OpenCPI
Tutorial 6hw: Creating a Simple HDL Worker

Revision History

Revision	Description of Change	Date
1.01	Creation from Lab 5 developed by CNF	2019-10-01
1.1	Complete and update for V2.4.0	2022-01-21
1.2	Update GUI screenshots, add external review feedback	2022-02-17
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1 Overview

Note: This tutorial demonstrates the same steps as Tutorial 6, but it includes a hardware platform in the demonstration; in this case, the ADALM-PLUTO (**`plutosdr`**) HDL platform.

This tutorial introduces you to working with HDL workers and simulation. Our example is once again, the **`peak_detector`** component in the **`ocpi.tutorial`** project. We used this component, both its RCC and its HDL implementations, in our application and assemblies in Tutorial 2, and in Tutorial 3, we went through creating the RCC implementation. In this tutorial, we'll step through the procedure used to create this component and its HDL worker implementation. We'll be able to reuse the component specification for the **`peak_detector`** component spec and its unit test that we created earlier, and then design, build and test a HDL worker that implements its function.

As stated previously, the peak detector function is to calculate and report the signed maximum and minimum peaks in the I/Q data arriving at its input port and then pass this input data through unchanged to its output port. Given an input of complex numbers, the peak detector component finds the biggest I or Q sample and the smallest I or Q sample. The process is as follows:

- current_biggest = max(current_biggest, max(I,Q))
- current_smallest = min(current_smallest, min(I,Q))
- Pass input complex samples to the output port

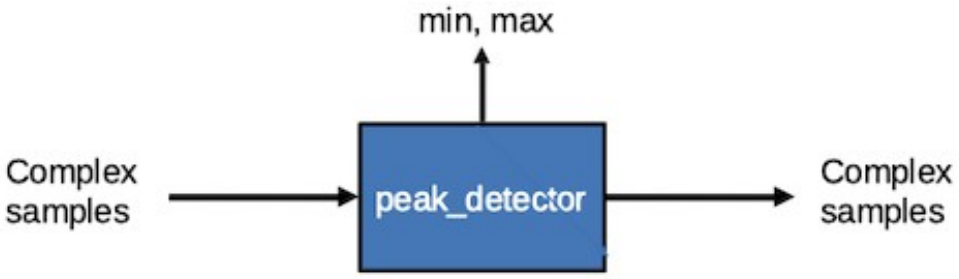


Figure 1: Peak Detector Component Function

1.1 Tutorial Objectives

The objective of this tutorial is to design, build and test an HDL application worker. The worker function is peak detection of a data stream (**`peak_detector.hdl`**).

This tutorial shows you how to:

- Re-create (or copy from the project you created in Tutorial 3) the peak detector component specification (properties and ports).
- Build a worker for an HDL platform.

It demonstrates how to use the Xilinx Vivado® Simulator (in OpenCPI, the **`xsim`** HDL platform) to:

- Run an OpenCPI component unit test suite (aka “unit test”) for the simulator.
- Open and view saved simulations.
- Perform basic navigation of the simulator (Vivado in this case).

It also demonstrates running a unit test on the Analog Devices ADALM-PLUTO (in OpenCPI, the **`plutosdr`** FPGA (HDL) platform).

Note: this part of the tutorial requires a machine with HDL platform support for the ADALM-PLUTO hardware device (HDL platform **`plutosdr`**). Details of how to set up and configure the platform are beyond the scope of this tutorial.

After running this tutorial, you should understand the basics of creating a HDL worker, how to use the OpenCPI unit test framework on an HDL worker, and how to view a saved simulation.

1.2 What's Provided for This Tutorial

The built-in OpenCPI tutorial project **`ocpi.tutorial`** provides source code for the following items in this tutorial:

- The **`peak_detector`** worker, written in HDL (VHDL source code)
- The unit test files **`generate.py`** and **`verify.py`**, written in Python
- The unit test **`bash`** shell script **`view.sh`**

The **`ocpi.tutorial`** project also provides the XML source for all of the assets used to build and run the example component, worker and tests.

