Updated LDACS1 Prototype Specification

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Abstract

This document represents the final deliverable D2 of the P15.2.4 EWA04-1 task T2, representing an update of the initial specification for LDACS1 prototype equipment that was produced in the course of the EUROCONTROL LDACS1 study. It implements further modifications elaborated within the SJU framework, being aligned with the updated LDACS1 system specification (Deliverable D1 of the P15.2.4 EWA04-1 task T2). This report provides a stable baseline for further LDACS1 prototyping and testing activities.

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EXECUTIVE SUMMARY

This document represents the final deliverable D2 of the P15.2.4 EWA04-1 task T2: Updating LDACS1 (L-Band Digital Aeronautical Communications System Type 1) specifications for prototype equipment. LDACS1 TX and RX prototypes shall be developed in the SESAR JU framework (P15.2.4) aiming at demonstrating the compatibility of LDACS1 with the existing systems operating in the L-band as well as showing that the LDACS1 performance is meeting the requirements.

Deliverable D1 of the P15.2.4 EWA04-1 task T2 provides an updated specification for LDACS1 system [SJU_LD1_1]. It will provide a solid baseline for all further LDACS1 design and validation activities.

Both deliverables – D1 and D2 – aim at updating the initial LDACS1 specifications [LDACS1_D2] and [LDACS1_D3] that were produced in the course of the *EUROCONTROL LDACS1 specification study*.

Deliverable D2 provides an update of the initial LDACS1 prototype specification [LDACS1_D3], implementing additional modifications that will further improve LDACS1 performance. It is aligned with Deliverable D1 except for the items indicated as highlighted text. Such modifications have been introduced in order to optimise the prototyping efforts while providing all functionality that is required for interference compatibility tests.

It is expected that some of the parameters provided in Deliverables D1 and D2 will be subject to further validation/confirmation and possibly adjustment in the course of the P15.2.4 Project. Further modifications are expected based on the feedback from the laboratory measurements with prototype LDACS1 radio equipment.

1 Introduction

1.1 Purpose of the Document

The Early Tasks activity EWA04 is linked with Task 3 (Recommendation for the terrestrial system) of the P15.2.4 original DoW v4.0 and is addressing the LDACS system: the terrestrial air-ground data link system.

The EWA04 activities aim to initiate the work that will facilitate the elaboration of a recommendation for the terrestrial air-ground data link system. There are 3 separate key tasks (with sub activities) identified as follows:

- EWA04-1: LDACS1 Refinement
- EWA04-2: LDACS Evaluation Criteria
- EWA04-3: LDACS1 Evaluation Support

The EWA04-1 activities aim to refine and making the LDACS1 specifications more mature in order to enable the development of a limited functionality prototype for spectrum compatibility testing (to be initiated under EWA04-3 activities and considering the evaluation framework defined in EWA04-2).

The main objectives of the EWA04-1 activities are the following:

- Propose solutions for LDACS interference mitigation techniques
- Critically review existing LDACS1 specifications both for completeness and correctness of proposed parameters
- Identify issues not perfectly addressed in existing specifications, propose solutions
- Produce an updated set of LDACS1 specifications

The EWA04-1 task covers both the refinement of the LDACS1 system specifications as well as the specifications for initial prototyping activities for the LDACS1 system.

There are two major activities identified in EWA04-1:

- T1: Investigating interference mitigation techniques, and
- T2: Updating LDACS1 specifications

Task T1 aims at improving the LDACS robustness against interference received from other L-band systems located on the same aircraft (co-site interference). It will also produce proposals for intra-network interference (produced by “other” LDACS transmitters) mitigation. Overall, task T1 will develop a report at the end of the Early Tasks phase, but it is expected that these activities will continue in the full P15.2.4 Project.

Task T1 will be organized into 2 sub-tasks:

- T1a: A preliminary analysis of interference mitigation techniques aiming to provide early input to the LDACS1 specifications,
- T1b: The continuing analysis and definition of general L-band interference mitigation techniques (task will start after the results of the SJU COM study are available and will continue to end of the Early Tasks part.

Sub task T1a will concentrate on co-site interference. T1a aims at feeding the LDACS 1 definition with preliminary inputs regarding the interference mitigation techniques, which will be subsequently further analyzed within the sub-task T1b.

The task T2 aims at increasing the maturity of the existing LDACS1 specifications (both the overall system specification and the specifications for initial prototyping activities). The final outcome will be an updated set of LDACS1 specifications, comprising all improvements that have been elaborated within this sub-task, and considering applicable intermediate results of the above Task T1a.

This document represents Deliverable D2 of the P15.2.4 EWA04-1 task T2: Updating LDACS1 Specifications. It provides an update of the initial specification for the prototypes of the L-Band Digital Aeronautical Communications System Type 1 (LDACS1).

The specification presented herein focuses on LDACS1 prototyping issues that are relevant for the subsequent laboratory assessment of the LDACS1 ability to co-exist with other L-band systems.

The updated LDACS1 system specification for prototype equipment (D2) is based on the updated LDACS1 system specification (D1) as well as the initial specification for the prototype LDACS1 equipment [LDACS1_D3].

In the course of reviewing the initial LDACS1 specification, some major modifications have been proposed in order to further improve LDACS1 design. The items that are relevant for the prototyping activities are captured in this report.

LDACS1 specifications being produced within the P15.2.4 EWA04-1 task T2 may require further iterations after completion of the testing of the prototypes. Further improvements are expected to be carried out with the framework of the SESAR JU development activities (P15.2.4) following the P15.2.4 Early Tasks.

1.1.1 Organisation of the Document

There may be significant differences between airborne and ground LDACS1 transmitters and receivers due to e.g. different frequency ranges, interference conditions in FL and RL or different operating profiles/duty-cycles. Hence, four LDACS1 radio prototypes are required, namely GS TX, AS TX, GS RX and AS RX[1].

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

This report is structured as follows:

- Introductory part, comprising:
    - Chapter 1 (this chapter) – general information about the purpose of this document, its organisation, intended readership and background. It also captures abbreviations used in the report and explains LDACS1-specific terms
    - Chapter 2 – Functional Scope of LDACS1 Prototypes, summarising the main characteristics of intended prototype equipment
- The main body of the LDACS1 prototype specification, comprising:
    - Chapter 3 – Physical Layer Protocols and Services (following chapters use this one as reference when describing the required PHY layer functionalities).
    - Chapter 4 – Ground Station Transmitter specification
    - Chapter 5 – Aircraft Station Transmitter specification
    - Chapter 6 – Ground Station Receiver specification
    - Chapter 7 – Aircraft Station Receiver specification
    - Chapter 8 – LDACS1 Airborne Duplexer - exemplary specification of band-pass filters to be used in laboratory investigations as a replacement for the LDACS1 airborne duplexer

[1] This, however, does not preclude implementing the TX and RX prototypes that can be re-configured to act as either airborne or ground equipment. 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.

    - Chapter 9 – References used throughout this report
- Appendices, providing supplementary information:
    - Exemplary LDACS1 Radio Architecture
    - Exemplary LDACS1 TX Architecture
    - Exemplary LDACS1 RX Architecture

1.1.2 Conventions

For the purposes of this specification the following conventions are used in Chapters 3-8 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.

As the LDACS1 specification may be revised once the results from the prototype tests become available, the category of requirements may change in the future versions of this specification.

The requirements themselves are formatted as normal text.

> *Explanatory items (e.g. rationales, references) are formatted as italics or inserted as NOTEs.*

1.2 Intended Readership

The updated specification for LDACS1 prototyping equipment is addressed mainly to the SJU Partners that are involved with tasks related to mobile air-ground data link communications in the long-time frame (beyond 2020).

In particular, Partners that will be involved with LDACS1 prototyping activities and system validation tasks will rely upon an updated system specification (D1) and updated prototype specification (D2). Understanding the system design, including trade-offs between system complexity, capacity/performance and its ability to be deployed in the aeronautical L-band, will be an important pre-requisite for planning the prototyping activities, laboratory validation tasks, as well as further specification improvements and development of detailed LDACS1 deployment concepts after the initial laboratory trials.

Partners involved with Multi-link (ML) operational concept as well Partners involved with other mobile technologies (AeroMACS, new AMSS link) may also benefit from understanding the features, constraints and limitations of the LDACS1 system.

Finally, final set of updated LDACS1 specifications will help in achieving the necessary acceptance for this new system within the world-wide aeronautical community.

1.3 Background

1.3.1 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] and [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 (LDACS) and supporting the continental airspace environment*

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

1.3.2 L-band Data Link System – LDACS

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 (LDACS) were identified. These options need further examination before the final selection of a single data link technology can be made.

The first option for LDACS (LDACS1) 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 Broadband - Aeronautical Multi-Carrier Communication (B-AMC) and TIA-902 (P34) technologies.

The second LDACS option (LDACS2) 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 a derivative of the L-band Data Link (LDL) and All-purpose Multi-carrier Aviation Communication System (AMACS) technologies.

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

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

- Develop detailed specifications for LDACS1 and LDACS2
- Develop and test LDACS1 and LDACS2 prototypes, and
- Assess the overall performance of LDACS1 and LDACS2 systems.

A specific EUROCONTROL contract covered the initial activities to develop detailed specifications for the LDACS1 system.

Note: A separate EUROCONTROL contract has been awarded for the development of the detailed specifications for LDACS2.

When doing the testing of the LDACS 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 EUROCONTROL contract has focussed on the development of the interference scenarios to be investigated and the definition of acceptability criteria for each scenario.

1.3.3 Objective and Scope of EUROCONTROL LDACS1 Study

The EUROCONTROL LDACS1 Study (contract PE 08-111383-E) was a necessary step 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 the LDACS1 study has been considered as input to the SESAR JU activities.

The prime objective of the EUROCONTROL LDACS1 study was to produce a proposal for an initial system specification for the entire LDACS1 system operating in Air-Ground (A/G) mode. Another parallel task has produced design specifications for LDACS1 prototype equipment by extracting items relevant to prototyping activities from the initial LDACS1 system specification and supplementing these items by specific radio issues.

The LDACS1 system specification and the LDACS1 prototype specification represent enablers for LDACS1 prototyping activities that in turn should clarify system compatibility issues that could not be covered analytically or via modelling.

There are two final deliverables of the LDACS1 study:

- Proposed LDACS1 specifications [LDACS1_D2]
- Design Specifications for LDACS1 TX and RX Prototype [LDACS1_D3]

A detailed specification for the LDACS1 Air-Air (A/A) mode was not within the scope of the LDACS1 Study. The current initial LDACS1 specification covers the Air-Ground (A/G) mode including support for digital voice.

The initial LDACS1 specification is widely based on the previous B-AMC system design. This baseline has been further improved within the course of the LDACS1 Study. Specifications of commercial systems like IEEE 802.16e and P34 have been considered, where appropriate. In addition, the scope for the target LDACS1 specification has been finally defined by inspecting and then merging items of specifications of other aeronautical communications systems (UAT, VDL Mode 3 and VDL Mode 4).

1.4 Acronyms and Terminology

Term	Definition
%	Prefix for binary numbers
A/A	Air-to-Air
A/C	Aircraft
A/G	Air-to-Ground
ACB	Adjacent Cell Broadcast
ACK	Acknowledgement

Term	Definition
ACM	Adaptive Coding and Modulation
AGC	Automatic Gain Control
AS	Aircraft Station
ATM	Air Traffic Management
ATN	Aeronautical Telecommunications Network
AWGN	Additive White Gaussian Noise
BCCH	Broadcast Control Channel used to announce the properties of the cell to newly arrived users (FL).
BER	Bit Error Rate
BW	Bandwidth
CCCH	Common Control Channel used by the Ground Station to announce control information for all users (FL).
CE	Channel Estimation
CP	Cyclic Prefix
CELL_EXIT	Cell exit
CELL_RQST	Cell entry request
CELL_RESP	Cell Entry Response
CMS_FL	CMS FL Map
CRC	Cyclic Redundancy Check
DC sub-carrier	Direct Current sub-carrier ("middle" sub-carrier in the spectrum of an OFDM signal, not being transmitted)
DC tile	Dedicated Control tile within the RL DC segment
DC segment	RL segment carrying Dedicated Control Channel (DCCH) information
DCCH	Dedicated Control Channel used for LLC signalling information (RL)
DCH	Logical channel used on FL/RL for the transmission of data DLL-PDUs
DLL	Data Link Layer
DLL_PDU	Data Link Layer Protocol Data Unit. Protocol unit exchanged between two LLC sub-layer (of the DLL) instances over the logical channels.

Term	Definition
DLS	Data Link Services Entity of the logical link control sub-layer (LLC)
DME	Distance Measuring Equipment
E-ATMS	European Air Traffic Management System
EIRP	Effective Isotropic Radiated Power
FCS	Frame Check Sequence
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FFT	Fast Fourier Transformation
FL	Forward Link (from the GS to the AS)
FL_ALLOC	FL Allocation
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/BC slot	MAC slot occupied by FL broadcast (BC) frame (comprising BC1+BC2+BC3 sub-frames)
FL/CC slot	MAC slot occupied by the FL Common Control (CC) frame
FL/DATA slot	MAC slot used for the transmission of Data Frame (DF)
FL PHY-PDU	Forward Link Physical Layer Protocol Data Unit (PDU)
GF	Galois Field
GLONASS	Global Orbiting Navigation Satellite System
GNSS	Global Navigation Satellite Systems
GS	Ground Station
GSM	Global System for Mobile Communications
HO_COM	Handover Command
ISI	Inter Symbol Interference
JTIDS	Joint Tactical Information Distribution System
KEEP_ALIVE	Keep alive

Term	Definition
LDACS1	L-band Digital Aeronautical Communication System 1
LLC	Logical Link Control sub-layer of the data link layer
LM_DATA	Link Management Data
Logical channel	Logical channels are defined by WHAT TYPE of information is transferred and can be classified into control channels (BCCH, RACH, SACH, DCCH, CCCH) for control plane data and traffic channels (DCH, VCH) for user data.
LSB	Least Significant Bit
MAC	Medium Access sub-layer of the data link layer
MAC slot	Reserved space in time controlled by the MAC comprising a set of PHY-SDUs used to convey a logical channel. Each PHY-SDU must be contained within exactly one MAC slot.
MACK_SEQ	Multiple Acknowledgements
ME	Medium Access Entity (within MAC sub-layer) that assigns transport channels to physical channels.
MF	Multi-frame. This item has two equivalent meanings in the LDACS1 context. At the PHY layer it denotes a repeating pattern of OFDM CC/Data frames of 58.32 ms length, at the MAC sub-layer it denotes repeating pattern of MAC slots of 58.32 ms length carrying payload for the corresponding OFDM frames
MIDS	Multi-Function Information Distribution System
MNWG	Multi-National Working Group
MPID_COM	Multiple PID completed
MRSC_RQST	Multiple resource request
NF	Noise Figure
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OFDM Frame	Fixed length combination of contiguous OFDM symbols, comprising AGC symbols, synchronization symbols, pilot symbols and symbols carrying payload data.
OFDM Symbol	Combination of modulated data symbols transmitted on several OFDM sub-carriers
OFDM Tile	The constellation of 150 symbols, spanning 25 contiguous symbols in frequency- and 6 contiguous symbols in time-direction. A tile comprises 4 PAPR reduction symbols, 12 pilot symbols and 134 data symbols. Note: Tiles are only used on the RL.
OOB	Out-Of-Band

Term	Definition
OSI	Open System Interconnect
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. A PHY-PDU represents a constellation of modulated data symbols within the OFDM frame, sub-frame or tile that carry the actual payload. The PHY-PDU size (number of modulated data symbols) and the number of FL PHY-PDUs within a particular frame depend on the OFDM frame type. On the RL each PHY-PDU corresponds to the data symbols of one RA frame, one DC tile or one Data tile. The PHY-PDU, by definition, excludes any non-data symbols like AGC symbols, synchronization symbols, symbols for PAPR reduction, pilot symbols or unmodulated DC symbols.
PHY-SDU	Physical Layer Service Data Unit. PHY-SDUs are exchanged between PHY layer and its local MAC sub-layer, containing the payload exchanged between PHY-SDUs. The size of PHY-SDU is expressed in uncoded data bits.
PID	Packet Identifier
PID_COMP	PID completed
POW_REP	Power report.
ppm	Parts per million
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RACH	Logical Random Access Channel used during cell-entry and hand-over to acquire the time advance value (RL) for an unsynchronised user.
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_ALLOC	RL Allocation
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.

Term	Definition
RL/DATA slot	MAC slot providing a transmission opportunity for RL data segment.
RL/DC slot	MAC slot providing a transmission opportunity for RL Dedicated Control (DC) segment.
RL/RA slot	MAC slot providing two transmission opportunities for RL Random Access (RA) frames.
RLE	Radio Link Entity (within MAC sub-layer), dealing with radio management
RL PHY-PDU	Reverse Link Physical Layer Protocol Data Unit (PDU)
RMS	Root-Mean-Square
RRM	Radio Resource Management Entity of the logical link control sub-layer.
RS	Reed-Solomon (coding)
RSBN	Радиотехническая система ближней навигации (Short-range radio-navigation system)
RSC_CANCEL	Resource Cancellation
RX	Receiver
SAC	Subscriber Access Code
SACK_SEQ	Single acknowledgement.
SAP	Service Access Point
SDU	Service Data Unit
SESAR	Single European Sky ATM Research Programme
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.
SF	Super-frame. This item has two equivalent meanings in the LDACS1 context. At the PHY layer it denotes a high-order repeating pattern of 240 ms length comprising OFDM frames/Multi-Frames, at the MAC sub-layer it denotes high-order repeating pattern of 240 ms length, comprising MAC slots/Multi-Frames.
SIB	System Identification Broadcast
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency.
SLOT_DESC	Slot Descriptor
SPID_COM	Single PID completed
SSR	Secondary Surveillance Radar

Term	Definition
SRC_RQST	Single resource request
STB	Scanning Table Broadcast
Symbol	In the LDACS1 context, one sub-carrier of one OFDM symbol
SYNC_POLL	SYNC signalling
TAV	Timing Advance Value
TBC	FL Transport channel carrying logical BCCH channel
TDMA	Time Division Multiple Access
TME	Transmission Multiplexing Entity (within MAC sub-layer), dealing with various QoS data streams
TRA	RL Transport channel carrying the logical RACH channel
Transport channel	The MAC layer provides data transfer services to the BSS entity on transport channels. Transport channels are defined by HOW the information is transferred. A set of transport channels (TBC, TRA, Tn) is defined for different kinds of data transfer services. The MAC-entity assigns transport channels to physical channels.
TX	Transmitter
UAT	Universal Access Transceiver
UMTS	Universal Mobile Telecommunications System
VCH	Logical channel used on FL/RL for the transmission of voice DLL-PDUs
VDL	VHF Digital Link
VI-Entity	Voice Interface Entity of the logical link control sub-layer
VoIP	Voice over IP
VSB	Voice Service Broadcast
Wide-area service	Aeronautical service with an operational range that exceeds the coverage range of a single LDACS1 cell. Such service must be installed at multiple LDACS1 cells, with seamless service handover between the cells.
WSSUS	Wide Sense Stationary Uncorrelated Scattering

2 Functional Scope of LDACS1 Prototypes

2.1 Objective of the Initial LDACS1 Prototyping

The major objective of the initial LDACS1 prototyping activities is to demonstrate the LDACS1 system spectral compatibility with other systems operating in the L-band and to assess the conditions under which the spectral co-existence would be possible. This should be demonstrated via laboratory trials.

Defining the detailed scope of the laboratory measurements is not the goal of this report (it is the remit of the SJU 15.2.4 EWA04-2-T2 task). However, it is impracticable to define the functional scope for the prototype LDACS1 equipment without having made some assumptions about these tests.

Laboratory investigations are expected to focus upon spectral compatibility and performance tests including LDACS1 transmitter (TX) and receiver (RX) prototypes as well as TXs of other L-band systems (UAT, SSR, JTIDS/MIDS, DME, RSBN, GSM/UMTS, GNSS) with associated RXs. Laboratory tests should identify the conditions under which LDACS1 transmitters would not interfere with the victim receivers of other L-band systems, as well as the conditions under which the operation of LDACS1 receivers would not be jeopardised by the interference received from other L-band transmitters.

Interference is a multi-dimensional problem, including both frequency dimension (frequency spacing Δf between systems) and the systems' topology – positions of the desired and undesired signal sources relative to the victim receiver – in the end represented through the ratio of the desired (D) to undesired (U) signal power at the input of the victim receiver. Therefore, the co-existence rules are expected to be finally expressed as the D/U ratio for a given frequency spacing Δf. The specification for the prototype equipment supports laboratory investigations related to both inlay- and non-inlay LDACS1 deployment options.

Laboratory trials are just a part of the full scope of tests that are required for the detailed LDACS1 technology assessment. LDACS1 cell capacity and performance aspects are out of the scope of the laboratory tests, as these would require multiple LDACS1 transmitters and receivers, representing the total population for a particular LDACS1 cell. Assessment of the capacity and performance implies that the LDACS1 protocol suite would have to be simulated rather than implemented in the laboratory prototype equipment.

Re-building in the laboratory the complete real L-band interference situation as it would be perceived by the real flying aircraft or deployed ground station would require a large number of interfering sources that probably cannot be made available for laboratory trials. Such large-scale aspects can only be reasonably assessed via simulations.

2.1.1 Requirements upon LDACS1 Prototype Equipment

Initial prototyping activities do not aim at demonstrating LDACS1 in-flight capability.

For testing the interference impact it is not required to implement a full-duplex LDACS1 link. The prototype equipment should just allow for testing each direction (FL/RL) separately.

The implementation of full LDACS1 protocol suite is not required for the interference assessment[2].

Therefore, the functional scope of laboratory prototypes at this stage can be reduced to just the aspects that are required for interference testing rather than requiring the full system functionality.

LDACS1 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 forthcoming laboratory trials.

[2] The implementation of the full LDACS1 protocol suite would be required later on, when performing in-flight tests with LDACS equipment. In this case full-size LDACS1 prototypes with full duplex functionality would be required. However, in-flight tests are out of scope of the ongoing prototyping activities.

The essential high-level features of laboratory LDACS1 prototypes can be described as follows:

- The prototype LDACS1 transmitters should operate at their representative (maximum) power levels, producing signals-in-space that closely resemble signals-in-space that would be produced by the real deployed ground- and airborne LDACS1 transmitter. The ground LDACS1 TX transmits continuously, so the transmitting time profile of an airborne LDACS1 transmitter shall be adjustable.
- Assuming an adequate LDACS1 TX implementation, the prototype LDACS1 receivers must be able to receive and process the desired LDACS1 signal at signal power levels that are reasonably close to those expected in the real environment. The receivers under test must perform satisfactorily in presence of L-band interference from the sources available in the laboratory, according to the pre-defined criteria.

2.1.2 Limitations due to the Proposed Functional Scope

The detailed specifications in the following chapters of this report are in line with the functional scope of the LDACS1 system. The deviations relative to the LDACS1 system specification [SJU_LD1_1] are shown as highlighted text.

The selected aspects of the LDACS1 radio front-end and the PHY layer represent the main body of the LDACS1 prototype specification. However, also some elementary LDACS1 protocol features above the PHY layer are described in this document.

