RPG-8CH-DP
4 Frequency, Dual Polarized Radiometer
(6.925 / 10.65 / 18.70 / 36.50 GHz h/v)

Version 5.5 (28. Oct. 2006)

Operating Manual

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1. Unpacking and Assembly of the Radiometer

1.1 Radiometer Modules and Positioner

The instrument is delivered in two boxes. Box A contains the elevation / azimuth positioner and the positioner / power / data cables. Unpack this box first. In box B you will find the radiometer modules mounted on a steel frame, the positioner controller, the PC and a LN calibration target, see Fig.1.1:

Fig.1.1: Content of box B. Radiometer modules are mounted to a steel frame that is also holding the two off axis parabola antennas for the low frequency channels.

Step 1: Dismount the antenna frame from the main steel frame. The antenna frame is screwed to the main frame by two threaded bolts with black knobs.
Step 2: Dismount the 10.65 GHz and 6.926 GHz receiver modules (see Fig.1.2) from the main frame.
Step 3: Unscrew the main frame from the wooden box's bottom plate (4 screws S1, see Fig.1.3).
Step 4: Lift the main frame together with the 18.7 and 36.5 GHz modules on top of the positioner and screw it tightly on the positioner's mounting plate (use S2 positions, Fig.1.3). Also mount the antenna frame back to the main frame. See Fig.1.4.
Step 5: Mount the 6.925 and 10.65 GHz modules back to the main frame (positions S3, Fig.1.3)

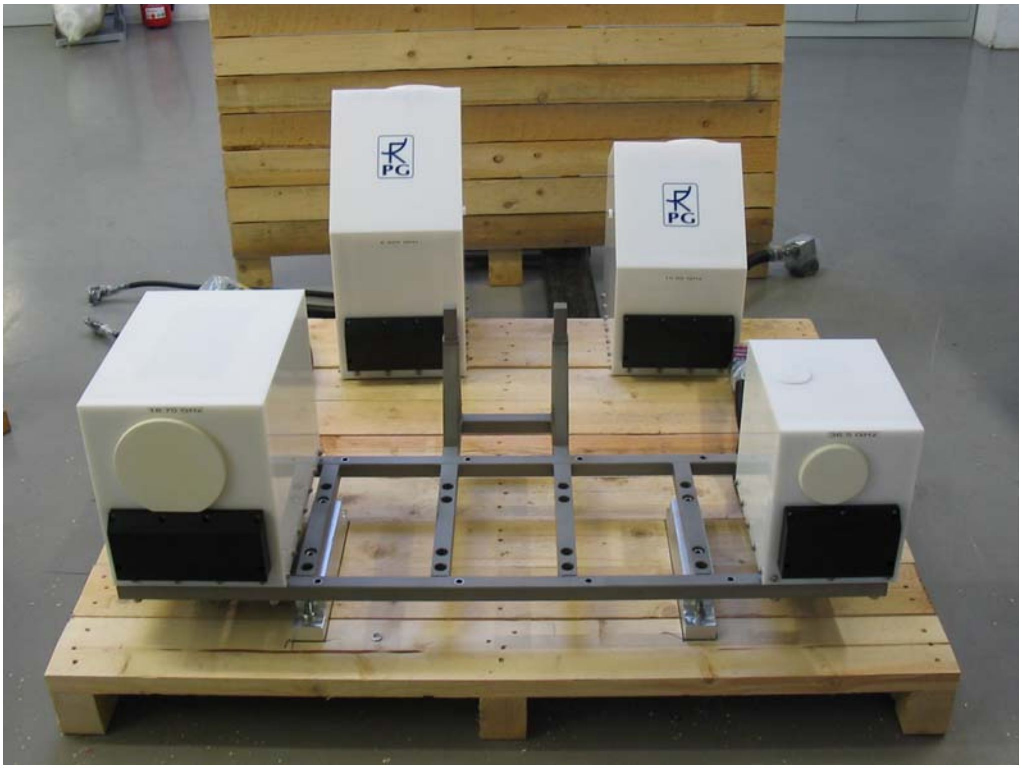


Fig.1.2: The low frequency modules (6.925 and 10.65 GHz) dismounted from the main frame.

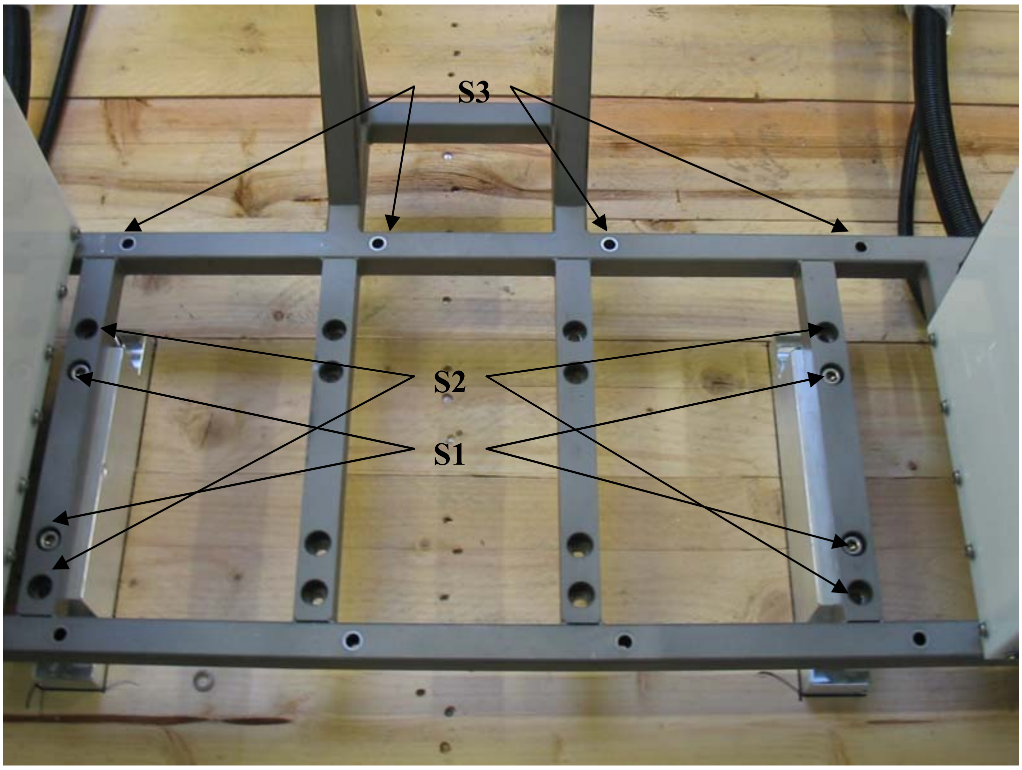


Fig.1.3: Dismounting the main frame from the box B base plate by unscrewing 4 S1 screws.

Fig.1.4: Mounting the main frame on top of the positioner's base plate.

1.2 Electrical Connections

Fig.1.4 shows the two power supplies PS1 and PS2 located close to the positioner's elevation axis.
Each receiver module has a main power cable (industry standard T12-4 CombiTec connector) and a receiver control cable (15 pin sub-D connector). Plug all sub-D connectors into their associated sockets on PS1 (see Fig.1.5) and screw them tight. They are labelled 1-4. Then plug in the T12-4 connectors (10.65 GHz and 36.5 GHz modules to PS1, 6.925 GHz and 18.7 GHz modules to PS2). The receiver modules are now connected to the data acquisition system.
Furthermore connect the radiometer power connector and the positioner connector to the rear side of the positioner controller box as shown in Fig.1.6. The positioner controller receives its commands from the host PC via an RS-232 cable with 25 pin sub-D connector on the controller side and a 9 pin sub-D connector on the PC side. Use the COM1 interface on the PC for this connection. Then plug in the PC power and monitor power cables into one of the sockets shown in Fig.1.6.
Finally fasten the modul cables with cable binders like shown in Fig.1.7.

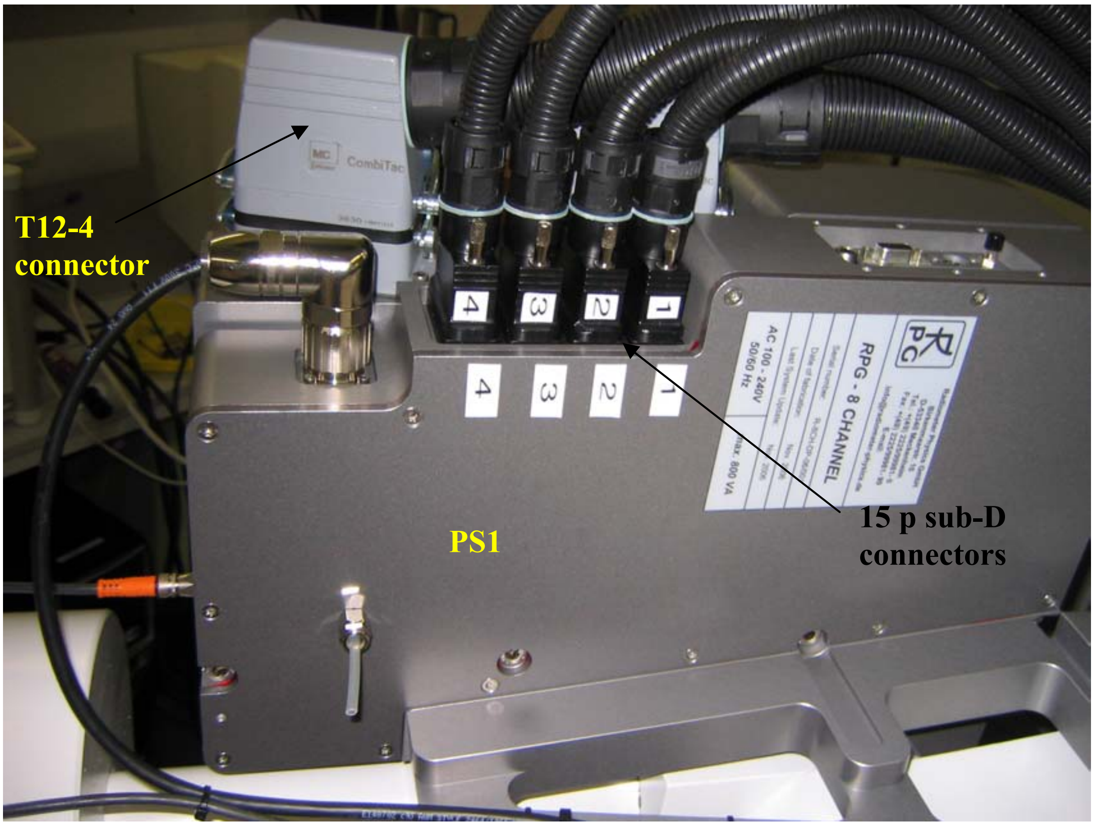


Fig.1.5: Connecting the receiver modules to PS1 / PS2.

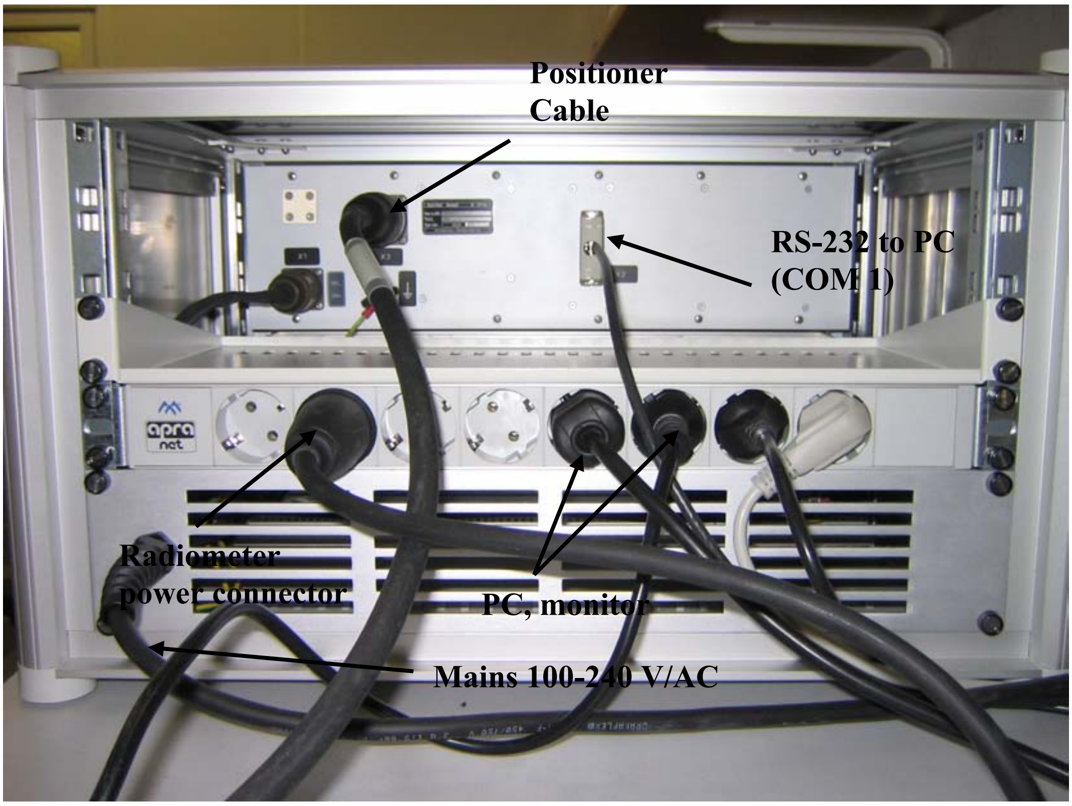


Fig.1.6: Rear panel of positioner controller unit with connections.

Fig.1.7: Rear side of assembled instrument.

1.3 Powering up the Radiometer

After all mechanical and electrical connections have been established the radiometer can be turned on (Fig.1.8: Power ON/OFF switch). The embedded PC takes about 60 seconds to boot and start the radiometer software. Also the positioner controller performs a boot-up procedure and automatically enters the remote control mode that is needed to communicate with it via RS-232. Wait at least 30 minutes for warm-up at operating temperatures >10°C and 45 minutes warm-up time at lower environmental temperatures. The stabilization process can be inspected in the DIAGNOSTICS menu on the host computer.
During warming up the system actively heats the receivers with a total power consumption of 500 Watts. Once the receivers are thermally stabilized, the power consumption drops down to less than 300 Watts.

Fig.1.8: Front side of power and positioner controller.

2. Instrument Hardware

2.1 Operating the Positioner Controller

The instrument positioner controller is by default set to automatically switch to REMOTE mode when the unit is powered on. In this mode the controller communicates with the external PC via RS-232 interface. In general this mode should not be changed. Otherwise the PC software might lose the ability to access the positioner status (elevation and azimuth position) and to initiate movements. When the PC software is active and has connected to the

radiometer, the REMOTE mode is essential for a smooth radiometer operation. **If the controller is accidentally in LOCAL mode while the PC software is active, the software might crash or stop execution until the controller is reset to REMOTE operation.**
However, it is sometimes useful to manually move the positioner without the control of the operating software. E.g. during the instrument setup process and horizontal alignment a manual controller operation is mandatory. The following description of the controller functions is limited to those commands that are needed for this system setup and does not include information about how to change the controller driver parameters or other critical parameters that affect the smooth operation of the device. For further details please refer to the controller operating manual delivered with the radiometer package.

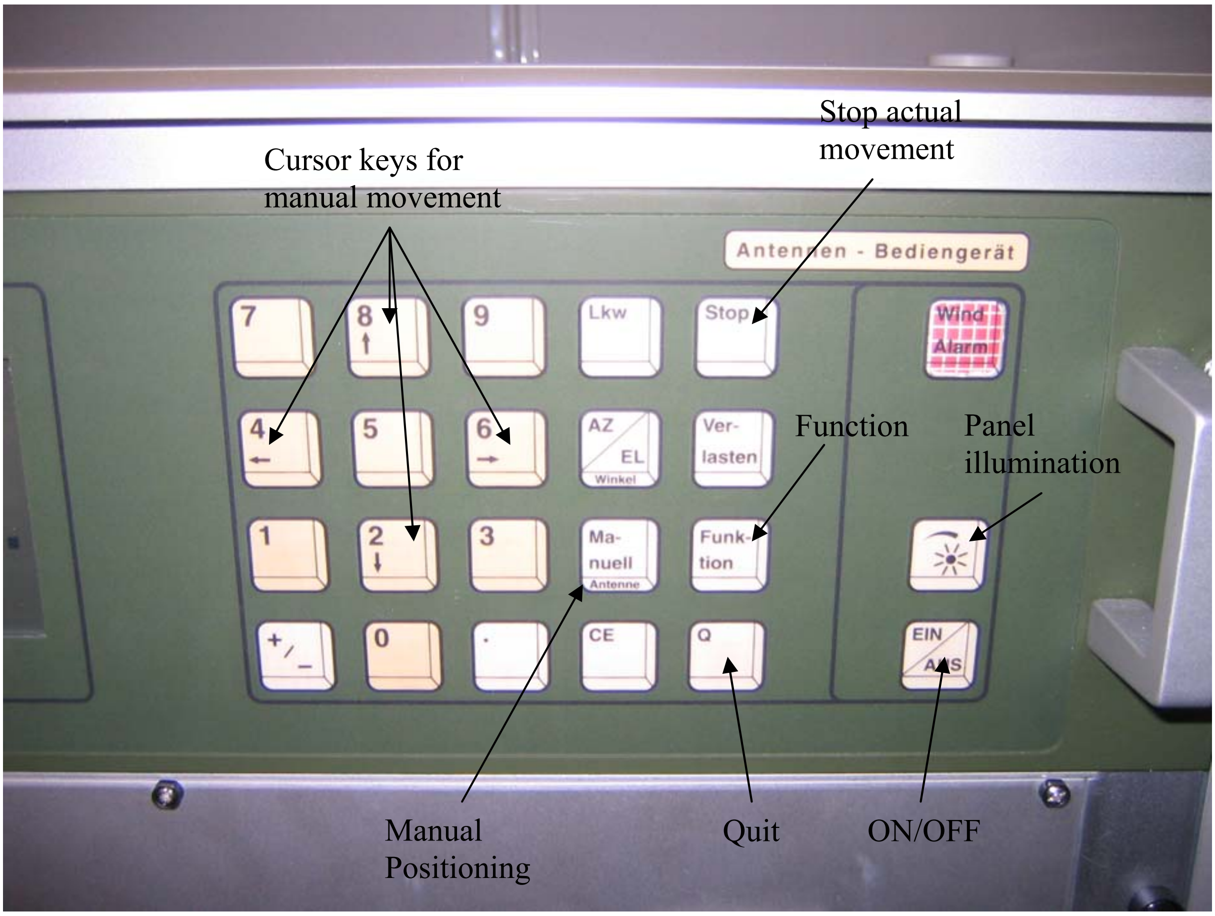


Fig. 2.1: Positioner controller operating panel.

Panel Keys:

AZ/EL: The positioner model AR/AE 1040 is a two axis positioning device with simultaneous axis control. The delivered controller unit can also handle other positioner models with only a single axis or two distinct positioners. In LOCAL mode the **AZ/EL**-key allows to enter elevation and azimuth coordinates for manual movement control. First the antenna no. is entered (always **1**). Then one enters the new azimuth target position. If the azimuth position shall be unchanged quit the entry with **Q** and continue with the elevation angle. Press the **Q**-key to leave this menu. The positioner will then move to the defined coordinates.

EIN/AUS: ON/OFF-key. The controller is programmed to turn on automatically when power is applied to the unit. If the user wants to turn the controller off without turning off the radiometer and PC (by switching the main switch shown in Fig.1.8) he can press this key. When power is applied to the controller or the **EIN/AUS**-key is pressed to turn the controller on, the device is running through a setup sequence for detecting the connected positioner model and to load the driver parameters. After this initialization procedure the controller automatically enters REMOTE mode.

Funktion:
NEVER change the settings accessible with the **Function**-key followed by the **1**-key, **2**-key or **3**-key. These settings are critical for the positioner operation and have been factory pre-defined. Changing these parameters might lead to strange positioner behaviour or damage the positioner!
Pressing the **Function-key** followed by the **4**-key one enters the AZ/EL step width menu. This step width is used during manual movements with the cursor keys. First of all the azimuth step width has to be entered with the numerical keys which is quitted with the **Q**-key. Then the elevation step width is entered and quitted in the same way.
Pressing the **Function**-key followed by the 7-key the user may switch between English and German for the LCD display language.
Pressing the **Function**-key followed by the **8**-key toggles between LOCAL and REMOTE mode for the power on default.
Pressing the **Function**-key followed by the **9**-key toggles the controller between REMOTE and LOCAL mode. The default is REMOTE mode when the unit is powered on. In this mode all keys except for the Function-key, the STOP-key and the **EIN/AUS**-key are disabled.

Panel illumination: see Fig.2.1. The user might change the panel illumination with this key. After pressing the key one of the 0 / 1 / 2 / 3 / 4 keys should be pressed to set the panel illumination to one of the four different illumination levels. Level 4 ist the brightest illumination level. Both, the LCD display and the keys are illuminated so that the controller can be operated at dark places. After switching on the controller the default level is 2. One can turn off the illumination by entering level 0.

Manuell: Manual movement key. When the controller is in LOCAL mode the operator can press the **Manuell**-key to move the positioner axis with the cursor keys. First the antenna number (aways 1) has to be entered and then the positioner will move as long as one of the cursor keys is pressed. The vertical arrow keys control the elevation axis and the horizontal arrow keys the azimuth axis. One can leave the menu by pressing **Q**.

Stop: The positioner movement can be stopped at any time by pressing the **Stop**-key. This works in both, LOCAL and REMOTE mode.

Offset Adjustment
When the radiometer is set up for the first time its horizontal adjustment has to be performed in order to remove a possible elevation offset angle. The radiometer is automatically calibrating itself by the sky tipping method (on regular intervals) which relies on the correct horizontal adjustment of the elevation axis. The following procedure is used for the adjustment:
Step 1: Move the positioner to the desired reference position which is intended to be azimuth 0.0° and elevation 0.0°. For the elevation axis the operator should use a leveler to adjust the radiometer table to be horizontally aligned.
Step 2: Turn off the controller with the **EIN/AUS**-key.
Step 3: Press and hold the **Function**-key and turn on the controller (**EIN/AUS**-key).

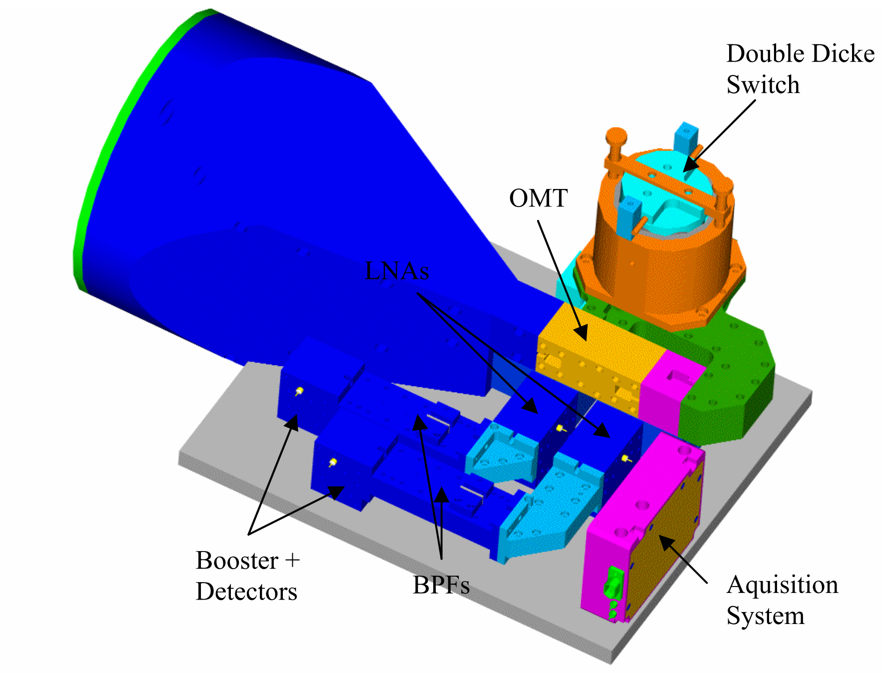
Step 4: Release the **Function**-key.
Step 5: Press the **1**-key, **2**-key and **3**-key in this order.
The new reference positions are then stored into an EEPROM inside the controller unit. From now on all positioning angles are displayed relative to the new references.

