

# Native Loopback Accelerator Functional Unit (AFU) User Guide

Updated for Intel® Acceleration Stack for Intel® Xeon® CPU with FPGAs: **1.2**



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## 1. About this Document

### 1.1. Conventions

**Table 1. Document Conventions**

Convention	Description
#	Precedes a command that indicates the command is to be entered as root.
\$	Indicates a command is to be entered as a user.
This font	Filenames, commands, and keywords are printed in this font. Long command lines are printed in this font. Although long command lines may wrap to the next line, the return is not part of the command; do not press enter.
<variable_name>	Indicates the placeholder text that appears between the angle brackets must be replaced with an appropriate value. Do not enter the angle brackets.

### 1.2. Acronyms

**Table 2. Acronyms**

Acronyms	Expansion	Description
AF	Accelerator Function	Compiled Hardware Accelerator image implemented in FPGA logic that accelerates an application.
AFU	Accelerator Functional Unit	Hardware Accelerator implemented in FPGA logic which offloads a computational operation for an application from the CPU to improve performance.
API	Application Programming Interface	A set of subroutine definitions, protocols, and tools for building software applications.
ASE	AFU Simulation Environment	Co-simulation environment that allows you to use the same host application and AF in a simulation environment. ASE is part of the Intel® Acceleration Stack for FPGAs.
CCI-P	Core Cache Interface	CCI-P is the standard interface AFUs use to communicate with the host.
CL	Cache Line	64-byte cache line
DFH	Device Feature Header	Creates a linked list of feature headers to provide an extensible way of adding features.
FIM	FPGA Interface Manager	The FPGA hardware containing the FPGA Interface Unit (FIU) and external interfaces for memory, networking, etc. The Accelerator Function (AF) interfaces with the FIM at run time.
FIU	FPGA Interface Unit	FIU is a platform interface layer that acts as a bridge between platform interfaces like PCIe*, UPI and AFU-side interfaces such as CCI-P.
<i>continued...</i>		

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Acronyms	Expansion	Description
MPF	Memory Properties Factory	The MPF is a Basic Building Block (BBB) that AFUs can use to provide CCI-P traffic shaping operations for transactions with the FIU.
Msg	Message	Message - a control notification
NLB	Native Loopback	The NLB performs reads and writes to the CCI-P link to test connectivity and throughput.
RdLine_I	Read Line Invalid	Memory Read Request, with FPGA cache hint set to invalid. The line is not cached in the FPGA, but may cause FPGA cache pollution. <i>Note:</i> The cache tag tracks the request status for all outstanding requests on Intel Ultra Path Interconnect (Intel UPI). Therefore, even though RdLine_I is marked invalid upon completion, it consumes the cache tag temporarily to track the request status over UPI. This action may result in the eviction of a cache line, resulting in cache pollution. The advantage of using RdLine_I is that it is not tracked by CPU directory; thus it prevents snooping from CPU.
RdLine-S	Read Line Shared	Memory read request with FPGA cache hint set to shared. An attempt is made to keep it in the FPGA cache in a shared state.
WrLine_I	Write Line Invalid	Memory Write Request, with FPGA cache hint set to Invalid. The FIU writes the data with no intention of keeping the data in FPGA cache.
WrLine_M	Write Line Modified	Memory Write Request, with the FPGA cache hint set to Modified. The FIU writes the data and leaves it in the FPGA cache in a modified state.

### 1.3. Acceleration Glossary

**Table 3. Acceleration Stack for Intel Xeon® CPU with FPGAs Glossary**

Term	Abbreviation	Description
Intel Acceleration Stack for Intel Xeon® CPU with FPGAs	Acceleration Stack	A collection of software, firmware, and tools that provides performance-optimized connectivity between an Intel FPGA and an Intel Xeon processor.
Intel Programmable Acceleration Card with Intel Arria® 10 GX FPGA	Intel PAC with Intel Arria 10 GX FPGA	PCIe accelerator card with an Intel Arria 10 FPGA. Programmable Acceleration Card is abbreviated PAC. Contains a FPGA Interface Manager (FIM) that connects to an Intel Xeon processor over PCIe bus.
Intel Xeon Scalable Platform with Integrated FPGA	Integrated FPGA Platform	A platform with the Intel Xeon and FPGA in a single package and sharing a coherent view of memory using the Intel Ultra Path Interconnect (UPI).



