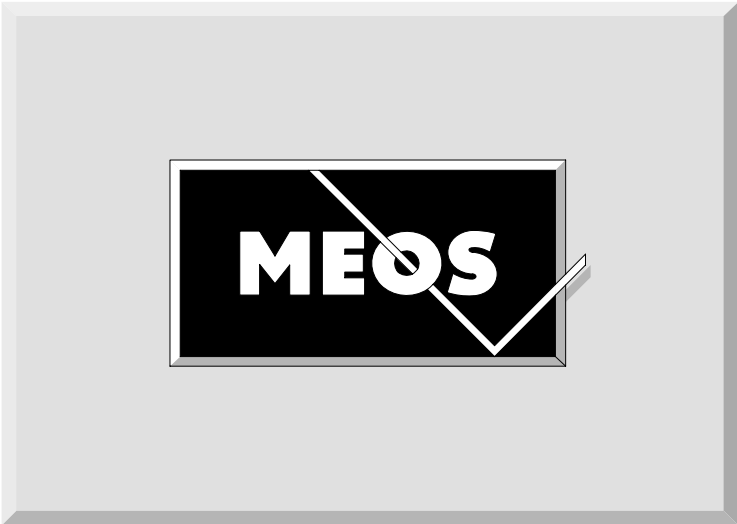
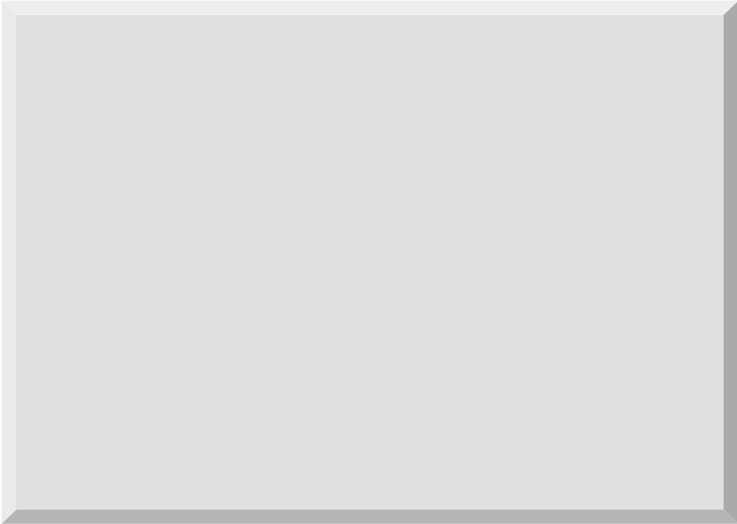
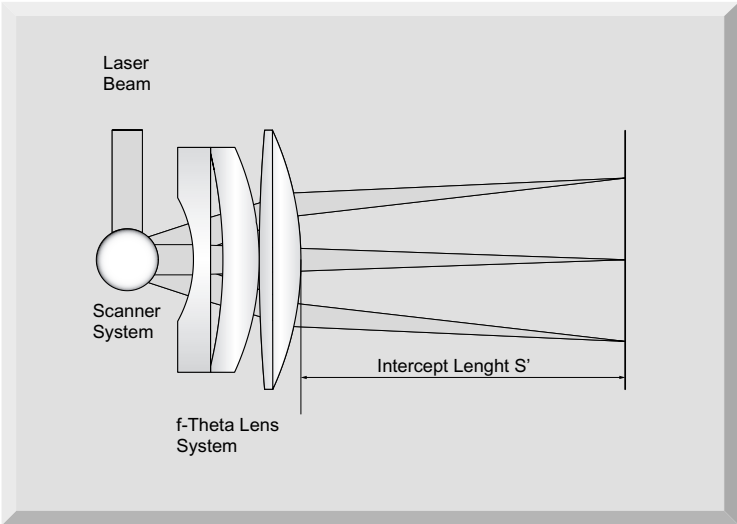
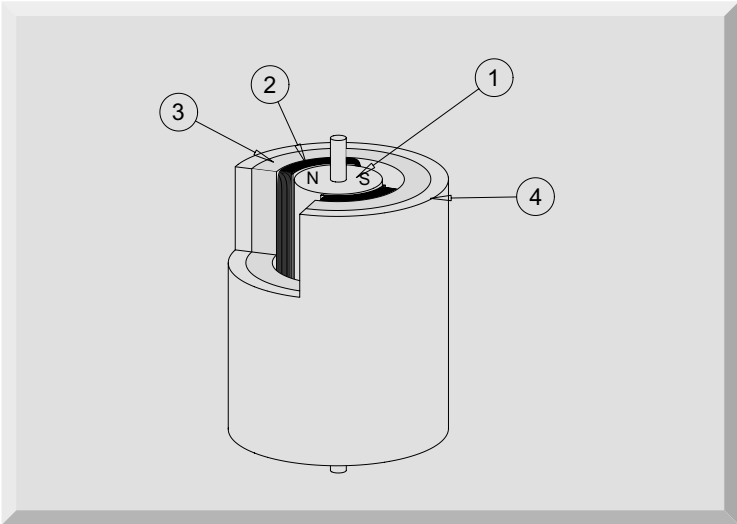


EXPERIMENT 28

LASER Scanner



1.0 Introduction

Fast and precise scribing or writing of information became a topic since the computer invaded the market. More and more so called Laser printers are replacing the existing printers technology. Another field of application in industry is the scribing on objects of mass production. In this case powerful Lasers are used to scribe permanent information into metal, plastic, paper etc. Last but not least Laser scanner will be used for the next generation of colour TV and large displays and they are even used for entertainment on festivals like the Olympic games and in modern discotheques. To generate arbitrary pattern the Laser



Thomson Galvanometer 1870

beam must be detected in two orthogonal directions as it is known from TV or oscilloscopes. Generally one has to distinguish two main fields of application, one is the fast material processing and the second is the entertainment. For the material processing it is necessary in almost all cases to focus the Laser beam onto the surface to

be processed. With simple lens systems this cannot be achieved since the location of the foci lies in the plane of a sphere. A special optical system has been designed to image the focus always in a plane and is termed as $f\theta$ lens system. For entertainment like Laser light shows etc. a focusing of the beam is not required. However for both applications the same beam detectors, so called Galvo scanner are used. This name stems from the historical Galvanometer, a moving coil instrument where a mirror was attached to the torsion band of the coil. Such instruments were used to demonstrate slow varying electric currents. The Galvo scanner use the same principle however, they are designed for rapid movement of the attached mirror. Instead of using a torsion band electromagnetic forces are applied. Commercial Galvo scanners are supplied with closed loop circuits to make sure that the desired position will be reached with high precision. Within this course an open frame Laser scanner system with two scanning mirrors, one for the X the other one for the Y direction including the necessary control electronics and personal computer are used to become well experienced in this exciting field.

2.0 Fundamentals

In principle the fundamentals to understand a Laser scanner system do not require a lot of basics, however the technical development of galvo scanner including the driver electronics as well as the software is a broad field which is still under investigation towards the way to Laser displays for large TV screens. It should be mentioned that for the time being, the mechanical scanner are still in use, especially for Laser engraving or marking as well as for professional Laser light shows. For this purpose the set-up is

equipped with professional software to create and perform Laser light shows and templates for Laser marking.

For the understanding of the concept of the galvo scanner the next following chapter gives an introduction to the basics of this devices.

2.1 Galvo Scanner

Galvo scanner are seeming to be a remnant of the times where the electrical current has been measured by means of moving coil instruments. Although a high precision has been achieved with such instruments the availability of digital operating instruments immediately removed the fine mechanical instruments from the market because they were expensive and sensitive against mechanical stress. Nowadays digital voltmeter are available with extreme high precision at affordable prices. Nevertheless the mechanical galvo scanner survived and it seems that they are still best choice for the application discussed here.

To understand the concept of a galvo scanner we will start with the explanation of moving coil instruments.

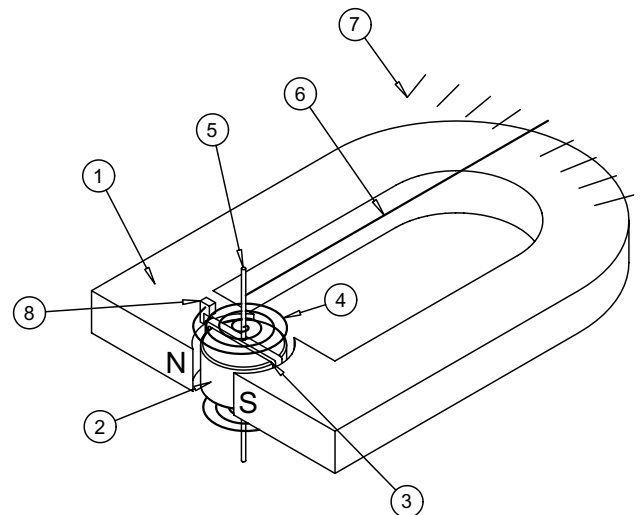


Fig. 1: Moving coil instrument

The basic idea is to exploit electromagnetically forces to generate an angular motion. For this purpose a moving coil (3) is placed inside a permanent magnet (1). By means of a spiral spring (4) which is fixed to the axis (5) the electrical current is supplied to the moving coil. The same arrangement is attached to the bottom side of the coil. Beside the transport of the electrical current to the coil the spiral springs are also used to balance the electromagnetically forces which appear when the current to be measured is flowing through the coil against its restoring force. A soft iron cylinder is mounted symmetrically between the curved pole pieces and generates a radial field distribution. The size of the gap between the cylinder and the pole pieces allows the coil to move freely inside the radial magnetic field. From the basics of electromagnetically phenomena we know that a current $\vec{u} \times \vec{j}$ always generates a magnetic field \vec{H} like:

$$\nabla \times \vec{H} = \frac{\partial \vec{D}}{\partial t} + \vec{j}$$

Since we consider here only conductors we can neglect the displacement field D . From the equation above we conclude that a linear current density which is present in a straight conducting wire, generates a curled magnetic field as shown in Fig. 2. If however the current flows in a curled conductor as it is the case of a coil then the generated magnetic field becomes linear.

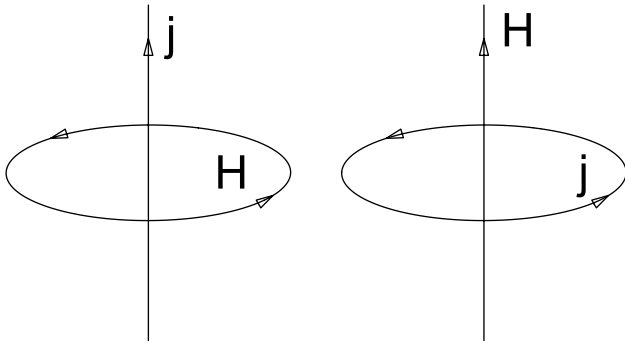


Fig. 2: A linear current j generates a curled magnetic field and a curled j generates a linear one

In the moving coil instrument the current flows in a curled manner thus generating a linear magnetic field H or magnetic flux density B . The superposition of the magnetic fields generated by the current flux and the permanent field results in a torque T of the moving coil:

$$T = N \cdot A \cdot I \cdot B$$

whereby N is the number of turns in the coil, A the area of the cross section of the coil, I the current flowing through it and B the magnetic flux density inside the gap. The torque T tries to turn the coil in such a way that the overall magnetic flux density becomes a maximum. However the spiral springs are generating a restoring torque T_r , which goes linear with the angular deflection α , i.e.

$$T_r = c \cdot \alpha$$

whereby c is the spring constant or the material property of it. The equilibrium is reached when both torques having the same value:

$$T = T_r \rightarrow \alpha = \frac{N \cdot A \cdot B}{c} \cdot I$$

From the equation above we can see that the deflection angle α is proportional to the current I flowing through the coil. All other parameters are system constants of the particular instrument. The intentional use of such an instrument was the measurement of a steady flowing current. But we want to exploit such an instrument for fast angular movements. Instead of attaching a pointer to the moving coil we try to attach a mirror to the spindle, which indeed has been done for the high precision mirror galvanometer and for so called light beam oscilloscopes. The basic idea of the mirror galvanometer was to increase the sensitivity. In Fig. 4 such a system is shown, where a light beam is deflected by means of an attached mirror. If the moving

coil rotates by the angle β , then the deflected light beam is deflected by 2β due to the reflection laws. Up to now we assumed that the current I which flows through the coil is slow varying in time so that the pointer or beam could follow the changes.

