

Sounds, spectra, audio illusions, and data representations

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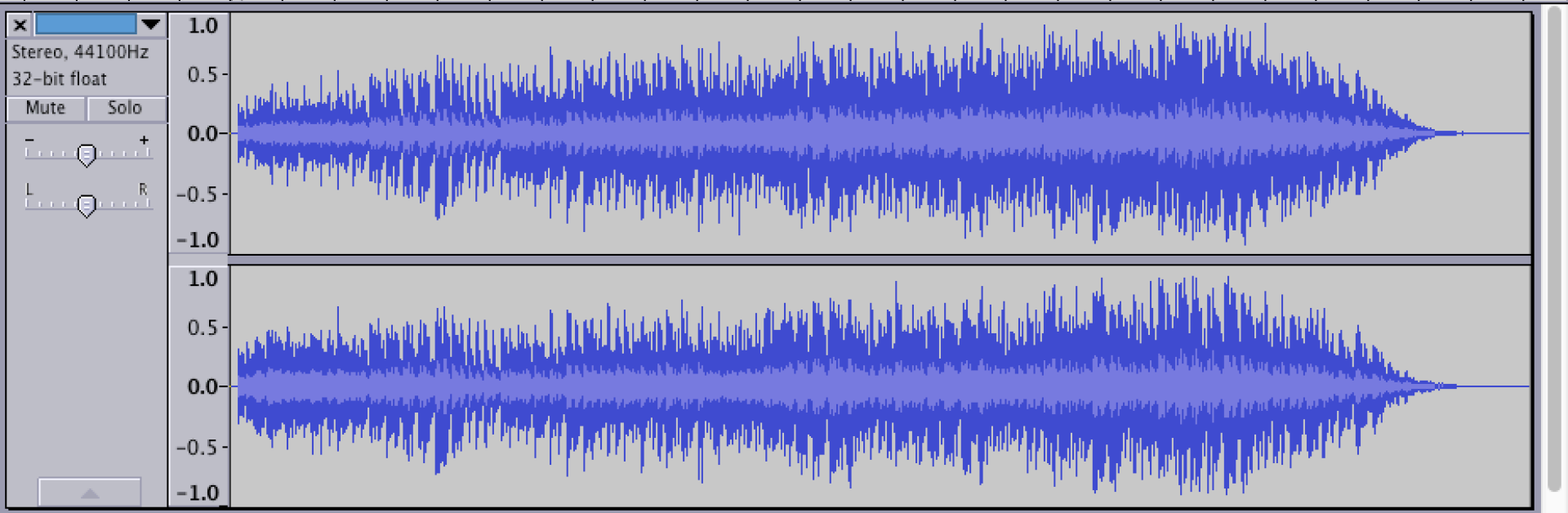
Introduction to Signal Processing Techniques

A. Y. 2016-17

Core Audio MIDI Setup interface showing two channels of audio data. The top channel is labeled "Click to Start Monitoring" and the bottom channel is labeled "Click to Start Monitoring". Both channels show a sequence of numbers: -57 -54 -51 -48 -45 -42 -39 -36 -33 -30 -27 -24 -21 -18 -15 -12 -9 -6 -3 0.

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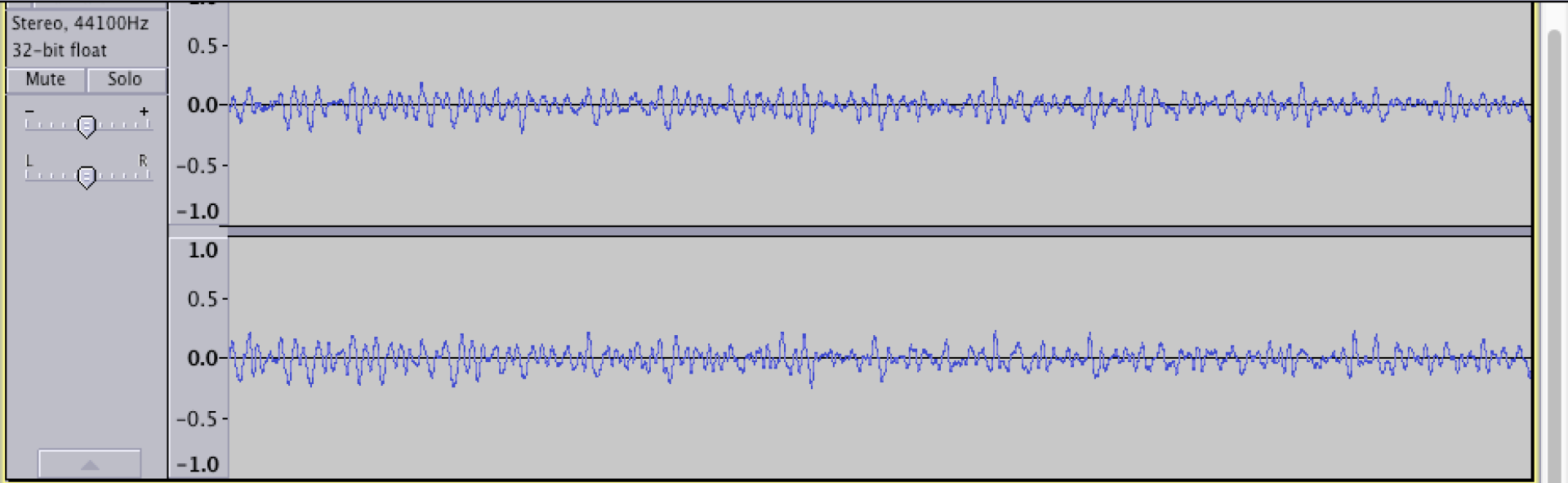
Project Rate (Hz): 44100
Snap To: Off
Selection Start: 00 h 00 m 00.000 s
End Length: 00 h 00 m 00.000 s
Audio Position: 00 h 00 m 00.000 s

Core Audio MIDI Setup interface showing two channels of audio data. The top channel is labeled "Click to Start Monitoring" and the bottom channel is labeled "Click to Start Monitoring". Both channels show a sequence of numbers: -57 -54 -51 -48 -45 -42 -39 -36 -33 -30 -27 -24 -21 -18 -15 -12 -9 -6 -3 0.

Core Audio MIDI Setup interface showing various control buttons and sliders. The buttons include a microphone icon, a speaker icon, a volume slider, a mute button, a solo button, a pan knob, a zoom in button, a zoom out button, a pan knob, a zoom in button, a zoom out button, a refresh button, and a volume slider.

Core Audio MIDI Setup interface showing the selected audio device and output. The selected device is "Built-in Microphone" and the output is "Built-in Output".

Core Audio MIDI Setup interface showing the time scale. The time scale ranges from 9.260 to 9.400 seconds.



Core Audio MIDI Setup interface showing the Project Rate (Hz) and Snap To settings. The Project Rate is set to 44100 Hz and Snap To is set to Off.

Core Audio MIDI Setup interface showing Selection Start and Audio Position settings. The Selection Start is set to 00 h 00 m 00.652 s and the Audio Position is set to 00 h 00 m 00.000 s.

Piano notes

PIANO KEYBOARD



1 2 3 4 5

ORGAN KEYBOARD

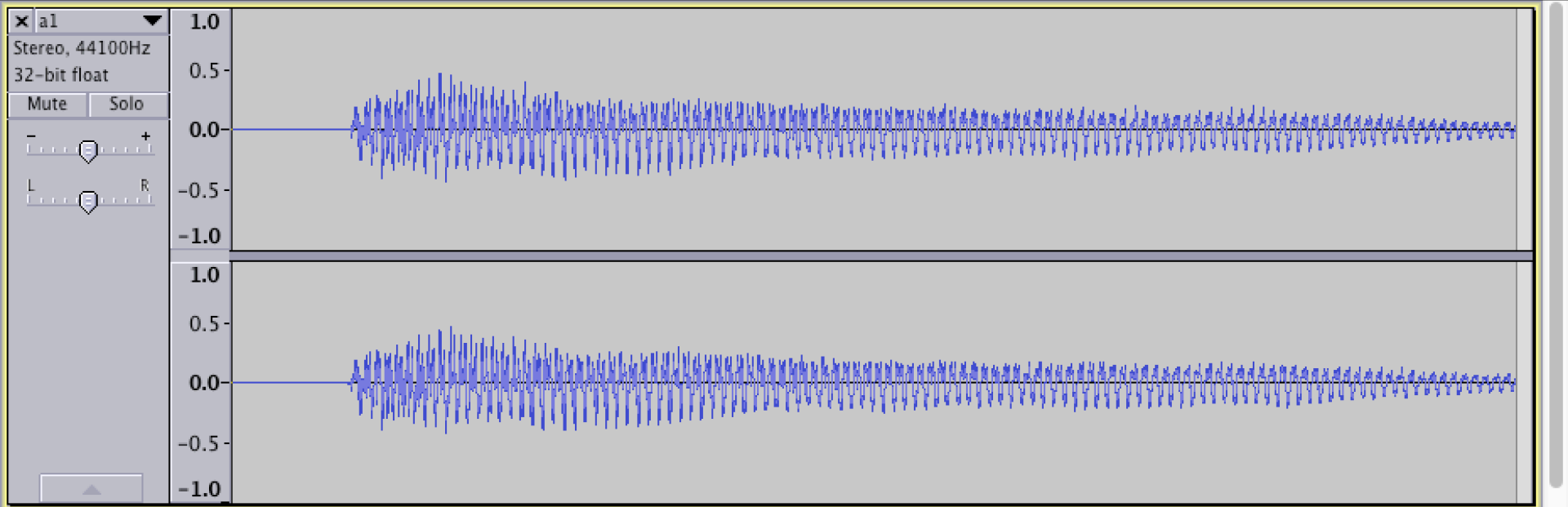
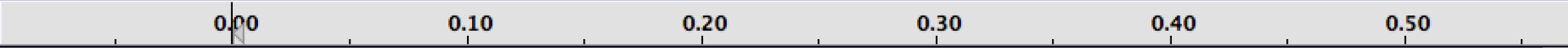


Pure 440 Hz sound





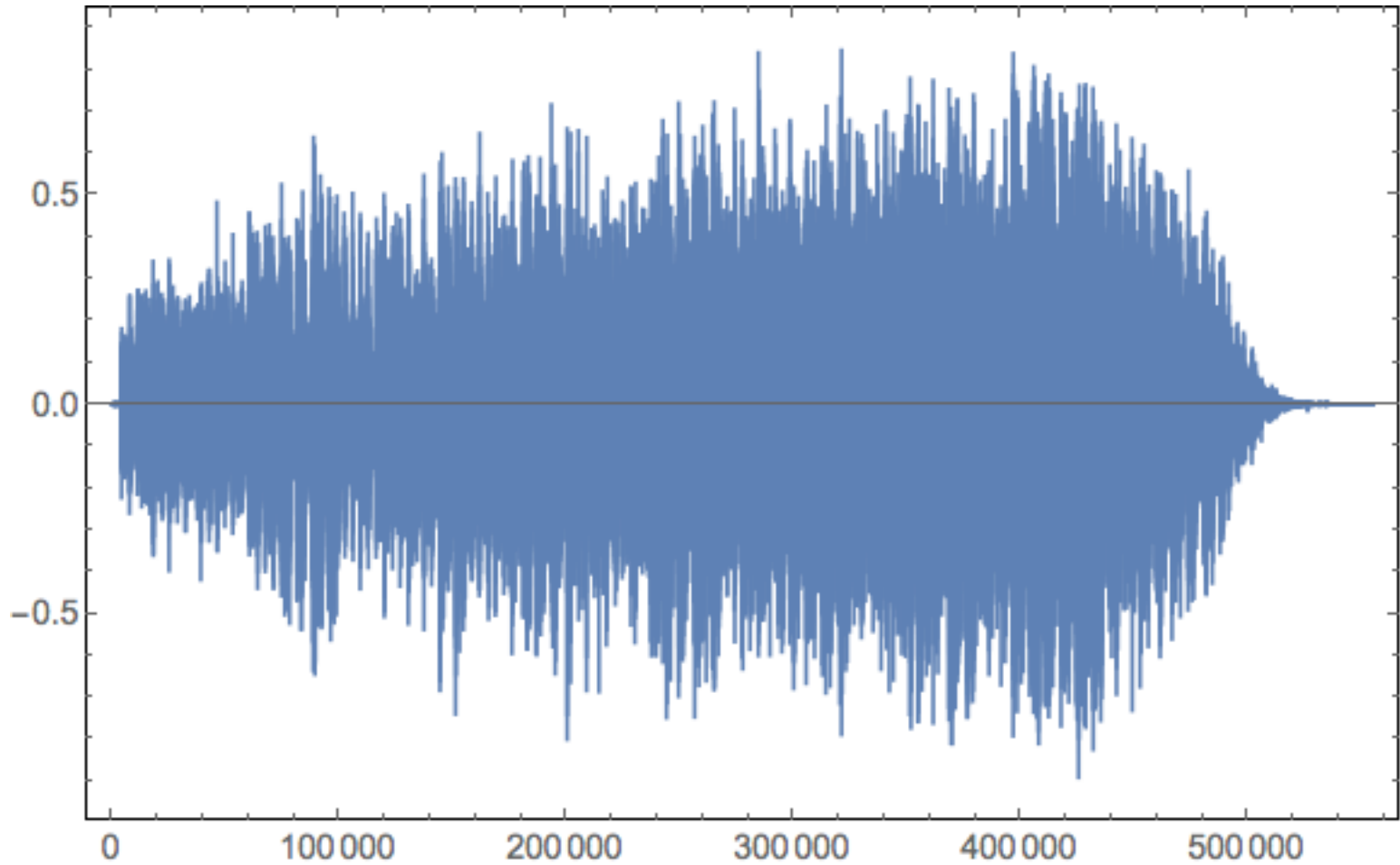
Core Au... Built-in Microphone 2 (Stereo... Built-in Output



