TECHNISCHE UNIVERSITÄT BERLIN

Work Package Descriptions

Radio Astronomy Project 2025

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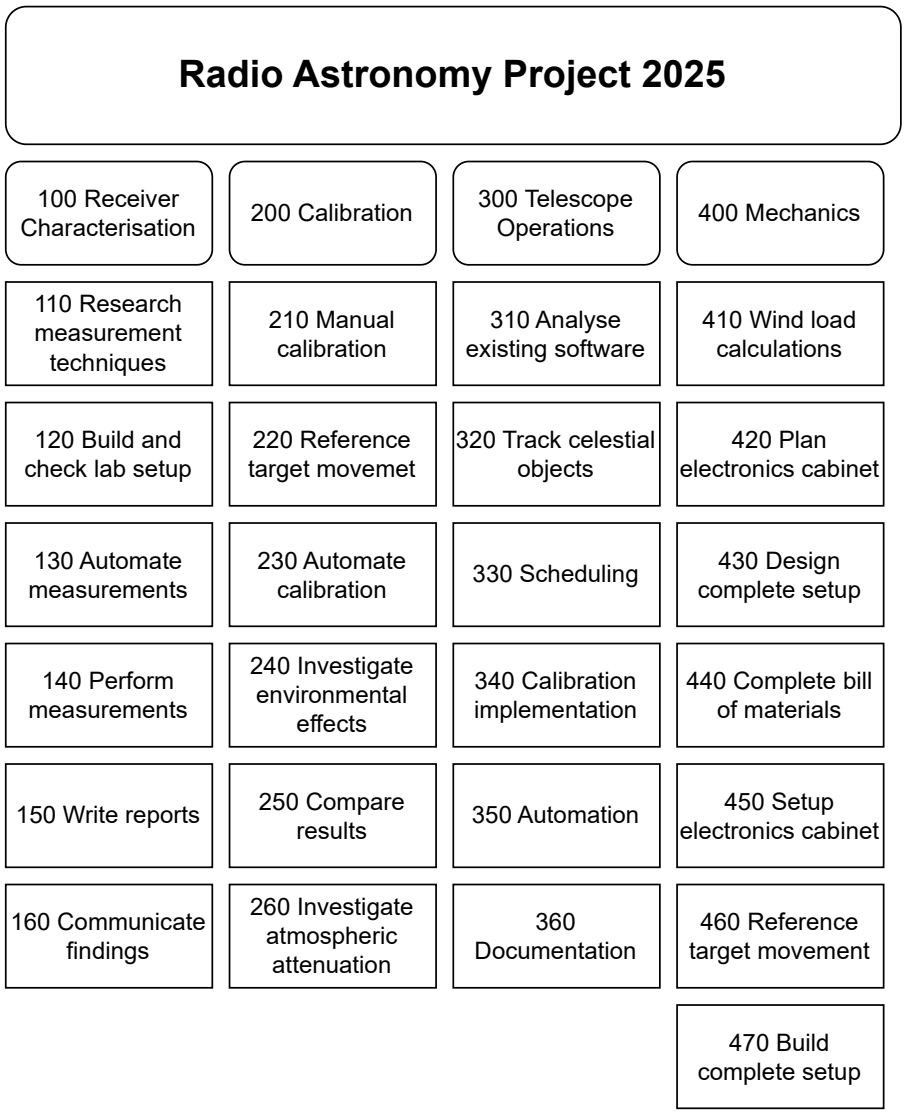
Technical Note

Version History

Version	Date	Changes	Processor
1.0	2025-04-17	document creation	Westerhof, Engler, Prinz

Contents

Work Breakdown Structure



100 Receiver Characterisation

For any radio astronomical measurement, it is important to fully understand the behaviour of the receiver used. The objective of this work package is to investigate the behaviour of a number of Software Defined Radios (SDRs) as well as the Bullseye Low-noise block downconverter-feed (LNBF), and to determine optimal operating parameters for use as radiometers.
For this, you shall measure noise figure, dynamic range and gain drift over time. To carry out quantitative measurements, you have to preform a SDR calibration and map dBFS given by the analog to digital converter to dBm, a quantitative power level.

