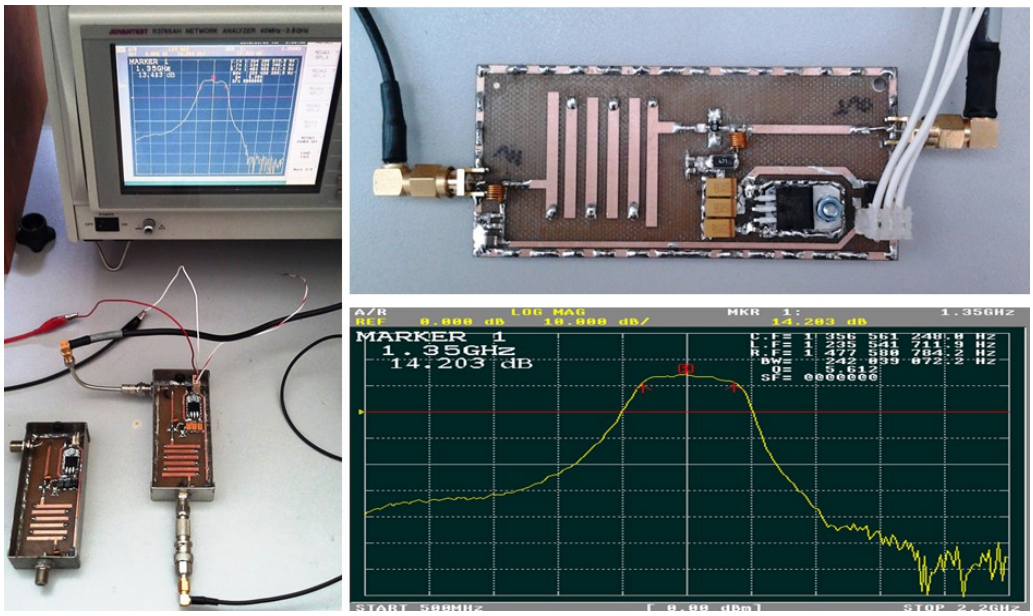
RadioAstroLab s.r.l.
60019 Senigallia (AN) - Italy
T +39 071 6608166
F +39 071 6612768
www.radioastrolab.it

Experiencing Radio astronomy with *RAL10* series *Total-Power* microwave receivers.

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.it

For lovers of science who are interested or curious about radio astronomy, it is now possible to start an interesting amateur research although not very experts in electronics and radio technologies. *RadioAstroLab*, a leader in this topic, offers a wide range of products for every need and cost, to allow everyone to approach, with the necessary support, to this wonderful discipline.

Amateur astronomers, amateurs, students, groups and associations that deal with science and technology, will always find new and interesting proposals to achieve radio telescopes amateur and semi-professional to start with them the observation of the sky in the radio waves band. This activity, yet unknown and innovative, if properly stimulated and developed, can become an important complement to traditional observations of amateur astronomers and amateur radio. Even schools, universities and institutions of science education can benefit from our proposals, discovering how it is easy and fun experiencing radio astronomy. Very important is the educational value of this topic, because for the construction, installation of a amateur radio telescope, complementary disciplines such as physics, astronomy, mathematics, radio-electric and electronic engineering, computer science and mechanics are involved.

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

The tools family that we are presenting is complete: it ranges from kit of pre-assembled and calibrated modules for those who want to "get their hands dirty" by building a small radio telescope in their garden, to the more sophisticated and ready to use instrumentation, complete with accessories like the antenna system and its mount necessary for the proper tracking of radio sources. With such equipment it is simple to install a microwave radio telescope remotely controllable through Internet. Of course, it is also provided the software for acquisition and automatic recording of data through PC. For each product we present detailed and important features that allow you, in addition to the normal use, also to optimize and customize performance (such as, for example, the serial communication protocol with which it is possible to acquire measurement data and check the instrument), our technicl office can evaluate changes and “ad hoc” hardware solutions in according to particular needs.

We are working on other interesting tools and they will be soon presented together with scientific projects proposals: the work and the attention of *RadioAstroLab* towards the amateur radio astronomy and science are constant and timeless!

RAL10 series Total-Power: radio astronomy to everyone. Which product choose?

The *RAL10* family includes a series of very sensitive receivers dedicated to radio astronomy, in particular *microwave radiometers* (11.2 GHz working frequency). They are *Total-Power* instruments, they measure the radiation emitted from any celestial object intercepted by the antenna.

The construction of simple and inexpensive radio telescopes operating at 10-12 GHz frequency band is economic and simplified if you use antenna systems and components from the market of TV satellite, available everywhere at low cost. Thanks to the commercial diffusion of TV satellite service, you can easily find modules such as low noise preamplifiers - converters and parabolic reflectors antennas available in various sizes, complete with mechanical support for the assembly and orientation.

To facilitate the approach to this discipline by using the availability and economy of this material, we have developed the *RAL10* family product so that everyone can install the first microwave radio telescope. Due to the short wavelength, it is relatively simple to build instruments with good directivity and acceptable resolution capabilities. Although in this frequency range there aren't 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 in the garden of the house in an urban area. Television geostationary satellites can be interference sources, you can avoid them without limiting the observed part, since their position is fixed and known.

