Tracking 75 GHz satellite beacon using PiKRON LX-RoCon motion control unit and digital radio (Orekit, GNU Radio, Julia).

\+ LX-RoCon engaged in development of gravitational waves mission LISA

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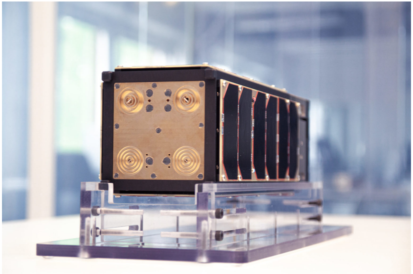
Goal

- Explore the new mm-Wave band – 75 GHz
  - mainly for telco use
- Reasons going to higher f:
  - lack of allocated bandwidth
  - $+$ better directional links
  - $-$ worse omni-directional links (both due to Friis formula)
- $\Rightarrow$ Propagation campaign
  (wave propagation through atmosphere)

Tool

- ESA W-Cube
  - Tx-only space segment



- Rx-only ground station
  - 1 already existing in Austria in frame of W-Cube project
  - attempt to build 2nd station at ESA
    - minimalist, independent, possibly running simultaneously w/others

Ground station

- Signal chain
  - antenna – 60cm dish ($\lambda = 4\,\mathrm{mm}$ surface quality!)
  - mm-Wave front-end – custom
  - digital radio – SDR USRP Ettus N210
- Antenna tracking
  - mount – astro Synta NEQ-6
  - motion control unit – PiKRON LX-RoCon
  - tracking SW
    - `https://github.com/esa/lxrmount`

Tracking SW – `lxrmount` suite

- $\lambda \Rightarrow \sim 0.1^\circ$ accuracy
  - still much relaxed vs. astro-optical
  - but more stringent than classic HAM sat
  - but combined with LEO, $\sim 0.1\,$s time vs. motor accuracy
- Constituents of tracking SW:
  - TrackPV: TLE $\rightarrow \alpha(t), \beta(t)$
    - based on Orekit
  - lxrmount: $\alpha(t), \beta(t) \rightarrow$ LX-RoCon
    - includes position-velocity outer control loop
  - stellio: stellarium $\rightarrow (\alpha, \beta) \rightarrow$ `.txt`
    - supports 1-point or multi-point entry for subsequent calibration

TrackPV – Orekit demo (1/2)

```java
TLE sat = new TLE(args[2], args[3]);
    //TLE(/* ISS (ZARYA) -- ARISS 2023-05-24 */
    //    "1 25544U 98067A   23145.32602431  .00014206  00000-0  25493-3 0  9995",
    //    "2 25544  51.6413  81.8570 0005396  18.1967 120.0030 15.50160974398246")

Frame inertialFrame = FramesFactory.getEME2000();
Frame ITRF = FramesFactory.getITRF(IERSConventions.IERS_2010, true);
OneAxisEllipsoid earth = new
    OneAxisEllipsoid(Constants.WGS84_EARTH_EQUATORIAL_RADIUS,
                     Constants.WGS84_EARTH_FLATTENING,
                     ITRF);

/* station coordinates */
lat = 52.1868056 * Math.PI/180.0; /* Lange Voort molen, Oegstgeest */
lon = 4.4730814 * Math.PI/180.0;
alt = -3.0;

GeodeticPoint station =new GeodeticPoint(lat, lon, alt);
TopocentricFrame station_frame = new TopocentricFrame(earth, station, "NL");
```

TrackPV – Orekit demo (2/2)

