Design, simulation, implementation and testing of search and tracking modules for a FPGA-based GPS receiver
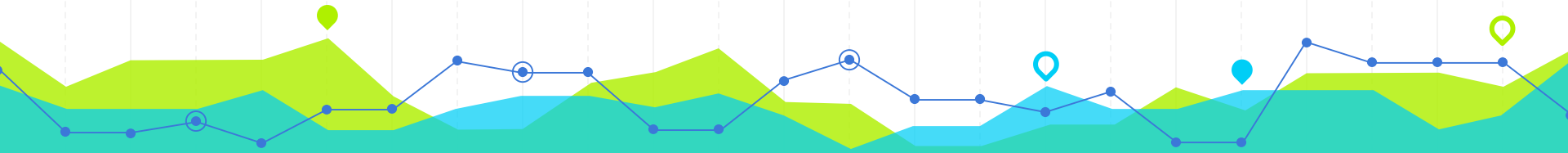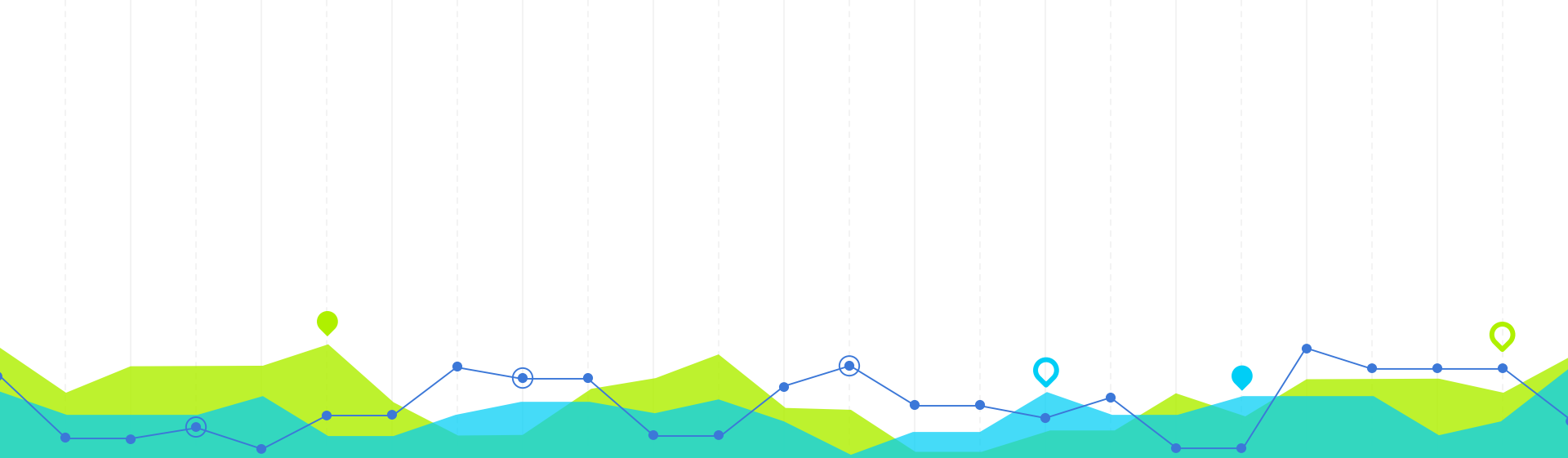
Author
Facundo S. Larosa
Universidad Tecnológica Nacional
Facultad Regional Haedo

X Southern Programmable Logic Conference
SPL 2019
Buenos Aires, Argentina
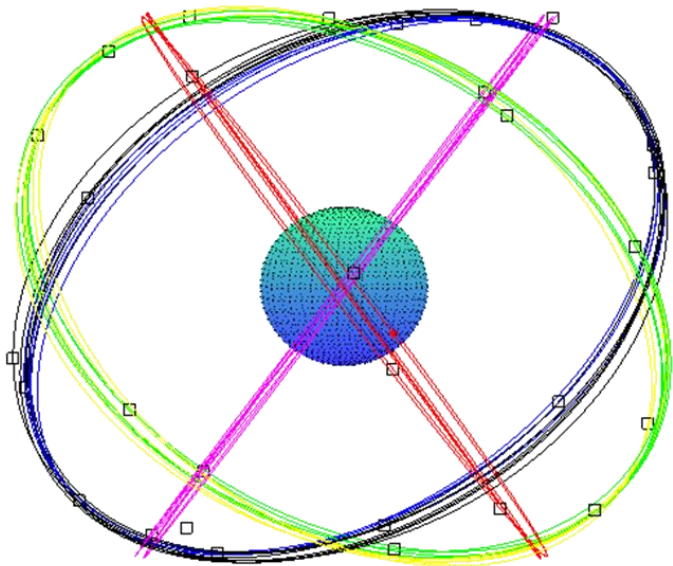
Summary

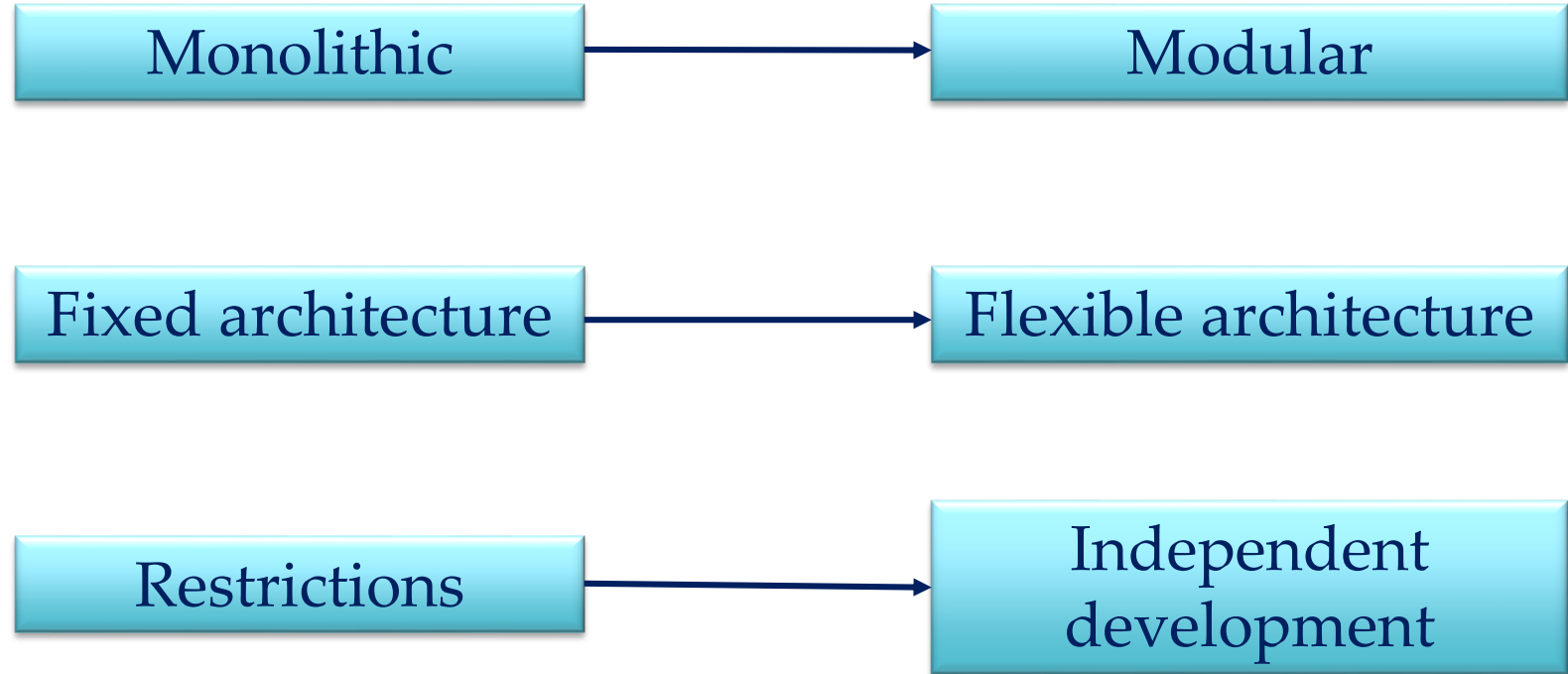# Introduction

1

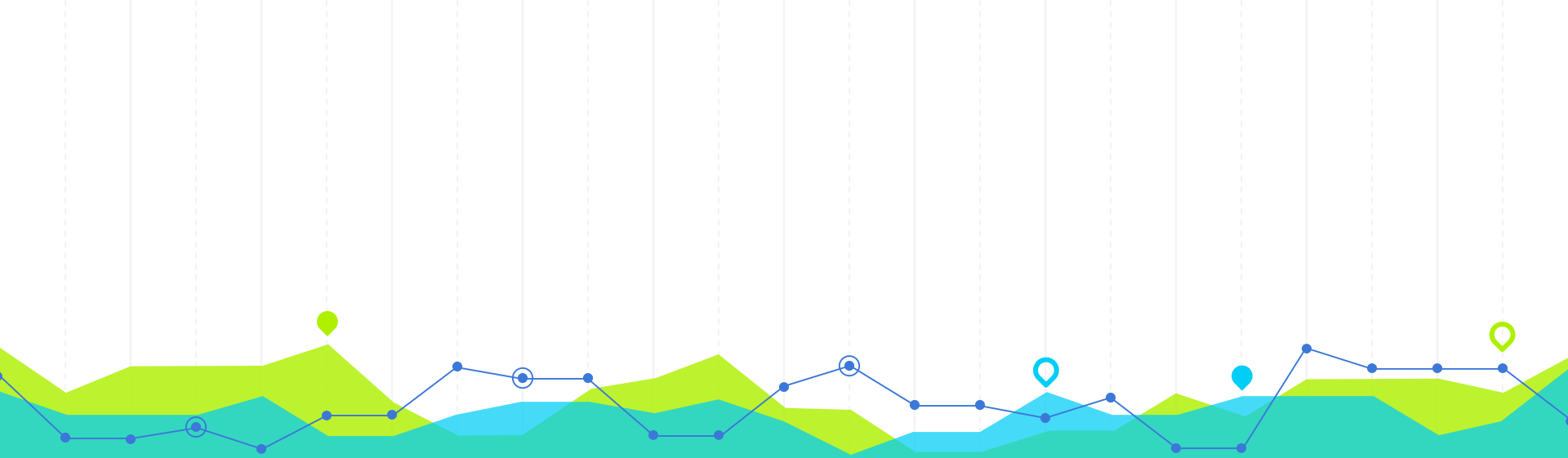# Global navigation satellite systems

GPS system orbits

Global navigation satellite systems are of great importance for military, commercial, economic and scientific activities.

