Radio Astronomy Project 2024

Work Package 200
Receiver Design & Temperature Compensation

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Technical Note

Version History

Version	Date	Changes	Processor
0.1	2024-07-01	Initial Documentation	Steinkohl, Speicher, Mohr, Jurk
1.0	2024-08-22	Final Documentation	Steinkohl, Speicher, Mohr, Jurk

Disclaimer

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List of Abbreviations

AfuTUB Amateurfunkgruppe der TU Berlin

ADC Analog Digital Converter

AR Acceptance Review

BOM Bill of Materials

BEECON Berlin Experimental and Educational Beacon

BEEGND Berlin Experimental and Educational Ground Station

BEESAT Berlin Experimental and Educational Satellite

COTS commercial off-the-shelf

DLR Deutsches Zentrum für Luft- und Raumfahrt

ESD Electrostatic Discharge

GNSS Global Navigation Satellite Systems

ILR Institut für Luft- und Raumfahrt

LSF Libre Space Foundation

LNA Low Noise Amplifier

LNBF Low Noise Block with Feedhorn

LO Local Oscillator

IF Intermediate Frequency

PCB Printed Circuit Board

PoE Power over Ethernet

SatNOGS Satellite Networked Open Ground Station

SDR Software Defined Radio

SNR Signal to Noise Ratio

RA Radio Astronomy

RF Radio Frequency

RFT Raumfahrttechnik

TUB Technische Universität Berlin

UHF Ultra High Frequency

VHF Very High Frequency

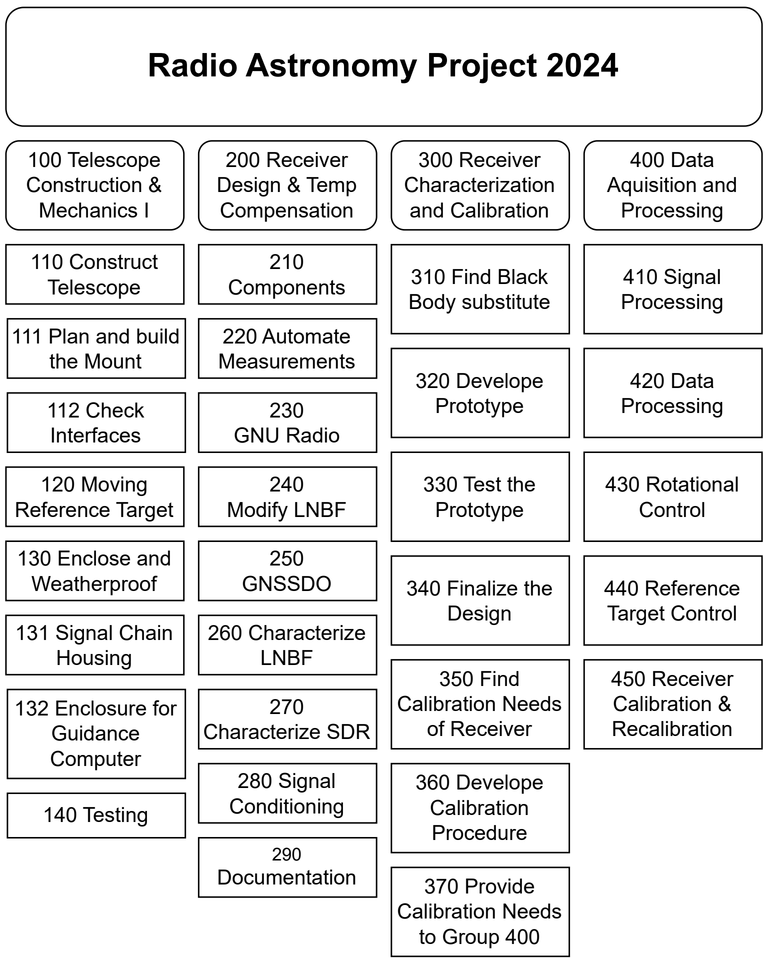
WPD Work Package Description

WP Work Package

Contents

1 Radio Astronomy 2024

The Radio Astronomy Project 2024 was carried out by groups of students, which had their own work packages. The goal of the project was, to build a fully functional, software defined radio (SDR) based radio telescope for X band at about 10 GHz. Group WP100 was responsible for the mechanical engineering and the overall system integration. WP300 was in charge to develop a receiver characterization and calibration routine, whereas WP400 was responsible for the overall data acquisition and processing. We, WP200, the authors of this document, where liable for the design as well as the temperature compensation for the whole receiver. The Work Breakdown Structure provides a more detailed overview of the individual subtasks. The output of work package 290 hereby represents this document.



2 WP200 Receiver Design & Temperature Compensation

The goal of this work package was to construct and characterize a total power receiver based on commercially available components from satellite TV or amateur radio applications and software defined radio. This included the physical construction, as well as measuring the temperature stability of the receiver and compensating for any instability if necessary. It also included the design or selection of an IF amplifier, if needed.

Therby, the team of WP200 consists of the following students:

- Dennis Jurk (Team Coordinator)
- Alexander Mohr
- Sara Speicher
- Felix Steinkohl

2.1 WP210 Components

Work package 210 focuses on system design and the associated component selection. In order to make qualified decisions, we researched the fundamentals of receiver design and analysed the requirements for our system design.

2.1.1 Receiver Basics

A receiver in a radio astronomy setup typically is designed to capture and process weak signals from celestial sources. The primary function of the receiver is to amplify the incoming radio frequency (RF) signals, in our case in the X-band (around 10 GHz), and convert them to a lower frequency for further analysis.

At X-band frequencies, the signals received are often very faint, necessitating a highly sensitive front-end that includes a low-noise amplifier (LNA). The LNA is crucial for minimizing the noise figure of the receiver, thereby preserving the weak astronomical signals. After initial amplification, the high-frequency signal is typically down converted to an intermediate frequency (IF) or directly to baseband. This is achieved through mixing the incoming signal with a local oscillator (LO) signal. Thereby, the choice of LO frequency is critical to ensure that the resulting IF is suitable for further processing and that image frequencies are adequately suppressed. Further, a low noise block with integrated feed horn (LNBF) combines all those stages into one device and are usually better in performance than individual components.

The receiver is designed to measure the total power of the incoming signal, such as the black body radiation from our sun. Thereby, the output power is integrated over time to improve the signal-to-noise ratio (SNR), making it possible to detect even extremely weak signals.

In a traditional total power receiver, the IF is then measured with a power detector, as shown in figure 2.1.

