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Laser Drawer

Dispositif de projection laser open source

Rapport final public

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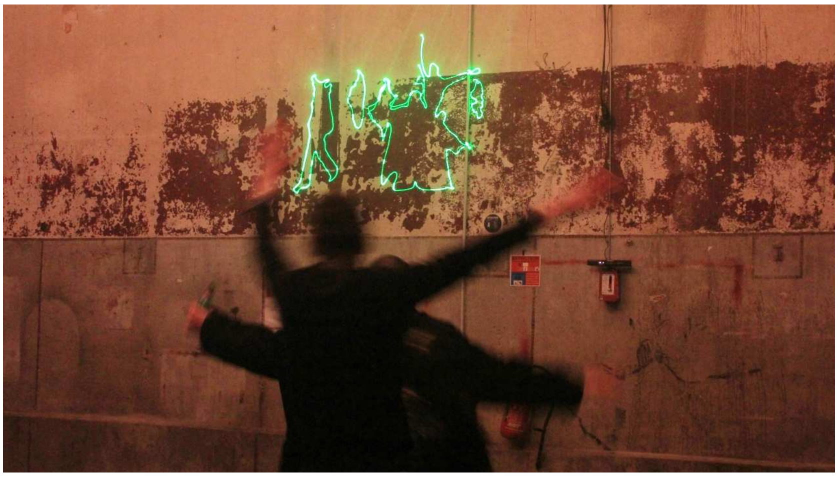


Contents

Laser Drawer is an open source laser projection apparatus. After a state of the art and technics around animation laser, this article introduce the device and how it is made. Two appendices presents electronic schematics and security issues.

1 State of the art and technics

Instead of making an exhautive state of the art and technics, I choose few pieces of artistic works involving laser and some solutions to drive them with a computer.

1.1 Pieces of artistic work

1.1.1 Jean-Michel Jarre – Laser harp – 1980's

Jean-Michel Jarre imagined a visual and musical instrument based on laser beam : the laser harp. There are several versions since the first in early 80's. The same interaction is still used : Jarre cuts a laser beam with his hand and this trigs a synthesiser.

According to Jarre, laser enables "to share with the audience, which is far away in the venue, [...] the music in a visible and sensible way". Nevertheless, this disposal has a limited expressivity. There is neither velocity nor aftertouch.

1.1.2 Alvaro Cassinelli – *Score Light* – 2008

Score Light is an Alvaro Cassinelli's project where a small laser beam follows shapes drawn in real time or moved on a desk (cf. 1). This installation uses a small laser associated with a video camera to detect contours. Alvara Cassinelli is currently working on *Laser Game* project : the laser beam is projected on a T-shirt and bounce on small printed dots like a flipper ball. The gamer should move himself to save the ball from falling down.

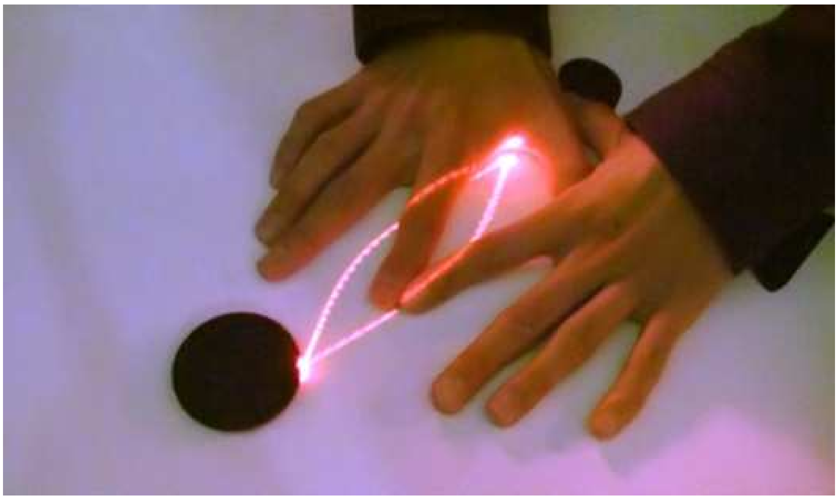


Figure 1: Alvaro Cassinelli – *Score Light*

1.1.3 Robin Fox – *Laser Show*

Robin Fox uses laser like an oscilloscope. He feeds the laser with the same signal he sends to loudspeakers. This is generated by a Max/MSP patch in real-time. Thanks to the smoke, the beam is visible in the space and volumes appears (cf. 2). The beam scans the audience, this is dangerous even if the smoke attenuates the beam. The show is impressive but the systematic correlation between sound and visual makes it boring quickly. Robin Fox uses a MOTU Traveller sound card and a his own electronics to drive his 350 mW laser.

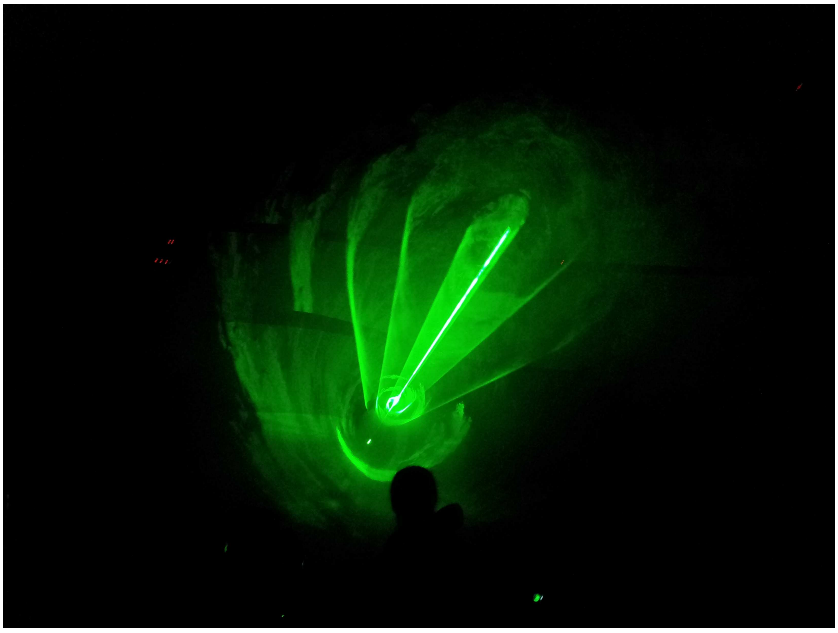


Figure 2: Robin Fox – *Laser Show*

1.1.4 UVA – *Speed of light* – 2010

Speed of light is a labyrinthic set of laser installations. Several installations show volumic figures drawn with few lasers deflected thanks to fixed mirrors. Another installation draws an interactive texte on a wall. In a video, we show the team working with Max/MSP, they probably use this software to drive lasers, but I have no proof.

