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New control system for radiotelescopes *RT2* and *RT5* in Ondřejov

1. Introduction

Radiotelescopes *RT2* (7.5m dish, *Fig. 1* left) and *RT5* (10m dish, *Fig. 1* right), located at the observatory of the Astronomical Institute of Czech Academy of Sciences in Ondřejov, are being used for radioastronomical research of the Sun already for decades. For technical reasons (quite a massive construction), they are mounted on the azimuth/elevation mount, which brings additional demands on their pointing to the celestial target – in our case the center of the solar disc: Motions in the azimuth and elevation axes are irregular, when tracking the Sun.

In this poster we present a brief historical overview of approaches adopted to this issue at our observatory, followed by more detailed description of the current implementation based on an autonomous micro-controller built at the popular *Arduino* platform, and our plans for its future extension.

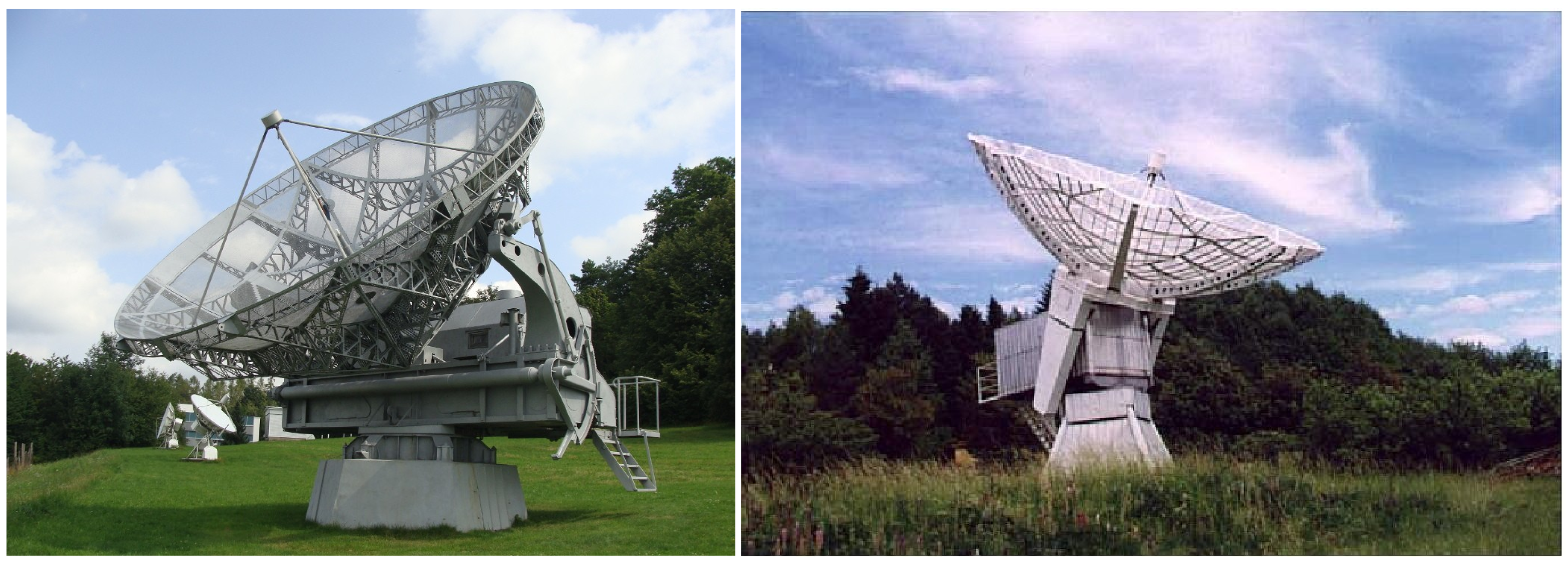

Fig 1: *Radiotelescopes RT2 (left) and RT5 (right) at the observatory AI CAS Ondřejov.*

2. Earlier implementations: A brief historical overview

Before the era of computers, the problem of simultaneous irregular motions in both axes, when tracking a celestial object in its daily motion on the sky, has been solved by a specifically designed mechanical converter (in fact, a kind of mechanical calculator). This device carried out the transformation of regular rotation of the clock machine to the irregular motions in the azimuth-elevation (Az/El) coordinates – see *Fig. 2*. System has been designed originally by Laffineur (1954) for the similar raditelescope (reconstructed, originally military, Würzburg-Riese radar) located in Paris-Meudon. The procedure relied on the accuracy of the entire mechanical system and did not contain any feedback for checks, whether the antenna is actually pointing to the Sun.

