RTL apparatus to study light intensity patterns produced by slits
## A didactic experiment developed within IRDIS project

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Within the IRDIS project (an Italian national project aimed at developing new tools for Science Teaching with Technology), we developed a prototype apparatus that allows easy but precise measurements of light intensity patterns produced by single or multiple slits , as well as immediate comparison with simulated spectra (in the approximation of infinite distance of source and observer from the slits). The present apparatus is an improved version of one described by other authors (1,2). A discussion of the importance of this topic in physics education may be found in (3).

Our main goal was to create a low-cost, user friendly device that allows accurate experimental investigations of the classical Fraunhofer patterns.

At the same time we wanted to give an example of the efficacy of using a general purpose software based on LINEAR probes. Because a *cheap* light probe coupled to displacement probe (suitable for our purpose) was not commercially available, we designed a new one, that turned out to be quite efficient, and easy to be used .
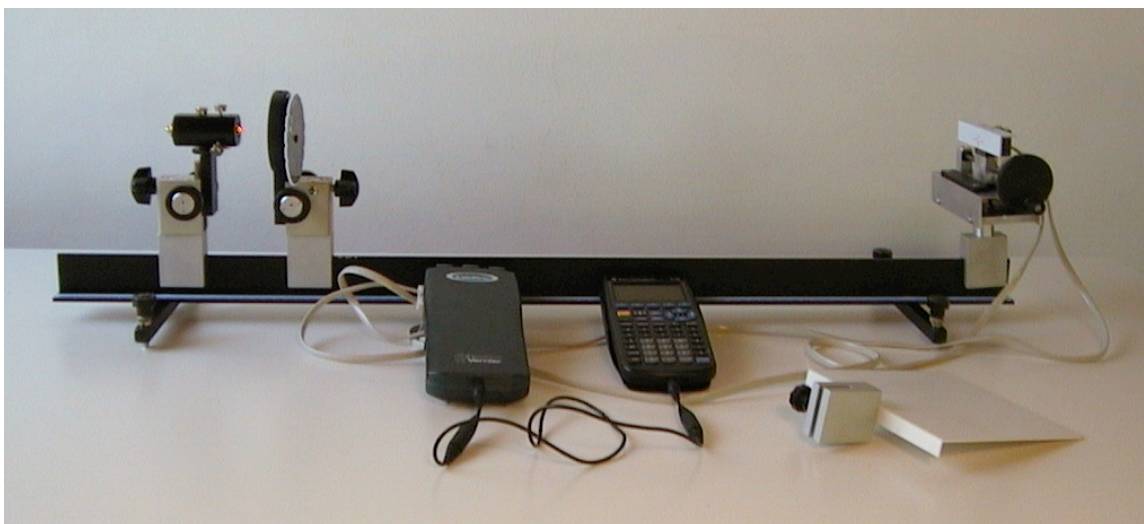

The apparatus consists of four elements, besides the RTL (as *portable* RTL we used CBL as interfaces, and TI89 pocket graphic calculator with PHYSICS software for data collection and handling; as *standard* RTL we used LabPro interface and LoggerPro software with Macintosh or Windows computers):

1) a source of monochromatic light well collimated (a low cost laser-diode pointer)
2) a slit-holder for PASCO slits
3) a preamplified photodiode mounted onto a slide coupled to a potentiometric position sensor.
4) a "T" shaped rail providing easy alignment

To record a spectrum one has to go through a few steps:

1) Choose the distance D between slit and image collection.
2) Adjust the source and slit heights .
3) Finely adjust spectrum horizontality by slight rotation of the slit on its holder
4) Connect sensors to interface
5) Start data acquisition on the graphic calculator
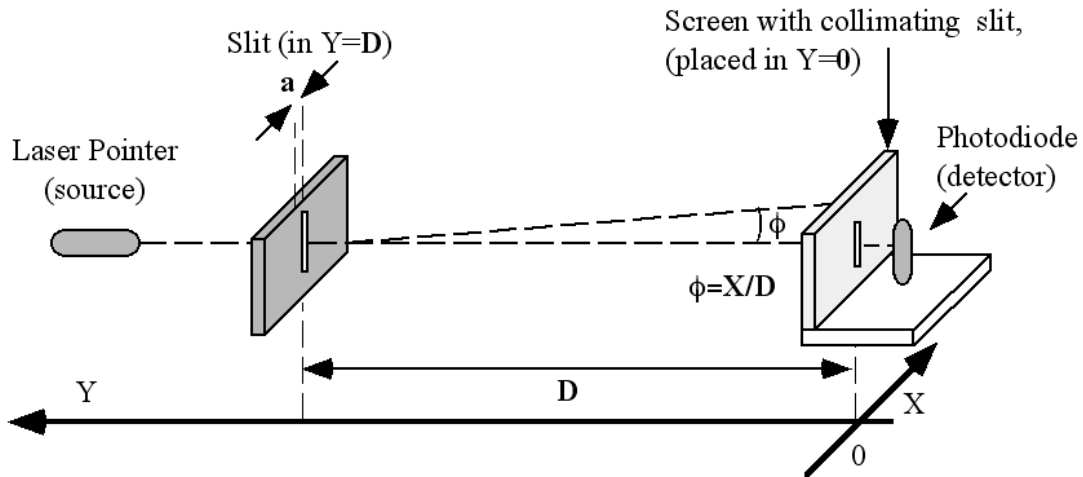
The light sensor is swept along the X direction by rotating a hand-wheel and the light intensity is recorded at the chosen constant rate together with the sensor position. Normally 100 points are more than enough to obtain a good record at 20 Hz rate in half a minute.

Procedure with portable RTL:
We connect the potentiometric displacement sensor to channel 1 (CH1) and the light sensor to channel 2 (CH2).
To instruct the interface about our choice we select on the MAIN MENU 1: SETUP PROBES and we choose 2: TWO. Then we look for the desired kind of probes on the list: on the third window we find "2:Linear Pot." that is the proper choice for the displacement sensor calibrated for a span of 10 cm, and on the first window we choose "7:LIGHT" for the photodiode.
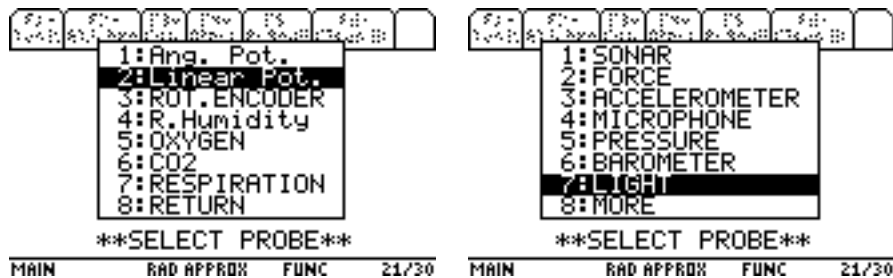

After a data collection the measured values will be stored into two lists as function of time (L1= time, CH1=L2=displacement, CH2=L3= light intensity).
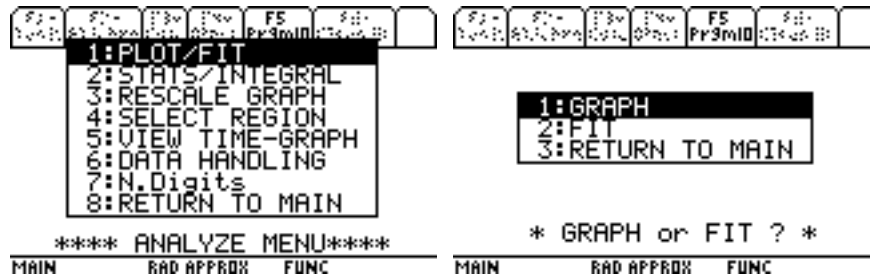
The software allows to access to the stored data taken as *time plots* , or as plots of the *light intensity* (CH2) *as a function of the displacement* (CH1) .
In this case we select **1: GRAPH** of the menu **PLOT/FIT**, and then we select the list for X axis and the list for Y axis..
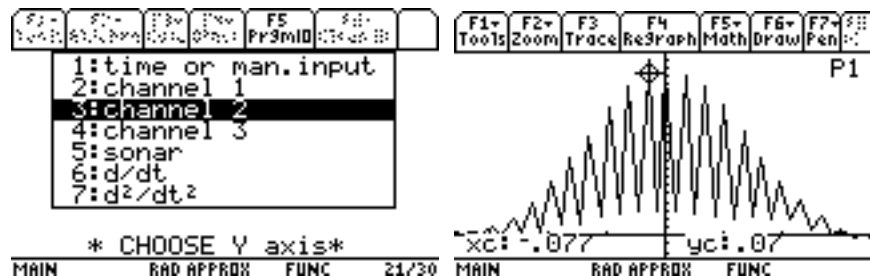
Predicted patterns

