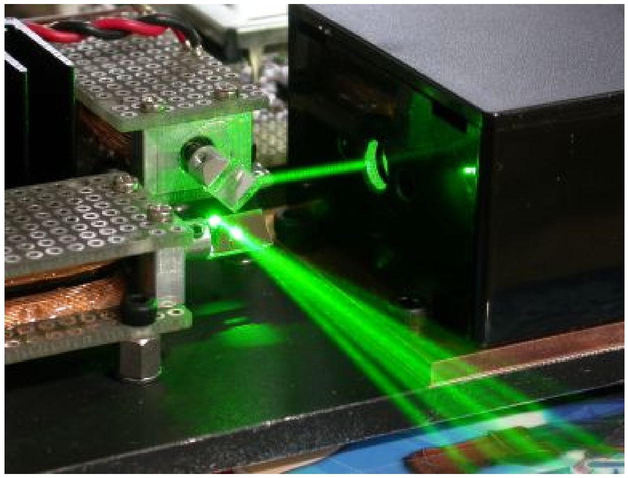
Home Built Laser Projector

Updated: August 16 2012



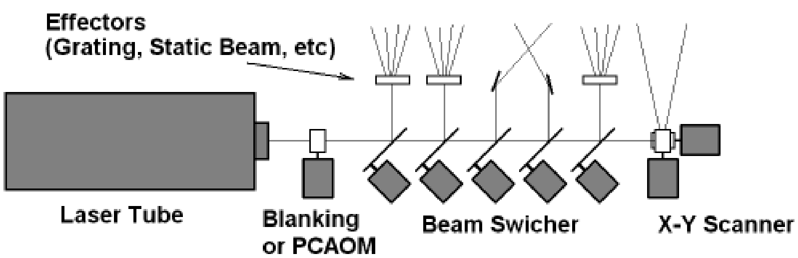
Abstract

I think everybody saw Laser Effects that shows up stages, discos or festivals. There are two categories on the laser effect. One is *Beam Effect*, it shows the laser beams that flying in the air to the audience. The other is *Screen Effect*, it shows the laser graphics that drawn on the screen by a moving laser spot. The first one is preferred better than second. The beam effect is very exciting, so that many *Laser Light Shows* are also being given. The laser equipments working in the laser light show are called *Laser Projector*.

This is a challenging project to build the laser projector with professional grade :-). The most important component used for laser projectors is the laser unit. He-Ne laser had been used in early days, multi-colored mixed gas laser is currently used for high end laser projector and solid state laser is one of the brand-new laser device that has been recently used. However the laser unit was very expensive and junk He-Ne gas laser cannot be modulated directly, so that I could not resolve to purchase the laser unit and modulator. At the first quarter of 2004, a reasonable solid state laser module was sold from Kyoritsu Denshi, and I determined to start this project that thinking for a long time.

Inside of the Laser Projector

Figure 1. Optical Table of Typical Laser Projector



Basically, the laser projectors are used for entertainment industry. Most high-end laser projectors are custom-built and some functions are incorporated accordance with which type of effect is required. *Figure 1* shows the optical function diagram of typical laser projector. It seems ready-made laser projectors have only X-Y scanner which can be used for the most generic effects. In this project, I chose only an X-Y scanner and aimed to project exact laser graphics and animations as a goal.

Laser

In old days, red He-Ne laser had been used for the laser art, and then white mixed-gas laser which can generate several number of color simultaneously has being used. The gas laser is very low efficiency and difficult to use. Recently, compact, high efficiency and easy to use solid state lasers, such as semiconductor laser and DPSS laser, increase its performance and have appeared on the market of laser art equipment. Most color of solid state laser is currently red and green. When blue one improves its performance, out of date gas lasers will be replaced with the solid state lasers.

Blanking/Modulator

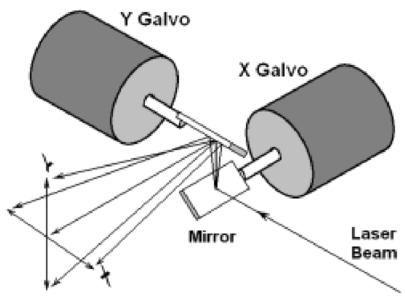
The blanking mechanism interrupts any unnecessary laser beam. Most gas lasers require this mechanism in front of laser output window because the gas laser cannot be modulated the output power quickly. A galvanometer is used for the blanking mechanism as its actuator to move the interrupter. For multi-colored system, such as mixed-gas laser, an optical modulator, called PCAOM, is used to control each color line. The mechanical blanking other than safety shutter is often omitted on the laser projector using PCAOM or solid state lasers which can be modulated directly.

