

Protoflight Model Development for Spaceborne LTCC RF-Modules

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Abstract

A specific RF-module technology is currently under development in a national research project named KERAMIS-2 funded by the German Space Agency (DLR). Typical microwave circuits like synthesizer, amplifier, switch and mixer are integrated on multilayer LTCC substrates which are part of a hermetic package. Optimized first and second level interconnects allow on one hand the integration of standard MMICs into such packages and on the other hand the assembly of those RF-modules on suitable RF-boards. This technology was optimized for satellite communication applications at frequencies around 20 GHz. The advantage is that low-cost, flexible and modular Tx/Rx-circuit design becomes feasible even for harsh environments. Further space heritage will be gained on a LEO exploration satellite with launch in July 2010. The project partners are implementing the user payload following the "Protoflight" model philosophy for ESA space borne equipment. This paper will discuss the entire qualification procedure for the "KERAMIS" technology, which is a composition of different board materials like PTFE, LTCC, Kovar-housing, flip chip and wire-bond assembly and transitions, heat dissipation measures, MMICs and SMD components.

Keywords: LTCC RF-Modules, Spaceborne Applications, Qualification and Reliability

1. Introduction

The project KERAMIS-2 aims at the development of innovative and inexpensive components for future applications in multimedia satellite communications. The principle of operation and potential benefit for satellite-based systems has been demonstrated. The rationale of the project is to exploit the possibility of integrating passive and active components in LTCC multilayer structures, and to minimize the complexity of semi-conducting components. LTCC technology offers a number of benefits such as low-cost production and assembly, compact size and hermetic sealing, which are of utmost importance for satellite-based applications. After a successful technology development the project partners intended to qualify the RF circuits in a real space mission. Such an opportunity was given by the German Space Agency. They offer user payloads an exploration platform on a mini LEO satellite. The bus-system is based on the proven BIRD satellite. The first vehicle will start in 2010 known as TET-1. The KERAMIS technology was approved as one of the user payloads. Hardware manufacturing and software development are subject to ESA requirements for space borne payloads. This paper gives a concise insight into the development and qualification of the specific KERAMIS payload, which has been developed by

the authors. A comprehensive reference list is given in chapter 8 for those readers, who are interested in special parts of these wide R&D activities.

2. Model Philosophy

The project partners are implementing the flight-hardware following the protoflight model philosophy for ESA space borne equipment. The development started with design and characterization of two different technology models (TM1 and TM2) followed by the structural and thermal model (STM) continued with the engineering model (EM) and finally resulting in the protoflight model (PFM). TM1, TM2 and STM have already passed qualification tests successfully. The qualification included different vibration and shock tests as well as functional tests under thermal cycling and vacuum conditions. The EM is currently in the manufacturing phase and will pass additional tests like radiation and EMC. The following sections specify these models and the requirements for qualification.

TM: Technology Models are optional for the On-Orbit-Verification Program of the DLR. The TM1 technology has already been developed in the preceding R&D project KERAMIS (Oct. 2003 - Sept. 2006) and has then been tested with regard to opera-

tion in Low Earth Orbit in the KERAMIS-2 project for the first time. A re-design of TM1 with several improvements rose to TM2 and the qualification tests have been repeated with success.

STM: The main purpose of the Structural and Thermal Model is the qualification and verification of the satellite's structural and thermal design. All user STMs will be utilized to test the payload integration and wiring. It is important that each STM fits to its final mechanical and thermal interface, weight and center of gravity. If one payload supplier fails to deliver the flight model in time, its STM will be integrated as a dummy, so that the entire mission continues untroubled.

EM: The Engineering Model is applied for functional tests and verification of the control software. It complies with the flight module in Form, Fit and Function and serves as a reference model.

PFM: The Protoflight Model is intended for the space mission. The selection of qualification tests depends on the launcher and orbit conditions.

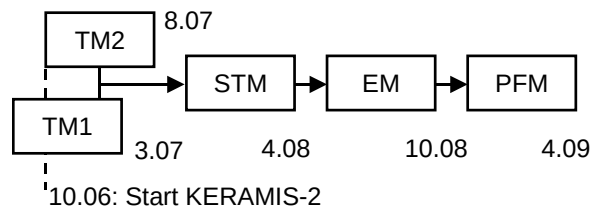


Fig. 1 Model development sequence and schedule.