1.1.5 Robert Henke – *Fragiles Territoires* – 2012

Fragiles Territoires is an interactive and generative installation by Robert Henke. It shows an animated network. The audience influences the audio and visual pattern generation. This installation have been shown in *Espace LU* in Nantes (FR). Robert Henke uses a MOTU Traveller sound card to drive four yellow-blue 5 W lasers. Due to the hazard of those powerful lasers and the indoor use, he deploys some special security measures (please refer to Appendix B to learn more).

1.1.6 Samuel Bianchini – *Sign* – 2012

Sign is a generative installation. Words taken from the scientific vocabulary and from the university website are written with a green laser on the front of a building. The words are drawn with a handwritten calligraphy with hesitations and crossing out as if someone were currently writing on a pen tablet. This installation uses a 10 W green laser driven by a Galaxy Show interface. A software have been developed to use this interface with Puredata under Linux (cf. 1.1.13 and figure 5).

1.1.7 Hyundai and WhiteVoid – *Fluidic - Sculpture in motion* – 2013

For the Milan's designer week 2013, Huyndai introduces *Fuildic - Sculpture in motion*, an interactive installation made by Whitevoid team. It uses a 3-dimensional motion capture disposal to track people gesture and to animate laser pattern projected on a cloud of thousand of ping-pong like balls (cf. figure 6).

1.1.8 Daito Manabe – *UV laser fade out* – 2010

Daito Manabe uses laser in several of his works. *UV laser fade out* involves a UV laser to draw on a phosphorescent board. The laser charges successively small points, the discharge makes different luminosity levels and a picture appears (cf. figure 7).

With *Pulse*, Daito Manabe uses laser mounted on robot and mirrors placed in a large space to deflect beams.

1.1.9 Antoine Villeret – *Silhouette* – 2013

Silhouette is an interactive installation in which a laser projector draws animated silhouettes. It was first showed during the open days of the ENSAD in January 25th and 26th, 2013.

The visitors entered the building through a sinous and narrow corridor. At its end, they saw a green shape and realized by getting closer that it was their contour projected on a paper screen by a laser (cf. 8).

This disposal uses a depth sensor (Kinect) that easily extracts the visitor's silhouettes. Those silhouettes are then vectorised and sent to the laser thanks to the custom interface decribed in the report. The whole video processing is achieved with puredata thanks to custom externals.

1.1.10 Marshmallow Laser Feast – *Laser Forest* – 2013

Laser Forest involves 150 lasers places on top of vertical 3 m tall metal tubes thus creating a "forest". The natural springness of tube makes it oscillating when somebody touches it and then the laser draws figures on the ceiling (cf. 9). A tone is associated with each tree, visitors can play sound and light just by touching the tree.

