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The MicroBlaze Soft Processor: Flexibility and Performance for Cost-Sensitive Embedded Designs

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For higher performance and long-term flexibility, the MicroBlaze soft processor core provides system developers with a uniquely powerful, extensible embedded design solution.

ABSTRACT

The Xilinx® MicroBlaze™ IP core is a highly configurable 32-bit microprocessor optimized for the programmable logic in Xilinx FPGAs and SoCs. Seamlessly integrated into the Xilinx Vivado® design environment, power users can leverage the MicroBlaze processor to create a customized, high-performance, SoC-based system. Alternatively, Xilinx provides a pre-configured MicroBlaze core with the most-used microcontroller, real-time, and application software presets, enabling the designer to get started with software development right away using freely available evaluation PC boards.

Initially designed over eighteen years ago, the MicroBlaze processor core boasts a stellar heritage, having proven itself across diverse applications for the industrial, medical, automotive, consumer, and communication markets, among others. Its rich feature set and high performance have evolved to offer a mainstream alternative to ARM® Cortex™-M CPUs, with the added benefit of being fully integrable into the developer's custom logic design.

The MicroBlaze processor core is included at no cost with all editions of the Vivado tools, and comes with Xilinx SDK, a full-featured software development environment.

Overview

Requirements for embedded systems can change over time, expanding in terms of complexity and sophistication. For an ASSP user, when the chosen ASSP no longer meets the application requirements for processing power or required peripheral set, the only choice is to upgrade or migrate to a newer ASSP that can meet the new requirements. Making this kind of system change is costly in both time and money, usually involving identification of a new ASSP with suitable processor frequency, peripheral set, and additional system design and bring-up—as well as porting software from the old solution to the new one. Preferably, the designer needs a solution that is flexible, scalable, and cost-effective, to meet the application requirements now and into the future.

Xilinx All Programmable devices, along with the MicroBlaze™ processor, deliver complete flexibility to select an optimal combination of processor, peripheral, memory, and interface features to provide the exact embedded system needed at the lowest cost possible on a single device.

This white paper describes MicroBlaze processor presets within the context of the complete Xilinx solution, including: Xilinx cost-optimized FPGAs and SoCs; reference designs and evaluation kits; a large library of peripherals IP; the Vivado® IP Integrator (IPI) tool; and Xilinx Software Development Kit (SDK), for rapid hardware design and software development.

Types of Embedded Systems

A variety of embedded processors available in the market today target different application domains. These can be broadly classified as shown in [Table 1](#).

Table 1: Typical Embedded Systems

Application	Persona	Description
Basic Control Applications	Microcontroller	Typically uses small, single-task oriented processors, often running bare-metal code. Used in printers, faxes, appliances, etc.
Time-Sensitive/Deterministic Processing	Real-Time	Fast, deterministic task-switching processor using an RTOS. Used in control systems, CNC machines, automatic driving assistance systems, etc.
High Performance Embedded Systems	Application	Uses a comprehensive operating system (such as Linux) with multiple tasks running. For complex embedded systems such as network switches, routers, video/image processing systems, signal processing, etc.

These systems differ in size, speed, processor performance, type of memory subsystem, and peripherals. Additionally, the software that runs on each system, including the OS, becomes increasingly complex. When developing with one of these standard classes of processors, many trade-offs need to be made, and often it is difficult to find the perfect fit.

The MicroBlaze processor offers the designer many exceptional advantages over other typical microprocessors or microcontrollers. Xilinx provides a vast library of peripherals to create embedded processing systems for various applications. The programmable nature of Xilinx FPGAs and SoCs provides complete flexibility to customize the MicroBlaze processor for specific application needs.

The MicroBlaze CPU is a highly customizable 32-bit RISC microprocessor, optimized for implementation in Xilinx FPGAs. Figure 1 shows a block diagram of the MicroBlaze processor core.