- ⦿ **GPS (United States of America)**
- ⦿ GLONASS (Russian Federation)
- ⦿ Beidou (People's Republic of China)
- ⦿ Galileo (European Union)
- ⦿ INSS (India) *

| Limitations	Characteristics
Monolithic	→ Modular
Fixed architecture	→ Flexible architecture
Restrictions	→ Independent development

GPS L1 signal basics

2

GPS signal generation

◉ **Navigation message:** It is composed by *ephemerides* (orbital parameters) and satellite's status variables.

◉ **C/A code**: It is a pseudorandom sequence defined uniquely for each satellite. It provides redundancy to the message and allows discrimination between satellites.

◉ **Carrier:** It allows the composite signal (navigation message plus C/A code) to be radiated. All satellites share the same carrier frequency.
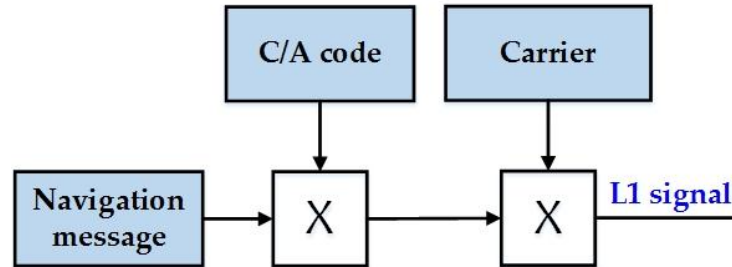
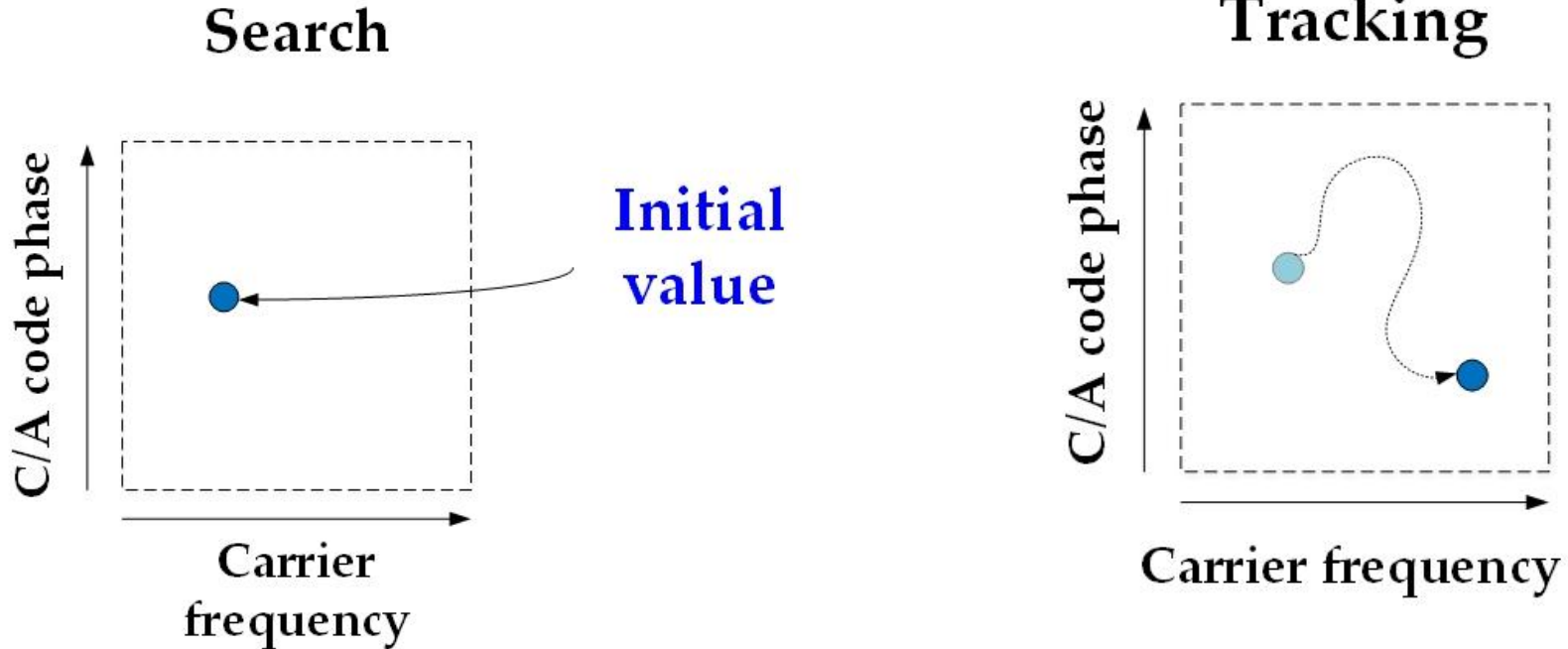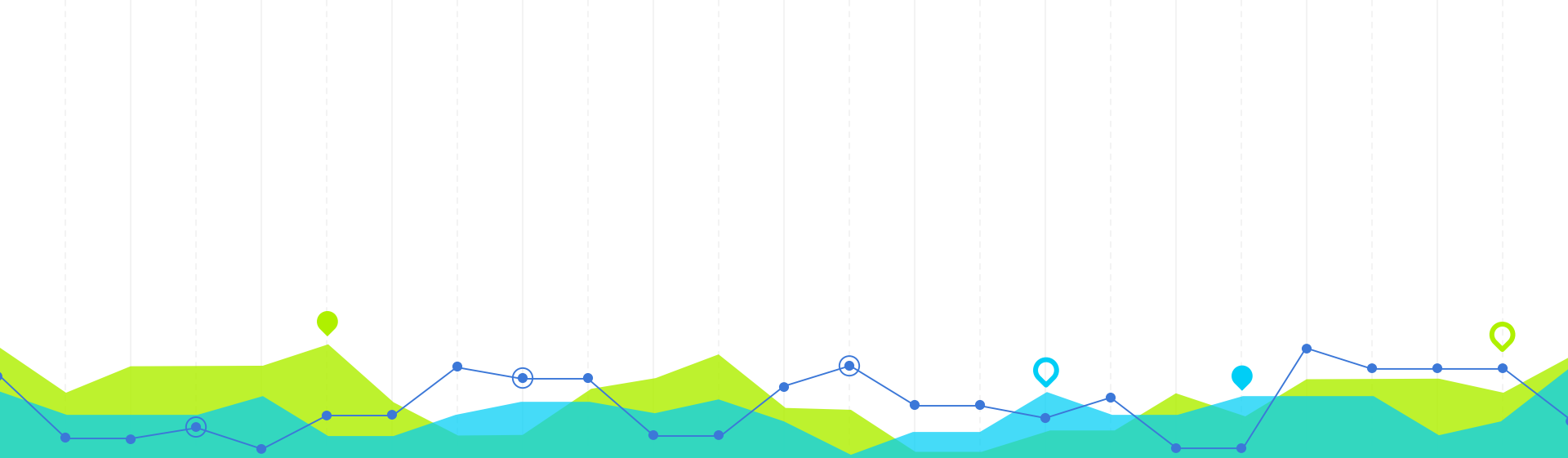# GPS signal generation and demodulation
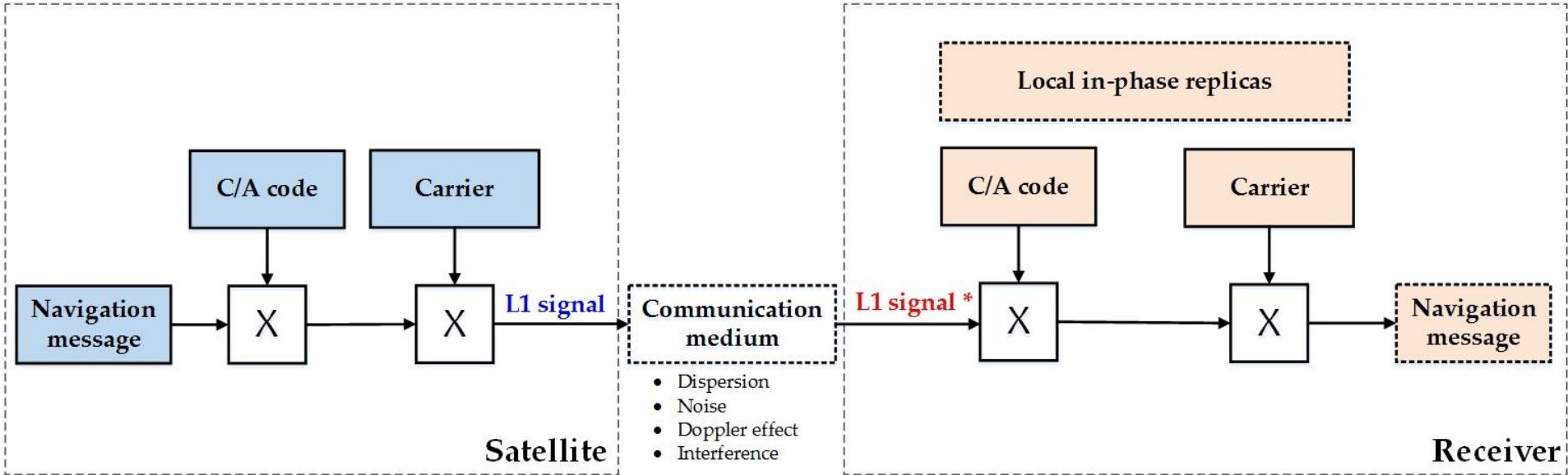
GPS signal demodulation
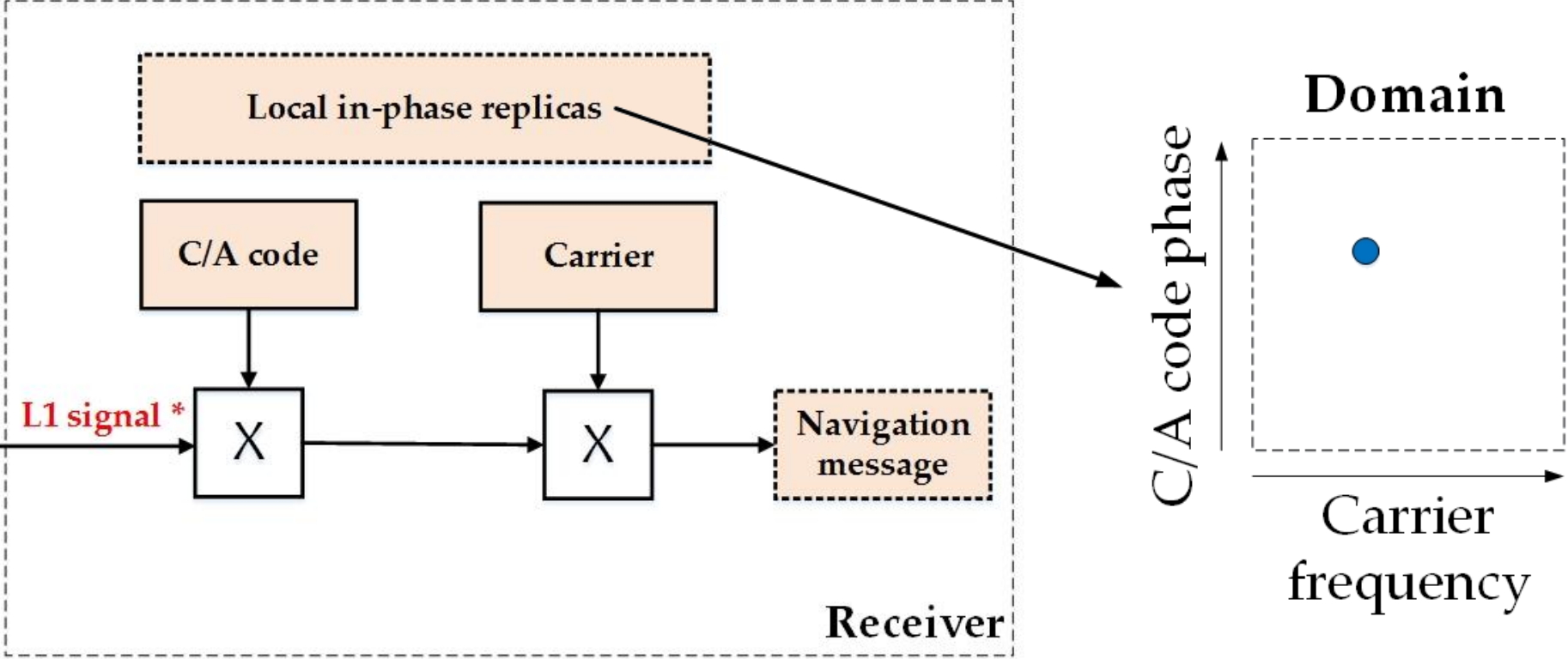
GPS signal demodulation

