A SIMPLE 11.2 GHZ RADIOTELESCOPE (HW PART)

一个简单的 11.2 GHZ 射电望远镜（硬件部分）

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Abstract : *In this post we describe the construction of a small amateur radio telescope operating at the frequency of 11.2 GHz. The construction of the radio telescope takes advantage of the satellite TV market which has made it easy and cheap to find parabolic reflector antennas with relative illuminator (feed horn) and LNB block (low noise amplifier-frequency converter). The performances of a similar instrument are naturally rather limited, however they still allow to make interesting observations of some of the most intense radio sources.*

摘要： 在这篇文章中，我们描述了一个工作频率为 11.2 GHz 的小型业余射电望远镜的构造。射电望远镜的建造利用了卫星电视市场，这使得找到带有相对照明器（馈电喇叭）和 LNB 块（低噪声放大器-变频器）的抛物面反射器天线变得容易且便宜。类似仪器的性能自然是相当有限的，但是它们仍然允许对一些最强的射电源进行有趣的观察。

Introduction 介绍

Radio astronomy is a difficult and fascinating science. It requires the use of bulky and expensive antennas, uses sophisticated radio-electronic technologies and sophisticated algorithms for signal processing. At first glance it would seem completely beyond the reach of an "amateur". In reality it is possible to make interesting radio astronomical observations even at an amateur level.

On our site we have already described some radio astronomy projects for specific applications:

射电天文学是一门困难而迷人的科学。它需要使用笨重且昂贵的天线，使用复杂的无线电电子技术和复杂的信号处理算法。乍一看，这似乎完全超出了 "业余 "的能力范围。在现实中，即使是业余水平也可以进行有趣的射电天文观测。
在我们的网站上，我们已经介绍了一些针对特定应用的射电天文项目：

- Loop Antenna for Very Low Frequency

  用于极低频的环形天线

- VLF Receiver for SID Monitoring

用于 SID 监控的 VLF 接收器

- Horn Antenna for the 21cm Neutral-Hydrogen Line

  用于 21cm 中性氢线的喇叭天线

- Low-Noise SDR-Based Receiver for the 21cm Neutral-Hydrogen Line

  用于 21cm 中性氢管线的基于低噪声 SDR 的接收器

- GNURadio Software for 21cm Neutral-Hydrogen Line

  用于 21cm 中性氢管线的 GNURadio 软件

Now we want to try to make an “amateur” radio telescope based on the principle of the **radiometer**. This is certainly not the place to give detailed information on radio astronomy and radio telescopes (there is a lot of information on the net and specific texts), so we limit ourselves to providing some hints on the main points that guided us in the construction of the radio telescope.

现在我们想尝试根据辐射计的原理制作一个“业余”射电望远镜。这当然不是提供有关射电天文和射电望远镜详细信息的地方（网上有很多信息和具体文本），因此我们仅限于提供一些指导我们建造射电望远镜的要点的提示。

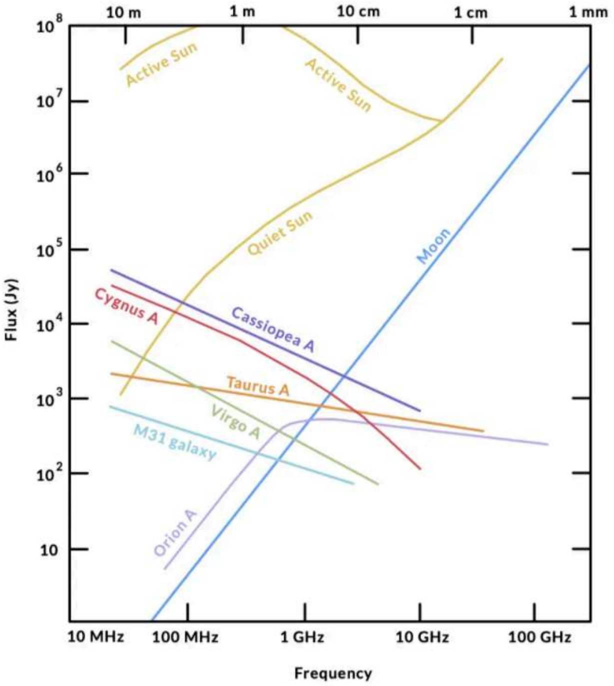
Radio astronomy studies celestial bodies by analyzing the radio waves emitted by objects in the sky: any object emits electromagnetic waves through various physical processes (thermal and non-thermal), these waves are picked up by the antenna and analyzed with appropriate instruments: in general the characteristics of the captured signal are no different from those that characterize a **broad spectrum electrical noise**. The purpose of the radio telescope is to pick up this radiation and measure the signal strength, such an instrument is called a radiometer. To be precise, we speak of power per unit area and per unit of bandwidth and is expressed in Jansky : **1Jy = 10^{-26} W/m^2 Hz**.

