

# CoWare® SPW LTE Library

*Accelerating Wireless Design Productivity for Next Generation Cellular System Design*

## **SPW Wireless Reference Libraries**

SPW Wireless Reference Libraries provide an unmatched increase in productivity for wireless physical layer system design. They can be used by network operators for investigation of system performance both for scenarios specified in the standard as well as in corner cases relevant to optimize network performance and cost. For basestation design teams as well as handset modem design teams, the SPW library not only provides a reference model for validation of their specifications but as well the provided source code provides very valuable insight into the standards definition, which may otherwise require months of perusing the written standards documents. Also the source code can be used as a starting point for today's mostly processor based implementation of wireless systems.

The reference models provide ideal receivers (with perfect knowledge of the channel) and non-ideal receivers (which must estimate the channel characteristics). The ideal receiver provides the maximum achievable performance for comparison against real and non-ideal receiver implementations.

Wireless Reference Libraries are organized into specific regression test benches which mirror the tests being specified in the standards reference documents. The user can immediately run these regressions and easily modify system parameters of interest in order to study performance impact. By replacing or modifying blocks or subsystems the user can quickly adapt the reference to the specific implementation for the end product. The ability of SPW to start as many regression simulations as possible limited only by the server infrastructure at hand provides wireless designers using the Reference Libraries with unmatched exploration opportunities hence improving product performance with the time-to-market window.

The Wireless Reference Libraries can be used for block level verification of hardware and software components. HDL Cosimulation as well as target code simulation either on the host or using an Instruction Set Simulator (ISS) for the target processor enables the use of the library as a verification environment.

The Wireless Reference Libraries are developed by a team of wireless system designers that collectively have 50+ years of wireless design expertise. They are validated against available references from the standard, test equipment as well as with lead customers.

## **Overview**

The LTE library supports downlink, uplink and cell search models. It also contains specific channel models that are specified in the standard. All models support the full range of MIMO configurations in the standard and can be extended easily as well to experiment with other configurations by the user. CoWare continues to update the library as the standard evolves.

## **LTE Version**

- Supports the design of 3GPP LTE products
- Conforms to 3GPP/TS36.101&104, rev. 8.7

## **Downlink Channel**

The SPW LTE Downlink Channel system is a complete end to end baseband model for simulating UE.

Demodulation of the Physical Downlink Shared Channel (PDSCH). While many aspects of the LTE Downlink can easily be simulated using this system, the system is pre-configured to verify the PDSCH demodulation performance requirements in 3GPP TS 36.101 section 8.2.

The system includes a complete PDSCH transmitter with control channels and an ideal receiver supporting both spatial multi-

## **H I G H L I G H T S**

- End-to-end physical layer (baseband) simulation model developed using CoWare Signal Processing Designer
- Supports the design of 3GPP LTE standard-based products
- Provides several LTE system test benches for throughput analysis
- Conforms to current standards for 3GPP LTE
- Includes fixed-point algorithmic design capture and datapath performance analysis
- Provides all models in hierarchical block diagrams with underlying leaf level blocks in C-source code.
- Enables co-simulation of C, C++, HDL, AMS and/or MATLAB blocks in a single simulation process
- Enables export of LTE blocks into CoWare Platform Architect PHY/MAC cross-layer joint optimization and verification
- Programmable Accelerators designed with CoWare Processor Designer can be integrated into LTE reference test benches for component level verification

plexing and transmit diversity with up to four antennas. It uses the Hybrid ARQ (HARQ) protocol and PDSCH channel coding and decoding for either one or two simultaneous data streams. In addition to layer mapping both transmitter and receiver supports precoding, including Cyclic Delay Diversity (CDD) and Codebook lookup when using spatial multiplexing.

The channel model adheres fully to the 3GPP LTE standard. In addition to static propagation it has the multi-path fading conditions and includes delay profiles for Extended Vehicular A (EVA), Extended Pedestrian A (EPA) and Extended Typical Urban (ETU) modes. It also has a MIMO channel with low, medium and high correlation matrices,

configurable for any number of transmit and receive antennas. The High Speed Train (HST) scenario mode is supported as well.

The ideal receiver model can be configured as a Zero Forcing (ZF), Minimum Mean Square Error (MMSE), Maximum Ratio Combining (MRC) or Maximum Likelihood (ML) receiver.

All models support Adaptive Modulation and Coding (AMC) during runtime where both the number of Resource Blocks and type of modulation, QPSK, 16-QAM or 64-QAM, can change on a frame by frame basis.

