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L-DACS1 System Definition Proposal:
Deliverable D3 - Design Specifications for L-DACS1 Prototype

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Abstract

This document is the third deliverable (D3) of the L-DACS1 System Specification Study, which aims at capturing all parameters relevant for the L-DACS1prototype implementation.

Keywords

L-DACS1	Data link	L-band	OFDM
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Authors

Miodrag Sajatovic, Bernhard Haindl, Christoph Rihacek (Frequentis)
Michael Schnell, Snjezana Gligorevic, Sinja Brandes (DLR)

Contact(s) Person	Tel	Unit
Nikolaos Fistas	+32 2 7294777	CND/COE/CNS

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Publications
EUROCONTROL Headquarters
96 Rue de la Fusée
B-1130 BRUSSELS

Tel: +32 (0)2 729 4715
Fax: +32 (0)2 729 5149
E-mail: publications@eurocontrol.int

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EXECUTIVE SUMMARY

This document - Design Specifications for L-DACS1 TX and RX Prototypes - is the final deliverable (D3) produced during the L-DACS1 Specification Study funded by EUROCONTROL. It captures aspects of the L-Band Digital Aeronautical Communications System Type 1 (L-DACS1) system design relevant for building the transmitter (TX) and receiver (RX) prototypes.

L-DACS TX and RX prototypes are planned to be developed under the SESAR JU framework (WP15), aiming at demonstrating that the L-DACS system does not introduce unacceptable interference towards receivers of other L-band systems, as well that the L-DACS system itself satisfactorily operates under presence of L-band interference coming from such external systems.

The complete L-DACS1 is specified in Deliverable D2 – L-DACS1 System Definition Proposal.

The deliverables of the L-DACS1 specification study (as well as the ones from the separate L-DACS2 specification study) will be proposed by EUROCONTROL as a starting point for further activities within the SESAR JU framework (WP15, project P15.2.4).

Some parameters captured in this document are subject to further validation and possibly adjustment prior to the laboratory tests. Similarly, some parameters e.g. L-DACS1 RX Interference Immunity Performance shall be considered as an outcome of the laboratory measurements with the prototype equipment rather than as an input for producing the prototype.

Although the airborne duplexer is essential for operational system deployment if the single airborne antenna is used, it is not essential for laboratory trials. Moreover, the preliminary duplexer specification as provided in this document may itself be further adjusted, dependent on the outcome of laboratory trials.

When testing the spectrum compatibility with L-band systems operating on fixed channels (UAT, TCAS, SSR) it is highly recommended using external band-pass (BP) filters[1] for both L-DACS1 TX and RX, according to the preliminary specification provided in this report.

[1] Such BP filters would apply to the situation where airborne L-DACS1 TX and RX use separate antennas.

CHAPTER 1 – Introduction

1.1 General Context

In EUROCONTROL, the Communications Domain within the Communications Systems and Programmes (CSP) Unit in EATM is leading the investigations on the Future Communications Infrastructure (FCI) which is required to support future aeronautical communications.

This work has been coordinated with FAA in the frame of Action Plan 17 (AP17) of the EUROCONTROL/FAA Memorandum of Cooperation and has been a key input to the Single European Sky ATM Research (SESAR) Definition Phase in Europe and NextGen in the USA. The results have also been endorsed by the ICAO Aeronautical Communications Panel (ACP).

The goal of the FCI was to support the future aeronautical communication requirements with a minimum set of globally deployed technologies. The FCI is the key enabler for new ATM services and applications that in turn will bring operational benefits in terms of capacity, efficiency, and safety. The FCI needs to support both data and voice communication with an emphasis on data communication in the shorter term. In terms of applications, the FCI must support the new operational concepts that are being developed in SESAR and NextGen.

The FCI will be a system of systems, integrating existing and new technological components. As described in the AP17 Final Report [OTH 1] and the SESAR Definition Phase Deliverables [OTH 2], [OTH 3], [OTH 4] there are three key recommendations for new data link developments:

[R1] Develop a data link based on the IEEE 802.16e standard operating in the C-band and supporting the airport surface environment

[R2] Finalise the selection of a data link operating in the L-band (L-DACS) and supporting the continental airspace environment

[R3] Develop a satellite system to support oceanic, remote and continental environments (complementing terrestrial systems)

1.2 Overview of L-band Data Link System Options

Under AP17 activities, various candidate technologies were considered and evaluated. Some of the considered and evaluated technologies shall operate in the L-band, supporting the [COCRv2] requirements. However, it was found that none of the considered technologies could be fully recommended primarily due to concerns about the operational compatibility (spectrum interference) with existing systems in the L-band. Nevertheless, the assessment of the candidate technologies led to the identification of desirable technology features that could be used as a basis for the development of an L-band data link solution that would be spectrally compatible.

Considering these features and the most promising candidates, two technology options for the L-band Digital Aeronautical Communication System (L-DACS) were identified. These options need further consideration before final selection of a single data link technology.

The first option for L-DACS (L-DACS1) is a frequency division duplex (FDD) configuration utilizing Orthogonal Frequency Division Multiplexing (OFDM), reservation based access control and advanced network protocols. This solution is closely related to the B-AMC and TIA-902 (P34) technologies.

The second L-DACS option (L-DACS2) is a time division duplex (TDD) configuration utilizing a binary modulation derivative (Continuous-Phase Frequency-Shift Keying - CPFSK - family) of the already implemented Universal Access Transceiver (UAT) system and of existing commercial (e.g. GSM) systems as well as custom protocols for lower layers, providing high quality-of-service management capability. This solution is mainly based on the All-purpose Multi-channel Aviation Communication System (AMACS) technology.

AP17 and SESAR proposed follow-on activities in order to further specify the proposed L-DACS options, validate their performance, aiming at a final decision (single technology recommendation for the L-band) by 2010.

Based on the information given above, in order to facilitate the selection of the L-DACS, it is required to:

- Develop detailed specifications for L-DACS1 and L-DACS2
- Develop and test L-DACS1 and L-DACS2 prototypes, and
- Assess the overall performance of L-DACS1 and L-DACS2 systems.

The ongoing work conducted under ECTL L-DACS1 Study covers the activities to develop detailed specifications for the L-DACS1 system.

Note: A separate contract addresses the development of the detailed specifications for L-DACS2. The other tasks will be covered by future actions in the frame of the SESAR JU.

When doing the testing of the L-DACS prototypes, it is important that the spectrum compatibility investigations are made in a consistent way (e.g. the same interference situation for both systems under consideration) to ensure a fair assessment of the two options.

Note: Another contract addresses the development of the interference scenarios to be investigated and the definition of acceptability criteria for each scenario.

Figure 1-1 explains for reference purposes the complete process applied to facilitate the selection of the L-DACS.

The activities conducted under this contract comprise only the shaded box and only for L-DACS1.

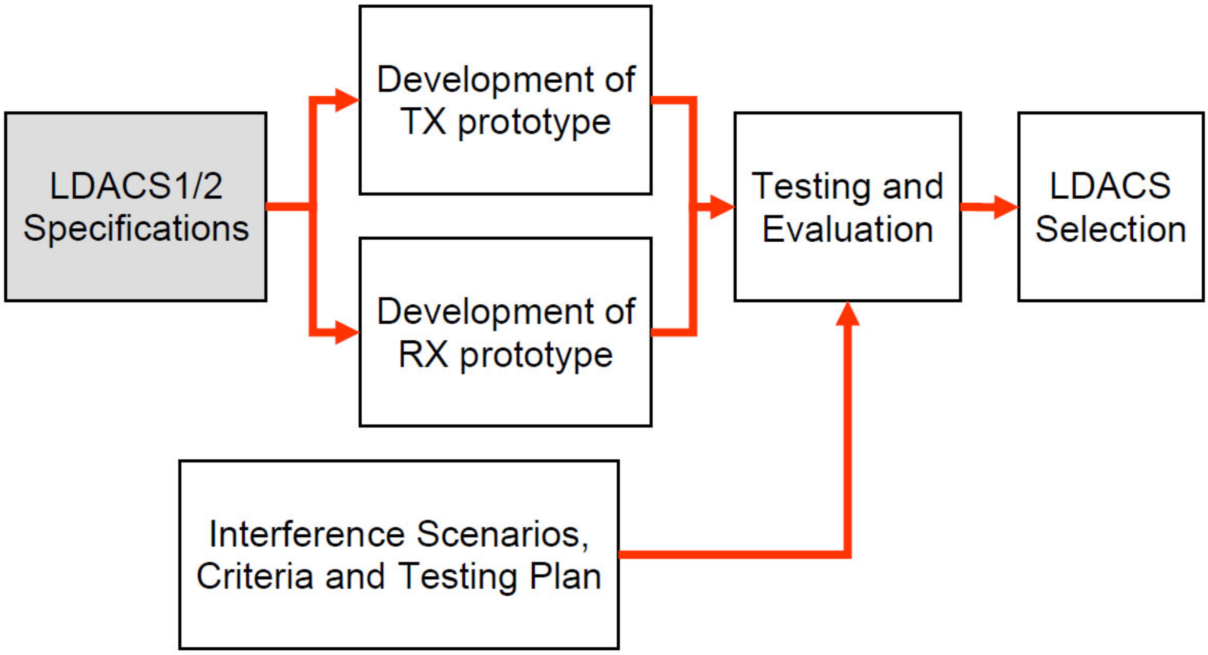

Figure 1-1: Process applied for selection of L-DACS

1.3 Objective and Scope of this Study

This EUROCONTROL L-DACS1 Study (contract PE 08-111383-E) will support the work to realise Recommendation 2 of AP17 - to develop an L-band data link. The development of the L-band data link is identified in the development activities for the SESAR Implementation Package 3 (IP3) in the post 2020 timeframe. Therefore, the outcome of this study will be used as input to the SESAR JU activities.

The prime objective of the EUROCONTROL L-DACS1 study is to produce a proposal for an initial system specification for the entire L-DACS1 operating in Air-Ground (A/G) mode. Another parallel task will produce design specifications for the L-DACS1 prototype equipment by extracting items relevant to prototyping activities from the L-DACS1 specification and supplementing these items by specific radio issues.

The L-DACS1 specification and the L-DACS1 prototype specification will enable prototyping activities that in turn should clarify system compatibility issues that could not be covered analytically or via modelling.

There are mainly two main deliverables foreseen for this study:

- draft version of the proposed L-DACS1 specifications (Deliverable D1), and
- finalized version of the proposed L-DACS1 specifications (Deliverable D2), considering review comments from external stakeholders (SESAR JU WP9 and WP9 participating industry, as well as other interested parties in the US).

Finally, it is planned to generate Design Specifications for L-DACS1 TX and RX prototypes (Deliverable D3).

This document is Deliverable D3 of the L-DACS1 specification study aiming at capturing all relevant L-DACS1 system parameters required to implement prototype equipment that will be later used for spectrum compatibility and performance measurements. However, some parameters captured in this prototype specification may need to be validated and, if required, adjusted, considering the outcome of the laboratory measurements using real radio equipment.

A detailed specification for the L-DACS1 Air-Air (A/A) mode is not in the scope of this contract and it is planned to be produced outside of this EUROCONTROL task. The current proposal covers the detailed specification for the A/G mode including support for digital voice.

The L-DACS1 specification is widely based on the previous Broadband Aeronautical Multi-carrier Communications (B-AMC) system design documents [B-AMC-x]. This baseline has been further improved within the course of this work.

In addition, the scope for the target L-DACS1 specification has been derived by inspecting and then merging items of specifications of other "similar" aeronautical and commercial communications systems (IEEE 802.16e, UAT, VDL Mode 3 and P34).

Specifications of commercial systems like IEEE 802.16e ([WiMAX_P], [802.16], [802.16e]) and P34 ([T-BAAB-A], [T-BAAC], [T-BAAD], [T-BAAE]) have been considered, where appropriate. Elements of existing aeronautical systems ([UAT_M], [V4 MOPS], [ETSI V2]) have been considered as well, where appropriate.

1.4 Project Partners and their Contributions

1.4.1 FREQUENTIS AG

FREQUENTIS AG (FRQ) is an Austrian company developing Communication and Information Systems for safety critical areas focusing on the field of Voice Communication for Air Traffic Control.

Within the ongoing EUROCONTROL task, FREQUENTIS leads and co-ordinates the project team in general and particularly the tasks carried-out under work packages WP 1 "L-DACS1 System Specification" and WP 2 "Specification of an initial L-DACS1 Prototype".

1.4.2 DLR

"Deutsches Zentrum für Luft und Raumfahrt e.V." (DLR) is the national German aerospace research centre. DLR is in charge of a wide scope of research and development projects in national and international partnerships. Within DLR, the Institute of Communications and Navigation contributes to the work within this project.

Within the ongoing task, DLR leads the activities carried-out under sub-work package WP 1.1 "L-DACS1 System Physical Layer Specification" and is responsible for defining these parts of the physical layer that are required for the implementation of an initial L-DACS1 TX and RX prototype.

1.4.3 University of Salzburg

Paris Lodron University of Salzburg (UniSBG) participates in the project with its Institute of Computer Sciences. Within this Institute, the Aeronautical Digital Communications group (ADC) is one of several research groups. The focus of this group lies on the development of the future digital aeronautical environment. This includes the design and evaluation of airborne mobile networks and their applications.

Within the ongoing work, UniSBG leads activities carried-out under the sub-work package WP 1.2 "L-DACS1 System Data Link Layer Specification" and contributes to the definition of those parts of the data link layer that are required for an initial L-DACS1 TX and RX prototype.

1.4.4 SELEX Communications

SELEX Communications is an Italian company owned by FINMECCANICA, and it is focusing on VHF/UHF Base Stations market segment for Ground-Air-Ground communications, with a strong presence in Europe, Asia and South America.

Within the ongoing work, S-COM is responsible for identifying the requirements for the L-DACS1 radio front-end and cross-checking these requirements with the requirements for the L-DACS1 PHY layer (WP 1). Furthermore, S-COM is responsible for reviewing and supplementing initial specifications for the TX and RX RF front ends and the TX/RX duplexer that are prepared and provided by FRQ. S-COM's feedback on P34 and on the RF issues is essential for the work of DLR and UniSBG.

1.5 Outline of the Specification for L-DACS1 Prototypes

The specification presented herein focuses on these elements of the L-DACS1 system design that are relevant for the prototyping activities with subsequent laboratory investigations of spectral compatibility and system performance. This initial specification may require further iterations after completion of the ongoing EUROCONTROL task. Further adjustments are expected to be carried out within the framework of the SESAR JU development activities (WP15).

This report is structured as follows:

  - CHAPTER 1 – (this chapter) provides a general overview of the L-DACS1, explains the scope of this report, also capturing conventions used when producing this specification.
  - CHAPTER 2 – describes the functional scope of the L-DACS1 prototype.
  - CHAPTER 3 – comprises specification of the ground L-DACS1 transmitter.
  - CHAPTER 4 – comprises specification of the airborne L-DACS1 transmitter.
  - CHAPTER 5 – comprises specification of the ground L-DACS1 receiver.
  - CHAPTER 6 – comprises specification of the airborne L-DACS1 receiver.
  - CHAPTER 7 – comprises the preliminary specification of an airborne TX/RX duplexer
- Annexes, providing supplementary information:
  - ANNEX 1 – describes exemplary an L-DACS1 radio architecture.
  - ANNEX 2 – describes exemplary an L-DACS1 TX architecture and provides some recommendations for prototyping.
  - ANNEX 3 – describes exemplary an L-DACS1 RX architecture and provides some recommendations for prototyping.
- Tables, comprising:
  - References used when producing this specification.
  - Abbreviations used in this document

1.6 Conventions

For the purposes of this specification the following conventions are used in Chapters 3-12 to emphasize the strength of a particular requirement:

- The word SHALL has the same meaning as the phrase "REQUIRED" and means that the definition is an absolute (mandatory) requirement of the specification.

- The word SHOULD or the adjective "RECOMMENDED", means that there may exist valid reasons in particular circumstances to ignore a particular item, but the full implications must be understood and carefully weighted before choosing a different course.
- The word MAY or the adjective "OPTIONAL", means that an item is truly optional.
- Deviations from the L-DACS1 system specification (Deliverable D2 of this study) that are proposed for more efficient prototyping are highlighted (grey background).

CHAPTER 2 – Proposed Functional Scope of L-DACS1 Prototypes

2.1 Objective of the L-DACS1 Prototyping Task

Deliverable D3 of the L-DACS1 study - Design Specifications for L-DACS1 Prototype - aims at specifying the L-DACS1 functionality required primarily for laboratory interference tests, i.e. for demonstrating the L-DACS1 system spectral compatibility with other systems operating in the L-band. The specification for the prototype equipment is developed in such a way that it supports laboratory investigations related to both inlay- and non-inlay deployment options.

2.1.1 Introduction

Laboratory trials are just a part of the full scope of tests that are required for the detailed L-DACS1 technology assessment. Initial prototyping activities do not aim at demonstrating in-flight capability. Important network capacity and performance aspects are out of the scope of the laboratory tests, as multiple L-DACS1 transmitters and receivers would be required, representing the total population for a particular L-DACS1 cell. Such large-scale aspects can only be reasonably captured via simulations.

It is also impossible to re-build the L-band interference situation as it would be perceived by the real flying aircraft or deployed ground station. This would require a large number of interfering sources that probably cannot be made available for laboratory trials. Therefore, laboratory investigations are expected to be focussed upon spectral compatibility and performance tests including L-DACS1 TX and RX prototypes as well as TXs of other L-band systems (UAT, SSR, JTIDS, DME) with associated RXs. From the test results with a single interfering TX[2], conclusions about the performance of the victim RX under composite L-band interference from multiple interfering TXs at several pre-set distances shall be drawn.

[2] It may be possible to re-build the airborne co-site situation in the laboratory by combining multiple airborne transmitters and single victim (L-DACS1) receiver. However, the contribution of “remote” interference sources cannot be considered. Composite interference from other-than-co-site sources is probabilistic and cannot be rebuilt in the laboratory.

2.1.2 Test Cases for Spectrum Compatibility/Performance Investigations

Defining the scope of the laboratory measurements is not the goal of this report. However, it is impossible to define the functional scope for the prototype L-DACS1 equipment without having made some assumptions about these tests.

Detailed specifications for the anticipated test cases, and in particular the specification of the TX transmission pattern, including duty-cycle, to be used with each case represent a stand-alone task (out of the scope of this document) that must be executed prior to any laboratory measurement. It will require plausible hypotheses about the size of the airborne population (PIAC) within the cell as well as agreed estimates of data volumes to be transmitted by an aircraft over a given period of time.

The coexistence of L-DACS1 and any other L-band system is expected to be tested according to two test scenarios, the first one where an L-DACS1 TX produces interference, and the second one where L-DACS1 RX is a victim of the interference produced by other L-band systems.

2.1.2.1 Interference from the L-DACS1 TX

In the first case, L-DACS1 TX would become the interfering transmitter TX_U (Figure 2-1), producing the undesired signal with the specified time profile (duty-cycle). TX_U shall operate at its maximum power level PU (maximum transmitting power normally represents the worst case with respect to interference). The transmitter TX_D of the victim system (selected non-L-DACS1 L-band system) produces the desired signal with the power PD. Desired and undesired signal are independently attenuated, combined via an RF combiner and applied to the input of the victim receiver RX_D. The power ratio of both signals D/U at the victim RX input can be adjusted via external variable RF attenuators A1 and A2.

During measurements, the TX_D is configured to send the desired signal as expected by the victim receiver. The desired signal power D at the RX_D input is adjusted as required. TX_D would normally be fed by the test data from an external test data source shown in Figure 2-1. The victim receiver RX_D demodulates and processes the desired signal in the presence of interference caused by TX_U. The undesired signal power U at the RX_D input is adjusted until the required RX_D performance threshold is reached. The resulting D/U ratio can vary dependent on the frequency separation between the desired and undesired signal.

It is expected that the victim RX will be tested in the laboratory by using external test equipment (shown in Figure 2-1 as “Test Data Sink”) that indicates the RX_D performance according to the criteria (e.g. BER, rate of successful NAV position determination, …) established for a particular victim system. Such external equipment would have to be “synchronised” (dotted line in Figure 2-1) with the test data source or locally configured (needs a-priori knowledge of the transmitted information in order to perform e.g. BER calculation).

The interface between an external source of test data and the TX_D, as well as the interface between then RX_D and the external equipment for evaluating the RX_D performance must be specified in detail (only guidance for such interfaces is provided within this document).

Optionally, the TX_D transmitter may internally implement the test data that are also a-priori known to the RX_D receiver. In such a case the RX_D could internally perform e.g. BER calculation and provide the result of RX_D performance evaluation on an external interface.

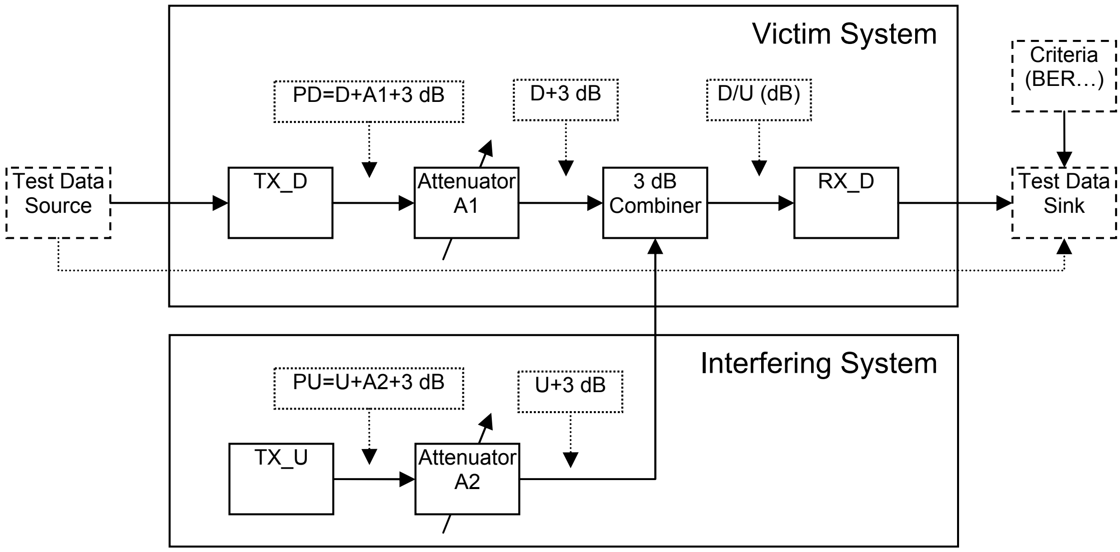

Figure 2-1: Generic Set-up for Interference Tests

2.1.2.2 Interference towards L-DACS1 RX

In the second case the roles are exchanged, so the L-DACS1 TX becomes the source of the desired signal TX_D and the L-DACS1 RX becomes the victim receiver RX_D. In such a case the transmitter of the concerned L-band system becomes the interfering transmitter TX_U. Except for these changes and different (system-specific-) RX_D acceptance criteria the test set-up remains the same as in the first case.

When testing an airborne L-DACS1 RX, an additional feasible option would be to let all avionics L-band transmitters that can normally be met at a single aircraft platform transmit "in parallel", according to their normal operating time patterns, and to test the airborne L-DACS1 RX against such composite co-site interference. In such a case further undesired transmitters, attenuators and combiners would have to be added to the test set-up shown in Figure 2-1. Such an option would also require a detailed specification of the composite interference profile – time patterns for all participating interfering signals, as well as a scenario for combining these patterns. In this case, operating powers U1, U2 … Un for the participating interfering signals may be kept constant, while the power of the desired signal D may have to be reduced until the acceptance criterion has been reached.

When testing a victim L-DACS1 RX_D, it is assumed that all mechanisms that enable the reception/processing of the test data by the RX_D (e.g. AGC, time synchronisation, channel equalisation, frequency synchronisation) have been implemented at the victim RX_D and work properly under L-band interference produced by TX_U. These mechanisms must be adequately supported by the L-DACS1 TX_D. Moreover, the RX_D should be able to automatically adapt to the eventually changing conditions during measurements (e.g. RX_D AGC should automatically adapt to the new setting of the attenuator A1).

2.1.3 High-level Requirements upon L-DACS1 Prototype Equipment

An important constraint is that the initial laboratory prototypes will have to be produced and tested within limited time if the outcome should be considered for preparing the WRC2011.

Therefore, it may be reasonable to restrict the functional scope of laboratory prototypes to just the aspects that can be tested in the laboratory rather than requiring the full system functionality in this phase. The essential high-level features of laboratory L-DACS1 prototypes can be captured as follows:

- The prototype L-DACS1 transmitters must operate at their representative power levels, producing signals-in-space that closely resemble signals-in-space that would be produced by the true deployed ground- and airborne

L-DACS1 transmitter. The transmitting time profile of an airborne L-DACS1 transmitter shall be adjustable.

- Assuming an adequate L-DACS1 TX implementation, the prototype L-DACS1 receivers must be able to receive and process the desired signal at reception power levels that are “reasonably close” to that expected in the real environment. The receivers under test must perform well in presence of L-band interference from the sources available in the laboratory.

In order to get good results, the L-DACS1 prototypes for laboratory tests must primarily exhibit representative RF performance. Other prototype TX and RX aspects like power consumption, form or size are important for the deployable equipment, but are less important for the intended laboratory trials.

Therefore, selected aspects of the L-DACS1 radio front-end and the PHY layer represent the main body of this specification, eventually being supplemented by some very elementary L-DACS1 protocol features above the PHY layer.

There may be significant differences between involved airborne and ground L-DACS1 transmitters and receivers due to e.g. different frequency ranges, interference conditions in FL and RL or different operating profiles/duty-cycles. Hence, four L-DACS1 radio prototypes are required, namely GS TX, AS TX, GS RX and AS RX[3].

The specific requirements upon prototype equipment for GS TX, GS RX, AS TX, AS RX and airborne duplexer are captured in separate chapters of this specification.

The airborne duplexer is specified separately, in Section 7.2 of this report. As no full duplex L-DACS1 link will be realised in the laboratory, the prototype duplexer implementation is not required/not expected for the laboratory tests. However, as the duplexer would also influence the performance of the L-DACS1 systems in presence of interference, it is recommended to implement external BP filters for both L-DACS1 TX and RX in order to emulate the duplexer behaviour. Appropriate TX and RX filters have been proposed in Section 7.3.

The detailed specifications in the following chapters of this report represent the functional scope of the L-DACS1 system that is sufficient for conducting all anticipated laboratory tests.

2.2 Options for Laboratory Investigations

The scenarios and metrics for laboratory trials are developed outside the scope of this study. Regardless of the detailed scenarios that will finally be proposed, the L-DACS1 team considers several options as realistic for conducting such tests, comprising ground and airborne L-DACS1 equipment.

In this section, the most important high-level system features have been highlighted for four assumed test cases, starting with the simplest one and ending with the most demanding case.

In the opinion of the L-DACS1 team, test case-oriented high-level requirements provided in this section may provide guidance in a hypothetical case that L-DACS1 laboratory tests with reduced scope should prove acceptable and/or necessary, e.g. due to time constraints.

In such a hypothetical case, “low-cost” tests involving only L-DACS1 TX equipment could be conducted first, based on the requirements captured in CHAPTER 3 – and CHAPTER 4 – of this report, while the more complex testing involving both L-DACS1 TX and RX equipment could be performed later on, considering additional requirements from CHAPTER 5 – and CHAPTER 6 –.

It is important to emphasize that the high-level requirements presented in this section should be understood as informative only. Moreover, only limited attempt has been made in

[3] It may be possible that the “same” baseband TX/RX part could be used in both implementations (AS and GS), however, the RF front-end must be adjusted to the corresponding frequency range.

Chapters 3, 4, 5 and 6 to state the detailed requirements separately for each test scenario described in this section.

2.2.1 Interference Produced by the L-DACS1 GS TX

In this case, one L-DACS1 GS TX is required, together with representative transmitters and receivers of other L-band systems. The GS TX should produce L-DACS1 signal-in-space with representative spectrum characteristics. The GS TX tests would be conducted according to the detailed test procedure to be developed outside the scope of this document.

2.2.1.1 GS TX

- GS TX shall operate within the currently proposed FL frequency sub-range (Section 3.1.1).
- GS TX channel frequency shall be adjustable (Section 3.1.1) in 0.5 MHz steps[4].
- GS TX shall operate at +41 dBm[5] (Section 3.1.3) nominal power level[6].
- GS TX shall always use N_u = 50 OFDM sub-carriers (Section 3.2.2).
- GS TX shall produce a continuous FL stream of modulated OFDM symbols (Section 3.1.10).
- GS TX shall implement FL framing (Section 3.3.2.2) aligned with the [D2] specification, respecting the FL SF structure as well as the internal MF structure.
- GS TX shall insert the FL synchronisation symbols at the proper positions (Section 3.3.2.1).
- GS TX should implement the pilot pattern over transmitted FL frames and provide an option for pilot boosting (Section 3.3.2.1, Section 3.3.4.1).
- GS TX shall accept specified pseudo-random[7] test data over a test interface (Section 3.5).
- GS TX shall apply QPSK[8] modulation (Section 3.3.3.3).
- Modulated OFDM symbols must have the proper length (Section 3.3.1.3).
- GS TX signal-in-space shall be shaped via TX windowing (Section 3.3.5).

2.2.1.2 AS RX

No L-DACS1 RX is involved in these tests!

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[4] This spacing allows for comfortable testing both inlay- and non-inlay options in laboratory tests.

[5] It is recommended to provide a possibility to manually reduce the power of the prototype GS TX by at least 10 dB (down to +31 dBm or less).

[6] This represents the worst-case, as with full power the spectral mask, IMD products and spurious products are at the highest level.

[7] Pseudo-random modulation content is required to capture possible effects of the TX PAPR. In this test case, the TX must either internally implement a pseudo-random data generator for the OFDM modulator, or must provide an interface to an external random data generator. In any case, the test data themselves or the test interface must be specified.

[8] QPSK shall be used for these tests as the most universal modulation type that is applicable to all kinds of FL/RL bursts. FEC coding, as well as protocol aspects are irrelevant when testing TX spectral shape.

2.2.2 Interference Produced by the L-DACS1 AS TX

In this case, one L-DACS1 AS TX is required, together with representative transmitters and receivers of other L-band systems. It is sufficient that the AS TX produces L-DACS1 signal-in-space, with representative time- and spectrum characteristics.

It is particularly important that the AS TX produces the RL signal with adjustable duty-cycle. This implies that the AS TX parameters that determine the duty-cycle must be configurable. The AS TX tests would be conducted according to the detailed test procedure to be developed outside the scope of this document.

2.2.2.1 AS TX

- AS TX shall operate within the corresponding RL frequency sub-range (Section 4.1.1).
- AS TX channel frequency must be adjustable in 0.5 MHz (Section 4.1.1) steps[9]
- AS TX shall operate at +41 dBm[10] (Section 4.1.3) nominal power level[11].
- AS TX shall use the number of OFDM sub-carriers as applicable (Section 4.3.2.1, Section 4.3.2.2) to the concerned frame/segment within the SF structure.
- AS TX SF structure (Section 4.3.2.2)[12] should be supported. Each SF shall comprise two opportunities for sending RA sub-frames and four MFs. Each MF shall comprise a DC segment and a Data segment with variable length.
- AS TX RL frames/segments containing modulated OFDM symbols shall be produced according to the RL framing structure (Section Section 4.3.2.2).
- AS TX should implement the RL pilot patterns (Section 4.3.2.1, Section 4.3.5.1) in all transmitted frames/segments.
- AS TX shall accept specified pseudo-random test data over a test interface (Section 4.5).
- AS TX shall apply QPSK[13] modulation (Section 4.3.3.3).
- Modulated OFDM symbols shall have the proper length (Section 4.3.1.3)
- AS TX shall transmit RL RA sub-frames with ramp-up and ramp-down phases defined by the OFDM windowing (Section 4.3.6).
- The RA sub-frames should be sent in the pre-defined opportunity within the RA frame (Section 4.3.2.1).

[9] This spacing allows for testing both inlay- and non-inlay options in laboratory tests.

[10] This represents the worst-case, as with full power the spectral mask, IMD products and spurious products are at the highest level.

[11] It is recommended to provide a possibility to manually reduce the power of the prototype AS TX by at least 10 dB (down to +31 dBm or less).

[12] The RL frames/segments should be produced with correct length at correct places within the SF. Each RL SF shall be configurable to comprise a specified number of RL RA sub-frames, as well as four MFs that are internally sub-divided into DC- and Data segments, with ramp-up and ramp-down phases defined by the TX windowing. The configuration should allow for selecting between two possible opportunities within the RL RA slot, as well as for specifying the number- and parameters of DC and Data segments. This configuration flexibility is required for determining the maximum L-DACS1 AS TX duty-cycle that can be tolerated by other L-band receivers.

[13] The same rationale with respect to the modulation characteristics applies here as for GS TX in the previous section. FEC coding, as well as protocol aspects are irrelevant when testing TX spectral shape.

- The number of RA sub-frames that are transmitted within the SF shall be configurable (Section 4.4).
- AS TX shall transmit the AGC preamble of the RL DC segment with ramp-up and ramp-down phases defined by the OFDM windowing (Section 4.3.2.1, Section 4.3.6).
- The number of AGC preambles that are sent per MF/per SF shall be configurable (Section 4.4).
- AS TX shall transmit a synchronisation symbol[14] of the RL DC segment with ramp-up and ramp-down phases defined by the OFDM windowing (Section 4.3.2.1, Section 4.3.6).
- The number of synchronisation symbols that are sent per MF/per SF shall be configurable (Section 4.4).
- AS TX shall transmit RL DC segments with ramp-up and ramp-down phases defined by the OFDM windowing (Section 4.3.2.1, Section 4.3.6).
- The DC segment size as well as the number/position of tiles[15] transmitted by a single airborne user within the DC segment shall be configurable (Section 4.4).
- AS TX shall transmit tiles in the RL Data segments with ramp-up and ramp-down phases defined by the OFDM windowing (Section 4.3.2.1, Section 4.3.6).
- The number of tiles in the RL Data segments that are sent per SF shall be configurable (Section 4.4).
- The Data segment size/length as well as the number and position of tiles transmitted by a single airborne user within the Data segment shall be configurable (Section 4.4).

2.2.2.2 GS RX

No L-DACS1 RX is involved in these tests!

2.2.3 L-band Interference towards AS RX

In this scenario the AS RX receiving performance is validated via measuring the corrected BER after decoding, under co-site and external L-band interference. It is expected that an external BER evaluation tool will be used. Optionally, AS RX itself may internally measure the BER and provide the result on an external interface.

One L-DACS1 GS TX and one L-DACS1 AS RX are required, together with representative transmitters of other L-band systems. The tests would be conducted according to the detailed test procedure to be developed outside the scope of this document. The basic required L-DACS1 GS TX and AS RX functionalities are as described below.

2.2.3.1 GS TX

In this case the GS TX shall implement all characteristics specified in Section 2.2.1.1. Additionally, some further features are required in order to produce the L-DACS1 desired signal that allows BER measurements at the receiver side:

[14] Within each RL MF the AS TX shall be configurable to produce/skip the AGC preamble of the DC segment, as well as to insert /skip sync symbol at the specified location.

[15] Normally, an AS TX cannot send more than a single tile in the DC segment. However, when measuring the BER at the GS RX the default configuration may be changed (an AS TX may be allowed to send test data in multiple tiles in DC segments).

- The test data for measuring AS RX corrected BER[16] shall be input into the GS TX via an appropriate test interface (Section 3.5)[17].
- For measurement of BER, FL Data/CC frames[18] (Section 3.4) shall be used.
- The parameters[19] of used FL Data/CC frames shall be configurable (Section 3.4).
- GS TX shall implement interleaving and the procedure for mapping FL data onto FL frames (Section 3.3.3.2, Section 3.3.3.4).
- GS TX shall apply over CC/Data frames a FEC[20] scheme (Section 3.3.3.1).

2.2.3.2 AS RX

In this scenario, the AS RX needs to implement the mechanisms that are required for enabling the radio receiving functions on FL and subsequent reception, processing and evaluation (BER) of test data contained in FL Data/CC frames.

All these mechanisms must work reliably under specified interference conditions, including co-site interference.