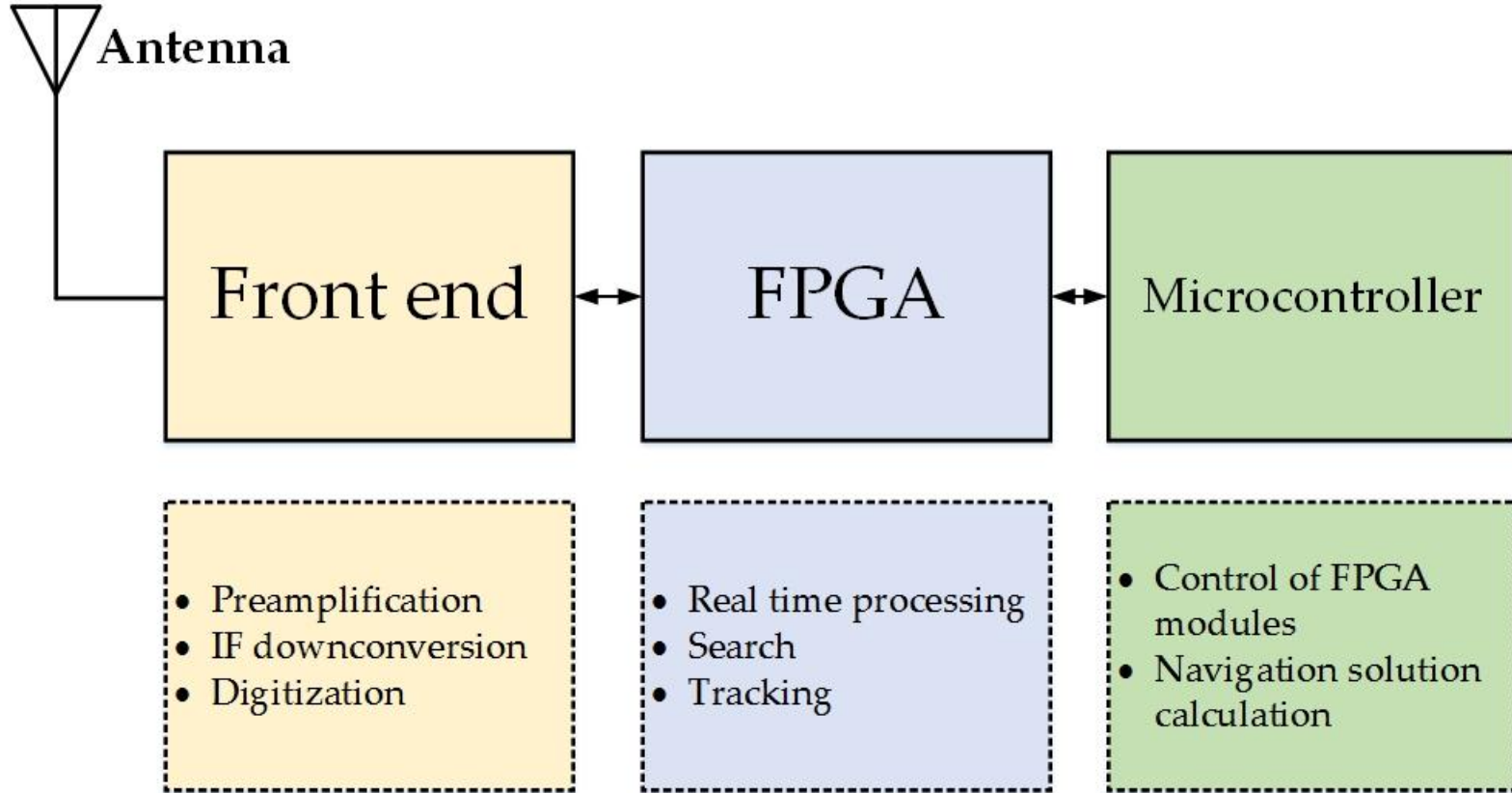In order to demodulate GPS signal, two fundamental operations must be done:
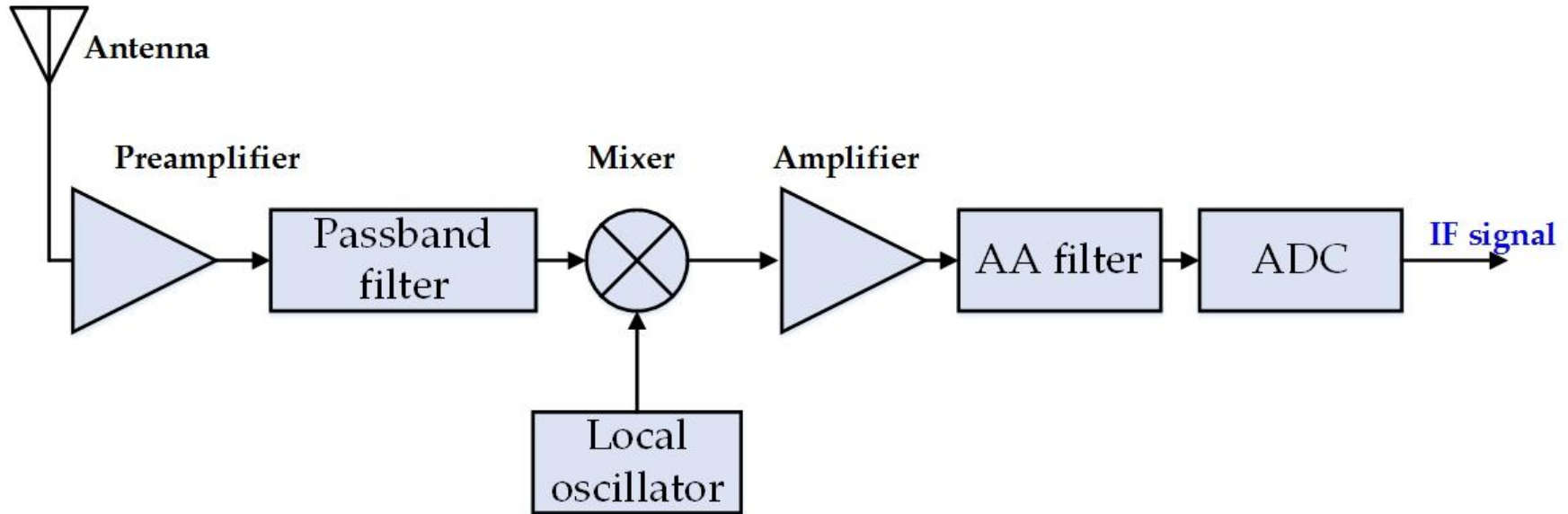
Proposed architecture

3

Receiver architecture

Front end 3.1

Front end: Functionality

The main functions of the front end are to:
- **Preamplify** input signal in order to improve noise figure
- **Filter** input signal
- Downconvert input signal to **intermediate frequency (IF)**
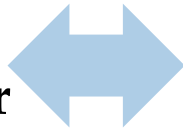- **Digitize** IF signal so it can be digitally processed

Front end

A PCB board was developed for the front end which could use an active or passive antenna for RF input and could be connected directly to FPGA development kit.

An integrated specific integrated circuit was used (Skyworks 4150):

