ASCAT – Metop's Advanced Scatterometer

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Introduction

Wind scatterometers already flown on ESA's ERS-1 and ERS-2 satellites have demonstrated the value of such instruments for the global determination of sea-surface wind vectors. These highly successful instruments – part of the Active Microwave Instrument (AMI) – were conceived about twenty years ago. During the intervening period, there has been a considerable evolution in the capabilities of spaceborne hardware.

ASCAT is an advanced scatterometer that will fly as part of the payload of the Metop satellites, which in turn form part of the Eumetsat Polar System. It is developed by Dornier Satellitensysteme under the leadership of Matra Marconi Space, the satellite Prime Contractor, for ESA. From its polar orbit, ASCAT will measure sea-surface winds in two 500 km wide swaths and will achieve global coverage in a period of just five days.**

The Advanced Scatterometer, known as ASCAT, is the successor to these instruments, and will be flown as part of the payloads of Metop-1, - 2 and -3. It represents advances in increased coverage, reduced data rate and power-efficient low-mass technology.

Principles of wind scatterometers

Wind scatterometers are instruments that are used to infer data on wind speed and direction from radar measurements of the sea surface. They rely for their operation on the fact that winds moving over the sea influence the radar backscattering properties of its surface in a manner that is related to wind speed and wind direction. Everyday experience of the sea surface suggests a variation of scattering with wind intensity: we observe a mirror-like surface with no wind, small ripples in gentle airs, and a rough surface under high-wind conditions. Figure 1 indicates the form of the variation of backscattering coefficient with relative wind direction (at a fixed incidence angle) for a range of wind speeds.

If an instrument were to be constructed that determined the sea-surface backscattering coefficient from a single look direction, the overlapping nature of the curves would limit its capabilities to providing a rather coarse estimate of wind speed and no information on wind direction. The earliest successful space-borne wind scatterometer, that of Seasat, used two dual-polarised antennas pointed at 45 and 135 deg with respect to the satellite's direction of flight to determine sea-surface scattering coefficients from two directions separated by 90 deg. The scattering characteristics of areas in the coverage region were firstly determined via the forward-looking antenna and subsequently, by virtue of the along-track motion of the satellite, via the rearward-looking antenna. Pairs of measurements so obtained could then be fitted to curves like those of Figure 1 to derive estimates of both wind speed and wind direction.

A weakness exists in two-beam single-polarisation scatterometers which Seasat sought to overcome, with only limited success, by use of dual polarisation. Owing to the shape of the backscatter functions shown in Figure 1, two-beam scatterometers are capable of producing a number of alternative solutions for wind speed and direction from the same set of measurement data. As an illustration, consider the case of measuring a real 16 m/s upwind – the two beams of the instrument would observe the characteristic at points A and would indicate a scattering coefficient of around –8.7 dB. The yellow curve in Figure 1

*Now Astrium GmbH.
**Now Astrium SAS.

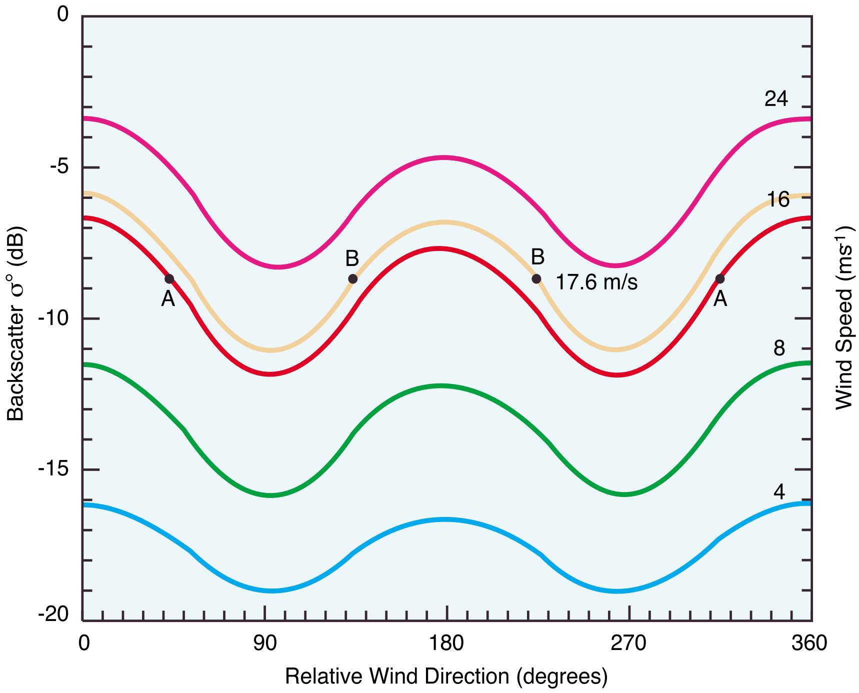


Figure 1. Variation of scattering coefficient with wind direction (35 deg incidence)

also has a pair of points at –8.7 dB seperated by 90 deg and represents an ambiguous solution to the wind-measurement problem in the form of a 17.6 m/s downwind. In order to overcome this ambiguity problem, a third beam oriented at 90 deg to the flight direction was introduced into the design of the scatterometers flown on ERS-1 and -2. This configuration has proven very effective, leading to a typical ambiguity rejection skill of 97%.

