

The Ganymede Laser Altimeter (GALA) for the Jupiter Icy Moons Explorer (JUICE): APD and Electronics

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The Ganymede Laser Altimeter (GALA) has been developed to observe the surface topography and albedo of Jupiter's icy moon Ganymede as an onboard instrument for ESA's Jupiter Exploration Mission (JUICE; JUperiter ICy moons Explorer). As of writing this, JUICE with GALA onboard is awaiting a launch scheduled for April 2023. GALA was jointly developed by teams from Germany, Japan, Switzerland, and Spain, with the Japanese team responsible for the development of the back-end optics (BEO), the avalanche photodiode (APD) sensor module, the focal plane assembly (FPA) that houses the APD module, and the analog electronics module (AEM). In this presentation, we introduce the development of APD module and AEM as the part of Japan team responsibility.

The APD sensor module in GALA was developed based on a commercially available product by Excelitas Technologies Corp., LLAM-1060-R8BH. The APD module consists of a hybrid IC, including an APD sensor (C30954E, Si APD), a pre-amplifier (trans-impedance amplifier, TIA), a temperature sensor, and a Peltier element. The APD sensor is based on a consumer APD with a high quantum efficiency of about 36% at 1060 nm, which is advantageous for devices using a 1064 nm YAG laser. The APD sensor, C30954E, is quite popular, it has a successful track record in many previous space missions. For example, this sensor was also used in the LALT onboard the Kaguya mission and the LIDAR onboard the Hayabusa 2 mission. Because the APD sensor used is a commercial product, the ones for flight and backups were carefully selected from a controlled manufacturing lot dedicated to GALA development to meet the required specifications shown in Table 1.

In order to satisfy the performance required by the GALA team and meet environmental tolerance as needed for the JUICE mission, the TIA built into the APD module as a pre-amplifier was designed to meet the bandwidth, gain, and noise level requirements. In developing the APD sensor module, a serious problem was performance degradation due to high-intensity electron beams in the Jovian magnetosphere. Therefore, an electron beam irradiation test was executed at ONERA, French Aerospace Lab, to investigate the radiation tolerance of the APD sensor. Proton irradiation test was also carried out at the radiation laboratory in the National Institute for Quantum and Radiological Science and Technology in Japan and the cobalt irradiation facility at Tokyo Institute of Technology, Japan. Those tests determined the degree of performance degradation of the APD sensor in response to electron irradiation.

The AEM has two major roles. The first is to drive the APD sensor module to operate under suitable conditions for light pulse measurements. The AEM has a high voltage circuit for applying a reverse bias voltage to the APD sensor, which is controllable in the range of 300 V to 400 V in 1-V steps to obtain the best responsivity of the APD sensor. The AEM also has a thermal control circuit for driving a Peltier device to control the temperature of the APD sensor to stabilize the signal gain since it is strongly temperature-dependent.

The second role of the AEM is to convert the analog signal that the APD sensor outputs via the TIA (continuously varying in a bandwidth of 100 MHz) into digital data using an ADC circuit and send it to the RFM in real time. To ensure that the output signal of the APD module does not degrade, we implemented an analog signal line with a gain control amplifier and differential conversion circuit, which leads the APD

output signal to the ADC circuit. As a result, the noise level of the input signal of the ADC was suppressed to meet the requirement shown in Table 2, as well as the other parameters.

Keywords: JUICE, Ganymede laser altimeter, optical sensor, APD, analog electronics, matched filter

Table 1. Major requirements for the development of GALA APD module

Parameter	Requirements	Achievements
Responsivity of APD sensor	> 700 kV/W	750 kV/W @ 1060 nm
Module bandwidth	> 90 MHz	> 100 MHz
Noise floor level at the TIA output	< 40 fW/ $\sqrt{\text{Hz}}$ in NEP for an entire bandwidth of 100MHz	27 fW/ $\sqrt{\text{Hz}}$ in NEP for an entire bandwidth of 100MHz

Table 2. Major requirements for the development of AEM

Parameter	Requirements	Achievements
Noise floor level at the input to the ADC	< 40 fW/ $\sqrt{\text{Hz}}$ in NEP	39 fW/ $\sqrt{\text{Hz}}$ in NEP
ADC sampling rate	\cong 200 Msamples/s	200 Msamples/s
ADC dynamic range	12bits	12bits
Cut-off frequency for analog signal line for -3dB gain	\cong 100 kHz and \cong 100 MHz	Lower limit: 50 kHz Upper limit: 100 MHz