

Travelling Wave and Fraunhofer Diffraction Simulations

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The software runs using Microsoft Excel 2003, 2007 and 2010 running under Windows XP, and using Excel 2007 it has been successfully tested running under Windows 7. It is provided “as is” without express or implied warranty of any kind, and with no claim as to its suitability for any purpose. In no event shall the authors or copyright holders be liable for any claim, damages or other liability, whether in an action of contract, tort or otherwise, arising from, out of or in connection with the software or the use or dealings in the software.

Please note that currently under Microsoft Excel 2007, and depending on the machine performance, some of the displays are not quite as smooth running as under Excel 2003 or 2010 (i.e., they are a little more “jerky”). This seems to be primarily associated with processor speed, display refresh rates and possibly the graphics card. It definitely varies from machine to machine and depends on what background tasks are being carried out. One thing that is worth trying to improve this is increasing the EXCEL.EXE “Processes” priority from “Normal” to “Realtime” (adjusted from within the “Windows Task Manager”, accessed by <Ctrl><Alt><Delete>), but note the warnings associated with changing these priorities. Clearly, if there are virus scans, file updating or web interactions of any sort in progress, this certainly has the potential for affecting real-time simulations. (See also comments below under Display 3, **Lissajous Figures**, regarding screen refresh rates. These comments apply to all displays, and indicate that screen update rates may be the critical factor.) As a final point we note that the spreadsheet has been saved in Excel 2003 compatible mode, but no noticeable improvement under Excel 2007 occurs if it is saved in incompatible mode. To summarise, we have not had complete success in rendering the Excel 2007 operation as smooth as the Excel 2003 or 2010 operation under all conditions. In fact the Excel 2010 operation appears to be the best of the three, although tests have been carried out on only one machine using it.

The fact that Excel 2007 is significantly slower than Excel 2003 for many operations is well known. We have carried out a simple test by running the mass-spring simulation spreadsheet produced by Oliveira and Nápoles* which has timing information easily available. On one machine we found it to run about 2.5 times as fast under Excel 2003 compared to Excel 2007, and on a second machine about 4 times as fast. Thus, in addition to the nature of the spreadsheet itself, the speed loss depends on the particular machine employed.

* Oliveira, Margarida Cristina and Nápoles, Suzana (2010) “Using a Spreadsheet to Study the Oscillatory Movement of a Mass-Spring System”, *Spreadsheets in Education* (eJSiE): Vol. 3: Iss. 3, Article 2. Available online at: <http://epublications.bond.edu.au/ejsie/vol3/iss3/2>

A second more minor but annoying known problem concerns the text boxes located within the chart areas. These display the time and other parameter values, as indicated by the facsimile shown below. They may sometimes move around the chart and be resized when the spreadsheet is closed and reopened, and we have not been able to correct this. However, the boxes may easily be moved and resized, as the individual components have been “grouped” or, if they prove too annoying, they may be deleted entirely, as they are intended to be informative only and do not affect the display in any way.

$t(s) =$	0.0
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The spreadsheet has been tested on a number of machines using both Excel 2003 and 2007 and works satisfactorily. Some of these machines, which are far from state-of-the-art, are listed below.

1. Leno IdeaPad S10-2 laptop (10-inch screen). Intel (R) Atom CPU N270 @ 1.60 GHz, 1.00 GB of RAM. Microsoft Windows XP Home Edition, Version 2002, Service Pack 3.
2. HP Compaq nx9420 laptop (17-inch screen). Intel (R) T2500 (Centrino duo core) @ 2.00 GHz, 2.00 GB of RAM. Microsoft Windows XP Professional, Version 2002, Service Pack 3.
3. IBM Desktop (19-inch screen). Intel (R) Pentium (R) 4 CPU @ 3.20 GHz, 2.00 GB of RAM. Microsoft Windows XP Professional, Version 2002, Service Pack 3.

The following machine was used for the successful testing using Excel 2007 under Windows 7. In fact with this system, excellent smooth and continuous motion was achieved.

Toshiba Portégé Notebook (12-inch screen). Intel (R) Core (TM) i5 CPU M520 @ 2.40 GHz, 4.00 GB RAM. Microsoft Windows 7 Professional (64 bit Operating System).

The following machine was used for the successful testing using Excel 2010.

HP Desktop (26-inch screen) Intel (R) Core (TM) 2 Duo CPU E8400 @ 3.00 GHz, 3.50 GB of RAM. Microsoft Windows XP Professional, Version 2002, Service Pack 3.