It is proposed to omit a complete implementation of the LDACS1 DLL in the prototype LDACS1 equipment. There would be no possibility for interaction between airborne and ground LMEs. Furthermore, none of the "in-the-loop" regulations would apply that are proposed in the LDACS1 system specification [SJU_LD1_1]. This leads to simplex rather than to full-duplex connectivity (single LDACS1 TX and single RX would be used) that is considered as sufficient for conducting the interference tests.

This restriction affects only the scenario where an airborne LDACS1 transmitter provides desired signal to be received under external interference by the ground LDACS1 receiver[3].

Assuming above limitations, the following considerations apply:

- Normally, AS TX would establish its SF timing based on observed GS TX FL frames. When transmitting RL RA frames, the AS TX can use two opportunities within the 6.72 ms window ("RA frame"). These two opportunities are calculated relative to the currently valid AS SF boundary. The GS RX would accept any RL RA frame (and perform AGC/frequency/timing adjustments based on it) as long as it falls within the corresponding RA sub-slot that is determined based on the GS local SF timing.
- When sending the RL RA frames, synchronisation tiles, AGC preambles, DC tiles in DC segment and blocks of Data tiles in the Data segment, the prototype AS TX should always transmit with a fixed declared transmitting power[4], using its local centre frequency and "free-running" local SF timing.

---

[3] The purpose of „in-the-loop" regulation mechanisms is to dynamically adjust the frequency, timing and transmitting power of the airborne TX such that the received desired signal at the input of the ground RX is received with the pre-adjusted desired power level, perfectly aligned with local ground reference SF timing and without frequency offset. Ground LDACS1 TX always transmits with fixed power, according to its local timing/frequency references. An airborne LDACS1 RX must anyway adapt to frequency/timing/power changes of the received FL signal ("in-the-loop" mechanisms do not apply to the FL reception).

[4] As the AS TX power is declared for the case where all 50 RL sub-carriers are used, correction when using reduced RL bandwidth would be required.

- Prior to any AS RL transmission, the prototype GS RX would initially use its own default centre frequency and SF timing.
- Prototype AS TX should send RA frames in a fixed opportunity (one or two) that must be a-priori known to the GS RX. An RA frame may be received anywhere within the GS local SF. The GS should be able to adjust its AGC, adapt its local SF timing and correct the frequency offset after having received the RL RA frame.
- The GS SF timing maintenance, frequency maintenance and power adaptation (AGC) should be enhanced by configuring the concerned AS TX to regularly send RL RA frames at positions a-priori known to the GS RX.
- The GS SF timing maintenance, frequency maintenance and power adaptation (AGC) should be further enhanced by configuring the concerned AS to regularly send synchronisation tiles at positions a-priori known to the GS RX.
- The GS power adaptation (AGC action) should be enhanced by configuring the concerned AS to regularly send AGC preambles in DC segments at positions a-priori known to the GS RX.
- Once updated, the GS RX AGC, time- and frequency setting shall remain stable until the next update.

As no full duplex LDACS1 link will be realised in the laboratory, the prototype duplexer implementation is not required for the laboratory tests. However, as the RF duplexer would influence the performance of the LDACS1 systems in presence of interference, it is recommended to implement external BP filters for both LDACS1 TX and RX in order to emulate the duplexer behaviour.

3 Physical Layer Protocols and Services

This chapter describes physical layer protocols and services that are common to ground and airborne transmitters and receivers.

3.1 Physical Layer Characteristics

The LDACS1 physical layer (PHY) is based on OFDM modulation and designed for operation in the aeronautical L-band (960 –1164 MHz). In order to maximise the capacity per channel and optimally use the available spectrum, LDACS1 is defined as an FDD system supporting simultaneous transmission in the Forward Link (FL) and the Reverse Link (RL) channels, each with an occupied bandwidth of 498.05 kHz.

LDACS1 FL is based on a continuous OFDM transmission using different kinds (BC/CC/Data) of FL frames. LDACS1 RL transmission is based on OFDMA-TDMA bursts assigned to different users on demand. On RL, RA frames, synchronisation tiles, DC tiles or blocks of Data tiles can be sent. All the FL/RL PHY layer structures – frames, tiles, AGC symbols – are described in Section 3.5.

3.2 FL Transmission

3.2.1 Frequency Domain Description

The typical structure of an FL OFDM symbol in the frequency domain is depicted in Figure 3-1.

An FL 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. Taking one DC sub-carrier into account, this results in N_u sub-carriers used for data symbols, pilot symbols and synchronisation sequences.

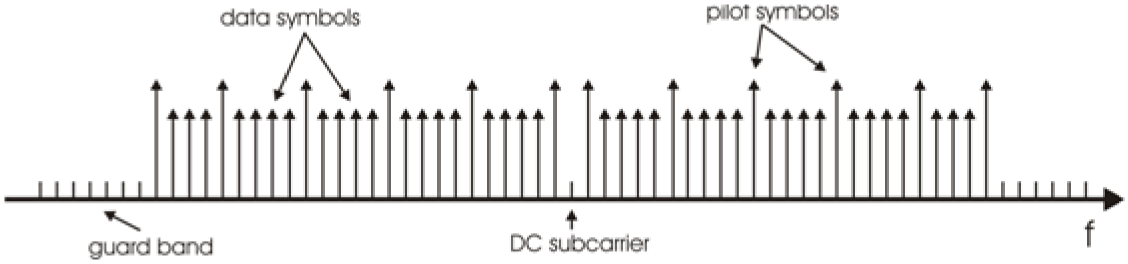

Figure 3-1: OFDM Symbol, Frequency Domain Structure

3.2.2 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 intersymbol 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 3-2 shows this procedure in two steps. The windowing method is addressed in Section 3.7.5.

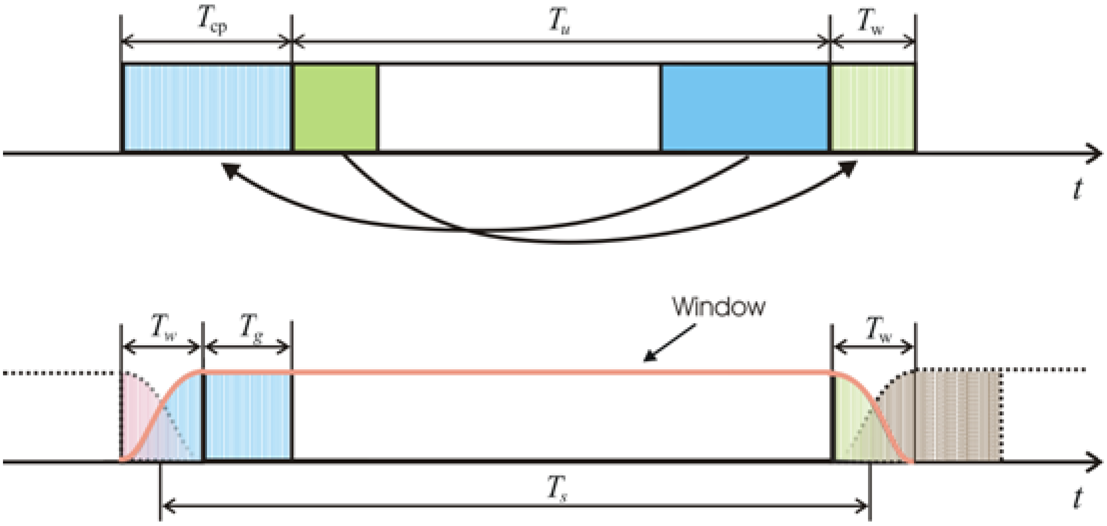

Figure 3-2: OFDM Symbol, Time Domain Structure

3.3 RL Transmission

3.3.1 Frequency Domain Description

Except for RL RA frames, the time-frequency domain is segmented into tiles assigned to different ASs.

A tile carries data, pilot, and PAPR reduction symbols and spans a half of the total number of sub-carriers available in the RL (25 contiguous sub-carriers) and six contiguous OFDM symbols. This structure allows two users to share the effective LDACS1 RL bandwidth in an OFDMA transmission. The OFDMA structure in the RL is clarified in Figure 3-3. The tile structure is further defined in Section 3.5.2.1.

Tiles as defined above are the main building blocks for RL DC segments and are also used to build up RL data segments. In addition to these tiles, the RL DC segment also comprises a special synchronisation tile and an AGC preamble (Section 3.5.2.2).

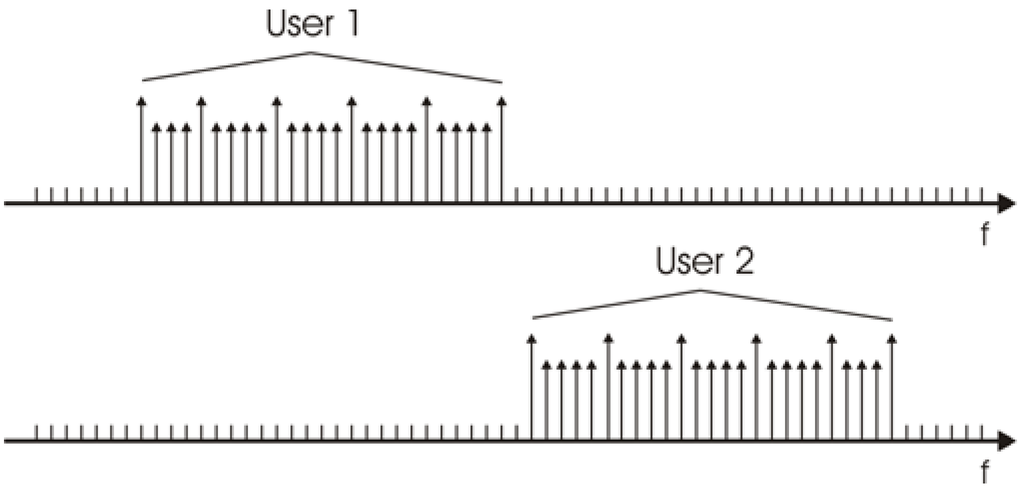

Figure 3-3: OFDMA Structure in the RL

In addition to tiles, RL RA frames and DC segments comprise also AGC preambles and synchronization sequences.

3.3.2 Time Domain Description

In the RL, each involved AS creates separately its time domain OFDM symbol as described in Section 3.2.2. In an OFDMA transmission, the GS receives a superposition of two separate time domain signals, requiring a synchronous reception of symbols 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 may already be used by another AS. Thus, subsequent received OFDM symbols belonging to different tiles can carry data from different ASs.

3.4 PHY Layer Parameters

3.4.1 OFDM Parameters

The parameters summarised in Table 3-1 are valid both in the FL and in the RL.

Table 3-1: OFDM Parameters

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	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
Sub-carrier indices of pilot sub-carriers	Defined in Table 3-2, Table 3-3 and Table 3-4 for the FL and in Table 3-5, Table 3-6, Table 3-7 and Table 3-8 for the RL
Sub-carrier indices of PAPR sub-carriers	-24, 23, only in the RL tiles

3.4.2 LDACS1 RF Channel Bandwidth

The total FFT bandwidth is $B_0 = N_{FFT} \cdot \Delta f = 625.0$ kHz. Due to the guard bands, an effective RF bandwidth of $B_{occ} = (N_u+1) \cdot \Delta f = 498.05$ kHz is obtained, that includes the DC sub-carrier. B_{occ} represents the occupied RF channel bandwidth on both the FL and the RL.

3.5 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 graphically 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 3-4.

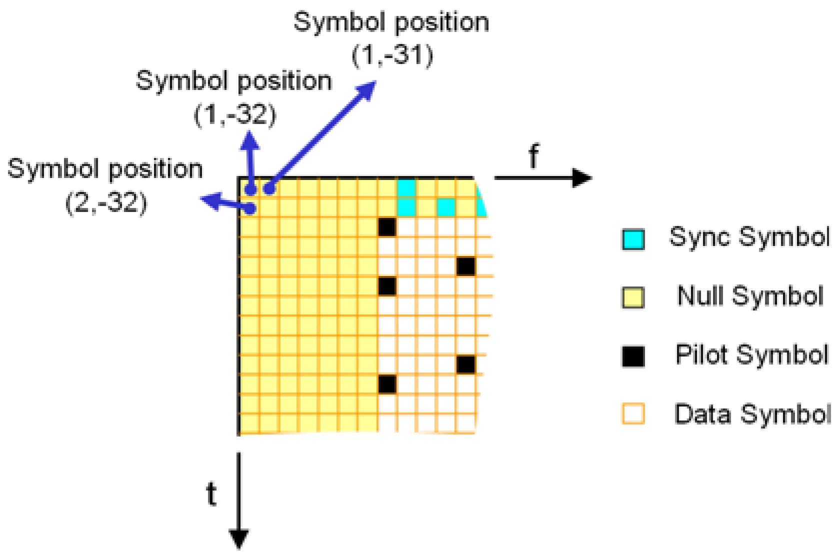

Figure 3-4: Numbering of the Symbols in the Time-Frequency Plane

3.5.1 Forward Link Frame Types

3.5.1.1 FL Data/Common Control Frame

The structure of an FL Data/Common Control (CC) frame is depicted in Figure 3-5. It contains 54 OFDM symbols resulting in a frame duration of $T_{DF/CC}$ = 6.48 ms.

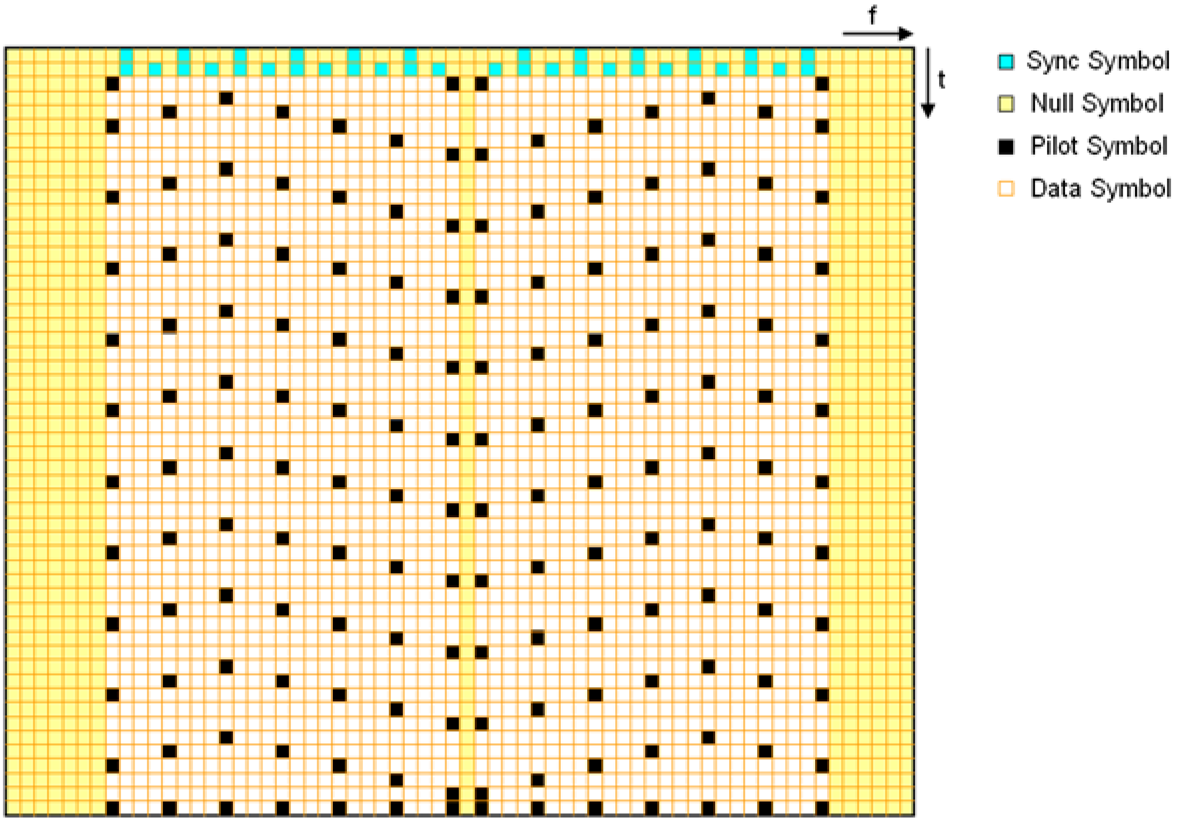

Figure 3-5: Structure of an FL Data/CC Frame

The first two OFDM symbols contain synchronisation sequences. The remaining 52 OFDM symbols contain data symbols as well as pilot symbols. The assignment of either user data or CC information onto the provided symbols is described in Section 3.5.3.1.

The pilot pattern is depicted in Figure 3-5 and described in Table 3-2. 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 3-2: 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

3.5.1.2 FL Broadcast Frame

A FL broadcast (BC) frame consists of three consecutive sub-frames (BC1/BC2/BC3). In these sub-frames, the GS broadcasts signalling information to all active ASs within its coverage range. Figure 3-6 shows the structure of these sub-frames.

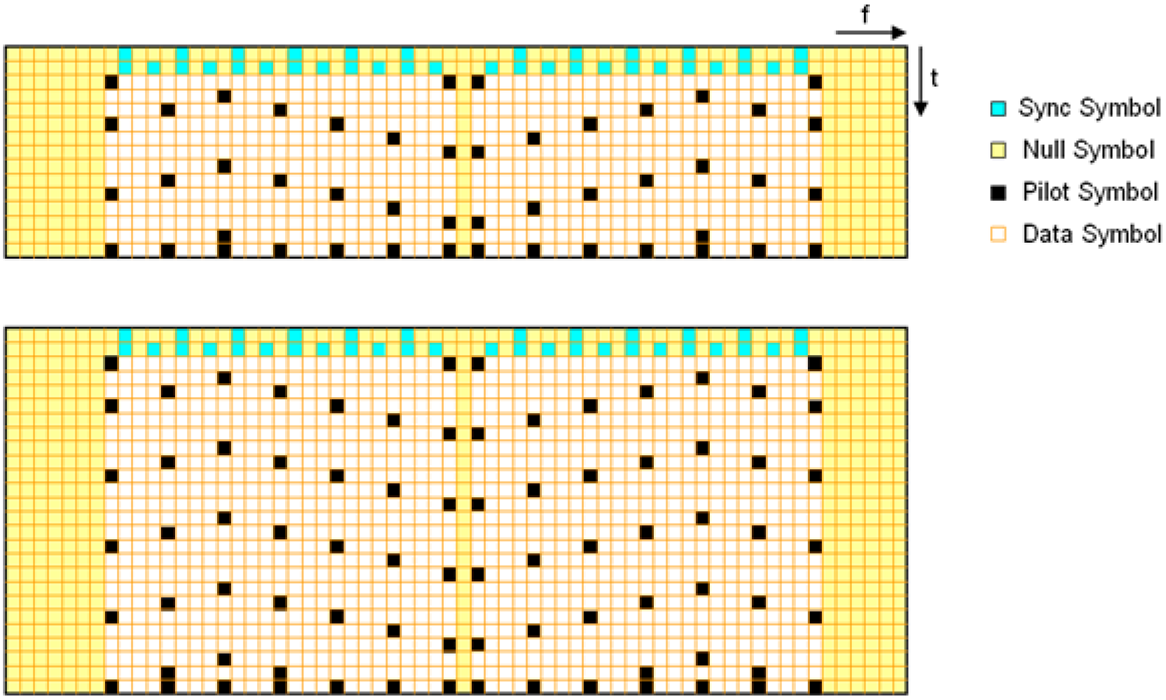

Figure 3-6: Structure of BC1 and BC3 Sub-frames (above) and BC2 Sub-frame (below)

All sub-frames start with the same synchronisation sequence (two consecutive synchronisation symbols), 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 pilot symbols are arranged following the patterns given in Table 3-3 and Table 3-4. 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. The total data capacity of the FL BC frame is 2·602 + 1120 = 2324 symbols.

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

<table>
<tr><th colspan="2">OFDM symbol position n</th><th>Pilot symbol positions</th></tr>
<tr><td colspan="2">n = 3</td><td>-25, -1, 1, 25</td></tr>
<tr><td rowspan="4">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>
</table>

Table 3-4: Pilot Symbol Positions for BC2 Sub-frame

<table>
<tr><th colspan="2">OFDM symbol position n</th><th>Pilot symbol positions</th></tr>
<tr><td colspan="2">n = 3</td><td>-25, -1, 1, 25</td></tr>
<tr><td rowspan="4">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>
</table>

	i = 5	-1, 1
n = 14		-17, 17
n = 15		-25, -21, -17,-13, -9, -5, -1, 1, 5, 9, 13, 17, 21, 25

	i = 5	-1, 1
n = 24		-17, 17
n = 25		-21, -13, 13, 21
n = 26		-25, -21, -17,-13, -9, -5, -1, 1, 5, 9, 13, 17, 21, 25

3.5.2 Reverse Link Frame Types

To realise multiple access via OFDMA-TDMA in the RL, except for the RA frame, the transmission is organised in segments and tiles/blocks of tiles within these segments, rather than in OFDM frames and sub-frames as in the FL.

3.5.2.1 RL Data Segment

In the RL, Data segment consists of tiles. One tile spans 25 symbols in frequency and 6 symbols in time direction and is illustrated in Figure 3-7. It comprises 4 PAPR reduction symbols and 12 pilot symbols. This leads to a data capacity of 134 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 3-5 for a tile on the left side of the DC sub-carrier and in Table 3-6 for a tile on the right side of the DC sub-carrier.

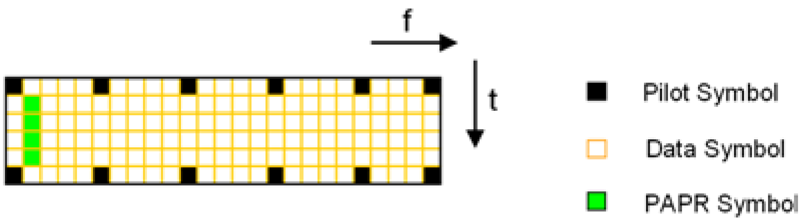

Figure 3-7: Structure of a Tile in the RL

Table 3-5: Pilot and PAPR Reduction Symbol Positions in a Left Tile

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

Table 3-6: Pilot and PAPR Reduction Symbol Positions in a Right Tile

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

An RL data segment, comprising 8 tiles, is depicted in Figure 3-8.

The length of an RL data segment is variable and is described in Section 3.5.3.2.

