LiDAR Hands-on Lab

Y. Unno (KEK)
with contribution of
Hamamatsu Photonics K.K.

TOF LiDAR Demo machine:
HPK C15122-1005 (1×16ch MPPC-PCI)

Precautions for use

HAMAMATSU
PHOTON IS OUR BUSINESS

Please be sure to follow the rule.
In order to use this product correctly and safely, be sure to read and observe the following safety precautions before using it.
Please note that we are not responsible nor liable for any damage caused by using the product in violation of these precautions.

1) Be sure to observe the following precautions when using this product. If it is used contrary to these precautions, it may affect the human health.
a)Since some ICs of this product will be at high temperature during operation, there is a risk of burns if touched during operation. Please do after having turned-off the power and the temperature has dropped.
b)Do not turn-on the power with the opposite polarity. It may damage parts or cause a fire.
c)Do not use in a place where condensation will form. There is a risk of electric shock due to electric leakage, damages to the parts due to short circuit, and causing a fire.
d)Be careful with the breakages or the scratches to the cable by placing a heavy object on it or bending it strongly. Using it with the damages may cause a fire or an electric shock.

2) This product is made extremely in high precision. Please do not use nor store it in the following places.
Places where the ambient temperature may be outside the temperature range for operation or storage.
Places with sudden temperature changes.
Places exposed to direct sunlight or near equipment that generates heat.
Place where condensation forms.
Places near the objects that generate strong magnetic fields or radio waves.
Places where vibration is.
Places where corrosive gas (chlorine, fluorine, etc.) is generated.
Places with dusts.

3) This product is made extremely in high precision. Please handle it with care.
Do not disassemble or modify it at all.
Do not drop or hit it.
The image sensor may be damaged or deteriorated by static electricity or electric surge.
Be careful when attaching a parts to this product.
If you do not use this product for a long time, unplug the power cord from the outlet.
If the image suddenly disappears, or if abnormal noise, strange odor, or smoke is generated, immediately turn-off the power of this device and stop using it.
Please contact us or our distributor immediately.

4) Please note following aspects in order to bring full performance out of this product.
When using an external power supply, be sure to use the included AC adapter.
Be sure to use the included accessories (USB cable, etc.) for proper operation.

5) When disposing this product, please dispose properly according to the Waste Management Law, or entrust it to an appropriate industrial waste disposal contractor who has obtained a license. When using it overseas and disposing it in that country, dispose it properly in accordance with the waste disposal laws and regulations of the country or the state.。

6) This product uses a 905nm pulse laser as a light source. The amount of emitted light during normal operation is equivalent to Laser class 1, but it does not have a fail-safe function. The laser class based on JIS is 3B. Laser class 2 or higher light may be output due to unexpected usage or abnormal operation. Never look into the outlet. When using this product, always wear laser protective goggles compatible with a wavelength of 905 nm and work in the laser controlled area.

Software license agreement

Please read the following conditions carefully (hereinafter referred to as "these license conditions").
Hamamatsu Photonics Co., Ltd. (hereinafter, "the company") licenses the use of the software (hereinafter, "this software") such as the application software, DLL files, etc. only for the users of our MCD head products and drive circuit products (hereinafter, "our products") who accept this license condition. By installing the software or copying these files, you have agreed to be bound by these terms and conditions. If you do not agree to all or a part of these terms and conditions, you may not install or use the software.

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Transfer or sublicense the right to use this software to a third party.
Lending, leasing or collateralizing this software to a third party.
Modify or remove part or all of this software, including this license and other annexes.
Reproduce all or part of this software, or attempt to unravel the source code by adaptation, translation, reverse engineering, disassembly or decompilation or other means.

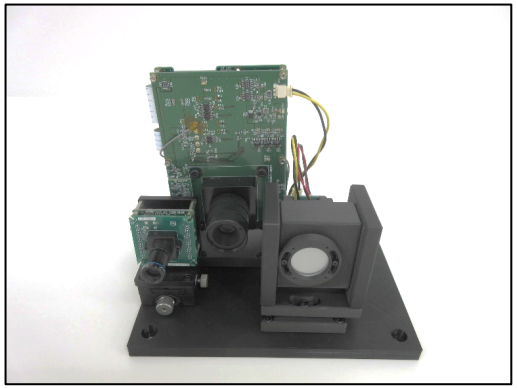
6. Limitation of liability

We do not guarantee the quality, the performance, or the suitability for other purposes, of this software and attached documents. In no event shall we be liable for any other direct or indirect damages, such as computer failure or damage, information loss, or any other direct or indirect damages resulting from the use of this software and its annexes. In addition, we do not maintain or support this software, and we do not take any responsibility, including repairs, in the event of a malfunction or failure.

We may modify this software without notice for improvement.

Included accessories with Demo machine

C15122-1005 Demo machine

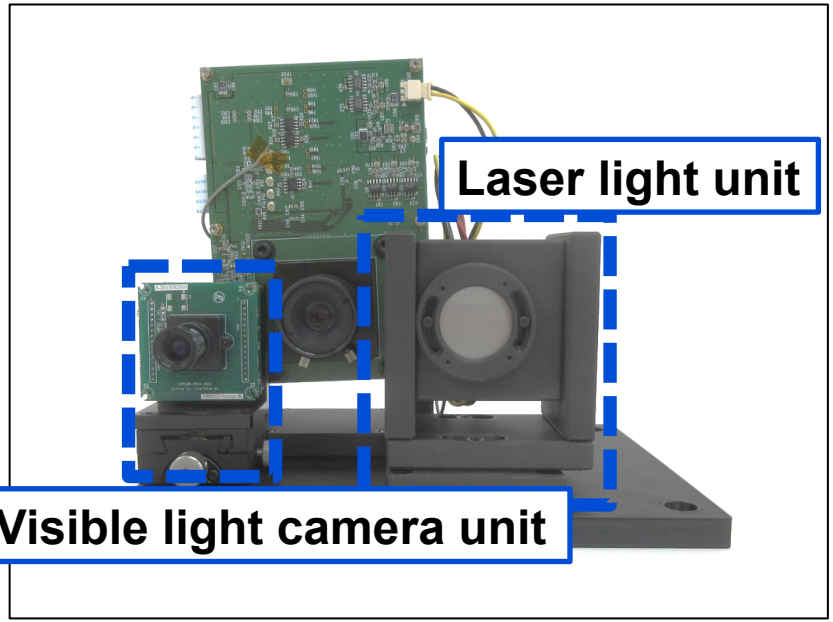


Micro USB cable

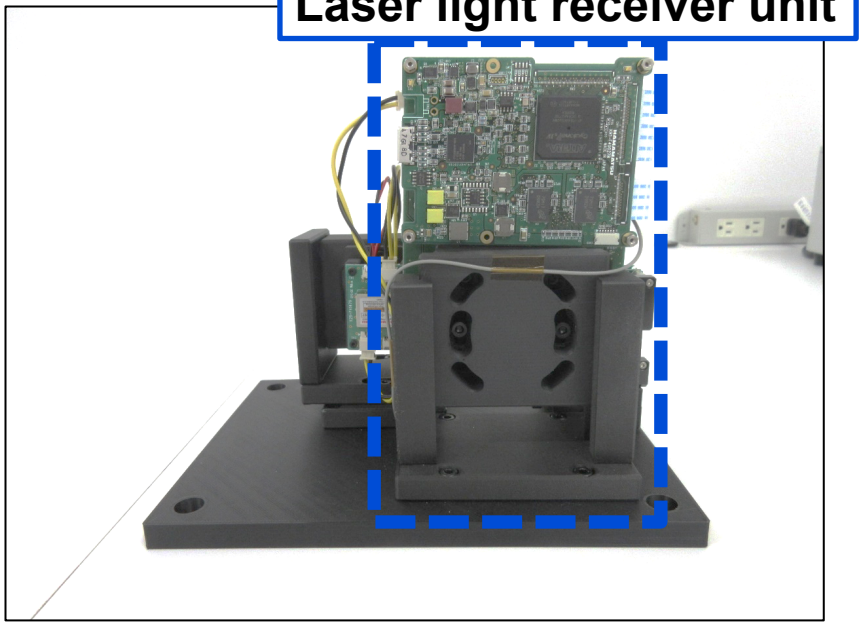
USB2.0 Type-B cable

Demo machine appearance

Front side

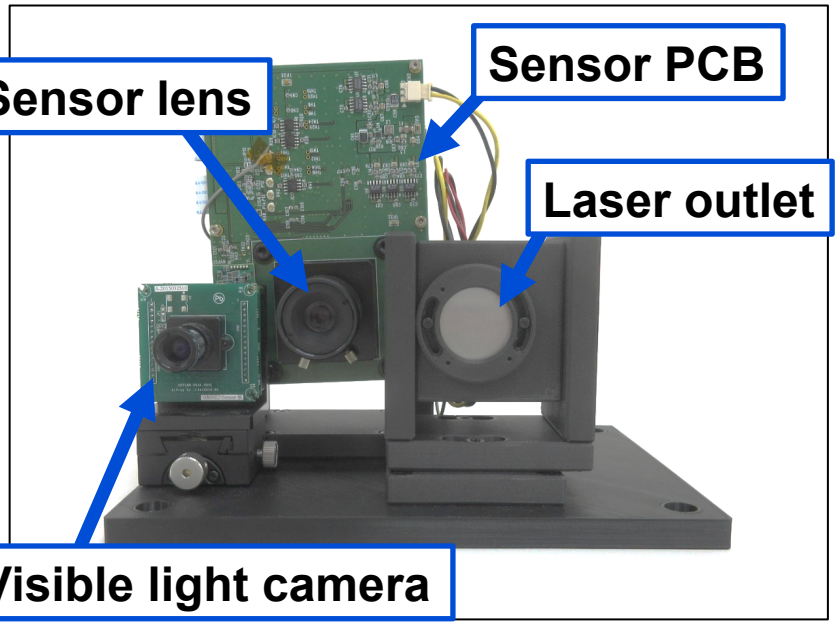


Back side

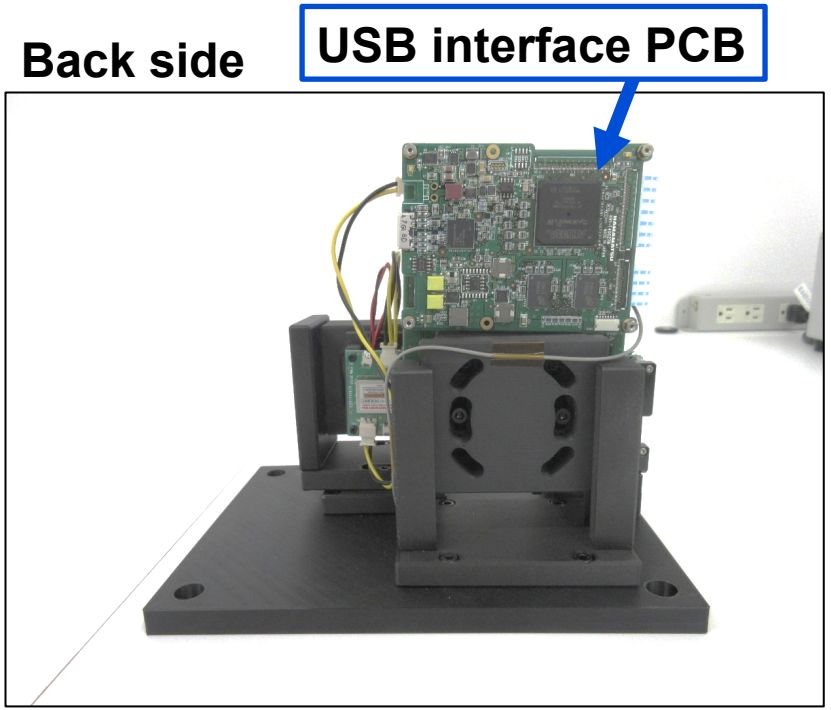


Demo machine appearance

Front side



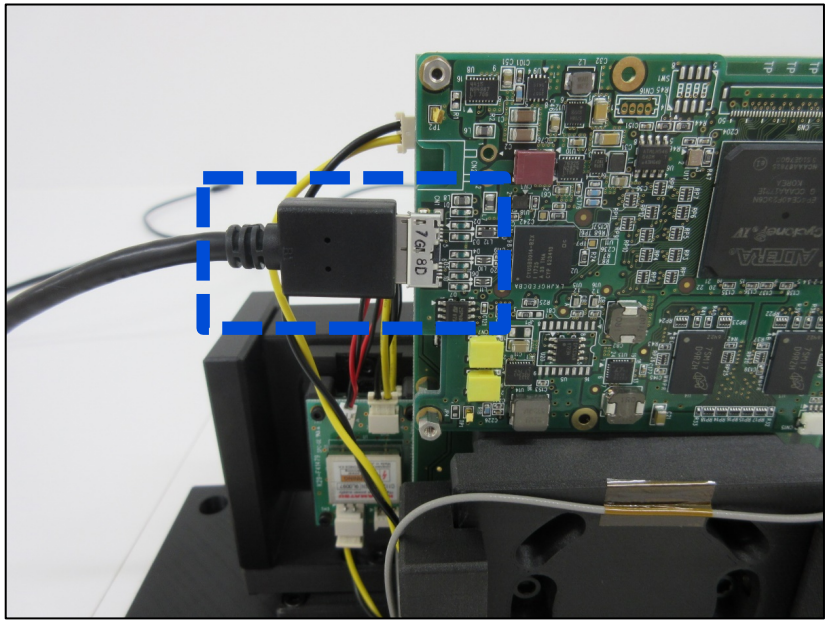
Back side



※Do not look into the laser outlet as it is dangerous.
Never disassemble the laser light unit. If any parts are missing or screws are loose, stop using them immediately and contact us.

Connection between Demo machine and PC

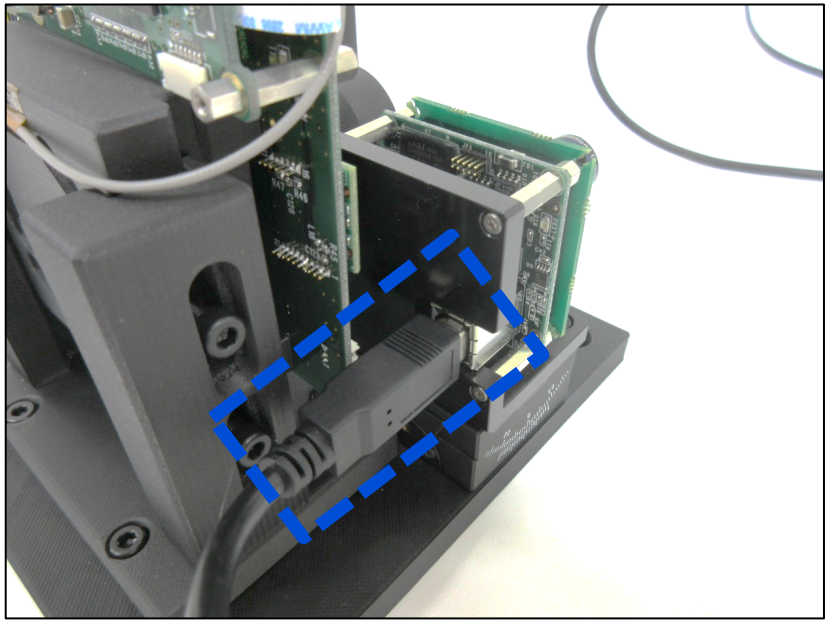
USB interface PCB



- **Connect the Micro USB3.0 cable with the USB interface board**
- **Connect the other side to the USB3.0 or higher port of the PC**
  - **Power** will be supplied **through the USB cable** to the demo machine.
  - Please connect to a USB port with **sufficient supply current**.