Fig. 1 shows the sequence of the model development and the schedule of availability for qualification within the KERAMIS-2 project, which started in October 2006 after the first KERAMIS project has been finished. The satellite launch is expected to be in July 2010 with a minimum one year mission in space. A successful verification could possibly lead to an extension of the operation and verification phase. Tab. 1 summarizes the required qualification tests and analysis for STM, EM and PFM as well as the preceding TM1 and TM2 tests. The matrix and its relevant specifications have been set up in accordance with the requirements for LEO satellite missions. The anticipated altitude in orbit is about 540 km and the prospective launcher is the Russian "Soyuz-Fregat".

Tab. 1 User payload qualification matrix.

Verification	Analysis	TM1	TM2	STM	EM	PFM
Dimensions				T	T	T
Mass				T	T	T
Center of Gravity				T	-	T
Mechanical I/F				T	T	T
Sinusoidal Vibration		T	T			T
Random Vibration		T	T			T
Shock Susceptibility		T	T			T
Thermal Vacuum /Thermal Cycling		T	T			T
Thermal Test					T	
Connector Verification				I	T	T
Signal Characterization					T	T
Bonding					T	T
Grounding/ Isolation					T	T
Conducted Emission					T	T
Conducted Susceptibility					T	T
Radiated Emission					-	T
Radiated Susceptibility					-	T
Magnetic Moment	A					
HW/SW Functions					T	T
Performance		T	T		T	T
Space Debris	A					
Single Point Failure	A					
Components List	A					
Materials, Process List	A					

Abbreviations: T: Tests, A: Analysis, I: Inspection

3. Synthesizer experiment

The authors are developing experiments for the verification of the Keramis-Technology as well as for specific LTCC-modules. Those modules consist of two different RF interfaces to a PTFE base-board (RT6002): The first one utilizes wire-bond transitions [3.2-3.4] and the second one is an LGA (Land Grid Array) with contacts on bottom of the ceramic layers [1.8-1.11] (see drawings in Fig. 2). Both transitions were optimised for the operation frequency and can be applied beyond that up to 40 GHz. IMST developed LTCC modules with different functionality. There are amplifiers like LNA, MPA and buffer amplifier, mixer, SPDT switch and a synthesizer. The synthesizer module is the heart of this payload experiment. Hence it is called "Synthesizer Experiment" or "Experiment 2", because it is the second of three KERAMIS experiments, which will be integrated into the exploration satellite. The block-

diagram in Fig. 2 illustrates the setup of Experiment 2. Two RF-boards made of multilayer PTFE substrates (RT6002) have been developed. The first board is assembled with “LGA-modules” of different functionality, while the second one is a redundant board, since it has the same function but with wire-bond transitions. Each board operates independently from each other. A common backplane serves as interface to a control and supply unit. This unit in turn is connected with the satellite to payload interface. It consists of relay lines to switch the experiments on and off, an I²C digital bus and a 20V DC supply.

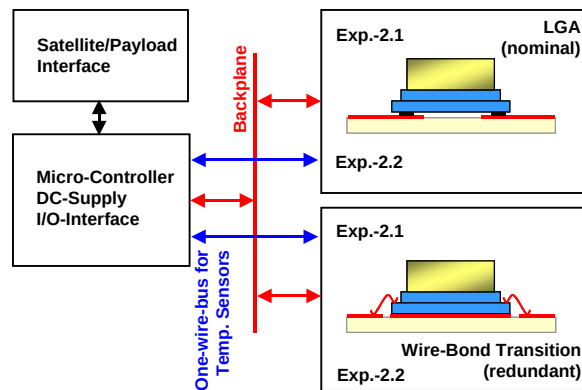


Fig. 2 Block-diagram of Experiment 2.

Each board comprises two sub-experiments in a specific circuit configuration, which allows qualifying the LTCC modules. Fig. 3 and Fig. 4 show the block-diagrams of both circuits. Each blue box represents one LTCC-module. RF signals around 20 GHz are generated with the synthesizer modules. Those signals will then be amplified, switched or mixed and the power levels will be measured by power detectors at different places within the circuits. The output voltage of the detectors is proportional to the RF power. Those figures will be digitized and stored together with house-keeping data like time stamp, temperature, satellite attitude and other general information. Specific control software will be responsible to start, operate and abort the experiments automatically. In case of regular operation the user will collect the data periodically and evaluate the results. In case of mal-function the operator will have the opportunity to up-load tele-commands from the ground control center of the German Space Agency (DLR) in Oberpfaffenhofen.

