Implementing OFDM Radar & DOA on Direct RF Platforms using IIO and GNURadio

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ANALOG DEVICES

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GNURadio

THE FREE & OPEN SOFTWARE RADIO ECOSYSTEM

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Abstract

- In this talk, we will discuss some of the challenges associated with controlling direct RF, or more generally high-speed-transceivers, using the IIO framework: These include computational/uplink bandwidth constraints and RX/TX timing synchronization, and how they can be addressed for bursty systems.

  We will then present gr-ofdmradar, a generic OFDM radar and MUSIC/ESPRIT based DOA estimator implementation, and new OOT gr-iio blocks that, in combination with gr-ofdmradar, enable a full OFDM radar system.

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Hardware

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Hardware

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Hardware

- Carrier: ZCU102
  - Xilinx Zynq UltraScale+ MPSoC
    - 4+2 Core ARM Application+Realtime Cores
    - FPGA
- RF: AD9081
  - 4x 16-Bit, 12GSPS DAC
  - 4x 12-Bit, 4GSPS ADC
  - 7.5 GHz Analog Bandwidth
  - 8+8 JESD 204 B/C lanes @ up to 25 Gbps / lane
    => up to 200 Gbps SERDES / direction

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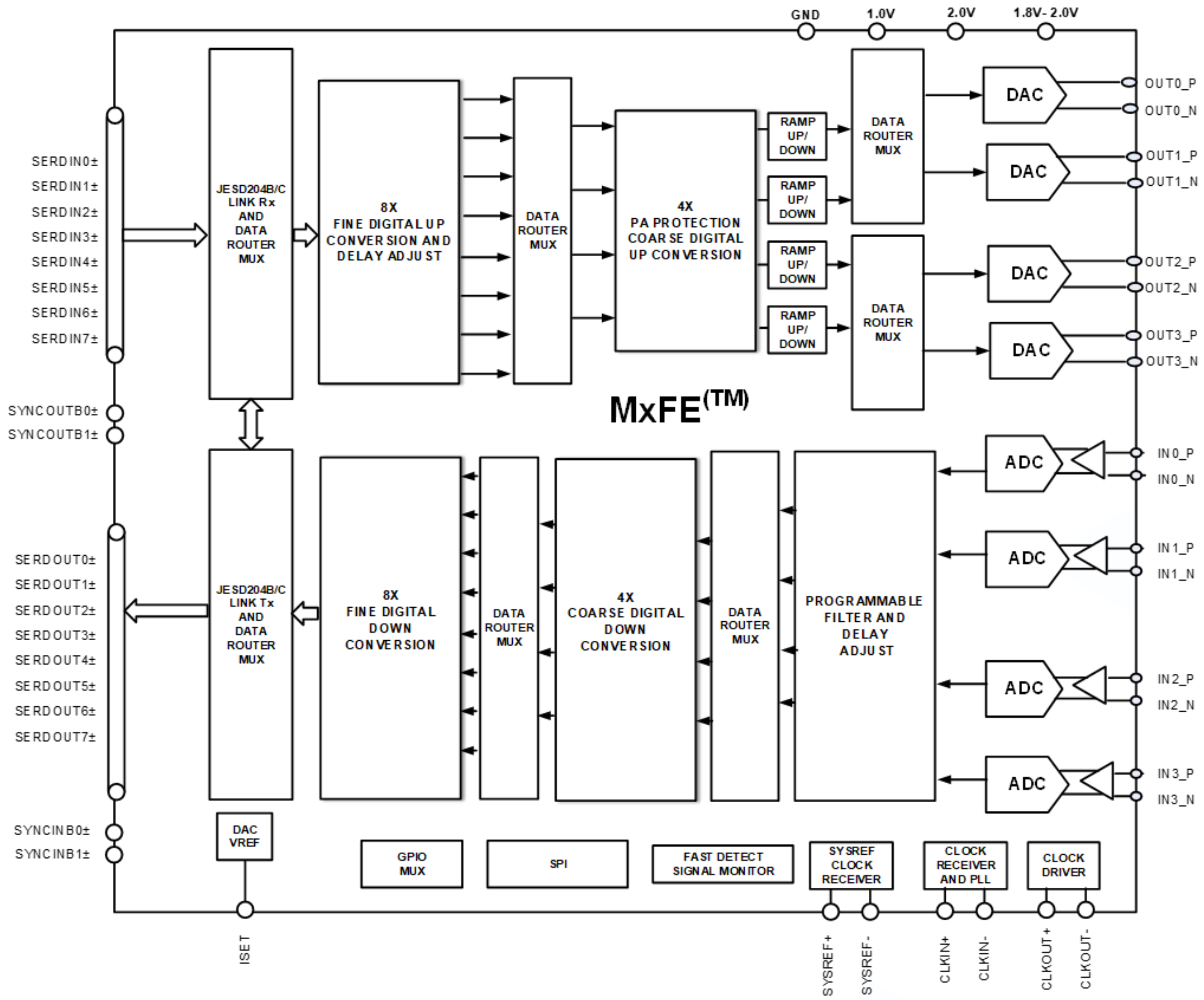
Hardware - AD9081



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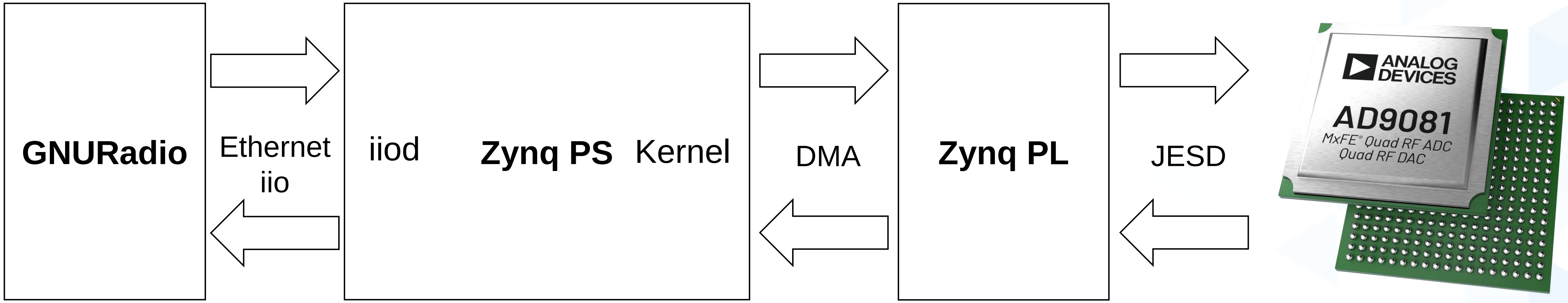
Hardware - Datapath



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Hardware - Configuration

- Sample rate: 250 MS/s / Channel, 32-bit complex samples
- Total: 32 Gbps
- Sample memory: Block RAM (2^{18} samples RX + 2^{18} samples TX)

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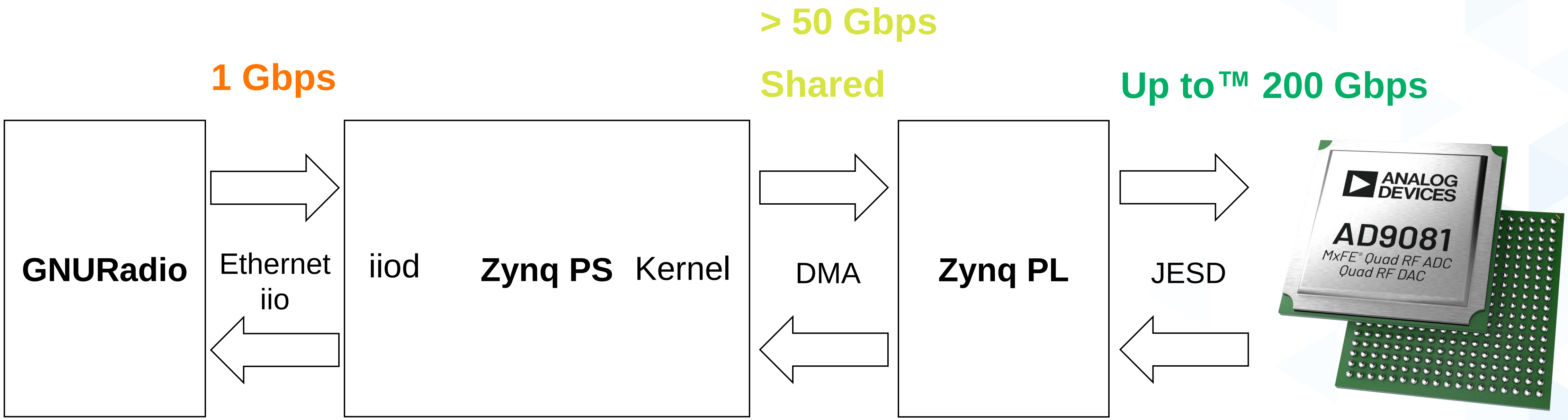
Hardware - Datapath



