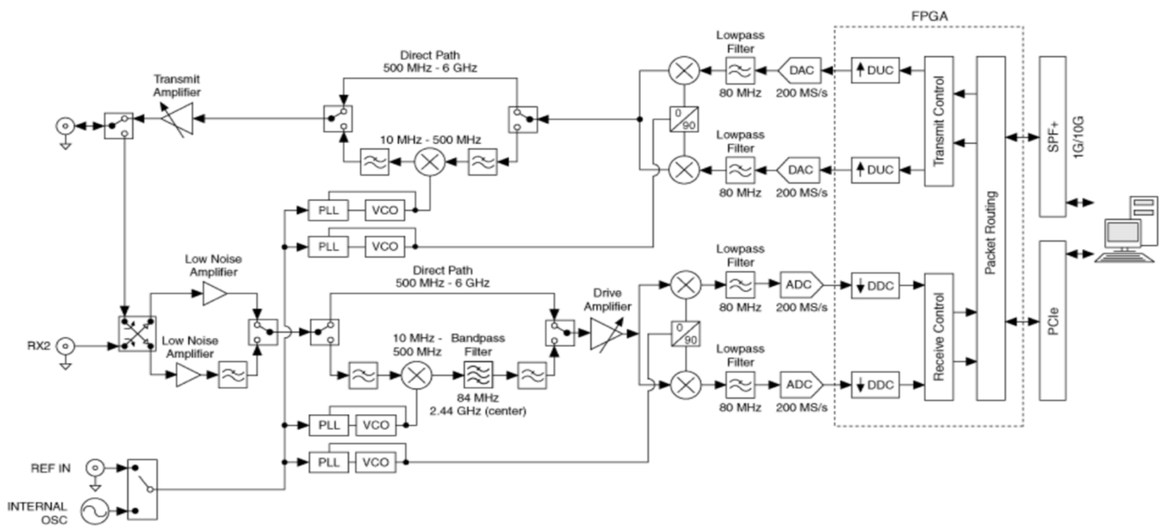
ECE 463 Lab 2: Introduction to USRP

1. Introduction

Following a common software-defined radio architecture, NI USRP hardware implements a direct conversion analog front end with high-speed analog-to-digital converters (ADCs) and digital-to-analog converters (DACs) featuring an FPGA for the digital down-conversion (DDC) and digital up-conversion (DUC). The receiver chain begins with a highly sensitive analog front end capable of receiving very small signals and digitizing them using direct down-conversion to **in-phase (I) and quadrature (Q)** baseband signals. Down-conversion is followed by high-speed analog-to-digital conversion and a DDC that reduces the sampling rate and packetizes I and Q for transmission to a host computer for further processing. The transmitter chain starts with the host computer where I and Q are generated and transferred over the PCIe to the NI USRP hardware. A DUC prepares the signals for the DAC after which I-Q mixing occurs to directly upconvert the signals to produce an RF frequency signal, which is then amplified and transmitted.



1.1. Contents

1. Introduction
2. USRP Transmitter
3. USRP Receiver

1.2. Report

Submit the answers, figures and the discussions on all the questions. The report is due at the beginning of the next lab.

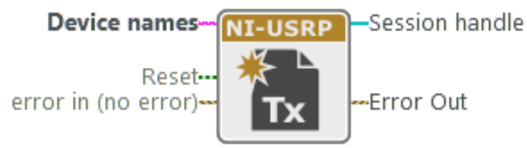
2. USRP Transmitter

2.1. Transmitter Overview

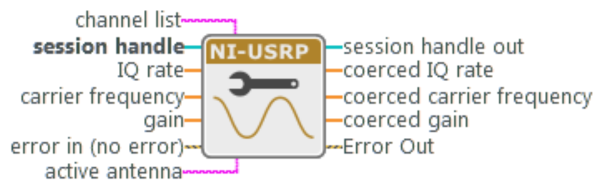
LabVIEW can interact with the USRP transmitter by the blocks under Hardware Interfaces→NI-USRP→Tx.

The diagram has the following main components:

- **Open Tx Session**: Opens a transmit (Tx) session to the device you specify in the device names input and returns session handle as output. You must add a control called “device names” that you will use to inform LabVIEW of the IP address or resource name of the USRP.



