!The numbering of these chapters corresponds to the ones in the .ppt presentation. E.g. " 1. Console Messaging Point to Point (wireless) – GNU Radio Example" has the same number here as in the .ppt presentation.

! Most of the commands that are required to be run in the terminal are also within terminal_commands.txt file from Desktop.

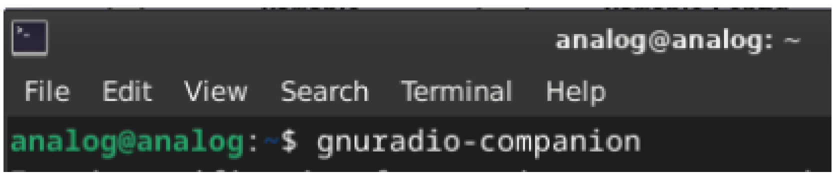
1. Console Messaging Point to Point (wireless) – GNU Radio Example

1.1. For this example, connect only one antenna to the RX1 of Pluto SDR as shown below. Wait for the presenters to start the transmission of the message before starting the flowgraph to run.

Open the Terminal by pressing "Ctrl + Alt + T"

$ gnuradio-companion

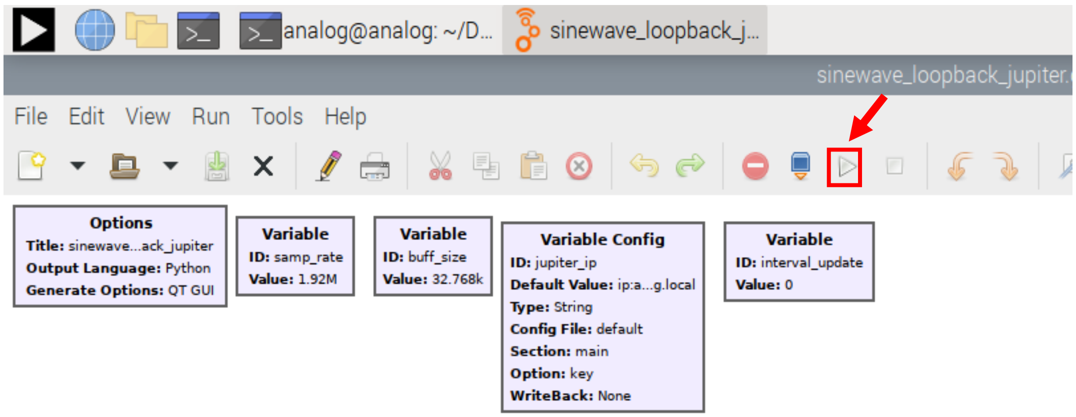
Press enter



1.2. In GNU Radio companion app, open from File -> Open "console_message_receiver_pluto.grc" from:

"/home/analog/Desktop/ftc_2025/1_console_message_point_to_point_gnuradio/receiver_pluto"

1.3. To run the flowgraph by pressing the arrow from the top bar inside the app as depicted below.

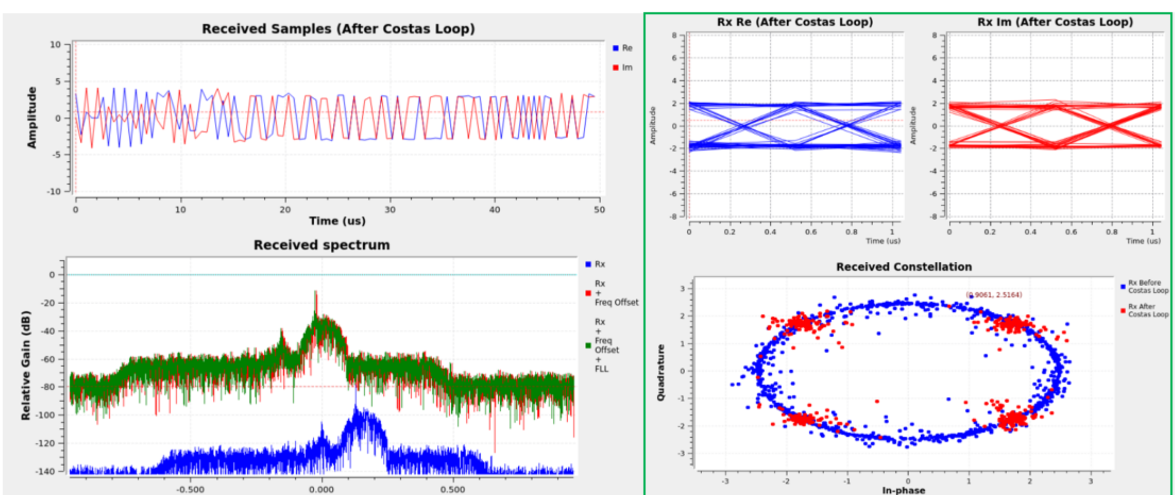


Observe the received message in the 'msg_rx' section:

'msg_rx': 'ANALOG DEVICES INC FTC2025'

Observe that in this example, because the data is sent in bursts, the constellation is more noisy because the digital loops don't have very much time to lock.

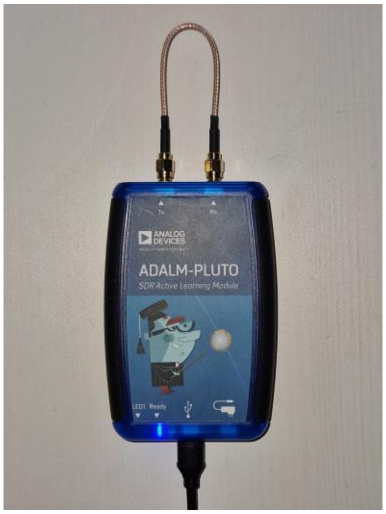
You will explore in the next examples some of the theory behind these GNU Radio blocks and how they work.



The Symbols are Noisier because the data is sent in bursts (not continuously)

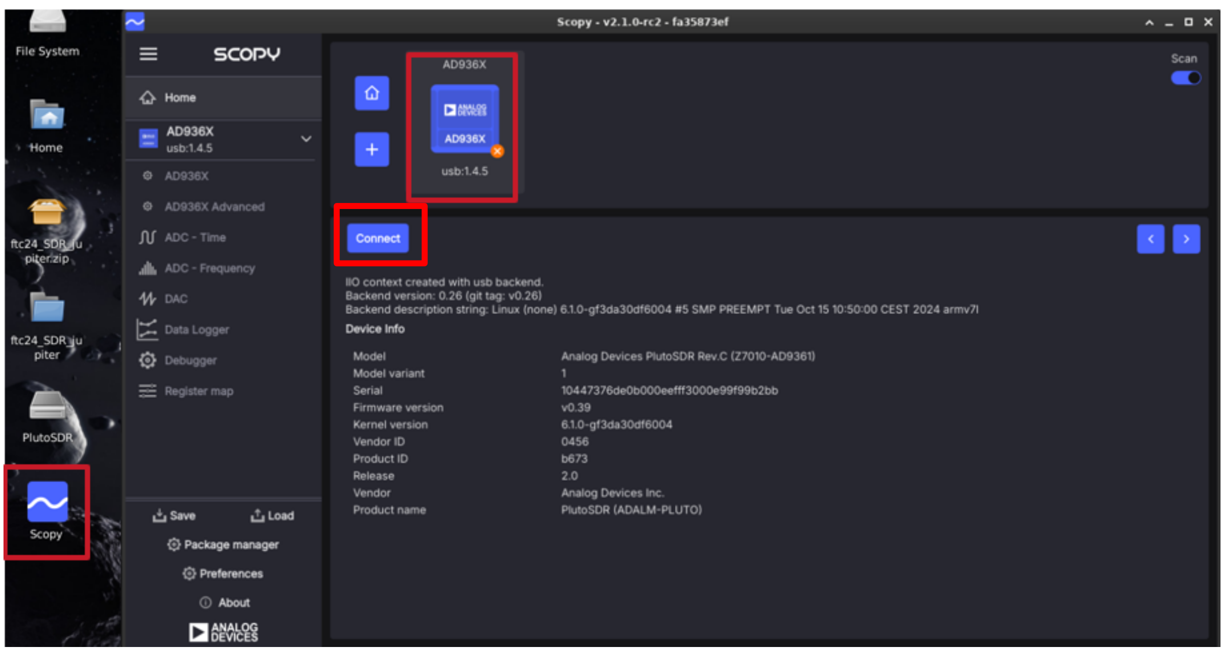
2.3. Sinewave Loopback – Scopy Example

Connect Rx and Tx using the SMA cable from the kit by making a loopback connection (as shown below).