射电天文学通过分析天空中物体发射的无线电波来研究天体：任何物体都通过各种物理过程（热和非热）发射电磁波，这些波被天线接收并使用适当的仪器进行分析：一般来说，捕获信号的特性与表征广谱电噪声的特性没有什么不同。射电望远镜的目的是接收这种辐射并测量信号强度，这样的仪器称为辐射计。准确地说，我们说的是每单位面积和每单位带宽的功率，以 Jansky 表示：1Jy = 10-26 W/m2 Hz。

The range of radio frequencies useful for radio astronomy observations is between **20 MHz** and about **20 GHz**: below 20 MHz there is absorption by the ionosphere, above 20 GHz there is absorption by of the gases present in the atmosphere.

可用于射电天文观测的无线电频率范围在 20 MHz 到大约 20 GHz 之间：低于 20 MHz 时被电离层吸收，高于 20 GHz 时被大气中存在的气体吸收。

To choose the most suitable frequency band for an amateur radio telescope we must make a compromise between the observation possibilities and the cost and feasibility constraints. The frequency spectrum of the radio-source emissions depends on the underlying physical process: for “thermal” emissions such as the sun or the moon, the intensity follows the **law of the black body** with maximums at high frequencies (according to the approximation of Rayleigh-Jeans $\mathbf{I \propto 1/\lambda^4}$), while for non-thermal emissions (for example synchrotron emission) the maximums are at lower frequencies, as can be seen in the graph below which shows the intensity of some radio sources as a function of frequency.



要为业余射电望远镜选择最合适的频段，我们必须在观测可能性与成本和可行性限制之间做出妥协。放射源发射的频谱取决于潜在的物理过程：对于太阳或月亮等"热"发射，强度遵循黑体定律，最大值为高频（根据 Rayleigh-Jeans I ∝ 1/λ4 的近似值），而对于非热发射（例如同步加速器发射），最大值为较低频率， 如下图所示，该图显示了一些无线电源的强度与频率的函数关系。

As we know the dimensions of the antenna are related to the wavelength of the radiation to be received, furthermore our antenna must be sufficiently directive, otherwise it would be practically useless: this means that to receive frequencies below 1 GHz the dimensions of the antenna should be significantly greater than 1m: large antennas are expensive and difficult to move.

Another aspect to consider is external radio interference. The ether, especially in the city, is now saturated with transmissions and RF signals from the most heterogeneous origin: radio and TV broadcasting, cellular networks, WiFi networks, disturbances from power lines, etc …. Not having the possibility to install the radio telescope in "quiet" places we must choose a frequency band that is not too disturbed.

众所周知，天线的尺寸与要接收的辐射的波长有关，此外，我们的天线必须具有足够的定向性，否则实际上将毫无用处：这意味着要接收低于 1 GHz 的频率，天线的尺寸应明显大于 1m：大型天线价格昂贵且难以移动。
另一个需要考虑的方面是外部无线电干扰。以太，尤其是在城市中，现在已经充斥着来自最异构来源的传输和射频信号：无线电和电视广播、蜂窝网络、WiFi 网络、电力线干扰等……由于无法将射电望远镜安装在"安静"的地方，我们必须选择一个不太受干扰的频段。

For the reasons described above, the choice is almost obligatory: the **10-12 GHz frequency band** is the one that seems most suitable for an amateur project like ours. At these frequencies, parabolic reflector antennas and devices designed for satellite television can be re-used. The costs of the equipment are affordable, the spatial resolution of the antenna is quite good and the interference is low (basically broadcasting satellites) and easily avoidable.

Working at lower frequencies would make it possible to easily receive more radio sources but with a considerable increase in terms of costs, not to mention the problem of interference.

