Projection over Hundre

Laser projector with servos

Gert Baars

We've already covered a laser projector in an earlier instalment of this series. This time however, we use a different projection mechanism. With a few servos, a laser module from eBay, a microcontroller and a little dexterity we can make a laser projector which, depending on the laser, can be seen from several hundreds of metres.

Laser projectors are often used for light effects at, for example, places of entertainment. These generally use powerful laser beams which generate striking light patterns. These types of laser projectors are not cheap however and even the individual parts such as laser modules and fast servos are not really that attractive either, considering their price. The alternative then, naturally, is to make your own.

Laser diodes and modules

Through eBay and the like, laser pointers and modules are frequently on offer for less than 10 pounds. These are typically red lasers with a power of less than 5 mW. This is more than enough to project something indoors during the day and outdoors at night up to a distance of about 100 metres. More powerful lasers, such as green lasers rated at 30 mW, can be used outdoors during the day over hundreds of meters and at night over several kilometres. Using this type of laser is not recom-

mended, in principle, because of safety considerations.

You can also use a single laser diode. But you will need a so-called collimator to obtain a parallel light beam.

Controller

The heart of the control system (see **Figure 1**) is an ATmega88 controller. Although it would be possible to drive the servos with a purely analogue system, from a music source for example, using a microcontroller offers additional possibilities such as the projection of text.

Analogue signals are required to drive the servos. We generate these with two PWM DACs (X-Servo and Y-Servo). The 78 kHz PWM frequency is strongly suppressed with a four-stage RC-filter. The two ADC inputs (X-in and Y-in) allow for analogue control, for use as a XYZ-plotter and an X-T oscilloscope. The Z-input (with internal pull-up) is

used to turn the laser on and off. An RS232 interface is added so that an LCD and keyboard interface are not required.

The HyperTerminal program that is part of any standard Windows installation can be used to communicate with the projector. The correct port settings are 9600 baud, 8 bits, 1 stop bit, no parity and no flow control.

The schematic for the laser controller shows that the laser is driven with a constant current. R_i defines the laser current and the quiescent current can be set with P1. This is sometimes better because laser diodes start to work at a certain threshold current but only produce optimal light when operating at a certain temperature. By setting the idle current just under the threshold current the light output is increased when used as a projector.

On pin 6 of the controller there is also an output called 'TTL optional'. This is because some laser modules are supplied with a control PCB which has a

ds of Metres

separate modulation input that can be driven directly.

Laser modules, such as the ones used in laser pointers, often have a photo diode which is used to control the laser current. These common modules are usually intended for 3 V battery operation. If you measure the current of the module at 3 V you can use this to determine what the value for Ri should be. In this case it is better if Ri is selected to be slightly smaller.

The servos

Making your own servos that are reasonably fast is not all that difficult. Servos targeted for the model-building world are not an option because they are too slow and inaccurate for this application. The servos for the laser projector can easily be made from a small DC motor that is often found in older CD/DVD drives. We refer here to the motor that opens and closes the tray, but sometimes a CD/DVD drive contains multiple motors of the same type.

To turn the DC motor into a servo an angle sensor is required. This angle sensor measures the rotation of the motor shaft. The result of this measurement is used to correct the position of the motor shaft. In a standard servo the angle sensor is generally a potentiometer which is connected to the motor shaft. This, however, creates a lot of friction and is not very accurate. The servos for the laser projector use a combination of a magnet and a Hall-effect sensor as the angle sensor. The magnet is an especially powerful Neodymium miniature magnet which measures only 2×2×2 mm.