2.3.1. Double click the Scopy icon on the Desktop to open the application.

2.3.2. Click on the Auto detected USB device “AD936x”, then click Connect.



2.3.3. Click on the “**AD936X” instrument** on the left side bar. (1) – as shown in the image below

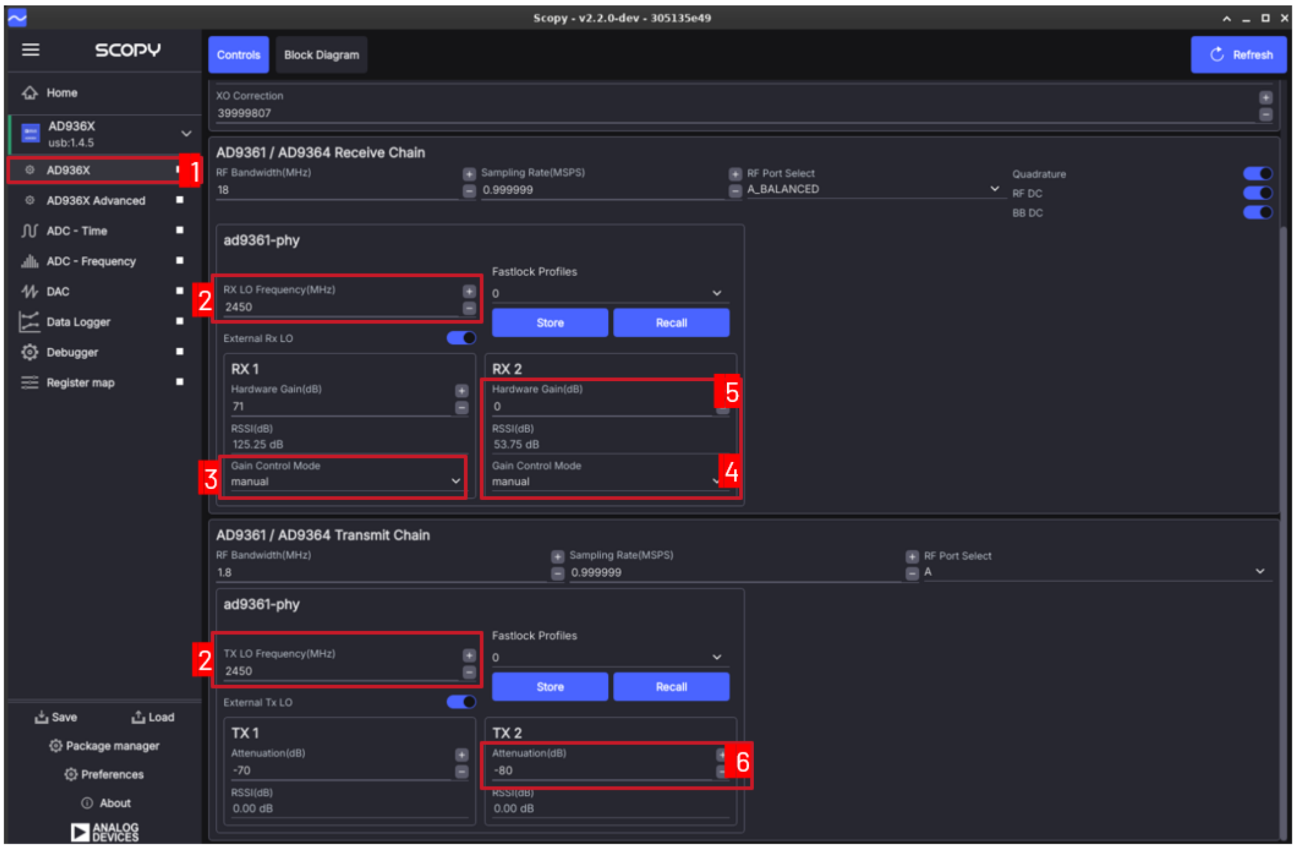
2.3.4. Change both the RX LO Frequency and TX LO Frequency to **2450** MHz. (2)

2.3.5. Change RX1 gain control mode to manual. (3)

2.3.6. Set the RX2 **gain control mode** to **manual** (Only if you have revC Pluto, on revB Tx2 and Rx2 are not exposed). (4)

2.3.7. Set the **RX2** gain to **0** dB (Only if you have revC Pluto, on revB Tx2 and Rx2 are not exposed). (5)

2.3.8. Set the **TX2** gain to **-80** dB (Only if you have revC Pluto, on revB Tx2 and Rx2 are not exposed). (6)



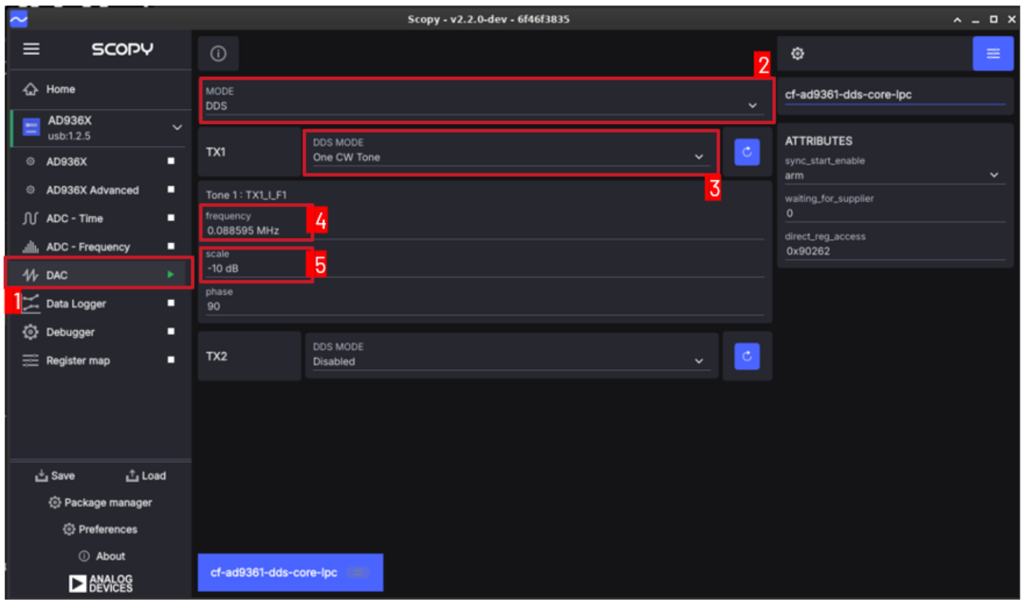
2.3.9. Click on the **DAC instrument** on the left side bar (1).

2.3.10. Change mode to **DDS**. (2)

2.3.11. Change DDS_MODE to **One CW Tone**. (3)

2.3.12. Change the Frequency to **0.089 MHz** (89 kHz). (4)

2.3.13. Change the Scale to **–10** dB. (5)



2.3.14. Click on the “**ADC Frequency” Instrument** in the left side bar. (1)

2.3.15. Click on the “**Complex”** button on the bottom left. (2)

2.3.16. Using **(+)** change the **FFT Size to 65536 samples** in the right side menu. (3)

2.3.17. Change the Window to **No Window** in the right side menu. (4)

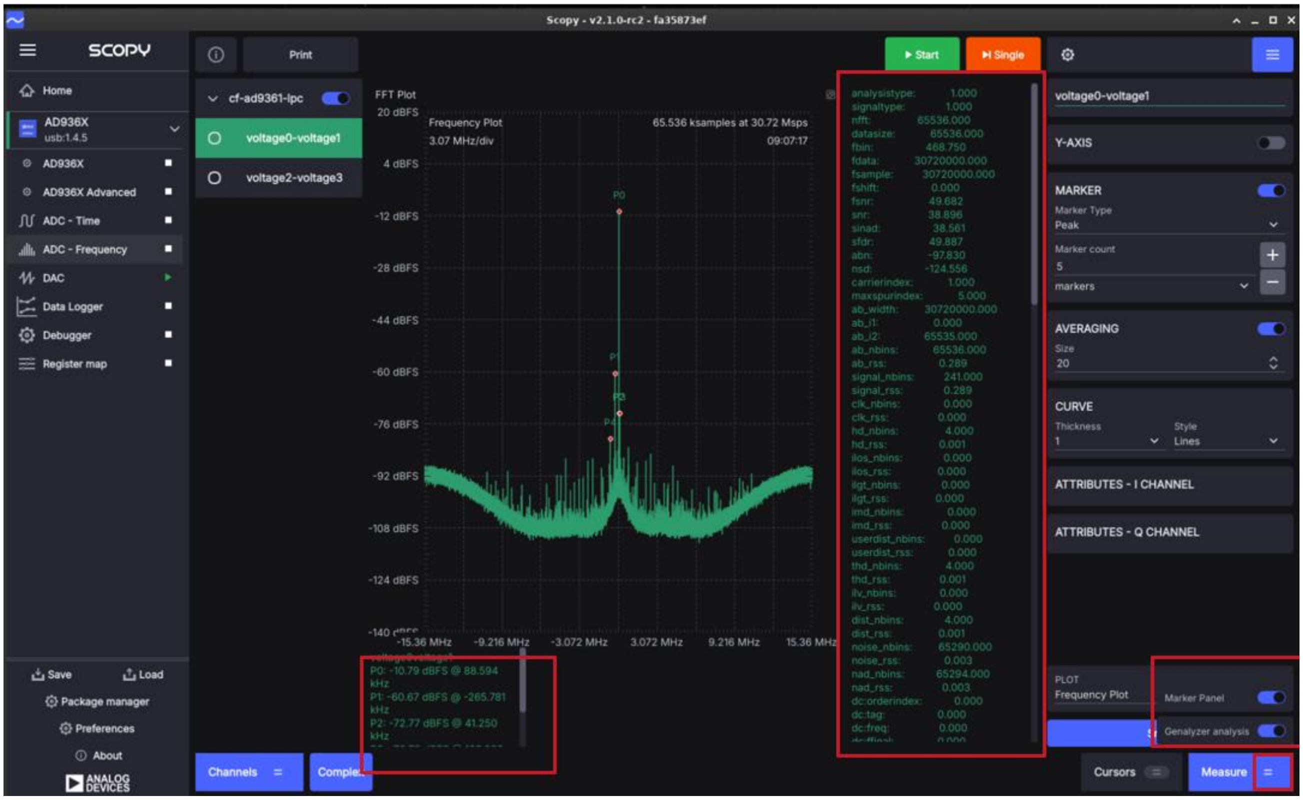
2.3.18. Click on the circle left to **voltage2-voltage3** to disable the channel (Only if you have revC Pluto, on revB Tx2 and Rx2 are not exposed). (5)

2.3.19. Click on the **voltage0-voltage1** channel to open the Settings and enable the **MARKER panel** from the right side menu.