You will also use the following script from the **`ocpi.tutorial`** project:

- The Python script code for plotting and viewing the output data, in **`scripts/PlotAndFft.py`**

Instructions for copying these items from the **`ocpi.tutorial`** project into the "demo" tutorial project are provided in the relevant sections of this document. The source code for these items is also 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.

Note: when copying and pasting text from this document, be sure to remove any line breaks in code or command lines.

1.3 Prerequisites to Using This Tutorial

This tutorial (Tutorial 6hw) has the system prerequisites described in ***OpenCPI Tutorial 1: Component-based Development***. See the prerequisites section in Tutorial 1 for details. In addition to these requirements, this tutorial uses the **`plutosdr`** platform, and so the corresponding OSP should be downloaded and installed. See the section "Installation Steps for Platforms" in the ***OpenCPI Installation Guide***.

Before you begin this tutorial, you should have successfully completed Tutorial 1 through Tutorial 5.

We recommend reading Briefing 8 HDL Application Workers before getting started with the tutorial.

For a guide on using the **`ocpiremote`** tool, see the video: OpenCPI - Framework Installation – Zedboard. It is timestamped and begins when **`ocpiremote`** is being set up and executed. **Note**: It will be necessary to disable the firewall for **`ocpiremote`** to function properly. For more information, see the section "Using Remote Containers from Client/Development Systems" in the ***OpenCPI Application Development Guide*** and the **`ocpiremote(1)`** man page.

1.4 Documentation References

The documents listed in the following table provide detailed information about subjects discussed in this tutorial. The documents listed here are not required reading for 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.pdf
OpenCPI Application Development Guide	OpenCPI	https://opencpi.gitlab.io/releases/latest/docs/OpenCPI_Application_Development.pdf
OpenCPI Component Development Guide	OpenCPI	https://opencpi.gitlab.io/releases/latest/docs/OpenCPI_Component_Development.pdf
OpenCPI HDL Development Guide	OpenCPI	https://opencpi.gitlab.io/releases/latest/docs/OpenCPI_HDL_Development.pdf
OpenCPI RCC Development Guide	OpenCPI	https://opencpi.gitlab.io/releases/latest/docs/OpenCPI_RCC_Development.pdf

2 Create New Project

We need to create a new, clean project for Tutorial 6; we'll call it **`DemoProject6`**. This project has the same requirements as the project we created for Tutorial 3.

To create the new project from the command line, use the following **`ocpidev`** command:

```
ocpidev -D ocpi.assets -D ocpi.tutorial create project DemoProject6
--register
```

3 Create Component Library

Before we can create our component, we need to create a component library for it. We only need one component library, so we can use the top-level **`components/`** directory as our library like we did in Tutorial 3. We just need to create this directory.

To create the **`components`** library with **`ocpidev`**, run the following command in the **`DemoProject6`** directory:

```
ocpidev create library components
```

4 Create Component

Now we need to create the OCS (OpenCPI Component Specification) for our peak detector function that defines its properties and ports.

4.1 Create Component Spec

We can now create a new **`peak_detector`** component spec in the library we just created.

To create the component spec with **`ocpidev`**, run the following command in the **`DemoProject6/components/`** directory:

```
ocpidev create component peak_detector
```

The command creates the component spec **`peak_detector-spec.xml`** in **`components/peak_detector.comp/`**. We'll add properties and ports to the component spec in the next step.

4.2 Create Component Properties and Ports

The **peak_detector** component function requires two properties: a **max_peak** property that returns the most positive I or Q value and a **min_peak** property that returns the most negative I or Q value. The worker implementation of the component uses these properties to keep track of maximum and minimum peak amplitudes and will change their values during execution, so they should be declared as ***volatile*** properties.

The **peak_detector** component also requires one input port and one output port for communication with other components in an application; both ports will use the **iqstream** protocol. This component spec is the same as the one used in Tutorial 3 and can be copied over to this project and reused.

