

OFDM MODULATION

Objective

In this lab, you will observe the OFDM modulation and demodulation building Simulink simulation. Then, the second stage will be understanding the impact of key parameters on the system performance.

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1. Prelab

- 1) Read the following OFDM tutorial to understand the basic concept of OFDM modulation:
<http://home.iitj.ac.in/~ramana/ofdm-tutorial.pdf>.
- 2) Simulation time and actual clock time are not the same. For example, if running a simulation for 10 seconds usually does not take 10 seconds as measured on an actual clock. The amount of time it actually takes to run a simulation depends on many factors including the complexity of the model, the step sizes, and the computer speed. Therefore, when we talk about data rate, the time we are referring to is based on the Simulink clock.

2. Building Simulink Model of OFDM Modulator and Demodulator

I. Understand the modifiable parameters

The Simulink model of OFDM modulator and demodulator is shown below

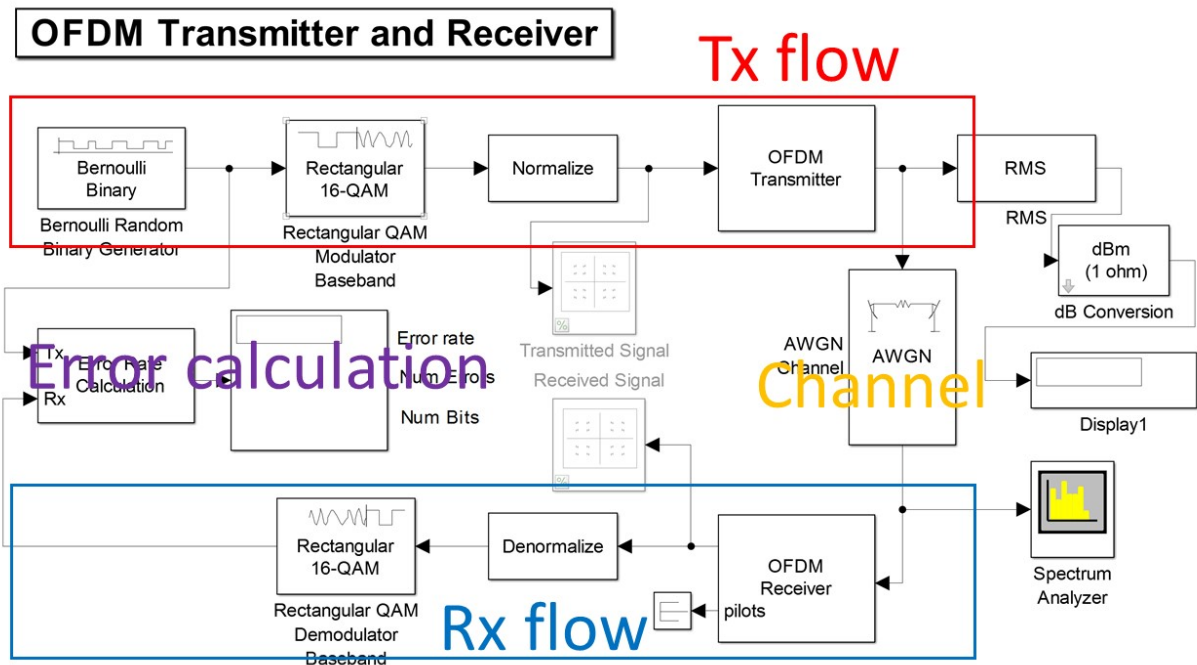
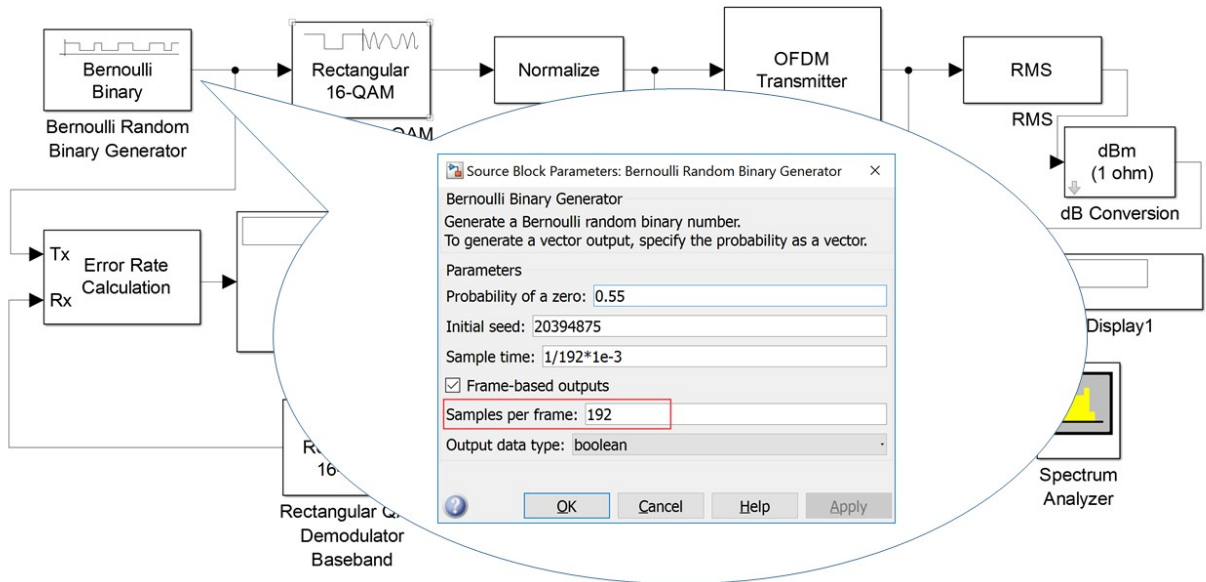