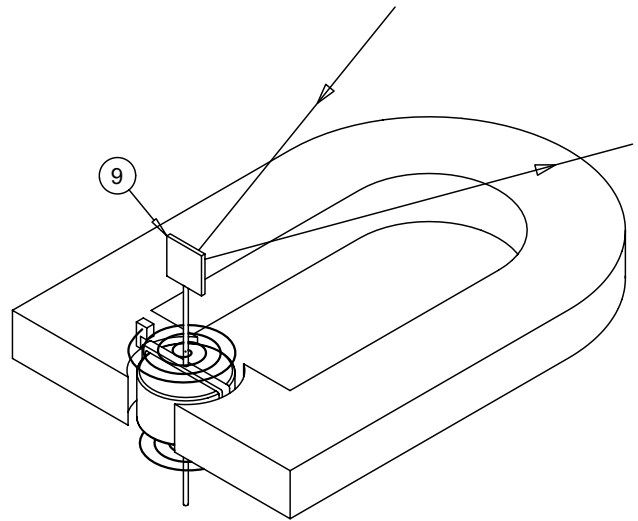


Fig. 3: Moving coil instrument with attached mirror

If we are now going to demand that the pointer or mirror has to follow also fast variations of the current we have to consider the dynamic of the system. In a first approximation the system consists of a mass and a spring which is driven by an external force.

$$\Theta \cdot \frac{d^2\alpha}{dt^2} + k \cdot \frac{d\alpha}{dt} + c \cdot \alpha = K_0 \cdot \cos(\omega \cdot t)$$

inertial + friction + restoring = driving torque

The equation above represents the differential equation for forced oscillation. Depending on the individual parameters as inertial moment, frictional (k) and restoring constants (spring constant c) such a system operates in four different modes:

1. Resonant mode
2. Damped oscillation
3. Maintained oscillation
3. Aperiodic mode

depending of the value of the relative damping factor γ :

$$\gamma = \frac{k}{\sqrt{\Theta \cdot c}}$$

We expect from a proper scanner, that it follows with highest possible speed the variation of the current I . This can only be achieved in the beginning of the aperiodic domain (critical damping), that means that a short and small overshooting of the desired mirror position occurs. For this case the following equation must be true:

$$k = 2 \cdot \sqrt{\Theta \cdot c} \text{ or } \gamma = 2$$

However, in this mode the amplitude decreases with

increasing frequency. To extend the range within the amplitude does not drop to much for higher frequencies the resonance frequency ω_R of the system:

$$\omega_R = \sqrt{\frac{c}{\Theta} - \frac{k^2}{\Theta^2}}$$

should be designed as high as possible. This can be achieved by reducing the friction (k) or the inertia moment of the rotating coil. That means that actually the mass of the coil must be reduced. But here we are faced with the problem that reducing the mass finally means reducing the mass of the used conductor. For this reason aluminium instead of copper is used. In more advanced systems therefore moving magnets are used. This has the advantage that no electrical connections to the moving part are required and furthermore it lifts the limitation of the maximum power which can be introduced into a moving coil. We have to consider that the current which flows through the coil produces besides the magnetic field also heat of power $P=I^2/R$ where R is the resistance of the coil. The coil is moving inside an air gap. Next to total vacuum air is the worst thermal conductor. The only real heat sink for the coil is the pick-off structure. The heat therefore is mainly dissipated by convection to the pole pieces. Consequently the main failure of moving coil scanners is the coil burn out and degradation of the permanent magnet. It has been verified that two major problems are limiting the performance of such scanners:

1. The thermal limit defined by the heat transfer capabilities of coils and the Curie temperature of the magnet
2. The coil creep and deformation of the coil under centrifugal acceleration

A moving magnet system solves the problems of both burn out and magnet degradation. The principle of such a system is shown in Fig. 4 .

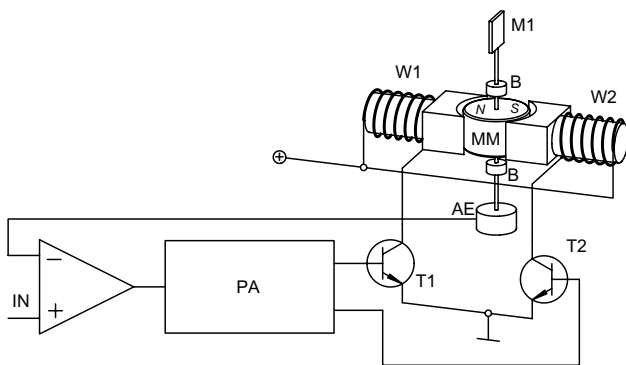


Fig. 4: Moving magnet arrangement

A permanent magnet (MM) is placed in the centre of two pole pieces which are supplied with two coils W1 and W2 which are thermally connected to the housing. High torque and high duty cycles, however, still require proper heat sinking to avoid thermal overload. A proper design of the magnet guarantees consistent properties beyond 135 °C. Compared to moving coil systems this arrangement can

accommodate three times the power dissipation of equivalent inertia and torque constant.

A spindle is attached to the magnet which is fixed in position by means of two ball bearings (B). Instead of using a mechanical spring a servo loop with a position sensor (AE) and controller is used.

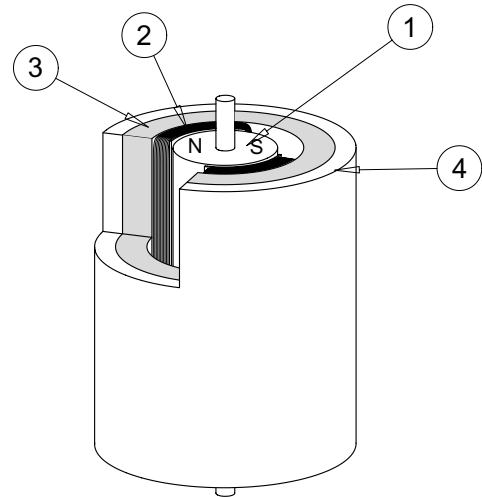


Fig. 5: Technical realisation of a moving magnet scanner

In the arrangement of Fig. 5 a cylindric permanent magnet (1) is used. Since the inertia of a solid cylinder is given by:

$$\Theta_{cyl} = \frac{1}{2} m \cdot r^2 = \frac{1}{2} \rho \cdot \pi \cdot L \cdot r^4$$

it is useful to use a cylinder which length is larger than the radius to obtain the smallest possible inertia.

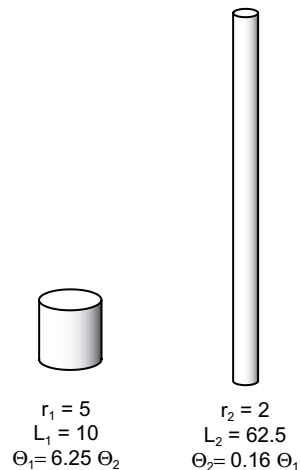


Fig. 6: Comparison of the inertia of two cylinders with equivalent volume

Permanent rotor magnets for scanners are manufactured from an alloy of Neodymium, Iron and Boron. This compound allows the strongest possible magnets for the time being. A small air gap is between the magnet and the coils (2) which are wound around the pole pieces of the return piece (3). The housing (4) is used as heat sink.

In this project are scanner used which has been manufactured from Cambridge Technologies, one of the leading manufacturer of optical scanners. The newest generation of the scanner are using optical instead of capacitive position decoder.

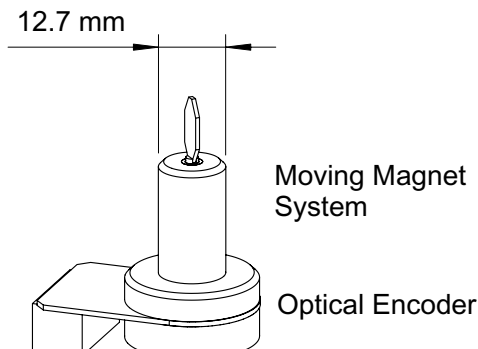


Fig. 6: Actual size of the scanner (Model 6800HP) used within this project

For more details about the scanner please see the attached instruction manuals for the scanner (Model 6800HP Galvanometer Optical Scanner) as well as the scanner drive electronics (6800/CB6588 Mirror Positioning System).

2.2 F-Theta Lens

A Laser beam which is deflected by a rotating or scanning mirror has an inherent circular plan

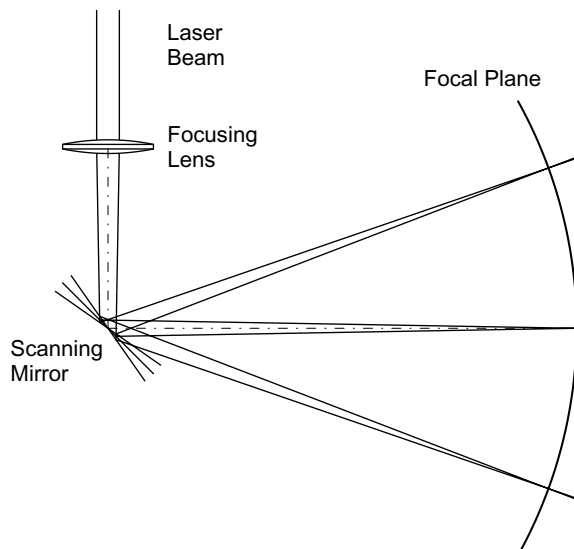


Fig. 7: Circular plan of deflected Laser beam

In Fig. 7 a laser beam is shown, which has been focused by means of a focusing lens. Due to the rotation symmetry of the scanner the foci of the deflected beams will be imaged in a circular or spherical plan. However, for engraving, labelling, phototype setting and material processing on plan work pieces such an arrangement will produce structures with different line width, especially for larger scan angle. To correct this behaviour so called f-theta lens systems (Fig. 8) are used. This lens system is a very special optical system which only a few in the optical community know how to design and fabricate. Commonly the

f-theta lens is designed for a specific laser wavelength and focal distance. Within this project a f-theta lens manufactured by Rodenstock designed for 532 nm with a focal length of 100 mm is used.

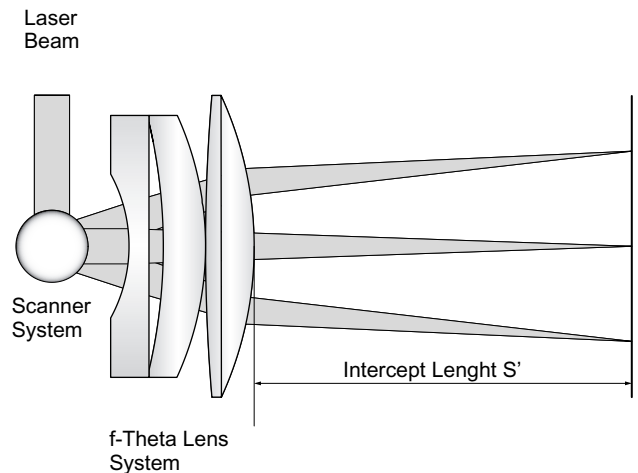


Fig. 8: Three Element f-Theta Lens system

The lens system is optimised in such a way, that for each scan angle θ the foci are located in a plan. The requirement for this is, that the so called f- θ condition must be fulfilled:

$$\text{Intercept Length } S' = F(f \cdot \theta) = \text{const.}$$

To design such a system Optics Engineers are using so called ray tracing software to optimise a basic layout. As free parameters the radii of curvature, the index of refraction and the spacing of the lenses are used for optimization. However, it should be mentioned, that the real art of the design is to find a solution which is not too sensitive against manufacturing tolerances. After creating the theoretical layout the Engineers are varying the variables within the production tolerances and study the tolerance of the final specification like the quality of the f- θ condition, minimum laser spot size and also the optical transmission. The f- θ lens system used in this project is optimised for the following specifications:

Wavelength	532 nm
Intercept Length S'	111.4 mm
f- θ condition accuracy	better than 0.1 %
Total scan angle θ	$\pm 25^\circ$
Entrance beam diameter	8 mm
Spot diameter (1/e ²)	12 μm
Transmission	> 90%

If the requirement concerning the resolution are even higher, as it is the case for phototype setting machines, then so called telecentric f- θ lens systems are used. This optics are further optimised in such a way that the deflected beam is always perpendicular to the plan to avoid elliptical beam deformations which will still occur in "simple" f- θ lens systems.