Project Rate (Hz): 44100 Snap To: Off Selection Start: 00 h 00 m 00.000 s End Length Audio Position: 00 h 00 m 00.000 s

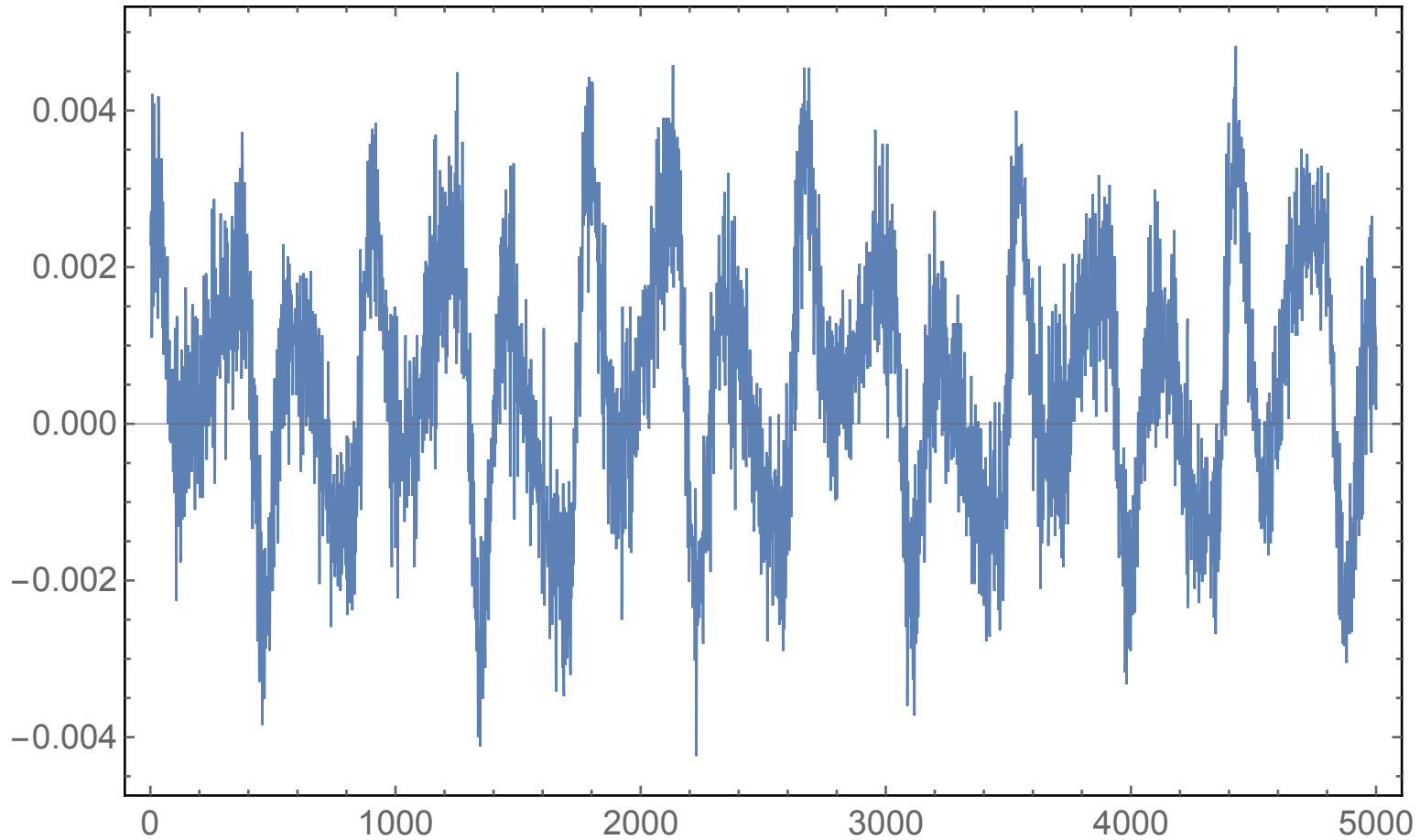
Back to the initial recording, left channel

amplitude (volt, ampere,
normalized amplitude units ...)



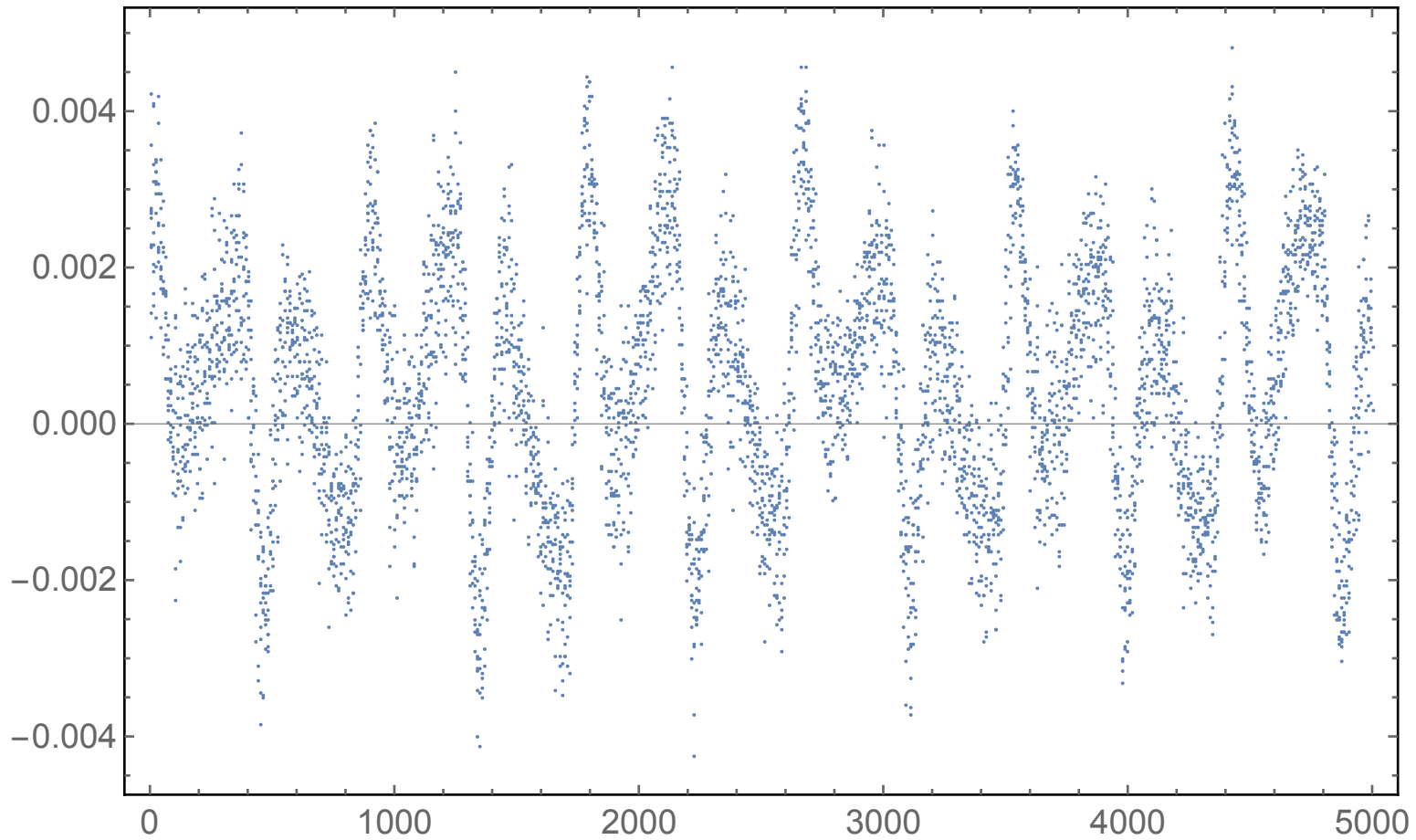
time (sample number)

amplitude (volt, ampere,
normalized amplitude units ...)



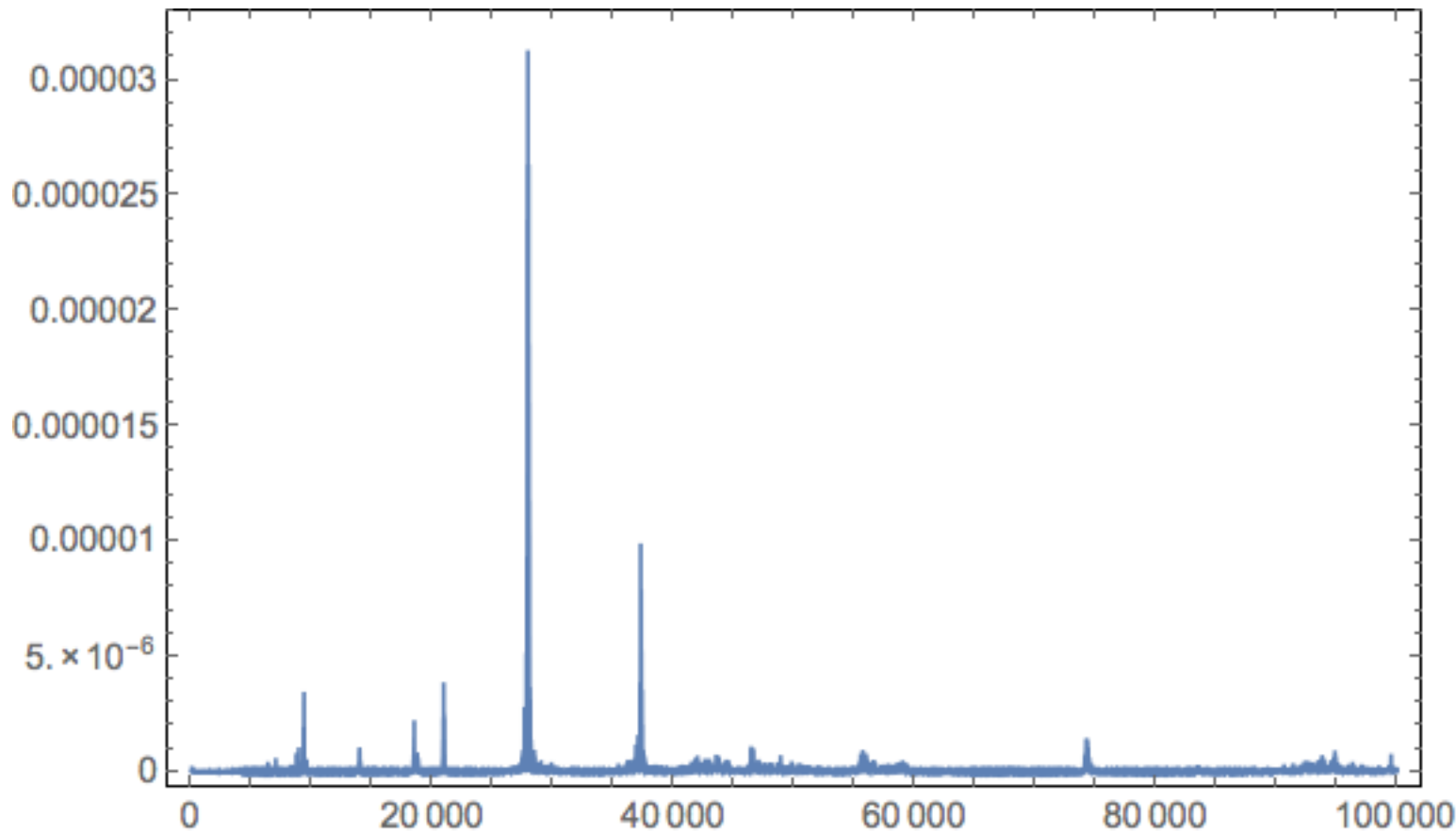
time (sample number)

amplitude (volt, ampere,
normalized amplitude units ...)