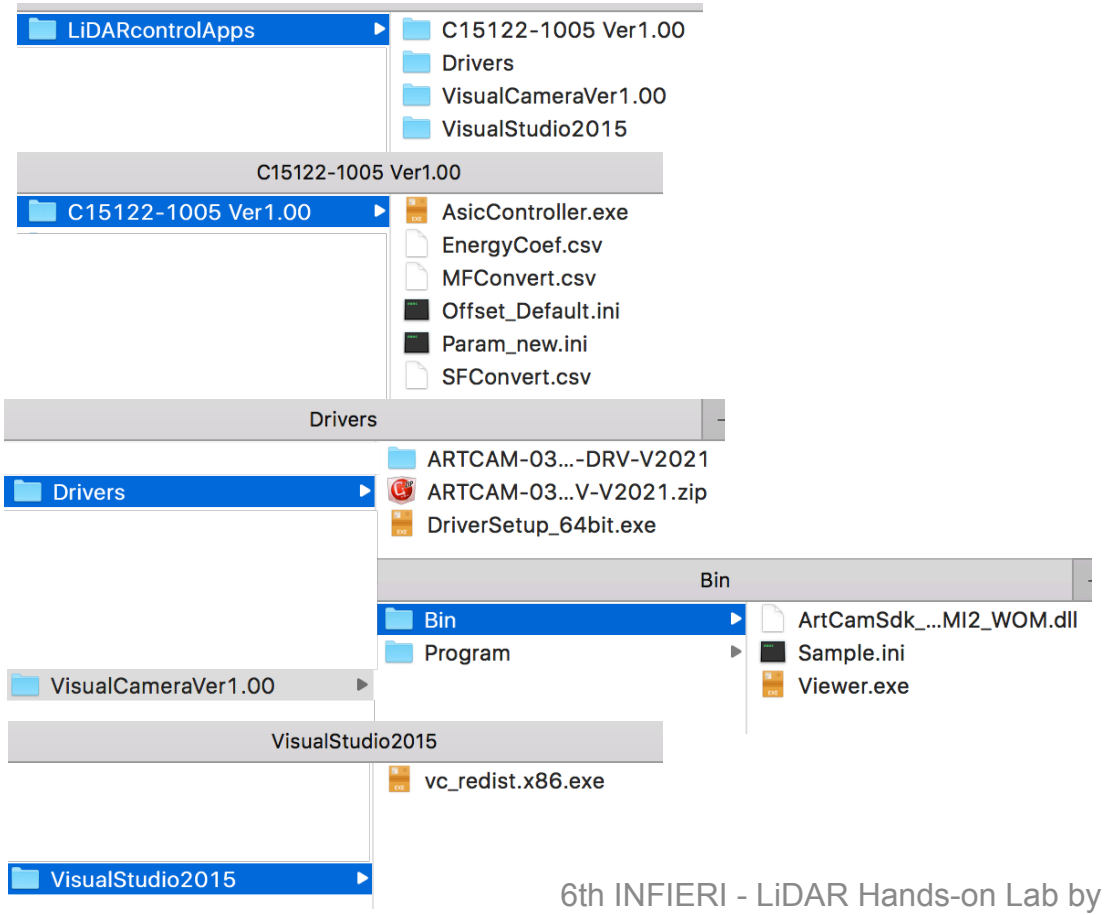
Connection between Demo machine and PC

Visible light camera



- **Connect the included USB2.0 Type-B cable to the back of the visible light camera.**
- **Connect the other side to the USB2.0 or higher port of the PC**
  - **Power** will be supplied **through the USB cable** to the camera unit.
  - Please connect to a USB port with **sufficient supply current**.

Software Installation



- **PC and OS**
  - Windows **8.1 Pro** or higher
- **Softwares**
  - HPK Co.Ltd
    - C15122-1005 Ver1.00/**AsicController.exe**
    - **DriverSetup_64bit.exe**
      - Installer of the driver software for MPPC
  - Microsoft Co.Ltd
    - **VisualStudio2015**
      - **mfc140u.dll** is required for the AsicController.exe
  - Artray Co.Ltd
    - VisualCameraVer1.00/Bin/**Viewer.exe**
    - **ARTCAM-036MI2-WOM-DRV-V2021**
      - **ArtCamSdk_036MI2_WOM.dll**
- **Installation**
  - Copy LiDARcontrolApps folder
  - Install drivers from Drivers folder
    - DriversSetup_64bit.exe
    - ARTCAM-03.../windows7/ia64/...
  - Install VS2015
    - vc_redist_x86.exe

Parameters of Demo machine

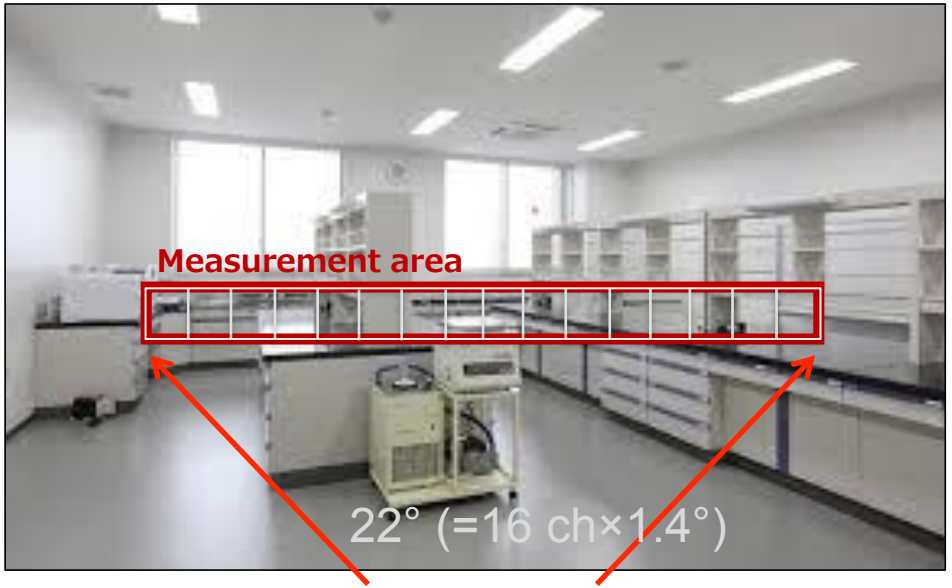
【MPPC-ASIC-EVAL-01】

Laser light source		
LD	L11854-336-05	-
LD driver	C14518	-
wavelength	905	nm
Output Laser power	80	w
pulse width	4	ns
emitter angle (H×V FWHM)	100× 0.5	degrees

Light receiving system		
sensor	S15022-0225GL-01	-
Sensor evaluation Board	C15122-0225GL-01	-
Lens mount	C or CS	-
Viewing angle (H×V) (*)	22×0.5	degrees
Lens focal length (*)	8	mm
Lens F# (*)	1.2-close	-
BPF transmission wavelength	905±5	nm

(*)Changeable by lens selection

General		
Max. Distance range	10	m
Measurement cycle	20000	Hz
Laser class	1	-



Laser Unit

Laser Driver Board – C14518

- **Pulsed Laser Diode**
  - Product – L11854-336-05

■ Features

- 3 stack PLD
- Peak output power: ≧100 W
- Peak emission wavelength: 905 nm
- Emitting area size: 360 µm × 10 µm

(Note: 905 nm is an infra-red.)

■ Applications

- Laser range finder
- Security
- Measuring instruments

PLD - L11854-336-05

■ Absolute maximum ratings ($T_{op(c)}$ = 25 °C)

Parameter	Symbol	Value	Unit
Pulsed forward current	I_{fp}	40	A
Reverse voltage	V_r	2.5	V
Pulse duration	t_w	100	ns
Duty radio	DR	0.1	%
Operating temperature	$T_{op(c)}$	-40 to +85	°C
Storage temperature	T_{stg}	-40 to +100	°C

■ Characteristics ($T_{op(c)}$ = 25 °C)

Parameter		Symbol	Conditions	Value			Unit
				Min.	Typ.	Max.	
Pulsed radiant power (Peak power)		Φ_{ep}	I_{fp} = 35 A	80	100	—	W
Peak emission wavelength		λ_p		895	905	915	nm
Forward voltage		V_{op}		—	12	15	V
Spectral radiation half bandwidth		$\Delta\lambda$		—	6	10	nm
Rise time		t_r		—	—	2	ns
Beam spread angle	Horizontal	$\theta_{//}$	I_{fp} = 35 A FWHM	4	8	12	degree
	Vertical	$\theta_{\perp}$		19	24	29	
Lasing threshold current		I_{th}	—	—	0.8	1.2	A
Emitting area size		—	Value at designing	—	360 × 10	—	μm × μm

Note: General operating condition: pulse width t_w = 50 ns, repetition frequency f_r = 1 kHz

Figure 1: Radiant flux vs. Forward current (Typ.)

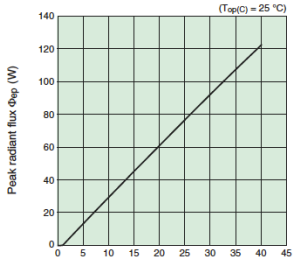


Figure 2: Emission spectrum (Typ.)

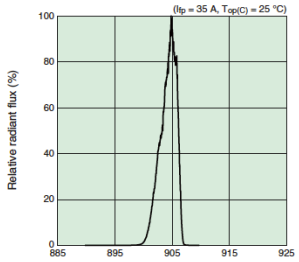


Figure 3: Directivity (Typ.)

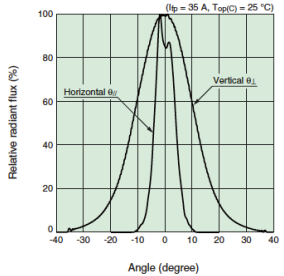


Figure 4: Emitting image of near filed pattern (NFP)

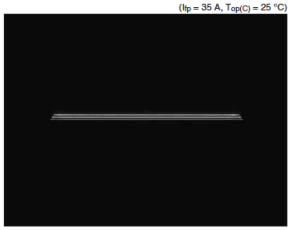
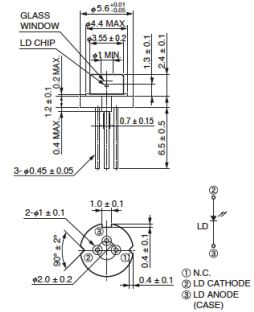
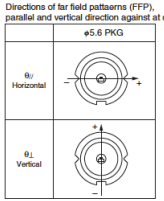


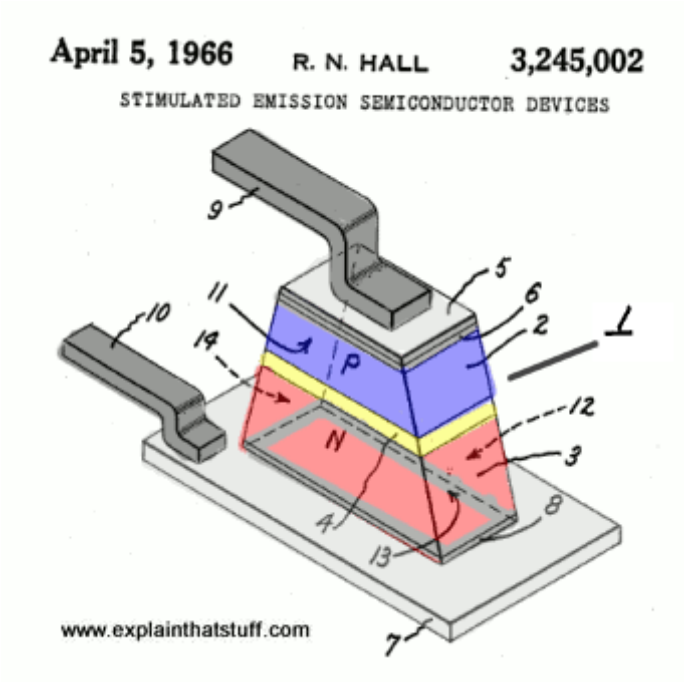
Figure 5: Dimensional outline (unit: mm)





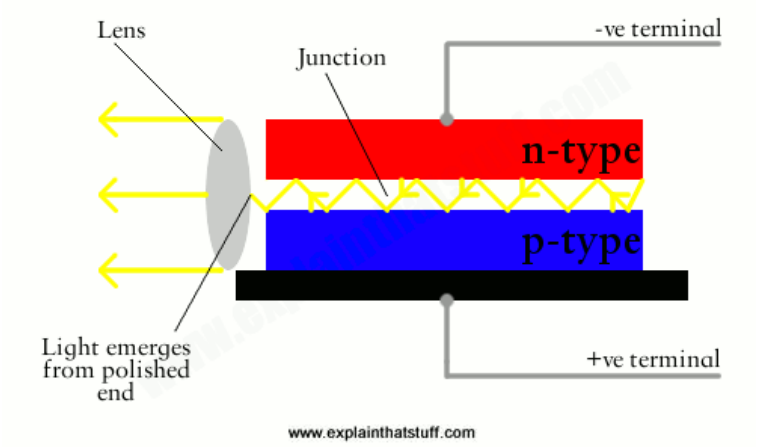
(Semiconductor) In-plane Laser Diode

- **Invention of Dr. Robert N. Hall, General Electric.**
  - who filed his **patent** for the idea ("Stimulated emission semiconductor devices") on October 24, **1962** (it was granted as US Patent #3,245,002 on April 5, 1966)
- **Structures**
  - 2: P-type region (blue).
  - 3: N-type region (red).
  - **4**: **P-N junction region (resonant cavity)** where light is produced by stimulated emission. This isn't drawn to scale! In Hall's original patent, it's described as being 0.1 micron thick.
  - **11**: Highly **polished front** surface.
  - **12**: Highly **polished rear** surface, which must be precisely parallel to the front surface to ensure standing waves of electromagnetic radiation (laser light) are produced and emitted efficiently in the resonant cavity between the p-type and n-type regions.
  - Surfaces 11 and 12 may be covered with mirrors or a metallic coating to improve the resonant effect.
  - **13, 14**: Side surface cut at an **angle** (or roughened) to **prevent** waves of light forming in other directions.



