Session C2: Multisensor Integrated System Technologies

Recent Enhancements of the Multi-Sensor Navigation Analysis Tool (MuSNAT)

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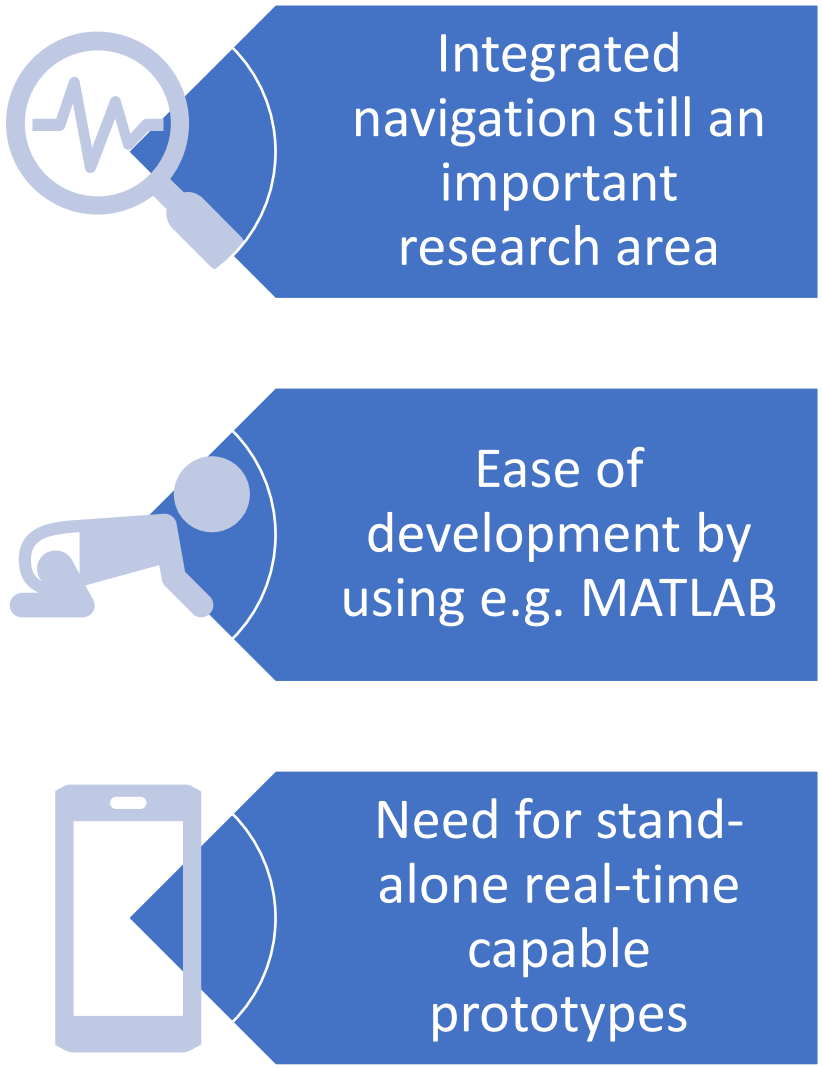
Motivation and Paper/Presentation Contents



Contents

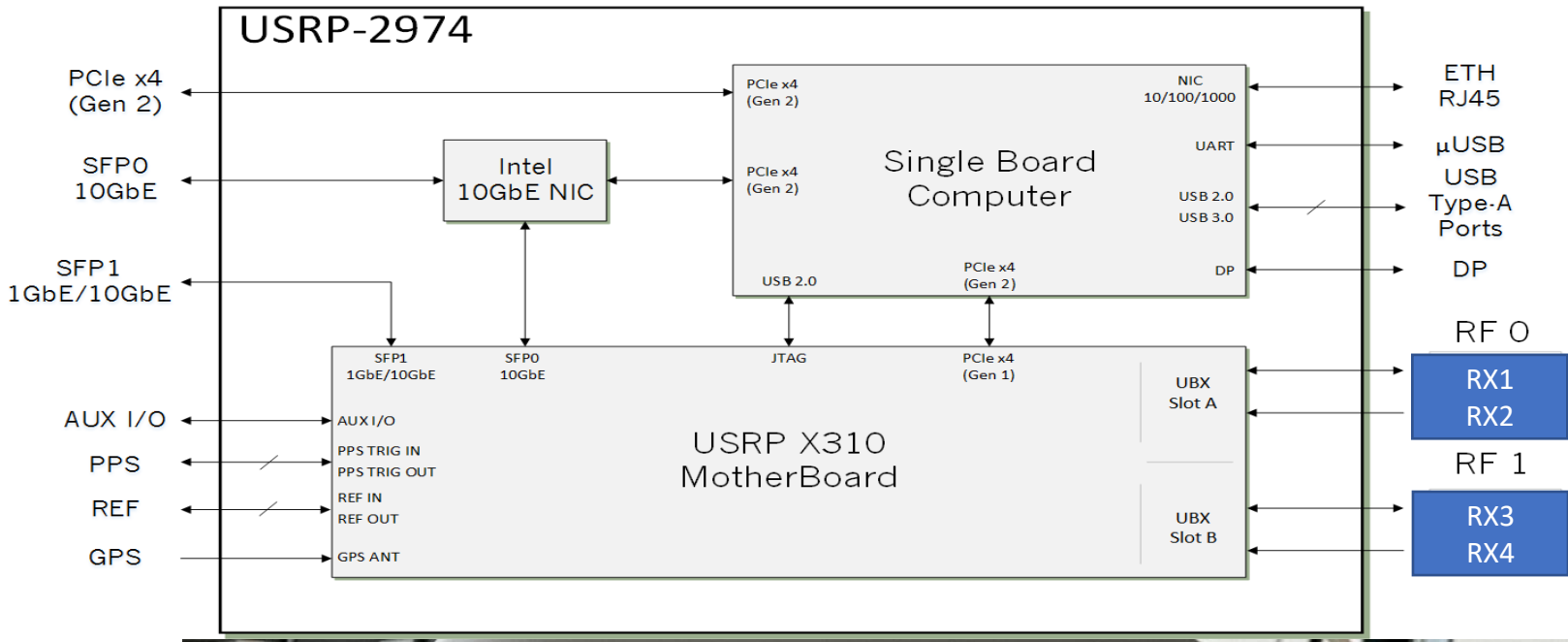
- Stand-Alone GNSS Software Receiver USRP 2974
  - Frontend, GNSS/LTE Processing Performance (real-time)
- C++/MATLAB Interface
  - PPP Module
  - LiDAR Module
  - GNSS/Deep-Coupling Interface
- Other points and future developments

Stand-Alone GNSS Software Receiver

How to use a modified USRP as generic GNSS SDR with LTE/5G and sensor data processing capabilities

