



Zynq Architecture

Zynq
Vivado 2015.2 Version

Objectives

➤ After completing this module, you will be able to:

- Identify the basic building blocks of the Zynq™ architecture processing system (PS)
- Describe the usage of the Cortex-A9 processor memory space
- Connect the PS to the programmable logic (PL) through the AXI ports
- Generate clocking sources for the PL peripherals
- List the various AXI-based system architectural models
- Name the five AXI channels
- Describe the operation of the AXI streaming protocol

Outline

- **Zynq All Programmable SoC (AP SoC)**
- **Zynq AP SoC Processing System (PS)**
- **Processor Peripherals**
- **Clock, Reset, and Debug Features**
- **AXI Interfaces**
- **Summary**

The PS and the PL

➤ The Zynq-7000 AP SoC architecture consists of two major sections

– PS: Processing system

- Dual ARM Cortex-A9 processor based
- Multiple peripherals
- Hard silicon core

– PL: Programmable logic

- Shares the same 7 series programmable logic as
 - Artix™-based devices: Z-7010, Z-7015, and Z-7020 (high-range I/O banks only)
 - Kintex™-based devices: Z-7030, Z-7035, Z-7045, and Z-7100 (mix of high-range and high-performance I/O banks)

➤ This section focuses on the PS

Zynq-7000 Family Highlights

➤ Complete ARM®-based processing system

- Application Processor Unit (APU)
 - Dual ARM Cortex™-A9 processors
 - Caches and support blocks
- Fully integrated memory controllers
- I/O peripherals

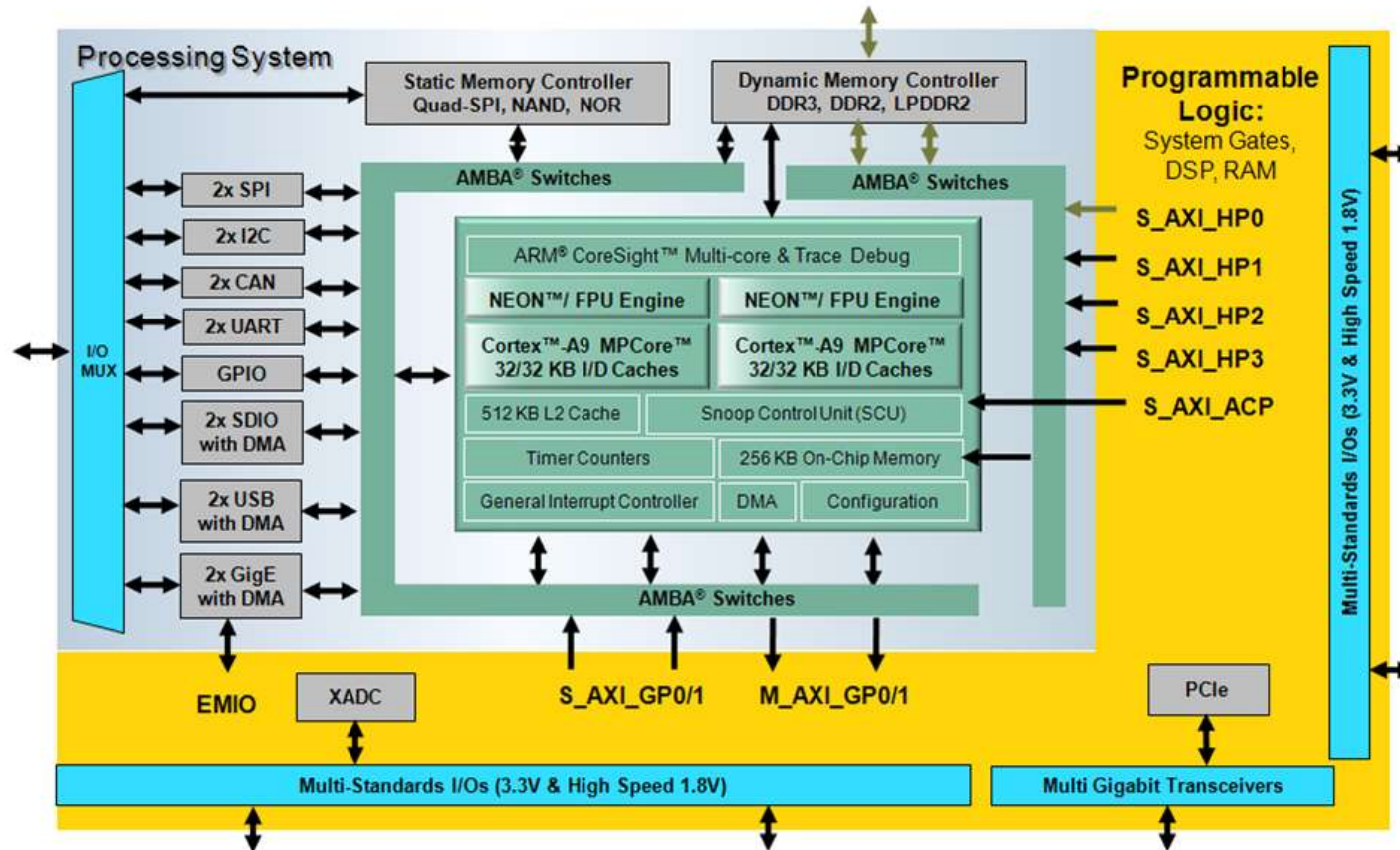
➤ Tightly integrated programmable logic

- Used to extend the processing system
- Scalable density and performance

➤ Flexible array of I/O

- Wide range of external multi-standard I/O
- High-performance integrated serial transceivers
- Analog-to-digital converter inputs

Zynq-7000 AP SoC Block Diagram



PS Components

- **Application processing unit (APU)**
- **I/O peripherals (IOP)**
 - Multiplexed I/O (MIO), extended multiplexed I/O (EMIO)
- **Memory interfaces**
- **PS interconnect**
- **DMA**
- **Timers**
 - Public and private
- **General interrupt controller (GIC)**
- **On-chip memory (OCM): RAM**
- **Debug controller: CoreSight**

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ARM Processor Architecture

➤ ARM Cortex-A9 processor implements the ARMv7-A architecture

- ARMv7 is the ARM Instruction Set Architecture (ISA)
- ARMv7-A: Application set that includes support for a Memory Management Unit (MMU)
- ARMv7-R: Real-time set that includes support for a Memory Protection Unit (MPU)
- ARMv7-M: Microcontroller set that is the smallest set

➤ The ARMv7 ISA includes the following types of instructions (for backwards compatibility)

- Thumb instructions: 16 bits; Thumb-2 instructions: 32 bits
- NEON: ARM's Single Instruction Multiple Data (SIMD) instructions

➤ ARM Advanced Microcontroller Bus Architecture (AMBA®) protocol

- AXI3: Third-generation ARM interface
- AXI4: Adding to the existing AXI definition (extended bursts, subsets)