Original Paper

The simulation is described in the paper “The Use of Microsoft Excel to Illustrate Wave Motion and Fraunhofer Diffraction in First Year Physics Courses”, by Garry Robinson and Zlatko Jovanoski, which has been submitted for publication to *Spreadsheets in Education* (eJSiE), March, 2011.

Suggestions for Usage

It is strongly recommended that before using this spreadsheet **you make a copy of the spreadsheet and work only on the copy**, as it is easy to accidentally alter the spreadsheet in a way which may be difficult to reverse.

For the users who wish to have all the controls visible, as far as possible, **it is recommended that you start with sheets 1, 2(b) and 12**. These may be the only ones that are of interest to you. The other displays are intended for those users who are happy to move the displays around and explore in greater depth how the displays are generated and possibly modify them. The sheets are independent in their functioning, and so one may delete those that are not of interest if it is desired, without affecting the running of the remaining sheets. (See below for further details.)

Summary of Simulations

The simulations are divided into twelve (12) separate “sheets”, as indicated below. The first eleven (11) relate to waves of various kinds and the last is related to Fraunhofer diffraction. Some of the simulations have been better developed than others. (Some were added in an ad hoc way at the suggestion of students, with the primary aim of getting them to work as quickly as possible, rather than rendering them user friendly.) **Perhaps the most important are contained in sheets 2(a), 2(b) and 12. We have found the interference/diffraction display (sheet 12) to be particularly well received by students. Note that 2(b) is a simplified version of 2(a) and, as fore-shadowed above, we would recommend it as starting point for those users who dislike cluttered displays, and wish to see all the controls at a glance.** The relevant displays (charts) are shown on each individual sheet itself, and on some it may be necessary to scroll down or move the charts around in order to locate all the underlying controls. With a number of displays on the one sheet, we have found it difficult to make the controls visible always, but the serious user should not find this a restricting inconvenience. Also, what is visible at any one time clearly depends on the screen size and shape. It has not proved to be an insurmountable problem to our students.

Note that a macro is used to control the time. Thus the security level must be reduced in order to allow the macro to run. (Under Excel 2003, go to **Tools / Macro / Security** and reduce the Security Level to, for example, “Medium”. Under Excel 2007, under “**Security Warning Macros have been disabled**”, click the “Options” box and enable the macros.) In fact, except for Sheet 1, all the macro does is to write the time (measured from zero when the clock is **Reset**) into cell F4 to an accuracy of 0.1 seconds, and the time direction (Forward or Reverse) into cell G4. No other macros are used. (As discussed below, in Sheet 1 time t and position x are stepped manually, and a very simple macro facilitates this.) To view the macro, under **Developer** select **Visual Basic** or **Macros**.

In each simulation only the numerical values in **red, blue or green and highlighted in yellow and surrounded by a thick black line**, as indicated below, should be altered initially, until the user is happy with the use of the spreadsheet.

1.0

For the **Wave Displays**, the main quantities that may be varied are the amplitudes, A , angular wave numbers, k , angular frequencies, ω , and phase angles, ϕ , of the component waves. Note that the wave velocity is given by $v_{\text{wave}} = \omega/k$ and so changing either ω or k changes v_{wave} . In addition, in some displays harmonics of the fundamental may also be turned on to simulate square waves or triangular waves. Square waves may also be simulated in the Lissajous pattern display. Finally, in some displays marker points may be turned on to illustrate, for example, the transverse motion of particles on a stretched string subject to a transverse wave motion.

The quantities which may be varied for the **Fraunhofer Diffraction displays** are listed below under sheet “12. Fraunhofer Diffraction Patterns”.

The Individual Sheets

1. **Travelling Periodic Waves, $y(x,t)$ — Sine waves shown at discrete times only, with the time, t , and x coordinates being stepped manually.** [Two displays: (i) $y(x,t)$ for time changing, and (ii) $y(t)$ for a fixed value of x .] This is a very simple display which may serve as an introduction. The main control panel appears as below. (The control panel shown below is a facsimile of the actual control buttons.) “Time Zero” and “ x Zero” re-set the time and x coordinates to zero respectively. “Time Minus” and “ x Minus” step the time and x coordinates by discrete amounts in the negative direction, and “Time Plus” and “ x Plus” step the time and x coordinates by discrete amounts in the positive direction. The default step sizes are ± 0.1 units. The filled circles in this and other displays represent simple markers to illustrate, for example, the motion of a point at a fixed value of x as a function of time.

