

ENVISAT-1 MWR, IN FLIGHT FUNCTIONAL AND PERFORMANCE VERIFICATION

M.L'Abbate⁽¹⁾, O.Bombaci⁽²⁾, G.Alberti⁽³⁾, P.Femenias⁽⁴⁾

⁽¹⁾Alenia Spazio S.p.A., Rome (Italy), Email: m.labbate@roma.alespazio.it

⁽²⁾Alenia Spazio S.p.A., Rome (Italy), Email: o.bombaci@roma.alespazio.it

⁽³⁾CO.R.I.S.T.A., Naples (Italy), Email: g.alberti@unina.it

⁽⁴⁾ESA-ESRIN, Frascati (Italy), Email: Pierre.Femenias@esa.int

ABSTRACT

ENVISAT Microwave Radiometer (MWR) is an instrument designed and developed as part of the Envisat-1 satellite scientific payload, with Alenia Aerospazio engaged in the phase C-D as instrument Prime Contractor, leading an industrial consortium of European and American companies. The Flight Model of the Instrument was delivered to ESA at the end of July 1997, after successful completion of design, test and calibration activities. An Engineering Model of the instrument was also developed and completed in March 1997. Alenia Spazio's Remote Sensing Division started in 1986 the study of microwave radiometers under Italian Space Agency fundings, and since 1989 the definition and development of radiometric systems under European Space Agency (ESA) contracts. In particular the Multifrequency Imaging Microwave Radiometer (MIMR see [9]) and the ENVISAT Microwave Radiometer (MWR) were both developed by the European Industry, with Alenia Spazio as Prime Contractor. Currently Alenia Spazio is leading the study phase of the EGPM mission (European contribution to Global Precipitation Mission), whose satellite will embark as primary payload a multi-frequency radiometer which will be an evolution of the MIMR radiometer.

Given the MWR in-flight calibration concept, a specific pre-flight calibration and characterization activity was performed to define a radiometer mathematical model and a relevant ground characterisation data base including all model coefficients. This model and its associated characterisation data base are used by on-ground processing during instrument in-flight operation to retrieve the antenna measured temperature. Standing its complexity and iterative measurement concept, the pre-flight characterisation and calibration of the instrument was the key activity of MWR development; the overall ground calibration tasks were performed through an iterative sequence of measurement and relevant model corrections, with an extensive instrument calibration in a thermal-vacuum environment, to derive the final radiometer model coefficients and to verify its performance in the expected in-flight environment.

Alenia Spazio has been also responsible for definition of the Level 1B processing algorithms of both ENVISAT MWR and RA-2, and for the development of SW prototypes used for validation of the relevant specifications (see [2]) in the first phase, and later for validation of ENVISAT ground segment processing chain.

As part of the MWR in flight Validation and Calibration activities, several tasks have been performed, with their main focus on the functional verification of MWR in flight performance during the ENVISAT commissioning phase : this paper provides a summary of these achievements. Simultaneously, the in-flight calibration of MWR has been also completed, and the relevant outcomes are summarised in [1] .

1 MWR Background and Instrument overview

The MWR design concept derives from the experimental radiometers embarked on ERS-1 (see [10] and [11]) satellite. It is a two channels passive microwave radiometer, operating at 23.8 and 36.5 GHz with Dicke architecture, and devoted to measure the amount of water content in the atmosphere beneath the satellite's track (Nadir pointing). While the ERS-1/2 instrument was of experimental type, the ENVISAT MWR was classified as ESA Developed Instruments (EDI), with significantly tighten requirements imposed by the scientific mission and by the Polar Platform (PPF) satellite. Therefore elements of the experimental radiometer of ERS were used as input, but a substantially new design was developed as necessary to : satisfy the ENVISAT requirements and qualify the Instrument according to ESA space requirements, improve instrument performance and its calibration accuracy, and for current technology upgrade. In particular the Calibration and characterisation approach, the radio frequency design and electromagnetic compatibility aspects, the thermal and structural design, have been completely re-addressed. The MWR output products are of prime importance for wind/wave products of the ENVISAT Radar Altimeter (RA-2) Instrument, as will allow the correction of atmospheric propagation errors of RA-2. MWR products are also useful for direct evaluation of brightness temperature in order to characterise polar ice, land surface

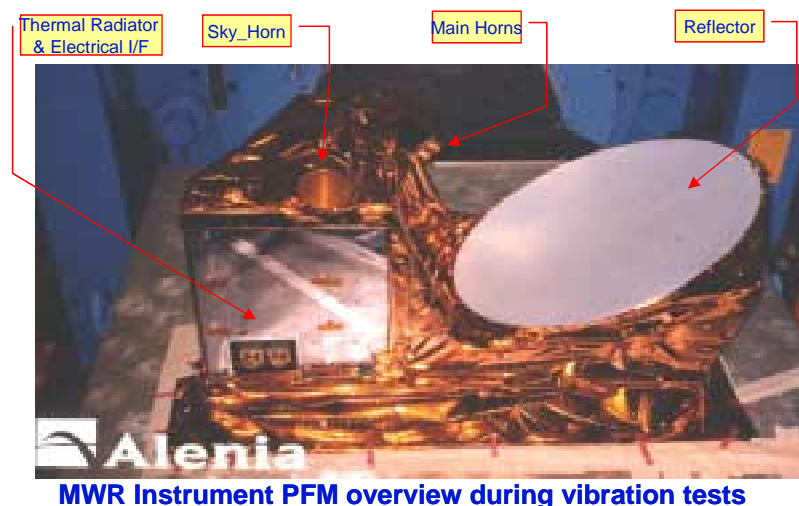
properties and sea surface temperature. In order to achieve the required accuracy and sensitivity performance, an in-flight two-point calibration concept is adopted, with hot and cold calibration reference points for each frequency channel. Periodically the measurements of earth scene radiation are interrupted to allow the measurement of an on-board calibration load and of the deep cold space.

A short summary of the instrument characteristics is given hereafter, as more details are available in references (more specifically, see [4], [5] and [6]). The driving requirements of the Instrument and the final achievements after the test campaign are summarised in Table 1. Based on the Dicke configuration, the radiometer will measure the difference between the antenna Noise Temperature (T_a) and a known internal reference temperature, thus reducing the effects of the overall system instabilities. Due to this mode of operation, the instrument will provide higher radiometric accuracy and sensitivity performance when T_a to be measured is of similar magnitude compared to the internal reference temperature (about 300 K).

<i>Performance</i>	<i>Requirement</i>	<i>Achievement</i>
Radiometric Sensitivity	< 0.6 K	0.4 K
Radiometric Stability	< 0.6 K	0.4 K
Dynamic Range	3K to 330K	3K to 335K
Non-linearity	< 0.5 K	0.35 K
Radiometric Accuracy (after calibration)	< 3 K with $T_{ant} = 300K$	1 K, with $T_{ant} = 300K$ < 3K with $T_{ant} = 85$ to 330K
On board settable Intercalibration period	38.4, 76.8, 153.7, 307.4 sec	38.4, 76.8, 153.7, 307.4 sec
Noise Figure	< 6.8 dB incl. Antenna	4.8 dB, incl. Antenna
Frequency accuracy 36.5 and 23.8 GHz	< ± 10.0 MHz	< ± 3.0 MHz
Antenna Radiation Efficiency	> 93 %	97 %
Antenna Main Beam Efficiency	> 89 %	94 %
Antenna Side Lobes Level (in 3° half angle)	-22 dB at 23.8 GHz -30 dB at 36.5 GHz	24 dB 31 dB
Antenna Half Power beamwidth (3 dB)	< 1.7°	1.5 °
Instrument Mass	< 30 Kg	24 Kg
Operational Power	< 50 Watts	18 Watts

Table 1 MWR key performance summary

As anticipated, a two points off-line absolute calibration scheme of the overall receiver has been implemented, by use of a cold and hot reference sources. The cold reference signal for absolute calibration is achieved via a dedicated feed-horn pointing towards the deep space, named the Sky-Horn, while an on-board precision load, kept by the thermal control at the instrument physical temperature, provides the required hot reference signal. An overview of the Instrument is provided in Fig. 1, while its functional architecture is reported in Fig. 2.