## 2. The Native Loopback Accelerator Functional Unit (AFU)

### 2.1. Native Loopback (NLB) AFU Overview

The NLB sample AFUs comprise a set of Verilog and System Verilog files to test memory reads and writes, bandwidth, and latency.

This package includes three AFUs that you can build from the same RTL source. Your configuration of the RTL source code creates these AFUs.

### 2.2. The NLB Sample Accelerator Function (AF)

The `$OPAE_PLATFORM_ROOT/hw/samples` directory stores source code for the following NLB sample AFUs:

- `nlb_mode_0`
- `nlb_mode_0_stp`
- `nlb_mode_3`

**Note:** The `$DCP_LOC/hw/samples` directory stores the NLB sample AFUs source code for the 1.0 release package.

To understand the NLB sample AFU source code structure and how to build it, refer to the *Intel Acceleration Stack Quick Start Guide for Intel Programmable Acceleration Card with Intel Arria 10 GX FPGA*.

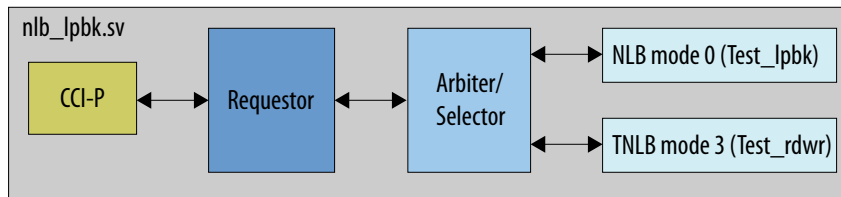
The release package provides the following three sample AFs:

- NLB mode 0 AF: requires `hello_fpga` or `fpgadiag` utility to perform the `lpbk1` test.
- NLB mode 3 AF: requires `fpgadiag` utility to perform the `trupt`, `read`, and `write` tests.
- NLB mode 0 stp AF: requires `hello_fpga` or `fpgadiag` utility to perform the `lpbak1` test.

**Note:** The `nlb_mode_0_stp` is the same AFU as `nlb_mode_0` but with Signal Tap debug feature enabled.

The `fpgadiag` and `hello_fpga` utilities help the appropriate AF to diagnose, test and report on the FPGA hardware.

**Figure 1. Native Loopback (nlb\_lpbk.sv) Top Level Wrapper**



The following files implement the loopback function shown in the figure above:

**Table 4. NLB Files**

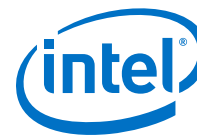
File Name	Description
nlb_lpbk.sv	Top-level wrapper for NLB that instantiates the requestor and arbiter.
arbiter.sv	Instantiates the test AF.
requestor.sv	Accepts requests from the arbiter and formats the requests according to the CCI-P specification. Also implements flow control.
nlb_csr.sv	Implements a 64-bit read/write Control and Status (CSR) registers. The registers support both 32- and 64-bit reads and writes.
nlb_gram_sdp.sv	Implements a generic dual-port RAM with one write port and one read port.