由于上述原因，选择几乎是强制性的：10-12 GHz 频段似乎最适合像我们这样的业余项目。在这些频率下，为卫星电视设计的抛物面反射器天线和设备可以重复使用。
设备成本合理，天线的空间分辨率相当好，干扰低（基本上是广播卫星）并且很容易避免。
在较低频率下工作将可以很容易地接收更多的无线电源，但成本会大大增加，更不用说干扰问题了。

Parabolic Dish Antenna

抛物面碟形天线

The antenna we found on the second-hand market is a **prime focus dish** with a diameter of 120 cm. For radio astronomy applications it is better that the dish is of the prime focus type: in these antennas the feed horn is placed in the focus of the dish. In offset-type dishes, the feed-horn is not placed in the center but on the side, this type has constructive advantages but is more difficult to aim to the source than the prime focus.

我们在二手市场上找到的天线是一个直径为 120 厘米的 Prime Focus 天线。对于射电天文应用，碟形天线最好是主要焦点类型：在这些天线中，馈电喇叭位于碟形天线的焦点上。在偏置式培养皿中，进料喇叭不是放在中心而是放在侧面，这种类型具有建设性的优势，但比主要焦点更难瞄准源头。

For this antenna we can calculate the gain and the directivity intended as half power band width HPBW (half power band width) :

对于这个天线，我们可以计算出增益和方向性，即一半功率带宽 HPBW （半功率带宽）：

$$G = \eta*(\pi*D/\lambda) = 40\ dB$$

G = η*（π*D/λ） = 40 分贝

$$HPBW = 65*\lambda/D = 1.45°$$

HPBW = 65*λ/D = 1.45°

Where

η : efficiency = 0.5

D : diameter = 120 cm

λ : wavelength = 2.68 cm (correspond to 11.2 GHz)

哪里
η： 效率 = 0.5
D： 直径 = 120 cm
λ： 波长 = 2.68 cm（相当于 11.2 GHz）

The images below show the antenna and the metal structure used for manual movement.

下图显示了用于手动移动的天线和金属结构。

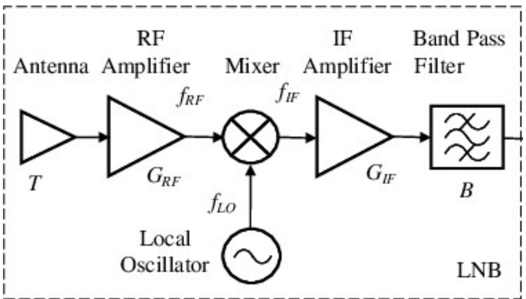

AUDIOVIDEO
SAT

LNB LNB 系列

The first component of the system is the converter-amplifier block, the so-called **LNB**. This is the most important component because system performance largely depends on it. Our system receives in the 10-12 GHz band, at these frequencies the use of cables is problematic, for this reason the LNB block provides for a frequency down conversion in a lower band so that normal coaxial cables can be used.

The following image shows the basic scheme of the LNB block: there is a first **RF amplification stage**, followed by the mixer which multiplies the RF signal with the signal generated by a **local oscillator (LO)**. The resulting signal contains the sum and difference frequencies, the next filter eliminates the high frequency sum components to let pass only the frequencies in the band of interest, called **intermediate frequencies (IF)**, which are further amplified by another amplifier stage. In practice it is a heterodyne scheme, in which the frequency of the local oscillator is fixed.

该系统的第一个组件是转换器-放大器模块，即所谓的 LNB。这是最重要的组件，因为系统性能在很大程度上取决于它。我们的系统在 10-12 GHz 频段接收，在这些频率下，使用电缆是有问题的，因此 LNB 块在较低频段提供频率下变频，以便可以使用普通同轴电缆。
下图显示了 LNB 模块的基本方案：第一个 RF 放大级，然后是混频器，该混频器将 RF 信号与本振 （LO） 产生的信号相乘。生成的信号包含和频率和差频，下一个滤波器消除高频和分量，只让目标频带中的频率通过，称为中频 （IF），这些频率由另一个放大器级进一步放大。在实践中，它是一种外差方案，其中本振的频率是固定的。



The LNB block we use is **Invacom's SNF-031** model which has **low noise** and **good stability** of the gain parameters with respect to variations in operating temperature. The actual antenna is located inside the waveguide which has a C120 flange on the outside to which the feed horn is fixed, which has the task of collecting the waves reflected by the dish and conveying them to the inside the waveguide.