Principle of (In-plane) Laser Diode

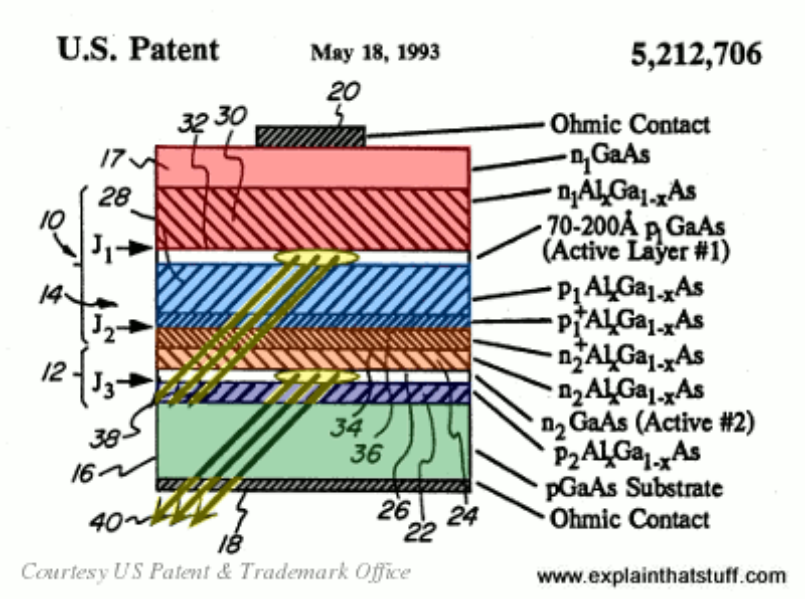
- Instead of using silicon as the semiconductor, an alloy of **aluminum and gallium arsenide**, AlGaAs, is used for having a **larger band-gap (1.42-2.16 eV)**.
  - Indium gallium arsenide phosphide, InGaAsP, is another popular choice.
  - GaAs n-type dopants: Silicon (Si), selenium (Se), tellurium (Te), and sulfur (S). GaAs p-type dopants: Carbon, beryllium, magnesium, zinc (Zn), and cadmium.
- **Electrons** are injected into the diode (i.e., “forward” biasing), they **combine with holes**, and some of their excess energy is converted into **photons**, which interact with **more incoming electrons**, helping to produce **more photons**—and so on in a kind of self-perpetuating process called resonance, analogous to the process of stimulated emission that occurs in a conventional, gas-based laser.
- A similar to "**pumping**" happens when the **photons** bounce **back and forth** in the microscopic junction (roughly one micrometer wide) between the slices of p-type and n-type semiconductor, which is technically known as a **Fabry-Perot resonant cavity** (a kind of interferometer).
- **The amplified laser light eventually emerges from the polished end of the gap in a beam parallel to the junction.**



Fabry–Pérot interferometer (FPI) is an optical cavity made from two parallel reflecting surfaces (i.e.: thin mirrors). **Optical waves** can **pass through** the optical cavity only when they are **in resonance** with it. It is named after Charles Fabry and Alfred Perot, who developed the instrument in 1899.

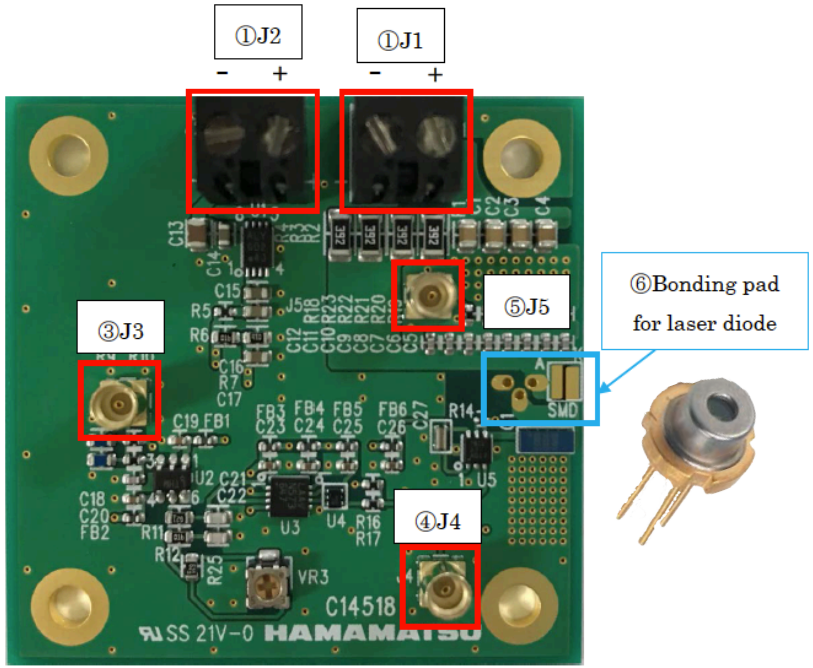
Stacked Laser Diode

- **More light...**
- **Stacking:**
  - Since the 1990s, one common approach has been to mount **a number of** laser diodes on **top of one another** (like an apartment building) and then **focus** their **individual** beams into a **single** output beam using a collimator and/or lens.
  - Instead of a single P-N junction, there are multiple ones, and the laser light beams emerge from the active layers in between them; typically, there's also at least one tunnel junction between the stacked layers.
- **Apart from making more power than a single laser diode,**
  - a stack opens up the possibility of generating **multiple different wavelengths** at the same time (because each laser in the stack can make a different one).
- **Caveat:**
  - **Cooling** is critical.



Laser Driver Board – C14518

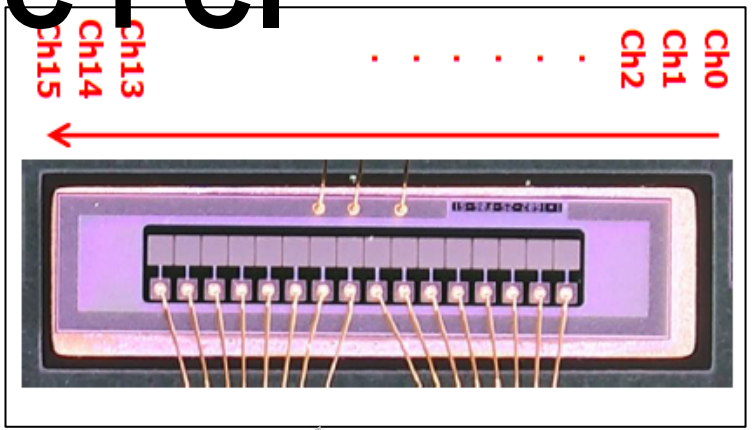
- **Circuit board**
  - J1: Charge voltage (*Vc*) input terminal
    - DC: 0 to + 90V, controls Laser power
  - J2: Forward voltage (*Vop*) input terminal
    - DC: +7 to +12 V
  - J3: Trigger input terminal
    - 0 to +5V square pulse (width 20-200 ns)
    - Repetition: 1 kHz to 150 kHz
    - Laser pulse width is fixed.
  - J4: Gate signal monitor terminal
    - Conversion factor (CF): 20 (50Ω termination)
  - J5: Current (*Ifp*) monitor terminal
    - *Ifp* < 40 A
    - Conversion factor (CF): 22.7 A/V (50Ω termination)
  - Bonding pad for laser diode

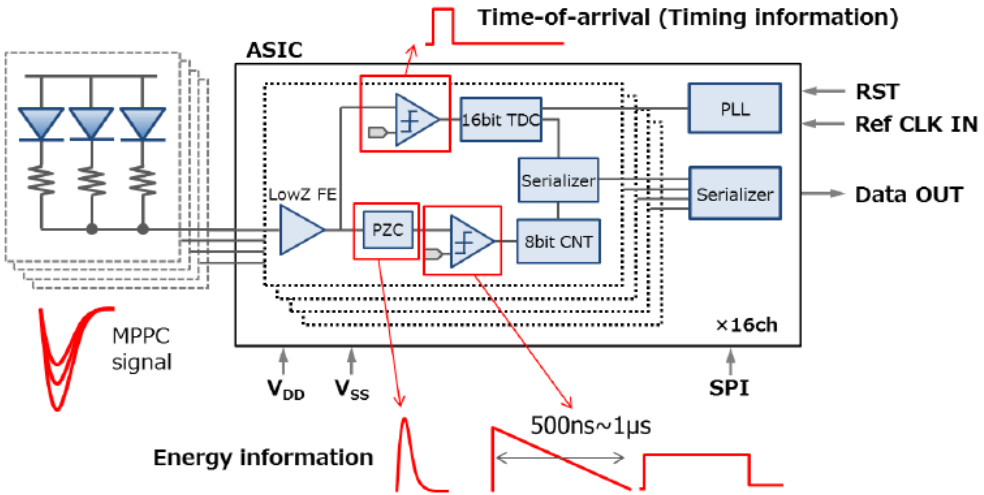


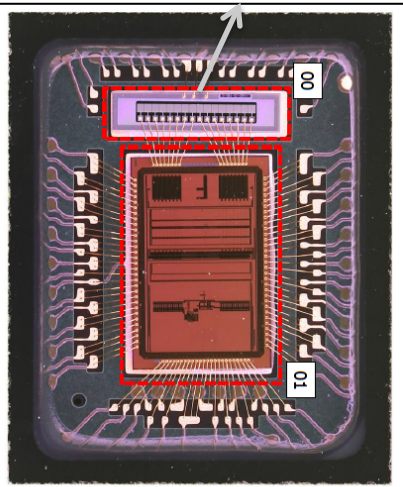
MPPC Evaluation Board

1D-16ch MPPC PCI

- **Product – S15022-0225GL-01**
  - 1D MPPC Photon Counting Image (PCI) Sensor
  - 16 channel
  - This 1D MPPC PCI is integrated with an ASIC,
    - a Time-to-Digital Converter (TDC), to provide time-of-flight information (TOF) and
    - the Time Over Threshold (TOT), a pulse height information.





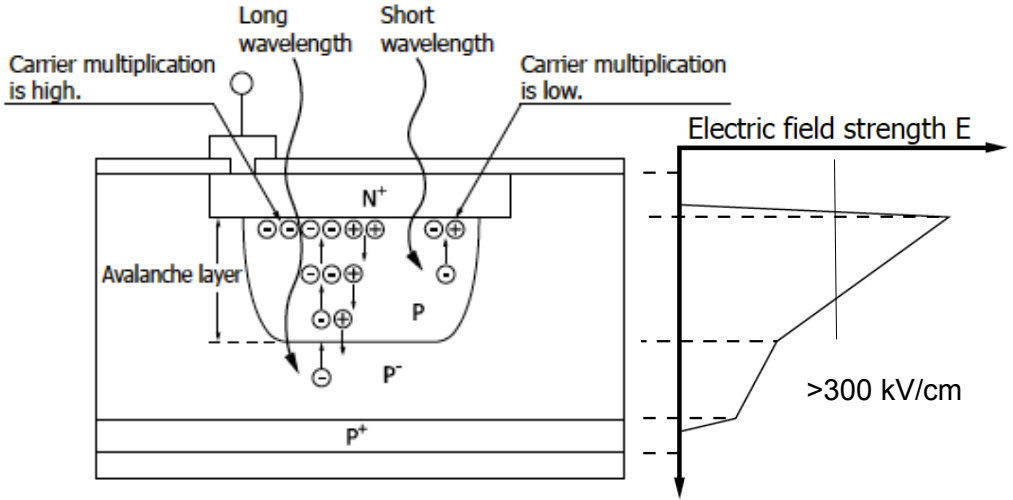


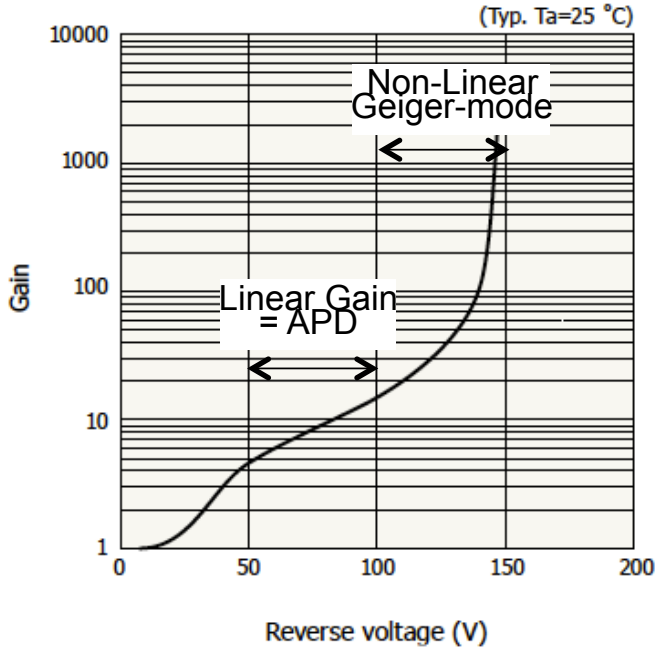
1D-16ch MPPC

ASIC (TOF-TOT)

Principle of MPPC

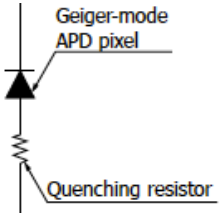
- **APD: Avalanche Photo Diode**
  - PIN diode with Avalanche layer
  - Avalanche multiplication occurs where E > 300 kV/cm
- **SPAD: Single Photon Avalanche (Photo) Diode**
  - Very high gain (10^5 to 10^6) Geiger-mode APD
  - so-called *Digital* photodetector or photomultiplier

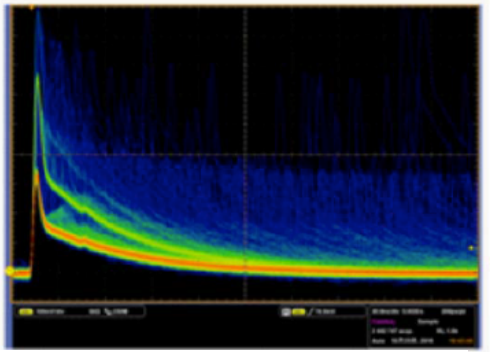


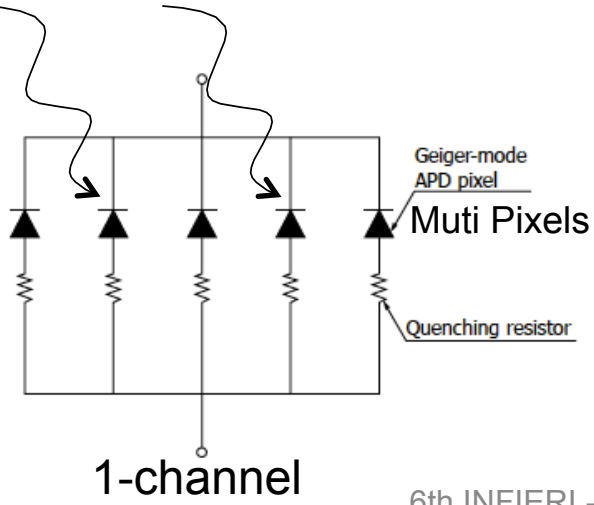


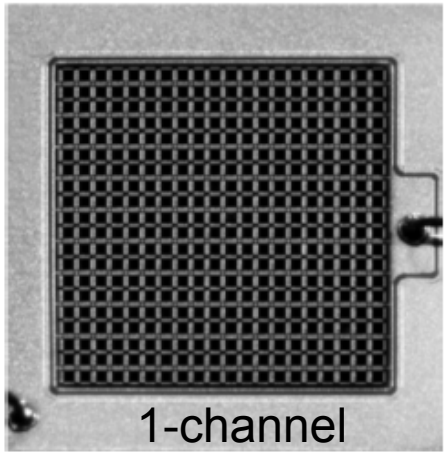
Principle of MPPC

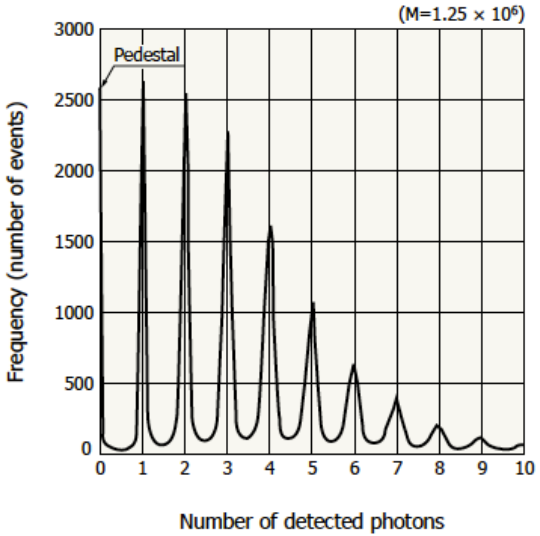
- **A quenching resistor (*Rq*)**
  - Once in the **geiger**-mode, current surge **continues**.
  - A **quenching** resistance, *Rq*, is required to **reduce** the bias voltage to **stop** Geiger-mode.
- **Si-PM = MPPC**
  - Si-PM: Silicon Photo Multiplier
  - MPPC: **Multi Pixel** (Multi) **P**hoton **C**ounter
  - Number of **hit pixels** = Number of **photons**
- **1D-16ch MPPC**
  - 16 array of (1ch) MPPC





