

OpenCPI

Tutorial 1: Component-based Development

OpenCPI Release: v2.3.4

Revision History

Revision	Description of Change	Date
1.0	Creation	2019-12-12
1.1	Update for release 2.2.0 (Remove refs to Makefile/*.mk and change to XML files)	2021-07-03
1.2	Finish makeless updates for release 2.3.0	2021-08-15

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1 Overview

This tutorial introduces you to the process of component-based development with OpenCPI. It describes the steps to develop and run a simple OpenCPI application using OpenCPI tools and provided data and source code.

The application consists of both user-defined and OpenCPI-provided components with implementations for software (Resource-Constrained C/C++, or **RCC**) and FPGA (Hardware Definition Language, or **HDL**) processor types. The target application execution platforms are the Xilinx Xsim FPGA simulator for the FPGA implementation and the CentOS 7 development host for the software implementation.

The application will use four processing components – **source**, **ramp**, **square**, and **ander** – that you will specify from scratch and one OpenCPI built-in utility component – **file_write** – to write output data to files on the development host. The following figure illustrates the application:

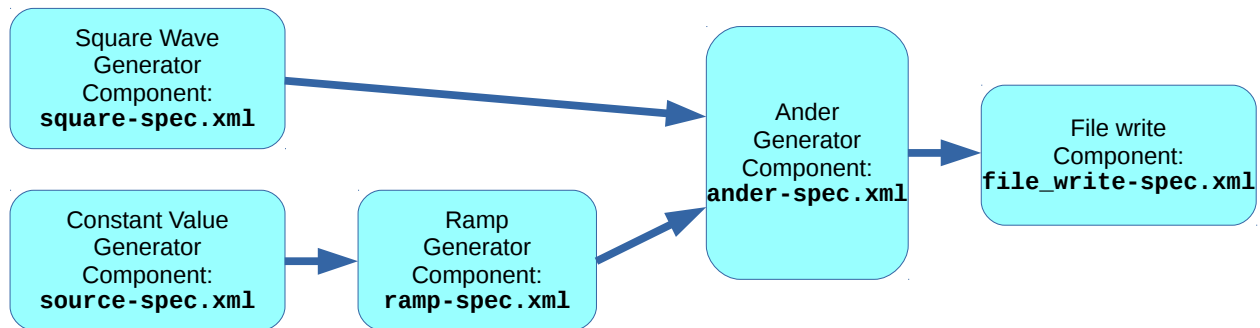


Figure 1: Simple Data Processing Application

1.1 Tutorial Objectives

The purpose of this tutorial is to step you through the basic OpenCPI application development process, showing you the tasks required and how to perform each task with the OpenCPI tools. The tutorial demonstrates how to:

- Create an OpenCPI project in which to develop your OpenCPI assets
- Create a library for components and their workers
- Create component specs for the **source**, **ramp**, **square** and **ander** components and define their properties and ports
- Create and build the workers and assemblies to be used to execute the components on the target platforms
- Create the application
- Run the application
- View the generated output data

The tutorial demonstrates how to develop the application and run it on the **xsim** platform using HDL workers, with the RCC workers in the application running on the CentOS 7 development host.

After following this tutorial, you should be familiar with the general process of OpenCPI application and component development, the tasks required to develop and run an OpenCPI application that uses built-in and user-defined components with implementations for software and FPGA platforms and how to use the OpenCPI tools to perform these tasks.

1.2 What's Provided for This Tutorial

The tutorial provides source code for the following tutorial items:

- The **source**, **ramp**, **square** and **ander** workers. The provided source code is written according to the APIs for the HDL (VHDL source code) and RCC (C++ source code) authoring models.
- A Python script that demultiplexes and plots the output data generated by the simple application.

This source code is available as text in the relevant sections of this document that you can copy and paste into the relevant files following the instructions given in the section.

The tutorial also provides the XML source for all of the assets used to build and run the example application, available as text in the relevant sections of the document.

Note that all of the OpenCPI built-in projects described in the [OpenCPI User Guide](#) are built for the CentOS 7 and Xilinx Vivado® XSim platforms as part of the OpenCPI installation process. You do not need to build or import these projects in order to use them in this tutorial.

1.3 Prerequisites to Using This Tutorial

This tutorial is designed to be run on a machine that has:

- The default OpenCPI source code installation (the latest OpenCPI source installed and built on CentOS 7)
- The default third-party FPGA simulator **xsim** installation (the Xilinx Vivado XSim simulator installed with the free, unlicensed variant, WebPack, of the Xilinx Vivado Design Suite HLx Edition tool set)
- (optional) The AV Eclipse-based GUI development tool (optionally installed with OpenCPI as a GUI alternative to the OpenCPI command-line tools)

The [OpenCPI Installation Guide](#) describes how to install these items. This tutorial assumes that you have, at a minimum, this OpenCPI environment set up on your development host.

To be able to use the OpenCPI command line tools, you need to run the OpenCPI environment setup script **opencpi-setup.sh** on your development host. If you have not already done so, follow the procedure in the [OpenCPI User Guide](#) to run this script.

Finally, we recommend reading the following briefings before getting started with the tutorial:

- Briefing 1, [Introduction to OpenCPI](#). This briefing introduces OpenCPI positioning, priorities and background as well as component and application terminology.
- Briefing 2, [Introduction to Development with OpenCPI](#). This briefing discusses OpenCPI elements and concepts from an application development perspective and introduces OpenCPI tools and building blocks for application development.

1.4 Documentation References

The documents listed in the following table provide detailed information about subjects discussed in this tutorial. These documents *are not* required reading for running this tutorial but will likely be of interest for more in-depth learning.

Table 1 - OpenCPI Reference Documentation

Title	Published By	Public URL
OpenCPI User Guide	OpenCPI	https://opencpi.gitlab.io/releases/latest/docs/OpenCPI_User_Guide.pdf
OpenCPI Application Development Guide	OpenCPI	https://opencpi.gitlab.io/releases/latest/docs/OpenCPI_Application_Development_Guide.pdf
OpenCPI Component Development Guide	OpenCPI	https://opencpi.gitlab.io/releases/latest/docs/OpenCPI_Component_Development_Guide.pdf
OpenCPI HDL Development Guide	OpenCPI	https://opencpi.gitlab.io/releases/latest/docs/OpenCPI_HDL_Development_Guide.pdf
OpenCPI RCC Development Guide	OpenCPI	https://opencpi.gitlab.io/releases/latest/docs/OpenCPI_RCC_Development_Guide.pdf

2 Create Project

The first step in the component-based application development process is to create a work area, called a **project**, where you can develop your OpenCPI assets. A project is a standard directory structure that holds your assets in both source code form and built form, along with the XML metadata files that describe them, and how they are built. It provides a place for collecting the assets you create for a specific application or assets that may be related to each other.

For our project, we'll use the name **DemoProject**.

Right now, we don't plan to share **DemoProject** or the assets we create in it with any other projects, so we don't need provide any project identification information about it when we create it. However, we do need to register it in OpenCPI's project registry so that we can use the command line tool **ocpidev** to display our project and its assets later on (the **ocpidev show** command currently displays only registered projects and their assets).

We'll use the **ocpidev** command line tool to create the **DemoProject** project:

- In a terminal/shell window, change directory to where you want to create the project.
- Use the command:
ocpidev create project DemoProject --register

The command creates the new project as a subdirectory of the directory you're in and registers it with the OpenCPI project registry. To demonstrate this, use the command:

ocpidev show projects

The output should look something like this:

Project	Package-ID	Path to Project	Valid/Exists
ocpi.assets_ts		/opt/opencpi/projects/assets_ts	True
ocpi.core		/opt/opencpi/projects/core	True
local.DemoProject		/home/tutdemos/DemoProject	True
ocpi.tutorial		/opt/opencpi/projects/tutorial	True
ocpi.assets		/opt/opencpi/projects/assets	True

DemoProject is given the default package ID **local**. Notice the projects listed with the package ID **ocpi**. These are the OpenCPI projects that come with the default OpenCPI installation. This tutorial's application uses the **file_write** component defined in the **ocpi.core** project.

Use the Linux **tree** command in the directory above **DemoProject** to observe the directory structure and the files created for **DemoProject**. Your output should look something like this:

```
$ tree DemoProject
|-- exports
|   |-- imports -> ../imports
|   |-- project-dependencies
|   |-- project-package-id
|-- imports -> /opt/opencpi/project-registry
|-- Project.exports
|-- project-metadata.xml
|-- Project.xml
```

The files of interest here are:

- **Project.exports**. This file specifies the project's assets and files that should be made visible, usable, and accessible from outside the project (usually by other projects).
- **Project.xml**. All assets have an XML file that provides metadata about the asset that OpenCPI needs for various purposes, including building and executing assets. This file contains metadata that the **ocpi**dev tool applies when building any assets in the project.

You won't need to make changes to any of these files in this tutorial; to read more about them, see the [OpenCPI Component Development Guide](#).

The files highlighted in red are directories and files that are internal to the OpenCPI framework and should not be touched.

If you want to use AV to create assets in **DemoProject**, you need to import it into AV. *Do not use AV to create OpenCPI projects.*

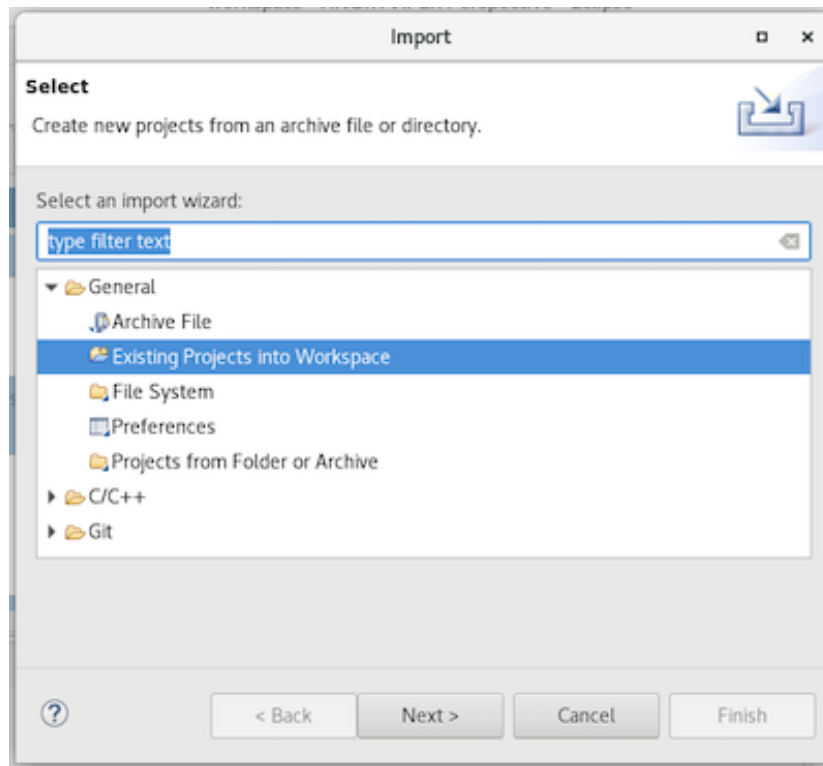
To import the **DemoProject** project:

- Start AV. To start it from the command line, use:

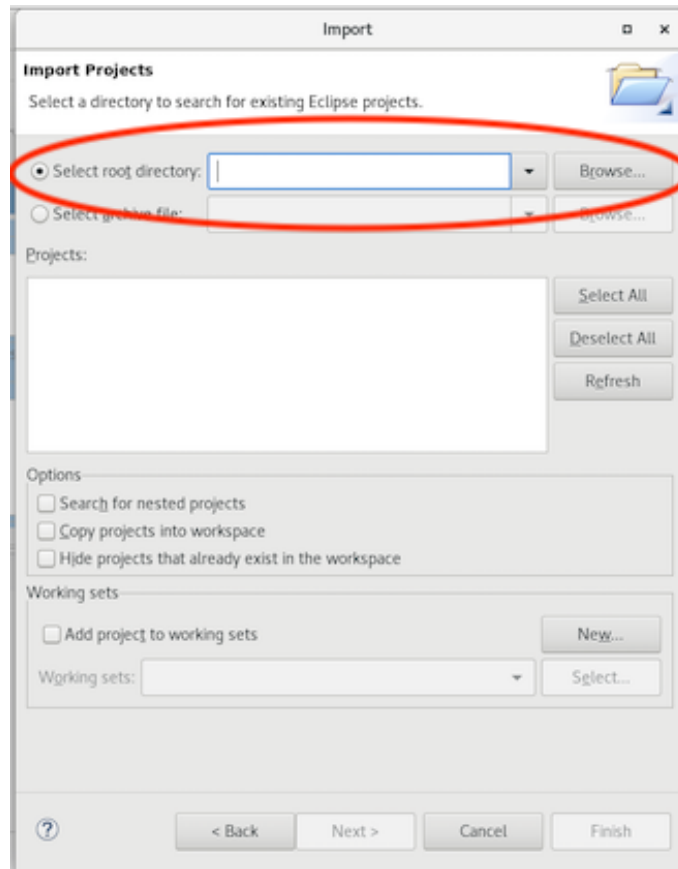
```
ocpiav run
```

You can also use **ocpiav** to set up AV to be started from your desktop. From the command line, use **ocpiav -help** for instructions.

