# A SIMPLE 11.2 GHZ RADIOTELESCOPE (SW PART)

一个简单的 11.2 GHZ 射电望远镜（软件部分）

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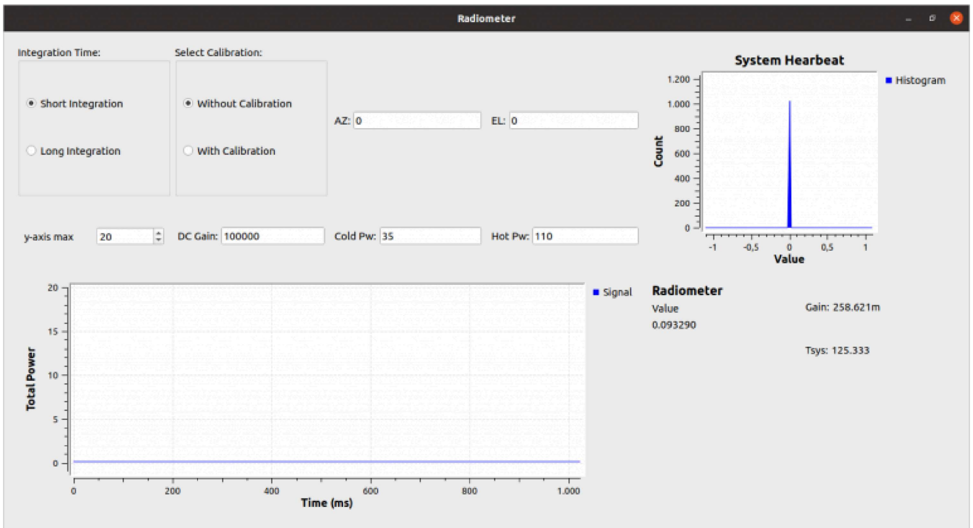



***Abstract :*** *In this post we continue the description of our diy microwave radio telescope. In the first part: A simple 11.2 GHz RadioTelescope (HW Part) we have described the hardware part of the instrument, including the parabolic reflector antenna, the LNB block and the receiver. Now we take care of the software that does the measurement of the signal strength and its integration over time.*

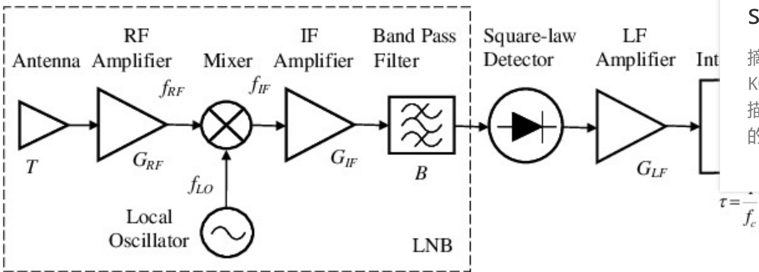
摘要： 在这篇文章中，我们继续描述我们的 diy 微波射电望远镜。在第一部分：一个简单的 11.2 GHz 射电望远镜（硬件部分）中，我们描述了仪器的硬件部分，包括抛物面反射器天线、LNB 块和接收器。现在我们负责测量信号强度及其随时间进行积分的软件。

## Introduction 介绍

The **radiometer** is basically a receiver that has the purpose of me electromagnetic signal captured by the antenna within a specific frequency ba radiometer is shown in the following image: there is an **antenna** conne converter-amplifier) followed by a **square-law detector** which measures the The next stage is an **integrator** (low-pass filter) which has the purpose of av with an appropriate time constant, in order to reduce the statistical fluctuat average), making the signal stand out. Additional components can be interm band-pass filters to limit the receiving band and DC amplifiers to increase the

辐射计基本上是一个接收器，其目的是测量天线在特定频段内捕获的电磁信号的功率。辐射计的基本图如下图所示：天线连 个平方律检测器，用于测量接收信号的功率。下一阶段是积分器（低通滤波器），其目的是以适当的时间常数对信号随时 （零平均值），使信号脱颖而出。其他组件可以是中频放大器、限制接收频段的带通滤波器和用于提高信号电平的直流放大





As it is clear, the detection of the signal strength and the subsequent temporal integration do not preserve the spectral characteristics of the signal: the signal is averaged over time and within the pass-band of the instrument to obtain the average power. The sensitivity of the radiometer increases as the bandwidth increases (more signal is collected as the band increases) and as the integration time increases (the incidence of noise of null mean value decreases). For long integration times it is necessary the **stability of the amplification parameters** and that the physical process under study is stationary.