In early 1990's it was therefore replaced by a simple computer-controlled system. From the known solar ephemeris it calculates the Az/El coordinates of the Sun and compares them (in regular 1-second intervals) with the antenna position as determined by the incremental rotation sensors connected to the azimuth and elevation axes. In case of difference between calculated position of the Sun and measured position of the antenna, an electric-current impulse is sent to the electromotive drive in the appropriate axis. This way a correction of the antenna position is done every second. The incremental sensors (their zero position) are calibrated once per day by driving the system to the reference point in the local meridian. The interfaces between the wires of the incremental rotation sensors (5V logics) and the PC, as well as that between the PC and electronic switch of the motors, have been implemented by means of specifically tailored cards inserted in slots of the ISA bus at the mainboard of the controlling PC.

Although this system has been successfully working for years, in 2020 we have decided for its essential reconstruction. It was motivated namely by highly risky obsolescence of the HW (PC Intel 286 with native MS DOS!) with practical impossibility to acquire the spare parts for replacement (e.g., similar motherboard with the ISA-bus slots) in case of their failure. Moreover, the system occupies two pairs (i.e. all available) of the optical fibers connecting the radiotelescope *RT5* with the radioastronomy building: One pair for remote control and second for the observed (radio spectrograph) data downlink. This is because none of those subsystems is implemented on a standard TCP/IP platform, but they use proprietary single-purpose communication protocols. And the third reason: Solar ephemeris is somewhat "hardwired" in the controlling PC, so it is not easily possible to follow other strong celestial radio sources (like Cas A), for example for the receiver calibration purposes. Therefore, a new realization of the radiotelescope control has been planed and later implemented that overcomes all the mentioned drawbacks.

