AALBORG UNIVERSITY DENMARK

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Pseudorange Estimation; Receiver Position Computation; Receiver Data Formats

GPS Signals And Receiver Technology MM15

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Today's Subjects

- Pseudorange estimation
- Receiver position basic computation
- Data formats used in GNSS receivers

Receiver Measurements

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- A GNSS receiver does a number of measurements
  - Signal time of transmission (code) measurements
  - "Carrier phase" based measurements
  - Doppler based measurements
  - Signal to noise ratio measurements
  - Some receivers estimate multipath
- Professional receivers do measurements on two or more carrier frequencies
- Measurements on all channels are done at the same time instance (epoch)

Receiver Position Computation

- In ordinary 3D position computation three distance measurements are needed to find three unknowns x, y, z
- In GNSS positioning the receiver clock offset is also unknown
- Therefore distances to at least four satellites must measured in order to find receiver position

Range And Pseudorange

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- The true (geometrical) range between satellite k and receiver i is denoted as ρ_i^k
- The range can be expressed throug satellite signal travel time (in GPS time):

$$\rho_i^k = c(t_i - t^k)$$

- But the signal delay causes that the receiver can measure only sum of true range and errors:

$$P_i^k = \rho_i^k + c(dt_i - dt^k) + T_i^k + I_i^k + e_i^k$$

Geometrical range

Clocks errors

Troposphere delay

Ionosphere delay

Other errors (including multipath)

Position Basic Computation

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$$P_i^k = \rho_i^k + c(dt_i - dt^k) + T_i^k + I_i^k + e_i^k$$

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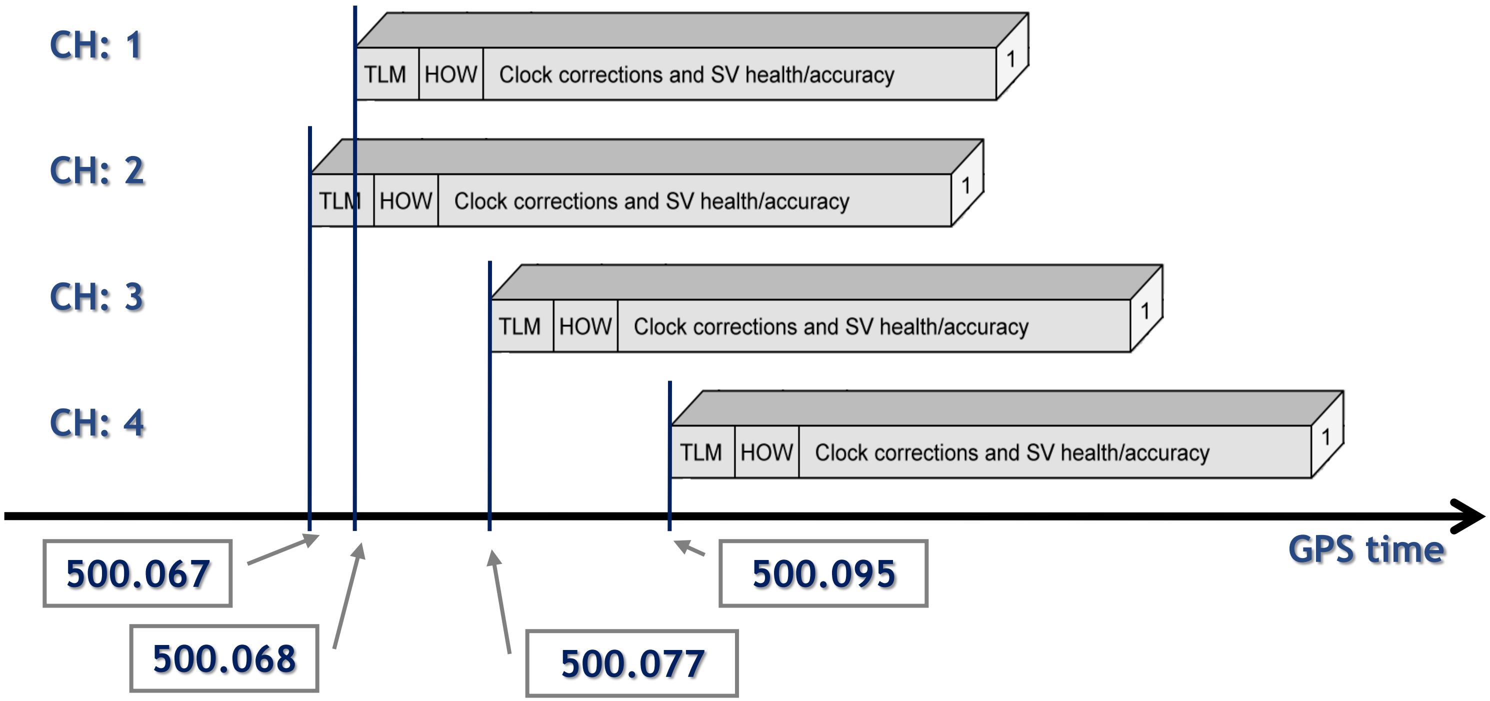
Time of Transmission

