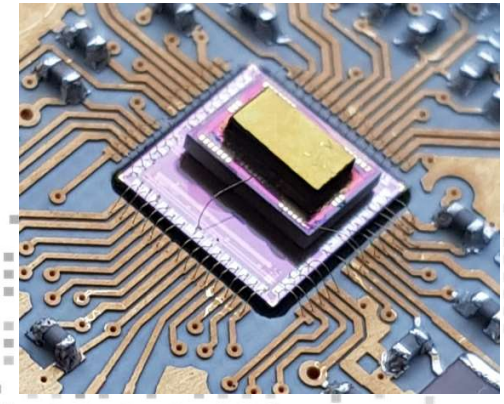

HgCdTe APD based detection module for LIDAR applications

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Univ. Grenoble Alpes, CEA, LETI, F38000 Grenoble, France

Workshop « Infrared Detection for Space Applications »

CONTEXT

LIDAR operational missions ask for small and affordable high performances instruments

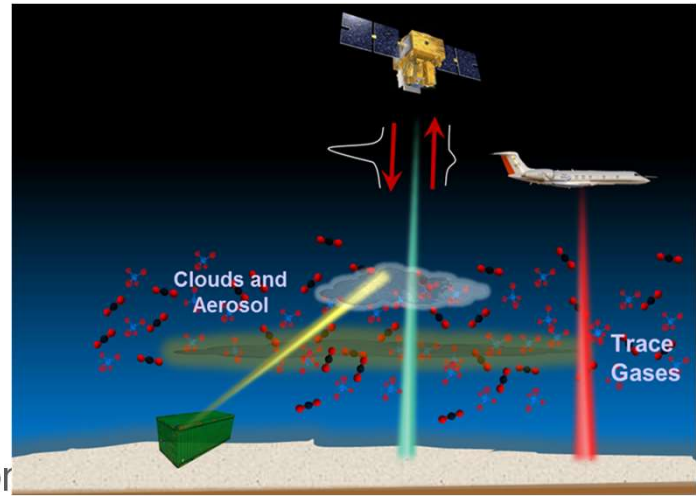
- Detectors able to detect every photon at high speed from UV to SWIR
- MCT APD technology: high quantum efficiency, low excess noise factor, large electrical bandwidth and large spectral range

HOLDON H2020 project

- Detection chain covering most of the atmospheric LIDAR application needs
- Gather end-users, test bench developers and detector manufacturers

Partners

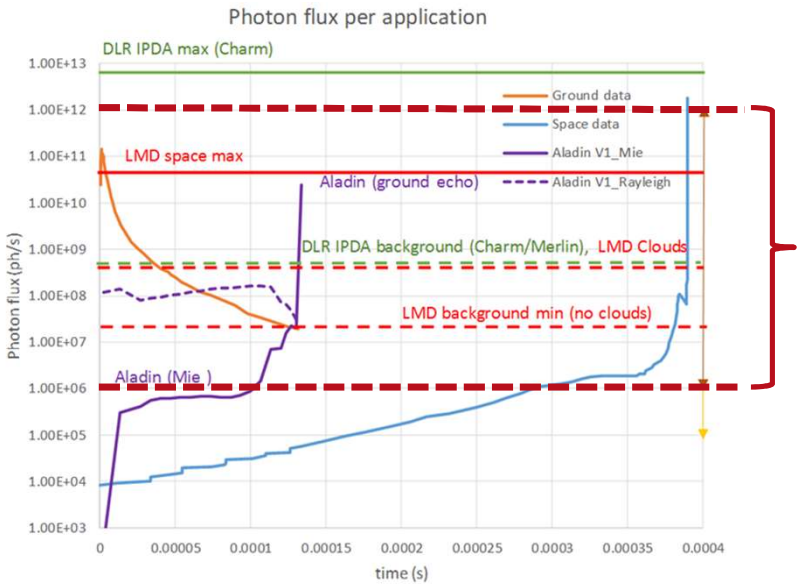
- CEA/Leti (France): LIDAR detection module development
  - Optimized HgCdTe APDs
  - Dedicated Si pre-amplifier: Read Out Integrated Circuit (ROIC)
- ID Quantique (Switzerland): proximity electronics
- ALTER TECHNOLOGY (Spain): UV to NIR LIDAR Echo Emulator
- DLR (Germany) for CH_4 & CO_2 IPDA demonstration
- LMD (France) for CO_2 DIAL demonstration
- AIRBUS DS (France) for wind and atmospheric profiling LIDAR evaluation
- Absiskey (France) for project management



DETECTION MODULE : GENERAL SPECIFICATIONS

Ideal detection module

- 60 dB of optical dynamic range (10^6 -10^{12} ph/sec)
  - Minimum optical flux : 1 photons/µs
- Detection wavelength : 0.35 – 2 µm
- Large optical sensitive area (> 150 µm to 600 µm)
- Low temporal persistence (DIAL or bathymetric)