我们使用的 LNB 模块是 Invacom 的 SNF-031 型号，它具有低噪声和增益参数相对于工作温度变化的良好稳定性。实际的天线位于波导内部，波导的外部有一个 C120 法兰，馈电喇叭固定在该法兰上，其任务是收集碟形天线反射的波并将其传输到波导内部。

LNB features: LNB 功能：

- Operating frequency band : 10.7 – 12.75 GHz

  工作频段： 10.7 – 12.75 GHz
- Intermediate frequencies (IF) : 950 – 2150 MHz, LO = 9.75 GHz

  中频 （IF） ： 950 – 2150 MHz， LO = 9.75 GHz
- **Noise Figure NF = 0.3 dB**

  噪声系数 NF = 0.3 dB
- **Gain G = 50 – 60 dB** 增益 G = 50 – 60 dB

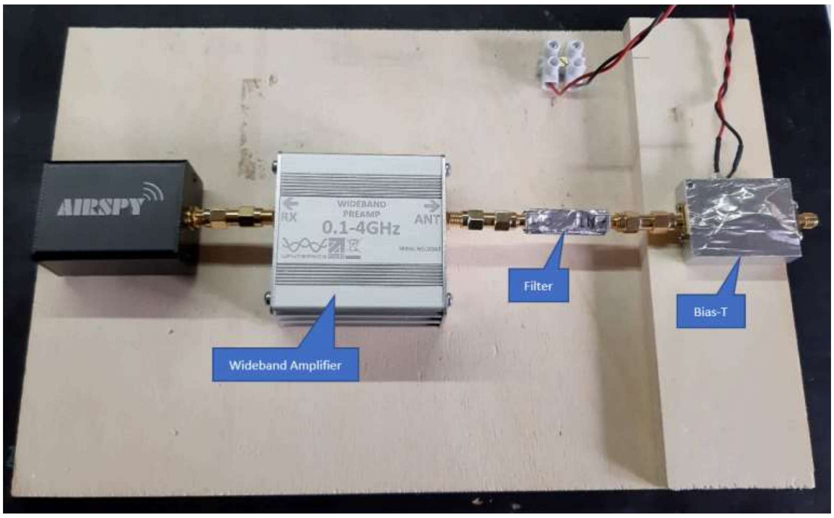
The following images show the LNB block with its feed horn fixed to the focus of the dish.

下图显示了 LNB 块，其进料喇叭固定在培养皿的焦点上。

The Receiver 接收器

The receiver consists of the few components, shown in the following image: there is a bias-T for feeding the LNB block, a bandpass filter centered at 1420 MHZ, a wide-band amplifier and the **Airspy R2 SDR receiver**. The “hardware” part has the function of limiting the receiving band and giving the signal a second amplification after the LNB stage. The signal is then acquired by Airspy and subsequently processed for the determination of the total power using **GNURadio** software. The **radiometer** function is practically realized through software.

接收器由几个元件组成，如下图所示：有一个用于馈送 LNB 模块的偏置 T、一个以 1420 MHZ 为中心的带通滤波器、一个宽带放大器和 Airspy R2 SDR 接收器。“硬件”部分具有限制接收频段并在 LNB 级之后对信号进行第二次放大的功能。然后由 Airspy 获取信号，然后使用 GNURadio 软件进行处理以确定总功率。辐射计功能实际上是通过软件实现的。



Features of our receiver :

Frequency Band = 80 MHz

G_{LNB} = 55 dB ; NF_{LNB} = 0.3 dB

G_{Filter} = 3.5 dB (insertion loss)

G_{Ampli} = 15 dB ; NF_{Ampli} = 0.75 dB

Gain : $G_{LNB} - G_{Filter} + G_{Ampli}$ = 55 -3.5 +15 = 66.5 dB

Noise Figure : $F = F_{LNB} + (F_{Ampli} - 1)/G_{LNB}$ = 0.3 dB

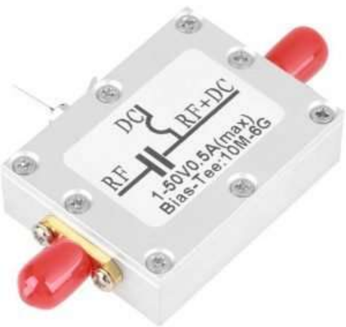
$T_e = (F - 1) * T_0$ = 20.3 °K (Receiver equivalent temperature)