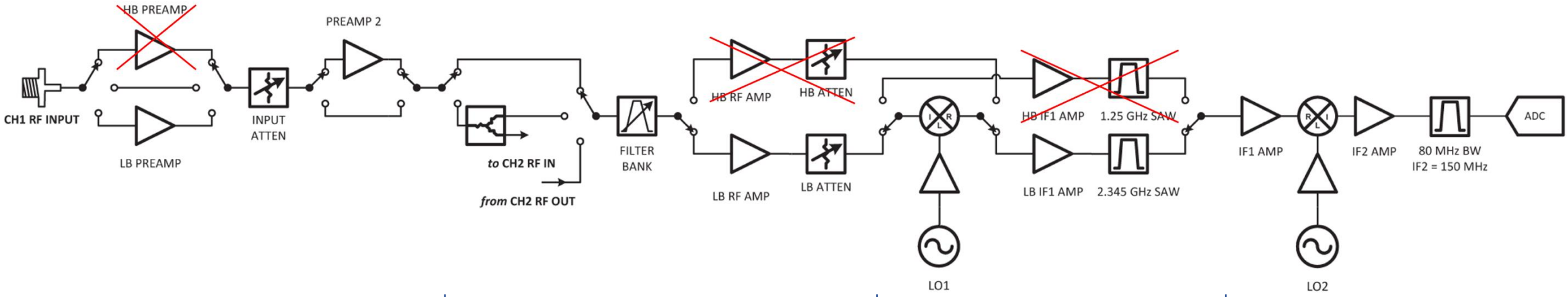
Stand alone GNSS Software Receiver

- “modified” USRP-2974
- 4 RF Channels (next slide)
  - ADC
  - 4 x PCI 2.0, 2GByte/s
- Intel Core i7-6822EQ with a release date Q4/2015
- Windows 10 OS



RF Frontend (with TwinRx daughterboards)

- superheterodyne architecture (G = 0 to 93 dB, N_f < 5 dB)
  - 4 channels, 80 MHz each, independent tuning, RF shielding, LO sharing capability (phase-aligned operation)



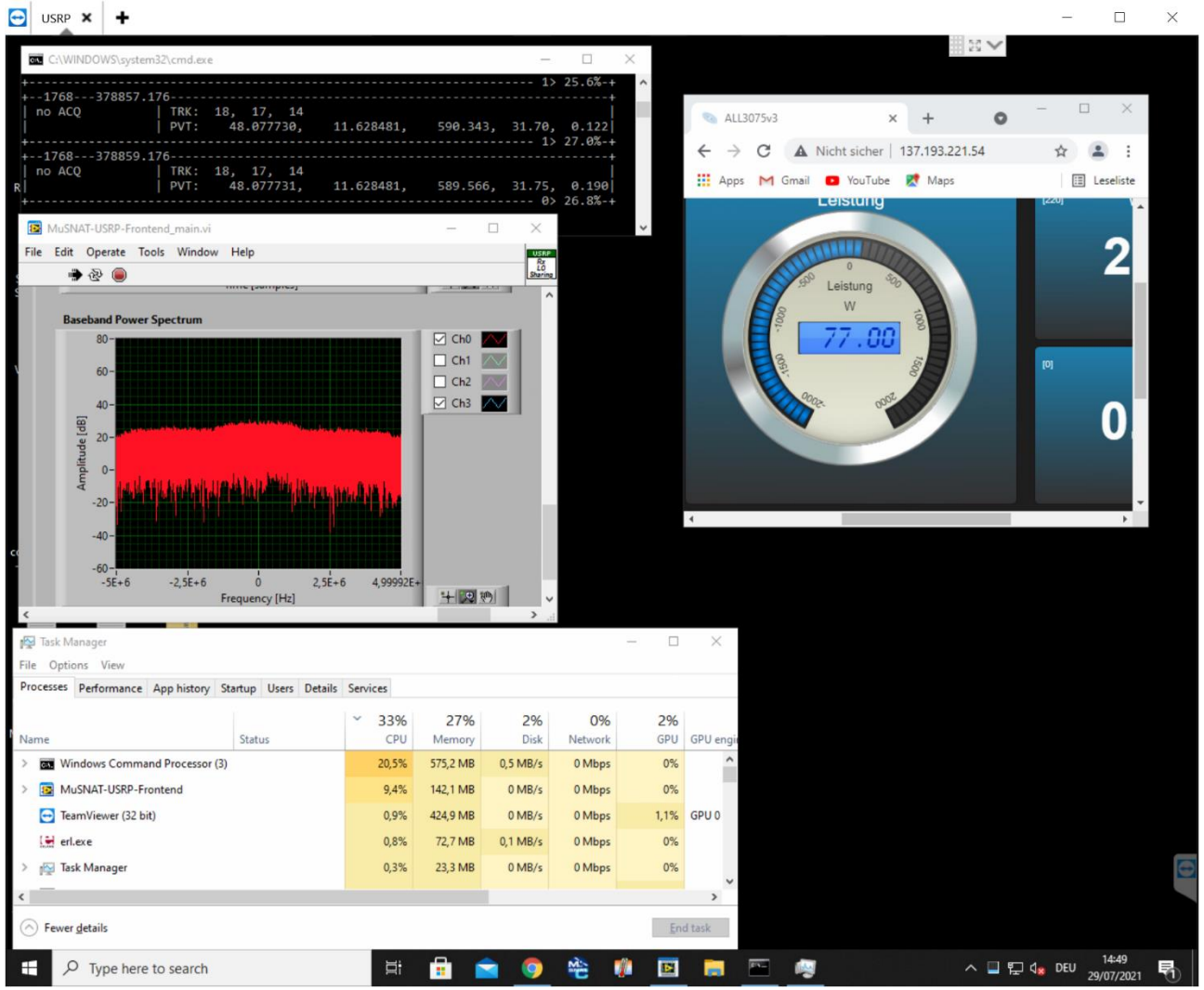
- switchable high-pass filter
- switchable 14-dB amplifier *(2x)*
  - PGA-102+ of Mini-Circuits
  - $N_f \approx 2.4$ dB
- 31-dB programmable attenuator
  - PE43503 of Peregrine Semiconductor
- f = (0.01 or) 0.8 to 6 GHz
- BW = (5.99 or) 5.2 GHz

- filter bank (4 LB configurations)
  - LB 4: f = 1.16 to 1.85 GHz, BW = 680 MHz
    - high-pass ceramic filter (HFCN-1100+)
  - LB 3: f = 0.76 to 1.24 GHz; BW = 480 MHz
    - high-pass ceramic filter (HFCN-740+)
    - low-pass ceramic filter (LFCN-1000+)
- 14-dB amplifier
- 31-dB programmable attenuator
- two high-pass ceramic filter
  - LFCN-1700+ of Mini-Circuits

