C-SPAD DETECTOR FOR YLARA STATION

Reception report: specifications and setup instructions

YLARA Project

YLARA-LS-20-I01 (CDT Technical Report 2020-13)

A. García Marín, J.C. Rodríguez Pérez, B. Vaquero Jiménez, J.A. López Pérez

Yebes Observatory, IGN-CNIG

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Contact information:

Observatorio de Yebes
Cerro de la Palera s/n
19141 (Yebes), Guadalajara
Tel.: 949 290 311
Email: b.vaquero@oan.es

Acknowledgments

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Index

Change index

Version	Date	Section	Change Description
V01	06-2020	All	Initial version

Applicable and reference documents

[RD01] *Single Photon Detector Package User Manual – Version C-SPAD*. Noviembre, 2019.

[RD02] *Solid State Photon Counting Module Time Walk Compensation Option C-SPAD Data Sheet.*

[RD03] *Solid State Photon Counters for Laser Ranging to Orbital Space Debris*. I. Prochazca, G. Kirchner, et al. Workshop on Laser solutions for Orbital Space Debris, 2015, Paris (France).

[RD04] *International Laser Ranging Service (ILRS), Stations List,* https://ilrs.cddis.eosdis.nasa.gov/network/stations/index.html

[RD05] *System Improvement and GIOVE-A Observation of Changchun SLR*. You, Zhao et al., 2006.

[RD06] *Graz kHz SLR system: design, experiences and results*. G. Kirchner, F. Koidl.

[RD07] *SP-DART: Single-Photon Detection, Alignment and Reference Tool*. G. Kirchner, M. A. Steindorfer, F. Koidl, P. Wang. Space Research Institute, Austrian Academy of Sciences, 2015.

[RD08] *The C-SPAD as a single-photon detector*, P. Gibbs and R. Wood, NERC Space Geodesy Facility, Herstmonceux, UK.

[RD09] *SPAD Time Walk Compensation and Return Energy Dependent Ranging.* Kirchner, G., Koidl, F., Prochazka, I. & Hamal, K., Proc. of 11th International Workshop on Laser Ranging, Deggendorf 1998, pp 521-525.

[RD10] *San Fernando Laser Station updates and new improvements*. M. Catalán, 2019.

[RD11] *The progress of laser ranging technology at Shanghai Astronomical Observatory*, Zhibo, Wu et al, 2019.

[RD12] *The New Mount Stromlo SLR System*, B. Greene, 2004.

[RD13] *History of the laser observations at Zimmerwald*, M. Ploner.

1. Introduction

A detector for the nominal reception path (i.e., at a wavelength of 532 nm) of the YLARA (Yebes Laser Ranging) station has been acquired to PESO Consulting (Czech Republic) in June, 2019, being received at Yebes Observatory in November, 2019.

This document starts providing a general overview of such detectors (*C-SPAD Detectors: general overview* section).

Then, it analyses the received material (detector, documentation and other stuff) in section *Acquired C-SPAD Detector*. In the context of this analysis, some technical questions to be clarified by the manufacturer have been identified and listed (Table 2).

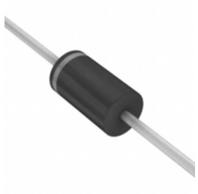
Finally, Annexes section 1 show how widespread its use is in the *Satellite Laser Ranging* (SLR) technique.

2. C-SPAD Detectors: general overview

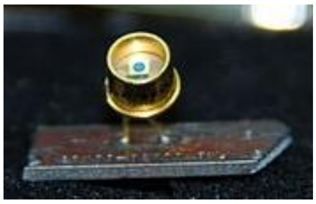
2.1. Introduction to the C-SPADs

The C-SPAD detectors (Compensated Single Photon Avalanche Photodiode) are SPAD (Single-Photon Avalanche Photodiodes) incorporating an internal circuit which compensates for the internal time walk, that is, reduces the change of the detection delay dependence on the input optical signal intensity in a dynamical range from single up to 1000 photoelectrons. Figure 1 shows the evolution of these devices.

Photomultiplier tuve (PMT)



Avalanche diode (AD)



Avalanche photodiode (APD)

Single-photon avalanche diode (SPAD)

Compensated SPAD (C-SPAD)

Figure 1. C-SPAD devices evolution.

