A Comprehensive Analysis of Large-Scale SDR Synchronisation with the OctoClock-G

Dennis Joosens

IDLab, imec research group at University of Antwerp

The chip lab of the world

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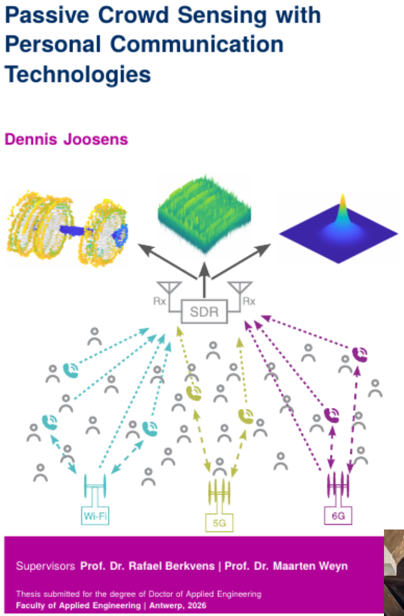
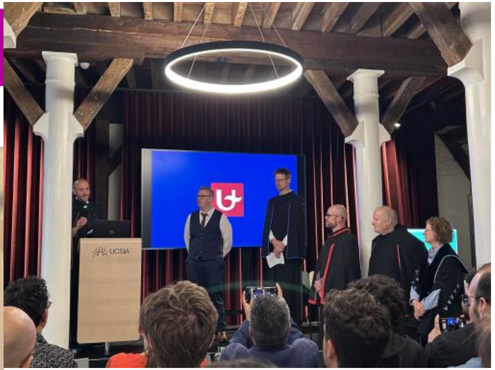
About last Monday…

- **Finished doctorate**

- **Topic:**
- **Passive Crowd Sensing with Personal Communication Technologies**





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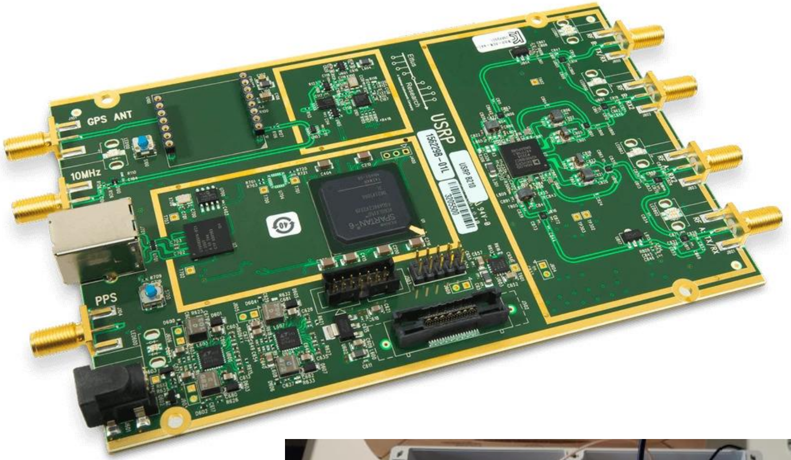
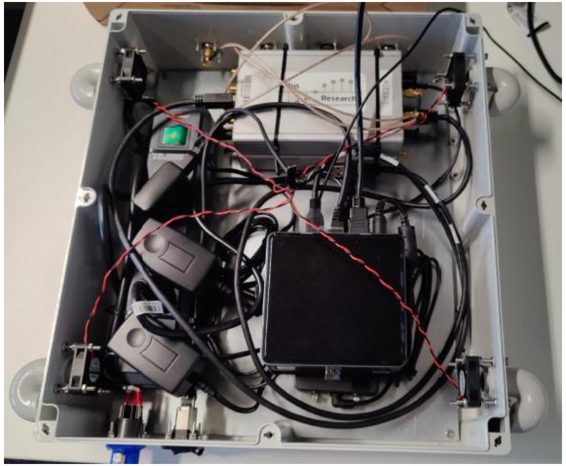
B210 for passive sensing crowds



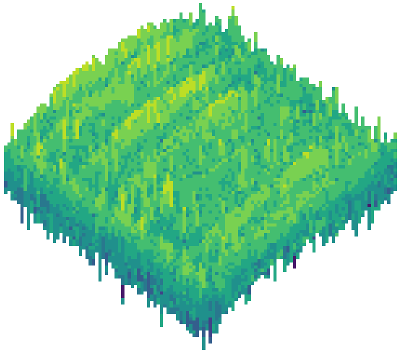
- **Passive sensing system… from scratch**
- **Data Capture Unit (DCU)**
- **Based on 2 x B210 SDRs**