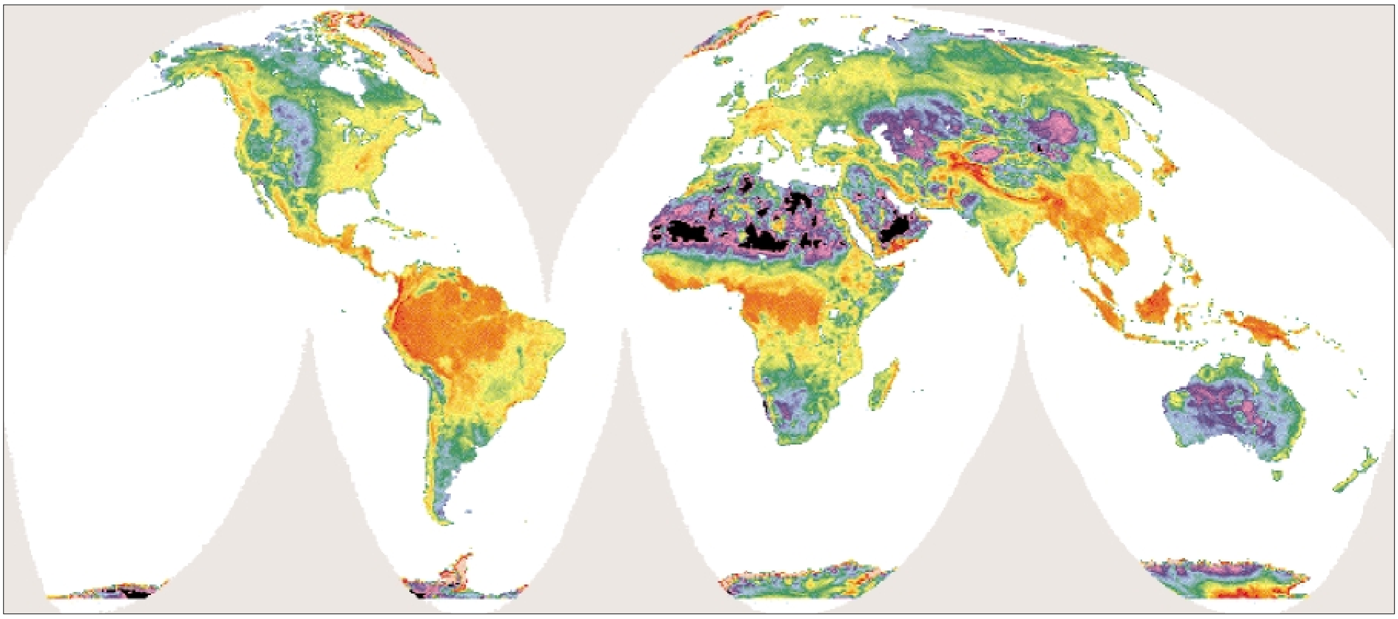
Figure 2. A typical scatterometer data product over land: the image shows the multi-year mean scattering coefficient at 40 deg incidence angle (courtesy of by V. Wismann and K. Boehnke)

In addition to their intended use for wind determination, the ERS scatterometers have been applied in both sea and land applications with objectives as diverse as monitoring of sea ice, snow, geophysics, soil moisture and vegetation. Figure 2 is a typical product over land. The advanced capabilities of ASCAT will inevitably continue to expand the range of emerging scatterometer applications.

Key elements in the specification of ASCAT

The engineering specifications of both the ERS and Metop scatterometers derive from a geophysical requirement to determine wind vectors over a coverage region consisting of 50 km-resolution cells. Determination of speeds in the range 4 – 24 m/s with an accuracy of 2 m/s (or 10%) and directions with an accuracy of ± 20 deg is required. Table 1 shows the key engineering performances of the ASCAT and the ERS scatterometers, which meet these requirements, and how the performance has evolved in respect of the following:

– Coverage: ASCAT offers twice the coverage of the instrument flown on ERS. Its twin swaths are offset to the left and right side of the satellite's ground track by about 384 km, and each offers full performance over a width of 500 km. This is especially important for the Metop mission, where quasi-global coverage on a daily basis is needed.
– Spatial resolution: Although driven by the requirement for 50 km spatial resolution, ASCAT also offers, on an experimental basis, the possibility of increased spatial resolution: a data product with 25 km spatial resolution will be produced in addition to the 50 km product.
– Radiometric accuracy and inter-beam stability: In order to meet the stringent requirements on wind speed and direction, it was necessary on ERS to apply strict control on overall gain variations in the instrument and on gain variations between its beams. Although the terminology differs somewhat between the ERS and Metop scatterometers, the same fundamental requirements apply: radiometric accuracy controls the extent to which the



ensemble of beams may be allowed to vary, and inter-beam stability controls the maximum extent by which the gain of any pair of beams may vary. The use of an on-board calibration network is of great value in this context, but satisfying these specifications still represents one of the most challenging problems of the ASCAT design.

– Radiometric resolution and ambiguities: In order to perform wind extraction on a reliable basis, it is important to limit the level of random errors in the measured data. The specification on radiometric resolution limits the level of such errors in the measurement due to the effects arising from speckle (the statistical behaviour of the radar target) and finite signal-to-noise ratio. The need to provide adequate radiometric resolution is a factor in the dimensioning of antenna gain, transmitter power and receiver noise figure. A second factor leading to random errors in the measured data is ambiguity energy. This is spurious energy arising from outside the measurement cell. The need to control ambiguities imposes constraints on the antenna side-lobe performances.

