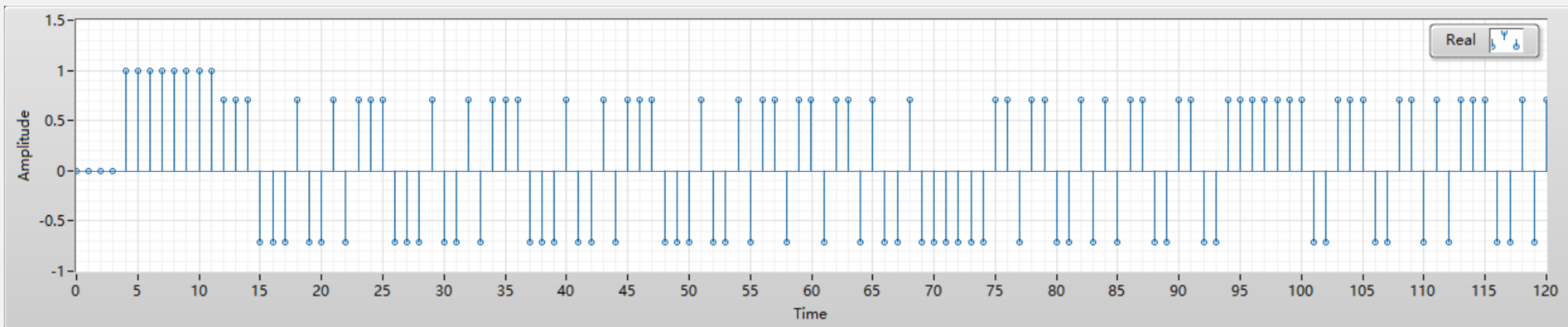


无线通信实验在线开放课程

主讲人：吴光 博士

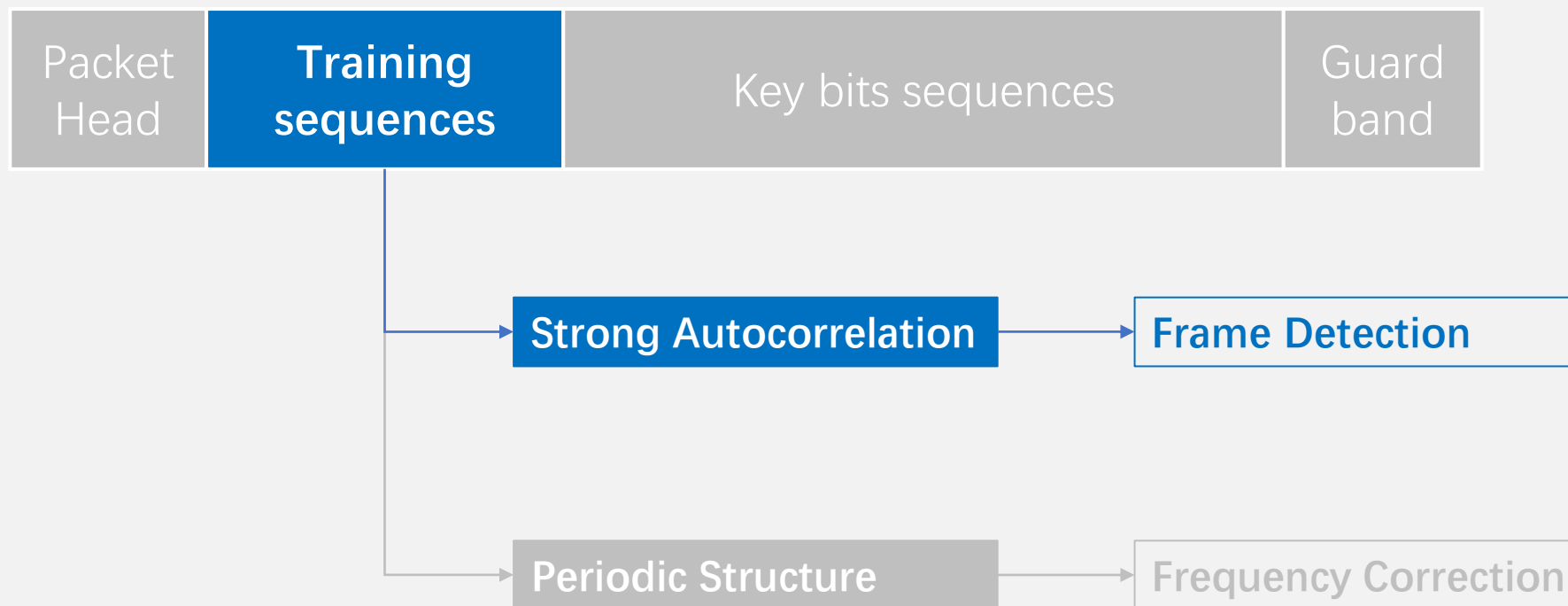
广东省教学质量工程建设项目





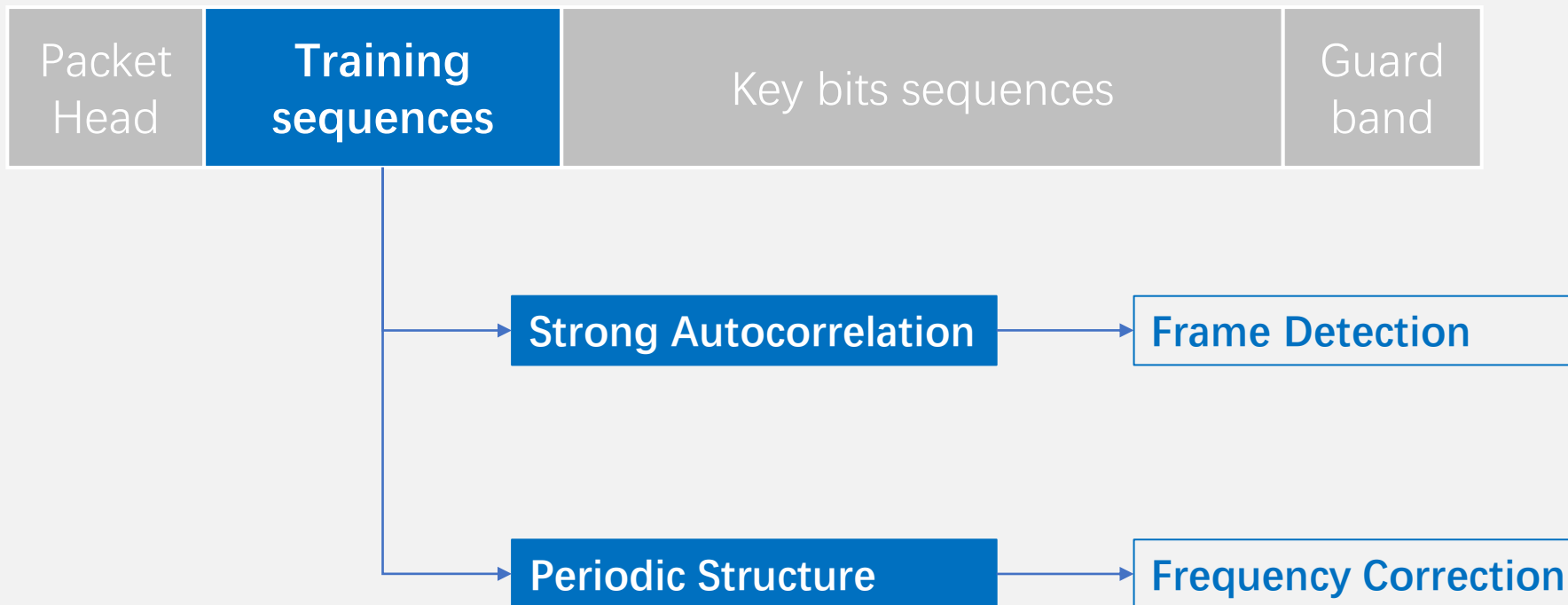


Training sequences





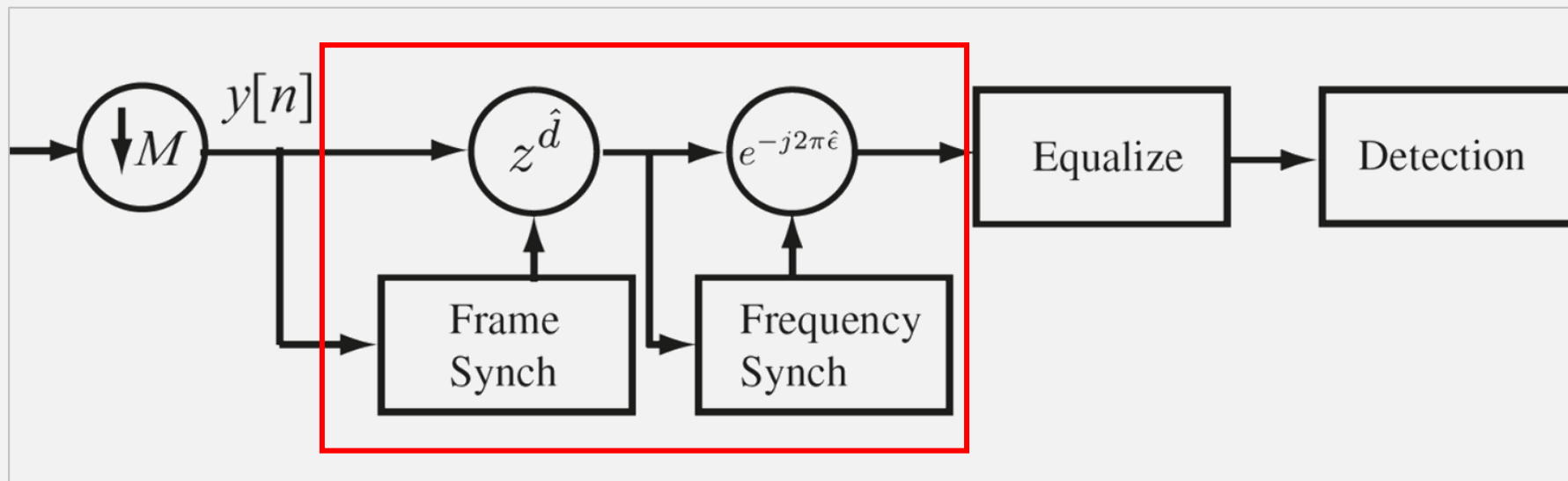
Training sequences



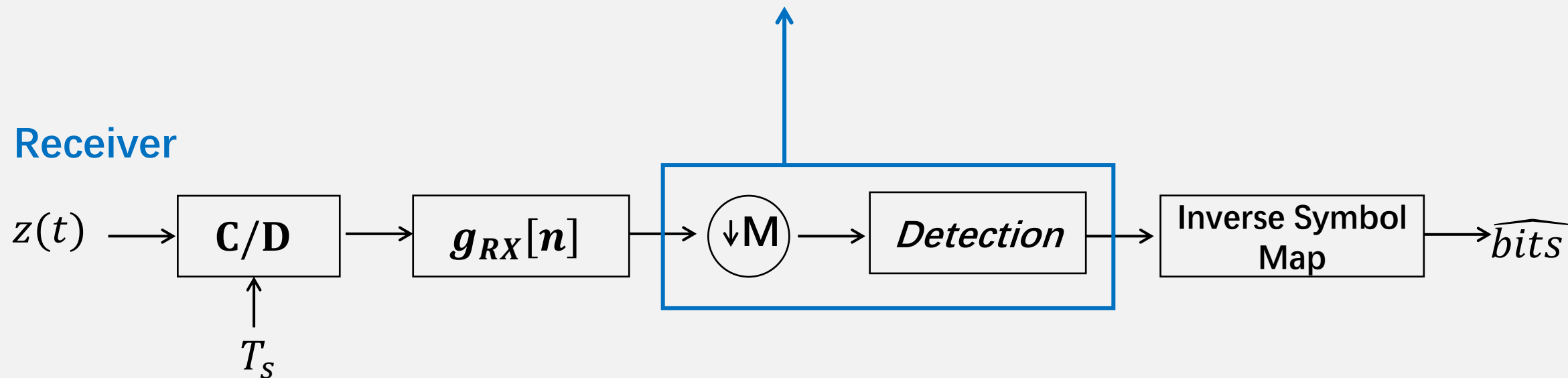
Lab 13 : Frame Detection and Frequency Correction

