Transceiver Facility Absolute Time Use Case

Transceiver Facility
where software defines the radio

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1 Introduction

The *Transceiver Facility PIM Specification* V2.1.0 [Ref1] produced by the Wireless Innovation Forum (WInnF), subsequently identified as the *specification*, provides interfaces, operations and attributes to address a wide range of transceivers type, grade and variation. This applies to the fields of application, cost, synchronization capabilities, number of channels, and so on. This openness resulted in a number of interfaces, operations and attributes most often exceeding what is required to implement a specific type of transceiver.

As generality comes at the expense of precision, zooming in on particular system constellations and profiles can be helpful for waveform and transceiver implementers.

This document (hereafter referred to as the *use case*) provides a detailed definition of the class of transceivers belonging to the use case of single-channel transceivers where the real-time control capability is provided by an absolute, monotonic clock based *Transceiver Time*. Particularly allowing a *radio application* to implement its waveform air-interface synchronization.

A transceiver satisfying the requirement for implementing monotonic clock based real-time control is referred to as an *Absolute Transceiver* throughout the *use case*.

An *Absolute Transceiver*'s monotonic clock may be synchronized with other components within the radio system providing additional functionalities for a *radio application* when using the respective Services (e.g. JTNC Timing Service [Ref2] or WInnForum Time Service Facility) and Devices available in the particular context.

1.1 Overview

The first part of the *use case* presumes the *Absolute Transceiver* to be a single channel Full-duplex Transceiver, i.e. a transceiver providing both one channel for transmit and one channel for receive at the same time. The second part of the *use case* complements this by specific considerations regarding the popular class of Half-duplex Transceivers.

The *use case* contains as follows:

a. Section 1, *Introduction*, contains the introductory material regarding the overview, and provides the *Absolute Transceivers* component view.

b. Section 2, *Absolute Time Controlled Transceiver Modelling*, describes the modelling approach chosen, and presents the transceivers class attributes deduced.

c. Section 3, *Services*, identifies the interfaces of the component, defines the service states and illustrates behavior. It outlines real-time control constraints. Sequence diagrams do complement the section.

d. Section 4, *Half-duplex Transceivers*, presents the specific class, service states, behavior, and sequence diagrams for a half-duplex transceiver.

e. Section 5, *Glossary*, recaps essential terminology.

1.2 Absolute Time Controlled Transceiver Component

Figure 1 depicts the UML component diagram of the *Absolute Transceiver*. It represents the system-level, architectural view of the specific type of transceivers considered by the *use case*. It is typical and representative for many transceivers.

For the interfaces the *Absolute Transceiver* provides and requires as well as for its service primitives and attributes, please refer to the *specification* [Ref1].

The relationship to the characteristics of a transceiver instance as identified by the *specification* with [Ref1, section *4, Properties*] is established subsequently. As the *use case* covers a certain class of transceivers rather than a super-specific transceiver instance, only the properties of particular interest and their values assigned are listed hereafter.

In the first place, there are properties that are significant for an *Absolute Transceiver*. On the other hand there are properties where values are exemplarily assigned in order to be more specific. Properties not listed are out of relevance or interest for the *use case*.

The *use case* confines itself with respect to the values of *Transceiver Properties* as identified hereafter.

Structure properties (see [Ref1, section 4.2, *Structure*]) are as follows:

Property	Value	Notes
TX_CHANNELS	1	To be specific, the number of transmit channels is fixed to one.
RX_CHANNELS	1	To be specific, the number of receive channels is fixed to one.
DUPLEX	fullDuplex, halfDuplex	The *use case* considers a full-duplex transceiver in the first place, complemented by half-duplex specific aspects (section 4)
TX|RX_SERVICES		Symmetrical services for Tx and Rx Channel
.absoluteCreation	TRUE	
.termination	TRUE	
.initialTuning	TRUE	
.retuning	TRUE	
.timeAccess	TRUE	
TIME_COUPLING	autonomous, coupled	The *use case* comprises considerations both for un-synchronized *Transceiver Time* and the case where it is synchronized within the system.

Table 1 Absolute Transceiver Structure Properties Values

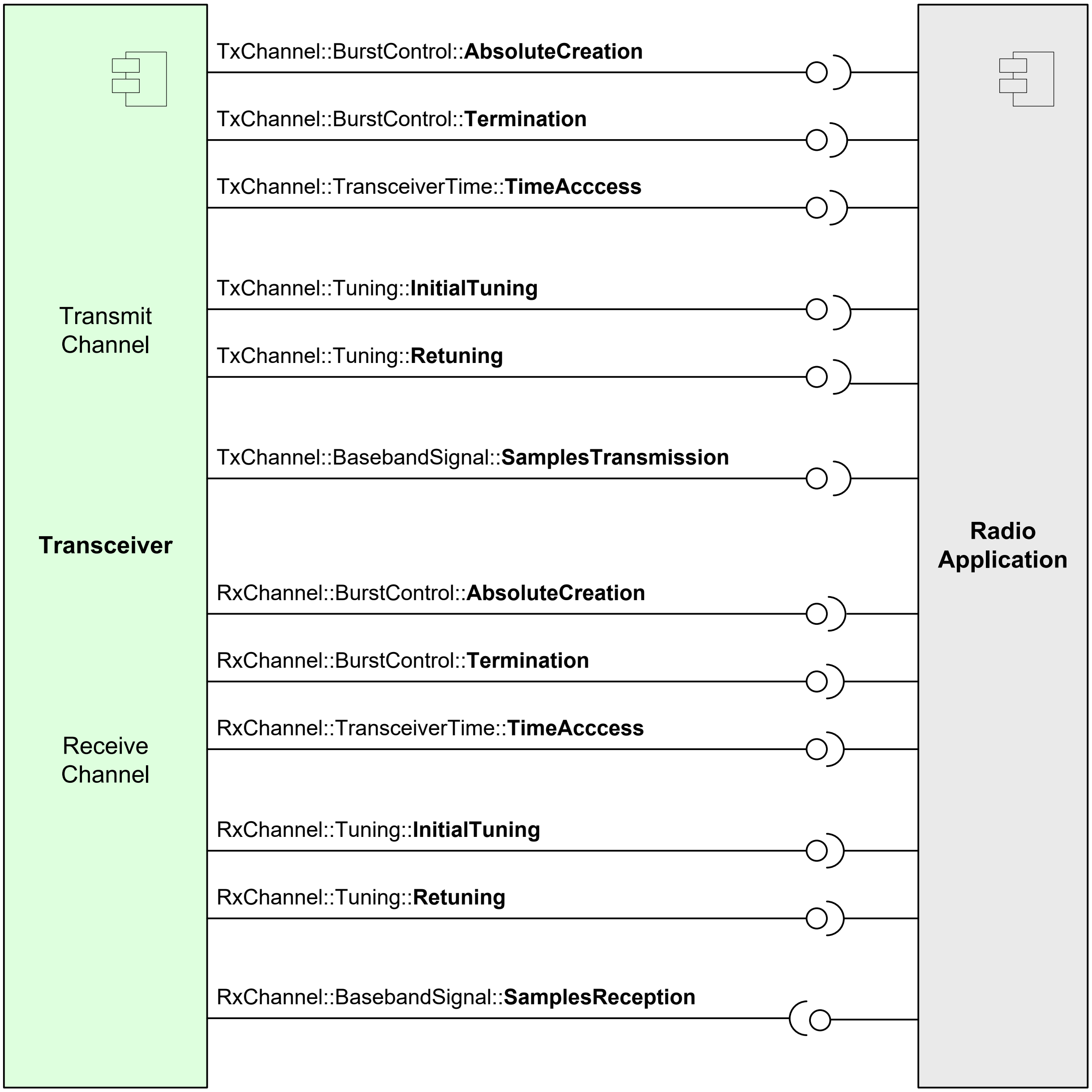

Figure 1 Absolute Time Controlled Transceiver Component

Behavior properties (see [Ref1, section 4.3, *Behavior*]) are as follows:

Property	Value	Notes
TUNING_ASSOCIATON	sequential	

Table 2 Absolute Transceiver Behavior Properties Values

Interface declaration properties (see [Ref1, section 4.5, *Interface declaration*]) are as follows:

Property	Value	Notes
CARRIER_FREQ_TYPE	32bit	To be specific
DELAY_TYPE	32bit	To be specific
TX_META_DATA	FALSE	To be specific, no user-defined meta-data associated to a Tx packet.
RX_META_DATA	FALSE	To be specific, no user-defined meta-data associated to a Rx packet.

Table 3 Absolute Transceiver Interface Declaration Properties Values

1.3 Referenced Documents

[Ref1] *Transceiver Facility PIM specification*, The Wireless Innovation Forum, WINNF-TS-0008 V2.1.1, 20 January 2022

[Ref2] *Timing Service Application Program Interface*, Joint Tactical Radio System Standard, Version 1.4.4, 26 June 2013

2 Absolute Time Controlled Transceiver Modelling

The *use case* recapitulates and distills a transceivers mathematical representation in order to enhance stand-alone readability and to emphasize the relationship with parameters controllable by the API. The *use case* also applies additional techniques for representation, modeling and abstraction of transceivers that go beyond and supplement the *specification*. Such different views may be helpful to deepen the understanding and in providing guidance when implementing a specific transceiver, its interfaces and operations. Particularly when it finally comes to presenting the *Transceiver API* to the *radio application* designer. In detail, the *use case* provides considerations as follows:

- Mathematical Model Viewpoint (Partly recap of the *specification*)
    - Digital Signal Processing and System Theory Considerations
- Object-oriented Model (OOM) Viewpoint
    - Transceiver Class Diagram
        - Transceiver attributes and characteristics
    - Transceiver API Class Diagram
    - Transceiver State Diagrams

That set of elements do represent a complete and consistent model in order to unambiguously identify structure, and particularly behavior of the *Absolute Transceiver*. This is in order to allow a *radio application* to fully utilize the transceiver resources on the one hand by safely avoiding usage faults on the other hand.

2.1 Mathematical Model Viewpoint

The *Transmit Channel*s mathematical representation is shown by Figure 2.

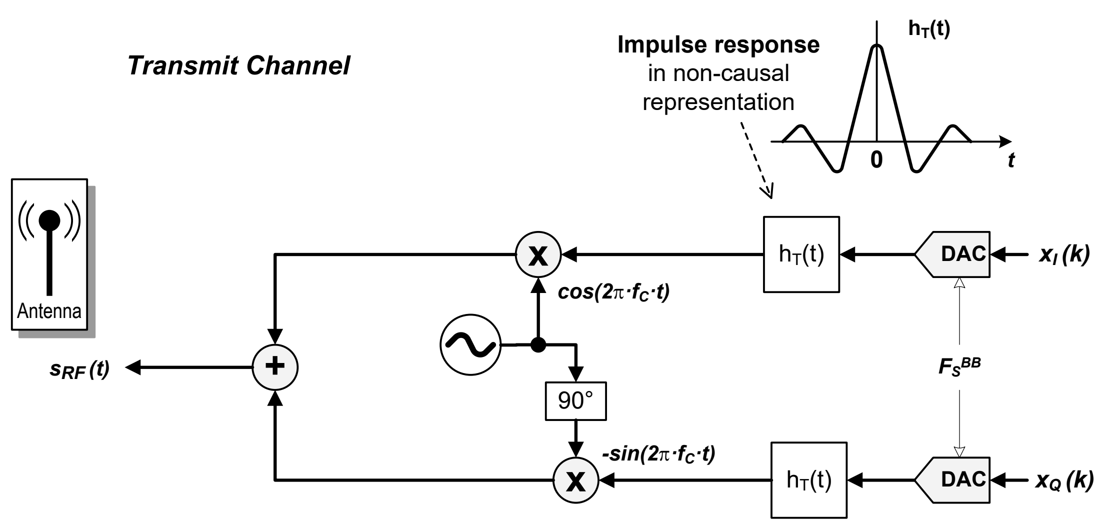

Figure 2 Transmit Channel Mathematical Model

The model represents the universal transmitter that allows to generate any type of modulated signal. It therefore assumes the transmitter to be a linear time-invariant (LTI) system that may be described by its impulse response $h_T(t)$ or, equivalently, by its transfer function $H_T(f)$. Commonly a low-pass characteristic providing the required *channel bandwidth*.

