessary to protect an uninterrupted VDE-TER reception during tests. It may even require coordinating VDE-TER transmissions with AIS ones originating from shore stations. Such a coordination may only be possible in direct cooperation with a specific maritime administration. However, because interference is very often ship originated, some coordination, as well as extensive filtering solutions onboard the vessel might also be needed. In general, extensive filtering, antenna separation, alongside other interference rejection solutions might be needed both onboard the vessel and onshore.

That being said, in case of inevitable interference, the minimum approach would be to exclude VDE-TER specific measurements interfered by AIS and voice communications from the analysis, or even better, to present and compare both cases – with and without disruptions.

3.3 GENERAL RECOMMENDATIONS AND CONCLUSIONS

Some general recommendations for any future VDE-TER measurements campaigns (especially those aiming at a direct comparison analysis with AIS/ASM) could be given as follows:

1. Generally, one needs to compare AIS/ASM transmissions quality and ranges with pi/4-QPSK VDE-TER in 25 kHz configuration. In this case sensitivities are comparable (when using FEC for VDE-TER) and multipath is negligible (flat fading) in 25 kHz channels. NLOS conditions have then also a similar effect on both AIS and VDE-TER.
2. One should use transmitter amplifiers with at least comparable RMS output powers for both GMSK and pi/4-QPSK modulations. If not possible, some detailed explanation should be provided describing the trade-off concerning at least higher throughput in case of VDE. Another approach would be to artificially decrease the AIS output power for sea trials' purpose by gain reduction or introduction of power attenuator into transmitter chain.
3. One needs to coordinate or at least analyse and avoid the AIS-like traffic and voice communications in the vicinity of VDE-TER equipment both on-board the vessel and onshore. The minimum solution would be the to employ antenna separation and filtering to reduce the interference or to exclude from the analysis any measurements potentially affected by AIS and VHF voice communications.

The goal of the above is to emphasize that there are many modes (Link IDs, physical layers) of operation in case of VDE-TER, and even more when other VDES components are included. Whenever one then carries out some trials, not just range of the system, but also its configuration and other advantages of the specific link should be considered. Moreover, one must always conduct fair comparative measurements between VDE and AIS/ASM systems, taking into account all merits and shortcomings of both modern and legacy solutions.

It is also important to present, in the measurements report, the transmitted power used as descriptively as possible. The minimum set of parameters should be as follows:

- RMS power of the transmitter.
- Peak power and PAPR.
- Amplifier back-off.
- EIRP average power radiated.

It is worth to underline and repeat, how crucial and necessary it is to provide radio link budget for each measurement case. Either the link budget should be similar between modern and legacy systems compared or a clear advantages and disadvantages for each transmission scenario should be pointed out – e.g. throughput, availability of services and functionalities (e.g.: R-mode, authentication, MCP with its registries and modern e-navigation services).

It is then important to note that adding up the amplifier back-off for the 16QAM transmission with reduced sensitivity (for 16QAM link) can easily lead to at least 16 dB deficit of signal power with respect to the AIS radio link budget! It is a really a huge value – and this is just for the case of a link under white noise conditions; a 100 kHz channel with multipath propagation can introduce additional loss, especially without proper equalization. One needs to be then fully aware of the above and make it clear within the sea trial report. Such a huge link budget reduction and consequently shorter ranges are a direct price to be paid for some additional advantages of modern systems. Those merits must then be underlined and clearly described in the report.

Additionally, photographic documentation is invaluable and should include at least pictures of installations, vessels used for measurements, environment near shore base stations as well as of different route sections.

General aspects to consider during measurements preparation, conducting and reporting:

- Transmission scenarios – general description of all communication cases.
- Link budget calculation – for each system, device configuration and scenario.
- Radio planning – propagation attenuation and range calculation as a minimum.
- Equipment technical specification and configuration – shore and ship side for each testing case.
- All possible interference sources description and their potential impact analysis:
  - Shore originated.
  - Ship originated.
  - Environment originated.
- Different sources of noise (e.g. man-made noise):
  - Noise measurements at the vessel should be conducted, if possible.
- Interference reduction methods used – their description and impact.
- Capacity limiting factors – other users' link usage description, vessel traffic density in the area.
- VDES standard revision and Link ID used.
- Higher level protocols used – their characteristic and measurement impact description (including overhead).
- Testbed area description (e.g. obstacles and potential multipath environment).
- Environment descriptions (including hydro-meteorological conditions, season, time of day, etc.).
- Dynamics of measurements and route description.
- Accurate PNT (GNSS) data supplementing the measurements.
- Vessel antenna facing the shore station – side of the vessel pointed at shore station matters.
- Statistical representativeness of the measured data – confidence intervals calculation and measurement error analysis.
- Successful communication criteria and thresholds (KPIs) detailed description: signal level, BER, FER, SNR, EVM, MER, throughput, delay.
- Comprehensive photographic documentation.

A special emphasis needs to be put on description of the solutions used for mitigating noise, multipath and interference. The measurement report should specify among others:

- Noise figure of LNA used as well as total NF of the receiver chain.
- External and man-made noise sources description and assessment with noise measurements at receiver location, if possible.
- Channel equalizer used at the receiver or spectrum measurements confirming flat fading, or at least detailed description of environment proving that multipath conditions are not significant, or 25 kHz should only be used, if multipath conditions cannot be avoided or their detailed impact assessed.
- Any coordination between VDE-TER, ASM, AIS and voice communications – detailed description and impact analysis.

- Collocation aspects and solutions used (e.g.: antenna separation, physical filters at the transmitter and receiver as well as potential Interference cancellation method) – description, impact and technical parameters.