主讲人：吴光 博士

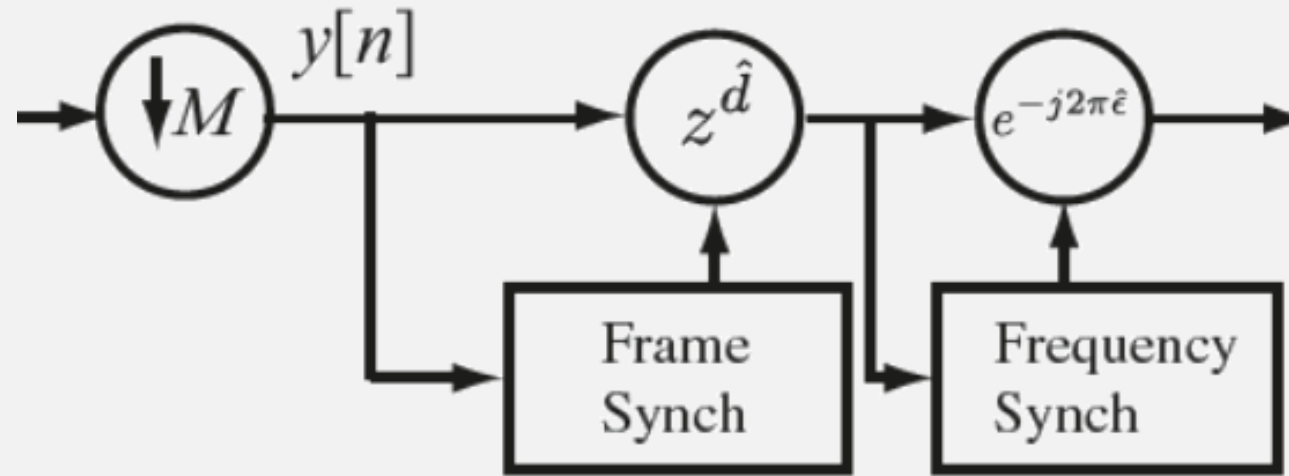
Email: wug@sustech.edu.cn



Receiver



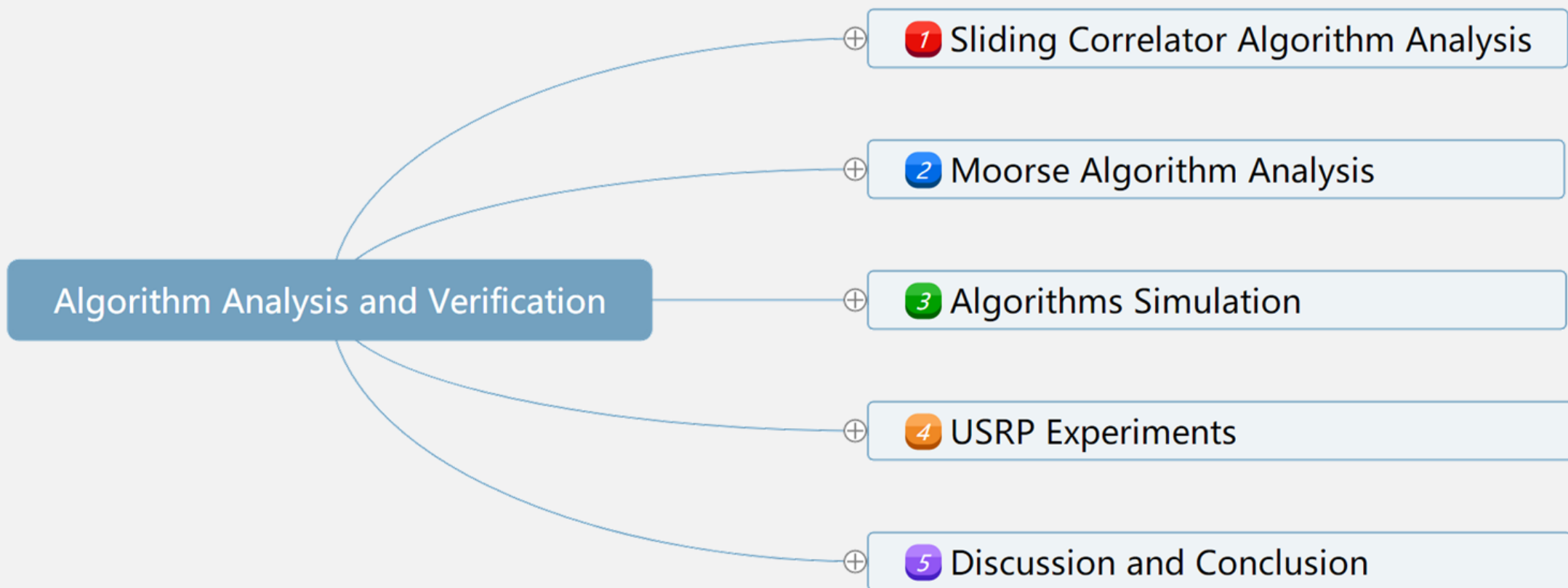
System Model





Objective: I have an ability to

- 1. Understand the function of **training sequence**.
- 2. Understand the **frame synchronization** problem.
- 3. Design and implement frame synchronization algorithm: **sliding correlator**.
- 4. Understand the **frequency offset correction** problem.
- 5. Design and implement frequency offset correction algorithm: **Moose**.
- 6. Evaluate the performance of the algorithms by simulation and USRP.

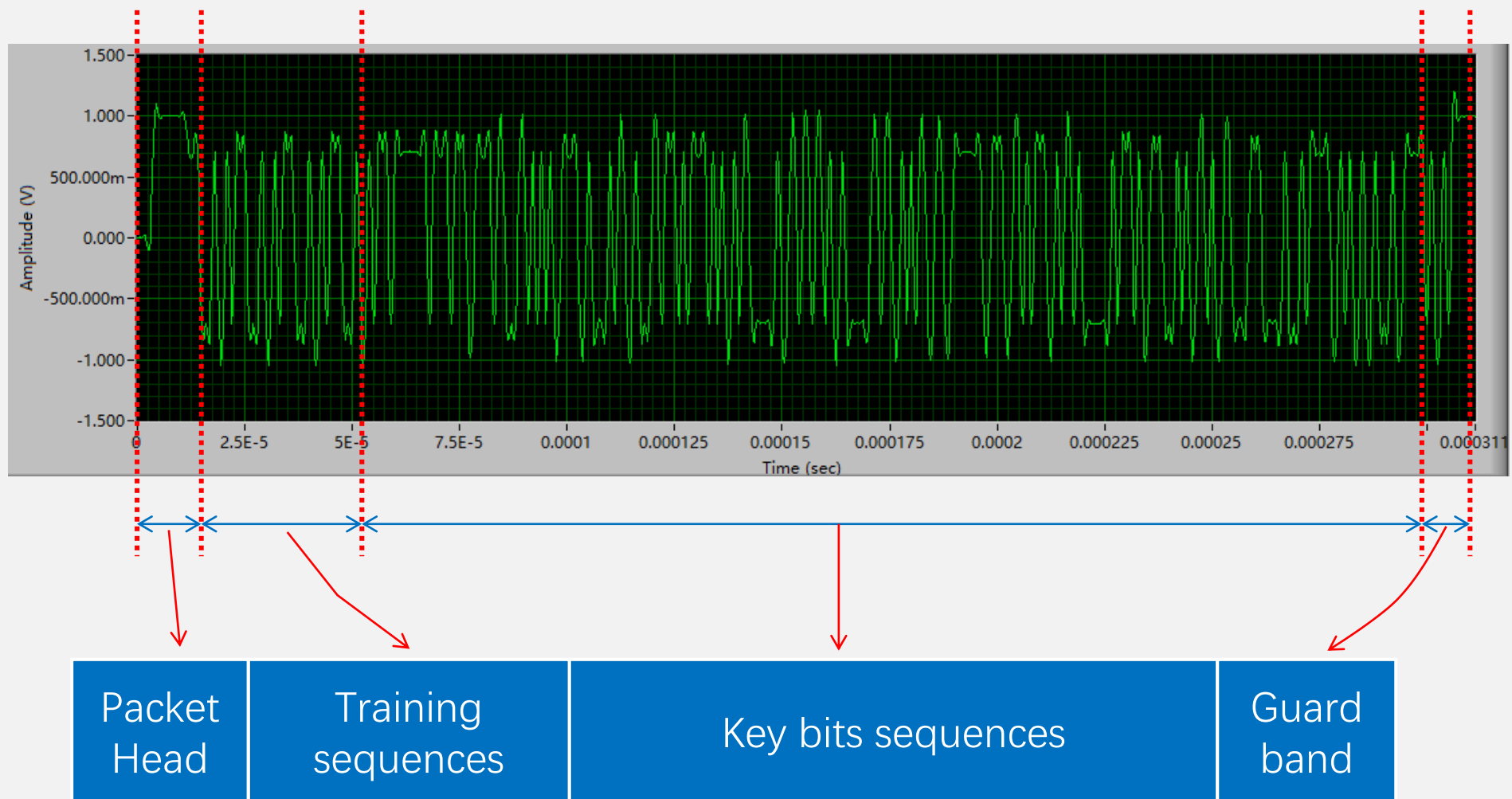


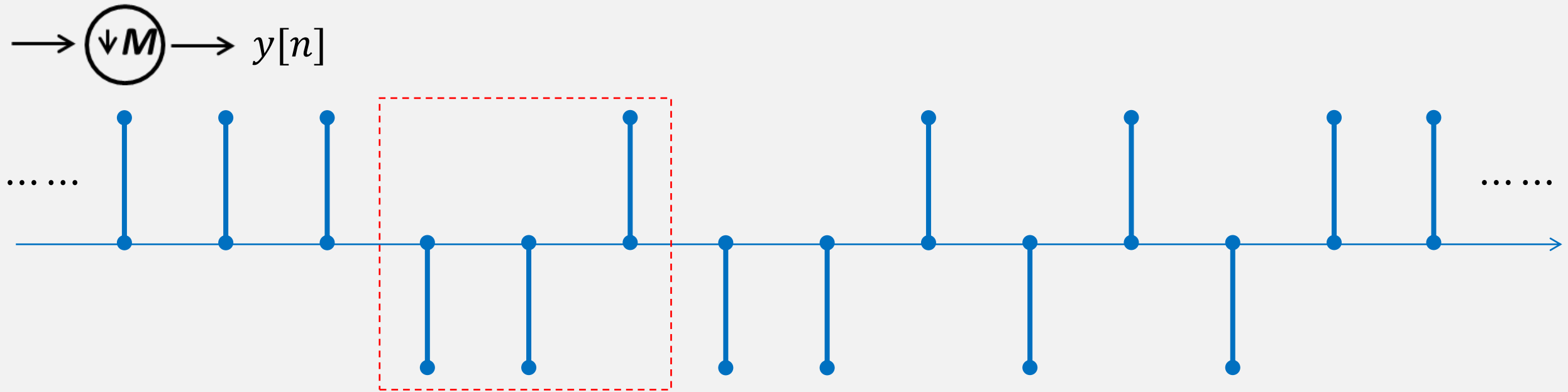


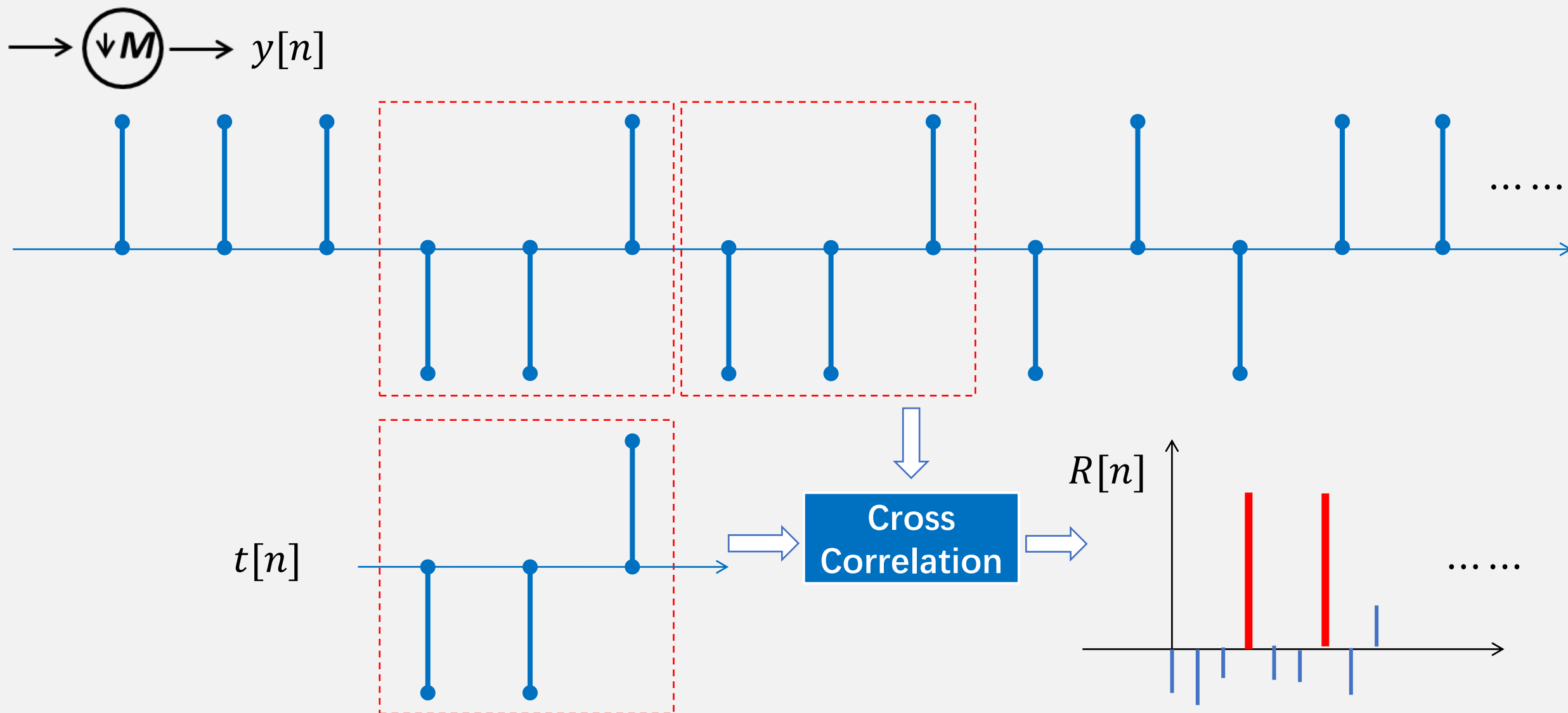
Demo: Training Sequence

3、观察训练序列波形，帧同步原理

How to locate the training sequence ?







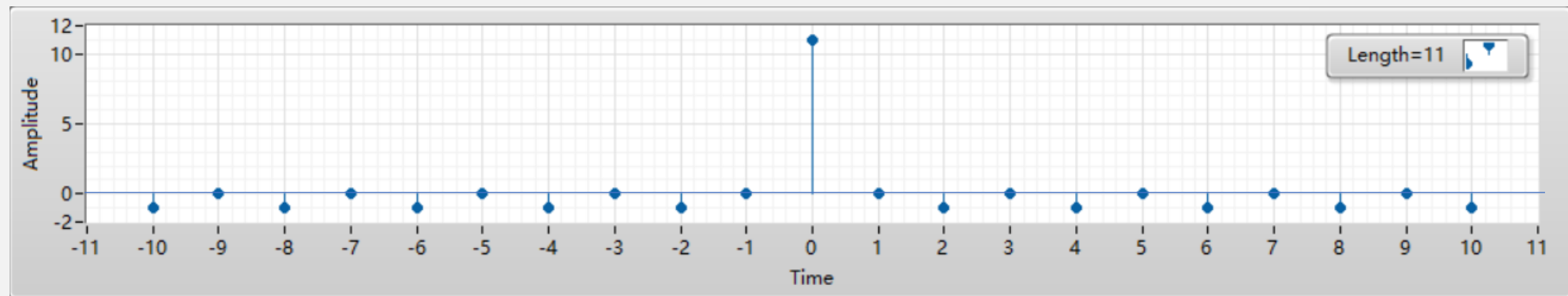
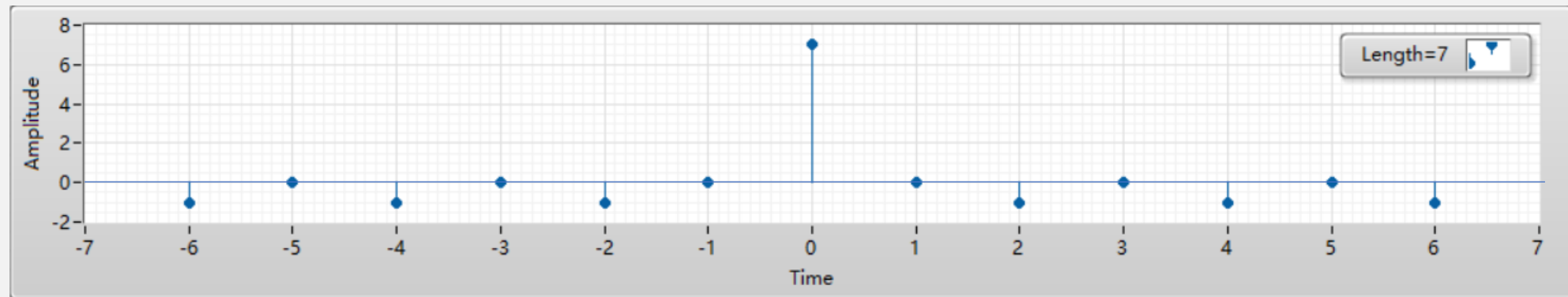
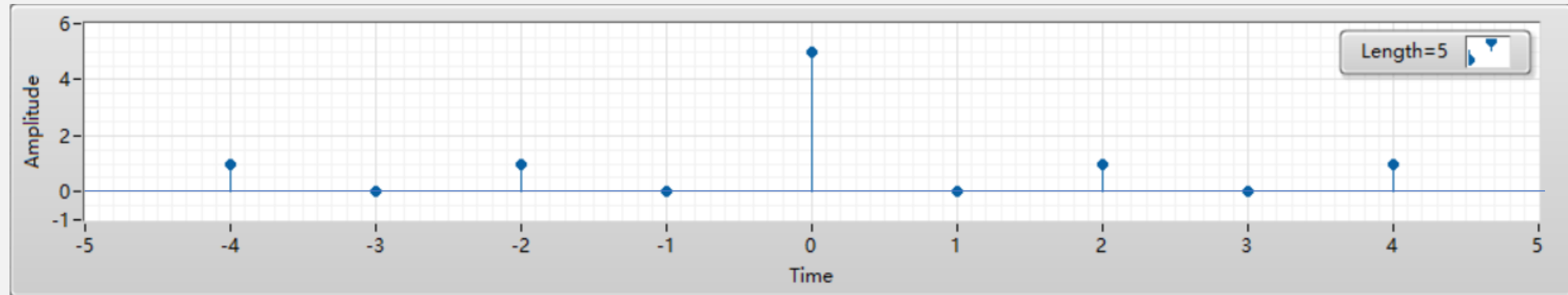


