# GEO1003 - Shared Notes

Master Geomatics Students

2024-12-07

# Contents

# Introduction

This is the introduction to the notes.

# Example

## Introduction

The goal of this chapter is just to demonstrate how things should be organized. It will be removed from the notes in the end.

## Markdown Basics

### Resources and Helpers

A nice cheat sheet about Markdown can be found at this link: https://www.markdownguide.org/cheat-sheet/.

On VS Code, there are some nice extensions that can help you write Markdown files:

- Markdown All in One to provide useful shortcuts and commands
- markdownlint to properly format your Markdown files

Feel free to ask me if you have questions about Markdown.

**Comments**

```
This <!--This is a comment.--> is
<!--
Comments are not rendered.
They can take multiple lines
-->
a
sentence.
```

This is a sentence.

**Headers**

```
<!-- Comment the fist headers to avoid messing up the outline of this file -->
<!--
# Level 1

## Level 2

### Level 3
-->

#### Level 4

##### Level 5

###### Level 6
```

**Level 4**

**Level 5**    Level 6

**Bold and Italic**

```
- Normal text
- **Bold text**
- _Italic text_
- **_Bold and italic text_**
```

- Normal text
- **Bold text**
- _Italic text_
- **_Bold and italic text_**

**Lists**

*Unordered list:*

```
- Unordered list item 1
- Unordered list item 2
  - Nested unordered list item
```

```
Ordered list:
```

```
1. Ordered list item 1
2. Ordered list item 2
   1. Nested ordered list item
```

Unordered list:

- Unordered list item 1
- Unordered list item 2

  – Nested unordered list item

Ordered list:

1. Ordered list item 1
2. Ordered list item 2

   1. Nested ordered list item

**Links**

`[Example link]`*(https://www.example.com)*

Example link

**Images**

`![Example image](../../../images/example.jpg)`{ width="250" }



Figure 1: Example image

### Blockquotes

> This is a blockquote.

> This is a blockquote.

### Code

Inline code: `print("Hello, World!")`

Code block:

```python
def hello_world():
    print("Hello, World!")
```

Inline code: `print("Hello, World!")`

Code block:

```python
def hello_world():
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```

### Tables

Table: A simple table

```
| Header 1 | Header 2 |
| -------- | -------- |
| Cell 1   | Cell 2   |
| Cell 3   | Cell 4   |
```

Table 1: A simple table

| Header 1 | Header 2 |
| --- | --- |
| Cell 1 | Cell 2 |
| Cell 3 | Cell 4 |

### Math

Inline math: $x^2$ is the square of $x$.

Block math:

$$
\int_0^\infty e^{-x^2} dx = \frac{\sqrt{\pi}}{2}
$$

Inline math: $x^2$ is the square of $x$.

Block math:

$$\int_0^\infty e^{-x^2} dx = \frac{\sqrt{\pi}}{2}$$

### Definition Blocks

```
**Lorem ipsum dolor sit amet**
:   Sed sagittis eleifend rutrum. Donec vitae suscipit est. Nullam tempus
    tellus non sem sollicitudin, quis rutrum leo facilisis.


**Cras arcu libero**
:   Aliquam metus eros, pretium sed nulla venenatis, faucibus auctor ex. Proin
    ut eros sed sapien ullamcorper consequat. Nunc ligula ante.
```

**Lorem ipsum dolor sit amet** Sed sagittis eleifend rutrum. Donec vitae suscipit est. Nullam tempus tellus non sem sollicitudin, quis rutrum leo facilisis.

**Cras arcu libero** Aliquam metus eros, pretium sed nulla venenatis, faucibus auctor ex. Proin ut eros sed sapien ullamcorper consequat. Nunc ligula ante.

### Definition Blocks + Lists

```
- **Lorem ipsum dolor sit amet**
  :   Sed sagittis eleifend rutrum. Donec vitae suscipit est. Nullam tempus
      tellus non sem sollicitudin, quis rutrum leo facilisis.

