# Amateur Radio Astronomy:

## we use the *RAL10KIT* to build our first radio telescope

Flavio Falcinelli

RadioAstroLab s.r.l. 60019 Senigallia (AN) - Italy - Via Corvi, 96
Tel: +39 071 6608166 - Fax: +39 071 6612768

info@radioastrolab.it www.radioastrolab.com


*RadioAstroLab* produces a range of instruments for amateur radio astronomy and scientific applications: they are tools ready to use and available in various configurations, they can be used by individual enthusiasts and groups of researchers or schools which look to the world of radio astronomy with approaches more or less demanding and for all budgets. The product range is constantly evolving, encompassing various fields of scientific interest and research.

At the same time, with the hope to have satisfied many requests, we thought about the experimenters who want to “get their hands dirty” with circuits and electronics, building their own tools with imagination, technical skill and economy. This is a practicable path in amateur radio astronomy, and it is also very interesting educationally: there are many examples available on the web that describe the construction of simple and inexpensive radio telescopes using components from the satellite TV market. We ourselves have contributed with some modest suggestion. It is undoubtedly interesting solutions and of immediate implementation. If, instead, we wish to obtain a significant improvement in quality, it will be preferable to move towards applications designed "ad hoc" for amateur radio astronomy, ensuring ease of use and economy.

From the information we have received and from our direct experience was born a module pre-

RadioAstroLab s.r.l.
60019 Senigallia (AN) - Italy
T +39 071 6608166
F +39 071 6612768
www.radioastrolab.it

assembled and tested that, combined with readily available commercial components, implements the receiving chain of a didactic radio astronomy receiver that includes the interface block for the communication with a PC and software management. The item is very easy to use and economic.

With these ideas in mind, we turned to the illustrious category of fans experimenters to which we propose the construction of an interesting amateur microwave radio telescope (11.2 GHz) using *RAL10KIT* provided by *RadioAstroLab*. The kit includes the radiometric module *microRAL10* (the "heart" of the receiver), the *RAL126* USB interface that allows interfacing with a computer, the acquisition and control software *DataMicroRAL10*. The initial chain of the receiving system is realized with commercial components from the market of satellite TV, not included in the kit: there is great freedom in choosing a parabolic reflector antenna with its LNB, feed and coaxial cable for connection to the system.

In this paper we describe how to connect and complete the various parts to build an efficient low-cost radio telescope which is the first safe approach to radio astronomy. The experimenters who wish to develop custom applications for the management of the instrument will find abundant information on the serial communication protocol used.

## Introduction

The construction of simple and inexpensive radio telescopes operating in from 10 to 12 GHz frequency band is now greatly simplified if you use antenna systems and components from the market of satellite TV, available everywhere at low cost. Remarkable is the educational value of a tool that enables a simple and immediate approach to radio astronomy and basic instrumental techniques. Thanks to the commercial deployment of the satellite TV service are readily available modules such as low noise preamplifiers-converters (*LNB: Low Noise Block*) and IF preamplifiers line. In this wide range of products are included parabolic reflectors antennas available in various sizes, complete with mechanical support for the assembly and orientation. In addition, to facilitate the installation of satellite reception system, can be found broadband detector modules called "*SAT-Finder*" used to verify the correct orientation of the antenna on the satellite: modifying this device, some amateur radio astronomers have built simple radiometers SHF with ultra-high bandwidth. Much information on these projects can be found on the web.

Using a parabolic reflector antenna, combined with specific LNB with feed and connecting the system to the *RAL10KIT* of *RadioAstroLab* you can build a radiometer operating at 11.2 GHz for the study of the thermal radiation of the Sun, Moon, and more intense radio sources, with sensitivity mainly function of the size of the antenna. It is a complete tool which also provides the USB interface circuit for communication with a management PC equipped with the *DataMicroRAL10* software. The user only needs to connect the components according to the instructions supplied, to provide a power source and assemble the system in an enclosure: the telescope is ready to begin the observations. The construction and development of this tool could be tackled successfully by students, radio amateur and radio astronomy enthusiasts, getting results more interesting as the larger the antenna used and the more "fancy" and expertise is used to expand and refining its basic performance.

Due to the short wavelength, it is relatively simple to build instruments with good directivity and acceptable resolution capabilities. Although in this frequency range is not "shine" particularly intense radio sources (excluding the Sun and the Moon), the sensitivity of the system is enhanced by the large bandwidth used and the reduced influence of artificial disturbances: the radio telescope can be installed on the roof or the garden of the house in an urban area. Television geostationary satellites can be interference sources, you can avoid them without limiting the scope of observation, since their position is fixed and known.

# The receiver: how work a *Total-Power* radiometer.

The *radiometer* is a microwave receiver very sensitive and calibrated, used to measure the temperature associated to the scenario intercepted by the antenna, since any natural object emits a noise power function of the temperature and of the physical characteristics.

In radiometry is convenient to express the power in terms of equivalent temperature: according to the *Rayleigh-Jeans law*, which applies at microwave frequencies, it is always possible to determine a temperature of a black body (called *brightness temperature*) that radiates the same power of the energy dissipated by a terminating resistor connected to the receiving antenna (*antenna temperature*). Considering an ideal antenna "seeing" an object characterized by a given brightness temperature, one can express the measured signal power from the antenna is expressible with the *antenna temperature*. Objective of the radiometric measurement is to derive the brightness temperature of the object from the antenna temperature with resolution and accuracy. The radiometer is a calibrated microwave radio receiver.

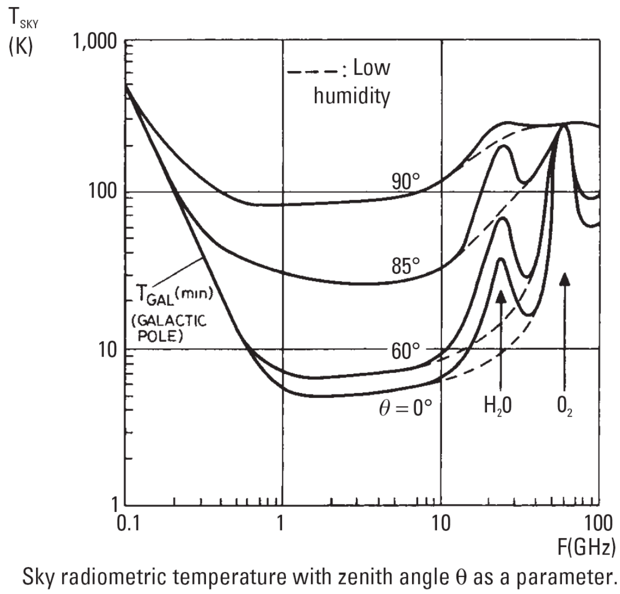


**Fig. 1:** Sky brightness temperature as a function of frequency and of the elevation angle of the antenna.

In radio astronomy the received signal is directly proportional to the power associated to the radiation mediated within the pass band of the instrument, then the brightness temperature of the region of sky "seen" by the antenna beam. *The radiometer behaves like a thermometer that measures the equivalent noise temperature of the observed celestial scenario*. Our radio telescope, operating at 11.2 GHz frequency, detects a temperature of very low noise (due to the fossil radiation approximately 3 K), generally in the order of 6-10 K (the *cold sky*) which corresponds to the lowest temperature measurable from the instrument and takes into account the instrumental losses (Fig. 1), if the antenna is oriented towards a region of clear and dry sky, where radio sources are absent (*clear atmosphere*, with negligible atmospheric absorption - Fig. 2). If the orientation of the antenna is kept at 15°-20° above the horizon, away from the Sun and the Moon, we can estimate an temperature of antenna between a few degrees and a few tens of degrees (mainly due to the secondary lobes). Pointing the antenna on the ground the temperature rises to values of the order of 300 K if it is interested in all the received beam.

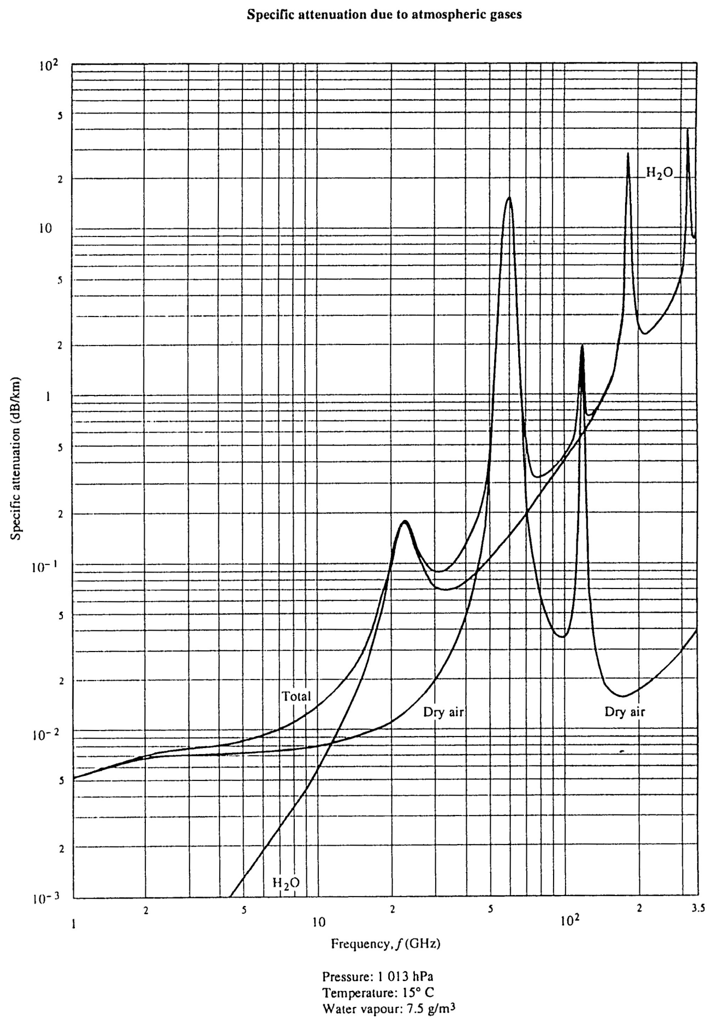


**Fig. 2:** Attenuation due to the absorption properties of the gas present on the atmosphere.

The most simple microwave radiometer (Fig. 3) comprises an antenna connected to a low noise amplifier (*LNA: Low Noise Amplifier*) followed by a detector with quadratic characteristic. The "useful information in radio astronomy" is the power associated with the received signal, proportional to its square: the device which provides an output proportional to the square of the applied signal is the detector, generally implemented with a diode operating in the region of its characteristic curve with the quadratic response. To reduce the contribution of the statistical fluctuations of the noise revealed, and then optimize the sensitivity of the receiving system, follows an integrator block (low-pass filter) that calculates the time average of the detected signal according to a given time constant.

The radiometer just described is called *Total-Power receiver* because it measures the total power associated with the signal received by the antenna and the noise generated by the system. The signal output of the integrator appears as a quasi-continuous component due to the noise contribution of the system with small variations (of amplitude much less than that of the stationary component) due to the radio sources that "transit" before the antenna beam. Using a differential circuit of post-detection, if receiver's parameters are stable, it is possible to measure only the power changes due to the radiation coming from the object "framed" by the receive beam, "erasing" the quasi-continuous component due to noise of the receiving system: this is the purpose of the reset signal of the baseline shown in Fig. 3. The main problem of the radioastronomical observations is related to the instability amplification factor with respect to temperature changes: you can observe drifts on quasi-continuous component revealed that "confuse" the instrument, partially canceling the compensation action of the base line. Such fluctuations are indistinguishable from "useful variations" of the signal. If the receiving chain amplifies greatly, due to instability, it is easy to observe fluctuations in the output signal such as to constitute a practical limit to the maximum value used for the amplification. This problem can be partially solved, with satisfactory results in applications amateur, thermally stabilizing the receiver and the outdoor unit (*LNB: Low Noise Block*) located on the antenna focus and more subject to daily temperature.