很明显，信号强度的检测和随后的时间积分并不会保留信号的频谱特性：信号随时间推移并在仪器的通带内平均，以获得平均功率。辐射计的灵敏度随着带宽的增加（随着频带的增加而收集更多的信号）和积分时间的增加（零平均值的噪声发生率降低）而增加。对于较长的积分时间，扩增参数的稳定性以及所研究的物理过程必须是平稳的。

### Equivalent Noise Temperature
### 等效噪声温度

The signal strength measured by the radiometer is usually expressed as a temperature and is called the equivalent noise temperature. This temperature and power are related by the following relationship:

辐射计测量的信号强度通常表示为温度，称为等效噪声温度。此温度和功率通过以下关系相关：

$$W = k*B*Tn$$

Where **k** is Boltzmann's constant, **B** is the frequency band, **W** is the power and **Tn** the equivalent noise temperature. Naturally Tn includes the contributions due to the internal noise of the receiver and the contributions of the signal picked up by the antenna. In turn, the signal picked up by the antenna will be given by the signal coming from the source we are studying, also expressed in terms of **brightness temperature**, added to the background noise (cosmic noise, atmospheric noise, radiation from the ground).

其中 k 是玻尔兹曼常数，B 是频带，W 是功率，Tn 是等效噪声温度。自然，Tn 包括接收器内部噪声的贡献和天线拾取的信号的贡献。反过来，天线接收到的信号将由来自我们正在研究的源的信号给出，该信号也以亮温表示，再加上背景噪声（宇宙噪声、大气噪声、来自地面的辐射）。

### Radiometer Equation 辐射计方程

We can theoretically determine the sensitivity of a radiometer using an equa **equation**, which provides the minimum variation **ΔT** of the equivalent noise can measure:

理论上，我们可以使用一个称为辐射计方程的方程来确定辐射计的灵敏度，该方程提供了系统可以测量的等效噪声温度的最

$$\Delta T = Tsys/\sqrt{(\tau*B)}$$ ΔT = Tsys/√（τ*B）

Where ***τ*** is the integration time, ***B*** is the band and ***Tsys*** is the equivalent tem by the sum of the antenna noise temperature and the receiver noise temperat From the equation above it can be seen how the sensitivity of the radio reception band increases (because more signal is collected) and as the signal i

其中 τ 是积分时间，B 是频带，Tsys 是系统的等效温度，由天线噪声温度和接收器噪声温度之和给出：Tsys = Ta + Tr。
从上面的方程式中可以看出，射电望远镜的灵敏度如何随着接收频段的增加（因为收集到的信号更多）和信号积分时间的增



## GNURadio Software GNURadio 软件

In the previous post **A simple 11.2 GHz RadioTelescope (HW Part)** we descri receiver, consisting of the LNB, a band-pass filter and a wideband amplifier. The signal, after the intermediate amplification stage, is sent to an **SDR device (Airspy)** which acquires and digitizes the signal.

The data stream is then processed via software (with the GNURadio framework) in order to create the radiometer functionality.

在上一篇文章 一个简单的 11.2 GHz 射电望远镜（硬件部分）中，我们描述了接收器的硬件部分，包括 LNB、带通滤波器和宽带放大器。信号在中间放大阶段之后被发送到 SDR 设备 （Airspy），该设备对信号进行采集和数字化。然后通过软件（使用 GNURadio 框架）处理数据流，以创建辐射计功能。

GNURadio is a free and open source software development toolkit that provides signal processing blocks for implementing radio software projects. It can be used with external RF hardware to create software defined radio (SDR) or even without hardware in a simulation environment. It is widely used in hobby, academic and commercial environments to support both wireless communications research and real world radio systems.