Input and Dependencies

- Schiavolini et al.: Low-Cost Calibrated Microwave Radiometers for Solar Observation: From Education to Science [1]
- F. Alunni: Misura del Rumore a Microonde Mediante Software Defined Radio: Caratterizzazione Sperimentale, Calibrazione e Applicazioni Radioastronomiche (Microwave Noise Measurement Using Software Defined Radio: Experimental Characterization, Calibration, and Radio Astronomy Applications)[2]
- Lecture of Prof. Alimenti on Noise [3]
- Knowledge base/video collection (ESD, RF/Lab Equipment, ...) [4]
- Software Defined Radios
  - Adalm Pluto
  - LimeSDR mini
  - USRP B200 mini
  - RTL-SDR
- Bullseye LNBF
- Lab Access to be coodinated w/ Advisors
  - Relevant lab equipment will be provided

[1] https://isis.tu-berlin.de/pluginfile.php/3540802/mod_folder/content/0/Schiavolini%20et%20al.%20-%202025%20-%20Low-Cost%20Calibrated%20Microwave%20Radiometers%20for%C2%A0Sola.pdf
[2] https://isis.tu-berlin.de/pluginfile.php/3540802/mod_folder/content/0/Tesi%20laurea%20triennale%20Francesco%20Alunni%20reduced%20EN.pdf
[3] https://isis.tu-berlin.de/mod/folder/view.php?id=2049330
[4] https://git.tu-berlin.de/steinkohl/linksammlung

    - Laser security briefing must be attended for lab access
- The findings will need to be incorporated into the telescope operations software (WP 300)

Subtasks

Assign a responsible team member to each subtask!

- 110 Research measurement techniques: What needs to be measured, what equipment is needed and how is it connected? Which measurements can be completed manually, which need to be automated?
- 120 Build and check lab setup: Perform all measurements manually to verify the validity of the plans.
- 130 Automate measurements: Write scripts in a programming language of your choice to perform automated measurements.
- 140 Perform measurements: Run your scripts and perform manual measurements to collect the necessary data.
- 150 Write reports: Analyse your data and document your findings.
- 160 Communicate findings to telescope operations (WP 300) and calibration (WP 200) and assist in integration.

Output

- Technical report detailing methodology and results of the SDR Characterisation for each device (see inputs):
    - SDR calibration (dBFS to dBm mapping), with signal generator and noise source
    - Dynamic range vs. gain setting
    - Ideal integration time constant
    - Gain drift over minutes/hours
    - Noise figure
- Technical report detailing methodology and results of the LNB Characterisation for each device (see inputs):
    - Dynamic range
    - Gain drift over minutes/hours
    - Noise figure

Milestones

1. Familiarisation with theory of measurements and lab equipment (week 6)
2. Test setup completed and automated (Week 7)
3. First quantitative measurements completed and documented (week 8: CDR)
4. All measurements complete (week 13)

Supervisors/Advisors

– Camille Westerhof (Advisor)

– Prof. Maurizio Burla (Supervisor)

Assigned Students

Enter student names here and highlight the WP coordinator in bold!

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200 Calibration

The objective of this work package is to assign physical meaning to the values measured by the Softare Defined Radio (SDR) through a calibration procedure. The neccessary steps to be taken are:

- Manual Calibration
- Suitable construction for reference target
- Automated calibration procedure
- Understand and process usable data

The manual calibration consists of a reference target (RAM: Radio Absorbing Material) being moved in front of the feed and then removing it after calibration. This is done while the antenna is pointed at a "cold sky". The integration time needed for the calibration can be discussed with WP 100.

The automation of this will take place by working with WP 400 to design a suitable linkage for moving the reference target. The mechanical means to automate this (servo/motor, linkage/arm) shall be designed and included in the construction of the telescope.

Simulations of the noise temperature for specific conditions (location, humidity, temperature, cloud coverage etc..) will be carried out and compared to data requested from the university of Perugia. Additionally a comparision with the data aquired by manually pointing the feed at the sun after a successful calibration, will be carried out to check the accuracy of the measurements.

The calibration process follows that carried out by F. Alumni, the paper included in section 200.

Input and Dependencies

- Schiavolini et al.: Low-Cost Calibrated Microwave Radiometers for Solar Observation: From Education to Science [1]
- F. Alunni: Misura del Rumore a Microonde Mediante Software Defined Radio: Caratterizzazione Sperimentale, Calibrazione e Applicazioni Radioastronomiche (Microwave Noise

[1] https://isis.tu-berlin.de/pluginfile.php/3540802/mod_folder/content/0/Schiavolini%20et%20al.%20-%202025%20-%20Low-Cost%20Calibrated%20Microwave%20Radiometers%20for%C2%A0Sola.pdf

Measurement Using Software Defined Radio: Experimental Characterization, Calibration, and Radio Astronomy Applications)[2]

- Software Defined Radio (Adalm Pluto)
- GNURadio[3] & GNURadio Companion
- Radio Absorber Material: RAM (Black Body)
- Information about sky temperature can be requested from Perugia via Advisors
- KURT: Kiel's University Radio Telescope: Simulation software [4]
- The results will need to be incorporated into the operations software (WP 300)

Subtasks

Assign a responsible team member to each subtask!