This LTI approach has been taken to obtain a generalized model, appropriate to identify and illustrate terminology essential to the *specification* and the *use case* by mathematical equations. It may be reduced to those used for a particular type of modulation.

A detailed discussion on baseband representation of modulated signals and theory of linear systems is beyond the scope of the *use case*. Plenty of literature is available that may be reviewed. [1]

The complex-valued *baseband signal* – within literature also called the complex envelope of the radio signal - is a sequence of samples

$$x(k) = x_I(k) + j \cdot x_Q(k)\,, \quad k = 0, 1, \ldots, L-1 \qquad \text{(Eq.1)}$$

where:

L The *burst length* in terms of the number of samples.

The discrete-time signal x(k) has an associated sampling rate referred to as *Baseband Sampling Frequency*, denoted F_S^{BB}, as introduced with the *specification*.

The signal $x_I(k)$ is referred to as in-phase (I) component and $x_Q(k)$ is referred to as the quadrature (Q) component. The radio frequency signal $s_{RF}(t)$ then can be written as

$$s_{RF}(t) = \sum_{k=0}^{L-1} \left[x_I(k) \cdot \cos(2\pi f_c t) - x_Q(k) \cdot \sin(2\pi f_c t) \right] \cdot h_T(t - t_{Start} - k \cdot T_S^{BB}) \qquad \text{(Eq.2)}$$

where:

f_C The transmit *carrier frequency*.

T_S^{BB} The *baseband signals* sampling interval. It holds $T_S^{BB} = 1 / F_S^{BB}$.

t_{Start} The *burst start time*.

$h_T(t)$ The equivalent baseband impulse response in non-causal representation, i.e. with its central peak at t = 0.

The *Burst Length* in terms of time is referred to as *Burst Duration*, denoted T_{Burst} hereafter. It holds

$$T_{Burst} = L \cdot T_S^{BB} \qquad \text{(Eq.3)}$$

Equation (Eq.2) is valid for

$$0 \le t - t_{Start} < T_{Burst} = L \cdot T_S^{BB}\,, \qquad \text{(Eq.4)}$$

what is defined as the *core* of a *Tx burst* by the *specification*.

The *use case* does not make any assumptions or statement on the nature of transient effects, e.g. regarding *carrier frequency* stability, power ramping, and time-variance of the transfer function outside of the *core*, i.e. outside of the time period identified by (Eq.4).

[1] e.g. Digital & Analog Communication Systems (8th Ed.), Leon W. Couch, Pearson, 2013, ISBN-13: 978-0-13-291538

With the universal transmitter, the envelope of the radio signal is directly controlled by the *baseband signal*, provided that signal bandwidth does not exceed *channel bandwidth*. Hence the *use case* assumes solely the *radio application* to control the shape of the RF signal following the aforesaid condition (by pushing a baseband signal with its sequence of samples starting and ending at the origin).

The case where a *radio application* relies on a specific transient system response in order to control the waveform shape for $t < t_{start}$ and $t > t_{start}+T_{Burst}$ is out of the scope of the *use case*.

The *Receive Channel*s linear system model is shown with Figure 3.

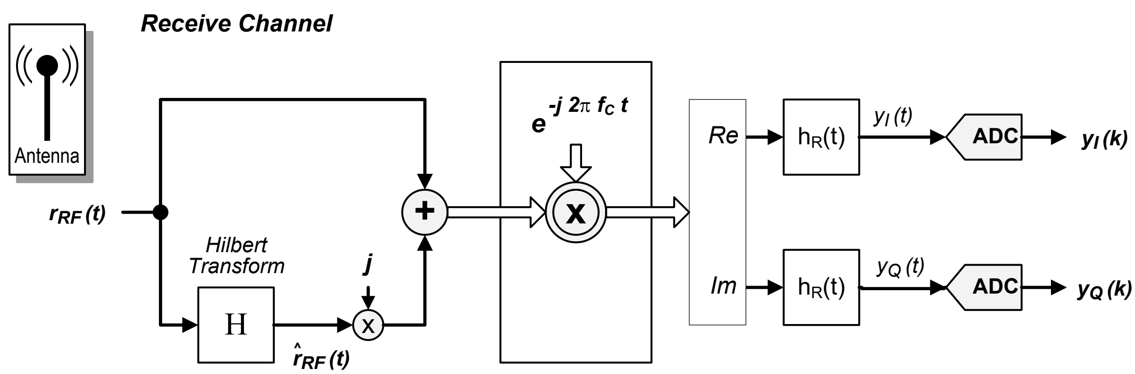

Figure 3 Receive Channel Mathematical Model

The discrete-time complex-valued *baseband signal* is a sequence of samples

$$y(k) = y_I(k) + j \cdot y_Q(k)\,, \quad k = 0, 1, \ldots, L\text{-}1. \qquad \text{(Eq.5)}$$

Inversely to transmit, the *baseband signal* is obtained by equidistant sampling of the continuous-time signal $y(t) = y_I(t) + j \cdot y_Q(t)$ and may be written as

$$y(k) = y(t = t_{Start} + k \cdot T_S^{BB}) = \left[\left\{ r_{RF}(t) + j \cdot \hat{r}_{RF}(t) \right\} \cdot e^{-j\,2\pi\,f_c\,t} \right] * h_R(t) \qquad \text{(Eq.6)}$$

where:

$\hat{r}_{RF}(t)$ The Hilbert transform of the received radio frequency signal $r_{RF}(t)$.

$*$ The convolution operator.

f_C The *carrier frequency.*

T_S^{BB} The *baseband signals* sampling interval. It holds $T_S^{BB} = 1 / F_S^{BB}$.

t_{Start} The *burst start time*.

$h_R(t)$ The equivalent baseband impulse response in non-causal representation, i. e. with its central peak at $t = 0$.

Provided that RF signal bandwidth does not exceed *channel bandwidth*, the *baseband signal* y(k) represents the complex envelope of the passband signal $r_{RF}(t)$ for

$$0 \le t - t_{Start} < T_{Burst} = L \cdot T_S^{BB}. \qquad \text{(Eq.7)}$$

2.2 Transceiver Characteristics Decomposition

Figure 4 shows the class diagram, representing an *Absolute Transceiver*s object-oriented model that allows identifying its essential structure. Compared to the *specification* it provides further abstraction that is used later on in order to illustrate an *Absolute Transceiver*s behavior as defined with the *specification*.

Objects and classes shaded in blue are the pieces of information that represent the *Absolute Transceivers* states and attributes of interest within the *use case*. Structures shaded in yellow are defined with the *Transceiver API* within the *specification*.

The monotonic clock aspect of the *Transceiver Time* is a key attribute of the *Absolute Transceiver* related to its real-time control capability. *Transceiver Time* is used as time reference both by *Transmit Channel* and *Receive Channel*, and relates to the transceivers antenna interface.

The *Transmit Channel* is characterized by the attributes and states as depicted and relies on the following classes:

- The *Transmit Channel*s composite state – Operational state, up-conversion state, gain control state, and burst control state as explained in section 3, *Services*.
- Tx Burst Reference – Maintaining the sample sequence number within a transmit burst.
- Tx Tuning Profile – Identifying currently applied tuning preset, *carrier frequency* and gain in effect.
- Baseband Sample Buffer – Storage for baseband samples pushed by the *radio application*.

The *Receive Channel* is characterized by attributes and states as shown and relies on the following classes:

- The *Receive Channel*s composite states - Operational state, down-conversion state, and burst control state as explained in section 3, *Services*.
- Rx Burst Reference – Maintaining the sample sequence number within a receive cycle.
- Rx Tuning Profile – Identifying currently applied tuning preset and *carrier frequency* in effect.

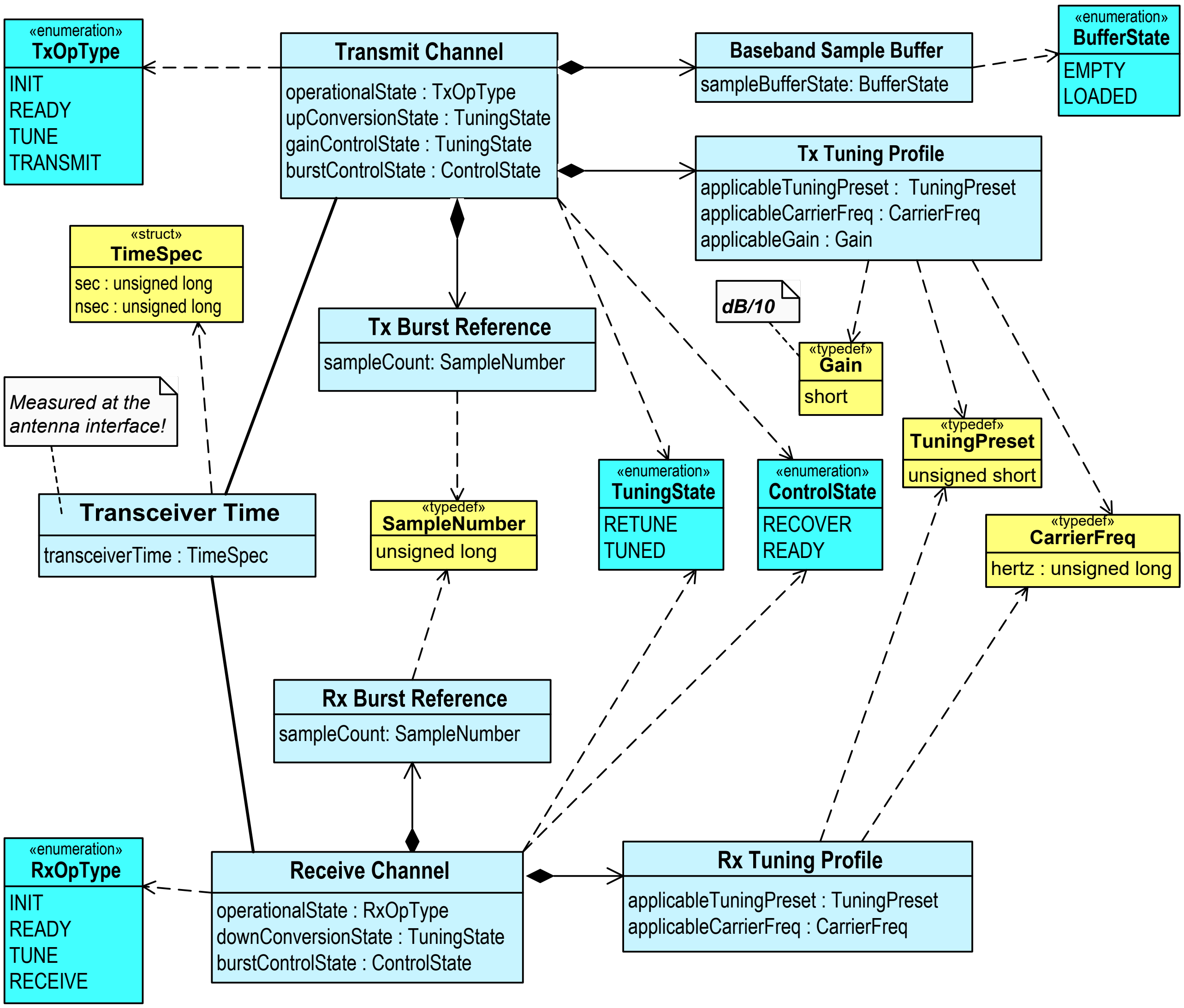

Figure 4 Full-duplex Absolute Time Controlled Transceiver Characteristics Decomposition

3 Services

3.1 Transceiver API Class Diagram

Figure 5 shows the composite interface class diagram of the *Absolute Transceiver*. It identifies the relevant subset of the *Transceiver API* as standardized by the *specification*.