3.0 Experimental Set-up

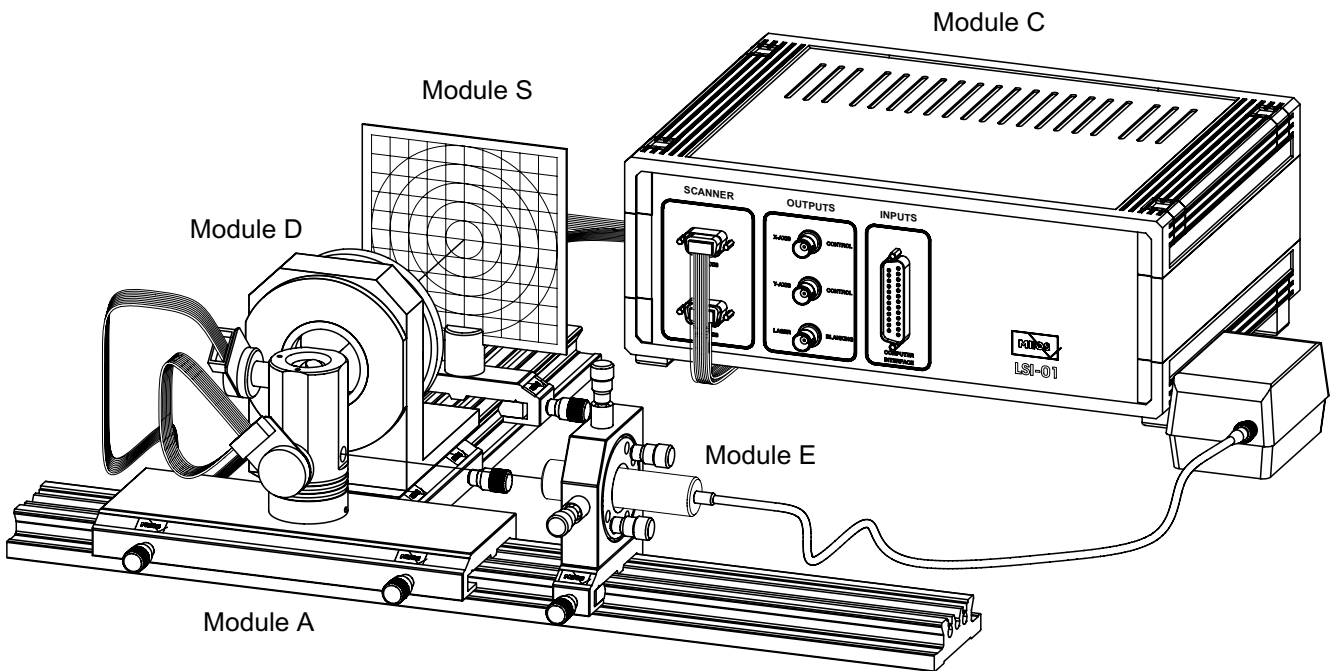


Fig. 9: Complete set-up without PC

For transport safety reason the sensitive and costly scanners are dismantled, so that after unpacking the system they have to be mounted to its holder Fig. 10 (1).

Step 3.: Place the holder for the f-θ lens onto the T-carrier piece as near as possible to the scanner holder and fix it with the M6 Allan screw.

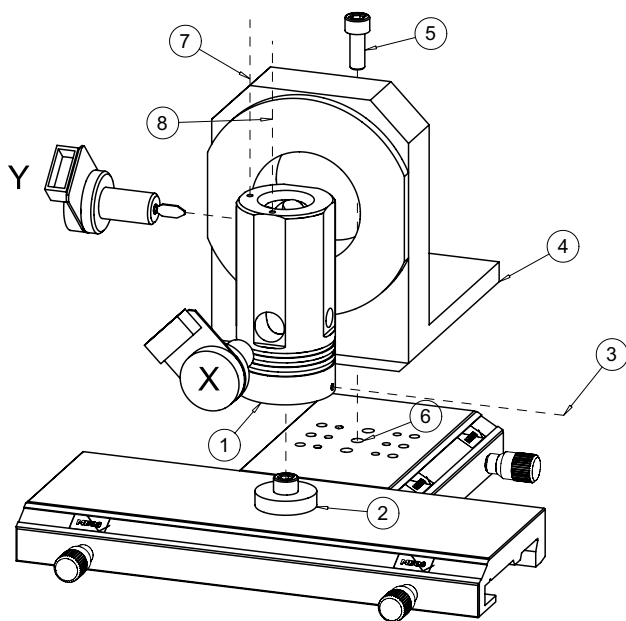


Fig. 10: Assembling of Module A

Step 1.: Place the scanner holder (1) onto the T carrier piece and clamp it by means of the tap bolt (3) to the holder (2)

Step 2.: Insert the scanner according to their marking (X and Y) into the mounting holes of the holder (1). Fix slightly the tap bolts 7 and 8. The scanner will fixed completely after they have been adjusted by means of the Laser beam.

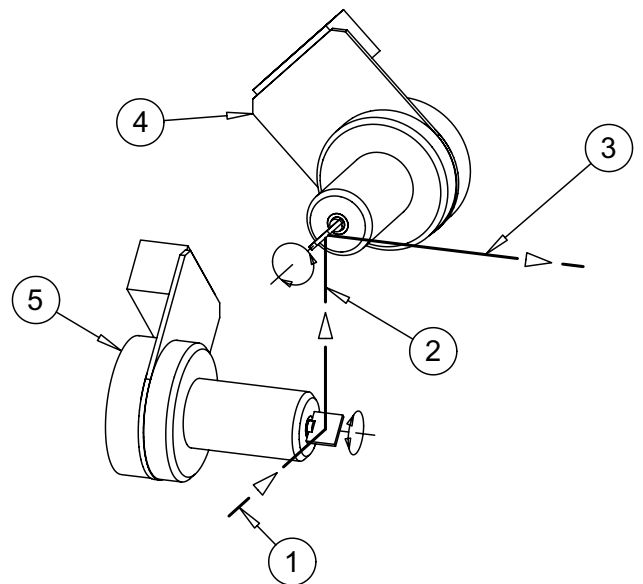


Fig. 11: XY - Scanner and Laser beam

The beam (1) of the provided Laser is bend by 90° by the mirror of the X-scanner (5) to the mirror of the Y-scanner (4).

Finally the beam (3) leaves the scanner assembly perpendicular to the incoming beam (1). In the last step of the set-up procedure the scanner will aligned in such a way, that the mirrors will be hit in their centre and the beam leaves the scanner holder centrally to the f-θ lens.

The system comes with all necessary tools for the alignment procedure. Before the alignment will be discussed, each module is described in the following.

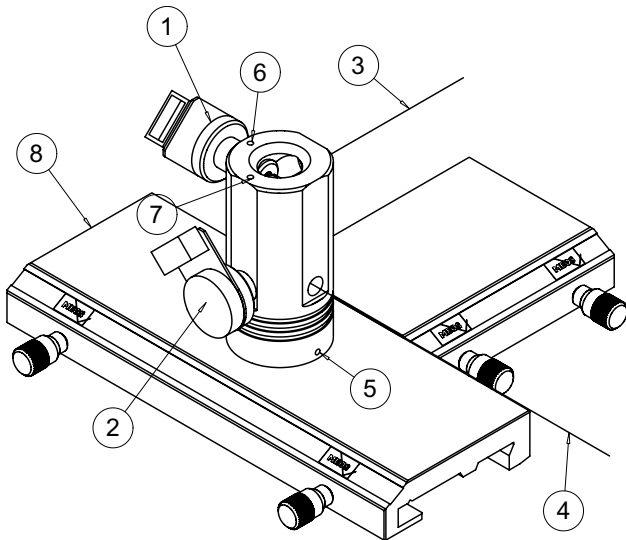


Fig. 12: Module A Laser Scanner

The scanner holder is mounted to the T carrier piece and can be turned around its vertical axis when loosening the stud bolt (5). The scanner for the X - coordinate (2) is fixed by means of a stud bolt (7) and that one for the Y coordinate (1) by the screw (6). The laser beam (4) enters the scanner assembly and leaves it in the direction of (3).

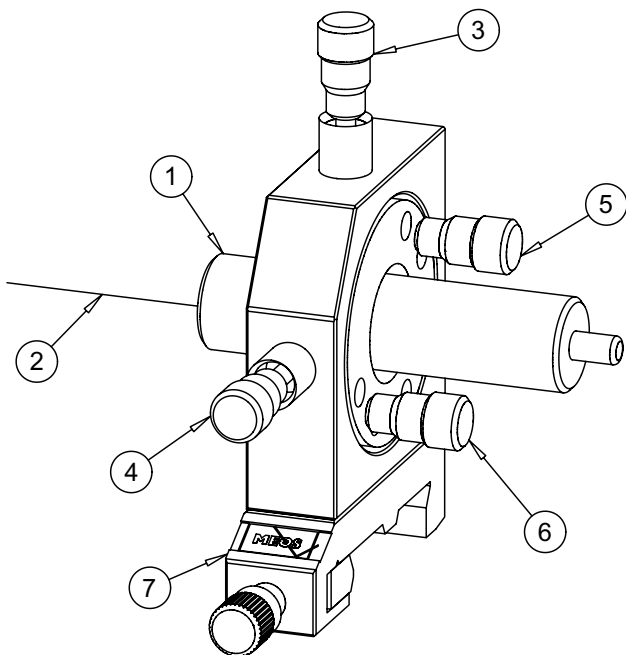


Fig. 13: Green (532 nm) emitting Laser

As Laser source a modern diode laser pumped solid state Laser with frequency doubling is used. The emission wavelength is 532 nm and the output power is 1.5 mW. The Laser (1) is mounted into an adjustment holder (7) which is placed onto the provided optical rail of 500 mm length. By means of four fine pitch adjustment screws the laser beam can be adjusted in the X (4) and Y (3) axis and tilted horizontal (5) and vertical (6).

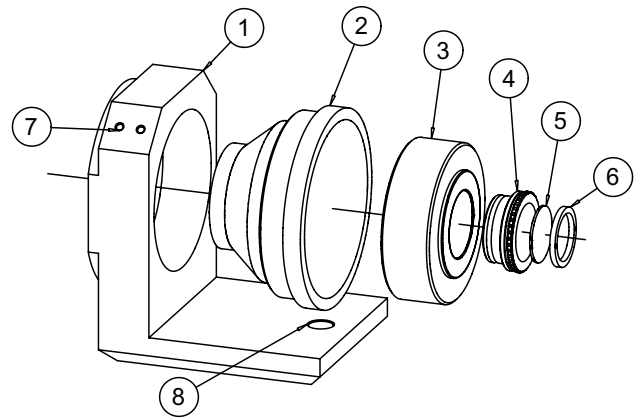


Fig. 14: Module D f-θ Lens Holder

The holder is fixed by means of a M6 Allan screw (8) to the T-piece carrier. The f-θ (2) as well as an ordinary plan-convex lens (5) can be attached to the holder (1) and fixed by stud bolts (7). The plan-convex lens (5) is mounted into a click mount (4) by means of threaded rings. The click mount (4) is inserted into the holder (3) where it is fixed in its position due to spring loaded balls. Either the simple lens with a focal length of 100 mm or the high sophisticated f-θ optics will be used during the experiment.

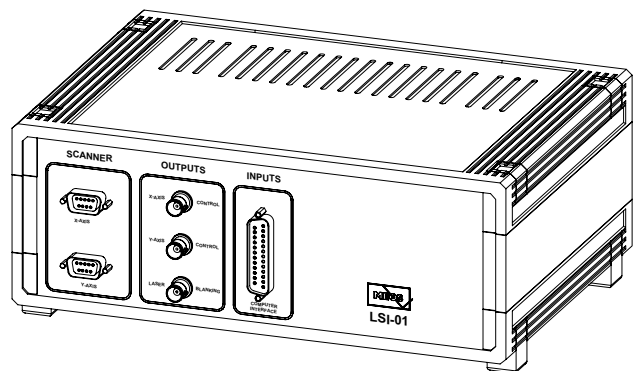


Fig. 15: Module C Scanner Amplifier

The scanners are connected to the power amplifier with a at line terminated on both sides with 9 pin sub D connectors. To monitor the individual scanner signals, two BNC connectors are provided at the front panel in the section "OUTPUTS". For blanking the laser beam an additional output is provided which will be connected to the power supply of the Laser. For this purpose the cable which is terminated on one side with a mini BNC connector is used. Finally the power amplifier is connected with the supplied 25 pin connection cable to the scanner controller board which is built into the PC which is either supplied as an option or by the user. The mains switch and connection is located at the rear panel of the power amplifier. For the operation and control of the scanner the professional software from Pengulin is used. The installation of the scanner PC board and the software is described in the attached manual of the manufacturer of the board as well as the software.

