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"Spaceborne Instrumentation for Atmospheric Sensing: ALENIA Aerospazio Experience"

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Spaceborne Instrumentation for Atmospheric Sensing: Alenia Aerospazio Experience

G. Angino, P. Spera

"Exploring the Atmosphere by Remote Sensing Techniques"

Trieste, 21 October 1999

Alenia

A E R O S P A Z I O

Introduction

- During the last ten years, the remote sensing engineering of Alenia Aerospazio has participated (mainly as instrument prime contractors) to several programmes and study on spaceborne instrumentation for atmospheric sensing. Thanks to these activities we have gathered a considerable knowledge on the techniques applicable in the micro-wave region of the spectrum for investigating on the atmospheric parameters.

- All the design activities has been always developed with a very deep interaction with the scientific aspect of the specific measurement technique, trading-off the expected instrument performance and the instrument complexity with the required scientific objectives.

Introduction

- Going all over those recent years the main programmes related to atmospheric sensing were:

  - MIMR
  - CLOUDS
  - MWR
  - MASTER
  - MECLIVAR

M.I.M.R.

Multifrequency Imaging Microwave Radiometer

Background: under ESA contracts, after a Phase B (1992) and its extension (1993) of instrument design, for an accommodation compatible with either U.S. EOS or European POEM-1 Platform, and breadboard development for critical technology items (antenna, receivers, mechanisms), MIMR has successfully passed a Phase C1/1 (1994) activity in which design and specification tasks have been performed propedeutic for:

- ❑ an instrument Demonstration Model development (1994-96)
- ❑ MIMR configuration and design up-grading for compatibility with the METOP-1 Platform, in the Phase B (1995-96) development stage

MIMR

- is a conical scanning, multifrequency total power microwave radiometer which shall image the Earth with 6 channels (6.8, 10.65, 18.7, 23.8, 36.5, 89 GHz) in both horizontal and vertical polarizations, day and night operation capability, near global daily coverage ($\approx$ 1600 Km swath).

- the radiometer measures the brightness temperature which is related to the emissivity of the Earth surface and its atmosphere providing capability to retrieve geophysical parameters in several scientific application fields.

MIMR CAPABILITY FOR WEATHER MONITORING OF THE ENVIRONMENT

Atmosphere:
- total water vapour content in the atmosphere
- total liquid water content
- rain rate
- cloud extent
- typhoon monitoring
- ice content in clouds

Ocean:
- wind speed
- sea surface temperature

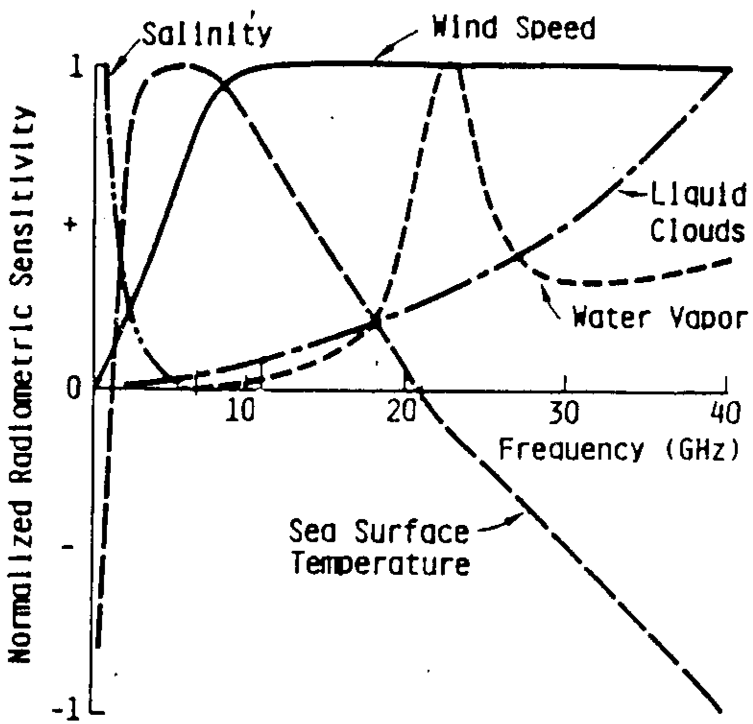
Ocean/Atmosphere interaction:
- carbon dioxide exchange

Cryosphere:
- sea ice concentration
- ice type
- ice mapping

Land:
- snow cover
- snow water content
- permafrost
- soil moisture, vegetation characteristics (semi-arid areas)

Spectral sensitivity

- The apparent temperature observed with a spaceborne radiometer is a function of several of the geophysical parameters of the atmosphere and the ocean surface.
- Considering frequencies where the oxygen absorbtion phenomena are negligible the main parameters of interest are:
  - sea surface temperature;
  - surface wind speed;
  - salinity;
  - atmospheric water vapour;
  - cloud liquid water content.



Frequency of Observation

PHYSICAL OBSERVABLE		FREQUENCY OF OBSERVATION (GHz)									
		1.4	6	10	18	21	37	50-60	90	160	183
Soil moisture		●	○								
Snow			○	○	●		●		●		
Precipitation	Ocean			◒	●	○	◒				
	Land				◒		●		●		◒
Sea surface temperature			●	◒	◒	◒	○				
Sea ice	Extent				●		●		○		
	Type		○	◒	●		●		◒		
Wind speed (sea surface)				●	◒	○	○				
Water vapor	Total (over ocean)				●	●	◒				
	Profile					◒	○	◒	○	◒	●
Cloud water (over ocean)						◒	●		◒		
Temperature profile						○	○	●	○		

Key: ● Necessary ◒ Important ○ Helpful

Frequency of Observation

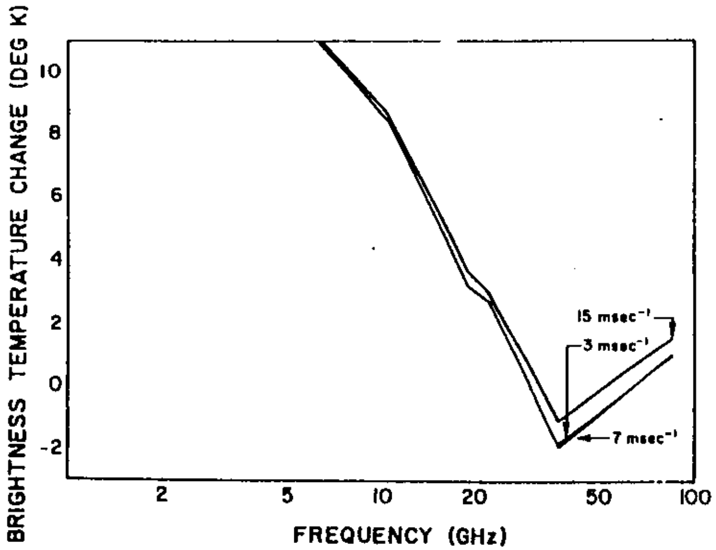
► In the following table the sensitivity of some channels already presented in the previous table are summarized, taking into account also the channel polarization. (Sensitivity is quoted in 5 steps).

Frequency (GHz)	6		10		18		21		37		85	
Sea-surface temperature	V	H	V	H	V	H	V	H	V	H	V	H
Wind stress	5	4	4	3	2	2	1					
Water vapour	1	3	3	4	3	4	3	4	2	5		
Precipitation				1	2	3	4	5	2	3	5	5
Liquid water			3.	1	4	2	3	3	4	5	5	5
Ice and snow	2	2	3	3	4	4	2	2	5	5	4	4
Soil moisture	5	5	4	4	3	3	1	1	2	2	1	1

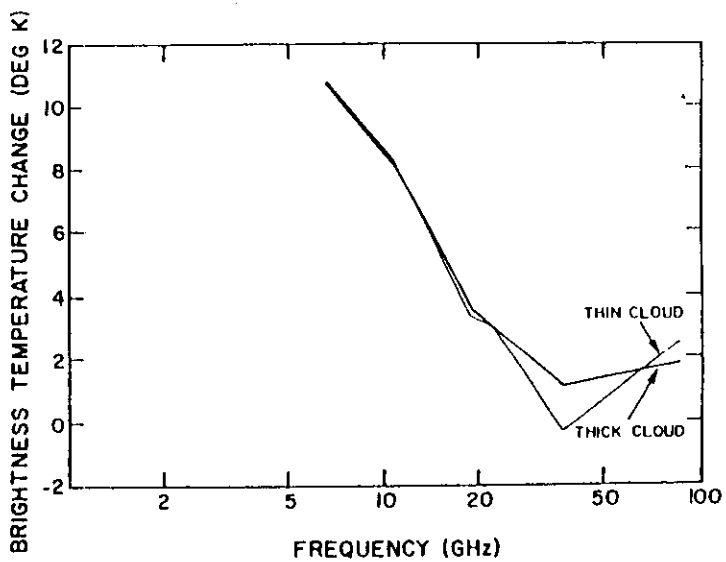
MIMR Choice of channel

Sensitivity of brightness temperature to geophysical parameters variations

- sea surface temperature -



Change in the vertical brightness temperature for a change in sea surface temperature from 5 to 25C for three different wind speeds.

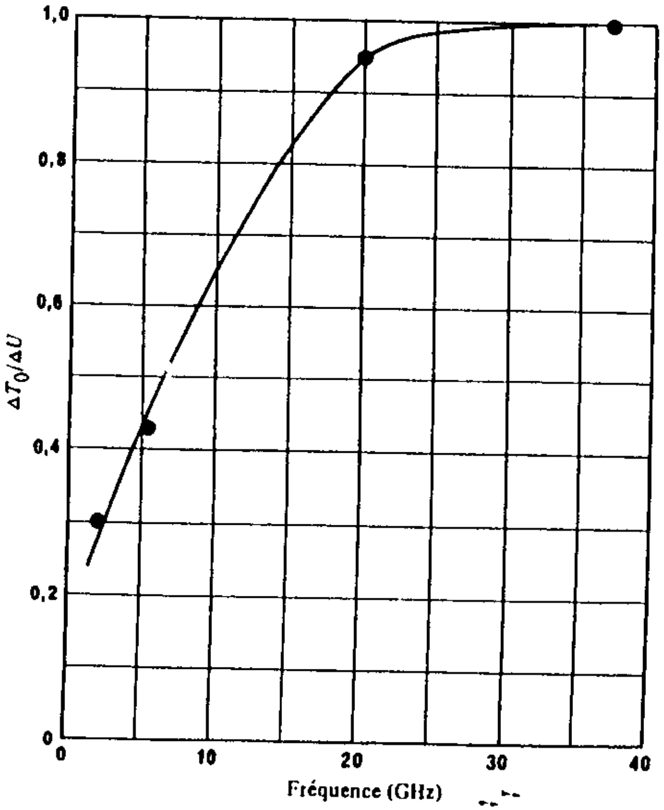


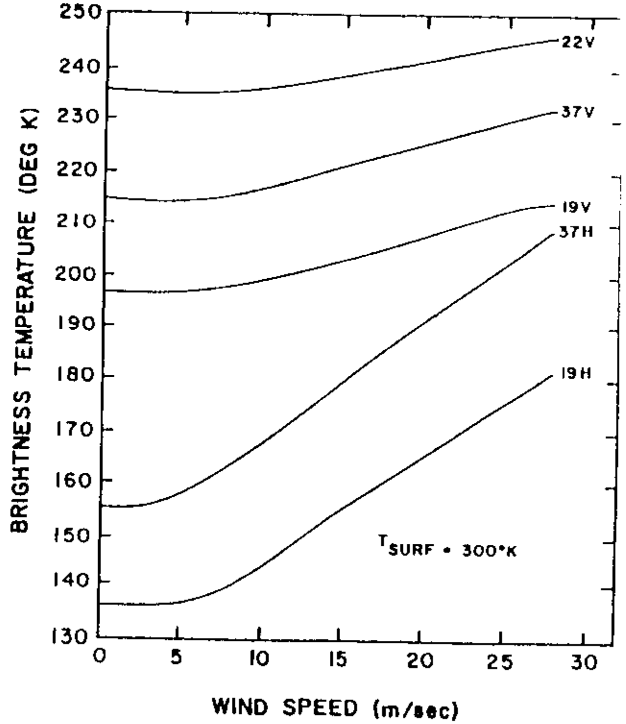
Change in the vertical brightness temperature for a change in sea surface temperature from 5 to 25C for two different and atmospheric conditions.

MIMR Choice of channel

Sensitivity of brightness temperature to geophysical parameters variations

- wind speed -





Brightness temperatures function of frequency and wind speed

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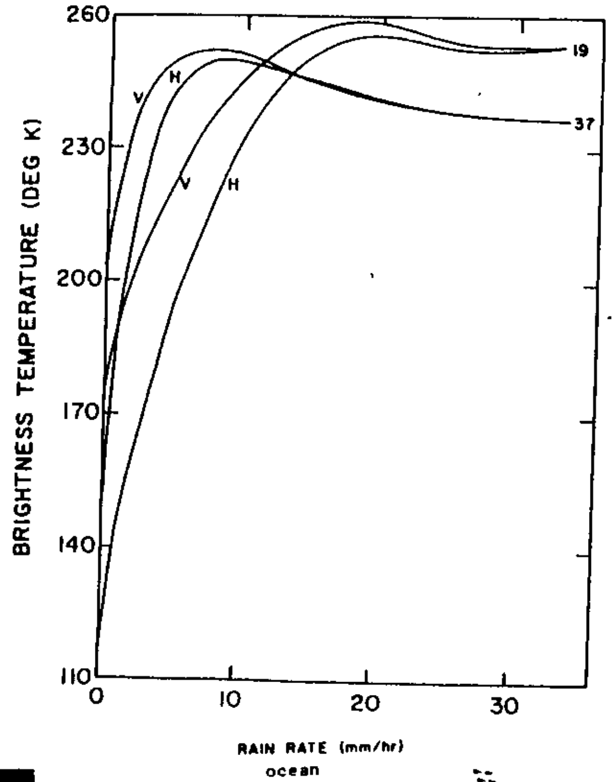
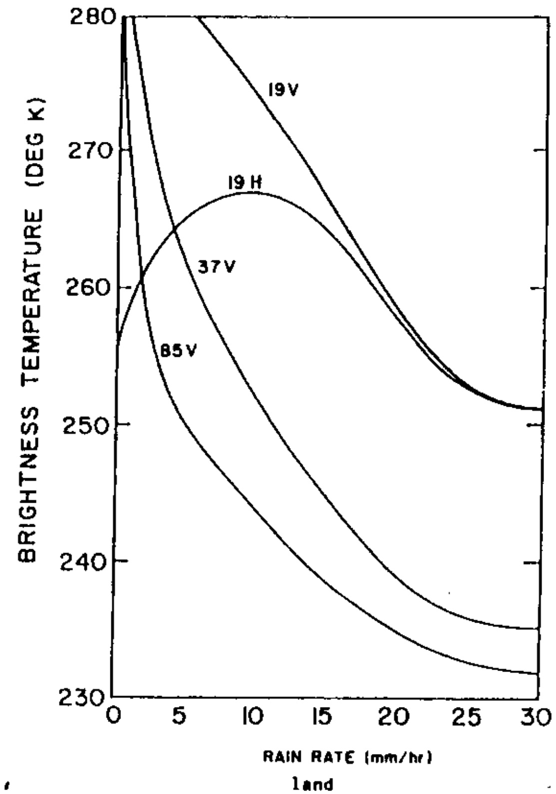
MIMR Choice of channel

Sensitivity of brightness temperature to geophysical parameters variations

- rain rate -





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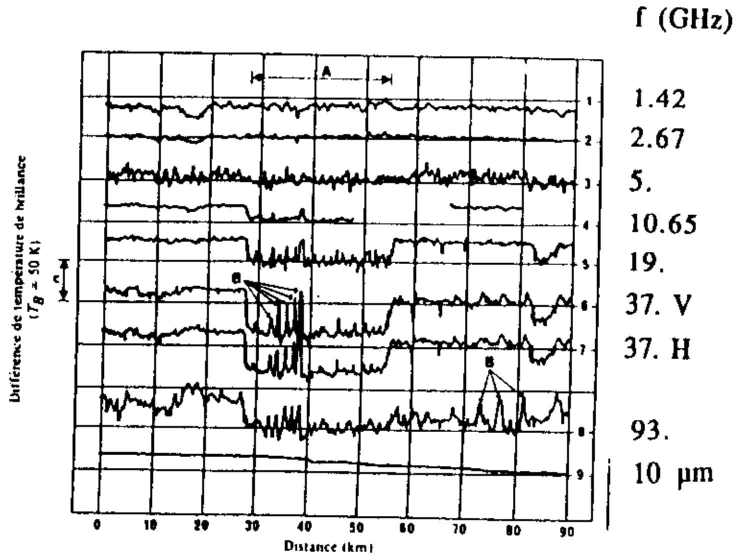
MIMR Choice of channel

Sensitivity of brightness temperature to geophysical parameters variations

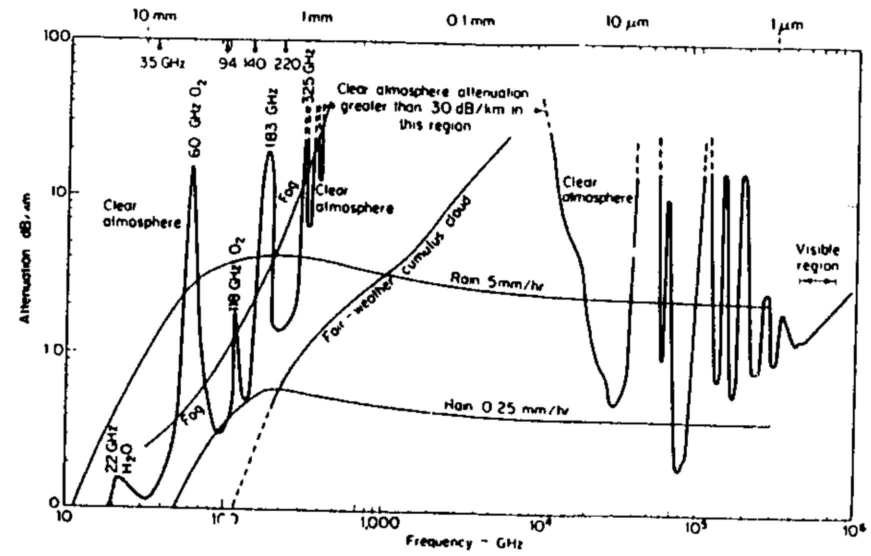
- ice -



A: Large Multiyear icefloe
B: Refrozen Leads

MIMR Choice of channel

atmospheric absorption



One-way attenuation of electromagnetic energy propagating in the clear atmosphere[87] (oxygen and water vapor at 7.5 g/m³, 1 atmosphere pressure, and absolute temperature equal 293 K), rain[88] at 293 K, the total attenuation of fog with a visibility of 300 m and at 293 K (includes attenuation through a clear standard atmosphere), and fair weather cumulus cloud with a mode radius of 4 μm, a water content of 0.063 g/m³, and a drop density of 100/cm³.[89,90]

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MIMR Choice of channel

RF regulations

Frequency allocated (GHz)	Applications
6.425 to 7.250	Sea Surface Temperature
10.6 to 10.7	Wind Speed
18.6 to 18.8	Snow, precipitation ocean, sea ice , wind speed
23.6 to 24.	Liquid water content
36. to 37.	Snow, ice - rain rate - water vapour, sea ice
86. to 92.	Ice mapping - rain rate land

MIMR FUNCTIONAL CONSTITUENTS (cont.)

