# Using Red Pitaya for radio applications (from LF to HF)

Pavel Demin

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# Introduction

# *My journey into radio*

- May 2009:

  Started to play with FPGA (Altera Cyclone III) and fast ADC (AD9228)

- September 2014:

  Discovered RTLSDR, GNU Radio and Gqrx thanks to Hackable Magazine №2

- December 2014:

  Started to play with Red Pitaya

- March 2015:

  Released Red Pitaya SDR receiver

- September 2015:

  Released Red Pitaya SDR transceiver

- November 2015:

  Joined Radio & Electronics Engineering Club ASBL (REEC)

# *Initial goals*

- Listen to the radio with ADC and FPGA
- Get familiar with new Xilinx chips and tools
- Keep the number of lines of code low
- Make use of the existing libraries and programs
- Keep the budget low

# Red Pitaya

# *Red Pitaya overview*

- A single-board computer designed in Slovenia
- Cost ≈ 250 € (tax included)
- Key features:

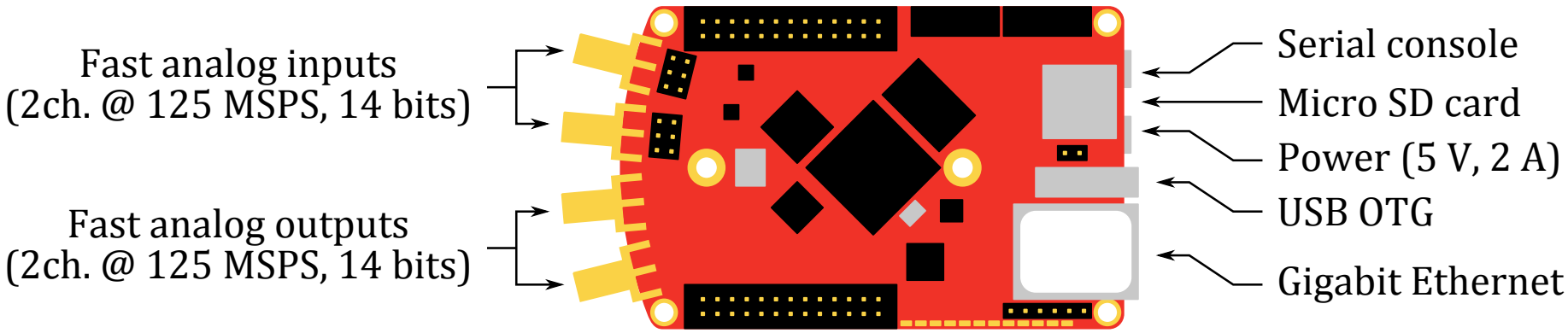
  open-source-software measurement and control tool

  stand-alone GNU/Linux platform

  Xilinx Zynq All Programmable System-on-Chip (ARMv7-A CPU + FPGA)

  fast analog inputs and outputs

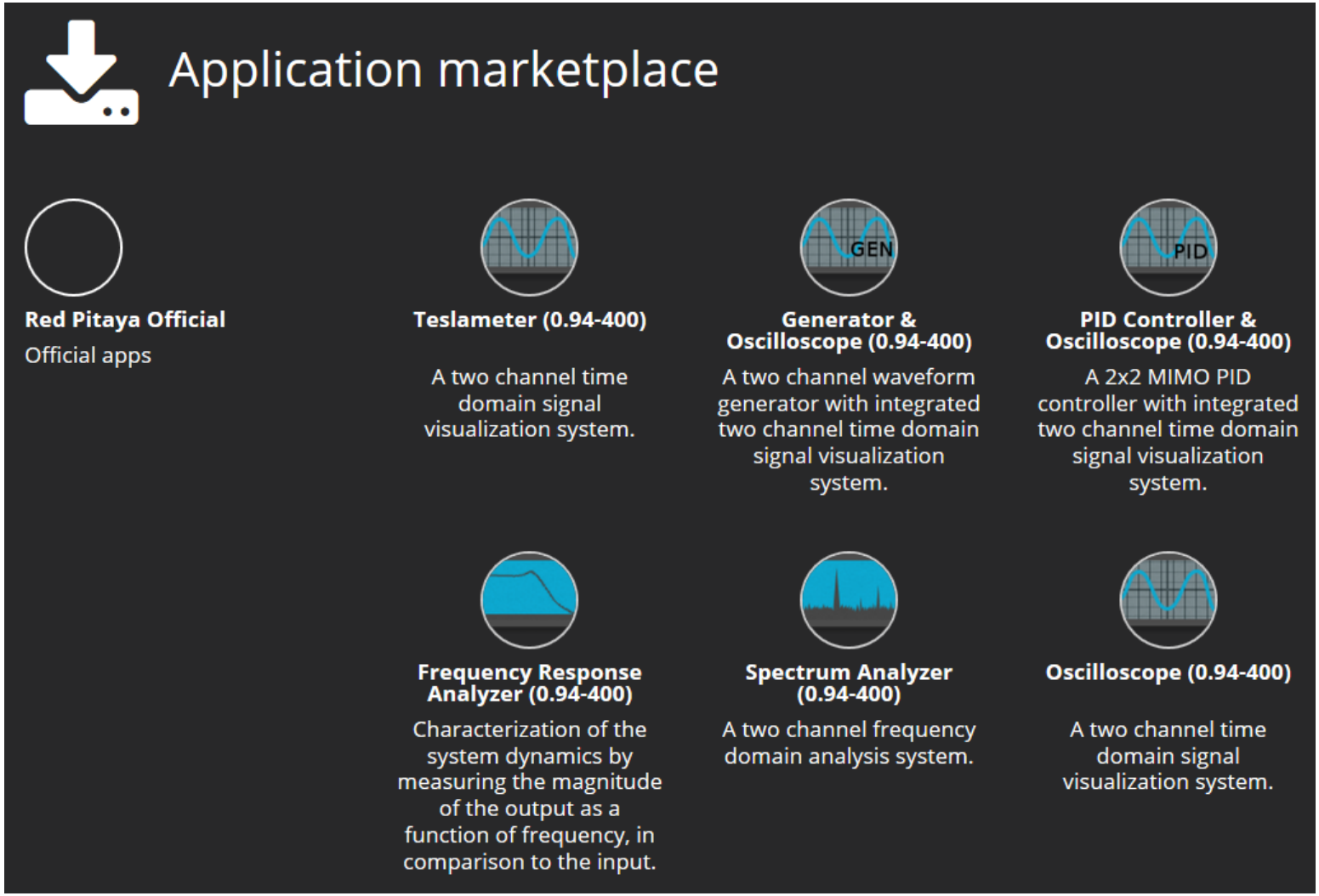
  wired and wireless (via a USB adapter) network connectivity