我们的接收器的特点：
频带 = 80 MHz
GLNB = 55 分贝;NFLNB = 0.3 分贝
GFilter = 3.5 dB（插入损耗）
GAmpli = 15 分贝 ;NFAmpli = 0.75 分贝
增益： GLNB – GFilter + GAmpli = 55 -3.5 +15 = 66.5 dB
噪声系数： F = FLNB + （FAmpli – 1）/GLNB = 0.3 dB
Te = （F – 1） * T0 = 20.3 °K（接收器等效温度）

Bias-T 偏置-T

The Bias-T has the function of “injecting” the supply voltage to the LNB block along the coaxial cable. In practice it is a simple circuit with a coupling capacitor to filter the DC component towards the RF side and an inductance at the DC input. Obtained on eBay, it can be easily self-built but attention must be paid to the “RF” quality of the components and the shielding.

Bias-T 具有沿同轴电缆向 LNB 模块“注入”电源电压的功能。在实践中，它是一个简单的电路，带有一个耦合电容器，用于过滤 RF 侧的 DC 分量，并在 DC 输入端有一个电感。在 eBay 上获得，它可以很容易地自建，但必须注意组件和屏蔽的“RF”质量。



1420 MHz Band Pass Filter

1420 MHz 带通滤波器

This filter is dedicated to amateur radioastronomers interested in the hydrogen line observations. It uses the TA2494A SAW component and measures only 50 x 10mm. It features edge pads for an easy soldering of a RF shield. Insertion loss is typically less than 3.5dB and bandwith 80MHz.

该滤波器专用于对氢线观测感兴趣的业余射电天文学家。它使用 TA2494A SAW 组件，尺寸仅为 50 x 10mm。它具有边缘焊盘，可轻松焊接 RF 屏蔽。插入损耗通常小于 3.5dB，带宽为 80MHz。

Technical Data :

Center Frequency **1420MHz**

Usable Bandpass **1380-1460MHz**

Insertion Loss, 1380 to 1460 MHz **3.5dB**

Amplitude Ripple, 1380 to 1460 MHz 1.0 dBpp

VSWR, 1380 to 1420 MHz 1.9:1

Rejection referenced to 0dB :