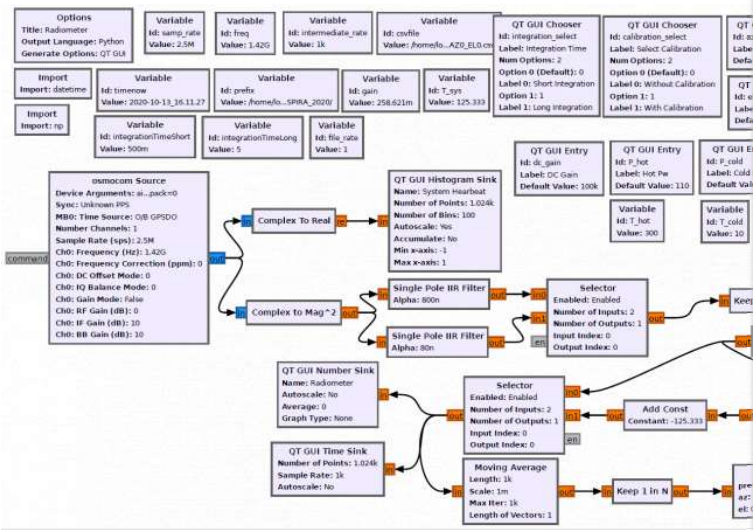
GNURadio 是一个免费的开源软件开发工具包，它为实现无线电软件项目提供信号处理块。它可以与外部射频硬件一起使用，以创建软件定义无线电 （SDR），甚至可以在仿真环境中无需硬件。它广泛用于业余爱好、学术和商业环境，以支持无线通信研究和现实世界的无线电系统。

We have already used and described GNURadio in the project on receiving the emission at 21 cm of neutral hydrogen. We refer to this post for more details: **GNURadio Software for 21cm Neutral-Hydrogen Line**.

我们已经在接收 21 cm 中性氢发射的项目中使用和描述了 GNURadio。有关更多详细信息，请参阅这篇文章：用于 21cm 中性氢管线的 GNURadio 软件。

The GNURadio application we need now is basically a radiometer. The signal picked up by the antenna and subsequently amplified and filtered by the RF components is sent to the SDR receiver which acquires it in digital format. At this point the signal must be processed in order to calculate its total power in the reception band and subsequently integrated over time (filtered) and recorded on file.
Our radiometer is depicted in the following diagram.

我们现在需要的 GNURadio 应用程序基本上就是一个辐射计。天线拾取的信号随后被 RF 组件放大和过滤，然后发送到 SDR 接收器，SDR 接收器以数字格式获取信号。此时，必须对信号进行处理，以计算其在接收频带中的总功率，然后随时间进行积分（滤波）并记录在文件中。
我们的辐射计如下图所示。






The **osmocomm source** block is the interface with the Airspy R2 SDR hardwar the bias-T option so in the argument string we have put "airspy = 0, bias = 0, parameter can be set to 2.5 MHz or 10 MHz, these values correspond to a use the first case and 10 MHz in the second. The Frequency parameter is set at 1 frequency of our HW band pass filter. The RF gain is set to 0, while the IF and BB gains are set to 10 dB. We have found that this gain configuration, with our RF hardware, allows for good system utilization. With different amplification chains, these parameters can, of course, be varied in order to optimize performance.

osmocomm 源块是与 Airspy R2 SDR 硬件的接口。在我们的例子中，我们不使用 bias-T 选项，因此在参数字符串中我们输入了 “airspy = 0， bias = 0， pack = 0”。Sample Rate 参数可以设置为 2.5 MHz 或 10 MHz，这些值对应于第一种情况下约为 2.5 MHz 的有用频段，在第二种情况下约为 10 MHz。Frequency 参数设置为 1420 MHz，这是我们的 HW 带通滤波器的中心频率。RF 增益设置为 0，而 IF 和 BB 增益设置为 10 dB。我们发现，这种增益配置与我们的 RF 硬件一起，可实现良好的系统利用率。对于不同的放大链，这些参数当然可以改变以优化性能。

The complex data coming from the SDR device (airspy R2) are sent to the block that determines the instantaneous signal strength in a way similar to a square-law detector:

来自 SDR 设备 （airspy R2） 的复杂数据被发送到块，该块以类似于平方律检测器的方式确定瞬时信号强度：

$$P = I^2 + Q^2$$ P = I2 + Q2

where I and Q are the components in phase (real component) and in quadrature (imaginary component). The signal is then filtered (integrated) with a **single-pole IIR filter**. There are actually two filters, alternative to each other, which provide two different time constants, one short and one long, which can be configured in the respective variables and selected from the radiometer GUI. The short time constant could be **0.5 s** while the long one **2 s**. The Alpha coefficient of the filter is calculated with the formula:

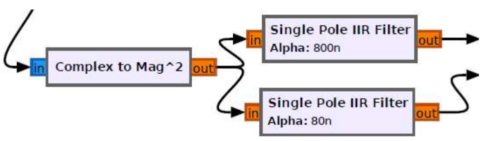
其中 I 和 Q 是同相（实部）和正交（虚部）的分量。然后用单极点 IIR 滤波器对信号进行滤波（集成）。实际上有两个过滤器，彼此交替，它们提供两个不同的时间常数，一个短时间常数和一个长时间常数，可以在相应的变量中进行配置，也可以从辐射计 GUI 中选择。短时间常数可以是 0.5 秒，而长时间常数可以是 2 秒。滤波器的 Alpha 系数使用以下公式计算：

***Alpha = 1/samp_rate*IntegrationTime***

Alpha = 1/samp_rate*集成时间

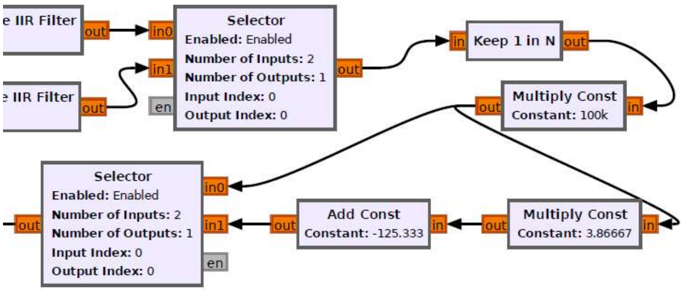
Where ***samp_rate*** is the sampling frequency (2.5 MHz or 10 MHz) and the ***integrationTime*** is the filter integration time constant. The flowchart is shown in the following image.

其中 samp_rate 是采样频率（2.5 MHz 或 10 MHz），integrationTime 是滤波器积分时间常数。流程图如下图所示。



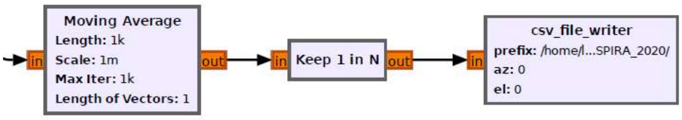

After the selector block that determines the IIR filter used, the data stream i reduce the number of samples and not to overload the computer. the decima by: ***int(sample_rate/intermediate_rate)***. Where ***intermediate_rate*** is the ir samples, configured at **1 KHz**. After decimation, the data is “amplified” by configurable from the GUI: **DC Gain.** Downstream of this block there is the GUI, the calibration can be “enabled” or “disabled” using the selector block. C next paragraph.

在确定使用的 IIR 滤波器的 selector 块之后，数据流进行抽取以减少样本数量并且不会使计算机过（sample_rate/intermediate_rate）。其中 intermediate_rate 是样本的中频，配置为 1 KHz。抽取后，数据被“放大”，Gain。该块的下游是校准部分。在 GUI 中，可以使用 selector 块“启用”或“禁用”校准。校准将在下一段中介绍。




In the last part of the flowchart the average (moving average) of the last 1000 samples is calculated, in order to have a further integration in order to improve the signal/noise ratio. Before recording the data on a file in csv format, the stream is decimated again with the decimation constant determined by: ***int(intermediate_rate/file_rate)***. Where ***file_rate*** is the frequency of writing data to file. The csv_file_writer block is a custom block made in python that records the input data and the timestamp in csv format.

