Photon Counting Module for Laser Time Transfer Space Mission

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Abstract

We are presenting the results of research and development of the Single Photon Avalanche Detector (SPAD) for application in a Laser Time Transfer (LTT) space mission.

For the joint project with the Shanghai Observatory, Academy of Sciences of China, we have developed the detector package dedicated for the project of synchronizing the hydrogen maser-based time scales by laser pulses. The technology demonstrator of a dual detector has been built and tested in our labs. The main parameters are: detection efficiency 10% at 532 nm, timing resolution 80 psec, dark count rate 8 kHz, non gated operation. The detector's active area is 25 um in diameter. The total mass, including bias stabilizing circuit, is 2 grams, and the total power consumption is below 0.5 Watt per detecting channel. The detector can be operated in a wide range of temperatures ranging from –30^o C to +60^o C without any additional temperature control.

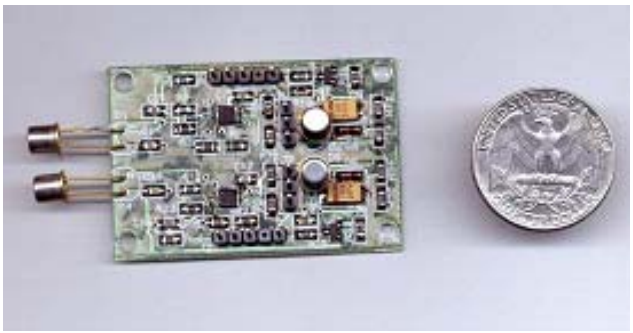


Figure 1: *The technology demonstrator of the dual photon counting detectors. The detection chips (protective caps installed for handling) are on the left.*

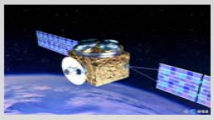
The ruggedness of the detector is superb. Optical power of 2 mW has been focused onto a sensitive area while the detector has been biased for 8 hours. No detectable degradation has been experienced. The overload tolerance negates the need for any mechanical Sun protection shutter in space. The recovery time from optical overload to full functionality is less than 0.1 second. The detector package has been successfully integrated into the LTT timing electronics and the pre-flight test was performed in China during the period July-September 2006.

GOALS

- Fast photon counting detectors for the Laser Time Transfer space mission, China
- BACKGROUND
  the K14 SPAD detectors have been launched onboard MARS 96 (Russia) and NASA Mars Polar Lander (USA) space missions
- REQUIREMENTS
- low mass, power, bias voltage
- high radiation in - sensitivity (> 5 years in space)
- high temperature range
- extreme optical damage threshold (full Solar flux, no shutter)

„LTT Module in Space", China, 2007-2008

- GOALs
- to synchronize the rubidium clocks in space, hydrogen masers in a future.
- Laser Time Transfer (LTT) between space and ground
- employing the existing China Satellite Laser Ranging network consisting of 5 fixed and 2 mobile systems



- required ~ 100 ps timing accuracy
- expected accuracy improvement
  >> 10x over RF techniques

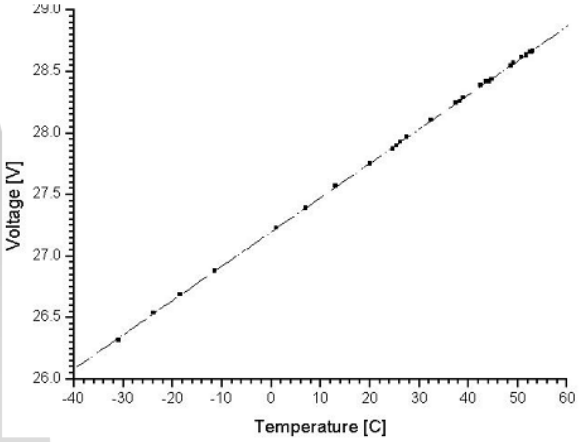
Detector Requirements - version LTT China

- single photon timing — K14 SPAD chips, two channels
- aperture — 25 μm each
- timing resolution — < 100 psec
- power, mass — < 2 W , 100 grams
- operating temperature — -30 ... +60°C
- lifetime in space — > 5 years
- high opt. damage threshold — direct exposure to the Sun (!!)
  in a focal plane of 2 mm aperture collecting optics
  no Sun safety shutter will be installed

- design & construction — 3 months (!)