$$\left| \sum_{i=1}^{N_t-k} a_i a_{i+k} \right| \leq 1 \qquad 1 \leq k \leq N_t$$

$$\left| \sum_{i=1}^{N_t-k} a_i a_{i+k} \right| = N_t \qquad k = 0$$



Code Length	Barker Sequence
2	$[-+, --]$
3	$[- - +]$
4	$[- + --, - + ++]$
5	$[- - - + -]$
7	$[- - - + + - +]$
11	$[- - - + + + - + + - +]$
13	$[- - - - - + + - - + - + -]$



Autocorrelation of barker sequences



$$y[n] = hs[n - d] + v[n]$$

Training signal Received signal

$$R[n] = \left| \sum_{k=0}^{N_t-1} t^*[k] y[n+k] \right|^2$$
A diagram illustrating the components of the equation for $R[n]$. Two blue rectangular boxes at the top are labeled "Training signal" and "Received signal". A blue arrow points from the "Training signal" box to the term $t^*[k]$ in the summation of the equation. Another blue arrow points from the "Received signal" box to the term $y[n+k]$ in the same summation.



Training signal

Received signal

$$R[n] = \left| \sum_{k=0}^{N_t-1} t^*[k]y[n+k] \right|^2$$

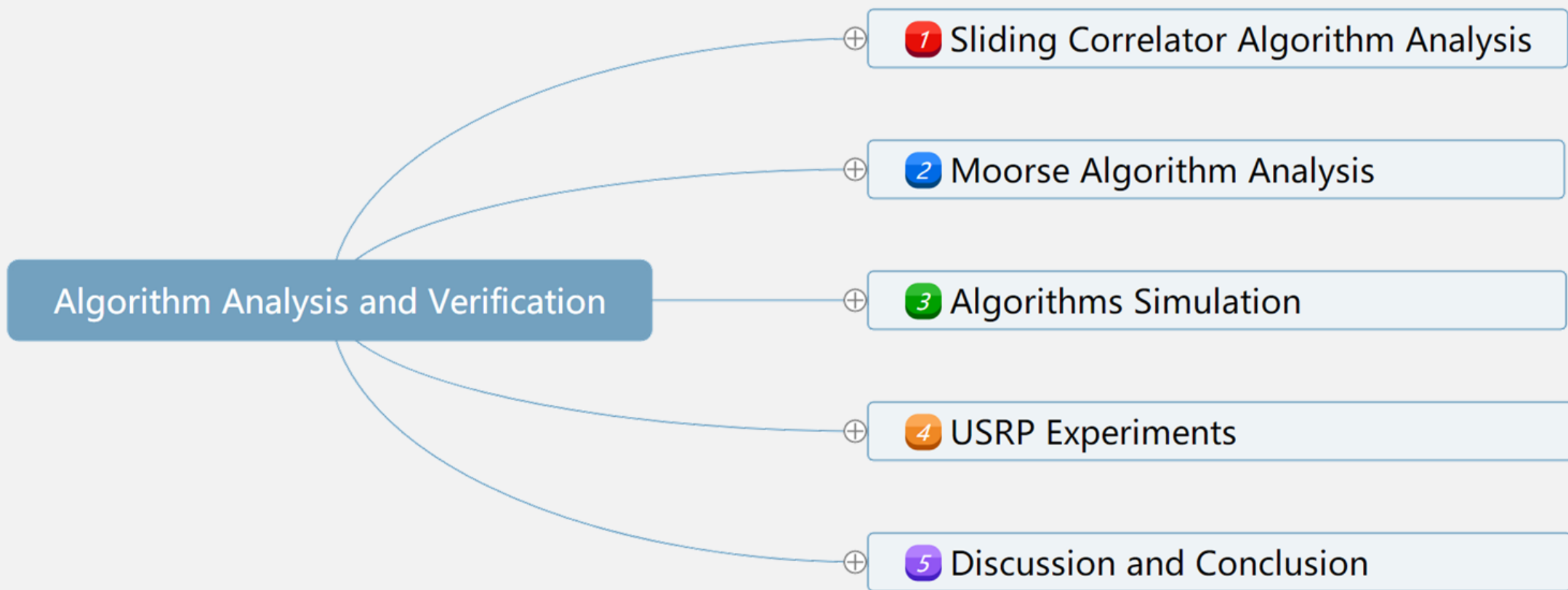


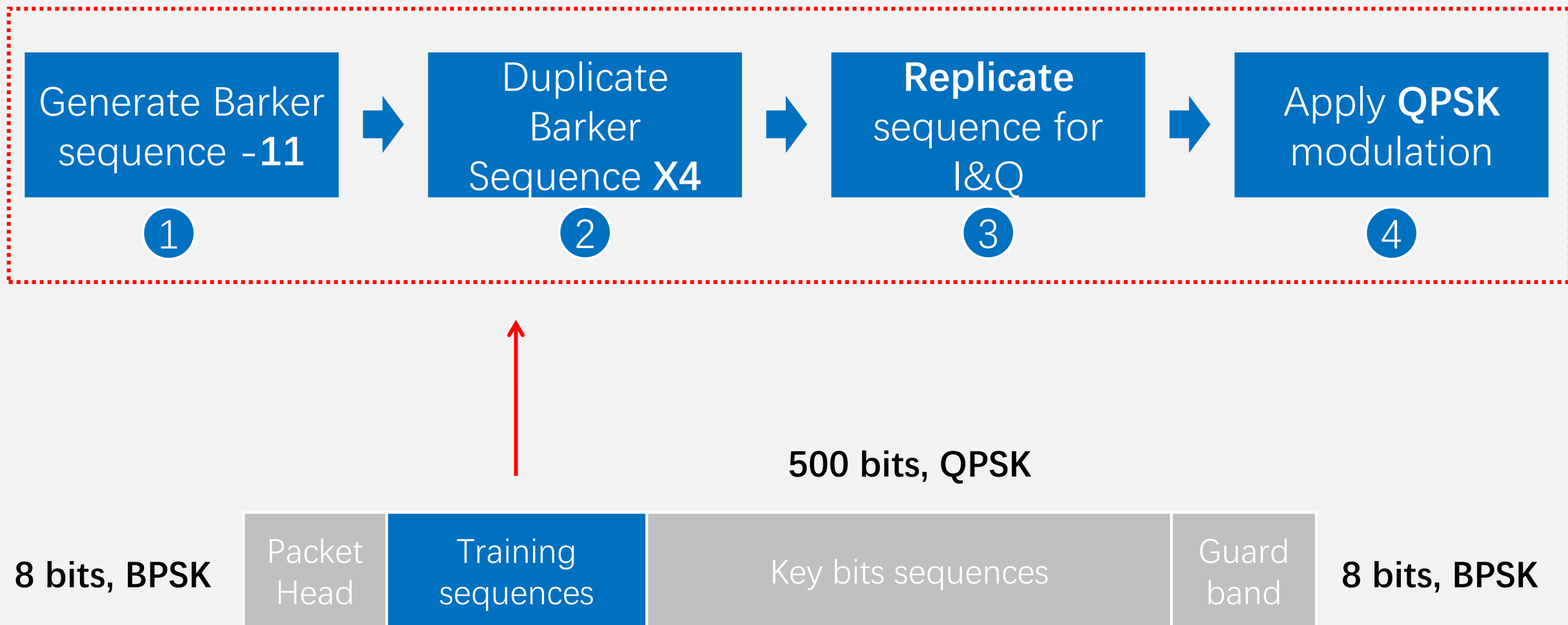
$$\hat{d} = \max_n R[n]$$



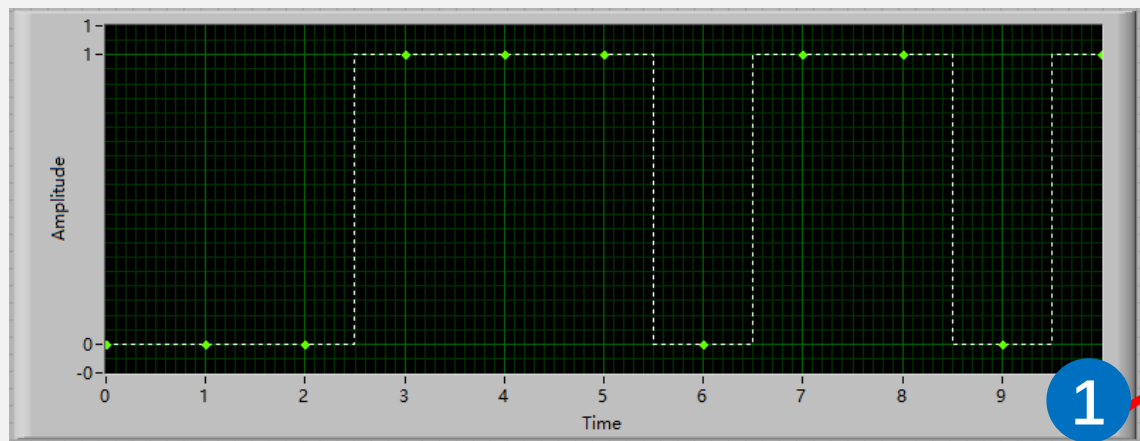
Algorithm Analysis

$$\hat{d} = \arg \max_n \sum_{p=0}^{P-1} \left| \sum_{k=0}^{N_{tr}-1} t^*[k] y[n + k + pN_{tot}] \right|$$

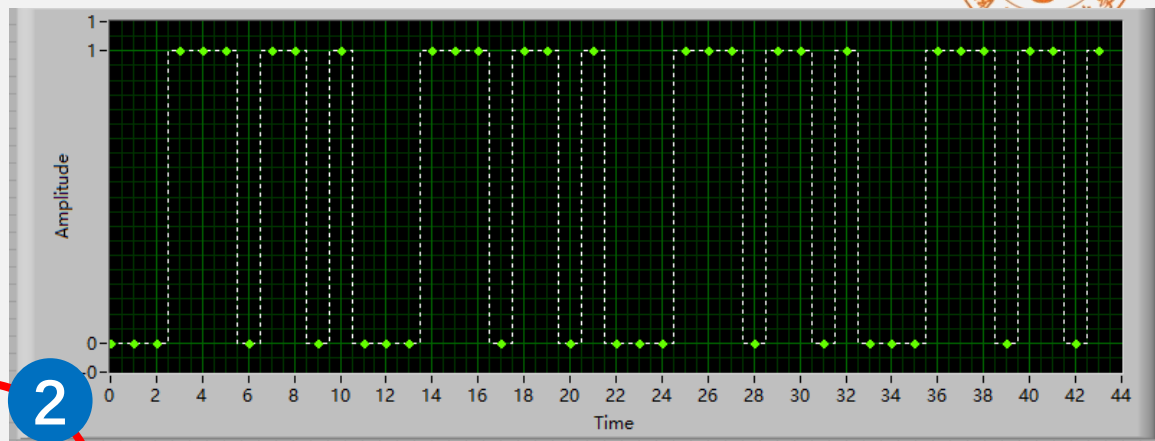




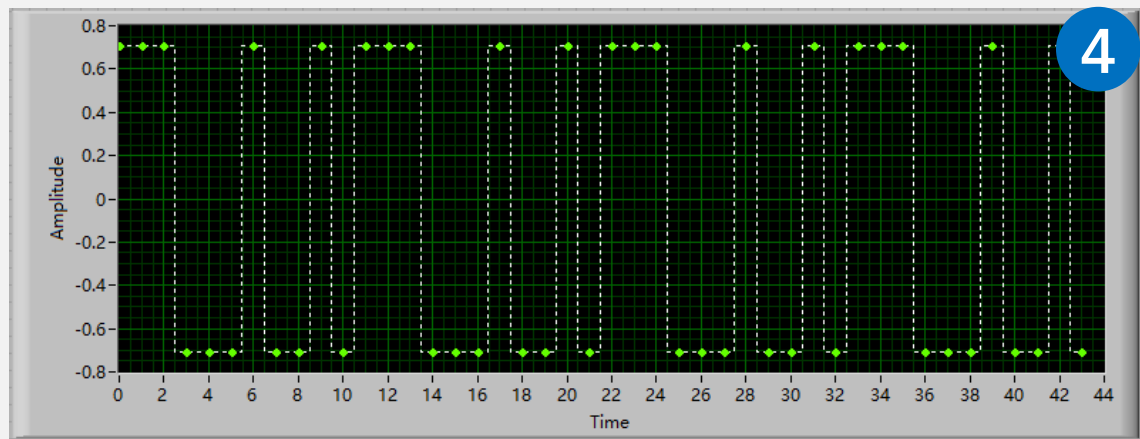
11	[- - - + + + - + + - +]
----	-------------------------