MWR Instrument PFM overview during vibration tests

Figure 1 MWR Overview

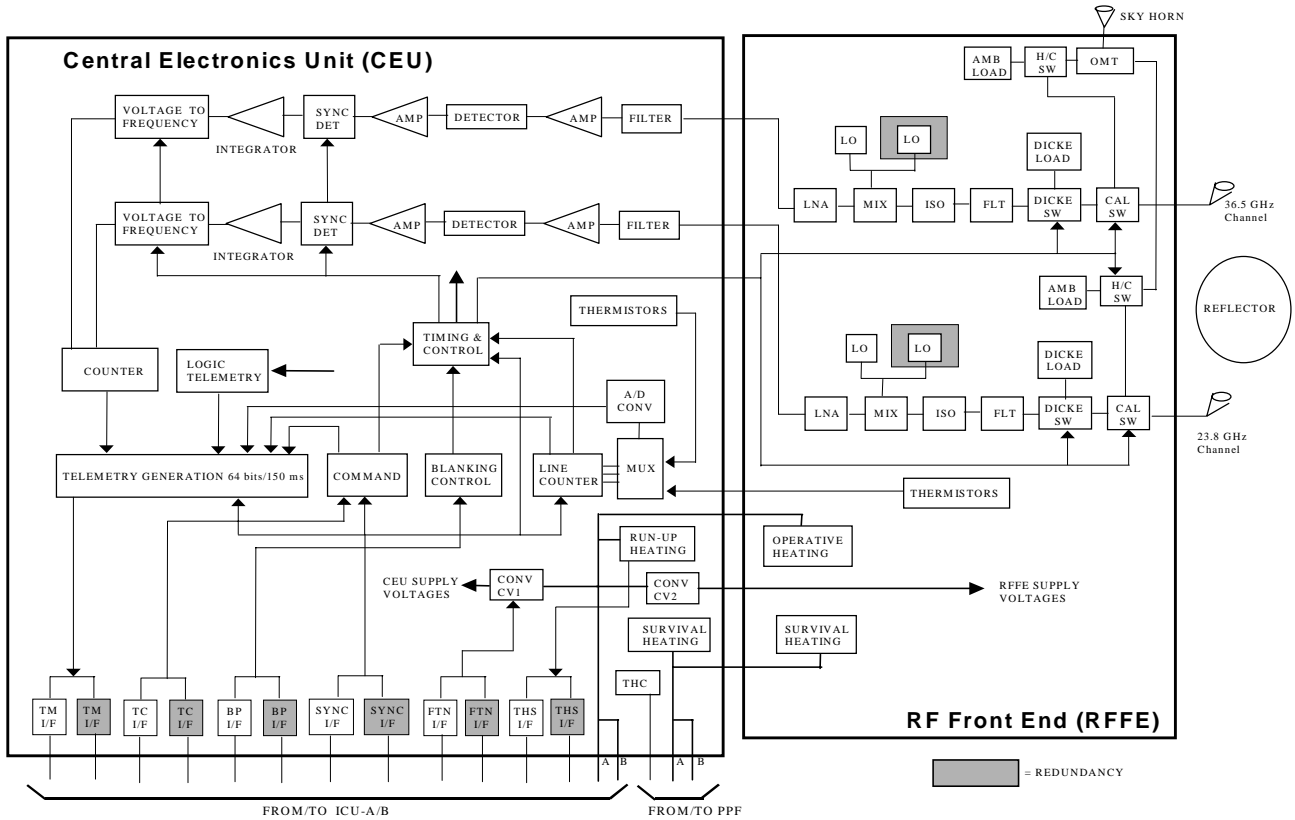


Figure 2 MWR Functional Block Diagram

The noise signals in the two bands are separately routed into the Radio Frequency Front-End, where they are filtered from sidebands spurious signals, down converted to Intermediate Frequency (IF) and low noise amplified. The band defining filtering, quadratic detection and conversion to digital of the antenna and calibration signals is performed by the Centralized Electronic Unit (CEU). Measurement of RF components physical temperatures is performed by use of high precision platinum thermistors (PRT), to use these data in the reconstruction of the Noise Temperature at Antenna input.

2 MWR instrument pre-flight calibration overview

In general terms, it is necessary to establish a relation between the digitised radiometric signal output (counts), that is the instrument reading, and the antenna temperature as seen by the measurement antenna, that is the desired scientific output. The digital counts to antenna temperature transfer function had to be characterised in all its fundamental parameters with high accuracy. This goal was reached through two major steps (see Fig. 3) : (i) the in flight calibration, with periodic calibration of the radiometric chain by use of the two reference temperatures acquired during flight, and (ii) the pre-flight characterisation and calibration, which characterises the main parameters which are outside of the calibration path. To establish the transfer function, a mathematical model of the radiometer was defined, as per Figure 3. Full details are provided within [2] and [3], while hereafter a summary overview is given. The model includes the RF front-end elements and groups all the receiver back-end electronics into a block that produces the digital counts of interest (C_a antenna measurement, C_c cold calibration, C_h hot calibration). The model is characterised by a gain G and an instrument temperature T_g . This model is used to evaluate the physical temperature in front of the main antenna, retrieving it from the radiometer output voltage during measurement and from the calibrated radiometer gain. The coefficients involved in the radiometric model, and their abbreviations (as used in Figure 3) are given in the appendix (Table A and Table B). In particular, Table A reports all the coefficients relevant to RF front-end elements (switches, wave-guides, feeds) in terms of transmission and isolation, and also the terms describing the non-linear behaviour of the receiver. Table B reports the instrument temperatures that are available from monitoring telemetry.

