What is the Doppler-Effect and why is it so disturbing for a good listening experience?

Summary:

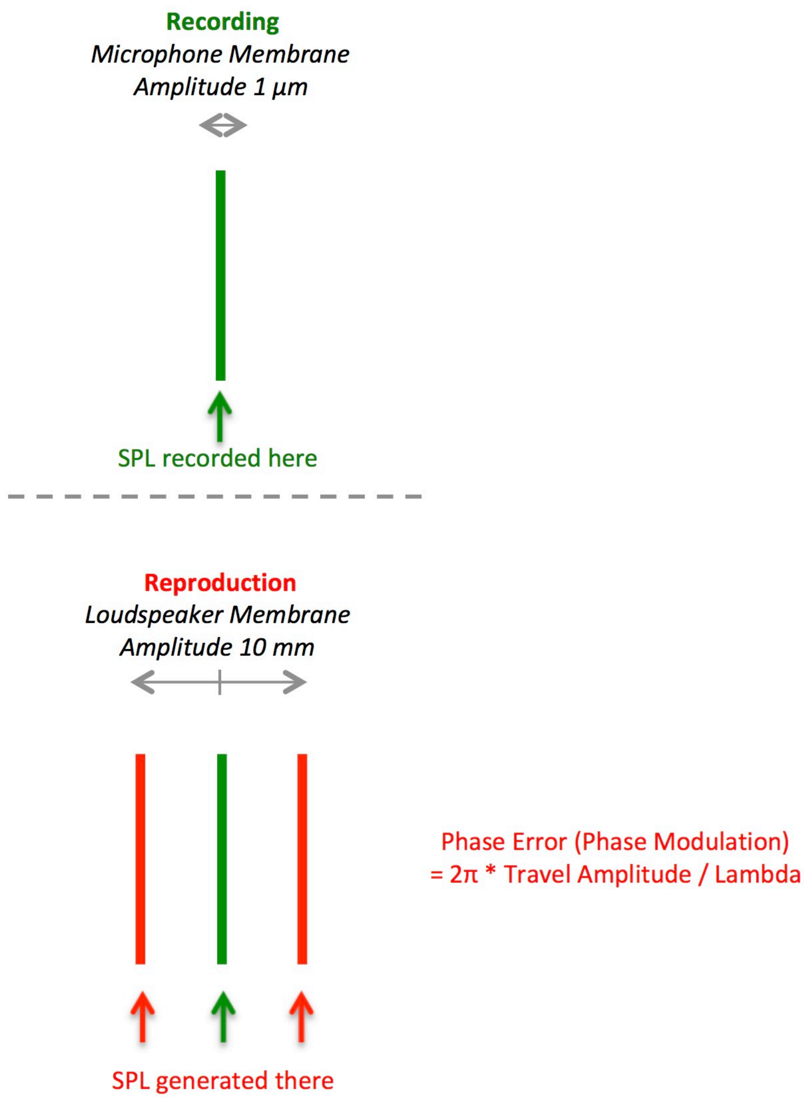
Each moving loudspeaker membrane generates, because of the varying distance to the listener, a phase modulation a.k.a. Doppler-Effect. The generated frequency components are non-harmonic and very disturbing to a good listening experience. AudioChiemgau offers an analogue audio processor (AAP), which eliminates the phase modulation of the moving loudspeaker membrane completely. This analogue signal processor is advantageous combined with a motion feed back system (MFB) for the loudspeaker which removes the non-linearity of the mechanical system and allows the lower corner frequency to be selected at will, e.g. at 16 Hz. The resulting product is then unique on the market.

What is the Doppler-Effect:

During a recording session high quality condenser microphones are used. They convert the sound pressure by tiny movements of their membranes into voltages, which are then further amplified and mixed down. The amplitude of the movement of the microphone membrane is in the order of 1 µm. One can assume that the sound pressure is recorded at exactly one point in the sound field.
During the reproduction of the sound the loudspeaker membrane needs to move significantly to reproduce especially deep notes with sufficient sound pressure. The amplitude of that movement lies in the order of 5 to 10 mm.
What happens to the sound, when it is reproduced at different positions by the speaker membrane contrarily to the recording situation?