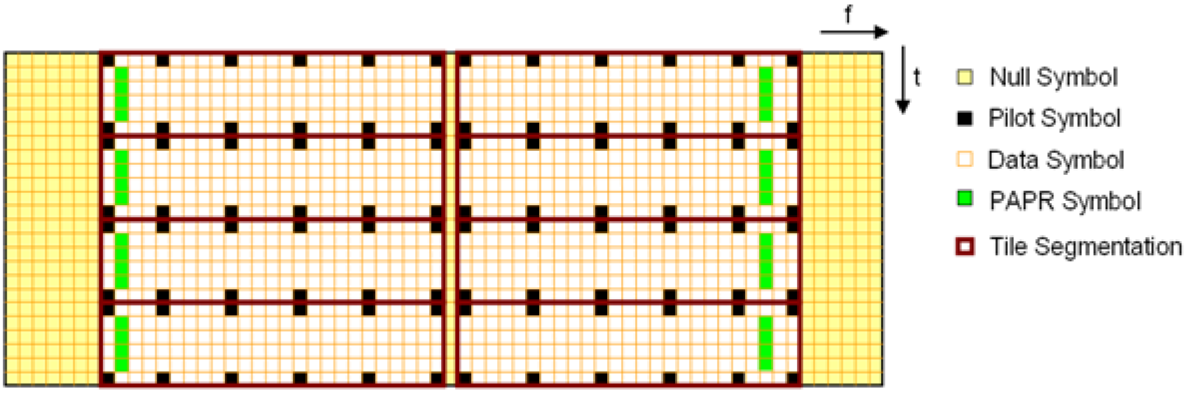

Figure 3-8: Structure of an RL Data Segment

3.5.2.2 RL Dedicated Control Segment

A dedicated control (DC) segment has the same tile structure as the RL data segment (see Figure 3-7).

The DC segment starts with a synchronisation tile, spanning 5 OFDM symbols in time direction and 51 sub-carriers, including the DC sub-carrier in frequency direction and is illustrated in Figure 3-9. The synchronisation tile starts with an AGC preamble, followed by two OFDM synchronisation symbols. The 4th and 5th OFDM symbol consist of pilot symbols. The total duration of the synchronisation tile is T_{SYNC} = 0.6 ms. The pilot positions are given in Table 3-7. The synchronisation tile provides a possibility for an AS to execute a Handover Type 2.

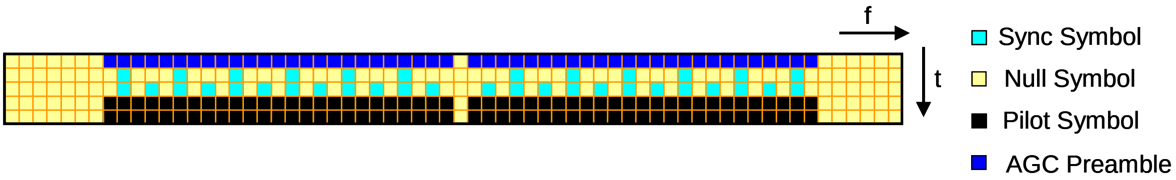

Figure 3-9: Structure of a Synchronisation Tile

Table 3-7: Pilot Symbol Positions in a Synchronisation Tile

OFDM symbol position n	Pilot symbol positions
n = 4, 5	-25, -24, …, -1, 1, 2, …, 25

The synchronisation tile is followed by an AGC preamble (single OFDM symbol) with a duration of T_{AGC} = 120 µs.

Within the remainder of the DC segment, exactly one tile is assigned to one AS. The length of a DC segment is variable and is described in Section 3.5.3.2. Therefore, the number of OFDM symbols in the DC segment (N_{dc}) is variable as well. As an example one DC segment comprising the synchronisation tile, the single AGC preamble and six tiles is depicted in Figure 3-10.

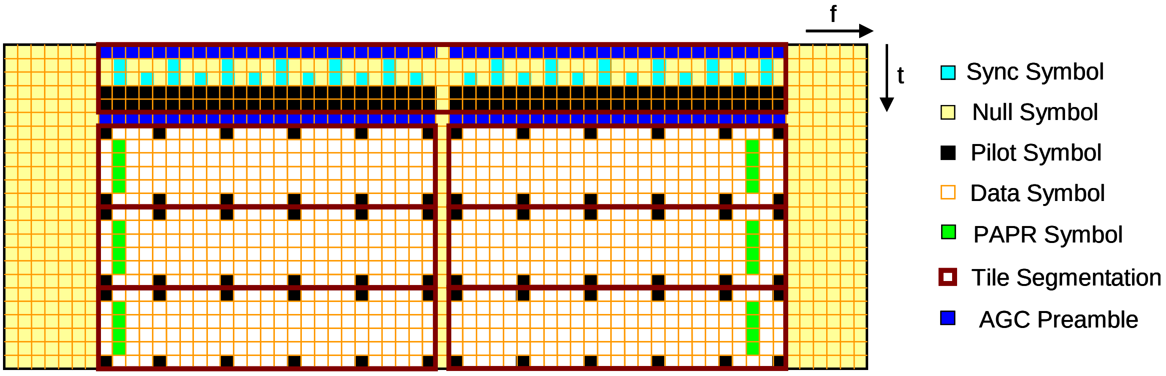

Figure 3-10: Structure of an RL DC Segment

3.5.2.3 RL Random Access Frame

NOTE: In the RL Random Access (RA) frame no OFDMA-TDMA is utilised, therefore the term 'frame' is used as in the FL.

An RL RA frame provides an opportunity for AS to send its cell entry request to the GS (Figure 3-11). Within each SF there are two opportunities for sending RA frames. Each RA frame can be preceded and followed by propagation guard times of length $T_{g,RA}$ = 1.26 ms, respectively.

This propagation guard time of 1.26 ms corresponds to a maximal AS-GS distance of 200 nm. When transmitting an RA frame, an AS is not yet synchronised to the GS. Under such conditions, an AS sends the first RA 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 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 frame to reach the GS. Thus, from the GS point of view, an RA frame in this case appears to be surrounded by two propagation guard times (Figure 3-11). Similar considerations are valid for the RA frame sent in the second opportunity that lags in time by 3.36 ms relative to the first one.

Figure 3-11: RA Access Opportunities

The RA frame contains seven OFDM symbols, resulting in a duration of $T_{sub,RA}$ = 840 µs. The structure of an RA frame is given in Figure 3-12.

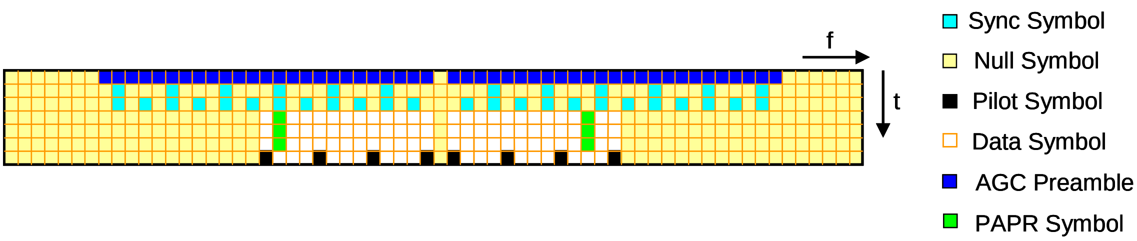

Figure 3-12: Structure of an RA Frame

The first OFDM symbol represents the AGC preamble, the following two OFDM symbols contain synchronisation sequences, while the remaining four OFDM symbols carry data, PAPR reduction symbols and pilot symbols. These four OFDM symbols use only 27 sub-carriers (including the DC sub-carrier), which leads to guard bands with $N_{g,left}$ = 19 and $N_{g,right}$ = 18 sub-carriers. The arrangement of the pilot symbols and PAPR reduction symbols follows the pattern given in Table 3-8. The number of 8 pilot symbols and 6 PAPR reduction symbols leads to a data capacity of (26·4 - 8 - 6) = 90 symbols per RA frame.

Table 3-8: Pilot and PAPR Reduction Symbol Positions for RL RA Frame

OFDM symbol position n	Pilot symbol positions
n = 7	-13, -12, …, -1, 1, 2, …, 13
	PAPR reduction symbol positions
n = 4, 5, 6	-12, 11

3.5.3 Framing

The LDACS1 physical layer framing is hierarchically arranged. In Figure 3-13 and Figure 3-14, this framing structure is summarised graphically, from the Super-Frame (SF) down to the OFDM frames. One SF has duration of T_{SF} = 240 ms. From the view of the GS, the SF transmission on the FL and the RL is synchronous.

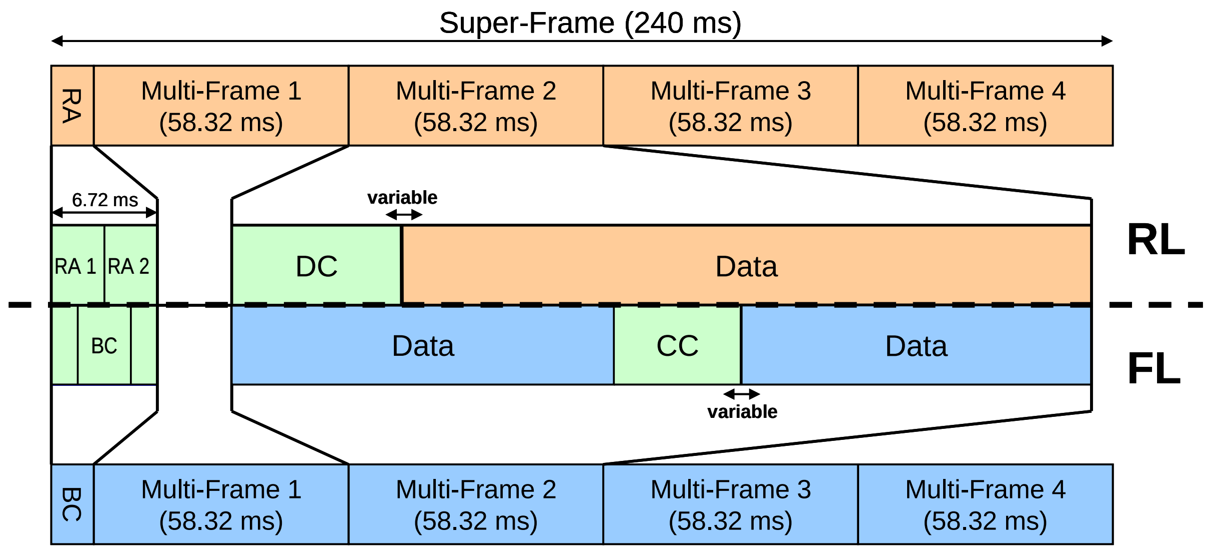

Figure 3-13: Super-Frame Structure

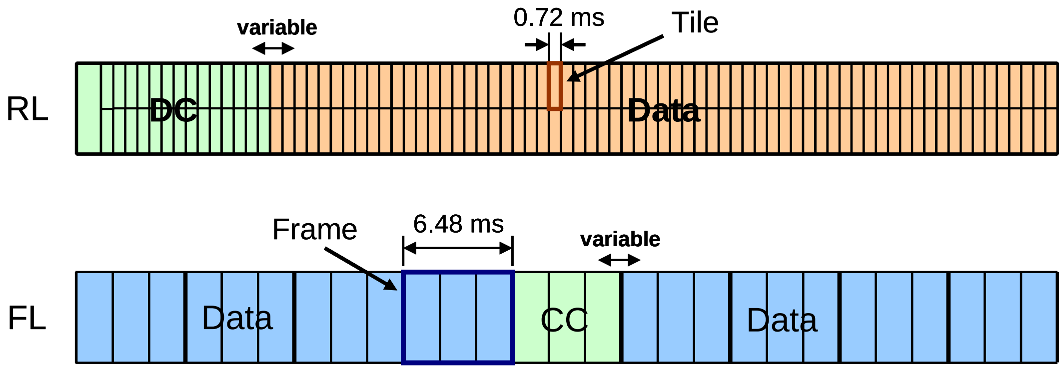

Figure 3-14: Multi-Frame Structure

The data to be transmitted on FL and RL are provided by the MAC layer in the form of FL PHY-SDUs and RL PHY-SDUs, respectively. The size of the FL/RL PHY-SDUs corresponds to the capacity of the PHY-PDUs in different types of frames and tiles. A PHY-PDU represents a constellation of modulated data symbols within the OFDM frame, sub-frame or tile that carry the actual payload – PHY-SDUs. The PHY-PDU, by definition, excludes any non-data symbols like AGC symbols, synchronization symbols, symbols for PAPR reduction, pilot symbols or unmodulated DC symbols.

3.5.3.1 Forward Link Framing

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/BC3 sub-frame, respectively. One FL BC2 PHY-PDU is mapped onto one BC2 sub-frame. The number of modulated 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 CC PHY-PDUs and FL Data PHY-PDUs are mapped. The size of an FL CC PHY-PDUs is 814 symbols, i.e. 1/3 of an FL Data/CC frame. Within the MF, starting from the frame number 5, N_{CC} = 3, 6, 9, or 12 FL CC PHY-PDUs can be mapped onto the subsequent frames. The remainder of the MF shall be filled with FL Data PHY-PDUs. The size of an FL Data PHY-PDU is 814 symbols, as well. The numbering of the FL PHY-PDUs shall start at the beginning of the MF.

3.5.3.2 Reverse Link Framing

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 frame. The number of modulated data symbols in an RA 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. RL DC and Data segments are sub-divided into tiles. Within one MF, the DC segment size and thus also the size of the data segment is variable. 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 a synchronisation tile followed by an AGC preamble 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 the 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 bits (PHY-SDU size) and coded bits in the PHY-PDUs is given in Section 3.6.2.5 and 3.6.2.6.*

Note: *Maximum length of the DC segment limits the number of AS that can be controlled by one GS to 208. More ASs can be accommodated by increasing the length of the control cycle to two SFs or more. In any case, the maximum number of ASs per GS cannot be greater than 512, limited by the maximum size (9 bits) of the control offset field defined at LDACS1 MAC sub-layer.*

3.6 Coding and Modulation

3.6.1 Randomizer

Prior to the channel coding, data randomization is applied to each PHY-SDU separately in the FL and the RL. The structure of the randomizer is depicted in Figure 3-15, comprising 2 XOR operations and 15 memory elements. The uncoded bits of each PHY-SDU enter the randomizer serially. For each PHY-SDU, the randomizer shall be used independently, which means that prior to each PHY-SDU, the memory elements shall be set to the begin-state, which is defined by the initial sequence

$$\{p_0, p_1, p_2, ..., p_{14}\} = \{0,0,0,0,0,0,0,1,0,1,0,1,0,0,1\}.$$

The output bits of the randomizer enter the channel coding.

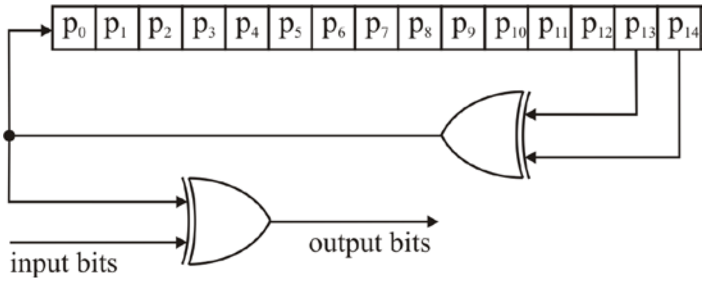

Figure 3-15: Randomizer Structure

A reverse operation of the randomization has to be applied after the channel decoding at the RX side.

3.6.2 Channel Coding

As FEC scheme, LDACS1 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 3-16.

At the TX side, the information bits after randomization first enter the RS encoder, followed by a block interleaver. Afterwards, zero-terminating convolutional coding is applied. In a final step, the coded bits are interleaved, using a helix interleaver.

The complementary operation is applied in reverse order at the RX side.

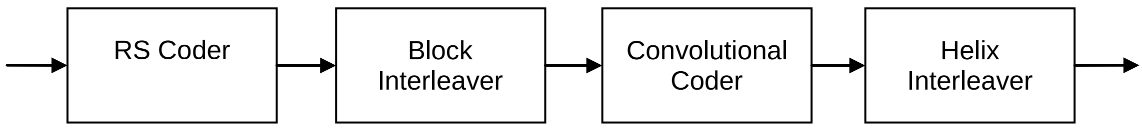

Figure 3-16: Channel Coding and Interleaving

For the termination of the inner convolutional code, six zero bits are added to the end of the data block before convolutional encoding. These bits are discarded at the RX side after decoding the convolutional code.

If the number of bits to be coded and modulated does not exactly fit to the size of one PHY-PDU, a corresponding number of zero pad bits shall be added after the convolutional coder. These bits are discarded at the RX side before decoding the convolutional code.

3.6.2.1 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 shortening shall be done by padding zeros in front of the uncoded bytes. 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

3.6.2.2 Inner Coding

Each output data block of the block interleaver 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 3-17. The coded bits streams $X^{(1)}$ and $X^{(2)}$ are combined by alternately taking bits from $X^{(1)}$ and $X^{(2)}$, i.e. $X^{(1)}_1$, $X^{(2)}_1$, $X^{(1)}_2$, $X^{(2)}_2$,… .Other coding rates can be derived by puncturing the native code. The puncturing patterns for the provided coding rates are given in Table 3-9, a “1” means a transmitted bit and a “0” denotes a removed bit, whereas $X^{(1)}$ and $X^{(2)}$ are in accordance to Figure 3-17.

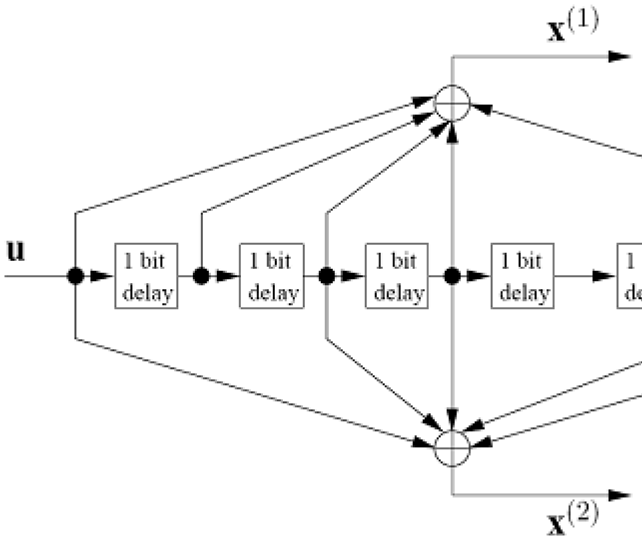

Figure 3-17: Block Diagram of Convolutional Coder (171, 133, 7)

Table 3-9: Puncturing Pattern for Convolutional Coder (171, 133, 7)

Coding rate	1/2	2/3	3/4
$X^{(1)}$	1	10	101
$X^{(2)}$	1	11	110
$X^{(1)}$ $X^{(2)}$	$X^{(1)}_1X^{(2)}_1$	$X^{(1)}_1X^{(2)}_1$ $X^{(2)}_2$	$X^{(1)}_1X^{(2)}_1$ $X^{(2)}_2X^{(1)}_3$

For the RL RA PHY-SDUs and the RL DC PHY-SDUs, an r_{cc} = 1/3 convolutional coder with a constraint length equal to 7 is used. In this case, no RS encoding and block interleaving is performed. The block diagram of the coder is given in Figure 3-18. The coded bits streams $X^{(1)}$, $X^{(2)}$ and $X^{(3)}$ are combined by alternately taking bits from $X^{(1)}$, $X^{(2)}$ and $X^{(3)}$, i.e. $X^{(1)}_1$, $X^{(2)}_1$, $X^{(3)}_1$,$X^{(1)}_2$, $X^{(2)}_2$,…

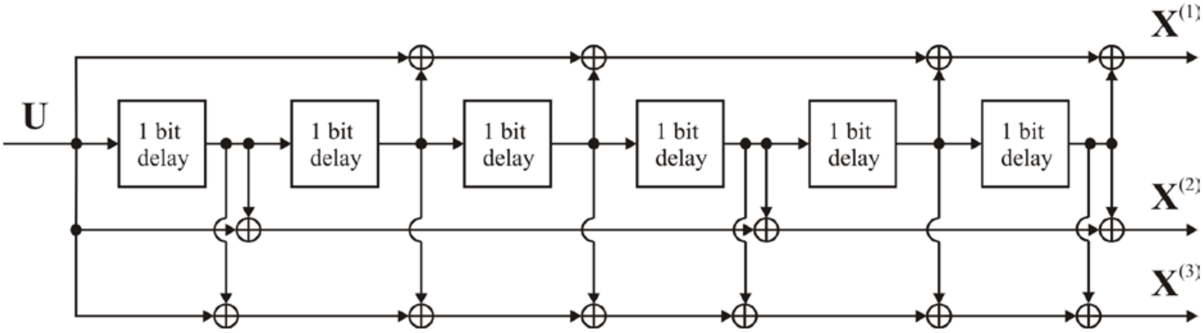

Figure 3-18: Block Diagram of Convolutional Coder (133, 145, 177, 7)

3.6.2.3 Block Interleaver

The output bytes of the RS encoder are interleaved by a block interleaver. The block interleaver is defined by a matrix. The number of rows is given by the number of RS code words which are interleaved together. The number of columns is defined by the number of coded bytes per RS codeword. For the interleaving, the bytes are written row-wise into the matrix and read out column-wise. These parameters are defined in the tables provided in Section 3.6.2.5 and 3.6.2.6.

3.6.2.4 Helix Interleaver

The interleaving of the output of the convolutional encoder is done by a helix interleaver. This ensures that the coded bits are evenly spread across the time-frequency plane. The block size of the interleaver $N_{I2} = a \cdot b$ complies with the coding block sizes. These are equivalent to the number of coded bits in the tables provided in Section 3.6.2.5 and 3.6.2.6. The following calculation specifies the pattern of the interleaver

for l = 0:a-1

for n = 0:b-1

$$k = l \cdot b + n + 1,$$

$$m_k = b \cdot (3 \cdot n + l)_{\text{mod}\, a} + n + 1$$

end

end

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

The de-interleaving operation in the receiver is the inverse of the interleaving operation.

3.6.2.5 FL Coding

The combination of QPSK modulation, a fixed RS code and a convolutional code with r_{cc} = ½ is mandatory for the FL BC PHY-SDUs. Each FL BC PHY-SDU is separately RS encoded, convolutional coded and helix interleaved. Table 3-10 gives the modulation schemes, channel coding parameters, interleaver parameters and block sizes for these FL PHY-SDUs.

The modulation schemes are described in Section 3.6.3.

The combination of QPSK modulation, a fixed RS code and a convolutional code with r_{cc} = ½ is mandatory for the FL CC PHY-SDUs. Each FL CC PHY-SDU is separately RS encoded. The block interleaving, convolutional coding and helix interleaving is performed jointly for all FL CC PHY-SDUs in a MF. Table 3-11 gives the modulation schemes, channel coding parameters, interleaver parameters and block sizes for the different number of FL CC PHY-SDUs per MF, which are defined in Section 3.5.3.1.

In Section 3.5.3.1, the number of PHY-PDUs and not PHY-SDUs is defined. However, after the modulation, the modulated symbols are subdivided into PHY-PDUs with the *total number of PHY-PDUs equal to the total number of PHY-SDUs. This does also hold for the Data PHY-SDUs.*

In the FL, Adaptive Coding and Modulation (ACM) is provided only for user data.

Adaptive Coding and Modulation (ACM) needs not to be implemented in the prototype LDACS1 equipment. Therefore, in FL Data PHY-SDUs only QPSK modulation with coding as in Table 3-12 shall be supported.

Due to the fixed size of FL Data PHY-PDUs of 814 modulated symbols, always $N_D = 27 - N_{CC} = \{15, 18, 21, 24\}$ FL Data PHY-SDUs are mapped onto a MF. The RS encoding is performed separately for each FL Data PHY-SDU.