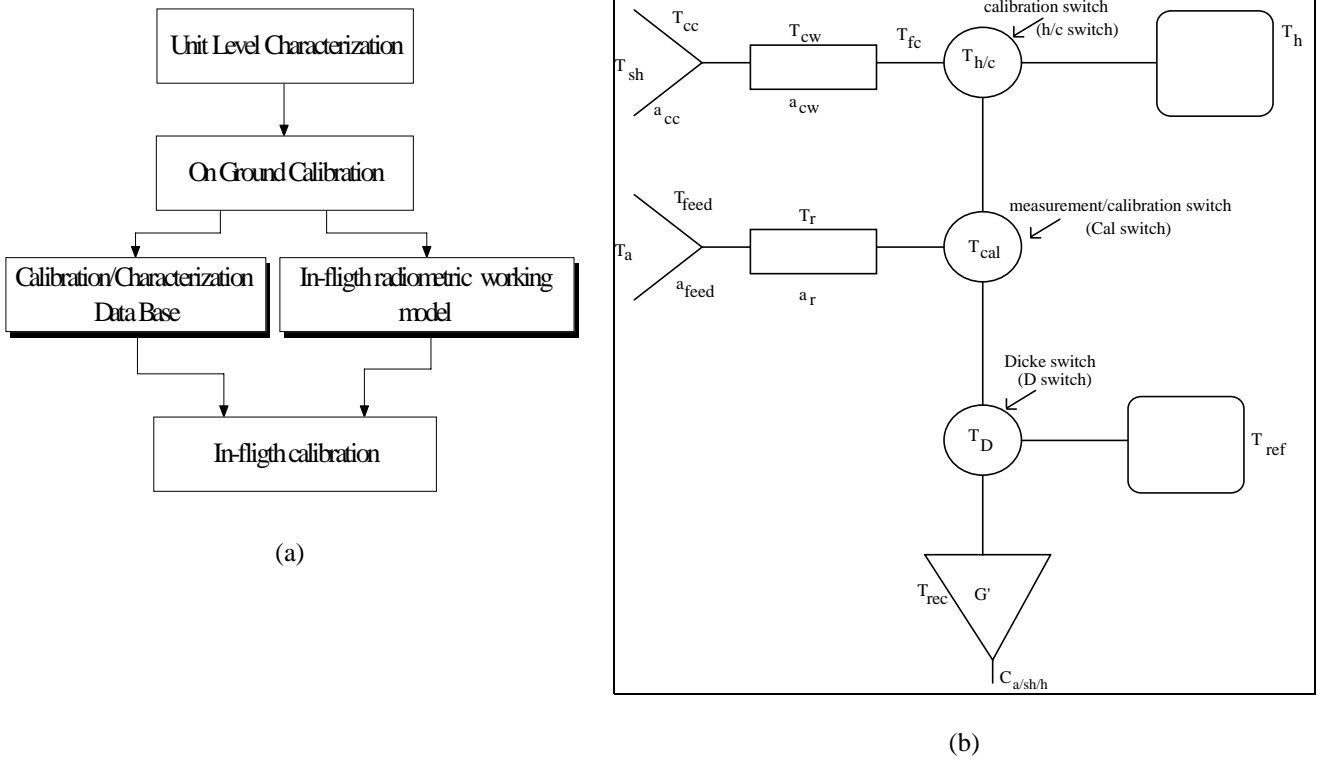


Figure 3 Calibration process (a), and MWR Radiometric Model (b)

The radiometric transfer function is evaluated as follows. During the Earth scene observation, the output digital counts are related to the antenna temperature by the following:

$$C_a - \text{off} = G T_a''' \quad (1)$$

where T_a''' is the noise temperature at receiver IF input (CEU), related to the input noise temperature and to the reference temperatures. From (1), it is possible to retrieve the CEU input noise temperature after having evaluated the gain using the hot and cold calibration. Knowing the input noise power (cold calibration input = cold sky temperature = 2.7K = T_{sh} , and hot calibration input = hot load temperature = T_h) and acquiring the output counts (C_h and C_c), the actual gain G can be calculated. Moreover, the gain shall be a function of all the variables involved during the calibration along the hot reference and sky horn paths.

$$G = \frac{C_h - C_c}{c_h \cdot T_h + c_{fc} \cdot T_{fc} + c_{hc} \cdot T_{hc}} \quad (2)$$

where

$$T_{fc} = [a_{cc} T_{sh} + (1 - a_{cc}) T_{cc}] a_{cw} + (1 - a_{cw}) T_{cw} \quad (3)$$

$$\begin{cases} c_{fc} = a_{c/h} \cdot \frac{a_{cal}}{a_a} - b_{h/c} \cdot \frac{a_{cal}}{a_a} \\ c_h = a_{h/c} \cdot \frac{a_{cal}}{a_a} - b_{c/h} \cdot \frac{a_{cal}}{a_a} \\ c_{hc} = c_{fc} - c_h \end{cases} \quad (4)$$

Having evaluated the gain G and the value of the CEU input temperature from (1), and knowing that:

$$T_a''' = \left\{ \left[\left(T_a a_{\text{feed}} + (1 - a_{\text{feed}}) \cdot T_{\text{feed}} \right) \cdot a_r + (1 - a_r) \cdot T_r \right] \cdot a_a + T_h \cdot b_{\text{cal}} + (1 - a_a - b_a) \cdot T_{\text{cal}} \right\} (b_{\text{re}} - a_m) + (a_m - b_{\text{re}} - a_{\text{re}} + b_m) T_D + (a_{\text{re}} - b_m) T_{\text{ref}} \quad (5)$$

it is possible to obtain

$$T_a = c_1 \left[b_1 \cdot T_{\text{ref}} + b_2 \cdot T_D + b_3 \cdot T_{\text{cal}} - b_4 \cdot T_h - c_2 \cdot T_r + TE_1 \right] - c_3 \cdot T_{\text{feed}} - \frac{C_a - \text{off}}{G} \quad (6)$$

where

$$\begin{cases} b_1 = \frac{a_{\text{re}} - b_m}{a_a (a_m - b_{\text{re}})}; & b_2 = \frac{1}{a_a} - 1 - b_4; & b_4 = \frac{b_a}{a_a} \\ b_3 = \frac{1}{a_a} - 1 - b_4; & c_1 = \frac{1}{a_r \cdot a_{\text{feed}}}; & c_3 = \frac{1}{a_{\text{feed}}} - 1 \\ c_2 = 1 - a_r \end{cases} \quad (7)$$

It is obvious that the characterisation of all these parameters affects the total accuracy of the scientific results. Since the objective of the MWR Characterisation/Calibration campaign is to achieve a final accuracy for the measured antenna temperature of less than 3K, the ground calibration tasks have been as follows:

- to accurately calibrate the thermometers used for MWR temperature monitoring in-flight (PRT calibration);
- to determine the transfer function of each receiver for antenna temperatures in the range 85-330 K;
- to measure the Instrument performance in an environment representative of its in-flight operating conditions;

These tasks were grouped in the following two main calibration phases.

- *Pre-Calibration*, to perform the PRT calibration and a preliminary instrument performance characterisation, allowing the detection of critical issues before the instrument final integration;
- *Thermal Vacuum calibration (T/V)*, to derive the final radiometer model coefficients and validate Instrument performance.

During the T/V calibration activities, the Instrument in-flight operational environment was simulated within a thermal vacuum chamber. Two cryogenic targets system were used to simulate the Earth and Cold Space radiation: VTTS (Variable Temperature Target System) settable in the range 85-330 K range, in front of main feed, and the FTTS (Fixed Temperature Target System) kept at 85 K, in front of the sky horn. The validity of the radiometer model (in terms of derived coefficients) and of the measured Instrument performance was therefore dependant mainly on the accuracy of the reference targets, and therefore their design and validation was one of the key objectives of the MWR programme (see [4], [5] and [6]).

A further step was the *measurement of the Antenna* radiation patterns and the assessment of its beam efficiency, in order to derive further parameters for the on ground characterisation data base. Specifically the measured antenna characteristics have been taken into account during Level 1B processing, as detailed in [1].

3 MWR instrument in flight functional and performance verification

The key targets of the MWR in-flight Calibration and Validation activity were:

- to calibrate and validate key performance parameters (such as Brightness Temperatures at 24 & 36 GHz, Water vapour content, Liquid water content, Water vapour path length correction) with respect to the MWR instrument and algorithms performances;
- To ensure continuity with ERS MWR (Cross-Calibration with ERS-2 MWR)

- In Flight Verification of the Instrument (Control of the functioning of the MWR sensor, of the radiometric counts, radiometer gains, hot and cold loads, radiometric resolution, residual error, etc.)
- Control of the antenna pointing angles (using measurements over coasts or islands)
- Direct comparison with ERS-2 measurements over the Antarctic plateau : ENVISAT/MWR frequencies are exactly the same than ERS-2/MWR ones, and this provides the possibility to compare brightness temperatures over this area with weak spatial and temporal variability
- Comparison with other in-flight radiometers: for the same set of ECMWF fields, comparison between simulations and measurements from ERS-2 MWR and/or TMR, JMR, SSMI, TMI, AMSR sensors.
- Validation and Long Term Survey, using also in-situ measurements.

The functional verification of the instrument was encompassing the following main activities:

- Support to the MWR in-flight calibration activity, and specifically in the review of calibration algorithms, and specific upgrades, whenever necessary;
- In Flight Verification of the Instrument, aimed to assess its functional behaviour and performance on the basis of the measured in-flight data;
- Maintenance and upgrades of the Level 1B prototype processor already developed, and use of the prototype processor to support the in-flight calibration activities executed using the ENVISAT ground segment processing chain, in particular for validation of the generated Level 1B products.

While more specific outcomes from the in flight Calibration are given in [1], hereafter a summary of the main achievements in terms of Instrument functional verification is provided.