- AS RX shall operate within the currently proposed FL frequency sub-range (Section 6.1.1).
- AS RX channel frequency must be adjustable (Section 6.1.1) in 0.5 MHz steps.
- AS RX shall operate down to the declared sensitivity power level S0 (Section 6.2.2).
- AS RX shall implement interference mitigation mechanisms[21] (Section 6.1.6, Section 6.3.7).
- AS RX shall implement AGC (Section 6.1.7) as required for the reception of FL frames[22].
- AS RX shall implement channel estimation mechanisms (Section 6.3.5) based on observing pilot symbols transmitted in the FL frames.
- AS RX shall implement initial time/frequency synchronisation to the GS TX based on synchronisation symbols inserted at the beginning of FL BC1/BC2/BC3 sub-frames (Section 6.2.5, Section 6.3.4).

[16] The pseudo-random test data for measuring BER may be different than the test data used when testing the impact of the L-DACS1 TX upon the L-band receivers.

[17] The same data shall be provided to the BER test equipment (or alternatively the AS RX itself) to be used as a reference for BER measurement. This can be either done by externally generating random data and providing them to both TX and RX BER measurement equipment via cable or generating a certain amount of random data in advance and pre-storing them at both TX and RX BER measurement equipment.

[18] For BER measurements all 9 FL Data/CC frames in each MF and all four MFs per SF can be used. FL BC1/BC2/BC3 sub-frames are not recommended to be used for BER calculation. This would require implementing two additional PHY-PDU types with FEC schemes different than the one used in FL Data/CC frames. There are enough opportunities for transferring test data in FL Data/CC frames.

[19] These parameters – type/number of used frames, their positions within the FL SF etc. – shall be made a-priori known to the RX under test.

[20] Opposite to spectral compatibility exercises where only the spectral content of the TX signal is relevant, not only the modulation, but also the FEC coding must be specified for BER measurements at an L-DACS1 RX.

[21] In order to provide representative BER data, the AS RX needs to implement all these mechanisms. In particular, blanking is required because of strong co-site interference.

[22] Once established, an initial AGC setting shall be either preserved (frozen-) over the duration of the BER measurements or it may be regularly updated by using the same mechanism as for initial AGC setting.

- AS RX shall perform permanent tracking/fine correction of time/frequency offsets during BER measurements (Section 6.2.6, Section 6.3.4).
- AS RX SF framing shall be aligned with the GS TX SF framing (based on the autonomously detected position of the GS TX SF boundary).
- AS RX shall support extracting and processing (only-) relevant FL CC/Data frames[23] containing data for BER measurements.
- AS RX shall implement mechanisms for demodulating the received signal (Section 6.3.2.5).
- AS RX shall de-interleave received test data (Section 6.3.2.6).
- AS RX shall decode test data (Section 3.3.3.1/Table 3-6).
- AS RX shall output FEC corrected data via an appropriate test interface (Section 6.5) to the external equipment for measuring the BER[24].

2.2.4 L-band Interference towards GS RX

In this scenario the GS RX receiving performance is validated via measuring corrected BER after FEC under external L-band interference. This scenario is the most complicated of all test cases discussed here. It is expected that external BER measuring equipment will be used. Optionally, GS RX itself may internally measure BER and provide the result on an external interface.

For testing the GS RX prototypes with full functionality all four components would be required: GS TX, AS RX, AS TX and GS RX. Besides the functionality required for AS RX tests (above), multiple additional features would be required, including full-duplex air-ground connectivity as well as local interactions between the AS/GS TX and RX equipment. All four involved entities would have to co-operatively work under full-duplex conditions in the presence of external interference, providing “in-the-loop” functions required for operating the GS RX at an “optimum working point”.

The fully functional GS RX would have to be able to adjust its input gain (AGC), synchronise (in time and frequency) to the AS TX RL RA frames and measure time/frequency/power deviations of the received AS TX signal from the GS RX own local reference settings. These measurements alone would require significant further extensions of the GS RX radio front-end and PHY layer functionality. Further, the GS RX would need to internally provide results of these measurements to the GS TX. The GS TX would in turn submit the corrections on the FL to the AS RX. Such a transmission of system messages implies additional MAC and LME functionality, as corrections are actually exchanged between LMEs as MAC messages that in turn are transferred in FL CCCH/RL DCCH logical channels, respectively, with precise mapping onto underlying PHY layer structures (frames and tiles). The AS RX would have to internally provide the corrections to the AS TX in order to adjust the AS TX settings.

The complexity of the prototype implementation may be extremely reduced and the measurement of the GS RX performance made much simpler if all “in-the-loop” regulating mechanisms (time/frequency/received signal power) could be removed or replaced by “equivalent” open-loop mechanisms in the test set-up.

Therefore, the L-DACS1 team proposes using a simplified test set-up that avoids “in-the-loop” mechanisms, while still allowing for representative assessment of spectral compatibility. This leads to simplex rather than full-duplex connectivity (single AS TX and single GS RX

[23] GS TX SF structure shall be a-priori known to the AS RX. However, the AS RX must be informed about which FL frames contain the test data.

[24] As an option, BER may be internally measured within the AS RX and the results (measured BER) provided via an external interface.

would be sufficient) that is still considered as sufficient for conducting the tests.

The proposed approach clearly requires some deviation from the original L-DACS1 system specification captured in the deliverable [D2] of this study. However the simplifying assumptions in the following section do not compromise the quality/validity of the outcome of the laboratory measurements.

It is important to note that all mechanisms and tracking procedures proposed in the following section will induce some residual frequency/time/power adjustment errors, allowing for the BER measurement to be done under "non-ideal" conditions.

The basic required L-DACS1 AS TX and GS RX functionalities are as described below.

2.2.4.1 AS TX

An AS TX shall implement all characteristics specified in Section 2.2.2.1. At the same time, additional features may be needed supplementary to these required in Section 2.2.2.1. Some TX settings may change as AS TX duty-cycle is not important when measuring the GS RX corrected BER.

Required new features as well as AS TX settings that deviate from those listed in Section 2.2.2.1 are indicated below.

- AS TX shall locally establish its SF framing (Section 4.3.2.2)[25].
- The configuration of RL RA sub-frames must be a-priori known to the GS RX (Section 4.4)[26].
- The configuration[27] of AS TX AGC preambles shall be made a-priori known to the GS RX (Section 4.4).
- The occurrence rate[28] and position[29] of synchronisation symbols in DC segments shall be made a-priori known to the GS RX (Section 4.4).
- Test data shall be transmitted in specified[30] RL Data (and optionally DC-) segments (Section 4.4).

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[25] Normally, AS TX would establish its SF boundary based on observed GS TX FL frames. When transmitting RL RA sub-frames, the AS TX can use any of two opportunities within the 6.72 ms window ("RA frame"). The GS RX must be able to synchronise to RA sub-frames, while for RL DC/Data segments the synchronicity is achieved via "in-the-loop" mechanisms. For test purposes, the prototype GS RX shall be able to synchronise to the RL RA sub-frame that may appear anywhere within the GS RX SF. This mechanism should be similar to that used by the AS RX on FL and should allow for acquiring the "autonomous" GS RX SF synchronisation without a-priori knowledge of the AS TX SF boundary. Alternatively, initial SF alignment between the GS RX and AS TX could be established via wired connections between the GS RX and the AS TX. GS RX would act as "time master" and would provide its SF framing to the AS TX via this interface (in the reality, it would be derived from the received GS TX FL SFs). In order to emulate non-ideal AS-GS SF alignment, at the AS TX an intentional configurable time offset with respect to the GS RX framing should be inserted. When testing the GS RX ability to receive RL RA sub-frames, this offset should be adjusted within the uncertainty limits that apply to the RA sub-frames within the RA frame/slot.

[26] Normally, the GS RX shall accept any RL RA sub-frame (and perform AGC/frequency/timing adjustments) as long as it falls within the corresponding RA sub-slot! In the proposed test set-up, the GS RX autonomously derives its SF timing from the RA sub-frames sent by the AS TX. In order to use this feature, RA sub-frame must be sent in a fixed opportunity (one of two) that must be a-priori known to the GS RX.

[27] GS RX normally knows this AS TX setting in advance. As the AS TX duty-cycle is irrelevant for BER measurements, it is recommended to send one AGC preamble in each RL MF. This should provide enough opportunities to the GS RX to maintain power/frequency/time synchronisation with the AS TX.

[28] AS TX duty-cycle is irrelevant for BER measurements, so it is recommended to send two synchronisation symbols in each RL MF and to send test data over all available DC/Data segments in all MF frames.

[29] GS RX normally knows this AS TX setting in advance. AGC preamble and synchronisation symbol that are isolated from the rest of the DC segment may be the most challenging case for both the AS TX and the GS RX. Therefore, it is recommended to send the synchronisation symbol in the fourth and fifth opportunity.

[30] As the AS TX duty-cycle is irrelevant for the BER measurements, all RL Data segments in all MFs can be used. Optionally, even RL DC segments may be configured to be used for BER measurements (as they apply the same FEC/modulation and the same tile size as the RL Data segments).

- The Data segment configuration (size) must be a-priori known to the GS RX (Section 4.4).
- Data (and optionally DC) segments used for BER measurements shall implement interleaving mechanisms and RL data mapping procedures (Section 4.3.3.2, Section 4.3.4).
- AS TX shall apply an FEC[31] scheme (Section 4.3.3).
- If DC segments are used for BER measurement, their size and the position of user data symbols sent by the AS TX shall be a-priori known to the GS RX (Section 4.4)[32].
- The test data for BER evaluation shall be input into the AS TX via an appropriate test interface (Section 4.5).
- The reference test data for measuring GS RX corrected BER shall be a-priori known to the external device for evaluating BER or GS RX (Section 4.4).

2.2.4.2 GS RX

With the proposed approach, one AS TX is sufficient for testing the GS RX corrected BER.

- GS RX shall operate within the currently proposed RL frequency sub-range (Section 5.1.1).
- GS RX channel frequency must be adjustable (Section 5.1.1) in 0.5 MHz steps.
- GS RX shall operate down to the declared sensitivity power level S0 (Section 5.2.2).
- GS RX shall implement interference mitigation mechanisms (Section 5.1.7, Section 5.3.8)[33].
- The detailed AS TX SF structure, including the parameters (start/length) of the RL DC/Data segments with test data should be a-priori known to the GS RX (Section 4.4, Section 5.4).
- GS RX shall implement channel estimation mechanisms (Section 5.3.6) based on observing pilot symbols in RL frames/segments.
- GS RX shall implement RX AGC (Section 5.1.6) and adjust its RF gain as required for the reception of RL RA sub-frames[34]. After being stimulated via an RL RA sub-frame, the GS RX shall apply the resulting AGC setting until the next update.
- GS RX shall allow its current AGC setting to be updated based on the received AGC preambles of the DC segments (Section 4.3.2.1). After being stimulated via an AGC preamble of the DC segment, the GS RX shall apply the resulting AGC setting until the next update[35].

[31] Opposite to spectral compatibility exercises where only the spectral content of the TX signal is relevant, not only the modulation, but also the FEC coding must be specified for BER measurement at an L-DACS1 RX.

[32] In this case AS TX would transmit more than one tile in the DC segment. The DC segment size may be coordinated via consistent configuration of the AS TX and GS RX.

[33] Blanking is only optional for the GS RX as no co-site interference exists here.

[34] After an initial SF synchronisation has been established, RA sub-frames may be eventually omitted and the GS RX AGC maintenance function performed solely based on the AGC preambles of the RL DC segments. Alternatively, AS TX may be configured to send repetitive “interpolating” RL RA sub-frames just for stimulating GS RX AGC.

[35] The AGC setting shall remain stable over the duration of the subsequent RL Data segment(s) used for BER measurements.

- GS RX shall adjust its SF boundary and implement initial time/frequency synchronisation to the AS TX based on sync symbols inserted at the beginning of RL RA sub-frames (Section 4.3.2.1)[36]. After being stimulated via an RL RA sub-frame, the GS RX shall apply[37] the resulting frequency/time setting until the next update.
- GS RX shall be able to re-adjust its time/frequency settings based on the sync symbols that are received at the start of the RL DC segment (Section 4.3.2.1). The position of the sync symbol should be agreed as a default value a-priori known to the GS RX.
- GS RX shall demodulate (Section 5.3.3.1) the received AS TX signal.
- GS RX shall implement de-interleaving (Section 5.3.3.2).
- GS RX shall apply a FEC[38] scheme (Section 4.3.3).
- GS RX shall support extracting (only-) the relevant RL Data segments (and optionally DC segments-) containing data for BER measurements[39].
- GS RX shall output FEC corrected data via an appropriate test interface (Section 5.5) to the external equipment for measuring the RX BER[40].

[36] After an initial SF synchronisation has been established, RA sub-frames may be eventually omitted and the GS RX synchronisation maintenance performed solely based on the synchronisation symbols of the RL DC segments.

[37] The GS RX time/frequency setting shall be tracked over the duration of the subsequent RL Data segment used for BER measurements.

[38] Opposite to spectral compatibility exercises where only the spectral content of the TX signal is relevant, not only the modulation, but also the FEC coding must be specified for BER measurement at an L-DACS1 RX.

[39] The exact constellation of AS TX RL SFs must be a-priori known to the GS RX.

[40] Optionally, the GS RX itself may internally perform the BER measurement based on a-priori known AS TX test data content and provide results (measured BER) on the external interface.

CHAPTER 3 – Ground Station Transmitter

This section comprises items that are specific to the prototype implementation of the L-DACS1 GS TX operating in the A/G mode.

Deviations from the L-DACS1 system specification (Deliverable D2 of this study) that are proposed for more efficient prototyping or any other reason are highlighted.

3.1 GS TX Radio Front-end Characteristics

3.1.1 GS TX Frequency Range and Tuning Step

L-DACS1 shall operate as a full duplex system in the 960 – 1164 MHz range [D2].

Prototype GS TX shall be capable of operating on any channel within the 985.5 – 1008.5 MHz range[41].

An extended prototype GS TX range (960 - 1025 MHz) would be beneficial for investigating the possibility of operating L-DACS1 FL/RL in other sub-ranges with modified duplexer settings, including closer frequency spacing to fixed-channel SSR systems.

Preliminary deployment concept based on the interference situation in the L-band and estimated duplexer feasibility anticipates that L-DACS1 FL/RL channel blocks would be placed "in the middle" between fixed L-band UAT/SSR channel allocations (978, 1030, 1090 MHz), providing also sufficient margin to the GPS/GALILEO channels in the upper part of the L-band. With that concept, the sub-range for the FL channels is 985.5 – 1008.5 MHz while the sub-range for L-DACS1 RL channels is 1048.5 - 1071.5 MHz.

GS TX shall be tuneable to any channel within the operating range with a 0.5 MHz step.

The operating channel shall be adjustable via an implementation-specific interface.

During the laboratory trials, prototype GS TX channel shall be tuned to the same channel that is selected for the corresponding AS RX. GS TX channel shall be set 63 MHz below the

[41] The channel frequency corresponds to the nominal position of the DC OFDM sub-carrier in the spectrum of the L-DACS1 signal.

corresponding AS TX channel.

The duplex spacing of 63 MHz is currently used by airborne DME equipment.

3.1.2 GS TX Centre Frequency Tolerance

GS TX centre frequency and the symbol clock frequency shall be derived from the same reference oscillator.

At the GS TX, the reference frequency accuracy shall be better than ± 0.1 ppm.

GS TX shall always transmit on the configured nominal channel frequency.

3.1.3 GS TX Nominal Transmitting Power

The GS TX nominal transmitting power measured at the TX output terminal averaged over an FL super-frame (240 ms) shall be +41 dBm.

This setting provides assurance that the GS TX can be built and operated at the representative power level (estimated from the L-DACS1 link budget in [D2] without interfering receivers of other L-band systems. Due to the transmitter peak-to-average power ratio (PAPR) instantaneous peak transmitting power may be higher than +41 dBm.

3.1.4 GS TX Power Setting

The GS TX shall transmit with its nominal power level.

GS TX operating power shall be adjustable via an implementation-specific interface.

It is recommended to provide a possibility to manually reduce the power of the GS TX by at least 10 dB (down to +31 dBm or less).

This would be desirable for estimating the effect of slightly reduced GS TX power in the laboratory upon the spectral content of the GS TX signal-in-space – spectral mask, spurious signals – therefore drawing conclusions about possible tradeoffs between cell size and the GS TX power.

Once selected, GS TX average power level does not change during operation.

During the laboratory measurements, the required power level of an L-DACS1 GS TX signal at the input of the receiver under investigation will be adjusted via variable attenuators rather than via changing the TX operating point.

3.1.5 GS TX Transmitter Spectral Flatness

GS TX is transmitting on all usable sub-carriers N_u (N_u = 50 is the maximum number of OFDM sub-carriers available on FL, see Section 3.2.2). In this case the following shall apply:

- Absolute average power difference between adjacent sub-carriers: ≤ 0.1 dB (2.5 dB allowance should be added for pilot sub-carriers in case pilot boosting is applied via GS TX configuration).
- Deviation of average power on each sub-carrier (Figure 3-1) from the measured power averaged over all N_u active tones:
  - Sub-carriers from [-12 to -1] and [1 to 12]: ≤ ±2 dB
  - Sub-carriers from [-25 to -13] and [13 to 25]: ≤ +2/–4 dB
- The average power transmitted at spectral line 0 shall not exceed –15 dB relative to the total average GS transmitted power of all data and pilot sub-carriers (excluding the pilot sub-carriers that are intentionally power-boosted[42]).

[42] See [AGI_RF]

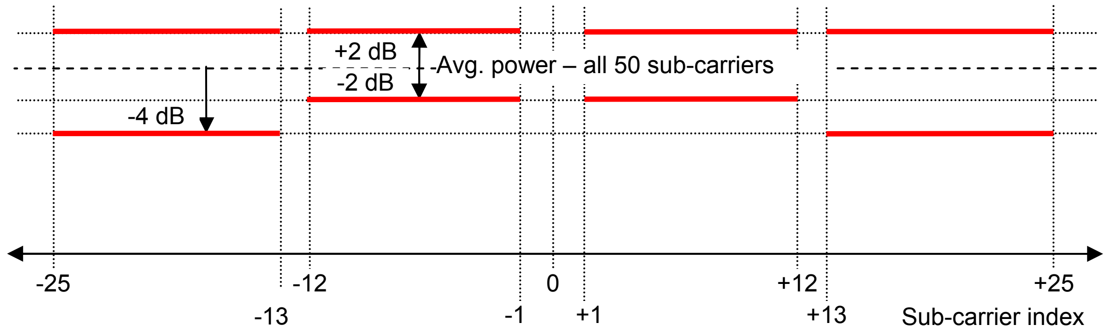

Figure 3-1: TX Spectral Flatness

3.1.6 GS TX Relative Constellation Error

The GS TX relative constellation Root Mean Square (RMS) error with QPSK modulation, averaged over sub-carriers, OFDM frames and packets, shall not exceed – 15 dB.

The relative constellation RMS error is calculated as

$$\left(Error_{RMS}\right)^2 = \frac{1}{N_f}\sum_{i=1}^{N_f}\frac{\sum_{j=1}^{L_p}\sum_{k\in S}\left[(I(i,j,k)-I_0(i,j,k))^2+(Q(i,j,k)-Q_0(i,j,k))^2\right]}{\sum_{j=1}^{L_p}\sum_{k\in S}\left[I_0(i,j,k)^2+Q_0(i,j,k)^2\right]}$$

where

L_p denotes the number of OFDM symbols used in a measurement (length of the OFDM frame with data relevant to the measurement),

N_f denotes the number of OFDM frames containing data used in the measurement,

[I_0(I,j,k), Q_0(I,j,k)] denotes the ideal symbol point in the complex plane (in the constellation diagram) of the i-th OFDM frame, j-th OFDM symbol of the OFDM frame, k-th sub-carrier of the OFDM symbol modulated with data relevant to this measurement,

[I(I,j,k), Q(I,j,k)] denotes the observed symbol point in the complex plane (in the constellation diagram) of the i-th OFDM frame, j-th OFDM symbol of the OFDM frame, k-th sub-carrier of the OFDM symbol modulated with data relevant to this measurement,

S denotes the group of modulated data sub-carriers where the measurement is performed.

The logarithmic value shall be calculated as 20 $\log_{10}$ ($Error_{RMS}$).

3.1.7 GS TX Noise and Spurious Emissions

The power of any GS TX spurious signal measured in an active mode at the GS TX output terminated in a matched impedance load shall not exceed -36 dBm.

Spurious emissions should be measured in a reference bandwidth of 100 kHz in the frequency range from 30 MHz to 1 GHz, and in a reference bandwidth of 1 MHz in the frequency band of 1 GHz to 5.1175 GHz.

The range of ±1.245 MHz around the TX operating frequency fc is defined as Out-Of-Band (OOB) range and is regarded separately (Section 3.1.8). The OOB domain boundary (1.245 MHz) is given in Figure 3-2 and in the last column of Table 3-1. The boundary has been calculated based on the occupied bandwidth of the L-DACS1 signal-in-space Beff = 498.05 kHz using the ITU-R definition for the start of the spurious domain [fc-Beff∗2.5 … fc+Beff∗2.5] that was also used for the UAT system [UAT M].

The GS TX broadband noise power density measured across the spurious domain (Figure 3-2) in an active mode at the GS TX output terminated in a matched impedance load shall not exceed -130 dBc/Hz.

This preliminary value needs to be confirmed.

A more stringent value (-140 dBc/Hz) may be required at larger frequency offsets to protect non-aeronautical systems operating below 960 MHz. The above relaxed requirement aims to not over-specify this challenging item, taking into account that additional broadband noise attenuation can be achieved via external duplexer or filtering equipment.

3.1.8 GS TX Spectrum Mask

The spectral density of the GS TX transmitted L-DACS1 signal within the OOB domain shall fall within the spectral mask shown in Figure 3-2 and Table 3-1.

The measurements shall be made by using a 10 kHz resolution bandwidth and a 30 kHz video bandwidth. The 0 dBr level is the L-DACS1 TX in-band power density.

The values in Figure 3-2 are not to scale. The "Δf" axis is linear and the "Att" axis is logarithmic. [802.16]/Table 341 has been used as a generic template for determining the frequency breakpoints B, C, and D for an OFDM signal, and then the bandwidth occupied by L-DACS1 has been applied (498.05 kHz, rounded-up to 500 kHz), The corresponding "Att" values have been elicited from the preliminary B-AMC spectral mask provided in [B-AMC D4]/Figure 7-2.

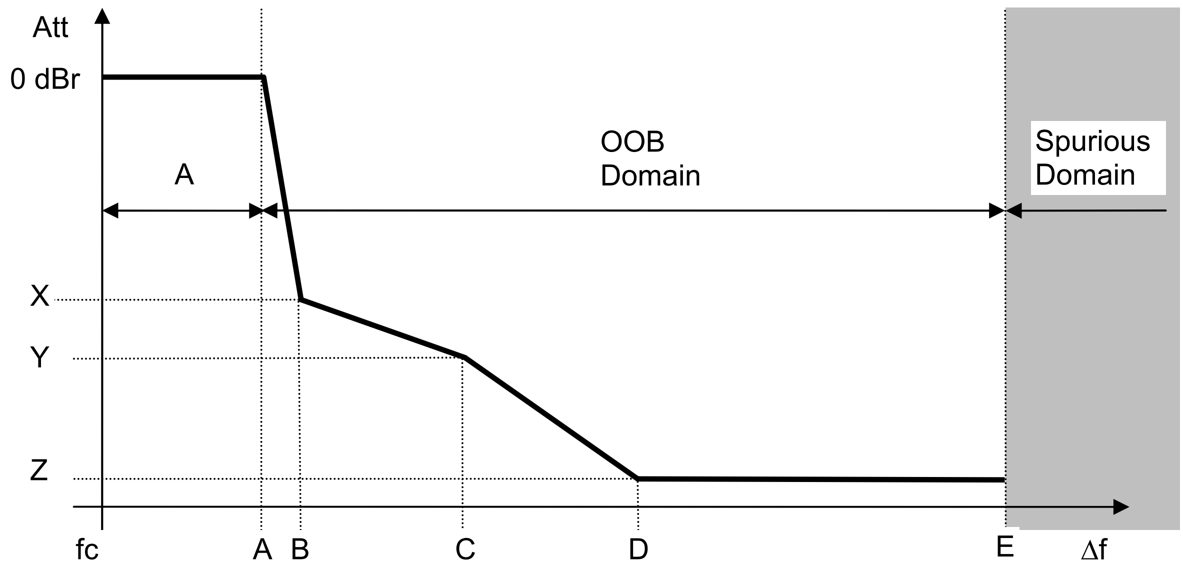

Figure 3-2: GS TX Spectral Mask

Table 3-1: GS TX Spectral Mask

	A	B = 1.15*A	C = 2.5*A	D = 3.1*A	E=2.5*B_{eff}	≥ E
Δf (kHz)	250	287.5	625	775	1.245	≥ 1.245
Att (dBr)	0	X=-40	Y=-56	Z=-76	Z=-76	<spurs>

3.1.9 GS TX Occupied Bandwidth

The 98% of the GS TX signal power shall lie within the nominal bandwidth B_{eff} = 498.05 kHz (Table 3-2).

3.1.10 GS TX Time/Amplitude Profile

GS TX transmissions are continuous, without ramp-up or ramp-down phases.

3.2 GS TX Baseband Characteristics

3.2.1 GS TX Symbol Clock Frequency Tolerance

GS TX centre frequency and the symbol clock frequency shall be derived from the same reference oscillator.

At the GS TX, the reference frequency accuracy shall be better than ± 0.1 ppm.

GS TX shall always send by respecting its current local clock status.

3.2.2 GS TX Maximum Number of Used Sub-carriers

The GS TX uses in all FL frames the maximum number of OFDM sub-carriers ($N_{used} = N_u =$ 50 sub-carriers) except for the synchronisation symbols where some sub-carriers are not transmitted (Section 3.3.2.1).

The N_u figure above does not include the DC sub-carrier at zero offset that is not transmitted.

3.3 GS TX PHY Layer Characteristics

In the GS TX prototype, only parts of the PHY layer functionality specified in [D2] have to be implemented. The basic functionality of the GS TX prototype is illustrated in a block diagram in Figure 3-3.

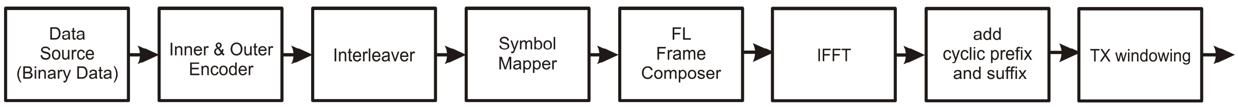

Figure 3-3: Simplified Block Diagram of GS TX

Binary input data are encoded and modulated as specified in Section 3.3.3. In the frame composer, OFDM frames are generated as specified in [D2]. Thereby, the special characteristics of different frame types (i.e. synchronisation symbols, pilot symbols) as well as the SF structure are fully taken into account. Afterwards, the OFDM signal is transformed to the time domain OFDM-symbol-wise and a cyclic prefix and suffix are added to enable TX windowing in the next step.

In the following, the parts of the PHY layer specification from [D2] relevant for the prototype GS TX are recapitulated.

3.3.1 FL – OFDM Transmission

3.3.1.1 Frequency Domain Description

The typical structure of an FL OFDM symbol in the frequency domain is depicted in Figure 3-4.

An OFDM symbol consists of N_{FFT} sub-carriers, which can be occupied by:

- Null symbols i.e. unmodulated sub-carriers in guard bands, the DC sub-carrier, and inactive sub-carriers,
- Data symbols, used for transmission of user data,
- Pilot symbols, used for channel estimation purposes,
- Synchronisation symbols, occupied by synchronisation sequences.

$N_{g,left}$ sub-carriers on the left and $N_{g,right}$ sub-carriers on the right side of the signal spectrum are used as guard bands, additionally the DC sub-carrier is not used. This results in N_u available sub-carriers used for data symbols, pilot symbols, and synchronisation sequences.

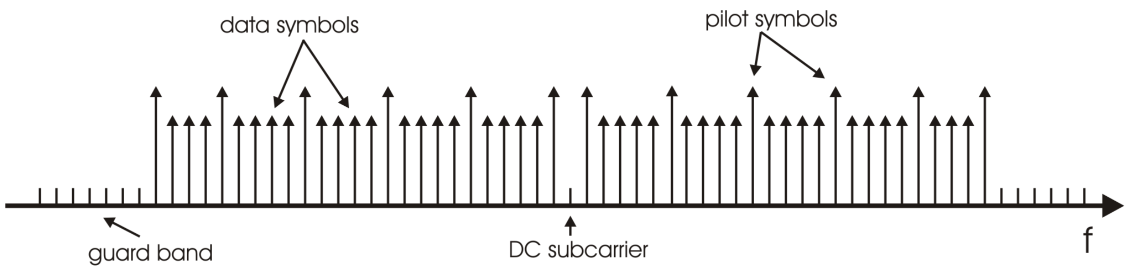

Figure 3-4: OFDM Symbol, Frequency Domain Structure

3.3.1.2 Time Domain Description

The inverse Fourier transform of a frequency domain OFDM symbol creates the OFDM time domain waveform. The duration of this signal is referred to as the useful symbol time T_u.

A copy of the last T_{cp} of the useful symbol period, termed cyclic prefix (CP), is added in front of the useful symbol period. A T_w part of this CP is used for windowing; a T_g part provides a tolerance for symbol time synchronisation errors and resistance to inter-symbol interference (ISI). In addition to the cyclic prefix, a cyclic postfix of length T_w is added. For applying windowing, the cyclic postfix and a T_w part of the cyclic prefix are multiplied with a decaying window.

Finally, the OFDM symbols are stringed together, whereby the postfix of an OFDM symbol overlaps with a T_w part of the CP of the subsequent OFDM symbol. Figure 3-5 shows this procedure in two steps. The windowing method is addressed in Section 3.3.5.

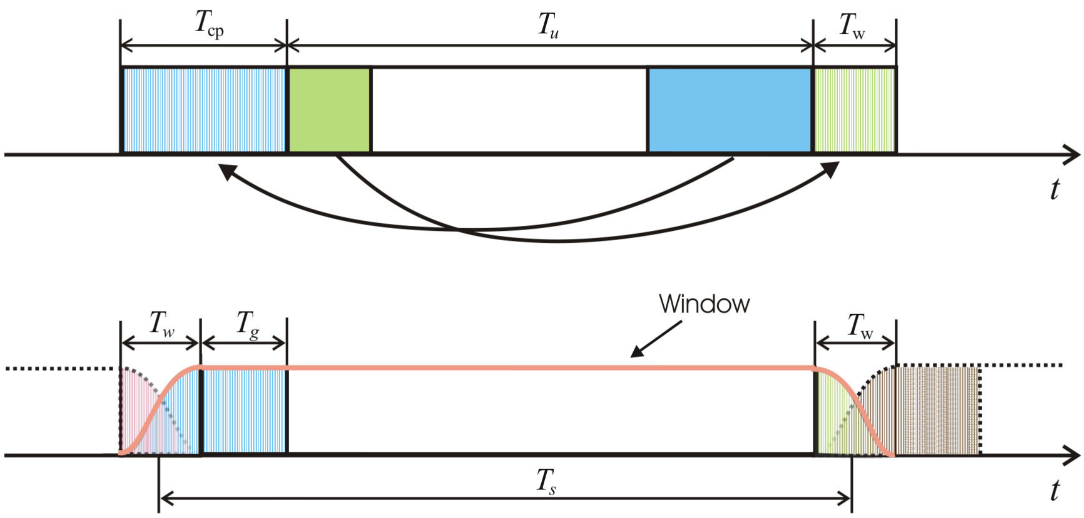

Figure 3-5: OFDM Symbol, Time Domain Structure

3.3.1.3 OFDM Parameters

The basic OFDM parameters relevant for the GS TX are listed in Table 3-2.

Table 3-2: OFDM Parameters in FL

Parameter	**Value**
FFT size: N_{FFT}	64
Sampling time: T_{sa}	1.6 µs
Sub-carrier spacing: Δf	9.765625 kHz
Useful symbol time: T_u	102.4 µs
Cyclic prefix ratio: $G = T_{cp} / T_u$	11/64

Cyclic prefix time: T_{cp}	17.6 µs
OFDM symbol time: T_s	120 µs
Guard time: T_g	4.8 µs
Windowing time: T_w	12.8 µs
Number of used sub-carriers: N_u	50
Number of lower frequency guard sub-carriers: $N_{g,left}$	7
Number of higher frequency guard sub-carriers: $N_{g,right}$	6
Sub-carrier indices of guard sub-carriers	-32, -31,…, -26 26, 27,…, 31
Total FFT bandwidth $B_0 = N_{FFT} * \Delta f$	625.0 kHz
Effective RF bandwidth $B_{eff} = (N_u+1) * \Delta f$	498.05 kHz (incl. DC sub-carrier)

3.3.2 Physical Frame Characteristics

OFDM symbols are organised into OFDM frames. Depending on the data to be transmitted different types of OFDM frames are defined, as described in the following sections. All frame types can be figuratively represented by a set of symbols in a time-frequency plane.

Symbol positions are noted with (t, f) indices, where the time index t takes the values between 1 and N_{OFDM}, with N_{OFDM} being the total number of OFDM symbols within one frame. The frequency index f takes values between -32 and 31 with f = 0 representing the DC sub-carrier. The numbering starts with the guard symbol in the upper left corner with the symbol position (1,-32), as illustrated in Figure 3-6.

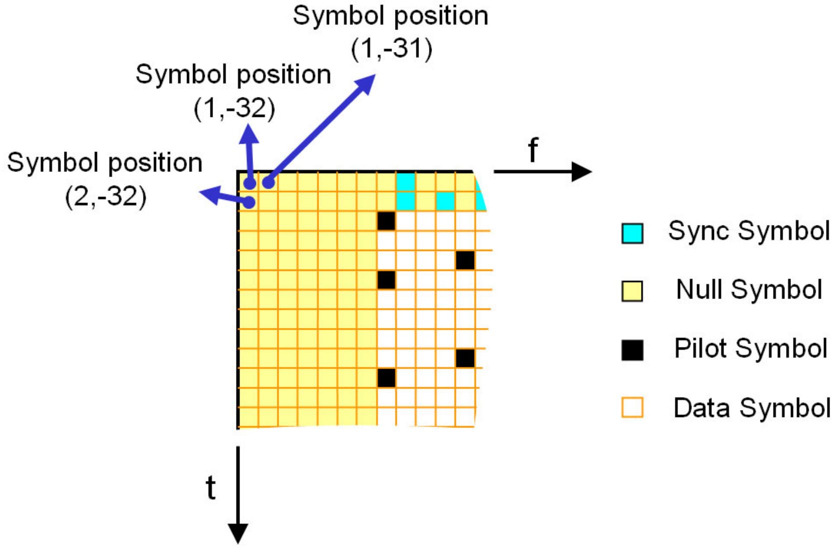

Figure 3-6: Numbering of the Symbols in the Time-Frequency Plane

3.3.2.1 Forward Link Frame Types

3.3.2.1.1 FL Data/Common Control Frame

The structure of an FL Data/Common Control (CC) frame is depicted in Figure 3-7. It contains 54 OFDM symbols resulting in a frame duration of $T_{DF/CC}$ = 6.48 ms.