3.1 Alignment of the system

- 1.) Install the scanner board and the software
- 2.) Switch off the computer
- 3.) Connect the scanner to the power amplifier by means of the at lines. (Make sure that the amplifier is switched off!)
- 3.) Connect the Computer Interface of the power amplifier to the scanner board
- 4.) Switch on the power amplifier. The scanner are no powered and turned into their zero position
- 5.) Switch on the Laser without connecting the blanking input to the power amplifier
- 6.) Move the Laser to the nearest position to the scanner assembly. Align the beam centrally to the entrance hole.
- 7.) Move the Laser to the farthest position on the rail and align the beam centrally to the entrance hole.
- 8.) Repeat step 6 and 7 to make sure that the beam travels parallel to the optical axis of the set-up.
- 9.) Check if the beam hits the mirror of the X-scanner in its centre and if the mirror is aligned under 45° so that the de ected beam hits the Y-mirror in its centre. If not realign the X and Y scanner in its holder until the beam leaves the scanner assembly and centrally passes the f- θ lens holder.
- 10.) The system now is aligned and ready to use the provided software. For this purpose the computer is switched on and the software is loaded.

The Penguin Software provides a rich variety of controlling the scanner. To take advantage of it, it is recommended to study the software description which is available either in the implemented Help system or as PDF files on the CD. The fundamentals are given within this manual on the following pages.

3.2 Measurements and Performance

It should be mentioned, that the scanner amplifier are already tuned to best performance and the software allows full control on offset, image size and ratio. Further more the software can be used to produce own Laser light shows as well as own defined patterns for material processing. Depending on the goals of the training many different tasks can be performed. The following list gives some examples for orientation.

3.2.1 Laser Scanner Properties

1. Determine the scanning angle
2. Measure the scanning amplitude versus the input voltage
3. Record the linearity
4. Measure the frequency response curve
5. Figure out the difference of raster and vector scanning
6. Check the scanner with ILA test pattern

3.2.2 Use of f- θ optics

1. Explain why f- θ optics are necessary and what they are doing
2. Set-up the system with the f- θ optics
3. Generate a test pattern
4. Use the screen to observe the pattern. If a digital camera is available, make shots from the pattern of the test screen
5. Set-up the system with the simple 100 mm plan-convex lens
6. Compare both optics and explain the difference if there is any

3.2.3 Laser Light Show

1. Without doubt this topic finds the highest interest of the students (and not only). The system can be used to generate and perform a Laser light show with all possibilities of modern software.
2. Generate the logo of your educational institution, let it turn, move etc.
3. Expanding the system with a sound card increases the even more the excitement.
4. To take advantage of the software possibilities, the study of the manuals (PDF File) or the implemented Help system is recommended.

4.0 LASER GRAPHICS FUNDAMENTALS

If you haven't worked with laser graphics before, there are a few things you need to know to get the best results. This Help file discusses how laser graphics differ from standard computer graphics, and what special considerations apply to designing, drawing, editing and displaying your laser images.

General topics:

Vector graphics vs. raster graphics
Optimizing your laser projector
How to draw effectively in laser
Synchronizing audio with visuals
Multimedia techniques (article by Mike Murray, Taylor Planetarium)
3D stereoscopic techniques

Of special interest:

The ILDA Test Patterns
Pre-emphasis circuit improves scanner performance by 50%
The 12,000 points per second speed limit
Tables showing scan angle, distance and width

Latest features (be sure to check this each time you get an update from Pangolin)

VECTOR GRAPHICS VS. RASTER GRAPHICS

Almost all computer graphics are raster graphics. This means the image is drawn out, line by line -- the same way a television screen draws. Every single pixel on the screen is either turned on or turned off, around 30 times per second.

By contrast, laser images are primarily vector graphics. The image is drawn from point to point -- the same way you'd draw with a pen. Computer plotters and specialized video arcade games such as *Asteroids* and *Star Wars* are examples of computer vector graphics.

Laser vector graphics have these special characteristics:

- Brighter than raster
- Simpler than raster
- Less detailed than raster
- Can flicker

Technical note

In this Help file, the term "vector graphics" is used in its broad sense to describe standard laser shows. There are two points which might be confusing, so let's clear them up before proceeding further.

- Standard laser projectors can now do some raster-type graphics. In 1995, Pangolin and Lightspeed Design Group co-invented a technique for making TV-like laser raster frames. Although this can be a powerful effect, most laser imagery is still vector graphics.
- Do not be confused over the terms "point-oriented" and "vector-oriented", which are used for two types of Lasershow Designer frames. The difference is in how they store data internally -- as points or as a list of vectors. But in terms of this Help file, they both create the laser-projected graphics discussed in the following topics.

Vector graphics are brighter

With raster television graphics, even if a picture is 90% black, the electron beam still scans across all pixels. However, in vector graphics only the image lines themselves are scanned.

This gives brighter images, since the laser beam does not need to scan every single pixel. It also means a high contrast ratio. The background is never scanned -- only the image area.

This is why laser graphics often seem to "float" in a planetarium dome. The dome "disappears" due to the high contrast ratio.

Vector graphics are simpler

Vector graphics are generally simpler than raster graphics. This can be good. Instead of storing the color of every single raster pixel, only the endpoints of lines need to be stored. Vector files are typically hundreds of times smaller than raster files.

Unfortunately, there is a large disadvantage to vector's simplicity. It is very difficult to do vector area fills. Two dimensional images almost always are outline drawings, whether done on a computer plotter, vector arcade game, or laser projector. Three dimensional objects are almost always shown in wireframe, where just the edges of the object are drawn.

So this is one of the compromises you make when creating laser graphics. Most of your drawings (except for laser raster frames) are going to be cartoon-like outlines.

About CRTs

A television tube is a Cathode-Ray Tube (CRT). Electrons are shot from one end onto the CRT face. Magnets steer the beam to create vector images, such as those in oscilloscopes, or raster images, such as those in televisions.

Vector graphics are less detailed

Laser scanners are much slower than CRTs. The scanners and scanner amplifiers cannot change direction fast enough to draw complex images in 1/30 second. Typically, scanners can only draw about 50 to 100 accurate vectors (lines) in a single image.

The result is that you can't do detailed drawings with a single set of scanners. To take one example, a client might come to you wanting her company name, "Acme Hardware and Software Incorporated", plus a complex logo all in a single frame. While this is simple for raster graphics, this just can't be done well in laser. (Her company name alone would take about 50 vectors in a simple, stick-type font.)

Therefore, you need to plan frames and animations so the information is simplified, broken into multiple frames, or both. In the example above, you could have each word fly in separately, with a simplified logo as the final image.

It is up to you to communicate early to your clients that they should not expect sophisticated movie- or TV-style computer graphics. More than one laser company has lost a client because of unrealistic expectations on the client's part.

Laser vector graphics can flicker

The "trick" that makes any kind of scanned image work, whether raster or vector, is the eye's persistence of vision. If an image is presented around 60 times per second, the eye sees it as a single image rather than a sequence of frames. Less than this, and the image appears to flicker.

The problem of flicker is especially crucial to laser graphics. The more detailed the image, the longer it takes to scan, and the more likely it is to flicker. There is no absolute number of points or scan speed that is best. Flicker differs depending on the brightness of the laser, the ambient (room) lighting, and even personal sensitivity.

Unfortunately, many people in the laser industry are relatively insensitive to flicker. A general audience will be more sensitive to flicker, so you should always err on the side of caution. If it looks just "OK" to you, it may be too flickery for someone else. Laser companies have sometimes had to scrap frames or entire shows because the client could not accept the flicker.

Speed, detail and flicker -- The Iron Triangle

So how can you get the best images? By paying attention to the interlocked factors of speed, detail and flicker. There is an "iron triangle" which dictates that you can get two out of three of these, but not all three at once.

For example, if you increase scanning speed, the flicker rate goes down -- but you lose detail. If you decrease scanning speed, you gain detail -- but the flicker rate goes up.

Let's take an example of a map. This is a good example because a map can be drawn with great detail -- all the bays and peninsulas -- or in a broad outline, and still be recognizable. You can actually try this example with some of the world map frames included in your Lasershow Designer system.

The "iron triangle" says that you can only get the map quality to a certain point, no matter how much detail you put into it. Say that you draw a detailed map, using 2000 points. If you scan it slowly, you see all the details -- but it flickers. As you speed up the scan rate, the scanners can no longer track every shifting point, so the map starts to round off and be simpler. At a flicker-free rate, the 2000-point map looks just like a simpler map digitized with only 500 points.

The important lesson is this: **For any given set of scanners, you can only scan so much information, and no more.** There is no point in digitizing every detail if the scanners can't display it.

At Pangolin, we have seen objects drawn with so many points that on the computer monitor, every point overlapped. This detail does not help, and is computationally and memory inefficient - why use 1400 fast-scanning points when 700 better placed slow points do the same job? (This is the theory behind Lasershow Designer's Renumber feature. Many frames can have dozens or hundreds of points removed, decreasing flicker, without significantly affecting the quality of the image.)

See also:

The 12,000 points per second speed limit

About laser raster frames

Until 1995, all graphics on standard galvanometer-based laser projectors were cartoon-like vector frames. In that year, Pangolin and Lightspeed Design Group co-invented a technique for easily making raster frames.

In some ways this was a breakthrough, since for the first time photorealistic images could be projected. (In fact, it won an ILDA Award for technical achievement in 1996.) But raster frames will not supplant vector images, for these reasons:

- **Limited resolution.** A typical image is formed with only 40 laser pixels on 40 lines. This 40 x 40 resolution is quite limited, compared with a computer screen of 640 x 400 pixels. This means the source image must have very little detail.
- **Difficult to do moving images.** Using Pangolin's current implementation, animations are difficult. First, it is currently cumbersome to load in individual still pictures and convert them to raster. Second, it is memory-inefficient since each must be stored in the computer (unlike vector frames, where Showtime can do manipulations to a single frame in realtime, requiring only one source frame). For these reasons, most LD raster animations are limited to a few seconds.
- **Limited colors.** In the current version of Lasershow Designer, there are only 256 laser-projected colors available in the system at any one time. A single raster frame can use up all 256 of these colors. Any further raster frames will have their colors "best-fitted" to match the available colors, but this may not cause an accurate color match.
- **Small projected size.** Raster frames cannot successfully be projected beyond a certain size. This size depends on the width of the laser beam at the screen. Generally, raster frames look best when the blank area between each laser-projected raster line is the same or smaller than the beam width. If the gaps between raster lines is too wide, it is harder to discern the picture. Thus, raster frames are always smaller than the maximum scan area.

Consider what would happen if there was a perfect laser raster system. It would have high resolution, easily do moving images, and have a wide variety of colors. In fact, it would be just like laser video! In essence, the laser is now merely a light source for standard video sources. Once you have a laser video projector, the same problems of raster video (relatively low brightness, relatively small size) are now present.

Summary

In terms of this Help file's discussion of vector vs. raster frames, the majority of standard laser show projectors still will be doing vector-type frames for the foreseeable future. While LD's raster frames are great special effects, most frames in a show will be vector.

OPTIMIZING YOUR LASER PROJECTOR

Laser graphics require top-flight equipment to get the best images. Step number one in optimizing your laser graphics system must be to ensure the highest performance from the existing scanners. If your scanners are not at their best, you'll waste time and resources trying to compensate for poor performance.

The goal is to have the scanners go as fast as possible while remaining accurate. This means you put up a test pattern and align your scanner amps to meet a standard. Use an industry-standard test pattern and an industry-standard scan speed. Instructions are elsewhere in this document.

If your scanners are already pretty well tuned, there's no point in re-tuning from scratch. Simply fine-tune to meet the standard.

If your scanners are far out of tune, it is best to start from scratch. To do this, follow the instructions that came with your particular scanner amps. Be careful and conservative, since some scanners can be damaged by improper tuning procedures. If you're unsure, seek help from your scanner amp manufacturer or someone experienced.

Setting a tuning size and offset

Scanners should be tuned for a particular scan angle. If you often do shows on the road, tune using the widest angle you expect to use. If you're at a fixed location, tune using the maximum size of your screen or scan field.

If you're starting from scratch, though, don't start right off at this size! Usually the tuning instructions tell you to gradually turn up the gain controls, so you slowly approach your maximum size.

Be sure to set your offset to the null position in the center of the scan field, unless your projector situation requires a constant offset (as it might in a fixed location).

Introduction to the ILDA Test Patterns

The International Laser Display Association (ILDA) has established two standard scanner tuning speeds:

- If you have slower scanners, tune when the 12K Test Pattern is projected at 12,000 points per second.
- If you have faster scanners, tune when the 30K Test Pattern is projected at 30,000 points per second.

For Lasershow Designer users, these test patterns can easily be accessed from the LD Control Window menu "Instant test frames". They can also be found in the LD\Frames\Scantest directory.