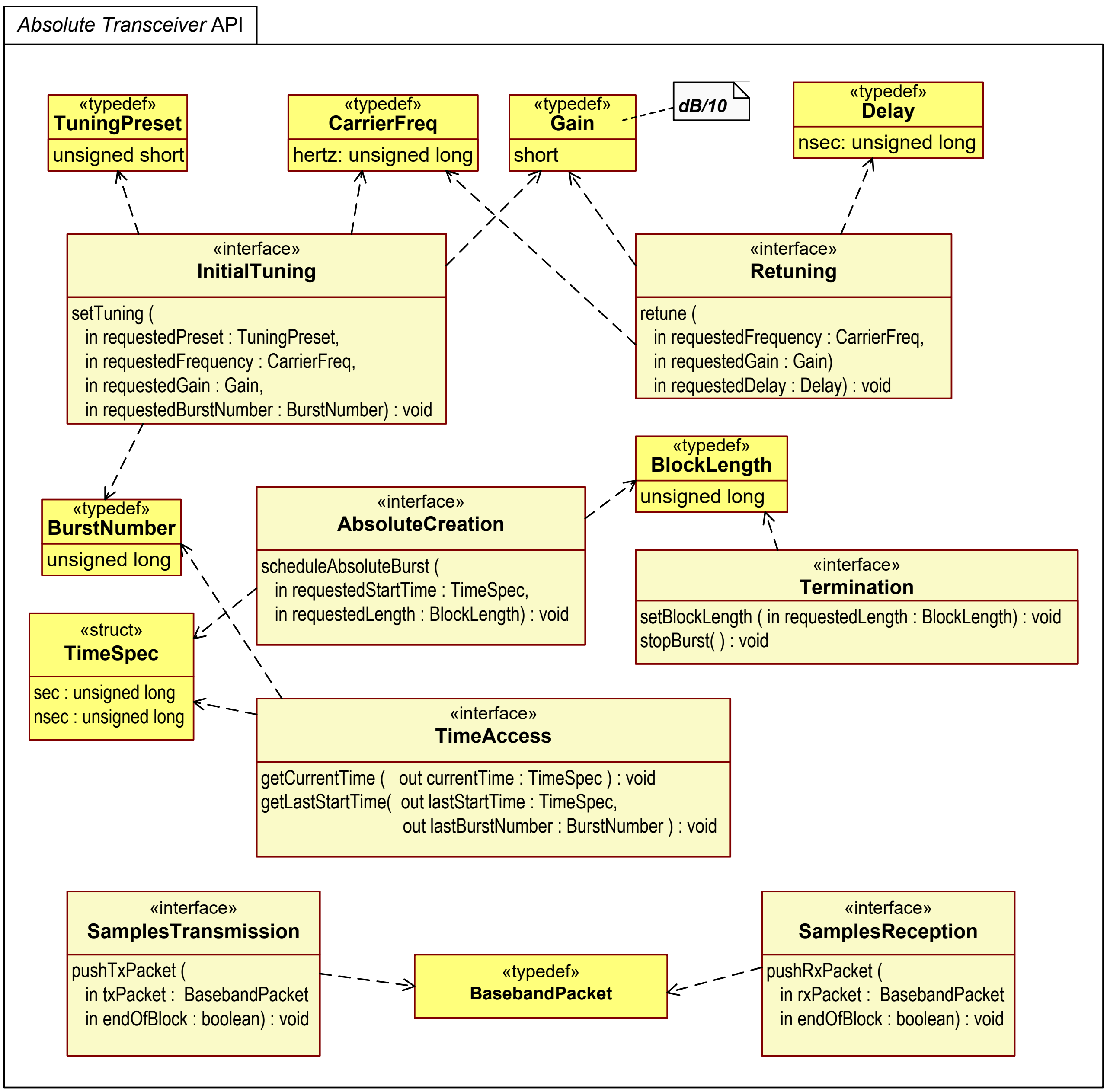

Figure 5 Transceiver API Interface Class Diagram

3.2 Service States / Transceiver Behavior

As already stated in section 2, *Absolute Time Controlled Transceiver Modelling*, the state diagrams presented within this section provide an additional viewpoint that supplements the viewpoint taken in the *specification* [Ref1].

The viewpoint looks at the *Transceiver API* interfaces and how the operations control the system behavior solely referencing the antenna interface.

It should be noticed as the key idea of the *use case* to 'translate' any state introduced by the *specification* to the antenna. By the way, this is also true for the latency and reactivity model presented later on.

Compared to the *Channel statechart* figure of the *specification* [Ref1, Figure 8], the *use case* provides a more detailed, specific view on both the *Transmit Channel* and the *Receive Channel*. Note that the differences in modeling between the *specification* and the *use case* result from the different viewpoints taken. The models in the two documents must not be confused, even if some state machines might in parts uses similar terms.

The *Absolute Transceivers* state diagrams presented hereafter exhibit the following crucial characteristics:

- The diagrams depict the states that have been identified within the object-oriented model of section 2.2, *Transceiver Class*, particularly Figure 4, and all possible transitions.
- The diagrams also depict the transceivers attributes, which are manipulated and evaluated in order to control the state machines.
- A consistent color code makes the states and different types of attributes easily identifiable. It is particularly notable that states shaded in yellow are transient states where the transceiver may not be used for transmitting or receiving due to internal processes with a respective residence time associated.
- The diagrams illustrate how a *radio application* triggers the state transitions by calling the *Transceiver API* operations and which guard conditions apply.
- The model allows the state transitions to take place at a particular point in time that has a straightforward relationship to explicitly available parameters like *burst start time* and *burst length/duration*. Therefore, the model provides full abstraction from internal workings of a transceiver. In particular, the model conceals all transceiver-internal aspects introduced in the specification like *activation time* and *up-conversion latency* and thus enhances portability.

This could only be achieved by putting a clear and undiluted focus on a *radio application* designer's perspective in the *use case*.

The operation calls shown within the *Transmit Channel* and *Receive Channel* state diagram do not need to take place at a particular point in time. In general almost any operation has a latest possible point in time where it can be issued (characterized by its *minimum invocation lead time*), and eventually an earliest point in time at which it can be called.

An operation call that is issued timely, i.e. within its admissible time frame, is queued and postponed until the system enters a state configuration where the operation call does not have to be deferred any longer. This not only includes entering a state, where the operation call is consumable, but also that all guard conditions concerning the transceivers attributes are true. The operation call is then processed and consumed as if it just occurred.

All state diagrams show behavior under normal operation conditions. Usage fault conditions are out of the scope of the *use case*.

The state machines of the *Transmit Channel* and the *Receive Channel* are complemented by a summary of the relevant latency and reactivity characteristics for the *Absolute Transceiver*. Note that any latencies that originate from implementation-specifics of a transceiver have to be hidden behind the corresponding performance parameters.

3.2.1 Transmit Channel

The *Absolute Transceiver*s *Transmit Channel* composite state diagram is shown in Figure 6.

The *Transmit Channel* state contains three orthogonal regions:

- The Operational State
- The Sample Buffer State
- The Burst Controller State

3.2.1.1 Operational State

The *Transmit Channel* operational states are as follows:

- READY – The state transitioned to upon successful startup, after a transmit cycle has been terminated, and after tuning has been established.
  - The *Transmit Channel* initializes its burst reference (*sampleCount=0*) on entry.
  - The *Transmit Channel* retains its current tuning or it may be retuned once.
- TRANSMIT – The state transitioned to when a *scheduleAbsoluteBurst* operation has been issued. Guard conditions do apply as follows:
  - Monotonic clock *transceiver time* (*transceiverTime*) has reached desired *burst start time* (*requestedStartTime*).
  - Baseband samples have been pushed timely (*sampleBufferState == LOADED*).
  - The *Transmit Channel* has recovered from a previous transmit cycle (*burstControlState==READY*). Note that there may be an imperative gap (*recoveryDuration*) between two consecutive bursts, even if there is no tuning.

  Radio emission takes place with properly established transfer characteristics.

  The state is exited after *Burst Duration*, i.e. when the requested number of baseband samples has been processed, or when a *stopBurst* operation has been issued. On exit an *Idle* signal is sent to the burst controller and to the sample buffer.
- TUNE – The state transitioned to when a *setTuning* operation has been issued for the current burst in progress. TUNE is a transient state that is exited as soon as the requested transposition characteristics are established (i.e. after *Tune Duration*).