Limiting Switches
The positioner is equipped with hardware limiting switches on both axis. When it reaches one of these switches the movement is stopped and cannot be continued in the same direction. The elevation axis limiting switches are close beyond the maximum angles of +/- 90°. The radiometer hardware mounted on the positioner platform cannot be damages accidentally due to the limiting switch protection.

2.2 General Radiometer Configuration

Fig.2.2 shows a schematic drawing of the inner radiometer components, illustrated as an example for the 18.7 GHz radiometer. The following functional blocks can be identified:

- Receiver optics comprising corrugated feed horn with aperture lens (encapsulated in thermal insulation)
- OMT (Ortho Mode Transducer) for splitting the signal into vertical and horizontal polarization channels.
- Calibration system comprising a double Dicke switch (system noise temperature calibration) and noise injection section (gain calibration).
- Signal processing components like isolators, LNAs, BPFs (band pass filters) and detectors.
- The instrument electronics sections
- Data aquisition system



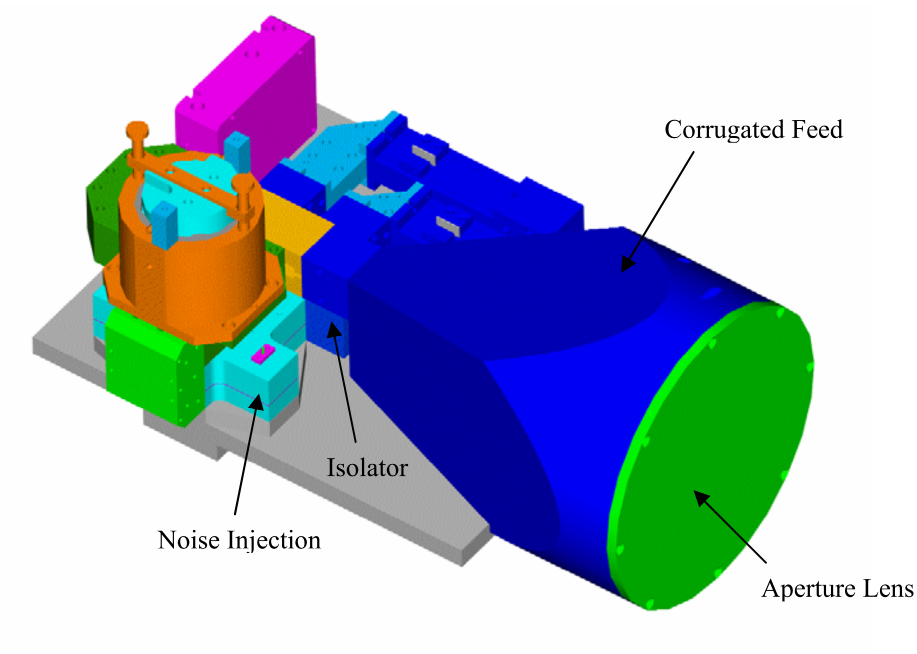


Fig. 2.2: Radiometer configuration (18.70 GHz radiometer).

The optical section is optimized for a beam of approximately 8.0° HPBW for all channels. At 6.925 GHz and 10.65 GHz the beam is formed by a combination of corrugated feed horn and off-axis parabola antenna while at 18.7 and 36.5 GHz a corrugated feed with aperture lens is sufficient to achieve the desired beam width. The corrugated feed horn offers a low cross polarization level and a rotationally symmetric beam pattern.
The receivers are integrated together with their feeds and lenses and are thermally insulated to achieve a high thermal stability.

2.3 Receivers

The RPG-8CH-DP receiver concept is motivated by the following design goals:

- The design of the receiver section focuses on maximum thermal and electrical stability, a compact layout with a minimum of connectors and thermally drifting components, an integrated RF design, low power consumption and weight.
- The receivers comprise a reliable calibration system with precision secondary standards and Dicke switches. The accuracy of calibration target temperature sensors and the minimization of thermal gradients are critical items to achieve an absolute brightness temperature accuracy of 1K.
- A high temporal resolution in the order of seconds is achieved. The minimum integration time for each channel is 1 second.

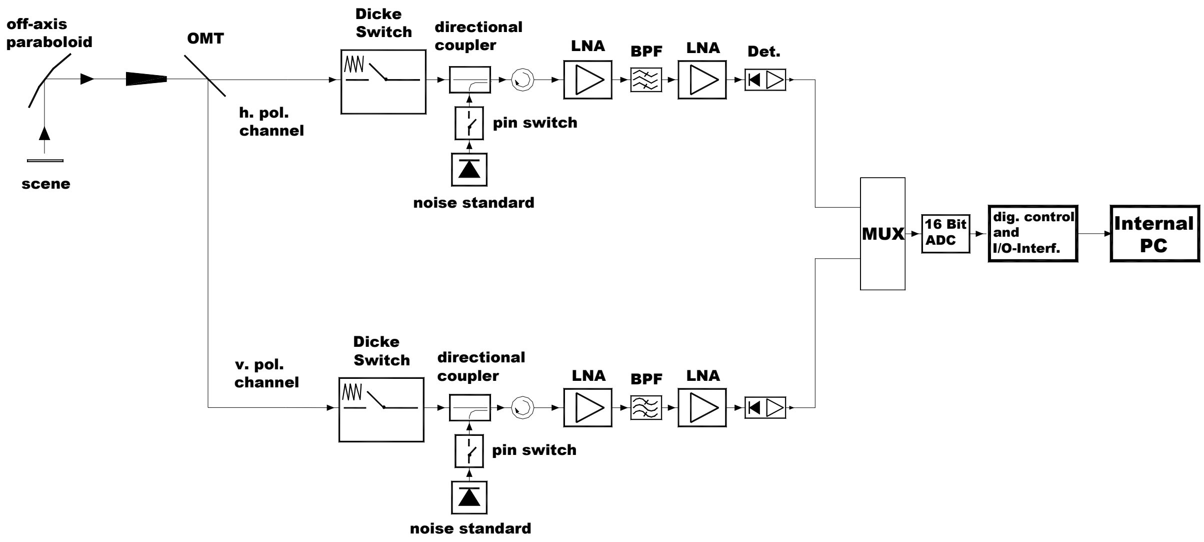


Fig.2.3: RPG-8CH-DP schematic receiver layout. All radiometers are direct detection systems without the need for local oscillators and mixers.

Fig.2.3 shows a schematic of the receiver system. At the receiver inputs a Dicke Switch periodically switches the receiver inputs to an internal black body with well know brightness temperature. It is used to continuously determine the system noise temperature of the radiometers. The Dicke Switch is followed by a directional coupler which allows for the injection of a precision noise signal generated by an on/off switching calibrated noise source. This noise signal is used to determine system nonlinearities (four point method, described in section 'Calibration') and system gain drifts during measurements.
A 40 dB low noise amplifier (LNA) boosts the input signal before it is filtered and again boosted by another 20 dB amplifier. The waveguide bandpass filters' (BPF) bandwidths and centre frequencies are listed in table 2.1.

f_c[GHz]	**6.925**	**10.65**	**18.70**	**36.50**
b[MHz]	400	400	400	400

Table 2.1: RPG-8CH-DP channel centre frequencies and corresponding bandwidths.

Each channel has its own detector diode. This allows for a parallel detection and integration of all channels. The detector outputs are amplified by an ultra low drift operational amplifier chain and multiplexed to a 16 bit AD converter for each of the four frequency modules.

The receivers are based on the direct detection technique without using mixers and local oscillators for signal down conversion. Instead the input signal is directly amplified, filtered and detected. The advantages over a heterodyne system are the following:

- No mixers and local oscillators required (cost reduction)
- Local oscillator drifts in amplitude and frequency avoided (stability improvement)
- Mixer sideband filtering not required (cost reduction)

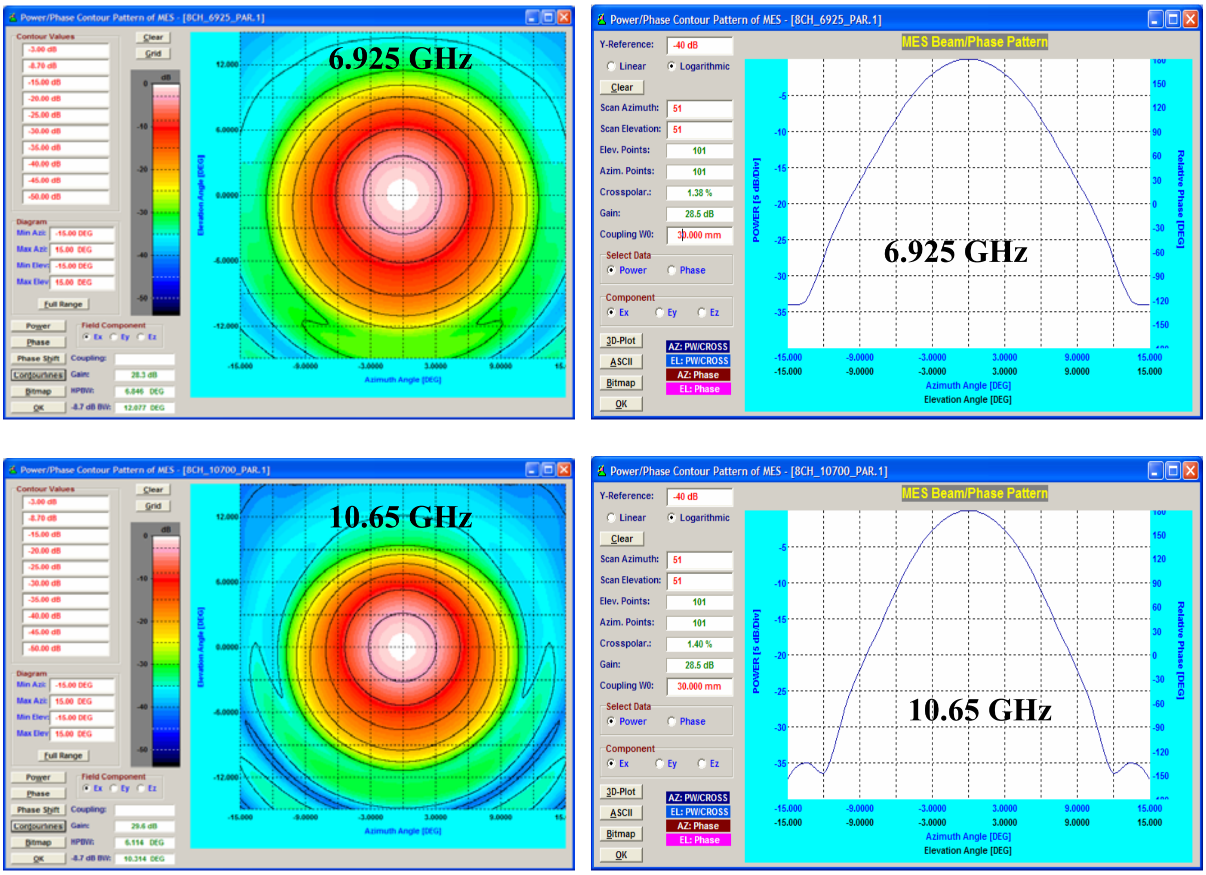
- Reduced sensitivity to interfering external signals (mobile phones etc.) due to avoidance of frequency down conversion

A high integration level is achieved due to the use of state of the art low noise amplifier MMICs, which offer superior sensitivity performance compared to mixers.
The total power consumption of each receiver package is < 4 Watts. This includes biasing of RF- and DC- amplifiers, noise diodes, Dicke switch drives, ADCs and digital control circuits. The low consumption simplifies the thermal receiver stabilization with an accuracy of < 0.05 K over the whole operating temperature range (-30°C to +40°C).

3. Detailed Description of Receiver Components

3.1 Antenna Performance

To meet the optical requirements of minimum reflection losses and compactness a corrugated feed horn is an optimal choice. It offers a wide bandwidth, low cross polarization level and a rotationally symmetric beam. Corrugated feed horns can be designed for a great variety of beam parameters. The horn should be as small as possible to reduce weight and costs.
In order to generate a beam with the desired divergence (8.0° HPBW) a focussing element is needed at 6.925 GHz and 10.65 GHz. An off axis parabola antenna has negligible losses.
The side-lobe levels produced by the feed horn/parabola system is below -30 dBc so that brightness temperature errors can be kept < 0.2 K in the case that the side-lobe crosses the sun.



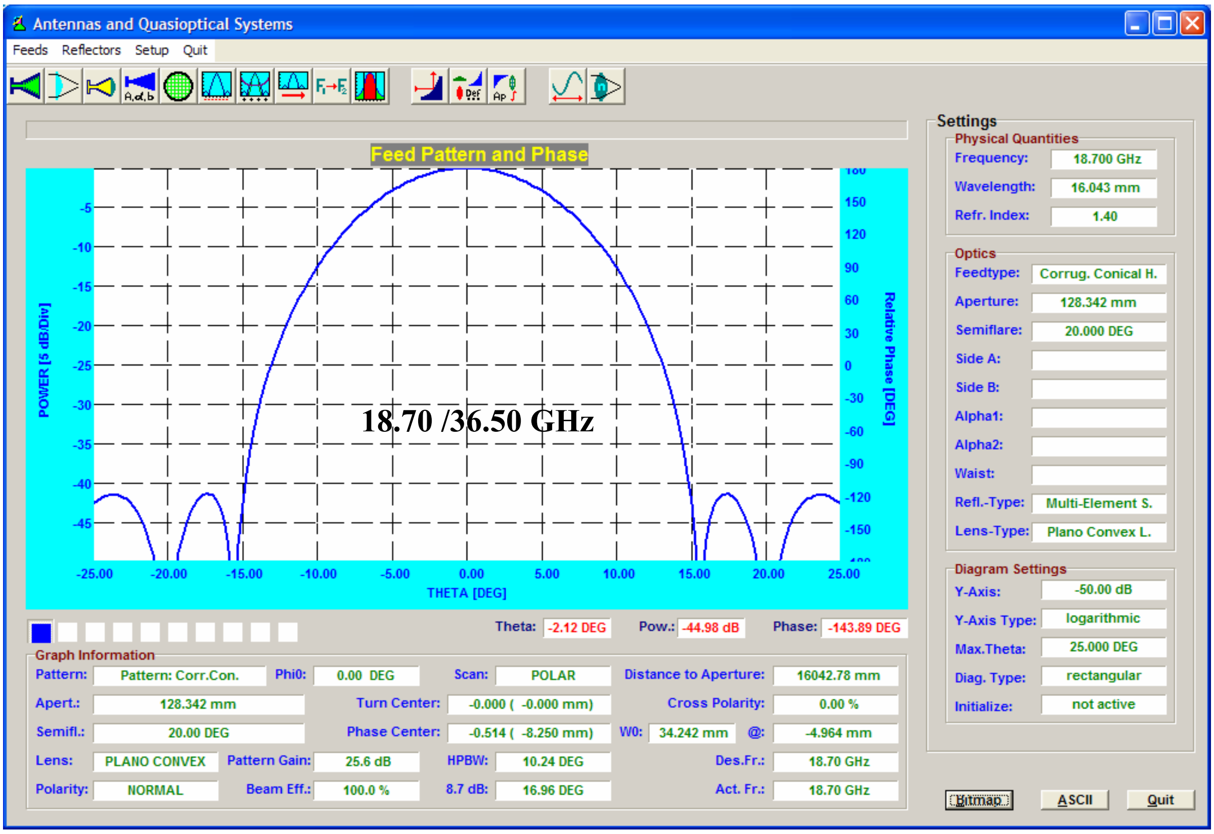


Fig.3.1: Left: 2d amplitude distributions of the parabola/corrugated feed @ 6.925 and 10.65 GHz and H-and E-plane cuts on the right. H/E plane cuts of the corrugated feed/lens system @ 18.70 and 36.5 GHz.

Frequency [GHz]	6.925	10.65	18.70	36.50
sidelobe level [dBc]	<-30	<-35	<-40	<-40
directivity [dB]	28.3	29.6	25.6	25.6
HPBW [°]	6.85	6.11	10.25	10.25
Aperture Diameter [mm]	450	330	128.4	65.0

Table 3.1: Optical antenna performance of corrugated feed / off-axis parabola systems.

3.2 Noise Diodes

The noise diode is one of the most critical receiver components because the system's brightness temperature critically depends on the calibration reliability. For this reason a careful circuit design and component selection is essential. The noise diode meets MIL-STD202, is hermetically sealed and has been burned in for 170 hours in order to achieve a precisely constant symmetrical white Gaussian noise level. The waveguide circuit layout including a -25 dB directional coupler guarantees the required mechanical stability needed to operate the calibration standard for several month without recalibration. The thermally stabilized diode is biased by a self adjusting current source. The directional coupler offers an isolation of >30 dB to the input signal path so that the noise injection does not significantly affect the antenna temperature. The equivalent noise temperature injected by the noise diode is in the range 150K-300K at the isolator input.

3.3 RF-Amplifiers

The advances in MMIC technology during recent years have led to low noise amplifiers up to 220 GHz. A key feature of this technology is the possibility of integrating the receiver into a compact planar structure without the need for bulky waveguide designs. In the frequency range between 7 and 40 GHz noise figures of 3.5 dB and bandwidth of 20 GHz are available. Each amplifier comprises a thermal compensation circuit to reduce gain drifts. The amplifier inputs are equipped with isolators to ensure a proper matching between successive stages. Assuming a 3.5 dB noise figure for the first amplifier and additional 1.0 dB for losses in the feed horn, isolator and directional coupler results in a system noise temperature of 450 K. With a scene temperature of 300 K the overall RMS noise, assuming a 400 MHz bandwidth and 1 second integration time) is 0.2 K in Dicke switch operation mode.

3.4 Bandpass Filters

The receiver channel bandwidths are determined by waveguide bandpass filters. The 3 pole Chebychev-type filters with 0.2 dB bandpass ripple and 1.0 dB typical transmission loss have a cutoff slope of 20 dB/200 MHz. The high Q design (2.0% rel. bandwidth) is realized by waveguide cavity resonators.

3.5 Detector, Video Amplifier, ADC

The zero bias highly doped GaAs Schottky detector diodes can handle frequencies up to 170 GHz with a virtually flat detection sensitivity from 7 GHz to 40 GHz. In addition, the detector diode offers superior thermal stability when compared to silicon zero bias Schottky diodes.
The rectified DC-signal enters an ultra stable OP-Amp circuit with internal analogue integrator. The utilized OP-Amps offer a thermal drift stability of 0.03 μV/°C which is roughly equivalent to a brightness temperature drift of 10 mK/°C assuming a broadband detector with a sensitivity of 1 mV/μW. The long term stability is 0.2 μV/month.
The 16 bit AD-converter is part of the video amplifier's circuit board to avoid noise from connecting cable pickup. It is optimized for low power dissipation (10 mW) and the high resolution makes a variable offset- and gain-control of the video amplifier superfluous.
The detector, video amplifier and ADC are integrated within a single hermetically shielded unit which is part of the receiver block (thermally stabilized to <0.03K).

3.6 Additional Sensors

Apart from the microwave receivers the RPG-8CH-DP radiometers are equipped with the following additional sensors:
Environmental Temperature Sensor: Accuracy: ±0.5°C, used to estimate T_{mr} (mean atmospheric temperature) needed for sky tipping calibration procedure.

Barometric Pressure Sensor: Accuracy: ±1 mbar, used to estimate T_{mr} (mean atmospheric temperature) needed for sky tipping calibration procedure and for the determination of liquid nitrogen boiling temperature (absolute calibration).

All meteorological sensors are calibrated without the need for further recalibration.

3.7 Other Radiometer Details

In order to fulfil the requirement of low maintenance regarding absolute calibrations, the instrument is equipped with a two-stage thermal control system for all receivers with an accuracy of ±0.05 K over the full operating temperature range. Due to this extraordinary high stability the receivers can run freely without any calibration (not even the automatic gain calibration) for 20 minutes while maintaining an absolute brightness temperature accuracy of ±0.5 K. Each receiver is equipped with a precision noise standard (long term stability) at its signal input which replaces the external cold target in the internal absolute calibration procedure.
The system performs many automatic tasks like data interfacing with the external host, data acquisition of all housekeeping channels and detector signals, controlling of azimuth/elevation positioner, backup storage of measurement data, automatic and absolute calibration procedures etc. These tasks are handled by a build in embedded PC with 250 Mbyte flash memory for data storage. This PC is designed for operating temperatures from –30°C to 60 °C and is therefore ideal for remote application. The software running on this PC can easily be updated by a password protected file transfer procedure between host and embedded PC.
The host computer software operates under Windows NT4.0, Windows 2000 and Windows XP. A complete host software description is given in chapter 5.

3.8 Instrument Specifications

Parameter	Specification
System noise temperatures	<500 K for all receiver
Radiometric resolution	0.2 RMS @ 1.0 sec integration time
Channel bandwidth	400 MHz
Absolute system stability	1.0 K
Radiometric range	0-350 K
Absolute calibration	with internal Dicke switch & external cold load
Internal calibration	gain: with internal Dicke Switch + noise standard automatic abs. cal.: sky tipping calibration
Receiver and antenna thermal stabilization	Accuracy <0.05 K
Gain nonlinearity error correction	Automatic, four point method
Brightness calculation	based on exact Planck radiation law
Integration time	>=1 second for each channel
Data interface	RS-232, 115 kBaud
Data rate	9.5 kByte/sec., RS-232
Instrument control	Desktop PC, Pentium based
Housekeeping	all system parameters, history documen-tation
Optical resolution	HPBW: 6.1° to 10°
Sidelobe level	<-30dBc

Pointing speed	elevation: 3°/sec, azimuth: 5°/sec
Operating temperature range	-30°C to +45°C
Power consumption	<350 Watts average, 500 Watts peak
Input voltage	90-230 V AC, 50 to 60 Hz
Weight	105 kg for receiver modules, 300 kg for positioner

4. Calibrations

Calibration errors are the major source of inaccuracies in radiometric measurements. The standard calibration procedure is to terminate the radiometer inputs with two absolute calibration targets which are assumed to be ideal targets, meaning their radiometric temperatures are equal to their physical temperature. This assumption is valid with reasonable accuracy as long as proper absorber materials are chosen for the frequency bands in use and barometric pressure corrections are applied to liquid coolants in the determination of their boiling temperature.

4.1 Absolute Calibration

A calibration target is considered to be an absolute standard when it is not calibrated by another standard. The RPG-8CH-DP is shipped with two calibration targets of this category.

