Using a CD laser head for building an optical profilometer

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1 Introduction

A CD reader is based on a head including for its optical part a diode emitting in the close IR wavelengths (around 780 nm), a receptor photodiodes quadrant as well as the lenses for focusing the laser beam, and for its mechanical part a coil used as an electro-magnet for varying the distance between the disc and the optical elements (figure 1).

In order to work properly, a CD reader head must be able to be positioned quickly and with great accuracy with respect to the reflecting surface of the disc. The aim is to position the focal point of the converging lens, which is defined by a disc with a diameter of about 1.7 μm, on the surface of the CD, and this result is obtained by nulling the signals received by the 4 or 6 quadrants of the reception photodiode (astigmatism effect: depending whether the focal point is closer or further from the surface of the CD, two diagonally opposite quadrants are illuminated – the aim is to simultaneously reach a null value for all 4 quadrants in order to correctly position the focal point).

We here use this optical system and its mechanical support to build a profilometer based on the principle of focalising a laser beam as depicted previously. We first describe how to power the laser diode in order to obtain a constant output intensity, we then present the problems linked to stability of the distance measurement, and finally we complete the circuit with a feedback loop so that we can work at constant focal point distance in order to minimize the diameter of the projected laser spot on the scanned sample and extend the measurement dynamics to a few millimeters.

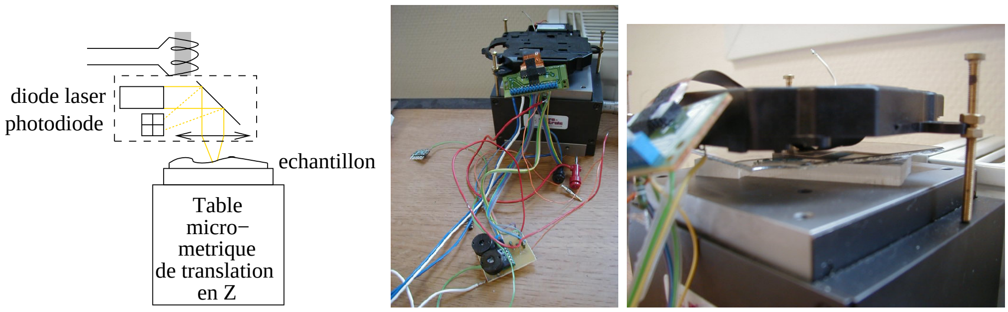

Figure 1: Experimental setup: the optical head of a CD reader is positioned over a reflective sample whose height can be adjusted so as to be able to bring it close to the focal point of the lens. This lens can itself be moved along the vertical axis by an electromagnet. A four-quadrant photodiode send a signal function of the distance between the focal point and the reflective surface.

2 Emitting laser diode principle

The laser diode includes a cavity for amplifying the infra-red laser beam and a photodetector used for monitoring the output power. Since the conductivity of the laser emitter decreases with temperature, one cannot supply power to a laser diode using a voltage generator (with which the intensity will quickly rise until the component is destroyed). The diode must thus be supplied with a current generator or, better, included in a feedback loop keeping the emitted laser power constant (by reading on the photodetector internal to the laser diode the emitted power). With this aim in mind, we developed the circuit depicted in figure 2, in which the wanted voltage is set using a potentiometer whose value is set to 90 mV (this voltage value was read with a voltmeter on the photodetector pin while the diode was working with its original control electronics). This feedback voltage means a supply current of around 60 mA is sent to the diode.

It seems that the functions of the pins of all laser diodes are similar. The diode suddenly starts emitting a laser beam for a supply current around 60 mA (figure 3). One must thus include a transistor in the feedback loop as a voltage follower, since the operational amplifier is unable to source such an intensity (the 2N2222 transistor used here