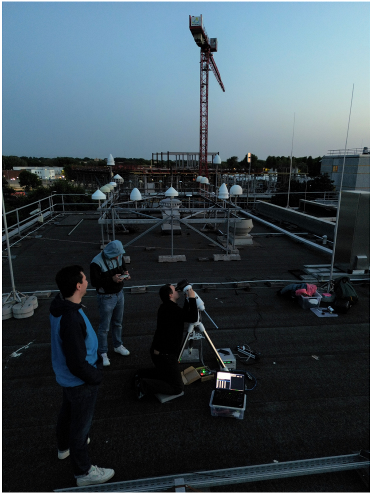
```
TLEPropagator propagator = TLEPropagator.selectExtrapolator(sat);

TimeScale utc = TimeScalesFactory.getUTC();
AbsoluteDate t0 = new AbsoluteDate(args[0], utc);
double t_end = Double.parseDouble(args[1]);
double dt = 1.0;
//System.out.println("# t0=" + t0);
for (double t = 0.0; t < t_end; t += dt) {
    AbsoluteDate tx = t0.shiftedBy(t);
    PVCoordinates pv = propagator.getPVCoordinates(tx, station_frame);

    Vector3D p = pv.getPosition(), v = pv.getVelocity();
    double t_out;
    if (abs_time) {
        long t_ms = tx.toDate(utc).getTime();
        t_out = t_ms/1000.0;
    }
    else {
        t_out = t;
    }
    output(MODE_EQ, abs_time ? t_out : t, p, v);
}
```

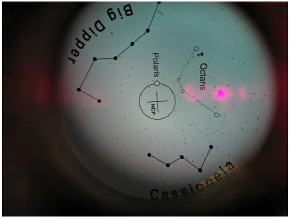
Mount calibrations

- Mount adjusted using Polaris
  - highly non-standard for radio, but for us easiest reference
- 1-point calibration (α_0, β_0) on Sun or other celestial body
  - no index marks nor abs. encoders
  - multi-point possible, but not needed at all for this λ

Ground station commissioning

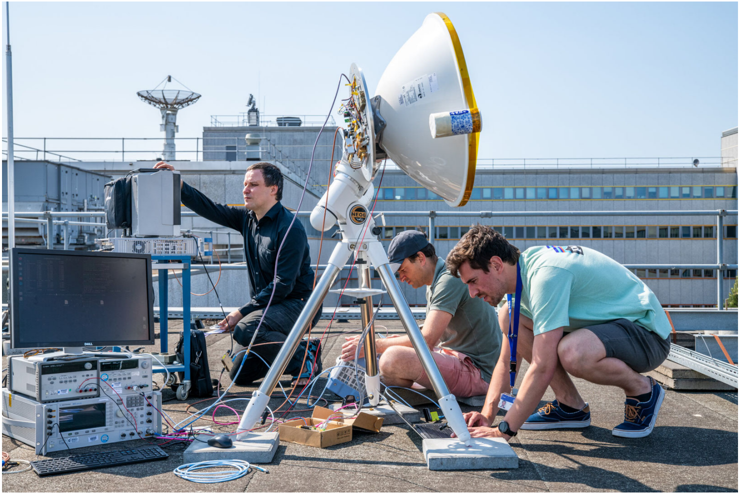
- 1st step: verify tracking telescope & visual





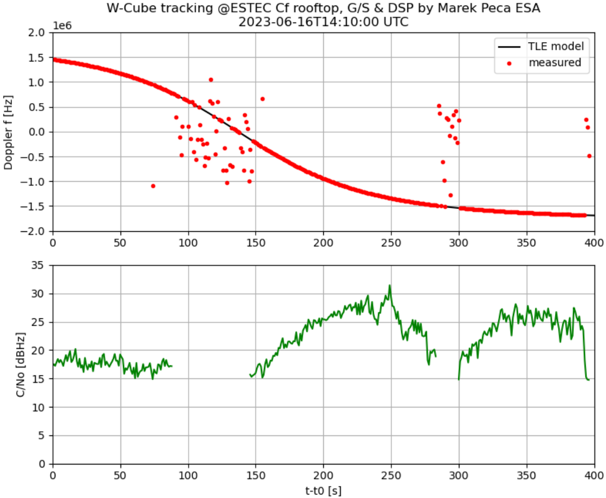
Ground station commissioning

- 2nd step: W-Cube pass!



