

## Acoustic Analog Model of Seismic Reflections

### REFERENCES

Halliday, D. and R. Resnick, A., Physics, 4th edition, New York: John Wiley and Sons, Inc, 1992, Volume I, Chapter 20-1, pp.445-446; Chapter 2003, pp.449-450.

(2 weights)

### INTRODUCTION



In this this experiment you will encounter some of the elementary principles that underlie seismic reflection surveying as it might apply to exploration geophysics. This is accomplished here with the aid of an acoustic analog laboratory model consisting of a loudspeaker producing audible clicks (the analogue of an explosive or hammered source) and an array of microphones (geophones) that record the disturbances that propagate away from the source following its excitation. The nature of the received signal can be shown to be indicative of the medium

through which it has travelled, since acoustic velocity is a characteristic property of materials. With this acoustic model you can measure the velocity and attenuation of acoustic signals in air and the acoustic reflection coefficients of an aluminum sheet or a concrete wall (non-reflecting rock strata) and plastic wrap (semi-reflecting strata). You also can observe seismic diffraction as the microphone array looks at the edge of a horizontal reflector. There is also the opportunity to study the nature of the signal picked up at the microphones (geophones). An interesting aspect of this experiment is that, although you may have some experience of propagation and interference of continuous waves, you have not, up to now, studied waves produced by pulses. You will find that the view of the world in the time domain is different from that in the frequency/phase domain.

### THE APPARATUS

The apparatus consists of a loud speaker driven by a square wave generator, an array of 48 pressure sensitive condenser microphones in a line spaced at regular 2 cm intervals and electronics that interfaces the equipment with a computer. A program called SEISMIC controls the apparatus.

This arrangement permits convenient activation of the source and, subsequently, automatic data collection so that there is no need for external timing with stopwatches. The data is in the form of an evenly spaced time series of induced voltages at user-specified channels of the receiving array (each of the microphones is a channel). The size of these induced voltages is proportional to the magnitude of the incident acoustic disturbance, hence a time domain acoustic waveform sampled at discrete intervals (usually 50  $\mu$ s) is constructed. It is possible to “stack” the signals some number of times in order to remove random noise from the waveform. Stacking a signal simply involves activating the source various times in succession to obtain separate acoustic waveforms that differ only by their random noise content.

These signals are then added together and averaged; the random noise cancels out, leaving only correlated signal.

It should be noted that the current signal to the loudspeaker is a square pulse, thus providing, ideally, a square pulse of the position of the speaker against time. This would then provide a pressure in front of the speaker that would be a delta function, with pressure being proportional to the time derivative of the displacement. The condenser microphones, being pressure sensitive, should then display output voltages that look like delta functions in time. In our less than ideal world, loud speakers and microphones have their own response functions. The wave forms observed in this experiment are the convolution of the impulse response of the reflector being studied with the response functions of the microphones and the loud speaker.

The rest of the apparatus consists of stands that can hold aluminium plates and plastic film, reflecting walls and furniture, sound-absorbing panels, and anything else that you wish to use as part of your working environment. Although seismic reflection work is done with the geophone array, the source and the reflecting strata all more or less horizontal (we do work on the surface of the earth studying strata under that surface) this apparatus has been arranged with the array and the reflecting planes positioned more or less vertically. This has been done for convenience in setting-up but does not detract from the analogy.

When you turn on the apparatus (computer plus controller), the instructions on the screen will tell you how to set-up your own directory on the computer. Please do so, and whenever you use the apparatus, first go into that directory so that all your own data is stored in the same place. You can then enter the Seismic program by typing SEISMIC.

Note that the Seismic program has its own help facility which can be accessed by either pressing the HELP button <F1>, or by typing HELP, or by using the mouse to select HELP. More detailed descriptions of this program are provided in APPENDIX 1 of this guide sheet.

## **GETTING TO KNOW THE EQUIPMENT**

Familiarize yourself with the apparatus by setting the speaker and the microphone array facing a flat wall, about 40 cm from that wall, with the speaker above and in-line with the microphones. Acquire one run of data. Identify where each line of reflections comes from. (There will be several such lines.) Decide whether channel 1 corresponds to the top or the bottom microphone. Note the relative phase of the reflected wave compared to the direct wave. Can you explain this phase?