RECEIVERS

Frequency/Polarisation	Noise Bandwidth	On-board Integration time
1× (H+V) @ 6.8 GHz	200 MHz	5 msec
1× (H+V) @ 10.65 GHz	100 MHz	2.5 msec
1× (H+V) @ 18.7 GHz	200 MHz	2.5 msec
1× (H+V) @ 23.8 GHz	400 MHz	2.5 msec
2× (H+V) @ 36.5 GHz	1000 MHz	1.25 msec
4× (H+V) @ 89 GHz	2700 MHz	0.625 msec

MIMR STEP FORWARD RATIONALE

w.r.t. already flown instruments (like e.g. SSM/I), the MIMR radiometer candidates for significant performance enhancement, due to:

- ❑ high spatial resolution thanks to the large (1.6 mt.) antenna
- ❑ extended frequency range in dual polarization
- ❑ pushbroom technique at the higher frequencies giving generous sampling along track and hence high data quality
- ❑ tight on-board sampling (both along and across track) giving high flexibility to processing techniques on ground for improving the spatial resolution at the lower frequencies

MIMR MAIN DESIGN DRIVERS (METOP REQUIREMENTS)

RADIOMETRIC PERFORMANCE

FREQUENCY (GHz)	6.8	10.65	18.7	23.8	36.5	89
SENSITIVITY (°K)	0.2	0.4	0.5	0.5	0.5	0.7
ACCURACY (°K)	1	1	1.5	1.5	1.5	1.5
STABILITY (°K)	0.2	0.4	0.5	0.5	0.5	0.7

INCIDENCE ANGLE : 55 °

POINTING ACCURACY : 0.08°

SPIN RATE : 26 RPM (baseline) ; 30 RPM (option)

TOTAL MASS : ≤ 180 Kg

POWER DEMAND : ≤ 190 W

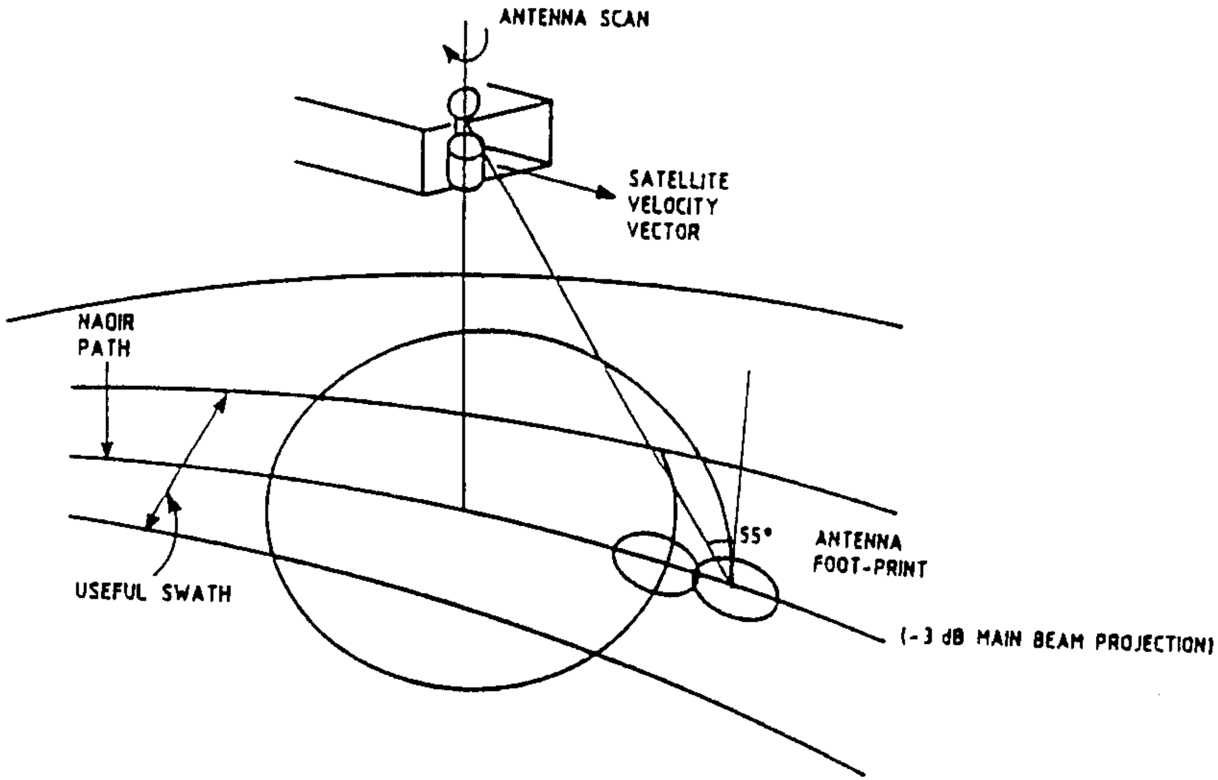
DATA RATE : ≤ 100 Kbit/sec

FIRST FULL RESONANCE FREQUENCY AT LAUNCH (EXTERNAL "DRUM") : ≥ 60 Hz

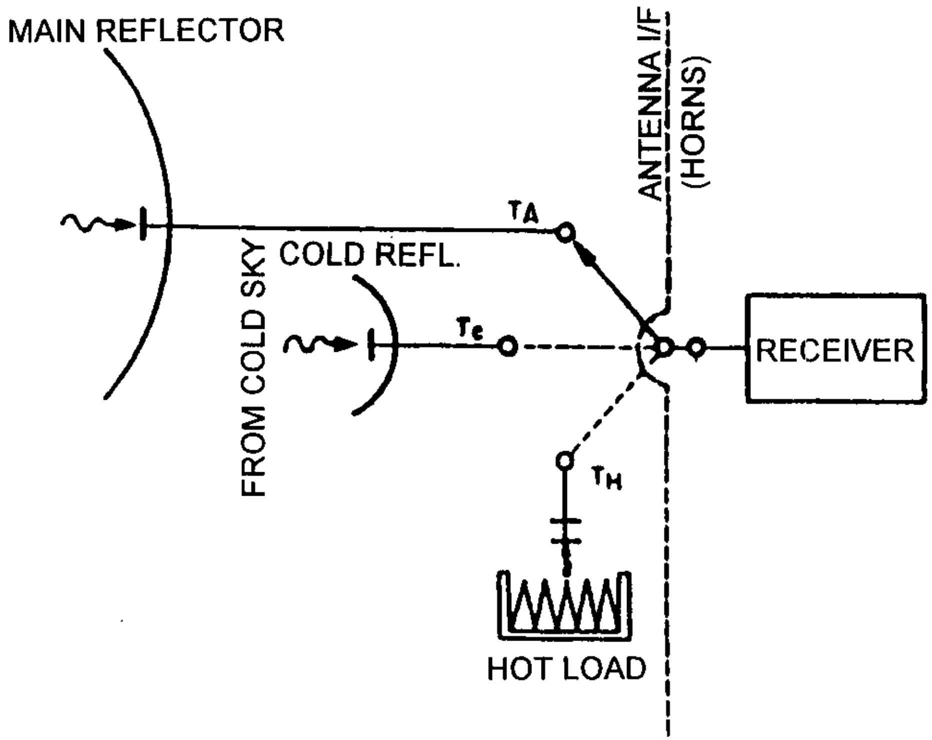
SPATIAL RESOLUTION

FREQUENCY (GHz)	6.8	10.65	18.7	23.8	36.5	89
ANTENNA HPBW	2.16°	1.38°	0.8°	0.73°	0.42°	0.174°
FOOTPRINT (Km)	82 x 47	53 x 30	31 x 17	30 x 17	16 x 9	6 x 4

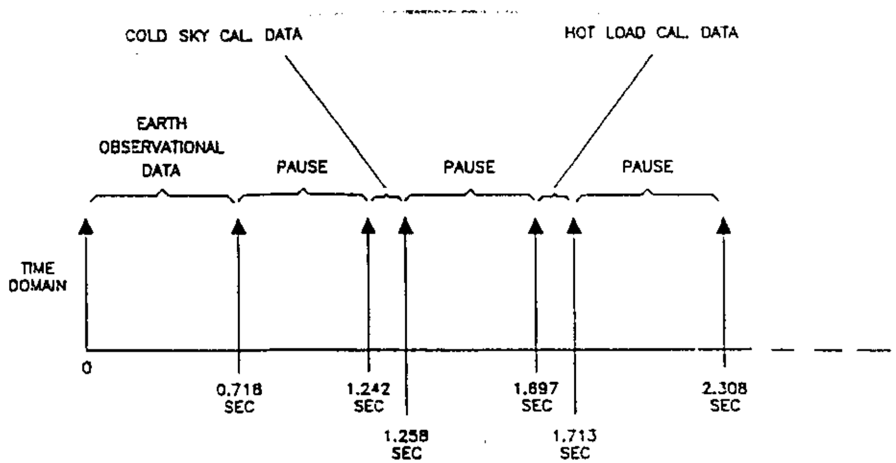
CONICAL SCAN OF MIMR ANTENNA



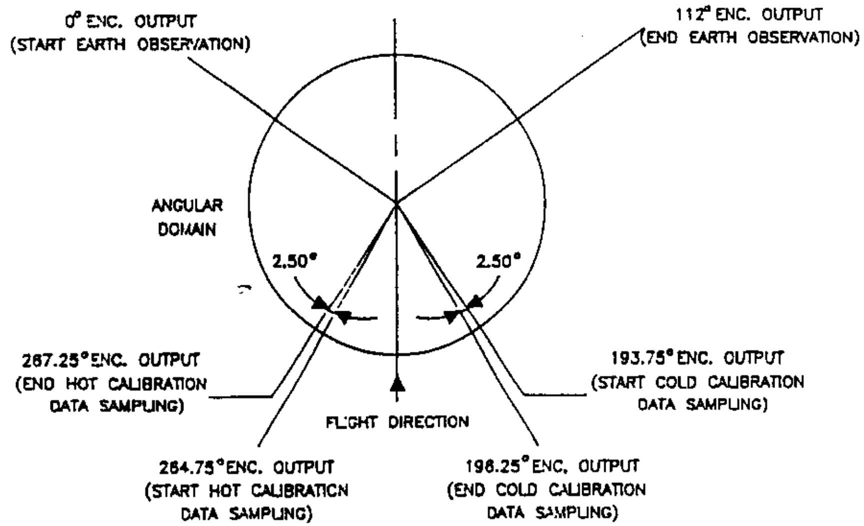
MIMR MEASUREMENT/CALIBRATION PRINCIPLE



MIMR OPERATION WITHIN ONE ANTENNA TURN



(typical)



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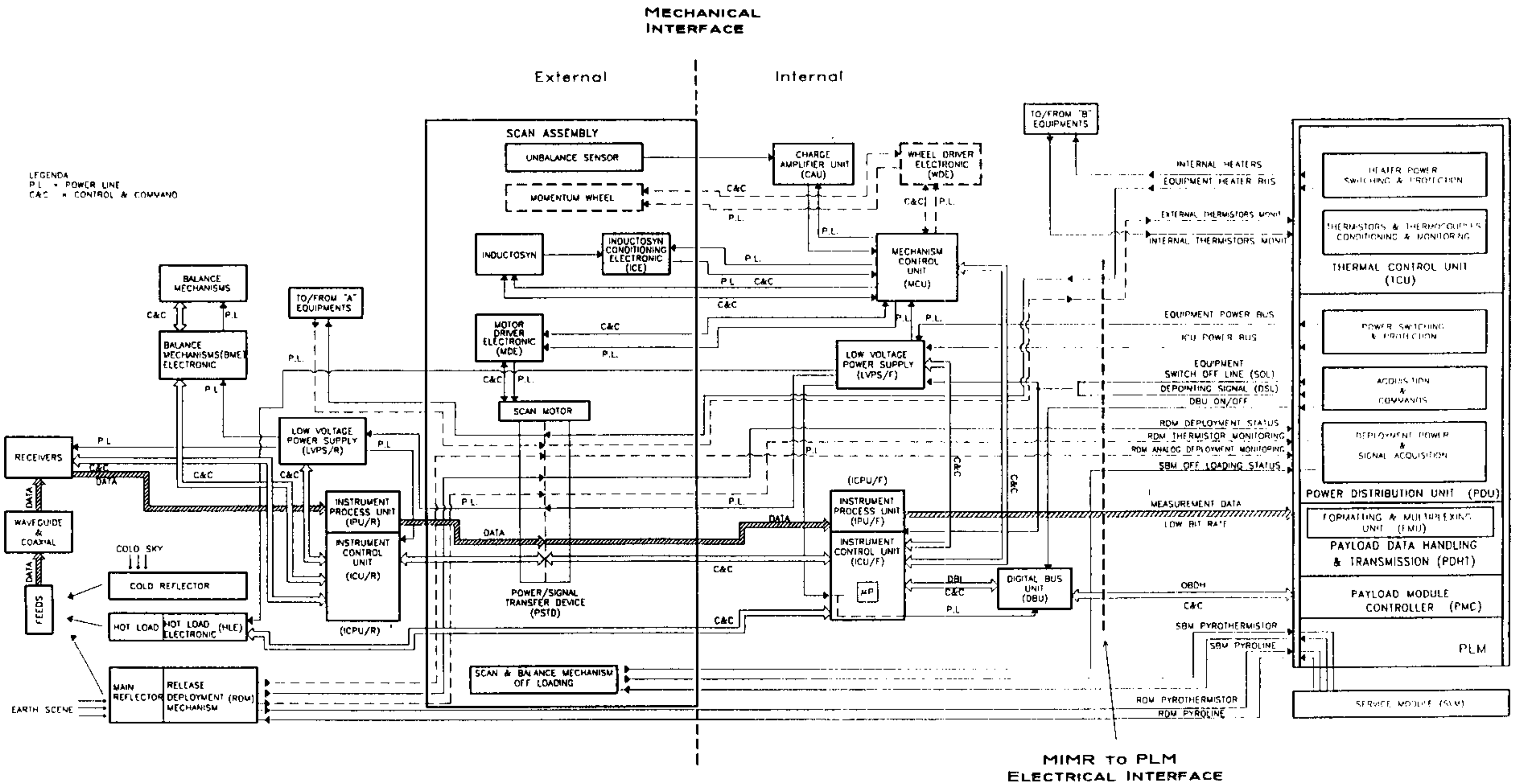
INSTRUMENT BLOCK DIAGRAM



