

# Stato di G-2 Trieste

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sabbatico da Soreq NRC Israele)

# Sommario

- Impegni e acquisti di materiale
- Misure in eterodina con sottrazione del fondo
  - Test preliminari
  - Misure a bassa frequenza su diodi veloci
- Prossime prove
- Conclusioni

# Impegni del gruppo G-2 Trieste

- Reperimento ed acquisto del laser impulsato per le prove iniziali del sistema di distribuzione
- Acquisto di fotodiodi ed amplificatori veloci per le prove sul laser
- Prove preliminari di stabilità sul sistema di rivelazione diodo-amplificatore
- Prove di validazione sul laser impulsato
  - stabilità in ampiezza
  - stabilità in tempo

# Principali acquisti fatti

- Fotodiodi veloci (\*)
  - Hamamatsu S5973-02 (5 pezzi)
  - Alphas UPD-40-UVIR-P con amplificatore (BW >8.5 GHz, risetime < 40 ps)  
⇒ UD
- Laser impulsato (\*)
  - “testa” PicoQuant ad alta potenza (⇒ driver già ad UD)
  - laser impulsato AlphaLas
- Materiale ottico vario

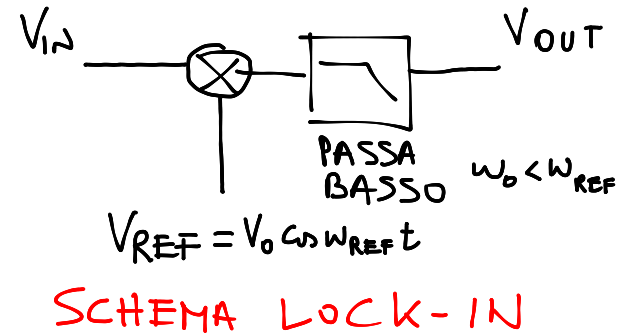
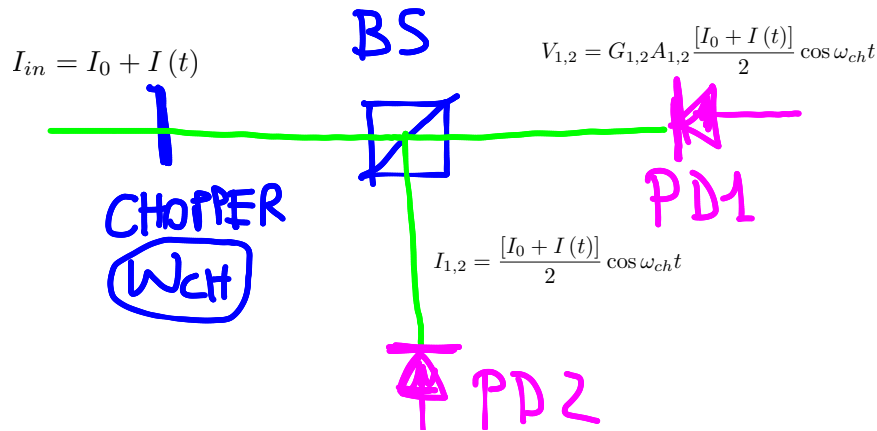
(\*) specifiche a fine presentazione

# Prove preliminari di stabilità su fotodiodi (e amplificatori)

- Prove fatte con materiale già presente nel laboratorio di Trieste
  - laser CW a 532 nm (mod. Prometheus della Innolight)
  - Amplificatori di transimpedenza Femto (BW massima 200 MHz)
- Sottrazione del fondo con rivelazione in eterodina
  - fascio principale ripartito in due bracci ottici equivalenti
  - modulazione in ampiezza del fascio principale (con chopper inizialmente)
  - monitoraggio della differenza dei segnali in intensità all'uscita dei due bracci

# Tecnica di sottrazione del fondo con eterodina

- L'intensità luminosa  $I_{in}$  proveniente dal laser, che contiene una parte costante  $I_0$  ed una fluttuante  $I(t)$ , è modulata in ampiezza con un chopper alla frequenza  $\omega_{ch}$  e separata in due fasci con un beam splitter (simmetrico per semplicità).
- La differenza  $\Delta$  tra i segnali dei due fasci è rivelata in eterodina con un amplificatore lock-in riferito a  $\omega_{ch}$
- L'uscita del lock-in contiene i parametri G (guadagno) e A (risposta del fotodiodo) ed è indipendente dalle fluttuazioni in intensità del laser



## SCHEMA ETERODINA

guadagno [V/A]      risposta diodo [A/W]

$$\Delta = V_2 - V_1 = (G_2 A_2 - G_1 A_1) \frac{[I_0 + I(t)]}{2} \cos \omega_{ch} t = K I_0 \cos \omega_{ch} t + K I(t) \cos \omega_{ch} t$$