2.2. C-SPADs historical overview

2.2.1. Photomultiplier tube (PMT)

Photomultiplier tubes (**photomultipliers** or **PMT**), members of the class of vacuum tubes, and more specifically vacuum phototubes, are extremely sensitive detectors of light in the UV, Vis, and NIR. They multiply the current produced by incident light by as much as x10^8 in multiple dynode (electrode in a vacuum tube that serves as an electron multiplier through secondary emission) stages, enabling (for ex.)) **individual photons** to be detected when the incident flux of light is low.

Properties: high gain, low noise, high frequency response or, equivalently, ultra-fast response, and large area of collection.

Semiconductor devices, particularly avalanche photodiodes, are alternatives to photomultipliers; however, photomultipliers are uniquely well-suited for applications requiring low-noise, high-sensitivity detection of light that is imperfectly collimated.

2.2.2. Avalanche diode (AD)

It is a diode (made from silicon or other semiconductor) designed to experience avalanche breakdown at a specified reverse bias voltage. The avalanche breakdown is due to minority carriers accelerated enough to create ionization in the crystal lattice, producing more carriers which in turn create more ionization. Its breakdown voltage is nearly constant with changing current when compared to a non-avalanche diode.

2.2.3. Avalanche photodiode (APD)

It is a highly sensitive semiconductor electronic device that exploits the photoelectric effect to convert light to electricity. APDs can be thought of as photodetectors that provide a built-in first stage of gain through avalanche multiplication.

From a functional standpoint, **they can be regarded as the semiconductor analogue of photomultipliers**. By applying a high reverse bias voltage (typically 100–200 V in silicon), APDs show an internal current gain effect (x100) due to impact ionization (avalanche effect). However, some silicon APDs employ alternative doping and bevelling techniques compared to traditional APDs that allow greater voltage to be applied (> 1500 V) before breakdown is reached and hence a greater operating gain (> x1000). In general, the higher the reverse voltage, the higher the gain.

Since APD gain varies strongly with the applied reverse bias and temperature, it is necessary to control the reverse voltage to keep a stable gain. Avalanche photodiodes therefore are more sensitive compared to other semiconductor photodiodes.

If very high gain is needed (10^5 to 10^6), certain APDs (single-photon avalanche diodes) can be operated with a reverse voltage above the APDs breakdown voltage. In this case, the APD needs to have its signal current limited and quickly diminished. Active and passive current-quenching techniques have been used for this purpose. APDs that operate in this high-gain regime are in Geiger mode. This mode is particularly useful for single-photon detection, provided that the dark count event rate and after pulsing probability are sufficiently low.

Typical applications for APDs are laser rangefinders. APD arrays are becoming commercially available.

APD applicability and usefulness depends on many parameters:

- Quantum Efficiency
- Total leakage current: the sum of the dark current and photocurrent and noise.

2.2.4. Single-photon avalanche diode (SPAD)

It is a solid-state photodetector in which a photon-generated carrier (via the internal photoelectric effect) can trigger a short-duration but relatively large avalanche current. This avalanche is created through a mechanism called impact ionization, whereby carriers (electrons and/or holes) are accelerated to high kinetic energies through a large potential gradient (voltage). If the kinetic energy of a carrier is sufficient (as a function of the ionization energy of the bulk material) further carriers are liberated from the atomic lattice. The number of carriers thus increases exponentially from, in some cases, as few as a single carrier.

This device is able to detect low-intensity ionizing radiation, including: gamma, X-ray, beta, and alpha-particle radiation along with electromagnetic signals in the UV, Vis and IR (in the optical case this can be down to the single photon level). SPADs are also able to distinguish the arrival times of events (photons) with a timing jitter (deviation of a presumably periodic signal from true periodicity, often in relation to a reference clock signal) of a few tens of picoseconds.

SPADs, like APDs, exploit the incident radiation triggered avalanche current of a p–n junction when reverse biased. The fundamental **difference between SPADs and APDs** is that SPADs are specifically designed to operate with a reverse-bias voltage (linear-mode) well above the breakdown voltage (Geiger-mode).

Applications: LIDAR, Time of Flight (ToF), single-photon experimentation within physics.