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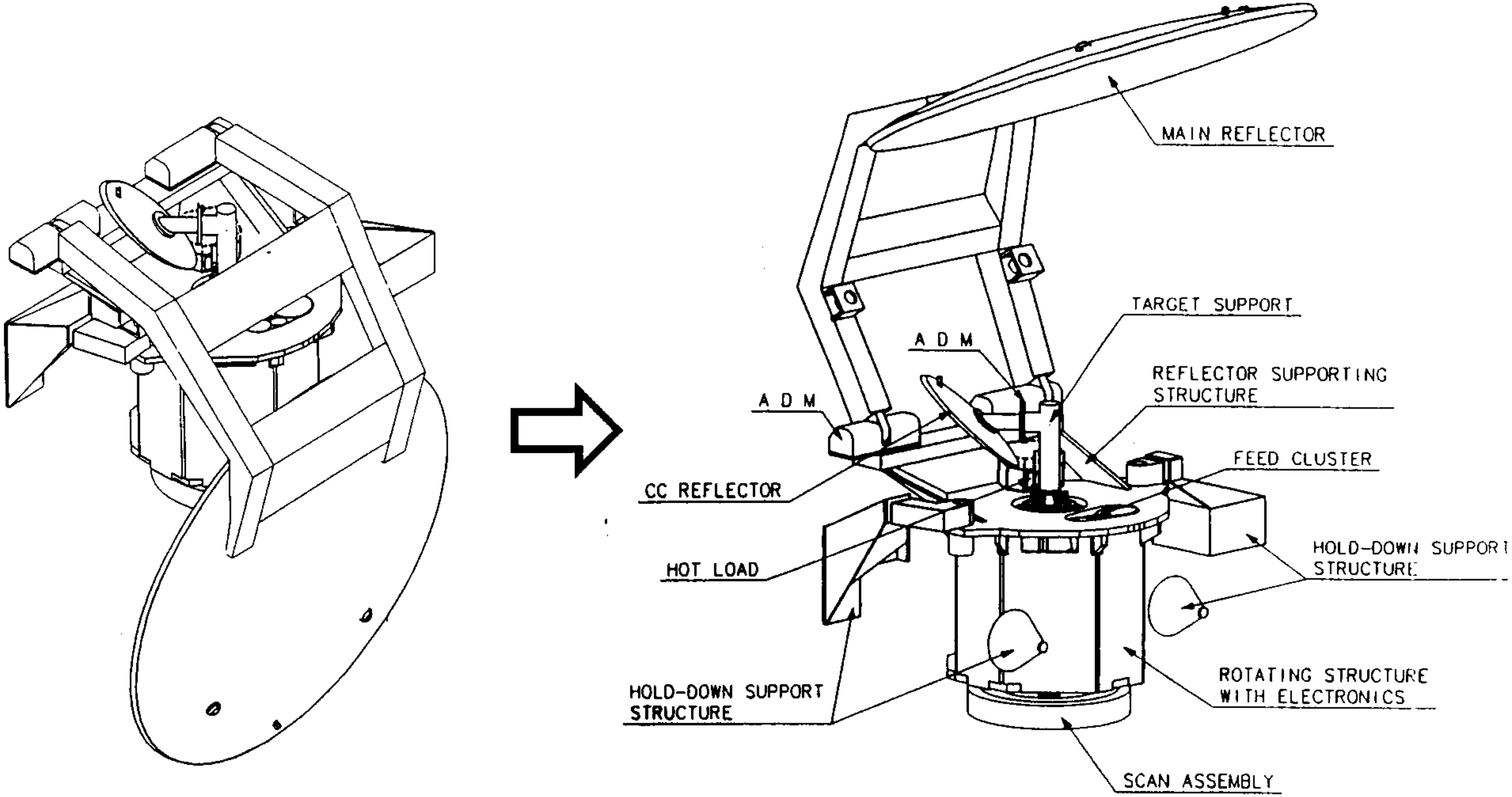
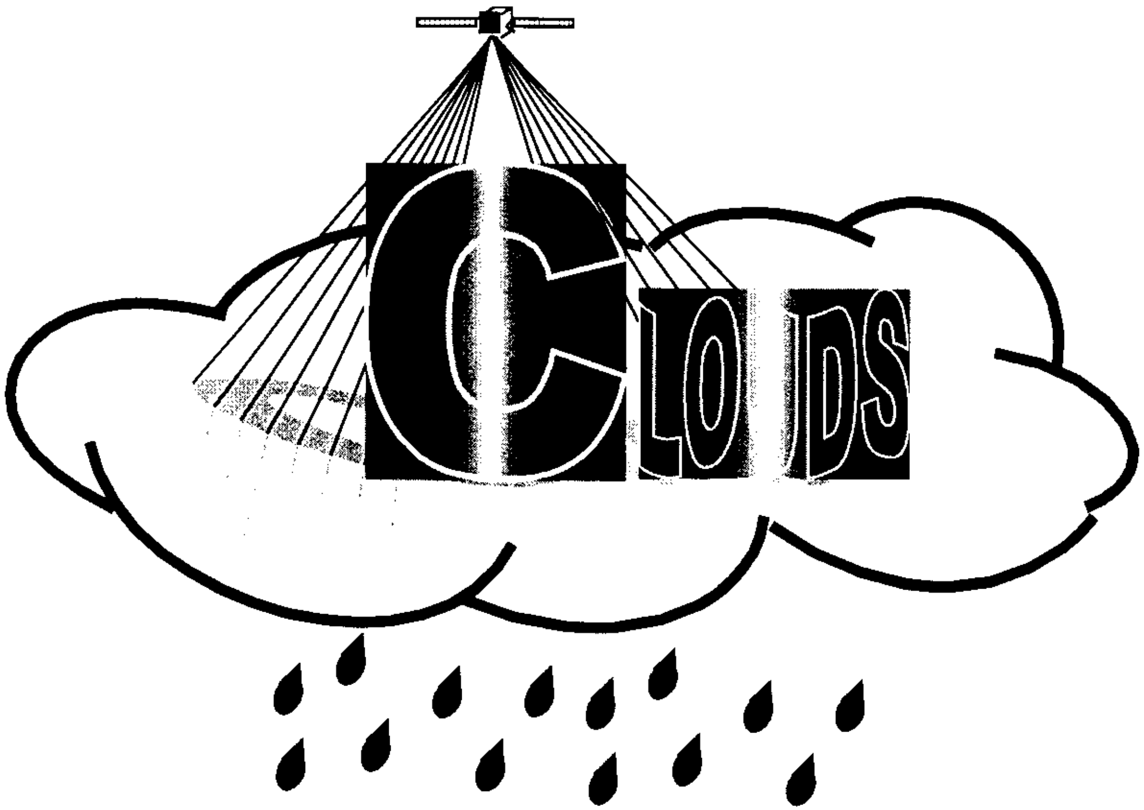
INSTRUMENT CONFIGURATION



some fixed units, accommodated inside the platform, are not shown

CLOUDS Satellite



CLOUDS
a Cloud and Radiation monitoring satellite

Project supported by the EC under FP-4 "Environment and Climate"

Project Coordinator: Bizzarro Bizzarri (*for Alenia Aerospazio*)

Partnership

Alenia Aerospazio, Divisione Spazio (Italy)	*Roberto Bordi*
Matra Marconi Space (UK)	*Norman Grant*
Radiometer Physics GmbH (Germany)	*Peter Zimmermann*
Officine Galileo (Italy)	*Peter Coppo*
Sofradir (France)	*Laurent Vial*
Imperial College of Science, Technology and Medicine (UK)	*John Harries*
CNRS/Laboratoire de Météorologie Dynamique (France)	*Michel Desbois*
Universität Bremen, Institut für Umweltphysik (Germany)	*Klaus Künzi*
CNR/Istituto di Fisica dell'Atmosfera (Italy)	*Alberto Mugnai*
UKMO, Hadley centre for climate prediction and research (UK)	*Anthony Slingo*
Servizio Meteorologico Regionale Emilia-Romagna (Italy)	*Stefano Tibaldi*
Università di Roma, Dipartimento di Fisica (Italy)	*Alfonso Sutera*

User Advisory Group

Wolfgang Benesch, *Deutscher Wetterdienst*	Jean Pailleux, *Météo France*
Franco Einaudi, *NASA/GSFC*	Hans Peter Roesli, *Swiss Met Institute*
Christian Jakob, *ECMWF*	Keith Shine, *University of Reading*
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Albin Gasiewski, *NOAA/ETL*	Graeme Stephens, *University of Colorado*
Paolo Pagano, *Italian Met Service*	Jens Sunde, *Norwegian Met Institute*

Observers: EC (Michel Schouppe), ESA (Paul Ingmann), EUMETSAT (Alain Ratier)

CLOUDS: Mission Objectives

The objective of CLOUDS is to study a new satellite to provide accurate, comprehensive, consistent and frequent information on cloud structures and on the associated radiative parameters. The information will be used by meteorological services and research centres to improve weather forecasting and climate modelling.

The lack of information on cloud internal structure and contextual radiation field is such that it is presently considered as probably the major limiting factor of long-term weather prediction and eventually climate prediction.

CLOUDS is proposed as a monitoring mission. Its strategic objective is to extend the overall European service of climate monitoring from Space, beyond what is achievable by the instrumentation presently foreseen for MSG and METOP/EPS, whose mission definition has been driven by nowcasting and short-medium term weather prediction

CLOUDS: User Requirements

User requirements

The core features to be observed for a Cloud and Radiation monitoring mission are:

- the ***cloud "classical" parameters*** mostly referring to the top surface, with emphasis on ice/liquid discrimination and size
- the ***cloud interior***, specifically water phase (ice or liquid) and whether drop size is likely to produce precipitation
- the ***outgoing radiation*** from Top of Atmosphere to Space
- the main parameter impacting with both clouds and radiation in the 3-D atmosphere, i.e. ***aerosol***
- the primary source of clouds, i.e. ***water vapour***, also primary factor of radiative processes in the 3-D atmosphere
- the indicator of final removal of water from the atmosphere, i.e. ***precipitation***.

The list of geophysical parameters addressed by *CLOUDS* is shown in ***Table 1***, which also shows a number of "parameters of opportunity" which will be observed by the instrumentation primarily defined to address the cloud and radiation parameters.

User requirements for the *CLOUDS* mission have been defined with the help of a *User Advisory Group*, starting from pre-existing collections tailored around the *CLOUDS* mission objectives. Two applications have been addressed:

- ***climate monitoring and research***
- ***weather prediction and research meteorology***.

Very detailed requirements have been established for the quality of each individual parameter to be observed (listed in Table 1). Their common features are shown in ***Table 2***. It can be observed that, if the mission requirements are established with regard to the user requirements for weather prediction, the requirements for climate are implicitly fulfilled after space and time averaging over less than one week.

Table 1 - *CLOUDS* observations

Geophysical parameters to be measured by *CLOUDS*
Cloud imagery (pattern, fronts, cyclones, ash plumes ...)
Cloud type, cover, top height and temperature
Cloud ice content and drop size (at cloud top)
Precipitation rate at ground, precipitation index (daily cumulative)
Water vapour - total column and gross profile
Cloud water (< 100 μm) - total column and gross profile
Cloud water (> 100 μm) - total column and gross profile
Cloud ice - total column and gross profile
Cloud optical thickness, short-wave reflectance, long-wave emissivity
Short-wave and long-wave outgoing radiation at Top of Atmosphere
Aerosol - total column and gross profile
Ozone - total column (for tropopause discontinuities)
Opportunity parameters, not part of the *CLOUDS* objectives
Sea-surface temperature and wind, sea-ice cover and type, icebergs
Land ice/snow imagery, snow cover and melting conditions
Soil moisture, apparent thermal inertia, vegetation indexes

Table 2 - Generic user requirements for cloud and radiation observation

Application	Quality feature	Representative requirements
Climate monitoring & research	Horizontal resolution: Vertical resolution: Accuracy: Observing cycle: Data available within:	100 km (target 30, threshold 300) 3-4 layers in the troposphere reached after average over < 1 week 12 h (integration from 3 h sampling) 3 d
Weather prediction & research meteorology	Horizontal resolution: Vertical resolution: Accuracy: Observing cycle: Data available within:	30 km (target 10, threshold 100) 3-4 layers in the troposphere level of bias < 20 % of r.m.s.d. 3 h 3 h

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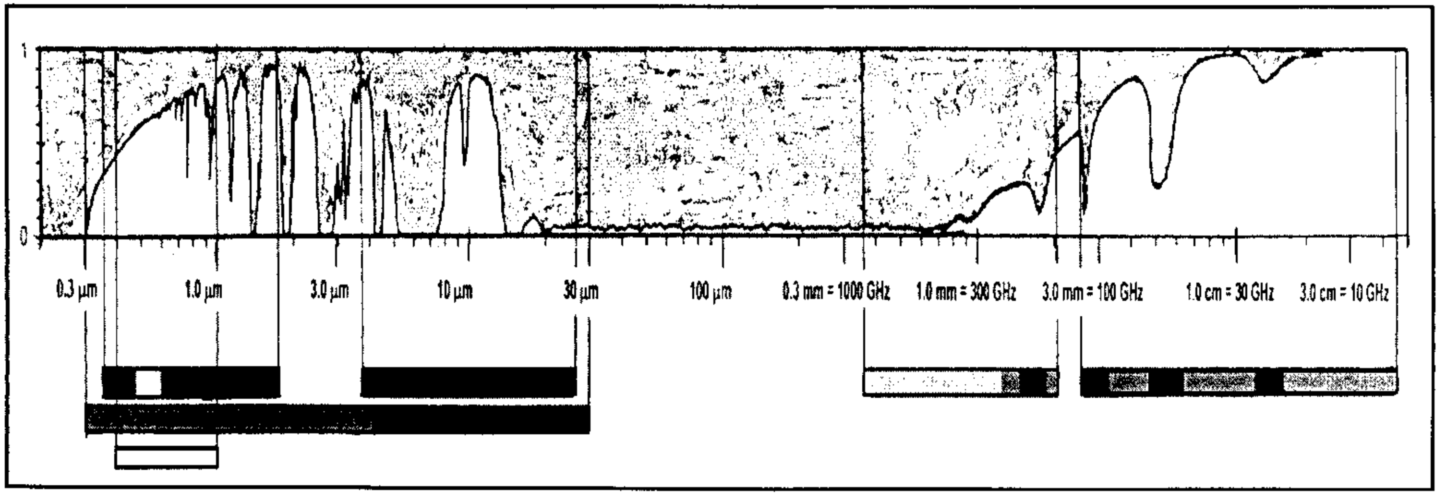
CLOUDS: Mission Requirements

Mission requirements

The mission requirements established for *CLOUDS* are strongly conditioned by the monitoring objective, which implies compliance with *long-term sustainability requirements*, and the requirement for an observing cycle consistent with routine use. The main consequences of these requirements are:

- only passive instruments can be used, to ensure a swath of at least 1400 km for a daily global coverage; also to achieve long life-time and to reduce power/weight requirements
- in exchange, all other means are allowed: e.g., measurements of more polarisations and observation under more viewing angles
- synergy with METOP is envisaged, in order to enable framing the *CLOUDS* information within basic meteorological fields, specifically accurate temperature and water vapour profiles.

The key aspect of the *CLOUDS* mission is the exploitation of a widest range of the e.m. field to collect as many "signatures" as possible of the different parameters to be measured. ***Fig. 2*** shows that *CLOUDS* instruments cover a range of wavelengths from ≈ 0.3 μm to ≈ 4 cm, spanning by 5 orders of magnitude !



CLOUDS: Mission Requirements

Table 3 lists the short-wave narrow-band channel requirements. Use of these channels, obviously only available in daylight, is:

- to detect most types of clouds over most types of background (sea, vegetated land, bare land, snow, ...)
- to classify several types of clouds and, specifically, discriminate ice from liquid at cloud top, with inference of drop size; and estimate cloud optical thickness
- to detect and measure aerosol, over sea and possibly over land, with inference of vertical distribution (specific for this are the U channels and the triple polarisation in a couple of channels)
- to measure components of the short-wave Earth radiation budget (in more spectral sub-ranges, from clouds, aerosol, water vapour

Table 3 - Mission requirements for short-wave narrow-band channels

λ	$\Delta\lambda$	SNR @ ρ=10 %	Calibration accuracy	Polarisations	Dual view	IFOV
334.5 nm	5 nm	1000				20 km
388.0 nm		500		not required		10 km
443.0 nm						
555.0 nm						
670.0 nm	20 nm		5 %	three	required	
865.0 nm		200		not required		5 km
910.0 nm						
1,240.0 nm				three		
1,380.0 nm	30 nm			not required		
1,610.0 nm						

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CLOUDS: Mission Requirements

Table 4 lists the narrow-band channels in the Thermal IR up to the limit of Far IR. Use of these channels is:

- to perform "classical" cloud observations (cover, type, top temperature and height) and to estimate cloud emissivity
- to particularly address cirrus clouds (for the "signature" of cirrus clouds in the 10-100 μm range)
- to measure components of the long-wave Earth radiation budget (in more spectral sub-ranges, from clouds, from water vapo ...).

<table>
<tr><th colspan="7">Table 4 - Mission requirements for TIR/FIR channels</th></tr>
<tr><th>λ</th><th>Δλ</th><th>NEΔT</th><th>Calibr. accur.</th><th>Polari-sations</th><th>Dual view</th><th>IFOV</th></tr>
<tr><td>3.74 μm</td><td>0.40 μm</td><td>0.50 K @ 300 K</td><td rowspan="10">1 K</td><td rowspan="10">not required</td><td rowspan="10">required</td><td rowspan="8">5 km</td></tr>
<tr><td>6.25 μm</td><td>1.00 μm</td><td>0.30 K @ 250 K</td></tr>
<tr><td>7.35 μm</td><td>0.50 μm</td><td>0.30 K @ 250 K</td></tr>
<tr><td>8.70 μm</td><td>0.50 μm</td><td>0.10 K @ 280 K</td></tr>
<tr><td>9.66 μm</td><td>0.50 μm</td><td>0.30 K @ 250 K</td></tr>
<tr><td>10.8 μm</td><td>1.00 μm</td><td>0.10 K @ 300 K</td></tr>
<tr><td>12.0 μm</td><td>1.00 μm</td><td>0.10 K @ 300 K</td></tr>
<tr><td>13.4 μm</td><td>0.50 μm</td><td>0.30 K @ 280 K</td></tr>
<tr><td>18.2 μm</td><td>1.40 μm</td><td>0.20 K @ 220 K</td><td rowspan="2">40 km</td></tr>
<tr><td>24.4 μm</td><td>0.80 μm</td><td>0.20 K @ 220 K</td></tr>
</table>

CLOUDS: Mission Requirements

Tables 5 and ***Table 6*** show the channels provided for Earth Radiation Budget at TOA. In addition to the "classical" broad-band shor and long- wave channels, there is one channel (0.4-1.0 μm) providing measurements at more viewing angles to infer bi-direction reflectance functions to enable flux computations. The ERB mission is greatly enhanced by the synergism with the narrow-ban channels covering the 0.3-30 μm range, with higher geometric resolution and more polarisations to identify both the spectral sub components and the reflectors/emitters distribution within the broad-band channels IFOV.

Table 5 - Mission requirements for broad-band channels

Channel	NEΔR	Calibration accuracy	Polari-sations	Dual view	IFOV
0.3-4.0 μm	0.5 $Wm^{-2}sr^{-1}$	1.0 $Wm^{-2}sr^{-1}$	two	required	40 km
4-30 μm	0.5 $Wm^{-2}sr^{-1}$	0.5 $Wm^{-2}sr^{-1}$	not required		

Table 6 - Mission requirements for the multi-viewing channel

Channel	Viewing geometry	SNR @ ρ = 10 %	Calibr. accur.	Polari-sations	Dual view	IFOV
0.4-1.0 μm	$\alpha = 21°$ $\alpha = 33°$ $\alpha = 45°$ $\alpha = 57°$	200	5 %	not required	required	5 km

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CLOUDS: Mission Requirements

Table 7 shows requirements for a novel spectral range, in the Sub-mm region, with additional channels in the water vapour absor band. The use of these channels is:

- to determine cloud phase and perform evaluation of cloud ice amount, possibly with inference of vertical distribution
- to make use of the water vapour structure observation to infer the depth of convective penetration in the troposphere.

