New Generation of Ka-Band Equipment for Telecommunication Satellites

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Abstract: — **A new generation of space-borne Ka-Band products has been for the emerging demand of telecommunication payloads for multimedia missions. The technical challenges that they impose together with sharpened cost objectives lead to necessary technological improvements.**

The described hardware includes Low Noise Amplifiers (LNA), Down and Up Frequency Converters, Channel Amplifiers (CAMP) and Linearizers. Some of these units are grouped in "assemblies" which allow the centralization of several commodities. New packaging concepts have been extensively used in parallel to a severe industrialization phase which included the complete space qualification of these technologies. Ultimate performance has been achieved thanks to an extensive modeling work for MMIC design. Finally, it is shown how a specific demand for a very compact Ka-Band antenna has led, for the very first time, to the adoption of non-hermetic hybrids for a space use.

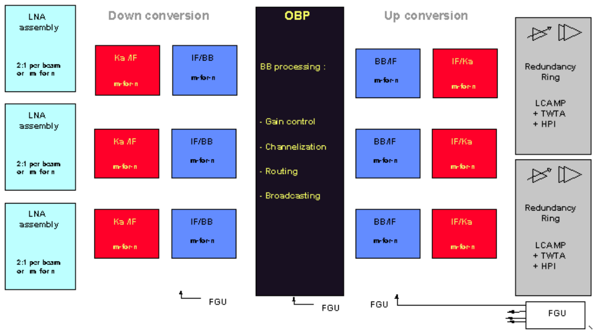
I. Introduction

While the telecom economy was at stand still in 2002/03, Alcatel Space was developing a new generation of microwave payload equipment at C, Ku and Ka-Band[1]. New sub-system units have been designed taking profit from the mastering of new packaging concepts. Among that new generation, the Ka-Band family is the most challenging with its higher spectrum and also because it requires a real production strategy as the number of individual units is higher than for lower frequencies[2]. With the return of positive perspectives, several new satellite systems now require Ka-Band payloads which provide better mission flexibility and broadband capability for multimedia applications.

Alcatel Space has already demonstrated its competence in delivering payload equipment and systems in Ka and even Q/V Bands (at 44 GHz). Its heritage includes the following programs: Astra 1K, Stentor, Syracuse 3, Optus C1, MTSAT 1R/2, W3A, Wild Blue, Hot Bird 6, DFH3 and Koreasat 5 with a total of more than 100 FM (Flight Model) units (LNA, Down/Up Converters, Beacons, CAMP, Linearizers) delivered since 1999.

Depending on the aimed mission, several scheme of payload architecture have been envisaged. Either single (30/20 GHz) or double (30/IF/20 GHz, where IF could be Ku, C or L-Band) or triple (30/IF/BaseBand/IF/20 GHz) frequency conversions are possible. In addition, the payload can be either transparent or regenerative, and can address different types of antennas, passive or active. All this contributes to many declinations as for the microwave equipment to be developed.

To cover most of the cases, a generic family of equipment has been designed which includes LNAs, Down and Up Converters (DoCon / UpCon) and (Linearized)CAMP. The more ambitious FAFR (Focal Array Fed Reflector) antenna requires very compact LNA modules. All of them are described here below.



Scheme of a telecommunication payload for a multimedia satellite

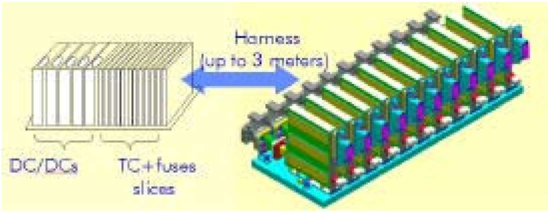
Most payload architecture are based on antenna with a large number of beams requiring very Low Noise Amplifiers. Then, the preferred solution is an "assembly" which allows to share several commodities. The centralisation of those functions induces a drastic reduction of mass, consumption, dimension and cost in comparison to an architecture with multiple stand-alone products. Nevertheless, it is also worth to mention that "stand alone" version of LNA and frequency converters is readily available too, thanks to the versatility of the packaging concept and to the availability of a full family of DC/DC converters.

