5 – Resonance in sound production

General role of resonance

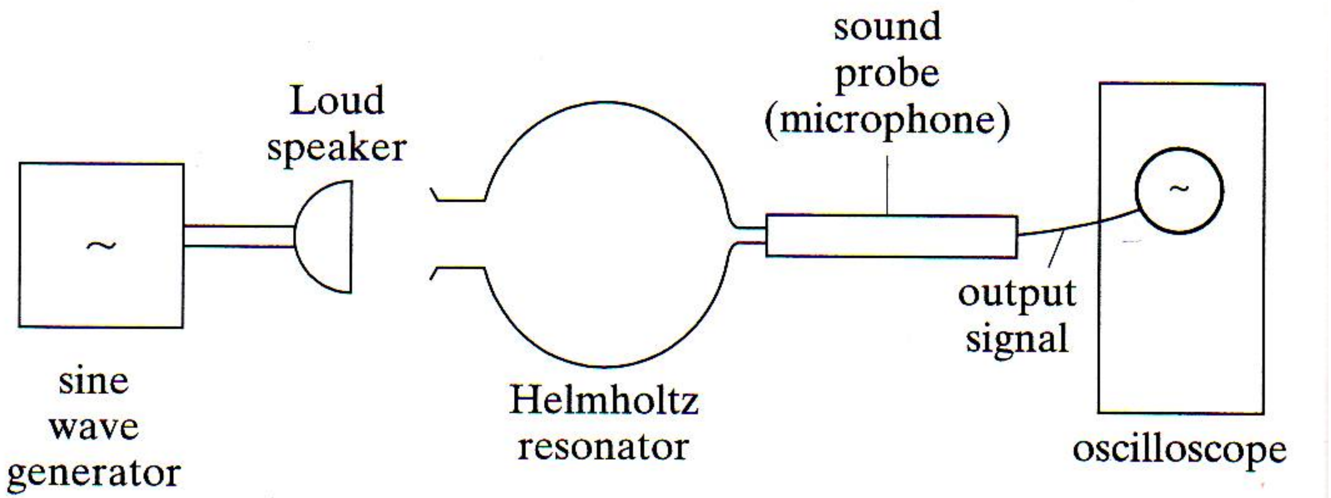
We have seen that in music instruments and other systems a particular set of standing waves (or vibrations modes) are allowed, the fundamental and the harmonics. This, of course, implies that there are resonances in the system. If an external perturbation at some frequency is applied, the system will respond by vibrations, and the response (the vibration amplitude) is high if the frequency of the external perturbation is close to the frequency of one of the system‘s vibration modes. In the case of a broadband external perturbation has a wide Fourier spectrum, that is, it is a superposition of oscillations or waves with all possible frequencies (like noise), the system will respond by vibrating at all its allowed frequencies. That is, the system can „select“ proper frequencies out of noise. For instance, if we shout at a guitar without a particular pitch, we will see that guitar strings are vibrating afterwards with their own frequencies.

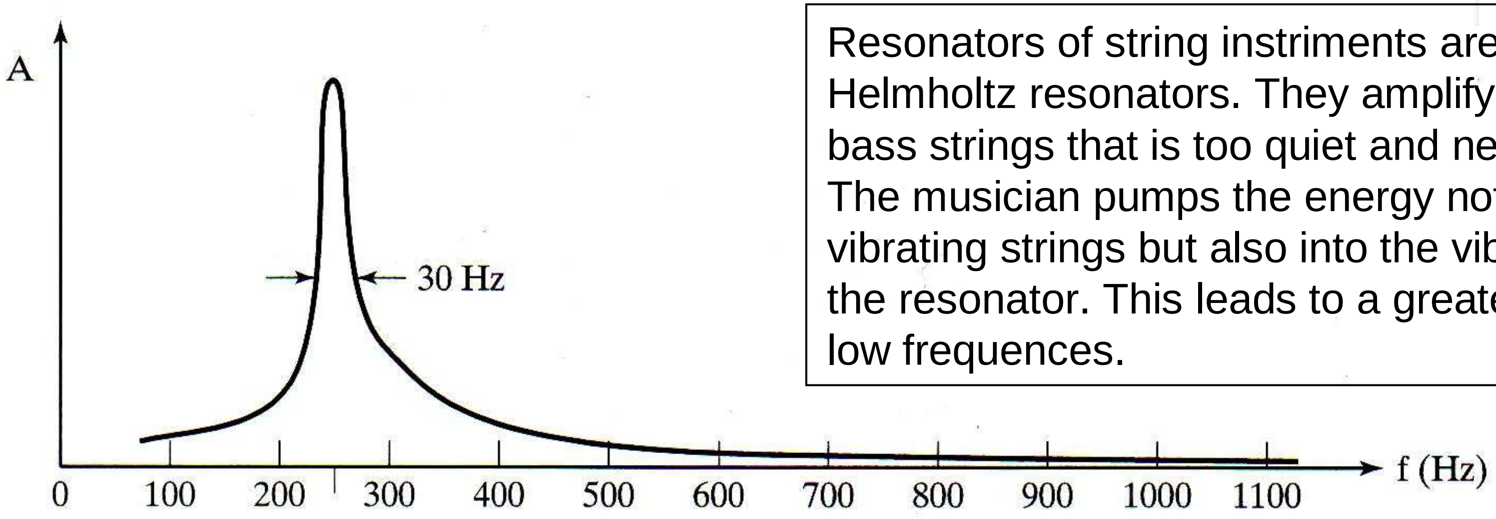
Practical application of resonance in the sound production is three-fold:

- Amplify the sound (Resonators in string instruments amplify the sound produced by strings)
- Shape the sound by selecting particular regions out of broadband spectrum (Throat, mouth, and nasal cavities act as resonators in shaping formants out of a broadband signal produced by voice bands)
- Create the sound (Blowing into whistles and wind instruments make them sound if the blowing strength exceeds some threshold – the most complicated case in sound production)

Amplifying resonators

Cavities with all dimensions close to each other (such as boxes with comparable sides) posess a single resonance or a group of resonances that responds in some range of frequences. An example if the Helmholtz resonator that is a spherical cavity with holes for sound input and output.





Resonators of string instriments are similar to Helmholtz resonators. They amplify the sound of bass strings that is too quiet and needs amplification. The musician pumps the energy not only into the vibrating strings but also into the vibrating air inside the resonator. This leads to a greater sound output at low frequences.

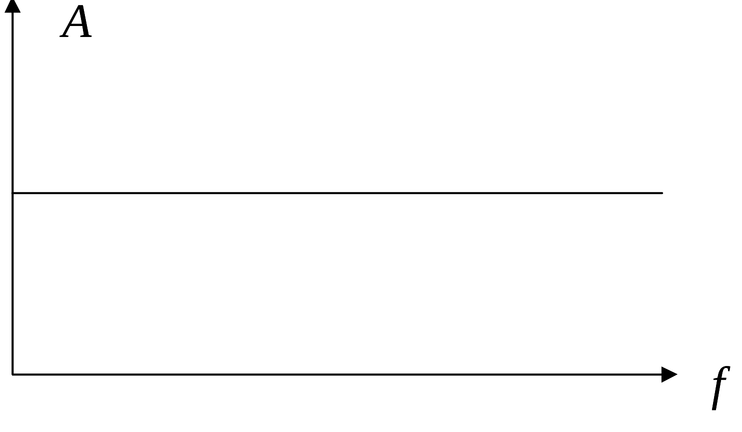
Shaping resonators, noise

As said above, resonators can shape the sound, that is, emphesize some regions of the spectrum and suppress the others. The input is a broadband signal. The extreme case of the broadband signal is noise, and the extreme case of the noise is the so-called while noise.

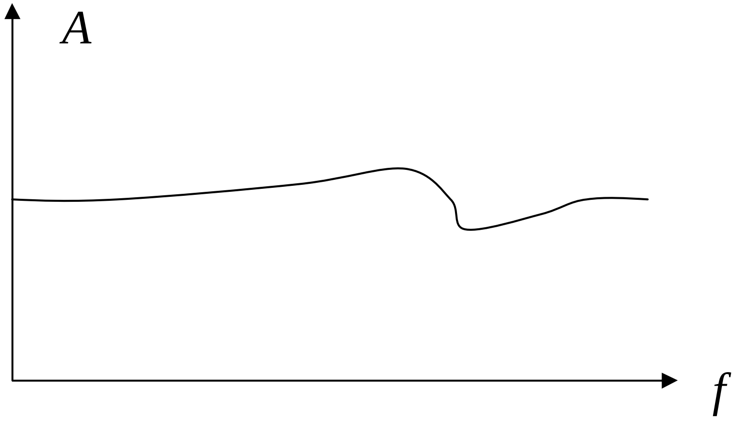
Noise in general is a superposition of signals with all possible frequences that are not overtones of some fundamental. With increasing the number of different signals in a superposition, any complex sigal becomes a noise, and the individial spikes in its Fourier spectrum cannot be resolved. That is, the Fourier spectrum of a noise is quasicontinuous.