Time Minus	Time Zero	Time Plus
x Minus	x Zero	x Plus

In Excel 2007, the simplest way of generating the **CommandButtons** shown above is as follows (there may be more sophisticated ways of producing them). Under **Insert / Illustrations / Shapes**, click on any **shape** and paste it into the spreadsheet. By right clicking within the shape (“button”) introduced into the spreadsheet one can, for example, (i) place text within the button (under “**Edit Text**”), (ii) change the format of the button (under “**Format Shape**”) and, most importantly, (iii) assign a macro to the button (under “**Assign Macro**”). (Before assigning a macro to the button, it may be necessary to enable the macros, as discussed above.) For example the “Time Minus” command button was generated by first creating the button, then typing *any* appropriate text into it (in this case “Time Minus”) and finally assigning to it the macro **TimeMinus** (see the macro listing).

- 2(a). **Travelling Periodic Waves — Sine waves and square waves.** [Three displays: (i) $y(x,t)$ for time changing, (ii) $y(t)$ for a fixed value of x , and (iii) $v_T(t)$ for a fixed value of x .] This display shows up to the 29th harmonic and illustrates the principle of linear superposition and standing waves. This is the primary waves display. A facsimile of the primary control panel for this and all subsequent displays appears as below. “Reset” resets the display to $t = 0$, “Reverse” runs time backwards, “Start” starts the display with time running forwards, and “Stop” stops the time. (It is **not** necessary to stop the display prior to **Resetting** the time.) The step time interval is 0.1 seconds, and is limited by the accuracy of the read-out of the system clock. As noted above there are three separate displays: (i) $y(x,t)$ with the t being varied, (ii) $y(t)$ for a fixed value of x (in fact x is fixed at zero), with t being varied, and (iii) $v_T(t)$ at $x = 0$, the latter representing the transverse “particle” velocity at $x = 0$. Note that sometimes the $y(t)$ and $v_T(t)$ displays for a fixed value of x [as opposed to the $y(x,t)$ displays for t being varied] have a known problem in that discontinuous curves may be produced. This appears to be primarily a function of processor speed and/or screen refresh rates. To turn extra harmonics on, the appropriate value for y_1 or y_2 (in the boxed areas highlighted in yellow, as described above) is changed from a zero (0) to a one (1). Similarly the individual marker points on each curve may be turned on by changing the appropriate zero (0) to a one (1).

Reset	Reverse	Start	Stop
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- 2(b). Travelling Periodic Waves — Sine waves and square waves (simplified).** [Single display: $y(x,t)$ for time changing.] This display is a simplified version of 2(a) above. Only the $y(x,t)$ display with t being varied [display (i) in 2(a) above] is shown. This means that (i), the control panel is largely unobscured by the displays and (ii) under Excel 2007 the motion is less jerky than 2(a).
- 3. Lissajous Figures.** [Three displays: (i) Lissajous figure, $y(t)$ versus $x(t)$ for time changing, (ii) $y(t)$, and (iii) $x(t)$.] A Lissajous figure is the resultant of two oscillations acting at right angles (i.e., in the x and y directions respectively) at the same point in a medium. This sort of display is usually demonstrated by applying sine waves to the x and y plates of a cathode ray oscilloscope. Note that harmonics up to the 29th may be included, a feature not usually available on other Lissajous figure displays that we have seen. The display was in fact improvised from existing wave displays at short notice, following the suggestion of a student, and seems to produce realistic results. Interesting displays are obtained when higher harmonics are added to the basic sine waves. In Excel 2007 we have found that deleting (removing) the two supplementary displays from this sheet causes the Lissajous pattern itself to move more smoothly, an indication that screen refresh rates are important (see the VBA macros command, **Application.ScreenUpdating** and also **Application.Calculation**, which may be of help). Alternatively, the same improvement occurs if the two supplementary displays are shifted off the visible area of the screen. In this case, although these displays are updated, as is easily verified by examining them, screen writes to them do not occur in real-time and do not slow the display down.
- 4. Travelling Periodic Waves — Sine waves and triangular (“saw-tooth”) waves.** [One display: $y(x,t)$ for time changing.] This display shows up to the 20th harmonic of triangular waves and also illustrates standing waves. It is essentially the same as display 2(b) above, but for triangular waves.
- 5. Non-Wave.** [Single display: $y(x,t)$ for time changing.] An illustration of a function not of the form $f(x - vt)$, which does not reproduce itself in time and therefore is not classified as a travelling wave.
- 6. Travelling Periodic Waves — Ocean waves.** Single display: $y(x,t)$ for time changing.] This shows a long wavelength wave passing under a short wavelength surface ripple, the longer wavelength wave travelling the faster. (Note that in reality ocean waves are immensely more complicated than this simple representation, being a combination of both transverse and longitudinal waves with the water particles, in general, moving in an ellipse.)
- 7. Travelling Pulses — Gaussian pulses.** [Single display: $y(x,t)$ for time changing.] Shows two Gaussian shaped pulses about to pass through each other. It may be used to clearly demonstrate the principle of linear superposition.
- 8. Travelling Pulses — Gaussian pulses with the front of the pulse slowing.** [Single display: $y(x,t)$ for time changing.] Here the pulse shape of the red wave changes with time. This was an attempt at showing a breaking sea wave, where the front of the wave travels slower than the back of the wave as it approaches shallow water, causing the wave to eventually “break”. In fact the situation for a breaking sea wave is very much more complicated, and the demonstration does not portray such a situation but rather merely illustrates a change of wave shape.