2.3.20. Enable the **AVERAGING** panel and set to **20** in the right side menu.

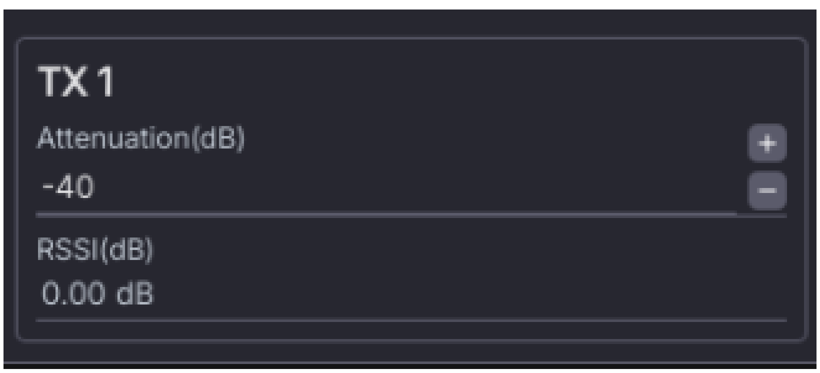
2.3.21. Click **Run** and observe the Plot.

2.3.22. Click the button on the right side of the bottom right **Measure** and enable both **Genalyzer analysis** and **Marker panel**.



2.3.23. Click the "**AD936X**" instrument on the left side bar,

Scroll down and change the **TX Attenuation** and observe the plot on "**ADC – Frequency**". **The range is [0, -89.5]**



2.3.24. Go back to the "ADC-Frequency" instrument and observe the plot.

2.3.25. When done, STOP 

the instrument (press the orange stop button) and close Scopy.

2.3.26. Reboot Pluto by removing and plugging back in the uUSB connector.

2.4. Sinewave Loopback – GNU Radio Example

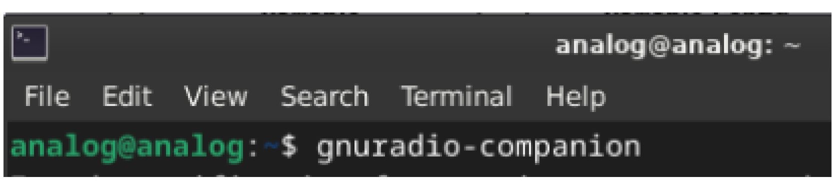
2.4.1. Connect Rx and Tx using the SMA cable from the kit by making a loopback connection (as shown below).

2.4.2. Open GNU Radio companion app, run the following commands:

Open the Terminal by pressing "Ctrl + Alt + T"

$ gnuradio-companion

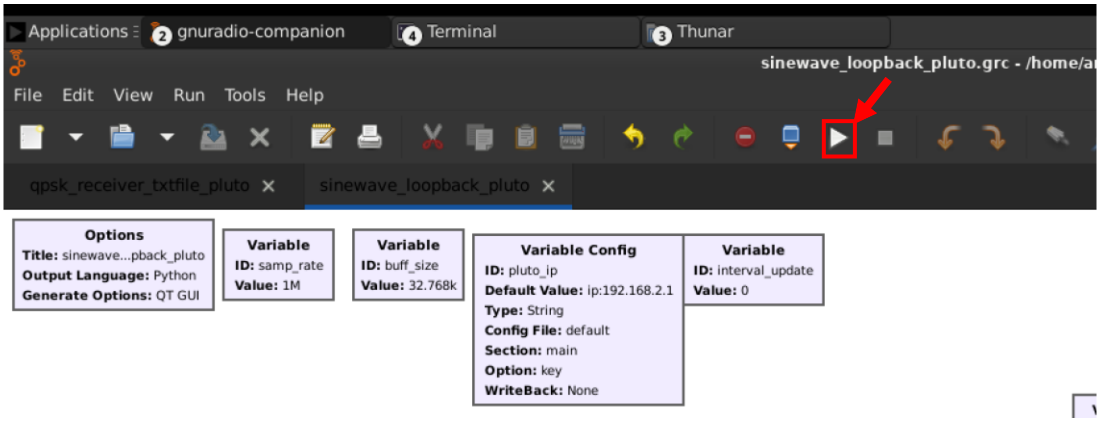
Press enter



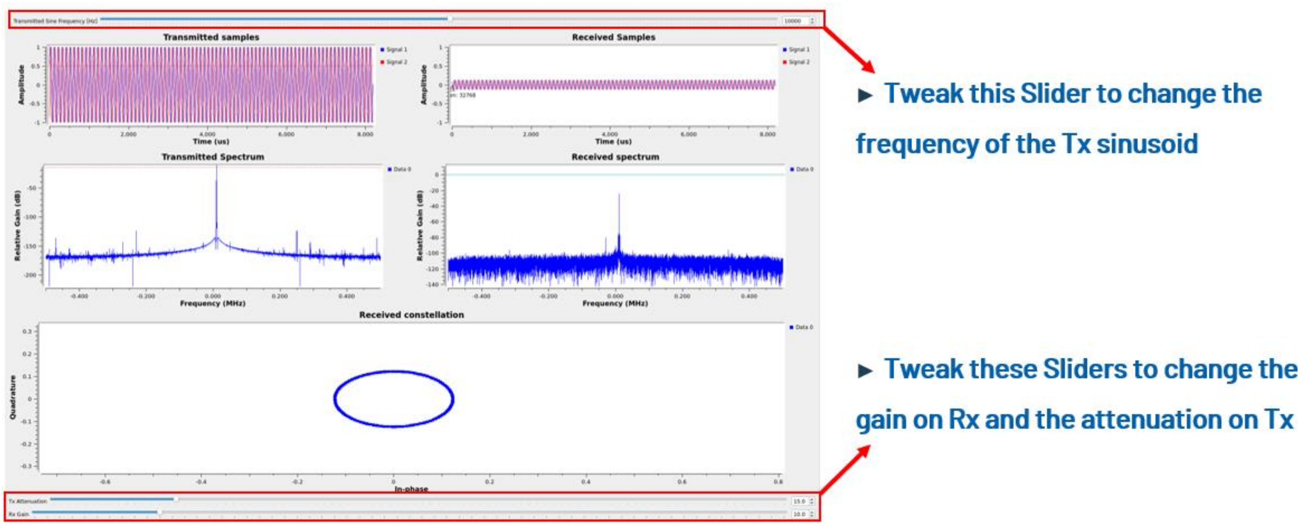
2.4.3. Within GNU Radio companion app, open the following ".grc" flowgraph from "File" -> "Open":

/home/analog/Desktop/ftc_2025/2_sinewave_loopback_gnuradio/sinewave_loopback_pluto.grc

2.4.4. To run the flowgraph press the arrow from the top bar inside the app as depicted below.



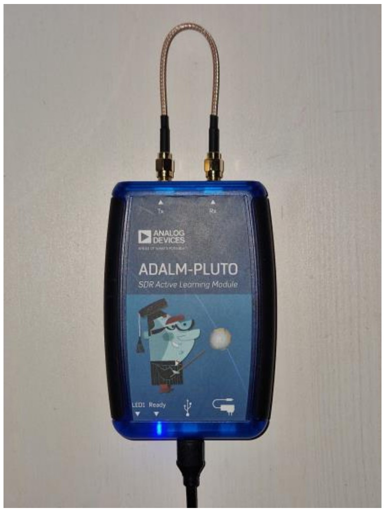
2.4.5. After you run the flowgraph, you can tweak the sliders to modify the frequency of the sinewave transmitted, the gain on RX path and the attenuation on TX path.



2.4.5. Close the running flowgraph

2.5. Sinewave Loopback – PyADI-IIO Example

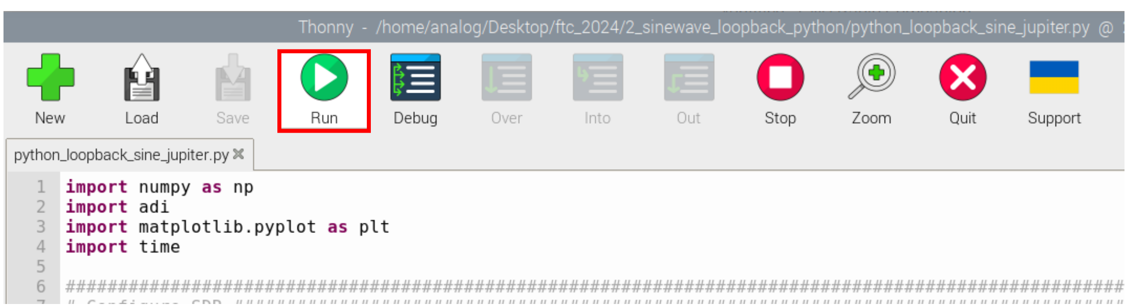
2.5.1. Connect Rx and Tx using the SMA cable from the kit by making a loopback connection (as shown below).



2.5.2. On, your Desktop, open "ftc_2025" folder and then open "3_sinewave_loopback_python" folder. In this folder, right click on "python_loopback_sine_pluto.py" and click on Open with "Thonny".

Thonny is an IDE that can be used to edit and run python code.

