OpenCPI
Tutorial 4: Using Third-party Libraries in RCC Workers

OpenCPI Release: v2.4.7

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, change to XML)	2021-07-03
1.2	Update for release 2.3.0 (complete makeless updates)	2021-08-15
1.3	Update for use with OpenCPI GUI	2021-11-14
1.4	Update for release 2.4.1 (incorporate feedback, change GUI section variable name)	2022-03-02
1.5	Update for release 2.4.3 (fix discrepancies)	2022-08-31
1.6	Update language regarding CentOS7 to make it clear that there are other available platforms	2023-01-20
1.7	Update file names for release 2.5	2023-01-25

Table of Contents

1 Overview

This tutorial continues to demonstrate the RCC worker design process that we introduced in Tutorial 3. In this tutorial, we'll re-create the **`complex_mixer`** component from the **`ocpi.tutorial`** project that we used in Tutorial 2. As we did in Tutorial 3, we'll step through the procedure used to create the component and its RCC worker implementation, including creating the component specification and designing, building and testing an RCC worker that implements its function. The example RCC platform used in this tutorial is **`centos7`**, but different development hosts can be used. If you are using a development host other than CentOS7, replace **`centos7`** with the relevant name (example, **`ubuntu20_04`**).

The complex mixer component consists of a Numerically Controlled Oscillator (NCO) and a complex multiplier. It receives I/Q data on its input port and then multiplies this signal by a tone generated by the NCO, shifting the input signal in the frequency domain by the frequency of the NCO. The component properties control the NCO frequency.

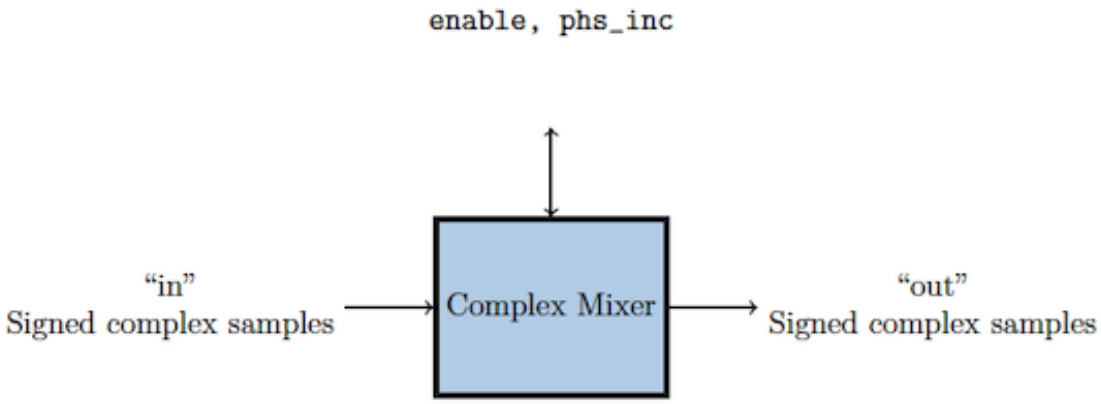


Figure 1: Complex Mixer Component Function

This tutorial shows you how to use a third-party library to implement the internal NCO tone generator for the RCC implementation of the component. To implement the NCO, we'll use the nco module from liquid-dsp, which is a free and open-source signal processing library for software-defined radios written in C and is included in the OpenCPI installation. For details on liquid-dsp and the nco module, see the URL https://liquidsdr.org/doc/nco.

1.1 Tutorial Objectives

The purpose of this tutorial is to demonstrate how to integrate a third-party library into an RCC worker.

This tutorial shows you how to:

- Create the complex mixer component specification (properties and ports).
- Create the complex mixer worker C++ code using the **`liquid-dsp`** API and build the worker for the target platform.
- Create, build and run the unit test for the RCC worker on the target platform.

It demonstrates how to use the RCC authoring model to:

- Integrate the **`liquid-dsp`** library into the RCC worker
- Create worker methods for initializing and releasing C++ resources
- Access worker data ports
- Use worker method result values to communicate worker states to the OpenCPI framework

After running this tutorial, you should understand how to use the RCC authoring model to integrate a third-party library into an RCC worker and how to use the OpenCPI unit test suite on an RCC worker implementation of a simple OpenCPI component.