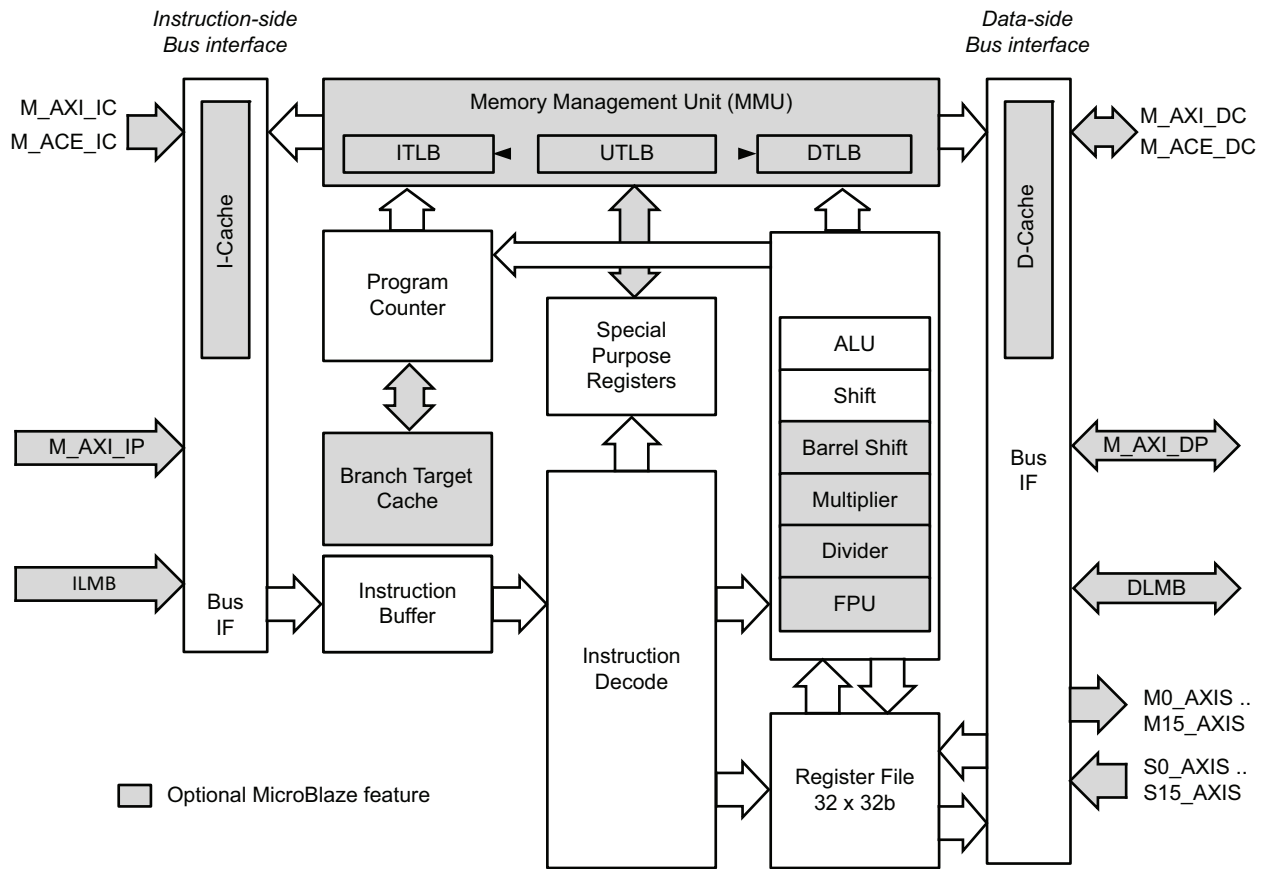
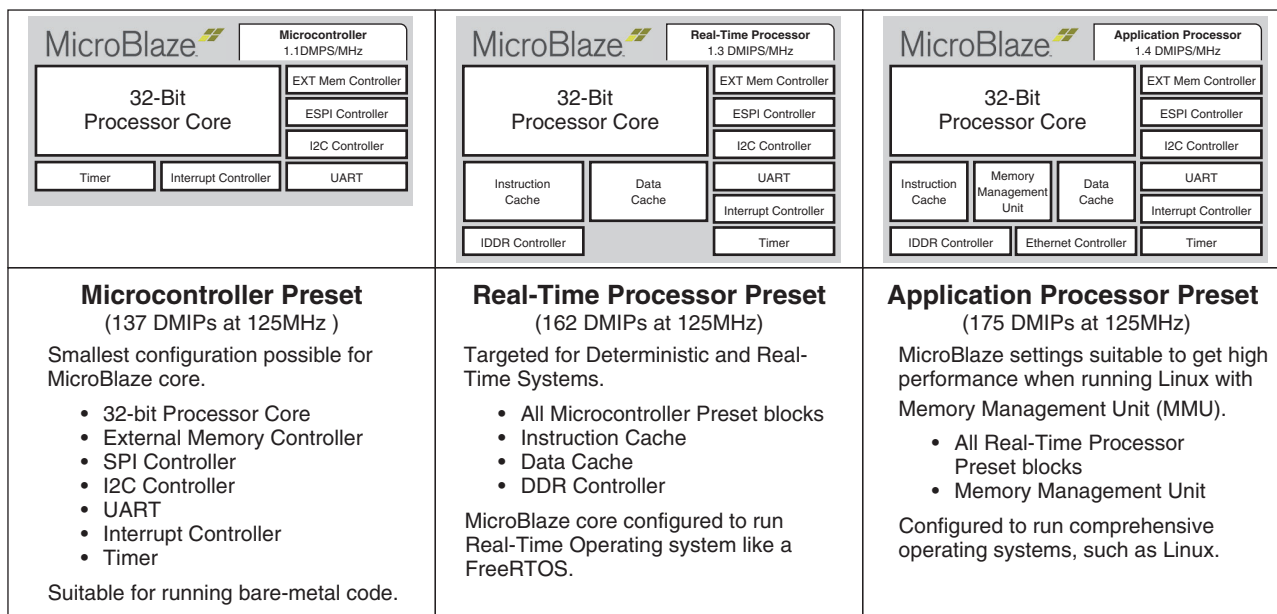