Beam switcher/Effector

The beam switcher is a mechanism that feeds a laser beam to the selected effector, and the effector interrupts a laser beam with any optical filter. Because switching speed and accuracy are not particularly required, open-loop galvos, stepping motors and solenoids are used to move the optics. The optical filter used for the effector is to spread or diffuse the laser beam. Some grating disks are often used for such effect. The laser beam passed through the effector creates splashed beams as beam effect, and an abstract pattern as screen effect.

X-Y scanner

Figure 2. X-Y Scanner



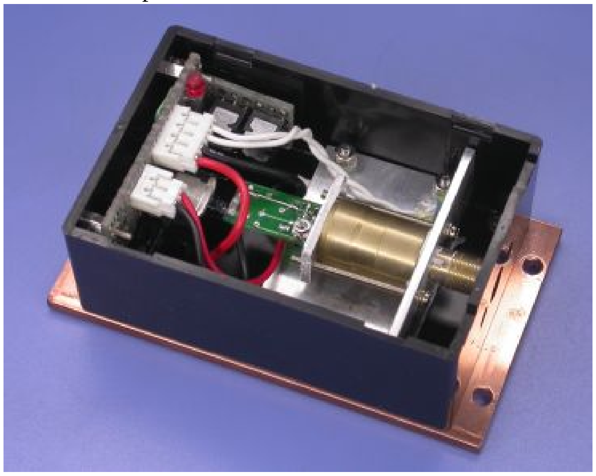
The X-Y scanner is the most generic component which can control the beam vector at will. *Figure 2* shows the principle of the X-Y scanner. Two galvos are mounted in orthogonal, incoming laser beam is bounced by X-axis galvo mirror and bounced again Y-axis galvo mirror and the beam goes into rendering space. The beam direction can be determined by combination of deflection angle of two mirrors. The scanned laser beam creates laser sheets or tunnel as beam effect, or draws laser graphics on the screen. For the screen effect, scanning speed is particularly required of X-Y scanner because it must scan fast and exactly as possible for good quality of the picture. Only closed-loop galvo is currently used for screen effect, and for simple abstract graphics, open-loop galvos and resonant galvos are sometimes used.

Other Components

The components other than optics explained above are scanner driver, laser power supply, laser cooling system, show controller/console and others. Laser projector consists of these components.

Building a Laser Unit

Photo 2. Temperature Controlled Laser Unit



I bought a green laser module for 6,720 Yen at Kyoritsu Denshi. This is a DPSS laser module rated 532nm/5mW(min). It can rise the output power up to several times stronger than rated power, of course it is out of warranty. The result of measured power is 15mW without any adjustment, and 20mW when adjusted its trimmer pot. This means the laser module should not be handled without any knowledge on basic laser safety. It seems this laser module is for pen type laser pointer infer from its shape, I think it will be very dangerous laser pointer :-).

However, there are not that only good features. When the laser module operates for a time, the output power dips due to heat rise. Most general purpose DPSS laser modules will be temperature controlled to stable operation. This laser module is for cheap laser pointer, it does not have such function, and so I built a laser unit with temperature control and external modulation. *Photo 2* shows the built green laser unit.

Because accuracy of the temperature control is not so required, simple PI control is used. MCU reads the resistance of thermister coupled with laser module, convert it to temperature and drive peltier module with error between module temperature and setting temperature. The laser output can be modulated by external modulation input via MCU and it is shut off to protect laser module when the module temperature is out of setting.