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Radar and IIO

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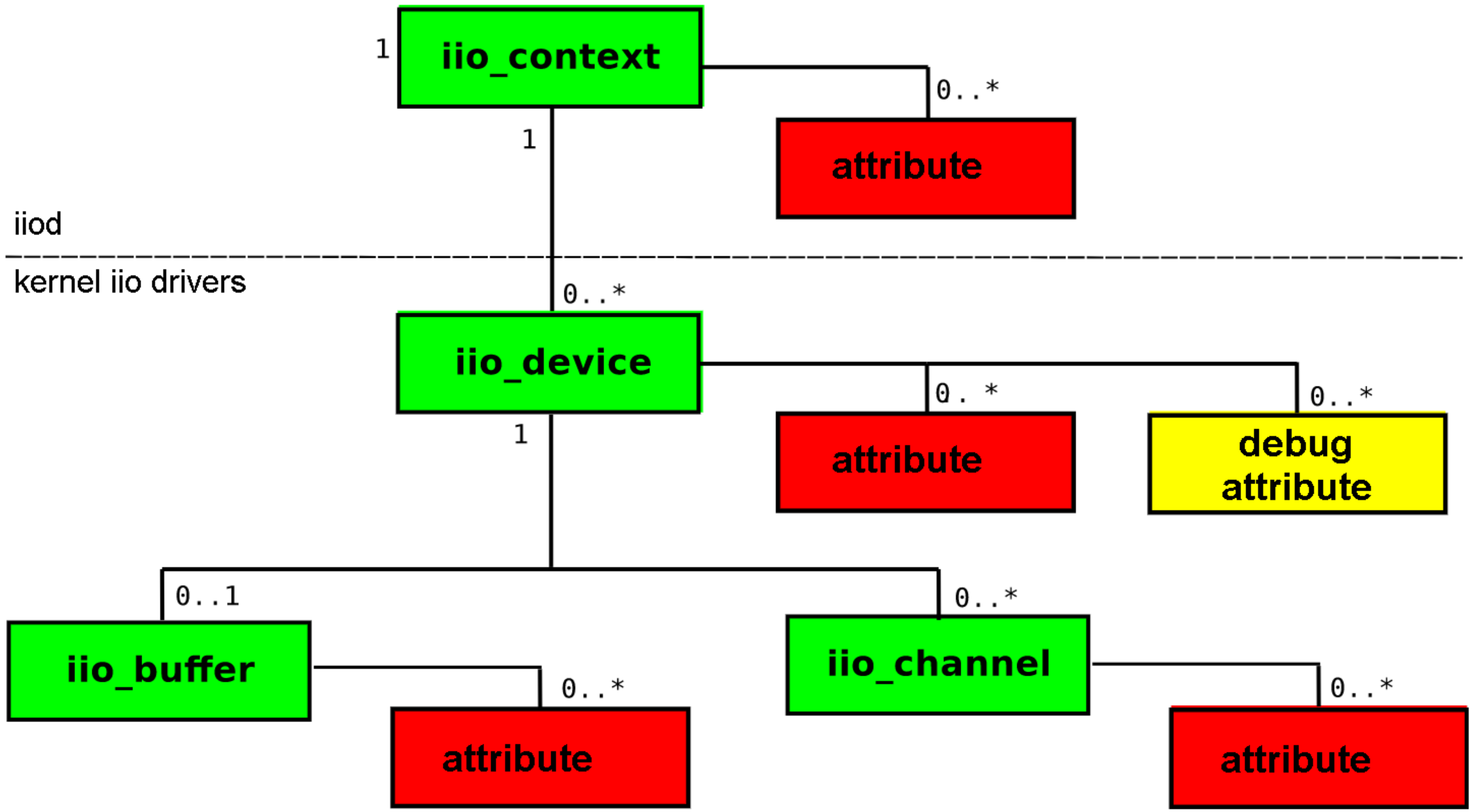
Sample timing and IIO



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Sample timing and IIO

```
IIO context has 3 attributes:
    ip,ip-addr: 192.168.3.1
IIO context has 4 devices:
    iio:device0: ams <...>
    iio:device1: hmc7044 <...>
    iio:device2: axi-ad9081-rx-hpc (buffer capable)
        17 channels found:
            voltage0_i:  (input, index: 0, format: le:S16/16>>0)
            15 channel-specific attributes found:
                attr  0: adc_frequency value: 4000000000
                <...>
            <...>
        4 device-specific attributes found:
                attr  0: adc_clk_powerdown value: 0
                attr  1: filter_fir_config ERROR: Permission denied (-13)
                attr  2: loopback_mode value: 0
                attr  3: multichip_sync value: 0
        3 buffer-specific attributes found:
                <...>
        9 debug attributes found:
                <...>
        No trigger on this device
    iio:device3: axi-ad9081-tx-hpc (buffer capable)
        24 channels found:
            voltage0_i:  (output, index: 0, format: le:S16/16>>0)
            4 channel-specific attributes found:
                <...>
                attr  3: sampling_frequency value: 250000000
```


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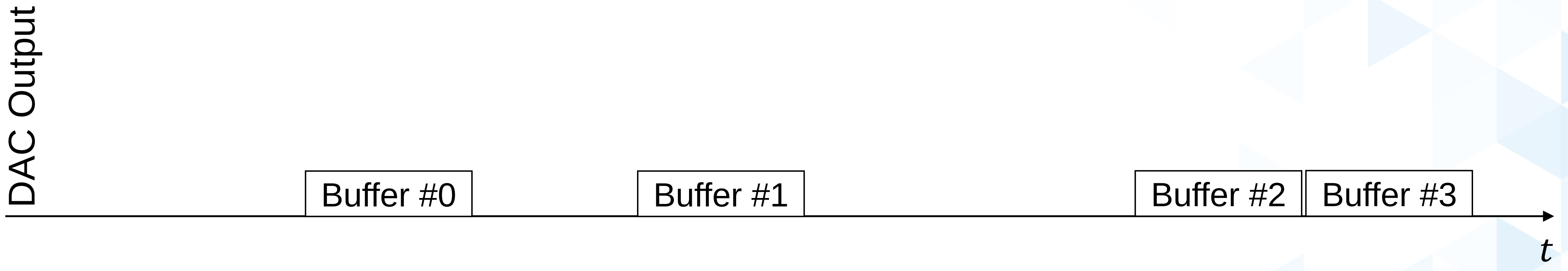
Sample timing and IIO

- IIO Buffers
  - On the target device: Multiple physically contiguous blocks of memory supporting each buffer
  - Only a single memory block will be accessible to userland at a time
  - The other blocks are either waiting to be read, or already empty
    - In both cases, their contents will be overridden as new samples become available
    - If the transport or client can‘t keep up: Samples may not be contiguous from buffer to buffer!
  - Conclusion: At high sample rates, our OFDM frame must fit into a single buffer