- All satellites transmit signals at the same time
- Due to different distances between receiver and satellites the GPS (GNSS) signals will arrive at receiver at different time instances



Transmission Time

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- There is direct relation between signal transmission time and code phase, number of complete codes and number of bits
- This means that signal transmission time can be determined in receiver by counting chips, complete codes and bits (+ time of week in handover word)
- The figure shows the concept, but it is out of scale

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Code Measurement Construction

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- Each receiver channel (for each tracked signal) has number of counters that are used to keep track of time of transmission
- Counters are synchronized to the received signal and later are tracked. Resynchronization may be required if tracking lock is lost
- Alternative counter setups exists
- Figure shows an example of counters for GPS signal

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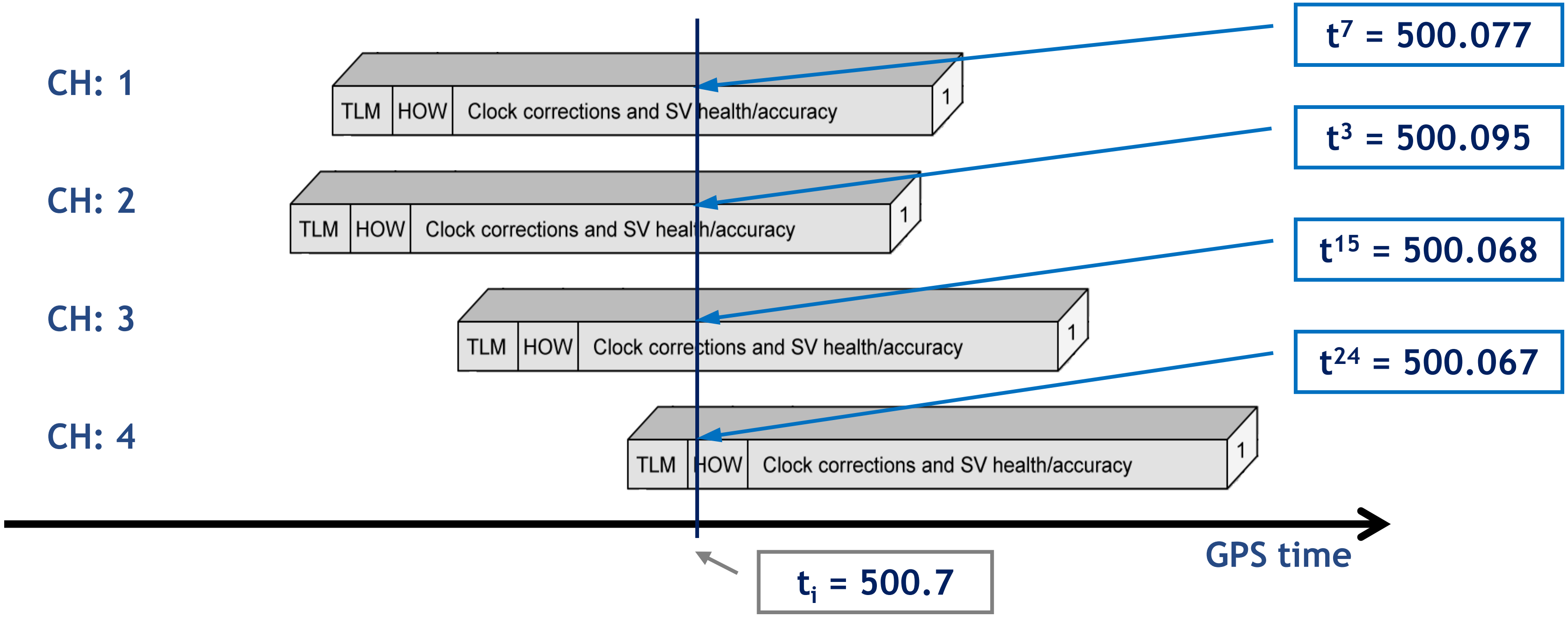
Time of Transmission Measurement