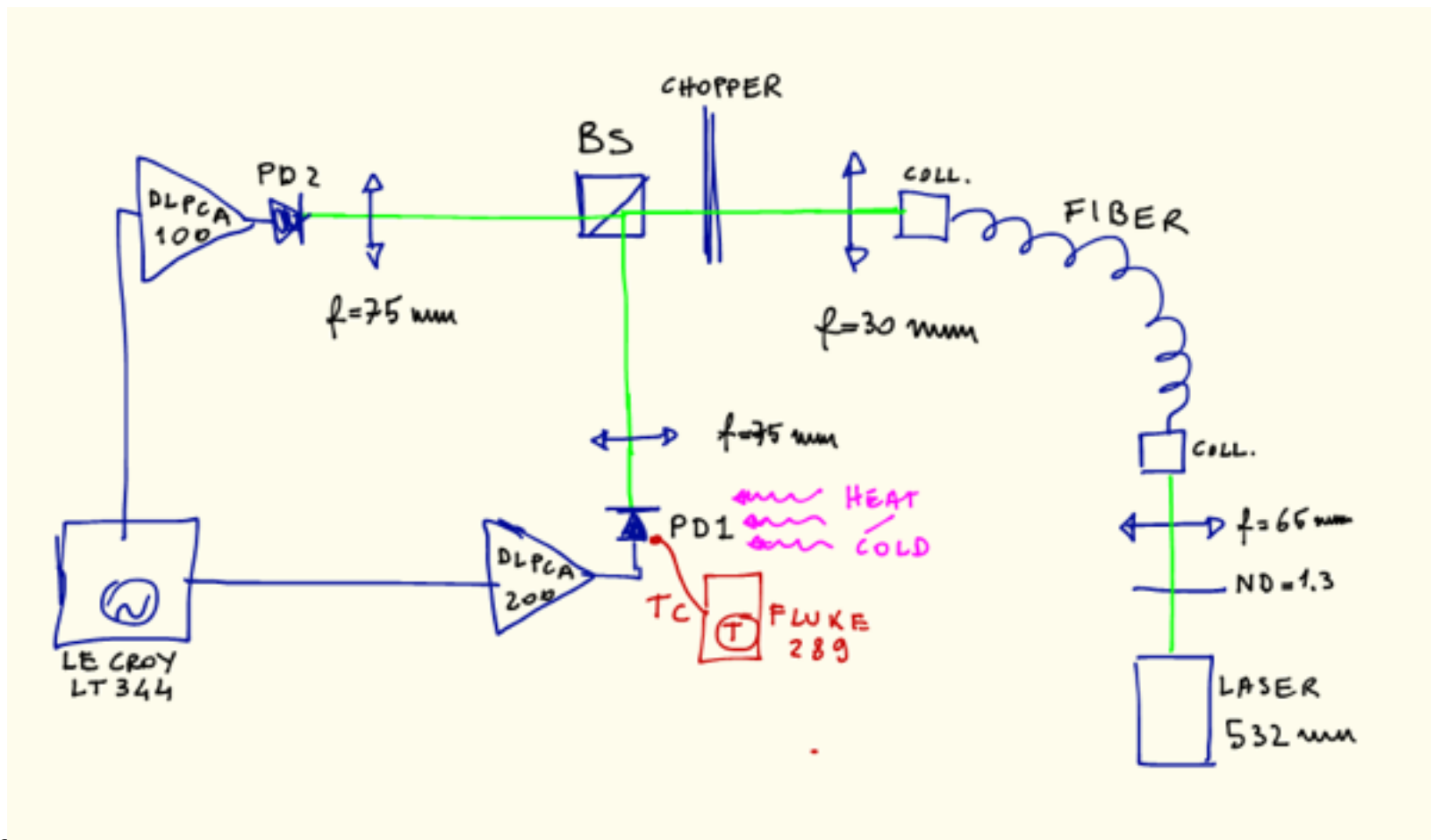
$$K = \frac{G_2 A_2 - G_1 A_1}{2}$$

$$\begin{aligned}
 V_{OUT} &= \Delta \cdot V_0 \cos \omega_{REF} t = K I_0 V_0 \cos^2 \omega_{ch} t + K I(t) V_0 \cos^2 \omega_{ch} t = \\
 &= \frac{K V_0}{2} [I_0 + I(t)] [1 + \cos 2\omega_{ch} t] = \\
 &= \frac{K V_0}{2} \{ \cancel{I_0 + I(t)} + \cancel{[I_0 + I(t)] \cos 2\omega_{ch} t} \} \simeq \frac{K V_0 I_0}{2} = \frac{V_0 I_0}{2} (G_2 A_2 - G_1 A_1)
 \end{aligned}$$

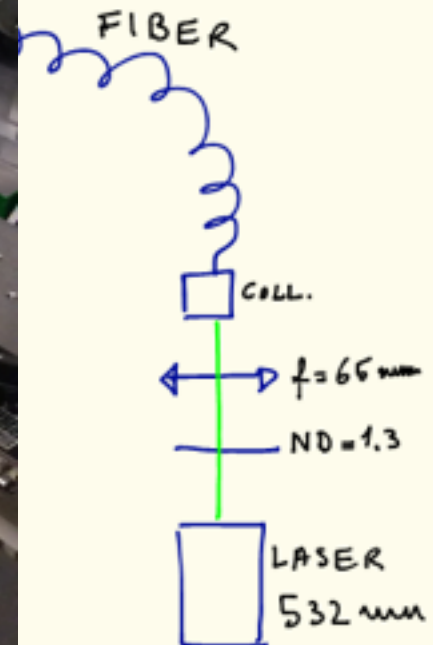
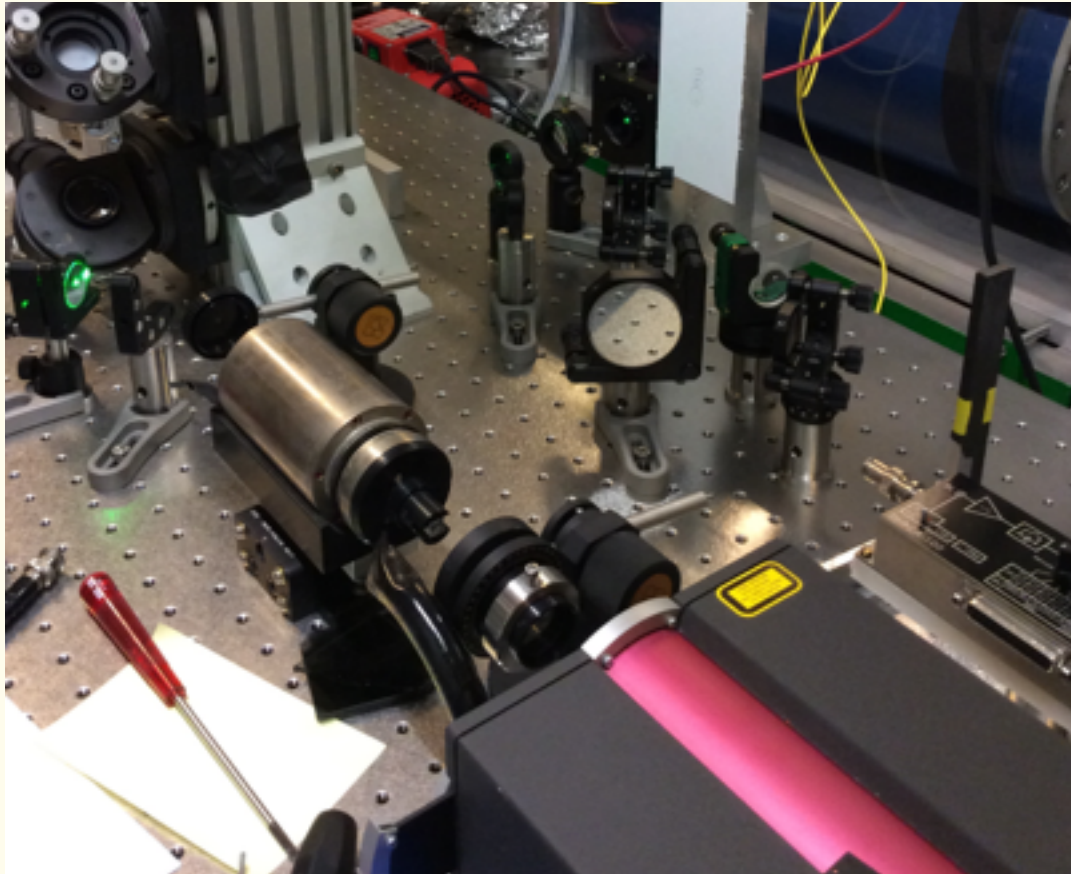
azione del filtro PB

# Schema prove iniziali

- fotodiodi InGaAs della Hamamatsu (BW ~10 kHz)
- due amplificatori diversi (Femto DLPCA 100 e DLPCA 200)
- fibra di trasporto multimodo (laser e sistema ottico sono su due banchi ottici separati)