There are several possibilities for attaching the little magnet to the spindle. Here we used the clamp from a plastic terminal strip as the coupling (see Figure 2). These have an internal diameter of 2.2 mm while the motor shaft has a diameter of 2 mm. Not really ideal, but the clamp can be fixed in place with the screw and the little magnet is easily glued to it. When gluing the magnet you need to make sure that the north- or south-pole
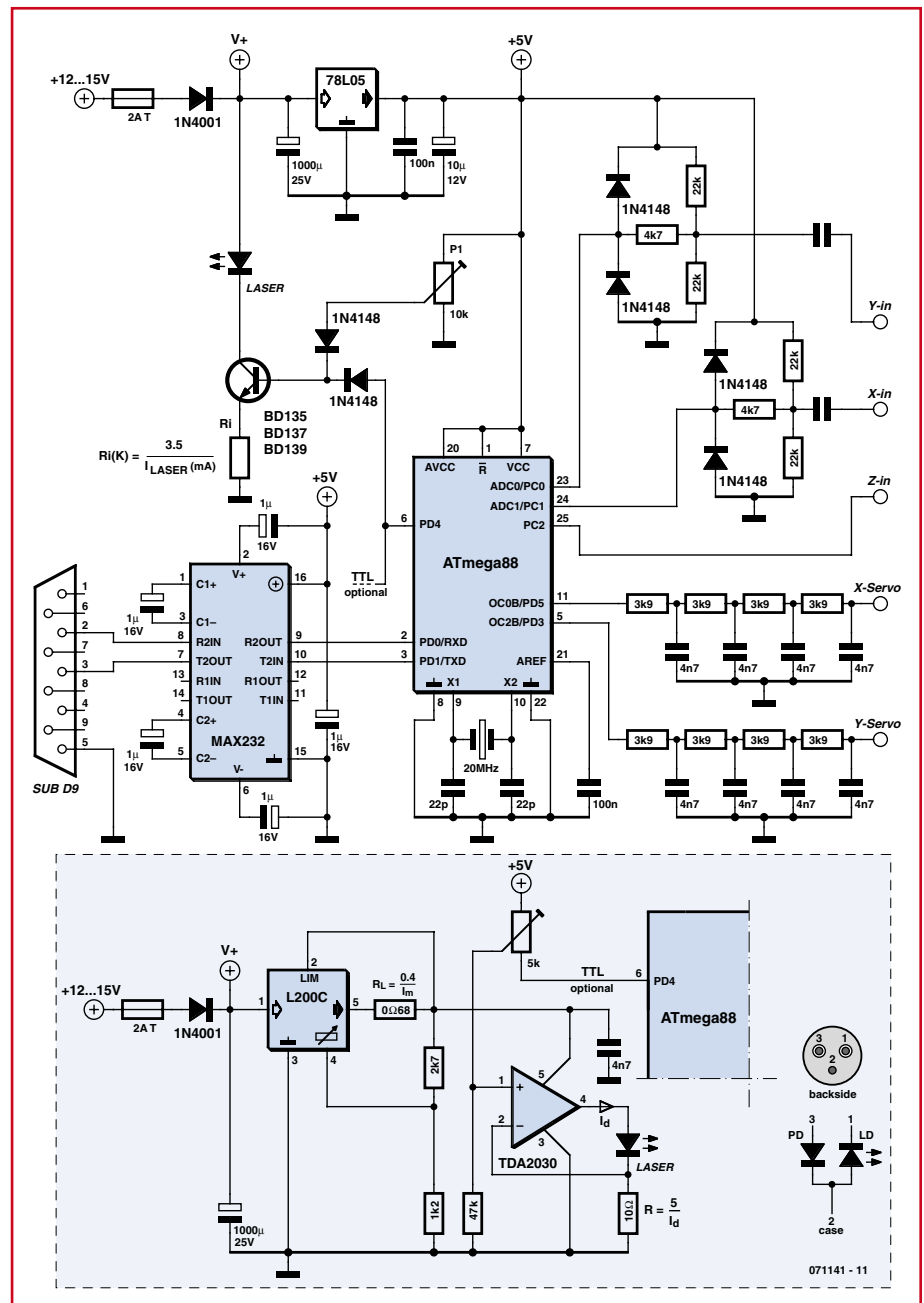

Figure 1. The schematic for the laser controller. The optional driver circuit can be used for larger lasers.

of the magnet does not face the shaft but is perpendicular to it. It is as if the side of the magnet is glued and not the end. Whether the North or South pole faces to the left or right does not matter. It is merely a case of reversing the motor wires to make everything right again. Finding the poles is not that hard. These are the sides where the

magnet is most powerful. When two magnets grab each other the joined surfaces are always the poles. The mirror that deflects the laser beam can be attached with instant glue.

When the motor shaft rotates from its neutral position, the polarity of the magnetic field in front of the sensor rotates as well. This is necessary for

Figure 2. This figure shows how the mirror is attached to the servo shaft and how the angle sensor is constructed.

the proper operation of the servo. Naturally, the construction of the clamp with the magnet and the mirror contribute to the inertia of the motor. However, tests showed that this contribution was smaller than the inertia of the rotor itself and this contribution can therefore be ignored.

