IAF-96-B.3.P213

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47th International Astronautical Congress
October 7-11, 1996/ Beijing, China

[1] IAF-96-B.3.P213

THE CENTRAL ELECTRONICS SUB-ASSEMBLY OF ENVISAT-1 ASAR. PRELIMINARY RESULT OF THE ENGINEERING MODEL TEST CAMPAIGN.

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ABSTRACT

The Central Electronic Sub-Assembly (CESA) forms part of the Advanced Synthetic Aperture Radar (ASAR) to be included in the Payload for ESA's ENVISAT-1 Mission. CESA is currently approaching its Engineering Model integration and testing phase, during which all its constituent sub-system are put together and, following a step to step turn-on philosophy, are tested firstly from a functional point of view (i.e. turn-on, turn-off, internal telecommands and telemetries generation, inter sub-system serial control bus troubleshooting, trigger signals generation, etc.) and then from a performance point of view (i.e. Tx signal generation and upconversion characteristics and Rx echo downconversion, digitization, pre-processing and formatting capabilities). The main functional features to be tested is related to ASAR capability to operate in a number of different modes, this implies the generation of the required triggers and the capability of storing a specified number of parameter sets to be used when the required operation mode is selected. The main performance characteristic to be tested are the CESA-added phase and amplitude errors on both the Tx RF signal and on the Rx echo data and overall stability of the Tx and Rx chains, on both main and calibration paths.
In this paper the main performance characteristics CESA has to fulfill in order to enable the Instrument to obtain measurement of the radar backscatter to prescribed performance specifications under defined system constraints are investigated and the preliminary CESA Engineering Model testing results are discussed and examined with respect to the higher level requirements.

1. INTRODUCTION

In order to improve the measurement initiated by the microwave payloads of ERS-1 and ERS-2, the ASAR instrument has been conceived to be able to operate in a number of different modes, which may be selected by the user to provide a combination of radiometric performances over specified coverage regions.

The main improvements to achieve are:

- capability to select the polarisation of the radar signal (V or H) and to use alternating polarisation
- much wider image swath capability than the previous SAR embarked on ERS-1 and ERS-2
- ability to have a wide swath, low resolution mode for monitoring of global features during an orbit

2. ASAR ARCHITECTURE GENERAL OUTLOOK

So as to highlight CESA placement within the whole ENVISAT satellite/ASAR instrument, the ASAR hardware tree is reported in fig. 2-1.
For functional reasons, ASAR has been subdivided into two subassemblies and one subsystem:

1. Antenna Subassembly (ASA)
2. Central Electronics Subassembly (CESA)
3. Instrument Distribution Subsystem (IDS), performing the interconnection between ASA and CESA.

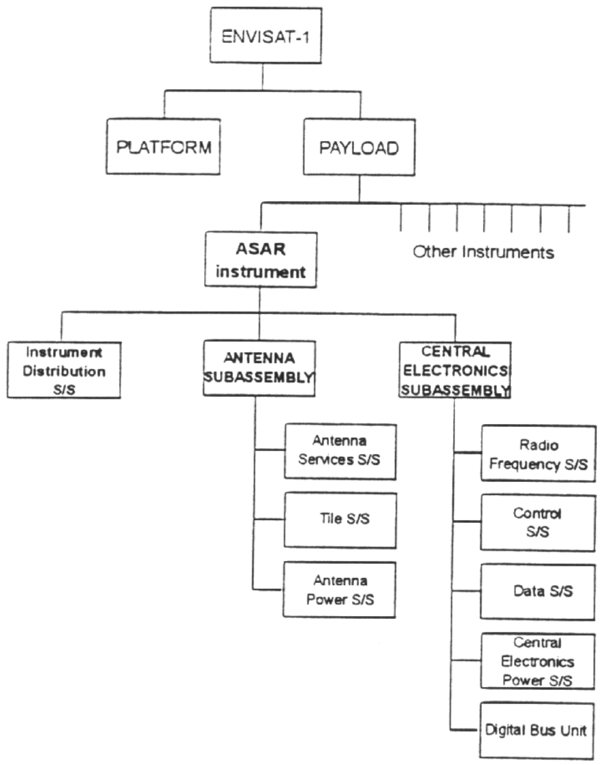

fig. 2-1 - ASAR hardware tree

2.1 ASA overview

The ASAR antenna is an active planar array of 320 independent radiating elements which operates at 5.331GHz centre frequency.

The functionality of the ASAR antenna has been divided into three major subsystems :

- Antenna Services Subsystem

The function of the Antenna Services Subsystem (ASS) is to provide all the services necessary to the proper functioning of the Antenna. This features structural support for both launch and operation, including hold down and release, deployment and alignment, attachment/interface hardware, thermal control and the provision to each Tile of RF, Digital and Power interfaces with the Central Electronics and/or Platform. It also carries out the deployment of the Antenna as initiated by the Platform.