White noise is the noise whose Fourier spectrum can be plotted as a horizontal line without any spikes, maxima, and minima. Noise whose Fourier spectrum is not a straight horizontal line is called „colored“ noise.

Fourier spectrum of the white noise (idealized)



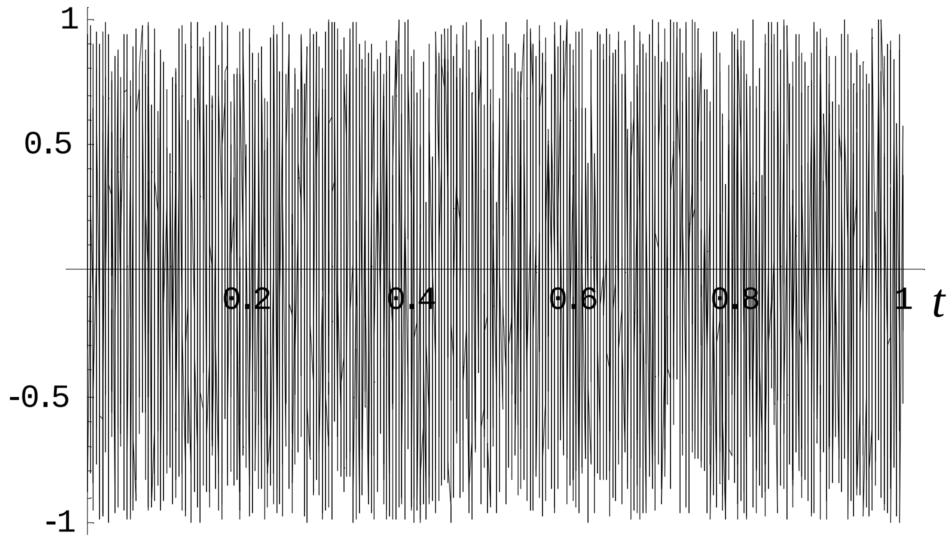
Fourier spectrum of the colored noise (idealized)



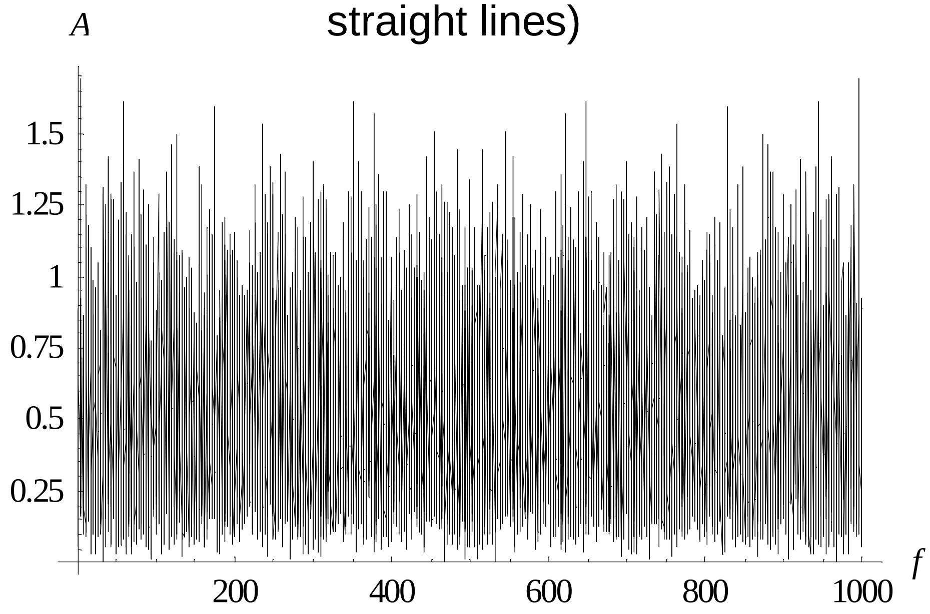
Real white noise

In the previous page an idealized description of the white noice was given. In reality it is more complicated. Here is the white noise generated by Wolfram Mathematica that is a function taking random values in the interval [-1,1]. Its Fourier spectrum looks similarly jagged, it is not a straight horizontal line, although one can argue that on average it goes horizontally.