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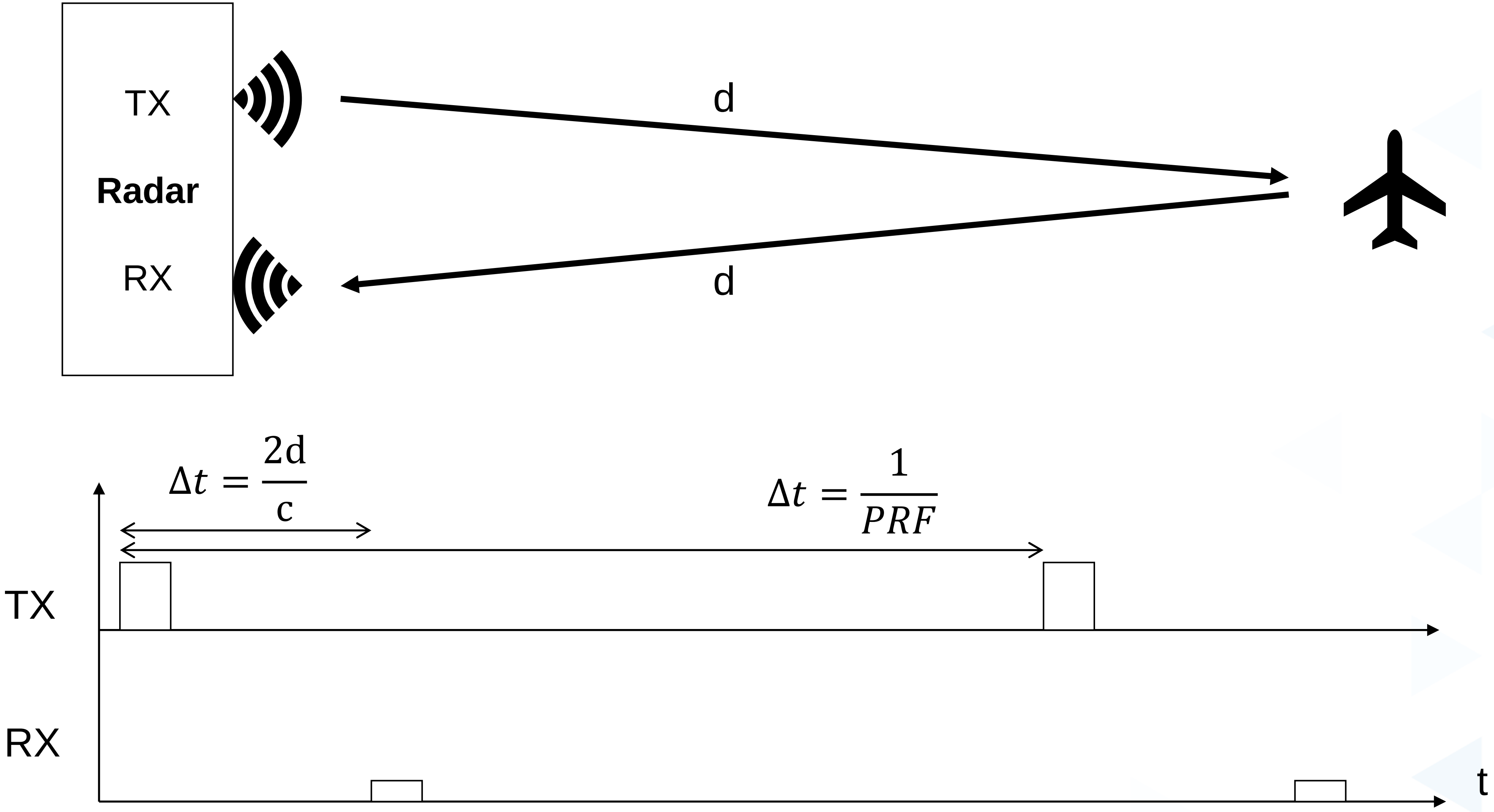
Pulse Radar



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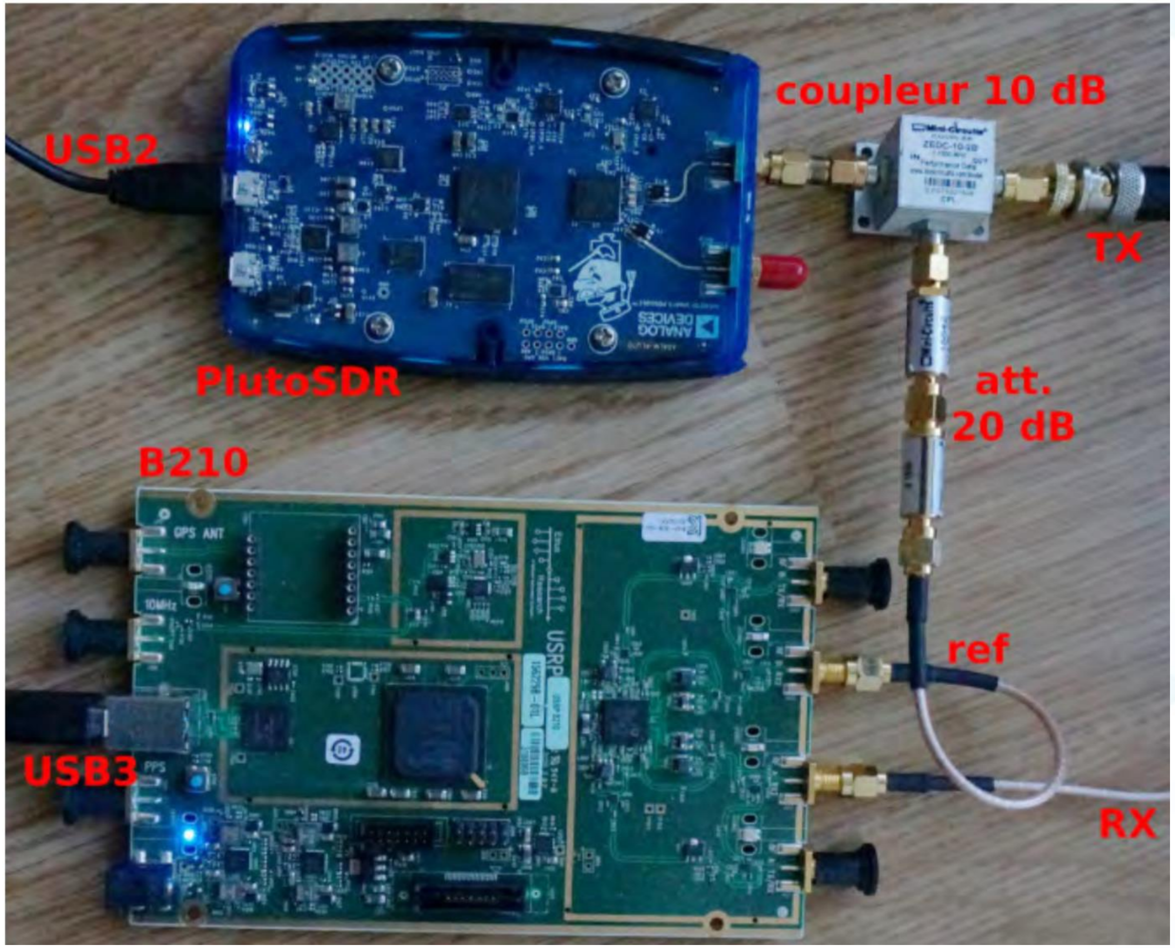
Radar



- FRIEDT, Jean-Michel; FENG, Weike. Software defined radio based Synthetic Aperture noise and OFDM (Wi-Fi) RADAR mapping. **Proceedings of the GNU Radio Conference**, [S.l.], v. 5, n. 1, sep. 2020. Available at: <https://pubs.gnuradio.org/index.php/grcon/article/view/71>. Date accessed: 03 sep. 2021.

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Sample timing and IIO

- But: RX and TX are provided by two different devices
  - Their buffers are independent
- IIO currently does NOT support operations similar to USRPs timed commands
  - Timestamped buffers are on the TODO list
- What we need:
  - Precise control over when the RX buffer is read from & the TX buffer is played
    - I.e. there should be a *fixed* time offset between every i-th RX and TX sample
  - Repeatable
  - Configurable

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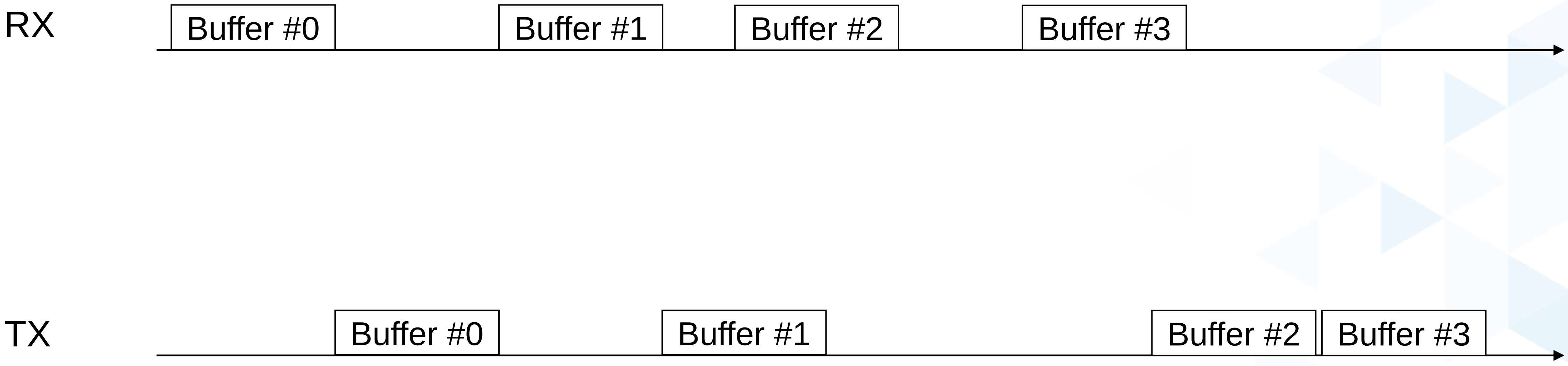
Sample timing and IIO

