Space Qualification of W-band Devices for the CloudSat Cloud Profiling Radar

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Abstract **— The 94 GHz Cloud Profiling Radar (CPR) instrument is on board the CloudSat spacecraft, launched in April, 2006. The Radio Frequency Electronics Subsystem (RFES) for this instrument consists of an Upconverter, a Receiver, and a Transmitter Calibrator assembly, which include W-band diodes (noise, Schottky and detector diodes) and MMIC amplifiers (LNA and MPA). W-band devices, in general, are not on the NASA parts selection list, and for most of them, CloudSat is their first use in a space application. Therefore, customized screening and qualification tests were developed for these devices, in order to insure high reliability to meet the 2 year CloudSat mission design life. High amplitude stability is also required for the noise source and transmitter power detector diodes, in order to provide accurate calibration of the overall cloud radar. The test approach and results are presented here.**

Index Terms **— Millimeter wave amplifiers, millimeter wave diodes, MMIC amplifiers, remote sensing, Schottky diode frequency converters, spaceborne radar.**

I. INTRODUCTION

CloudSat is a new low earth orbit (LEO) satellite mission in the Earth System Science Pathfinder (ESSP) series and is a joint development of the National Aeronautics and Space Administration (NASA), the Jet Propulsion Laboratory (JPL), and the Canadian Space Agency (CSA). The CloudSat mission is part of the A-Train of 5 remote sensing satellites and is providing the first global measurements of cloud profiles over the entire Earth. The design and test results of the overall Radio Frequency Electronics Subsystem (RFES) for this instrument have been previously reported [1]. The RFES for this instrument consists of an Upconverter, a Receiver, and a Transmitter Calibrator assembly, which include W-band diodes (noise, Schottky and detector diodes) and MMIC low noise amplifiers (LNA) and medium power amplifiers (MPA). In the block diagrams for the Upconverter and Receiver, shown in Fig. 1 and 2 respectively, the various W-band devices are highlighted. The diodes are mounted within WR-10 waveguide assemblies and the MMIC amplifiers are contained within hermetically sealed hybrid circuit assemblies, as shown in the Receiver top assembly view (Fig. 3).

The general CloudSat approach was to use electrical, electronic and electro-mechanical (EEE) parts with flight heritage, based on NASA Parts Selection List (NPSL) Level 2 parts, (equivalent to MIL-STD-975, Grade 2) with Particle Impact Noise Detection (PIND), Destructive Physical Analysis (DPA) and X-ray upscreening. This level of parts screening is somewhat more stringent than MIL-883 Level B and is consistent with the medium cost, low-to-medium risk of the mission. However, most of the W-band devices have no previous flight history. Therefore, customized screening and qualification tests were developed in order to meet the intent of NPSL Level 2 as closely as possible, while keeping parts costs at an acceptable level. Some typical results from the diode and MMIC qualification tests are presented, along with photos of some of the devices and their mounting configurations.

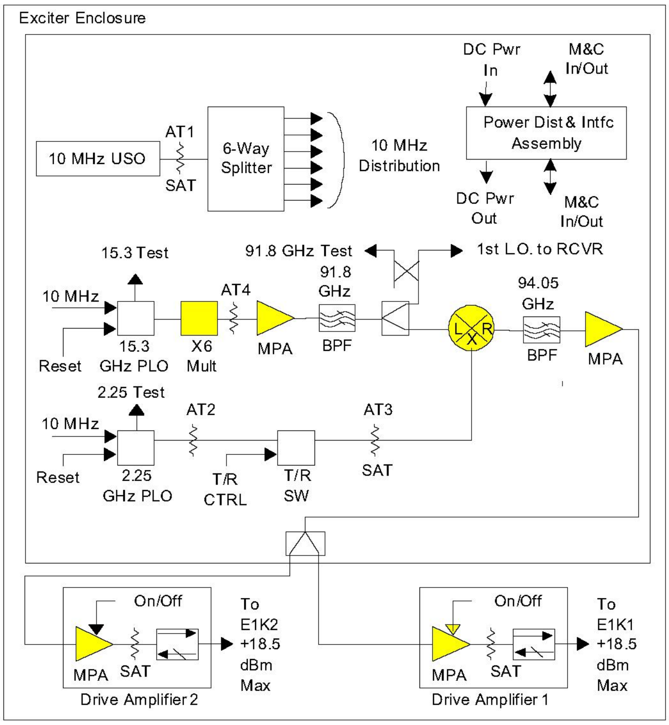

Fig. 1. Upconverter block diagram.