The definition of the on ground characterisation data base of MWR was executed as part of the instrument development activities. Basically, 5 sets of coefficients were derived on the basis of full radiometric calibrations executed with the instrument operating temperature fixed at 5 points within the specified operating temperature range (these points were 0°C, +10°C, +20°C, +30°C, +40°C). The 5 sets of coefficients would have to be used by the on ground processing according to the currently measured MWR operating temperature. During the in flight calibration activities, two basic tasks were executed, when considering the measured instrument thermal behaviour: initially the values of the thresholds temperatures to select the use of each of the 5 set of coefficients were refined, considering the actual operating temperatures and the achieved accuracy. Furtherly, since the instrument in flight temperature is normally between +15°C and +20°C, an improvement of the initial algorithm was introduced, consisting in the determination of some specific coefficients using a *polynomial approximation* on the basis of the values belonging to different sets of coefficients. This was applied specifically to the Acc coefficient (see equations above), whose value is now a polynomial approximation achieved considering the values of this coefficient belonging to the +10°C and +20°C data sets. It is worth to highlight that some coefficients, like Acc and Afeed, play very critical roles in the retrieval of the antenna temperature. Actually these parameter were initially set during on ground characterisation according to the measured parameters value (loss of Sky-horn feed and of main antenna feed-horns), but were later modified in order to compensate the characterisation error along the entire sky-horn calibration path or the main antenna measurement path; they have been adjusted in the same way during the in flight calibration. Besides, the implementation of the polynomial approximation, especially for Acc parameter, allowed also to reduce the errors due to some noisy measurement among those collected during on ground tests. Finally, the newly derived polynomial coefficients used in MWR in flight calibration, were validated using MWR measurement data collected during on ground characterisation, and comparing the retrieved antenna temperatures.

Additional parameters of the on ground characterization data base were related to the main antenna reflector loss coefficients. It was of interest the study of these parameters since the on ground characterization was executed, as usual for microwave radiometers, without the reflector in the measurement setup (as large black body targets capable of interfacing the reflector in far field, within a controlled thermal vacuum environment for calibration, would have significantly degraded accuracy with respect to those normally used). Besides the ENVISAT MWR antenna reflector emissivity (and hence losses) were not measured during on ground tests, as this reflector was inherited (completely recurring) from ERS-2 program. Therefore the reflector ohmic losses values included in the characterisation data base were derived by estimates for similarity with previous experiences. These were fixed to 0.07 dB for 23.8 GHz, and 0.1 dB for 36.5 GHz channel. However, as the reflector is full aluminium made, these figures were considered conservative. Standing the above, it was considered very important to assess the validity of these figures during the in flight calibration.

Comparisons were executed with similar parameters in the ERS-1/2 existing calibration models, and, in addition, a further verification was executed considering the reflector emissivity tests executed at 36.5 GHz for MIMR radiometer (demonstrator programme). The MIMR reflector chord was 1.6 m (bigger than MWR), and was made of CFRP with a

surface coating of a thin layer of aluminium. This MIMR experiment provided the conclusion that within a frequency range of 5 to 34 GHz the MIMR reflector emissivity certainly below 0.001, and probably approaching that of a full aluminium plate (0.00024 to 0.00064). The 0.001 emissivity value would imply a loss in the order of 0.004 dB, which is significantly lower than the values initially considered for ENVISAT MWR reflector. Redefined reflector loss values, similar to these, were tested during in flight calibration, and found more appropriate than the initially estimated values.

Further activities, concerning the characterisation data base, were related to the optimisation of processing control thresholds. These thresholds are used in the Level 1B processing to set some flags indicating a reduced data quality. Those of interest were related to minimum and maximum brightness temperature of channels 1 and 2, and other related to the minimum and maximum physical temperatures of some instrument parts (mainly the components within the calibration model). Each of these parameters is compared to the specific threshold included within the Characterisation Files, and some “global” processing error flags are set whenever the number of non nominal parameters (BT and physical temperatures) exceeds an overall thresholds which is also defined in the Characterisation Files. After statistical considerations of parameters values after flight data processing (brightness and physical temperatures), these thresholds have been progressively made tighter (nominal range is reduced) : as example, physical temperatures thresholds was set within $\pm 10^{\circ}\text{C}$ of nominal values (the instrument is very stable, when continuously operating). As summary, after optimisation of BT and temperature thresholds, it has been possible to set the thresholds related to the “global” processing errors in order to have flags set whenever 10-20 % of parameters is out of range.

Concerning the MWR in flight behaviour, it has to be first noted that few on-board anomalies occurred since the switch-on of the instrument (< 10), and were due to an ICU software counter problem. The ICU is not part of MWR, as a common ICU has been developed to control both the MWR and DORIS instruments. A corrective patch for the ICU software has been uploaded in September 2002 to solve these anomalies, but some problem still occurs. These ICU problems forces the switch down of MWR instrument, and therefore they are affecting more the MWR data availability than the sensor performances itself. The only effect on the instrument is the slowing down of the instrument thermal stabilisation, due to the several switch down and restart cycles. The temperature of MWR Thermistor C, placed on the instrument Temperature Reference Point (TRP) located on thermal radiator plate, is reported in the following Fig. 4.

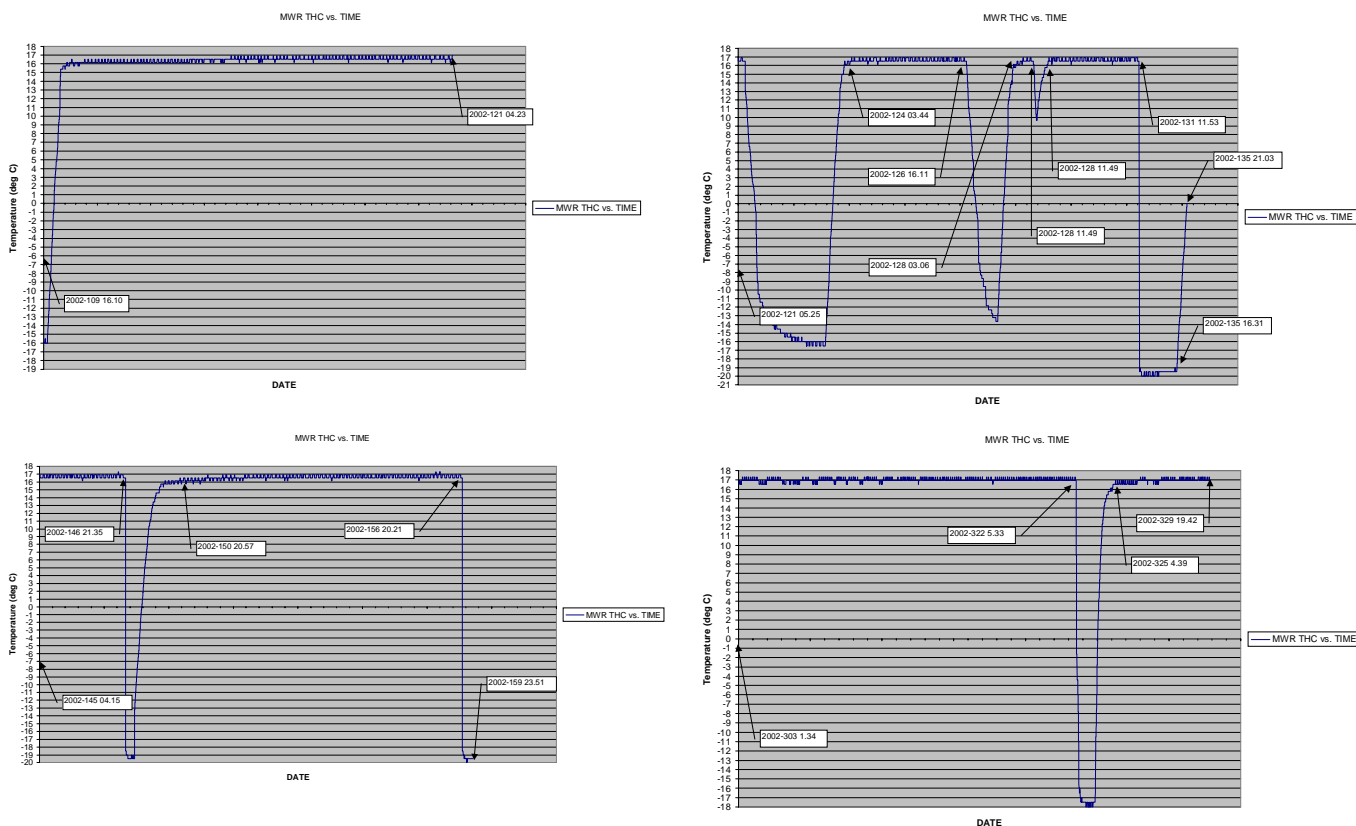


Figure 4 Samples of MWR reference temperature over flight time (external thermal radiator)