- Streaming samples over slow™ link, without hardware changes



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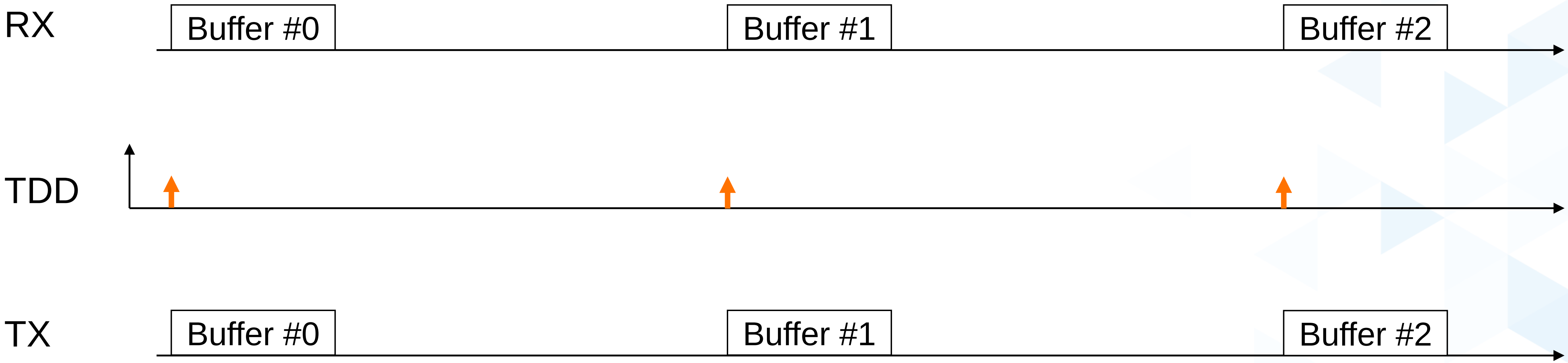
Sample timing and IIO

- Streaming samples over slow™ link, with timing division duplexing (TDD) hardware



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Sample timing and IIO – Timing Division Duplexing Engine

- A 24 bit counter with a bunch of configurable registers to compare against
- Simplified: Used to gate RX DMA input valid / TX DMA output ready
- Synchronous RX and TX clock domains guarantee cycle-accurate operation
  - Note: This configuration requires symmetrical sample rates

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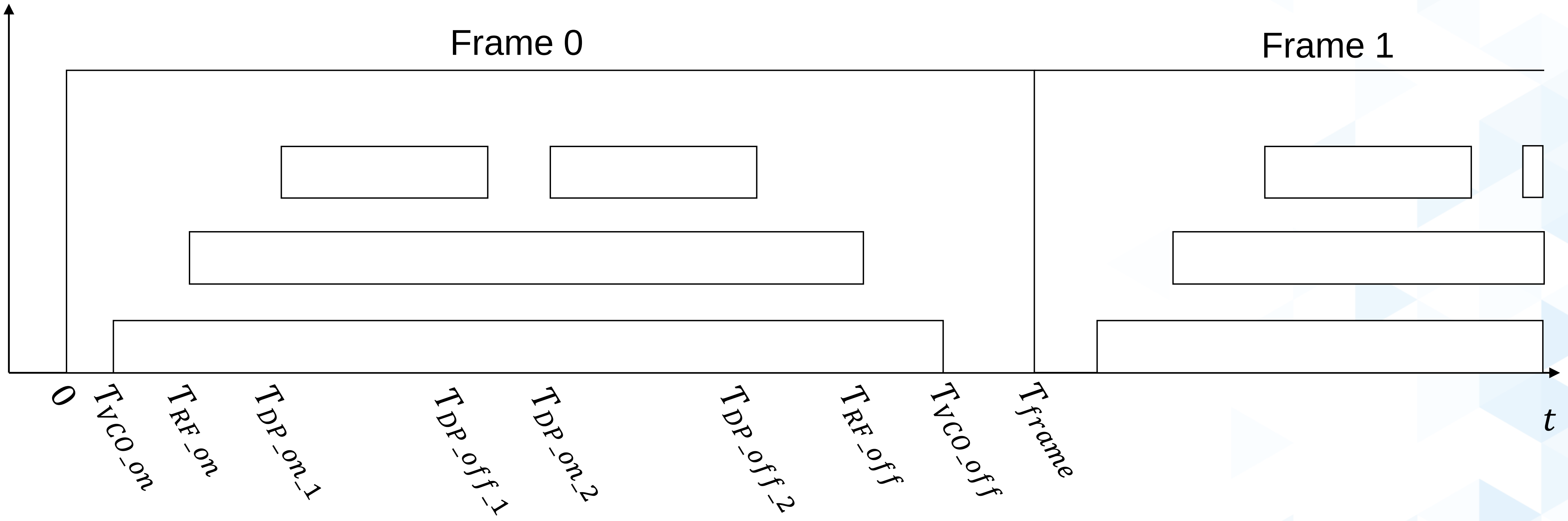
Sample timing and IIO – TDD Engine



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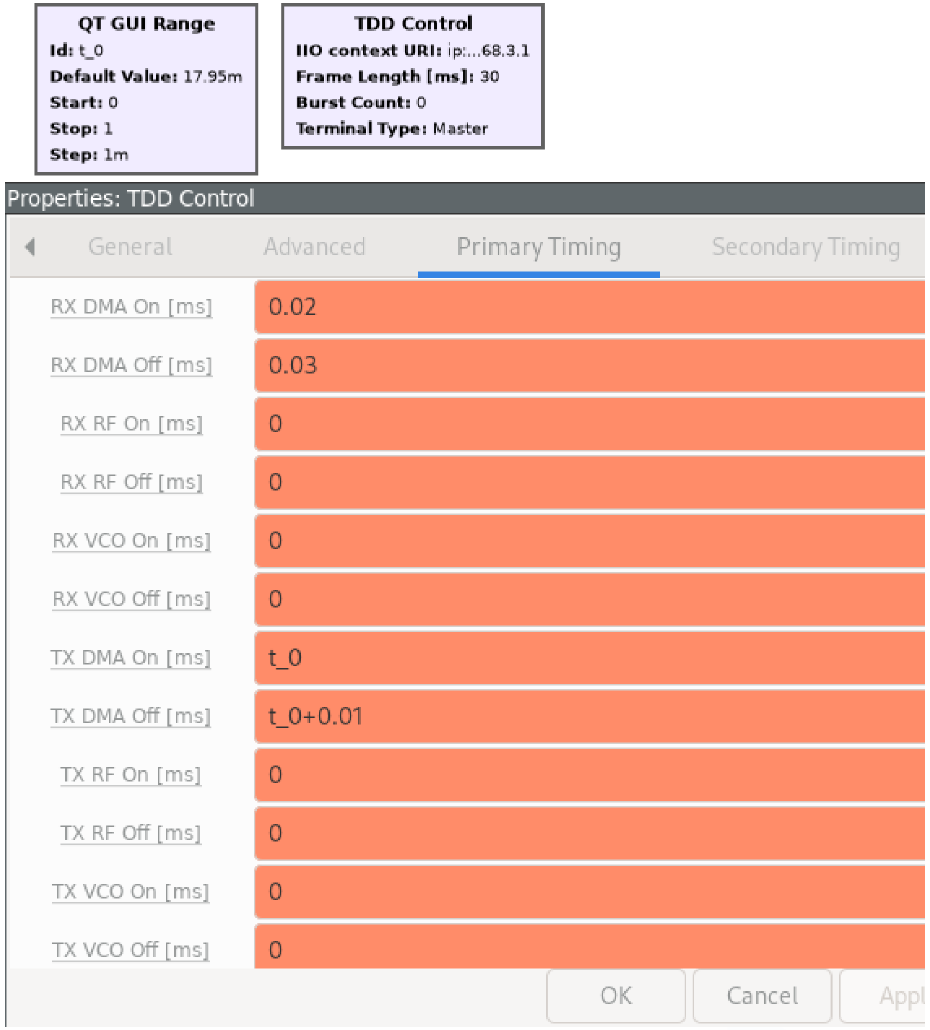
Sample timing and IIO – TDD Engine



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Sample timing and IIO

```
                            -------------------------------------
                            |                                   |
           -------    -------------                    -------  |
Antenna -> | ADC | -> | JESD Link | -----------------> | DMA | -------
           -------    -------------                 ^  -------  |    |
                            |                       |           |    |      -------
                            |                 --------------    |    -----> |     |
                            |   FPGA Fabric   | TDD Engine |    |           | CPU |
                            |                 --------------    |    ------ |     |
                            |                       |           |    |      -------
           -------    -------------                 v  -------  |    |
Antenna <- | DAC | <- | JESD Link | <----------------- | DMA | <------
           -------    -------------                    -------  |
                            |                                   |
                            -------------------------------------
```