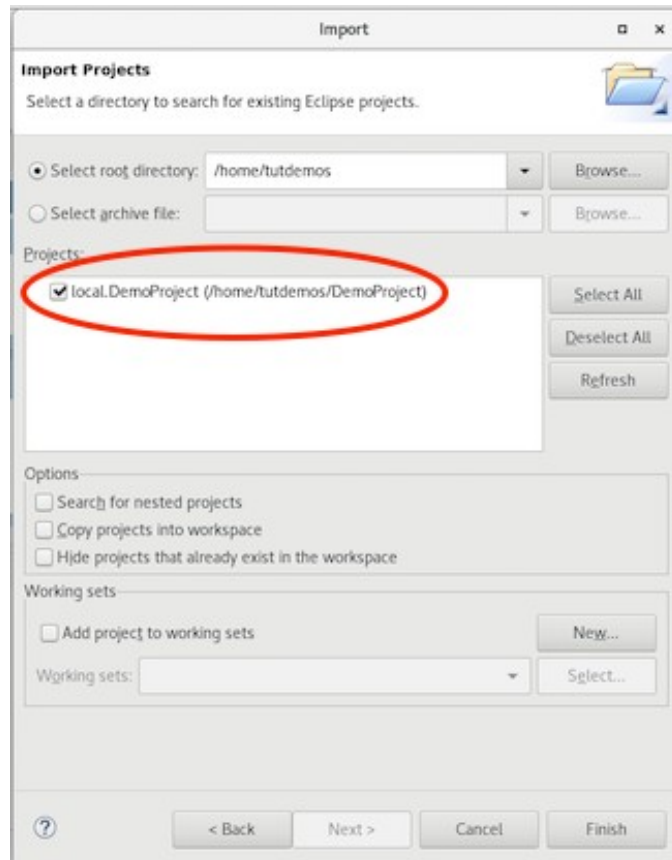
- From the AV menu bar at the top of the window, select **File > Import**. In the pop-up dialog, select **Existing Projects into Workspace** and then click **Next**.



- In the Import Projects dialog, make sure **Select Root Directory** is checked and then click **Browse** on the right.



- Navigate to the directory where you created **DemoProject** and then click **OK**. You'll see **local.DemoProject** listed and selected.



- Leave all of the other fields blank and click **Finish**. The **local.DemoProject** project is displayed in the (Eclipse) Project Explorer view.
- In the OpenCPI Projects view, click **Refresh**. You should now see **local.DemoProject** displayed in the OpenCPI Projects view.
- Use the Project Explorer view to look at the **DemoProject** directory structure and the files.

Now you can use AV to create, build and run assets in **DemoProject**. AV can perform most (but not all) of the same functions as the command line interface (CLI). For each subsequent step in this tutorial, both the AV way and the CLI way of performing the step are presented. You can choose to use either method; using both for a single step is redundant.

Now change directory to **DemoProject**:

```
cd DemoProject
```

We'll run all of the subsequent **ocpidev** and **ocpirun** commands for this tutorial from the **DemoProject** directory.

3 Create Component Library

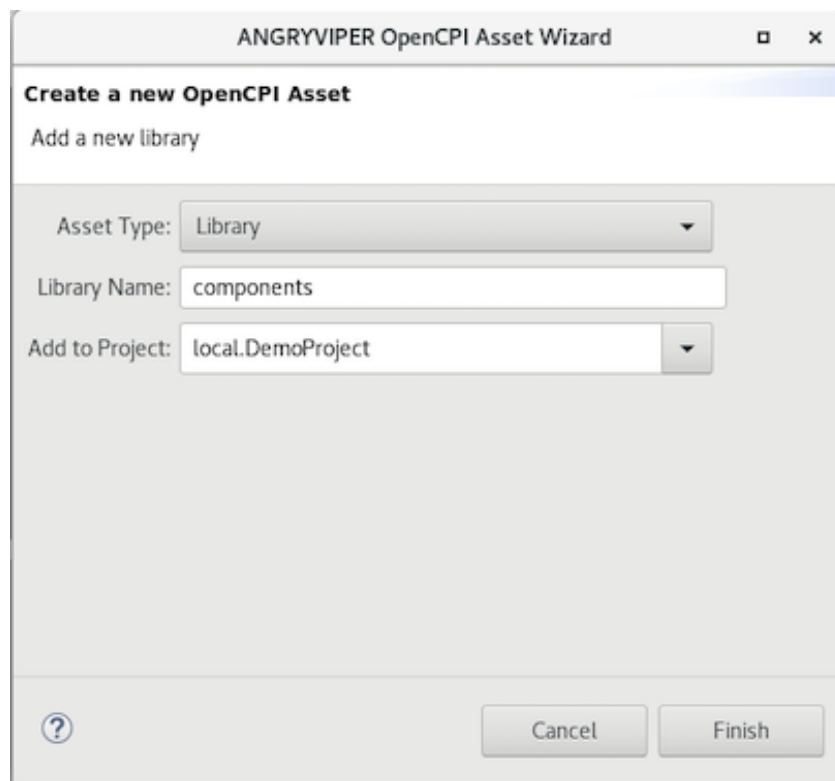
OpenCPI components are developed in **libraries**. OpenCPI component-based applications are defined as a composition of components, and the components are developed and built in component libraries.

In complex projects, a directory named **components** represents the top level of a hierarchy and individual component libraries are created underneath it.

In our case, we only need one component library, so we can use the top-level **components** directory as our library. We just need to create this directory.

To create the **components** library with AV:

- In OpenCPI Projects, click on **local.DemoProject**. Right click and then select **asset wizard**.
- In the drop-down list, select the **Library** asset type. The asset creation dialog for a library is displayed. We want to use the defaults that AV presents, so click **Finish** to accept them.



- The **components** library is displayed in the OpenCPI Projects view and the Project Explorer view. Use either view to examine the directories and files created.

Notice the Console tab and open window on the right. AV executes **ocpidev** commands to carry out its operations. You can see the output from the **ocpidev** command for the operations you just performed in the Console tab window, including error messages.

To create the **components** library with **ocpidev**, run the following command in the **DemoProject** directory:

```
ocpidev create library components
```

Run the **tree** command on **DemoProject** again to observe the directory structure and files that have been created:

```
DemoProject
|-- components
|   |-- lib
|   |   |-- package-id
|   |   '-- workers
|   |-- components.xml
|-- exports
|   |-- imports -> ../imports
|   |-- project-dependencies
|   |-- project-package-id
|   |-- project-package-id:local.DemoProject
|-- imports -> /opt/opencpi/project-registry
|-- Project.exports
|-- project-metadata.xml
|-- Project.xml
```

Notice the **components** directory and the **components.xml** file underneath it. This file is analogous to the project's ***.xml** file and doesn't need to be changed in this tutorial.

The output highlighted in red indicates directories and files that are internal to the OpenCPI framework and should not be touched.

4 Create Components

A **component** is a defined function that has properties and ports. **Properties** configure and control the component. **Ports** are where data messages are sent and received. Ports support **protocols**, which define the allowed/expected messages.

A component is specified in a small XML document called a **component spec** (acronym **OCS**). A component spec defines its properties and ports and may refer to **protocol specs** (acronym **OPS**) that are common to different components' ports.

The component spec is the basis for all of a component's implementations. Each component spec includes the details that are to be consistent across authoring models; meaning that if there are various implementations of a single component – for example, a software (RCC) implementation and an FPGA (HDL) implementation – both implementations will expect the same input and both should have the same output regardless of which architecture they run on.

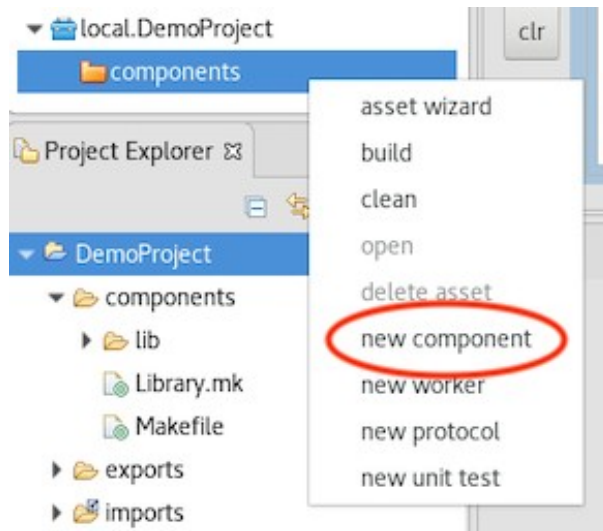
Creating a component spec is the first step to having a component implementation built and ready for use in an application. In this section, we'll generate the component specs for the **source**, **ramp**, **square** and **ander** components and then edit them to define each component's properties and ports.

4.1 Create Component Specs

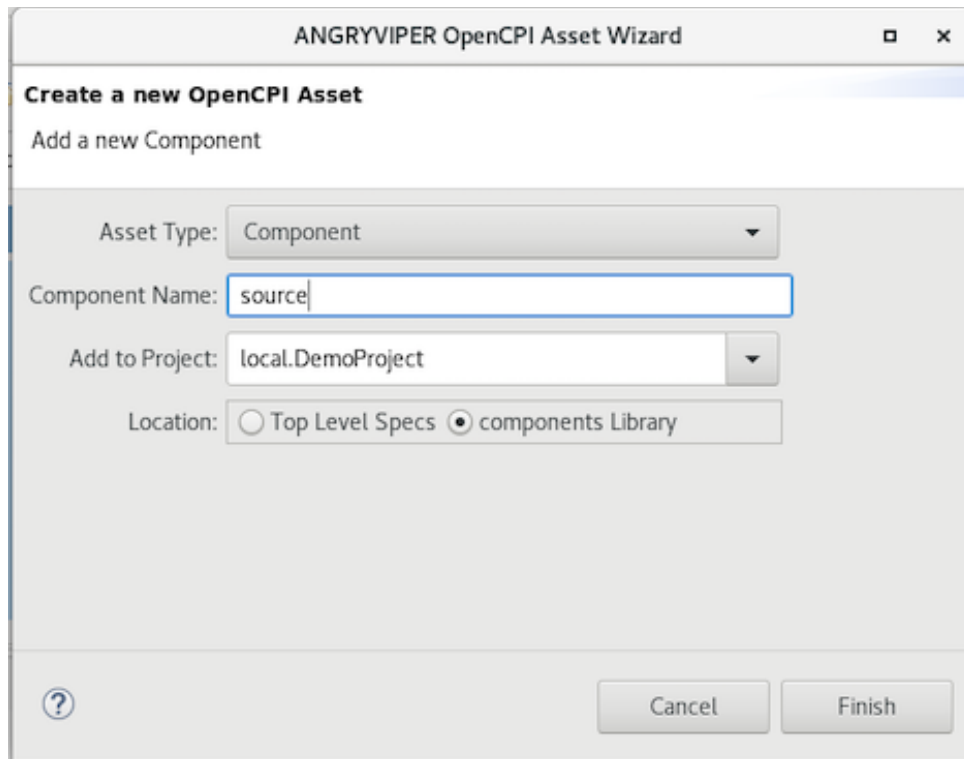
Our application requires four components, so we need to generate four component specs.

To create the four template specs with AV:

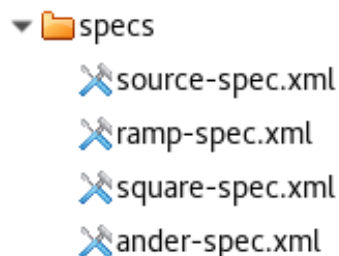
- In the OpenCPI Projects view, click on the **components** library. Right click and then select **New component**.



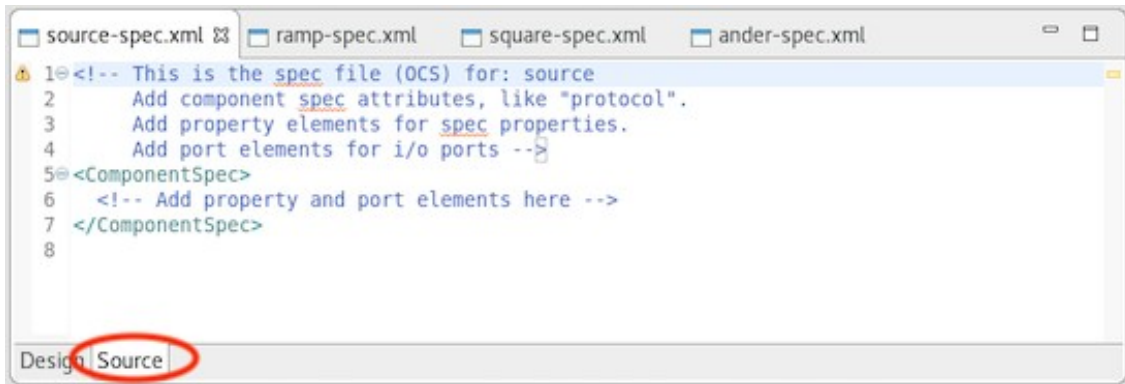
- The asset creation dialog for a component appears. In **Component Name**, enter **source**. Leave the other fields as they are so that AV uses the default values.



- Click **Finish**. When the operation completes, you should see a **specs** subdirectory in the **components** directory displayed in the Project Explorer and the source's component spec file **source-spec.xml** file displayed in the OCS Editor in the text editor panel.
- Repeat these steps for the **ramp**, **square** and **ander** components.
- Use the Project Explorer or OpenCPI Projects view to expand the **specs** directory. You should see the four component specs you just created.



- The OCS Editor should have four tabs open, one for each spec file. Click a component spec tab and then click the Source tab at the bottom of the window to display the initial XML code for the component. As you can see, there isn't much there: just the **Component Spec** XML element and instructions for completing the spec. Repeat this step for the other components.