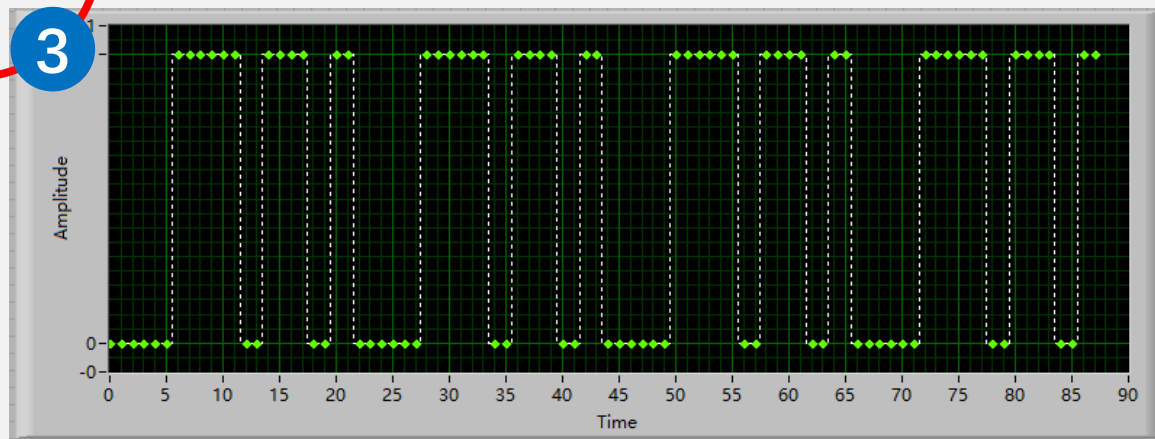
Barker code



Barker code X4



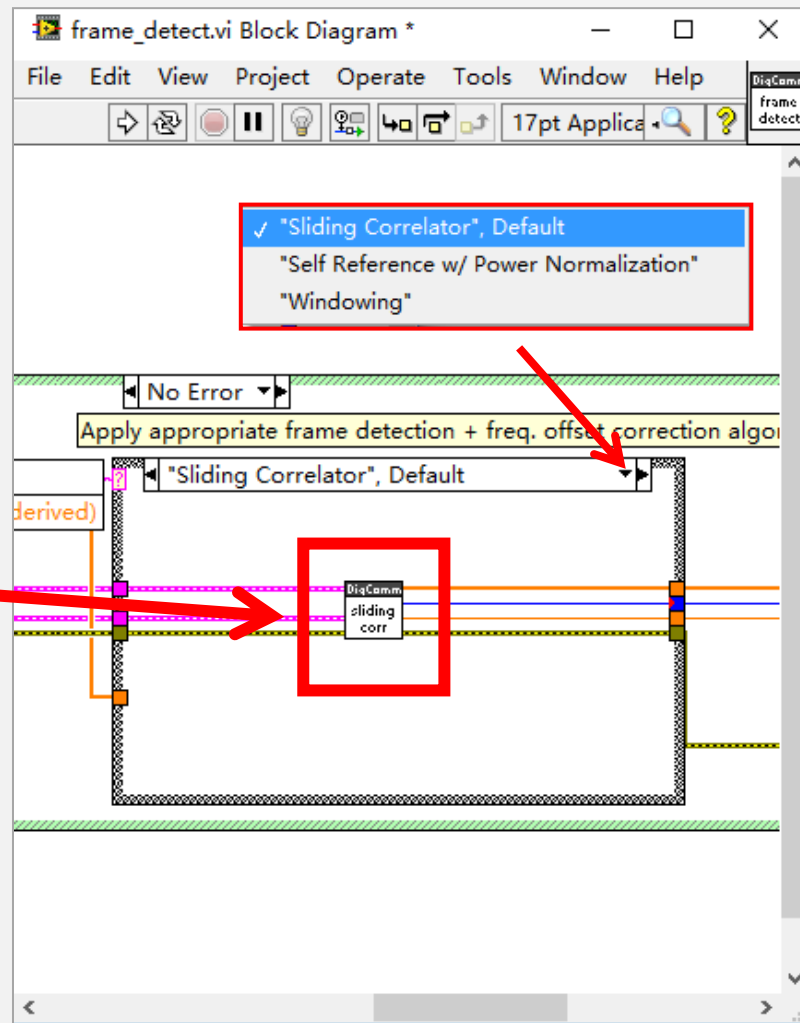
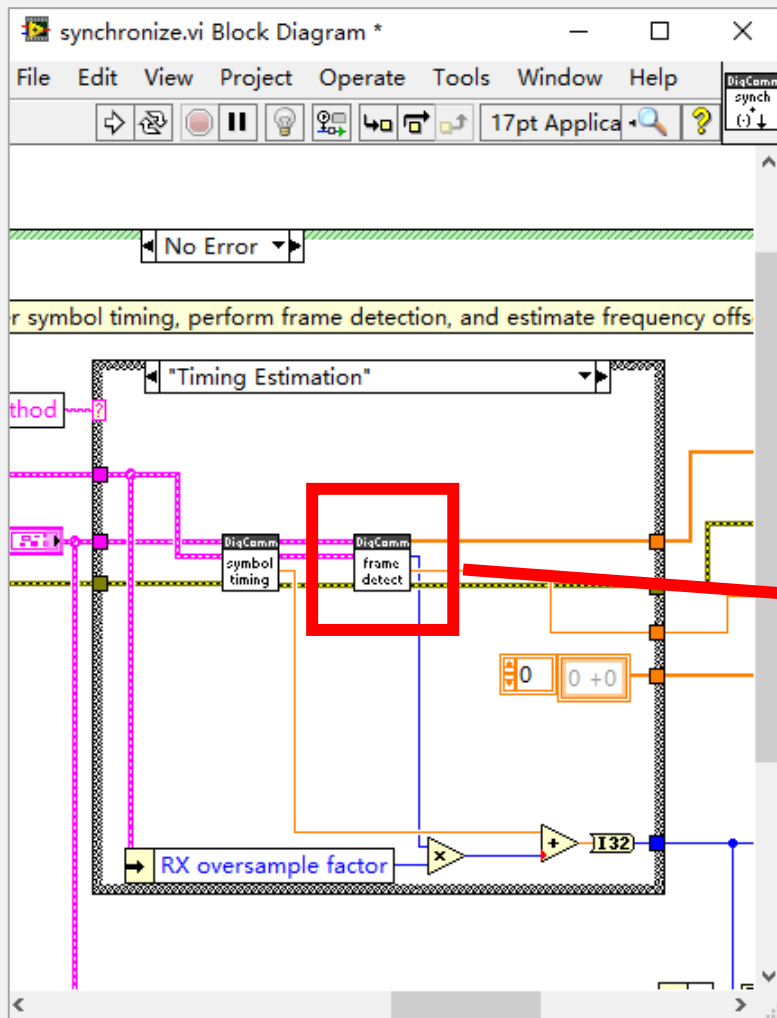
I/Q Barker sequence

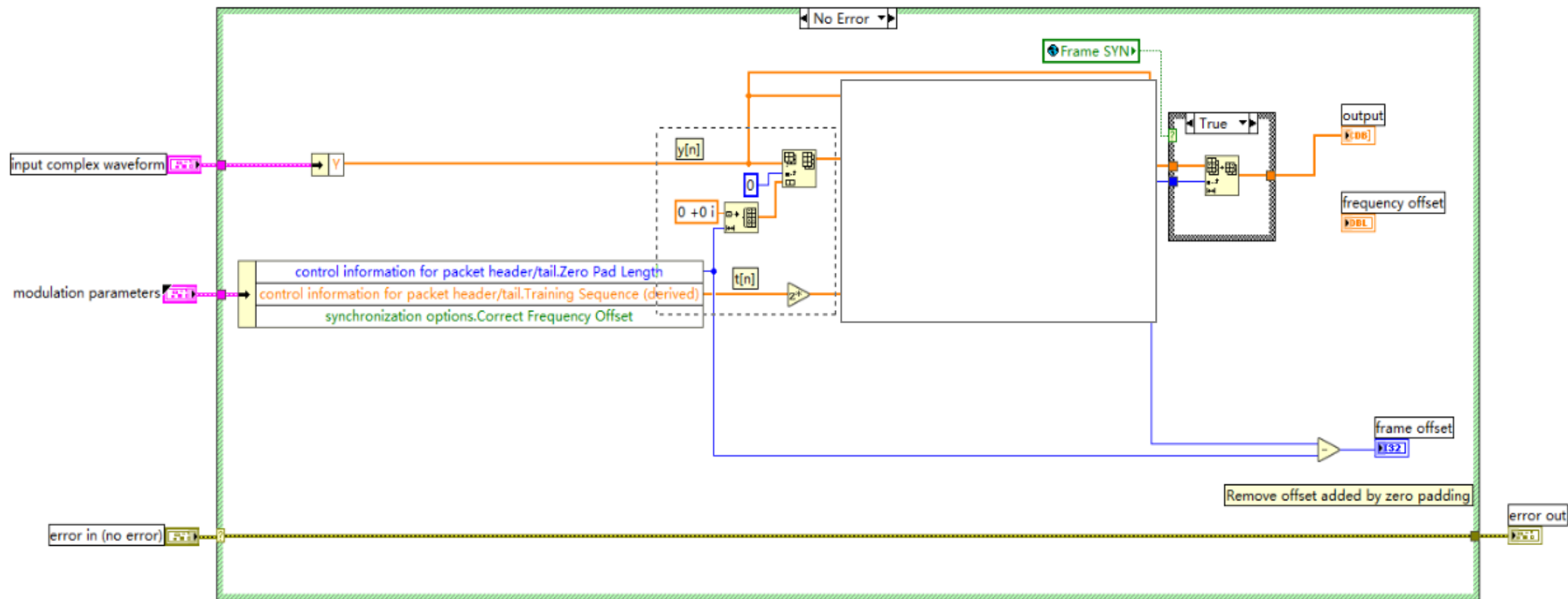


Replicate sequence



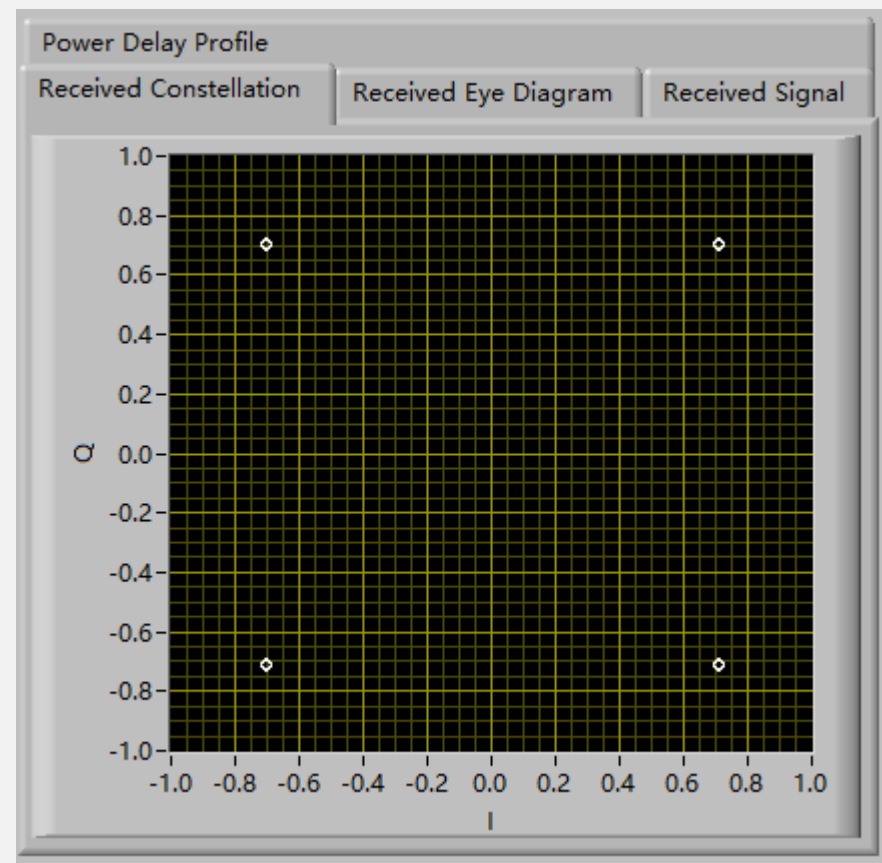
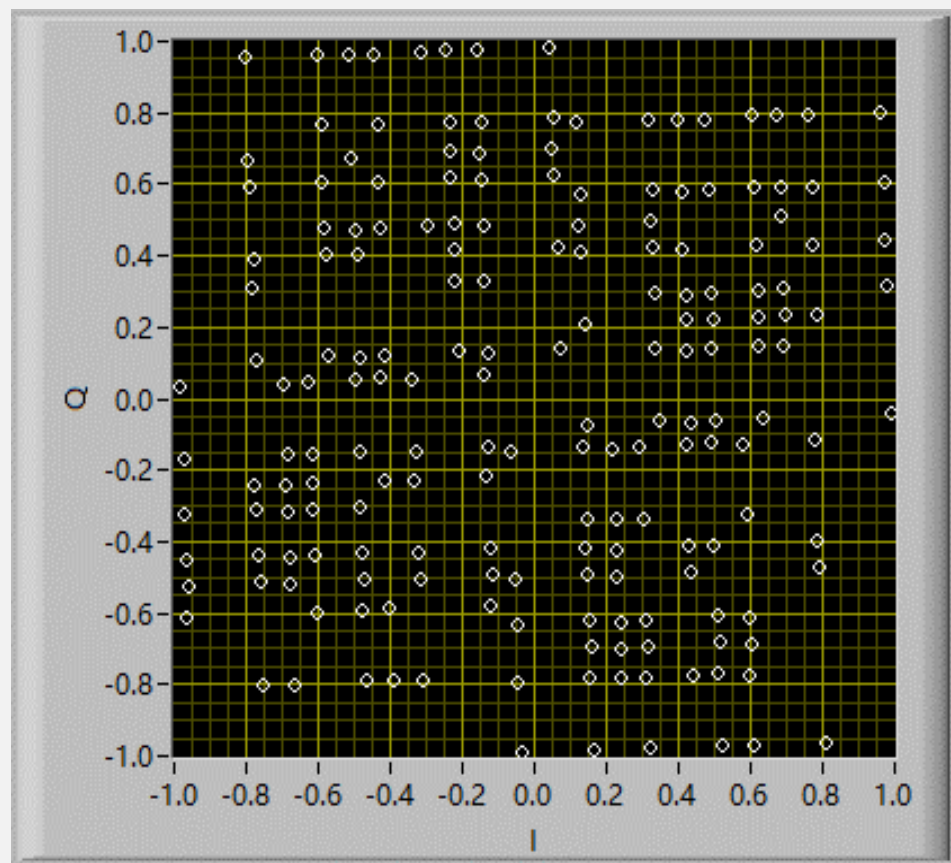
Frame Synchronization