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OFDM Radar

- Less conventional approach - processing very similar to that of OFDM
- Operating principle:
  - FDE, transform estimated channel response to time domain
  - Comparing repeated estimates yields doppler information
- Advantages
  - Facilitates the combination of Radar and Communications (Not covered here)
  - Very high processing gain (Low TX power)
  - Nice properties for DSP
- Disadvantages
  - OFDM => High PAPR
  - Comparatively low range / supported delay spread
  - Simultaneous RX & TX, possibly high dynamic range requirement due to TX-RX coupling

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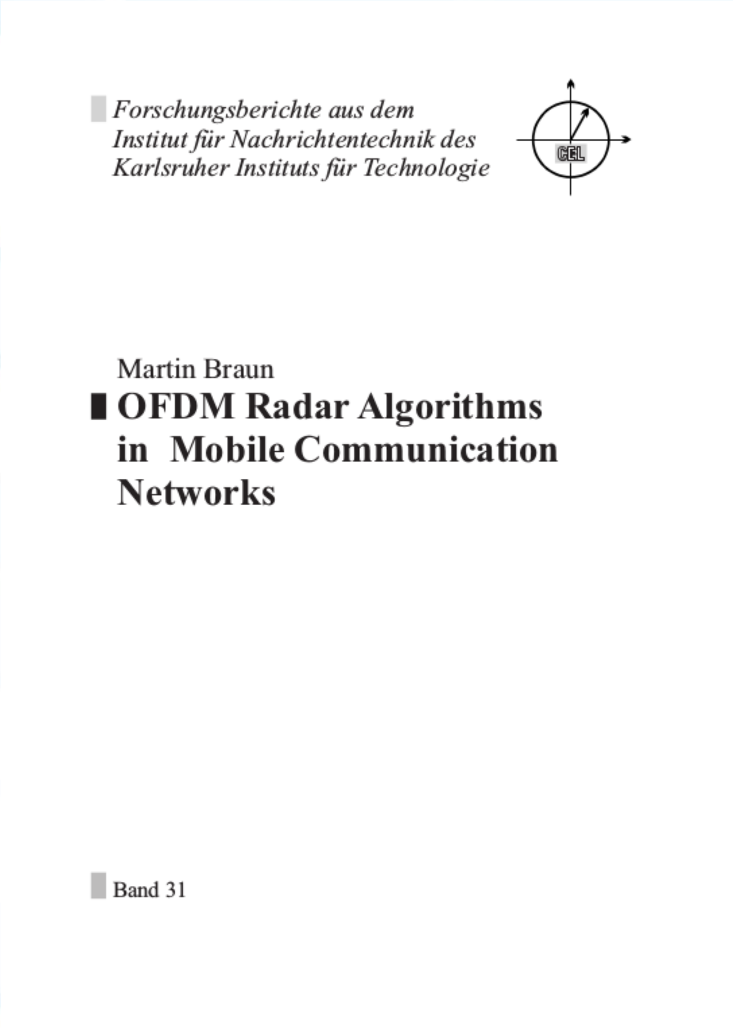
OFDM Radar

- Described by Martin Braun in „OFDM Radar Algorithms in Mobile Communication Networks“, Karlsruher Institut für Technologie (KIT), 2014 https://publikationen.bibliothek.kit.edu/1000038892


Forschungsberichte aus dem Institut für Nachrichtentechnik des Karlsruher Instituts für Technologie

Martin Braun

OFDM Radar Algorithms in Mobile Communication Networks

Band 31

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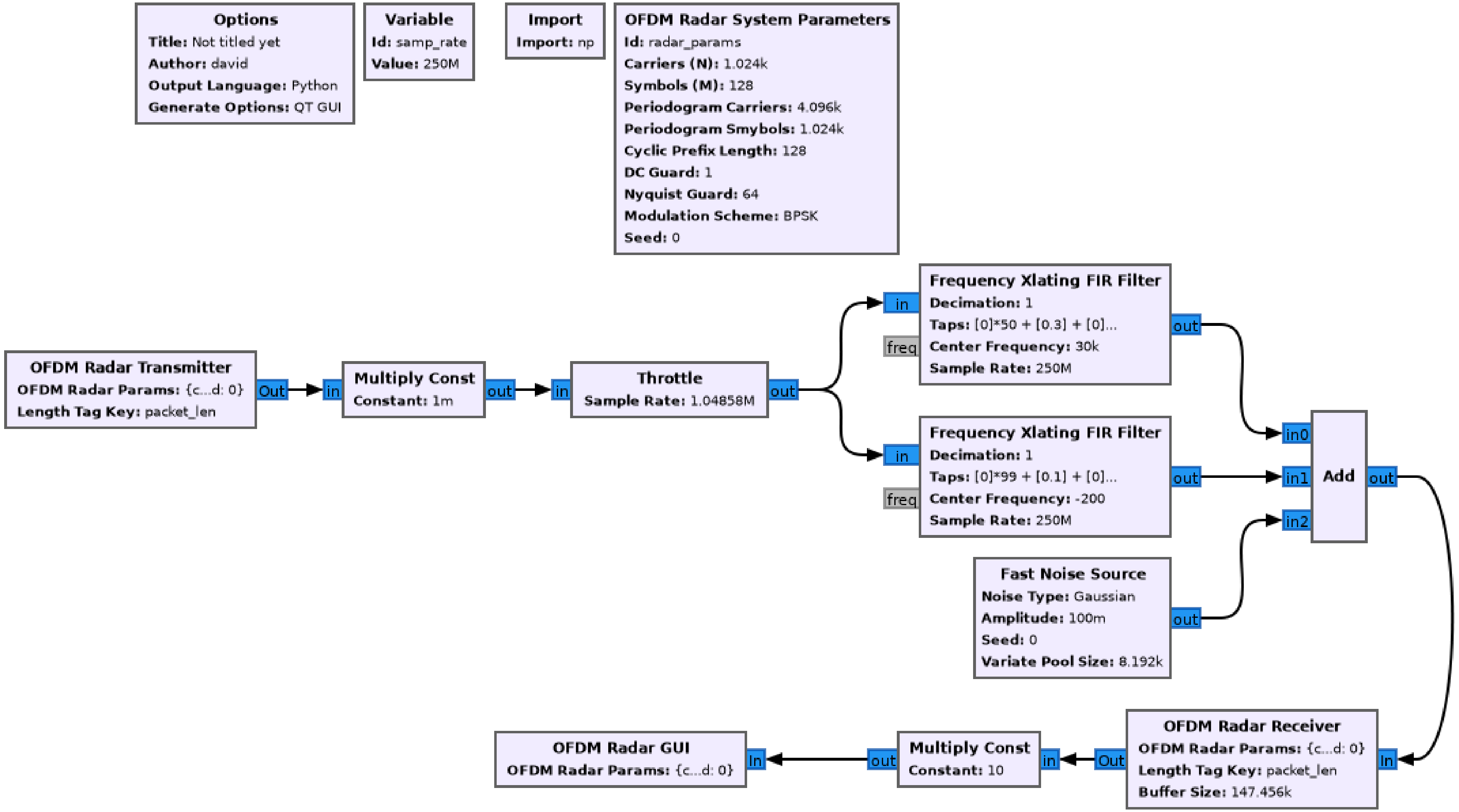
gr-ofdmradar