- Tile Subsystem

The Tile Subsystem will receive RF signals and Calibration signals centred on 5.331 GHz from the ASAR RF Subsystem via the Distribution Subsystem and the Antenna Services Subsystem. The Tile Subsystem will apply changes to phase and power amplification of the RF signal prior to transmission via the Radiating Panel. A higly attenuated return signal will be received from the Earth. The Tile Subsystem will also apply changes to phase and amplification of this echo signal. The Tiles are arranged in a 2x10 matrix to form an overall radiating aperture of of 1.3 m. x 10 m. Each Tile Subsystem contains 16 Transmit/Receive (T/R) modules.
Control functions within each Tile are performed through a Tile Control Interface Unit (TCIU). This receives higher level commands and sends telemetry data via an Instrument Control Bus (ICB) which interfaces with the Control Subsystem of the CESA which also deal with the instrument timing signals.

- Antenna Power Subsystem

The Antenna Power Subsystem consists of an Antenna Power Switching and Monitoring equipment (APSM). The APSM switches and monitors the primary power fed to the to the Antenna Services Subsystem. It interfaces to the CESA Control Subsystem to relay its internal telemetry.

2.2 CESA description

The tasks performed by the Central Electronics Subassembly (CESA) within ASAR are mainly those to provide control, data handling and power interfaces with the Payload Service Modules in the Platform, to generate the transmit radar waveform, and to sample and digitise the received radar echoes.

To achieve these tasks, the CESA has been functionally split according to the block diagram as shown in figure 2.2-1.

In detail, the primary features of the CESA are the following:

- It provides all centralised control facilities in response to commands (called macrocommands) from the PMC (Payload Module Controller) and produces telemetry formats on demand; through the macrocommands, the ground segment controls the instrument state and selects its operation mode setting all the parameters necessary to enable the correct operation of the chosen measurement mode. Through the formats (whose level of detail is selectable) the ground control can be informed of the current instrument state.
- It provides DC Power Management for either CESA and ASA units; while the CESA based power conditioning units are used to supply regulated power to all CESA subsystems, an ASA based power switching unit (managed and powered by CESA) is used to supply power to the ASA subsystems according to the chosen redundancy configuration.
- It provides RF and Calibration interfaces to the ASA; these interfaces consist of two waveguides, one named Tx chirp/Rx echo (the path used by the Tx and Rx signals exchanged between the subassemblies) and one named Tx/Rx calibration. This last path is used to implement the complex calibration scheme for the CESA internal RF path, the ASA internal RF path and the overall instrument (CESA + ASA) RF path.
- It produces a TX drive pulse at C-band fed to the ASA. It is a digitally generated chirped pulse with the following features:
  - ⇒ Bandwidth ranging from 0 Hz (a single tone used for calibration purposes) to 16 MHz;
  - ⇒ Tx pulse length ranging from 11.3 μs to 41.3 μs
  - ⇒ Output power ranging from + 26 dBm to + 33 dBm
  - ⇒ PRF (pulse repetition frequency) ranging from 1580 Hz to 2150 Hz
- It downconverts the received Echo signal and digitises and formats it prior to its transmission to the platform DMS (Data Management System). The echo signal can be processed for data rate reduction purposes.
- It provides the instrument timing reference and triggers. The various ASAR subsystems are orchestrated together by means of many timing and trigger signals so that the chosen measurement mode is actually implemented. In order to accomodate for individual subsystems' units tolerances and misalignments (for example when using different redundancies) and being the measurement mode timelines very tight, the CESA can apply to the entire set of triggers a pre-programmed set of fine tuning shifts which take into consideration the time response of the unit(s) under use so that the correct instrument operation is achieved.
- It provides command and control facilities and periodic health monitoring tasks for the whole instrument. If enabled by the ground control, the CESA can autonomously decide to undertake a recovery action should any of the gathered telemetries fall outside a predefined range during a predefined number of times.
- It controls all mode changes in response to commands. As a consequence of each mode switching macrocommand, the CESA shall issue a defined sequence of ASAR internal telecommands necessary to implement the requested mode change.

2.2.1 CESA subsystems

The block diagram of fig. 2.2-1, show the four subsystems which constitute the CESA:

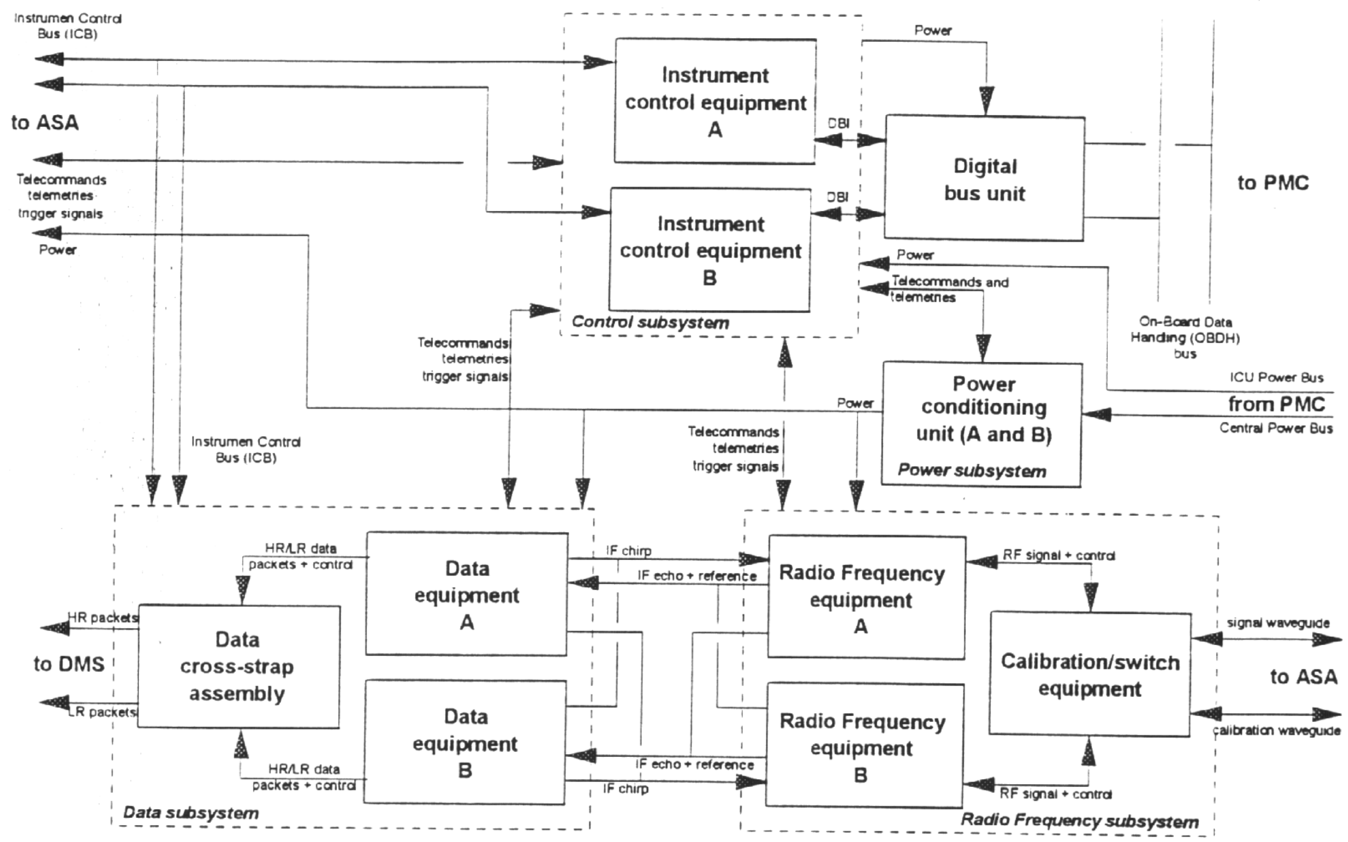

fig. 2.2-1 - CESA block diagram

RFSS - RF Subsystem; it is equipped with two Radio Frequency Equipments (RFE A and B, connected in a cold redundancy configuration) and a Calibration Switch Equipment (CSE) which is non redundant as the RF interfaces to the ASA are.

The RF Subsystem performs frequency reference generation for instrument timing and radar signal generation; it contains transmit and receive signal paths with a calibration path between them which is also connected to the Tile Subsystem (ASA) calibration feeds in order to perform the whole RF path calibration. The RF Subsystem receives, filters and amplifies the radar signals necessary for the operation of the ASAR. It also monitors the transmit power and allows injection of regenerated pulses through various RF paths and into the receive chain for calibration purposes.

CSS - Control Subsystem; it is equipped with two Instrument Control Equipments (ICE A and B, connected in a cold redundancy configuration).

The main functions of the Control Subsystem are to manage the overall ordering and timing of events in the various ASAR activities. It also provides data to the Tile Subsystem to point the antenna beam in the required direction and to the Data subsystem in order to enable the generation of the desired chirped pulse and to enable the received echo data processing. It is the Control Subsystem which receives macrocommands from the Platform decodes and expands them and produces commands to control the operation of other subsystems. During activity modes, it controls the other ASAR equipments by means of high-speed control signals. With these, via the Instrument Control Bus, it commands the Data

Subsystem, the RF Subsystem and the Tile Subsystem to transmit the radar pulses, to receive and digitise the echoes and to perform periodical calibration measurements. It also determines the frequency with which the radar pulses are transmitted (the PRF).

The other main function of the Control Subsystem is to control power to other ASAR equipments, to monitor the instrument through telemetries and to report its state to the ground and to perform any autonomous actions required to keep it in a safe state. The CSS provides secondary power to the DBU whenever the ICU Power Bus is active.

The CSS stores in the memory all antenna steering data, transmit pulse characteristics and echo sample timing for all possible beams of all operational modes. It implements macrocommands to allow this database to be modified. It also downloads the data to the Antenna TCIU's and the Data Subsystem as required for the operation mode.