➤ Cortex is the new family of processors

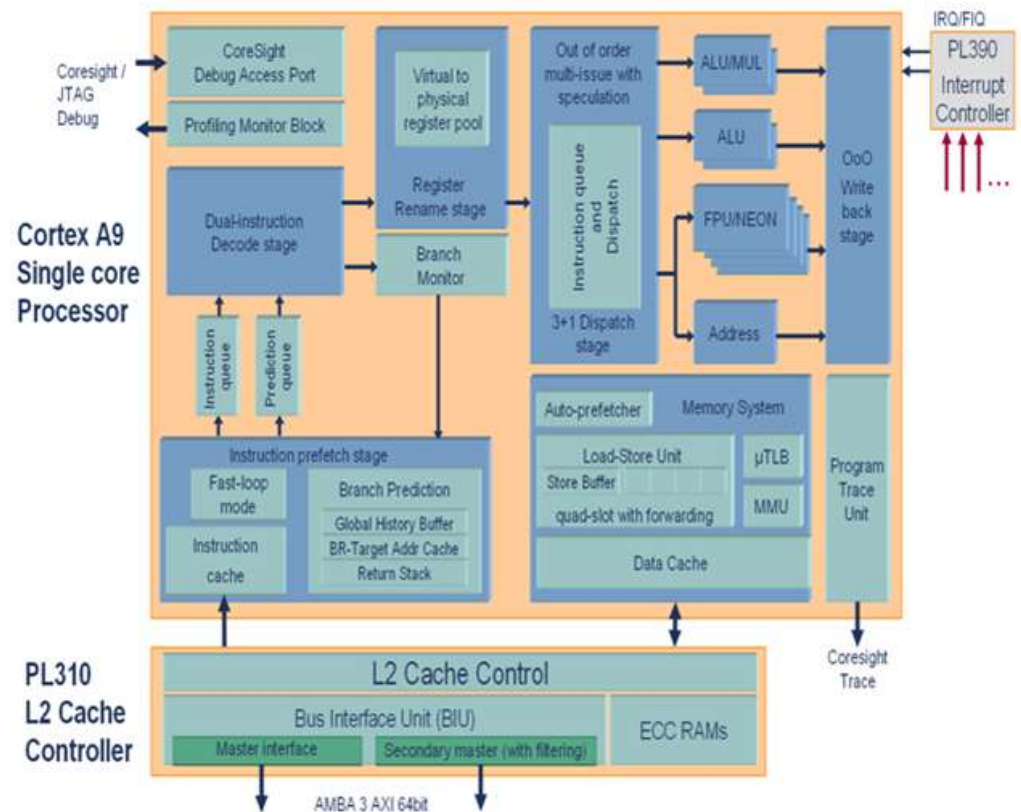
- ARM family is older generation; Cortex is current; MMUs in Cortex processors and MPUs in ARM

ARM Cortex-A9 Processor Power

- Dual-core processor cluster
- 2.5 DMIP/MHz per processor
- Harvard architecture
- Self-contained 32KB L1 caches for instructions and data
- External memory based 512KB L2 cache
- Automatic cache coherency between processor cores
- 1GHz operation (fastest speed grade)

ARM Cortex-A9 Processor Micro-Architecture

- Instruction pipeline supports out-of-order instruction issue and completion
- Register renaming to enable execution speculation
- Non-blocking memory system with load-store forwarding
- Fast loop mode in instruction pre-fetch to lower power consumption



ARM Cortex-A9 Processor Micro-Architecture

➤ Variable length, out-of-order, eight-stage, super-scalar instruction pipeline

- Advanced pre-fetch with parallel branch pipeline enabling early branch prediction and resolution
- Multi-issued into
 - Primary data processing pipeline
 - Secondary full data processing pipeline
 - Load-store pipeline
 - Compute engine (FPU/NEON) pipeline

➤ Speculative execution

- Supports virtual renaming of ARM physical registers to remove pipeline stalls due to data dependencies
- Increased processor utilization and hiding of memory latencies
- Increased performance by hardware unrolling of code loops
- Reduced interrupt latency via speculative entry to Interrupt Service Routine (ISR)

Processing System Interconnect (1)

► Programmable logic to memory

- Two ports to DDR
- One port to OCM SRAM

► Central interconnect

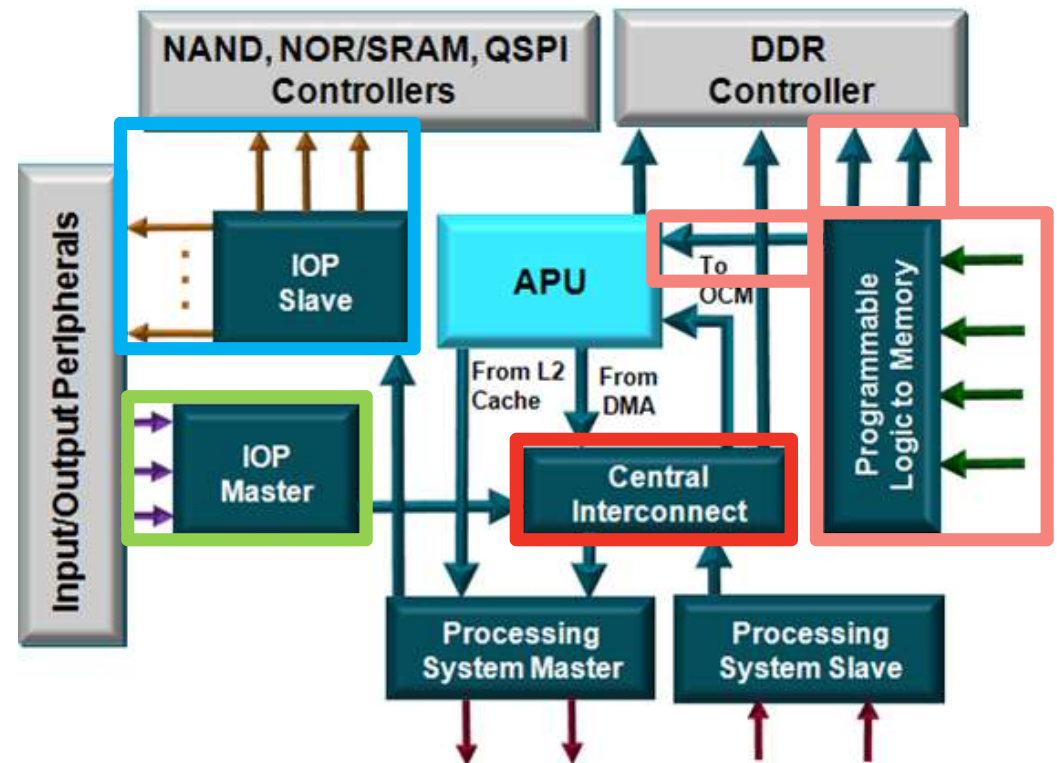
- Enables other interconnects to communicate