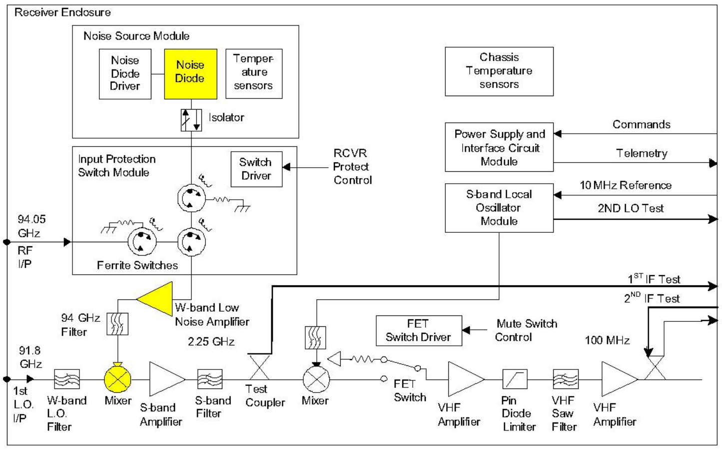

Fig. 2. Receiver block diagram.

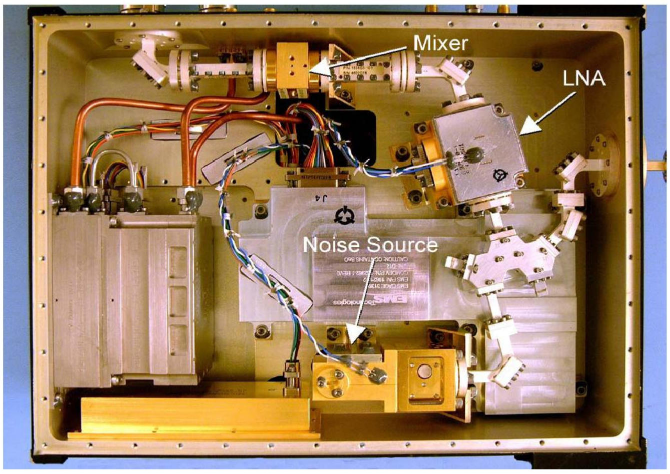

Fig. 3. Receiver W-band side.

II. W-BAND DIODE QUALIFICATION APPROACH

The frequency conversion functions of the RFES are performed by multiple use of a Spacek GaAs Schottky barrier diode. This same device is used in the up and downconversion mixers and in the x2 and x3 multipliers for the 91.8 GHz local oscillator (LO) generation. These diodes are implemented as whisker contact diodes in cylindrical, hermetic packages (Fig. 4). This packaging approach was chosen for its flight heritage at V-band and below. At the time of the CloudSat development, there were no W-band planar Schottky diodes with flight heritage available. The 100% lot testing on 80 parts is a subset of tests from the MIL-PRF-38534D standard. These tests included 10 temperature cycles, hermeticity tests, 48 hour high temperature reverse bias (HTRB) tests, and 336 hour power burn-in followed by final electrical tests. A sub-lot of 10 samples was subjected to an additional 50 temperature cycles (–55 to +125ºC), followed by electrical and hermeticity tests. Due to the critical nature of the internal mechanical connection of the whisker diode, X-ray images (Fig. 5) and a DPA of the diode were performed on 5 lot samples. Part of the DPA was a 600x and 4000x scanning electron microscope (SEM) photo, to verify correct contact of the whisker to a diode dot (Fig. 6). The integrated waveguide mixer, shown in Fig. 7, and multiplier assemblies were additionally subjected to thermal shock and random vibration tests.