Building Galvanometer Scanners

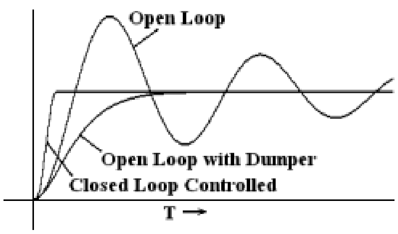
I had looked for existing project on building closed-loop galvos, however I could not find such project on the web. Most home-built scanners ware made of speaker without any feedback. It seems nobody has tried to build the closed-loop galvo yet. I was compelled to start the project from zero, and I could build the closed-loop galvos with sufficient performance on some trial. I believe that this report helps laserists who have similar project.

What is Galvanometer?

The galvanometer is one of the electrical instruments used to detect small current, its schematic symbol is *(G)*. When detect very small current, the galvanometer had being used with attached mirror and light source instead of needle to enlarge the deflection, and current existing galvos also inherits this principle. The galvos have very thin rotor to minimize the rotor inertia for fast movement. The moving coil is replaced with high rigidly solid rotor, such as moving magnet and moving iron, and the armature coil is moved to stator to increase heat radiation. This structure can be said "Servo Motor" rather than galvanometer.

Closed-loop Control

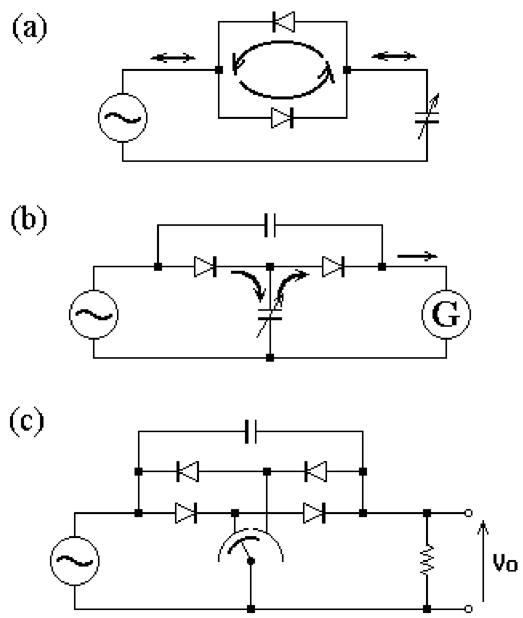
Figure 3. Step Response of Galvos



The open-loop galvo's shaft is held with a torsion-rod spring, the rotor moves to a position where balancing between generated torque of the rotor and restoring torque of the torsion-rod spring. This is same principle as traditional galvanometer. It can be controlled one-way, rotor moves to a position that proportional to the coil current. However the control bandwidth of open-loop galvos is limited because it has a resonant frequency determined by rotor inertia and spring constant.

In closed-loop control, rotor position is detected with a position detector, it is compared to commanded position and the rotor position is controlled to track the commanded position. This is also called *feed-back contorl* or *servo contorl*. It can improve scanning speed and accuracy compared to open-loop control (*Figure 3*). Power efficiency is also improved because there is no power loss due to a torsion-rod spring. However the closed-loop control requires cost of position detector, servo amplifier and related. This project builds the closed-loop controlled galvos.

Figure 4. Capacitive Position Detector



Position Detector

The position detector is the most significant part for closed-loop control, there are various kind of sensing method, such as optical (position sensitive device), magnetical (resolver) and conductive (potentiometer). I chose a simple capacitive method which utilizes a principle that when an AC voltage is applied to a capacitor, current flow through the capacitor proportional to the capacitance value. Its structure is similar to tuning capacitor used in radio. In practical design, one electrode is grounded because it is convenient considering the structure, but a consideration is needed to circuit design when measure the capacitor current in such structure.

The schematic shown in *Figure 4a*, a DC component indicated with arrows is generated, and open the DC current path as shown in *Figure 4b*, the rectified DC component will able to be detected by the galvanometer(G). In fact the capacitance change is very small and it will not able to be detected stably due to parasitic capacitance and any interference. *Figure 4c* shows the schematic used for practical design, two differential electrodes and diodes are joined in opposite polarity each other. Sum of the rectified currents becomes difference between them, any factor affects accuracy can be canceled and it can be detected stably. In this figure, when the moving electrode moves to left, positive voltage will appear at the Vo, and vice versa. The position detector built in this project changes the difference capacitance only several pF in full scale (90° mechanical deflection), and a sufficient output voltage change could be got.