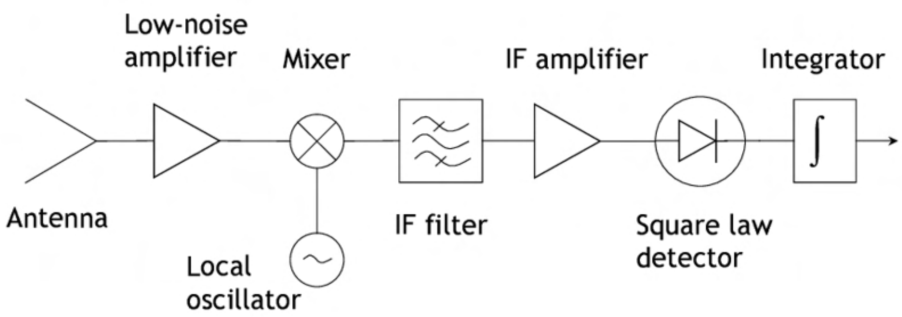


Figure 2.1: Block Diagram of a non-SDR-based Total Power Receiver

In our case, an SDR-based receiver design was demanded. In this case, the IF signal is digitized using high-speed analog-to-digital converters (ADCs). The digital signal is then processed using software-defined algorithms to extract the desired information. This approach provides flexibility in filtering, demodulation, and data analysis, allowing for real-time adjustments and enhancements.

2.1.2 Design Architecture

For the system design, the following focus areas have to be considered carefully:

- **High Sensitivity:** The Receiver needs a high gain to be able to detect very weak signals. Black body radiation is orders of magnitude weaker then most signals dealt with in RF communication.
- **Temperature Stability:** LNAs are highly susceptible to gain drifts caused by altering temperature. To overcome this issue, the behavior of the devices have to be precisely known or the components have to be kept at a certain temperature.
- **Low Noise Figure:** System noise has to be as small as possible, so that the measured signal remains dominant with minimal degradation.
- **Noise Calibration:** Noise intrinsically generated from our Receiver-System has to be measured and accounted for. Since the noise is dependent on multiple factors, especially temperature, the calibration has to be done for multiple temperature settings.
- **Stable Local Oscillator:** Keeping the mixers of the LNBF and SDR locked, allows to do a very fine noise calibration in regard to frequency resolution, since no LOs are drifting apart from each other. A frequency and phase locked receiver also helps in foresight to Radio Interferometry.
- **Shielding:** Since the receiver shall be mounted on a roof of the TUB, it is likely that nearby emitted large signals might couple into the receiver. To block noise from outside sources has as good as possible, a metal shielding for the receiver is needed.
- **Wide Dynamic Range:** The Amplitude range of the receiver should be as large as possible. When highly amplifying small signals from black bodies, emissions from other RF source might look hugh in comparison. This is why a high dynamic range is needed, to avoid LNA saturation and thereby degrading the linearity in frequencies nearby.
- **Large Signal Resistant:** System has to withstand strong signals (satellites e.g.) without damage.
- **Low Cost:** Goal of the project is to develop a cheap total power receiver.

Figure 2.2 shows the design we came up with. Since we only have one semester to realize our design, we decided to only use commercial out the shelf (COTS) components. The system comprises of a LNBF, a SDR, a GNSS disciplined oscillator as an external reference clock, as well as a signal condition block in the IF stage. The signal conditioning will be discussed further in section 2.7.

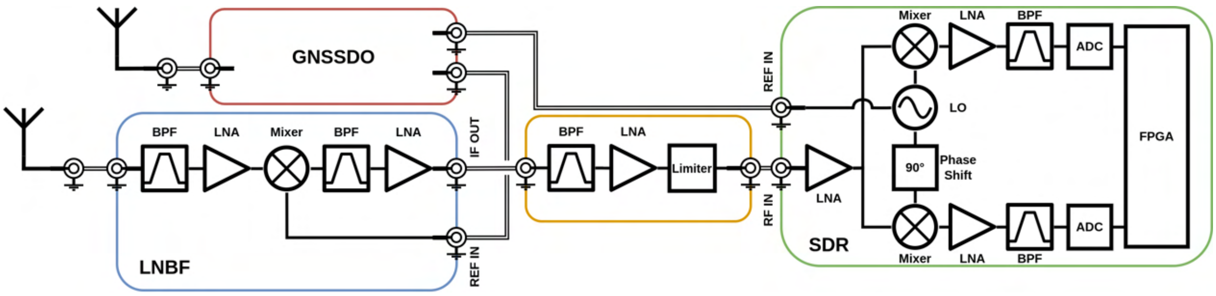


Figure 2.2: Block Diagram of our SDR-based Total Power Receiver Design

2.1.3 Choice of Components

In this sub section we discuss the reasoning behind the selection of the individual components and devices.

2.1.3.1 LNBF

Regarding LNBFs, the market is split into two sections. One section is the consumer market LNBFs as used for receiving satellite television and on the other side, there is the industrial and research market. While industrial LNBFs, like the Swedish Microwave Ku LNB, are superior in quality and longevity, they are very expensive and cost thousands of euros. Consumer LNBFs are extremely cheap in comparison and sometimes deliver similar in performance.[1]

Device	**Swedish Microwave Ku LNB**	**Bullseye BE01**
Input Frequency	10.7-12.75 GHz	10.5 - 12.75 GHz
Output Frequency	950 - 1950 MHZ / 950 - 2000 MHz	739 - 1950 MHz / 1100 - 2150 MHz
TCXO	2.5 ppm	2 ppm
Ext. LO In	Yes	No (Yes)
Price	1800€	20€
Lead Time	8 weeks	few days

Table 1: Comparison of LNB(F)s Hardware Specifications

The chosen Bullseye BE01, shown in figure 2.3, is also well researched and understood within the amateur radio community, as shown in the detailed analysis by PABR Technologies.[2] We also found an online guide offering information on how to modify the LO of the device, so that it supports an external reference as an clock source as later shown in section 2.4.

[1] https://www.pabr.org/radio/lnblineup/lnblineup.en.html
[2] https://www.pabr.org/radio/otherlnb/otherlnb.en.html

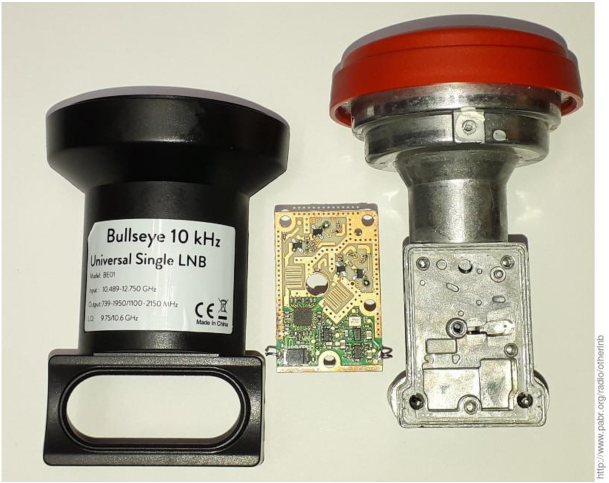


Figure 2.3: Disassembled Bullseye BE01 LNBF

2.1.3.2 SDR

The following table 2 lists the most commonly used SDRs, which also have been evaluated by the Libre Space Foundation (LSF)[3] within their comprehensive SDR evaluation.[4]