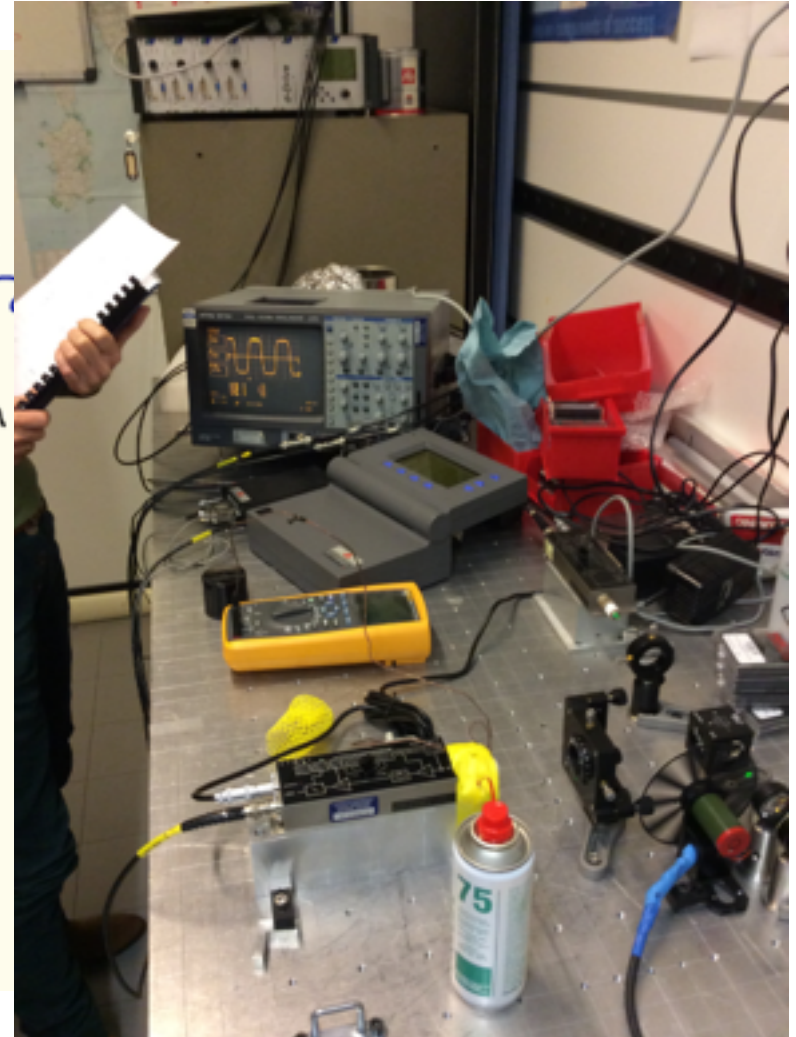
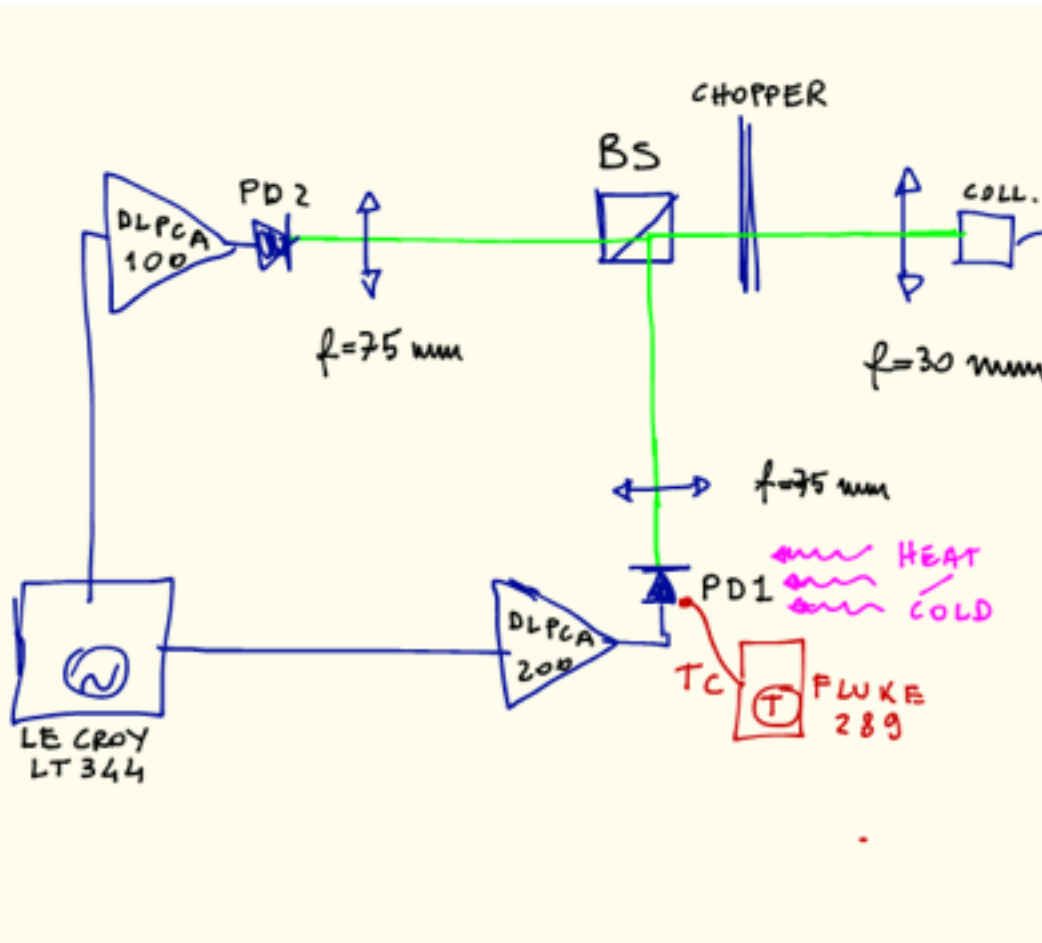