Figure 1. OFDM Simulation Model

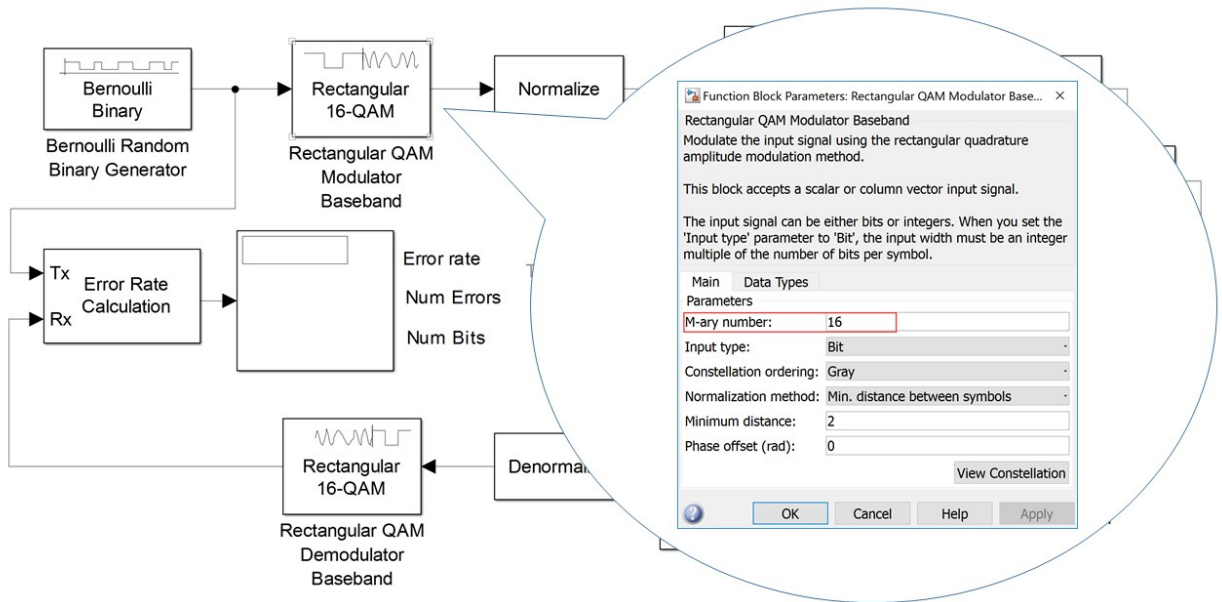
- The Simulink model example is given in the file OFDM_16QAM.mdl.
- **Sample per frame** of Bernoulli Random Binary Generator block. This value determines the number of bits carried by one OFDM symbol. This value needs to be consistent with the value of bits per symbol in AWGN block.

