

# SFP communication with third-party devices

PN109 | Posted on January 22, 2026 | Updated on February 2, 2026



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## Table of Contents

- [SFP, Aurora and imperix](#)
- [Setup overview](#)
- [Supported devices](#)
- [User application template](#)
- [Generate the bitstream](#)
- [Startup procedure](#)
- [Address mapping](#)
- [To go further](#)
  - [How to exchange more signals](#)
  - [How to assign a different SFP port](#)
  - [Implementation details](#)

While imperix controllers are typically programmed by building applications in Simulink or PLECS, imperix also provides direct access to FPGA resources through its FPGA development environment, known as the sandbox.

This level of access enables a wide range of applications, including direct control of the controller transceivers and the implementation of Aurora communication over the physical SFP ports. Such flexibility makes it well suited to accommodate the diverse Aurora configurations used by major simulator vendors, such as OPAL-RT, Plexim and RTDS.

This page explains how to set up this communication by combining a user application running on the CPU with additional logic in the FPGA bitstream. For a quick and straightforward integration, a ready-to-use user application template is provided, along with generation scripts to easily generate the bitstreams for several vendors.

This page is designed for users interested in Aurora communication and does not require any prior experience with FPGA programming.

For now, this page applies to the following imperix controllers: [B-Box RCP 3.0](#), [B-Board PRO](#), [Programmable Inverter \(TPI\)](#).

## SFP, Aurora and imperix

With three Small Form-factor Pluggable (SFP) ports, the imperix controllers are naturally built for multi-devices topologies, such as wide multi-master and master-slave [RealSync](#) networks.

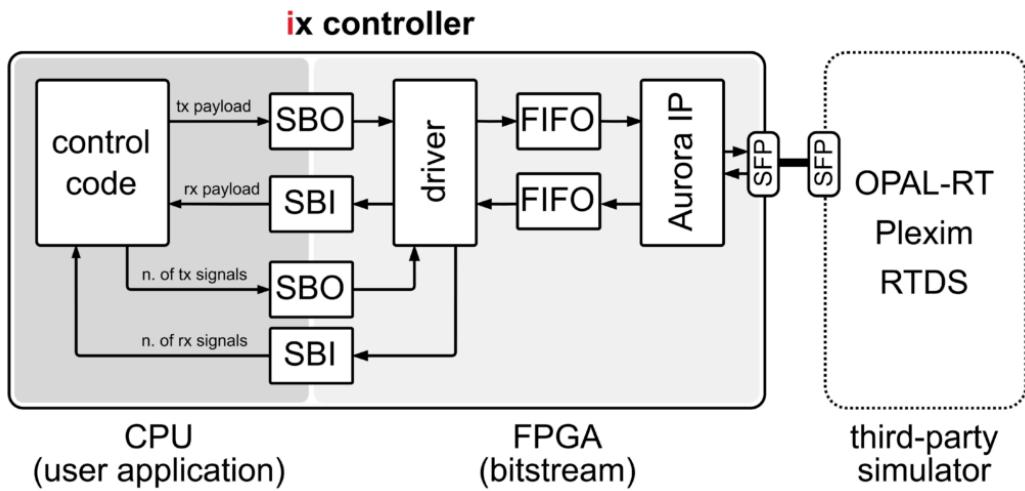
To fully leverage these high-speed SFP connections, the [Aurora protocol](#) from Xilinx provides a lightweight, high-throughput protocol. By using native transceivers with minimal overhead, Aurora delivers low latency and near line-rate performance without the complexity of protocols like Ethernet, making it an efficient and practical choice for high-bandwidth, point-to-point links.

Although simple, Aurora requires identical configurations at both ends of the link. This usually makes interoperability between devices from different vendors challenging, as vendors often opt for slightly different settings.

To avoid this bottleneck and remain compatible with all (or most) Aurora-compatible devices on the market, imperix gives full access to the SFP ports. Off-the-shelf drivers and synthesis-ready Vivado projects are provided for various vendors such as Plexim, OPAL-RT and RTDS, along with simple loopback and more advanced examples.

## Setup overview

The setup considered to exchange data with a third-party device is depicted below. It is composed of three main parts: the **user application**, the **FPGA bitstream** and the **third-party application**.



The **user application** is running in the CPU of the imperix controller and contains the code designed by the user, typically a control algorithm. This application has no special requirements, except that it contains SBO blocks to send data to the driver and SBI blocks to access incoming data from the SFP connection.