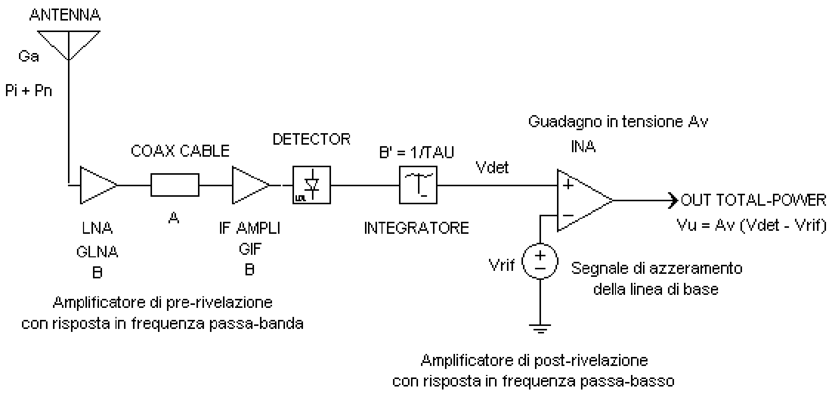


**Fig. 3:** Simplified block diagram of a *Total-Power radiometer*.

Before entering into the construction of the receiver briefly describe the characteristics of the *microRAL10* radiometric module that forms the core of the system. Figure 4 shows a block diagram of the radio telescope. For simplicity it is not shown the power supply. You can see the three main sections of the receiver: the first is the *LNB* (*Low Noise Block*), which amplifies the received signal and converts it down in the standard IF frequency band [950-2150] MHz of satellite TV reception. This device is a commercial product, usually supplied with the antenna and to the mechanical supports needed for assembly. The power gain of the unit is of the order of 50-60 dB, with a noise figure variable between 0.3 and 1 dB.

The signal at the intermediate frequency (IF) is applied to the *microRAL10* module that provides filtering (with a bandwidth of 50 MHz, centered at the frequency of 1415 MHz), amplifies and measures received signal power. A post-detection amplifier adjusts the level of the detected signal to the dynamics of acquisition of the analog-digital converter (ADC with 14 bit resolution) that "digitizes" the radiometric information. This final block, managed by a micro controller, generates a programmable offset for the radiometric baseline (signal $V_{ref}$ in Fig. 3) calculates the moving average of an established number of samples and forms the packet of serial data that will be transmitted to the central unit. The last stage is the *RAL126* USB interface card that handles communication with the PC on which the *DataMicroRAL10* software will be installed for the acquisition and instrument control. The processor executes the critical functions of processing and control minimizing the number of external electronic components and maximizing the flexibility of the system due to the possibility to schedule the operating parameters of the instrument. The use of a module specifically designed for radio astronomy observations, which integrates the functionality of a radiometer, ensures to the experimenter who wants to build his own instrument, safe and repeatable performance.

Assuming you use a good quality LNB with a noise figure of the order of 0.3 dB and an average gain of 55 dB, you get an equivalent noise temperature of the receiver of the order of 21 K and a power gain of the radio frequency chain of about 75 dB. As you will see, these benefits are adequate to implement an amateur radio telescope able to observe the most intense radio sources in the band 10-12 GHz. Receiver sensitivity will be dependent on the characteristics of the antenna which is the collector of cosmic radiation, while the thermal excursions influence the stability and repeatability of the measurement.

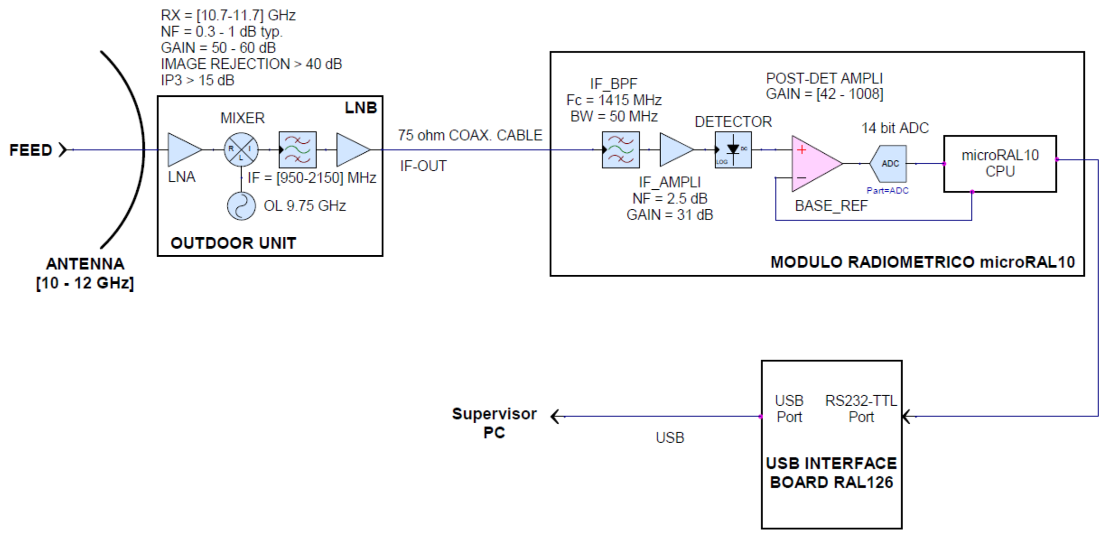


**Fig. 4:** Block diagram of the radio telescope described in the article. The outdoor unit LNB (with feed) is installed on the focus of the parabolic reflector: a coaxial cable TV-SAT from 75 Ω connects the outdoor unit with the *microRAL10* module that communicates with the PC (on which you have installed the *DataMicroRAL10* software) through the interface *RAL126* USB. The system uses a proprietary communication protocol. In the scheme does not appear the power supply.

The use of antennas with a large effective area is an indispensable requirement for radio astronomy observations: there is no limit regarding the size of the antenna usable, except economic factors, space, and installation related to the structure of support and system pointing motorization. These are the areas where the imagination and skill of the experimenter are crucial to define the instrument's performance and can make the difference between an installation and the other. While using *RAL10KIT* that ensure the minimum requirements for the radio telescope, the work of optimizing your system with a choice and proper installation of RF critical parts (antenna, feed and LNB), the implementation of techniques that minimize the negative effects of temperature ranges, gives you advantages in the performance of the instrument.

The radiometric module has been designed considering the following requirements:

- Complete radiometric receiver that includes a band pass filter, IF amplifier, detector with quadratic characteristic (temperature compensated), post-detection amplifier with programmable gain, offset and integration constant, acquisition of radiometric signal with 14-bit resolution ADC, micro controller for management of the device and for serial communication. A regulator powers the LNB through the coaxial cable by switching on two different voltage levels (about 12.75 V and 17.25 V) allowing the select of the polarization on reception (horizontal or vertical).
- Center frequency and bandwidth compatible with the protected radio astronomy frequency of 1420 MHz and the values of the standard IF satellite TV (typically 950-2150 MHz). The ability to define and limit the bandwidth of the receiver, including inside the frequency 1420 MHz, it is important to ensure repeatability in performance and to minimize the effects of external

interference (frequencies close to 1420 MHz should be free enough to emissions to time reserved for radio astronomy research). The receiving frequency of the radiotelescope will be 11.2 GHz.

- Very low power consumption, modularity, compactness, economy. The internal electronics of the *microRAL10* module are shown in Fig. 5.

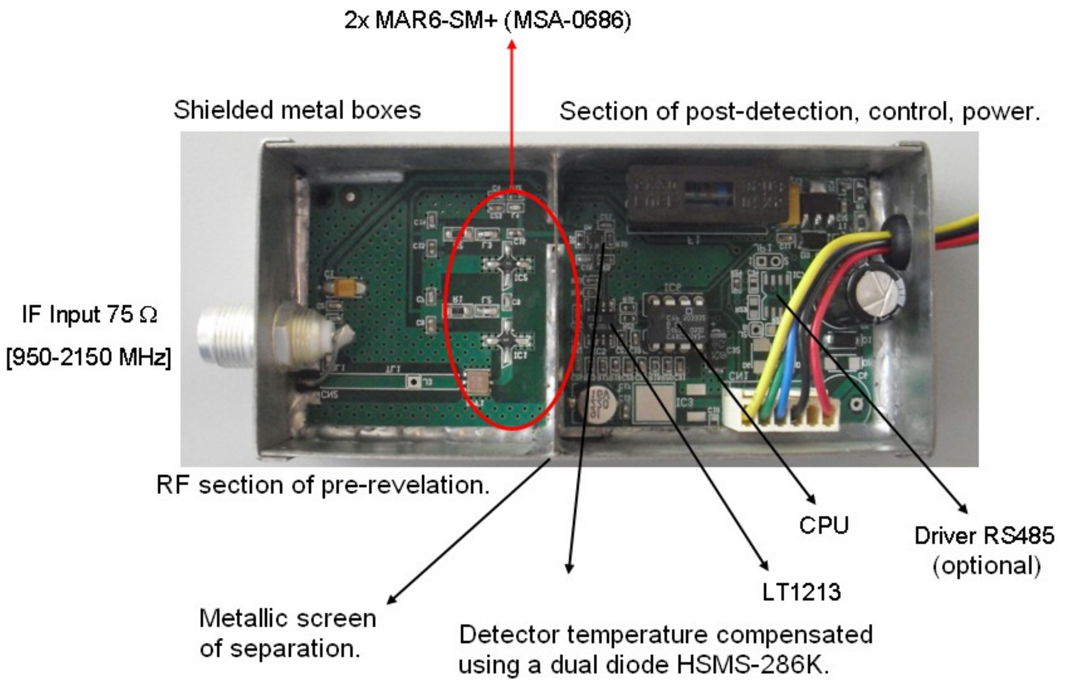


**Fig. 5:** Internal parts of the radiometric *microRAL10* module, the "heart" of the radio telescope.

The electronics are assembled within a metallic box comprising a coaxial F connector for the signal from the LNB and a pass-cable from which they exit the cables that connect to the *RAL126* USB interface module and those for the connection to the power supply (Fig. 5).