2.2.5. Compensated SPAD (C-SPAD)

The time-walk compensated version of the SPAD, the so-called C-SPAD, has several improvements over previous SPAD detectors:

- A larger chip makes for easier alignment.
- The detector chip itself is cooled to -60°C and is much less noisy.
- The electronics are temperature stabilized to minimize response time variations with temperature (particularly important for us since our detector is exposed at the Cassegrain focus of the telescope).
- A second output channel has been added for which the timing of the emitted electrical pulse is delayed by an amount equal to the time-walk induced by the particular energy of the incoming photon pulse.

3. Acquired C-SPAD Detector

3.1. Purchase selection justification

This type of detector has been selected due to its complete adjustment to the requirements of our application, SLR. In particular, part of its evolution has been conditioned to this application. The evidence of this is reflected in the fact that it can be found implemented in many SLR stations throughout the world (Table 3 shows some of them).

With this detector, SLR and Space Debris (SD) can be performed (however, the infrared version of the C-SPAD is currently the more used for SD). The appendix section 1 shows some references in SLR applications.

The version purchased has been specifically developed for SLR ([RD01]).

SINGLE PHOTON DETECTOR PACKAGE	
General	self consistent all solid state photon counter with high timing resolution, time walk compensation, temperature stabilization
Principle of operation	Single Photon Avalanche Photodiode (SPAD) pulse biased above the break voltage
Version / application	Laser ranging to space objects

Figure 2. C-SPAD version for SLR.

3.2. Description

The acquired detector is a Compensated Single Photon Avalanche Diode (C-SPAD). A general overview of them has been provided in the previous section. A description of the characteristics of the one acquired for YLARA follows.

The Compensated Solid State Photon Counting Module is a self consistent detector package which detects optical pulses within the signal strength ranging from single photons up to hundreds of photons over the spectral range 0.35-1.10 µm with ps timing resolution and time walk.

The module utilises a unique Silicon avalanche photodiode (APD), which is connected in the active quenching and gating circuit and pulse biased above its break voltage. An extreme gain of the order of 10^9 is achieved by biasing the diode above the break.

Single photon arrival times can be measured with a resolution better than 25 ps rms (in single photon detection) and < 5 ps rms (in thousands of photons detection). The detection internal delay long term stability is within the units of ps.

To reduce the diode dark count, the detection chip is cooled by a stage thermoelectric cooler.

The detector package is operated in a gated mode (the first photon after the gate opening is detected). The detector package with time walk compensation has been optimised for gate repetition rates up to 10 kHz.

The detector is fully described in its User Manual ([RD01]) and Data Sheet ([RD02]).

This model of detector is widely used in SLR and SD applications: see appendix for a general overview on it.

3.3. Received items

- Parts:
  - C-SPAD detector package (item 1/2): detector.

Figure 3. Detector package.

  - C-SPAD detector package (item 2/2): power supply.

Figure 4. Detector power supply.

- The material received matchs with that described in the Packing List being its S/N (0459) correctly marked on both items.
- The cable is 4.8 m long: it must be verified if it is enough for our installation. (Note: Perhaps it would be convenient to ask if there are limitations to change it for a longer one)

- Documentation:
  - Commercial Invoices
  - Packing List
  - User Manual

3.4. Documentation analysis after reception

The documentation received, C-SPAD User Manual ([RD01][RD02]), has been analyzed. From it, two tables have been generated:

- Table 1 shows some comments to be considered for testing and integrating it at system level.
- Table 2 shows some points which have been clarified after contacting the manufacturer.

Information received	Comments
External gating insulation > 10^9 (optical) logic FLIP-FLOP built in delay typ. 35 nsec impedance 50 Ohms levels TTL low < 1V high > 2.5 V connector SMA gate pulse > 8 ns wide rise time ~< 3 ns gate is opened by the pulse leading edge and closed by the first output pulse. For top performance, apply the gate > 100 ns before the photon of interest arrival	A pulse generator is available in the Yebes Observatory: Keysight 33250A. To be analysed if it generates these kind of pulses in order to open the reception gate. Pulse Frequency: 500 µHz to 50 MHz (1 kHz requested) **Pulse** Period: 20.00 ns to 2000.0 s Pulse width: 8.0 ns to 1999.9 s Variable edge time: 5.00 ns to 1.00 ms Overshoot: < 5% Jitter (rms): 100 ppm + 50 ps The other option is to use the Gate generator. For a top performance, the excitation laser source should be synchronized with the "gate" of the sensor. Until this source is available, this cannot be verified.