DC to 1300 MHz 28dB

1550 to 3000 MHz 30dB

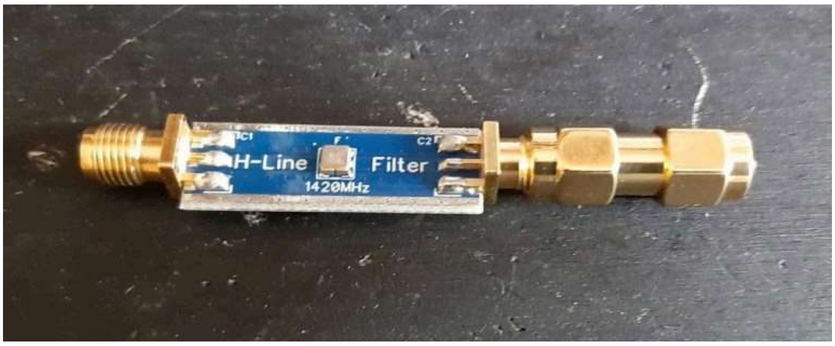
Impedance 50Ω

Maximum Input Power Level 10 dBm

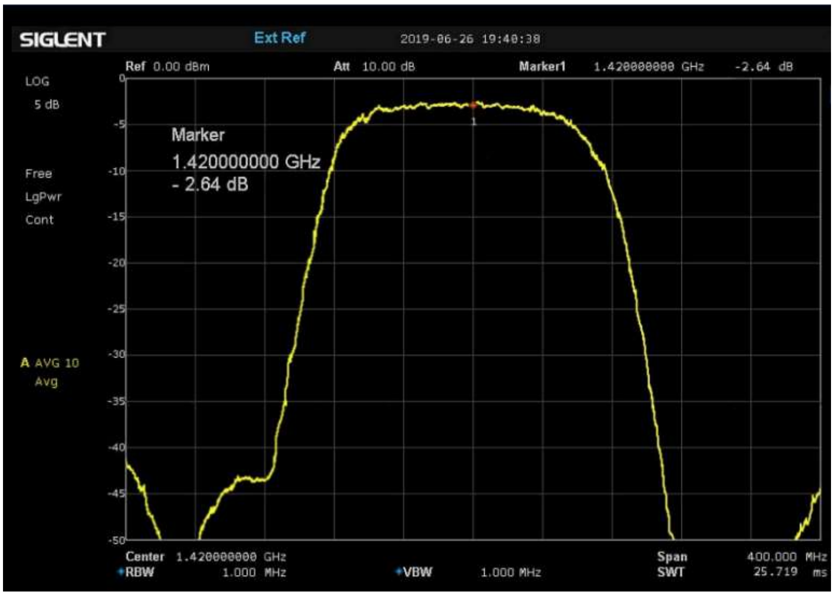
技术数据：
中心频率 1420MHz
可用带宽通 1380-1460MHz
插入损耗，1380 至 1460 MHz 3.5dB
幅度纹波，1380 至 1460 MHz 1.0 dBpp
VSWR，1380 至 1420 MHz 1.9：1
抑制参考 0dB：
直流至 1300 MHz：28dB
1550 至 3000 MHz，30dB
阻抗 50Ω
最大输入功率电平 10 dBm

In the images below we show the unit and its frequency response. We have soldered two wires between the SMA female headers and we wrapped the filter with aluminum tape in order to shield the filter.

在下图中，我们显示了该装置及其频率响应。我们在 SMA 母头之间焊接了两根电线，并用铝带包裹过滤器以保护过滤器。



Frequency (MHz) 频率（MHz）	***Gain (dB)*** 增益（dB）
1300	**-50** -50
1420	**-3.5** -3.5
1500	**-50** -50



Wideband Amplifier 宽带放大器

This unit HAB-FLTNOSAW built by UPUTRONICS is a preamp designed to go between a software defined radio receiver and an antenna. The LNA used inside is a MiniCircuits PSA4-5043. This particular model has the SAW filter removed to cover the 0.1MHz to 4GHz. There are 2 options for powering the unit : either by the USB header or via bias-tee. Devices such as the Airspy can enable bias-tee and power the device. Alternatively any mini USB cable can be used to power the device. We chose to power the unit via USB line.

由 UPUTRONICS 制造的 HAB-FLTNOSAW 装置是一个前置放大器，旨在介于软件定义的无线电接收器和天线之间。内部使用的 LNA 是 MiniCircuits PSA4-5043。这个特定的型号去掉了 SAW 滤波器以覆盖 0.1MHz 至 4GHz。为设备供电有 2 个选项：通过 USB 接头或通过偏置三通。Airspy 等器件可以启用 bias-tee 并为器件供电。或者，可以使用任何 mini USB 电缆为设备供电。我们选择通过 USB 线路为设备供电。

Technical Data :

Gain 24db @ 100MHz -> **15.2db @ 1415MHz**

NF 0.75dB

Supply Voltage USB or Bias tee 5V

技术数据：
增益 24db @ 100MHz -> 15.2db @ 1415MHz
噪声系数 0.75dB
电源电压 USB 或偏置 3V

In the images below we show the unit and its frequency response.

在下图中，我们显示了该装置及其频率响应。

Frequency (MHz) 频率（MHz）	***Gain (dB)*** 增益（dB）
1300	**16**
1420	**15**
1500	**14**

Airspy R2 SDR Receiver

Airspy R2 SDR 接收器

From the manufacturer's site : The Airspy R2 sets a new level of performance in receiving the VHF and UHF bands thanks to its low-IF architecture based on the **Rafael Micro R820T2 chip** and a **high quality 12-bit Oversampling ADC** and state-of-the-art DSP. In Oversampling mode, the Airspy R2 applies analog RF and IF filters to the signal path and increases the **resolution up to 16 bits** using software decimation. Coverage can be extended to HF bands via the up-converter companion SpyVerter (not used by us). Airspy R2 is 100% compatible with all existing software, including the SDR # scan standard, but also with a number of popular software-defined radio applications such as SDR-Radio, HDSDR, GQRX and **GNU Radio**. The stability and precision of the clock for the local oscillator, given at 0.5ppm, is also important for our application.