4.1.1 The Internal Dicke Switch Calibration Target

The Dicke switch target (see Fig.2.2 and Fig.2.3) is one of the instrument's key components. The switch inserts an absorber blade of well known physical temperature into the input waveguide of each receiver (ON position). This absorber serves as a termination of the same brightness temperature and is thus equivalent to a quasi-optical target (of the same temperature) when positioned in front of the receiver. The Dicke switch is located behind the feed horn and cannot calibrate changes in the feed horn BT. It is therefore essential to thermally stabilize the feed horn and lens of each receiver to keep this contribution constant. The switches are operated once per second and are used to adjust drifts in the system noise temperature. Of course it is important to measure the Dicke switch physical temperature as accurate as possible.
The main advantage of using a Dicke switch instead of a quasi-optical target for absolute calibration is that this calibration can be performed frequently (every second!) while the radiometers are pointing to the scene. The switches work in combination with the built-in noise injection system which is used to calibrate gain drifts. In contrast to the Dicke switches (these are absolute standards), noise diodes are secondary standards that have to be calibrated by a hot/cold calibration with liquid nitrogen or by a tip curve calibration on the clear sky.

4.1.2 External Liquid Nitrogen Cooled Calibration Target

Another absolute calibration standard is the liquid nitrogen cooled target (see Fig.4.1). This target is only used during absolute calibrations. The positioner's elevation axis is tilted down to -90° and the target is located underneath the receiver antenna of the module which is actually calibrated. The calibration is repeated for each model. This standard - together with the internal Dicke switch target - is used for the absolute calibration procedure. The cooled load is stored within a 40 mm thick polystyrene container. 25 litres of liquid nitrogen is needed for one filling.

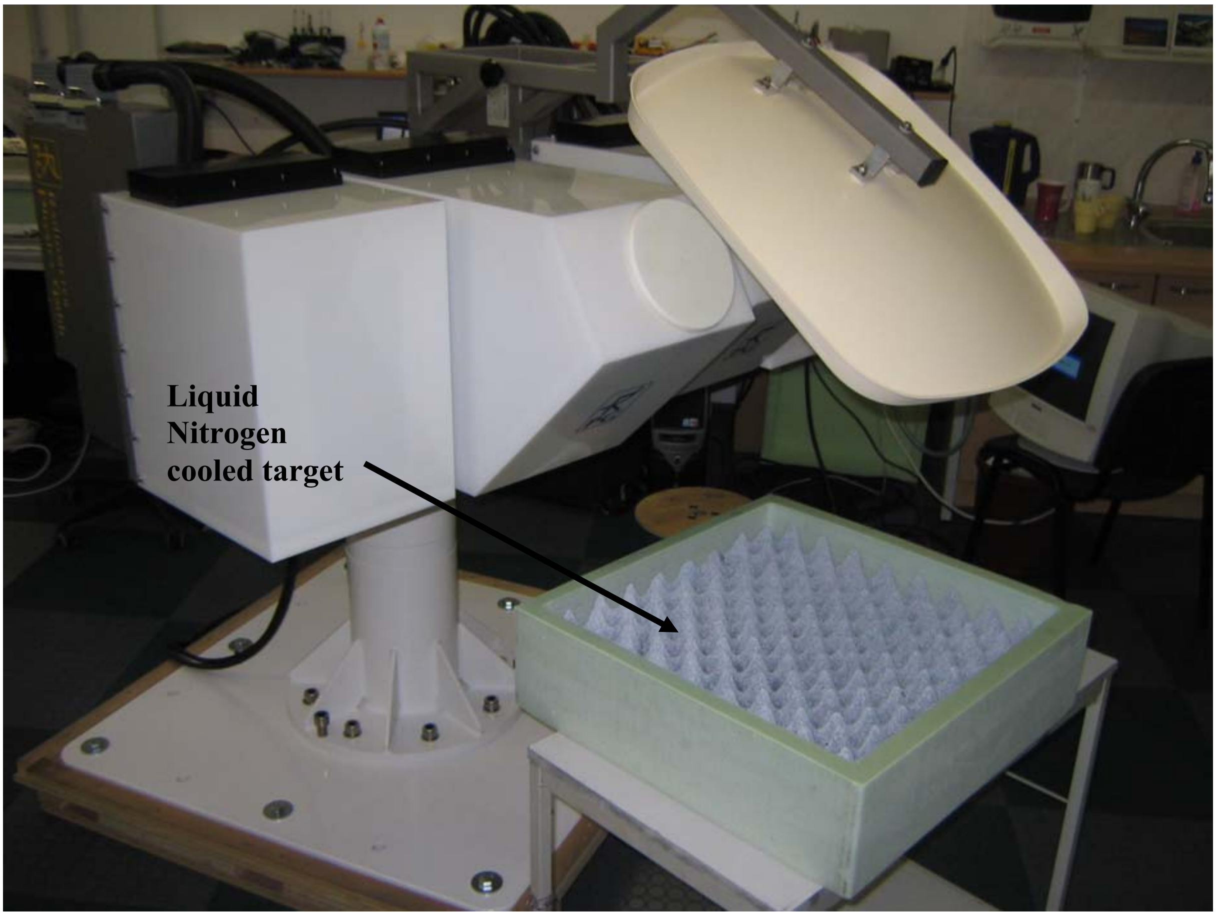


Fig.4.1: External cold load attached to the radiometer box.

The boiling temperature of the liquid nitrogen and thus the physical temperature of the cold load depends on the barometric pressure p. The radiometer's pressure sensor is read during absolute calibration to determine the corrected boiling temperature according to the equation:

$$T_c = T_0 - 0.00825 \cdot (1013.25 - p)$$

T_0 = 77.25 K is the boiling temperature at 1013.25 hPa.
The calibration error due to microwave reflections at the LN/air interface is automatically corrected by the calibration software (embedded PC). It is recommended to wrap a plastic foil around the load + radiometer (wind protection) during absolute calibration to avoid the formation of condensed water above the liquid surface (caused by wind etc.).

4.1.3 General Remarks on Absolute Calibrations

After the system has been turned on, at least 30 minutes are required for warming up and stabilization of all receiver components. To ensure accurate measurements, an absolute calibration should be performed only after completed warm-up.
The liquid nitrogen calibration was performed once at RPG to calibrate the noise standards. Usually it is not required to repeat this calibration when the radiometer regularly performs sky tipping calibrations. Sky tipping is the most accurate calibration method.

4.1.3.1 System Nonlinearity Correction

A common simplification in the design of calibration systems for total power receivers is the assumption of a linear radiometer response. In this case a simple two point calibration (hot/cold) is sufficient to determine the system noise equivalent temperature (T_{sys}, offset noise) and system gain (G, slope of the linear response). Accurate noise injection measurements [2], [3] have shown that the assumption of linear system response is not valid in general. Calibration errors of 1-2 K have been observed at brightness temperatures in between the two calibration target temperatures. This system nonlinear behaviour is mainly caused by detector diodes [1] needed for total power detection. Even in the well defined square law operating regime (input power < -30 dBm) the detector diode is not an ideal element with perfect linearity. The noise injection calibration algorithm implemented in all RPG radiometers corrects for these nonlinearity effects.
The system nonlinearity is modelled by the following formula:

$$U = GP^{\alpha} \quad , \quad 0.9 \le \alpha < 1 \qquad (1)$$

where U is the detector voltage, G is the receiver gain coefficient, α is a nonlinearity factor and P is the total noise power that is related to the radiometric brightness temperature T_R through the Planck radiation law:

$$P(T_R) \cong \frac{1}{e^{\frac{h\nu}{k_B T_R}} - 1}$$

(the proportionality factor is incorporated in G). T_R is the sum of the system noise temperature T_{sys} and the scene temperature T_{sc}.

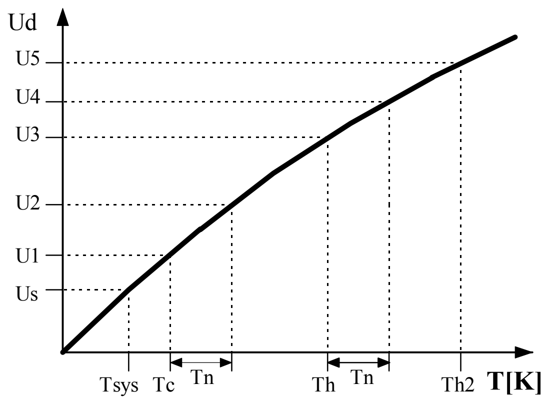


Fig.4.7: Detector response as a function of total noise temperature. T_{sys} is the system noise temperature, T_n the additionally injected noise, T_c the total noise when the radiometer is terminated with a cold load (e.g. liquid nitrogen cooled absorber) and T_h the corresponding noise temperatures for the ambient temperature load.

The problem is how to determine G, α and T_{sys} experimentally (three unknowns cannot be calculated from a measurement on two standards). A solution is to generate four temperature points by additional noise injection of temperature T_n which leads to four independent equations with four unknowns (G, α , T_{sys} and T_n) The procedure is illustrated in Fig.4.7:
During the calibration cycle the elevation mirror automatically scans the two absolute targets.

The initial calibration is performed with absolute standards and leads to the voltages *U1* and *U3*. By injection of additional noise *U2* and *U4* are measured. For example *U2* is given by

$$U_2 = G(P(T_{sys}) + P(T_{cold}) + P(T_n))^{\alpha} \qquad (2)$$

where T_{cold} is the radiometric temperature of the cold target. The evaluation of the corresponding equations for *U1*, *U3* and *U4* results in the determination of T_{sys}, G, α and T_n. It is important to notice that the knowledge of the equivalent noise injection temperature T_n is not needed for the calibration algorithm. It is only assumed that T_n is constant during the measurement of U1 to U4.
After finishing the procedure the radiometer is calibrated. With the four point calibration method also the noise diode equivalent temperature T_n is determined. Assuming a high radiometric stability of the noise injection temperature, following calibrations can use this secondary standard (together with the built-in ambient temperature target) to recalibrate T_{sys} and G (considering α to be constant) without the need for liquid nitrogen.

References

[1] Cletus A. Hoer, Keith C. Roe, C. McKay Allred, 'Measuring and Minimizing Diode Detector Nonlinearity', IEEE Trans. on Instrumentation and Measurement, Vol. IM-25, No.4, Dec. 1976, page 324 pp.

[2] Sandy Weinreb, 'Square Law Detector Tests', Electronics Division Internal Report No. 214, National Radio Astronomy Observatory, Charlottesville, Virginia, May 1981

[3] Hvatum Hein, 'Detector Law' Electronics Division Internal Report No.6, National Radio Astronomy Observatory, Green Bank, West Virginia, Dec. 1962

4.3 Noise Injection Calibration

It is not convenient to use a liquid nitrogen cooled load for each calibration. For this reason the radiometer has four built-in noise sources (one for each receiver) that can be switched to the receiver inputs. The equivalent noise temperature T_n of the noise diode is determined by the radiometer after a calibration with two absolute standards (hot/cold or sky tipping) and is in the range 100 K to 300 K. The noise diode is also used to correct for detector diode nonlinearity errors. The accuracy of a calibration carried out with this secondary standard and the Dicke Switches is comparable to the results obtained with a liquid nitrogen cooled load. The advantage of the secondary standard is obvious: A calibration can be automatically done at any time. All system parameters are recalibrated including system noise temperatures.
The noise diode is optimized for precision built-in test equipment (BITE) applications and meets MIL-STD202 standard with 170 hours burn-in. This process guarantees highest reliability and performance repeatability. The repeatability error is expected to be <0.1 K / month.
Due to the fact that only two calibration points are generated with this calibration type (T_a= Dicke Switch temperature, T_{a+n} = Dicke Switch temperature + noise standard), it has to be assumed that the non-linearity factor α does not change with time. This is a reasonable assumption because α is basically an intrinsic detector diode parameter.

4.4 Sky Tipping (Tip Curve)

Sky tipping (often referred to as tip curve calibration) is a calibration procedure suitable for those frequencies where the earth's atmosphere opacity is low (i.e. high transparency) which means that the observed sky brightness temperature is influenced by the cosmic background radiation temperature of 2.7 K. All RPG-8CH-DP channels are candidates for this calibration mode.
Sky tipping assumes a homogeneous, stratified atmosphere without clouds or variations in the water vapour distribution. If these requirements are fulfilled the following method is applicable:
The radiometer scans the atmosphere from zenith to around 20° in elevation and records the corresponding detector readings for each frequency. The path length for a given elevation angle α is 1/sin(α) times the zenith path length (often referred to as "air mass"), thus the corresponding optical thickness should also be multiplied by this factor (if the atmosphere is stratified!).
The optical thickness is related to the brightness temperature by the equation:

$$\tau(\infty) = -\ln\left(\frac{T_{mr} - T_i}{T_{mr} - T_{B0}}\right)\sec(\theta)$$

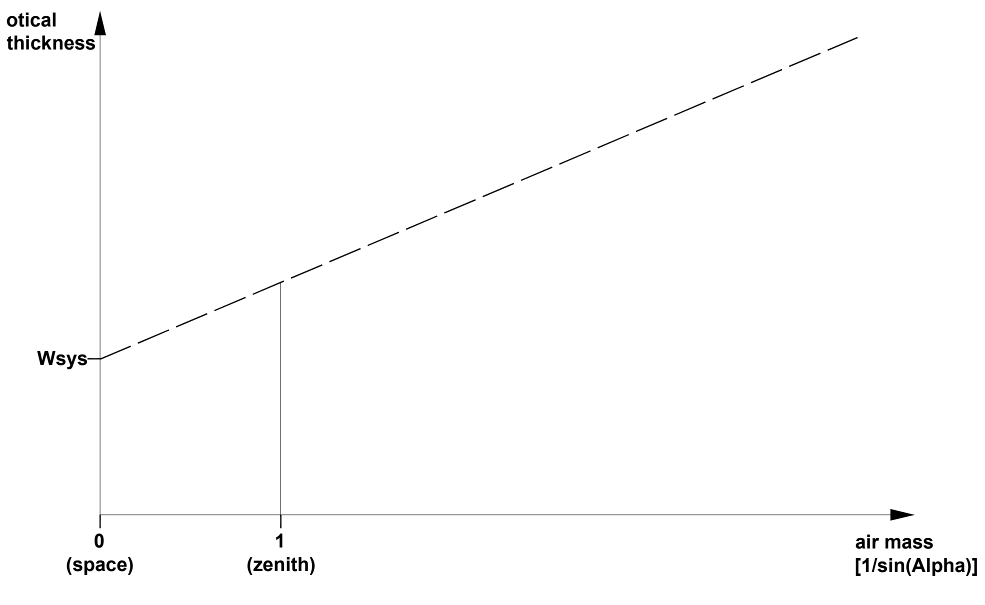


Fig.4.9: Extrapolation of tipping response to 2.7 K free space temperature.

T_{mr} is a mean atmospheric temperature in the direction θ, T_{B0} is the 2.7 K background radiation temperature and T_i is the brightness temperature of frequency channel i. T_{mr} is defined as:

$$T_{mr} = \frac{\int_0^\infty T(z)\, e^{-\tau(z)}\, \sigma_a\, dz}{1 - e^{-\tau(\infty)}}$$

T_{mr} is a function of frequency and is usually derived from radiosonde data. A sufficiently accurate method is to relate T_{mr} with a quadratic equation of the surface temperature measured directly by the radiometer.
The optical thickness as a function of air mass is a straight line (see Fig.4.9) which can be extrapolated to zero air mass. The detector reading U_{sys} at this point corresponds to a radiometric temperature which equals to the system noise temperature plus 2.7 K: $U_{sys} = G*(T_{sys} + 2.7\ K)$. The proportionality factor (gain factor) G can be calculated when a second detector voltage is measured with the radiometer pointing to the ambient target with known radiometric temperature T_a. The sky tipping calibrates the system noise temperature and the gain factor for each frequency without using a liquid nitrogen cooled target.
The disadvantage of this method is that the assumption of a stratified atmosphere is often questionable even under clear sky conditions due to invisible inhomogeneous water vapour distributions (e.g. often observed close to coast lines). The built-in sky tipping algorithm investigates certain user selectable quality criteria to detect those atmospheric conditions that do not fulfil the calibration requirements. The most important criteria are:

- Linear correlation factor. This measures the correlation of the optical thickness samples (as a function of air mass) with a straight line. Typical linear correlation factor thresholds are >0.9995. The linear correlation factor is not sensitive for the noise of the optical thickness samples caused by clouds etc.
- χ^2-test. This measures the variance of the optical thickness samples relative to the straight line in Fig.4.9. Typical threshold values are <0.8 for a good quality calibration.

The tip curve calibration is considered to be the most accurate absolute calibration method. The brightness temperatures acquired in the elevation scan are close to the scene temperatures measured during zenith observations.

5. Software Description

The following conventions are used in this software description:

- Messages generated by the program that have to be acknowledged are printed in red. Example: ***The specified port in 'R2CH.CFG' has no data cable connected to it!***
- Button labels are printed in green: ***Cancel***
- Messages that have to be answered by ***Yes*** or ***No*** are printed in light blue: ***Overwrite the existing file?***
- Labels produced by the software are printed in grey: ***UTC***
- Names of group boxes are printed in blue. Example: ***Radiometer Status*** on the main screen.
- Names of tabs are printed in violet: ***Sky Tipping***
- Names of menus are printed in black: ***File Transfer***
- When a speed button shall be pressed this is indicated by its symbol: 
- Hints to speed buttons are printed in brown: ***Define Serial Interface***
- Selections from list boxes are printed in magenta: ***Celsius***
- Selections from radio buttons are printed in dark green: ***COM1***
- File names are printed in orange: ***MyFileName***
- Directory names are printed in dark blue: ***C:\Programs\RPG-HATPRO***

5.1 Installation of Host Software

5.1.1 Hardware Requirements for Host PC

The hardware requirements for running the host software are:

- Pentium based PC, 500 MHz clock rate minimum
- 30 MB free RAM for software execution
- Serial interface (RS-232), 9 pin Sub-D connector

A desktop PC is included in the standard delivery package and pre-installed software comes with it. However the host software R2CH.EXE can be installed and run on any other computer that fulfils the hardware requirements listed above.

5.1.2 Directory Tree

By clicking on the desktop icon  the executable host program ***R2CH.EXE*** is invoked (runs on Windows NT4.0, Windows 2000, Windows XP). On pre-installed PCs this file is located in ***C:\RPG-8CH-DP***. This directory path can be changed to any other path (in the following referred to as ***MY_DIRECTORY\RPG-8CH-DP***). Of course the corresponding desktop link has to be modified accordingly.
In the case that the user wants (or has) to install the software himself the following steps should be performed:

- Start your Windows operating system
- Start the Windows Explorer
- Insert the Radiometer CD-ROM
- In Windows Explorer click on the CD-ROM drive icon

- Click on the ***RPG-8CH-DP***-folder and drag the whole folder to ***MY_DIRECTORY*** (user selectable).

Example: If '***MY_DIRECTORY***' is the directory ***D:\Programs*** the complete tree should look like this:

```
D:
 |---Programs
        |---RPG-150-90
        |      |---DATA
        |      |---MBFs
        |      |---MDFs
```

The ***RPG-8CH-DP*** -directory contains the following files:

- *VCL50.BPL* : System library extension file
- *VCLX50.BPL* : System library extension file
- *BORLNDMM.DLL* : Dynamic link library, Memory Management functions
- *CC3250MT.DLL* : Dynamic link library, Core functions
- *INPOUT32.DLL* : Dynamic link library needed for serial communication
- *R2CH.EXE* : Radiometer software
- *R8CH.CFG* : Radiometer software configuration file

The ***MBFs*** and ***MDFs*** directories are empty after installation and are intended for the Measurement Batch Files and Measurement Definition Files needed to initiate a measurement. ***DATA*** is reserved for measurement data files including user defined sub-directories. Of course the user can create any other directory for his data file storage.
Click into ***MY_DIRECTORY\RPG-150-90***\ and locate *R2CH.EXE*. When clicking on this file with the right mouse button a list of actions is displayed. Select the 'Desktop (Create Shortcut)' option to generate an icon on the desktop.

5.2 Getting Started

When clicking on the desktop icon  to start the host software (*R2CH.EXE*) the program first tries to locate a data cable connected to any of the RS-232 host serial interfaces. If it does not find a data cable the message ***The specified port in 'R8CH.CFG' has no data cable connected to it!*** is generated as shown in Fig. 5.1. This message is referring to the file *R8CH.CFG* (located in ***MY_DIRECTORY\RPG-150-90***) which is a configuration file that is loaded by *R2CH.EXE* at program start. This file contains information (among other data) about the standard serial interface port used for the communication link to the radiometer.
For certain reasons it is desirable to operate the software even without a data link to the radiometer. For instance, the user may wish to inspect recorded data files, calibration history or prepare MDFs (Measurement Definition Files) for the next measurements etc. These tasks do not require a radiometer communication link. In this case the message ***The specified port in 'R8CH.CFG' has no data cable connected to it!*** can be ignored. All commands requiring a radiometer connection are then disabled.

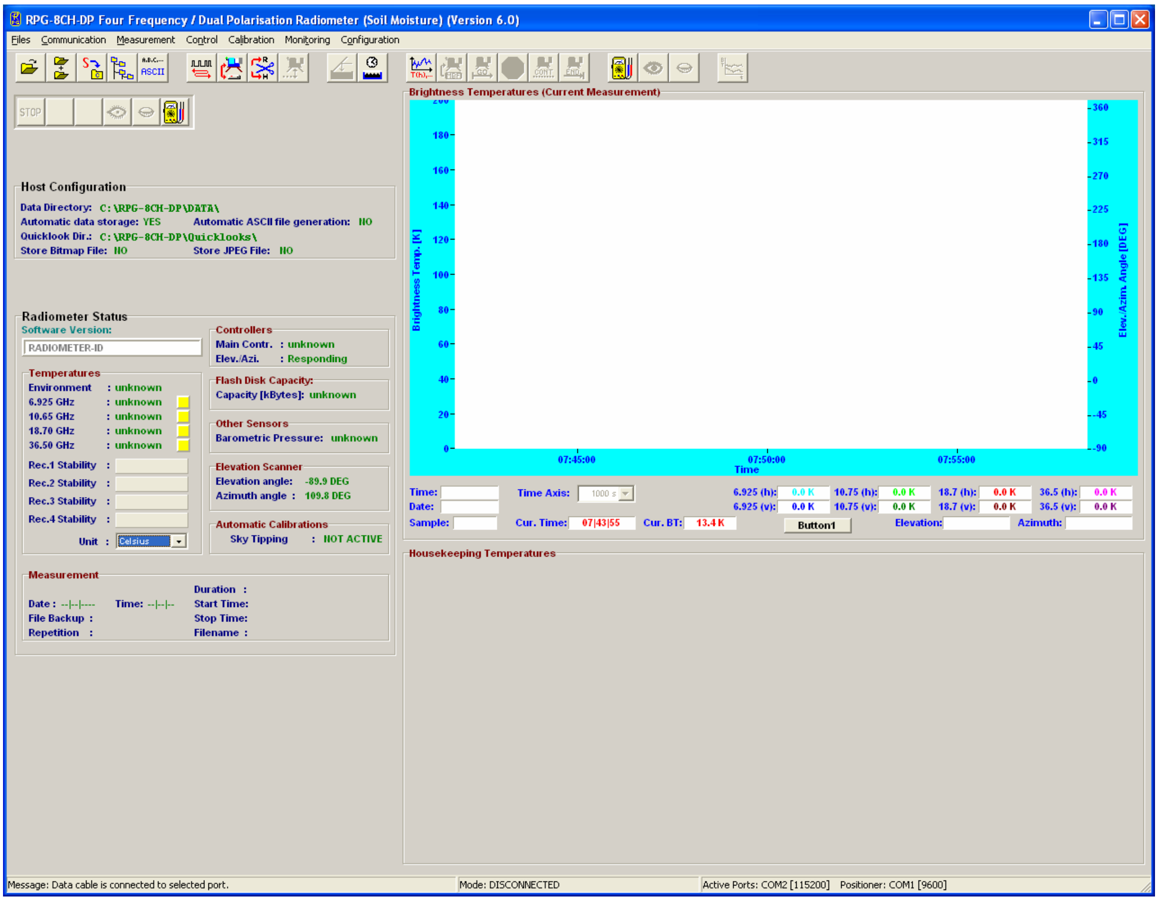


Fig.5.1: Starting host software with a data cable connected to one of the RS-232 interfaces.