1.2 What's Provided for This Tutorial

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

- The **`complex_mixer_tutorial.rcc`** worker, written according to the API for the RCC (C++ source code) authoring model. This source code uses the **`liquid-dsp`** library that is included with OpenCPI and installed as part of the OpenCPI installation process.
- The unit test files **`generate.py`** and **`verify.py`**, written in Python
- The unit test **`bash`** shell script **`view.sh`**

The tutorial also provides the XML source for all of the assets used to build and run the example component, worker and tests described in this tutorial.

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 4) has the same system prerequisites as ***OpenCPI Tutorial 1: Component-based Development***. See the prerequisites section in Tutorial 1 for details.

Before you begin this tutorial, you should have successfully completed Tutorials 1 through 3.

We recommend reading Briefing 7 OpenCPI Unit Test Framework Details before getting started with this tutorial.

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

As we did in Tutorial 3, we'll create a new, clean project for Tutorial 4; we'll call it **`DemoProject4`**. This project has the same requirements as the project we created for Tutorial 3.

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

```
ocpidev -D ocpi.assets -D ocpi.tutorial create project DemoProject4
--register
```

3 Create Components Library

We can use the top-level **`components/`** directory as our library like we did in Tutorial 3.

To create the **`components`** library with **`ocpidev`**, run the following command in the **`DemoProject4`** directory:

```
ocpidev create library components
```

4 Create Component

Like we did in Tutorial 3, we need to create the OCS (OpenCPI Component Specification) for our complex mixer function that defines its properties and ports.

4.1 Create Component Spec

As we did for the new **`peak_detector`** component in Tutorial 3, we'll create the complex mixer component spec in the **`components/`** library.

To create the component spec with **`ocpidev`**, run the following command from the **`DemoProject4/components/`** directory:

```
ocpidev create component complex_mixer
```

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

4.2 Add Properties and Ports

The **complex_mixer** component function needs to define two properties:

- The **phs_inc** ("phase increment") property, which stores the results of the computation (that is, setting the tune frequency for the input signal using the output of the internal NCO). This property is valid for both RCC and HDL component implementations.
- The **enable** property, which controls whether a worker implementation performs the computation on the incoming data or simply passes the incoming data through without any processing ("bypass" mode). This property is valid for both RCC and HDL component implementations.

We want to set default values for the **phs_inc** and **enable** properties in the component spec and allow the worker implementation to override these values. We'll use the **default** attribute in our property definitions to specify the default values and use the **writeable** attribute to indicate that the worker can override them. You can read more about how the framework interprets these attributes in the ***OpenCPI Component Development Guide***.

The **complex_mixer** component has the same simple port configuration as the **peak_detector** component and uses the same OPS. It requires one input port and one output port for communication with other components in an application and both ports will use the **iqstream** protocol.

To add properties and ports from the command line, open the spec with a text editor.

Now add the following XML code (highlighted in red) between the **ComponentSpec** elements:

```
<ComponentSpec>
    <Property Name="enable" Type="bool" Writable="true"
Default="true"/>
    <Property Name="phs_inc" Type="Short" Writable="true"
Default="8192"/>
    <DataInterfaceSpec Name="in" Producer="false"
Protocol="iqstream_protocol.xml"/>
    <DataInterfaceSpec Name="out" Producer="true"
Protocol="iqstream_protocol.xml"/>
</ComponentSpec>
```

5 Create Worker

Recall from Tutorial 3 that we implemented a **`run`** method for the **`peak_detector`** worker. This is the only required method in the RCC authoring model. We also implemented a **`start`** method for the worker; this method, along with the **`initialize`**, **`release`** and **`stop`** methods, are optional. We need to use the **`initialize`** and **`release`** methods in our complex mixer worker to prevent segmentation fault errors from being generated.

Because we're using a third-party library in our complex mixer worker, the procedure to design it has a few more steps than the procedure we used for the peak detector worker in Tutorial 3.

For the complex mixer, the steps are as follows:

- Create the worker OWD and skeleton file
- Edit the worker OWD to add information about the **`liquidsp`** library and the optional RCC authoring model methods to be used
- Write the C++ code that uses the **`liquidsp`** API and implements the authoring model
- Edit the worker skeleton file to add the C++ code
- Build the worker for target platform

5.1 Create Worker OWD and Skeleton File

To create the **`complex_mixer`** worker with **`ocpidev`**, run the following command in the **`DemoProject4/components/`** directory:

```
ocpidev create worker complex_mixer.rcc
```

5.2 Edit Worker OWD

Recall from Tutorial 1 that RCC worker OWDs generated by **`ocpidev`** don't generally need to be updated. In this case, however, we need to add two attributes:

- A **`ControlOperations`** attribute that indicates our worker will have **`initialize`** and **`release`** methods; because the **`run`** method is mandatory, its presence is assumed. You can read more about this attribute in the ***OpenCPI Component Development Guide***.
- A **`StaticPreReqLibs`** attribute that indicates our worker will use the liquidDSP library. You can read more about this attribute in the ***OpenCPI RCC Development Guide***.