time (sample number)

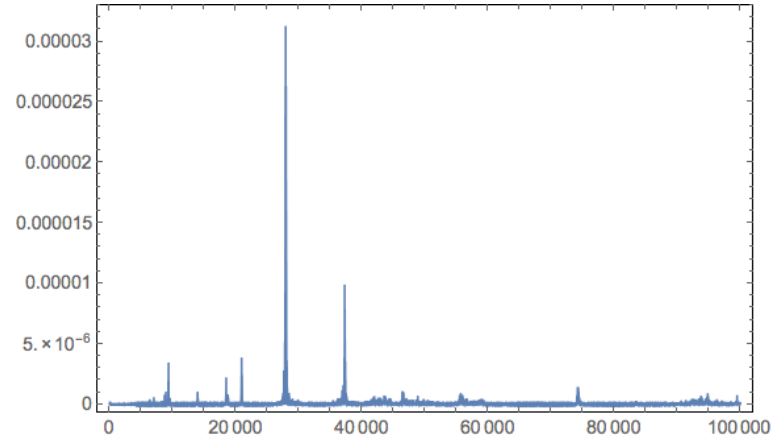
squared amplitude



frequency (frequency index)

Short Time Fourier Transform (STFT)

Fourier Transform



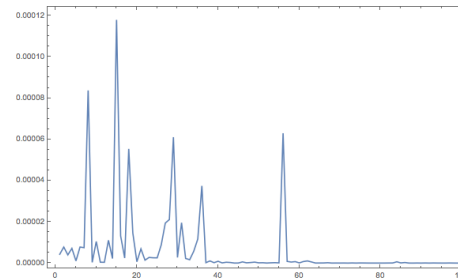
A single block of data



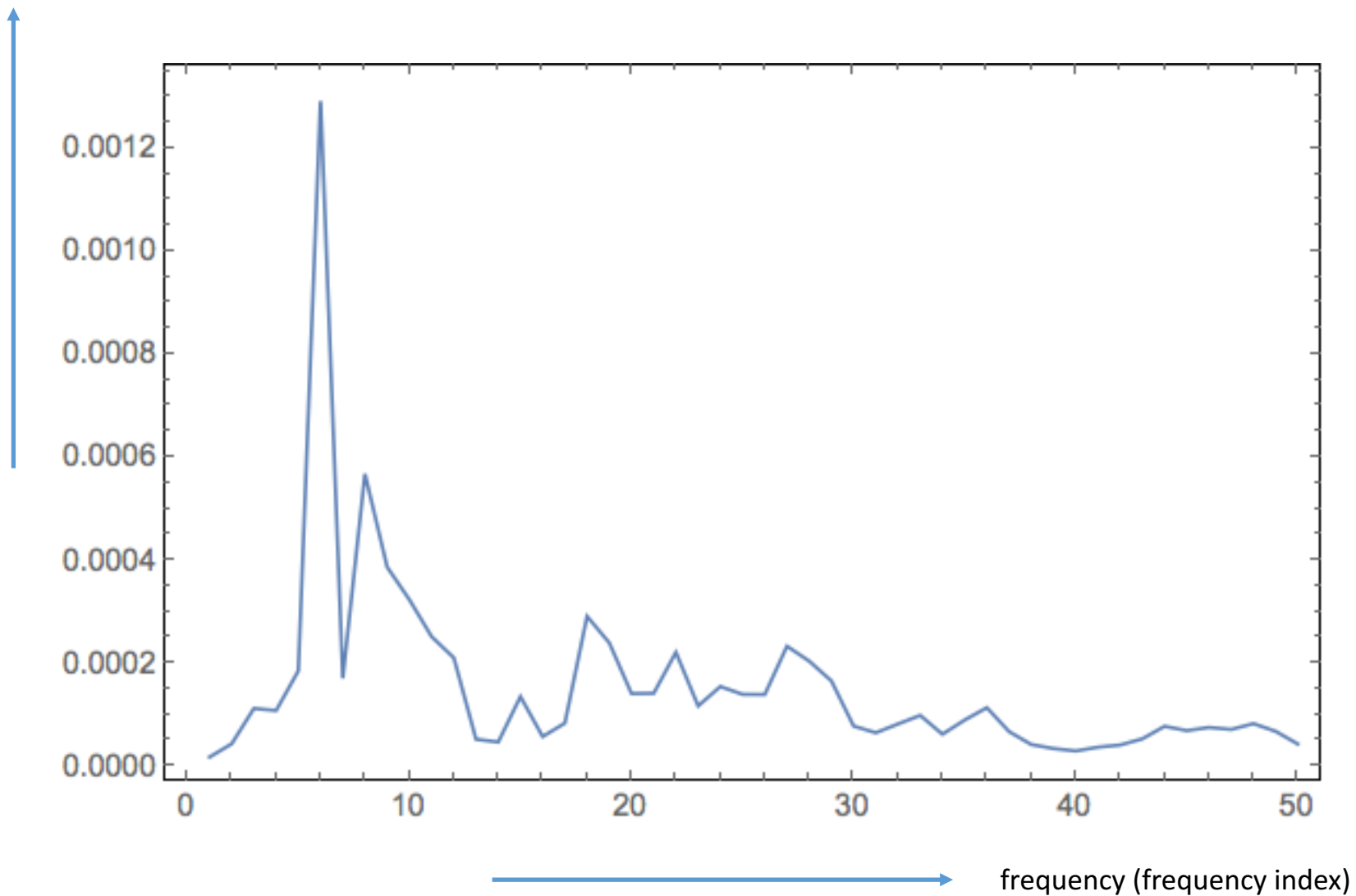
Segmented data



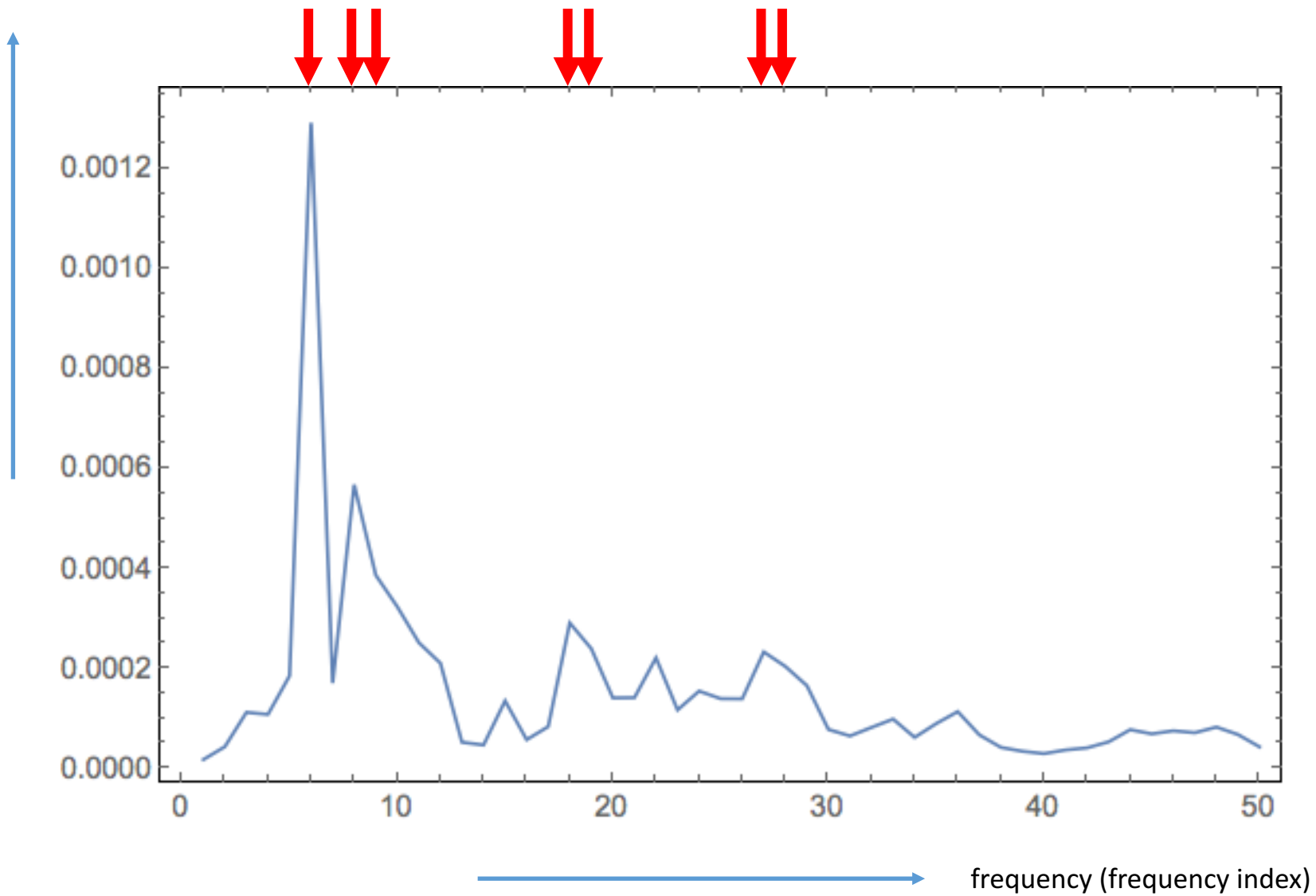
Fourier Transform



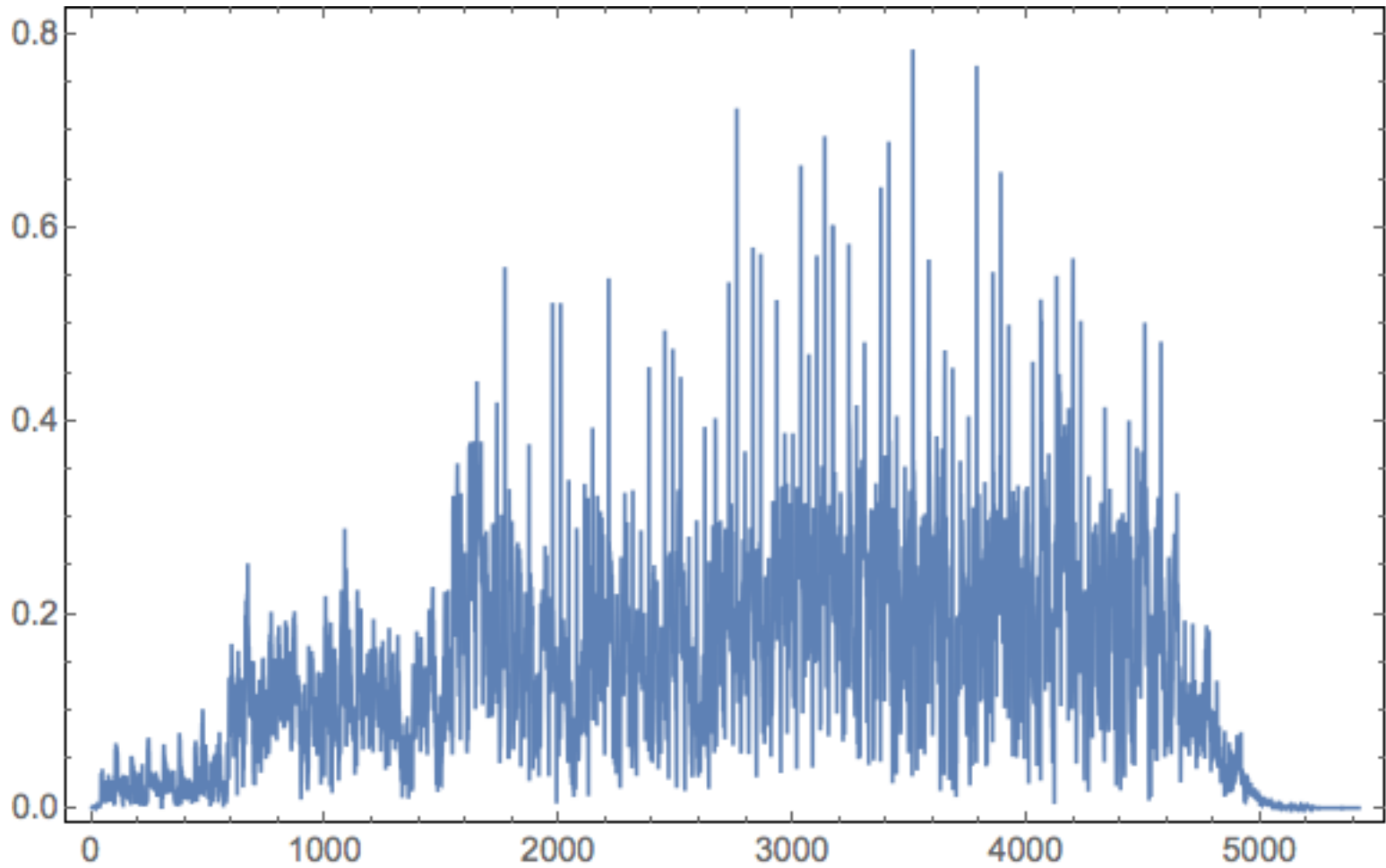
squared amplitude



squared amplitude

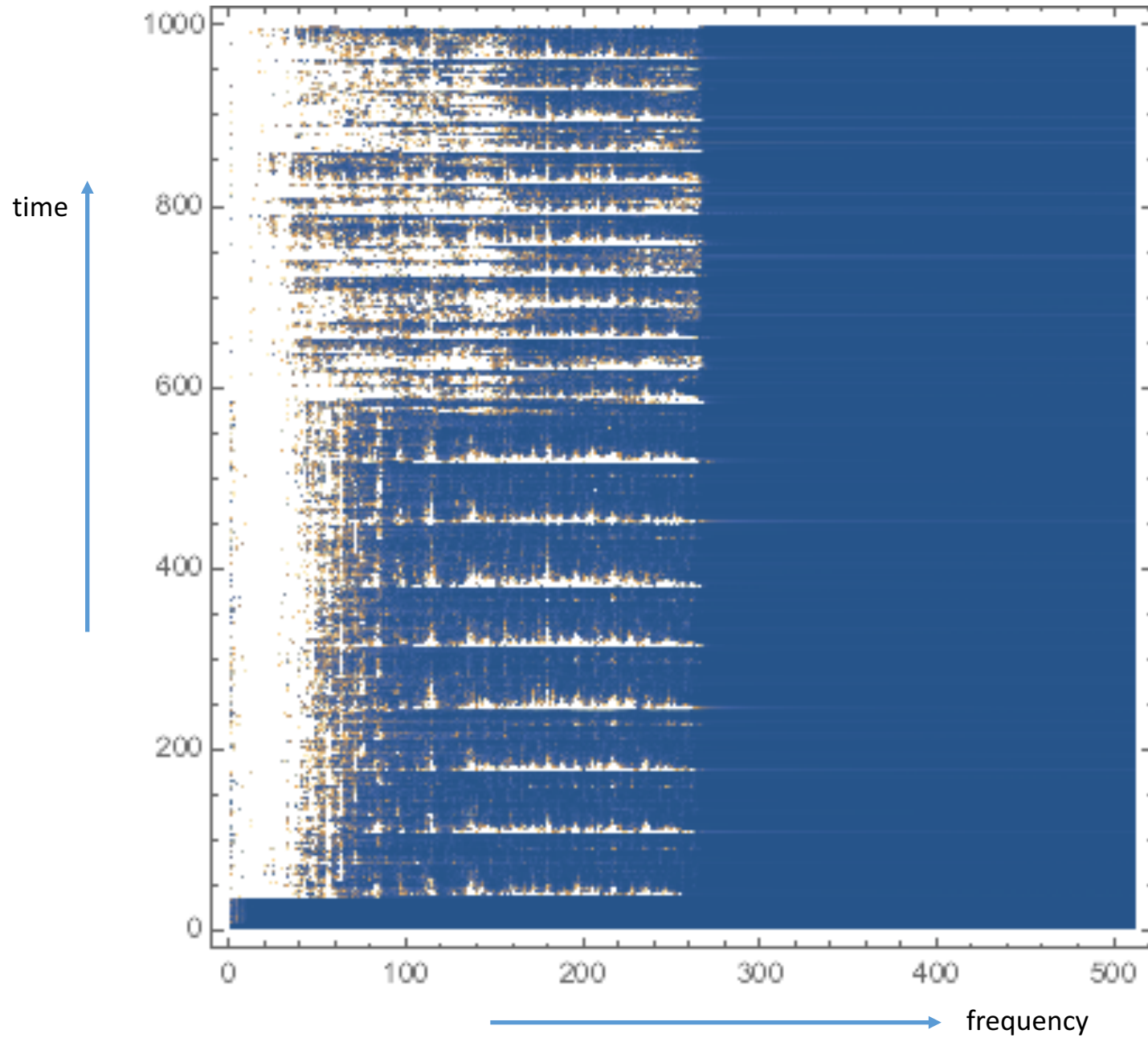


amplitude of most important
Fourier component



time

Spectrogram



- **Original audio file**



- Reconstruction with the largest amplitude frequency component only



- Reconstruction with 7 frequency components



- Reconstruction with 7 frequency components + phase information

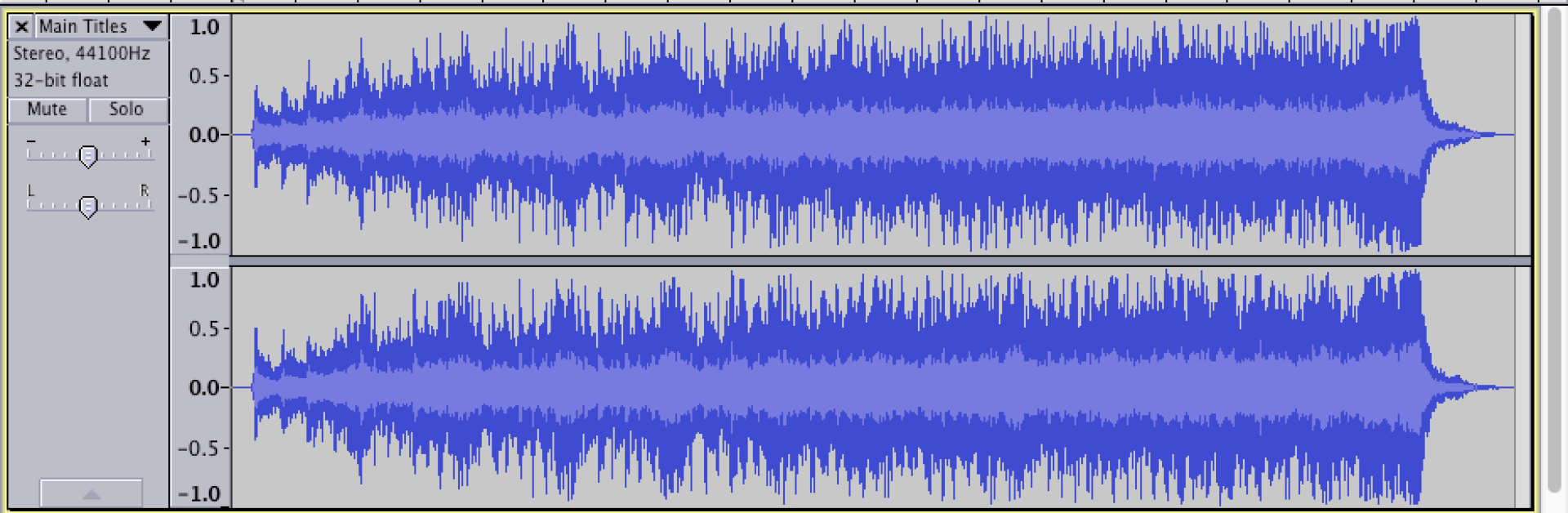