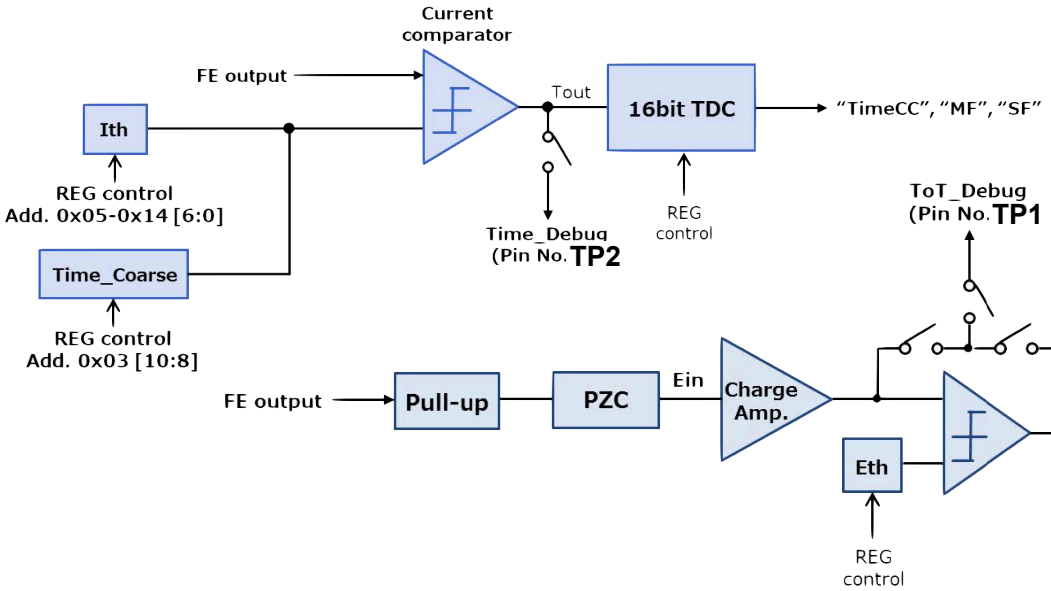


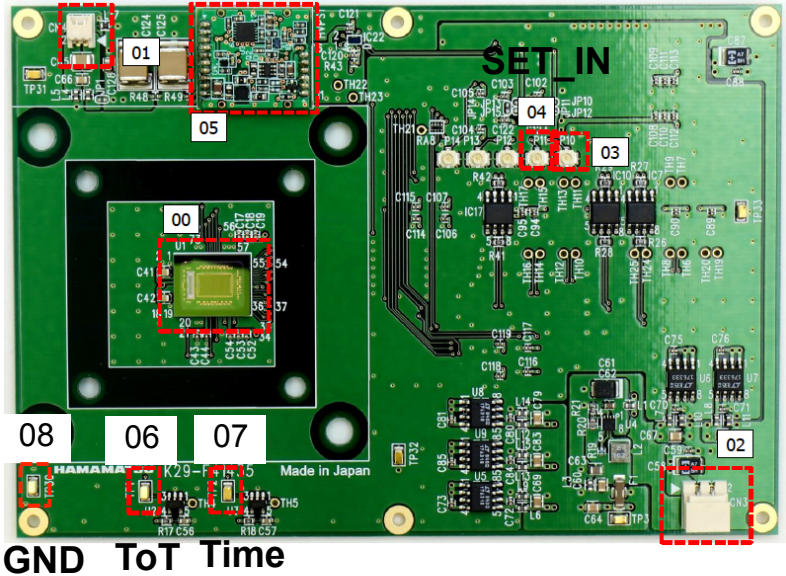




Evaluation Board

- **Product#: C15122-0225GL-01**
  - 03: (P10) PLD Trigger signal to Laser Unit
  - 04: (p11) **SET_IN** signal (debug signal)
  - 06: (TP1) **ToT**_Debug monitor pin
  - 07: (TP2) **Time**_Debug monitor pin
  - 08: (TP30) **GND**

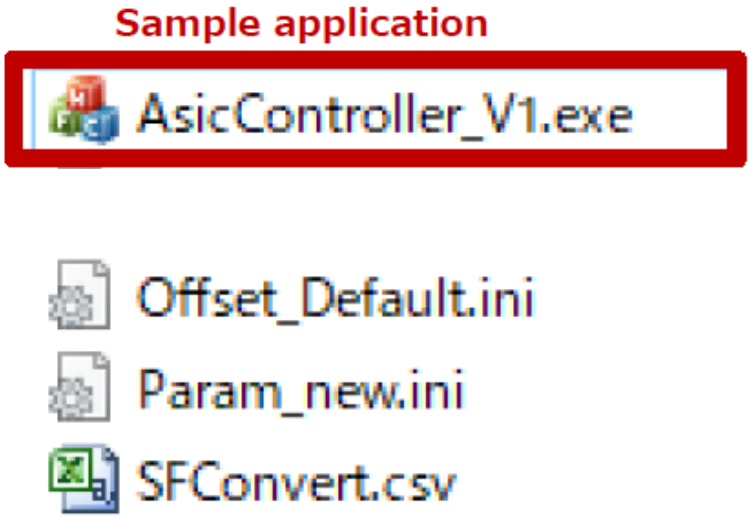




Running the Software

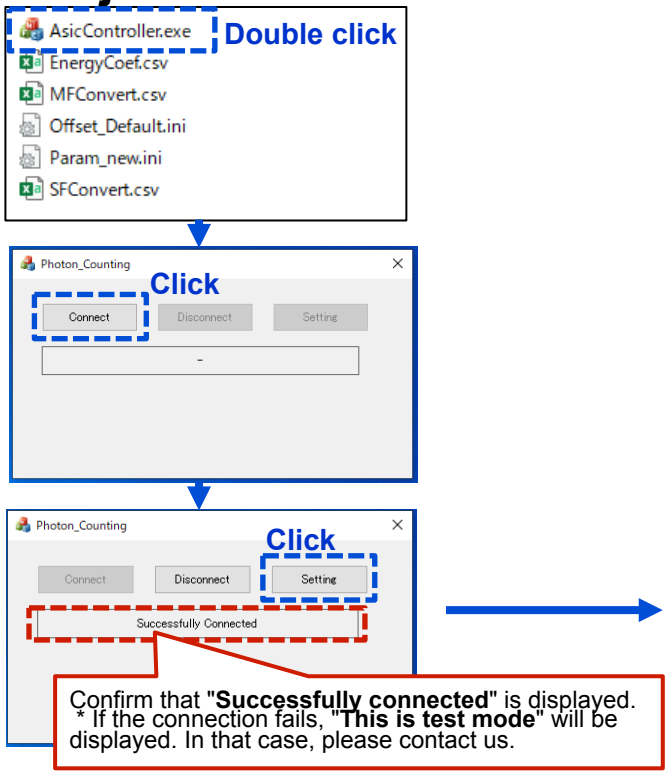
Application Software

- **Project files**
  - There are an **application** and parameter files. They should be in the **same** directory.
  - Sample application for the ASIC controller
    - **AsicController_V1.exe**
  - parameters setting for measurement
    - **Param_new.ini**