- At time instance t_i a snapshot is taken of all counters for all receiver channels (at the same time)
- Values from channel counters are combined after appropriate scaling to form the time of transmission
- Figure shows the concept but is out of scale



Carrier (Doppler) Phase Measurements

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- Carrier phase has much smaller period than than the code rate, therefore measurements can be done at millimeter level (1% of wavelength => 0.0019 Meters)

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- Problem: initial number N of waves is unknown
- N can be solved with dual frequency receivers

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Carrier Doppler Phase Measurements – the Principle

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Carrier (Doppler) Phase Measurements

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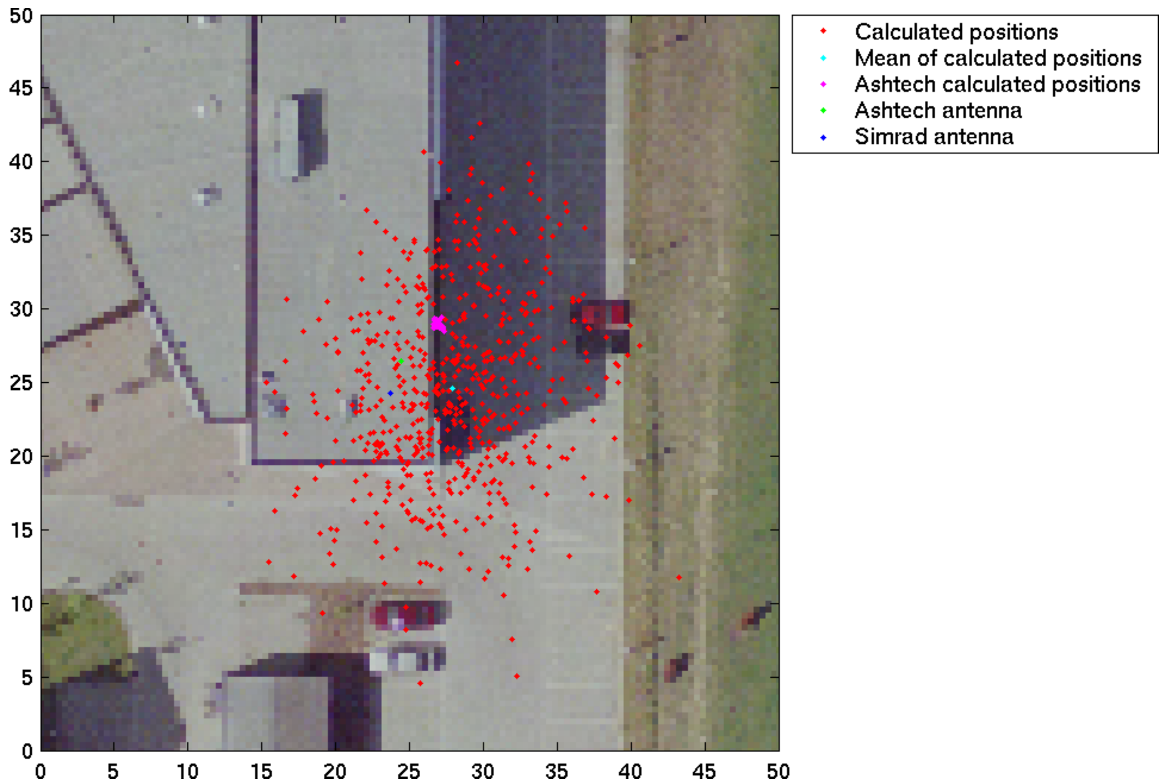
- Carrier (Doppler) phase measurements (values form "delta cycle counter") are used for:
  - Delta pseudorange – distance change between two measurement epochs (not the same as in the last line in the table). Measurements derived from delta pseudorange:
    - Doppler (less noisy measurement than from the tracking loop)
    - Range rate in m/s
  - Integrated Doppler (the same as in the last line in the table)