Device	**USRP B2X0**	**ADALM Pluto**	**HackRF One**	**RTL-SDR**
RF Range	70 MHz to 6 GHz	325 MHz to 3.8/6 GHz	1 MHz to 6 GHz	500 kHz to 1.766 GHz
Bandwidth	56 MHz	20 MHz	20 MHz	2.4 MHz
ADC	12 bits	12 bits	8 bits	8 bits
FPGA	Xilinx Spartan-6	Xilinx Zynq Z-7010	None	None
Duplex	Full	Full	Half	Rx Only
TCXO	1 ppm	25 ppm	1 ppm	1 ppm
Ref In	Yes	Yes	Yes	No
Price	1500-3000€	250€	300€	35€

Table 2: Comparison of SDR Hardware Specifications

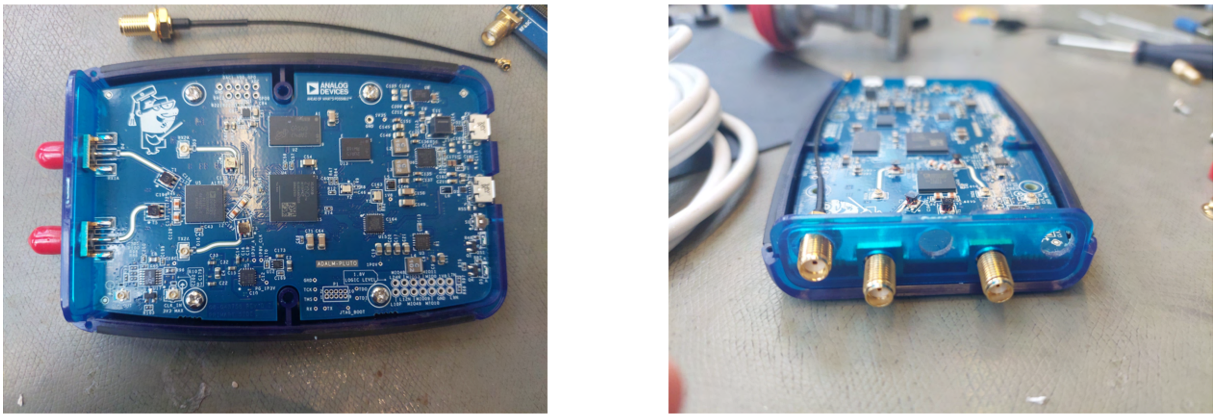
According to the data from the LFS SDR evaluation as shown in table 3, the Adalm Pluto performed even slightly better in the noise figure measurement within 1.28 GHz and 2.25 GHz, compared to all other tested SDRs. This matches with the IF of the chosen Bullseye BE01 LNBF, with mixes the RF down to 739 MHz to 2.15 GHz.

This is why we chose the Adam Pluto, and also because it can be easily modified to support a reference clock signal input due to the already built-in U.FL connectors on the PCB as shown in figure 2.4. Furthermore, it is not too expensive and has a good 12 bit ADC resolution.

[3]https://libre.space/
[4]https://gitlab.com/librespacefoundation/sdrmakerspace/sdreval/

Device	145 MHz	437 MHz	1.28 GHz	2.25 GHz	2.425 GHz	5.83 GHz
RTL-SDR	5.8	5.4	11.9	-	-	-
Airspy Mini	7.1	7.4	10.7	-	-	-
SDRplay RSPduo	2.1	2.5	5.4	-	-	-
LimeSDR Mini	11.1	13.8	15.6	-	-	-
BladeRF 2.0 micro	5.0	4.9	7.4	9.0	9.5	15.8
USRP B210	5.5	4.4	5.7	4.8	6.3	9.6
PlutoSDR	6.2	6.1	4.1	4.7	5.0	9.3

Table 3: Lowest measured Noise Figure (dB) across Various Frequencies according to LFS SDR Evaluation



(a) Pluto SDR (PCB with U.FL Connectors)

(b) Pluto SDR with added Clock input

Figure 2.4: Comparison of Pluto SDR and Pluto SDR with added Clock input

2.1.3.3 GNSSDO

For suppling an external clock reference for the LNBF and the SDR, we chose a GNSS disciplined oscillator (GNSSDO). This system locks its internal oscillator to the clocks within the Global Navigation Satellite Systems (GNSS), which them selfs typically have atomic standards on board. A subcategory of GNSSDOs are GPSDOs which lock to the US american GPS navigation system.

We chose the Leo Bodnar GPSDO[5] (Fig. 2.5) because of its two outputs, which are synced to its LO, but separately frequency adjustable. The two outputs are needed, since the SDR requires an LO of 40 MHz and the LNBF will need a 25 MHz clock after its modification. Furthermore, the device has sufficient frequency range and is widely used in amateur radio setups without issues. The internal LO is only a TCXO though, if we would have to buy the GNSSDO again, we would chose the DXPatrol GPSDO V3[6] with an builtin OCXO, which was released during

[5] https://www.leobodnar.com/shop/index.php?main_page=product_info&cPath=107&products_id=234
[6] https://www.wimo.com/de/dxpatrol-gpsdo-v3

Device	**Stanford Research FS740**	**Leo Bodnar Dual GPSDO**	**DXPatrol GPSDO V3**
Output Frequency	10 MHz	450 Hz - 800 MHz	350 kHz - 350 MHz
Number Outputs	1	2	4
LO Type	OCXO	TCXO	OCXO
Supported GNSS	GPS, Galileo	GPS	GPS, Galileo
Price	>4800$	246€	199€
Lead Time	8 weeks	few days	released Aug 2024

Table 4: Comparison of GNSSDO's Hardware Specifications

Figure 2.5: Leo Bodnar Dual GPSDO Precision Reference Clock

the project.

2.1.3.4 Enclosure

We have communicated with the group of WP100 regarding the design and specifications of the receiver enclosure. Together we agreed on the need for a robust metal housing to ensure adequate shielding from electromagnetic interference, which is critical for maintaining the integrity of the weak signals processed by our receiver. Additionally, we requested that the enclosure be equipped with thermal insulation. This is essential to maintain a stable internal temperature, minimizing thermal drift and ensuring consistent performance of the sensitive components within the receiver. Further this enables us to use the temperature sensors on the SDR to judge the overall receiver temperature, with can be used to select the correct noise calibration data. In worst case, this box then also could be heated to provide a "oven controlled" receiver setup. The WP100 group has acknowledged these requirements and is incorporating them into their design plans.