It is best if the mirrors are so-called first surface (or front surface) mirrors. These do not have glass in front of the reflective surface, which avoids additional refraction and means that the angle of incidence is always equal to the angle of reflection. This ensures that the laser beam remains nice and focussed after reflection. First surface mirrors can often be found in older (laser) printers/scanners/bar code readers and can be cut to size reasonably easily using a glass cutter. The mirrors in the laser projector are cut with dimensions of about 6×8 mm. When gluing the mirrors you have to make sure which side has the reflecting layer. The rear side (the side with the glass) is obviously the side that is to be glued.

Once the glue has set properly the servo can be assembled. The motor has to be mounted on a piece of circuit board, preferably using the original
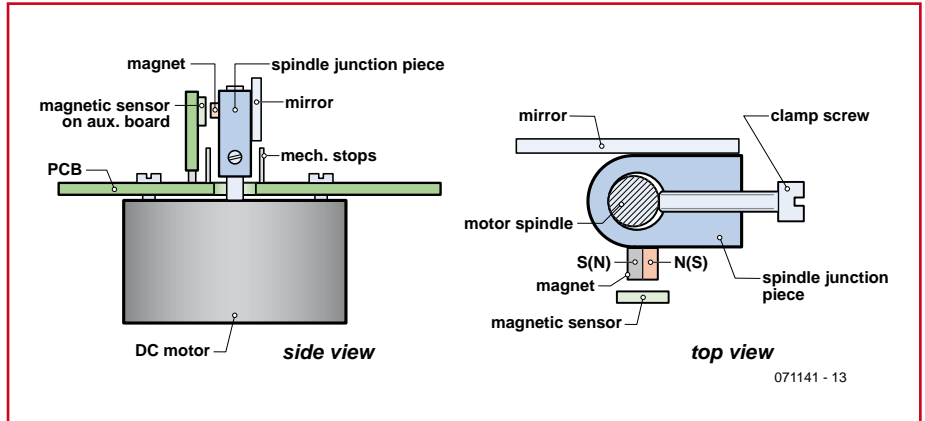
mounting screws. Make sure that the screws do not protrude too far into the motor so that they touch the rotor. The shaft coupling, complete with magnet and mirror, can now be attached to the shaft. After this, the Hall effect sensor has to be mounted in front of the little magnet. The Hall sensor used in the prototype was in an SMD package and therefore a small piece of circuit board was used as the mounting support for the sensor. The same sensor is also available in a SIP package, which

makes things somewhat easier.

When positioning the sensor you have to take into account the desired mirror position, which will usually be 45 degrees for a 90° reflection. The centre of the sensor package has to be exactly opposite the magnet at a distance of about 1-2 mm. This is precision work, but is not hard to do.