来自制造商的网站： Airspy R2 凭借其基于 Rafael Micro R820T2 芯片的低 IF 架构和高质量的 12 位过采样 ADC 和最先进的 DSP，在接收 VHF 和 UHF 频段方面树立了新的性能水平。在过采样模式下，Airspy R2 将模拟 RF 和 IF 滤波器应用于信号路径，并使用软件抽取将分辨率提高到 16 位。覆盖范围可以通过上变频器配套 SpyVerter（我们未使用）扩展到 HF 频段。Airspy R2 与所有现有软件 100% 兼容，包括 SDR # 扫描标准，但也与许多流行的软件定义无线电应用程序兼容，例如 SDR-Radio、HDSDR、GQRX 和 GNU Radio。本振时钟的稳定性和精度（0.5ppm）对于我们的应用也很重要。

Key Features of the AirSpy SDR Receiver :

● Continuous **24 – 1700 MHz** native RX range, down to DC with the SpyVerter option (not used)

● 3.5 dB NF between 42 and 1002 MHz

● Maximum RF input of +10 dBm

● Tracking RF filters

● 35dBm IIP3 RF front end

● **12bit ADC @ 20 MSPS** (10.4 ENOB, 70dB SNR, 95dB SFDR)

● 10MSPS IQ output

● **0.5 ppm high precision, low phase noise clock**

● 10 MHz panoramic spectrum view with up to 9 MHz alias/image free

● **No IQ imbalance**, DC offset or 1/F noise at the center of the spectrum1 x RF Input

● 4.5v software switched Bias-Tee to power LNAs and up/down-converters (not used)

● Operating temperature: -10°C to 40°C

AirSpy SDR 接收器的主要特点：
● 连续 24 – 1700 MHz 原生 RX 范围，使用 SpyVerter 选项（未使用）低至 DC
● 3.5 dB NF 在 42 至 1002 MHz 之间
● 最大射频输入 +10 dBm
● 跟踪射频滤波器
● 35dBm IIP3 射频前端
● 12 位 ADC @ 20 MSPS（10.4 ENOB、70dB SNR、95dB SFDR）
● 10MSPS IQ 输出
● 0.5 ppm 高精度、低相位噪声时钟
● 10 MHz 全景频谱视图，最高 9 MHz 无混叠/图像
● 频谱中心无 IQ 不平衡、直流偏移或 1/F 噪声1 x RF 输入
● 4.5v 软件开关偏置三通，为 LNA 和上/下变频器供电（未使用）
● 工作温度：-10°C 至 40°C

In the configuration of the device (done through the **osmocom** driver in **GNU radio**) the RF gain is set to 0 (default setting), while the IF and BB gains are each set to 10 dB. These very low gain values show the effectiveness of the components placed upstream of the receiver : from the antenna to the LNA and Wideband amplifiers. The bias-T option is also disabled.

在设备的配置中（通过 GNU 无线电中的 osmocom 驱动程序完成），RF 增益设置为 0（默认设置），而 IF 和 BB 增益分别设置为 10 dB。这些非常低的增益值显示了放置在接收器上游的组件的有效性：从天线到 LNA 和宽带放大器。bias-T 选项也被禁用。

References 引用

There are many references on the internet. Here are just some particularly interesting links for those who want to deal with "amateur" radio astronomy :

https://www.radioastrolab.it/radioastronomia/

https://www.haystack.mit.edu/haystack-memo-series/vsrt-and-mosaic-memos/

https://www.haystack.mit.edu/haystack-public-outreach/srt-the-small-radio-telescope-for-education/

互联网上有很多参考资料。以下是一些特别有趣的链接，供那些想要处理 "业余" 射电天文的人使用：
https://www.radioastrolab.it/radioastronomia/
https://www.haystack.mit.edu/haystack-memo-series/vsrt-and-mosaic-memos/
https://www.haystack.mit.edu/haystack-public-outreach/srt-the-small-radio-telescope-for-education/

Conclusions 结论

We have described the construction of a small and inexpensive microwave radio telescope. We took advantage of the wide availability of radio components for satellite TV. The radiometer function, ie the actual measurement of the signal strength, will be implemented via software using the GNURadio framework : this will be the subject of the next post.

我们已经描述了一种小型且廉价的微波射电望远镜的构造。我们利用了卫星电视无线电组件的广泛可用性。辐射计功能，即信号强度的实际测量，将通过使用 GNURadio 框架的软件实现：这将是下一篇文章的主题。

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