#### Transmitter Models

- HARQ protocol data generation
- Transport Block CRC
- Code Block Segmentation
- Code Block CRC
- Turbo Coding
- Sub-block Interleaving
- Bit Collection
- Scrambling
- Symbol Modulation
- Layer Mapping
- Precoding
- Resource Element Mapping
- OFDM Symbol Generation
- Cyclic Prefix Insertion

#### Channel Model

- Static Propagation
- Multi-path fading (EPA, ETU, EVA)
- High Speed Train
- MIMO

#### Receiver Models

- Sub-carrier Extraction
- Resource Element Demapping
- MIMO Receiver
- Predecoding
- Symbol Demodulation
- Descrambling
- Sub-block Deinterleaving

- Soft Buffer Combining
- Turbo Decoding
- ACK/NACK Signal Generation

#### Practical LTE Downlink Channel System

This system is similar to the LTE Downlink Channel system except that it uses a practical channel estimator. In this system model, the channel estimates at each sub-carrier for each combination of transmit to receiver antenna pairs are generated from the received signal alone without any knowledge of the radio channel state. The estimates are generated by extracting the transmit antenna specific reference signals from the received antenna signals and dividing by the actual reference signal values to give the channel estimates at the reference signal locations. These channel estimates are then filtered over one sub frame using a 2 dimensional separable filter to produce channel estimates at all resource element locations. These channel estimates are then used by the MIMO receiver to form an estimate of the signal from each transmit antenna.

#### LTE Downlink Control Channel System

This system is similar to the LTE Downlink Channel system except that in addition to the Physical Downlink Shared Channel (PDSCH) it includes the transmission and reception of the downlink control channels. The SPW LTE Downlink Control Channel system is a complete end to end baseband model for simulating eNodeB to UE transmission of the Physical Downlink Control Channel (PDCCH), the Physical Control Format Indicator Channel (PCFICH) and the Physical Hybrid-ARQ Indicator Channel (PHICH). The LTE Downlink Control Channel system was designed to run the 3GPP TS 36.101 section 8.4 PDCCH/PCFICH demodulation performance tests.

In addition to the PDSCH transmitter and channel models in the Downlink Channel system, the following models are in the Downlink Control Channel system:

#### Transmitter Models

- DCI Encoder
- Convolutional Encoder
- Control Bit Collection
- PDCCH Transmitter
- Quadruple Sub-block Interleaver
- PCFICH Transmitter
- PHICH Group Generator
- PHICH Diversity Transmitter
- Control Symbol Mapping

#### Receiver Models

- Control Channel Demapping
- PCFICH Receiver
- PDCCH Receiver
- DCI Decoder
- Viterbi Decoder
- Quadruple Sub-block Deinterleaver

The PDCCH includes the Downlink Control Information (DCI) encoder which includes CRC, convolutional coding, interleaving and bit collection. It is scrambled, modulated, interleaved, layer mapped and coded for transmit diversity with the PDCCH Transmitter model. Similarly the system includes a PDCCH receiver and DCI Decoder model. The models can be easily combined to simulate a system with multiple PDCCHs.

The PCFICH transmitter includes coding, scrambling, modulation, layer mapping and transmit diversity. Similarly the PCFICH receiver includes layer demapping, demodulation, descrambling and decoding.

The PHICH model includes support for multiple PHICH Groups with up to 8 users in each group where the code and power of each user can be individually set. It also includes encoding, scrambling and PHICH transmit diversity.

#### Additional Downlink Models

The LTE Downlink Channel and Downlink Control Channel transmitters can be modified to include the Primary Synchronization Signal (PSS), the Secondary Synchronization

Signal (SSS) and the Physical Broadcast Channel (PBCH) signals. There is also receiver for the Physical Hybrid ARQ Indicator Channel (PHICH) available.

- Primary Synchronization Signal (PSS) Generator
- Secondary Synchronization Signal (SSS) Generator
- Physical Broadcast Channel (PBCH) Encoder
- Physical Broadcast Channel (PBCH) Transmitter
- Downlink Channel Mapping
- Physical Hybrid ARQ Indicator Channel (PHICH) Receiver

### ***Uplink Channel***

The SPW LTE Uplink Channel system is a complete end to end baseband model for simulating UE to eNodeB transmission modeling the Physical Uplink Shared Channel (PUSCH). The LTE Uplink system model is set up by default to run all of the 3GPP TS 36.104 section 8.2.1 receiver performance tests.

The SPW LTE Uplink transmitter includes the full Hybrid ARQ (HARQ) protocol, PUSCH channel encoding, symbol mapping for QPSK, 16-QAM or 64-QAM transmission, reference signal generation, transform precoding for SC-FDMA baseband signal generation, and resource mapping with frequency hopping.