Figure 3: UVA – *Speed of light*

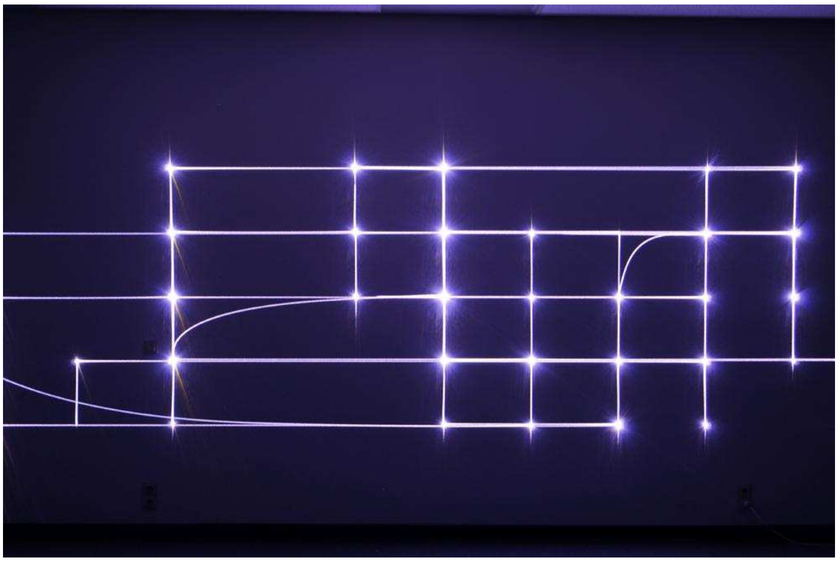


Figure 4: Robert Henke – *Fragiles Territoires*

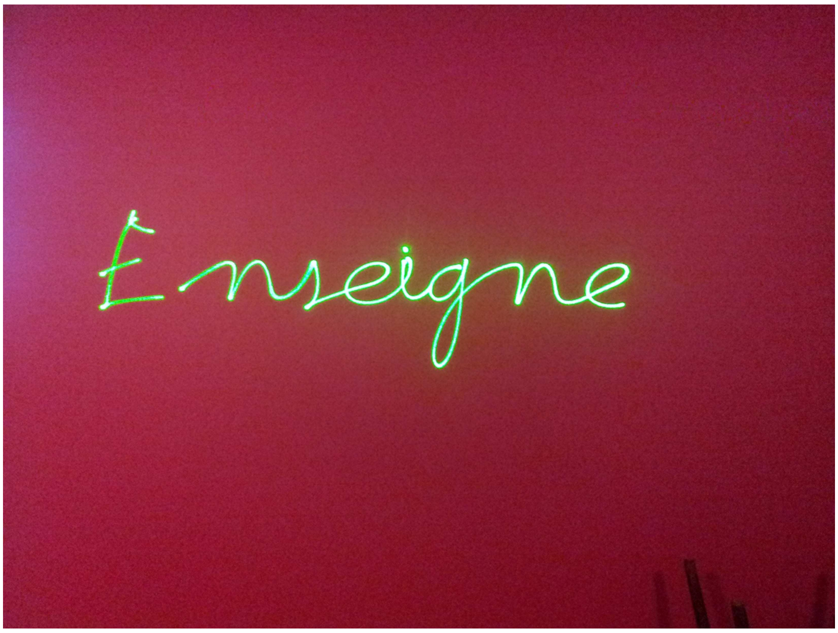


Figure 5: Samuel Bianchini – *Sign*

Figure 6: Hyundai and WhiteVoid – *Fluidic - Sculpture in motion*

Figure 7: Daito Manabe – *UV laser fade out*

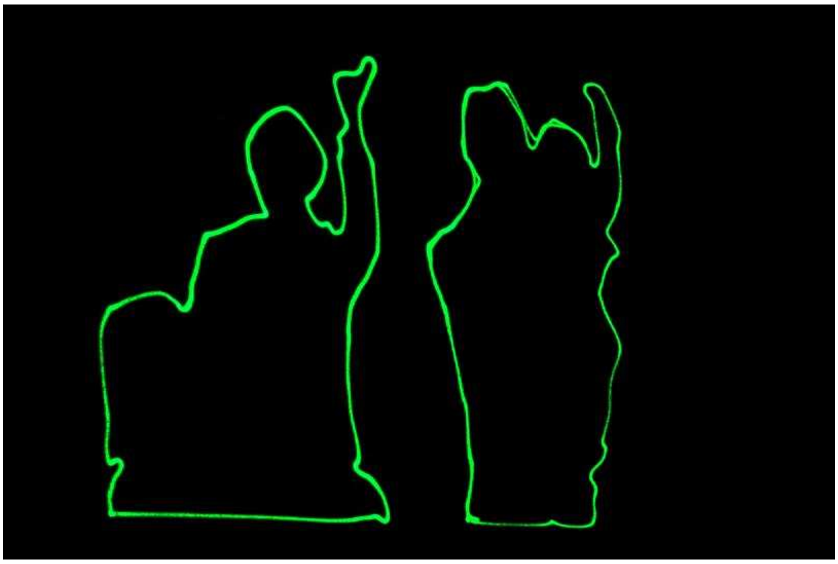


Figure 8: Antoine Villeret – *Silhouette*

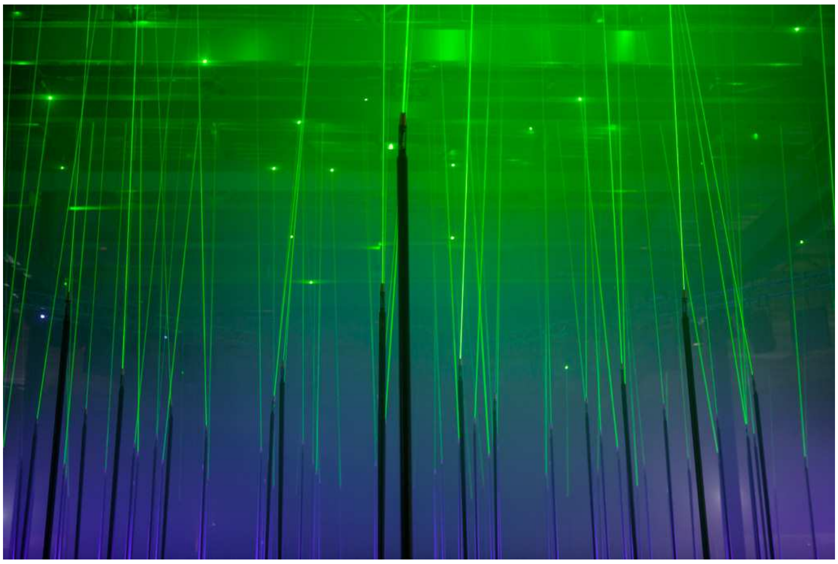


Figure 9: Marshmallow Laser Feast – *Laser Forest*

1.1.11 A bit of history

The laser was conceptualized by Albert Einstein around 1917. The first laser has been build around 1958. Its industrial use starts in the late 70's, especially for cutting. Since it is widely used in thousand of applications : optical drive, bar code reader, material cutting, weapon industry, distance sensor... Jean-Michel Jarre was the first I know to use it in an artistic purpose with his laser harp.

1.1.12 Laser projectors

Inside laser projectors, the beam is deflected by high speed moving mirrors. The mirrors constantly scan the picture, thanks to the retinal persistence we saw a line and not a moving dot. Some projectors have a DMX input but the DMX data could only choose pattern from a hard-coded library. To draw arbitrary picture with a laser, we should drive the mirrors directly. This is the aim of the ILDA protocol. With this analog protocol, we can also control the intensity of the laser diode.

1.1.13 ILDA interfaces

Even if the ILDA protocol is widely used on laser projectors, there are only few solutions to drive them with a computer.

Pangolin The world leader is Pangolin which has a complete technical chain from the software to the hardware. On the software side, there are several solutions to make small shows or even huge ones. There is also a SDK to develop custom software and some tools to vectorize bitmap images.

On the hardware side, there are ILDA interfaces with USB or Ethernet input and even an OEM solution to integrate the driver with another electronic device. There are also devices to distribute ILDA signal between several projectors and a set of optical lenses to cover a 360° angle.

Unfortunately, those solutions are only available for Windows based computers and those are quite expensive. The smallest device costs 650€ and professional tools start around 4 000€.

Electro-concept Electro-concept[1] developed two USB to ILDA interfaces, Miniilda and Maxiilda, respectively sold at € 259 and € 349. Those two interfaces works under Windows with their own software. I've tested the Miniilda which works under Linux thanks to a piece of software I've written. Unfortunately it's not stable enough and Electro-concept doesn't appear to be interested in such a development. So this way was early given up.

[1] `http://www.boutique-electroconcept.com/boutique/`

Galaxy Laser Show For the *Sign* project by Samuel Bianchini (cf. 5), we worked with Sonatronic, who produces the Galaxy Laser Show interface, to port it on Mac OS X and Linux. This was a good initiative, even if the software source was not open, this is the first cross-platform interface I know. It is based on a server written in C# from the .NET framework[2]. This server communicates with the interface which includes a FPGA. Potentially any software capable of sending UDP packet can be used to draw with a laser projector.

I've tested the releases 2 and 3 of the interface. With the revision 2, the software stops the communication with the hardware if network packets are too small or if scanners' frequency is above 20 kpps. The version 3 I have to test was broken : as soon as something is plug in the Sub-D25 the interface is no more available to the software.

bILDA project bILDA is an open source USB to ILDA interface project. It comes with an electronic board and a software. This is unfortunately obsolete : the board is based on the chip `AN2135SC` from Cypress Semiconductor which is no more produced. Moreover its performances were not very good : only 8 bit DAC.

Etherdream[3] Etherdream is an open source and versatile ILDA interface. It supports streaming playback over ethernet up to 100 kpps. All features can be controlled through OSC and it provides a perspective correction tool. It could run standalone thanks to its microSD card reader. Unfortunately I only discover this interface after designing my own one. The both provide similar functionnalities and are open source. Etherdream interface is available with case and power suppy for $ 249.

Alternative solutions As is was seen in 1.1, several artists use sound card to drive laser and especially the MOTU Traveller. This sound card has no DC filters on output so that we can produce an asymmetrical signal from the ground and thus translate the drawing horizontally or vertically from the projection center. Those artists uses their own software (often made with Max/MSP) and their own electrical adaptation electronic.

[2].NET is a Microsoft technology available on Mac OS X and Linux thanks to the open source Mono framework.

[3]`http://ether-dream.com/`

2 The *Laser Drawer* project

2.1 Specifications

Versatility The most important thing is to be compatible with commercial laser projectors. Those laser mostly use the ILDA protocol. So that the interface should be ILDA compliant.

Price Commercial solutions cost several hundred euros, *Laser Drawer* should be cheap thanks to the use of widespread electronic devices and a free and open source software.

Laser Drawer should work with most of operating system (Microsoft Windows, Apple Mac OS X, and Linux distros like Debian-based system (Ubuntu and Raspbian)).

2.2 Software and hardware design

Laser Drawer has a hardware part and its associated software.

2.2.1 Hardware

The hardware part is based on a sound card and a electric adaptation board.

