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TECHNICAL NOTE

LED Pulser: A Light-Emitting Diode–Based Light Source for 2D Detectors

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Contents

1 Introduction

This report describes a light-emitting diode (LED)–based light source, or LED pulser. The purpose of the LED pulser is to produce signal in 2D detectors, primarily for a test of veto capability of the detectors. The LED pulser is required to produce a single light pulse during the “XFEL pulse train”, tagging a single image out of all acquired.

The LED pulser is designed to produce pulses as short as 100 ns. This pulse duration is shorter than the envisaged period[1] of image acquisitions by the 2D detectors at the European XFEL. The pulse duration is close to a typical integration time of the 2D detectors.

Previous experience with the two-tile LPD detector[1] shows that light produced by two passively driven LEDs is sufficient to produce signal in the LPD detector, but the LEDs must be positioned such that the LED tips are at a distance of ≈ 5 mm to an edge of an LPD sensor. If the light output of the LEDs can be increased, the LEDs can be positioned further away from the sensor, minimizing risk of accidental contact with it. Moreover, for a megapixel LPD detector, the previously used position of LEDs is not feasible. The light needs to be reflected to an LPD sensor from the sensor's support structure.

The LED pulser is intended for pulsed operation at a low repetition rate, typically 10 Hz, and with a low duty cycle of $\approx 10^{-6}$–10^{-5}. A simple circuit based on a MOSFET[2]-gate driver has been developed to operate LEDs with high pulsed current.

[1] Period of 4.5 MHz clock is 221.5 ns and is defined as 288 periods of 1.3 GHz clock.
[2] Metal–Oxide–Semiconductor Field-Effect Transistor

2 Description of the LED pulser

To operate the LED pulser, one needs a DC power source and a source of signals. Requirements for these two sources are described in the following sections.

2.1 LED pulser board

The LED pulser board is build upon a dual MOSFET-gate driver IXYS IXDN604SI[2], as shown in Figure 2.1. The schematics of the LED pulser board is shown in Figure 2.2 below and the Bill-Of-Materials in Table A.1 in "Bill of materials".

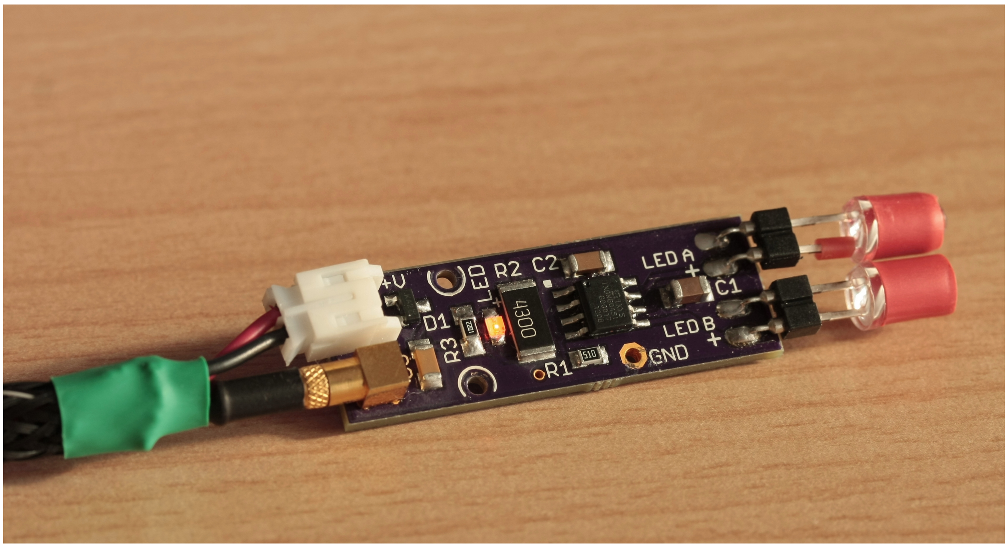


Figure 2.1: Photograph of an LED pulser board with two LEDs installed in sockets. Housing for the LED pulser is removed.

Each output of the MOSFET-gate driver is connected directly to an LED. The LED current is limited only by the driver's output resistance R_{OH}. Upon a high level signal on the input of the driver, the anodes of the LEDs are pulled to the supply voltage VCC, and capacitor C1 (partially also capacitor C2) starts to discharge through the LEDs. The discharge time constant is defined by R_{OH}*C1, and the charging-up time constant is R2*C1. The maximum current to the driver is limited by the resistor R2 and equals VCC/R2. In the case of a failure of the MOSFET-gate driver, assuming a short circuit between its VCC and the ground, this also would be the maximum short circuit current through the driver.

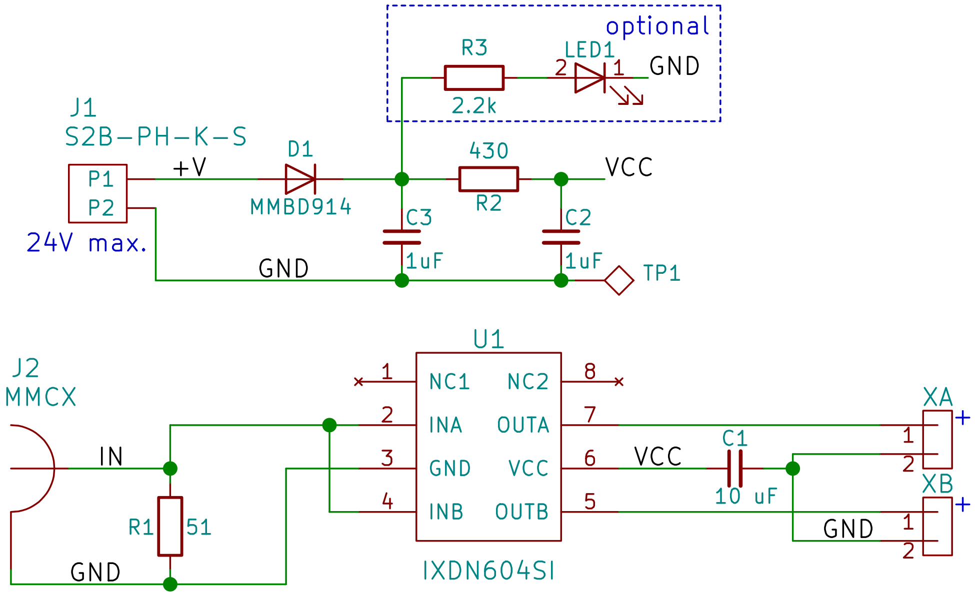


Figure 2.2: Schematics of the LED pulser

The light pulse intensity can be varied by change of the supply voltage. The light pulse width can be varied by pulse width of the input signal.