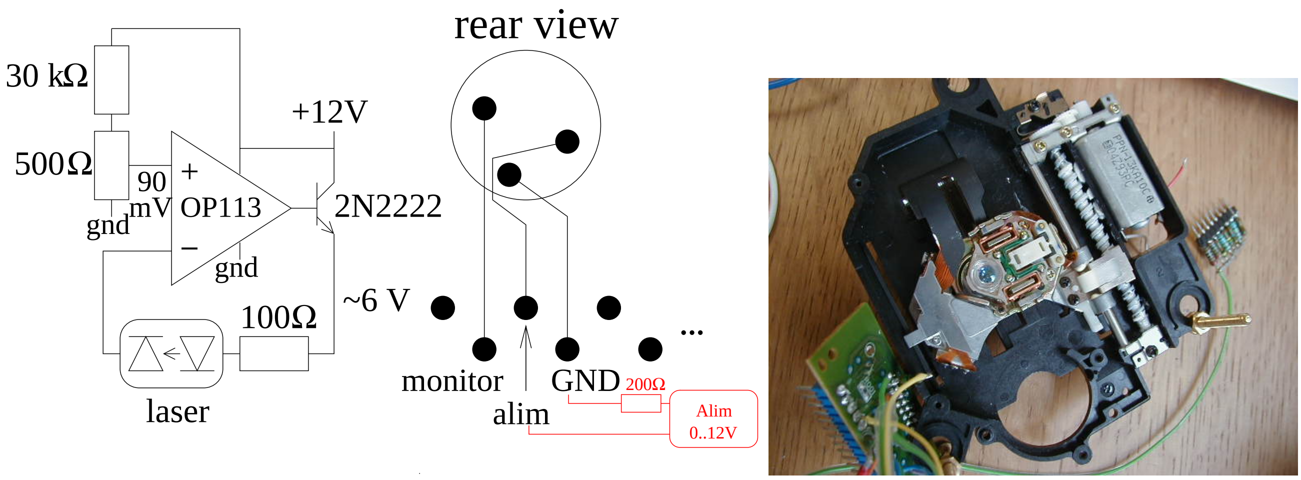

Figure 2: Left: circuit for supplying a laser diode regulated to emit a constant power. Right: functions of the 3 pins available at the back of the laser diode, and connection points for a voltage generator to check if the diode is still working.

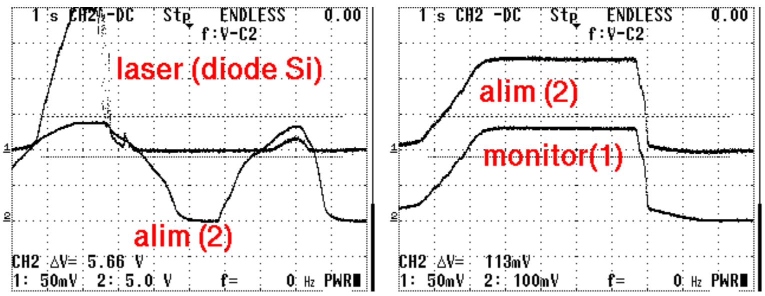

Figure 3: Left: power as monitored on a Si diode positioned in front of the focusing lens, and supply voltage of the laser diode. Right: voltage output as observed on the internal monitoring photodetector (pin named "monitor") and supply voltage of the laser diode.

is slightly too small for this task and must be cooled using a heat sink). The laser emission is first monitored using a Si photodiode. Once the laser emission at the output of the focalising lens is observed, write down the monitoring photodetector output voltage and set the output of the potentiometer to this value. The feedback loop will then aim at adapting the voltage output of the operational amplifier by regulating the current supplying the laser diode in order to keep the emitted beam intensity constant.

3 Connecting and using the reception photodiodes

A multiple quadrants photosensor is used in the following way when a disc is read:
- one 4-quadrants receiver monitors the focus of the laser on the reflective surface
- two receivers on both sides of the 4-quadrants receiver are used to keep the head over the track.