A white-noise signal

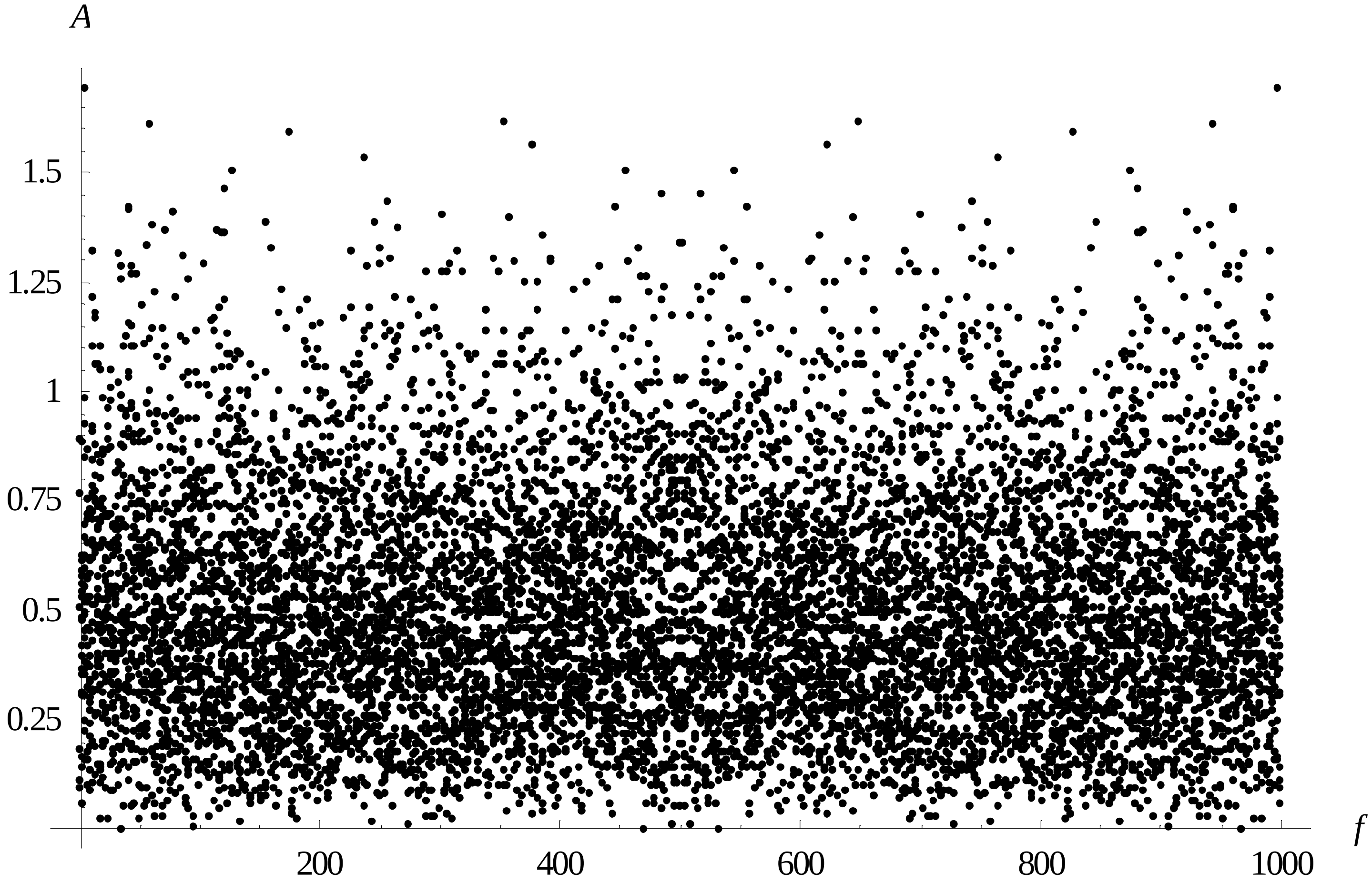


Its Fourier spectrum (points connected by straight lines)



The same applies to the colored noise: The Fourier spectrum of noise is always jagged, not smooth.

Here is another, even more striking form of the representation of the Fourier spectrum of the white noise on the preceding page with pure points, not connected by straight lines. One can see that it is a random function, too, like the original white-noise signal. This Fourier spectrum was obtained by using 10000 points along the frequency axis.

