

OpenCPI

Complex Mixer Tutorial Component Data Sheet

OpenCPI Release: v2.4.8

Revision History

Revision	Description of Change	Date
v1.2		8/2017
v1.3		2/2018
v1.4		10/2018
v1.5	Convert Worker to Version 2 HDL API	4/2019
v1.7	Updated port/property/interface tables for accuracy. Resource Utilization Table removed	6/2020

Summary - Complex Mixer Tutorial

Name	Complex_Mixer_Tutorial
Worker Type	Application
OpenCPI Release	v2.4.8
Last Update	06/2020
Component Library	ocpi.training.components
Workers	Complex_Mixer_Tutorial.hdl
Tested Platforms	c7-x86_64, Ettus E310(PL), linux-x13.3-arm, linux-x13.4-arm, Matchstiq-Z1(PL)(Vivado 2017.1), xsim

Functionality

The Complex Mixer consists of a Numerically Controlled Oscillator (NCO) and a complex multiplier. Complex IQ data is received on the input port and is multiplied with the output of the NCO and put on the output port.

Worker Implementation Details

Complex_Mixer_Tutorial.hdl

Figure 1 diagrams the complex mixer.

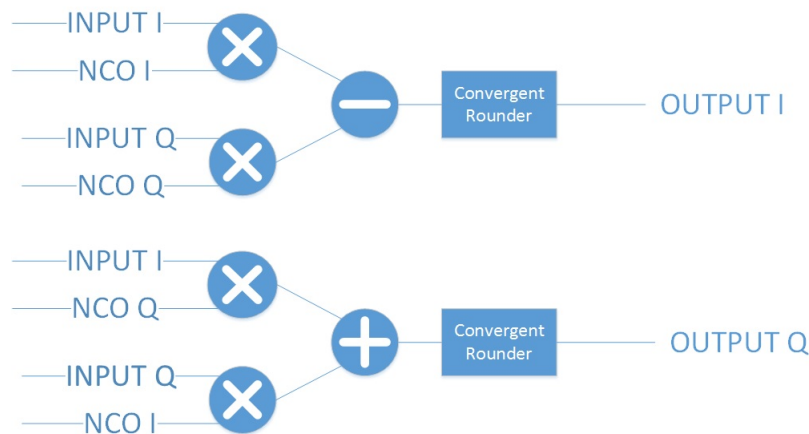


Figure 1: Complex Mixer Functional Diagram

The control properties for all implementations provide the ability to *enable*(or bypass) the worker and set the tune frequency via *phs_inc*.

The HDL worker leverages Xilinx Vivado cores to implement the NCO (DDS Compiler v6.0.13) and complex multiply (Complex Multiplier v6.0.12) functions. The Vivado IP Catalog tool was used to generate both cores. For both cores, their respective default configuration settings were chosen with the following exceptions:

- DDS Compiler 6.0.13 (dds_compiler.xci)
 - Parameter Selection = Hardware Parameters
 - Output Width = 16
 - Phase Increment Programmability = Streaming
 - Optional Pins: Has Phase Out is unchecked and ARESETn checked
- Complex Multiplier v6.0.12 (complex_multiplier.xci)
 - Control Signals: ACLKEN and ARESETn checked

The `dds_compiler` v6.0.13 implements a phase generator and sin/cos look-up tables (LUT), and has a latency of 7. The `complex_multiplier` v6.0.12 uses 3 DSP48E1s and has a latency of 6.

In conjunction with the `enable`(or `bypass`) control property, the HDL worker provides the ability to select different (`data_select`) data to output in bypass mode: input or output of the NCO.

Complex_Mixer_Tutorial.rcc

The RCC worker leverages `liquid-dsp` v1.2 and its `nco` class to generate the internal NCO used in the algorithm. More information on this `liquid-dsp` module can be seen in the online documentation: `liquid-dsp`.

In the RCC version of this component the samples are converted from fixed point to floating point numbers in order to do that math on a GPP. This conversion introduces a small amount of error in the output data and should be accounted for when it is used in an application. The conversion equations are as follows:

$$iq_float = \frac{iq_fixed}{2^{15} - 1} \quad (1)$$

$$iq_fixed = iq_float * (2^{15} - 1) \quad (2)$$

In the RCC worker a conversion needs to be done for the phase increment to adhere to the way the HDL phase increment is implemented. The conversion was done in the RCC version of this component because the division operation is very resource intensive in HDL. The conversion from the component property to the `liquid-dsp` interface input property is as follows:

$$liquid_phs_inc = phs_inc * \frac{2\pi}{0x7FFF * 2} \quad (3)$$

Theory

The Complex Mixer worker inputs complex signed samples and performs a complex multiply with a digital sine wave produced by an numerically controlled oscillator (NCO). The resulting output data is a frequency shifted version of the input data.

The magnitude of the frequency shift is determined by the output frequency of the NCO, which can be calculated with the following equation:

$$nco_output_freq = sample_freq * \frac{phs_inc}{2^{phs_acc_width}} \quad (4)$$

In this component, `phs_inc` is runtime configurable and has a data type of 16 bit signed short. `phs_acc_width` is fixed at 16. The input clock frequency is the sample rate of the samples. The amplitude of the NCO's sine wave is fixed at the full range of a signed 16 bit value.