To create the properties and ports from the command line, open **peak_detector-spec.xml** with a text editor and add the following XML between the **ComponentSpec** elements (highlighted in red):

```
<ComponentSpec>
  <Property Name="min_peak" Type="Short" Volatile="true"/>
  <Property Name="max_peak" Type="Short" Volatile="true"/>
  <Port Name="in" Protocol="iqstream_protocol"/>
  <Port Name="out" Protocol="iqstream_protocol" Producer="true"/>
</ComponentSpec>
```

5 Create Worker

We've defined the **`peak_detector`** component spec. Now we need to create the workers that implements them. In this case, we only need to create one implementation – an HDL implementation.

Recall from the ***HDL Development Guide*** that an ***HDL worker*** only runs in response to control operations that tell the worker when to begin and stop. The OWD can be edited to expand on the spec file we created previously.

In Tutorial 3, we created an RCC worker, which generated an **`rcc/`** subdirectory with the worker's OWD XML file and a "skeleton" source code file in the C++ language that we updated to include the C++ code for the worker. This time, we will be producing an **`hdl/`** subdirectory that also contains an OWD XML file and a "skeleton" source code, this time in VHDL. The creation process is mostly the same, except that we will be specifying the creation of an HDL worker, and not an RCC one.

5.1 Create HDL Worker OWD and Skeleton File

To create the worker with **ocpidev**, run the following command in the **DemoProject6/components/** directory:

```
ocpidev create worker peak_detector.hdl
```

Recall from Tutorial 1 that the suffix of the worker's name - **.hdl** in this case - directs the tool to generate an HDL worker. Run the **tree** command and you'll see that the **components/** directory now has a subdirectory **peak_detector.hdl** with the files **peak_detector.xml** (the OWD) and **peak_detector.vhd** (the skeleton file).

In this tutorial, you will have to edit the XML for the worker to run properly. The **peak_detector.vhd** skeleton file is the basis for writing the worker's execution code. We will need to add the VHDL code to this file for the worker to function properly; we'll create this code in the next step.

In **peak_detector.hdl/gen/**, you'll see an assortment of files that do not need to be edited. They are automatically generated when the worker has been created, and if they are removed will be recreated when the **ocpidev build** command is invoked.

5.2 Edit Worker XML

Unlike the RCC version, this worker requires us to edit the worker XML. The XML should come with the **`Version`** attribute set to 2, the language selected properly, and the spec selected. We are adding those **`StreamInterface`** elements, which as a reminder are FIFO-like, to define the widths of the ports and an **`InsertEOM`** attribute to ensure there is an EOM asserted automatically and the worker does not have to worry about it. The completed worker XML should look like this (the additions are highlighted in red):

```
<HdlWorker language='vhdl' spec='peak_detector-spec' Version="2">
    <StreamInterface Name="in" DataWidth="32"></StreamInterface>
    <StreamInterface Name="out" DataWidth="32"
InsertEOM="1"></StreamInterface>
</HdlWorker>
```

5.3 Write HDL Worker VHDL Code

The skeleton **.vhd** file is an empty architecture. The entity is generated VHDL based on the OCS and the OWD, and located in the **gen/*<worker-name>*-impl.vhd** subdirectory. We want to replace the skeleton .**vhd** file with the **.vhd** provided in the **ocpi.tutorial** project. From the **DemoProject6/components/peak_detector.hdl/** directory, run the following command:

```
cp -f
$OCPI_ROOT_DIR/projects/tutorial/components/peak_detector.hdl/
peak_detector.vhd .
```

Taking a deeper look at the code, we can see a few things. The first chunk of code initializes signals to be used internally by the worker. These are used as carriers for data and other external signals.

```
signal s_valid        : std_logic;
signal s_i            : signed(c_data_width-1 downto 0);
signal s_q            : signed(c_data_width-1 downto 0);
signal s_min_peak_rst : std_logic;
signal s_max_peak_rst : std_logic;
signal s_min_peak     : signed(c_data_width-1 downto 0);
signal s_max_peak     : signed(c_data_width-1 downto 0);
```