◉ Low cost
◉ Interoperability
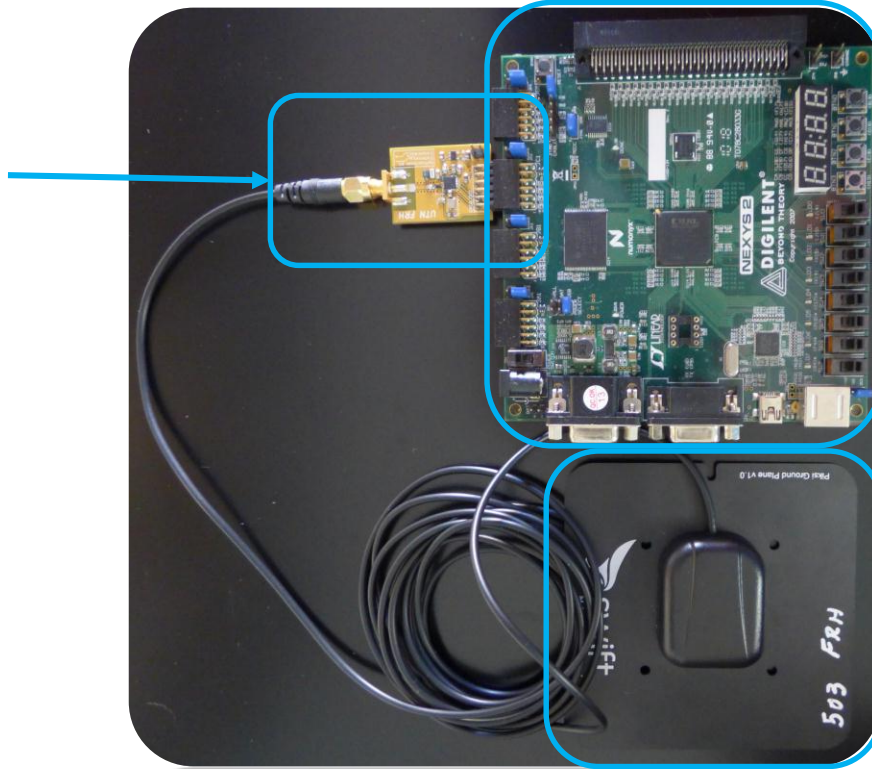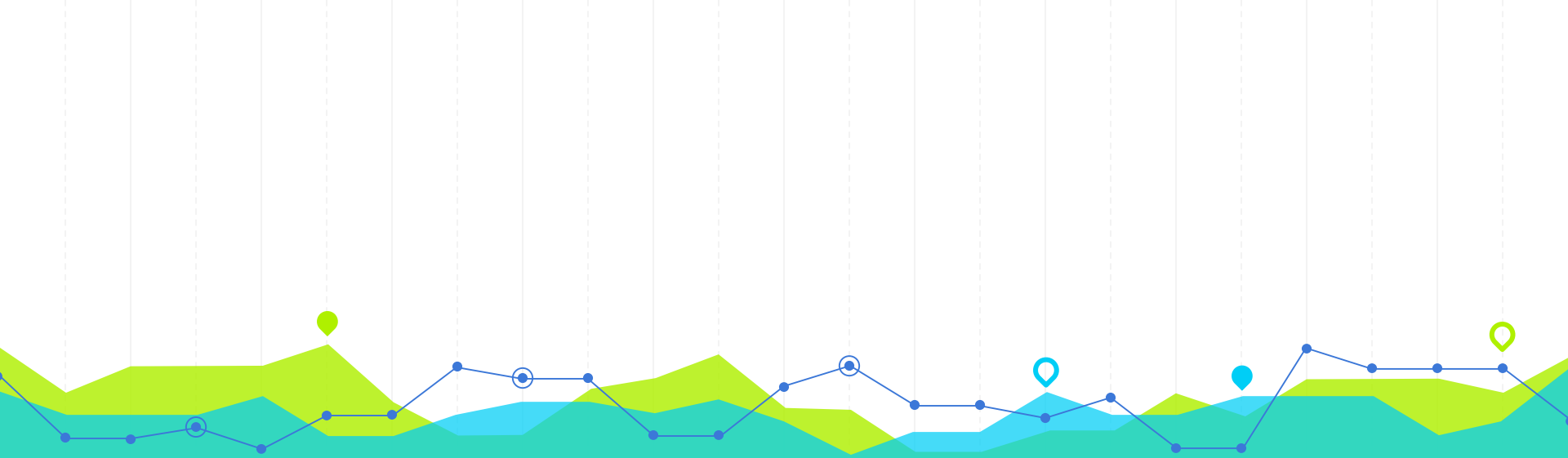◉ Different configuration alternatives

FPGA kit / front end integration

Front end

FPGA development kit

Active antenna

Search module 3.2

Workflow
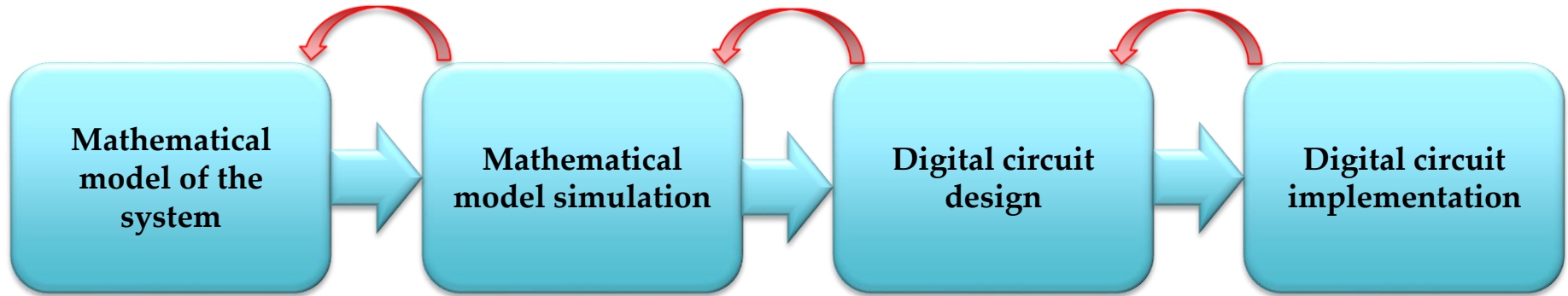
| Mathematical model of the system	Mathematical model simulation	Digital circuit design	Digital circuit implementation
Analysis of equations which describe system operations (discrete time, Z domain, etc.)	Simulation of models using synthetic and real signals	A digital circuit which implements the simulated mathematical model is implemented	Digital circuit is described using a HDL (VHDL)

Search module

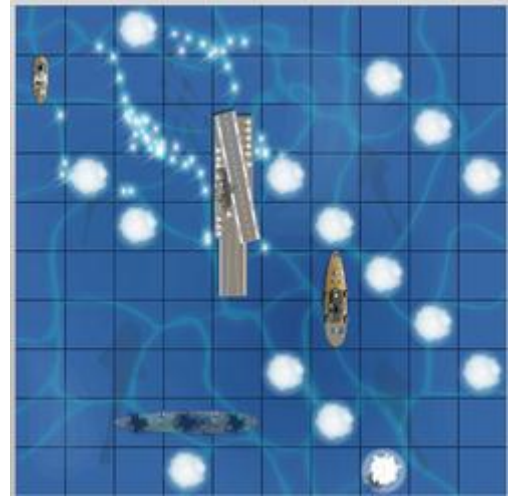Search operation involves finding for the input signal of a given satellite:
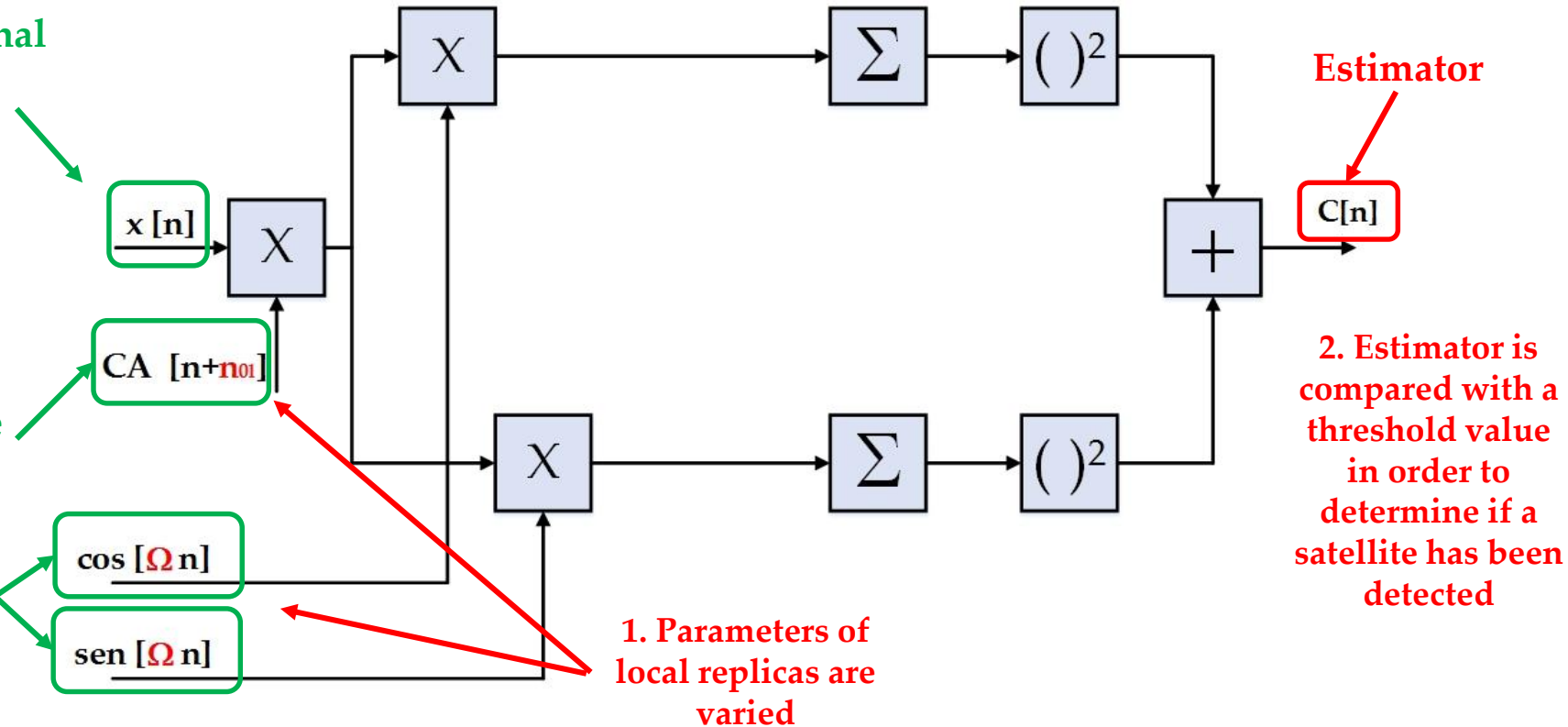
◉ C/A code phase

◉ Carrier frequency

Image credit: kde.org
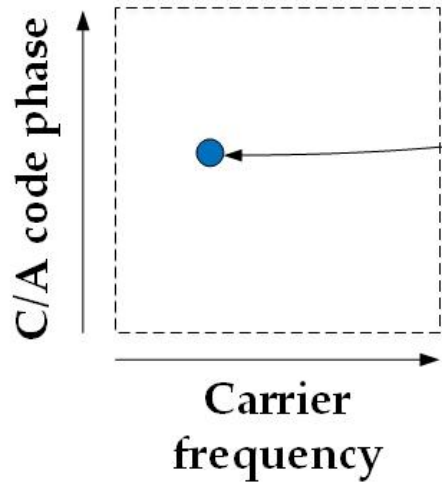
Search module: structure

Search module operation

As a result of search operation, a C estimator is obtained for different pairs of the domain for a particular satellite.