If a data cable is installed between the host and the radiometer (see section 1.2), the user can define the serial interface parameters for the communication (only required the first time when the host PC is installed). This is done by clicking (***Define Serial Communication Ports***). The command opens the following menu:

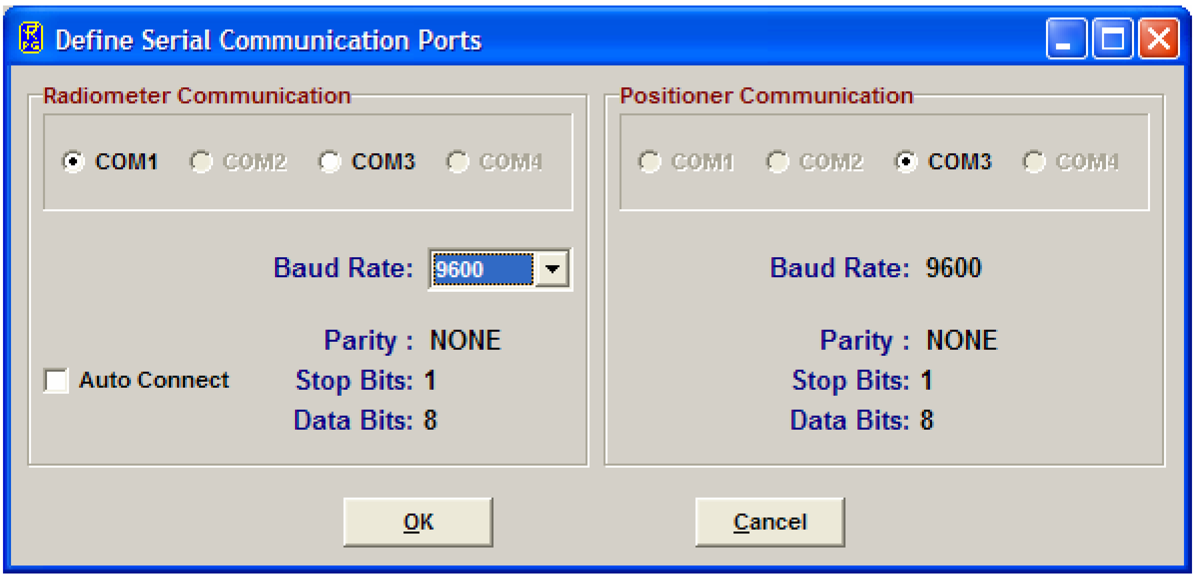


Fig.5.2: Definition of radiometer and positioner controller interface parameters.

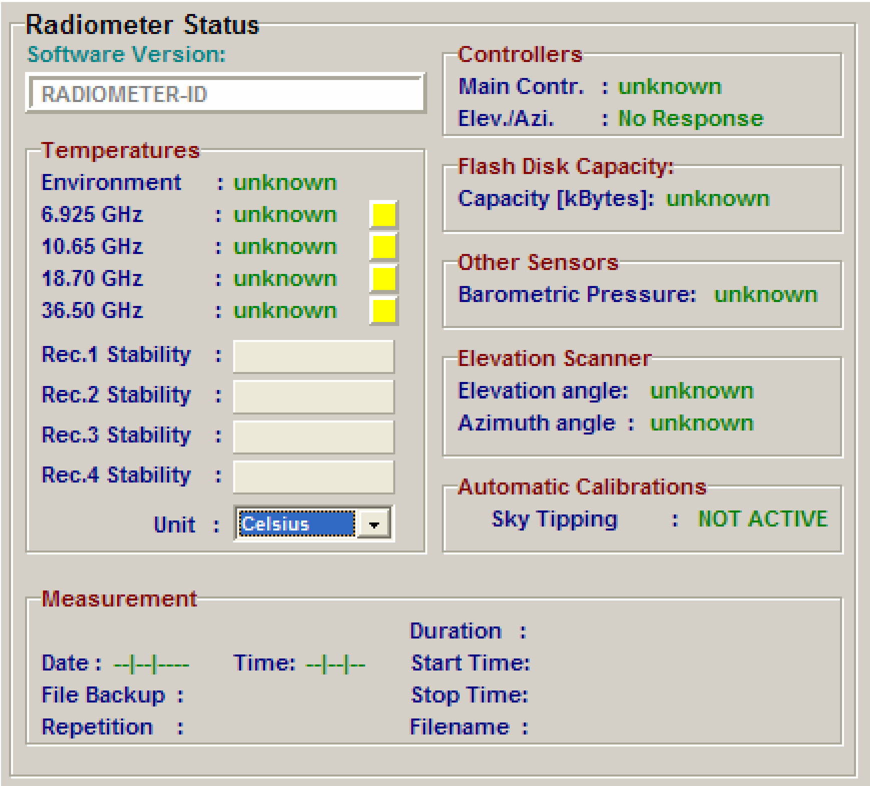
The selectable COM-ports are enabled in the upper button list. The user can select only one of the possible ports for interconnection with the radiometer and another one for the communication with the positioner controller.
The baud rate parameter defines the communication speed. For cable lengths up to 40 m the highest baud rate should be used (*115200*). This is particularly important when files that have been backed up on the radiometer Flash Memory need to be transferred to the host. Some of these data files might be several MBytes in size so that an optimally fast transfer rate is desirable. At *115200* baud the transfer speed is about 9 kByte/sec.
The positioner controller is only operated with 9600 Baud. We recommend to use COM1 for the connection to this controller and COM3 or COM4 for the connection to the radiometer.
If ***Auto Connect*** is checked, the host software automatically tries to connect to the radiometer (if a data cable is detected) when it is started. This feature enables an auto-start up function after a power failure of the host PC. The radiometer embedded PC will automatically continue a measurement when the power returns after a power failure. To start the host software automatically after reboot of the operating system, the ***R2CH.EXE*** should be copied into the Auto Start directory of the operating system or an appropriate task should be defined in the operating system scheduler.
The interface parameters are stored in the configuration file (***R2CH.CFG***) that is loaded each time ***R2CH.EXE*** is started. This file is backed up on exiting ***R2CH.EXE***. A definition of the serial interface parameters is only necessary at the first start of ***R2CH.EXE*** or when the transfer speed must be reduced due to longer cable length.
The sequence for setting up a communication link to the radiometer is the following:

- Install the interface cable between host and radiometer as described in section 1.2 (the radiometer power has to be turned off).
- Turn on the system power, see section 1.3.
- Wait for 2 minutes until the radiometer PC has booted up.
- Start the host software (if not already done) and define the serial interface parameters as described above (if necessary).
- The next step is to initiate the communication between the host and radiometer PC by pressing (***Connect to Radiometer***). ***R2CH.EXE*** then establishes the same baud rate on the radiometer embedded PC as was selected in ***Define Serial Communication Port***. This operation takes a couple of seconds. If successful, the message ***Connection to radiometer successfully established. Baud Rate adjusted.*** is displayed. Otherwise the message ***Radiometer does not respond! Connection could not be established...*** appears. In this case try the following to handle the problem:
    - Repeat the command.
    - If not successful, check the data cable (is it properly connected to host and radiometer?).
    - Check that the radiometer power is turned on.
    - Repeat the turn on procedure.
    - If not successful, contact RPG.

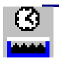
The connection status is displayed in the status bar (bottom line of the main screen) and includes the COM port number and baud rate. The radiometer responds to the host by sending the status report (listed in ***Radiometer Status*** on the host main screen) comprising its ID, the status of the various controllers, the system's housekeeping data (temperatures, surface sensor readings, inclination in elevation axis and azimuth position) and Flash Memory capacity (disk on module, the embedded PC's hard disk. When a measurement is started, additional information is displayed here like the calibration status, reference time and date, the duration of the actual measurement, its start and end time, the measurement filename, whether file backup is enabled on the embedded PC or not and the repetition number of the running batch (explained later). The radiometer status display can be disabled ( ) or enabled ( ) at any time. In general the display should be enabled because certain automatic tasks (like logging of all calibration activities) are only performed when the status display is enabled.

5.3 Radiometer Status Information

The various status displays in the ***Radiometer Status*** group box are:



- Software Version: Indicates the version number of the radiometer PC software ***8CH.EXE*** for reference (the host software version is printed in the main window caption).
- Instrument ID: The radiometer identifies itself by sending the instrument ID to the host when a connection is established (e.g. ***RPG-8CH-DP***, ***RPG-LWP***, ***RPG-LWP-U***, etc.).
- ***Controllers***: Lists the status of the two instrument controllers:
  - The main controller handles all communication activities between the radiometer PC and the radiometer hardware.
  - The elevation / azimuth controller generates the driving signals for the positioner.
- ***Flash Memory Capacity***: The radiometer PC is equipped with a flash memory hard disk (no movable parts) called DOM. Its capacity – when empty - is 250 Mbytes. The status indicates, how much memory (measured in kBytes) is left for the backup of measurement files. If the remaining free memory is less than 20 Mbytes the backup files should be flushed (see section 5.4). When 10 Mbytes are reached no further file backup is performed.

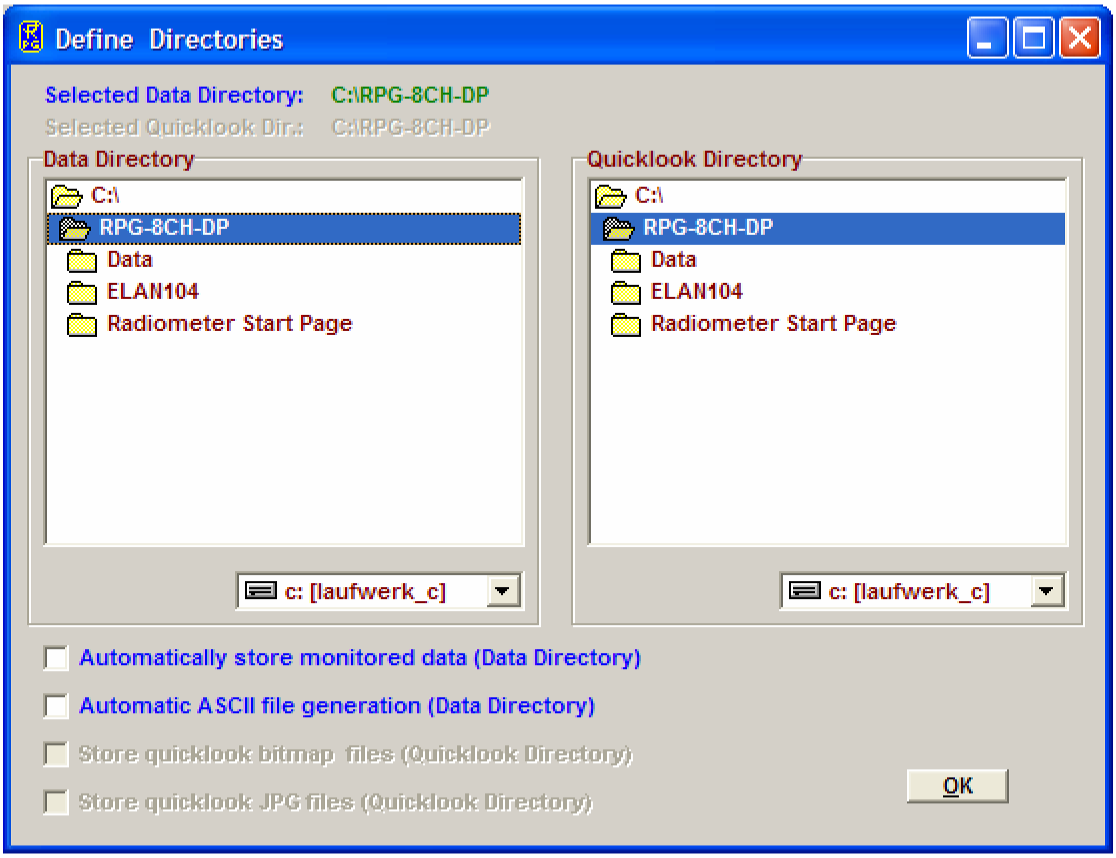
- *Temperatures*: Five temperature sensors are implemented:
  - The environmental temperature sensor is located outside of the radiometer box below the positioner mounting plate. The sensor data is an important parameter for the absolute calibration hot target temperature measurement and is also used to derive T_{mr} (needed for tip curve calibrations, see section 4.4).
  - Receiver1 / Receiver 2 / Receiver 3 / Receiver 4: These temperature sensors reflect the physical temperatures of the receiver modules which are stabilized to an accuracy of < 0.05 K. Typical sensor readings are around 40°C. The thermal receiver stabilisation is continuously monitored. If the receiver temperature is kept constant to within +/- 0.03 K the status indicator on the right of the temperature display is green. If it turns to red the stability is worse than this threshold. In addition the actual stabilisation values are listed. The colour of the stability status indicator turns to yellow if not enough temperature samples have been acquired to determine the stability.
- *Other Sensors*:
  - Barometric Pressure: The pressure sensor measures the barometric pressure in mbar (accuracy ±1.0 mbar). The data is used in the determination of the precise boiling temperature of the liquid nitrogen coolant used in the external calibration target during absolute calibration.
- *Automatic Calibrations*: Here the status of automatic calibrations (sky tipping, see section 4) is monitored during measurements. All calibration data is automatically logged in the *CAL.LOG* file located in ***MY_DIRECTORY\RPG-8CH-DP***. The contents of that file can be inspected with the  command (described later).
- *Elevation Scanner*: The data displayed here is the current position of the elevation and azimuth scanner.
- *Measurement*: During measurements this group box displays details like the file name of the current measurement, when the measurement was started and when it will end, if file backup is enabled on the radiometer PC and the batch repetition factor.

5.4 Data Storage Host Configuration

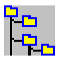
There are two different ways of data storage during measurements:

- Data files are stored on the radiometer PC by enabling the file backup option in the measurement definition file (MDF, explained later). The data transferred to the host for online display are not stored by the host PC. If the data files need to be inspected or further processed then they have to be transferred from the radiometer to the host PC. This procedure can be quite time consuming due to the relatively low transfer speed via the RS-232 connection (9 kBytes / sec. max.). The only advantage of this storage mode is that once the measurement has started, the host can be disconnected from the radiometer (it is then replaced by a Host Replacer Termination) while the radiometer continues its operation. No positioner activity is possible while the host PC software is out of use because the positioner is controlled directly by the host PC.
- File backup on the radiometer PC is enabled or disabled and the data transferred to the host PC is stored by the host in a predefined data directory. This is the most common operation mode for long term measurements because data files are transferred online from the radiometer to the host. Of course the host computer has to be permanently connected to the radiometer PC. When the host is connected to a network it can regularly send the data files to an FTP server located far away from the measurement

site. The file backup on the radiometer is only used as a safety option for the case that the host PC has a power failure or hard disk problem.



Define Directories Menu including data file directory and quicklook file directory selection.

The ***Host Configuration*** group box on the main screen displays the data storage details. It is possible to change the settings by clicking  (***Define Directories***). The automatic host data storage during measurements can be enabled or disabled and the data storage directory is selected from the directory tree shown in ***Data Directory***. In the same menu one can specify if an ASCII version of the data files (which are in binary format by default) shall be generated. ASCII files will then (if this option is selected) be stored to the same data directory as the binary files.

Quicklooks are bitmaps or JPG files showing the contents of the binary data files in graphical form. A separate directory can be defined for quicklooks and the available file formats are bitmap or JPG. Quicklooks are useful when the radiometer data files are regularly transferred to an FTP server and the data shall be displayed automatically using script programming etc.

5.5 Exchanging Data Files

The radiometer PC's hard disk has two directories which are accessible from the host computer:

- Data Files Directory
- System Files Directory

The data files directory is used to store all backup measurement files with unlimited access for READ and WRITE. The system files directory contains files that are essential for the radiometer operation. That is why the access for this directory is READ ONLY. Its files should not be manipulated or deleted by the user. If one tries to write to this directory the host prompts for a password to be entered. Only the radiometer administrator should know this password for software updating (overwriting *8CH.EXE*). **Overwriting *8CH.EXE* with a non-operating software or deleting this executable file will disable all radiometer functions and requires a system re-initialisation by RPG!**

To get access to the radiometer directories click (***Exchange Data and System Files with the Radiometer***)**.** The menu in Fig.5.2 will be displayed**.**

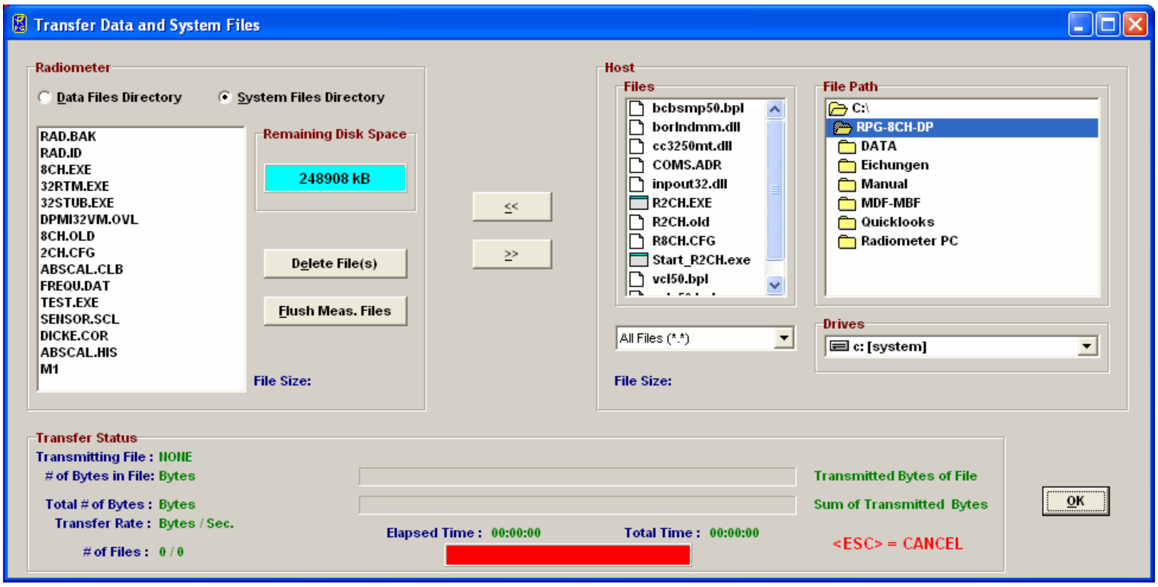


Fig.5.2: File transfer menu.

File transfer is necessary when backup data files need to be copied from the radiometer hard disk to the host computer. If file backup is enabled for a measurement, the instrument stores all data files in its **Data Files Directory**.
The **System Files Directory** contains the following files:

- *32RTM.EXE* runtime library
- *32STUB.EXE* stub file loaded by *8CH.EXE* to enter protected mode
- *DPMI32VM.OVL* overlay file for DOS protected mode interface
- *8CH.EXE* radiometer software
- *FREQU.DAT* contains frequency list of radiometer
- *RAD.ID* contains radiometer ID (RPG-8CH-DP, etc.)
- *SENSOR.SCL* sensor calibration file
- *ABSCAL.CLB* absolute calibration parameters
- *ABSCAL.HIS* absolute calibration history file

8CH.EXE is the executable that boots up when the radiometer is turned on. The program handles all automatic tasks like detector readout, calibrations, scanning, file storage etc. The only reason for writing to the system file directory is the installation of a *8CH.EXE* software update. Write operations to the system files directory are password protected and are reserved for authorized personnel only (contact RPG for password information).

Reading from the system files directory is required when the absolute calibration history file shall be inspected. The file ***ABSCAL.HIS*** stores all absolute calibrations (including successful tip curve calibrations). Once copied to any directory on the host hard disk its contents can be browsed by the command (see section 5.6).
Toggling between data files directory and system files directory display is achieved by pressing the ***Data Files Directory*** or ***System Files Directory*** radio buttons in the ***Radiometer*** group box.
By double clicking on one of the files in the list, the file size in bytes is displayed. In order to delete the backup files from the data files directory press ***Flush Meas. Files***. This will delete all backup files from the radiometer. It is not possible to delete single backup files because they are packed together in bigger files to reduce the total number of files on the flash drive. DOMs have problems in handling large numbers of files. During a 18 month continuous operation up to 20.000 data files are generated by the RPG-8CH-DP radiometer which would overload the DOM file system capabilities if they were stored as single files. Packing these files is the only way to handle the problem. Before flushing the backup files they should all be copied to the host first (if the data was not monitored on the host PC with automatic data storage). By pressing ***Delete Files*** only single files are removed from the system files directory (password entry required).
When a file needs to be copied from the host to the radiometer, first browse through the host directory tree and mark the file in the file list. Then select ***Data Files Directory*** or ***System Files Directory*** and press <<. The copy progress is displayed in the ***Transfer Status*** group box. Copying in the other direction (from radiometer to host) is done with the >> command.
Multiple files may be selected for deleting and file transfer in both directions. If a file transfer in progress is aborted, the user may terminate the operation by pressing <ESC>.

5.6 Inspecting Absolute Calibration History

As mentioned in section 5.4 the ***ABSCAL.HIS*** file located in the system file directory on the radiometer PC stores all absolute calibration results. This also includes the successful tip curve calibration of the water vapour line channels. In order to inspect this calibration history, first copy ***ABSCAL.HIS*** from the radiometer to the host. Then press (***Open Data Files***) and select to invoke the ***Absolute Calibration History*** menu. Load the previously copied ***ABSCAL.HIS*** file with ***Load History File*** and the list of calibrations is displayed (see Fig.5.3).

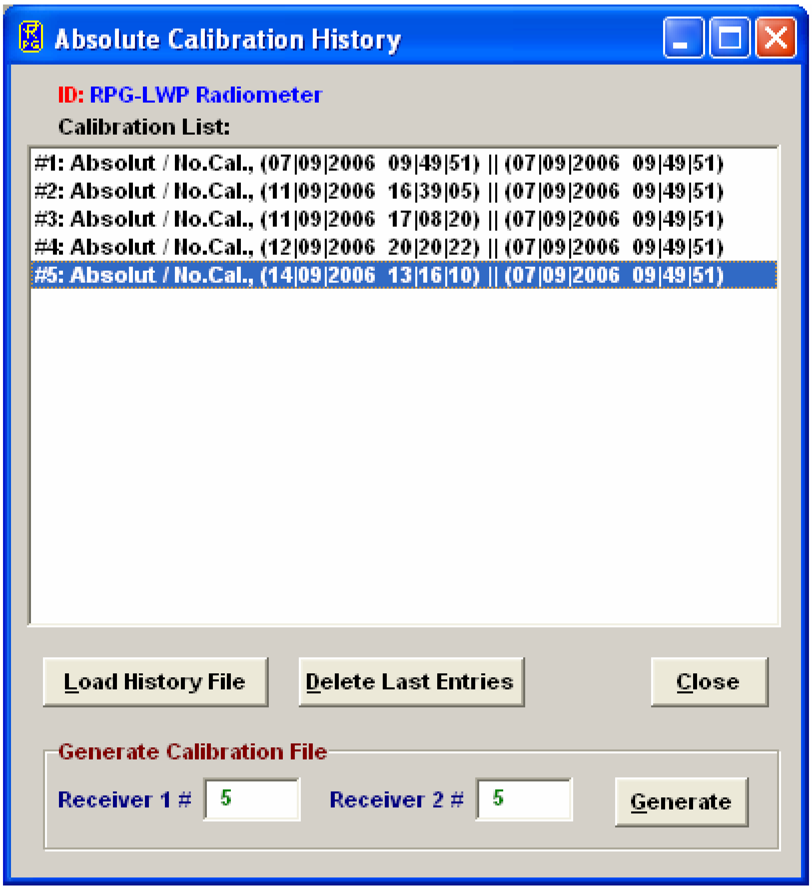


Fig.5.3: Loading the calibration log file ABSCAL.HIS into the calibration history list.