NLB is a reference implementation of an AFU compatible with the *Intel Acceleration Stack for Intel Xeon CPU with FPGAs Core Cache Interface (CCI-P) Reference Manual*. NLB’s primary function is to validate host connectivity using different memory access patterns. NLB also measures bandwidth and read/write latency. The bandwidth test has the following options:

- 100% read
- 100% write
- 50% read and 50% writes

**Related Information**

- [Intel Acceleration Stack Quick Start Guide for Intel Programmable Acceleration Card with Arria 10 GX FPGA](#)
- [Acceleration Stack for Intel Xeon CPU with FPGAs Core Cache Interface \(CCI-P\) Reference Manual](#)
- [Understanding the Extracted Intel PAC with Intel Arria 10 GX FPGA Release Package](#)
- [Running the Hello FPGA Example](#)



## 2.3. Native Loopback Control and Status Register Descriptions

**Table 5. CSR Names, Addresses and Descriptions**

Byte Address (OPAE)	Word Address (CCI-P)	Access	Name	Width	Description
0x0000	0x0000	RO	DFH	64	AF Device Feature Header.
0x0008	0x0002	RO	AFU_ID_L	64	AF ID low.
0x0010	0x0004	RO	AFU_ID_H	64	AF ID high.
0x0018	0x0006	Rsvd	CSR_DFH_RSVD0	64	Mandatory Reserved 0.
0x0020	0x0008	RO	CSR_DFH_RSVD1	64	Mandatory Reserved 1.
0x0100	0x0040	RW	CSR_SCRATCHPAD0	64	Scratchpad register 0.
0x0108	0x0042	RW	CSR_SCRATCHPAD1	64	Scratchpad register 2.
0x0110	0x0044	RW	CSR_AFU_DSM_BASE L	32	Lower 32-bits of AF DSM base address. The lower 6 bits are 4x00 because the address is aligned to the 64-byte cache line size.
0x0114	0x0045	RW	CSR_AFU_DSM_BASE H	32	Upper 32-bits of AF DSM base address.
0x0120	0x0048	RW	CSR_SRC_ADDR	64	Start physical address for source buffer. All read requests target this region.
0x0128	0x004A	RW	CSR_DST_ADDR	64	Start physical address for destination buffer. All write requests target this region
0x0130	0x004C	RW	CSR_NUM_LINES	32	Number of cache lines.
0x0138	0x004E	RW	CSR_CTL	32	Controls test flow, start, stop, force completion.
0x0140	0x0050	RW	CSR_CFG	32	Configures test parameters.
0x0148	0x0052	RW	CSR_INACT_THRESH	32	Inactivity threshold limit.
0x0150	0x0054	RW	CSR_INTERRUPT0	32	SW allocates Interrupt APIC ID and Vector to device.
<b>DSM Offset Map</b>					
0x0040	0x0010	RO	DSM_STATUS	32	Test status and error register.

**Table 6. CSR Bit Fields with Examples**

This table lists the CSR bit fields that depend on the value of the CSR\_NUM\_LINES, <N>. In the example below <N> = 14.

Name	Bit Field	Access	Description
CSR_SRC_ADDR	[63:<N>]	RW	2 <sup>^(N+6)</sup> MB aligned address points to the start of the read buffer.
	[<N>-1:0]	RW	0x0.
CSR_DST_ADDR	[63:<N>]	RW	2 <sup>^(N+6)</sup> MB aligned address points to the start of the write buffer.
	[<N>-1:0]	RW	0x0.
CSR_NUM_LINES	[31:<N>]	RW	0x0.

*continued...*



Name	Bit Field	Access	Description
	[<N>-1:0]	RW	Number of cache lines to read or write. This threshold may be different for each test AF. <i>Note:</i> Ensure that source and destination buffers are large enough to accommodate the <N> cache lines. CSR_NUM_LINES should be less than or equal to <N>.
For the following values, assume <N>=14. Then, CSR_SRC_ADDR and CSR_DST_ADDR accept 2^20 (0x100000).			
CSR_SRC_ADDR	[31:14]	RW	1MB aligned address.
	[13:0]	RW	0x0.
CSR_DST_ADDR	[31:14]	RW	1MB aligned address.
	[13:0]	RW	0x0.
CSR_NUM_LINES	[31:14]	RW	0x0.
	[13:0]	RW	Number of cache lines to read or write. This threshold may be different for each test AF. <i>Note:</i> Ensure that source and destination buffers are large enough to accommodate the <N> cache lines.