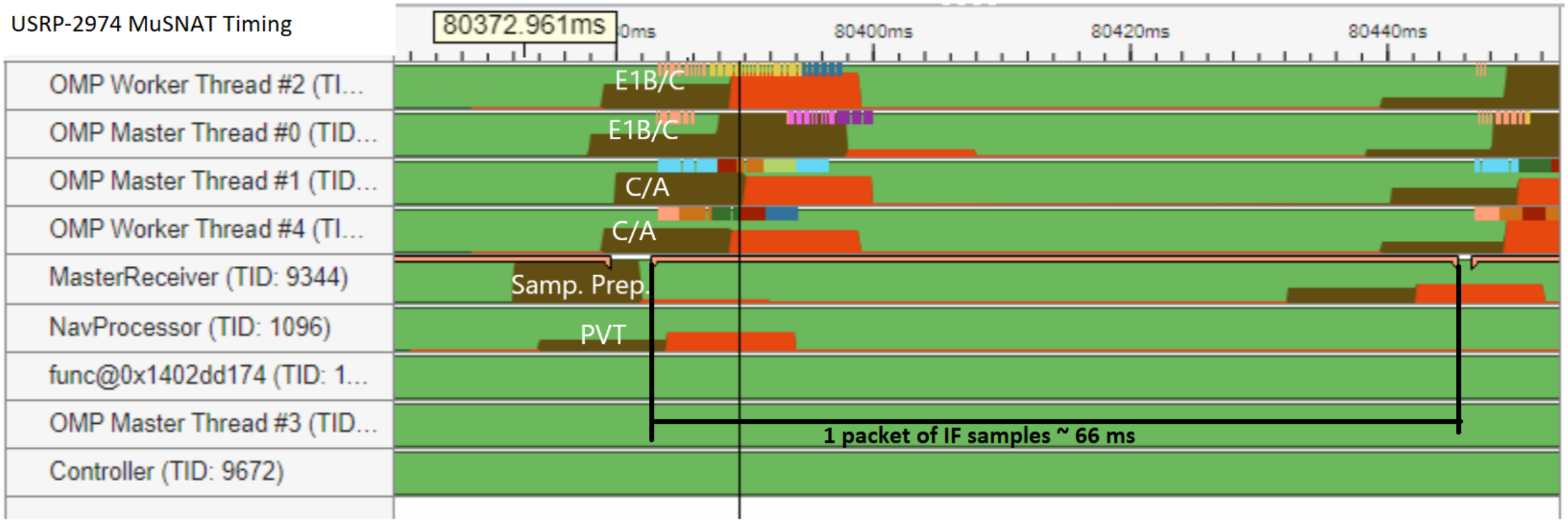
- *wide-band frequency mixer*
  - SIM-722MH+ of Mini-Circuits
- 14-dB amplifier (2x)
- SAW filter
  - TA0581A of TAI-SAW
- f_{IF} = 2.345 GHz, BW = 90 MHz

- *wide-band frequency mixer*
  - LTC 5510 of LLTC/Analog Devices
- 14-dB amplifier
- bandpass filter (NI custom)
- f_{IF} = 125 MHz, BW = 40 MHz, or
- f_{IF} = 150 MHz, BW = 80 MHz
- ADC (complex, f_s = 200 MHz)
  - ADS62P48 of Texas Instruments

Power Consumption and Real-Time Processing

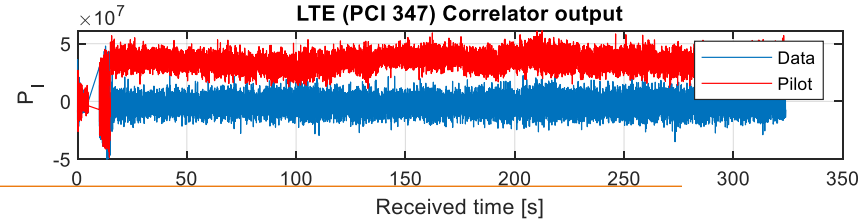


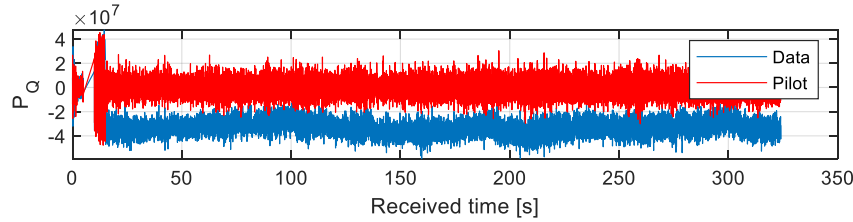
GNSS Real-Time Processing Timing

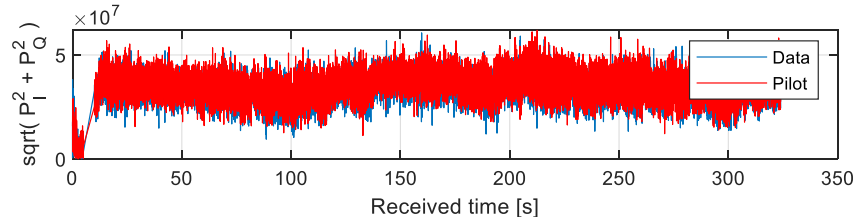


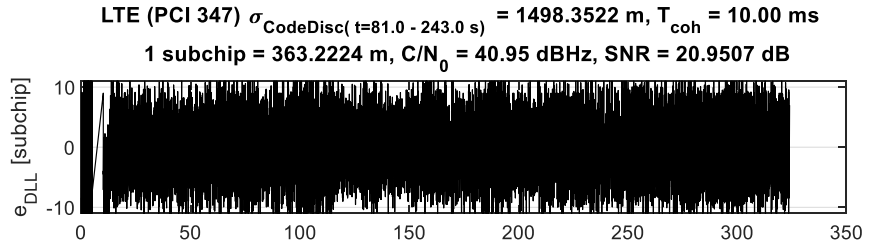
GNSS/LTE Tracking

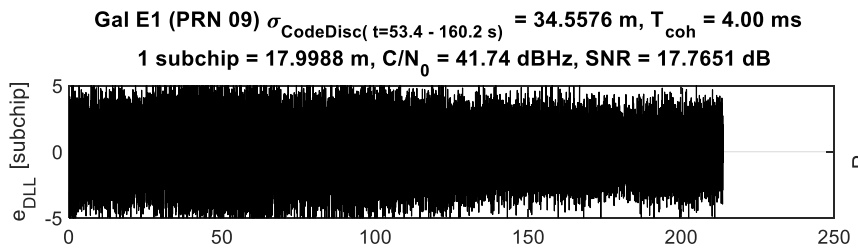
- The LTE acquisition/tracking is based on a combined PSS/SSS sequence (10 ms long)
- The combined GNSS + LTE processing is now possible
- 5G signal acquisition/tracking (and its combination with GNSS) is currently under test