Operating Temperature - 20° C … + 35° C	For operation in summer, where ambient T can be > 35°C, some thermal control must be provided in the design of this subsystem to keep the sensor T below 35ºC.

Table 1. Information to be internally clarified.

Information received	Information to be requested	Manufacturer answer
External gating insulation > 10^9 (optical) logic FLIP-FLOP built in delay typ. 35 nsec impedance 50 Ohms levels TTL low < 1V high > 2.5 V connector SMA gate pulse > 8 ns wide rise time ~< 3 ns	Concept of *insulation:* to be clarified.	It is the detector capability to do not respond to short optical pulses containing up to 10^9 photons in a Gate OFF status.
Collecting optics doublet, AR for 532 nm accepts collimated beam 12 mm	Should it be possible to have its Zemax or optics prescription file?	Drawing with all info included (Annexes section 2) No Zemax or similar format is available.
	Does the sensor incorporate a narrow band pass filter around 532 nm?	No
	Is 12 mm the optics clear aperture diameter or the 1/e diameter of the accepted laser beam?	It is the recommended FULL diameter of a beam. Physically, the optics input diameter is 15 mm. For detector the uniform signal distribution over the aperture (12mm) is expected. That is why "1/e" estimate is not appropriate.
Detector holder Use the cylindrical part of detector to hold the detector in position and to remove the excess heat generated.	Is the junction sensor head – sensor body robust enough to avoid any mechanical bending if holding the sensor that way?	Yes
	Is it needed to put some metal component in contact with that cylindrical part in order to facilitate the heat removal?	The holder is expected to be metallic. No special configurations are needed. Even having a non-metal holder the heat removal by detector body should be acceptable.
Operating Temperature	Non-operative and Survival Temperature ranges to be	Non-operating temp. range is -55 … +50°C

Information received	Information to be requested	Manufacturer answer
- 20° C ... + 35° C	communicated.	
	If the detector reaches an upper T (e.g., 38°C), could it be damaged or it would only impact in the data quality (noisy)?	The detector operation will not be correct above an upper T. Heating it above +50°C will cause its permanent damage.
Heat removal conduction via detector holder and ambient temperature air circulation	To be clarified if detector holder means detector external case (i.e., housing).	Both parts. See also above.
Detector chip housing front window Do not touch the detector chip housing front window. Never change the adjustment of the collecting optics! Screwing it too deep in will result in a window break and detector damage.	Should it be possible to have its Zemax or optics prescription file for the sensor optical window?	It is not available. The housing is provided by an US company.
For the top performance maintain the recommended temperature of the detector housing. Assure the free air circulation near the package and power supply, avoid direct sunlight on the package.	To be clarified if the temperature shown in the power supply corresponds to the temperature of the detector or the one of the detector housing.	The displayed temperature is a SPAD chip one.
Avoid strong light pulses on the detector input, pulse energies >1 nJ on the detector input will cause its damage. Avoid laser backscattered light on detector input.	To be clarified if the "detector input" refers to the first surface of the collecting optics or to the detector surface. Damage threshold is specified as the maximum allowed irradiance (W/m^2). Here, only an energy value is specified. Convert it to power by considering the pulse duration.	The limit is a total energy hitting the detector chip SPAD surface. It is valid for short optical pulses, FWHM ~< 1 ns. **Understanding:** The maximum allowed power per pulse would be: P=E/t= 1 nJ / 1 ns = 1 W Assuming a 200 microns circular spot (area: 3.14E-4 cm^2), the maximum irradiance fixing the damage threshold is: E=Pmax/area= 1 W / 3.14E-4 cm2 = 3.2 kW/cm2.
Keep the detector ON all the time to maintain operation stability.	Is there any stabilization (warm) time after turning on the detector before to use it?	Certainly yes. But its length depends on your stability requirements. For ~ 1mm ranging stability **a warm up time of a few minutes is ok.**