Both patterns include in the center a square drawn with many points, and a circle drawn with a few points. The tuning goal is to get the circle the same size as the square -- it just touches the midpoints of the square's sides -- at a speed of either 12,000 or 30,000 points per second.

Note that Lasershow Designer's Scan Rate dialog (under Settings/ Projector/ Scan rate) has buttons pre-set for these speeds.

ILDA 12K standard All closed-loop scanners should be able to tune to the ILDA 12K standard. If you cannot, you may have a significant mis-tuning, excessively large mirrors, poor quality scanners or amps, or damaged equipment. Less expensive open-loop scanners can also reach this performance with specialized scanner amps such as the Accelerator 124. Pangolin feels that the ILDA standard is a minimum for representational laser graphics. If you can't reach this speed, your scanners are best suited for abstract graphics and beam positioning.

ILDA 30K standard This has become the standard for professional graphics. Currently, a speed of 30,000 points per second can only be reached by General Scanning G-120 type scanners when used with the Turbo Track scanner amp, and by Cambridge Technology model 6800 scanners. (Also, any projector which meets the ILDA Standard Projector specification *must* use 30K scanners.)

Intermediate 18K non-standard Some good quality scanner amp boards can go significantly faster than 12,000 pps, but cannot reach 30,000 pps. One such board is the CL150 single-channel board manufactured by Laser Artistry Inc. You may wish to tune to an intermediate speed of 18K. The only disadvantage is that you may find fewer sources of artware and laser clip art created for the 18K speed.

Pangolin strongly recommends that you use one of these three speeds. You'll be able to buy and trade frames much easier, and you'll be able to show your work on other projectors set to the same standard. Note that the Turbo Track board was specifically designed with two sets of speeds, so you can have both 12K and 30K available by changing a few DIP switches.

Tuning speeds only

The two ILDA speeds, 12,000 and 30,000 points per second, are standards *only for tuning to an ILDA Test Pattern*. ILDA does not have any standard speed for creating or displaying frames.

By tuning to 12K or 30K, you ensure that your scanners will work like anyone else's scanners. Once you have tuned using these speeds, you are free to create and display frames at whatever point rate you like. Setting a default scan rate is a complex topic discussed elsewhere in this Help file.

Using the ILDA Test Patterns

Both the 12K and 30K ILDA Test Patterns use the same tests. The only difference is that in the 30K Test Pattern, the tests are within a smaller square, not full-sized:

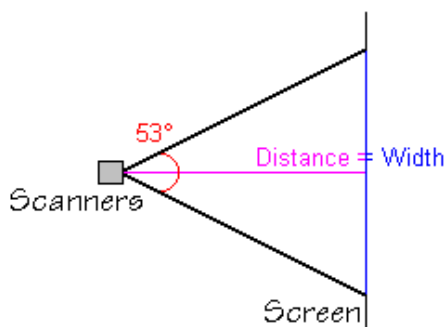
Let's go through the main steps you take in tuning to the ILDA Test Patterns.

Picking your tuning speed

You probably already know whether your projector should be tuned to the 12K or 30K standard. If not, see the topic Introduction to the ILDA Test Patterns. So set the LD scan rate to either 12,000 or 30,000 points per second, using the Projector Settings menu.

Scan size (angle)

The second consideration in tuning is the scan size. Tuning for both the 12K and 30K Test Patterns is ideally done at 53 degrees optical (peak-to-peak). This can also be expressed as a 1:1 throw -- the distance from the scanners to the screen equals the width (and height) of the projected test pattern:



Now, this does not mean that all images must scan at 53 degrees. Fifty-three degrees is just the ideal tuning size. If you need to set other angles (or distances, or widths), see the topic Tables showing scan angle, distance and width.

The absolute maximum scan size is the rated scan angle limit. In the case of G-120 scanners, at 12,000 pts/sec the limit is 40 degrees peak-to-peak. (Since you cannot tune G-120 scanners for 12K at 53 degrees, you tune them for 12K at 40 degrees.) For G-138 scanners, the nominal limit is 76 degrees.

Normally your maximum scan size will be below this limit. For example, in an auditorium the screen may be far away, so you can scan only 20 degrees. When tuning for this venue, output the ILDA Test Pattern so the outer square is scanned at 20° before starting the tuning procedure.

However, in many cases you want the maximum scan angle. Tune to about 10% under this, to give yourself a margin of safety. For G-120 scanners, this is roughly 35° at 12,000 pts/sec.

If you are tuning faster, the maximum scan angle is reduced. For both CT-6800 and G-120 scanners, the limit is about 20° at 30,000 pts/sec.

Tune to the largest safe angle

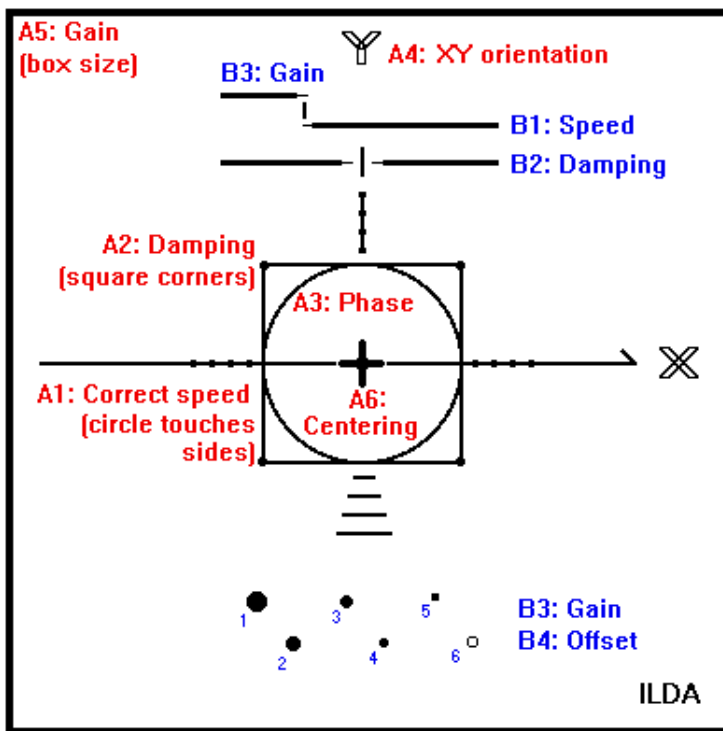
Once you tune to a certain safe angle, scanner response is then flat up to that angle. This means that a full-size image will not distort when it gets smaller (on a zoom-out, for example). However, the image may distort if it is enlarged past the maximum tuning size.

For this reason, tune to the largest safe angle that you'll encounter at your studio or show site.

There is one time when you do not start tuning at the largest safe angle. This is when the scanner amps are in an unknown state. In such a case, begin with a small image. Tune to get it "in the ballpark" before increasing the size.

What to look for

Your goal is to tune the scanner amps so the main part of each test pattern looks like this:



There are two sets of tests incorporated into the ILDA Test Patterns. The "A" set is for scanner alignment. The "B" set is for blanking alignment.

"A" tests: Scanner alignment

A1: Correct scanner speed. The circle should be the same size (width and height) as the square. It should touch the midpoint of each side of the square, as shown.

This is the most important requirement for speed matching. If the circle is smaller than the square, then the scanner is not being driven as hard as it should be. Increase servo gain (position) a bit, then increase damping (velocity) to compensate for any over- or undershoot.

On most scanner amps, the image size will also change, so adjust input gain to keep the same image size. Continue increasing servo gain, and adjusting damping (and input gain as needed) until the circle just touches the square's sides.

If the circle is larger, then the scanners are being driven too "hot" beyond the ILDA spec. Decrease servo gain, and adjust damping (and input gain) to match.

You will probably find the circle is a bit sensitive. This is actually good -- if it wasn't sensitive then there would be no point in tuning to it! You can be assured that if your scanners show the test pattern properly, then other scanners tuned using the same speed will match your scanner.

A2: Correct damping. Corners of the square should be sharp, with no overshoot or undershoot.

This is the most important requirement for good looking images. The damping control, described above, is the primary control for setting corners.

As you tune, adjust the scanner amp damping back and forth. Watch the corners of the square go too far (overshoot) or not enough (undershoot). You need to over and undertune to get a feel for when the corners are correct. The procedure is similar to tuning an analog FM radio receiver, where you go back and forth until you find the clearest signal.

When adjusting damping, it is easiest to switch to a separate frame with a 7/8ths size quadrature square (about 50 dots at each of four corners). Don't use a full-size quad square, since you need a little headroom in cases of overshoot.

For LD/Windows users, the 7/8 size quadrature square is one of the 14 frames in the "scantsts.ldb" file ("ScannerTests.14fr" for LD/Amiga users).

A3: Correct phase (same scanner speeds). The circle should be circular, not elliptical or pulled to one side.

This is easiest to do when your scanner mirrors are the same size. Unfortunately, some users have one mirror smaller, so that scanner can go faster. There is no point to this. Diagonals will distort, and images will look different as they rotate.

You want both scanner mirrors traveling at the same speed and with the same response, so use the same size mirrors. As a bonus, this means you only have to stock one mirror size.

A4: Correct XY orientation. The "Y" should be at the top; the "X" should be at the right.

If your scanner amp has invert switches, use these to get the correct orientation. You can also use controls in your console or computer software, but the place to get the orientation right is at the scanner amp if possible.

A5: Correct gain. The outer box shows the limits of the scanner.

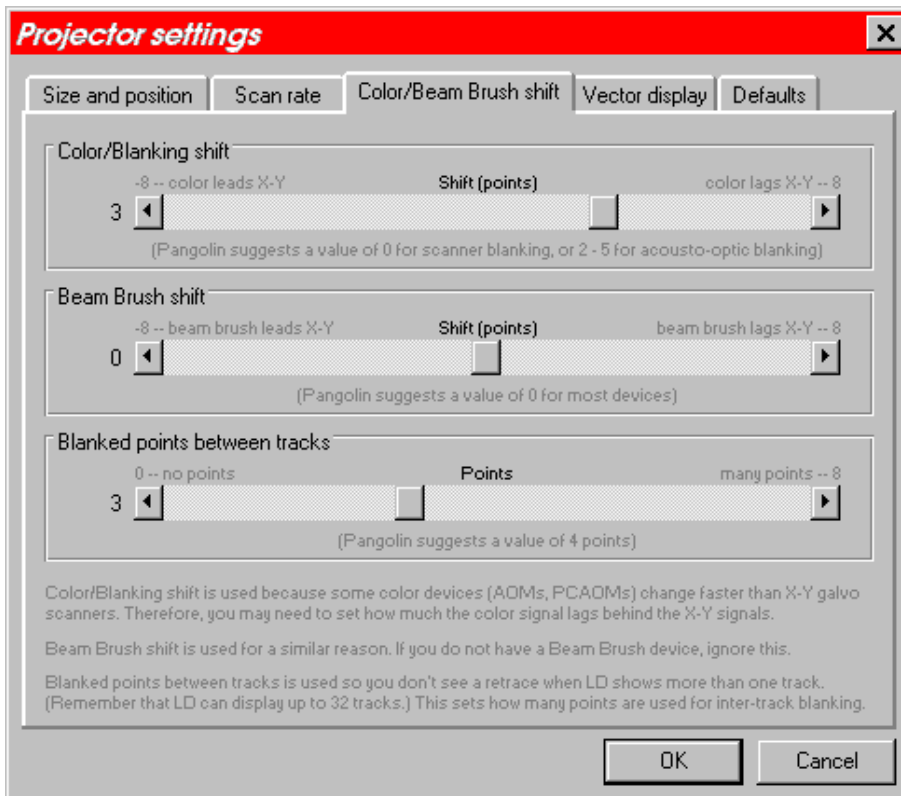
As discussed earlier, set the maximum scan size for your screen, before doing final tuning.

A6: Correct centering. The "+" marks the center of the screen.

"B" tests: Blanking alignment

These tests were originally developed for scanner blanking. They can be used for any type of blanking.

For Lasershow Designer, adjust the Color/Blanking Shift slider to get the blanking point B1 roughly correct. Then, adjust the gain, offset and damping (if you use scanner blanking) of your blanking device.



B1: Correct blanking speed. The upper and lower horizontal lines meet at the small vertical line.

B2: Correct blanking damping. Adjust blanking damping (if you have scanner blanking) so the two horizontal lines are equally spaced from the small vertical line.

B3: Correct blanking gain and **B4:** Correct blanking bias. The fifth dot in this group should be barely visible; the sixth dot should be completely blanked. Also, the lines in B1 should approximately meet at the vertical line.

This is only for those using Laser Fantasy or similar pulse-width modulation scanner techniques. Most AOM and PCAOM systems can show the sixth dot with no problem. A few AOM or PCAOM systems may have built-in filters that emulate the slow rise and fall of scanner blanking. If so, then the B3 test should be used to fine-tune the filter.