OFDM Transmitter and Receiver

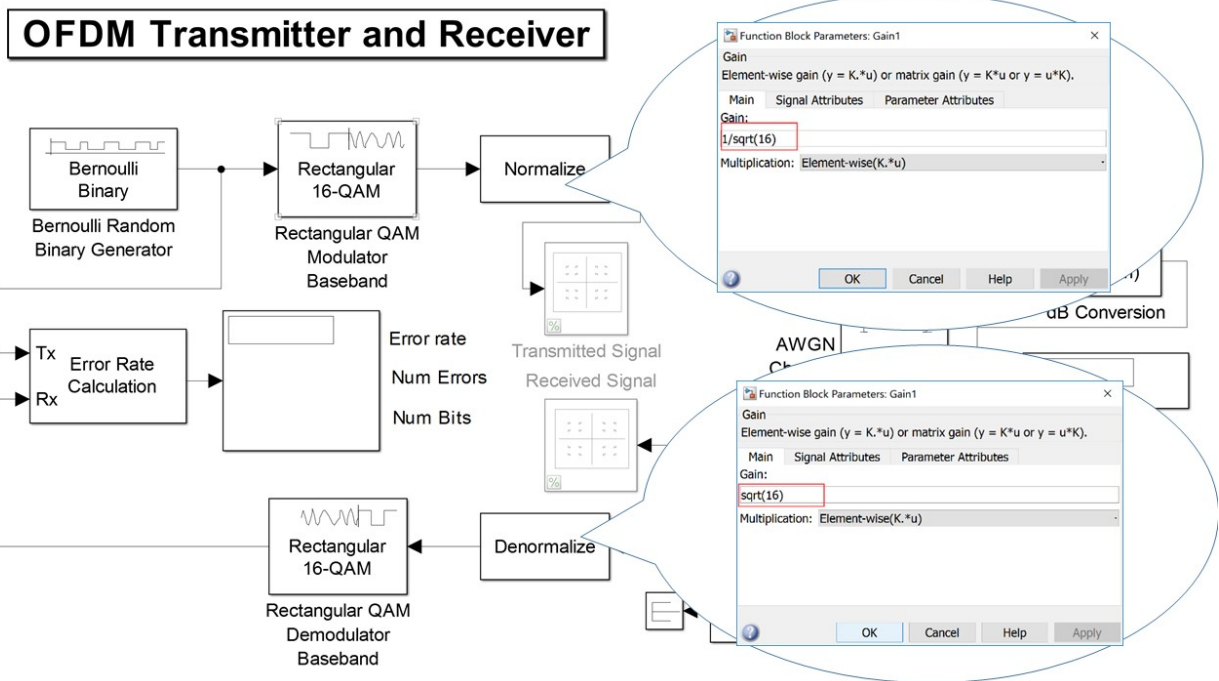


- **M-ary** of QAM modulation and demodulation blocks. This value determines the number of bits on each subcarrier. Here for example the number of bits per subcarrier is $\log_2 16 = 4$.

OFDM Transmitter and Receiver



- **Gain** of Normalize and Denormalize blocks. Normalization blocks are used to guarantee the same transmitted signal power for different modulation schemes. This gain is corresponding to the 16-QAM. If 64-QAM is applied, the gains need to be changed to $1/\sqrt{64}$ and $\sqrt{64}$, respectively.



II. Build and evaluate OFDM with different modulation schemes

In this experiment, you will first learn about how to setup the parameters for OFDM-16QAM.

- Set the value of “Samples per frame” in Bernoulli Random Binary Generator block to 192. With 16QAM, $\frac{192}{\log_2 16} = 48$ symbols are generated and assigned on 48 data subcarriers.
- Set the value of “M-ary number” in Rectangular QAM Modulator Baseband block to 16. For BPSK or QPSK, this block needs to be changed.
- Set the value of “Gain” in Normalize block to $1/\sqrt{16}$. For BPSK, QPSK, or 64QAM, the gain needs to be changed correspondingly.
- Set the value of “Gain” in Denormalize block to $\sqrt{16}$. For BPSK, QPSK, or 64QAM, the gain needs to be changed correspondingly.

Based on the OFDM-16QAM setting, you need to finish the following lab tasks:

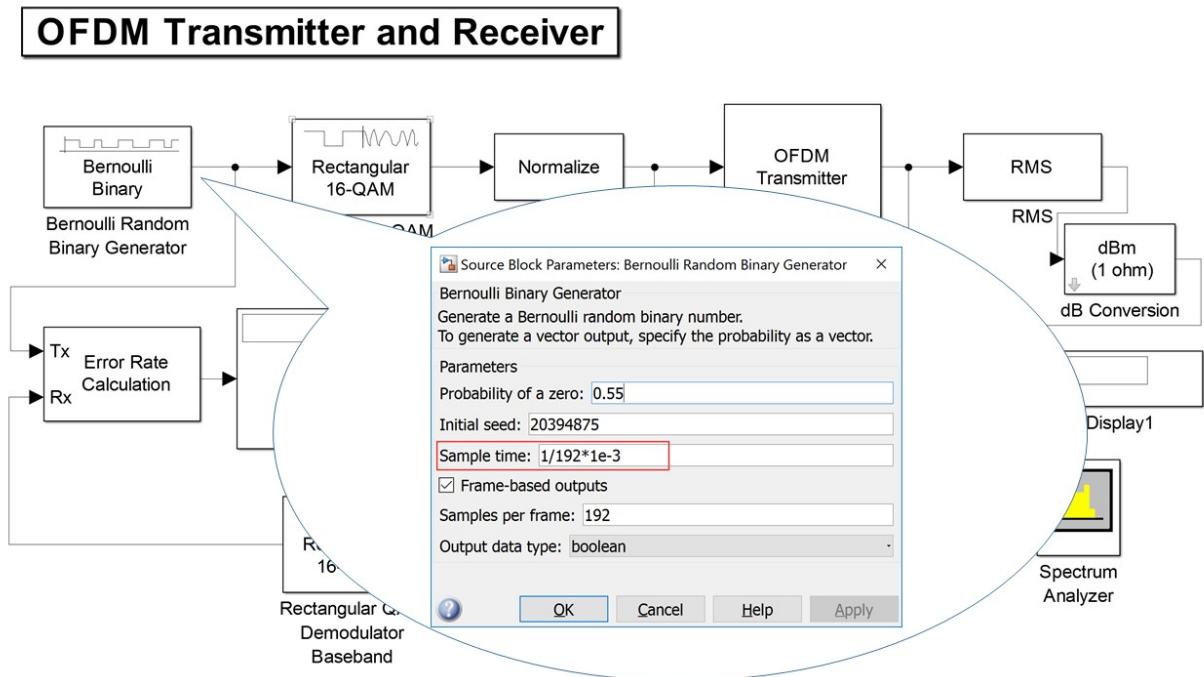
1. Change the value of “Eb/No” in the AWGN block from 5 to 15, increment by 1 in each step. Check the value of BER. Plot the curve of BER vs. Eb/No for OFDM-16QAM.
2. Based on the settings of OFDM-16QAM, modify the parameters correspondingly to simulate OFDM-64QAM, OFDM-QPSK, OFDM-BPSK. Plot the curves of BER vs. Eb/No for OFDM-64QAM, OFDM-16QAM, OFDM-QPSK, OFDM-BPSK.
3. Based on the plots in task 2, explain which modulation scheme is more appropriate in terms of different distance and channel conditions. And why?

3. Evaluate the impact of key parameters on the system performance

In this part, you will learn the impact of important OFDM parameters (i.e. symbol period, FFT length, cyclic prefix, guard bands, AWGN) on the channel bandwidth and system performance. For each important parameter, you will need to finish one or two lab tasks.

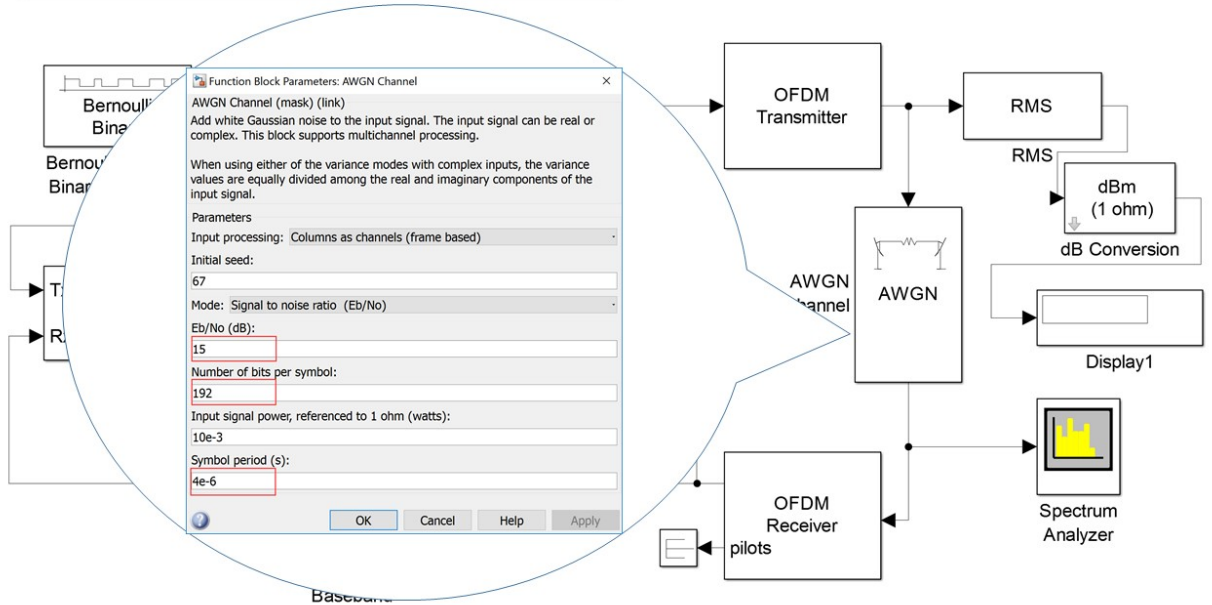
I. Understand the modifiable parameters

- **Sample time** of Bernoulli Random Binary Generator block. This value determines the bit rate of the source block. Here for example the bit rate is $1/(1/192 \cdot 1e-3) = 192$ kbps.