Making Parts and Build

Photo 3. Galvo Parts

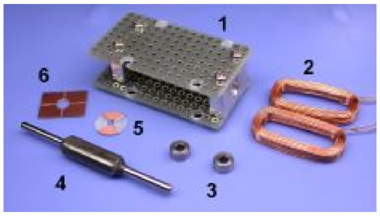


Photo 3 shows the main parts of the galvos to be built. Explanation for each part is as follows:

1. Base Frame. Glass-epoxy proto-boards cut in proper size, two base boards are set to end blocks and it makes the galvo's body.
2. Stator Windings. Wind a UEW (urethane enameled wire) in diameter of 0.3mm 60 turns to a bobbin and set the form with vanish and then exitract it from the bobbin.
3. Ball Bearings. These are from optional parts of MINI-4WD model kit (OD=5, ID=2, L=2.5)
4. Moving Magnet Rotor. The solid rotor is rigider than coiled one, any harmful resonance does not occur. The carbon steel shaft is got from a junk motor (D=2, L=45), and neodymium magnets are got from scraped hard disks. The magnets are cut and bonded to the shaft and then shaped with a water-cooling grinder. The shaft should be thin and light as possible to minmize the rotor inertia.
5. Moving Electrode for PD. A butterfly shaped electrode is formed on the thin glass-epoxy PCB (D=8, t=0.2). The working angle range is 90° at butterfly shaped electrode and 180° at half-moon shaped one. 90° is sufficient for galvanometer scanner.
6. Stator Electrode for PD. This is same material as moving electrode and divided in four quadrants.

Photo 4. Close-up Views

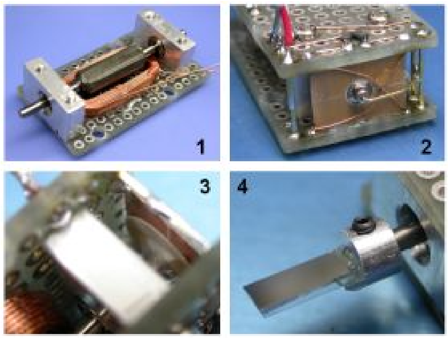


Photo 4 shows close-up views of the built galvanometer, the schematic is available in tech notes.

1. A galvo being built. Two stator coils are placed and fixed as surrounding the rotor magnet. I could not make accurate stator core so that I adopted complete core-less structure to avoid unnecessary reluctance torque. It results that the torque constant is pretty small, 2.5mN-m/A.
2. PD stator side. A sharp spring wire (phosphor bronze, 0.4mm dia) pressing the shaft gives a ground potential to the moving electrode and apply a pre-pressure to the bearings to eliminate vibration simultaneously. The contact point must be on the center of the shaft in order to minimize friction, or it will cause a hysteresis error. A little electric contact oil increases conduction and stability.
3. PD rotor side. The PD rotor is bond at behind it and the electrodes are tied to the shaft with conductive paint. The gap between rotor and stator should be close and parallel as possible, or sensibility and linearity will be worse.
4. Mirror mount. Cut a first surface mirror and bond it onto the mirror mount made of aluminium rod (D=5).

Building Servo Amplifiers

How Servo Works

Figure 5. Servo Operation Diagram (Simplified)

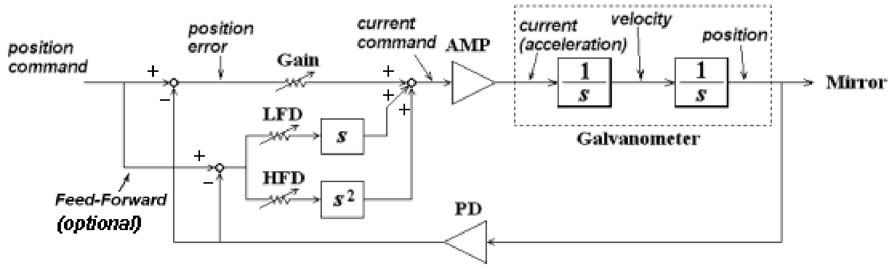
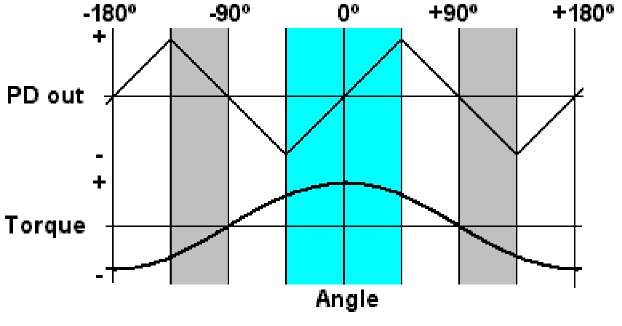


