RA-2 SIGMA-0 ABSOLUTE CALIBRATION

M. Roca(1), H. Jackson(2) and C. Celani(3)

(1)ESA/ESTEC, Keplerlaan 1, 2200AG Noordwijk, (The Netherlands), Email: Monica.Roca@esa.int
(2)ESA/ESTEC, Keplerlaan 1, 2200AG Noordwijk, (The Netherlands), Email: Harry.Jackson@esa.int
(3)Telespazio s.p.a. via Tiburtina 965, I-00156 Rome (Italy), Email: cristina_celani@telespazio.it

ABSTRACT

Measurement of the vertical-incidence backscatter coefficient, sigma-0, by radar altimeters has been used for the determination of wind-speed over the ocean. The models used are empirical and so it has been sufficient to perform relative calibration between missions. These are traced back to GEOS-3 resulting in a minimum uncertainty in the absolute sigma-0, for all altimeters, of more than 1 dB. Recent applications of the altimeter sigma-0, such as physically based models of sea-state bias and wave period, require **an absolute sigma-0** measurement.

A dedicated activity has been developed at ESA for the EnviSat altimeter, RA-2, Sigma-0 absolute calibration. The measurement technique makes use of a newly-developed transponder, using a delay-line for clutter suppression. The altimeter operates in a preset mode, and it also acquire individual echoes over the transponder. Special data-processing techniques are also being developed. We describe the principle, measurement and data processing techniques and the results obtained during the EnviSat Commissioning phase.

1. INTRODUCTION

The EnviSat-1 satellite will embark an innovative radar altimeter, the RA-2 which represents a new generation of radar altimeters compared to previous instruments such as the ERS altimeters and TOPEX/Poseidon. This is due to its integration of many important features.

Measurement of the vertical-incidence backscatter coefficient, sigma-0, by radar altimeters has largely been used for the determination of wind-speed over the ocean. The models used are empirical and so it has been sufficient to perform relative calibration between missions. These are traced back to GEOS-3 and it is shown that there is an uncertainty in the absolute calibration of sigma-0, for all altimeters, of at least 1 dB.

The importance of accurate global satellite altimeter measurements of oceanic winds and waves is well recognised. However, the algorithms for operational retrieval of wind and wave parameters have not significantly changed since they were formulated for GeoSat data. Consequently parameters extracted from altimeter measurements (wind speed and significant wave height) and the accuracy specifications on these parameters (–2 m/s and –0.5 m) have changed little since Geosat.

The techniques which have been used until now, provide only a relative calibration with respect to GeoSat, and require an assumption of stationarity in the sigma-0 climate over space and time. The latter assumption, in particular, may well be erroneous.

Recently new applications of the altimeter sigma-0 measurement have been proposed, such as physically-based models of sea-state bias and wave period, which require an absolute measure of sigma-0 of a challenging **0.2 dB accuracy**.

In response to this requirement an absolute calibration of the EnviSat altimeter sigma-0 has been performed. By relative calibration this absolute calibration may then be extended to all other altimeters.

The measurement technique makes use of a newly-developed transponder. This shares some heritage with the transponders developed at ESTEC to support the ERS AMI and subsequent satellite SAR's but needs specific design to the RA-2 characteristics. The altimeter will operate in a preset mode to acquire transponder echoes due to the long delay-line in the transponder, needed for clutter suppression. Acquisition of individual echoes (no pre-averaging) by RA-2 will be commanded over the transponder. Special data-processing techniques are also being developed.

Detailed description of the tasks performed regarding this activity, the concept, the data processing and operations, the system requirement specification and the plan can be found in the RA-2 Sigma-0 Absolute Calibration Plan [1].

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2. PRINCIPLE

2.1. Introduction

The purpose of any absolute calibration is to get an independent value from the instrument to be calibrated of the same target. In other words make the instrument measure a well known target. This value has to be obtained as accurate as possible and in turn it also has to be calibrated. The accuracy of this independent measurement will limit the accuracy of the overall calibration. Therefore this measurement will also have to be constantly calibrated. The comparison between the two: a) the theoretical value provided by the well known target, and b) the measurement by the instrument to be calibrated, will give us the error the instrument is introducing when making this measurement. If this error can be assumed to be a constant error, regardless the conditions, it will provide the bias of the instrument. If, on top of that, this measurement is repeated after a certain period of time, this measurement can also provide us a measurement of the instrument drift.

A transponder has been identified to be the best method in order to obtain the independent measurement.

The purpose of a transponder is to return an echo of the input signal received from a radar. Knowing the relationship between the input power signal and the echoed power signal, the transponder can be used to calibrate the radar measurement of the surface backscatter. This is described in the following sections.

2.2. Preset_Loop Output mode

RA-2 follows changes in height and power of the surfaces by means of the so called Alpha-Beta Trackers. The range window is defined as the range domain in which the instrument can measure simultaneous echoes. The position of this window moves as the surface changes in order to keep the return pulse within the window. This is the nominal way in which the instrument works to obtain measurements.

However, this window movement would not allow the instrument to see the transponder point target response in a clear way since the altimeter would follow the surface. The RA-2 has a special mode, the Preset_Loop_Output mode, that allows the window not to follow the surface. This mode sets the position of the window for each return pulse so that the instrument does not follow the surface any more. It can fix the initial position and the rate. The way this mode works is depicted in Fig.1. One can see that the point target response of the transponder moves all along the altimeter range window. In the nominal mode this would not be possible because the window would follow the surface. We can also see that the clutter is distorting the pulse. The avoidance of the clutter is the major requirement in the definition of the transponder, the length of the delay line. For more details on the transponder requirement see [1].