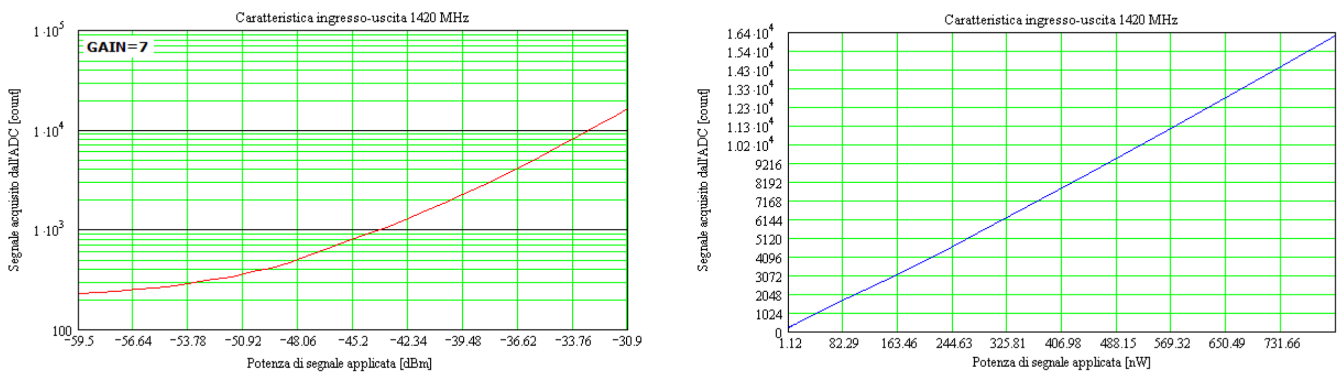


**Fig. 6:** Input-output characteristic of the *microRAL10* module measured in the laboratory with a post-detection gain *GAIN=7*, (gains voltage equal to 168). The abscissa shows the power level of the RF-IF signal applied, in ordinate you see the level of signal acquired from the internal analog-digital converter (expressed in relative units [*ADC count*]).

Figure 6 shows the response of the radiometer when is set a post-detection gain *GAIN=7*. The curve is expressed in relative units [*ADC count*] when applied to the input is a sinusoidal signal with a frequency of 1415 MHz. The tolerances in the nominal values of the components, especially when it relates to the gain of the active devices and the detection sensitivity of the diodes, generate differences in the in-out characteristic (slope and offset level) between different modules. You will need to calibrate the scale of the instrument if you want to get an absolute evaluation of the power associated to the radiation received.

We complete the description explaining the serial communication protocol developed to control the radio telescope: This information is useful for those who want to develop custom applications software alternatives to *DataMicroRAL10* supplied by us. A PC (master) transmits commands to the radiometer (slave) which responds with the data packets comprising the measures of the acquired signals, the values of the operating parameters and the status of the system. The format is asynchronous serial with bit rate of 38400 bits/s, 1 start bit, 8 data bits, 1 stop bit and no parity control. The package of commands transmitted from the master device is the following:

| | |
|---|---|
| **Byte 1: *address*=135** | Address (decimal value) associated with the *RAL10KIT* module. |
| **Byte 2: *command*** | **Command code with the following values:**<br>*command=10*: Sets the reference value for the parameter *BASE_REF* (expressed in two bytes LSByte and MSByte).<br>*command=11*: Sets the post-detection gain *GAIN*.<br>*command=12*: Command sending a single packet of data (*ONE SAMPLE*).<br>*command=13*: Start/Stop sending data in a continuous loop. We have:<br>TX OFF: [LSByte=0], [MSByte=0].<br>TX ON: [LSByte=255], [MSByte=255].<br>*command=14*: Force radiometer *RESET* software.<br>*command=15*: Stores the values of the radiometer parameters in E2PROM.<br>*command=16*: Sets the value for the constant of integration *INTEGRATOR*.<br>*command=17*: Sets the polarization reception *A POL*, *B POL*.<br>*command=18*: Not used.<br>*command=19*: Not used.<br>*command=20*: Enable automatic calibration *CAL* of the baseline. |
| **Byte 3: *LSByte*** | Least significant byte of data transmitted. |
| **Byte 4: *MSByte*** | Most significant byte of data transmitted. |
| **Byte 5: *checksum*** | Checksum calculated as the 8-bit sum of earlier byte. |

The meaning of the parameters is the following:

***BASE_REF***: 16-bit value [0÷65535] proportional to the reference voltage $V_{ref}$ (Fig. 2) used to set an offset on the base line radiometric.
It can automatically adjust the value of *BASE_REF* with calibration procedure *CAL* (*command=20*) in order to position the reference level of the received signal (which corresponds to "zero") in the middle of the scale of measurement.
This parameter can be saved in the internal memory of the processor using *command = 15*.

***GAIN***: Voltage post-detection gain. You can select the following values:
*GAIN=1*: actual gain 42.
*GAIN=2*: actual gain 48.
*GAIN=3*: actual gain 56.
*GAIN=4*: actual gain 67.

*GAIN=5*: actual gain 84.
*GAIN=6*: actual gain 112.
*GAIN=7*: actual gain 168.
*GAIN=8*: actual gain 336.
*GAIN=9*: actual gain 504.
*GAIN=10*: actual gain 1008.
**The amplification factor value from 1 to 10 are symbolic: verify the matches to know the actual values.**
This parameter can be saved in the internal memory of the processor using *command = 15*.

***INTEGRATOR***: Integration constant of the radiometric measurement. You have:
*INTEGRATOR=0*: integration constant short "A".
*INTEGRATOR=1*: integration constant "B".
*INTEGRATOR=2*: integration constant "C".
*INTEGRATOR=3*: integration constant "D".
*INTEGRATOR=4*: integration constant "E".
*INTEGRATOR=5*: integration constant "F".
*INTEGRATOR=6*: integration constant "G".
*INTEGRATOR=7*: integration constant "H".
*INTEGRATOR=8*: integration constant long "I".
The radiometric measurement is the result of a calculation of the moving average performed on $N=2^{INTEGRATOR}$ samples of signal acquired. Increasing this value reduces the importance of the statistical fluctuation of the noise on the measurement, by introducing a "leveling" in the received signal that improves the sensitivity of the system.

The parameter INTEGRATOR "smooths" the fluctuations of the detected signal with an efficiency proportional to its value. As with any process of integration of the measurement, it should be considered a delay in the recording of the signal related to the time of sampling information, to the conversion time of the ADC and to the number of samples used to calculate the average.

Fig. 11 illustrates the notion. It is possible to estimate the value and the corresponding value of the time constant τ in seconds using the following table:

| ***INTEGRATOR*** | **Integrator time constant τ [seconds]** |
|---|---|
| 0 | 0.1 |
| 1 | 0.2 |
| 2 | 0.4 |
| 3 | 0.8 |
| 4 | 2 |
| 5 | 3 |
| 6 | 7 |
| 7 | 13 |
| 8 | 26 |

***A POL, B POL***: defines the polarization in reception of LNB:
*POL=1*: B polarization B (*B POL.*).
*POL=2*: A polarization A (*A POL.*).

RadioAstroLab s.r.l.
60019 Senigallia (AN) - Italy
T +39 071 6608166
F +39 071 6612768
www.radioastrolab.it

In function of the characteristics of the unit used and its positioning on the focal point of the antenna, the symbols *A POL.* and *B POL.* indicate the vertical or horizontal polarization.
This parameter can be saved in the internal memory of the processor using *command = 15*.

For each command received the radiometer responds with the following data packet:

| | |
|---|---|
| **Byte 1: ADDRESS=135** | Address (decimal value) associated to *RAL10KIT*. |
| **Byte 2: *GAIN + INTEGRATOR*** | Post-detection gain and integration constant. |
| **Byte 3: *POL*** | Polarization in reception (A o B). |
| **Byte 4: LSByte of *BASE_REF*** | Least significant byte of the parameter *BASE_REF*. |
| **Byte 5: MSByte of *BASE_REF*** | Most significant byte of the parameter *BASE_REF*. |
| **Byte 6:** | Reserved. |
| **Byte 7:** | Reserved. |
| **Byte 8: LSByte of *RADIO*** | Least significant byte of the radiometric measurement. |
| **Byte 9: MSByte of *RADIO*** | Most significant byte of the radiometric measurement. |
| **Byte 10:** | Reserved. |
| **Byte 11:** | Reserved. |
| **Byte 12:** | Reserved. |
| **Byte 13:** | Reserved. |
| **Byte 14: *STATUS*** | State variable of the system. |
| **Byte 15: *CHECKSUM*** | Checksum (8-bit sum of all previous bytes). |

The 4 least significant bits of the received Byte2 contain the value of post-detection gain *GAIN* while the 4 most significant bits contain the value *INTEGRATOR* for the integration constant. The 4 least significant bits of the received Byte3 contain the variable *POL* indicating the polarization set in reception.

The Byte 14 *STATUS* represents the state of the system: the bit_0 signals the condition *STOP/START* the continuous transmission of data packets by the radiometer to the PC, while the bit_1 signals the activation of the automatic calibration *CAL* for the parameter *BASE_REF*. The value *RADIO* associated with the radiometric measurement (ranging from 0 to 16383) is expressed with two bytes (*LSByte* and *MSByte*), calculated using the equation: $RADIO = LSByte + 256 \cdot MSByte$ . The same rule applies to the value of the parameter *BASE_REF*.

Using *command=15* it is possible saving in the non-volatile memory of the processor the radiometer's parameters *GAIN*, *BASE_REF* and *POL*, so as to restore the calibration conditions saved each time you power the device.

## Technical characteristics of *RAL10KIT*

- Operating frequency of the receiver: 11.2 GHz (using standard LNB for satellite TV).
- Input frequency (RF-IF) radiometric module: 1415 MHz.
- Bandwidth of the receiver: 50 MHz.
- Typical gain of the RF-IF section: 20 dB.
- Impedance F connector for the RF-IF input: 75 Ω.
- Double diode as quadratic temperature compensated detector for measuring the power of the received signal.
- Setting the offset to the baseline radiometric.
- Automatic calibration of the baseline radiometric.
- Programmable constant integration: Programmable moving average calculated on

RadioAstroLab s.r.l.
60019 Senigallia (AN) - Italy
T +39 071 6608166
F +39 071 6612768
www.radioastrolab.it

$N=2^{INTEGRATOR}$ acquired adjacent samples.
Time constant ranging from about 0.1 to 26 seconds.

- Voltage post-detection programmable gain: from 42 to 1008 in 10 steps.
- Acquisition of the radiometric signal: 14-bit ADC resolution.
- Storing of receiver's operating parameters in the internal non-volatile memory (E2PROM).
- Microprocessor for the control of the receiving system and manage the serial communication.
- USB interface (type B) for connection to a PC using proprietary communication protocol.
- Management of the change of polarization (horizontal or vertical) with the voltage jump, if you use LNB that have this feature.
- Supply voltages: 7 ÷ 12 VDC – 50 mA.
  20 VDC – 150 mA.
- LNB supply through coaxial cable, protected by a fuse inside the radiometric module.

## *DataMicroRAL10 s*oftware for data acquisition and control.

The supply of the *RAL10KIT* includes *DataMicroRAL10* software acquisition and control: it is all you need, as basic level, to manage our radio telescope.

*DataMicroRAL10* is an application developed to monitor, capture, view (in graphical form) and record the data from the radio telescope based on our kit. The program is simple, developed for immediate use and "light" on PCs equipped with *Windows* operating systems (32-bit and 64-bit), *Mac OS X (intel and PPC) and Linux (32-bit and 64-bit)*, equipped with at least a standard USB port. You can use the program without license restrictions and/or number of installations.

Following the instructions to install the program.