DSS - Data Subsystem; it is equipped with two Data Equipments (DE A and B, connected in a cold redundancy configuration) and a Cross Strap Assy (CSA) which is internally redundant as the interfaces to the DMS are.

The Data subsystem provides for the generation of the digitally controlled chirp signals with I and Q components, modulated on to an IF carrier (123 MHz) to form a composite chirped pulse. This IF CHIRP is then passed to the RF subsystem for the upconversion to the transmit frequency (5.331 GHz). The Data subsystem also provides for the detection of the echo signal, the digitation of the resultant baseband signal and the interface to the DMS (Data Management Subsystem) for transmission of formatted data.

Among DSS features, it is noteworth mentioning the capability of the DSS to digitally modify the output chirp to account for distorsions the signal will undergo at later stages of the Tx Rx path. The so-called predistortion coefficients are pre-programmed into the CSS and are applied to the signal by the DSS.

PSS - Power Subsystem; it is internally redundant as the Central Power bus is.

The Central Electronics Power Subsystem consists of a Power Conditioning Unit (PCU). The PCU converts primary power to 28 V which is fed to all CESA equipments but the CSS and the DBU ones.

In addition to these subsystems, a further unit can be found as part of the CESA:

DBU - Digital Bus Unit; it is internally redundant as the OBDH is.

The Digital Bus Unit is the interface to the platform On-board Data Handling (OBDH) Bus. The DBU receives macrocommands from the OBDH and passes them to the CESA for further processing. The DBU also relays telemetry information from the CESA to the OBDH. It is simply a code converter from the OBDH Litton code to the Digital Bus Interface (DBI) serial NRZ-L code.
There are no cross strapping facilities between the DBU sides and the CSS sides (i.e. DBU A can be connected only to ICE A).

3. CESA OPERATION

Besides to the already mentioned instrument control and housekeeping functions, the CESA is the core of the implementation of the many operational modes the ASAR instrument has been designed for.
A list of the measurement modes follows, together with the related CESA capabilities.

a. Image Mode

The Image mode provides continuous coverage over a single swath nominally 100 km x 100 km. The swath can be selected from within a 500 km region to the right of the satellite ground track (incidence angle range 15° - 45°). To this end, CESA uploads to the antenna the correct set of gain and phase, Tx and Rx parameters to be used by each of the 320 radiator sub-elements so that the chosen swath is implemented (antenna beam electronic "steering").
The imaging is performed by transmitting a continuous series of pulses and acquiring the required echo information, it is performed whilst the spacecraft is in view of a ground station so that it can transmit its high rate data (100 Mb/s over two channels) directly to ground.
Interleaved to each Image mode cycle (composed by 1024 PRIs) there are a few calibration PRIs

intended to give Tx/Rx status information for the ground processing phase.

For nominal operation seven swaths, IS1 to IS7, are defined providing the required performance over this region. CESA (Control S/S) provides the capability of storing one set of parameters for each swath. During the transition to the mode, the correct parameters are uploaded to the Data S/S (for the chirp generation) and to the ASA (for the antenna electronic steering). Each swath is chosen at the beginnign of the mode.

b. Wide Swath Mode

The Wide Swath mode provides continuous coverage over a swath nominally 400 km wide. This swath is divided into 5 subswaths ranging from 60 to 100 km. Using the ScanSAR technique ASAR transmits bursts of pulses to each of the subswaths in turn such that on return to any subswath a continuous along track image is formed. The strips relating to each subswath can then be merged together in the ground processor to form a single wide swath image. This technique is achieved at the expense of relaxing the resolution to 100 m.

The instrument design will allow a wide swath sequence of up to 14 subswaths if desired. The wide swath mode also generates high rate data that is transmitted directly to the ground as it is acquired. Differently for Image mode, from cycle to cycle the CESA uploads to the ASA different beam sets in order to implement the required sequence of subswaths.

c. Wave Mode

The Wave mode is a sampled Image mode, allowing the acquisition of 5 km x 5 km vignettes at regular along track intervals. The separation between the start of one vignette and the next is 100 km. Two vignettes in the same or different swaths are defined, and are visited alternately.

Full orbit coverage can be obtained with this mode with the tape recorders downloading data to the ground during overflight of the ground station. CESA implements the required data reduction scheme during each low rate mode so that the data rate is reduced to fulfil the requirements of the on-board tape recorder.

d. Global Monitoring Mode

The Global Monitoring mode provides continuous along track sampling across a 400 km swath. This is achieved in a similar manner to Wide Swath mode, using ScanSAR techniques. The mode has a low data rate due to a slightly reduced along track duty ratio and the use of digital filtering for reduction in the across track direction. The same subswaths as defined for Wide Swath mode will be used.