# *Red Pitaya application marketplace*

– Applications can be installed through the application marketplace:

http://bazaar.redpitaya.com



# *Availability*

– Its network of distributors makes Red Pitaya easily available worldwide:

**LIST OF RED PITAYA DISTRIBUTORS:**

**Global Authorized Distributor:**

MOUSER ELECTRONICS

**EU:**

RS, reichelt elektronik, Pollin ELECTRONIC, trenz electronic, ALLDAQ Competence in Measurement

**North America:**

Concurrent EDA Measurably Faster

**India:**

Ajitech Solutions

**China:**

DFROBOT DRIVE THE FUTURE

**Asia & Pacific:**

RS

**South Korea:**

INIPRO

# *Fast analog inputs and outputs*

- RF inputs:

  Bandwidth: 50 MHz (3 dB)

  Input impedance: 1 MΩ // 10 pF

  Full scale voltage: 2 Vpp

  Linear Technology LTC2145-14 ADC:

  - two channels, 14 bits, 125 MSPS
  - 90 dB SFDR, 73.1 dB SNR, 11.9 ENOB

- RF outputs:

  Bandwidth: 50 MHz (3 dB)

  Load impedance: 50 Ω

  Full scale power: > 9 dBm

  NXP DAC1401D125 DAC:

  - two channels, 14 bits, 125 MSPS
  - 92 dB SFDR

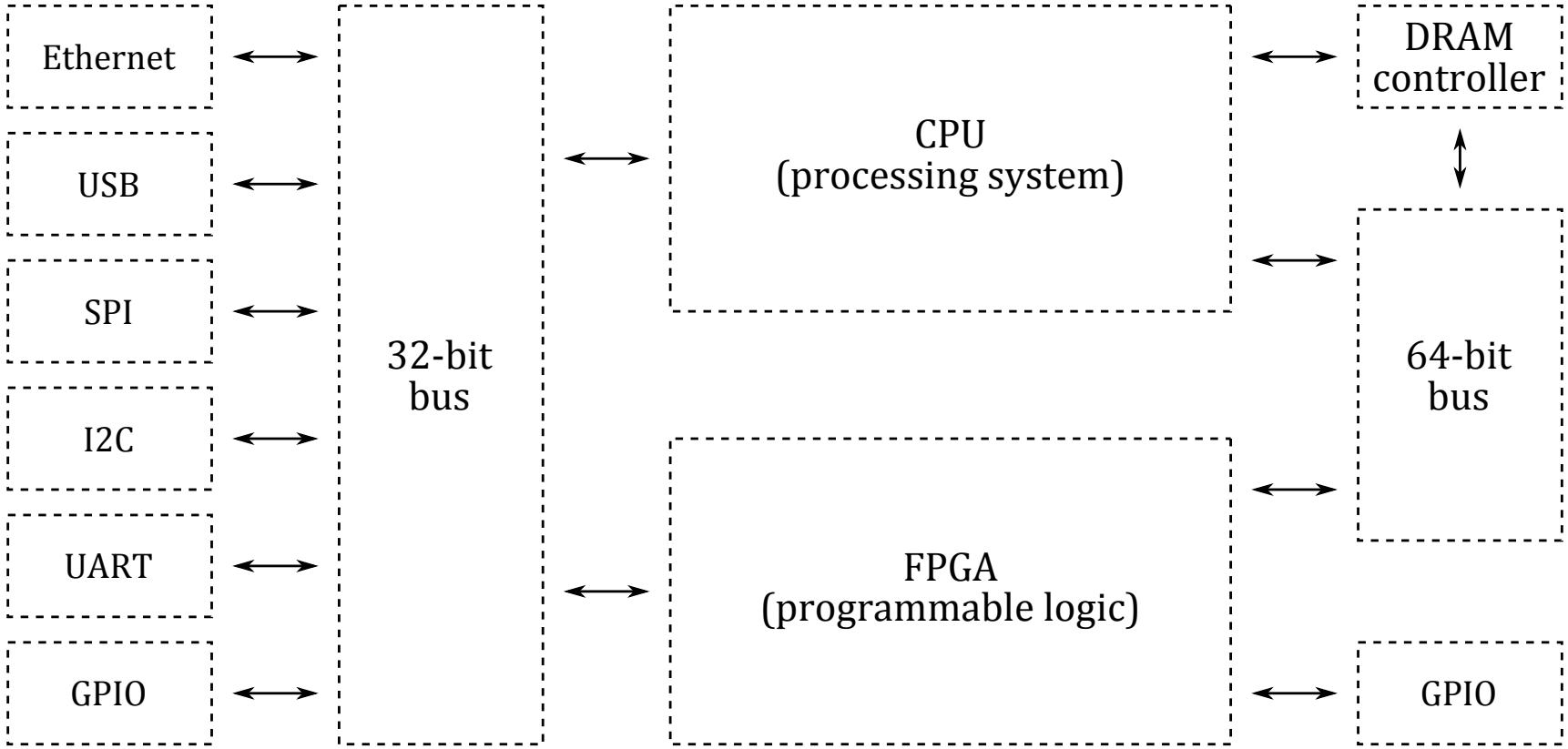
# *CPU, FPGA and DRAM*

– Xilinx Zynq Z-7010 All Programmable System-on-Chip (AP SoC):

CPU: Dual-core ARM Cortex-A9, 667 MHz

FPGA: 2200 logic blocks (CLB), 80 DSP blocks, 60 RAM blocks

– On-board DRAM: 512 MB, DDR3, 1066 MHz, 16-bit wide



# *FPGA components*

– 2200 configurable logic block (CLB):

  8× 6-input look-up tables (LUT)

  16× flip-flops

– 80 DSP block:

  18 × 25 signed multiply

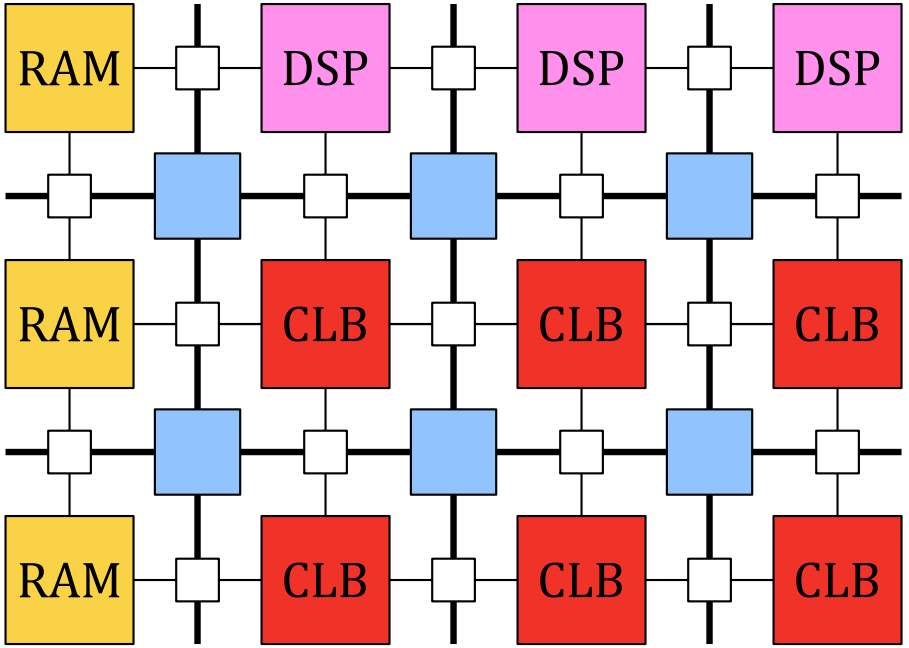
  48-bit adder/accumulator

  25-bit pre-adder

– 60 RAM block:

  dual-port

  36 Kb



# *FPGA tools*

– Xilinx Vivado Design Suite provides the following tools:

Hardware description languages (Verilog and VHDL)

Rich library of IP cores (DSP, math, video, imaging, etc)

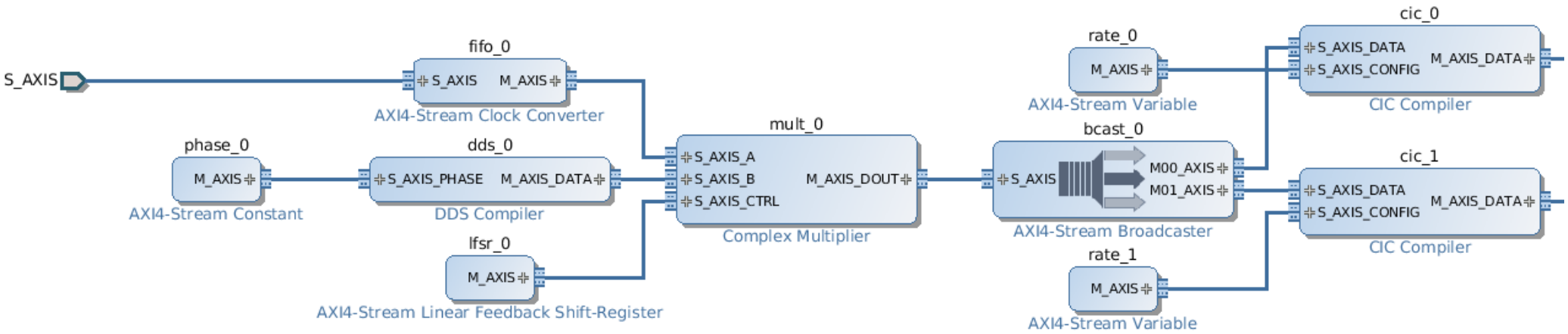
IP Integrator (supports graphical and Tcl-based design flows)

High-Level Synthesis for C, C++ and SystemC

– For my projects, I'm currently using:

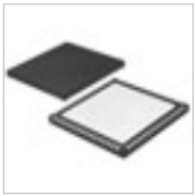
**Verilog** to write custom IP cores

**Tcl** to glue IP cores together



# *Some thoughts about cost*

– ADC, AP SoC and SMA connectors are relatively expensive parts:

| Image | Part Number | Description | Customer Reference | Available Quantity | Backorder Quantity | Unit Price | Extended Price |
|---|---|---|---|---|---|---|---|
|  | LTC2145CUP-14#PBF-ND | IC ADC DUAL 14BIT 125MSPS 64-QFN | LTC2145-14 ADC | 1 Immediate | 0 | 68,91000 | € 68,91 |
|  | 122-1854-ND | IC SOC CORTEX-A9 ARTIX-7 400BGA | Zynq Z-7010 AP SoC | 0 Immediate | **1** Lead Time | 57,43000 | € 57,43 |
|  | J502-ND | CONN SMA JACK 50 OHM EDGE MNT | SMA connectors | 4 Immediate | 0 | 4,66000 | € 18,64 |
|  | 1450-1095-ND | IC SDRAM DDR3 256M X 16 96-FBGA | 512 MB DDR3 DRAM | 1 Immediate | 0 | 8,68000 | € 8,68 |
| | | | | | | **Subtotal** | **€ 153,66** |

– Components in small quantities would cost more than the assembled board

# *Minimal kit for radio applications*

| | | |
|---|---|---|
| 1× | Red Pitaya Open Source Instrument | 250 € |
| 1× | Fan, 30 × 30 × 15 mm, 5 V | 15 € |
| 1× | Power supply, micro USB, 5 V, 2 A | 10 € |
| 2× | SMA tee adapter, SMA plug, SMA jack, SMA jack | 35 € |
| 2× | SMA terminator, 50 Ω | 10 € |
| 4× | SMA-BNC adapter, SMA plug, BNC jack | 25 € |
| 4× | SMA cable, SMA jack, SMA plug, RG-174, 15 cm | 15 € |