# Banco ottico laser



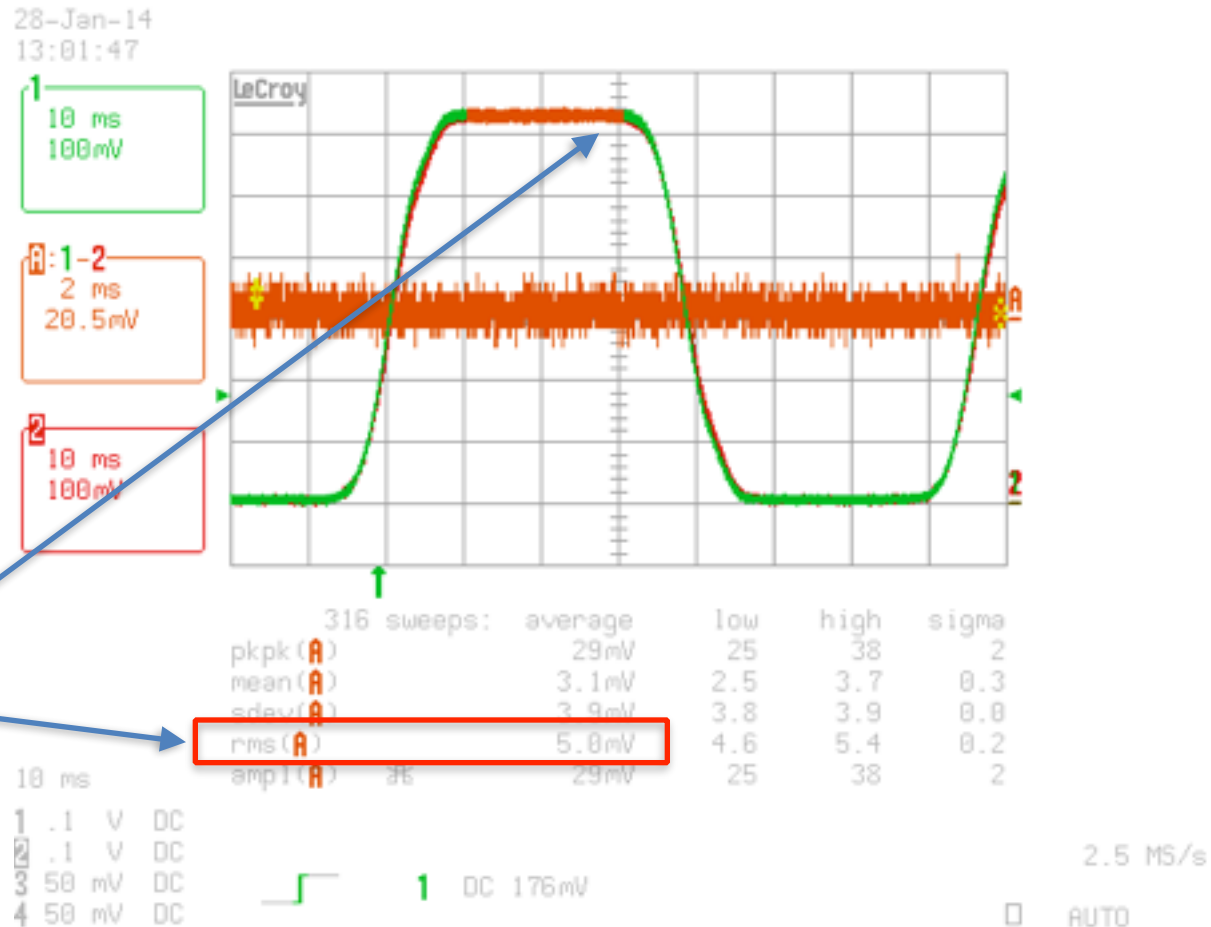


# Banco ottico con sistema eterodina



# Misura ON-OFF con chopper

- Differenza tra i due canali (PD1 e PD2) punto per punto con il DSO LeCroy LT344
- Chopper a 13 Hz
- Misure nella zona «luce»
  - mean = valore medio della differenza
  - sdev = deviazione dalla media
  - rms = ampiezza delle fluttuazioni
- Esempio di figura
  - $T_{mis} = 31.6$  s
  - mean =  $3.1 \pm 0.3$  mV
  - rms =  $5.0 \pm 0.2$  mV
- La «zona buio» serve a controllare che non ci siano offset elettronici diversi tra i due rami
- Segnale “Luce” = 630 mV
- Fluttuazioni RMS della differenza = 5 mV
- Sensibilità del sistema  
 $5/630 = 0.8 \%$



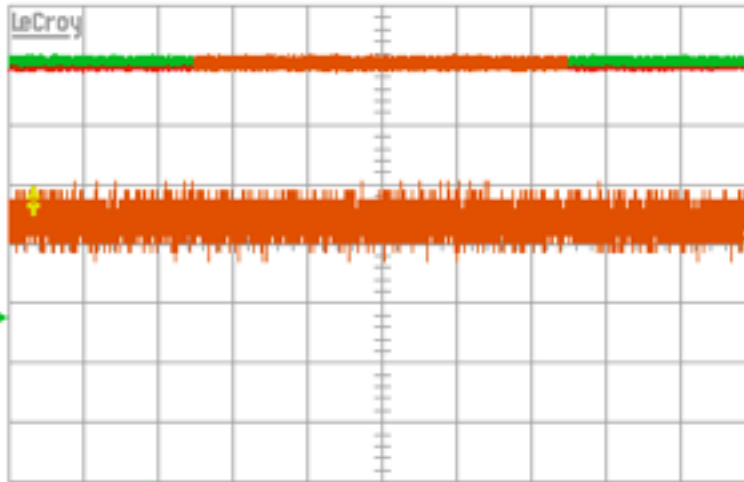
# Misura di controllo senza chopper ( $T_{\text{mis}} = 2$ ore)

30-Jan-14  
16:46:38

1  
.1 s  
100 mV

1-2  
50 ms  
20.5 mV

2  
.1 s  
100 mV



5861 sweeps:				
	average	low	high	sigma
pkpk (A)	38 mV	25	41	2
mean (A)	7.2 mV	-0.4	13.8	3.3
sdov (A)	7.8 mV	3.6	4.8	0.1
rms (A)	8.3 mV	3.7	14.3	2.7
amp1 (A)	38 mV	25	41	2