2.5.3. To run the "python_loopback_sine_pluto.py" python script, click on the run button.



3.2. How to debug and tweak IIO attributes. Example for Rx Gain

3.2.1 Open "iio_explore_pyadi.py" file using "Thonny" IDE from: "/home/analog/Desktop/ftc_2025/iio_context_exercises"

3.2.2 To run the python script, click on the Run button and observe the output.

Close Thonny to get to the next exercise.

3.2.3 Now let's use the IIO_ATTR util instead.

Open the Terminal by pressing "Ctrl + Alt + T"

$ iio_attr -u ip:pluto.local -c -i ad9361-phy 'voltage0' hardwaregain

Press enter

```
analog@analog:~/Desktop$ iio_attr -u ip:pluto.local -i -c ad9361-phy voltage0 hardwaregain
10.000000 dB
```

You will see the previously set value.

3.2.4 Now let's set it to 5 dB.

Go back to the terminal and run:

$ iio_attr -u ip:pluto.local -c -i ad9361-phy 'voltage0' hardwaregain 5

```
analog@analog:~/Desktop$ iio_attr -u ip:pluto.local -i -c ad9361-phy voltage0 hardwaregain 5
5.000000 dB
```

You are going to see an automatic readback for the new value.

3.2.5 Let's do the same using the Scopy Debugger instrument.

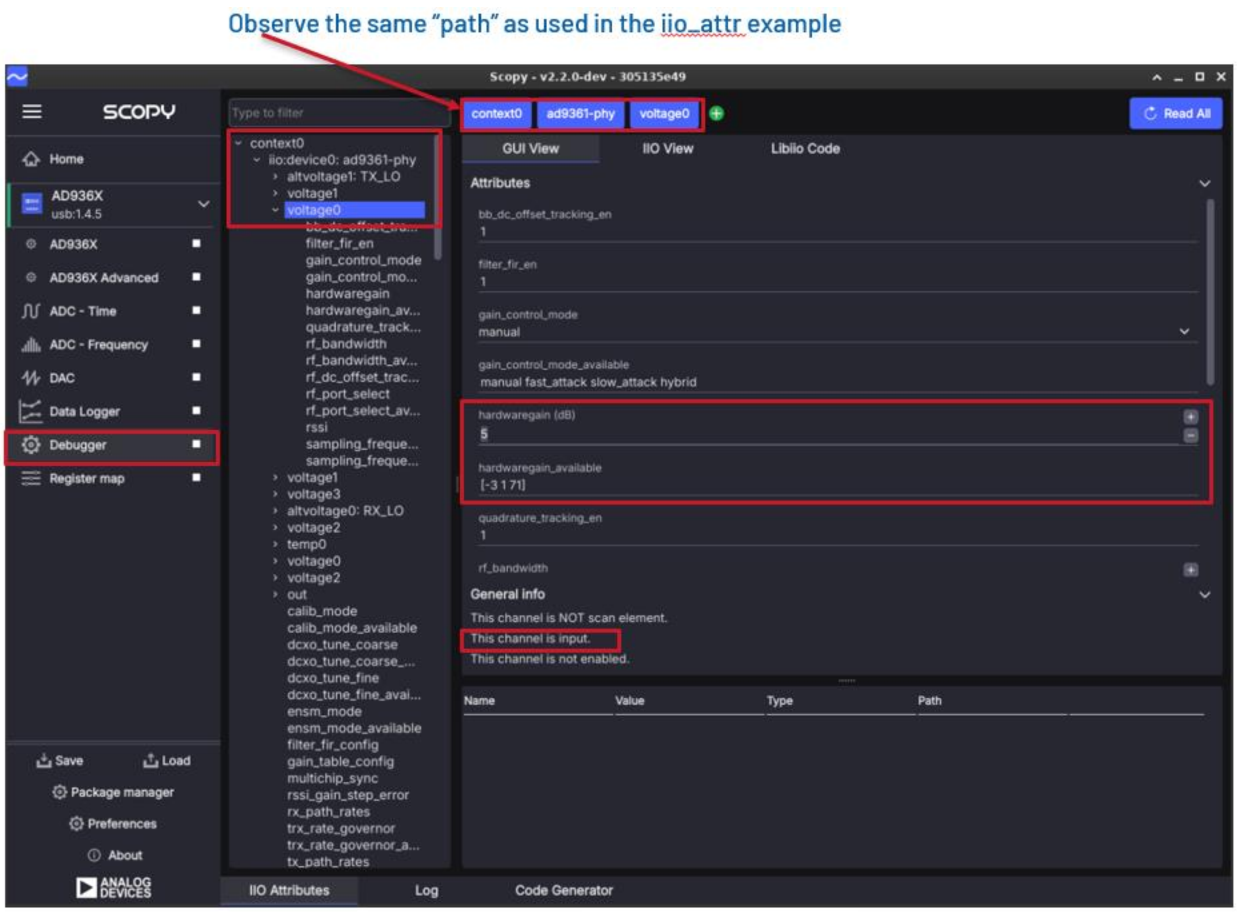
Start Scopy as described in the previous example 2.3. Sinewave Loopback – Scopy Example.

3.2.6 Click on the Debugger instrument on the left sidebar.

3.2.7 Expand the objects as seen in the screenshot below:

context0 → iio:device0:ad9361-phy →voltage0

3.2.8 Observe the value we set in the previous exercise for hardwaregain.



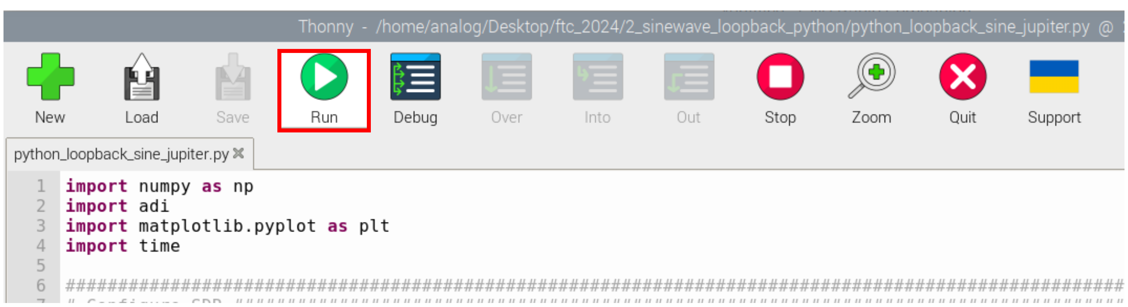
3.2.9 Stop Scopy when done. Reset any Pluto configuration by unplugging and plugging the USB Connector.

4. BPSK Loopback – PyADI-IIO Example

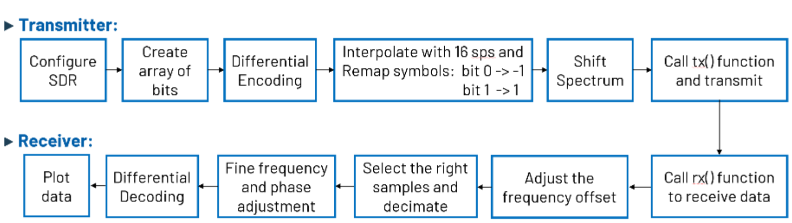
4.1. For this example, connect Rx and Tx using the SMA cable from the kit use it to make a loopback between RX1 and TX1 as shown below.

4.2. On, your desktop, open "ftc_2025" folder and then open "4_bpsk_loopback_python" folder. Here right click on "bpsk_loopback_pluto.py" and click on Open with "Thonny". Thonny is an IDE that can be used to edit and run python code.

4.3. To run the "bpsk_loopback_pluto.py" python script, click on the run button.



4.4. Observe how the data looks after each section of code, which corresponds to a block from the diagram below:



5. QPSK Loopback – GNU Radio Example

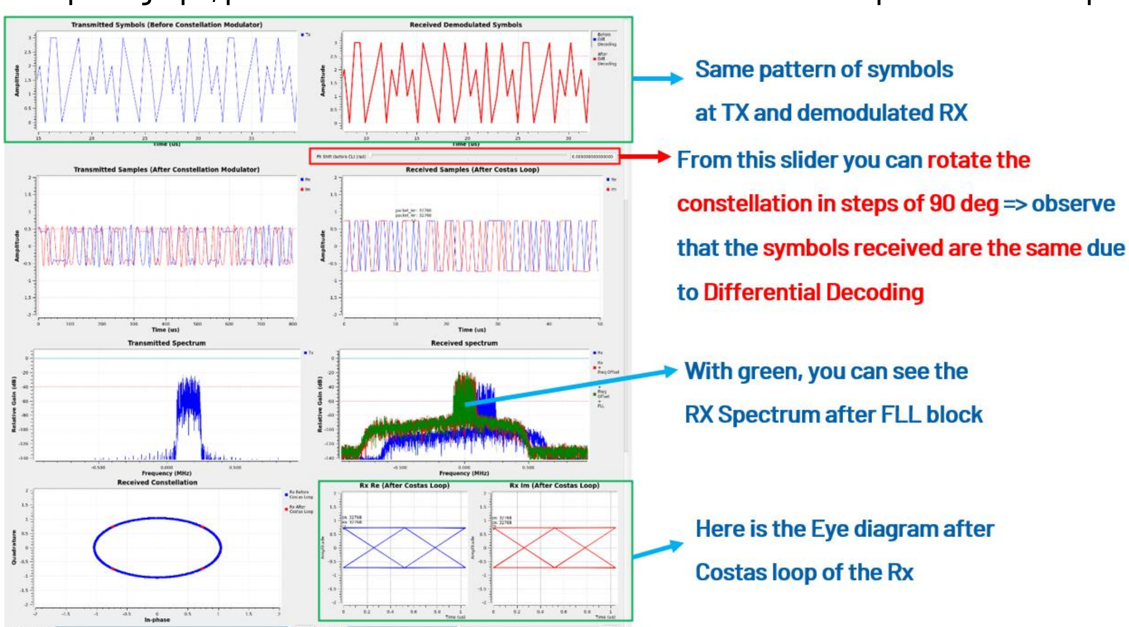
5.1. For this example, connect Rx and Tx using the SMA cable from the kit use it to make a loopback between RX1 and TX1 as shown below.