9. **Travelling Pulses — Gaussian wave packets.** [Two displays: (i) $y(x, t)$ for time changing, and (ii) as in (i) but showing the sum only.] This display shows two Gaussian shaped envelopes modulating cosine waves, where the velocities of the envelopes and the cosine waves may be adjusted. The idea was to simulate wave packets and pilot waves as occur in quantum mechanics.
10. **Travelling Periodic Waves — Sine waves, showing beats.** [Single display: $y(x, t)$ for time changing.] This illustrates two waves of slightly different frequency travelling in the same direction with the same speed, illustrating the phenomena of “beats”.
11. **Travelling Pulses — $[\sin(x)/x]^2$ travelling pulse.** [Single display: $y(x, t)$ for time changing.] This was a first attempt at representing the function $[\sin(x)/x]^2$, which represents the “diffraction envelope” of a Fraunhofer diffraction pattern (see display 12 below). As an extension it was extended to represent a travelling pulse.
12. **Fraunhofer Diffraction Patterns.** [Three displays: Multiple-slit diffraction patterns for (i) one wavelength, (ii) two wavelengths, and (iii) three wavelengths.] This illustrates single-slit, double-slit and multiple-slit Fraunhofer diffraction patterns, with up to three discrete spectral lines or wavelengths (i.e., colours). The number of slits N , wavelength λ , slit separation d and slit width a , may all be varied independently and/or simultaneously. Note that there are three separate displays on this sheet, and one must scroll down in order to see the lower two displays. The upper one is for a single wavelength (by default a red line), the second is for two lines (a red and a blue line), and the third is for three lines (a red, a blue and a green line). Note also that only the red wavelength, preset at 0.65 microns, can be changed easily, without delving into the spreadsheet further. The blue wavelength is set to 0.45 microns and the green wavelength to 0.55 microns. We have found this display, in particular, to be greatly appreciated by students.
13. **CD Diffraction Pattern Image.** This shows two photographs of the Fraunhofer diffraction pattern produced by Compact Disks (CDs) illuminated by rays from the Sun. These diffraction patterns are thus for a source (the Sun) with a continuous distribution of wavelengths or colours (i.e., a so-called “white-light” spectrum) and are intended for comparison with the Fraunhofer diffraction patterns generated in display 12 above. For those unfamiliar with Fraunhofer diffraction, it may be noted that two spectra are visible in the image from each CD and that one “overlaps” the other (called “overlapping orders” of interference). The first order (inner-most) red spectrum overlaps the violet region of the second order (outer-most) spectrum, thus corrupting it. This is an undesirable effect when Fraunhofer diffraction is used in diffraction gratings, the purpose of a diffraction grating being to produce a faithful reproduction of the spectrum of the source, in this case the Sun.

Acknowledgements

Real-time motion was originally based on the macro “Active_Clock”, written by Aaron T. Blood (<http://www.xl-logic.com/>). This was modified and greatly extended by Mathew Singers. It goes without saying that without these macros real time displays would not have been possible, and the contributions of both are greatly appreciated. Additional modifications were made by the present authors.

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