RFNoC (UHD 3.0)

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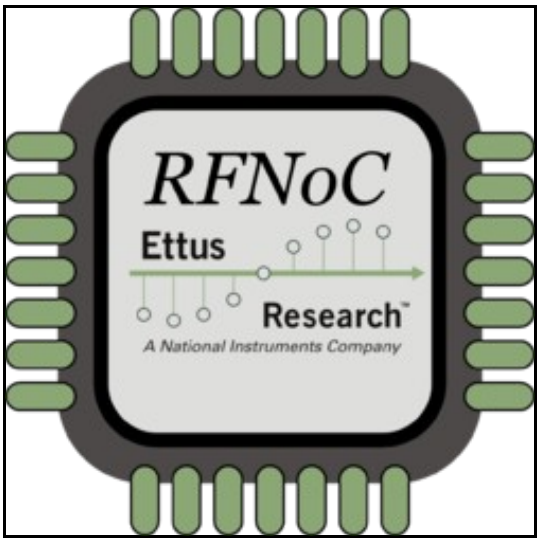
RFNoC is a network-distributed heterogeneous processing tool with a focus on enabling FPGA processing in USRP devices. It allows you to move data on and off of an FPGA in a transparent way, thus enabling seamless use of both host-based and FPGA-based processing in an application. It provides a way to leverage FPGA processing capabilities and IP in your application which can scale across multiple FPGAs and devices across a network.

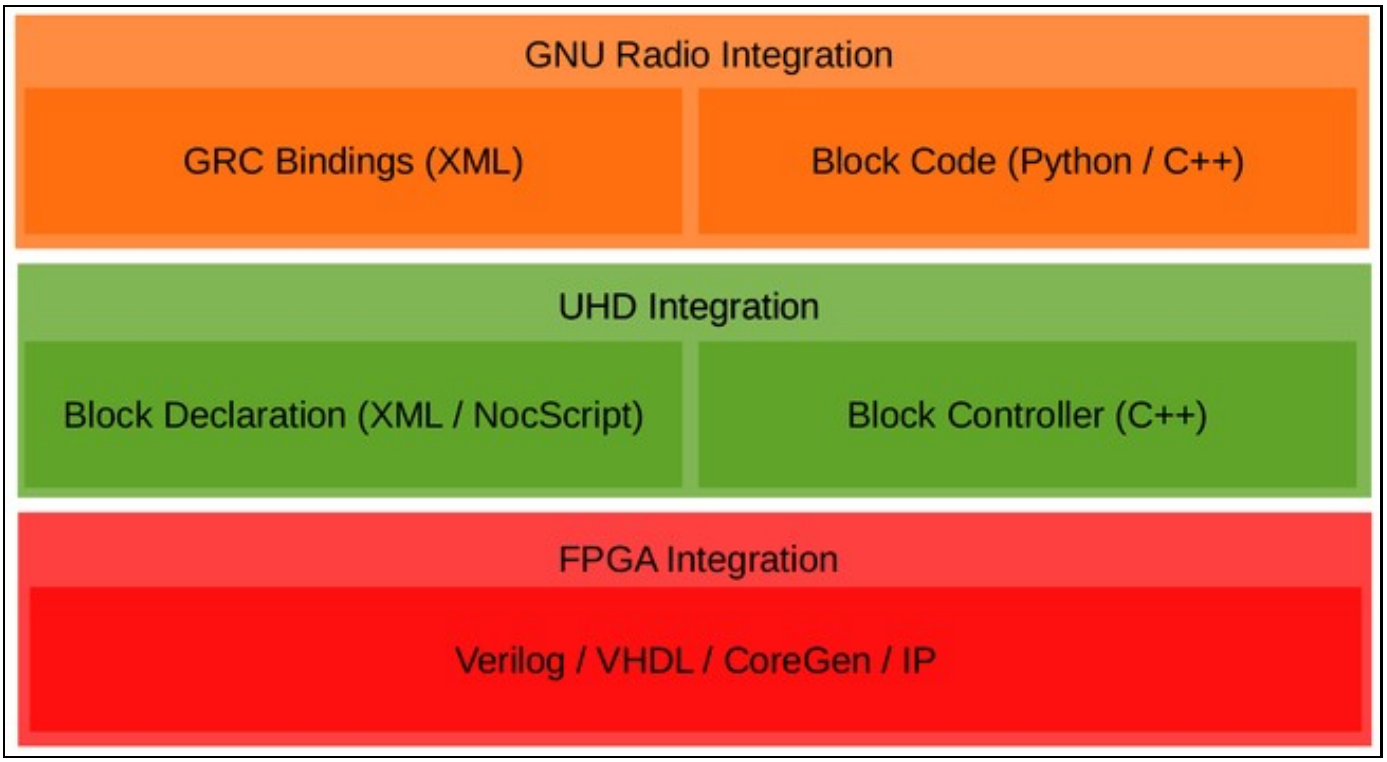
Signal processing algorithms are contained modules known as "Computation Engines" or "RFNoC Blocks", and an interface wrapper is provided to encapsulate existing or external IP to use with RFNoC. This allows you to import Xilinx? CoreGen? IP blocks, for example, and use them immediately in your RFNoC application. The internals of a RFNoC block are wholly independent from any other block, and can be designed with any tool that supports AXI stream interfaces, including VHDL, Verilog, and Xilinx? Vivado? HLS.