Figure 1: MicroBlaze Processor Block Diagram

Presets for the MicroBlaze Processor

To simplify development, three preset configurations have been defined that generally fit the typical processor personas described in Table 1. These presets are suitably named: microcontroller, real-time, and applications. More details about these configurations are included in Figure 2.



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Figure 2: MicroBlaze Processor Presets

The three processor presets are available as ready-to-use blocks in the programmable logic of Xilinx FPGAs and SoCs. These are then augmented with processor “system” presets, which are available in the form of configurable example designs.

Xilinx Cost-Optimized Portfolio and MicroBlaze Processor Performance

Development time and component costs are the two primary considerations that system designers have when developing high-volume applications. However, other aspects (like system BOM cost, field upgradeability, and development of derivative products) need to be considered as well.

Major cost drivers of a typical system's BOM includes components such as:

- Processors (e.g., CPUs, SoCs, DSPs, MPUs)
- Digital logic components (e.g., FPGAs, ASSPs)
- Mixed-signal and analog components (e.g., amplifiers, ADCs, DACs)
- Sensors (e.g., temperature, pressure, humidity)
- Power supplies and thermal management components
- Volatile and nonvolatile memory components
- Passive components (e.g., resistors, capacitors, inductors)
- Safety, security, and reliability components
- Protocol PHY components
- Clocking components

Devices from the Xilinx Cost-Optimized Portfolio can integrate much of this functionality on a single chip. High-density system integration like this not only lowers BOM cost, but because such

integration reduces board space and overall power consumption, it lowers the cost of the PCB itself, as well as the complexity and cost of the system's power and thermal management solution. Additionally, by integrating all functionality into a single device, concerns about the lead-time and life cycle of multiple ICs are eliminated.

The Xilinx All Programmable Cost-Optimized Portfolio comprises device families that are optimized for specific capabilities:

- o **Spartan®-7 FPGAs** for I/O optimized design and with the highest performance-per-watt
- o **Artix®-7 FPGAs** for transceiver optimization and highest DSP bandwidth
- o **Zynq®-7000 All Programmable SoCs** for systems optimization with scalable processor integration

See [Table 2](#).

Here it is specifically worth mentioning, with Zynq-7000 SoCs, a MicroBlaze implementation can be used to augment the processor power of the integrated ARM® Cortex™-A9 MPCore Processing System. In fact, multiple MicroBlaze soft IP cores can be implemented on an SoC to create a system limited only by the designer's imagination.

Table 2: Xilinx Cost-Optimized Portfolio at a Glance

	Spartan-7	Artix-7	Zynq-7000
Process Node:	28nm	28nm	28nm
Logic Density Range:	6K → 102K	12K → 200K	28K → 444K
Local Memory:	22.5KB → 540KB	90KB → 1.6MB	481KB → 3.5MB
External Memory Support:	DDR3-800	DDR3-1066	DDR3-1066
LVDS I/O Performance:	1.08Gb/s	1.25Gb/s	1.25Gb/s
Transceiver Performance:	N/A	6.6Gb/s	6.25Gb/s
Applications:	<ul style="list-style-type: none"> • Any-to-Any Connect • Sensor Fusion • Precision Control • Safety and Security 	<ul style="list-style-type: none"> • Any-to-Any Connect • Sensor Fusion • Precision Control • Safety and Security • Image Processing 	<ul style="list-style-type: none"> • Any-to-Any Connect • Sensor Fusion • Precision Control • Safety and Security • Image Processing • Analytics and Cloud

By way of example, [Table 3](#) shows MicroBlaze processor performance for the three different presets using Xilinx Cost-Optimized FPGAs and SoCs. These results are based on Vivado Design Suite 2017.4.