If the input pulse width is comparable or shorter than the rise and fall time of the MOSFET driver($<$ 10 ns at VCC = 18 V), the amplitude of the pulses will also decrease.

The size of the double layer PCB[1] is 38.4 mm $\times$ 12.7 mm. The PCB has two 1.6 mm mounting holes separated by 9.65 mm.

2.2 DC power and input signal

Any suitable laboratory DC power supply can be used. Absolute maximum supply voltage for the MOSFET-gate driver is 40 V. This voltage, however, is above the voltage rating of the capacitor C1, which is 35 V (see Table A.1 in "Bill of materials"). The recommended voltage supply for the driver is 4.5–35 V. The higher the voltage, the shorter the rise and fall times and propagation delay. The highest tested supply voltage for the LED pulser is 24 V. The diode D1 protects the circuit from incident reverse of polarity. The voltage drop on the diode is $\approx$ 0.6 V.

Due to operation at a low repetition rate and a low duty cycle, the current supply of the

[1] Manufactured by OSH Park, Oregon, USA; Gerber files are available in [3]

MOSFET-gate driver is low, hence the board can be powered from a suitable battery, if necessary.

A set of cables is available for powering the LED pulser board: a cable adapter (a JST PH connector (P1 in Table A.1) to an XT30 female plug), an adapter from an XT30 male plug to “banana” connectors, and a 8.5 m long extension cable (an XT30 female plug to an XT30 male plug).

Minimum input voltage V_{IH} of the MOSFET-gate driver is 3 V, hence a TTL signal can be used. Note that the on-board resistor R1 is for the signal termination. The drive capability of the TTL signal should be no less than 60 mA.

Since the LED pulser is intended to be used with 2D detectors, an X2Timer[4] with an ETA board[5] is a convenient source of input signal. The X2Timer provides signals with variable delay time relative to the start of the X-ray FEL pulse train and variable pulse width. The ETA board converts signals from LVDS to TTL level. An adapter cable to connect the LED pulser (MMCX female connector) to the ETA board (LEMO 00 coaxial connector) is available.

The X2Timer is controlled by a graphical user interface JDDD (Java DOOCS Data Display)[6].

Throughout this Internal Note, reported pulse width values are calculated with[2]:

$$\Delta T = (\text{JDDDparameter} + 1) * 9.23\,\text{ns}.$$

For example, for a JDDD parameter 10, the pulse width is 101.53 ns. Note that the duration of the light pulse from LEDs may differ from the pulse width reported by the JDDD.

[2] Twelve periods of 1.3 GHz clock = 9.23 ns

3 Characterization of the LED pulser

For the characterization of the LED pulser, infrared emitting diodes VSLY5940[7] are used.

The most important features of the LED are:

- Short rise and fall times (10 ns)
- Ability of high pulse current operation
- Narrow angle of half intensity ± 3°

The LED's leads are shortened as much as possible to minimize load capacitance for the MOSFET-gate driver. In this test, the leads are just inserted into the sockets XA and XB. For operation with a 2D detector, the LEDs need to be soldered either on the board directly, or into the sockets. The anode of an LED must be connected to the socket pin labeled with a plus sign (+).

3.1 Power consumption

The supply current of the LED pulser is measured with a Brymen BM869s digital multimeter at the 24 V setting of a DC power supply. The actual measured voltage on the power supply output is 24.073 V. Without input signal, the current consumed by the LED pulser is $I_{DC} = 9.683$ mA. Measurements of the LED pulser current with input signals of different pulse width are summarized in Table 3.1.

Pulse width (JDDD setting)	**I_{DC}, mA**	**I_{AC}, mA**
101.53 ns (10)	9.699	0.09
1116.83 ns (120)	9.832	0.09
110.8 µs (12000)	10.689	5.04
99.7 ms (10800000)	57.27	0.0

Table 3.1: LED pulser current vs. pulse width of the input signal

During operation of the LED pulser with a short input pulse width, most of the current is consumed by the power indicator (orange) LED.

This current can be estimated with

I_{LED} = (24 V - 0.6 V - V_F) / 2.2 kΩ = 9.7 mA,

where V_F = 2.05 V is the forward voltage specified for that orange LED.

To demonstrate the effect of the current limit by the resistor R2, the pulse width was increased up to 99.7 ms. The MOSFET-gate driver then operates in a quasi-continuous mode with a duty cycle of

t_{pulse}/T_{period} = 99.7 ms / 100 ms = 0.997.

In this case, the current is lower than the maximum continuous output current of the MOSFET-gate driver (I_{DC} = ±1 A)[2] and LEDs (I_F = unit[100]mA)[7]. No LED or MOSFET-gate driver was damaged during the test.

Note that such long pulse width can occur only when an operator manually decreases the value with JDDD. If the value accidentally decreases below zero, it will change to a large value, close to the period of the repetition rate (e.g. 100 ms). Such a long pulse width setting should not be intentionally used for prolonged times.

Powering configuration for continuous LED light

In spite of the fact that the LED pulser is designed to operate in a pulsed mode, there is a way to operate LEDs to produce continuous light (see also “LED pulse energy”). This configuration could simplify the alignment of the LED pulser if used in an optical setup, since one could use an IR indicator card[1] to monitor the light from the LEDs.

To test the powering configuration, 4.5 V DC voltage level was supplied to the input (with a “banana”-socket – BNC adapter) and the power connectors. Note that the power dissipated in resistor R1 is 4.5 V * (4.5 V / 51 Ω) = 0.4 W, which is more than three times higher its power rating, see “Bill of materials)”. The resistor R1 and the MOSFET-gate driver dissipate the heat into the LED pulser PCB. This results in “scaringly” hot LED pulser, which is still possible to touch without a problem. Note that the large heat dissipation contributes to increased risk of failure of all components of the LED pulser. Use of this powering configuration should be reduced as much as possible.