We are quickly building out the library of ready-to-use RFNoC blocks and already have many available, including the blocks necessary for an OFDM stack (e.g., detection, synchronization, equalizer, packet demodulator).

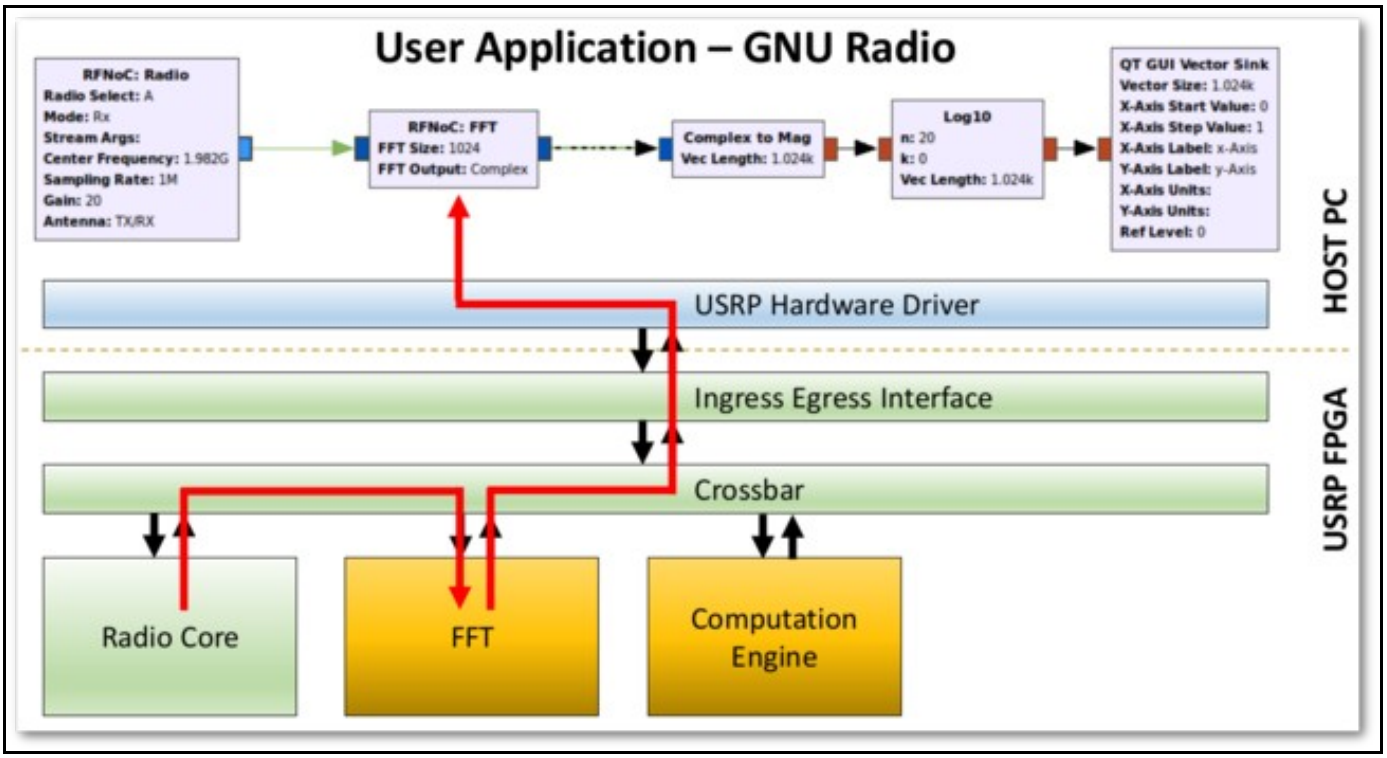
RFNoC is integrated with the UHD? software, and all USRP devices from the third-generation on (X300 Series, E300 Series) are supported by RFNoC out-of-the-box. Like UHD, RFNoC is also Free and Open Source Software (LGPL), and the full source code can be found in our public code repositories.