II. LNA Assembly

In order to keep the noise figure at a minimum, an obvious need for G/T, the losses between the antenna and the front-end should be minimized. Therefore, the LNA should be located very close to the antenna. Then, size and power dissipation must be reduced to achieve an efficient thermal control. To comply with all theses requirements, the LNA assembly is split as follows:

- ♦ An aluminum base-plate bearing up to 12 RF slices with the following functions : 30 GHz low noise amplification ; voltage regulation ; gain control (an appreciated feature at system level).
- ♦ A remote centralized sub-assembly with a DC/DC Converter (including redundancy), feeding the RF slices with appropriate supplies from the satellite power bus ; and a TM/TC (Telemetry & Telecommands) unit ruling the ON/OFF and the gain setting of all slices.

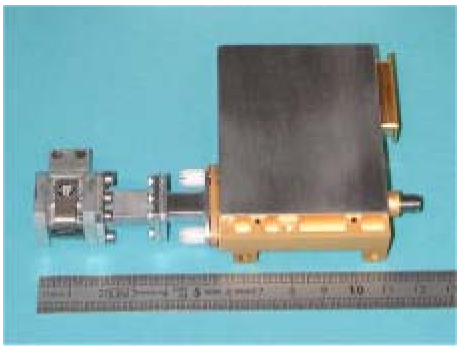
A DC harness connects both sub-assemblies.



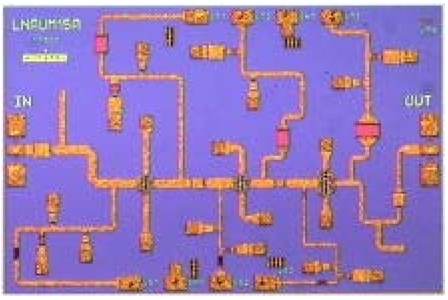
The LNA assembly

Every LNA slice is packaged using the so-called "macrohybrid" concept developed by Alcatel Space for their FM telecommunication hardware units. This has the advantage of being a single level housing incorporating the various MMICs and bearing all necessary connectors. This consequently allows the minimization of the losses at the input of the amplifier.

In order to make the LNA mounting easier while keeping a minimum noise figure, an in-line low loss waveguide to microstrip transition has been developed. This represents significant improvement compare to the former perpendicular transitions. This transition is both low loss (<0.25 dB) and preserve the module as hermetic.



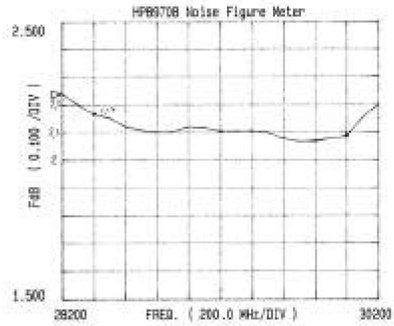
The LNA slice with its in-line wg/µs transition
(overall dim: 12.7x7.3x2.7 cm^3, weight <200g)



30 GHz LNA MMIC (Process PH15-UMS)
(dim: 3x2 mm^2)

The core of the LNA is constituted by its first stage of amplification. This is performed by a 0.15 µm PHEMT MMIC amplifier designed by Alcatel Space whose NF has been measured less than 1.3±0.1 dB at ambient temperature over 27–30 GHz[3].

The overall LNA slice presents a maximum gain of 50dB, adjustable over 10dB. The worst case (min. gain) linearity is IP3>20dBm and the noise figure is <2.5dB at 60°C.



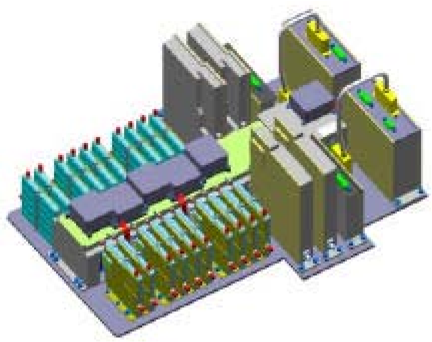
Measured Noise Figure at 31°C of the LNA slice (min. gain)

III. Down-Converter Assembly

As for the LNAs, the "assembly" concept leads to a real advantage. The Ka/IF Down-Converter assembly is made of a unique base-plate bearing:

- ♦ 20 RF slices performing the following functions: 30 GHz amplification and down-conversion to RF (from 1 to 20 GHz) ; Local Oscillator (LO) amplification ; RF amplification and filtering ; voltage regulation ; gain control (with possible extension to Automatic Level Control or Output Level Control)
- ♦ a DC/DC Converter (including redundancy), powering RF, TM/TC and LO slices.
- ♦ a centralized redunded Local oscillator slice with its distribution circuit towards the RF slices.
- ♦ a centralized redunded TM/TC interface board.
- ♦ a DC harness and internal serial bus for TTC.