1. ***Windows* operating systems with 32-bit architecture (x86) and 64-bit (x64):**
   Copy the folder *DataMicroRAL10 X.X Win x86* or *DataMicroRAL10 X.X Win x64* on your desktop (or another directory specifically created). Within the previous folders are located, respectively, the installers *DataMicroRAL10 X.X setup x86.exe* or *DataMicroRAL10 X.X setup x64.exe*. Open the file for your system to launch the installation and follow the installation wizard instructions. The setup will install the program in the *C:\program files\DataMicroRAL10 X.X*.
   ***Mac OS X* operating systems:**
   Copy the folder *DataMicroRAL10 X.X Mac os x* on your PC (such as your desktop or another directory specifically created): inside the file is located *DataMicroRAL10 X.X.app*, the program does not require installation.
   ***Linux* based operating systems with 32-bit architecture (x86) and 64-bit (x64):**
   Copy the folder *DataMicroRAL10 X.X Linux x86* or *DataMicroRAL10 X.X Linux x64* on your desktop (or another directory specifically created). Within the previous folders are located, respectively, *DataMicroRAL10_X.X_x86.sh and DataMicroRAL10_X.X_x64.sh*, the programs does not require installation.
2. Before you start the program it is essential to install the driver interface to the PC's USB port. The drivers for various operating systems (which emulate a serial COM port) and installation instructions are available for download at the website:
   http://www.ftdichip.com/Drivers/VCP.htm
   Choose from the options available for the *FT232R* chip (used in the USB interface module) that is compatible with your operating system and architecture of your PC. This way you ensure you always get the latest version of the firmware. On the page of the site are also given the simple instructions for installing the driver.
3. Completion of the steps above, connect the USB cable to the PC and power the radio telescope.

4. Now the system is ready for the measurement session. You can launch the *DataMicroRAL10 X.X* acquisition software by double-clicking the icon created on the desktop or the start menu.

Program updates will be downloaded free of charge from the website www.radioastrolab.com.

*DataMicroRAL10* is a terminal window that combines the functions of the program: a graphic area displays the time trend of the acquired signal, a box displays the numeric value of each sample (*Radio [count]*), there are buttons for controlling and for general settings. During the start up of the program (double click on) activates a check on the available virtual serial ports on your PC, listed in the *COM PORT* window. After selecting the port engaged by the driver (the other, if any, do not work) opens the connection by pressing the *Connect* button. Now you can start collecting data by pressing the green button *ON*: the graphic trace of the signal is updated in real time along with the numerical value of the amplitude, expressed in relative units on the *Radio [count]* window. The flow of data between the instrument and the PC is indicated by the flashing of the lights (red and green LED) on the USB interface module.

The *General Settings* panel includes controls for the general settings of the program and to control the receiver. The parameter *SAMPLING* defines the number of samples to be averaged (therefore each much time should be updated the graphic trace): it sets the feed speed of the chart, then the total amount of data recorded for each measurement session (logged to a file **.TXT* for each graphic screen). The choice of the value to assign to this parameter is a function of the characteristics of the variability of the signal and filtering needs.

The application checks the instrument: the *GAIN* amplification factor setting, the reference *BASE REF* for the baseline setting, the receiver *RESET* command, the *CAL* automatic calibration procedure activation, the acquisition of a single signal sample *ONE SAMPLE*. All parameter settings, except for the *RESET* command, will be accepted by the instrument only when it is not acquiring data continuously. The time and date at the location will be visible on the *Time* window in the top right.

The left side of the graphics area includes two editable fields where you set the lower value (*Ymin*) and the upper (*Ymax*) for the ordinate scale, the limits of the graphical representation: in this way you can highlight details in the evolution of the acquired signal by performing a “zoom” on the track. The *CLEAR* button clears the graphics window while the option *SAVE* enables the recording of the data acquired at the end of each screen in a formatted text file (extension **.TXT*) is easily imported from any electronic spreadsheet products for further processing. **Data logging only occurs if, during a screen, the acquired signal exceeds the threshold values *ALARM THRESHOLD High and Low* previously set (continuous tracks green).** In particular, the following condition must be verified:

***Radio >= Threshold H*** or ***Radio <= Threshold L.***

It is possible to enable an audible alarm that activates whenever the radiometric signal exceeds the thresholds specified above (Fig. 7).

Each file is identified by a name “root” followed by a serial number identical to the sequence of the graphic screens. An example of a file recorded from *DataMicroRAL10* is the following:

```
DataMicroRAL10
Sampling=1
Guad=10
Ref_Base=33880
Integrator=3
Polarization=A
Date=29/3/2013
```

```
TIME RADIO
14:31:50 3777
14:31:50 3781
14:31:50 3770
14:31:50 3816
14:31:50 3788
…….
…….
```

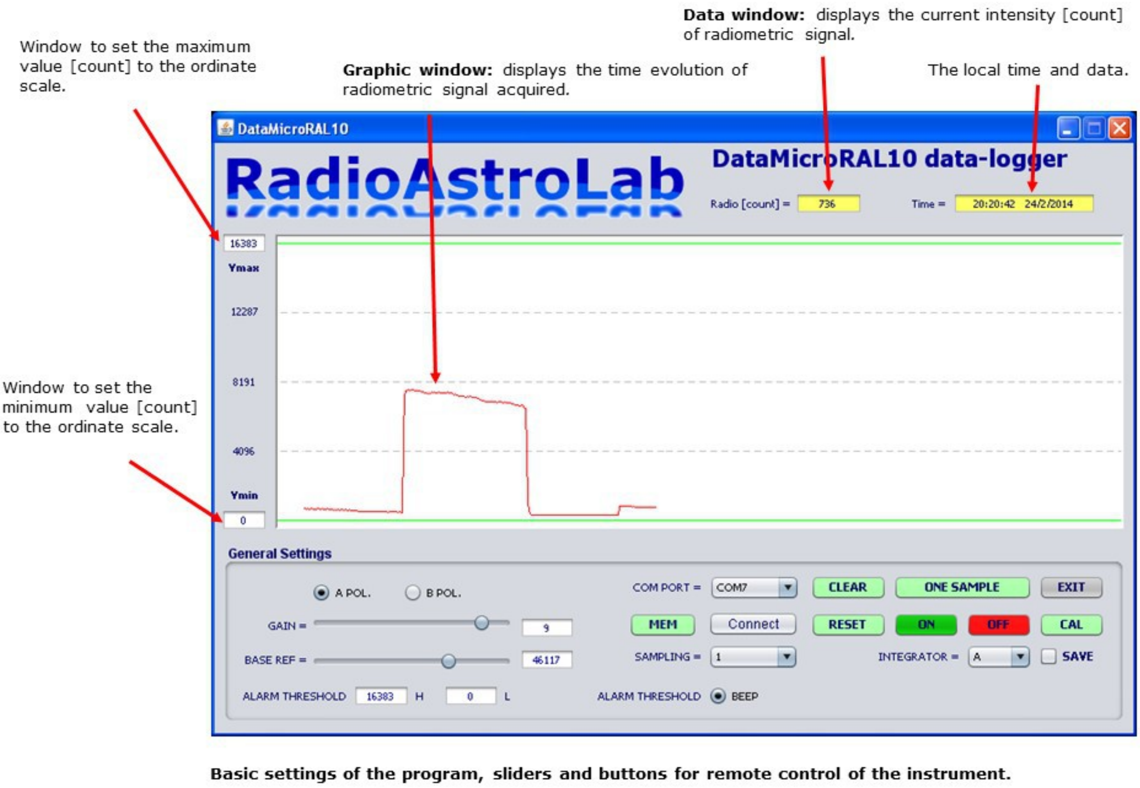


**Fig. 7:** *DataMicroRAL10* software.

You see a header that contains the name of the program, the parameters settings and the start date of the measurement session. Each row of data includes the local time of acquisition of the single sample and its value expressed in relative units [$0 \leq ADC\ count \leq 16383$], separated by a space. The maximum value of the scale, then the resolution of the measurement is determined by the dynamic characteristics of the receiver analog to digital converter (14 bit).

It is possible saving the receiver's operating parameters in a non-volatile memory (post-detection gain *GAIN*, offset for radiometric base-line *BASE_REF* and polarization in reception *POL*) via *MEM* command: in this way, every time you turn on the instrument, the optimum working conditions will be restored, they have been obtained after appropriate calibration and depend on the characteristics of the chain receiver and the scenario observed.

For your convenience, we attach the utility *ImportaDati_DataMicroRAL10*: it is a spreadsheet with macros (in EXCEL) that allows you to import a previously recorded file from *DataMicroRAL10*. You can automatically create graphs (freely editable in the settings) every time you press the button *OPEN FILE* and select a file to import: new data will be overwritten in the table, while the graphics are simply overlapping. You must move the graphics to highlight what is interesting. You need to activate the "macro" from EXCEL when you open *ImportaDati_DataMicroRAL10*.

## Performance of the radio telescope.

Critical parameters of a radio telescope are:

- *Antenna*: gain, width of the main lobe, the shape of the reception diagram.
- *Noise figure*, *overall gain* and *bandwidth* of the blocks of pre-detection.
- *Detection sensitivity*: depends on the type of detector used.
- *Post-detection gain*.
- *Time constant of the integrator*: it reduces the statistical fluctuations of the output signal.

We have verified the theoretical performance of a radio telescope that uses a common antenna for satellite TV (with typical diameters ranging from 60 cm to 200 cm) and an LNB connected to the *RAL10KIT*: it is calculated, using a simulator developed "ad hoc", system sensitivity necessary to conduct a successful amateur radio astronomy observations. As sources of test the simulations were used the Moon (flux of the order of 52600 Jy) and the Sun (flow of the order of $3.24 \cdot 10^6$ Jy at 11.2 GHz), observed using a parabolic reflector antenna circular 1.5 meters in diameter. These radio sources are characterized by flows known and can be used as "calibrators" to characterize the telescope and to measure the diagram of the antenna. The use of large antennas will provide a mapping of the sky with sufficient contrast and observation of other fainter objects such as the galactic center, the radio sources *Cassiopeia A* and *Taurus A*. At the wavelengths of the work of our receiver, the thermal emission of the Moon originate in regions close to its surface will be measurable changes in soil temperature that occur during the lunar day. Equally interesting are the radiometric emission during lunar eclipses and occultations by other celestial bodies. **The simulations have only theoretical value, since they consider an ideal behavior of the receiving system, free of drifts in the amplification factor. Are useful for understanding the operation of the radio telescope and estimate its performance.**

The response of the radio telescope was calculated by setting, for each observation, the value for the post-detection gain providing a quadratic response of the detector. Approximating the reception diagram of antenna and the emission of the radio source as uniformly illuminated circular apertures is possible to determine, in a first approximation, the effects of "filtering" of the spatial shape of the gain function of the antenna on the true profile of radio source, demonstrating how important to know the characteristics of the antenna to ensure proper radiometric measurement of the observed scenario.

The temperature of the antenna is the signal power available at the input port of the receiver. As you will see, the antenna of a radio telescope aims to "level", then to "dilute" the true distribution of brightness that will be "weighted" by its function gain. If the source is extended with respect to the antenna beam, the observed brightness distribution approximates the true one. The estimation of the antenna temperature is complex: many factors contribute to its determination and not all are of immediate evaluation. The contribution to the antenna temperature comes from space that surrounds it, including the soil. The problem that arises observer is to derive the true distribution of the brightness temperature from the temperature measurement of antenna, performing the operation of *de-convolution* between the distribution of brightness of the observed scenario and the function of antenna gain. So it is very important to know the power-pattern of a radio telescope: the temperature of the antenna measured by pointing the main lobe of a given region of space, can contain a non-negligible contribution to energy from other directions if it has side lobes level too high.

The brightness temperature of the soil typically takes values of the order of 240÷300 K, produced with the contribution of the side lobes of the antenna and the effect of other sources such as vegetation. Since the antenna of a radio telescope is oriented toward the sky with elevation angles generally greater than 5°, can pick up thermal radiation from the earth only through the secondary lobes: their contribution depends on their amplitude than that of the main lobe. Since the total noise captured by the antenna is proportional to the integral of the brightness temperature of the observed scenario weighted by its gain function, it happens that a very large object and warm as the soil can make a substantial contribution if the antenna diagram of directors is not negligible in all directions that look at the ground.