Below is a figure of the RFNoC stack.



The example below shows basic data flow of an RFNoC application. While this shows one possible data flow, there are many possible combinations from Host block to FPGA block, FPGA block to Host block, Host to Host, FPGA to FPGA, etc.



- E310/E312
- E320
- X300/X310
- N300/N310/N320/N321

- FIFO
- FFT
- FIR
- fosphor (real-time spectrum analyzer)
- Decimator (Keep 1 in N)
- Log Power Calculator
- Radio Interface
- Vector IIR (moving average)
- Window multiplier (for FFT)
- OFDM: Burst detection + synchronization, equalizer, packet demodulator
- and more...

When writing or reading a settings register in a RFNoC block, the block receives a command packet (with the register address / value to write as the payload) and sends out a response packet. The response packet acknowledges the command packet and includes readback data as the payload. In the write case, the readback data is usually discarded. In the read case, the readback data payload will be the value of the register read in the block.

The signal `rb_stb`, called readback strobe, is used to control the the output of the response packet. After receiving a command packet, Noc Shell?s command packet processor will not output a response packet unless `rb_stb` is asserted. This functionality can be used to throttle the reception of command packets / settings register read/writes.

Most blocks should keep `rb_stb` asserted. Note, the `rb_stb` bit width is as wide as the number of block ports in use. For example, a two block port RFNoC block should set `rb_stb` to `2?b11`, otherwise a command packet timeout will occur.

Error message example:

```
RuntimeError: EnvironmentError: IOError: 0/FIR_0 user_reg_read64() failed: EnvironmentError: IOError: [0/FIR_0] sr_read64() failed: Environme
in uint64_t ctrl_iface_impl::wait_for_ack(bool)
at /home/ettus/src/uhd/host/lib/rfnoc/ctrl_iface.cpp:205
```

- Check `ce_clk` / `ce_rst` are correctly connected in `rfnoc_ce_auto_inst_<device>.v` file where `<device>` is `x300`, `x310`, or `e310`.
- Check block is correctly connected to the crossbar. Generally this is only an issue if manually connecting RFNoC block?s signals to the crossbar.
- Check if Noc Shell?s `rb_stb` signal is properly asserted. Note, `rb_stb` bit width must be as wide as the number of block ports in use, i.e. if using 2 block ports, `rb_stb` must be `2?b11`.
- RFNoC block is using timed commands (`USE_TIMED_CMDS`) with Noc Shell and the command FIFO depth parameter (`CMD_FIFO_SIZE`) on Noc Shell is too small. UHD will issue up to 64 commands at once, so set `CMD_FIFO_SIZE` to at least `8`.