To add these attributes to the OWD from the command line, in **`DemoProject4`**, open /**`components/complex_mixer.rcc/complex_mixer-rcc.xml`** with a text editor.

Now add the following XML (highlighted in red) between the **`RccWorker`** elements:

```
<RccWorker spec='complex mixer'
    Language='c++'
    Version='2'
    controlOperations="initialize,release"
StaticPreReqLibs="liquid"/>
```

5.3 Write C++ Code

We'll use the nco module from **liquid-dsp**, which is a free and open-source signal processing library for software-defined radios written in C and is supplied with the OpenCPI installation. For details on **liquid-dsp** and the nco module, see the URL https://liquidsdr.org/doc/nco.

Our worker code will use the following routines from the **liquid-dsp** nco module:

- **nco_crcf_create(type)** - creates an nco object of type **LIQUID_NCO** or **LIQUID_VCO**. We'll use this routine in our initialize method to create an NCO object of type **LIQUID_NCO**.
- **nco_crcf_destroy(q)** - destroys an nco object, freeing all internally-allocated memory. We'll use this routine in our **release** method to remove the **LIQUID_NCO** object we created.
- **nco_crcf_set_frequency(q,f)** - sets the frequency *f* (equal to the phase step size Δθ). We'll use this routine in our **run** method.
- **nco_crcf_set_phase(q,theta)** - sets the internal nco phase to θ. We'll use this routine in our **initialize** method to set the internal NCO object's phase to 0.
- **nco_crcf_step(q)** - increments the internal nco phase by its internal frequency, θ←θ+Δθ. We'll use this routine in our **run** method.
- **nco_crcf_mix_down(q,x,*y)** - rotates an input sample *x* by e−jθ, storing the result in the output sample *y*. We'll use this routine in our **run** method.

All of the I/O data samples are of type **liquid_float_complex**:

```
liquid_float_complex sample;
sample.I = 0;
sample.Q = 0;
```

5.4 Update RCC Worker Skeleton File

Now we'll add the C++ source code to the **`complex_mixer.cc`** skeleton file. To do this, you can either:

- Copy the tutorial project's **`complex_mixer_tutorial.cc`** reference file directly into your **`DemoProject4/components/complex_mixer.rcc/`** subdirectory, overwriting the skeleton file. If you choose this method, you will need to edit the **`.cc`** file and remove all instances of the strings **`_tutorial`** and **`_TUTORIAL`** from the file.
- Open the skeleton file for editing and copy/paste the code provided below to it.

You can choose to do one or the other. Doing both is redundant.

5.4.1 Copy Tutorial Project Reference File

To copy the file directly from the tutorial project, navigate to the **`complex_mixer.rcc/`** subdirectory in **`DemoProject4`** and then use the command:

```
cp
$OCPI_ROOT_DIR/projects/tutorial/components/complex_mixer_tutorial
.rcc/complex_mixer_tutorial.cc complex_mixer.cc
```

Now open the **`complex_mixer.cc`** file with a text editor and remove all instances of the strings **`_tutorial`** and **`_TUTORIAL`** from the file.

Once you've copied the file into your project, you can move to the next section to learn more about what the C++ code does.

5.4.2 Edit Worker Skeleton File

To edit the worker skeleton file from the command line, navigate to the **`components/complex_mixer.rcc/complex_mixer.cc`** file and open it with a text editor.