2.1.3.5 Bill of Materials

The selection of all components resulted in the following BOM:

Pos	Description	Priority	Supplier	Partnumber	Quantity	Unit Price	Total Costs	Notes
1	Ettus USRP B210 SDR	optional	Mouser	424-471-043	1	2.090,64 €	2.090,64 €	
2	Adalm Pluto SDR	required	Mouser	584-ADALM-PLUTO	1	220,47 €	220,47 €	
3	Leo Bodnar 2-Port GPSDO	required	FUNKAMATEUR	GPSDO-2-Port	1	285,00 €	285,00 €	
4	Bullseye BE01 LNBF	required	elektor	20684	2	24,95 €	49,90 €	
5	Bias Tee	required	Mini-Circuits	ZFBT-282-1.5A+	1	75,83 €	75,83 €	
6	75Ohm to 50Ohm Impedance Transformer	required	Mini-Circuits	Z7550R-FMSF+	2	88,48 €	176,96 €	
7	LNA Ultra low NF (0.38dB), 15dB Gain	optional	Mini-Circuits	ZX60-P33ULN+	1	145,41 €	145,41 €	
8	LNA Ultra low NF (0.36dB), 27dB Gain	optional	Mini-Circuits	ZKL-33ULN-S+	1	208,66 €	208,66 €	
9	Right Angle SMA Adapter	optional	Mini-Circuits	SFR-SM50+	2	35,35 €	70,70 €	
10	Semi-Rigid Hand-Flex Coax Cable 1,5m	required	Mini-Circuits	141-60SM+	3	41,97 €	125,91 €	
11	Coax Precision Test Cable 1m	optional	Mini-Circuits	CBL-1M-SMSM+	2	109,99 €	219,98 €	For meausurements in thermal chamber
12	Band Pass Filter 1000-1200MHz	optional	Mini-Circuits	ZX75BP-1100-S+	1	75,83 €	75,83 €	
13	Band Pass Filter 1215-1285MHz	optional	Mini-Circuits	ZX75BP-1250-S+	1	101,13 €	101,13 €	
14	U.FL to SMA Pigtail	required	Mouser	712-CSH-SGFB100-UFFR	4	5,43 €	21,72 €	Needed for injecting reference signal into Pluto
15	Programmable Powersupply	optional	Reichelt	KD3005P	1	69,00 €	69,00 €	For powering, switching and monitoring LNBF
16	RF Adapter N Male to SMA Female	required	Mini-Circuits	NM-SF50+	3	29,03 €	87,09 €	
17	RF Adapter SMA Male to SMA Male	required	Mini-Circuits	SM-SM50+	5	7,52 €	37,60 €	
18	RF Adapter SMA Male to BNC Female	required	Mini-Circuits	SM-BF50+	2	6,90 €	13,80 €	
19	BNC Adapter 4mm	required	Reichelt	GE 860	3	1,95 €	5,85 €	
20	Measuring lead 2m black	required	Reichelt	PJP 2217/200SW	2	13,43 €	26,86 €	
21	Measuring lead 2m red	required	Reichelt	PJP 2217/200R	2	13,81 €	27,62 €	
22	SMA Limiter	required	Mini-Circuits	VLM-73-1W-S+	1	65,71 €	65,71 €	Protection for Spectrumanalyzer (SDR)
23	DC Block N	required	Mini-Circuits	BLK-6-N+	1	30,29 €	30,29 €	Protection for Spectrumanalyzer
24	DC Block SMA	required	Mini-Circuits	BLK-18-S+	1	27,76 €	27,76 €	Protection for SDR
25					0	0,00 €	0,00 €	
26					0	0,00 €	0,00 €	
27					0	0,00 €	0,00 €	
28					0	0,00 €	0,00 €	
29					0	0,00 €	0,00 €	
30					0	0,00 €	0,00 €	
31					0	0,00 €	0,00 €	
32					0	0,00 €	0,00 €	
33					0	0,00 €	0,00 €	
34					0	0,00 €	0,00 €	
35					0	0,00 €	0,00 €	
36					0	0,00 €	0,00 €	
						Total required	1.278,37 €	
						Total optional	2.981,35 €	
						Total	4.259,72 €	

Figure 2.6: Bill of Materials

2.2 WP220 Automated Measurements

An automated test setup is needed in order to precisely control the thermal chamber, the voltage of the LNBF, and the parameters of the SDR for quantitative measurements. This ensures accurate management of these variables, leading to reliable and repeatable measurement results. Additionally, it enhances efficiency, allowing for the collection and analysis of large data sets while minimizing human error.

2.2.1 WP221 Thermal Chamber

For our measurements, we could use the thermal chamber of the BEECON project at the RFT. Figure 2.7 shows the Vötschtechnik VT4002 climate chamber, which can be controlled via a python script.[7]

Figure 2.7: Thermal Chamber Vötschtechnik VT4002

The provided code is designed to control and interact with a Vötschtechnik climate chamber using a network connection. The main functionalities offered by the code include setting and getting temperature values, querying the status of the chamber, and controlling certain features like a dryer or compressed air system. However, our specific climate chamber (VT4002) only supports temperature settings ranging from -40°C to 130°C and does not have features like a dryer or compressed air, so do not use those options.

[7] https://github.com/SengerM/VotschTechnik-climate-chamber-Python

2.2.2 WP222 Spectrum Measurement

We intended to use a Siglent SSA3032X-R Spectrumanalyzer for characterizing the gain and the noise floor of the Bullseye LNBF. Therefore we wanted to use the channel power measurement function, which can be arbitrarily configured via SCPI. This way we could have measured the total power within the LNBF spectrum in eg. 1kHz steps.

However, due to the hugh delay in the delivery of the noise source, which would have been necessary to calibrate the spectrumanalyzer, we decided to skip WP222 and to do a characterization of the whole receiver setup instead. The scripts which have been written during the initial testing can be found in our repository.[8]

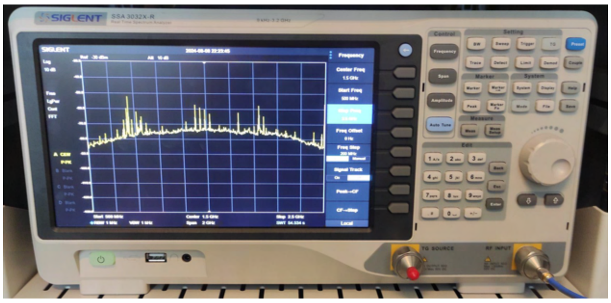


Figure 2.8: Siglent SSA3032X-R Realtime-Spectrumanalyzer

2.2.3 WP223 Power Supply

For powering the LNBF, the Korad KC3405P lab power supply shown in figure 2.9 was used, since we wanted to investigate how the LNBF is behaving with voltage fluctuations. Unfortunately the device is not fully SCPI compliant as stated by the vendor. The vendor supplies a propriety control software which only works under the Windows OS and does not support any interface. This is why had to implement the interface our self.