We refer to other articles published on our website for further information about the operation of a radio telescope, the structure of a *Total-Power* reciever and the possibility of observing amateur radio astronomy: in this paper we will focus on the range of *RAL10* products, differentiating and highlighting the main features of each instrument in order to simplify the choice. We are aware that this discipline, very fascinating and not very widespread, often mysterious for profanes, may seem difficult at first: with these notes we hope that the investigator can win the initial uncertainty, we confirm, in any case, the availability of our staff to clarify any doubt abou the purchase, installation and using of the instrumentation.

We begin with an overview of the *RAL10* Total-Power receivers family and their characteristics. In the next section we will see how to guide the instrument choice based on the type of test you want to address, on the personal experience in amateur radio astronomy, and of course, considering the budgets. A setting that makes the difference and that can affect the success of an amateur radio astronomy project, especially if ambitious, regards the possibility to organize the construction of the radio telescope and subsequent

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

radio astronomy observations taking inspiration by the programs of amateurs circles (which often handle small observatories with activities open to the public) and amateur associations. In this case it is easier and instructive the construction and management of large and complex tools.

1. RAL10KIT

It is a kit for self-builders with a minimum of practice in the electronic assembly. As seen in Fig.1, the package includes the *microRAL10* radiometric module, the USB interface for connection with the PC, the assembly instructions and the control software. The modules are pre-assembled: these have to be enclosed in a suitable case, complete with a power supply (as specified in the instructions), with a coaxial cable and a common antenna with LNB operating in the 10-12 GHz satellite TV band. In this way the first microwave radio telescope has been created.

With the *RAL10AP* receiver (see notes below) it represents the starting point for the first radio astromomy experiences.

Fig. 1: *RAL10KIT,* designed for self-builders.

2. RAL10AP

It is the smallest radiometer of the *RAL10* series, complete, assembled and ready to use, "big brother" of *RAL10KIT*. The basic characteristics of the receiver are identical to those of the previous device, with the difference that the instrument is supplied already mounted in a robust and elegant metal case. To start

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

working, connect the antenna (with LNB), the external power supply and the PC: activating the *DataMicroRAL10* software (Fig.3), starts the acquisition of the measures. A peculiar characteristic of *RAL10AP* is an audio output (downstream of the detector) useful for monitoring purposes. The USB interface for connection to the PC and the control software are identical to that of the previous product, the main power can be supplied via a 12V external power supply (supplied separately on request), a rechargeable battery or our *RAL10BT Rechargeable Battery Unit* (available on request).

Fig. 2: *RAL10AP* receiver with its power supply (supplied separately on request): the picture shows the product in a test lab connected to the PC for data acquisition, equipped with the *RAL10_LNB* external unit and the *RAL10_FEED* antenna feed.

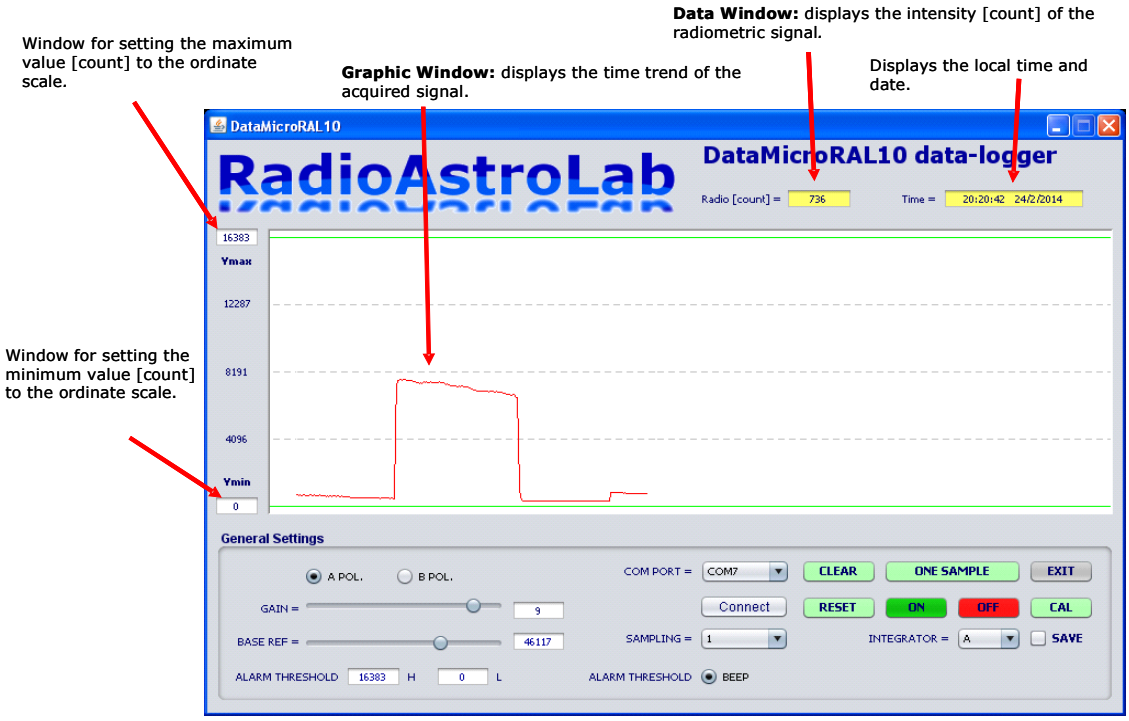


Fig. 3: *DataMicroRAL10* software for acquisition and control of *RAL10KIT* and *RAL10AP*.