The current consumption of the LED pulser was 0.3 A. This value is also set as the current limit of the DC power supply. Almost third of the whole consumed current

[1] IRI 4400 obtained from *conrad.de*, order number 184977-62

is drawn by the resistor R1. Current of an LED (on the “LED A” output) was 92 mA, close to its maximum value of 100 mA. The measured DC forward voltage was 1.4 V. After an hour of operation the LED pulser still provided power to the LEDs.

3.2 Optical pulse shape

Temporal shape of the LEDs light pulses is obtained with a detector based on an OSRAM SFH203 pin-photodiode with rise and fall times of 5 ns (see Figure 3.1).

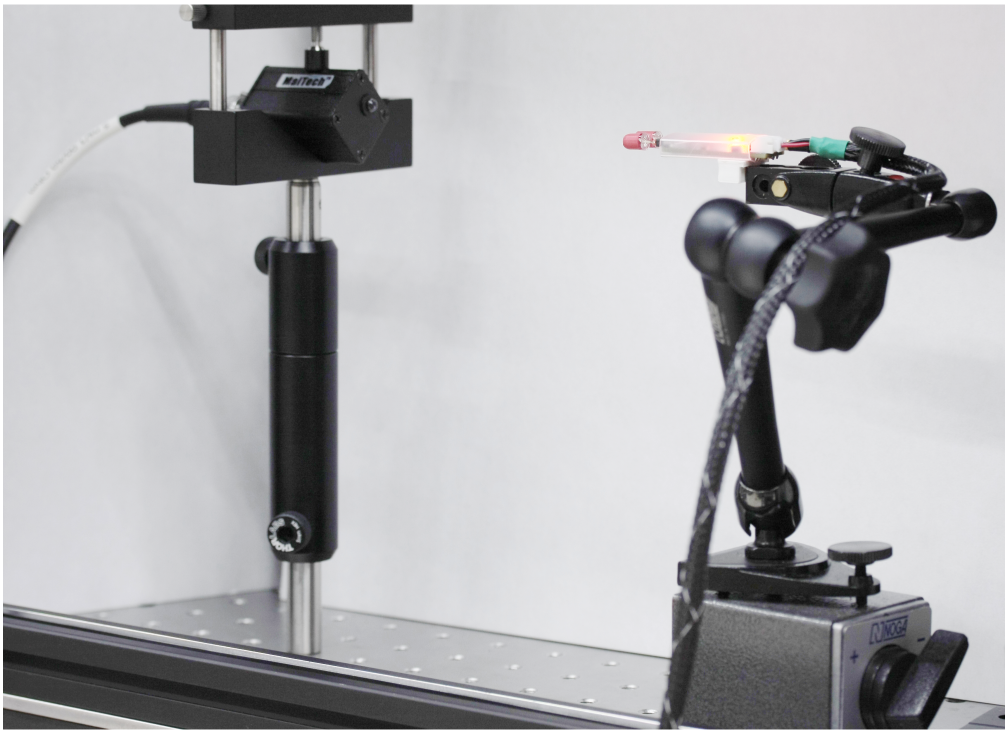


Figure 3.1: Setup to study the temporal shape of the LED light pulses. The LED pulser (on the right) in its housing (see “Housing”), mounted on a custom made adapter (see “Mounting adapter”) for a NOGA articulated arm. The detector (on the left) mounted at a fixed distance from the LED pulser.

The light intensity drops as the input pulse width increases (see Figure 3.2) since capacitor is discharged faster than it is recharged via the resistor R2. Another possible reason for the intensity drop is the heating of the LED die by the current pulse, since the light yield drops as its temperature increases.

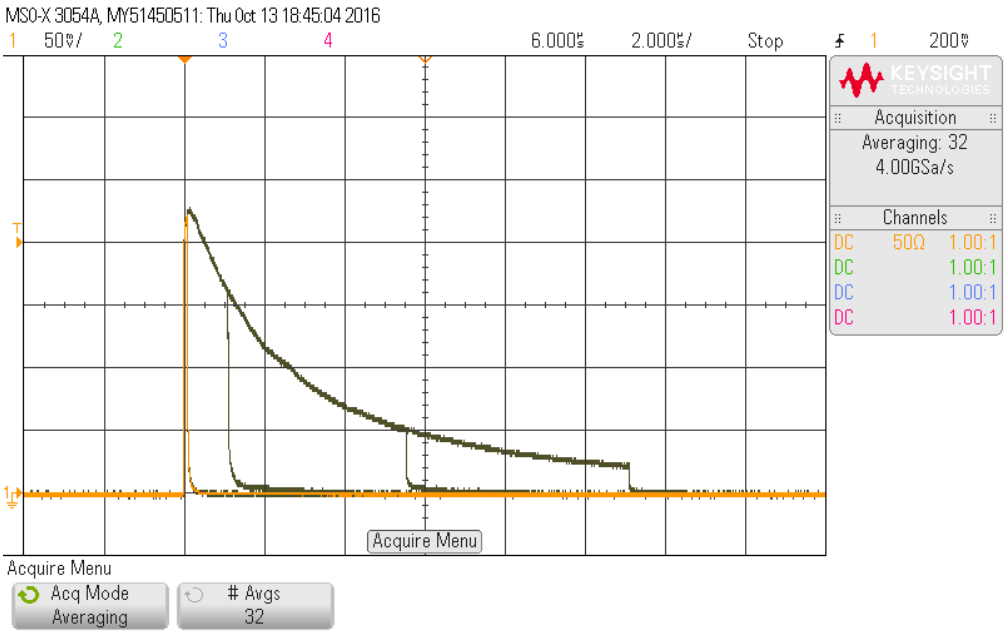


Figure 3.2: Signals from the pin-photodiode. Four waveforms overlayed (persistence mode) on a single oscilloscope screenshot. Input pulse durations are: 101.53 ns (JDDD = 10), 1116.83 ns (JDDD = 120), 5547.23 ns (JDDD = 600), and 11085.23 ns (JDDD=1200). Note the time scale of 2 µs per division.

Assuming an exponential drop of the amplitude, the discharge time constant R_{OH}*C1 is estimated to be ≈ 4.6 µs (see Figure 3.2).