Figure 5 shows the block diagram of the servo amplifier for this project. In position servo system, delay order at the controlled object becomes high and it cannot be controlled stably unless any phase compensation suitable for the servo system. The control method for the closed-loop galvo is PD-control, as for D-control, compensation of current-velocity delay and velocity-position delay each are done separately. I-control is omitted because it can affect servo stability. In this system, there is hardly any friction nor static torque so that it seems there is no problem for positioning accuracy even if without the I-control.

Characteristics of Position Detector

Figure 6. PD Output and Rotor Position



The stator electrode of the position detector is divided in four quadrants and the working angle range becomes ±45° like shown in *Figure 6*. The servo system locks in the painted area that polarity of rotor torque and PD output matches for proper servo operation. It can lock at gray area that is incorrect position, but when apply scanner power with position command of center, rotor returns to the center wherever it is. Normal operating range is set to ±20° (±40° optical deflection) that sufficient for galvanometer scanners.

Building Circuit Boards

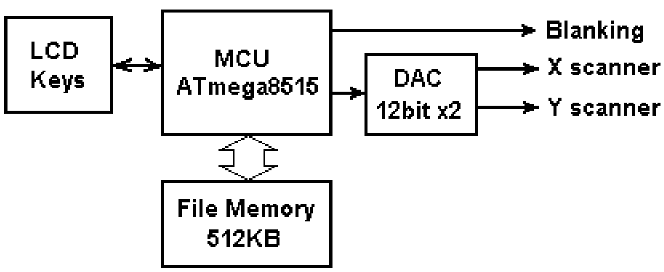
This is the built servo amplifier and circuit diagram. This is a simple and ordinary op-amp circuit, there is nothing difficult. However it has power amplifier and small signal amplifier on the board together. You have to pay attention to unintentional coupling on board design otherwise you will be afflicted with oscillation, distortion or instability, and the servo gain will be limited. Currently the PD circuit is a little affected by power amplifier, it may be better to move it on the galvo like existing galvos.

The servo amplifier requires a dual output power supply of ±20 volts. It is generated with a simple DC-DC converter powered from a single +12 volts DC supply. It is not that must be regulated, a traditional transformer-bridge-capacitor type power supply will also work well.

This is a wave form which is a step response of the servo amplifier. It must be current controlled however the output voltage is saturating due to coil inductance. The supply voltage should be high as possible to minimize this effect. The voltage dip at high output current also be found. It is due to a current limiting of the LM675, a high power opamp, such as LM12, might be better than LM675. However such the strong opamp can burn the galvo coil with over load or oscillation so that any thermal protection will be needed to the galvo.