Table 3-10: Parameters for FL BC PHY-SDUs

PHY-SDU type	Modulation scheme	Conv. Coding Rate	RS Parameter	Total Coding Rate	PHY-SDU size (uncoded bits)	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
FL $BC_{1,3}$ PHY-SDU	QPSK	1/2	RS(74, 66, 4)	0.45	528	(43, 28)	1204
FL BC_2 PHY-SDU	QPSK	1/2	RS(139, 125, 7)	0.45	1000	(40, 56)	2240

Note: For the BC frame, the block interleaver is obsolete, as the number of RS codewords per interleaving block is 1.

Table 3-11: Parameters for FL CC PHY-SDUs

PHY-SDU type	Modulation scheme	Conv. Coding Rate	RS Parameter	Total Coding Rate	PHY-SDU size (uncoded bits)	Number of RS code words per PHY-SDU	Number of PHY-SDUs per interleaving block	Block interleaver matrix size in byte	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
FL CC PHY-SDU	QPSK	1/2	RS(101, 91, 5)	0.45	728	1	3	(3, 101)	(66, 74)	4884
							6	(6, 101)	(132, 74)	9768
							9	(9, 101)	(111, 132)	14652
							12	(12, 101)	(132, 148)	19536

Table 3-12: Parameters for FL Data PHY-SDUs

PHY-SDU type	Modulation scheme	Conv. Coding Rate	RS Parameter	Total Coding Rate	PHY-SDU size (uncoded bits)	Number of RS code words per PHY-SDU	Number of PHY-SDUs per interleaving block	Block interleaver matrix size in byte	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
FL Data PHY-SDU	QPSK	1/2	RS(101, 91, 5)	0.45	728	1	15	(15, 101)	(111, 220)	24420
							18	(18, 101)	(132, 222)	29304
							21	(21, 101)	(154, 222)	34188
							24	(24, 101)	(264, 148)	39072

3.6.2.6 RL Coding

The combination of QPSK modulation and a convolutional code with r_{cc} = 1/3 is mandatory for the RL DC and the RL RA PHY-SDUs. In this case Table 3-13 gives the modulation schemes, channel coding parameters, interleaver parameters and block sizes for these FL PHY-SDUs.

The modulation schemes are described in Section 3.6.3.

Table 3-13: Parameters for RL DC and RL RA PHY-SDUs

PHY-SDU type	Modulation	Convolutional Coding Rate	Total Coding Rate	PHY-SDU size (uncoded bits)	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
RL DC PHY-SDU	QPSK	1/3	0.33	85	(67, 4)	268
RL RA PHY-SDU	QPSK	1/3	0.33	54	(15, 12)	180

In the RL, ACM is supported only for data segments.

In general, N_{SDU} PHY-SDUs of an AS in a MF are jointly RS coded, convolutional coded and helix interleaved. However, the number of jointly coded PHY-SDUs is limited either by the maximum size of a RS codeword (255 byte) or 10 PHY-SDUs. In Table 3-14 the limit N_{lim} is given for the different ACM parameter sets.

Table 3-14: Maximum Coding Block Size for RL Data PHY-SDUs

Modulation	Convolutional Coding Rate	*Maximal Coding Block Size, N_{lim}*
QPSK	1/2	10

If more than N_{lim} PHY-SDUs are assigned to one AS, the PHY-SDUs are separated into different coding blocks in the following way:

Calculate the number of coding blocks:

$$N_{\text{cod}} = \left\lceil \frac{N_{\text{SDU}}}{N_{\text{lim}}} \right\rceil$$

Calculate the sizes of the coding blocks:

- *Auxiliary calculation:*

$$u = \left\lfloor \frac{N_{\text{SDU}}}{N_{\text{cod}}} \right\rfloor; \quad v = \left(N_{\text{SDU}}\right)_{\text{mod}\, N_{\text{cod}}}$$

- *Number of coding blocks comprising u + 1 PHY-SDUs:* v
- *Number of coding blocks comprising u PHY-SDUs: Ncod -* v

Since the maximal coding block size is limited by one RS codeword, no block interleaver is needed.

Table 3-15 provides the parameters for PHY-SDU-based ACM in the RL data segments.

Adaptive Coding and Modulation (ACM) needs not to be implemented in the prototype equipment. Therefore in RL Data PHY-SDUs only QPSK modulation, with coding as in Table 3-15 shall be supported.

Table 3-15: Parameters for RL Data PHY-SDUs

PHY-SDU type	Modulation scheme	Conv. Coding Rate	PHY-SDU size (uncoded bits)	Number of PHY-SDUs per coding block	RS Parameter	Total Coding Rate	Helix Interleaver Parameter (a, b)	Number of coded bits after helix interleaver
RL Data PHY-SDU	QPSK	1/2	112	1	RS(16, 14, 1)	0.44	(67, 4)	268
				2	RS(32, 28, 2)	0.44	(67, 8)	536
				3	RS(48, 42, 3)	0.44	(67, 12)	804
				4	RS(66, 56, 5)	0.42	(67, 16)	1072
				5	RS(82, 70, 6)	0.43	(67, 20)	1340
				6	RS(98, 84, 7)	0.43	(67, 24)	1608
				7	RS(116, 98, 9)	0.42	(67, 28)	1876
				8	RS(132, 112, 10)	0.42	(67, 32)	2144
				9	RS(150, 126, 12)	0.42	(67, 36)	2412
				10	RS(166, 140, 13)	0.42	(67, 40)	2680

3.6.3 Modulation

Adaptive Coding and Modulation (ACM) needs not to be implemented in the prototype LDACS1 equipment. Therefore only QPSK modulation shall be supported.

After the interleaving, the encoded data bits enter serially the constellation mapper. Gray-mapped QPSK shall be supported. Figure 3-19 shows the constellation diagrams for QPSK. 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 3-19, b_0 denotes the Least Significant Bit (LSB).

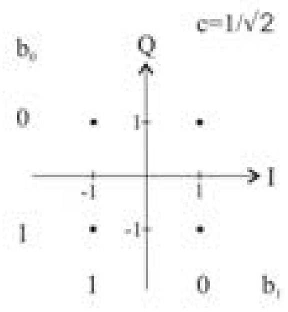

Figure 3-19: Constellation Diagrams for QPSK, 16QAM and 64QAM

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

3.6.4 Data mapping onto frames

Multiplexing of the signalling, header and user data into one PHY-PDU is done by the MAC sub-layer and is described in Chapter 8. PHY layer makes sure that the payload received from the MAC sub-layer (PHY-SDUs) is encoded, modulated and properly mapped onto PHY-PDUs within FL frames (that the available modulated symbols in the time-frequency plane are used in the proper order). The mapping of the blocks of modulated symbols onto PHY-PDUs shall be carried out as follows:

- Each FL BC PHY-SDU is encoded and modulated separately and each block of modulated symbols shall be mapped onto the corresponding PHY-PDU.
- N_{CC} FL CC PHY-SDUs within a MF are first RS coded (separately for each PHY-SDU) and then jointly convolutional coded, interleaved and modulated. After the modulation, each block of modulated symbols shall be mapped onto N_{CC} PHY-PDUs.
- For cell-specific ACM, N_D FL Data PHY-SDUs within a MF are RS coded (separately for each PHY-SDU) and then jointly convolutional coded, interleaved and modulated. After the modulation, each block of modulated symbols shall be mapped onto N_D PHY-PDUs.
- For user-specific ACM, all N_D FL Data PHY-SDUs within a MF possessing the same ACM parameter sets are RS coded (separately for each PHY-SDU) and then jointly convolutional coded, interleaved and modulated. After the modulation, each block of modulated symbols shall be mapped onto N_D PHY-PDUs.
- Each RL RA PHY-SDU is encoded and modulated separately and each block of modulated symbols shall be mapped onto the corresponding PHY-PDU.
- Each RL DC PHY-SDU is encoded and modulated separately and each block of modulated symbols shall be mapped onto the corresponding PHY-PDU.
- All RL Data PHY-SDUs assigned to an AS within a MF are jointly coded and modulated. After the modulation, each block of modulated symbols shall be mapped onto the corresponding number of PHY-PDUs.

3.6.4.1 FL Data Mapping

Before mapping FL PHY-PDUs onto a BC sub-frame or a Data/CC frame, two OFDM symbols with the synchronisation sequences and pilot symbols shall be inserted into an FL frame. Pilot insertion follows the pilot pattern defined in Section 3.5.

The FL PHY-PDUs shall be mapped in frequency direction onto the FL frame or sub-frame, i.e. symbols are placed subsequently on the free positions in the following order: (1,-25) (1,-24) (1,-23) … (2,-25) (2,-24) etc. Symbol positions are defined in Section 3.5.

In each MF, the N_{CC} FL CC PHY-PDUs shall be mapped onto the frames numbered 5,…,4 + N_{CC}/3. The N_D FL Data PHY-PDUs shall be mapped onto the remaining frames, starting with frame number 1. For both types, exactly 3 PHY-PDUs are mapped onto one frame.

Table 3-16 provides the indices of the OFDM symbols and sub-carriers, on which the FL CC and FL Data PHY-PDUs shall be mapped. Note that these tables ignore pilot symbols and the DC sub-carrier, i.e. the encoded and modulated content of PHY-PDUs shall be mapped only onto data symbols at free positions in the frame as given by the indices.

Table 3-16: Mapping Indices for CC and 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

3.6.4.2 RL Data Mapping

In the RL, the DC segment and the data segment are subdivided into tiles. Data mapping shall map RL DC PHY-PDUs and RL Data PHY-PDUs onto tiles, where one PHY-PDU is always mapped exactly onto one tile. Before mapping a PHY-PDU onto a tile, pilot symbols and PAPR reduction symbols shall be inserted into the tile. RL PHY-PDUs shall be mapped onto the tile in frequency direction, i.e. symbols are placed subsequently on the free positions within the tile in the following order: (1,-25) (1,-24) (1,-23) … (2,-25) (2,-24) etc. The RL PHY-PDU order for mapping is controlled by the MAC sub-layer.

In the RA frame, the mapping procedure follows the steps described for the BC FL sub-frames in Section 3.6.4.1.

3.6.5 Data Rate

The data rates provided in this section consider overhead produced by controlling channels, such as the DC segment, the CC information, the RA frame and the BC frame, as well as overhead due to pilot symbols, synchronisation sequences or PAPR reduction symbols.

3.6.5.1 FL Data Rate

Table 3-17 shows the data rates for QPSK modulation and r_{cc} = ½. The associated RS coding parameters are not given here, but can be found in Table 3-12.

Table 3-17: Data Rate in the FL (QPSK)

Modulation	Convolutional Coding Rate	Total Coding Rate	Data Rate [kbit/s]
QPSK	1/2	0.45	291.2

Adaptive Coding and Modulation (ACM) needs not to be implemented in the prototype equipment. Therefore only QPSK modulation shall be supported.

When calculating data rates, three CC PHY-PDUs are assumed, resulting in num_{PHY_PDU} = 24 Data PHY-PDUs per MF. The number of uncoded bits num_{unc} per PHY-PDU (PHY-SDU size) is given in Table 3-12. Taking T_{SF} = 0.24 s and num_{MF} = 4 MF per SF into account, the data rate for QPSK, r_{cc} = ½ is calculated as follows:

$$r_{data} = \frac{num_{unc} \cdot num_{PHY\_PDU} \cdot num_{MF}}{T_{SF}} = \frac{728bit \cdot 24 \cdot 4}{0.24s} = 291.2\frac{kbit}{s}.$$

3.6.5.2 RL Data Rate

In the RL, data rates cannot be easily specified, since the ratio of DC segment duration to data segment duration is variable. However, assuming QPSK modulation and an average DC segment duration of 15.84 ms, average data rate shown in Table 3-18.

Table 3-18: Data Rate in the RL (QPSK)

Modulation	Convolutional Coding Rate	Total Coding Rate	Data Rate [kbit/s]
QPSK	1/2	0.44	220.3

3.7 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.

3.7.1 Pilot Sequences

Pilot sequences defined in this section shall be inserted in the FL frames and 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 3-2, Table 3-3 and Table 3-4 for the FL and in Table 3-5, Table 3-6, Table 3-7 and Table 3-8 for the RL.

For the frames in the FL, for each set of pilot positions within an OFDM symbol, a pilot sequence is defined, which is given in Table 3-19.

Table 3-19: Pilot values for FL frames

Sub-carrier indices of pilots	Pilot values
-25, -1, 1, 25	1, -1, -1, -1
-17, 17	1, -1
-21, -13, 13, 21	1, 1, j, -j

-25, -9, 9, 25	1, -1, -j, -j
-5, 5	1, -j
-1, 1	1, -1
-25, -21, -17, -13, -9, -5, -1, 1, 5, 9, 13, 17, 21, 25	1, -j, j, 1, j, j, -1, -1, j, j, 1, j, -j, 1

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

$$S_{RA}(k) = \exp\left(j \cdot \frac{2\pi}{64} P_{RA}(k) \right), k = 1,\ldots,8$$

with

$$P_{RA} = \{61, 46, 11, 57, 40, 50, 18, 28\}.$$

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

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

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.

The pilot symbols may be transmitted with a boosting of n_B = 0 …4 dB over the average power of each data symbol. The boosting level for FL/RL shall be separately adjustable (n_{B_FL}/ n_{B_RL}).

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.

3.7.2 PAPR Reduction Symbols

For reducing the Peak to Average Power Ratio (PAPR), four symbols shall be inserted into every tile for RL transmission. The sub-carrier indices of these symbols are defined in Table 3-5, Table 3-6 and Table 3-8. These symbols carry no information and can be discarded at the receiver. They are calculated data-dependent, in order to reduce the PAPR.

3.7.3 Synchronisation Sequences

All synchronisation OFDM symbols are structured as depicted in Figure 3-20. 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 3-20. 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.

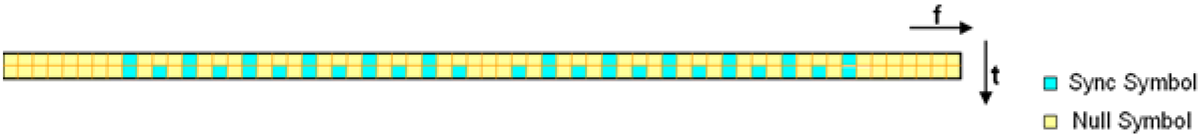

Figure 3-20: Structure of the Synchronisation OFDM Symbols

Table 3-20: 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 3-21. 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).

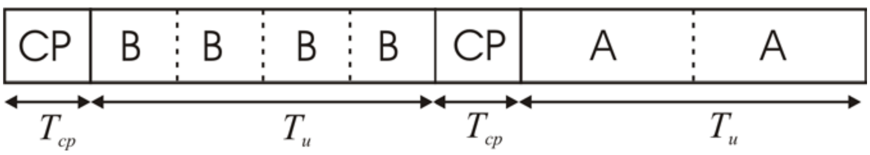

Figure 3-21: Time Domain Representation of Synchronisation OFDM Symbols

Note: The chosen synchronisation sequences are so called CAZAC (constant amplitude, zero autocorrelation) sequences, which preserve their good correlation properties when transforming them from the frequency to the time domain.

3.7.4 AGC Preamble

The first OFDM symbol in an RL RA frame, the first OFDM symbol in a synchronisation tile and the OFDM symbol preceding the DC tiles contain AGC preambles. 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:

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

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}.

3.7.5 TX Windowing

In Section 3.2.2, the generation of the time domain TX signal is described, including windowing. TX windowing is the mandatory method that must be implemented at the LDACS1 TX in order to reduce the undesired influence of L-DASC1 onto existing L-band systems.

TX windowing is applied in order to smooth the sharp phase transitions between consecutive OFDM symbols which would otherwise cause out-of-band radiation. The windowing function is illustrated in Figure 3-22.

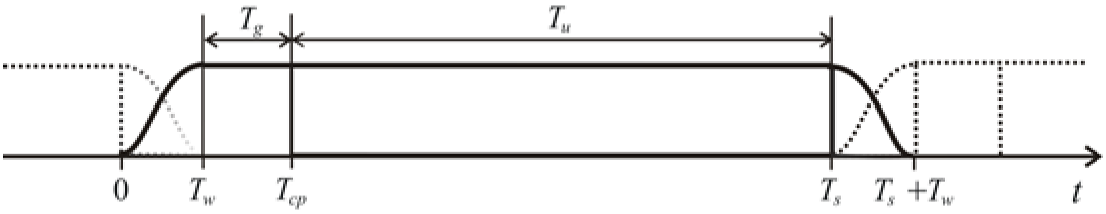

Figure 3-22: Windowing Function

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 flanks 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:

$$s(t) = s_{0,wi}(t) + s_{1,wi}\left(t - T_s\right) + s_{2,wi}\left(t - 2T_s\right) + \ldots.$$

3.8 Physical Layer Services

This entire section is for information only. It explains how the existing PHY layer facilities could be used by external entities for their specific purposes, but does not prescribe the detailed implementation (practical implementation may deviate from the description provided here).

3.8.1 Support for AS RX AGC

As the transmission in the FL is continuous, no dedicated preamble is needed for supporting the AGC in the airborne RX.

3.8.2 Support for GS RX AGC

In the RL, the RA frames and the synchronisation tiles in the DC segments start with an AGC preamble. In addition, the first OFDM symbol following the synchronisation tile is occupied by an AGC preamble. This symbol shall be sent by the AS that occupies the first left DC tile in the DC segment.

3.8.3 AS RX Synchronisation to FL Frames

3.8.3.1 Time Synchronisation Maintenance

In the FL, every frame and BC sub-frame begins with two synchronisation symbols. The structure of these two symbols is described in Section 3.7.3. This structure can be exploited in the AS RX for time synchronisation maintenance, applying an appropriate time domain correlation. As the length of these frames and sub-frames is $T_{DF/CC}$ = 6.48 ms, $T_{BC1/3}$ = 1.8 ms and T_{BC2} = 3.12 ms, the time synchronisation can be updated at least every 6.48 ms based solely on the received synchronisation symbols.

3.8.3.2 Frequency Synchronisation Maintenance

The OFDM synchronisation symbols at the beginning of every frame and BC sub-frame can be used for the frequency synchronisation maintenance. Like for time synchronisation, the frequency synchronisation can be updated at least every 6.48 ms based solely on FL synchronisation symbols.

3.8.4 GS RX Synchronisation to RL Frames

3.8.4.1 Time Synchronisation Maintenance

In the RL, each RA frame starts with two OFDM synchronisation symbols. The structure of these OFDM symbols is described in Section 3.7.3. Hence, GS RX can measure the timing offset of RA frames sent by an AS which executes a cell entry relative to the GS own SF timing. The results would be communicated to the AS. Based on these results, the AS can apply the timing advance and transmit with pre-compensated timing offset.

An update of the timing offset compensation can be produced by the GS, based on the measurements performed over DC tiles sent by each AS in the DC segment, depicted in Figure 3-10.

Between the cell entry and the update of the timing offset, an AS shall track the time synchronisation, e.g. by employing the OFDM synchronisation sequences in the FL frames. As this tracking is a differential procedure, errors may accumulate, which justifies the update procedure.

> *In-the-loop timing corrections need not to be supported in the prototype LDACS1 equipment.*

3.8.4.2 Frequency Synchronisation Maintenance

Like for time synchronisation, the two OFDM synchronisation symbols at the beginning of each RA frame can be used for frequency synchronisation. Hence, it is possible for a GS to measure the frequency offset of an AS which executes a cell entry. The results will be communicated to this AS. Based on these results, the AS can pre-compensate on the RL the measured frequency offset.

An update of the frequency offset compensation can be produced by the GS, based on the measurements performed over DC tiles sent by each AS in the DC segment, depicted in Figure 3-10.

Like for time synchronisation, an AS shall track the frequency synchronisation between the cell entry and the update, e.g. by employing the OFDM synchronisation sequences in the FL frames.

In-the-loop frequency corrections need not to be supported in the prototype LDACS1 equipment.

3.8.5 Notification Services

3.8.5.1 Ground Station RX RL Signal Power Measurements

Initial signal power measurement is performed during the cell entry of an AS, based on RL RA frames. In the following, the GS PHY layer shall monitor the received signal power separately for each RL user and report results to the GS LME. This monitoring can be executed based on the DC tiles sent by the particular AS. Since an AS regularly transmits DC tiles, the GS can continuously monitor the received signal power for each AS.

This feature is optional for the prototype LDACS1 equipment.

3.8.5.2 AS RX FL Signal Power Measurements

An AS PHY layer shall regularly monitor the FL transmission of its controlling GS and report the received signal power to the AS LME.

During a BC frame, an AS may be requested to scan the channels of adjacent non-controlling GSs. In this case the AS PHY layer shall measure the received signal power of the specified neighbouring cell and report the received signal power to the AS LME.

This feature is optional for the prototype LDACS1 equipment.

3.8.6 AS TX Power Management

A power management algorithm shall be supported for the RL with both an initial power calibration during cell entry and a periodic adjustment during normal operation. The objective of the power management algorithm is to let the AS LME adapt the transmitting power of the AS TX, therefore aligning the received power density from all ASs to a similar level. For this purpose, the GS has to instruct the AS whether it should increase or decrease the current transmit power level.

In-the-loop frequency corrections need not to be supported in the prototype LDACS1 equipment.

3.9 PHY Interface to Service Users

The physical layer shall provide an interface to its service users.

Internal interfaces in the prototype LDACS1 equipment are considered to be a local implementation issue.

3.10 Physical Layer Parameters

Table 3-21 summarises all parameters, which were defined or mentioned in this chapter. In addition, a reference to the corresponding sections is provided.