The considerations that can be drawn from this analysis, when considering the sequence of on/off cycles, are:

- Analysis of instrument data and performance, both from radiometric and functional/thermal view point, shall be executed only using data acquired during the stable operation periods.
- Concerning the instrument stability, it is important to notice that while the external radiator may have reached a stable value, the internal stability and equilibrium conditions may be achieved after significant time intervals (minutes, hours, depending from transients and active thermal control of instrument).
- The longest period of MWR powered on appears to be in the order of 61 days, and after this period the instrument reference point reached a temperature of about +17.3°C, while in other long periods it was around 16-16.5 °C. So a total drift of 1.3 °C has been experienced with longer stabilisation periods.

Nevertheless all instrument internal temperatures are nominal, and their values are consistent with thermal analysis predictions. Some temperatures (antennas) show a visible round-orbit variation, while the temperatures of the internal RF Front End plate show fluctuations of 2-5°C. This behaviour is nominal, due to the internal active thermal control operating to keep the RF Front End within +10°C to +30°C range for RF electronic performance optimisation. Actually MWR consumes much less power than ERS-1/2, and colder temperatures would have resulted if no thermal control was implemented. During MWR on ground characterisation in thermal vacuum environment, this thermal control was active when MWR external radiator temperature was below +16.7°C (set point of internal thermostats) : the instrument performance are of course nominal also under these circumstances, as it was designed to operate with thermal control active. However, the predictions were that after a long stabilization period the active thermal control should be no more active, as the mean temperature may raise above the 16.7 °C. This is also confirmed by experimental data, as after longer operating periods the radiator temperature was increasing and the thermostats were switched off.

As summary, the overall thermal behaviour is nominal, and the only identified anomaly is the significant number of switch on/off cycles who prevented from the achievement of an optimal thermal equilibrium. Some samples of the internal temperatures are shown in Figures 6 and 7, where it can be seen that also the behaviour of some components on the two channels is very similar. A temperature drop on LO CH2 seems to be occurred in the days 210-220; this is not explained, as the instrument was properly working before, during and after this event. The anomaly may be due to a measurement error. Verification of the instrument power consumption was also executed, and the values are nominal.

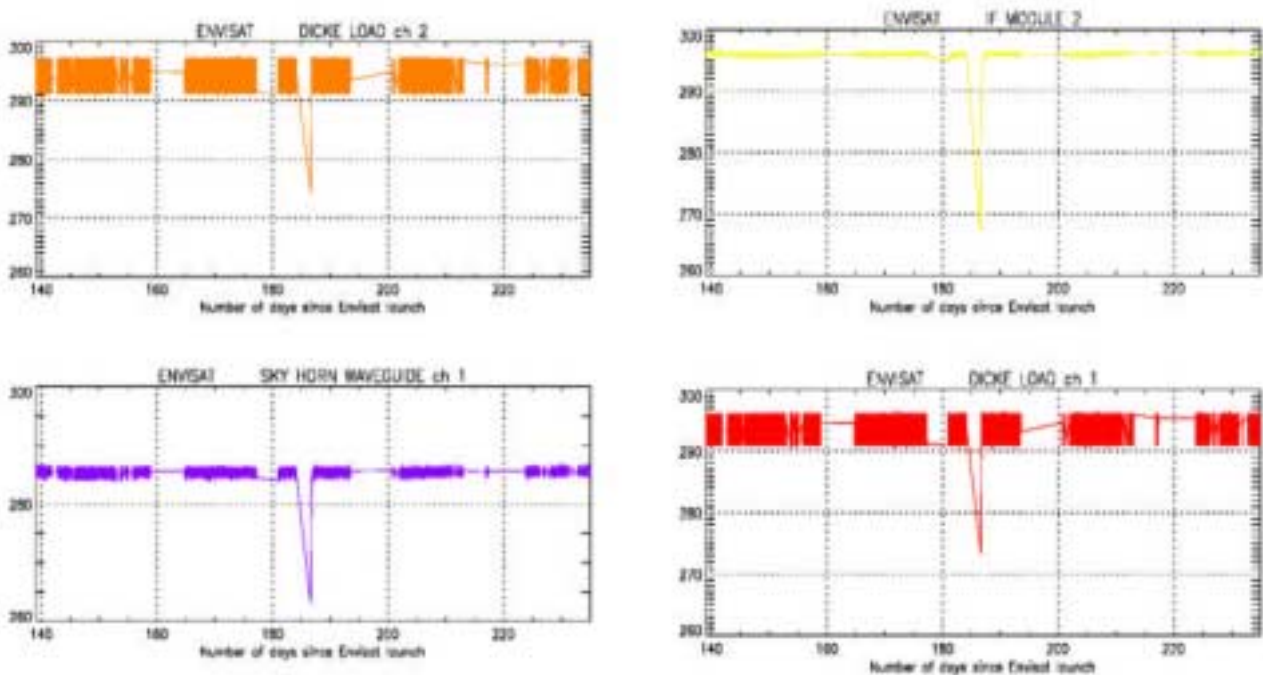


Figure 6 Samples of MWR internal temperatures vs. orbits (1 of 2)