The **FPGA bitstream** defines the logic executed on the imperix controller's FPGA. Together with the controller firmware, it implements the functionality required for Aurora communication. The core components of this communication are the **driver**, **FIFOs** and the Xilinx **Aurora IP**:

- The **driver** receives the outgoing data from the user application through the SBO blocks, packages it into frames compatible with the third-party simulator and transfers the frames to the Aurora IP. In parallel, it receives incoming frames from the Aurora IP, decodes them and makes the values available to the user application via SBI blocks.
- The **FIFOs** are essential for the clock domain crossing. It makes the bridge between the main clock domain of imperix controllers, running at 250 MHz, to the clock domain of the Aurora IP. The frequency of the Aurora IP depends on the configuration of the Aurora channel and is therefore different for each vendor.
- The **Aurora IP** is provided by Xilinx. As explained in its [presentation page](#), the IP enables easy implementation of transceivers while providing a light-weight user interface on top of which designers can build a serial link.

Because major market vendors use different Aurora channel configurations and, in some cases, specific frame structures, the bitstream is **vendor-specific** and must be generated using the corresponding generation scripts.

Finally, the **third-party application** runs on a third-party device and is not directly related to imperix products. In this example, it is required that the application enables an Aurora communication on an SFP port of the third-party simulator.

More information about the CPU-FPGA communication can be found in [Exchanging data between the CPU and the FPGA](#).

## Supported devices

The supported devices are listed below. Devices marked in **bold** have been expressly tested and validated.

Vendor	Compatible devices	Related page(s)
OPAL-RT	<b>OP4510, OP4512</b>	<a href="#">Aurora link with OPAL-RT via SFP</a>
Plexim	<b>RT-Box 1, RT-Box 2, RT-Box 3</b>	<a href="#">Aurora link with Plexim via SFP</a>
RTDS	<b>GTSOC V2</b>	<a href="#">SFP communication with an RTDS MMC simulator (*)</a>

(\*) For this device, the communication chain, driver and address mapping differ in order to match the frame structure expected by the MMC model running on the GTSOC V2.



The Aurora configuration applied by each vendor is summarized in the following table.

Vendor	Aurora protocol	Line rate (Gbps)	Endianness	CRC check	Frame structure
OPAL-RT	Aurora 8B10B	5	Little	Yes	–
Plexim	Aurora 64B66B	6.25	Big	Yes	Custom
RTDS	Aurora 8B10B	2	Little	No	Custom