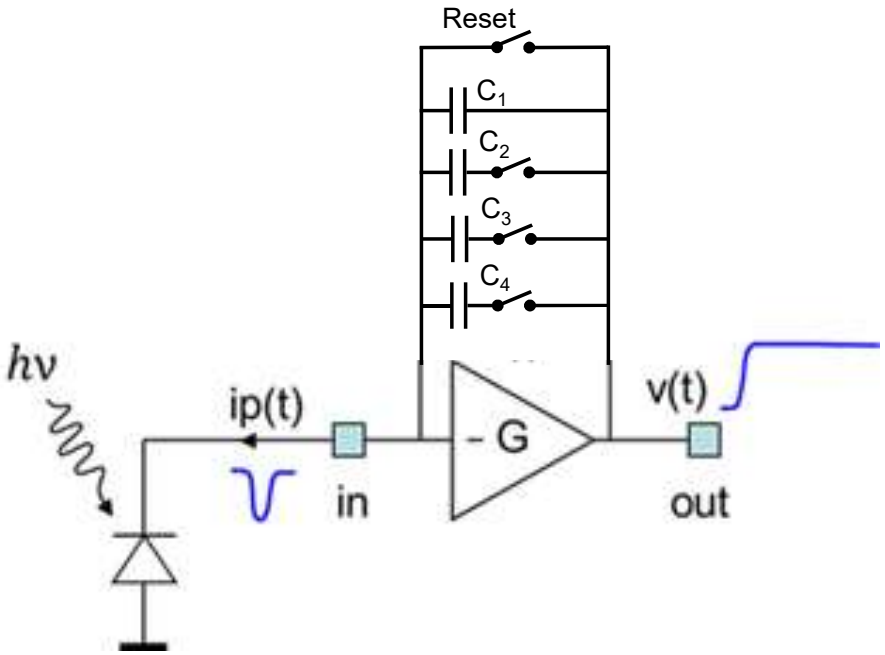


Excepted optical signal for atmos. LIDAR scenarios

ROIC DESIGN

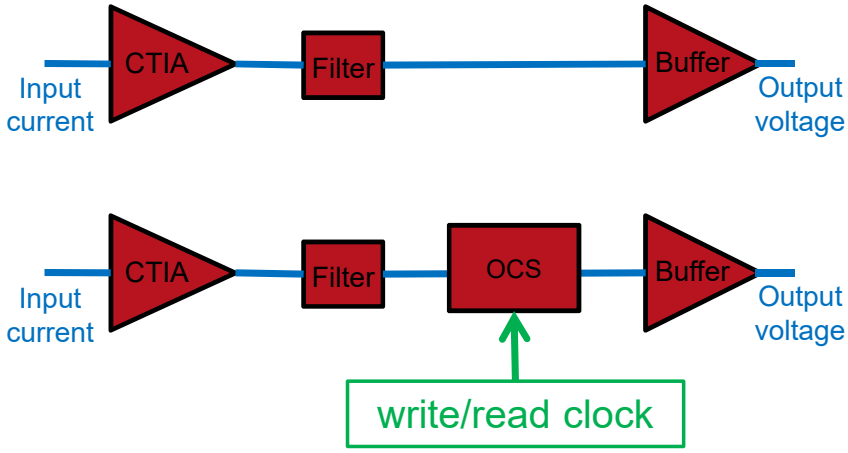
Input stage

- CTIA: integrates the photocurrent
  - Photon pulse is translated in a voltage step
    - ➢ Need to reset the capacitance
- 4 integration capacitances to cover a wide input dynamic
  - Cint values from 10 fF to 10 pF
  - Cint can be dynamically change with or without reset



Amplification chain

- 2 modes of operation
  - **Continuous: output voltage sampled with a fast external ADC**
  - On Chip Sampling: CTIA output sampled and memorized by the ROIC (2048 samples @ freq. up to 200 Ms/sec) and then digitized outside at lower frequency with high vertical resolution
- Optional low pass filter: 3 MHz, 30 MHz, 300 MHz, by-pass
- Optional Auto-reset of the CTIA with user defined voltage value



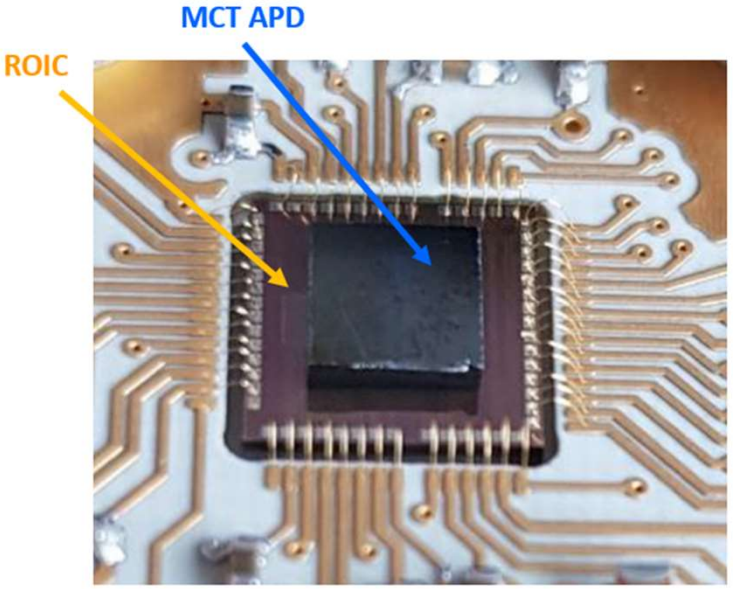
ROIC POST LAYOUT EXPECTED PERFORMANCES

Gain	C (fF)	Signal range (V)	Charge capacity (Melectrons)	Noise (µV)	Electron noise rms M=1	Electron noise rms M=100	Dynamic range (dB)	Full range linearity fluctuations (%)	BW (MHz)
G1	10	2.4	0.15	390	24.3	0.2	75.8	2	3
G2	100	2.4	1.50	90	56.2	0.6	88.5	0.2	30
G3	1000	2.4	14.98	60	374.5	3.7	92.0	0.04	300
G4	10000	2.4	149.81	60	3745.3	37.5	92.0	<0.01	300