Table 1. Key engineering performance parameters for ASCAT and the ERS scatterometers

Performance Parameter	Unit	ASCAT	ERS
Coverage:			
Number of swaths		2	1
Full performance width	km	500	400
Reduced performance width	km	550	500
Length	km	continuous	continuous
Mid-swath inclination	deg	37.6	29.3
Spatial Resolution:			
Nominal	km	50	45
Experimental	km	25	none
Radiometric accuracy	dB	0.57	-
Common mode stability		-	0.57
Interbeam stability	dB	0.46	0.46
Radiometric resolution at minimum cross wind	%	3.0 – 9.9	8.5 – 9.7
Radiometric resolution at	%	3.0	6.5 – 7.0
Ambiguity contribution	%	1 (near swath) 3 (far swath)	included in radiometric resolution specification

ASCAT's operating principle

In contrast to the scatterometers used on ERS, which relied on the transmission of continuous-wave pulses with durations of around 100 µsec and peak powers of several kilowatts, ASCAT transmits linear frequency-modulated pulses with a markedly longer duration of around 10 msec, at a relatively low peak power of 120 W.

Echo signals are received by the instrument and may be thought of as a large number of superimposed echo pulses arriving over a range of times corresponding to the width of the instrument swath; signals outside the area of interest are largely suppressed by the antenna side-lobe pattern. The received echo is mixed with a suitably delayed pulse, which is a frequency-modulated replica of the transmitted signal. Figure 3 illustrates the principle of the mixing process for two echo pulses with flight times t_1 and t_2; because of the linear frequency modulation, the pulses are offset from the local oscillator pulse for the duration of the echo by frequencies f_1 and f_2, respectively. These frequency differences allow the discrimination of signals originating at different ranges. For the real received echo, the mixer output is a spectrum of signals, which is present for a time corresponding to the time that the transmit pulse is present within the swath. By sampling the mixer output in time and Fourier-transforming the time series into a frequency series, the frequency spectrum may be extracted from the data and the height and frequency of its spectral lines may be interpreted in terms of power and range, respectively.

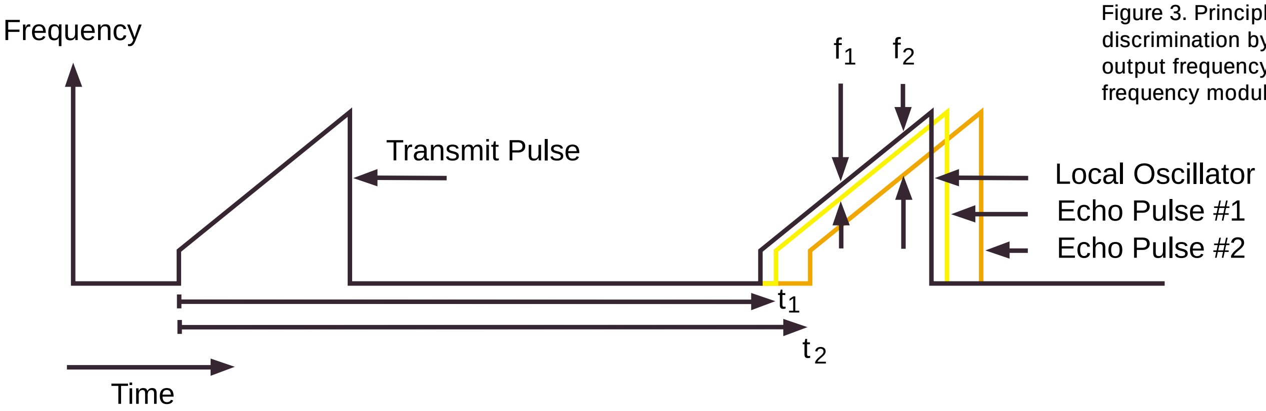


Figure 3. Principle of range discrimination by mixer output frequency in a linear frequency modulation radar