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OFDM Radar

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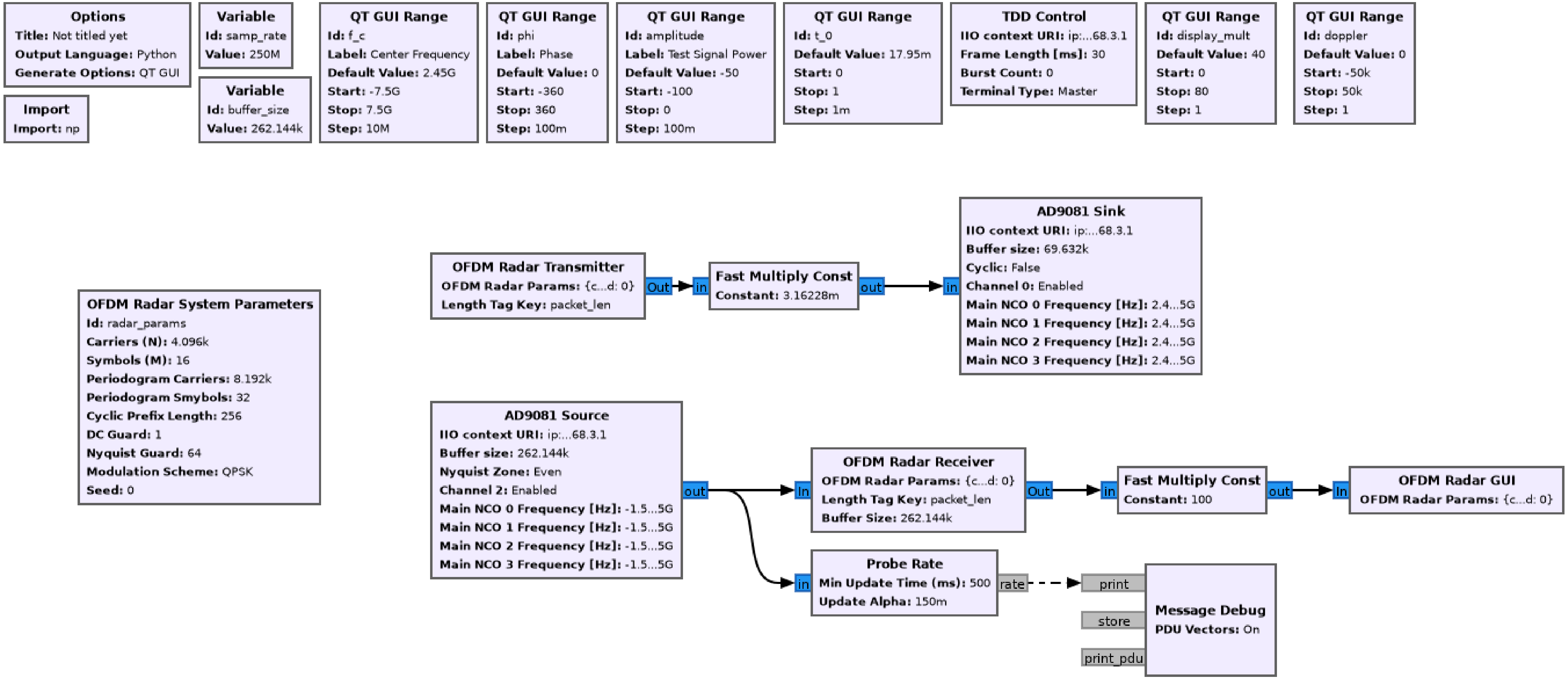
gr-ofdmradar



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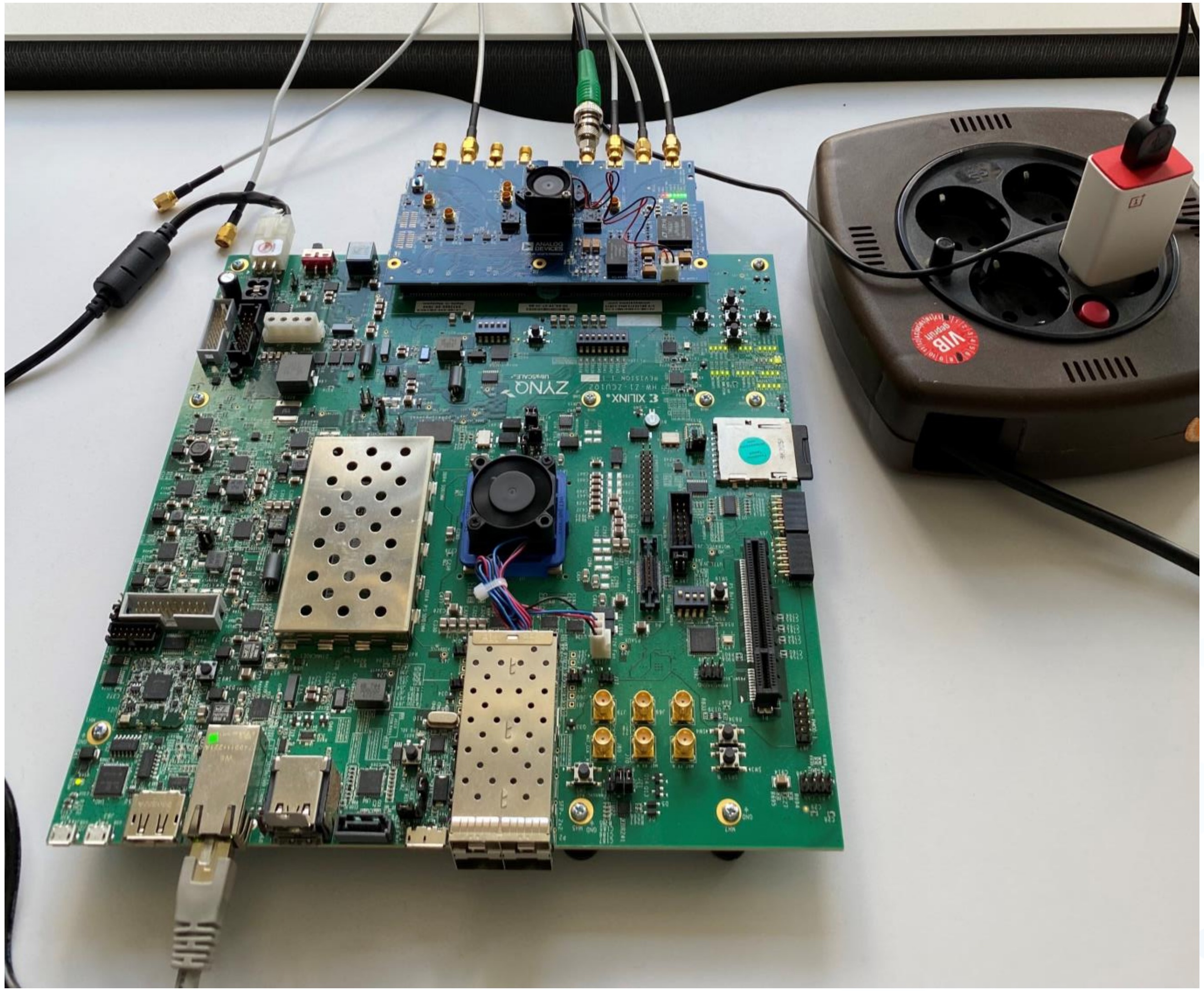
OFDM Radar - Demo



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OFDM Radar - Demo

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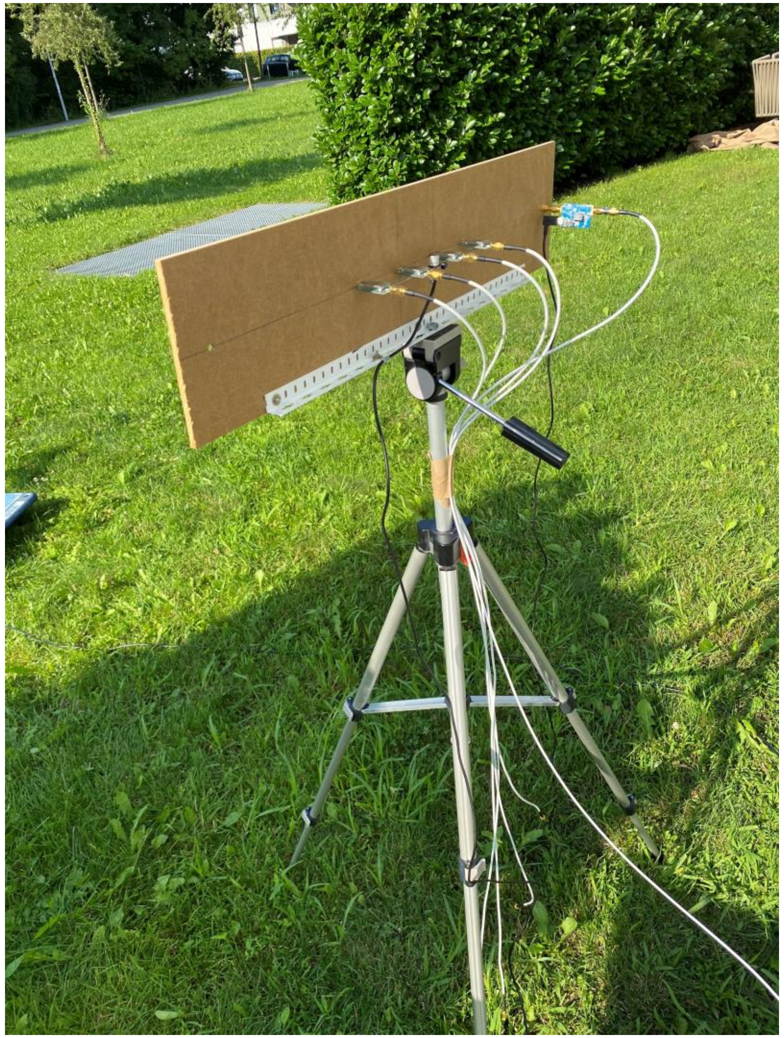
GRCon