The turn-off characteristic of the LEDs reveal signal decay with a "kink" that is most prominently visible at longer input pulse width. For example, at the pulse width 1116.83 ns, signal rapidly decays from 150 mV to about 25 mV; after that, it decays much slower. This is presumably related to the dynamics of carriers in the LED junction when potential across the LED approaches the forward voltage.

Such signal tail is not expected to make an appreciable signal in the following image, since it will appear during the "reset" phase of the image acquisition.

As the input pulse width gets shorter and compares with the rise or fall times of the MOSFET-gate driver, the LEDs, the pin-photodiode, the ETA's receiver, and the LVDS transceiver of the X2TIMER, the light intensity rapidly drops (see Figure 3.3). At the JDDD setting of 0 (pulse width = (0+1)*9.23 ns = 9.23 ns), no signal can be observed, even if the LED lens is brought into direct contact with the lens of the pin-photodiode. This allows to "switch the light off" without powering down the LED pulser, which may turn out to be be useful for taking "dark"-images with 2D detectors.

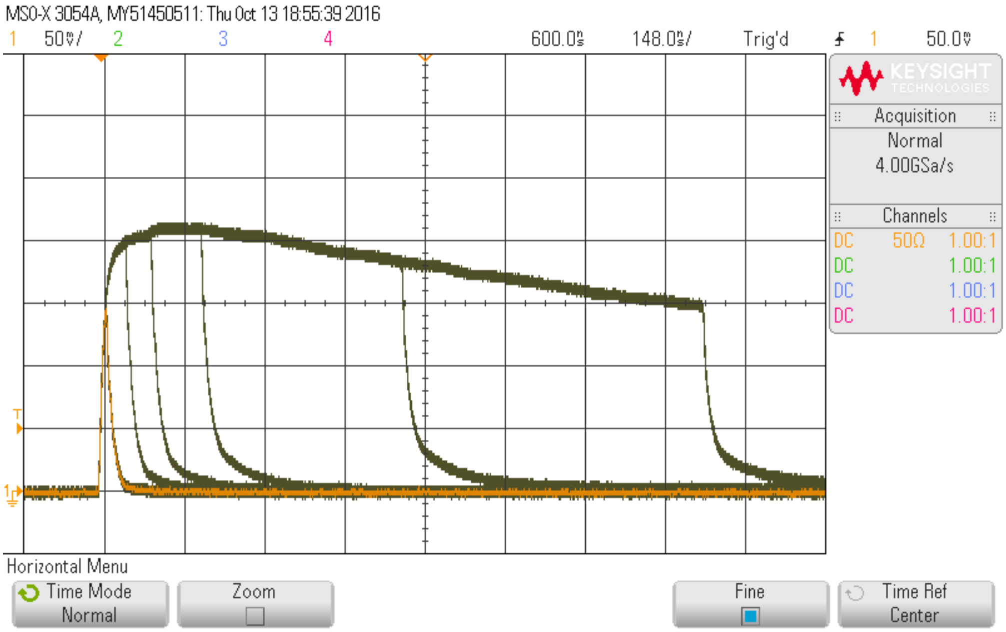


Figure 3.3: Signals from the pin-photodiode. Six waveforms overlayed (persistence mode) on a single oscilloscope screenshot. Input pulse durations are: 18.46 ns (JDDD = 1), 55.38 ns (JDDD = 5), 101.53 ns (JDDD = 10), 193.83 ns (JDDD = 20), 563.03 ns (JDDD = 60), and 1116.83 ns (JDDD = 120). Note the time scale of 148 ns per division.

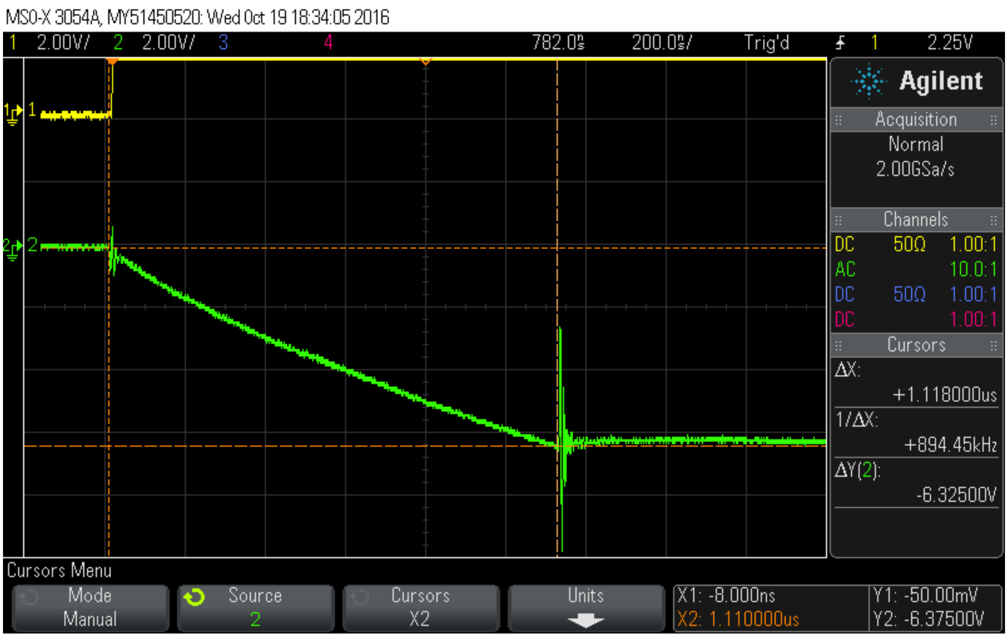


Figure 3.4: Potential measured directly on the electrode of the C1 capacitor, using a 1 MOhm scope-probe (AC mode). $V_{\text{LED pulser}}$ = 24 V, pulse width 1116.83 ns (JDDD=120). The oscilloscope is triggered from an additional output of the ETA-board.

The pulse width of 1116.83 ns (JDDD = 120) appears to be useful for certain tests with 2D detectors, like timing scans. The pulse width spans five periods of the 4.5 MHz clock. This allows to produce signal in five consequent images.