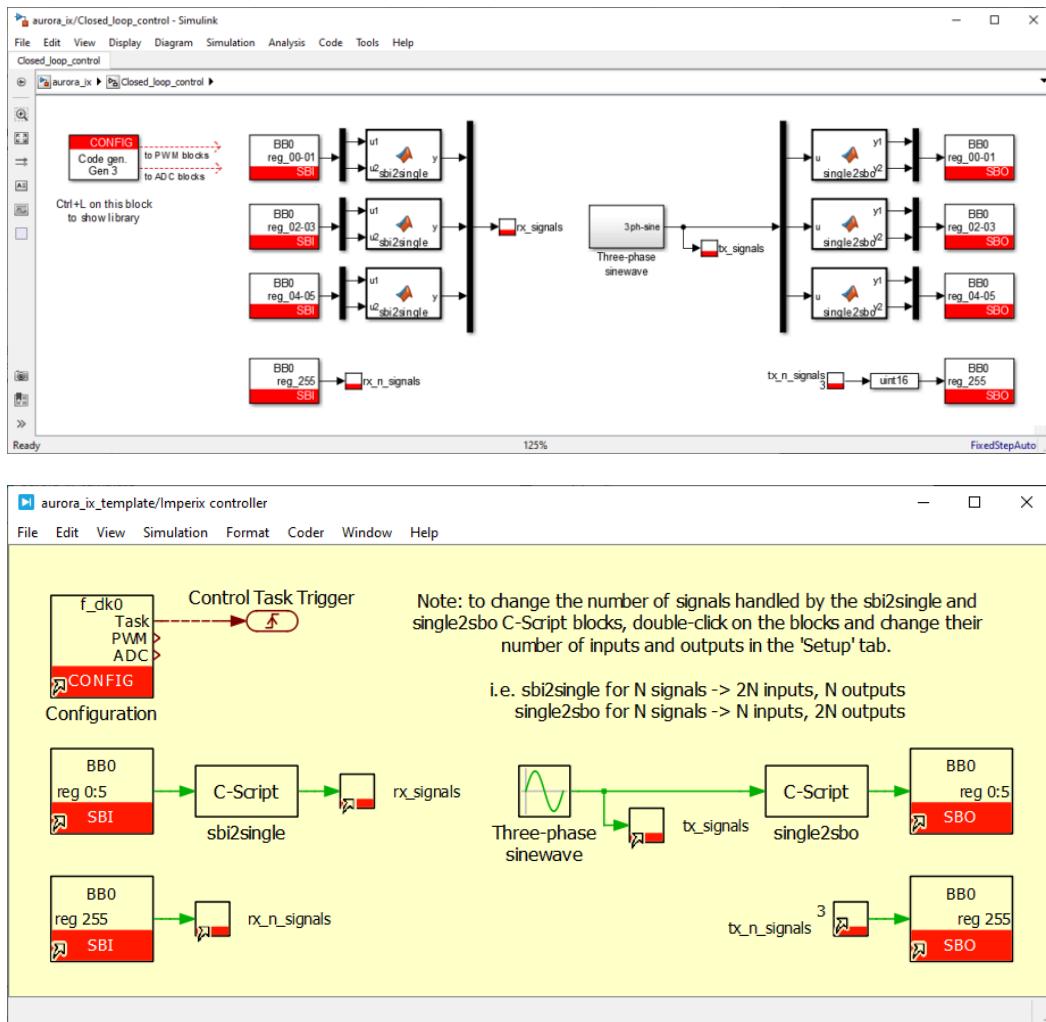
# User application template

As mentioned, the user application has no special requirements, except that it contains [SBO](#) and [SBI](#) blocks to communicate with the driver running in the FPGA.

For a quick start, a simple user application template that sends and receives three signals via SFP is provided below as a starting point, either in Simulink or PLECS:

[Download aurora\\_ix\\_template.slx](#)

[Download aurora\\_ix\\_template.plecs](#)



As presented in details in [Exchanging data between the CPU and the FPGA](#), the communication between the CPU and the FPGA is handled by the SBIO bus. Thanks to the related [SBI](#) and [SBO](#) blocks, the CPU generates read and write requests on the SBIO bus and interacts with the registers located in the FPGA.

As the SBIO bus is intended to carry 16-bit data, the 32-bit values are split into two 16-bit words to be transferred over the bus. The conversion is handled by the *single2sbo* and *sbi2single* Matlab/C-Script functions.

The address mapping is detailed in the [dedicated section](#) below.

To build the user application, make sure that the **Automated Code Generation** mode is selected in the **CONFIG** block and press **Ctrl+B** (Simulink) or **Ctrl+Alt+B** and then **Build** (PLECS).

## Generate the bitstream

To generate the bitstream running in the imperix controller, please follow the steps outlined below:

1. Install the **Vivado Design Suite** (version **2022.1** is recommended). The step-by-step installation procedure is detailed in [Installation of AMD Xilinx Vivado Design Suite](#).
2. Download the **imperix source files** (version **3.10 Rev. 0 or later** is mandatory). The source files are available for free at [Download of the imperix firmware IP for FPGA sandbox](#).
3. Download the generation scripts corresponding to the targeted vendor in the table below and mimic [the procedure of this page](#) to generate the bitstream from the scripts.

Vendor	Compatible devices	Generation scripts
OPAL-RT	OP4510, OP4512	<a href="#">aurora_ix_opalrt_gen_scripts.zip</a>
Plexim	RT-Box 1, RT-Box 2, RT-Box 3	<a href="#">aurora_ix_plexim_gen_scripts.zip</a>

The provided FPGA logic is connected to the port **SFP 0 (UP)** and supports the exchange of **up to 32 signals** in each direction. To extend the number of signals or assign another SFP port, refer to the [How to extend more signals](#) and [How to assign a different SFP port](#) sections below.

## Startup procedure

To start using the setup and exchange data with the third-party device:

1. Connect the imperix controller to the third-party simulator with an SFP cable. By default, the Aurora communication is connected to the port SFP 0 (UP) on the controller.
2. Generate the bitstream, as explained in the [dedicated section](#) above.
3. Load the bitstream on the imperix controller via Cockpit.
4. Download the [user application template](#) in Simulink or PLECS (or use your own model). If you use your own model, it is recommended to add [probes](#) on the

exchanged signals (see the screenshots in the [user application template](#) section for reference).