Try changing various parameters in the system (Rate, Samples, Stacks, Gain, Fill) and be sure you understand what each does. Note that you can always return to the default settings of the parameters using RESET (<F5>). Try various commands such as “xscale 2”, “set stacks 5”, “help set”, “graph 20:25 50:150”. Try storing and retrieving the file.

The rightmost window on the computer screen monitors the induced voltages at the currently activated channel as a function of time. These voltages are, of course, primarily due to the clicking of the loudspeaker. Set the stacking number. The extraneous lab noises should be averaged out after stacking. This data can be browsed through forwards and backwards. Choose the appropriate menu option to do this.

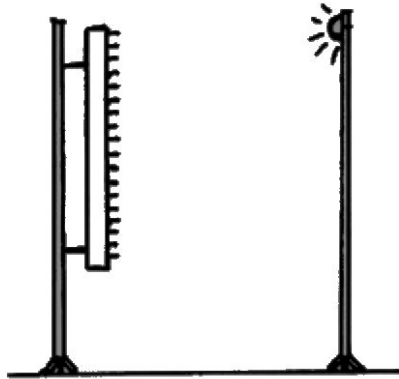
To interpret your data more easily, you can toggle the plot to display the voltages in graphical form.

The amplitudes of the horizontal bars are proportional to the magnitude of the acoustic disturbance. Adjusting the plot gain scales the display. Can you identify the time of the first signal arrival? Store the signals in conveniently labelled files.

## VELOCITY AND ATTENUATION OF SOUND IN AIR

You are now ready to measure the velocity of sound in air. Position the loud speaker in front of, and directly facing one of the microphones in the array (Figure 1). Collect data on only this channel, and determine the first signal arrival time for several different speaker-microphone separation distances. The velocity of sound will then be the slope of a distance vs. time graph. Use stacking for better results. As an alternative method you can monitor the first arrival times on all channels.

Figure 1.



From your data, carefully measure the velocity of sound in air by plotting first arrival times against source-receiver separation. Estimate the experimental uncertainty on each of your measured parameters (i.e. first arrival times, source-receiver separations) and propagate these uncertainties through your calculation properly so that you can determine how precise your measurement of the velocity of sound in air is. Compare your value to the accepted value. Determine how the signal amplitudes attenuate with increasing source-receiver distance  $r$ , i.e., is the amplitude of the form  $1/r$ ?,  $e^{-\alpha r}$ ?, etc. and interpret the results.

## REFLECTION COEFFICIENTS

Now place the loud speaker so that it faces the array of microphones at a distance of about 1 m and is lower than the centre of the array. Acquire the data. You can expect to observe the direct wave and the reflection from the floor. Which line is the reflection from the floor? Can you prove it? How? You can use the metal sheets provided as reflectors. Place an aluminum sheet on the floor between the loud speaker and the microphones. What do you observe now?

For our purposes, the acoustic reflection coefficient of a material may be defined as the ratio of the maximum voltage received after a click has been reflected from the material to the maximum voltage received after reflection from a perfect reflector, **keeping the total travel time of the acoustic signal fixed.**

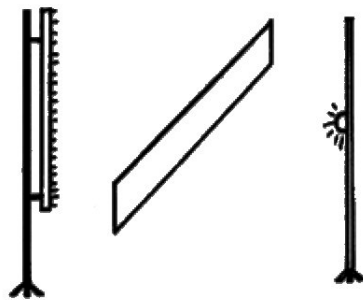
The method of images in electrostatics can be applied to set up a perfect reflector. Work out how to arrange the apparatus to find out what is the signal entering the microphone from a perfect reflector. Then, collect the single channel data necessary to measure the reflection coefficients of a couple of reflectors available to you. These reflection coefficients are useful for seismic prospectors to interpret field data. Comment on values obtained for different materials (i.e., aluminum sheet, plastic film and fabric screen).