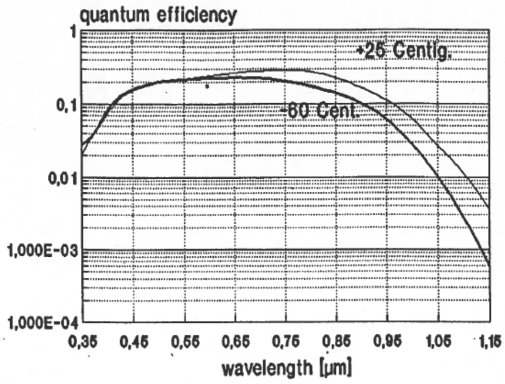
Information received	Information to be requested	Manufacturer answer
 Detection chip quantum efficiency in relative units, for C-SPAD configuration for SLR the QE at 532 nm is typically reaching 40 %.	From the figure, QE @532nm seems to be around 20% while in the figure foot is said that it has a typical value of 40% (@ 25°C).	In this figure the QE in RELATIVE UNITS is plotted, see figure capture. The absolute value of QE at 532 nm wavelength was measured by CNES in 2006. **The QE value of 42% was measured repeatedly**.

Table 2. Information to be clarified by the manufacturer.

3.5. Material inspection after reception

After a visual inspection, no external damage has been detected.

3.6. Performance verification

Detector performances verification can be done at module or system level.

With regard to the optical performance, next verifications are expected:

- **Module level**. The next equipment is needed:
    - A laser source emitting at 532nm and performance similar to the one envisaged for YLARA.
    - A beam expander.
    - Two flat folding mirrors and their mounts.
    - A set of neutral filters.
    - Optical table.
    - Power / energy meter.
- **System level**. The detector must be integrated in YLARA to proceed with it.

4. Annexes

4.1. C-SPAD detector's heritage in SLR

Several SLR stations, most of them located in Europe, have this detector implemented in (roughly, more than 20). Some of them, a part of SLR, perform SD with the same detector which adds versatility of finality ([RD03]). Table 3 shows some of them and, after it, some are described in more detail.

Datos Site Logs estaciones más relevantes

Estación	Changchun	ESA	Graz	Graz - SP-DART	Herstmonceux	Mount Stromlo	San Fernando	Shanghai	Zimmerwald
0. Fecha site log	10/04/2018	En desarrollo	26/06/2018		05/02/2018	20/07/2018	11/06/2015	14/11/2015	05/03/2018
2. Site Location Info									
City or Town	Changchun	Tenerife	Graz	Graz	Hailsham	Canberra	San Fernando	Shanghai	Zimmerwald
Country	China	Spain	Alemania	Alemania	Reino Unido	Australia	España	China	Suiza
6. Receiver System									
Primary chain /Detector type	CSPAD (532 nm)	CSPAD (532 nm)	CSPAD (532 nm)	CSPAD (532 nm)	CSPAD (532 nm)	CSPAD (532 nm)	C-SPAD (532nm)	CSPAD (532 nm)	CSPAD (532 nm)
Manufacturer	Peso /Graz	Peso /Graz	Peso/Graz	Peso/Graz	PESO	Peso / Graz	PESO	Peso /Graz	PESO / Graz
QE (%)	20		> 20	> 20	20	20	20	20	18
Rise time	1500 ps		< 2400 ps		1500 ps		< 2400 ps		-
FoV	40-60 "		40-60 "		100 micras	12 "	40-60 "	60 "	> 8 "
Signal Processing	Time walk Comp.		Time walk compensated		-	Time walk comp. Graz	CFD (Tennelec) (start detector only)	Time walk Comp.	Time Walk Comp.
Mode of operation	Single to multi		Multi photon		single photon	Single to multiple	Single to Multi photon	Single to multi	Single to few photons
ToF observation	Event timer	Event Timer	Event timer		Event timer	Event timer	Interval	Event timer	Event Timer
Manufacturer	Riga, A033	Riga	Dassault / Graz		Thales modules	EOS	Stanford Reasearch	Riga, A033	RIGA, A032
Resolution	1 ps		1,22 ps		1 ps	0.7 ps	4 ps	1 ps	1 ps
Precision	5 ps		2 ps		5 ps	10 ps	30 ps	5 ps	10 ps

Table 3. ILRS stations performing SLR with the detector acquired for YLARA

4.1.1. CHAL - Changchun (China)

See [RD04] and [RD05].

```
6.   Receiver System

6.01.01 Primary Chain
        Wavelength          [nm]: 532
        Detector Type           : C-SPAD
          Manufacturer          : PESO Consulting/CZECH
          Model                 : 0432
          Quantum Efficiency [%]: 20
          Nominal Gain          :
          Rise Time         [ps]:
          Jitter (Single PE)[ps]: 20
          Field of View Diam ["]: 80
          Date Installed        : 2013-01-14
          Date Removed          : 2013-11-25
```