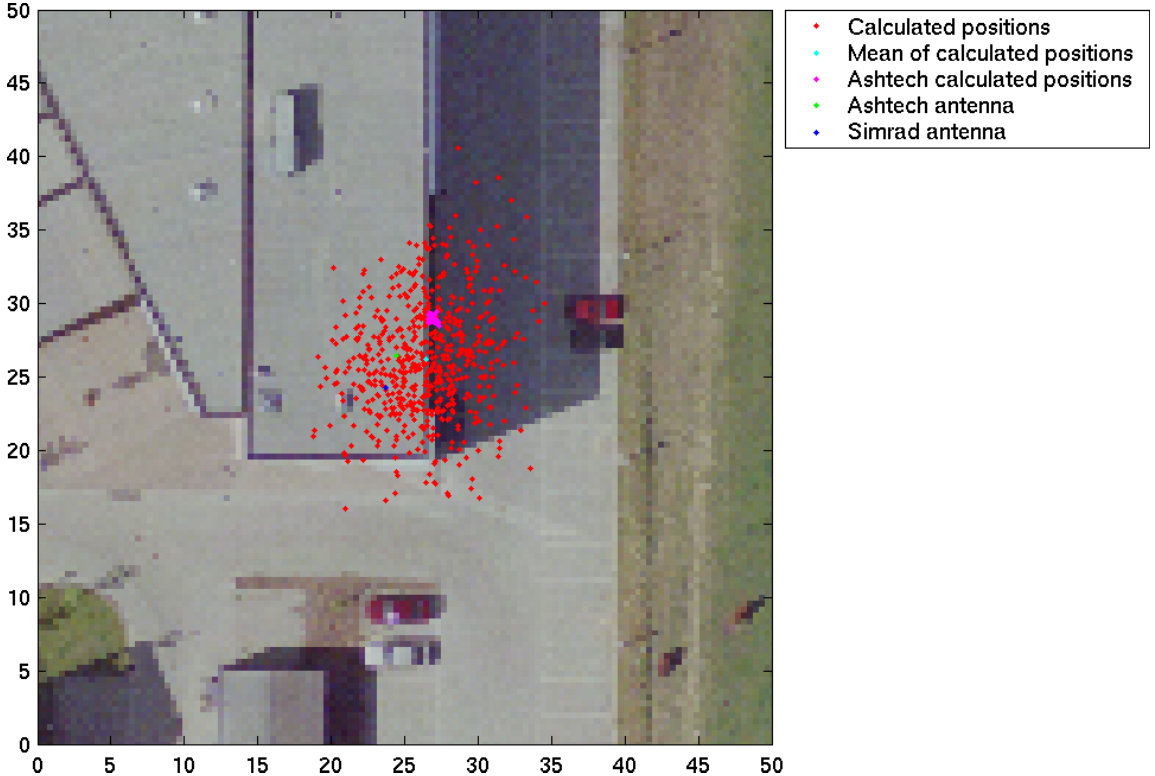
Smoothing The Code Phase

- **An example from student project – the positions are obtained without carrier phase smoothing (only C/A measurements are used)**