3. RAL10

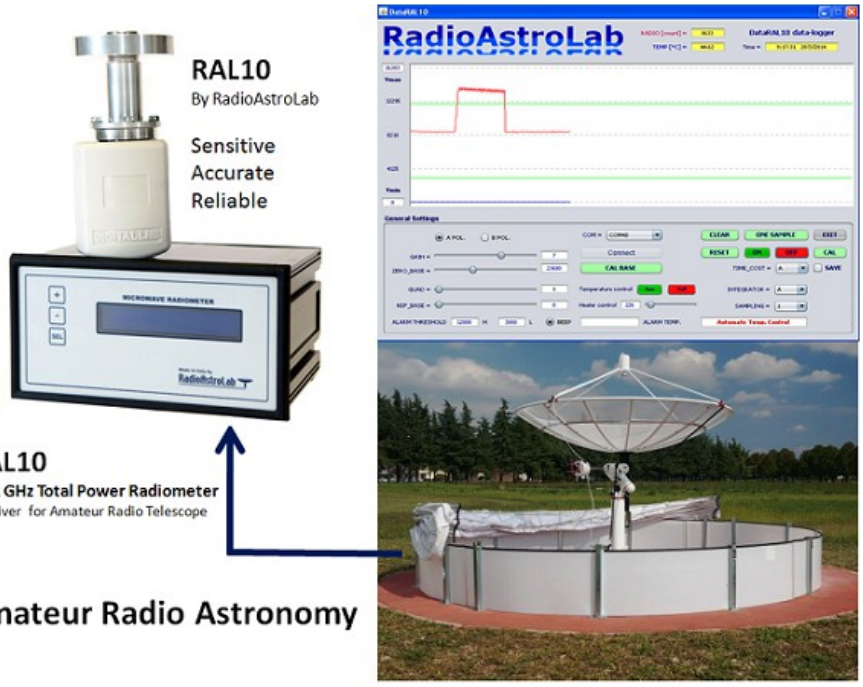
It is the most complete version (installation of radio telescope with the receiver positioned inside a laboratory, near the acquisition PC). The receiver electronic is inside a robust metal case, the receiver is thermally stabilized (to optimize the reproducibility and accuracy of the measurement). It has a front panel with keypad for manual setting of the controls and a backlit LCD display for displaying functions (Fig. 4). A USB port connects the PC station managed by the supplied software.

RAL10 is a *Total-Power* radiometer characterized by high sensitivity and stability, as required by the most advanced amateur radio astronomy observations. The wide possibility of programming and control the operating parameters make it the tool tip of the *RAL10* family.

4. RAL10PL

Receiver combined with the *RAL230ANT* antenna (2.3 meter diameter) and designed to be installed outside. Its technical characteristics are identical to that of the RAL10: the instrument is characterized by high sensitivity and measurement stability (the internal temperature is controlled with a PID controller). *RAL10PL* is assembled inside a robust plastic casing resistant to rain and moisture, with additional metal protection of the internal electronic circuits. The receiver does not have a display that shows the operating functions because it has been designed for remote control via an Ethernet port: you can network the device, implementing a monitoring and management of the radio telescope via web. A peculiar characteristic of *RAL10PL* is the robust construction, suitable for installation of automatic radio astronomical systems that don't require the presence of operators.