Sound card I choose the ESI UDJ-6 sound card because it's USB Audio 1.0 compliant, thus it will run driver free on most current OS. It has 6 analog outputs and no input, perfect to drive a RGB laser. It runs at 48 Hz on 24 bit so it allows to drive laser up to 48 kpps with a very good precision.

This sound card has DC filter on output. To remove them, it's just needed to short circuit some condensers by solder wire as shown in figure 10.

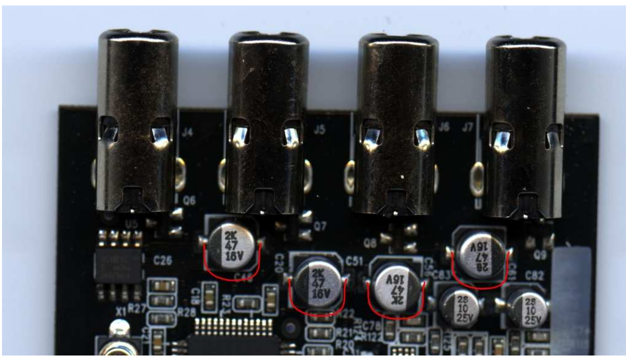


Figure 10: DC filter bypassed

Electrical adaptation stage The sound card deliver a 0.6 V peak-to-peak signal whereas the ILDA protocol requires 10 V peak-to-peak signals. Then an electrical adaption stage is needed. For practical reasons, I choose to power this stage directly from the USB power of the sound card. I choose a rail-to-rail op-amp to reach the power supply value (5 V). Moreover the laser projector I have is not really ILDA compliant (and yes, it's a pity) : the ILDA input is not balanced. So I've decided to make the prototype not ILDA compliant but at least working with this projector.

This has several consequences. First the signal is more sensitive to electro-magnetic perturbations, so the cable length should be as short as possible between the interface and the laser. Then we keep only the positive part of the signal and instead of 10 V peak-to-peak we get only 5 V. The scanning area is also divided by two but this simplifies the electronic.

2.2.2 Software

The software is mainly an OSC server. It receives points in several OSC blobs[4] packed in one OSC message. All blobs should have the same size. They correspond respectively to channel X, Y, red, green and blue. Three, four or five blobs should be send simultaneously to update as many tables. The projections parameters are sent separately with one OSC message per parameter. The table 1 shows all supported messages. Five tables keep the points in memory and then they are played and transformed according to projection parameters.

The end line correction offsets the intensity table playhead by a small amount to compensate the diode switching latency. This assumes the latency is constant but this was not verified.

The OSC server and its associated client are build in Puredata. Both depend on the ILDA library for Puredata. This library provides three externals and is part of the *Laser Drawer* project. The `ildasend` external formats and sends data over network whereas `ildareceive` receives and decodes them. The `ildafile` external, based on `binfile` by Martin Peach, reads `.ild` files and load their content frame by frame into a table.

The server/client architecture allows to run each one on a separate computer. I ran the server on Raspberry Pi but unfortunately I got crackles on sound and it results in artifacts in the drawing. This is due to some issue on the internal firmware. This could be fix by tuning some parameters like disabling the turbo mode of the Ethernet controller. But I didn't try it yet.

Software sources and examples are available on my github : `https://github.com/avilleret/laser_driver`.

[4] `blob` is an OSC datatype with which we can transmit arbitrary data.

Message	**Parameter** `b : blob f : float`	**Effect**
`/arrays`	`bbb{b}{b}`	Update tables values
`/setting/offset`	`fff`	Offset on each channel, resp. X, Y and intensity
`/setting/scale`	`fff`	Scale on each cahnnel, resp. X, Y and intensity
`/setting/invert`	`fff`	Invert each channel, resp. X, Y and intensity
`/setting/intensity`	`fff`	Intensity on each color channel, resp. R, G and B
`/setting/blanking_off`	`f`	Turn off blanking
`/setting/angle_correction`	`f`	Angle correction parameter (not implemented yet)
`/setting/end_line_correction`	`f`	End line correction
`/setting/scan_freq`	`f`	Scanner frequency in kHz
`/setting/perspective_correction`	`f`	Turn perspective correction on and off
`/setting/dst_point`	`ffffffff`	4 corners coordinates to define projection area and to correct perspective

Table 1: Handled OSC messages

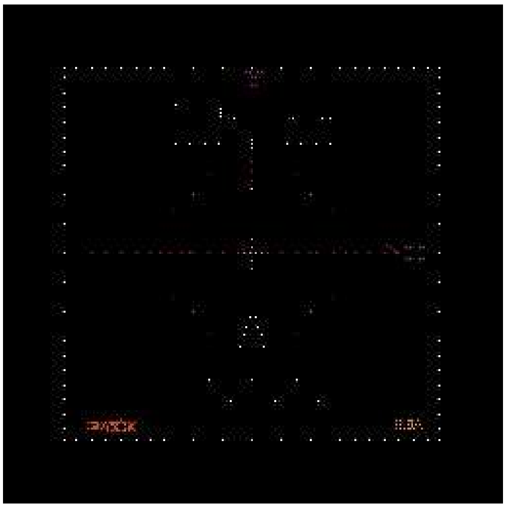
2.3 Laser Drawer vs. Galaxy Laser Show

This section shows the performances of *Laser Drawer* and *Galaxy Laser Show* side by side. I use the ILDA test pattern (cf. figure 11) and observe it both with an oscilloscope and projected by the laser. This pattern is used to tune projector by changing the high and low damping of galvanometers. On the figure 11c the blue circle appears inside the green square whereas on the vector image 11b it appears outside. This is how a well tuned laser should responds according to ILDA recommendation.

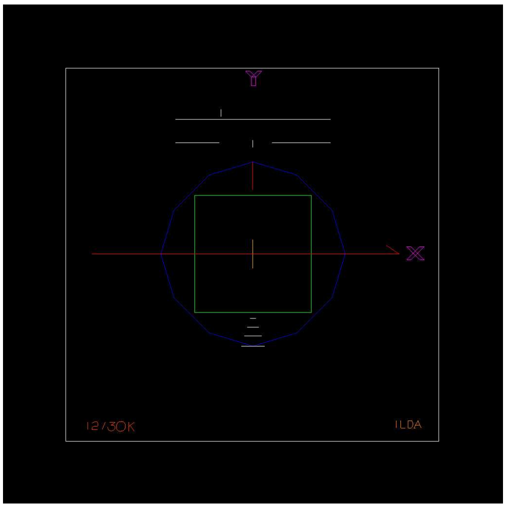
The first observation is that Galaxy interface doesn't interpolate continuously between points. We show only points, not lines. On the figure 11a, the blue circle is made of 12 points whereas on the figure 12b there are 30 and on figure 12a the circle line is continuous. This is an issue for two reasons. First we will see points instead of lines with a low latency laser diode. And then by adding points, the drawing is not right (according to ILDA recommendation), the circle appears outside of the square with a well tuned laser (cf. figure 14b).