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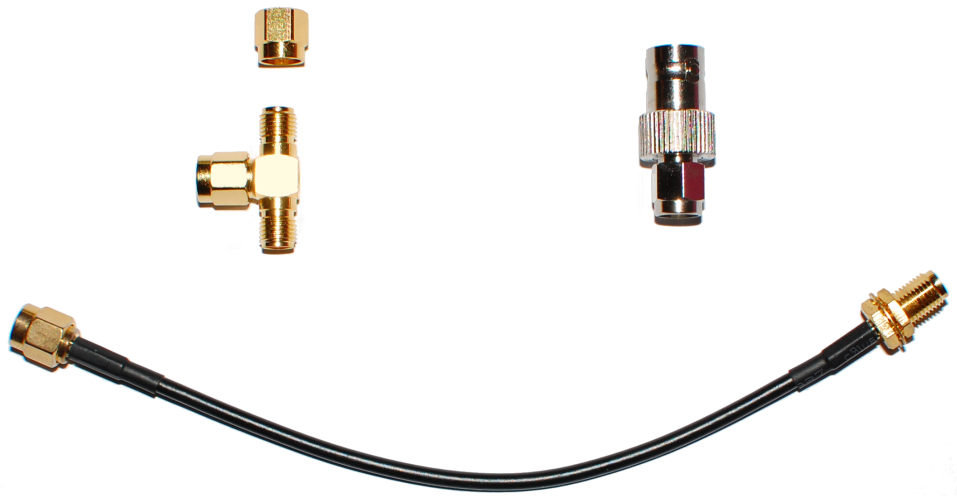
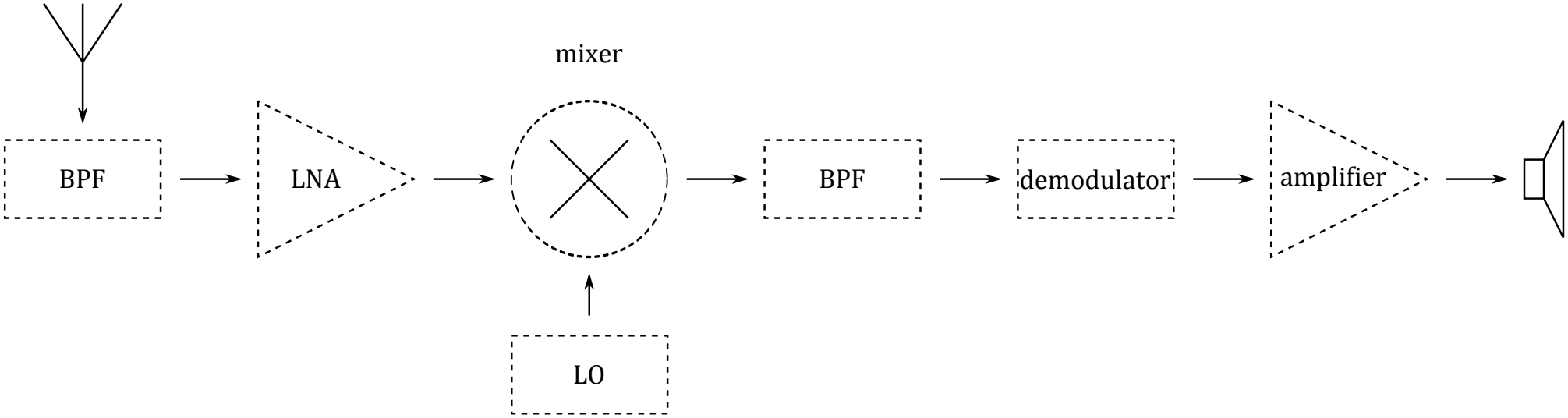
Total 360 € (tax included)



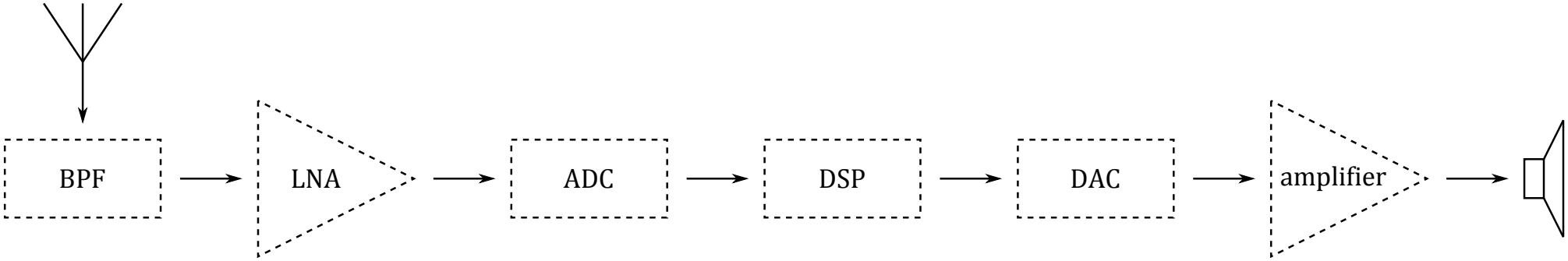
# Software defined radio (SDR)

# *Software defined radio (SDR)*

– Superheterodyne receiver:



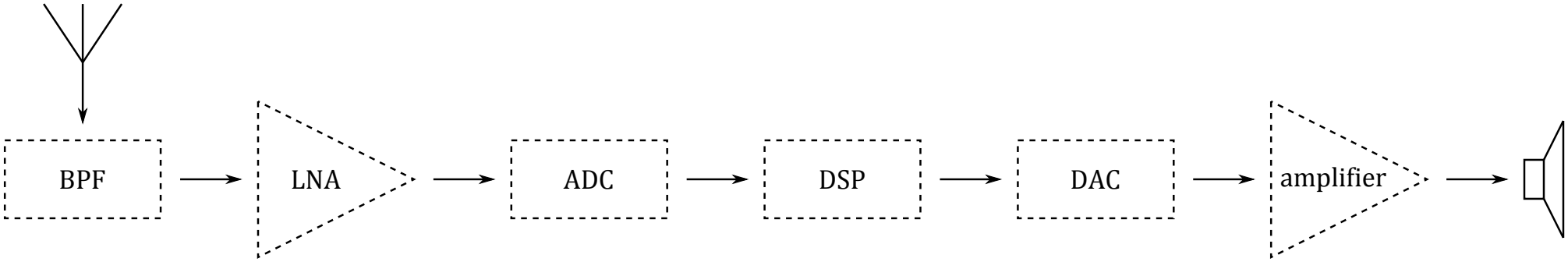

– SDR receiver:



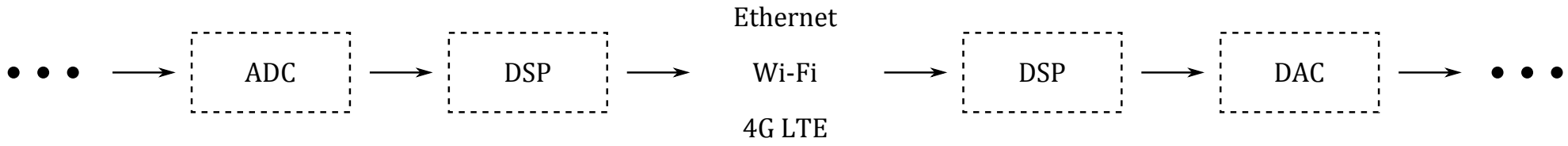

– LO, mixer, filter and demodulator are done by digital signal processing (DSP)

# *Localized and distributed DSP*

– DSP can be localized (e.g. GNU Radio running on the on-board CPU):