The listed entries are incrementally numbered (preceded by #). The entry syntax is:

***#calibration number**: **Hum. Profiler cal. type** / **Temp. Profiler cal. type**, (**date and time of Hum. Profiler calibration** || **date and time of Temp. Profiler calibration**)*

When an entry in the list is marked, ***Delete Last Entries*** removes all entries after the marked entry. This feature is useful to remove 'bad' calibrations from the list (typically the last calibration). With ***Generate*** a new calibration file ***ABSCAL.CLB*** is generated using the calibration numbers specified for receiver 1 and 2. If the modified ***ABSCAL.CLB*** file is copied to the system files directory (password protected) the radiometer will load the new calibration parameters from ***ABSCAL.CLB*** when ***8CH.EXE*** boots up the next time.
Double clicking on one of the entries opens the ***Calibration Results*** menu in Fig.5.4. For each receiver channel the four parameters G,α, T_{sys} and T_n (see section 4.1.3) are listed. In addition the calibration type, calibration time and physical temperature of calibration targets and the environmental temperature are stated.

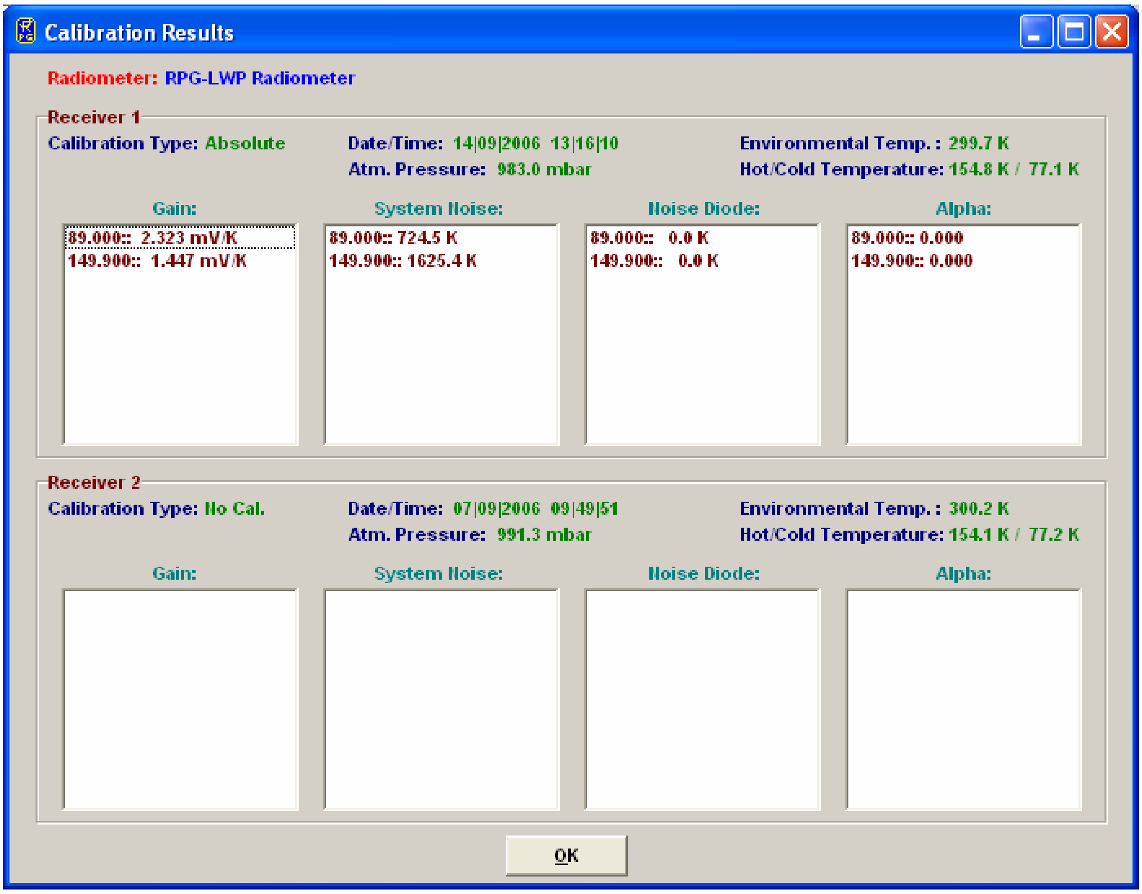


Fig.5.4: Display of absolute calibration parameters.

5.7 Inspecting Automatic Calibration Results

Automatic calibrations are those described in section 4.3, 4.4 and 4.5 (Gain, Noise, Tip Curve). These calibrations are performed automatically by the radiometer following the calibration settings in the measurement definition file (see section 5.8). Monitoring of automatic calibrations is carried out by the (enabled) ***Radiometer Status*** window on the main screen. The corresponding log file is ***CAL.LOG*** located in ***MY_DIRECTORY\RPG-150-90***.

For inspecting this log file press (***Display Automatic Calibration History***). The menu in Fig.5.5 appears. In the ***Gain Calibrations*** group box only gain parameters are displayed (the only parameter that is adjusted by this calibration type, see section 4.4) while also T_{sys} (***Tsys***) and T_n (***Tnoise***) are selectable in ***Noise Calibrations*** and ***Sky Tipping Calibrations***. The user may zoom into the data by clicking on the graphics display (holding the left mouse button pressed) and dragging the mouse cursor to a second position. When the mouse button is released the new data window appears. ***Zoom Out*** reverts to the previous zoom. The precise moment of each calibration is indicated by a dot (• and – toggle this feature). All diagrams are synchronized if ***Synchronize Diagrams*** is active. Then zooming and zooming out is performed on all displays so that a common time axis is maintained. ***Independent Diagrams*** switches back to the non-synchronized display mode.

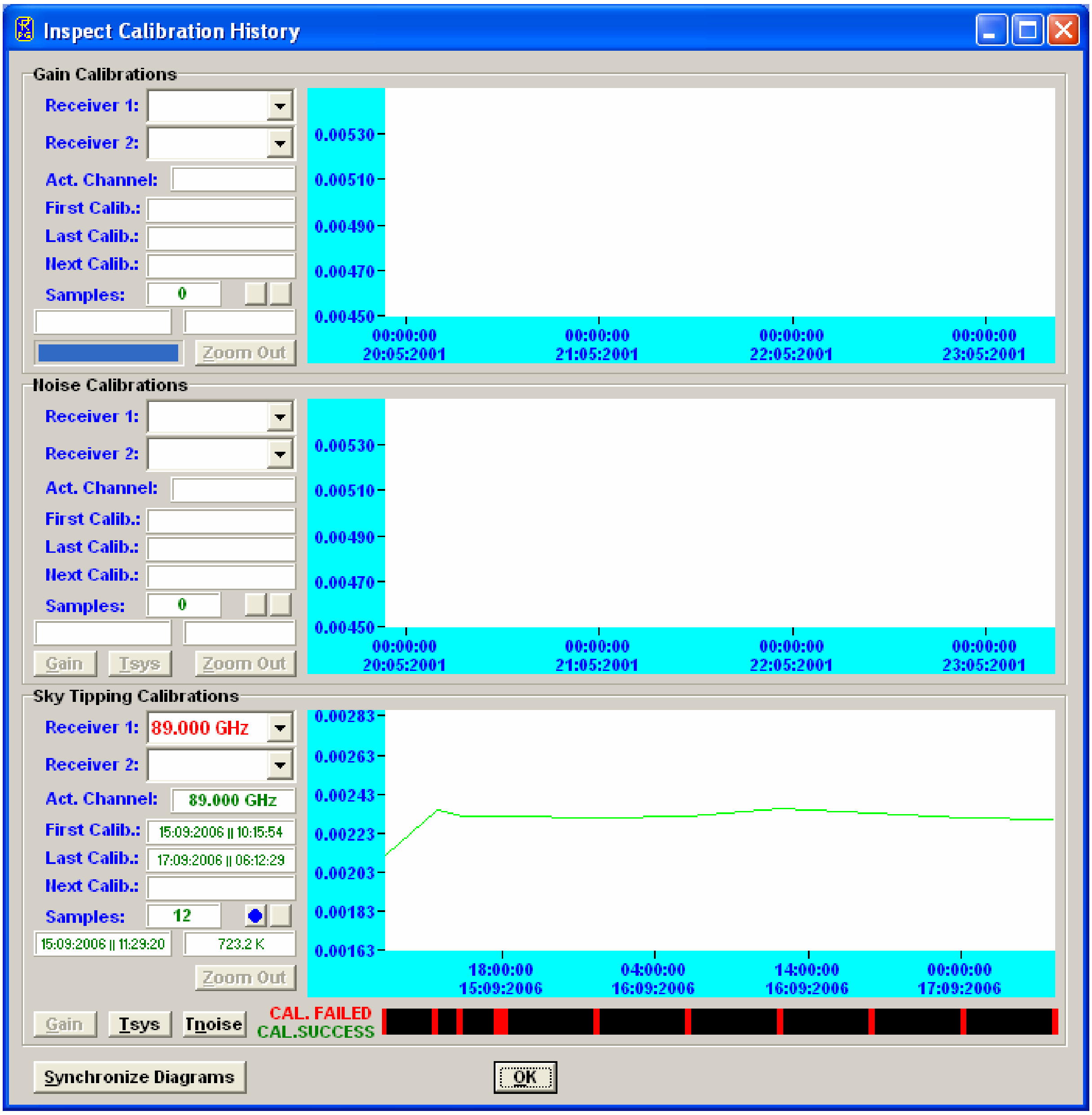


Fig.5.5: Display of automatic calibration parameters.

Below the ***Sky Tipping Calibrations*** data display the successful calibrations are marked by a green bar while failed calibrations are marked in red. By clicking on one of these bars the tip curve calibration details are listed and a graphical display of the sky dip is shown.

5.8 Absolute Calibration

After setting up the external cold target as described in chapter 4.1.2, an absolute calibration is initiated by pressing  (***Perform Absolute Calibration***). The menu in Fig.5.6 is shown.

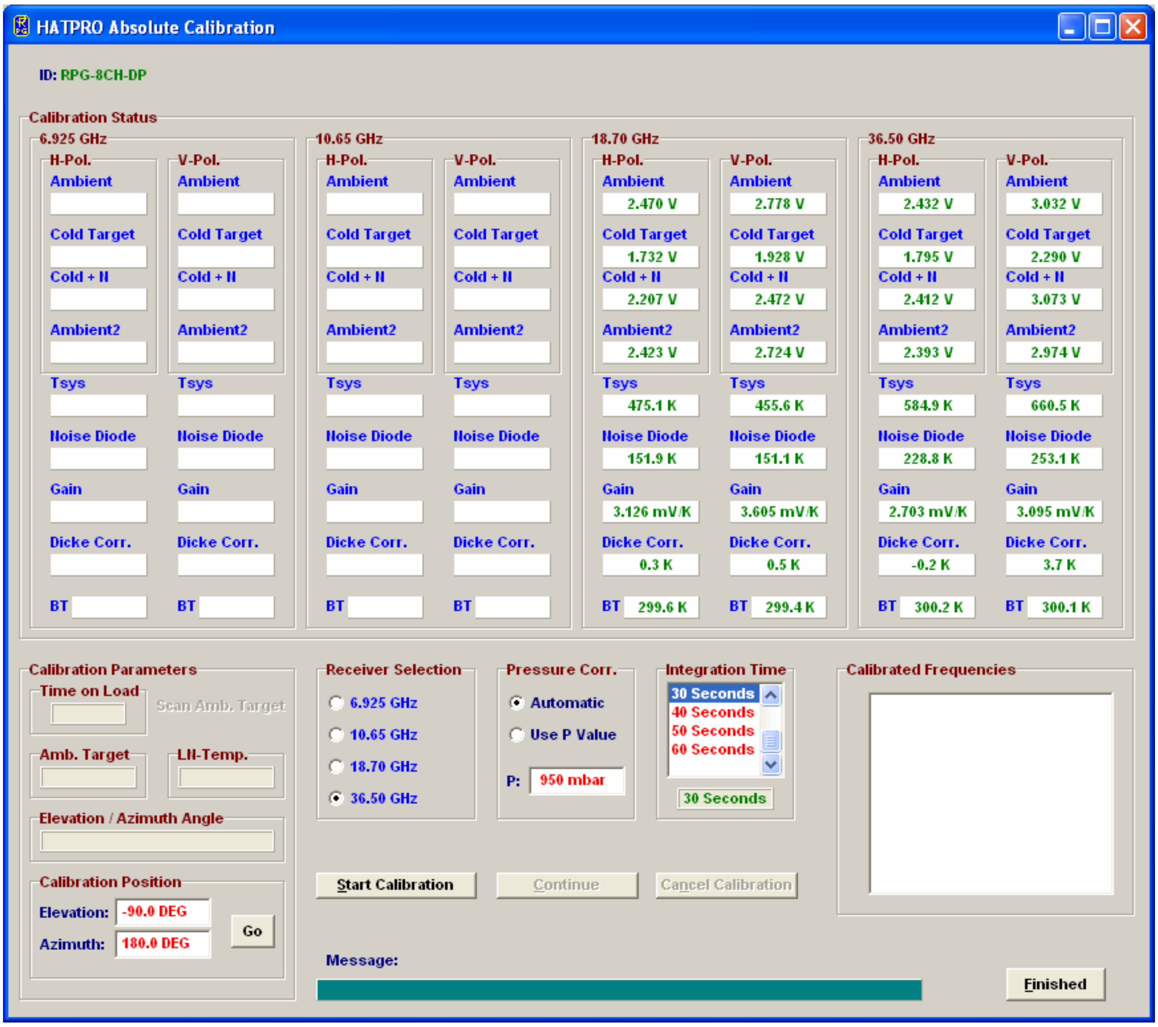


Fig.5.6: Absolute calibration menu.

The integration time T_i is selectable between ***5 Seconds*** and ***60 Seconds*** (***Integration Time*** group box) and defines the integration time period for each calibrated channel.
The four receivers are calibrated independently because the cold target has to be pushed underneath the antenna of each receiver package. The receiver to be calibrated is specified in the ***Receiver Selection*** group box.
Start Calibration starts the absolute calibration procedure. During calibration the current activity is displayed in the message line. When the integration cycles have completed, the message ***Calibration successful! Save?*** is displayed and the user has to confirm to save the calibration with ***Continue***. The absolute calibration parameters are then stored on the radiometer PC. Leave the calibration menu by clicking ***Finished***.
If the error message ***No response to cold load. Calibration terminated!*** appears, the cold target was probably not filled with liquid nitrogen or was not installed at all.
No noise diode response. Calibration terminated! indicates a malfunction of one of the noise sources. Contact RPG for help in this case.

5.9 Defining Measurements

Before a measurement can be started, it has to be defined. The various measurement parameters are then stored in a MDF (Measurement Definition File, extension ***.MDF***). The radiometer is capable of processing multiple MDFs automatically which are combined in a

MBF (Measurement Batch File, extension ***.MBF***). The MBF is a batch file similar to DOS batch files but only intended to group MDFs. Only MBFs can be sent to the radiometer, not MDFs, even if just a single MDF shall be sent. It has to be encapsulated in a MBF file first!

To enter the ***Definition of Measurement and Calibration Parameters*** menu press (***Define Measurement Parameter Files (MDF and MBF)***).
The measurement definition menu has several tab sheets (***Sky Tipping***, ***Standard Calibrations***, ***Products + Integration***, ***Elevation Scanning***, ***Timing + …***, ***MDF + MBF Storage***) which should be processed from left to right (see Fig.5.7).

5.9.1 Sky Tipping

The sky tipping (or tip curve) calibration is described in detail in section 4.4. Fig.5.7 shows the corresponding definition tab sheet.
The scanning angles listed in the ***Elev. Scan Angles [DEG]*** group box are predefined to give equidistant air mass samples in the sky tipping scan (the air mass is proportional to 1 / sin(α), see section 4.4). They can be modified by ***Add*** and ***Delete*** but it is recommended to only define angles >20°. If the radiometer's horizontal view is blocked by obstacles the lowest elevation angle should be adjusted appropriately but should not be >30° to maintain the calibration accuracy. The calibration success may be improved by checking ***Bilateral Tipping*** (***Handling*** group box). With bilateral tipping the radiometer also scans the elevation angles of the second quadrant (90°-180°) if the scan in the first quadrant (0°-90°) was not successful. This of course assumes a free view to both observation sides.

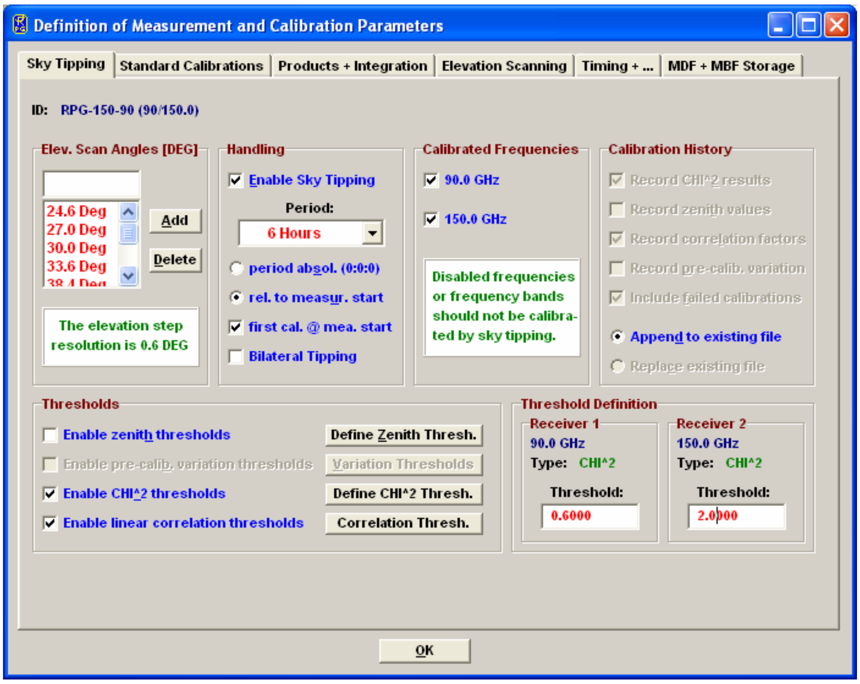


Fig.5.7: Measurement definition file menu, sky tipping tab sheet.

Sky Tipping is enabled by checking ***Enable Sky Tipping***. The user can specify how often a calibration shall be performed by selecting a period between ***10 Minutes*** and ***24 Hours***. Practical periods are 2 to 24 hours because the radiometer gain is continuously calibrated by the noise standards and a noise diode recalibration is not required so frequently. In addition a

tip curve interrupts the measurement for more than three minutes which should be kept to a minimum.
Furthermore it is possible to define the time of the first tip curve calibration in the measurement. By checking ***period absol. (0:0:0)*** the calibration will start relative to midnight time, e.g. with a period of 6 hours and a measurement start at 3:00 pm the first calibration will take place at 18:00 assuming that ***first cal. @ mea. start*** is not checked. If ***rel. to measure. start*** is checked the calibration timing is relative to measurement start time.
So far two quality checks (thresholds) are implemented which can be individually enabled or disabled:

- Linear correlation factor. This measures the correlation of the optical thickness samples (as a function of air mass) with a straight line. Typical linear correlation factor thresholds are >0.9995. The linear correlation factor is not very sensitive to the noise of the optical thickness samples caused by clouds etc.
- χ^2-test. This measures the variance of the optical thickness samples relative to the straight line. Typical threshold values are <=0.3 for a good quality calibration.

With ***Define CHI^2 Thresh.*** and ***Correlation Thresh.*** the corresponding thresholds can be entered in the ***Threshold Definition*** group box.

5.9.3 Products + Integration

On the ***Products + Integration*** sheet the user selects the products he wants to be acquired and calculated by the system.
For each enabled product a separate integration time is selectable.
Another feature of the ***Products + Integration*** tab sheet is the ability to enable a file backup on the radiometer PC. When backup is enabled, the checked products will be automatically stored in the radiometer’s data directory. This is usually done for safety reasons because the standard mode of measurements is to enable automatic data storage on the host (online monitored data). With this method the data transfer virtually does not require any time. Without monitoring the data on the host and only storing it on the radiometer as backup the user will sooner or later have to transfer the data from the embedded PC to the host with the ***Transfer Data and System Files*** menu.