The figure 13 shows *Galaxy* is more stable than *Laser Drawer's* when increasing scanners frequency. But with *Galaxy*, some point become lighter when increasing scanner frequency.

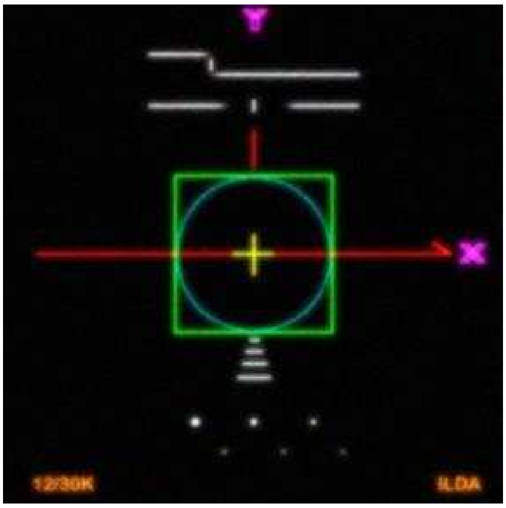
The small artifacts on the circle in figure 13a are non-linearities of op-amp due to power supply reaching the op-amp's limits. During the tests, the board was supplied by the laser's main 15 V/-15 V. The `LM358` op-amp were about to fire. The use of other op-amp and lowser power supply should fix this.



(a) Points

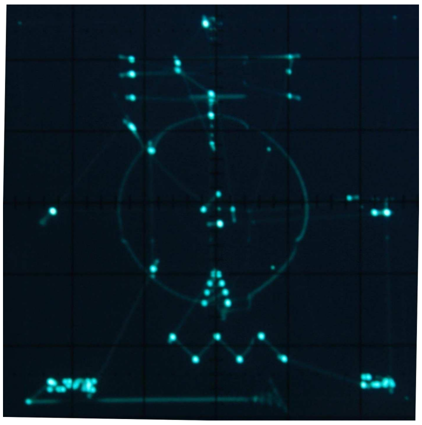


(b) Vectors

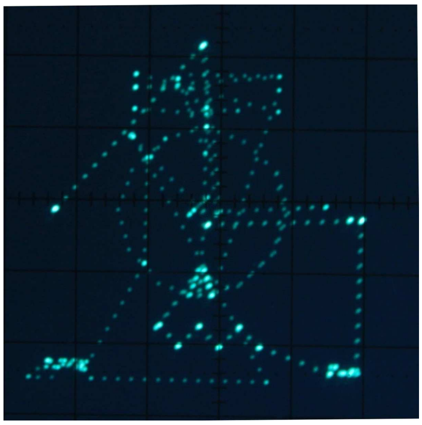


(c) Projected with a well tuned laser

Figure 11: ILDA pattern : points, vectors and reference projection

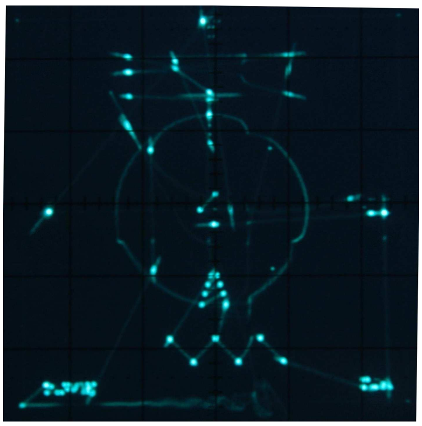


(a) Laser Drawer

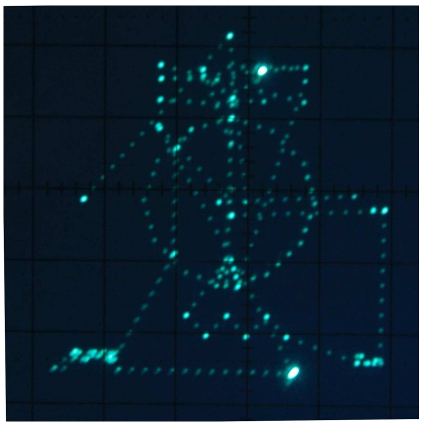


(b) Galaxy

Figure 12: On oscilloscope at 12 kpps

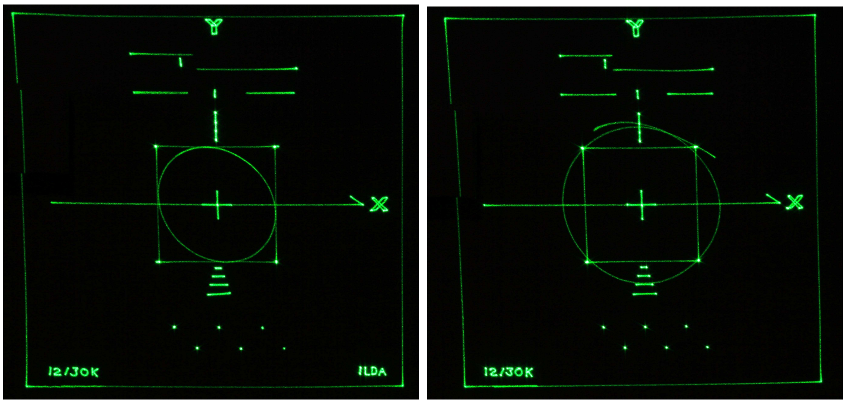


(a) Laser Drawer – 48 kpps



(b) Galaxy – 100 kkps

Figure 13: Highest speed shown on oscilloscope



(a) Laser Drawer (b) Galaxy

Figure 14: Laser projection at 12 kpps

Appendix A Electronic Schematics

The prototype schematic on figure 15 works but has some defects. First it's not really ILDA compliant since the output isn't balanced. Also there is no short circuit protection on outputs. The op-amps could be damaged by a connection error or a hardware failure.

The board was powered by USB but there is only 4.85 V on the end and it's not enough for DC/DC converter to work properly.

It will be easier to use a DC/DC 5 V to 9 V converter. In this case, we could choose better op-amp (not rail-to-rail, so cheaper) like NE5532.

There is an improved schematic on figure 16 to drive a RGB laser. On this, outputs are balanced and there are capacitors in the feedback loop of op-amp, so that spontaneous oscillations are avoided. Some resistors on the output protect op-amp against short circuit.

The DC/DC converter `XP-POWER IH0509S` has a wide range of input voltage (from 4, 5 V to 9 V) and a dual regulated output. Thus I can choose non-rail-to-rail and then cheaper op-amp. I choose NE5532 for its good quality/price ratio and its good audio performances. Jumpers JP1 to JP6 are on-board wires to avoid double face PCB. The jumpers connections are drawn in yellow on the component implemantation schematic 17 page 22.

The figure 18 shows the PCB and the table 2 is the list of components.