To create the four component specs with **ocpidev**, run the following commands in the **DemoProject/components** directory:

```

ocpidev create component source
ocpidev create component ramp
ocpidev create component square
ocpidev create component ander

```

Now use the **tree** command again to observe the directory structure and files created:

```

DemoProject
|-- components
|   |-- lib
|   |   |-- ander-spec.xml -> ../specs/ander-spec.xml
|   |   |-- package-id
|   |   |-- ramp-spec.xml -> ../specs/ramp-spec.xml
|   |   |-- source-spec.xml -> ../specs/source-spec.xml
|   |   |-- square-spec.xml -> ../specs/square-spec.xml
|   |   |-- workers
|   |-- components.xml
|   |-- specs
|   |   |-- ander-spec.xml
|   |   |-- ramp-spec.xml
|   |   |-- source-spec.xml
|   |   '-- square-spec.xml
|-- exports
|   |-- imports -> ../imports
|   |-- project-dependencies
|   |-- project-package-id
|   |-- project-package-id:local.DemoProject
|-- imports -> /opt/opencpi/project-registry
|-- Project.exports
|-- project-metadata.xml
|-- Project.xml

```

The **components** directory now contains a **specs** subdirectory that contains the four generated component spec templates (aka the OCS files). You can easily identify them by the **-spec.xml** suffix that appears after the component name. We'll edit these template files in the next step.

The output highlighted in red indicates directories and files that are internal to the OpenCPI framework and should not be touched.

4.2 Define Component Properties and Ports

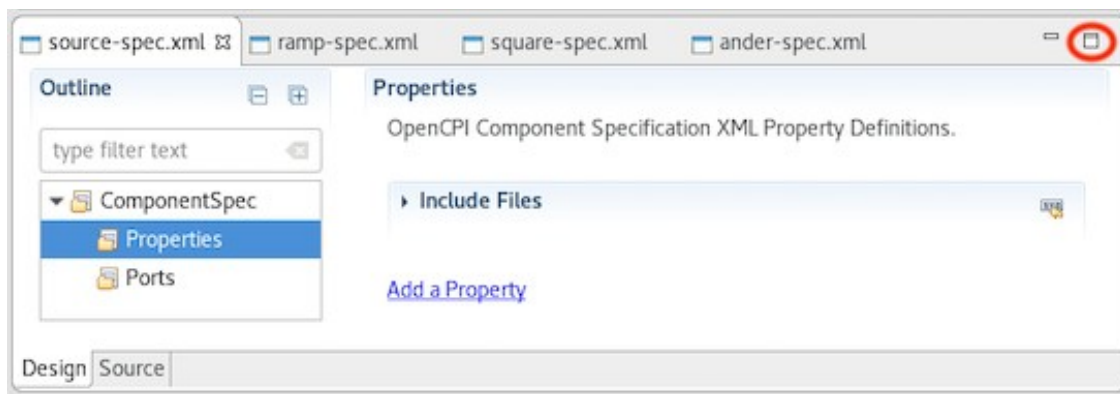
Now we need to edit each component spec to define its properties and ports.

Component properties configure and control the component. The **source** component's worker implementation will drive the application at runtime, so it needs two properties defined for it: a property that specifies the size of each data sample to be passed to the **ramp**, **square** and **ander** components for processing and then on to **file_write** for output to a file, and a property that specifies the total number of data samples to be processed and output. We'll use the **initial** attribute to provide flexibility as to when the property can be set. You can read more about this attribute in the [OpenCPI Component Development Guide](#).

Our remaining components don't require any runtime configuration or control values for their worker implementations, so we don't need to define any properties for them. They do, however, need port definitions, because each component will communicate with the other components when they are used in our application. Each component port must define the direction – input or output, consumer or producer – and the format – the **protocol** – of the messages they will send or receive. For our components, we will use the **rstream** protocol for all component ports except for the **ander** component's output port, which will use the **iqstream** protocol. The difference between the two is that **rstream** is a stream of 16-bit "real" numbers, while **iqstream** is a stream of complex numbers, each of which is represented by a 16-bit I ("in-phase") value and a 16-bit Q ("quadrature") value. All these numbers are signed.

To define the properties and ports using the AV OCS Design Editor:

- Click the **source-spec.xml** tab and then click the Design tab. In Outline, click **Properties** and then click **Add a Property**. You might need to scroll down to see this selection (use the scroll bar on the right). Alternatively, you can right-click on **Properties** and then select **Add Ocs Property** from the context menu.



- The OCS Property Definition page is displayed. Click the Maximize icon (circled in red in the figure above) to expand the page. In **Name**, enter **value**. In **Type**, select **short** from the drop down list.

OCS Property Definition

Property Data Type

Name: value

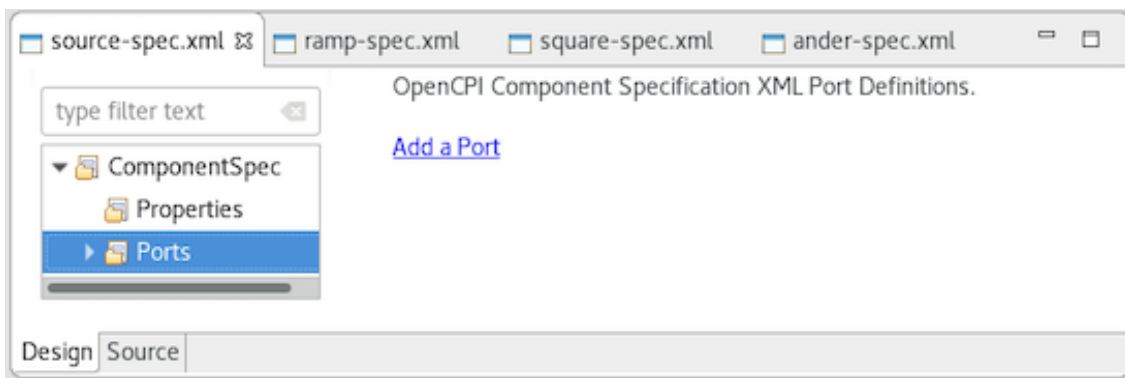
Type: short

Description:

SequenceLength:

ArrayDimensions:

- In **Property Accessibility**, check **Initial**.
- In Outline, click **Properties** and **Add a Property** again. In **Name**, enter **nsamples**. Leave **Type** set to **uLong**. In Property Accessibility, check **Initial**.
- In Outline, click **Ports** and then click **Add a Port** (alternatively, you can right-click on **Ports** and then select **Add a Port** from the context menu).



- The OCS Port Definition dialog is displayed. In **Name**, enter **out**. In **Protocol**, select **rstream_protocol**. Check **Producer**.

OCS Port Definition

Name: out

Protocol: rstream_protocol

Producer: ☒

Optional: ☐

Advanced Port Attributes

- Now click the Source tab for the **source** component. You can see the two properties and one port defined in XML between the **ComponentSpec** elements.
- Click the **ramp-spec.xml** tab and then click the Design tab. In Outline, two folders are displayed: **Properties** and **Ports**. The **ramp** component doesn't have any properties, so ignore the **Properties** folder. In Outline, click the **Ports** folder and then click **Add a Port**.

- The OCS Port Definition dialog is displayed. In **Name**, enter **in**. In **Protocol**, select **rstream_protocol** from the drop-down list. Leave the remaining fields blank.
- Click **Ports > Add a Port** again. In **Name**, enter **out**. In **Protocol**, select **rstream_protocol** from the drop-down list. Check **Producer**.
- Now click the Source tab. You can see the two ports defined in XML between the **ComponentSpec** elements.
- Click the **square-spec.xml** tab and then click the Design tab. In Outline, you see **Properties** and **Ports**. The **square** component has no properties, so ignore the **Properties** folder. In Outline, click **Ports** and then click **Add a Port**.
- In **Name**, enter **out**. In **Protocol**, select **rstream_protocol**. Check **Producer**. Leave the other fields blank.
- Click the **ander-spec.xml** tab and then click the Design tab. In Outline, ignore the **Property** folder, since the **ander** component has no properties. Click **Ports** and then click **Add a Port**. In **Name**, enter **in1**. In **Protocol**, select **rstream_protocol**. Leave the other fields blank.
- Click **Ports > Add a Port** again. In **Name**, enter **in2**. In **Protocol**, select **rstream_protocol** from the drop-down list. Leave the other fields blank.
- Click **Ports > Add a Port** again. In **Name**, enter **out**. In **Protocol**, select **iqstream_protocol** from the drop-down list. Check **Producer**. Leave the other fields blank.
- Click Save All (the stacked floppy disks icon in the tool bar underneath the main menu). This action saves the changes you've made to the component specs.
- Click Restore (the icon at the top right of the OCS Editor window) to collapse the OCS Editor view.

To define the properties and ports inline in the XML, edit each component spec with a text editor as follows:

- For the **source** component (**source-spec.xml** in the **specs** subdirectory), insert the following XML snippet between the **ComponentSpec** XML tags in the template file:

```
<ComponentSpec>
  <Property name="value" initial="true" type="short"/>
  <Property name="nsamples" initial="true"/>
  <Port Name="out" Producer="true" Protocol="rstream_protocol"/>
</ComponentSpec>
```

Here, you're defining the constant (the **value** property), defining the maximum values to be output (the **nsamples** property) and declaring an output port that uses the **rstream** protocol.

- For the **ramp** component (**ramp-spec.xml** in the **specs** subdirectory), insert the following XML snippet between the **ComponentSpec** XML tags in the template file:

```
<ComponentSpec>
<Port Name="in" Producer="false" Protocol="rstream_protocol"/>
<Port Name="out" Producer="true" Protocol="rstream_protocol"/>
</ComponentSpec>
```

Here, you're declaring an input port (consumer) that uses the **rstream** protocol (defined by the **rstream_protocol.xml** OPS, which is an asset in the OpenCPI core project) and an output port (producer) that also uses the **rstream** protocol.

- For the square component (**square-spec.xml** in the **specs** subdirectory), insert the following XML snippet between the **ComponentSpec** XML tags in the template file:

```
<ComponentSpec>
<Port Name="out" Producer="true" Protocol="rstream_protocol"/>
</ComponentSpec>
```

Here, you're declaring an output port that uses the **rstream** protocol.

- For the **ander** component (**ander-spec.xml** in the **specs** subdirectory), insert the following XML snippet between the **ComponentSpec** XML tags in the template file:

```
<ComponentSpec>
<Port Name="in1" Producer="false" Protocol="rstream_protocol"/>
<Port Name="in2" Producer="false" Protocol="rstream_protocol"/>
<Port Name="out" Producer="true" Protocol="iqstream_protocol"/>
</ComponentSpec>
```

Here, you're declaring two input ports that use the **rstream** protocol and one output port that uses the **iqstream** protocol (defined by the **iqstream_protocol.xml** OPS, which is an asset in the OpenCPI **core** project).

Now our component specs are complete. The next step is to create worker implementations for the components.

5 Create Workers

Now that we've defined the component specs, we're ready to create the workers that implement them. A **worker** is a specific implementation of a component. More than one worker can implement a component. Our example application uses only one implementation – one worker – per component.

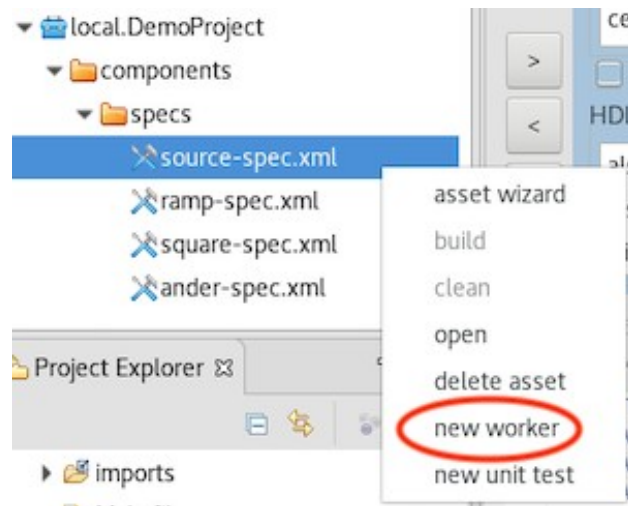
When we create a worker, we need to specify an authoring model to tell the OpenCPI framework what type of worker we want to create. Right now, we'll start with the RCC model for the **source** worker, and the HDL authoring model for the rest (We'll create RCC versions of these same workers later on.) More details about HDL workers and how to develop them can be found in the [OpenCPI HDL Development Guide](#). Details about RCC workers and how to develop them can be found in the [OpenCPI RCC Development Guide](#).

5.1 Create Workers

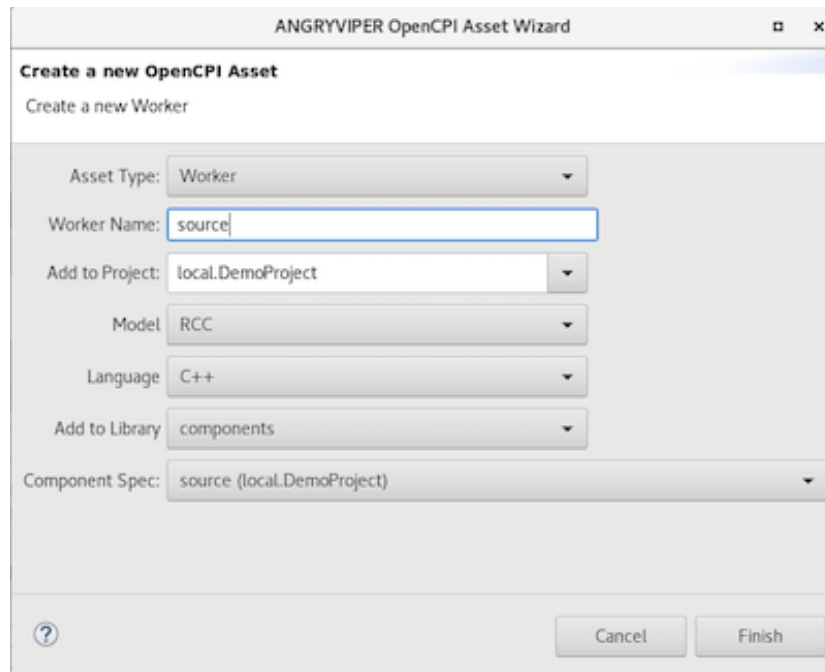
In this step, we want to create an RCC worker for our **source** component because it'll run outside the FPGA simulator platform and HDL workers for the remaining components so that we can run them on the **xsim** FPGA simulator platform.