As for Wide Swath mode, the Global Monitoring mode repetition cycle is made up of (up to) five subcycles. During each subcycle, every subswath is visited at least once for a short burst of transmissions. The dwell time on each subswath is determined by the number of pulses required for a look and then the time interval for all the associated returns to be collected.

e. Alternating Polarisation Mode (Copolar, Cross-polar H and Cross-polar V)

The Copolar Alternating Polarisation mode provides imaging in VV and HH polarisations of the same image. This is achieved by interleaving looks of each polarisation along track within the synthetic aperture. The imaging is performed in any Image mode swath, but on a single swath within the mode. Effectively, a ScanSAR technique is used but without varying the subswath.

The echo measurement is made within repetition cycles containing two bursts of transmissions on each of the polarisations. As the same PRFs will apply to both polarisations, there is no need to incur gaps in the timeline to collect echoes prior to switching to the next block as is the case in Wide Swath mode.

In the Cross-polar modes, the transmit pulses are all H or all V polarisation, with the measurement chain operating alternatively in H and V as in the Copolar mode.

During all the modes, the CESA compensates for the varying satellite to ground track distance (and hence for the varying echo delay) by updating the Sampling Window Start Time (SWST) and Length (SWL) so that the echo always hits the DSS sampling window (at constant PRF). The pre-programmed values of SWST and SWL can be updated up to 12 times around the orbit and synchronously to it.

4. CESA PERFORMANCE

The following main performance areas have been envisaged as regards CESA:

Amplitude and Phase Tx chirp errors

The generation of a 8 MHz bandwidth (for each I&Q channel) digital chirp with a sampling rate of 38 MHz allows to obtain :

1. a very good performance with regards to the chirp in terms of Amplitude and Phase errors (+/- 0.1 dB and +/- 1° peak global)
2. negligible parabolic phase errors and then no degradation on Instrument performances
3. Amplitude stability both within the chirp and among consecutive chirps of about 0.2dB peak to peak

For what concerns the Rx channel, it is noteworth to stress that the optimization of filters in baseband leads to performances better than the ones of ERS.

Amplitude and Phase Rx channel errors

The CESA design, centered around a sophisticated baseband, allows to achieve an RF section with a very high band (about 250 MHz for the Tx path and about 65 MHz for the Rx path). Consequently the phase response is practically linear within the useful 16MHz.

Calibration method

It has been chosen to only use the internal pulse generator, this simplifies the design without compromising the performances. A first overall calibration is obtained by feeding the Tx signal into the Rx path output at RF, afterwards a separate calibration is performed on the Rx and Tx path.
Such a choice is coherent with the already existing studies performed for the Ground Segment. These allow very precise radiometric measurements. The intrinsic calibration stability is 0.01 dB, this value does not exceed 0.1 dB in case of external calibration accounting for all the tolerances relevant to feed, lines and comparison network. The teorethic achievable value is 0.13 dB as regards external calibration and 0.3 dB for normal paths.

On board digital data processing

This function was initially conceived to be totally implemented in a digital way. A FIR digital filter was foreseen which should have guaranteed the maximum flexibility. Nonethless the only component that could have fulfilled the requirements was not space qualified due to a decision of the manufacturer.
It was found an alternative solution by using two analog filters: one devoted to support the Global Monitoring mode the other for all other instrument modes.
The remaining part of on board data processing was kept fully digital. It features a 38Ms of real time processing capability. It also includes a FIFO for data handling and organization purposes.

Overall Timing

The CESA timing jitter features are better than 5 ns. both on transmitted pulse leading edge(ordinary and calibration) and on the acquisition, noise, data and calibration windows gates.

Amplitude and Phase stability

In order to guarantee the maximum amplitude stability at CESA level, a design philosophy was chosen which imposes an Amplitude stability to the DSS, a Gain stability to the RFSS, minimizes the armonical distorsion and satisfies the requirements for the out-of-band spurious.
As regards the phase stability a project driver has been the growing interest of scientific community related to interferometry. To this end the Local Oscillator requirements have been changed during the project to reduce the short term stability (now better than 1 sec.) by two orders of magnitude. Any CESA reference, both primary and derived, performs better than 2.5x10e-10 featuring as one of the best system currently developed.

CESA Control functions

The instrument control functions are performed through two levels :

- external, by using macrocommands handled by the CSS
- internal, by using an Instrument Control Bus. Communications are settled between the CSS primary processor and the secondary processors housed within the DSS and the TSS.

This hierarchy allows to manage the complex system including 22 processors (1 belonging to the CSS, 1 belonging to the DSS, 20 belonging to the TSS) in a very flexible way as regards the parameter setting both at CESA (for the different operative modes) and at Antenna (Temperature and phase corrections) level.

22 further processors are also included for redundancy purposes.

5. TECHNOLOGICAL ASPECTS

Digital Chirp generation at baseband

The commonly used technologies allow the chirp generation at Video Band by using one digital generator, one Converter and one mixer. This results in a quite simple way of controlling the chirp generation (i.e. it is to be taken care only of the jitter) whilst the limit is that it is not possible to get a broad band.