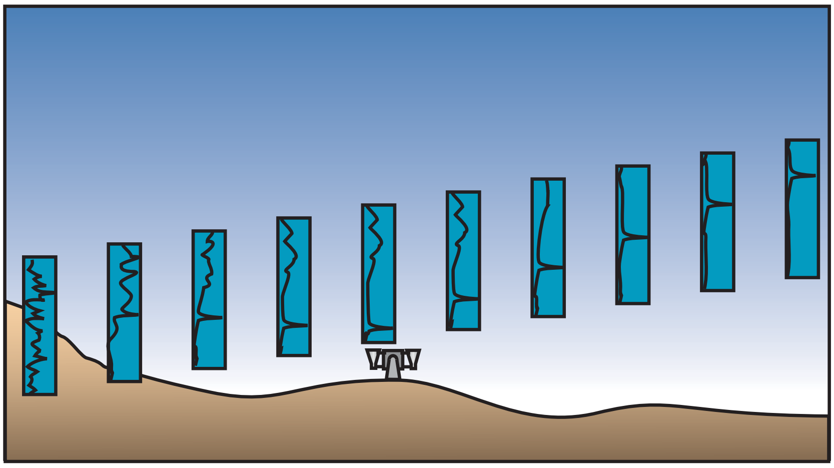


Fig. 1: Preset_Loop_Output mode sketch.

2.3. General Equation

The received power from a radar which is illuminating a surface defined by a Radar Cross Section equal σ, is given by

$$P_r = \frac{P_t \cdot G^2 \cdot \lambda^2}{(4\pi)^3 \cdot h^4 \cdot L} \cdot \sigma \qquad [\mathrm{W}] \tag{1}$$

where

P_r is the received power by the radar;

P_t is the transmitted power by the radar;

$G_T = G_R = G$ is radar transmitting and receiving antenna gain and electronics (monostatic radar);

λ is the radar wavelength;

h is the altitude distance between the radar and the illuminated surface;

L are all possible attenuation suffered by the signal when is travelling through the atmosphere; and

being the effective area of the antenna $A_{ef} = G_R \cdot \frac{\lambda^2}{4\pi}$

2.4. Altimeter equation over a distributed target

The altimeter measures from nadir the power from a distributed target. The radar cross section, σ, of this target can be expressed by the backscatter coefficient per unit of area $\sigma°$, times the area illuminated by the radar altimeter, S:

$$\sigma = RCS = S \cdot \sigma° \tag{2}$$

For a pulse limited altimeter this area, S, is expressed as:

$$S = \pi h c \cdot \tau_c \qquad [\mathrm{m}^2] \tag{3}$$

where c is the speed of light and τ_c is the altimeter compressed pulse.

Therefore the power received by the altimeter when flying over a distributed target is given by the following expression:

$$P_r = \frac{P_t \cdot G^2 \cdot \lambda^2}{(4\pi)^3 \cdot h^4 \cdot L} \cdot \pi h c \cdot \tau_c \cdot \sigma° \qquad [\mathrm{W}] \tag{4}$$

2.5. Altimeter equation over a transponder

In the case the altimeter is measuring the power coming from a single point target the radar cross section of the illuminated area losses its sense. Now the radar cross section is the radar cross section of the transponder, and it will depend up on the transponder gain and the signal wavelength as:

$$RCS = \frac{\lambda^2}{4\pi} \cdot G_T \cdot G_R \cdot G_{elec} \qquad [\mathrm{m}^2] \tag{5}$$

Therefore,

$$P_r = \frac{P_t \cdot G^2 \cdot \lambda^2}{(4\pi)^3 \cdot h^4 \cdot L} \cdot \frac{\lambda^2}{4\pi} \cdot G_R \cdot G_{elec} \cdot G_T \qquad [\mathrm{W}] \tag{6}$$

where

P_r is the received power by the altimeter;

P_t is the transmitted power by the altimeter;

$G_T = G_R = G$ is radar transmitting and receiving antenna gain and electronics (monostatic radar);

G_R is transponder receiving antenna gain;

G_{elec} is the gain of the transponder electronics;

G_T is transponder transmitting antenna gain;

h is the altitude distance between the radar and the transponder;

λ is the radar altimeter wavelength; and

L are all possible attenuation suffered by the signal when is travelling through the atmosphere (input from the user)

2.6. Conclusion

The term

$$\frac{P_t \cdot G^2 \cdot \lambda^2}{(4\pi)^3 \cdot h^4 \cdot L} \tag{7}$$

is repeated in the altimeter equation over a distributed target and the altimeter equation over the transponder. By accurately knowing the term

$$\frac{\lambda^2}{4\pi} \cdot G_R \cdot G_{elec} \cdot G_T \tag{8}$$

we can easily calibrate t he power received by the altimeter. The accuracy of the transponder gains calibration is, therefore, of great importance, since the total accuracy of the power calibration depends directly on it.

3. TRANSPONDER REQUIREMENTS

For the technique described above to be effective it must be guaranteed that the only signal received by the radar is that from the transponder; there must be no **clutter** due to the surface.

In the case of the RA-2, the transponder has to provide a signal which is equivalent to the power reflected by the distributed target illuminated by the radar in its normal measurement condition. The transponder is a point target and it has to provide a Radar Cross Section (RCS) equal to a large distributed target. Therefore it must provide **gain**, by a combination of antenna gain and amplification.

A further point, which must be ensured by the transponder design, is that power from its transmitting antenna must not contribute significantly to the input signal it receives from the radar, typically by **coupling**.

These points determine the general transponder requirements.