Other considerations

- It cannot be stressed enough: **Although you tune to the ILDA Test Pattern at 12K (or 30K), you do not have to show frames at this speed.** You probably will set your scanning speed slower, for example to 8K (or 18K). Otherwise, you'll be putting too many points at corners and sharp angles. Pangolin suggests that you pick a standard speed and stick with it. This makes working with frames easier, especially if you trade frames with others using the same speed. Because ILDA has not set standard playback speeds, we recommend that you use 8K, 12K, 18K or 24K if at all possible.
- If you have other test patterns, such as the ubiquitous Laser Media pattern, they may not look good at the 12K or 30K speeds. If so, you can use these test patterns to help determine what your everyday scanning speed should be. Incidentally, there are many Laser Media look-alike patterns. Most have great differences in actual point placement, so they cannot be used for system-to-system comparisons. (The "LM test pattern" frame provided by Pangolin is very close to Laser Media's but is not identical.) A few versions are so bad that they are worthless or even dangerous for tuning purposes.
- It may seem obvious, but there are no differences between computer graphics systems when it comes to single-frame point output such as test patterns. If software A shows the ILDA Test

Pattern at 12,000 points per second, software B will look the same when showing that frame at that speed, on the same projector. In fact, for any given frame (e.g., set of points) and speed, all computer systems will output identical points. This is how you can be assured of tuning the same as a colleague across the country.

- Some software systems don't provide the scan rate in points per second. This is bad, since there is little reason to tune to the ILDA 12K or 30K standard if you don't know how fast you're running. Use an oscilloscope or check with the system provider, to determine your absolute point rate. If a system uses microseconds per point, the formula is: $1/\text{seconds}$. For example, 80 microseconds is .00008 sec. Using the formula, this is $1/.00008$ or 12,500 pts/sec. The ILDA 12K speed is 83 microseconds per point; the 30K speed is 33.3 microsec/pt.
- The theory behind the circle-and-square tuning is that the square has many points while the circle has a few. The square will hold its shape at fast speeds, but the scanner/amp system has trouble with the circle. If we had perfect scanning systems, then the circle would be larger than the square, touching its corners -- the same way it was digitized. Since we can't get perfect response, we settle for the circle being the same size as the square. The sizes of the circle and square are not measuring anything exact (such as a 3dB rolloff point). They merely serve as a fast, convenient reference standard for in-field tuning.
- The ILDA Test Patterns are not the ultimate testing method. Pangolin believes that a set of scanner test frames, each optimized for a particular feature, is best. However, the ILDA Test Patterns are good single-frame patterns, and of course are the only reference standard in the industry. While you might be able to get some performance improvement using other patterns, smaller angles, etc., it is better to be not quite perfect but to be compatible with the rest of the industry.

ILDA 12K Test Pattern (1996 version)

This is used when tuning slower scanners which cannot reach the ILDA 30K standard. Both the speed and size of this frame needs to be set before tuning.

12,000 pts/sec speed

The output rate for this frame should be set to 12,000 points per second before tuning the scanner amps. After tuning is complete, any speed can be used for creating or displaying frames -- the 12,000 pts/sec speed is just during the tuning process.

53 degree scan angle

Before tuning, set LD's output size controls (or your scanner amp inputs) so the test pattern is as wide as the distance to the screen. This corresponds to a 53 degree scan angle.

If your scanners cannot go this wide, then tune to the widest angle they can go. This may be the case for General Scanning G-120 scanners, as they can only go to a 40 degree peak-to-peak (optical) scan angle.

This will also be the case if your screen is small, and the laser projector is far away. You will have to tune at an angle smaller than the recommended 53 degrees. In this situation, fill the screen with the test pattern, then do the tuning. (However, be careful if you later move the projector so it can scan wider. Since you originally tuned to a smaller-than-normal angle, scanning at a wider angle may give poor results or could even damage the scanners.)

For angles other than 53 degrees, see the topic Tables showing scan angle, distance and width.

ILDA 30K Test Pattern (1996 version)

This is used for tuning faster scanners which can reach the ILDA 30K standard. These include:

- Cambridge Technology 6800 used with CT 6588 scanner amps
- General Scanning G-120 scanners used with "turbo"-type scanner amps certified to reach the 30K speed (e.g., TurboTrack).

30,000 pts/sec speed

The output rate for this frame should be set to 30,000 points per second before tuning the scanner amps. After tuning is complete, any speed can be used for creating or displaying frames -- the 30,000 pts/sec speed is just during the tuning process.

53 degree scan angle

Before tuning, set LD's output size controls (or your scanner amp inputs) so the outer square on the 30K Test Pattern is as wide as the distance to the screen. This corresponds to a 53 degree scan angle.

If your scanners cannot go this wide, then tune to the widest angle they can go. This may be the case for General Scanning G-120 scanners, as they can only go to a 40 degree peak-to-peak (optical) scan angle.

This will also be the case if your screen is small, and the laser projector is far away. You will have to tune at an angle smaller than the recommended 53 degrees. In this situation, fill the screen with the test pattern, then do the tuning. (However, be careful if you later move the projector so it can scan wider. Since you originally tuned to a smaller-than-normal angle, scanning at a wider angle may give poor results or could even damage the scanners.)

For angles other than 53 degrees, see the topic Tables showing scan angle, distance and width.

Alternate method using the 12K Test Pattern

On the 30K Test Pattern, note that the inner square, with all the tests, will be at a 7 degree scan angle (when the outer square is at 53 degrees). If you do not have an ILDA 30K Test Pattern, you can use the 12K Test Pattern sized down to scan at 7 degrees.

To do this in Lasershow Designer, first use the Drawing Window's "Numeric resize, rotate, move" menu. Resize the 12K pattern so the X and Y sizes are 12% of normal. Next, project this so that the distance-to-screen ratio is approximately 8:1. For example, if the scanners are 80 meters from the screen, the shrunk-down 12K test pattern will be 10 meters wide. Finally, set LD's point output rate at 30,000 points per second, and begin tuning.

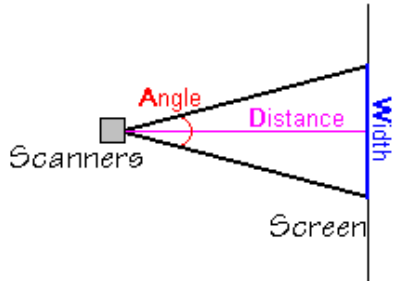
Caution: Not for use on certain systems

The ILDA Test Patterns will not work with certain scanner amps designed for small-step response only. For these amps, special software is used that never permits a large jump between points in an image. Such amps may blow fuses or may be damaged used with Lasershow Designer software (or with an unmodified ILDA Test Pattern).

These scanner amps are rare -- most systems can handle large jumps without a problem. However, if you have any concerns, please check with your system provider before using the ILDA Test Patterns.

Tables showing scan angle, distance and width

For some applications, it may be necessary to figure out the scanning angle, the screen distance or the image width. The formulas and table below will make this easy. To use the formulas, you must know the two of the following three parameters:

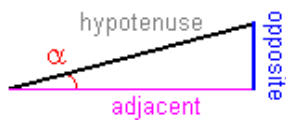


- **A** = Scanning **angle** in degrees, peak-to-peak. This is also known as the "optical" angle.
- **D** = Throw **distance** from the scanners to the screen.
- **W** = Projected image **width** (Of course, the image height should also be the same, so both scanners are tuned to the same angle).

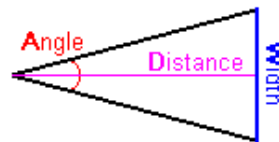
The distance and width must be in the same units, such as feet or meters. The units themselves do not matter.

There are two ways to find the unknown (third) parameter. One is by calculations involving the tangent of **A** (actually, **A** divided by two, since the half-angle must be used). The other is by inspecting the distance-to-width ratio listing in the chart below. Both methods are described below. Either gives the same result, so use whichever you feel is easiest.

This diagram may help to explain how the calculation formulas were derived:



$$\tan \alpha = \frac{\text{opposite}}{\text{adjacent}}$$



$$\tan\left(\frac{A}{2}\right) = \frac{1/2 W}{D}$$

$$D = \frac{1/2 W}{\tan\left(\frac{A}{2}\right)}$$

$$W = D * \tan\left(\frac{A}{2}\right) * 2$$

To find the scan angle **A**, knowing the width **W** and distance **D**

- By calculation: $\tan(A/2) = W / (D * 2)$. For example, **W** is 109 meters and **D** is 150 meters. First, multiply **D** times 2 to get 300. Then, **W** (109) divided by 2***D** (300) is 0.3633. Next, look in the chart below, to find the closest angle which has a tangent of 0.3633. This is 20 degrees (at 0.3640). We have just found the half-angle of scanning; the actual peak-to-peak angle is twice this, or 40 degrees. Thus, the desired scan angle **A** is about 40 degrees.
- By inspection: $\text{chartwidth}@A = (W * 100) / D$. For example, **W** is 109 meters and **D** is 150 meters. First, multiply **W** (109) by 100 to get 10,900. Divide this by the distance **D** (150) to get 72.6. Finally, look down the chart at the "Distance-to-width ratio" column until you find the angle **A** where the chart width is closest to 72.6. This is at 40 degrees, where the ratio is 100 : 72.8. Thus, the desired scan angle **A** is about 40 degrees.

To find the distance **D**, knowing the scan angle **A** and the width **W**

- By calculation: $D = W / (\tan(A / 2) * 2)$. For example, A is 40 degrees and W is 109 meters. First, look in the chart below to find the tangent of half of 40, or 20 degrees; this is 0.3640. Next, multiply 0.3640 times 2. The equation is now W (109) divided by 0.7280, or 149.7. Thus, the desired distance D is about 150 meters.
- By inspection: $D = (W / \text{chartwidth}@A) * 100$. For example, A is 40 degrees and W is 109 meters. First, look in the chart below and find 40 degrees. The distance-to-width ratio is given as 100 : 72.8. Using the formula, divide W (109) by 72.8 (the chart width at A), to get 1.497. Finally, multiply this by 100 to find 149.7 meters, the desired distance D .

To find the width W , knowing the scan angle A and the distance D

- By calculation: $W = D * (\tan(A / 2) * 2)$. For example, A is 40 degrees and D is 150 meters. First, look in the chart below to find the tangent of half of 40, or 20 degrees; this is 0.3640. Next, multiply 0.3640 times 2. The equation is now D (150) times 0.7280, or 109.2. Thus, the desired width W is about 109 meters.
- By inspection: $W = (D / 100) * \text{chartwidth}@A$. For example, A is 40 degrees and D is 150 meters. First, look in the chart below and find 40 degrees. The distance-to-width ratio is given as 100 : 72.8. Using the formula, divide D (150) by 100 to get 1.5. Finally, multiply this by 72.8 (the chart width at A) to find 109 meters, the desired width W .

Caution: Although in the calculation formulas you first multiply by two and then divide by two (or vice versa), these do operations not cancel each other out. This is because the tangent is involved and it is non-linear. So don't skip any steps in the formulas above.