Table 7 - Mission requirements for Sub-mm and H_2O channel

ν	Δν	NEΔT	Calibr. accur.	Polari-sations	Dual view	IFOV
874.38 ± 6.0 GHz	3.0 GHz					
682.95 ± 6.0 GHz	3.0 GHz	1.0 K @ 240 K		two		
462.64 ± 3.0 GHz	2.0 GHz					
220.50 ± 3.0 GHz	2.0 GHz		1.5 K		required	10 km
183.31 ± 1.0 GHz	1.0 GHz	1.0 K @ 240 K				
183.31 ± 3.0 GHz	2.0 GHz	1.0 K @ 260 K		not required		
183.31 ± 7.0 GHz	4.0 GHz	1.0 K @ 280 K				
150 GHz	4.0 GHz	1.0 K @ 300 K		two		

CLOUDS: Mission Requirements

Table 8 shows requirements for MW channels, inclusive of the O_2 bands around 55 and 118 GHz. The purpose is:

- to observe precipitating clouds over both sea and land
- to attempt deriving as much information as possible on water phase, drop size and vertical distribution of liquid and precipitati clouds by sensing at frequencies differently affected by different drop size and air temperature.

Table 8 - Mission requirements for MW channels including O_2

ν	Δν	NEΔT	Calibr. accur.	Polari-sations	Dual view	IFOV
118.75 ± 1.0 GHz	1.0 GHz	0.5 K @ 230 K	1.5 K	not required	required	10 km
118.75 ± 1.5 GHz		0.5 K @ 250 K				
118.75 ± 2.0 GHz		0.5 K @ 270 K				
118.75 ± 4.0 GHz		0.5 K @ 290 K				
89.0 GHz	3.0 GHz	1.0 K @ 300 K		two		5 km
55 GHz	0.5 GHz	0.5 K @ 230 K		not required		10 km
54 GHz		0.5 K @ 250 K				
53 GHz		0.5 K @ 270 K				
50 GHz		0.5 K @ 290 K				
36.5 GHz	1.0 GHz	0.7 K @ 300 K		two		
23.8 GHz	0.4 GHz	0.6 K @ 250 K				20 km
18.7 GHz	0.2 GHz	0.5 K @ 300 K				
10.6 GHz	0.1 GHz	0.4 K @ 300 K				40 km
6.9 GHz	0.3 GHz	0.3 K @ 300 K				

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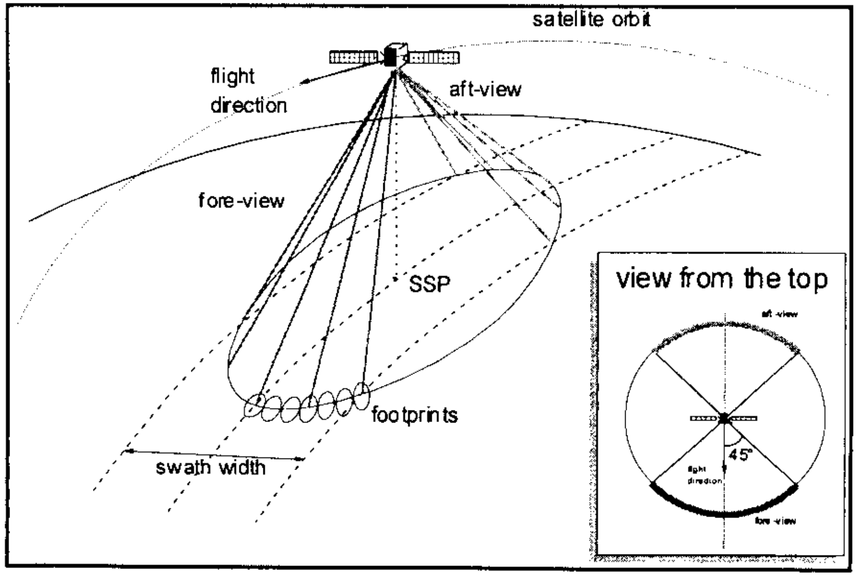
CLOUDS: Instrument Requirements

Instrument requirements

An important requirement to note is that all channels in *CLOUDS* must have consistent scanning mechanism, so as to ensure compati viewing geometry and make possible accurate co-registration, for a true multi-spectral approach, as necessary when dealing with frac fields. Since most channels require differential polarisation, ***conical scanning*** is most suitable.

Six instruments have been defined, to comply with the mission requirements as set up in Tables 3 to 8, respectively. The four opti instruments will rotate at 1 scan / 8 s, the MW and Sub-mm instruments at 1 scan / 2 s. To be noted that conical scanning ensu constant IFOV size across the observed field. For most channels of the optical instruments the IFOV will be 5 km (exceptions: the t broad-band channels and the two channels near to FIR, which however will be sampled at 5 km for co-registration purposes). M channels of the MW and Sub-mm instruments will have 10 km IFOV (exceptions: 89 GHz with 5 km and low-frequency MW chann with IFOV degrading according to the diffraction limit).

All instruments will have in-flight calibration. Co-registration requirements are rather stringent, ranging from 1/16 to 1/2 of a pix depending on the specific set of channels to be co-processed.



CLOUDS: System Requirements

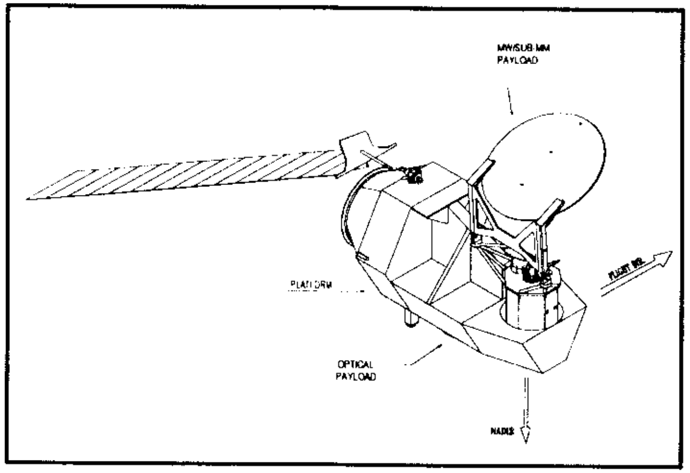
System requirements

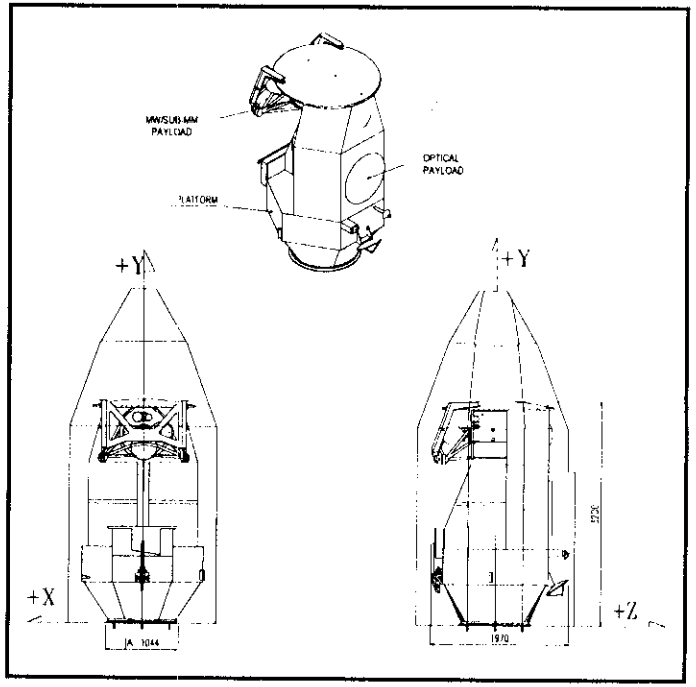
The main ***system requirements*** of *CLOUDS* are:

- orbit: sun-synchronous, to chase METOP de-phased by 30 min (H = 840 km, ε = 98°, T = 101.7 min, LST = 10 h)
- design lifetime: 5 years, to ensure a total mission duration of 15 years by three successive satellites
- both direct read-out and global acquisition to be provided
- commonality of ground segment with METOP/EPS.

After one year of studies (*Phase 0* and *pre-Phase A*) a ***system baseline*** has been defined. Preliminary size estimates are:

- satellite mass: 750 kg
- electric power requirement: 1000 W
- data rate for local read-out (S-band): 1.1 Mbps
- data rate for global acquisition at CDA (X-band): 30 Mbps.





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CLOUDS: Programmatics

Programmatics

The *CLOUDS* project envisages now a full *Phase A* study, to confirm technical feasibility and provide a design at level of system a major sub-systems. The supporting scientific studies will attempt demonstrating that, if the instrument performances are achieved expected, the output products will have quality sufficient to meet the user requirements. This will, i.a., enable to outline a prelimina configuration of the *ground segment*.

If *CLOUDS* is confirmed to be feasible within the programmatic constraint of a small-medium size satellite, a proposal for a follow-activity will be put forward. The aim is, first, to add this "small" element (< 20 % of METOP mass) to complement the METOP/E mission, and then to have a first component of a possible post-METOP system where the overall meteo-climatological operation monitoring mission is split to be implemented by more small-medium size satellites.

ENVISAT-1 MWR

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ENVISAT-1 MICROWAVE RADIOMETER

Background

Designed and developed by the European Industry under ESA contract, will be part of the ENVISAT-1 satellite scientific payload.
Alenia Aerospazio is the Instrument Prime Contractor, responsible for design and development, leading an Industrial Consortium of European and American companies.

Instrument Flight Model development was completed end of July 1997; it is the first flight model instrument delivered to the Envisat-1 Mission Prime.

Engineering Models and breadboards of all the Instrument constituents were developed, providing a sound baseline for Instrument Flight Model.

MWR Mission Overview

- Two channel passive microwave radiometer operating at 23.8 GHz and 36.5 GHz, based on the Dicke radiometer principle.

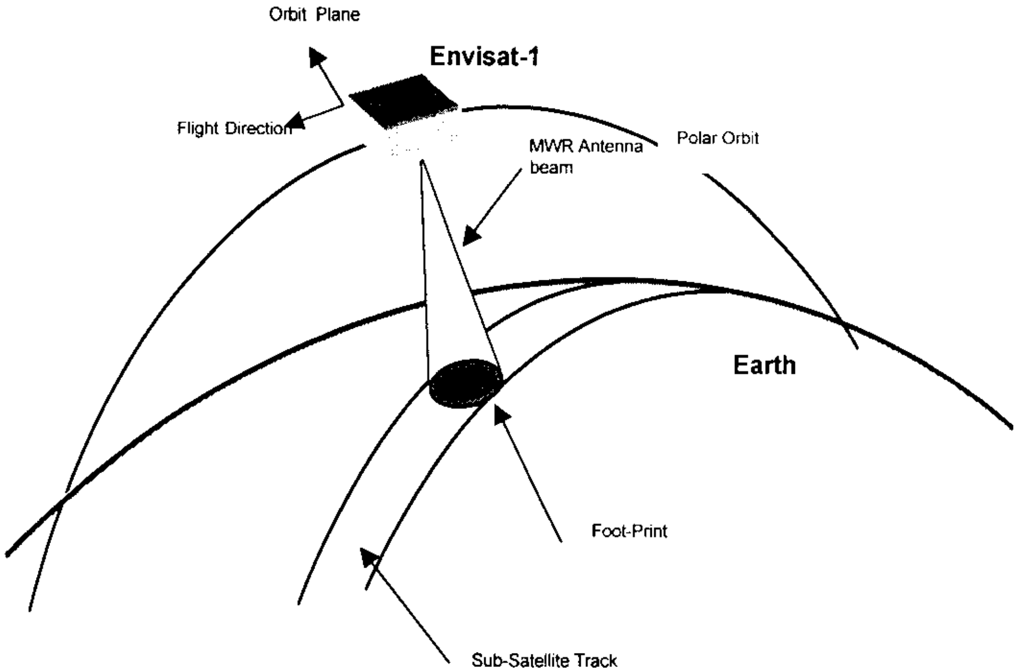
- Designed primarily to measure the total atmospheric water vapor and atmospheric liquid water along the sub-satellite track.

- Scientific data produced will be primarily used for correction of range measurement of ENVISAT-1 Radar Altimeter, *(delay in the return of the altimeter pulse throughout the troposphere)*.
  Also they will be useful for meteorological research and operational meteorological modeling, as part of a series of important atmospheric monitoring instruments.

- Data gathered by MWR are also used for atmospheric studies, land studies (i.e. soil moisture, surface emissivity), and ice characterization (i.e., ice boundaries associated with the RA2, and surface ice properties).

MWR Mission Overview (Cont.'d)

Geodetic Polar Orbit due to the pitch control oft the Envisat-1 satellite, *platform Z axis pointed nominally normal to the Earth surface at the sub-satellite point*, not to the Earth center like geocentric case



Incidence angle, between the beam electrical boresigth direction and the normal to Earth surface: *feeds orientation is such that two antenna off-nadir angles are achieved for the 23.8 and 36.5 GHz channels (afterward and forward looking feeds, squint of about 3°)*

MWR Mission Overview (Cont.'d)

Geometrical Parameters

- Spatial resolution is related with the ground footprint determined by the antenna main beam projection onto the earth surface

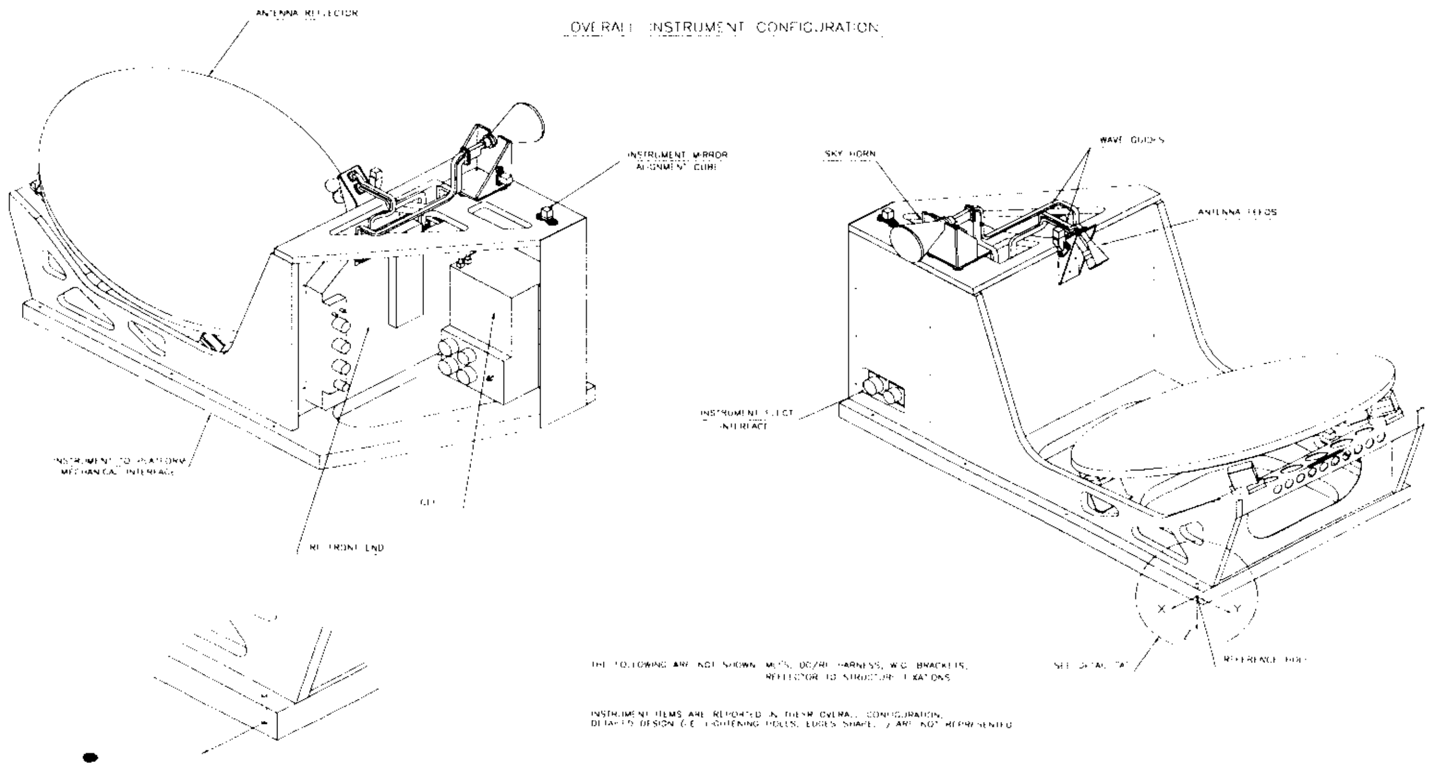
- Longitudinal Footprint dimension FPL (along track) and a Transverse Footprint dimension FPS (across track) can be defined

Channel	*Angular Resolution (θ in degree)*	*MIN Orbit Altitude FPS (= FPL), Km*	*MAX Orbit Altitude FPS (= FPL), Km*
23.8 GHz	1.527	20.82	21.62
36.5 GHz	1.429	19.66	20.42

The sampling distance along track considering the sampling interval of 150 msec, and the satellite velocity on ground of 7 Km/sec, is equal to 1.05 Km .