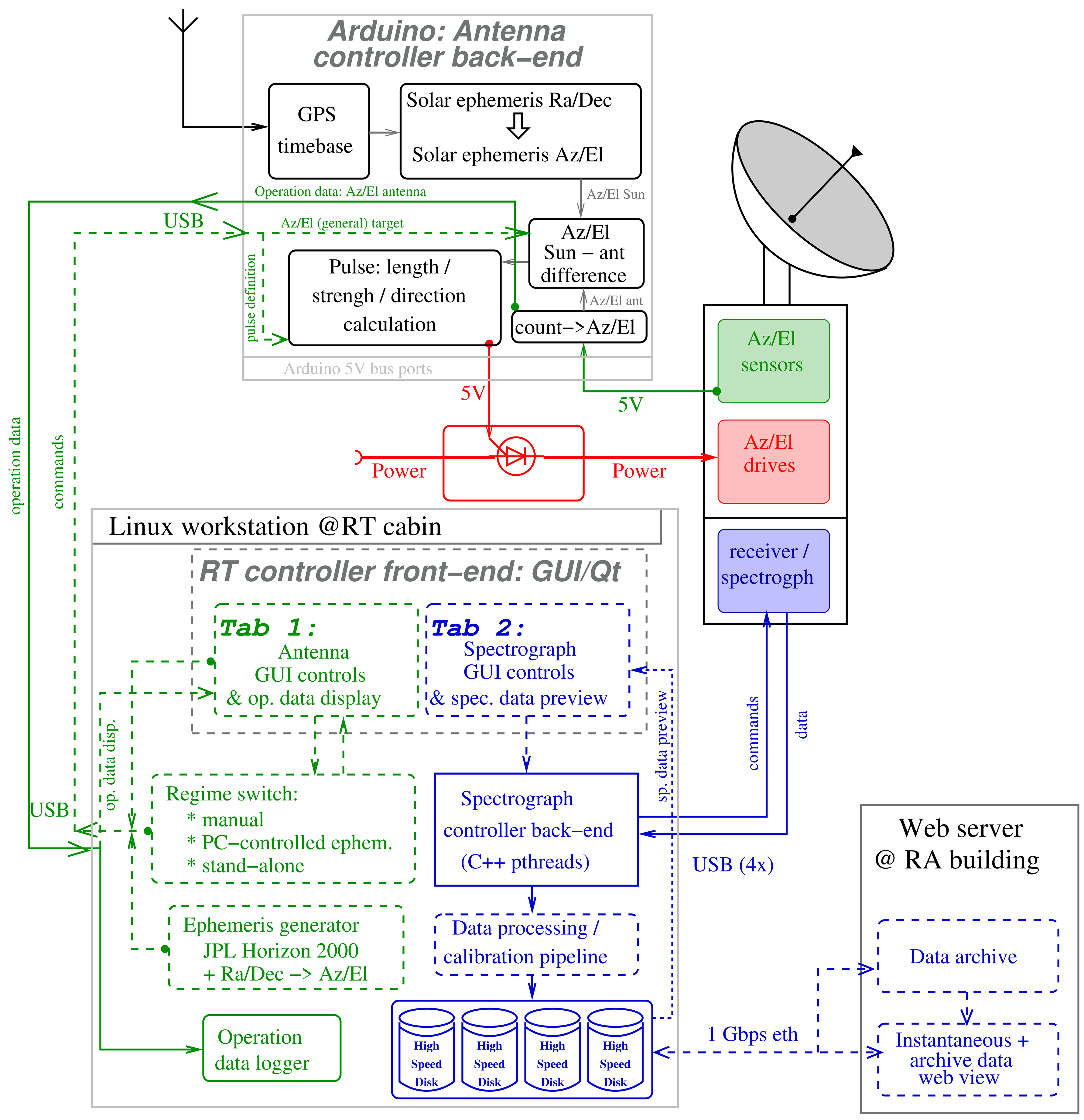

Fig 3: *Block scheme of the RT (antenna + receiver) controller. Modules and communication lines in solid are already implemented, the dashed-line features are yet in development.*