To ensure that the magnet cannot turn too far away from the sensor, two end-stops are fitted that prevent this from happening. The end stops are easily
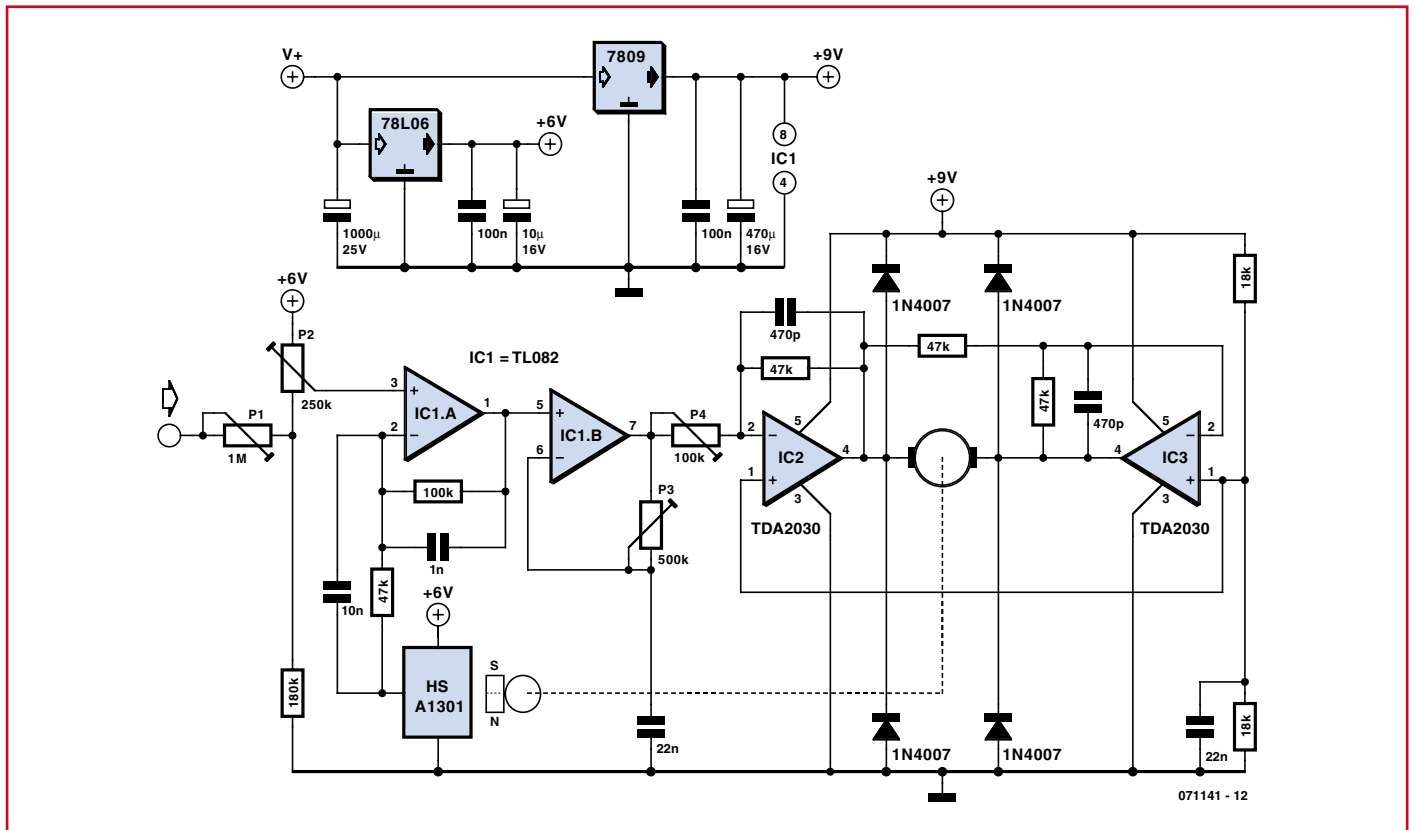

Figure 3. Each servo motor is controlled by this circuit. The input is therefore connected to the X-servo and Y-servo outputs of the main schematic (Figure 1).
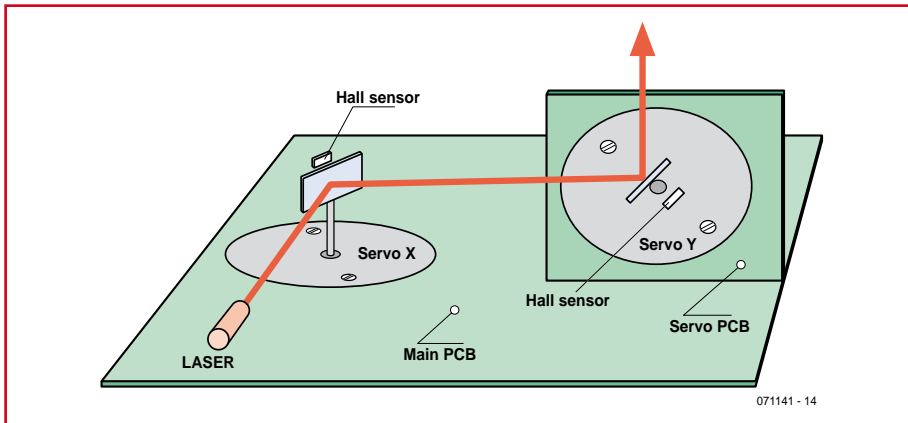
Figure 4. To enable control in both the x- as well as the y-direction the servos can be positioned like this.

mounted and are in the form of two pieces of wire, cut from a resistor lead, for example. These can be soldered onto the motor PCB to the left and right of the screw for the shaft coupling. This completes the servo.