The ASAR Chirp generation at baseband concept is based on the use of both the I&Q components that are converted by two converters and modulate two subcarriers I&Q at IF.
This implies an increased complexity and criticality in terms of performance control parameters (i.e. Phase error between the channel carriers, Amplitude error between channel, alignment of converters, jitter between channels). In spite of this, the quality of ASAR generated chirp is very good and extremely promising for future applications involving chirp generation at Broadband.
An other advantage of such a kind of generation is that it is possible to compute predistorsion coefficients to equalize the system and apply them via the SW.

Flexible Block Adapter Quantizer (FBAQ) chip

This is not a brand new concept but the following implementative aspects made it very interesting :

- the receiving channel is doubled (i.e. I&Q), the BAQ itself operates on complex data and then gets a double computation capability.

- full programmatic flexibility. In fact it is possible to change data statistical model in order to support different situations. If for same targets the signal statistics change the chip can be reprogrammed and optimized.

- the current achievable throughput time is about 20 MHz but it is possible to ipothise future improvement up to 100 MHz on a single chip and 400 Mhz by using a multichip parallel implementation.

- it well suits in the digital section : interface problems with the input converters and with the output data formatter are minimized.

Control Subsystem Single Processor

The initial design choice to use two "G iteration" of 1750 processor, and the subsequent availibilty of "J iteration" with improved capability (up to 3Mips), lead to the redesign the CSS and use just one processor in order to unify its main functions of Instrument Control Unit (ICU) and MCE (Mode Control Equipment) previously running separately.
It was then achieved a centralization both in terms of the operative SW and of different functions (control, monitor, radar operative modes execution).
A considerable mass saving (6 kgs. on a total of 28) was also achieved.

6. PRELIMINARY RESULTS OF CESA SUBSYSTEM

Main first interesting results obtained during the CESA Subsystems test campaign are presented herefollowing:

RFSS Amplitude and Phase errors

The Amplitude and Phase errors at RFSS level have been defined in terms of :

- Linear,Quadratic,Ripple and Noise Amplitude
- Linear,Quadratic,Ripple and Noise Phase

for both TX and AUX TX channels in the two cases of Pulse to Pulse and Within Pulse.

The same definition, with different specified values, apply for both RX and AUXRX channels.

For the purpose of measurement, which envisaged a "loopback" test (i.e. by feeding the TX section with an IF signal and reading its IF echo from the RX port) for the three different cal path 1 (TX-AUXRX), 2 (AUX TX-RX), 3 (AUX TX-AUXRX), see figure 6-1, the above requirements were combined in a RSS way to define a set of "TEST REQUIREMENTS".

The comparison of the measured performance with the "TEST REQUIREMENTS" show that a comfortable margin is achieved.

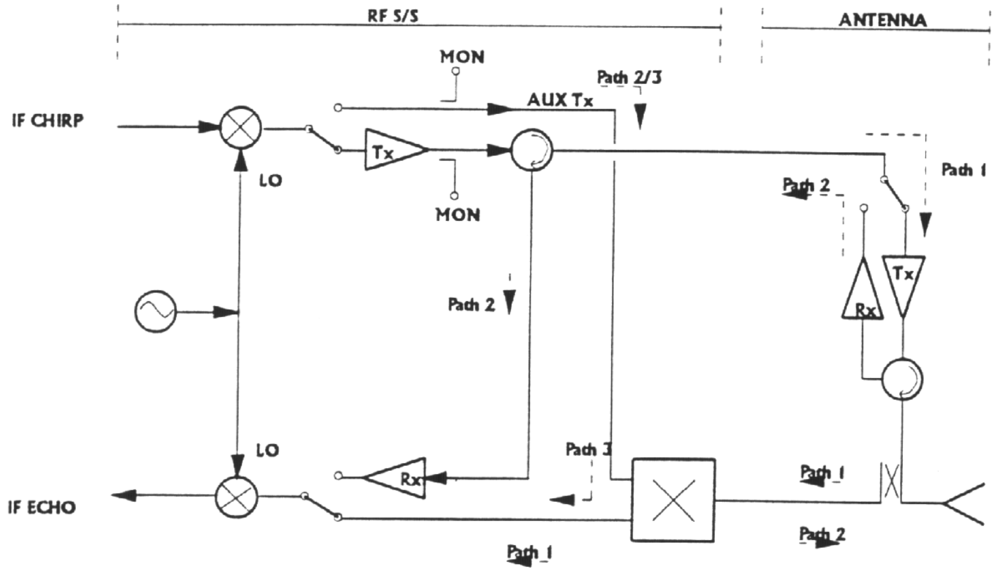

fig. 6-1 - ASAR Calibration Paths

DSS TX and RX path characteristics

The test campaign on the DSS EM carried out at Saab-Ericsson has shown very good performance of both the TX and receiving path w.r.t the most critical requirements.

For the TX path the amplitude stability of the Chirp measured over a 21 sec period was required in terms of linear, quadratic, ripple and noise error. The following figures have been measured against the requirement in brackets : linear 0.025 dB (0.05 dB), quadratic 0.04 dB (0.05 dB) ripple 0.0 dB (0.05 dB) and 0.09 dB (0.2 dB).