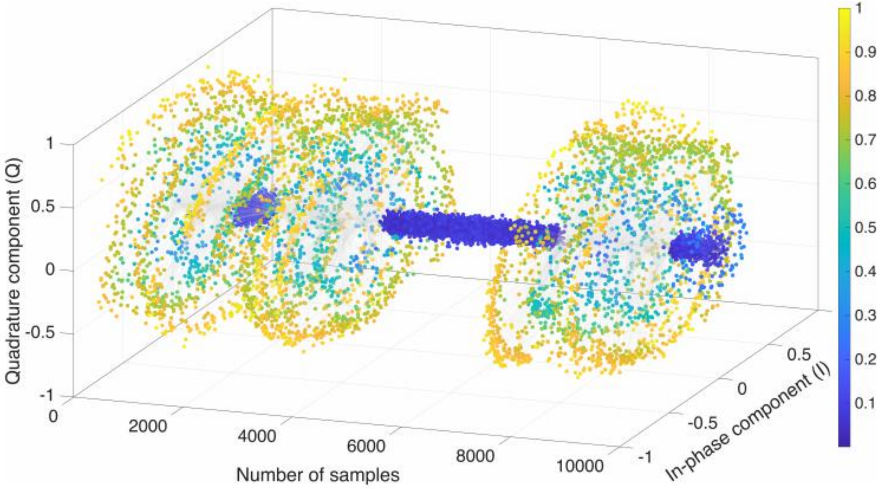


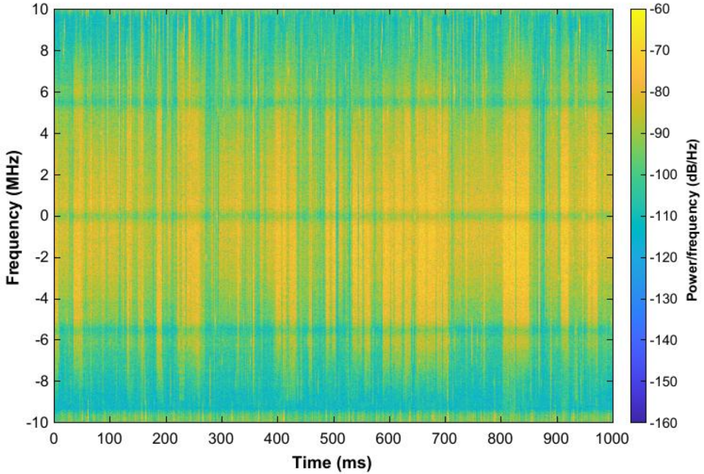
Measurement Environment

B210 for passive sensing crowds

- **Sensing based on available radio wave energy**
- **Generated by Wi-Fi/LTE-enabled devices**







Measuring Crowds

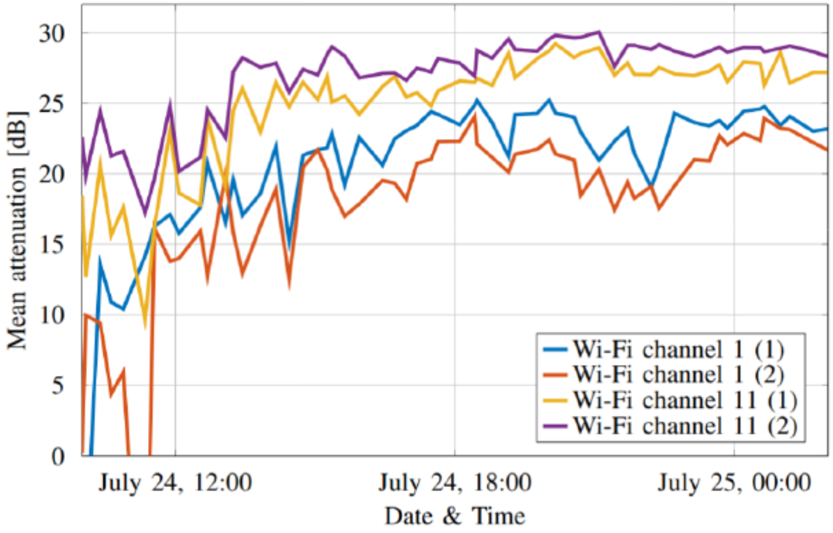
- **Issue**

- **No power calibration**
- **Radio artifacts…**

- **No time/frequency/phase synchronization**

What is the effect?

Can we measure this?



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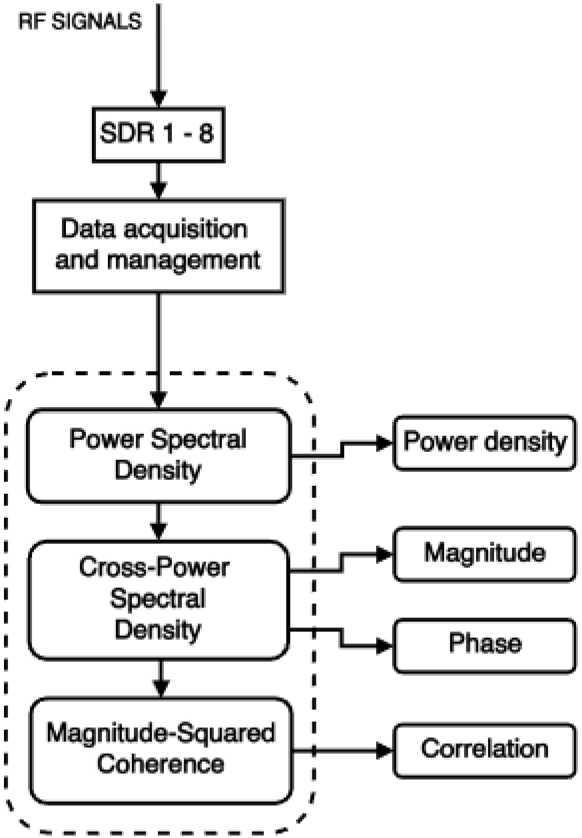
Previous Processing Pipeline

- **Short-time Fourier Transform**

- **Magnitude Extraction**
- **CPSD**
- **MSC**



So I want to start with synchronization,… but how?

1. **Synchronization device, OctoClock-G**
2. **SDR(s)**
3. **MultiUSRP (C++ or Python API)**

OctoClock-G

- Synchronization device
- GPSDO inside
- 1 Pulse-Per-Second
- 10 MHz

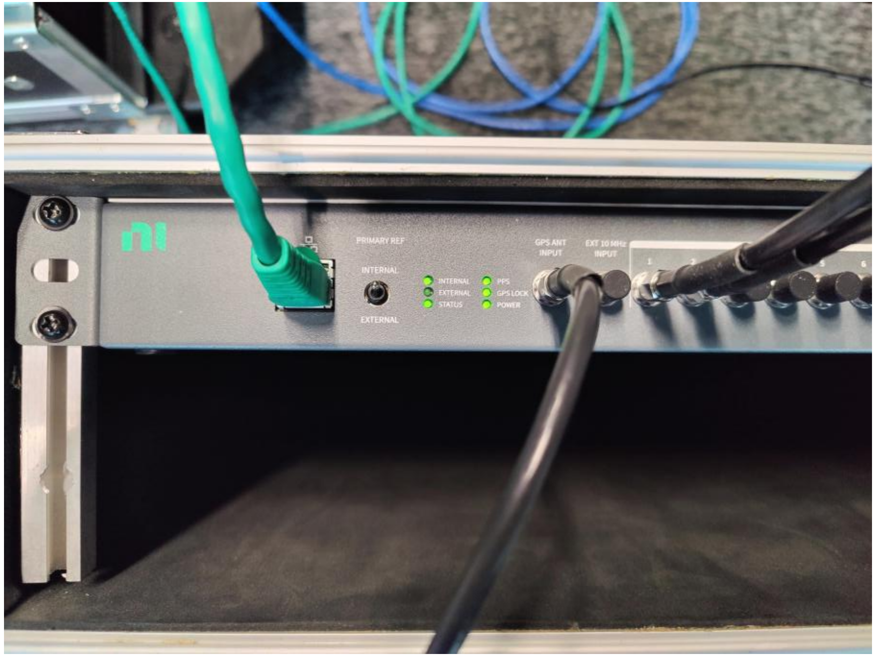
- External PPS
- External 10 MHz
- Ethernet for querying