在流程图的最后一部分，计算了最后 1000 个样本的平均值（移动平均值），以便进一步积分以提高信噪比。在以 csv 格式将数据记录到文件上之前，流会再次被抽取，抽取常数由以下公式确定：int（intermediate_rate/file_rate）。其中 file_rate 是将数据写入文件的频率。csv_file_writer 块是用 python 制作的自定义块，它以 csv 格式记录输入数据和时间戳。




## Calibration 校准

The calibration of the radio telescope has the aim of calibrating the signal measured by the instrument with emitters with a known brightness temperature. As described in the first paragraph, the signal obtained at the receiver output is the sum of the useful signal with the antenna and receiver noise. To use our radio telescope efficiently and to obtain accurate measurements, however, we need to separate, as far as possible, the contribution of the signal from the noise: this is done with the
If we assume that the behavior of the system is **linear** then it is sufficient
known temperatures and sufficiently distant from each other. The measureme
**cold point**, for example by pointing the antenna to the **zenith**, in the absence
brightness temperature has a value of around 10 °K; and pointing the ante
example the **ground**, for which a brightness temperature of about 300 °K is as
The values obtained are entered directly into the GUI and then the system
selected. In this way the system output is directly the equivalent noise
antenna. For further details on the calibration procedure, please refer to **GN
Neutral-Hydrogen Line**.

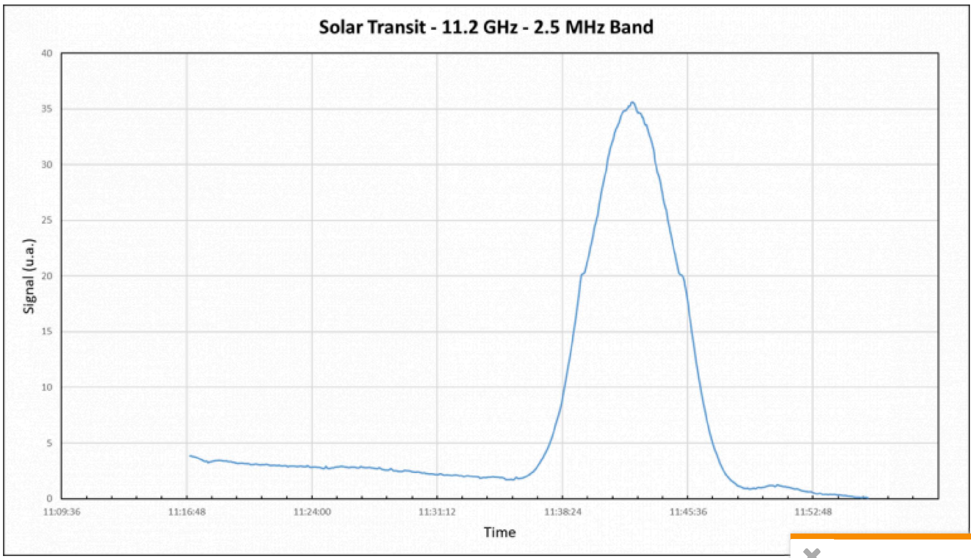
射电望远镜的校准目的是用具有已知亮度温度的发射器校准仪器测量的信号。如第一段所述，在接收器输出端获得的信号是
为了有效地使用我们的射电望远镜并获得准确的测量结果，我们需要尽可能地将信号的贡献与噪声分开：这是通过校准程序
如果我们假设系统的行为是线性的，那么测量两个点就足够了，这两个点具有已知的温度并且彼此之间足够远。测量通常
将天线指向天顶，其中亮度温度约为 10 °K;并将天线指向热点，例如地面，其假定亮度温度约为 300 °K。
获得的值直接输入到 GUI 中，然后选择"带校准"的系统模式。这样，系统输出直接与从天线看到的等效噪声温度。有关校
管线的 GNURadio 软件。

## Solar Transit 太阳能运输

The simplest observations for an amateur system like ours are the **transit registrations**. In practice, the radio telescope is pointed towards a predetermined direction and waits for the radio source to pass within the antenna beam, while recording the strength of the received signal. This technique is especially applicable to “point” radio sources such as the sun and the moon.