- **Cras arcu libero**
  :   Aliquam metus eros, pretium sed nulla venenatis, faucibus auctor ex. Proin
      ut eros sed sapien ullamcorper consequat. Nunc ligula ante.
```

- **Lorem ipsum dolor sit amet** Sed sagittis eleifend rutrum. Donec vitae suscipit est. Nullam tempus tellus non sem sollicitudin, quis rutrum leo facilisis.

- **Cras arcu libero** Aliquam metus eros, pretium sed nulla venenatis, faucibus auctor ex. Proin ut eros sed sapien ullamcorper consequat. Nunc ligula ante.

### Empty Section

An other section that is empty.

# How does GNSS work?

### Introduction

GPS (Global Positioning System), also known as NAVSTAR (NAVigation Satellite Time And Ranging) had its first satellite launched in 1978.

## GPS segments

The GPS system consists of *three segments*:

1. **Space segment** (satellites with atomic clocks)
2. **Control segment** (ground stations for clock offsets)
3. **User segment** (receivers)

## Radio Signal

The GPS radio signal contains:

- the **L-band carrier frequency** between 1 and 2 GHz
- the **Pseudo Random Noise** (PRN, also called the **spreading code**), unique to each satellite, publicly available
- the **navigation message** containing the satellite orbit and clock information
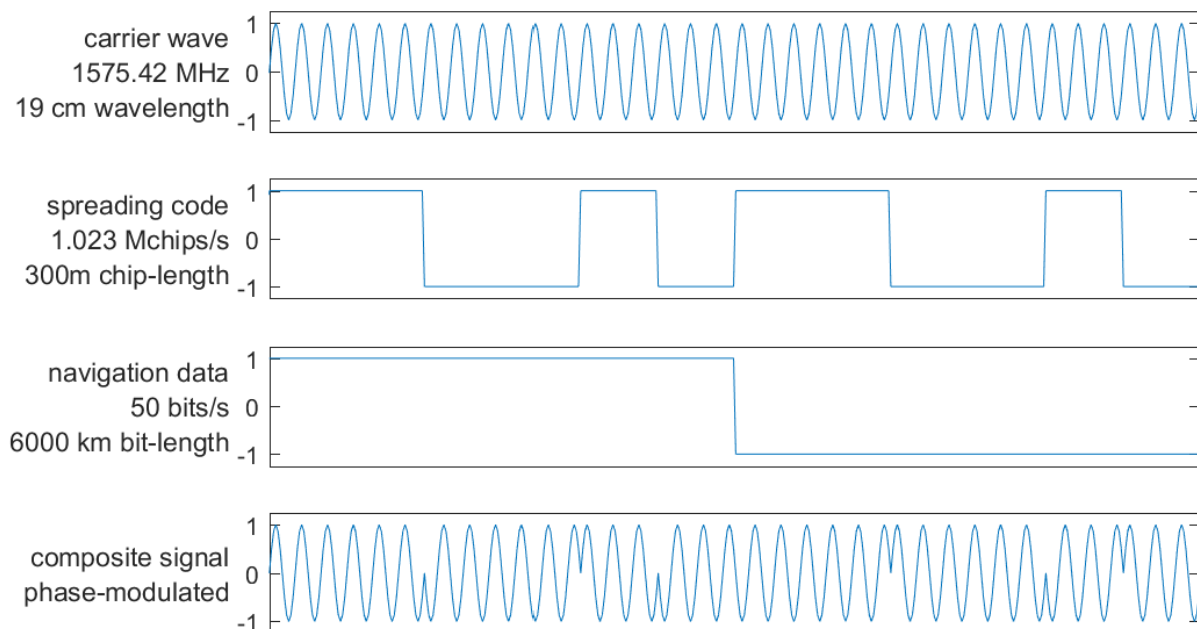


Figure 2: GPS L1 CA-signal (scale is not accurate)

## Initialisation

When starting, GPS receivers try to find a particular GPS satellite on *each of their channels* (tens to hundreds). This is done by **overlaying the received signal** with a replica of the **spreading code** and then shifting it until correlation shows a maximum (best fit, or match).

## Pseudorange Measurement

The **pseudorange** $p_{r,s}$ is calculated by multiplying the travel time $\tau_{r,s}$ by the speed of light $c$:

$$p_{r,s} = c \cdot \tau_{r,s} \text{ where } \tau_{r,s} = t_r - t_s$$

## Carrier Phase Measurement

Carrier Phase Measurement:

- Measures **fractional phase difference** between the received *carrier wave* from the satellite and a locally generated *replica.*
- Provides a **very precise distance** measure (satellite to receiver)
- Needs to be **initialized** by finding the initial number of carrier wave cycles.
- Is much more precise than pseudorange code measurement. thanks to the **carrier period** being **much smaller** than code chip duration (in L1 CA-code signal, *1540 carrier periods* fit in one PRN spreading code chip).

## Jamming and Spoofing

There are multiple mays a GNSS signal may be threatened, jamming and spoofing being intentional attacks.

### Jamming

By the time GNSS signals arrive at the antennas of a GNSS positioning system, the power level of these signals is very low. This low power level makes the signals susceptible to interference from other signals transmitted in the GNSS frequency range.