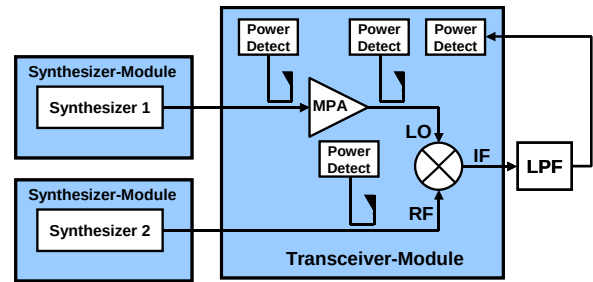


Fig. 3 Block-diagram of Sub-Experiment 2.1.

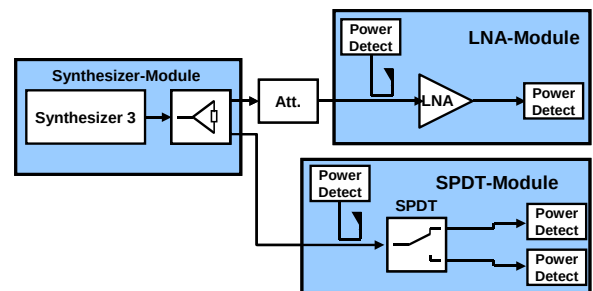


Fig. 4 Block-diagram of Sub-Experiment 2.2.

Fig. 5 shows a photograph of the “Synthesizer 3” module above the design artwork of the EM board. LTCC modules will be mounted onto the dark areas of the multilayer PTFE. The circuitry around the RF part monitors and controls the entire experiment with DC supply and power detector logging. Two boards will be inserted into the KERAMIS box (see Fig. 8), which contains the three experiments. The synthesizer module is explained in details in [3.1, 3.6, 4.1, 4.2].

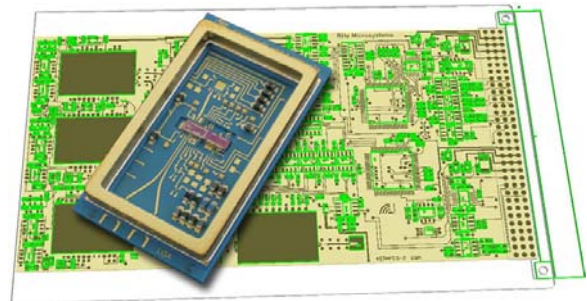


Fig. 5 EM: Photograph of Synthesizer Module above the design artwork of the ml-board.

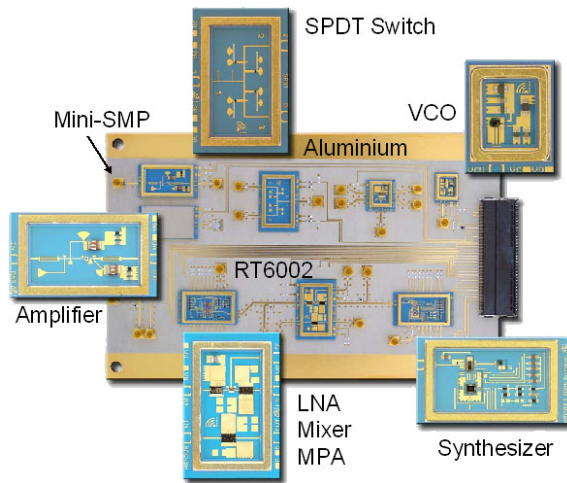


Fig. 6 TM2-board with LTCC modules.

The EM modules are ready for assembly, and the EM boards are being manufactured, therefore results will be available later. However, TM2 boards have already been tested against the matrix of Tab. 1. Fig. 6 shows a photograph with the TM2 PTFE substrate on an aluminium carrier. The LTCC modules are mounted on the RT6002 board but still uncapped for testing purposes. Each module consists of 5 layers LTCC with a KOVAR frame on top. This part is brazed on a specific screen-printed metallization (DuPont 5062D/5063D) and will be closed afterwards with a Kovar lid by utilizing parallel seam-welding. This process ensures a hermetic sealing of the housings, which is a requirement for space applications.

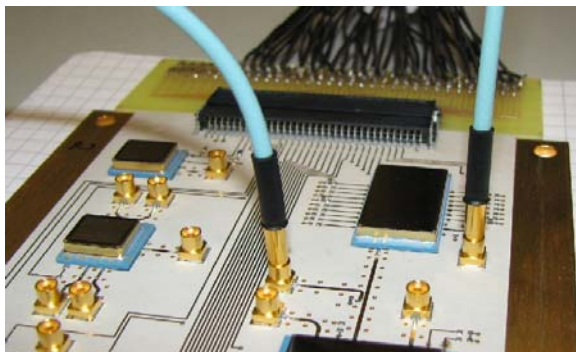


Fig. 7 TM2-board with DC supply and RF testing.