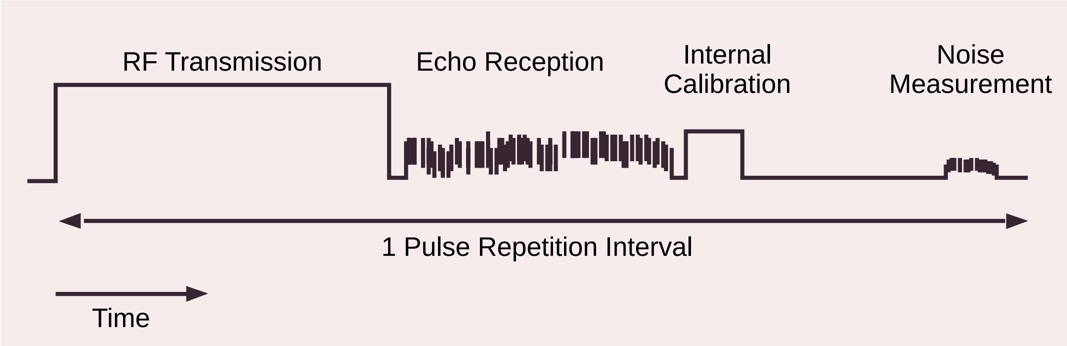


Figure 4. Processes occurring within a single pulse-repetition interval

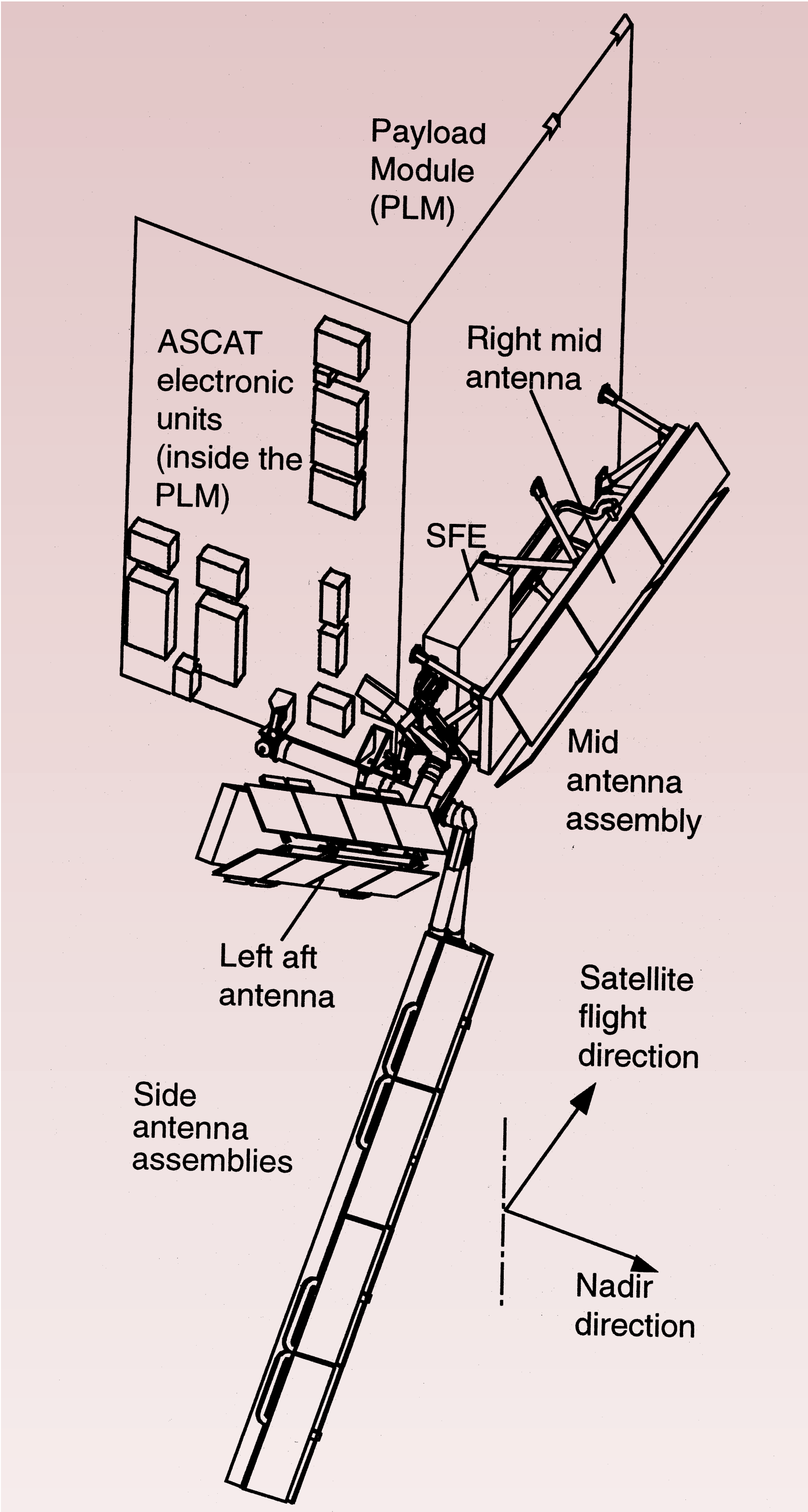


Figure 5. The ASCAT hardware on the Payload Module

In addition to the processing of echo signals, the instrument also performs an internal calibration process within each pulse repetition interval. This consists of a measurement of the output power during the transmit pulse, the injection into the receiver of a signal proportional to the transmit pulse at a point in the inter-pulse period, and monitoring of the magnitude of this signal at the receiver output. This gives an indication of how the combination of transmitter power and receiver gain is varying and allows changes in these parameters to be compensated.

Also contained within the pulse-repetition interval is a period after all echoes have decayed, during which the receiver noise output is monitored. This enables the contribution of the receiver noise to the radar measurement to be estimated and a correction performed. Figure 4 shows the time-lining scheme of the processes occurring within a single pulse-repetition interval.

Because ASCAT is a dual-swath instrument, it has a total of six antennas, three looking to each of the two swaths. In operation, the transmit-receive cycle outlined above is performed by each of the six antennas in turn over a total period of approximately 0.2 sec. Data from each pulse-repetition interval is processed on board to yield instrument data packets, which either contain echo and ancillary data or noise measurement data. This on-board processing, in the case of both packet types, involves a considerable compression of the raw data and results in a reduction in the instrument raw data rate of around 1.4 Mbit/sec to a 55 kbit/sec data stream for delivery to the satellite payload data-handling and transmission system, thereby simplifying the on-board data handling.

On-board hardware

The ASCAT hardware on the Payload Module (PLM) is shown in Figure 5, where the dominating elements are the three ASCAT antenna assemblies mounted outside the Module. All electronics boxes are located inside the Payload Module with the exception of the

Scatterometer Front-End electronics (SFE), which is located below the mid-antenna assembly.

A block diagram of the ASCAT constituent elements is shown in Figure 6: black shadows indicate the existence of a redundant unit. Although the SFE contains only one set of the wave-guide elements, it does have some internal redundancy – there are two low-noise amplifiers, two sets of control electronics, and redundant coils in its switching circulators.