Block Diagrams

Top level

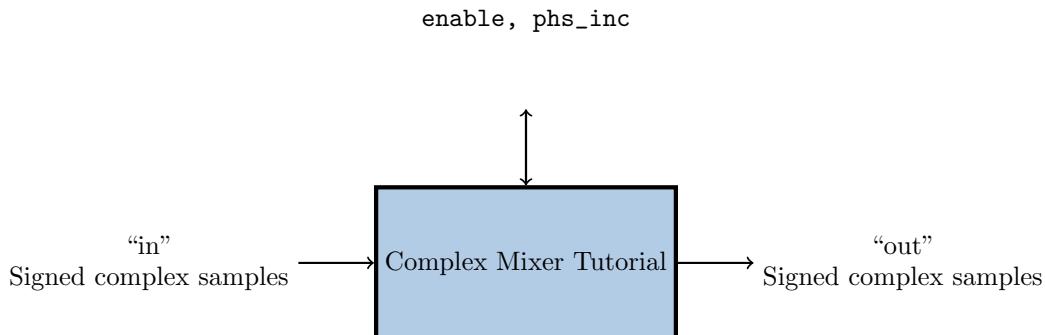


Figure 2: Complex Mixer Top Level Block Diagram

Source Dependencies

Complex_Mixer_Tutorial.rcc

- Liquid DSP (provided with opencpi RPMs)

Complex_Mixer_Tutorial.hdl

- training_project/components/complex_mixer.hdl/vivado_ip/complex_multiplier_stub.vhd
- training_project/components/complex_mixer.hdl/vivado_ip/complex_multiplier_sim_net.vhd
- training_project/components/complex_mixer.hdl/vivado_ip/complex_multiplier.vho
- training_project/components/complex_mixer.hdl/vivado_ip/complex_multiplier.xci
- training_project/components/complex_mixer.hdl/vivado_ip/complex_multiplier.edf
- training_project/components/complex_mixer.hdl/vivado_ip/dds_compiler_stub.vhd
- training_project/components/complex_mixer.hdl/vivado_ip/dds_compiler_sim_net.vhd
- training_project/components/complex_mixer.hdl/vivado_ip/dds_compiler.vho
- training_project/components/complex_mixer.hdl/vivado_ip/dds_compiler.xci
- training_project/components/complex_mixer.hdl/vivado_ip/dds_compiler.edf

Component Properties

Name	Type	SequenceLength	ArrayDimensions	Accessibility	Valid Range	Default	Description
enable	Bool	-	-	Writable	Standard	True	Enable(true) or Bypass(false) mixer
phs_inc	Short	-	-	Writable	Standard	8192	Phase increment of NCO

Worker Properties

complex_mixer_tutorial.hdl

Name	Type	SequenceLength	ArrayDimensions	Accessibility	Valid Range	Default	Description
enable	Bool	-	-	Writable	Standard	True	Enable(true) or Bypass(false) mixer
phs_inc	Short	-	-	Writable	Standard	8192	Phase increment of NCO
data_select	Bool	-	-	Writable	Standard	False	In Bypass Mode: selects data to output: 0=input data, 1=output of NCO

complex_mixer_tutorial.rcc

Name	Type	SequenceLength	ArrayDimensions	Accessibility	Valid Range	Default	Description
enable	Bool	-	-	Writable	Standard	True	Enable(true) or Bypass(false) mixer
phs_inc	Short	-	-	Writable	Standard	8192	Phase increment of NCO

Component Ports

Name	Producer	Protocol	Optional
in	False	iqstream_protocol	False
out	True	iqstream_protocol	False

Worker Interfaces

complex_mixer_tutorial.hdl

Type	Name	Producer	Protocol	Optional	DataWidth	Clock	ClockDirection	WorkerEOF	InsertEOM
StreamInterface	in	False	iqstream_protocol	False	32	(control clock)	-	False	False
StreamInterface	out	True	iqstream_protocol	False	32	(control clock)	-	False	True

complex_mixer_tutorial.rcc

Name	Producer	Protocol	Optional
in	False	iqstream_protocol	False
out	True	iqstream_protocol	False

Control Timing and Signals

The Complex Mixer HDL worker uses the clock from the Control Plane and standard Control Plane signals.

There is a startup delay for this worker. Once the input is ready and valid and the output is ready, there is a 6 clock cycle start delay (pipeline delay of complex multiplier). After this startup delay, valid output data is given 6 clock cycles after input data is taken.

Latency
6 clock cycles

Performance and Resource Utilization

Complex_Mixer_Tutorial.hdl

Test and Verification

Test cases are derived from the number of properties, and their respective values, as listed in the complex_mixer-test.xml.

- 1) Bypass (RCC & HDL): The input data is forwarded to the output port. For verification of this case, the output file is byte-wise compared to the input file.
- 2) Normal mode (RCC & HDL): The NCO is configured to tune the input signal to baseband. For verification, an FFT of the output data is performed and the max value of the FFT is checked to be at DC (0 Hz).

For all cases, the input file contains a tone of 12.5 Hz sampled at 100 Hz and an amplitude of 32767.