The main logic for the worker is set up as follows (only the minimum logic will be shown from here on):

```
if s_min_peak_rst = '1' then
  s_min_peak <= (c_data_width-1 => '0', others => '1');
```

When the reset is set to high, the min peak is set to the largest possible value. When the signals are valid, we check if either the input I data or input Q data is a new minimum. **s_min_peak_iq** is then updated as appropriate:

```
elsif s_valid = '1' then
  if (s_i < s_q and s_i < s_min_peak) then
    s_min_peak <= s_i;
  elsif (s_q < s_i and s_q < s_min_peak) then
    s_min_peak <= s_q;
  end if;
```

The **s_min_peak** signal is set to drive our volatile property that can be read by the control interface:

```
props_out.min_peak <= s_min_peak;
```

This is repeated for max peak, except the reset drives the signal to the smallest value, and the larger number is the one that is drives our property instead of the smaller one.

5.4 Build HDL Worker

Now we need to compile the **peak_detector** worker for the platforms on which we want to run it; for this tutorial, it's the **xsim** and **plutosdr** HDL platforms. Although workers are normally built as part of building an entire component library or as part of an entire project, we'll build our **peak_detector** worker separately.

To build the worker for **xsim** with **ocpidev**, run the following command from the **DemoProject6/components/peak_detector.hdl** directory:

```
ocpidev build --hdl-platform xsim
```

To build the worker for **plutosdr** with **ocpidev**, run the following command from the **DemoProject6/components/peak_detector.hdl** directory:

```
ocpidev build --hdl-platform plutosdr
```

Navigate to **components/peak_detector.hdl/.** There should be two new subdirectories **target-*<platform>*** - one for **xsim** (**target-xsim**) and one for **plutosdr** (**target-zynq**) that contain the artifacts needed to run the worker on these platforms.

```
ls -l target-xsim
generics.vh         peak_detector-defs.vh   xvhdl.log
generics.vhd        peak_detector-defs.vhd  xvhdl.pb
generics.vhd.deps   peak_detector-impl.vhd  xelab.log
generics.vh.deps    peak_detector.prj       xelab.pb
peak_detector       peak_detector-xsim.out  xsim.dir

ls target-zynq/
generics.vh               peak_detector.hw
generics.vhd              peak_detector-impl.vhd
generics.vhd.deps         peak_detector-imports.tcl
generics.vh.deps          peak_detector.ip_user_files
peak_detector.cache       peak_detector.sources
peak_detector-defs.vh     peak_detector-vivado.out
peak_detector-defs.vhd    peak_detector.xpr
peak_detector.edf         vivado.jou
```

Next, we'll create the unit test for **peak_detector** and then run it.

6 Create Unit Test

Recall from Tutorial 3 that we created the **peak_detector.test/** component unit test suite (aka "unit test") for the **peak_detector** RCC worker. We even set it up to support a **peak_detector** HDL worker by setting up the OpenCPI Test Suite Description (OTSD) to use HDL file I/O.

We can re-use this same unit test for our **peak_detector** HDL worker by copying Tutorial 3's **DemoProject3/components/peak_detector.test/** subdirectory to our **DemoProject6/components/** directory. To do this, in **DemoProject6**, navigate to the **components/** directory and then run the command:

```
cp -r
$OCPI_ROOT_DIR/<your-top-level-projects-dir>/DemoProject3/
components/peak_detector.test .
```

Note: before copying the unit test you used in Tutorial 3, it's a good idea to run the **ocpidev clean** command in the **peak_detector.test/** subdirectory to remove the generated files you created when you ran Tutorial 3.

You can also copy the **peak_detector.test** unit test directly from the **ocpi.tutorial** project into your **DemoProject6/components/** directory and use it as is, since it's the reference unit test for the **peak_detector** worker. To do this, in **DemoProject6**, navigate to the **components/** directory and then run the command:

```
cp -r
$OCPI_ROOT_DIR/projects/tutorial/components/peak_detector.test .
```

Note: Make sure your unit test scripts have read and execute permissions before using them to build and run the **peak_detector** unit test. For example:

```
chmod 755 generate.py
chmod 755 verify.py
chmod 755 view.sh
```

7 Build Unit Test

Now we'll build the unit test for the **`xsim`** and **`plutosdr`** target platforms.