- 210 Manual radiometer calibration: To turn the received noise into a temperature measurement, the receiver needs to be calibrated. An example of this can be seen in the paper from F. Alumni
- 220 Black body movement: To allow periodic recalibration, the black body used in the calibration process needs to be mechanically inserted into and removed from the signal path.
- 230 Automated radiometer calibration: The recalibration should be automatically performed whenever needed, without operator involvement.
- 240 Environmental effects: Analyse how environmental factors influence the measurements and how to mitigate them.
- 250 Result comparision: The results from the calibration should be compared to requested data from University of Perugia and analysed for validity.
- 260 Atmospheric attenuation: Investigate the atmospheric attenuation relative to local conditions (humidity/temperature/location/elevation of celestial object), compare these values to requested data from university of Perugia / literature sources.

[2] https://isis.tu-berlin.de/pluginfile.php/3540802/mod_folder/content/0/Tesi%20laurea%20triennale%20Francesco%20Alunni%20reduced%20EN.pdf
[3] https://www.gnuradio.org/
[4] https://portia.astrophysik.uni-kiel.de/~koeppen/jsindex.html

Output

- Git Repository containing the code to perform automated calibration
- Documentation for the above, including
  - Description of the process and explanation of the rationale
  - Compilation/installation instructions
  - Usage instructions
  - Example output, examining the achieved accuracy

Milestones

1. Manual calibration completed (Week 9): After calibration, the software is able to output a plot of the measured temperature. This shall be demonstrated using various objects of known temperature.
2. Automated calibration completed (Week 12): The calibration can be scheduled and performed automatically, without operator involvement.

Supervisors/Advisors

- Anna Engler (Advisor)
- Prof. Maurizio Burla (Supervisor)

Assigned Students

Enter student names here and highlight the WP coordinator in bold!

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300 Telescope Operations

This work package is centered around data aquisition and analysis. The end goal is to develop an automated workflow for performing radioastronomy observations and processing the received signals into easily readable data (e.g. graphs). The software package should be able to

- Automatically track celestial objects such as the sun, moon, galactic center and/or geostationary satellite belt (compensating for the earths' rotation)
- Process aquired data into a format from which conclusions can be drawn
- Integrate automatic calibration procedure (Consult WP 200): Moving a reference target used for calibration in and out of the "field of view" of the antenna
- Warn about, avoid and/or compensate for interfering signals originating from noisy sources such as geostationary satellites

The data aquisition software (tracking and scanning) shall run unattendedly on a Raspberry Pi running Linux, and control the antenna rotation, reference target and the SDR. It shall perform initial receiver calibration, save the raw data in a suitable and documented file format and recalibrate the receiver as needed. (Calibration needs should be discussed with WP 200)

The data processing software shall run on any current Linux computer. The aquired raw data file from a measurement shall be downloaded and processed into a suitable output file for the observation, e.g. an image file.

Interfering signals from satellites should be compensated or avoided completely, and/or the operator must be warned of interfering/abnormal signals. When analysing the aquired data, local conditions (wind, temperature, atmospheric noise) should be considered, the atmospheric attenuation should be taken into account and can be analysed through simulations [1].

Input and Dependencies

- Schiavolini et al.: Low-Cost Calibrated Microwave Radiometers for Solar Observation: From Education to Science [2]
- F. Alunni: Misura del Rumore a Microonde Mediante Software Defined Radio: Caratterizzazione Sperimentale, Calibrazione e Applicazioni Radioastronomiche (Microwave Noise

[1] https://portia.astrophysik.uni-kiel.de/~koeppen/jsindex.html
[2] https://isis.tu-berlin.de/pluginfile.php/3540802/mod_folder/content/0/Schiavolini%20et%20al.%20-%202025%20-%20Low-Cost%20Calibrated%20Microwave%20Radiometers%20for%C2%A0Sola.pdf

Measurement Using Software Defined Radio: Experimental Characterization, Calibration, and Radio Astronomy Applications) [3]

- `gnuradio`[4]: Flowgraph based SDR and data processing software
- SatNOGS Rotator v3 [5]
- SatNOGS Rotator controller [6]
- `rotctld` / `hamlib`[7]: A software library for controlling devices like rotators and radios via a common (TCP-)interface
- A running setup consisting of: Small Parabolic Dish, Bias-T, Bullseye LNB, Adalm Pluto
- Report template[8]

Subtasks

Assign a responsible team member to each subtask!

- 310 Analyse existing software: Understand and test the state of the software from RA24. Perform a scan of a selected portion of the sky and convert the data into a suitable file.
- 320 Tracking of celestial objects: Implement the necessary features to track celestial objects.
- 330 Scheduling: Implement automated observations at a predetermined time.
- 340 Calibration implementation: Work with WP 200 to integrate calibration procedures with the reference target (black body).
- 350 Automation: Perform automated measurements including the tracking of an object and the processing of the aquired data to demonstrate the capabilities of the telescope.
- 360 Documentation: Write a guide to performing measurements using the telescope.