- Expected CTIA noise for APD gain100 with G1 or G2 < 1 photon
  - ROIC need low noise biases
- Non linearity increases at high ROIC gain (low Cint)

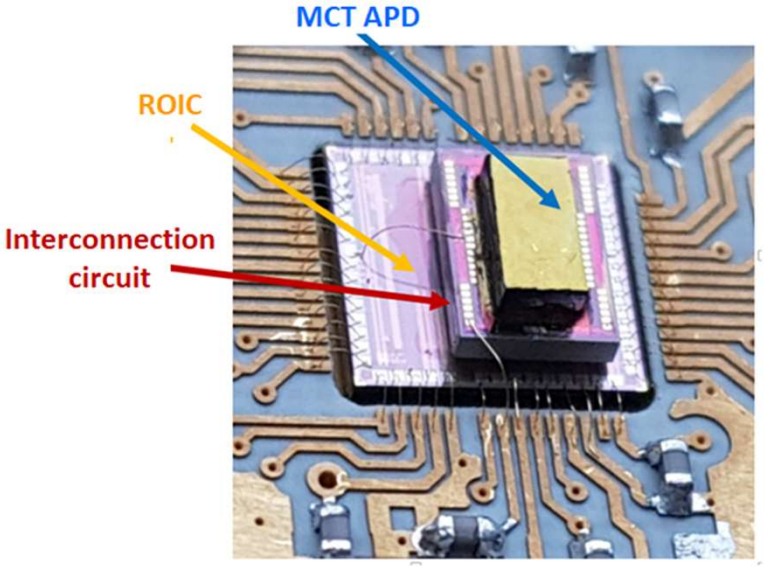
DETECTION MODULE

- **ROIC 111 : designed for indium bump flip-chip hybridization between APD and ROIC**
  - ROIC requires a fully dedicated CMOS batch
  - Less sensitive to Electro-Magnetic Interferences
  - One device tested OK
  - Others hybrid devices shows CMOS via issues



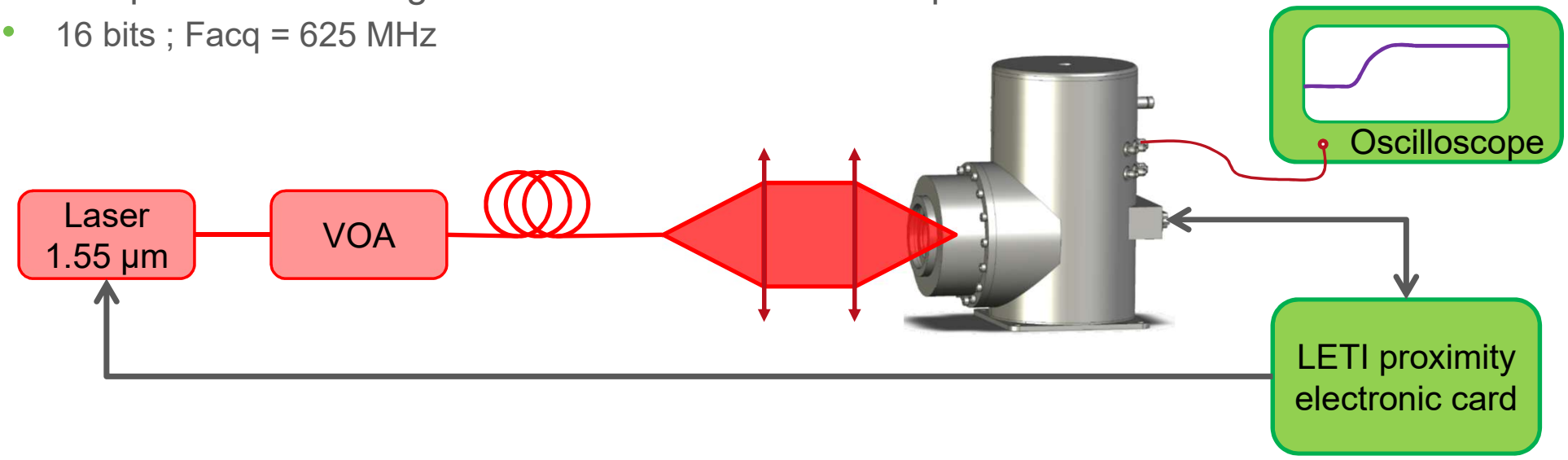
Tested device: APD with 150 µm sensitive diameter : cluster of 76 photodiodes @ 15µm pitch

- **ROIC 112 : APD photodiode hybridized to a Si Interconnection Circuit and connected to the ROIC by wire-bonding**
  - ROIC can be realized on multi-project CMOS wafer
  - APD can be tested before assembly