## DIFFRACTION

1. You can observe seismic diffraction around a reflector edge by collecting 48-channel data for a fixed receiver array positioned behind the aluminum sheet with the midpoint of the receiver array centred on the edge of the sheet. You will need data for the loud speaker stationed in front of the reflector. Centre the source on the edge of the sheet and take data. Then move the source to different positions above and below the edge of the reflector. Ensure that there are no gaps between successive sets of data. Explain qualitatively the main features of the diffraction seismogram. By observing the data display on the computer, determine approximately the position of the edge. Make sure that your result makes a sense.

2. Observe seismic diffraction around a relatively narrow aluminum reflector. Place the narrow reflector between the source and the receiver array so that the reflector's long side is horizontal (Figure 2). The midpoint of the receiver array should be centred on the reflector. Collect data for the source centred on the reflector, then positioned above the upper edge and below the lower edge of the aluminum reflector.

Figure 2



3. Build a horizontal diffraction slit using two aluminum sheets. Repeat the previous experiment using the slit instead of a narrow reflector. Compare the results of the last two experiments.

## **IDENTIFYING REFLECTORS FROM THE REFLECTED SIGNALS**

Set up various arrangements of reflectors, and with both the loud speaker and the receiving array facing the reflector(s), see what you can deduce from the pattern of first arrivals. Possible reflectors include the concrete walls, a table, chair, a small or large metal plate either parallel to the array or inclined to it, the absorbing screen, the plastic sheet, or combination of these objects. You might also want to produce different reflectors such as a cube, an inside corner, irregularly shaped aluminium foil, a rippled surface. In each case try to predict the outcome and verify it experimentally.

## **APPENDIX I**

### **Transient Electromagnetic System Data Logger**

Original software: G. Horel and D. MacDonald, Sea Turtle Systems Inc. 1989

Rewritten by Stephen Cheesman, University of Toronto, 1991-1993

#### **Overview**

This seismic software is intended to acquire data from the acoustic reflection experiment in the Geophysics Undergraduate lab at the University of Toronto. The data logging system consists of a DOS based micro-computer equipped with a Data Translation DT2812-A high speed A/D converter. This program controls the acquisition, display and logging of data from the A/D converter.

Data obtained can be stored in a file in SEG-Y format for use in other seismic analysis software such as VISTA66.

#### **Display**

The display has four areas, the status display panel, the graphics/menu area, the command dialogue area, and the mouse button display.

#### **Status Display Panel**

This display is at the top of the screen. It displays the current settings of the DT2812-A board, as well as parameters related to data acquisition. The following user resettable parameters are displayed;

- a) The current Channels
- b) The current Sampling Rate
- c) The current Number of Samples per measurement
- d) The Number of stacks per record
- e) The current Transfer Type
- f) The current Transfer Method
- g) The current Hardware Gain
- h) The current Method for Data Display

In addition, the following information is displayed in the status display panel:

- i) The current Stack number (increments during each acquisition, up to the value determined in d) above)
- j) The current Record number (increments by one for each data acquisition)

Parameters a-h above are highlighted in white and surrounded by a blue box to indicate that they are mouse buttons.

**Graphics/Menu area**

This area takes most of the centre of the screen. It is used to display the help screens or graph the data.

**Command dialogue area**

This area is the second and third lines from the bottom of the screen. The line immediately above the mouse buttons is used to enter typed commands and the line above that is the area the system uses to display messages.

**Mouse Buttons**

The last line on the screen contains several mouse buttons. If the mouse is pointed within the boundary and a mouse button is pressed then the system executes the mouse command indicated by the text within the boundary. In addition, those parameters highlighted in white in the status window may be changed using the mouse (see section on the Status Display Panel).

**User Interface**

The user interacts with the program with the keyboard or with a mouse. There are three types of commands available to the user: Function Key commands, Mouse commands, and Text commands.