The SPW LTE radio channel model included in the LTE Uplink system model adheres fully to the 3GPP LTE standard. In addition to static propagation it has the multi-path fading conditions and includes delay profiles for Extended Vehicular A (EVA), Extended Pedestrian A (EPA) and Extended Typical Urban (ETU) modes. It also has a MIMO channel with low, medium and high spatial correlation matrices, configurable for any number of transmit and receive antennas. The High Speed Train (HST) scenario mode is supported as well.

The SPW LTE Uplink receiver is an ideal receiver which uses knowledge of the radio channel model state to produce an ideal

channel estimate at each sub-carrier location from the transmit antenna to each receive antenna. The MIMO receiver uses the channel estimates to perform frequency domain equalization of the received signal, using either the Zero Forcing (ZF) or Minimum Mean Squared Error (MMSE) method. Transform decoding is applied and the signal estimate is then demodulated, decoded and then the CRC is checked to produce the ACK/NAK response to complete the HARQ protocol.

The SPW LTE Uplink system model is pre-configured to measure the average throughput to test compliance with the requirements of the 3GPP TS 36.104 receiver performance tests though the modular and hierarchical nature of the design allow any aspect of the LTE Uplink physical channel to be measured and studied. The hierarchical nature of the design also allows alternate receiver implementations to be quickly implemented and tested and for final implementations in software or hardware to be imported and characterized.

### **Transmitter Models**

- HARQ protocol data generation
- Transport Block CRC
- Code Block Segmentation
- Code Block CRC
- Turbo Coding
- Sub-Block Interleaving
- Bit Collection
- Scrambling
- Symbol Modulation
- Transform Precoding
- Reference Signal Generation
- Frequency Hopping Pattern Generation
- Resource Mapping
- SC-FDMA Signal Generation
- Cyclic Prefix Insertion

### **Radio Channel Model**

- MIMO
- Static Propagation

- Multi-path fading (EPA, ETU, EVA)
- High Speed Train
- Arbitrary Spatial Correlation
- Antenna Polarization
- Antenna Gain Imbalance

### **Receiver Models**

- Ideal Channel Estimation
- Sub-Carrier Extraction
- Resource Element Demapping
- MIMO Receiver
- Transform Decoding
- Soft Symbol Demodulation
- Descrambling
- Sub-Block Deinterleaving
- Soft Buffer Combining
- Turbo Decoding
- ACK/NAK Generation
- Throughput Calculation

### ***Uplink Control Channel***

The SPW LTE Uplink Control Channel system is a complete end to end baseband model for simulating UE to eNodeB transmission modeling the Physical Uplink Control Channel (PUCCH). The LTE Uplink Control system model can be easily set up to run all of the tests in 3GPP TS 36.104 section 8.3 Performance requirements for PUCCH.

The SPW LTE Uplink Control transmitter includes all supported PUCCH formats, scrambling, mapping to cyclically shifted sequences and spreading by orthogonal sequences, insertion of reference signals, and resource mapping to physical resources allocated for PUCCH.

The SPW LTE radio channel model included in the LTE Uplink Control system is identical to one used in LTE Uplink system.

The SPW LTE Control Uplink receiver is an ideal receiver which uses knowledge of the radio channel model state to produce an ideal channel estimate at each sub-carrier location from the transmit antenna to each receive antenna. The MIMO receiver uses the channel estimates and the received signal to

form an estimate of the transmitted signal, using the Zero Forcing (ZF), Minimum Mean Squared Error (MMSE) or Maximum Likelihood (ML) method. The signal estimate is then decoded using known cyclically shifted and orthogonal sequences, and demodulated to recover the transmitted control information.

The SPW LTE Uplink system model is configured to measure the missed detection probability of transmitted control information (ACK/NACK or CQI) to test compliance with the requirements of the 3GPP TS 36.104 receiver performance tests.

#### Main LTE PUCCH System Blocks

**LTE PUCCH Symbol Transmit**—Generate control bits, apply proper coding and scrambling (when needed) and modulation to form the control symbols that are to be cyclically shifted and orthogonally spread

**LTE PUCCH Cyclic Shift**—Generate the orthogonal sequence and scrambling sequence used for spreading of modulated PUCCH symbols in formats 1/1a/1b as well as the orthogonal sequence used for generation of reference symbols for all PUCCH formats. Additionally, generate the cyclic shift used to generate the cyclically shifted sequence and finally the parameter determining the physical resource block used for transmission of PUCCH in a given slot.

**LTE PUCCH Symbol Receive**—Recover transmitted control bits by demodulating, decoding and descrambling (when necessary) the received control symbols that are recovered by combining the received cyclically shifted sequences.

**LTE Uplink Sounding Reference Signal**—The SPW LTE Uplink Sounding Reference Signal system models the transmission of these Uplink reference signals used to facilitate frequency dependent scheduling.