Figure 2.9: Korad KC4305P Programmable Power Supply

After some research, we could find parts of the interface documentation, provided by some resellers, but they were missing a lot of commands. Because of this, we used Wireshark[9] to listen

[8] https://git.tu-berlin.de/sierra/sierra24/ra200-receiver-design-and-compensation/
[9] https://www.wireshark.org

to the ethernet communication and realised that the communication was in plain text via UDP protocol. By observing the traffic we could figure out the missing bits for a working interface.

Our Python implementation[10] is designed to facilitate remote control and monitoring of the KC3405P programmable power supply through UDP communication (USB is currently not supported). This includes setting and reading voltages and currents, as well as enabling or disabling outputs on a per-channel basis. Additionally, the script provides comprehensive tools for configuring safety features such as overcurrent protection (OCP) and overvoltage protection (OVP), ensuring that the power supply operates within safe parameters. There are commands to adjust voltage and current settings, retrieve real-time data on the power supply's output, and monitor the status of each channel. The script is also equipped with robust error handling mechanisms that validate commands and raise alerts if the power supply does not respond as expected, thereby enhancing reliability during operation.

2.2.4 Run Automated Measurements

The main script controlling the whole setup is called *master_measure_script.py*[11] and features the following parameters:

```
temperatures = [60, 50, 40, 30, 20, 10, 0, -10]  # chamber temp in
   Celsius
voltages = [11, 12, 13, 17, 18, 19]  # LNBF supply in V
start_frequency = 730e6  # start of sweep in Hz
stop_frequency = 2000e6  # stop of sweep in Hz
bin_resolution = 1000  # width of power channels in Hz
average_n = 2**8
sampling_rate = 20e6
overlap_percent = 0.9
output_dir = "/media/hilbilly/HDD1_1TB/Measurements/automated/"
```

The raw IQ data as well as the measurement results are then written to the given output directory. Keep in mind, that the measurements produce a lot of data, the given configuration generates roughly 1 TB of IQ data.

[10] https://github.com/steinkohl/korad_powersupply

[11] https://git.tu-berlin.de/sierra/sierra24/ra200-receiver-design-and-compensation/-/blob/main/Scripts/master_measure_script.py

2.3 WP230 GNU Radio

GNU Radio is perfect for our SDR-based total power receiver setup because it's flexible, free and open-source. It supports a wide range of hardware and allows for processing of signals, even in real-time. Its modular design makes it easy to scale and customize which make it a perfect middle layer for signal processing performed by the group aroud work package 400.

2.3.1 Prerequisites

In order to be able to execute our flowgraph, the following requirements have to be met.

2.3.1.1 Hardware Requirements

For the realization of a working flowgraph a computer, a USB-A to micro-USB adapter and the modified PlutoSDR[12] were used. The SDR modification also included a firmware manipulation, described in the Adalm Pulto documentation[13]. Here we configured the SDR to be ad9361 compatible (to support RX2, TX2 and frequencies up to 6 GHz), set refclk_source external and ad936x_ext_refclk_override "<40000000>" to enable the external clock input.

2.3.1.2 Software Requirements

The GNU Radio version used for the realization of the absolute power detector flowgraph[14] is v3.10.9.2[15]. All the required modules were already integrated in the vanilla version of GNU Radio.

2.3.2 Flowgraph Design

The PlutoSDR Source block interfaces with the PlutoSDR to receive the RF signals and to convert the analog signals into digital ones. The source block is also used to configure sampling rates, gains and bandwith settings. The source block streams the RF data into the GNU radio flowgraph to further process the signals.

The Head block limits the data that is let through by the number of data points multiplied by the averaging factor.

Stream to Vector converts the stream of items into a stream of vectors that contains.

The FFT block transforms the signal into the frequency domain using the rectangular window function.

[12] https://wiki.analog.com/university/tools/pluto
[13] https://wiki.analog.com/university/tools/pluto/users/customizing
[14] https://git.tu-berlin.de/sierra/sierra24/ra200-receiver-design-and-compensation/-/blob/main/Flowgraphs/NoiseMeasuring.grc
[15] https://wiki.gnuradio.org/index.php/InstallingGR

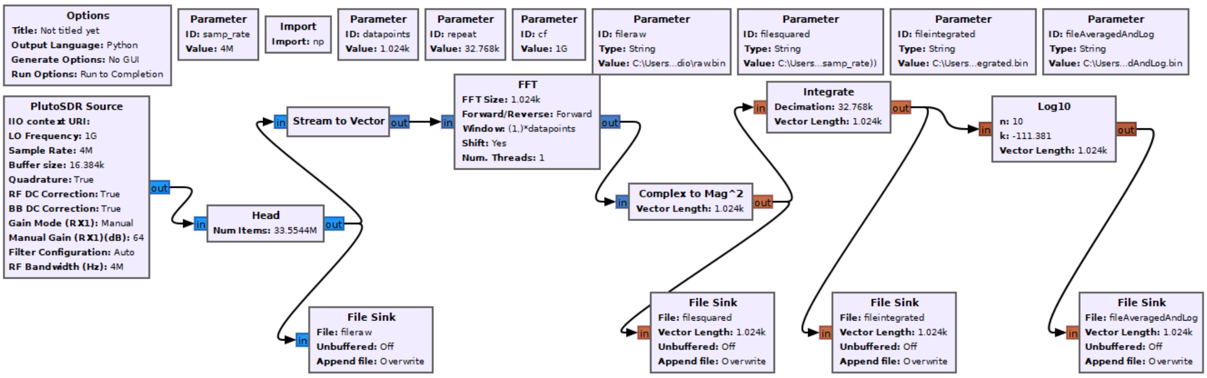


Figure 2.10: Absolute power detector flowgraph in GNU Radio

Complex to Mag Squared converts the complex vectors into a real vector, to get the absolute power of the signals.

The Integrate block adds together the amplitudes of all the measurements of each data point, depending on the averaging factor (repeat).

Log10 scales the data to dBFS levels, accounting for the averaging.

The File Sink blocks save the data at different points of the flowgraph for easier data analyzation.

2.3.3 Flowgraph Operation

A Python script[16] was used to alternate the center frequencies, to cover the whole bandwidth of the receiver. For the temperature- and voltage-dependency measurements the script was also used to alternate those variables.

[16] https://git.tu-berlin.de/sierra/sierra24/ra200-receiver-design-and-compensation/-/blob/main/Scripts/master_measure_script.py

2.4 WP240 Modify LNBF

As stated previous, the Bullseye BE01 LNBF originally ships without a reference clock input. However, it come with an LO output port which is intended to be used for monitoring the LO. The radio amateure N1BUG showed in his blog[17], that it is possible to remove the internal TCXO (shown in figure 2.11) and then inject an external reference via the "LO output".