To create the workers with AV:

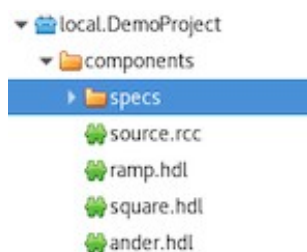
- In the OpenCPI Projects view, expand **local.DemoProject** and then navigate to **components > specs**.
- Select **source-spec.xml**. Right click and then select **new worker** from the context menu.



- The asset creation dialog for a worker appears. In **Worker Name**, enter **source**. We want to use RCC as the authoring model and C++ as the language, so leave the displayed values in the other fields as they are.

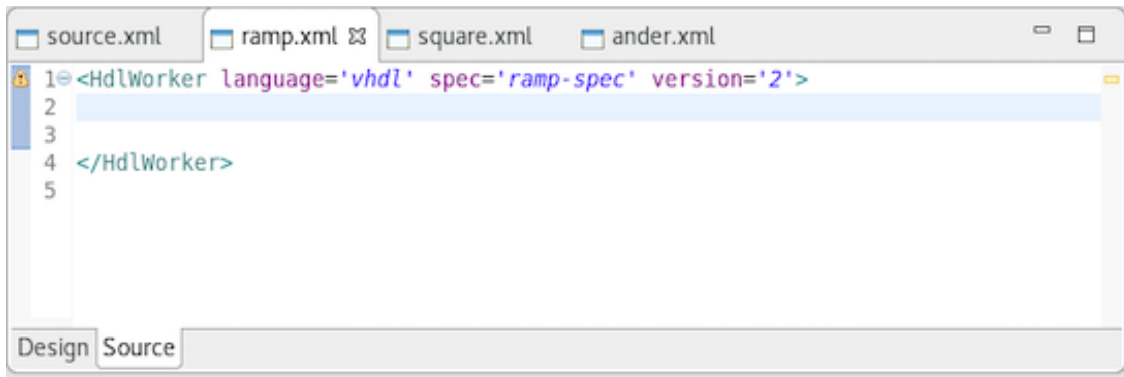


- Click **Finish**. When the operation completes, you should see a tab labeled **source.xml** displayed in the text editor panel and the RCC App Worker OWD Design Editor displayed in the tab.
- In the OpenCPI Projects view, select **ramp-spec.xml**. Right-click and select **new worker**. In **Worker Name**, enter **ramp**. In **Model**, select **HDL**. Leave the other fields as they are and click **Finish**.
- In the OpenCPI Projects view, select **square-spec.xml**. Right-click and select **new worker**. In **Worker Name**, enter **square**. In **Model**, select **HDL**. Leave the other fields as they are and click **Finish**.
- In the OpenCPI Projects view, select **ander-spec.xml**. Right-click and select **new worker**. In **Worker Name**, enter **ander**. In **Model**, select **HDL**. Leave the other fields as they are and click **Finish**.
- The new workers are displayed in the OpenCPI Projects view and the Project Explorer view.



- In the text editor panel, an OWD Editor should be open for each new worker. Click on the Source tab for one of the HDL workers to view its XML. Notice the **HdlWorker** XML definition elements with the VHDL language defined, a reference to the component spec, and the worker version (2). We'll use the OWD Editor to

update the HDL worker OWDs in the next step (the RCC source worker OWD is fine as it is.)



To create the workers with **ocpidev**, run the following commands in the **DemoProject/components** directory:

```
ocpidev create worker source.rcc
ocpidev create worker ramp.hdl
ocpidev create worker square.hdl
ocpidev create worker ander.hdl
```

The suffix of the worker's name, **.rcc** or **.hdl**, directs the tool to generate RCC or HDL workers, respectively.

Now run the command:

```
ocpidev show workers
```

The command displays all workers that reside in all libraries of all projects. The workers you just created should be listed at the top of the output.

To view the directories and files created, run the **tree** command. The project should now look similar to this output:

```

DemoProject/
|-- components
|   |-- ander.hdl
|   |   |-- ander.vhd
|   |   |-- ander.xml
|   |   |-- gen
|   |       |-- ander-build.xml
|   |       |-- ander-defs.vhd
|   |       |-- ander-defs.vhd.deps
|   |       |-- ander-impl.vhd
|   |       |-- ander-impl.vhd.deps
|   |       |-- ander-skel.vhd
|   |       |-- ander-skel.vhd.deps
|   ...
|   |-- ramp.hdl
|   |   |-- gen
|   |       |-- ramp-build.xml
|   |       |-- ramp-defs.vhd
|   |       |-- ramp-defs.vhd.deps
|   |       |-- ramp-impl.vhd
|   |       |-- ramp-impl.vhd.deps
|   |       |-- ramp-skel.vhd
|   |       |-- ramp-skel.vhd.deps
|   |   |-- ramp.vhd
|   |   |-- ramp.xml
|   |-- specs
|   |   |-- ander-spec.xml
|   |   |-- ramp-spec.xml
|   |   |-- source-spec.xml
|   |   |-- square-spec.xml
|   |-- source.rcc
|   |   |-- gen
|   |       |-- source-build.xml
|   |       |-- source_map.h
|   |       |-- source-skel.cc
|   |       |-- source-skel.cc.deps
|   |       |-- source-worker.hh
|   |       |-- source-worker.hh.deps
|   |   |-- source.cc
|   |   |-- source.xml |
|   |-- square.hdl
|   |   |-- gen
|   |       |-- square-build.xml
|   |       |-- square-defs.vhd
|   |       |-- square-defs.vhd.deps
|   |       |-- square-impl.vhd
|   |       |-- square-impl.vhd.deps
|   |       |-- square-skel.vhd
|   |       |-- square-skel.vhd.deps
|   |   |-- square.vhd
|   |   |-- square.xml
|   ...

```

Notice that creating the **source**, **ramp**, **square**, and **ander** workers generated an **.rcc** or **.hdl** directory for each one. Each worker's **.rcc** or **.hdl** directory contains two files of interest:

- **<worker_name>.xml**. This is the worker's OpenCPI Worker Description (OWD). The OWD is where that worker's specific properties and port protocols are defined. The definitions in the OWD are specific to each individual worker and may override some of the definitions specified in the OCS. Later on, we'll edit the OWD for each worker.
- **<worker_name>.vhd** or **<worker_name>.cc**. This is the worker's initial source code file, in the language associated with the authoring model specified when creating the worker; in our case, in the VHDL language for **ramp**, **square**, and **ander** because we specified an HDL worker, and the C++ language for **source** because we specified an RCC worker. This file is a "skeleton" that can be compiled but has empty logic; it allows the worker to be test-built before any changes are made. We'll edit the skeleton file for each worker later on to add the VHDL or C++ logic that makes the worker perform its intended function.

The **gen** subdirectory in **<worker>.hdl** contains code that is generated from the OpenCPI framework. Do not edit this code. For more details about the **gen** directory, see the [OpenCPI Component Development Guide](#).

5.2 Update HDL Worker Descriptions (OWDs)

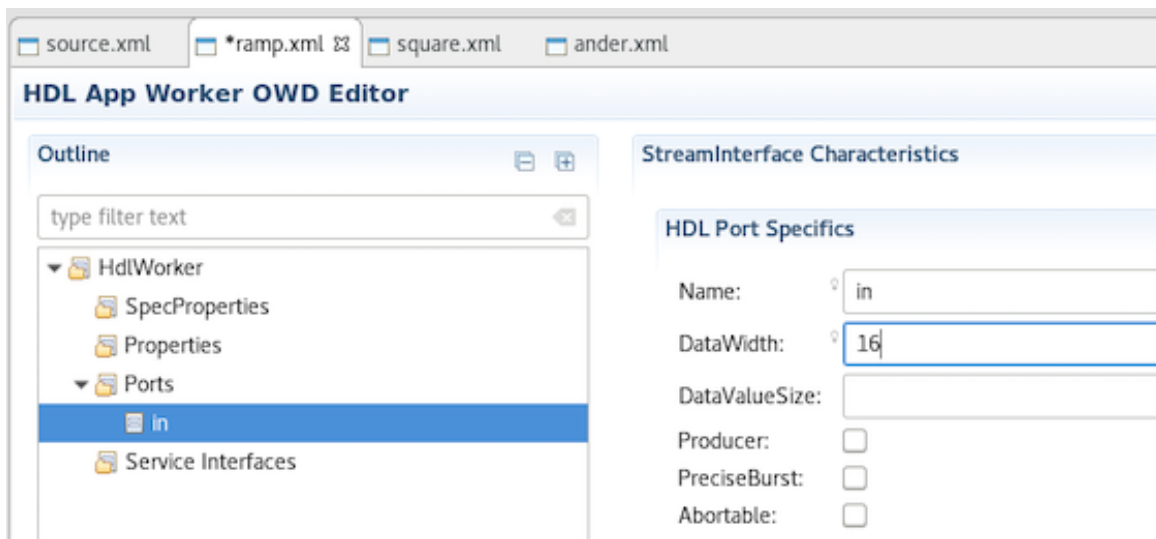
Now we'll update the HDL worker OWD files to provide any necessary implementation-specific information for the ports that the component spec defines abstractly. For our example workers, we need to add the following information to each OWD:

- The physical width of data ports for each worker. The protocol specified in the component OCS for the component ports (in our case, **rstream**) defines a default data width; we want to override this OCS default in our worker ports. We'll use the **DataWidth** attribute of the **StreamInterface** element to specify each port's data width. Specifying it this way means that the **DataWidth** value applies only to that port.
- Whether or not the end of message (EOM) signal in a worker's output ports will be automatically asserted as necessary or asserted explicitly by the worker. We want to use the automatic assertion method for our worker output ports using the **InsertEOM** attribute of the **StreamInterface** element for each output port.

The generated OWD for the **source.rcc** worker is fine as it is and doesn't need to be edited. The OWDs of RCC workers usually don't need any editing.

To update the HDL worker OWD files with the AV OWD Design Editor:

- Click the **ramp.xml** tab. In Outline, select **Ports** (you may need to scroll down using the scroll bar on the right to display it) and then click **Add a StreamInterface**. In **Name**, enter **in**. In **DataWidth**, enter **16**. Leave the other fields blank.



- In Outline, select **Ports** again and then click **Add a StreamInterface**. In **Name**, enter **out**. In **DataWidth**, enter **16**. Leave the other fields blank.
- Click the **square.xml** tab. In Outline, select **Ports** and then click **Add a StreamInterface**. In **Name**, enter **out**. In **DataWidth**, enter **16**. Leave the other fields blank.

- Click the **ander.xml** tab. In Outline, select **Ports** and then click **Add a StreamInterface**. In **Name**, enter **in1**. In **DataWidth**, enter **16**. Leave the other fields blank.
- In Outline, select **Ports** again and click **Add a StreamInterface**. In **Name**, enter **in2**. In **DataWidth**, enter **16**. Leave the other fields blank.
- In Outline, select **Ports** again and click **Add a StreamInterface**. In **Name**, enter **out**. In **DataWidth**, enter **32**. Leave the other fields blank.
- The OWD Design Editor doesn't currently provide a field for adding the **InsertEOM** attribute, so we'll need to edit the XML directly. Click the Source tabs for each worker and then add the following XML definition at the end of each **out StreamInterface** line (see the XML definitions below for reference):

InsertEOM="true"

For example, for the **ander** component:

```
<StreamInterface Name="out" DataWidth="32"
InsertEOM="true"></StreamInterface>
```

- In the Source tabs for each worker, remove any blank lines in between the **HdlWorker** XML definitions.
- Click Save All (the stacked floppy disks icon in the tool bar underneath the top menu bar.)

To update the worker OWD files from the command line, navigate to each worker's OWD XML file. Open it with a text editor and make the following updates:

- For the **ramp** worker, insert the following XML snippet between the **HdlWorker** XML tags in the template worker OWD **components/ramp.hdl/ramp.xml**:

```
<HdlWorker language="vhdl" spec="ramp-spec" version="2">
  <StreamInterface Name="in" DataWidth="16"/>
  <StreamInterface Name="out" DataWidth="16" InsertEOM="true"/>
</HdlWorker>
```
- For the **square** worker, insert the following XML snippet between the **HdlWorker** XML tags in the template worker OWD **components/square.hdl/square.xml**:

```
<HdlWorker language="vhdl" spec="square-spec" version="2">
  <StreamInterface Name="out" DataWidth="16" InsertEOM="true"/>
</HdlWorker>
```
- For the **ander** worker, insert the following XML snippet between the **HdlWorker** XML tags in the template worker OWD **components/ander.hdl/ander.xml**:

```
<HdlWorker language="vhdl" spec="ander-spec" version="2">
  <StreamInterface Name="in1" DataWidth="16"/>
  <StreamInterface Name="in2" DataWidth="16"/>
  <StreamInterface Name="out" DataWidth="32" InsertEOM="true"/>
</HdlWorker>
```


You have now completed the worker OWDs for the **ramp**, **square** and **ander** workers. The next step is to add the code that implements each worker function to the skeleton file created for each worker.