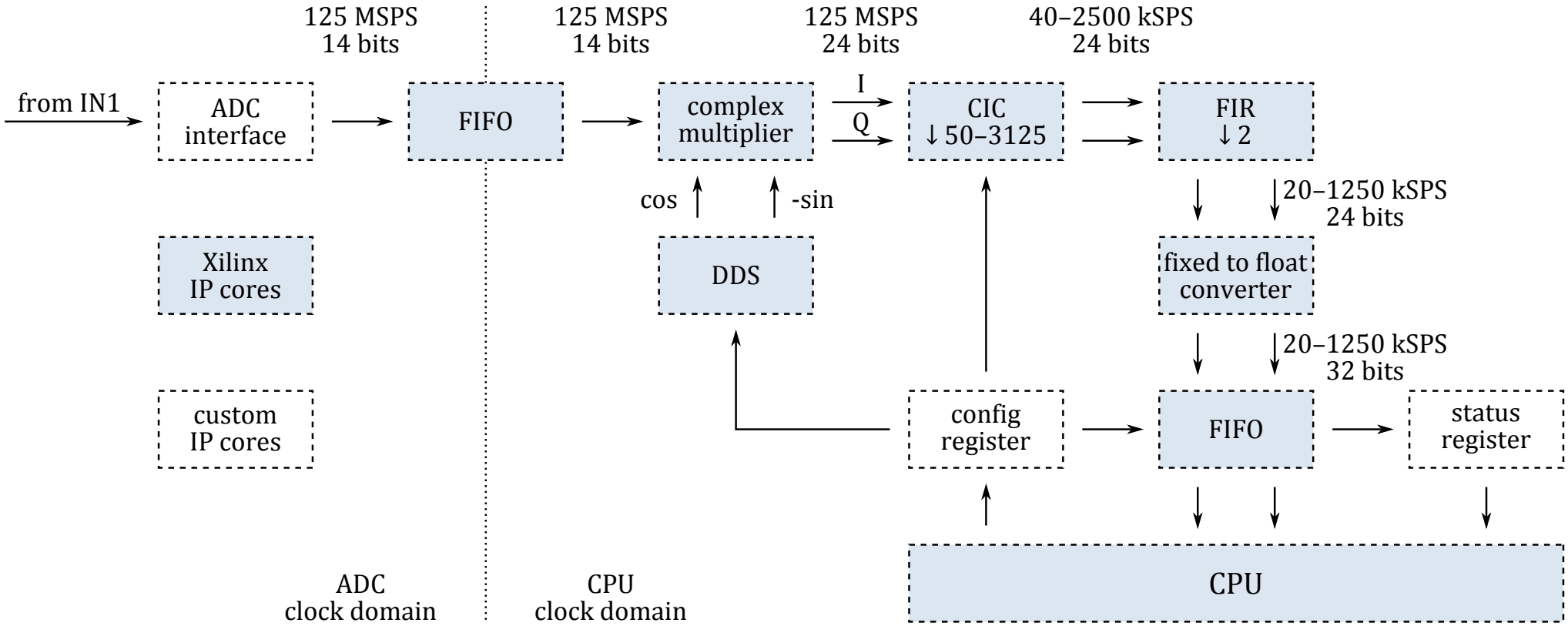

– or distributed:




| | |
|---|---|
| ADC samples (125 MSPS, 16 bits) | 2000 Mb/s |
| Ethernet | 500 Mb/s |
| Wi-Fi | 50 Mb/s |
| 4G LTE | 5 Mb/s |
| Audio (48 kSPS, 16 bits) | 1 Mb/s |

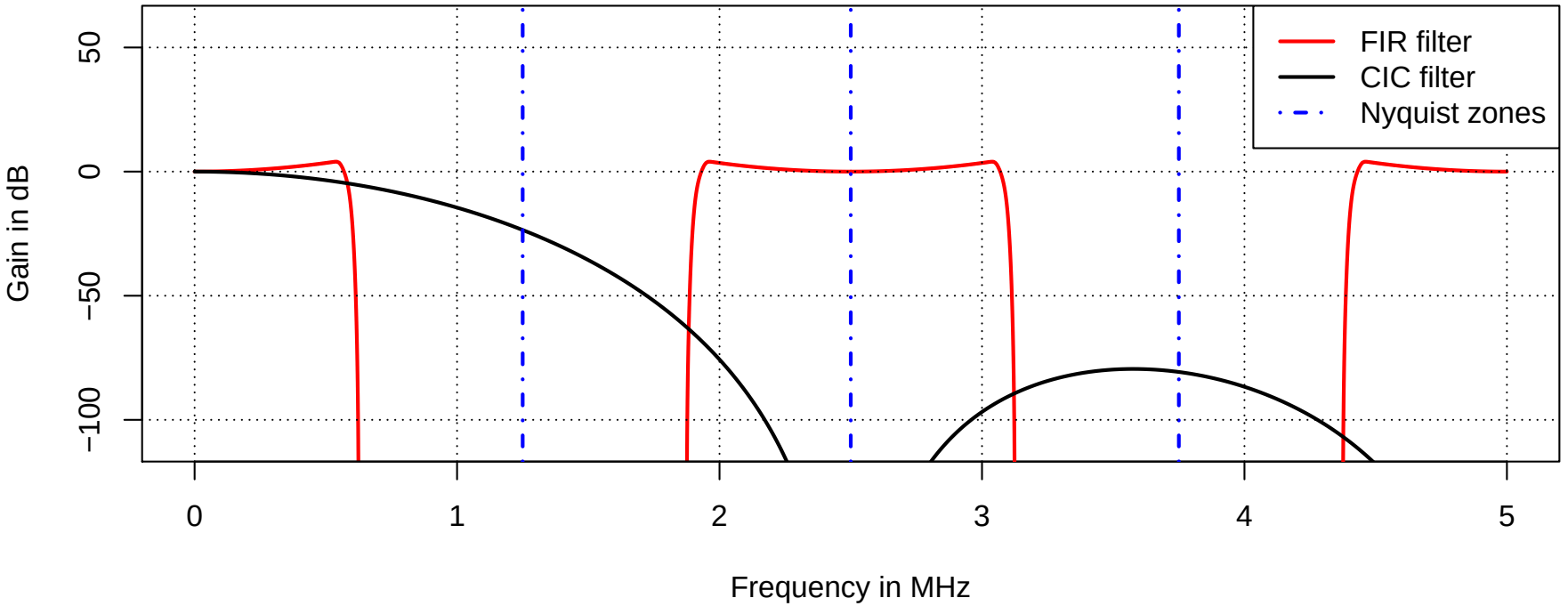
# *Digital down-converter (DDC)*

– ADC samples are processed by a digital down-converter (DDC) running on the Red Pitaya's FPGA:

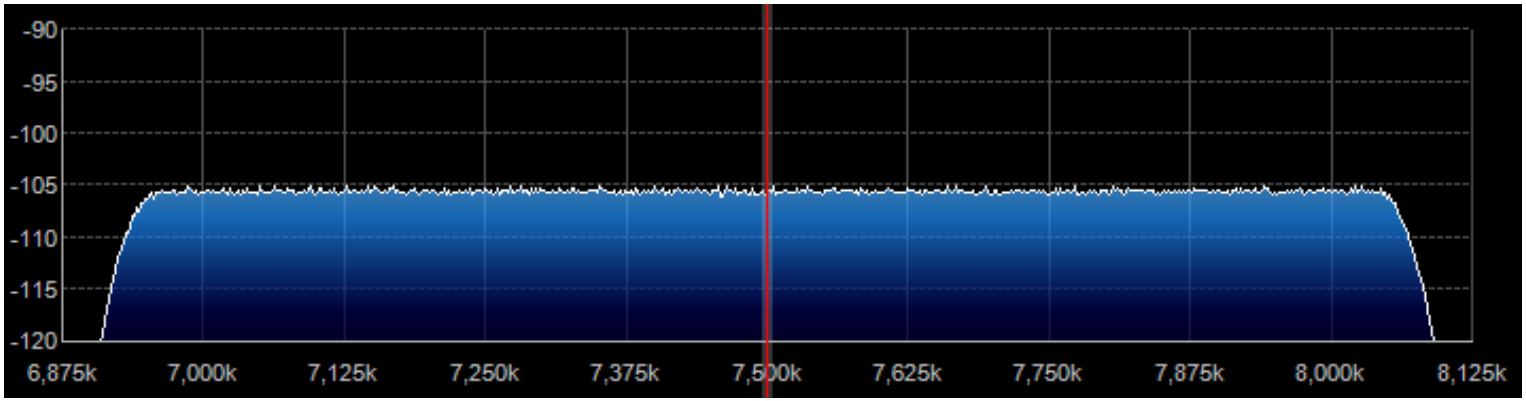


# *CIC and FIR filters*

– Calculated frequency response (decimation by a factor of 50):

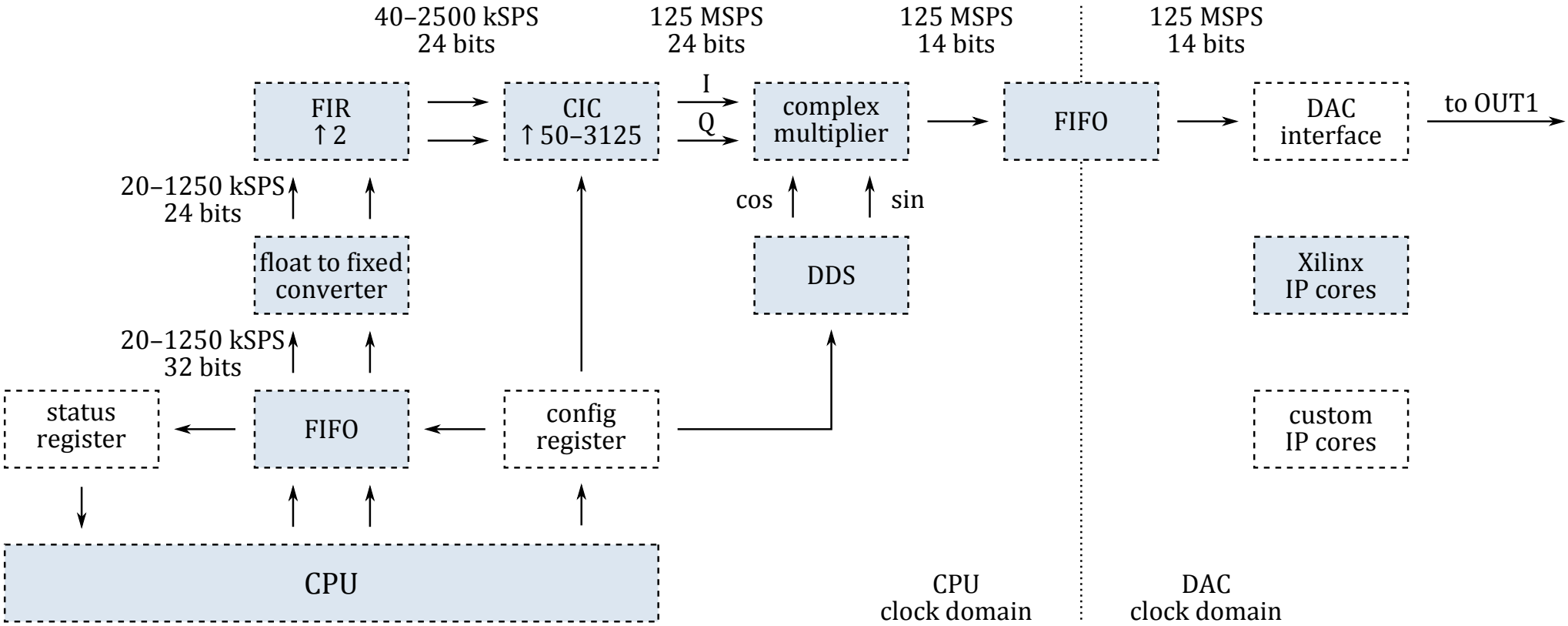



– Measured frequency response:



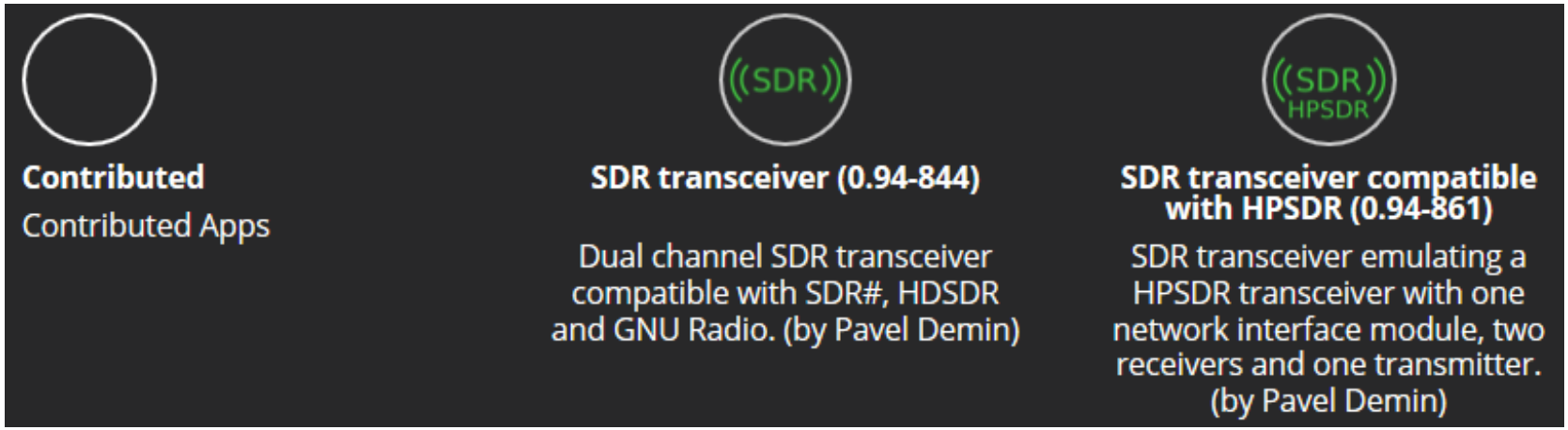
# *Digital up-converter (DUC)*

– Digital up-converter (DUC) consists of the similar blocks but arranged in an opposite order:

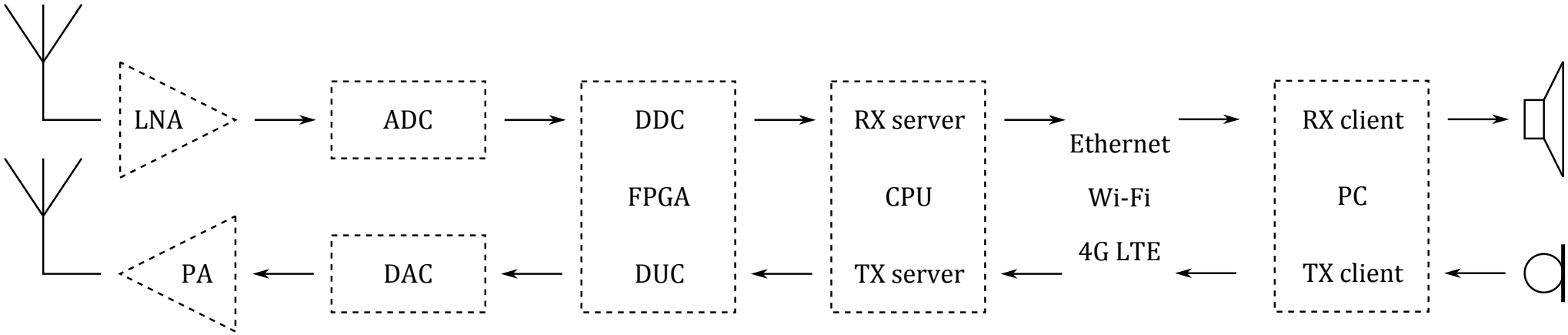


# *Putting it all together*

– Two SDR transceiver applications are available from the Red Pitaya application marketplace:




– These applications configure FPGA and start TCP or UDP servers that communicate with SDR programs running on a remote PC:



# *SDR programs*

– SDR programs provide:

graphical user interface

spectrum display

modulation/demodulation

– Red Pitaya SDR transceiver applications work with the following programs:

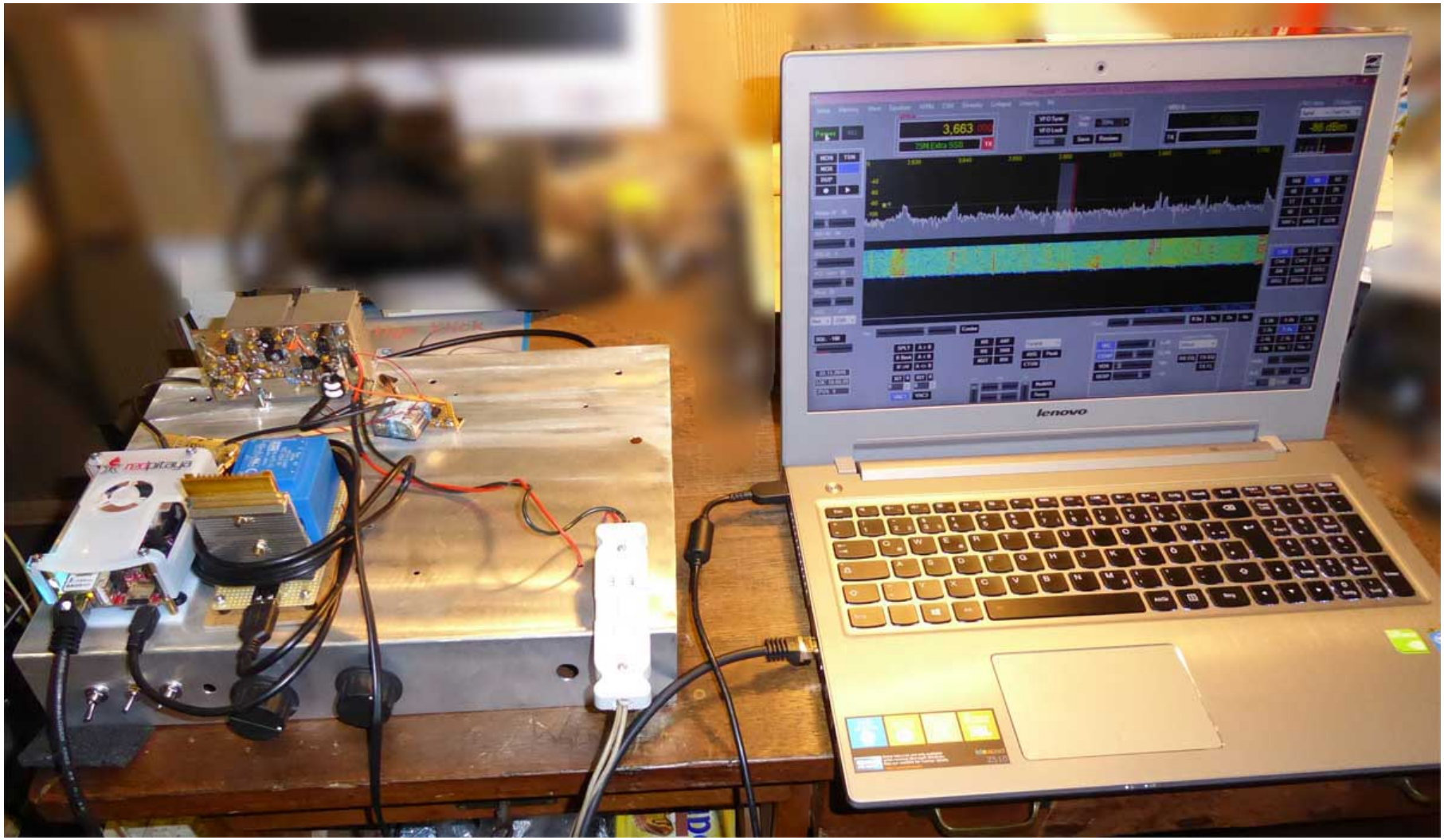
| plug-ins/libraries/protocols | SDR programs |
|---|---|
| ExtIO_RedPitaya_TRX plug-in (only RX) | HDSDR<br>SDR# (≤ 1.0.0.1361) |
| gr-osmosdr/lib/redpitaya | GNU Radio and GNU Radio Companion<br>Gqrx |
| SoapySDR/SoapyRedPitaya | Pothos<br>CubicSDR |
| HPSDR/Metis communication protocol | PowerSDR mRX PS<br>QUISK<br>ghpsdr3-alex<br>openHPSDR Android Application<br>Ham VNA vector network analyzer |