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



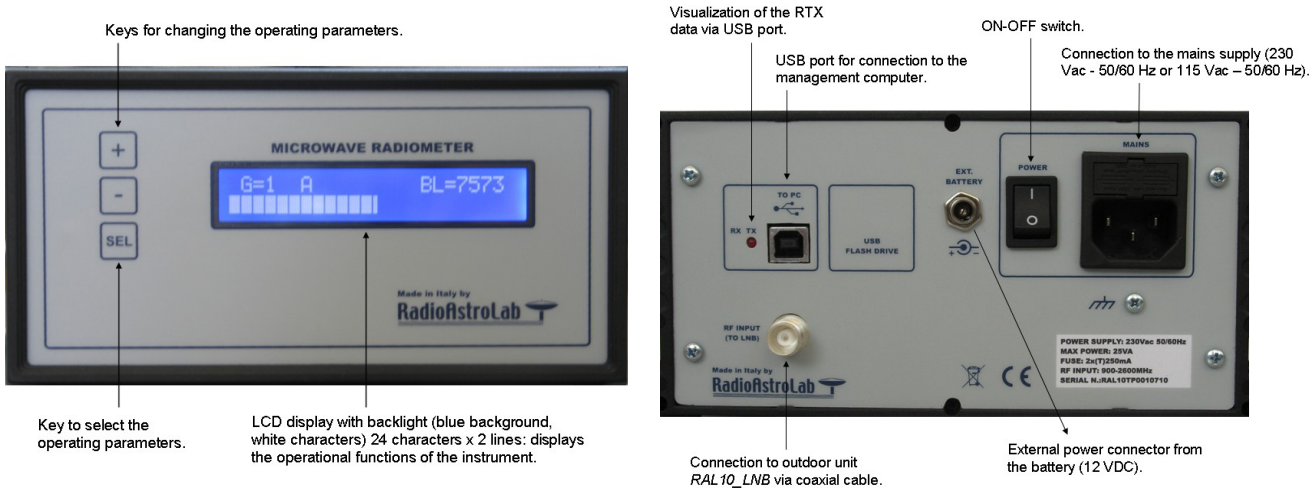


Fig. 4: *RAL10*: receiver details.

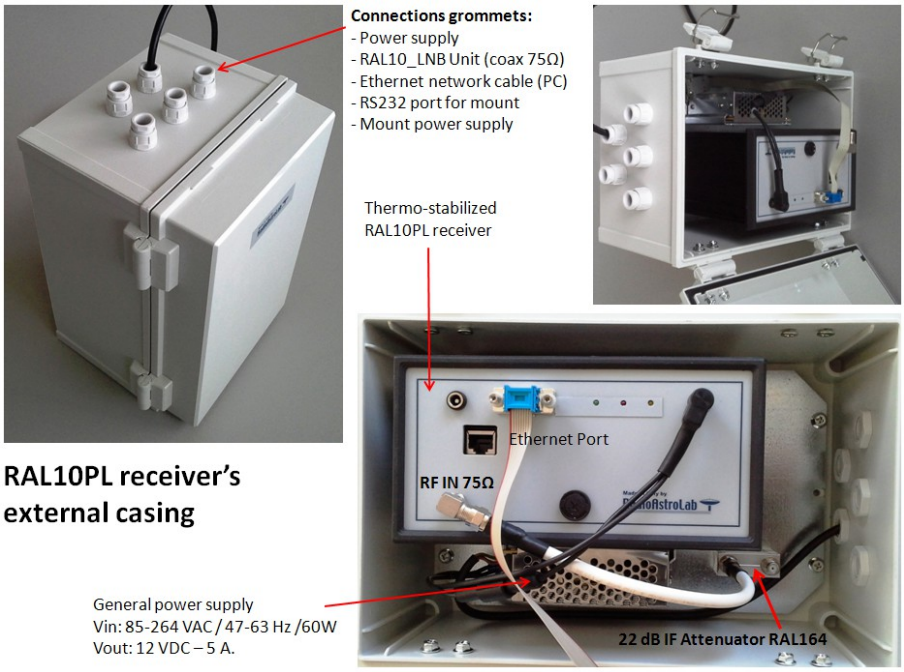


Fig. 5: *RAL10PL*: robust radiometer, designed for remote radio astronomical installations, not controlled by operatives.

Each instrument of *RAL10* family can be used with commercial components for the TV satellite reception: you can connect to our devices any 10-12 Ghz satellite dish and LNB kit (950-2250 Mhz output). These components, together with the accessories (line amplifiers, antennas mechanical supports, coaxial cables, connectors and fittings ...) are commonly used by TV-SAT installers and are available at low cost at any supermarket electronics.

Indispensable requirement for radio astronomy observations is the use of antennas with large effective area: there is no limit on the size of the antenna, if not economic factors, practical limitations of space and of installation due to the support structure and to motorization of pointing system. 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 each installation. While using *RAL10* modules that guarantee the minimum requirements for the radio telescope, the optimization of the system ensures important advantages for instrument's performance.

The following accessories are available to optimize and specialize the radio telescope performance:

5. RAL10_LNB outdoor unit

It is a LNB (*Low Noise Block*) with a 10-12 GHz input frequency, designed for radio astronomy applications where high sensitivity and stability are required(Fig. 6). The device can be equipped with *RAL10_FEED* corrugated for circular parabolic reflector antennas, it will be installed on the antenna focal point and, via a TV-SAT coaxial cable, can be connected to all the *RAL10* family receivers. The unit, built in a robust insulated aluminium casing, is thermally stabilized with an internal regulator: an electric cable (separate from the coaxial cable) supplies low voltage (12 V) power to the stabilization circuit. The user can choose to power the thermal stabilization circuit in those observations in which is required high precision, at the price of higher power consumption.

As repeatedly said, *RAL10* receivers can be used with any LNB outdoor unit available for TV-SAT applications: *RAL10_LNB* is ideal when you want to optimize the performance of the radio telescope in terms of stability of the measurement.

6. *RAL10_FEED for circular parabolic reflector antennas*

It is the feed for *RAL10_LNB* outdoor unit, usable with circular parabolic reflector antennas.