◉ Satellite is present

Carrier frequency variation [Hz]

CA code phase [chips]
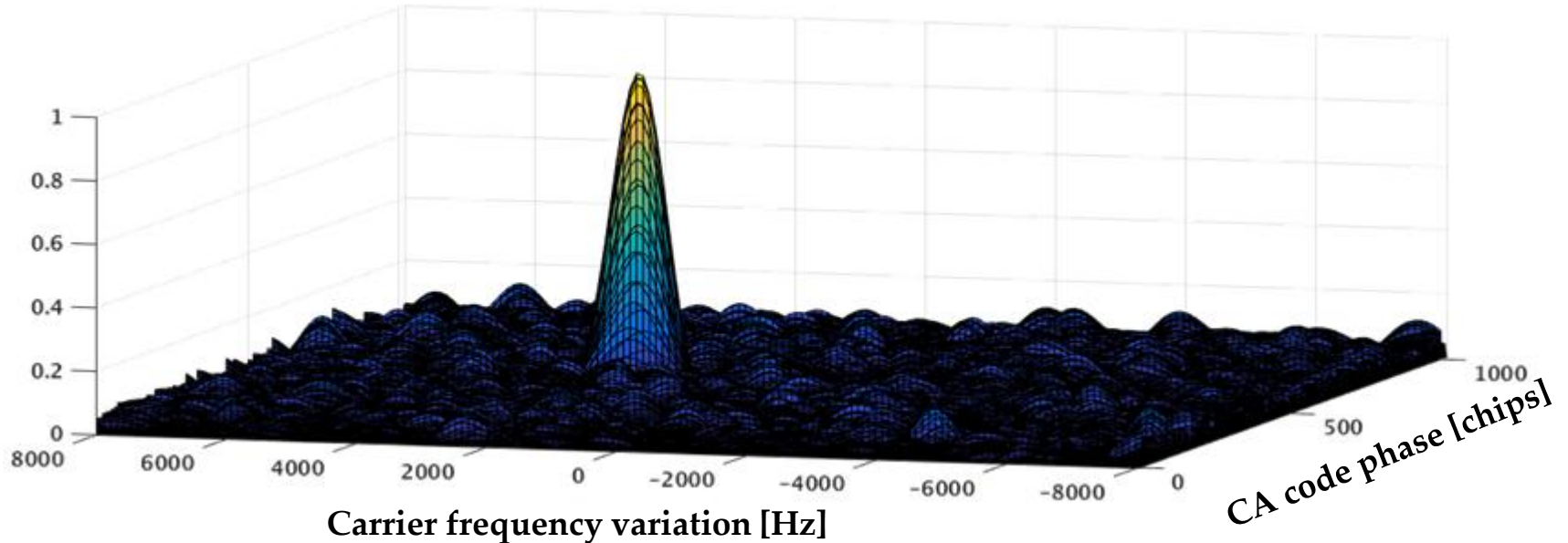
Search module operation

As a result of search operation, a C estimator is obtained for different pairs of the domain for a particular satellite.
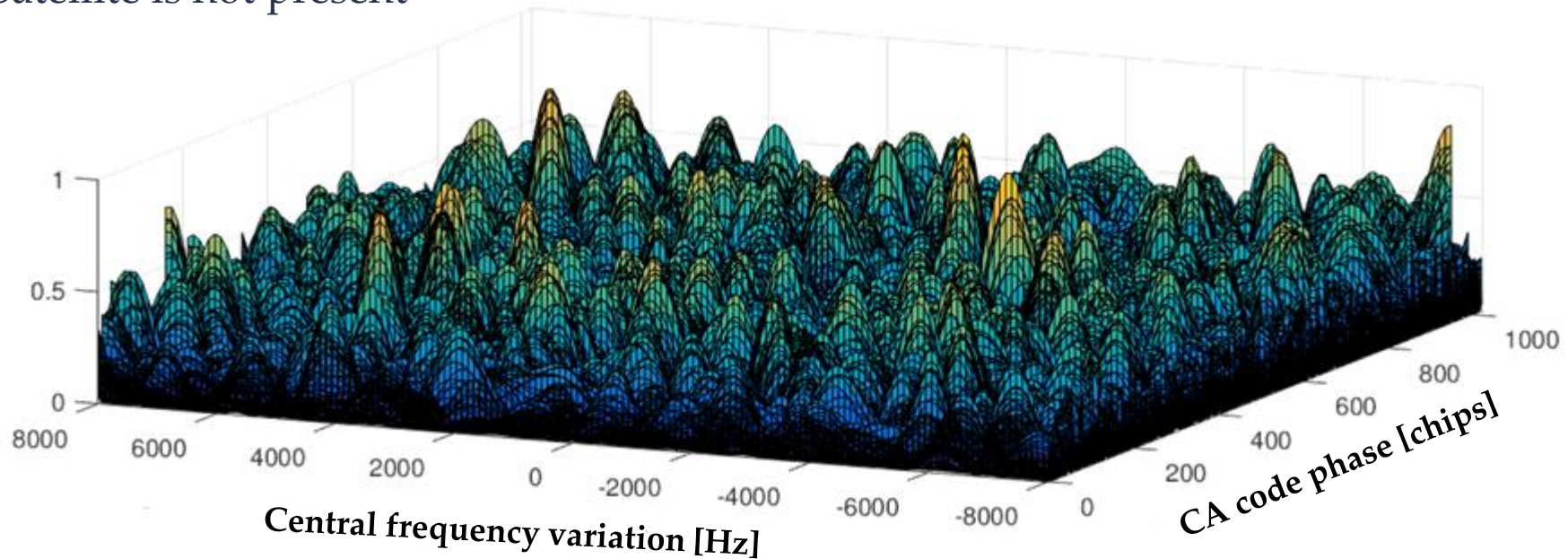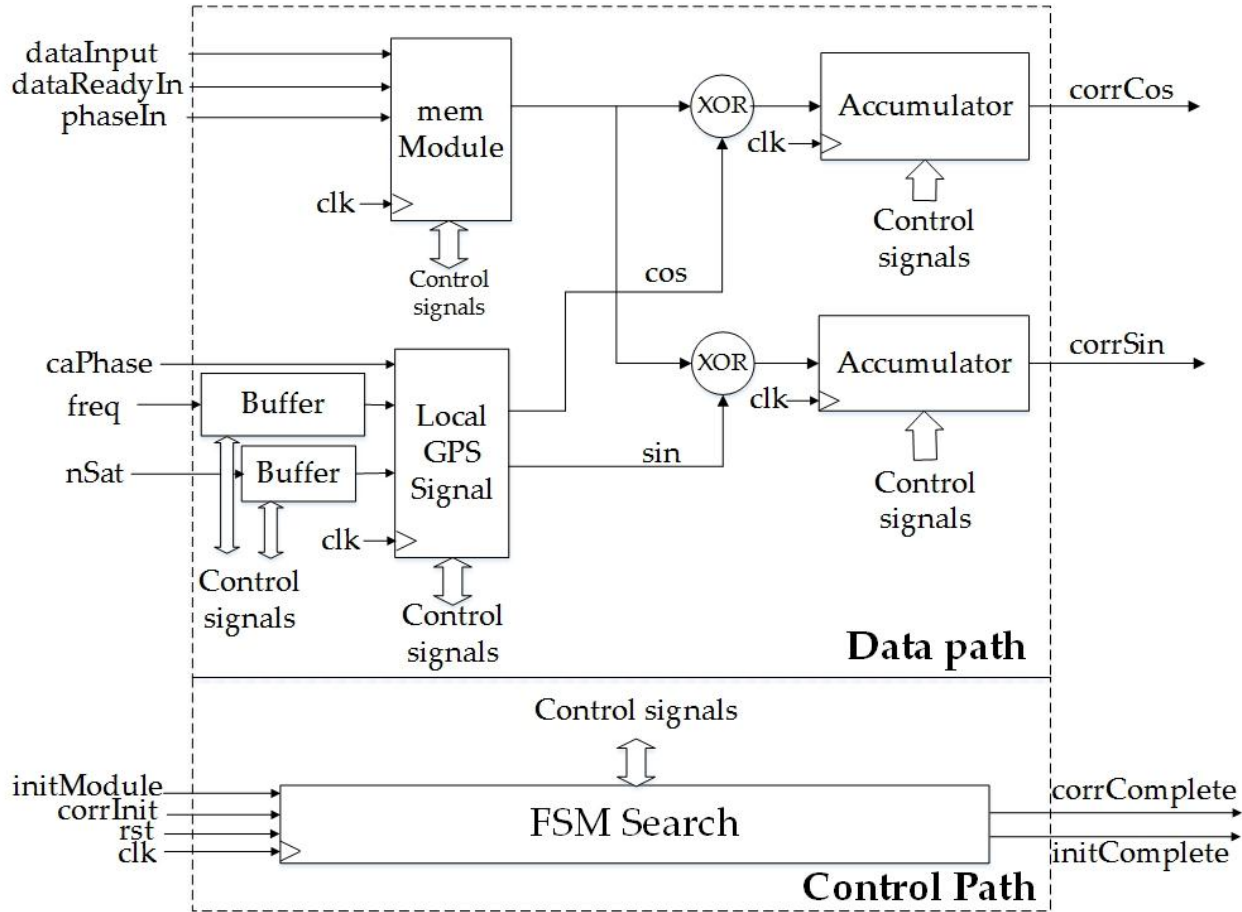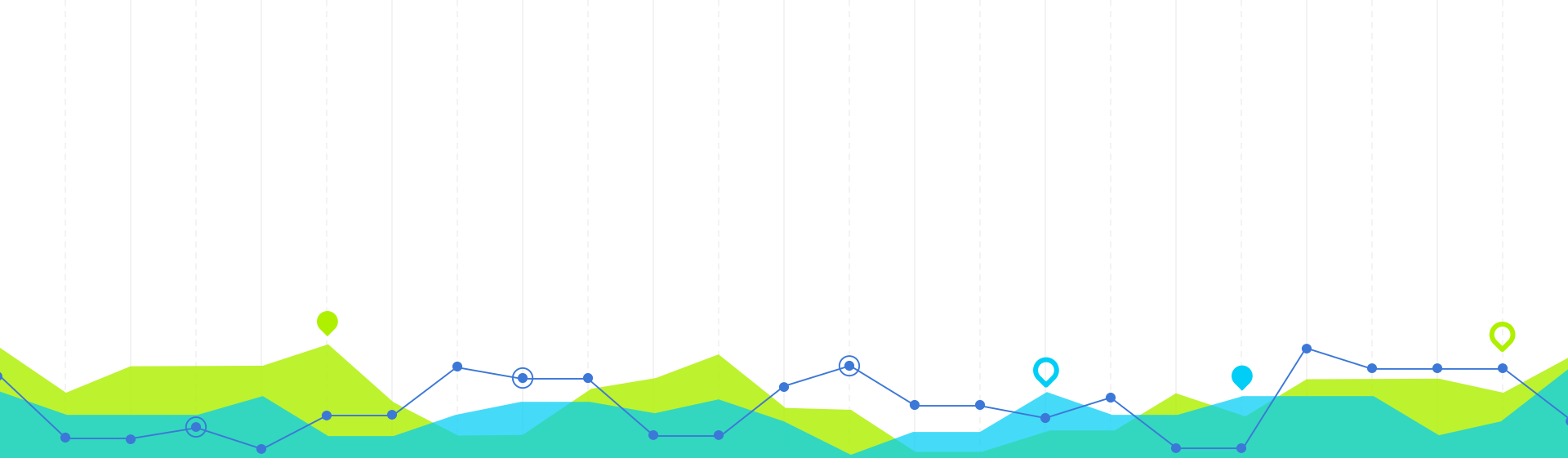
◉ Satellite is not present