The following paragraphs briefly describe the various hardware elements of the ASCAT instrument and indicate their major functions and some of the design considerations. The numerical performance data given in Table 2 are taken from the results of engineering-model testing and are typical values at about room temperature, which is close to the expected in-flight temperatures of the units.

Antennas

ASCAT has six antennas, which are mounted in pairs in a V-shaped configuration on the three antenna assemblies. The two mid antennas, fixed-mounted on the Payload Module, point in an across-track direction towards the right and the left swaths with respect to the flight direction. In contrast to the mid assembly, the two side assemblies are deployed after the launch by motors. They are then latched in well-defined positions such that the antenna beams are oriented at ± 45 deg with respect to the mid beams.

All six antennas are slotted-waveguide arrays manufactured from aluminium. The main considerations for the electrical design have been high gain to ensure an adequate link budget, and low gain slopes, high gain stability and high pointing stability to minimise radiometric errors. Side-lobe performance has also driven the antenna design in order to minimise the reception of echo signals from outside the desired measurement cells.

In addition, the design had to take account of electromagnetic scattering from the satellite. Early analysis showed that the pattern of the right mid antenna was distorted by reflections from the Payload Module surface, and that of the left fore antenna by reflections from the solar array. The mid-antenna problems were solved by minimising the antenna back radiation and by the introduction of a deflector on the Payload Module to reduce the pattern distortion further. The success of this method was proven by tests of the mid-antenna development model on a full-scale satellite mock up.

For the side antennas, the pattern has been constrained by the need to minimise side lobes in the solar-array direction. This has a consequent negative impact on the gain slope, and a compromise has been necessary between the latter and side-lobe suppression in order to maintain acceptable performances in terms of both radiometric accuracy and ambiguity.

Another important parameter is antenna gain

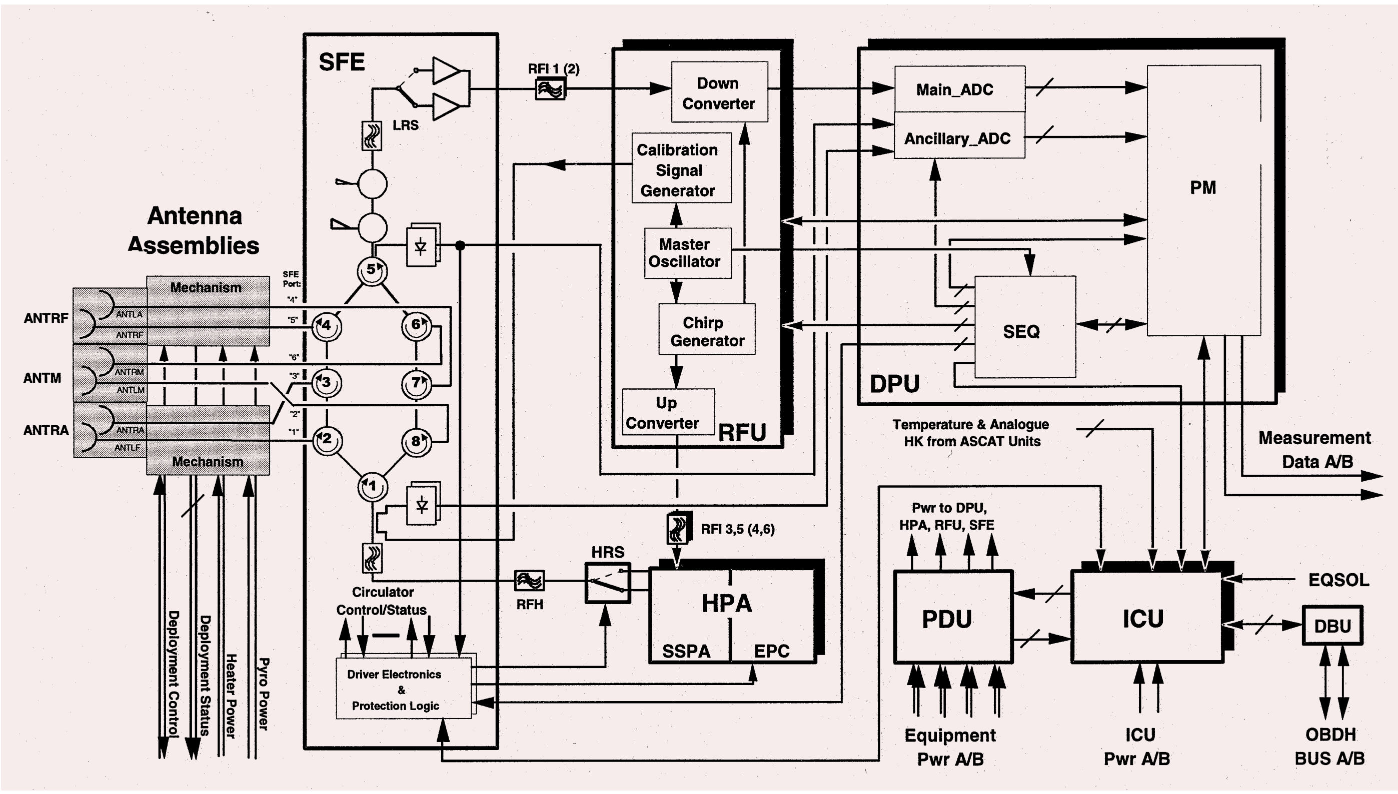


Figure 6. The constituent elements of ASCAT

stability, which is ensured a combination of low antenna-temperature variation over the orbit and low antenna-gain sensitivity to temperature. The former is achieved by careful design of the antennas' passive thermal-control elements. The aperture surfaces are covered with a combination of aluminium tape and silver paint in a carefully selected ratio in order to achieve good thermal stability over the orbit. Good thermal control is the basis for low thermal gradients within the antenna assemblies, which keeps the aperture surface stable and leads to high pointing stability. Electrically, stable gain performance is promoted by splitting the antenna aperture into sub-panels with short waveguide elements.