Core Audio MIDI Setup interface showing two channels of audio levels. The top channel is labeled "Click to Start Monitoring" and the bottom channel is labeled "Click to Start Monitoring". Both channels show levels for L and R channels, with values ranging from -57 to 0.

Core Audio MIDI Setup interface showing various control buttons and sliders. The buttons include a microphone icon, a speaker icon, a volume slider, a mute button, a solo button, a copy button, a paste button, a delete button, a redo button, a undo button, a zoom in button, a zoom out button, a zoom reset button, and a refresh button.

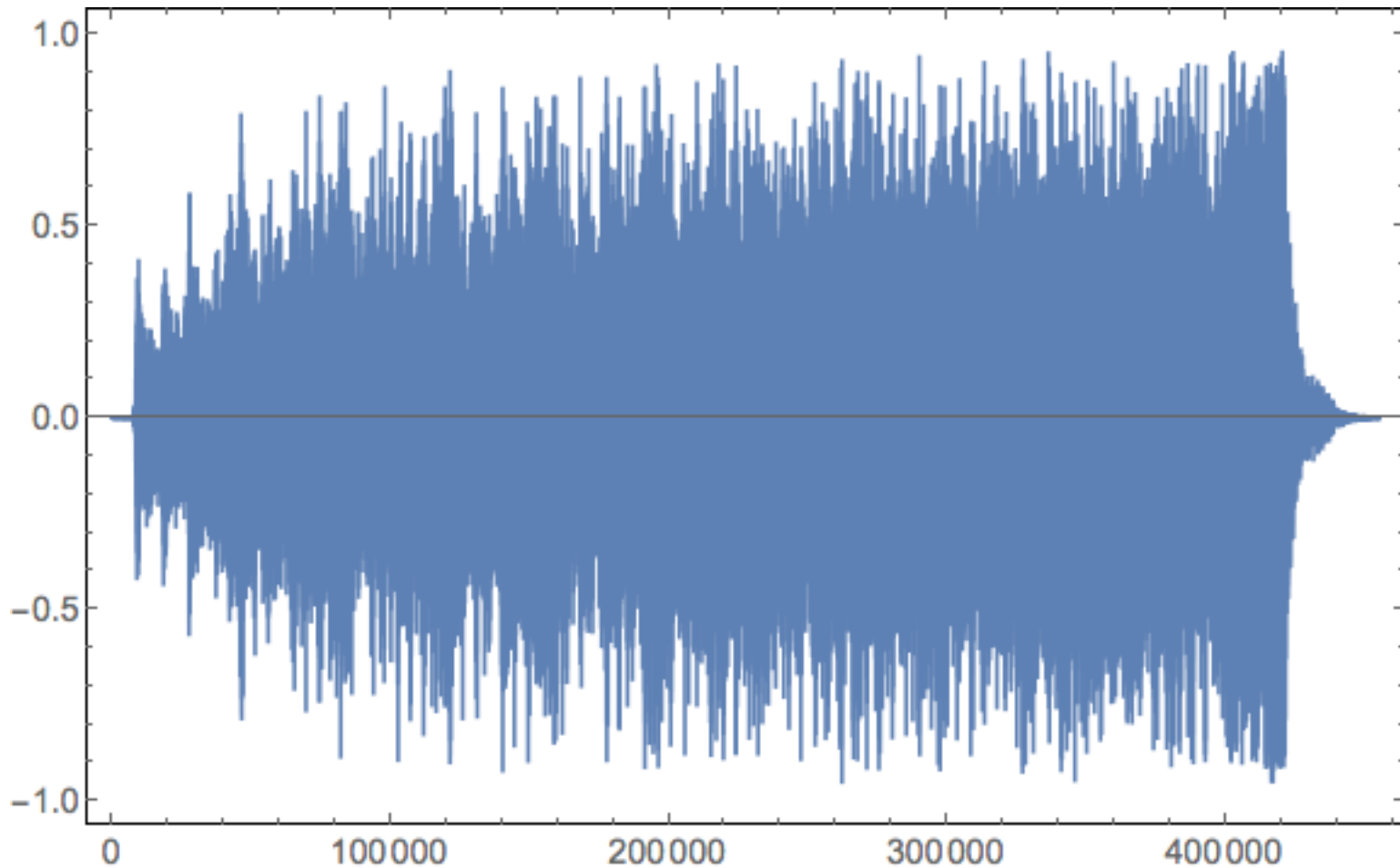
Core Audio MIDI Setup interface showing the selected audio device and output. The selected device is "Built-in Microphone" and the output is "Built-in Output".