An **RFNoC FIFO** is needed in your flowgraph in the following 2 conditions:

First, if you are running a GNU Radio flowgraph that is structured as follows:

`Host block -> RFNoC block -> Host block`

In this case, you need to do either:

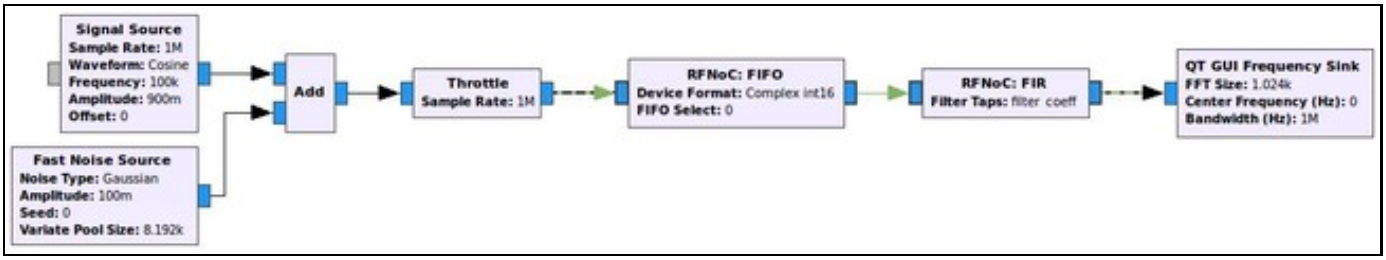
`Host block -> RFNoC FIFO -> RFNoC Block -> Host block`

-OR-

`Host block -> RFNoC Block -> RFNoC FIFO -> Host block`

The order doesn't matter. This structure also benefits from having the GNU Radio Throttle block in the sequence. The reason behind the need to add the FIFO is because of performance inside of GNU Radio, so that the RX/TX work functions in the GNU Radio RFNoC block implementations run in separate threads.

Use `RFNoC: FIFO` (`AXI_FIFO_LOOPBACK`) in this case. See the following figure as an example.



Second, in the case where you are transmitting out to the antenna on the X3xx series devices, i.e.