SFE

Figure 6 includes a schematic representation of the contents of the Scatterometer Front End. Central to the unit is a matrix of eight switching circulators, which allows each of the six antennas to be operated in turn, with the sequence repeating after all six antennas have been exercised.

Each pulse-repetition interval has four phases with a dedicated setting of the circulators, i.e. high-power signal transmission, echo reception, internal calibration and noise power measurement. During the transmit phase, the ferrite circulators route the transmit pulse towards the desired antenna. At the same time, another part of the SFE measures both the transmitted signal power via a directional 'calibration' coupler and a forward power detector, and the reflected signal power via a second directional coupler and a reflected power detector. The pair of measurements may be used to correct the measurement data for power reflected at the antenna interface. During the transmit period, it is necessary to protect the SFE low-noise amplifier from damage by transmit leakage signals. This is achieved by the activation of a shutter, a pair of switches between the switch matrix and the low-noise amplifier. In the receive phase, the shutter is opened to allow the reception of the echo from the ground.

During the calibration phase, the switch matrix is reconfigured so that a calibration signal that is injected into the SFE at the calibration coupler is routed towards the receiver. This coupler is a key element of the ASCAT internal calibration system, which allows the correction of variations in transmit power and receiver gain. The coupling coefficient of the calibration coupler is the reference for the internal calibration loop, and it is therefore vital that this coupling coefficient remains stable over temperature and over the instrument lifetime. The coupler is a metallic waveguide component, the electrical stability of which depends on its geometry which, in turn, depends on temperature. It is therefore manufactured from Invar. Like the other waveguide elements, it is silver-plated internally for good electrical conductivity.

The last phase in every pulse-repetition interval is the noise power measurement. It starts after all echoes from the ground have ended. The circulators are reset in this phase to the receive configuration, which ensures correct noise power subtraction.

A further important element of the SFE is the low-noise amplifier, which as the first active element of the receive chain has an important role in determining the system noise figure.

RFU

The Radio Frequency Unit generates the low-level transmit signal (which drives the high-power amplifier); it also generates the calibration signal and provides the echo down-conversion and amplification within the receive module.

Signal generation within the RFU is based on the use of a thermally controlled crystal oscillator. All clock signals for the ASCAT timing and the radio-frequency signals for up- and down-conversions are derived from the crystal frequency.

The chirped signals necessary for the transmitter and receiver are generated within a digital chirp generator. Start frequencies and chirp slopes are freely selectable by digital control words. A set of chirp parameters is transmitted to the RFU after start-up and allows selection of the desired signal characteristics during the measurement phase. In nominal operation, three different chirp signals are used for the three antenna types, as well as a continuous-wave signal for internal calibration.

Another important function of the RFU is in gain and level setting. It provides an injected calibration signal which is matched to the detected level of the transmit pulse with a resolution of 0.03 dB and is updated every pulse repetition interval. The transmit signal level also is adjustable by appropriate on-board parameter setting and the receiver section, which down-converts the signals to the baseband, also amplifies the signal with an adjustable gain.

HPA

The ASCAT High Power Amplifier (HPA) consists of two separate hardware items, an electronic power conditioner and a solid-state power amplifier. Amplification is performed by GaAs FET transistors, and the high output power is achieved by combining the outputs of parallel transistors.

The main design requirements of the HPA are to generate sufficient output power at as high an efficiency as possible with a constant output level over the pulse's duration. In order to be compatible with other instruments on the satellite, harmonic and spurious outputs from the amplifier are tightly controlled.

DPU

The Digital Processing Unit digitises the analogue echo data and the transmitted and reflected power data using three analogue-to-digital converters; it also processes these data. It also controls the ASCAT calibration loop and generates the instrument timing signals.

After digitisation of the DPU input signals, the main echo processing steps are: windowing of the digital samples, Fourier transformation, squared-modulus detection, data compression and finally formatting of the data, together with time stamps and further auxiliary data, into data packages.

In parallel with the data processing, the DPU adjusts the calibration signal level within the RFU on the basis of readings from the ancillary ADC. In addition, there is a two-way communication with the ICU in order to acquire the timing and temperature information for inclusion within the measurement data packets, and to pass housekeeping telemetry parameters to the ICU for instrument monitoring.

The unit provides a large number of timing signals, which control the circulators of the SFE, perform chirp selection, RFU triggering, HPA gating and control the digital processing. The on-board software is controlled by a set of parameter tables. There is a special external calibration mode for the instrument that is obtained by reloading the sequencer parameter table that controls the instrument timing. The parameter tables allow great flexibility in instrument operation and, as they can be changed in flight, the ASCAT timing can be easily modified if that should ever be deemed necessary.

PDU

The Power Distribution Unit switches the power lines for the ASCAT unit and provides the unregulated voltage to the ASCAT units. Its main functions are switching unit power lines according to the instrument redundancy selected, and monitoring the voltages and currents of the different units.