Jamming is a special case of signal interference where an attacker tries to block the incoming GNSS signal to a specific person/area.

GNSS receivers can use several methods to protect against interference and jamming:

- Signal filtering
- Multiple navigation sensors. For short-term interference, other sensors can help the receiver bridge brief periods of GNSS outage.
- Multi-frequency/multi-constellation GNSS makes it much harder to jam a signal on multiple different frequencies at once.
- Anti-jam antennas use multiple antenna elements to control the amount of signal received from a particular direction. When an anti-jam system senses interference from a direction, it turns down the antenna gain for it.

**Spoofing**

Unlike interference where GNSS is denied by overpowering the satellite signal, spoofing tricks the receiver into reporting an incorrect position. Spoofing is done by first jamming the GNSS receiver and then providing a false satellite signal that is either created by a signal generator or is a rebroadcast of a pre-recorded GNSS signal. Unlike interference, spoofing is always an intentional attack.

To protect against spoofing the same methods apply as against interference. Additionally, one of the most effective ways to protect against spoofing is to track encrypted signals that are broadcast by several of the GNSS constellations. Access to the encrypted signals is restricted and not available to all users.

**Signal blockage**

The GNSS signal can be blocked by many objects like trees or buildings, especially in urban areas. The main protection is again using multiple constellations and using additional sensors like an IMU.

**Constellation failure**

Although it is extremely unlikely that an entire constellation will fail, receivers that can track more than one constellation protect against this unlikely scenario.

# GNSS performance

## Introduction

## Error Sources

### Pseudorange Calculation

Multiple issues affect the calculation of the pseudorange:

- **satellite clock offset** (known).
- **receiver clock offset** (unknown).
- **ionosphere delay** (unknown).
- other errors, such as *multipath* (unknown).

The calculation is very sensible since $c \approx 3 \times 10^8$ m/s, and a **1 µs** error will cause a **300 m** error in the calculated distance.

**Ionosphere Delay**

Ionospheric delay:

- Is due to **free electrons** in the ionosphere.
- Is highly variable (depends on **time** and **space**).
- Ranges from *a few meters to hundreds of meters.*
- Is maximum near geomagnetic equator, around local noon and during solar maxima.
- Is proportional to $1/\text{frequency}^2$.
- Can be estimated using two frequencies. This is why satellites emit at **L1** (1575.42 MHz) and **L2** (1227.60 MHz).

## Accuracy and Precision

The quality of the measurement can be assessed through the carrier-to-noise-density ratio $C/N_0$ (signal strength).