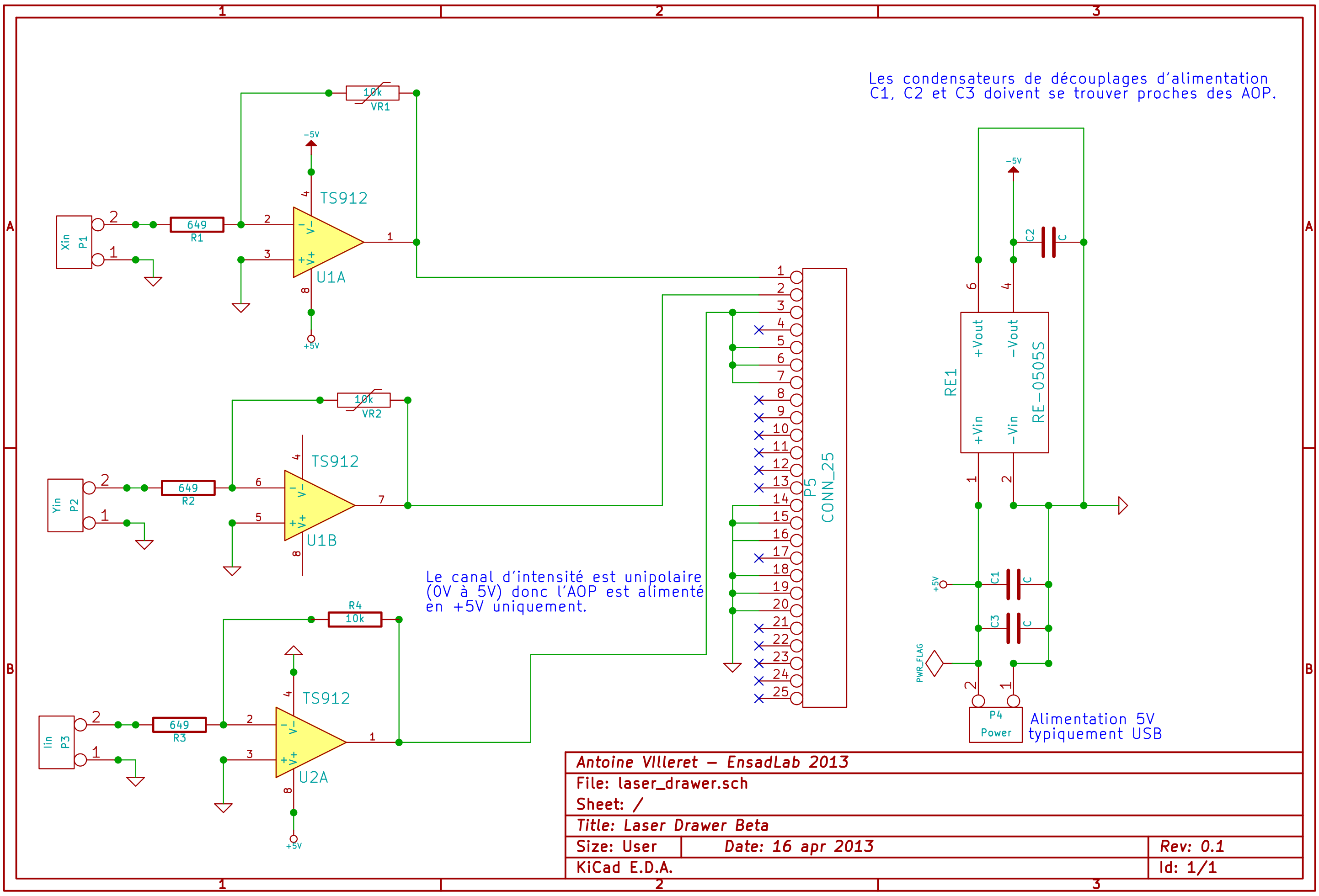


Figure 15: Prototype Schematic

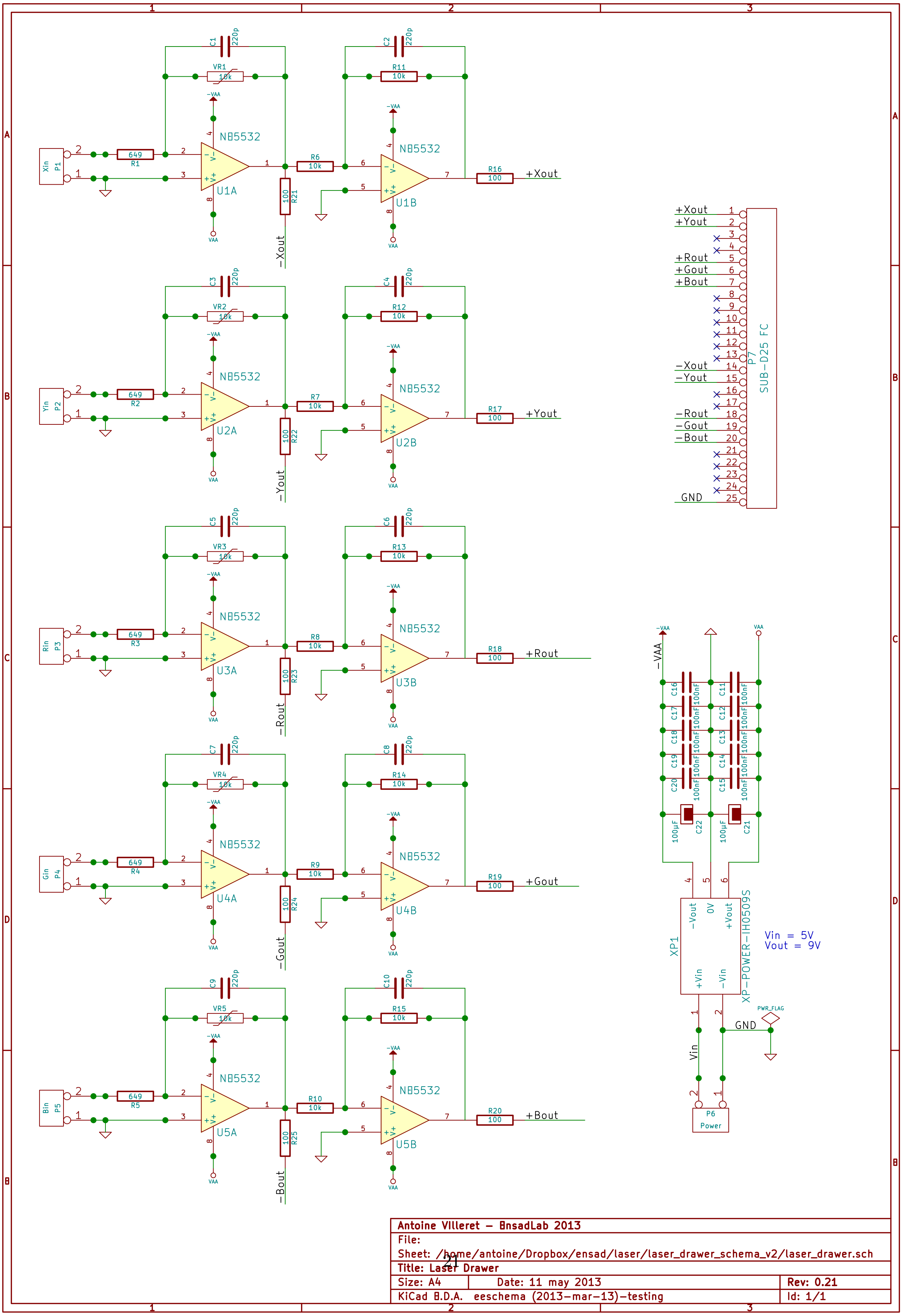


Figure 16: Balanced Output and 3 Color Channel Schematic

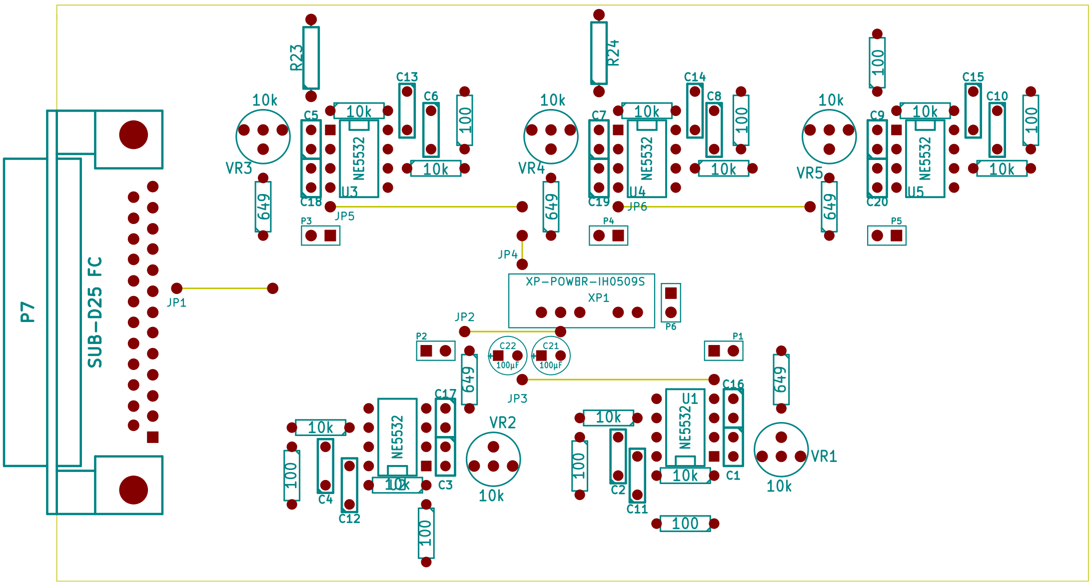


Figure 17: PCB

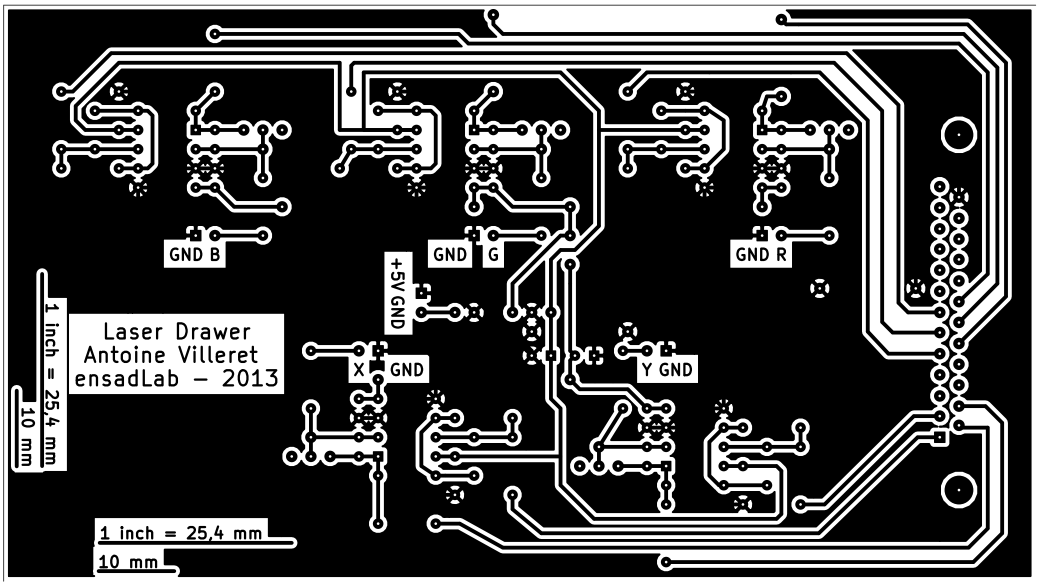


Figure 18: Offset Film

Ref.	Value	Quantity	Ref. Farnell
C1 à C10	220 pF	10	
C11 à C20	100 nF	10	
C21, C22	100 μF	2	
JP1 à JP6	JUMPER	6	
P1 à P6	2x1 PIN HEADER	6	9731148
P7	SUB-D25 FC	1	1099296
R1 à R5	649 Ω	5	
R6 à R15	10 kΩ	10	
R16 à R25	100 Ω	10	