Table 3: MicroBlaze Preset Performance in Xilinx Cost-Optimized Portfolio Devices

Device (Speed Grade)		Microcontroller (1.1DMIPs/MHz)		Real-Time Processor (1.3DMIPs/MHz)		Applications Processor (1.4DMIPs/MHz)	
		F _{MAX}	DMIPs	F _{MAX}	DMIPs	F _{MAX}	DMIPs
FPGA:	Spartan-7 (-2)	194	260	161	216	131	140
	Artix-7 (-3)	226	303	184	247	153	164
SoC:	Zynq-7000S (-2)	185	248	155	208	125	134
	Zynq-7000 (-3)	224	300	181	243	168	180

MicroBlaze preset performance is comparable to off-the-shelf processors of a similar class. If the needs of the application change such that more processing power and/or peripherals are required, the costly process of migrating to a better discrete processor solution can be avoided completely. With the MicroBlaze processor, the designer can choose a higher-performance processor preset, change the configuration parameters of the processor, or make changes to the mix of peripherals in the system, all without changing the device package or the PCB.

Tailoring the MicroBlaze Processor Preset

In cases where additional peripherals or hardware needs to be added to the design, either a different preset can be used, or the parameters of the chosen preset can be modified to tailor it for the specific needs of the application. Creating a full embedded system using the presets is a matter of using the catalog of driver-enabled peripherals to satisfy the specific needs of the application. Some of the most commonly used "Drag 'n' Drop" IPs include:

- Multichannel DMA
- Ethernet subsystem
- Controller Area Network
- Streaming FIFO
- HDMI Camera/Display Interface
- MIPI-CSI, MIPI-DSI
- Video DMA
- Timer / Watchdog
- Mutex / Mailbox
- UART
- USB 2.0
- Quad SPI
- General Purpose I/O (GPIO)
- Pulse-Width Modulator (PWM)

As an example, the designer can select *Microcontroller* as the default preset and then increase the local memory or add an additional PWM controller to the design. Then a timer, a UART, and some GPIO can be specified as a starting point for the development. As the requirements of the design become more demanding, more peripherals can be added, or changes can be made to the MicroBlaze processor itself, such as changing the pipeline or enabling caches.

Additionally, MicroBlaze processor configurable example designs are available from Xilinx and many of its partners. These example designs use the MicroBlaze processor presets and add board-specific peripherals to the processor to create an off-the-shelf, fully functional embedded system. These example designs are available in the Vivado Design Suite or can be installed with a preset package available from a Xilinx partner. See [Figure 3](#) and [Figure 4](#) for examples of MicroBlaze processor configurable example designs.