The precision of the measurement depends on the method used:

Table 2: Precision of GNSS measurements

|  | Pseudorange | Carrier Phase |
|---|---|---|
| Precision | Few meters to few decimeters | Few centimeters to millimeter |

## Dilution of Precision

## Availability, Continuity and Integrity

**Availability**

**Continuity**

**Integrity**

## PPP-RTK

**Abbreviations**

- **SV**: space vehicles or orbiting space vehicles
- **RTK**: Real-Time Kinematic
- **PPP**: Precise Point Positioning
- **PPP-RTK**: Hybrid of PPP and RTK
- **CORS**: Continuously Operating Reference Station
- **NRTK**: Network RTK
- **OSR**: Observation State Representation
- **SSR**: State Space Representation

**PPP**

- **PPP** achieves decimetre-level or better accuracy by leveraging corrections transmitted via satellite or the internet.
- It utilises the **SSR** message format for efficient data transmission.
- **PPP** is suitable for global applications due to its independence from regional base stations.
- The primary limitation of **PPP** is its long convergence time, typically ranging from 5 to 30 minutes.
- **PPP** primarily corrects for orbit errors, clock errors, and biases to achieve its positioning solution.
- **PPP** offers a trade-off between accuracy and coverage, providing moderate accuracy over a wide area.
- Variations like PPP-AR and A-PPP exist, offering enhanced accuracy or specialized capabilities.

**RTK**

- **RTK** provides centimetre-level accuracy, achieving the highest precision among the discussed technologies.
- **RTK** relies on the **OSR** message format, which requires a two-way communication channel between the base station and the rover.
- The coverage area of **RTK** is limited to a short range (30-50 km) due to signal degradation with distance.
- **RTK** boasts a near-instantaneous convergence time, typically under 5 seconds.
- **RTK** corrects for various errors, including orbit errors, clock errors, bias, ionospheric delay, and tropospheric delay.
- **RTK** is widely adopted in applications demanding high accuracy within a limited area, such as surveying and agriculture.
- Developments like Network RTK (NRTK) address range limitations by incorporating networks of base stations.

**PPP-RTK**

- **PPP-RTK** combines the strengths of PPP and RTK, offering high accuracy, global coverage, and fast convergence.
- **PPP-RTK** achieves centimetre-level accuracy comparable to RTK while offering global coverage.
- **PPP-RTK** employs the efficient **SSR** message format, enabling broadcast corrections and lower bandwidth requirements.
- **PPP-RTK** utilises a network of CORS stations for precise atmospheric and clock corrections.
- **PPP-RTK** converges significantly faster than PPP, typically within 1-10 minutes, and potentially seconds under ideal conditions.