3.1. High Level Transponder Requirements in Ku Band

1 High stability.

2 Accurately known Radar Cross Section up to 0.1 dB.

3 To perform the absolute calibration of Sigma_0 a working point has to be decided. In case the on-board AGC would be perfectly linear the decision on the working point would not be specially important. Due to small imperfections on the hardware this on-board AGC is not linear, although is characterised. Therefore the working point of the AGC should be taken as the most common value of the AGC in the real case. This is the ocean case for both Ku band:

- 12 dB σ^0 for Ku-band

4 Suitably low RCS background.

3.2. Ku-Band Transponder Requirements

Altimeter Parameters Relevant to the Transponder Design:

Altimeter antenna diameter = 1.2 m
Ku-band carrier frequency = 13.575 GHz
Ku-band radar footprint diameter = 18.8 km

Required RCS

Based on the requirement for the AGC working point given in Section 3.1 point 3, the power seen by the altimeter in Ku-band should be equivalent to 12 dB Sigma-0. The RA-2 is a pulse limited altimeter. Therefore, although the radar footprint is, in Ku-band, around 20 km diameter, the maximum illuminated area before it becomes an annulus is much smaller. This last one, so called altimeter footprint, has a radius of about 866 m. This means that the total power in this area is the one the transponder should emulate, giving us the radar cross section (RCS) needed.

$$RCS = 12dB + 10 \cdot \log(\pi R_f^A) = 75.7dBm^2 \tag{9}$$

where R_f^A is the radius of the altimeter footprint in Ku-band.

The result is a required RCS for the Ku-band antenna of 75.7 dBm^2.

Clutter Discrimination: Delay Line

A time delay is necessary to ensure that clutter, return echoes from other part of the surface, do not interfere the expected return corrupting the transponder waveform. Taking into account a mean satellite altitude of 800 km and a footprint radius of 9.4 km we obtain that a 55 m of delay are necessary, which in terms of time would be 0.37 µsec. Any return signal inside the altimeter footprint is already gone when the transponder return arrives at the altimeter range window. However, this is considering that the surface is approximately flat. Since the range window in the altimeter higher resolution is of about 60 meters (128 samples of 0.46 metres per sample), with the window in a fixed position not letting it follow the surface (see Section 2.2) this leads in to a dynamic range of 120 meters. Therefore, to really ensure that no clutter comes into the range window while obtaining the transponder waveform a delay of about 120 meters (0.8 µsec) has been considered more secure.

Longer time delays may also be used.

Note that the movement of the satellite position can be considered negligible during the round trip time.

Transmitting and receiving antennas and electronics

A RCS equals 75.7 dBm^2 of the transponder antenna implies an overall the gain of the receiving antenna, transmitting antenna and electronic of:

$$G_{antR}^T[dB] + G_{antT}^T[dB] + G_{elec}^T[dB] = RCS_{Ku} + 10\log\left(\frac{4\pi}{\lambda_{Ku}^2}\right) = 120dB \tag{10}$$

where

G^T_{antR} is the receiving transponder antenna gain in Ku-band;
G^T_{antT} is the transmitting transponder antenna gain in Ku-band;
G^T_{elec} is the overall gain of the transponder electronics between antenna and ports; and
λ_{Ku} is the radar altimeter wavelength at Ku-band.

Final Transponder Requirements

The complete list of requirement are given in Table 1:

Centre Frequency	13.575	GHz
Bandwidth	320	MHz
RCS	75.7	dBm^2
RCS stability	0.1	dB
Absolute calibration accuracy	0.2	dB
Trigger dynamic range	> 15	dB
Gain slope over BW	< 0.5	dB
Gain slope rate	< 0.05	dB/MHz
Time delay	55	μsec
3dB RCS beamwidth	> 2.6	degree

Table 1: Transponder requirements.

4. TRANSPONDER PERFORMANCE AND CALIBRATION

The transponder was tested in the laboratory, calibrated in a field, and the performance were obtained. The testing, calibration and final performances are described in the following section.

4.1. RCS Stability

The overall RCS stability of the transponder is primarily governed by three aspects:

Electronics gain stability.

The net gain of the electronics unit of approximately 52dB is comprised of some 92dB gain and, mostly due to the optical delay, 40 dB of loss. In order meet the requirement of 0.1dB RCS stability over an operational temperature range some means of gain stabilisation was clearly needed. The approach adopted utilizes a coupler-bridge configuration which, in conjunction with the internal time delay, allows the use of internal calibration signals and an AGC system. This arrangement is similar to that used for ERS SAR and ENVISAT ASAR radiometric calibration with the significant difference that the internal delay is longer than the RA-2 pulse, allowing a single antenna to be used. This scheme was originally devised for METOP ASCAT calibration which is currently being implemented by industry.

Fig. 2 shows gain stability with the electronics unit subjected to two -15 degree to +40 degree temperature cycles over 44 hours.

Antenna gain and sidelobes.

The two-way gain contribution of the antenna is 66dB and stability aspects must also be considered. The antenna used is a lensed, 30cm aperture horn manufactured from high stability material which was custom designed for this application. Simulations by the manufacturers suggest that thermal-gain variation is insignificant.

Sidelobe performance is also important in order to minimize RCS errors due to bistatic multipath. Analysis shows that a worst case contribution would be 0.05dB, this value does not consider the range gating effect of the RA-2 processing which would further reduce this error.

Antenna pointing and polarisation

The electronics unit and antenna are mounted on an elevation over azimuth position (see Fig. 3) such that:

- Polarization adjustment for ascending/descending passes is easily accomplished.
- The antenna aperture can be placed vertical to avoid the accumulation of detritus.