Angle data table

Angle (deg.)	Tangent	Distance-to-width ratio
1	0.0175	100 : 1.7 (If distance is 100 units, width is 1.7 units)
2	0.0349	100 : 3.5
3	0.0524	100 : 5.2
4	0.0699	100 : 7.0
5	0.0875	100 : 8.7
6	0.1051	100 : 10.5
7	0.1228	100 : 12.2 This is an 8:1 ratio
(distance is 8 times the width)		
8	0.1405	100 : 14.0
9	0.1584	100 : 15.7
10	0.1763	100 : 17.5
11	0.1944	100 : 19.3
12	0.2126	100 : 21.0
13	0.2309	100 : 22.8
14	0.2493	100 : 24.6
15	0.2679	100 : 26.3
16	0.2867	100 : 28.1
17	0.3057	100 : 29.9
18	0.3249	100 : 31.6
19	0.3443	100 : 33.5 This is a 3:1 ratio (distance is three times the width)
20	0.3640	100 : 35.3
21	0.3839	100 : 37.1
22	0.4040	100 : 38.9
23	0.4245	100 : 40.7
24	0.4452	100 : 42.5

25	0.4663	100	: 44.3	
26	0.4877	100	: 46.2	
27	0.5095	100	: 48.0	
28	0.5317	100	: 49.9	This is a 2:1 ratio (distance
is twice the width)				
29	0.5543	100	: 51.7	
30	0.5774	100	: 53.6	
31	0.6009	100	: 55.5	
32	0.6249	100	: 57.3	
33	0.6494	100	: 59.2	
34	0.6745	100	: 61.1	
35	0.7002	100	: 63.1	
36	0.7265	100	: 65.0	
37	0.7536	100	: 66.9	This is a 3:2 ratio
38	0.7813	100	: 68.9	
39	0.8098	100	: 70.8	
40	0.8391	100	: 72.8	This is the nominal limit of
G-120 scanners.				
41	0.8693	100	: 74.8	
42	0.9004	100	: 76.8	
43	0.9325	100	: 78.8	
44	0.9657	100	: 80.8	
45	1.0000	100	: 82.8	
46	1.0355	100	: 84.9	
47	1.0724	100	: 87.0	
48	1.1106	100	: 89.0	
49	1.1504	100	: 91.1	
50	1.1918	100	: 93.3	
51	1.2349	100	: 95.4	
52	1.2799	100	: 97.5	
53	1.3270	100	: 99.7	This is a 1:1 ratio; the
distance almost exactly equals the width.				
54	1.3764	100	: 101.9	
55	1.4281	100	: 104.1	
56	1.4826	100	: 106.3	
57	1.5299	100	: 108.6	
58	1.6003	100	: 110.9	
59	1.6643	100	: 113.2	
60	1.7321	100	: 115.5	
61	1.8040	100	: 117.9	
62	1.8807	100	: 120.2	
63	1.9626	100	: 122.6	
64	2.0503	100	: 125.0	
65	2.1445	100	: 127.4	
66	2.2460	100	: 129.9	
67	2.3559	100	: 132.4	
68	2.4751	100	: 134.9	
69	2.6051	100	: 137.5	
70	2.7475	100	: 140.0	
71	2.9042	100	: 142.7	
72	3.0777	100	: 145.3	
73	3.2709	100	: 148.0	
74	3.4874	100	: 150.7	This is a 2:3 ratio
75	3.7321	100	: 153.5	

76	4.0108	100	: 156.3	
77	4.3315	100	: 159.1	
78	4.7046	100	: 162.0	
79	5.1446	100	: 164.9	
80	5.6713	100	: 167.8	This is the nominal limit of
CT 6800 scanners...				
81	6.3138	100	: 170.8	...the remaining entries are
for mathematical completeness.				
82	7.1154	100	: 173.9	
83	8.1443	100	: 176.9	
84	9.5144	100	: 180.1	
85	11.430	100	: 183.3	
86	14.300	100	: 186.5	
87	19.081	100	: 189.8	
88	28.636	100	: 193.1	
89	57.290	100	: 196.5	
90	--	100	: 200.0	

Setting a default scan rate

You should tune your scanners using the ILDA Test Patterns at 12,000 or 30,000 points per second. However, this does not mean that all your frames should be designed or shown at 12,000 or 30,000 points per second. You can use any scan rate you wish to make new frames. Tuning to the ILDA standard means that any two projectors tuned to the same speed, and outputting points at the same rate, should be able to show the same images.

At this time, ILDA has not set a standard rate for frame creation and display. It is up to you to establish a default scan rate for your system. Pangolin suggests that you normally run at about 2/3 of your tuning rate:

- If you tuned at 12K, use a default scan rate of 8,000 points per second.
- If you tuned at 30K, use a default scan rate of 18,000 points per second.

Compatibility with existing frames

These rates offer the most compatibility with existing frames from companies like Laser Media and Aura Technologies, and with many of the frames and shows which come with LD.

You can see for yourself what the best speed is for these Laser Media-compatible frames. First, ensure that your scanners are tuned properly to the ILDA 12K or 30K standard. Next, display the "Laser Media test pattern" frame, from the Instant test frames menu:



When this frame is displayed using the tuning speed, it looks very bad -- corners are rounded and lines do not meet. Go to the Projector settings menu, and slow down the scan rate until this frame looks close to the above diagram. You should find that the scan rate will be about 2/3 of your tuning speed.

The result is that any frame created on a system which properly displayed the Laser Media test pattern, will be properly displayed. Since this test pattern is so widespread in the laser industry, there are a lot of compatible frames. If you want to use these frames, then it is easiest if your default scan rate is set to make these frames look good.

Other considerations

Some people feel that to "get the most out of the scanners", they must create and display frames at the tuning speed of 12K or 30K. However, this is not true. Any gains in showing more flicker-free points at higher speeds are negated by having to use more points to anchor corners, add blanking points, etc. This idea is discussed in greater depth in the topics "Speed, detail and flicker -- the Iron Triangle" and "The 12,000 points per second speed limit."

Also, Showtime can only process up to 30,000 points per second. If you are showing frames running faster than this, then there may occasionally be a glitch. This is another reason to keep your default digitizing and display rate well below 30,000 points per second.

Advanced scan rate considerations

A few laser show companies tune their scanners and digitize their frames at very high point rates -- as fast as 40,000 points per second. These companies feel they have an advantage by getting even more information into the image.

Pangolin does not agree with this philosophy. While it may work for the companies involved (they do excellent work), we believe that most laserists should not tune higher than the fastest ILDA standard speed (30K).

Our reasons are listed below. Please note that this is not to criticize any specific company. We just believe that for most laserists, the disadvantages of higher speeds far outweigh the advantages. In this discussion, we'll use the made-up name "FastCo" to refer to any company working beyond the ILDA 30K standard speed.

Tune to the ILDA standard

FastCo starts by tuning to the ILDA test pattern at 40,000 points per second (40K). This has two unwanted effects, in Pangolin's opinion.

- FastCo frames are now by definition no longer ILDA compatible. There may not be a horrible difference when ILDA frames are shown on FastCo projectors, or vice versa. But there will be a difference, and the whole point of standards is complete interchangeability. Certainly if the ILDA Technical Committee felt that all laser companies could successfully run faster than 30K, they would have set the standard speed higher.
- Scanner and amp problems show up much more at 40K. For example, if there are two objects being projected (e.g., two Showtime tracks), as one object is moved around, the other will shift noticeably. Just as your car works fine at 60 mph, but may start to shake and shudder at 100 mph, most scanning systems have problems at 40K. Again, the 30K speed was set for a reason!

Artists should not compensate for scanner inaccuracies

So if scanners operate differently at 40K, how does FastCo make good-looking frames?

The scanner instabilities are usually compensated for by the digitizer, when he or she is drawing the frame. At FastCo, they do not watch the computer screen while digitizing; instead they only look at the laser image. If there are instabilities, the digitizer through literally years of training knows to back off and put in extra points. The digitizer may not know consciously that they are adding extra compensation points or pulling points, but they are definitely doing this.

This, of course, leads to the same problem discussed in the pulling points topic. FastCo's frames look good on their particular scanners and amps. But if future systems come along which have different response curves, the frames will probably look so bad that they then become worthless.

FastCo may have one other trick up their sleeve. To project using 40K-tuned scanners, it helps if certain components on the scanner amp are changed. If this is done, then the scanner instabilities are reduced. Pangolin does not know if any of the faster-scanning companies have done this; we suspect not.

Artists are adding too many points

Here is perhaps the primary reason why we believe frames should not be digitized at 40K: It is far beyond what the scanners need to see. Digitizing at 40K wastes the digitizer's time in creation, and the computer system's time in feeding data to the scanners. This is more fully discussed in the topic "The 12,000 points per second speed limit".

Another way to look at this is that at 40K, points must be placed closer together. There must be more anchor and blank points at the end of each line. For example, on a 40K system we suggest using 8-10 blank points, instead of the 3-4 used at 18K. This means that many, if not all, of the benefits of faster scanning are negated by having to use more points.

This phenomenon of an "Iron Triangle" between speed, detail and flicker was discussed in a previous topic. Scanners can only go so fast. If you tune them faster, then you need to add more points so they don't round off the graphics. The points take up more time, meaning the scanners are moving slower. You cannot get something from nothing.

If you must scan at non-standard speeds

We had one client with a system that included 40K-tuned scanners. When he looked at typical LD frames, they looked bad; he thought this proved that 40K was better. But it turned out that when he adjusted LD's parameters to match the 40K digitizing and projection techniques, that LD frames looked fine. Ironically, then some of the other problems of 40K scanning became apparent, like the multi-track problem mentioned earlier.

Normally we would recommend that the client re-tune to 30K, and not show the non-standard material. But this particular client could not do this, since he ran the 40K material daily. Instead, we suggested one of two options:

- **Digitize using 40K-type parameters.** This does not mean to run LD at 40,000 points per second. Pangolin does not certify Showtime for use above 30,000 points per second, so this is the maximum output speed we recommend. Remember that, even though you are tuned to a certain speed, you do not have to digitize at this speed. The client with 40K scanners could digitize at whatever speed he wished; we recommended 30K in his case. Certainly, at this speed additional points are necessary. For example, the number of AutoBlank points was changed from 3 to 9.
- **Use a hardware circuit to simulate 30K tuning.** A relatively simple circuit can be built which lets images designed for slower scanners still look good on faster (e.g., 40K) scanners. This would be the best solution for anyone with 40K scanners who wants to present ADAT or similar pre-recorded shows designed to ILDA's 30K standard. (Should you need such a circuit, please contact Pangolin directly).

The 12,000 points per second speed limit

Some companies feel that if they digitize at 30,000 points per second (30K) or even faster, they get better quality. This belief is false. There may be other reasons they get good quality, but it is not due to the scan speeds.

In fact, the scanners themselves do not see any speed faster than about 12,000 points per second. Thus, at 30,000 points per second, *60% of all points are wasted* -- completely unnecessary!

Said another way, you can take a frame digitized at any speed -- 30K, 40K, whatever -- and resample it down to a 12K frame. When laser-projected, this resampled frame will look exactly, precisely 100.00% the same as the original faster frame.

This may be a bit hard to believe, but just go through the reasoning below. At the end, you should understand why LD does not have to go at top speed in order for you to still have excellent graphics.

5 KHz limit for scanners

Standard laser light shows use galvanometer-type scanners. The fastest currently available are Cambridge Technology 6800 scanners with 6588 amps, and General Scanning G-120 scanners with Turbo Track amps.

How fast can these scanners move? To find out, take a sine wave (the easiest wave for scanners to produce) and gradually increase its frequency. At low frequencies, the scanner mirror can move full angle -- 80 degrees for the CT 6800; 60 degrees for the GS G-120's. You will find that at around 1,000 cycles per second (1 KHz), the scan angle begins to shrink. The scanner is moving too fast to go all the way back and forth. As the frequency continues to increase, the scan angle gets smaller and smaller. By 5 KHz, the scanner is not moving at all.

Thus, the limit of today's laser show scanners is about 5,000 cycles per second.

Only 10K points per second needed

How many points per second is this? A basic tenet of digital signal processing, the Nyquist Theorem, states that if you want to reproduce a signal, you have sample it twice as fast as the highest frequency that you want to keep in the signal.

For example, humans can hear sounds up to about 20,000 *cycles* per second (20 KHz). Thus, to digitally record audio signals for human ears, the sample rate needs to be twice the cycle rate, or 40,000 *samples* per second. (To make it a little easier for the playback process, the actual rate used for standard CD-audio discs is set slightly higher, at 44,100 samples per second.)

It is important to keep in mind the difference between the original analog waveform and the resulting digitally sampled equivalent. The analog waveform is measured in Hertz, or cycles per second. The digitally sampled waveform is measured in samples or points per second.

For laser graphics, the Nyquist Theorem states that if we want to reproduce laser signals of 5,000 *cycles* per second (5 KHz), the fastest we need to go is 10,000 *samples* per second (10K points per second).

To give ourselves a bit of headroom, let's bump this up to 12,000 points per second (12K). The exact number does not matter. The main principle is that the computer only needs to send points to the scanner amps at a rate of about 12,000 every second in order to reproduce *any* image that can be shown on laser scanners.*

It does not matter if the original image is from an analog signal generator (older-style planetarium show lissajous generators), from the world's best laser computer (LD, naturally), from music being input into the scanners, or any other signal source. The scanner and amp system cannot go faster than 5,000 cycles per second. Thus, an equivalent waveform can be *exactly* reproduced using just 10,000 points per second.

Scanners reproduce CD-quality sound?

Here is another way to consider the situation. A few companies are tuning to, and digitizing at, 40,000 points per second. Think about this for a moment -- this is nearly the same rate at which CD-quality audio is digitized (44,100 samples per second). Are these companies actually claiming that scanners are small, accurate speakers? There are two ways to disprove this.

