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# Laser galvo mirrors: perfect instrument for the demonstration of Lissajous figures

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# Laser galvo mirrors: perfect instrument for the demonstration of Lissajous figures

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## Abstract

A pair of galvo mirrors reflecting light from a laser pointer is suggested for use as a school demonstration of Lissajous figures. The device is small, cheap and easy to assemble. Combined with a two-channel waveform generator, a full spectrum of excellently stable Lissajous figures can be generated (concerning frequency ratio, amplitude ratio and initial phase angle difference). The operation at frequencies faster than the vision persistence allows us to draw the figures on a normal projection screen or on a wall. When operated with a violet laser pointer and a thermoluminescent foil, the frequencies can be decreased and the advance in figure drawing can be followed. The memory effect of the thermoluminescent foil also enables us to record and observe several Lissajous figures simultaneously.

 Supplementary material for this article is available [online](#)

## 1. Introduction

In our previous contribution [1], we raised a question of proper demonstration of perpendicular oscillations in class experiments. In such a demonstration, the total oscillatory movement should rely on the principle of superposition, requiring linear superposition of oscillations in linear environments. In the case of the perpendicular oscillations, this superposition is of vector nature. We pointed out that the application of digital storage oscilloscopes (DSO) or school dataloggers working in the XY regime should be avoided. When the output of two signal generators is sensed by the two-channel DSO, the generated signals are only resampled back into the instrument memory. The observed Lissajous figures are then only a product of the plotting software,

running in the DSO or datalogger. As a solution, we suggested the use of classical Y-suspended double pendulum (Blackburn pendulum) in [1] and we showed, how the pendulum with a small violet laser pointer attached can draw impressive Lissajous figures on a (thermo)luminescent foil.

On the other hand, the use of a Blackburn pendulum is not free of drawbacks. First, the setting of the pendulum to a specific frequency ratio (by changing the lengths of the suspending fibres) is time consuming and mostly only approximate, avoiding the generation of stable Lissajous figures. Second, the initial phase angles of both oscillations can be set with difficulties. Last but not least, the naturally demanded frequency ratio 1:1 producing an ellipse, circle or abscissa as the simplest Lissajous figures cannot be set for the pendulum.

As we will show in this article, another instrument, a pair of galvo mirrors used e. g. in laser projectors, provides a perfect solution to the problem. The device is small, cheap and easy to assemble. Combined with a two-channel waveform generator, a full spectrum of Lissajous figures can be easily generated (concerning frequency ratio, amplitude ratio and initial phase angle difference). The final figure is also excellently stable. Operation at low frequencies, especially with the violet laser and the thermoluminescent foil, provides helpful insight into the drawing of Lissajous figures.

Several papers focused on the generation of Lissajous figures have been published recently e. g. a solution based on little mirrors located on a pair of electrodynamic loudspeakers was described in [2]. A method of writing images on a luminescent surface by a laser attached to a moving pendulum was described in [3]. A smartphone in a frame attached to two perpendicular springs recorded Lissajous patterns in [4].

However, in our opinion, none of the mentioned solutions are so simple and as powerful as the presented approach. The example of the output created by galvo mirrors in a lecture room is displayed in figure 1.

## 2. Galvo mirrors

The galvo mirrors are in principle high-speed mirror galvanometers, which change their angle of tilt according to the electrical signal. Assembling two mirrors into a perpendicular pair, a XY scanner, reflecting a laser beam into a specific direction, is formed. Galvo mirror systems are typically used in laser projection systems, laser beam machining or in laser confocal microscopes. For our purpose, a low-cost version with costing around 100 EUR is fully sufficient.

The galvo mirror scanners are available as sets of several components. Besides the assembled pair of perpendicular galvo mirrors, the set contains the driver board, capable of driving the mirrors directly according to two  $\pm 5\text{V}$  analog voltage signals and another board providing a power supply for the driver board (itself powered from the mains). Additional components for conversion of graphics into analog voltage signals may be included, but they are useless for the presented purpose.