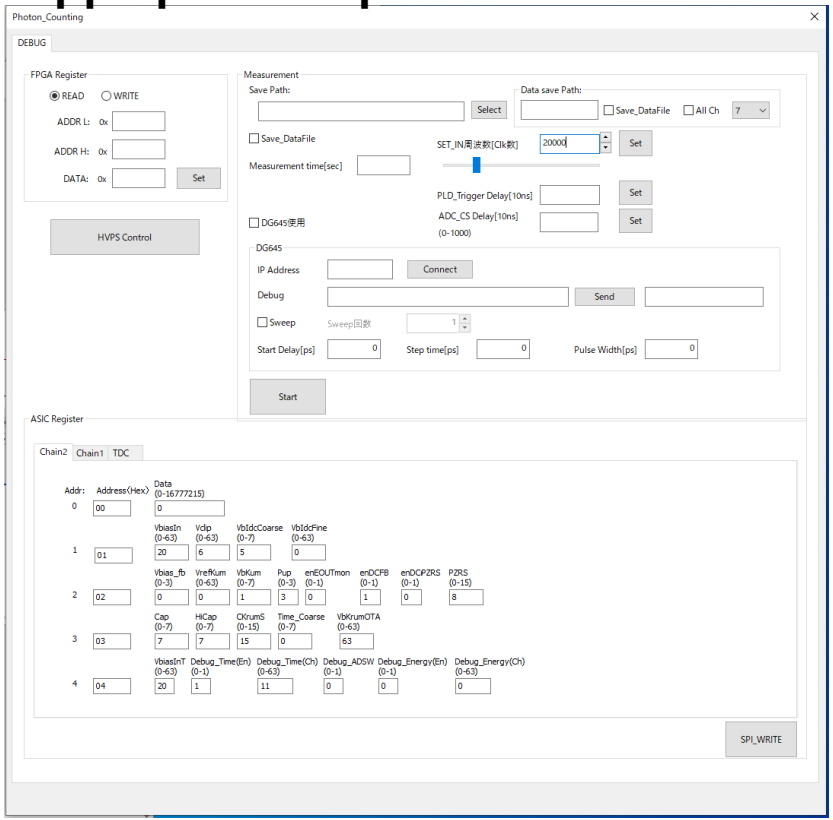


Launching the ASICcontroller app

Project folder

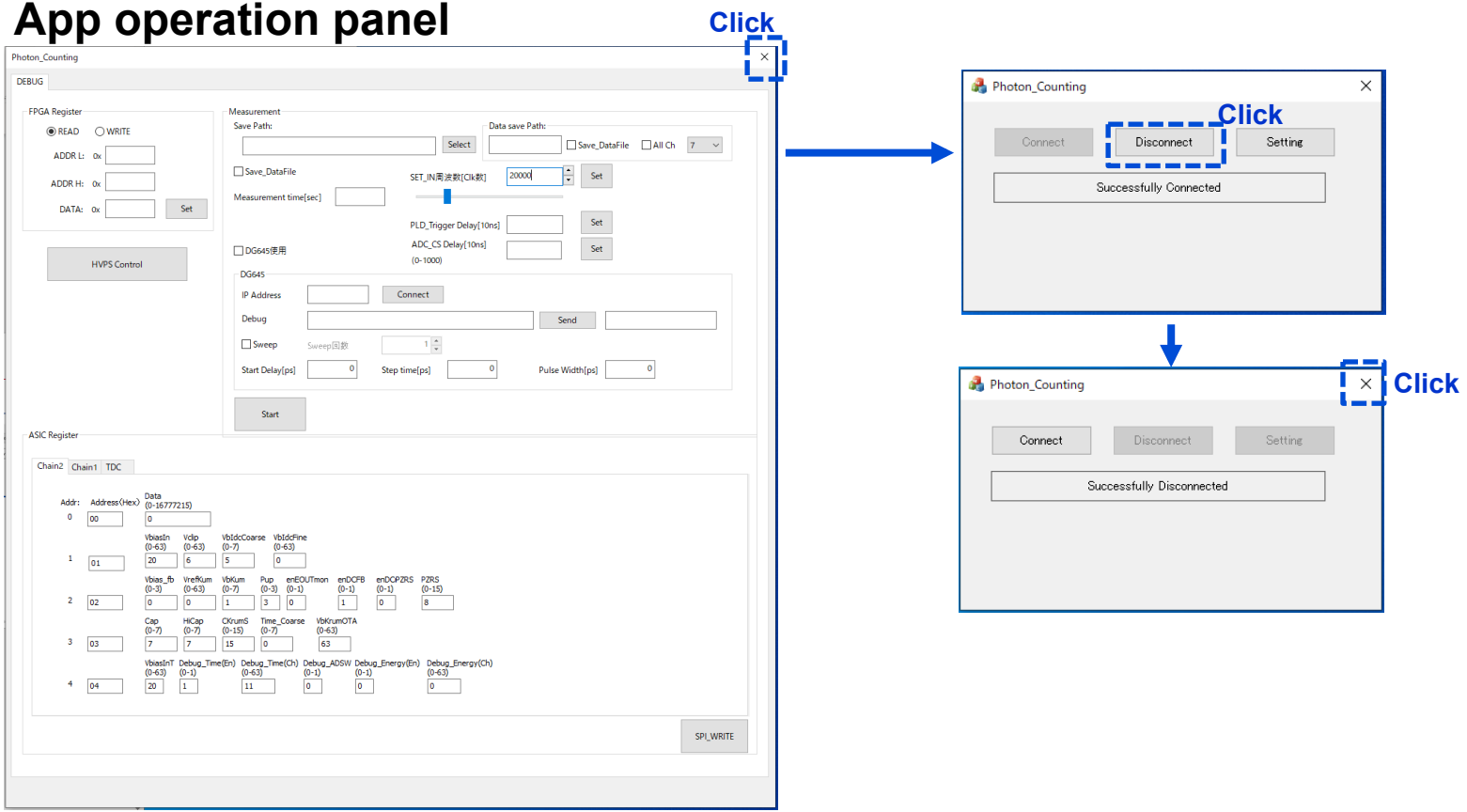


App operation panel



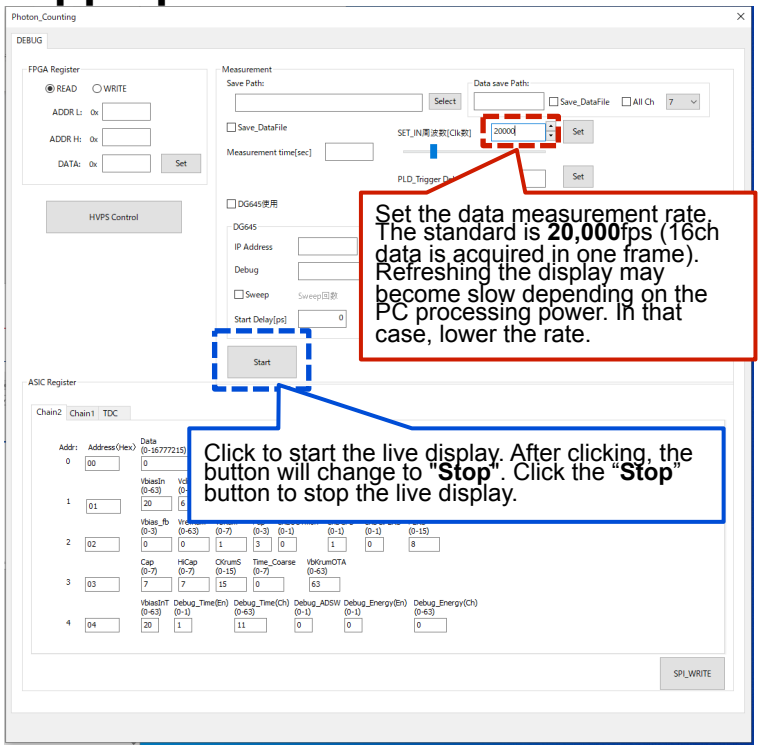
Closing the ASICcontroller app

App operation panel



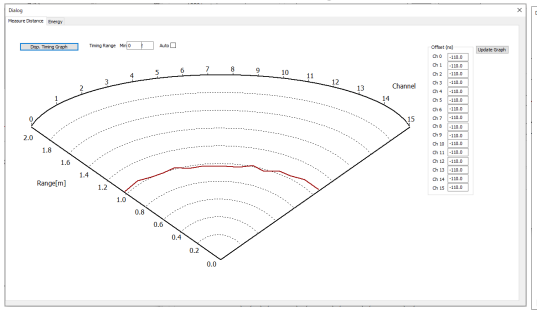
Live displays

App operation screen



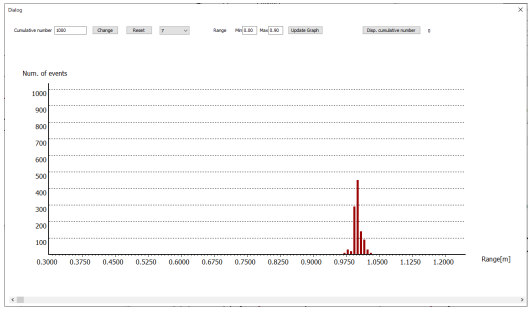
Live display panels

Real time display



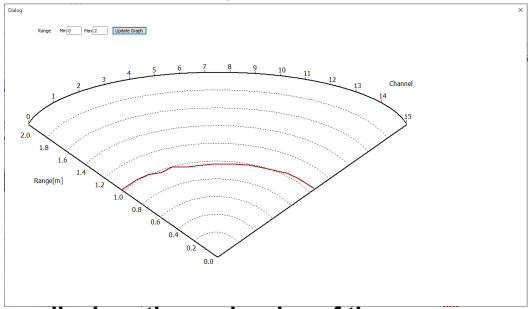
displays 16ch measurement data of the latest frame

Histogram display



Histogram display of measurement data for the specified number of times of the specified channel

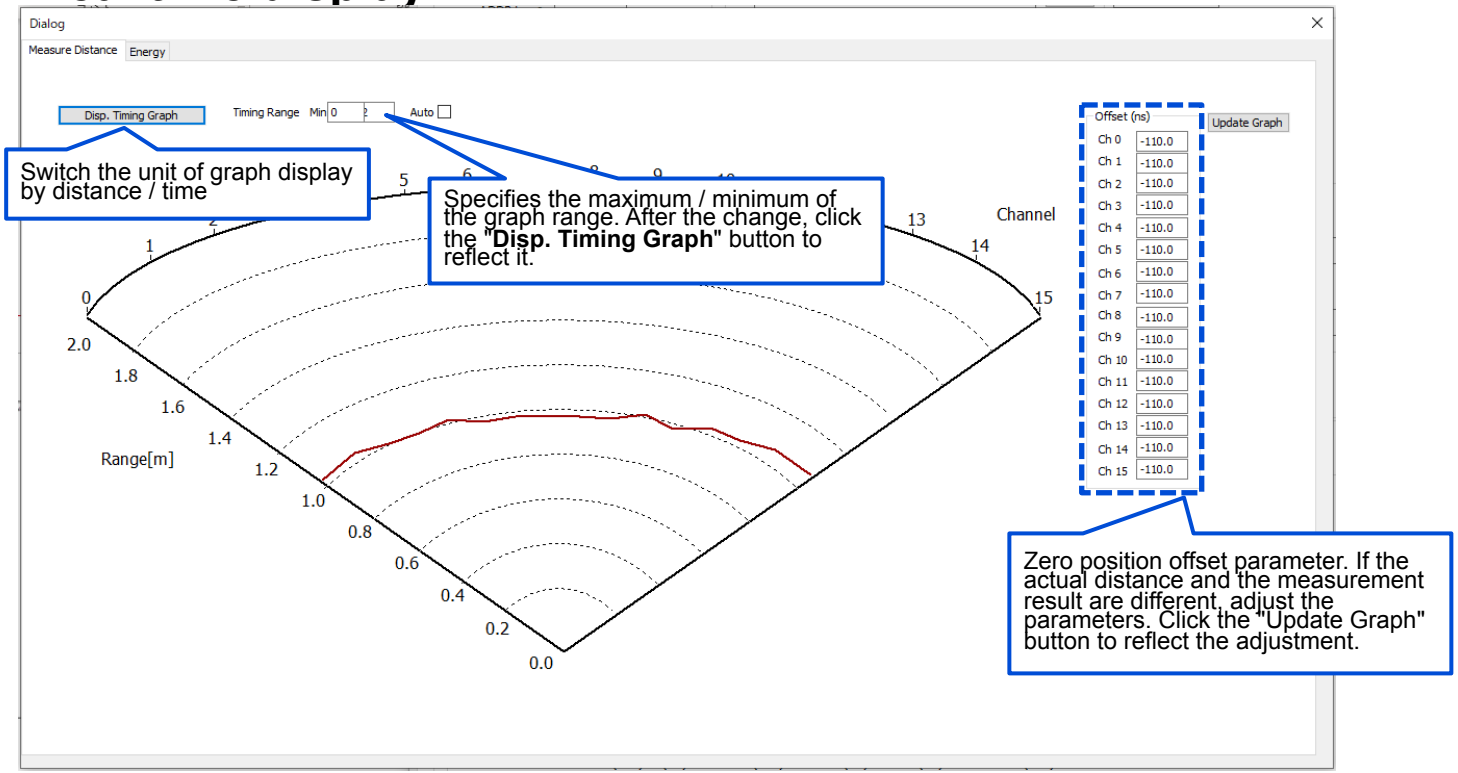
Statistically processed display



displays the peak value of the histogram for 16 channels

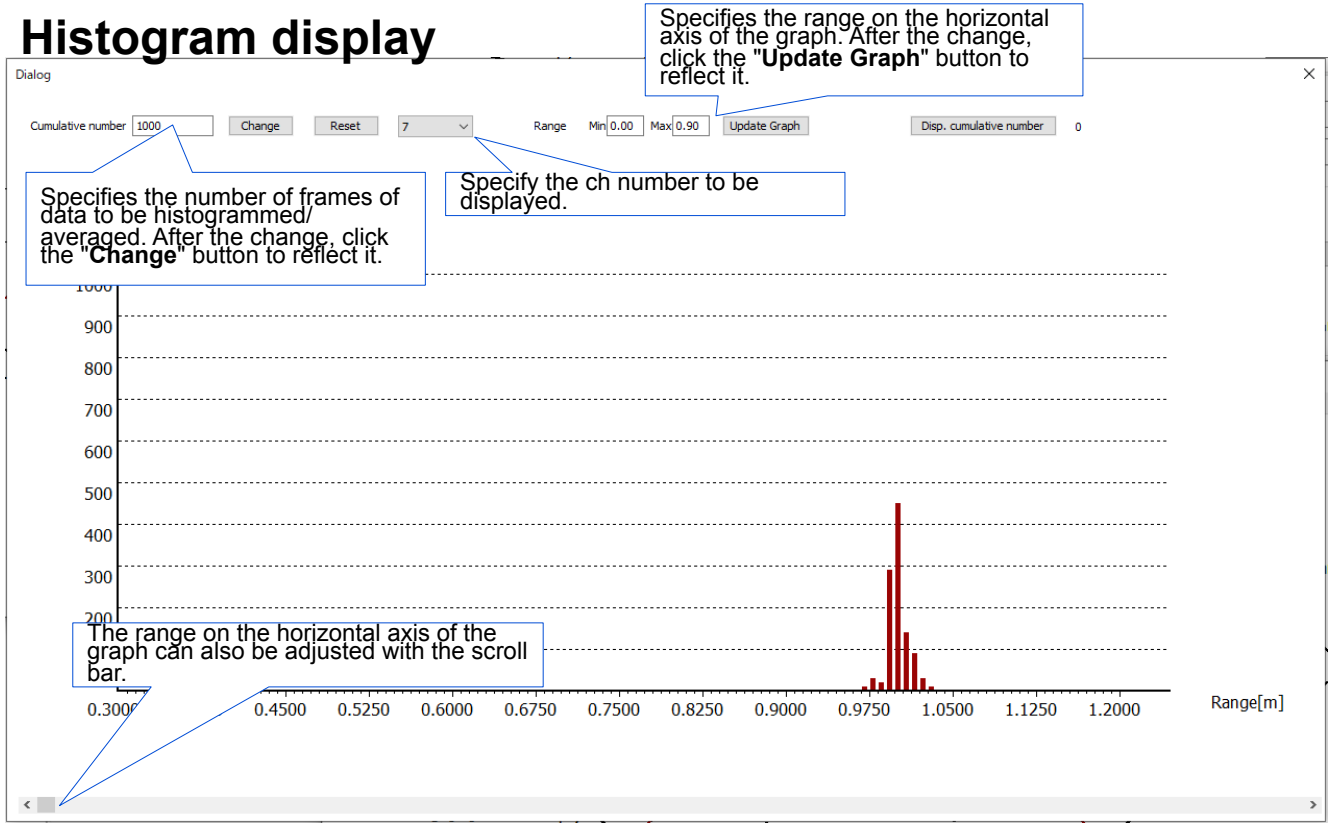
Live displays

Real time display



Live displays

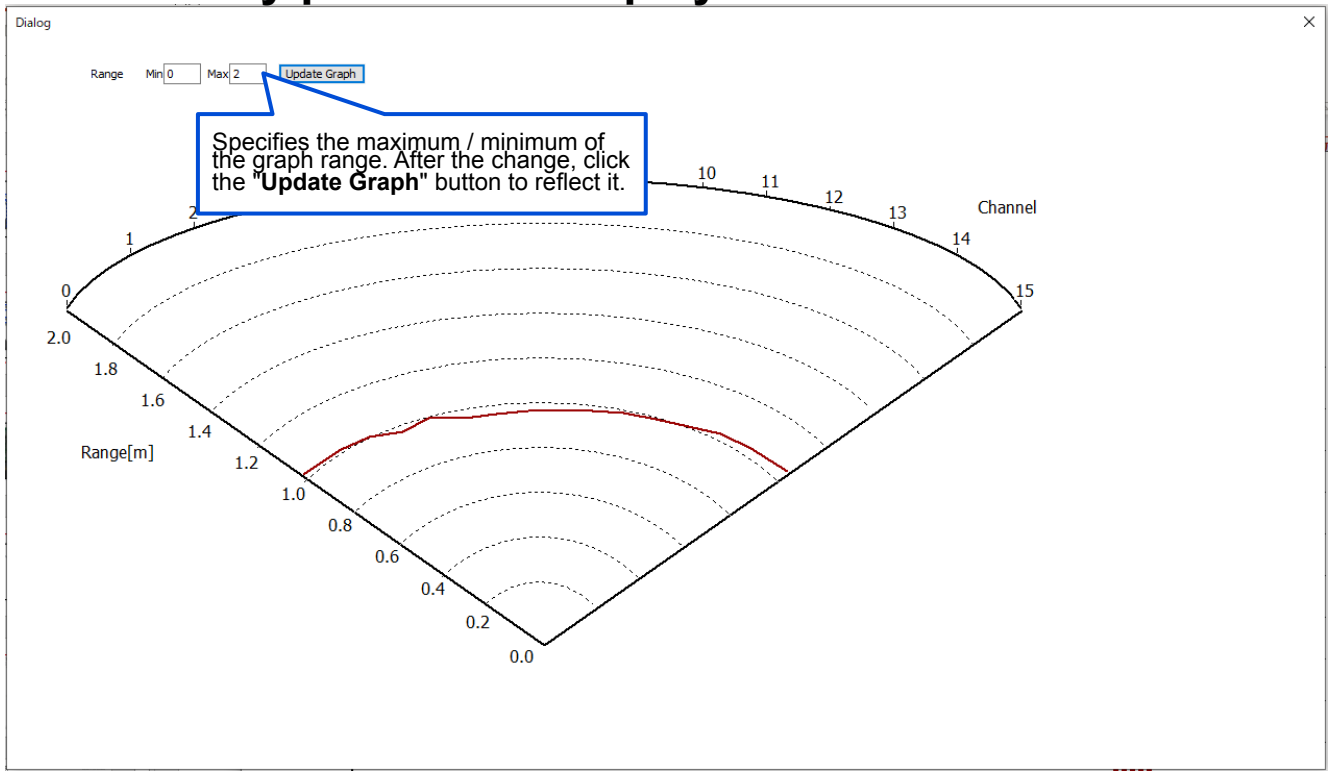
Histogram display



- Number of data to be **averaged** can be set with
  - **Histogram display**
  - **Cumulative number**