Core Audio MIDI Setup interface showing a time scale from -15 to 1:45. The scale is marked at -15, 15, 30, 45, 1:00, 1:15, 1:30, and 1:45.



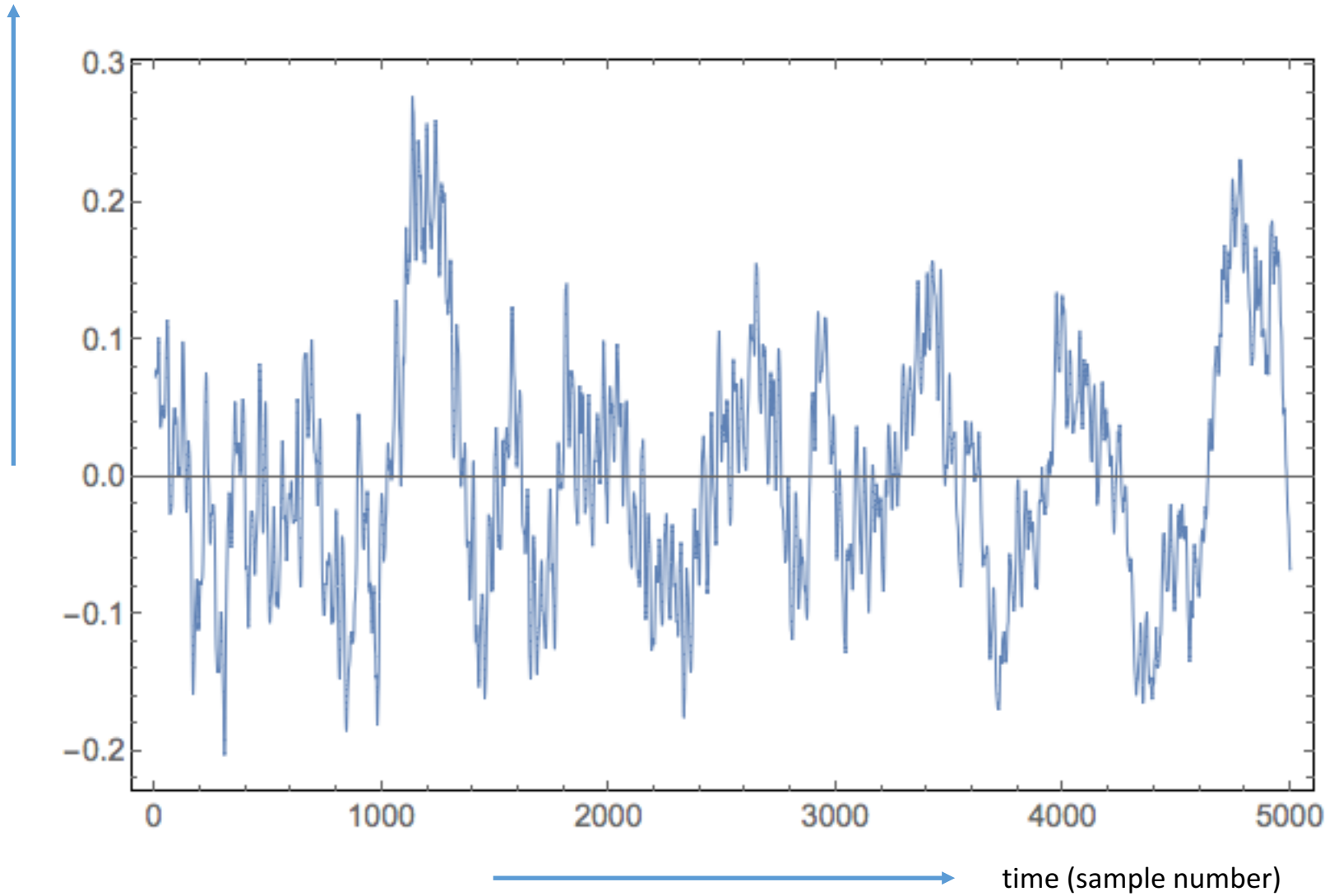
Core Audio MIDI Setup interface showing project settings. The Project Rate (Hz) is 44100. The Snap To is Off. The Selection Start is 00 h 00 m 00.000 s. The Selection End is 00 h 00 m 00.000 s. The Audio Position is 00 h 00 m 00.000 s.

amplitude (volt, ampere,
normalized amplitude units ...)

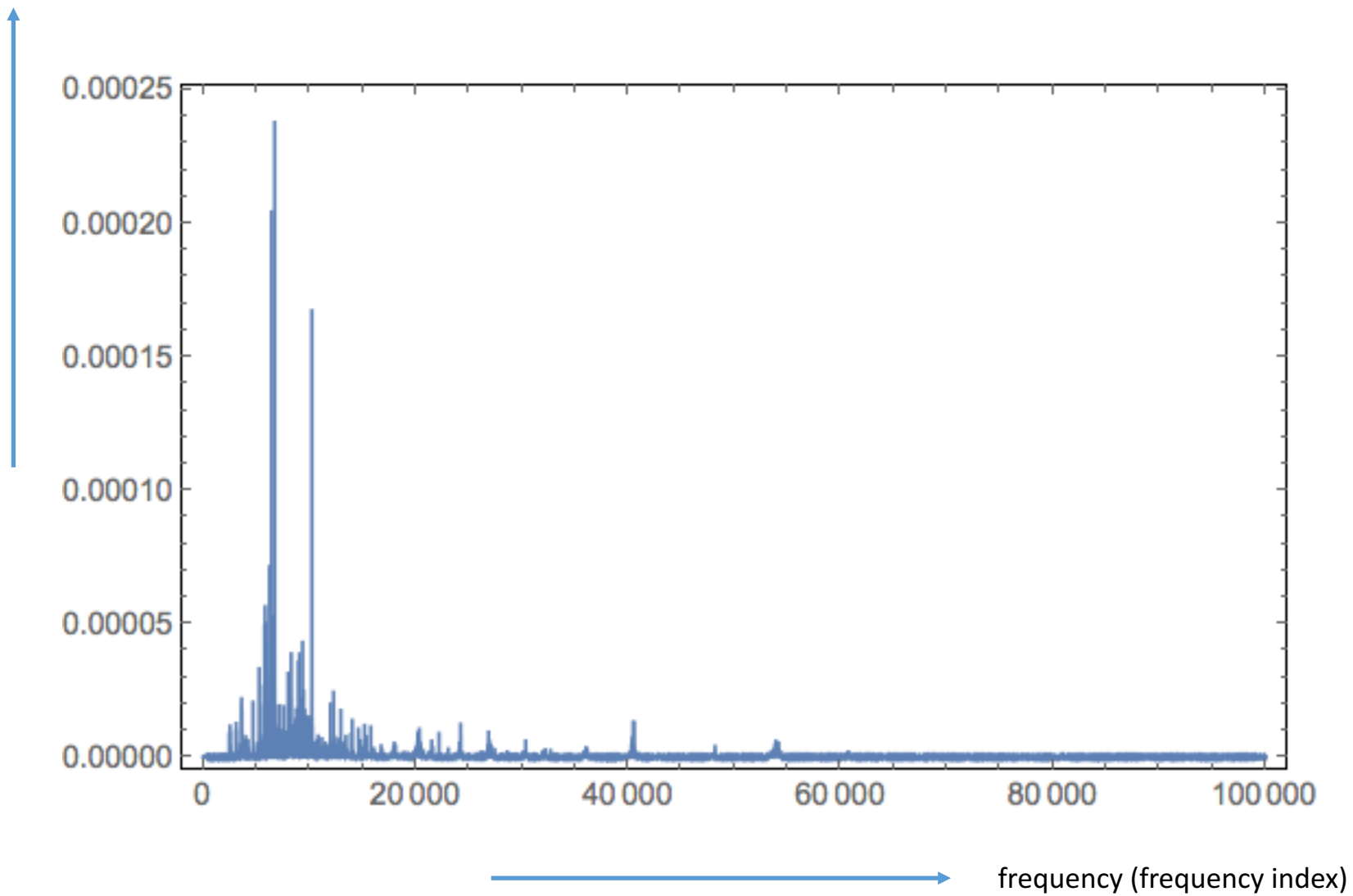


time (sample number)

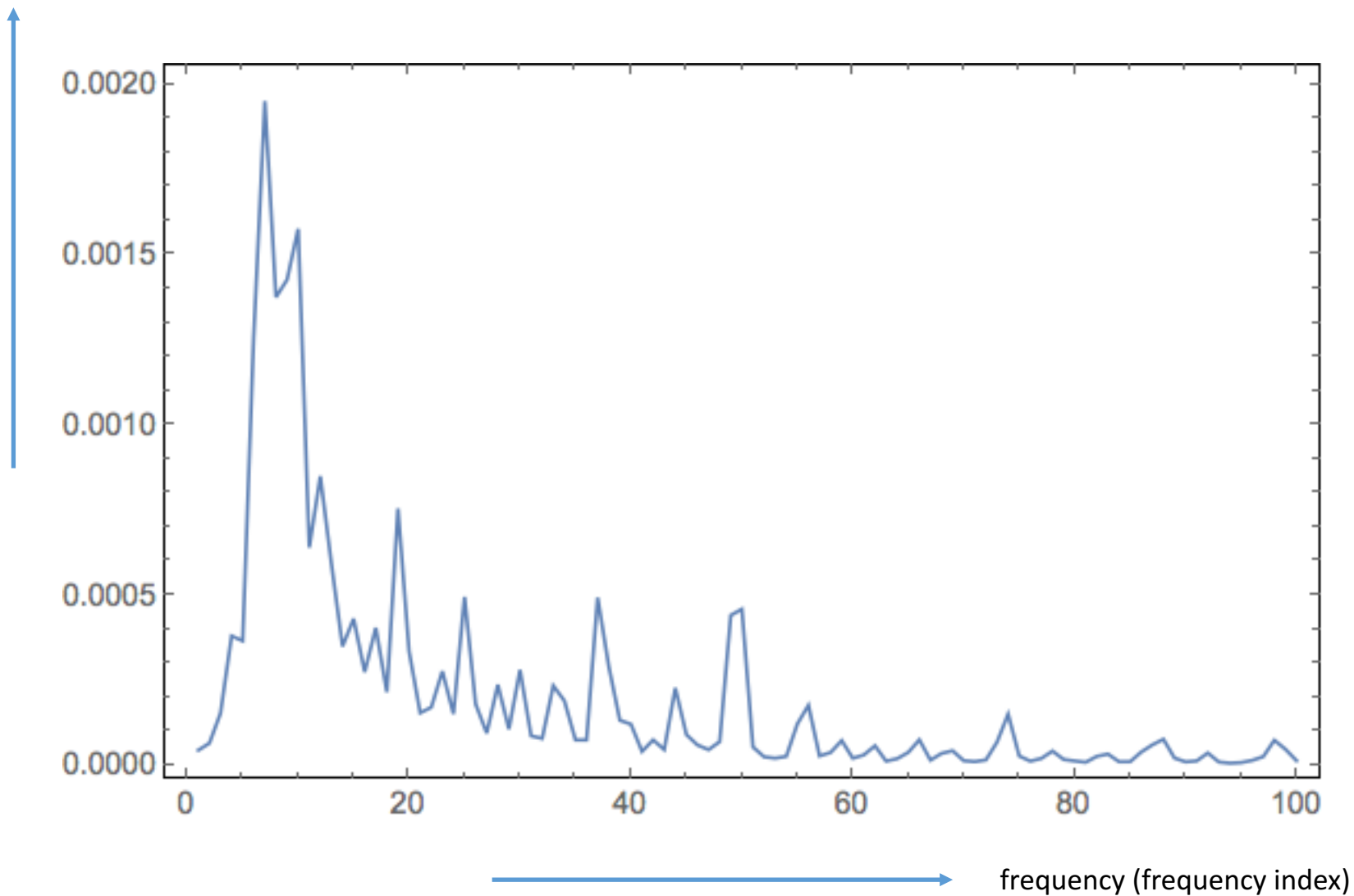
amplitude (volt, ampere,
normalized amplitude units ...)