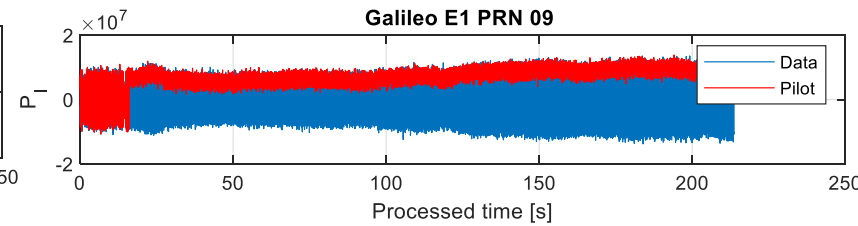


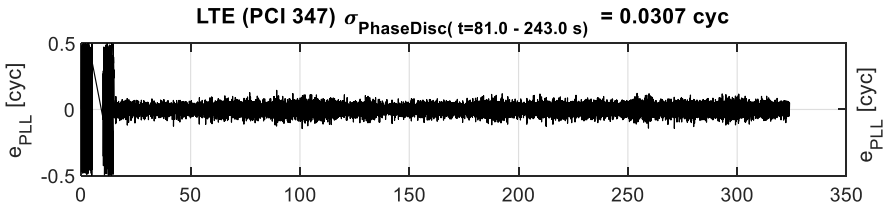


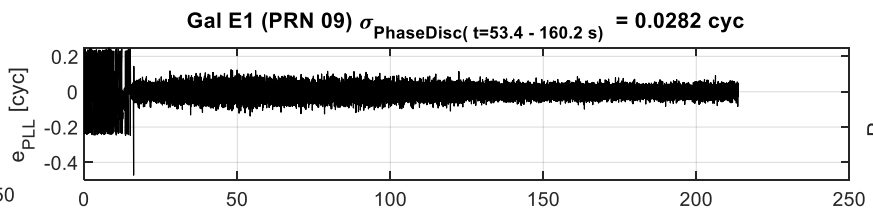


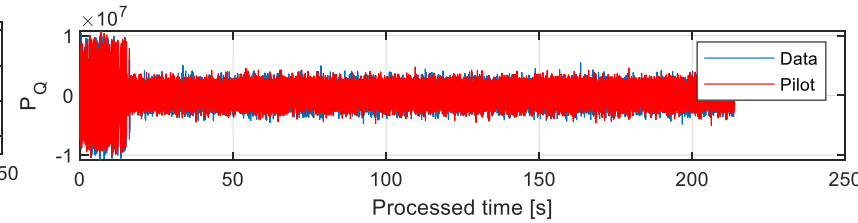


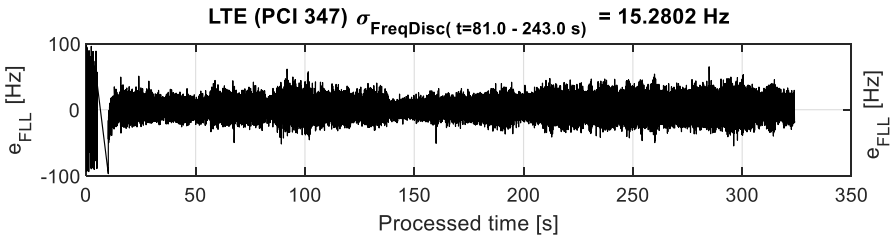


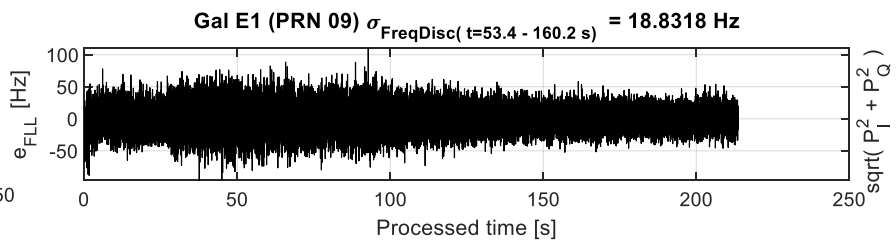


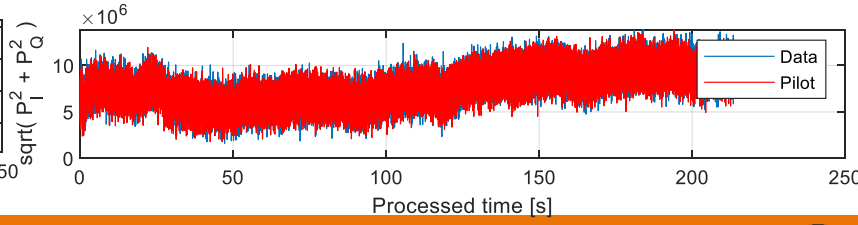












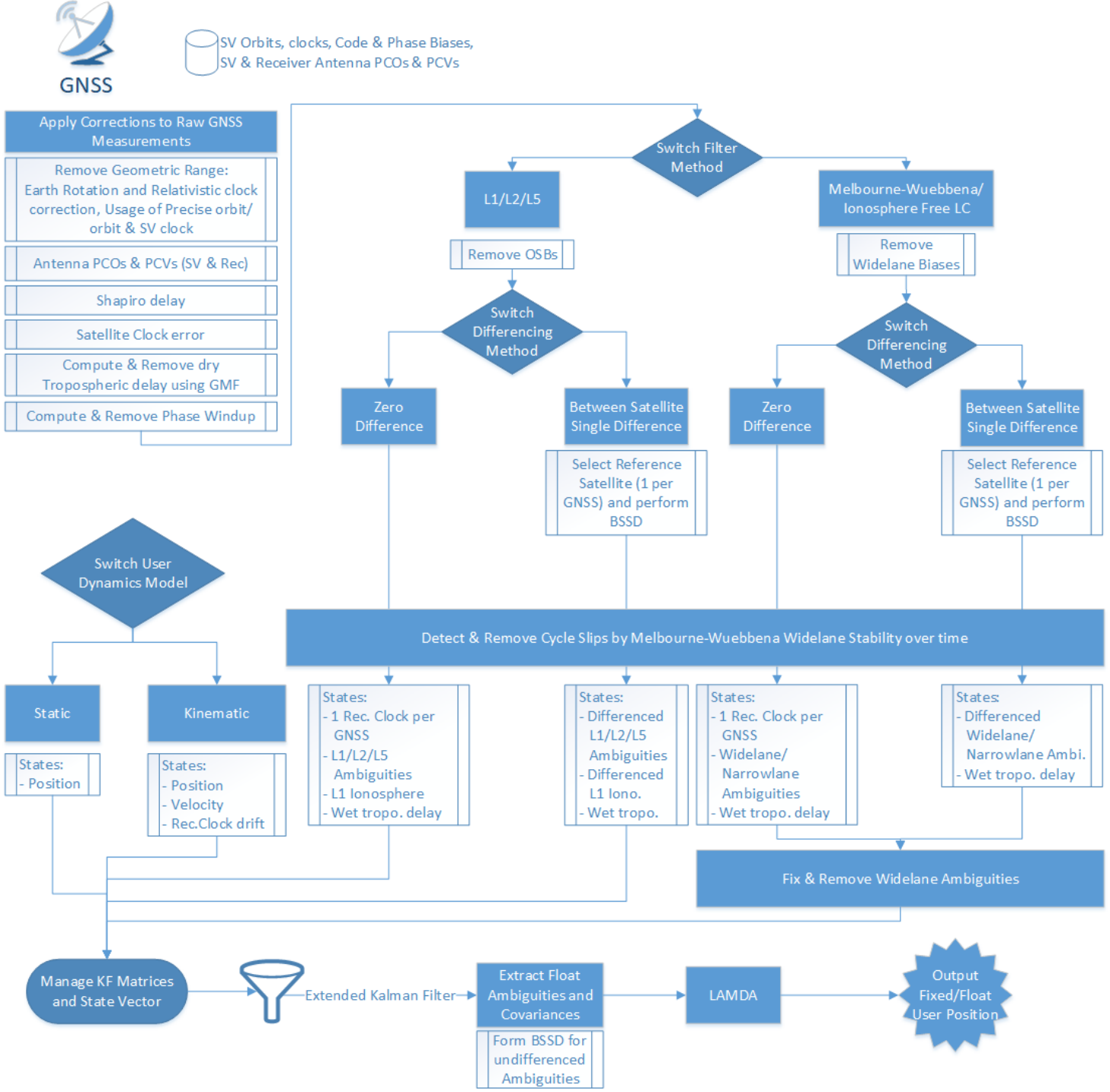
C++/MATLAB Interface

How to integrate MATLAB into the GNSS SDR (MuSNAT) C++ code to ease the development cycle

C++/MATLAB Interface

- MATLAB runs as a separate process under WINDOWS OS
- C++ header files plus libraries provided by MathWorks
- Support of various MATLAB data structures (array, cells, …) in C++
- Execution of MATLAB scripts. (call latency **a few ms**)

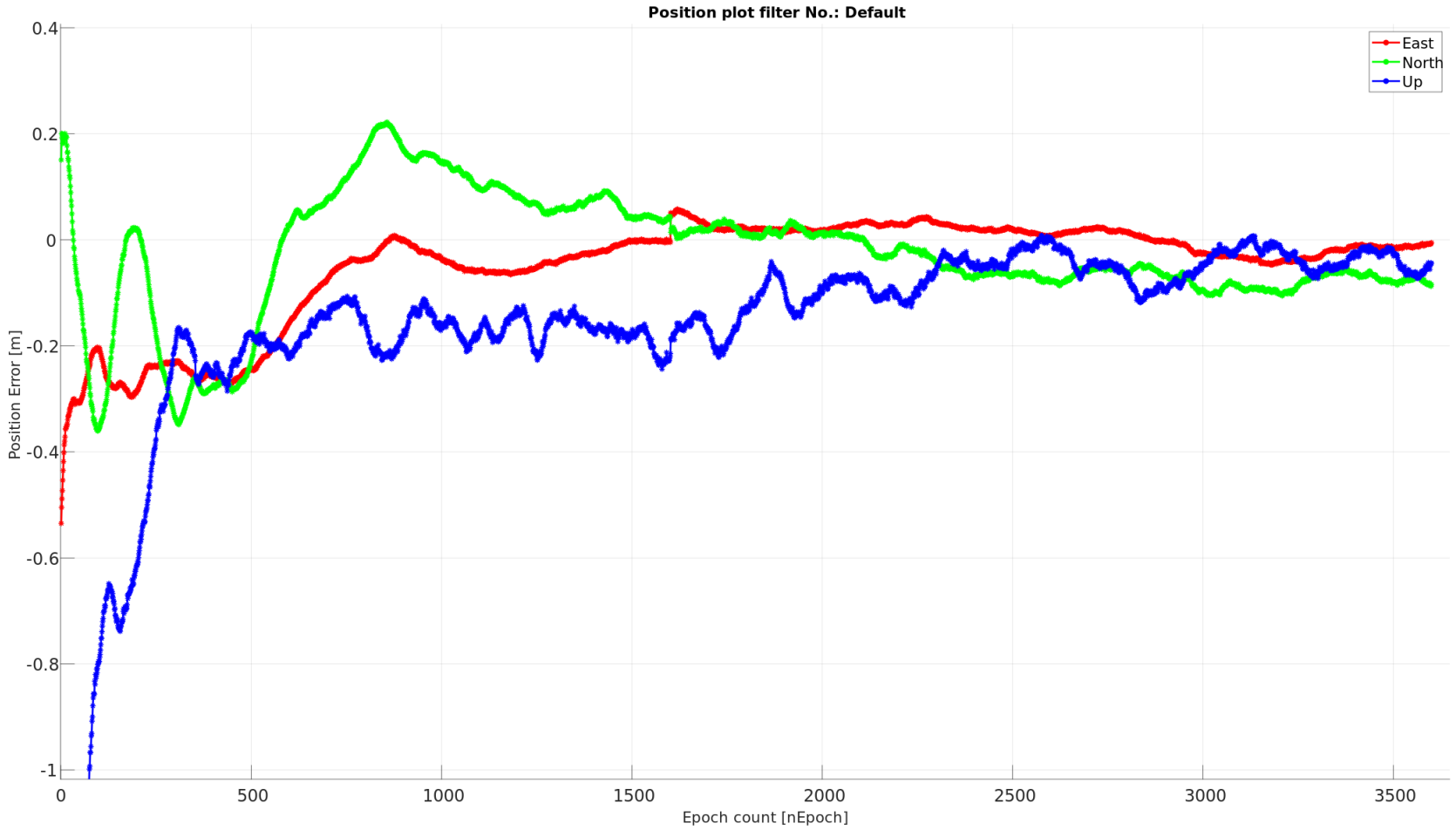
```
254         if (nImuDataCnt)
255         {
256             // create matrix for MATLAB, 0 ... time, 1..3 acc, 4..6 gyro
257             IMU_dat = __dc__factory.createArray<double>({ nImuDataCnt, 8 });
258
259             // iterate through sensor data list
260             nImuDataCnt = 0;
261             for (it = theData.listpAccSensorData.begin(); it != theData.listpAccSensorData.end(); ++it)
262             {
263                 // check if it is a IMU record and from correct IMU id (in case of multiple imus connected)
264                 if ((it->get()->nType == it->get()->MemsImu))
265                 {
266                     DSensorRecordImu* imuData = (DSensorRecordImu*)it->get();
267
268                     IMU_dat[nImuDataCnt][1] = double(imuData->myDat.vfAcc[0]);