Live displays

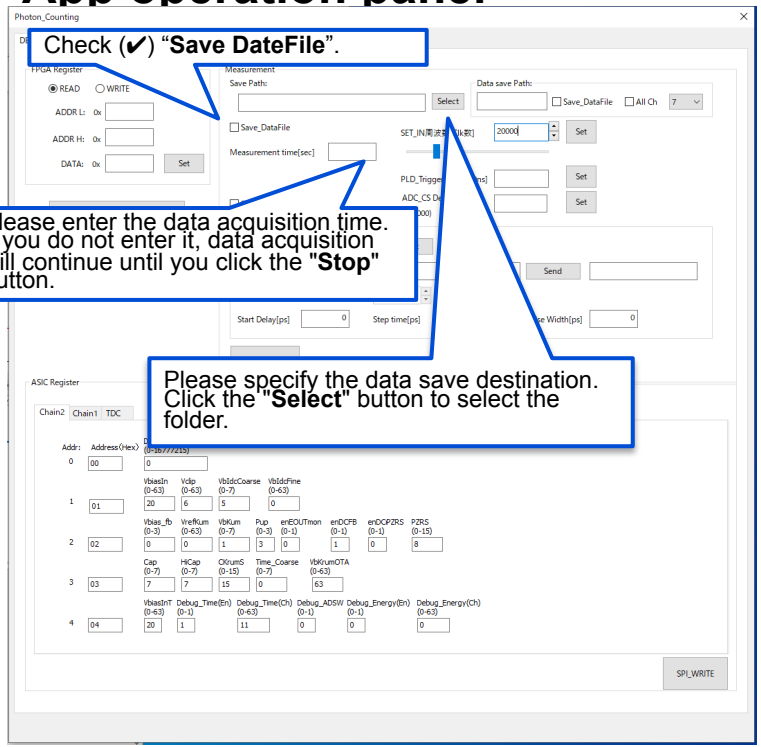
Statistically processed display



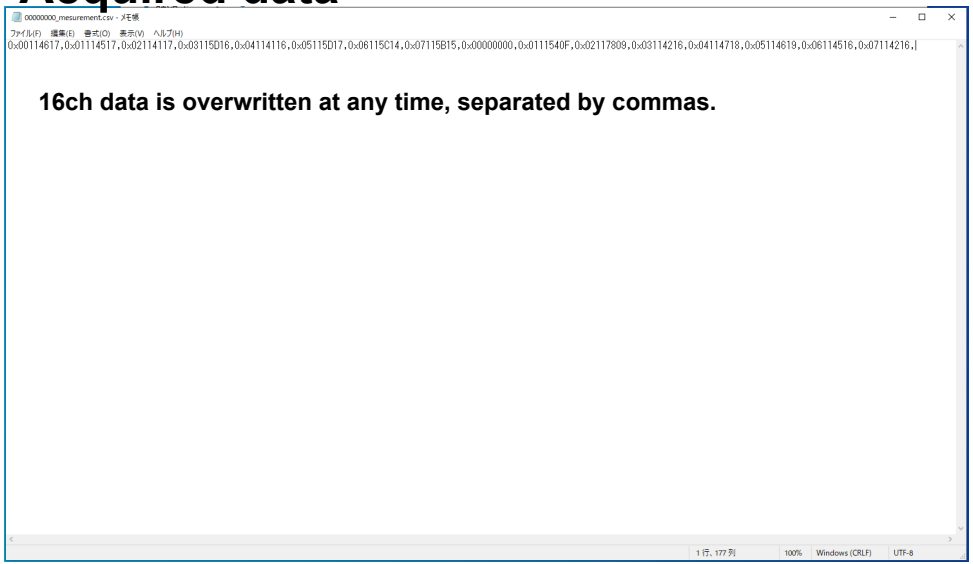
- Number of data to be **averaged** can be set with
  - **Histogram display**
  - **Cumulative number**