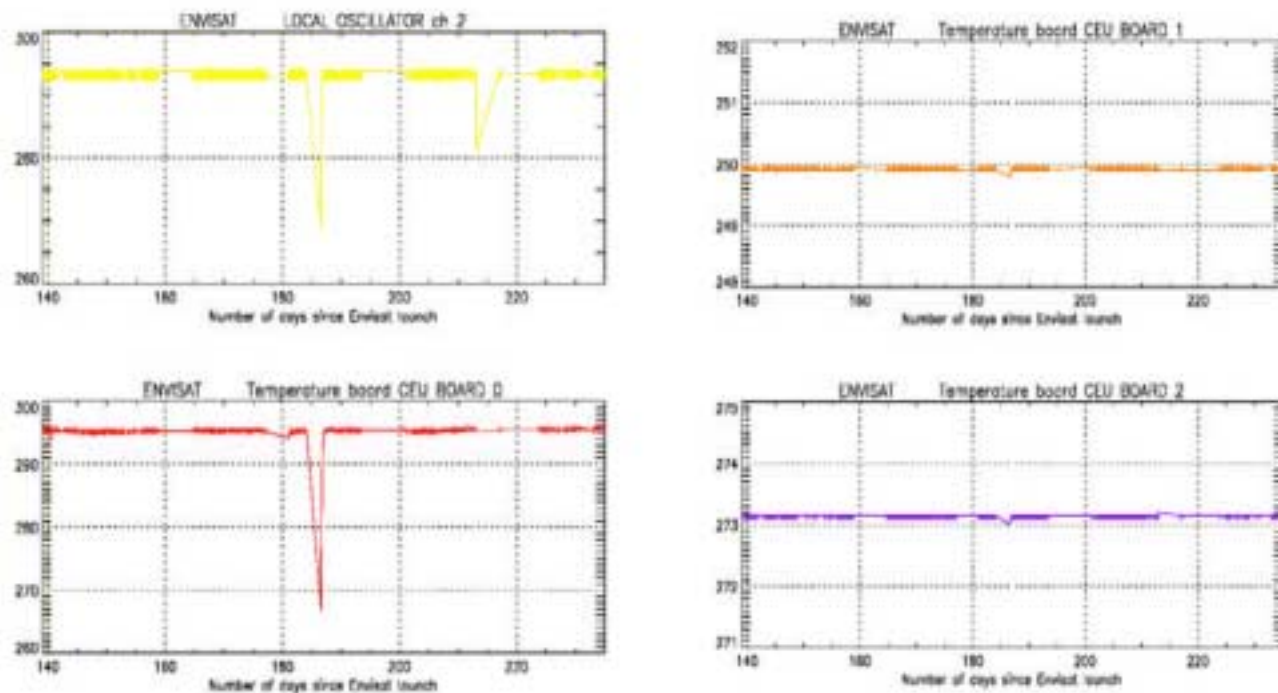


Figure 7 Samples of MWR internal temperatures vs. orbits (2 of 2)

Concerning the MWR radiometric performance, it can be stated that ENVISAT MWR radiometric gain trend from the first Measurement Data Set was already very close to the MWR on-ground characterization, as shown in Fig. 8 (nominal on ground values were 9.7 counts/K for CH1 and 10.2 counts/K for CH2).

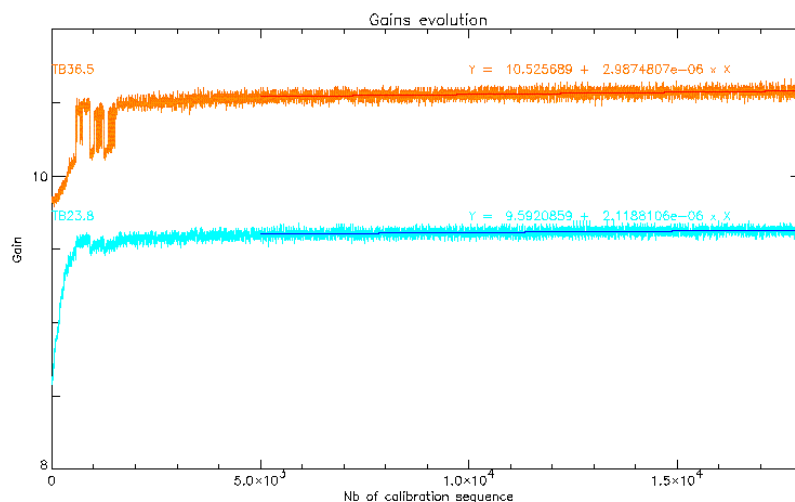


Figure 8 MWR in flight radiometric gain, early acquisitions

Radiometric Counts, see Fig. 9, were also nominal. Hot Counts (Hot Load) mean values were about 558 (CH1) and 661 (CH2), which are well compared to reference measurement made on ground, with the instrument at a temperature between 0°C (549 for CH1, and 671 for CH2) and +20°C (531 CH1, and 650 CH2). Cold counts (Sky Horn) mean values are 3290 and 3585 (CH1, CH2), for which, of course, no reference are available from on ground tests (targets were at 80 K), but

considering the gain these values are nominal. Offset Counts values are nominally around (almost constant) 520 for CH1 and 642 (CH2); the measured on ground offset are 522 (CH1) and 643 (CH2) at 0°C, 519 (CH1) and 641 (CH2) at +20°C .

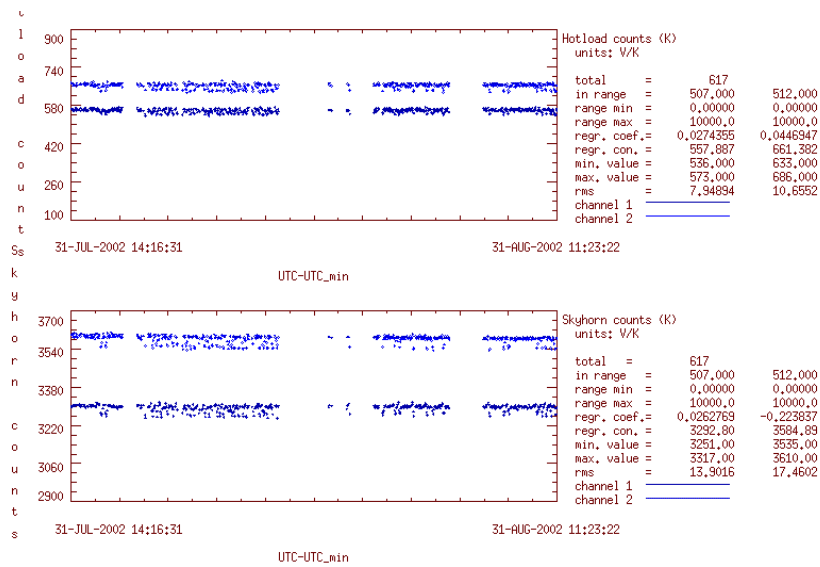


Figure 9 MWR in flight radiometric counts

The MWR radiometric resolution (calculated as the standard deviation of the Brightness Temperature for both channels), see Fig. 10, is of particular significance when the condition $T_A = T_{REF}$ is met. The achieved ΔT is well below 0.3-0.4 K, as during on ground tests. However it has to be pointed out that only a preliminary characterisation has been executed, due to the different changes in the MWR characterization parameters performed during these months for calibration optimisation. Radiometric Resolution characterisation will be extensively pursued over predefined and low variability geographical targets, and over these same targets, but considering long terms observation periods, also a characterisation of the instrument Radiometric Stability will be performed.

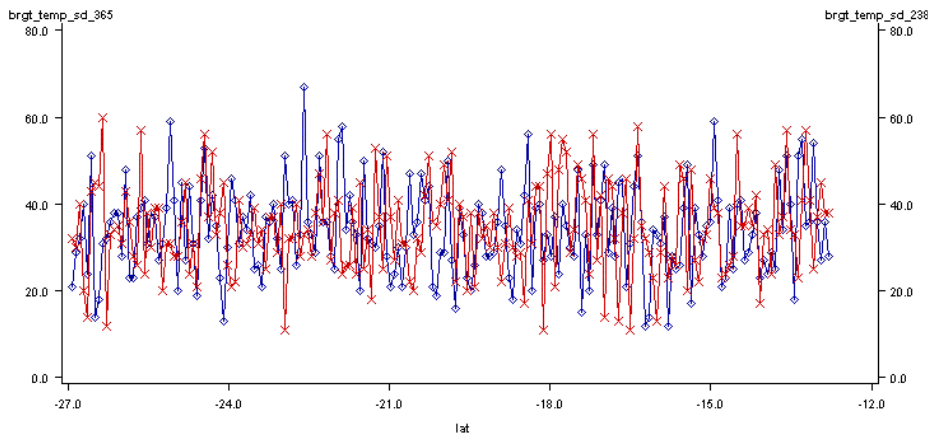


Figure 10 MWR radiometric resolution from in flight data

The Residual Temperature (T_e) parameter, as can be identified in eq.(6), is a residual Temperature offset entering in the computation of the T_a . The computations from Envisat MWR initial flight data provide a T_e values ~ 0.8 K for Channel 1 and ~ 1.5 K for channel 2, as plotted in Fig. 11. Analysis of data from on ground test, stated that the Residual Temperature is expected to be around 0.5 K for Channel 1 and a bit higher, 0.5-0.7 K for channel 2, values which are very close to the ERS ones. In any case this parameter has a very low influence on the retrieved T_a ; for example, a variation of T_e from 0.5 K to 1-

2 K produces only marginal changes (few cents) on Ta. Concerning the channel 2 Te, it may be helpful to extend the number of averaged Hot Load counts, due to the fluctuations within the 8 samples normally averaged by the ground processing. However some differences in Te values with respect to ERS may be nominal, since TE is computed using several terms (see [2]) which are essentially temperature by losses. Losses are of course stable (in the model), but slightly lower than ERS. Temperatures are stable from flight data analysis, but the internal distribution of temperature values is different from ERS MWR. Also, offset counts (which enters into Te computation) are different from ERS, as these were requested to be increased to solve ERS radiometer problem to retrieve antenna temperatures above 300K (spec was 330K on ENVISAT).