269                     IMU_dat[nImuDataCnt][2] = double(imuData->myDat.vfAcc[1]);
270                     IMU_dat[nImuDataCnt][3] = double(imuData->myDat.vfAcc[2]);
271
272                     IMU_dat[nImuDataCnt][4] = double(imuData->myDat.vfGyro[0]);
273                     IMU_dat[nImuDataCnt][5] = double(imuData->myDat.vfGyro[1]);
274                     IMU_dat[nImuDataCnt][6] = double(imuData->myDat.vfGyro[2]);
275
276                     IMU_dat[nImuDataCnt][7] = double(imuData->myDat.nSampleCounter);
277                     imuData->ptRefTime.toGPS(gpsWeek, gpsSec);
278                     IMU_dat[nImuDataCnt][0] = gpsSec;
279
280                     nImuDataCnt++;
281                 }
282             }
283         }
284     }
285
286     // Pass data to Matlab
287     try
288     {
289         if (nImuDataCnt) __dc__matlabPtr->setVariable(u"curImuDat", std::move(IMU_dat));
290         __dc__matlabPtr->setVariable(u"curSatStruct", std::move(satStruct));
291         __dc__matlabPtr->eval(u"dcProcessEpoch;", {}, __dc__error);
292         dcPos = __dc__matlabPtr->getVariable(u"curElemToExtract");
293     }
294     catch (...)
295     {
296         String error_ = matlab::engine::convertUTF16StringToUTF8String((__dc__error.get()->str()));
297         String str;
298         str.format("DeepCouplingMatlabInterface::process -> MATLAB error '%s'", matlab::engine::convertUTF16S
299         throw SoftRecError(SoftRecError::SoftRecErrorMatlabInterface, error_.c_str());
300     }
301
```