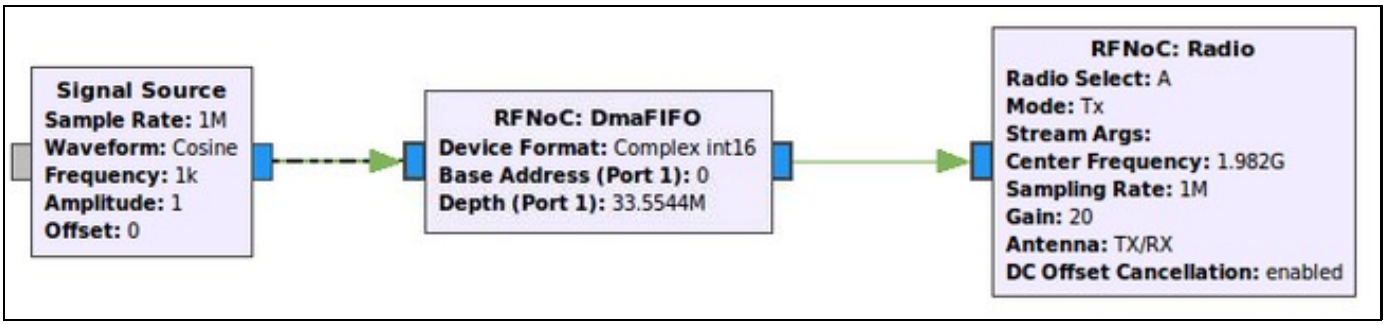
`Host -> DmaFIFO -> Radio`

-OR-

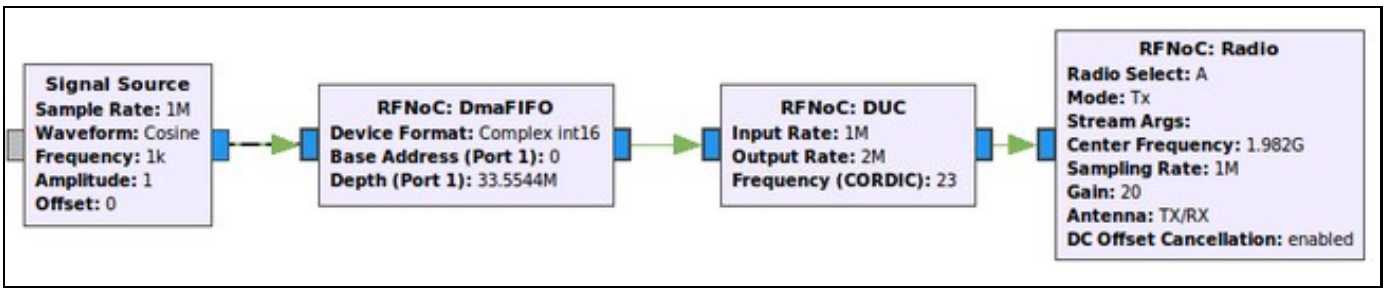
`Host -> DmaFIFO -> DUC -> Radio`

Ethernet introduces a latency in flow control from the X3x0 back to the host. The latency will cause underruns unless a large buffer, i.e. `DMA_FIFO`, is added to the flowgraph.

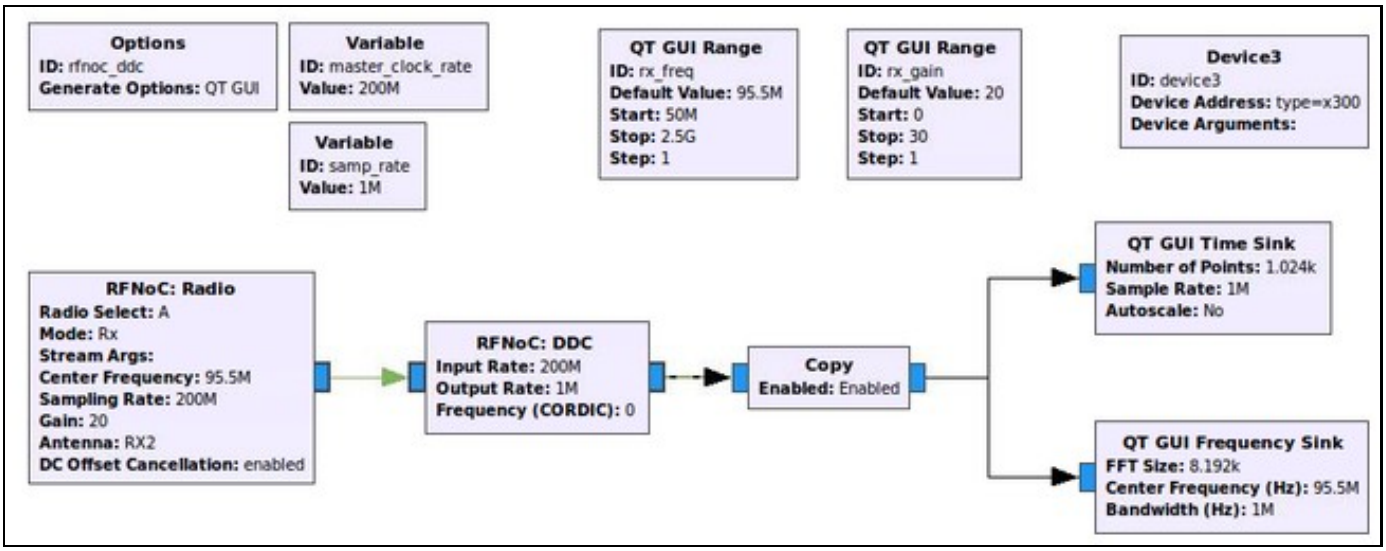
Use `RFNoC: DmaFIFO` (`AXI_DMA_FIFO`) in this case. See the following figures as examples.