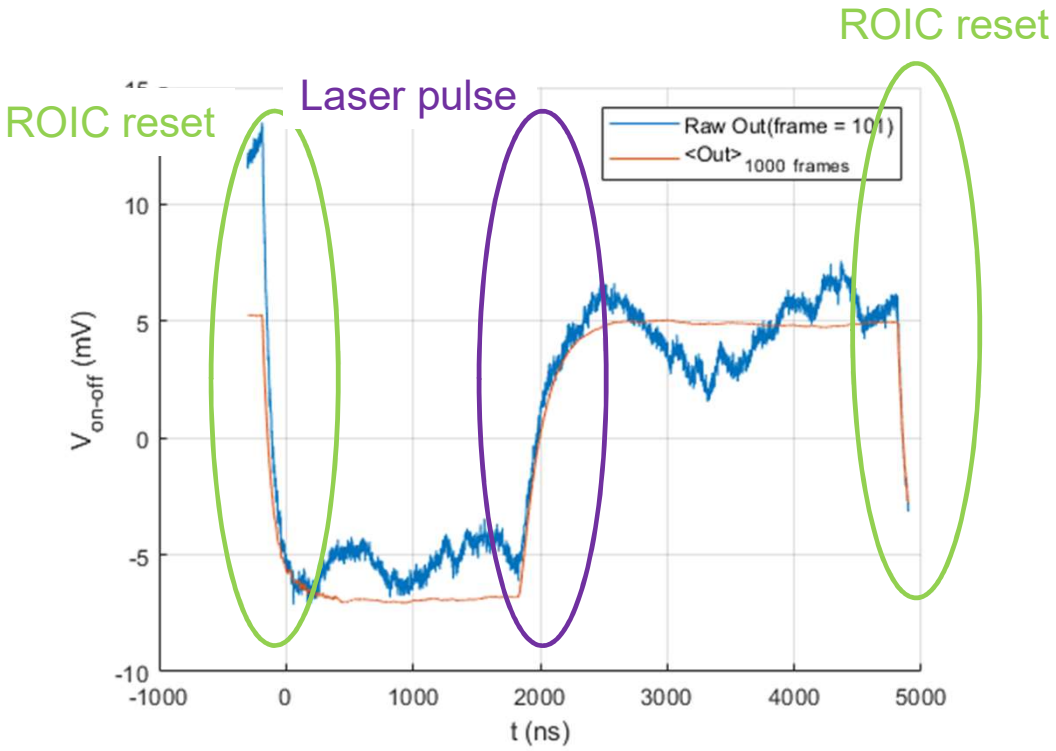
TEST SET UP

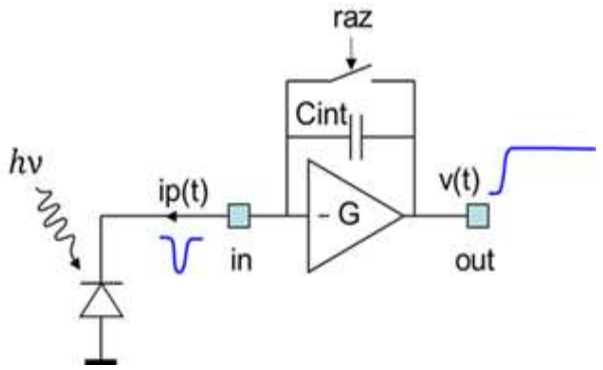
- Detection module passively cooled Dewar with F/4 cold aperture and 2.4 µm low pass filter
- 1.55 µm continuous or pulsed Laser (30 ps pulses)
- **V**ariable **O**ptical **A**ttenuator : control the laser power (accuracy 2.3 %)
- LETI proximity electronic card for biasing and clocking the detector module
- ROIC works in continuous mode
- Data acquisition with a high vertical resolution oscilloscope
  - 16 bits ; Facq = 625 MHz



EXAMPLE OF ACQUISITION AND DATA TREATMENT

- **Raw and averaged recorded output signal (after background subtraction)**
  - Laser pulse : 16 photons/pulse, 1 pulse/frame
  - Cint=10fF, 3MHz filter and APD gain of 78
  - 1000 frames / record