The capped LTCC modules are shown in Fig. 7, where the DC supply and RF testing cables are connected to the TM2 board. The RF properties

of the technology models have been tested via RF connectors (here Mini-SMP) to qualify the performance of the RF circuits. Such testing will not be possible during space operation, so power detectors have been included into the EM circuits as shown in Fig. 3 and Fig. 4.

4. KERAMIS experiment

The three KERAMIS experiments are a development by seven project partners with different tasks. Three partners have the responsibility for the experiments (see references):

- Experiment 1: “Switch Matrix”, Technische Universität Ilmenau (see section 8.2)
- Experiment 2: “Synthesizer”, IMST GmbH (see section 8.3)
- Experiment 3: “Transceiver”, Technische Universität Hamburg-Harburg (see section 8.1)

The R&D-work is supported by industry partners with the following contributions:

- DC, control board and backplane: Kayser-Threde GmbH
- Housing and qualification tests: Astro- und Feinwerktechnik Adlershof GmbH
- LTCC manufacturing and assembly: MSE Microsystem Engineering GmbH
- PTFE board manufacturing and assembly: RHe Microsystems GmbH

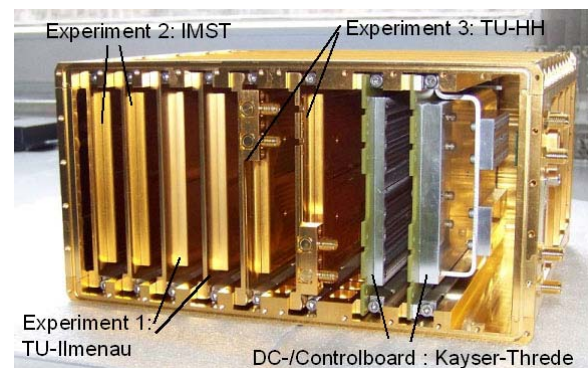


Fig. 8 Open STM KERAMIS-box.

Fig. 8 shows the open STM housing of the KERAMIS payload. The box includes six boards (two of each experiment) on the left followed by the DC and control boards on the right. The dimensions are $(200 \times 214 \times 110) \text{ mm}^3$ and the weight is roughly 4 kg. Further parts of the KERAMIS payload are a transponder box and an S-band antenna. The transceiver experiment includes an up- and down-link with conversion to S-band frequencies.

5. On-Orbit-Verification

The KERAMIS experiment will be one of eleven user payloads for qualification in space. The German Space Agency (DLR) has initiated an On-Orbit-Verification (OOV) program based on the successful BIRD satellite. The new platform is called TET, which stands for Technology Exploration Carrier. TET-1 is planned to be the first one of a series of exploration satellites. Its launch is scheduled for July 2010. The platform consists of the satellite bus with user supply unit and solar panels as well as an area for the user payloads. The construction and accommodation drawing illustrates the satellite in Fig. 9. The platform has an envelope of $(0.65 \times 0.5 \times 0.88) \text{ m}^3$ and a mass of 110 kg. All user hardware components together must not exceed 40 kg.

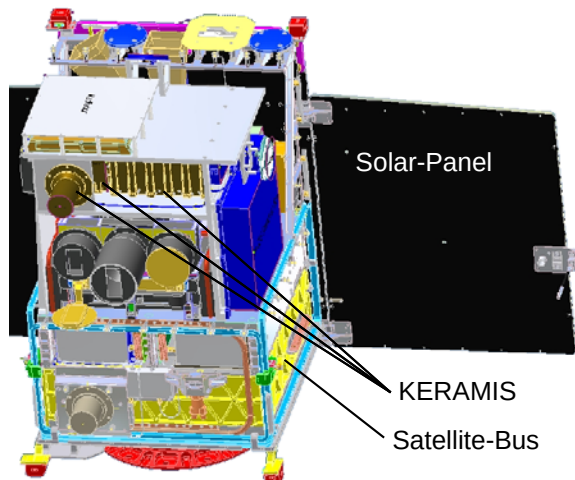


Fig. 9 TET construction and accommodation drawing (courtesy of “Astro und Feinwerktechnik” and “Kayser-Threde”).

6. Conclusion and Outlook

This paper was aiming to give an intermediate overview of an exciting and still ongoing technology development program, which offers the opportunity to test the presented KERAMIS-technology in space. This view has been given from the authors of one payload experiment supplier. The whole story covers a lot more research and development work published by the authors and the other project partners. Therefore an entire publication list is given in chapter 8.

7. Acknowledgement

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8. Publications

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