-OR-



Copy Block: In the RFNoC domain, streams of data can not be split as easily as they are in the GNU Radio domain. The `Copy` block depicted in the screenshot below serves the function as a stream splitter at the FPGA-Host boundary. It?s main purpose, when `Enabled`, is to copy the samples it is getting at its input and putting then into the output, but here it is also serving as a boundary between a RFNoC-domain and a GNURadio-domain. In the flowgraph above. after this boundary is passed, the data stream can easily be split into the two sinks to have them run simultaneously (standard GNU Radio functionality). It is possible to connect the GNU Radio blocks directly to RFNoC blocks without a `Copy` block, but only one would work at a time (the other ones would have to be disabled). Another way to split data streams from the RFNoC-domain is to use the `RFNoC: Split Stream` block, which would split the streams in the RFNoC domain, but this is not very useful here as we are moving into the GNURadio-domain.

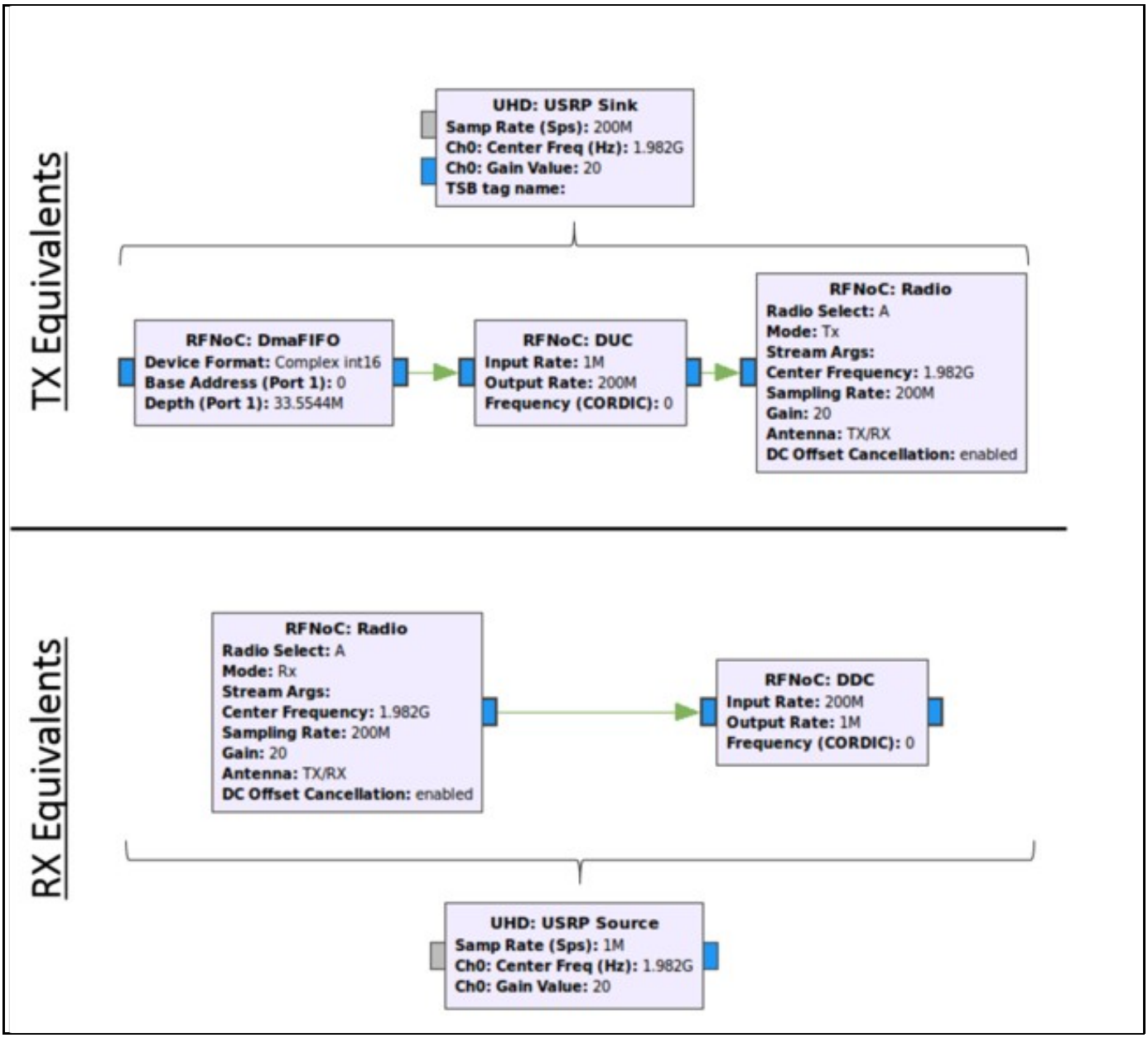


The USRP Source and Sink blocks use the `multi_usrp` API, whereas the `RFNoC:Radio` block uses the RFNoC API. In general, unless RFNoC features are desired, there is no need to use the `RFNoC:Radio` block. The `RFNoC:Radio` block is most useful when its output is connected directly to another RFNoC block. Below is a list of differences as well as a GRC screenshot to help differentiate between the two blocks.

Distinctions:

- The USRP Source/Sink blocks work with any version of UHD, and does not require `gr-ettus`. The `gr-ettus` Out-Of-Tree GNU Radio module is currently needed to use any RFNoC Blocks. This requirement will be removed as more RFNoC components are migrated into UHD.