To estimate the pulse current in LEDs, potential on the capacitor C1 is measured directly on its electrode (on VCC), using a 1 MOhm scope-probe. The LED pulser power is 24 V and the input pulse width dT is 1116.83 ns (JDDD=120) (see Figure 3.4). The current during the pulse is I = C*dU / dT, where C is the capacitance of C1, and dU = 6.325 V is the change of the potential on C1. At the 24 V bias, the effective capacitance of the C1 is ≈ 80% lower than its nominal value (see "Datasheet of the 10µF capacitor"); therefore, the value of 2 µF is taken. The average current during the pulse is then ≈ 11 A. It is assumed that the most of the pulse current is shared by the infrared LEDs (2 * 5.5 A), and the current for the MOSFET-gate driver switching is taken from C2.

It is observed that the LED pulser board produces audible noise ("clicks") at the same repetition rate of 10 Hz. The source of the noise is most probably the capacitor C1, which dielectric (X7R) has piezoelectric properties.

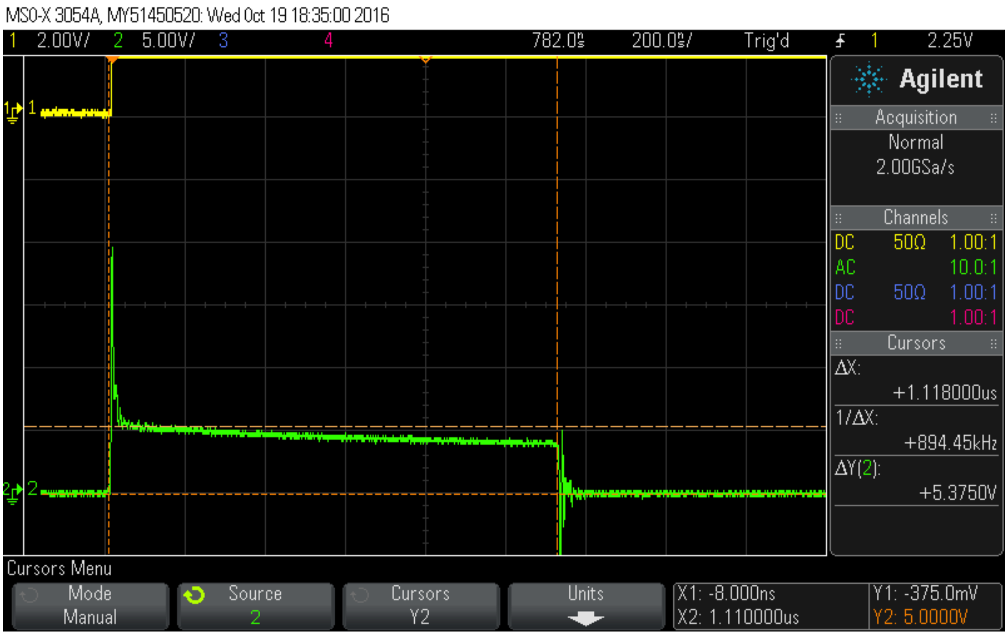


Figure 3.5: Potential measured on anode of the "LED A" using a 1 MOhm scope-probe(AC mode). The oscilloscope is triggered from an additional output of the ETA-board.

Potential on the anode of the "LED A" is measured with a 1 MOhm scope-probe (see Figure 3.5). The voltage peak at the very beginning of pulse builds up until the LED starts to conduct. Toward the end of the pulse, the voltage drops, which may indicate heating up of the LED die.

3.3 LED pulse energy

Pulse energy is measured with a pyroelectric sensor Coherent EnergyMax EM-RS J-10MB-LE (10 mm diameter). The LED pulser is installed such that the distance between the sensor and the lens' tips of the "LED A" and the "LED B" is only few millimeters. This should maximize collection of the light by the sensor.

Pulse energy of two LEDs (the "LED A" and the "LED B" used at the same time) for 8–24 V DC power supply voltage is measured for 101.53 ns and 1116.83 ns pulse widths, as shown in Figure 3.6.

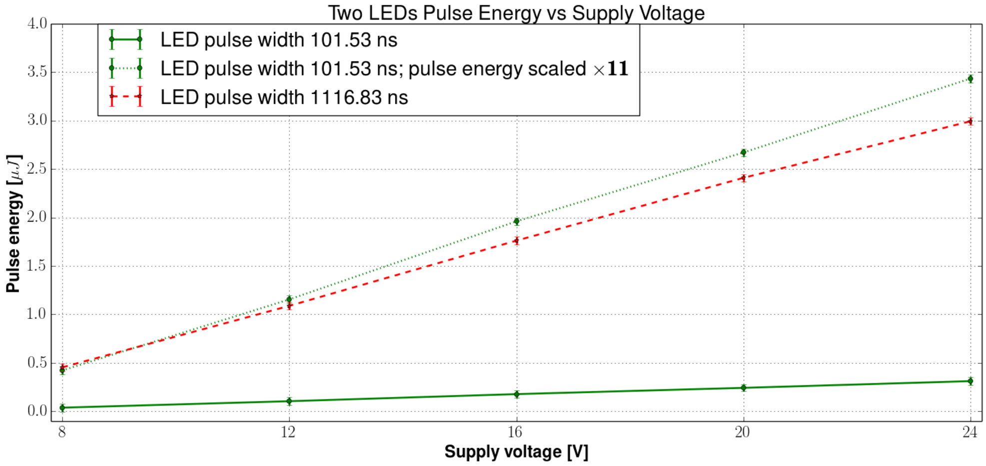


Figure 3.6: Pulse energy vs. supply voltage, for 8, 12, 16, 20, and 24 V. Pulse widths: 101.53 ns (solid line), 1116.83 ns (dashed line), 101.53 ns with energy scaled by 1116.83 ns / 101.53 ns = 11 (dotted line). Lines are just guides for the eye.

Due to the drop of signal at the end of the 1116.83 ns pulse (see Figure 3.3), the pulse energy is smaller than the one from the 101.53 ns pulse. This is demonstrated by scaling values of the pulse energy measurement for the short pulse width by factor 11 (1116.83 ns / 101.53 ns), as shown in Figure 3.6. At 24 V, the peak power is 3.1 W for the 101.53 ns pulse and 2.7 W for the 1116.83 ns pulse.

Assuming the peak power is equal for both LEDs, one LED produces pulses with 1.55 W peak power. With the half of the peak power (0.78 W) radiated into the solid angle of 8.6 msr, the radiant intensity is 90 W/sr.