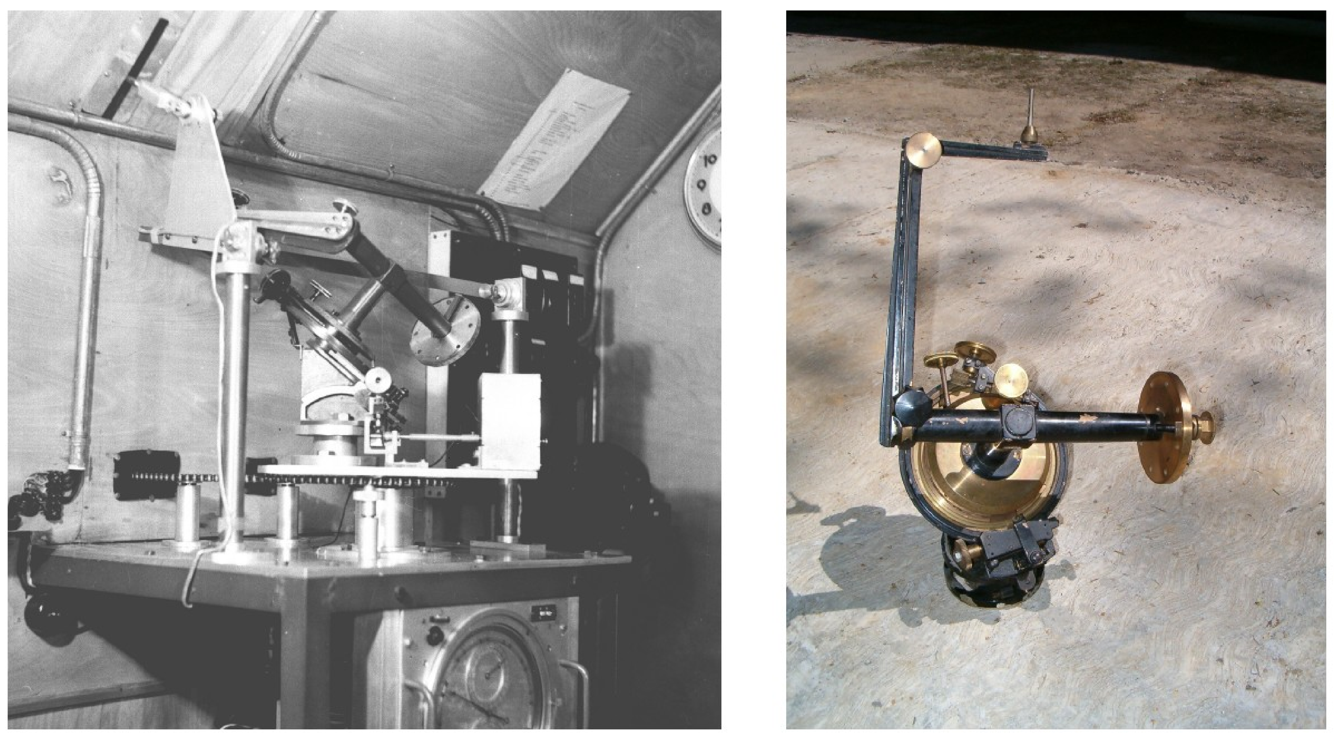

Fig 2: *Paralactic mount – a mechanical converter from Ra/Dec to Az/El motions: In use in the (former) RT1 cabin (left) and dismounted as a museum piece (right).*

3. New implementation

During the reconstruction, the incremental rotation sensors has been replaced by their absolute counterparts. Both 5V-logics interfaces (sensors to PC, and PC to electronic motor switch) were completely newly implemented on the popular programmable *Arduino* platform. This "micro PC" contains also autonomous controller for (i) computing the solar ephemeris in Ra/Dec coordinates, (ii) its instant conversion to Az/El, (iii) comparison of calculated position of the Sun with the antenna direction as measured by the sensors at axes, and (iv) decision/logic on how long electric pulses and in which direction to be sent to the electric drives of the antenna in order to track the Sun with minimum difference. Entire controlling system is connected to the new Linux workstation via the USB port. The workstation at the same moment serves as a primary data storage and main controller for the also recently newly reconstructed radiospectrograph – see *Figs. 3* and *4*, and the talk "*Advances in (not solely solar) radio astronomy*" by M.Bárta for details. So far, as we are in the acceptance test regime, the USB link is used just for logging the positions of the antenna and the Sun for debugging purposes. However, we plan to use it as a standard communication line between controller *GUI front-end*, implemented in Qt/C++ on the Linux workstation, and the *back-end* running at the *Arduino* module (see below in *Future plans*). The block scheme is illustrated in *Fig. 3*.

In addition to getting rid of the risky dependence on the highly obsolete HW, the new system has also other advantages. It allows – in line with the modern trends – for automatic calibration of the antenna-position sensors by searching for the maximum of signal. This is similar to, e.g., ALMA antenna *pointing calibration* performed before each execution block. Furthermore, it checks the elevation of the Sun above the local horizon and ensures soft start/stop of the entire system according to its value (so far we have used hard start/stop managed by the timer-controlled power socket). And last but not least: The new system allows for its easy extension (see *Future plans* below) that will enable tracking of the other celestial bodies (besides the Sun), too. This can be utilized for flux calibration of the receiver or for a prospective night observing programme of the radiotelescopes.

Prototype of the new control system has been recently finished and currently it runs in a test regime in the *RT2* dish. After the test completion (November 2020) it shall be replicated and its copy will drive also the radiotelescope *RT5*.