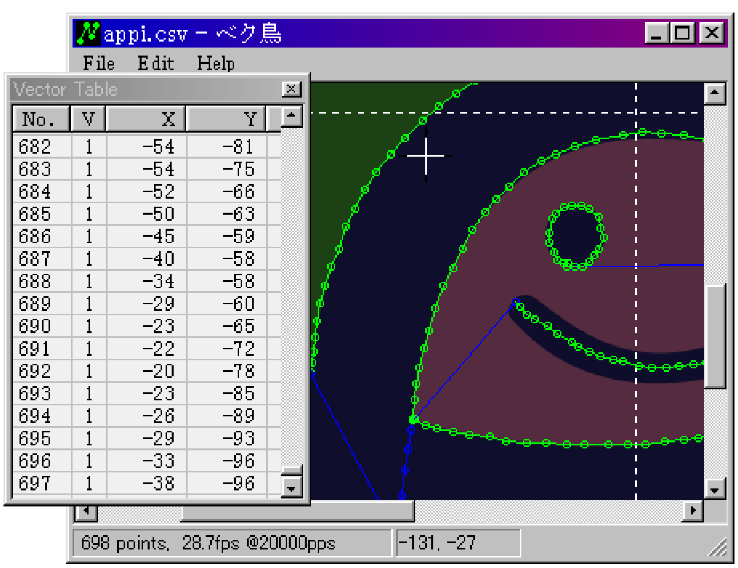
Building a Controller

Figure 7. Controller Block Diagram



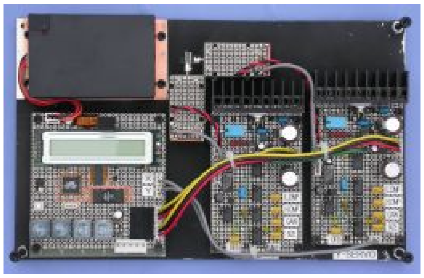
The laser controller must generate two vector signals (±1V analog) for galvos and a blanking signal (TTL) to modulate laser output, al least. These signals will able to be generated by any microcontroller board found in junk box or a simple D/A adapter attached to PC's parallel port. In this project, I designed and built a new controller board to minimize the board size. *Figure 7* shows the block diagram for the controller board, and the circuit diagram is available in tech notes. The controller only generates vector data with stored frame and there is no more control. It will not needed to explain each function of the controller board and its firmware because you must have a skill to design a laser display controller if you are going to build galvos.

Frame Creation Tools

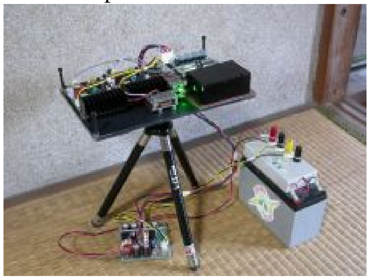


Because the graphic data used in laser projector is vector based, not rastar based, generic graphic tools cannot be used to create frame data. Any vector based graphic tool is needed to create vector frames. There are some laser creation tools specified for vector graphics, but they are too expensive for hobby use or temporary project, so I developed a simple vector tracing tool. It handles the frame files in generic csv format because I also wish to use it for any other purpose :-). This is a freeware and is available in tech notes. A script to convert ild frame file into csv file is included too.

Results

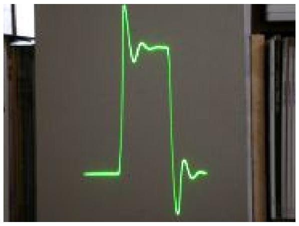


Built laser projector
Each components are mounted on the base board of 240×150×5 mm aluminium.

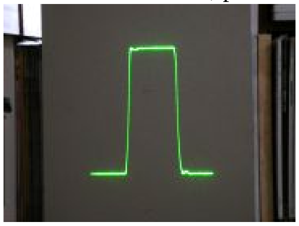


Battery operation
The laser projector including a battery and a PSU can be held in an attache case.

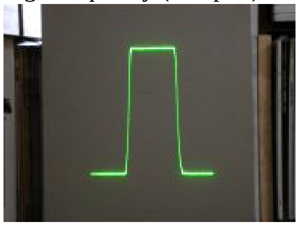
Adjustment



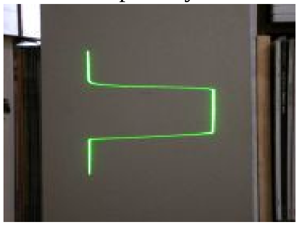
When apply a square wave for Y-axis and a saw wave for X-axis, the step response of Y-axis will be projected. This means less phase compensation. When it is too much, pulse edges will be dulled.



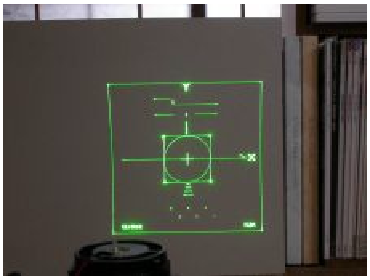
Minimize the ringings with LFD trimmer-pot for low frequency (1st poll) compensation. Left small ringings can be removed with HFD trimmer-pot for high frequency (2nd poll) compensation.



Y-axis is adjusted perfectly. Now, you will able to find an asymmetry between rising edge and falling edge. This is due to asymmetry between source and sink capability of the LM675.