- **Configure Signal**: Configures parameters of Tx or Rx. IQ rate is the sampling rate of the baseband I/Q data in samples per second (S/s). Carrier frequency is the carrier frequency of the RF signal in Hz. Gain is the Tx gain applied to the RF signal in dB. Active antenna is the antenna port to use for this channel. Coerced IQ rate/carrier frequency/gain are the actual corresponding values supported by the device.



- **Write Tx data**: writes complex, 16-bit signed integer data to the specified channel. The baseband samples to transmit as an array of complex, 16-bit signed integer data. The real and imaginary components of the data correspond to the in-phase (I) and quadrature-phase (Q) data, respectively. I and Q are interleaved [I, Q, I, Q, ...] in the array.

- **Close Session**: Closes the session handle to the device.

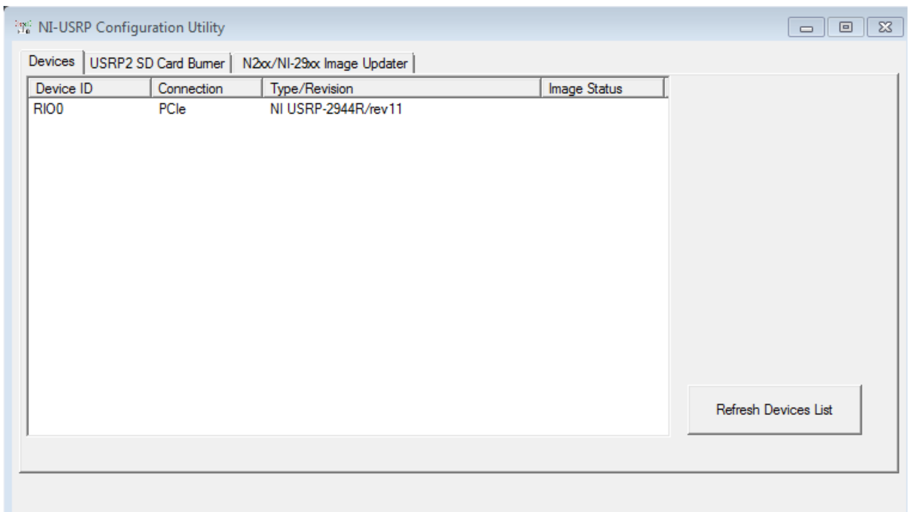
2.2. Construct the USRP Transmitter

In this section, we will simply transmit a sinusoidal signal.

1. Make sure the USRP is connected to the machine and turned on.

2. Run the NI-USRP Configuration Utility software by clicking Windows Start → National Instruments Folder → NI-USRP Configuration Utility.

3. Find the device ID and the connection type. The USRP device is not hot-pluggable over PCI express. **NOTE: The USRP SHOULD be power-on prior to your computer.**



4. Open a blank VI and rename as "carrier.gvi".

5. Place **Open Tx Session**, **Configure Signal**, **Write Tx Data**, and **Close Session**.

6. Click Open Tx Session and find "Create Constant" button in the item panel in the right side. Input your USRP device ID in the constant box.

7. Create a "cluster properties" block. In Behavior tab, set all to write.

8. Wire the session handle ports through all four USRP blocks (**Open Tx Session**→ **Cluster Properties** → **Configure Signal**→ **Write Tx Data**→ **Close Session**).

9. Click the cluster properties block and select Configuration → Enabled Channels. Left-click the port and create a constant. Input “0” for the enabled channel. This will enable “RF0” channel in the front panel of the USRP.