Smoothing The Code Phase

- The positions computed using carrier phase smoothing (C/A and L1 measurements are combined together)



Receiver Position Computation

Position Basic Computation

$$P_i^k = \rho_i^k + c(dt_i - dt^k) + T_i^k + I_i^k + e_i^k$$

Position Computation

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- Least squares
  - Basic single point positioning
- Kalman filter
  - Advanced positioning that predicts user motion
  - Integration of measurements from other measurement devices

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Least Squares

- The set of linearized equations is solved according to the rules of linear algebra
  - The ”estimated residuals” are defined as the difference between the actual observations and the new, estimated model for the observations
  - The least squares solution can be found by varying the value of initial position estimate until the sum of squares of the estimated residuals is minimized
- If some observations considered less accurate then others, the Weighted Least Squares (WLS) method can be used to take into account this fact

Kalman Filter

- A recursive algorithm that provides optimum estimates of user PVT (Position Velocity Time) based on noise statistics and current measurements
- The filter contains dynamical model of the GNSS receiver platform motion and outputs a set of user receiver PVT state estimates as well as associated error variances

The Final Software Receiver

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- Tasks to perform position computations in a GPS receiver
  - Acquisition of GNSS signals
  - Track all acquired satellite signals
  - Do measurements of transmission time (in other words take “snapshots” of all types of counters)
  - Decode the navigation messages from all satellites
  - Compute satellite position at transmission time
  - Compute pseudoranges to all satellites
  - Compute the receiver position based on the pseudoranges and satellite positions (include compensations for atmosphere and Earth rotation)

Receiver Data Formats

Or: The Languages That The GNSS Receivers Talk

Receiver Data Formats

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- Data formats for measurement and navigation data records
  - RINEX
  - BINEX
  - SP3
- Data formats for GNSS (receiver to receiver)
  - RTCM
- ”Human to receiver” or ”machine to receiver” data formats
  - ASCII formats (NMEA, Propriertary)
  - Binary (BINEX, Proprietary)

Data Formats: RINEX

Receiver Independent Exchange Format (RINEX)

- RINEX has been developed by the Astronomical Institute of the University of Berne for an easy exchange of the GPS data
- The standard defines file contents and recommends file naming conventions (4 character station name, day, year etc.)
- Version 3 has major changes. It includes Galileo and SBAS information.

http://www.aiub.unibe.ch/download/rinex/rinex300.pdf

- There is a new, binary version developed which is called BINEX

RINEX

- **Currently the format consists of six ASCII file types:**
  1. **Observation Data File (v2.10 and v3.0)**
  2. **Navigation Message File (v2.10 and v3.0)**
  3. **Meteorological Data File (v2.10 and v3.0)**
  4. **GLONASS Navigation Message File (v2.10)**
  5. **GEO Navigation Message File (v2.10)**
  6. **Satellite and Receiver Clock Date File (v2.10)**

RINEX File Format

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- Each file type consists of a header section and a data section
- The header section contains global information for the entire file
- The header section contains header labels in columns 61-80 for each line contained in the header section