ICU

The Instrument Control Unit provides the interface between the Payload Module controller and the ASCAT instrument. Its main functions are to handle and process commands and timing signals from the controller, to monitor telemetry from the different ASCAT units, to initiate recovery actions where necessary, and to provide the housekeeping data.

Ground processing, calibration and data products

In flight, the ASCAT instrument is only intended to operate in two modes, namely 'measurement mode' or 'calibration mode'. Normal operation will be in measurement mode, and calibration mode will only be used during certain limited periods in the satellite's lifetime specifically assigned to the observation of external calibration transponders.

During measurement-mode operation, the ASCAT instrument generates two types of data packet for each antenna beam, echo packets and noise packets. Noise packets are produced less frequently than echo packets because more extensive on-board averaging along-track is carried out for noise reception windows compared to that for echo reception windows. These two types of data packets are interleaved in the data stream given to the operational ground processor.

For instrument measurement-mode ground processing, the echo and noise packets are split into two different streams. Noise packets are used as part of the instrument calibration process to estimate the shape of receiver-chain spectral-transfer characteristic and also to compute and subtract receiver noise power. These items must be determined before the relevant lines of echo data can be processed.

During calibration-mode operation, the ASCAT instrument also generates echo and noise packets. In this mode, the instrument is configured to prevent on-board along-track averaging of echoes. In order to suppress ground echoes, the calibration transponder delays its echo so that it is received in the reception window following the one in which reception would normally take place. The transmitted pulse preceding this reception window is transmitted from one of the other antennas directed away from the transponder. The transponder echo is therefore received together with only thermal noise. During overflight of a transponder, four or five samples are obtained through an along-track cut through the antenna gain pattern. The overall in-flight antenna gain pattern and the orientation of each antenna beam can be determined when a sufficiently large number of azimuth cuts have been obtained which are suitably distributed in elevation.

The fundamental approach, which will be adopted for ground processing in the operational ground processor, is the use of automatic baseline procedures and baseline algorithms, which can, where necessary, be modified or overridden manually. This approach ensures, in particular, that calibration information is only introduced or modified in a fully controlled fashion.

The operational data products from ASCAT are classified by level according to how much processing has been performed: the Level-0 product is all relevant raw data, the Level-1A product is reformatted raw data with supplemental information for subsequent processing appended, and the Level-1B product is calibrated sigma-zero data at 25 km and 50 km spatial resolution (and full-resolution sigma-zero fields). The operational ground processing of ASCAT data is partitioned into five steps: (i) Raw data association and validation, (ii) Level-1A processing, (iii) Production of full-resolution sigma-zero data, (iv) Level-1B processing and (v) Product formatting.

The central chain algorithms required for converting the source-packet echo data into sigma-zero triplet products are presented below in greater detail and are depicted in Figure 7. The echo data is first corrected to compensate for the shape of the receiver-chain spectral transfer characteristic. An estimate of the receiver noise power is then subtracted and the resulting signal is divided by the power-gain product, which compensates for variations in transmitted radio-frequency power and receiver-chain gain. The power gain products are computed for each line of source-packet echo using various power measurements made by the instrument for internal-calibration purposes.

The resulting signal is then divided by a normalisation function, which converts the signal-power values to sigma-zero values; this function varies with both across-track and orbital position. The normalisation function is essentially determined by summing up the contributions to the power at a particular discriminator frequency from all elemental areas on the surface of the Earth. Each contribution is appropriately weighted by a factor accounting for slant range, antenna gain pattern and orientation, incidence angle, instrument configuration, etc. The normalisation function is computed as a function of discriminator signal frequency and orbit time, and is then stored as a look-up table since its determination is computationally very heavy. If any of the various contributing elements are changed, the look-up table has to be recomputed.

After the normalisation process, spatial coordinates are associated to the sigma-zero values, which allows localisation in terms of latitude and longitude and along-track and across-track position. First, the relation between slant range and discriminator signal frequency is established. Then, the slant range and orbital position allow the corresponding position on the surface of the Earth to be

