MetOp Second Generation Millimetre-Wave Instruments and Technology Needs

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***Abstract*- This paper will describe the present MetOp Second Generation (MetOp-SG) system, concentrating on the Microwave Imager (MWI) and Ice Cloud Imager (ICI), which are the (sub)-millimetre-wave instruments currently being studied by European Space Agency (ESA). The paper will also discuss ESA's past, on-going and planned technology developments, which are enabling the instruments performance and reliability as required by the users.**

INTRODUCTION

The EUMETSAT Polar System (EPS) is Europe's first polar orbiting operational meteorological satellite system consisting of Metop satellites [1]. This joint EUMETSAT – European Space Agency (ESA) programme is the European contribution to the Initial Joint Polar-Orbiting Operational Satellite System (IJPS) [1]. The current MetOp series has three identical satellites. MetOp-A was launched in 2006 and will be followed by MetOp-B in 2012 and MetOp-C in 2016. These first three MetOp satellites guarantee the continuous delivery of high-quality data for medium- and long-term weather forecasting and for climate monitoring until at least 2020. Fig. 1 below shows the spacecraft of the current MetOp series..

Figure 1 MetOp spacecraft (credits ESA)

MetOp Second Generation (MetOp-SG) will replace the current MetOp system in the 2019-2020 timeframe and will continue operations at least until 2035. ESA, together with Eumetsat, started the phase A/B1 studies of the EUMETSAT Polar System - Second Generation (EPS-SG) beginning of 2011. These studies are continuation to the Phase 0 studies, which were conducted 2008-2009. The Phase A/B1 studies will continue until end of 2012, after which the phase B2/C/D will start.

While the MetOp series consisted of a single satellite embarking all instruments, the current MetOp-SG system study consists of two satellites carrying different instrument suites, according to Table 1 below. The Metop-SG instrument suite consists of a total of 14 different instruments, divided between two satellites. Instruments are jointly provided by ESA, NOAA, CNES and DLR. Table 1 below shows an overview of the MetOp-SG system and lists the instruments currently embarked.

Table 1 MetOp Second Generation Concept

	Satellite A	**Satellite B**
Launch	~2019	~2020
Orbit	LEO, polar, Sun-synchronous	LEO, polar, Sun-synchronous
Altitude	817 km	817 km
Mass	~3000 kg	~2400
Lifetime	8.5 years	8.5 years
Intstruments		
	Visible Infrared Imager (DLR)	Microwave Imager (ESA)
	Microwave Sounder (NOAA)	Ice Cloud Imager (ESA)
	Infrared Sounder (CNES)	Scatterometer (ESA)
	Radio Occultation (ESA)	Radio Occultation (ESA)
	Multi-view Multi-channel Multi-polarization imager (ESA)	Argos Data Collection Service (NOAA/CNES)
	Radiation Energy Radiometer (NOAA)	Search and Rescue (COSPAS-SARSAT)
	Sentinel-5 (ESA/GMES)	Space Environment Monitor (NOAA)
	Low Light Imager (NOAA)	

The on-going Phase A/B1 studies were kicked-off in January 2011 and two competing industrial consortia have been selected for the mission study. These studies are lead by Astrium SAS (France) and ThalesAlenia Space (France).Phase A/B1 studies include the overall space segment system study and the system design of all ESA provided instruments.

Instrument system designs done in Phase A/B1 include the instrument system level definition and requirements specification of the instrument. They do not include any hardware breadboarding or testing. Therefore in addition to the main system study, several technology activities, concentrating on hardware and breadboard manufacturing are currently on-going. The final goal being to be able to state a full compliance to the performance requirements at the end of Phase B1.

MILLIMETRE-WAVE INSTRUMENTS

ESA-provided instruments include two (sub)-millimetre-wave instruments, the Microwave Imager (MWI) and Ice Cloud Imager (ICI). The main applications of these instruments are precipitation and cloud parameters. Both precipitation and clouds are seminal parameters for weather conditions and they are not currently well taken into account in weather forecast, compared to clear air measurements. Therefore, the MWI and ICI instruments will improve greatly the global and regional numerical weather prediction (NWP) models. In addition, they will contribute to improve nowcasting and very short range forecasting [2].

Both MWI and ICI instruments view the scene with observation zenith angle (OZA) around 53º and in both instruments the primary calibration is done using standard on board calibration target (OBCT) and cold sky mirror. Both the OBCT and the cold reflector are static and the instrument views them once per rotation cycle through the feedhorns and therefore the main antenna is outside the calibration cycle. The main difference between these instruments is the spectral range to be observed. MWI covers the lower frequency part of microwave spectrum, while ICI covers the highest frequency. The MWI and ICI share one common frequency (183 GHz). This allows using a cross-instrument calibration between the instruments.