Let us do a mental experiment: A deep note is reproduced with an amplitude of the loudspeaker membrane of e.g. 10mm. The membrane moves back and forth by that amplitude and changes the distance to the listener periodically by ± 10mm.
We add now a high note to that sound. It becomes immediately clear, that the high note is reproduced periodically at different distances to the listener by the moving speaker membrane. That creates the well-known effect, that C. Doppler, an Austrian scientist described: When the speaker membrane moves towards the listener, the high note changes its original frequency to a higher frequency and when the speaker membrane moves away from the listener, the frequency of the high note gets lower than its original frequency. Everybody has made this experience when a police car with its siren is approaching and leaving – the siren frequency changes heavily from a higher tone to a lower tone.

The above-described effect does not only exist for the high note, but for each frequency, which a moving loudspeaker membrane reproduces. In fact this is a Phase Modulation (PM) created by the different distances at which the sound is reproduced with respect to the listener. The figure below illustrates that effect.



Why is the Doppler-Effect so disturbing for a good listening experience?

Even a very well designed loudspeaker shows a certain non-linearity. This non-linearity mixes all frequency components, which are reproduced, and creates in this way alias frequencies.
Well known are the harmonic distortions, which are often played down with the argument, that each music instrument shows a certain harmonic frequency content already.
Less well known, but simultaneously created are the intermodulation products, frequency components that are non-harmonic and therefore significantly disturbing.
The non-linearity of a loudspeaker can be very well and significantly reduced by motion feedback (MFB) systems, a technology that AudioChiemgau offers for High-End users. The movement of the speaker membrane is exactly measured, compared whit the driving signal and continuously corrected. That motion feedback system works at the speed of light and reduces all non-linearity-caused distortions to an un-audible level.

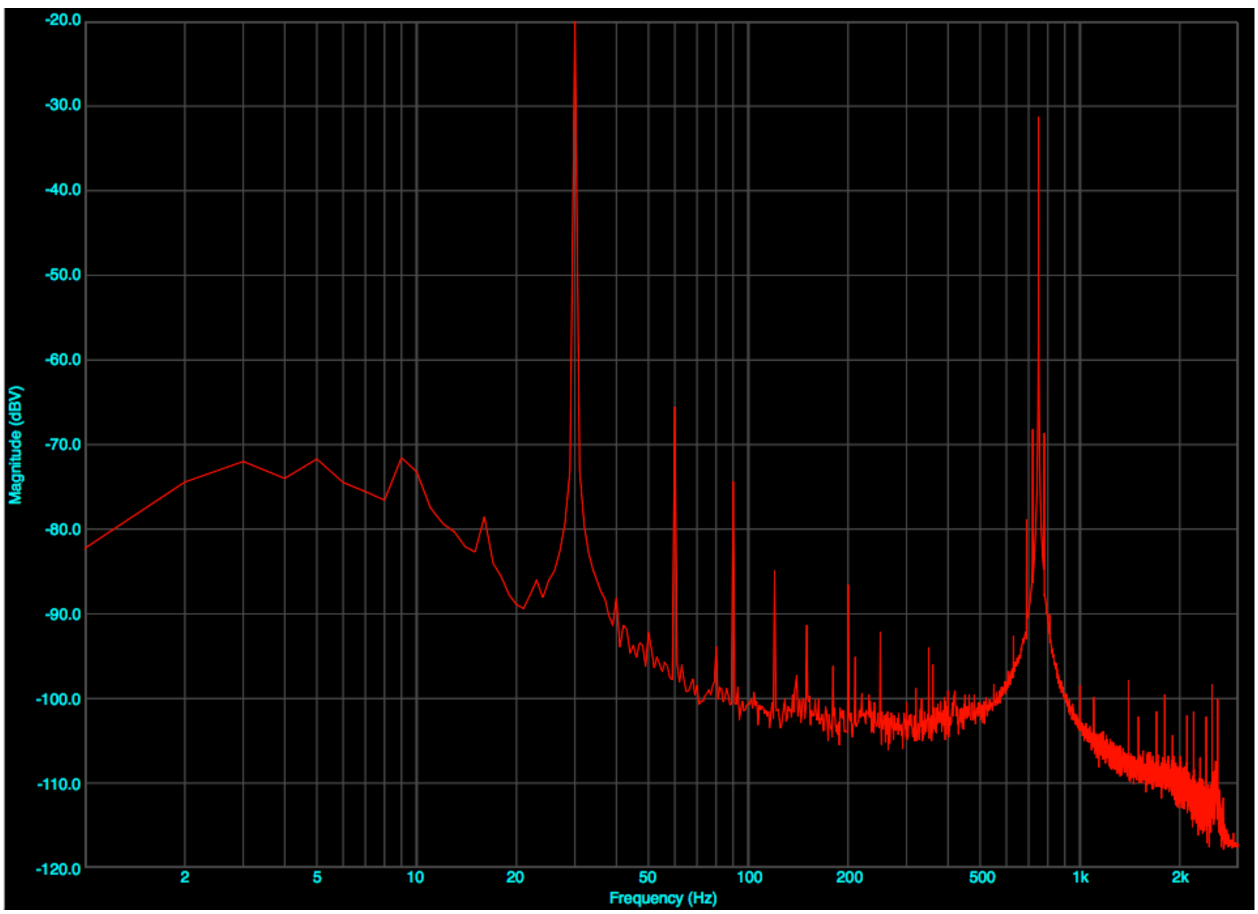
However, there remains the phase modulation created by the movement of the loudspeaker membrane, which is a well audible distortion. This is a physical effect, which would be created even by an ideal loudspeaker as the membrane moves.