.1 s  
1 .1 V DC  
2 .1 V DC  
3 50 mV DC  
4 50 mV DC  
4 50 mV DC

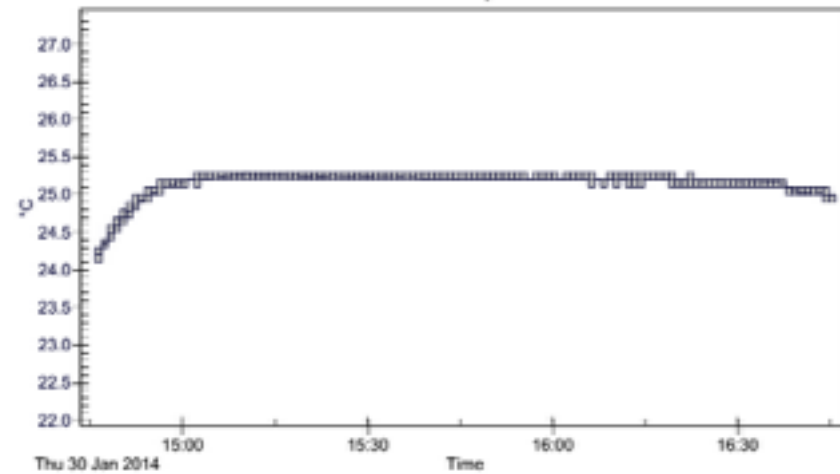
1 DC 176 mV

CHANNEL 2

Trace  
OFF

Coupling

Temperatura di PD1



Thu 30 Jan 2014 15:00 15:30 16:00 16:30 Time

250 kS/s

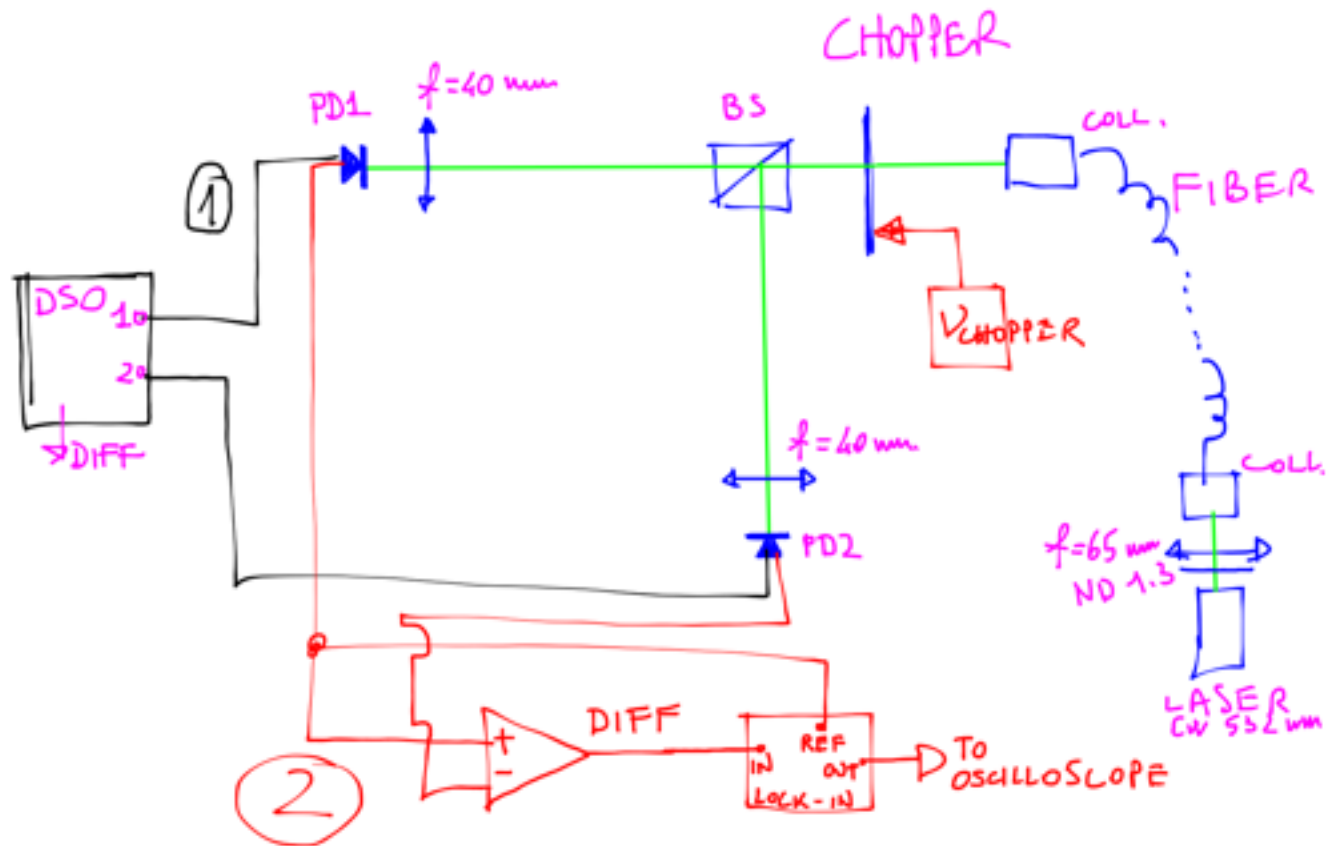
STOPPED  
 STOPPED

Sensibilità (no eterodina) =  $8 \text{ mV} / 650 \text{ mV} = 1.2 \%$

# Prove con diodi PIN veloci

- Fotodiodi tipo PIN Hamamatsu (S5973-02, BW 1 GHz)
- Amplificatori Femto DLPCA200
- Due modalità
  1. DSO - digitalizzazione all'oscilloscopio dei segnali dei due bracci e calcolo della differenza
  2. Sottrazione analogica + rivelazione con amplificatore lock-in
    - 2.1. sottrazione analogica con circuito
    - 2.2. uscita rivelata con lock-in riferito alla frequenza del chopper  $\Rightarrow$  segnale in DC proporzionale alla differenza istantanea tra i due bracci

# Schema prove in eterodina

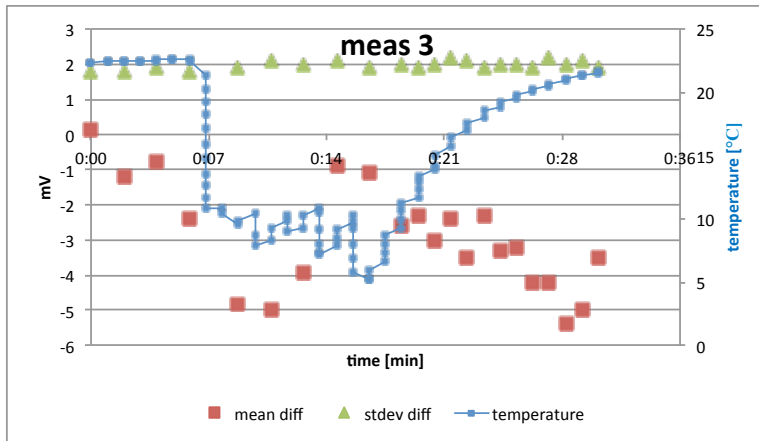


PD1 & PD2 = HAMAMATSU S5973-02  
+ FEMTO DLPCA200

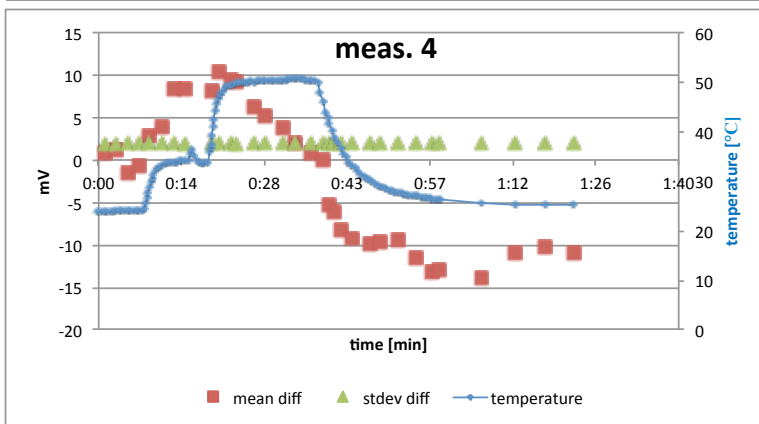
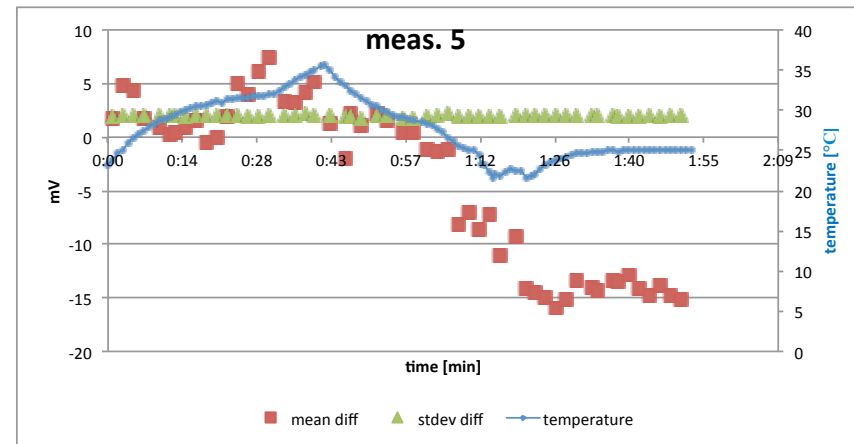
# Differenza digitale (modalità 1)

- Differenza tra i due bracci dopo digitalizzazione all'oscilloscopio
- Uno dei due diodi (amplificatori) riscaldato o raffreddato

PD2 - ciclo di raffreddamento (sopra) e di riscaldamento (sotto)