► Peripheral master

- USB, GigE, SDIO connects to DDR and PL via the central interconnect

► Peripheral slave

- CPU, DMA, and PL access to IOP peripherals



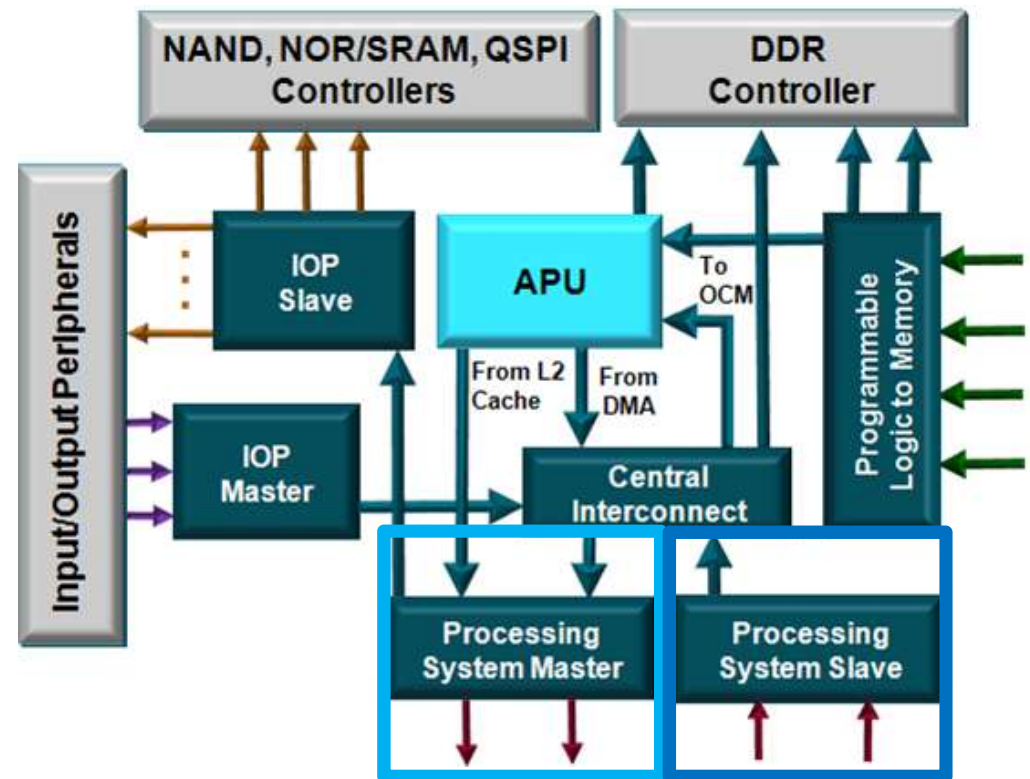
Processing System Interconnect (2)

► Processing system master

- Two ports from the processing system to programmable logic
- Connects the CPU block to common peripherals through the central interconnect

► Processing system slave

- Two ports from programmable logic to the processing system



Memory Map

- The Cortex-A9 processor uses 32-bit addressing
- All PS peripherals and PL peripherals are memory mapped to the Cortex-A9 processor cores
- All slave PL peripherals will be located between **4000_0000 and 7FFF_FFFF (connected to GP0)** and **8000_0000 and BFFF_FFFF (connected to GP1)**

FFFC_0000 to FFFF_FFFF	OCM
FD00_0000 to FFFB_FFFF	Reserved
FC00_0000 to FCFF_FFFF	Quad SPI linear address
F8F0_3000 to FBFF_FFFF	Reserved
F890_0000 to F8F0_2FFF	CPU Private registers
F801_0000 to F88F_FFFF	Reserved
F800_1000 to F880_FFFF	PS System registers,
F800_0C00 to F800_0FFF	Reserved
F800_0000 to F800_0BFF	SLCR Registers
E600_0000 to F7FF_FFFF	Reserved
E100_0000 to E5FF_FFFF	SMC Memory
E030_0000 to E0FF_FFFF	Reserved
E000_0000 to E02F_FFFF	IO Peripherals
C000_0000 to DFFF_FFFF	Reserved
8000_0000 to BFFF_FFFF	PL (MAXI_GP1)
4000_0000 to 7FFF_FFFF	PL (MAXI_GP0)
0010_0000 to 3FFF_FFFF	DDR(address not filtered by SCU)
0004_0000 to 000F_FFFF	DDR(address filtered by SCU)
0000_0000 to 0003_FFFF	OCM

Zynq AP SoC Memory Resources

➤ On-chip memory (OCM)

- RAM
- Boot ROM

➤ DDRx dynamic memory controller

- Supports LPDDR2, DDR2, DDR3

➤ Flash/static, memory controller

- Supports SRAM, QSPI, NAND/NOR FLASH

PS Boots First

- **CPU0 boots from OCM ROM; CPU1 goes into a sleep state**
- **On-chip boot loader in OCM ROM (Stage 0 boot)**
- **Processor loads First Stage Boot Loader (FSBL) from external flash memory**
 - NOR
 - NAND
 - Quad-SPI
 - SD Card
 - Load from JTAG; not a memory device—used for development/debug only
- **Boot source selected via package bootstrapping pins**
- **Optional secure boot mode allows the loading of encrypted software from the flash boot memory**

Configuring the PL

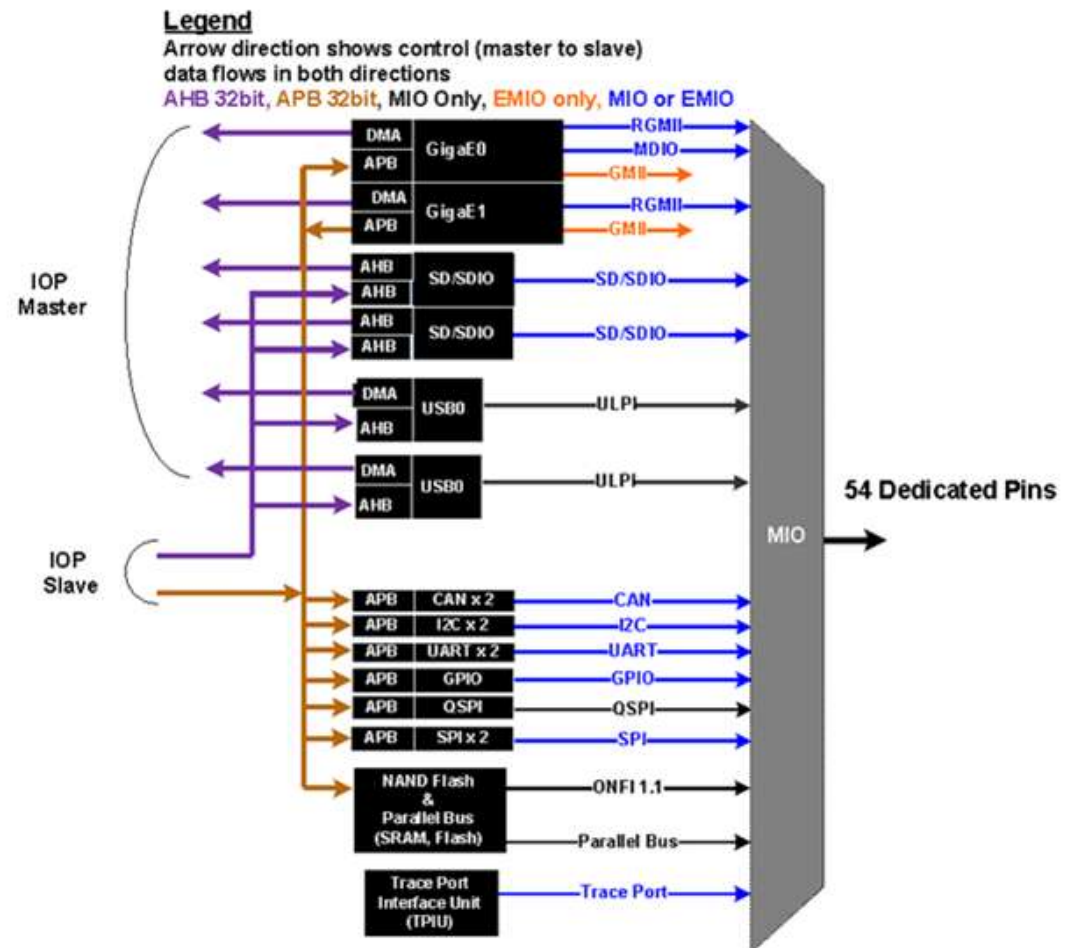
- **The programmable logic is configured after the PS boots**
- **Performed by application software accessing the hardware device configuration unit**
 - Bitstream image transferred
 - 100-MHz, 32-bit PCAP stream interface
 - Decryption/authentication hardware option for encrypted bitstreams
 - In secure boot mode, this option can be used for software memory load
 - Built-in DMA allows simultaneous PL configuration and OS memory loading