OFDM Radar - Demo



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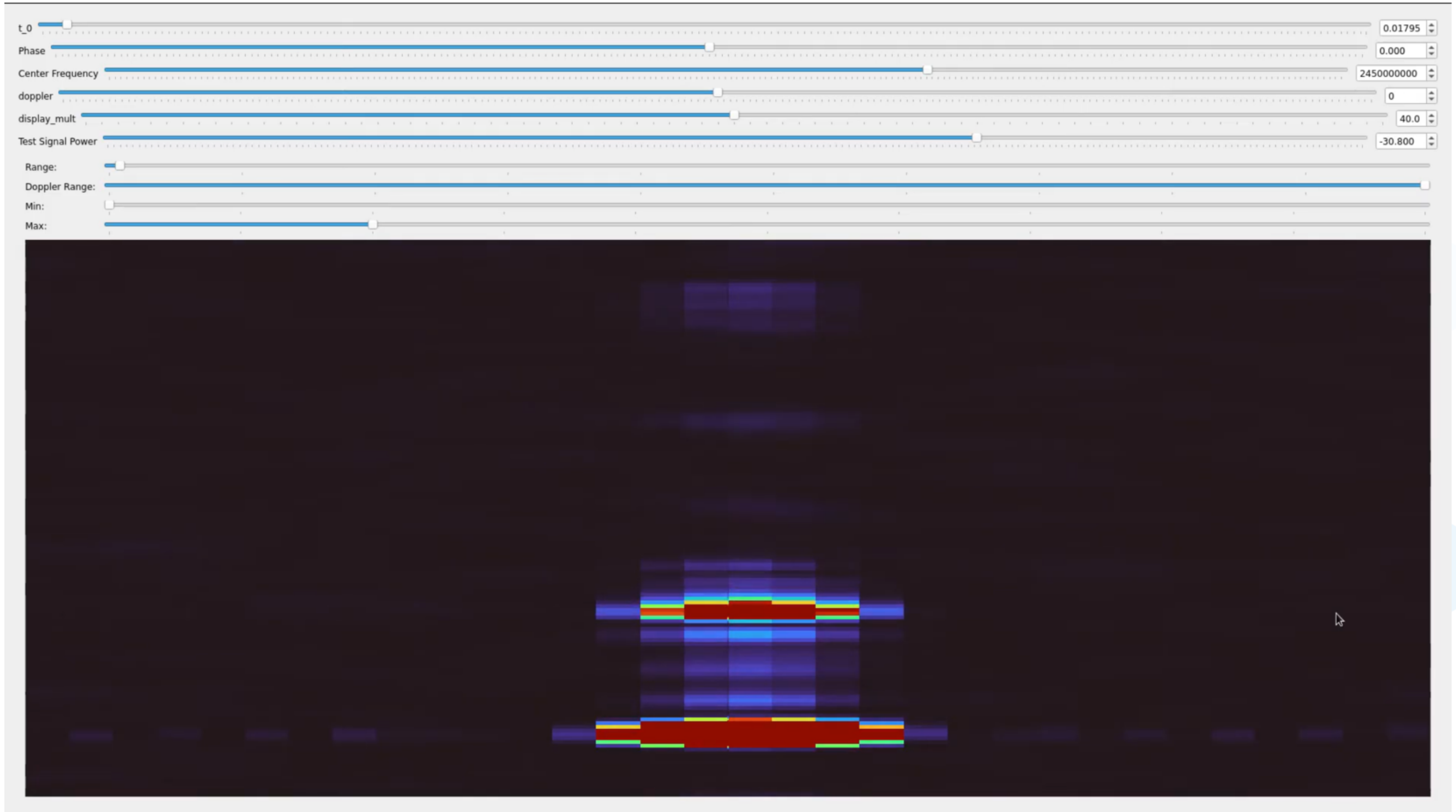
OFDM Radar - Demo



https://www.youtube.com/watch?v=gtTILs929aU

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Direction of Arrival

gr-ofdmradar

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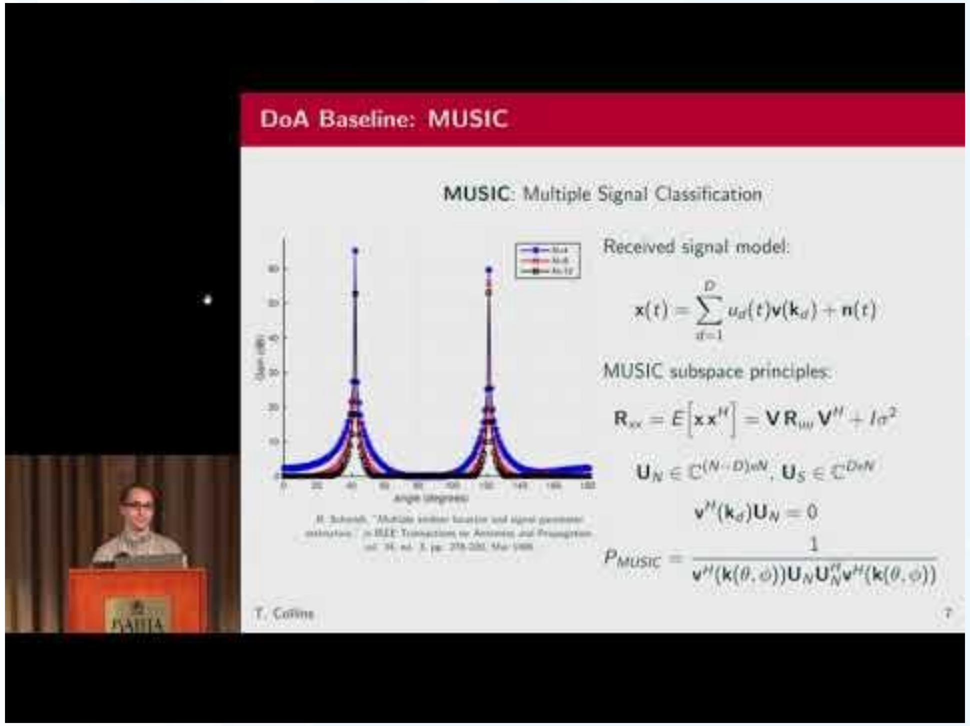
Direction of arrival (DoA)

- For a module dedicated to DOA see gr-doa: github.com/EttusResearch/gr-doa
- „GRCon17 - gr-doa: GNU Radio Direction Finding - Travis Collins“: https://www.youtube.com/watch?v=_UBPVi1vp2s



„GRCon17 - gr-doa: GNU Radio Direction Finding - Travis Collins“

https://www.youtube.com/watch?v=_UBPVi1vp2s

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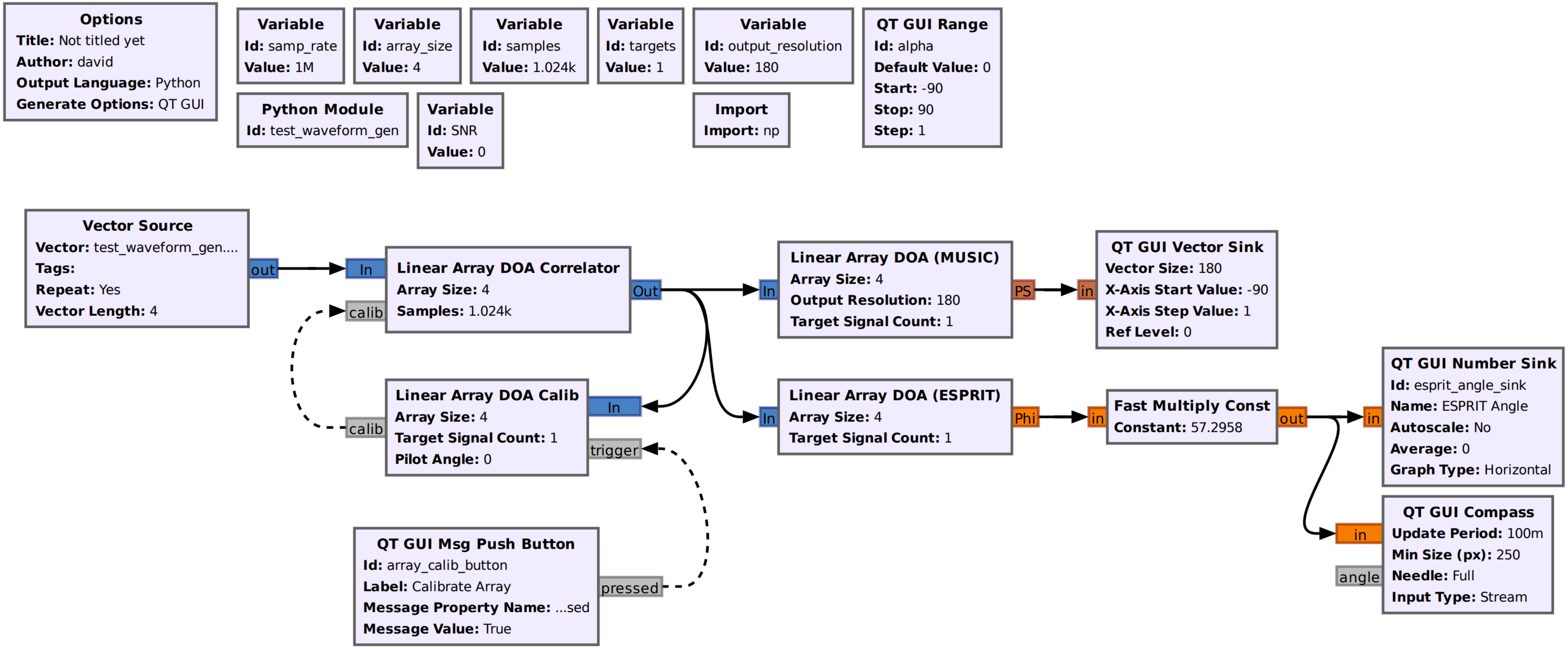
DOA - Flowgraph