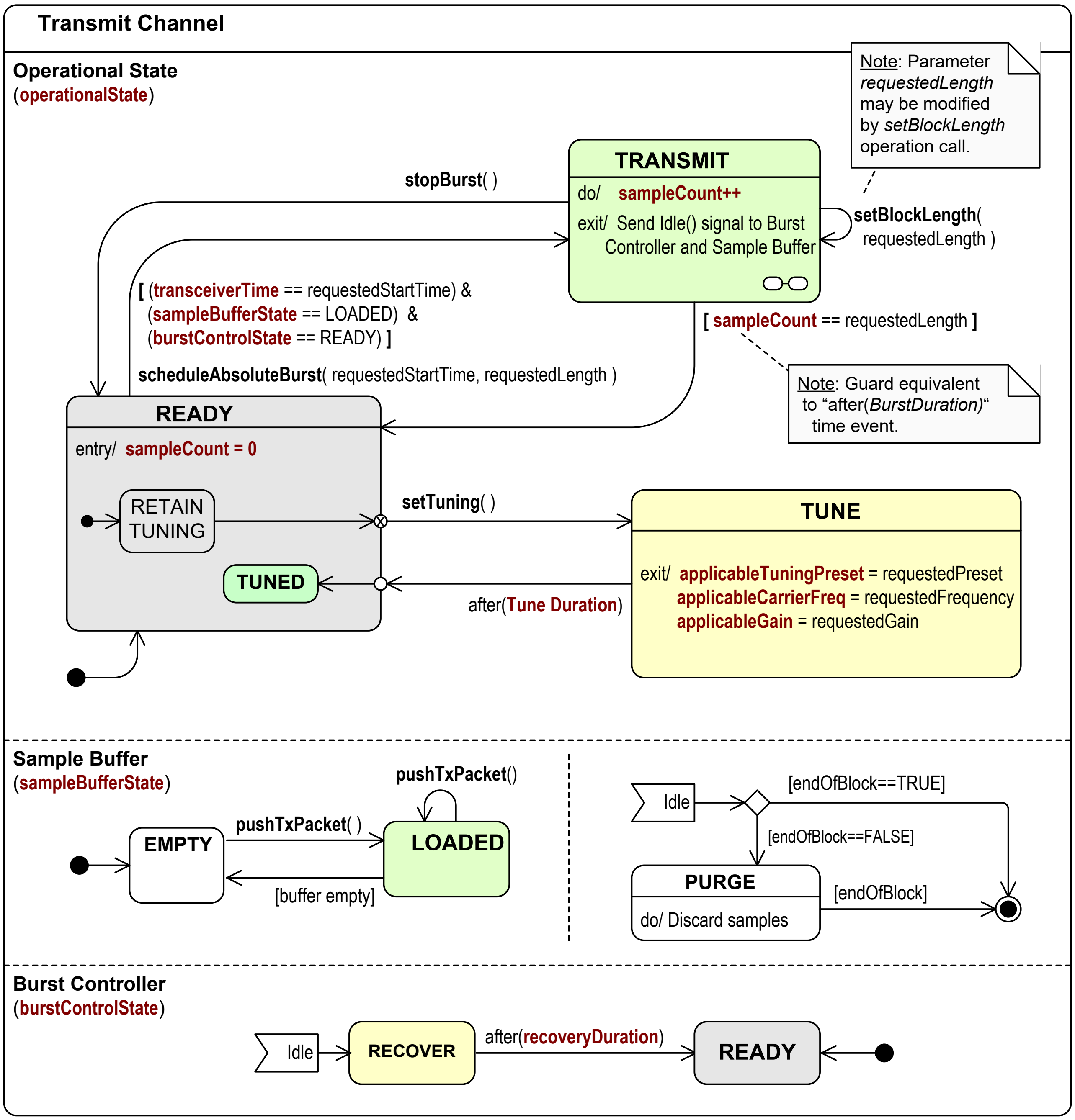

Figure 6 Transmit Channel State Diagram

3.2.1.1.1 TRANSMIT Detail and Substates

The TRANSMIT state has substates as depicted with Figure 7. The TRANSMIT state has two orthogonal regions:

- The Up-Converter State
- The Gain Controller State

The states within both the concurrent regions are as follows:

- TUNED – The state transitioned to on entry.
- RETUNE – The state transitioned to when a *retune* operation has been issued. A transient state that is exited as soon as the requested characteristics have been established, i.e. after *frequencyTuneDuration* or *powerTuneDuration* respectively.

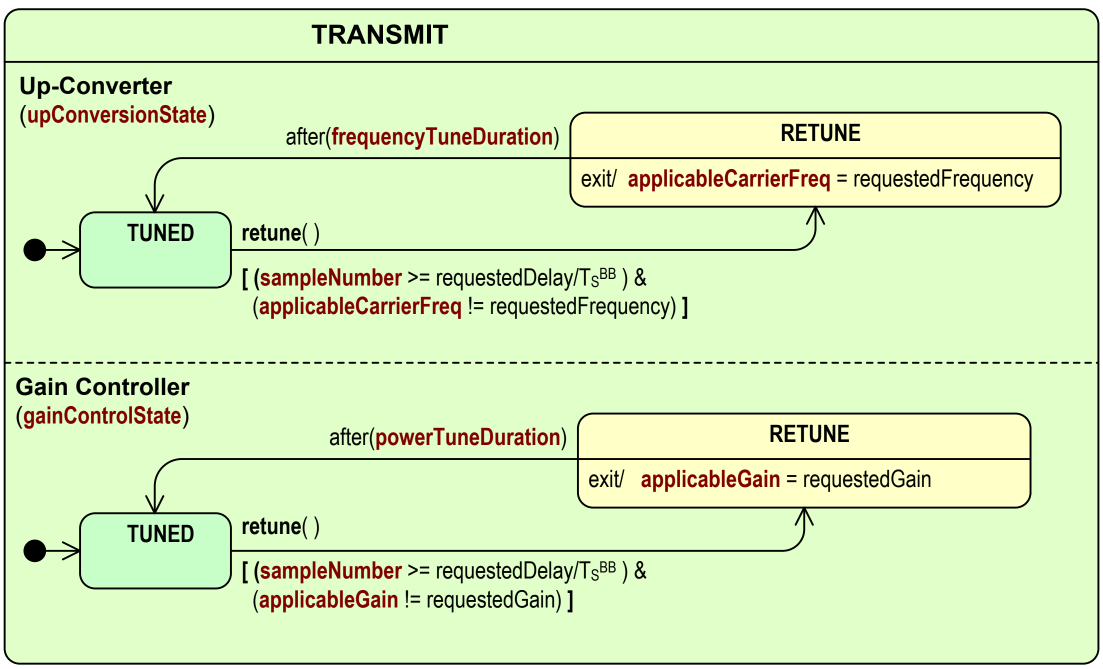

Figure 7 Transmit Channel Operational State Diagram (TRANSMIT Substates)

3.2.1.2 Burst Controller State

The *Transmit Channel* burst controller states are as follows:

- READY – The state transitioned to on successful startup and after recovery from a previous transmit cycle.

- RECOVER – The state transitioned to on *Idle* signal reception (from Operational State). A transient state that is exited as soon as the *Transmit Channel* has recovered from a previous transmit cycle (*recoveryDuration*).

The burst controller region allows to consider time intervals where usability of the transmitter is intermitted due to recovery, even if no tuning needs to take place.

3.2.1.3 Sample Buffer State

The *Transmit Channel* baseband sample buffer state has two orthogonal regions. The states within the main region are as follows:

- EMPTY – The state transitioned to on successful startup.
- LOADED – The state transitioned to when a *pushTxPacket* operation has been issued.

Baseband samples are read out from the sample buffer while operational state is TRANSMIT.

There is also a need to remove samples from the sample buffer if a burst is terminated prior to having completely processed the baseband sample packets pushed for the particular burst. That is presented in another state within an ancillary region:

- PURGE – The state transitioned to on *Idle* signal reception (from Operational State) if *endOfBlock* indication was not detected yet. Surplus samples are discarded till *endOfBlock* is detected TRUE.

3.2.2 Receive Channel

The *Absolute Transceivers Receive Channel* composite state diagram is shown in Figure 8.

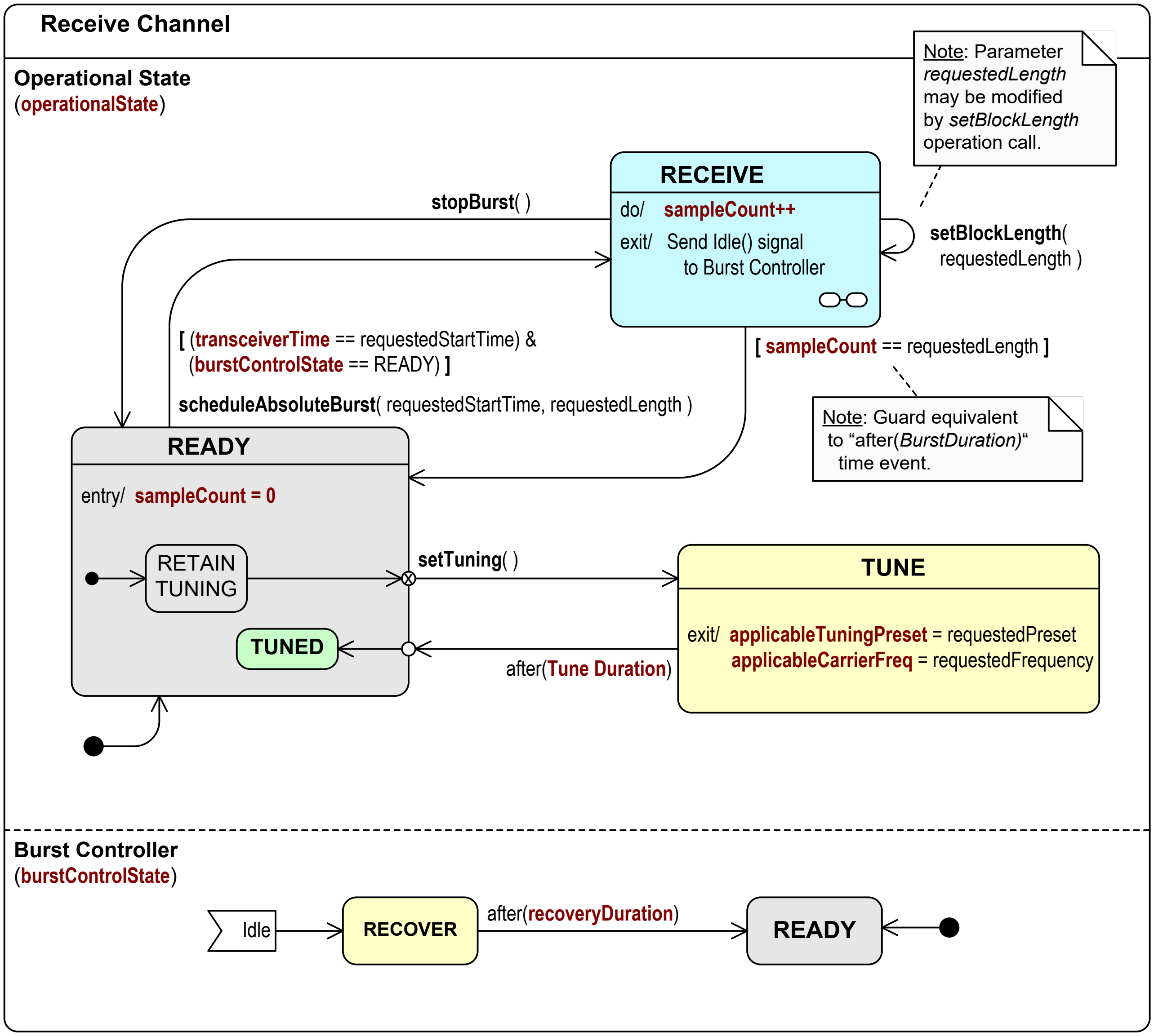

Figure 8 Receive Channel State Diagram

The *Receive Channel* state contains two orthogonal regions:

- The Operational State
- The Burst Controller State

3.2.2.1 Operational State

The *Receive Channel* operational states are as follows:

- READY – The state transitioned to upon successful startup, after a receive cycle has been terminated, and after tuning has been established.
  - The *Receive Channel* initializes its burst reference (*sampleCount=0*) on entry.
  - The *Receive Channel* retains its current tuning or it may be retuned once.
- RECEIVE – The state transitioned to when a *scheduleAbsoluteBurst* operation has been issued. Guard conditions do apply as follows:
  - Monotonic clock *Transceiver Time* (*transceiverTime*) has reached desired *burst start time* (*requestedStartTime*).
  - The *Receive Channel* has recovered from a previous receive cycle (*burstControlState==READY*). Note that there may be an imperative gap (*recoveryDuration*) between two consecutive receive cycles, even if there is no tuning.

  Radio signal reception takes place with properly established transfer characteristics.

  The state is exited after *Burst Duration*, i.e. when the requested number of baseband samples has been processed or when a *stopBurst* operation has been issued. On exit an *Idle* signal is sent to the burst controller.
- TUNE – The state transitioned to when a *setTuning* operation has been issued for the current burst in progress. TUNE is a transient state that is exited as soon as the requested transposition characteristics are established (i.e. after *Tune Duration*).