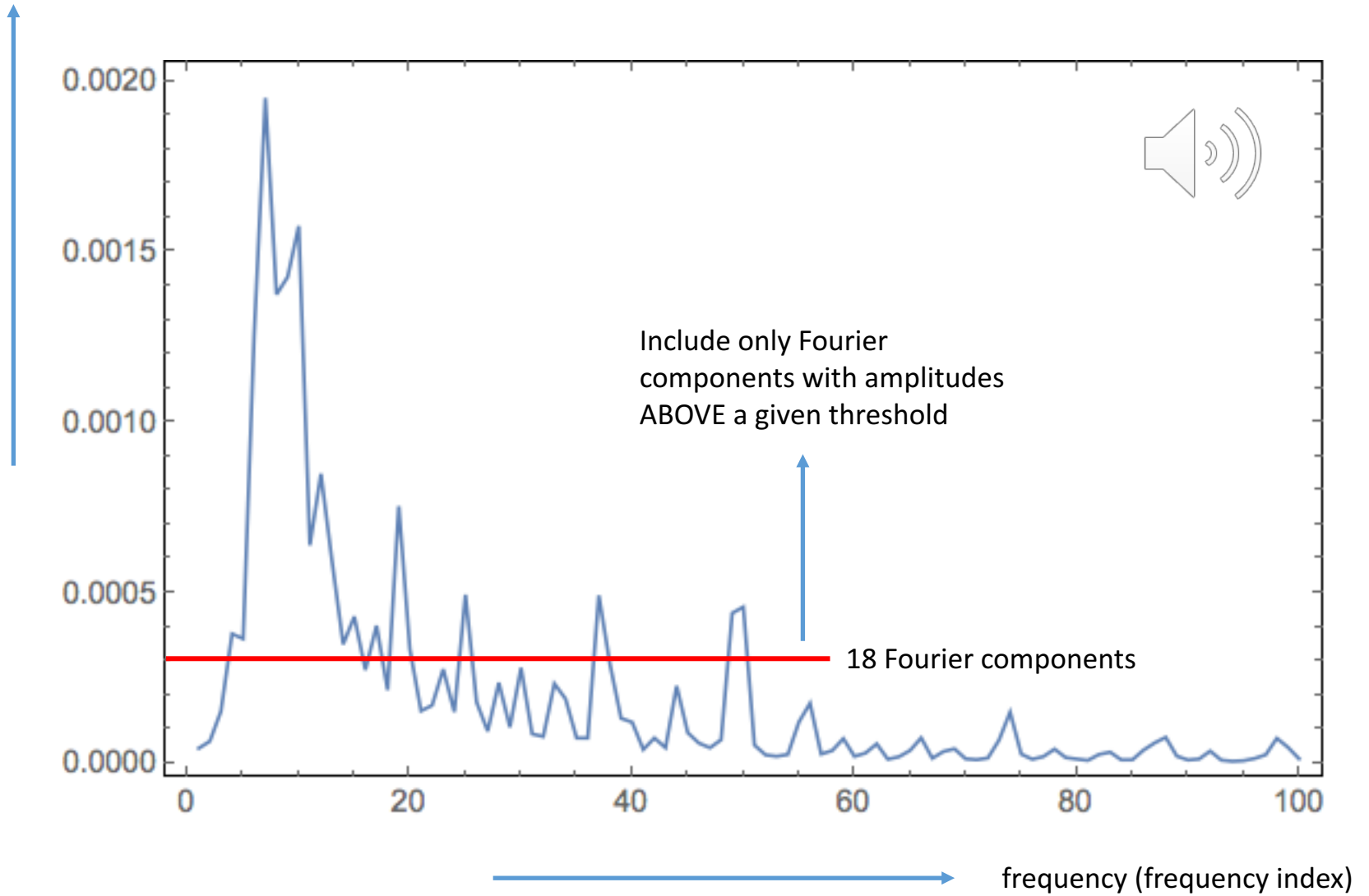
squared amplitude



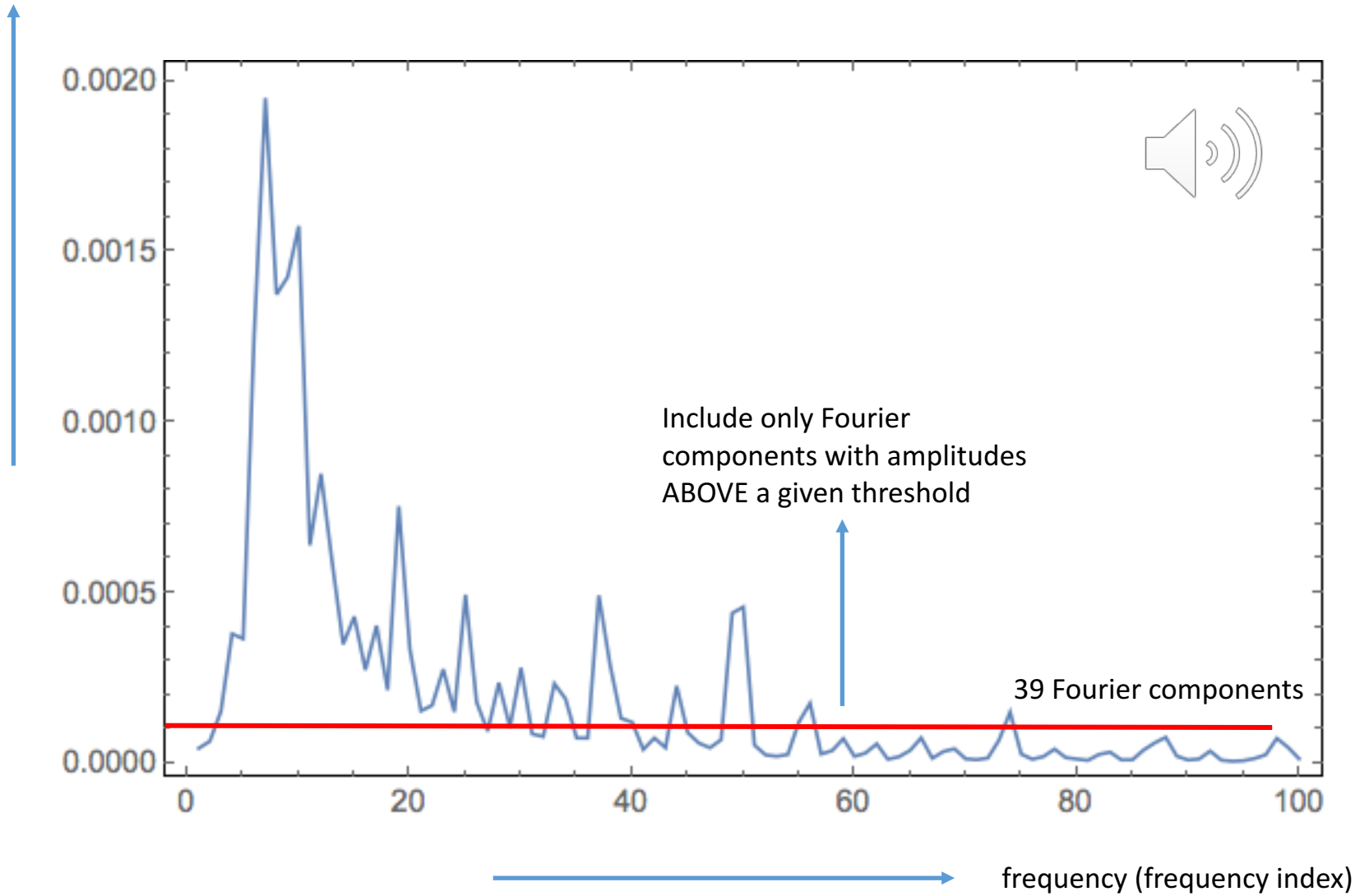
squared amplitude



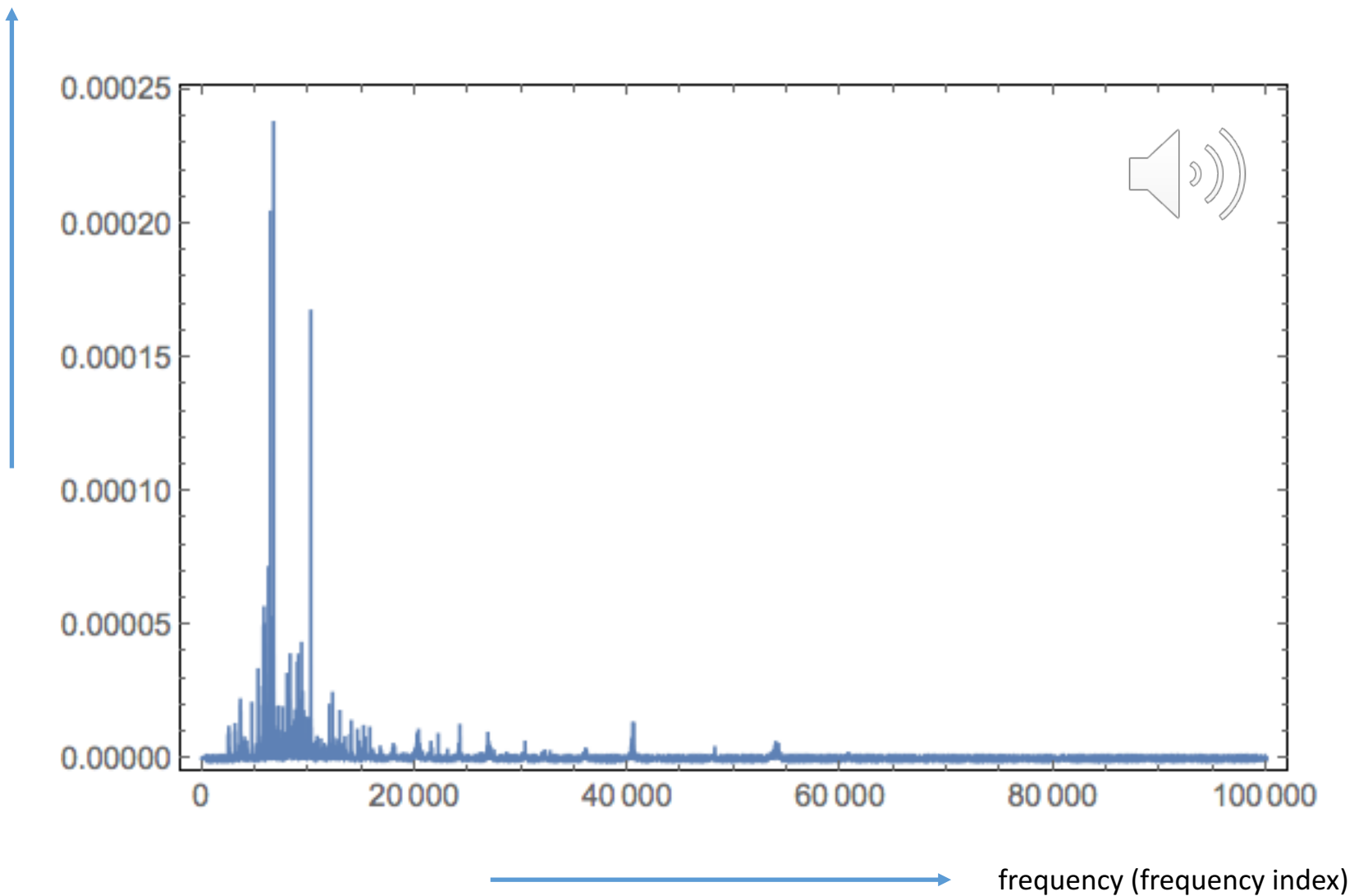
squared amplitude



squared amplitude



squared amplitude



Glissando

In music, a glissando [glis'sando] (plural: glissandi, abbreviated gliss.) is a glide from one pitch to another. It is an Italianized musical term derived from the French glisser, to glide.