5. Build the model and launch it on the imperix controller via Cockpit.

6. Compile/build the code for the third-party simulator and launch it.

Applications are provided for several vendors in the dedicated pages listed in the [Supported devices](#) section above. Refer to the vendor's documentation for advanced guidance and details.

7. Use Cockpit to monitor the exchanged signals.

## Address mapping

As introduced in the [setup overview](#), the internal CPU-FPGA communication in imperix controllers is managed by the SBIO bus. This topic is explored in details in [Exchanging data between the CPU and the FPGA](#).

As they correspond to 16-bit words, SBI and SBO addresses are grouped by two to transfer the 32-bit words of the payload, starting at address 0. For instance, the first word to be transmitted must be written in the SBO 1 (MSB) and SBO 0 (LSB), and the first word received from the simulator is available in SBI 1 (MSB) and SBI 0 (LSB).

The number of signals to transmit to the third-party device must be specified in SBO 255. Similarly, the number of received signals is available in SBI 255.

SBO address		Transmitted signals (tx payload)	SBI address		Received signals (rx payload)
1	0	tx_signal_00	1	0	rx_signal_00
3	2	tx_signal_01	3	2	rx_signal_01
...		...			
63	62	tx_signal_31	63	62	rx_signal_31
(free for extension)			(free for extension)		
-	255	n_tx_signals	-	255	n_rx_signals

## To go further

### How to exchange more signals

The current implementation supports the exchange of 32 signals in each direction. This section describes how to extend the number of signals.

- 1. Change the number of ports of the provided VHDL driver.**

The driver is located in `<folder>/hdl/sfp_aurora_rtbox.vhd` and the instructions are clearly indicated at the top of the file. These changes are basically consist in adding more ports, insert them in the interfaces and link their value with the two internal arrays.

- 2. Adapt the surrounding modules.**

Make sure that the surrounding modules support the desired number of signals, namely the `sbio_256_registers`, `convert_16b_to_32b` and `convert_32b_to_16b` modules. Do not forget to extend the length of the `axis_data_fifo_0` FIFO.

- 3. Regenerate the bitstream.**

- 4. Adapt the Simulink model.**

Add the corresponding SBI and SBO blocks in the Simulink model.

- 5. Make sure that the third-party device is configured accordingly.**

## How to assign a different SFP port

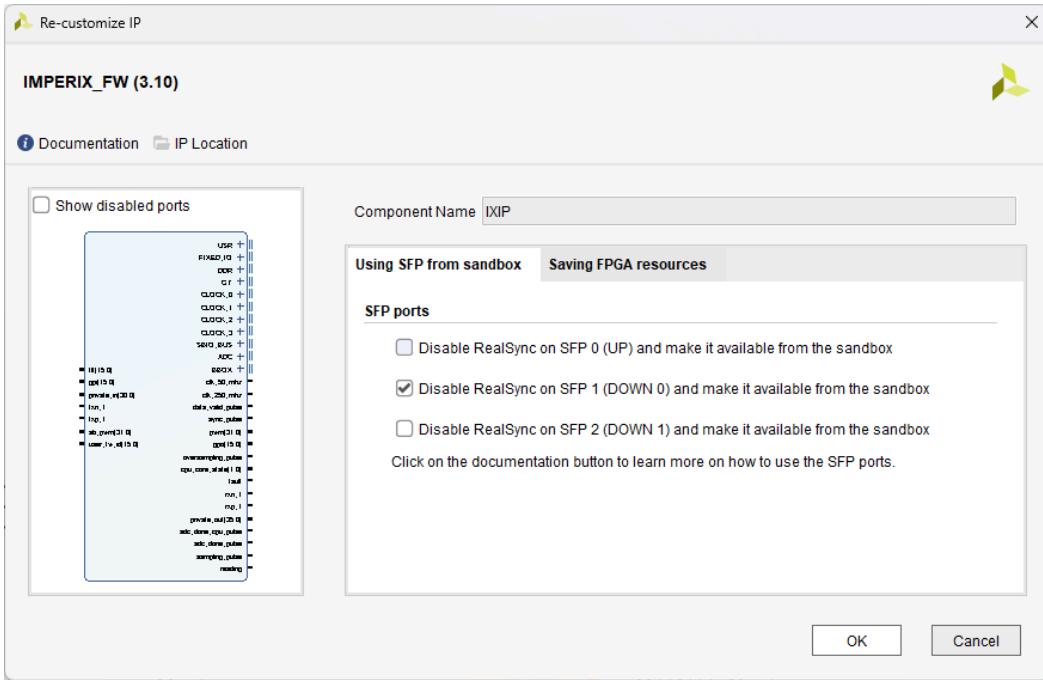
In the provided implementation, the communication with the RT-Box is configured on the SFP port 0 (UP). To assign the SFP communication to another SFP port (e.g., SFP 1 (DOWN0)):