5.3 Edit RCC Worker Skeleton File

After creating the **source.rcc** worker, (and without having to edit its OWD file), the next step is to edit its C++ skeleton files to add the C++ code that implements that worker's function.

If you're using AV, you can use the Project Explorer to locate the worker skeleton file. Select it and then right-click. Select **Open** (or **Open with**) to open it with a text editor. With the worker's skeleton file tab open, click the Maximize button at the top right to maximize its display. When you finish editing the file, click Save (the floppy disk icon in the tool bar underneath the main menu) and then click the Restore button at the top right to collapse the file tab.

Using a text editor, replace the C++ worker class definition section in the **source.cc** skeleton file in **components/source.rcc/source.cc** with the following C++ code:

```
class SourceWorker : public SourceWorkerBase {
    size_t samples;
public:
    SourceWorker() : samples(0) {}
    RCCResult run(bool /*timedout*/) {
        size_t n = std::min(out.data().real().capacity(),
                            properties().nsamples - samples);
        if (n) {
            out.data().real().resize(n);
            samples += n;
            for (int16_t *p = out.data().real().data(); n--;
                *p++ = properties().value)
                ;
            return RCC_ADVANCE;
        }
        out.setEOF();
        return RCC_ADVANCE_DONE;
    }
};
```

This code produces a specified number of constant values to its output, even when the output buffer/message size might be less than the number of values it needs to produce.

See the [OpenCPI RCC Development Guide](#) for the specifics of writing RCC workers.

5.4 Edit HDL Worker Skeleton Files

After creating the HDL workers and editing their OWDs, the next step is to edit each HDL worker's VHDL skeleton file to add the VHDL code that implements that worker's function.

If you're using AV, you can use the Project Explorer to locate each worker skeleton file. Select it and then right-click. Select **Open** (or **Open with**) to open it with a text editor. With the worker's skeleton file tab open, click the Maximize button at the top right to maximize its display. When you finish editing the file, click Save (the floppy disk icon in the tool bar underneath the main menu) and then click the Restore button at the top right to collapse the file tab.

Using a text editor, replace the VHDL architecture section in the **ramp.vhd** skeleton file in **components/ramp.hdl/ramp.vhd** with the following VHDL:

```
architecture rtl of worker is
    signal do_work : bool_t;
    signal out_data_i, buff_data : std_logic_vector(15 downto 0);
begin
    -- When we are allowed to process data:
    do_work <= out_in.ready and in_in.valid;
    -- Outputs:
    in_out.take <= do_work;
    out_out.valid <= do_work;
    out_data_i <= std_logic_vector(signed(in_in.data)
                                + signed(buff_data));

    out_out.data <= out_data_i;
    -- Initialize or save off previous value when valid:
    ramp : process(ctl_in.clk)
    begin
        if rising_edge(ctl_in.clk) then
            if ctl_in.reset = '1' then
                buff_data <= (others => '0');
            elsif its(do_work) then
                buff_data <= out_data_i;
            end if;
        end if;
    end process ramp;
end rtl;
```

Replace the VHDL architecture section in the **square.vhd** skeleton file in **components/square.hdl/square.vhd** with the following VHDL:

```

architecture rtl of worker is
    signal do_work : bool_t;
    signal cnt : unsigned(7 downto 0);
begin
    -- When we are allowed to process data:
    do_work <= out_in.ready;
    -- Outputs:
    out_out.data <= (others => '1') when cnt < 32 else
                    (others => '0');
    out_out.valid <= do_work;
    -- Generate the square pulse's counter
    square : process(ctl_in.clk)
    begin
        if rising_edge(ctl_in.clk) then
            if ctl_in.reset = '1' then
                cnt <= (others => '0');
            elsif its(do_work) then -- advance when we are pushing
                cnt <= cnt + 1;
                if cnt = 63 then
                    cnt <= (others => '0');
                end if;
            end if;
        end if;
    end if;
    end process square;
end rtl;

```

Replace the VHDL architecture section in the **ander.vhd** skeleton file in **components/ander.hdl/ander.vhd** with the following VHDL:

```

architecture rtl of worker is
    signal do_work : bool_t;
begin
    -- When we are allowed to process:
    do_work <= out_in.ready and in1_in.valid and in2_in.valid;
    -- Outputs:
    in1_out.take <= do_work;
    in2_out.take <= do_work;
    out_out.valid <= do_work;
    out_out.data(15 downto 0) <= in1_in.data and in2_in.data;
    out_out.data(31 downto 16) <= in1_in.data;
end rtl;

```

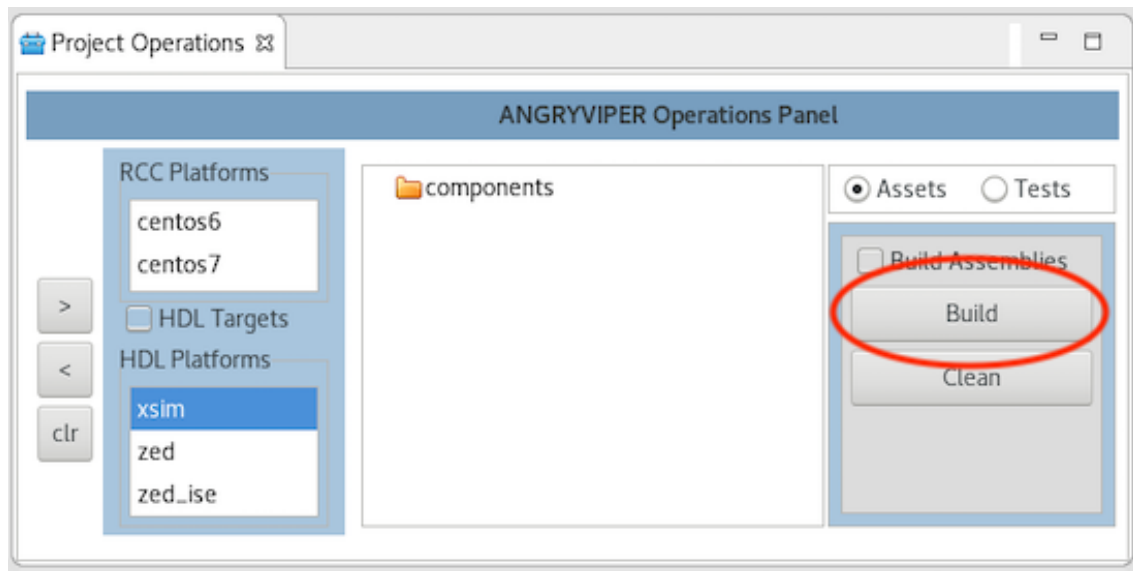
You've now completed the HDL worker VHDL files. The next step is to build the RCC and HDL worker source files you created.

5.5 Build Workers

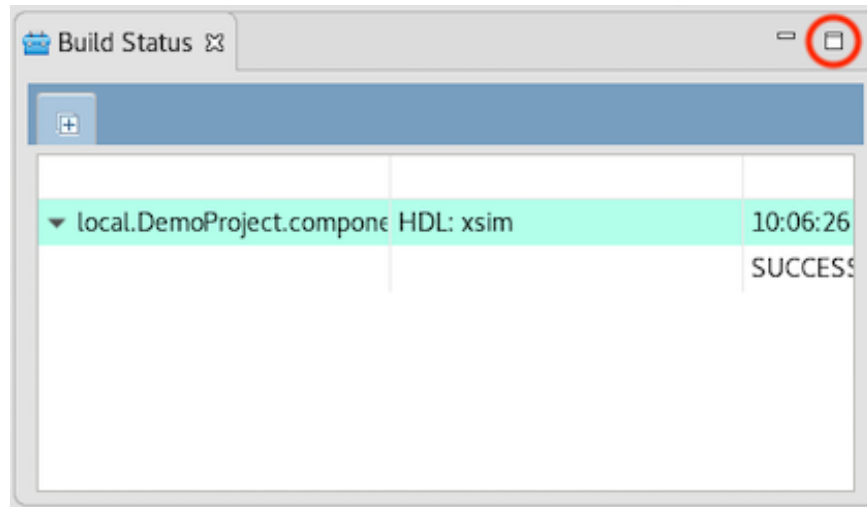
Now we need to compile the workers for the platform on which we want to run them; in our case, this is the **xsim** FPGA simulator for the HDL workers. Workers are normally built as part of building an entire component library or as part of an entire project, although they can also be built separately. Since all of our workers reside in the **components** library, we'll build this library and specify the **xsim** platform for our HDL workers; the platform for the source RCC worker is implicitly the development system (CentOS 7) on which we're running.

To build the **components** library and the workers in it with AV:

- In the OpenCPI Projects view, select the **components** library.
- Click the > button in the Operations Panel to move the library to this panel.
- In HDL platforms, select **xsim**.
- Click **Build**.



- If the build succeeds, you'll see a message in the Build Status tab with the DemoProject and what you've built (**components**, in this case) highlighted in green. You can click the Maximize button (circled in red in the figure below) to view the entire message.



To build the **components** library and the workers in it with the **ocpidev** command, from the **DemoProject** directory, run the command:

```
ocpidev build library components --hdl-platform xsim
```

This command builds all the workers in the **components** library, and when the worker being built is an HDL worker, we've specified that the target platform to build them for is **xsim**.

Note that worker implementations (both RCC and HDL) for the OpenCPI **file_write** component already exist in the **ocpi.core** project and are already built for the **xsim** (and **centos7**) platforms as part of the OpenCPI installation process.

6 Create HDL Assembly

Artifacts are binary executables compiled from one or more workers, built for a platform. OpenCPI applications require supporting artifacts in order to execute on platforms. We want our application to be able to execute on an FPGA (simulator) platform, so we need to transform the compiled/built HDL workers that implement the components that the application will use into artifacts that can be executed on an FPGA platform.

To do this, we'll create an **HDL assembly**: a collection of connected HDL workers that are built into a complete FPGA configuration bitstream that acts as an artifact. The resulting bitstream is executed on an FPGA to implement a part or all of an application's components. Although HDL assemblies are generally created with a particular application in mind, they can be designed for use by more than just one application. They can be used for any application where the workers in the assembly form a subset of the components in the assembly (and are connected together as specified in the application).

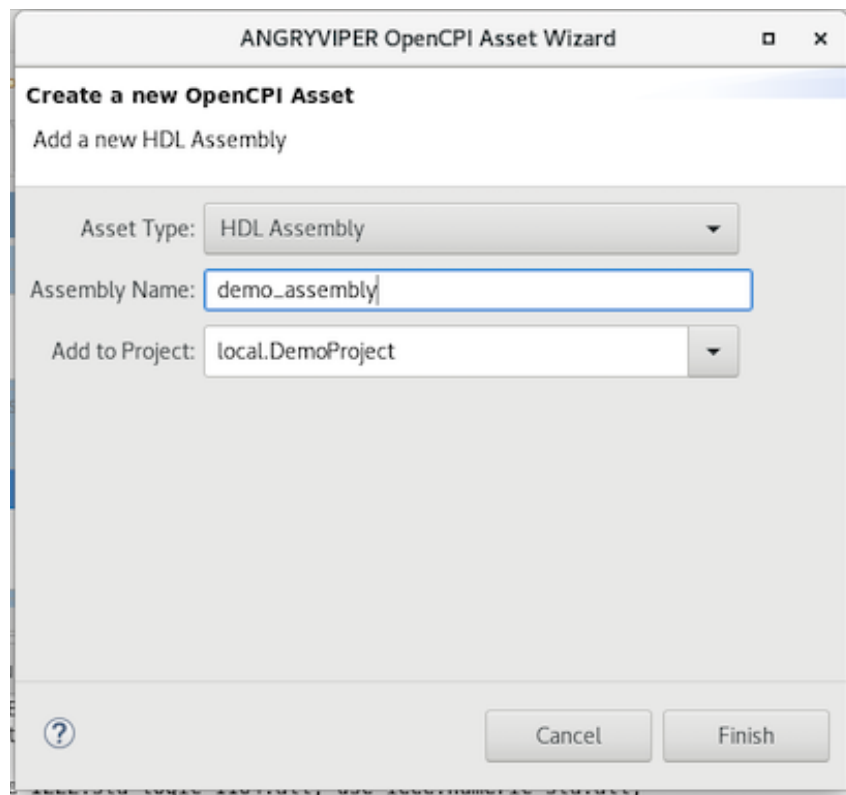
More details about HDL assemblies and how to develop them can be found in the [OpenCPI HDL Development Guide](#).

6.1 Create HDL Assembly

First, we'll create the HDL assembly asset in **DemoProject**. We'll name the HDL assembly **demo_assembly**.

To create the HDL assembly with AV:

- In the OpenCPI Projects view, click **local.DemoProject**. Right click and then select **asset wizard**.
- In the drop-down list, select the **HDL Assembly** asset type.
- In **Assembly Name**, enter **demo_assembly**.
- In **Add to Project**, leave **local.DemoProject** selected.



- Click **Finish**.
- When the operation completes, the new assembly is displayed in the OpenCPI Projects view in a new **assemblies** subdirectory in **DemoProject** and in the Project Explorer view in a new **hdl** subdirectory in **DemoProject**. Use one of these views to observe the directories and files created. In the text editor panel, notice that the OpenCPI HDL Assembly Description (OHAD) Diagram is open for the assembly. We'll use this editor to update the HDL assembly description in the next step.