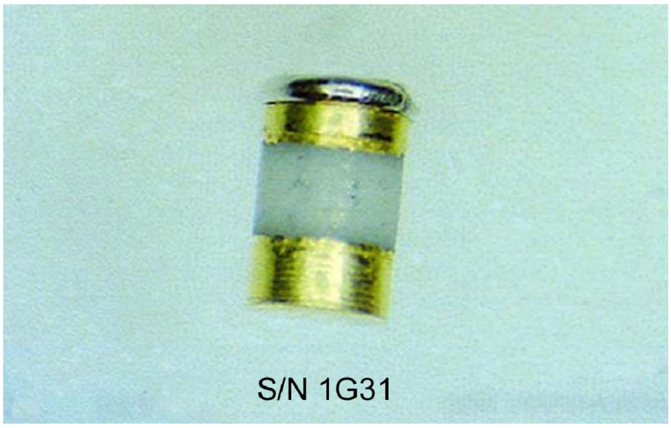

Fig. 4. Whisker contact diodes – hermetic package.

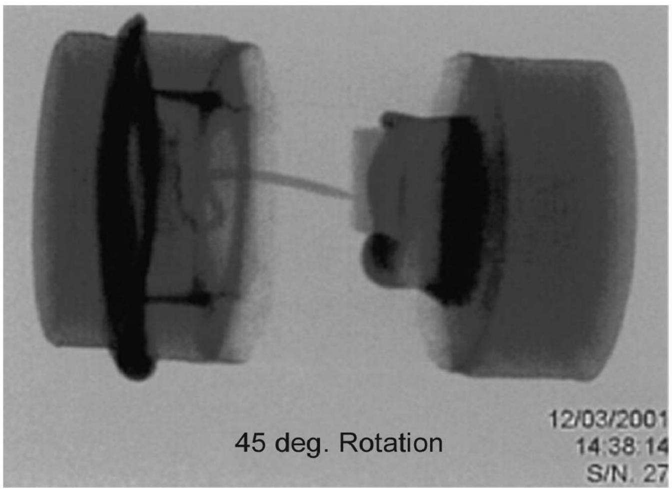

Fig. 5. Whisker diode – X-ray.

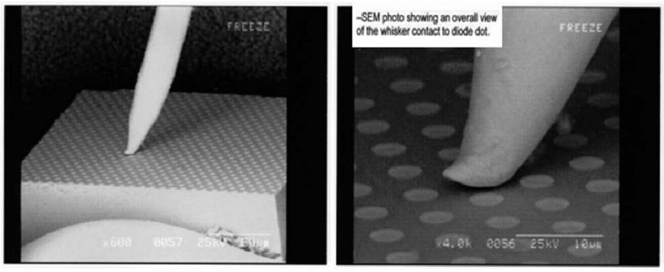

Fig. 6. Whisker contact – SEM photos: 600x and 4000x.

Fig. 7. W-band mixer assembly.

The W-band noise source is implemented with an M-pulse Si step recovery diode (SRD) operated in avalanche breakdown mode. The noise source is required to be highly stable in order to meet the 0.4 dB knowledge accuracy of the Receiver gain over the mission life. Similar to the Schottky diodes, this stability is achieved by random vibration, temperature cycling and burn-in. The peak power detector is implemented with an Agilent GaAs beam-lead detector diode in the Transmitter Calibrator assembly. This diode has a similar stability requirement to the noise diode and was subjected to similar environmental tests at the waveguide assembly level (Fig. 8).

III. W-BAND MMIC QUALIFICATION APPROACH

In order to achieve the output power and noise figure requirements of the radar subsystem, some recent MMIC designs were utilized which implement the amplifiers in 0.1 μm GaAs HEMT technology, for the MPA [2] and 0.1 μm InP HEMT technology for the LNA [3]. Both of these MMIC's are being used for the first time in space. In order to estimate the mean-time-to-failure (MTTF) for these devices, an accelerated life test was run on wafer lot samples. For the MPA, this was a 1-temperature test at 150ºC, with a sample size of 8. The failure criteria was defined as a 20% decrease in Idss (Ids at Vgs of 0 volts).