3.2.2.1.1 RECEIVE Detail and Substates

The RECEIVE state details are depicted with Figure 9.

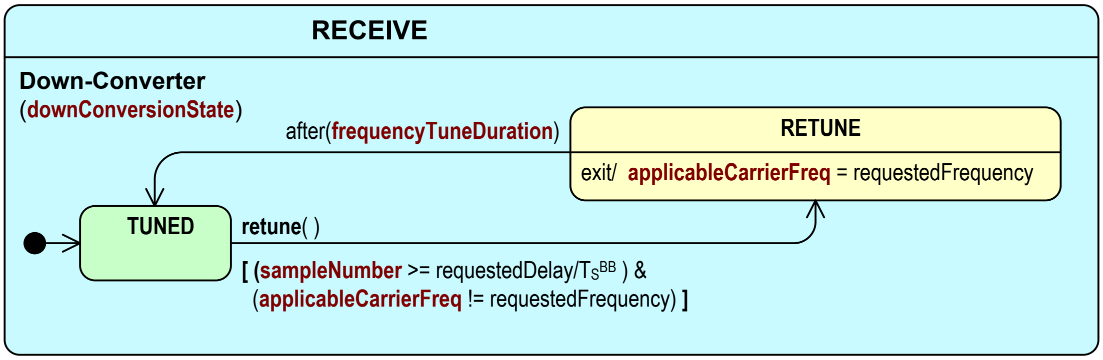

Figure 9 Receive Channel Operational State Diagram (RECEIVE Substates)

The Down-Converter states are as follows:

- TUNED – The state transitioned to on entry.
- RETUNE – The state transitioned to when a *retune* operation has been issued. A transient state that is exited as soon as the requested characteristics have been established, i.e. after *frequencyTuneDuration*.

3.2.2.2 Burst Controller State

The *Receive Channel* burst controller states are as follows:

- READY – The state transitioned to on successful startup and after recovery from a previous receive cycle.
- RECOVER – The state transitioned to on *Idle* signal reception (from Operational State). A transient state that is exited as soon as the *Receive Channel* has recovered from a previous receive cycle (*recoveryDuration*).

The burst controller region allows to consider time intervals where usability of the receiver is intermitted due to recovery, even if no tuning needs to take place.

3.2.3 Latencies and Reactivity Summary

Previous clauses show the *Absolute Transceiver*s behavior under normal operation conditions. That particularly requires to obey any of the transceivers implementation real-time constraints. The characteristics necessary to consider in order to avoid usage fault conditions with regard to time can be grouped into categories as follows:

- Timely operation invocation constraints, identifying the latest (and if so, the earliest) point in time where an operation may be invoked:
    - *Minimum Invocation Lead Time* – An operation has to be issued early enough in order to be executed and to be effective at the required point in time.
    - With sequential tuning association an earliest point in time is associated with *setTuning* and *retune* operations.
- Downtime of a transceiver due to internal processes, identifying the validity of a requested *Transceiver Time* for scheduling an absolute burst:
    - Tune Duration – The minimal gap between two bursts due to tuning activities. Tune duration represents the base term, which specific values for preset, frequency and power tuning are inherited from.
    - Recovery Duration – The gap between two bursts even if no tuning is necessary at all.

Figure 10 shows the *Absolute Transceiver*s latencies and reactivity model applied with the *use case*.

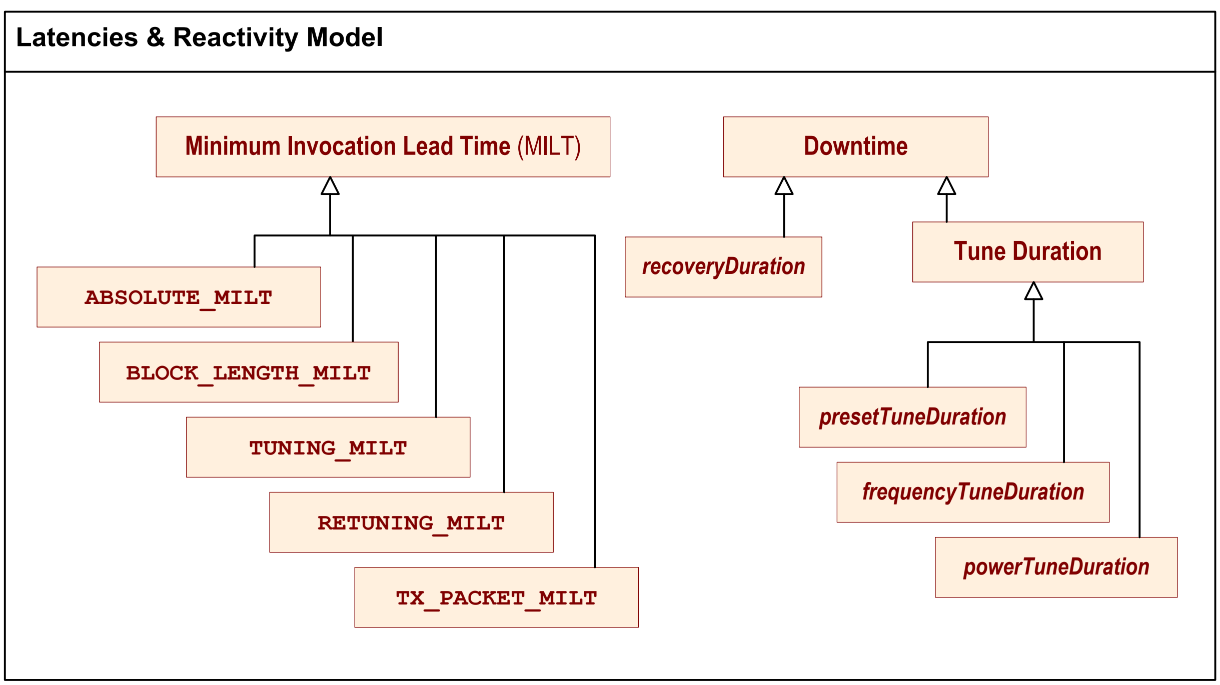

Figure 10 Transceiver Latencies and Reactivity Model Class Diagram

3.2.3.1 Minimum Invocation Lead Time

For the *Absolute Transceiver* considered with the *use case* a *Minimum Invocation Lead Time* as defined with [Ref1, section 4.14, *Invocation delay*] will be associated (refer also to Figure 5, Transceiver API Interface Class Diagram) with operations as follows:

- *AbsoluteCreation::scheduleAbsoluteBurst()*
- *SamplesTransmission::pushTxPacket()*
- *InitialTuning::setTuning()*
- *Retuning::retune()*
- *BlockLength::setBlockLength()*

3.2.3.2 Tune Duration and Recovery Duration

Downtimes of the system need to be considered in order to validate a desired *burst start time*.

The *use case*, for the sake of simplicity and evident presentation, presumes potential downtimes with quantified and known values as follows:

- *frequenyTuneDuration*
- *powerTuneDuration*
- *presetTuneDuration*
- *recoveryDuration*

Inherited parameters for tune duration allow for considering when only frequency, power, or preset is tuned. Any combination thereof will get applied the maximum duration of the respective set.

The *recoveryDuration* characteristic allows for considering an imperative gap between two bursts even if no tuning takes place at all.

Mapping to rapidity properties as specified with [Ref1, section 4.8, *Rapidity*] is as follows:

Downtime characteristic as introduced by *use case*	**Rapidity property** as defined by the *specification*	**Notes**
Tune Duration	**INTER-BURST**	The base term for the residence time in the TUNE state.
presetTuneDuration	**INTER-BURST__NEW_TUNING_PRESET**	
frequencyTuneDuration	**INTER-BURST__NEW_FREQUENCY** **RETUNING_DURATION__NEW_FREQUENCY**	Assumed to be the same value for TUNE and RETUNE state.
powerTuneDuration	**INTER-BURST__NEW_GAIN** **RETUNING_DURATION__NEW_GAIN**	Assumed to be the same value for TUNE and RETUNE state.
recoveryDuration	**INTER-BURST__NO_TUNING_CHANGE**	

Table 4 Use Case Latency Model Mapping to Rapidity Properties

Figure 11 illustrates the Latencies and Reactivity Model applied with the *use case* using the *Transmit Channel*.

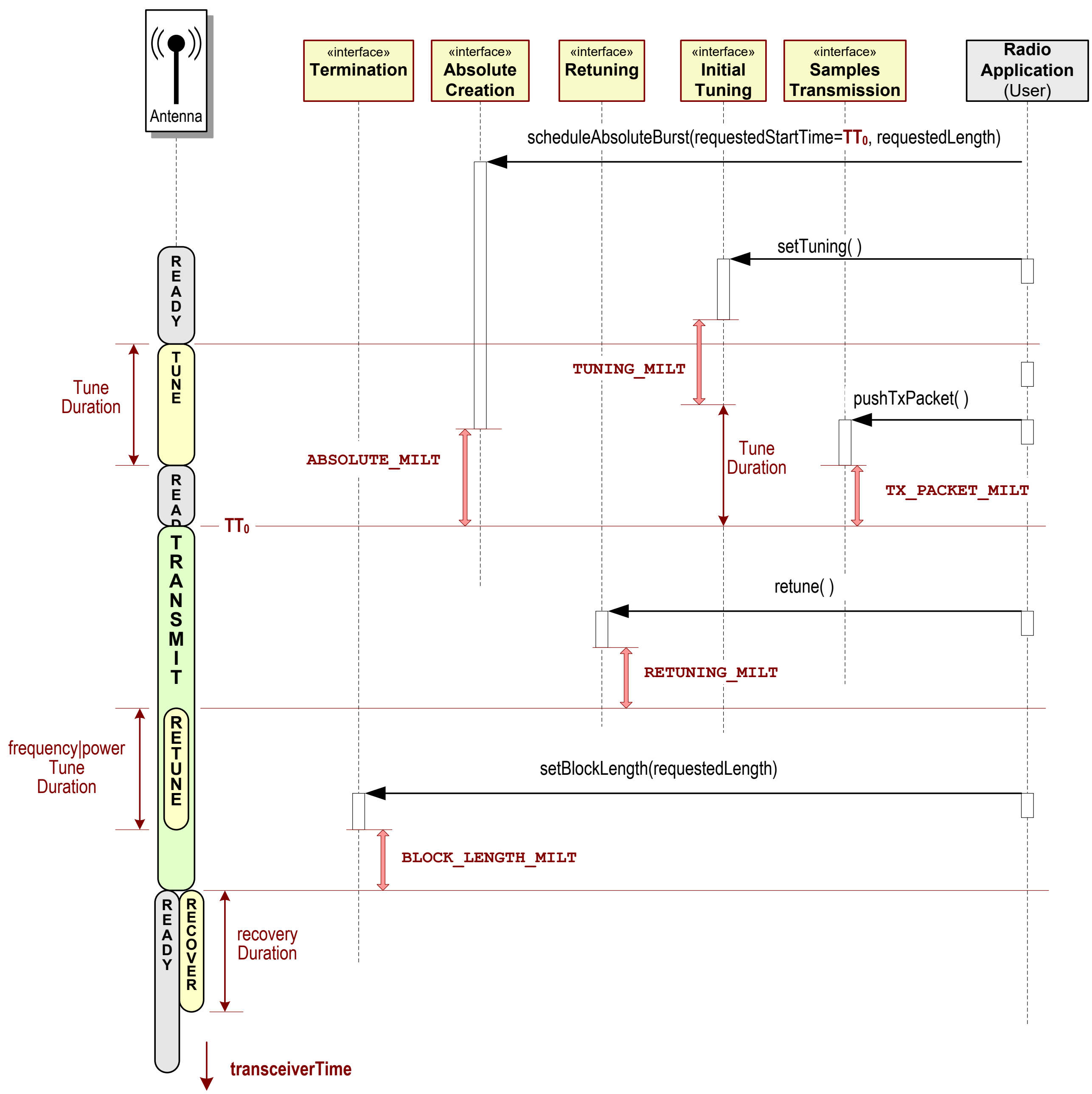

Figure 11 Latencies and Reactivity Model Sequence Diagram Illustration

3.3 Sequence Diagrams

3.3.1 Schedule Absolute Burst for a particular time (in terms of UTC)

Description

The *Transmit Channel* creates a transmit cycle at a particular time in terms of Coordinated Universal Time (UTC). The transmitter is part of a system where *Transceiver Time* is synchronized within the system and where a 'Timing Service' provides the capability to query UTC together with an associated timestamp in terms of *Transceiver Time*.