- 1. Open the Vivado project.**

- 2. Change the enabled SFP port.**

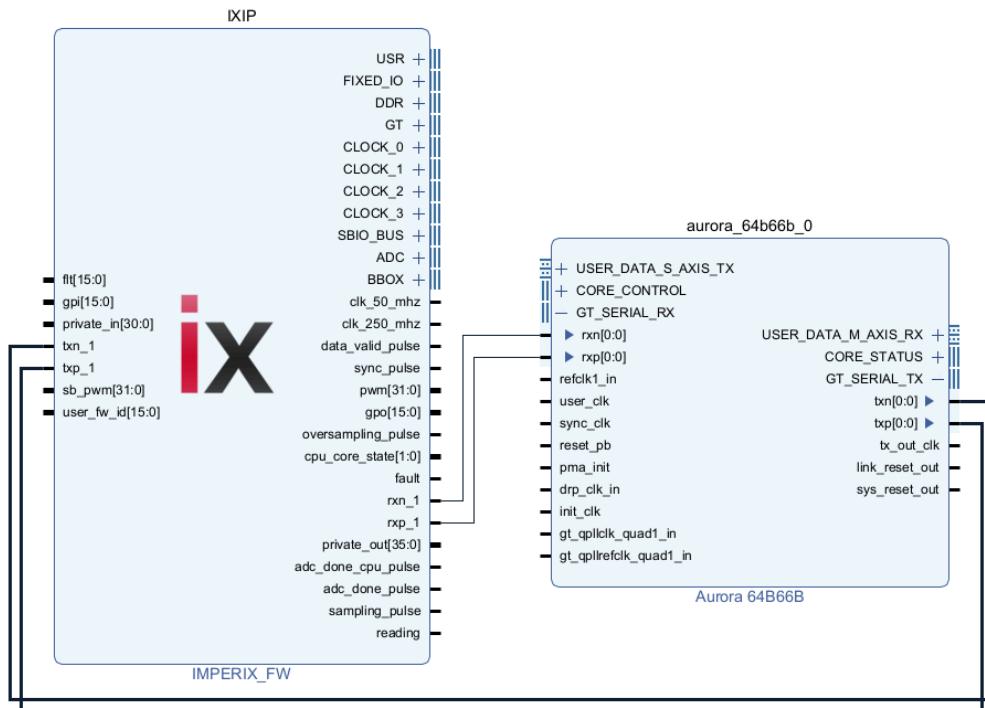
Double-click on the IX IP block in the block diagram to open the configuration panel. Once opened, in the Using SFP from sandbox tab, check the entry of the desired SFP port and uncheck the entry for SFP 0.

This will re-enable RealSync on port 0 (UP) and disable it on the selected port. Concretely, it automatically removes the `txn_0`, `txp_0`, `rxn_0`, `rxp_0` ports of the imperix firmware IP and exposes the ports of the selected SFP port instead.



### 3. Connect the ports.

Connect the four ports exposed during step 3 to the Aurora IP, as illustrated below.



### 4. Regenerate the bitstream.

## Implementation details

For advanced users willing to understand the current implementation of the SFP communication down to the details or modify it for their own needs, please note that:

- The transmission is triggered once per control period, as soon as the SBIO values are ready (i.e., when `data_valid_pulse` is high).
- The triggering of the transmission is ignored during an ongoing transmission.
- Received frames with an invalid checksum are dropped by the Plexim IP (called `rtbox_aurora_adapter` in the block design). This can be manually changed by double-clicking on the IP and uncheck the 'Drop packages with invalid checksum' checkbox.
- The `rx_vld` signal is available at the output of the driver. This signal is asserted during one cycle at the exact instant the registers of `RX_SIGNALS` are updated with the content of a new frame.
- The driver and the FIFOs are reset each time the code is launched on the target (i.e., when `sync_pulse` is high).