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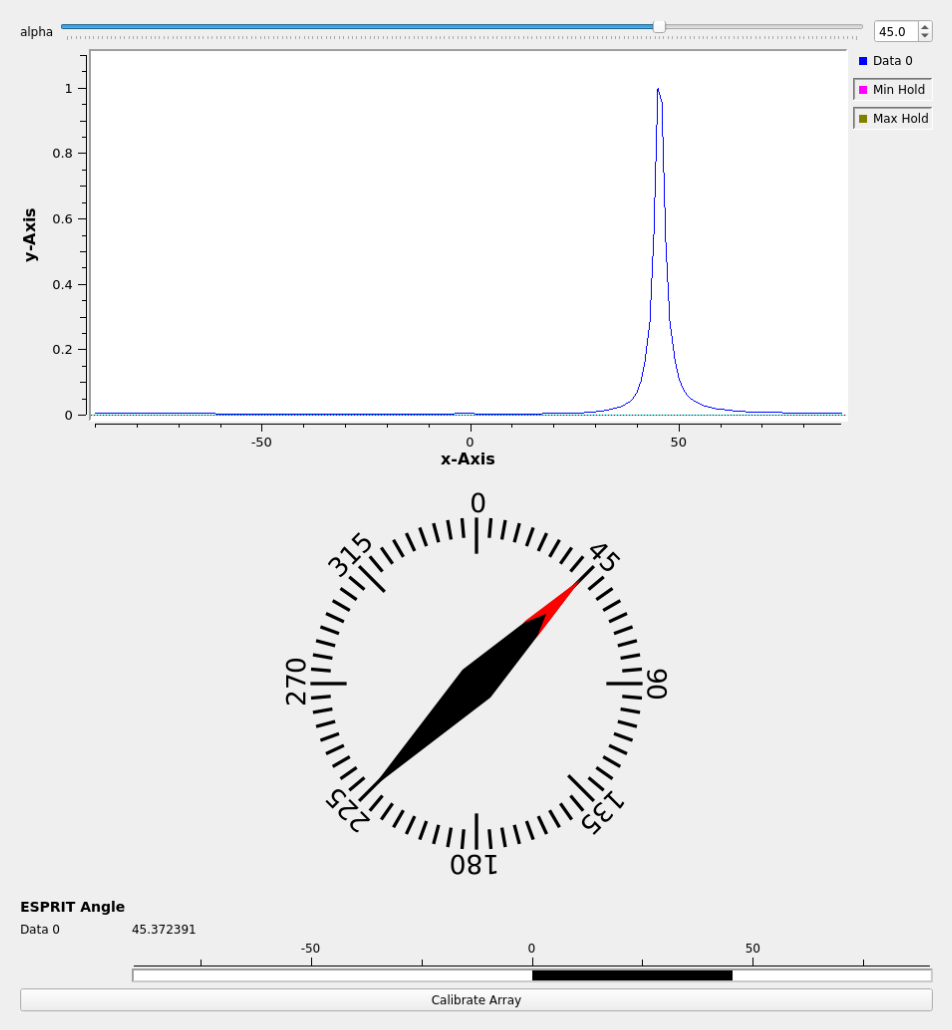
DOA - Simulation



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Conclusion

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gr-ofdmradar

- Hardware agnostic module implementing
  - OFDM Radar
  - DOA
    - MUSIC Pseudo-Spectrum
    - ESPRIT
    - Calibration by pilot
- https://github.com/Yamakaja/gr-ofdmradar

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TDD Engine

- Implementing timing critical applications requires hardware support
- The TDD engine provides an easy option to time repetitive operations accurately
- **Only transfer interesting data over congested links!**

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TDD Engine - Pluto

- The TDD engine is already a part of the Pluto, but not exposed
  - The IIO Interface can be enabled by including the driver and a modified device tree
  - May be available in future firmware versions: https://github.com/analogdevicesinc/linux/pull/1655
  - Functionality is slightly different, for more information see the Wiki page below
- https://wiki.analog.com/resources/eval/user-guides/ad-pzsdr2400tdd-eb/reference_hdl

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Outlook

- IIO buffer metadata (Smiliar to VRT)
  - RX/TX Timestamps
  - GPIO Control (Amplifiers, FFH, etc.)
  - Buffer loss detection
- IIO speed improvements
  - Async (network) protocol
  - Zero copy operation
- https://github.com/analogdevicesinc/libiio

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Links

- **System Deep Dive**: https://wiki.analog.com/resources/eval/user-guides/ad9081_fmca_ebz/radar

- gf-ofdmradar
  - „OFDM Radar Algorithms in Mobile Communication Networks“, Karlsruher Institut für Technologie (KIT), 2014 https://publikationen.bibliothek.kit.edu/1000038892
  - https://github.com/Yamakaja/gr-ofdmradar
  - AD9081 / TDD blocks: https://github.com/Yamakaja/gnuradio/tree/feature/gr-iio-tdd
  - https://github.com/EttusResearch/gr-doa
- AD9081 / ZCU102 Reference Design
  - Product Page: https://www.analog.com/en/products/ad9081.html
  - HDL Reference Design: https://wiki.analog.com/resources/eval/user-guides/ad9081_fmca_ebz/ad9081_fmca_ebz_hdl
  - Linux Driver: https://wiki.analog.com/resources/tools-software/linux-drivers/iio-mxfe/ad9081

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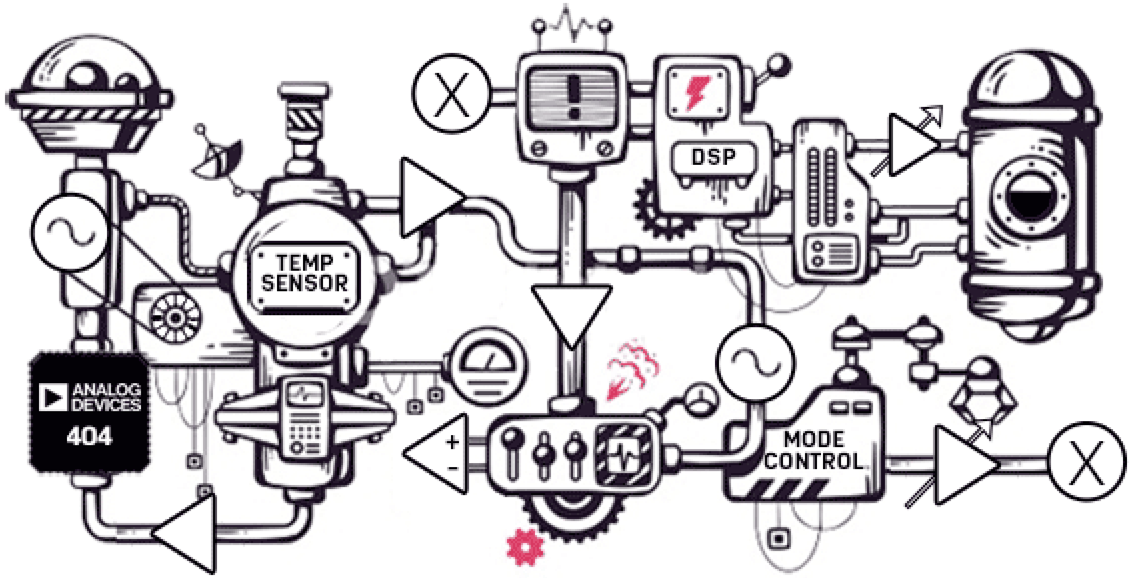

Ahhh, technology. We can't find that page.

Thanks

Q & A

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