SPAD Bias Temperature Control

- SPAD break down voltage 29 Volts
- bias accuracy required 100 mV
- temperature range requested -30 … + 60° C
  no temperature control or cooling
- SPAD break voltage temperature drift - 30 mV / K
- => temperature controlled bias circuit



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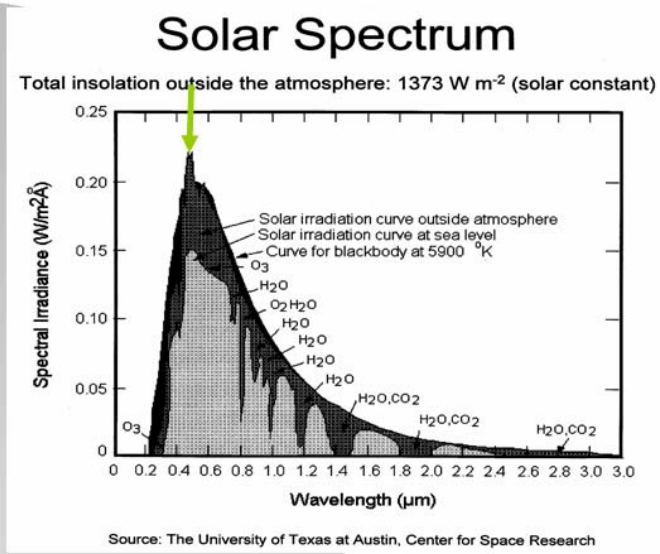
Optical Damage Threshold



Source: The University of Texas at Austin, Center for Space Research

- Irradiance 0.2 W/m²/0.1 nm @ 532nm wavelength
- receiver
  aperture 2 mm
  f / d ~ 1.0
  field of view ~ 0.5°
  entire Solar disc
- bandwidth 100 nm blocking glass filter
- => 1 mW max. on SPAD

Surprisingly, the total flux on the detector aperture is not exceeding 1 mW /100 nm for any aperture (!), due to the field of view limitation.

Larger telescope is not capable to focus all the incoming Sun light onto small SPAD aperture.

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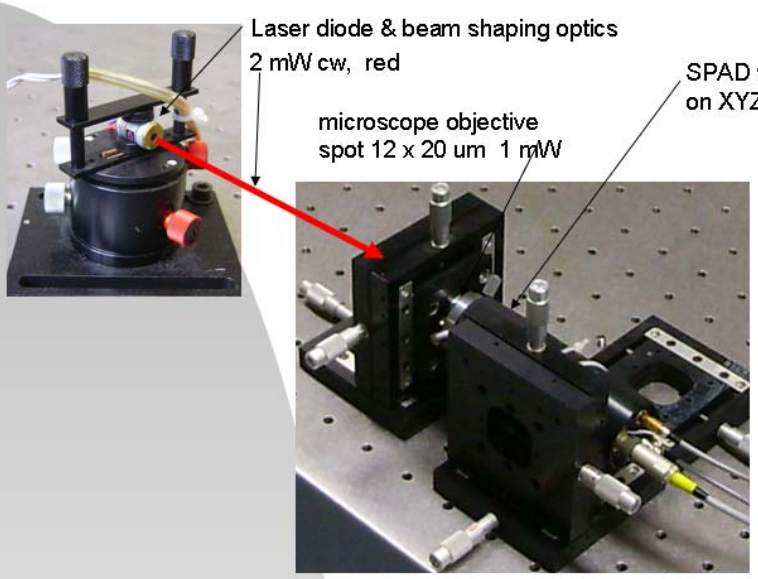
Optical Damage Tests



- exposure tests :
- no bias 3 x 8 hr
- biased 3 x 8 hr

- NO detectable detector degradation after all optical irradiation tests
- Any size telescope with SPAD detector may be pointed toward the Sun without the damage (< 100 nm bandwidth)

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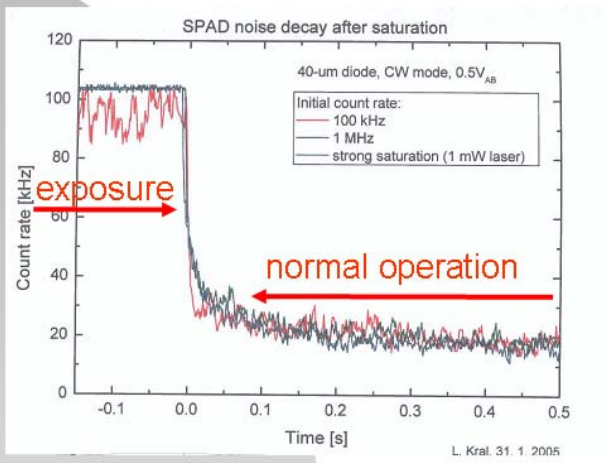
Optical Saturation Recovery