5.2. In GNU Radio companion app, open from File -> Open:

/home/analog/Desktop/ftc_2025/5_qpsk_loopback_gnuradio/qpsk_loopback_pluto.grc

5.3. Run the flowgraph and observe that the pattern of symbols received is the same as the one transmitted

To stop the graph, press the middle scroll on the mouse and select stop on the desired plot.



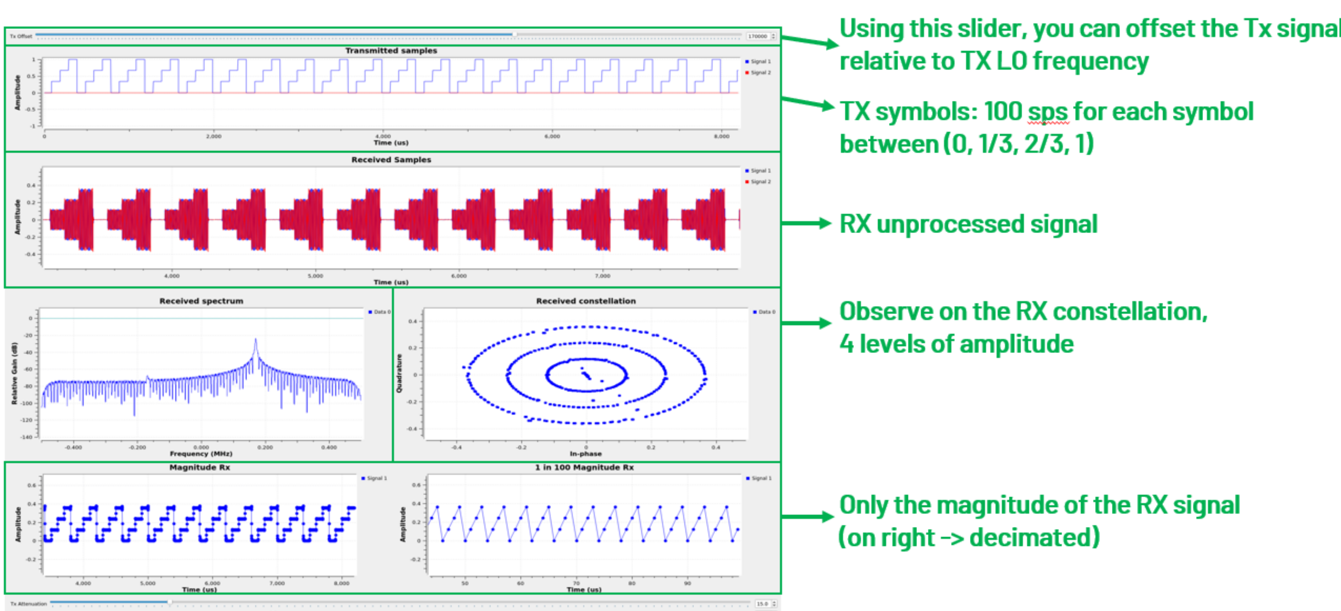
6. Amplitude Shift Keying Modulation – GNU Radio Example

6.1. For this example, connect Rx and Tx using the SMA cable from the kit use it to make a loopback between RX1 and TX1 as shown below.

6.2. In GNU Radio companion app, open from File -> Open, "ASK_loopback_pluto.grc" from:

"/home/analog/Desktop/ftc_2025/6_ask_loopback_gnuradio"

6.3. Run the flowgraph and observe the four different amplitudes of the received signal corresponding to the four symbol transmitted:



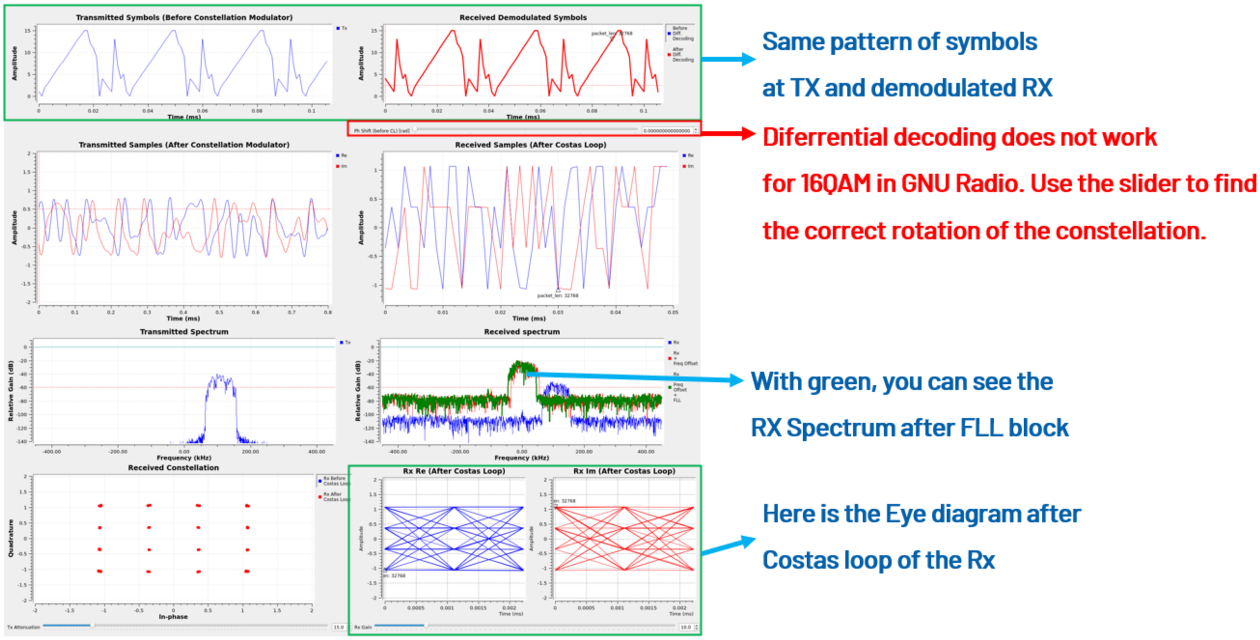
7. Digital QAM Modulation 16QAM Loopback with EVM Measurements – GNU Radio Example

7.1. For this example, connect Rx and Tx using the SMA cable from the kit use it to make a loopback between RX1 and TX1 as shown below.

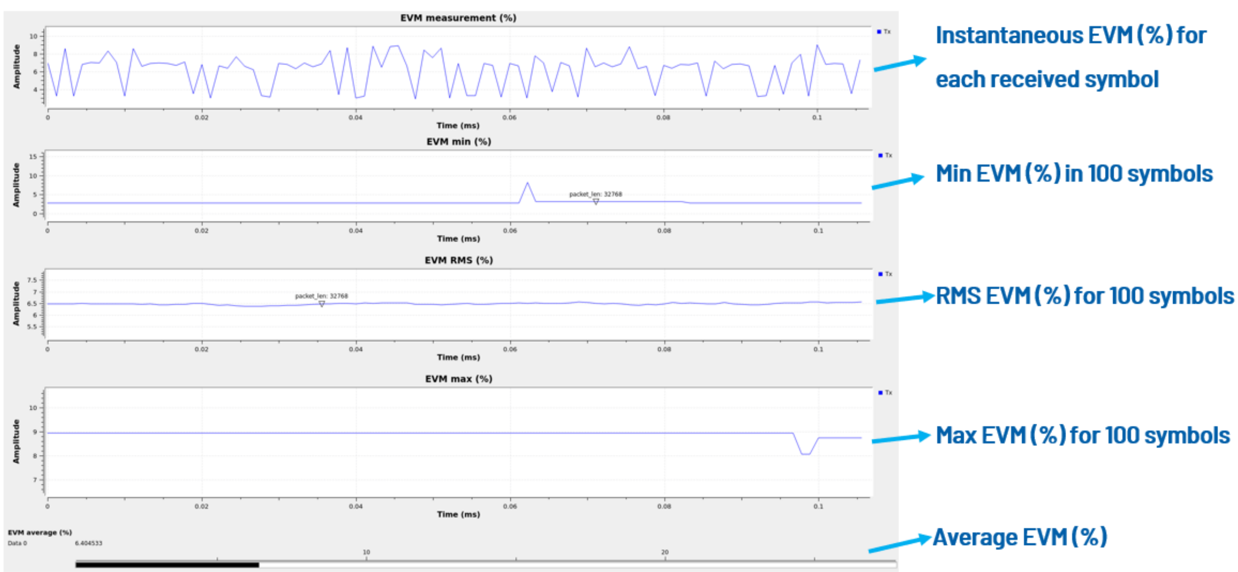
7.2. In GNU Radio companion app, open from File -> Open, "16QAM_loopback_pluto.grc" from:

"/home/analog/Desktop/ftc_2025/7_16QAM_loopback_gnuradio"

7.3. Run the flowgraph and observe that now there are symbols in the constellation with the same phase but different magnitude. For this example, the differential encoding and decoding blocks within gnuradio does not work for 16QAM and you have to rotate manually the constellation using the slider under "Received Demodulated Symbols" plot (multiples of 90 degrees) until the "Received Demodulated Symbols" pattern is the same as the transmitted pattern:



7.4. Scroll down in the window with running graphs and observe the EVM measurements for Tx + Rx chain. Min, Max and RMS EVM are implemented in separate "Python blocks" to make calculations on 100 symbols at a time.