MWR Outline Characteristics

Performance	Requirement	Achievement
Instrument Mass	< 30 Kg	24 Kg
Operational Power	< 50 Watts	18 Watts
Scientific Data rate	426.66 bit/sec	426.66 bit/sec
Command Interface	24 bits serial, 150 msec rate	24 bits serial, 150 msec rate
Data interface	64 bits serial, 150 msec rate	64 bits serial, 150 msec rate



MWR Concept

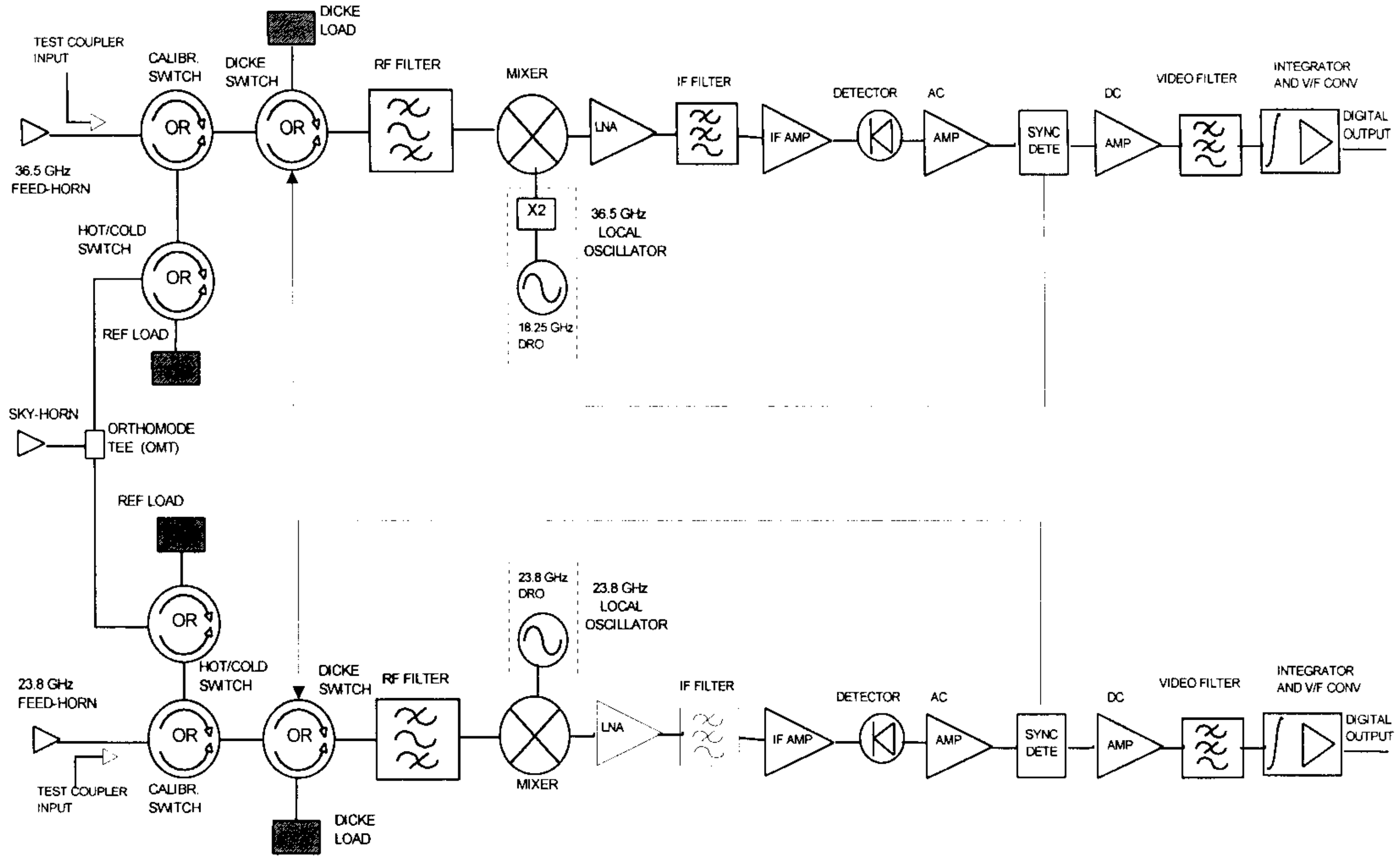
Functional Characteristics, Features

Architecture based on the Dicke configuration:

- reduces the effects of the receiver short term instabilities
- measures the difference between the observed scene temperature and a known internal reference temperature *(not directly the antenna noise temperature like in Total Power radiometer case)*.
- provides higher radiometric sensitivity and accuracy performance when the antenna noise temperature is similar compared to the internal reference temperature (Dicke Load).

In addition the Instrument includes a two points off-line absolute calibration of the overall receiver, by use of a cold and hot reference sources.

MWR Concept (Cont.'d)



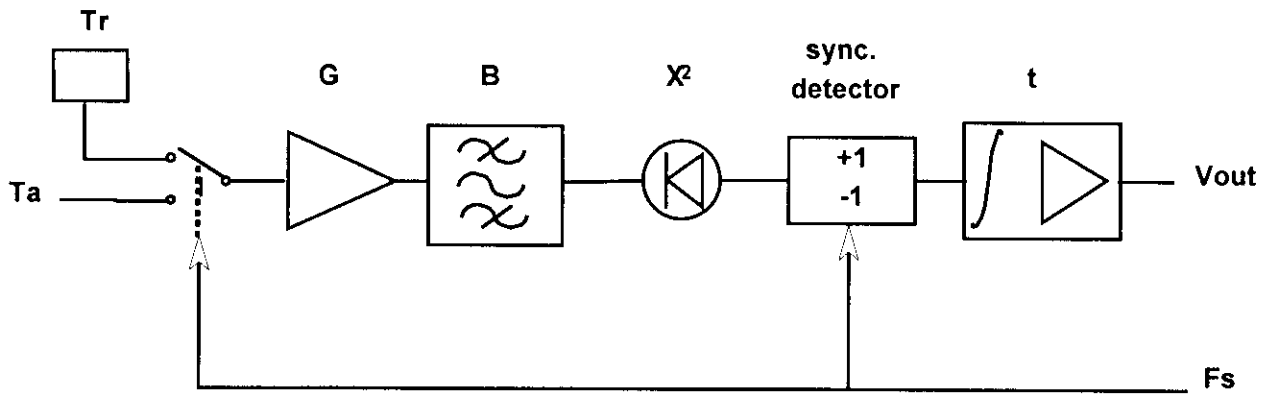
MWR Concept (Cont.'d)

- The noise signals are filtered from sidebands spurious signals, down converted and low noise amplified in the Radio Frequency Front-End
- IF amplification, band defining filtering, quadratic detection and sampling of the signals is performed by the Centralized Electronic Unit (CEU)
- RF components physical temperatures is measured by precision platinum thermistors (PRTs): *data are used for reconstruction of the Antenna Temperature on ground by use of a calibration mathematical model.*
- Two points calibration implemented via dedicated feed-horn pointing the deep space (cold), and on-board precision ambient load (hot)
- The calibration model and the ground characterization data-base allows the calibration of measured data.

Several inter-calibration periods actionable by ground command, to establish the number of antenna measurements before of hot and cold calibration.

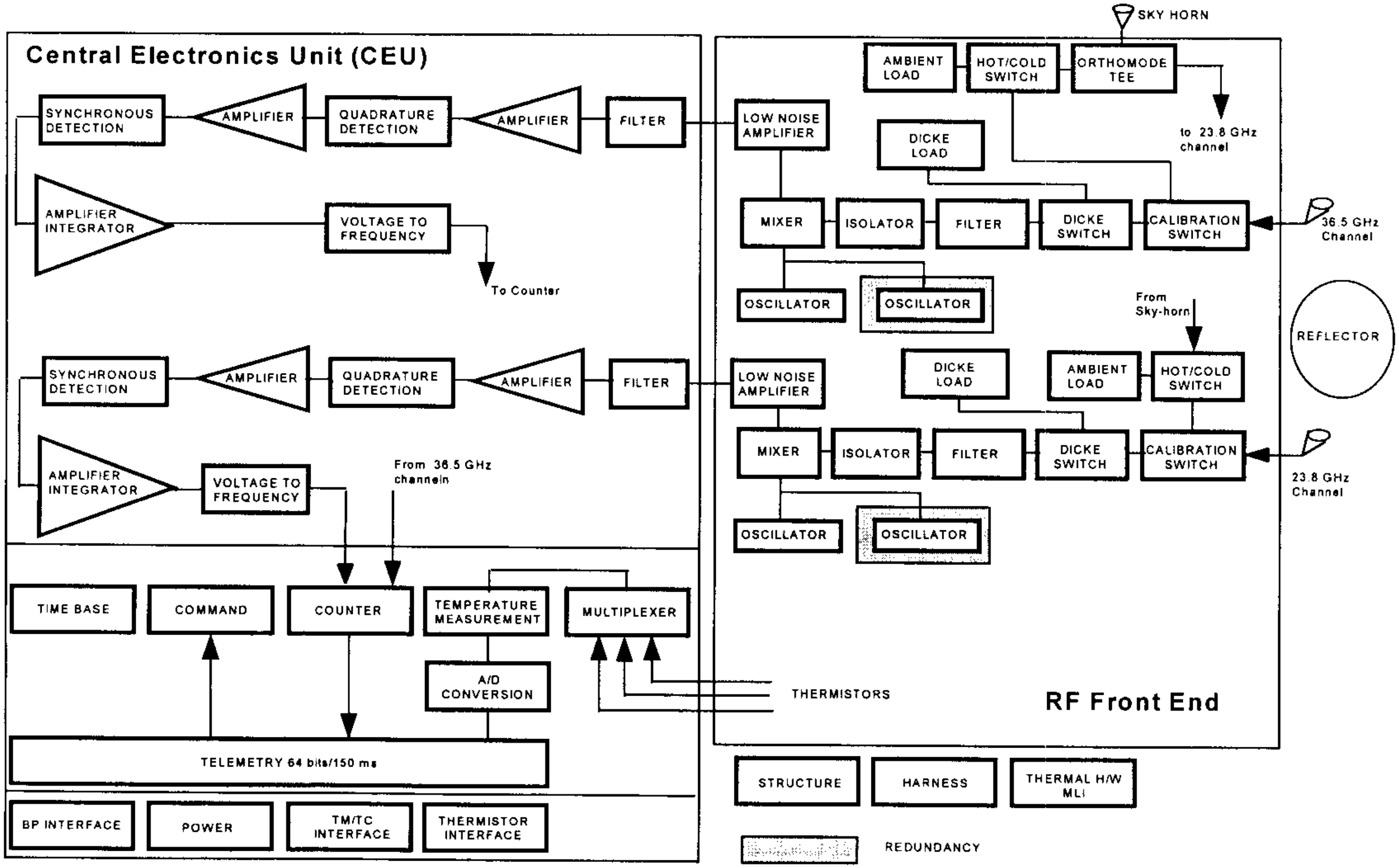
MWR Concept (Cont.'d)

Dicke Radiometer Architecture



- Improved short term gain stability but degraded (1/2 according to theory) radiometric sensitivity performance when compared to Total power radiometer concept
- The input of the receiver is switched between the Antenna temperature (Ta) and the reference temperature (Tr), at Fs typically about 1 KHz.
- Square law detector output is multiplied synchronously to the Dicke switch position by +1 or -1
- Fs is selected in order that Ta, Tn and G can be regarded as constant over the period, thus reducing the receiver intrinsic instabilities (1/f flicker noise, etc.)

MWR System Architecture



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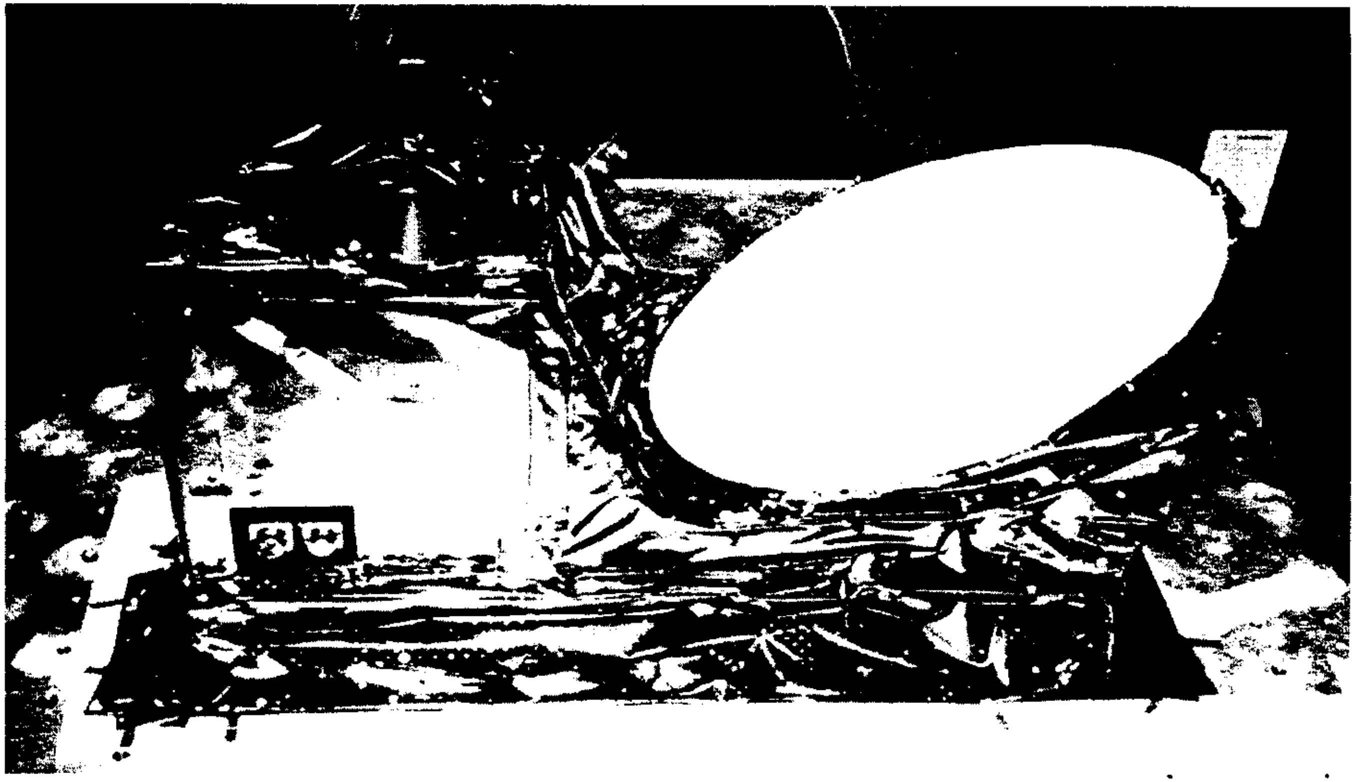
MWR view



MWR Calibration Philosophy

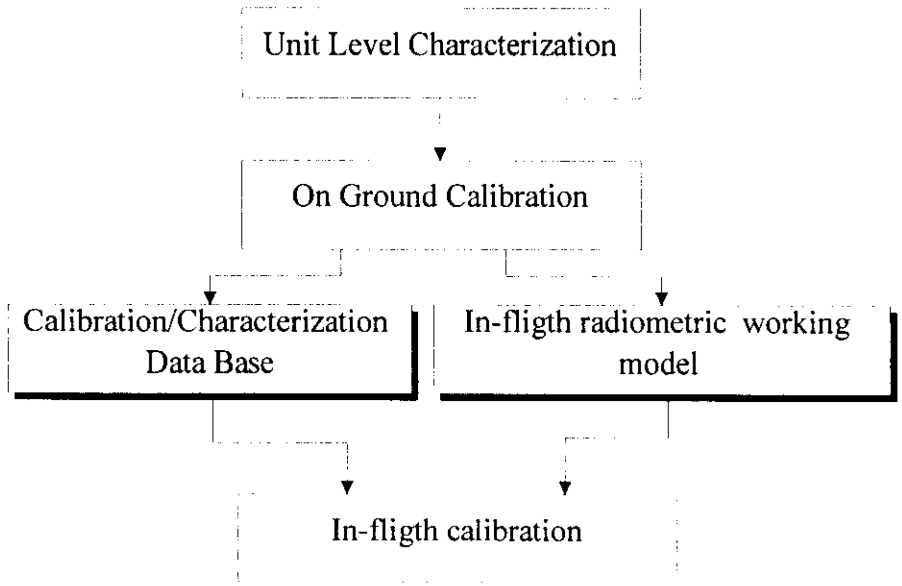
The calibration of MWR radiometer is based on

- the identification of a radiometric model,
- the on-ground characterization of the model itself,
- on-board use of two calibrated temperature provided by an hot load and by the cold sky as seen by a dedicated horn

MWR CALIBRATION

The radiometric calibration has been divided into two main activities:

- pre-flight calibration, during which the parameter values involved in antenna temperature retrieval (and their uncertanties) were assessed with the instrument fully integrated (after unit level characterization) and organized in a data base to be used during flight.
- in-flight calibration, in order to periodically calibrate the radiometric path using pre-flight charaterized reference loads (reference temperatures).



MWR Key Performance Summary

Performance	Requirement	Achievement
Radiometric Sensitivity	< 0.6 K	0.4 K
Integration Time	150 msec	150 msec
Radiometric Stability	< 0.6 K	0.4 K
Dynamic Range	3K to 330K	3K to 335K
Non-linearity	< 0.5 K	0.35 K
Radiometric Accuracy (after calibration)	< 3 K with Tant = 300K	1 K, with Tant = 300K < 3K with Tant = 85 to 330K
On board settable Intercalibration period	38.4, 76.8, 153.7, 307.4 sec	38.4, 76.8, 153.7, 307.4 sec
Noise Figure	< 6.8 dB incl. Antenna	4.8 dB incl. Antenna
Center Frequency accuracy 36.5 and 23.8 GHz	< ± 10.0 MHz	< ± 3.0 MHz
Center Frequency Stability (temperature and life)	< 0.75 MHz/°C	< 0.2 MHz/°C
RF Pass Band, both channels 40 dB stop-band, both channels	± 200 MHz ± 340 MHz	± 200 MHz ± 340 MHz
Antenna Polarization	Linear (Vertical)	Linear (Vertical)
Antenna Reflector diameter	0.6 mt.	0.6 mt.
Antenna Radiation Efficiency	> 93 %	97 %
Antenna Main Beam Efficiency	> 89 %	94 %
Antenna Side Lobes Level (in 3° half angle)	-22 dB at 23.8 GHz -30 dB at 36.5 GHz	24 dB 31 dB
Antenna Pattern Ellipticity	< 0.4°	< 0.3 °
Antenna Half Power beamwidth (3 dB)	< 1.7°	1.5 °

ACE Mission

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☑ Mission Objectives

❍ Mission Primary Objectives

the ACE **mission primary objectives** are:

- to focus on the chemistry of the upper troposphere / lower stratosphere ;
- to investigate the exchange of trace gases (in particular water vapour and ozone);
- to investigate the exchange of radiative and kinetic energy, between these two regions.