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Input/Output Peripherals

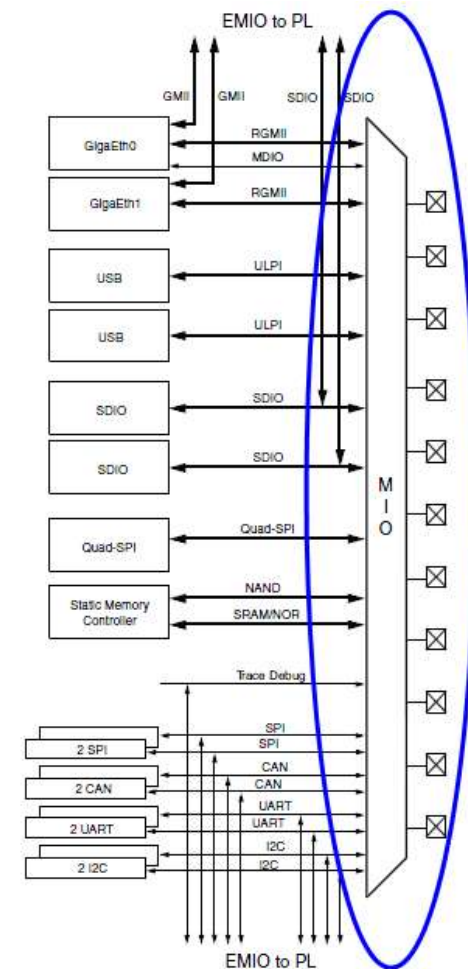
- Two GigE
- Two USB
- Two SPI
- Two SD/SDIO
- Two CAN
- Two I2C
- Two UART
- Four 32-bit GPIOs
- Static memories
 - NAND, NOR/SRAM, Quad SPI
- Trace ports



Multiplexed I/O (MIO)

➤ External interface to PS I/O peripheral ports

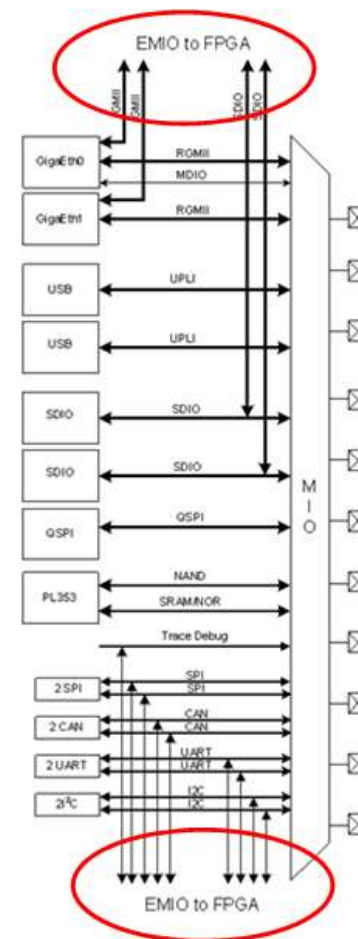
- 54 dedicated package pins available
- Software configurable
 - Automatically added to bootloader by tools
- Not available for all peripheral ports
 - Some ports can only use EMIO



Extended Multiplexed I/O (EMIO)

► Extended interface to PS I/O peripheral ports

- EMIO: Peripheral port to programmable logic
- Alternative to using MIO
- Mandatory for some peripheral ports
- Facilitates
 - Connection to peripheral in programmable logic
 - Use of general I/O pins to supplement MIO pin usage
 - Alleviates competition for MIO pin usage



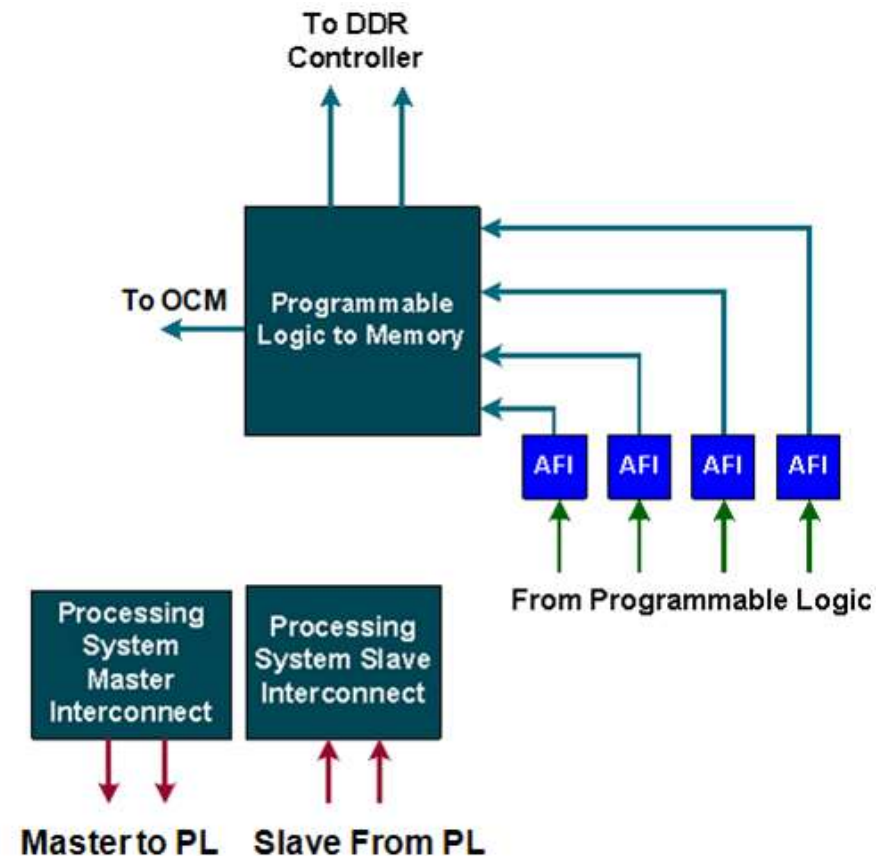
PS-PL Interfaces

➤ AXI high-performance slave ports (HP0-HP3)

- Configurable 32-bit or 64-bit data width
- Access to OCM and DDR only
- Conversion to processing system clock domain
- AXI FIFO Interface (AFI) are FIFOs (1KB) to smooth large data transfers

➤ AXI general-purpose ports (GP0-GP1)

- Two masters from PS to PL
- Two slaves from PL to PS
- 32-bit data width
- Conversation and sync to processing system clock domain