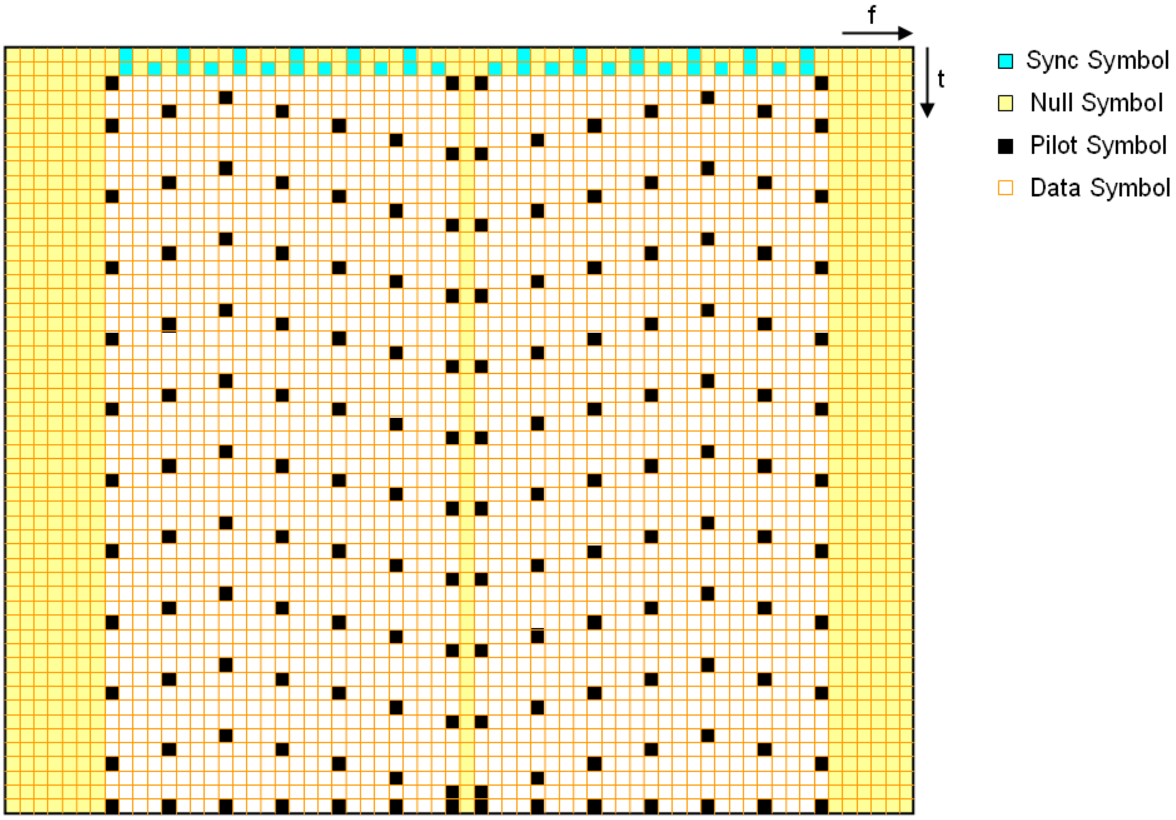

Figure 3-7: Structure of an FL Data/CC Frame

The first two OFDM symbols contain synchronisation sequences. The remaining 52 OFDM symbols contain data symbols as well as pilot symbols.

The pilot pattern is depicted in Figure 3-7 and described in Table 3-3. Apart from the first and last OFDM symbol in the frame, the pilot pattern repeats every 5 OFDM symbols. The total number of 158 pilot symbols leads to a total data capacity of $(52 * 50 - 158) = 2442$ symbols per FL Data/CC frame.

Table 3-3: Pilot Symbol Positions for FL Data/CC Frame

OFDM symbol position n		Pilot symbol positions
n = 3		-25, -1, 1, 25
n = 3+5·p + i, p = 0,...,9	i = 1	-17, 17
	i = 2	-21, -13, 13, 21
	i = 3	-25, -9, 9, 25
	i = 4	-5, 5
	i = 5	-1, 1
n = 54		-25, -21, -17,-13, -9, -5, -1, 1, 5, 9, 13, 17, 21, 25

3.3.2.1.2 FL Broadcast Frame

A FL broadcast (BC) frame consists of three consecutive sub-frames (BC1/BC2/BC3). Figure 3-8 shows the structure of these sub-frames.

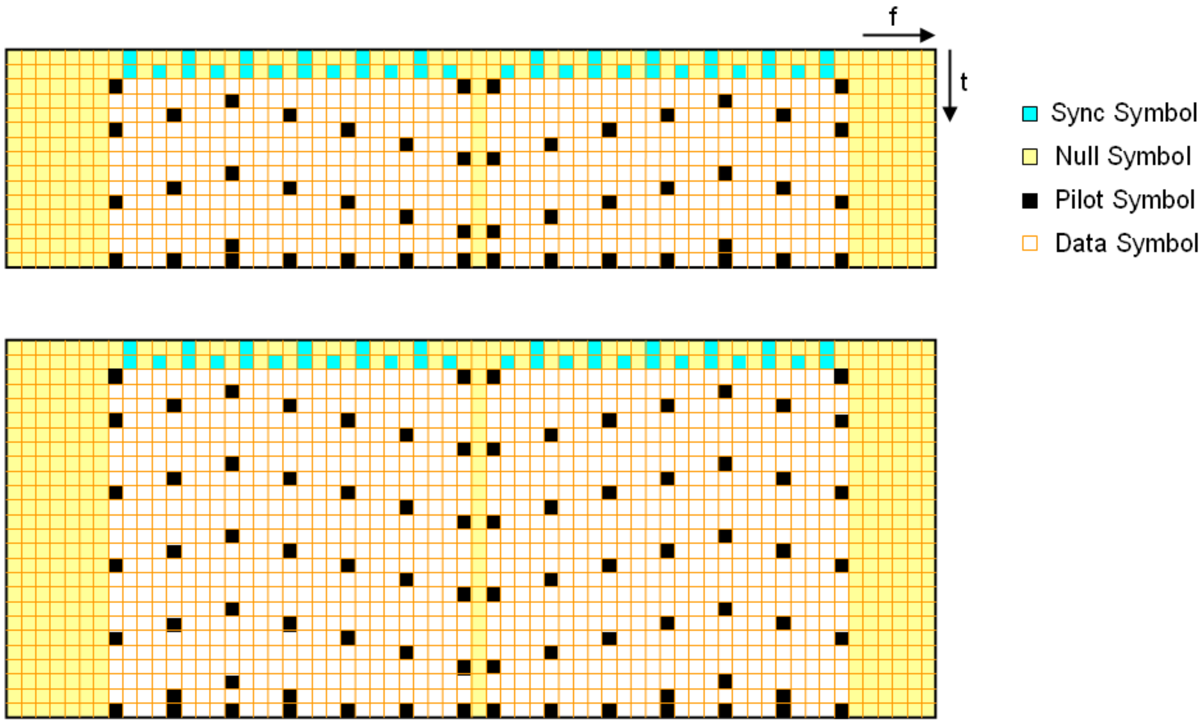

Figure 3-8: Structure of BC1/BC3 Sub-frames (above) and BC2 Sub-frame (below)

All sub-frames start with the same synchronisation sequence (two consecutive synchronisation symbols) that is also used in FL CC/Data frames, followed by 13 OFDM symbols in the BC1 and the BC3 sub-frame and by 24 OFDM symbols in the BC2 sub-frame. The frame duration is T_{BC1} = T_{BC3} =1.8 ms for the BC1 and the BC3 sub-frame and T_{BC2} = 3.12 ms for the BC2 sub-frame, resulting in an overall duration of the broadcast frame of T_{BC} = 6.72 ms.

The arrangement of the pilot symbols follows the pattern given in Table 3-4 and Table 3-5. The number of pilot symbols is 48 for the BC1 and the BC3 sub-frame and 80 for the BC2 sub-frame, resulting in a data capacity of (13∗50 – 48) = 602 symbols for the BC1 and the BC3 sub-frame and (24∗50 – 80) = 1120 symbols for the BC2 sub-frame, respectively. The total data capacity of the FL BC frame is 2∗602 + 1120 = 2324 symbols.

Table 3-4: Pilot Symbol Positions for BC1 and BC3 Sub-frame

<table>
<tr><td colspan="2">OFDM symbol position n</td><td>Pilot symbol positions</td></tr>
<tr><td colspan="2">n = 3</td><td>-25, -1, 1, 25</td></tr>
<tr><td rowspan="5">n = 3+5·p + i, p = 0,1</td><td>i = 1</td><td>-17, 17</td></tr>
<tr><td>i = 2</td><td>-21, -13, 13, 21</td></tr>
<tr><td>i = 3</td><td>-25, -9, 9, 25</td></tr>
<tr><td>i = 4</td><td>-5, 5</td></tr>
<tr><td>i = 5</td><td>-1, 1</td></tr>
<tr><td colspan="2">n = 14</td><td>-17, 17</td></tr>
</table>

Table 3-5: Pilot Symbol Positions for BC2 Sub-frame

<table>
<tr><td colspan="2">OFDM symbol position n</td><td>Pilot symbol positions</td></tr>
<tr><td colspan="2">n = 3</td><td>-25, -1, 1, 25</td></tr>
<tr><td rowspan="5">n = 3+5·p + i, p = 0,...,3</td><td>i = 1</td><td>-17, 17</td></tr>
<tr><td>i = 2</td><td>-21, -13, 13, 21</td></tr>
<tr><td>i = 3</td><td>-25, -9, 9, 25</td></tr>
<tr><td>i = 4</td><td>-5, 5</td></tr>
<tr><td>i = 5</td><td>-1, 1</td></tr>
<tr><td colspan="2">n = 24</td><td>-17, 17</td></tr>
</table>

n = 15	-25, -21, -17,-13, -9, -5, -1, 1, 5, 9, 13, 17, 21, 25

n = 25	-21, -13, 13, 21
n = 26	-25, -21, -17,-13, -9, -5, -1, 1, 5, 9, 13, 17, 21, 25

3.3.2.2 Framing

The L-DACS1 physical layer framing is hierarchically arranged. In Figure 3-9 and Figure 3-10, this framing structure is illustrated from the SF down to the OFDM frames. One SF has a duration of T_{SF} = 240 ms.

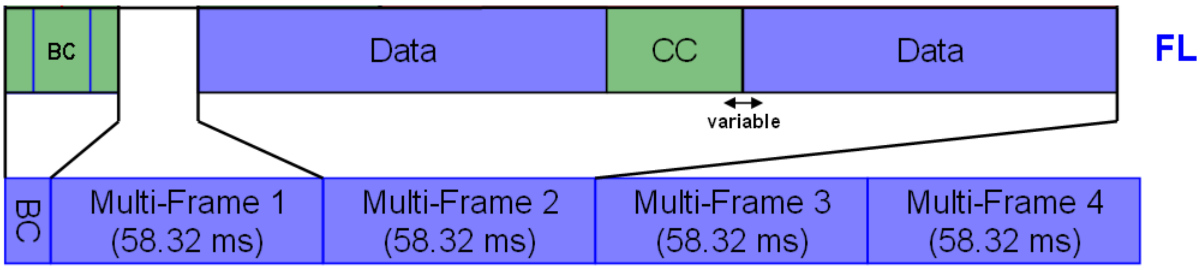

Figure 3-9: Super-Frame Structure

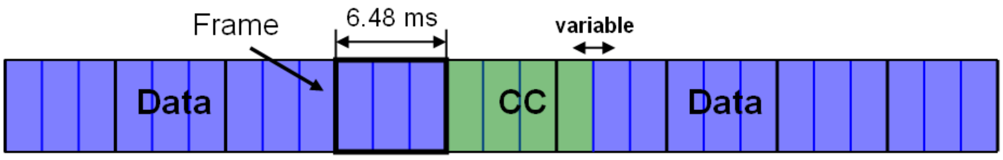

Figure 3-10: Multi-Frame Structure

In the FL, an SF contains a broadcast frame (BC) of duration T_{BC} = 6.72 ms, and four Multi-Frames (MF), each of duration T_{MF} = 58.32 ms. One FL BC1/BC3 PHY-PDU is mapped onto one BC1 and one BC3 sub-frame, respectively. One FL BC2 PHY-PDU is mapped onto one BC2 sub-frame. The number of data symbols in the BC sub-frames corresponds to the size of the FL BC PHY-PDUs. One MF is subdivided into 9 Data/CC frames. Onto these frames, FL Data PHY-PDUs are mapped. The size of an FL Data PHY-PDU is 814 symbols, i.e. 1/3 of an FL Data/CC frame. The numbering of the FL PHY-PDUs shall start at the beginning of the MF.

3.3.2.3 Framing Specifics for GS TX Prototype Implementation

Since transmission of random data is sufficient for laboratory testing at the physical layer, there is no need to distinguish between CC and Data PHY-PDUs. Hence, 27 FL Data PHY-PDUs and no FL CC PHY-PDU are mapped onto one MF.

The data to be transmitted on FL are provided by a random source that provides FL PHY-PDUs. The size and the number of FL PHY-PDUs shall match the capacity of the different types of frames.

3.3.3 Coding and Modulation

3.3.3.1 Channel Coding

As FEC scheme, L-DACS1 uses a concatenation of an outer Reed-Solomon (RS) code and an inner variable-rate convolutional code. The coding and interleaving procedure is illustrated in Figure 3-11.

At the TX side, the information bits first enter the RS encoder. Afterwards, zero-terminating convolutional coding is applied. In a last step, the coded bits are interleaved, using a permutation interleaver.

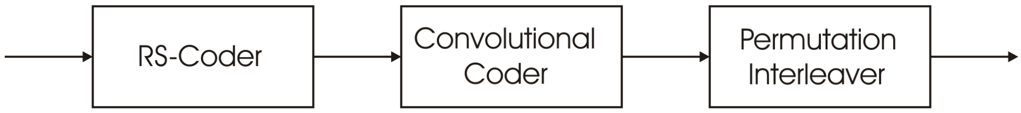

Figure 3-11: Channel Coding and Interleaving

For the termination of the inner convolutional code, six zero bits are added to the end of the data block before convolutional encoding.

If the number of bits to be coded and modulated does not fit to the size of one PHY-PDU, a corresponding number of zero pad bits shall be added after the convolutional coder.

3.3.3.1.1 Outer Coding

An RS code obtained by shortening a systematic RS(N = 2^8-1, K, F) code using Galois field GF(2^8). The primitive polynomial

p(x) = $x^8 + x^4 + x^3 + x^2 + 1$

and the generator polynomial

$$g(x) = \prod_{i=1}^{2F} \left(x + \lambda^i \right), \quad \lambda = 02_{HEX}$$

shall be applied for outer encoding. The RS parameters are as follows:

- K: number of uncoded bytes,
- N: number of coded bytes,
- $F = floor\left(\frac{N-K}{2}\right)$ is the number of bytes that can be corrected

3.3.3.1.2 Inner Coding

Each output data block of the RS encoder is encoded by a non-recursive binary convolutional coder. Zero-termination of each data block is applied. The generator polynomials of the coder are given by:

- $G_1 = 171_{OCT}$, for the first output
- $G_2 = 133_{OCT}$, for the second output.

The native coding rate is r_{cc} = ½, the constraint length is equal to 7. The block diagram of the coder is given in Figure 3-12.

Other coding rates can be derived by puncturing the native code. However, this is not required in the GS TX prototype.

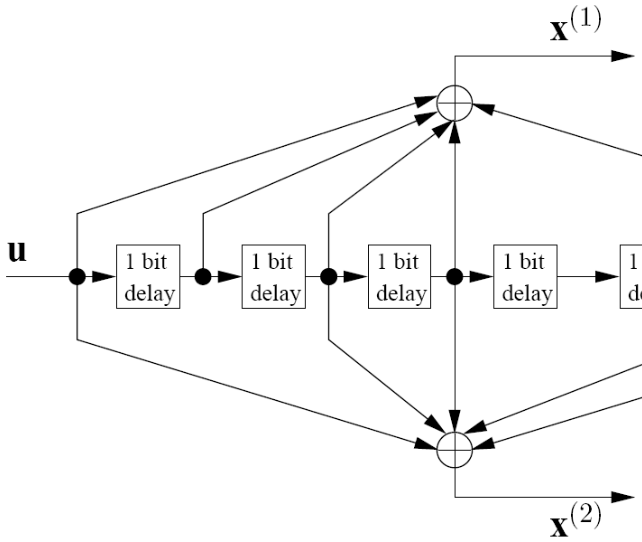

Figure 3-12: Block Diagram of Convolutional Coder (171,133,7)

In the prototype implementation, QPSK modulation, a fixed RS code and a convolutional code with rcc = ½ is mandatory for the FL Data and BC PHY-PDUs. Adaptive Coding and Modulation (ACM) needs not to be implemented.

Table 3-6 gives the modulation schemes, channel coding parameters and block sizes only for the FL PHY-PDUs that must be implemented for GS TX prototype equipment.

In the prototype, no FL CC PHY-PDUs are used and only FL Data PHY-PDUs are mapped onto the MF. Hence, no coding parameters are given for FL CC PHY-PDUs in Table 3-6.

The modulation scheme is described in Section 3.3.3.3.

Table 3-6: Parameters for FL Data and FL BC PHY-PDUs

PHY-PDU type	Modulation	Convolutional Coding Rate	RS Parameter	Total Coding Rate	Number of uncoded bits	Number of coded bits
FL Data PHY-PDU	QPSK	1/2	RS(101, 91, 5)	0.45	728	1628
FL $BC_{1/3}$ PHY-PDU	QPSK	1/2	RS(74, 66, 4)	0.45	528	1204
FL BC_2 PHY-PDU	QPSK	1/2	RS(139, 125, 7)	0.45	1000	2240

In case the BC frames are not used for the BER measurements, coding can be omitted in the BC PHY-PDUs. Then, the size of the BC PHY-PDU has to be increased to the maximum capacity. In this case, the size of the BC1/3 PHY-PDU and the BC2 PHY-PDU is 1204 and 2240 bits, respectively.

3.3.3.2 Interleaving

The interleaving of the output of the convolutional encoder is done by a permutation interleaver. This ensures that the coded bits are evenly spread across the time-frequency plane.

The block size of the interleaver N_I complies with the coding block sizes. These are equivalent to the number of coded bits in Table 3-6.

The following equation specifies the permutation of the interleaver

$$m_k = \left(16 \cdot k + floor\left(\frac{16 \cdot k}{N_I} + floor\left(\frac{\left(16 \cdot k\right)_{\mathrm{mod}\,N_I} + floor\left(\frac{16 \cdot k}{N_I}\right)}{N_I} \right) \right) \right)_{\mathrm{mod}\,N_I} \qquad k = 0,1,\ldots,N_I - 1.$$

Here, k is the index of an encoded data bit before the permutation and m_k is the index of the encoded data bit after the permutation.

3.3.3.3 Modulation

After the interleaving, the encoded data bits enter serially the constellation mapper. In addition to QPSK, [D2] specifies 16-QAM and 64-QAM as possible modulation options for FL Data PHY-PDUs.

Only Gray-mapped QPSK as shown in Figure 3-13 shall be supported by the GS TX prototype.

The constellation diagram of the modulation is normalised to an average power of 1 by multiplying the constellation points with the indicated factor c. In Figure 3-13, b_0 denotes the Least Significant Bit (LSB).

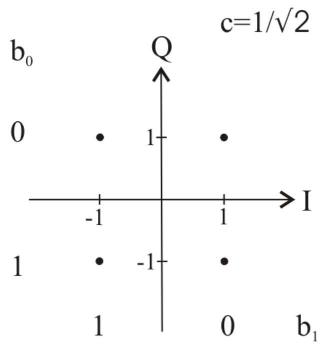

Figure 3-13: Constellation Diagram for QPSK

The modulation rate r_{mod} is 2 bits/modulation symbol for QPSK.

3.3.3.4 Data mapping onto frames

The MAC sub-layer provides the PHY layer with PHY-PDUs of the correct size. The PHY layer maps the PHY-PDUs onto frames by just positioning the complex symbols onto the time-frequency plane after coding and modulation.

As a part of the layer interaction, described in Section 3.4, additional signalling information is locally exchanged between the PHY and the MAC sub-layer, but is not transmitted from TX to RX.

Before mapping modulated symbols onto a BC or a Data/CC frame, two OFDM symbols with the synchronisation preamble and pilot symbols shall be inserted into an FL frame. Pilot insertion follows the pilot pattern defined in Section 3.3.4.1.

Modulated symbols shall be mapped in time direction onto the FL frame or sub-frame, i.e. symbols are placed subsequently on the free positions in the following order: (1,-25) (2,-25) (3,-25) … (1,-24) (2,-24) etc. Symbol positions are defined in Section 3.3.2. Data mapping in time direction is illustrated in Figure 3-14.

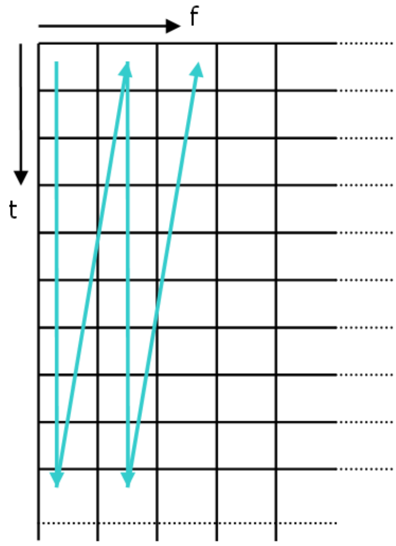

Figure 3-14: Mapping of Modulated Data onto Frames

In the BC sub-frames, exactly one FL PHY-PDU shall be mapped onto one sub-frame.

In Data/CC frames, three FL Data PHY-PDUs are mapped onto one frame. Table 3-7 provides the indices of the OFDM symbols and sub-carriers, on which the FL Data PHY-PDUs shall be mapped. Note that the table ignores pilot symbols and the DC sub-carrier, i.e. the PHY-PDUs shall be mapped only onto free positions in the section of the frame as given by the indices.

Table 3-7: Mapping Indices for Data PHY-PDUs

Number of the FL PHY-PDU	OFDM symbol index	Sub-carrier index
1	3,…,19	-25,…,-1,1,…,25
	20	-25,…,-12
2	20	-11,…,-1,1,…,25
	21,…,36	-25,…,-1,1,…,25
	37	-25,…,-1,1,2
3	37	3,…,25
	38,…,54	-25,…,-1,1,…,25

3.3.4 Pilot- and Synchronisation-Sequences

In this section, the sequences and preambles used for synchronisation and channel estimation (CE) are described.

3.3.4.1 Pilot Sequences

Pilot sequences defined in this section shall be inserted in the FL frames. The mapping shall be applied in frequency direction, i.e. consecutively on the OFDM symbols which contain pilot symbols. The exact pilot positions on which the pilot symbols shall be mapped are defined in Table 3-3, Table 3-4 and Table 3-5 for the FL.

For the frames in the FL, the following pilot sequence S_{pilot} shall be used:

S_{pilot} = {-1, 1, -1, 1, 1, 1, 1, 1, 1, -1, 1, 1, 1, -1, 1, 1, 1, 1, -1, 1, -1, 1, -1, 1, -1, 1, 1, -1, 1, 1, 1, 1, 1, 1, 1, -1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, -1, 1, 1, -1, 1, 1, 1, -1, -1, 1, -1, -1, -1, 1, -1, 1, -1, -1, -1, 1, -1, 1, -1, 1, 1, 1, -1, 1, -1, 1, 1, 1, 1, -1, 1, -1, 1, 1, 1, -1, 1, 1, -1, 1, 1, 1, -1, 1, -1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, -1, -1, 1, 1, 1, 1, -1, 1, 1, -1, -1, -1, -1, 1, 1, -1, 1, -1, -1, -1, 1, 1, -1, -1, -1, 1, 1, -1, 1, -1, -1, -1, -1, 1, -1, -1, -1, 1, 1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, 1, -1, -1}

For the particular FL frames, the pilot sequences are defined as follows:

- In an FL Data/CC frame: $S_{Data/CC} = S_{pilot}$ (1,…, 158)
- In an FL BC1/3 sub-frame: $S_{BC1/3} = S_{pilot}$ (1,…, 48)
- In an FL BC2 sub-frame: $S_{BC2} = S_{pilot}$ (1,…, 80)

Prototype GS TX shall allow to boost pilot tones 2.5 dB above other modulated symbols or to transmit these tones without boosting. The boosting level shall be configurable via a parameter.

3.3.4.2 Synchronisation Sequences

All FL synchronisation OFDM symbols in all FL frames are structured as depicted in Figure 3-15. In the first OFDM symbol, every forth sub-carrier of the used spectrum is occupied by a synchronisation symbol. The indices of these sub-carriers are given in Table 3-8. As a result, the time domain waveform of the first OFDM symbol consists of four identical parts. The occupation of the even sub-carriers of the used spectrum in the second synchronisation OFDM symbol yields a time domain waveform with two identical halves.

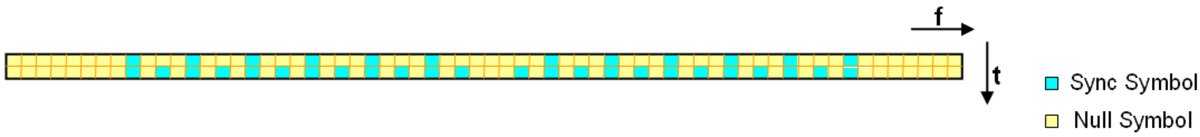

Figure 3-15: Structure of the Synchronisation OFDM Symbols

Table 3-8: Synchronisation Symbol Position

Synchronisation OFDM symbol number	Synchronisation symbol positions
1	-24, -20, -16, -12, -8, -4, 4, 8, 12, 16, 20, 24
2	-24, -22, -20, -18, -16, -14, -12, -10, -8, -6, -4, -2, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24

The structure of the two synchronisation OFDM symbols in the time domain is depicted in Figure 3-16. The synchronisation sequences in the frequency domain shall be calculated by

$$S_{sy1,k} = \sqrt{4}\exp\left(j \cdot \pi \frac{5k^2}{N_{sy1}}\right) \quad ,k = 0,\dots,N_{sy1}-1$$

and

$$S_{sy2,k} = \sqrt{2}\exp\left(j \cdot \pi \frac{k^2}{N_{sy2}}\right) \quad ,k = 0,\dots,N_{sy2}-1$$

with

- $S_{sy1/2}$: Synchronisation symbols for the first and the second OFDM synchronisation symbol,

- $N_{sy1/2}$: Number of synchronisation symbols per OFDM synchronisation symbol (12 for the first OFDM synchronisation symbol and 24 for the second OFDM synchronisation symbol).

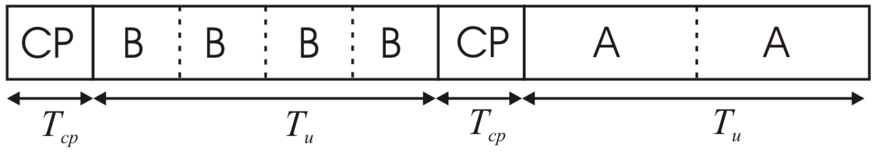

Figure 3-16: Time Domain Representation of Synchronisation OFDM Symbols

3.3.5 Reduction of Out-of-Band Radiation by Means of TX Windowing

In Section 3.3.1.2, the generation of the time domain TX signal is described, including windowing. In this section, the windowing operation is described more detailed.

TX windowing is applied in order to smooth the sharp phase transitions between consecutive OFDM symbols which cause out-of-band radiation. The windowing function is illustrated in Figure 3-17.

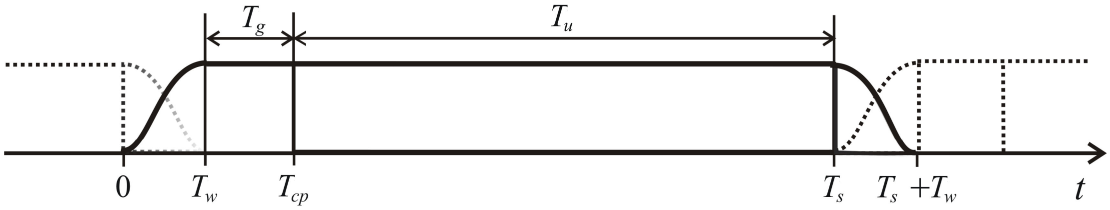

Figure 3-17: Windowing Function

The raised cosine (RC) function with a roll-off factor of α = 0.107, given by

$$w(t) = \begin{cases} \frac{1}{2} + \frac{1}{2}\cos\left(\pi + \frac{\pi t}{T_w}\right) & 0 \le t < T_w \\ 1 & T_w \le t < T_s \\ \frac{1}{2} + \frac{1}{2}\cos\left(\frac{\pi\left(t - T_s\right)}{T_w}\right) & T_s \le t < T_s + T_w \\ 0 & else \end{cases}$$

shall be applied for windowing. The duration of the rising/falling edges of the window is defined as

$$T_w = \left(T_u + T_g\right)\frac{\alpha}{1-\alpha}.$$

The following equation specifies the complex baseband signal of the l-th OFDM symbol within one frame, before windowing the signal

$$s_l(t) = \begin{cases} \sum_{k=-N_u/2}^{N_u/2-1} c_{k,l} \cdot \exp\left\{ j2\pi k\Delta f\left(t - T_{cp}\right)\right\} & 0 \le t < T_s + T_w \\ 0 & else \end{cases}$$

where $c_{k,l}$ specifies data symbols, pilot symbols, synchronisation symbols, PAPR reduction symbols or AGC preamble symbols. TX windowing results from the following multiplication

$$s_{l,wi}(t) = s_l(t) \cdot w(t).$$

Finally, the continuous complex baseband signal is obtained by partially overlapping the consecutive OFDM symbols:

$$s(t) = s_{0,wi}(t) + s_{1,wi}\left(t - T_s\right) + \ldots + s_{l,wi}\left(t - l \cdot T_s\right).$$

3.3.6 Physical Layer Parameters

Basic OFDM parameters are given in Table 3-2. Parameters of the framing structure and all other parameters which were defined or mentioned in this chapter are listed in Table 3-9. In addition, a reference to the corresponding section in this chapter is provided.

Table 3-9: Physical Layer Parameters

Parameter (defined in Section)	Abbr.	Value	Unit
Number of OFDM symbols within one frame (3.3.2)	N_{OFDM}	54 (Data/CC frame) 56 (BC frame)	
Duration of a Data/CC frame (3.3.2.1)	$T_{DF/CC}$	6.48	ms
Duration of a BC1 and BC3 sub-frame (3.3.2.1)	$T_{BC1/3}$	1.8	ms
Duration of a BC2 sub-frame (3.3.2.1)	T_{BC2}	3.12	ms
Duration of a BC frame (3.3.2.1)	T_{BC}	6.72	ms
Duration of a Super-Frame (3.3.2.2)	T_{SF}	240	ms
Duration of a Multi-Frame (3.3.2.2)	T_{MF}	58.32	ms
Number of input byte of a RS code word (3.3.3.1)	K	variable	
Number of output byte of a RS code word (3.3.3.1)	N	variable	
Native coding rate of convolutional coder (3.3.3.1)	r_{CC}	1/2	
Size of a coding block (3.3.3.1)	N_I	variable	
Multiplication factor for the modulation (0)	c	$1/\sqrt{2}$	
Modulation rate (0)	r_{mod}	2	bits/modulation symbol
Roll-off factor for RC window (3.3.5)	α	0.107	

3.4 GS TX Protocol Characteristics

A detailed specification for L-DACS1 protocol entities above PHY layer is provided in [D2].

For laboratory testing purposes, the full-size MAC sub-layer described in [D2] can be replaced by a reduced functionality which regulates the segmentation and packaging of a continuous data stream from an external interface.

The pseudo-random data to be transmitted in the FL PHY-PDUs are expected to be generated by an external source. The simple GS TX MAC layer shall support segmenting and packaging of the test data received from an external test source, which shall provide PHY-PDUs that can be directly mapped onto the GS TX FL frames (Section 3.3.3.4). The size and number of the FL PHY-PDUs corresponds to the capacity of the different types of frames and complies with the defined SF timing (Section 3.3.2.2).

In the prototype GS TX implementation, multiple PHY parameters that would be normally set via MAC sub-layer are configured directly at the PHY layer, e.g.

- All Data/CC frames are filled with FL Data PHY-PDUs, i.e. one MF contains 27 FL Data PHY-PDUs.
- In the Data PHY-PDUs coding and modulation are set to QPSK and convolutional coding with rate r_{cc}=½ in concatenation with a RS code as given in Table 3-6.
- If only TX spectrum measurements and AS RX BER evaluation of the Data/CC frames are of interest, coding in the BC sub-frames can be switched off. Otherwise, coding has to be implemented according to Table 3-6.
- The detailed data content of BC sub-frames is irrelevant for both GS TX spectrum measurements (as long as these data are pseudo-random allowing for realistic PAPR values) and AS RX BER evaluation of the Data/CC frames. However, the BC sub-frames have to be filled with arbitrary data in order to enable a continuous FL transmission.
- An optionally boosting of pilot tones shall be enabled for testing purposes, i.e. the boosting level parameter can be set to 2.5 dB/ 0 dB above the average power of each data symbol.

The parameters to be set are summarised in Table 3-10.

Table 3-10: PHY Layer Framing Parameters for Testing

Parameter	Value
number of FL Data PHY-PDUs per MF	27
number of FL CC PHY-PDUs per MF	0
pilot boosting level	0 or 2.5 dB

These settings must be provided (a priori known) to the AS RX in order to properly emulate the exchange of control messages and to enable proper data detection and decoding.

3.5 GS TX Test Interface

In the normal operation, the GS TX SNDCP functional block would accept IP network data packets on an external interface. These data packets would be further handled by the GS TX DLS function and then handed-over to the GS TX MAC and further to the PHY layer.

However, a much simpler test interface is sufficient for the laboratory GS TX prototype.

The GS TX MAC layer shall support segmenting the test data received from an external test source over the test interface. In order to enable BER measurements, the randomly generated data stream provided to the GS TX has to be stored as a reference. The test data sequence detected by the AS RX is also stored and forwarded to an external evaluation tool.

It is proposed to perform the comparison of TX and RX bits separately for each SF, based on the data content of an entire SF. In this case, the BC frame may be used to provide SF numbering as an indication for a correct mapping/correct comparison of TX data to RX data. The usage of BC frames for BER measurements is only optional.

Alternatively, BER measurements can be performed directly by the AS RX, if no external test source is available. In that case, always the same data would be repetitively transmitted. A-priori known TX data sequence would be pre-stored at the RX as a reference, compared to the received test data and the outcome (measured BER) provided on an external interface. However, this option is only considered as the second choice.

CHAPTER 4 – Aircraft Station Transmitter

This section comprises specification items that are specific to the prototype implementation of the L-DACS1 Airborne Station (AS) TX operating in the A/G mode.

Deviations from the L-DACS1 system specification (deliverable D2 of this task) that are proposed for more efficient prototyping or any other reason are highlighted.

4.1 AS TX Radio Front-end Characteristics

4.1.1 AS TX Frequency Range and Tuning Step

L-DACS1 shall operate as a full duplex system in the 960 –1164 MHz range [D2]. In order to reduce the airborne co-site interference towards the L-DACS1 AS RX, only the spectrum range between 1025.5-1149.5 MHz, currently used by airborne DME interrogators, should be used for AS TX transmission only.

Prototype AS TX shall be capable of operating on any channel within the 1048.5 – 1071.5 MHz range[43].

An extended prototype AS TX range (1025 – 1087 MHz or 1025 – 1150 MHz) would be beneficial for investigating the possibility of operating L-DACS1 FL/RL in other sub-ranges with modified duplexer settings, including closer frequency spacing to fixed-channel SSR systems.

The preliminary deployment concept based on the interference situation in the L-band and estimated duplexer feasibility anticipates that L-DACS1 FL/RL channel blocks would be placed “in the middle” between fixed L-band UAT/SSR channel allocations (978, 1030, 1090 MHz), providing also sufficient margin to the GPS/GALILEO channels in the upper part of the L-band. With that concept, the sub-range for the FL channels is 985.5 – 1008.5 MHz while the sub-range for L-DACS1 RL channels is 1048.5 - 1071.5 MHz.

An AS TX shall be tuneable to any channel within the operating range with a 0.5 MHz step.

The operating channel shall be adjustable via an implementation-specific interface.

[43] The channel frequency corresponds to the nominal position of the DC OFDM sub-carrier in the spectrum of the L-DACS1 signal.

During the trials, prototype AS TX channel shall be tuned to the same channel that is selected for the corresponding GS RX. AS TX channel shall be set 63 MHz above the corresponding GS TX channel.

The duplex spacing of 63 MHz is currently used by airborne DME equipment.

4.1.2 AS TX Centre Frequency Tolerance

AS TX transmit centre frequency and the symbol clock frequency shall be derived from the same reference oscillator.

The accuracy of the AS reference oscillator shall be ± 1 ppm or better.

For the prototype implementation an AS TX shall transmit all RL frames/segments on its nominal, fixed RL frequency.

As an AS TX always transmits on the selected nominal frequency, without applying any frequency pre-adjustment, there is no requirement for implementing the AS TX frequency pre-compensation in the prototype equipment. GS RX shall be able to compensate an initial AS TX-GS RX frequency offset, synchronise in frequency and perform subsequent frequency tracking to any RL frame/segment by adjusting its local frequency based on received synchronisation symbols as it normally does when receiving RL RA frames.