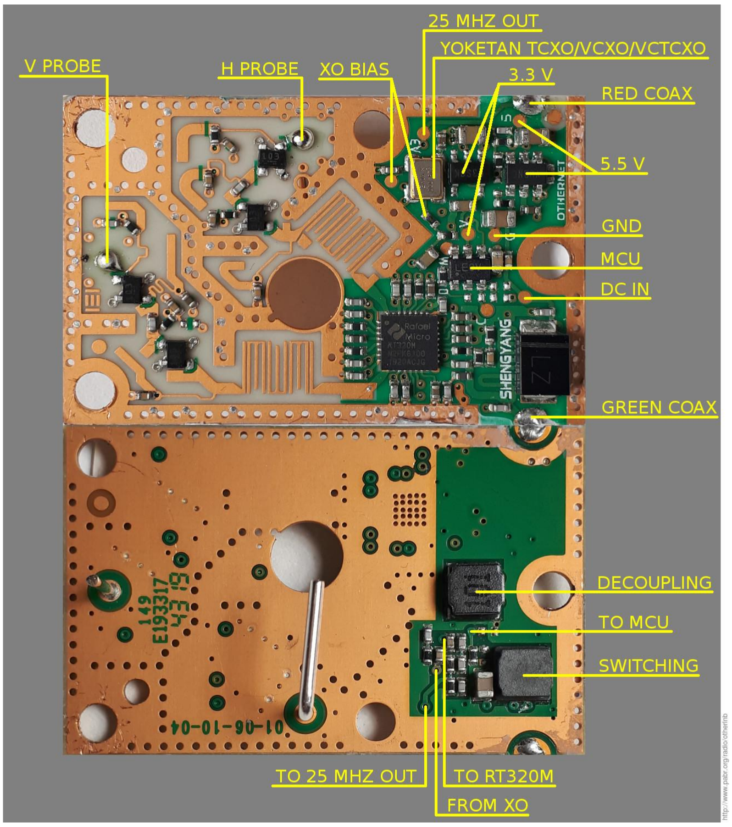


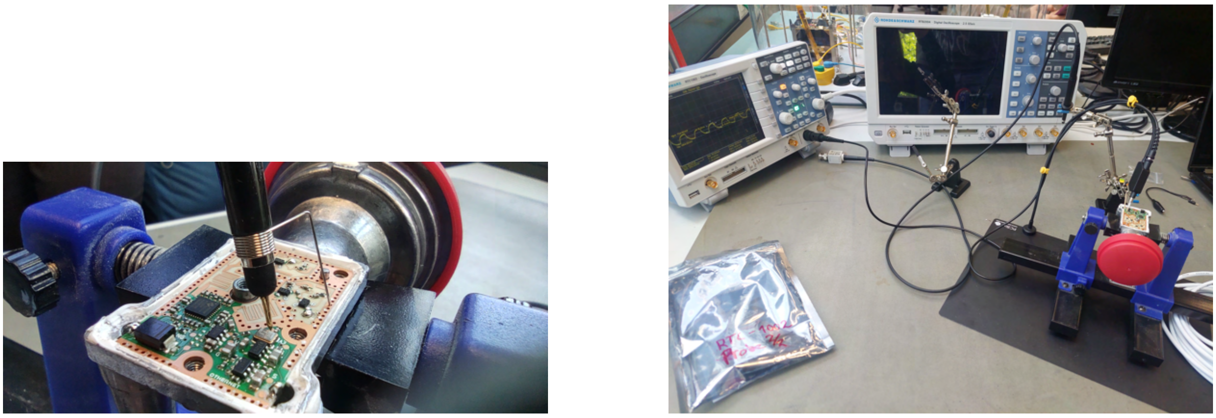
Figure 2.11: Bullseye BE01 PCB

2.4.1 WP241 Remove TCXO

Before removing the TCXO, we measured the amplitude of the LO using a oscilloscope using an 10:1 passive probe with an impedance of 1 MΩ (Fig. 2.12), since the TCXO was already terminated with a 50 Ω load internally. This helped us to reproduce the exact same amplitude during the LO injection later on.

After that we removed the internal TCXO using a hot air gun in combination with a soldering iron, due to the high thermal conductivity of the LNBF housing. Through the red input, we could use the GNSSDO to feed an external reference signal into the LNBF.

[17] http://www.n1bug.com/10ghz/



(a) LNBF Clock Measure Probe

(b) LNBF Clock Measure Setup

Figure 2.12: Measurement setup for LNBF clock. (a) Probe positioning and (b) overall setup.

Figure 2.13: 75Ω to 50Ω Impedance matching block

2.4.2 WP242 Impedance Matching

Since the F-Type connector, which is used to inject the reference input, has an impedance of 75 Ω, impedance matching is needed in order to avoid negative side effects like standing waves due to signal reflection.

For the matching of the GNSSDO output and the LNBF reference signal input, we used the 75Ω to 50Ω Impedance Transformer of Mini-Circuits (part number: Z7550R-FMSF+, shown in figure 2.13). The impedance transformer has an attenuation of 6dB. We also measured the LNBF's internal clock's signal Amplitude and Waveform, to adjust our own signal from the GNSSDO accordingly. The 6dB attenuation was enough and the waveform similar (Square Wave) so, that PLL of the LNBF locked to our fed in reference signal.

2.5 WP250 GNSSDO

To be able to use the Leo Bodnar GPSDO, we first had to configure it, since at factory settings it is set to 10 MHz.

2.5.1 Configure Frequency Channels

We use a reference signal of 25 MHz for the LNBF and 40 MHz for the SDR. To configure the GNSSDO we used the Configuration Software GPSClockConfigV9.12[18] available on the Leo Bodnar website[19].

Setting 40 MHz as your first output, doesn't automatically give you 25 MHz as an option for your second output, therefore it is necessary to manually set it. There are resources online[20][21] that explain how to do it. Figure 2.14 shows the configuration.

2.5.2 LO Verification

In order to verify our settings, we use a oscilloscope in 50 Ω mode to check if the two channels are set to 40 MHz and 25 MHz, as shown in figure 2.15.