- Put test signals such as sine waves into scanners. Increase the frequency until the scanner mirror no longer moves. As discussed above, the scanner cannot reproduce any signal above 5,000 Hz -- while audio extends to about 20,000 Hz.
- Listen to a compact disc being played through scanners. While you do hear music, you hear none of the high frequencies. It is like listening to a cheap transistor radio, or to a stereo with the "Treble" control turned all the way down. This again confirms that scanners cannot reproduce 40,000 samples (points) per second.

Where do the points go?

So if points are being wasted, where do they go? It is not as simple as one out of every two or three points being ignored. If this was so, then a resampling algorithm would be trivial -- just remove every second or third point.

Instead, all points are blended together into one waveform. Each point contributes something to the waveform. This is why moving a single point can change the projected image.

This combined waveform contains frequency components above the 5 KHz limit of the scanners. For example, a frame digitized and shown at 40,000 points per second may have measurable energy in the 20 KHz region. But remember that scanners do not see this!

What we are throwing away when we resample is the energy in the region between 5 KHz and 20 KHz. If we were recording music, this would be lost information, since we can hear in this region. But from a laser scanning standpoint, this information is completely wasted since scanners cannot move more than 5,000 times per second (5 KHz).

This is how a resampling algorithm can work. It converts the original digital waveform into its frequency components, throws out all information above 5 KHz, then makes a new waveform containing only the samples necessary to reproduce frequencies below 5 KHz.

The result is a laser frame with 60% fewer points. On the computer screen, the new points have been moved slightly compared to the old points, but the laser-projected frame does not look different in any way.

Why digitize faster?

So why does Lasershow Designer output points faster than 12,000 per second? There are two main reasons.

- A human digitizer cannot know exactly where to place points to get perfect results. The human must therefore oversample, or put down more points than are strictly necessary. Once the human is finished, then the computer can resample the frame to have far fewer points.
- Pangolin has not yet written a resampling algorithm of sufficient quality. To do 100% accurate resampling takes some time to code. (The algorithms themselves are well-known, as they are

the subject of intense study in digital signal processing circles.) Until this time, it is better to have laser companies continue working as they have for the last decade or two.

For these reasons, you should set your default scan speed at a reasonable rate, such as 2/3 of the speed at which your scanners are tuned.

Why this is important to you

Although you may create and digitize faster than the 12,000 points per second "speed limit", It is still important for you to be aware of this limit:

- You should not waste time trying to "beat the system" by tuning faster than the ILDA speeds, or by digitizing at high speeds. Certainly anything beyond 30K is unnecessary. Any alleged benefits from higher-than-normal speeds are really due to the digitizer's skills and experience.
- Some laser graphics systems may claim higher speeds because it sounds better in advertising. (One company says they output 300,000 points per second. If the scanners could move at 150 KHz, you could use them for ultrasonic cleaning!) Just based on point output rate, anything over 12,000 points per second is unnecessary.
- Pangolin only guarantees Showtime shows up to 30,000 points per second. If Showtime must output points faster, then certain calculations cannot keep up and small "hiccups" may occur in the show. Therefore, keep the point output rate at or below 30K.

Questions?

This topic seems to be particularly hard for people to understand. If you have any questions about this, please feel free to call or write Pangolin. We would be happy to help discuss it in more depth, so you can see why faster is not always better.

* Note: The above analysis only addresses X-Y scanners. With a PCAOM, colors can change much faster than 5,000 times per second. If color data is changing faster than point data, higher sample rates would be necessary to accurately retain the color information. But in practical terms, this will not affect any LD frames, because LD cannot change color faster than once per point.

How to improve your scanning speed

Here are some tips for increasing your scanners' speed and the quality of your images:

- You may want to switch to smaller mirrors with lower mass. Too many companies with General Scanning scanners use GS-10A mounts (a square slab with a screw through one end), 7 x 7 mm X-axis mirrors and 7 x 14 mm Y-axis mirrors. We recommend a General Scanning M-10A mount with 5 x 8 mm mirrors for both scanners. The M-10A mount has half the inertia of the GS-10A.
- Use the same mirror size for both scanners. If you don't, you'll have problems -- for example, bowing of lines when rotating a graphic 90 degrees. In a vector situation it makes no sense to have one axis going faster than the other. It is far better to have both scanners identical. There are also minor benefits -- you stock only one size for replacement mirrors, and it is easier to swap scanners.
- Build a circuit which can get 50% greater performance out of common scanner amps. Pangolin's Bill Benner has developed a simple but very effective pre-emphasis circuit. It compensates for the scanner's lack of response. Many Pangolin users with standard performance scanner amps have built this and have reported speed gains of around 50%.
- There may be cases where you simply have to buy higher performance scanners or amps. It is better to pay money for the equipment than to pay for the extra time and trouble of pulling points.

HOW TO DRAW EFFECTIVELY IN LASER

So far, we've covered the limitations of scanning, and how to get the best performance out of your scanners. Now in the next topics, we can consider how to draw effective laser graphics.

Start with good artwork

If you're digitizing from pre-existing art, make sure it's good. The best laser software and hardware won't turn a so-so image into a masterpiece. Be sure that the original is simple and clear enough to translate well into the outline images typical to laser graphics.

Animation

Starting with good artwork is especially important for animation. Good animation is not only the art itself, but the skillful use of timing, viewpoint, exaggerated movement, and other elements that bring drawings to life. If you have the budget, hire an experienced animator. (Be sure to check their portfolio!) It is easier to have them work within the limits of laser graphics, than to have a skillful laser digitizer learn animation.

If you wish to learn animation yourself, two good resources are:

- **The Animator's Workbook**, Tony White (Watson-Guption Publications, New York, 1988, \$18.95, ISBN 0-8230-0229-2)
- **Timing for Animation**, Harold Whitaker and John Halas (Focal Press (Butterworth/Heinemann Ltd), Northants, England, 1981, \$41.50, ISBN 0-240-51310-X)

A shortcut to good animation is to rotoscope. Using videotape, you can freeze and trace each frame of filmed motion. It is simple to genlock to video. This means that the computer background color is replaced by the video. You see the LD Drawing Window on top of the video, making tracing easy.

The genlock we currently recommend is TelevEyes Pro, from Digital Vision. (Do not get the regular TelevEyes, as it does not have genlock capability.) The cost is approximately \$750.

A lower-cost alternative is to trace the frames on a TV monitor using clear acetate or tracing paper. Then you can tape the tracings to your digitizing tablet or PC monitor and trace them into Lasershow Designer for Windows.

3D objects

As with animation, drawing in three dimensions is a learned skill. Lasershow Designer makes it as easy as possible, but there still are some techniques which are gained only through experience.

It helps to have a model or a multiple-view drawing of the object you're creating. The Space Shuttle frame included with LD was drawn with the help of front, top and side scale drawings from a book about the Shuttle. The drawings were photocopied onto transparencies and then taped to the monitor for guidance during the initial stages.

You may want to create sub-parts in different frames. This lets you draw them in one axis, then move points to create curves. You can also rotate the objects in 3D space if they are not oriented exactly in a front, top or side axis. Finally, when the sub-parts are done, copy them into the main frame.

This is how the Space Shuttle windows were done. If you examine the frame, you'll see that there are some complex curves to the windows which were done by rotating different groups of points.

Try to use features such as Extrude and Spin to easily make the "raw materials" of your 3D object. For example, the killer whale frame started as a curve which was spun into a football shape. The whale's dorsal fin was done by moving points on one of the spun "ribs"; the tail was done by progressively resizing groups of points to flatten that section.

Expect the process to take some time. High-quality 3D objects with compound curves, multiple sub-parts and subtle refinements take from four to eight hours to create.

Know your Lasershow Designer tools

Lasershow Designer makes laser drawing as easy as possible, with tools that automatically draw lines, circles, rectangles and other common shapes. Specialized tools such as Stream with Auto-Spacing make creating constant-brightness lines effortless.

Sometimes we see users fight against these tools. For example, we have seen people draw a 2D soda can by using an ellipse for the top and bottom, two lines for the sides, and manually-placed type to make the word "Coke" look curved. It is far simpler to create a 3D can once, and then be able to view it from any angle, rotate it in 3D, etc.

Another example: we have seen users painfully hand-digitize objects that were made up of straight lines, or that were rotationally symmetric, or that included repeated elements, all by tracing artwork on a digitizing tablet. Don't do this! Switch to the straight line or polygon tools for objects made of straight lines. Use the Mirror horizontal or vertical menu item to make symmetrical objects. Grab previously-drawn elements with the brush tool.

Shortcuts such as these can reduce or even eliminate hand-tracing time, and give better looking results as well. Unlearn old habits learned on previous systems, or non-vector drawing programs. Know your Lasershow Designer tools and work with them, not against them.

Use the right quality level

For the ultimate in quality, you should place every single point by hand. This is how 1980's laser graphics were created: one expert, hand-entering every point using a digitizing tablet, watching the results on a laser tuned the same as the final show laser. This takes an enormous amount of time, but gives the highest quality results.

In the 1990's, most users don't have the luxury and budget to hand-digitize every frame. This is why LD provides so many drawing and editing tools. You'll get 80% of the quality of hand-digitized images, in just 20% of the time.

One analogy we often make is to traditional film animation. You can hand-draw every frame in the classic Disney-style, and get Disney-quality results for a few magnificent motion pictures. Or, you can quickly do smaller numbers of frames "on twos" or "on threes" and get Hanna-Barbara style results to turn out lots of Saturday morning cartoons.

Neither technique is "right". Each is appropriate for the financial and time budget. Fortunately, Lasershow Designer gives you the tools for whatever quality level your project requires.

Don't pull points when digitizing

A laser digitizer "pulls points" when he or she deliberately overshoots corners and stretches out sharp turns. By definition, pulling points means making artificial graphics which don't look right on the computer screen and which won't look right on faster (or slower) scanner amp systems.

This is going to get you in trouble -- if not now, then later when you trade frames or go to faster scanners. Take a look at the frames Pangolin and others have created. Most of these look fine on the computer screen, with no pulled points. If you have to pull points to get these to look good (at a reasonably flicker-free point output rate), then you should be first fixing up your scanning system as described above.

One solution is to put less points throughout a line and more points at the corners. Curves especially can often be done with fewer points, although you want to avoid having such a disparity that some sections become dimmer because they have a lower point density than others.

Another solution is to re-do the artwork. Drop unnecessary details, use stick fonts instead of outline, or split information into two or more frames. For example, instead of putting "Welcome to the Smithville Planetarium" in a single frame, do it as "Welcome to the", "Smithville", and "Planetarium".

An excellent example of point placement is the 2D frame Lisa2. This does a fine job with less than 150 points. Notice how there are far fewer points in the hair than in the eyes. The curve of the hair does not need to be precise, while the eyes are tight curves. Points are placed only where necessary. Notice also that the frame looks the same on the monitor as on the laser -- pulled points were not necessary to get this low point count.

Synchronizing audio with visuals

In laser shows, audio is often synchronized with visuals. If the synchronization is not done well, or drifts during the show, the audience will notice the flaw.

In general, synchronization problems are noticed if:

- audio is more than 45 milliseconds late. This is 1.5 frames at 30 frames (refreshes) per second.
- audio is more than 20 milliseconds early. This is .66 frames at 30 frames (refreshes) per second.

More crucial for speaking, special effects

These guidelines are more crucial for lip synching, or if there are special effects such as an explosion.

For music synching, you can be off by a bit more, since musical events often fade in or have an envelope (example: a violin sound does not abruptly begin, but instead has a gradual rise).

Frames vs. refreshes

In laser graphics, we can't talk about frame timing in the same way as film or video. But it is possible to calculate the frame rate for any given frame.

- In film and video, the frame rates are fixed. 35mm film is projected at 24 frames per second. (It is slightly more complex than this. Each frame is held in the gate while the shutter opens and closes 3 times. This gives a flicker rate of 72 flashes per second, with new frames appearing every 1/24 of a second.) PAL-format video is projected at 25 frames per second (50 fields per second; each field is 1/2 frame). NTSC-format video is projected at almost 30 frames per second (60 fields per second).
- In traditional laser graphics, what is fixed is the point output rate -- the number of points per second. Since each frame has a different number of points, there is no fixed "frame rate".

Instead of "frame rate", the laser term you will hear is "refresh". One "refresh" is the time it takes to display all the points in a laser frame. If there are few points in the laser frame, then the refresh rate is fast. If there are many points in the frame, then the refresh rate is slow.

To find out your refresh rate, take the scan rate in points per second, and divide it by the number of points in the laser frame you are displaying. For example, if you are scanning at 20,000 points per second, and your laser frame has 500 points, your refresh rate is 40 per second (20000/500). Each frame is on for 1/40 of a second, or 25 milliseconds (1000 milliseconds divided by 40 events per second = 25 milliseconds per event).