Search module implementation
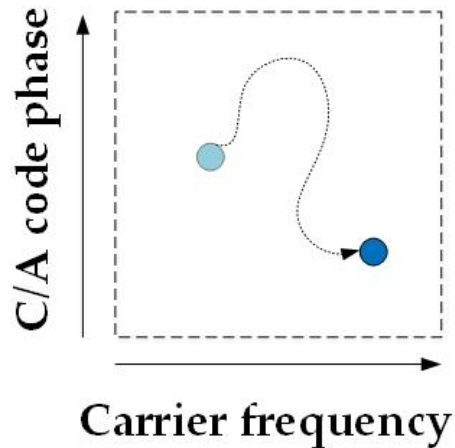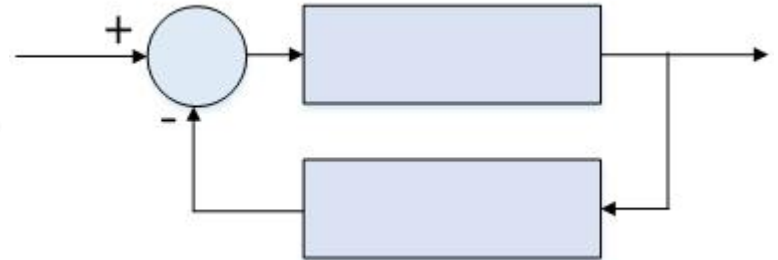
Tracking module 3.3

Tracking module

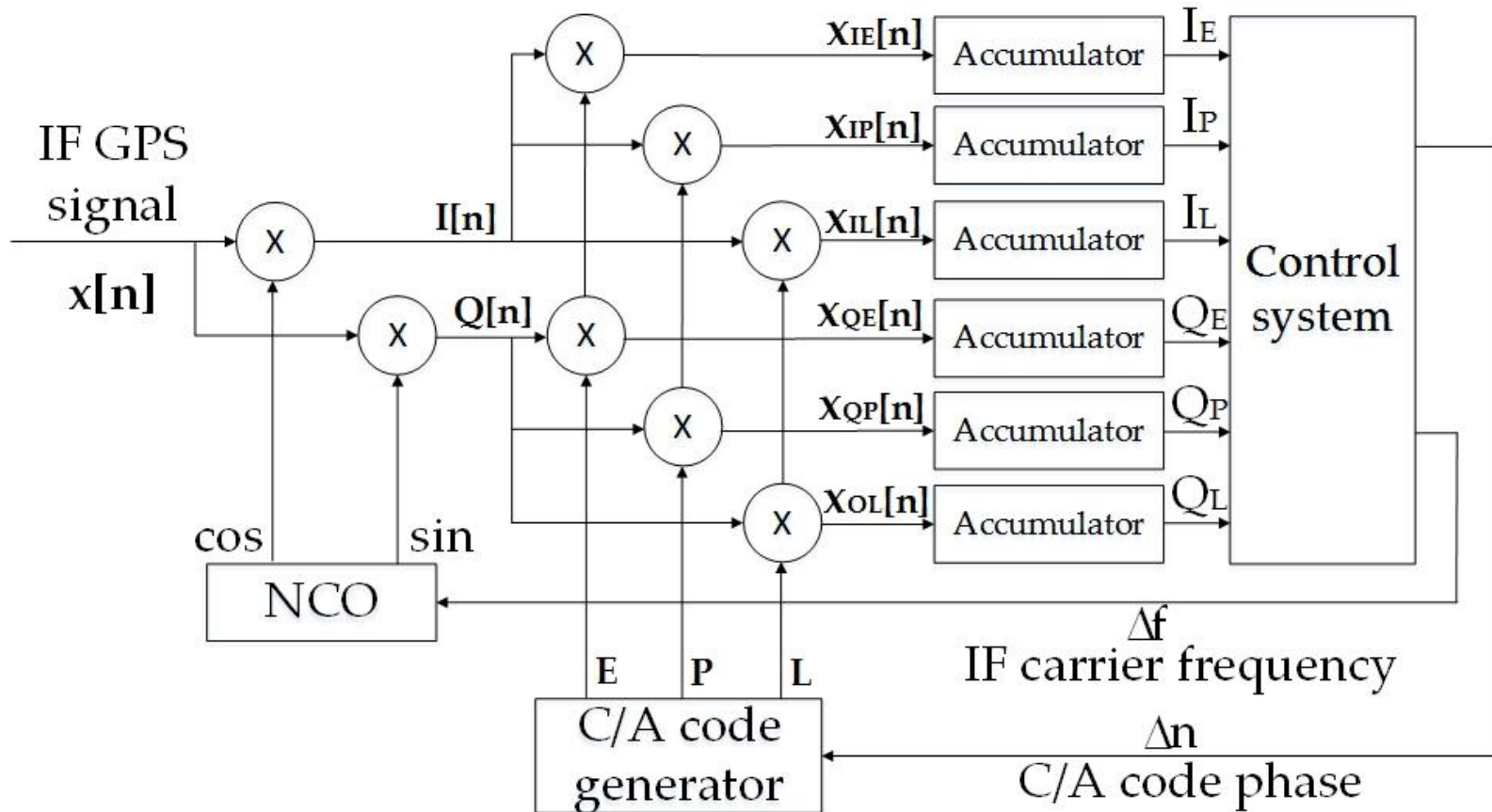Tracking operation maintains synchronization between local replicas and input signals regarding:

◉ CA code phase

◉ Carrier frequency

Control system

Tracking module: proposed structure

# *Tracking module: proposed structure*

Control loops can be decoupled for analysis:

⦿ **C/A code:** considering that input carrier phase and frequency matches local replica then the feedback loop concerning C/A code can be analyzed separately.

⦿ **Carrier:** considering that C/A code phase matches local replica then the feedback loop concerning only the carrier can be analyzed separately.

Tracking module: CA code loop

Assuming that carrier replica is in phase the tracking loop can be reduced only to the operations regarding CA code phase control:
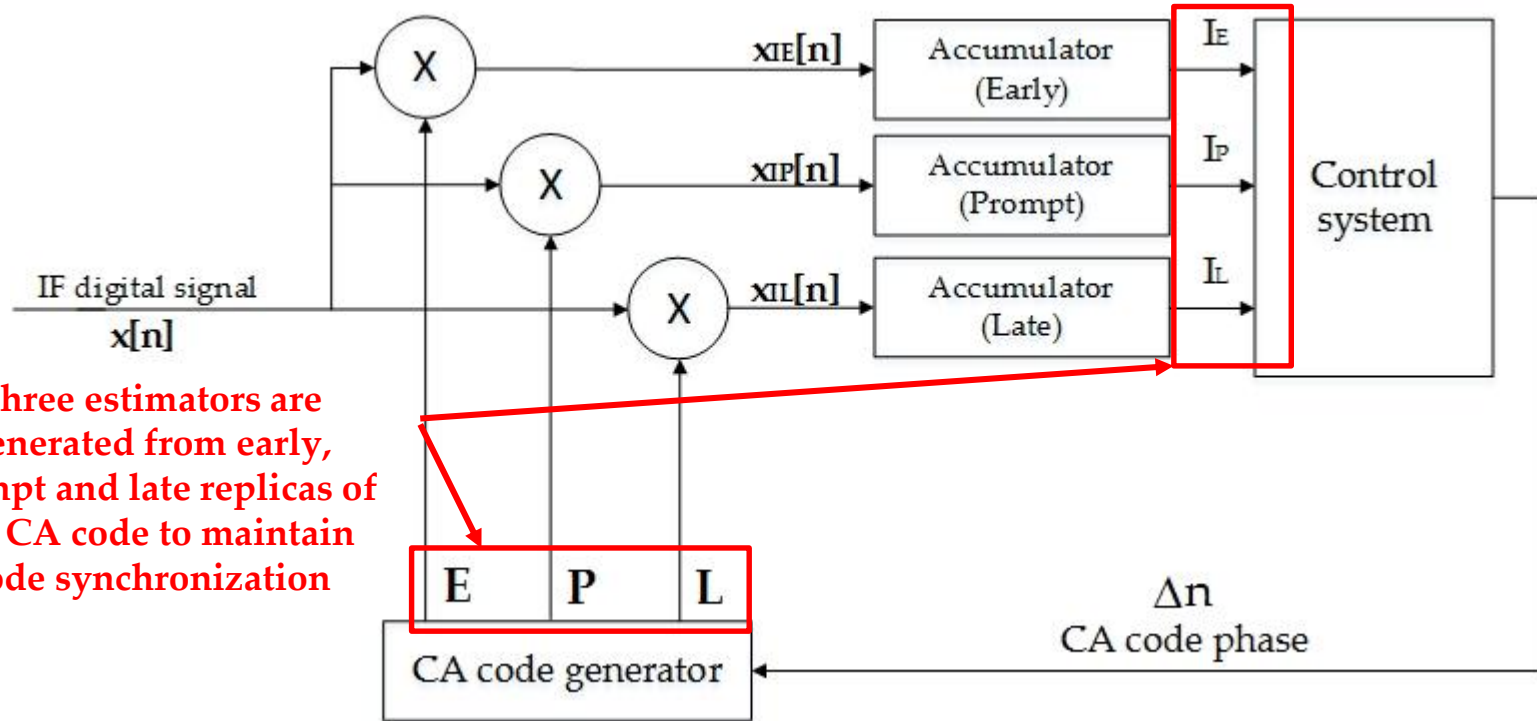
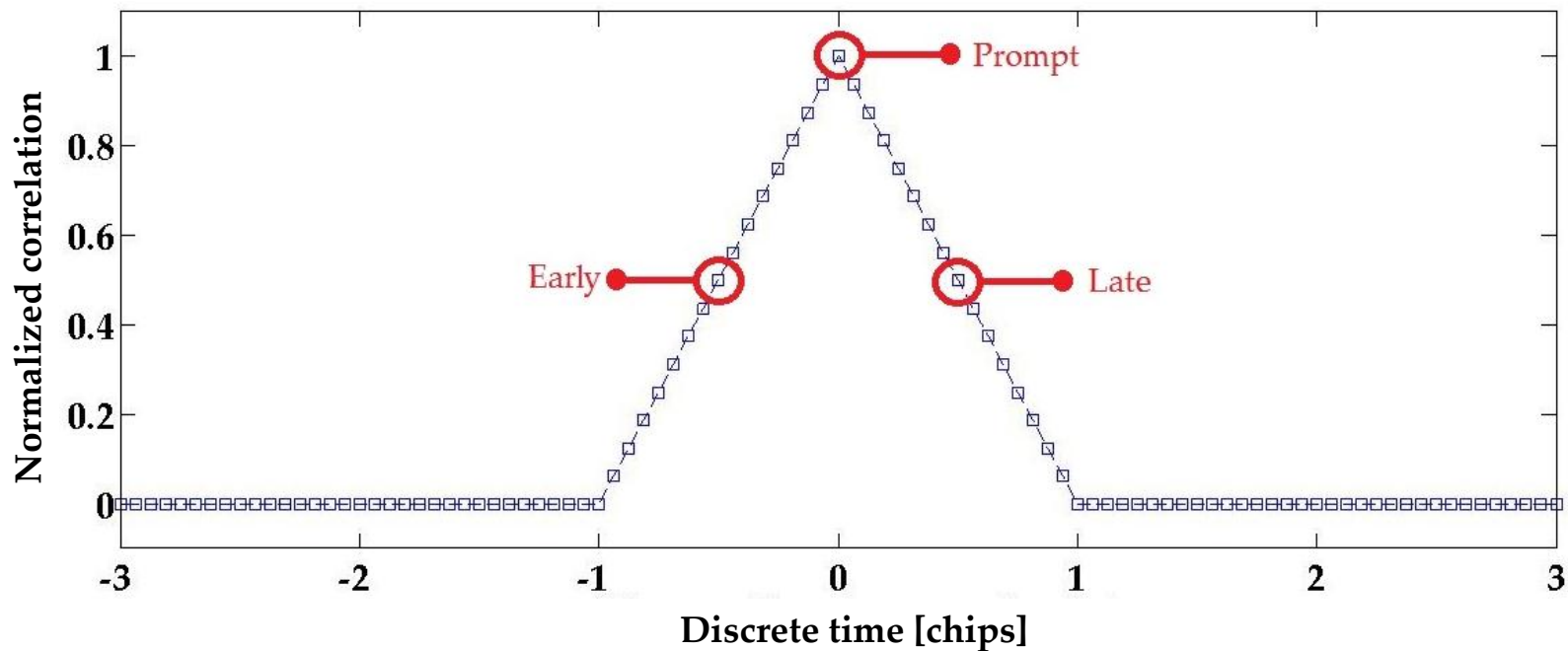**Three estimators are generated from early, prompt and late replicas of the CA code to maintain code synchronization**