Table 3-21: Physical Layer Parameters

Parameter	Abbr.	Value	Unit
FFT size (3.4.1)	N_{FFT}	64	
Sampling time (3.4.1)	T_{sa}	1.6	µs
Sub-carrier spacing (3.4.1)	Δf	9.765625	kHz
Useful symbol time (3.4.1)	T_u	102.4	µs
Cyclic prefix ratio (3.4.1)	G	11/64	

Parameter	Abbr.	Value	Unit
Cyclic prefix time (3.4.1)	T_{cp}	17.6	µs
OFDM symbol time (3.4.1)	T_s	120	µs
Guard time (3.4.1)	T_g	4.8	µs
Windowing time (3.4.1)	T_w	12.8	µs
Number of used sub-carriers (3.4.1)	N_u	50	
Number of lower frequency guard sub-carriers (3.4.1)	$N_{g,left}$	7	
Number of higher frequency guard sub-carriers (3.4.1)	$N_{g,right}$	6	
Total FFT bandwidth (3.4.2)	B_0	625.0	kHz
Effective RF bandwidth (3.4.2)	B_{occ}	498.05	kHz
Number of OFDM symbols within one frame (3.5)	N_{OFDM}	variable	
Duration of a Data/CC frame (3.5.1.1)	$T_{DF/CC}$	6.48	ms
Duration of a BC1 and BC3 sub-frame (3.5.1.2)	$T_{BC1/3}$	1.8	ms
Duration of a BC2 sub-frame (3.5.1.2)	T_{BC2}	3.12	ms
Duration of a BC frame (3.5.1.2)	T_{BC}	6.72	ms
Duration of a synchronisation tile (3.5.2.2)	T_{SYNC}	0.6	ms
Duration of an AGC preamble (3.5.2.2)	T_{AGC}	0.12	ms
Number of OFDM symbols in a DC segment (3.5.2.2)	N_{dc}	variable	
Guard time in a RA frame (3.5.2.3)	$T_{g,RA}$	1.26	ms
Duration of a RA frame (3.5.2.3)	$T_{sub,RA}$	840	µs
Duration of a Super-Frame (3.5.3)	T_{SF}	240	ms
Duration of a Multi-Frame (3.5.3.1)	T_{MF}	58.32	ms
Number of CC PHY-PDUs per MF (3.5.3.1)	N_{CC}	variable	
Duration of a RA frame (3.5.3.2)	T_{RA}	6.72	ms
Duration of a DC segment (3.5.3.2)	T_{DC}	variable	ms
Duration of an RL Data segment (3.5.3.2)	T_{DF}	variable	ms
Number of input byte of a RS code word (3.6.2.1)	K	variable	
Number of output byte of a RS code word (3.6.2.1)	N	variable	
Native coding rate of convolutional coder (3.6.2.2)	r_{CC}	variable	
Size of a helix interleaver block (3.6.2.4)	N_{I2}	variable	
Number of FL Data PHY-PDUs per MF (3.6.2.5)	N_D	variable	
Number of RL Data PHY-SDUs, assigned to an AS (3.6.2.6)	N_{SDU}	variable	
Number of coding blocks of an AS in a MF (3.6.2.6)	N_{cod}	variable	
Maximum coding block size for RL Data PHY-SDUs (3.6.2.6)	N_{LIM}	variable	

Parameter	Abbr.	Value	Unit
Multiplication factor for the modulation (3.6.3)	c	variable	
Modulation rate (3.6.3)	r_{mod}	variable	
Roll-off factor for RC window (3.7.5)	α	0.107	

4 Ground Station Transmitter

This section comprises items that are specific to the prototype implementation of the LDACS1 GS TX operating in the A/G mode.

Deviations from the LDACS1 system specification [SJU_LD1_1] that are proposed for more efficient prototyping are highlighted.

4.1 GS TX Radio Front-end Characteristics

4.1.1 GS TX Frequency Range and Tuning Step

LDACS1 shall operate as a full duplex system in the 960 – 1164 MHz range [SJU_LD1_1].

Prototype GS TX shall be capable of operating on any channel within the following ranges:

- 985.5 – 1008.5 MHz
- 1048.5 – 1071.5 MHz
- 963.5 – 970.5 MHz
- 1149.5 – 1156.5 MHz

Different deployment options have been considered in [SJU_LD1_1]. As none of these options has yet been selected for the LDACS1 deployment, the prototype GS TX should support all currently proposed options.

GS TX shall be tuneable to any channel[5] 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.

4.1.2 GS TX Operating Frequency

GS TX shall transmit on its adjusted operating frequency.

4.1.3 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 ± 0.1 ppm or better.

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

4.1.4 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 (+41 dBm, as estimated from the LDACS1 link budget in [SJU_LD1_1]) 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.*

[5] The channel frequency corresponds to the nominal position of the DC OFDM sub-carrier in the spectrum of the LDACS1 signal.

4.1.5 GS TX Power Setting

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

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

GS TX shall permanently transmit with its adjusted power level.

During the laboratory measurements, the required power level of an LDACS1 GS TX signal at the input of the victim receiver under investigation will be adjusted via variable attenuator rather than via changing the TX operating point.

4.1.6 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). In this case the following shall apply:

- Absolute average power difference between adjacent sub-carriers: ≤ 0.1 dB ("n_{B_FL}" dB allowance should be added for pilot sub-carriers in case pilots are boosted by "n_{B_FL}" dB).
- 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]: ≤ ±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 total average GS transmitted power (excluding the sub-carriers intentionally power-boosted or suppressed).
- *All above requirements apply to the RF output connector of the equipment.*

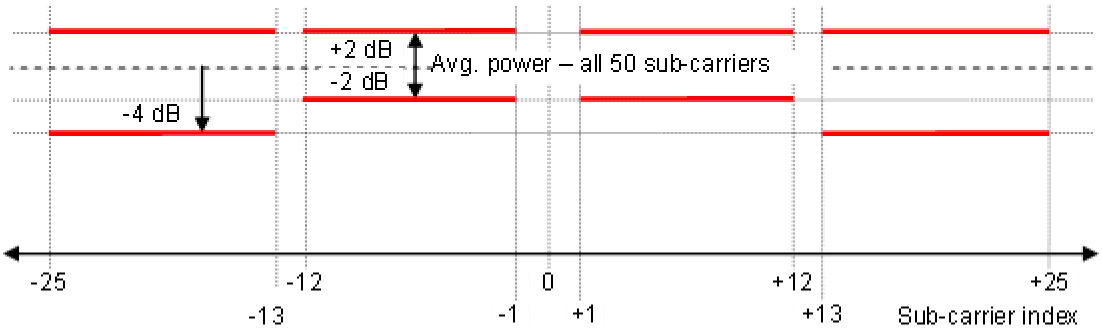

Figure 4-1: GS TX Spectral Flatness

The boosting level n_{B_FL} shall be adjustable (Section 3.7.1).

4.1.7 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

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

where

- L_p denotes the number of OFDM symbols used in a test run (length of the OFDM frame with data relevant to the measurement),
- N_f denotes the number of OFDM frames containing data used in the test run,
- $[I_0(I,j,k), Q_0(I,j,k)]$ 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 $\log_{10}$ ($Error_{\text{RMS}}$).

4.1.8 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 domain starts at an offset $\pm B_{occ}\cdot 2.5$ from the LDACS1 nominal transmit frequency f_c. B_{occ} = 498.05 MHz is the occupied bandwidth of the LDACS1 GS TX signal, see Section 4.1.10.*
>
> *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 GS TX broadband noise power density measured across the spurious domain (Figure 4-2) in an active mode at the GS TX output terminated in a matched impedance load shall not exceed -133 dBc/Hz.

> *A more stringent value may be required at larger frequency offsets to protect non-aeronautical systems operating below 960 MHz as well as GNSS receivers. Additional spurious and broadband noise attenuation can be achieved via external duplexer or filtering equipment. The target broadband noise power density, including such RF post-filtering, should be -145 dBc/Hz or less at frequency offset $\Delta f \geq 4.0$ MHz measured from the edge of the LDACS1 GS TX transmission range.*

4.1.9 GS TX Spectrum Mask

The spectral density of the LDACS1 signal within the OOB domain transmitted by the GS shall fall within the spectral mask shown 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 average LDACS1 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. The point "A" represents the half of the occupied bandwidth (Section 4.1.10).*
>
> *The range of ±1.245 MHz around the TX operating frequency fc is defined as Out-Of-Band (OOB) range. The OOB domain boundary (1.245 MHz) is given in Figure 4-2 and Table 4-1. The boundary has been calculated based on the occupied bandwidth of the LDACS1 signal-in-space B_{occ} = 498.05 MHz using the ITU-R definition for the start of the spurious domain $[f_c\text{-}B_{occ}\cdot 2.5 \ldots f_c\text{+}B_{occ}\cdot 2.5]$ that was also used for the UAT system [UAT_M].*

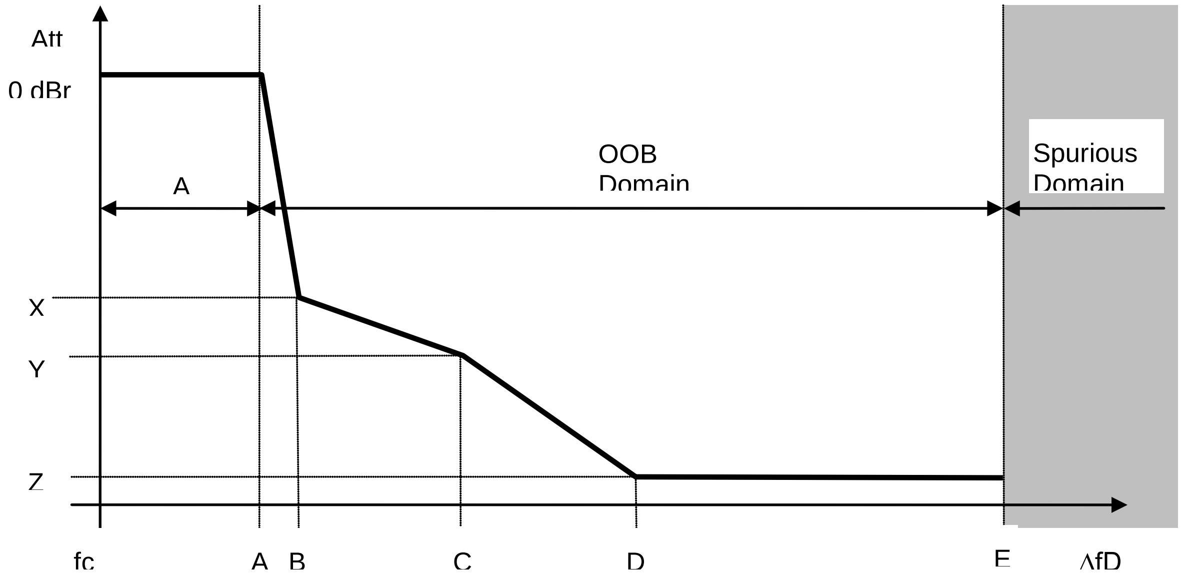

Figure 4-2: GS TX Spectral Mask

Table 4-1: GS TX Spectral Mask

	A = B_{occ}/2	**B = 1.35·A**	**C = 2.5·A**	**D = 3.1·A**	**E= 5·A**	**≥ E**
Δf (kHz)	250	337.5	625	775	1.245	≥ 1.245
Att (dBr)	0	X = 40	Y = 56	Z = 76	Z = 76	<spurs>

4.1.10 GS TX Occupied Bandwidth

More than 96% of the GS TX signal power shall lie within the nominal bandwidth B_{occ} = 498.05 kHz.

4.1.11 GS TX Time/Amplitude Profile

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

4.2 GS TX Baseband Characteristics

4.2.1 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 produce FL symbols and frames by respecting its current local clock status.

4.3 GS TX PHY Layer Characteristics

GS TX PHY layer shall be implemented as specified in Section 3, except for the highlighted items below.

> *Only parts of the PHY layer functionality specified in [SJU_LD1_1] have to be implemented in the first GS TX prototype.*

4.3.1 GS TX Maximum Number of Used Sub-carriers

The GS TX shall use 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.

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

4.3.2 Framing

GS TX FL framing shall be implemented as specified in Section 3.5.3.1.

The internal structure of FL frames (including the synchronisation sequences and pilot tones) shall be implemented as specified in Sections 3.5.1 and 3.5.1.2.

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

The prototype GS TX shall generate a required number of BC sub-frames, CC and Data frames per SF. The corresponding parameters of BC sub-frames, CC and Data frames are provided in Section 4.4.

4.3.3 Coding

GS TX FL coding shall be implemented as specified in Sections 3.6.2 and 3.6.2.5.

Data frames implemented within the prototype GS TX shall use modulation schemes, channel coding parameters and block sizes as listed in Table 3-12.

BC sub-frames implemented within the prototype GS TX shall use modulation schemes, channel coding parameters and block sizes from Table 3-10.

4.3.4 Modulation

GS TX FL modulation shall be implemented as specified in Section 3.6.3.

Gray-mapped QPSK as shown in Figure 3-19 shall be supported by the GS TX prototype.

> *Other modulation types need not to be supported by the GS TX prototype.*

4.3.5 Data Mapping

GS TX FL data mapping shall be implemented as specified in Section 3.6.4.1.

4.3.6 Pilot Sequences

GS TX FL pilot sequences shall be implemented as specified in Sections 3.5.1 and 3.7.1.

GS TX shall allow for transmitting pilot tones boosted by n_{B_FL} = 0 …+4 dB relative to other modulated symbols.

The parameter "n_{B_FL}" that defines the GS TX boosting level shall be configurable via an application-specific interface.

4.3.7 Synchronisation Sequences

GS TX FL synchronisation sequences shall be implemented as specified in Sections 3.5.1 and 3.7.3.

4.3.8 TX Windowing

GS TX windowing shall be implemented as specified in Section 3.7.5.

4.4 GS TX Protocol Characteristics

A detailed specification for LDACS1 protocol entities above PHY layer is provided in [SJU_LD1_1].

For laboratory testing purposes, the full functionality of the MAC sub-layer described in *[SJU_LD1_1]* can be reduced in order to regulate the segmentation and packaging of a continuous data stream received via an external interface. The service primitives specified in Section 6 of *[SJU_LD1_1]* should be seen as guidance, but their implementation is not mandatory for the LDACS1 prototype.

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-SDUs that can be directly mapped onto the GS TX FL frames (Section 3.6.4.1). The size and number of the FL PHY-SDUs corresponds to the capacity of the different types of frames and complies with the defined SF timing (Section 3.6.2.5).

> *As a part of the layer interaction, additional signalling information is locally exchanged between the PHY and the MAC sub-layer, but is not transmitted to LDACS1 RX.*

In the prototype GS TX implementation, multiple PHY parameters that would be normally set via the MAC sub-layer can be configured directly at the PHY layer, according toTable 4-2. This table covers two different sets of parameters, one for assessing the LDACS1 TX impact onto receivers of other systems, another one for assessing the LDACS1 AS RX performance (BER) under presence of external L-band interference. These settings must be provided (a priori known) to the AS RX in order to properly emulate the impact of control messages and to enable proper data detection and decoding. With respect to Table 4-2 the following remarks apply:

Interference from LDACS1 GS TX

In this case a realistic TX power and duty cycle is crucial, but the exact data content of the transmitted information is less relevant.

- Full FL structure is used (FL transmissions are continuous, duty-cycle = 100%).
- All FL frames/sub-frames shall be implemented as described in Section 3.5.1 and filled with pseudo-random data.
- The detailed data content of FL frames and sub-frames is irrelevant for GS TX spectrum measurements (as long as these data are pseudo-random allowing for realistic PAPR values), therefore coding can be switched off. However, all frames and sub-frames have to be filled with arbitrary data in order to enable a continuous FL transmission.
- Boosting of pilot tones shall be configurable and enabled for testing purposes, i.e. the boosting level parameter can be set between 0 dB and 4 dB above the average power of each data symbol.

AS RX BER Measurements

In this case a realistic TX duty cycle is less relevant, but the data content of the transmitted information is important (restricted to FL PHY-SDUs over which the BER measurement is conducted).

- Full FL structure is used (FL transmissions are continuous, duty-cycle = 100%)
- All FL frames/sub-frames shall be implemented as described in Section 3.5.1 and filled with pseudo-random data.
- For BER measurements all Data frames in all MFs shall be filled with pseudo-random data (FL Data PHY-SDUs). Data frames use QPSK modulation with r = 1/2 convolutional coding and RS coding/interleaving according to Table 3-12.
- CC frames filled with pseudo-random data (FL CC PHY-SDUs) may be optionally used for BER measurements along with Data frames. CC frames use QPSK modulation with r = 1/2 convolutional coding and RS coding/interleaving according to Table 3-11.
- BC sub-CC frames filled with pseudo-random data (FL BC PHY-SDUs) may be optionally used for BER measurements along with Data frames. BC1/2/3 sub-frames use QPSK modulation with r = 1/2 convolutional coding and RS coding/interleaving according to Table 3-10.

Table 4-2: Parameters Defining LDACS1 FL SF Structure

FL SF Structure					
	Parameter	**Interference from LDACS1**		**LDACS1 BER measurement**	
		Range	**Recommended**	**Range**	**Recommended**
Number of BC1 sub-frames per SF	BC1_num	[1]	1	[1]	1
Number of BC2 sub-frames per SF	BC2_num	[1]	1	[1]	1
Number of BC3 sub-frames per SF	BC3_num	[1]	1	[1]	1
Length of CC frame [PHY-PDU] in MF_x	CC_len	{3,6,9,12}	3	{3,6,9,12}	3
Position of CC frame [CC/Data frame Nr. within MF_x]	CC_pos	5	5	5	5
Length of Data frame [PHY-PDU] in MF_x	Data_len	{15,18,21,24}	24	{15,18,21,24}	24
Position of Data frame [CC/Data frame Nr. within MF_x]	Data_pos	{1, 2, 3, …, 9}	{1, 2, 3, …, 9}	{1, 2, 3, …, 9}	{1, 2, 3, …, 9}

The last three parameters (CC_pos, Data_len and Data_pos) are not directly adjustable. CC_pos has a fixed value (5), Data_len depends on CC_len (Data_len = 27 – CC_len) and Data_pos comprises all nine CC/Data frames within an MF except for the fifth one that is occupied by the CC frame.

4.5 GS TX Test Interface

In the normal operation, the GS TX SNDCP functional block would accept network data packets via 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 simplified 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 received and decoded 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 sub-frames 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 sub-frames and CC frames for BER measurements is 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.

This option is only considered as a fall-back for the first one proposed above.

5 Aircraft Station Transmitter

This section comprises specification items that are specific to the prototype implementation of the LDACS1 Airborne Station (AS) TX operating in the A/G mode.

> Deviations from the LDACS1 system specification *[SJU_LD1_1]* that are proposed for more efficient prototyping or any other reason are highlighted.

5.1 AS TX Radio Front-end Characteristics

5.1.1 AS TX Frequency Range and Tuning Step

LDACS1 shall operate as a full duplex system in the 960 – 1164 MHz range [SJU_LD1_1].

Prototype AS TX shall be capable of operating on any channel within the following ranges:

- 985.5 – 1008.5 MHz
- 1048.5 – 1071.5 MHz
- 963.5 – 970.5 MHz
- 1149.5 – 1156.5 MHz

> *Different deployment options have been considered in [SJU_LD1_1]. As none of these options has yet been selected for LDACS1 deployment, the prototype AS TX should support all currently proposed options.*

It shall be possible to tune the AS TX to any channel[6] 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 AS TX channel shall be tuned to the same channel that is selected for the corresponding GS RX.*

5.1.2 AS TX Operating Frequency

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

5.1.3 AS TX Centre Frequency Tolerance

AS TX transmit centre frequency and the symbol clock frequency[7] shall be derived from the same reference oscillator.

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

5.1.4 AS TX Nominal Transmitting Power

The AS TX nominal transmitting power measured at the TX output terminal averaged over any continuous RL transmission that uses all N_u OFDM sub-carriers shall be +42 dBm.

> *This setting provides assurance that the prototype AS TX can be built and operated at the representative power level (estimated from the LDACS1 link budget in [SJU_LD1_1] 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.*

---

[6] The channel frequency corresponds to the nominal position of the DC OFDM sub-carrier in the spectrum of the LDACS1 signal.

[7] The same requirement applies to the AS RX centre frequency.

When the AS TX transmits OFDM data symbols with less than N_u sub-carriers, the average per-OFDM symbol transmitting power of an AS TX shall linearly scale with the number of used OFDM sub-carriers.

5.1.5 AS TX Power Dynamic Range

The AS TX shall be able to transmit with declared nominal power level (Section 5.1.4).

Airborne LDACS1 transmitter shall support monotonic AS TX power level reduction below the declared nominal AS TX power within a control range not less than 50 dB.

The smallest TX power adjustment step shall not be greater than 1 dB.

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

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

> *For an early AS TX prototype, there is no requirement for implementing the AS TX "in the loop" power regulation. However, AS TX power should be adjustable within 50 dB range, in order to check the impact of reduced power upon AS TX spectral content.*

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

> *During the laboratory measurements, the required power level of an interfering LDACS1 AS TX signal will be adjusted via variable attenuators rather than via changing the TX operating point.*

5.1.6 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), the following shall apply:

- Absolute power difference between adjacent sub-carriers: ≤ 0.1 dB ("n_{B_RL}" dB allowance should be added for pilot sub-carriers in case pilots are boosted by "n_{B_RL}" dB).
- Deviation of average power on each sub-carrier (Figure 5-1) 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 total average GS transmitted power (excluding the sub-carriers intentionally power-boosted or suppressed).

All above requirements apply to the RF output connector of the equipment.

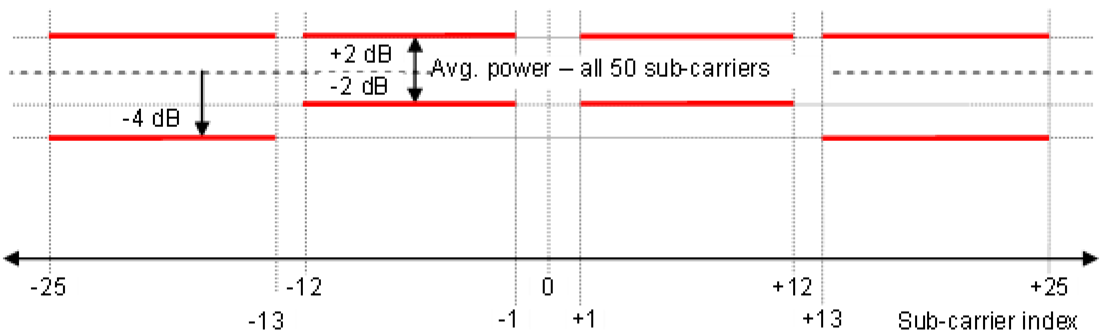

Figure 5-1: AS TX Spectral Flatness

The boosting level n_{B_RL} shall be adjustable (Section 3.7.1).

5.1.7 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

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

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 $\log_{10}$ ($Error_{RMS}$).

5.1.8 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.

Spurious domain starts at an offset $\pm B_{occ}\cdot 2.5$ *from the LDACS1 nominal transmit frequency* f_c. B_{occ} *= 498.05 MHz is the occupied bandwidth of the LDACS1 TX signal, see Section 5.1.10.*

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 aligned 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.

The broadband AS TX noise power density measured across the spurious domain (Figure 5-2) in an active mode at the AS TX output terminated in a matched impedance load shall not exceed -133 dBc/Hz.

A more stringent value may be required at larger frequency offsets to protect non-aeronautical systems operating below 960 MHz. Additional spurious and broadband noise attenuation can be achieved via airborne duplexer, but as none of the possible options has yet been selected for LDACS1 deployment, the duplexer is considered not to be available in the laboratory. Therefore, when testing the laboratory LDACS1 airborne TX, it is proposed using RF band-pass filters instead of a duplexer. The target broadband noise power density, including such RF post-filtering, should be -145 dBc/Hz or less at a frequency offset $\Delta f \geq 4.0$ *MHz measured from the edge of the LDACS1 AS TX transmission range.*

5.1.9 AS TX Spectrum Mask

The spectral density of the GS TX transmitted LDACS1 signal within the OOB domain shall fall within the spectral mask shown in Figure 5-2 and Table 5-1.

The measurements shall be made using 10 kHz resolution bandwidth and 30 kHz video bandwidth. The 0 dBr level is the average LDACS1 TX in-band power density.