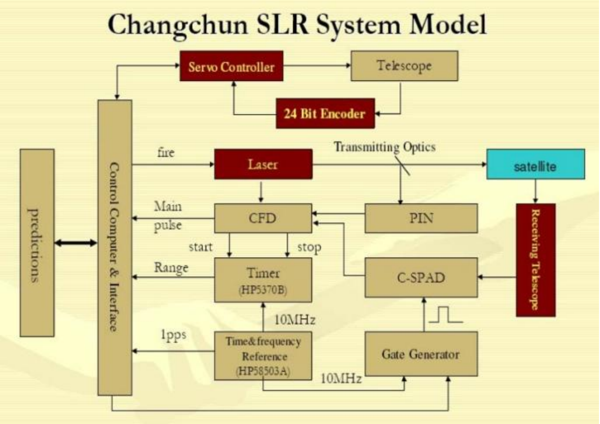


Figure 5. CHAL - Changchun . Site Log and SLR system model showing the C-SPAD as detector.

4.1.2. ELRS (ESA Laser Ranging Station) - Tenerife (España)

System setup: in progress. No references yet.

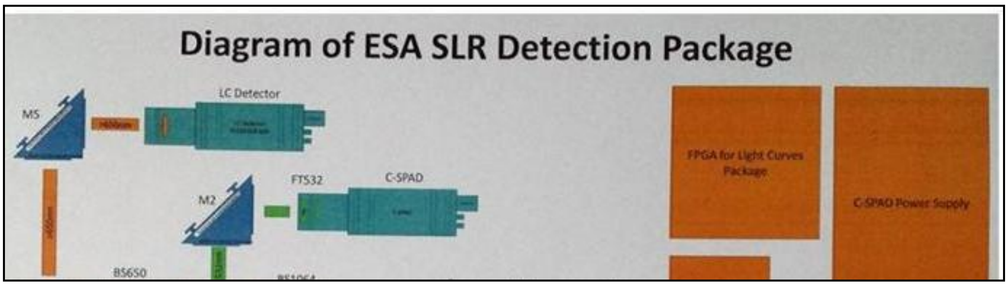


Figure 6. ESA SLR system model showing the C-SPAD as detector.

4.1.3. GRZL - Graz (Austria)

See [RD04] and [RD06].

```
6.   Receiver System

6.01.01 Primary Chain
        Wavelength          [nm]: 532
        Detector Type           : CSPAD
          Manufacturer          : Chip: PESO Consulting; Electronics: Graz
          Model                 :
          Quantum Efficiency [%]: 20
          Nominal Gain          :
          Rise Time         [ps]: 2400
          Jitter (Single PE)[ps]: 30
          Field of View Diam ["]: 40 - 60
          Date Installed        : 1988-01-01
          Date Removed          :
```

Figure 7. GRZL – Graz - Site Log.

GRAZ KHZ SLR SYSTEM: DESIGN, EXPERIENCES AND RESULTS

G. Kirchner, F. Koidl
Austrian Academy of Sciences. Institute for Space Research
Lustbuehelstrasse 46. A-8042 GRAZ, AUSTRIA
kirchner@flubpc04.tu-graz.ac.at

Abstract

Within the last years, we have prepared our Graz SLR system for kHz operation; since October 2003, this 2 kHz SLR system is operational.

Our previous 10 Hz laser (35 mJ @ 532 nm, 35 ps pulse width) has been replaced by a 2 kHz, DPSS Nd:Van laser system, using a SESAM seed laser with a Regenerative amplifier and a post amplifier; this laser delivers 400 µJ @ 532 nm per shot, with a pulse width of 10 ps FWHM; due to the low energy per shot, we receive mainly single photons from higher orbiting satellites, like LAGEOS or higher; from Low Earth Orbiters (LEOs) we still get multi – photon returns, resulting in close to 100% return rates.

As single photon detector we use a standard C-SPAD (Single Photon Avalanche Diode, Peltier cooled) with Time Walk Compensation; the Range Gate Generator with 500 ps resolution was implemented with an FPGA chip in Graz. Time of flight is measured with our Graz E.T. (based on Dassault Event Timer modules) with 1.2 ps resolution; the system is capable of handling up to 500 shots in flight simultaneously.