Fig. 6: *RAL10_LNB* outdoor unit with *RAL10_FEED* for circular parabolic antenna. The object must to be installed on the focal point of the antenna, "prime focus" with a ratio F/D between 0.32 and 0.43. The *RAL10_LNB* and *RAL10_FEED* units have a flange in circular waveguide type C-120.

7. *RAL164 attenuator*

Essential accessory when observing the Sun with very sensitive instruments (*RAL10* and *RAL10PL*) combined with large antennas (such as, for example, *RAL230ANT*). The function of the device, which is inserted at the input receiver after the descent of the coaxial cable from the antenna, is to attenuate the powerful solar radiation avoiding distortion and non-linearity in the system response.

Fig. 7: 22 dB *RAL164 attenuator.*

8. *RAL230ANT circular parabolic reflector antenna*

It is a mesh circular parabolic reflector antenna (*prime focus*), with a diameter of 2.3 meters which, combined with our receivers, allows the immediate use of a microwave radio telescope (Fig. 8). The antenna has been designed to provide a large diameter disc (so with high gain), a minimum weight and reduced resistance to wind compared to TV-SAT conventional antennas. These features, together with the supplied accessories (mechanical parts and counterweights, telescope alignment and protective dome polyethylene reinforced with tubular aluminum) allow the *RAL230ANT* mounting on a normal equatorial

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

mount (available on request), such as those used by amateur astronomers for optical astronomical observations. The *RadioUniverse* control software, combined with the *RAL10PL* receiver, manages the radio telescope with advanced and programmable features including the location and the automatic movement of the antenna, the setting of the receiver operating parameters: it will be possible to record the radioemtric data coming from sky pointed but also transits and radio images of celestial sources. A graphical window shows the entire sky with the position of the radio sources with respect to the stars and the constellations.

Of course you can also install *RAL230ANT* on different mounts (such as, for example, those used by radio amateurs) "ad hoc" realized for its own radio telescope, or think to transit instruments with fixed orientation or with manual handling: in all cases our antenna is the ideal solution for amateur radio telescopes in terms of performance and ease of use.

Fig. 8: *RAL230ANT* parabolic reflector antenna (2.3 meter diameter, mesh construction) installed on equatorial mount and complete with supports and counterweights.

9. RAL10BT Rechargeable Battery Unit

It is a source of low voltage power supply rechargeable designed to allow the use *RAL10AP* and *RAL10* receivers in areas not served by electricity mains (Fig. 9). The device, equipped with a hermetic rechargeable battery able to ensure high operational autonomy, includes the electronic circuit of charge of the battery from the mains.

Fig. 9: *RAL10BT* low voltage energy source for radio astronomy measurements "in field".

microRAL10 radiometric module: an identical "heart" for all.

The *RAL10* family responds to the needs of each investigator who want to approach seriously the amateur radio astronomy. The instruments differ in performance, cost and effort of installation: it is possible to satisfy self-builder's needs who can find satisfaction in achieving and customize his own instrument, the needs of those who want a finished product ready for use and prefer to focus on research. Even software developers will be able to customize their own instrument performance (development and control) since, for each device, it is described the serial communication protocol.

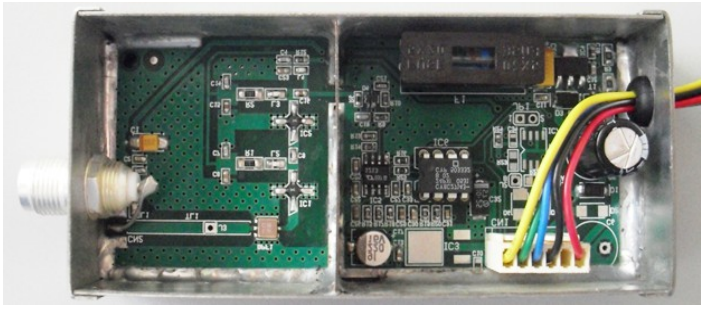


Fig. 10: Internal view of *microRAL10* radiometric module, the "heart" of *RAL10* receivers.

The *microRAL10* radiometric module is common to all *RAL10* products: is the central unit of the receivers and includes the basic functions. It is a radiometer (Fig. 10) managed by a microprocessor which amplifies the signal from the outdoor unit (LNB), performs the calculation of the RF power (quadratic detector temperature compensated), "digitizes" the detected signal with high resolution (14-bit analog-to-digital internal converter) and communicates with the PC station (USB port) via a serial data channel with proprietary protocol. The module provides power to the outdoor unit LNB via the coaxial cable (fuse protected against accidental short-circuits), with the voltage jump for polarization change in

reception. The processor controls the parameters of the *Total-Power* radiometer such as the offset setting and the automatic calibration of radiometric baseline, the setting gain and the post-detection constant of integration (with time from about 0.1 up to 26 seconds), the selection of the polarization in reception (if is allowed by the choosen LNB). ***microRAL10*** **implements functions necessary for a microwave radiometer suitable for radio astronomy, with special attention to the requirements for sensitivity and stability that the application requires.**

