

OFDM Spectrum

Introduction

In this lab you will create an OFDM transmitter using GNU Radio Companion and an Analog Devices [ADALM-Pluto SDR](#). You will then measure the effect of changing various parameters on the power spectrum of the OFDM signal.

Create an OFDM Transmitter

The OFDM transmitter is shown in Figure 1 and is composed of the blocks described below. For each block you can click on the link in the Documentation tab to get more information on the block.

- The block contains four **Variable** blocks to configure the flowgraph:
 - samp_rate** the sample rate, initially set to 1 MHz
 - fft_len** the OFDM symbol length in samples, initially 128
 - ncarrier** the number of data subcarriers placed in each OFDM symbol, initially 32
 - cp_len** the length of the cyclic prefix added to each OFDM symbol, set to 16
- the **GLFSR**¹ Source block generates random 0/1 values (bits). The period of the sequence is $2^{\text{Degree}} - 1$. The sequence will repeat after 65535 bits when using the value shown below.

General	Advanced	Docum
Type	byte	
Degree	16	
Repeat	Yes	
Mask	0	
Seed	1	

- the **Repack Bits** block groups/ungroups bits. In this case it collects two one-bit samples and creates one two-bit value (i.e. value between 0 and 3).

¹Galois linear feedback shift register

General	Advanced	Docum
Bits per input byte	1	
Bits per output byte	2	
Length Tag Key	""	
Packet Alignment	Input	
Endianness	LSB	

- the **Chunks to Symbols** block is configured to map 2-bit numbers into a complex value representing one of four QPSK constellation points. The array with the four possible complex values must be in Python syntax. Imaginary values are indicated with a **j** suffix.

General	Advanced	Documentation
Input Type	byte	
Output Type	complex	
Symbol Table	<code>[-1-1j,-1+1j,1-1j,1+1j]</code>	
Dimension	1	
Num Ports	1	

- the **Stream to Tagged Stream** block adds a “tag” object to the sample stream. Here the tag is being used indicate the length of a group of samples that should be processed together. In this case the number of subcarriers to be placed in each OFDM symbol (**ncarrier**) is placed in a tag labelled **packet_len**.

General	Advanced	Documentati
Type	complex	
Vector Length	1	
Packet Length	ncarrier	
Length Tag Key	"packet_len"	

- the **OFDM Carrier Allocator** block places the data and pilot values into the correct subcarrier locations in an array of **fft_len** values (with zeros elsewhere). The data values are placed on the subcarriers nearest the carrier but not on the carrier frequency itself (index 0).

Pilots subcarriers are not needed since we are not implementing a receiver. However, the