# Feedback from radio amateurs

# *Red Pitaya SDR with 5W power amplifier*

– Wolfgang Kiefer (DH1AKF) published pictures of his 5W station:

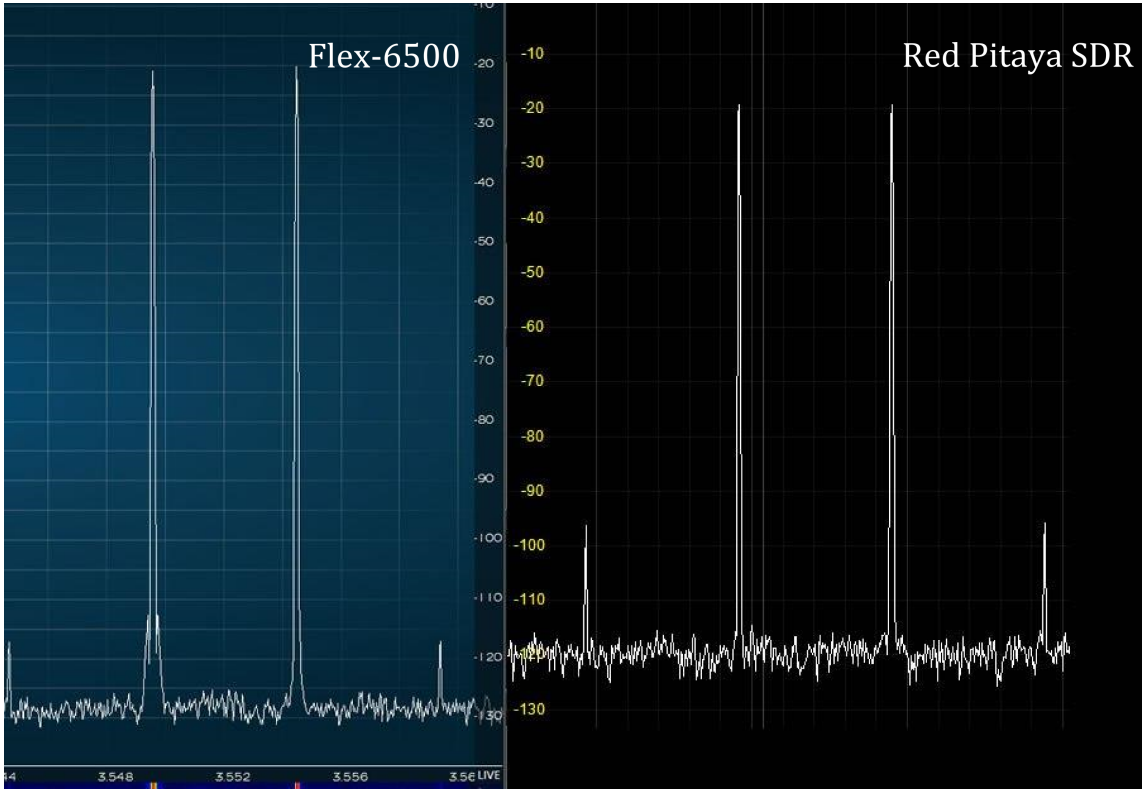
http://www.mikrocontroller.net/topic/385102



# *Comparison with Flex-6500*

– Ger Metselaar (PAØAER) compared Red Pitaya SDR with Flex-6500:

http://www.pa0aer.com/projecten/red-pitaya




| | Flex-6500 | Red Pitaya SDR |
|---|---|---|
| Noise floor level | -130 dBm | -120 dBm |
| Suppression of the intermodulation products | 97 dB | 75 dB |

# *Red Pitaya SDR in the news*

– Johan van Dijk (PA3ANG) published an article about Red Pitaya SDR in the January, 2016 issue of DKARS Magazine:

http://dkars.nl/index.php?page=magazine

# Concluding remarks

# *Summary*

- Red Pitaya is a very interesting platform for

  building various measurement and control systems,

  experimenting with FPGA and DSP algorithms,

  sharing knowledge and experiences.

- It is a nice SDR building block thanks to the excellent open-source SDR tools.

# *Where is the source code?*

– The source code and more details about my projects can be found at:

http://pavel-demin.github.io/red-pitaya-notes

Red Pitaya Notes Source Issues

1. List of components
2. Links
3. Development machine
4. LED blinker
5. SDR receiver
6. SDR transceiver
7. SDR transceiver compatible with HPSDR
8. SDR transceiver with FFT
9. Embedded SDR transceiver
10. Wideband SDR transceiver
11. Pulsed Nuclear Magnetic Resonance
12. Multichannel Pulse Height Analyzer
13. Scanning system
14. Debian with Red Pitaya ecosystem

# *Interesting links*

- Red Pitaya

  http://redpitaya.com

- The Scientist and Engineer's Guide to Digital Signal Processing

  http://www.dspguide.com

- dspGuru: Digital Signal Processing Articles

  http://www.dspguru.com/dsp/articles

- ARRL: Software Defined Radio

  http://www.arrl.org/software-defined-radio

- GNU Radio: Suggested Reading

  http://gnuradio.org/redmine/projects/gnuradio/wiki/SuggestedReading