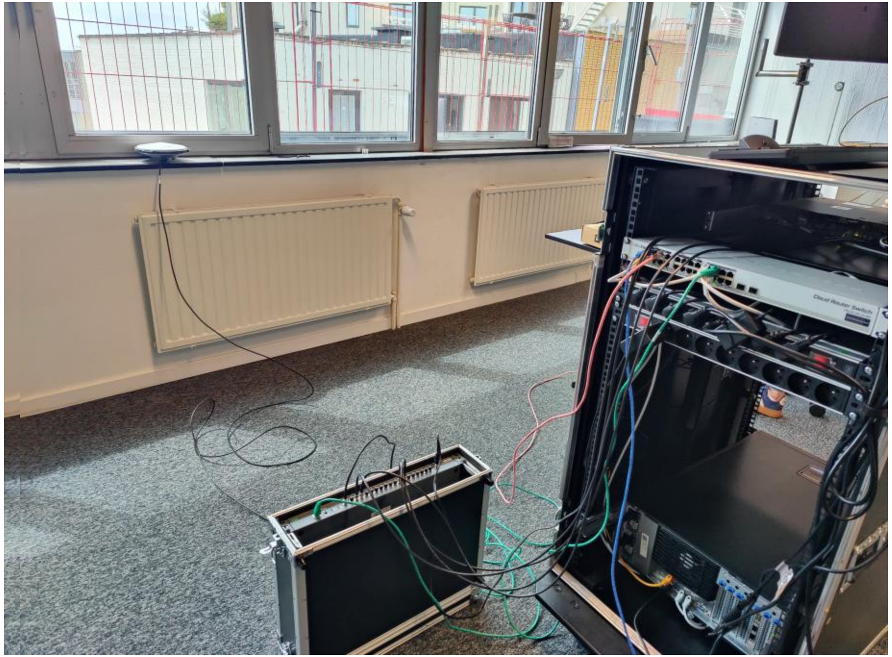
- External GPS connected

OctoClock-G - External GNSS antenna

- **5V (active) antenna**
- **Inside, next to window**
- **Fast GPS fix**
- **Querying possible with MultiUSRP**

OctoClock-G - External GNSS antenna





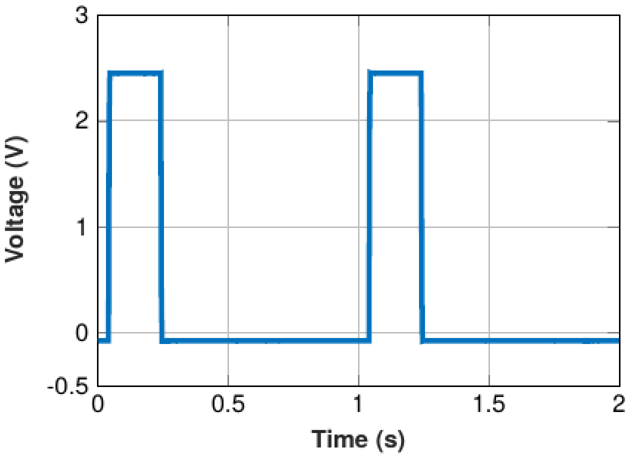
OctoClock-G - Querying

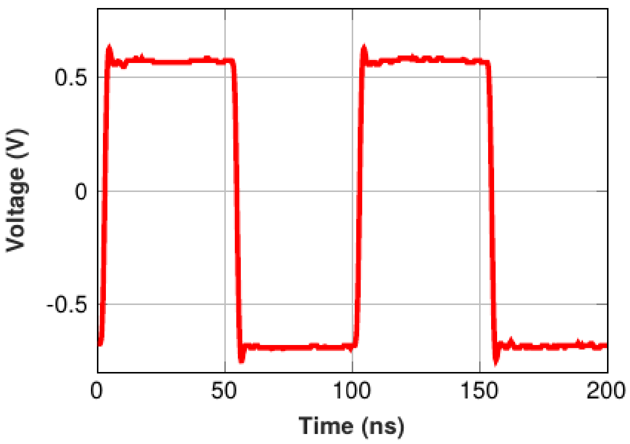
```
idlab-wi-fi-gw-2@idlab-wi-fi-gw-2:~/Desktop$ python3 hello_octoclock.py
[INFO] [UHD] linux; GNU C++ version 11.4.0; Boost_107400; UHD_4.7.0.0-113-g8208bad1
[INFO] [OCTOCLOCK] Opening an OctoClock device...
[INFO] [OCTOCLOCK] Detecting internal GPSDO...
[INFO] [GPS] Found an internal GPSDO: LC_XO, Firmware Rev 1.101
[INFO] [OCTOCLOCK] Detecting external reference...false
[INFO] [OCTOCLOCK] Detecting switch position...Prefer internal
[INFO] [OCTOCLOCK] Device is using internal reference
> get_pp_string():  Single USRP Clock Device
  Board 0
    Reference: internal

> get_num_boards():  1
> get_time():  1733861598
> get_sensor_names():  ['ext_ref_detected', 'gps_detected', 'using_ref', 'switch_pos', 'gps_gpgga', 'gps_gprmc', 'gps_time', 'gps_locked', 'gps_servo']
>  Sensor query >  ext_ref_detected:  External reference detected: false
>  Sensor query >  gps_detected:  GPSDO detected: true
>  Sensor query >  using_ref:  Using reference: internal
>  Sensor query >  switch_pos:  Switch position: Prefer internal
>  Sensor query >  gps_gpgga:  GPS_GPGGA: $GPGGA,201318.00,0000.0000,N,00000.0000,E,0,04,2.9,0.0,M,0.0,M,,*5B
>  Sensor query >  gps_gprmc:  GPS_GPRMC: $GPRMC,201318.00,V,0000.0000,N,00000.0000,E,0.0,0.0,101224,,*29
>  msg.timestamp 20:13:18+00:00 - lat 0000.0000 - lat_dir N - lon 00000.0000 - lon_dir E - gps_qual 0 - num_sats 04 - horizontal_dil 2.9 - altitude 0.0 - altitude_units M - geo_sep 0.0 - geo_sep_units M
 age_gps_data  - ref_station_id
>  timestamp  20:13:18+00:00 - Lat 0000.0000 - Lon 00000.0000 - Lat_dir N - Lon_dir E
>  Sensor query >  gps_time:  GPS epoch time: 1733861599 seconds
>  Sensor query >  gps_locked:  GPS lock status: unlocked
>  Sensor query >  gps_servo:  GPS_SERVO: 24-12-10 4714 44980 25.94 2.03E-10 12 3 1 0x10
```