❍ User Needs

Stratosphere:

a) changes arising from increases in the concentrations of tropospheric gases,

b) the radiative energy balance at the tropopause level,

c) the dynamical structure of the lower stratosphere / upper troposphere.

Troposphere:

a) accurately determine the changes in the oxiding properties of the troposphere and in radiative forcing, both at the surface and at the tropopause,

b) to advance knowledge of the chemical processes involved, in particular those controlling the life time of greenhouse gases.

☑ Mission Requirement and Constraints

❍ Functional Requirements

Geophysical Parameters to be estimated

Geophysical Variables	Mission Objectives		
	Lower Stratosphere	Upper Troposphere	Stratosphere/Troposphere Exchange
O_3	*	*	*
ClO_x	*		
NO_x	*	*	*
BrO_x	*		
HO_x	*	*	
CO		*	*
H_2O	*	*	*
CH_4		*	*
N_2O			*
$ClONO_2$	*		
HNO_3	*	*	*
HCl	*		
SO_2	*	*	*
Temperature	*	*	*
Aerosols/PSCs	*	*	
Clouds		*	

☑ Mission Requirement and Constraints

❍ Functional Requirements

Geophysical Parameters Distributions in 3-D: Combination of limb measurements optimised for vertical resolution with nadir measurements optimised for horizontal resolution.

ACE Payload Required Properties: MASTER and OSIRIS.

Data Product Quality: the quality of the data product is directly affected by the sophistication of the ground segment which has to be considered as an integral part of the mission.

Coverage: Full coverage of latitudinal, longitudinal and seasonal variability are required (including polar areas) for each geophysical parameter to be estimated.
Significant gap in data provisions (whether in the observed geophysical variables or in the spatial coverage of the observations) are still acceptable provided they can occasionally be filled by data from complementary sources (i.e. ground based, balloon borne or air borne) or atmospheric models.

☑ Mission Requirement and Constraints

❍ Functional Requirements

Data Sources: The list of geophysical parameters required to fulfil the mission objectives can be covered processing the data taken with:

- the payloads on-board ACE spacecraft: MASTER, OSIRIS (and GRAS),
- some complementary data taken with the instruments on-board other satellite such as METOP and ENVISAT
- data from fields campaigns that use ground-based, balloon and aircraft measurements.

Measurement Coregistration: Near simultaneous observations of the same air sample with both nadir sounding (i.e. OMI/GOME and IASI on board METOP) and limb sounding instruments (MASTER and OSIRIS on board ACE and MIPAS/SCHIAMACHY on ENVISAT).

Orbit: as METOP.

☑ Mission Requirement and Constraints

❍ Operational Requirements and Constraints

ACE/METOP Configuration Maintenance: the time difference between the observations of a given part of the atmosphere by MASTER and OSIRIS on one side and IASI and OMI/GOME on the other side is less than the difference inherent to limb and nadir sounding instruments if they were located on the same platform (i.e. +/- 7 minutes equivalent to about 2800 km of distance along the subsatellite track).

Mission Operational Duration: four years, but consumables have to be planned for six years.

Schedule: The launch date is assumed to be 1 January 2003.

ACE Mission Spacecraft Class: in the range of 1000 kg of mass and less than 1000 W of power.

Special Operations: could be requested to the ACE mission to observe particular events.

LEOP: LEOP are expected to be standard.

Launchers: Dedicated European launchers, e.g. Eurockot, shall be considered as reference. Alternative American dedicated launchers shall be considered as back-up.

☑ Mission Operations Analysis and Design

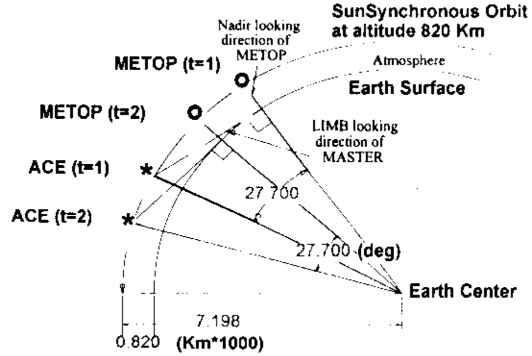
❍ Mission Operations (definition):

Mission operations shall be devoted to manage the spacecraft and the ground system, they have to be defined with the objective to provide the required data to the user community (mission objective), remaining at the same time within the constraints on the available resources.

❍ Mission Scenario Operational Implications :

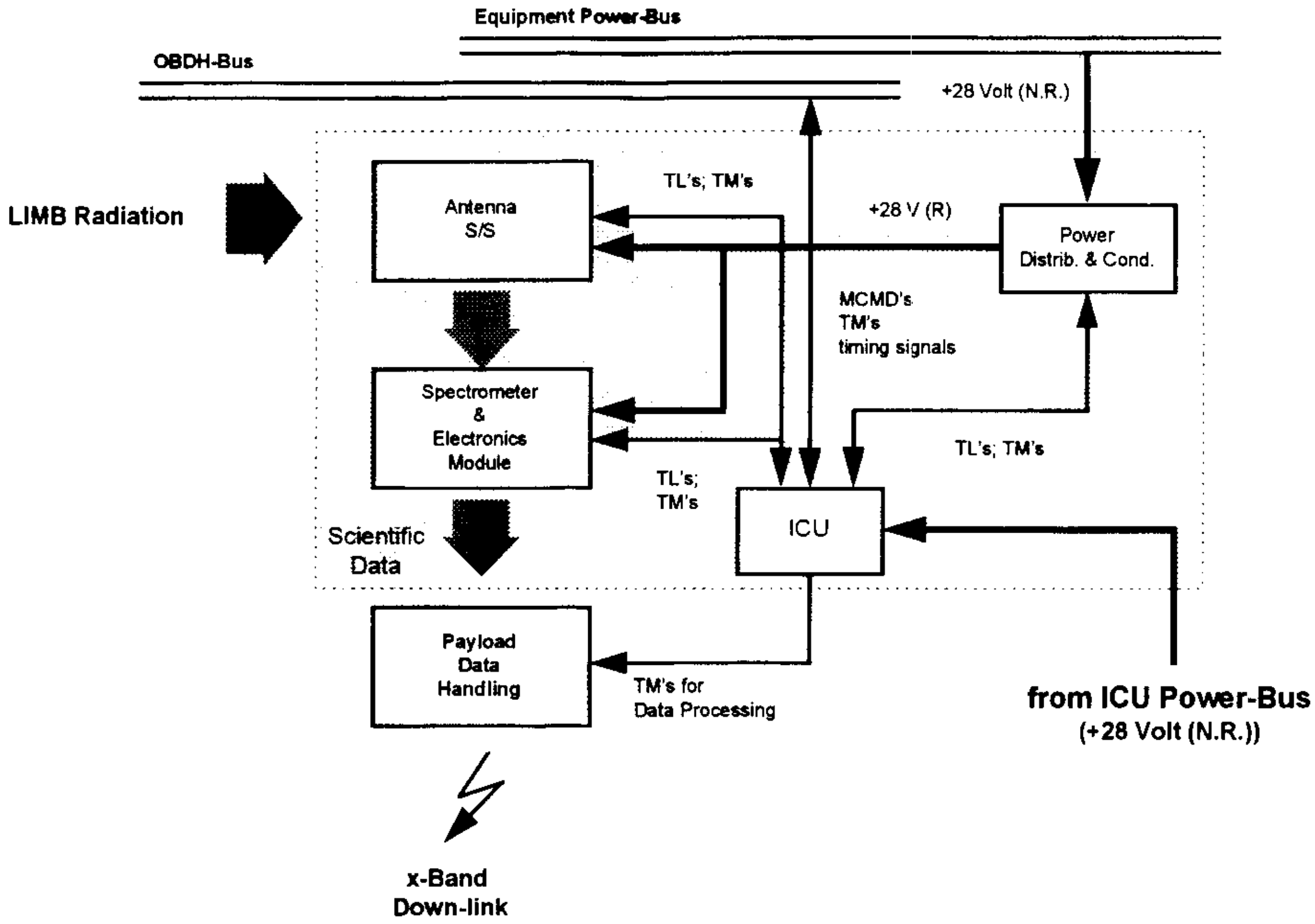
The synergy between the instruments of METOP and ACE is the basis for the orbit determination and orbit maintenance strategy of the ACE satellite.

Orbit Determination : same orbit as METOP, i.e. SSO, 820 km altitude, 09:30 LTDN.
ACE has to be placed ahead of METOP, no orbit maintenance requirements are imposed by ACE mission on METOP platform.

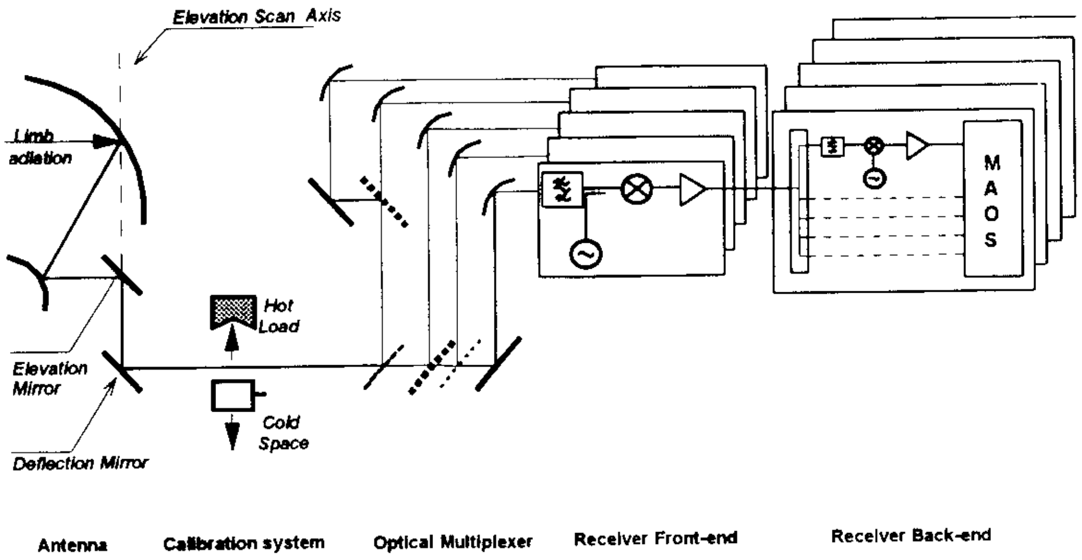


ACE - METOP Tandem Configuration Geomet

❑ Master general block-diagram and platform interfaces



❑ Instrument Design Concept



Instrument baseline block-diagram

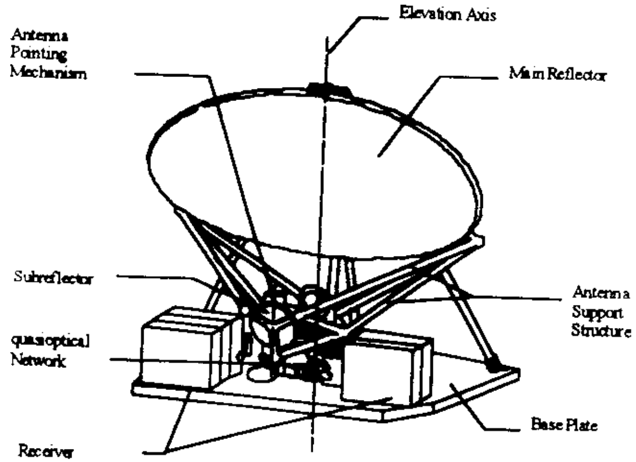
❑ Instrument Design Concept (cont.)

- **Instrument baseline main features:**

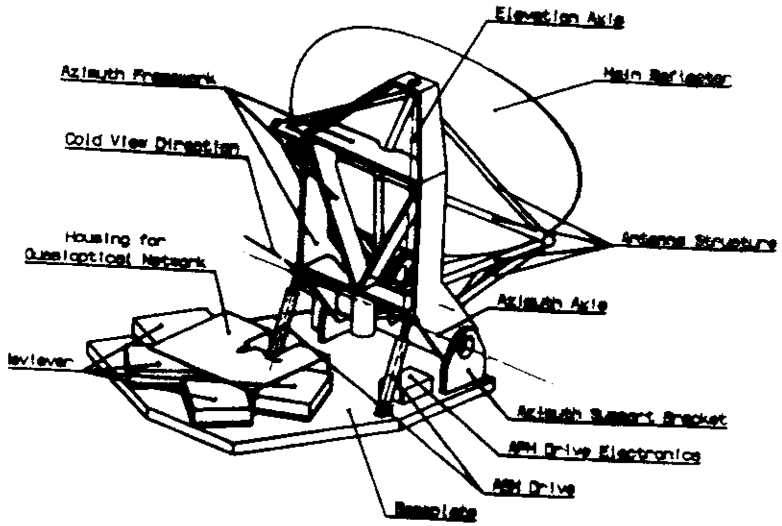
Baseline features	Remarks
Reflector Antenna : Off-set Cassegrain	compact, low cross-pol, no blockage, long effective focal-leng
1.9x0.95 main reflector size	beam efficiency requirements
Scan of the complete telescope (elevation direction) plus BWG system	no beam efficiency degradation
Elevation Continuos Scan	minimised platform induced disturbance
Star Sensor for attitude determination	platform attitude data not sufficiently accurate
In flight calibration: hot load and cold space views	radiometric accuracy requirement
Optical Mux: Single beam concept 5 independent receivers one for each band	coaxial beams for tropospheric observations
Front-end receiver: L.O.injection and SSB filtering performed with dichroic plates	compact size, limited complexity, reduced temperature sensitivity
No front-end cooling	
Spectrometers: Multichannel Acousto-optic	volume, mass and power consumption minimisation
Redundancy concept:	each receiving chain completely redunded

❑ Instrument Design Concept (cont.)

- **Mechanical configuration of the Antenna s/s:**



Master Ex. Antenna s/s mechanical configuration



Master Pre-phase “A” antenna mechanical configuration

❑ System Budgets Summary

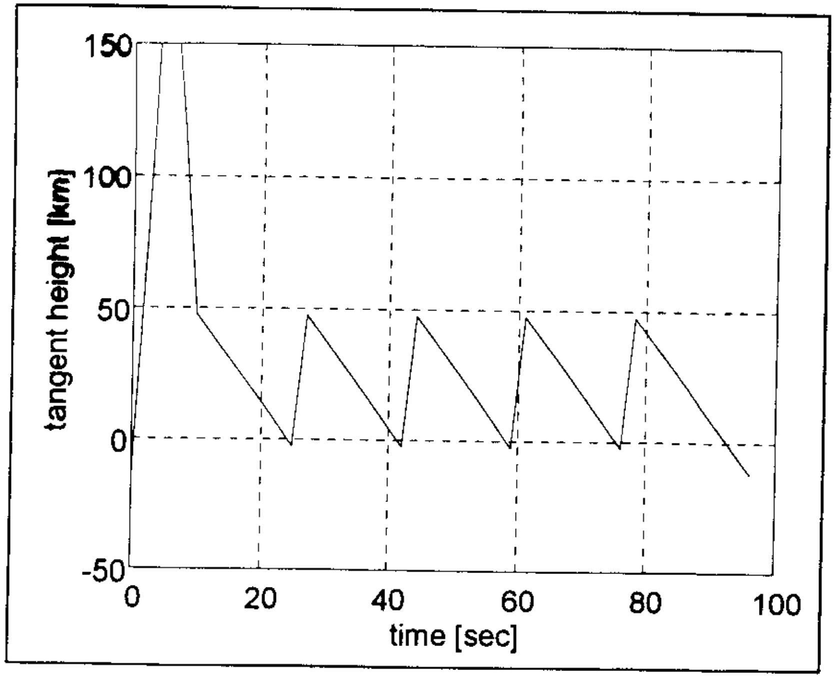
Sub-Systems	Mass (Kg)	Power (Watts)	Data-Rate (Kbit/sec)	Reliability	Pointing (degree)
Antenna s/s sensor package	**201.3**	**127.0**	-	**0.984**	-
Spectrometer & electronics module	**117.0**	**169.0**	-	**0.879**	-
Instrument total	**318.3**	**296.0**	**208.0**	**0.865**	**0.006**

Remarks:

- Mass: Thermal h/w excluded; baseplate excluded; 294.4 Kg no-scan option.
- Power: 5-front-end; MSG mechanism; star sensor not included; 5 MAOS.
- Pointing: accuracy.

