Qsys and IP Core Integration

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IP Cores
Cyclone V SoC: A Mix of Hard and Soft IP Cores

IP = Intellectual Property  Core = block, design, circuit, etc.
Hard = wires & transistors  Soft = implemented w/ FPGA

Source: Altera
Example IP Cores

**CPUs:** ARM (hard), NIOS-II (soft)

**Highspeed I/O:** Hard IP Blocks for High Speed Transceivers (PCI Express, 10Gb Ethernet)

**Memory Controllers:** DDR3

**Clock and Reset signal generation:** PLLs
Cyclone V SoC: FPGA layout

Source: Altera
Cyclone V SoC: HPS Layout

Source: NARD, LLC.
Stratix V: FPGA Layout

Source: Altera
Stratix V: Solarflare AoE PCB Layout

Source: Solarflare FDK
Stratix V: Solarflare AoE Qsys Layout

Source: Solarflare FDK
Stratix V: Solarflare AoE Qsys Example

Source: Solarflare FDK
Bridges

A bridge connects two, often different, buses.

Enables multiple clock domains, different protocols (e.g., AXI ↔ Avalon), bus widths, etc.

Example Bridge Types:

SOC HPS ↔ FPGA Bridge

Avalon MM Clock Crossing Bridge

Avalon MM Pipeline Bridge
Cyclone V SoC: FPGA ↔ HPS Bridge

Source: Altera
Clock Crossing Bridge Example
Pipeline Bridge Example

Source: Altera
Altera’s IP Core Integration Tools
The Quartus Megawizard

Source: Altera
Megawizard: Example 10Gb Ethernet PHY

Source: Altera
Megawizard IP Cores

**Arithmetic:** Addition, Subtraction, Multiplication, Division, Multiply-(add|accumulate), ECC

**Floating Point:**

**Gate Functions:** Shift Registers, Decoders, Multiplexers

**I/O Functions:** PLL, temp sensor, remote update, various high speed transceiver related

**Memory:** Single/Dual-port RAM or ROMs, Single/Dual-clock FIFOs, (RAM) Shift registers

**DSP:** FFT, ECC, FIR, etc (large suite specifically for graphics as well)

Note: some megafuunctions are only available on certain FPGAs
Qsys is Altera’s system integration tool for building Network-on-Chip (NoC) designs connecting multiple IP cores.

<table>
<thead>
<tr>
<th>You</th>
<th>Qsys</th>
</tr>
</thead>
<tbody>
<tr>
<td>List the IP components and how you want them connected</td>
<td>Generates the interconnect (arbiters, etc.) adds adapters as necessary, warns of errors</td>
</tr>
</tbody>
</table>
Qsys: Raising Level of Abstraction

Source: Altera
Qsys UI

Source: Altera
System Level Design: Why Use Qsys

Avoids manually developing custom interconnect fabrics and signaling.

Instead of cycle-to-cycle coordination between every individual IP core, focus on transaction-level designs.

Design IP without knowing exactly when data will transfer and instead only focus on how (once it does).

(Only valid if you design your individual components to one of the standardized interfaces)
Qsys-based Method of Design

Generated by Qsys

Processor (32-bit Master)
- Bus Interface
- Address Decoder
- Interrupt Controller

PCI Express (64-bit Master)
- Bus Interface
- Address Decoder

Burst Adapters

Arbiters
- Width Adapter
- Bus Interface

Slaves
- Slave 1: 8-Bit
- Slave 2: 32-Bit
- Slave 3: 16-Bit
- Slave 4: 32-Bit
- Slave 5: 64-Bit

Source: Altera
Connecting IP Cores
Interface Types

**Memory-mapped** Interfaces:

Avalon MM (Altera)

AXI (ARM, supported by Qsys now for SoC)

**Streaming** Interfaces: Avalon ST:

Avalon ST source port: outputs streaming data

Avalon ST sink port: receives incoming streaming data
Control vs. Data Planes

**Control Plane:** Memory mapped registers typically used for configuring devices, querying status, initiating transactions, etc (low bandwidth)

**Data Plane:** Streaming directed graphs for actually moving and processing large amounts of data (audio/video, network packets, etc); high bandwidth

A single IP core can have both MM and ST interfaces (including multiple of each).
Control and Data Planes Example

Source: Altera
Control and Data Planes Example: Solarflare AoE

Source: Altera
Qsys signal types

Clock
Reset
Interrupt
Avalon MM signals (Memory-Mapped)
Avalon ST signals (Streaming)
Tristate
Conduit (your own custom signals)
Why explicitly label signal types?

...vs. simply making everything a wire/conduit

Allows Qsys to protect you from yourself!

Ensure matching between signal types (e.g., “clock out” → “clock in”)

Detect and automatically insert dual clock crossing domains (only if it knows which clock domains IPs are in)

Automatically convert data widths, formats, error flags (convert 32 bit master into four 8-bit slave reads, etc)

