# Exercise 3: Data Processing

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## Abstract

Several experimental data sets are examined and processed using MATLAB v9.9.0. The frequency-dependent attenuation of a Perspex block was measured as a monotonously increasing function; the frequency-dependent reflection coefficient of an adhesive joint connecting two aluminium plates in immersion was measured; and an automated thickness measurement of a steel bearing casing was developed, finding the thickness to be **---mm** at **---mm**.

## Introduction and background

Ultrasonic Non-Destructive Testing (NDT) provides a means of examining the internal structure of some object by channelling ultrasonic waves into some medium to be inspected. The key application of interest for the work outlined here is measurement of properties of the inspection medium, which can be determined entirely from the ultrasonic signal measured using a transducer after interaction with the medium.

As the ultrasonic signal travels through the medium, its propagation can be modelled with a transfer function using the linear system approach [1] with a transfer function . The transfer function describes how the wave changes as it propagates, typically defined as a product of terms which act on the frequency-domain spectrum of the signal, as opposed to the time-domain signal . It is typically defined as

where describe the transmitter and receiver transducer characteristics, including effects like directivity, transducer frequency response characteristic; describes the time delay of the signal due to propagation; is the beam spread of the wave; is a coefficient which describes the change in amplitude of the wave from reflection from and transmission through boundaries; and is the attenuation.

The reflection and transmission coefficient is the product of the individual reflection and transmission coefficients , respectively, which can be determined by considering the properties of the wave at a boundary. As both wave amplitude and pressure are continuous at the boundary, these conditions can be combined to define the coefficients as

where , , are the incident, reflected and transmitted amplitudes respectively, and is the acoustic impedance of the th medium defined as

where is acoustic pressure, is particle velocity, is the density of the medium and is the wave velocity.

Attenuation is a measure of energy loss through a system, usually due to scattering and absorption [2]. Scattering results from inhomogeneity of the medium, usually from grain boundaries leading to differences in density or wave velocity. Absorption results from the conversion of mechanical sound energy to heat. The resulting loss of energy with propagation distance from both effects is defined by the attenuation coefficient, which is well described by an exponential decay with distance [1]:

## Frequency-dependent attenuation of perspex

The time-domain signal was obtained from a pulse-echo immersion test on a 7.8mm Perspex plate using a 2.5 MHz transducer, and is shown in fig 1.

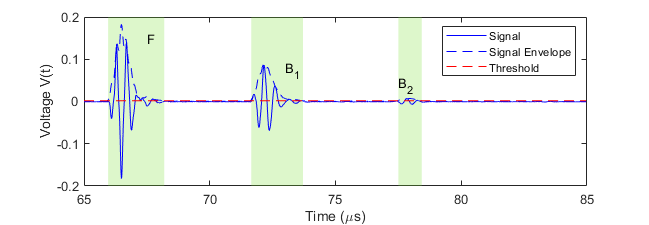


Fig. 1 Time-trace obtained from a pulse-echo immersion test on a Perspex plate. Response F is the first reflection from the front of the plate, and B1 and B2 are subsequent reverberations through the plate from the back of the plate. The envelope of the signal is shown as a dashed blue line, with the threshold shown in red.

The response from each reflection was isolated so that it could be processed independently from the others. This was done using a threshold on the signal, such that any section of data with envelope greater than the threshold ( maximum envelope voltage) was treated as a single response. These are shown as green bands in fig 1, labelled , and respectively. Using the transfer function in equation 1, the spectra of these signals can be approximated by considering the reflection and transmission of the wave through the geometry:

These frequency spectra were calculated using a Fast Fourier Transform, and are plotted in fig 2. The attenuation coefficient was then obtained by dividing the spectra ,

and is plotted in fig 3, where transmission and reflections were calculated from equation 2 assuming that the perspex block was immersed in water.

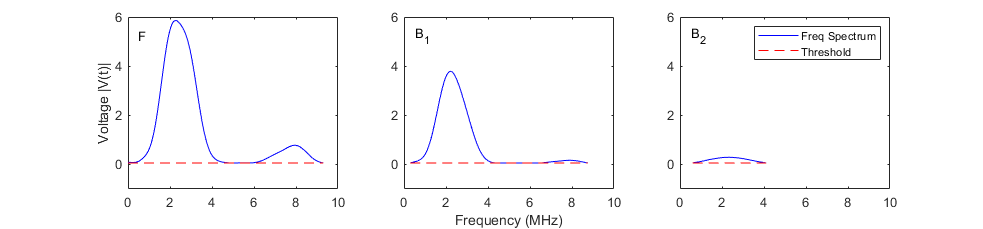


Fig. 2 Fourier transforms of voltage for each signal in fig 1. Note that only the voltage greater than a threshold ( maximum value) has been plotted, such that any frequencies with negligible value are excluded from subsequent calculation.