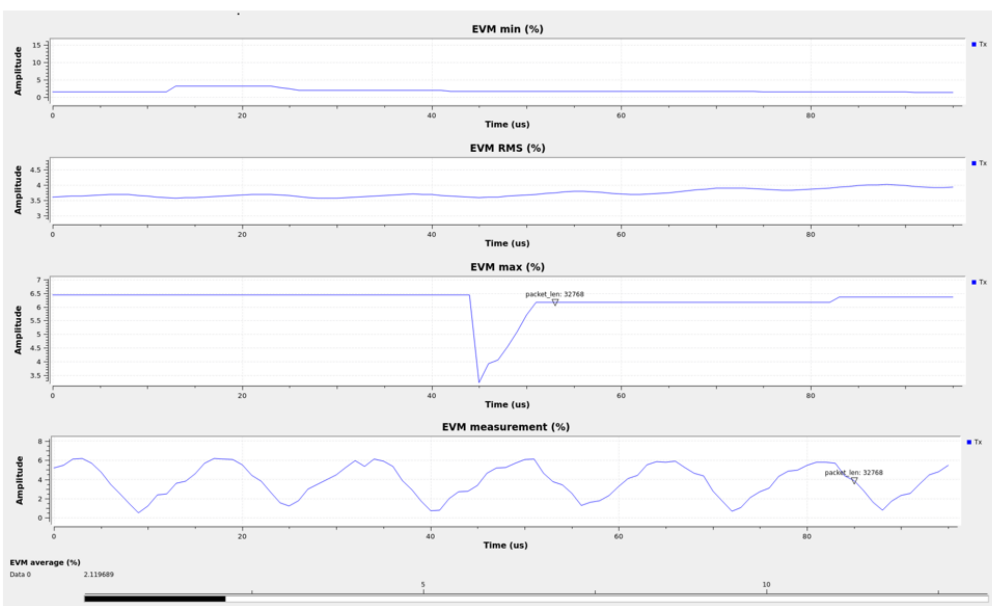
8. Text File Messaging Point to Point (Wireless) – GNU Radio Example

8.1. For this example, connect only one antenna to the RX1 of Jupiter as shown below. Wait for the presenters to start the transmission before running the flowgraph.

8.2. In GNU Radio companion app, open from File -> Open “qpsk_receiver_txtfile_pluto.grc”:

/home/analog/Desktop/ftc_2025/8_qpsk_point_to_point_txtfile_gnuradio/receiver_pluto

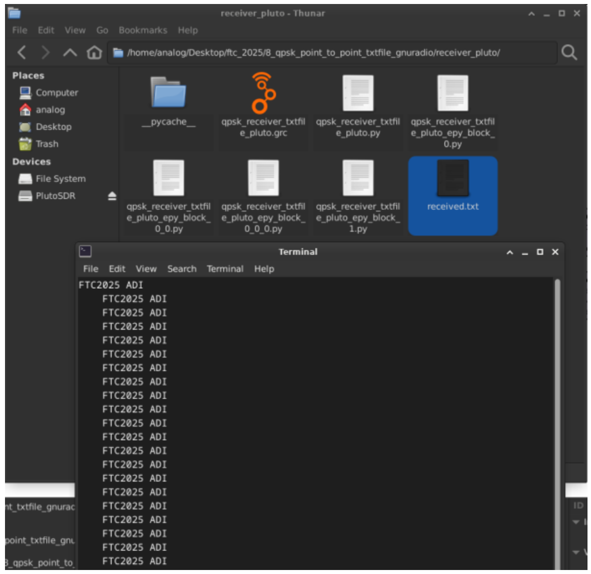
8.3. Run the example and observe the EVM measurements for wireless QPSK transmission.



After you analyzed the running plots, stop the running flowgraph and open "receive.txt" file from:

"/home/analog/Desktop/ftc_2025/8_qpsk_point_to_point_txtfile_gnuradio/receiver_pluto"

You should see inside there are multiple instances of the received message. You can delete that file and run again the flowgraph.



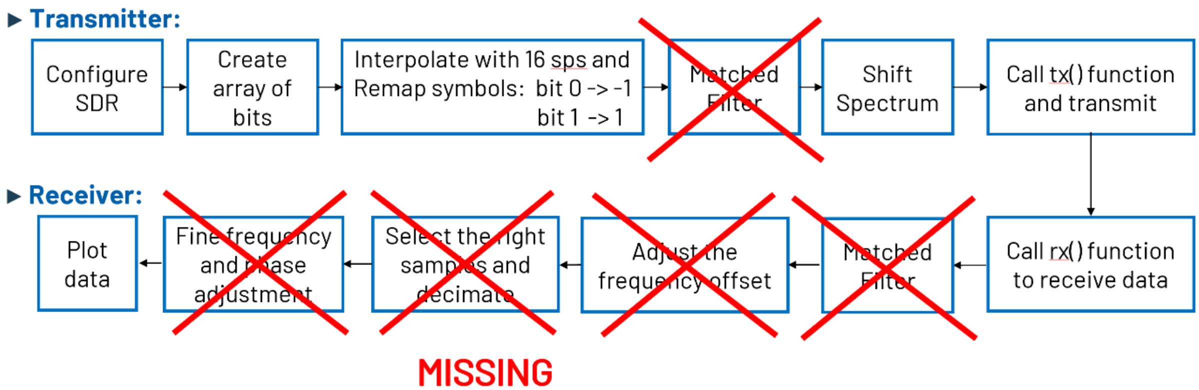
9. Enabling 2nd Tx and Rx Channels of Pluto SDR – PyADI-IIO

9.1 . This example is worth doing if you modded your Pluto SDR and added loopbacks not only between Tx1 and Rx1 but on Tx2 and Rx2 too. In this workshop we don't have modded Pluto SDRs for each of you but you can download the workshop at home, mod your Pluto and try this example.

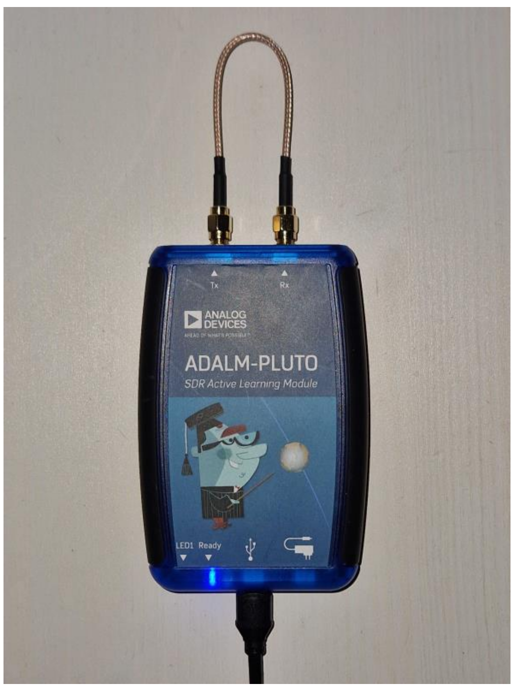
9.2. You can find the example in /home/analog/Desktop/ftc_2025/9_sinewave_loopback_python_2rx_2tx/python_loopback_sine_pluto_2rx_2tx.py and run it with "Thonny" IDE.

10. QPSK without additional digital processing – GNU Radio

In the following examples you will see why so many DSP blocks are required fore receiving digital signals modulated with phase shift keying. All the DSP blocks required for synchronizing the received signal were removed and one at a time will be added back in the following examples.



10.1. For this example, connect Rx and Tx using the SMA cable from the kit use it to make a loopback between RX1 and TX1 as shown below.