Example Of RINEX Header

- This is an example of a header for an observation file

```
     2.10           OBSERVATION DATA    G (GPS)             RINEX VERSION / TYPE
JPS2RIN 1.07        RUN BY              04-SEP-01 13:20     PGM / RUN BY / DATE
build October 30, 2000 (c) Topcon Positioning Systems       COMMENT
RUN BY;COMMENT;MARKER NAME;MARKER NUMBER;OBSERVER;AGENCY;   COMMENT
ANT #;ANT TYPE - You can set in profile.                    COMMENT
kai10001.jps                                                COMMENT
Site                                                        MARKER NAME
                                                            MARKER NUMBER
OBSERVER            AGENCY                                  OBSERVER / AGENCY
MT301513219         JPS EUROCARD        2.2 Apr,25,2001 r   REC # / TYPE / VERS
kai10001            -Unknown-                               ANT # / TYPE
  3427819.3209   603664.0433  5326880.6438                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
     1     1                                                WAVELENGTH FACT L1/2
  2001     9     4     9    40    0.0000000     GPS         TIME OF FIRST OBS
  2001     9     4     9    40   22.0000000     GPS         TIME OF LAST OBS
     1.000                                                  INTERVAL
    13                                                      LEAP SECONDS
     7                                                      # OF SATELLITES
     7    C1    P1    P2    L1    L2    D1    D2            # / TYPES OF OBSERV
   G 1    23    23    23    23    23    23    23            PRN / # OF OBS
   G 4    23    23    23    23    23    23    23            PRN / # OF OBS
   G 7    23    23    23    23    23    23    23            PRN / # OF OBS
   G13    23    23    23    23    23    23    23            PRN / # OF OBS
   G20    23    23    23    23    23    23    23            PRN / # OF OBS
   G24    23    23    23    23    23    23    23            PRN / # OF OBS
   G25    23    23    23    23    23    23    23            PRN / # OF OBS
                                                            END OF HEADER
```

RINEX Observation Files

- Observation file contains data from one site and one session
- Version 2 allows to include observation data from several sites (static or kinematic app.)
- There are 3 fundamental observables:
  - TIME – the time of measurement
  - PSEUDORANGE – stored in meters, includes all offsets and biases
  - PHASE – carrier phase measurements in whole cycles (no systematic drifts from receiver)

RINEX Observation Data

- **Observation block consists of observation time and observation set for each satellite**

```
                                                            END OF HEADER
 01  9  4  9 40  0.0000000  0  7G 1G 4G 7G13G20G24G25
  20532012.14648  20532011.55846  20532016.22546 107896448.4014   84075170.1284
       -702.033        -547.047
  21255524.69947  21255524.94445  21255529.02045 111698540.8774   87037834.1244
        799.589         623.056
  24648794.02245  24648792.88941  24648801.63741 129530300.6484  100932694.9344
      -3425.352       -2669.144
  21267718.45748  21267718.52445  21267722.00945 111762613.2534   87087766.9504
       1911.882        1489.773
  21900010.88847  21900009.74444  21900015.95344 115085325.1934   89676892.5064
      -3011.439       -2346.579
  23828505.41246  23828504.07842  23828511.81542 125219643.5474   97573763.5014
       2743.177        2137.544
  24104647.59546  24104646.97742  24104654.81342 126670763.8784   98704504.1444
      -2800.638       -2182.275
 01  9  4  9 40  1.0000000  0  7G 1G 4G 7G13G20G24G25
  20532145.71148  20532145.21946  20532149.91946 107897150.6724   84075717.3514
       -702.345        -547.270
  21255372.73948  21255372.85245  21255376.88845 111697741.6174   87037211.3244
```

RINEX Navigation Files

- In order not save space the redundant information is minimized
- The Navigation Message File from one receiver may be used by other receivers
- A composite Navigation Message File can be created containing non-redundant information from several receivers in order to make the most complete file