The pattern predicted by Fraunhofer model for a slit of width a, at the distance D from the screen, is described by the function $I(x)/I_0 = [\sin(\pi a \sin\phi /\lambda)]^2/(\pi a \sin\phi /\lambda)^2$ or, in the approximation, $\sin\phi = x/D$, $I(x)/I_0 = [\sin(\pi ax/\lambda D)/(\pi ax/\lambda D)]^2$, where λ is the wavelength of the used light ($\lambda = 0.65$ μm).

For a *single slit* theory predicts the secondary peaks of index i to decrease as $I_i/I_0 = 4/[\pi (2i+1)]^2$, i.e. : $I_1/I_0 = 4.5\%$, $I_2/I_0 = 1.6\%$, $I_3/I_0 = 0.8\%$.

Minima positions x_m are solution of the equation $\sin(\pi ax/\lambda D) = 0$, or $\pi ax/\lambda D = m\pi$: therefore $x_m = m\lambda D/a$. Distance between adiacent minima is $\Delta x = \lambda D/a$. Predicted secondary peak positions are approximated by $X_m = 1.5m\, \lambda D/a$.

For *N slits* (pitch=p, width=a) with the approximation $\sin\phi = x/D$, and letting $\sin\alpha = p/D$ the predicted pattern is described by the function:

$I(x)/I_0 = [\sin^2 (\pi a \sin\phi /\lambda)]/(\pi a \sin\phi /\lambda)^2 [\sin(N\pi x \sin\alpha /\lambda)]/ [N \sin (\pi x \sin\alpha /\lambda)]^2$

Now the secondary peak intensity decreases as $I_i/I_0 = [(Np)/(\pi ia)]^2[\sin^2(i\pi a/D)]$ approximated by $I_i/I_0 = 2N^2 p/i\pi a$, inversely proportional to index i with slope (for $N=2$) of about 2.55 p/a.

The minima positions x_m depend on the ratio λ/a: $x_m = m\lambda D/a$, while the peak positions X_m depend on the ratio λ/p : $X_m = m\lambda D/p$. Distance between adiacent peaks is $\Delta X = \lambda D /p$.

Therefore a complete *quantitative* analysis of the experimental spectra offer many useful tasks to be assigned to the students. Using hand held graphing calculators these tasks may be easily performed just after the experiment (if theory has been introduced in advance), without need of the standard mathematical and graphical facilities offered by a PC.

Typical results:

The marker may be moved on the graphing calculator screen following the line, and the corresponding position (xc)and light intensity (yc) is traced.
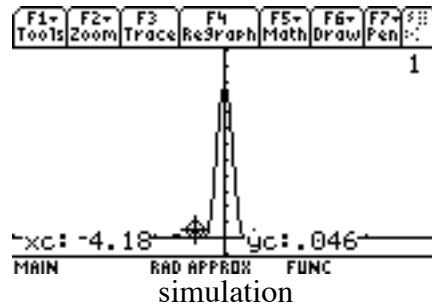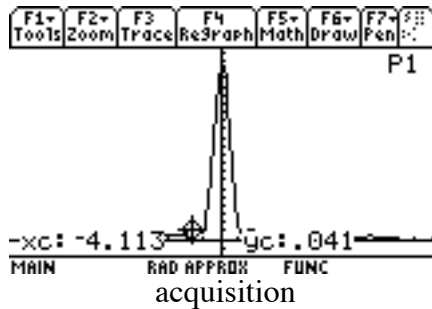
Comparison between simulated and experimental spectra is easily obtained, once the simulated spectrum has been normalized to the experimental value of central peak.