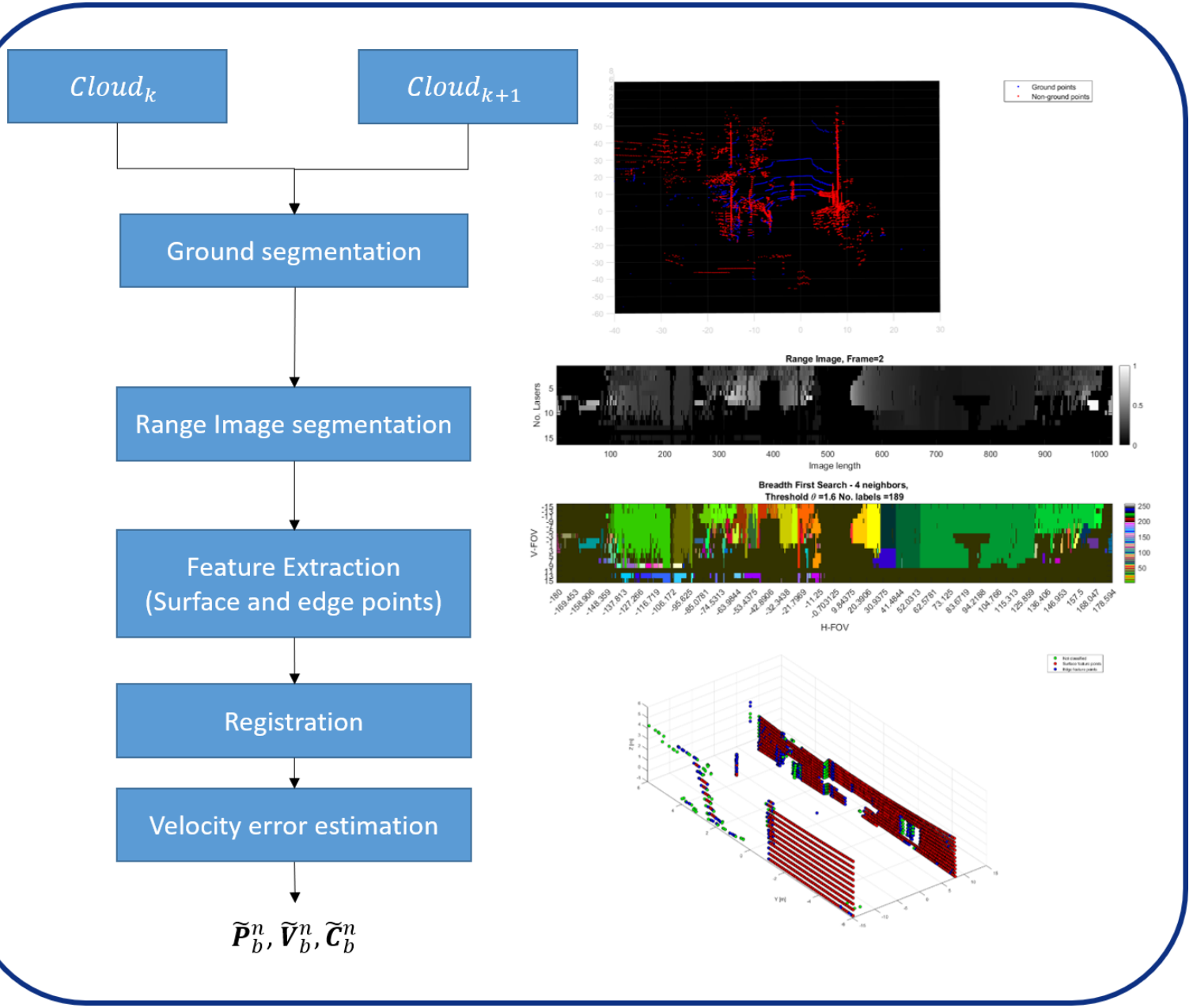


MATLAB PPP Processing

- Support of GPS L1/L2 Gal E1/E5a
- Undifferenced/BSSD
- Uncombined/ Widelane – Narrowlane
- Static/Kinematic Processing
- Cycle Slip detection using MW Measurements
- Realtime capable
- Convenient implementation (KF state handling), testing and development, use of built-in MATLAB functions;
- Processing Speed slower than pure C++