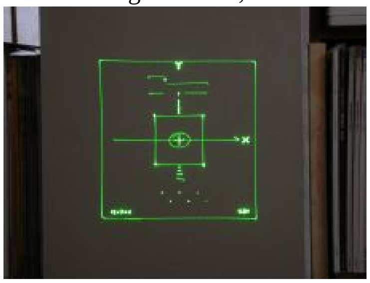


Adjust X-axis in same way. The pulse test can express the step response better than square test. The pulse width is 8 ms for these tests.



ILDA 12K@20°

This is a magic circle..., rather an ILDA test pattern. For more information about this, refer to the link in tech notes.



ILDA 30K@8°

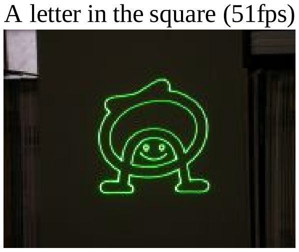
My scanner could not achieve ILDA 30K standard. Who will reach this goal first? :-)

ILDA 18K@8°

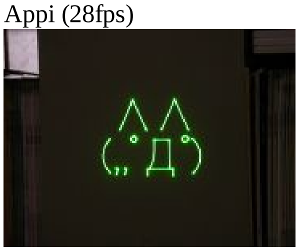
It seems the limit of my scanner is ILDA 18K, still it is sufficient performance for hobby use.

Various laser graphics

A letter in the square (51fps)

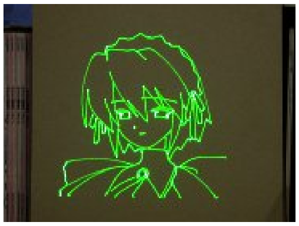


Appi (28fps)

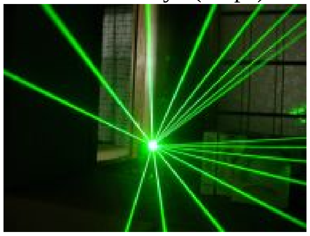


Giko-cat projected on the wall from distance of 60m (38fps)

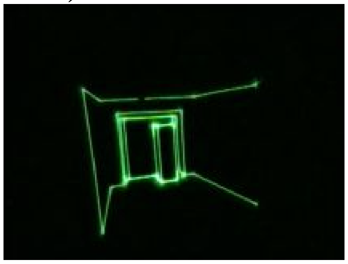
It can also project on the cloud!



Yuki Kotonomiya (12fps)



For in-door light show, oil mist generators called Hazer are used to improve beam visibility and to minimize the laser power. Mosquito coils also work well :-)



Sample frame set from International Laser Production. (frasamp.avi)
Generated 3D frame. (crown.avi)

Technical Notes and Related Links

Specs (ver.2)

Controller	MCU: ATmega64 (Atmel) Data Memory: MMC/SD LCD, X-Y outputs, Modulation output
X-Y Scanner	Speed: ILDA 18K @8°, ILDA 12K @20° Working Deflection: 80° (optical) Mirror Size: 5×8 [mm]
Laser Unit	Wave Length: 532nm(Green) Output Power: 20mW Modulation Input: TTL
Power Requirement	Controller/Laser: 5V/1.5A X-Y Scanner: ±20V/1A
Power Consumption	Idle: 7W Working: 22W (ILDA 18K @8°)
Dimensions	240(W), 150(D), 40(H) [mm]
Weight	1.0kg

Reference

- Updates Feb 12, 2006
- Controller board (ver.1), Circuit diagram and Firmware.
- Controller board (ver.2), Circuit diagram and Firmware. Feb 12, 2006
- Servo amplifier board (ver.1), Circuit diagram, Step response(P3.1:P3.2:TP4, @8°), Step response(TP4, @30°), 120Hz sqare wave response (TP2:TP4, @8°), 400Hz sin wave response(TP2:TP4, @8°)
- Servo amplifier board (ver.2), Circuit diagram Feb 12, 2006
- Circuit diagram for scanner power supply
- Galvanometer and its Circuit diagram
- Control circuit of Green laser unit
- Frame Editor for Win32 [mkv2.zip] Aug 16, 2006
- Source files for Frame Editor [mkvsrc.zip] Sep 2, 2011
- Development Diary [ja]