For the optimum tracking performance at the GS RX, an AS TX shall provide a sufficient number of synchronisation symbols within the SF.

The number of synchronisation symbols is configurable (Section 4.4).

AS TX RL transmission shall be frequency locked to the GS. The deviation between the AS TX centre frequency and the GS RX centre frequency shall be less than 2% of the sub-carrier spacing.

As the AS TX is assumed to operate without being supported by the AS RX (and in turn the GS TX), this parameter is not applicable to the prototype AS TX.

4.1.3 AS TX Nominal Transmitting Power

The AS TX nominal transmitting power measured at the TX output terminal averaged over an FL super-frame (240 ms) shall be +41 dBm.

This setting provides assurance that the prototype AS TX can be built and operated at the representative power level (estimated from the L-DACS1 link budget in [D2]) without interfering receivers of other L-band systems.

Due to the transmitter peak-to-average power ratio (PAPR) the instantaneous peak transmitting power may be higher than +41 dBm.

The average transmitting power of an AS TX shall linearly scale with the number of used OFDM sub-carriers.

4.1.4 AS TX Power Dynamic Range

The AS TX shall support monotonic power level control range of minimum 50 dB.

The upper limit of the dynamic range is determined by the rated airborne TX power.

The minimum TX power adjustment step shall be ≤ 1 dB.

TX power level minimum relative step accuracy shall be ± 0.5 dB or better.

The prototype AS TX shall transmit with its nominal power level, without applying any power reduction.

AS TX operating power shall be adjustable via an implementation-specific interface.

The maximum AS TX power setting would normally apply to the boundary of the coverage range where no power correction applies. At a reduced distance to the GS, the GS would *modify AS TX power within the AS TX power dynamic range.*

With the early prototypes no “closed-loop” corrections of the AS TX power-, frequency-, and timing offset will be possible, so there is no requirement for implementing the AS TX variable power regulation within AS TX dynamic range in the prototype equipment. During the laboratory measurements, the required power level of an interfering L-DACS1 AS TX signal will be adjusted via variable attenuators rather than via changing the TX operating point. For fine input signal level adjustments, the GS RX will have to implement AGC that operates over all types of RL frames/segments.

It is recommended to provide a possibility to manually reduce the power of the prototype AS TX by at least 10 dB (down to +31 dBm or less).

This would be desirable for estimating the effect of slightly reduced AS TX power in the laboratory upon the AS TX signal-in-space spectral content (spectral mask, spurious signals). This in turn would allow drawing conclusions about possible tradeoffs between the cell size and the AS TX power.

4.1.5 AS TX Transmitter Spectral Flatness

When AS TX is transmitting on all usable sub-carriers N_u (N_u = 50 is the maximum number of OFDM sub-carriers that are available on RL as specified in Section 4.2.2, the following shall apply:

- Absolute power difference between adjacent sub-carriers: ≤ 0.1 dB (2.5dB allowance should be added for pilot carriers in case pilot boosting is applied via TX configuration).
- Deviation of average power on each sub-carrier (Figure 4-1) from the measured power averaged over all N_u active tones:
    - Sub-carriers from [-12 to -1] and [1 to 12]: ≤ ±2dB
    - Sub-carriers from [-25 to -13] and [13 to 25]: ≤ +2/–4 dB
- The average power transmitted at spectral line 0 shall not exceed –15 dB relative to the total average AS transmitted power of all data and pilot sub-carriers (excluding the pilot sub-carriers that are intentionally power-boosted [44]).

All requirements on the GS transmitter apply to the RF output connector of the equipment.

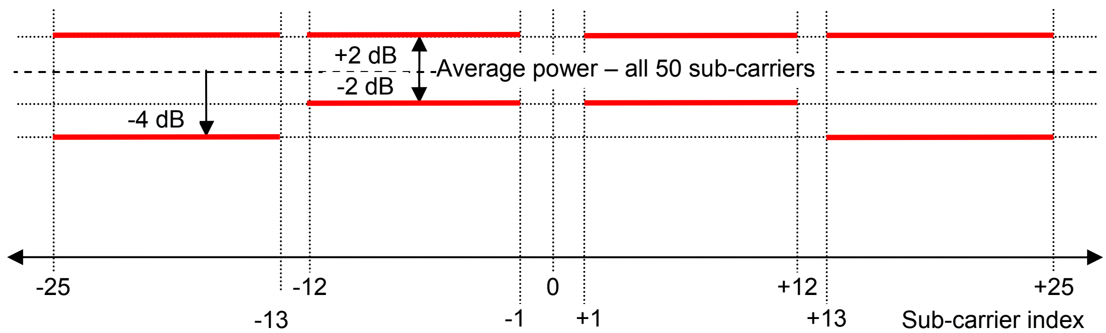

Figure 4-1: TX Spectral Flatness

4.1.6 AS TX Relative Constellation Error

The AS TX relative constellation Root Mean Square (RMS) error with QPSK modulation, averaged over sub-carriers, OFDM frames and packets, shall not exceed – 15 dB.

The relative constellation RMS error is calculated as

[44] See [AGI_RF]

$$\left(Error_{RMS}\right)^2 = \frac{1}{N_f}\sum_{i=1}^{N_f}\frac{\sum_{j=1}^{L_p}\sum_{k\in S}\left[(I(i,j,k)-I_0(i,j,k))^2+(Q(i,j,k)-Q_0(i,j,k))^2\right]}{\sum_{j=1}^{L_p}\sum_{k\in S}\left[I_0(i,j,k)^2+Q_0(i,j,k)^2\right]}$$

where

L_p denotes the number of OFDM symbols used in a measurement (length of the OFDM frame with data relevant to the measurement),

N_f denotes the number of OFDM frames containing data used in the measurement,

[I_0(I,j,k), Q_0(I,j,k)] denotes the ideal symbol point in the complex plane (in the constellation diagram) of the i-th OFDM frame, j-th OFDM symbol of the OFDM frame, k-th sub-carrier of the OFDM symbol modulated with data relevant to this measurement,

[I(I,j,k), Q(I,j,k)] denotes the observed symbol point in the complex plane (in the constellation diagram) of the i-th OFDM frame, j-th OFDM symbol of the OFDM frame, k-th sub-carrier of the OFDM symbol modulated with data relevant to this measurement,

S denotes the group of modulated data sub-carriers where the measurement is performed.

The logarithmic value shall be calculated as 20 $\log_{10}$ ($Error_{\mathrm{RMS}}$).

4.1.7 AS TX Noise and Spurious Emissions

The power of any AS TX spurious signal measured in an active mode at the AS TX output terminated in a matched impedance load shall not exceed -36 dBm.

Spurious emissions should be measured in a reference bandwidth of 100 kHz in the frequency range from 30 MHz to 1 GHz, and in a reference bandwidth of 1 MHz in the frequency band of 1 GHz to 5.1175 GHz.

The range of ±1.245 MHz around the TX operating frequency fc is defined as Out-Of-Band (OOB) range and is regarded separately (Section 4.1.8). The OOB domain boundary (1.245 MHz) is given in Figure 3-2 and in the last column of Table 4-1. The boundary has been calculated based on the occupied bandwidth of the L-DACS1 signal-in-space Beff = 498.05 kHz using the ITU-R definition for the start of the spurious domain [fc-Beff ∗ 2.5 … fc+Beff ∗ 2.5] that was also used for the UAT system [UAT M].

Above 1 GHz, the level of any spurious signal measured in an active mode at the properly terminated AS TX output shall not exceed -60 dBm.

This requirement is based on [V4 MOPS] Section 3.2.3.5 and may be further revised to be brought in line with related requirements for other L-band systems. In particular, it should be clarified whether it should be valid for all frequencies above 1 GHz or just over special sub-bands, e.g. around SSR/GPS/GALILEO channels. For the measurement method, please refer to Section 3.1.7.

The broadband AS TX noise power density measured across the spurious domain (Figure 4-2) in an active mode at the AS TX output terminated in a matched impedance load shall not exceed -130 dBc/Hz.

This preliminary value needs to be confirmed. A more stringent value (-140 dBc/Hz) may be required at larger frequency offsets to protect non-aeronautical systems operating below 960 MHz. Additional AS TX broadband noise attenuation can be achieved via external duplexer or filtering equipment.

A prototype duplexer implementation is not required/not expected for the laboratory tests. However, as the duplexer would also influence the interference performance of the AS TX (in particular out-of-band noise and spurious emissions), it is recommended to implement an external RF BP filter after the AS TX in order to emulate the duplexer behaviour.

The AS TX RF BP filter is described in Section 7.3.

4.1.8 AS TX Spectrum Mask

The spectral density of the AS TX signal shall fall within the spectral mask defined in Figure 4-2 and Table 4-1.

The measurements shall be made by using a 10 kHz resolution bandwidth and a 30 kHz video bandwidth. The 0 dBr level is the L-DACS1 TX in-band power density.

The values in Figure 4-2 are not to scale. The "∆f" axis is linear and the "Att" axis is logarithmic. [802.16]/Table 341 has been used as a generic template for determining the frequency breakpoints B, C, and D for an OFDM signal, and then the bandwidth occupied by L-DACS1 has been applied (498.05 kHz, rounded-up to 500 kHz), The corresponding "Att" values have been elicited from the preliminary B-AMC spectral mask provided in [B-AMC D4]/Figure 7-2.

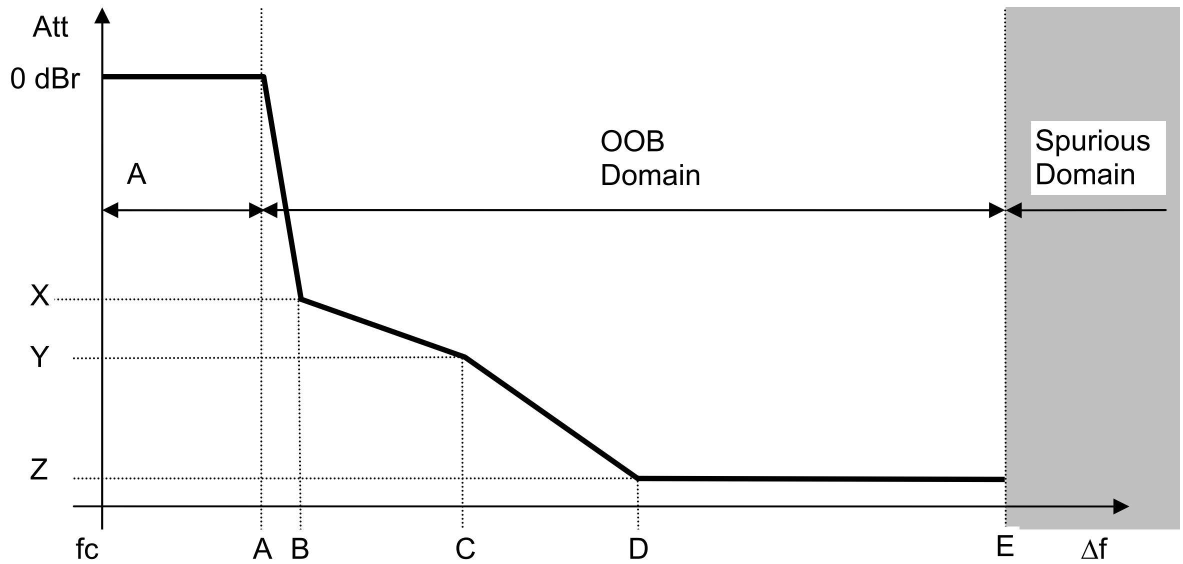

Figure 4-2: AS TX Spectral Mask

Table 4-1: AS TX Spectral Mask

	A	B = 1.15∗A	C = 2.5∗A	D = 3.1∗A	E=2.5∗B_{eff}	≥ E
∆f (kHz)	250	287.5	625	775	1.245	≥ 1.245
Att (dBr)	0	X=-40	Y=-56	Z=-76	Z=-76	<spurs>

4.1.9 AS TX Occupied Bandwidth

With all 50 sub-carriers used, the 98% of AS TX signal spectrum power shall lie within the nominal bandwidth B_{eff} = 498.05 kHz (Table 4-2).

4.1.10 AS TX Time-Amplitude Profile

The ramp-up/ramp-down behaviour of the RL RF shall be as determined by the RC windowing function (Section 4.3.6). The RF burst duration is determined by the duration of the corresponding RL frame and the resource allocation within the frame (Section 4.3.2).

4.2 AS TX Baseband Characteristics

4.2.1 AS TX Symbol Clock Frequency Tolerance

AS TX transmit centre frequency and the symbol clock frequency shall be derived from the same reference oscillator.

The accuracy of the AS reference oscillator shall be ± 1 ppm or better.

Under real circumstances the RL SF reference point would be derived from observed GS TX FL SF boundaries. Initial RL RA transmission is conditioned by the requirement that it shall occur within the RA “frame”.

With the early prototypes no interaction between an AS RX and AS TX will be possible.

For the prototype AS TX it is not required that its SFs should be “sufficiently” aligned with the GS RX SFs prior to the RL transmission attempt.

AS TX SF structure shall be derived from the AS TX local clock.

The prototype GS RX shall derive its SF structure from the RA sub-frames that may initially appear anywhere within the GS RX SF. After that, GS RX SF boundary becomes aligned with the SFs of the transmitting AS TX.

Alternatively, the prototype GS RX may provide its current internal SF framing to the AS TX via an external interface. This interface shall allow for controlling the AS TX SF boundary relative to the GS RX SF boundary, and therefore for adjusting mutual TX-RX timing offset. Via such an adjustment, conditions can be set-up that are similar to these that would apply in reality, when an AS RX determines the GS TX framing on FL and provides it to the AS TX to be used on RL. An intentional timing offset could be injected at the AS TX interface, reflecting the real situation where some residual timing error remains after initial FL time synchronisation.

When transmitting, AS TX shall not apply any timing pre-adjustment.

There is no requirement for implementing the AS TX timing pre-compensation in the prototype equipment.

4.2.2 AS TX Maximum Number of Used Sub-carriers

The AS TX shall be configurable to use either $N_{used} = N_u /2$ or $N_{used} = N_u$ OFDM sub-carriers, where $N_u = 50$ is the maximum possible number of sub-carriers), except for the RL RA frames where a fixed pre-defined number of sub-carriers is used (Section 4.3.2).

This parameter shall be adjustable via an implementation-specific interface.

4.3 AS TX PHY Layer Characteristics

In the AS TX prototype, parts of the PHY layer functionality as specified in [D2] have to be implemented. The basic functionality of the AS TX prototype is illustrated in the block diagram in Figure 4-3.

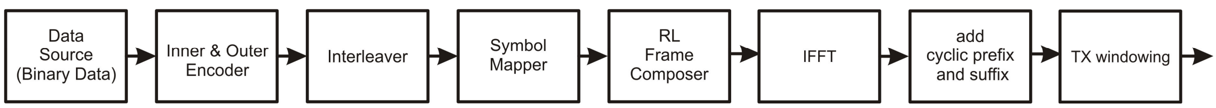

Figure 4-3: Simplified Block Diagram of AS TX

Binary input data are encoded and modulated as specified in Section 4.3.3. In the frame composer, OFDM frames are generated as specified in [D2]. Thereby, the special characteristics of different frame types (i.e. AGC preamble, synchronisation symbols, pilot symbols) as well as the SF structure are fully taken into account. Afterwards, the OFDM signal is transformed to the time domain OFDM-symbol wise and a cyclic prefix and suffix are added to enable TX windowing in the next step.

In the following, the parts of the PHY layer specification from [D2] relevant for this prototype are recapitulated.

4.3.1 RL – OFDMA-TDMA Transmission

4.3.1.1 Frequency Domain Description

An OFDM symbol consists of N_{FFT} sub-carriers, which can be occupied by:

- Null symbols i.e. un-modulated sub-carriers in guard bands, the DC sub-carrier, and inactive sub-carriers,
- Data symbols, used for transmission of user data,
- Pilot symbols, used for channel estimation purposes,
- Synchronisation symbols, occupied by synchronisation sequences,
- PAPR reduction symbols, used for reduction of the PAPR, and
- Preamble symbols, used to support receiver AGC.

$N_{g,left}$ sub-carriers on the left and $N_{g,right}$ sub-carriers on the right side of the signal spectrum are used as guard bands. In addition, the DC sub-carrier is not used. This results in N_u sub-carriers to be used for data symbols, pilot symbols, synchronisation sequences, AGC preambles and PAPR reduction symbols.

In the RL, except for the RA sub-frames, the time-frequency plane is segmented into tiles assigned to different ASs. One tile spans a half of the total number of sub-carriers available in the RL (25 contiguous sub-carriers) and six contiguous OFDM symbols in the time-frequency plane. This structure allows two users (two ASs) to share the effective L-DACS1 RL bandwidth when transmitting DC and Data segments. The OFDMA structure in the RL is clarified in Figure 4-4. The tile structure is further defined in Section 4.3.2.1.

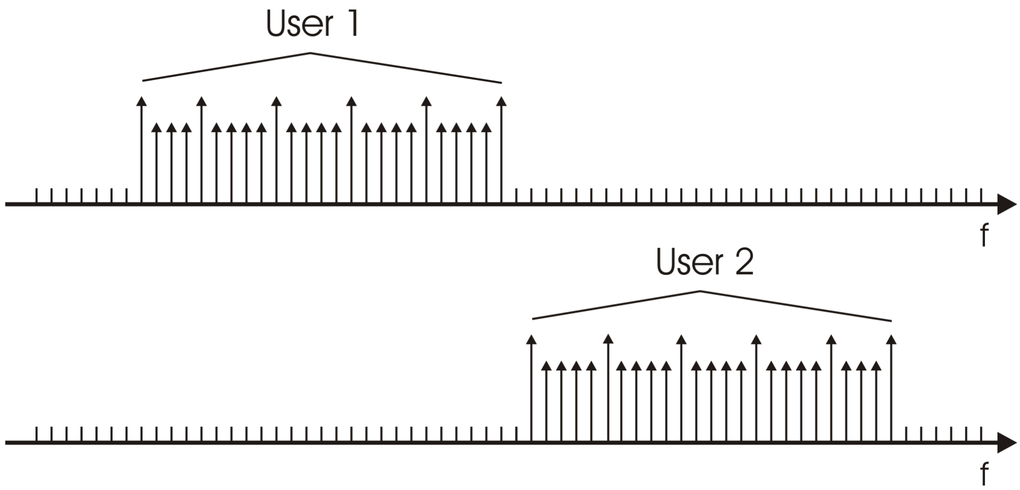

Figure 4-4: OFDMA Structure in the RL

4.3.1.2 Time Domain Description

The inverse Fourier transform of a frequency domain OFDM symbol creates the OFDM time domain waveform. The duration of this signal is referred to as the useful symbol time T_u. A copy of the last T_{cp} of the useful symbol period, termed cyclic prefix (CP), is added in front of the useful symbol period. A T_w part of this CP is used for windowing; a T_g part provides a tolerance for symbol time synchronisation errors and resistance to inter-symbol interference (ISI). In addition to the cyclic prefix, a cyclic postfix of length T_w is added.

For applying windowing, the cyclic postfix and a T_w part of the cyclic prefix are multiplied with a decaying window. Finally, the OFDM symbols are stringed together, whereby the postfix of an OFDM symbol overlaps with a T_w part of the CP of the subsequent OFDM symbol. Figure 4-7 shows this procedure in two steps. The windowing method is addressed in Section 4.3.6.

In the RL, each involved AS creates separately its time domain OFDM symbol. In an OFDMA transmission, the GS receives a superposition of two separate time domain signals, requiring a synchronous transmission of these two ASs in time and frequency, as well as power alignment between these two ASs.

One tile is assigned to only one AS, but the following tile in the time direction can be used by another AS. Thus, subsequent received OFDM symbols belonging to different tiles can carry data from different ASs.

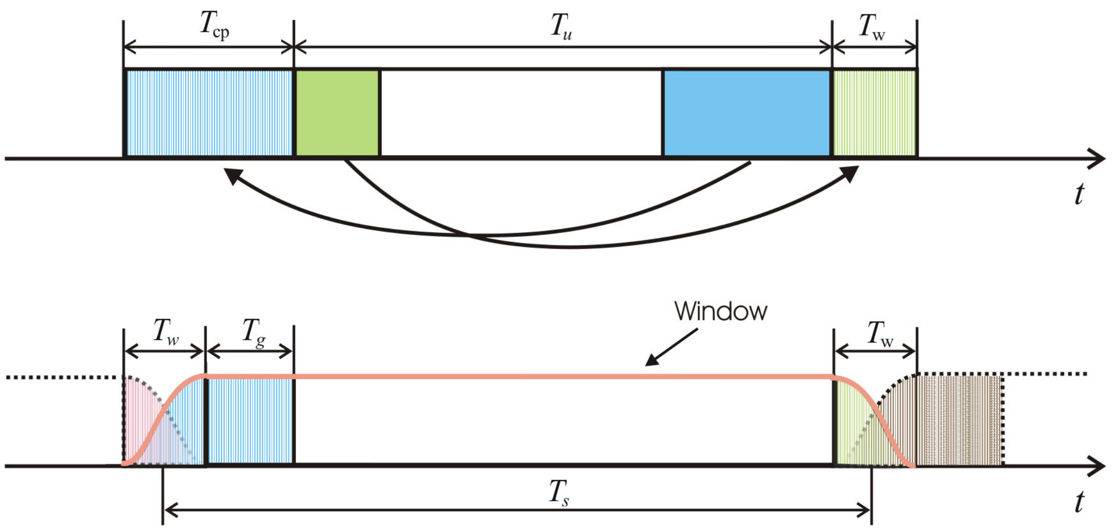

Figure 4-5: OFDM Symbol, Time Domain Structure

4.3.1.3 OFDM Parameters

The basic OFDM parameters relevant for the AS TX are listed in Table 4-2.

Table 4-2: OFDM Parameters in RL

Parameter	Value
FFT size: N_{FFT}	64
Sampling time: T_{sa}	1.6 µs
Sub-carrier spacing: Δf	9.765625 kHz
Useful symbol time: T_u	102.4 µs
Cyclic prefix ratio: $G = T_{cp} / T_u$	11/64
Cyclic prefix time: T_{cp}	17.6 µs
OFDM symbol time: T_s	120 µs
Guard time: T_g	4.8 µs
Windowing time: T_w	12.8 µs
Number of used sub-carriers: N_u	50
Number of lower frequency guard sub-carriers: $N_{g,left}$	7
Number of higher frequency guard sub-carriers: $N_{g,right}$	6
Sub-carrier indices of guard sub-carriers	-32, -31,…, -26

	26, 27,…, 31
Total FFT bandwidth $B_0 = N_{FFT} \cdot * \Delta f$	625.0 kHz
Effective RF bandwidth $B_{eff} = (N_u+1) * \Delta f$	498.05 kHz (incl. DC sub-carrier)

4.3.2 Physical Frame Characteristics

OFDM symbols are organised into OFDM frames. Depending on the data to be transmitted different types of OFDM frames are defined, as described in the following sections. All frame types can be figuratively represented with symbols in a time-frequency plane.

Symbol positions are noted with (t, f) indices, where the time index t takes the values between 1 and N_{OFDM}, with N_{OFDM} being the total number of OFDM symbols within one frame. The frequency index f takes values between -32 and 31 with f = 0 representing the DC sub-carrier. The numbering starts with the guard symbol in the upper left corner with the symbol position (1,-32) as illustrated in Figure 4-6.

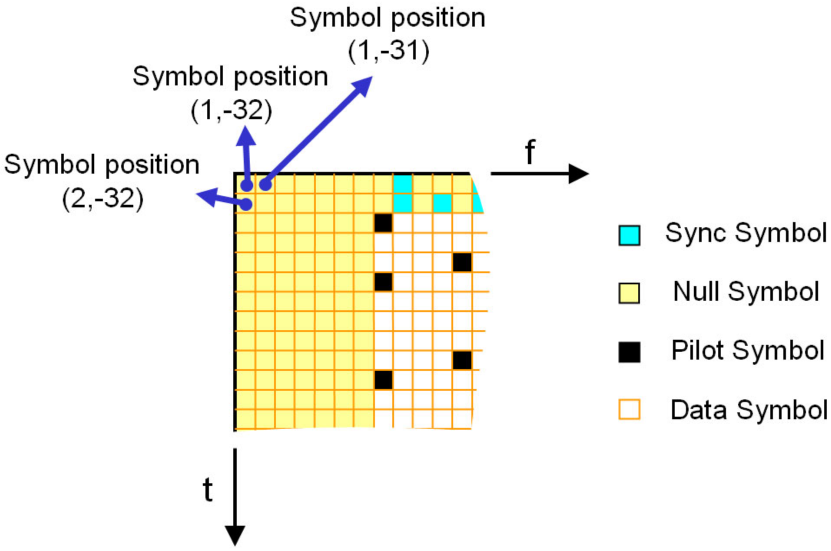

Figure 4-6: Numbering of the Symbols in the Time-Frequency Plane

4.3.2.1 Reverse Link Frame Types

To realise multiple access via OFDMA-TDMA in the RL, the transmission is organised in segments and tiles rather than in OFDM frames and sub-frames as in the FL.

4.3.2.1.1 RL Data Segment

In the RL, data segments consist of tiles. One tile spans 25 symbols in frequency and 6 symbols in time direction and is illustrated in Figure 4-7. Each tile comprises 4 PAPR reduction symbols and 12 pilot symbols. This leads to a capacity of 134 data symbols per tile, representing the smallest allocation block in the RL. The pilot pattern and position of the PAPR reduction symbols within a tile are given in Table 4-3 for a tile on the left side of the DC sub-carrier and in Table 4-4 for a tile on the right side of the DC sub-carrier.

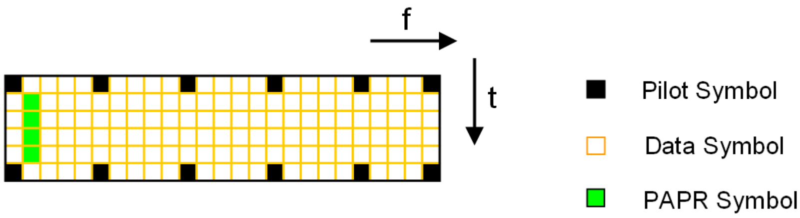

Figure 4-7: Structure of a Tile in the RL

Table 4-3: Pilot and PAPR Reduction Symbol Positions in a Left Tile

OFDM symbol position n	Pilot symbol positions
n = 1, 6	-25, -21, -16, -11, -6, -1
	PAPR reduction symbol positions
n = 2, 3, 4, 5	-24

Table 4-4: Pilot and PAPR Reduction Symbol Positions in a Right Tile

OFDM symbol position n	Pilot symbol positions
n = 1, 6	1, 6, 11, 16, 21, 25
	PAPR reduction symbol positions
n = 2, 3, 4, 5	23

An RL Data segment, comprising 8 tiles, is depicted in Figure 4-8.

The length of an RL Data segment is variable and is described in Section 4.3.2.2.

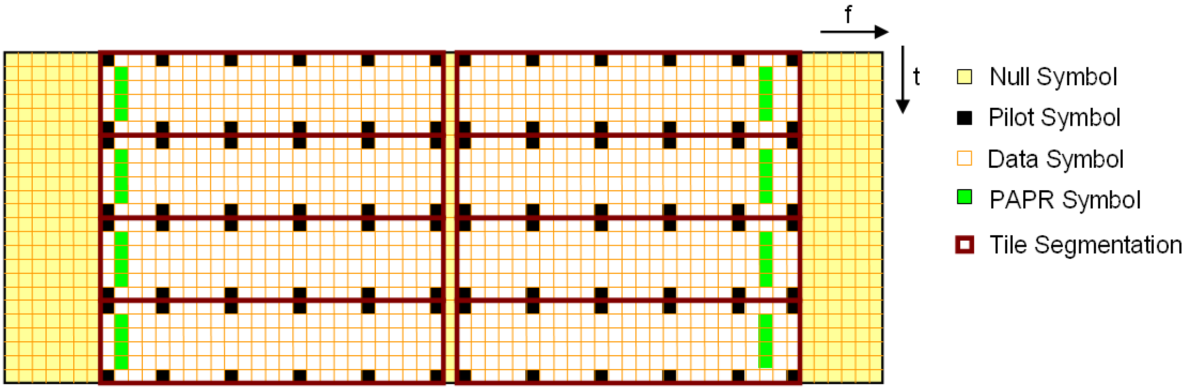

Figure 4-8: Structure of an RL Data Segment

4.3.2.1.2 RL Dedicated Control Segment

A dedicated control (DC) segment has the same tile structure as the RL data segment (see Figure 4-7).

The first OFDM symbol of a DC segment carries an AGC preamble followed by K_{sy} opportunities for OFDM symbols carrying synchronisation sequences for the corresponding number of users. The minimal number of OFDM synchronisation symbol opportunities is denoted by $K_{sy,min}$ = 5. If more than 5 OFDM synchronisation symbols per DC segment are required, K_{sy} can be increased by multiples of 6. The OFDM synchronisation symbols provide a possibility for the GS to update the synchronisation of several ASs.

The length of a DC segment is variable and is described in Section 4.3.2.2. As an example one DC segment comprising five OFDM synchronisation symbols and six tiles is depicted in Figure 4-9.

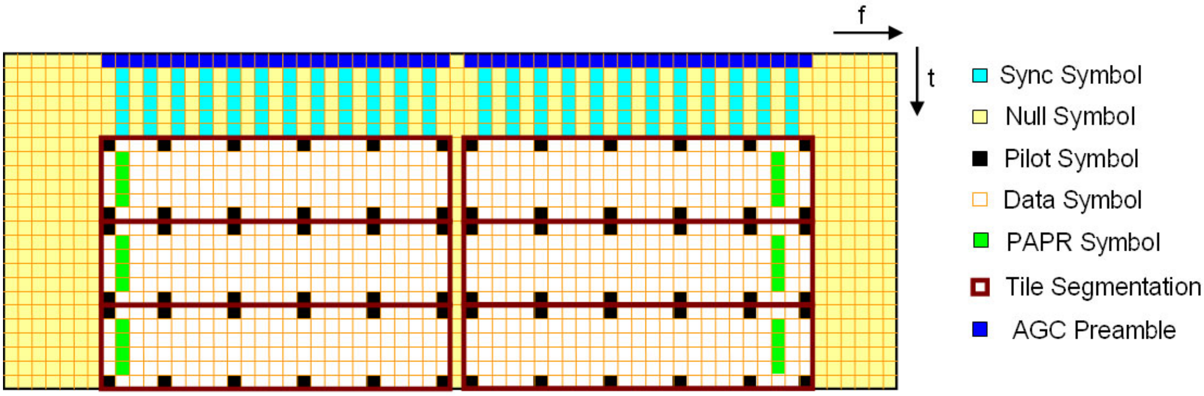

Figure 4-9: Structure of an RL DC Segment

4.3.2.1.3 RL Random Access Frame

As in the RL Random Access (RA) frame no OFDMA-TDMA is utilised, the wording 'frame' and 'sub-frame' as in the FL is used.

Two RL RA sub-frames provide two opportunities for ASs to send their cell entry request to the GS (Figure 4-10). Propagation guard times of length $T_{g,RA}$ = 1.26 ms precede or follow each RA sub-frame, respectively.

This propagation guard time of 1.26 ms corresponds to a maximal AS-GS distance of 200 nm. When transmitting an RA sub-frame, an AS is not yet synchronised to the GS. Under such conditions, an AS sends the first RA sub-frame directly after the start of an RL SF that in turn has been determined from the GS FL signal that needs 1.26 ms to reach an AS at the maximum distance from the GS. From the GS point of view, such an AS starts the transmission of the first RL RA sub-frame with 1.26 ms delay relative to the GS local timing. Another propagation guard time of 1.26 ms is required for the RL RA sub-frame to reach the GS. Thus, from the GS point of view, an RA sub-frame in this case appears to be surrounded by two propagation guard times (Figure 4-10). Similar considerations are valid for the second RA sub-frame that lags in time by 3.36 ms relative to the first one.

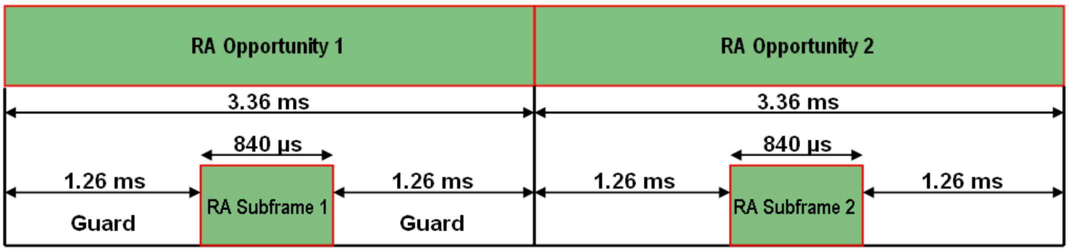

Figure 4-10: RA Access Opportunities

The RA sub-frame itself contains seven OFDM symbols, resulting in a duration of $T_{sub,RA}$ = 840 µs. The structure of an RA sub-frame is given in Figure 4-11.

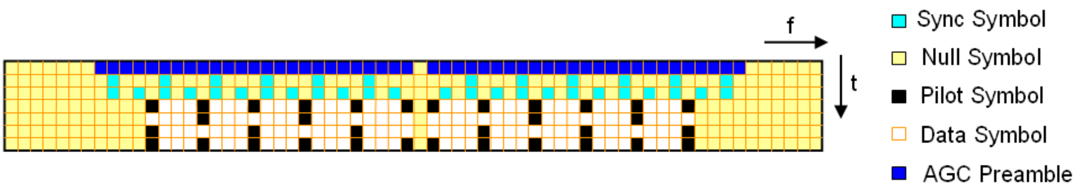

Figure 4-11: Structure of an RA Sub-frame

The first OFDM symbol represents the AGC preamble, the following two OFDM symbols contain synchronisation sequences, while the remaining four OFDM symbols carry data and pilot symbols. These four OFDM symbols use only 43 sub-carriers (including the DC sub-carrier), which leads to guard bands with $N_{g,left}$ = 11 and $N_{g,right}$ = 10 sub-carriers. The arrangement of the pilot symbols follows the pattern given in Table 4-5. The number of 34 pilot symbols leads to a data capacity of (42·4 – 34) = 134 symbols per RA sub-frame.

Table 4-5: Pilot Symbol Positions for RL RA Frame

OFDM symbol position n	Pilot symbol positions
n = 4, 7	-21, -17, -13, -9, -5, -1, 1, 5, 9, 13, 17, 21
n = 5	-17, -9, 9, 17
n = 6	-21, -13, -5, 5, 13, 21

4.3.2.2 Framing

The L-DACS1 physical layer framing is hierarchically arranged. In Figure 4-12 and Figure 4-13, the RL framing structure is summarised graphically, from the SF down to the OFDM frames. One SF has a duration of T_{SF} = 240 ms.

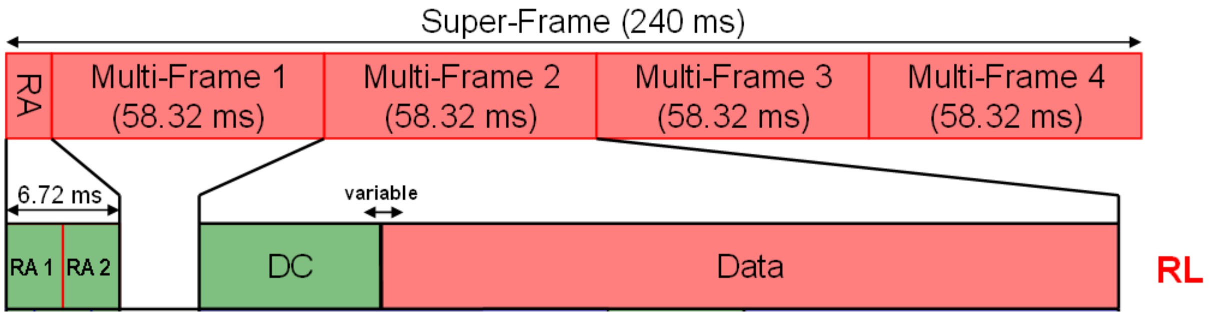

Figure 4-12: RL Super-Frame Structure

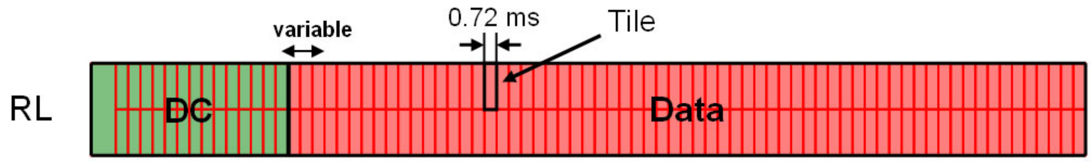

Figure 4-13: RL Multi-Frame Structure

The data to be transmitted on RL are provided by the MAC layer in the form of RL PHY-PDUs. The size of the RL PHY-PDUs corresponds to the capacity of the different types of frames and tiles.