For the RX path great performance have been experienced for Gain Imbalance between the I and Q channels. Against a requirement of 0.25 dB a worst case figure of 0.09 dB has been measured.

The RX chirp Amplitude stability over 21 sec, defined as per transmit path, linear 0.015 dB (requested 0.05 dB), quadratic 0.012 dB (0.05 dB) ripple 0.0 dB (0.05 dB) and 0.035 dB (0.2 dB).
Very good values have been also measured for phase stability over 21 sec of the RX Chirp: linear error 0.15 degrees (requirement 2.0 degrees), quadratic error 0.12 degrees (requirement 1.0 degrees), ripple 0 degrees (requirement 0.1 degrees) and noise 0.23 degrees (requirement 1.5 degrees)
All the above figures are worst case values measured over the whole temperature range, from -20 to +55 degrees in Thermal Vacuum.

Amplitude Stability

The following results have been achieved for the EM's:

- RFSS range is +0.6 dB to -0.8 dB accounting the overall Temperature range (-20°c to +55°C)
- DSS range is +03 dB to -0.0 dB accounting the overall Temperature range (-20°c to +55°C)
- RFSS range is +0.5 dB to -0.5 dB over 15 minutes at ambient Temperature

Preliminary results of CESA level Tx signal phase and amplitude errors

During the CESA level test campaign, some not predistorted chirps (i.e. with predistortion coefficients set to zero) out of the Tx path have been acquired at 5.331 GHz center frequency. The chirps have been downconverted to baseband within the CESA-EGSE and afterwards sampled by digital oscilloscope. The chirp characteristics are as follows:

- Bandwidth: 16 MHz (maximum allowed);
- Pulse duration: 25 μsec;
- PRF: 1667 Hz;

Figures 6-2 to 6-4 show the preliminary results of the phase and amplitude errors evaluation.
It is noteworth remarking that the comparison of the obtained results with respect to the required ones show a better behaviour of the system than the specified one (see table 6-1 for details).

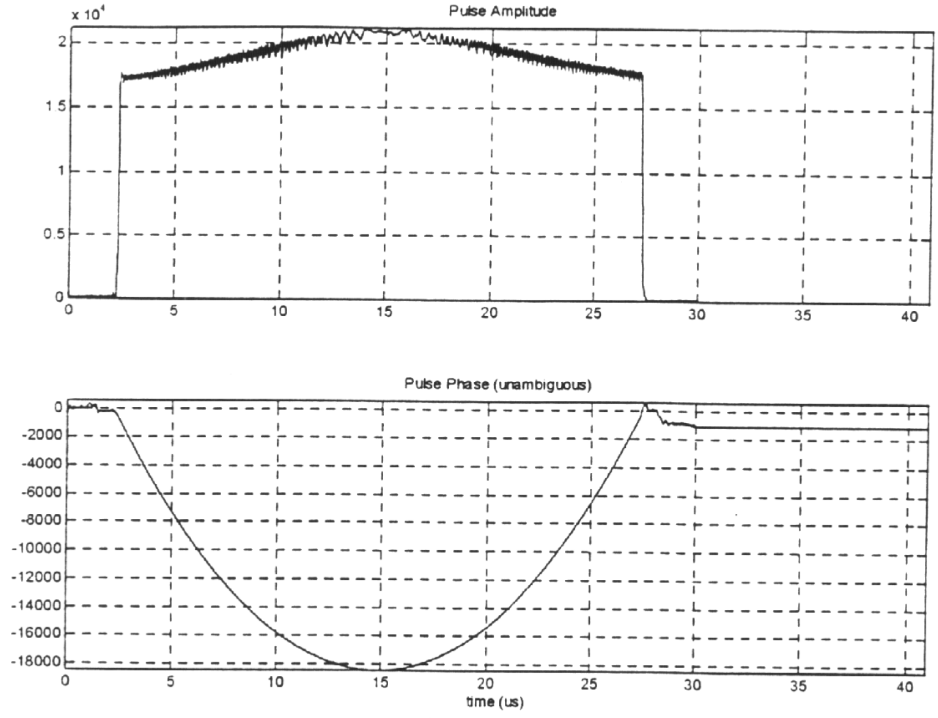

fig. 6-2 - CESA Tx path: pulse amplitude (not normalized units) and unwrapped pulse phase (degrees)