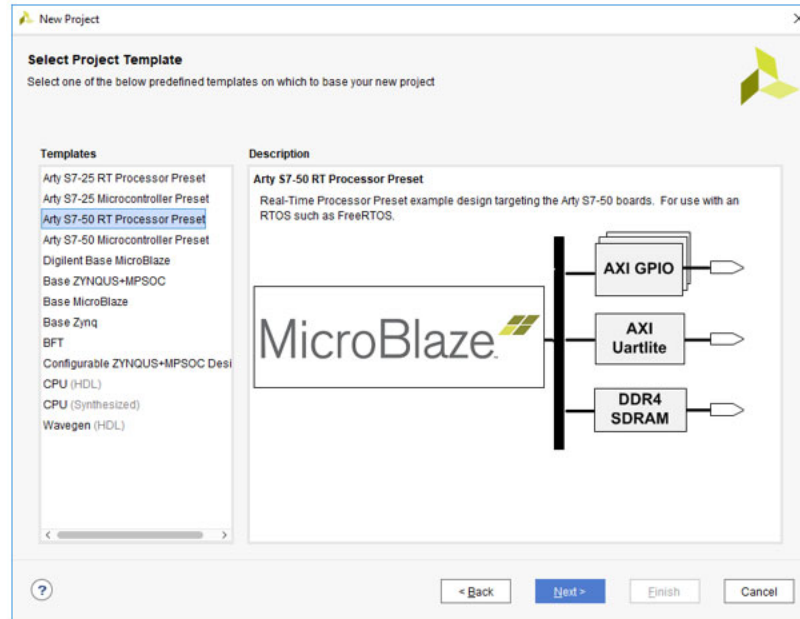
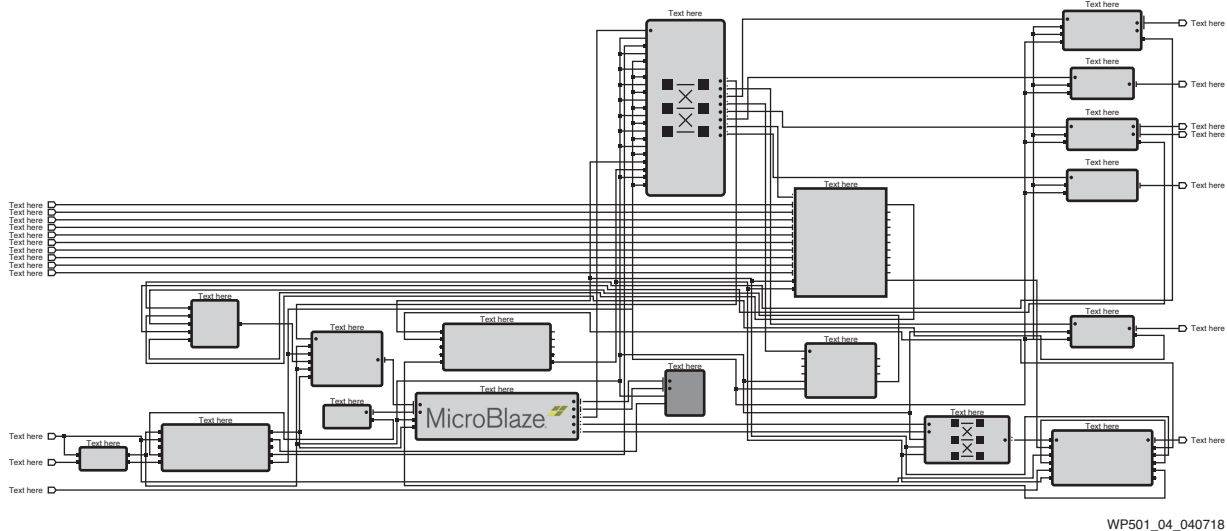


Figure 3: MicroBlaze Processor Presets as Project Templates

Open the example project of the desired processor preset for the required board, and the Vivado project is built and configured in the Vivado IPI tool.



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Figure 4: MicroBlaze Real-Time Preset Example Design

MicroBlaze processor preset configurable example designs can be modified using additional peripherals or blocks either from the IP Catalog, C-based algorithm designs, or DSP IP built using the Xilinx System Generator tool. Much of the design shown in Figure 4 is automatically generated by various automation wizards in the IPI tool. After system design is complete, the new design can be quickly exported to Xilinx SDK to begin software development.

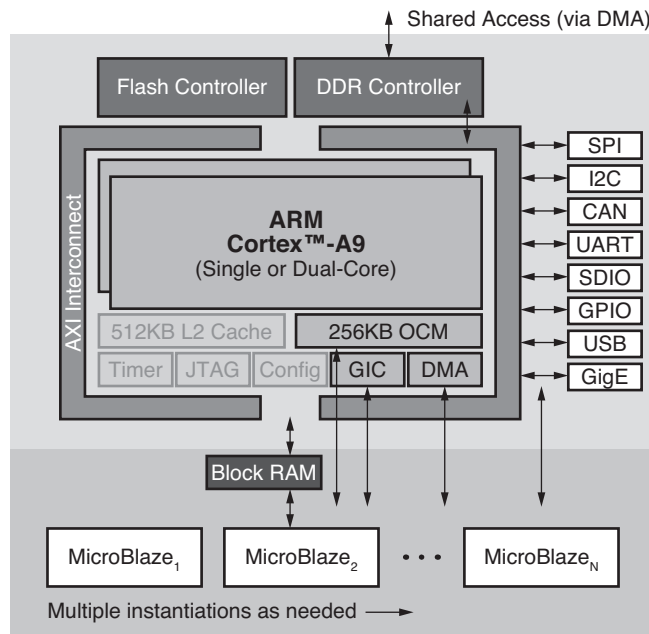
Multiple MicroBlaze Processors

Embedded systems often need to handle diverse workloads concurrently, such as real-time processing for industrial applications along with an immersive user-interface application. When diverse workloads are assigned to a single processor, a more powerful, costly, power-hungry processor might be required—but not desired.