To generate and build the unit test with **`ocpidev`**, run the following command from **`DemoProject6/components/peak_detector.test`**:

```
ocpidev build --hdl-platform xsim --hdl-platform plutosdr
```

Navigate to **`peak_detector.test/gen/`** and observe the artifacts created. The following files and directories are of interest:

- **`cases.txt`**. This file is user-readable and lists various test configurations.
- **`cases.xml`**. This file is used by the OpenCPI framework to execute tests.
- **`cases.xml.deps`**. This file contains a list of dependent files.
- **`applications/`**. This directory contains OAS files and scripts used by the OpenCPI framework to execute applications.

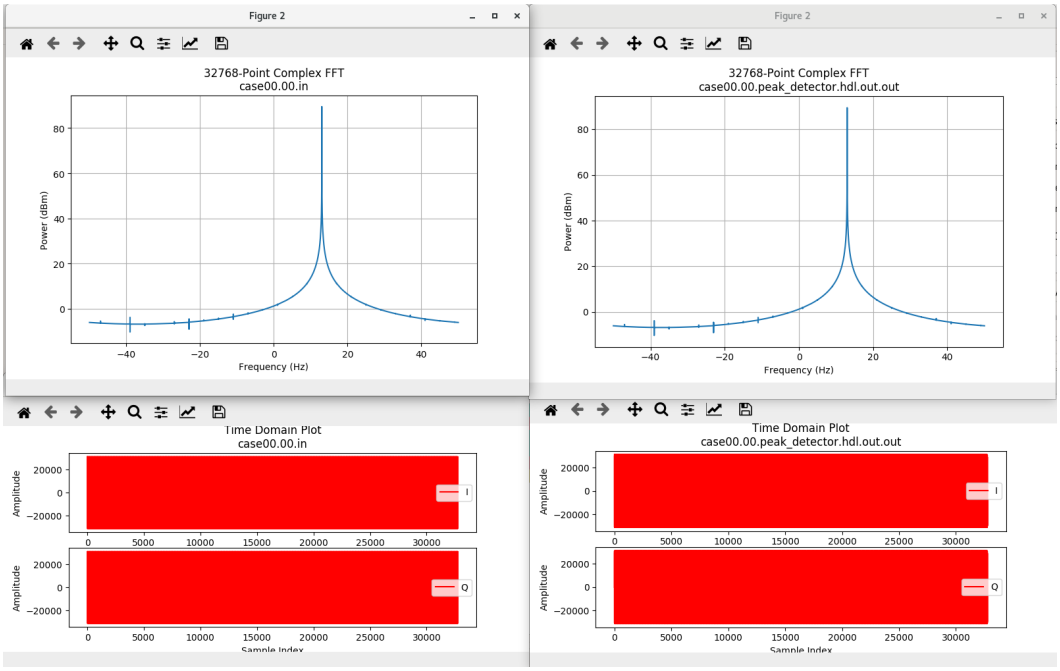
8 Run Unit Test (XSIM)

Now we'll run the unit test and view the results.

To run the test and view the output from the command line, run the following **`ocpidev`** command from **`DemoProject6/components/peak_detector.test:`**

```
ocpidev run --mode prep_run_verify --only-platform xsim --view --
keep-simulations
```

You should see this output (note that the input and output are the same):