❑ Spatial Performance : Elevation scan

❍ Scan Concept : Master equipped with the elevation scanning mechanism

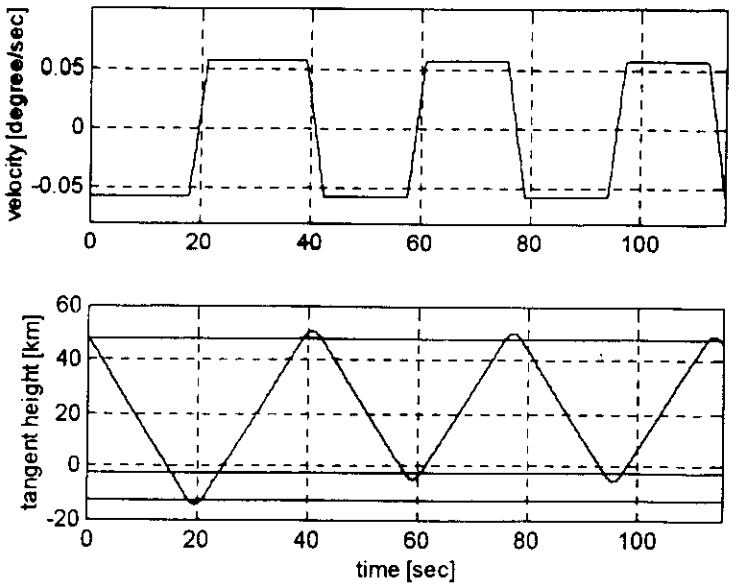


Nominal Scan Down-going measurement elevation profile

- The nominal elevation scan duration : less than **98 sec.**,(including cold sky calibration).
- Maximum torque disturbance at mechanism sites of 1.5 Nm (to be filtered through the transfer function up to the reaction wheels).
- Acceptable disturbance torque at reaction wheels level of 0.2 Nm.
- Overall dead time during one orbit: **12.5 min** (spec. 20 min)

❑ Spatial Performance : Elevation scan

○ Scan Concept : Master without the elevation scanning mechanism

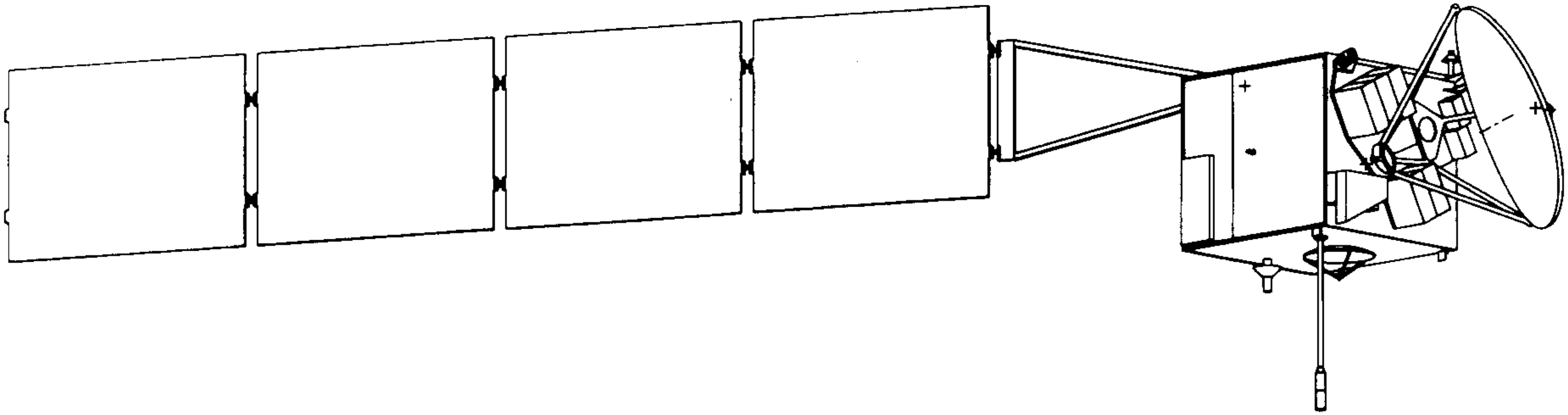


Nominal Scan Down-going/Up-going measurements elevation profile

- Reaction Wheels : **0.2 Nm**
- Nominal scan duration (without cold sky pointing): **116.5 sec**
- Dead time per nominal scan cycle : **20.5 sec**
- Cold sky pointing duration : **36.4 sec** (scan speed twice the nominal one)
- **49** nominal scan cycles per orbit
- Overall dead time during one orbit : **22 min** (8 cold sky calibration per orbit)
- Compatible with OSIRIS scanning range

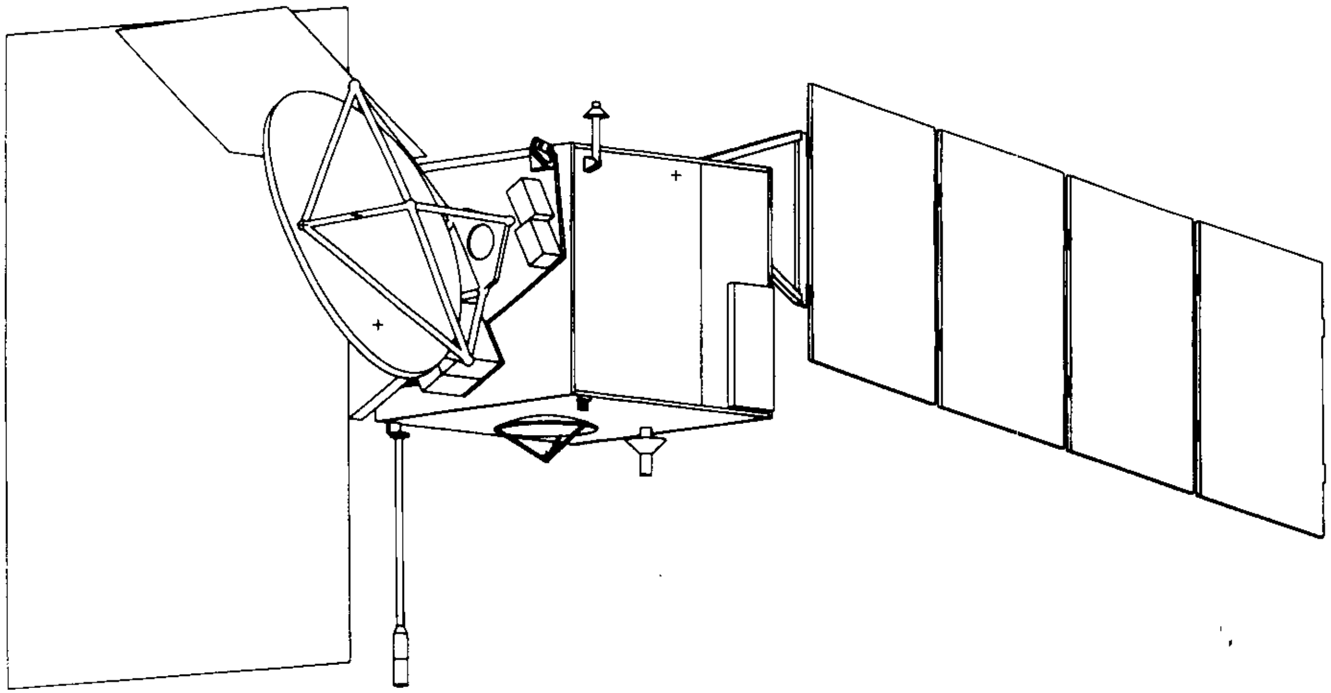
❑ System Parametric Study and Trade-Off's (cont'd)

- Configuration #1 with MASTER anti-sun accommodation



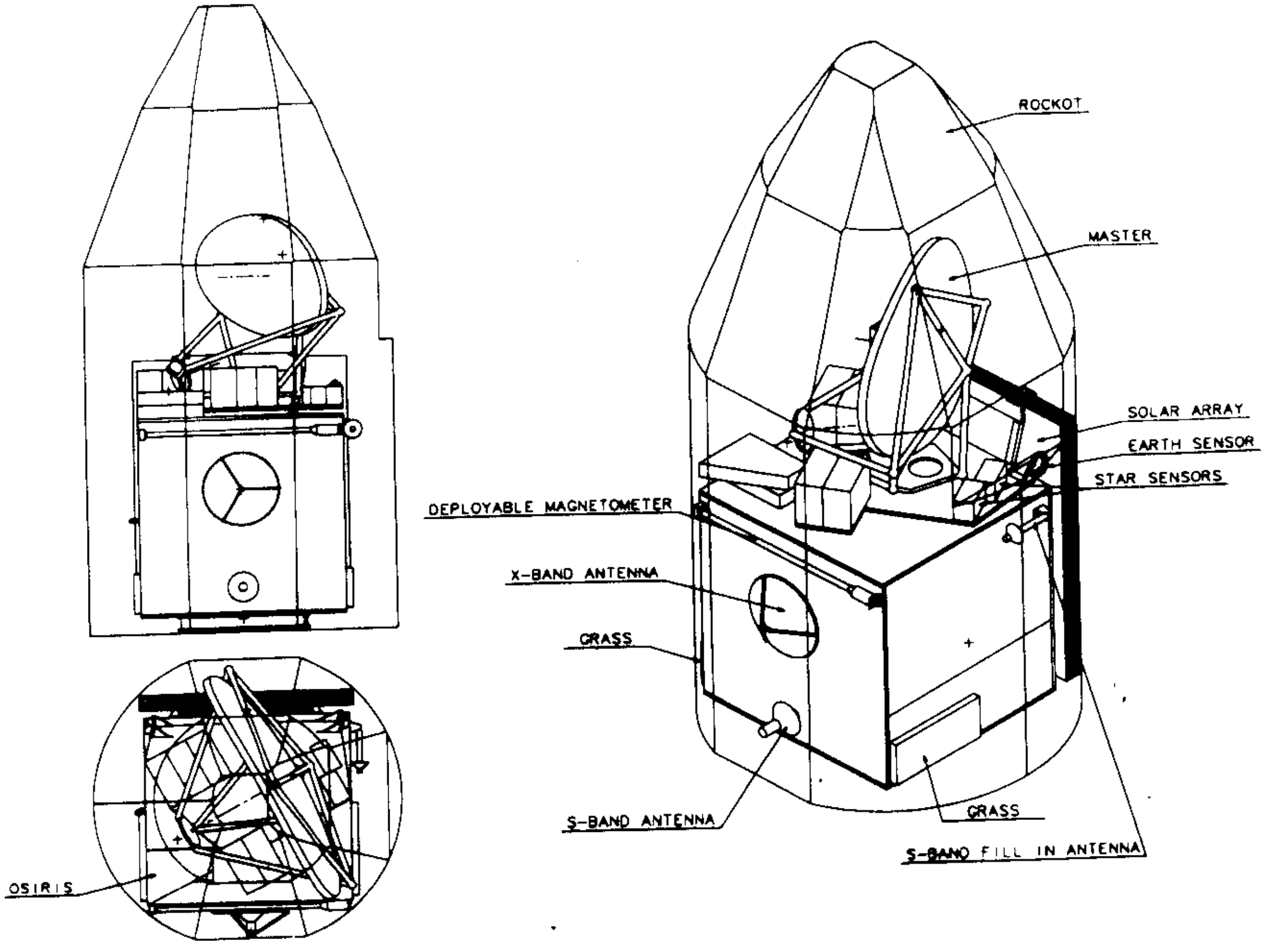
❑ System Parametric Study and Trade-Off's (cont'd)

- Configuration #1 with MASTER anti-sun accommodation



❑ System Parametric Study and Trade-Off's (cont'd)

- Configuration #1 with MASTER anti-sun accommodation/ROCKOT compatibility



MECLIVAR STUDY

ALS Study Objective

- Objective of this study, from Alenia Aerospazio point of view, is to verify the possibility to conceive an instrument which is able to provide significant information about the meteo climatic variables, trying to use the Cassini radar design and eventually the EQM itself.

- These variables can be classified as:
  - "classical" as, for instance:
    - rain rate
    - wind velocity
  - and "non-classical" as, for instance
    - vertical velocity
    - divergence of the vertically integrated flow of tropospheric water

- Vertical velocity (up-draft) and water flow divergence will be considered as primary objective, while rain rate profile and microwave backscattering will considered as secondary targets

Reference Scientific Requirements & Key Parameters

Rain Reflectivity	**dBZmin < 0 dBZ**
Rain height	**$\Delta H < 5$ Km**
Horizontal Resolution	**r > 5 Km**
Vertical Resolution	**$r_h < 250$ m**
Observation range	**A = 100 Km**
Target Velocity resolution	**1 m/s**

Reference Cassini Radar key parameters

Transmission frequency	**ft = 13.7775 GHz**	$\Rightarrow$	**λ = 2.1778 cm**
Transmission bandwidth	**B = 0.85 MHz**		
	B = 4.25 MHz		
Programmable Pulse width	**$\tau = 10\mu sec \div 1000\mu sec$**		
Transmitted Power	**Pt = 70 W**		
Receiving Filter bandwidth	**Bw = 9.35e5 Hz**		
	Bw = 5 MHz		
Noise Figure	**NF = 3.5 dB**		
Transmission Losses	**Lrf = 0.5 dB**		

Reference Mission key parameters

Platform height	**250 ÷ 400 Km** (Low Earth Orbit - LEO Satellite)

System Concept for Divergence analysis

Two system concepts have been analyzed in the assumption that two different modes can be pointed out:

1. Up-draft mode during which the scientific target is the small (~cm/s) vertical velocity of "visible rain" (dBZmin > 0 dBZ);

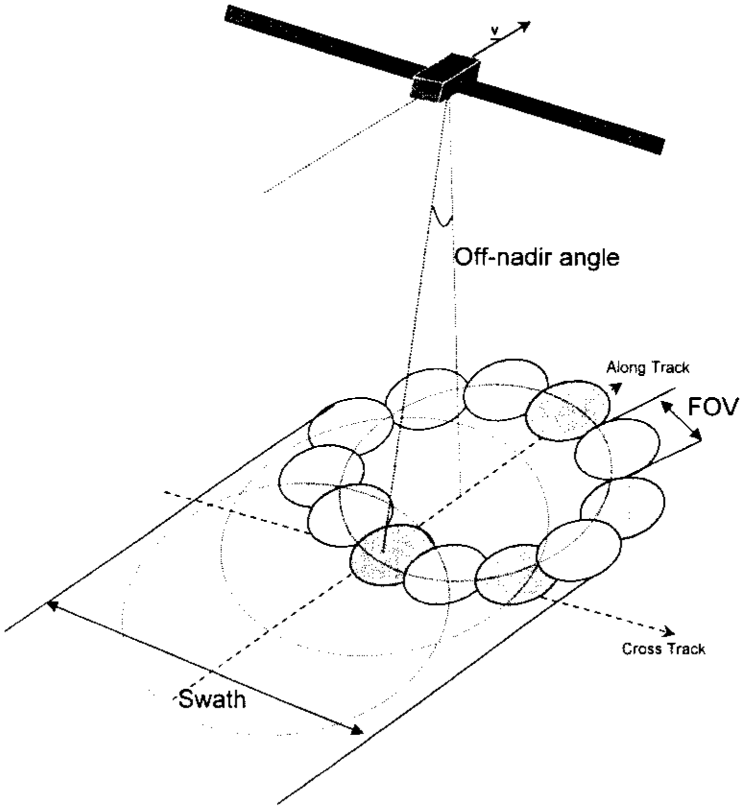
2. Divergence mode during which the scientific target is the divergence of the horizontal velocity (~m/s) of a tropospheric water (dBZmin < -5 dBZ)

Meclivar Radar: Risultati dello Studio di sistema

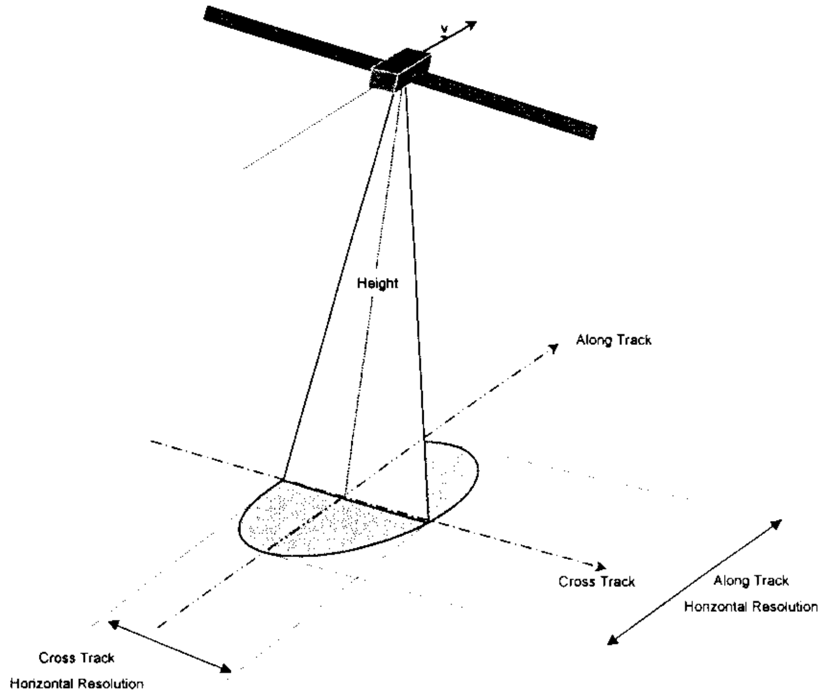
Parametri	Divergence Mode	Up Draft Mode
Frequenza diTrasmissione	13.7795 GHz	13.7795 GHz
Segnale trasmesso	Modulazione lineare di frequenza (Chirp)	Modulazione lineare di frequenza (Chirp)
Diametro dell'Antenna (parabola)	2.8m	2.8m
Puntamento	Off nadir (7 deg) + scansione conica	Nadir
Risoluzione Orizzontale (FOV)	4 Km	4 Km
Risoluzione Verticale (r)	180 m	180 m
Diametro dello Swath	98 Km	4 Km
Risoluzione della velocità orizzontale	2 m/s	NA
Sampling rate della velocità orizzontale	Strisce di diametro 4km campionate ogni 98km	NA
Risoluzione della velocità verticale	NA	40 cm/s
Sampling rate della velocità verticale	NA	4 Km
Velocità della Scansione Conica	550 deg/s	NA
dBZ min	10 dBZ	-10dBZ
N (Impulsi non correlati)	8	252
Lunghezza dell'impulso	0.414 ms	0.405 ms
Banda trasmessa	850 kHz	850 kHz
PRI/PRF	1.03 ms / 967.2 Hz	1.03 ms / 967.2 Hz
Numero di bits del ADC	12	12
Frequenza di campionamento dell'ADC	2MHz	2MHz
Media Frequenza del ricevitore	500kHz	500kHz
Data Rate dei dati Scientifici (verso Terra)	1.24Mbps	39.5kbps