The photosensors are polarized by a +5 V voltage in order to increase the bandwidth to a frequency above a MHz (remember that 74 minutes of music hold on a 650 MB CD, hence a required bandwidth of at least 1.2 Mb/s).

$$\frac{S}{R}=\frac{\frac{1}{R}+\sum_{i=1}^{I}\frac{1}{R_i}}{\frac{1}{Q}+\sum_{j=1}^{J}\frac{1}{Q_j}}\left(\sum_{j=1}^{J}\frac{W_j}{Q_j}\right)-\sum_{i=1}^{I}\frac{V_i}{R_i}\underbrace{\Longrightarrow}_{R_i=R,\ Q_j=Q}S=\frac{I+1}{J+1}\sum_{j=1}^{J}W_j-\sum_{i=1}^{I}V_i\underbrace{\Longrightarrow}_{I=J}S=\sum_{j=1}^{J}W_j-\sum_{i=1}^{I}V_i$$

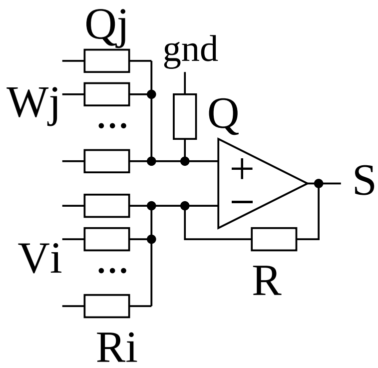

Figure 4: Circuit used at the output of the photodiodes in order to sum and subtracts the signals and generate a usable output voltage. The output S is connected to the input of a A/D converter and informs on the distance between the focusing lens and the sample.

We indeed have with this circuit the ability to sum the signals from two diodes, and to subtract the result to the sum of the two other diodes (figure 4). We can thus generate a signal proportional to the distance separating the convergent lens focusing the laser from the reflective surface (figure 5).

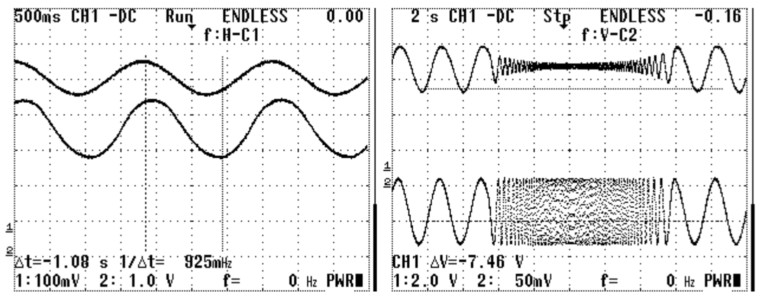

Figure 5: Signal driving the optical head (top) and signal observed after appropriately combining the outputs of the reception diodes. Right: evolution of the amplitude of the monitoring signal when driving the head with a constant amplitude signal of varying frequency.

4 Stability problem

The laser diodes heats up after being switched on. The expansion of the elements of the head under the additional heat implies a slight but visible drift of the head-sample distance during the first ten minutes after switching the experiment on (figure 6). One thus must wait long enough (about an hour) for the temperature of the head to stabilize and the head-sample distance to stop drifting before performing a measurement.

5 Feedback loop for constant distance scanning

After a first attempt of constant height scan which allowed us to conclude that the measurement range is very reduced (a few hundred microns at most, 7), we have focused on developing a feedback loop aimed at keeping the head at a constant distance from the sample (and thus reach a working range of a few millimeters).

The aim is to keep the distance between the focusing lens of the laser and the reflective surface of the sample constant during the scan. The measurement range is thus increased and we avoid non-linearities in the signal-distance function ("signal" being the output of the combination of the voltages read on the four-quadrants photodiode).