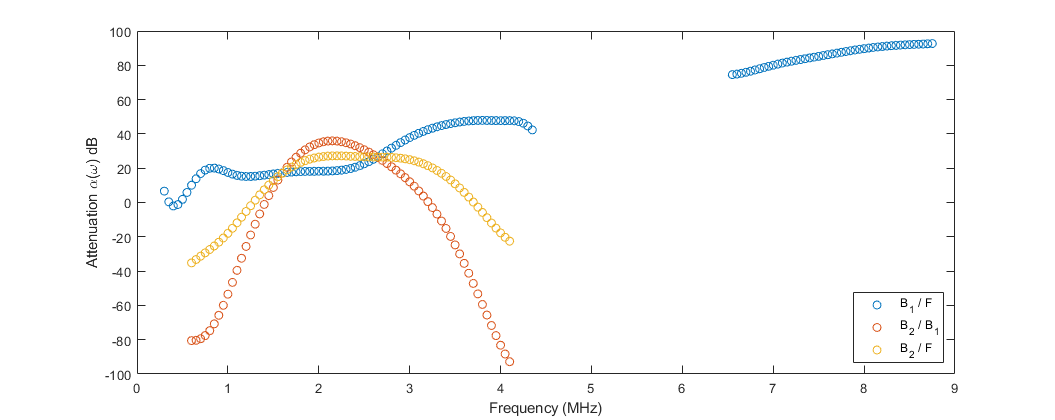


Fig. 3 Attenuation coefficient calculated from fig 2 and equation 6. Note that there is no data available for some frequencies (particularly for the data): this is because these voltages fall below the threshold plotted in fig 2, and thus are excluded from this calculation.

Of particular interest here is that the attenuation calculated from the and responses (blue circles) is close to a monotonously increasing function [3, 4]. There are some local extreme points at around , contradicting this behaviour. As these points are close to the edges, this suggests that the threshold used on the frequency spectra was not large enough. This is further supported by the fact that the attenuation plot calculated from the (orange circles) and the (yellow circles) responses are not monotonously increasing, and instead show single large maxima points. The main cause of this is that the spectrum in fig 2 is very small with respect to the other spectra, suggesting that this may fall below the value of the threshold which would be required to accurately achieve a monotonously increasing function.

Note also that this analysis has assumed that the only difference between the , and responses is the reflection coefficient and attenuation, but does not take into account the beam spreading of the wave as it passes through the **medium…**

## Frequency-dependent reflection coefficient from an adhesive joint

Two time-domain signals were obtained in a pulse-echo immersion experiment using a 10 MHz transducer. This data was filtered using a Hanning window on the frequency spectra, centred on the frequency of the transducer: this data is shown in fig 4.

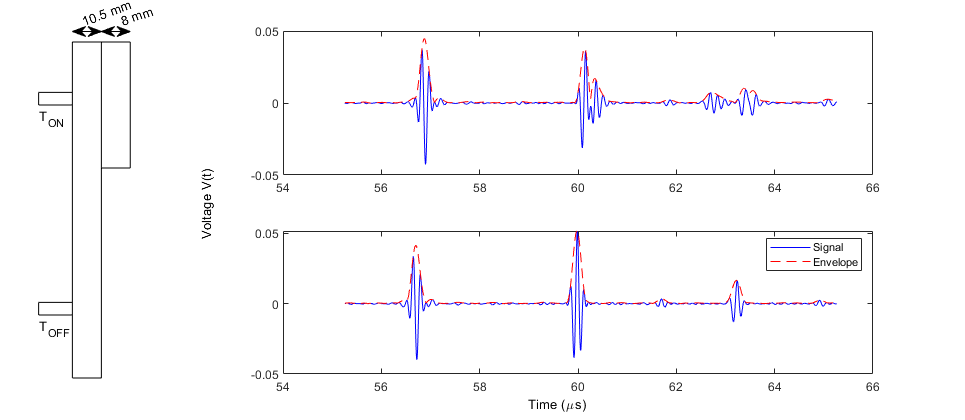


Fig. 4 Voltage time-traces from the immersion setup. The first plot was taken when the transducer was positioned over a 10.5mm aluminium plate, bonded to an 8mm aluminium plate with some adhesive of negligible thickness. The second plot was taken over an unbonded region of the plate.