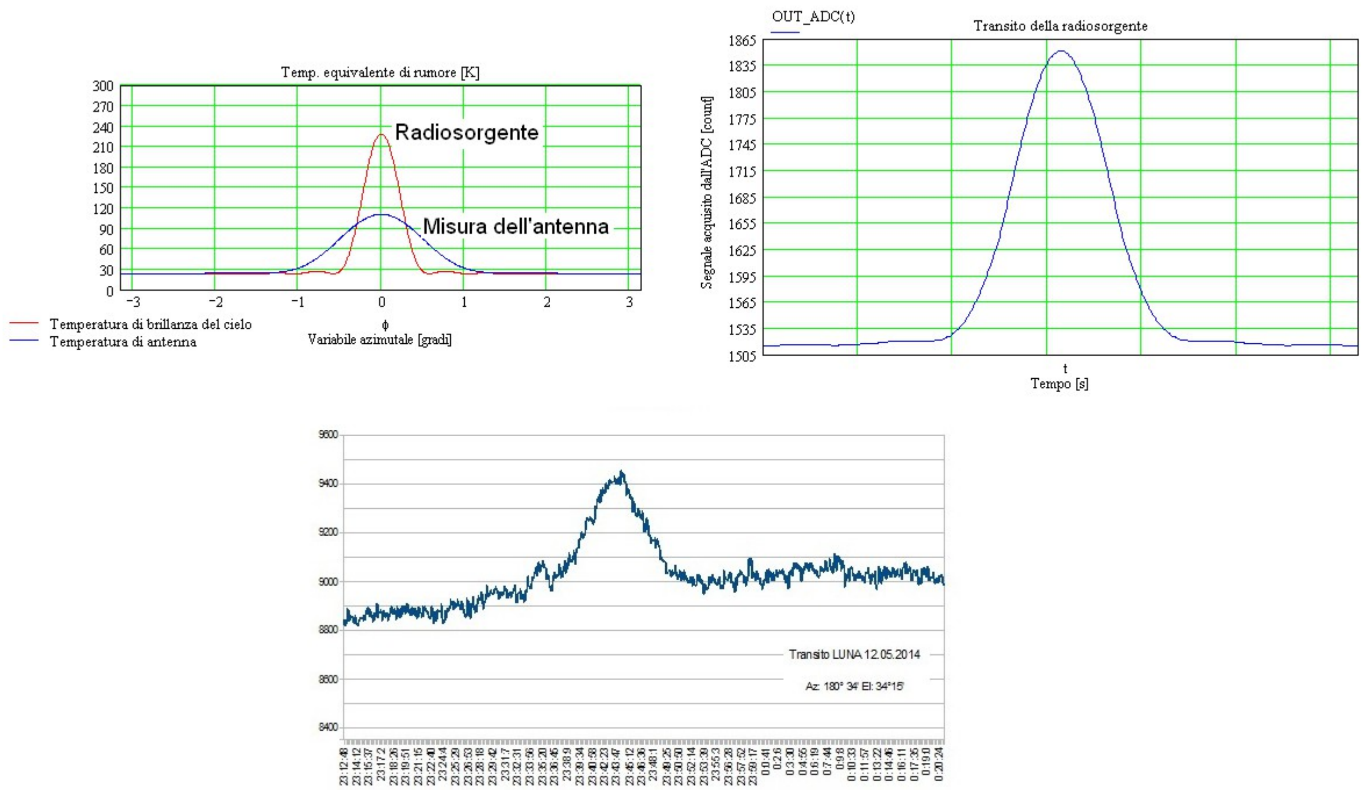


**Fig. 8:** The profile of brightness measured (of the Moon – up right graph) is determined by a *convolution relationship* between the brightness temperature of the scenario and the antenna gain function. The antenna of a radio telescope tends to level out the true brightness distribution of observed (left): the magnitude of the instrumental distortion is due to the characteristics of "spatial filtering" of the antenna and is linked to the relationship between the size angle of the receive beam and those of the apparent radio source. No distortion occurs if the reception diagram of the antenna is very narrow compared to the "radio" angular extension as the source (the case of very directive antenna).
The figure compares the recording theoretical lunar transit simulated and experimental recording (bottom graph) performed with *RAL10KIT* by our client (Mr. Giancarlo Madai - La Spezia, and we thank them): a different part of the reference level of the baseline, there is an amplitude comparable on intensity peak reception, estimated around 300-350 units [ADC_count].

Figure 8 shows the traces (simulated and real) of the transit of the Moon "seen" by the radio telescope: because the flow of the source is of the order of 52600 Jy at 11.2 GHz, we set a value for the gain *GAIN=10.* The Moon a radio source easily detectable. The profile of brightness is expressed in terms of designated numerical units acquired by the ADC [*ADC_count*].

To observe the Sun (flux of the order of $3.24 \cdot 10^6$ Jy) using the same antenna you will need to reduce gain values *GAIN=7*. In Figure 9 you can see the trace of the transit of the Sun: these theoretical results confirm the suitability of the radio telescope to observe the Sun and the Moon when it is equipped with the commercial antennas normally used for satellite TV reception.

A procedure used by radio astronomers to determine the radiation pattern of the antenna of a radio telescope requires the registration of the transit of a radio source with an apparent very small diameter compared to the width of the main lobe of the antenna.

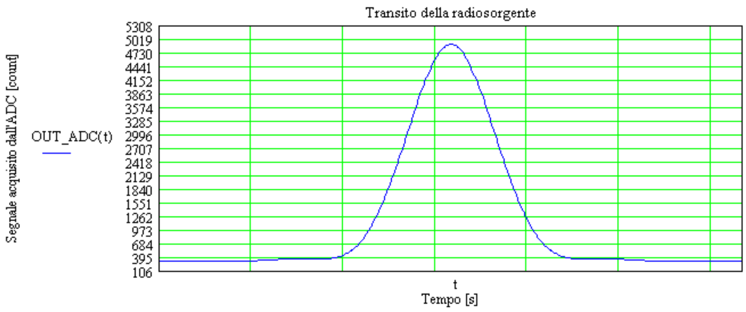


**Fig. 9:** Simulation of the transit of the Sun in the receive beam of the radio telescope.

A source "sample" widely used is *Cassiopeia A (3C461)*, intense galactic source of easy directional setting in the northern hemisphere, with a spectrum (in bi-logarithmic scale) on the band from 20 MHz to 30 GHz, with a decrease in flux density equal to 1.1%/year. To calculate the flow of radio source at 11 GHz frequency we use the expression:

$$S(f) = A \cdot f^n \quad [\frac{W}{Hz \cdot m^2}]$$

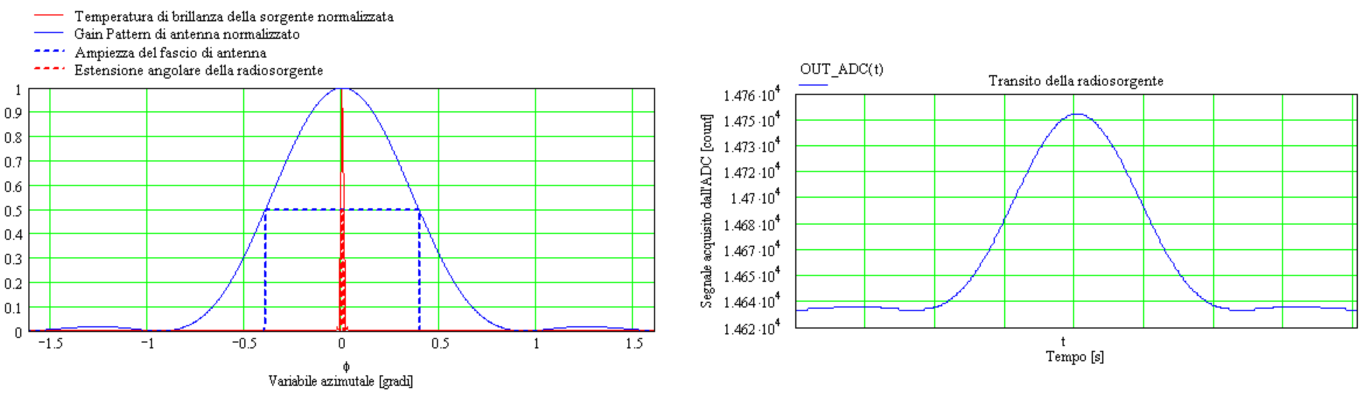


**Fig. 10:** Theoretical simulation of the transit of *Cassiopeia A (3C461)* recorded by our receiver equipped with a parabolic reflector antenna of 2 meters in diameter. We have inserted an IF line amplifier (12 dB - standard commercial product used in systems for receiving TV-SAT) connected to the output of the LNB to amplify the weak signal variation due to the radio source.

where the constant *A* is obtained taking into account that *S (1 GHz)=2723 Jy* with spectral index *n=-077* (period 1986). Performing calculations and taking into account the secular decrease of the flow it is obtained an emission of approximately 423 Jy.

Using these data we simulated the transit of *Cassiopeia A* with an antenna of 2 meters in diameter (Fig. 10). The configuration and the parameters set for the receiving system are identical to those previously used for the reception of the Moon, with the addition of a commercial IF line amplifier with 12 dB gain (component used in installations TV-SAT to amplify the signal from the LNB) inserted immediately after the LNB, which is necessary to amplify the weak signal variation due to the transit of the radio source. The emission profile of the *CassA* looks very “diluted” by the significant difference between the amplitude of the received beam antenna and the angular extent of the source (see graph on the left of Fig. 10).

We conclude this section highlighting the effects of a correct setting of the integration constant in the radiometric measurement (Fig. 11).

To reduce the statistical fluctuations of the detected signal in the radiometers, improving the sensitivity of the system, one generally uses a high value for the integration constant $\tau$ (corresponding to the parameter *INTEGRATOR* previously described). As shown in Fig. 11, the slightest variation in the temperature of antenna (the theoretical sensitivity of the radio telescope) is inversely proportional to the square root of the product of the bandwidth *B* of the receiver for the time constant of the integrator.

In the expression, $T_{sys}$ is the noise temperature of the receiving system and $\xi$ is a constant which, for *Total-Power* radiometers, is ideally 1. In any process of measurement integration, to increase $\tau$ means applying a gradual filtering and “leveling” on the characteristics of the variability of the observed phenomenon: they are “masked” all the variations less than $\tau$ and alter (or are lost ) information on the evolution of the temporal greatness studied, being distorted the true profile of the radio source. For proper recording of phenomena with their own variations of a certain duration is essential to establish a value for the constant of integration sufficiently less than that duration.