Tracking module: CA code loop

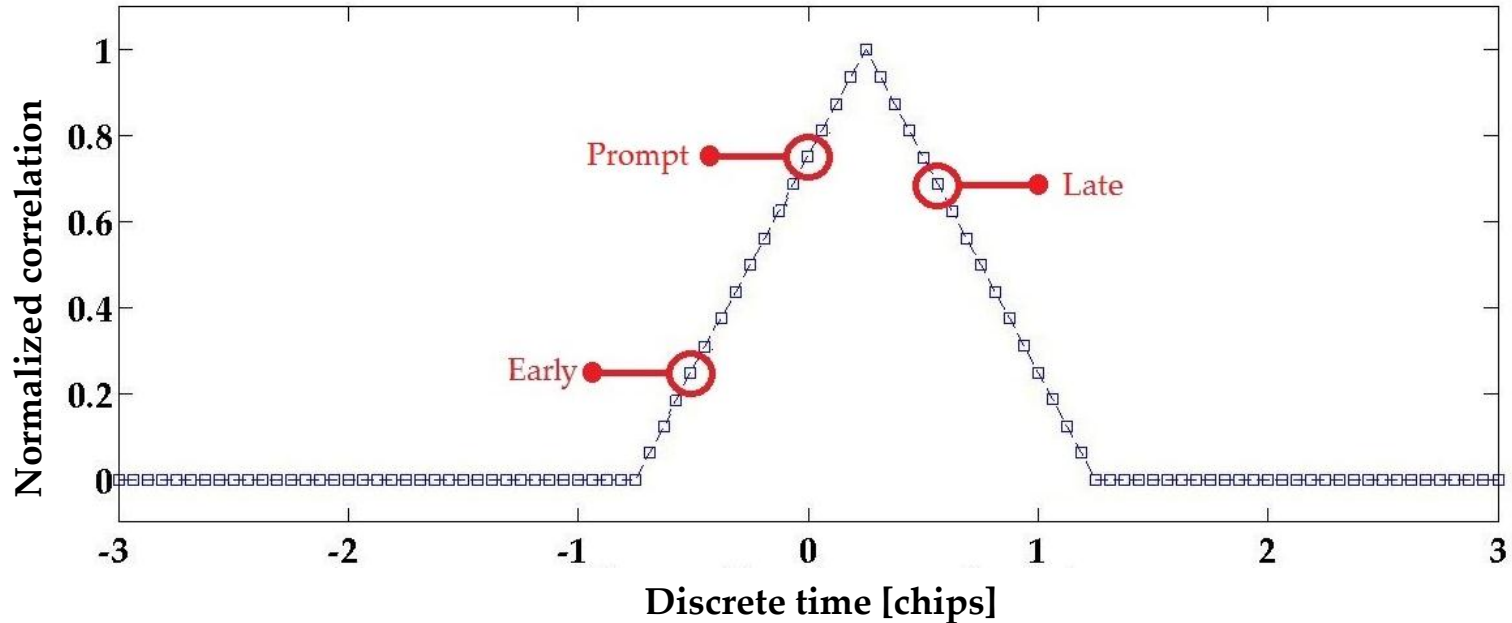Three CA code replicas are generated in such a way that when CA code loop:
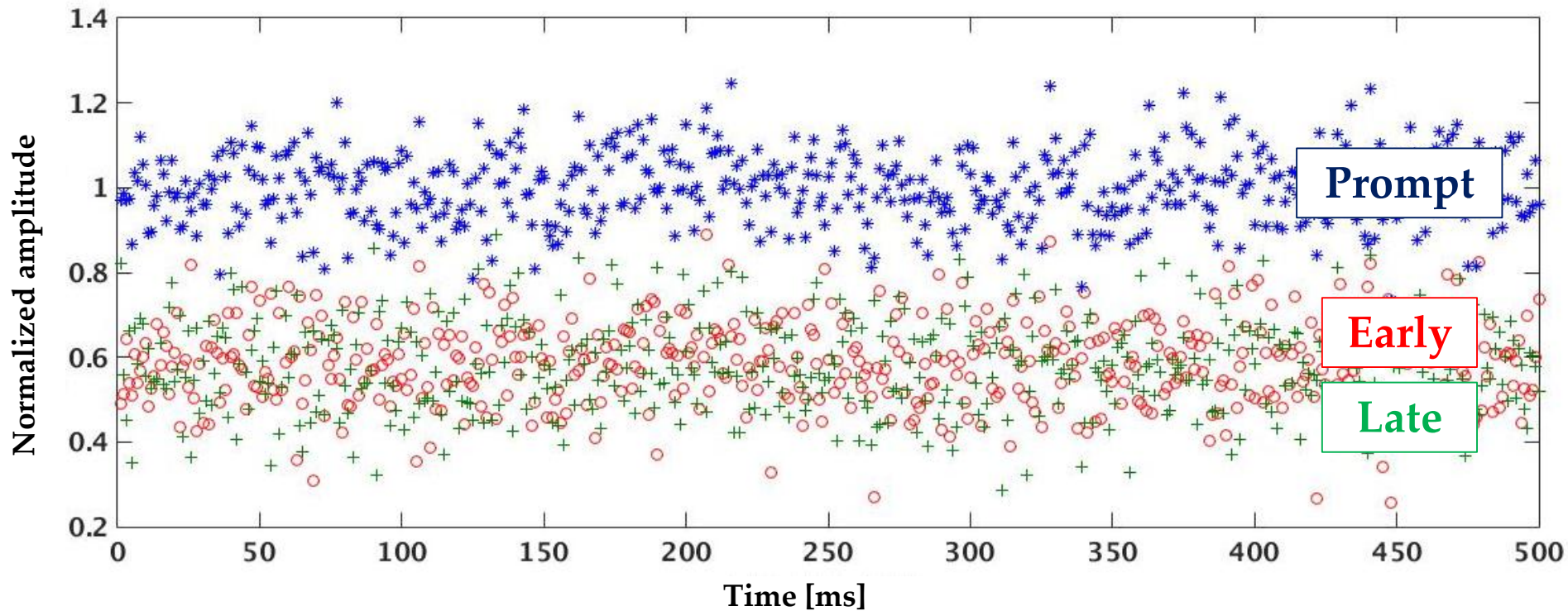
◉ Is synchronized…

Tracking module: CA code loop

Three CA code replicas are generated in such a way that when CA code loop:
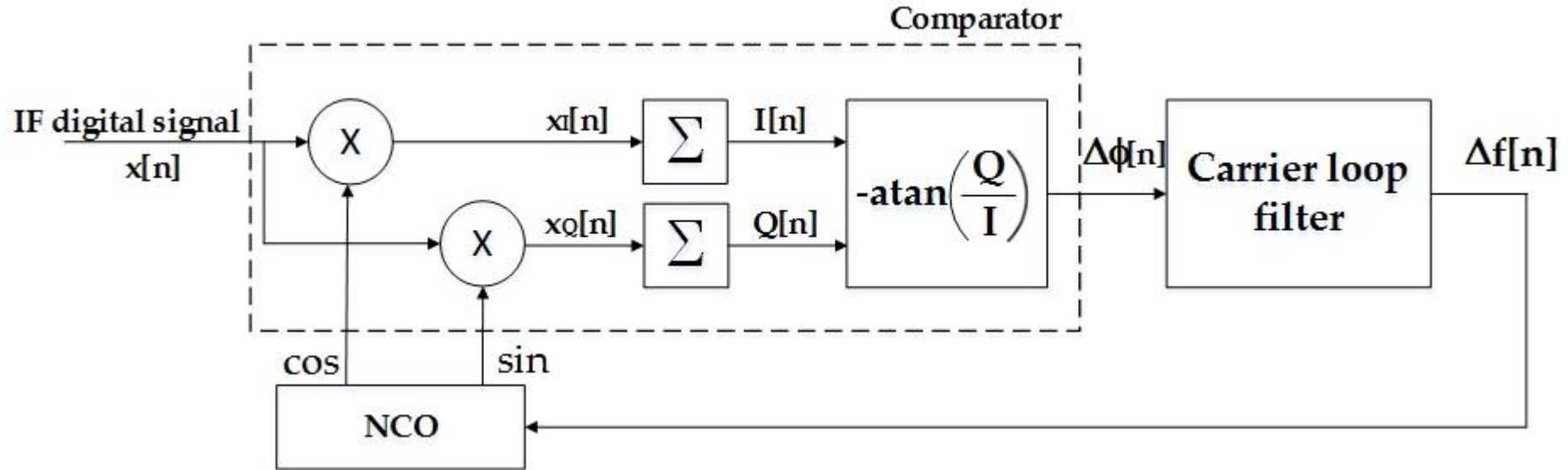
◉ Begins to lose synchronization…