[18] https://www.leobodnar.com/files/GPSClockConfigV9.12.exe
[19] https://www.leobodnar.com
[20] https://www.darc.de/fileadmin/filemounts/distrikte/o/ortsverbaende/38/Downloads/GPSDO_Leo_Bodnar.pdf
[21] https://wiki.n18.de/lib/exe/fetch.php?media=qo100:berechnung_leobodnar_gpsdo.pdf

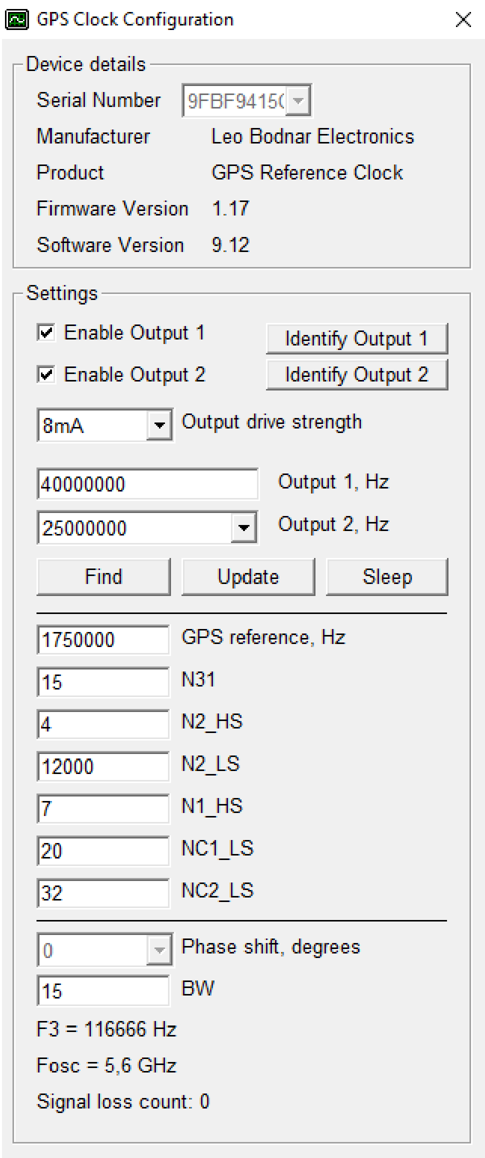
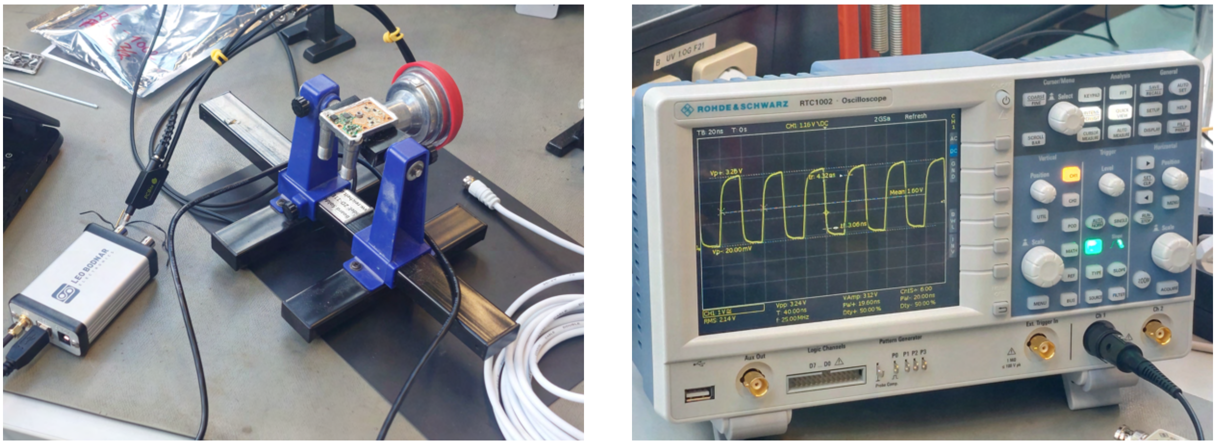


Figure 2.14: GNSSDO Frequency Configuration



(a) GPSDO Measure Setup

(b) GPSDO Signal

Figure 2.15: GPSDO Setup and Signal Captured by Oscilloscope

2.6 WP260 Charaterize LNBF & WP270 Characterize SDR

We merged the work packages WP260 and WP270 together, because the noise source to calibrate the spectrum analyzer came late. Therefore, we took measurements for the whole receiver unit in the thermal chamber. The results of the measurements are visualized in figure 2.16. The measurements did not deliver the results we expected, as they suggest, that the noise floor is stable across the whole frequency bandwidth and for different temperatures and input voltages.

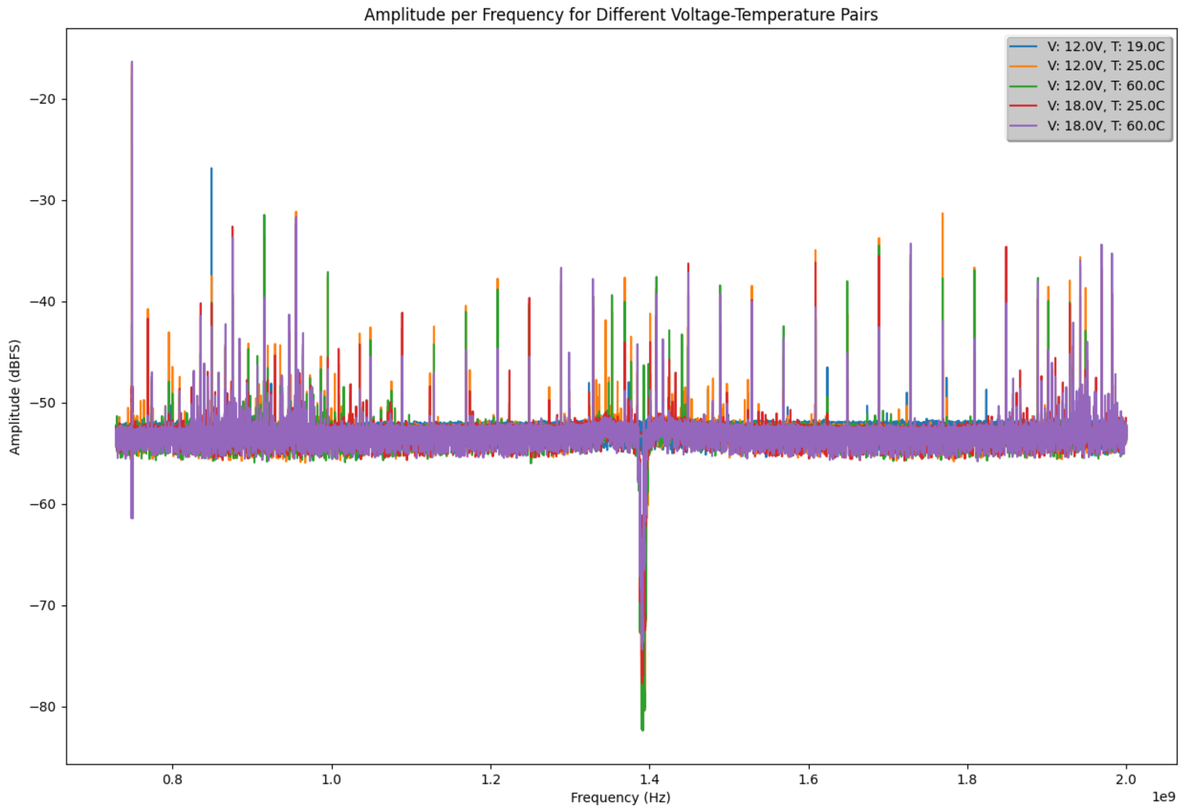


Figure 2.16: Plotted Averaged GNU Radio Flowgraph Outputs

Our analysis narrowed down the cause of this behavior to the SDR itself or the SDR source block. There is the possibility that, because the noise floor measurements are a composition of many measurements with a narrow bandwidth, the SDR internally regulates the floor to the same level for each of those measurements, what makes the composition appear to have the same noise level overall.