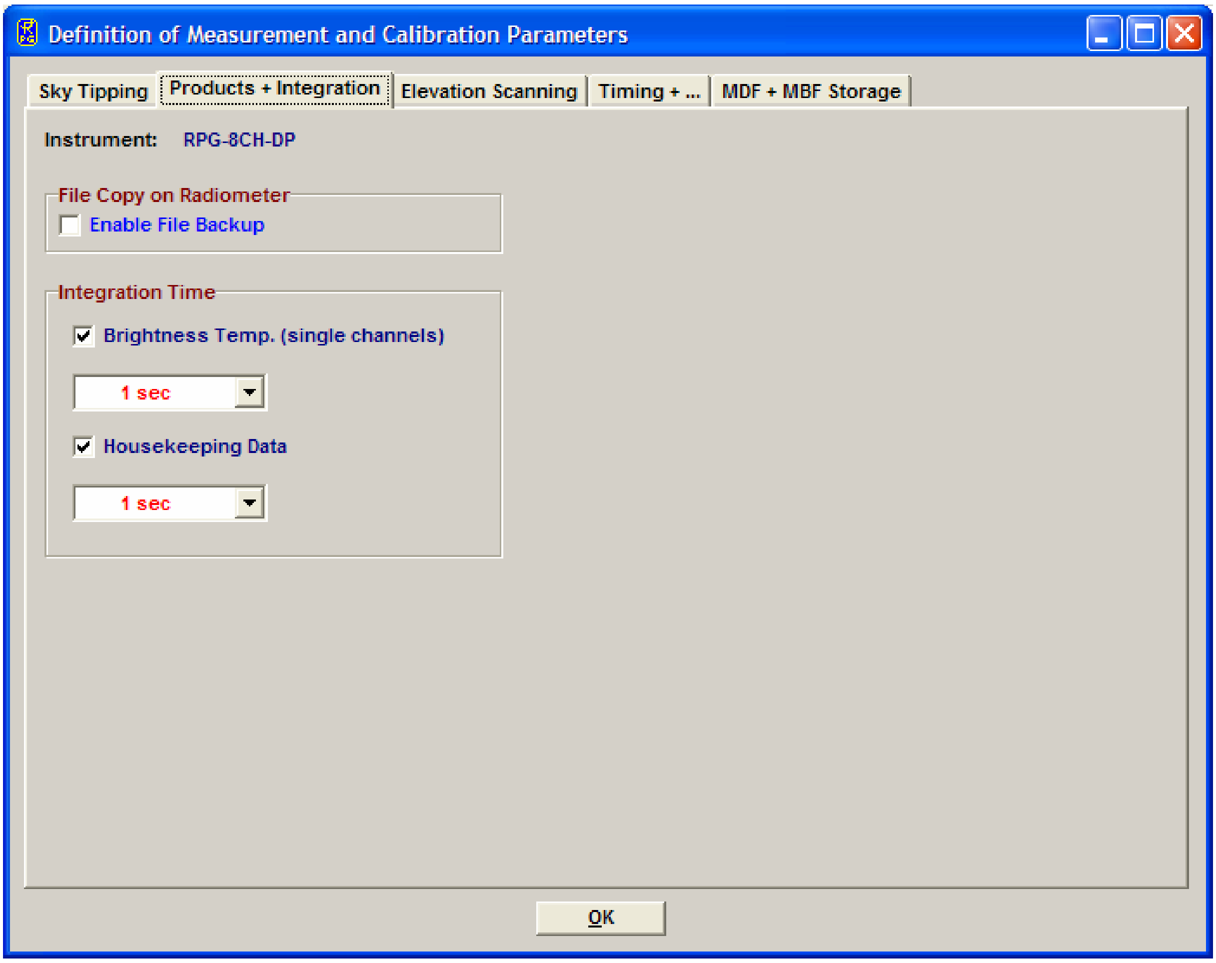
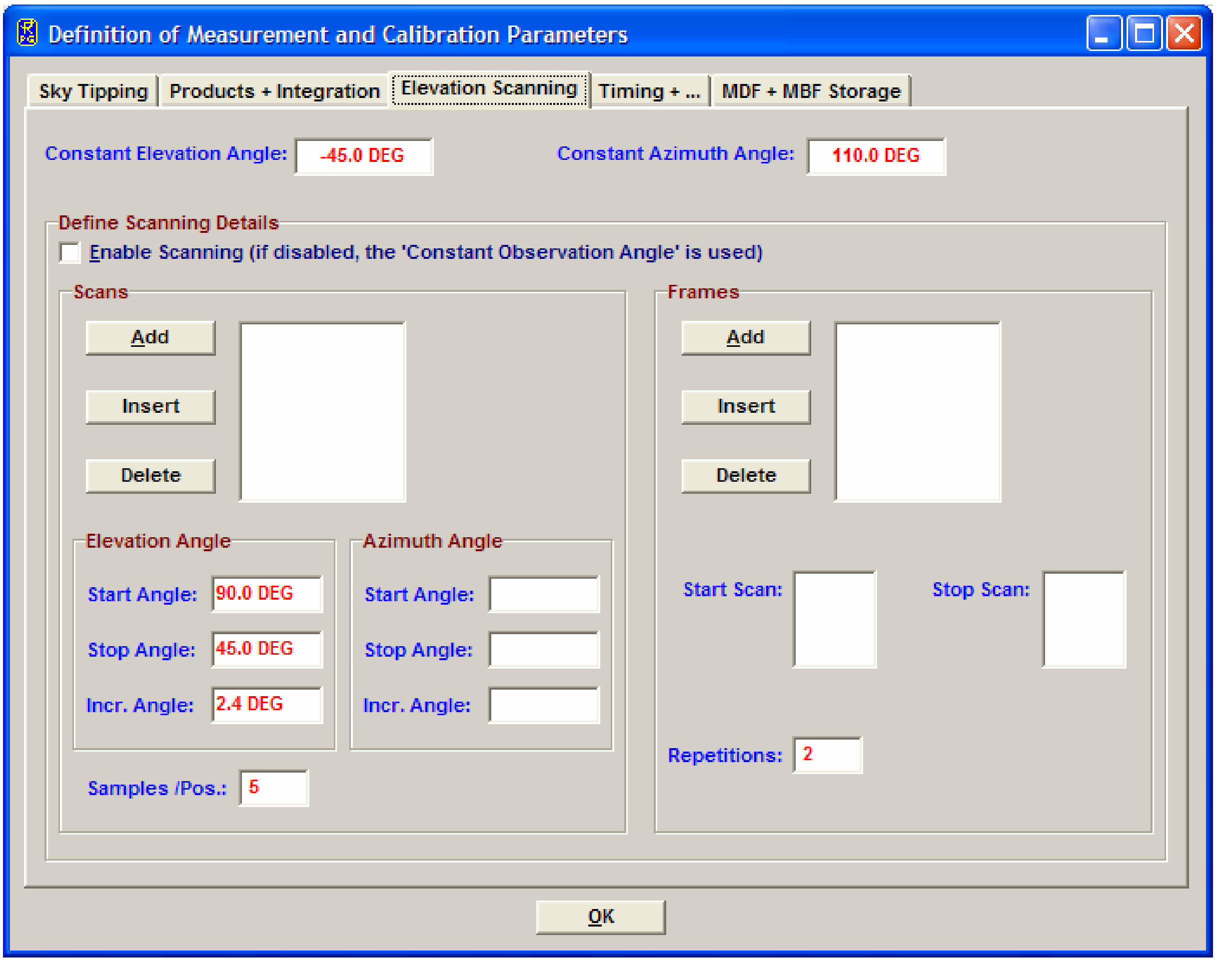


Fig.5.8: Specifying the products available for the radiometer configuration.

5.9.4 Elevation Scanning



Sometimes it is desirable to scan the elevation / azimuth angle while taking measurement samples. The details for this scanning are defined in the ***Elevation Scanning*** tab sheet. When scanning is disabled a constant elevation / azimuth angle is used for observations.
.The positioner moves are subdivided into elementary scans from a start angle to a stop angle with a certain incremental angle and a given number of samples measured at each position. These scans are numbered as Scan#1, Scan#2.
The radiometer does not execute single scans but only frames of scans. Each frame has a start scan and a stop scan (can be identical) which form a 'loop' of scans that can be repeated arbitrarily. The concept of having two levels of movement definitions allows for designing complex scan procedures. The positioner speed is always constant.
A frame is simply defined by clicking on one of the scans in the start scan list and then clicking on one in the stop scan list. After entering the repetition number the frame is added (or inserted) to the frame list (***Add*** or ***Insert***). Three examples illustrate how a frame is executed:

1) Start: Scan#4, stop: Scan#6, repetitions: 3 ⇒
   Scan#4,Scan#5,Scan#6,Scan#4,Scan#5,Scan#6,Scan#4,Scan#5,Scan#6
2) Start: Scan#4, stop: Scan#2, repetitions: 2 ⇒
   Scan#4,Scan#3,Scan#2,Scan#4,Scan#3,Scan#2
3) Start: Scan#2, stop: Scan#2, repetitions: 1 ⇒
   Scan#2

5.9.5 Timing +...

Start time and end time are important parameters for a measurement setup.
There are two ways of triggering a measurement: Immediately after launching the measurement batch or at a certain time and date. Using a start time before the current time is equivalent to an immediate start.
Two options are available for measurement termination. In LIMITED mode the user can set a duration or termination time. If the stop time is before the start time the measurement duration is adjusted to 100 seconds.
In the case that the measurement has a well-defined end time (automatic measurement termination, LIMITED mode) the radiometer needs a filename for storing backups. The user may enter any filename not longer than 8 characters. The host also uses this filename when it is operated in automatic storage mode. If measurement timing is set to UNLIMITED mode the radiometer automatically generates filenames deduced from the actual time and date and ignores the measurement filename entry.
In UNLIMITED mode the user must terminate the measurement manually. A new filename is generated every X hours where X is selected from the 'New Filename every' list box. The file format is one of 14 possible versions given in the 'Filename convention' list box. In the format string HH=hours, DD=days, MM=month and YY=year of the actual time and date. During measurement this filename is also transmitted to the host, which uses it for file storage of monitored data (assuming that the host is operated in "Automatic Storage" mode).

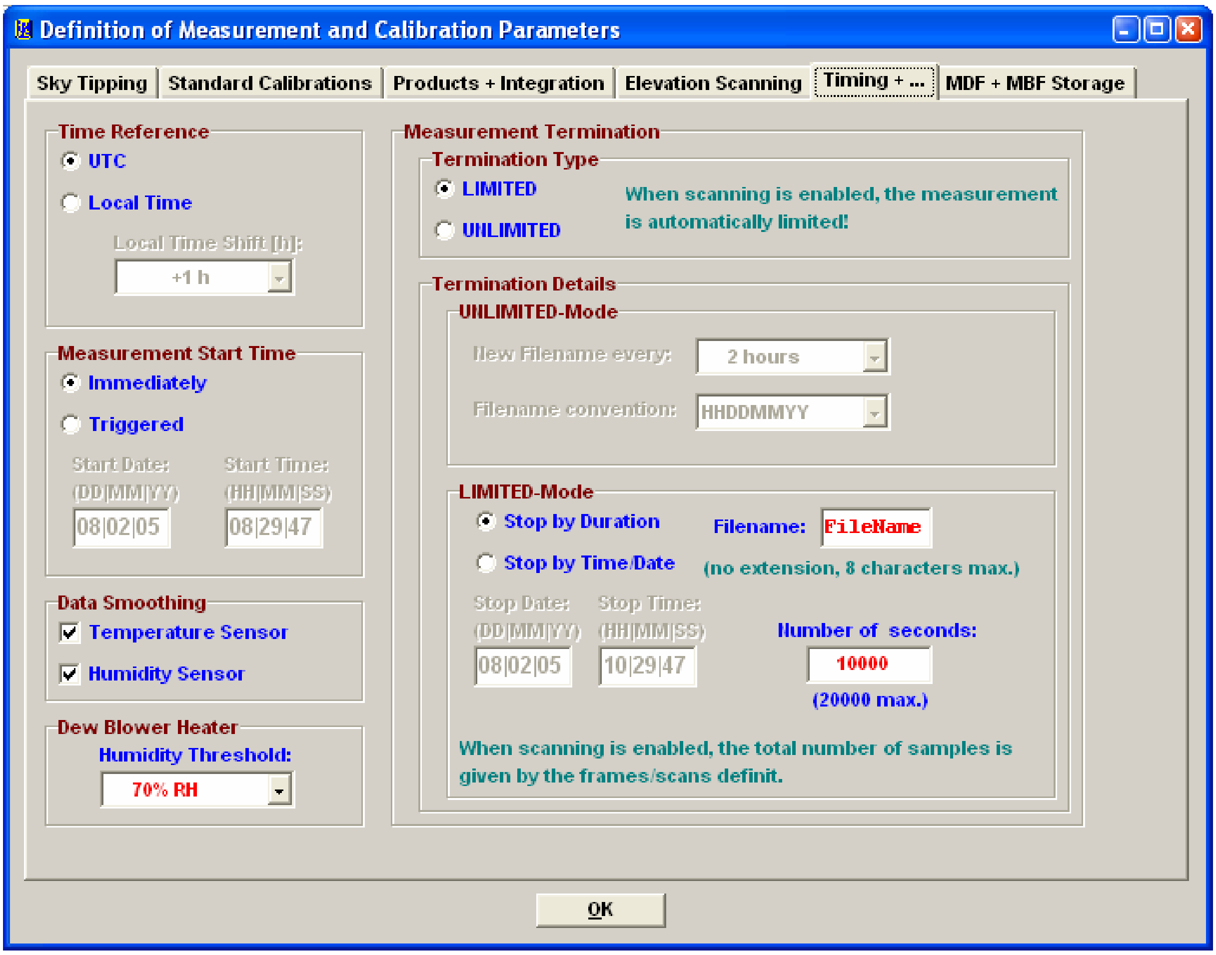


Fig.5.9: Timing definition menu.

Since the temperature environmental sensor responds quickly to changes of the corresponding parameter (caused by turbulence in the vicinity of the radiometer) it is sometimes desirable to smooth the data samples of temperature. The detailed surface turbulence at the radiometer location are not of interest. In ***Data Smoothing*** one can activate a 10 minutes LIFO filter to smooth the environmental temperature readings.

5.9.6 MDF + MBF Storage

It is **not** possible to send a MDF directly to the radiometer. MDFs are gathered into a MBF (measurement batch file). The concept is similar to the Scan/Frame relationship for scanning.

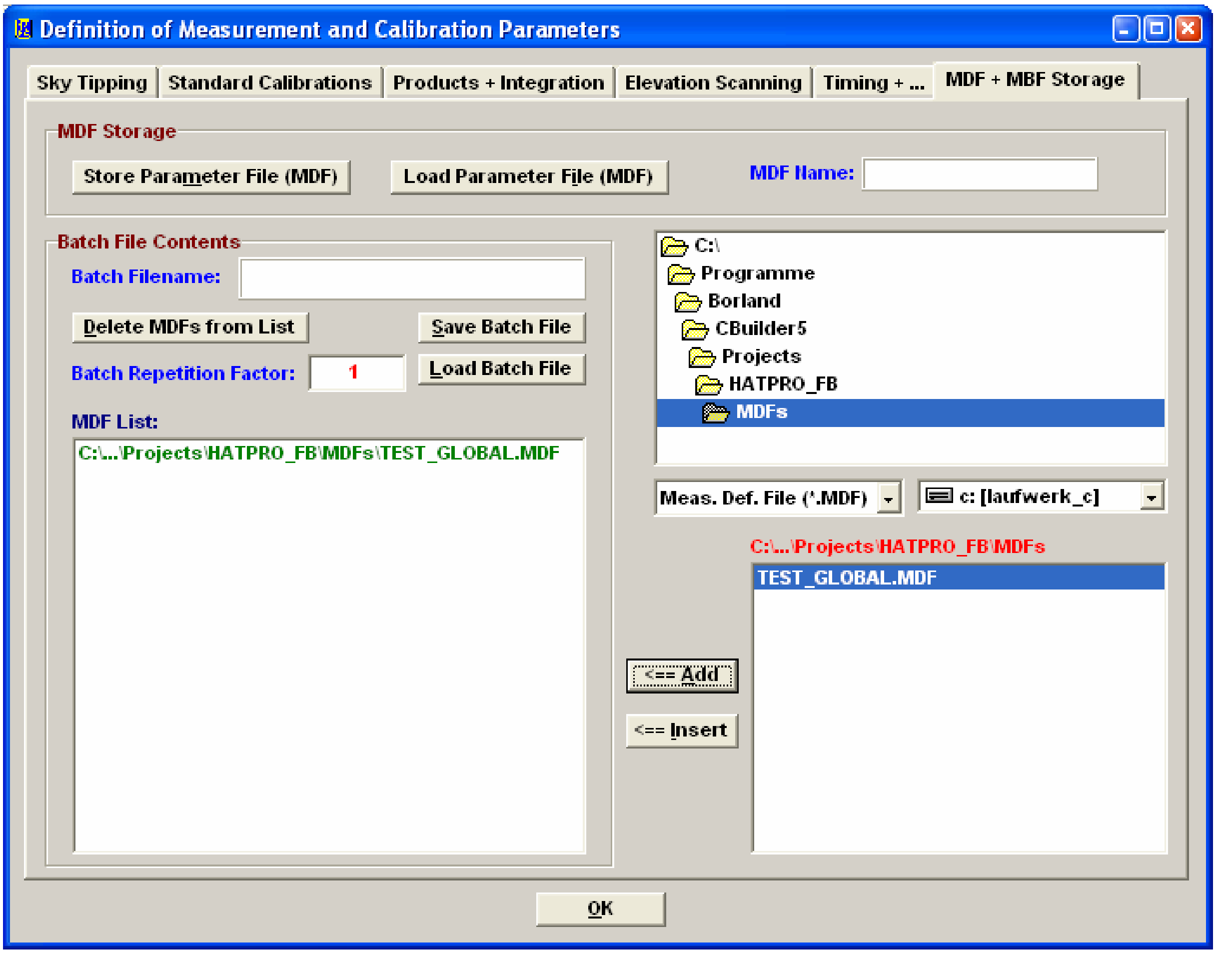


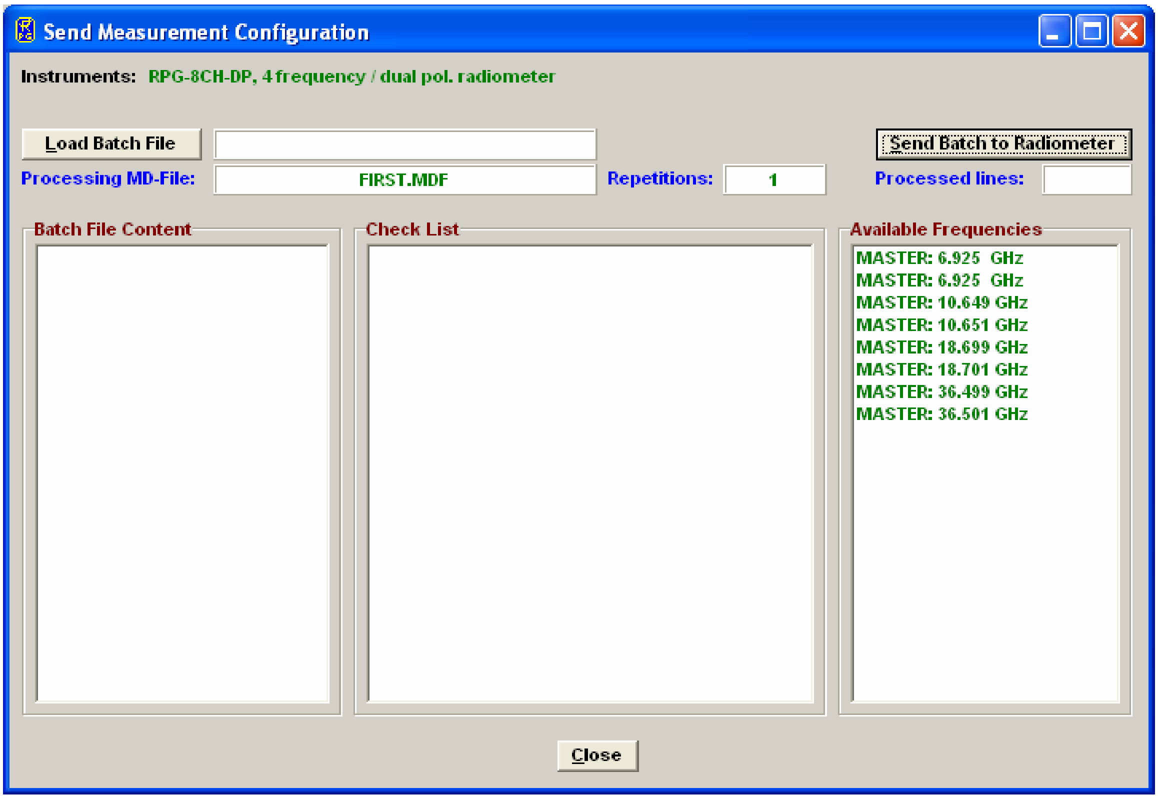
Fig.5.10: Batch file configuration menu.

The MDFs in a batch file are executed sequentially in the order they are listed in the MDF list (see Fig.5.10). The batch repetition number has the same meaning as the frame repetition factor for scanning: The MDF list forms a loop, which is repeated an arbitrary number of times. This offers the user a flexibility of combining different measurement tasks, which would otherwise not be compatible in a single MDF, e.g. if one wants to do a scanning measurement (not possible with retrieved products) followed by a temperature profiling measurement (a retrieved product) and repeat this 100 times the solution is to define two different MDFs, one for scanning and one for temperature profiling and combine them in a batch file with a repetition factor of 100. The only restriction for MDFs in multi-MDF batches is that the UNLIMITED mode should be avoided.

It is a good practice to store all MDFs in one directory (e.g. ***…\RPG-8CH-DP\MDF_MBF***). All MDFs in the selected directory are listed in the box in the lower right corner. From this list the user may select each MDF he wants to add or insert to the MDF batch list (with ***<==Add*** and ***<==Insert***). MDFs may also be deleted from the MDF batch list. Store your measurement batch files (MBFs) in a single directory (like "…***\RPG-8CH-DP \MDF-MBF***"). If file backup is enabled in the MDFs and the batch repetition factor is >1 there is only one filename for each MDF available. The data of successive executions of a certain MDF in the batch loop is stored to a single file. Each time the MDF is repeated in the loop, its measurement data is appended to the file.

5.10 Sending a MBF to the Radiometer

After a batch is created it can be sent to the radiometer (assuming the host is connected to it). This is done with  (***Send Measurement Batch File to Radiometer***).



By entering this menu the host determines the current radiometer configuration (RPG-8CH-DP in the example to the left).
When an MBF is loaded (***Load Batch File***) its contents and repetition factor are displayed. In addition some pre-checks are performed, e.g. correct radiometer configuration, frequency list consistency, etc. A variety of other checks ensure that no erroneous command data is sent.
When the consistency check of a MDF is finished, the test result is displayed in the ***Check List***. The batch can only be sent to the radiometer if all consistency checks have finished with the status OK. Then the MBF is transmitted with ***Send Batch to Radiometer***.

5.11 Commanding the Radiometer Processes

When a valid non-empty batch has been transmitted to the instrument the following functions are enabled:

(***Start Processing Batch***)
Although the batch is now stored on the radiometer's embedded PC, *8CH.EXE* remains in STANDBY mode, displayed in the status line on the bottom of the screen. By pressing the batch process is initiated. The status line entry changes to "MEASUREMENT RUNNING...".

(***Halt Running Batch***)
A running measurement can be halted any time. This might be useful when the user wants to change the elevation angle manually. The status bar display changes to "MEASUREMENT HALTED" and the manual control button (, discussed later) is enabled which offers manual control over elevation stepper and other radiometer features.

(***Continue Interrupted Batch***)
Used to continue a halted measurement. The status bar display changes back to "MEASUREMENT RUNNING" and the manual control button is disabled.

(***Terminate Running Batch***)
This command terminates the execution of the currently running batch. The radiometer switches to STANDBY mode and is ready to receive the next MBF.

5.12 Monitoring Data

The best way to perform measurements is:

- Define a MDF with "File Backup" enabled and include it in a batch file ().
- Check ***Automatically store monitored data*** in the ***Define Data Directory***.
- Send the batch file to the radiometer ().
- Start the batch file on the radiometer ().

The monitoring windows of the products that were selected in the MDF are automatically opened and the measured data is displayed (see Fig.5.11). Since the data is transmitted online from the radiometer to the host no additional file transfer is required afterwards. The file backup on the radiometer is activated for safety reasons to prevent data loss in the case of a host PC malfunction (e.g. hard disk crash, etc.).
The time axis scale is modified by selecting the time axis width in the drop-down list of the window. The monitor window displays the current time, date, sample number, sample value and cursor position (if the mouse cursor is moved into the display area).

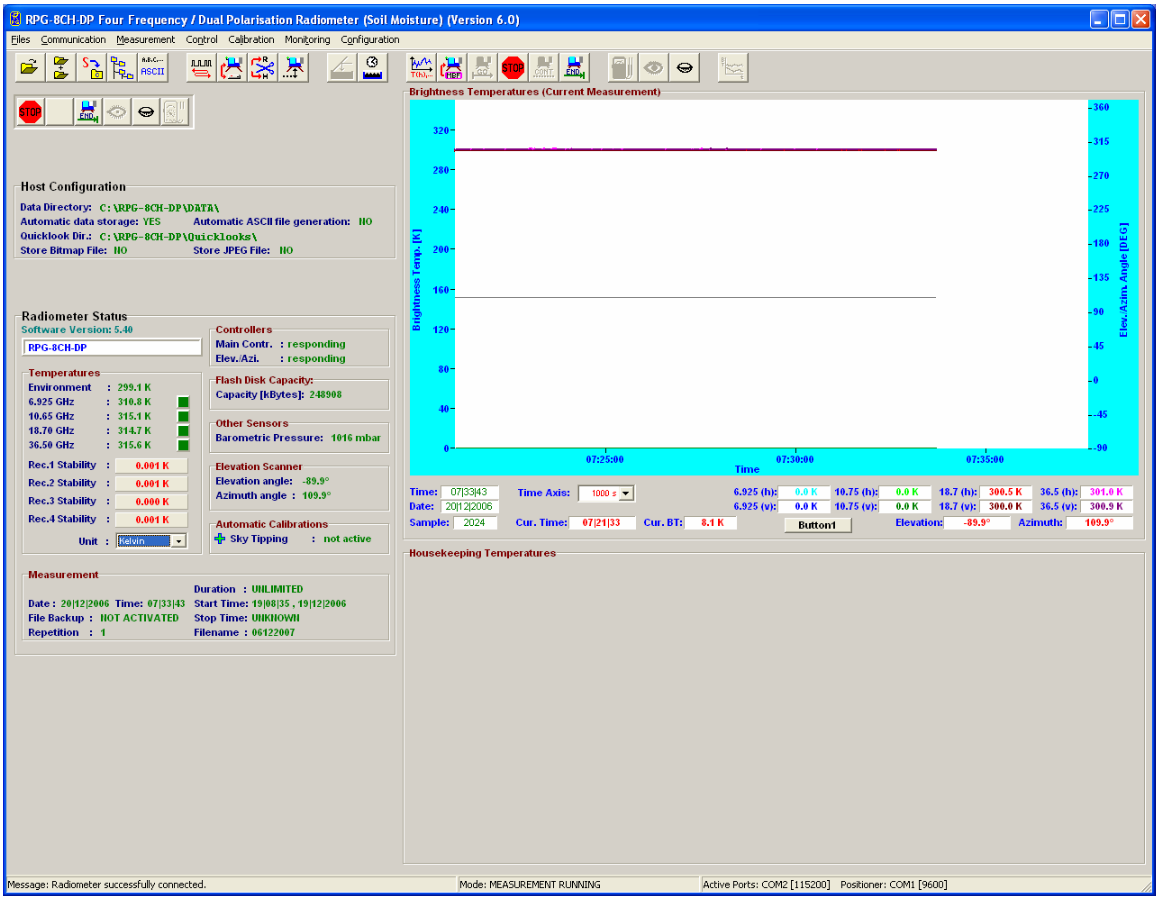
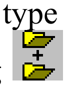


Fig.5.11: Active monitoring windows.