In the RL, each SF starts with an RA frame of length T_{RA} = 6.72 ms followed by four MFs. One RL RA PHY-PDU is mapped onto one RA sub-frame. The number of data symbols in an RA sub-frame corresponds to the size of an RL RA PHY-PDU.

The duration of an MF is T_{MF} = 58.32 ms as in the FL. Each MF in the RL starts with an RL DC segment, followed by an RL data segment. Within one MF, the DC segment size and thus also the size of the data segment is variable and shall be configurable in the AS TX prototype. One RL Data/DC PHY-PDU is mapped onto one tile. The size of an RL Data PHY-PDU and an RL DC PHY-PDU corresponds to the number of data symbols of a tile.

The minimal size of the DC segment is 12 OFDM symbols, corresponding to the AGC preamble followed by five OFDM synchronisation symbols and two allocated RL DC PHY-PDUs (one in a left and one in a right tile), which leads to a minimum RL DC segment duration of $T_{DC,min}$ = 1.44 ms. The maximal duration is $T_{DC,max}$ = 19.44 ms.

The duration of one data segment in the RL is $T_{DF} = T_{MF} – T_{DC}$, resulting in $T_{DF,min}$ = 38.88 ms and $T_{DF,max}$ = 56.88 ms.

Note: In this context, the "size" of a PHY-PDU is given in complex symbols. The corresponding number of uncoded and coded bits in the PHY-PDUs is given in Section 4.3.3.1.

4.3.2.3 Framing Specifics for Prototype AS TX Implementation

The maximum length of the DC segment limits the number of AS controlled by a single GS to 208. More ASs can be accommodated by increasing the length of the control cycle to two SFs, or more. However, this option is not applicable to the AS TX prototype.

RA sub-frames

The number of transmitted RA sub-frames per SF shall be configurable, i.e. no, one or two RA sub-frames can be transmitted per SF.

When evaluating the interference from the L-DACS1 AS TX towards other systems, the AS TX shall insert a configurable number of RA sub-frames per SF. Together with other configurable framing parameters, this should result in a realistic TX AS duty-cycle.

In case of BER measurements at GS RX AS TX shall send two RA sub-frames in each RL SF for synchronisation purposes. The detailed data content of the RA sub-frames is not relevant, as it is not evaluated in the BER measurements.

In case an RA sub-frame is not used, the corresponding time slot in the SF structure shall be left empty while the actual timing structure of the SF is maintained.

AGC Preambles

The number of AGC preambles per SF shall be configurable (an AS TX shall insert "n" AGC preambles per SF).

When evaluating the interference from the L-DACS1 AS TX towards other L-band systems, the parameter "n" can be set to a relatively low value to reflect the situation that in the real system one aircraft does not always use the AGC preamble. Together with other configurable framing parameters, this should result in a realistic TX AS duty-cycle.

In case of BER measurements at the GS RX, AS TX shall send one AGC preamble in each MF.

Synchronisation Symbols in DC Segments

The total number of opportunities for synchronisation symbols in a DC segment shall be fixed (K_{sy}=5).

When evaluating the interference from the L-DACS1 AS TX towards other L-band systems, the framing parameter that controls the number of transmitted synchronisation symbols per SF shall be set in accordance to the assumed number of aircraft in the cell, in order to reflect the fact that an AS transmits a synchronisation symbol only upon request by the GS. The probability of such request in turn depends on the number of aircraft in the cell. In case a synchronisation symbol is sent, AS TX shall insert its synchronisation symbol in the third opportunity. Together with other configurable framing parameters, this should result in a realistic TX AS duty-cycle.

In case of BER measurements at GS RX, AS TX shall send one synchronisation symbol pair in each DC segment in all MFs. These symbols shall be inserted in the fourth and fifth opportunity at the beginning of the DC segment.

DC Segments

The length of the DC segment shall be kept variable, defined by the corresponding framing parameter (that implicitly also determines the length of the Data segment). Furthermore, the number and positions of tiles to be transmitted by a single user in the DC segment shall be configurable.

When evaluating the interference from the L-DACS1 AS TX towards other systems, the AS TX shall insert a single tile at a configurable position within the DC segment and the remaining DC segment tiles should be left empty. AS TX shall send exactly one tile per SF. Together with other configurable framing parameters, this should result in a realistic TX AS duty-cycle.

In case of BER measurements at the GS RX, AS TX shall use all RL DC PHY-PDUs in all

DC segments of all RL MFs for transmitting test data. The size of the DC segment is reduced to the minimum, i.e. the AGC preamble followed by five OFDM synchronisation symbol opportunities and two allocated RL DC PHY-PDUs (one in a left and one in a right tile).

Data Segments

The length of the Data segment shall be kept variable, but depends on the length of the DC segment. Since the Data segment is just the remainder of the MF, which is not used as DC segment, the length of the Data segment is defined by the framing parameter that already determines the length of the DC segment.

When evaluating the interference from the L-DACS1 AS TX towards other L-band systems, the duration of the single AS TX transmission within the RL Data segment as well as the number of successive MFs occupied by the data of one user shall be configurable via corresponding framing parameters. Together with other configurable framing parameters, this should result in a realistic TX AS duty-cycle.

In case of BER measurements at the GS RX, AS TX shall send test data in all Data segments of all RL MFs. Since the size of the DC segment is minimal, the size of the Data segment becomes maximal for BER measurements and contains 158 RL Data PHY-PDUs.

4.3.3 Coding and Modulation

4.3.3.1 Channel Coding

As FEC scheme, L-DACS1 uses a concatenation of an outer Reed-Solomon (RS) code and an inner variable-rate convolutional code. The coding and interleaving procedure is illustrated in Figure 4-14.

At the TX side, the information bits first enter the RS encoder. Afterwards, zero-terminating convolutional coding is applied. In a last step, the coded bits are interleaved, using a permutation interleaver.

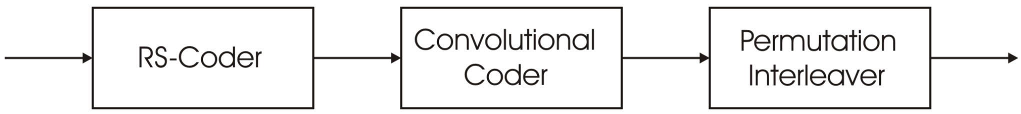

Figure 4-14: Channel Coding and Interleaving

For the termination of the inner convolutional code, six zero bits are added to the end of the data block before convolutional encoding.

If the number of bits to be coded and modulated does not fit to the size of one PHY-PDU, a corresponding number of zero pad bits shall be added after the convolutional coder.

4.3.3.1.1 Outer Coding

An RS code obtained by shortening a systematic RS($N = 2^8$-1, K, F) code using Galois field GF(2^8), the primitive polynomial

$p(x) = x^8 + x^4 + x^3 + x^2 + 1$

and the generator polynomial

$$g(x) = \prod_{i=1}^{2F} \left(x + \lambda^i \right), \quad \lambda = 02_{HEX}$$

shall be applied for outer encoding. The RS parameters are as follows:

- K: number of uncoded bytes,
- N: number of coded bytes,
- $F = floor\left(\frac{N-K}{2}\right)$ is the number of bytes that can be corrected

4.3.3.1.2 Inner Coding

Each output data block of the RS encoder is encoded by a non-recursive binary convolutional coder. Zero-termination of each data block is applied. The generator polynomials of the coder are given by:

- $G_1 = 171_{OCT}$, for the first output
- $G_2 = 133_{OCT}$, for the second output.

The native coding rate is r_{cc} = ½, the constraint length is equal to 7. The block diagram of the coder is given in Figure 4-15.

Other coding rates can be derived by puncturing the native code. However, this is not required in the GS TX prototype.

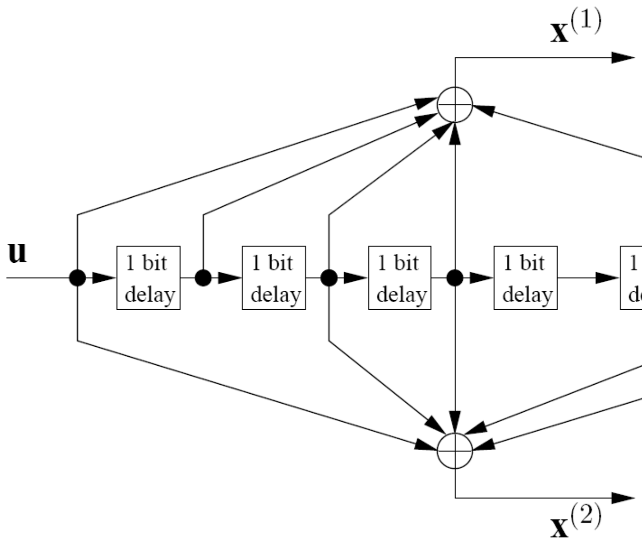

Figure 4-15: Block Diagram of Convolutional Coder (171,133,7)

The combination of QPSK modulation, a fixed RS code and a convolutional code with r_{cc} = ½ is mandatory for the RL DC, the RL RA PHY-PDUs.

In the prototype implementation, QPSK modulation, a fixed RS code and a convolutional code with r_{cc} = ½ is also mandatory for the FL Data PHY-PDUs. Adaptive Coding and Modulation (ACM) needs not to be implemented.

Table 4-6 gives the modulation schemes, channel coding parameters and block sizes only for the RL PHY-PDUs that must be implemented for AS TX prototype equipment.

The modulation scheme is described in Section 4.3.3.3.

Table 4-6: Parameters for RL DC, RL Data, and RL RA PHY-PDUs

PHY-PDU type	Modulation	Convolutional Coding Rate	RS Parameter	Total Coding Rate	Number of uncoded bits	Number of coded bits
RL DC PHY-PDU	QPSK	1/2	RS(16, 14, 1)	0.44	112	268
RL RA PHY-PDU	QPSK	1/2	RS(16, 14, 1)	0.44	112	268
RL Data PHY-PDU	QPSK	1/2	RS(16, 14, 1)	0.44	112	268

4.3.3.2 Interleaving

The interleaving of the output of the convolutional encoder is done by a permutation interleaver. This ensures that the coded bits are evenly spread across the time-frequency plane.

The block size of the interleaver N_I complies with the coding block sizes. These are equivalent to the number of coded bits in Table 4-6.

The following equation specifies the permutation of the interleaver

$$m_k = \left(16 \cdot k + floor\left(\frac{16 \cdot k}{N_I} + floor\left(\frac{(16 \cdot k)_{\mathrm{mod}\,N_I} + floor\left(\frac{16 \cdot k}{N_I}\right)}{N_I} \right) \right) \right)_{\mathrm{mod}\,N_I} \qquad k = 0,1,\ldots,N_I - 1$$

Here, k is the index of an encoded data bit before the permutation and m_k is the index of the encoded data bit after the permutation.

4.3.3.3 Modulation

After the interleaving, the encoded data bits enter serially the constellation mapper. In addition to QPSK, [D2] specifies 16-QAM and 64-QAM as possible modulation options for RL Data PHY-PDUs.

Only Gray-mapped QPSK modulation as shown in Figure 4-16 shall be supported by the AS TX prototype.

The constellation diagram of the modulation is normalised to an average power of 1 by multiplying the constellation points with the indicated factor c. In Figure 4-16, b_0 denotes the Least Significant Bit (LSB).

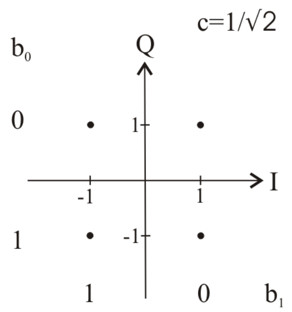

Figure 4-16: Constellation Diagram for QPSK

The modulation rate r_{mod} is 2 bits/modulation symbol for QPSK.

4.3.4 Data mapping onto frames

The MAC sub-layer provides the PHY layer with PHY-PDUs of the correct size. The PHY layer maps the PHY-PDUs onto frames by just positioning the complex symbols onto the time-frequency plane after coding and modulation.

> *Note: As a part of the layer interaction, described in Section 4.4, additional signalling information is locally exchanged between the PHY and the MAC sub-layer, but is not transmitted from TX to RX.*

In the RL, the DC segment and the Data segment are subdivided into tiles. Data mapping shall map RL PHY-PDUs onto tiles. Before mapping modulated symbols onto a tile, pilot symbols and PAPR reduction symbols shall be inserted into the tile. Modulated symbols shall be mapped onto the tile in time direction, i.e. symbols are placed subsequently on the free positions in the following order: (1,-25) (2,-25) (3,-25) … (1,-24) (2,-24) etc. Symbol positions are defined in Section 4.3.5.1. Data mapping in time direction is illustrated in Figure 4-17.

Analogously, one RA PHY-PDU is mapped onto the RA frame in time direction as illustrated in Figure 4-17.

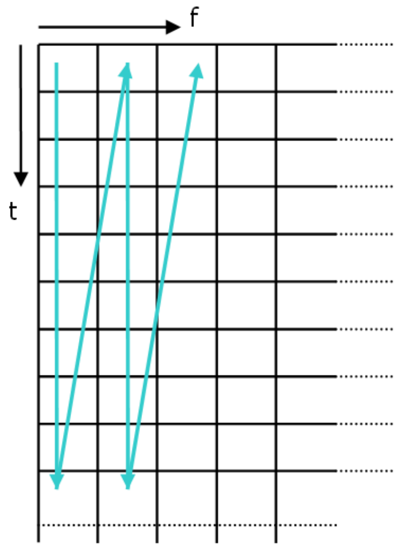

Figure 4-17: Mapping of Modulated Data onto Frames

4.3.5 Pilot-, Synchronisation-, PAPR- and AGC-sequences

In this section, the sequences and preambles used for synchronisation, channel estimation (CE), PAPR reduction and AGC issues are described.

4.3.5.1 Pilot Sequences

Pilot sequences defined in this section shall be inserted in the RL tiles. The mapping shall be applied in frequency direction, i.e. consecutively on the OFDM symbols which contain pilot symbols. The exact pilot positions on which the pilot symbols shall be mapped are defined in Table 4-3, Table 4-4, and Table 4-5 for the RL.

In the RL RA frame, the pilot sequences of each sub-frame shall be calculated as follows:

$$S_{RA}(k) = \exp\left(j \cdot \frac{2\pi}{64} P_{RA}(k) \right), k = 1,...,34$$

with

P_{RA} = {58, 48, 53, 1, 60, 34, 13, 56, 15, 39, 41, 16, 3, 59, 25, 49, 60, 49, 6, 33, 6, 11, 58, 48, 53, 1, 60, 34, 13, 56, 15, 39, 41, 16}.

In the RL DC and data segment, the pilot sequences of each tile shall be calculated as follows:

$$S_{tile}(k) = \exp\left(j \cdot \frac{2\pi}{64} P_{tile,l/r}(k) \right), k = 1,...,12$$

with

- $P_{tile,l}$ = {2, 40, 10, 2, 56, 4, 2, 40, 10, 2, 56, 4}, for left tiles and
- $P_{tile,r}$ = {4, 56, 2, 10, 40, 2, 4, 56, 2, 10, 40, 2}, for right tiles.

Prototype AS TX shall allow to boost pilot tones 2.5 dB above other modulated symbols or to transmit these tones without boosting. The boosting level shall be configurable via a parameter.

As the phases of the pilot symbols have no influence on the performance of the channel estimation, they have been chosen to provide a low PAPR.

4.3.5.2 PAPR Reduction Symbols

For reducing the Peak to Average Power Ratio (PAPR), two symbols shall be inserted into every OFDM symbol in the RL in which no pilot symbols occur. The sub-carrier indices of these two symbols are defined in Table 4-4. These symbols carry no information and shall be discarded at the receiver. They are calculated data-dependent, in order to reduce the PAPR.

4.3.5.3 Synchronisation Sequences

For measuring the AS TX spectrum, the actual RL signal has to be represented as close as possible to the real system. In that case, the usual RL synchronisation symbols are inserted at adjustable positions in the DC segment.

In the real system, the synchronisation in the RL is derived from synchronisation in the FL. Time and frequency offsets are adjusted in a closed-loop procedure by measuring and signalling the required adjustments on FL and RL. Since the RL prototype shall be independent of the FL, a stand-alone synchronisation procedure has to be implemented in the prototype, when BER measurements shall be performed at the GS RX. In that case, the synchronisation symbols used in the FL will be inserted in the RL frame-structure. In order not to significantly modify the RL frame structure, synchronisation symbols are inserted in the DC segment at the fourth and fifth OFDM synchronisation symbol position as described in Section 4.3.2.3.

4.3.5.3.1 Synchronisation Symbols for AS TX Spectrum Measurements

For measuring the impact of the AS TX spectrum upon other L-band systems, the prototype AS RX actual RL shall produce RF signal-in-space with structure and duty-cycle that closely resembles the signal that would be produced by the real system. In that case, the RL synchronisation symbols are inserted at adjustable positions in the DC segment exactly following the system specification [D2].

Synchronisation OFDM symbols in the RL are structured as depicted in Figure 4-18. In the synchronisation OFDM symbol, every second sub-carrier of the used spectrum is occupied by a synchronisation symbol. The indices of these sub-carriers are:

> -24, -22, -20, -18, -16, -14, -12, -10, -8, -6, -4, -2, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 24.

As a result, the time domain waveform of the first OFDM symbol consists of two identical parts as depicted in Figure 4-19.

Figure 4-18: Structure of the Synchronisation OFDM Symbol

The synchronisation sequence in the frequency domain shall be calculated by

$$S_{sy,k} = \sqrt{2}\exp\left(j \cdot \pi \frac{k^2}{N_{sy}}\right) \quad ,k = 0,\ldots,N_{sy}-1$$

with

- $S_{sy,k}$: kth synchronisation symbols in the OFDM synchronisation symbol,
- N_{sy}: Number of synchronisation symbols per OFDM synchronisation symbol (=24).

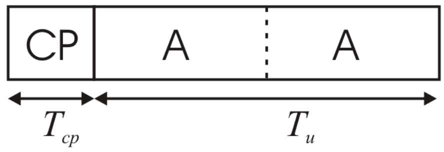

Figure 4-19: Time Domain Representation of Synchronisation OFDM Symbol

4.3.5.3.2 Synchronisation Symbols for BER measurements

With single L-DACS1 prototype TX and single prototype RX, in-the-loop mechanisms for adjusting AS TX power, frequency, and timing will not be available.

In order to be able to perform BER measurements at the GS RX, a stand-alone synchronisation procedure has to be implemented in the prototype GS RX that also must be supported by the AS TX. Such a procedure deviates from the system specification provided in [D2], but would simplify the test set-up and is considered as suitable as the AS TX duty-cycle aspects are not important when performing BER measurements at the GS RX side.

In that case, the synchronisation symbol pairs normally used in the FL and also for the RL RA sub-frames are proposed to be inserted in the RL DC segments (where, according to [D2], only a single synchronisation symbol would occur).

Synchronisation symbol pairs are proposed to be inserted in the DC segment at the fourth and fifth synchronisation OFDM symbol position, as described in Section 4.3.2.2.

RL synchronisation symbol pairs to be inserted into DC segments are structured as depicted in Figure 4-20. In the first synchronisation OFDM symbol, every forth sub-carrier of the used spectrum is occupied by a modulated synchronisation symbol. The indices of these sub-carriers are given in Table 4-7. As a result, the time domain waveform of the first OFDM symbol consists of four identical parts.

In the second synchronisation OFDM symbol only even sub-carriers are used. This yields a time domain waveform with two identical halves.

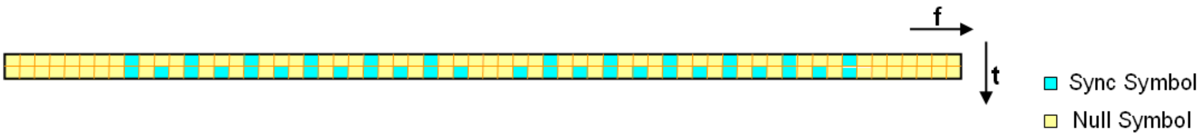

Figure 4-20: Structure of the Synchronisation OFDM Symbols

Table 4-7: Synchronisation Symbol Position

Synchronisation OFDM symbol number	Synchronisation symbol positions
1	-24, -20, -16, -12, -8, -4, 4, 8, 12, 16, 20, 24
2	-24, -22, -20, -18, -16, -14, -12, -10, -8, -6, -4, -2, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24

The structure of the two synchronisation OFDM symbols in the time domain is depicted in Figure 4-21. The synchronisation sequences in the frequency domain shall be calculated by

$$S_{sy1,k} = \sqrt{4}\exp\left(j \cdot \pi \frac{5k^2}{N_{sy1}}\right) \quad ,k = 0,\ldots,N_{sy1}-1$$

and

$$S_{sy2,k} = \sqrt{2}\exp\left(j \cdot \pi \frac{k^2}{N_{sy2}}\right) \quad ,k = 0,\ldots,N_{sy2}-1$$

with

- $S_{sy1/2}$: Synchronisation symbols for the first and the second OFDM synchronisation symbol,
- $N_{sy1/2}$: Number of synchronisation symbols per OFDM synchronisation symbol (12 for the first OFDM synchronisation symbol and 24 for the second OFDM synchronisation symbol).

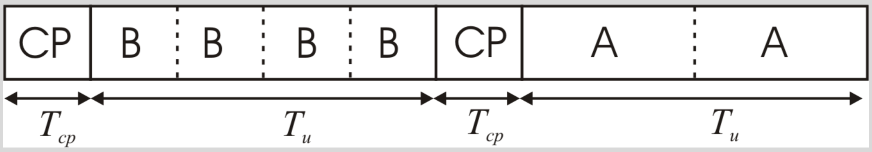

Figure 4-21: Time Domain Representation of Synchronisation OFDM Symbols

4.3.5.4 AGC Preamble

The first OFDM symbol in an RL RA sub-frame and an RL DC segment contains an AGC preamble. The AGC preamble in the frequency domain shall occupy all used sub-carriers, numbered by: -25, -24, …, -1, 1, 2, …, 25, and it shall be calculated by:

$$S_{AGC}(k) = \exp\left(j \cdot \frac{2\pi}{64} P_{AGC}(k) \right), k = 1,...,50$$

with

P_{AGC} = {29, 8, 35, 53, 30, 17, 21, 16, 7, 37, 23, 35, 40, 41, 8, 46, 32, 47, 8, 36, 26, 53, 12, 26, 33, 4, 31, 42, 0, 6, 48, 18, 60 24, 2, 15, 16, 58, 48, 37, 61, 22, 38, 52, 23, 3, 63, 36, 49, 42}.

Note: This sequence was chosen by minimising the PAPR of the AGC preamble.

4.3.6 Reduction of Out-of-Band Radiation by Means of TX Windowing

In Section 4.3.1.2, the generation of the time domain TX signal is described, including windowing.

TX windowing is applied in order to smooth the sharp phase transitions between consecutive OFDM symbols which cause out-of-band radiation. The windowing function is illustrated in Figure 4-22.

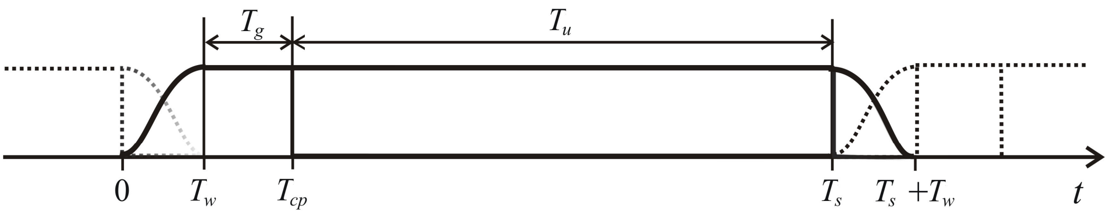

Figure 4-22: Windowing Function

The raised cosine (RC) function with a roll-off factor of α = 0.107, given by

$$w(t) = \begin{cases} \frac{1}{2} + \frac{1}{2}\cos\left(\pi + \frac{\pi t}{T_w}\right) & 0 \le t < T_w \\ 1 & T_w \le t < T_s \\ \frac{1}{2} + \frac{1}{2}\cos\left(\frac{\pi\left(t - T_s\right)}{T_w}\right) & T_s \le t < T_s + T_w \\ 0 & else \end{cases}$$

shall be applied for windowing. The duration of the rising/falling edges of the window is defined as

$$T_w = \left(T_u + T_g\right)\frac{\alpha}{1-\alpha}.$$

The following equation specifies the complex baseband signal of the l-th OFDM symbol within one frame, before windowing the signal

$$s_l(t) = \begin{cases} \sum_{k=-N_u/2}^{N_u/2-1} c_{k,l} \cdot \exp\left\{ j2\pi k\Delta f\left(t - T_{cp}\right)\right\} & 0 \le t < T_s + T_w \\ 0 & else \end{cases}$$

where $c_{k,l}$ specifies data symbols, pilot symbols, synchronisation symbols, PAPR reduction symbols or AGC preamble symbols. TX windowing results from the following multiplication

$$s_{l,wi}(t) = s_l(t) \cdot w(t).$$

Finally, the continuous complex baseband signal is obtained by partially overlapping the consecutive OFDM symbols:

$$s(t) = s_{0,wi}(t) + s_{1,wi}\left(t - T_s\right) + ... + s_{l,wi}\left(t - l \cdot T_s\right).$$

4.3.7 Physical Layer Parameters

In addition to the basic OFDM parameters given in Table 4-2, Table 4-8 summarises the parameters of the framing structure and all other PHY layer parameters for the AS TX which were defined or mentioned in this chapter. In addition, a reference to the corresponding sections is provided.

Table 4-8: Physical Layer Parameters

Parameter	Abbr.	Value	Unit
Number of OFDM symbols within one frame (4.3.2)	N_{OFDM}	variable	
Number of OFDM symbols, carrying sync sequences in a DC segment (4.3.2)	K_{sy}	5, 0, 1 or 2 OFDM symbols used	
Number of OFDM symbols in a DC segment (4.3.2)	N_{dc}	variable	
Guard time in an RA frame (4.3.2)	$T_{g,RA}$	1.26	ms
Duration of an RA sub-frame (4.3.2)	$T_{sub,RA}$	840	µs
Duration of a Super-Frame (4.3.2.2)	T_{SF}	240	ms
Duration of an RA frame (4.3.2.2)	T_{RA}	6.72	ms
Duration of an RL Data segment (4.3.2.2)	T_{DF}	variable	ms
Number of input byte of an RS code word (4.3.3.1)	K	14	
Number of output byte of an RS code word (4.3.3.1)	N	16	
Native coding rate of convolutional coder (4.3.3.1)	r_{CC}	1/2	

Parameter	Abbr.	Value	Unit
Size of a coding block (4.3.3.2)	N_I	268	
Multiplication factor for the modulation (0)	c	$1/\sqrt{2}$	
Modulation rate (0)	r_{mod}	2	bit/modulation symbol
Roll-off factor for RC window (4.3.6)	α	0.107	

4.4 AS TX Protocol Characteristics

A detailed specification for the L-DACS1 protocol entities above the PHY layer is provided in [D2].

In the prototype AS TX implementation, multiple PHY parameters that would be set via MAC sub-layer in normal operation are fixed and internally pre-set at the PHY layer, e.g.

The PHY layer framing parameters to be configured at the PHY layer are:

- number of MFs per SF, where synchronisation symbols are used in the DC segment,
- number of MFs per SF, where AGC preamble is used in the DC segment,
- number of MFs per SF, where the considered AS uses tile(s) in the DC segment,
- length of DC segment (in tiles),
- number and position of tile(s) in DC segment carrying data of the considered AS
- length of Data segment (already determined by the length of DC segment),
- number and position of tiles in Data segment carrying data of the considered AS,
- number and position of RA sub-frames within one SF sent by the considered AS,
- the total number of opportunities for synchronisation OFDM symbols in a DC segment (fixed, Ksy=5),
- number of synchronisation OFDM symbols sent by the considered AS TX per SF,
- position of synchronisation OFDM symbol(s) in the DC segment,
- pilot boosting level (0 or 2.5 dB for pilot boosting off or on)

These settings also have to be provided (must be a-priori known) to the GS RX in order to emulate the exchange of control messages and enable proper data detection and decoding.

The above settings have to be chosen depending on the test setup, e.g. AS TX spectrum measurements, where a realistic duty cycle is crucial, or GS RX BER measurements, where a large amount of transmitted data is required for high statistical reliability and a reasonable synchronisation procedure without the FL signalling is required.

The RA sub-frames have to be filled with arbitrary data in order to emulate a typical RL transmission. However, the detailed data content of the RA sub-frames is irrelevant for both AS TX spectrum measurements (as long as these data are pseudo-random allowing for realistic PAPR values) and GS RX BER evaluation of the Data and DC segments.

In Table 4-9 and Table 4-10, parameter settings are proposed separately for the two test cases mentioned above.

Table 4-9: PHY Framing Parameters for AS TX Spectrum Measurements

Parameter	Value
number of MFs per SF, where synchronisation symbols are used in DC segment	max. 1
number of MFs per SF, where an AGC preamble is used in the DC segment	max. 1
number of MFs per SF, where the considered AS uses tile(s) in the DC segment	1
length of DC segment (in tiles)	variable, e.g. 16
number and position of tile(s) in DC segment carrying data of the considered AS	1 tile, arbitrary position
length of Data segment (in tiles)	determined by length of DC segment
number and position of tiles in Data segment carrying data of the considered AS	variable
number and position of RA sub-frames within one SF sent by the considered AS	variable
the total number of opportunities for synchronisation OFDM symbols in a DC segment	K_{sy}=5
number of synchronisation OFDM symbols sent by the considered AS TX per SF	Max. 1
position of synchronisation OFDM symbol(s) in the DC segment	3rd opportunity
pilot boosting level	0 or 2.5 dB

Table 4-10: PHY Framing Parameters for GS RX BER Measurements

Parameter	Value
number of MFs per SF, where synchronisation symbols are used in DC segment	4 (all)
number of MFs per SF, where an AGC preamble is used in the DC segment	4 (all)
number of MFs per SF, where the considered AS uses tile(s) in the DC segment	4 (all)
length of DC segment (in tiles)	2
number and position of tile(s) in DC segment carrying data of the considered AS	2 (all)

Parameter	Value
length of Data segment (in tiles)	158
number and position of tiles in Data segment carrying data of the considered AS	158 (all)
number and position of RA sub-frames within one SF sent by the considered AS	2
total number of opportunities for synchronisation OFDM symbols in a DC segment shall be fixed	K_{sy}=5
number of synchronisation OFDM symbols sent by the considered AS TX per SF	8 (two in each DC segment)
position of synchronisation OFDM symbol(s) in the DC segment	4^{th} and 5^{th} opportunity
pilot boosting level	0 or 2.5 dB

The pseudo-random data to be transmitted in the RL PHY-PDUs are expected to be generated by an external source. The simple AS TX MAC layer shall support segmenting and packaging of the test data received from an external test source, which shall provide PHY-PDUs that can be directly mapped onto the AS TX RL frames (Section 4.3.4).

According to the setting of the above parameters, simple MAC sub-layer provides the PHY layer with RL PHY-PDUs, i.e. RL RA PHY-PDUs, RL DC PHY-PDUs or RL Data PHY-PDUs. The size of the RL PHY-PDUs corresponds to the capacity of the different types of frames and tiles.

4.5 AS TX Test Interface

In normal operation, the AS TX SNDCP functional block would accept IP network data packets on an external interface. These data packets would be further handled by the AS TX DLS function and then handed-over to the AS TX MAC and further to the PHY layer.

A much simpler test interface would be appropriate for the laboratory AS TX prototype.

The AS TX MAC layer shall support segmenting the test data received from an external test source over the test interface. In order to enable BER measurements, the randomly generated data stream provided to the AS TX has to be stored as a reference. The test data sequence detected by the GS RX is also stored and forwarded to an external evaluation tool.

It is proposed to perform the external comparison of TX and RX bits separately for each SF, based on the data content of an entire SF.

Alternatively, BER measurements can be performed at the RX, if no external test source is available. In that case, the a-priori known TX data sequence has to be stored at the RX as a reference, compared to the received test data and the outcome – BER – provided on an external interface. However, this option is only considered as the second choice.

CHAPTER 5 – Ground Station Receiver

This section comprises items that are specific to the prototype implementation of the L-DACS1 GS RX operating in the A/G mode.

Deviations from the L-DACS1 system specification (Deliverable D2) that are proposed for more efficient prototyping or any other reason are highlighted.

5.1 GS RX Radio Front-end Characteristics

5.1.1 GS RX Frequency Range and Tuning Step

L-DACS1 shall operate as a full duplex system in the 960 –1164 MHz range. In order to reduce the airborne co-site interference towards the L-DACS1 AS RX, the spectrum range between 1025.5-1149.5 MHz, currently used by airborne DME interrogators, should be used for AS TX transmission only [D2].

The prototype GS RX shall be capable of operating on any channel within the 1048.5 – 1071.5 MHz range[45].

An extended prototype GS RX range (1025 – 1087 MHz or even 1025 – 1150 MHz) would be beneficial for investigating the possibility of operating L-DACS1 FL/RL in other sub-ranges with modified duplexer settings, including closer frequency spacing to fixed-channel SSR systems.

Preliminary deployment concept based on the interference situation in the L-band and estimated duplexer feasibility anticipates that L-DACS1 FL/RL channel blocks would be placed “in the middle” between fixed L-band UAT/SSR channel allocations (978, 1030, 1090 MHz), providing also sufficient margin to the GPS/GALILEO channels in the upper part of the L-band. With that concept, the sub-range for the FL channels is 985.5 – 1008.5 MHz while the sub-range for L-DACS1 RL channels is 1048.5 - 1071.5 MHz.

GS RX shall be tuneable to any channel within the operating range with a 0.5 MHz step.

The operating channel shall be adjustable via an implementation-specific interface.

[45] The channel frequency corresponds to the nominal position of the DC OFDM sub-carrier in the spectrum of the L-DACS1 signal.

During the trials, the prototype GS RX channel shall be tuned to the same channel that is selected for the corresponding AS TX. The GS RX channel shall be set 63 MHz above the corresponding GS TX channel.

The duplex spacing of 63 MHz is currently used by airborne DME equipment.

5.1.2 GS RX Centre Frequency Tolerance

GS RX centre frequency and the symbol clock frequency shall be derived from the same reference oscillator.

At the GS RX, the reference frequency accuracy shall be better than ± 0.1 ppm.

5.1.3 GS RX Available Bandwidth

GS RX shall be able to receive AS TX signal with the occupied bandwidth B_{eff} = 498.05 kHz (Section 4.3.1.3/Table 4-2).

5.1.4 GS RX Maximum Tolerable Input Signal Power

The GS RX shall tolerate at its input a pulsed interference signal with peak power of up to +25 dBm without damage.

Due to the possible co-location with GSs of other aeronautical systems, the same (stringent) value is proposed for the GS RX as for an AS RX (see Section 6.1.5).

For the prototype implementation, the usage of an external RF BP filter between the GS antenna and the GS RX input is recommended that operates over the GS RX reception range (Section 5.1.1) emulating the duplexer selectivity.

If an RF pre-selection filter is used, the GS RX shall tolerate at its input a pulsed interference signal with peak power of up to -10 dBm[46] without damage.

The above value has been estimated based on the preliminary specification of TX and RX BP filters as provided in Section 7.3.

5.1.5 GS RX Maximum Acceptable Desired Signal Power

The GS RX shall be capable of decoding on-channel desired L-DACS1 signal (D) with the peak power of –10 dBm (measured at the RX input).