From the datasheet of the VSLY5940, the typical radiant intensity is 5100 mW/sr at I_F=1 A and t_p= 100 [µs]. Assuming the best-case scenario when the radiant intensity linearly scales with the pulse current, for a 5.5 A current pulse, one obtains 5.1 W/sr * (5.5 A / 1 A) = 28 W/sr, three times lower than the one derived from the measurement.

Pulse energy as a function of pulse width for 9.23 ns, 101.53 ns, 1116.83 ns, and 11085.23 ns is shown in Figure 3.7. An interesting feature of the MOSFET-gate driver is observed when no DC power is applied: With a long input pulse, the LEDs can still produce signal detectable by the pyroelectric sensor. It appears as if the input signal would go into an internal power line of the driver. One possible explanaition would be presence of an internal diode which connects the input to the power line.

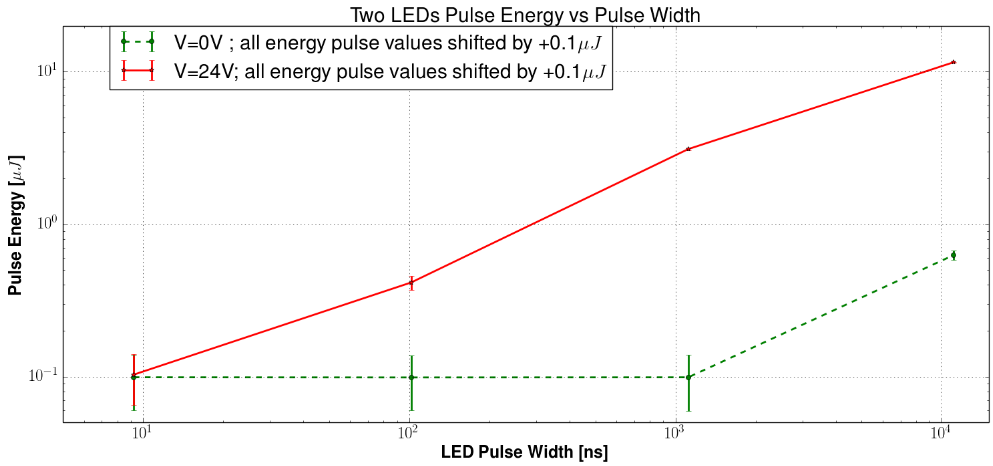


Figure 3.7: Pulse energy of two LEDs measured at 24 V (solid line) and no DC power (V = 0V, dashed line). Pulse width: 9.23 ns, 101.53 ns, 1116.83 ns, and 11085.23 ns. Due to logarithmic energy scale, all pulse energy values are shifted up by 0.1 μJ. Lines are just guides for the eye.

4 Test of an LED pulser prototype with the AGIPD single-module prototype detector

A test of an LED pulser prototype was performed with the AGIPD single-module prototype[8]. In the LED pulser prototype that was used, the R2 value was 500 Ω and C1 was 1 µF. Its PCB was somewhat larger and a version of the MOSFET-gate driver in a DIP package was used.

Because the megapixel AGIPD detector to be placed in a vacuum vessel, the LED light needs to be delivered through a window in the vessel. To keep the size of the LED spot on the sensor and hence the level of signal produced by the LEDs, it is foreseen to use a plano-convex lens to focus and collimate the LED light.

The estimated focal length of the used lens is 10 cm. The lens was installed at a distance of ≈ 15 cm from the sensor of the AGIPD detector and LEDs are ≈ 24 cm from the lens. The LED pulser operated at 24 V and the input pulse width is 323.05 ns (JDDD = 35). A set of AGIPD dark images is averaged and used for dark image subtraction. An example of an image(average dark image subtracted) with signal produced by LEDs is shown in Figure 4.1. The LED signal is clearly visible as two spots in the middle of the images. The signal is above 300 ADC-units.

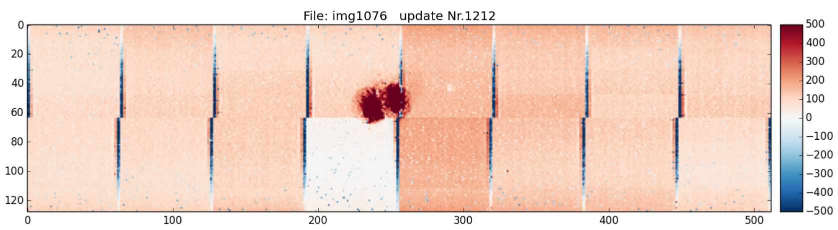


Figure 4.1: An image (average dark image subtracted) acquired with an AGIPD detector prototype. The LED signal is visible as two spots in the middle of the images. The colour scale range is ±500 ADC-units and the signal is above ≈ 300 ADC-units.

5 Conclusion

An LED-based light source has been developed for use with 2D detectors. A first test of (a prototype of) the LED pulser with the AGIPD single-module prototype showed that the signal produced in the AGIPD sensor is sufficient to tag an acquired image.

The capability to produce ≈ 1 µs signals will be used to speed up timing scans with AGIPD and LPD detectors.

There is a small signal tail, which is not expected to make an appreciable signal in the following acquired image. The signal due to the tail will appear during the “reset” phase, not the signal integration phase.

Due to absence of failed LEDs and MOSFET-gate drivers during numerous tests, the long-term reliability of the LED pulser is not yet understood. It is foreseen to test the light output of LEDs before and after each test with a 2D detector.

The main parameters of the LED pulser are summarized in Table 5.1

Parameter	**Minimum**	**Typical**	**Maximum**	**Units**
Supply voltage (V_{pwr})	4.5	24	24	V
Input voltage, high level(on 50 Ω)	3.0[2]		V_{pwr} - 0.6 V	V
Input pulse width			1.2	µs
Pulse repetition rate		10	10	Hz
Supply current(24 V, 10 Hz)			10	mA
Pulse energy (t_p=101 ns, Two VSLY5940)		0.3		µJ

Table 5.1: Main parameters of the LED pulser

6 Acknowledgments

Maximilian Lederer and Laurens Wißmann (WP78) are acknowledged for providing the pyroelectric sensor. The AGIPD Consortium is acknowledged for providing the AGIPD single-module prototype.