> *The values in Figure 5-2 are not to scale. The "Δf" axis is linear and the "Att" axis is logarithmic.*
>
> *The point "A" represents the half of the occupied bandwidth (Section 5.1.10).*
>
> *The range of ±1.245 MHz around the TX operating frequency fc is defined as Out-Of-Band (OOB) range. The OOB domain boundary (1.245 MHz) is given in Figure 5-2 and Table 5-1. The boundary has been calculated based on the occupied bandwidth of the LDACS1 signal-in-space B_{occ} = 498.05 MHz using the ITU-R definition for the start of the spurious domain [f_c-B_{occ}·2.5 … f_c+B_{occ}·2.5] that was also used for the UAT system [UAT_M].*

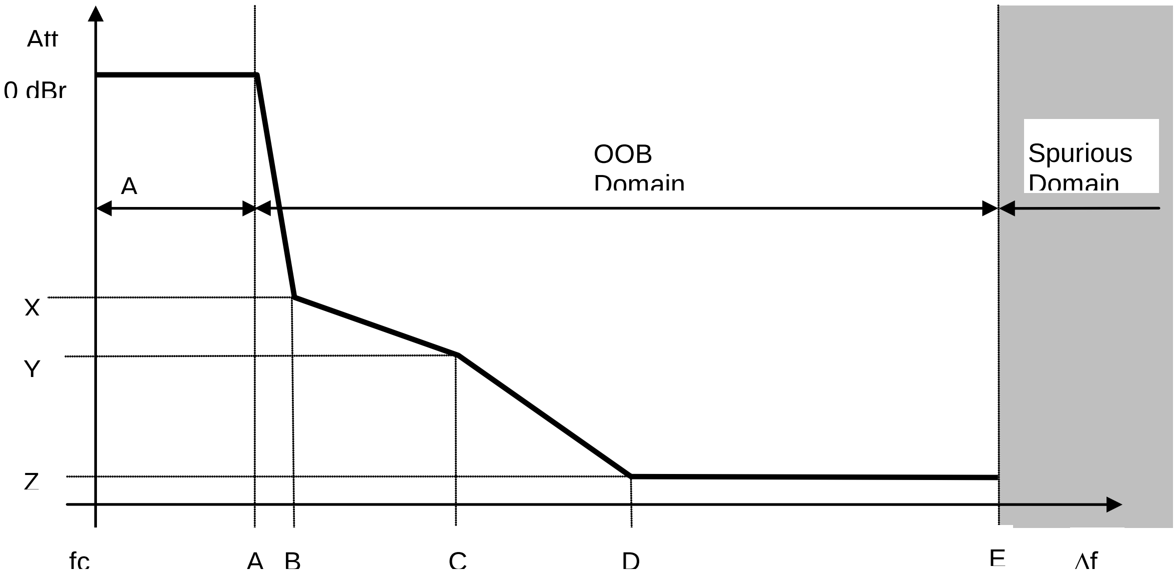

Figure 5-2: AS TX Spectral Mask

Table 5-1: AS TX Spectral Mask

	A = B_{occ}/2	**B = 1.35·A**	**C = 2.5·A**	**D = 3.1·A**	**E= 5·A**	**≥ E**
Δf (kHz)	250	337.5	625	775	1.245	≥ 1.245
Att (dBr)	0	X = 40	Y = 56	Z = 76	Z = 76	<spurs>

5.1.10 AS TX Occupied Bandwidth

If all 50 sub-carriers are used, more than 96% of AS TX signal spectrum power shall lie within the nominal bandwidth B_{occ} = 498.05 kHz.

5.1.11 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 3.7.5). Therefore, the ramp-up/ramp-down time roughly corresponds to the window time T_W (12.8 µs) as defined in Section 3.4.1.

The RF RL burst duration is variable. The minimum RF burst duration corresponds to the length of a single synchronisation tile sent in the DC segment. Otherwise, dependent on the type of the RL transmission, the burst duration is determined by the duration of the RL RA frame, duration of the DC tile or the number/total duration of successive (in time) Data tiles allocated to that AS.

5.2 AS TX Baseband Characteristics

5.2.1 AS TX Symbol Clock Frequency Tolerance

AS TX transmit centre frequency and the symbol clock frequency[8] shall be derived from the same reference oscillator.

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

5.2.2 AS TX Timing

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

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

5.3 AS TX PHY Layer Characteristics

AS TX PHY layer shall be implemented as specified in Section 3, except for the highlighted items indicated below.

> *The laboratory GS TX prototype implements only parts of the PHY layer functionality specified in [SJU_LD1_1].*

5.3.1 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 ($N_u = 50$ 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 in OFDM symbols carrying data (Section 3.5.2.3).

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

5.3.2 Framing

AS TX RL framing shall be implemented as specified in Section 3.5.3.2.

The internal structure of RL RA frames, synchronisation tiles, DC segments and Data segments (including the AGC preambles, synchronisation sequences and pilot tones) shall be implemented as specified in Sections 3.5.2 and 3.5.3.2.

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

> *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”. As no full duplex will be implemented in laboratory prototype LDACS1 equipment, no interaction between an AS RX and AS TX will be possible. For the prototype AS TX it is therefore not required that its SFs should be “sufficiently” aligned with the GS RX SFs prior to the RL transmission attempt. The AS TX would be not aware of GS TX SF boundaries and must apply its local timing when creating RL SFs.*

[8] The requirement also applies to AS RX centre frequency and symbol clock frequency when no in-the-loop mechanisms are available.

The prototype AS TX shall generate a configurable number of RA frames, synchronisation tiles, DC tiles and Data tiles per SF. Parameters related to the number and positions of RA frames, synchronisation tiles, DC tiles and Data tiles (blocks) within a RL SF are provided in Section 5.4.

5.3.3 Coding

AS TX RL coding shall be implemented as specified in Sections 3.6.2 and 3.6.2.6.

Modulation schemes, channel coding parameters and block sizes from Table 3-14 and Table 3-15 shall apply to RL Data tiles transmitted by the prototype AS TX.

5.3.4 Modulation

AS TX RL modulation shall be implemented as specified in Section 3.6.3.

Gray-mapped QPSK as shown in Figure 3-19 shall be supported by the AS TX prototype.

Other modulation types need not to be supported by the AS TX prototype.

5.3.5 Data Mapping

AS TX RL data mapping shall be implemented as specified in Section 3.6.4.2.

5.3.6 Pilot Sequences

AS TX RL pilot sequences shall be implemented as specified in Sections 3.5.2 and 3.7.1.

AS TX shall allow for transmitting pilot tones boosted by n_{B_RL} = 0 …+4 dB relative to other modulated symbols.

The parameter "n_{B_RL}" that defines the AS TX boosting level shall be configurable via an application-specific interface.

5.3.7 Synchronisation Sequences

AS TX RL synchronisation sequences shall be implemented as specified in Sections 3.5.2 and 3.7.3.

5.3.8 TX Windowing

AS TX windowing shall be implemented as specified in Section 3.7.5.

5.3.9 AGC Preamble

AS TX RL AGC preambles shall be implemented as specified in Sections 3.5.2 and 3.7.4.

5.4 AS TX Protocol Characteristics

A detailed specification for the LDACS1 protocol entities above the PHY layer is provided in [SJU_LD1_1].

For laboratory testing purposes, the full-size MAC sub-layer described in [SJU_LD1_1] can be replaced by a reduced functionality which regulates the segmentation and packaging of a continuous data stream received via an external interface. The service primitives specified in Section 6 of [SJU_LD1_1] should be seen as guidance, but their implementation is not mandatory for the laboratory prototype LDACS1 equipment.

The pseudo-random data to be transmitted in the RL PHY-PDUs are expected to be generated by an external data 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-SDUs that can be directly mapped onto the AS TX RL frames (Section 3.6.4.2). The size and number of the RL PHY-SDUs corresponds to the capacity of the different types of frames and complies with the defined SF timing (Section 3.6.2.5).

As a part of the layer interaction, additional signalling information is locally exchanged between the PHY and the MAC sub-layer, but is not transmitted from LDACS1 TX to RX.

In the prototype AS TX implementation, multiple PHY parameters that would be normally set via MAC sub-layer can be configured directly at the PHY layer, according to Table 5-2. This table covers two different sets of parameters, one for assessing the LDACS1 TX impact onto receivers of other systems, another one for assessing the LDACS1 GS RX performance (BER) under presence of external L-band interference. These settings must be provided (a priori known) to the GS RX in order to properly emulate the impact of control messages and to enable proper data detection and decoding.

According to the setting of parameters in Table 5-2, simple MAC sub-layer provides the AS TX PHY layer with RL PHY-SDUs, i.e. RL RA PHY-SDUs, RL DC PHY-SDUs or RL Data PHY-SDUs. The size of the RL PHY-SDUs corresponds to the capacity of the different types of frames and tiles. With respect to Table 5-2 the following remarks apply:

Interference from LDACS1 AS TX

In this case a realistic TX power and duty cycle is crucial, but the exact data content of the transmitted information is less relevant.

The contribution of RA frames, synchronisation tiles, AGC sequences and DC tiles to the total LDACS1 AS TX duty-cycle is limited (can be estimated).

- *RA frames are sent only when the AS contacts the GS for the first time and after handover Type 1. RA frame cannot be sent in the same SF where synchronisation tile has been sent and vice versa. If sent, an RA frame contributes to the SF duty-cycle by 0.35%.*
- *Synchronisation tiles are sent only when the AS contacts the GS after handover Type 2. If sent, a synchronisation tile contributes to the SF duty-cycle by 0.25%.*
- *AGC sequence is sent only by the AS that has been assigned the first DC tile in the DC segment. If sent, an AGC sequence contributes to the SF duty-cycle by 0.05%.*
- *DC tile is sent by each AS, but only one DC tile is sent per SF. The DC tiles contribute to the overall SF duty-cycle by 0.3%.*
- *The upper limit for the DC caused by RA frames, synchronisation tiles, AGC sequences and DC tiles is 0.6%. This figure would be valid only over a single SF where the synchronisation tile has been sent along with the DC tile. The same contribution to the SF duty-cycle would be generated by increasing the block size of Data tiles by 4 Data tiles.*
- *In all cases where the duty-cycle is calculated over more than one SF the realistic duty-cycle value (obtained without synchronisation tile) is 0.35 %. The comparable duty-cycle contribution (0.3 %) would be generated by omitting system-related transmissions and increasing the block size of Data tiles by 2 Data tiles.*

Therefore, RA frames, synchronisation tiles, AGC sequences and DC tiles can be completely omitted when assessing the LDACS1 AS TX impact upon other L-band systems. The comparable duty-cycle contribution (0.6% in the worst-case) can be generated by increasing the block size of Data tiles by 4 Data tiles.

Block length increase by 6 OFDM symbols (0.72 ms) corresponds to the per-SF duty-cycle increase of 0.3%.

Therefore, for interference measurements the following considerations apply:

- RL SF structure is used as described in Section 3.5.3.2
- RL transmissions are discontinuous, with adjustable duty-cycle

- LDACS1 AS TX duty-cycle for contiguous blocks of Data tiles is adjustable via two parameters: LD_mf and ND (Table 5-2). LD_mf describes the length of the contiguous transmission in each applicable MF, while ND describes the number of MFs to which such LD_mf applies.
- LD_mf should be increased for four tiles to compensate for omitted RL components (RA rames, synchronisation tiles, AGC sequences and DC tiles).
- Once adjusted, duty-cycle shall be maintained over a number of SFs used for interference measurements.
- RL Data tiles shall be implemented as described in Section 3.5.2.1 and filled with pseudo-random data (RL Data PHY-SDUs).

  The detailed data content of DC tiles is irrelevant for AS TX spectrum measurements (as long as these data are pseudo-random allowing for realistic PAPR values), therefore coding in DC tiles can be switched off.
- Boosting of pilot tones shall be configurable and enabled for testing purposes, i.e. the boosting level parameter can be set between 0 dB and 4 dB above the average power of each data symbol.

Total per-SF duty-cycle due to Data tiles can be calculated (ND * LD_mf). By combining ND and LD_mf, any RL duty-cycle between 0.3 % and 4 * 23.7 = 94.8 % can be adjusted. Same duty-cycle can be derived by different combinations of ND and LD_mf, e.g. duty-cycle of 2.4 % can be obtained by (ND=1, LD_mf=16) and (ND=4, LD_mf=4).This allows for testing the victim receiver sensitivity against internal structure of RL SF while maintaining the constant duty-cycle.

The worst-case duty-can be selected, imposing limits to both the duration of the single LDACS1 AS TX transmission (LD_mf) and the internal distribution of such transmissions within the SF (ND).

GS RX BER Measurements

In this case a realistic AS TX duty cycle is less relevant than the proper encoding of the transmitted information (restricted to RL PHY-SDUs over which the BER measurement is conducted). For GS RX BER measurements without “in-the-loop” mechanisms, where a large amount of transmitted data is required for high statistical reliability, a reasonable synchronisation maintenance procedure is additionally required. Therefore, for BER measurements the following considerations apply:

- RL SF structure is used as described in Section 3.5.3.2
- RL transmissions are discontinuous, with adjustable duty-cycle
- LD_mf (Table 5-2) should be set to the maximum value (158 tiles) and ND should be set to 4 (transmissions in all four MFs). This would provide the maximum capacity for transmitting RL data, reducing the time required for BER measurements.
- Once adjusted, the duty-cycle shall be maintained over a number of SFs used for BER measurements.
- RL Data tiles shall be implemented as described in Sections 3.5.2.1 and 3.6.2.6 and filled with pseudo-random data (RL Data PHY-SDUs). Coding parameters are provided in Table 3-12.
- Boosting of pilot tones shall be configurable and enabled for testing purposes, i.e. the boosting level parameter can be set between 0 dB and 4 dB above the average power of each data symbol.
- One RA frame should be generated in each SF, filled with the pseudo-random content, in the fixed opportunity, for regular stimulation of the GS RX AGC, frequency- and time synchronisation. RA frames use QPSK modulation with r = 1/2 convolutional coding and RS coding/interleaving according to Table 3-13. However, the data content of RA frames is irrelevant for BER measurements.
- Synchronisation tiles should be generated in each MF, for regular stimulation of the GS RX AGC, frequency- and time synchronisation.

- AGC sequences should be generated in each MF, for regular stimulation of the GS RX AGC.
- DC tiles are not required for BER measurements and should not be transmitted.

Table 5-2: Parameters Defining LDACS1 RL Super Frame Structure

RL SF Structure (Single AS)					
	Parameter	Interference from LDACS1		LDACS1 BER measurement	
		Range	Recommended	Range	Recommended
Number of sent RA frames per SF	RA_num	{0, 1}	0	{0, 1}	1
Position of sent RA frame (RA opportunity)	RA_pos	{1, 2}	N/A	{1, 2}	1
Number of sent synchronisation tiles per SF	SYN_num	{0, 1, 2, 3, 4}	0	{0, 1, 2, 3, 4}	4
Position(s) of sent synchronisation tiles (MF number(s) within SF)	SYN_pos	{1, 2, 3, 4}	N/A	{1, 2, 3, 4}	1, 2, 3, 4
Number of sent AGC sequences in DC segments per SF	AGC_num	{0, 1, 2, 3, 4}	0	{0, 1, 2, 3, 4}	4
Position(s) of sent AGC sequences (MF number(s) within SF)	AGC_pos	{1, 2, 3, 4}	N/A	{1, 2, 3, 4}	1, 2, 3, 4
Number of sent DC tiles per SF	DC_num	{0, 1}	0	{0, 1}	0
Position of sent DC tiles (MF number within SF)	DC_pos	{1, 2, 3, 4}	N/A	{1, 2, 3, 4}	N/A
DC tile offset from the beginning of the MF DC segment (in OFDM symbols)	DC_off	[6…156]	6	[6…156]	6
Length of the DC segment (in OFDM symbols)	DCS_len	[12…162]	12	[12…162]	12
Data segment offset from the MF begin (in OFDM symbols)	DS_off	[12…162]	12	[12…162]	12
Offset of Data tile block from the beginning of the MF Data segment (in tiles)	DT_off	[0…157]	0	[0…157]	0
Length of contiguous block of Data tiles within the MF (in tiles)	LD_mf	[1…158]	variable, 1…158	[1…158]	158
Adjustment step for LD_mf (in tiles)	LD_s	1	1	1	1
Number of MFs per SF containing identical blocks of Data tiles	ND	{1, 2, 3, 4}	variable, 1…4	{1, 2, 3, 4}	4

5.5 AS TX Test Interface

In normal operation, the AS TX SNDCP functional block would accept IP network data packets via 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 simplified test interface would be sufficient 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 tiles content of an entire SF.

Alternatively, BER measurements can be performed at the RX, if no external test source would be 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 via an external interface.

This option is only considered as a fall-back for the first one that would use an external BER evaluation tool.

6 Ground Station Receiver

This section comprises items that are specific to the prototype implementation of the LDACS1 GS RX operating in the A/G mode.

> *Deviations from the LDACS1 system specification [SJU_LD1_1] that are proposed for more efficient* prototyping or any other reason are highlighted.

6.1 GS RX Radio Front-end Characteristics

6.1.1 GS RX Frequency Range and Tuning Step

LDACS1 shall operate as a full duplex system in the 960 – 1164 MHz range [SJU_LD1_1].

Prototype GS RX shall be capable of operating on any channel within the following ranges:[9]

- 985.5 – 1008.5 MHz
- 1048.5 – 1071.5 MHz
- 963.5 – 970.5 MHz
- 1149.5 – 1156.5 MHz

> *Different deployment options have been considered in [SJU_LD1_1]. As none of these options has yet been selected for the LDACS1 deployment, the prototype GS RX should support all currently proposed options.*

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.

> *During the laboratory trials, the channel of the prototype GS RX shall be tuned to the same channel that is selected for the corresponding AS TX.*

6.1.2 GS RX Centre Frequency Tolerance

Both the GS RX centre frequency and the symbol clock frequency[10] shall be derived from the same reference oscillator.

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

6.1.3 GS RX Available Bandwidth

GS RX shall be able to receive AS TX signal with the occupied bandwidth B_{occ} = 498.05 kHz (Section 5.1.10).

6.1.4 GS RX Maximum Tolerable Input Signal Power

The GS RX shall tolerate directly 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 7.1.4).*

> *For the prototype GS RX implementation, usage of an external RF BP filter between the GS antenna and the GS RX input is recommended. That RF filter would span the GS RX reception range. External RF filter would reduce the interference levels at the*

[9] The channel frequency corresponds to the nominal position of the DC OFDM sub-carrier in the spectrum of the LDACS1 signal.

[10] The requirement also applies to GS TX centre frequency and symbol clock frequency.

RX input. However, the above requirement remains valid regardless whether the RF filter is used, or not.

6.1.5 GS RX Maximum Acceptable Desired Signal Power

The GS RX shall be capable of decoding on-channel desired LDACS1 signal (D) with the peak instantaneous power of –10 dBm (measured at the RX input).

An AS TX on the ground operating with +42 dBm average AS TX power at 100 m distance to the GS antenna would produce -28.5 dBm average power at the GS RX input, assuming 0 dBi gain airborne antenna, 3.5 dB airborne cable and duplexer losses, free-space propagation, 8 dBi ground antenna gain and 2 dB ground cable losses, Assuming 17 dB provision for TX PAPR[11], the peak received LDACS1 signal power becomes -11.5 dBm (rounded-up to -10 dBm).

6.1.6 GS RX Automatic Gain Control (AGC)

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

The GS RX AGC shall be available/updated during reception of RL RA frames.

The GS RX AGC shall be available/updated during reception of RL synchronisation tiles.

The GS RX AGC shall be available/updated during reception of RL DC segments.

The detailed method to be applied for the GS RX AGC is implementation specific.

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

6.1.7 GS RX Interference Mitigation

Details of these techniques are considered to be an implementation issue.

The GS RX interference mitigation mechanisms shall be configurable such that a particular method can be separately switched on or off.

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

If implemented, 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 RF gain (controlled by the AGC) prior to blanking should be re-established after the interference that caused blanking disappeared.

If blanking is implemented, the blanking status shall be made available to the GS RX baseband unit via an implementation-specific interface.

6.2 GS RX Baseband Characteristics

6.2.1 GS RX Reference Bit Error Rate

GS RX reference corrected BER (after FEC) shall be less than 10^{-6}.

[11] In 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 (Section 3.7.2).

Prototype GS RX shall implement a test interface for measuring the corrected BER or do the BER measurement internally to the RX.

If the prototype GS RX itself measures BER, the measured BER value shall be made available via an implementation-specific interface.

6.2.2 GS RX Sensitivity

When using all RL sub-carriers ($N_{used} = N_u$) with QPSK modulation, convolutional coding with $r_{cc} = ½$, interleaving over 6 tiles and Reed-Solomon RS (98, 84, 6) coding in RL data segments, the ground LDACS1 RX shall fulfil the reference BER requirement (Section 6.2.1) when operating at the level S0 ≤ -102.83 dBm[12].The requirement shall be fulfilled when the desired airborne TX signal is produced with the maximum tolerable frequency offset on RL (see Sections 5.1.2 and 6.1.2) and is simultaneously subject to the maximum Doppler shift relative to the GS (1.7 kHz at 850 knots and 1156.5 MHz).

The receiver sensitivity shall be measured as follows:

- *Using the defined standardized message packet formats (Section 5.4)*
- *Using an AWGN channel (no interference)*
- *Using a specified RL channel (RL data transmission with Data tiles where AS uses full RL bandwidth)*

The 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 ground receiver noise figure NF = 5 dB, both referenced to the antenna port. The sensitivity figure S0 may have to be further fine adjusted.

When the AS TX is on RL using $N_{used} < N_u$ sub-carriers, the correction factor of $10 \cdot \log_{10}(N_{used}/N_u)$ shall be added to the above sensitivity figure that was obtained with all sub-carriers (N_u).

6.2.3 GS RX Operating Point

The LDACS1 GS RX shall fulfil the BER specified in Section 6.2.1 when the signal S1[13] as defined in Table 6-1 or greater is present at the RX input. The LDACS1 AS TX shall use RL Data tiles that span the full RL bandwidth/use all RL sub-carriers ($N_{used} = N_u$), with QPSK modulation, convolutional coding with $r_{cc} = ½$, interleaving over 6 tiles and Reed-Solomon RS (98, 84, 6) coding,

Table 6-1: GS RX Operating Point S1

Parameter	Unit	ENR	TMA	APT
TX-RX distance (d)	nm	120	40	10
RX sensitivity @ interference (S0)	dBm	-101.03	-101.03	-93.43
RX operating point (S1)	dBm	-95.83	-95.03	-87.43

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), considering an appropriate aeronautical channel and applicable banking margin.

[12] The S0 value has been derived from the LDACS1 link budget in [SJU_LD1_1], Appendix A - LDACS1 Link Budget for the case without interference, considering ENR environment and including the effects of the mobile channel.

[13] The S1 value has been derived from the LDACS1 link budget in [SJU_LD1_1], Appendix A - LDACS1 Link Budget and may have to be further adjusted.

6.2.4 GS RX Interference Immunity Performance

The required interference immunity performance cannot be stated based on the currently available LDACS1 parameters. Instead, it should be measured in the laboratory on LDACS GS RX prototype.

6.2.5 GS RX to AS TX Frequency Synchronisation

The GS RX frequency capture range shall be sufficient for accommodating both imperfect AS TX - GS RX reference frequency accuracy (Sections 5.1.2 and 6.1.2) and the maximum applicable GS - AS Doppler shift (1.7 kHz at 850 knots and 1156.5 MHz).