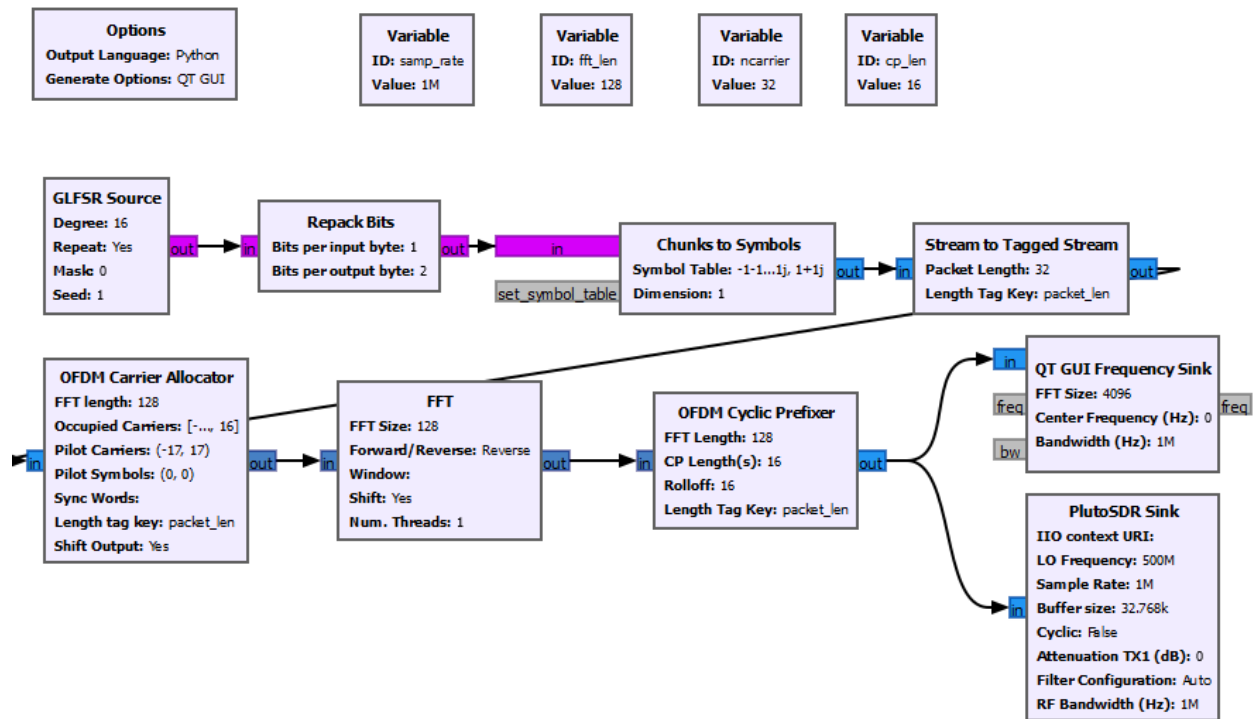


Figure 1: GRC flowgraph for an OFDM transmitter.

block does not work properly without them so zero-value pilots are added on either side of the data subcarriers.

General	Advanced	Documentation	Generated Code
FFT length	fft_len		
Occupied Carriers	[list(range(-ncarrier//2,0))+list(range(1,ncarrier//2+1))]		
Pilot Carriers	((-ncarrier//2+1),(ncarrier//2+1),)		
Pilot Symbols	((0,0),)		
Sync Words	0		
Length tag key	"packet_len"		
Shift Output	Yes		

- the **FFT** block performs an inverse FFT on **fft_len** frequency-domain values (the complex subcarrier values) to generate **fft_len** complex time-domain samples

General	Advanced	Document
Input Type	complex	
FFT Size	fft_len	
Forward/Reverse	Reverse	
Window		
Shift	Yes	
Num. Threads	1	

The Shift parameter sets the middle of the frequency-domain input as the zero frequency. This makes negative indices correspond to frequencies below the carrier.

- the **OFDM Cyclic Prefix** block adds a cyclic prefix of **cp_len** samples to each OFDM symbol

General	Advanced	Documen
FFT Length	fft_len	
CP Length(s)	cp_len	
Rolloff	cp_len	
Length Tag Key	packet_len	

- the **Pluto SDR Sink** block configures and writes samples to the SDR. The SDR's RF output is connected to the spectrum analyzer so you can measure the power spectrum of the OFDM signal.

General Advanced Filter Documentation

Input Type Complex float32 ▾

IIO context URI

LO Frequency 500000000

Sample Rate samp_rate

Buffer size 32768

Cyclic False ▾

Attenuation TX1 (dB) 0

Packet Length Tag

General Advanced Filter

Filter Configuration Auto ▾

RF Bandwidth (Hz) samp_rate

- a **QT GUI Frequency Sink** block that displays the baseband spectrum of the signal. In the control panel you may be able to increase the averaging.

General Advanced Trigger

Type Complex ▾

Name

FFT Size 4096

Window Type Rectangular ▾

Normalize Window Power False ▾

Center Frequency (Hz) 0

Bandwidth (Hz) samp_rate

Grid No ▾

Autoscale No ▾

Average High ▾

Y min -60

Y max 10

Y label Relative Gain

Y units dB

Number of Inputs 1

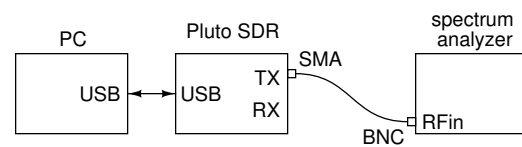
Update Period 0.10

GUI Hint

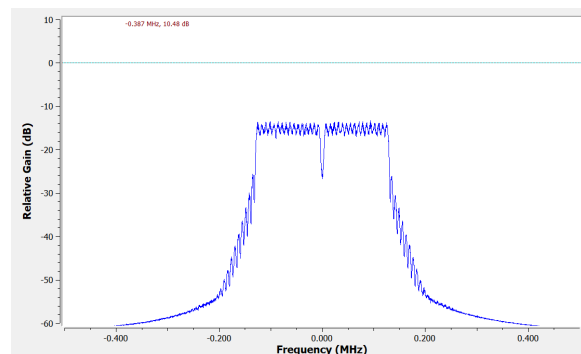
Show Msg Ports True

Measure the Power Spectrum

Connect the Pluto SDR's USB port (the one marked with the USB symbol) to a USB port on the PC. Connect the TX output of the Pluto SDR to the RF input of a spectrum analyzer using the supplied SMA-to-BNC cable:



Run the flowgraph. You will see the calculated spectrum of the OFDM signal and be able to distinguish the subcarriers:



Spectrum Analyzer Settings

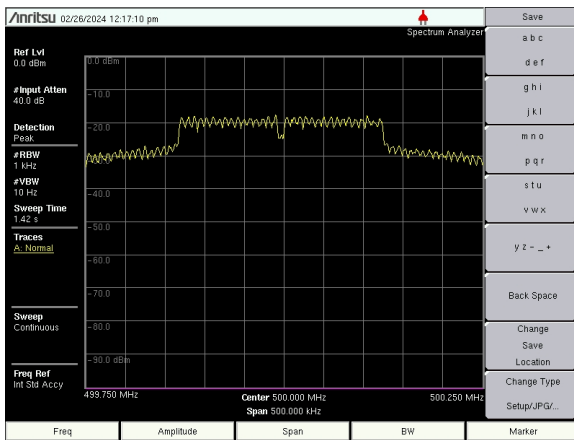
The resolution bandwidth (RBW) should be narrower than the frequency detail you want to see. In this case it is the subcarrier spacing. Since the data, and thus the signal is random, the video bandwidth (VBW) should be low enough to average multiple symbols and get an average reading.

You will need to add front-end attenuation (30 dB in this case) to avoid over-driving the spectrum analyzer.

You can start with the following spectrum analyzer settings:

Center frequency	500	MHz
Span	500	kHz
RBW	1	kHz
VBW	10	Hz
Attenuation	40	dB
Reference Level	0	dBm
Scale	10	dB/div

For these settings you should see a spectrum approximately as follows:



You can adjust the spectrum analyzer settings (e.g. change the span reference level, and dB/division) as you change the OFDM signal parameters.

If the spectrum trace turns red and a warning appears asking you to increase the attenuation, increase the attenuation of the spectrum analyzer or reduce the RF gain of the Pluto Sink block.

Saving Measurements

Use the following procedure to capture the displayed spectrum to a file:

- plug a USB drive into the USB slot in the front or top
- press Shift-7 (File) and the soft-key Save
- press the soft-key Change Save Location
- use the wheel to navigate to your USB drive (labelled USB1) and press the soft-key Set Location
- press the soft-key labelled Change Type
- use the wheel to select JPEG and press Enter
- edit the file name by following the instructions on the display and press the Enter key to save. Note that saving the screen will take 10 or more seconds during which the save dialog box will be removed and then displayed again briefly.

The dialog box will then disappear and then reappear with a status message (and then disappear again). You may now remove the USB drive.

Alternately, if the spectrum analyzer is connected to your PC with a USB cable, you can use the Anritsu Master Software Tools application on the lab

PC to download an image of the current measurement. Select Connection > Connect - USB and wait for the instrument to be recognized. Then select Sync > Capture Current Measurement to display the current measurement. Then right-click on the measurement window and select File > Save As.. to save the measurement.

Change Parameters

Create a table with the following columns:

- sample rate,
- sample period,
- samples per OFDM symbol,
- OFDM symbol period,
- subcarrier spacing,
- number of subcarriers, and
- bandwidth.

Calculate the expected values for subcarrier spacing and bandwidth for the default parameters (above) and the following three additional test conditions (make the following changes relative to the first measurement rather than cumulative):

- change **fft_len** from 128 to 256
- change **ncarrier** from 32 to 64
- change **samp_rate** from 1 MHz to 2 MHz
- change the spectrum analyzer span from 500 kHz to 5 MHz

Change each of the parameters and observe the effect on the spectrum. Capture the spectrum in each case. By the end of the lab you should have a screen capture of your flowgraph and five spectrum analyzer capture files for your report.

Lab Report

Your lab report, in addition to the usual identification information, should contain:

- a screen capture of your Gnu Radio Companion flow graph
- the spectrum analyzer screen captures for the five conditions listed above
- brief explanations of the shape of the initial spectrum and how each change affected the observed spectrum.