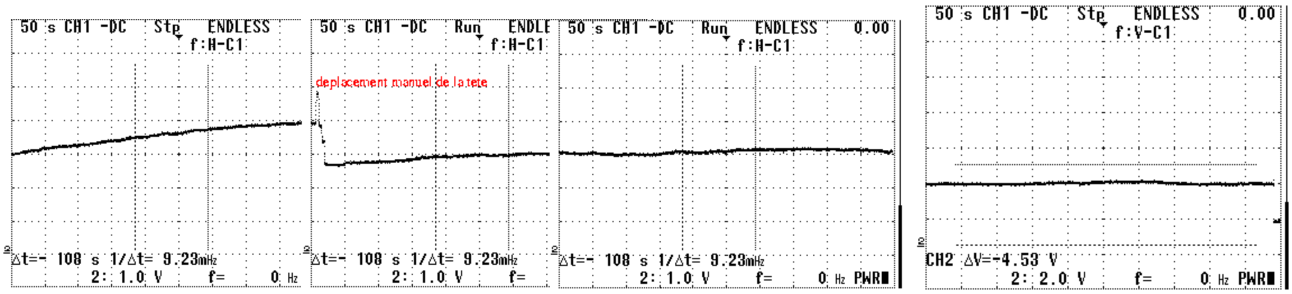

Figure 6: Left: evolution of the lens-sample distance as measured during the first minutes after switching on the laser diode (the sample is kept at a fixed position during that time). This drift is attributed to the thermal expansion due to the laser diode heating. Right: stability example one the temperature of the diode is set after running for a few hours.

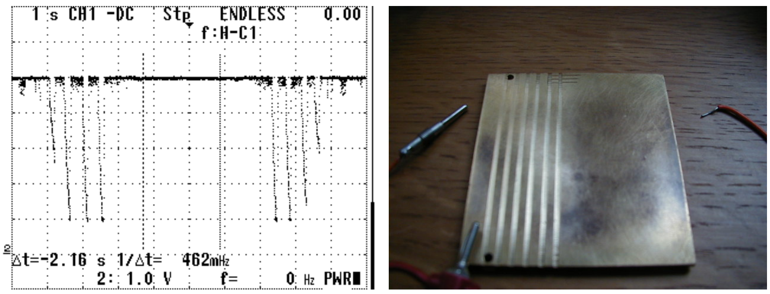

Figure 7: Work at constant height: 5 grooves of increasing depth between 100 μm and 500 μm as well as a line of unknown depth (below 100 μm) have been milled in a flat brass piece.

We use, for mobility and simplicity purposes, a 68HC11 microcontroller for the acquisitions (8 bits) and the control of the position of the optical head. This latter operation is realized by varying the current sent in the coil of the electromagnet: the digital output of one of the 8 bit ports of the 68HC11 is converted to a D/A converter by a network of resistors with values $X.2^i$ (we have chosen $X = 1000\ \Omega$, $i = 0..7$. See figure 8). The feedback loop is limited to simply comparing the current lens-sample distance estimate to the wanted value (initially fixed), and a feedback on the D/A converter aimed at bringing the head closer or further from the sample. The command for moving the head is also sent to a PC through the serial port (RS232) for drawing the topography map of the sample (figure 9).

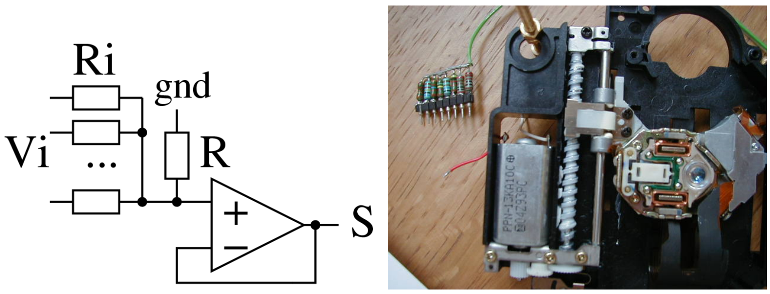

Figure 8: Circuit used at the output of the 68HC11 for converting a 8 bit TTL output to an 255 values D/A converter. The output supplies, through a transistor, current to the coil of the electromagnet used for moving the head and tuning its distance to the sample.

$$S\left(1+R\sum_{i=1}^{I}\frac{1}{R_i}\right)=R\sum_{i=1}^{I}\frac{V_i}{R_i}\underbrace{\Longrightarrow}_{R_i=\frac{X}{2^i},\ I=7}S\left(1+\frac{R}{X}.255\right)=R\sum_{i=1}^{I}V_i\frac{2^i}{X}\Rightarrow S_{max}=\left(1-\frac{X}{X+255R}\right)V_{TTL}$$

In our case, $X = 1000\ \Omega$ so if we want $S_{max} = \frac{9}{10}V_{TTL}$, we chose $R = \frac{9X}{255} = 35\ \Omega$. We have actually used $R = \infty$.