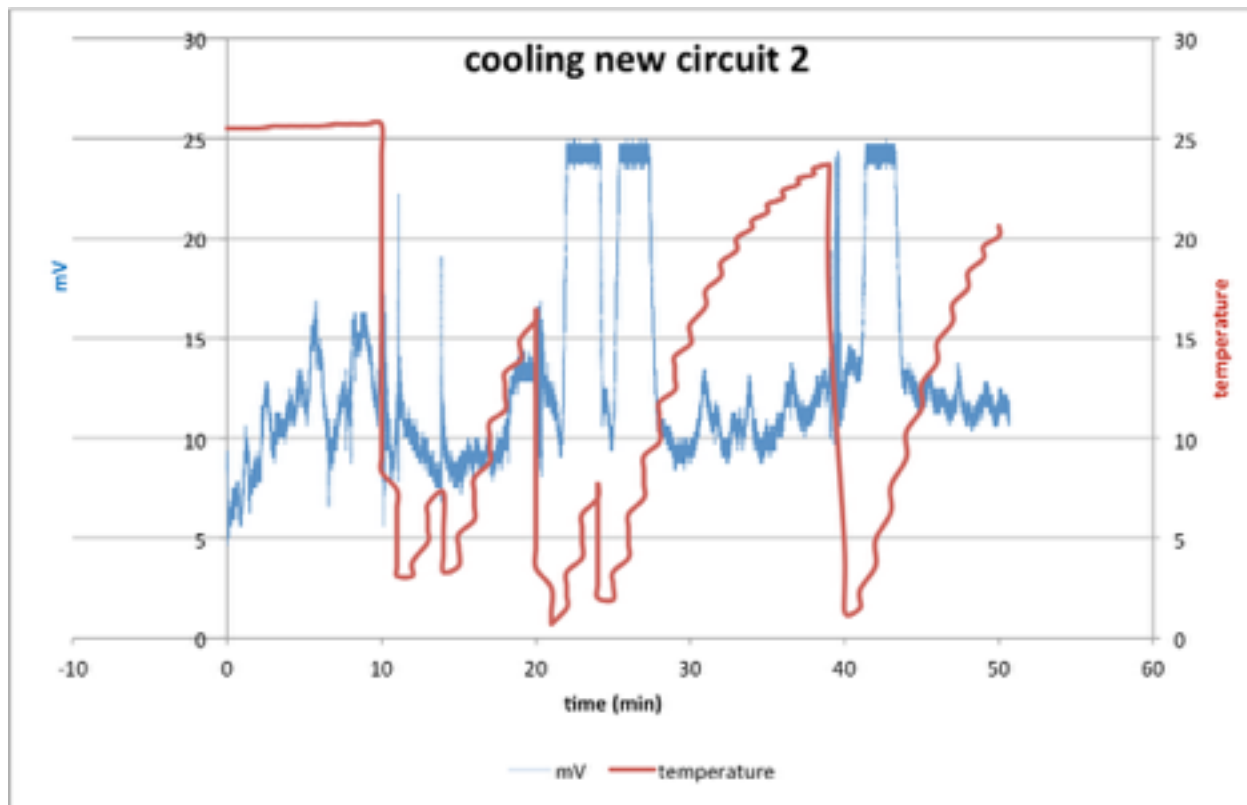


Riscaldamento del solo amplificatore di PD2



# Differenza analogica (modalità 2)

- Differenza analogica e rivelazione in eterodina con lock-in (curva blu) - esempio di ciclo di raffreddamento del fotodiiodo PD2



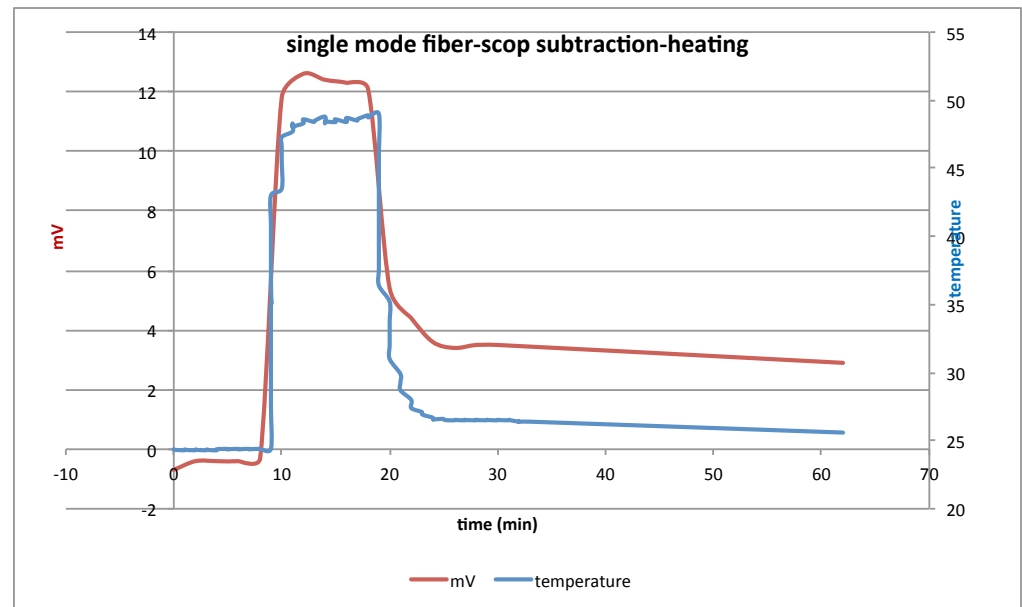
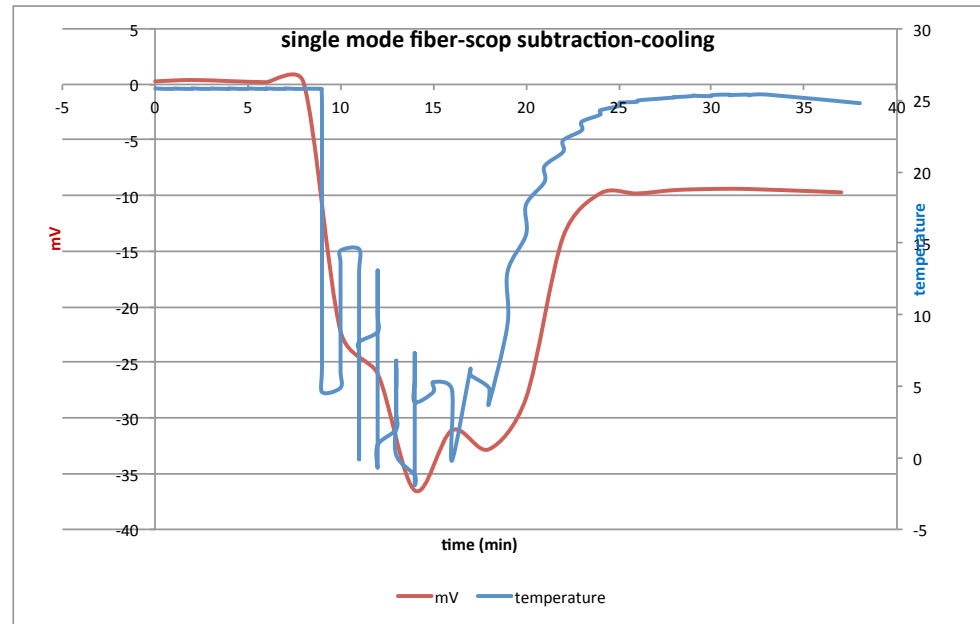
# Prove con fibra singolo modo

- La fibra di collegamento tra laser e banco di prova è stata cambiata da multimodo a singolo modo
- Ci si aspetta un miglioramento globale dovuto alla riduzione del rumore in ampiezza del fascio trasmesso dalla fibra