The system single shot RMS now is 2.5 mm for satellites with low signature; due to high data density of Normal Points – up to 100.000 returns per NP – this system offers in principal accuracies far below the 1 mm level.

Due to the high data density and the high single shot accuracy, the Graz kHz SLR system now can detect single retro-reflector tracks from many satellites; this allows to select only echoes from the nearest retro-reflectors, resulting in a much better defined mean point of reflection, improving again the accuracy. In addition, it is also possible to derive the rotation of passive sphere satellites.

Figure 8. GRZL – Graz – System overview.

4.1.4. SP-DART - Graz (Austria)

See [RD07].

Single-Photon detector Units

For the application of SP-DART in non-SLR telescopes (e.g. astronomy telescopes), suitable single-photon detectors have been designed, built, installed and aligned. Three different options are possible.

The C-SPAD offers a 200 µm chip, is Peltier-cooled to -60°C and has fully time-walk compensated electronics [Kirchner 1996] and offers single shot accuracy of 2-3mm and a resolution down to 0.2mm. The quantum efficiency is larger than 20%. However, the small chip size limits the accepted field of view of the sensor.

Figure 9. SP-DART – Graz detection subsystem overview.

4.1.5. HERL - Herstmonceux (Reino Unido)

See [RD04] and [RD08].

```
6.01.05 Primary Chain
        Wavelength          [nm]: 532
        Detector Type           : CSPAD
          Manufacturer          : PESO Consulting
          Model                 :
          Quantum Efficiency [%]: 20
          Nominal Gain          :
          Rise Time         [ps]: 1500
          Jitter (Single PE)[ps]: 30
          Field of View Diam ["]: 20 - 250
          Date Installed        : 2002-10-16
          Date Removed          :
```

Figure 10. HERL - Herstmonceux - Site Log.

They have used Single-Photon Avalanche Diode (SPAD) detectors at its Herstmonceux SLR station since 1992.

Their principal advantages over the traditional photo-multiplier tubes (PMTs), which they replaced, are the fast rise time of the avalanche to give good epoch timing, and the fact that they are compact, stable and robust. But they do have some disadvantages: they are intrinsically noisier than PMTs; there is time-walk (the response time is dependent on both light pulse energy and the temperature of the device); and the tiny chip can make alignment difficult. However, the effects of these drawbacks can be minimized at the telescope by using neutral density filters to attenuate the energy of return pulses at the level of single photons, and by frequent calibration, especially when the temperature is changing rapidly. In routine operation the advantages far outweigh the drawbacks.

At the end of 1998 they purchased a time-walk compensated version of the SPAD, the so-called C-SPAD ([RD09]), which has several improvements over previous SPAD detectors.

4.1.6. SFEL - San Fernando (España)

See [RD04] and [RD10].

```
6.01.02 Primary Chain
        Wavelength          [nm]: 532
        Detector Type           : C-SPAD
          Manufacturer          : PESO Consulting/Graz
          Model                 :
          Quantum Efficiency [%]: 20
          Nominal Gain          :
          Rise Time         [ps]: 2400
          Jitter (Single PE)[ps]: 30
          Field of View Diam ["]: 50
          Date Installed        : 2001-01-24
          Date Removed          :
```

Figure 1. SFEL – San Fernando - Site Log.

4.1.7. SHA2 - Shanghai (China)

See [RD04] and [RD11].

```
6.01.02 Primary Chain
        Wavelength          [nm]: 532
        Detector Type           : C-SPAD
          Manufacturer          : PESO Consulting/CZECH
          Model                 : 0433
          Quantum Efficiency [%]: 20
          Nominal Gain          :
          Rise Time         [ps]:
          Jitter (Single PE)[ps]: 20
          Field of View Diam ["]: 60
          Date Installed        : 2013-11-25
          Date Removed          :
```

Figure 12. SHA2 - Shanghai - Site Log.

4.1.8. STL3 - Mount Stromlo (Australia)

See [RD04] and [RD12].

```
6.   Receiver System

6.01.01 Primary Chain
        Wavelength          [nm]: 532
        Detector Type           : CSPAD 0419
          Manufacturer          : PESO Consulting
          Model                 : -
          Quantum Efficiency [%]: 20
          Nominal Gain          : N.A.
          Rise Time         [ps]: N.A.
          Jitter (Single PE)[ps]: 20
          Field of View Diam ["]: 12
          Date Installed        : 2004-04-08
          Date Removed          :
```

Figure 13. STL3 - Mount Stromlo - Site Log.