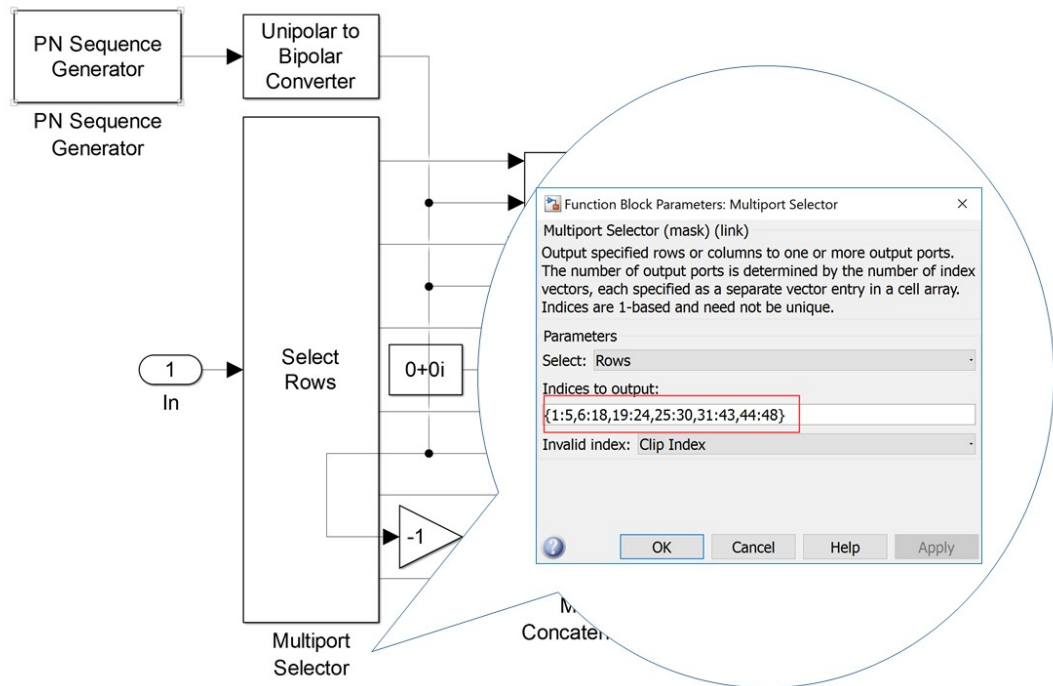


- **E_b/N_0** is the signal-to-noise ratio per bit. It is especially useful when comparing the bit error rate (BER) performance of different digital modulation schemes without taking bandwidth into account. **Number of bits per symbol** is corresponding to the value of samples per frame in Bernoulli Random Binary Generator block. **Symbol period** of AWGN block needs be consistent with the symbol period defined in OFDM transmitter block.