Now replace the contents of the skeleton file with the following code:

```
#include "complex_mixer-worker.hh"
#include <liquid/liquid.h>
#include <cmath>
#include <iostream>
#include <climits>

using namespace OCPI::RCC; // for easy access to RCC data types and
constants
using namespace Complex_mixerWorkerTypes;
using namespace std;

#define Uscale(x)  (float)((float)(x) / (pow(2,15) -1))
#define Scale(x)   (int16_t)((float)(x) * (pow(2,15) -1))

class Complex_mixerWorker : public Complex_mixerWorkerBase
{
  nco_crcf q;

  RCCResult initialize()
  {
    q = nco_crcf_create(LIQUID_NCO);
    nco_crcf_set_phase(q, 0.0f);

    return RCC_OK;
  }

  RCCResult release()
  {
    nco_crcf_destroy(q);

    return RCC_OK;
  }

  RCCResult run(bool /*timedout*/)
  {
    const IqstreamIqData* inData = in.iq().data().data();
    IqstreamIqData* outData = out.iq().data().data();
    const size_t num_of_elements = in.iq().data().size(); // size
in IqstreamIqData units
    out.iq().data().resize(num_of_elements);

    // set each time so that if the container changes it gets
updated
    // might be better to put this into a write sync function but
this is for training
```

```
   float phase_inc = properties().phs_inc * ((2*M_PI)/(SHRT_MAX *
2));
    nco_crcf_set_frequency(q,phase_inc);

    liquid_float_complex out_sample;
    liquid_float_complex in_sample;

    for (unsigned int j = 0; j < num_of_elements; j++)
    {
      if (properties().enable)
      {
        in_sample.real = Uscale(inData->I);
        in_sample.imag = Uscale(inData->Q);
        nco_crcf_step(q);
        nco_crcf_mix_down(q, in_sample, &out_sample);
        outData->I = Scale(out_sample.real);
        outData->Q = Scale(out_sample.imag);

        inData++;
        outData++;
      }
      else
      {
        outData->I = inData->I;
        outData->Q = inData->Q;
        inData++;
        outData++;
      }
    }

    return num_of_elements ? RCC_ADVANCE : RCC_ADVANCE_DONE;
  }
};

COMPLEX_MIXER_START_INFO
// Insert any static info assignments here (memSize, memSizes,
portInfo)
// e.g.: info.memSize = sizeof(MyMemoryStruct);
COMPLEX_MIXER_END_INFO
```

5.5 Build Worker

Now we need to compile the **complex_mixer** worker for the platform on which we want to run it; for this tutorial, it's our development host (**centos7**).

To build the worker with **ocpidev**, run the following command from the **DemoProject4** directory:

```
ocpidev build worker complex_mixer.rcc --rcc-platform centos7
```

6 Create Unit Test

Like we did in Tutorial 3, we'll generate an OpenCPI component unit test suite (aka "unit test") for our complex mixer worker.

To create the unit test with **`ocpidev`**, run the following command from the **`DemoProject4/components`** directory:

```
ocpidev create test complex_mixer
```

6.1 Edit Test Suite Description

Like we did in Tutorial 3, we need to add the generate and verify scripts with the necessary parameter values for the scripts to the OpenCPI Test Suite Description (OTSD) for the complex mixer worker.

To edit the test suite description from the command line, open the **`components/complex_mixer.test/complex_mixer-test.xml`** file with a text editor.

Now replace the contents of the file with the following XML:

```
<!-- This is the test xml for testing component "complex_mixer" -->

<Tests UseHDLFileIo='true'>
  <!-- Here are typical examples of generating for an input port
       and verifying results at an output port -->
  <Input Port='in' Script='generate.py 100 12.5 32767 16384'/>
  <Output Port='out' Script='verify.py 100 16384' View='view.sh'/>

  <!-- Set properties here. Use Test='true' to create a test-
exclusive property. -->
  <Property Name='phs_inc' Values='8192'/>
  <Property Name='enable' Values='0,1'/>
</Tests>
```

6.2 Update Unit Test Scripts

We're going to use the input and view unit test scripts again like we did for the peak detector worker in Tutorial 3, so we need to update the **`generate.py`**, **`verify.py`**, and **`view.sh`** scripts with our input data and our test parameters. As in Tutorial 3, make sure these files have read and execute permissions before proceeding to build and run the **`complex_mixer`** unit test.

6.2.1 Copy generate.py Script from Tutorial Project

The **`ocpi.tutorial`** project provides a reference **`generate.py`** script that you can simply copy into your **`DemoProject4`** instead of editing the empty file you just created. To do this, in **`DemoProject4`**, navigate to the **`components/complex_mixer.test/`** subdirectory and use the command:

```
cp
$OCPI_ROOT_DIR/projects/tutorial/components/
complex_mixer_tutorial.test/generate.py .
```

6.2.2 Copy verify.py Script from Tutorial Project

The **`ocpi.tutorial`** project provides a reference **`verify.py`** script that you can simply copy into your **`DemoProject4`** instead of editing the empty file you just created. To do this, in **`DemoProject4`**, navigate to the **`components/complex_mixer.test/`** subdirectory and use the command:

```
cp
$OCPI_ROOT_DIR/projects/tutorial/components/
complex_mixer_tutorial.test/verify.py .
```

6.2.3 Copy and Edit view.sh Script (Editing Required)

The **`ocpi.tutorial`** project provides a reference **`view.sh`** script that you can simply copy into your **`DemoProject4`** instead of editing the empty file you just created. To do this, in **`DemoProject4`**, navigate to the **`components/complex_mixer.test/`** subdirectory and use the command:

```
cp
$OCPI_ROOT_DIR/projects/tutorial/components/
complex_mixer_tutorial.test/view.sh .
```

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

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

6.3 Build Unit Test

Now we'll build the unit test for the target platform, which is our development host.