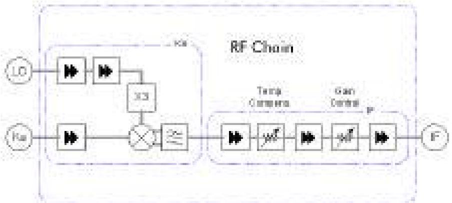
A complete MMIC chipset has been developed in order to cover all IF bands: L, C, Ku and Ka. Every RF slice is a macrohybrid which can easily be adjusted to cope with novel requirements (frequency band, gain, etc.).



The Down-Converter assembly

There are some frequency plans where the LO design can be quite challenging. This is for instance the case for the 30/20 GHz Down-Converter where the second LO (10 GHz) harmonic falls in or near the useful bandwidth. The rejection of the embedded LO filters and the performance of the VCO and its PLL deserve a lot of attention.

On the Ka/L version, the gain is variable from 25 to 35dB, the output level is 0dBm, the input NF is <12dB and the output IP3 is >22dBm at lowest gain. The Ka/Ku version has 30dB gain, 11dB NF and 27 dBm IP3 for a 5dBm output level. For 24 slices (8.5x8.5x1.9cm^3, 240g each), the dimensions of the Down-Converter assembly are: 50x35x20 cm^3, it weights 10 Kg and the DC consumption is <150 W.



Schematic of the Down-Converter RF slice

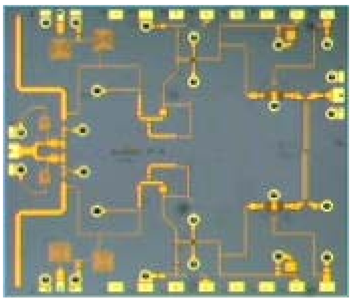
Both LNA and Down-Converter assemblies have been breadboarded and the respective EQM have been thoroughly designed and manufactured.

IV. UP-CONVERTER ASSEMBLY

The Up-Converter is also based on an assembly and it presents several similarities with the Down-Converter. For both cases, it has been noted a trend in system demand for more stringent linearity specification. This induces larger sizes of active devices used for mixing or amplification, leading to an increase of power dissipation and, then, to more severe thermal constraints. An attractive response is the use of AlSi material for the RF slices housing rather than the conventional Kovar (iron alloy with Ni-Co). The AlSi is 10 times more conductive and also 3 times lighter than the Kovar. AlSi has been selected for the Up-Converter assembly and this will lead to a 40% weight reduction for the whole unit.

Both L and Ku to Ka versions are under development using the same architecture. The necessary MMIC chipset has been designed and fabricated using either PHEMT or HBT technologies.

Among them, there is the IF to Ka mixer. This function is very critical and it has been carefully designed and optimized. It is a subharmonically pumped image rejection mixer: the local oscillator is fed on chip at the half of the pump frequency. The insertion loss is of the MMIC mixer is lower than 3dB.



1.5 to 20 GHz subharmonic(LO:10GHz)image rejection mixer. (Process ED02AH-OMMIC)(dim: 3.5x3 mm^2)

V. CHANNEL AMPLIFIER AND LINEARIZER

The Ka-Band (20 GHz) CAMP is an extension of the successful new generation channel amplifier family previously developed in Alcatel Space for C, X and Ku-Band with more than one thousand units delivered.

HTCC MCM-C has been selected here as the optimized technology[4] because it allows a direct connection to the supply and commands through the multilayer substrate. This technology is intrinsically one of the most reliable one because multilayer ceramics have been used for a long time to build hermetic packages, leaded or leadless, for space-borne hardware. The MCM presents several cavities designed to contain parasitic resonance and undesired coupling by extensive 3D EM simulations. Embedded microwave lines inside the substrate have been designed to go through the inner walls. This concept makes a simpler and cheaper MCM package and has proven validity up to 35 GHz.

An empty HTCC MCM-C package showing the cavities and the embedded DC and RF interconnects under the walls

Two versions of this equipment has been made available: a regular CAMP and a “LCAMP” where a linearizer follows the CAMP section into a single mechanical housing. Based on a modular architecture, a complete (L)CAMP portfolio is available offering state-of-the-art performance along with a large panel of features like : Fixed Gain or ALC (Automatic Level Control) for both CAMP and LCAMP; wide band linearizer (> 2GHz) with output control, output limiter and TWTA overdrive protection, I/O power telemetry, RF blanking (or mute), etc. The gain dynamic range goes up to 60dB.