- Detector operation recovery after strong optical signal exp.
- detector illumination
- ambient light 100 kHz
- attenuated laser 1 MHz
  out of range when illuminated
- full laser 1 mW NA
  out of range when illuminated
- instrument time constant ~ 0.02 s

- Detector recovery time after saturation is well below 100 ms
- within this time, the dark count rate drops to 1.1 times the standard value

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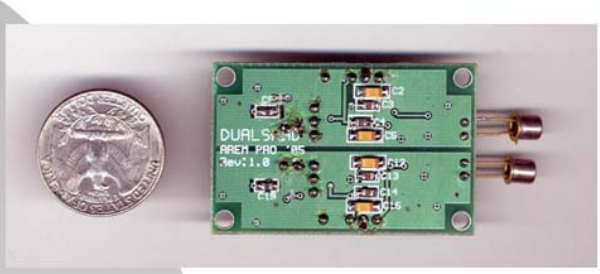
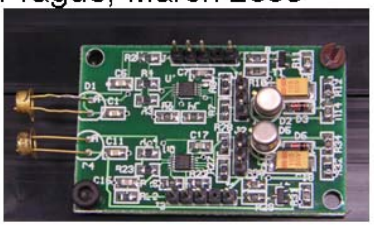
Photon Counting Module for Space Mission LTT



Technology demonstrator
Prague, March 2005



Detector package sample
for pre-flight tests
Shanghai, China, July 2006

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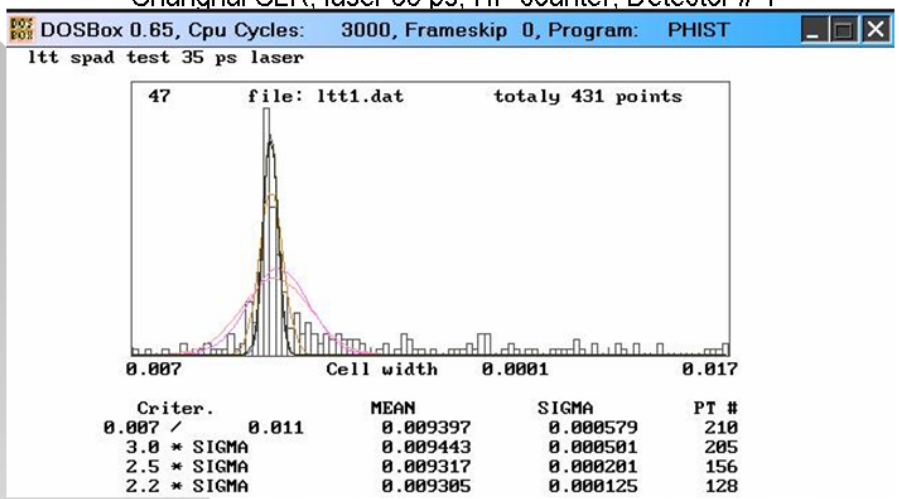
SPAD Timing Resolution Tests, Shanghai July 2006

Shanghai SLR, laser 35 ps, HP counter, Detector # 1



- Jitter detector # 1 125 psec
- detector # 2 120 psec
- Detection delay difference 440 +/- 20 psec

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Dual Single Photon Counting Module

Detector Technology Demonstrator - Specifications

configuration	dual photon counting detector based on Silicon K14 SPAD
quenching	active
active area	circular 25 um diameter
quantum efficiency	~ 10 % @ 532 nm
timing resolution	75 psec
dark count rate	< 8 kHz @ +20°C
operating temp.	-30 … +60°C no cooling, no stabilisation
power consumption	< 400 mW
mass	4 grams
optical damage th.	full Solar flux 100 nm BW, > 8 hr
lifetime in space	> 10 years

CONCLUSION

Photon Counting Module for Space Mission LTT

- the Technology Demonstrators have been completed Prague, March 2005

- the Flight Unit detector version has been completed Shanghai, July 2006
- Solar flux resistant using moderate wavelength filtering
- radiation resistant, 100 kRads without parameter change
  => lifetime in space > 10 years
- pre-flight tests, Shanghai, Beijin , fall 2006