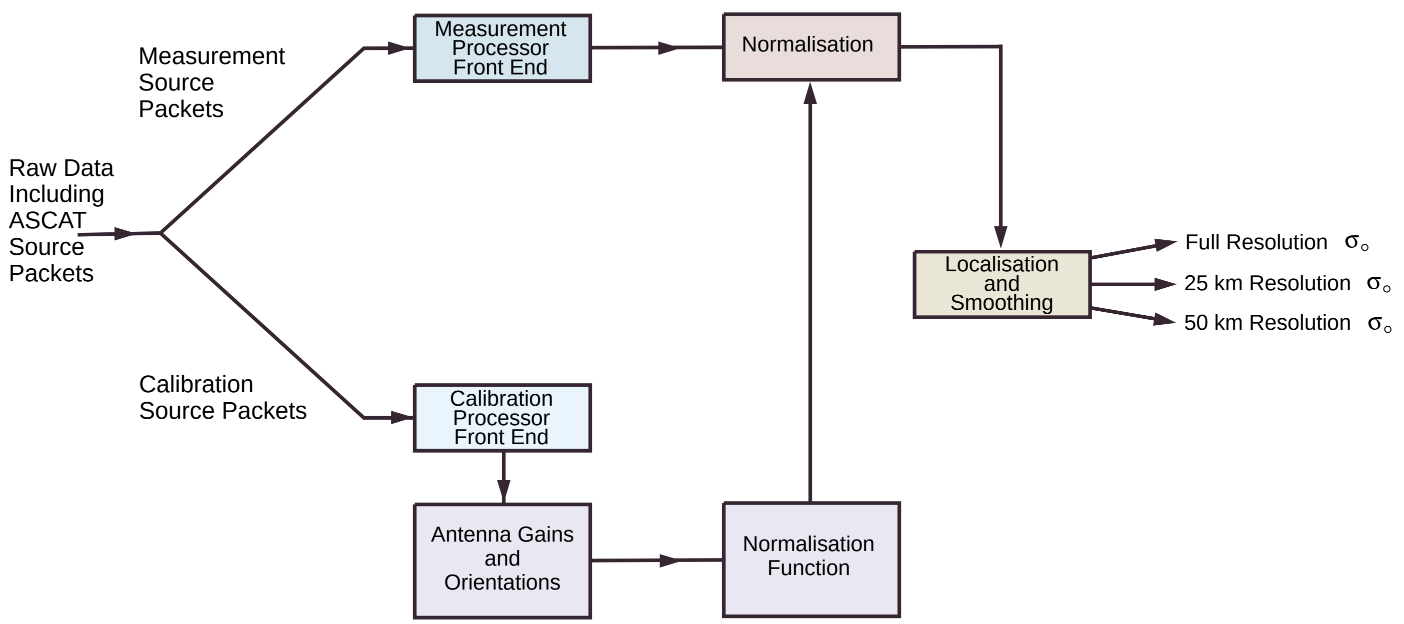


Figure 7. Outline of ASCAT Ground Processor central-chain algorithms

determined using an Earth model and a model of the satellite's orbit and attitude. Finally, the full-resolution sigma-zero data is smoothed to generate the Level-1B products with the desired spatial and radiometric resolutions. This is done by use of a two-dimensional weighting function, which is centred at the position where the smoothed sigma-zero value is to be produced. The raw sigma-zero data are weighted according to their position within the weighting-function envelope and summed; this sum is then normalised with respect to the weighting function. It is expected that the weighting function will be a product of two one-dimensional Hamming functions, one across- and the other along-track. The size of this function will vary with swath position.

Two fully radiometrically calibrated products will be produced for ASCAT, namely a 50 km spatial-resolution product and a 25 km spatial-resolution product. These two products will be distributed in near-real-time to key users (including the national weather services of the Eumetsat Member States and the Eumetsat Satellite Application Facilities), in addition to being archived at Eumetsat itself. A product containing all the raw data (either the Level-0 or the Level-1A product) will also be permanently archived at Eumetsat (to allow reprocessing to be performed in future, if required).

The stability and quality of the ASCAT products will be monitored by observing various natural targets and via transponder measurements. In addition, various instrument and processor-derived parameters will be monitored in order to detect any anomalous instrument behaviour.

Expected in-flight performance

The ASCAT performance parameters are applicable to the measured backscattering coefficients, provided in the radiometrically calibrated product. These results depend not only on the actual instrument hardware and design, but also on the ground-processing algorithms and the external calibration. The performance analysis considers error contributions from all of these areas.

Table 2 summarises the predicted performance parameters for the nominal measurement mode (50 km-resolution cells) and for the high-resolution mode (goal of 25 km resolution). Several of the engineering parameters depend on the different antennas or on the location of the measurement cell within the swath: in such cases, a range is given which covers the different cases. esa

ASCAT Industrial Participation

Alcatel Espace (F)	- HPA, RFU
Alcatel ETCA (B)	- EPC
Alcatel Space Switzerland (CH)	- ICU, EGSE (part)
Alcatel Space Norway (N)	- RFU (part)
Alenia (I)	- PDU
CASA (E)	- Antenna mechanical/thermal, harness
Comdev Europe (UK)	- SFE, EGSE (part)
Crisa (E)	- DPU, EGSE (part)
Dornier Jenoptik (D)	- EGSE (part)
Dornier Satellitensysteme (D)	- Instrument design, integration, ICU software Ground processor prototype (part)
Kongsberg Defence and Aerospace (N)	- Antenna deployment mechanism
Kongsberg – Spacetek (N)	- Ground processor prototype (part)
Saab Ericsson Space (S)	- Antenna electrical
Sener (E)	- Antenna hold-down and release mechanism

Table 2. Predicted performance of the ASCAT engineering model in nominal and high-resolution mode

Performance Parameter	Unit	Nominal mode	High-resolution mode
Spatial resolution	km	50	25 to 37
Spectral resolution	1/km	0.0195	
Sampling interval	km	25	12.5
Radiometric resolution at low wind (minimum back scattering)	%	2.5 to 7.1	6.0 to 17.6
Radiometric resolution at high wind (maximum back scattering)	%	2.0 to 2.7	5.0 to 9.1
Radiometric accuracy	dB pp	0.47 to 0.55	0.48 to 0.56
Interbeam radiometric stability	dB pp	0.33 to 0.41	0.33 to 0.41
Ambiguity under worst case scenario	%	0.34 to 3.3	0.34 to 3.3
Dynamic range (backscatter coefficients on the ground at near swath and far swath)	dB	-8.6 to 4.3 (near) -28.6 to -8.8 (far)	-8.6 to 4.3 (near) -28.6 to -8.8 (far)
Aliasing error	%	0.08	0.08
Centre frequency	GHz	5.255	5.255
Swath length		continuous	continuous
Swath width (full performance)	km	500	500
Swath width (reduced performance)	km	550	550
Incidence angle mid near at H_{min}	deg	25	25
Localisation accuracy	km	4.4	4.4
Polarisation		vertical	vertical
Cross polarisation	dB	>20	>20