U1 à U5	NE5532	5	1106091
VR1 à VR5	10 kΩ trimer	5	9354301
XP1	XP-POWER IH0509S	1	8727880

Table 2: Bill of materials

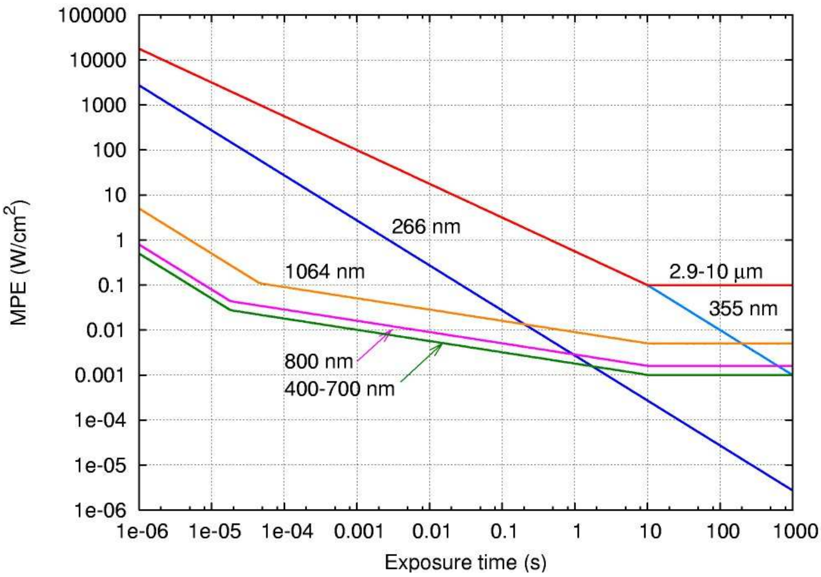


Figure 19: MPE for several wavelenght (source : Wikipedia)

Appendix B Legal and security issues with the lasers

Lasers could be dangerous. A high level of coherent light concentrated on a small surface heats quickly. That is why we use lasers to cut materials. But this property is also dangerous, both for things and people. A 5 W laser can burn the skin or lighten a cigarette.