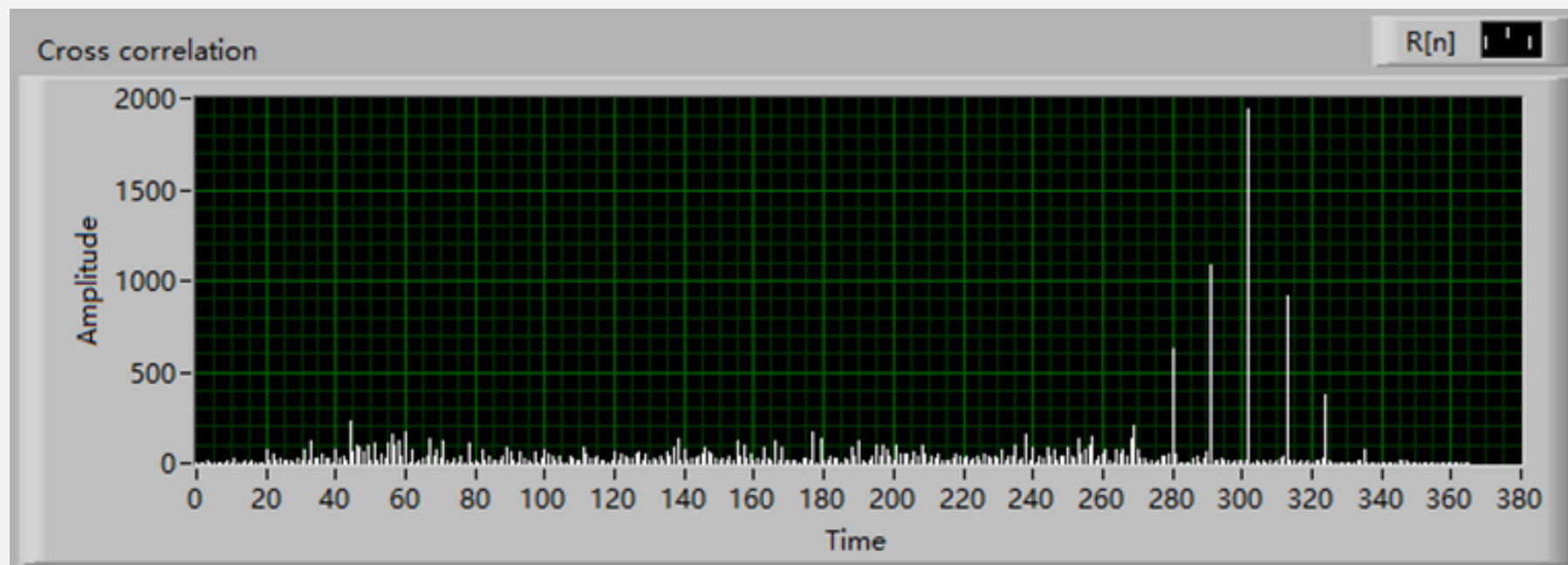






参数	设置值
调制类型	QPSK
训练序列类型	11位巴克码
Synchronization Method	Timing
下采样因子	10
Frame Detection Method	Sliding
发射接收端采样率 (Hz)	10M
包长度 (bits)	500



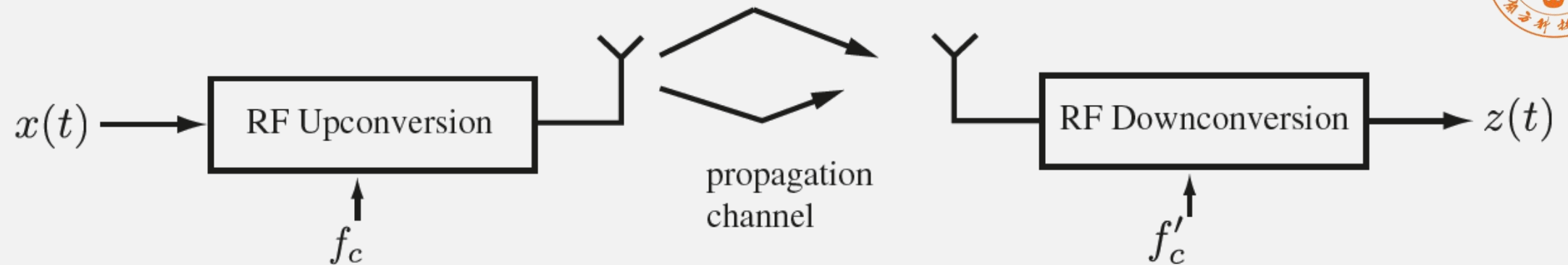


d

302



Demo: Frequency Correction



Frequency offset:

$$f_o = f_c - f'_c$$

$$z(t) = x(t)e^{j2\pi f_c t} \cdot e^{-j2\pi f'_c t} = x(t)e^{j2\pi(f_c - f'_c)t} = x(t)e^{j2\pi f_o t}$$



Moose Algorithm

- Step 1: to estimate $\epsilon = f_0 T$ with the training sequences $y[n]$,

$$\begin{aligned} y[n + N_t] &= e^{j2\pi\epsilon N_t} y[n] + v[n + N_t] \\ &\approx e^{j2\pi\epsilon N_t} y[n] \end{aligned}$$

- Step 2: solve this problem by LLSE,

$$J(a) = \sum_{l=L}^{N_t-1} \|y[l + N_t] - ay[l]\|^2$$

$$\begin{aligned} \hat{\epsilon} &= \frac{\text{phase} \sum_{l=L}^{N_t-1} y[l + N_t] y^*[l]}{2\pi N_t} \\ \hat{f}_e &= \frac{\text{phase} \sum_{l=L}^{N_t-1} y[l + N_t] y^*[l]}{2\pi T N_t} \end{aligned}$$

- Step 3: Frequency offset correction by:

$$\tilde{y}[n] = e^{-j2\pi\epsilon n} y[n]$$



Algorithm Analysis

- Let $\hat{y}(t)$ denotes the demodulated signal,

$$y(t) = x(t)e^{j2\pi f_c t}$$

$$\hat{y}(t) = x(t)e^{j2\pi f_c t} \cdot e^{-j2\pi f' t} = x(t)e^{j2\pi(f_c - f')t} = x(t)e^{j2\pi f_o t}$$

- If the $x(t) = x(t + N)$ is periodical,

$$\hat{y}(t + N) = x(t + N)e^{j2\pi f_o(t+N)}$$

$$\hat{y}(t + N) = x(t)e^{j2\pi f_o(t+N)} = x(t)e^{j2\pi f_o t} \cdot e^{j2\pi f_o N} = \hat{y}(t)e^{j2\pi f_o N}$$

Accuracy

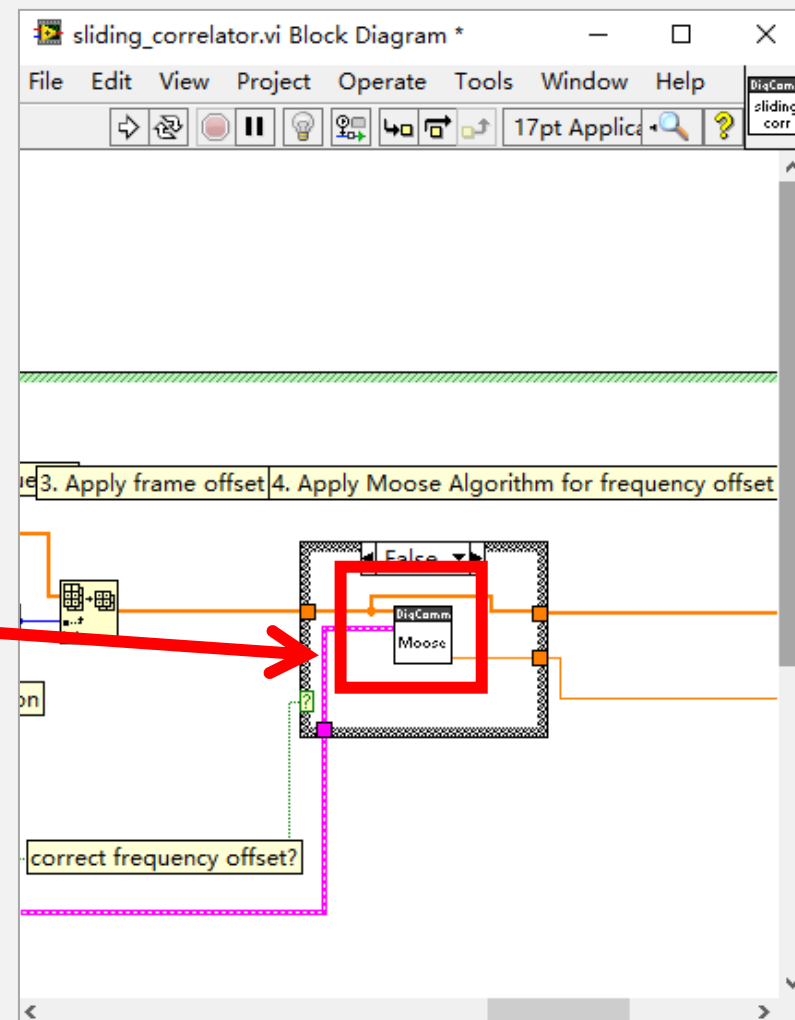
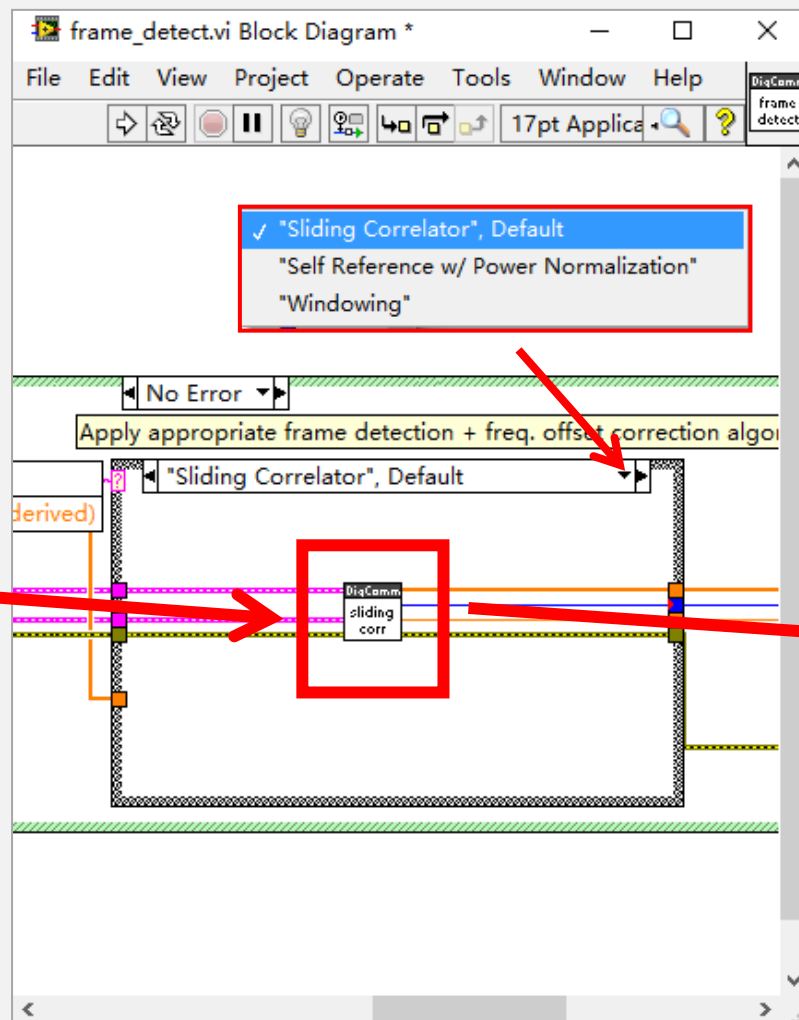
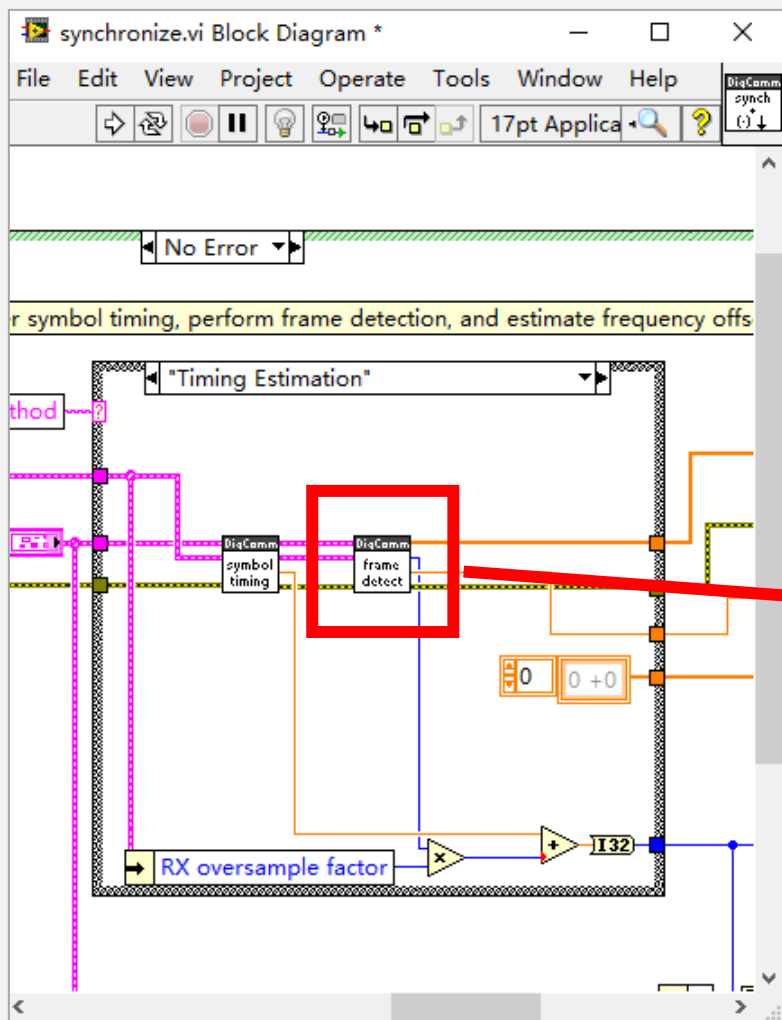


$$\hat{f}_e \in \left[-\frac{1}{2T_s N_t}, \frac{1}{2T_s N_t} \right]$$



Frequency Offset Correction

Replace moose.vi



Steps



$$\hat{f}_e = \frac{\text{phase} \sum_{l=L}^{N_t-1} y[l + N_t] y^*[l]}{2\pi T N_t}$$