To create the HDL assembly with **ocpidev**, run the following command from the **DemoProject** directory:


```
ocpidev create hdl assembly demo_assembly
```

Run the **tree** command to view the directories and files created.

```
DemoProject/hdl/  
|-- assemblies  
|   |-- demo_assembly  
|   |   |-- demo_assembly.xml
```

Notice the **hdl** directory, an **assemblies** directory within it and a **demo_assembly** directory within the **assemblies** directory. Each HDL assembly is defined within its own directory. The **demo_assembly** directory contains one file of interest:

- **demo_assembly.xml**. This is the assembly's OpenCPI HDL Assembly Description (OHAD). The OHAD is where the assembly's HDL worker instances, property/parameter settings, connections and external ports are defined. We'll edit this initial XML file next to specify the HDL workers to be included and the connections between them.

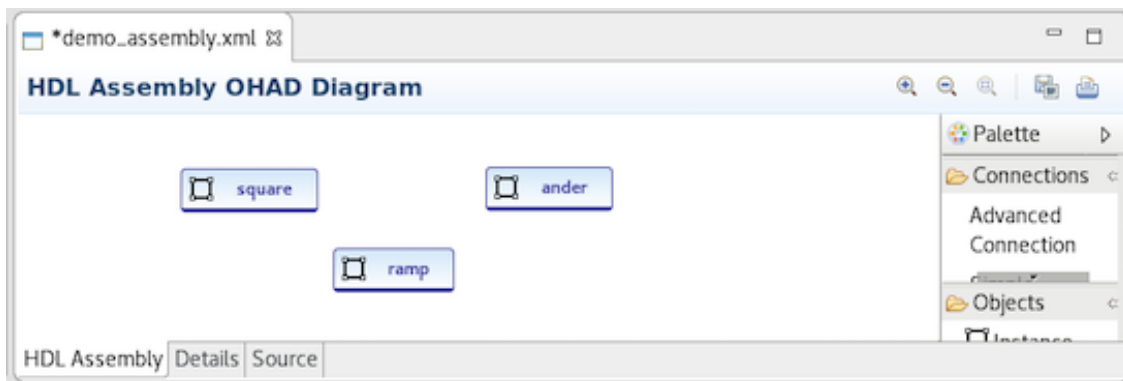
6.2 Update HDL Assembly Description

Now we'll update the initial HDL assembly description (OHAD) we just created to describe the worker instances and connections for our application's use. Most HDL assemblies describe a subset of the components (and thus HDL workers) that an application uses. We want to be able to run the processing components **ramp**, **square** and **ander** (and thus HDL workers) on the FPGA simulation platform, so our HDL assembly needs to specify instances and connections for these workers, but not for **source** and **file_write**.

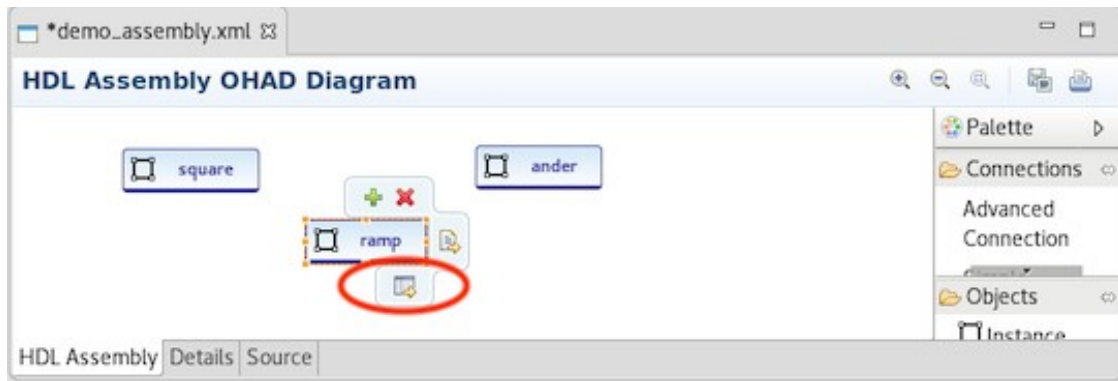
We'll update our template **demo_assembly** to define instances for the **ramp**, **square** and **ander** workers. We'll also update it to define connections to the **ander** component's two input ports: one from the **ramp** component's output port and one from the **square** component's output port.

To update the HDL assembly OHAD using the AV HDL Assembly OHAD Diagram:

- Click on the **nothing** worker and then click the red X to delete it. This is a placeholder worker that is automatically added to an assembly so that it will build.
- We'll use drag and drop to add the HDL workers to the diagram: in the Project Explorer view, select the ramp worker's OWD XML (**components/ramp.hdl/ramp.xml**). Left-click and hold the mouse button. Drag the file into the OHAD Diagram and then release the mouse button. The icon for the worker XML appears in the diagram.
- Follow the same steps for the **square** worker (**components/square.hdl/square.xml**) and the **ander** worker (**components/ander.hdl/ander.xml**) OWD XML files.
- Arrange the worker icons in the diagram so that it looks something like this:



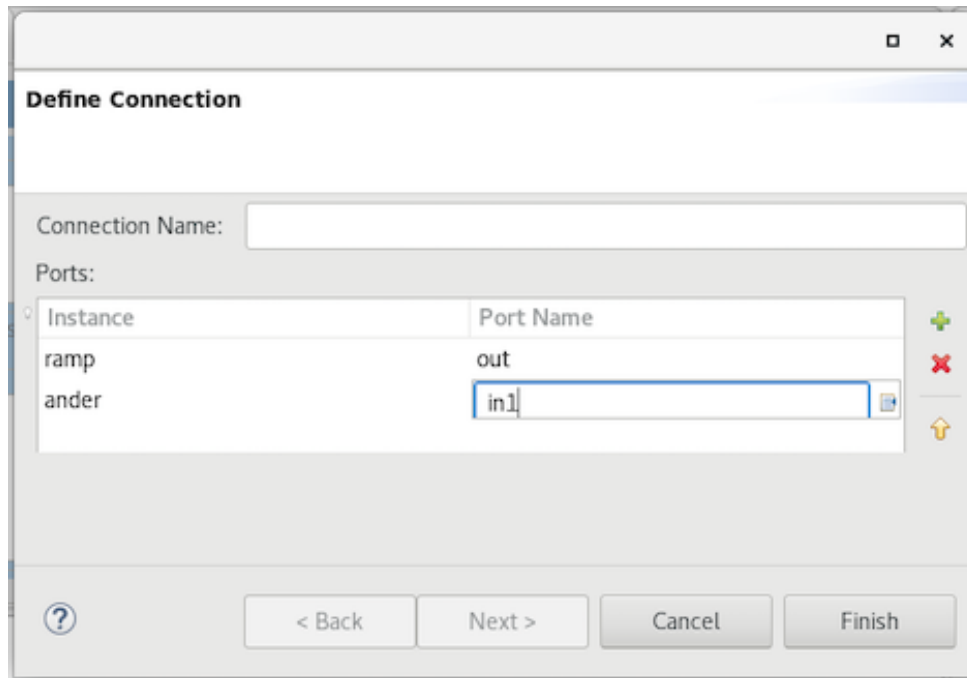
- In the OHAD Diagram, click **ramp** to display a set of controls. Click the control displayed below the component icon.



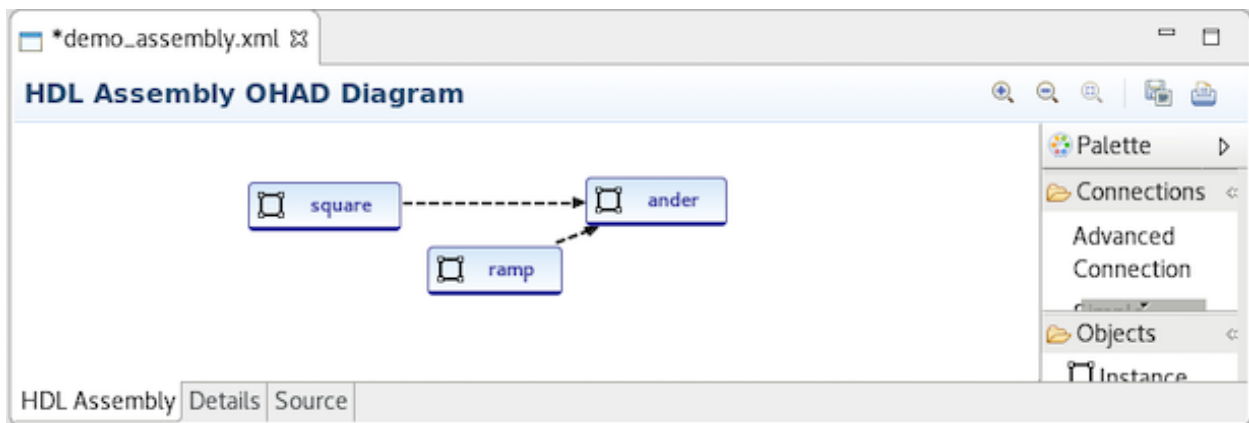
- The Properties tab is displayed on the lower right section of the AV display, next to the Problems and Console tabs. In the Properties tab, check **Externals**. Leave the other fields blank.

The screenshot shows the 'Properties' tab for the 'Ramp' component. The 'Name' field is 'ramp' and the 'Worker' field is 'ramp'. The 'Externals' checkbox is checked. The 'External' field is empty. The 'Connect' field is empty. The 'From' field is empty. The 'To' field is empty.

- Return to the OHAD Diagram. In Palette on the right, click **Advanced Connection**. Click **ramp**, drag the cursor to **ander**, and then click **ander**. A pop-up dialog Define Connection is displayed with default ports of **out (ramp)** and **in (ander)**. In the Port Name column, double-click on **in** and then enter **in1**. Leave **Connection Name** blank.



- Click **Finish**.
- Click in the OHAD Diagram. Notice there's a dotted-line arrow pointing from **ramp** to **ander**. This notation indicates an advanced connection (it's advanced because **ander** has two input ports to connect to, not just one.)
- In Palette, click **Advanced Connection** again. Click **square**, drag the cursor to **ander**, and then click **ander**. In the Port Name column in the Define Connection dialog, double-click on **in** and then enter **in2**. Click **Finish**.
- Click on **ander**. In the Properties tab on the right, check **Externals**.
- Click in the OHAD Diagram. It should now look something like this:



- In the Properties tab for the HDL assembly, enter **demo_assembly** in **Name**.
- Click the Source tab. The XML for **demo_assembly** should look similar to the XML snippet shown below. (It will be similar, but not the same, because the OHAD Editor makes its own XML coding decisions.)

- Click Save (the floppy disk icon in the toolbar underneath the main menu) to save your **demo_assembly** OHAD definition.

To update the assembly OHAD from the command line, navigate to the **demo_assembly** directory. Open **demo_assembly.xml** with a text editor and then insert the following XML (highlighted in red) between the **HdlAssembly** tags:

```
<HdlAssembly>
  <Instance Worker="ramp" externals='true' />
  <Instance Worker="square" />
  <Instance Worker="ander" externals='true' />
  <Connection>
    <Port Instance="ramp" Name="out" />
    <Port Instance="ander" Name="in1" />
  </Connection>
  <Connection>
    <Port Instance="square" Name="out" />
    <Port Instance="ander" Name="in2" />
  </Connection>
</HdlAssembly>
```

Notice the use of the **externals** attribute in the **ramp** and **ander** worker instances. It means that any unconnected ports for the instance are made external to the assembly to whatever the application specifies. The [OpenCPI HDL Development Guide](#) provides more information about this attribute.

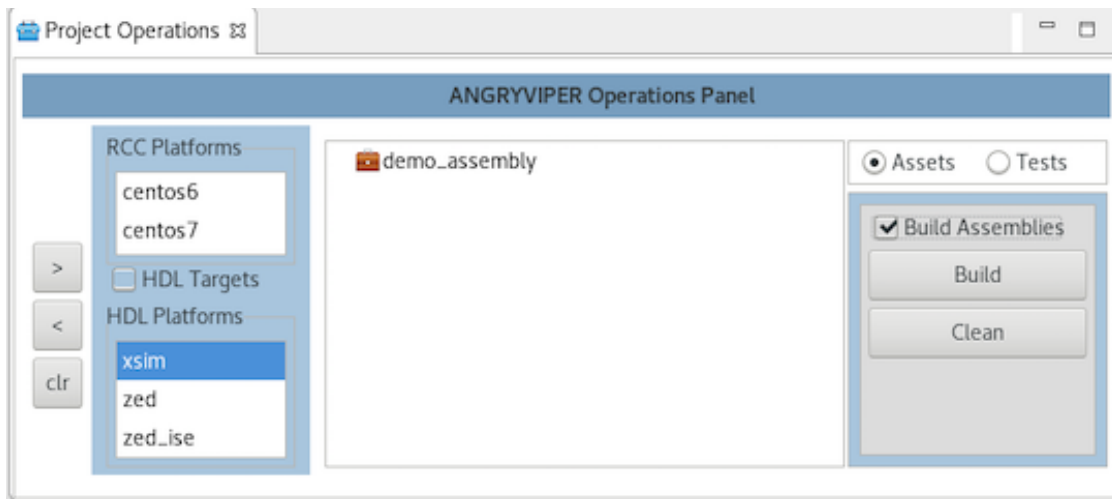
The assembly OHAD is now complete. The next step is to generate an FPGA artifact for the **xsim** platform from the assembly OHAD.

6.3 Build HDL Assembly

In this step, we build the HDL assembly and create the FPGA artifact for the example application.

To build the HDL assembly with AV:

- In the Operations panel, click **clr** to clear the component library we previously built.
- In the OpenCPI Projects view, expand the **assemblies** subdirectory and then select **demo_assembly**.
- In the Operations panel, click the **>** button to move **demo_assembly** into this panel.
- In **HDL platforms**, select **xsim**.
- Check **Build Assemblies**.