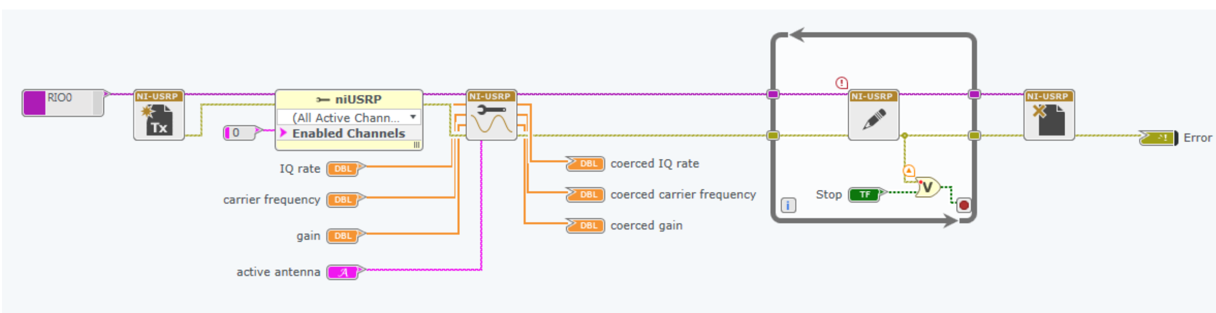
10. Create three DBL-type controls: **IQ rate**, **Carrier Frequency**, and **Gain**. Create a string-type control, **Active Antenna**. Create three DBL-type indicators: **Coerced IQ rate**, **Coerced Carrier Frequency**, and **Coerced Gain**. Connect the controls and the indicators to the corresponding ports of the **Configure Signal**.

11. Create a while loop and place the **Write Tx Data** block inside.

12. Wire the Error out ports through all four USRP blocks. Create an Error indicator and wire the Error out port of **Close Session**.

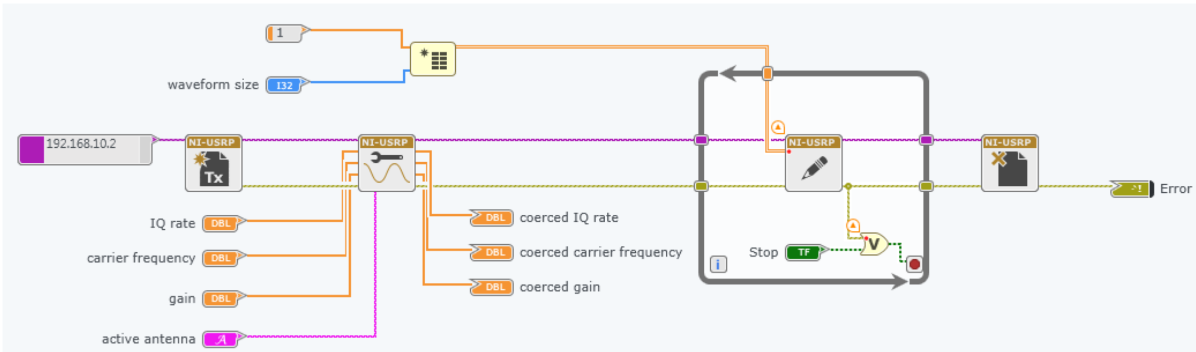
13. Create a Stop button and place it inside the loop. Use OR block to take the stop signal and the error out from the **Write Tx Data** block. Feed the output of OR block to the terminal condition.

14. **The diagram will look like the following figure**. Save the current vi and duplicate it. Rename the new vi as “tx_template.gvi”. We will re-use the vi in the next following labs, so keep it. Go back to “carrier.gvi”.



15. As described in the introduction, USRP Tx/Rx is quadrature modulation system. It mixes the in-phase (I) signal with the cosine wave (whose frequency is the “carrier frequency”) and the quadrature-phase (Q) signal with the sine wave. The **Write Tx Data** block takes the IQ baseband-samples and modulates them with the two sinusoids. Note that the input data of the **Write Tx Data** block can have various different types. We’ll use the complex double (CDB) array. Click the block and change the function configuration to **Write Tx Data** (**CDB)**. The real and imaginary parts of this complex data array correspond to the in-phase (I) and quadrature-phase (Q) data, respectively.

16. We will now generate a single sinusoid signal. To do that, we will input a constant number of array for the baseband-samples. Use “Initialize Array” block. The diagram will look like as the following figure.



17. Set the parameters as follows:
    - IQ rate = 1M
    - Carrier frequency = 2G
    - Gain = 0
    - Active antenna = TX1
    - Waveform size = 1000

18. Connect the TX1 output port to the spectrum analyzer using SMA cables and a 20dB attenuator. Verify that a right signal is generated.

19. Change the carrier frequency to 4G and verify that you see the correct frequency on the spectrum analyzer.

2.3. Transmitting Sinusoidal Signal

We will now generate a sinusoidal signal with a frequency offset around the carrier frequency. Instead of the constant value for the waveform, we will feed a cosine waveform to in-phase data and a sine waveform to quadrature-phase data.