Data output

App operation panel

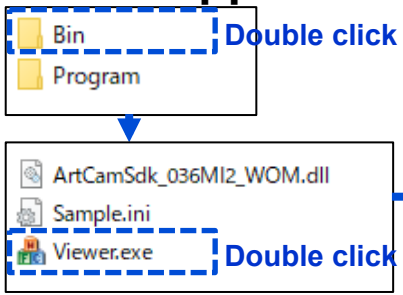


Acquired data

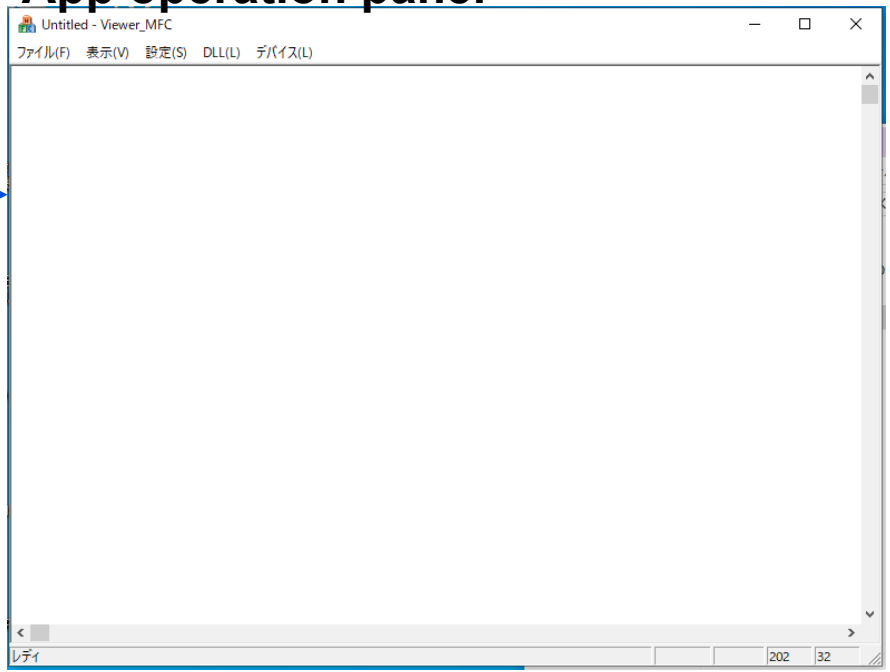


Launching the camera app

Camera app folder

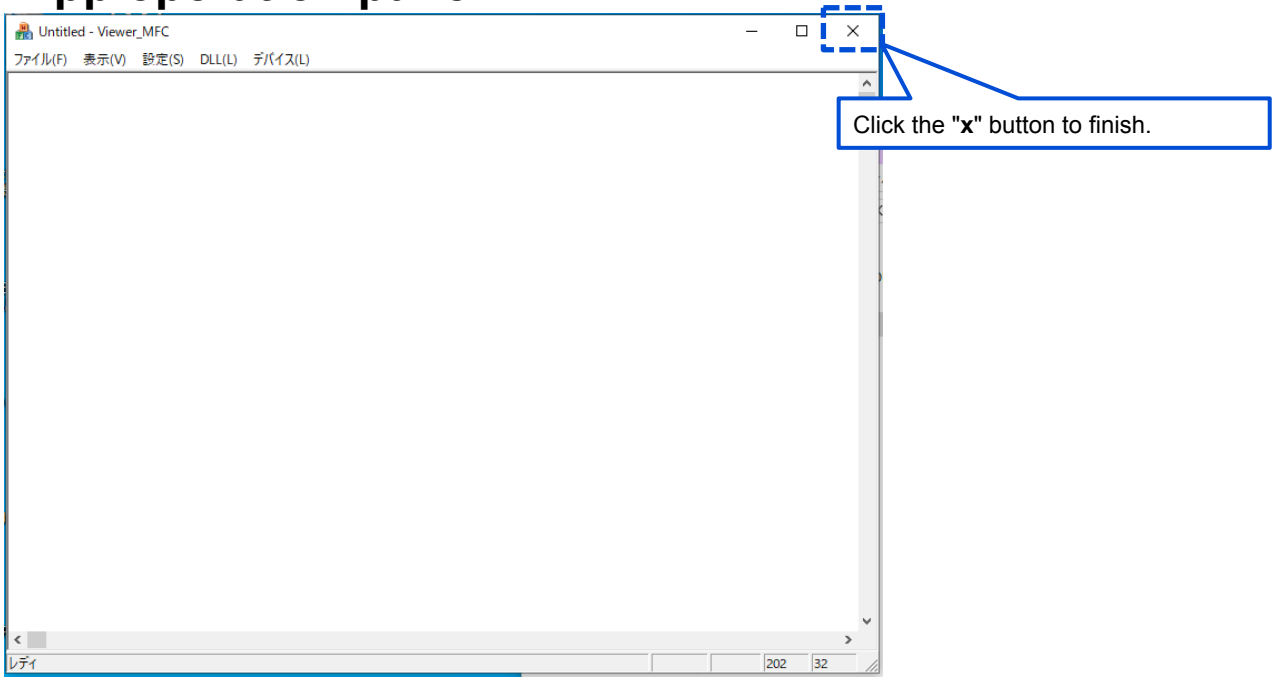


App operation panel



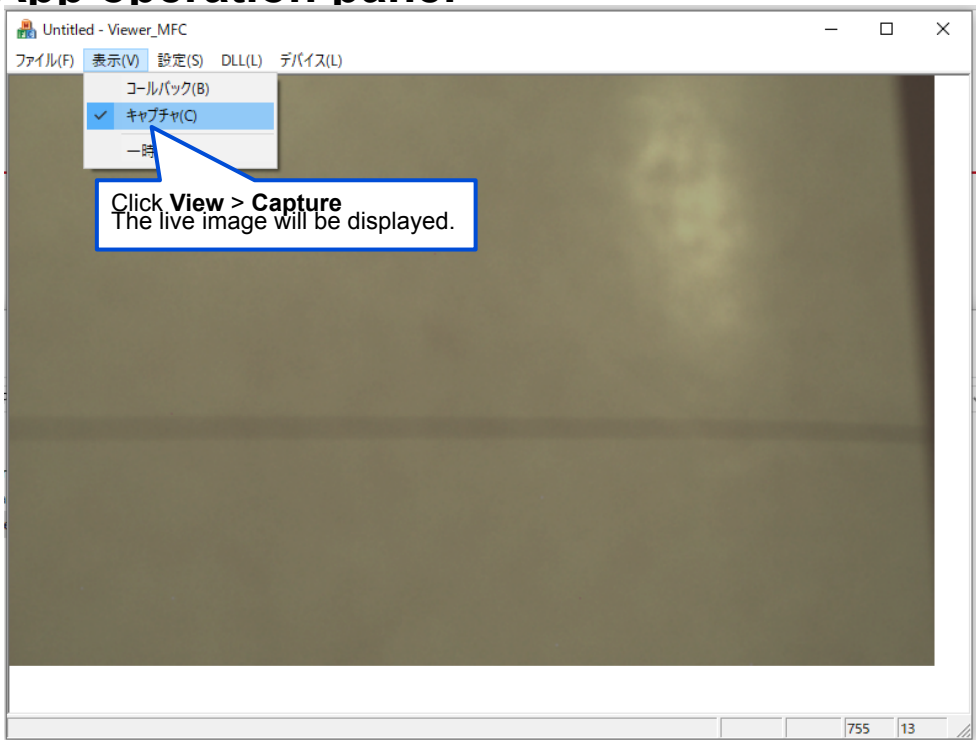
Closing the camera app

App operation panel



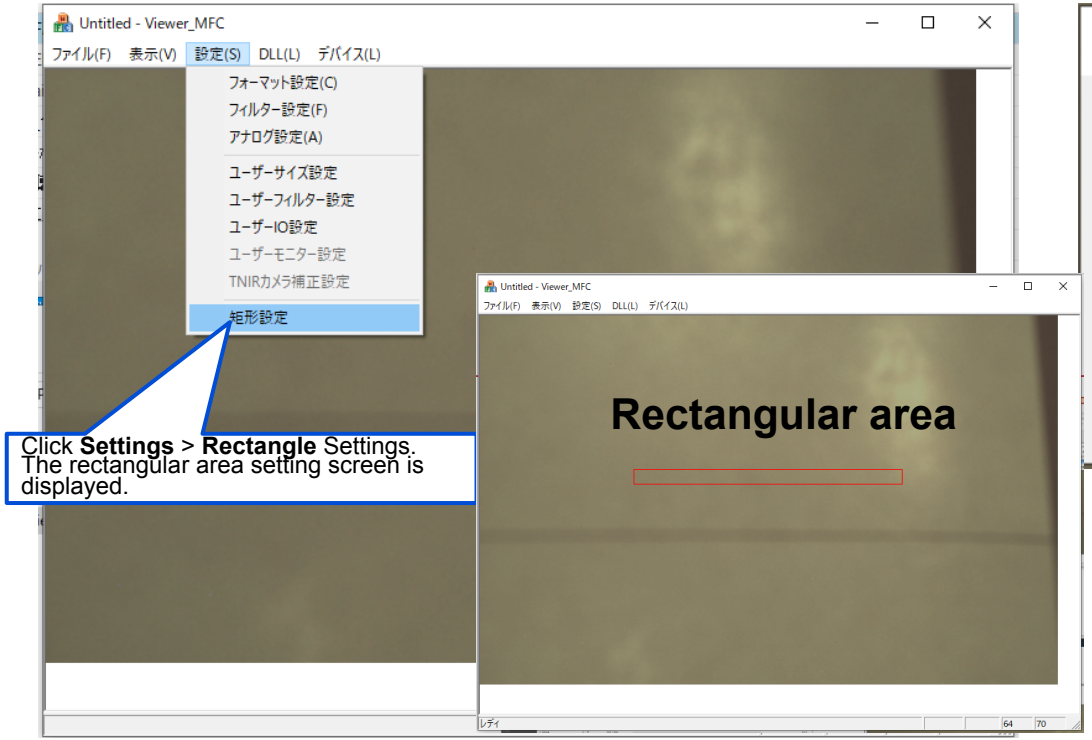
Display live image

App operation panel

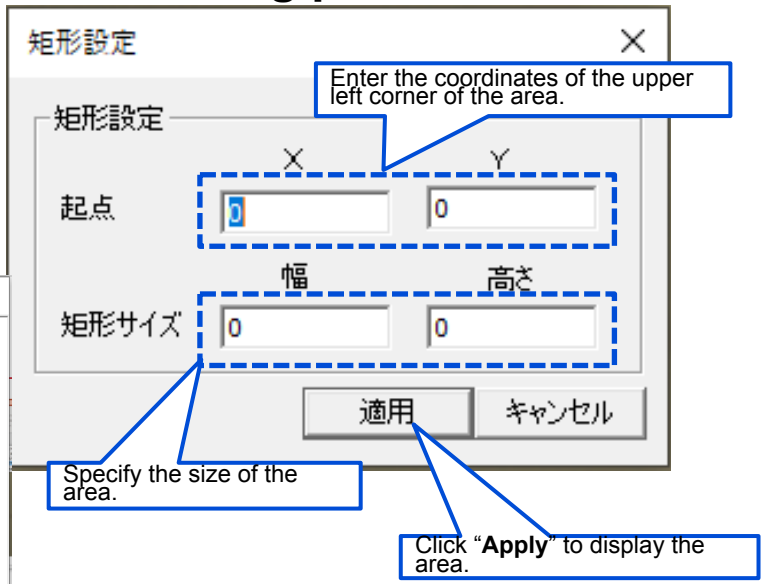


Display a rectangular area to detection

App operation panel

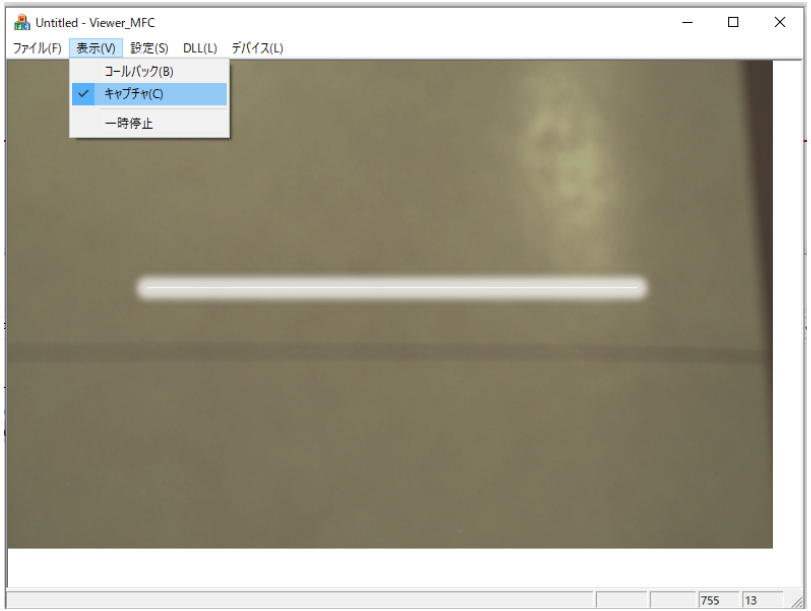


Area setting panel



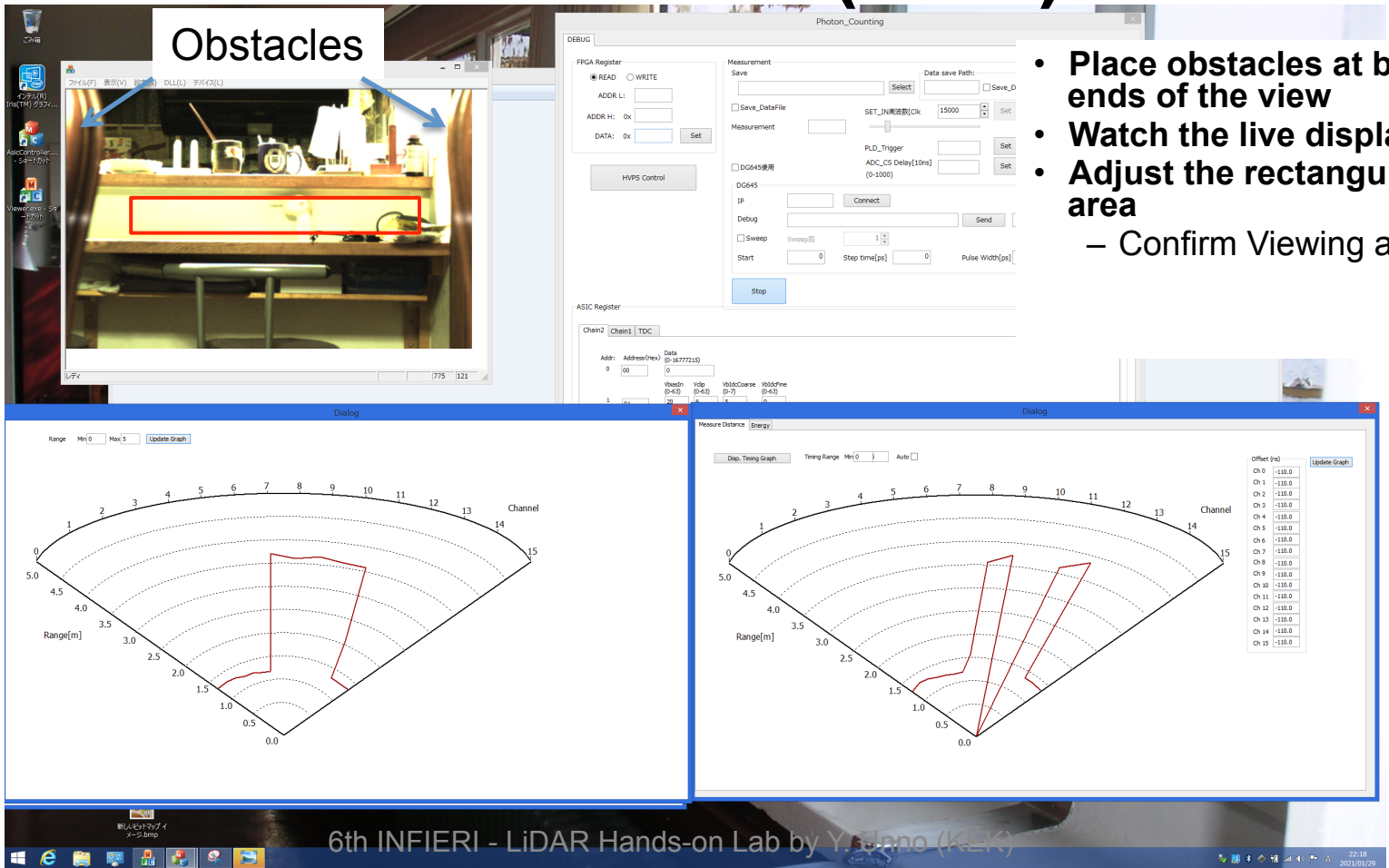
Monitoring

Emission angle of the laser



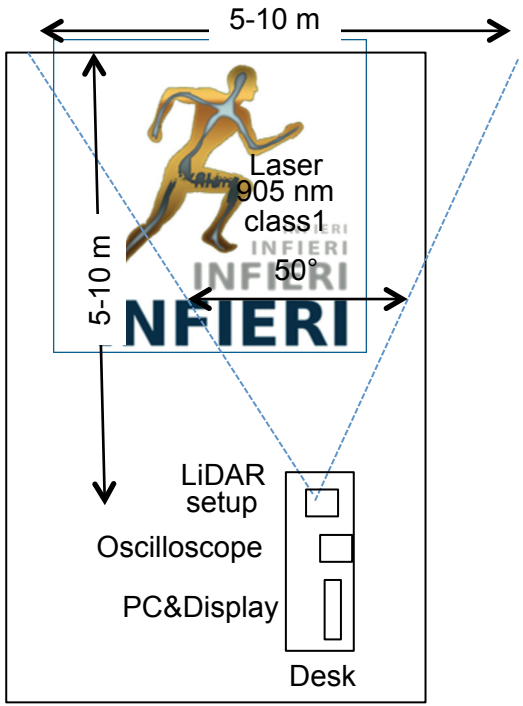
- **Launch the apps**
  - ASICcontroller
  - Viewer
- **Face the machine on a wall**
- **Darken the room**
- **Watch visual image of the laser light**
  - Confirm the emitter angle

Field of View (FOV)

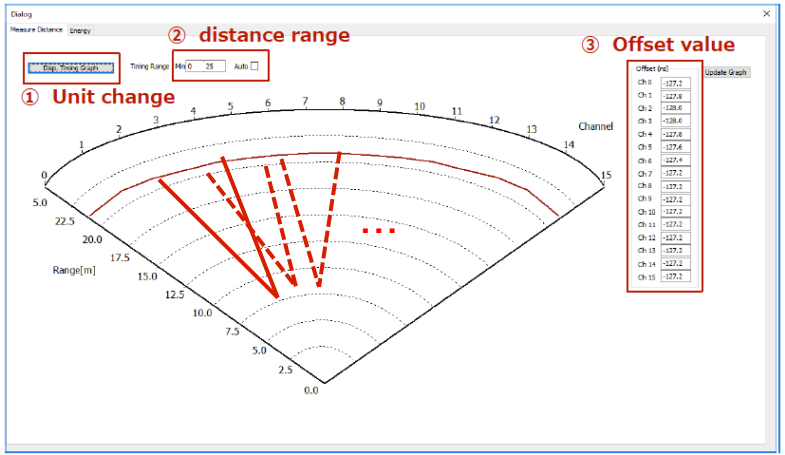


- **Place obstacles at both ends of the view**
- **Watch the live display**
- **Adjust the rectangular area**
  - Confirm Viewing angle

Moving object (e.g. human)

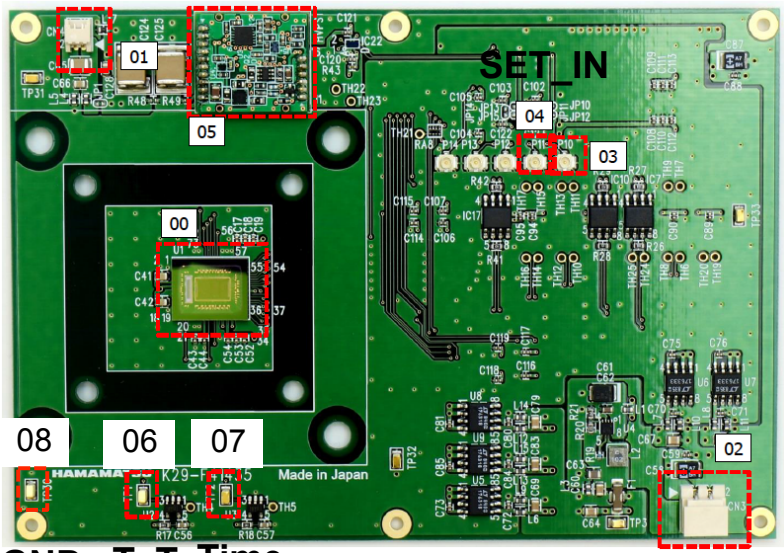


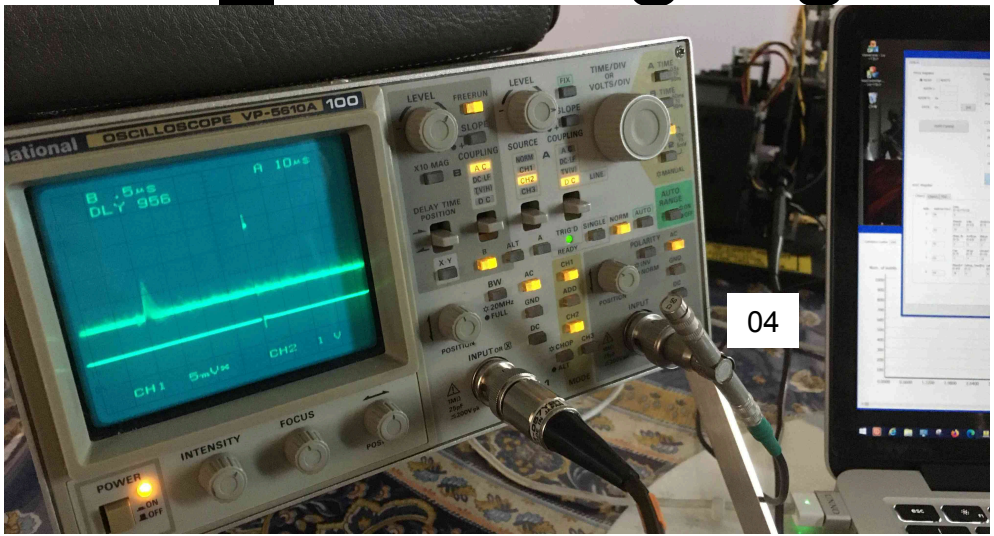
- **Walk across the FOV**
- **Watch the live display**



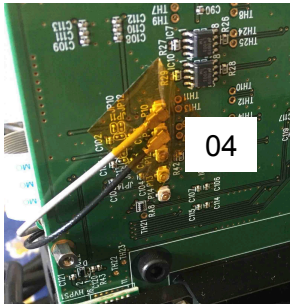
Debugging

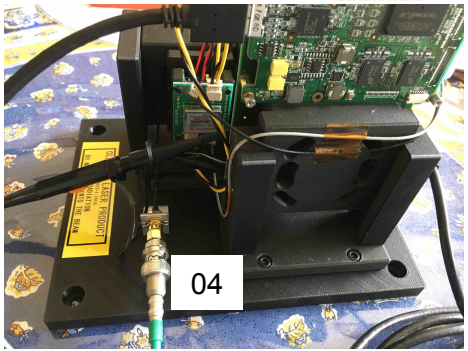
Triggering with SET_IN debug signal





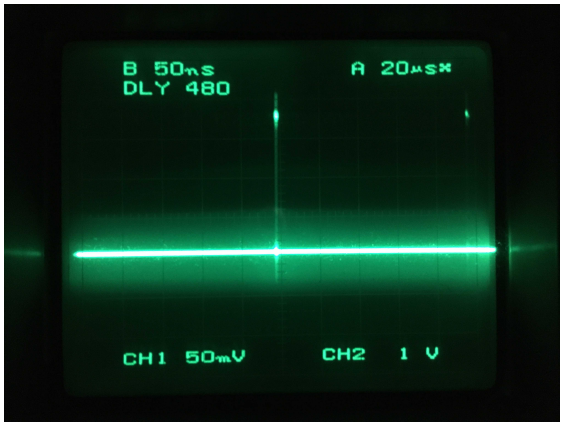
GND ToT Time

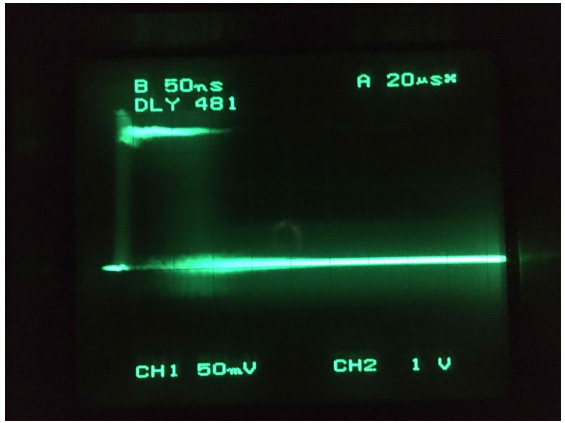


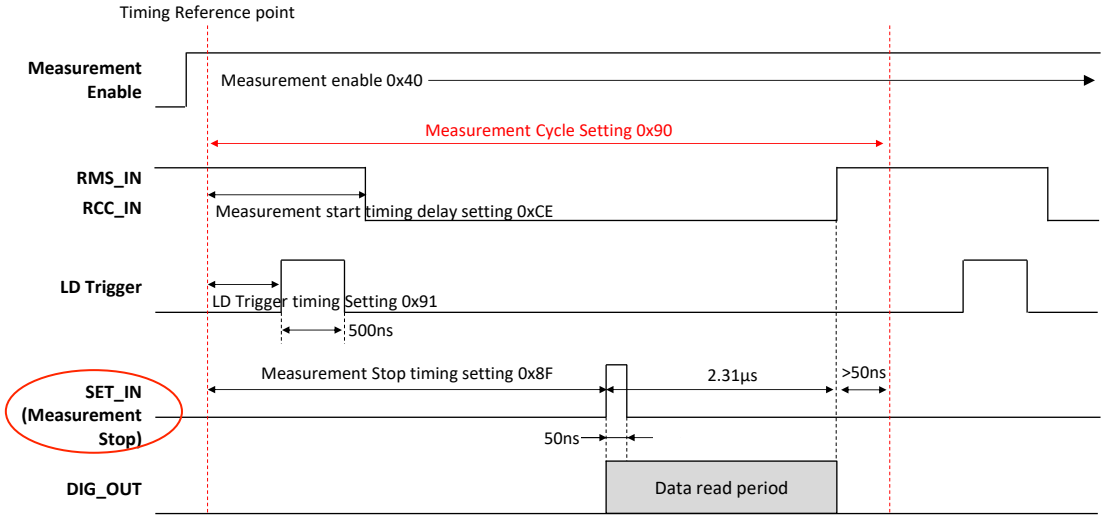


- **Connect the SET_IN (04) signal to TRIGGER**
  – to fix the timing to the laser light