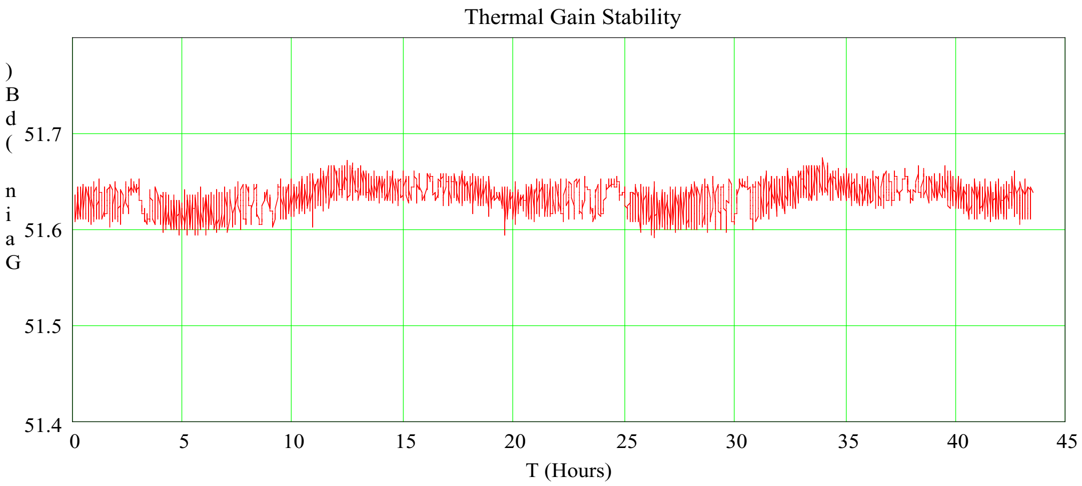


Fig. 2: Electronics unit gain stability (-15 to + 40 deg).

Positioner repeatability is quoted as 0.05 degree and analysis shows that, with a stable platform and accurate initial alignment, the mispointing effect on RCS is insignificant.

Fig. 3: Complete Transponder.

4.2. RCS Calibration

The method used was identical to that for ERS, RSAT-1,JERS and ASAR transponders.

- A short, nominal amplitude, CW test pulse is transmitted by the transponder toward a known RCS target at known range (Fig. 4 shows the calibration scenario).
- The transponder receive path is then enabled.
- The test pulse is reflected from the target and received by the transponder.
- The amplitude of both transmitted and received pulses is monitored and compared to derive a loop gain.
- Repeat the above at offset angles in both elevation and azimuth (see Fig. 5).

The transponder RCS is then simply given by:

$$RCS = 16\pi^2 \cdot R^4 \cdot \left(4 \cdot \frac{\lambda^2}{\pi^3 \cdot D^4}\right) \cdot \frac{P_{Rx}}{P_{Tx}} \tag{11}$$

Where D is the target plate diameter and R is the transponder antenna phase centre to target range.

Fig. 4: Calibration range and reference target.

An estimate of multipath distortion is obtained by varying the transponder to target range, taking loop gain measurements at each position and analysing the resulting interference pattern.

Range clutter measurements were performed before placement of the reference target. An estimate of multipath distortion was obtained by varying the transponder to target range, taking loop gain measurements at each position and analysing the resulting interference pattern.

4.3. Errors

All values used to derive the final RCS value have associated errors which are identified and quantified in Table 2.

Error source	**Derived from:**	**RCS Cal.**	**RCS Stability**
Thermal stability	Std Fig. 2	0.03	0.03
Range measurement	TOS-MTE (~1cm)	0.00	-
Target plate flatness	Analysis	0.03	-
Cal range clutter	Measurement	0.09	-
RCS cuts	Analysis	0.02	-

Table 2: Transponder performance.

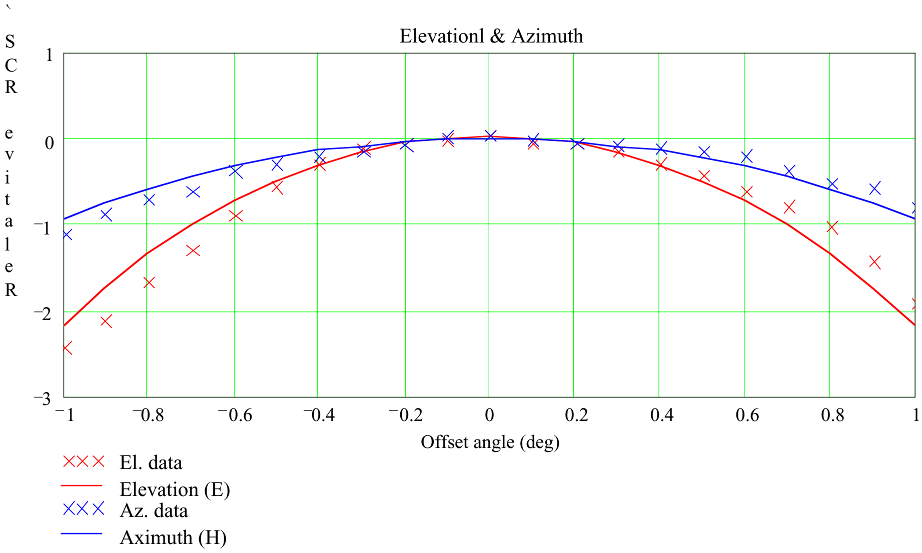


Fig. 5: El & Az Calibration cuts.

Error source	Derived from:	RCS Cal.	RCS Stability
Cal range multipath	Meas./analysis	0.02	-
RF unit bandpass	Meas./analysis	0.02	-
Antenna bandpass	Meas./analysis	0.00	-
Site bistatic multipath	Analysis	-	0.05
RSS (dB)		0.11	0.06

Table 2: Transponder performance.

Therefore, the transponder RCS is 75.08 dBm^2, given an equivalent Sigma-0 of 11.35 dB.

5. DATA PROCESSING FOR SIGMA-0 BIAS RETRIEVAL AND RESULTS

The data processing for the retrieval of the Sigma-0 absolute bias is depicted in Fig. 6

The algorithm has been developed at ESTEC within the Instrument Engineering Calibration Facility (IECF) and operations have been defined within the ROP Generation Tool (RGT). Details on these operations can be found in [3], and more information about data processing in [1] and [2].

The RA-2 will be moved to the Preset_Loop_Output mode, every time it over flies the transponder. A brief description of this mode is given in Section 2.2.