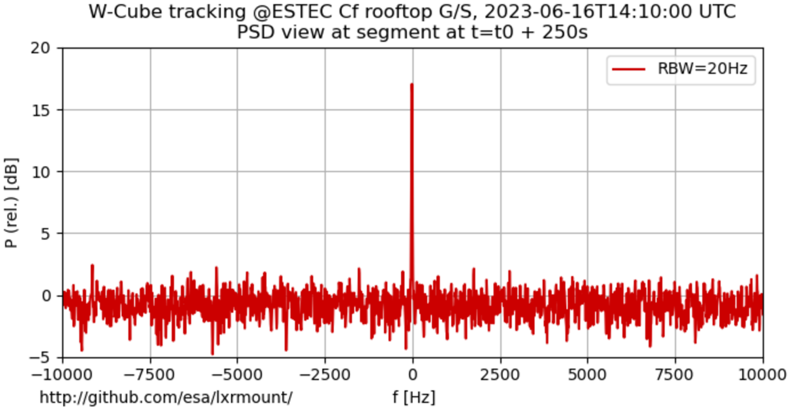
Ground station commissioning

- 3rd step: DSP in Julia – offline, heavy Doppler-rate



DSP of CW carrier

- PSD after removing Doppler-rate



W-Cube tracking challenges & Credits

Challenges

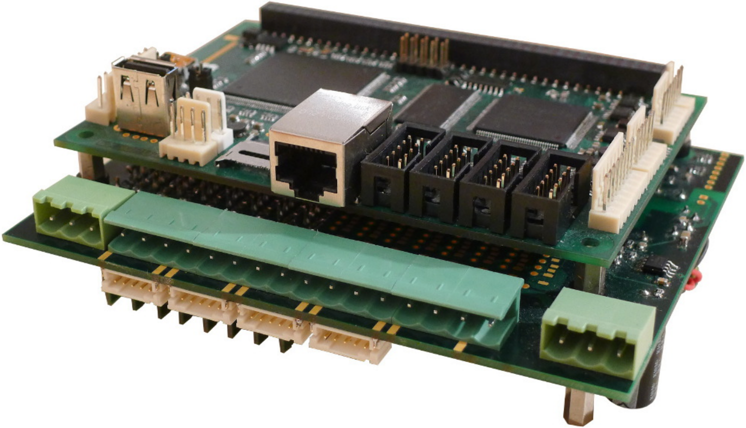
- Smooth and accurate motion control
  - impossible with built-in mount's controller
  - LX-RoCon saved the day
- Low SNR (C/N_o)
- High Doppler-rate

Credits

- Václav Valenta & Hugo Deberges: RF front-end and roof-top fun
- W-Cube mission participants for providing the sat

See more at `https://www.esa.int/ESA_Multimedia/Images/2023/06/W-band_on_the_run`

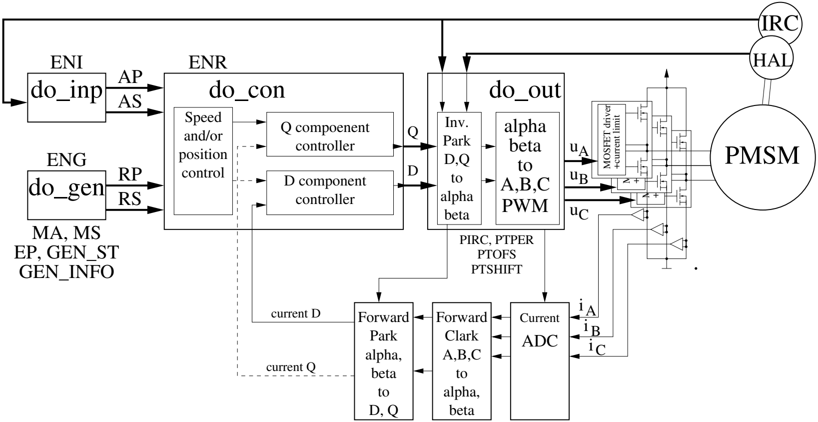
LX_ROCON – DC, BLDC/PMSM and Stepper Controller