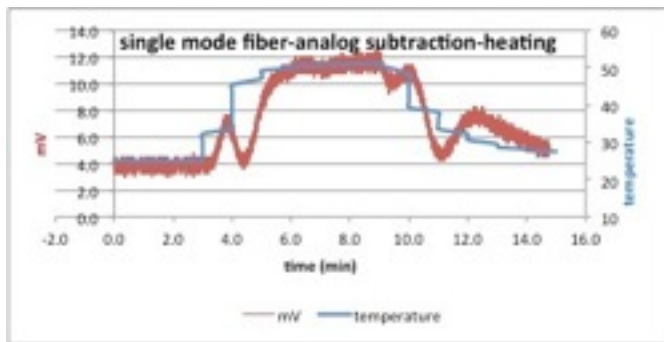
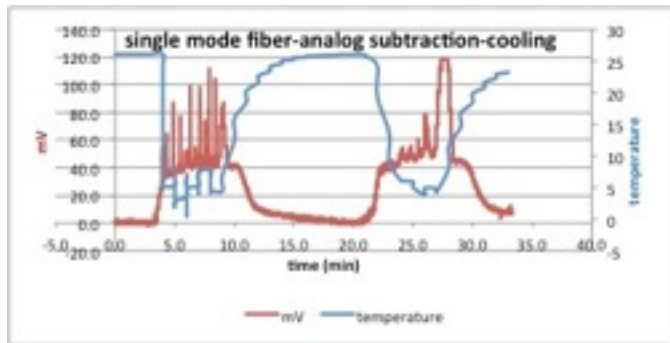
# Differenza digitale (mod. 1) - fibra singolo modo

- Cicli di raffreddamento (sopra) e di riscaldamento (sotto) di PD2

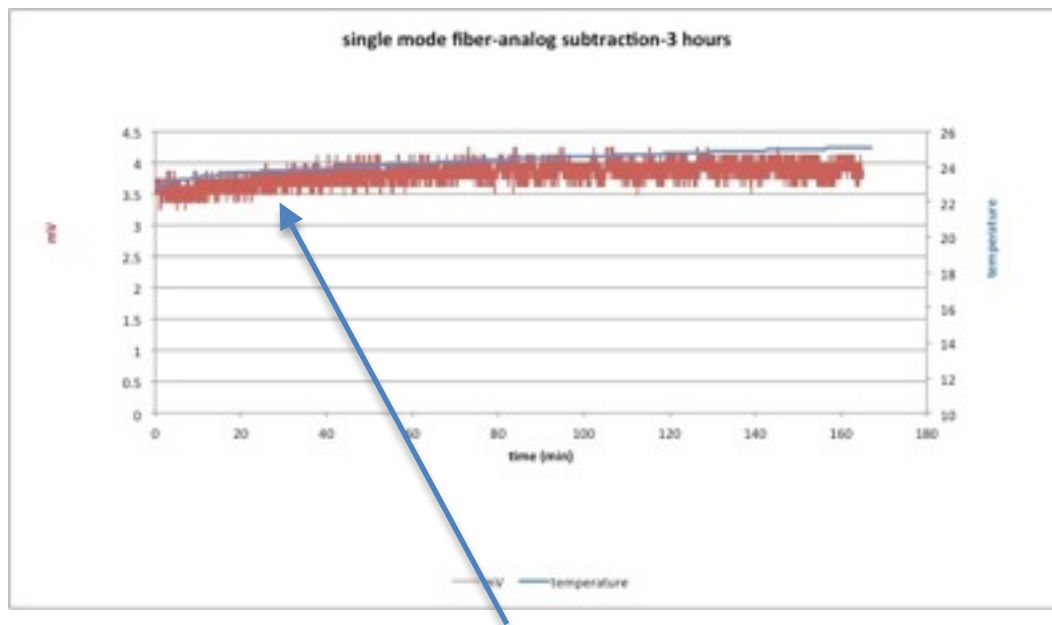


# Differenza analogica (mod. 2) - fibra singolo modo

PD2 - ciclo di raffreddamento (sopra) e di riscaldamento (sotto)



Prova di stabilità su 3 ore di misura



Sensibilità su 30 minuti:  
 $3.6 \text{ mV} / 650 \text{ mV} = 0.5 \%$

# Prossime prove

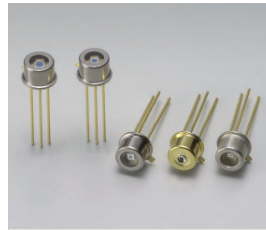
- Modulazione in ampiezza con Photo-Elastic Modulator (PEM) + polarizzatore
  - freq. di modulazione 20 kHz -
- Fotodiodi Hamamatsu+Amplificatori veloci “LNF”
- Modulazione in ampiezza con AOM (Acousto Optic Modulator)
  - risetime  $\sim 20$  ns
- Test sul laser AlphaLas con Hamamatsu+LNF ampli

# Conclusioni

- Acquisiti elementi principali da provare: laser e fotodiodi PIN veloci
- Montato e provato un sistema ottico per le prove preliminari di stabilità su diodi e amplificatori:
  - sottrazione del fondo con tecnica eterodina -> indipendente dalle fluttuazioni in intensità del laser di test
  - sensibile a variazioni di parametri nella catena di lettura diodo-amplificatore dello 0.5 % su 30 minuti, 0.6 % su di diverse ore
- Prossime prove
  - monitoraggio parametri con eterodina a frequenza più alta (10 kHz)
  - validazione laser impulsato

# DATASHEETS

## Si PIN photodiode



S5971

S5972

S5973 series

### High-speed photodiodes (S5973 series: 1 GHz)

S5971, S5972 and S5973 series are high-speed Si PIN photodiodes designed for visible to near infrared light detection. These photodiodes provide wideband characteristics at a low bias, making them suitable for optical communications and other high-speed photometry. S5973 series includes a mini-lens type (S5973-01) that can be efficiently coupled to an optical fiber and a violet sensitivity enhanced type (S5973-02) ideal for violet laser detection.

#### Features

- **High-speed response**  
**S5971 : 100 MHz (V<sub>R</sub>=10 V)**  
**S5972 : 500 MHz (V<sub>R</sub>=10 V)**  
**S5973 series: 1 GHz (V<sub>R</sub>=3.3 V)**
- **Low price**
- **High sensitivity**  
**S5973-02: 0.3 A/W, QE=91 % (λ=410 nm)**
- **High reliability**

#### Applications

- **Optical fiber communications**
- **High-speed photometry**
- **Violet laser detection (S5973-02)**

#### General ratings / Absolute maximum ratings

Type No.	Dimensional outline/ Window material *1	Package (mm)	Active area size (mm)	Effective active area (mm <sup>2</sup> )	Absolute maximum ratings			
					Reverse voltage V <sub>R</sub> Max. (V)	Power dissipation P (mW)	Operating temperature T <sub>opr</sub> (°C)	Storage temperature T <sub>stg</sub> (°C)
S5971	③/K	TO-18	φ1.2	1.1	20	50	-40 to +100	-55 to +125
S5972			φ0.8	0.5				
S5973			φ0.4	0.12				
S5973-01	②/L							
S5973-02	③/K							