In order to identify the reflection coefficient of the adhesive joint, the response corresponding to the first reflection from the back of the 10.5 mm plate was isolated in both time-traces using thresholding identical to the previous attenuation calculation: the response of interest is located at . By considering the reflection and transmission of the wave through the geometry, the frequency spectra of these responses can be written as

The spectra are plotted in fig 5a. By calculating the value of for the aluminium-to-water interface as 0.838 and multiplying this by the ratio of the frequency spectra, the frequency-dependent reflection coefficient of the adhesive joint was calculated: this is shown in fig 5b.

Of particular interest in this plot is the minimum value at frequency .

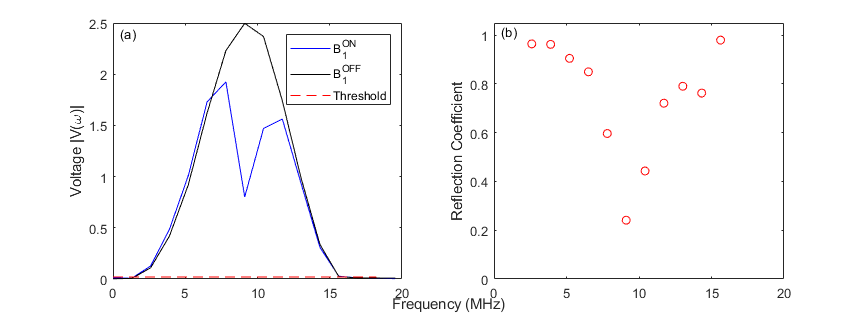


Fig. 5 (a) Frequency spectra for the bonded (blue) and unbonded (black) plate. The threshold plotted here (all data below which is excluded from subsequent calculation) is maximum value. (b) Reflection coefficient calculated by multiplying by the ratio of and .

The report required for this course must be submitted as a PDF file in precisely the format described in this document. Strict formatting and "house styles" are common requirements when writing internal company reports, as well as when writing academic papers for journals and conference proceedings.

### The template and paragraph styles [Heading 3]

This example document is written in Word 2007 and contains all the necessary styles, the names of which are in square brackets and highlighted in red. Paragraphs in the body of the document should be in the [Normal] style. You are recommended to use this document as the starting point for each report. If you wish to use an alternative word processing package, the final result must still be a single PDF file in the same format (i.e. with the same font, margins, page limits etc.).

If, as recommended, you are using this document as a template then you should use the paragraph styles that have been defined, which will ensure that the spacing, font, format etc. is correct. To select the style for a paragraph, make sure that the cursor is somewhere in the paragraph and either use the buttons in the toolbar or the shortcut keys that are listed below.

#### Titles [Heading 4]

Start the description of each exercise with the title of the exercise in the [Heading 1] style, which will force it to start on a new page. On the front page of the whole report, the text on the next line after the title should be your name in the [Author] paragraph style. Within the description of each exercise, you should use subheadings (styles [Heading 2], [Heading 3] and [Heading 4]) as necessary.

#### Page setup

The page size is A4 and the margins are 20 mm all around.

#### Shortcut keys and brief description of main styles

Alt+1 [Main title] (bold Arial 16 point, page break before)

Alt+2 [Sub-heading] (bold Arial 10 point, small caps)

Alt+3 [Sub-sub-heading] (bold italic Arial 10 point)

Alt+4 [Sub-sub-sub-heading] (italic Arial 10 point)

Alt+N [Normal paragraph text] (Arial 10 point, 5pt gap before and after)

Alt+E [Equation] (25.4 mm indent, right justified tab at 170 mm for numbering)

Alt+F [Figure] (centred, locked to following paragraph)

Alt+R [Reference] (Arial 8 point, 12.7 mm hanging indent, with tab stop at 12.7 mm)

### Using other people's material

If you use material from anywhere else, you must reference the source. List the references at the end of each report under the subheading "References" in a numbered list (the style for each item in the list is [Reference]) and cite each reference at the appropriate point in the text by placing the relevant reference number in square brackets, like this [1]. The first citations to each reference in the text should be in numerical order (change the order of the reference list if necessary so that this is achieved). All references in the list must be cited explicitly in the text. Here is an example of a citation to a journal paper [2] that describes some interesting work. You can also find material in conference proceedings [3] or websites [4]. Use the examples in the list to determine the exact way in which references to different types of source should be formatted. The most important requirement is that the reference must provide enough information to allow someone else to retrieve the same information.

### Page limits

The maximum number of pages (excluding the appendices containing Matlab code) for the exercises are as follows:

Exercise 3: 6 pages

Exercise 5: 10 pages

Each one should be submitted as a single PDF document.