The GS RX shall be able to synchronise (in frequency) to the AS TX during reception of RL RA frames (Section 3.5.2.3).

For the optimum tracking performance at the GS RX, it is essential that the AS TX provides a sufficient number (more than it would produce under normal operating conditions) of RA frames and synchronisation tiles carrying synchronisation symbol pairs within the SF (Section 5.4).

The GS RX shall be able to synchronise (in frequency) to the AS TX during reception of RL synchronisation tiles.

After having been regularly stimulated via an RL RA frames and synchronisation tiles, the prototype GS RX shall acquire and maintain frequency synchronisation on RL within the tolerance that is sufficient for satisfactory reception of Data segments on the RL for BER measurements (sensitivity requirement, as specified in Section 6.2.2).

Some guidance about the required performance can be derived from [SJU_LD1_1] Section 5.4.2, where the deviation between the AS TX centre frequency – as seen by the GS RX - and the GS RX nominal centre frequency shall be less than 2% of the sub-carrier spacing (less than 195 Hz) after having applied in-the-loop frequency regulation. Considering that an in-the-loop mechanism is not available, the same value (195 Hz) may be roughly attributed to the residual frequency error after the frequency synchronisation on the RL.

It should be possible to assess the frequency synchronisation performance on the RL via an implementation-specific interface.

6.2.6 GS RX to AS TX Time Synchronisation

The GS RX shall be able to synchronise (in time) to the AS TX during reception of RL RA frames.

For the optimum tracking performance at the GS RX, it is essential that the AS TX provides a sufficient number (more than it would produce under normal operating conditions) of RA frames and synchronisation tiles carrying synchronisation symbol pairs within the SF (Section 5.4).

The prototype GS RX shall be able to accept RL RA frames regardless of the AS TX SF relative offset to the initial GS RX local SF boundary.

As there are no in-the-loop mechanisms available for LDACS1 prototype equipment, the AS TX SF framing will be at an unpredictable offset relative to the GS RX SF framing.

The GS RX shall be able to synchronise (in time) to the AS TX during reception of RL synchronisation tiles.

GS RX should be able to re-synchronise (re-adjust its local SF timing), based on received synchronisation tiles the similar way as it would do when receiving RL RA frames.

The prototype GS RX shall be able to maintain the time synchronisation to the AS TX during reception of RL DC segments.

After having been regularly stimulated via an RL RA frames and synchronisation tiles, the prototype GS RX shall acquire and maintain time synchronisation on RL within the tolerance that is sufficient for satisfactory reception of Data segments on the RL for BER measurements (sensitivity requirement, as specified in Section 6.2.2).

Some guidance about the required performance can be derived from [SJU_LD1_1] Section 5.4.3, where it is required that, after having applied in-the-loop time regulation, all non-RA RL OFDMA symbols arrive at the GS time-coincident with the local GS SF timing to an accuracy of ± 1/3 · T_g or better (T_g = 4.8 µs is the OFDM guard time). Considering that in-the-loop mechanism is not available, the same value (± 1/3 · T_g = 1.6 µs) may be roughly attributed to the residual allowed timing error after the time synchronisation on RL.

It should be possible to assess the time synchronisation performance on RL via an implementation-specific interface.

6.2.7 Channel Estimation

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

6.2.8 Equalisation

The specific method for channel equalisation is implementation-specific.

6.3 GS RX PHY Layer Characteristics

GS RX PHY layer shall be implemented as specified in Section 3, except for the items indicated below.

In the laboratory GS RX prototype, only parts of the PHY layer functionality specified in [SJU_LD1_1] have to be implemented.

6.3.1 Framing

GS RX shall respect the AS TX RL framing implemented as specified in Sections 3.5.3.2 and 5.3.2.

The internal structure of RL SF (including the AGC preambles, synchronisation sequences and pilot tones) shall be implemented by the AS TX as specified in Sections 3.5.2 and 3.5.3.2. Parameters related to the number and positions of RA frames, synchronisation tiles, DC tiles and Data tiles (blocks) within a RL SF are provided in Section 5.4. Different sets of parameters may be be used for the case where the AS TX interference impact upon other L-band systems is investigated and the case where GS RX susceptibility to interference is investigated.

6.3.2 Decoding

GS RX RL decoding shall be implemented as specified in Sections 3.6.2 and 3.6.2.6.

Modulation schemes, channel coding parameters and block sizes from Table 3-14 and Table 3-15 shall apply to RL Data tiles transmitted by the prototype AS TX and received by the GS RX.

6.3.3 Demodulation

GS RX RL demodulation shall be implemented as specified in Section 3.6.3.

At least, gray-mapped QPSK as shown in Figure 3-19 shall be supported by the GS RX prototype.

6.3.4 Data De-mapping

GS RX RL data de-mapping shall be implemented as specified in Section 3.6.4.2.

6.3.5 Windowing

GS RX shall implement the procedure that is reverse to the TX windowing. The procedure shall be implemented as specified in Section 3.7.5.

6.4 GS RX Protocol Characteristics

Detailed specification for LDACS1 protocol entities above PHY layer is provided in [SJU_LD1_1].

For laboratory testing purposes, not all features of the MAC sub-layer described in [SJU_LD1_1] have to be implemented. The service primitives specified in Section 6 of [SJU_LD1_1] should be seen as guidance, but their implementation is not mandatory for the laboratory prototype LDACS1 equipment.

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-SDUs 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 5-2).

6.5 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, simplified test interface would be 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 Data segment (Section 3.6.4.2). 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 calculate the BER and provide the result on the implementation-specific 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.

7 Aircraft Station Receiver

This section comprises items that are specific to the prototype implementation of the LDACS1 AS RX operating in the A/G mode.

Deviations from the LDACS1 system specification [SJU_LD1_1] that are proposed for more efficient prototyping or any other reason are highlighted.

7.1 AS RX Radio Front-end Characteristics

7.1.1 AS RX Frequency Range and Tuning Step

LDACS1 shall operate as a full duplex system in the 960 – 1164 MHz range [SJU_LD1_1].

Prototype AS RX shall be capable of operating on any channel[14] within the following ranges:

- 985.5 – 1008.5 MHz
- 1048.5 – 1071.5 MHz
- 963.5 – 970.5 MHz
- 1149.5 – 1156.5 MHz

Different deployment options have been considered in [SJU_LD1_1]. As none of these options has yet been selected for the LDACS1 deployment, the prototype AS RX should support all currently proposed options.

It shall be possible to tune the AS RX 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 AS RX channel shall be tuned to the same channel that is selected for the corresponding GS TX.

7.1.2 AS RX Centre Frequency Tolerance

As RX centre frequency and the symbol clock frequency[15] shall be derived from the same reference oscillator.

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

7.1.3 AS RX Available Bandwidth

AS RX shall be able to receive GS TX signal with the occupied bandwidth B_{occ} = 498.05 kHz (Section 4.1.10).

7.1.4 AS RX Maximum Tolerable Input Signal Power

The AS RX shall tolerate directly at its input a pulsed interference signal with peak power of up to +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 LDACS1 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 LDACS1 RX input becomes +21.5 dBm. Additional 3.5 dB margin have been added to that value.

[14] The channel frequency corresponds to the nominal position of the DC OFDM sub-carrier in the spectrum of the LDACS1 signal.

[15] The requirement also applies to AS TX centre frequency when no in-the-loop mechanisms are available.

For the prototype AS RX implementation, the usage of an external RF BP filter between the AS antenna and the AS RX input is recommended that spans the AS RX reception range emulating the duplexer selectivity. External RF filter would reduce the interference levels at the RX input. However, the above requirement remains valid regardless whether the RF filter is used or not.

7.1.5 AS RX Maximum Acceptable Desired Signal Power

The AS RX shall be capable of decoding on-channel desired LDACS1 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 -29.5 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, 3.5 dB airborne cable and duplexer losses as well as an 0 dBi gain airborne antenna. Assuming 17 dB provision for TX PAPR[16], the peak received LDACS1 signal power becomes -12.5 dBm (rounded-up to -10 dBm).

7.1.6 AS RX Automatic Gain Control (AGC)

The AS RX shall implement 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.

Detailed method for AS RX AGC is an implementation issue.

The AS RX AGC should be permanently available and active during reception of FL frames from the controlling GS.

7.1.7 AS RX Interference Mitigation

Details of these techniques are considered to be implementation-dependent.

The AS RX interference mitigation mechanisms shall be configurable such that a particular method can be separately switched on or off, to allow for separate pre-testing the performance of each proposed method and define the optimum operating configuration prior to the laboratory interference tests.

Prototype AS RX shall implement an autonomous interference blanking mechanism (that works without airborne 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 (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 AS 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 RF gain (controlled by the AGC) prior to blanking should be re-established after the interference that caused blanking disappeared.

If blanking is implemented, the blanking status shall be made available to the AS RX baseband over an implementation-specific interface.

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

For the prototype testing, it is recommended using an external RF BP filter between the AS antenna and the AS RX input that would span the AS RX reception range emulating the selectivity of an airborne duplexer.

7.1.8 AS RX Interface to Common Suppression Bus

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

This non-mandatory requirement would allow for testing the usability of the suppression bus, if available in the laboratory. In this case, the suppression bus could be used instead of or in addition to an autonomous blanking mechanism.

7.1.9 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 ≤ 5 ms referred to the moment when the switching command has been given.

This requirement shall be verified via an implementation-specific interface.

The requirement has been relaxed relative to the original [SJU_LD1_1] requirement (0.5 ms) in order to ease the implementation of prototypes, bearing in mind that the switching time is not really relevant for spectral compatibility investigations (the synthesiser will be internally muted during the frequency transient).

7.2 AS RX Baseband Characteristics

7.2.1 AS RX Target Bit Error Rate

AS RX reference corrected BER (after FEC) shall be less than 10^{-6}.

Prototype AS RX shall provide a test interface for measuring the corrected BER or perform the BER measurement internally to the RX.

If the prototype AS RX itself measures the BER, the measured BER value shall be made available over an implementation-specific interface.

7.2.2 AS RX Sensitivity

When GS is using all FL sub-carriers ($N_{used} = N_u$) with QPSK modulation, convolutional coding with r_{cc} = ½, interleaving over 8 FL data frames and Reed-Solomon RS (101,91,5) coding in FL data frames, the airborne LDACS1 RX shall fulfil the reference BER requirement Section 7.2.1 when operating at the level S0 ≤ -104.13 dBm[17]. The requirement shall be fulfilled assuming the maximum GS TX – AS RX frequency offset as well as maximum AS Doppler shift relative to the GS (1.7 kHz at 850 knots and 1156.5 MHz).

The receiver sensitivity shall be measured as follows:

- *Using the defined standardized message packet formats (Section 4.4)*
- *Using an AWGN channel (no interference)*
- *Using a specified RL channel (FL data transmission in CC/Data frames)*

[17] The S0 value has been derived from the LDACS1 link budget in [SJU_LD1_1], Appendix A - LDACS1 Link Budget, for the case without interference, considering ENR environment and including the effects of the mobile channel.

7.2.3 AS RX Operating Point

When using all FL sub-carriers ($N_{used} = N_u$) with QPSK modulation, convolutional coding with r_{cc} = ½,interleaving over 8 FL data frames and Reed-Solomon RS (101,91,5) coding in FL CC/Data frames, the airborne LDACS1 RX shall fulfil the BER specified under Section 7.2.1 when the signal S1[18] as defined in Table 7-1 is present at the RX input.

BC1 and BC2 sub-frames may also be optionally used for this measurement, with coding parameters as specified in Table 3-10.

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 7-1: AS RX Operating Point S1

Parameter	Unit	ENR	TMA	APT
TX-RX distance	nm	120	40	10
RX sensitivity @ interference	dBm	-101.93	-101.43	-98.73
RX operating point	dBm	-95.93	-95.43	-92.73

7.2.4 AS RX Interference Immunity Performance

The required interference immunity performance cannot be stated based on the currently available LDACS1 parameters. Instead, it should be measured in the laboratory on LDACS GS RX prototype.

7.2.5 AS RX to GS TX Frequency Synchronisation

AS RX shall acquire and maintain frequency synchronisation on the FL within the tolerance that is sufficient for fulfilling the sensitivity requirement, as specified in Section 7.2.2.

Detailed method for AS RX frequency synchronisation is an implementation issue.

The tolerance for the FL synchronisation performance cannot/needs not to be exactly specified – it will be indirectly confirmed via AS RX sensitivity check (like AGC, synchronisation is just an enabler for the normal operation of the AS RX). A guidance can be derived from [SJU_LD1_1] Section 5.4.2, where the deviation between the AS TX centre frequency – as seen by the GS RX - and the GS RX nominal centre frequency shall be less than 2% of the sub-carrier spacing (less than 195 Hz). A half of this total value (98 Hz) may be roughly attributed to the residual frequency error after the frequency synchronisation on FL.

The AS RX frequency capture range shall be sufficient for accommodating both imperfect GS TX – AS RX reference frequency accuracy (see Section 4.1.2 and Section 7.1.2) and the maximum applicable GS TX – AS RX Doppler shift (1.7 kHz at 850 knots and 1156.5 MHz).

During normal operation, the AS RX shall track the frequency changes by estimating the FL frequency offset.

The frequency synchronisation acquisition and maintenance should be based on observing the synchronisation symbol pairs that repetitively occur within the FL stream (marking the start of BC1, BC2, BC3, FL Data and FL CC frames).

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[18] The S1 value has been derived from the LDACS1 link budget in [SJU_LD1_1], Appendix A - LDACS1 Link Budget and may have to be further adjusted.

Detailed methods for time/frequency acquisition and tracking are an implementation issue.

The AS RX frequency synchronisation performance on FL should be assessed via an implementation-specific interface.

7.2.6 AS RX to GS TX Time Synchronisation

AS RX shall acquire and maintain time synchronisation on FL within the tolerance that is sufficient for fulfilling the sensitivity requirement, as specified in Section 7.2.2.

Detailed method for AS RX time synchronisation is an implementation issue.

The tolerance for the FL synchronisation performance cannot and needs not to be exactly specified – it will be indirectly confirmed via AS RX sensitivity check (like AGC, synchronisation is just an enabler for the normal operation of the AS RX). Guidance can be derived from [SJU_LD1_1] Section 5.4.3, where the timing deviation between the received AS TX symbols – as seen by the GS RX - and the GS RX local symbol timing shall be ± 1/3 of the OFDM guard time T_g or better. Approximately the same value (± 1/3 · T_g) may be roughly attributed to the residual timing error on FL.

AS RX shall achieve and maintain time synchronisation by continuously monitoring the FL stream of the controlling GS.

The time synchronisation acquisition and maintenance should 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).

Detailed methods for time/frequency acquisition and tracking are an implementation issue.

The AS RX time synchronisation and tracking performance should be assessed via an implementation-specific interface.

7.2.7 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.

7.2.8 Channel Estimation

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

7.2.9 Equalisation

The specific method for channel equalisation is an implementation issue.

7.3 AS RX PHY Layer Characteristics

AS RX PHY layer shall be implemented as specified in Section 3, except for the items indicated below.

In the laboratory AS RX prototype, only parts of the full PHY layer functionality specified in [SJU_LD1_1], have to be implemented.

7.3.1 Framing

AS RX shall respect the GS TX FL framing implemented as specified in Section 3.5.3.1.

The internal structure of FL frames (including the synchronisation sequences and pilot tones) shall be implemented as specified in Sections 3.5.1 and 3.5.1.2.

The AS RX shall assume that 9 FL Data frames and no CC frames were mapped onto each MF.

Transmission of Data PHY-SDUs with random data content is sufficient for laboratory testing at the physical layer. There is no need to distinguish between CC and Data frames. This applies to both tests of interference produced by the LDACS1 TX and testing the BER at the LDACS1 RX.

7.3.2 Decoding

AS RX FL decoding shall be implemented as specified in Sections 3.6.2 and 3.6.2.5.

Modulation schemes, channel coding parameters and block sizes from Table 3-12 shall apply to FL Data frames transmitted by the prototype GS TX and received by the AS RX.

Modulation schemes, channel coding parameters and block sizes from Table 3-10 should apply to BC sub-frames transmitted by the prototype GS TX and received by the AS RX.

7.3.3 Demodulation

AS RX FL demodulation shall be implemented as specified in Section 3.6.3.

Gray-mapped QPSK as shown in Figure 3-19 shall be supported by the AS RX prototype.

Detailed method for the demodulation is an implementation issue.

7.3.4 Data De-mapping

The AS RX FL data de-mapping shall be implemented as specified in Section 3.6.4.1.

7.3.5 Windowing

AS RX shall implement the procedure that is reverse to the TX windowing. The procedure shall be implemented as specified in Section 3.7.5.

7.4 AS RX Protocol Characteristics

Detailed specification for LDACS1 protocol entities above PHY layer is provided in [SJU_LD1_1].

For laboratory testing purposes, the full-size MAC sub-layer described in [SJU_LD1_1] can be replaced by a reduced functionality. The service primitives specified in Section 6 of [SJU_LD1_1] should be seen as guidance, but their implementation is not mandatory for the laboratory prototype LDACS1 equipment.

The pseudo-random data received in the FL PHY-PDUs are expected to feed the BER test equipment that is external to the LDACS1 AS RX prototype. The simple AS RX MAC layer shall support re-assembling of received FL PHY-SDUs 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 FL frames (Section 3.6.2.5) and complies with the defined SF timing.

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 as at the GS TX (see Section 4.4) must be configured in order to properly emulate the impact of control messages and to enable proper data detection and decoding.

7.5 AS RX Test Interface

In the normal operation, the AS RX SNDCP functional block would produce IP packets at the external test interface. The content of 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 simplified test interface would be 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 3.6.2.5). 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 calculate the BER and provide the result on the implementation-specific external interface.

This option is only considered as a fall-back for the first one proposed above.

In the BER measurements, the data that may be optionally transmitted in the BC sub-frames or CC frames shall be evaluated separately or completely neglected.

8 LDACS1 Airborne Duplexer

This section comprises items that are specific to the emulation of the LDACS1 AS RF duplexer.

8.1 Preliminary LDACS1 Deployment Concepts

Detailed deployment concepts are not part of the LDACS1 specification, therefore only an outline is provided here. The final decision about FL/RL channel allocations, also influencing the final duplexer specification, will depend on the outcome of the laboratory tests.

Under these constraints, multiple options for the LDACS1 system deployment are possible:

- The selected system RF bandwidth (0.5 MHz) enables an inlay deployment, where LDACS1 FL/RL channels, separated by the duplex spacing, are placed at 0.5 MHz offset from DME channels.
- LDACS1 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.
- LDACS1 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.

With any deployment option, co-location constraints of an airborne platform apply to an LDACS1 AS. Additionally, fixed L-band channels (978/1030/1090 MHz) must be sufficiently isolated from LDACS1 channels by appropriate guard bands.

LDACS1 is intended to operate as a FDD system in the lower part of the L-band (960-1164 MHz). Currently, three basic options for the LDACS1 deployment within that range are visible (further options may be possible):

- Option proposed in [LDACS1_D3] for laboratory LDACS1 prototyping (inlay, with 1 MHz LDACS1 channel grid). LDACS1 FL channels would be placed in the area 985 -1009 MHz, while the RL channels would be placed in the area 1048 - 1072 MHz.
- Option with reversed frequency blocks for FL and RL as proposed in [LDACS1_D3] for laboratory LDACS1 prototyping (inlay, with 1 MHz LDACS1 channel grid). LDACS1 FL channels would be placed in the area 1048 - 1072 MHz, while the RL channels would be placed in the area 985 -1009 MHz[19].

Alternative options for LDACS1 deployment have been recently proposed (no inlay, with 0.5 MHz LDACS1 channel grid, over areas not heavily occupied by DMEs)[20].

- LDACS1 FL channels would be placed in the area 1150 - 1156 MHz, while the RL channels would be placed in the area 964 - 970 MHz
- LDACS1 FL channels would be placed in the area 964 - 970 MHz, while the RL channels would be placed in the area 1150 - 1156 MHz

These four options are shown in Figure 8-1.

[19] This option has been recently proposed by the JTIDS/MIDS Multi-National Working Group (MNWG).

[20] This proposal has recently been submitted by the DFS Deutsche Flugsicherung GmbH.

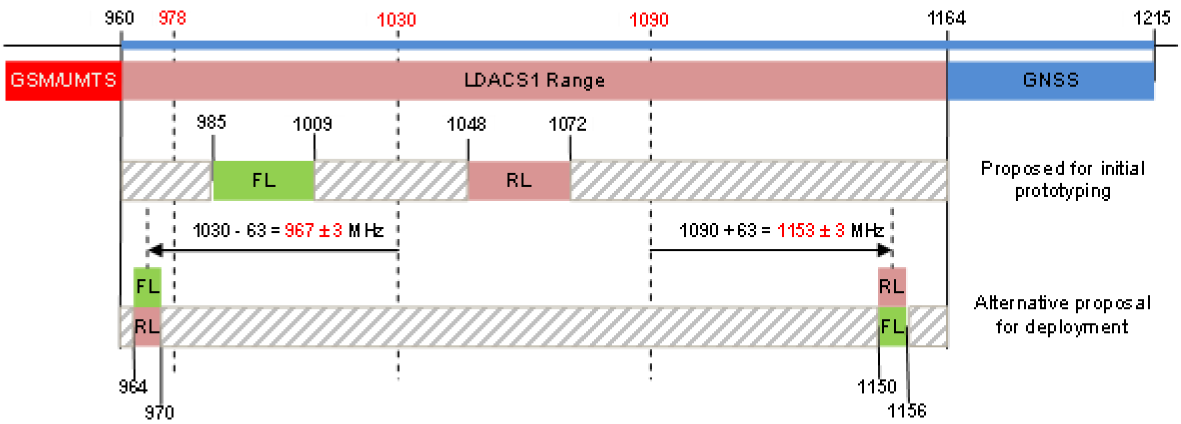

Figure 8-1: Preliminary LDACS1 Deployment Concepts

8.2 Recommendations for LDACS1 Prototyping

As prototype LDACS1 equipment will not support FDD, an airborne RF duplexer is not required 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 L-band systems. Similarly, the duplexer could reduce the levels of out-of-band noise and spurious signals radiated by the LDACS1 AS TX towards other L-band receivers.

As the detailed test scenarios are not fully specified yet, the following recommendations can be made with respect to the prototype LDACS1 radio implementations:

- When testing the AS RX BER, the duplexer should be replaced by the RF band-pass (BP) filter that operates over the AS RX reception range 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) and adjacent ranges (UMTS/GSM, GNSS).
- When testing the AS TX impact on victim L-band receivers operating on fixed channels (978 MHz, 1030 MHz, 1090 MHz) and in adjacent ranges (UMTS/GSM, GNSS), the duplexer should be replaced by the RF BP filter that operates over the LDACS1 AS TX transmission range with an insertion loss comparable to that expected from the airborne duplexer and sufficient attenuation of above L-band channels/ranges.
- Characteristics of the BP filters should be recorded during laboratory tests.

Testing the LDACS1 radios with BP filters provides a degree of confidence that with the real duplexer the performance would be even better. Like the LDACS1 AS duplexer itself, these filters shall be considered as external to the AS and GS, respectively. The filters shall be fitted with RF connectors in order to be able to use any of them as either TX or RX pre-selection filter for both LDACS1 AS and GS equipment.