Servo control

The electronics for the servo drive can be kept quite simple (see **Figure 3**). P1 is used to set the input signal sensitivity and determines the maximum projection format. P2 sets a DC-offset, which is used to move the projection image a little, for example. IC1a amplifies the difference between the signal from the magnet sensor and the input signal. When this difference is positive, the motor turns in the opposite direction compared to when this signal is negative. In this way a closed loop is created which is necessary for controlling the servo. IC1b is a proportional-differential (PD) amplifier. This is indispensable to correct the phase of the feedback loop.
IC2 and IC3 are connected as a bridged amplifier for driving the motor. These

ICs, type TDA2030, are intended as an audio amplifier but are functionally just big difference amplifiers that can deliver about 3 A. More than enough for this type of motor. Four diodes prevent the inductive flyback voltage of the motor from damaging the IC.
The power supply voltage for these ICs is provided by a 7809 regulator. With a 9-V power supply, IC2 and IC3 can drive the motor with plus and minus 6 volts. In the prototype IC2, IC3 and the 7809 were all mounted without insulation on a common heatsink.
The current consumption of the servos depends on the amount of drive. This is typically not more than 100-200 mA each. The average power consumption of the entire projector including a 5 mW red laser module is about 300 mA. Batteries will therefore not last very long, but powering from a mains adapter or a small lead-acid battery for 'in-the-field operation' are good options.

Adjusting the servos

When a servo is connect to the drive PCB for the first time, all the potenti-

ometers have to be set to their centre positions. When the power supply is connected, and all is well, the motor now turns such that the magnet is exactly opposite the sensor. If the magnet turns away from the sensor then the motor wires need to be swapped around.

Using HyperTerminal we can send commands via the serial port to the projector. There are two commands for adjusting the step response of the servos: AX and AY (adjust X/Y). After issuing an AY command the step response of the Y-servo is projected. The potentiometers for the PD controller and motor driver now need to be adjusted so that the projection is a nice, clean pulse waveform without showing any oscillation artefacts. The same is true for the X-servo after issuing the AX command. Repeat the adjustment of both servos once more. Measured with an oscilloscope (at the sensor output), the step response time of the prototype was about 2-4 ms, depending on the step size. The –3 dB sine response is about 150 Hz.

In operation

Once the servos are working and are adjusted properly, the projector itself can be tried. The serial port of the projector is connected to the serial port of a PC/laptop. Start HyperTerminal and enter the COM-port settings. A connection can now be established with the ATmega88. You can now enter commands using the keyboard. With the LC command (list commands) the list of available commands is displayed on the screen. Each command consists of two (capital) letters. If there are no parameters this is then immediately followed by pressing the enter key. Commands with parameters are
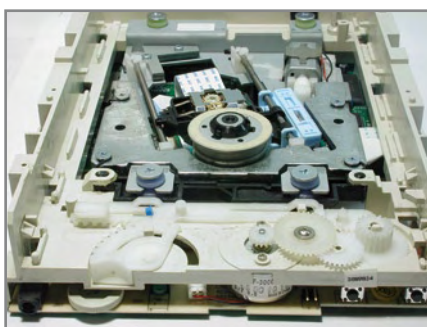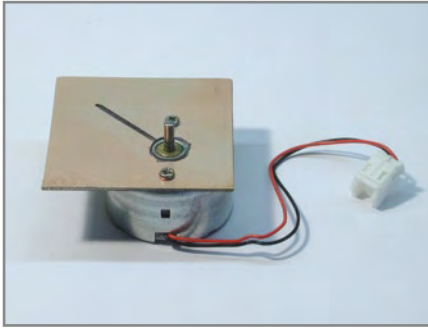

An opened CD-drive. The little DC-motor under consideration sits at the front in the middle.

The little DC-motor as removed from the CD-drive (keep the little mounting screws).
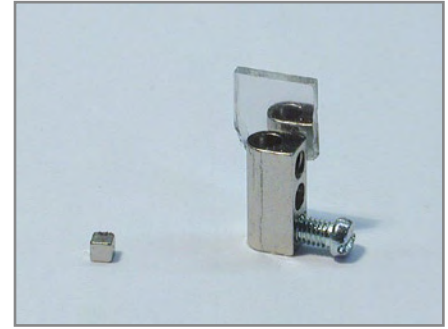

All parts of the servos together: mirror, shaft coupling, magnet sensor and the little magnet.