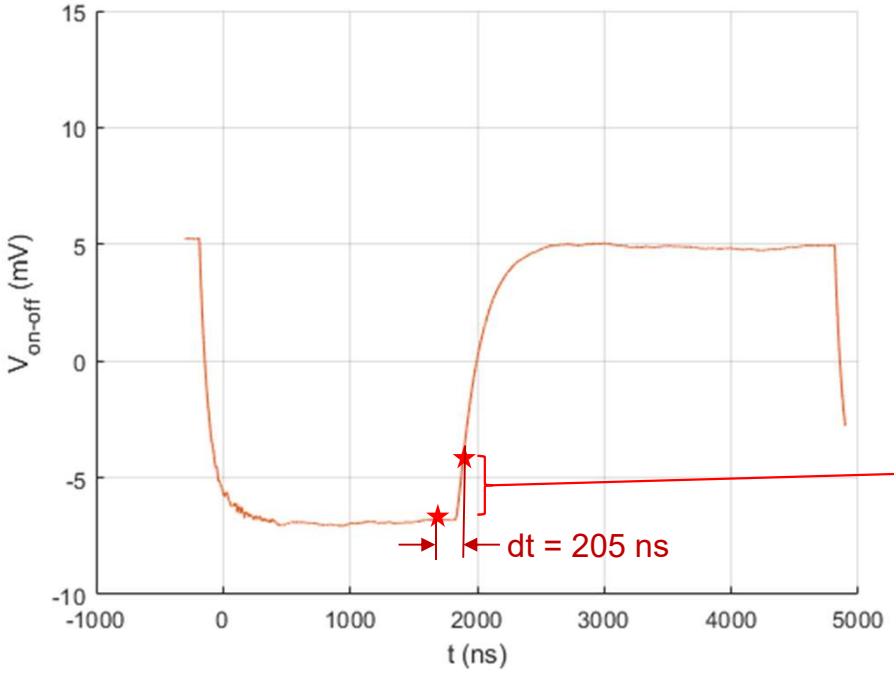


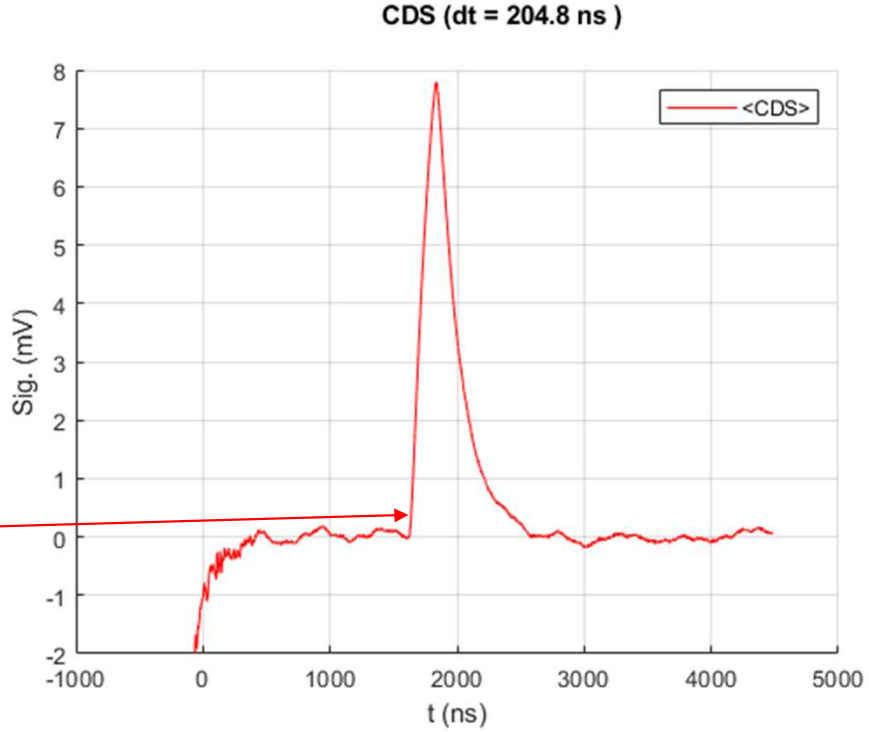


EXAMPLE OF ACQUISITION AND DATA TREATMENT

- **Averaged output signal**
  - 16 photons/pulse, 1 pulse/frame
  - Integrated photonic signal
  - Cint=10fF, 3MHz filter and APD gain of 78
  - 1000 frames / record

- **Example of data treatment**
- Extract direct signal and remove reset noise
  - CDS : signal derivation for dt = 205 ns





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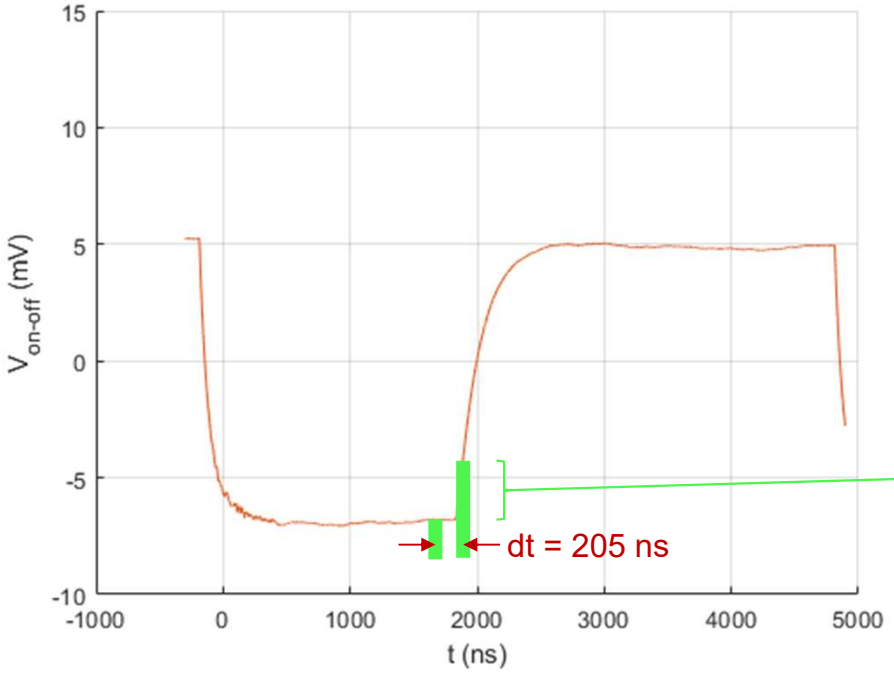
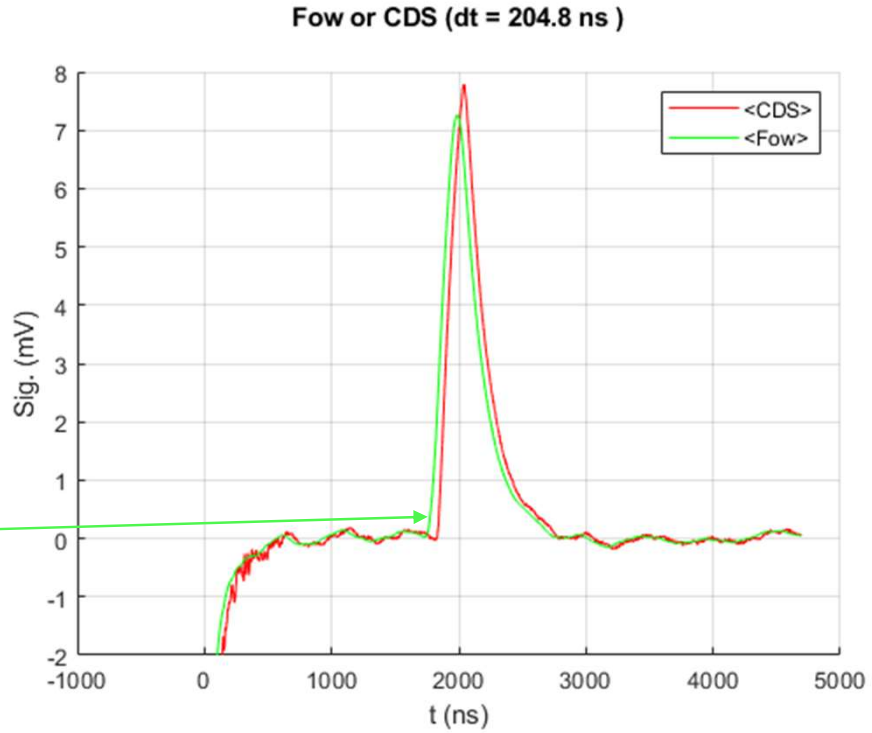
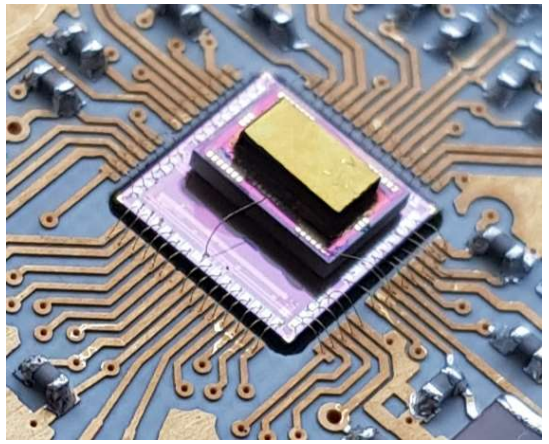