AS TX on the ground operating with +41 dBm average AS TX power at 100 m distance to the GS antenna would produce -27.9 dBm average power at the GS RX input, assuming 0 dBi airborne antenna gain, 3 dB airborne cable losses, 0.5 dB duplexer losses, free-space propagation, 8 dBi ground antenna gain and 2 dB ground cable losses, Assuming 17 dB provision for TX PAPR[47], the peak received L-DACS1 signal power becomes -10.9 dBm (rounded-up to -10 dBm).

5.1.6 GS RX Automatic Gain Control (AGC)

GS RX shall implement RF_AGC that should prevent saturation of any part of the RX front end up to and including the Analogue-to-Digital-Converter (ADC).

Parameters of the AGC circuit (e.g. AGC threshold) shall be adjustable via an implementation-specific interface.

The GS RX RF_AGC shall be available during reception of RL RA frames.

Under operational circumstances, the GS would measure the received power of the RL RA

[46] An airborne BP filter would attenuate all co-site signals to -10 dBm (or less). It has been assumed that the same value could be achieved by the proposed ground BP filter for close ground L-band sources.

[47] In the practical implementation it should be possible to reduce the maximum possible PAPR value with 50 OFDM sub-carriers (17 dB) by using PAPR reduction techniques.

frames and issue a corrective command to the AS TX in order to reduce its transmitting power such that the following DC segments and Data segments sent by different AS TXs are all received with approximately the same power.

With initial prototypes no "closed-loop" corrections of the AS TX power, frequency, and timing offset will be possible.

When receiving non-RA RL frames, the GS RX shall use RF AGC as used for RL RA frames.

The prototype GS RX RF AGC shall be available during reception of RL DC segments. After being re-stimulated via an AGC preamble of the RL DC segment, the GS RX shall update the AGC setting and maintain the setting until the next update (at least over the duration of the subsequent RL Data segment).

5.1.7 GS RX Interference Blanking

Autonomous interference blanking is considered as an option for the deployable GS RX and also as an option for an initial prototype GS RX. It would make the GS RX operation possible in the presence of strong interference from co-located DME GS or close JTIDS aircraft/JTIDS ground station.

Blanking of strong interferers close to the GS RX operating at sufficient frequency distance from it could in a practical implementation be supplemented by the RF BP filter that operates over the GS RX reception range (Section 5.1.1). A preliminary specification of such a BP filter is provided in Section 7.3.3.

GS RX should implement an autonomous interference blanking mechanism, based on the fast detection of short interfering signals within the RX front-end.

If configured/activated, the blanking circuit shall be active only if the interference level is above the blanking threshold (value to be defined).

Parameters of the blanking circuit (e.g. blanking threshold) shall be adjustable via an implementation-specific interface.

Temporary RF muting of the GS RX over the duration of short RF pulses due to interference blanking shall not cause irregularities or long recovery times within the RX RF part. In particular, the AGC status prior to blanking should be re-established immediately (within TBD μs) after the interference caused by the transmission of another L-band TX has ceased.

If blanking is implemented, the blanking status shall be made available to the GS RX baseband unit.

The L-DACS1 GS RX may use this information for improving its performance under co-site interference (e.g. triggering interference mitigation procedures within the baseband processor).

5.2 GS RX Baseband Characteristics

5.2.1 GS RX Target Bit Error Rate

GS RX target corrected BER shall be less than 10^{-6} at the input signal power level that corresponds to the GS RX sensitivity for standard message and test conditions (Section 5.2.2).

The same target BER value is used when specifying the RX operating point (Section 5.2.3) and RX interference immunity performance (Section 5.2.4).

GS RX shall provide a test interface for measuring corrected PHY Bit Error Rate (BER).

In case the GS RX itself measures the BER, it is recommended to make the target BER value adjustable via an implementation-specific interface.

5.2.2 GS RX Sensitivity

GS RX sensitivity level shall be S0 ≤ -103.83 dBm when using all RL sub-carriers (N_{used} = N_u = 50), QPSK modulation, convolutional coding with rate r_{cc}=1/2 and Reed-Solomon RS(16,14,1) coding in RL Data segments.

The requirement shall be fulfilled when the desired AS TX signal is produced with the maximum tolerable frequency offset on RL (see Section 5.1.2 and Section 4.1.2) and is simultaneously subject to the maximum relative Doppler shift to the GS RX at the maximum GS operating frequency of 1071.5 MHz (Section 5.1.1) and the aircraft speed of 850 KTAS.

The minimum input level (receiver sensitivity) is measured as follows:

- Using the defined standardized message packet formats
- Using an AWGN channel (no interference)
- Using a specified RL channel

The GS RX sensitivity figure S0 stated above has been derived by assuming an implementation loss of 4 dB (which includes non-ideal receiver effects such as channel estimation errors, tracking errors, quantization errors and phase noise), as well as GS RX noise figure NF = 5 dB, both referenced to the RX input. The sensitivity figure S0 may have to be further fine adjusted.

5.2.3 GS RX Operating Point

The GS RX shall fulfil the BER specified in Section 5.2.1 in presence of cumulative L-band interference when the signal S1 as in the last row of Table 5-1 is present at the RX input.

The test shall be conducted using all RL sub-carriers (N_{used} = N_u), QPSK modulation, convolutional coding with rate r_{cc}=1/2 and Reed-Solomon RS(16,14,1) coding in RL Data segments.

S1 defines the RX operating point – a minimum required RX input signal power at the RX input under real interference conditions (cumulative L-band interference, comprising both co-site interference and interference from "remote" sources), considering an appropriate aeronautical channel and including safety margin.

Table 5-1: GS RX Operating Point S1

Antenna Conversion	Unit	ENR	TMA	APT	Equation
TX-RX distance	nm	120	40	10	d
RX sensitivity @ interference	dBm	-103.03	-100.03	-90.03	S0
RX operating point	dBm	-97,03	-94,03	-84,03	S1

As a complete picture of L-band interference – including large aircraft population - cannot be produced in the laboratory, this item cannot be fully tested in the laboratory.

5.2.4 GS RX Interference Immunity Performance

The Interference Rejection (IR) represents the power difference (in dB) between the interfering undesired signal (U) at specified frequency offset from the L-DACS1 channel and the on-channel desired L-DACS1 signal, for specified desired signal level (D) and specified bit error rate.

IR shall be measured by setting the desired L-DACS1 signal power to the level "D" (dBm) that is "m" dB (e.g. 6 dB) above the rate dependent receiver sensitivity S0 (as specified for the case with interference in Table 5-1) and raising the power level "U" (dBm) of the interfering signal until the target bit error rate (as specified in Section 5.1.1) is obtained.

IR shall be separately assessed and declared for each applicable type of interfering signal (e.g. DME, SSR, UAT, JTIDS/MIDS). Each interfering signal must be specified in terms of its operating frequency (or frequency offset to the L-DACS1 channel), peak power, and duty-cycle.

Table 5-2 illustrates one example of stating IR for a particular interfering L-band system "X". IR is frequency-dependent and shall be stated for different frequency offsets between the desired L-DACS1 signal and the undesired interference signal.

In order to fulfil above requirements, prototype GS RX will have to implement methods for mitigating the impact of interference, e.g. one of the methods proposed in Section 5.3.8 or a combination of them.

As the GS RX is a single-channel device, an external RF BP filter with the minimum necessary bandwidth for the selected operating channel should be inserted in front of the GS RX in order to improve GS RX RF selectivity.

For the prototype implementation, it is recommended inserting an external RF BP filter between the GS antenna and the GS RX input that operates over the GS RX reception range (Section 5.1.1). Such a filter would emulate the narrowband RF pre-filter mentioned above.

The GS RX BP filter has been described in Section 7.3.3.

Optionally, interference blanking may be implemented as proposed in Section 5.1.7.

Table 5-2: Interference Rejection (IR) Requirements for GS RX (System "X")

Desired signal power D (dBm)	D				
Frequency offset ∆f (MHz)	∆f_1	∆f_2	∆f_3	∆f_4	∆f_n
Tolerable undesired system "X" signal power U (dBm)	U_1	U_2	U_3	U_4	U_n
IR=U/D (System „X", dB)	U_1/D	U_2/D	U_3/D	U_4/D	U_n/D

The ∆f values in Table 5-2 should be selected as appropriate for the System "X".

In particular, for tests with the DME equipment, the appropriate ∆f values may be ± 0.5 MHz, ±1 MHz, ± 1.5 MHz, ±2 MHz, ± 2.5 MHz etc.

In case of testing the impact of the DME interference, D shall be set equal to the GS RX operating point S1 (Section 5.2.3).

Note: Power levels D1 and U1 in the following text are referenced to the input of the GS RX BP filter rather than the RX input, assuming the GS RX BP filter as specified in Section 7.3.3. Therefore, the desired signal power D1 at the BP filter input is 0.5 dB above the D value measured ad the RX input.

The following preliminary[48] requirements apply for the prototype GS RX:

GS RX shall be capable of achieving specified BER (Section 5.2.1) when the desired signal level D1 is between -96.53 dBm and -9.5 dBm when subjected to DME interference under the following conditions:

- DME pulse pairs at a nominal rate of 3,600 pulse pairs per second at either 12 or 30 microseconds pulse spacing at a level U1 = -54.5 dBm[49]
- Multiple DME ASs operating on any 1 MHz DME channel frequency between 1025 and 1150 MHz.

[48] Specifying the interference environment for laboratory measurements is not within the scope of this task.

[49] As no detailed RL simulations were performed during the B-AMC study [B-AMCx], the same preliminary value was assumed for the cumulative RL interference from multiple DME ASs as for the L-DACS1 AS RX being exposed to the interference from a single DME GS.

In order to fulfil above requirements, GS RX shall implement methods for mitigating the impact of interference, e.g. one of the methods proposed in Section 5.3.8 or a combination of them.

5.2.5 GS RX S/N Measurement

Under normal operating conditions, GS RX shall continuously measure S/N for RL frames/segments received from the controlled ASs. The S/N value shall be permanently updated and averaged after each new RL RA sub-frame or user's tiles within a DC/Data segment has been received from the controlled AS.

This item is required for normal system operation where in-the-loop mechanisms are in place and is provided as information for the radio vendor.

S/N measurement is not required for the prototype GS RX.

5.2.6 GS RX to AS TX Frequency Synchronisation

GS RX shall be able to individually synchronise to, receive, and decode AS TX RL RA frames (Section 4.3.2.1).The GS RX frequency synchronisation to RL RA frames shall be based on observing the synchronisation symbol pairs that occur at the start of RL RA frames.

After being stimulated via an RL RA frame, the GS RX shall apply and maintain the resulting frequency setting until the next update.

After the initial frequency synchronisation to the RL RA sub-frame, the GS RX centre frequency deviation from the centre frequency of the prototype AS TX shall be less than 2 % of the OFDM sub-carrier spacing (less than 195 Hz)[50].

The synchronisation performance shall be assessed/verified via an implementation-specific interface.

The GS RX normally operates on a fixed reception frequency that is derived from the GS local frequency reference, except when receiving RL RA frames. AS TX sends RL RA frames on its nominal frequency that may be offset with respect to the GS RX nominal frequency due to a non-compensated TX-RX frequency error and/or Doppler shift. In this case the GS RX initially waits on its nominal frequency, but when the RL RA frame arrives at some frequency offset, the GS RX must synchronise to that frame by adjusting its local frequency.

The GS RX frequency capture range shall be sufficient for accommodating both imperfect GS TX - AS RX reference frequency accuracy (see Section 5.1.2 and Section 4.1.2) and the maximum applicable GS TX - AS RX Doppler shift (1.675 kHz at 850 knots and 1149.5 MHz).

As RL RA frames are relatively short, no frequency tracking is explicitly required over these frames.

Under normal conditions, after an initial RL contact and subsequent FL correction, the AS TX is synchronised with the GS RX (it has applied the frequency correction and tries to track further frequency variations on FL in order to maintain "proper" frequency setting on RL). An AS TX adjusts its RL transmission frequency for non-RA RL frames rather than using its nominal RL frequency. After having received the RL RA sub-frame, the GS RX would switch back to its fixed nominal frequency and measure frequency deviation of received RL frames/segments relative to it, issuing further corrective commands to the AS TX. For the synchronisation maintenance the GS may require that the selected AS TX sends a synchronisation symbol at the beginning of the RL DC segment.

With initial prototypes no "closed-loop" corrections of the AS TX power/frequency/timing offset will be possible.

For the prototype implementations it is proposed that the AS TX sends all RL

[50] Requirement from [D2] Section 5.6.2 has been adapted to the situation without in-the-loop mechanisms.

frames/segments on its nominal, fixed RL frequency.

A prototype AS TX always transmits on the selected nominal frequency (there is no requirement for implementing the frequency correction in the prototype AS TX).

The GS RX shall be able to synchronise in frequency to the AS TX and perform subsequent frequency tracking by adjusting its local frequency.

Frequency tracking can be based on received DC segment synchronisation symbols as well as synchronisation symbols in the RL RA sub-frames).

After being re-stimulated via a synchronisation symbol of the RL DC segment, the GS RX shall update the frequency setting and track/maintain the setting until the next update (at least over the duration of the subsequent RL Data segment).

For frequency synchronisation maintenance, the synchronisation OFDM symbols in the RA sub-frames as well as the synchronization symbols in the DC segments are available.

During frequency tracking, the GS RX centre frequency deviation from the centre frequency of the AS TX shall be less than 2 % of the OFDM sub-carrier spacing (less than 195 Hz).

The frequency synchronisation performance shall be assessed/verified via an implementation-specific interface.

For the optimum tracking performance at the GS RX, it is essential that the AS TX provides a sufficient number of RL synchronisation symbols within the SF. This is achieved via inserting more synchronisation symbols in the DC segments than it would be required in the normal operation. Additionally, two RA sub-frames per SF are transmitted (Section 4.4).

5.2.7 GS RX to AS TX Time Tracking

The GS RX shall be able to individually lock onto, receive, and decode RL RA frames received with different power-, frequency-, and timing settings, relative to the GS reference values.

The GS RX normally operates with fixed local SF structure. AS TX sends RL RA frames that may be offset in time with respect to the GS RX local framing. In this case the GS RX maintains its nominal framing, but when the RL RA frame arrives with some time offset, the GS RX must synchronise in time to that frame.

Under normal conditions, after an initial RL contact and subsequent FL correction, the AS TX is synchronised in time with the GS RX (it has applied the time advance correction and tries to track further timing variations on FL in order to maintain "proper" timing on RL). An AS TX adjusts its RL timing for non-RA RL frames rather than using its local timing based on observed FL framing. After having received the RL RA sub-frame, the GS RX would not attempt to synchronise to non-RA RL frames, but would rather measure the time offset of received RL frames/segments relative to its local framing, issuing further corrective commands to the AS TX. For the timing maintenance the GS may require that the selected AS TX sends special synchronisation symbol at the beginning of the RL DC segment.

With initial prototypes no "closed-loop" corrections of the AS TX power-, frequency-, timing offset will be possible. Still it must be made sure that the SF synchronisation between the AS TX and GS RX is in place. The mechanism proposed below is similar to that used by the AS RX on FL and should allow for acquiring an "autonomous" GS RX SF synchronisation without a-priori knowledge of the AS TX SF boundary.

During start-up, the prototype GS RX shall be able to accept RL RA frames regardless of the AS TX SF offset to the initial (free-running) GS RX local SF boundary.

Under normal circumstances, GS RX should accept only RL RA sub-frames that are received within the time window that corresponds to the "RL RA frame" (that exactly overlaps with the FL BC frame). With the proposed modification, this window should be initially extended to the entire SF frame.

After being stimulated via an RL RA frame, the prototype GS RX shall establish its SF framing (align it with the AS TX SF framing), acquire symbol timing and maintain the resulting time setting until the next update.

For initial time synchronisation, the prototype GS RX looks for the synchronisation OFDM symbols in the RA sub-frames. They are characterised by a certain time interval between the two synchronisation symbol pairs that differs from the time interval between synchronisation symbol pairs in the DC segments. This pattern will repeat each SF. Thus, after some time the GS RX will be able to detect the start of the RL SF.

Alternatively, initial SF alignment between the GS RX and AS TX could be established via wired connections between the GS RX and the AS TX. GS RX would act as "time master" and would provide its SF framing to the AS TX via this interface (in the reality, it would be derived from the received GS TX FL SFs). In order to emulate non-ideal AS-GS SF alignment, at the AS TX an intentional configurable time offset with respect to the GS RX framing should be inserted. When testing the GS RX ability to receive RL RA sub-frames, this offset should be adjusted within the uncertainty limits that apply to the possible position of RA sub-frames within the RL SF. With the above proposal, AS TX RL RA frames would be sent at a fixed offset relative to the GS RX SF framing that still places them within the "proper" RA time slot This however is considered just as an option for the laboratory prototype equipment.

GS RX must be able to re-synchronise, based on received DC segment synchronisation symbols (as it normally does when receiving RL RA frames) by adjusting its local timing. After being re-stimulated via a synchronisation symbol of the RL DC segment, the GS RX shall update the time setting and track/maintain the setting until the next update (at least during the duration of the subsequent RL Data segment used for BER measurements).

This is not required in the normal operation, due to the closed-loop regulation (the GS RX adjusts the AS TX timing rather than its own timing). For the optimum tracking performance at the GS RX, it is essential that the AS TX provides a sufficient number of DC segments with RL synchronisation symbols within the SF.

For the timing synchronisation maintenance, the synchronisation OFDM symbols in the RA sub-frames as well as the synchronization symbols in the DC segments are evaluated based on the repetitive pattern of RL synchronisation symbols.

After the initial time synchronisation, the time offset between the prototype AS TX SF and the prototype GS RX SF shall be less than 1/3 of the OFDM guard time (less than 1.6 μs)[51].

The GS RX time tracking performance shall be determined using an implementation-specific interface.

5.2.8 GS RX Measurement of RL Frequency Error

When receiving RL RA frames and RL synchronisation symbols in DC frames, the GS RX shall be able to measure frequency offset between the incoming RL centre frequency and the local frequency reference applicable to RL. The measurement tolerance shall be better than 1% of the sub-carrier spacing.

This item is required for normal system operation where in-the-loop mechanisms are in place and is provided as information for the radio vendor. This feature is not required (optional) for the prototype GS RX.

With initial prototypes no "closed-loop" corrections of the AS TX power-, frequency-, timing offset will be possible. The GS RX will compensate RL power-, frequency-, and timing errors, but does not need to measure them.

5.2.9 GS RX Measurement of RL Timing Error

When receiving RL RA frames and RL synchronisation symbols in DC frames, the GS RX

[51] Requirement from [D2] Section 5.6.3 has been adapted to the situation without in-the-loop mechanisms.

shall be able to measure the time offset between the incoming RL frames and the local reference frame timing to an accuracy of ± 1/6 of the guard time T_g or better.

This item is required for normal system operation where in-the-loop mechanisms are in place and is provided as information for the radio vendor. This feature is not required (optional) for the prototype GS RX.

With initial prototypes no "closed-loop" corrections of the AS TX power-, frequency-, timing offset will be possible. The GS RX will compensate RL power-, frequency-, and timing errors, but does not need to measure them.

5.2.10 GS RX Symbol Clock Frequency Tolerance

GS RX centre frequency and the symbol clock frequency shall be derived from the same reference oscillator.

At the GS RX, the reference frequency accuracy shall be better than ± 0.1 ppm.

5.3 GS RX PHY Layer Characteristics

In the GS RX prototype, parts of the PHY layer functionality specified in [D2] have to be implemented. The basic functionality of the GS RX prototype is illustrated in the block diagram in Figure 5-1.

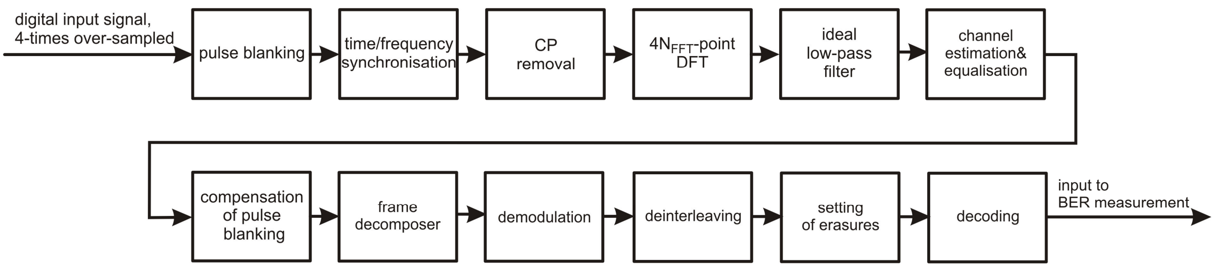

Figure 5-1: Simplified Block Diagram of GS RX

The input is the digital received signal with recommended sampling rate corresponding to at least four-times the usual OFDM sampling rate.

Over-sampling is introduced as an option in order to reduce aliasing effects and to keep the impact of interference from other L-band systems at a minimum (see Section 5.3.8.2).

The sampled input signal shall be processed, before providing the received data to the simple MAC layer, according to the following steps:

- Start of the frame shall be detected
- *Optionally, pulse blanking may be applied*
- Based on the OFDM synchronisation sequences, the time and frequency offset shall be estimated
- The frame shall be de-rotated based on the estimated frequency offset
- The serial data stream shall be converted into a matrix, so that one OFDM symbol occupies one row of the matrix
- Since TX windowing is performed at the AS TX, the GS RX shall extract the useful part of each OFDM symbol by removing the cyclic prefix. Thereby, the estimated time offset determined in the synchronisation procedure shall be taken into account. Since the cyclic suffix of length T_w overlaps with the cyclic prefix of the following OFDM symbol (see Section 4.3.6), it is sufficient to discard the entire cyclic prefix when discarding the guard interval.

- The extracted part of each OFDM symbol shall be transformed via an FFT operation into the frequency domain.

  If over-sampling is applied, the relevant sub-carriers coinciding with the OFDM system bandwidth shall be extracted after the FFT operation.
- Complex channel response coefficients shall be estimated based on the received pilot symbols and the data symbols shall be multiplied with the corresponding coefficients.
- *If pulse blanking is applied, the impact of pulse blanking on the desired signal may be eventually compensated.*
- The frame shall be decomposed by extracting the useful data symbols
- Reliability information for each bit shall be computed via the Euclidean distances of the data symbols to the constellation points. This procedure relates to the demodulation
- Permutation de-interleaving and convolutional decoding, making use of the reliability information shall be performed. *If pulse blanking is not applied, erasure decoding is applied and reliability information of bits affected by interference shall be set to 0 (see Section 5.3.8.1.1).*
- RS decoding shall be performed

In the following, the parts of the PHY layer specification from [D2] relevant for the GS RX prototype are recapitulated. In order to avoid replications, references to corresponding sections of the AS TX specification are given.

5.3.1 RL – OFDMA-TDMA Transmission

5.3.1.1 Frequency Domain Description

Frequency domain description for an RL L-DACS1 signal is provided in Section 4.3.1.1.

5.3.1.2 Time Domain Description

Time domain description for an RL L-DACS1 signal is provided in Section 4.3.1.2.

5.3.1.3 OFDM Parameters

The basic OFDM parameters relevant for the GS RX are listed in Section 4.3.1.3/Table 4-2.

5.3.2 Physical Frame Characteristics

The description of physical frame characteristics for RL is provided in Section 4.3.2.

5.3.2.1 Reverse Link Frame Types

The description of RL frame types is provided in Section 4.3.2.1.

In reality, the GS itself determines the length of the RL Data segment via resource allocation over the FL. In order to emulate the behaviour of the real system, the length of the RL Data segment is assumed to be known at the GS RX.

5.3.2.2 Framing

The L-DACS1 physical layer framing on RL is as described in Section 4.3.2.2.

5.3.2.3 Framing Specifics for GS RX Prototype Implementation

RA sub-frames

The number of transmitted RA sub-frames per SF shall be configurable, i.e. no, one or two RA sub-frames can be transmitted per SF.

In case of BER measurements at GS RX AS TX shall send two RA sub-frames in each RL

SF for synchronisation purposes.

In case an RA sub-frame is not used, the corresponding time slot in the SF structure shall be left empty while the actual timing structure of the SF is maintained.

AGC Preambles

The number of AGC preambles per SF shall be configurable (an AS TX shall insert "n" AGC preambles per SF). At the GS RX, it is assumed to be known whether or not the received data contain an AGC preamble.

In case of BER measurements at the GS RX, AS TX shall send one AGC preamble in each MF.

Synchronisation Symbols in DC Segments

The total number of opportunities for synchronisation symbols in a DC segment shall be fixed (K_{sy}=5).

The number of synchronisation symbols sent by an AS TX per SF shall be configurable. In case of BER measurements at GS RX, AS TX shall send two synchronisation symbols on the fourth and fifth OFDM synchronisation symbol position in each DC segment.

DC Segments

The length of the DC segment shall be kept variable, defined by the corresponding parameter. A single parameter determines the length of both DC segment and Data segment. Furthermore, the number and positions of tiles to be transmitted in the DC segment shall be configurable.

In case of BER measurements at the GS RX, AS TX shall send test data in all DC segments of all RL MFs. The length of the DC segment is set to the minimum length which is two tiles.

Data Segments

The length of the Data segment shall be kept variable, defined by the same parameter that already determines the length of the DC segment.

In case of BER measurements at the GS RX, the length of the Data segment is set to the maximum length in accordance to the length of the DC segment. The AS TX shall transmit test data in all Data segments of all RL MFs.

5.3.3 Decoding and Demodulation

At the RX side, the equalised data symbols first enter the demodulator. Afterwards, permutation deinterleaving and convolutional decoding are applied. In a last step, the RS decoding is applied. The block sizes of the coding, interleaving and modulation blocks are given in Table 4-6.

5.3.3.1 Demodulation

Modulation aspects applicable to the prototype equipment are described in Section 4.3.3.3.

The detailed method for the demodulation is an implementation issue. However, it is intended that the demodulator provides soft-input for the convolutional decoder.

5.3.3.2 Deinterleaving

The interleaver permutation is described in Section 4.3.3.2. The permutation in the deinterleaver is the inverse of the permutation in the interleaver.

The block size of the interleaver N_I complies with the coding block sizes.

5.3.3.3 Channel Decoding

5.3.3.3.1 Inner Decoding

The convolutional decoder shall be able to handle soft-input values, which are provided by the demodulator. The decoder should provide hard-output. Six termination bits, inserted at TX before encoding, are discarded before passing the resulting sequence on to the RS decoder.

It is proposed to use a Viterbi algorithm, which can be found in [For73].

5.3.3.3.2 Outer Decoding

The RS decoding is done by means of algebraic decoding. The decoding is done in three steps:

- syndrome calculation
- error location calculation
- error value calculation

The input of the RS decoder is the output of the convolutional decoder. First of all, the syndrome vector in the frequency domain of the finite field is calculated. Since the undisturbed codeword possesses d-1 consecutive zeros in the frequency domain, the error vector is equal to the syndrome vector at these places. The task of the error location calculation is to determine the missing error vector coefficients out of the known syndrome coefficients. The error location calculation can be done by the Berlekamp-Massey algorithm [Mas69], which uses a linear shift register to generate the error location vector out of the syndrome vector. Once the correct error location vector has been found, the error values can be calculated with the Forney algorithm [For65]. At the end, the received codeword is subtracted by the error values at the error positions.

5.3.3.4 RL Coding Parameters

In the real system, the selection of a coding and modulation scheme for certain AS is carried out by the GS and communicated to this AS via the CMS RL MAP [D2].

In the prototype, a fixed coding and modulation scheme is selected for each type of PHY-PDU. The combination of QPSK modulation, a fixed RS code and a convolutional code with r_{cc} = ½ is mandatory for the RL DC, the RL RA PHY-PDUs and also for the data PHY-PDUs since Adaptive Coding and Modulation (ACM) is not implemented in the prototype.

The modulation schemes, channel coding parameters and block sizes for the PHY-PDUs applicable to the prototype equipment are given in Section 4.3.3.1.

5.3.4 Frame Decomposer

After transforming received OFDM symbols in the frequency domain, channel estimation and equalisation shall be performed before decomposing the frame. Frame decomposition is performed by extracting the data symbols in time direction from the time- frequency plane and mapping them on a data stream. For extracting the data symbols the position of the pilot and PAPR-reduction symbols have to be known. They can be found in Table 4-3, Table 4-4 and Table 4-5.

5.3.5 Synchronisation

In the real system, the synchronisation in the RL is derived from synchronisation in the FL. Time and frequency offsets are adjusted in a closed-loop procedure by measuring and signalling the required adjustments on FL and RL.

Since the RL prototype shall be independent of the FL, a stand-alone synchronisation procedure has to be implemented when measuring the BER at the GS RX. In order to stimulate such autonomous synchronisation or the GS RX on RL, the similar procedure is proposed as normally used for synchronising the AS RX on FL. The synchronisation symbol pairs as normally used in the FL and in RL RA frames should be also inserted in the RL DC segments. Synchronisation symbol pairs should be inserted in the DC segment at the fourth and fifth OFDM synchronisation symbol position as described in Section 5.3.2.3.

For synchronisation, these synchronisation OFDM symbols should be exploited by calculating appropriate metrics, given e.g. in [Sch97] for the second OFDM synchronisation symbol. Based on these metrics, the synchronisation algorithm itself is split up in an initial acquisition and a tracking procedure.

5.3.5.1 Initial Acquisition

The initial acquisition of the timing- and frequency-synchronisation is based on the synchronisation symbol pair that appears at the beginning of the RA sub-frames. The number of RA sub-frames per SF shall be configurable, but it is recommended to transmit two RA sub-frames per SF and consider the initial synchronisation as successful if the GS RX could independently synchronise to both RA sub-frames.

5.3.5.2 Tracking

Based on the initial acquisition, the timing- and frequency synchronisation shall be tracked, based on the synchronisation OFDM symbols in the DC segments. A further refinement could be achieved by exploiting an additional metric, obtained by correlation the cyclic prefix of each data OFDM symbol with its corresponding section of the useful part.

Detailed methods for acquisition and tracking are an implementation issue.

5.3.6 Channel Estimation

For DC/Data segments, the linear interpolation is executed tile-wise, for RA frames sub-frame based.

The position of the pilot symbols is given in Table 4-3, Table 4-4 and Table 4-5. The pilot sequences itself are described in Section 4.3.5.1.

The specific interpolation method for channel estimation is an implementation issue.

5.3.7 Equalisation

The specific method for channel equalisation is an implementation issue.

For equalisation, a zero-forcing equaliser is intended to be used. Based on the estimated channel coefficients, the equalisation is performed symbols-wise. Note that the chosen equaliser has to be taken into account for soft-demodulation (see Section 5.3.3.1).

5.3.8 RX – Interference Mitigation from Existing L-Band Systems

As in the aeronautical L-band environment many other systems are already operational, there is a need to reduce the interference impact produced by these systems onto L-DACS1 receivers. Three candidate techniques for interference reduction are briefly presented in the following sub-sections.

Details of these techniques are considered to be an implementation issue and are therefore not specified in this document.

Moreover, it has to be mentioned that the proposed interference mitigation mechanisms cannot be combined arbitrarily. The interference mitigation mechanisms have to be configurable such that a particular method can be switched on or off separately to allow for pre-testing the performance of all proposed methods individually and define the operating configuration prior to the laboratory interference tests.

5.3.8.1 Erasure Decoding

For applying erasure decoding, the interference power received in the guard bands of the used FFT bandwidth can be measured[52].

[52] Observing the interference power in the guard bands is enabled by the RX IF bandwidth that exceeds the minimum of 500 kHz. The IF filter with 600 kHz BW proposed in ANNEX 3 – would enable such an observation with only a minimum impact onto RX sensitivity.

5.3.8.2 *Over-Sampling*

In order to relax the impact of aliasing associated with strong out-of-band interference signals, it is recommended to over-sample the received time domain signal at least by a factor of N_{ov}=4.

5.3.8.3 *Pulse Blanking*

Interference mitigation approaches like pulse blanking may be applied (Section 5.1.7) for mitigating the interference from existing L-band systems.

In the GS RX prototype, the compensation of the impact pulse blanking on the desired signal can be implemented optionally in addition to pulse blanking.

5.3.9 Physical Layer Parameters

At the GS RX, all physical layer parameters used at the AS TX are assumed to be known. These parameters are given in Section 4.3.7.

5.4 GS RX Protocol Characteristics

Detailed specification for L-DACS1 protocol entities above PHY layer is provided in [D2].

For laboratory testing purposes, the full-size MAC sub-layer described in [D2] can be replaced by a reduced functionality.

The pseudo-random data received in the RL PHY-PDUs are expected to feed external BER test equipment. The simple GS RX MAC layer shall support re-assembling of received RL PHY-PDUs and formatting the received test data into a format acceptable to the external BER test equipment.

In the prototype GS RX implementation, multiple PHY parameters that would be normally set via MAC sub-layer are configured directly at the PHY layer.

For the purpose of BER measurements at the GS RX side, the RX PHY layer parameters shall be internally adjusted to basically the same values as proposed for the AS TX configured for BER measurements (Table 4-10). This is required in order to properly emulate the exchange of control messages and to enable proper data detection and decoding.

5.5 GS RX Test Interface

In normal operation, the GS RX SNDCP functional block would produce IP network data packets on an external interface. These data packets would be provided by the GS RX DLS function that in turn receives data from the GS RX MAC and further from the PHY layer.

However, a much simpler test interface is sufficient for the laboratory GS RX prototype.

The GS RX MAC layer shall support re-assembly of PHY-PDUs received in the AS TX RL frames (Section 4.3.2). It shall then produce packages of test data and forward such data to the external BER test equipment.

The content and structure of test data produced by the external source feeding the AS TX must be a-priori known to the external evaluation tool.

Alternatively, the content of test data can be made a-priori known at the GS RX prototype enabling the receiver to directly process the BER and provide the result on the external interface.

The comparison of TX and RX bits based on the data content of an entire SF is proposed (to be done separately for each SF). In this case, the RA frame may provide an indication for a correct allocation of TX and RX data. However, in the BER measurements, the data transmitted in the RA frames shall be evaluated separately or neglected completely.

CHAPTER 6 – Aircraft Station Receiver

This section comprises items that are specific to the prototype implementation of the L-DACS1 AS RX operating in the A/G mode.

Deviations from the L-DACS1 system specification (Deliverable D2) that are proposed for more efficient prototyping or any other reason are highlighted.

6.1 AS RX Radio Front-end Characteristics

6.1.1 AS RX Frequency Range and Tuning Step

L-DACS1 shall operate as a full duplex system in the 960 –1164 MHz range [D2].

Prototype AS RX shall be capable of operating on any channel within the 985.5 – 1008.5 MHz range[53].

An extended prototype AS RX range (960 - 1025 MHz) would be beneficial for investigating the possibility of operating L-DACS1 FL/RL in other sub-ranges with modified duplexer settings, including closer frequency spacing to fixed-channel SSR systems.

Preliminary deployment concept based on the interference situation in the L-band and estimated duplexer feasibility anticipates that L-DACS1 FL/RL channel blocks would be placed "in the middle" between fixed L-band UAT/SSR channel allocations (978, 1030, 1090 MHz), providing also sufficient margin to the GPS/GALILEO channels in the upper part of the L-band. With that concept, the sub-range for the FL channels is 985.5 – 1008.5 MHz while the sub-range for L-DACS1 RL channels is 1048.5 - 1071.5 MHz.

An AS RX shall be tuneable to any channel within the operating range with a 0.5 MHz step.

The operating channel shall be adjustable via an implementation-specific interface.

During the trials, prototype AS RX channel shall be tuned to the same channel that is selected for the corresponding GS TX. AS RX channel shall be set 63 MHz below the corresponding GS RX channel (the duplex spacing of 63 MHz is currently used by airborne

[53] The channel frequency corresponds to the nominal position of the DC OFDM sub-carrier in the spectrum of the L-DACS1 signal.

DME equipment).

6.1.2 AS RX Centre Frequency Tolerance

As RX centre frequency and the symbol clock frequency shall be derived from the same reference oscillator.

The accuracy of the AS reference oscillator shall be ± 1 ppm or better.

6.1.3 AS RX Available Bandwidth

AS RX shall be able to receive GS TX signal with the occupied bandwidth B_{eff} = 498.05 kHz (Section 3.3.1.3/Table 3-2).

6.1.4 AS RX Maximum Acceptable Desired Signal Power

The AS RX shall be capable of decoding on-channel desired L-DACS1 signal with a peak power of –10 dBm (measured at the AS RX input).