The student may compare the measured peak intensities and positions with the value predicted by the theory.
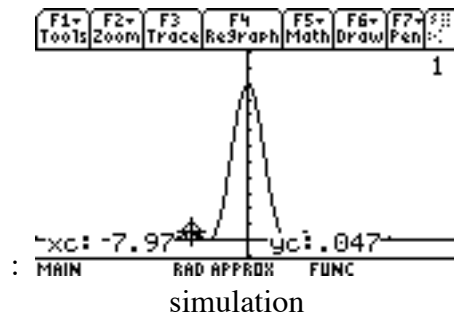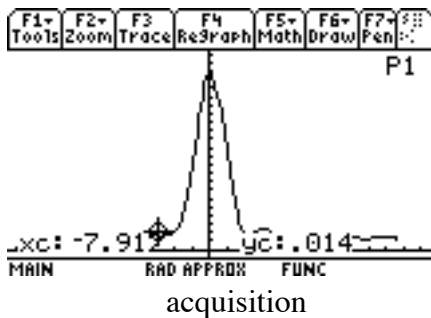
Depending on the teacher's preferences, the task may be to determine, from the experimental data, the values of unknown parameters (wavelength, slit width…) or to study the differences between predicted and experimental spectra (e.g. those due to the detector resolution limited by its finite aperture).

Here some examples of experimental and simulated spectra obtained with *single slits* of different width and with D=720 mm are shown, to give an idea of the system performance.
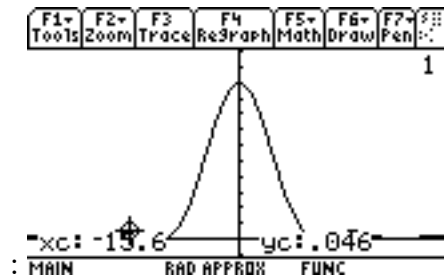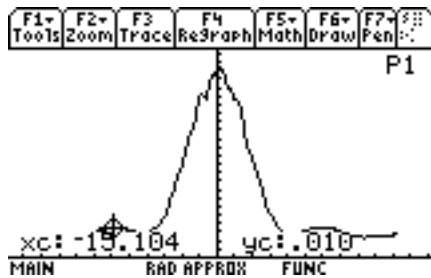
width **a =0.16** mm

F1▾ F2▾ F3 F4 F5▾ F6▾ F7▾
Tools Zoom Trace ReGraph Math Draw Pen
P1
xc: ‾4.113   yc:.041
MAIN   RAD APPROX   FUNC
acquisition

F1▾ F2▾ F3 F4 F5▾ F6▾ F7▾
Tools Zoom Trace ReGraph Math Draw Pen
1
xc: ‾4.18   yc:.046
MAIN   RAD APPROX   FUNC
simulation

width **a =0.08** mm

F1▾ F2▾ F3 F4 F5▾ F6▾ F7▾
Tools Zoom Trace ReGraph Math Draw Pen
P1
xc: ‾7.91   yc:.014
MAIN   RAD APPROX   FUNC
acquisition

F1▾ F2▾ F3 F4 F5▾ F6▾ F7▾
Tools Zoom Trace ReGraph Math Draw Pen
1
xc: ‾7.97   yc:.047
MAIN   RAD APPROX   FUNC
simulation

width **a =0.04** mm

F1▾ F2▾ F3 F4 F5▾ F6▾ F7▾
Tools Zoom Trace ReGraph Math Draw Pen
P1
xc: ‾15.104   yc:.010
MAIN   RAD APPROX   FUNC

F1▾ F2▾ F3 F4 F5▾ F6▾ F7▾
Tools Zoom Trace ReGraph Math Draw Pen
1
xc: ‾15.6   yc:.046
MAIN   RAD APPROX   FUNC