RINEX Navigation Data

- **One block of data per satellite, ephemeris update: PRN, year, month, day, hour, minutes, seconds, sat. clock correction and the orbit parameters**

```
                                                            END OF HEADER
 7 01  9  4  9 59 44.0  .394901260734D-03  .387672116631D-10  .000000000000D+00
    .228000000000D+03 -.138750000000D+02  .543415492579D-08 -.101085380239D+01
   -.417232513428D-06  .120551300934D-01  .368431210518D-05  .515375120926D+04
    .208784000000D+06  .931322574615D-08 -.123603373253D+01  .264495611191D-06
    .944765906161D+00  .300218750000D+03 -.199943296834D+01 -.870929134837D-08
   -.653598653579D-10  .000000000000D+00  .113000000000D+04  .000000000000D+00
    .200000000000D+01  .000000000000D+00 -.186264514923D-08  .228000000000D+03
    .208799000000D+06
13 01  9  4  9 59 44.0 -.481214374304D-05 -.454747350886D-12  .000000000000D+00
    .600000000000D+01 -.225000000000D+02  .473519723997D-08  .781274356790D+00
   -.122375786304D-05  .188760610763D-02  .259466469288D-05  .515369892502D+04
    .208784000000D+06  .335276126862D-07  .193650899233D+01  .149011611938D-07
    .969553772961D+00  .333250000000D+03  .901582558418D-01 -.838142054838D-08
   -.188936441390D-09  .000000000000D+00  .113000000000D+04  .000000000000D+00
    .200000000000D+01  .000000000000D+00 -.116415321827D-07  .774000000000D+03
    .208799000000D+06
 1 01  9  4 10  0  0.0  .193310435861D-03  .147792889038D-11  .000000000000D+00
```

Data Stream Protocols

General Structure Of Messages

- Messege construction
  - Message start symbols
  - Message type
  - Message contents
  - Checksum
  - End of message Symbols
- Messages can be binary or ASCII type
- Examples of protocols
  - RTCM
  - NMEA
  - SOC

Data Formats: RTCM

RTCM

- RTCM SC-104 is a standard for differential GPS service
- Author – Radio Technical Commission for Maritime Services
- Version 3.x has major changes from version 2.x

RTCM Format

- RTCM messages are constructed from GPS like words
- Words are 30 bit long and use GPS parity
- Message consists of a header (2 words) and the message it self (length may vary)
- There about 64 types of messages but less then 30 are used by GNSS

Data Formats: NMEA

NMEA 0183

NMEA

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- The interface standard defines electrical signal requirements, data transmission protocol and time, and specific sentence formats for a 4800-baud serial data bus
- GNSS receivers often send data at higher baud rates
- Each bus may have only one talker but many listeners
- There is also a high-speed addendum of NMEA 0183. This standard operates at a 38.4K-baud rate.

NMEA

- Maintained by the National Marine Electronics Association
- NMEA messages are used by several types of instruments
- There is a set of standard messages for each type of instruments (Loran C, GPS, Integrated Instruments etc.)
- NMEA protocol can be extended by use of proprietary messages (e.g. $PXXYYY,… etc.)

