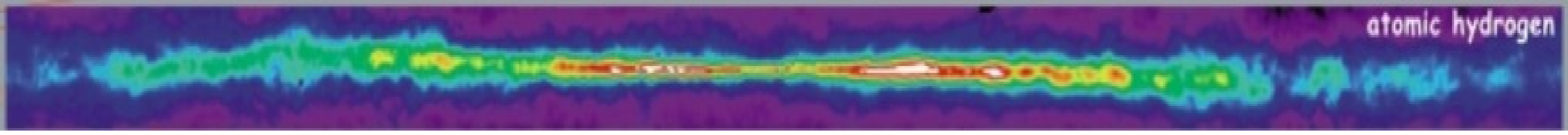


Leonardo Rossoni – 01/10/2024

DEV - RADIOASTRONOMY

Report number 7: New RF front-end

Introduction
In this report, I will describe the development and construction of the first version of the radio front-end for my radio telescope. This front-end represents a crucial step in moving away from off-the-shelf components/devices and towards designing and integrating a custom-built solution.

Design and Component Selection
The design of the radio front-end followed a modular approach to ensure flexibility and ease of future upgrades. I carefully selected each component to minimize signal losses and maximize performance in the 1420 MHz frequency range. Here’s an overview of the key components used in this version of the front-end:

- Band-pass Filters: I implemented two Mini-Circuits ZX75BP-1450+ filters, centered at 1450 MHz, with a bandwidth of 260 MHz. These filters were chosen not only for their ability to reduce out-of-band noise but also for their potential to detect signals from the OH maser. Astrophysical masers, such as the OH maser, are natural sources of microwave radiation that are often associated with star-forming regions or the late stages of stellar evolution. These masers emit strong and narrow spectral lines, and the frequency range of the OH maser falls within the capability of this filter, making it suitable for future detections (link to datasheet).

Figure 1: Mini-Circuits ZX75BP-1450+, BandPass Filter

- <u>RF Amplifiers</u>: To boost weak signals captured by the antenna, I used three RF amplifier modules ([link to product]()). These amplifiers were selected because they are commonly used in amateur radio astronomy, making them easily accessible at a low cost. Despite their affordability, they provide high gain and low noise, which are critical for amplifying faint signals without introducing significant interference.

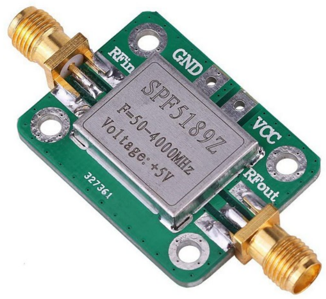


Figure 2: SPF5189Z RF Amplifier

- <u>Power Supply</u>: I opted for a USB-C based power supply system to simplify the power management while ensuring stable voltage levels. To minimize RF noise from the power source, I also integrated a simple ferrite core filter on the USB-C input. This helps to reduce interference and ensures cleaner power delivery to the front-end.
- <u>Aluminum Enclosure</u>: To shield the entire front-end from external RF interference, I enclosed all components in an aluminum case with dimensions of 54 x 145 x 200 mm and a thickness of 1.4 mm (link to product). The aluminum enclosure provides effective shielding, protecting the sensitive RF components from environmental noise, ensuring the stability and integrity of the signal.