The Doppler-Effect creates spectral lines (frequencies) which are e.g. the sum and the difference of the different frequencies contained in the sound. Mathematical this is described by the Bessel functions. These newly created frequency components are non-harmonic and therefore highly disturbing. This answers the question asked in the headline.

Acoustic measurement:

The acoustic spectrum below shows the Doppler effect, when a 30 Hz tone with 80% amplitude and a 750 Hz tone with 20% amplitude are reproduced by a loudspeaker with total membrane amplitude of 2 mm.

The 30 Hz tone is adjusted to -20 dB (top of the spectrum plot). The 750 Hz tone is at -12 dB corresponding to the 20/80 ratio. Next to the 750 Hz tone the Doppler lines at frequency distances of – 30 Hz and + 30 Hz are well visible. They are in this example 37 dB below the amplitude of the 750 Hz tone disturbing significantly a good listening experience.



How to eliminate the Doppler-Effect?

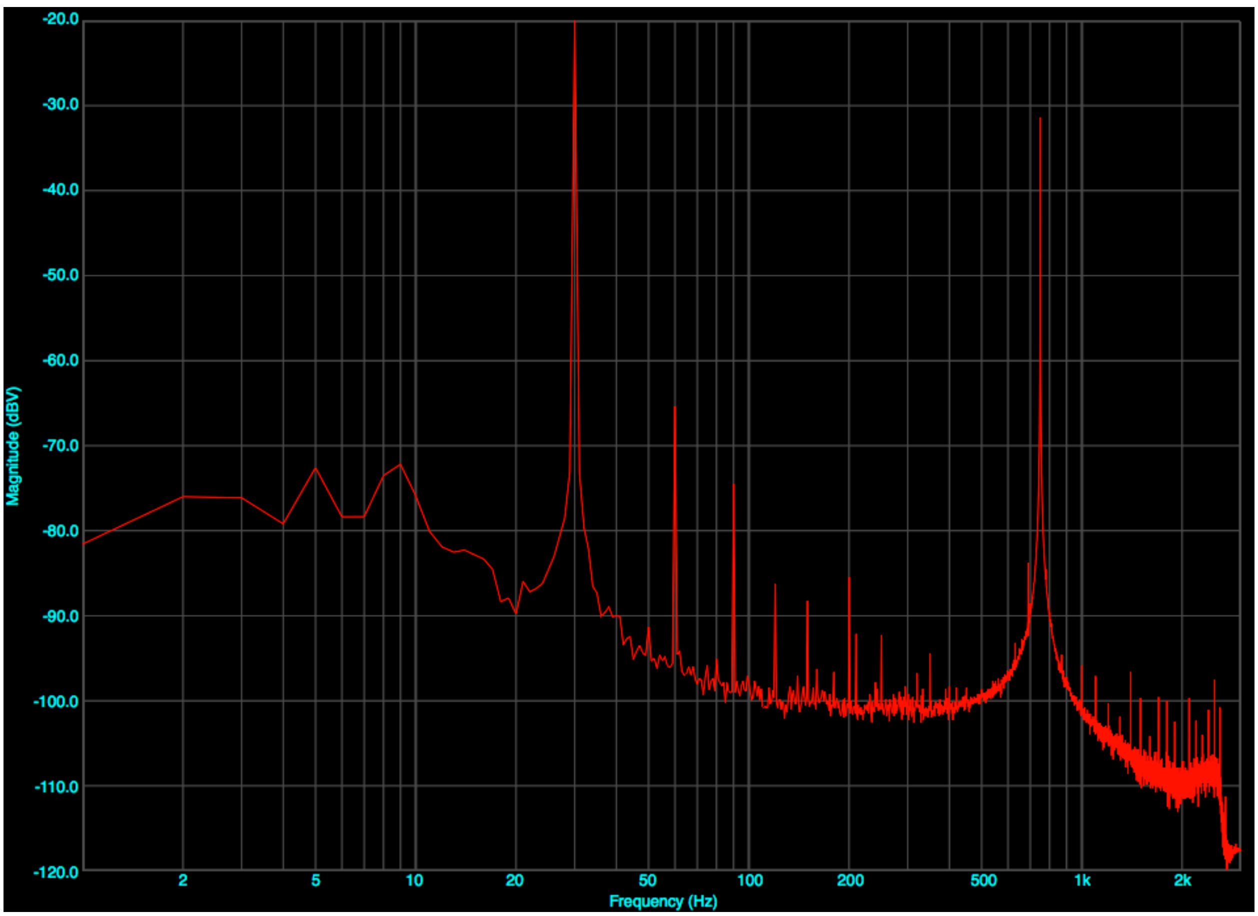
There are two ways to get rid of the Doppler-lines:

1. One uses a very large area loudspeaker membrane with an amplitude equal to the recording amplitude – i.e. 1 µm. This is obviously not very practicable.

2. One calculates continuously and precisely the position of the membrane at any point in time and compensates the phase modulation created by the varying distance to the listener by an inverse phase modulation of the electrical signal feeding the loudspeaker. That is a practical solution, which AudioChiemgau puts into practise completely in the analogue signal domain.