**Arrow Keys**

Pressing an arrow key has the following effects:

If there is no graph displayed:

left/right arrow:	moves cursor left or right on the command line
up/down arrow:	selects previous or next command

If there is a graph displayed:

<ctrl> left/right:	select next or previous channel to highlight
<ctrl> up/down:	moves cursor bar up or down one sample
<alt> left/right:	select tenth channel to the left or right to highlight
<alt> up/down:	moves cursor bar up or down ten samples

## **Mouse Button Commands and Function Keys**

Mouse Button Commands are executed by placing the tip of the mouse pointer arrow inside the border of the button area and pressing either of the mouse buttons. This action is referred to as clicking a mouse button. Each mouse button area has a blue border around it and the name of the command inside the border. The Function Key commands echo the bottom mouse button commands; the first mouse button command is the same as F1, the second as F2, etc., while the last mouse button, "quit", is F10.

In addition, the parameters in the status window which may be set by the user are highlighted in bright white. By clicking the mouse once on these parameters, a pop-up menu, with all or a selection of possible parameter values, is displayed (do not continue to hold the mouse button down, or the menu will disappear -- click just once). The values in the menus may then be selected with the mouse by positioning the mouse cursor over the selection and clicking a mouse button. If no new selection is desired, move the cursor out of the pop-up menu and click a mouse button.

### **Help** (Function Key F1)

Clicking this mouse button causes the help screen to be displayed. Clicking it a second time displays the "set" help screen.

### **Acq** (Function Key F2)

Clicking this mouse button causes the system to begin the acquisition of data. The record number is incremented. The DT2812-A acquires the data specified by the status display parameters and graphs it.

### **Graph** (Function Key F3)

Clicking this mouse button graphs the data that has just been stored.

### **Fill** (Function Key F4)

Clicking this mouse button toggles the graphed display between plain graphed curves and curves with highlighted filled-in areas in the higher amplitude positive swings of the curves.

### **Reset** (Function Key F5)

Clicking this mouse button clears the system and resets the DT2812-A parameters to the default values. If a seismic.set file exists, these values are used, otherwise, there are defaults set in the software.

### **Quit** (Function F10)

Clicking this mouse button ends the program.

## **Text Commands**

Text commands are used whenever parameters are required from the user. The command line is just above the mouse button line at the bottom of the screen. The normal editing functions work to allow editing of input. The command is executed by pressing the <enter> button. The user does not have to type the entire word required for the command but abbreviations must uniquely identify the command. The minimum abbreviation is highlighted in bold print. This command interface is case insensitive but case is preserved. In the following descriptions optional parameters are encased in <>.

### **Clw**

syntax: **CLW**

By default, the graphics window is cleared before every plot. This command clears the plot window.

### **Cursor Channel**

syntax: **CU** channel

parameters:

channel = number of channel

When recording more than one channel, this command sets the graphics cursor to the desired channel. The minimum and maximum values as well as the current x and y values for the cursor channel will be displayed.

### **Exit/Quit**

syntax: **EXIT** or **QUIT**

These commands close all open files and exit the system. The temporary file TEMP.EM is NOT deleted and contains the last trace acquired.

### **Get File**

syntax: **GET** filename

parameters:

filename = name of SEG-Y file to read in

example: get test.sgy

errors: unable to open file

This command retrieves a previously written SEG-Y file from disk. It writes the contents to a temporary buffer, and sets the DT2812-A parameters to the values used to write the file. The time at which the trace was obtained is displayed. Finally, it graphs the file.

### **Graph**

syntax: **GRaph** <x:y> <a:b>

parameters:

x = starting channel to graph

y = ending channel to graph

a = starting sample to graph

b = final sample to graph



examples:

graph	graphs all channels, all points
graph 5	graphs all points in channel 5
graph 1:10 200:300	graph points 200 to 300 in channels 1 to 10

NOTE: Commonly, each point represents 50  $\mu$ s.

This command graphs the data. The x and y parameters specify the start and end data points. If no x or y values are given, the entire data set will be plotted. Data points are numbered from 1 to n where n is the current number of samples.

When a graph is displayed, clicking the mouse in the graph area moves the cursor to the nearest channel and sample. The channel number and sample number, along with the time of the sample and sample voltage, are displayed at the bottom of the graph.