1. Duplicate the VI and rename as "upper-side_IQ.gvi". Remove the Initialize Array, its numeric constant and the wire to the **Write Tx Data.**

2. Create two more double-type controls: Tone frequency and Tone amplitude.

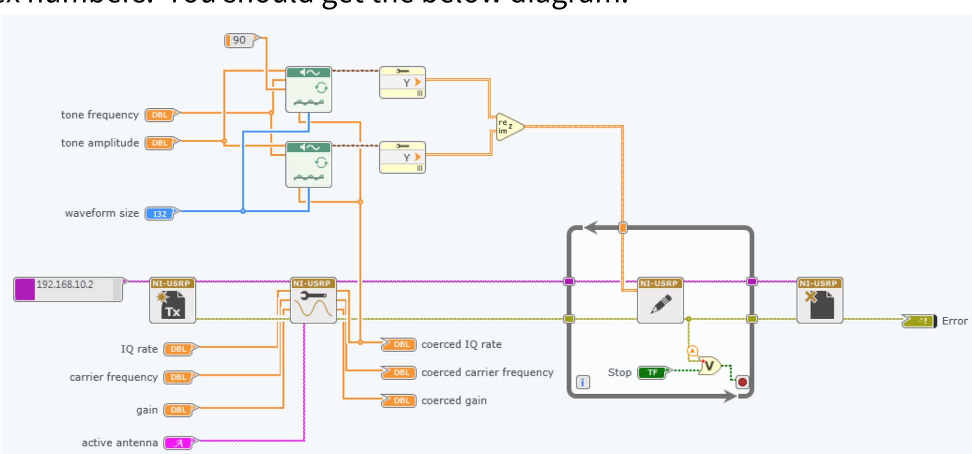
3. Place two "Wave Generator" blocks from Analysis→Signal Processing→Generation. By default, the block is "Sine" wave and "Waveform" data type.

4. Wire the Tone frequency control to the Frequency port of the two Wave Generator blocks and the Tone amplitude control to the Amplitude port. Wire the Waveform size control to the Samples port. Wire the Sample rate port to the Coerced IQ rate indicator.

5. Create a numeric constant of "90" and wire it to the "Phase in" port of one of the Wave Generator blocks. The 90-degree phase-offset will generate a cosine wave. By default, the phase-offset is 0 for sine wave.

6. Use "Waveform Properties" to get the cosine and sine samples from the Wave Generator blocks.

7. Use "Real and Imaginary to Complex" to receive the cosine and sine samples and convert them to complex numbers. You should get the below diagram.



8. Set the parameters as follows:
    - IQ rate = 1M
    - Carrier frequency = 2G
    - Gain = 0
    - Active antenna = TX1
    - Waveform size = 1000
    - Tone frequency = 1k
    - Tone amplitude = 1

9. Connect the TX1 output port to the spectrum analyzer using SMA cables and a 20dB attenuator. Verify that a right signal is generated.

10. Change the tone frequency to 100k and verify that the correct tone appears on the spectrum analyzer.

Assignment 1 [20 points]

1. (5 points) Compare the results from "carrier.gvi" and "upper-side_IQ.gvi". Include the spectrum of 2GHz carrier frequency and 100kHz tone frequency.

2. (5 points) For 2GHz carrier frequency and 100kHz tone frequency, change the waveform size to **1005** and measure the spectrum. Include the spectrum in the report. Explain the result.
   Hint: How many periods given the IQ rates and waveform size? Is the period an integer?

3. (5 points) Create "lower-side_IQ.gvi" which implements a similar code to "upper-side_IQ.gvi" but **the main tone is located lower than the carrier frequency tone.** Highlight the block diagrams.
   Hint: $e^{j2\pi f_{tone}t} = cos\,(2\pi f_{tone}t) + jsin\,(2\pi f_{tone}t)$*. How about the negative tone frequency?*

4. (5 points) Create "double-side_IQ.gvi" which implements a similar code to "upper-side_IQ.gvi" but with **two tones that are located on both the upper and lower side of the carrier frequency tone**. Highlight the block diagrams.