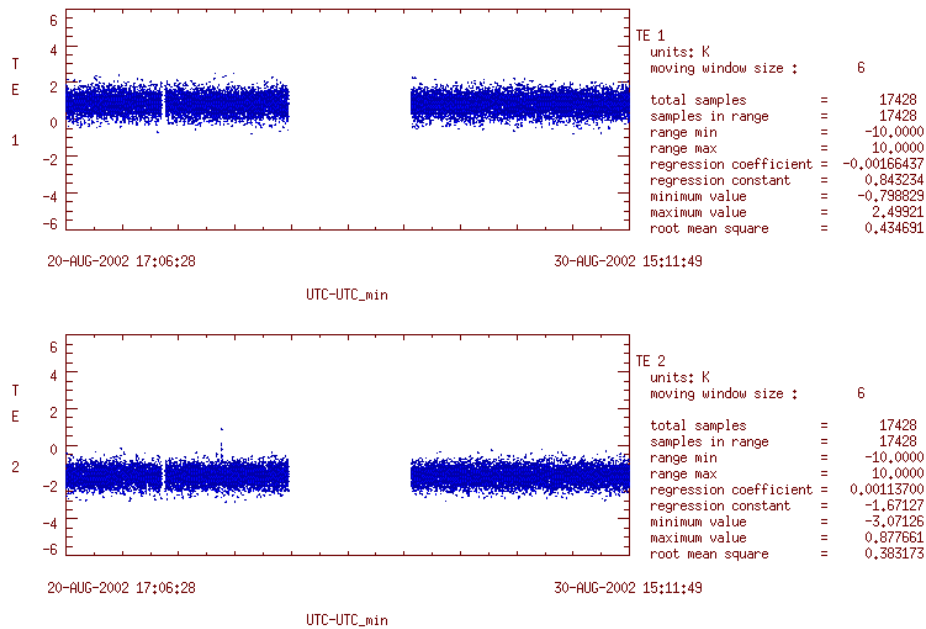


Figure 11 MWR residual temperature (Te) parameter, computed from in flight data

When extending the MWR data analysis over the entire flight period of ENVISAT, a drift of radiometric gain for 36.5 GHz channel (CH2) was identified, as plotted in Fig. 12.

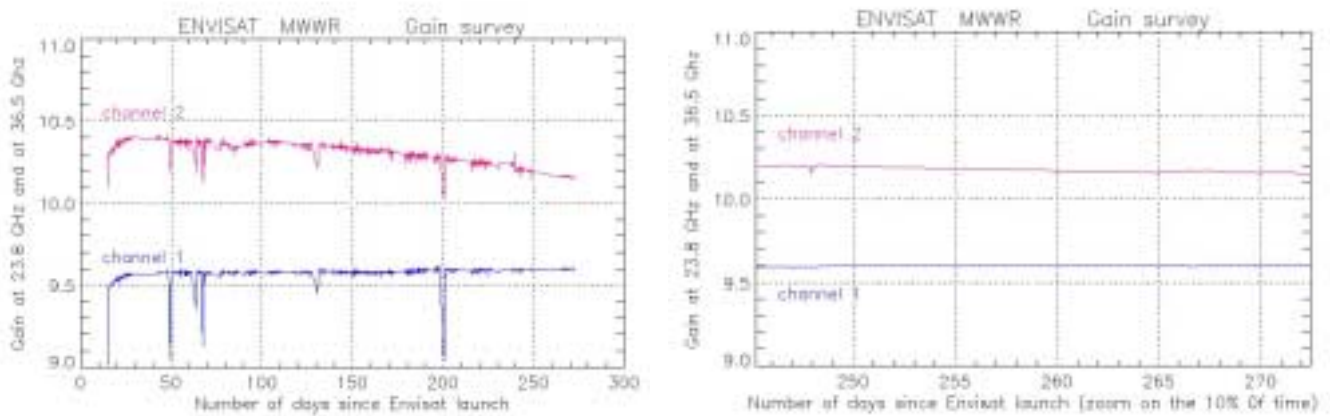


Figure 12 MWR CH2 gain drift over entire ENVISAT flight period

A first verification was executed on Hot Load and Sky Horn counts, which show a drift with same behaviour (see Fig. 13); therefore the receiver gain is actually drifting.

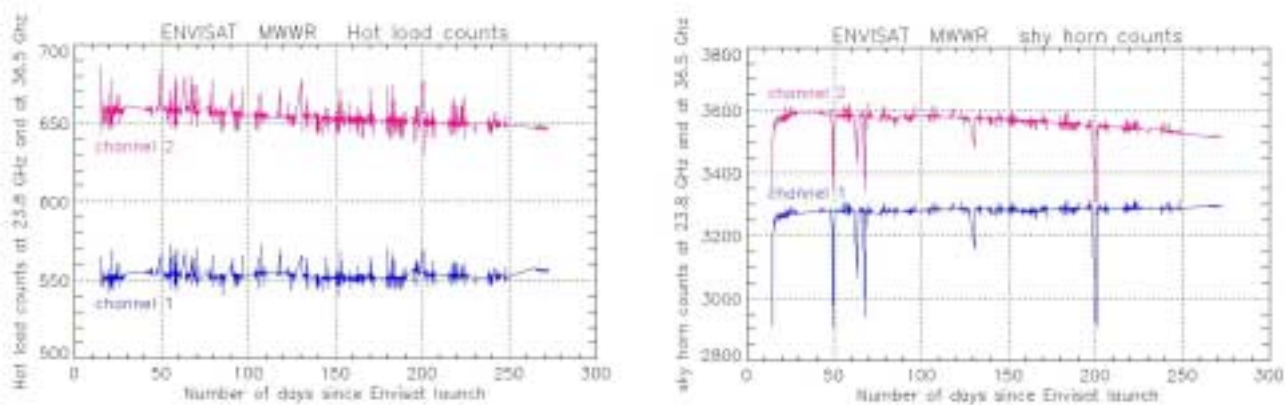


Figure 13 MWR CH2 Hot Load and Sky Horn counts drift over entire ENVISAT flight period

Also the residual Temperature parameters of Ch2, Te, shows the same drift as gain; this is nominal, due to the fact that TE is computed proportionally to gain itself.

As summary, this CH2 gain drift can be quantified as ≈ 0.25 counts/K over an initial gain of ≈ 10.4 counts/K, which corresponds to a 2.4 % gain variation or 0.103 dB. Concerning Ch1, the drift is much lower, ≈ 0.05 counts/K over an initial gain of ≈ 9.5 counts/K, which means 0.52 % gain variation or 0.03 dB.

On the other hand, it has to be considered that the specified gain variation for MWR receiver was ± 2 dB, over a receiver nominal gain in the order of 80 dB. Therefore the current drifts, in absolute terms, may be due to normal stabilization of the receiver gain and Local Oscillators due to initial aging and to temperature stabilization effects. The different behaviour among the two channels may be explained considering different technologies. Besides the measured gain stability during on ground tests (thermal vacuum environment) shown in Fig. 14, are of the same order of magnitude.