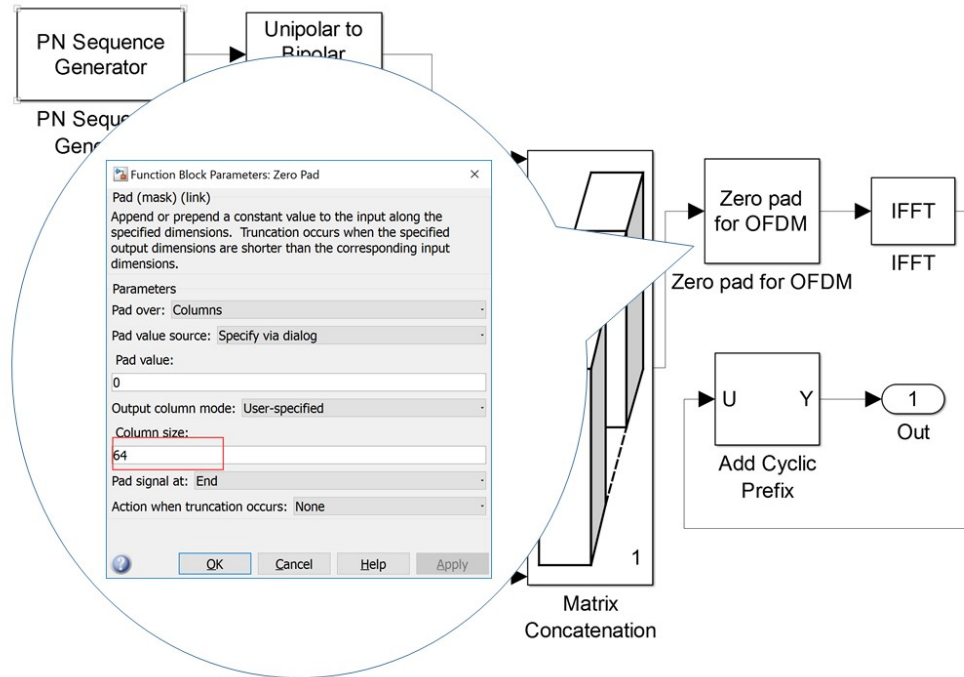
OFDM Transmitter and Receiver



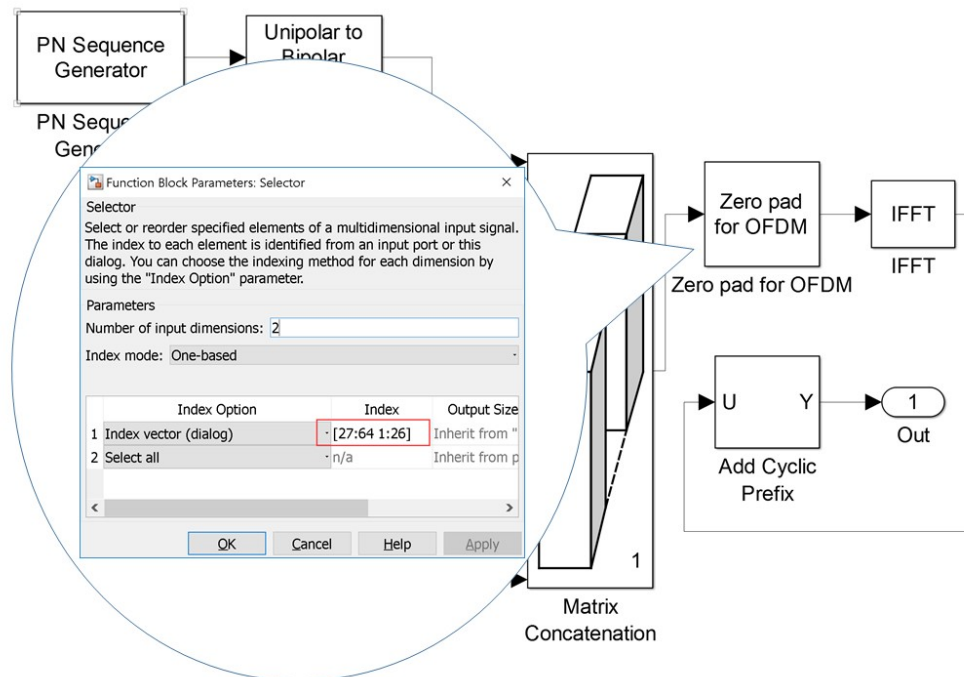
- **Data subcarrier indices** of OFDM transmitter. Here we have 48 data subcarriers, 4 pilot subcarriers and a DC subcarrier inserted among data subcarriers. If the FFT length is 64, the number of guard bands will be $64 - 48 - 4 - 1 = 11$.



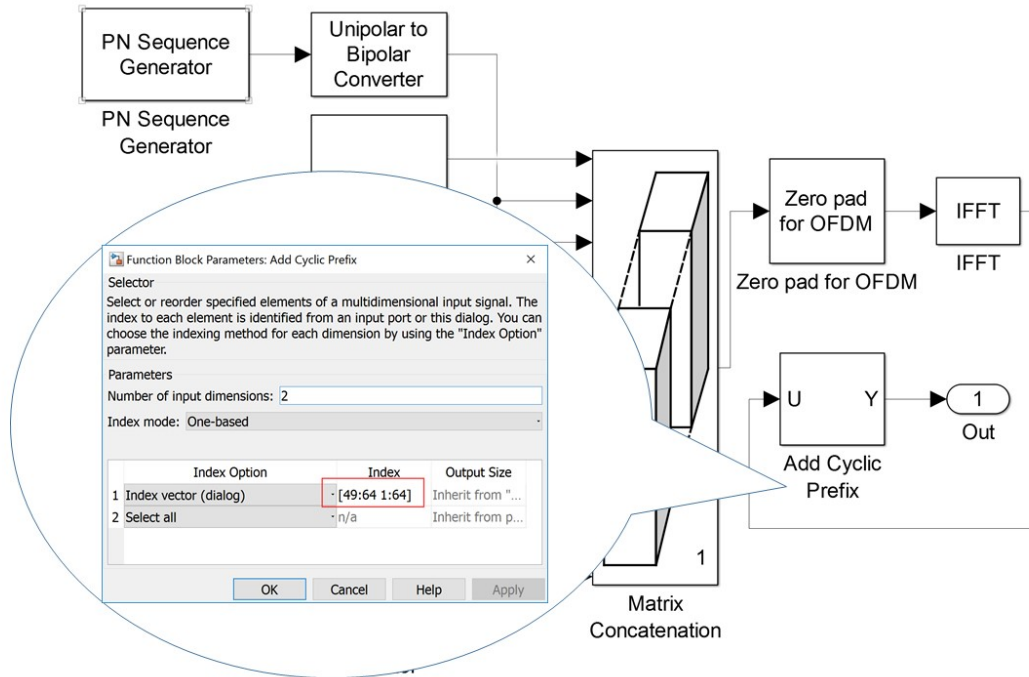
- **FFT length**. Change the column size of Zero padding block. FFT length is equivalent to the number of subcarriers.