Simulation Results



TRANSMITTER

TX oversample factor TX sample rate
4 4M

TX channel model parameters

channel model
AWGN

noise power (dB)
-Inf

channel response
0 0 + 0i 0 + 0i 0 + 0i

frequency offset
0

delay (sec)
0

RECEIVER

RX oversample factor RX Sample Rate
4 4M

synchronization options

Synchronization Method fixed offset
Timing 0

Symbol Timing Recovery Method
Max Energy

Frame Detection Method
Sliding

Correct Frequency Offset
☒

channel estimation/equalizer parameters

Equalization Method
Direct

channel estimate length
4

equalizer length
4

equalizer delay
-1
(set delay to -1 for equalizer to choose optimal delay)

SHARED

modulation type packet length (bits) # of iterations
QPSK 500 1

control information for packet header/tail

Training Sequence Type
Length 11 Barker Sequence

Zero Pad Length
8

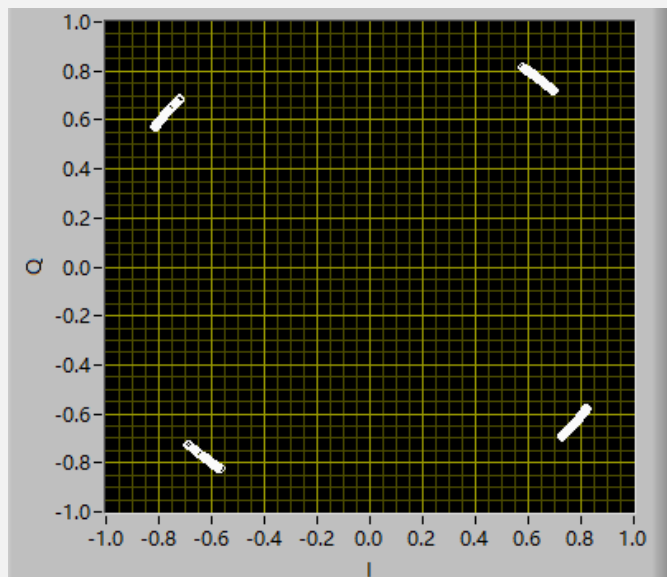
pulse shaping parameters

modulation type
PSK

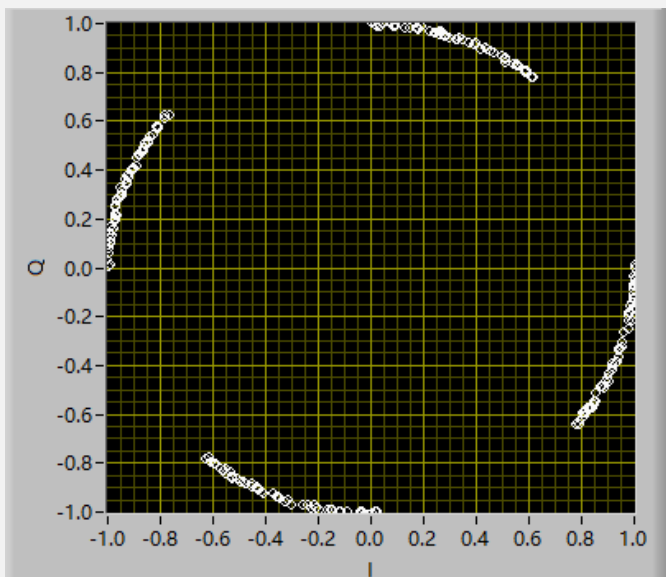
pulse shaping filter
Raised

filter parameter
0.5

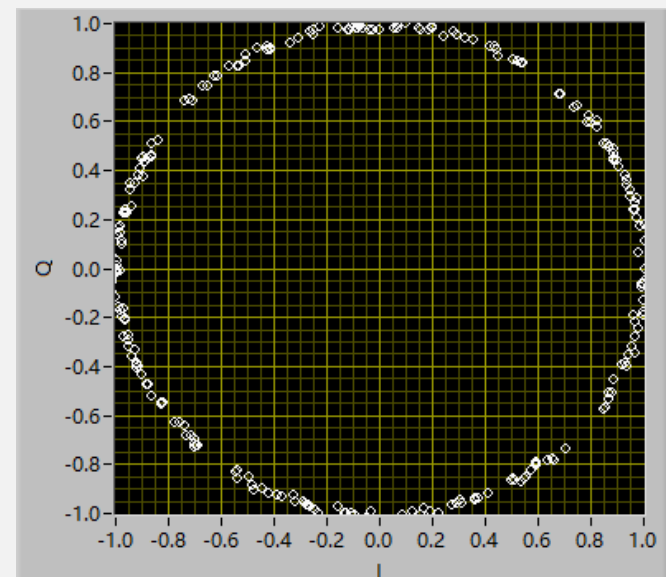
filter length (symbols)
8



$$f_o = 100\text{Hz}$$



$$f_o = 450\text{Hz}$$

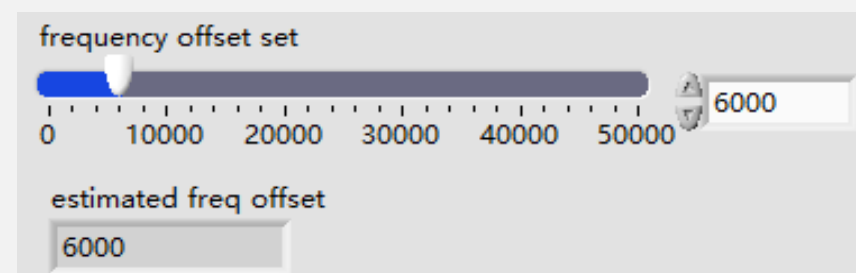
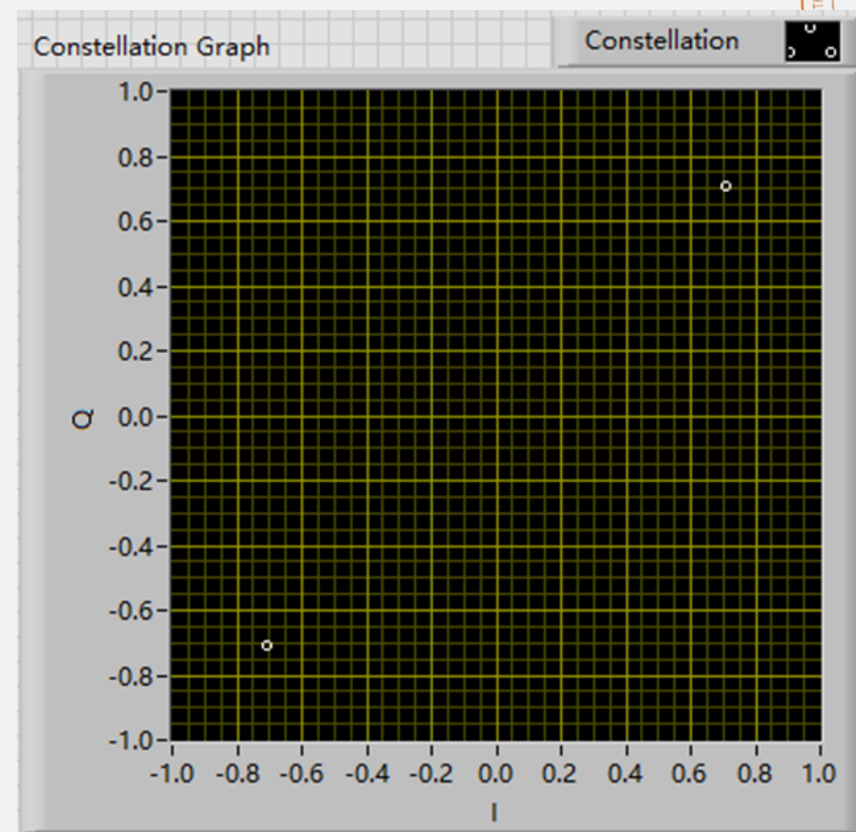
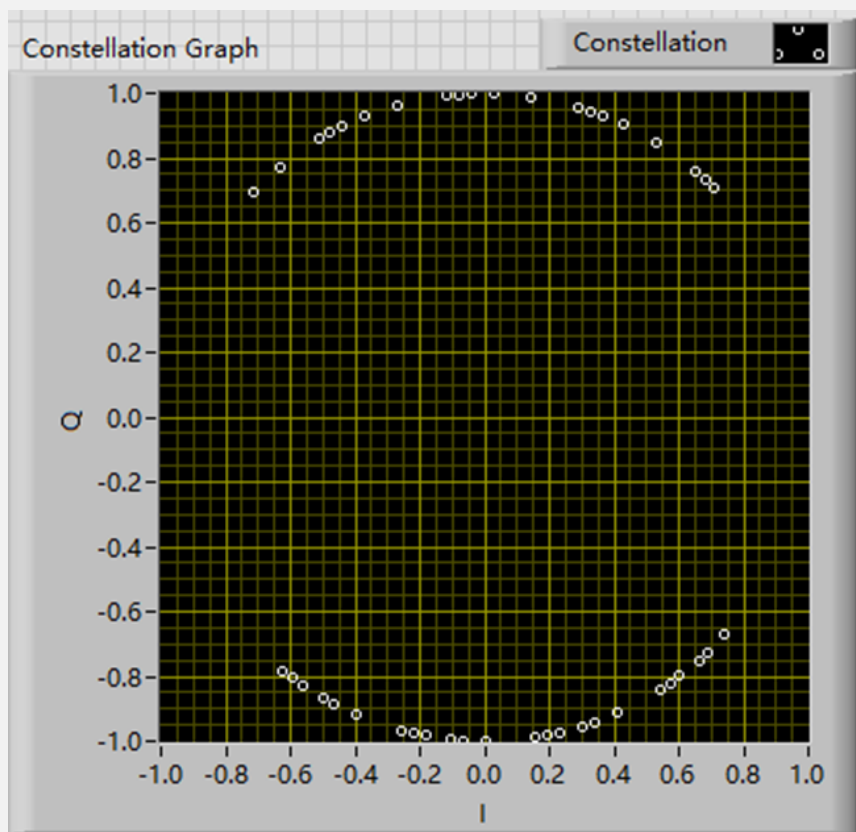
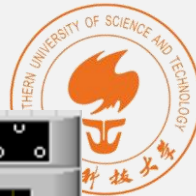


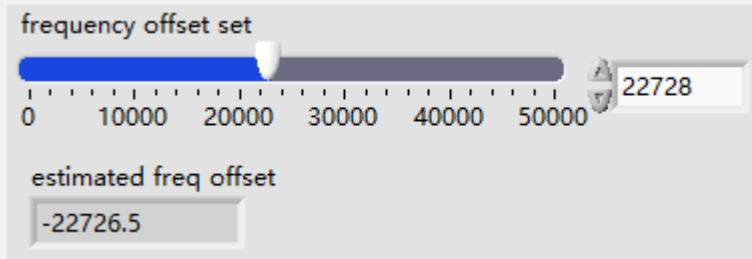
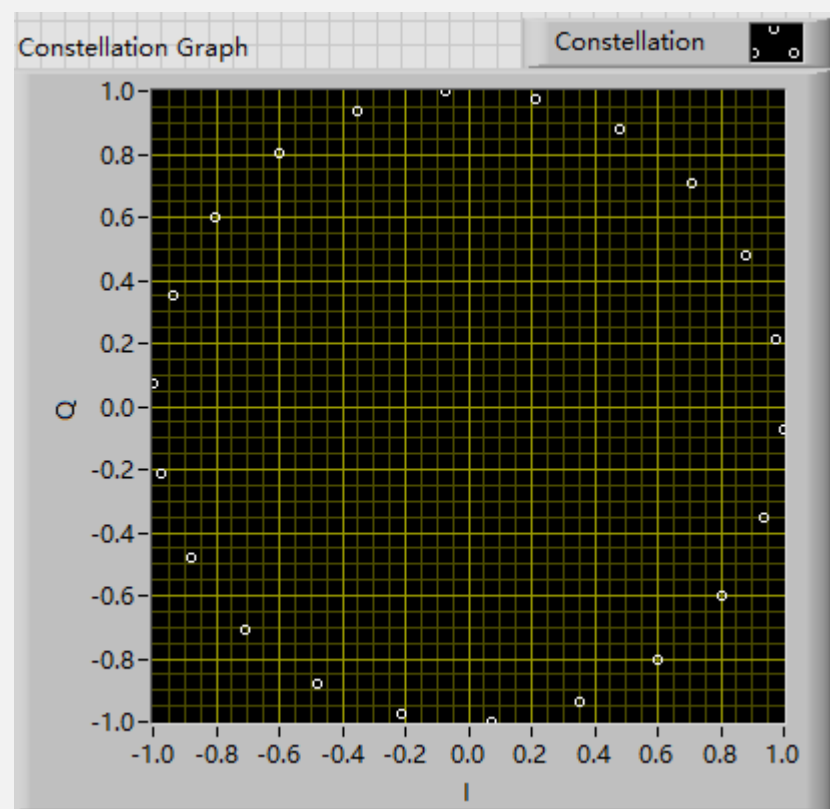
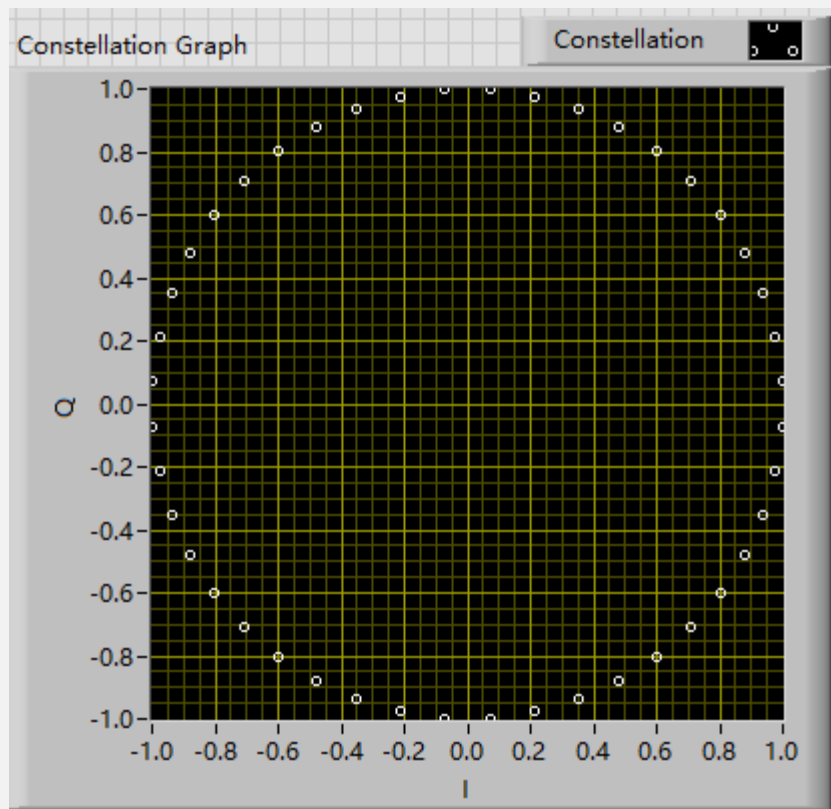
$$f_o = 900\text{Hz}$$