Automatically synchronize and OR-gate multiple resets

Automatically insert pipeline stages to improve fmax
# Avalon MM Master Signals

<table>
<thead>
<tr>
<th>Signal type</th>
<th>Width</th>
<th>Direction</th>
<th>Required</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>address</td>
<td>1-64</td>
<td>Output</td>
<td>Y</td>
<td>Byte address corresponding to slave for transfer request <em>(discussed later)</em></td>
</tr>
<tr>
<td>waitrequest</td>
<td>1</td>
<td>Input</td>
<td>Y</td>
<td>Forces master to stall transfer until deasserted; other Avalon-MM interface signals must be held constant</td>
</tr>
<tr>
<td>waitrequest_n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>read</td>
<td>1</td>
<td>Output</td>
<td>N</td>
<td>Indicates master issuing read request</td>
</tr>
<tr>
<td>read_n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>readdata</td>
<td>8, 16, 32, 64, 128, 256, 512, 1024</td>
<td>Input</td>
<td>N</td>
<td>Data returned from read request</td>
</tr>
<tr>
<td>write</td>
<td>1</td>
<td>Output</td>
<td>N</td>
<td>Indicates master issuing write request</td>
</tr>
<tr>
<td>write_n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>writedata</td>
<td>8, 16, 32, 64, 128, 256, 512, 1024</td>
<td>Output</td>
<td>N</td>
<td>Data to be sent for write request</td>
</tr>
<tr>
<td>byteenable</td>
<td>2, 4, 8, 16, 32, 64, 128</td>
<td>Output</td>
<td>N</td>
<td>Specifies valid byte lane(s) for readdata or writedata <em>(width = data width / 8)</em></td>
</tr>
<tr>
<td>byteenable_n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lock</td>
<td>1</td>
<td>Output</td>
<td>N</td>
<td>Once master is granted access to shared slave, locks arbiter to master until deasserted</td>
</tr>
<tr>
<td>lock_n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Altera
# Avalon MM Slave Signals

<table>
<thead>
<tr>
<th>Signal type</th>
<th>Width</th>
<th>Direction</th>
<th>Required</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>address</td>
<td>1-64</td>
<td>Input</td>
<td>N</td>
<td>Word address of slave for transfer request (<em>discussed later</em>)</td>
</tr>
<tr>
<td>waitrequest</td>
<td>1</td>
<td>Output</td>
<td>N</td>
<td>Allows slave to stall transfer until deasserted (other Avalon-MM interface signals must be held constant)</td>
</tr>
<tr>
<td>waitrequest_n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>read</td>
<td>1</td>
<td>Input</td>
<td>N</td>
<td>Indicates slave should respond to read request</td>
</tr>
<tr>
<td>read_n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>readdata</td>
<td>8, 16, 32, 64, 128, 256, 512, 1024</td>
<td>Output</td>
<td>N</td>
<td>Data provided to Qsys interconnect in response to read request</td>
</tr>
<tr>
<td>write</td>
<td>1</td>
<td>Input</td>
<td>N</td>
<td>Indicates slave should respond to write request</td>
</tr>
<tr>
<td>write_n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>writedata</td>
<td>8, 16, 32, 64, 128, 256, 512, 1024</td>
<td>Input</td>
<td>N</td>
<td>Data from the Qsys interconnect for a write request</td>
</tr>
<tr>
<td>byteenable</td>
<td>2, 4, 8, 16, 32, 64, 128</td>
<td>Input</td>
<td>N</td>
<td>Specifies valid byte lane for readdata or writedata (width = data width / 8)</td>
</tr>
<tr>
<td>byteenable_n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>begintransfer</td>
<td>1</td>
<td>Input</td>
<td>N</td>
<td>Asserts at the beginning (first cycle) of any transfer</td>
</tr>
<tr>
<td>begintransfer_n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Altera
Avalon ST Signals

<table>
<thead>
<tr>
<th>Signal type</th>
<th>Width</th>
<th>Direction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>read</strong></td>
<td>1</td>
<td>Sink → Source</td>
<td>Indicates the sink can accept data</td>
</tr>
<tr>
<td><strong>valid</strong></td>
<td>1</td>
<td>Source → Sink</td>
<td>Qualifies all source to sink signals</td>
</tr>
<tr>
<td><strong>data</strong></td>
<td>1-4096</td>
<td>Source → Sink</td>
<td>Payload of the information being transmitted</td>
</tr>
<tr>
<td><strong>channel</strong></td>
<td>1-128</td>
<td>Source → Sink</td>
<td>Channel number for data being transferred (if multiple channels supported)</td>
</tr>
<tr>
<td><strong>error</strong></td>
<td>1-255</td>
<td>Source → Sink</td>
<td>Bit mask marks errors affecting the data being transferred</td>
</tr>
</tbody>
</table>

**Packet transfer signals**

<table>
<thead>
<tr>
<th>Signal type</th>
<th>Width</th>
<th>Direction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>startofpacket</strong></td>
<td>1</td>
<td>Source → Sink</td>
<td>Marks the beginning of the packet</td>
</tr>
<tr>
<td><strong>endofpacket</strong></td>
<td>1</td>
<td>Source → Sink</td>
<td>Marks the end of the packet</td>
</tr>
<tr>
<td><strong>empty</strong></td>
<td>1-8</td>
<td>Source → Sink</td>
<td>Indicates the number of symbols that are empty during cycles that contain the end of a packet</td>
</tr>
</tbody>
</table>

Source: Altera
Example Qsys Layout: 10Gb Reference Design

Source: Altera
Advanced: Qsys Hierarchical Designs

Source: Altera
Advanced: Qsys Automatic Pipelining

Source: Altera
Advanced: Qsys Testbench Generation

Source: Altera
Additional References

Altera online training lectures: (HIGHLY recommended; many of these slides are taken directly from them)

http://www.altera.com/education/training/curriculum/trn-curriculum.html

Introduction to Qsys

Advanced System Design Using Qsys

Custom IP Development Using Avalon and AXI Interfaces