(from Wikipedia)



J. S. Bach - Musicalisches Opfer - 6. Canon A 2



G. Ligeti – Glissandi and Artikulation

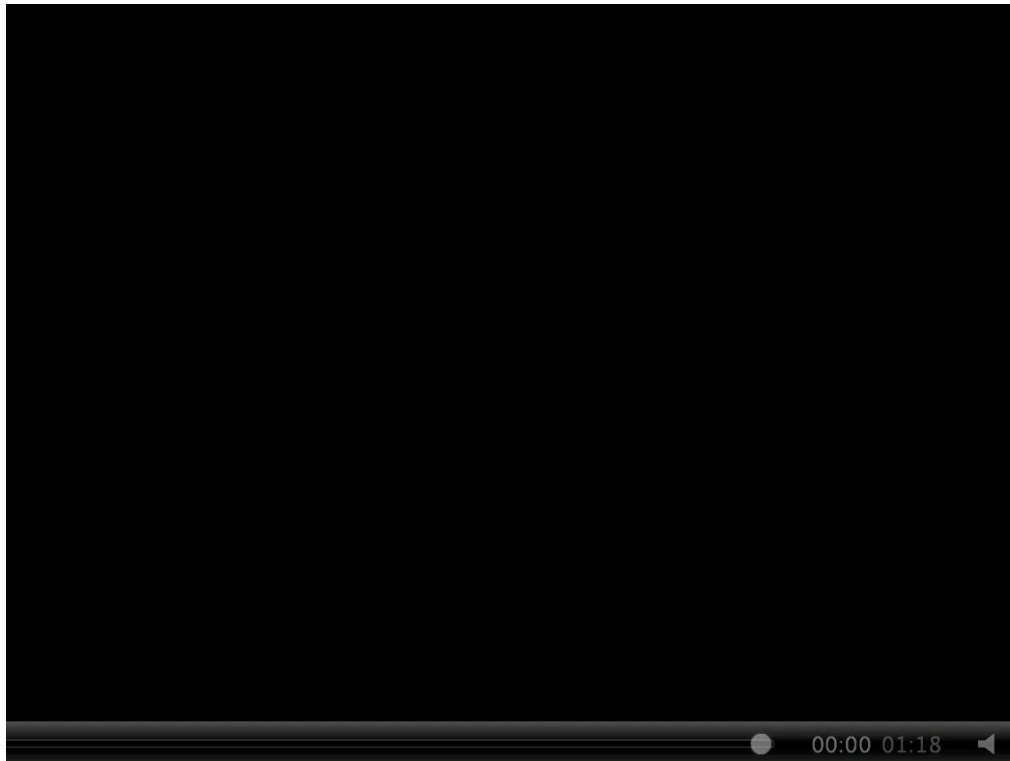
The Shepard-Risset Glissando

<https://www.youtube.com/watch?v=MShclPy4Kvc>

frequency



time



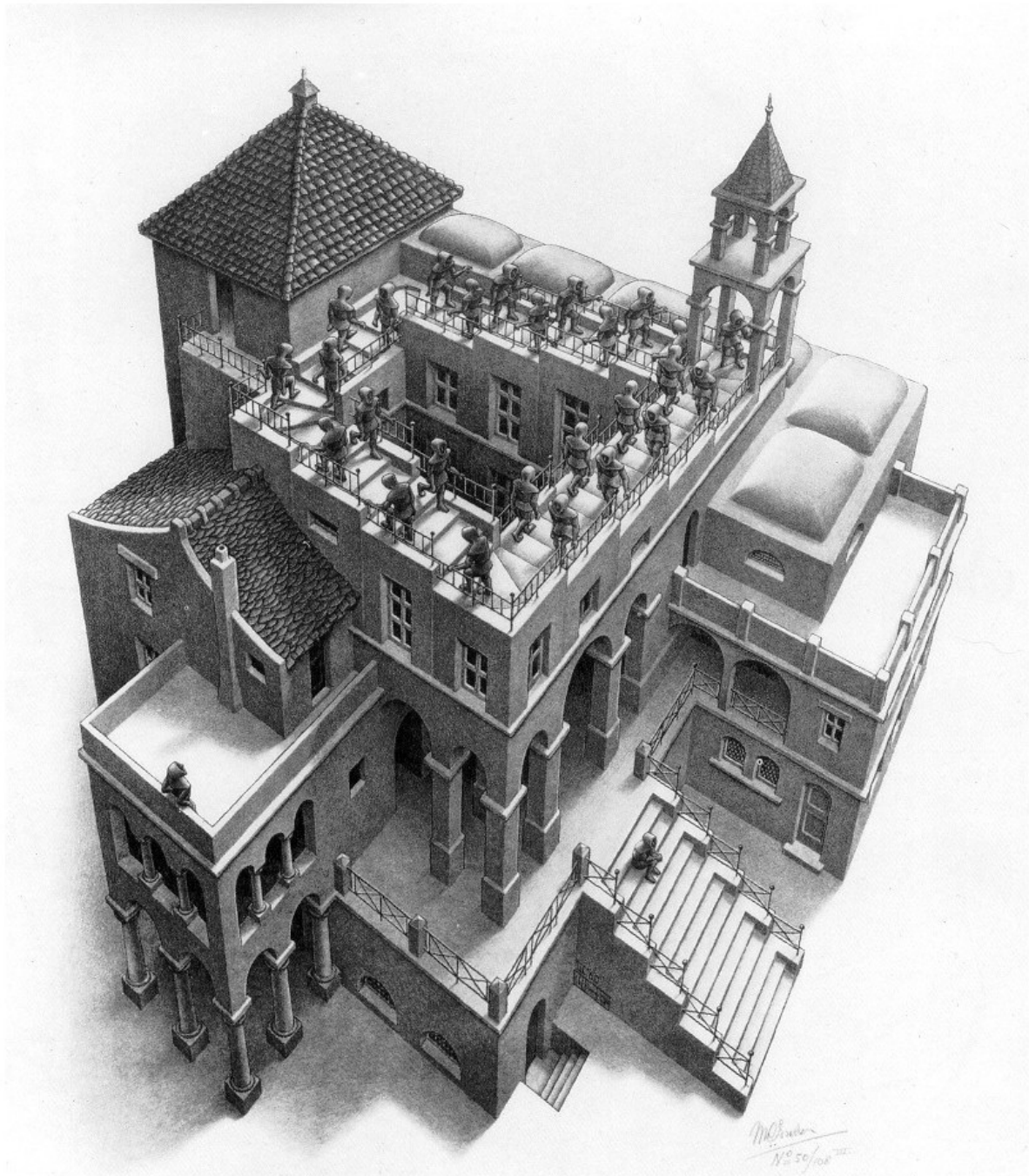
A Pair of Paradoxes utilizes two sensory illusions in one — the visual illusion called the Penrose Steps (popularized by MC Escher) of the endlessly climbing staircase, and the lesser-known audio correlation — the endlessly ascending tone, called a Shepard tone. Roger Shepard and Edward Zajac made this film in 1967. Zajac, a Bell scientist, is also credited with the very first computer-animated film.

The Penrose Steps were a visual trick discovered in 1958 by a family team, Lionel Penrose and his son Roger. The artist MC Escher used the technique to create his artwork *Kimmen en Dalen* (Ascending and Descending) in 1960. He followed it up with a similar work on the same theme in 1961, *Waterval* (Waterfall).

The Shepard Tone is a sound consisting of groups of sine waves separated by octaves, fading from one to the other and back again. It's an auditory illusion—and can be made in an ascending or descending version. It's been described as a "sonic barber's pole." This illusion is the 1964 invention of psychologist Roger Shepard, a cognitive specialist who worked at Bell Labs until 1966, when he went to Stanford as a psychology professor.

Footage courtesy of AT&T Archives and History Center, Warren, NJ

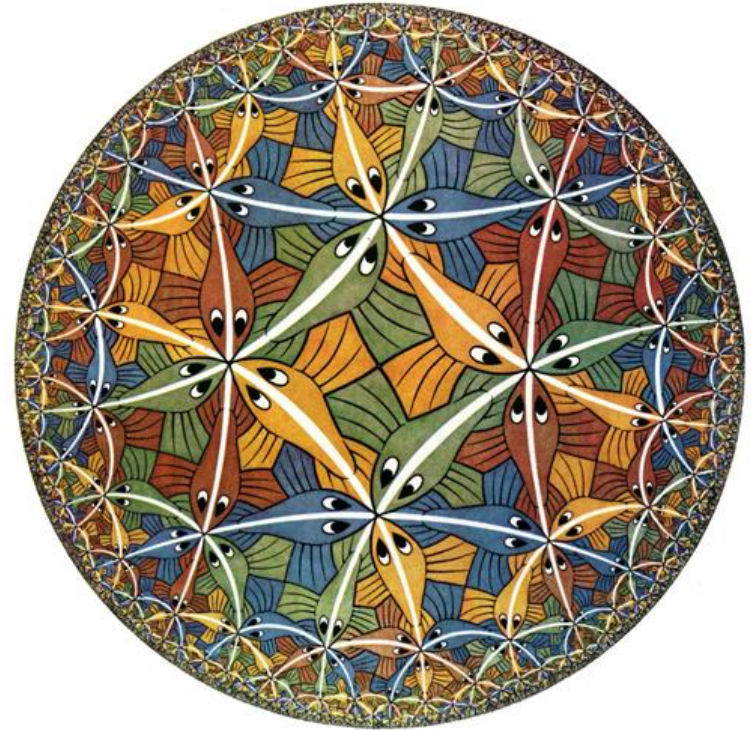
<http://techchannel.att.com/play-video.cfm/2011/10/10/AT&T-Archives-A-Pair-of-Paradoxes>



Ascending and Descending by M. C. Escher.



Maurits Cornelis Escher (17 June 1898 – 27 March 1972)
Self-portrait



Circle Limit III (1959), is one of a series of four woodcuts by Escher depicting ideas from hyperbolic geometry.

IMPOSSIBLE OBJECTS: A SPECIAL TYPE OF VISUAL ILLUSION

By L. S. PENROSE AND R. PENROSE

(University College, London, and Bedford College, London)

Two-dimensional drawings can be made to convey the impression of three-dimensional objects. In certain circumstances this fact can be used to induce contradictory perceptual interpretations. Numerous ideas in this field have been exploited by Escher (1954). The present note deals with one special type of figure. Each individual part is acceptable as a representation of an object normally situated in three-dimensional space; and yet, owing to false connexions of the parts, acceptance of the whole figure on this basis leads to the illusory effect of an impossible structure. An elementary example is shown in Fig. 1. Here is a perspective drawing, each part of which is accepted as representing a three-dimensional rectangular structure. The lines in the drawing are, however, connected in such a manner as to produce an impossibility. As the eye pursues the lines of the figure, sudden changes in the interpretation of distance of the object from the observer are necessary. A more complicated structure, not drawn in perspective, is shown in Fig. 2. As this object is examined by following its surfaces, reappraisal has to be made very frequently.

