ELEX 7860 : Wireless System Design
2019 Winter Term

OFDM Spectrum

Updated March 22, 2019. No Pre-Lab report is required for this lab.

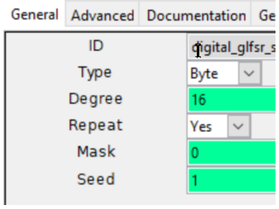
Introduction

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

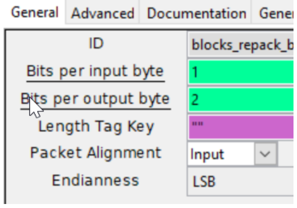
The OFDM transmitter is shown in Figure 1 and is composed of the following blocks:

- 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, initially 16
- the **GLFSR**[1] Source block generates random 0/1 values (bits). The period of the sequence is $2^{\text{Degree}} - 1$. In this case the sequence will repeat after 65535 bits.



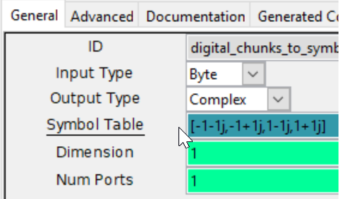
ID	digital_glfsr_s
Type	Byte
Degree	16
Repeat	Yes
Mask	0
Seed	1

- 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).



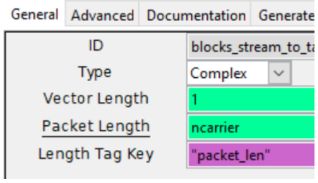
ID	blocks_repack_b
Bits per input byte	1
Bits per output byte	2
Length Tag Key	""
Packet Alignment	Input
Endianness	LSB

- 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.



ID	digital_chunks_to_symb
Input Type	Byte
Output Type	Complex
Symbol Table	[-1-1j,-1+1j,1-1j,1+1j]
Dimension	1
Num Ports	1

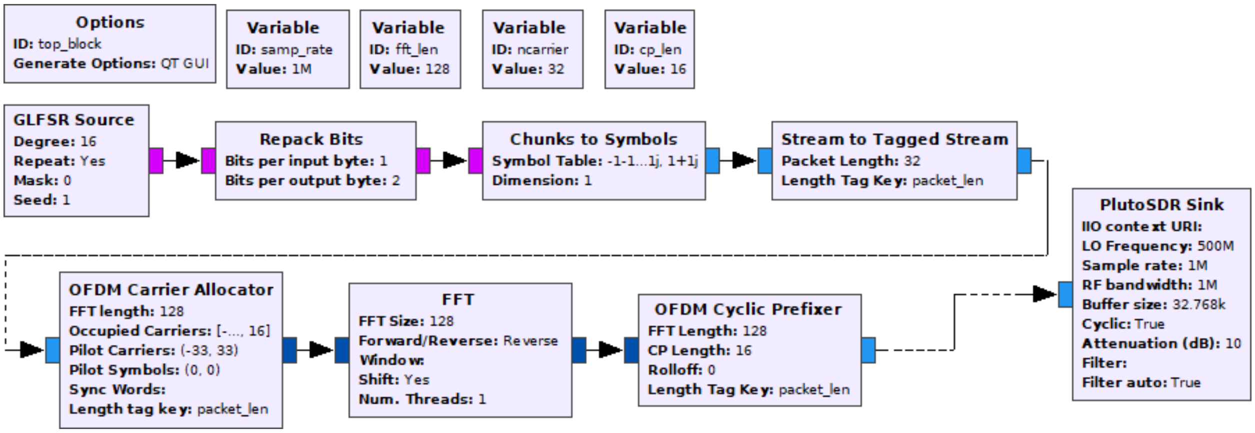
- the **Stream to Tagged Stream** block adds a "tag" object to the sample stream. Here the tag is being used indicate the length of a group of samples that should be processed together. In this case the number of subcarriers to be placed in each OFDM symbol (**`ncarrier`**) in placed in a tag labelled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



ID	blocks_stream_to_ta
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 subcarriers 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).

[1] Galois linear feedback shift register



Options
ID: top_block
Generate Options: QT GUI

Variable
ID: samp_rate
Value: 1M

Variable
ID: fft_len
Value: 128

Variable
ID: ncarrier
Value: 32

Variable
ID: cp_len
Value: 16

GLFSR Source
Degree: 16
Repeat: Yes
Mask: 0
Seed: 1

Repack Bits
Bits per input byte: 1
Bits per output byte: 2

Chunks to Symbols
Symbol Table: -1-1...1j, 1+1j
Dimension: 1

Stream to Tagged Stream
Packet Length: 32
Length Tag Key: packet_len

PlutoSDR Sink
IIO context URI:
LO Frequency: 500M
Sample rate: 1M
RF bandwidth: 1M
Buffer size: 32.768k
Cyclic: True
Attenuation (dB): 10
Filter:
Filter auto: True

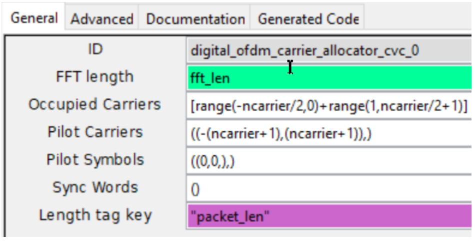
OFDM Carrier Allocator
FFT length: 128
Occupied Carriers: [-..., 16]
Pilot Carriers: (-33, 33)
Pilot Symbols: (0, 0)
Sync Words:
Length tag key: packet_len

FFT
FFT Size: 128
Forward/Reverse: Reverse
Window:
Shift: Yes
Num. Threads: 1

OFDM Cyclic Prefixer
FFT Length: 128
CP Length: 16
Rolloff: 0
Length Tag Key: packet_len

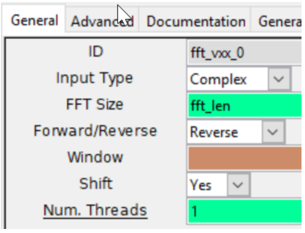
Figure 1: GRC flowgraph for an OFDM transmitter.