- Click **Build**.
- The build takes a minute or two to run. If the build succeeds, you'll see a message in the Build Status tab with the **DemoProject** and what you've built (**demo_assembly**, in this case) highlighted in green. You can click the Maximize button to view the entire message.

To build the HDL assembly with **ocpidev**, run the following command from the **DemoProject** directory:

```
ocpidev build hdl assembly demo_assembly --hdl-platform xsim
```

The build takes a couple of minutes to run. You can confirm that it succeeded by locating the ***.bitz** file in the **artifacts** subdirectory of **DemoProject**. This file is the artifact file that is ready for loading and execution and can be used at runtime when executing the application on the FPGA platform.

7 Create Application

An OpenCPI application consists of an OpenCPI Application Specification (OAS), which is an XML file that specifies the components that should be instantiated (using some artifacts), how the resulting workers should be connected, and how they should be configured via their properties.

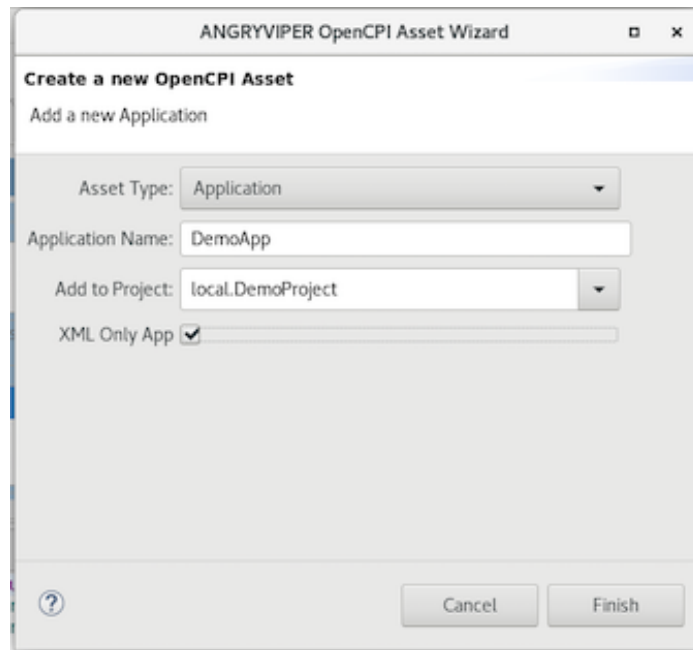
One of the easiest ways to create an OAS is to use the OpenCPI tool option to create an empty OAS in an **applications** directory and then edit this initial XML file with our XML definitions. In our case, this option also creates the **applications** directory, since it doesn't exist. The next sections describe these steps.

7.1 Create Template App XML (OAS)

We'll use the name **DemoApp** for our application.

To generate the initial OAS with AV:

- In the OpenCPI Projects view, select **local.DemoProject**. Right click and then select **asset wizard**.
- In the drop-down list, select the **Application** asset type.
- In **Application Name**, enter **DemoApp**.
- Check **XML Only App**.



- Click **Finish**.
- When the operation completes, the new application asset **DemoApp** is displayed in both the OpenCPI Projects view and the Project Explorer view. The initial OAS is displayed in the text editor panel.
- Use the OpenCPI Projects view or the Project Explorer view to observe the directories and files created.

To generate the initial OAS with **ocpidev**, run the following command from the **DemoProject** directory:

```
ocpidev -X create application DemoApp
```

Now run the **tree** command to view the created directories and files.

```
DemoProject
|-- applications
|   |-- DemoApp.xml
|   ...
```


Notice that this command has generated the **applications** directory as well as the initial OAS file **DemoApp.xml**. We'll edit this empty file next to define our application.

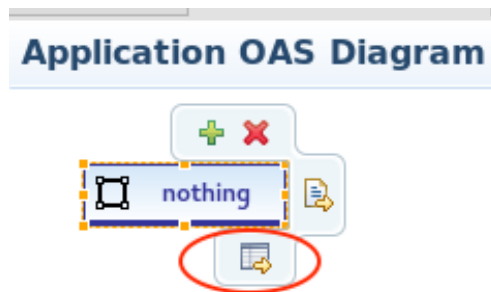
7.2 Update Empty App XML (OAS)

Now we'll edit **DemoApp.xml** with the necessary XML definitions. We need to supply the following values:

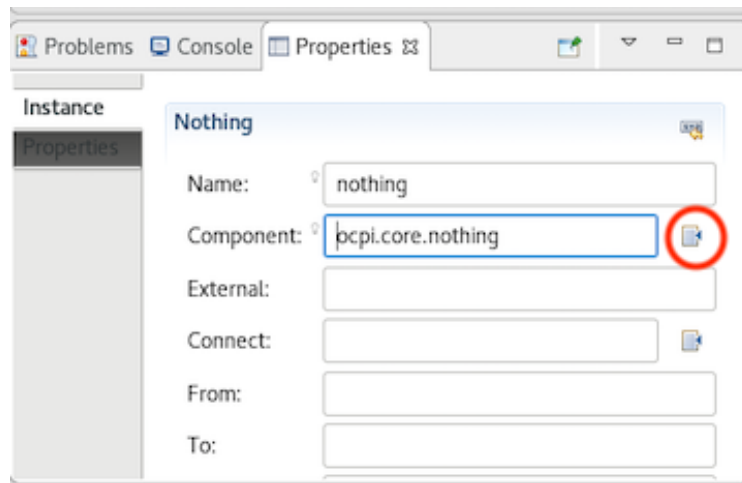
- The names of the component instances (**Instance Component=**) and their connections (the full **Port Instance =** definition in the **Connections** element or the **Connect=** shorthand in the component instance element, similar to the HDL assembly definition).
- For the **file_write** component instance, the value of the **fileName** property. The **fileName** property specifies where the **file_write** component will write the output data out of the application (in our case, **output_file.bin**).
- For the **source** component instance, the runtime values for the **value** and **nsamples** properties. We'll set these to 128 and 2000, respectively.
- The package ID for our project. The **package=** attribute tells the OpenCPI framework where to find the component specifications for the component instances in the application. We'll specify our project (**local.DemoProject**) in this attribute to identify where **source**, **ramp**, **square** and **ander** are located, but we'll also explicitly give the package ID (**ocpi.core**) for the **file_write** component.
- The component instance to be used to determine when the application is finished executing (**done=**). When the indicated instance is "done", then the whole application is considered "done". We'll declare the application to be finished executing when the **file_write** component is finished executing.

To update the initial OAS using the AV Application OAS Diagram:

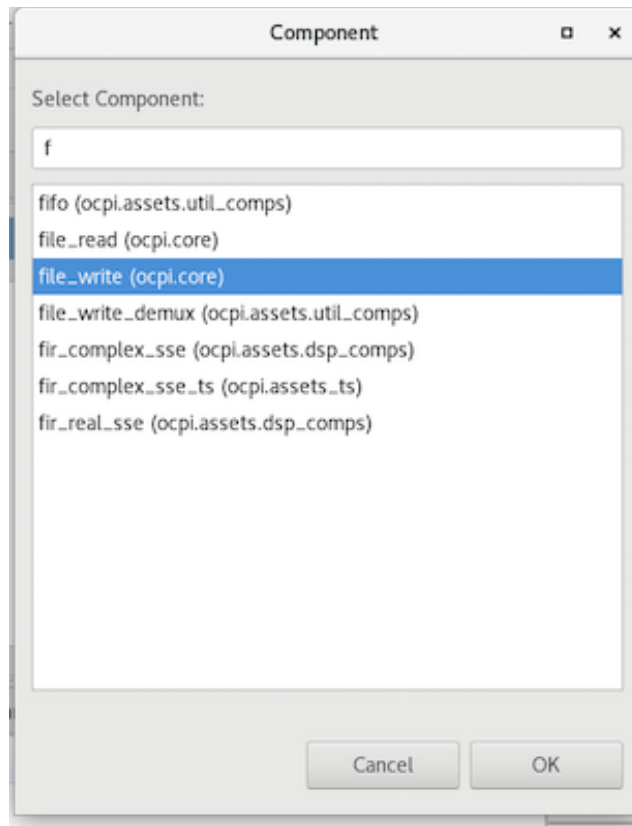
- In the text editor panel, click the Application tab to display the Application OAS Diagram (if it is not already displayed). You'll see one component named "nothing". This component is automatically added to an OAS so that it can build even before any changes are made to it.
- Click on the **nothing** component. You'll see a set of control icons like the ones you saw when you clicked on workers while creating the HDL assembly. We're going to use the Properties control to find and select the **file_write** component, which is part of the **ocpi.core** project.
- Click on the icon below the **nothing** component icon to display its Properties tab.



- In the Properties tab, click the Browse button to the right of **Component** **ocpi.core.nothing**.

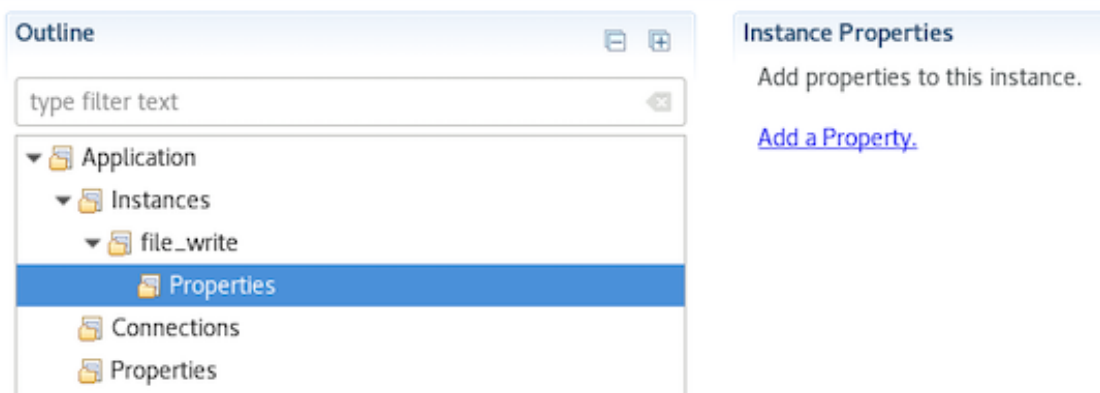


- From the pop-up list, select the **file_write** component and then click **OK**. (To find the **file_write** component quickly, type **f** in **Select Component** to display the components whose names begin with "f".)



- You'll see that the "nothing" component has changed to **file_write** in the OAS Diagram window and in the Properties tab displayed on the right.
- Define the **file_write** property: Click the Details tab. In Outline, expand Instances and then **file_write**. Click Properties and then click **Add a Property**.

OAS Editor



- The Instance Property dialog appears. In **Name**, enter **fileName**. In **Value**, enter **output_file.bin**. Leave the rest of the fields blank.

Instance Property

Modify attributes of this property.

Name:

Value:

ValueFile:

DumpFile:

- Add the rest of the components in **local.DemoProject** to the OAS Diagram using drag and drop from the Project Explorer: in the Project Explorer window, navigate to **local.DemoProject > components > specs**. Select **source-spec.xml**. Left click and then hold the mouse button. Drag the component into the OAS Diagram window and then release the mouse button. Do the same for the **ramp**, **square** and **ander** component specs.
- Now we have all the components we want to use in our application represented in the OAS Diagram. Click the Maximize button at the top right of the OAS Diagram to enlarge the view of the diagram and the components in it. Arrange the components in the diagram so that it looks something like this:



- Define the properties for the **source** component: Click the Details tab. Expand Instances and then source. Click Properties and then click **Add a Property**. In the Instance Property dialog, enter **value** in **Name** and **128** in **Value**.

Instance Property

Modify attributes of this property.

Name:

Value:

ValueFile:

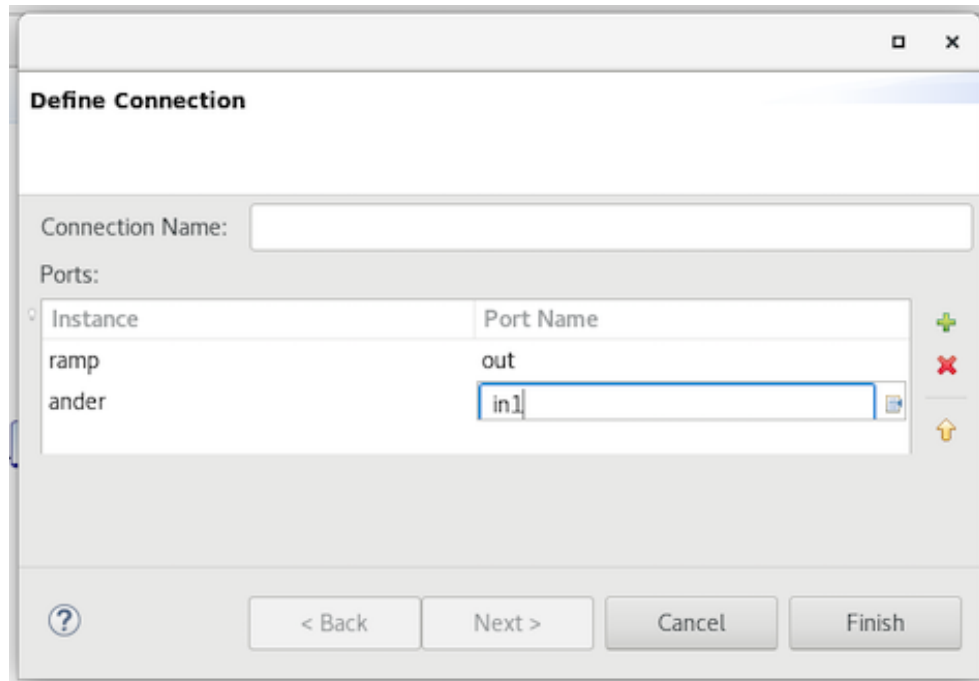
DumpFile:

- Click Properties under source and then click **Add a Property** again. In the Instance Property dialog, enter **nsamples** in **Name** and **2000** in **Value**.