PPP, typical result



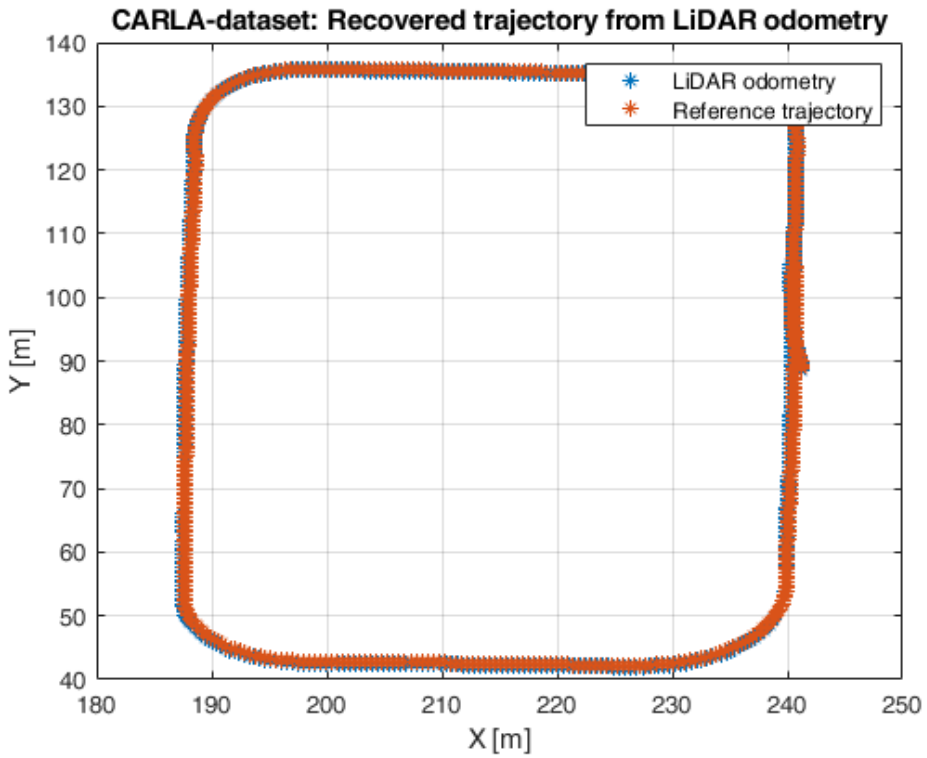


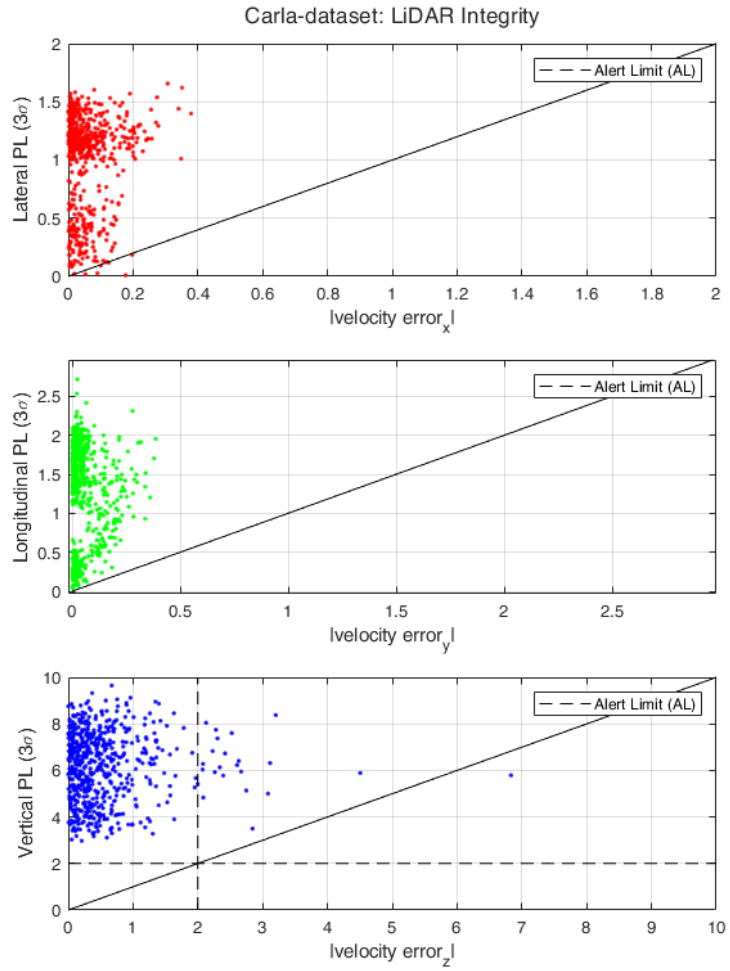
MATLAB LiDAR Processing

- Support of PCAP LIDAR data stream for VLP16 and synthetic data generated with CARLA
- Implementation of state of the art algorithms, specific designed for real time applications (most of them) and that can handle sparse 3D point clouds.
- The LiDAR update consist in the position, velocity and velocity error estimate.

- Facilitates evaluation, testing and visualization of the individual processing modules as it can run independently from the MuSNAT.
- It also accelerates integration with the MuSNAT as the connection with MATLAB is straight forward.
- Integration/testing of opensource libraries may be difficult to include within the matlab environment.