- It effectively corrects for orbit errors, clock errors, bias, ionospheric delay, and tropospheric delay, allowing for integer ambiguity resolution.
- **PPP-RTK** gracefully degrades to standard PPP performance when outside the range of the CORS network.

**Comparing RTK, PPP, and PPP-RTK**

| Feature | RTK | PPP | PPP-RTK |
|---|---|---|---|
| **Accuracy** | **cm-level** (up to 1 cm + 1 ppm) | **dm-level or better** (less than 10 cm) | **cm-level**, similar to RTK |
| **Coverage Area** | **Limited range** (typically 30-50 km from the base station) | **Global** | **Global** with graceful degradation to standard PPP outside the range of the CORS network |
| **Message Format** | **OSR** (Observation Space Representation) | **SSR** (State Space Representation) | **SSR** (State Space Representation) |
| **Transmission Channel** | **Two-way communication** between base station and rover | Corrections delivered via **satellite or the internet** | Corrections **broadcast to users**, enabling a large number of users to connect simultaneously |
| **Convergence Time** | **Near-instantaneous** (typically less than 5 seconds) | **Relatively long** (typically 5-30 minutes) | **Fast** (typically 1-10 minutes, potentially within seconds under ideal conditions) |
| **Errors Solved** | Orbit errors, clock errors, bias, **ionospheric delay, tropospheric delay** | Orbit errors, clock errors, bias | Orbit errors, clock errors, bias, **ionospheric delay, tropospheric delay**, enabling **integer ambiguity resolution** |
| **Key Strengths** | High accuracy, very fast convergence time | Global coverage, no reliance on local base stations | High accuracy, fast convergence time, global coverage, lower bandwidth requirements compared to RTK, graceful degradation outside CORS range |
| **Key Limitations** | Limited range, high bandwidth requirements, reliance on local base stations | Long convergence time, lower accuracy compared to RTK | Still requires a CORS network (though less dense than RTK) and may degrade to standard PPP with increasing distance from CORS station |
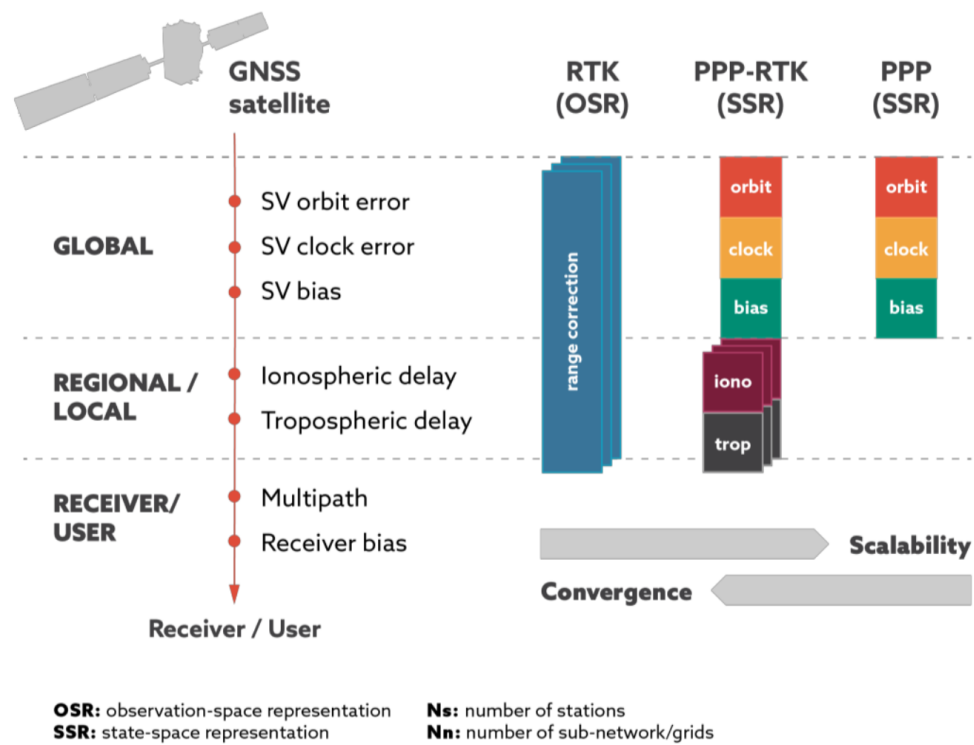
Figure 3: difference in message format and resolved errors

## DGNSS

## GNSS in the built environment (outdoor, indoor and in between)

### Introduction

### Multipath

### Urban Canyon

### Shadow Matching

## CRS

### Introduction

### Coordinate Systems

#### Coordinate Reference Systems

#### Geographic Coordinate Reference Systems

#### Projected Coordinate Reference Systems

#### Linear Reference Systems

### Terrestrial Reference Systems and Frames

### Datum and Transformations

#### Transformations and conversions

### Datums

### Map Projections

### RDNAP

## Wi-Fi-monitoring / Fingerprinting

### Introduction

### Wi-Fi-Based Approaches

#### Wi-Fi Monitoring

#### Wi-Fi Fingerprinting