A GS operating with +41 dBm average TX power would produce -27.9 dBm average power at the RX input of an AS being on the ground at 100 m distance to the GS antenna, assuming 8 dBi ground antenna gain, 2 dB ground cable losses, free-space propagation, 3 dB airborne cable loses, 0.5 dB duplexer losses as well as an 0 dBi airborne antenna gain. Assuming 17 dB provision for TX PAPR[54], the peak received L-DACS1 signal power becomes -10.9 dBm (rounded-up to -10 dBm).

6.1.5 AS RX Maximum Tolerable Input Signal Power

Without a duplexer or RF pre-selection filter, the AS RX shall tolerate at its input a peak pulsed interference signal power of +25 dBm without damage.

The strongest interference comes from an on-board DME interrogator. Assuming +63 dBm peak DME TX power, 3 dB DME cable losses, 3.5 dB L-DACS1 RX airborne cable and duplexer losses as well as 35 dB antenna isolation (antennas on the same side of an aircraft), peak DME power at the L-DACS1 RX input becomes +21.5 dBm. Additional 3.5 dB margin have been added to that value.

Without a duplexer or pre-selection filter, the RX itself must be able to withstand maximum possible input power levels. Under real conditions, the external duplexer and/or the avionics suppression bus could significantly relax the requirement upon the RX input robustness.

For the prototype implementation it is recommended using an external RF BP filter (see Section 7.3.1) between the AS antenna and the AS RX input that operates over the AS RX reception range (Section 6.1.1).

If RF pre-selection filter is used, the AS RX shall tolerate at its input a pulsed interference signal with peak power of up to -10 dBm without damage.

The above value has been estimated based on the preliminary specification of such a filter as provided in Section 7.3.1. As proposed, the RF BP would reduce the signal power of any on-board L-band source to -10 dBm or less.

6.1.6 AS RX Interference Blanking

The prototype AS RX shall implement an autonomous interference blanking mechanism (that works without suppression bus), based on the fast detection of short interfering signals within the RX front-end.

If configured/activated, the blanking circuit shall be active only if the interference level is above defined threshold.

[54] In the practical implementation it should be able to reduce the maximum possible PAPR value with 50 OFDM sub-carriers (17 dB) by using PAPR reducing techniques.

Parameters of the blanking circuit (e.g. blanking threshold) shall be adjustable via an implementation-specific interface.

Temporary RF muting of the L-DACS1 RX over the duration of short RF pulses due to interference blanking shall not cause irregularities or long recovery times within the RX RF part. In particular, the AGC status prior to blanking should be re-established immediately (within TBD µs) after the interference caused by the transmission of another L-band TX has ceased.

If blanking is implemented, the blanking status shall be made available to the AS RX baseband circuitry.

The L-DACS1 AS RX may use this information for improving its performance under co-site interference (e.g. for triggering interference mitigation within the baseband processor).

Autonomous blanking is an option to prevent the damage and enable L-DACS1 AS RX operation and testing under heavy interference from close interference sources (on-board L-band equipment) independently of the availability of the suppression bus.

The airborne duplexer may relieve the requirements upon the blanking circuit, but is considered not to be available in the laboratory. If the suppression bus should be available, it can be used instead of, or supplementary, to an autonomous blanking mechanism.

For the prototype implementation it is recommended using an external RF BP filter between the AS antenna and the AS RX input that operates over the AS RX reception range (Section 6.1.1). As proposed (Section 7.3.1), the RF BP would emulate the duplexer by reducing received signal power of any on-board L-band source (UAT, TCAS, DME, SSR/ES) to -10 dBm or less at the AS RX input.

6.1.7 AS RX Automatic Gain Control (AGC)

The AS RX shall implement RF_AGC that would prevent saturation of any part of the RX front-end, up to- and including the Analogue-to-Digital-Converter (ADC).

Parameters of the AGC circuit (e.g. AGC threshold) shall be adjustable via an implementation-specific interface.

The RF_AGC shall be permanently available and active during reception of FL frames from the controlling GS.

As only one GS TX will be available, there is no need for the AS RX AGC to adapt to the FL BC2 sub-frames or another GS.

The AS RX AGC status shall be updated based on observing the FL frames.

6.1.8 AS RX Interface to Common Suppression Bus

The AS RX shall provide an interface to the airborne suppression bus.

Under normal operating conditions an airborne duplexer and/or a blanking circuit should sufficiently protect the AS RX against high-level signals of other L-band transmitters. However, this cannot remove the out-of-band noise of other transmitters that would de-sensitise the AS RX.

This requirement allows for testing the usability of the suppression bus if it should be available in the laboratory.

Where suppression bus is installed, another L-band AS TX wishing to transmit would announce its intentions on the suppression bus. The AS RX could internally use this information for interference suppression.

6.1.9 AS RX Switchover Time

When commanded to switch the FL RF channel, an AS RX synthesizer shall achieve the required frequency accuracy on the new channel within ≤ 0.5 ms referred to the moment when the switching command has been given.

This parameter shall be assessed via an implementation-specific interface.

6.1.10 AS RX S/N Measurement

AS RX shall continuously measure and report S/N for FL frames received from the controlling GS. The S/N value shall be permanently updated and averaged after each new FL frame has been received from the controlling GS.

This item is required for normal system operation where in-the-loop mechanisms are in place and is provided as information for the radio vendor. S/N measurement is not required (optional) for the prototype AS RX.

6.2 AS RX Baseband Characteristics

6.2.1 AS RX Target Bit Error Rate

AS RX target corrected BER shall be less than 10^{-6} at the input signal power level that corresponds to the AS RX sensitivity for standard message and test conditions (Section 6.2.2).

The same target BER value is also used when specifying the RX operating point (Section 6.2.3) and RX interference immunity performance (Section 6.2.4).

AS RX shall provide a test interface for measuring corrected PHY Bit Error Rate (BER).

In case the AS RX itself measures the BER, it is recommended to make the target BER value adjustable via an implementation-specific interface.

6.2.2 AS RX Sensitivity

AS RX sensitivity level shall be S0 ≤ -102.83 dBm when receiving FL Data/CC frames with all sub-carriers ($N_{used} = N_{u} = 50$) with QPSK modulation and coding as specified in Table 3-6.

BC1 and BC3 sub-frames may also be optionally used for this measurement, with parameters as specified in Table 3-6.

The requirement shall be fulfilled assuming maximum GS TX/AS RX frequency offset (see Section 3.1.2 and Section 6.1.2), as well as the maximum AS RX relative Doppler shift to the GS TX at the aircraft speed of 850 KTAS and the maximum AS RX operating frequency of 1008.5 MHz (Section 6.1.1).

The minimum input level (receiver sensitivity) is measured as follows:

- Using the defined standardized message packet formats
- Using an AWGN channel (no interference)
- Using a specified RL channel

The AS RX sensitivity figure S0 stated above has been derived by assuming an implementation loss of 4 dB (which includes non-ideal receiver effects such as channel estimation errors, tracking errors, quantization errors and phase noise), as well as the AS RX noise figure NF = 6 dB, both referenced to the RX input. The sensitivity figure S0 may have to be further fine adjusted.

6.2.3 AS RX Operating Point

The AS RX shall fulfil the BER specified in Section 6.2.1 in presence of cumulative L-band interference when the signal with the power S1 as in the last row of Table 6-1 is present at the RX input.

The test shall be conducted using all FL sub-carriers ($N_{used} = N_{u} = 50$), QPSK modulation and coding as specified in Table 3-6 for FL Data/CC frames.

BC1 and BC2 sub-frames may also be optionally used for this measurement, with parameters as specified in Table 3-6.

S1 defines the RX operating point – a minimum required RX input signal power at the RX input under real interference conditions (cumulative L-band interference, comprising both co-site interference and interference from "remote" sources), considering an appropriate aeronautical channel and including safety margin.

Table 6-1: AS RX Operating Point S1

Antenna Conversion	Unit	ENR	TMA	APT	Equation
TX-RX distance	nm	120	40	10	d
RX sensitivity @ interference	dBm	-101.83	-99.53	-90.83	S0
RX operating point	dBm	-95,83	-93,53	-84,83	S1

As a complete picture of L-band interference – including large DME GS population - cannot be produced in the laboratory, this item cannot be fully tested in the laboratory.

6.2.4 AS RX Interference Immunity Performance

The Interference Rejection (IR) represents the power difference (in dB) between the interfering signal at specified frequency offset and the on-channel desired L-DACS1 signal, for the specified desired signal level and specified error rate.

IR shall be measured by setting the desired L-DACS1 signal's power to the level "D" (dBm) that is "m" dB (e.g. 6 dB) above the rate dependent receiver sensitivity S0 (as specified for the case with interference in Table 6-1) and raising the power level "U" (dBm) of the interfering signal until the error rate (as specified in Section 6.1.1) is obtained.

In case of testing the impact of the DME interference, D shall be set equal to the GS RX operating point S1 (Section 6.2.3).

IR shall be separately assessed and declared for all applicable types of interfering signals (e.g. DME, SSR, UAT, JTIDS/MIDS). Each interfering signal must be specified in terms of its operating frequency (or frequency offset to the L-DACS1 signal), peak power, and duty-cycle.

Table 5-2 *illustrates one example of stating IR for a particular interfering L-band system "X".*

Note: Power levels D1 and U1 in the following text are referenced to the input of the AS RX BP filter rather than the RX input, assuming the AS RX BP filter as specified in Section 7.3.1. Therefore, the desired signal power D1 at the BP filter input is 0.5 dB above the D value measured ad the RX input.

A prototype duplexer implementation is not required/not expected for the laboratory tests. However, as the duplexer would significantly influence the interference performance of the AS RX in presence of interference, it is recommended to insert an external RF BP filter in front of the AS RX in order to emulate the duplexer behaviour and improve the AS RX RF selectivity. The AS RX pre-selection BP filter shall be as described in Section 7.3.1.

The following preliminary[55] requirements apply to the prototype AS RX:

1. AS RX shall be capable of achieving specified BER (Section *6.2.1*) when the desired signal level D1 is between -95.3 dBm and -9.5 dBm when subjected to DME interference under the following conditions:

[55] Specifying the interference environment for laboratory measurements is not within the scope of this task.

- DME pulse pairs at a nominal rate of 3,600 pulse pairs per second at either 12 or 30 microseconds pulse spacing at a level U1 = -54.5 dBm[56]
- DME GS operating on any 1 MHz DME channel frequency between 962 MHz and 1213 MHz.

2. AS RX shall be capable of achieving specified BER (Section 6.2.1) when the desired signal level D1 is between -95.3 dBm and -9.5 dBm when subjected to co-site DME interference under the following conditions:

- DME pulse pairs at a nominal rate of 300[57] pulse pairs per second at either 12 or 30 microseconds pulse spacing at a level U1 = +22 dBm[58]
- DME AS operating on any 1 MHz DME channel frequency between 1025 and 1150 MHz.

3. Following a 21 microsecond pulse at a level U1 = +19 dBm and at a frequency of 1030 or 1090 MHz, the AS RX shall return to within 3 dB of the specified desired signal level (D1 = -95.3 dBm) within 12 (TBC) microseconds[59].

In order to fulfil above requirements, AS RX shall implement methods for mitigating the impact of interference, e.g. one of the methods proposed in Section 6.3.7 or a combination of them.

6.2.5 AS RX to GS TX Frequency Synchronisation Tolerance

The AS RX shall acquire frequency synchronisation with the GS TX within the specified tolerance during the synchronisation period.

After the initial frequency synchronisation, the AS RX centre frequency deviation from the centre frequency of the prototype GS TX shall be less than 2 % of the OFDM sub-carrier spacing (less than 195 Hz)[60].

The AS RX frequency synchronisation tolerance shall be assessed via an implementation-specific interface.

The initial AS RX to GS TX frequency synchronisation is achieved by continuously monitoring the synchronisation symbol pairs that repetitively occur within the FL stream of the controlling GS (marking the start of BC1/2/3, Data/CC FL frames).

The AS RX frequency capture range shall be sufficient for accommodating both imperfect GS TX – AS RX reference frequency accuracy (see Section 3.1.2 and Section 6.1.2) and the maximum applicable GS TX – AS RX Doppler shift at the aircraft speed of 850 KTAS and the maximum AS RX operating frequency of 1008.5 MHz (Section 6.1.1).

During normal operation, the AS RX shall track the frequency changes by estimating the FL frequency offset.

During frequency tracking, the AS RX centre frequency deviation from the centre frequency of the GS TX shall be less than 2 % of the OFDM sub-carrier spacing (less than 195 Hz).

The AS RX frequency tracking tolerance shall be assessed via an implementation-specific interface.

The frequency synchronisation maintenance shall be based on observing the synchronisation symbol pairs that repetitively occur within the FL stream (marking the start of

[56] Preliminary value based on the previous simulation work within the B-AMC study [B-AMCx]. No received DME GS power values above -55 dBm could be identified in these simulations.

[57] Two on-board DME interrogators assumed, each operating with max. 150 ppps.

[58] Preliminary value, based on the estimated received co-site DME power level that needs to be confirmed. UAT SARPs – Receiver Tolerance to Pulsed Interference [UAT_S] specify -36 dBm at the RX input.

[59] Preliminary value, based on estimated received co-site TCAS/SSR power level that needs to be confirmed. UAT SARPs – Receiver Tolerance to Pulsed Interference [UAT_S] specify 0 dBm at the RX input.

[60] Requirement from [D2] Section 5.6.2 adapted to the situation without in-the-loop mechanisms.

BC1, BC3, FL Data/CC frames, excluding the BC2 sub-frame).

6.2.6 AS RX to GS TX Time Tracking Tolerance

AS RX shall achieve and maintain time synchronisation by continuously monitoring the FL stream of the controlling GS.

After the initial time synchronisation, the time offset between the prototype GS TX SF and the prototype AS RX SF shall be less than 1/3 of the OFDM guard time (less than 1.6 µs)[61].

The AS RX time tracking tolerance shall be assessed via an implementation-specific interface.

The initial time synchronisation shall be based on observing and evaluating the synchronisation symbol pairs that repetitively occur within the FL stream (marking the start of BC1/2/3, FL Data/CC frames). During time synchronisation maintenance the FL BC2 sub-frames shall be ignored.

6.2.7 AS RX Symbol Clock Frequency Tolerance

As RX centre frequency and the symbol clock frequency shall be derived from the same reference oscillator.

The accuracy of the AS reference oscillator shall be ± 1 ppm or better.

6.3 AS RX PHY Layer Characteristics

In the AS RX prototype, parts of the PHY layer functionality specified in [D2] have to be implemented. The basic functionality of the AS RX prototype is illustrated in a block diagram in Figure 6-1.

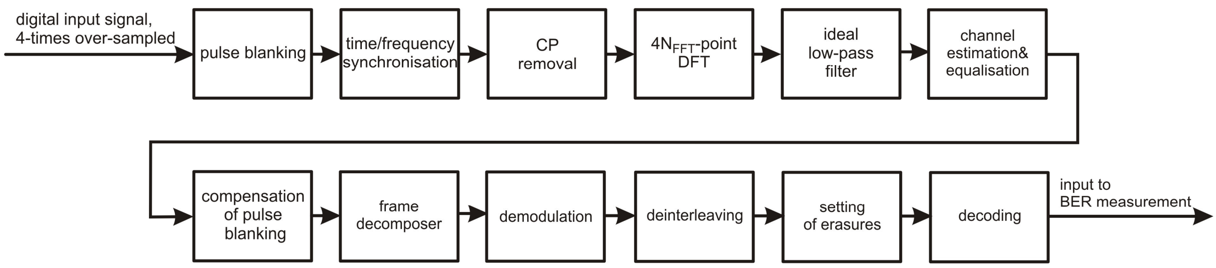

Figure 6-1: Simplified Block Diagram of AS RX

The input is the digital received signal with recommended sampling rate corresponding to at least four-times the usual OFDM sampling rate[62] (see Section 6.3.7.2).

The sampled signal shall be processed, before providing the data to the MAC layer, according to the following steps:

- Start of the frame shall be detected
- Optionally, pulse blanking may be applied
- Based on the OFDM synchronisation sequences, the time and frequency offset shall be estimated
- The frame shall be de-rotated based on the estimated frequency offset
- The serial data stream shall be converted into a matrix, so that one OFDM symbol occupies one row of the matrix

[61] Requirement from [D2] Section 5.6.3 adapted to the situation without in-the-loop mechanisms.

[62] Oversampling is recommended for reducing aliasing effects that would otherwise be invoked due to the strong out-of-band interference.

- Since TX windowing is performed at the GS TX, the AS RX shall extract the useful part of each OFDM symbol by removing the cyclic prefix. Thereby, the estimated time offset determined in the synchronisation procedure shall be taken into account. Since the cyclic suffix of length T_w overlaps with the cyclic prefix of the following OFDM symbol (see Section 3.3.5), it is sufficient to discard the entire cyclic prefix when discarding the guard interval.
- The extracted part of each OFDM symbol shall be transformed via an FFT operation into the frequency domain.

  If over-sampling is applied, the relevant sub-carriers coinciding with the OFDM system bandwidth shall be extracted after the FFT operation
- Complex channel response coefficients shall be estimated based on the received pilot symbols and the data symbols shall be multiplied with the corresponding coefficients
- *If pulse blanking is applied, the impact of pulse blanking on the desired signal may be eventually compensated (optional).*
- The frame shall be decomposed by extracting the useful data symbols
- Reliability information for each bit shall be computed via the Euclidean distances of the data symbols to the constellation points. This procedure relates to the demodulation
- Permutation de-interleaving and convolutional decoding, making use of the reliability information shall be performed. *If pulse blanking is not applied, erasure decoding is applied and reliability information of bits affected by interference shall be set to 0 (see Section 6.3.7.1).*
- RS decoding shall be performed

In the following, the parts of the PHY layer specification from [D2] relevant for the AS RX prototype are recapitulated. In order to avoid replications, references to corresponding sections of the GS TX specification are given.

6.3.1 FL – OFDM Transmission

6.3.1.1 Frequency Domain Description

Frequency domain description for a FL L-DACS1 signal is provided in Section 3.3.1.1.

6.3.1.2 Time Domain Description

Time domain description for a FL L-DACS1 signal is provided in Section 3.3.1.2.

6.3.1.3 OFDM Parameters

The basic OFDM parameters relevant for the AS RX are listed in Section 3.3.1.3/Table 3-2.

6.3.2 Physical Frame Characteristics

Physical frame characteristics relevant for the AS RX are listed in Section 3.3.2.

6.3.2.1 Forward Link Frame Types

Forward link frames relevant for the AS RX are described in Section 3.3.2.1.

6.3.2.2 Framing

The FL framing is described in Section 3.3.2.2.

6.3.2.3 Framing Specifics for AS RX Prototype Implementation

Since transmission of random data is sufficient for laboratory testing at the physical layer, there is no need to distinguish between CC and Data PHY-PDUs. Hence, 27 FL Data PHY-PDUs and no FL CC PHY-PDU are mapped onto one MF.

The data to be transmitted on FL are provided by a random source that provides FL PHY-PDUs. The size and the number of FL PHY-PDUs shall match the capacity of the different types of frames.

6.3.2.4 Decoding and Demodulation

At the RX side, the equalised data symbols first enter the demodulator. Afterwards, permutation deinterleaving and convolutional decoding is applied. In a last step, the RS decoding is applied. The block sizes of the coding, interleaving and modulation blocks are given in Table 3-6.

Adaptive Coding and Modulation (ACM) is not implemented in the prototype. The modulation schemes, channel coding parameters and block sizes for the PHY-PDUs applicable to the prototype equipment are given in Section 3.3.3.1/Table 3-6.

6.3.2.5 Demodulation

Modulation aspects applicable to the prototype equipment are described in Section 3.3.3.3.

Detailed method for the demodulation is an implementation issue. However, it is intended that the demodulator provides soft-input for the convolutional decoder.

6.3.2.6 Deinterleaving

The interleaver permutation is described in Section 3.3.3.2. The permutation in the deinterleaver is the inverse of the permutation in the interleaver.

The block size of the interleaver N_I complies with the coding block sizes.

6.3.2.7 Channel Decoding

6.3.2.7.1 Inner Decoding

The convolutional decoder shall be able to handle soft-input values, which are provided by the demodulator. The decoder should provide hard-output. Six termination bits, inserted at TX before encoding, are discarded before passing the resulting sequence on to the RS decoder.

It is proposed to use a Viterbi algorithm, which can be found in [For73].

6.3.2.7.2 Outer Decoding

The RS decoding is done by means of algebraic decoding. The decoding is done in three steps:

- syndrome calculation
- error location calculation
- error value calculation

The input of the RS decoder is the output of the convolutional decoder. First of all, the syndrome vector in the frequency domain of the finite field is calculated. Since the undisturbed codeword possesses d-1 consecutive zeros in the frequency domain, the error vector is equal to the syndrome vector at these places. The task of the error location calculation is to determine the missing error vector coefficients out of the known syndrome coefficients. The error location calculation can be done by the Berlekamp-Massey algorithm [Mas69], which uses a linear shift register to generate the error location vector out of the syndrome vector. Once the correct error location vector has been found, the error values can be calculated with the Forney algorithm [For65]. At the end, the received codeword is subtracted by the error values at the error positions.

6.3.3 Frame Decomposing

After transforming received OFDM symbols in the frequency domain, channel estimation and equalisation shall be performed before decomposing the frame. Frame decomposition is performed by extracting the data symbols in time direction from the time- frequency plane and mapping them on a data stream. For extracting the data symbols the position of the pilot symbols have to be known. They can be found in Table 3-3, Table 3-4 and Table 3-5.

6.3.4 Synchronisation

For synchronisation, the synchronisation OFDM symbols at the beginning of the Data/CC frames and BC1/2/3 sub-frames should be exploited by calculating appropriate metrics, e.g. in [Sch97] for the second OFDM synchronisation symbol. Based on these metrics, the synchronisation algorithm itself is split up in an initial acquisition and a tracking procedure.

6.3.4.1 Initial Acquisition

The initial acquisition of the timing- and frequency-synchronisation is based on the synchronisation symbol pair that appears at the beginning of the BC1/2/3 sub-frames. The initial synchronisation can be stated as successful if the AS RX could independently synchronise to all of the three sub-frames.

6.3.4.2 Tracking

Based on the initial acquisition, the timing- and frequency synchronisation shall be tracked, based on the synchronisation OFDM symbols in the Data/CC frames. A further refinement could be achieved by exploiting an additional metric, obtained by correlation the cyclic prefix of each data OFDM symbol with its corresponding section of the useful part.

Detailed methods for acquisition and tracking are an implementation issue.

6.3.5 Channel Estimation

For Data/CC frames the interpolation is executed frame-wise, for BC frames, sub-frame based.

The position of the pilot symbols is given in Table 3-3, Table 3-4 and Table 3-5. The pilot sequences itself are described in Section 3.3.4.1.

The specific interpolation method for channel estimation is an implementation issue.

6.3.6 Equalisation

The specific method for channel equalisation is an implementation issue.

For equalisation, a zero-forcing equaliser is intended to be used. Based on the estimated channel coefficients, the equalisation is performed symbols wise. Note that the chosen equaliser has to be taken into account for soft-demodulation (see Section 6.3.2.5).

6.3.7 RX – Interference Mitigation from Existing L-Band Systems

As in the aeronautical L-band environment many other systems are already operational, there is a need to reduce the interference impact produced by these systems onto L-DACS1 receivers. Three candidate techniques for interference reduction are briefly presented in the following sub-sections.

Details of these techniques are considered to be an implementation issue and are therefore not specified in this document.

Moreover, it has to be mentioned that the proposed interference mitigation mechanisms cannot be combined arbitrarily. The interference mitigation mechanisms have to be configurable such that a particular method can be switched on or off separately to allow for pre-testing the performance of all proposed methods individually and define the operating configuration prior to the laboratory interference tests.

6.3.7.1 Erasure Decoding

For applying erasure decoding, the interference power received in the guard bands of the used FFT bandwidth can be measured.

6.3.7.2 Over-Sampling

In order to relax the impact of aliasing associated with strong out-of-band interference signals, it is recommended to over-sample the received time domain signal at least by a factor of N_{ov}=4.

6.3.7.3 Pulse Blanking

Interference mitigation approaches like pulse blanking may be applied for mitigating the interference from existing L-band systems (Section 6.1.6).

In the AS RX prototype, the compensation of the impact of pulse blanking on the desired OFDM-signal can be implemented optionally in addition to pulse blanking.

6.3.8 Physical Layer Parameters

At the AS RX, all physical layer parameters used at the GS TX are assumed to be known. These parameters are given in Section 3.3.6.

6.4 AS RX Protocol Characteristics

Detailed specification for L-DACS1 protocol entities above PHY layer is provided in [D2].

For laboratory testing purposes, the full-size MAC sub-layer described in [D2] can be replaced by a reduced functionality.

The pseudo-random data received in the FL PHY-PDUs are expected to feed external BER test equipment. The simple AS RX MAC layer shall support re-assembling of received FL PHY-PDUs and formatting the received test data into format acceptable to the external BER test equipment.

The size and number of the FL PHY-PDUs corresponds to the capacity of the different types of frames and complies with the defined SF timing (Section 3.3.2.2).

In the prototype AS RX implementation, multiple PHY parameters that would be normally set via MAC sub-layer are configured directly at the PHY layer. The same parameters also must be configured at the GS TX (see Section 3.4) in order to properly emulate the exchange of control messages and to enable proper data detection and decoding.

6.5 AS RX Test Interface

In the normal operation, the AS RX SNDCP functional block would produce IP network data packets on an external interface. These data packets would be provided by the AS RX DLS function that in turn receives data from the AS RX MAC and further from the PHY layer.

However, a much simpler test interface is sufficient for the laboratory AS RX prototype.

The AS RX MAC layer shall support re-assembly of PHY-PDUs received in the GS TX FL frames (Section 3.3.2). It shall then produce packages of test data and forward such data to the external BER test equipment.

The content and structure of test data produced by the external source feeding the GS TX must be a-priori known to the external evaluation tool.

Alternatively, the content of test data can be made a-priori known at the AS RX prototype enabling the receiver to directly process the BER and provide the result on the external interface.

The comparison of TX and RX bits based on the data content of an entire super-frame is proposed (to be done separately for each SF). In this case, the BC frame may provide an indication for a correct allocation of TX and RX data. However, in the BER measurements, the data transmitted in the BC frames shall be evaluated separately or neglected completely.

CHAPTER 7 – L-DACS1 Airborne Duplexer

This section comprises items that are specific to the implementation of the L-DACS1 AS RF duplexer.

7.1 Preliminary L-DACS1 Deployment Concept

L-DACS1 is intended to operate as a FDD system in the lower part of the L-band (960-1164 MHz). The elaboration of a detailed deployment concept is not within the scope of the L-DACS1 specification, therefore only an outline is provided here.

With any deployment option, co-location constraints of an airborne platform apply to an L-DACS1 AS. Additionally, fixed L-band channels (978/1030/1090 MHz) must be sufficiently isolated from L-DACS1 channels by appropriate guard bands.

Under these constraints, multiple options for the L-DACS1 system deployment are possible:

- The selected system RF bandwidth (0.5 MHz) enables an inlay deployment, where L-DACS1 FL/RL channels, separated by the duplex spacing, are placed at 0.5 MHz offset from DME channels.
- L-DACS1 can also be deployed as non-inlay system with FL/RL channels placed within contiguous blocks of the L-band spectrum, which are not occupied by the DME system.
- L-DACS1 can be deployed alongside with the DME system by re-using a set of non-contiguous DME channels that have been vacated for that purpose.

The non-inlay deployment options[63] would provide better performance and higher capacity than the inlay option, as with these options L-DACS1 would operate in an environment with considerably reduced interference.

The final decision about FL/RL channel allocations, also influencing the final duplexer specification, will depend on the outcome of the laboratory tests with system prototypes.

A generic method for allocating L-DACS1 FL and RL channels is shown in Figure 7-1 that is

[63] Additional guidance about the deployment options is provided in L-DACS1 deliverable [D2]/Annex 4.

applicable to all deployment methods.

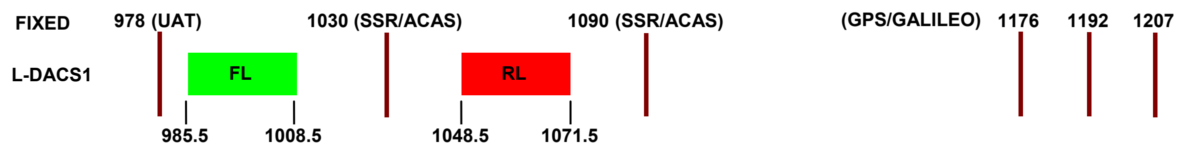

Figure 7-1: Preliminary L-DACS1 Deployment Concept

An airborne L-DACS1 system (AS) using FDD with a single airborne antenna relies upon an airborne TX/RX duplexer. Due to the physical duplexer feasibility constraints, the blocks of FL and RL channels must be sufficiently separated in frequency domain. The currently anticipated duplexer transition area of about 40 MHz[64] is currently centred at the lower SSR frequency (1030 MHz). In this case, L-DACS1 FL channels would be placed in the area between 960 MHz and 1009 MHz, while the RL channels would be placed in the area between 1048 MHz and 1164 MHz[65]. The duplex spacing is 63 MHz (as with the current DME system).

7.2 Airborne L-DACS1 Duplexer Specification

This specification applies to the airborne TX/RX duplexer. The duplexer shall allow for using a common antenna for L-DACS TX and RX while preserving full reception capability on FL during L-DACS1 TX transmission on RL.

Generally, the duplexer usability for resolving airborne co-location problems with other L-band systems is questionable, as no changes (RF pre-filtering) are allowed on the side of legacy airborne systems and some of the existing systems (e.g. DME) definitively do not include any RF filters.

The duplexer (Figure 7-2) has three RF ports, T (TX port), R (RX port) and A (antenna port).

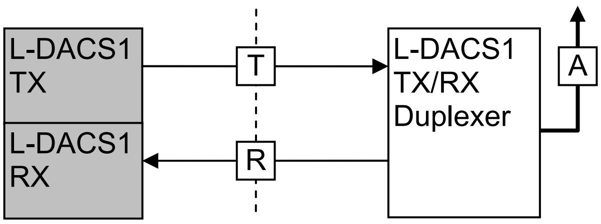

Figure 7-2: Block Diagram of a B-AMC Duplexer Prototype

Figure 7-3 shows the principle of a realisation of an airborne L-DACS1 TX/RX duplexer. The green curve (left) roughly resembles the UAT duplexer curve specified in [UAT_M]. The red curve (right) represents the high-power BP filter that should be realised as a part of the duplexer to reduce out-of-band radiation of the L-DACS1 TX.

Table 7-1 provides draft L-DACS1 airborne duplexer parameters. At a relatively large minimum TX-RX spacing (Δf=40 MHz separation between the highest RX channel, 1008.5 MHz, and the lowest TX channel, 1048.5 MHz) the total received AS TX out-of-band noise power within the AS RX bandwidth (500 kHz) is at least 76 dB (value "Z" in Table 3-1) below

[64] 40 MHz has been assumed to be the minimum practical width of a transition area for an airborne duplexer. The feasibility of the duplexer using this value should be confirmed.

[65] In the course of the previous B-AMC work a draft deployment concept for an inlay system was produced where B-AMC FL/RL channels were placed in the 985.5-1008.5/1048.5-1071.5 MHz range, respectively, a pair of FL/RL channels being separated by 63 MHz. The preliminary frequency planning exercise produced in the course of the B-AMC activities for an inlay system has indicated that the deployment would be easier if more flexibility were allowed with respect to the selection of FL and RL channels and their duplex spacing. Therefore, extended areas for blocks of FL/RL channels as well as variable duplex spacing for FL/RL channel pairs should be investigated within the corresponding deployment concept.

the total AS TX in-band signal power (+41 dBm). The corresponding absolute received noise power received within 0.5 MHz AS RX bandwidth is -35 dBm.

By requiring that received AS TX noise power be equal to the thermal noise power (-117 dBm within 0.5 MHz RX bandwidth) at the AS RX input, the total AS RX noise would increase by less than 0.5 dB during AS TX transmitting phases. Therefore, the duplexer must provide ≥ 82 dB (117 dBm – 35 dBm) additional attenuation of the AS TX noise over RX receiving band.

In the practice, this requirement may be probably slightly relaxed as the out-of-band AS TX noise floor is expected to further slowly decay beyond the point "D" in Table 3-1.This could be achieved by implementing internally an RF BP post-filter after the AS TX power amplifier.

Assuming AS TX signal at +41 dBm power level, AS RX ultimate IF attenuation of 70 dB at Δf=40 MHz and requiring that received AS TX out-of-band signal power also be equal to the thermal noise power (-117 dBm), the duplexer must provide ≥ 88 dB (117 dBm – 29 dBm) additional AS RX isolation over the AS TX band.

This requirement could be relaxed if the AS RX IF filter could be made more selective (i.e. providing more than 70 dB attenuation at 40 MHz offset). It is expected that an internal RF BP pre-selection filter would be implemented within the AS RX over the planned reception range (Section 6.1.1). This could relieve requirements upon the airborne duplexer.

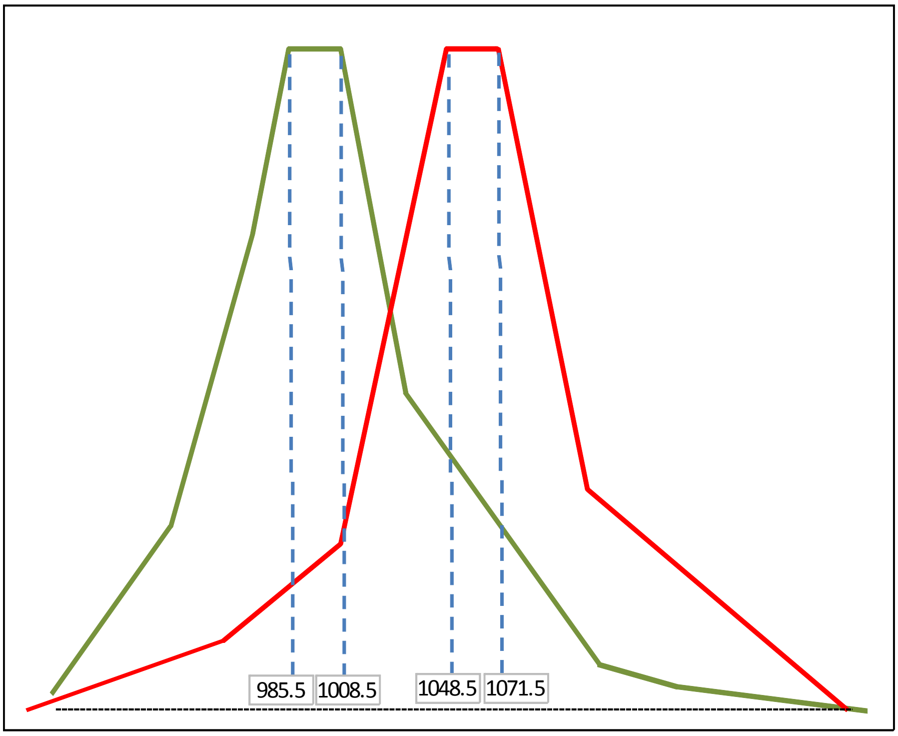

Figure 7-3: L-DACS1 Duplexer RX and TX Selectivity

Table 7-1: Airborne TX/RX Duplexer Parameters

Parameter	**Unit**	**Value**
Avg. PWR handling capability	dBm	+41
Peak PWR handling capability (incl. 17 dB PAPR)	dBm	+58
Temperature range	°C	-60…+60
Max. VSWR (AS TX and AS RX port)		1.2:1
AS TX band	MHz	1048.5-1071.5

AS RX band	MHz	985.5-1008.5
AS TX noise suppression over AS RX band	dB	>82
AS RX isolation over AS TX band	dB	>88
Insertion loss AS TX band	dB	<0.5
Insertion loss AS RX band	dB	<0.5

7.3 Recommendations for L-DACS1 Prototyping

An airborne RF duplexer may not be available for laboratory trials.

However, the duplexer would influence the interference performance of the AS RX in presence of interference by attenuating co-site interfering signals coming from on-board DME interrogators, TCAS interrogators, SSR transponders and UAT transmitter. Similarly, the duplexer would reduce the levels of out-of-band noise and spurious signals radiated by the AS TX towards UAT, SSR and TCAS receivers.