OctoClock-G - Validation

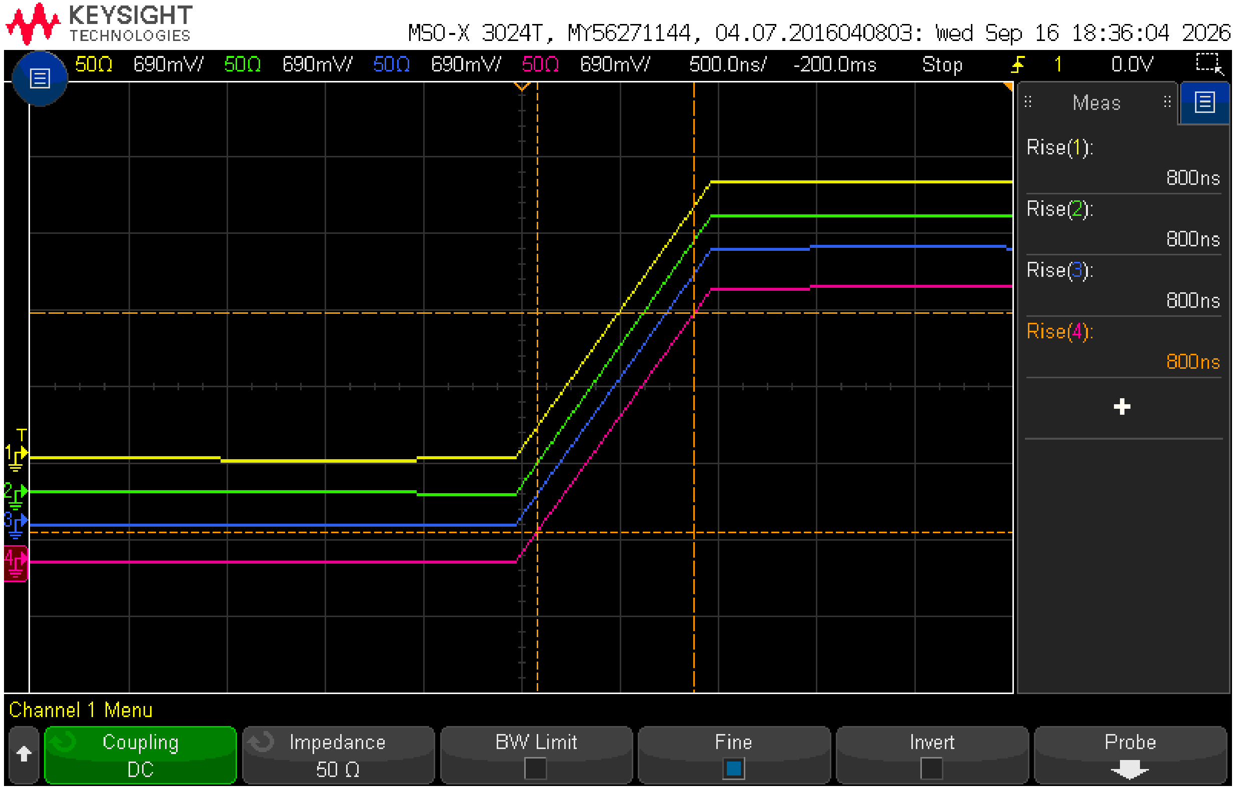
- **50 ohm input scope**
- **1 Pulse-Per-Second**
- **10 MHz**