The *radio application* sets tuning profile, usually tuning preset, frequency and gain (step 1) as required.

The *radio application* then queries UTC from the timing service (step 2) and calculates the corresponding *burst start time* (in terms of *Transceiver Time*, step 3) as follows:

$$\textit{requestedStartTime} = TT_1 = UTC_1 - UTC_0 + TT_0$$

The *radio application* then schedules a transmit burst for the desired point in time in terms of UTC (step 4) and pushes the baseband samples (step 5).

Pre-conditions

The *Transmit Channel* is in READY operational state and no operations are pending on any of the interfaces.

Post-conditions

The sequence of samples has been subject to transposition to radio frequency signal and emitted over the antenna interface.

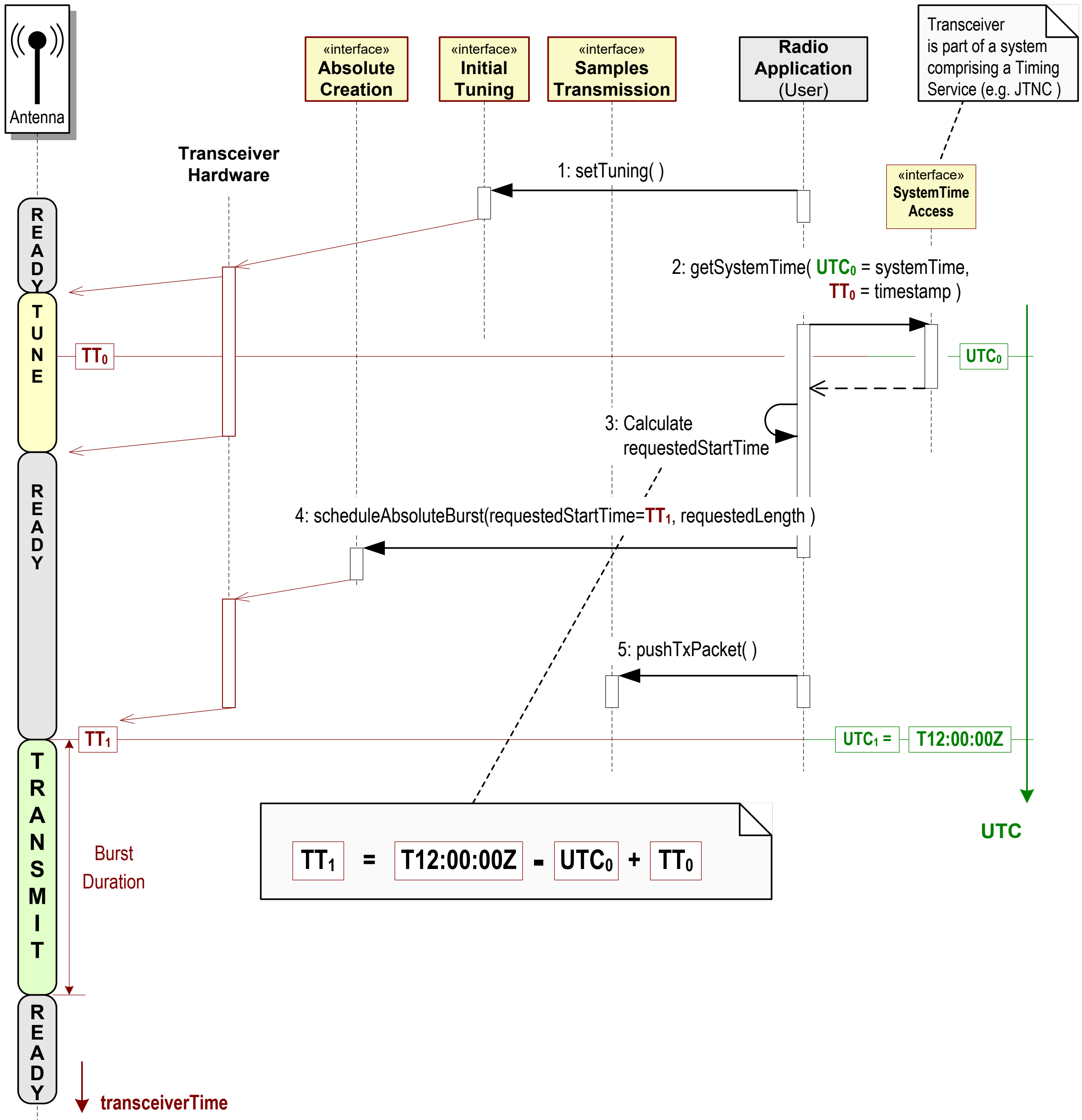

Figure 12 Transmit Channel Schedule Absolute Burst Sequence Diagram

3.3.2 Schedule successive Absolute Burst after minimal downtime

Description

The *Transmit Channel* creates a transmit cycle at a particular time in terms of *Transceiver Time*, followed by a second and third transmit cycle while down-times of the system due to tuning and recovery activities are kept at minimum feasible values.

The *radio application* sets tuning profile, usually tuning preset, *carrier frequency* and gain (step 1) as required and pushes L1 baseband samples (step 2). The *radio application* then queries current *Transceiver Time* (step 3) and schedules a transmit burst of *burst length* L1 for *Transceiver Time* TT1 (step 4).

The *radio application* issues a *setTuning* operation for the successive burst, using a tuning profile where only a new *carrier frequency* F2 is used (step 5).

The *radio application* calculates the corresponding *burst start time* (in terms of *Transceiver Time*, step 6) for the second burst, considering *burst duration* of the first burst, as follows:

$$requestedStartTime = TT_2 = TT_1 + L1*T_S^{BB} + \max(frequencyTuneDuration, recoveryDuration)$$

The *radio application* then schedules a transmit burst for the desired point in time (step 7) and pushes L2 baseband samples (step 8).

The valid *burst start time* for the third burst is calculated (step 9) to

$$requestedStartTime = TT_3 = TT_2 + L2*T_S^{BB} + recoveryDuration$$

The *radio application* issues the respective *scheduleAbsoluteBurst* (step 10) and *pushTxPacket* (step 11) operations.

Pre-conditions

The *Transmit Channel* is in READY operational state and no operations are pending on any of the interfaces.

Post-conditions

The sequence of samples relating to any of the tree bursts have been subject to transposition to radio frequency signal and emitted over the antenna interface.

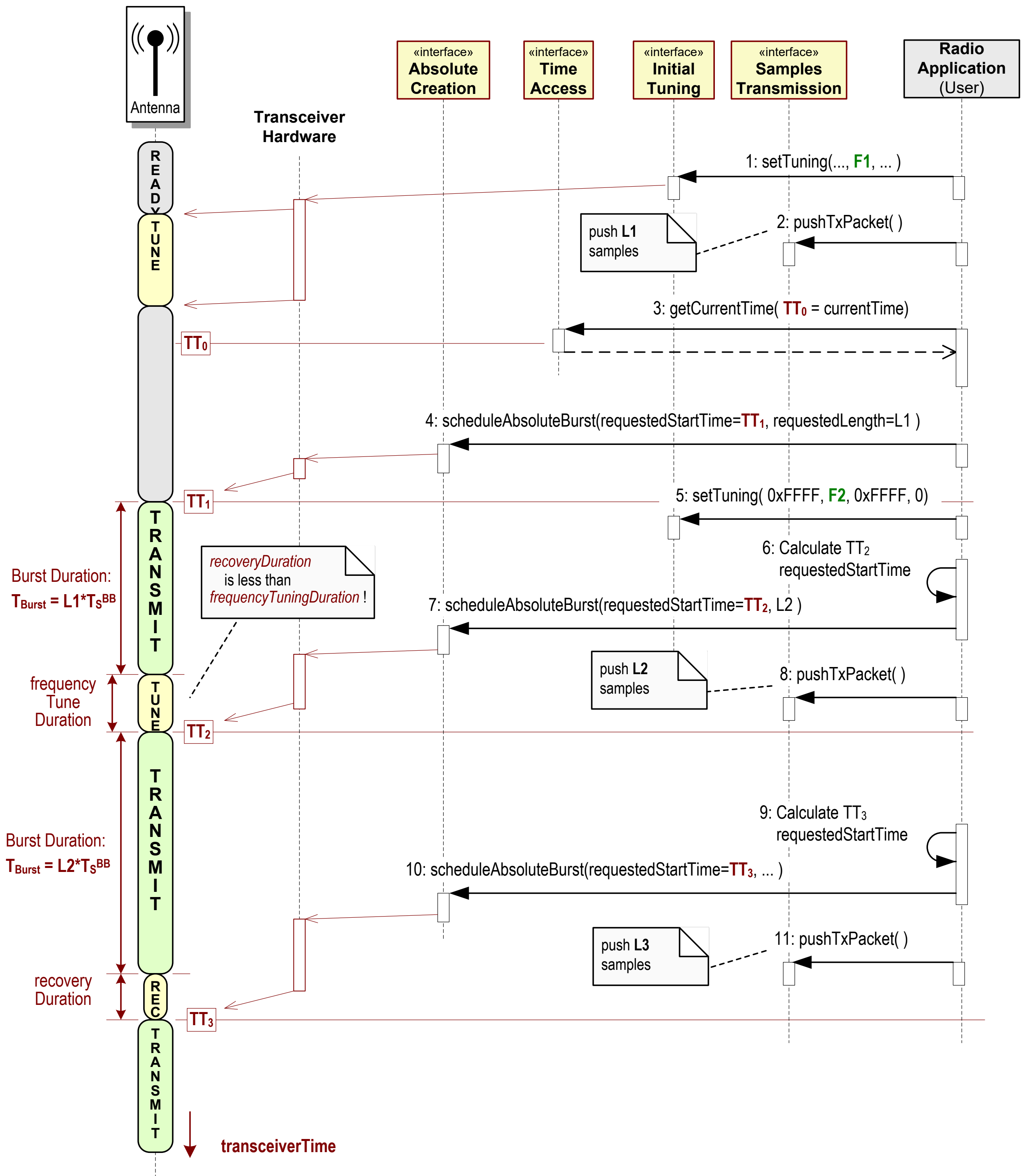

Figure 13 Transmit Channel Schedule Successive Absolute Bursts Sequence Diagram

3.3.3 In-burst Tuning

Description

The Transmitter creates a transmit cycle at a particular time in terms of *Transceiver Time*.