LX_ROCON – Features

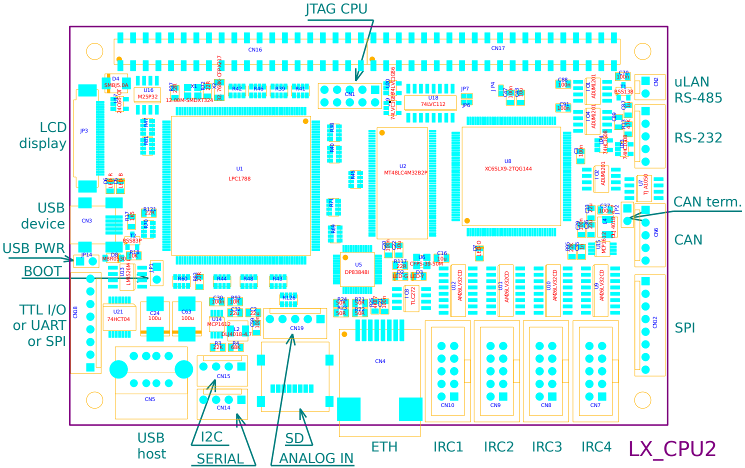
- Industry-proven Electric Motor Control libraries and system
- FPGA-based Based on Cortex-4 MCU and Xilinx Spartan 6 FPGA
- Fully configurable, 16 power outputs can be assigned up to 4× BLDC/PMSM, stepper motors and or up to 8× DC motor
- FPGA design with inferred blocks only
- Portable to MicroSemi FPGAs, does not use vendor-specific blocks
- CAN, ETHERNET, Serial, RS-485 and USB communication
- RTEMS, Nuttx and mbed supported