OctoClock-G - Validation

- 1 Pulse-Per-Second
- Rise time
- 800 ns



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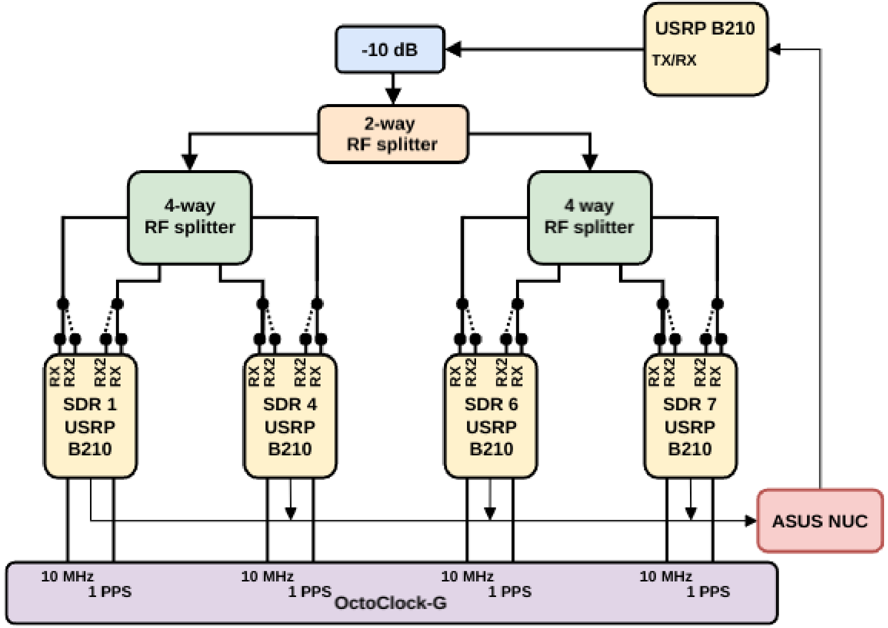
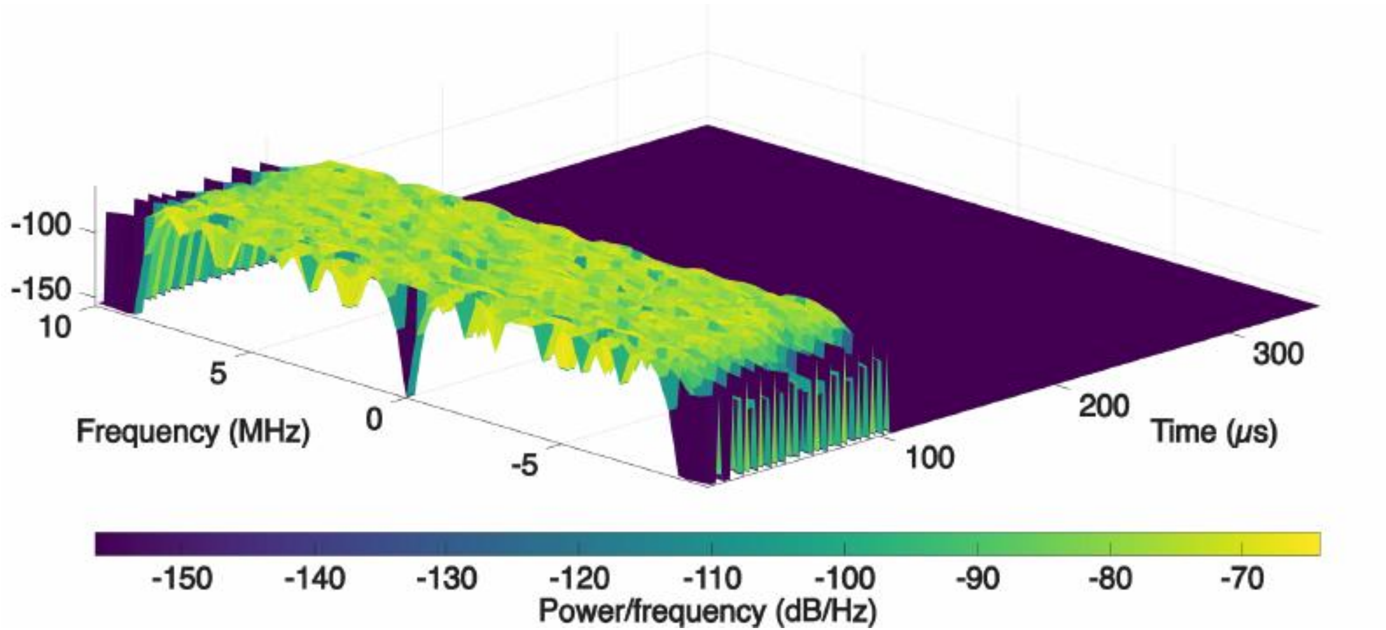
The SDRs

- **2, 4, (8) USRP B210**
- **2 USRP X410**



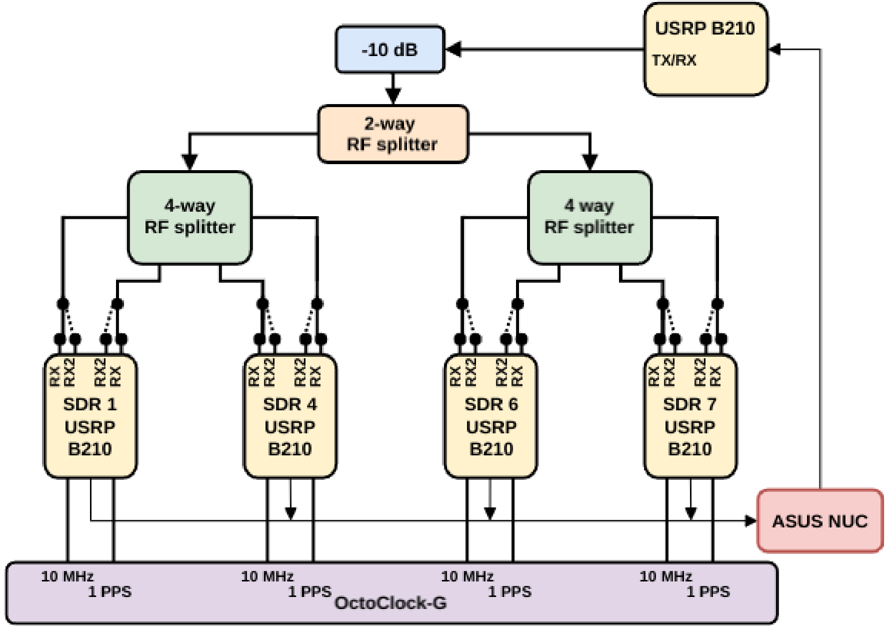
The SDRs

The SDRs - Baseband Signal Generation



The Measurements - Data sets

- **B210**
  - **Three frequency bands**
    - **2412 MHz, 2437 MHz, 2462 MHz**
    - **20 MHz**
    - **1 second**
  - **11 normalized gains**
    - **5 measurements per gain set**
  - **TX/RX and RX channels**
  - **Complex short 16 data**



- **X410**
  - **Same measurements as B210**
  - **Added sine wave and sine wave offset measurements**