The sun has an apparent diameter of **0.31°**, while our antenna has a beam of **1.45°**. The result obtained will be the **spatial convolution** between the radio-source distribution and the beam diagram of our antenna: in practice the spatial distribution of the radio-source is “diluted” by the antenna over a greater space. In the image below we show the recording of the transit of the sun made with our 1.2 m antenna on a 2.5 MHz band.

对于像我们这样的业余系统来说，最简单的观察是过境登记。在实践中，射电望远镜指向预定的方向，等待射电源在天线波束内通过，同时记录接收到的信号的强度。该技术特别适用于“点”射电源，例如太阳和月亮。
太阳的视直径为 0.31°，而我们的天线的波束为 1.45°。获得的结果将是无线电源分布和天线波束图之间的空间卷积：在实践中，无线电源的空间分布在更大的空间上被天线“稀释”。在下图中，我们显示了使用 1.2 m 天线在 2.5 MHz 频段上进行的太阳凌日记录。

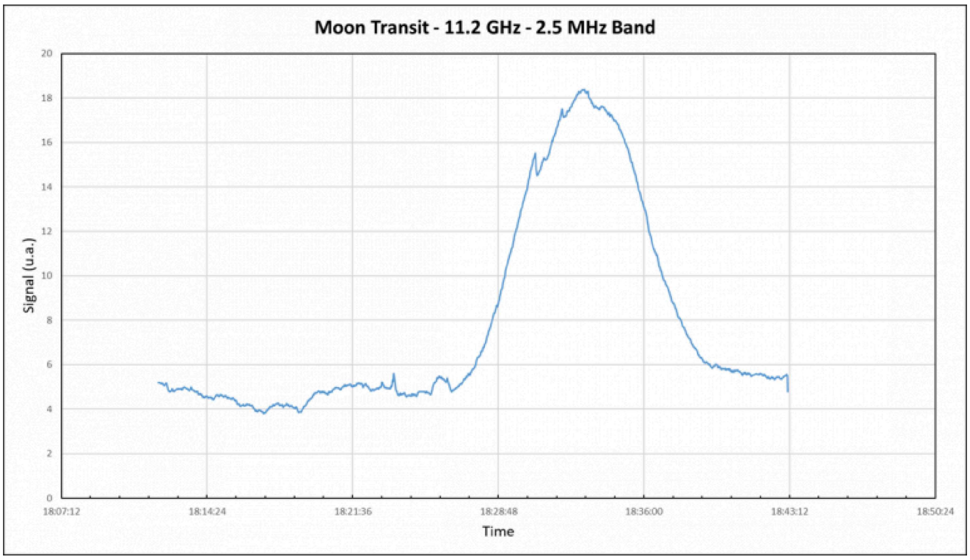



## Moon Transit 月球过境

Using the same transit registration technique, we measured the radio emiss has an apparent diameter equal to that of the sun: 0.31° and therefore the the image below we show the recording of the transit of the moon made with MHz band.

使用相同的凌日配准技术，我们测量了月球的无线电发射。月亮的视直径等于太阳的视直径：0.31°，因此得到的结果是相 在 2.5 MHz 频段上进行的月球凌日记录。






## Conclusions 结论

At 11.2 GHz the main radio sources (excluding sun and moon) are quite weak and difficult to receive with a 1.2 m parabolic reflector. The distributed emission of the **Milky Way** should be within our reach, but radio-sources such as **Cassiopeia A**, **Taurus A** and **Cygnus A** are at the limit of the possibilities of our instrument, but an attempt can be made! It could be useful to increase the reception band: 10 MHz still with airspy or using a broadband HW RF power detector. In this last case we would have the whole band of our system available: the 80 MHz determined by the band-pass filter. But this will be the subject of another post on our Blog.

在 11.2 GHz 时，主要无线电源（不包括太阳和月亮）非常微弱，很难用 1.2 m 的抛物面反射器接收。银河系的分布式发射应该在我们触手可及的地方，但仙后座 A、金牛座 A 和天鹅座 A 等放射源已经达到了我们仪器可能性的极限，但可以进行尝试！增加接收频段可能很有用：10 MHz 仍然使用 airspy 或使用宽带硬件射频功率检测器。在最后一种情况下，我们将有系统的整个频段可用：由带通滤波器确定的 80 MHz。但这将是我们博客上另一篇文章的主题。

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