Table 7. Additional CSR Bit Fields

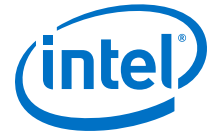
Name	Bit Field	Access	Description
CSR_CTL	[31:3]	RW	Reserved.
	[2]	RW	Force test completion. Writes test completion flag and other performance counters to <code>csr_stat</code> . After forcing test completion, the hardware state is identical to a non-forced test completion.
	[1]	RW	Starts test execution.
	[0]	RW	Active low test reset. When low, all configuration parameters change to their default values.
CSR_CFG	[29]	RW	<code>cr_interrupt_testmode</code> tests interrupts. Generates an interrupt at the end of each test.
	[28]	RW	<code>cr_interrupt_on_error</code> sends an interrupt when upon error detection.
	[27:20]	RW	<code>cr_test_cfg</code> configures the behavior of each test mode.
	[13:12]	RW	<code>cr_chsel</code> selects the virtual channel.
	[10:9]	RW	<code>cr_rdsel</code> configures the read request type. The encodings have the following valid values: <ul style="list-style-type: none"> <li>1'b00: RdLine_S</li> <li>2'b01: RdLine_I</li> <li>2'b11: Mixed mode</li> </ul>
	[8]	RW	<code>cr_delay_en</code> enables random delay insertion between requests.
	[6:5]	RW	Configures test mode, <code>cr_multiCL-len</code> . Valid values are 0,1, and 3.
	[4:2]	RW	<code>cr_mode</code> , configures test mode. The following values are valid: <ul style="list-style-type: none"> <li>3'b000: LPBK1</li> <li>3'b001: Read</li> <li>3'b010: Write</li> <li>3'b011: TRPUT</li> </ul>

continued...



## 2. The Native Loopback Accelerator Functional Unit (AFU)

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Name	Bit Field	Access	Description
			For more information about the test mode, refer to the <i>Test Modes</i> topic below.
	[1]	RW	<p>c_cont selects test rollover or test termination.</p> <ul style="list-style-type: none"> <li>When 1'b0, the test terminates. Updates the status CSR when CSR_NUM_LINES count is reached.</li> <li>When 1'b1, the test rolls over to the start address after it reaches the CSR_NUM_LINES count. In rollover mode, the test terminates only upon error.</li> </ul>
	[0]	RW	<p>cr_wrthru_en switches between WrLine_I and WrLine_M request types.</p> <ul style="list-style-type: none"> <li>1'b0: WrLine_M</li> <li>1'b1: WrLine_I</li> </ul>
CSR_INACT_THRESHOLD	[31:0]	RW	<p>Inactivity threshold limit. Detects the duration of stalls during a test run. Counts the number of consecutive idle cycles. If the inactivity count &gt; CSR_INACT_THRESHOLD, no requests are sent, no responses are received, and the inact_timeout signal is set. Writing 1 to CSR_CTL[1] activates this counter.</p>
CSR_INTERRUPT0	[23:16]	RW	The Interrupt Vector Number for the device.
	[15:0]	RW	apic_id is the APIC OD for the device.
DSM_STATUS	[511:256]	RO	Error dump form Test Mode.
	[255:224]	RO	End Overhead.
	[223:192]	RO	Start Overhead.
	[191:160]	RO	Number of Writes.
	[159:128]	RO	Number of Reads.
	[127:64]	RO	Number of Clocks.
	[63:32]	RO	Test error register.
	[31:16]	RO	Compare and exchange success counter.
	[15:1]	RO	Unique ID for each DSM status write.
	[0]	RO	Test completion flag.