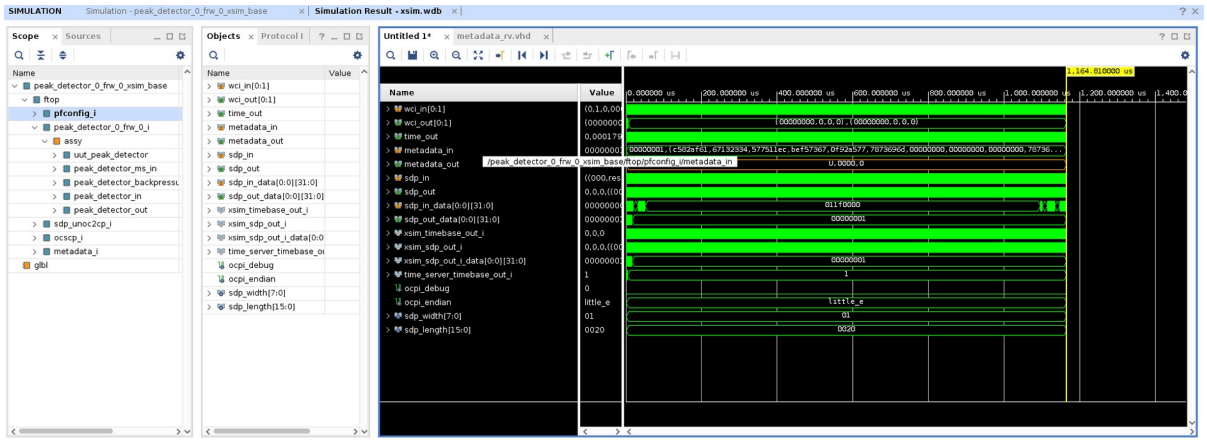


8.1 View Simulation Waveforms (XSIM)

Now, since we decided to use the **`keep-simulations`** option, we can use **`ocpiview`** to view waveforms that the simulator saved.

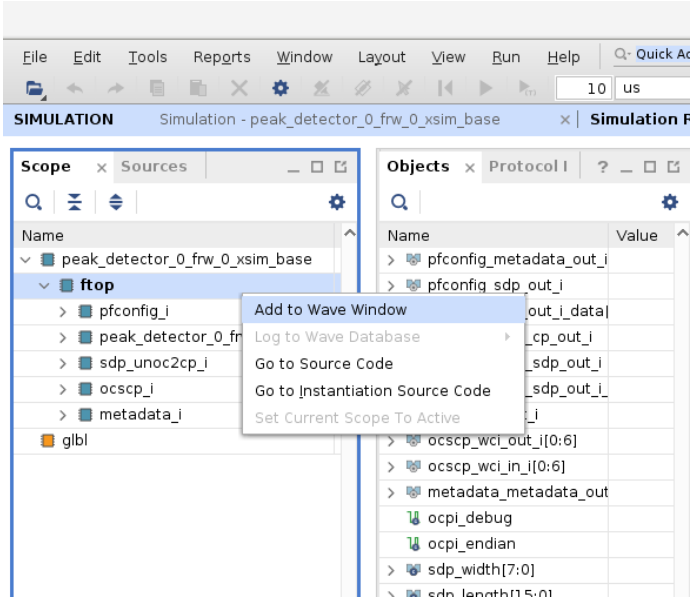
To invoke the simulator, run the following command in the **`peak_detector.test/`** directory.

```
ocpiview run/xsim/case00.00.peak_detector.hdl.simulation &
```