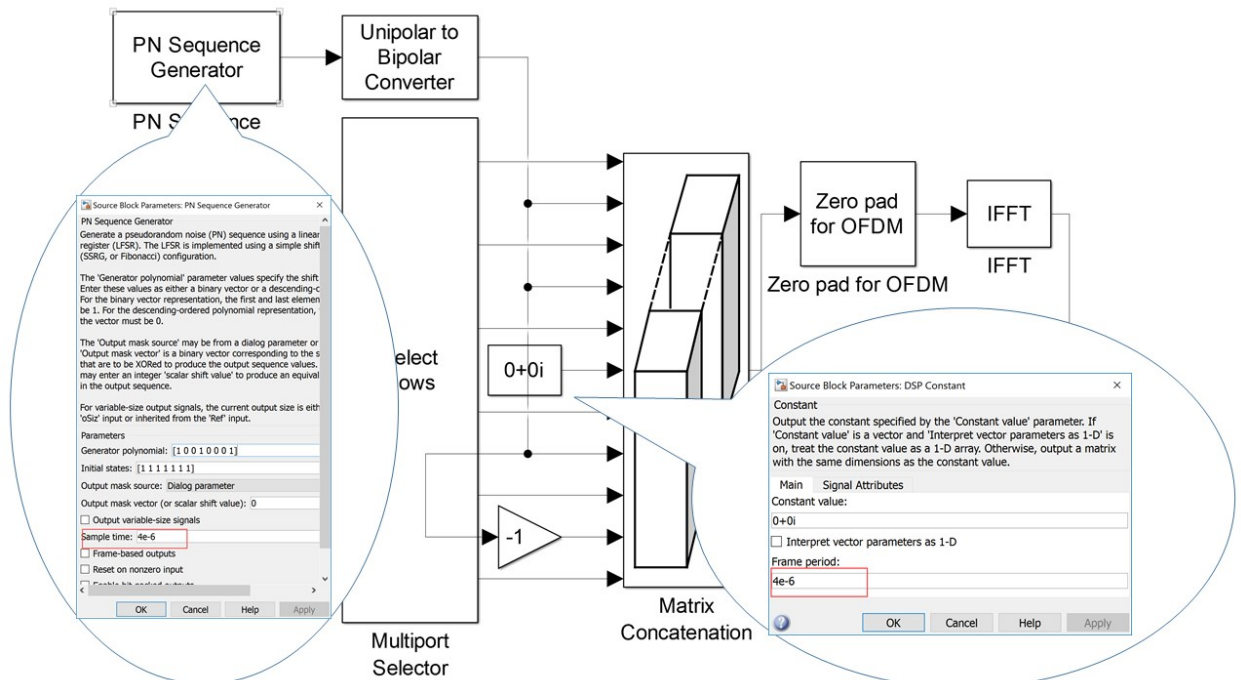
- **Guard bands placement.** Zero padding block will add all the zeros to the end of each vector (i.e. each OFDM symbol). Use this selector to adjust the places of guard bands (i.e. zeros).