5.13 Concatenate Data Files

In UNLIMITED termination mode the radiometer periodically generates new data filenames (e.g. every hour). It is often desirable to concatenate data files of the same type (*.BRT, *.HK etc.) to form bigger files (e.g. 24 hour files). This is possible by clicking  (***Concatenate Data Files***) which opens the menu in Fig.5.12. A set of filenames is selected from the list and then concatenated to a single file with ***Generate Concatenated File***.

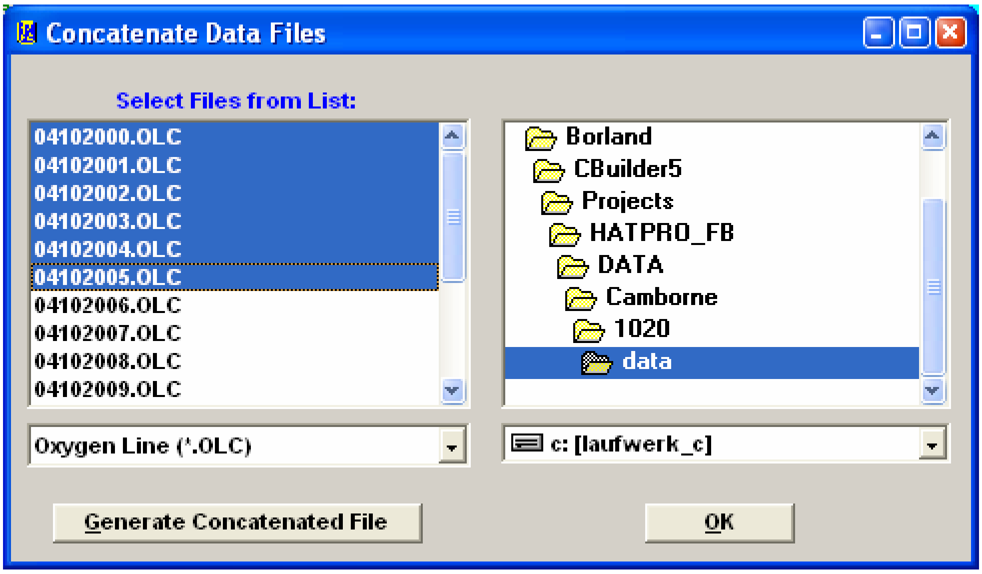


Fig.5.12: Concatenating data files.

5.14 Cutting Connection

 (***Cut Connection to Radiometer***)
If the user wants to disconnect the host from the interface cable or turn off the radiometer after having been connected this command should be used first. It ensures that all communication activities between host and radiometer are disabled so that the host will not crash after disconnection.

5.16 Data Display Menus

For each measurement data product a display window is available. Click on the open button  and select a product from the pull down list. Then load a product data file. Fig.5.14a is an example of a BT chart.
All data display menus indicate start time, end time, time reference, duration, and number of samples.
One may zoom into the data by pressing the left mouse button in the display area and drag the mouse to a different position (mouse button still pressed) to define a rectangle (indicated by a black frame). For zooming back click ***Zoom Out***.
Brightness temperature data files always contain the elevation / azimuth angle information for each sample. The elevation angle display can be toggled (***Show Angles***, ***Blank Angle***).
Most display menus can be stretched in size (resized) by positioning the mouse on the menu window edge and drag it to the desired position. The display is then adjusted in size.

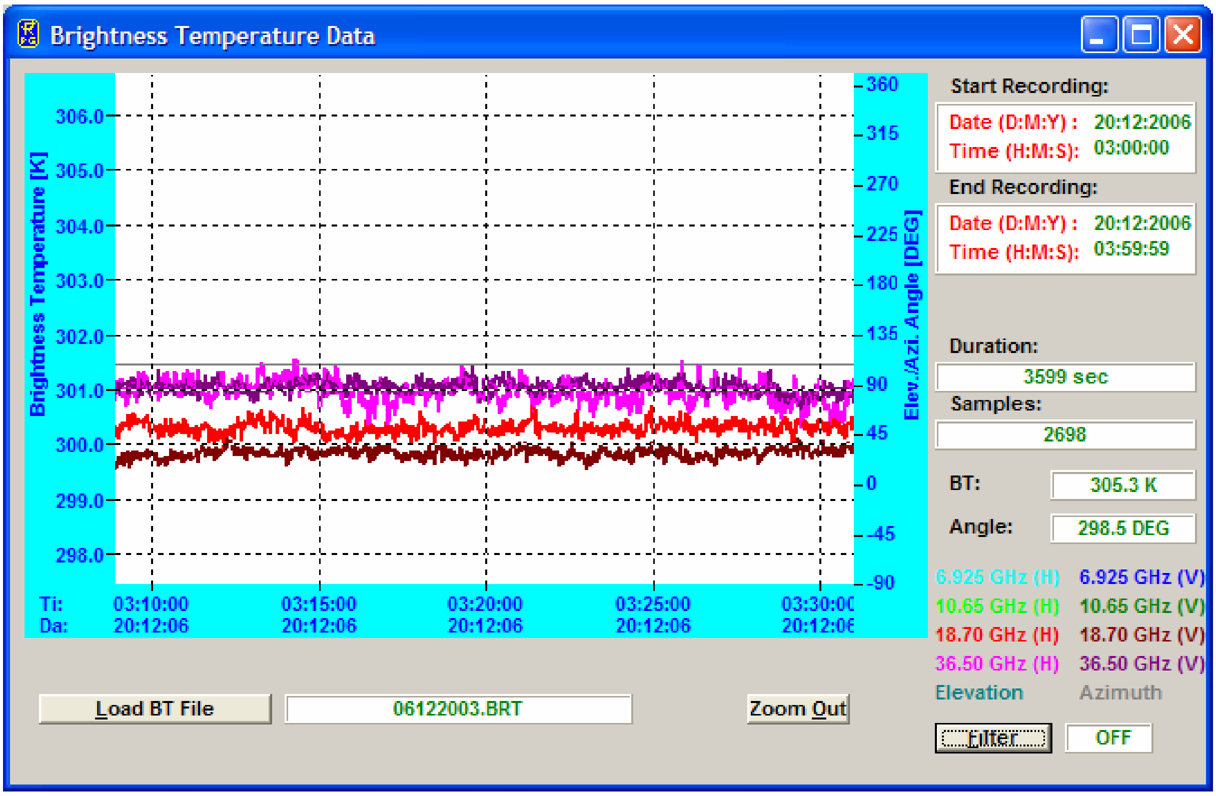


Fig.5.14: Boundary layer temperature profile chart window.

5.16.1 Data filters

The brightness temperature data display (*.BRT) offers a filter function sub-menu accessed by clicking ***Filter***. The window in Fig.5.15 appears. The filter can be turned on/off by checking/unchecking ***Enable Filter***.

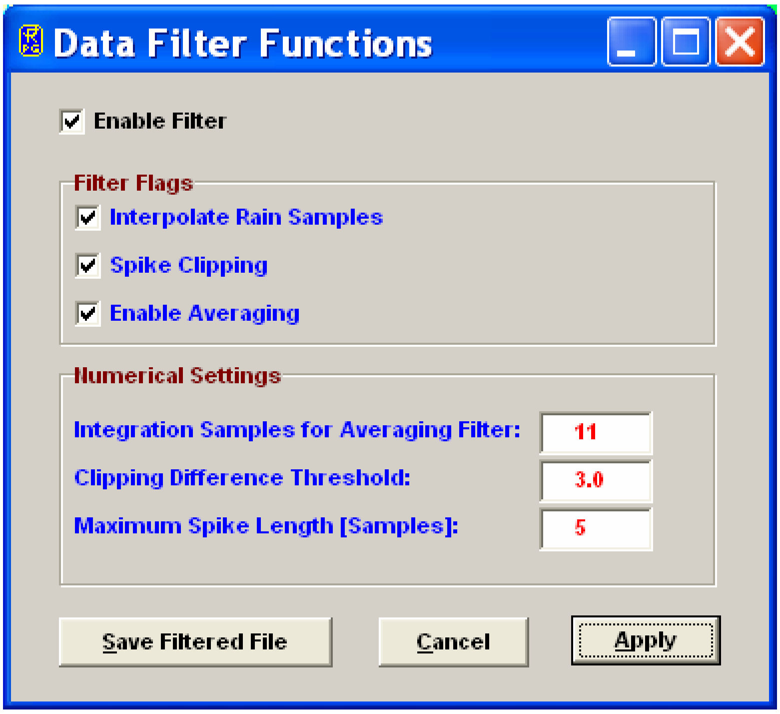


Fig.5.15: Filter functions sub-menu.

Two filter flags can be selected:

Spike Clipping: This filter eliminates sharp spikes in the data caused by blocking the microwave window during the measurement (e.g. by human beings, birds etc.). The maximum spike length measured in samples can be defined in ***Maximum Spike Length [Samples]*** and a clipping threshold is entered in ***Clipping Difference Threshold*** to distinguish the spike from general noise.
Enable Averaging: Noise on the data may be reduced by this filter. It generates the mean value of the number of samples given in ***Integration Samples for Averaging Filter***. These samples are centred around the filter sample.

When pressing ***Apply*** the filter with its new settings is executed. The resulting filtered data file can be stored with the ***Save Filtered File*** command.

5.17 Manual Radiometer Control

When the host is connected to the instrument and the radiometer is in STANDBY- or HALTED-mode, the manual control functions are enabled. Click (***Manual Radiometer Control***) to enter the ***Diagnostics and manual control*** menu in Fig.5.16.
The reason of implementing these functions is mainly for diagnostic purposes. When a radiometer is assembled every single electronic component must be tested. The receivers' long term stability is checked for several weeks by monitoring the detector voltages. However, some of the diagnostic functions are also useful for other tasks.

5.17.1 Stepper Control

The ***Positioner*** tab sheet is used (for instance) to change the observation angle during a measurement in HALTED mode. If ***Reset Position*** is checked the stepper is reset to its original position after leaving the diagnostics menu. If the user wishes to keep the new position he must uncheck ***Reset Position***.
Stepping positions can be set relative or absolute in DEG. The absolute elevation stepper positions in elevation are as follows:

- Zenith: +90°
- Horizontal: 0°
- To ground: -90°

The angular stepper resolution is 0.1°. The azimuth value range is set to 0° to 360°

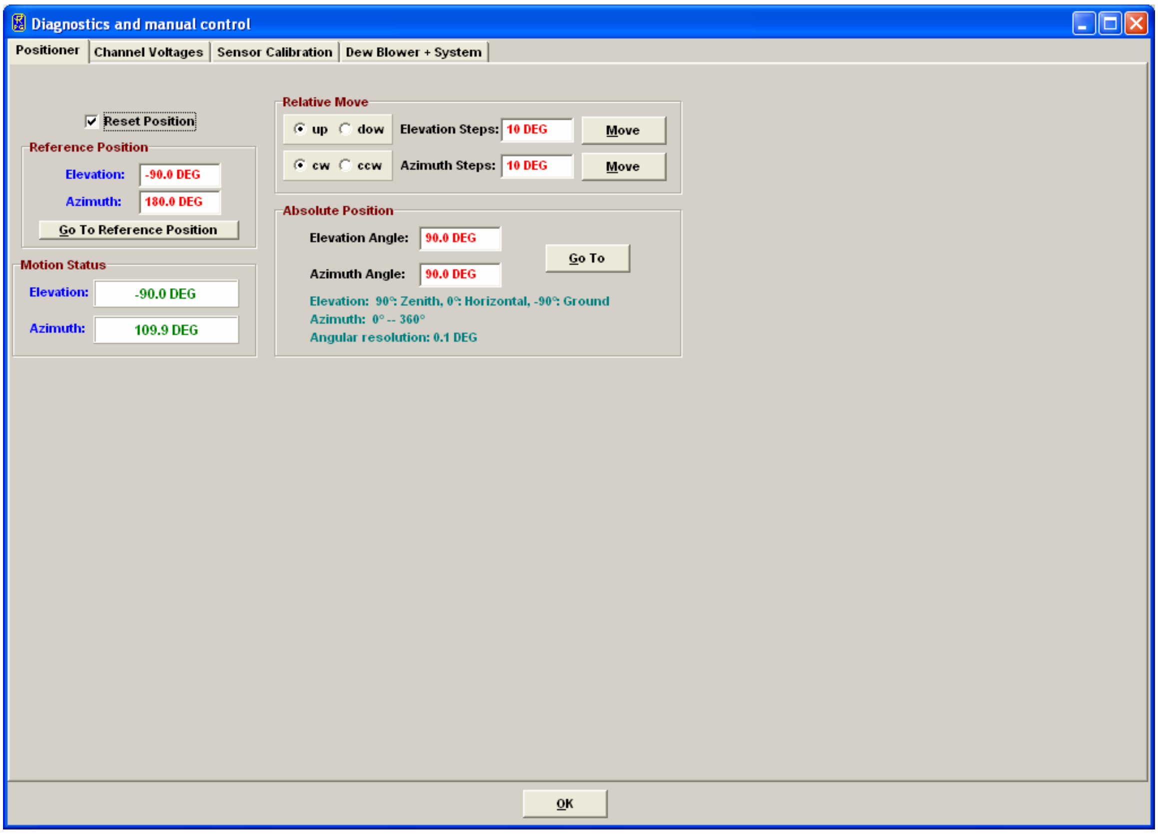


Fig.5.16: The positioner control tab sheet.

5.17.2 Channel Voltages

The ***Channel Voltages*** tab sheet is the main diagnostics tool (Fig.5.17).
Each of the four acquisition channels (not to be mixed up with receiver channels!) can be configured to sample one of the following data sources:

- Receiver 1-4 detector voltages (1:1)
- Receiver 1-4 board temperatures (T=voltage*100 [K])
- Environmental temperature (T=voltage*100 [K])
- Barometric pressure (P=voltage*1000 [mbar])

The sample rate and maximum number of samples are set in ***General Parameters***.
While sampling detector voltages, one can manually turn the noise diodes on and off to check for a correct operation (***Noise Diode***). The channel readings are displayed graphically and also in the ***Receivers*** frame. Data zooming is possible. After stopping the sampling one can use a ruler to measure the precise voltage at a certain time (↕).
Reset clears the acquisition display and sets the Y-axis to +5 V (maximum).

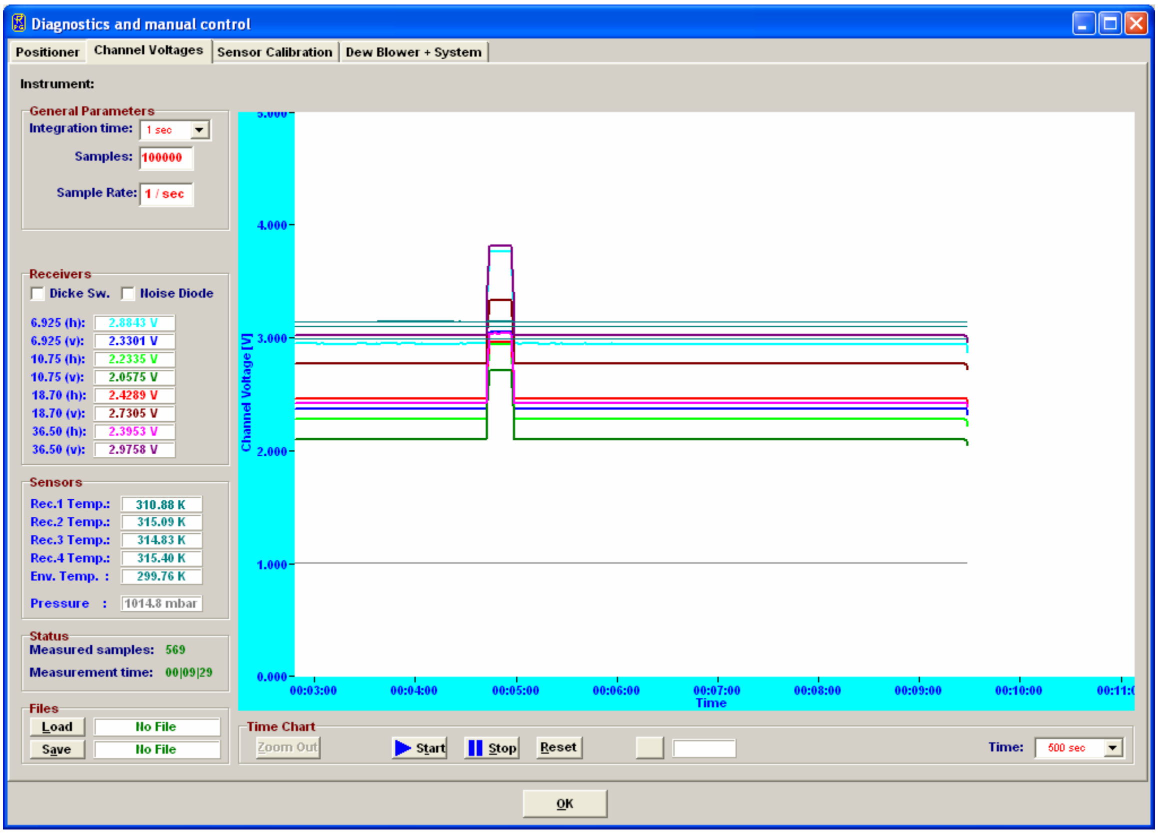


Fig.5.17: Channel voltages tab sheet.

5.17.3 Sensor Calibration

This tab sheet is needed to calibrate the thermal sensors and pressure sensor. It is not intended for user purposes. The sensor calibration must be performed by qualified personal only and is done before the radiometer delivery.

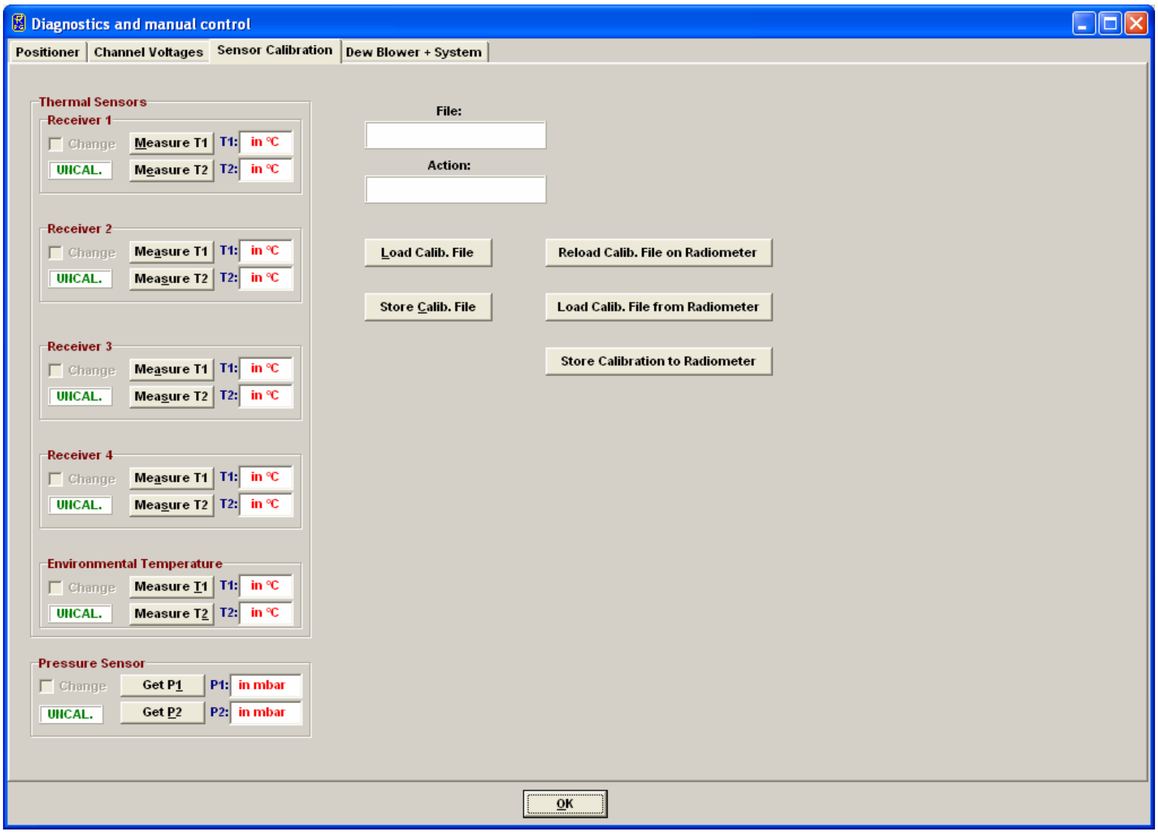


Fig.5.18: Sensor calibration tab sheet.

5.17.4 System

The tab sheet in Fig.5.18 is related to system issues.
A very useful feature is the ***Reset Radiometer PC*** function. When an update of the radiometer software has been performed by transferring a new *8CH.EXE* file to the radiometer's system file directory, a radiometer reset is required to run the new software version. When clicking on the ***Reset Radiometer PC*** button a warning message is displayed to inform the user that if he confirms to continue this command this will result in a radiometer reset and requires a re-connection to the radiometer afterwards.
The ***Reload Configuration*** function sends a configuration inquiry to the radiometer which is then displayed in the ***Radiometer Configuration*** box. The information shown gives an overview of the types of installed hardware and important system settings.