PS-PL Interfaces

- **One 64-bit accelerator coherence port (ACP) AXI slave interface to CPU memory**
- **DMA, interrupts, events signals**
 - Processor event bus for signaling event information to the CPU
 - PL peripheral IP interrupts to the PS general interrupt controller (GIC)
 - Four DMA channel RDY/ACK signals
- **Extended multiplexed I/O (EMIO) allows PS peripheral ports access to PL logic and device I/O pins**
- **Clock and resets**
 - Four PS clock outputs to the PL with enable control
 - Four PS reset outputs to the PL
- **Configuration and miscellaneous**

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PL Clocking Sources

➤ PS clocks

- PS clock source from external package pin
- PS has three PLLs for clock generation
- PS has four clock ports to PL

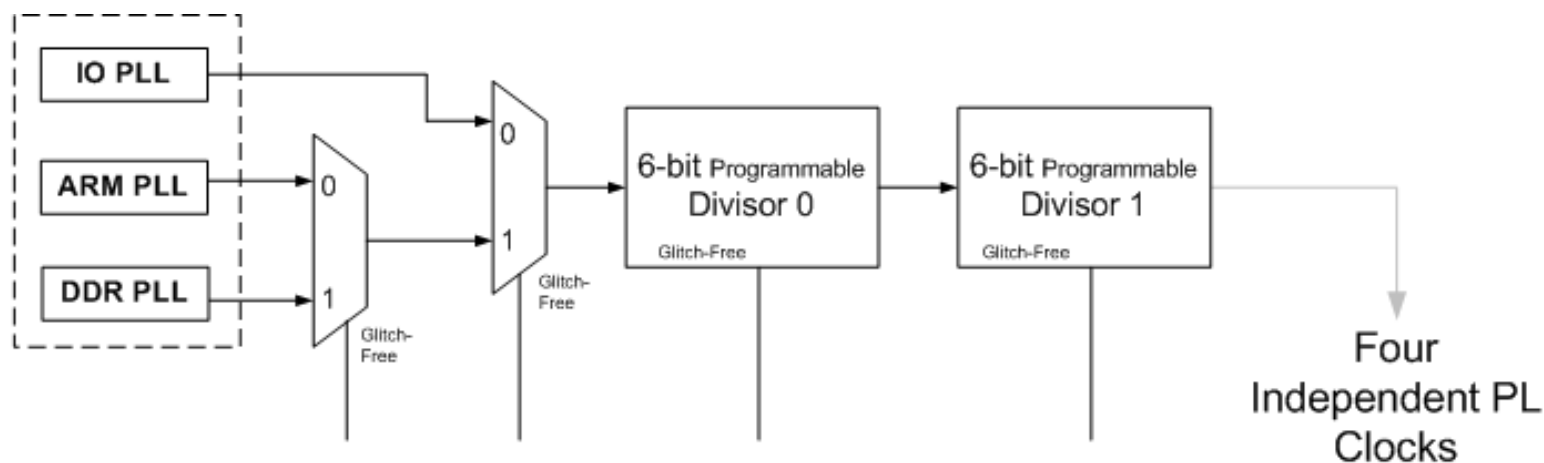
➤ The PL has 7 series clocking resources

- PL has a different clock source domain compared to the PS
- The clock to PL can be sourced from external clock capable pins
- Can use one of the four PS clocks as source

➤ Synchronizing the clock between PL and PS is taken care of by the architecture of the PS

➤ PL cannot supply clock source to PS

Clocking the PL

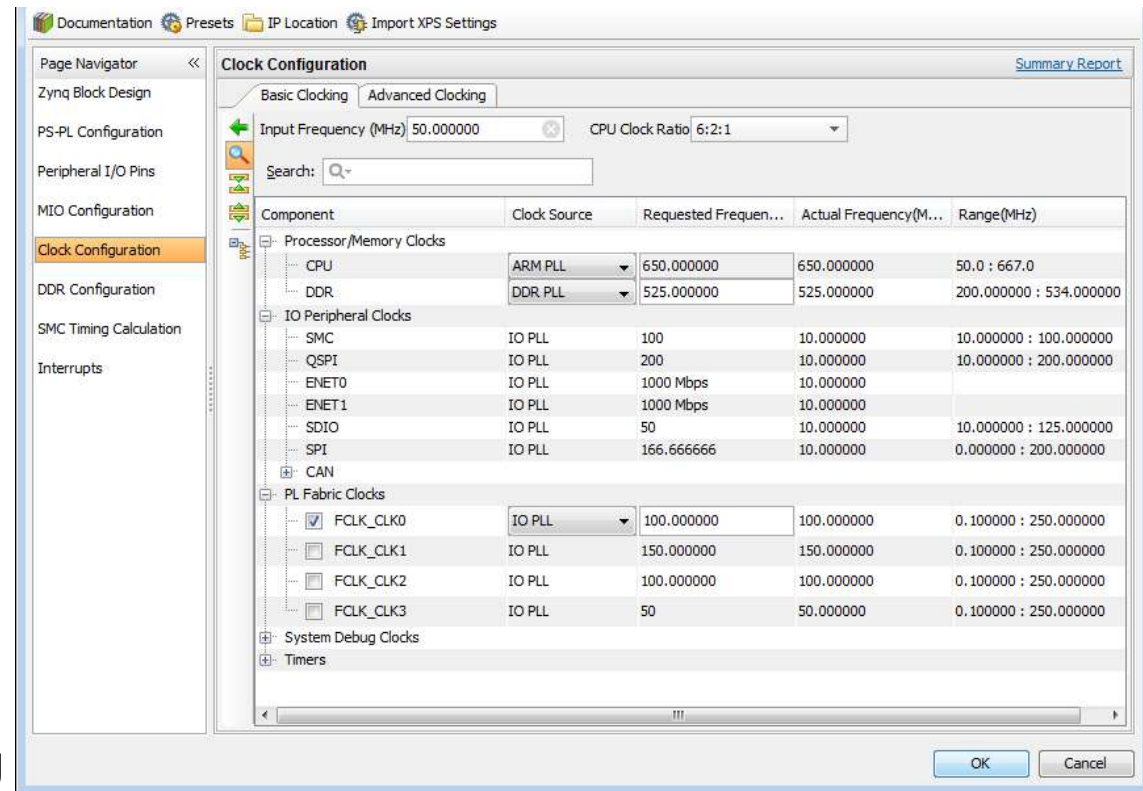


PL Fabric Clock	Control Register	Mux Ctrl Field	Mux Ctrl Field	Divider 0 Ctrl Field	Divider 1 Ctrl Field
PL Fabric 0	FPGA0_CLK_CTRL	SRCSEL, 4	SRCSEL, 5	DIVISOR 0, 13:8	DIVISOR 1, 25:20
PL Fabric 1	FPGA1_CLK_CTRL	SRCSEL, 4	SRCSEL, 5	DIVISOR 0, 13:8	DIVISOR 1, 25:20
PL Fabric 2	FPGA2_CLK_CTRL	SRCSEL, 4	SRCSEL, 5	DIVISOR 0, 13:8	DIVISOR 1, 25:20
PL Fabric 3	FPGA3_CLK_CTRL	SRCSEL, 4	SRCSEL, 5	DIVISOR 0, 13:8	DIVISOR 1, 25:20

—→ FCLKCLK0
 —→ FCLKCLK1
 —→ FCLKCLK2
 —→ FCLKCLK3

Clock Generation (Using Zynq Tab)

- The Clock Generator allows configuration of PLL components for both the PS and PL
 - One input reference clock
- Access GUI by clicking the Clock Generation Block, or select from Navigator
 - PS uses a dedicated PLL clock
 - PS I/O peripherals use the I/O PLL clock and ARM PLL
- Clock to PL is disabled if PS clocking is present