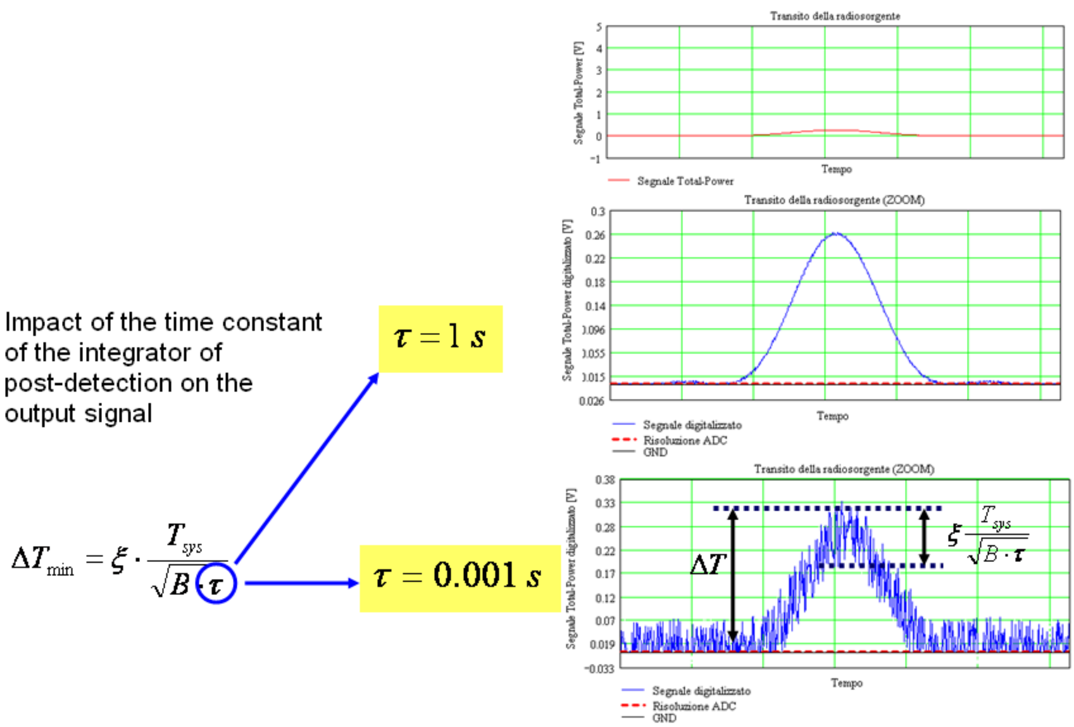


**Fig. 11:** Importance of a correct setting of the constant of integration in the radiometric measurement.

RadioAstroLab s.r.l.
60019 Senigallia (AN) - Italy
T +39 071 6608166
F +39 071 6612768
www.radioastrolab.it

## Calibration of the radio telescope.

If you want to make a measuring instrument, the radio telescope must be calibrated to obtain the output data consistent with an absolute scale of flux density or equivalent noise antenna temperature. The purpose of calibration is to establish a relationship between the temperature of antenna [K] and a given amount in output from the instrument [count]. This operation, understandably complex and delicate, will be the subject of a specific article regarding the application to the amateur systems: here we will provide some general guidelines that can be used to calibrate the radio telescope observing external sources easily "available" and minimum instrumentation support.

Setting the post-detection gain of receiver in such a way that the input-output characteristic is linear between the power level of the IF signal applied and the value [count] acquired by the ADC (Fig. 6), it is possible to calibrate the system by measuring two different levels of noise: it is observed before a "hot" target (object typically at room temperature like the ground T≈290 K), then a "cold" target (object at a much lower temperature such as, for example, the free radio sources sky) calibrating directly in K degrees temperature of the antenna. In practice:

- *"COLD" Target*: you must direct the antenna towards the clear sky (standard model of the atmosphere). The $T_2$ brightness temperature of the cold sky (approximately 6 K ) can be easy calculated at the frequency of 11.2 GHz (using the graph of Figure 1), being little disturbed by the atmosphere.
- *"HOT" Target*: you must orient the antenna of the radiometer to a wide masonry (such as, for examples, the wall of a building), large enough to cover the whole field of view of the antenna. Assuming an emissivity of 90% of the material and knowing the physical temperature of the target, you can estimate a brightness temperature $T_1$ equal to about 90% of the corresponding physical temperature.

If the responses of the instrument (expressed in units *count* of measurement of the ADC) when it "sees" objects at different temperatures $T_1$ and $T_2$ are, respectively:

$count_1$ when the instrument "sees" $T_1$ ("HOT" target);
$count_2$ when the instrument "sees" $T_2$ ("COLD" target);

you express the $T_a$ generic antenna temperature in function of the corresponding response *count* as:

$$T_a = T_1 + \frac{count - count_1}{count_1 - count_2} \cdot (T_1 - T_2) \qquad [K]$$

The accuracy of the scale depends on the accuracy in determining the brightness temperatures of the target "hot" and "cold": estimates suggested are largely approximate and can only be used to get an idea about the magnitude of the measurement scale. We refer to further investigation the sensitive issue of the calibration of microwave radiometers. The test procedure is, however, always valid when the instrument operates in a linear region of its input-output characteristic (Fig. 6).

## Construction of the radio telescope.

Once you know how the instrument works, it is very simple to build a radio telescope using the *RAL10KIT* (Fig. 13). With reference to Fig. 4, we listed the necessary components:

- Parabolic reflector antenna for TV-SAT 10-12 GHz (circular symmetrical or offset type) complete with mechanical support for the installation and pointing.
- LNB outdoor unit with suitable feed for the antenna used.
- 75 Ω coaxial cable for TV-SAT good quality addressed with standard connectors of type F.
- IF line amplifier with 10 to 15 dB gain (optional).
- *RAL10KIT.*
- Stabilized power supply (possibly linear low-noise, well filtered) able to provide the voltages [7÷12 VDC - 50 mA] and [20 VDC-150 mA].
- Box container for the receiver (preferably metallic, with shield functions).
- Standard USB cable with Type A connectors (side PC) and Type B (side *RAL10KIT*).
- Computer for measurement acquisition and instrument control.
- *DataMicroRAL10* software.
- EXCEL tool (with macro) *ImportaDati_DataMicroRAL10* to import files recorded by the software *DataMicroRAL10* and display it in graphical form.

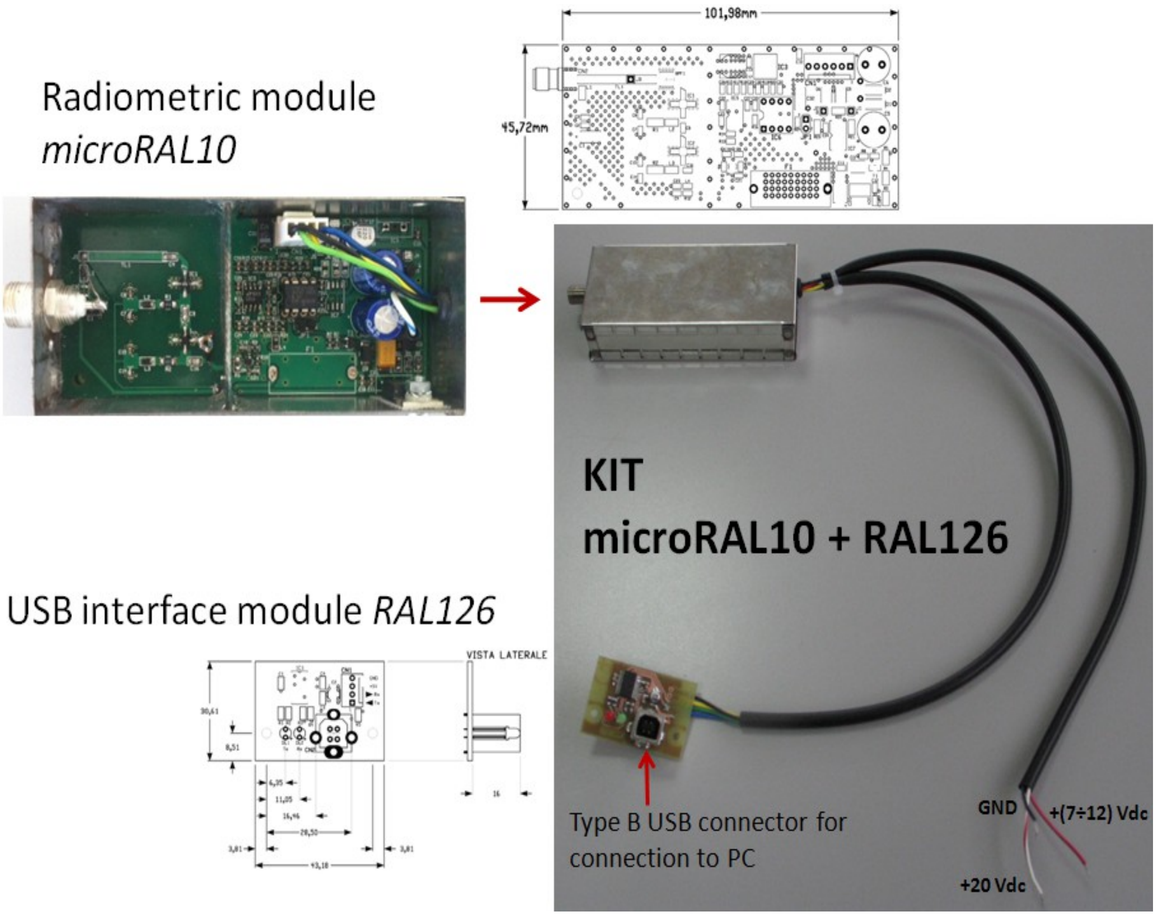


**Fig. 13:** *RAL10KIT* provided by *RadioAstroLab*.

RadioAstroLab s.r.l.
60019 Senigallia (AN) - Italy
T +39 071 6608166
F +39 071 6612768
www.radioastrolab.it

The kit provided by *RadioAstroLab*, as shown in Fig. 13, includes the parts specified in paragraphs (5), (10) and (11) that form the “heart” of the receiver for radio astronomy.

The market for satellite TV offers many choices for the antenna, the feed and the LNB: the experimenter decide according to the budget and space. Are available antennas circular symmetrical or offset, all suitable for our application. Importantly, to guarantee operation, use kits that include, in one package, with LNB feed and support coupled with the specific antenna, ensuring a correct “illumination” and a best focus for that kind of reflector. These products are readily available in any supermarket or consumer electronics at the best TV-SAT installers. Using a bit of imagination and building skills, it is possible to build systems of automatic tracking, at least for not too large antennas, drawing on the market of equipment for radio amateurs of the electronics surplus or using equatorial mounts commonly used by amateur astronomers for optics astronomical observations.

There are many examples of interesting and ingenious creations on the web. Very useful for the correct pointing and for planning observing sessions are mapping programs of the sky that reproduce, for any geographical area, date and time the exact location and movements of celestial objects with great detail and accuracy.

As previously mentioned, can be used virtually all devices available on the market LNB for satellite TV at 10-12 GHz with output at intermediate frequency of 950-2150 MHz. In modern devices you can manage the change of polarization (horizontal or vertical) with a voltage jump typically V 12.75 - 17.25 V: *RAL10KIT* enables this functionality through a control, as described in the communication protocol.