The laws define some restrictions that could be difficult to follow. I will try to clarify those and to relativise according to what we are doing with lasers.

The risks

Lasers can burn the skin and the retina. Retina's injuries are irrevocable. Man can become blind by directly looking into a laser diode. Class 4 lasers can easily trig a fire.

To be safe, the exposure shouldn't go above the Maximum Permissible Exposure (MPE). MPE is defined as the tenth of the dose which has half chance to make an irrevocable injury. This is measured on the cornea or on the skin for a given wave length and exposure time. MPE used to be expressed in W/cm^2 ou J/cm^2. Figure 19 shows the continuous exposition of cornea to visible laser is dangerous above 1 mW.

Lasers could also be dangerous for aviation. Even if the planes fly high enough to not be damaged by a laser beam, pilot could be dazzled.

Class 1	A Class 1 laser is safe under all conditions of normal use. This means the maximum permissible exposure (MPE) cannot be exceeded when viewing a laser with the naked eye or with the aid of typical magnifying optics (e.g. telescope or microscope). To verify compliance, the standard specifies the aperture and distance corresponding to the naked eye, a typical telescope viewing a collimated beam, and a typical microscope viewing a divergent beam. It is important to realize that certain lasers classified as Class 1 may still pose a hazard when viewed with a telescope or microscope of sufficiently large aperture. For example, a high-power laser with a very large collimated beam or very highly divergent beam may be classified as Class 1 if the power that passes through the apertures defined in the standard is less than the AEL for Class 1; however, an unsafe power level may be collected by a magnifying optic with larger aperture.
Class 1M	A Class 1M laser is safe for all conditions of use except when passed through magnifying optics such as microscopes and telescopes. Class 1M lasers produce large-diameter beams, or beams that are divergent. The MPE for a Class 1M laser cannot normally be exceeded unless focusing or imaging optics are used to narrow the beam. If the beam is refocused, the hazard of Class 1M lasers may be increased and the product class may be changed. A laser can be classified as Class 1M if the power that can pass through the pupil of the naked eye is less than the AEL for Class 1, but the power that can be collected into the eye by typical magnifying optics (as defined in the standard) is higher than the AEL for Class 1 and lower than the AEL for Class 3B.
Class 2	A Class 2 laser is safe because the blink reflex will limit the exposure to no more than 0.25 seconds. It only applies to visible-light lasers (400–700 nm). Class-2 lasers are limited to 1 mW continuous wave, or more if the emission time is less than 0.25 seconds or if the light is not spatially coherent. Intentional suppression of the blink reflex could lead to eye injury. Many laser pointers and measuring instruments are class 2.
Class 2M	A Class 2M laser is safe because of the blink reflex if not viewed through optical instruments. As with class 1M, this applies to laser beams with a large diameter or large divergence, for which the amount of light passing through the pupil cannot exceed the limits for class 2.
Class 3R	A Class 3R laser is considered safe if handled carefully, with restricted beam viewing. With a class 3R laser, the MPE can be exceeded, but with a low risk of injury. Visible continuous lasers in Class 3R are limited to 5 mW. For other wavelengths and for pulsed lasers, other limits apply
Class 3B	A Class 3B laser is hazardous if the eye is exposed directly, but diffuse reflections such as those from paper or other matte surfaces are not harmful. The AEL for continuous lasers in the wavelength range from 315 nm to far infrared is 0.5 W. For pulsed lasers between 400 and 700 nm, the limit is 30 mJ. Other limits apply to other wavelengths and to ultrashort pulsed lasers. Protective eyewear is typically required where direct viewing of a class 3B laser beam may occur. Class-3B lasers must be equipped with a key switch and a safety interlock. Class 3B lasers are used inside CD and DVD writers, although the writer unit itself is class 1 because the laser light cannot leave the unit.
Class 4	Class 4 is the highest and most dangerous class of laser, including all lasers that exceed the Class 3B AEL. By definition, a class 4 laser can burn the skin, or cause devastating and permanent eye damage as a result of direct, diffuse or indirect beam viewing. These lasers may ignite combustible materials, and thus may represent a fire risk. These hazards may also apply to indirect or non-specular reflections of the beam, even from apparently matte surfaces—meaning that great care must be taken to control the beam path. In most states it is illegal to sell preassembled class 4 lasers, however a citizen can construct a class 4 laser for personal use. Class 4 lasers must be equipped with a key switch and a safety interlock. Most industrial, scientific, military, and medical lasers are in this category.

Table 3: Laser classification (source : Wikipedia)

The law

Lasers are classified according to their dangerousity (see table 3). The first classification in roman numbers takes only the diode power into account. The 2007 revision takes also the wavelength and the divergence into account.

Laser from class 3 and above could only be used outdoor. Only a qualified technician could manipulate the laser, but I can't find any compagny in France that delivers an agreement for animation lasers. People have to learn laser safety themselves and take their responsability.

Due to this dangereousity, laser must have a security system to cut the beam if a failure occurs. On some new lasers, the diode is switched off if the scanning area is not wide enough. The bigger the scanning area is, the less the beam stay on the same place, so the less it is dangerous. But with such a system we can't draw arbitrary patterns with laser even if we take compensatory arrangement like constraining beam or a fireproofed projection screen.

In practice

In practice, the laws are very restrictive and moreover they can afraid technical director if they are not explained properly. As soon as we use a Class 3 or above laser, audience scanning should be avoided. If it is really needed to scan an area accessible to people, we must take some special measures to be sure that the audience exposure is below the MPE.

Robert Henke uses class 4 laser indoor for *Fragiles Territoires*. He had to setup an IR barrier to cut of all lasers if someone enters in the forbidden area. Thus nobody can be reached by the laser beam. He had to go through a lot of discussions before this was approved.

For *Sign* by Samuel Bianchini, the laser is constrained into a small black metal window. Through this window the laser beam can only reach its target : a front of a building 250 m far. If in any case the beam leave the window, the surrounding metal absorbs it.

Concerning Robin Fox, he places the laser projector in front of the audience so that the beam can reach our eyes easily. He seems to be aware of the laser's hazards but doesn't know his laser is forbidden indoor, in France at least.

Appendix C Image credit

Picture 9 is reproduced with courtesy of Marshmallow Laser Feast.
Picture 6 is reproduced with courtesy of White Void.
Picture 4 is reproduced with courtesy of Robert Henke himself.
Pictures 5 and 2 are mine.

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