B210 Normalized Gains

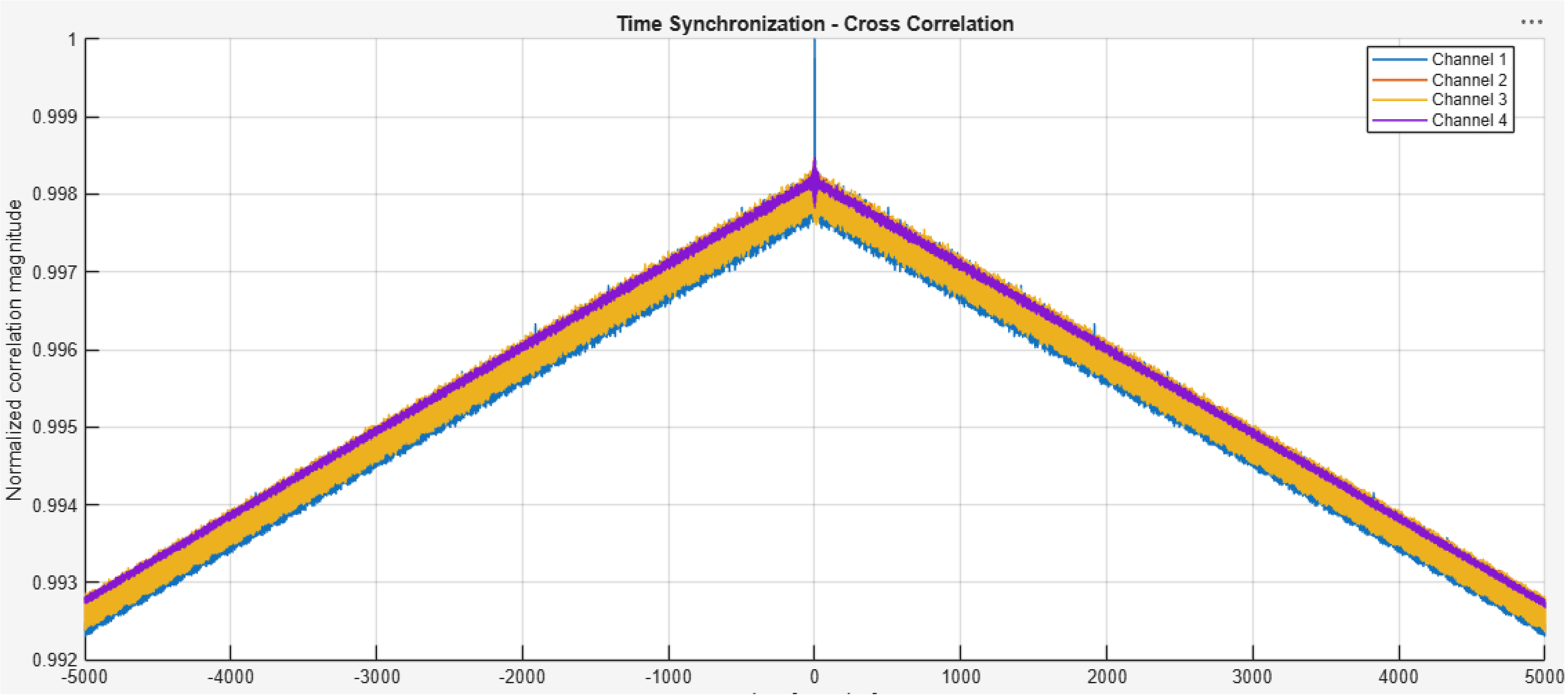
Configured normalised gain	Effective normalised gain	Absolute gain (dB)
0.0	0.0000	0.0
0.1	0.0921	7.0
0.2	0.1974	15.0
0.3	0.2895	22.0
0.4	0.3947	30.0
0.5	0.5000	38.0
0.6	0.5921	45.0
0.7	0.6974	53.0
0.8	0.7895	60.0
0.9	0.8947	68.0
1.0	1.0000	76.0

Result

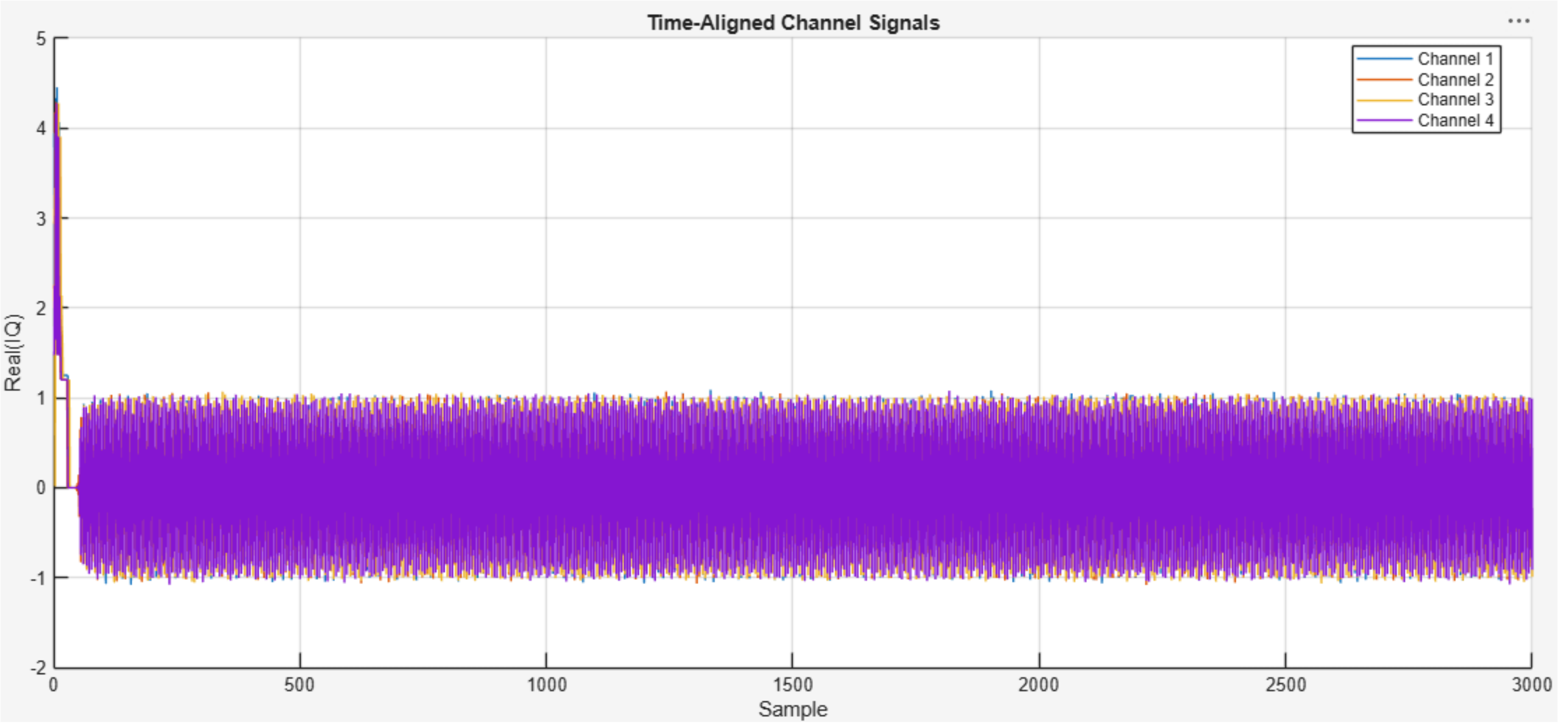
X410 - Synchronization

- **Tx: Sine wave (2412, 2437, 2462 MHz)**
- **Rx: Tuned with CFO of 400 kHz**
- **Sample rate: 960032 samples/s (20000032 OFDM) (X410)**
- **Recording time: 1 second**