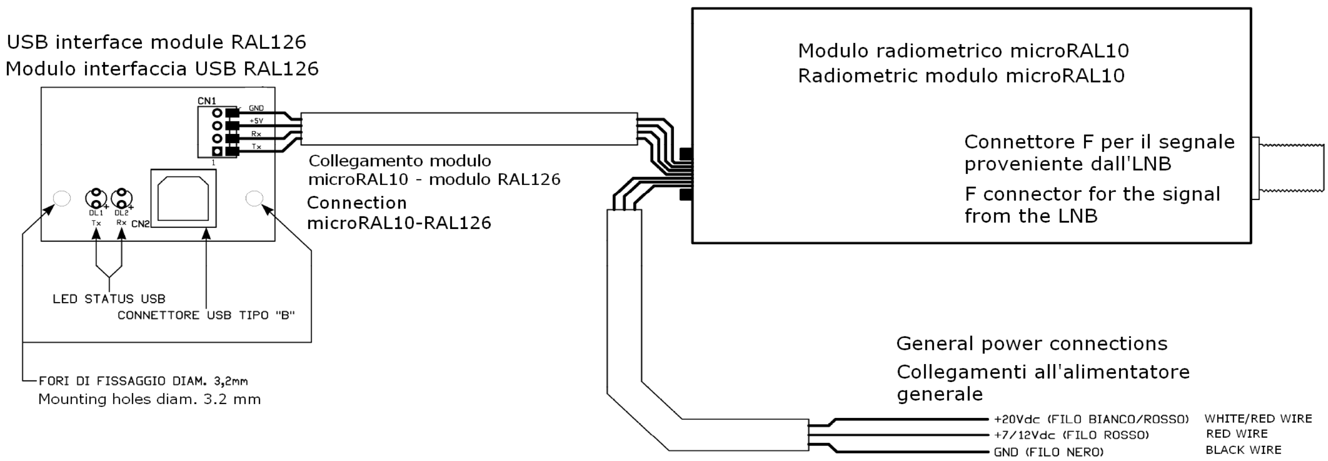


**Fig. 14** Wiring diagram of the *RAL10KIT* group: the radiometric module (supplied assembled and tested) is contained within a metal box screen that provides a coaxial F connector for connection with signal from the LNB (via 75 Ω coaxial cable for TV-SAT), and a pass-rubber cable with either of the connections for the USB interface and the power supply.

A coaxial cable TV-SAT from 75 Ω to suitable length, terminated with F connectors, connect the output RF-IF outdoor unit LNB with the input of the radiometric module. It is recommended to choose high quality cables, with low losses.

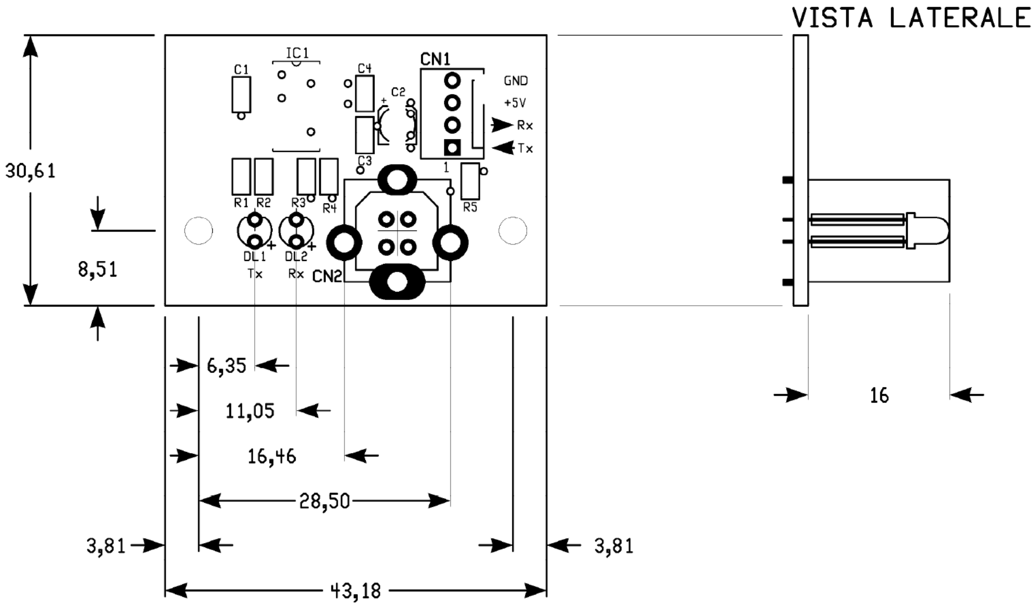


**Fig. 15:** Details of the USB interface module *RAL126* used for communication with the PC. The device is designed for a chassis assembly: holes and slots on the wall mounting of the container allow the visibility of DL1 and DL2 (which indicate the activity of the serial communication line) and the accessibility of the USB type B that connects to the PC.

In some cases, when you observe radio sources of low intensity or when the coaxial line is very long, it may be necessary to insert an IF line amplifier (10 to 15 dB of gain) between the LNB and the *RAL10KIT*. Figure 13 shows the hardware components of the kit provided by *RadioAstroLab*, figure 14 shows the dimensions of the boards and the wiring diagram of the power cables: the group can be powered from any circuit stabilized and well filtered, or use a commercial power supply, as long as they are able to provide the voltages and currents specified. It is advisable to enclose the modules, including power supply, in a metal container that also serves as a screen for the receiver. As seen in Figure 13 and 14, the USB interface module is designed for panel mounting: you will need to prepare holes and slots for the mounting screws for the red and green LEDs that indicate the serial communication and for the connector USB type B.

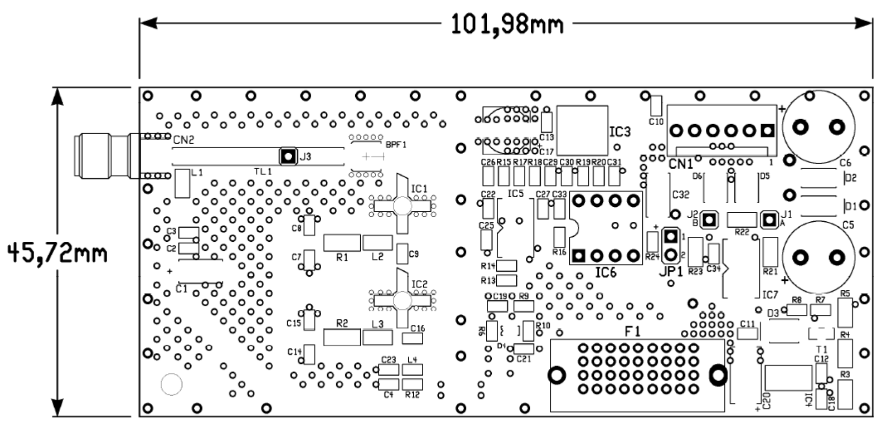


**Fig. 16:** Size of the circuitry inside of the *microRAL10* radiometric module. You see, below, the fuse protection for the power supply line of the LNB through the coaxial cable RF-IF.

RadioAstroLab s.r.l.
60019 Senigallia (AN) - Italy
T +39 071 6608166
F +39 071 6612768
www.radioastrolab.it

# Performance optimization.

Before you begin an observation, we suggest to observe the following rules:

- **Power on the receiver and wait until the instrument has reached thermal stability.** The instability of the system are mainly caused by changes in temperature: before you begin any observation, it is necessary to wait at least one hour after switching on the instrument to achieve the operating temperature regime in the internal circuits. This condition is checked by looking at a long-term stability of the radiometric signal when the antenna point a "cold" region of sky (absence of radio sources): appear minimal fluctuations displayed by the graphic trace on the *DataMicroRAL10* program.

- **Initial setting of *GAIN* amplification factor minimum values (typically *GAIN*=*7*).** Each installation will be characterized by different performance, not being predictablein advance the characteristics of the components chosen by the users. It is convenient to adjust gain starting with minimum values of test (to avoid saturation), optimizing with repeated and successive scans of the same region of the sky. To observe the Sun is advisable to set ***GAIN=7***, to observe the Moon start with ***GAIN=10***. It is recalled that these settings are very influenced by the size of the antenna and the characteristics of the LNB.

- **Found the appropriate values for amplification factor, you can adjust the value of the constant of integration *INTEGRATOR* to stabilize the measurement.** The system is initially set to the measurement with a short integration constant (***A***), corresponding to a time constant equal to approximately 0.1 seconds. This value, corresponding to the calculation of the moving average on the radiometric signal using few samples, it is generally appropriate in most cases. You can improve the sensitivity of the measurement, with the disadvantage of a slower system response with respect to changes of signal, using a greater time constant. It is recommended to set the value of ***A*** during the initial calibration of system, then increase time constant during the measurement session of radio sources characterized by stationary emissions. When recording rapidly varying phenomena or of a transitory nature (such as, for example, the solar flares wave) will be appropriate to select the shorter time constant. By properly setting *SAMPLING* parameter by *DataMicroRAL10* software, an additional integration on the radiometric signal is done.

- **Setting the parameter *BASE_REF* which establishes the reference level (offset) of the baseline radiometric.** Also for this parameter are valid the foregoing considerations, given that its correct setting depends on the receiver amplification. As a general rule, ***BASE_REF*** should be set so that the minimum level of the radiometric signal corresponds to the "cold sky" (ideal reference), in conditions of clear atmosphere, when the antenna "sees" a region of sky without radio sources: an increase compared to the reference level would be representative of a scenario characterized by higher temperature (radio source).
  **The position of the baseline on the scale of measurement is a function of *GAIN* and of the *BASE_REF* value set. If, due to drift inside, the signal is located outside the measuring range (start-scale or full-scale), you must change the value *BASE_REF* or activate automatic calibration (*CAL* command) to properly position the track.**

1. If you are using suitable LNB, you can change the polarization for the study of radio sources with emission which is dominated by a polarized component. In most of the observations accessible to amateur, radio sources emit with random polarization: in these cases the change in the polarization reception may be useful to minimize the possibility of interference with signals of artificial origin.

- **Optimization of the installation of the antenna feed.** By purchasing products for commercial TV-SAT is generally fixed the position of the feed in the focal line of the antenna. If it was mechanically possible and you want to improve the performance of the radio telescope, you should adjust the antenna in the direction of a radio source sample (such as the Sun or the Moon) and toggle back and forth the position of the feed along the axis of the parabola in order to record a signal of maximum intensity. Repeated measures help to minimize errors.

The correct setting of the parameters of the receiver requires the registration of certain observations test before starting the actual work session. This procedure, which normally also used by professional radio-observers, allows you to “tune” the system so that its dynamic response and the scale factor are adequate to record the observed phenomenon without errors. If properly executed, this initial setup (needed especially when you require long observation periods) will adjust the gain and the offset of the scale for a proper measurement, avoiding the risk of saturation or zeroing of the signal resulting in loss of information.

After the initial calibration process, it will be possible to save the radiometer settings using the *MEM* button (*command = 15*) of *DataRAL10* software.