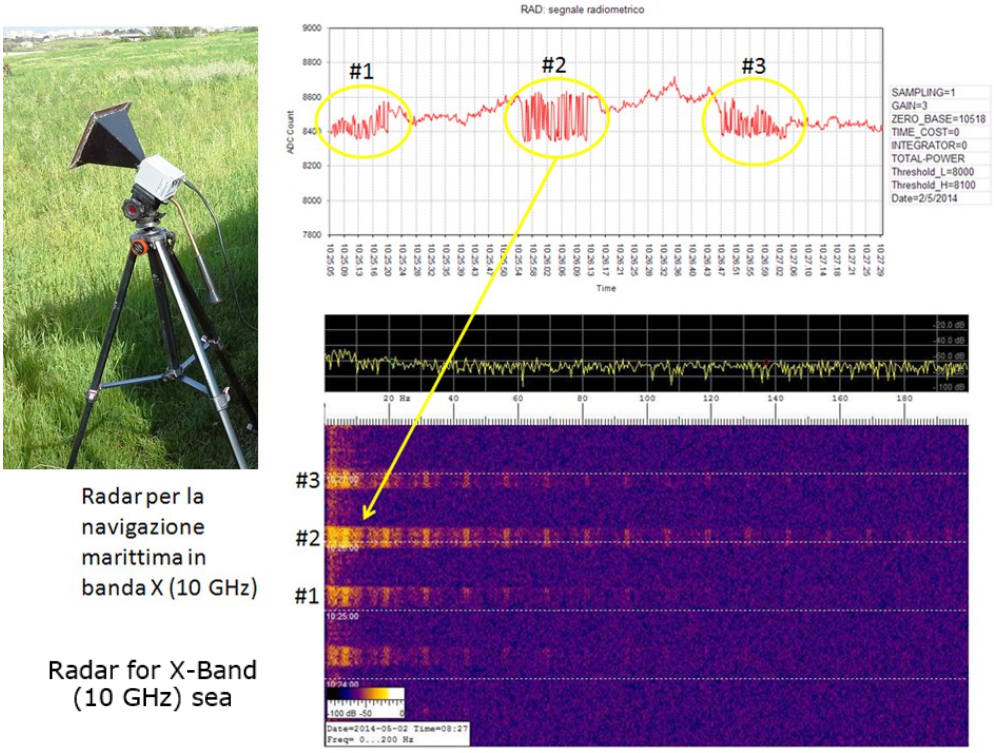


Fig. 11: Recordings made with *RAL10AP*. For the experiment we have used the *RAL10_LNB* outdoor unit equipped with a horn truncated pyramid antenna (20dB gain), positioned on a photo tripod (on top left). The *RAL10_LNB* output has been connected to the *RAL10AP* receiver by a coaxial cable. A portable PC records the radiometric signal at 11.2 GHz receiving data from the USB port by *DataMicroRAL10* software (graph on top) while simultaneously the detector audio signal is recorded (*RAL10AP* post-revelation audio output), it is displayed as a spectrogram by *Spectrum Lab* software (http://www.qsl.net/dl4yhf/spectra1.html).
Records show the X-band radar signals of the boats when the antenna is oriented towards the sea.

After this introduction, we analyze the specific characteristics of each instrument and the differences between them.

The starting point: *RAL10KIT* e *RAL10AP*

The "entry level" instruments are represented by *RAL10KIT* and *RAL10AP* receiver. The first one (Fig. 1), cheaper version, is designed for self-builder who will assemble the parts into a suitable case, completing it with a power supply, as specified in the instructions. After the receiver realization it will be possible to connect the antenna system with a coaxial cable and start the observations by installing and activating the provided software. **For all instruments of RAL10 family, you can use any commercial antenna and LNB suitable for 10-12 GHz satellite reception.**

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

For those who want to buy the instrument ready to use, inside a compact anodized aluminum housing, we suggest *RAL10AP* (Fig. 2): it is a radiometer with technical characteristics comparable to those of *RAL10KIT*, combined with a 12V - 2A common external power supply (available on request). On the front panel there are protection fuses (with interruption led signaled) for the main power and for the LNB power supplied through the coaxial cable. **An additional and unique feature of this model is the post-revelation audio output: if connected to an external amplifier or to the audio input of a PC, allows monitoring of detected signals through one of the many free downloaded software for the analysis of spectrograms.** Fig. 11 shows an example of use of the audio output, not exactly radio astronomy, but useful for identifying potential interference artificial.

RAL10KIT and *RAL10AP* are *Total-Power* radioemters with a bandwidth of 50 MHz, centered on the IF-SAT frequency of 1415 Mhz, if they are combined with a standard TV-SAT LNB with local oscillator at 9.75 GHz, they allow the reception at 11.2 GHz frequency.

For the more experienced: *RAL10* e *RAL10PL*

The two models, *RAL10* and *RAL10PL*, are an evolution of the previous versions: developed with professional performance and equipped with a pair of microprocessors that manage all functions, they are the best instruments for the construction of amateur radio astronomical systems with semi professional features.