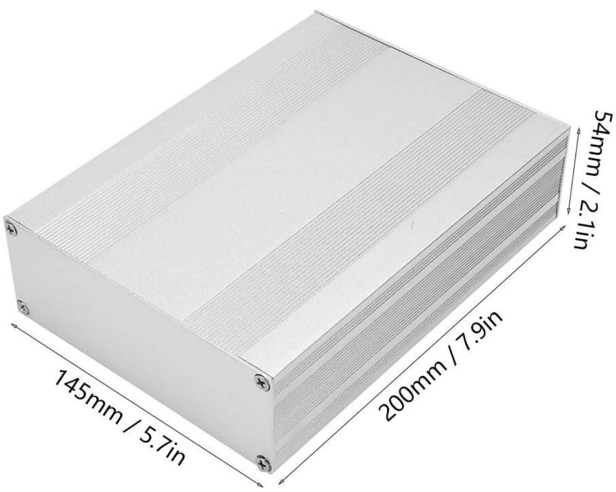


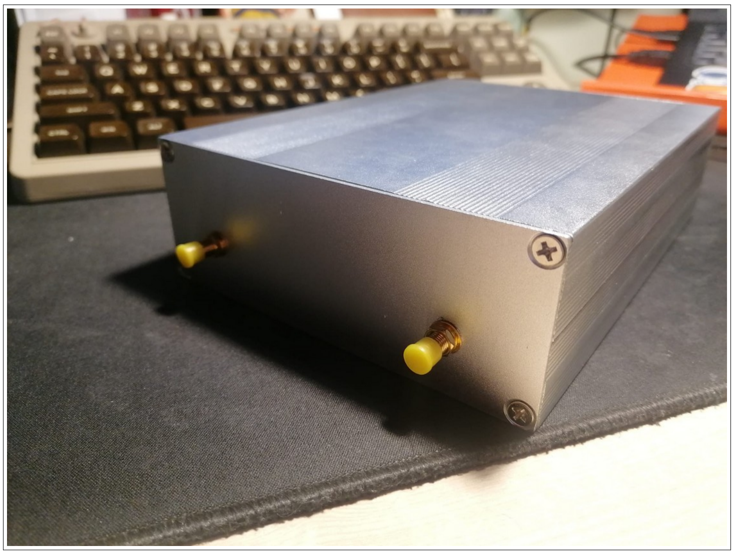
Figure 3: Aluminum Enclosure, 54 x 45 x 200 mm

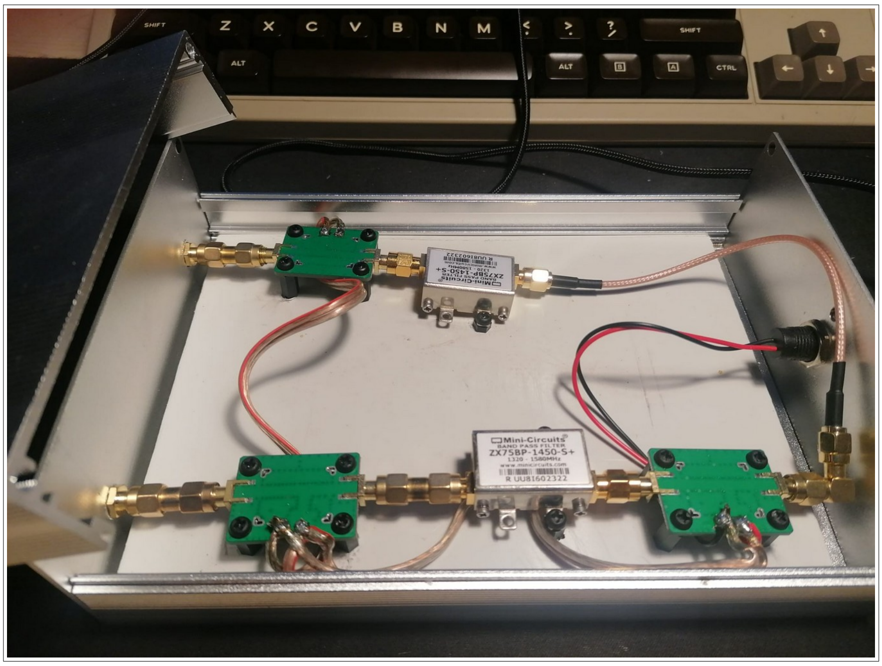
Assembly of the RF Front-End

After purchasing and individually testing each component, I proceeded with the assembly of the RF front-end. I carefully planned the layout of the components inside the aluminum enclosure, ensuring that all parts would fit neatly while minimizing signal path lengths and avoiding potential interference. To facilitate future maintenance, I mounted all components onto a single surface that can be easily inserted and removed from the aluminum case as a single unit. This design allows for quick access to the components for repairs or adjustments.

Once the layout was finalized, I drilled the necessary holes in the aluminum case. Two SMA connectors were installed for the RF input and output, and an additional hole was created to house the USB-C port for power supply. After securing the connectors and the power input, I wired all components together and connected them to the internal power supply system.