For the LNA, this was a 2-temperature test, at 175ºC and 200ºC, also with a sample size of 8. For the LNA devices, the failure criteria was defined as a 20% decrease in transconductance (Gm).

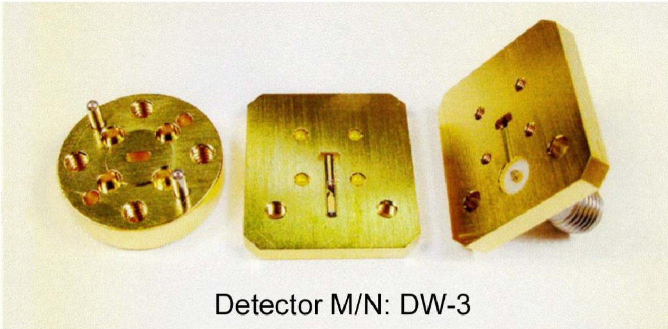

Fig. 8. W-band detector diode assembly.

IV. QUALIFICATION TEST RESULTS

The asymptotic behavior of the noise source ENR output over temperature cycles is shown in Fig. 9. This test was designed to demonstrate that the noise source had settled to its final value and will meet the 0.4 dB stability requirement over mission life.

For the MPA, the resulting MTTF was 2.9E5 hours for a junction temperature (Tj) of 50ºC. An RF overdrive test at 150ºC was also performed on 1 additional sample, to demonstrate graceful degradation of output power (Fig. 10) and asymptotic behavior of the 1st and 2nd stage Ids after 300 hours (Fig. 11).

For the LNA, the resulting Arrhenius plot, for lifetime vs. temperature, is shown in Fig. 13 and the Gm vs. time is shown in Fig. 12. The resulting MTTF for Tj = 50ºC is approximately 1E8 hours. A destructive RF overdrive test was also performed to determine the RF input level at which the MMIC will fail (+15 dBm). This test demonstrated an operating margin of >20 dB above the nominal transmit leakage pulse level.

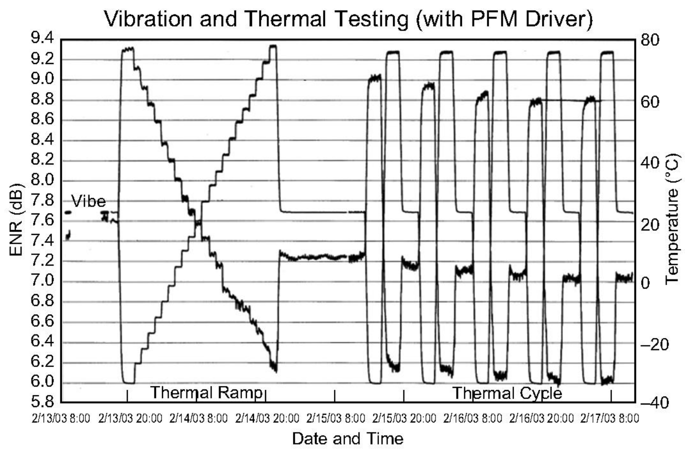

Fig. 9. Noise source burn-in test.

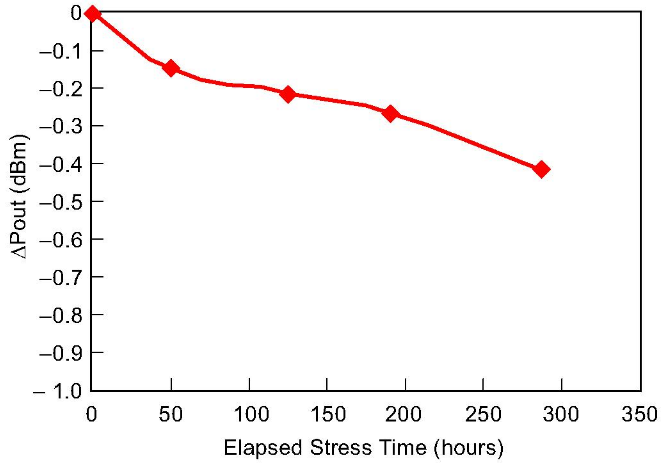

Fig. 10. MPA overdrive test – Pout vs. time for Pin = +17 dBm, T = 150ºC.