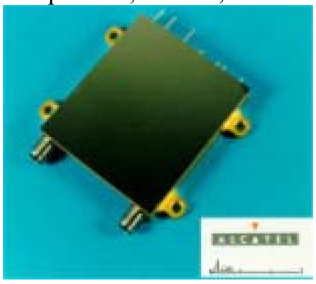
20 GHz LCAMP EQM (dim: 13x10x3 cm^3)

The whole CAMP family supports a large number of TM/TC protocol formats to interface with all the spacecraft data handlings (from simple pulse command to OBDH including various serial links).

The simplification of the tuning process and the strong optimization of manufacturing steps lead to mass production capability, competitive cost within short schedules. More particularly, thanks to a proven linearizer tuning strategy, good performance can be guaranteed while keeping independent the manufacturing flow chart of LCAMP and TWTA, limiting the industrial constraints and shortening the overall schedule.

For complete family offer, a stand alone 20 GHz Linearizer has also been designed and manufactured. This one uses the macrohybrid concept too.

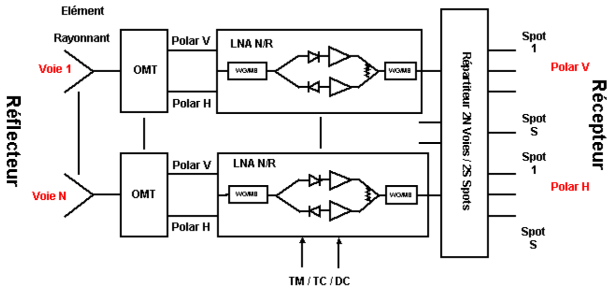
Alcatel has delivered Ka-band (L)CAMP and linearizers on the programs Optus C1, Stentor, Koreasat 5 and DFH3.



Flight Model 20 GHz Stand Alone Linearizer

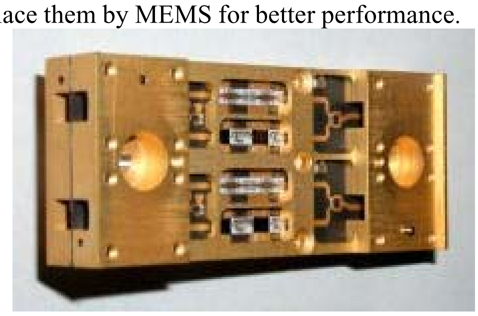
VI. LNA FOR ACTIVE ANTENNA

Multi-beam antennas require a high number of miniaturized 30 GHz LNA modules[5]. Several hundreds – low cost – modules are needed whose width and height must fit within the step between the feeds (about 12.8 mm). Moreover, every LNA should present a 2:1 redundancy.



Scheme of the self-redunded LNA for FAFR antenna

An original concept, based on a non-hermetic approach, has been developed. It consists of using organic substrate on which MMIC LNAs are bonded. The substrate is then sandwiched between the two halves of a wave-guide. In order to stay in the same plane, a Vivaldi fin-line transition has been developed with very low insertion loss. The switches follow a patented architecture which presents no single point failure. PIN diodes are used at the moment and studies are on-going to replace them by MEMS for better performance.



Very compact dual self-redonded 30 GHz LNA for active antenna application. Size is only 54x25x9 mm³

11 DM (demonstration models) have been realized and present very good performance on both paths. Weight is only 25g per dual self-redunded module. The gain is 30 dB and the noise figure does not exceed 3.2 dB.
The fabrication of 32 EQM is now in progress in order to equip a receiving FAFR antenna.

V. CONCLUSION

A complete offer of active Ka-Band Flight Model hardware (LNA Assembly, Down-Converter assembly, Up-Converter assembly, Channel Amplifier with/without Linearizer, LNA for active antennas) has been developed at Alcatel Space. They represent the building blocks of new multimedia Ka-Band payloads, and are able to fulfil the market needs either in short or medium term.
The major difference with existing conventional C or Ku-Band telecommunication equipment lies in a significant increase of quantity to be delivered for a given program. This naturally implies that sharpened cost objectives are imposed whereas higher frequency and miniaturization are heavily pushing to much more ambitious performance. Then, the design of those products is a real technical challenge which, at the end, led to many technological improvements and the emergence of new techniques.
This strongly impacts the industry at many levels where the organization of work has to be revised. Every product needs an exhaustive industrialization phase to ensure that it will be manufactured with good yield, minimum labor and cycle time and fully space qualified processes. Such a severe phase has been endured for every products presented in this paper and this endeavor is beginning now to receive a deserved commercial recognition.

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