RAL10 is a desk instrument. Assembled in a robust anodized aluminum housing (Fig. 4), it includes a front panel with backlit LCD display and a keyboard commands for manual setting of the operating parameters and for displaying functions. The parameters can be set either manually or remotely via the serial channel (USB connection to PC acquisition managed by software). If you need to do measurements where there is not available the supply voltage of the electricity network, you can connect *RAL10* to an 12V external power source (rechargeable battery or *RAL10BT Rechargeable Battery Unit* - Fig. 9) by a socket on the rear panel. This possibility, combined with the compactness and portability, make *RAL10* the ideal product, for convenience and completeness, for radio astronomy measurements "on field".

***RAL10PL* is the suitable version for fixed installations, is a receiver developed for remote radio telescope (see antenna *RAL230ANT* - Fig. 8), installed near the antenna system in the area not controlled by operatives.** The instrument is assembled in a robust polycarbonate box, resistant to rain and moisture (Fig 5), with the electronic circuits of the receiver further protected by a metallic thermo-stabilized case.

RAL10PL is only remotely controllable, it communicates with the outside world via an Ethernet port that connects to the network the system and allow the control through the web. **The main feature (and only one) of *RAL10PL* is the ability to manage an equatorial mount (such as those used for astronomical optical instruments, well known to amateur astronomers - Fig. 8) for moving the radio astronomy antenna. The serial port of mount (typically RS232) can be connected to the *RAL10PL* receiver and sent through a single Ethernet cable the PC station. With the help of the provided software (*RadioUniverse*) it will be possible to program, control and monitor the functions of the radio telescope.**

The *RAL10* and *RAL10PL* radiometers are identical in terms of performance: the main difference, as underlined, is their destination use. During designing and construction we paid attention to optimize, with reasonable cost, the performance of a microwave radiometer, in particular those considered indispensable to a radio astronomy receiver, such as the sensitivity and stability of the measurement. **The sensitivity is ensured by a wide bandwidth (the order of 250 MHz) and a high gain of the IF section, while the measurement stability and repeatability are optimized by the control (PID) of the receiver internal temperature which minimizes the variations of the amplification factor and the instrument operating parameters according to the environment temperature changes.**

An analog-digital converter with high resolution (14 bits) and the possibility to set a wide range of values for the post-detection gain and for the integration constant of the measure (selectable from 0.1 seconds up to over 100 minutes), classify *RAL10* series receivers as the ideal devices to cover all installation requirements for a semi-professional amateur radio telescope.

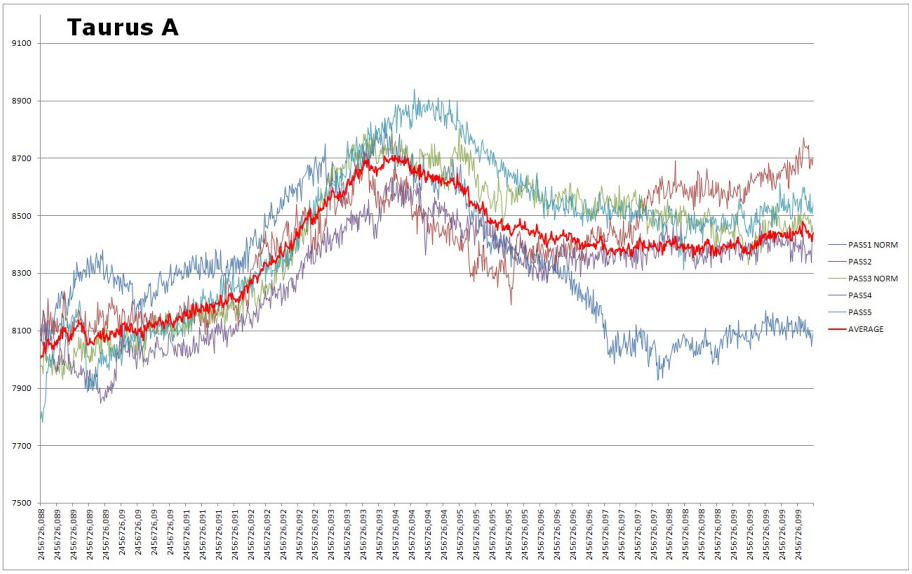


Fig. 12: *Taurus A* (M1) radio source transits recorded by *RAL10* and by *RAL230ANT* antenna system.
The transit technique used for measurement consists of identify the object for which you want to record the radio emission, point the telescope in the sky area in which the object will move in the near future (eg 30 minutes later) and stop the telescope in that position. Because of the apparent sky rotation (caused by the rotation of Earth), the object will move towards the area of sky pointed by the antenna, will be intercepted by the receive beam and will pass through.
In the described registration, 5 consecutive transits of the same area of the sky have been performed, this time 4 degrees each: *RadioUniverse* software *(*which controls *RAL10* receiver and *RAL230ANT* antenna*)* allows you to automatically record consecutive transits. Then the results obtained can be processed by averaging the values (red trace) to reduce random noise and to increase the visibility of the radio source.