	0°C GAIN (Counts/K)	+10°C GAIN (Counts/K)	+20°C GAIN (Counts/K)	+30°C GAIN (Counts/K)	+40°C GAIN (Counts/K)	+22°C GAIN (Counts/K)	POSIT. DEVIAT. (%)	POSIT. DEVIAT. (dB)	NEG. DEVIAT. (%)	NEG. DEVIAT. (dB)	SPECIFIED (+/- dB)
CH-1 NOM	-9.313	-9.347	-9.679	-10.2806	-11.088	-9.772	13.47%	0.549	-4.70%	-0.209	2.0000
CH-2 NOM	-9.948	-9.688	-10.161	-10.498	-11.078	-10.228	8.31%	0.347	-5.28%	-0.236	2.0000
CH-1 RED	-9.366	-9.308	-9.599	-10.061	-10.801	-9.784	10.39%	0.429	-4.87%	-0.217	2.0000
CH-2 RED	-10.25	-9.9706	-10.369	-10.598	-10.981	-10.637	3.23%	0.138	-6.26%	-0.281	2.0000

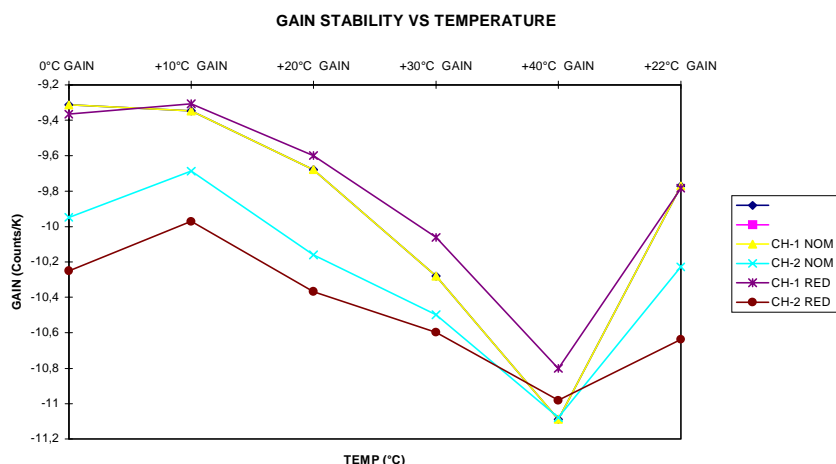


Figure 14 MWR measured gain stability vs. temperature during on ground tests

As summary, the analysis have not identified any specific problem which may explain the current behaviour. This drift may be nominal, considering that the variation is limited (same order of the on ground tests) and that 36 GHz channel is more sensitive in terms of gain variation. This is mainly due to the fact that the Local Oscillator of channel 2 is generated at 18.25 GHz with a fundamental Dielectric Resonator Oscillator (DRO), and than multiplied by two with an active multiplier with a power amplifier. This approach was selected because of technological limitations to qualify for ENVISAT a DRO directly at 36.5 GHz. For channel 1, the Local Oscillator is generated with a direct DRO at 24 GHz. This technological difference may require some stabilization due to aging and thermal cycling of those components.

However continuous monitoring of the gain drift and LO CH2 behaviour is recommended, to assess possible stabilization or increase in the radiometric gain drift. To execute some further testing, the redundant LO at 36.5 GHz could be used for an observation period, even if this test is not yet recommended at this stage.

4 Summary

As summary the activity related to the ENVISAT MWR in flight calibration and validation was successful, and the instrument performance are fully validated. In particular the following specific considerations can be summarised:

- ENVVISAT MWR thermal behaviour and radiometric performance are nominal, and very similar to the on ground tests; therefore performance well beyond specification limits are expected, as on ground.
- MWR Lev 1 B data products are validated, and validated Lev 1 B algorithm proposed upgrades shall be implemented in the ESA IPF processing chain after the Commissioning Phase (see also the outcomes in [1]). It is also recommended to furtherly maintain and keep update the Level 1B software prototype, in order to furtherly support the IPF processing chain during operational phase.
- Updated MWR Characterisation data base files have been implemented at the end of the commissioning phase.
- It is recommended to continue a close monitoring of the instrument performance, in order to furtherly analyse the currently experienced gain drift of channel 2 and assess possible recovery solution in case it will furtherly degrade.

5 REFERENCES

1. E. Obligis, Eymard L. , Dorandeu J. , Mertz F. and Y. Faugère, *"In-Flight Calibration/Validation of the Envisat MWR"*, Proceedings of the EnviSat Geophysical Validation Workshop, December 2002
2. Alenia Spazio document *"MWR algorithms specifications for level 1b software prototyping"*, reference TNO/RAS/0010/ALS.
3. Alenia Spazio document *"MWR Calibration and Characterisation Plan"*, reference PO-PL-ALS-MR-0005.
4. Alenia Spazio document *"MWR Qualification Report"*, reference PO-TR-ALS-MR-0012.
5. O.Bombaci, M.L'Abbate, C.Svara, F.Caltagirone, J. Guijarro *"ENVISAT-1 Microwave Radiometer (MWR): Validation Campaign Achievements"*, EUROPTO 1998 proceedings.
6. N.Atkinson, O.Bombaci, M.L'Abbate, M.Ricketts *"ENVISAT-1 MWR: Calibration Targets and Pre-Flight Calibration"*, EUROPTO 1998 proceedings.
7. O.Bombaci, M.L'Abbate, F.Caltagirone, *"ENVISAT-1 Microwave Radiometer (MWR): Current Design Status"*, European Symposium on Satellite Remote Sensing III, September 1996, Taormina (Italy)
8. O.Bombaci, M.L'Abbate, F.Caltagirone, *"Calibration and expected performances of Envisat-1 MWR"*, European Symposium on Satellite Remote Sensing III, September 1996, Taormina (Italy)
9. R. Bordi, M. L'Abbate, P. Spera, C. Svara, *"MIMR Demonstrator model Calibration and Validation campaign"*, EUROPTO 1998 proceedings.
10. R. Bernard, A. Le Cornec, L. Eymard, L. Tabary, *"The microwave radiometer aboard ERS-1: part 1 - characteristic and performances"*, IEEE Trans. on Geoscience and Remote Sensing, Vol. 31, n° 6, Nov. 1993
11. L. Eymard, A. Le Cornec, , L. Tabary, *"The ERS-1 microwave radiometer"*, Int. J. Remote Sensing, Vol. 15, n° 4, 1994

Appendix – radiometer model coefficients

<i>Variables</i>	<i>Description</i>
$a_{c/h}$	sky horn transm coeff hot-cold cal switch
$a_{h/c}$	hot load transm coeff hot-cold cal switch
$b_{c/h}$	sky horn isol coeff hot-cold cal switch
$b_{h/c}$	hot load isol coeff hot-cold cal switch
a_a	meas ant transm coeff meas cal switch
a_{cal}	transm coeff meas/cal switch.
b_a	meas antenna isol coeff meas/cal switch
b_{cal}	isol coeff meas/cal switch
a_m	meas antenna transm coeff Dicke switch
a_{re}	cal transm coeff meas-Dicke switch
b_m	meas antenna isol coeff Dicke switch
b_{re}	isol coeff meas-Dicke switch
a_{cw}	Sky Horn Waveguides transm coeff
a_r	Meas Antenna Waveguides transm coeff
a_{cc}	Sky Horn transm coeff
a_{feed}	Meas Antenna transmission coefficient

Table A - Radiometric Model Coefficients

<i>Temperatures</i>	<i>Description</i>
T_{cc}	Physical antenna temperature
T_{cw}	Sky horn waveguide physical temperature
$T_{h/c}$	Hot/Cold calibration switch
T_r	Measurement antenna waveguide temperature
T_{cal}	Measurement/calibration switch temperature
T_d	Dicke switch temperature
T_{rec}	RF amplifier + Detector retrieved temperature
T_g	RF amplifier + Detector physical temperature
T_{ref}	Reference (Dicke) load temperature
T_{feed}	Measurement Antenna feed temperature
T_{sh}	Sky horn target temperature
T_h	Ambient load target temperature

Table B - Temperature Telemetry