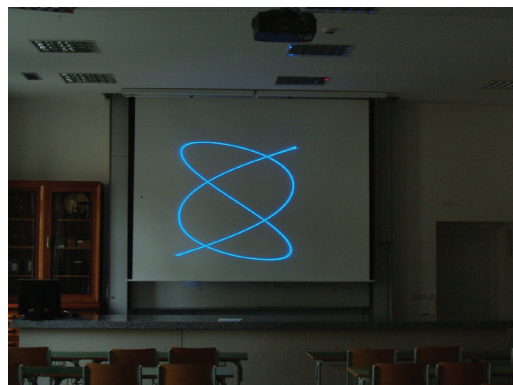


**Figure 1.** Large Lissajous figure created by galvo mirrors on the projection screen in a lecture room.



**Figure 2.** Setup of galvo mirrors and two-channel waveform generator.

Our instrument, made in-house from such a galvo-mirror set, is displayed on the right side of figure 2). The black plastic box contains both the driver and the power-supply boards. Two BNC connectors on the front panel access the inputs of the driver board. The white box residing on the black one contains the mirrors, interconnected with the outputs of the driver board. The top wall of the white box is made out of plexiglass, so the mirrors are visible, but at the same time mechanically protected against hazard. A holder attached on the top of the black box provides a place for fixing a normal laser pointer.

A two-channel signal generator visible on the left side of figure 2 supplies signals for the driver board through the BNC inputs. The use of the two-channel arbitrary waveform generator is of great advantage. First, it provides two coherent signals with perfect synchronization and easily set phase angle difference. Second, various modes with specific frequencies, voltage amplitudes and the phase angle differences may be saved into the device memory and quickly invoked. Third, the possibility to generate other signals besides the

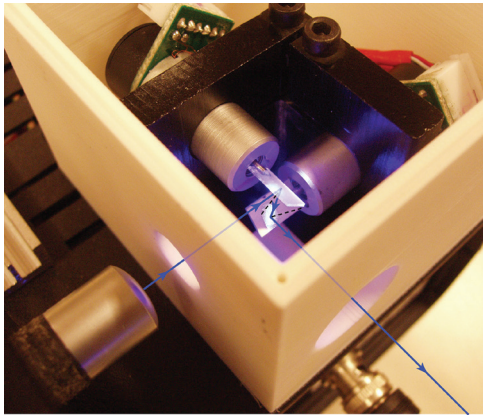


**Figure 3.** Galvo mirrors with the light path marked.

harmonic signals further enhances the setup versatility e. g. using the ramp signal on the horizontal voltage input, the analog oscilloscope can be simulated.

Details of the galvo mirror pair located in the white box are displayed in figure 3. A light beam from the laser enters the input hole of the box, first it is reflected on the upper mirror, then on the lower mirror, heading to an output hole. The output hole must be large enough to send the light beam into various directions. A video showing the mirror movement at low signal frequencies is available ([stacks.iop.org/PhysED/54/055002/mmedia](https://stacks.iop.org/PhysED/54/055002/mmedia)).

After having been assembled, the device needed an adjustment of the angle amplitudes in order to generate 1:1 figures. For this purpose, the same voltage amplitudes but incommensurable frequencies were set in order to observe a rectangle filled with the laser light. Adjusting the trimmers on the driver board, the rectangle was finally turned into the square. After the setting, the maximal angle deviations of the light beams are about  $\pm 10^\circ$ . It is clear, however, that a 1:1 figure can be obtained in reality with unequal angle amplitudes, when the laser beam is not sent perpendicularly to the screen (e.g. due to the different vertical positioning of the device and the screen).

### 3. Examples

#### 3.1. Diffuse screen

The example of a Lissajous figure created by the galvo mirrors on a large projection screen is shown in figure 1. The figure is clearly visible

in the whole lecture room. Since the screen is a normal projection screen only reflecting the laser light diffusively, the frequencies of the mirror oscillations must be high enough ( $\approx 100$  Hz) to create the illusion of the full Lissajous figure (by the vision persistence). The more complicated figure, the higher frequency is needed in order to obtain the stable figure.

As a mechanical device, the mirrors are capable of responding to a signal only up to a certain frequency. In our case, frequencies up to 500 Hz can be used without a problem. The mirrors start to whiz at higher frequencies and their tilt angle amplitude may be also reduced. The limitations become more evident, when an anharmonic signal with overtones (e.g. a ramp) is applied to the mirror.

A green or a red laser pointer is sufficient for projection onto normal diffuse surfaces. The green laser is recommended due to the highest eye sensitivity to that wavelength. A careful handling is always necessary when class 3R laser pointers are used (power output up to 5 mW) owing to the potential hazard for the eyes. When the laser light is sent through the classroom, the use of a class 2 laser is recommended (laser light intensity up to 1 mW).