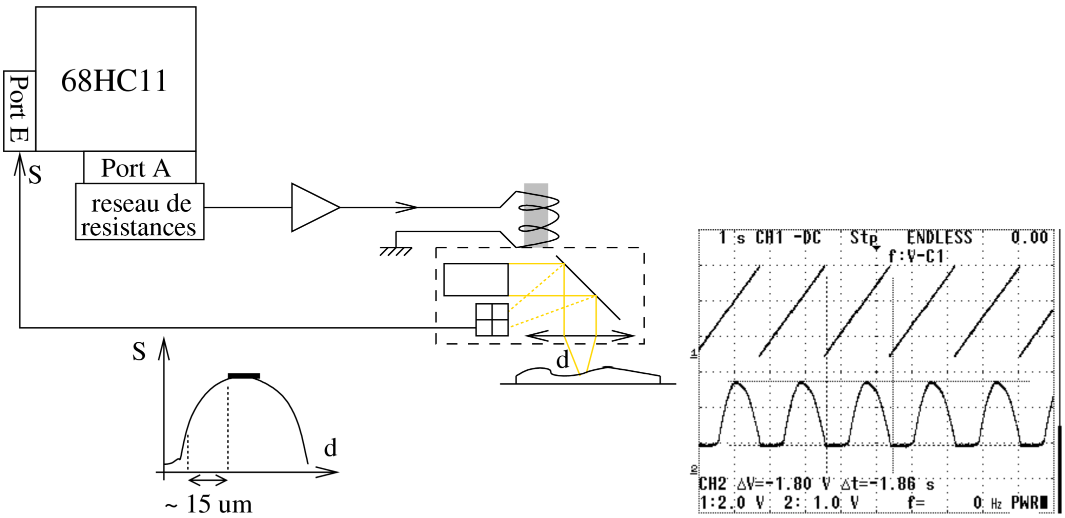

Figure 9: Principle of the feedback loop: the microcontroller reads the voltage output from the combination of the signals from the diodes, and compares this value to the predefined wanted value. An appropriate action on the electromagnet (increase or decrease of the current in the coil) is performed in order to get closer to the wanted value. For too large a focal point-sample distance, the slope of the diode signal-distance relationship changes (cf right image) and the feedback is no longer efficient.

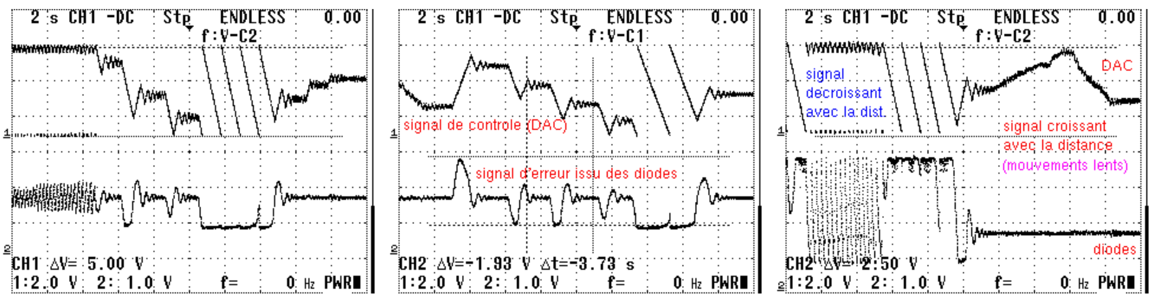

Figure 10: Left and center: two examples of feedbacks on the head position in order to keep the output of the combination of the diodes signals at the wanted value (while the table holding the sample is manually moved). Right: illustration of the incapacity of the feedback loop to work properly in a region in which the derivate of the signal (issued from the diodes)-distance changes sign (left part of the image – as opposed to the right side of the image in which the sample was positioned properly in order to again have the right sign of the derivate.