NMEA Message Structure

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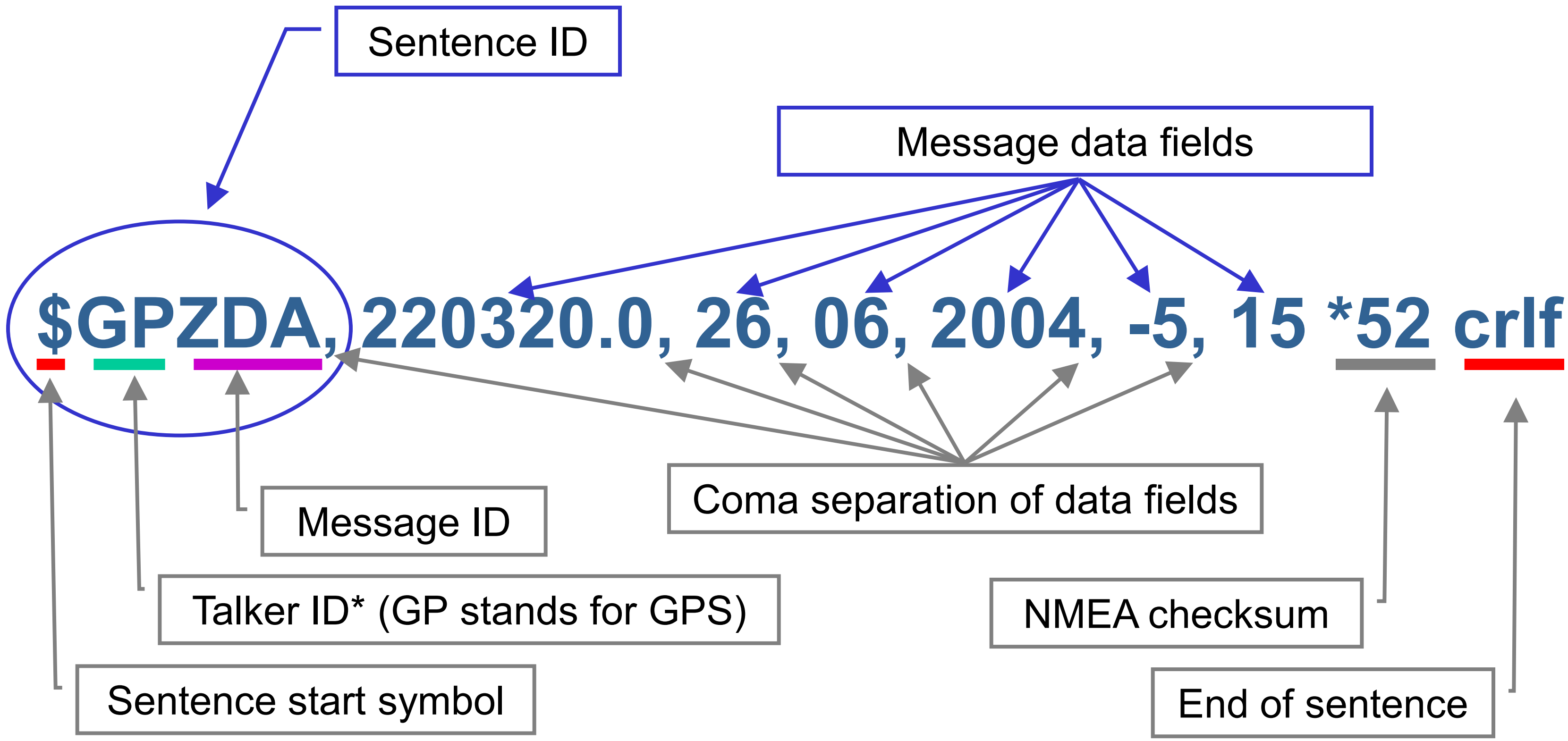
- **An example of an NMEA message:**



* **GNSS talker IDs: GP, GL, GN. Galileo support under development (2009).**

NMEA Checksum

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- Checksums are mandatory
- Checksum is calculated for all symbols, including commas but excluding the“$” and “*” delimiters
- The checksum consists of the byte-wise exclusive OR (XOR)
- The hexadecimal result is converted to two ASCII characters

NMEA Short Summary Of Messages (not complete)

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- **GGA (GPS Fix Data)** Time, position, and fix related data
- **GLL (Position Data)** Position fix, time of position fix, and status
- **GRS (GPS RangeResiduals)** GPS range residuals
- **GSA (GPS DOP and Active Satellites)** GPS position fix mode, SVs used for navigation, and DOP values
- **GST (GPS PRN)** GPS Pseudorange Noise (PRN) statistics
- **GSV (GPS Satellites in View)** Number of SVs visible, PRN numbers, elevation, azimuth, and SNR values
- **ZDA (Time and Date)** UTC time, day, month, and year, local zone number, and local zone minutes
- **RMC** Contains recommended minimum specific GPS/transit data

Questions And Exercises

Today's Exercise

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- Load the mat file from: */afs/ies.auc.dk/project/softgps/public/data_long2.mat*
- Acquisition on the first millisecond data (or the next millisecond)
- Track all the visible satellites
- Decode the navigation messages on all satellites
- Calculate pseudoranges to all the available satellites
- Calculate the satellite positions at transmit time
- Calculate the position based on the pseudoranges and satellite positions