More examples of data obtained with *double slits* and *D*=600 mm show the various effects of changing pitch *p* or width *a*. Measured peaks intensity and positions may be compared to the predicted values. Here the student may also investigate on possible deviations from nominal values of *a* and *p*.
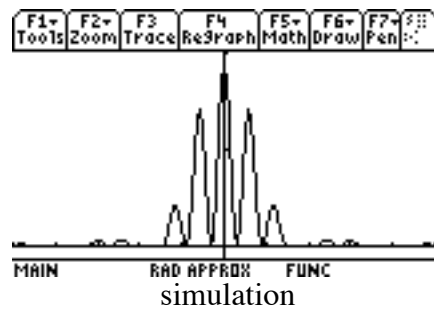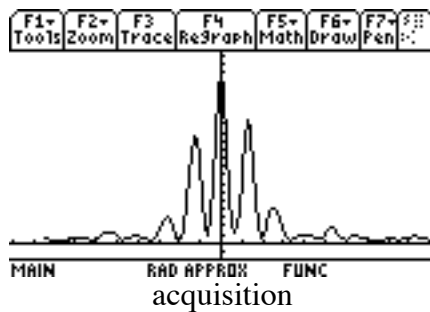
width **a =0.08** mm , pitch **d=0.25** mm

acquisition   simulation

width **a =0.04** mm, pitch **d=0.25** mm

acquisition   simulation
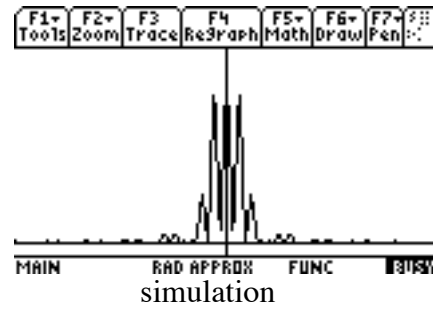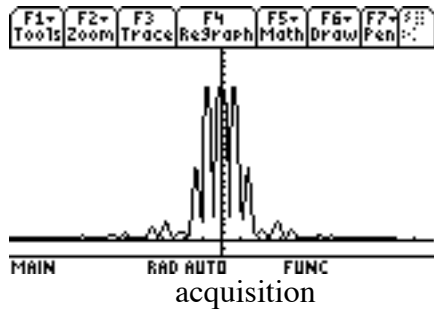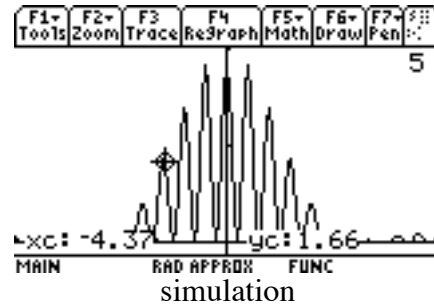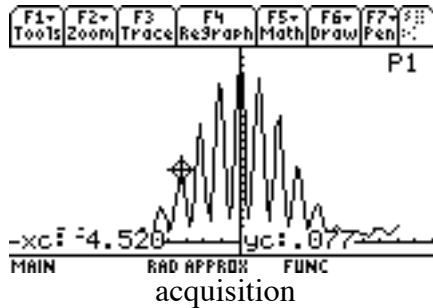
width **a =0.04** mm,   pitch **d=0.125** mm

acquisition   simulation

5

Appendix : Spectra simulation using TI graphing calculators

We can easily plot a simulated spectrum in the ambient Y= (Function and Plot Editor) by typing in the Command-Line the spectral function (that can be splitted into several sub-functions for easier handling).

For the single slit:
aa =a= slit width
dd =D= slit-screen distance
$y2(x) = (\pi/\lambda)(a/D)x$
Io =intensity measured at central peak
y2(x) is the function $I(x)=I_o [\sin (y3)/y3]^2$
$y3(x) = (\pi/\lambda)(a/D)x$.

For N slits :

nn=N= slit number , pp=p=pitch
aa=a= slit width
dd =D= slit-screen distance
Io =intensity measured at central peak
y2(x) describes diffraction from each slit
y4(x) describes interference
y6 (x) gives combined diffraction and interference

References
(1) F Corni, V Mascellani, E Mazzega, M Michelini, G Ottaviani, *A simple on-line system employed in diffraction experiments*, in *Light and Information*, Girep book, L C Pereira et al. Eds, Univ. do Minho, Braga 1993, p.381-388
(2) A Frisina, M Michelini, *Physical optics with on-line measurements of light intensity*, in *Teaching the Science of Condensed Matter and New Materials*, GIREP-ICPE Book, Forum 1996, p.162
(3) B. S. Ambrose, P. S. Shaffer, R. N. Steinberg, and L. C. McDermott, 'An investigation of student understanding of single-slit diffraction and double-slit interference'', Am. J. Phys. **67**, 146–155 1999