4.1.9. ZIML - Zimmerwarld (Suiza)

See [RD04] and [RD13].

```
6.01.02 Primary Chain
        Wavelength          [nm]: 423
        Detector Type           : CSPAD
          Manufacturer          : PESO Consulting
          Model                 : 0410
          Quantum Efficiency [%]: 18
          Nominal Gain          : 1e10
          Rise Time         [ps]: N.A.
          Jitter (Single PE)[ps]: 30
          Field of View Diam ["]: 9
          Date Installed        : 2003-03-11
          Date Removed          :
```

Figure 14. ZIML – Zimmerwarld - Site Log.

	1996-2008	Since 2008
Laser		
Type	Titanium-Sapphire	Nd:YAG
Manufacturer / Model	Thales	Thales
Wavelength	423 & 846 nm	532 nm
Frequency	10 Hz	100 Hz
Pulse Energy	100 mJ @ 846 nm 40 mJ @ 423 nm	24 mJ @ 1064 nm 10 mJ @ 532 nm
Pulse Width	100 ps @ 423 nm	58 ps @ 532 nm
Echo detection		
Type	PMT / CSPAD	CSPAD
Time of Flight	Interval counter (Stanford)	Event timer (Riga)
Epoch Timing	Quartz controlled by GPS	Quartz controlled by GPS

Figure 15. Laser and receiver systems used at the 1 m ZIMLAT telescope (since 1996).

4.2. C-SPAD optical configuration

The detector package (Figure 6) includes an air separated doublet (Figure 7).

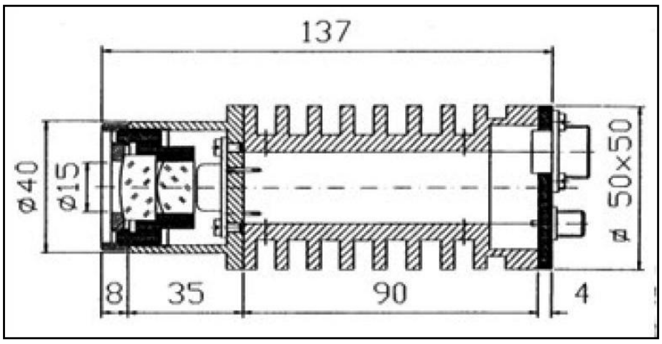


Figure 16. C-SPAD detector package dimensions. The 8mm dimension could vary due to focus adjustment.

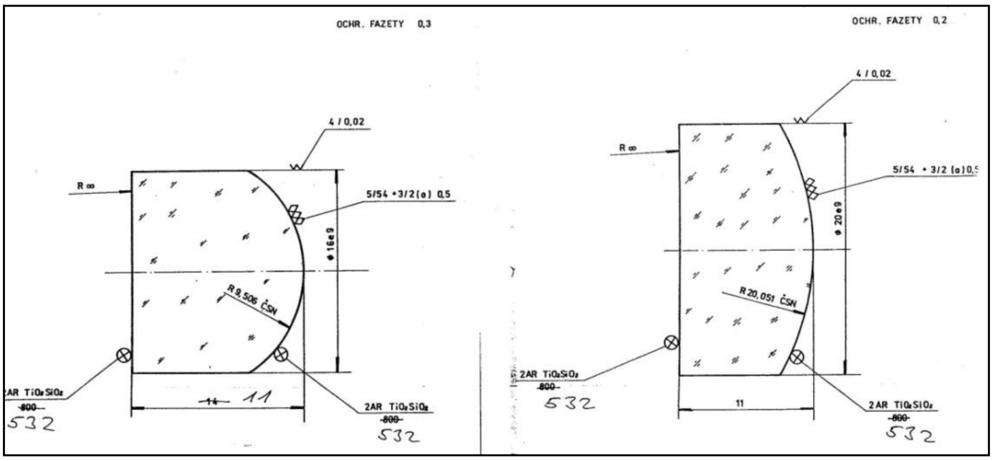


Figure 17. C-SPAD detector package optical components of the air separated doublet.

C-SPAD Detector for YLARA Station
Yebes Observatory, June 2020