#### Electrical and optical characteristics

Type No.	Spectral response range λ (nm)	Peak sensitivity wavelength λ <sub>p</sub> (nm)	Photo sensitivity S (A/W)			Short circuit current I <sub>sc</sub> 100 lx (μA)	Dark current I <sub>d</sub>		Temp. coefficient of I <sub>d</sub> T <sub>cd</sub> (times/°C)	Cut-off frequency f <sub>c</sub> (GHz)	Terminal capacitance C <sub>t</sub> f=1 MHz (pF)	NEP V <sub>R</sub> =10 V λ=λ <sub>p</sub> (W/Hz <sup>1/2</sup> )		
			λ <sub>p</sub>	660 nm	780 nm		830 nm	Typ. (nA)					Max. (nA)	
														λ <sub>p</sub>
S5971	320 to 1060	900	0.64	0.44	0.55	0.6	1.0	0.07 *3	1 *3	1.15	0.1 *3	3 *3	7.4 × 10 <sup>-15</sup>	
S5972		800	0.57		0.55	0.42	0.01 *3	0.5 *3				3.1 × 10 <sup>-15</sup>		
S5973	320 to 1000	760	0.52	0.45	0.51	0.47	0.42	0.001 *4	0.1 *4		1 *4	1.6 *4	1.1 × 10 <sup>-15</sup> *4	
S5973-01					0.42	0.37	0.07							1.9 × 10 <sup>-15</sup> *2, *4
S5973-02					0.3 *2	0.42	0.37	0.07						

\*1: Window material K: borosilicate glass, L: lens type borosilicate glass

\*2: λ=410 nm

\*3: V<sub>R</sub>=10 V

\*4: V<sub>R</sub>=3.3 V

# Picosecond Pulse Diode Lasers with Driver

PICOPOWER™-LD Series

Available with the standard wavelengths: 375, 405, 450, 488, 635, 670, 785, 976, 1030, 1064, 1300, 1550 nm as well as many other custom-specific wavelengths!



Laser pulses shorter than 40 ps. Up to 3 W peak power for specific wavelengths. Exchangeable laser heads.

## Features

- Laser pulses shorter than 40 ps
- Up to 3 W peak power for specific wavelengths
- Proprietary high-frequency design for the shortest & highest peak power laser diode pulses available on the market
- Collimated output with spatial filtering
- Exchangeable laser heads with different wavelengths for greatest flexibility
- Proprietary laser diode driver generating picosecond high-current pulses
- Built-in Direct Digital Synthesis (DDS) frequency generator for repetition rate adjustment up to 20 MHz in steps of 0.1 Hz (optional 40 MHz & 80 MHz)
- External TTL trigger capability and synchronized TTL output
- Optional fiber coupling

## Applications

- Fluorescence lifetime measurements
- Pump-probe experiments
- Photodetectors & optoelectronics time response measurements
- Optical communication tests
- Optical Time Domain Reflectometry (OTDR)
- Seeding of fiber lasers
- Optical tomography

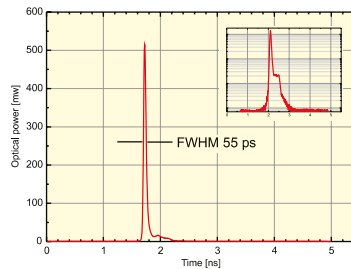
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# LDH Series



## Picosecond Laser Diode Heads for PDL 800-B/-D/808/828



- Wavelengths from 375 to 1990 nm
- Peak power up to 1 W
- Pulse widths as short as 50 ps (FWHM)
- Repetition rates from single shot to 80 MHz
- Collimating optics, optional fiber, coupler and peltier cooling
- Optional dual mode: CW and pulsed operation



### Applications

- Time-resolved fluorescence spectroscopy/microscopy
- Biochemical analytics
- Time-response characterization of opto-electronic devices
- Diffuse Optical Tomography (DOT)
- Seed for fiber lasers
- Single photon sources
- Quantum optics
- Optical Time Domain Reflectometry (OTDR)



# Ultrafast Photodetectors

UPD Series

NEW MODELS:  
Faster Rise Times & Wider  
Wavelength Ranges



The UPD series of ultrafast photodetectors are best suited for measurement of optical waveforms from DC to 25 GHz. Various models feature rise times as short as **15 ps** and cover the spectral range from **170 to 2600 nm**.

All photodetectors are enclosed in compact and solid aluminum housings and can be biased with a battery or an external power supply.

The UV-extended versions of the silicon type photodetectors are the only commercial products that cover the spectral range from 170 to 1100 nm.

Another type of unique UV-sensitive InGaAs photodetectors can be used for detecting laser pulses in the range from 350 to 1700 nm, thus having the widest spectral range and the highest speed commercially available.

Perfect impedance matching and state-of-the-art microwave technology assure pulse form measurements without any ringing or artefacts. The customer is free to use a 50  $\Omega$  terminating resistor for highest speed operation, or a high impedance load for obtaining large signals. This guarantees maximum flexibility for diverse applications.

In combination with our BBA series of wideband high-gain amplifiers, the high-speed photodetectors are an advantageous alternative to the expensive and cumbersome avalanche photodiodes.

The UPD series high-speed photodetectors are indispensable tools for laser and photonics research.

## Features

- Ultra High-Speed Operation
- Rise Times: **starting from 15 ps**
- Bandwidths: **up to 25 GHz**
- Spectral Ranges: **170 - 2600 nm**
- Compact Design
- Battery or External Power Supply
- Models for Free-Space Beam, or with FC/PC Receptacle or Pigtailed with SM Fiber

## Applications

- Pulse Form Measurements
- Pulse Duration Measurements
- Precise Synchronization
- Mode Beating Monitoring
- Heterodyne Measurements

## New Models Available: Faster Rise Times & Wider Wavelength Ranges

- **UPD-15-IR2-FC**: Ultrafast InGaAs PIN photodetector, rise time < 15 ps, bandwidth > 25 GHz, spectral range 800 - 1700 nm, fiber-coupled input with FC/APC connector
- **UPD-35-IR2-P**, **UPD-35-IR2-D**: Ultrafast InGaAs PIN photodetectors, rise time < 35 ps, bandwidth > 10 GHz, spectral range 800 - 1700 nm, with polished or diffuse window
- **UPD-35-UVIR-P**, **UPD-35-UVIR-D**: Ultrafast InGaAs PIN photodetectors, rise time < 35 ps, bandwidth > 10 GHz, spectral range 350 - 1700 nm, with polished or diffuse window
- **UPD-50-SP**, **UPD-50-SD**, **UPD-50-UD**, **UPD-50-UP**: Ultrafast Si PIN photodetectors, rise time 50 ps, fall time 50 ps, bandwidth > 7 GHz, spectral range 170 - 1100 nm or 320 - 1100 nm, with polished or diffuse window
- **UPD-100-IR1-P**: Ultrafast Ge photodetector, rise time < 100 ps, pulsewidth (FWHM) 300 ps, spectral range 400 - 2000 nm
- **UPD-3N-IR2-P**: Fast InGaAs photodetector, extended infrared range up to 2.1  $\mu\text{m}$ , rise time 150 ps
- **UPD-5N-IR2-P**: Fast InGaAs photodetector, extended infrared range up to 2.6  $\mu\text{m}$ , rise time 200 ps

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