Meclivar Radar: System Configurations

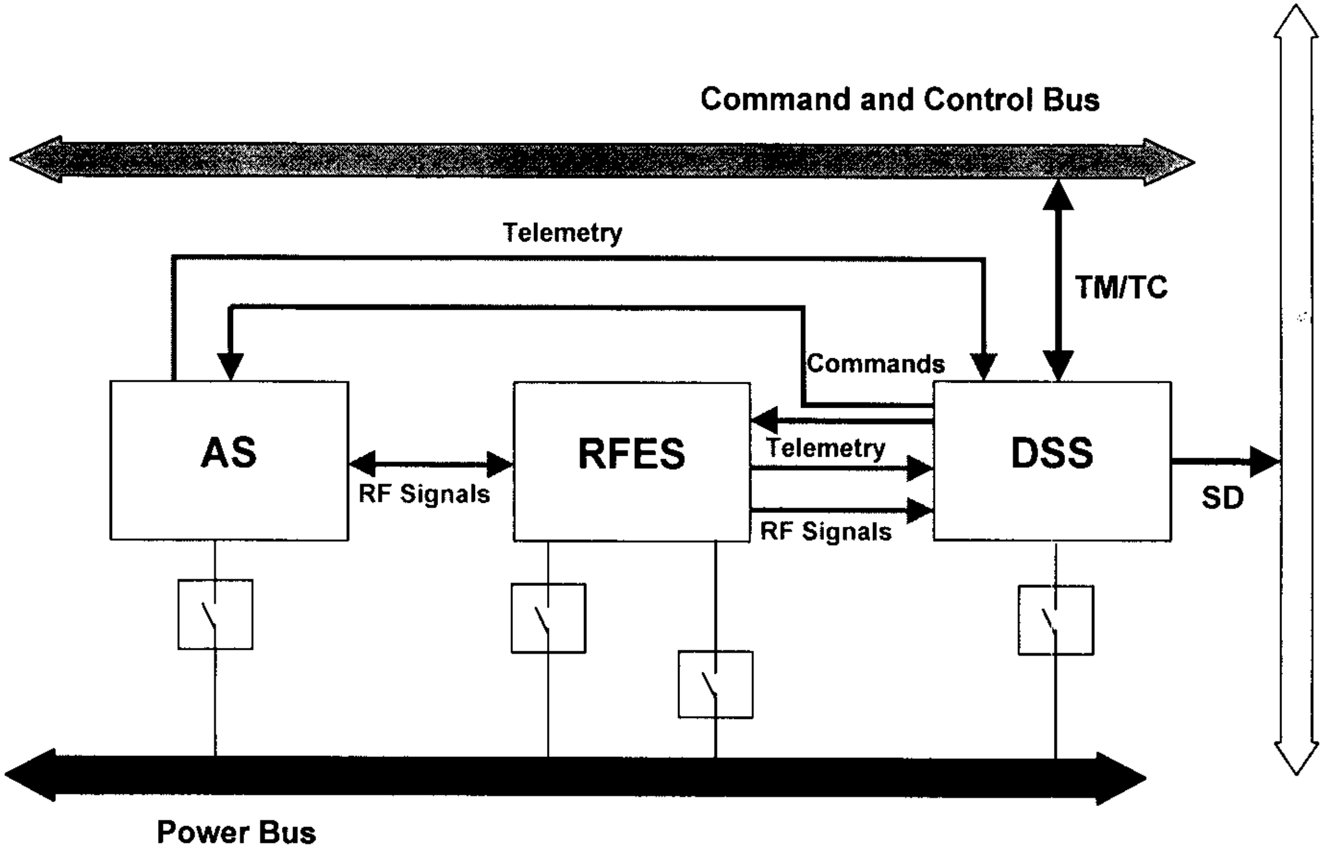
Divergence Mode



Up-Draft Mode



Meclivar Radar: Instrument Configuration



AS: Antenna Subsystem **RFES: Radio Frequency Subsystem** **DSS: Digital Subsystem**

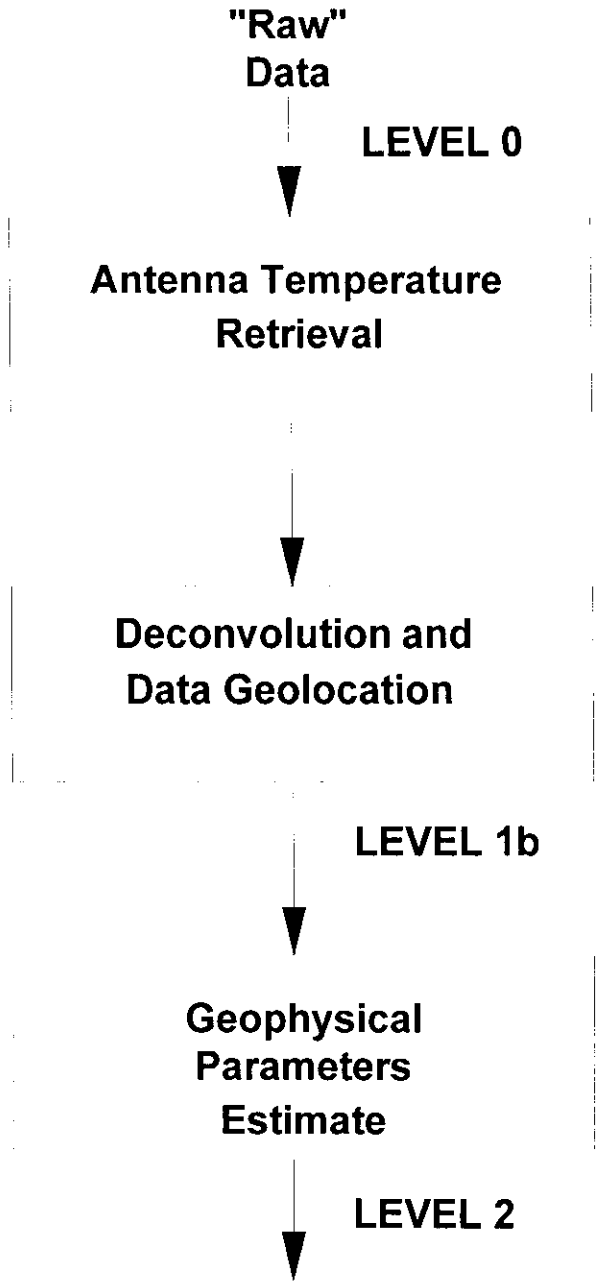
Meclivar Radar: Mass Budget

Sub-system	Mass [kg]
RFES (already existing)	26.28
DSS	4.2
AS	57.0
Harness, Waveguide, etc.	1
Contingency [10%]	8.85
TOTAL	**97.33**

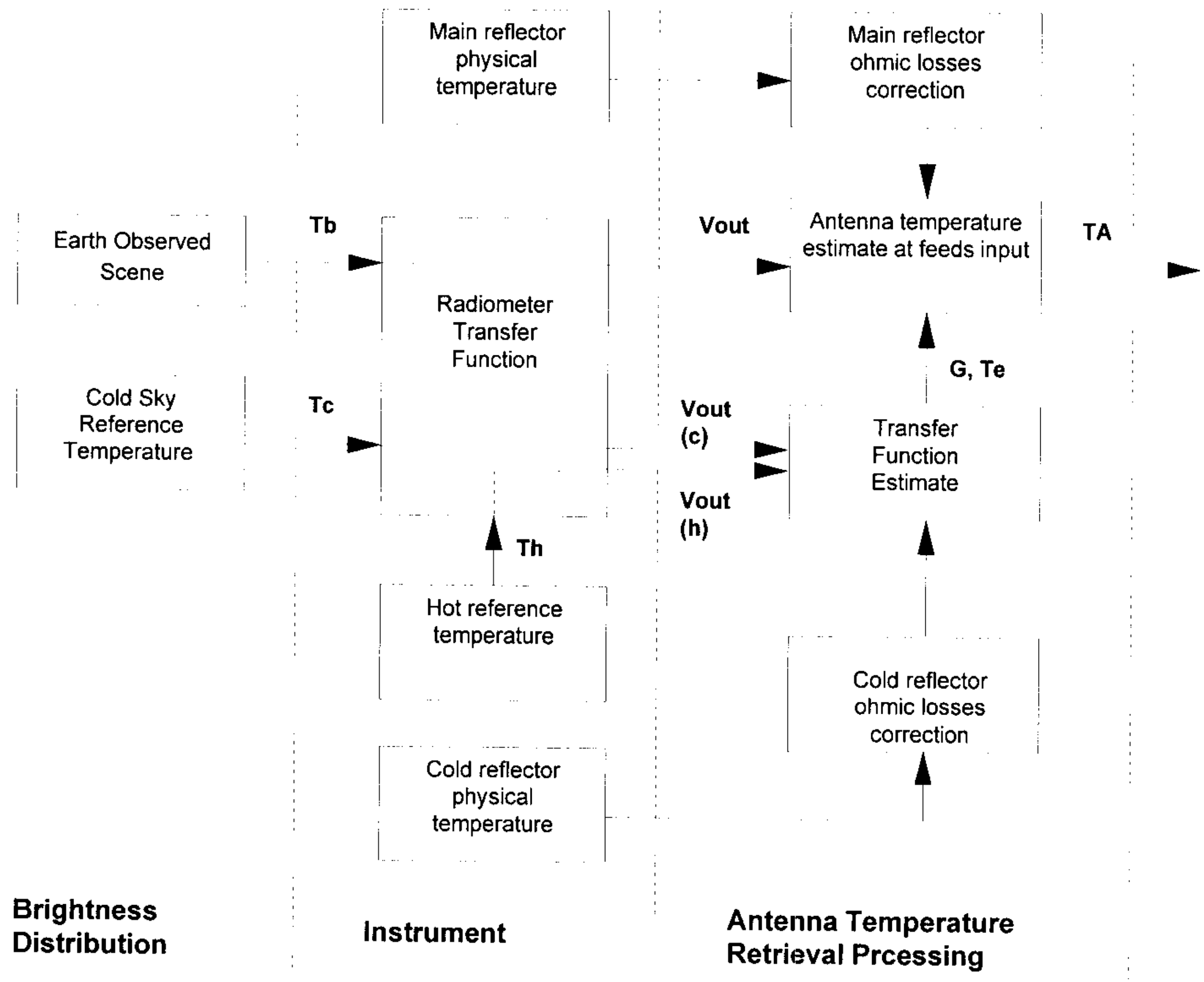
Meclivar Radar: Conclusions

- An optimal configuration has been identified, which satisfies all the scientific requirements.
- The Cassini RFES has been included in the baseline configuration.
- The on-board processing has been deeply studied (Digital sub-system).
- The most critical item is related to the mechanical design of the antenna S/S, due to its dimensions (2.8 m diameter) and the high rotating speed in the Divergence Mode (550deg/sec).
- The instrument concept can be validated by means of a dedicated on-ground measurement campaign.

On-ground Processing on Radiometric Data



Antenna Temperature Retrieval



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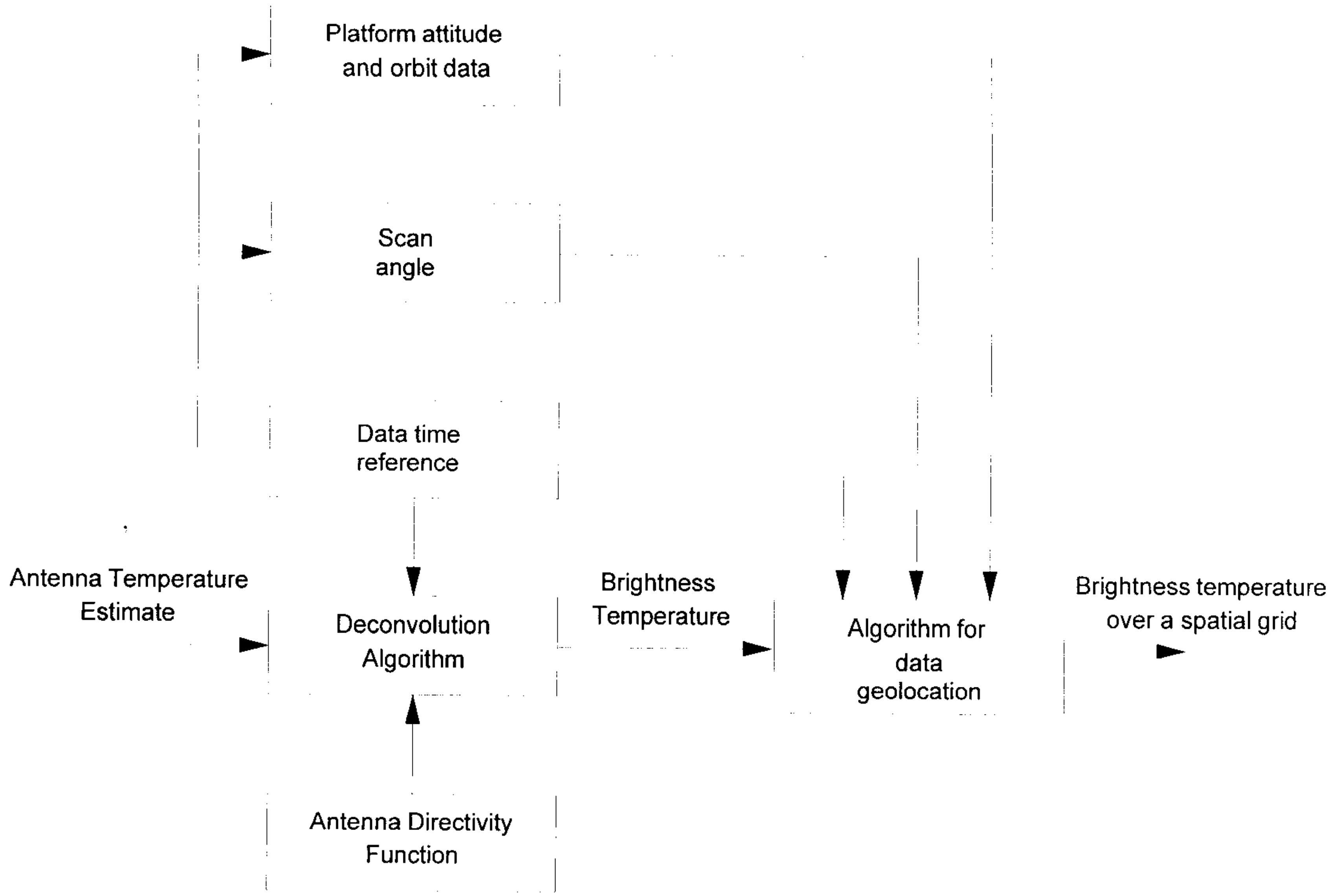
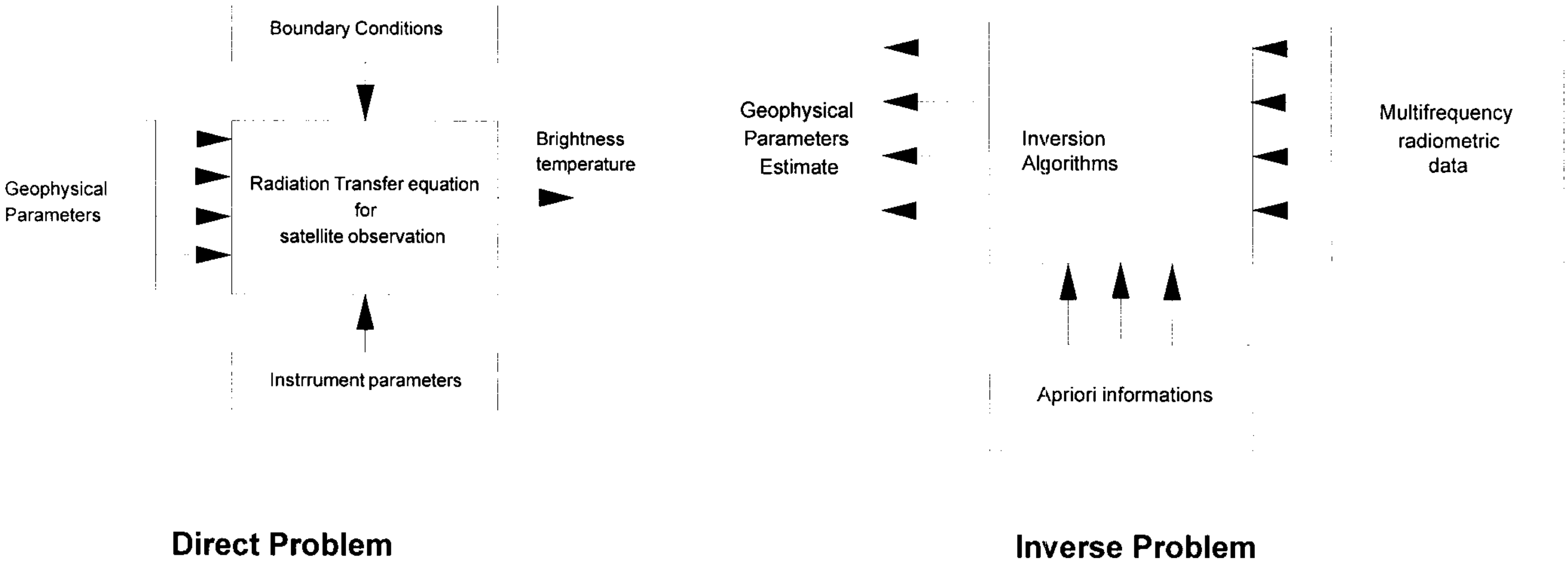
Deconvolution and data geolocation



Geophysical Parameters Estimate



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