SET_IN signal

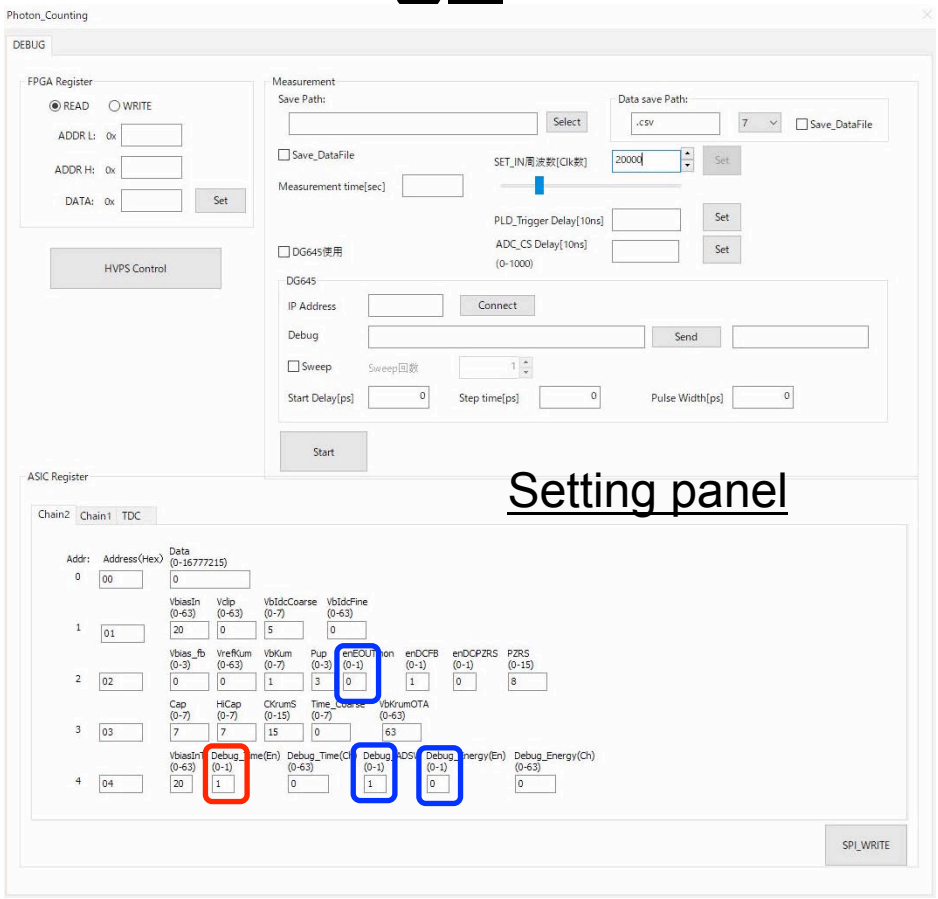




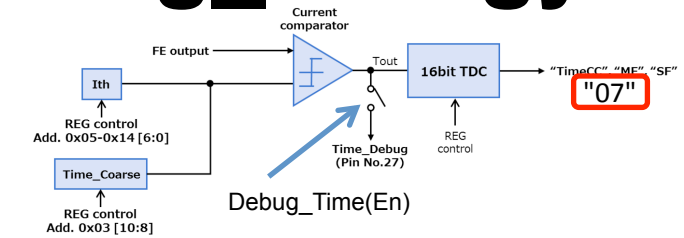


- **SET_IN signal = "Measurement Stop"**
- **Set SET_IN frequency to 10000 Hz**
  - Pulse interval = 100 µs = 5x20 µs (top-left photo)
  - The second pulse is seen at 100 us after the first pulse ((at scan start)
- **Expand the second pulse by delayed trigger (sweep width = 50 ns)**
  - SET_IN signal – square wave
    - Width: ~50 ns
    - Pulse height: ~3 V

Debug_Time and Debug_Energy



Setting panel



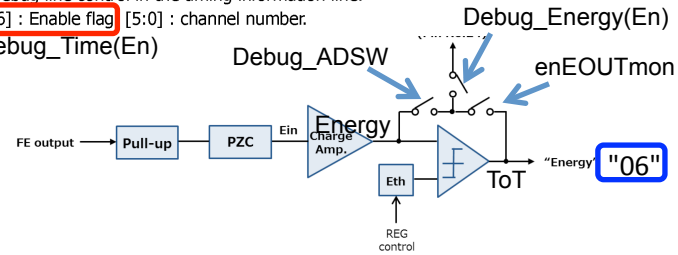
■ **Timing Block Debug Characteristics (Address 0x04[14:8])**

Debug line control in the timing information line.

[6] : Enable flag [5:0] : channel number.

Debug_Time(En)

Debug_Energy(En)



■ **Energy Block Debug Characteristics (Address 0x03[7], 0x04[6:0])**

Charge amp out is enable:

Address 0x03[7] is [0] Address 0x04[7] is [1]

EOUT is enable:

enEOUTmon Debug_ADSW

Address 0x03[7] is [1]. Address 0x04[7] is [0].

Note) Be sure to set both at the same time. The debug signal will not be output with different combinations.

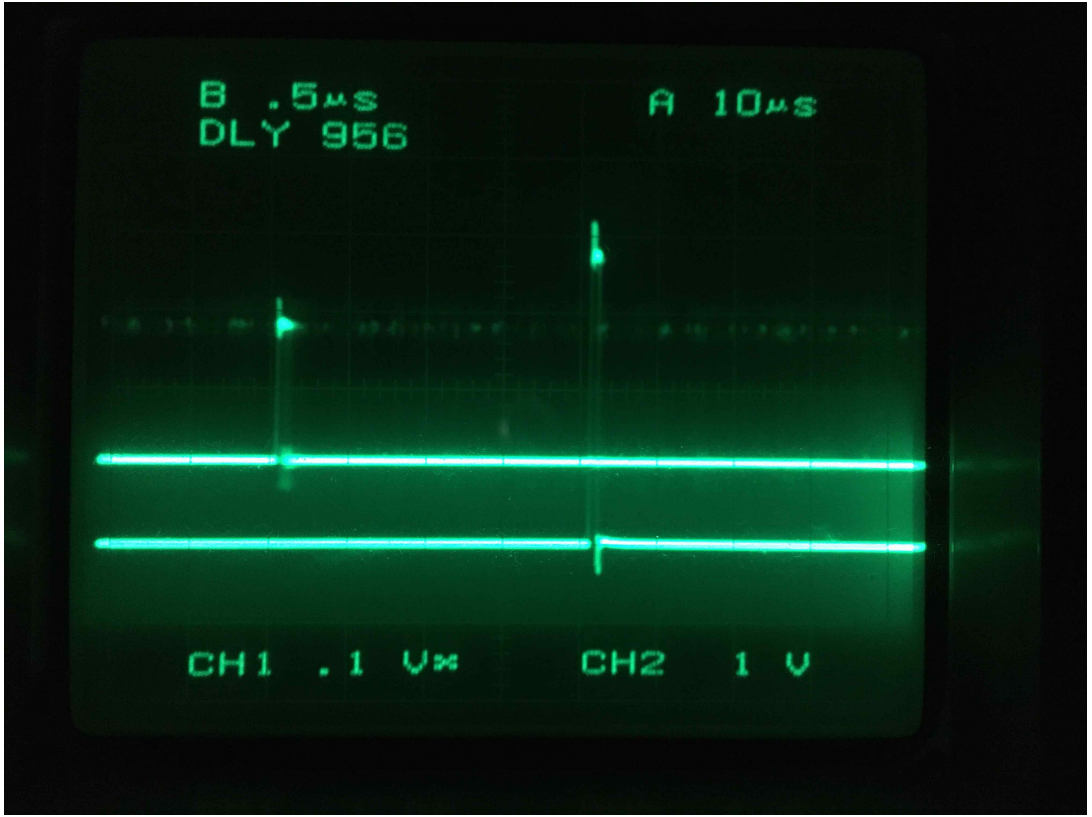
Address 0x04[6:0] Energy

Debug line control in the ~~timing~~ information line.

[6] : Enable flag [5:0] : channel number.

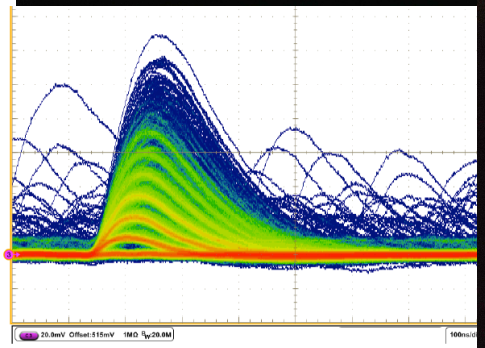
Debug_Energy(En)

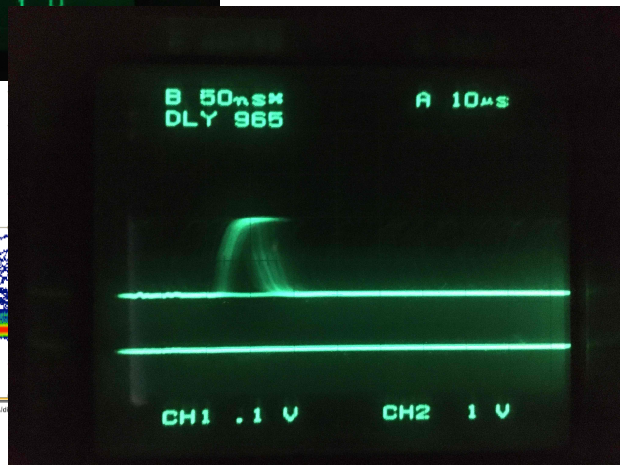
Debug_Time signal



- **CH1: Debug_Time signal**
  - Probe (07, 08)
  - Select e.g. Ch.6 of MPPC
  - Reflected light (top)
- **CH2: SET_IN signal**
  - Delayed trigger: (bottom)
- **SET_IN signal**
  - Measurement Stop
  - Preset at 4x0.5=2 µs after PLD (Pulsed Laser Diode) trigger signal
- **Debug_Time signals**
  - Pulses associated with the laser light are at a fixed timing
  - Random pulses are due to noises
- **Cover the setup to reduce external light**
  - with dark cloth or cartoon box
  - If random noises are reduced, they are due to external light
  - If not, due to internal electrical noise...
- **Changing the threshold (*Ith*) of the timing circuitry (see slide 47, e.g.)**

Debug_Energy signal

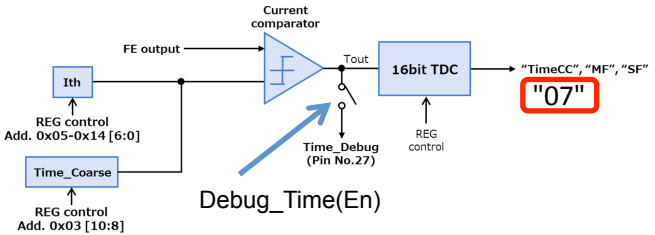




- **CH1: Debug_Energy/Debug_ToT signal**
  - Probe (06, 08)
- **CH2: SET_IN signal**
  - Delayed trigger: CH2
- **Debug_Energy signal (charge amp output, top-left)**
  - enEOUTmon=0, Debug_ADSW=1
  - Distance to object – about 4m
  - Pulse height of external lights is about half of the laser light (reflected)
  - Reflected lights may become smaller if longer distance or of lower reflectivity
- **Debug_ToT signal (bottom)**
  - enEOUTmon=1, Debug_ADSW=0
  - Debug_ToT signal
    - 2V amplitude with 1/10 probe
    - Dull shape due to 1MΩ input impedance (could be sharp with 50Ω))
    - ToT is width of Energy. The rising edge is at a constant time but the trailing edge fluctuates as pulse height fluctuates (as expected)

Changing *Ith* of Debug_Timing Signal

■ **Block diagram of Timing Block**



- **Re-connect settings**
  - Oscilloscope probe to terminal "07"
  - "Debug_Time(En)" to 1 in ASIC Register pane "Chain 2"
- **Change "ASIC Register" pane to "Chain 1"**
  - Change *Ith* value of 11(6ch) to low/high...
  - Observe the rate of random pulses

ASIC Register

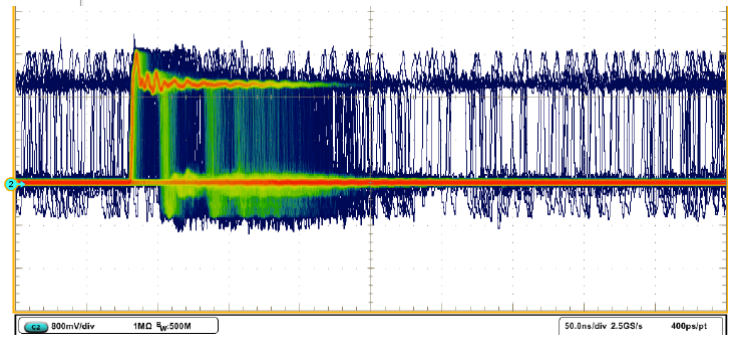
Chain2 | Chain1 | TDC

Addr:	Address(Hex)	Eth (0-255)	Voffset (0-63)	VbKrumF (0-7)	Ith (0-127)
5(0ch)	05	170	40	7	8
6(1ch)	06	170	40	7	58
7(2ch)	07	160	40	7	40
8(3ch)	08	160	40	7	80
9(4ch)	09	160	40	7	70
10(5ch)	0A	160	40	7	70
11(6ch)	0B	160	40	7	25
12(7ch)	0C	170	40	7	40

Addr:	Address(Hex)	Eth (0-255)	Voffset (0-63)	VbKrumF (0-7)	Ith (0-127)
13(8ch)	0D	170	40	7	36
14(9ch)	0E	160	40	7	54
15(10ch)	0F	170	40	7	47
16(11ch)	10	170	40	7	18
17(12ch)	11	170	40	7	52
18(13ch)	12	170	40	7	52
19(14ch)	13	170	40	7	27
20(15ch)	14	160	40	7	18

ALL Ch 0 0 0 0 Set

SPI_WRITE



Concluding remarks

- **There could be two classes of LiDAR, "Static" or "Dynamic".**
  - "Static": static objects
  - "Dynamic": moving objects
- **"Static" LiDAR is easy, perhaps...**
  - Remote sensing (Topography, Vegetation, ...), 3D mapping
    - High cost might be tolerable
    - Low cost might open up a new application, e.g., in augmented reality (AR)
- **"Dynamic" LiDAR is where rapid progress is being made**
  - Automotive LiDAR, e.g.
  - The issues are
    - Long range (e.g., 200 m)
    - Signal-to-Noise ratio
    - Low cost
  - There are still spaces where improvement can be made in hardware and software, but not easy, perhaps
    - i.e., you maybe able to make it ☺

Backup