A. Microwave Imager

The MWI is a conically scanning microwave radiometer, covering the frequency range from 18 GHz up to 190 GHz, consisting of 28 channels, taking into account dual polarization channels. With an antenna size below one meter, instantaneous footprint varies between 50 km at lowest frequencies down to 10 km at the highest frequencies. The instrument will be mounted on the zenith side of the spacecraft and it will provide a forward azimuth view of >±60º. The details of the MWI performance requirements are given in Table 2 below.

The MWI is a multi-purpose instrument, serving several different applications. These include precipitation over sea and land, cloud liquid water, water vapor total column and profile, snowfall, sea ice and snow imagery.

Table 2 Microwave Imager Performance Requirements

Frequency (GHz)	Pol.	Bandwidth (MHz)	Footprint (km)	NEDT (K)	Accuracy (K)
18.7	V, H	200	≤ 50	0.6	< 0.5
23.8	V, H	400	≤ 50	0.6	< 0.5
31.4	V, H	200	≤ 30	0.6	< 0.5
50.3	V, H	400	≤ 30	1	< 0.5
52.61	V, H	400	≤ 30	1	< 0.5
53.24	V, H	400	≤ 30	1	< 0.5
53.75	V, H	400	≤ 30	1	< 0.5
89	V, H	4000	≤ 10	1	< 1
100.49	V, H	4000	≤ 10	1	< 1
118.7503±4.0	V	2x1000	≤ 10	1.2	< 1
118.7503±2.1	V	2x400	≤ 10	1.2	< 1
118.7503±1.4	V	2x400	≤ 10	1.2	< 1
118.7503±1.2	V	2x400	≤ 10	1.2	< 1
166.9	V	1425	≤ 10	1	< 1
183.31±8.4	V	2x3000	≤ 10	0.8	< 1
183.31±6.1	V	2x1500	≤ 10	1	< 1
183.31±4.9	V	2x1500	≤ 10	1	< 1
183.31±3.4	V	2x1500	≤ 10	1	< 1
183.31±2.0	V	2x1500	≤ 10	1.2	< 1

B. Cloud Ice Imager

The ICI is also a conically scanning radiometer, covering frequencies from 175 GHz up to 670 GHz, consisting of 13 channels taking into account dual polarization channels. With an antenna size below 0.5 meter, instantaneous footprint is ~15 km. In contrast to the MWI, the ICI will be mounted on the nadir side of the spacecraft and it will provide a forward azimuth view of >±60º. The details of the Cloud Ice performance requirements are given in Table 3 below.

The ICI is also serving several applications, including cloud ice water path, cloud liquid water, cloud ice, cirrus clouds and water vapor profile.

Table 3 Ice Cloud Imager Performance Requirements

Frequency (GHz)	Pol.	Bandwidth (MHz)	Footprint (km)	NEDT (K)	Accuracy (K)
183.31±8.4	V	2x3000	≤ 15	0.5	< 1
183.31±3.4	V	2x1500	≤ 15	0.6	< 1
183.31±2.0	V	2x1500	≤ 15	0.7	< 1
243.2±2.5	V, H	2x3000	≤ 15	0.6	< 1.5
325.15±9.5	V	2x3000	≤ 15	0.8	< 1.5
325.15±3.5	V	2x2400	≤ 15	1	< 1.5
325.15±1.5	V	2x1600	≤ 15	1.1	< 1.5
448±7.2	V	2x3000	≤ 15	1.2	< 1.5
448±3.0	V	2x2000	≤ 15	1.4	< 1.5
448±1.4	V	2x1200	≤ 15	1.9	< 1.5
664±4.2	V,H	2x5000	≤ 15	1.5	< 1.5

TECHNOLOGY NEEDS

The high number of channels, stringent performance requirements and long lifetime requirements require large variety of technologies to be used. The final implementation decisions are still to be taken, especially in terms of receiver architecture and calibration approach, but basic technology needs of the MWI and ICI are already known regardless of the final implementation.

A. Passive Components

Accommodation of the feedhorns into the focal point of the antenna is very challenging due to high number of frequencies required. Therefore multi-frequency feedhorns are required, covering two or more frequency bands in a single horn. It is also possible to use quasi-optics instead of feed cluster in the focal plane. This eases the accommodation, but creates other challenges for the frequency selective surfaces, which need to cover large frequency range, often with dual polarization. In addition, quasi-optical network requires also large volume.