By leveraging the programmability of a Xilinx FPGA or SoC, tremendous flexibility to partition the workloads exists in the MicroBlaze processor paradigm; the time-critical pieces can be assigned to a MicroBlaze microcontroller or real-time processor, and the user interface and housekeeping functions can be addressed by a MicroBlaze application processor. Thus, it is possible to tailor the overall system as a more cost-optimal fit for the operations required of the design—all this can be realized *within a single FPGA or SoC*, while also maintaining full support by the hardware and software tool chains.

MicroBlaze as a Co-processor in Zynq®-7000 SoC

In some cases, the embedded designer might need even more processing power for the applications processor. The Zynq-7000 All Programmable SoC is an ideal match for this situation. It contains either one or two ARM Cortex-A9 processors that can be run independently or in tandem with an OS using both cores. Then the other functions, such as the real-time processing, can be executed in a MicroBlaze microcontroller or real-time processor residing in the programmable logic. See [Figure 5](#).



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Figure 5: MicroBlaze Core(s) as Ancillary CPUs with the Zynq-7000 SoC Processing System

Additional MicroBlaze processors can be added to the programmable logic and attached to the system via the processing system’s programmable logic interfaces, allowing each MicroBlaze core to run its own software application; this makes it possible for each MicroBlaze processor to

communicate with the other processor through shared memory. The on-chip memory or DDR memory can be shared between the MicroBlaze processors in the programmable logic and the ARM Cortex processor cores. The Zynq-7000 SoC provides coherency between the Cortex-A9 processor(s) and the MicroBlaze processor via the Accelerator Coherency Port (ACP).

Accelerators in Programmable Logic

Another compelling reason to choose a programmable device with an embedded processor is the flexibility to make trade-offs between hardware and software, thus maximizing efficiency and performance. For example, if an algorithm is identified as a software bottleneck, a custom co-processing engine can be designed in the FPGA specifically for that algorithm. This co-processor can be attached to the FPGA's embedded processor through special low-latency channels.

Unlike off-the-shelf processor vendors, Xilinx provides design tools supporting features and flows like Vivado High-Level Synthesis (HLS), which enables IP creation from C/C++ and SystemC without needing to manually write the RTL. This approach provides designers and system architects with a faster and more robust way of delivering quality designs.

MicroBlaze Processor in Safe and Reliable Systems

For systems that require high reliability, MicroBlaze provides a number of options, including Fault Tolerance for error detection and correction in the memory subsystem and Triple Modular Redundancy (TMR) for soft error detection, correction, and recovery for MicroBlaze processors running on Xilinx FPGAs.

Fault Tolerance

The fault tolerance features included in the MicroBlaze processor provide error detection for internal block RAM and support for error detection and correction in local memory bus (LMB) block RAM. When fault tolerance is enabled, all soft errors in block RAM are detected and corrected, which significantly reduces overall failure intensity. Instruction cache and data cache protection, MMU protection, and exception handling features are also supported.

Lock-step and TMR Options

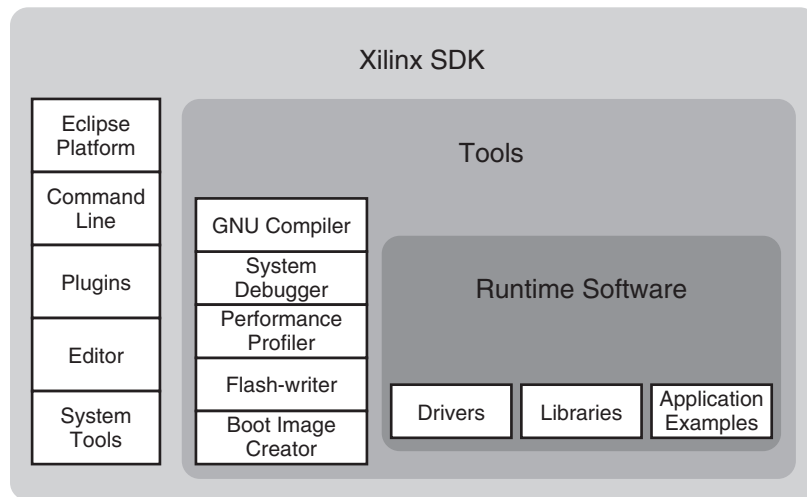
The lock-step and triple module redundancy (TMR) options are two of the key features implemented in the MicroBlaze processor, used to facilitate fault-tolerant system design. For lock-step, the processor system is configured with two identical MicroBlaze processor cores executing the same program. By comparing the outputs of the cores, any tampering attempts, transient faults, or permanent hardware failures can be detected. When a failure is detected, an error can be flagged and the system halted. In contrast, the TMR solution uses three MicroBlaze cores combined with a voting block so that when a mismatch is detected in the state of one of the cores, the system can continue nominal operation using the majority voted result. (See [PG268](#), *Triple Modular Redundancy Product Guide*, for more information.)