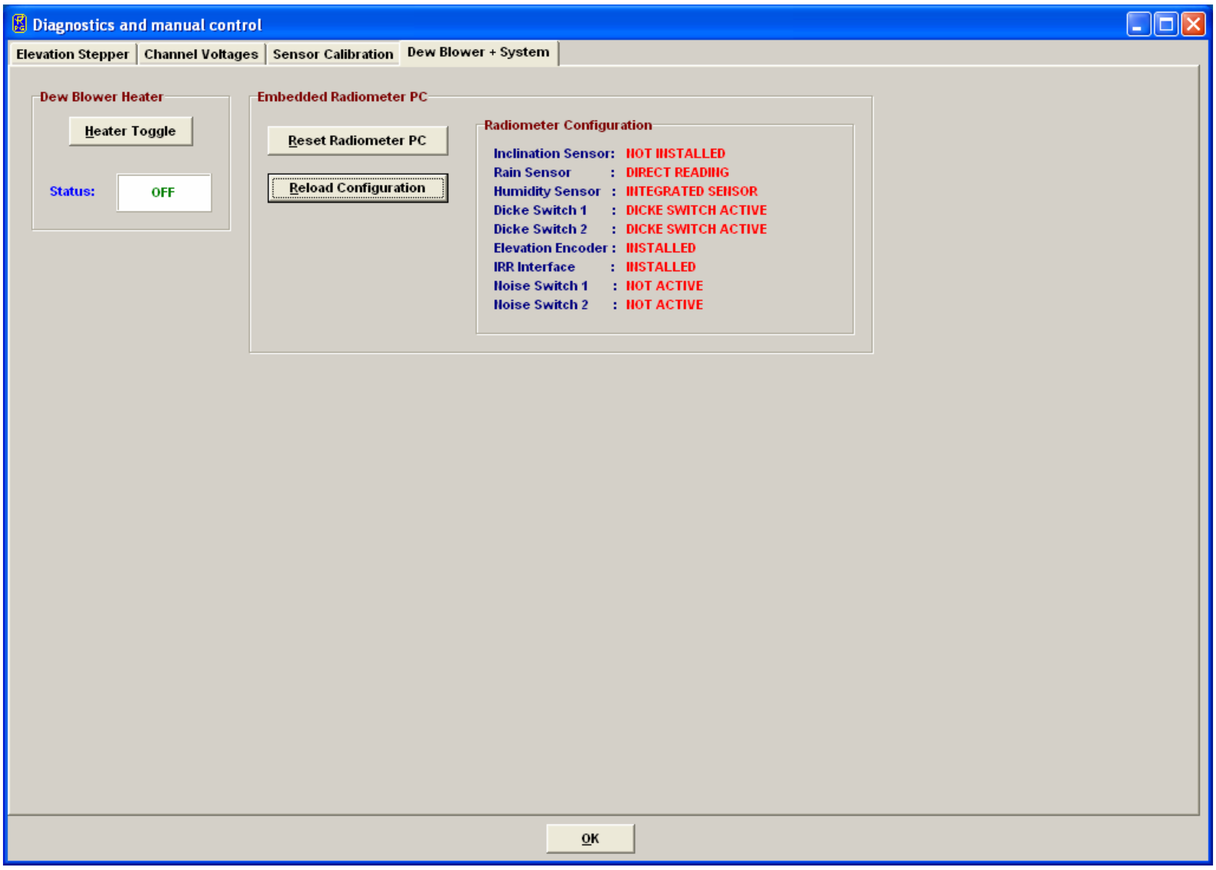


Fig.5.19: How to reset the radiometer software.

5.18 Transform Data Files to ASCII Format

The standard data file format is binary (file structures listed in Appendix A) because it is more compact than other formats. In the case that a readable format is required the binary files can be transformed to ASCII. By using the  command (***Transform Data Files to ASCII Format***) a binary data file is converted to an ASCII file. The file name of the new file is the binary file name with appended '.ASC', e.g. the BT binary format file ***MyFileName.BRT*** is converted to ***MyFileName.BRT.ASC***.
Beside this manual ASCII file generation it is possible to automatically store data in ASCII format during the monitoring process (active measurement). See section 5.4 for details.
Examples of ASCII files are described in Appendix B.

6 Instrument Viewing Range

Fig.6.1 shows the requirement for the free viewing range. When sky-dip (tip curve) calibration is enabled, the radiometer performs an elevation scan from zenith to 20° elevation. No obstacles should be in that viewing range to ensure a good calibration.

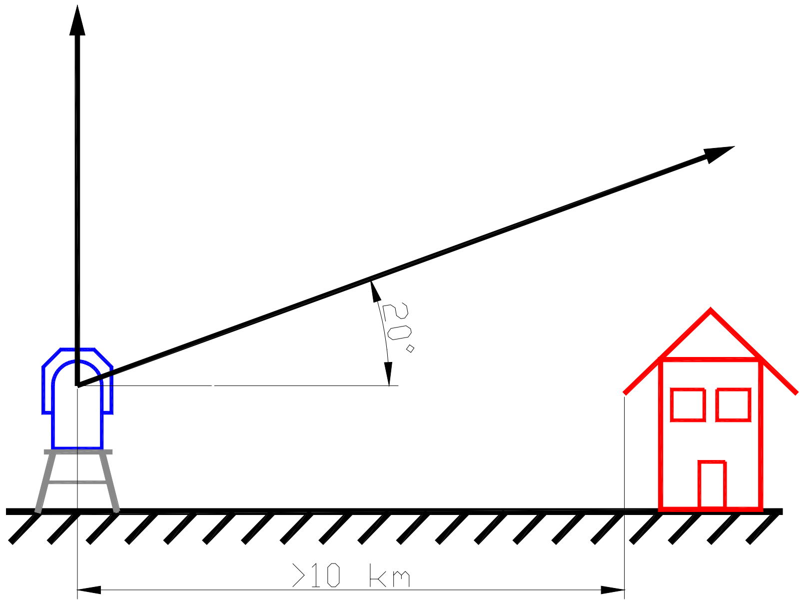


Fig.6.1: Tip curve calibration viewing range.

Appendix A (File Formats)

A1: BRT-Files (*.BRT), Brightness Temperature (Single Channels)

Variable Name	Type	# Bytes	Description
BRTCode	int	4	BRT-File Code (=837854832)
N	int	4	Number of recorded samples
BRTMin	float	4	Minimum of recorded BRT values
BRTMax	float	4	Maximum of recorded BRT values
T_1	int	4	Time of sample 1 (# of sec. since 1.1.2001)
BRT_1(0)	float	4	Br. Temp. sample 1, frequency 1 [K]
…	…	…	…
BRT_1(7)	float	4	Br. Temp. sample 1, frequency 8 [K]
EL_ANG_1	float	4	Elevation angle of sample 1 (DEG)
AZ_ANG_1	float	4	Azimuth angle of sample 1 (DEG)
…	…	…	…
BRT_N(0)	float	4	Br. Temp. sample N, frequency 1 [K]
…	…	…	…
BRT_N(7)	float	4	Br. Temp. sample N, frequency 8 [K]
EL_ANG_N	float	4	Elevation angle of sample N (DEG)
AZ_ANG_N	float	4	Azimuth angle of sample N (DEG)

A2: HK-Files (*.HK), Housekeeping Data

Variable Name	Type	# Bytes	Description
METCode	int	4	MET-File Code (=599658943)
N	int	4	Number of recorded samples
METMinP	float	4	Minimum of recorded pressure values
METMaxP	float	4	Maximum of recorded pressure values
METMinT	float	4	Minimum of environmental temp. values
METMaxT	float	4	Maximum of environmental temp. values
METMinH	float	4	Minimum of recorded rel. humidity values
METMaxH	float	4	Maximum of recorded rel. humidity values
METTimeRef	int	4	Time reference (1: UTC, 0: Local Time)
T_1	int	4	Time of sample 1 (# of sec. since 1.1.2001)
RF_1	char	1	Rainflag of sample 1 (0: no rain, 1: rain)
MET_1(0)	float	4	Pressure value sample 1 [mbar]
MET_1(1)	float	4	Temp. value sample 1 [K]
MET_1(2)	float	4	Rel. humidity value sample 1 [%]
…	…	…	…
MET_N(0)	float	4	Pressure value sample N [mbar]
MET_N(1)	float	4	Temp. value sample N [K]
MET_N(2)	float	4	Rel. humidity value sample N [%]

A3: Structure of Calibration Log-File (CAL.LOG)

Variable Name	Type	# Bytes	Description
STACode	int	4	CAL.LOG -File Code (=657643)
N_Gain	int	4	Number of recorded gain cal. samples
N_Noise	int	4	Number of recorded noise cal. samples
N_SkyTip	int	4	Number of recorded tip curve cal. samples
N_CH_Rec1	int	4	Number of receiver 1 channels
N_CH_Rec2	int	4	Number of receiver 2 channels
Frequ[]	float	4* ChanNo	Frequencies of Rec1 and Rec2
CalType1	int	4	Type of calibration sample 1 (0=gain, 1=noise, 2=tip curve results, 3=tip curve with full fit information)
CalTime1	int	4	Time of sample 1 (# of sec. since 1.1.2001)
TipCurveStat1	int	4	Status of tip curve calibration (only if CalType1=2 or 3), 3 = FAILED, 2 = SUCCESS
Gain1[]	float	4* ChanNo	Gains of calibration sample 1
Tsys1[]	float	4* ChanNo	system noise temps of calibration sample 1 (only if CalType1=1 or CalType1=2 or CalType1=3)
LinCorr1[]	float	4* ChanNo	Linear correlations for calibration sample 1 (only if CalType1=2 or 3)
ChiSqr1[]	float	4* ChanNo	Chi square factors for calibration sample 1 (only if CalType1=2 or 3)
NoiseTemp1[]	float	4* ChanNo	Noise source temperatures for calibration sample 1 (only if CalType1=2 or 3)
SkyTipAngAnz1	float	4	Number of sky tip for calibration sample 1 (only if CalType1= 3)
Airmass1[]	float	4* SkyTipAngAnz1	Airmass array (only if CalType1=3)
SkyDipUs1[i][j] i=0, … , N_CH_Rec1-1 j=0, … , SkyTipAngAnz1	float	4* N_CH_Rec1* (SkyTipAngAnz1+1)	Sky dip detector voltages (only if CalType1=3). For each frequency the det. Voltage is given at all angles. The last entry is the voltage on the hot target
TauSuccess1[]	int	4* N_CH_Rec1	Flag that indicates if the Tau calculation during the skydip was successful (0=no, 1=yes) (only if CalType1=3)

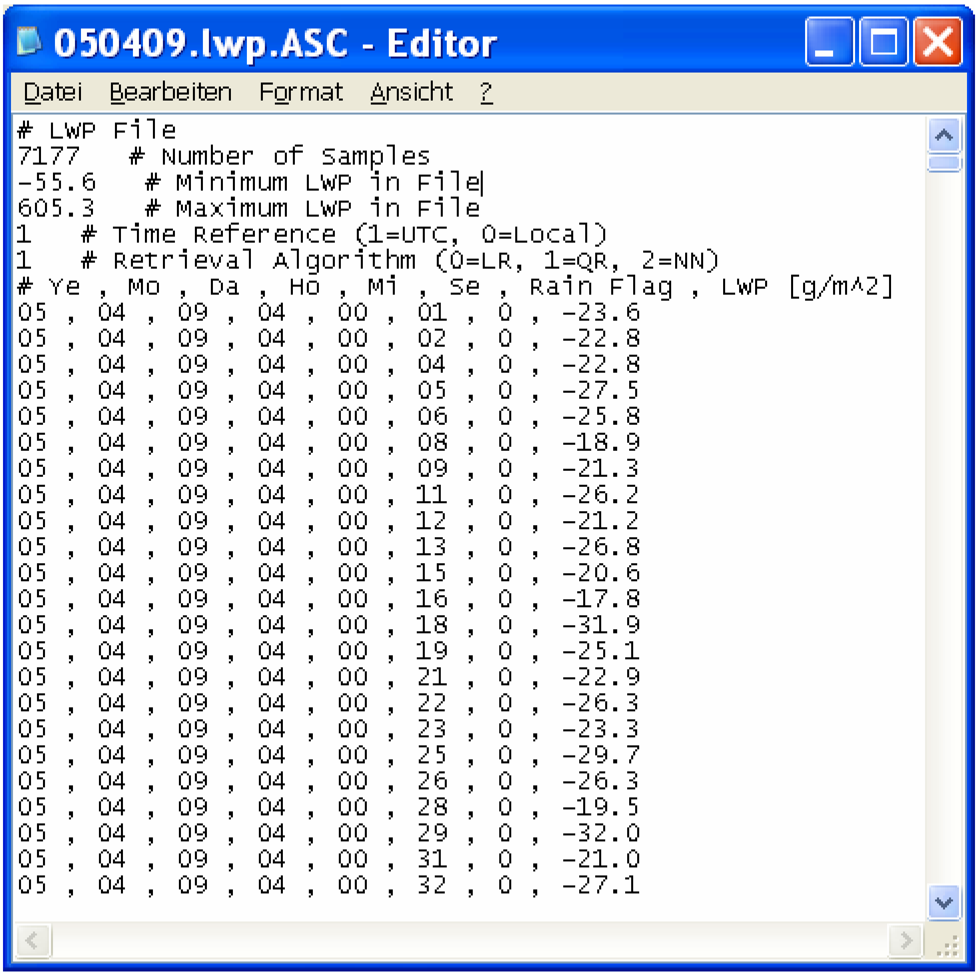
TauArr1[0][j]	**float**	**4* SkyTipAngAnz1**	**Tau array for channel 1 (only if CalType1=3 and TauSuccess1 [0]=1)**
LinFit1A[0]	**float**	**4**	**Linear Fit parameter A (offset) for channel 1 (only if CalType1=3 and TauSuccess1[0]=1)**
LinFit1B[0]	**float**	**4**	**Linear Fit parameter B (slope) for channel 1 (only if CalType1=3 and TauSuccess1[0]=1)**
…	**…**	**…**	**…**
TauArr1[N_CH_Rec1-1][j]	**float**	**4* SkyTipAngAnz1**	**Tau array for last channel (only if CalType1=3 and TauSuccess1 [N_CH_Rec1-1]=1)**
LinFit1A[N_CH_Rec1-1]	**float**	**4**	**Linear Fit parameter A (offset) for channel 1 (only if CalType1=3 and TauSuccess1[N_CH_Rec1-1]=1)**
LinFit1B[N_CH_Rec1-1]	**float**	**4**	**Linear Fit parameter B (slope) for last channel (only if CalType1=3 and TauSuccess1 [N_CH_Rec1-1] =1)**
…	**…**	**…**	**…**
CalTypeN	**int**	**4**	**Type of calibration sample N (0=gain, 1=noise, 2=tip curce)**
CalTimeN	**int**	**4**	**Time of sample N (# of sec. since 1.1.2001)**
TipCurveStatN	**int**	**4**	**Status of tip curve calibration (only if CalTypeN=2), 3=FAILED, 2=SUCCESS**
GainN[]	**float**	**4* ChanNo**	**Gains of calibration sample 1**
TsysN[]	**float**	**4* ChanNo**	**system noise temps of calibration sample N (only if CalTypeN=1 or CalTypeN=2)**
LinCorrN[]	**float**	**4* ChanNo**	**Linear correlations for calibration sample N (only if CalTypeN=2)**
ChiSqrN[]	**float**	**4* ChanNo**	**Chi square factors for calibration sample N (only if CalTypeN=2)**
NoiseTempN[]	**float**	**4* ChanNo**	**Noise source temperatures for calibration sample N (only if CalTypeN=2)**
SkyTipAngAnzN	**float**	**4**	**Number of sky tip for calibration sample N (only if CalType1= 3)**
AirmassN[]	**float**	**4* SkyTipAngAnzN**	**Airmass array (only if CalType1=3)**
SkyDipUsN[i][j] i=0, … , N_CH_Rec1-1 j=0, … , SkyTipAngAnzN	**float**	**4* N_CH_Rec1* (SkyTipAngAnzN+1)**	**Sky dip detector voltages (only if CalType1=3). For each frequency the det. Voltage is given at all angles. The last entry is the**

			voltage on the hot target, sample N
TauSuccessN[]	int	4* N_CH_Rec1	Flag that indicates if the Tau calculation during the skydip was successful (0=no, 1=yes) (only if CalType1=3), sample N
TauArrN[0][j]	float	4* SkyTipAngAnzN	Tau array for channel 1 (only if CalType1=3 and TauSuccessN [0]=1)
LinFit1A[0]	float	4	Linear Fit parameter A (offset) for channel 1 (only if CalType1=3 and TauSuccessN[0]=1)
LinFit1B[0]	float	4	Linear Fit parameter B (slope) for channel 1 (only if CalType1=3 and TauSuccessN[0]=1)
…	…	…	…
TauArr1[N_CH_Rec1 -1][j]	float	4* SkyTipAngAnzN	Tau array for last channel (only if CalType1=3 and TauSuccessN [N_CH_Rec1 -1]=1)
LinFit1A[N_CH_Rec1 -1]	float	4	Linear Fit parameter A (offset) for channel 1 (only if CalType1=3 and TauSuccessN[N_CH_Rec1 -1]=1)
LinFit1B[N_CH_Rec1 -1]	float	4	Linear Fit parameter B (slope) for last channel (only if CalType1=3 and TauSuccessN [N_CH_Rec1 -1] =1)

with N = N_Gain + N_Noise + N_SkyTip and ChanNo = N_CH_Rec1+ N_CH_Rec2.

Appendix B (ASCII File Formats)

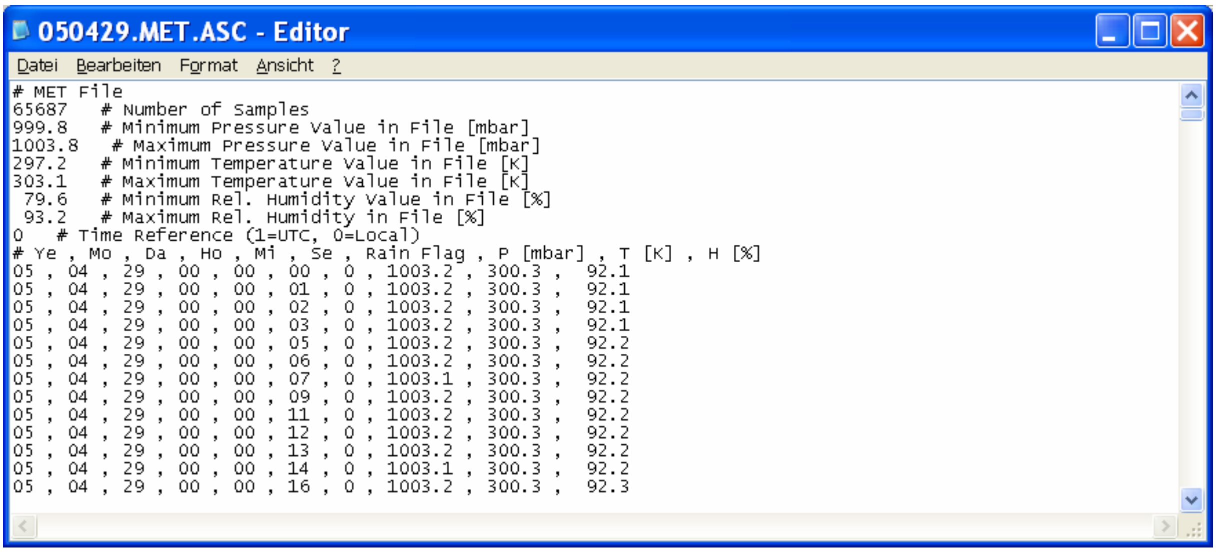
Fig.B1 shows an example of an ASCII data file structure (BRT). All ASCII files start with a header giving information about the number of samples in the file, Minimum and Maximum values of the measured or retrieved quantities for scaling purposes, the time reference (UTC or local time) and the type of retrieval if any (0 = linear regression, 1 = quadratic regression, 2 = neural network). Comments are preceded by '#'.
Each sample line starts with the date and time (Ye = Year, Mo = Month, Da = Day, Ho = Hour, Mi = Minute, Se = Second) this sample was measured followed by the rain flag (0 = no rain, 1 = raining). All data columns are separated by ',' from each other. Each line ends with CR/LF.



```
# LWP File
7177    # Number of Samples
-55.6    # Minimum LWP in File
605.3    # Maximum LWP in File
1    # Time Reference (1=UTC, 0=Local)
1    # Retrieval Algorithm (0=LR, 1=QR, 2=NN)
# Ye , Mo , Da , Ho , Mi , Se , Rain Flag , LWP [g/m^2]
05 , 04 , 09 , 04 , 00 , 01 , 0 , -23.6
05 , 04 , 09 , 04 , 00 , 02 , 0 , -22.8
05 , 04 , 09 , 04 , 00 , 04 , 0 , -22.8
05 , 04 , 09 , 04 , 00 , 05 , 0 , -27.5
05 , 04 , 09 , 04 , 00 , 06 , 0 , -25.8
05 , 04 , 09 , 04 , 00 , 08 , 0 , -18.9
05 , 04 , 09 , 04 , 00 , 09 , 0 , -21.3
05 , 04 , 09 , 04 , 00 , 11 , 0 , -26.2
05 , 04 , 09 , 04 , 00 , 12 , 0 , -21.2
05 , 04 , 09 , 04 , 00 , 13 , 0 , -26.8
05 , 04 , 09 , 04 , 00 , 15 , 0 , -20.6
05 , 04 , 09 , 04 , 00 , 16 , 0 , -17.8
05 , 04 , 09 , 04 , 00 , 18 , 0 , -31.9
05 , 04 , 09 , 04 , 00 , 19 , 0 , -25.1
05 , 04 , 09 , 04 , 00 , 21 , 0 , -22.9
05 , 04 , 09 , 04 , 00 , 22 , 0 , -26.3
05 , 04 , 09 , 04 , 00 , 23 , 0 , -23.3
05 , 04 , 09 , 04 , 00 , 25 , 0 , -29.7
05 , 04 , 09 , 04 , 00 , 26 , 0 , -26.3
05 , 04 , 09 , 04 , 00 , 28 , 0 , -19.5
05 , 04 , 09 , 04 , 00 , 29 , 0 , -32.0
05 , 04 , 09 , 04 , 00 , 31 , 0 , -21.0
05 , 04 , 09 , 04 , 00 , 32 , 0 , -27.1
```

Fig.B1: LWP ASCII data file structure.

Fig.B2 is an example for a meteorological surface sensor data file (MET). Here the header lists minimum and maximum values for each sensor type.



```
# MET File
65687   # Number of Samples
999.8   # Minimum Pressure Value in File [mbar]
1003.8   # Maximum Pressure Value in File [mbar]
297.2   # Minimum Temperature Value in File [K]
303.1   # Maximum Temperature Value in File [K]
 79.6   # Minimum Rel. Humidity Value in File [%]
 93.2   # Maximum Rel. Humidity in File [%]
0   # Time Reference (1=UTC, 0=Local)
# Ye , Mo , Da , Ho , Mi , Se , Rain Flag , P [mbar] , T [K] , H [%]
05 , 04 , 29 , 00 , 00 , 00 , 0 , 1003.2 , 300.3 ,  92.1
05 , 04 , 29 , 00 , 00 , 01 , 0 , 1003.2 , 300.3 ,  92.1
05 , 04 , 29 , 00 , 00 , 02 , 0 , 1003.2 , 300.3 ,  92.1
05 , 04 , 29 , 00 , 00 , 03 , 0 , 1003.2 , 300.3 ,  92.1
05 , 04 , 29 , 00 , 00 , 05 , 0 , 1003.2 , 300.3 ,  92.2
05 , 04 , 29 , 00 , 00 , 06 , 0 , 1003.2 , 300.3 ,  92.2
05 , 04 , 29 , 00 , 00 , 07 , 0 , 1003.1 , 300.3 ,  92.2
05 , 04 , 29 , 00 , 00 , 09 , 0 , 1003.2 , 300.3 ,  92.2
05 , 04 , 29 , 00 , 00 , 11 , 0 , 1003.2 , 300.3 ,  92.2
05 , 04 , 29 , 00 , 00 , 12 , 0 , 1003.2 , 300.3 ,  92.2
05 , 04 , 29 , 00 , 00 , 13 , 0 , 1003.2 , 300.3 ,  92.2
05 , 04 , 29 , 00 , 00 , 14 , 0 , 1003.1 , 300.3 ,  92.2
05 , 04 , 29 , 00 , 00 , 16 , 0 , 1003.2 , 300.3 ,  92.3
```

Fig.B2: MET meteorological sensor ASCII data file structure.