Simplified PMSM Vector Control

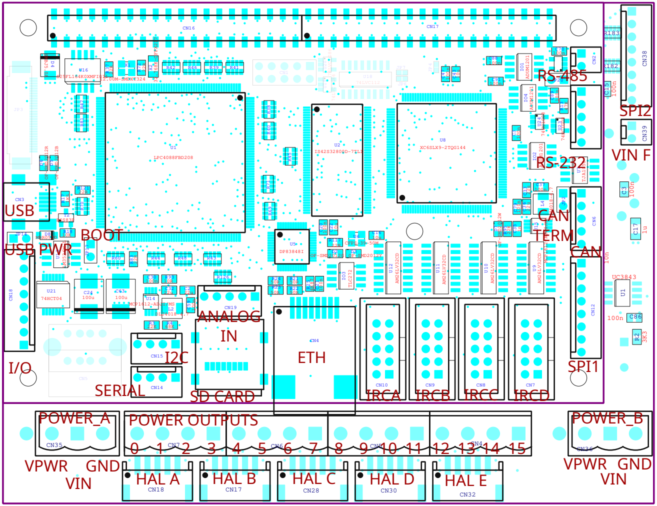


Source: PiKRON PXMC library

LX_ROCON – LX_CPU Board

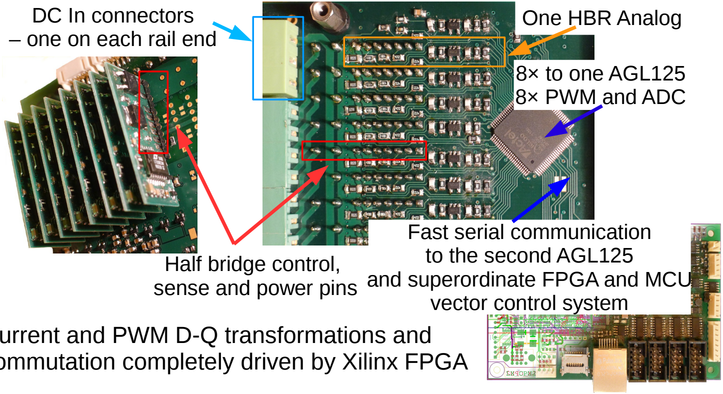


LX_ROCON – LX_CPU & LX_PWR Boards



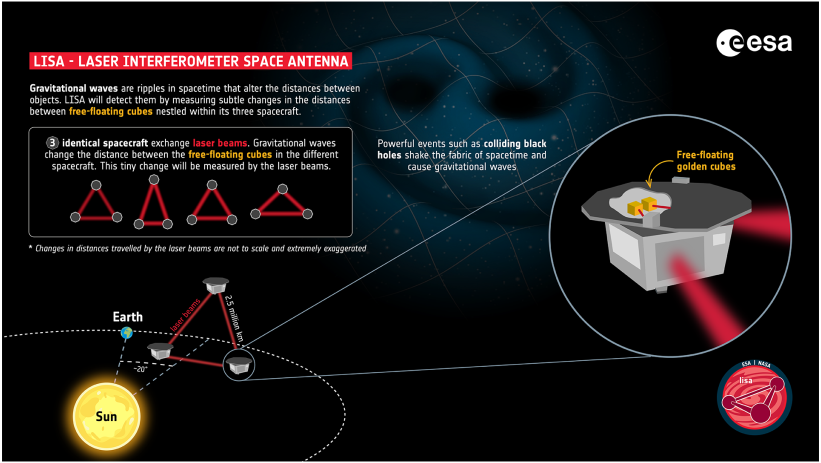
LX_ROCON – Power Stage with CPLD Implemented ADC

- Example: up to 4 BDLC/PMSM and IRC equipped or sensor-less stepper motor control (16× 5 A, up to 28 VDC, fully protected phase half-bridges)

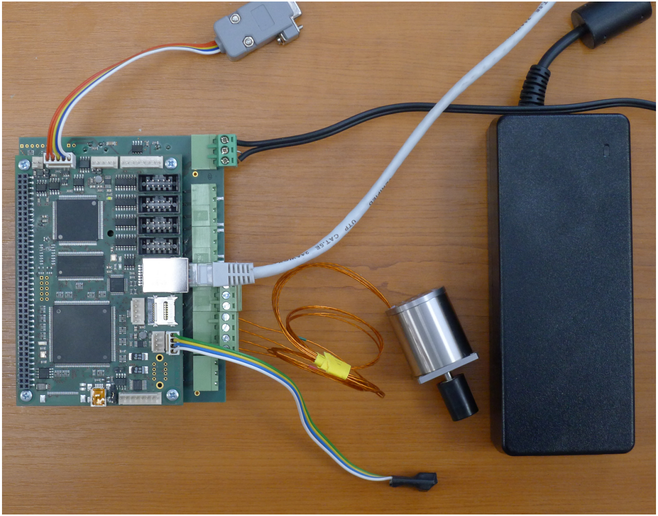


- Current and PWM D-Q transformations and commutation completely driven by Xilinx FPGA