Pilots subcarriers are not needed since we are not implementing a receiver. However, the block does not work properly without them so zero-value pilots are added on either side of the data subcarriers.



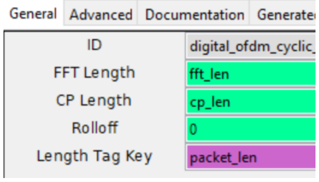
ID	digital_ofdm_carrier_allocator_cvc_0
FFT length	fft_len
Occupied Carriers	[range(-ncarrier/2,0)+range(1,ncarrier/2+1)]
Pilot Carriers	((-(ncarrier+1),(ncarrier+1)),)
Pilot Symbols	((0,0,),)
Sync Words	()
Length tag key	"packet_len"

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



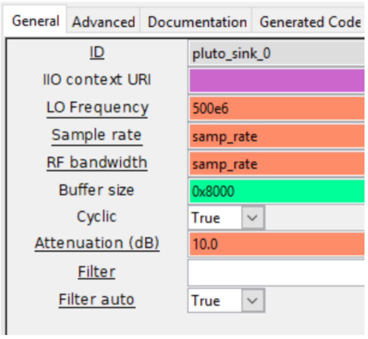
ID	fft_vxx_0
Input Type	Complex
FFT Size	fft_len
Forward/Reverse	Reverse
Window	
Shift	Yes
Num. Threads	1

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



ID	digital_ofdm_cyclic_
FFT Length	fft_len
CP Length	cp_len
Rolloff	0
Length Tag Key	packet_len

- the **Pluto SDR Sink** block represents the software that 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.

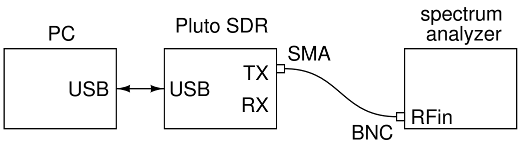


ID	pluto_sink_0
IIO context URI	
LO Frequency	500e6
Sample rate	samp_rate
RF bandwidth	samp_rate
Buffer size	0x8000
Cyclic	True
Attenuation (dB)	10.0
Filter	
Filter auto	True

If the Pluto SDR sink block is not available, follow the instructions at: **`https://tcom.bcit.ca/`** under the link "how to Add Pluto SDR Support" and click on the Reload Blocks (🔄) button.

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. Ignore warnings about missing xterm or broken libusb. This flowgraph has no GUI widgets so you will just see a blank window while it is running.

Spectrum Analyzer Settings

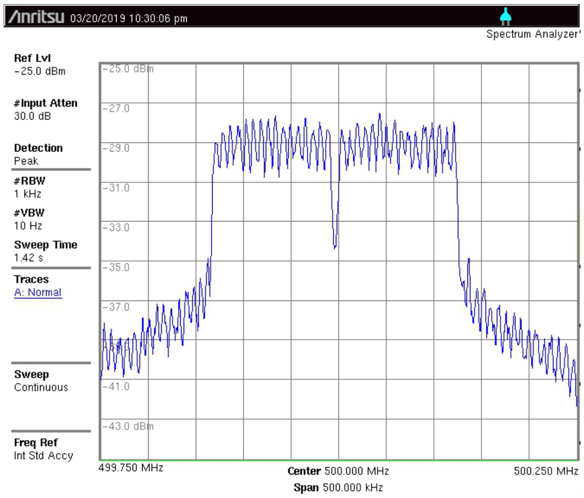
The resolution bandwidth (RBW) should be narrower than the frequency detail you want to see. In this case it is the subcarrier spacing. Since the data, and thus the signal is random, the video bandwidth (VBW) should be low enough to average multiple symbols and get an average reading.

You will need to add front-end attenuation (30 dB in this case) to avoid over-driving the spectrum analyzer[2].

You can start with the following spectrum analyzer settings:

Center frequency	500	MHz
Span	500	kHz
RBW	1	kHz
VBW	10	Hz
Attenuation	30	dB
Reference Level	-25	dBm
Scale	2	dB/div

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



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Spectrum Analyzer

Ref Lvl
-25.0 dBm

#Input Atten
30.0 dB

Detection
Peak

#RBW
1 kHz

#VBW
10 Hz

Sweep Time
1.42 s

Traces
A: Normal

Sweep
Continuous

Freq Ref
Int Std Accy

Center 500.000 MHz
Span 500.000 kHz

You may need to adjust the spectrum analyzer settings (e.g. change the span or reference level) 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 the attenuation of the Pluto SDR 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 Enter
- 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.

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

Change Parameters

Change each of the following parameters and observe the effect on the spectrum. To keep things simple, 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

In each case, try to predict the effect of the change. 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 captures files for your report.

[2] Or you could increase the attenuation setting in the Pluto SDR Sink block by the same amount.

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.