IP Integrator – Advanced Clocking in Zynq

- **Basic Clocking allows selection of desired frequency**
 - Tools will auto calculate nearest achievable frequency
- **Advanced clocking allows access to clock multiply and divide values for various PLLs in the Zynq PS**
- **Provides more control for user**

Clock Configuration [Summary Report](#)

Basic Clocking | Advance Clocking

Input Frequency (MHz): 33.333333 CPU Clock Ratio: 6:2:1

☒ Override Clocks

PLL Divisors	ARMPLL	DDRPLL	IOPLL
Multiplier	60	32	60
PLL Freq(MHz)	2000.000	1066.667	2000.000

Search:

Component	Clock Source	First Divisor	Second Divisor	Actual Freq...	Range(MHz)
Processor/Memory Clocks					
CPU	ARM PLL	3	NA	666.666660	50.0 : 867.0
DDR	DDR PLL	2	NA	533.333328	200.000000 : 534.000000
IO Peripheral Clocks					
SMC	IO PLL	1	NA	10.000000	10.000000 : 100.000000
QSPI	IO PLL	10	NA	199.999998	10.000000 : 200.000000
ENET0	IO PLL	16	5	25.000000	0.1 : 125
ENET1	IO PLL	1	1	10.000000	0.1 : 125
SDIO	IO PLL	40	NA	50.000000	10.000000 : 125.000000
SPI	IO PLL	1	NA	10.000000	0.000000 : 200.000000
DCI	DDR PLL	35	3	10.158730	0.100000 : 177.000000
PCAP	IO PLL	10	NA	199.999998	10.000000 : 300.000000
CAN					
CAN	IO PLL	1	1	10.000000	0.100000 : 100.000000
PL Fabric Clocks					
FCLK_CLK0	IO PLL	40	1	50.000000	0.100000 : 250.000000
FCLK_CLK1	IO PLL	40	1	50.000000	0.100000 : 250.000000
FCLK_CLK2	IO PLL	40	1	50.000000	0.100000 : 250.000000
FCLK_CLK3	IO PLL	40	1	50.000000	0.100000 : 250.000000
System Debug Clocks					
TPIU	External	NA	NA	200.000000	10.000000 : 300.000000
Timers					
WDT	CPU_1X	NA	NA	111.111110	0.100000 : 200.000000
TTC0					
TTC1					

Zynq Resets

➤ Internal resets

- Power-on reset (POR)
- Watchdog resets from the three watchdog timers
- Secure violation reset

➤ PS resets

- External reset: PS_SRST_B
- Warm reset: SRSTB

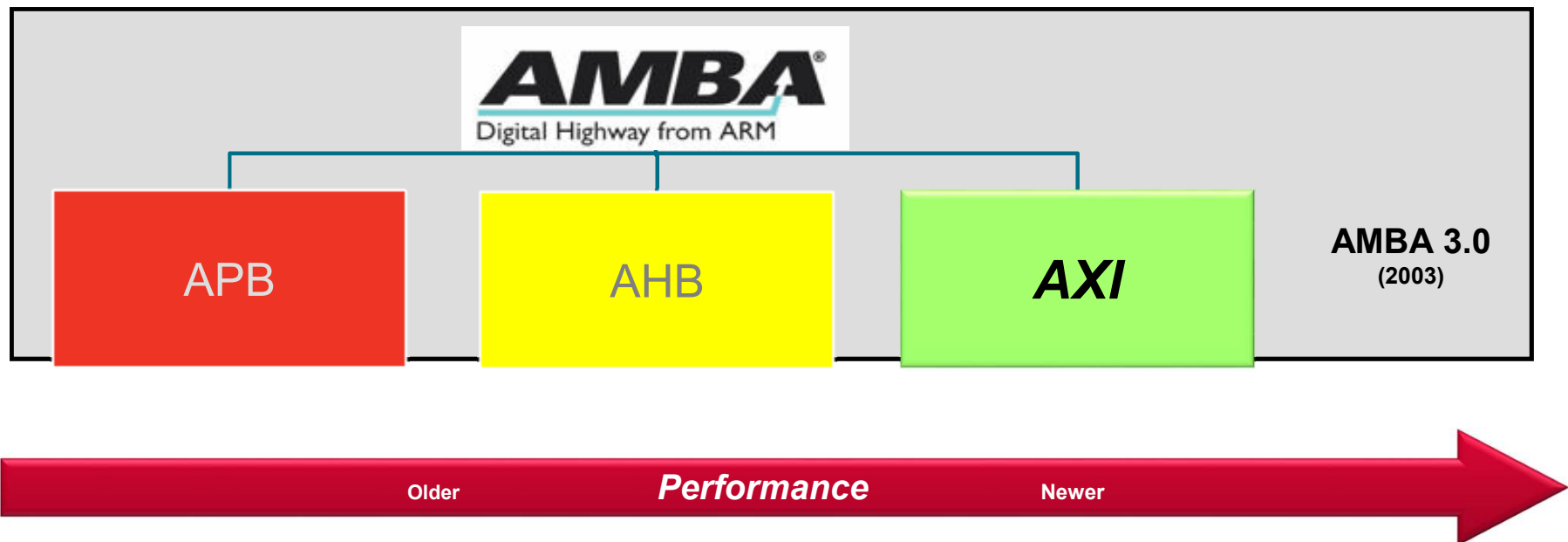
➤ PL resets

- Four reset outputs from PS to PL
- FCLK_RESET[3:0]