The second acoustic spectrum below demonstrates this compensation of the Doppler-Effect. The two Doppler-lines at 750 Hz ± 30 Hz are completely gone. The Doppler-compensation works perfectly.

In both acoustic spectra there are the same harmonic spectral lines visible of the 30 Hz tone with 2 mm Membrane amplitude: K_2 at -45 dB and k_3 at -55 dB. This extremely high linearity of the loudspeaker is accomplished by the applied motion feed back (MFB) technology (the original resonance frequency of the loudspeaker in this example is 70 Hz).



A Question and its Answer:

Why has this Doppler compensation never be done in the past – even by the most well known manufacturers of Hi-End loudspeakers?
The answer to the question lies in the fact, that only motion feed back speakers achieve sufficient linearity even at very low frequencies, which do not mask the Doppler spectral lines. Even High-End speakers of well-known manufacturers show non-linear distortion in the 50% range when low frequencies are to be reproduced at sufficient sound pressure level. Those extreme distortions would mask the Doppler lines, as intermodulation products show inter alia the same frequency components.
A top performance speaker needs both, the motion feed back (MFB) as well as the Doppler compensation. The resulting product is best of class and unique on the market.

AudioChiemgau offers both: Motion Feed Back systems for loudspeakers and the Doppler compensation as one of several processing elements of their Analogue Audio Processor.