Using the diffuse screen and the high frequency, the drawing of the figure itself cannot be observed. On the other hand, the figure drawing can be followed at low frequency, but the complete shape of the Lissajous figure is not available. This didactic puzzle can be overcome with a luminescent screen, which has the ability to ‘remember’ the drawn shape through a process of thermoluminescence.

#### 3.2. Luminescent screen

It is more illustrative to operate the galvo mirrors with a thermoluminescent foil (with a luminescence decay time varying from minutes up to several hours, see [1] for details). In order to initiate the foil luminescence, a violet laser pointer has to be used (wavelength of 405 nm in our case). Then, the frequencies of the mirror oscillations can be reduced to very low values ( $\approx 0.1$  Hz), at which the laser spot movement can be well followed, but the complete shape of the Lissajous figure still stays visible due to the memory effect of the foil.

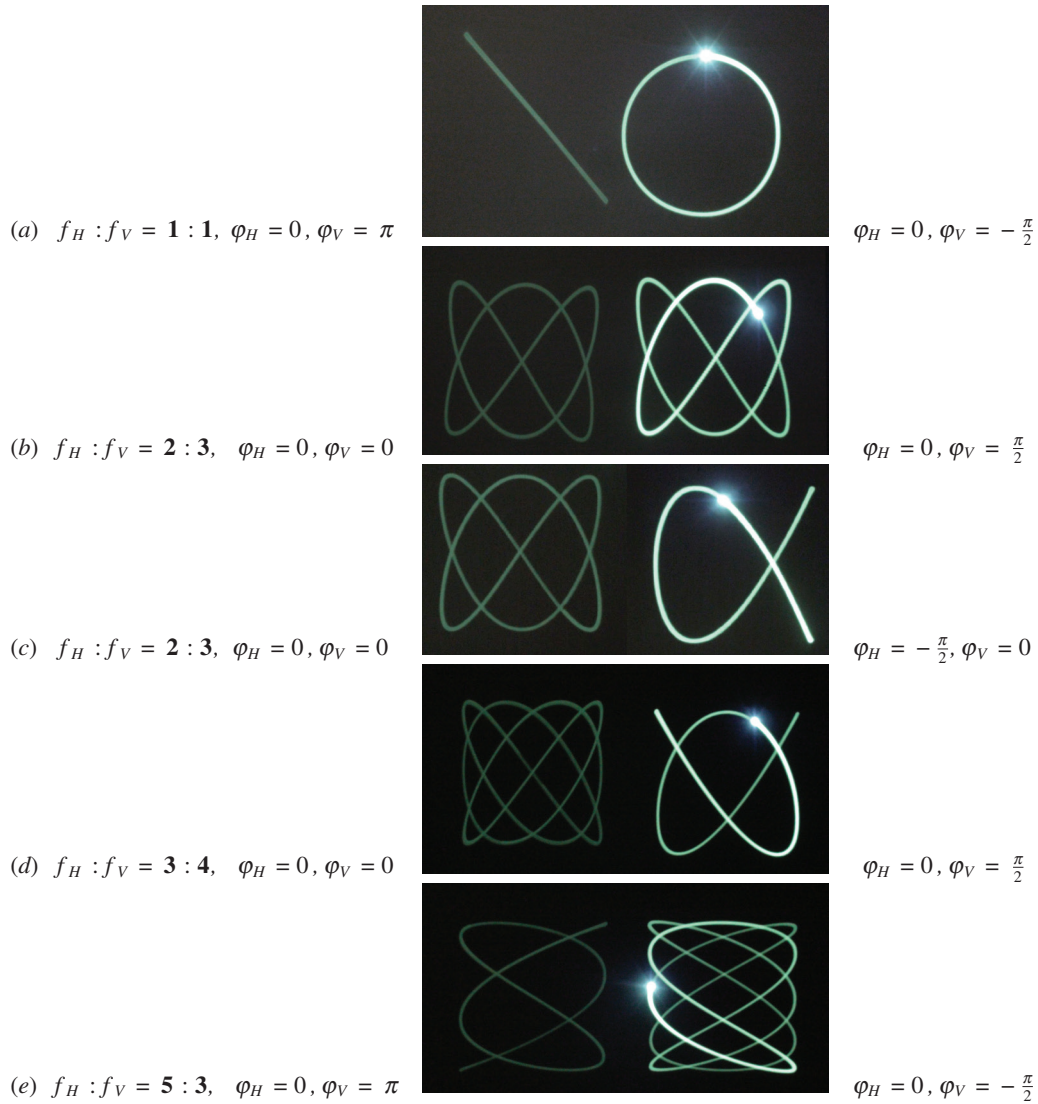


**Figure 4.** Examples of the Lissajous figures obtained for the same amplitudes, specific frequency ratios and two initial phase angles. The figures are drawn on the thermoluminescent foil with a violet laser. For an explanation of constants see the text.