The *radio application* schedules the transmit burst (step 1) and pushes L1 samples to be transmitted at *carrier frequency* F1 (step 2).

The *radio application* then issues a *retune* operation in order to change the *carrier frequency* after L1 samples have been transmitted (step 3). Down-time due to retuning is considered by calculating (step 4) the respective number of ‘zero samples’ that will not be subject to transposition into radio signal as follows:

$$L0 = \mathit{frequencyTuningDuration} / Ts^{BB}$$

The L0 zero samples are pushed (step 5).

The *radio application* finally pushes L2 samples to be transmitted at *carrier frequency* F2 (step 6) and terminates the transmit cycle properly (step 7).

Pre-conditions

The *Transmit Channel* is in READY operational state and no operations are pending on any of the interfaces. The *Transmit Channel* has been tuned to *carrier frequency* F1.

Post-conditions

The sequence of L1 and L2 samples has been subject to transposition to radio frequency signal and emitted over the antenna interface.

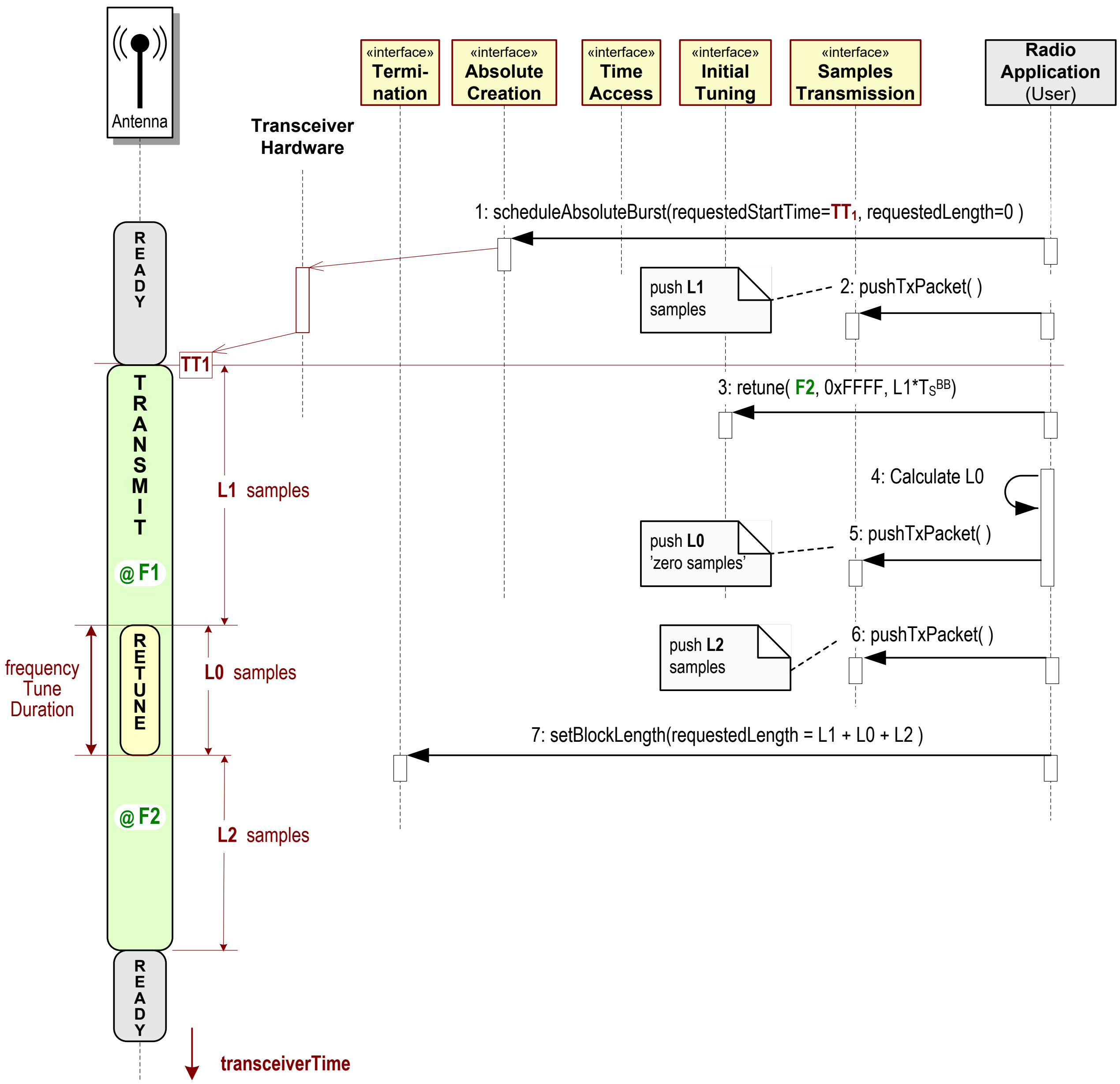

Figure 14 Transmit Channel In-burst Tuning Sequence Diagram

4 Half-duplex Transceivers

Half-duplex transceivers are a popular class of transceivers where transmit and receive cannot happen at the same time.

4.1 Transceiver Characteristics Decomposition

By the class diagram presented with Figure 15 the object-oriented model of the half-duplex *Absolute Transceiver* is identified.

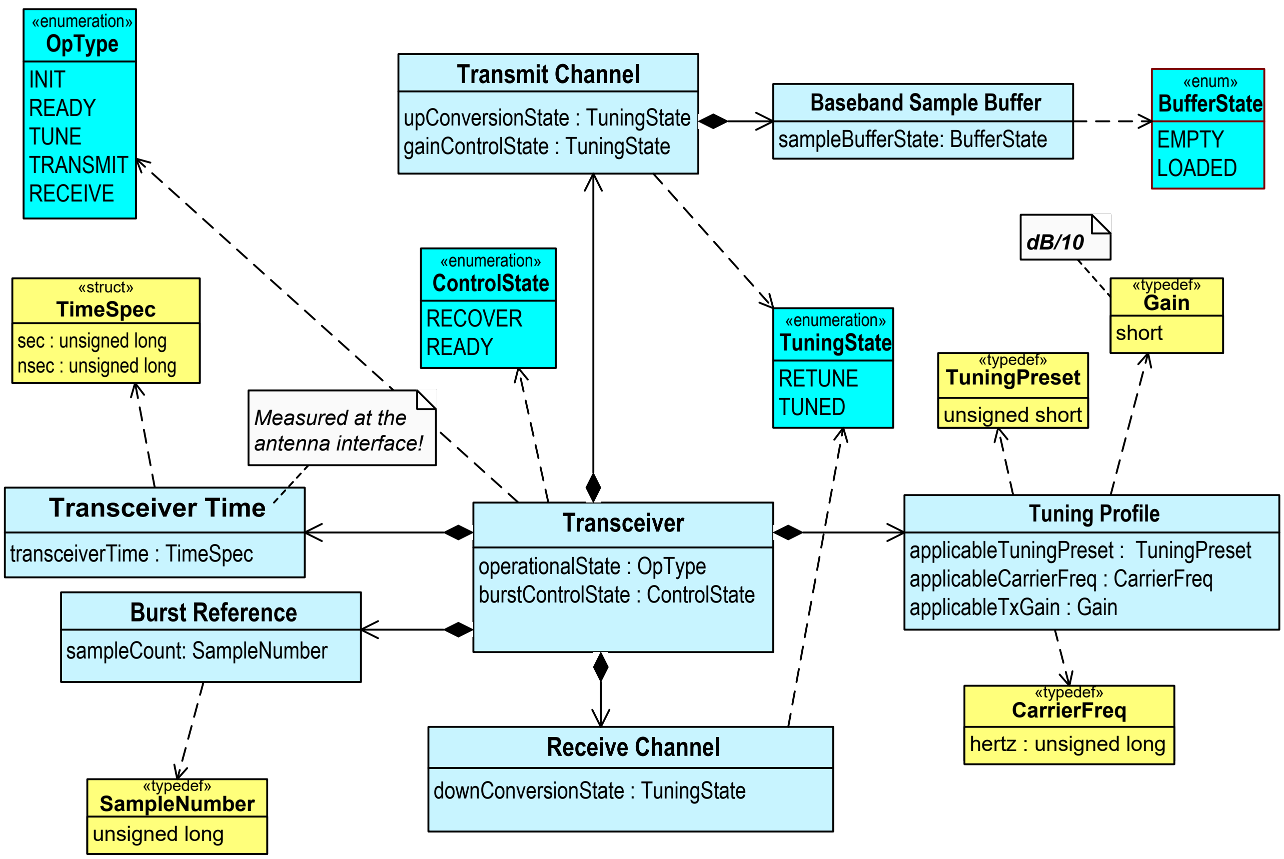

Figure 15 Half-duplex Absolute Time Controlled Transceiver Characteristics Decomposition

Comparison with the full-duplex transceiver model, presented with Figure 4 in section 2.2, *Transceiver Characteristics* Decomposition, shows the following significant differences:

- State machines from the previously independent channels are no longer orthogonal and do collapse, particularly the operational state.
- Beside *Transceiver Time* there is only a single burst reference necessary.
- Likewise there is only a single tuning profile.

Attributes that are specific to the *Transmit Channel* and *Receive Channel* are preserved.

4.2 Service States

The half-duplex *Absolute Transceiver*s composite state diagram is shown in Figure 16. It contains three orthogonal regions:

- The Operational State
- The *Transmit Channel* Sample Buffer State
- The Burst Controller State

4.2.1.1 Operational State

The Transceiver operational states are as follows:

- READY – The state transitioned to upon successful startup, after a transmit or receive cycle has been terminated, and after tuning has been established.
  - The Transceiver initializes its burst reference (*sampleCount=0*) on entry.
- TRANSMIT – The state transitioned to when a *scheduleAbsoluteBurst* operation has been issued. Guard conditions do apply as follows:
  - Monotonic clock *Transceiver Time* has reached or is greater than the desired *burst start time* (Note: The latter is a specific behavior of the transceiver considered here).
  - Baseband samples have been pushed timely (*sampleBufferState == LOADED*).
  - The transceiver has recovered from a previous transmit or receive cycle (*burstControlState == READY*). Note that there may be an imperative gap (*recoveryDuration*) between two consecutive bursts, even if there is no tuning.

  Radio emission takes place with properly established transfer characteristics.

  The state is exited after *Burst Duration*, i. e. when the requested number of baseband samples has been processed or when a *stopBurst* operation has been issued. On exit an *Idle* signal is sent to burst controller and transmit channel sample buffer.