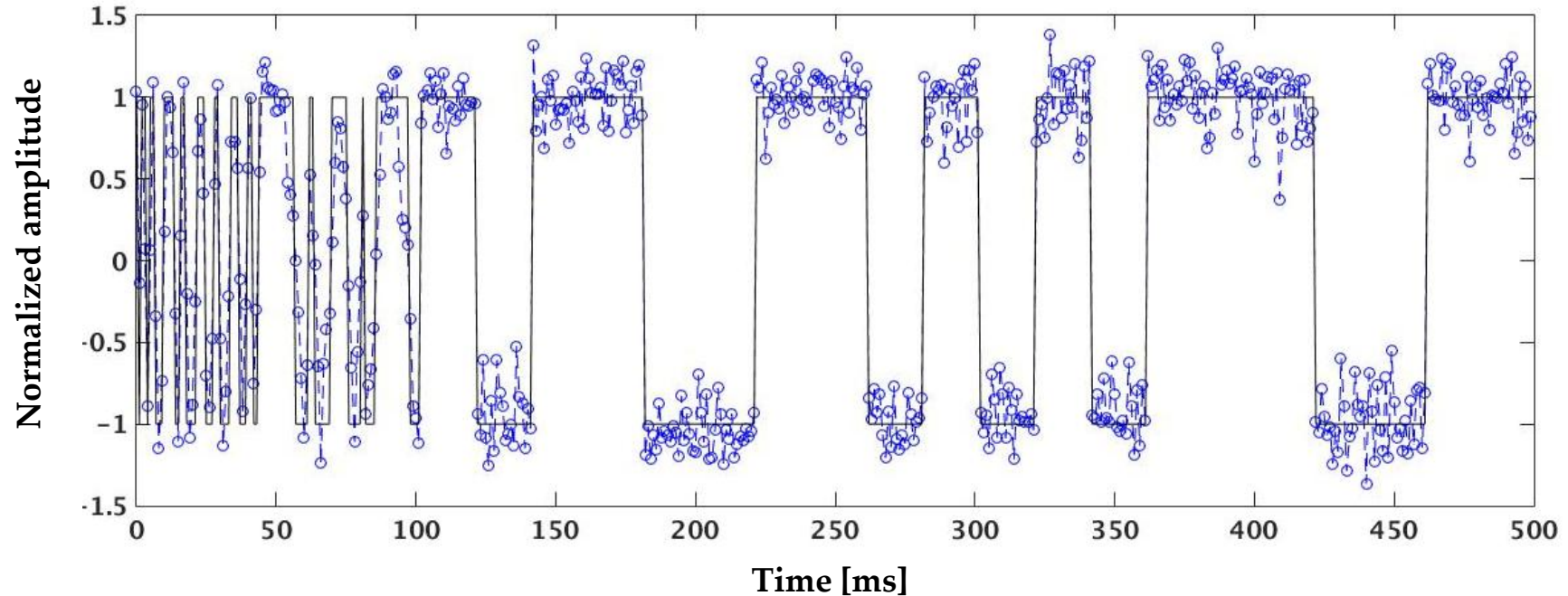# Tracking module: CA code loop

Tracking module: carrier loop

Assuming that CA code replica is in phase the tracking loop can be reduced only to the operations regarding carrier control:
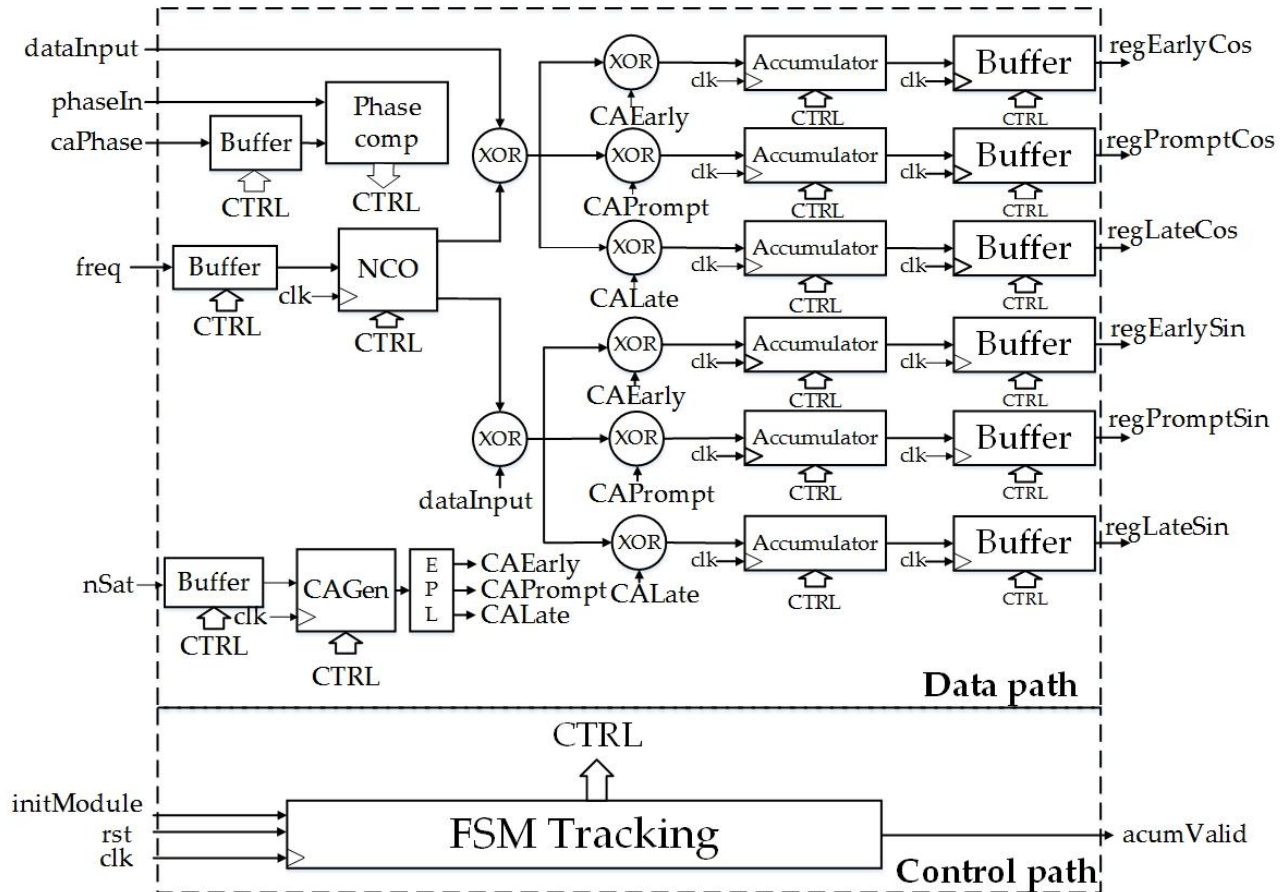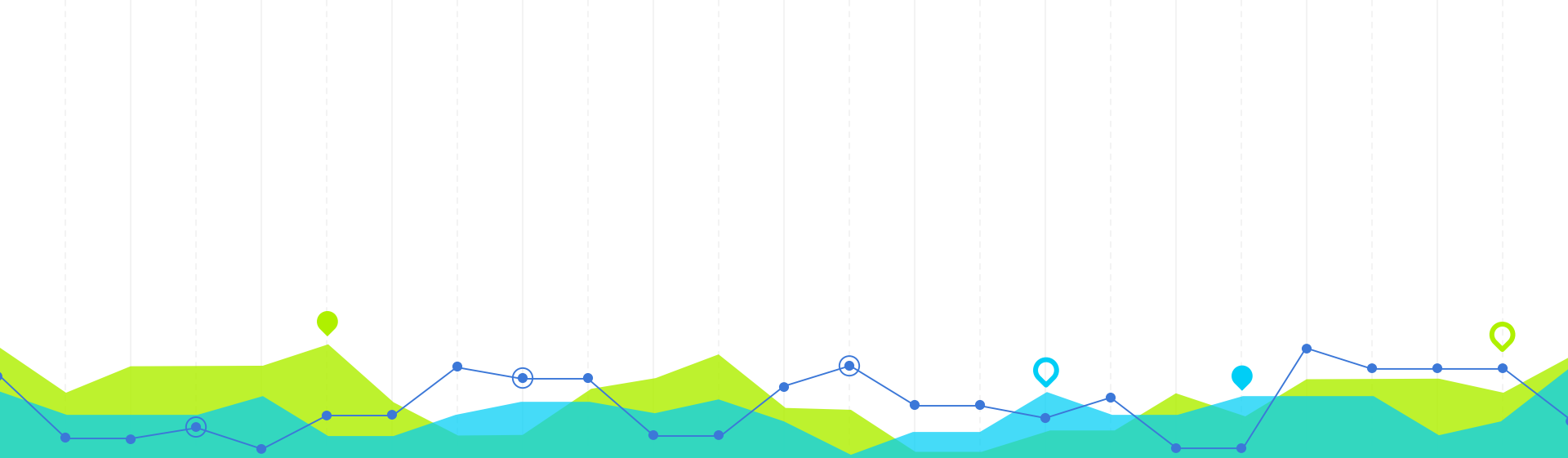
Tracking module: demodulated signal

Navigation message can be demodulated directly from the in-phase branch of the tracking loop when synchronization is achieved.

Tracking module implementation

Results

4

Results

- Design, manufacturing and validation of a GPS front end

- Design, simulation, implementation and validation using synthetic and real signals of a search module based on programmable logic.

- Design, simulation, implementation and validation using synthetic and real signals of a tracking module based on programmable logic.

Results

◉ Search and tracking modules were designed using a portable and flexible approach

◉ Resources were used efficiently compared with similar approaches in bibliography

Search module		
Resource	**Quantity**	**Occupation**
Slice FFs	399	4%
4 Input LUTs	470	5%
Slices	425	9%

Tracking module		
Resource	**Quantity**	**Ocupation**
Slice FFs	470	5%
4 Input LUTs	432	5%
Slices	464	10%

Thank you for your attention!

Any questions?