- **Example of data treatment**
- Extract direct signal and remove reset noise
  - CDS : signal derivation for dt = 205 ns
  - Fowler sampling: averaging before derivation
    - Green curve : averaging during dt/2



ROIC 112 BASED DETECTION MODULE TEST

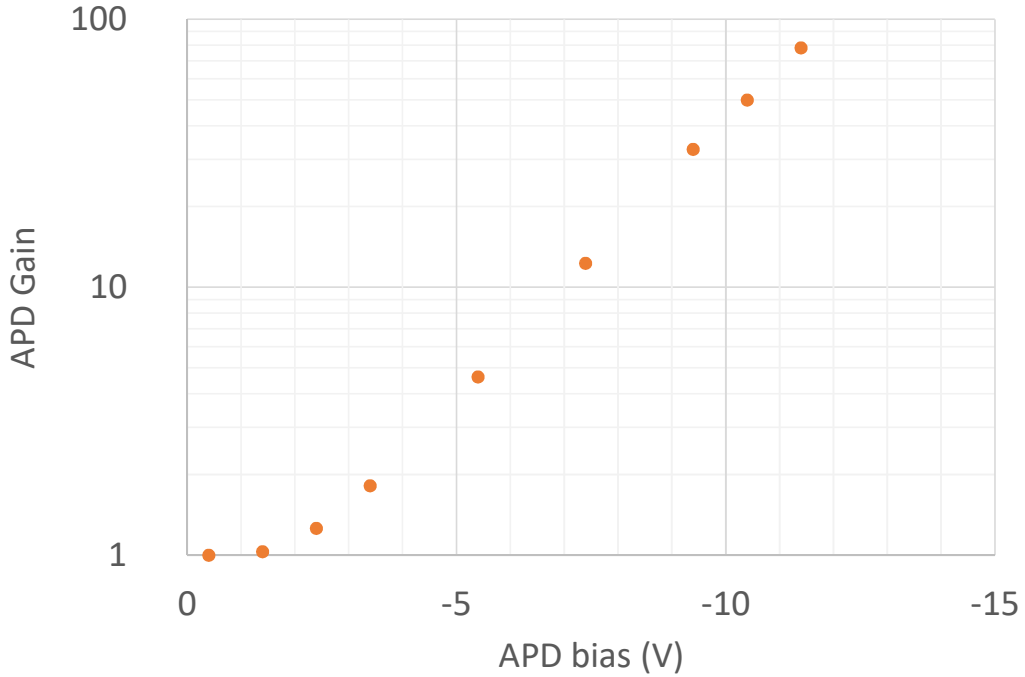
- **ROIC functionalities**
  - Continuous and OCS modes ☺
  - Dynamic change of Cint ☺
  - Auto-reset ☺ (function OK, but logical output NOK)
  - Bandwidth filtering ☺
- **Read out circuit capacitances**
  - Values are near the designed ones



ROIC Gain	Cint designed	Cint evaluated	Ratio to previous
i	fF	fF	G_{i+1}/G_i
G4	10 000	9 500	-
G3	1 000	962	9.87
G2	100	110	8.76
G1	10	12	9.44