The preliminary specification of the AS and GS BP filters that cover LDACS1 preliminary deployment options (1, 2, 3 and 4, proposed in Section 8.1) is given in Sections 8.2.1 and 8.2.2, respectively. All filters have been specified for power levels applicable to the LDACS1 AS TX equipment (+42 dBm average power). This shall allow for using AS RX filters when testing the GS TX and vice versa.

The in-band loss for the BP has been made equal to the expected duplexer loss (0.5 dB). Other BP characteristics are shown in Table 8-1.

Table 8-1: BP Filter Parameters

Parameter	Unit	Value
Avg. PWR handling capability	dBm	+42
Peak PWR handling capability (incl. 17 dB PAPR)	dBm	+59
Temperature range	°C	20…40

8.2.1 Pre-selection BP Filters for Deployment Options 1 and 2

These filters have 24 MHz bandwidth and are centred at 997 MHz and 1060 MHz, respectively. Figure 8-2 and Figure 8-3 provide estimated attenuation values for these filters, showing the expected attenuation for fixed L-band channels (UAT, SSR).

997	MHz
f (MHz)	F24_997 Att (dB)
897	-70
904	-70
915	-70
932	-70
942	-66
952	-60
957	-57
964	-49
967	-45
969	-42
973	-35
978	-25
980	-20
983	-3
985	-1
987	-0,5
997	-0,5
1007	-0,5
1009	-1
1011	-3
1014	-20
1016	-25
1021	-35
1025	-42
1027	-45
1030	-49
1037	-57
1042	-60
1052	-66
1062	-70
1079	-70
1090	-70
1097	-70

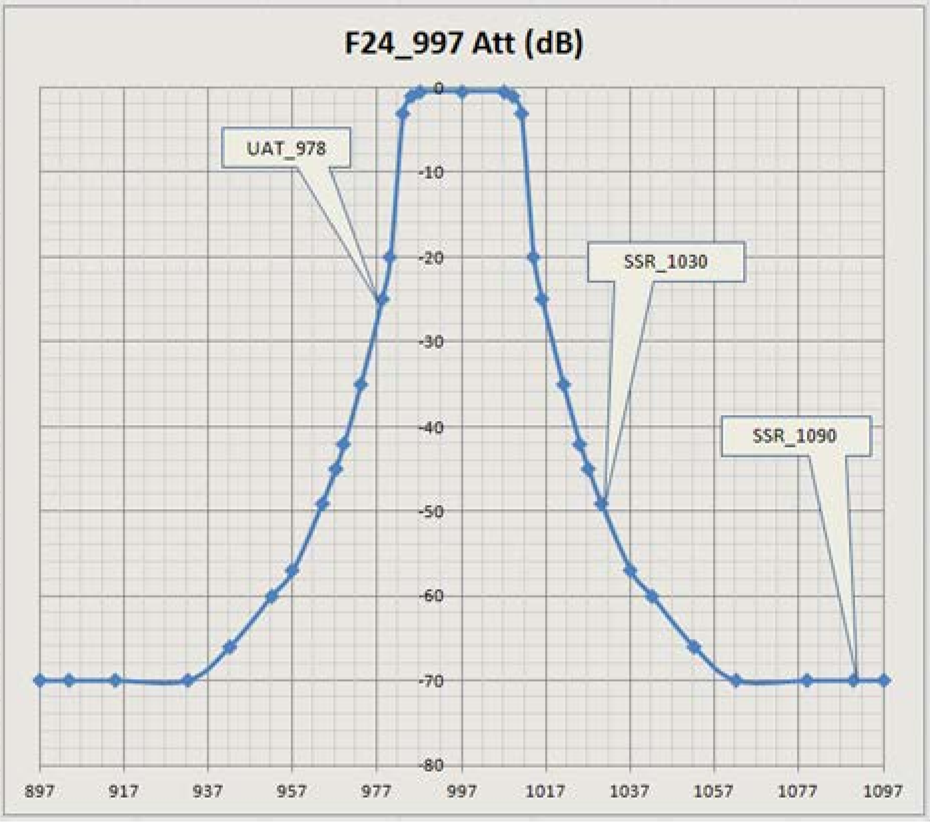

Figure 8-2: Band-pass Filter with 24 MHz Bandwidth Centred at 997 MHz

1060	MHz
f (MHz)	F24_1060 Att (dB)
960	-70
967	-70
978	-70
995	-70
1005	-66
1015	-60
1020	-57
1027	-49
1030	-45
1032	-42
1036	-35
1041	-25
1043	-20
1046	-3
1048	-1
1050	-0,5
1060	-0,5
1070	-0,5
1072	-1
1074	-3
1077	-20
1079	-25
1084	-35
1088	-42
1090	-45
1093	-49
1100	-57
1105	-60
1115	-66
1125	-70
1142	-70
1153	-70
1160	-70

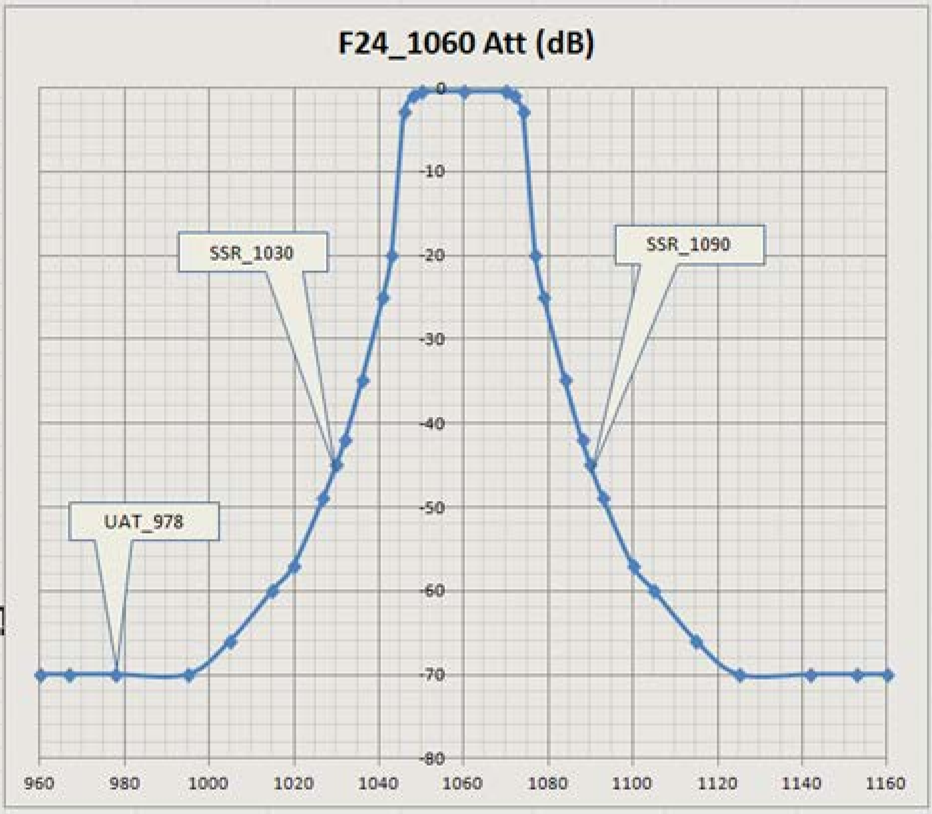

Figure 8-3: Band-pass Filter with 7 MHz Bandwidth Centred at 1060 MHz

8.2.2 Pre-selection BP Filters for Deployment Options 3 and 4

These filters have 7 MHz bandwidth and are centred at 967 MHz and 1153 MHz, respectively.

Figure 8-4 and Figure 8-5 provide estimated attenuation values for these filters, showing the expected attenuation for fixed L-band channels (UAT, SSR) and adjacent bands (GSM, GNSS).

967	MHz
f (MHz)	F7_967 Att (dB)
867	-70
874	-70
885	-70
902	-70
912	-70
922	-70
925	-70
939	-62
945	-56
954	-39
956	-31
958	-25
960	-16
961	-7
963,5	-1
964	-0,5
967	-0,5
970	-0,5
970,5	-1
973	-7
974	-16
976	-25
978	-31
980	-39
989	-56
995	-62
1009	-70
1012	-70
1022	-70
1032	-70
1049	-70
1060	-70
1067	-70

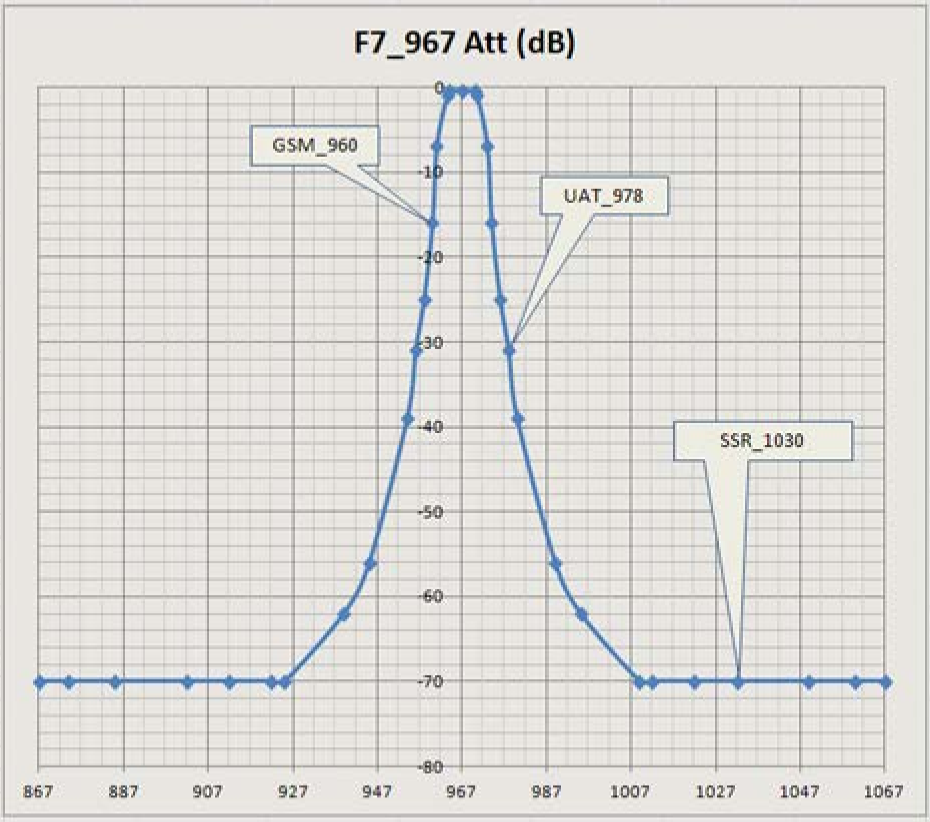

Figure 8-4: Band-pass Filter with 7 MHz Bandwidth Centred at 997 MHz

1153	MHz
f (MHz)	F7_1153 Att (dB)
1053	-70
1060	-70
1071	-70
1088	-70
1098	-70
1108	-70
1111	-70
1125	-62
1131	-56
1140	-39
1142	-31
1144	-25
1146	-16
1147	-7
1149,5	-1
1150	-0,5
1153	-0,5
1156	-0,5
1156,5	-1
1159	-7
1160	-16
1162	-25
1164	-31
1166	-39
1175	-56
1181	-62
1195	-70
1198	-70
1208	-70
1218	-70
1235	-70
1246	-70
1253	-70

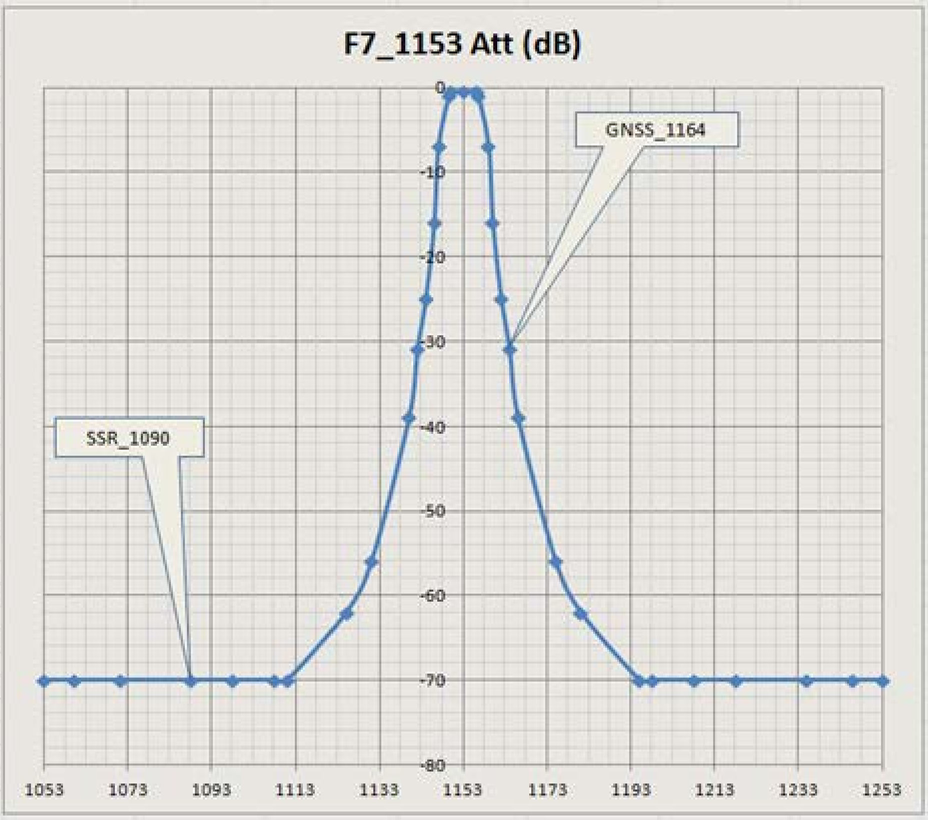

Figure 8-5: Band-pass Filter with 7 MHz Bandwidth Centred at 997 MHz

9 REFERENCES

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ANNEX 1 - Exemplary LDACS1 Radio Architecture

The information in this ANNEX is just for information (non-mandatory), and is provided as guidance for prototyping tasks.

A1.1 Airborne LDACS1 Radio

Figure Annex 1 shows the conceptual block diagram for an LDACS1 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 guidance for prototyping purposes. In particular, the architecture does not mandate any physical packaging of LDACS1 functions. Similarly, different internal interfaces are possible.*

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 LDACS1 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.

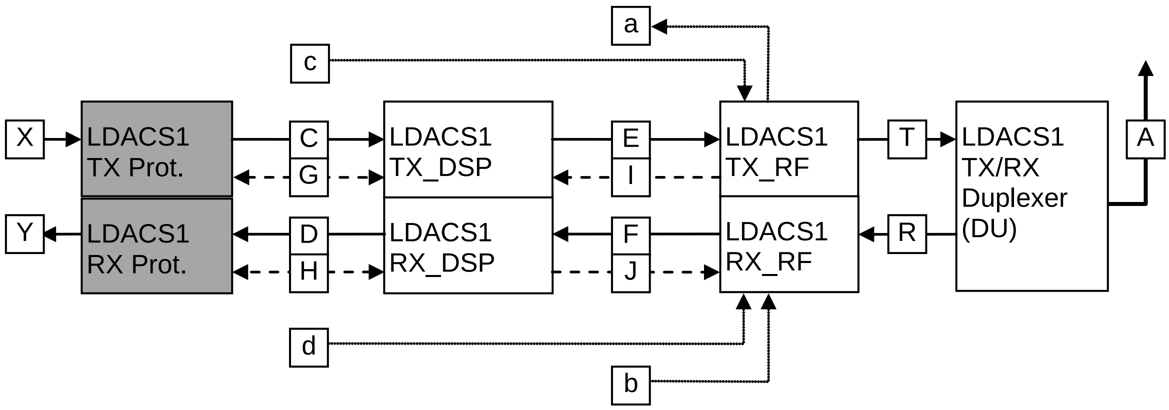

Figure Annex 1: Block Diagram of an Airborne LDACS1 System (A/G Mode)

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 is 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 that will produce data loads during the 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 LDACS1 Radio

The airborne LDACS1 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 is not required 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 7.1.1) and provides attenuation for 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 5.1.1) 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 8.2.

AS TX neither transmits continuously, nor must it use all OFDM sub-carriers. Basically, AS TX transmissions are RF bursts of specified duration.

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 (+42 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 (around 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 LDACS1 AS RF duplexer inserted between the antenna and the LDACS1 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 LDACS1 AS RX even if the AS duplexer were in place.

Similarly, other L-band receivers (e.g. DME RX) operating at close frequency spacing to the airborne LDACS1 TX would be jammed each time the LDACS1 AS TX starts transmitting. Note that in this case the frequency separation between the airborne LDACS1 TX and the victim DME RX may 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 in such a case be influenced by both directly received LDACS1 TX power and radiated out-of-band LDACS1 TX noise or discrete spurious signals.

Within some 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 LDACS1 AS TX and RX provide an interface to the airborne suppression bus.*

LDACS1 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 LDACS1 AS TX transmission has ceased.

Effectively, the pattern on the bus caused by the LDACS1 TX (excluding other TXs) would roughly resemble the LDACS1 AS TX operating duty-cycle[21].

> *If suppression bus is available, the LDACS1 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 LDACS1 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 LDACS1 RX interference blanking is configured/active during tests, blanking signal may be used for informing the PHY-layer processor that the reception of an ongoing LDACS1 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 LDACS1 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 LDACS1 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 LDACS1 Radio

The architecture shown in Figure Annex 1 with similar interfaces basically applies to the LDACS1 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 LDACS1 GS TX transmits continuously, always using all OFDM sub-carriers, therefore also full FL RF bandwidth (498.05 kHz).

LDACS1 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.

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.

[21] The maximum acceptable airborne LDACS1 TX duty-cycle should be defined outside this report. Generally, the duty-cycle should be kept as low as possible as it would block other airborne receivers.

ANNEX 2 - Exemplary LDACS1 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, 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 LDACS1 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).

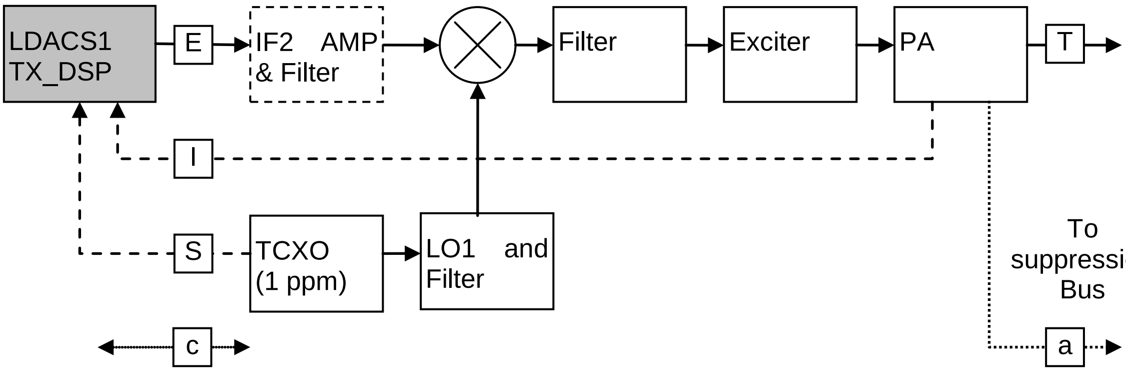

Figure Annex 2: Exemplary Block Diagram of an LDACS1 TX Prototype (A/G Mode)

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 LDACS1 TX Supplementary RF Specification

Table Annex 1: Supplementary Airborne LDACS1 TX Parameters

TX Specification	Recommended Value	Comment
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[22]	-88 dBc/Hz	@ Δf = 1 kHz
	-90 dBc/Hz	@ Δf = 10 kHz

[22] 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.

	-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 LDACS1 signal BW, from the OFDM modulator up to the antenna (value is for UHF DVB-T COFDM TX, TBC)
Amplitude variation	±2 dB	Across LDACS1 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 LDACS1 TX Supplementary RF Specification

The supplementary (non-mandatory) characteristics of the LDACS GS transmitter RF front-end (TX_RF) are the same as for an airborne TX_RF.

ANNEX 3 - Exemplary LDACS1 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.

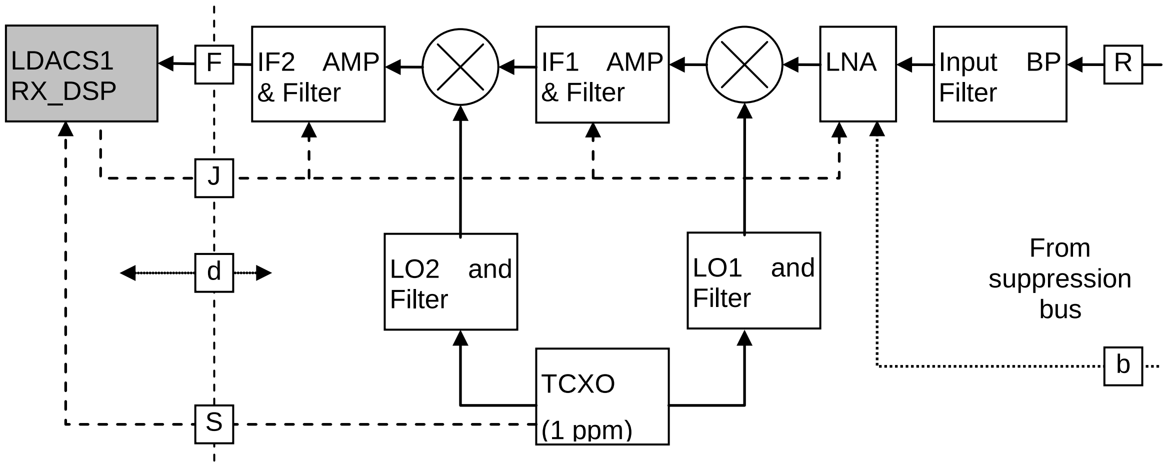

Figure Annex 3: Exemplary Block Diagram of an LDACS1 RX Prototype (A/G Mode)

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 LDACS1 RX Supplementary RF Specification

Table Annex 2: Airborne LDACS1 RX Parameters

RX Specification	Recommended Value	Comment
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	120 µs	Not specified. 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[23]	-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 LDACS1 signal BW, from the antenna up to OFDM demodulator (value is for UHF DVB-T COFDM TX, TBC)
Amplitude variation	±2 dB	Across LDACS1 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)

Expected LDACS1 RX IF filter selectivity characteristics (for the IF filter part realised in the hardware) is shown in Table Annex 3. It should provide the minimum achievable in-band ripple at frequency offsets less than ± 0.3 MHz (first row in Table Annex 3).

LDACS1 RX IF selectivity is provided for information only. Different IF filter characteristics may be used in the prototype RX equipment.

Table Annex 3: Exemplary LDACS1 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

A3.3 Ground LDACS1 RX Supplementary RF Specification

The supplementary (non-mandatory) characteristics of the ground LDACS RX are the same as for an airborne RX.

[23] 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.