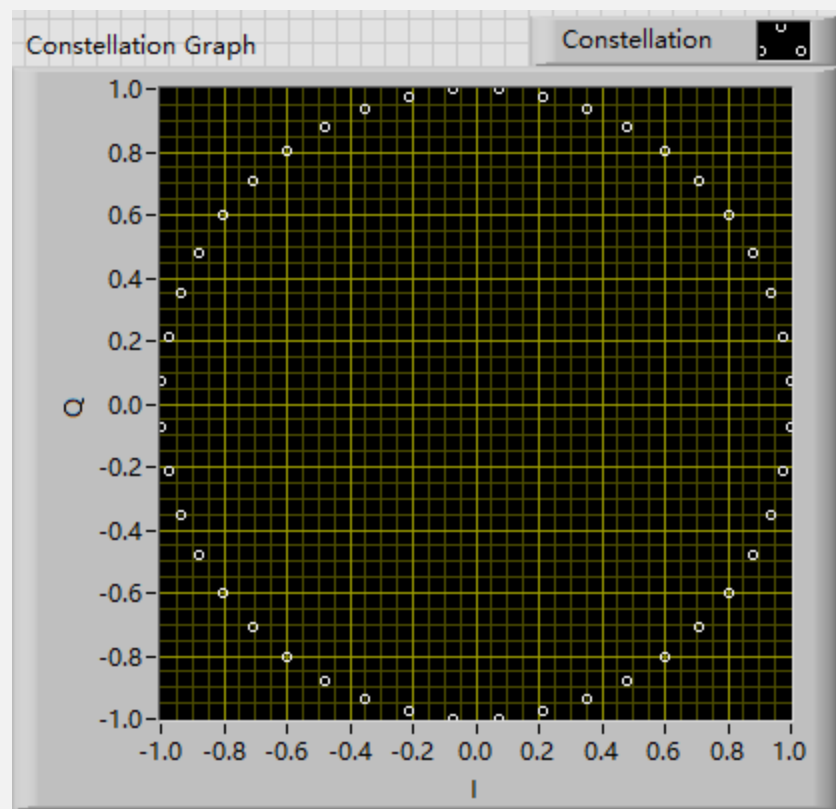
$$\text{Phase deg.} = 2 \cdot 180^\circ \cdot f_o \cdot n_{\max} \cdot \frac{1}{f_s}, \quad n_{\max} = 299, f_s = 1\text{M/s}$$

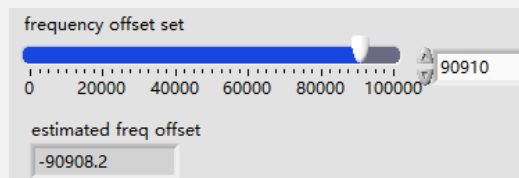
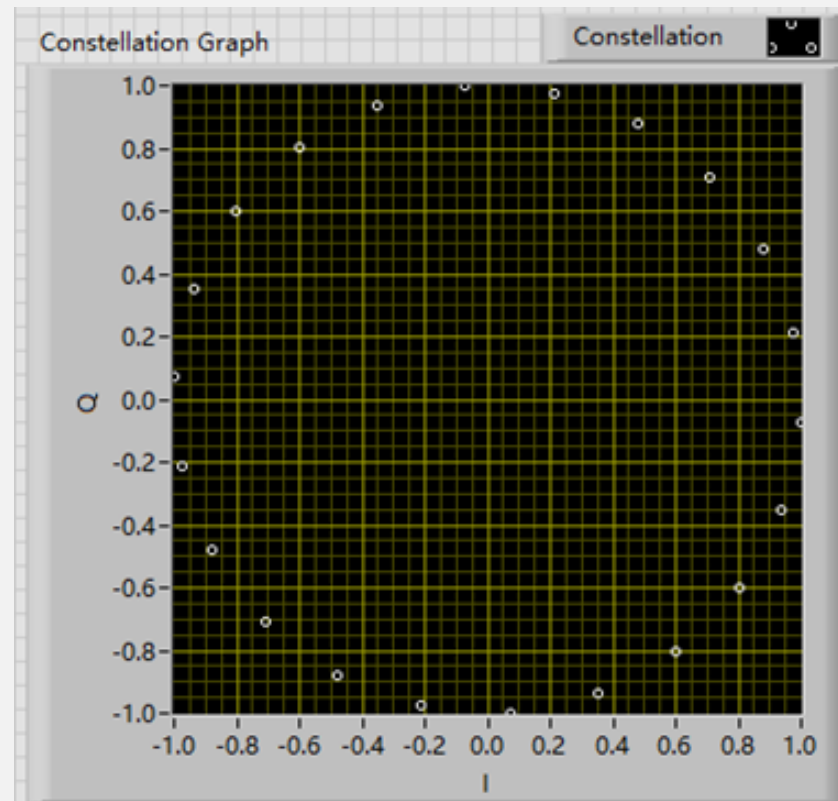
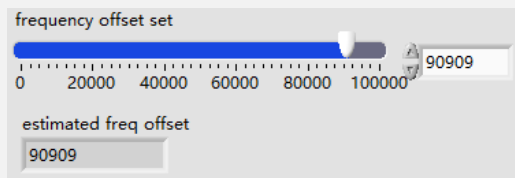
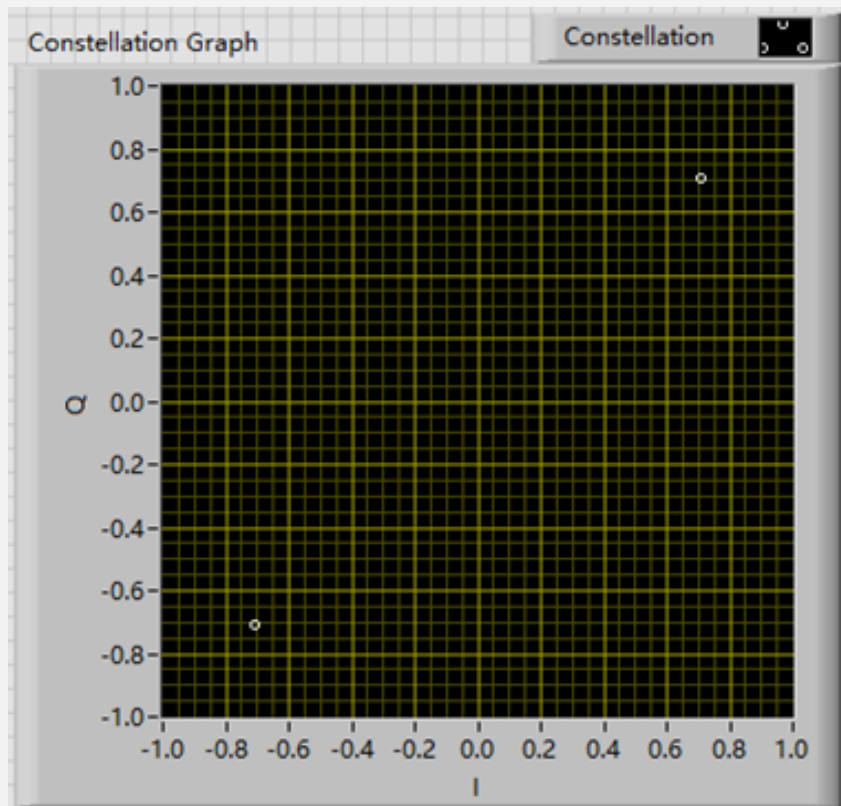


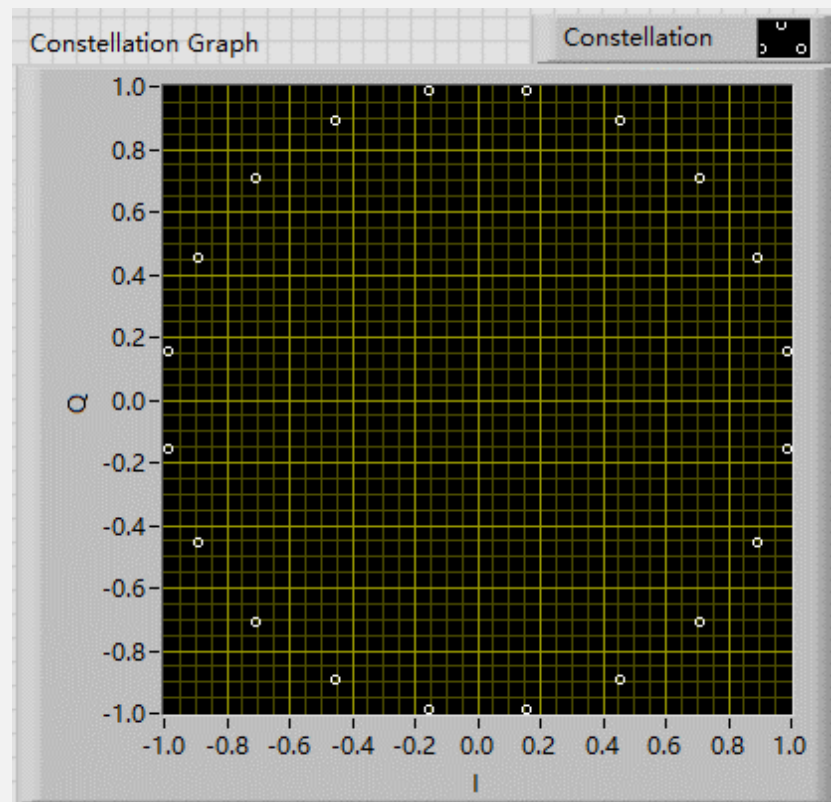
Performance Analysis

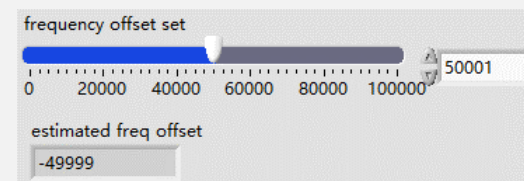
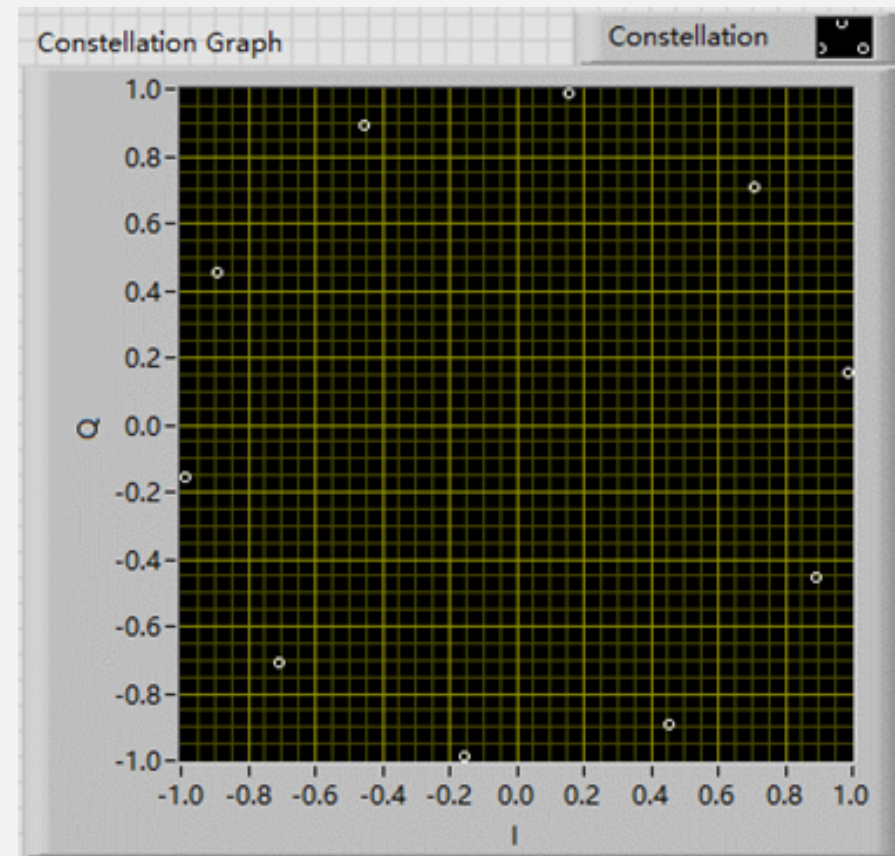
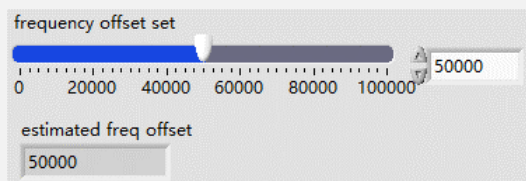
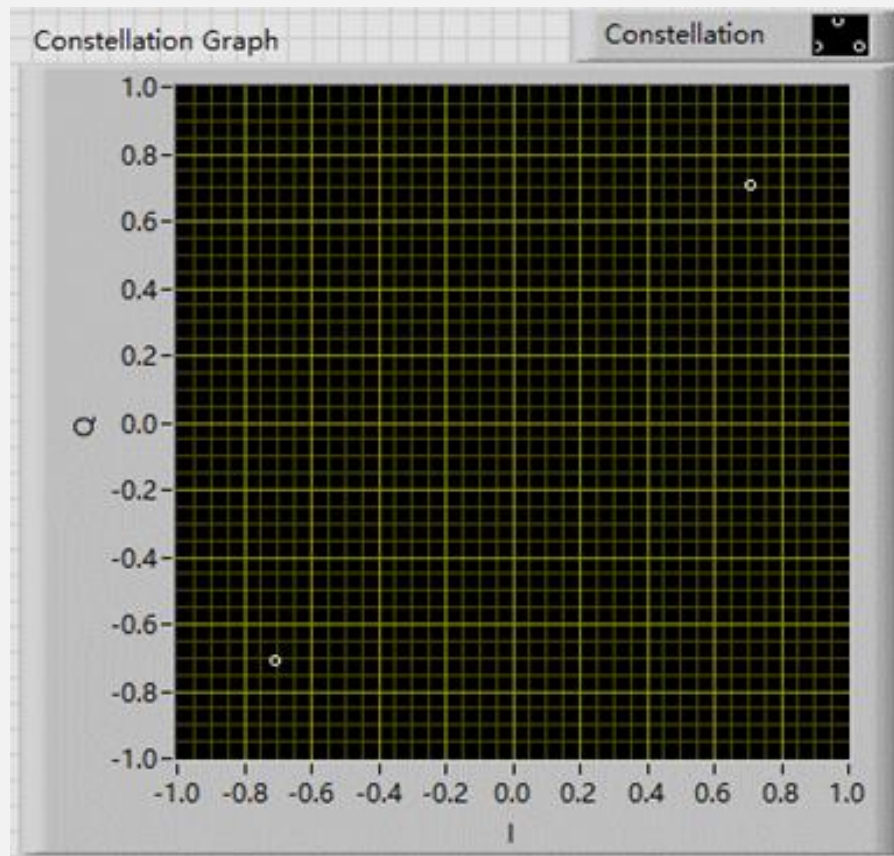