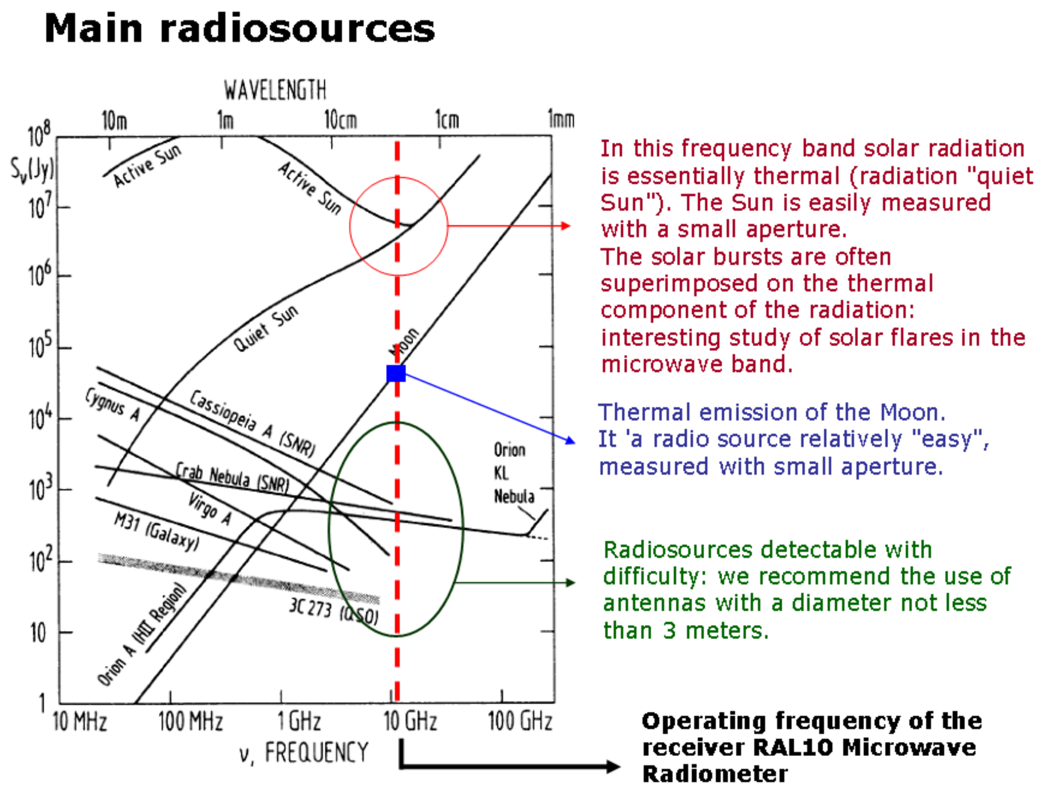


**Fig. 17:** Operational capabilities of the radio telescope built with *RAL10KIT*.

The simplest radio astronomy observation implies the orientation of the radio telescope to the south and its placement at an elevation as to intercept a specific radio source during its *transit to the meridian*, the transition of the apparent source for the *local meridian* (the one containing the poles and the point of installation of the radio telescope). Our instrument, generally characterized by a broad beam antenna to some degree, "forgive" us a lack of knowledge of the position of radio sources: it is therefore acceptable a precision pointing in much less than that used in the optical observations. Setting the acquisition program at a sampling rate such as to obtain a screen about every 24 hours (*SAMPLING* parameter in the *DataMicroRAL10* software) it can verify if, during the course of the day, the antenna intercepts radio sources and if the parameters chosen values (gain and level of the baseline) are suitable for the observation. You might have to increase *GAIN* to amplify the track, or change the level of the baseline *BASE_REF* to prevent, to some point on the graph, the signal goes down and scale. After the procedure of tuning you can start long automatic recording sessions unattended by an operator.

| Radiosorgenti | A.R. | Declinazione | Flusso Jy @ 10 GHz |
|---|---|---|---|
| Sole | | | > 1 000 000 |
| Luna | | | 30 000 |
| Giove | | | 30 |
| Sagittarius A (centro galattico) | 17h 42m | -29° | 300 |
| Cassiopeia A (supernova) | 23h 21m 7s | 58° 34' | 600 |
| Cygnus A (radiogalassia) | 19h 57m 45s | 40° 36' | 100 |
| Taurus A (Crab Nebula) (supernova) | 5h 31m 30s | 21° 58' | 500 |
| Virgo A (radiogalassia) | 12h 28m 18s | 12° 40' | 30 |
| Andromeda (galassia) | 0h 40m | 41° | 30 |
| 3C 273 (quasar) | 12h 26m 33s | 2° 20' | 20 |

The *flow units Jy* (in honor of K. Jansky) is $10^{-26}$ W/(m$^2$·Hz), a measure that quantifies the emitting properties of the radio sources. Are shown the main radio sources accessible to our radio telescope when it is equipped with an antenna sufficiently large.

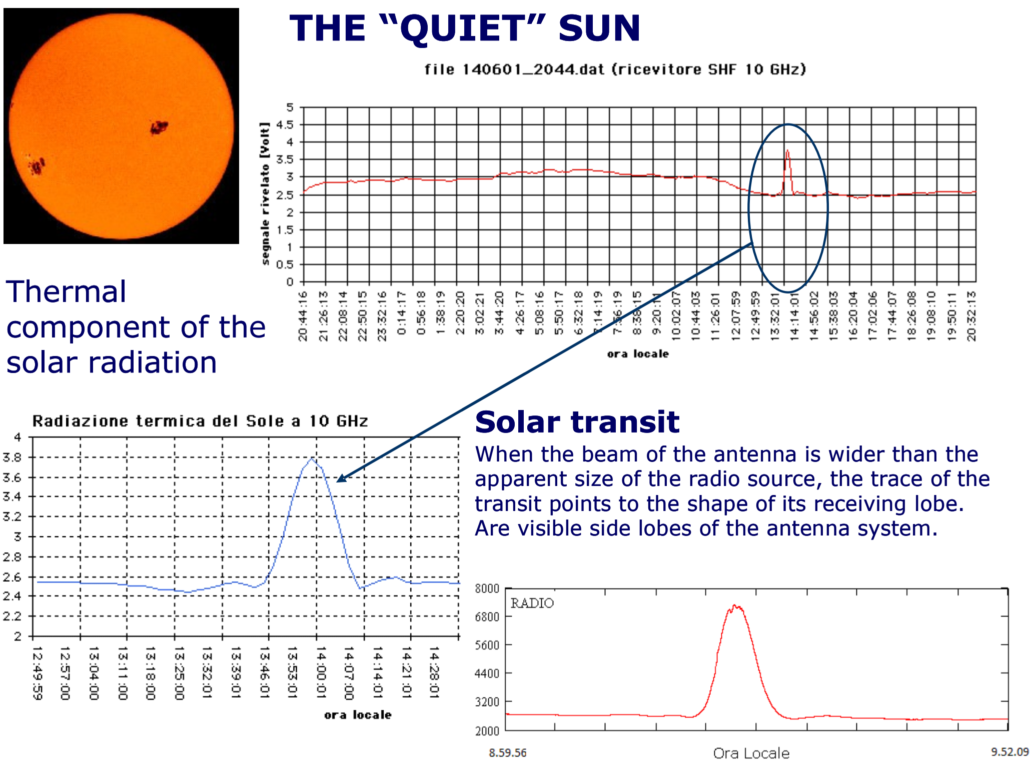


**Fig. 18:** Transit of the Sun.

RadioAstroLab s.r.l.
60019 Senigallia (AN) - Italy
T +39 071 6608166
F +39 071 6612768
www.radioastrolab.it

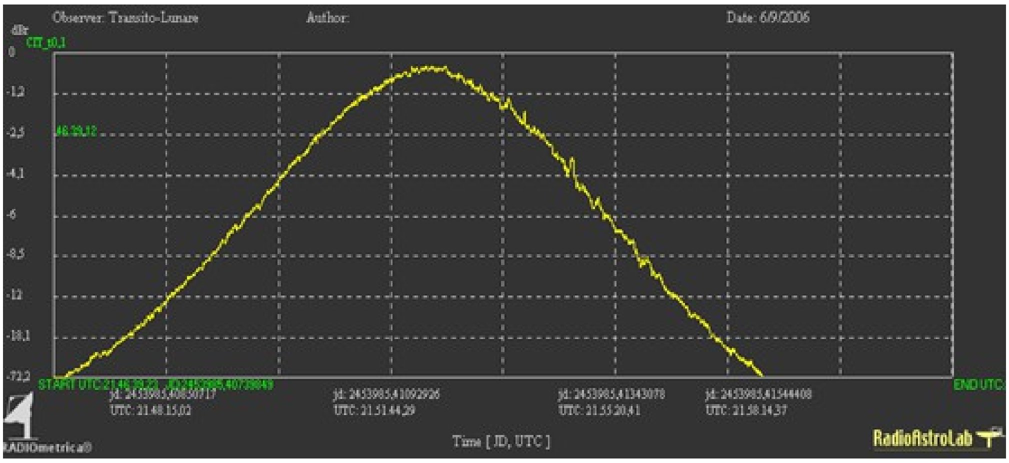


**Fig. 19:** Diagram of a lunar transit. The thermal radiation of the Moon is visible: its emission is a result of the fact that the object emits approximately as a black body characterized by a temperature of the order of 300 K. If the visible emission of the Moon is almost exclusively due to the reflected light of the Sun, in the 11.2 GHz there is an issue due to the temperature of the object that contrasts with that of the "cold" sky.

You can imagine interesting experiments to verify the sensitivity of our system receiver, such as that point the LNB to the fluorescent lamps: these components emit a significant amount of microwave radiation can easily be measured (according to different mechanisms emissive, some of which are not simply related with the physical temperature of the source). Powering on and off the lamp, you will note an appreciable variation of the received signal, proportional to the intensity and the angular size of the source.

Figure 17 and the table give the radio sources receivable with our radio telescope, not forgetting how the weakest among them, are observable only by using antennas that are large enough. Some test observations recordings below.

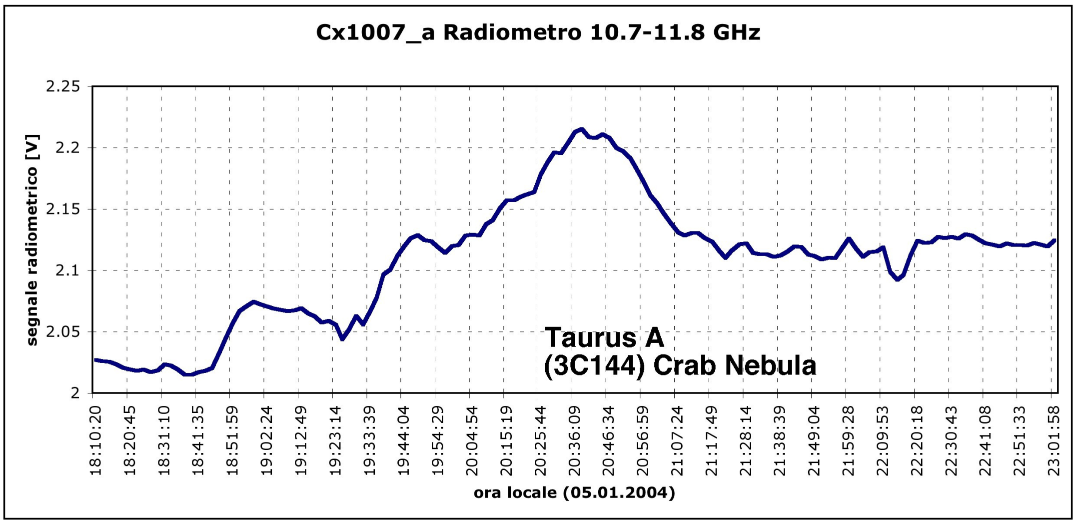


**Fig. 20:** Transit of the *Taurus A* radio source.

## References


- N. Skou, D. Le Vine, "MICROWAVE RADIOMETER SYSTEMS (DESIGN AND ANALYSIS).", 2006 Edition, Artech House.
- J. D. Kraus, "RADIO ASTRONOMY", 2nd Edition, 1988, Cygnus-Quasar Books.
- R. H. Dicke, "THE MEASUREMENT OF THERMAL RADIATION AT MICROWAVES FREQUENCIES.", 1946 – The Review of Scientific Instruments, N. 7 – Vol. 17.
- F. Falcinelli, "RADIOASTRONOMIA AMATORIALE.", 2003 – Ed. Il Rostro (Segrate, MI).
- F. Falcinelli, "TECNICHE RADIOASTRONOMICHE.", 2005 – Ed. Sandit (Albino, BG).


Doc. Vers. 2.1 del 19.03.2015


RadioAstroLab s.r.l., Via Corvi, 96 – 60019 Senigallia (AN)
Tel. +39 071 6608166 Fax: +39 071 6612768
Web: www.radioastrolab.com Email: info@radioastrolab.it