B. Active Components

Direct detection radiometers are typically preferred in microwave radiometers for space applications due to simplification of the receiver architecture and therefore the need for less hardware. Currently only the technology limits the use of direct detection receivers at all frequencies. Therefore there is a continuous need for low noise amplifiers, filters and detectors operating from the lowest frequency up to the highest frequency. Low noise amplifiers should be well matched, provide low noise figure, small gain ripple and good gain stability. For the receiver final amplifier stages high compression point becomes necessary in order to guarantee high receiver linearity. In addition large bandwidth is preferred for amplifiers, especially in cases, where a single amplifier can cover two or more frequency channels. Filter design for direct detection radiometers is also challenging due to low amplitude ripple, very high out-of-band ejection and narrow relative bandwidth. This combined with a stringent frequency stability requirement over temperature and lifetime makes the filter design very challenging. Finally high frequency detectors are also challenging due to high linearity, high sensitivity, low input power, low noise and high stability that are needed for direct detection radiometers.

At highest frequencies (>200 GHz), direct detection radiometer implementation becomes very difficult due to technology limitations. Therefore the heterodyne receivers are the only option for the highest frequency receivers in the MetOp-SG timeframe. Well matched, low noise, low conversion loss mixers are required, together with preferably low local oscillator power need. In addition to mixers, the necessary local oscillator (LO) power generation is also challenging requiring high efficiency frequency multipliers and high frequency power amplifiers.

C. Calibration

Besides the receivers implementation itself, the calibration of the MWI and ICI is challenging. The accuracy and stability of conically scanning instruments has been problematic in the past [3], limiting the instrument usefulness for NWP and therefore there is a clear need for improvement in calibration accuracy. The final selection of MWI and ICI calibration strategy is still to be done, but improvements in calibration performance require developments in calibration hardware, both passive and active may be needed..

D. Performance Verification

In addition to technologies required for the instrument operation and performance, the final performance verification also poses a challenge. High absolute, inter-channel and inter-pixel radiometric accuracy requirements pose stringent requirements for on-ground testing accuracy. Large frequency range also poses several testing challenges. Therefore improvements or upgrades to existing testing facilities may be necessary.

E. Reliability

Besides performance and performance verification, reliability poses additional challenges. Reliability requirement of 0.8 over 8.5 years lifetime is very challenging and necessitates a need for comprehensive reliability and lifetime testing.

Redundancy may be required in many parts of the receiver, but due to the nature of the microwave radiometers, many components are single point failures and implementing redundancy is extremely difficult or impossible, without complete duplication of receivers. Because of many single point failures, there is a need to provide high reliability and long lifetime at component level.

SUPPORTING ACTIVITIES

Several improvements in performance and reliability of components/subsystems are required by the MWI and ICI and therefore, in addition to the main system/instrument studies, ESA has technology developments running in parallel.

An activity implementing several frequencies into a single feedhorn antenna is currently on-going, combining 50 GHz and 118 GHz channels..

Low noise amplifier activities are on-going at 118 GHz, 166 GHz, 183 GHz and 230 GHz. These development activities will be followed in 2011 by a reliability assessment activity and an activity to build a low noise amplifier for 325 GHz. For the generation of the LO signal, the development of power amplifiers for W-band using MHEMT and GaN technologies is also currently on-going.

Mixers have been developed in the past years in several different activities, covering frequencies from 180 GHz up to 664 GHz and the next step is also the test of the reliability. Also frequency multipliers have been developed in the past years, using both Schottky and HBV technologies, and covering typically the LO needs for sub-harmonic mixers.

Detector development activity is also on-going covering frequencies 89 GHz 166 GHz. This activity will also be followed by a reliability assessment activity.

Active cold loads as a radiometer internal calibration target have been studied during past years by ESA and currently a complete calibration hardware activity is on-going, covering frequencies at 23 GHz 50 GHz and 89 GHz.

In addition to component level developments, ESA has several activities going at receiver and at system level. ESA initiated an aircraft instrument upgrade, providing receivers covering frequency range from 118 GHz up to 664 GHz. This activity supports the complete receiver system development and in addition provides users with an instrument that can be used to improve the radiative transfer models at the highest frequencies. A 54 GHz radiometer, using an autocorrelation spectrometer to cover the full bandwidth, is currently being built. In addition, the development of a direct-detection radiometer for 243 GHz will be started shortly.

CONCLUSIONS

An overview of the Metop-SG programme was presented, concentrating on MWI and ICI instruments, which are the millimeter/ sub-millimetre wave instruments that are provided by ESA. In addition to instrument overview, technology needs of the Microwave Imager and Ice Cloud Imager were presented together with an overview of already on-going and planned technology developments.

REFERENCES

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