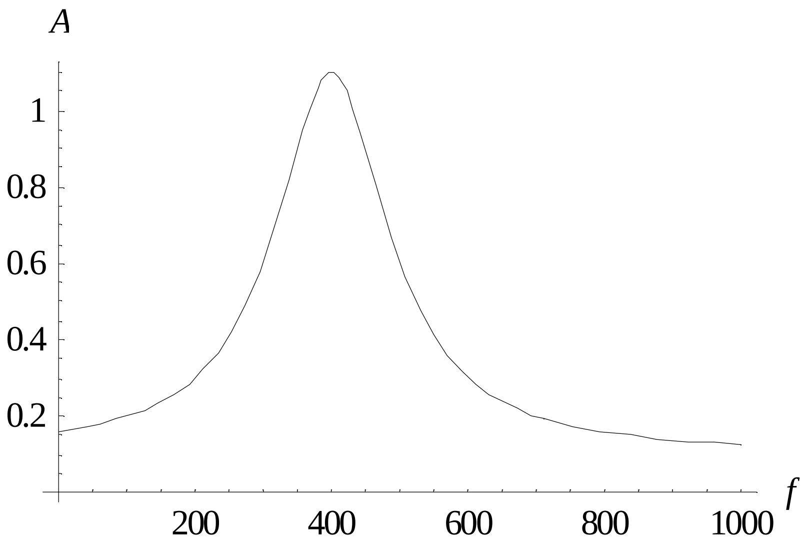


Note: In wave editors like Audacity, the Fourier spectra of sounds are smoothed (that is, averaged over some small frequency range around any particular frequency) for a nicer presentation. As a result, the Fourier spectrum of the noise looks like the idealized Fourier spectrum above.

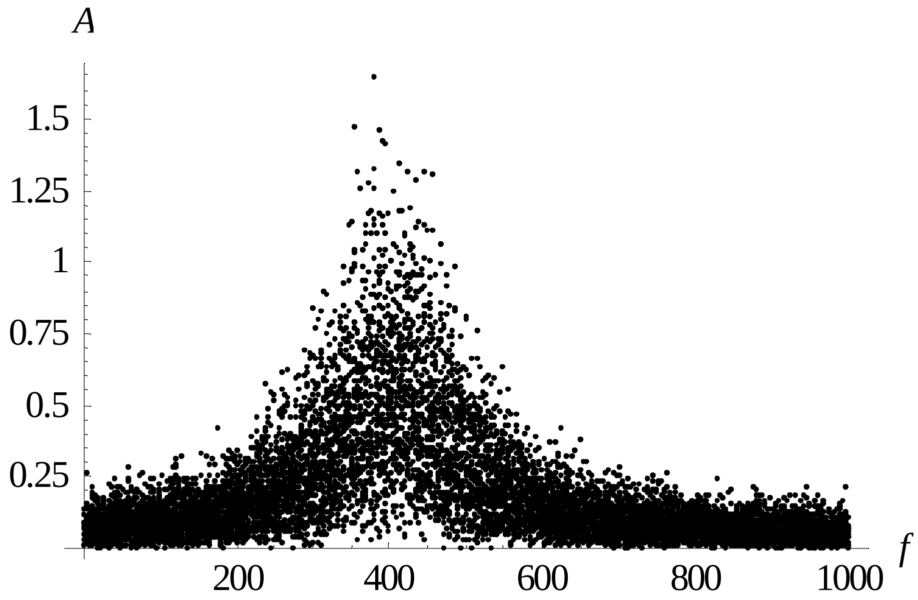
Filtering of a white noise by a resonator

When a broadband signal is sent into a resonator, the Fourier spectrum of the output signal is the product of the Fourier spectrum of the input signal and the resonance curve of the resonator. Below are shown a resonance curve of a resonator with only one resonance (like the Helmholtz resonator) and the Fourier spectrum of the output signal if the input signal is a white noise on the preceding page:

Resonance curve of a resonator



Fourier spectrum of the output (filtered) signal with the white-noise input



The output signal is not the white noise but a colored noise. It has a maximum at the resonance frequency (here f_0=400 Hz), so that the ear can hear this frequency above the hiss.

Filtering of other kinds of the broadband noise by a resonator

An example is filtering of the pulse-train signal produced by our voice bands (the so-called glottal wave) by our throat, mouse, and nasal cavities. This will be considered in more detail in the next lecture.

Creation of sound in whistles and wind instruments

This is a complicated topic, as creation of sound in this case is not just filtering of the input sound, typically a hiss of the blown air that splits on the sharp edge of the whistle. To the contrary, the sound is produced only if the intensity of blowing exceeds some threshold value. Usually after that the sound at the fundamental frequency is generated. If the intensity of blowing further increases, the sound can deteriorate and become a hiss. However, if the blowing strength increases further, the sound corresponding to the second or third harmonic of the fundamental can be produced, and this sound can be much louder than the initial fundamental sound. The physical explanation of such a behavior depends on the details of the particular wind instrument. This will be discussed later.