There are a few things, that we can still take from those measurements. The spikes in the measurements are caused by reflections inside the thermal chamber, but there are still consecutive gaps between the spikes, where you can observe the supposed noise floor level.

Because of the problems with the SDR, we measured the noise floor of the LNBF with the spectrum analyzer Siglent SSA3032X-R and took a screenshot as seen in figure 2.17. The noise floor is not as constant across the frequency range as suggested by the previous measurements.

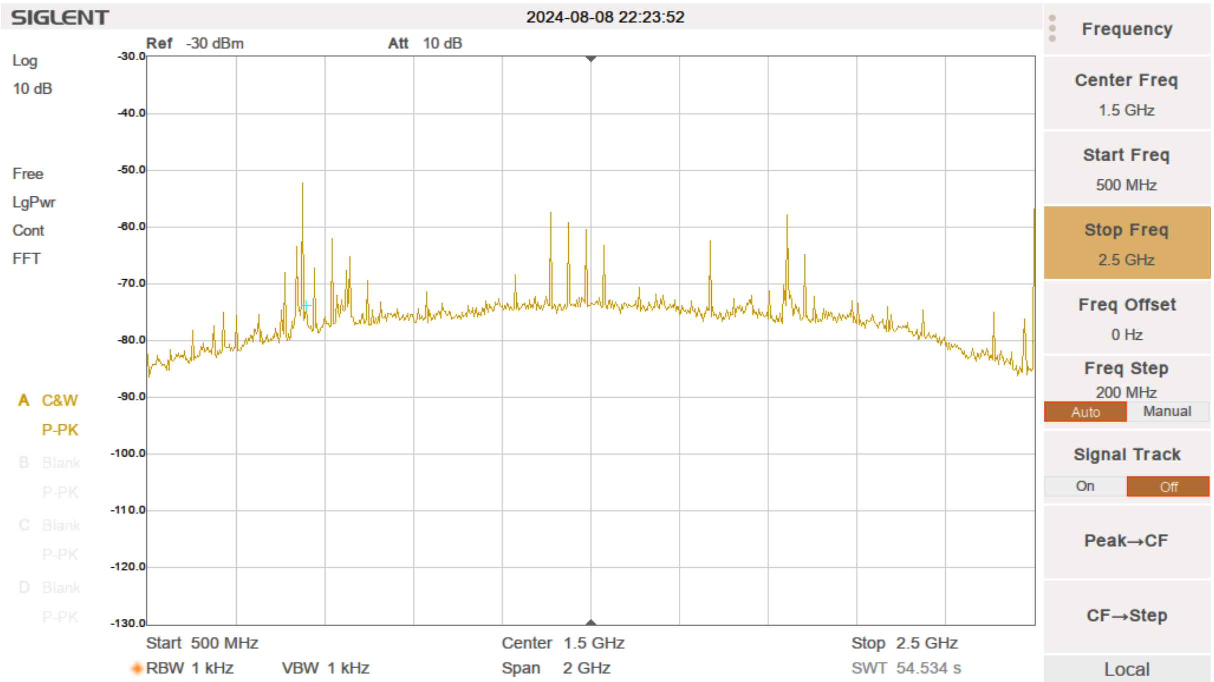


Figure 2.17: Screenshot of Siglent SSA3032X-R Spectrumanalyzer measuring the Noise Floor of the LNBF

2.7 WP280 Signal Conditioning

Since the Bullseye BE01 LNBF is designed for the reception of relatively strong signals from broadcast satellites, its gain and filter capabilities might not be sufficient for extremely weak signals.

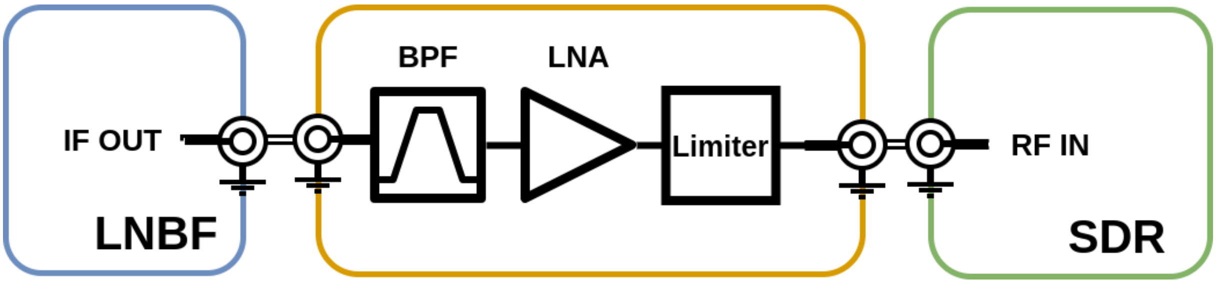


Figure 2.18: Block Diagram with additional Components for Signal Conditioning

To increase the sensitivity of the receiver, it might be applicable, to add an LNA into the signal line. Therefore a LNA with a low noise figure should be chosen, in order to minimize the introduced additional noise.

This has the risk of exceeding the SDR's maximum HF-input tolerance, which is 2.5dBm. So in order, for the LNA to work as part of our receiver, a limiter is needed to protect the SDR.

By introducing a band pass filter and varying the LO frequency of the LNBF, the noise power can be measured within narrow frequency bins. Varying the LO frequency in combination with the band pass filter archives a windowing effect for the whole measured spectrum. This also diminishes distortion in the SDR, because the band selection is analog and not digital, thus eliminating the risk of clipping from the ADC due to a large spike at the edge of the relevant spectrum.

This has to be tested in practice, to evaluate the downsides of adding more components, which introduce noise, and the upsides of further amplifying the signal.

Device	**LNA**	**Limiter**	**Bandpass**
IDN	ZKL-33ULN-S+	ZFLM-252-1WL-S+	ZX75BP-1100-S+
Frequency Range	400 MHz - 3 GHz	100 MHz - 2.5 GHz	1 GHz - 1.2 GHz
Gain@IF	27dB	-0.57dB	-0.4dB
Noise Figure@IF	0.50dB	0.57dB	0.4dB

Table 5: List of additional Hardware for Signal conditioning

Appendix

Used GitLab-Repositories:

– Repository 1: RA200 - Receiver Design and Compensation