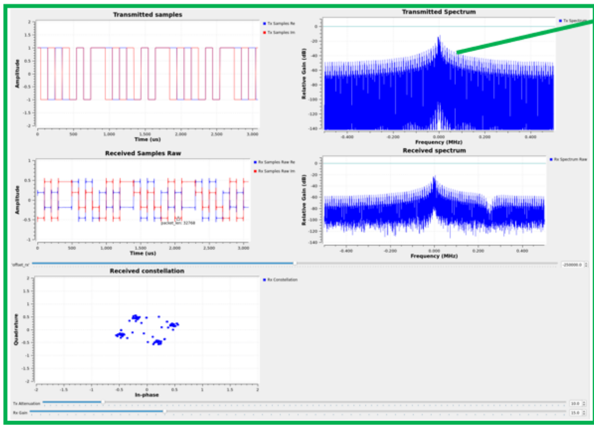


10.2. In GNU Radio companion app, open from File -> Open "QPSK_raw_loopback_pluto.grc" flowgraph from:

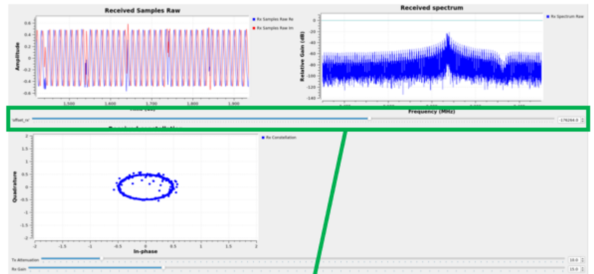
"/home/analog/Desktop/ftc_2025/10_qpsk_raw_loopback_gnuradio"

10.3. Run the flowgraph and observe the following:

10. QPSK without additional digital processing – GNU Radio



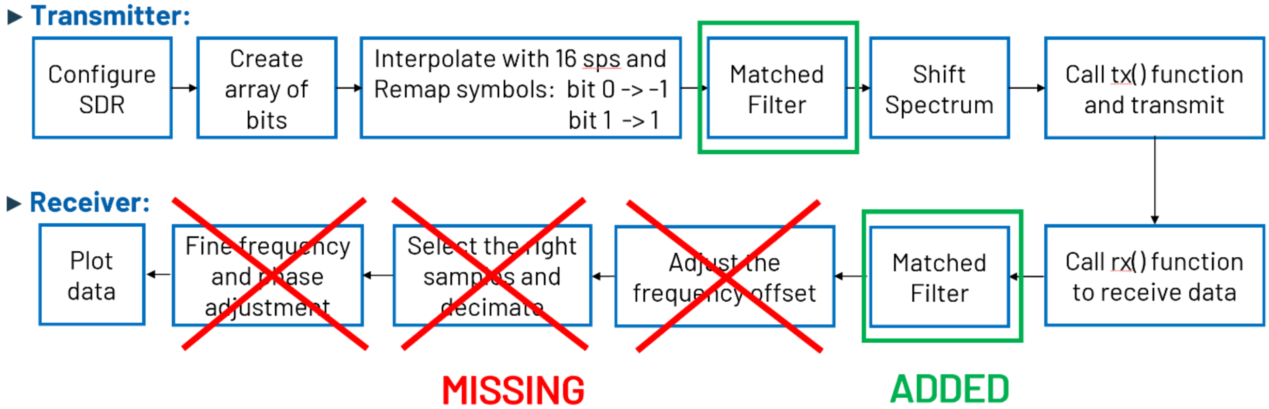
The spectrum is inefficiently used
(spectrum of square wave)



No frequency offset because the example works on loopback and the LO is the same for RX and TX but has a phase offset between the two paths.

Try tweaking the frequency offset between TX and RX and see how the data looks -> this happens when we transmit and receive between two different devices.

11. QPSK – Constellation Modulator in GNU Radio

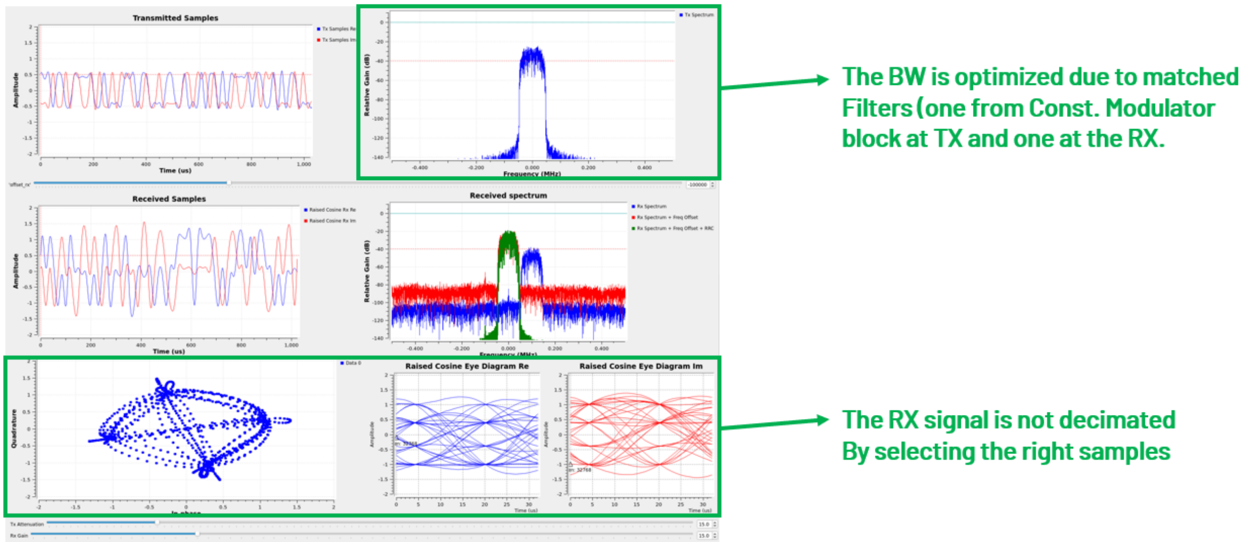


11.1. Connect Rx and Tx using the SMA cable from the kit by making a loopback between RX1 and TX1.

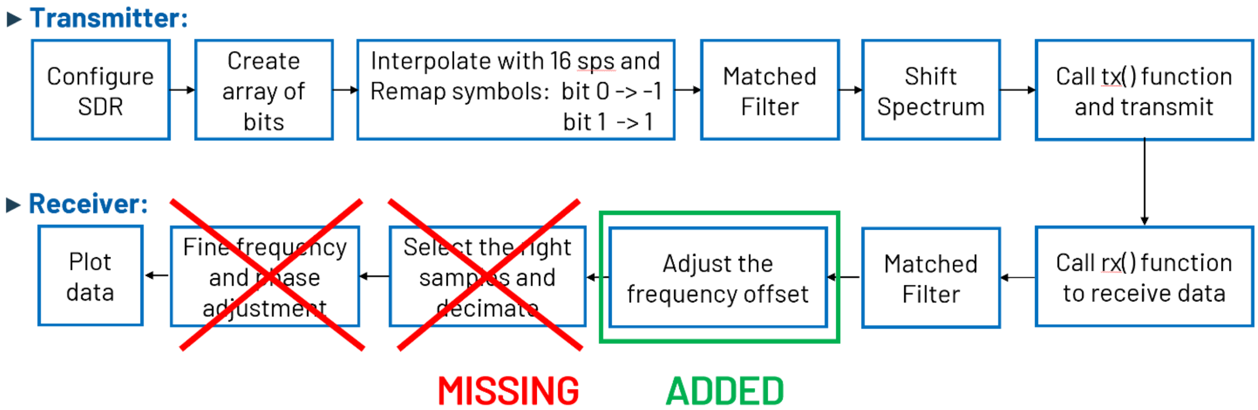
11.2. In GNU Radio companion app, open from File -> Open "constellation_modulator_loopback_pluto.grc" flowgraph from:

"/home/analog/Desktop/ftc_2025/11_constellation_modulator_loopback_gnuradio"

11.3. Run the flowgraph and observe that the spectrum used is now optimized by adding matched filters at TX and RX.



12. QPSK – Frequency Locked Loop in GNU Radio

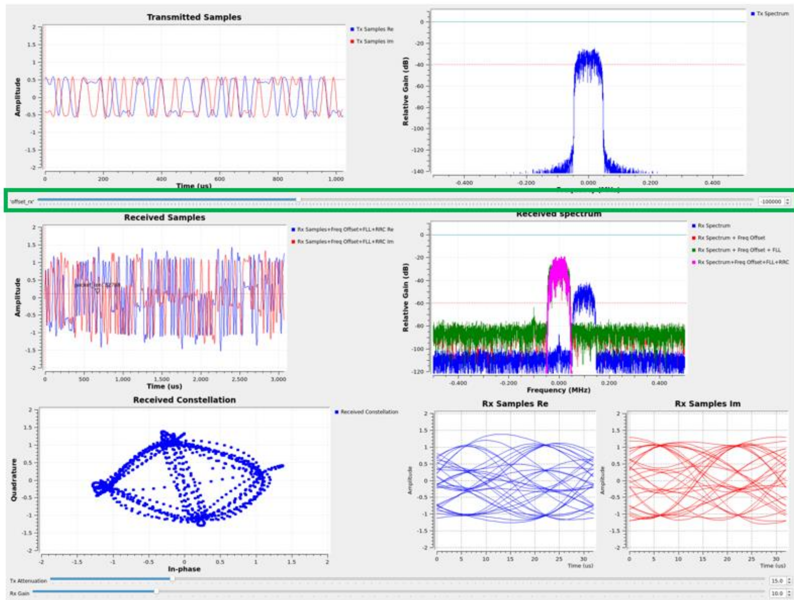


12.1. Connect Rx and Tx using the SMA cable from the kit by making a loopback between RX1 and TX1.

12.2. In GNU Radio companion app, open from File -> Open, "FLL_loopback_pluto.grc" from:

"/home/analog/Desktop/ftc_2025/12_fll_loopback_gnuradio"

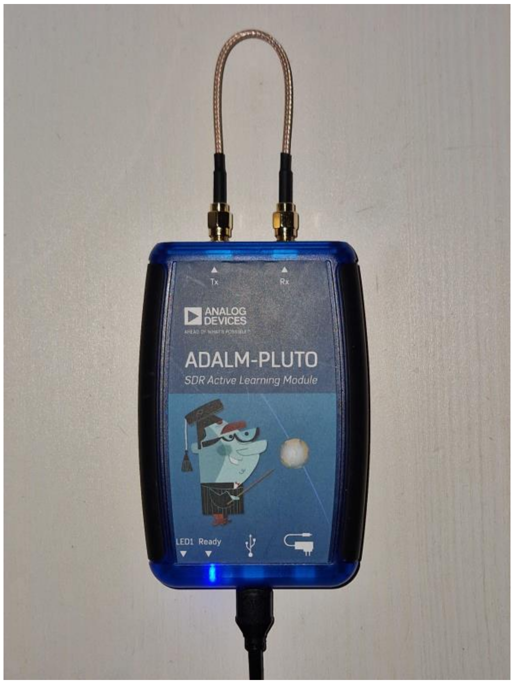
12.3. Run the flowgraph and observe how the spectrum after FLL block stays centered around DC at RX when you tweak the frequency offset slider:



Use this slider to tweak the frequency offset between TX and RX.
Observe how the spectrum after FLL block stays centered around DC.
A more precise frequency offset Correction still needs to be applied

13. QPSK – Symbol Sync in GNU Radio

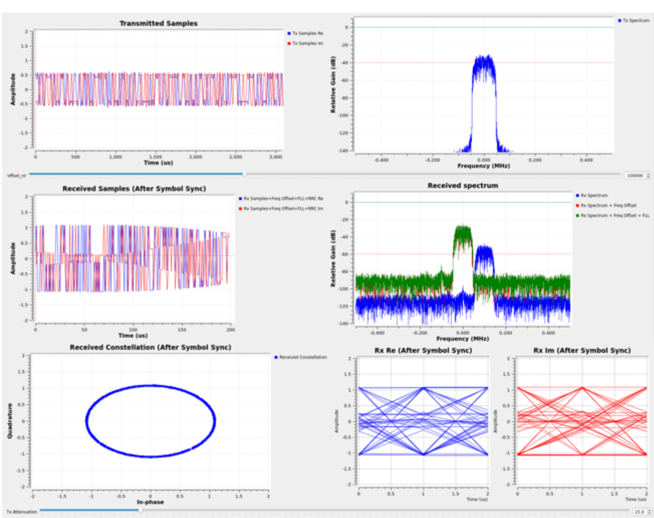
13.1. Connect Rx and Tx using the SMA cable from the kit by making a loopback between RX1 and TX1.

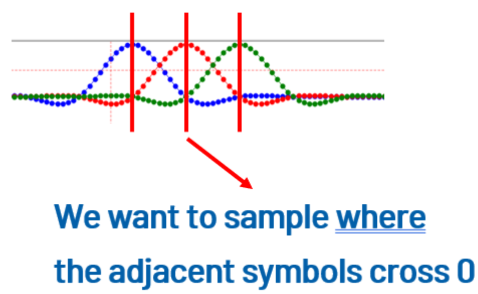


13.2. In GNU Radio companion app, open from File -> Open “symbol_sync_loopback_pluto.grc” flowgraph from:

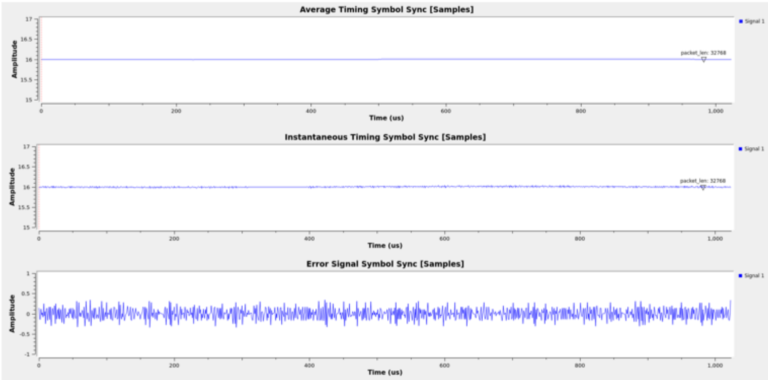
“/home/analog/Desktop/ftc_2025/13_symbol_sync_loopback_gnuradio”

13.3. Run the flowgraph and observe how all the symbols have the same amplitude in the constellation plot and observe that a remaining frequency and phase offset is still there because the FLL block cannot correct these with a very high precision. This block also applies a matched filter at RX.



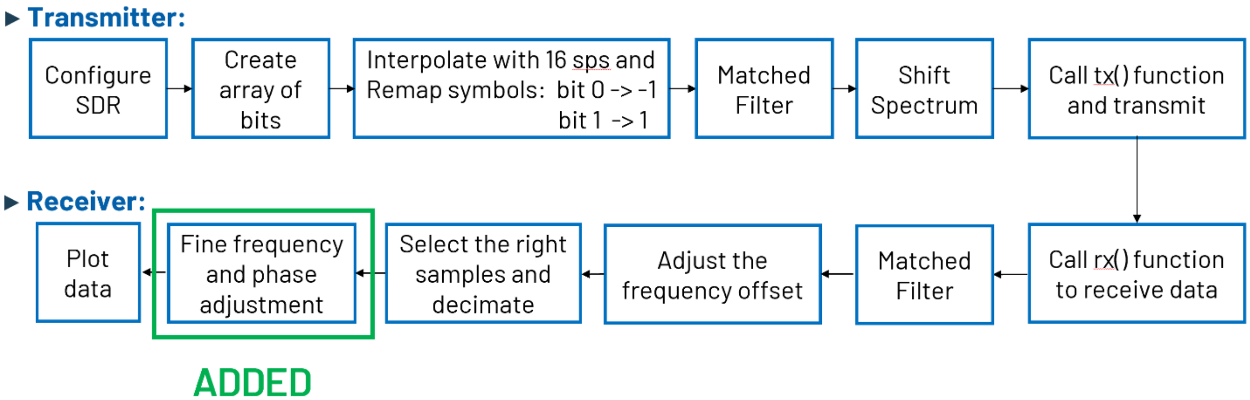


Observe that now all the symbols have the same amplitude on the constellation plot but the imaginary and real parts of the data are still varying due to a remaining frequency and phase offset.



Here are plotted the main dynamic parameter of the symbol sync block. Observe that the timing stays around 16 = sps setting and the error stays around 0.

14. QPSK – Costas Loop in GNU Radio

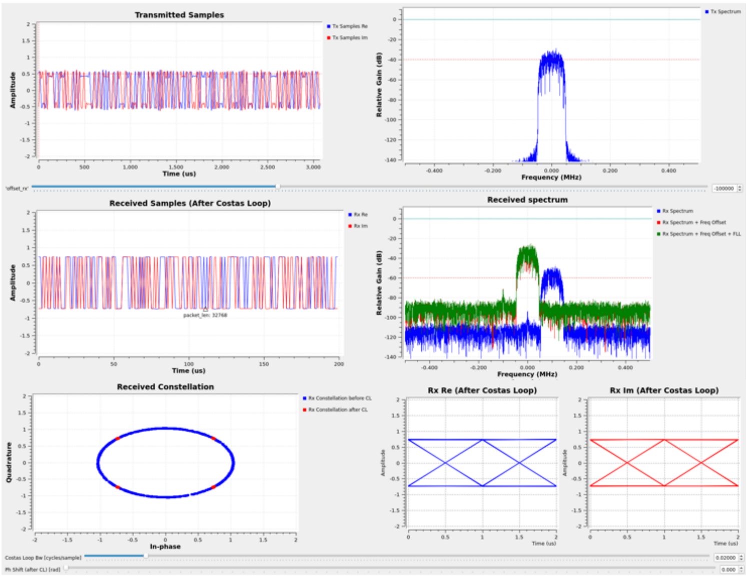


14.1. Connect Rx and Tx using the SMA cable from the kit by making a loopback between RX1 and TX1.

14.2. In GNU Radio companion app, open from File -> Open “costas_loop_loopback_pluto.grc” flowgraph from:

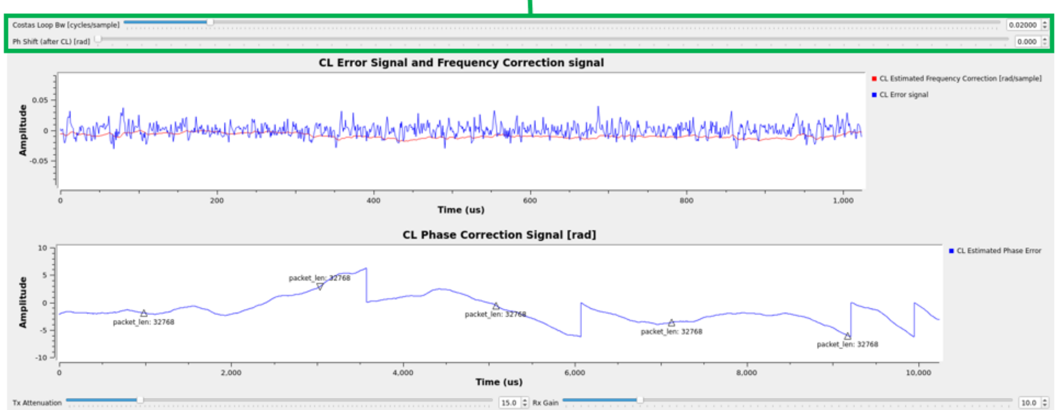
“/home/analog/Desktop/ftc_2025/14_costas_loop_loopback_gnuradio”

14.3. Run the flowgraph and observe how now the phase offset and frequency offset are removed completely.



Observe how the symbols are now separated as we wanted and the transitions in the Eye diagrams are less nosy.

Here you can tweak the bandwidth of the Costas Loop and see how it influences the error signal and the constellation plot. You can also add a phase shift in radians after Costas Loop.



Observe that the error signal is centered around 0 and the Phase Correction signal sits between 0 and 2*Pi.