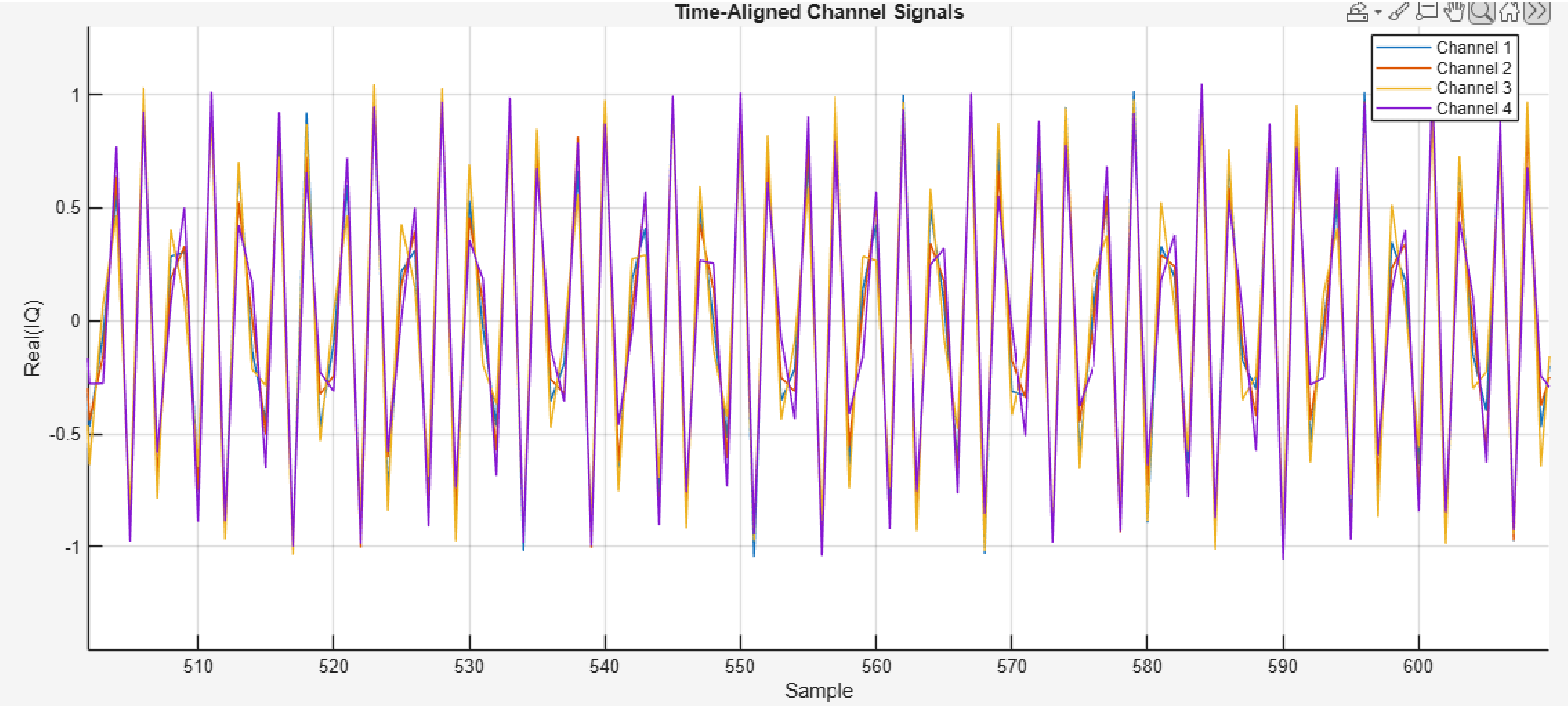
X410 - Time Synchronization



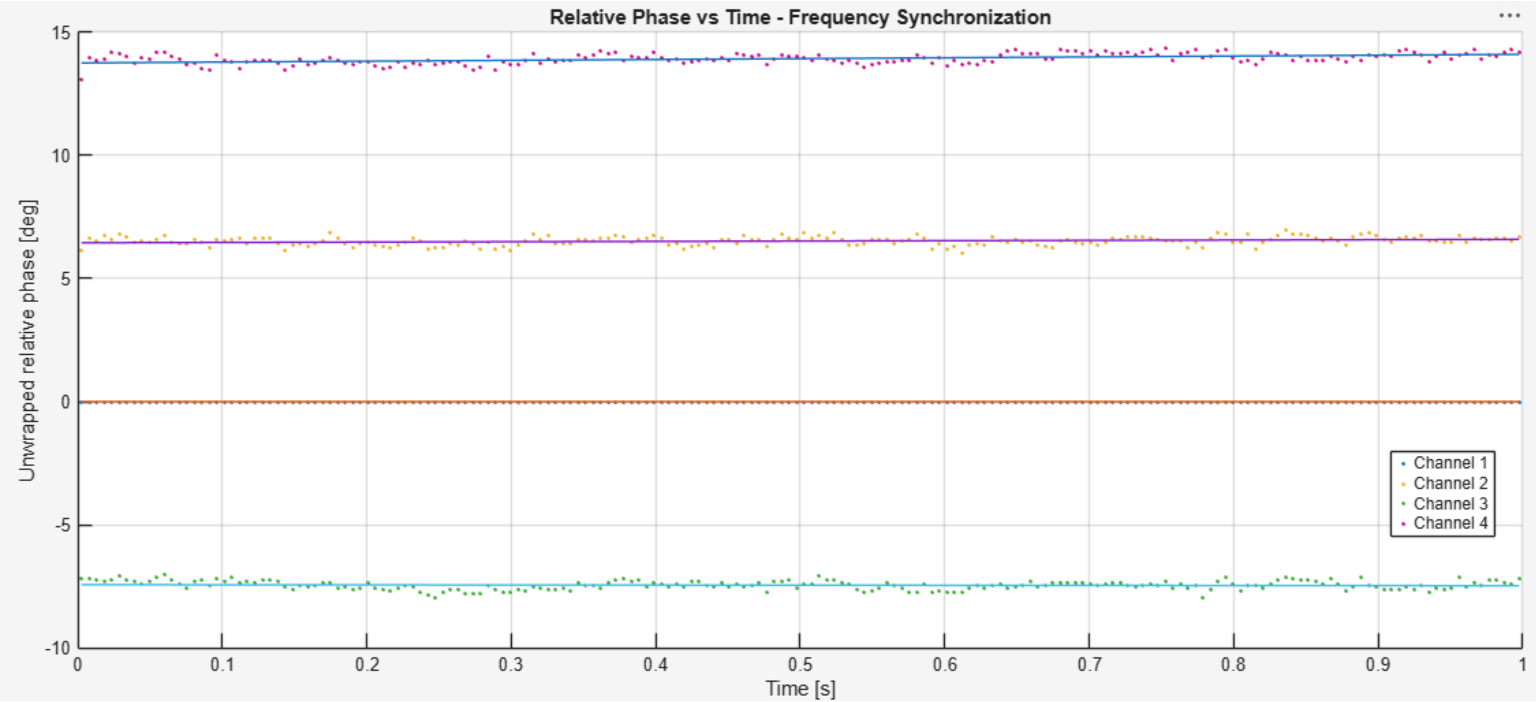
X410 - Time Synchronization



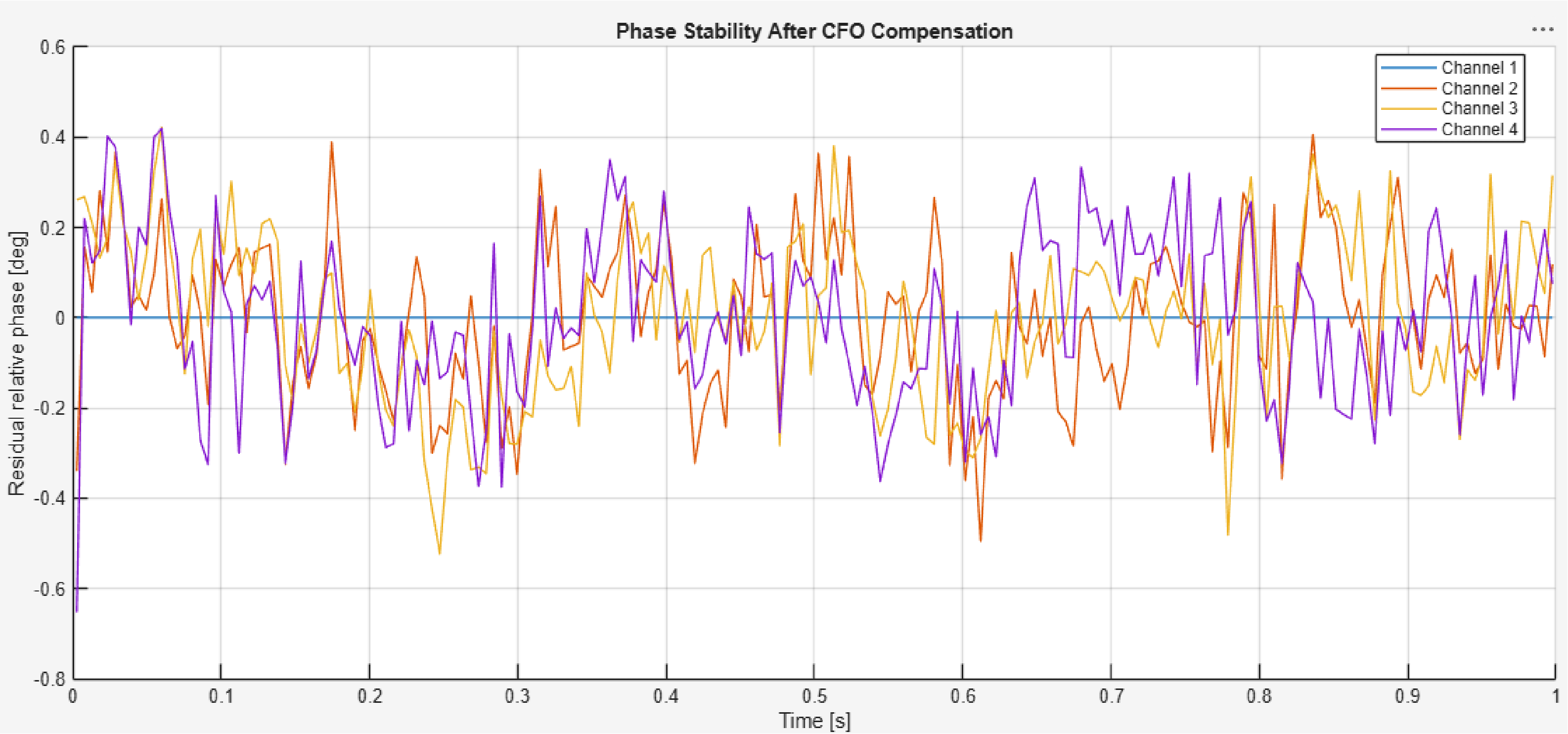
X410 - Time Synchronization



X410 - Frequency Synchronization



X410 - Phase Synchronization



X410 - Conclusion

FINAL SYNCHRONIZATION RESULTS

Channel	IntegerDelay_samples	Delay_samples	Delay_us	Delay_ns	CorrelationPeak	FrequencyOffset_Hz	PhaseOffset_deg	PhaseSTD_deg
1	0	0	0	0	1	0	0	0
2	2	1.9824	2.065	2065	0.99846	0.00038342	6.4529	0.16949
3	-3	-2.8861	-3.0063	-3006.3	0.99845	-0.00011202	-7.4367	0.18078
4	1	1.0736	1.1183	1118.3	0.99847	0.00096958	13.757	0.18588

Code and datasets

- **2, 4, 8 SDR synchronization B210/X410**
- **Raw data available: https://doi.org/10.5281/zenodo.20692477**
- **30.42 GB of data**

- **Synchronisation code:**
- **https://gitlab.ilabt.imec.be/octoclock-g/multi-sdr-sync**

- **Data processing code will be added (conversion to Python)** embracing a better life

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