To build the unit test with **`ocpidev`**, run the following command from the **`components/complex_mixer.test/`** directory in **`DemoProject4`**:

```
ocpidev build test --rcc-platform centos7
```

7 Run Unit Test

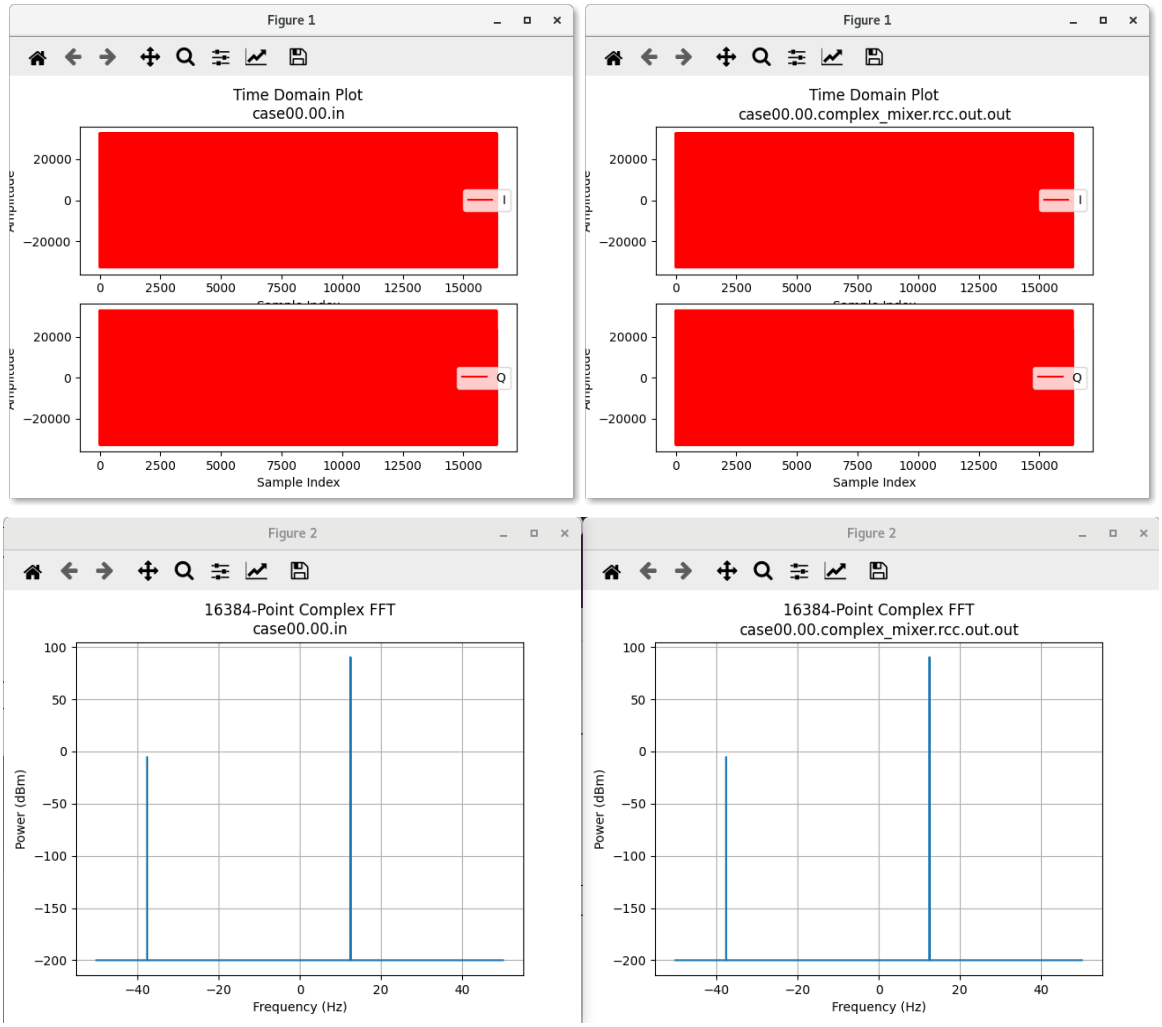
Now we'll run the unit test for the complex mixer worker.