## 2.4. Test Modes

CSR\_CFG[4:2] configures the test mode. The following four tests are available:

- **LPBK1:** This is a memory copy test. The AF copies CSR\_NUM\_LINES from the source buffer to the destination buffer. Upon test completion, the software compares the source and destination buffers.
- **Read:** This test stresses the read path and measures read bandwidth or latency. The AF reads CSR\_NUM\_LINES starting from the CSR\_SRC\_ADDR. This is only a bandwidth or latency test. It does not verify the data read.
- **Write:** This test stresses the write path and measures write bandwidth or latency. The AF reads CSR\_NUM\_LINES starting from the CSR\_SRC\_ADDR. This is only a bandwidth or latency test. It does not verify the data written.
- **TRPUT:** This test combines the reads and writes. It reads CSR\_NUM\_LINES starting from CSR\_SRC\_ADDR location and writes CSR\_NUM\_LINES to CSR\_SRC\_ADDR. It also measures read and write bandwidth. This test does not check the data. The reads and writes have no dependencies

The following table shows the CSR\_CFG encodings for the four tests. This table sets and CSR\_NUM\_LINES, <N>=14. You can change the number of cache lines by updating the CSR\_NUM\_LINES register.

**Table 8. Test Modes**

Test Mode	Encoding CSR_CFG[4:2]	Cache Line Threshold CSR_NUM_LINES	Cache Line Threshold for <N>=14
LPBK1	3'b000	2<N>	14'h3FFF
Read	3'b001	2<N>	14'h3FFF
Write	3'b010	2<N>	14'h3FFF
TRPUT	3'b011	2<N>	14'h3FFF

### 2.4.1. FPGA Diagnostics: fpgadiag

The fpgadiag utility includes several tests to diagnose, test, and report on the FPGA hardware. Use the fpgadiag utility to run all the test modes. For more information about using the fpgadiag utility, refer to the fpgadiag section in the [OPAE FPGA Tools Guide](#).

### 2.4.2. NLB Mode0 Hello\_FPGA Test Flow

1. Software initializes Device Status Memory (DSM) to zero.
2. Software writes the DSM BASE address to the AFU.  
CSR Write(DSM\_BASE\_H), CSRWrite(DSM\_BASE\_L)
3. Software prepares source and destination memory buffer. This preparation is test specific.
4. Software writes CSR\_CTL[2:0]= 0x1. This write brings the test out of reset and into configuration mode. Configuration can proceed only when CSR\_CTL[0]=1 & CSR\_CTL[1]=1.



5. Software configures the test parameters, such as `src`, `destaddress`, `csr_cfg`, `num_lines`, and so on.
6. Software CSR writes `CSR_CTL[2:0] = 0x3`. The AF begins test execution.
7. Test completion:
  - Hardware completes when the test completes or detects an error. Upon completion, the hardware AF updates `DSM_STATUS`. Software polls `DSM_STATUS[31:0] == 1` to detect test completion.
  - Software can force test completion by writing CSR writes `CSR_CTL[2:0] = 0x7`. Hardware AF updates `DSM_STATUS`.

### 3. Document Revision History for the Native Loopback Accelerator Functional Unit (AFU) User Guide

Document Version	Intel Acceleration Stack Version	Changes
2018.12.04	1.2 (supported with Intel Quartus® Prime Pro Edition 17.1.1)	Maintenance release.
2018.08.06	1.1 (supported with Intel Quartus Prime Pro Edition 17.1.1) and 1.0 (supported with Intel Quartus Prime Pro Edition 17.0.0)	Updated the location of the source code for the NLB sample AFU in <i>The NLB Sample Accelerator Function (AF)</i> section.
2018.04.11	1.0 (supported with Intel Quartus Prime Pro Edition 17.0.0)	<ul style="list-style-type: none"> <li>Added new <code>nlb_mode_0_stp</code> NLB sample AFU.</li> <li>Updated the location of the source code for the NLB sample AFU in <i>The NLB Sample Accelerator Function (AF)</i> section.</li> </ul>
2017.12.22	1.0 Beta (supported with Intel Quartus Prime Pro Edition 17.0.0)	Initial release.