The just explained finesse of the luminescent foil has been already used with the Blackburn pendulum, which has a long, about one second, period [1]. However, the Lissajous figures obtained by the pendulum are typically unstable due to the error in setting the correct frequency. This error  $\delta f$  evolves into a slow time-dependent initial phase shift  $\phi(t) = 2\pi\delta f t$  in one channel. The pendulum then goes slowly through all initial phase angles. In contrast to the pendulum, the frequencies of

the mirror oscillations can be set very precisely using the waveform generator and the Lissajous figures obtained for specific initial angles can be easily generated and compared.

The examples of the obtained Lissajous figures recorded on the thermoluminescent foil for various frequency ratios are shown in figures 4(a)–(e). Two versions, differing in the initial phase angles are shown. (The time dependence of horizontal  $x(t)$  and

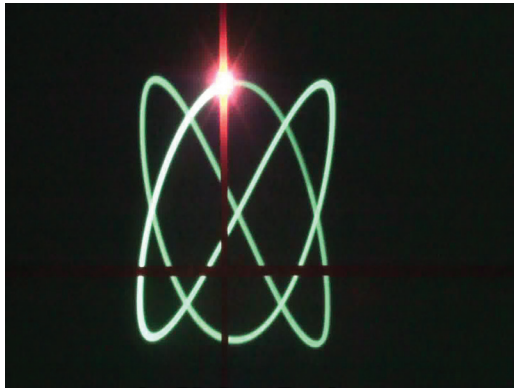


**Figure 5.** Determination of the frequency ratio from the numbers of intersections of the figure with the vertical and horizontal lines. Horizontal and vertical frequencies were 200 and 300 mHz, respectively.

vertical  $y(t)$  deflection is assumed in a form  $x(t) = A \sin(2\pi f_H t + \varphi_H)$ ,  $y(t) = A \sin(2\pi f_V t + \varphi_V)$ . The displayed patterns are generally different, but sometimes the figures look the same in the pair (figure 4(b)). However, it is visible at a slow laser spot movement, that the laser spot follows the track in the mutually opposite direction. One example is also given in the supplemental video. The direction of the movement is also apparent in the right figures from the luminescence decay in the track.

As expected, circle, abscissa or ellipse is generated by the frequency ratio 1:1 (figure 4(a)). It should be, however, noted that the correct evaluation of the phase angles from the figures on the screen depends on the correct orientation of mirrors and the voltage polarity applied to the mirrors. For example, even though the waveforms of the same frequencies and with zero phase difference were set in the waveform generator, the abscissa has the orientation typical for phase angle difference of  $\pm\pi$ . Therefore, orientation of the mirror should be changed in order to draw figures in accordance with the theory.

It is well known that the frequency ratio of perpendicular oscillations can be estimated from the number of intersections of the Lissajous figure with the vertical and horizontal lines, drawn across the figure. With a blue laser, the number of the intersections are easily observed when a luminescent paper is used as the lines (figure 5). In the presented case, the horizontal line is crossed 6 $\times$ , the vertical 4 $\times$ . The ratio is therefore 3:2. The horizontal and vertical frequencies were 200 and 300 mHz, respectively. A better idea is again obtained from the supplemental video.

#### 4. Conclusion

The galvo mirror based setup for the demonstration of perpendicular oscillation resembles the classical method of an analog oscilloscope with an electron beam. However, the output of the galvo mirrors can be scaled up to metre-sized figures in contrast to the small cathode ray tubes. In contrast to the second classical demonstration of perpendicular oscillation, Blackburn pendulum, the figure can be drawn vertically on the standard projection screen and the simplest figures as a circle, ellipse or abscissa for a 1:1 frequency ratio can be easily drawn. The use of luminescent foil provides didactic benefits helping to understand the formation of the Lissajous figures.

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