We have concluded this brief overview of the *RAL10* series features, further informations can be found in the documentation available on www.radioastrolab.it. The *RadioAstroLab* sales and technical staff is available for any information.

I take this opportunity to report and give right importance to one aspect that makes *RadioAstroLab* unique: the ability to propose, in addition to the standard tools of the catalog, also an important consulting service and an "ad hoc" production of equipment for amateur radio astronomy and for scientific applications in general. It can range from the changes or the customizations (hardware and software) proposed directly by customers relatively standard models, to the design and "ad hoc" production of radio astronomical complete systems and amateur and semi-professional radio telescopes. This service is necessary to provide answers not only to the requests of individuals, but also to those of groups (such as, for example, amateur astronomers and radio amateurs), of the scientific working groups, of schools and universities, of government and private research institutions, of museums, of science institutions, these kind of organizations often ask customized solutions.

Thanks to our experience in amateur radio astronomy, to the original technical solutions developed (and patented) for the production of microwave radiometers, to the modular features of our products, we are able to offer this service, providing to customers *RadioAstroLab* technical staff and laboratories: we listen everyone and discuss with anyone, evaluating the technical and

economic feasibility of each idea.we heed and discuss with anyone, evaluating the technical and economic feasibility of each idea.

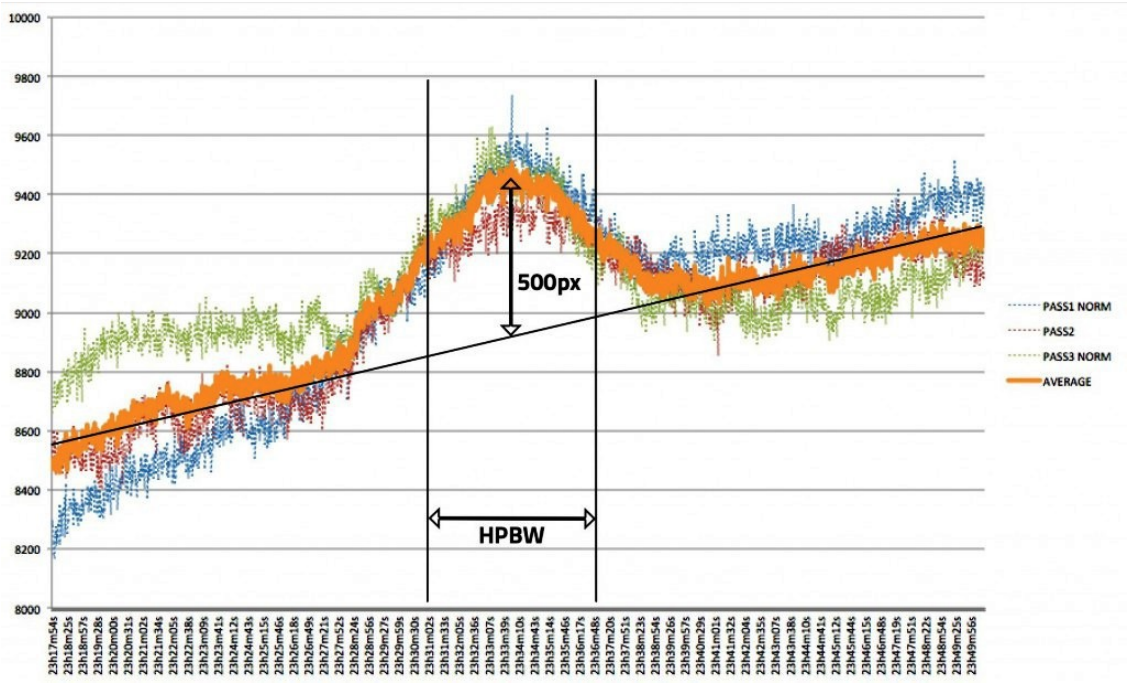


Fig. 13: *Cassiopea A* radio source transits recorded by *RAL10* and by *RAL230ANT* antenna system. Cassiopea A is an object "almost punctiform", it is often used by radio astronomers as a radio source sample to verify the characteristics of the diagram of the receiving radio telescope. In applications, it is interesting to obtain the HPBW parameter (Half Power Beam Width) which represents the amplitude at half power of the main lobe of the antenna (expressed in degrees). It uses the following formula:

$$HPBW = 0.25 \cdot t \cdot \cos(\delta)$$

where t is the transit time of the radio source in minutes and δ is the declination in degrees. By analyzing the recordings illustrated in figure (orange trace represents the average over 5 consecutive transits) it can be seen as the time taken by *Cassiopea A* to cross the two points at half power (indicated by the vertical lines) is approximately 6 minutes. Considering that its declination is $\delta=59°$, the calculation gives:

$$HPBW = 0.25 \cdot 6 \cdot \cos(59) = 0.77\,°$$

in agreement with the value *HPBW = 0.8°* obtained from the model of the *RAL230ANT* antenna used in the simulations.

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