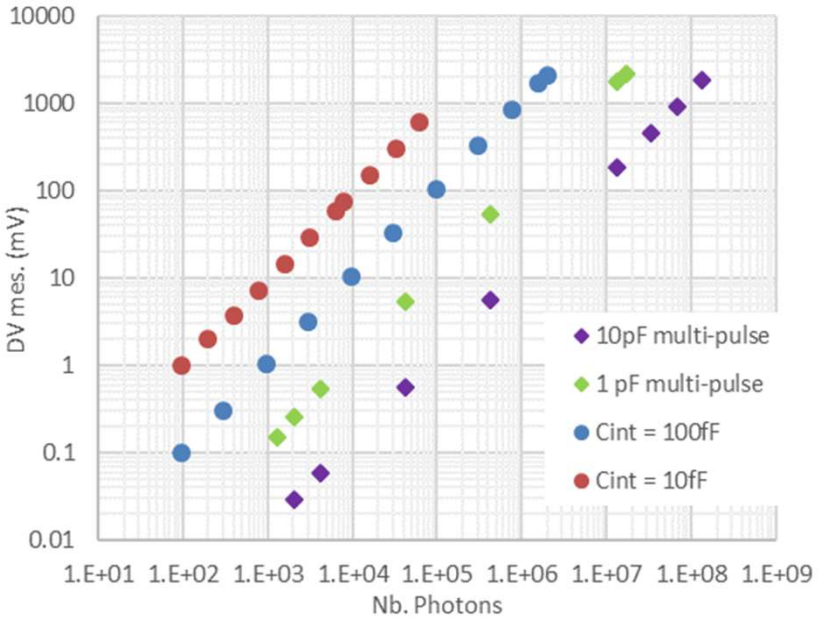
ROIC 112 APD MODULE PERFORMANCES

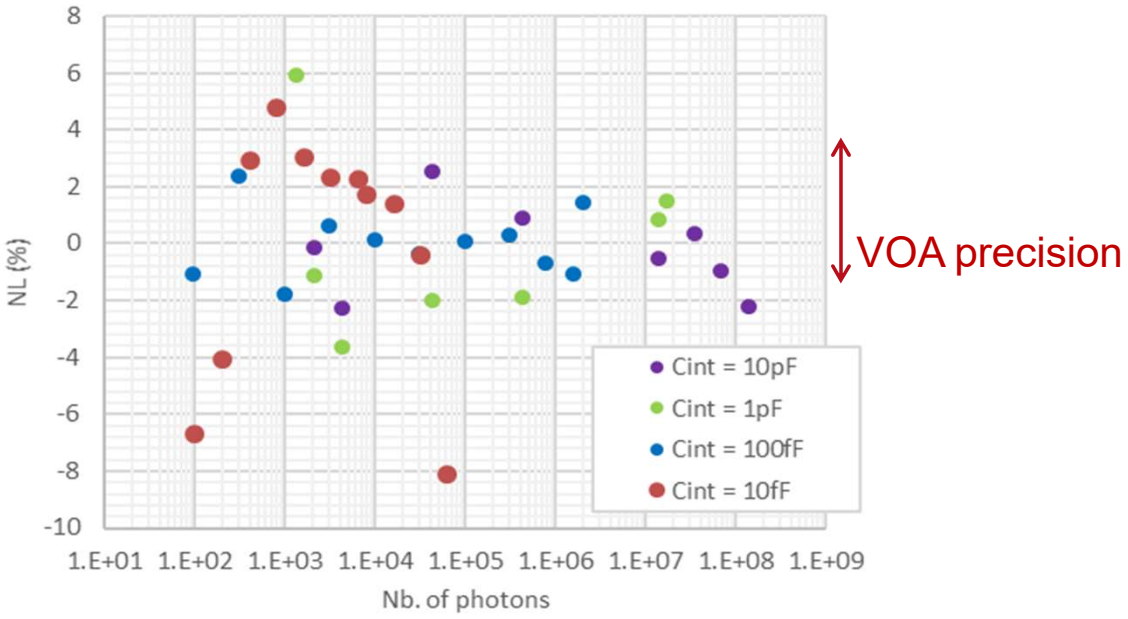
- **APD figure of merit**
  - QE = 0.7
  - APD gain up to 78 (limited by Leti prox. Elec. @ V_{APD} = -11.4 V)
  - Excess noise factor = 1.28



ROIC 112 APD MODULE PERFORMANCES

- **Linear dynamic range : 6 orders of magnitude**
  - No APD gain applied
  - Laser pulse $1x10^2$ to $1.5x10^8$ photons/pulse
  - For G2 (100fF) to G4 (10pF) : **non-linearity** contained within the precision of the VOA (+/- 2.3 %)
  - Lowest capacitance gives highest NL: excepted from ROIC simulations