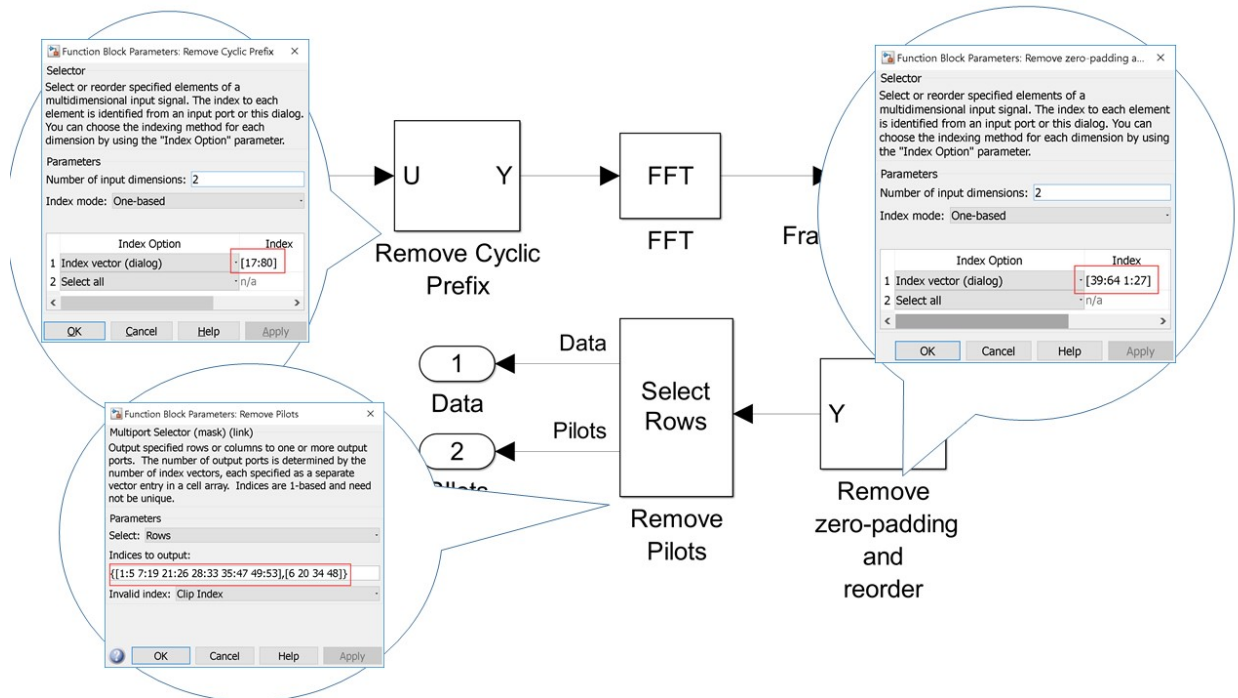
- **Cyclic prefix.** The process of adding cyclic prefix is prefixing of a symbol with a repetition of the end. Here the length of cyclic prefix is 16 (i.e. 49:64)



- **OFDM symbol period.** This value and the number of samples per OFDM symbol determine the bandwidth occupied by each OFDM symbol. If the number of samples per OFDM symbol is 80 (including the OFDM samples generated by IFFT and cyclic prefix), the bandwidth here is $80/4e-6 = 20$ MHz.



- **Cyclic prefix removal, guard bands removal and data subcarrier indices identifier** for OFDM Receiver. Here the length of cyclic prefix is 16, the number of guard bands is 11, and we have 48 data subcarriers, 4 pilot subcarriers and one DC subcarrier.



II. Evaluate key parameters

- **Symbol period.** Set the bit rate of Bernoulli random binary generator to 1.92 kbps, change the OFDM symbol period within the range from 4 us to 4 ms (increment by 10 times in each step) by varying the sample time of PN sequence generator and the DC subcarrier input (in OFDM Transmitter block).
- Lab task 1 for symbol period: observe the variation of sample rate/bandwidth of one OFDM symbol via the spectrum analyzer. Explain how the OFDM symbol period affects the bandwidth of one OFDM symbol.
- Lab task 2 for symbol period: for the given OFDM-16QAM example, one OFDM symbol consists of 64 OFDM samples generated from IFFT process and 16 cyclic prefix samples, if the period of one OFDM symbol is x , what is the value of the sample rate/bandwidth of one OFDM symbol?
- **FFT length.** In OFDM, the FFT length is equivalent to the number of subcarriers used by one OFDM symbol. Change the FFT length of the OFDM transmitter by *doubling the number of data subcarriers*. Set the number of pilot subcarriers to 4, the length of FFT to 128, the length of cyclic prefix to 32. Note that simply changing the column size in the zero padding block can only add more guard bands.
- Lab task 1 for FFT length: observe the variation of sample rate/bandwidth of one OFDM symbol via the spectrum analyzer. Derive the sample rate/bandwidth mathematically.
- Lab task 2 for FFT length: to maintain the orthogonality of OFDM signals, we have to guarantee $f = f_s/N$, where f is subcarrier spacing, f_s is the sample rate of one OFDM symbol and N is the FFT length. Try to figure out what is the value of subcarrier spacing after adding more data subcarriers.

- **Cyclic prefix.** In OFDM, cyclic prefix is used to mitigate inter-symbol interference. However, increasing the length of cyclic prefix will increase the bandwidth of one OFDM symbol.
- Lab task 1 for cyclic prefix: Double the length of cyclic prefix and observe the variation of bandwidth of one OFDM symbol via the spectrum analyzer

- **Guard bands.** In OFDM, guard bands are used to mitigate inter-channel interference. However, increasing the number of guard bands will increase the channel bandwidth.
- Lab task 1 for guard bands: Double the number of guard bands and observe the variation of channel bandwidth via the spectrum analyzer.

- **AWGN.** Add AWGN block between OFDM transmitter and OFDM receiver. Choose the mode signal to noise ratio (E_b/N_0).
- Lab task 1 for AWGN: Explain the settings of the number of bits per symbol and symbol period.
- Lab task 2 for AWGN: Set the input signal power to 10 mW. Change the value of E_b/N_0 from 10 to 15, increment by 1 in each step and observe the effect on the received signal constellation and BER.