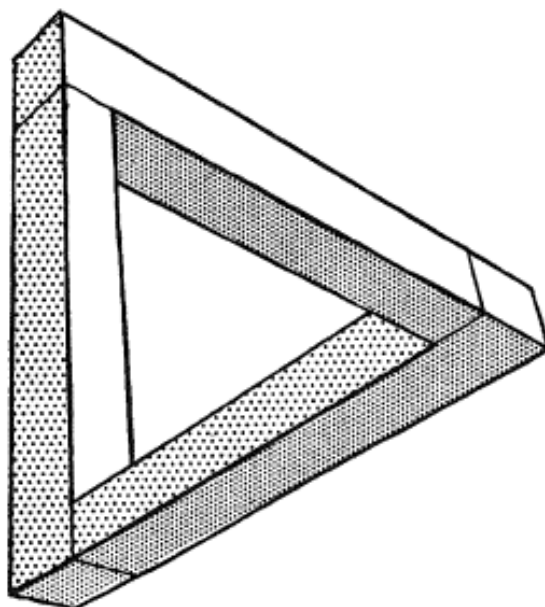


Fig. 1. Perspective drawing of impossible structure.

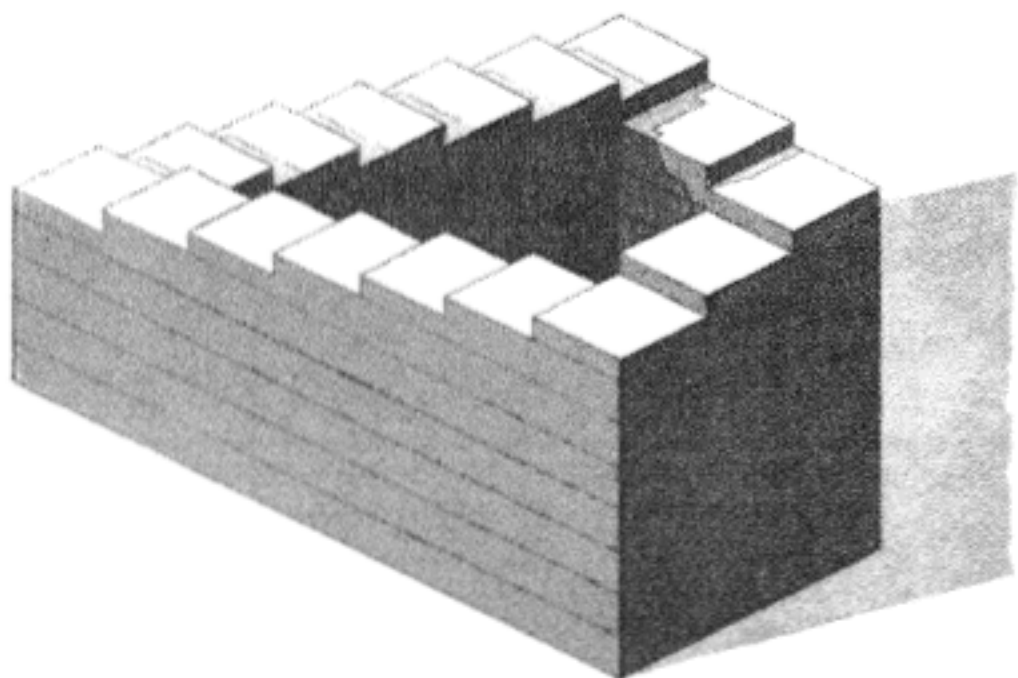


Fig. 3. Continuous flight of steps: shadowed drawing.

The Penrose stairs or Penrose steps, also dubbed the impossible staircase, is an impossible object created by Lionel Penrose and his son Roger Penrose. A variation on the Penrose triangle, it is a two-dimensional depiction of a staircase in which the stairs make four 90-degree turns as they ascend or descend yet form a continuous loop, so that a person could climb them forever and never get any higher. This is clearly impossible in three dimensions.

The "continuous staircase" was first presented in an article that the Penroses wrote in 1959, based on the so-called "triangle of Penrose" published by Roger Penrose in the *British Journal of Psychology* in 1958. M.C. Escher then discovered the Penrose stairs in the following year and made his now famous lithography *Klimmen en dalen* (Ascending and Descending) in March 1960. Penrose and Escher were informed of each other's work that same year. Escher developed the theme further in his print *Waterval* (Waterfall), which appeared in 1961.

In their original article the Penroses noted that "each part of the structure is acceptable as representing a flight of steps but the connexions are such that the picture, as a whole, is inconsistent: the steps continually descend in a clockwise direction."

At an Escher conference in Rome in 1985, Roger Penrose said that he had been greatly inspired by Escher's work when he and his father discovered both the tri-bar structure (i.e., the Penrose triangle) and the continuous steps, although Escher, in the 1950s, had not yet drawn any impossible figures and was not aware of their existence. Roger Penrose had been introduced to Escher's work at the International Congress of Mathematicians in Amsterdam in 1954. He was "absolutely spellbound" by Escher's work, and on his journey back to England he decided to produce something "impossible" on his own. After experimenting with various designs of bars overlying each other he finally arrived at the impossible triangle. Roger showed his drawings to his father, who immediately produced several variants, including the impossible flight of stairs. They wanted to publish their findings but didn't know in what field the subject belonged. Because Lionel Penrose knew the editor of *British Journal of Psychology* and convinced him to publish their short manuscript, the finding was finally presented as a psychological subject. After the publication in 1958 the Penroses sent a copy of the article to Escher as a token of their esteem.

While the Penroses credited Escher in their article, Escher himself noted in a letter to his son in January 1960 that he was:

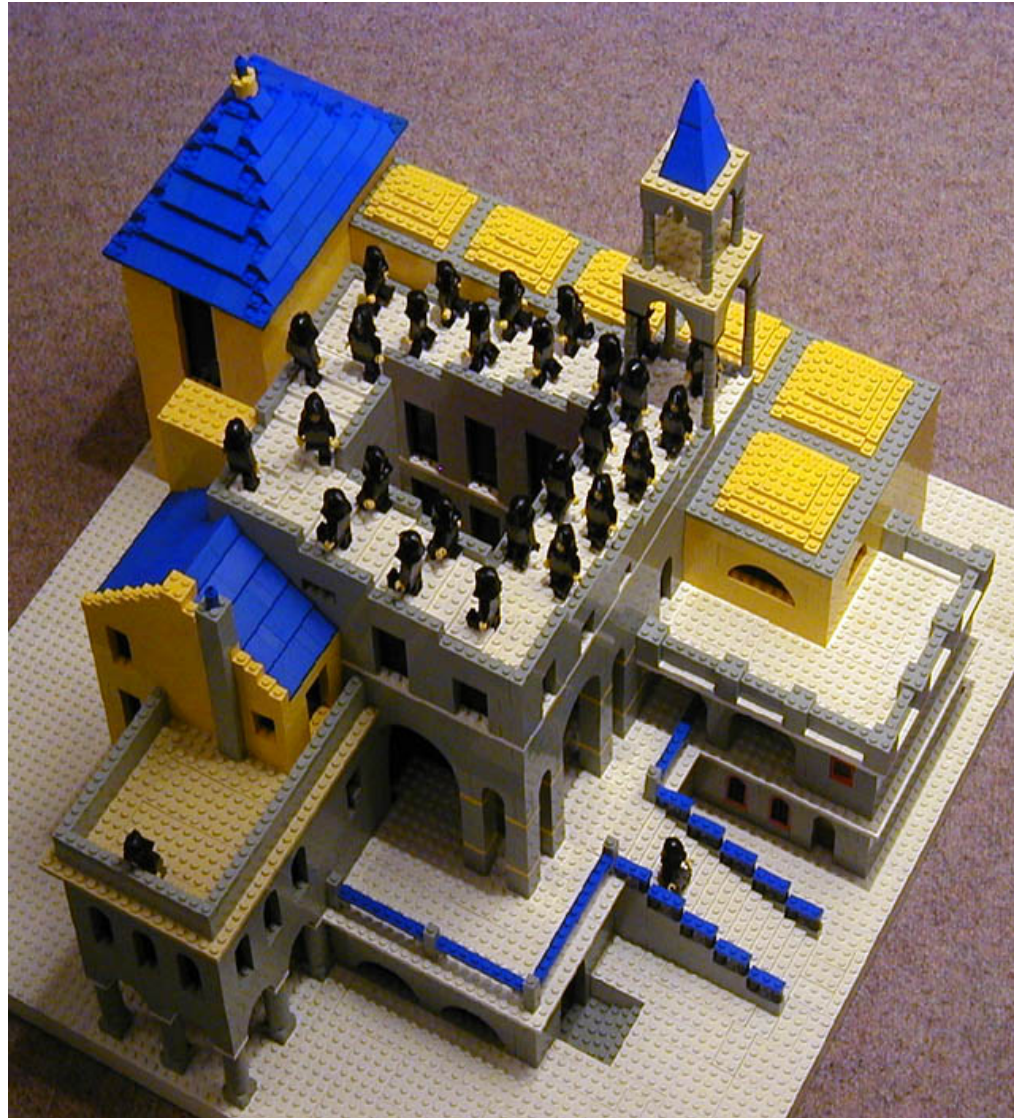
working on the design of a new picture, which featured a flight of stairs which only ever ascended or descended, depending on how you saw it. [The stairs] form a closed, circular construction, rather like a snake biting its own tail. And yet they can be drawn in correct perspective: each step higher (or lower) than the previous one. [...] I discovered the principle in an article which was sent to me, and in which I myself was named as the maker of various 'impossible objects'. But I was not familiar with the continuous steps of which the author had included a clear, if perfunctory, sketch, although I was employing some of his other examples.

Escher was captivated by the endless stairs and subsequently wrote a letter to the Penroses in April 1960:

A few months ago, a friend of mine sent me a photocopy of your article... Your figures 3 and 4, the 'continuous flight of steps', were entirely new to me, and I was so taken by the idea that they recently inspired me to produce a new picture, which I would like to send to you as a token of my esteem. Should you have published other articles on impossible objects or related topics, or should you know of any such articles, I would be most grateful if you could send me further details.

(from the Wikipedia article https://en.wikipedia.org/wiki/Penrose_stairs)

A LEGO bricks rendition ...



<http://www.andrewlipson.com/escher/ascending.html>

The Penroses

- James Doyle Penrose, (9 May 1862 – 2 January 1932) was an Irish painter.
- Lionel Sharples Penrose, (11 June 1898 – 12 May 1972) son of James, was a British psychiatrist, medical geneticist, mathematician and chess theorist.
- Sir Roland Algernon Penrose, (14 October 1900 – 23 April 1984) son of James, was an English artist, historian and poet. He was a major promoter and collector of modern art and an associate of the surrealists in the United Kingdom.[1] During the Second World War he put his artistic skills to practical use as a teacher of camouflage.
- Oliver Penrose, (born 1929) is a British theoretical physicist. He is the son of the scientist Lionel Penrose, brother of the mathematical physicist Roger Penrose, and brother of chess master Jonathan Penrose. His areas of interest include statistical mechanics, phase transitions in metals and physical chemistry of surfactants. He is particularly known for the concept of off-diagonal long-range order, which is central to our present-day understanding of superfluids and superconductors. Other more abstract topics in which he has worked include understanding the physical basis for the direction of time and interpretations of quantum mechanics.
- Sir Roger Penrose, (born 8 August 1931) is an English mathematical physicist, mathematician and philosopher of science. He is the son of the scientist Lionel Penrose, brother of the theoretical physicist Oliver Penrose, and brother of chess master Jonathan Penrose. He is known for his work in mathematical physics, in particular for his contributions to general relativity and cosmology. He has received several prizes and awards, including the 1988 Wolf Prize for physics, which he shared with Stephen Hawking for their contribution to our understanding of the universe.
- Jonathan Penrose, (born 7 October 1933, in Colchester) is an English chess Grandmaster and International Correspondence Chess Grandmaster (1983) who won the British Chess Championship ten times between 1958 and 1969. He is the son of Lionel Penrose, a world famous professor of genetics, the grandson of the physiologist John Beresford Leathes, and brother of Roger Penrose and Oliver Penrose. He is a psychologist and university lecturer by profession.
- Shirley Victoria Hodgson, (née Penrose, born 22 February 1945) is a British geneticist. She is Professor of Cancer Genetics at St George's, University of London.

Diana Deutsch's Scale Illusion

<https://www.youtube.com/watch?v=XS7IAcsRcgA>