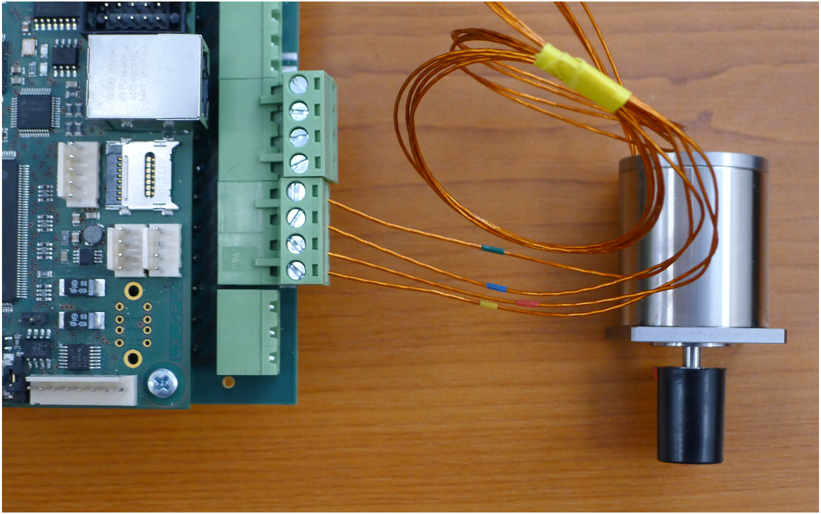
ESA LISA Mission



LX-RoCon with Phytron motor

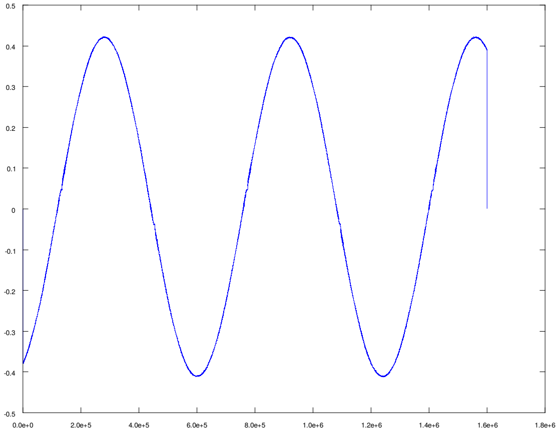


LX-RoCon with Phytron motor – close-up



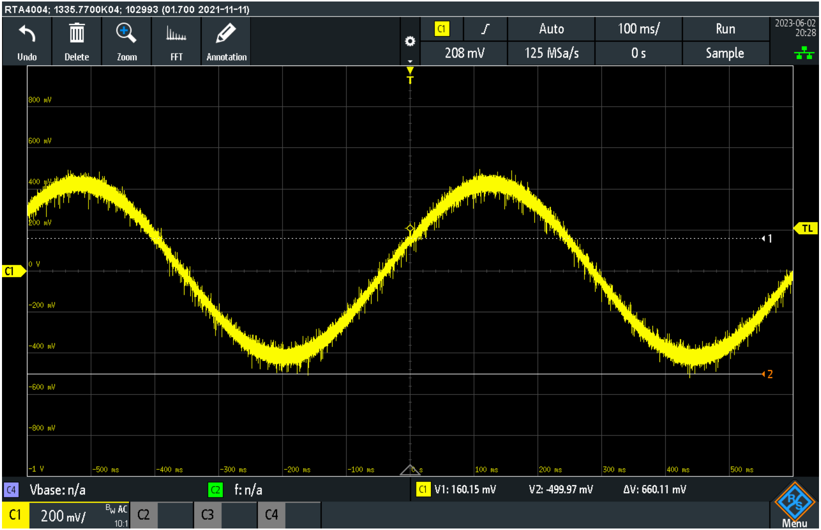
Winding current

As digitised by unit's internal ADC

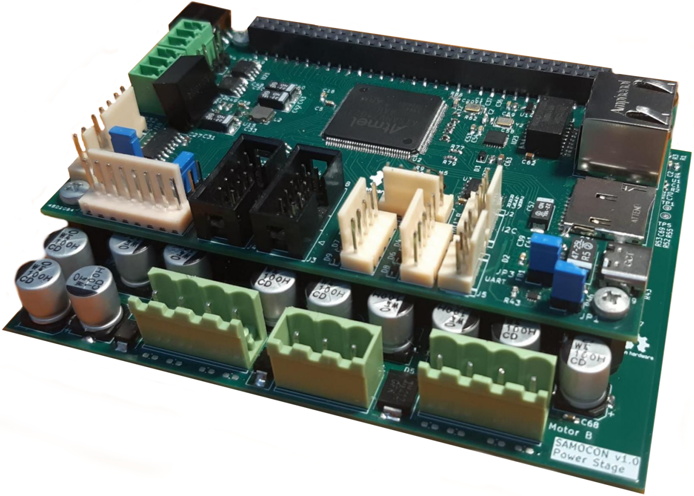


Winding current

Measured externally

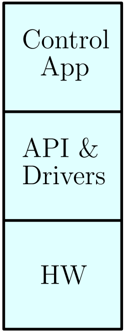


Continuation of LX-RoCon: SaMoCoN



Introduction

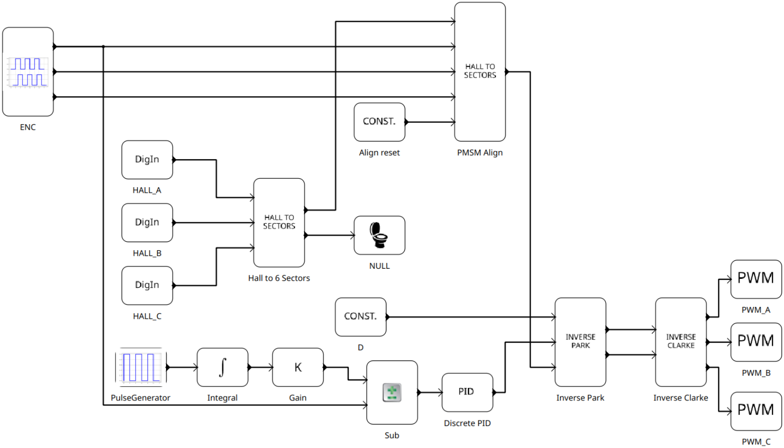
- Currently a part of a bachelor thesis supervised by Pavel Píša
- A continuation of PiKRON LX-RoCoN controller
- Funded by ÚTIA, AV ČR & PiKRON.com
- Main design requirements
    - Be open - open hardware and open software, using open software for development too
    - Be modular
        - drive various kinds of motors - stepper, PMS, DC motors
        - rich connectivity, usage of RTOS
        - design of control applications using high level model based design



Using pysimCoder to create control apps

- Matlab/Simulink experimental alternative
- model based design
  - the design of control apps/algorithms with the help of blocks
  - the block schematic resembles a circuit with data flow
  - if C function is provided for each block, a complete program in C can be created and then the binary can be run on the target hardware
- business logic (the GUI, JSON parsing) implemented in Python

pysimCoder - block example



NuttX - API & Drivers

- Using NuttX RTOS for API, drivers, scheduling
- POSIX compliant
- Peripherals registered as files (`/dev/adc0`, `/dev/pwm0`)
- Accessing MCU's peripherals using `open`, `read`, `write`, `ioctl`

```
const ssize_t channels = 8;
struct adc_msg_s sample[channels];
int readsize = channels * sizeof(struct adc_msg_s);

int fd = open("/dev/adc0", O_RDONLY);
if (fd < 0) {
    printf("Error␣opening␣ADC0!\n");
    return ERROR();
}
ioctl(fd, ANIOC_RESET_FIFO, 0);
```

AD converter reading

2)

```
while(1) {
    ioctl(fd, ANIOC_TRIGGER, 0);
    int nbytes = read(fd, sample, readsize);
    if (nbytes == readsize) {
        for (int i = 0; i < channels; ++i)
            printf("%d\n", sample[i].am_data);
        putchar('\n');
    }
    usleep(1000*100);
}
```