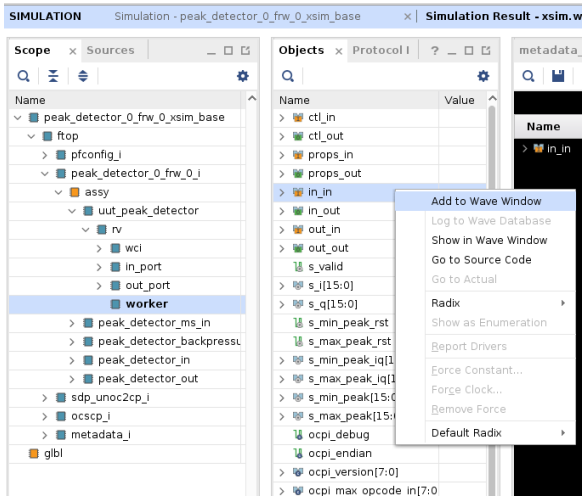


8.2 Navigating the Simulator (optional guide)

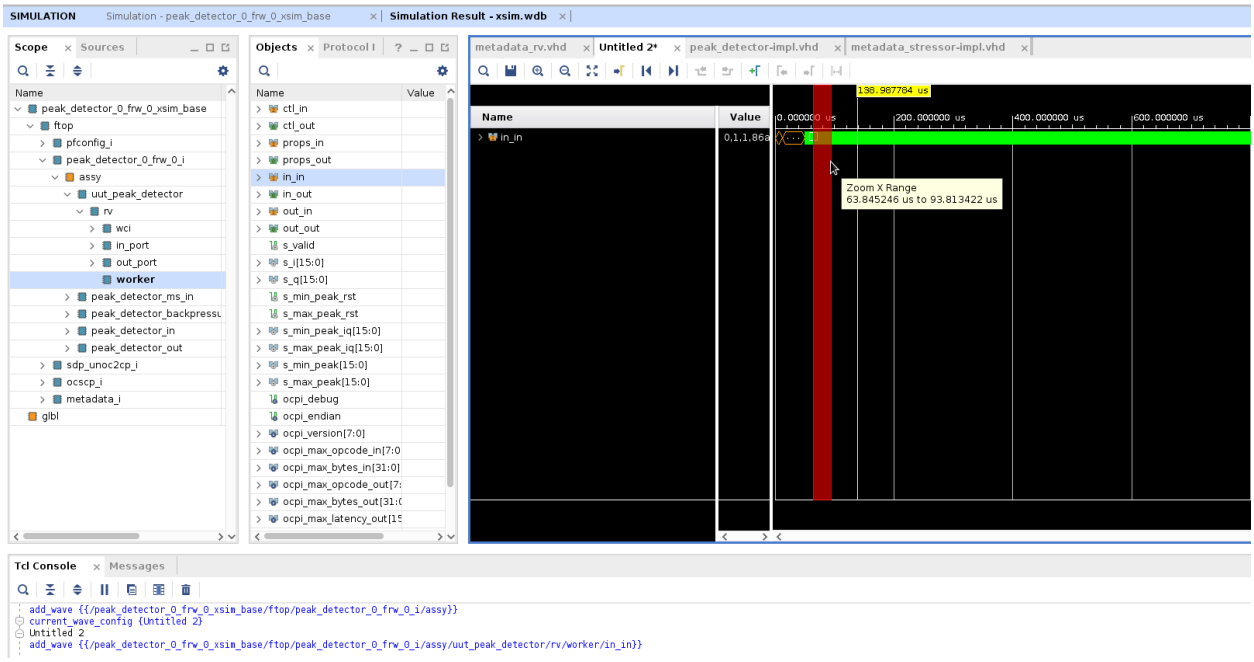
This part of the tutorial is optional and is intended for those unfamiliar with navigating the Vivado GUI. To add signals to a wave window, right click in the **scope** section and click **Add to Wave Window**. Doing so on **ftop** in this case gets you the image shown in the previous section.



You can open up the scopes by double-clicking on the ones with **>** next to them. You can use this to get access to lower-level signals. You can also add individual signals by using those listed in the **Objects** window.

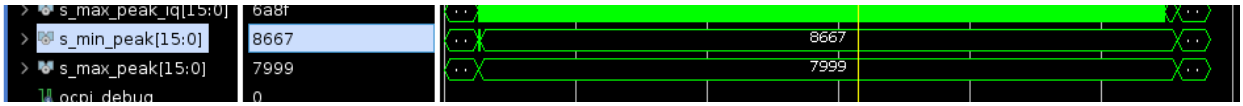


There are a few ways to zoom in on the waveforms being viewed in the wave window. One way is to left-click and drag across the section you wish to zoom in on. Another way is to click the magnifier button above the window, and finally you can use ctrl and the + key on the keypad.



Finally, when you have a signal selected, you can use the left and right arrow keys to move to the next (right arrow) or previous(left arrow) that the signal changed. This is the same function as clicking the **Next Transition** button.