[3] https://isis.tu-berlin.de/pluginfile.php/3540802/mod_folder/content/0/Tesi%20laurea%20triennale%20Francesco%20Alunni%20reduced%20EN.pdf
[4] https://www.gnuradio.org/
[5] https://wiki.satnogs.org/SatNOGS_Rotator_v3
[6] SatCom20 final report, section 3.3 https://isis.tu-berlin.de/pluginfile.php/3540802/mod_folder/content/0/SatCom20_Final_Report.pdf
[7] https://github.com/Hamlib/Hamlib
[8] https://git.tu-berlin.de/beegnd/templates

Output

- Git Repository containing the code of the operations software
- Documentation for the above, including
  - Description of the process and explanation of the rationale
  - Compilation/installation instructions
  - Processed data files
  - Usage Instructions

Milestones

1. Manual measurements (week 8): Adapt tracking and scanning software to given setup and deliver a quantitative sky scan and prove implementation of tracking.
2. Schedule and carry out a "complete" measurement (week 12): This includes automatic tracking, scanning and processing of data and compensation for atmospheric attenuation and interfering signals.

Supervisors/Advisors

- Anna Engler (Advisor)
- Prof. Maurizio Burla (Supervisor)

Assigned Students

Enter student names here and highlight the WP coordinator in bold!

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400 Mechanical

The objective of this work package is to construct a radio telescope for observations of strong extraterrestrial radio sources. The tripod/base, rotator, dish, software defined radio and telescope control computer will be provided[1]. These shall be assembled together. Where necessary required interfaces (flanges, adapters, cables etc.) shall be designed, manufactured and/or purchased. Cooperation with the HFT Workshop is encouraged, but should only be done after discussions with the tutors.

The telescope must be designed to withstand permanent outdoor use. Wind loads shall be calculated or researched and considered during assembly, they can also be simulated using open access software. Appropriate weatherproofing (rain, solar heating, wind ...) of the electronics must be carried out, and components must be easily accessible to allow replacement and maintenance. This may be done through use of an electrical cabinet, whose design can be based on those of the SatCom 22 and 23 projects.

The reference target built by WP 200 „ Calibration“ needs to be considered in the construction. This consists of a linkage and servo motor that can be used to move the reference target (radio absorbing foam) in and out of the field of view of the antenna after specified periods of time.

Input and Dependencies

- Mast base and mast segments
- SPID Big RAS Antenna Rotator and Rot2Prog controller
- Raspberry Pi as control computer
- 1.5 m parabolic dish
- Documentation for the above, where applicable
- Consult with HFT workshop for construction feedback and manufacturing
- Construction location: Roof of the HFT building
- Reports from SatCom 22 and 23 and 24: BOMs, Drawings for the Electronics Compartment

[1] The advisors will select these parts and take care of purchasing, if necessary

– Satcom 22 Ground station handbook, especially section 2.2 [2]

– An interface for control of the reference target shall be provided to WP 200“Calibration”

– Report template[3]

Subtasks

Assign a responsible team member to each subtask!

– 410 Wind load: Calculate and simulate max wind load and ensure the setup is planned accordingly

– 420 Plan electrical cabinet: create a dependency graph of all electronic parts and organise spacing

– 430 Design complete setup: Design and plan the completed setup including the mast, rotor, dish, and electrical cabinet

– 440 Complete BOM (Bill of Materials): Finalise a list of all materials to be purchased based on the design of the setup

– 450 Set up electronics cabinet: Assemble electronical cabinet according to approved plans

– 460 Reference target movement: Communicate with WP 200 "Calibration" to build setup for moving reference target in and out of field of view of antenna at specified times

– 470 Mechanical setup: Integrate and assemble all components into one working system

Output

– Constructed and operational radiotelescope (excluding receiver) at HFT building roof

– Documentation for the above, including
  – Description of the hardware and it’s technical parameters
  – Bill of Materials and description of the construction process
  – Usage Instructions

[2] https://isis.tu-berlin.de/pluginfile.php/3540802/mod_folder/content/0/SatCom22_Ground_Station_Handbook.pdf
[3] https://git.tu-berlin.de/beegnd/templates

Milestones

1. Procurement underway (week 9): Finalised dependency graph for all electronic and mechanical components, finalised BOM (Bill of Materials).
2. Mechanical setup complete (week 12): The mast, rotator, dish and electrical cabinet are set up and working.

Supervisors/Advisors

– Camille Westerhof (Advisor)

– Prof. Maurizio Burla (Supervisor)

Assigned Students

Enter student names here and highlight the WP coordinator in bold!

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