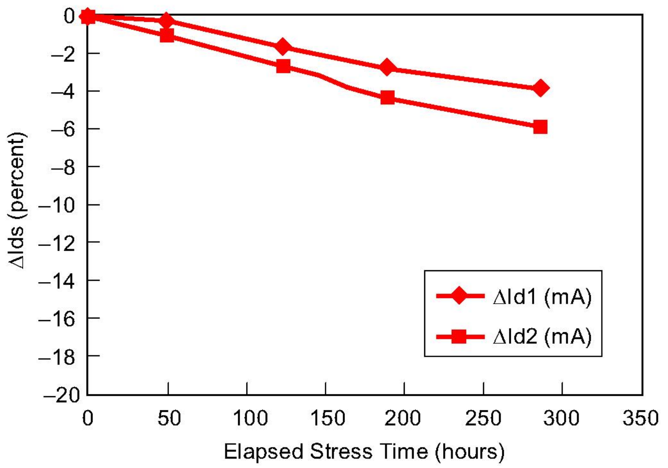

Fig. 11. MPA Ids vs. time for Pin = +17 dBm, T = 150ºC.

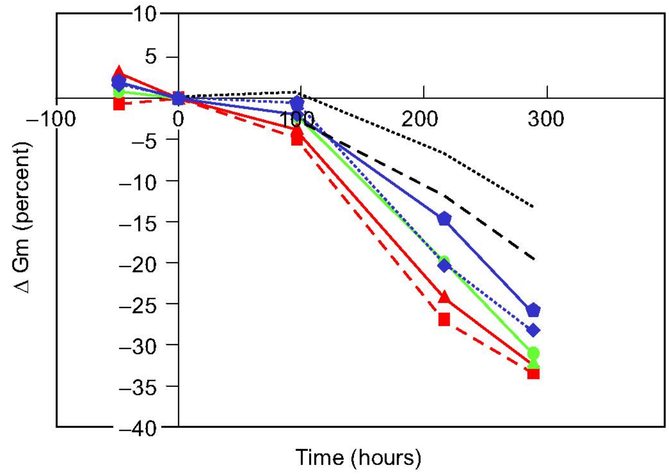

Fig. 12. LNA life test – Gm vs. time for T = 175ºC for 8 samples.

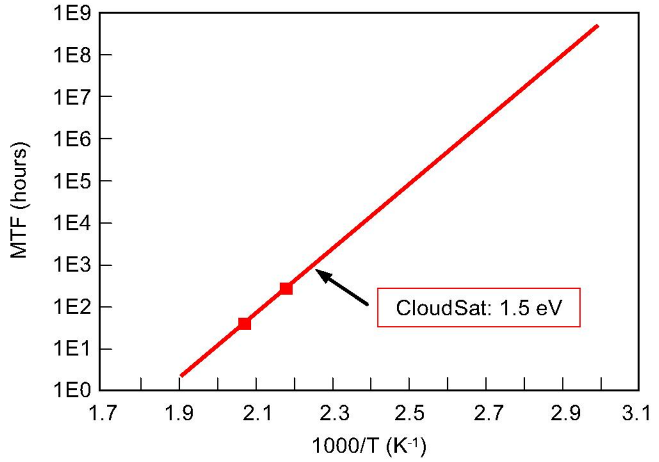

Fig. 13. LNA Arrhenius plot: 2-T lifetest, T = 175 and 200ºC for activation energy = 1.5 eV.

CONCLUSION

This paper has described a new, customized set of qualifications tests for W-band diodes and MMIC amplifiers that was developed for the CloudSat mission. Most of the W-band devices are being used for the first time in a space application. The customized set of tests was designed, on a limited budget and schedule, to meet the mission assurance requirements of the project and at the same time insure that the RF subsystem will meet the high amplitude stability requirements over the 2 year mission life. As of June, 2006, the CPR instrument is operating nominally on orbit in the A-Train.

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