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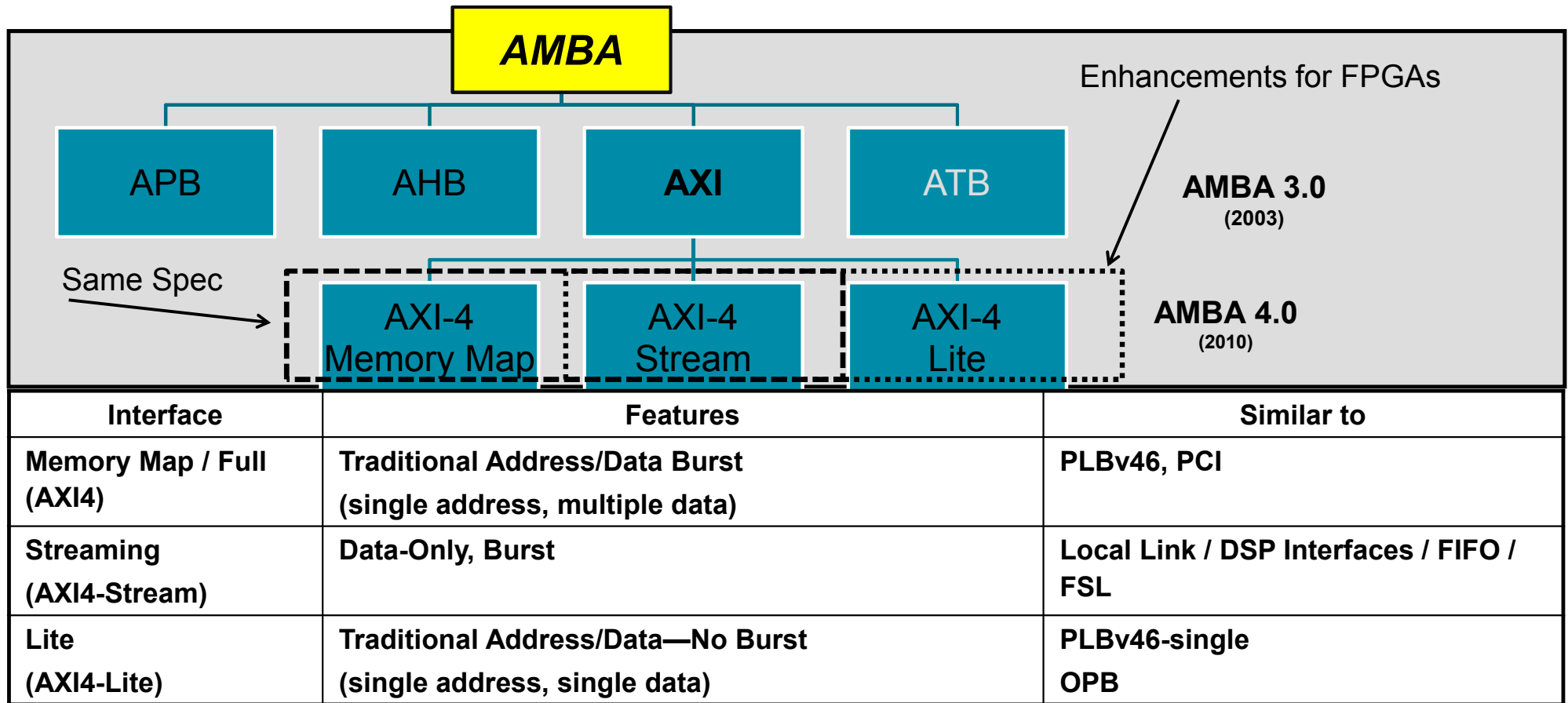
AXI is Part of ARM's AMBA



AMBA: Advanced Microcontroller Bus Architecture

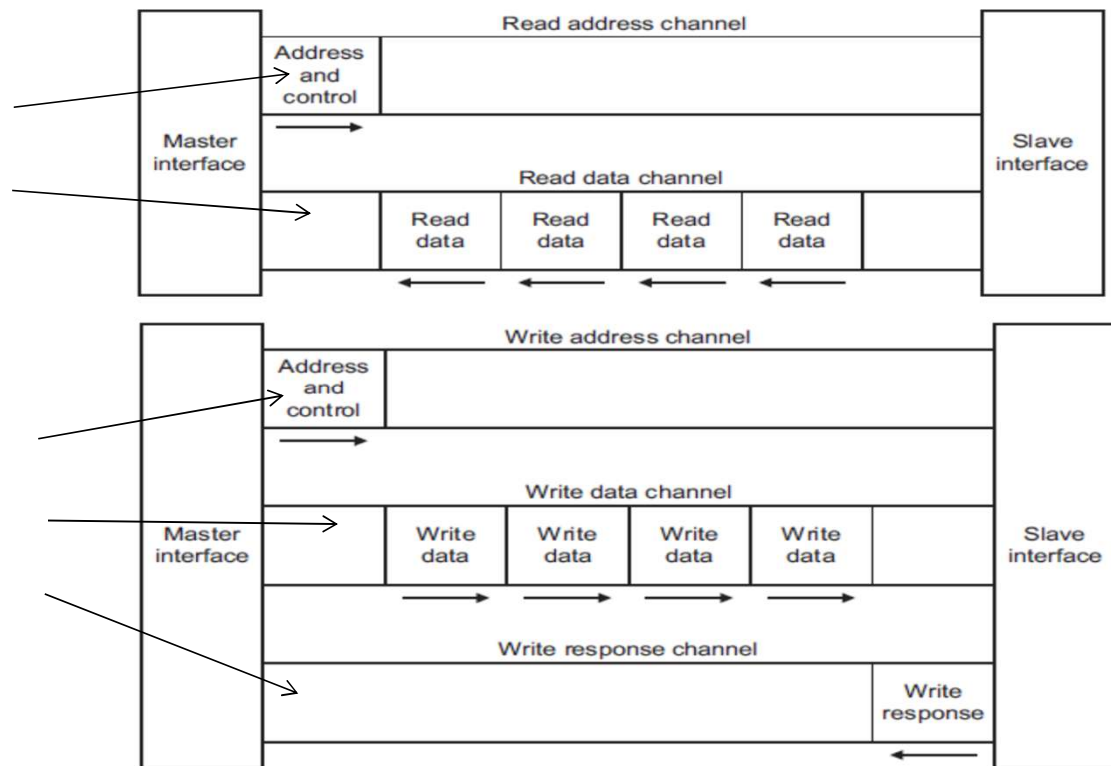
AXI: Advanced Extensible Interface

AXI is Part of AMBA



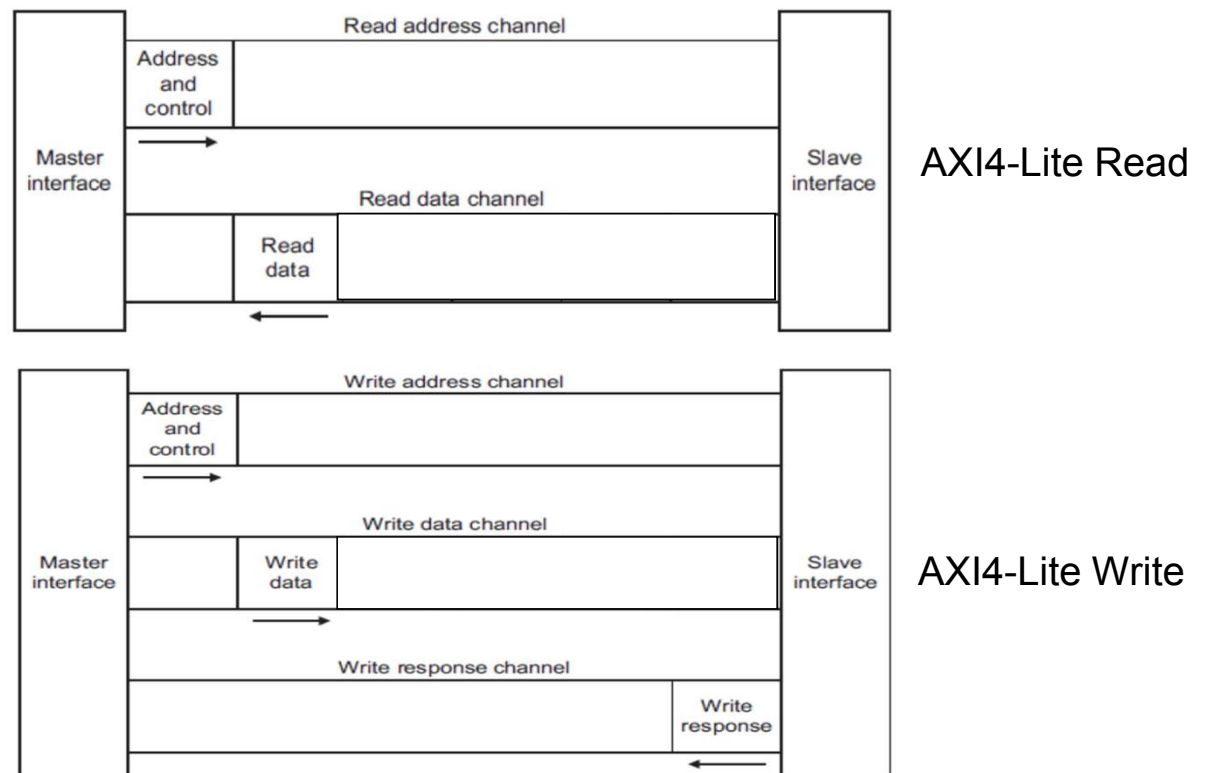
Basic AXI Signaling – 5 Channels

1. Read Address Channel
2. Read Data Channel
3. Write Address Channel
4. Write Data Channel
5. Write Response Channel



The AXI Interface—AXI4-Lite

- No burst
- Data width 32 or 64 only
 - Xilinx IP only supports 32-bits
- Very small footprint
- Bridging to AXI4 handled automatically by AXI_Interconnect (if needed)