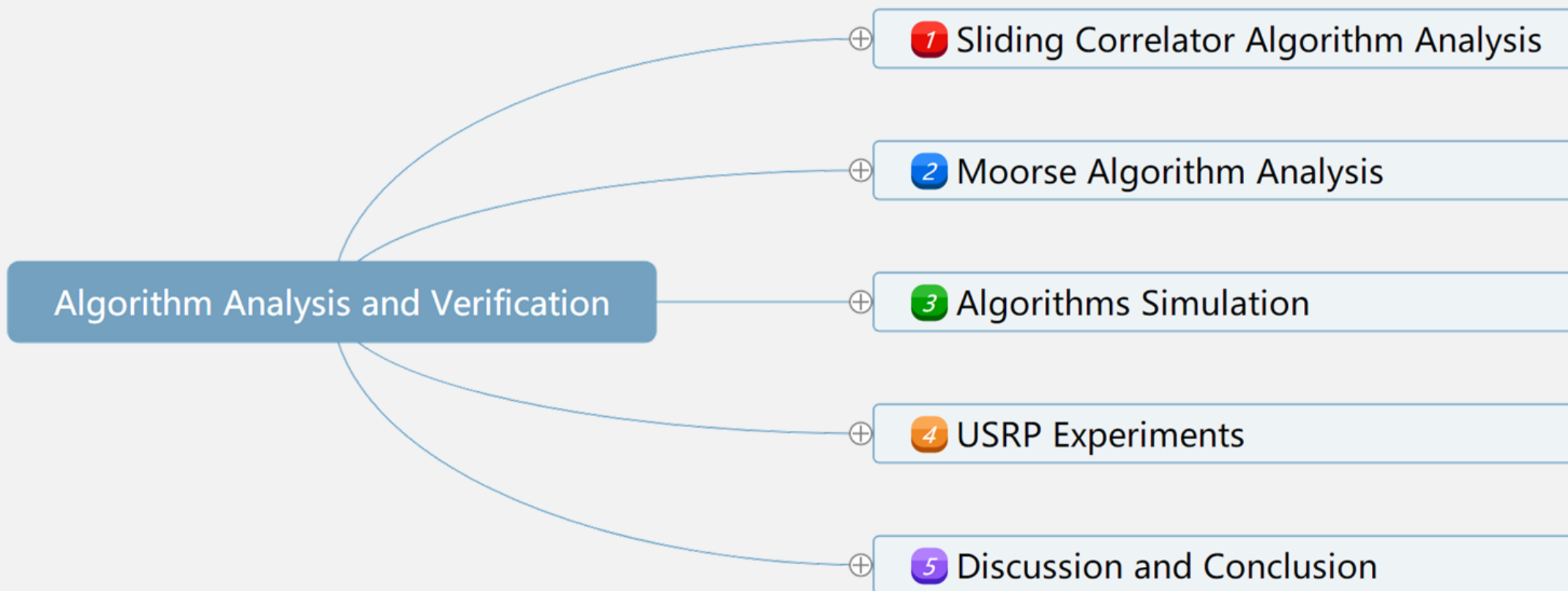














USRP Experiment Setup

channel model

AWGN

noise power (dB)

channel response

frequency offset

delay (sec)

channel model

ISI

noise power (dB)

channel response

frequency offset

delay (sec)

channel model parameters

HW parameters modulation parameters

modulation type TX oversample factor TX sample rate

QPSK 20 4M

packet length (bits)

pulse shaping parameters

modulation type

PSK

pulse shaping filter

Raised

filter parameter

0.5

filter length (symbols)

8

control information for packet header/tail

Training Sequence Type

Length 11 Barker

Zero Pad Length

HW parameters modulation parameters

modulation type RX oversample factor RX Sample Rate

QPSK 20 4M

number of data symbols (derived)

pulse shaping parameters

modulation type

PSK

pulse shaping filter

Raised

filter parameter

0.5

filter length (symbols)

8

control information for packet header/tail

Training Sequence (derived) Zero Pad Length

channel estimation/equalizer parameters

Equalization Method

Direct

channel estimate length

equalizer length

equalizer delay

(set delay to -1 for equalizer to choose optimal delay)

synchronization options

Synchronization Method

Timing Estimation

fixed offset

Symbol Timing Recovery Method

Max Energy

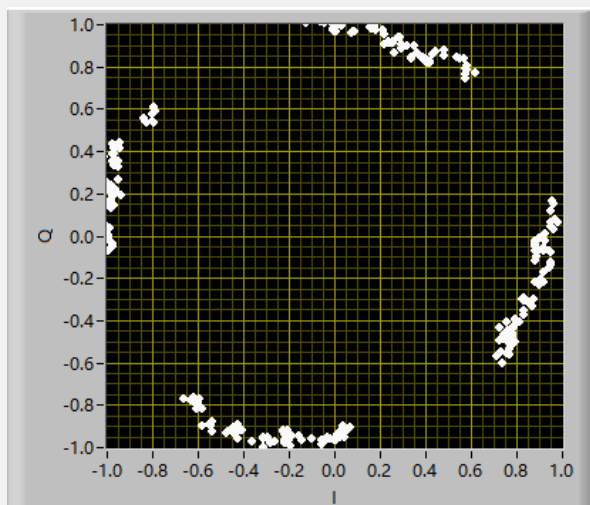
Frame Detection Method

Sliding

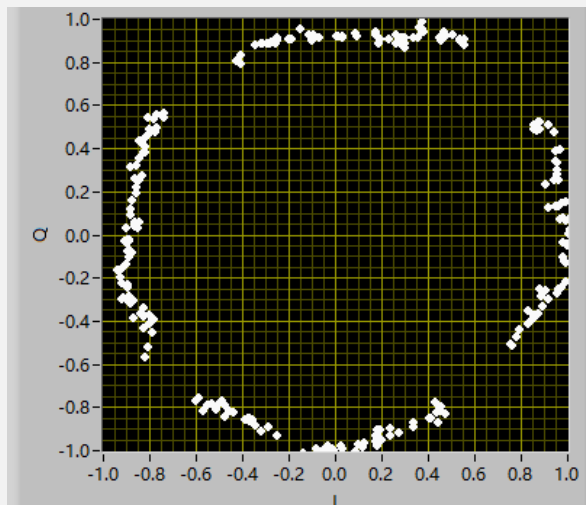
Correct Frequency Offset



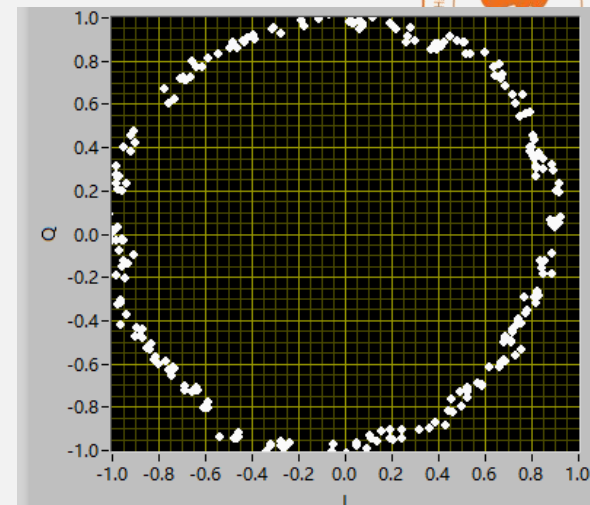
No Correction



$f_o = 100\text{Hz}$



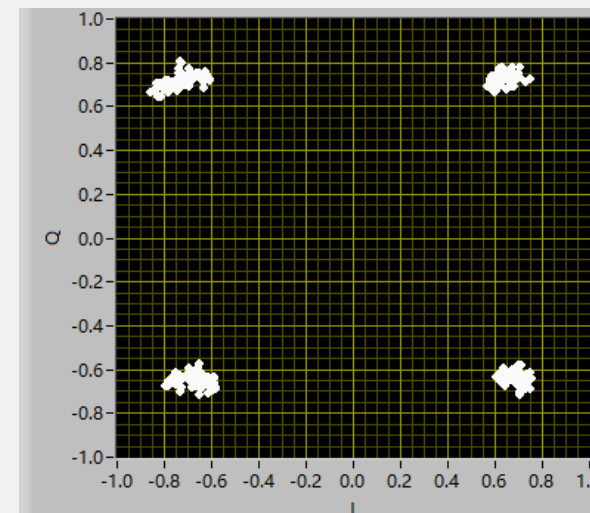
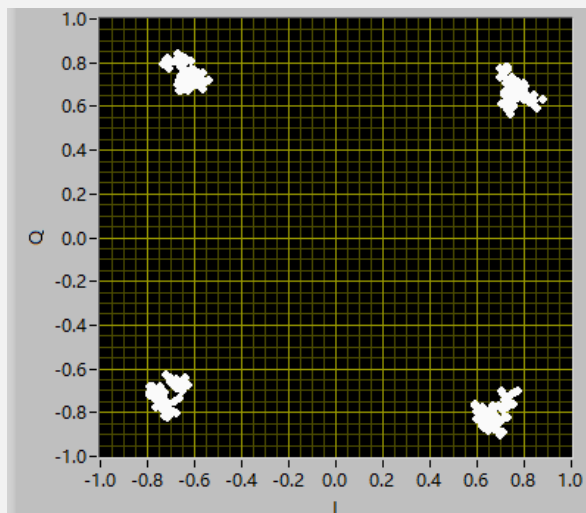
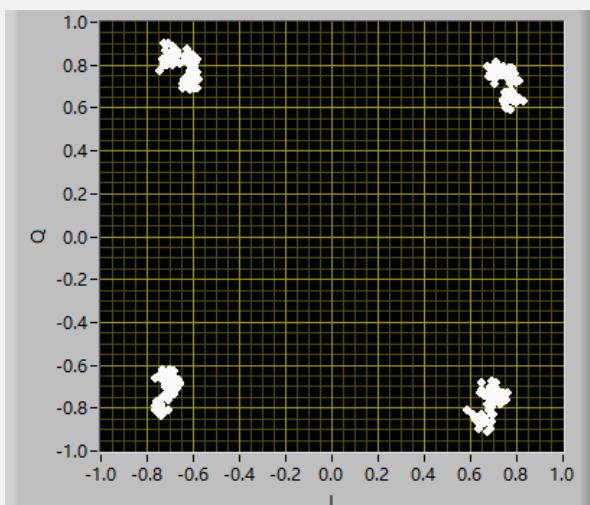
$f_o = 150\text{Hz}$

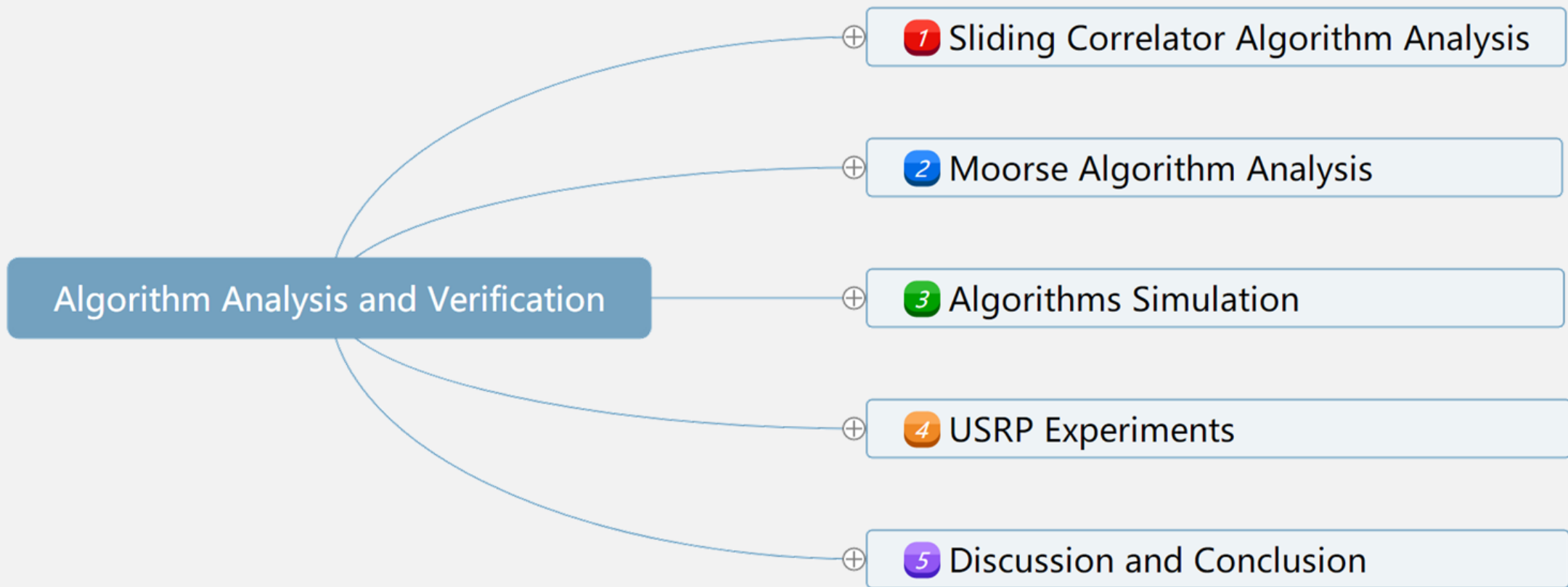


$f_o = 200\text{Hz}$



Correction







- Question ?

