Analog Representations of Sound

Magnified phonograph grooves, viewed from above:

When viewed from the side, channel 1 goes up and down, and channel 2 goes side to side.
Analog to Digital Recording Chain

Microphone converts acoustic to electrical energy. It’s a transducer.

Continuously varying electrical energy is an analog of the sound pressure wave.

ADC (Analog to Digital Converter) converts analog to digital electrical signal. Digital signal transmits binary numbers.

DAC (Digital to Analog Converter) converts digital signal in computer to analog for your headphones.
Analog versus Digital

Analog
Continuous signal that mimics shape of acoustic sound pressure wave

Digital
Stream of discrete numbers that represent instantaneous amplitudes of analog signal, measured at equally spaced points in time.
Analog to Digital Conversion

Instantaneous amplitudes of continuous analog signal, measured at equally spaced points in time.

A series of “snapshots”
Analog to Digital Overview

Sampling Rate
How often analog signal is measured
[samples per second, Hz]
Example: 44,100 Hz

Sampling Resolution
[a.k.a. “sample word length,” “bit depth”]
Precision of numbers used for measurement: the more bits, the higher the resolution.
Example: 16 bit
Sampling Rate

Determines the highest frequency that you can represent with a digital signal.

**Nyquist Theorem:**

Sampling rate must be at least twice as high as the highest frequency you want to represent.

Capturing just the crest and trough of a sine wave will represent the wave exactly.
Aliasing

What happens if sampling rate not high enough?

A high frequency signal sampled at too low a rate looks like ...

... a lower frequency signal.

That’s called **aliasing** or **foldover**. An ADC has a low-pass **anti-aliasing filter** to prevent this. Synthesis software can cause aliasing.
Common Sampling Rates

Which rates can represent the range of frequencies audible by (fresh) ears?

<table>
<thead>
<tr>
<th>Sampling Rate</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>44.1 kHz (44100)</td>
<td>CD, DAT</td>
</tr>
<tr>
<td>48 kHz (48000)</td>
<td>DAT, DV, DVD-Video</td>
</tr>
<tr>
<td>96 kHz (96000)</td>
<td>DVD-Audio</td>
</tr>
<tr>
<td>22.05 kHz (22050)</td>
<td>Old samplers</td>
</tr>
</tbody>
</table>

Most software can handle all these rates.
3-bit Quantization

A 3-bit binary (base 2) number has $2^3 = 8$ values.

A rough approximation

Amplitude

Time — measure amp. at each tick of sample clock

A rough approximation
A 4-bit binary number has $2^4 = 16$ values.

4-bit Quantization

A better approximation

Time — measure amp. at each tick of sample clock
Quantization Noise

Round-off error: difference between actual signal and quantization to integer values...

Random errors: sounds like low-amplitude noise
The Digital Audio Stream

It’s just a series of sample numbers, to be interpreted as instantaneous amplitudes: one for every tick of the sample clock.

Previous example:

11 13 15 13 10 9 6 1 4 9 15 11 13 9

This is what appears in a sound file, along with a header that indicates the sampling rate, bit depth and other things.
<table>
<thead>
<tr>
<th>Word length</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-bit integer</td>
<td>Low-res web audio</td>
</tr>
<tr>
<td>16-bit integer</td>
<td>CD, DAT, DV, sound files</td>
</tr>
<tr>
<td>24-bit integer</td>
<td>DVD-Video, DVD-Audio</td>
</tr>
<tr>
<td>32-bit floating point</td>
<td>Software (usually only for internal representation)</td>
</tr>
</tbody>
</table>
16-bit Sample Word Length

A 16-bit integer can represent $2^{16}$, or 65,536, values (amplitude points).

We typically use **signed** 16-bit integers, and center the 65,536 values around 0.
Audio File Size

CD characteristics...

- Sampling rate:
  44,100 samples per second (44.1 kHz)

- Sample word length:
  16 bits (i.e., 2 bytes) per sample

- Number of channels:
  2 (stereo)

How big is a 5-minute CD-quality sound file?
Audio File Size

How big is a 5-minute CD-quality sound file?

44,100 samples * 2 bytes per sample * 2 channels
= 176,400 bytes per second

5 minutes * 60 seconds per minute
= 300 seconds

300 seconds * 176,400 bytes per second
= 52,920,000 bytes = c. 50.5 megabytes (MB)