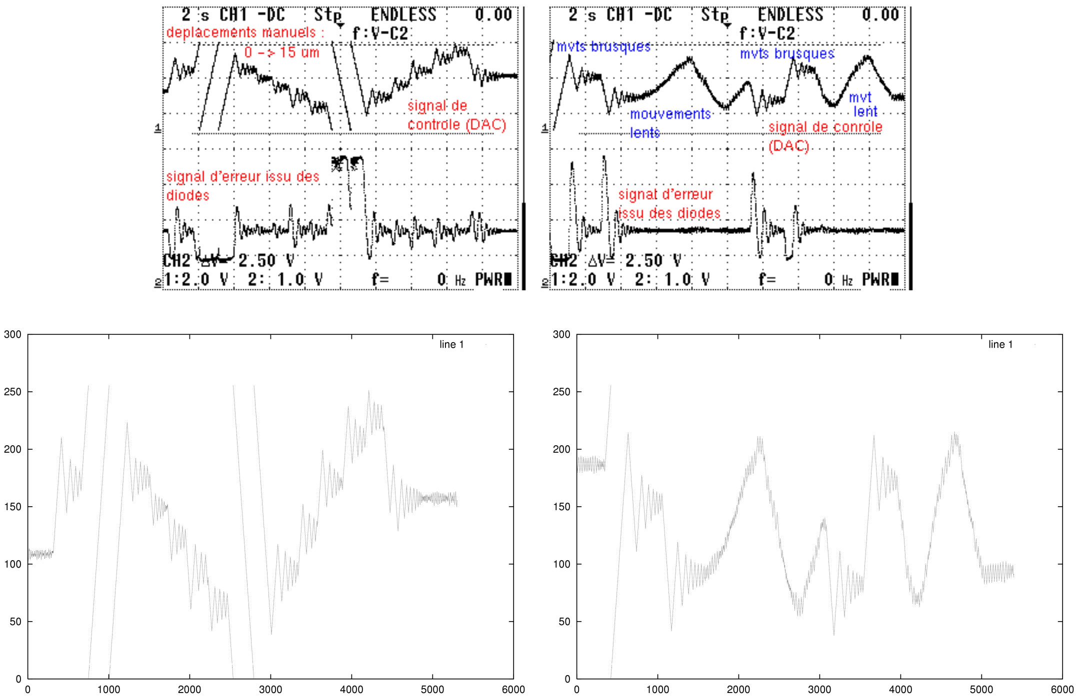

Figure 11: Top: error signal (difference between the voltage read at the output of the diodes and the wanted value) and control signal (as sent by the D/A converter). Under each image: signal transmitted by the 68HC11 to the PC through the serial link including the control signal used for plotting the topography of the sample.

```
8E 00 FF     lds #0h00FF
CE 10 00     ldx #0h1000
86 FF        ldaa #0hFF        ; port A : output
A7 01        staa 0h01,x       ; |
86 90        ldaa #0h90        ; setup AD converters
A7 39        staa 0h39,x       ; |
1C 28 20     bset 0h28,x,#0h20; setup serial port : port D OR mode
6F 2C        clr  0h2C,x       ; set 2400 N81
CC 33 0C     ldd  #0h330C      ; |
A7 2B        staa 0h2B,x       ; |
E7 2D        stab 0h2D,x       ; |
C6 80        ldab #0h80

86 24  ici: ldaa    #0h24    ; trigger A2D : AD port 4 (tout a droite)
A7 30       staa    0h30,x   ; |
8D 14       bsr ad_read       ; result dans le port A

81 50       cmpa #0h50      ; 0h50=0d80
22 0A       bhi fwd           ; PAS bge (cpl a 2 signe)
81 55       cmpa #0h55        ; 0d55=0d85
25 09       blo rev           ; PAS ble (cpl a 2 signe)
E7 00 rien: stab 0h00,x
8D 0F       bsr snd
20 EC       bra ici
      ; ---------------------------------------------------------------
5A     fwd: decb
20 F7       bra rien
5C     rev: incb
20 F4       bra rien
A6 30  ad_read:ldaa 0h30,x
2A FC       bpl ad_read
A6 34       ldaa 0h34,x
39          rts
1F 2E 80 FC snd: brclr 0h2E,x,#0h80,snd
E7 2F       stab 0h2F,x       ; send B : position
39          rts
```

Table 1: 68HC11 feedback program (expects the A/D converter 4 as input for reading the signal, and the D/A converter to be connected to port A).