The text rows directly to the left and to the right of the graph may be used as a large mouse button to plot a subset of the displayed data. In these areas, move the mouse to the vertical position of the minimum time desired, and click the right button. A message such as "Subset: low sample = 250" will appear. Then move the mouse down to the maximum time desired and click the right mouse button. The new subset will then be graphed. If only the right button is clicked, the points from start of the current graph to the indicated position will be immediately plotted. If the mouse is moved beyond the ends of the graph (still within these blank areas), and either mouse button is clicked, the entire range of points will be plotted.

## Help

syntax: **HElp** <set>

Prints out the help menu. If set is specified, prints the set menu.

## Macro

syntax: **MACro** <macrofile>

Creates a macro file containing the current setup variables. If macrofile is not specified, the parameters are stored in the file **seismic.set**

## Quit (see EXIT)

## Repeat Macro

syntax: **REpeat** macro time

parameters:

macro = name of file containing macro

time = time between executions of macro

errors: can't find macro file

This command cause the macro contained in the file specified by the parameter "macro" to be executed every "time" seconds. The execution is synchronous with the PC clock. If the macro takes longer to execute than the parameter "time" allows the execution rate occurs at the first multiple of "time" that allows complete execution. for example if a macro takes 16 seconds to execute and time was specified as 5 seconds it would execute every 20 seconds. If the macro file could not be opened an error occurs. The remedy is to check the pathname given.

## Reset

syntax: **RE**set

This command clears the system and resets the DT2812-A parameters to the default values.

## Run Macro

syntax: **RU**n macro

parameters:

macro = name of file containing macro

errors: can't find macro file

This command causes the macro continued in the file specified by parameter "macro" to be executed once. If one of the commands contained in the macro file is another RUN or REPEAT macro command then execution of the first macro stops at that point and the program chains to the second macro. No commands in the first macro after the RUN or REPEAT command will be executed. If the macro file could not be opened an error occurs. The remedy is to check the pathname given.

## Set Parameter

syntax: **SE**t <paramid> <value>

parameters:

paramid = name of parameter to change

value = new value for the parameter

errors: No such Set Command as <paramid>

This command allows the user to set various parameters by specifying paramid and value. Legal parameter id's are:

**Channel:** set channels to read from <value> is a single channel, or a range of channels.

e.g. "set ch 1:64"

"set ch 10"

"set ch 30:40"

**Clip:** set clipping on or off. With values of **xsc** larger than 1, the traces may overlap with their neighbours. If clip is set to on, the traces will be clipped at the edges of their fields.

eg. "set cl on"

"se cl off"

**Display:** set the display method if <value> is:

**raw\_data:** the raw data is displayed after each channel is read. After the final reading, the stacked results are shown. This is the slowest method.

**intermediat\_stack:** the data, stacked to that point, is displayed after each cycle through the channels.

**final\_stack:** only the final stack is shown, after the data acquisition is finished. This is the fastest method.

**Gain:** set the gain inside the DT2812-A. Valid values are 1, 2, 4 or 8.  
eg. "set g 4"

**Rate:** <value> may range from .1 to 100.  
eg. "set r 50"

**SAmple:** sets number of samples per channel <value> can range from 1 to n, where n = 65536 / number of channels (ie 1024 for 64 channels, 4096 for 16).  
eg. "set sa 1024"

**Stacks:** set the number of stacks to take.  
eg. "set st 100"

## Store

syntax: **STore** <segy\_filename>

example: st test.sgy

This command stores data in SEG-Y format to the specified file.

## X Scaling

syntax: **Xsc** value

examples: xsc 5

Sometimes the amplitude of signals is too small to be effectively displayed. The **xsc** command increases the x scaling by a factor of "value". Graphics output is truncated at the edge of the graphics window. A message to the screen alerts the user to the fact that a scaling factor has been applied. If **clipping** has been enabled, the traces will be truncated at the edges of their fields.

## Defaults

The initial setup that we have provided for your startup is that put in the file seismic.set. A copy of the file follows:

```
set chan 1:48
set sam 256
set gain 8
set type tb
set method s
set rate 20
set stacks 1
set fill off
set display final_stack
set clip off
xsc 1.000000
```