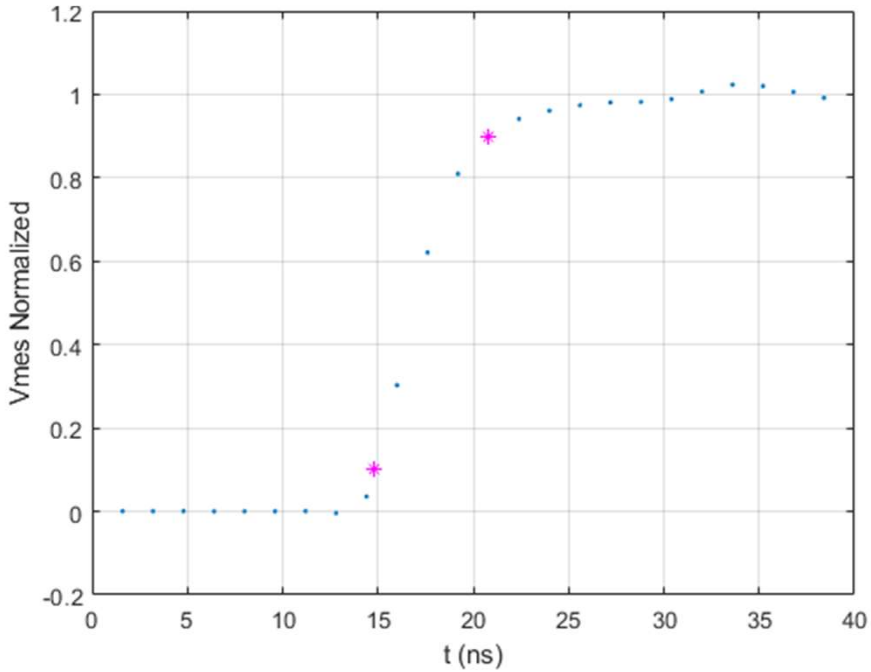




ROIC 112 APD MODULE PERFORMANCES

- **Bandwidth**
  - Bandwidth evaluated from 10-90 % laser pulse rise time measurement
  - Values are lower than excepted but compatible with most of the HOLDON LIDAR scenarios

ROIC Gain	Cint design	Rise time	BP meas.
	F	ns	MHz
G4	10 p	6	58.3
G3	1 p	8.4	41.7
G2	100 f	20.6	17.0
G1	10 f	175	2.0



ROIC 112 APD MODULE PERFORMANCES

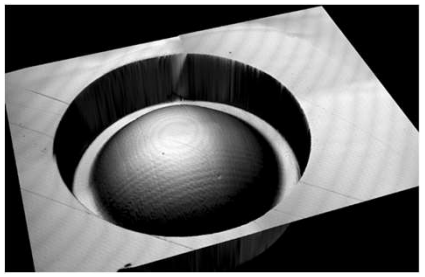
- **Dark current and noise @ M_{APD} = 78**
  - Closed cold aperture
  - Dark current/M_{APD} : **0.2 pA** ($1.6x10^6$ e-/s)
  - Noise evaluated on raw record for Δt = 205 ns
    - **RMS dark noise : 0.6 photons for Cint min**
    - Near the ROIC design extracted values
- **Background current and noise @ M_{APD} = 78**
  - F/4 cold aperture and 2.4 µm low pass filter
  - Background current/M_{APD} : **1 pA** ($8.6x10^6$ e-/s)
  - Noise evaluated on raw record for Δt = 205 ns
    - **RMS background noise : 0.9 photons for Cint min**

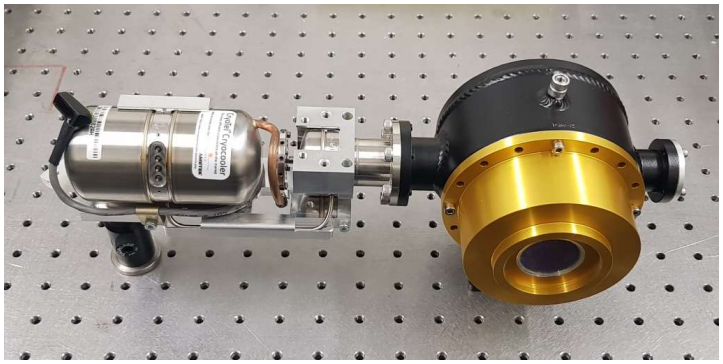
ROIC 112 module **simulated** values				
	Cint	Noise		
	fF	µV	e-	Photons (M = 78, QE = 0.7)
	10	390	24	0.5
	100	90	56	1.0
	1000	60	375	7.0
	10000	60	3745	70.0

ROIC 112 module **measured** values				
	Cint	Noise		
	fF	µV	e-	Photons (M = 78, QE = 0.7)
Dark	12	419	30	**0.6**
	110	81	56	**1.0**
	962	67	400	**7.5**
	9500	52	3056	**57.1**
Background	12	678	49	0.9
	110	182	124	2.3
	962	65	390	7.3
	9500	60	3564	66.6

CONCLUSION AND PERSPECTIVES

- **Versatile and high performances detector for atmospheric LIDAR applications**
  - More than 60 dB of linear dynamic range with less than 1 photon of noise
  - Bandwidth : up to 60 MHz
  - APD QE = 70%
  - APD gain of 78 with excess noise factor F = 1.3
  - Persistence evaluated 600 ns after laser pulse < 10^{-5}
- 2 modules delivered to Airbus in the frame of HOLDON project
- HOLDON project was ended before we deliver the 2 other detectors
  - Next steps: integrate, test and deliver 2 new modules to DLR and LMD
    - Micro-lens to increase the APD sensitive diameter up to 600 µm
    - Use of a cryo-cooler for easier system integration

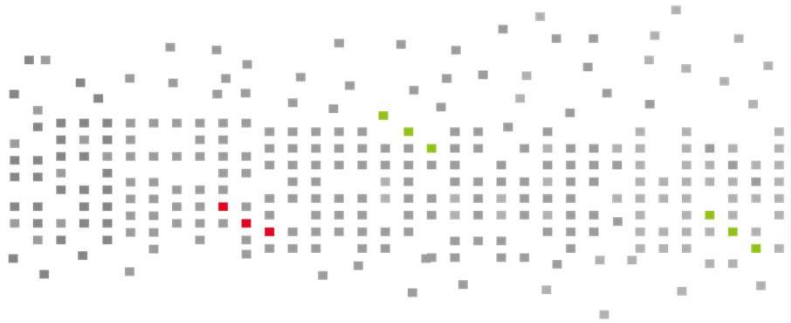




THANKS !

- To HOLDON project partners and the LETI team !

- This work was supported by the CNES and the European Union’s Horizon 2020 research and innovation program under grant agreement no 776390



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