Some of the features included with the MicroBlaze TMR option include:

- Five IP cores that work together to provide higher reliability processing.
 - *TMR Manager* controls the redundancy state and supervises soft error mitigation
 - *TMR Voter* implements self-checking majority and mask faults in the triplicated sub-blocks to maintain nominal functionality
 - *TMR Comparator* compares outputs and generates mismatch errors if non-identical
 - *TMR Inject* injects faults during testing
 - *TMR Soft Error Mitigation (SEM) interface* encapsulates the Xilinx SEM IP core
- Block automation in Vivado IP Integrator creates a TMR MicroBlaze processor subsystem
- A TMR Manager example design

Embedded Design Tools and Software Support

Xilinx SDK (see [Figure 6](#)) is an Integrated Design Environment (IDE) for creating embedded applications for the MicroBlaze soft processor, as well as for the Zynq-7000 AP SoC. Xilinx SDK provides homogeneous (one or more MicroBlaze processors) and heterogeneous multi-processor (ARM Cortex-A9 plus MicroBlaze processor) software design and debug.



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Figure 6: Xilinx SDK

Xilinx SDK is an Eclipse-based development platform for embedded software designers. The SDK supports configuration and generation of board support packages (BSPs), either as stand-alone toolsets or as operating system-specific environments included within the Vivado Design Suite, where they appear as projects in the SDK Navigator view. BSPs support complete software design and debug flows, and include an editor, compilers, build tools, FreeRTOS and Yocto-built Linux kernels, flash memory management, JTAG system debugger / GDB debug integration, and a full suite of libraries and device drivers.

Xilinx SDK is used to develop bare-metal, FreeRTOS, and Linux applications. Xilinx provides project templates for the BSP, boot loader, C/C++, memory, and peripheral tests; Xilinx SDK automatically deploys to the target, connects the debugger, and begins program execution. This works with both MicroBlaze and ARM Cortex-A9 targets. See [Figure 7](#).

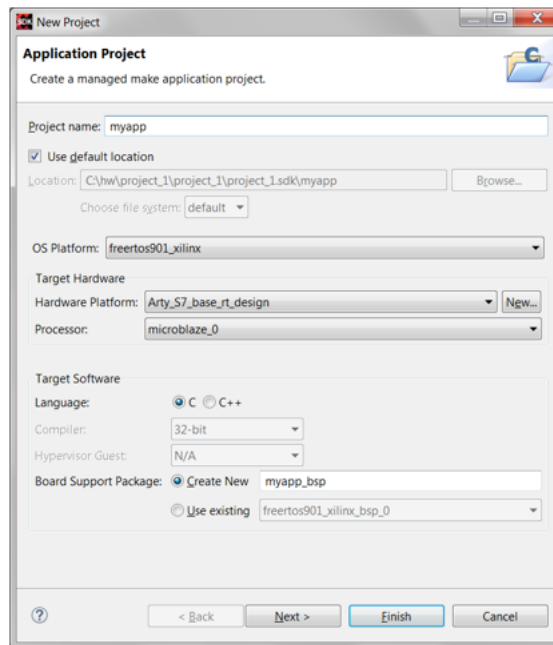


Figure 7: An Application Project in Xilinx SDK

Software engineers can quickly start porting their applications with pre-built MicroBlaze processor hardware preset designs in the Xilinx SDK platform. All the designer needs to do is open an empty workspace in the SDK Eclipse IDE, create a new application project, and select the target hardware that corresponds to the targeted development board and the preset MicroBlaze processor to be used.