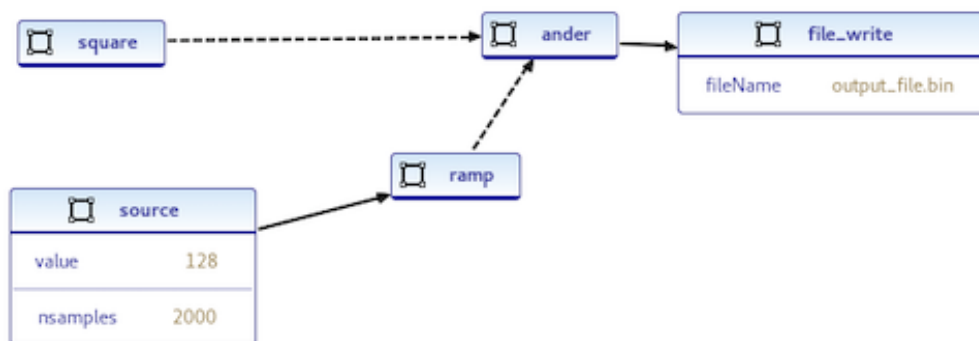
- The properties for **file_write** and **source** have now been defined. The next step is to define the connections between components. There are four of them to define. Two are simple connections and two are advanced connections.
- Click the Application tab to return to the OAS Diagram. Use the mouse to move the component icons so that they're organized like the figure in the [Overview](#) section.
- Connect the **source** component **out** port to the **ramp** component **in** port: In Palette, click **Simple Connection**. Click on the **source** icon, move the cursor to the **ramp** icon, and then click the **ramp** icon. A solid-line arrow pointing from the **source** component to the **ramp** component is displayed in the OAS Diagram.



- Connect the **ander** component **out** port to the **file_write** **in** port: In Palette, click **Simple Connection**. Click on the **ander** icon, drag the cursor to the **file_write** icon, and then click the **file_write** icon. A solid-line arrow pointing from the **ander** component to the **file_write** component is displayed in the OAS Diagram.
- Connect the **ramp** component **out** port to the **ander** component **in1** port: in Palette, click **Advanced Connection**. Click on the **ramp** icon, drag the cursor to the **ander** icon, and then click the **ander** icon. A pop-up dialog for defining the connection is displayed, showing default port names **out** (for **ramp**) and **in** (for **ander**). In the Port Name column, double-click on **in** and then enter **in1**.



- Leave the other fields as they are and click **Finish**. A dotted-line arrow between **ramp** and **ander** is displayed in the OAS Diagram.
- Connect the **square** component out port to the **ander** component **in2** port: in Palette, click **Advanced Connection**. Click on the **square** icon, drag the cursor to the **ander** icon, and then click the **ander** icon. A pop-up dialog for defining the connection is displayed, showing default port names **out** (for **square**) and **in** (for **ander**). In the Port Name column, double-click on **in** and then enter **in2**. Leave the other fields as they are and click **Finish**.
- The connections between the components should now look something like this:



- Define the application attributes: Click the Details tab. In Outline, Application is selected and the Application attributes dialog is displayed on the right. In **Name**, enter **DemoApp**. In **Package**, enter **local.DemoProject**. In **Done**, enter **file_write**. Leave **MaxProcessors** blank.

Application

Modify attributes of the Application.

Name: DemoApp

Package: local.DemoProject

Done: file_write

MaxProcessors:

- Click the Source tab. The XML for DemoApp should look similar to the XML snippet shown below. (It will be similar, but not the same, because the OAS Design Editor makes its own XML coding decisions.)
- Click Save (the floppy disk icon in the tool bar underneath the top menu bar) to save your **DemoApp.xml** OAS definition.
- Click Restore at the top right of the OAS Diagram to minimize it.

To update the initial OAS from the command line, in the **DemoProject** directory, open **applications/DemoApp.xml** with a text editor and then replace the contents with the following XML:

```

<Application package='local.DemoProject' done='file_write'>
  <Instance Component="source" Connect='ramp'>
    <property name="value" value="128"/>
    <property name="nsamples" value="2000"/>
  </Instance>
  <Instance Component="ramp"/>
  <Instance Component="square"/>
  <Instance Component="ander" Connect="file_write"/>
  <Instance Component="ocpi.core.file_write">
    <Property Name="fileName" Value="output_file.bin"/>
  </Instance>
  <Connection>
    <Port Instance="ramp" Name="out"/>
    <Port Instance="ander" Name="in1"/>
  </Connection>
  <Connection>
    <Port Instance="square" Name="out"/>
    <Port Instance="ander" Name="in2"/>
  </Connection>
</Application>

```

Notice that the XML shows the two ways that connections between components can be specified. When a component has one output and the component to which it will be connected has one input, we just use the **connect** attribute.

We have now created the application. In the next section, we'll run the application.

8 Run Application

Executing an application on a given platform requires the following items:

- The application itself, defined in an XML file that describes a collection of components. We supplied this item when we created the **DemoApp** OAS.
- Artifact libraries that consist of (binary/executable) artifacts compiled from workers that implement requested components. We supplied this item when we created the **demo_assembly** HDL assembly and when we built the **source** RCC worker.
- Runtime environments called **containers** that can load and run the artifacts (and thus workers) needed by the application. This item is supplied with the OpenCPI installation, which provides an OpenCPI container for the **xsim** FPGA platform as well as one for the development host CPU running CentOS7.

We've satisfied all these requirements, so we're ready to run the application. From the top level of your project (in this case, the **DemoProject** subdirectory), execute the following command:

```
ocpidev run application DemoApp.xml
```

The application runs the assembly in an **xsim** simulation while running the **source** and **file_write** workers on the development host (in our case, CentOS7), within the **ocpidev run** command's process, with the **file_write** component writing the output to the file **output_file.bin**.

For more details on **ocpidev run** and running applications, see the [OpenCPI Application Development Guide](#).

9 View Output Data

To observe the output generated by the application, we'll use a Python script to demultiplex and plot the data. Create a file **plot_output.py** and then insert the following Python code into the file:

```
import numpy as np
import matplotlib.pyplot as plt
import sys
# read data from input file
data=np.fromfile(sys.stdin,dtype=np.int16)
# plot the upper 16-bits
plt.figure(1)
plt.plot(data[1::2]) # odds to the upper 16-bits
plt.title("Output Data - Upper 16")
plt.grid()
# plot the lower 16-bits
plt.figure(2)
plt.plot(data[0::2]) # evens to the lower 16 bits
plt.title("Output Data - Lower 16")
plt.grid()
plt.show()
```

To plot the generated output, run the following command from the **applications** directory:

```
python3 plot_output.py <output_file.bin
```

The following figures show the upper and lower 16 bits of the **ander** output. The upper 16 bits are the output of **ramp**, passed through for display. The lower 16 bits are the result of “anding” this input with a square wave from **square**.

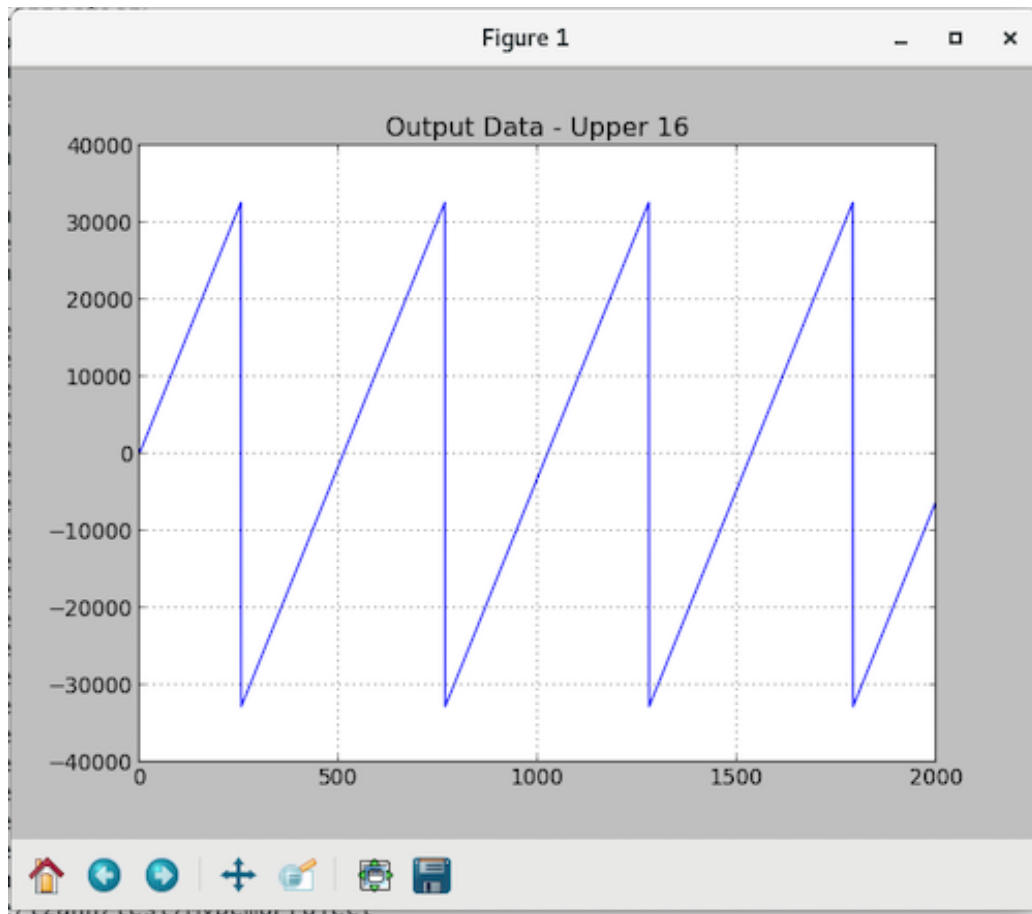


Figure 2: *ramp* Output (passed through by *ander*)

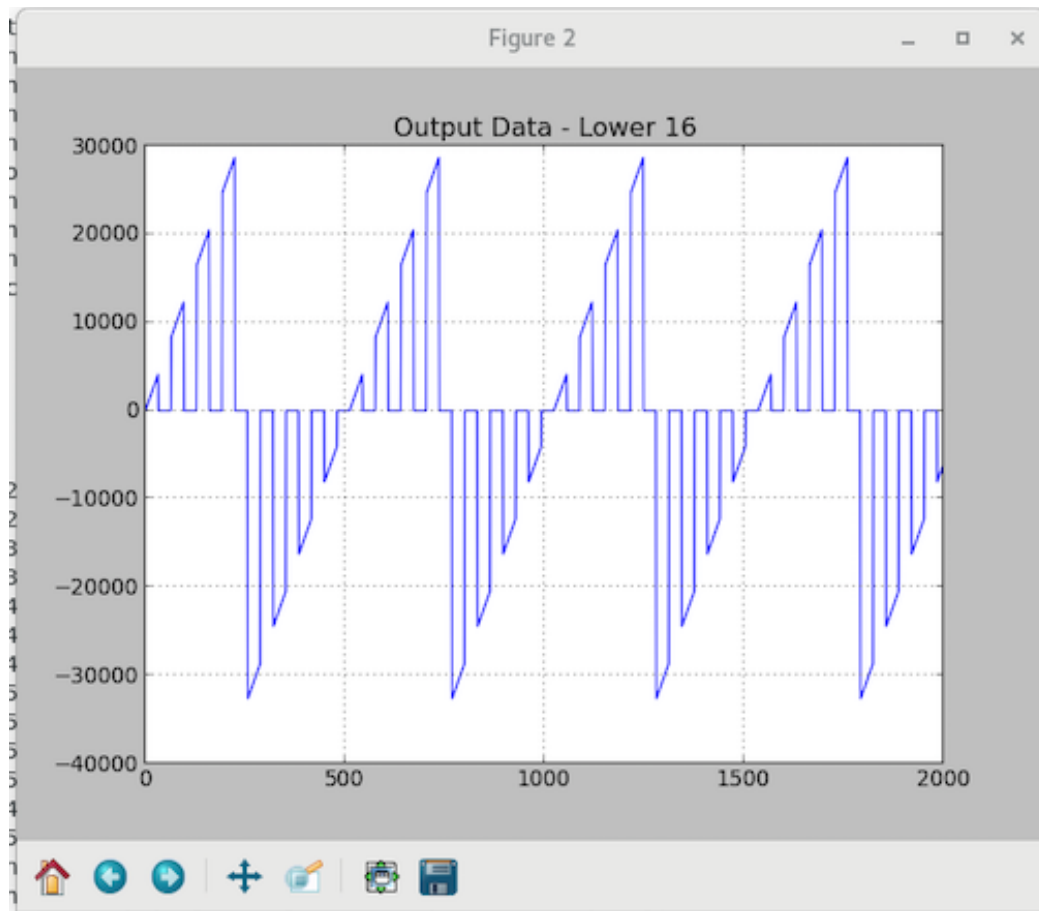


Figure 3: *ander* Output

10 Tutorial Summary

Now that you've completed this tutorial, you should be familiar with the general process of OpenCPI application and component development, the tasks required to build and run a simple OpenCPI application that uses both built-in and user-defined components with implementations for software (RCC) and FPGA (HDL) platforms, and how to use the OpenCPI tools to perform these tasks.

You can now move to the next tutorial in the series – Tutorial 2 – where you will learn how to create, build and run different HDL assemblies for the same sample application.