A Bill of materials

Part	Value or type	Available at	Order no.
-	IR-LED Vishay VSLY5940	Farnell	250-4138
U1	MOSFET-gate driver IXYS IXDN604SI	Conrad	160847-62
D1	MMBD914 SOT-23-3 100 V 200 mA	Conrad	1264775-62
R1	Resistor 51 Ω ±0.1% 0.125 W, SMD 0805	RS Components	8280702
R2	Resistor 430 Ω ±1% 2 W, SMD 2512	RS Components	7551230
R3	Resistor 2.2k Ω ±1% 0.5 W, SMD 0805	RS Components	7217775
C1	Ceramic capacitor X7R, 10 µF ±10% / 35 V, SMD 1206	RS Components	7661104
C2,C3	Ceramic capacitor X7R, 1µF ±10% / 50 V dc SMD 1206	RS Components	6911195
LED	ROHM SML-212DTT86Q Orange LED, 611 nm, 17 deg, clear, SMD 0805	RS Components	7007904
XA, XB	2 Position Socket Connector 0.100" (2.54 mm) Through Hole, Right Angle Gold	RS Components	7019626
J1	Pin-header, male, JST S2B-PH-K-S (LF)(SN)	Conrad	740197-05
J2	MMCX-connector, female 50 Ω	RS Components	6807440
	Wires, Cables, Connectors, Mechanics		
P1	Connector PH2.0 mm, female, with wires	Conrad	546821-05
P2	MMCX (male)-SMA (female) adapter with 910 mm RG178 50 Ω coaxial	RS Components	8861204
	Cable UNITRONIC® LiHH 2 x 0.25 mm² (RAL 7032) LappKabel 0037120	Conrad	603274-05
	XT30 connector, male	Conrad	1373197-05
	XT30 connector, female	Conrad	1373198-05
	Screw M1.6 10 mm DIN 912 ISO 4762 8.8	Conrad	888024-05
	Hex-nut M1.6 DIN 934	Conrad	888715-05

Table A.1: Bill of materials for the LED pulser

B Housing

The housing of the LED pulser PCB is made of a thin sheet of semi-rigid plastic, scored and folded as shown in Figure B.1.

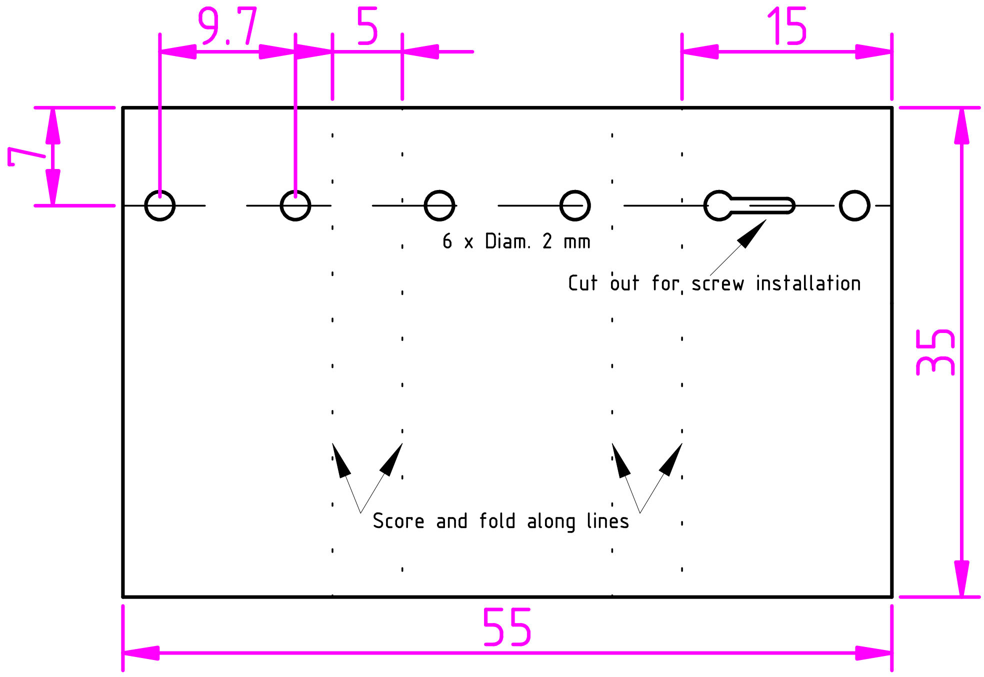


Figure B.1: Drawing of the housing of the LED pulser's PCB

C Mounting adapter

After rendering in OpenSCAD, an STL-file can be exported for 3D printing.

Listing C.1: OpenSCAD source code for the LED pulser mounting adapter.

```
// Dovetail adapter, to mount LED pulser PCB on a NOGA holder
// Library for a nut(-trap) is from https://github.com/JohK/nutsnbolts
include
</home/kaukher/.local/share/OpenSCAD/libraries/nutsnbolts/cyl_head_bolt.scad>;

module trapezoid(width_base, width_top,height,thickness) {
  linear_extrude(height = thickness) polygon(points=[[0,0],
  [width_base,0],
  [width_base-(width_base-width_top)/2,height],
  [(width_base-width_top)/2,height]],
  paths=[[0,1,2,3]]);
}// from https://github.com/robofun/openscad-utils/blob/master/trapezoid.scad

module prism(base, width, height) {
   rotate(a=[180,-90,0])
   linear_extrude(height = width, center = true, convexity = 10, twist = 0)
   polygon(points=[[0,0],[height,0],[0,base]], paths=[[0,1,2]]);
}

w = 3.6; // tuned for "nice" bevel
h = 8.5; // tuned for "nice" bevel
dovetail_width = 6.25; // normally : 1/4 inch (6.35 mm)
dovetail_thickness = 1.6;
dovetail_end = dovetail_width - 2*(dovetail_thickness * tan(60/2));
mainbody_width = 12.7 + 2*2; // from PCB design, with 2mm extra on sides
mainbody_height = 10- 1.6 - 1; // 10mm M1.6 screw, 1.6 mm PCB, 1mm extra
hole_position = 5; // middle of the piece

// from center of a hole to the closest pin on PCB: 5mm, so make symmetric
mainbody_length = 5*2-dovetail_thickness;
stopper_height = 2; // keep contacts on PCB 2mm away from the NOGA holder
hole_distance = 38*0.254; // from PCB design
hole_diameter = 1.8; // somewhat larger than an M1.6 screw needs

difference(){ // result = union1 - union2
 union(){ // union1
  // dovetail
  translate([-dovetail_width/2,0,stopper_height])
     trapezoid(dovetail_width, dovetail_end, dovetail_thickness,
                                 mainbody_height - stopper_height);
  // main body
  translate([-mainbody_width/2, dovetail_thickness,0])
        cube([mainbody_width, mainbody_length, mainbody_height]);

  // PCB stopper, to keep pins from touching the NOGA holder
  translate([-mainbody_width/2,0,0]) cube([mainbody_width,
                              dovetail_thickness, stopper_height]);
 }
 union(){// union2
  // Bevels, sort of
  translate([-3.1,1.6,10]) rotate([90,-30,0]) cylinder(5,5,5,$fn=3);
  translate([3.1,1.6,10]) rotate([90,-30,0]) cylinder(5,5,5,$fn=3);
  translate([0,3.2,7.2]) rotate([0,0,-30]) cylinder(0.2,1.6,1.6,$fn=3);

  // Mountung holes
  translate([-hole_distance/2, hole_position, 0])
    cylinder(mainbody_height, hole_diameter/2, hole_diameter/2);
  translate([hole_distance/2, hole_position, 0])
    cylinder(mainbody_height, hole_diameter/2, hole_diameter/2);

  // Nut traps
  translate([-hole_distance/2, hole_position, mainbody_height]) nut("M1.6");
  translate([hole_distance/2, hole_position, mainbody_height]) nut("M1.6");
 }
}
// EOF
```