The altimeter measures the power of a target, the transponder, which has a well known radar cross section (RCS). By applying the radar equation it is possible to compute the theoretical power the altimeter would be supposed to measure. The theoretical power (P_r^{theo})seen by the altimeter should be the one given by Eq.6.

In this case the altimeter is looking at a ground fixed point target and therefore the altimeter is not measuring at nadir but at a certain angle given by the geometry. At the same time, the transponder is not seen by the altimeter from zenith. Since the radar cross section of the transponder depends on the transponder antenna gain, the angle in which the transponder is seen by the altimeter also becomes important. Fig. 7 is a simplified diagram in which the situation of the satellite flying over a fixed target, the transponder, is depicted.

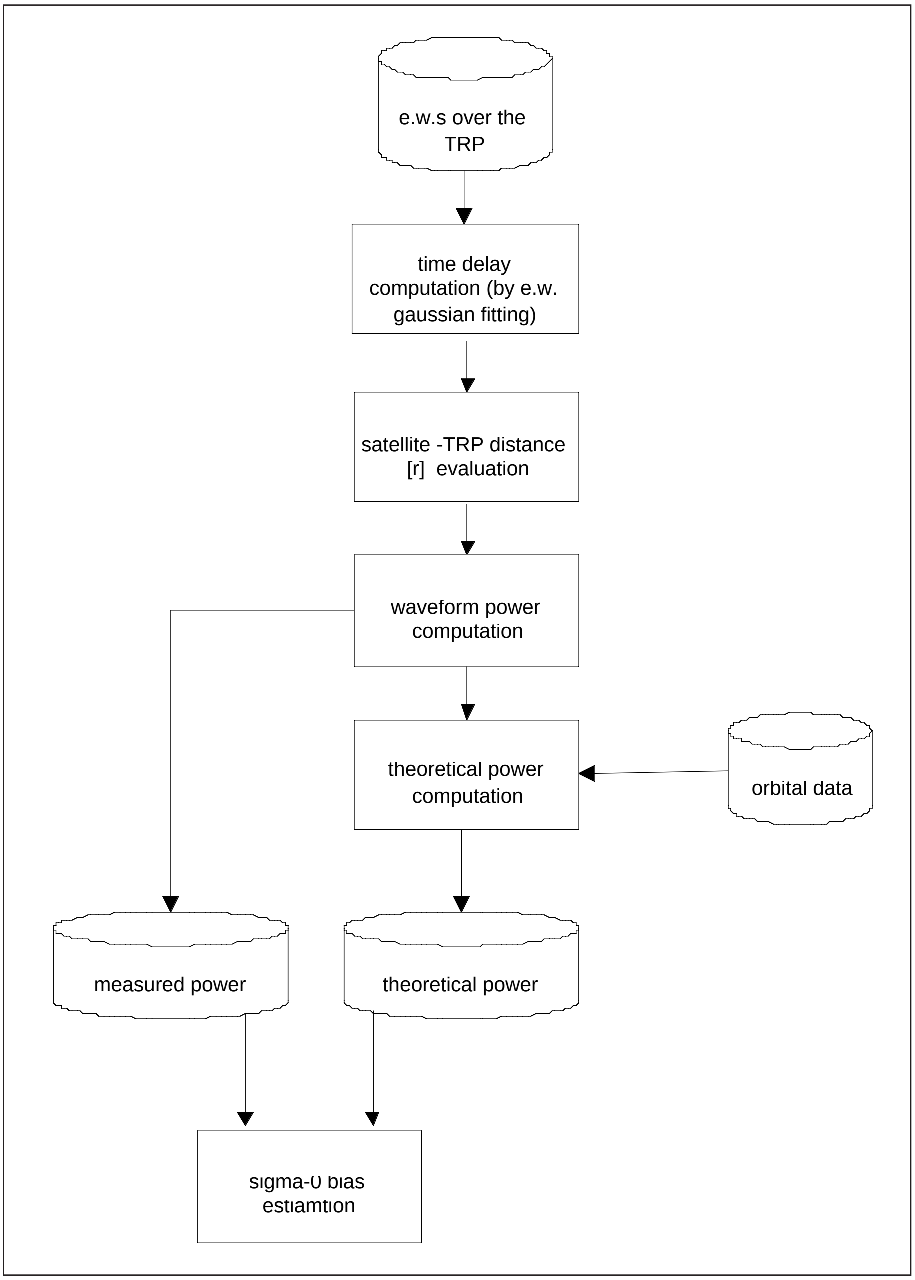


Fig. 6: Sigma-0 absolute bias computation diagram (e.w. stands for echo waveforms).

Assuming circular orbit, a difference in height of Δr (the range window width) implies a maximum along track distance d within which the transponder is visible. The equivalent time, taking into account a constant satellite velocity of v, is $\delta t = d/v$, and the total observing time, t, is $2\times\delta t$. The corresponding maximum angle from boresight that the transponder antenna is looking at the altimeter antenna is φ. The relation between this angle and the off-nadir angle from the altimeter to the transponder, ϕ, is (Eq.12):

$$\phi(t) = \operatorname{asin}\left\{\frac{R}{R+h}\cdot\sin[180-\varphi(t)]\right\} \tag{12}$$

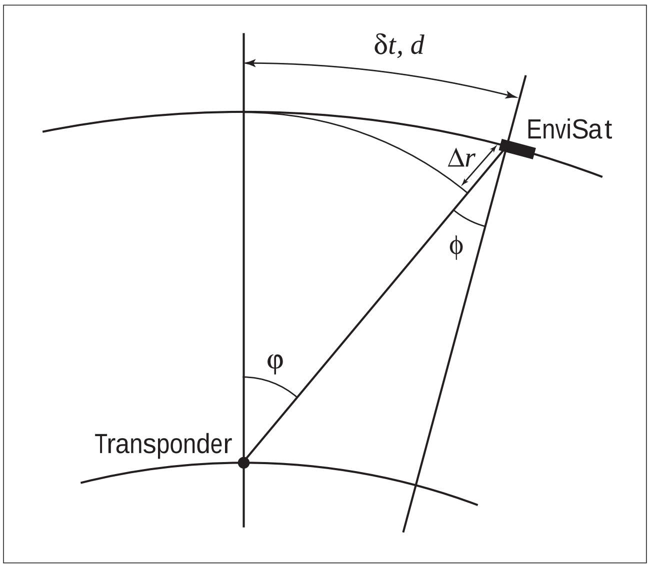


Fig. 7: Geometry of the satellite approaching the transponder.

where R is the Earth radius, and h the mean satellite altitude.