### Grammar

Only capitalise (a) the first word of sentences, (b) proper nouns, even in titles and (c) the first letters of words that are used to define an acronym, for example "ultrasound is widely used in Non-Destructive Testing (NDT)". Define all acronyms the first time they are used. It is preferable in technical reports to write in the third person using the passive voice. This means for example writing "the fields from transducers were investigated" rather than "we investigated the fields from transducers".

## Equations, figures and references

### Equations

The paragraph style for equations is [Equation]. This indents the equation and provides a right justified tab at the right-hand margin where you can insert a number. For example, here is a famous equation:

(1)

Remember to define all terms in equations!

### Figures

The paragraph style for figures is [Figure]. The figure placement should be "in line with text". The [Figure] style centres the figure and puts a box around it. Do not wrap text around figures. Label sub-figures with (a), (b) etc. as in the example below. The style of the paragraph immediately after the figure should be [FigureCaption]. Identify the figures in each report as Fig. 1, Fig. 2 etc. and press tab after the number before typing the caption. The [FigureCaption] style provides a hanging indent so that the caption text is properly aligned after the number. All figures must be referenced in order in the main text, e.g. "Fig. 1(a) shows an image …"

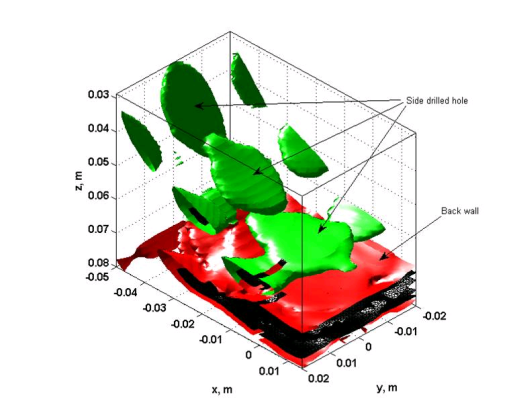
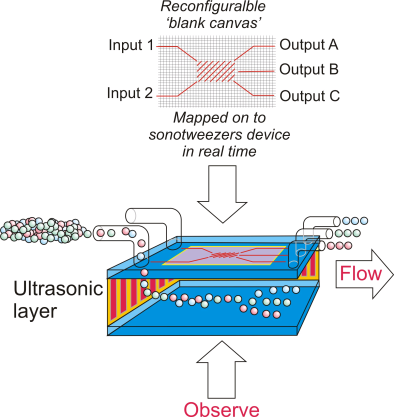
(a)  (b) 

Fig. 1 Some pictures of (a) 2D array image of holes in a test sample and (b) a particle manipulation device. If the caption runs onto multiple lines, they will be aligned like this.

## References

In the example reference list below, the style for each entry is [Reference]. Type the reference number, a period and then press tab before entering the details of the reference itself.

1. Velichko, A., “The Frequency Domain”, *Ultrasonic NDT*, 29 Mar 2021, University of Bristol. Lecture.
2. Krautkrämer, J., & Krautkrämer, H. (1990). Attenuation of Ultrasonic Waves in Solids. In Ultrasonic Testing of Materials (pp. 108-116). Berlin: Springer.
3. O’Donnell, M., Jaynes, E. T. and Miller, J. G., “Kramers-Kronig relationship between ultrasonic attenuation and phase velocity”, *Acoust. Soc. Am.*, **69**, pp. 696-701, 1981.
4. Zellouf, D., Jayet, Y., Saint-Pierre, N., Tatibouët, J., and Baboux, J. C., “Ultrasonic spectroscopy in polymeric materials. Applications of the Kramers-Kronig relations”, *J. Appl. Phys.* **80**(5), pp. 2728-2732, 1996.

1. Wilcox, P. D., "Research things", *Nature*, **12**(3), pp. 145-155, 2001. {example of a reference to a journal paper}

2. Holmes, C., Drinkwater, B. W. and Wilcox, P. D., "Post-processing of the full matrix of ultrasonic transmit receive array data for non-destructive evaluation”, *NDT & E Int.*, **38**(8), pp 701-711, 2005. {another example of a reference to a journal paper}

3. Monkhouse, R. S. C., Wilcox, P. D. and Cawley, P., “Flexible Interdigital PVDF Lamb Wave Transducers for the Development of Smart Structures” in *Annual Review of Progress in QNDE*, eds. Chimenti, D. E., Thompson, D. O., **16**(A), pp. 877-884, Plenum Press, New York, 1997. {example of a reference to a conference paper}

4. University of Bristol, "Useful information and resources", http://www.bris.ac.uk/currentstudents/, accessed 27 January 2010. {example of a reference to a website}

# Exercise 3: Data Processing

## Abstract

The propagation of a pulse is simulated by applying phase delays to its spectrum in the frequency domain. Etc. Etc. Etc.