D Datasheet of the 10µF capacitor

SAMSUNG
SAMSUNG ELECTRO-MECHANICS

Multi Layer Ceramic Capacitor (MLCC)

RoHS+Halogen Compliant
Ecoparts

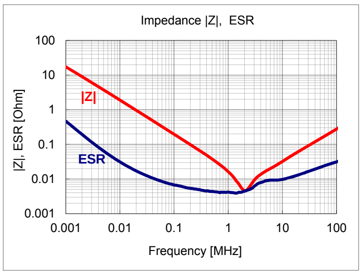
1. Model : CL31B106KLHNNNE

2. Description

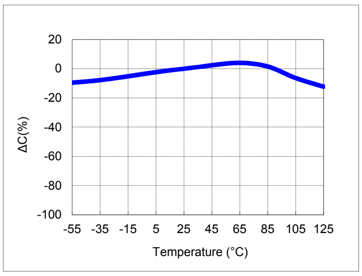
Part no.	Size (inch(mm))	Thickness (mm)	Temperature charateristics	Capacitance value	Capacitance tolerance(%)	Voltage (V)
CL31B106KLHNNNE	1206/3216	1.6mm	X7R	10uF	± 10 %	35

3. Characteristics data

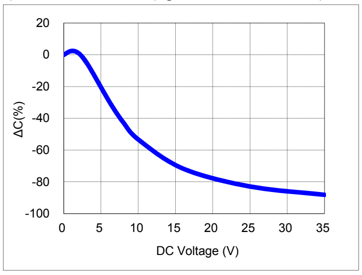
1) Frequency characteristics
Agilent E4294A, 0.5Vrms, 1kHz to 100MHz



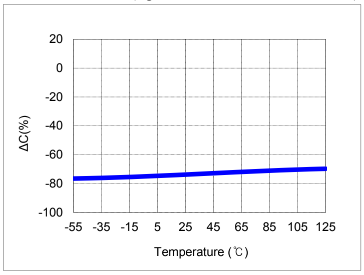
2) Temperature characteristics of capacitance(TCC)
Agilent 4284A, 1kHz, 1Vrms



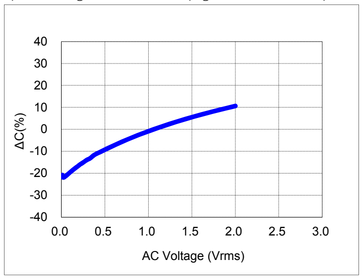
3) DC Bias characteristics (Agilent 4284A, 1kHz, 1Vrms)



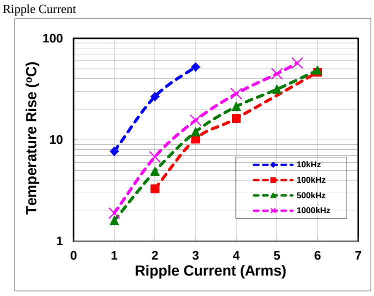
4) Bias TCC characteristics (Agilent 4284A, 1kHz, 1Vrms, 17.5Vdc)



5) AC voltage characteristics (Agilent 4284A, 1kHz)



6) Ripple Current



⚠ Any data in this sheet are subject to change, modify or discontinue without notice.
The data sheets include the typical data for design reference only. If there is any question regarding the data sheets, please contact our sales personnel or application engineers.

Figure D.1: Datasheet of the 10 μF capacitor

Bibliography

[1] A. Kaukher, M. Kuster, and P. Lang. *Test of the LPD Veto Mechanism with a Two-Tile LPD System*. IN-2016-001-01. December 2016.

[2] IXYS Integrated Circuits Division. *IXD_604 4-Ampere Dual Low-Side Ultrafast MOSFET Drivers*. November 8, 2012. DS-IXD_604-R05; accessed 10 November.

[3] A. Kaukher. *https://svnsrv.desy.de/desy/EuXFEL/WP75/users/kaukher/LED_Pulser_GerberFiles*. SVN respository. May 9, 2016.

[4] University of Stockholm. *AMC Fast Timing System x2timer*. 2013. Accessed 10 November 2016.

[5] B. Fernandes. *ETA*. on Alfresco.

[6] *http://jddd.desy.de/webstart.html*. Accessed 10 November 2016.

[7] Vishay Semiconductors. *High Speed Infrared Emitting Diode, 940 nm, Surface Emitter Technology*. Rev. 1.2, 29-May-15 Document Number: 84240; accessed 10 November.

[8] A. Kaukher. *Test of AGIPD timing / focused light from two IR LEDs*. April 25, 2016. ELOG “AGIPD single-module prototype”.