The little motor mounted on a piece of printed circuit board with the 45-degree line where the magnet sensor has to come.

The mirror, the shaft coupling and the little magnet, ready to be glued together.

The mirror glued to the shaft coupling; the magnet is next.

entered by typing the command, followed by a space, then a parameter, then another space, etc. Parameters are a number, usually 0-9. There is no checking of the input and therefore there are no error messages either!

Using the command MS (mode set), one of four modes can be selected. If the projector is used on an occasion where music is played, it can be nice to show the music as an oscilloscope image on the wall. In this case the sound output from a CD-player, or from a microphone with pre-amplifier, is connected to the Y-input of the controller. After issuing the command MS 3, the projector operates as a projection oscilloscope. The command SS (save settings) can now be used to save everything. If the projector is now switched back on, after having been switched off, it will continue to operate with these same settings and can therefore operate 'stand-alone'.

If the projector is to be used as a non-stop text display this can be accomplished as follows: the text is entered with the TX command. The text size and scroll speed are set with TS. The entered text is now projected as a running text display. If the text is displayed in mirror image or upside down then this can be corrected with the RE

command. Once all is correct, the SS command can be used to store everything (including the entered text).

To project text, the MS 1 or MS 2 command need to be issued. In mode 1 the text scrolls letter by letter and in mode 2 word by word. With the latter there is the possibility that a word is too long when the letter size is too large. No error detection for this situation is programmed in, users will have to look out for this themselves.

An important adjustment is the timing. The software assumes predictable response times of the servos. These are stored as two parameters. Using the TM command with 2 parameters these can be altered and saved with SS. In the TM command the first parameter is a fixed time and the second causes a delay proportional to the size of the projection. The default is: TM 3 4. The projector works well with the default settings, but experimenting with the settings gives you a better feeling for the workings of the projector. For example, TM 1 4 distorts the projection and with TM 4 4 is slower than necessary. Fine adjustment is possible however and can gain some speed which means that texts with larger scroll widths can be used. These would otherwise be delayed too much which results

in a flickering image. This is however only a problem with large letters and a scroll width of more than about 5 characters.

Should this experimenting with the settings result in some problems with the display, the LD command (load defaults) can be used to set everything back to the initial state. Don't forget to store this 'reset' with the SS command.

Positioning

Figure 4 and the photos show how the servos can be positioned. It is advisable that the position of at least one servo and also that of the laser is made to be mechanically adjustable. It is important that no laser light misses the mirrors. With a little bit of adjustment of the laser position (height and direction) all of the correct settings are usually easily found.

Note that with laser modules the housing is often the + connection. A little piece of heatshrink sleeving is then required for insulation.
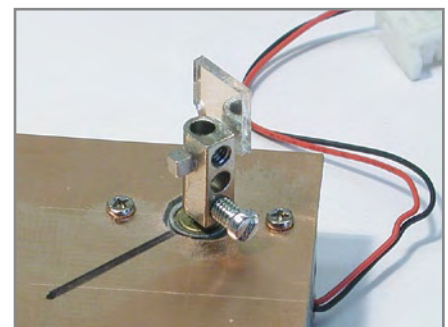
Lasers with larger powers

As mentioned before, working with red lasers can be considered safe for pow-
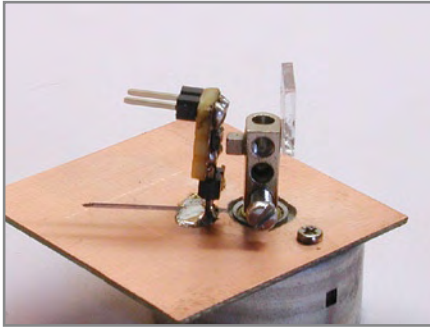

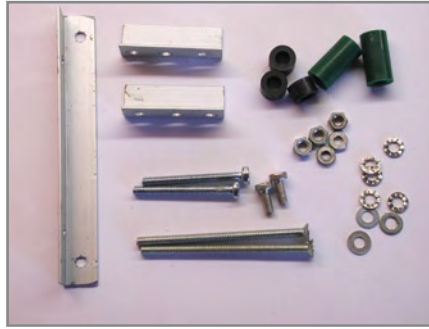A small nail holds the magnet in place for gluing.