As the detailed test scenarios are not fully specified yet, the following recommendations can be made with respect to the prototype L-DACS1 radio implementations:

- When testing the AS RX BER, the duplexer should be replaced by the RF BP filter that operates over the AS RX reception range (Section 6.1.1) with an insertion loss comparable to that expected from the airborne duplexer and sufficient attenuation of fixed L-band channels (978 MHz, 1030 MHz, 1090 MHz).
- When testing the AS TX impact on victim receivers operating on fixed channels (978 MHz, 1030 MHz, 1090 MHz), the duplexer should be replaced by the RF BP filter that operates over the AS TX transmission range (Section 4.1.1) with an insertion loss comparable to that expected from the airborne duplexer and sufficient attenuation of above fixed L-band channels.

Like the duplexer itself, these filters shall be considered as external to the AS TX/AS RX, respectively[66].

The noise figure for the AS RX /GS RX has been specified at the RX input, filter insertion loss and cabling losses have been taken into account separately.

The preliminary specification of the AS RX and TX BP filters is given in Section 7.3.1 and Section 7.3.2.

Both filters have been specified for power levels applicable to the L-DACS1 TX equipment. This shall allow for using AS RX filter when testing the GS TX (Section 7.3.4).

7.3.1 AS RX Pre-selection BP Filter

This filter primarily aims at reducing the directly received signal power from other on-board sources at the AS RX input. This in turn influences the requirements upon AS RX maximum tolerable input signal power (Section 6.1.5), AS RX interference performance in presence of interference (Section 6.2.4) and interference blanking (Section 6.1.6).

The values for the required attenuation for the AS RX pre-selection BP filter have been selected such that the resulting interference signal power for the co-site case is made equal to the maximum AS RX desired signal power (-10 dBm), assuming representative transmitting power levels for interfering airborne transmitters (UAT: 55.6 dBm, TCAS/SSR:

[66] The AS TX and RX BP filters could be used instead of duplexer if two separate antennas were available for the AS TX and AS RX.

60 dBm, DME: 63 dBm). Assuming 3 dB cable loss for an interfering transmitter, 35 dB TX-RX antenna isolation and 3 dB cable loss for the victim AS RX, this leads to the power levels at the BP input of 14.6 dBm (UAT), 19 dBm (TCAS/SSR) and 22 dBm (DME).

The in-band loss for the BP has been made equal to the expected duplexer loss (0.5 dB).

Table 7-2: AS RX BP Filter Attenuation

Offset from BP f_mid (MHz)	0.0	12.0	13.8	17.3	19.0	24.2	28.0	30.0	33.0	82.0
Required attenuation (dB)	-0.5	-0.5			-24.6		-32.0		-29.0	-29.0
Exemplary BP attenuation (dB)	-0.5	-0.5	-3.0	-20.0	-25.0	-30.0	-32.5	-33.0	-33.5	-40.0

Table 7-2 shows the calculated attenuation values for different L-band co-site transmitters as well as a possible BP filter implementation. The attenuation is given vs. absolute offset of the L-band co-site TX operating frequency with respect to the middle frequency of the AS RX BP filter (997 MHz).

The AS RX BP filter shall provide attenuation values as indicated in Table 7-3.

The indicated required attenuation can be achieved via an exemplary BP filter with characteristics shown in the third row of Table 7-2.

Both required attenuation and exemplary implementation are shown in Figure 7-4.

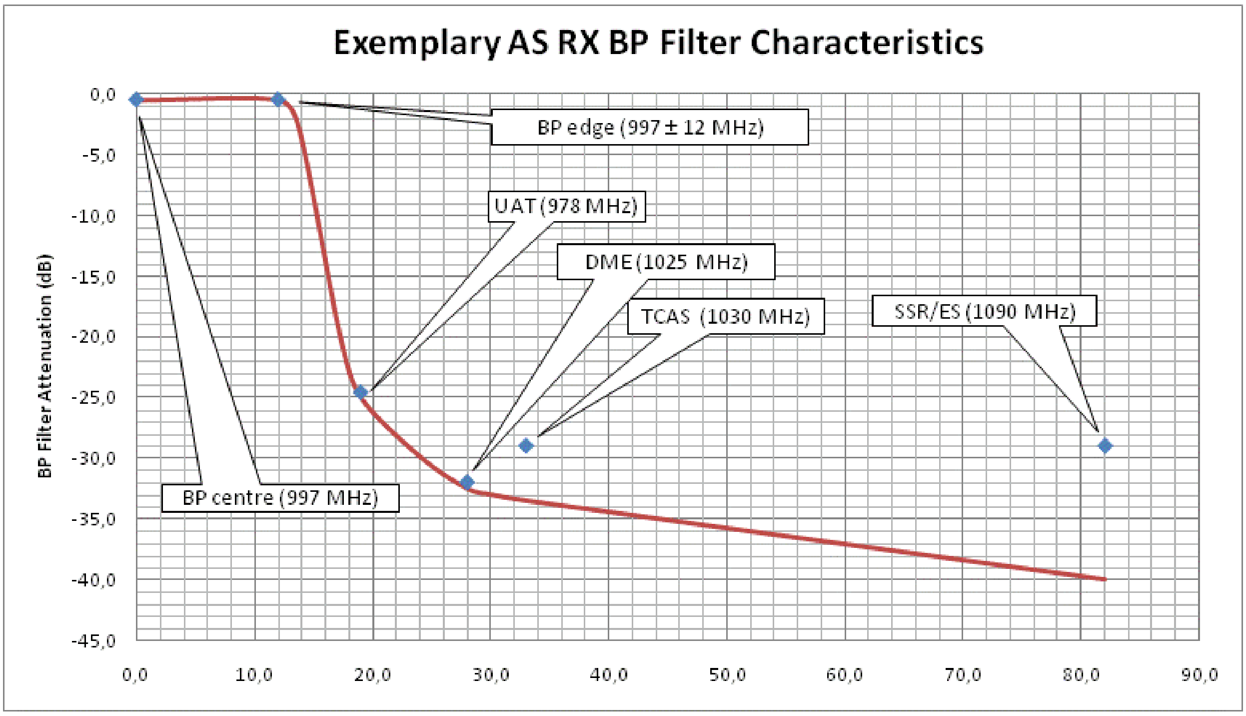

Figure 7-4: AS RX BP Filter Attenuation

As specified, the AS RX pre-selection filter can be used as a TX BP when testing GS TX.

Table 7-3: AS RX BP Filter Parameters

Parameter	Unit	Value
Avg. PWR handling capability	dBm	+41
Peak PWR handling capability (incl. 17 dB PAPR)	dBm	+58
Temperature range	°C	20…40
AS RX band	MHz	985.5-1008.5
AS RX band centre frequency	MHz	997
Insertion loss AS RX band	dB	< 0.5
Minimum attenuation at 978 MHz	dB	>24.6
Minimum attenuation at 1025 MHz	dB	>32
Minimum attenuation at 1030 MHz	dB	>29
Minimum attenuation at 1090 MHz	dB	>29

Comparing Table 7-3 with Table 7-1, it can be seen that the requirements for the BP have been significantly relaxed when compared to the duplexer requirements. The proposed filters are still considered as suitable for tests with other L-band systems.

The duplexer is mainly concerned with suppressing the signal of the own AS TX at the RX input as well as by suppressing the out-of-band products (noise, spurious components) of the own AS TX – aspects that cannot be tested in the laboratory (both GS TX and AS TX would be required).

As the attenuation provided by the duplexer is better than with BP filters, testing the L-DACS1 radios with BP filters provides a degree of confidence that with the real duplexer the performance would be even better.

7.3.2 AS TX BP Filter

This filter primarily aims at reducing the AS TX out-of-band noise and spurious signals radiated towards other on-board receivers. It should provide RF selectivity comparable to that expected from the airborne duplexer unit.

While no exact criteria could be produced for this BP filter, it is recommended to use the same filter shape as for AS RX BP filter, with a modified centre frequency. Table 7-4 provides expected attenuation values for fixed L-band channels assuming the filter shape from Figure 7-4.

As specified, the AS TX BP filter can be used as a RX BP when testing GS RX.

Table 7-4: AS TX BP Filter Parameters

Parameter	Unit	Value
Avg. PWR handling capability	dBm	+41
Peak PWR handling capability (incl. 17 dB PAPR)	dBm	+58
Temperature range	°C	20…40
AS TX band	MHz	1048.5-1071.5
AS TX band centre frequency	MHz	1060

Insertion loss AS TX band	dB	< 0.5
Minimum attenuation at 978 MHz	dB	>40
Minimum attenuation at 1024 MHz	dB	>34
Minimum attenuation at 1030 MHz	dB	>33
Minimum attenuation at 1090 MHz	dB	>33

7.3.3 GS RX Pre-selection BP Filter

The usage of a duplexer is not mandatory for the L-DACS1 GS. As the GS RX will be a single-channel radio, it is expected and recommended using an RF BP filter for the GS RX. While the detailed specification of such a filter is out of scope of this report, it is recommended conducting the GS RX tests using the AS TX filter (Section 7.3.2) as a GS RX pre-selection filter.

While this will provide no improvement with regard to the DME sources at close frequency spacing, it may help to get more realistic values when performing tests with fixed channel L-band equipment (UAT, TCAS, SSR/ES).

7.3.4 GS TX BP Filter

As the GS TX will be a single-channel radio, it is expected and recommended using RF BP filters behind the GS TX.

It is recommended to perform tests on the GS TX using as a GS TX filter the proposed BP filter (Section 7.3.1) for an AS RX.

While this will provide no improvement with regard to the DME victims at close frequency spacing, it may help to get more realistic values when performing tests with fixed channel L-band equipment (UAT, TCAS, SSR/ES).

ANNEX 1 – Exemplary L-DACS1 Radio Architecture

The information in this ANNEX is just for information (non-mandatory), and is provided as guidance for prototyping tasks.

A1.1 Airborne L-DACS1 Radio

Figure Annex 1 shows the conceptual block diagram for an L-DACS1 AS operating in the A/G mode.

The proposed splitting of AS TX and RX functions as well as the resulting internal interfaces shown in Figure Annex 1 *are exemplary (different allocations are possible), intended as a guidance for prototyping purposes. In particular, the architecture does not mandate any physical packaging of L-DACS1 functions.*

The AS radio front-end comprises a transmitter (TX_RF) and receiver (RX_RF) simultaneously operating in the FDD mode using the same antenna via a TX/RX duplexer unit (DU).

The TX_RF and RX_RF units are supported by the associated DSP or FPGA platforms that perform baseband tasks associated with processing of L-DACS1 OFDM signals. These baseband components are presented in Figure Annex 1 as separate units (TX_DSP, RX_DSP), but this separation is not mandatory. In the practical implementation a single physical radio enclosure may host the radio transmitter, radio receiver and the corresponding baseband units. Moreover, TX and RX part of an airborne radio may be further combined into a single radio package, so the number of visible interfaces would be significantly reduced.

Finally, a separate platform (grey "TX/RX Prot.” box in Figure Annex 1) is supposed to handle TX and RX protocols above PHY/MAC layers, also providing a data interface towards external data systems.

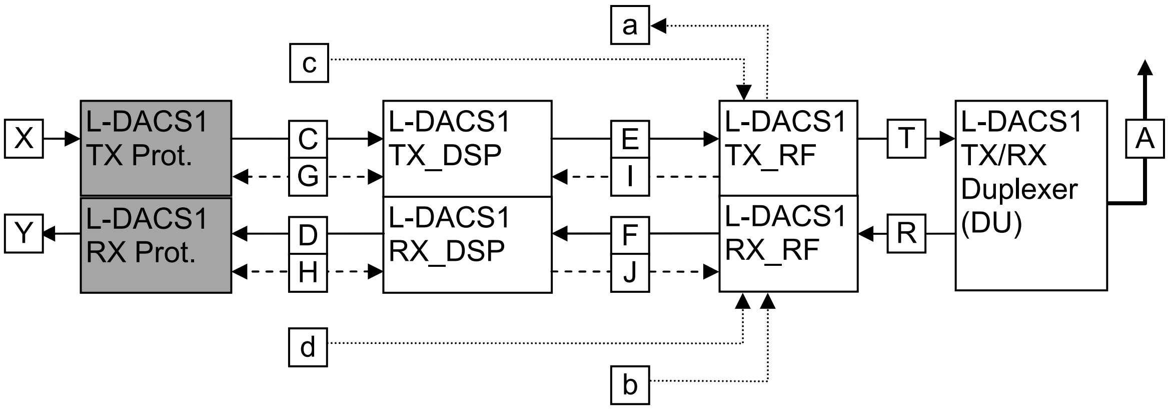

Figure Annex 1: Block Diagram of an Airborne L-DACS1 System (A/G Mode)

The interfaces shown in Figure Annex 1 are as follows:

- X/Y represent TX/RX data interfaces towards an external local data system
- C/D are user data interfaces between the protocol unit and TX DSP/RX DSP unit
- E is the IF interface (I/Q) between the TX DSP unit and the TX RF unit
- F is the IF interface (I/Q) between the RX DSP unit and the RX RF unit
- G/H are control interfaces between the protocol unit and TX DSP/RX DSP unit
- I is the RX_DSP- RX_RF control interface (e.g. for Cartesian loop in the TX DSP unit)
- J is the TX_DSP-TX_RF control interface (e.g. if AGC loop is partially implemented in RX DSP unit)
- T is the RF interface (50 Ohm) between the TX_RF and duplexer unit
- R is the RF interface (50 Ohm) between the RX_RF and duplexer unit
- a and b are TX_RF and RX_RF interfaces to the common suppression avionics bus
- c and d are control interfaces for TX_RF and RX_RF radio (e.g. common frequency reference, tuning, power…)

The fully functional protocol unit may be not required for laboratory measurements. Instead, a depleted "X" interface (not identical with X shown in* Figure Annex 1*) will be required between the TX and the external equipment (probably PC) that will produce data loads during tests. Another depleted interface "Y*" (not identical with Y shown in* Figure Annex 1*) may be required between the RX and the external BER measuring equipment. Similarly, depleted control interfaces "G*", "H*", "c*" and "d*" may be required.*

A1.1.1 Specifics of an Airborne L-DACS1 Radio

The airborne L-DACS1 installation requires a true multi-channel radio.

With a full airborne installation, the airborne duplexer is mandatory as it allows for undisturbed operation of the AS RX when the AS TX transmits.

An airborne RF duplexer may not be available for laboratory trials.

When testing the AS RX BER, the duplexer should be replaced by the RF BP filter that operates over the AS RX reception range (Section 6.1.1) and provides attenuation of fixed channels (978 MHz, 1030 MHz, 1090 MHz) as well as DME RL channels comparable to that expected from the airborne duplexer.

When testing the AS TX impact on the victim receiver operating on fixed channels (978 MHz, *1030 MHz, 1090 MHz), the duplexer should be replaced by the RF BP filter that operates over the AS TX transmission range (Section 4.1.1) and provides attenuation on fixed channels comparable to that expected from the airborne duplexer.*

The AS RX and the AS TX BP filters have been described in Section 7.3.

AS TX neither transmits continuously, nor must it use all OFDM sub-carriers. Basically, AS TX transmissions are RF bursts of specified duration.

> *Note: Ramp-up/ramp-down times of RL RF bursts between zero power state and full power state or vice versa are determined solely by the time behaviour of the first/last OFDM symbol in the burst that in turn is set-up by the raised cosine filter (RC), leading to 12.8 μs total rise/fall time.*

The number of transmitted OFDM sub-carriers in RL non-RA frames can be either 25 or 50 sub-carriers (excluding the DC sub-carrier). Therefore the effective occupied bandwidth on RL may be less than the FL occupied bandwidth (498.05 kHz) that always uses the maximum number of sub-carriers (50).

The average TX power on RL automatically scales with the number of OFDM sub-carriers used on RL, regardless of the current closed-loop power regulation setting. Coming closer to the GS, the maximum RL TX power (+41 dBm) that was used at the coverage boundary is reduced via power regulation mechanisms.

A1.1.2 Impact of Co-site Interference

Due to the very limited isolation between airborne L-band antennas (35 dB), impossibility to add new selective RF components (filters) to existing airborne L-band radio units and relatively high operating powers of airborne L-band transmitters (up to +63 dBm for airborne DME interrogators), an AS RX will be de-sensitized/jammed (will be temporarily unable to receive GS TX signal) each time some other airborne L-band transmitter (e.g. DME interrogator, SSR transponder, TCAS interrogator) on the same aircraft starts to transmit.

At relatively large frequency separations the L-DACS1 AS RF duplexer inserted between the antenna and the L-DACS1 RX input would remove the most of the direct interference power. However, regardless of the frequency spacing, out-of-band noise and radiated spurious components of other L-band transmitters would de-sensitise the L-DACS1 AS RX even if the AS duplexer was in place.

Similarly, other L-band receivers (e.g. DME RX) operating at close frequency spacing to the airborne L-DACS1 TX would be jammed each time the L-DACS1 AS TX starts transmitting. Note that in this case the frequency separation between the airborne L-DACS1 TX and the victim DME RX may – even with careful frequency planning - be as low as 0.5 MHz. As the DME RX out-of-band rejection is limited to some 70 dB, the DME receiver would be influenced by both directly received L-DACS1 TX power and radiated out-of-band L-DACS1 TX noise or discrete spurious signals.

Within the existing airborne architecture existing L-band TXs advertise their intentions to transmit on the common suppression bus. Other L-band TXs monitor the bus and may decide to delay their own transmissions. Attached L-band RXs can also benefit from monitoring the suppression bus status, e.g. to protect their input RF circuitry from dangerously high received power levels.

It is recommended that L-DACS1 AS TX and RX provide an interface to the airborne suppression bus.

L-DACS AS TX should advertise its intentions to transmit a yet to be defined time before the start of the actual transmission. The bus status should revert to the "non-transmitting" state immediately after the L-DACS1 AS TX transmission has ceased.

Effectively, the pattern on the bus caused by the L-DACS1 TX (excluding other TXs) would roughly resemble the L-DACS1 AS TX operating duty-cycle[67].

The L-DACS1 AS RX should monitor the airborne suppression bus.

When any other L-band TX decides to transmit, it should announce its intentions on the suppression bus. The L-DACS1 RX may use this information for informing the baseband processor that short interference will appear soon – the processor may then apply erasures on the affected samples of the input signal.

If interference blanking is configured/active during tests, blanking signal may be used for informing the PHY-layer processor that the reception of an ongoing L-DACS1 OFDM symbol is jammed by the ongoing transmission of some on-board L-band TX and the corresponding samples should be erased.

Temporary RF muting of the L-DACS1 AS RX and/or erasures within the baseband processor over duration of short transmissions of other L-band TXs should not cause irregularities or long recovery times within the L-DACS1 RX RF part. In particular, the AGC status should be re-established immediately (within μs) after the transmission of another L-band TX has ceased.

A1.2 Ground L-DACS1 Radio

The architecture shown in Figure Annex 1 with similar interfaces basically applies to the L-DACS1 GS. However, a duplexer unit is not mandatory for the GS.

Opposite to the AS, the GS radio system is configured as a single-channel radio. The L-DACS1 GS TX transmits continuously, always using all OFDM sub-carriers, therefore also full FL RF bandwidth (498.05 kHz).

L-DACS1 GS TX and RX can be considered to be separate radio units using separate antennas with (optional) external RF band-pass filters. This does not preclude using a TX/RX duplexer also on the ground side, but there is no stringent requirement for it.

Even if in the practical implementation ground L-DACS1 radio is a single-channel device, prototype ground TX/RX components should be tuneable to any L-DACS1 RF channel within the applicable TX and RX tuning range. This would enable laboratory interference measurements against legacy L-band systems at arbitrarily selectable frequency separations.

On the ground side the common suppression bus is not available, so corresponding TX and RX interfaces from Figure Annex 1 need not to be implemented.

[67] The airborne L-DACS1 TX duty-cycle depends on external factors as the amount of transmitted data per aircraft and number of aircraft per L-DACS1 cell and should be specified outside this report. Generally, the duty-cycle should be kept as low as possible as it would block other airborne receivers.

ANNEX 2 – Exemplary L-DACS1 TX Architecture

The information in this ANNEX is just for information (non-mandatory), and is provided as guidance for prototyping tasks.

A2.1 Exemplary TX RF Architecture

Figure Annex 2 provides the conceptual (informative and not mandatory) view of possible TX_RF (TX front-end) architecture. It has been assumed that the first frequency up-conversion is done within the L-DACS1 TX_DSP block, so this block interfaces with the TX_RF front-end at the intermediate frequency IF2. Exciter denotes the driving stage before the Power Amplifier (PA).

The prototyping efforts should preferably produce a common TX baseband solution that can be configured as either airborne or ground TX, with limited modifications of the RF front-end, using a minimum number of exchangeable modules.

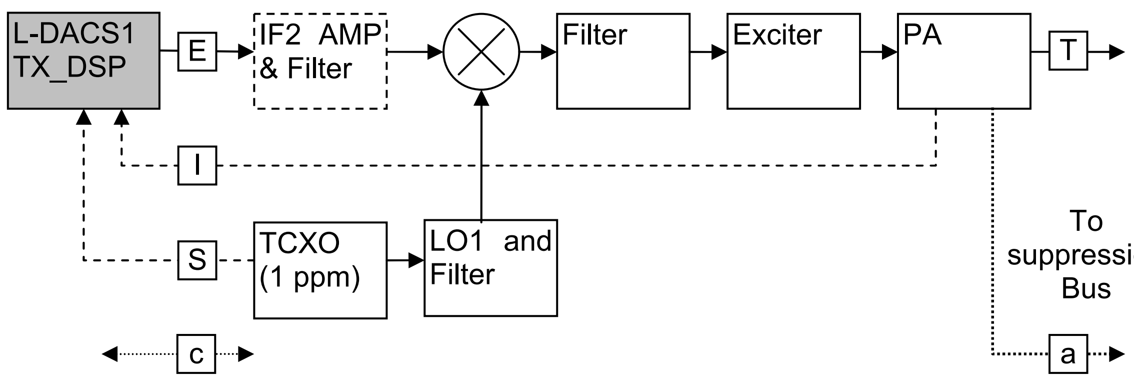

Figure Annex 2: Exemplary Block Diagram of an L-DACS1 TX Prototype (A/G Mode)

The meaning of the functional blocks and interfaces is as shown in Figure Annex 1.

An additional interface "S" is shown in Figure Annex 2 as the common Temperature Compensated Crystal Oscillator (TCXO) should be commonly used for both TX_RF unit and as a clock source for the supporting TX_DSP unit.

In the practical implementation an additional external interface (not shown in Figure Annex 2) is required as the TCXO should be phase-locked to an external frequency reference.

The following sections address some TX aspects that are not part of the official TX specification (not mandatory), but may be useful as guidance for prototyping activities.

A2.2 Airborne L-DACS1 TX Supplementary RF Specification

Table Annex 1: Supplementary Airborne L-DACS1 TX Parameters

TX Specification	Value	Comment
TX Frequency range	1048.5-1071.5 MHz	This range is considered as sufficient for prototyping. Current duplexer specification assumes this range.
TX Frequency range	1025-1087 MHz [1025-1150 MHz]	Desired - extended L-DACS1 RL TX range would allow for laboratory testing of close SSR channels and FDD spacing greater than 63 MHz! This in turn may lead to the adjustment of duplexer specification.
Frequency tuning step	0,1 MHz	0,1 MHz would allow for fine offset tuning (may be usable during tests, probably not available at the SSR/DME side)
IF input signal level	0 dBm	(From the baseband processor, at IF2)
Input signal IF	70 MHz	70 MHz may be appropriate for the first up-conversion.
LO1		Low phase noise variable oscillator (frequency range TBD, dependent on IF2)
LO1 phase noise[68]	-88 dBc/Hz	@ Δf = 1 kHz
	-90 dBc/Hz	@ Δf = 10 kHz
	-118 dBc/Hz	@ Δf = 100 kHz
	-135 dBc/Hz	@ Δf = 1 MHz
	-140 dBc/Hz	@ Δf = 10 MHz
	-140 dBc/Hz	@ Δf = 100 MHz
Group delay variation	±1 µs	Across L-DACS1 signal BW, from the OFDM modulator up to the antenna (value is for UHF DVB-T COFDM TX, TBC)
Amplitude variation	±2 dB	Across L-DACS1 signal BW, from the OFDM modulator up to the antenna (TBC)
DC power supply	x V/ y A DC	TBD (power supply must be available in the lab)

A2.3 Ground L-DACS1 TX Supplementary RF Specification

The supplementary (non-mandatory) characteristics of the L-DACS GS transmitter RF front-

[68] Presented phase noise figures are for an L-band LO and may have to be scaled up/down, dependent on the actual LO frequency band selection.

end (TX_RF) are the same as for an airborne TX_RF, except for the differences indicated below.

Both airborne and ground TX_RF components should be preferably produced as a configurable RF hardware using a minimum number of exchangeable modules.

Table Annex 2: Ground L-DACS1 TX Parameters (Differences to Airborne TX)

TX Specification	Value	Comment
TX Frequency range	985.5-1008.5 MHz	This range is considered as sufficient for prototyping. Current duplexer specification assumes this range.
TX Frequency range	960-1025 MHz	Extended ground TX frequency range (e.g. 962-1024 MHz) would be desired for similar reasons as for airborne TX.

ANNEX 3 – Exemplary L-DACS1 RX Architecture

The information in this ANNEX is just for information (non-mandatory), and is provided as guidance for prototyping tasks.

A3.1 Exemplary RX RF Architecture

Figure Annex 3 provides a conceptual view (informative and not mandatory) of possible AS RX RF front-end (RX_RF) architecture.

The prototyping efforts should preferably produce a common RX baseband solution that can be configured as either airborne or ground RX, with limited modifications of the RF front-end, using a minimum number of exchangeable modules.

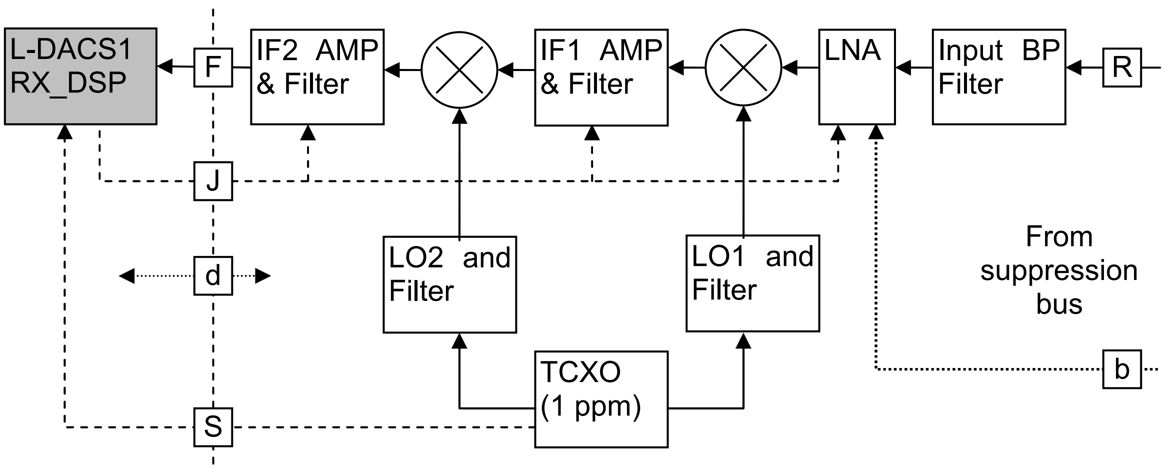

Figure Annex 3: Exemplary Block Diagram of an L-DACS1 RX Prototype (A/G Mode)

The meaning of the functional blocks and interfaces is as shown in Figure Annex 1.

An additional interface "S" is shown in Figure Annex 3 as the common TCXO should be used for the RX_RF unit and as a time source for the supporting baseband RX_DSP unit.

Further external interface (not shown in Figure Annex 3) is required as the TCXO should be phase-locked to the external frequency reference.

The following sections address some RX aspects that are not a part of the official RX specification (not mandatory), but may be useful as guidance for prototyping activities.

A3.2 Airborne L-DACS1 RX Supplementary RF Specification

Table Annex 3: Airborne L-DACS1 RX Parameters

RX Specification	Value	Comment
RX Frequency range	985.5-1008.5 MHz	This range is considered as sufficient for prototyping. Current duplexer specification assumes this range.
RX Frequency range	960-1025 MHz	Desired - for "close" testing against GSM/SSR/UAT TXs
RX AGC range	S … (S+50 dB)	In the laboratory, the RX should adapt automatically to any new TX power setting, 50 dB (from the sensitivity value "S") should be enough for laboratory tests.
RX AGC settling time	10 µs	Not specified (could be specified as less than OFDM symbol CP, TBD). As the FL transmissions are continuous, no special provisions for AGC have been foreseen on FL. However, with the scanning approach an airborne RX would need to change the frequency to another RF FL channel and catch/decode the BC frame of another GS on that channel.
Input impedance	50 Ω	Connector type TBC (N, SMA, BNC…)
Output IF2 signal level	-10 dBm	To be discussed with radio vendor
Output signal IF2	70 MHz	70 MHz (or even a higher IF2) may be appropriate choice for prototyping.
2nd LO		Low phase noise fixed oscillator (frequency TBD)
1st LO		Low phase noise variable oscillator (frequency range TBD)
1st LO phase noise[69]	-88 dBc/Hz	@ Δf = 1 kHz
	-90 dBc/Hz	@ Δf = 10 kHz
	-118 dBc/Hz	@ Δf = 100 kHz
	-135 dBc/Hz	@ Δf = 1 MHz
	-140 dBc/Hz	@ Δf = 10 MHz
	-140 dBc/Hz	@ Δf = 100 MHz
Group delay variation	±1 µs	Across L-DACS1 signal BW, from the antenna up to OFDM demodulator (value is for UHF DVB-T COFDM TX, TBC)
Amplitude variation	±2 dB	Across L-DACS1 signal BW, from the antenna up to OFDM demodulator (TBC)
DC power supply	x V/ y A DC	TBC (power supply must be available in the lab)

[69] Presented phase noise figures are for an L-band LO and may have to be scaled up/down, dependent on the actual LO frequency band selection.

Expected L-DACS1 RX IF filter selectivity characteristics (for the IF filter part realised in the hardware) is shown in Figure Annex 4. It should provide the minimum achievable in-band ripple at frequency offsets less than ± 0.3 MHz (first row in Table Annex 4).

Table Annex 4: L-DACS1 RX IF Filter Selectivity

ATT (dB)	Δf (MHz)
0 ± 2 (TBC)	±0.3
-6	±0.45
-20	±0.56
-40	±0.59
-60	±0.6
-70	≥ ±2.5

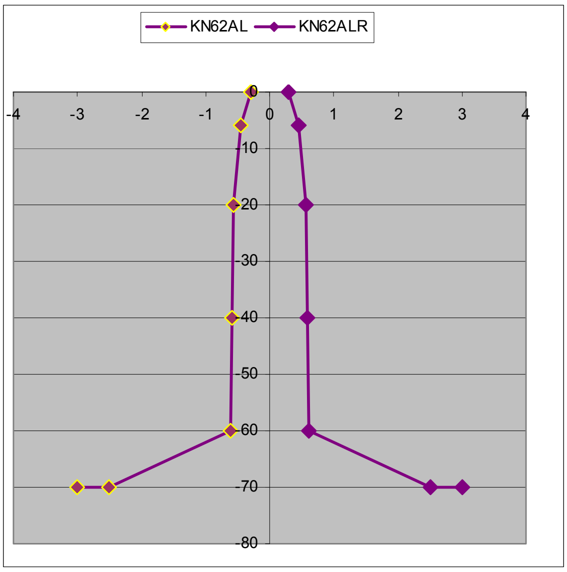

Figure Annex 4: L-DACS1 RX IF Filter

A3.3 Ground L-DACS1 RX Supplementary RF Specification

The supplementary (non-mandatory) characteristics of the ground L-DACS RX are the same as for an airborne RX, except for the differences indicated below.

Both airborne and ground RX should be preferably produced as a single configurable RF hardware.

Table Annex 5: Ground L-DACS1 RX Parameters (Differences to Airborne RX)

RX Specification	Value	Comment
RX Frequency range	1048.5-1071.5 MHz	This range is considered as sufficient for prototyping. Current duplexer specification assumes this range.
RX Frequency range	1025-1087 MHz [1025 -1150 MHz]	Desired (would allow for "close" testing against SSR TXs and FDD spacing greater than 63 MHz!)

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[T- BAAC]	TIA-902.BAAC (Wideband Air Interface Media Access Control/Radio Link Adaptation Specification)
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ABBREVIATIONS

Term	Definition/Description
A/A	Air-to-Air
A/C	Aircraft
A/G	Air-to-Ground
ACM	Adaptive Coding and Modulation
AGC	Automatic Gain Control
AS	Aircraft Station
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BP	Bandpass (filter)
BW	Bandwidth
CE	Channel Estimation
CP	Cyclic Prefix
CRC	Cyclic Redundancy Check
DC sub-carrier	Direct Current sub-carrier ("middle" sub-carrier in the spectrum of an OFDM signal, not being transmitted)
DLL	Data Link Layer
DLS	Data Link Services Entity of the logical link control sub-layer (LLC).
DME	Distance Measuring Equipment
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FFT	Fast Fourier Transformation
FL	Forward Link (from the GS to the AS)
FL BC frame	FL Broadcast OFDM frame - control information is broadcast to all users
FL Data/CC frame	FL frame containing either broadcast control information for all users or addressed data or control information for multiple users, together with pilot symbols, prefixed by synchronisation symbols.
FL PHY-PDU	Forward Link Physical Layer Protocol Data Unit (PDU), being a contiguous group (1/3) of data symbols in the FL Data/CC frame
GF	Galois Field
GS	Ground Station

ISI	Inter Symbol Interference
JTIDS	Joint Tactical Information Distribution System
L-DACS1	L-band Digital Aeronautical Communication System 1
LLC	Logical Link Control sub-layer of the data link layer
LLR	Log-Likelihood-Ratio
LSB	Least Significant Bit
MAC	Medium Access sub-layer of the data link layer.
MF	Multi-frame
MIDS	Multi-Function Information Distribution System
ML	Maximum Likelihood
NF	Noise Figure
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OFDM Frame	Combination of OFDM symbols comprising synchronisation symbols, pilot symbols, and payload data. Several OFDM frame types exist.
OFDM symbol	Combination of modulated data symbols transmitted on several OFDM sub-carriers.
OOB	Out-Of-Band
P34	Denotes TIA-902 standard (public safety communications)
PAPR	Peak-to-Average Power Ratio
PDU	Protocol Data Unit
PHY-PDU	Physical Layer Protocol Data Unit. Protocol unit exchanged between two physical layers.
ppm	Parts per million
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
Radio burst	Time-limited transmission event, containing a (number of-) physical OFDM frames with optional radio overhead (ramp-up/ramp-down times, AGC provisions), but excluding propagation guard times
RC	Raised-Cosine (window)
RF	Radio Frequency
RL	Reverse Link (from the AS to the GS)
RL DC segment	RL Dedicated Control segment, containing control data of a particular user
RL Data segment	RL Data segment, containing user's data or control information together with pilot symbols and PAPR reduction symbols.

RL RA frame	RL Random Access frame, containing users' cell entry requests.
RL PHY-PDU	Reverse Link Physical Layer Protocol Data Unit (PDU), comprising 24 contiguous OFDMA sub-carriers and 6 contiguous OFDM symbols in the RL Data/DC segment
RMS	Root-Mean-Square
RS	Reed-Solomon (coding)
RX	Receiver
SF	Super-frame
SSR	Secondary Surveillance Radar
Symbol	In the L-DACS1 context, one sub-carrier of one OFDM symbol
TBC	To be confirmed
TDMA	Time Division Multiple Access
Tile	Smallest allocation entity in the L-DACS1 RL, spans 24 contiguous sub-carriers in frequency and 6 contiguous OFDM symbols in time direction.
TX	Transmitter
UAT	Universal Access Transceiver
VDL	VHF Digital Link
Wide-area service	Aeronautical service with an operational range that exceeds the coverage range of a single L-DACS1 cell. Such service must be installed at multiple L-DACS1 cells, with seamless service handover between the cells.
WSSUS	Wide Sense Stationary Uncorrelated Scattering