To run the test and view the output from the command line, run the following **`ocpidev`** command from **`DemoProject4/components/`**:

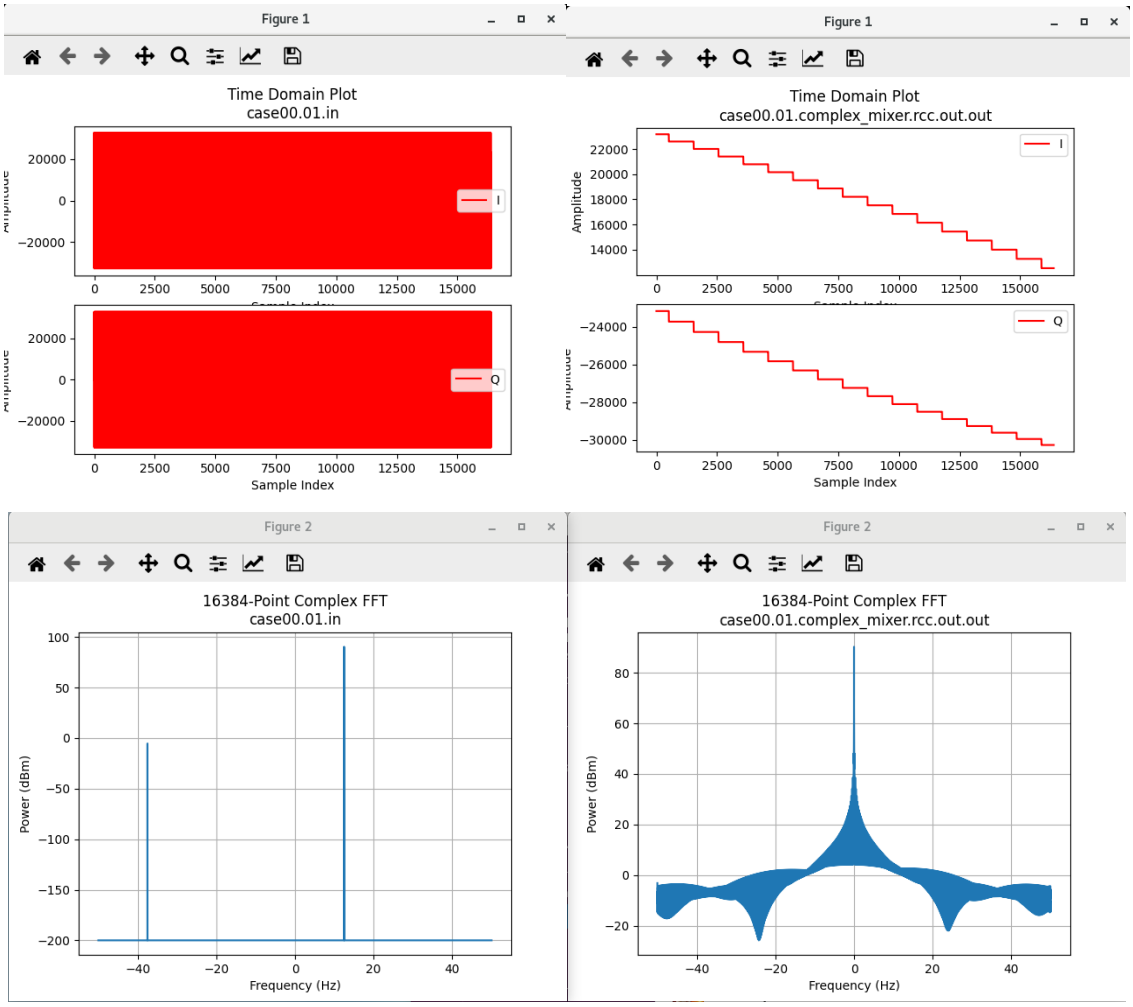
```
ocpidev run --mode prep_run_verify --only-platform centos7 --view
```

You should see this output:

Case00.00: enable = 0



Case00.01: enable = 1



8 Tutorial Summary

Now that you've completed this tutorial, you should be familiar with the basic concepts of developing an RCC worker that integrates a third-party library and running OpenCPI component unit tests on RCC workers. You can now proceed to Tutorial 5, which demonstrates how to use multiple opcodes in RCC workers.