We can finally, having account for all these considerations, express the altimeter radar equation for a transponder as (Eq.13):

$$P_r(t) = P_t \cdot \frac{\{G^A[\theta, \phi(t)]\}^2 \cdot \{G^T[\theta, \varphi(t)]\}^2 \cdot \lambda^4}{(4\pi)^4 \cdot r^4(t) \cdot L} \tag{13}$$

where

P_r is the received power by the altimeter;

P_t is the transmitted power by the altimeter;

G^A is altimeter total gain (antenna gain, antenna diagram and total internal gain) both transmitting and receiving;

θ is the azimuth angle of the altimeter and transponder antenna patterns;

$\phi(t)$ is the elevation angle in the satellite frame (which is the same than the altimeter antenna elevation angle);

$\varphi(t)$ is the angle between the line of sight of the altimeter antenna with respect to the transponder and the transponder zenith;

G^T is the transponder total gain (antenna gain, antenna diagram and internal electronics), both transmitting and receiving;

λ is the radar altimeter wavelength;

r is the range or distance between the spacecraft and the transponder, that varies with time or position of the spacecraft in the orbit; and

L are all possible attenuation suffered by the signal when is travelling through the atmosphere (input from the user).

The range, r, is evaluated by modelling the theoretical function that describes the range distance between the altimeter and the transponder accounting for the satellite trajectory and velocity. This equation is given by (Eq.14):

$$r^2(t) = b_0 + b_1 \cdot t + b_2 \cdot t^2 \tag{14}$$

where the 2 degree polynomial is a hyperbola.

The power actually measured by the altimeter over the transponder, $P_r^{meas}(t_i)$ will be evaluated from the altimeter data. The power is computed from each averaged waveform or data block, (which is equivalent to approximately a 20th of a second, t_i) by computing the area below the return pulse.

Fig. 8 shows the real waveforms as seen by the altimeter when flying over the transponder obtained from the data products, and the evaluation of the area of each waveform to calculated the measured power.

The theoretical power, $P_r^{theo}(t_i)$, is compared with the measured by the altimeter, $P_r^{meas}(t_i)$. Different methods can be used for this comparison, from which we have selected to minimise the root mean square error. The bias is defined as the multiplicative constant ***k*** (in linear), that multiplied by the $P_r^{theo}(t_i)$, minimises the *rms* between the theoretical, $P_r^{theo}(t_i)$, and the measured, $P_r^{meas}(t_i)$,power (Eq.15):

$$\frac{d}{dk}\sqrt{\sum_{i\,=\,DB1}^{DBn}[(P_r^{meas}(t_i))^2-(P_r^{theo}(t_i)\times k)^2]} = 0 \qquad (15)$$

where DB is the data block, and the sum is from the first data block with transponder signature to the last one, n.

5.1. Measurements and Results

Due to the limited temporal sampling of the 35-day repeat cycle of EnviSat, for a given location we have less than one measurement per month, unless we locate the transponder on a cross-over to duplicate the number of measurements. This would be a total of about 10 passes during the EnviSat commissioning phase. We also have to take into account that during the commissioning phase the RA-2 on-board parameters, operations, Level 1b, etc., are being optimised and calibrated. Therefore, this limits the availability of useful passes.

Three cross-overs tracks were selected in the vicinity of ESTEC for the calibration campaign, Hoek van Holland, Gouda, and Utrecht. Due to several problems, the most serious one being the lack of data, only 3 passes have been evaluated. In some other passes the measurements were successfully taken and they will be analysed when the data are available. The ones analysed are given in Table 3

Orbit#	Date	Location	Coordinates
999	9 May 2002	Hoek van Holland	51:58:57.31874 N; 4:06:48.59123 E
1500	13 June 2002	Hoek van Holland	51:58:57.31874 N; 4:06:48.59123 E
2001	18 July 2002	Hoek van Holland	51:58:57.31874 N; 4:06:48.59123 E

Table 3: Transponder passes successfully analysed for the Sigma-0 bias evaluation.

The results of these three processed orbits are given in Table 4:

Orbit#	*k* [Watts]	std of power rations	*k* [dB]
999	1.290	0.044	1.106
1500	1.195	0.053	0.774
2001	1.215	0.103	0.969

Table 4: Power biases obtained for each of the 3 available passes.

As an example, Fig. 9 shows the measured power together with the calculated theoretical power for pass #999. It also shows the *rms* function (Eq.15), the minimum of which gives the estimated ***k***, or linear power bias.