LiDAR, typical results

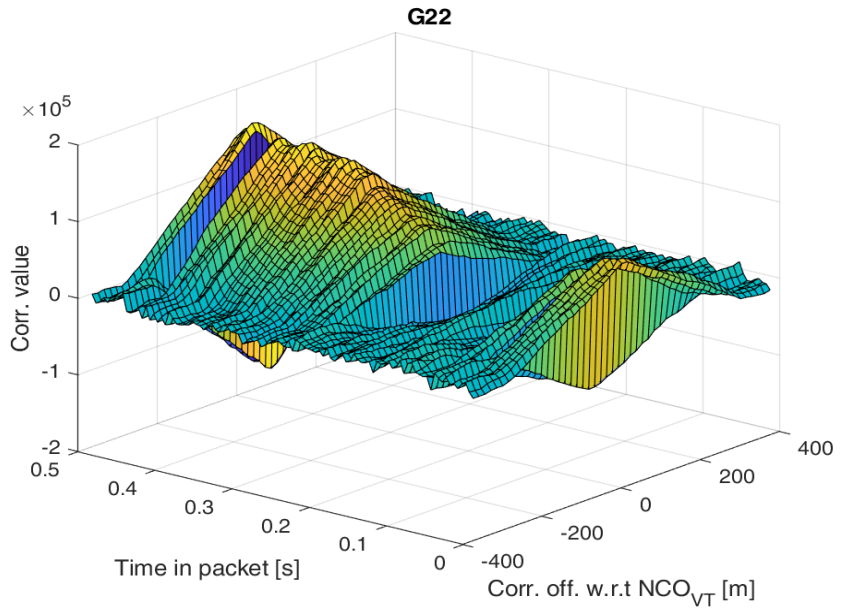




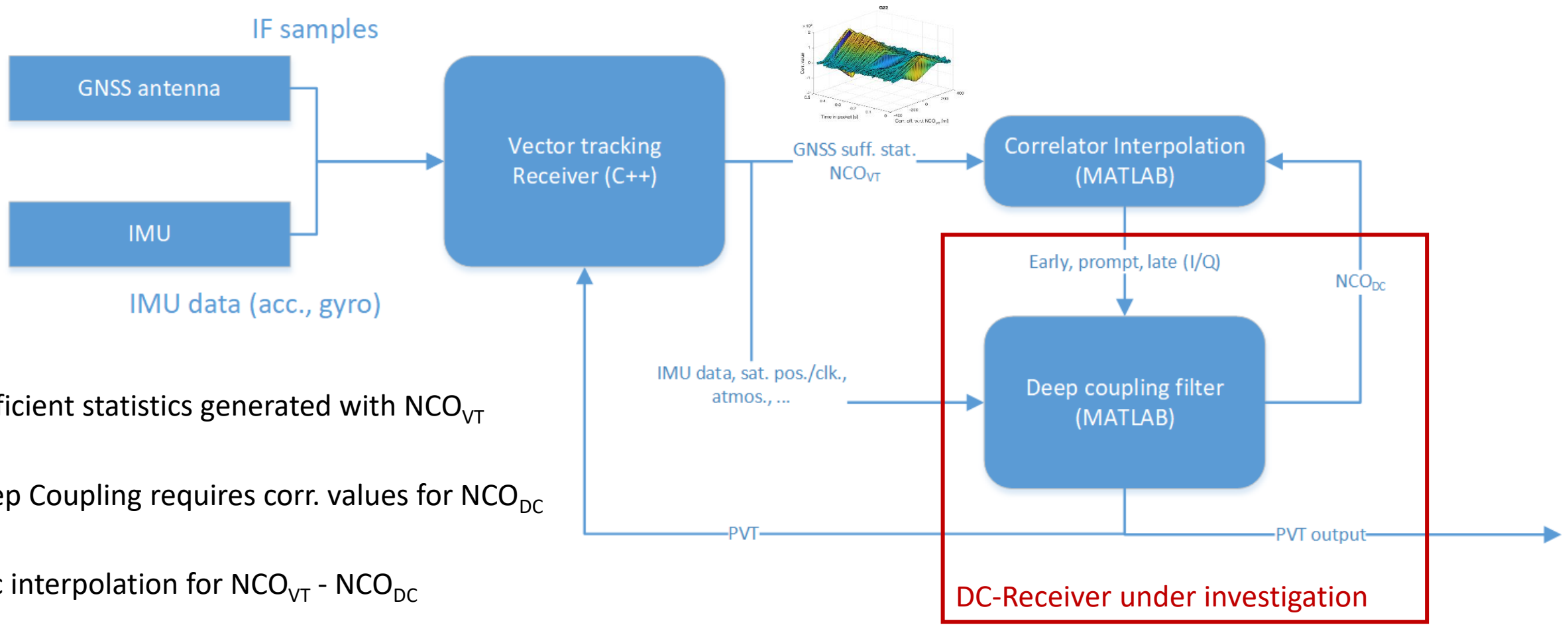
Deep Coupling C++/MATLAB Interface

- GNSS/INS Deep Coupling
  - NCO values, correlator values
  - IMU strapdown and Kalman filter
  - High bidirectional rate
    - 50 Hz … 1 kHz
- Rate incompatible for direct use of C++/MATLAB interface due to call latency
- Another solution required

- Sufficient statistics
  - I.e. multi-correlator value
  - contain full GNSS signal contents
- Batch-wise generation passing to MATLAB for all signals and satellites (e.g. every 0.5) -> latency problem solved
- “sinc”-interpolation to get actual values



Deep Coupling C++/MATLAB Interface

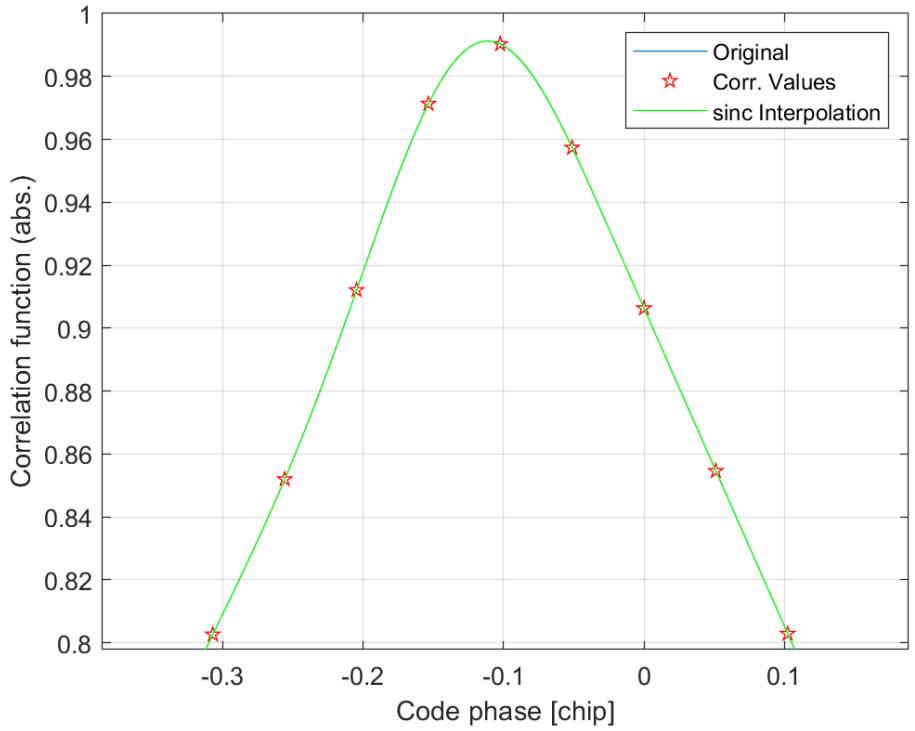


Sufficient statistics generated with NCO_{VT}

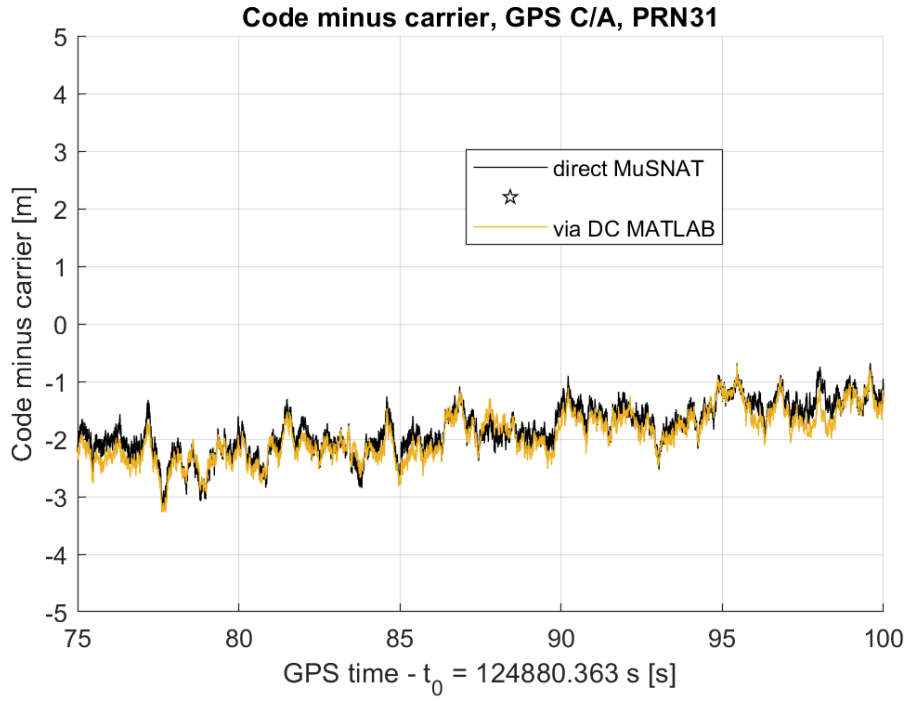
Deep Coupling requires corr. values for NCO_{DC}

sinc interpolation for NCO_{VT} - NCO_{DC}

Deep Coupling C++/MATLAB Interface



Validation of sinc-interpolation



Validation of interface with
standard (scalar) DLL/PLL are real signals

Other points and Outlook

Further points in the paper

- Performance on high-end PCs/laptops
- IQ/IF conversion
  - To support various input formats
  - Loss-less FFT based conversion
  - Benefits for multipath estimating algorithms (and C/N0)

Outlook

- Bit decimation and band selection on USRP2974 FPGA
- Synchronized IMU/GNSS data collection on USRP 2974 FPGA
- Off-loading of GNSS/LTE/5G correlation to GPU within Deep Coupling Interface (low latency)
- Open-Source policy for MATLAB code (TBC)