The measured minimum and maximum peak values can be viewed by observing the **s_min_peak[15:0]** and **s_max_peak[15:0]** signals in the wave window as shown below.



The minimum and maximum peak property values may also be shown by viewing the output file:

`peak_detector.test/run/xsim/case00.00.peak_detector.hdl.props`

9 Run Unit Test (ADALM-PLUTO)

First we'll check that the ADALM-PLUTO device is connected. Details of how to set up and configure the deployment platform are beyond the scope of this tutorial. See the prerequisites section in this tutorial for more information.

```
export OCPI_SERVER_ADDRESSES=<Pluto_IP>:12345
ocpiremote status -p analog
```

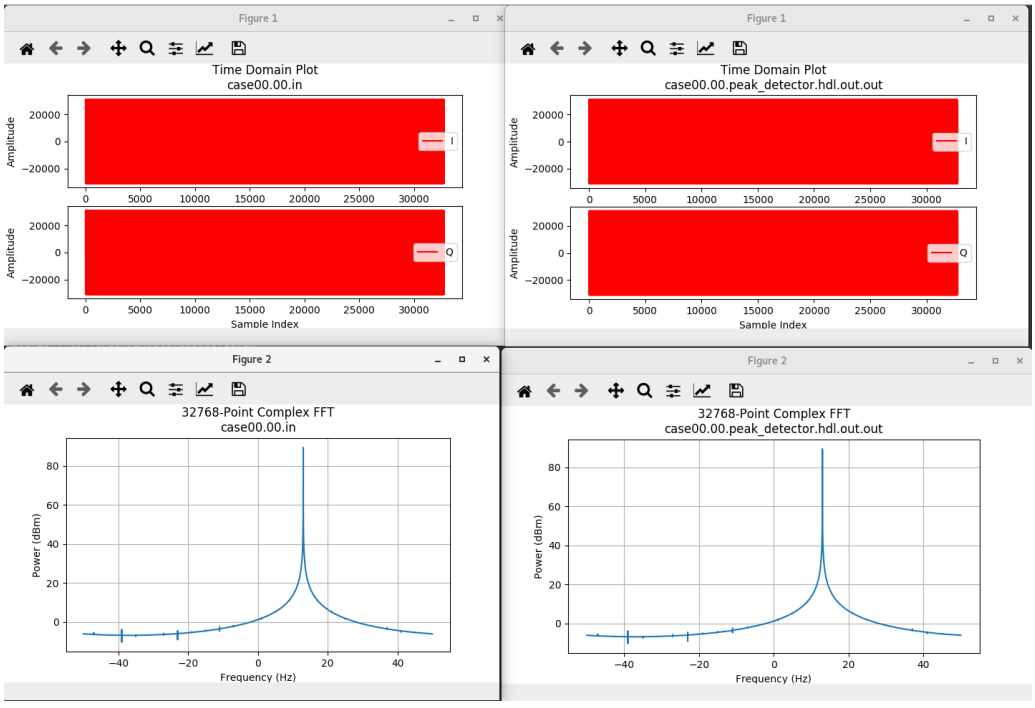
There should be output that reads something similar to:

```
Executing remote configuration command: status
Server is running with port: 12345 and pid: 26224
```

Now we can run the unit test and view the results. From the command line in the **`DemoProject6/components/peak_detector.test`** directory, run the following **`ocpidev`** command:

```
ocpidev run --mode prep_run_verify --only-platform plutosdr  \
--view --keep-simulations
```

You should see that the test runs much faster on hardware when compared to the simulator. The output should look like this (note that the input and output are the same):



10 Tutorial Summary

Now that you've completed this tutorial, you should be familiar with the basic concepts of developing an HDL worker and the OpenCPI component unit test suite and how to use OpenCPI tools to perform unit testing on an HDL worker. If you are creating a work alike, you should be able to save some time by reusing the component spec and component unit test suite for the worker you created previously. You can now move on to Tutorial 7 (or to Tutorial 7hw), which introduces you to OpenCPI HDL primitives and primitive libraries.