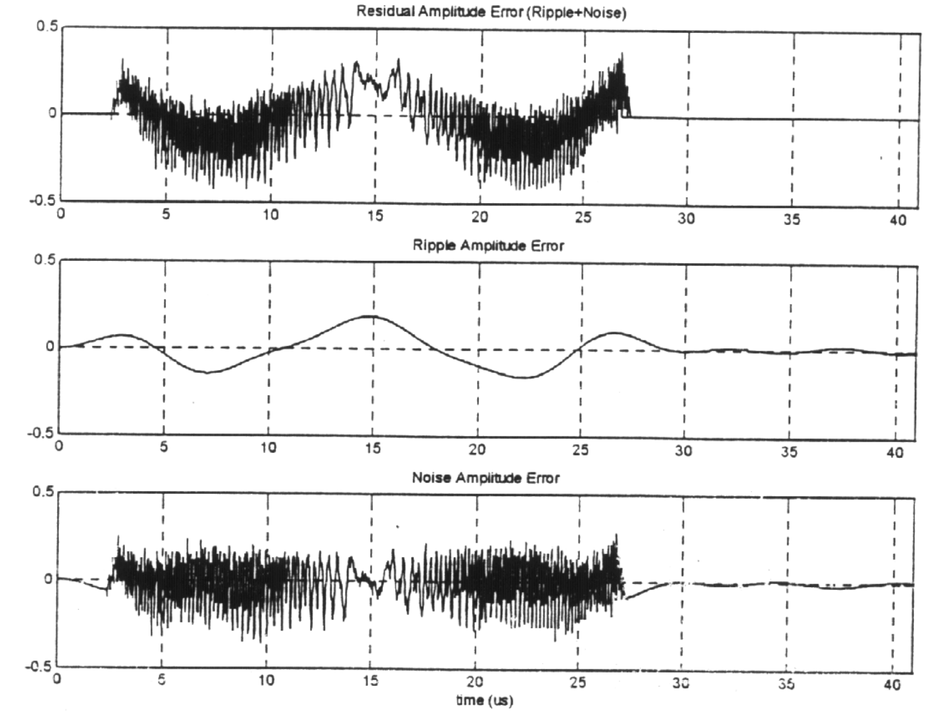

fig. 6-3 - CESA Tx path: residual amplitude error after the removal of linear and quadratic components (dB), ripple amplitude error (dB) and noise amplitude error (dB)

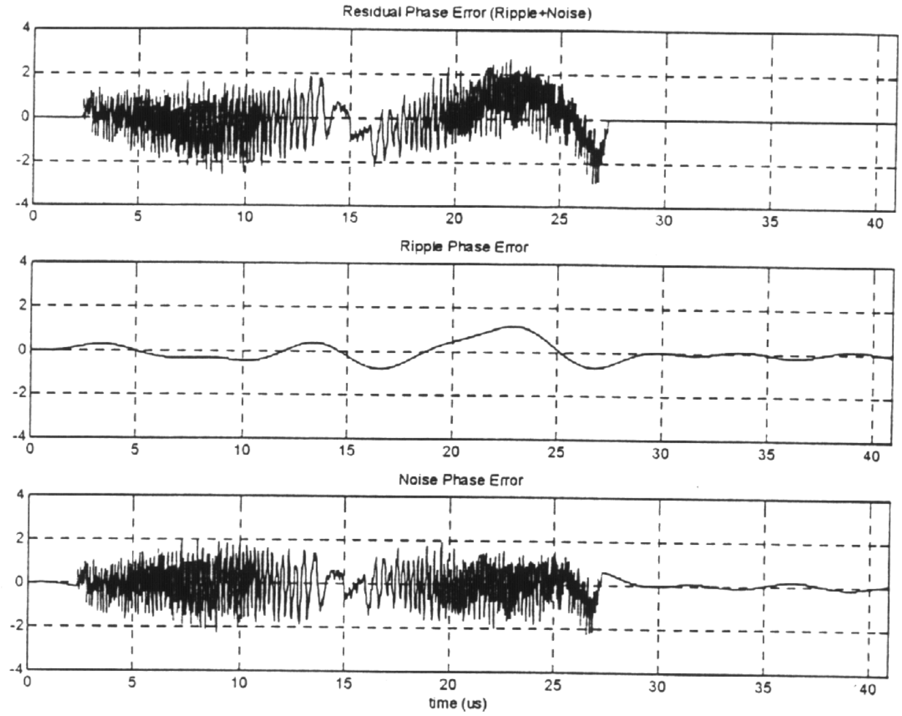

fig. 6-4 - CESA Tx path: residual phase error after the removal of linear and quadratic components (degrees), ripple phase error (degrees) and noise phase error (degrees)

Referenced figure	Parameter name	Required value	Achieved value
6-3	Ripple amplitude error	0.4 dB	better than 0.2 dB
6-3	Noise amplitude error	0.21 dB (rms)	0.1 dB
6-4	Ripple phase error	1.8 degree	1 degree max over full badwidth
6-4	Noise phase error	3.61 degree (rms)	1 degree

Table 6-1 - CESA Tx path error evaluation wrt requirements (preliminary evaluation)

7. ACKNOWLEDGEMENTS

This work is being carried out under contract for the European Space Agency (ESA).

The authors would like to acknowledge the effort of the whole ASAR teams at European Space Technology Centre (ESTEC), at Dornier, Matra Marconi Space, ETCA, Saab Ericsson Space and at Alcatel Espace.