The SPW LTE Sounding Reference Signal system uses the cell-specific parameter *srsSubframeConfiguration* to support periodic transmission of SRS over all 15 possible sets of subframes in which SRS can be sent in a given radio frame. It also uses cell-specific

parameter *srsBandwidthConfig* to select one of the eight sets of four SRS bandwidths that can be simultaneously supported in each possible system bandwidth.

#### Main LTE SRS System Blocks

**LTE SRS Transmit**—Generate a full radio frame containing the SRS carrying subframes at their given location

**LTE SRS Length & Index**—Generate the length of the SRS vector and the location index of the SRS symbols within the allocated resource blocks

**LTE SRS Receive**—Recover the SRS symbols from the received radio frame

#### LTE Cell Search

The LTE Cell Search reference system models the procedure a mobile terminal must perform to find a cell (i.e. a base station) to connect to. During the cell search procedure, the mobile obtains the *physical-layer cell identity* as well as the frame timing of the desired cell in presence of signals from interfering cells.

The mobile terminal uses the primary and secondary synchronization signals (P-SCH and S-SCH) to detect the cell ID and frame timing of the desired cell. The primary and secondary synchronization signals are embedded in the middle 72 subcarriers of the sixth and fifth OFDM symbols of first slot of sub frames zero and five, respectively. P-SCH is repeated every 5 ms, while two different S-SCH sequences (S-SCH1 & S-SCH2) are sent over sub frames zero and five.

The cell search is done in two phases. First the primary synchronization signal (P-SCH) is used to obtain slot synchronization. Next, the secondary synchronization signal (S-SCH) is used to obtain frame synchronization and the cell identity.

The LTE Cell Search system is comprised of the following main blocks:

**LTE Cell Model**— This block represents either the desired cell or the interfering cells and the channel between these cells and the mobile terminal.

**LTE Slot Timing**—During cell search, the mobile terminal uses P-SCH to estimate the *symbol* timing of the desired cell in LTE Slot Timing block.

**LTE Strong Cell**—The cell search procedure is required to be able to detect the desired cell in presence of two known stronger interfering cells.

**LTE Frame Time**—After symbol timing is detected in LTE Slot Time block, the received signal is then converted into frequency domain. In LTE Frame Time block, an estimate of P-SCH signal is used as a reference to coherently detect the S-SCH signal, which is then further processed to detect the frame timing of the desired cell.

#### LTE Random Access Channel

The LTE Random Access reference system models the procedure a mobile terminal must perform to gain access and register with a cell (i.e. a base station). During the random access procedure, the mobile sends a random access preamble message to the base station which, if detected will be acknowledged by the base station.

The mobile terminal uses the information from the broadcast channel (P-BCH) to determine the random access channel (RACH) parameters and then selects a RACH preamble from a set of cyclic shifts of a base Zadoff-Chu sequence. The selected preamble is then sent during a prescribed RACH transmission period using 1.25KHz subcarrier spacing. The base station detects this preamble and uses this to determine timing between the mobile and base station.

The RACH preamble detection is done using a frequency domain cross-correlation with the known Zadoff-Chu sequence. Detected peaks in the cross-correlation are examined for their offset from possible cyclic shift locations and this determines the timing offset. The system measures and reports the probably of detection and the probably of false detection of the transmitted RACH preamble messages.

The LTE Random Access reference system includes the following models:

- Transmitter Models
- RACH preamble selection
- Zadoff-Chu sequence generation
- Transform Precoding
- RACH baseband signal generation
- Cyclic Prefix Insertion
- Preamble repeating
- Variable delay offset

#### **Radio Channel Model**

- SIMO
- AWGN propagation model
- Multi-path fading (EPA, ETU, EVA)
- High Speed Train
- Arbitrary Spatial Correlation
- Antenna Polarization
- Antenna Gain Imbalance

#### **Receiver Models**

- Sub-Carrier Extraction
- Frequency domain cross-correlation with known sequence
- Antenna combining
- Preamble repetition combining
- Peak detection and offset calculation
- RACH detection statistics calculation

#### ***Customer Focus***

CoWare provides a complete range of training, support, design methodology consulting, and integration services. Technical support requests are handled directly by experienced design engineers who are fully familiar with the application of CoWare tools and methodologies to real-world designs. Training courses are available at CoWare offices or at the customer site and can be tailored to meet the specific needs of the design team.

#### ***Sales Offices***

CoWare has sales offices in the U.S., Europe, Asia Pacific and Japan. For a complete listing with contact information visit [www.CoWare.com](http://www.CoWare.com). For technical or sales information call 1-888-CoWare8 or email [info@CoWare.com](mailto:info@CoWare.com).



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