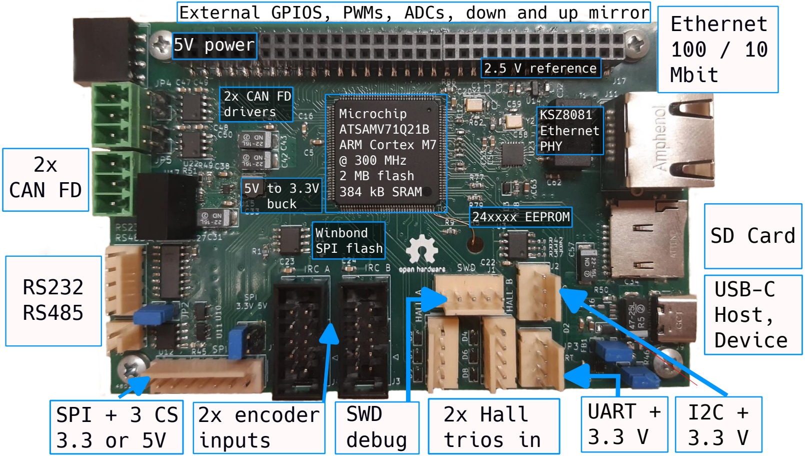
Hardware description

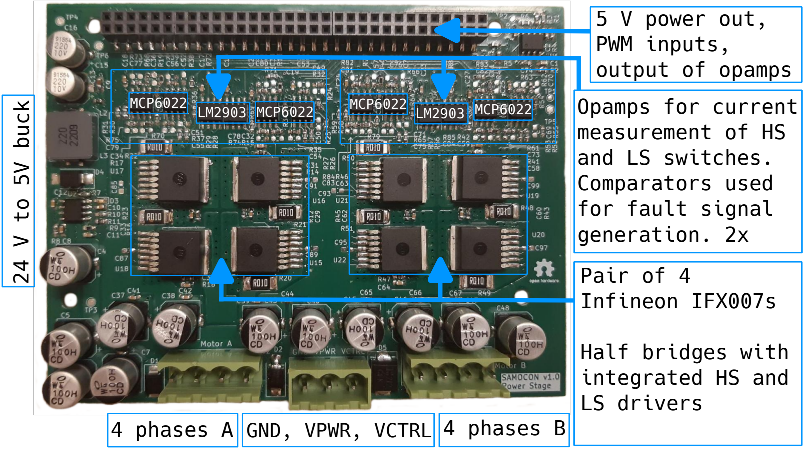
MCU and the Power board. Capable of driving two actuators/motors.

- MCU board
  - Microchip ATSAMV71Q21B microcontroller
    - ARM Cortex M7, 2 MB flash, 384 kB SRAM
    - Support for double precision float arithmetics
  - 100Base-TX/10Base-T Ethernet support with KSZ8081 PHY
  - USB-C connector, I^2C, SPI, RS232, RS485, 2x CAN-FD
  - Feedback support: 2x encoder (can be differential), 2x Hall sensors
  - 2×32 connector used to connect the power board, includes PWMs, ADCs, extra GPIOs
  - 5V powering. Either from the power board or from the USB-C connector.

Hardware description

- Power board
  - Designed to switch 24 V
  - 2x four IFX007 half bridges for power switching
  - 24 V to 5 V buck to power the MCU board
  - MCP6022 opamps to amplify measured currents, used for field oriented control of the motors


External GPIOS, PWMs, ADCs, down and up mirror
5V power
2.5 V reference
Ethernet 100 / 10 Mbit
2x CAN FD drivers
Microchip ATSAMV71Q21B ARM Cortex M7 @ 300 MHz 2 MB flash 384 kB SRAM
KSZ8081 Ethernet PHY
2x CAN FD
5V to 3.3V buck
24xxxx EEPROM
SD Card
Winbond SPI flash
RS232 RS485
USB-C Host, Device
SPI + 3 CS 3.3 or 5V
2x encoder inputs
SWD debug
2x Hall trios in
UART + 3.3 V
I2C + 3.3 V


5 V power out,
PWM inputs,
output of opamps
Opamps for current measurement of HS and LS switches. Comparators used for fault signal generation. 2x
Pair of 4 Infineon IFX007s
Half bridges with integrated HS and LS drivers
24 V to 5V buck
MCP6022
LM2903
MCP6022
MCP6022
LM2903
MCP6022
4 phases A
GND, VPWR, VCTRL
4 phases B
Motor A
Motor B
SAMOCON v1.0
Power Stage