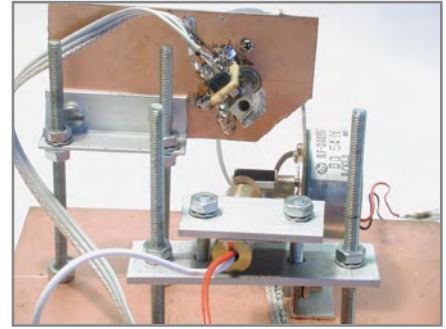The shaft coupling with mirror and magnet, all glued together.

The complete shaft coupling, mounted on the motor shaft. Now the Hall-sensor.

The complete servo including the magnet sensor which is held in the correct place with a small PCB.

We make the mechanical construction with M3 hardware and aluminium angle profile.

The two mounted servos with the laser module in the foreground.

ers up to a few milliwatts (still, *never* look into the beam). The advantage of a green laser compared to a red one is that the eye is much more sensitive to green light, so that the projection appears much brighter. Green lasers are usually DPSS (Diode Pumped Solid State) types, where the beam of an 808 nm infrared laser diode drives a pair of crystals. These crystals convert the 808 nm beam in two steps to 532 nm (green). The efficiency of this is much smaller than 100% so that, in principle, a big infrared laser diode is required. To illustrate this: a 5 mW red laser diode requires a drive of about 40 mA, a 5 mW green DPSS module needs typically 200 mA.

If you must work with more power, then for a few tens of Euro you can purchase a green laser pointer rated at, for example, 30 mW. These will have to be dismantled, which usually involves sawing to gain access to the driver PCB.

The driver PCB often delivers too little current and/or is too slow. Driving the diode directly with a current source is often the best solution for optimum speed and light output. When the driver PCB is removed, after determining which are the connections to the laser diode, it is best if the laser diode and photo diode are connected in antiparallel. This is just a case of soldering two pins to each other (usually pin 1 and pin 3, pin 2 is the housing). This is because a laser diode typically has a reverse blocking voltage of no more than 2 V and the photo diode prevents this from being exceeded. Laser diodes are also sensitive to static discharge, so take the necessary precautions. In the circuit of **Figure 1** there is an

additional circuit for driving a bigger laser diode with a constant current and to modulate it. The assumption here is for a current of 500 mA for a 30 mW DPSS module obtained from a laser pointer.

The TDA2030 is configured as a current
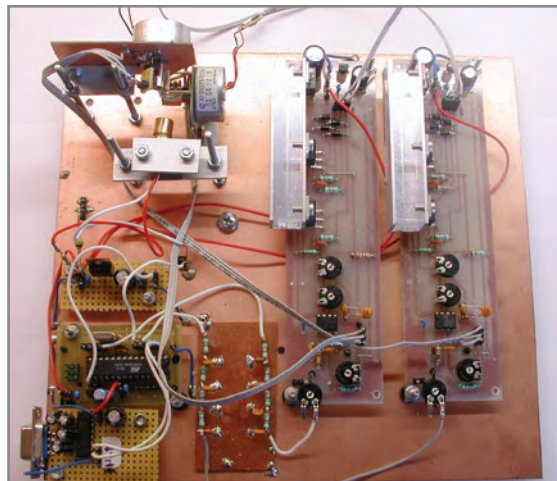
The complete laser projector: the two servo driver PCBs are on the right, the servos are at back left and the controller and RS232 interface are in front on the left.

source which can be modulated with TTL signals and the L200 is added as regulator with current limiter. This is additional safety to protect the expen-

sive laser module from currents greater than about 550 mA. The potentiometer sets the quiescent current which is just below the threshold at which the module starts to 'laser' This serves to slightly increase the average temperature (for optimal light output).

The resistor R is used to set the current through the laser diode and R_L is for the current limit. If the nominal current needs to be 500 mA, for example, it is safe to calculate R_L for 550 mA (500 + 10%).

Applications

There are of course a number of interesting applications for a laser projector. It is, for example, possible to use it for chatting. Two people and two tables with a computer on each can be positioned against opposite walls. The chatters can then see the text of the other person behind/above their monitor on the wall. Using the wall of a larger building it is possible to chat in a group, provided each participant has their own projector, of course.

Another application is the projection of advertising messages in a shop window, for example. This can be done from the inside because the text can be projected mirror-reversed. The text can then be read normally from the outside.

Many other applications can be conceived of, but we leave those up to you.

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