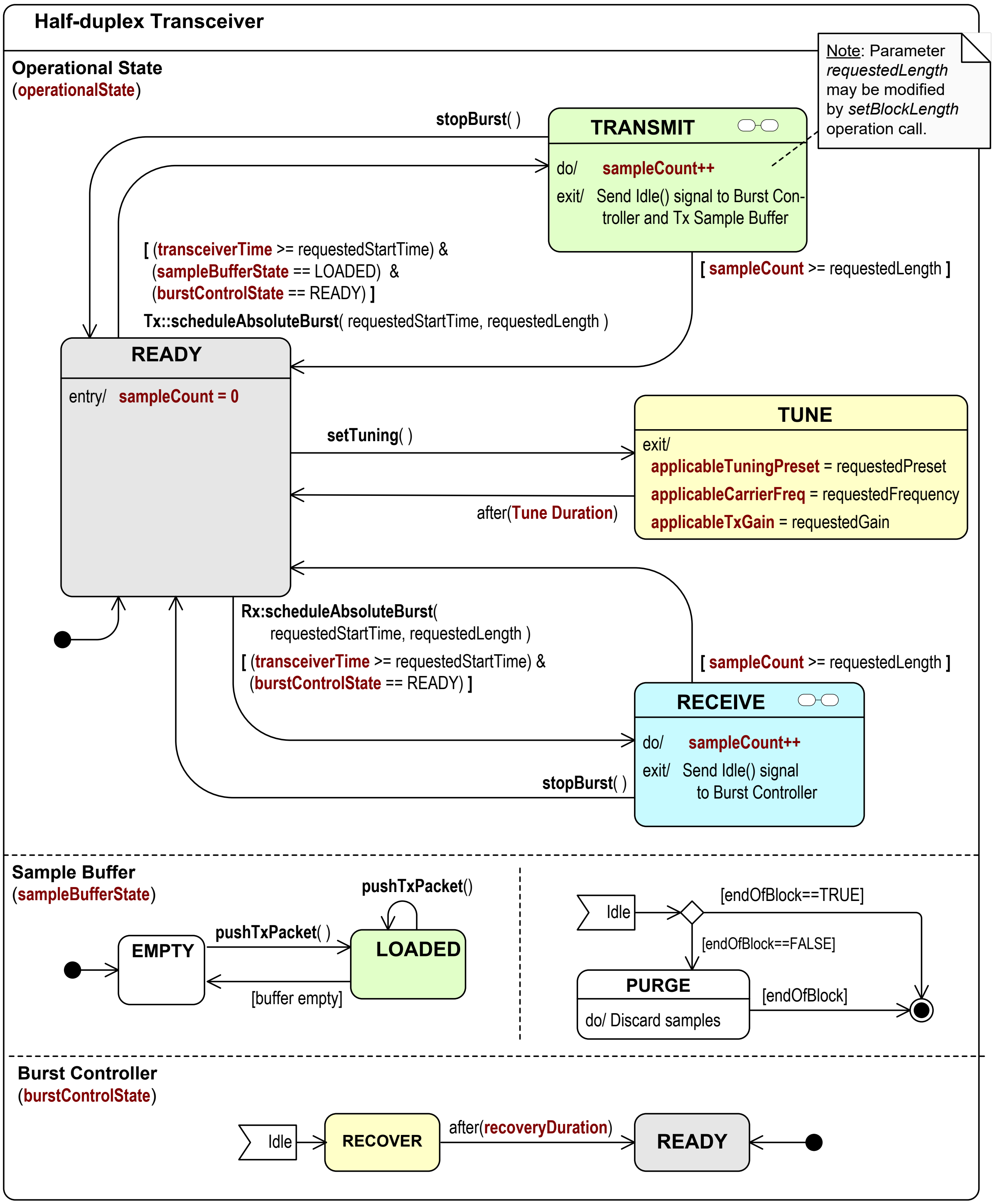

Figure 16 Half-duplex Transceiver Operational State Diagram

- RECEIVE - The state transitioned to when a *scheduleAbsoluteBurst* operation has been issued for the current burst in process. Guard conditions do apply as follows:
    - Monotonic clock *Transceiver Time* has reached or is greater than desired *burst start time* (Note: The latter is a specific behavior of the transceiver considered here).
    - The transceiver has recovered from a previous transmit or receive cycle (*burstControlState == READY*). Note that there may be an imperative gap (*recoveryDuration*) between two consecutive bursts, even if there is no tuning.

  Radio signal reception takes place with properly established transfer characteristics.

  The state is exited after *Burst Duration*, i.e. when the requested number of baseband samples has been processed or when a *stopBurst* operation has been issued. On exit an *Idle* signal is sent to burst controller.
- TUNE – The state transitioned to when a *setTuning* operation has been issued for the current burst in progress. TUNING is a transient state that is exited as soon as the requested transposition characteristics are established (*tuningDuration*).

4.2.1.1.1 TRANSMIT and RECEIVE Substates

TRANSMIT and RECEIVE substates are as with the full-duplex transceiver. See section 3.2.1.1.1, *TRANSMIT Detail* and Substates and section 3.2.2.1.1, *RECEIVE Detail and Substates*.

4.2.1.2 Burst Controller State

The Transceiver burst controller states are as follows:

- READY – The state transition to on successful startup and after recovery from a previous transmit or receive cycle.
- RECOVER – The state transitioned to on *Idle* signal reception (from Operational State). A transient state that is exited as soon as the transceiver has recovered from a previous transmit or receive cycle (*recoveryDuration*).

The burst controller region allows to consider time intervals where usability of the transceiver is intermitted due to recovery, even if no tuning needs to take place.

4.2.1.3 Sample Buffer State

The *Transmit Channels* baseband sample buffer state is the same as with the full-duplex Transceiver. See section 3.2.1.3, *Sample Buffer State*.

4.3 Sequence Diagrams

4.3.1 Schedule Transmit Burst after waveform time synchronization over the Air

Description

The *radio application* synchronizes by receiving its time information over the air and controls the transmitter in order to create a transmit cycle at a particular time in terms of its waveform time.

The *radio application* sets tuning profile (step 1) as required and schedules a receive cycle (step 2) that is directly started.

The transceiver pushes received samples to the *radio application* (step 3).

The *radio application* looks for a useful signal within the received sequence of samples containing waveform specific time information (step 4).

The *radio application* then queries the *burst start time* of the current receive cycle (step 5) and terminates the receive cycle (step 6).

From that information the *burst start time* (*requestedStartTime*) in terms of *Transceiver Time* for a radio channel access can be calculated (step 7). The required tuning is done (step 8), the transmit burst is scheduled (step 9) and finally the baseband samples to be transmitted are pushed (step 10).

Pre-conditions

The Transceiver is in READY operational state and no operations are pending on any of the interfaces.

Post-conditions

The sequence of samples pushed to the *Tx channel* has been subject to transposition to radio frequency signal and emitted over the antenna interface.

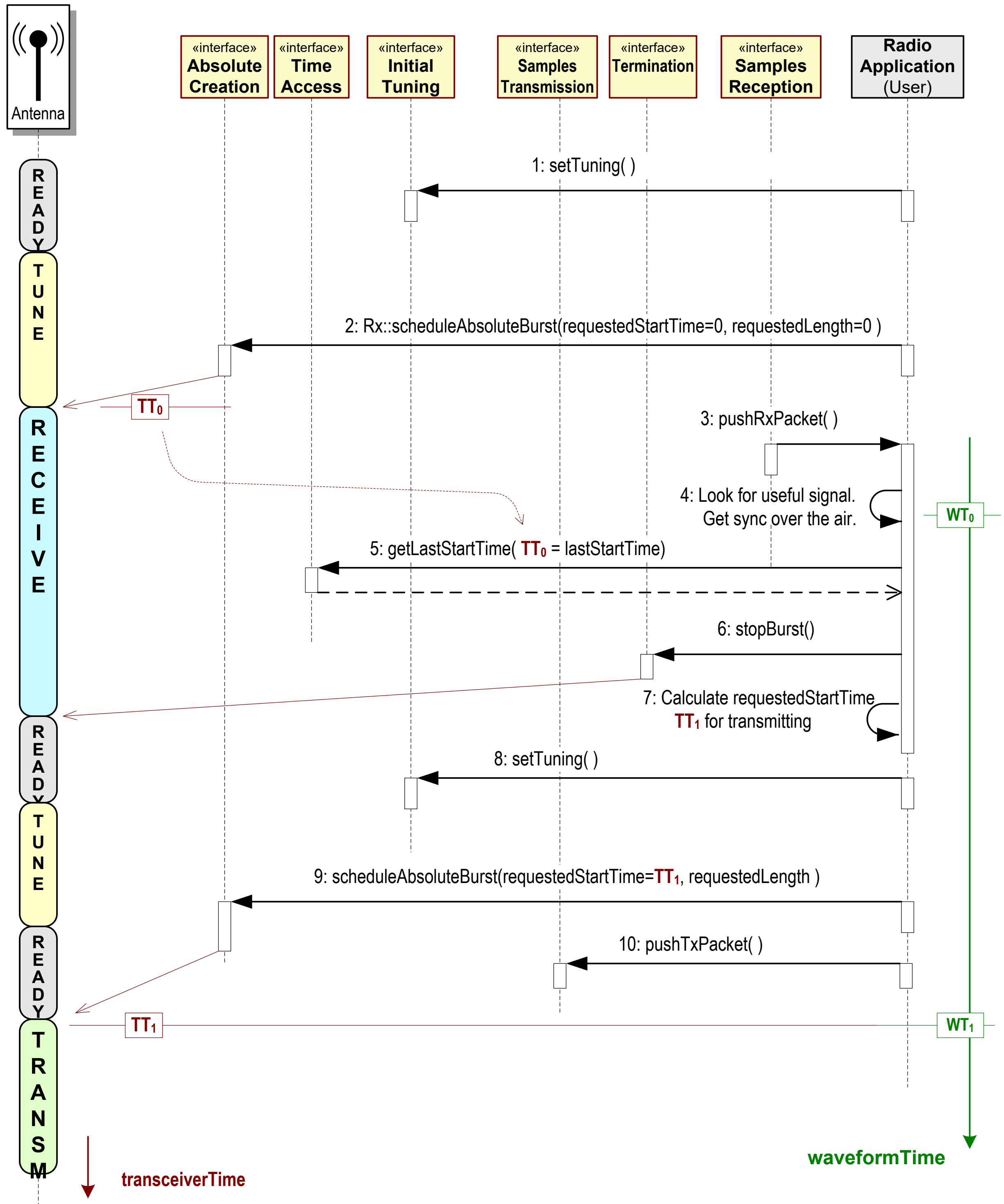

Figure 17 Waveform Synchronization over the Air Sequence Diagram

5 Glossary

The glossary covers and recaps (from the *specification*) the essential terms used throughout this document.

Absolute Transceiver A Transceiver implementing a monotonic clock in order to maintain its time scale. That time scale, referred to as *Transceiver Time*, is then used for providing a *radio application* with real-time burst control capability.

Baseband Signal The sequence of complex-valued samples exchanged between *radio application* and *Tx channels* or *Rx channels*.

Baseband Sampling Frequency The discrete-time *baseband signals* associated sampling rate, denoted Fs^{BB} throughout this document.

Burst Duration The length of a burst in terms of time.

Burst Length The number of samples that are transposed from baseband into RF for a transmit cycle. Also the number of samples that are generated when transposing RF to baseband for a receive cycle.

Burst Start Time The instant of time - for an *Absolute Transceiver* in terms of *Transceiver Time* maintained at the antenna - when a transmit or receive cycle begins, denoted t_{Start} throughout *specification* and *use case*.

Carrier Frequency The frequency of the sinusoidal carrier signal that is modulated by the digital complex-valued baseband signal (complex envelope).

Channel Bandwidth The (single-sided) width of the passband at radio frequency the transmit channel, respectively receive channel provides.

Specification The Transceiver Facility PIM Specification Version V2.0.0

Transceiver Time An *Absolute Transceivers* monotonic clock based time scale, maintained with respect to the antenna.

Use case This document.

END OF THE DOCUMENT