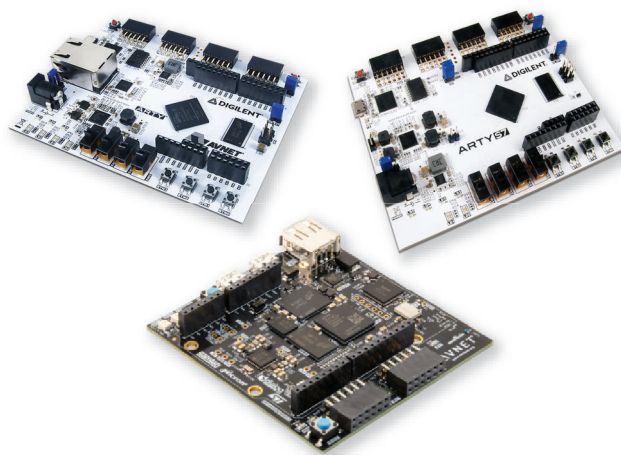
When creating the application project in Xilinx SDK, the user must choose the target operating system on top of which the application runs. Currently, the supported operating systems in Xilinx SDK are bare-metal (stand-alone), FreeRTOS, and Linux. To further simplify the application development process, Xilinx SDK provides sample examples and peripheral test programs that aid the user in bringing up and testing the hardware system quickly.

Xilinx SDK also supports debugging a program running on an FPGA or Zynq-7000 AP SoC device. By default, the debug logic on the preset MicroBlaze processor(s) is enabled. This provides advanced debugging capabilities (such as hardware breakpoints, read/write memory, watchpoints, and safe-mode debugging) as well as full visibility into the MicroBlaze processor(s) internal state.

Available Development Kits

Many development kits are available from Xilinx partners such as Digilent and Avnet, as illustrated in [Figure 8](#). These boards, kits, and modules provide the embedded designer with an out-of-the-box hardware platform that both reduces development time and enhances productivity.

Whether the designer is in the concept phase of a project and looking for a development board or complete kit, or is wanting to accelerate time-to-market and lower risk with a production board or module, Xilinx and its ecosystem partners offer the industry's most comprehensive set of hardware platforms to help jump-start a faster time-to-revenue model. See [Figure 8](#).



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Figure 8: Cost-Optimized Portfolio Development Boards from Digilent and Avnet

Conclusion

Xilinx offers comprehensive, cost-effective embedded solutions comprising the MicroBlaze processor presets and the Xilinx Cost-Optimized Portfolio of FPGAs and SoCs. Additionally, the AXI4-based Plug-'n'-Play IPs (with included bare-metal and Linux device drivers) and the Vivado IPI and SDK tools help customers build embedded applications faster. This reduces the overall development time for hardware, firmware, and application software, allowing the designer to create a low-cost system that exactly meets specifications.

To get started, customers can download the Vivado WebPACK™ edition (which includes the Xilinx SDK software development tools) and start developing MicroBlaze processor-based embedded designs. See Xilinx.com for additional details on the [Xilinx Cost Optimized Portfolio](#) and [MicroBlaze processor](#). Other useful starting points are given in the [Additional Reading](#) section.

Additional Reading

For more information, see:

1. Xilinx website: *MicroBlaze Soft Processor Core*,
<https://www.xilinx.com/products/intellectual-property/microblazecore.html>
2. Xilinx website: *MicroBlaze Documentation Design Hub*,
<https://www.xilinx.com/support/documentation-navigation/design-hubs/dh0020-microblaze-hub.html>
3. MicroBlaze Processor Quick Start Guide
https://www.xilinx.com/support/documentation/quick_start/microblaze-quick-start-guide.pdf
4. Xilinx Wiki: *MicroBlaze Getting Started*,
<http://www.wiki.xilinx.com/MicroBlaze>
5. Xilinx [WP469](#), *Using the MicroBlaze Processor to Accelerate Cost-Sensitive Embedded Systems Development*,
https://www.xilinx.com/support/documentation/white_papers/wp469-microblaze-for-cost-sensitive-apps.pdf
6. Xilinx Vivado: *Tutorials*,
<https://www.xilinx.com/video/category/vivado-quicktake.html>
7. Xilinx SDK: *Help*,
https://www.xilinx.com/html_docs/xilinx2017_2/SDK_Doc/index.html
8. Zedboard.org:
<http://zedboard.org/>
9. Digilent.com:
<http://store.digilentinc.com/embedded-processors/>

Revision History

The following table shows the revision history for this document:

Date	Version	Description of Revisions
04/13/18	1.0	Initial Xilinx release.

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