- The USRP Source/Sink blocks include a superset of the not only the components of an `RFNoC:Radio`, but also `DDC/DUC` chains, and the `DRAM FIFO` (specific to X3xx series). When using the `RFNoC:Radio` block, the `DDC/DUC` blocks need to be added explicitly. See the figure below.
- When using the USRP Source/Sink blocks, it is not possible to connect to any RFNoC blocks.
- USRP Source/Sink blocks can only be used when using a `multi_usrp` API FPGA image (when looking in the USRP FPGA images directory they are the images without the term ?RFNOC? in them), or an FPGA image that includes `RFNoC:Radio` and `RFNoC:DDC/DUC` blocks.

NOTE: The RFNOC:DmaFIFO block is only needed for the X3xx series devices.



Problem: The Xilinx Vivado License Manager looks for an Ethernet adapter with the name `eth0`, but Ubuntu 16.04 and later now use a persistent naming scheme, with interface names such as (e.g. `np6s0`, `enp4s0`, `enp2s0f0`, `enp2s0f1`, `enx00ef5c620935`).

Solution: Rename the ethernet adapter to `eth0`.

Create this file: `70-persistent-net.rules` in this `/etc/udev/rules.d/` directory And adding the following line to the file (substitute `xx:xx:xx:xx:xx:xx` for the MAC address of the Ethernet adapter):

```
SUBSYSTEM=="net", ACTION=="add", DRIVERS=="?*", ATTR{address}=="xx:xx:xx:xx:xx:xx", ATTR{dev_id}=="0x0", ATTR{type}=="1", NAME="eth0"
```

Ubuntu information:

http://askubuntu.com/questions/767786/changing-network-interfaces-name-ubuntu-16-04

Xilinx information:

https://www.xilinx.com/support/answers/60510.html

- Licensing FAQ

- Getting Started with RFNoC Development
- GNU Radio 2016 Conference Presentation
- Virginia Tech Video Presentation
- Virginia Tech Presentation - Introduction to RFNoC
- Virginia Tech Presentation - RFNoC Deep Dive: Host Side
- Virginia Tech Presentation - RFNoC Deep Dive: FPGA
- sigcom 2013 Paper