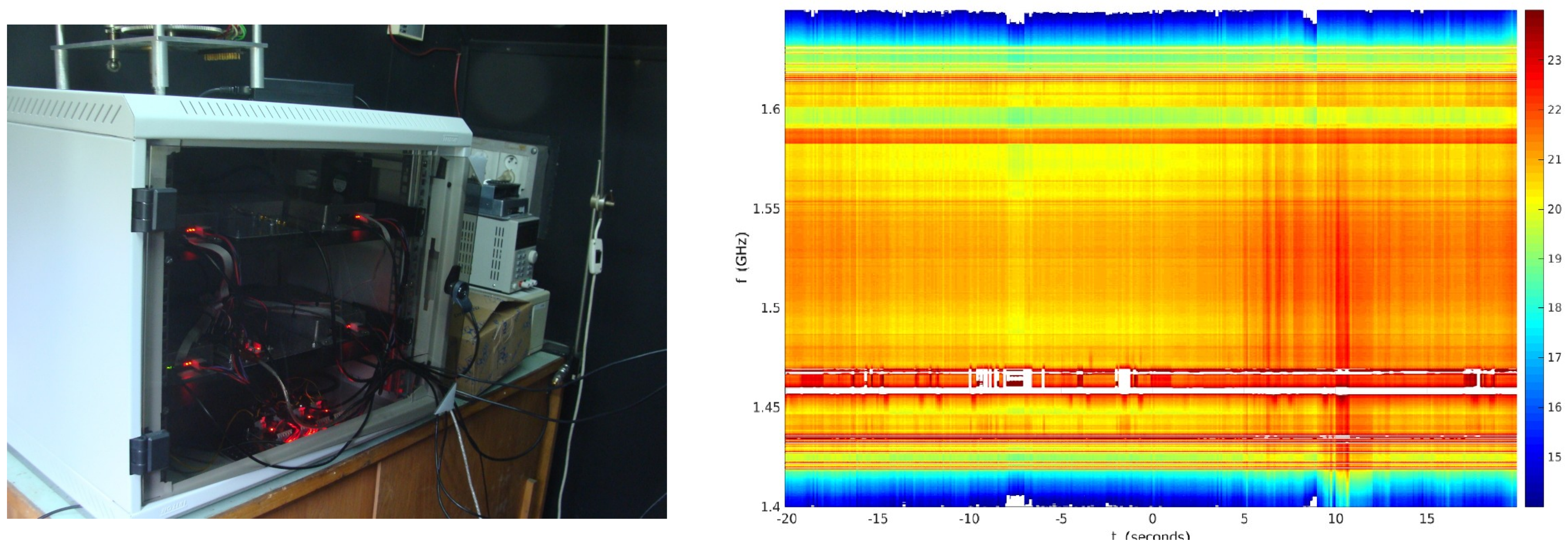

Fig 4: *New 4-channel FFT-based (a.k.a. Software-Defined Radio technology) radio spectrograph operating in the range of 1GHz – 2GHz (with Δf = 1MHz, Δt = 1ms) located for testing operations in the RT2 cabin (left), and a sample radio spectrum received by this instrument on March 20, 2019.*

4. Future plans

First of all, the working prototype – namely peripheries to the *Arduino* controller – will be set up onto a more professional board and embedded into a box. Replicated copy of the system will then be installed into the *RT5* cabin, which shall release one pair of the optical fibers for standard TCP/IP connection with the main radioastronomy building. This is critically important for construction of further observing infrastructure in the nearby area, the *Cherenkov Telescope Array* (CTA). These are the immediate steps to be undertaken yet in Fall 2020.

Implementation of our more general vision, as shown by the dashed lines in *Fig. 3,* will take more time and manpower, but we are aiming at the following status of the *RT5* (*RT2* shall remain as a test-bed for further technical improvements) in 2021:

- GUI controller for the entire radiotelescope with two sub-systems – front-ends to the antenna-motion control and spectrograph data-acquisition & processing software – realised as its tab widgets. To be coded in Qt/C++ and installed at the Linux workstation in the *RT5* cabin; GUI controls will be available also remotely via VNC connection.
- Front-end to antenna controller (@Linux PC) shall enable switching among three regimes of operation of its back-end (@Arduino): (i) Stand-alone regime (the default in case of higher-level functionality failure) – represented by the current version of the Arduino SW, with solar ephemeris calculated directly at the back-end (in reasonably accurate approximation), (ii) Automated regime controlled by the Linux PC – Az/El coordinates (of any object) supplied by the front-end (using exact JPL Horizon 2000 ephemeris and library-based coordinate conversions routines), the antenna-target comparison and motion control being done by the back-end, and (iii) Manual: The electric-current pulses to the motors will be generated by keyboard/mouse events catched by the GUI. Antenna GUI interface shall also display operation data (Az/El of the antenna & target and their difference).
- Front-end to the receiver/spectrograph (@ Linux PC) for easier communication with its already implemented back-end (also @Linux PC) – start, stop, reset of the spectrograph + quick preview of the recently acquired data (*Fig. 4*).
- Automated calibration pipeline plus pre-selection of data to be stored in the science archive (burst detection).
- Science data archive with a user-friendly web interface for the on-demand preview and download of the data.

References

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