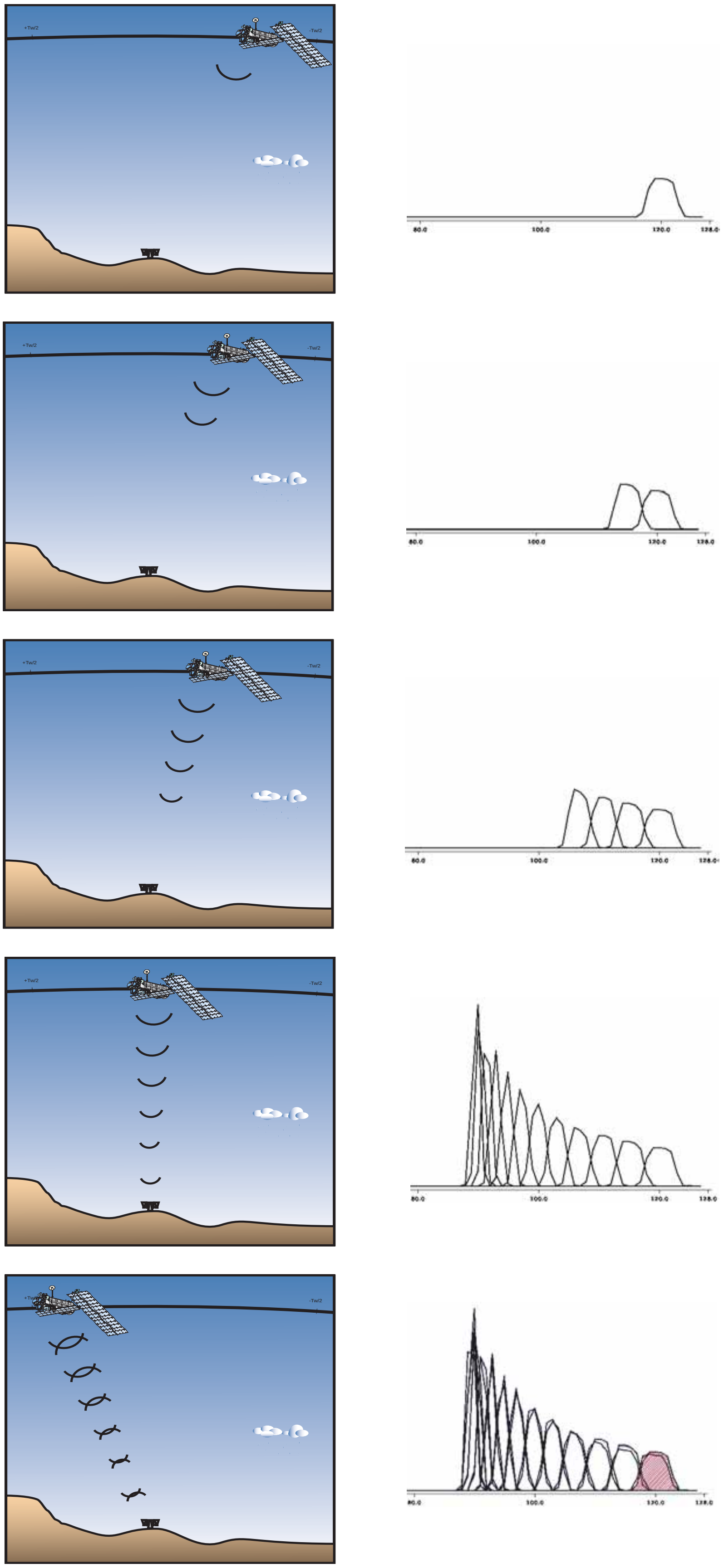
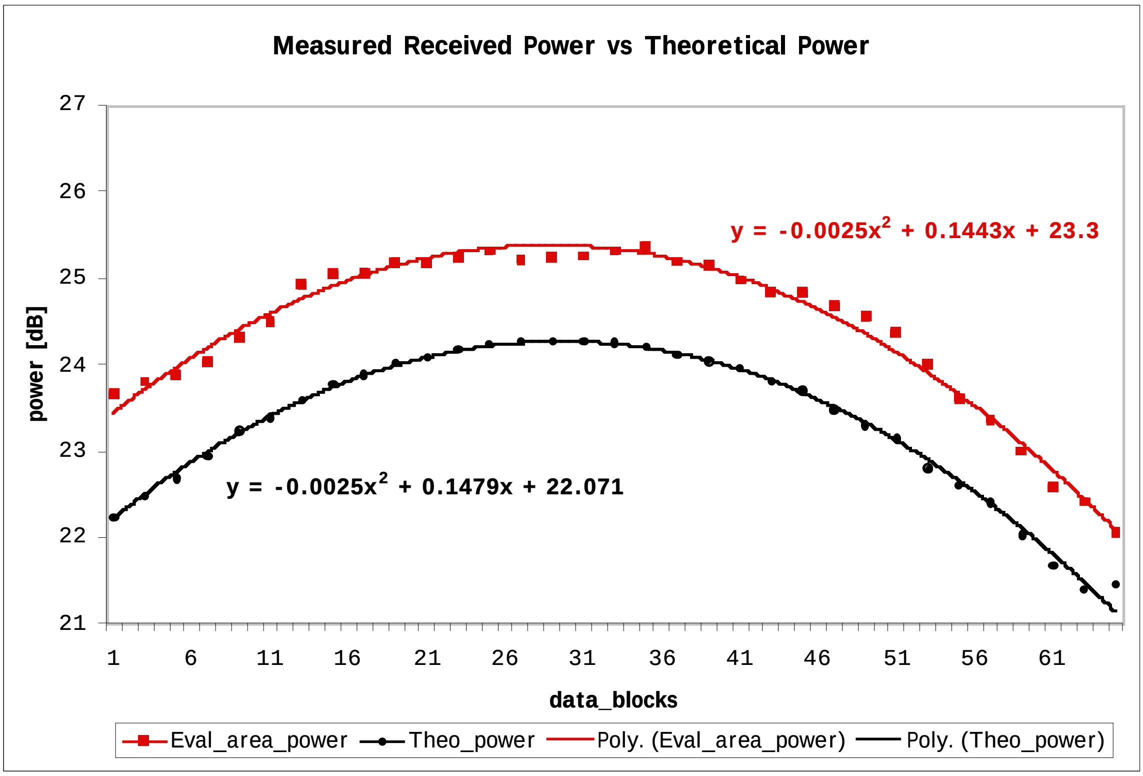


Fig. 8: Waveforms as seen by the altimeters when flying over the transponder.