The result:





Testing and Results
The first step in testing the RF front-end (and perhaps the most entertaining) was connecting the power supply and checking for any smoke or sparks. Fortunately, everything was in order, and I was able to proceed with the tests.

The primary test I conducted was using my Nano VNA, which is a Vector Network Analyzer capable of measuring the S-parameters of a device, such as reflection (*S11*) and transmission (*S21*). To avoid damaging the Nano VNA with overly strong amplified signals, I used several RF attenuators, applying -40 dB of attenuation to protect the device.

Figure 4: S21 Chart from NanoVNA

The first measurement I performed was the S21 parameter, analyzing the frequency response from 10 kHz to 2.3 GHz. This was crucial to verify if the device was amplifying the correct frequency range and filtering out unwanted noise and interference. The results were very satisfactory: the frequencies amplified ranged from approximately 1240 MHz to 1610 MHz, meaning that my primary frequency of interest (1420 MHz) was well within this range. The measured gain was about 34.7 dB, which closely matched the performance of my previous H1 SawBird setup. The attenuation at the edges of this frequency range was steep and significant, which is ideal.

However, I was expecting a higher total gain, around +58 dB. My theoretical calculation, assuming the components worked perfectly, was as follows:

- Each RF amplifier should have provided +20 dB of gain, for a total of +20 dB * 3 = +60 dB.
- The two band-pass filters would attenuate the signal slightly, reducing the total by about -1 dB per filter, leading to +58 dB of total amplification.

After reviewing my test results, I found that the RF amplifiers were providing only +15 dB of gain, rather than the +20 dB specified in the datasheet. This discrepancy appears to be common, as I discovered online, and is due to the actual quality of these modules. Still, +15 dB is reasonable. This adjustment gives a total amplification of approximately +15 dB * 3 = +45 dB, minus the attenuation of the band-pass filters, resulting in a net gain of +43 dB, which is still somewhat higher than the measured +34.7 dB.

Figure 5: Smith Chart from NanoVNA

To investigate further, I used the Smith chart feature of the Nano VNA to measure the characteristic impedance of the RF front-end. The result showed an impedance of *90 ohms + 3.85 nH* at 1420 MHz, which deviates from the ideal. Based on this mismatch, we can calculate the reflection coefficient and the corresponding attenuation in dB, which likely explains part of the difference in the expected and actual gain.

1. Inductive reactance:

The inductive reactance X_L is calculated using the formula:

$$X_L = 2\pi f L$$

Where:

- $f = 1420 \times 10^6$ Hz is the operating frequency,
- $L = 3.5 \times 10^{-9}$ H is the inductance.

Thus:

$$X_L = 2\pi \times 1420 \times 10^6 \times 3.5 \times 10^{-9} = 31.23\ \Omega$$

2. Complex Impedance of the Load: Z_L= 90Ω +j31.23Ω

3. Reflection Coefficient Calculation

The reflection coefficient Γ is calculated using the formula:

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

Where $Z_0 = 50\ \Omega$ is the characteristic impedance of the transmission line.

Substituting the values:

$$\Gamma = \frac{(90 + j31.23) - 50}{(90 + j31.23) + 50} = 0.32 + j0.15$$

4. Calculate dB attenuation

$$|\Gamma| = \sqrt{(0.32)^2 + (0.15)^2} = 0.354$$

To express Γ in dB, we use the formula:

$$\Gamma_{\text{dB}} = 20 \log_{10} |\Gamma|$$

Thus:

$$\Gamma_{\text{dB}} = 20 \log_{10}(0.354) = -9.03\ \text{dB}$$

Factoring this into the total gain: +43dB − 9dB = +34dB
This closely matches the measured +34.7 dB, with small deviations due to simplifications in calculations and measurements.

This attenuation likely stems from a combination of factors, such as the use of various SMA adapters and non-straight SMA cables inside the front-end. These can introduce minor mismatches in impedance, affecting overall performance. Additionally, the way the boards are connected within the enclosure could contribute to impedance mismatches. Although this was the most practical way to build the first version of the front-end, it's clear that improving impedance matching and signal path integrity could significantly enhance performance.

Through this testing, I’ve learned that reproducing the performance of a commercial LNA is absolutely achievable. With further optimizations in component selection and better impedance matching between signal lines and the front-end, the system’s performance could be greatly improved.