The AXI Interface—AXI4

➤ Sometimes called “Full AXI” or Memory Mapped”

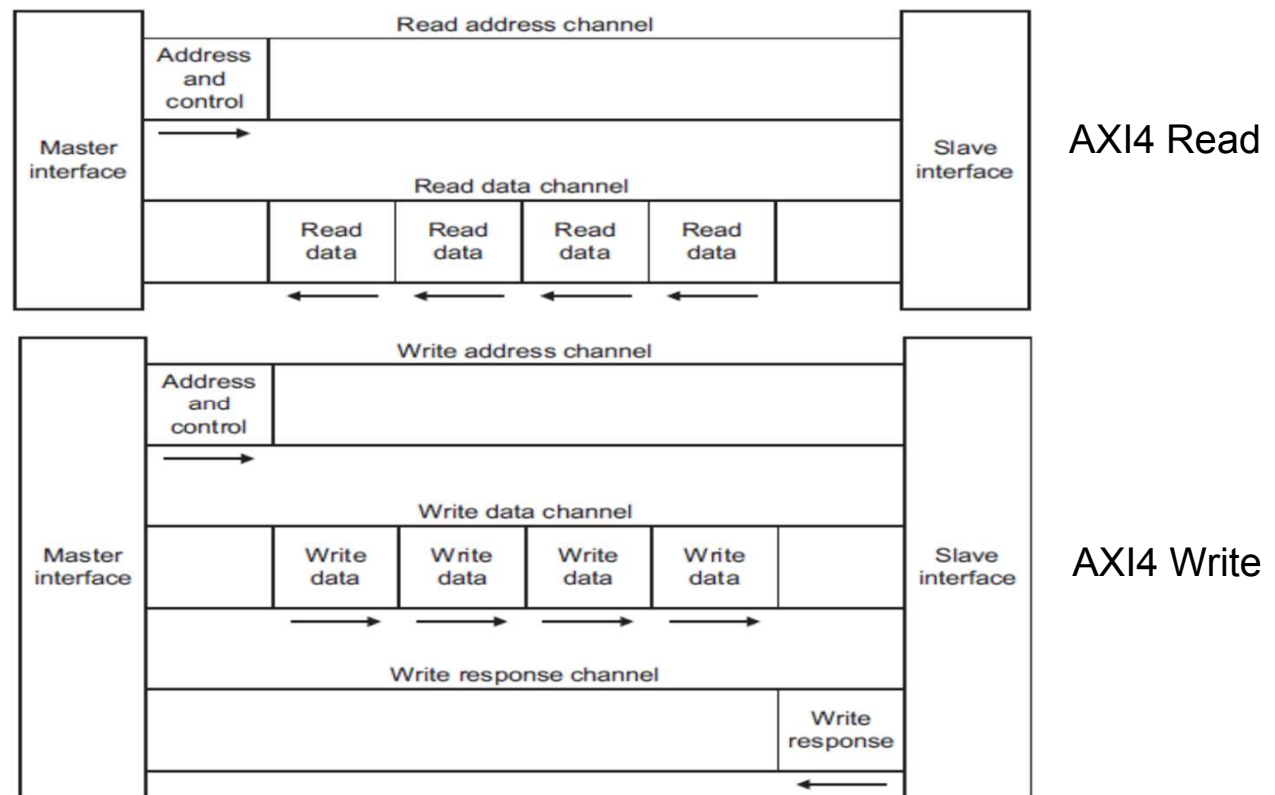
- Not ARM-sanctioned names

➤ Single address multiple data

- Burst up to 256 data beats

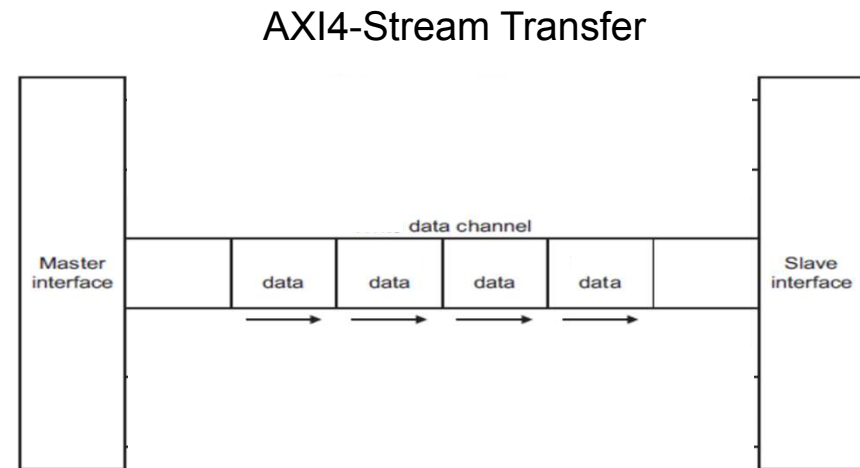
➤ Data Width parameterizable

- 1024 bits



The AXI Interface—AXI4-Stream

- **No address channel, no read and write, always just master to slave**
 - Effectively an AXI4 “write data” channel
- **Unlimited burst length**
 - AXI4 max 256
 - AXI4-Lite does not burst
- **Virtually same signaling as AXI Data Channels**
 - Protocol allows merging, packing, width conversion
 - Supports sparse, continuous, aligned, unaligned streams



Streaming Applications

➤ May not have packets

- E.g. Digital up converter
 - No concept of address
 - Free-running data (in this case)
 - In this situation, AXI4-Stream would optimize to a very simple interface

➤ May have packets

- E.g. PCIe
 - Their packets may contain different information
 - Typically bridge logic of some sort is needed

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Summary

- **The Zynq-7000 processing platform is a system on a chip (SoC) processor with embedded programmable logic**
- **The processing system (PS) is the hard silicon dual core consisting of**
 - APU and list components
 - Two Cortex-A9 processors
 - NEON co-processor
 - General interrupt controller (GIC)
 - General and watchdog timers
 - I/O peripherals
 - External memory interfaces

Summary

- The programmable logic (PL) consists of 7 series devices
- AXI is an interface providing high performance through point-to-point connection
- AXI has separate, independent read and write interfaces implemented with channels
- The AXI4 interface offers improvements over AXI3 and defines
 - Full AXI memory mapped
 - AXI Lite
 - AXI Stream
- Tightly coupled AXI ports interface the PL and PS for maximum performance
- The PS boots from a selection of external memory devices
- The PL is configured by and after the PS boots
- The PS provides clocking resources to the PL
- The PL may not provide clocking to the PS