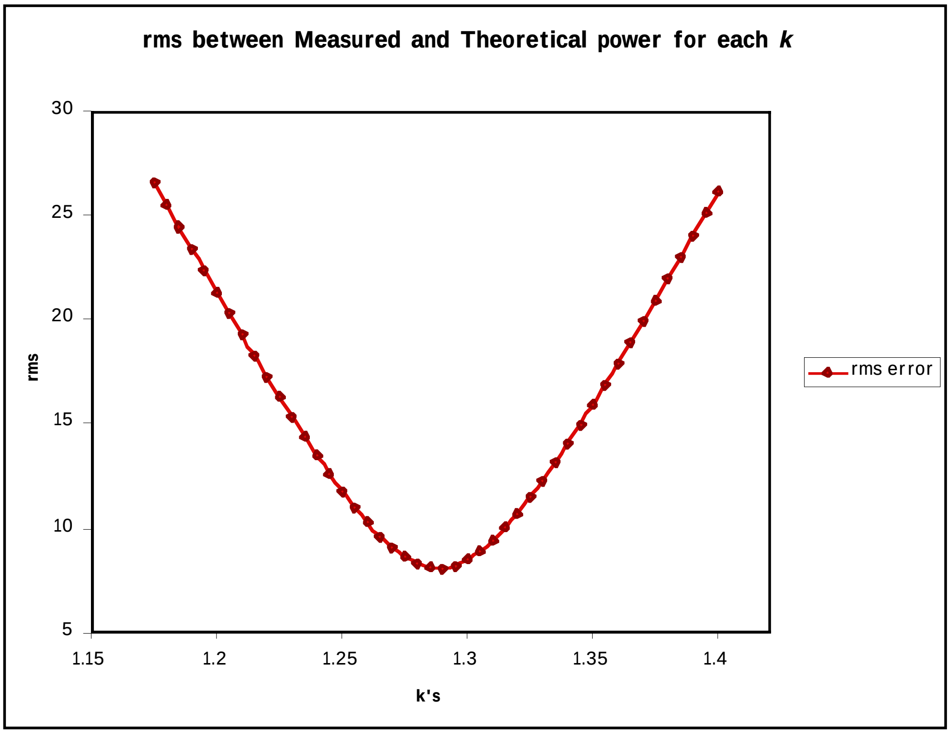


Fig. 9: (a) Measured and calculated theoretical power for passe #999. (b) *rms* function (Eq.15), the minimum of which gives the estimated ***k***, or linear power bias.

The standard deviation of the power rations for each t_i or data block gives a measure of the error on the bias estimation in each case. The final bias is computed by averaging the bias in each orbit.

The atmosphere attenuates the radar signal. This attenuation is seen in the real measured power but it has not been taken into account in the theoretical one. This attenuation is of the order of tenths of a dB. For this preliminary result the attenuation has been retrieved from the EnviSat radiometer using RA-2/MWR data. The radiometer only provides with valuable measurement of the tropospheric attenuation over ocean surfaces and not land, however the transponder was located on the coast. Assuming that the attenuation does not vary in tens of meters, and ensuring that the attenuation value is used only when the radiometer antenna is not contaminated by the land, this value can be consider accurate enough for this preliminary result. The transponder passes used for this campaign have always been taken with good weather, which reduces the water vapour attenuation. In the future a radiometers will be located together with the transponder so that the measurement will be more accurate. The attenuations found in the RA-2/MWR products are the same in the three case and equal to 0.18 dB. Therefore, the preliminary result of the power bias estimated during the EnviSat Commissioning phase, with the available data, are (Table 5):

Power Bias from 3 passes [dB]	**Std among different passes [dB]**	**Atmospheric attenuation from altimeter product [dB]**	**Final Power Bias from commissioning phase [dB]**
0.95	0.167	0.18	**1.13**

Table 5: Preliminary result of the RA-2 estimated power bias.

6. CONCLUSIONS

An altimeter power bias can be estimated by a radiometric transponder. The RA-2 power bias has been determined using a transponder designed at ESTEC. The estimated power has been retrieved using only 3 passes due to the lack of data. The result is a power bias of **1.13 dB**, the RA-2 measuring too large. More data shall be processed to increment the accuracy of this estimation.

The final users of altimeter data are not interested in the power itself but in the measurement of the sigma-0. Sigma-0 is retrieved from the received power through the radar equation. All the RA-2 constant parameters that are related to the power received (e.g. power transmitted, receiver gain, antenna pattern, etc.) are contained in a characterisation file.Two important remarks shall be made for the RA-2 data users.

1 In Level 2, Sigma-0 is evaluated as:

Sigma-0 = k_cal [dB] + A(retracked_waveform) [dB]

where k_cal [dB] computed from radar equation, is function of:

- instrument parameters: total_Tx/Rx_gain, antenna_gain, total_AGC, chirp_slope, wavelength, pulse length.
- geometry parameters: height, earth_oblateness (semimajor axis).

some of the above parameters like the geometric ones, can not be calibrated with the transponder. Their effect, however, shall be very small compared to the effect of the instrumental ones.

2 This is the intrinsic RA-2 power bias, using the parameters as result of the testing performed by the developing industry (Alenia Aerospazio, in Rome). As described above, this power bias implies a Sigma-0 bias. If the parameters in the characterisation file are modified, the for example in order to match the power measured by RA-2 with the power measured by other altimeters like the ERS altimeter; or to be able to use the same wind models as used in previous ESA altimeters; the Sigma-0 given in the product is, as a consequence, automatically modified by the same amount. This would change the Sigma-0 bias in the product compared with the real one of RA-2.

After the Commissioning phase the transponder will be located in the vicinity of ESRIN for long term monitoring purposes. A radiometer will also be located besides the transponder in order to have a measurement of the atmospheric correction. A time series file will be kept in the IECF and provided to the users with the information of the altimeter sigma-0 measurements.

7. REFERENCES

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