listener should be similar, not deviating by more than 20–30 cm, which is normally not a problem in loudspeaker design.

- Group delay changes have to be about 3–5 ms with speech and music before they can be perceived. If the changes are of the order of 5–10 ms, they begin to be detectable if the effect of the listening room is minimal. With some phase-insensitive signals, such as noise or diffuse sound, changes in group delay may not be perceived even with longer delays.
- Although the changes in group delay may be perceived as changes in the timbre of sound, the effect on communication, or on speech intelligibility, can be small. For example, even 100-ms group delay changes can be introduced into speech signals before intelligibility starts to vanish.

If the group delay introduced by a communication channel is not smooth with frequency, and has abrupt phase delay differences in adjacent frequencies, the above-mentioned rules no longer apply. One such typical response is reverberation, where, at frequencies over the critical frequency (see Section 2.4.4), the phase response behaves randomly. In practice, most of the phase-related effects are not audible at all in reverberant conditions. When a buzzy signal is filtered with such a random phase response, the buzzyness vanishes, and the firing rate spectrogram resembles the lower-right plot in Figure 11.11. If the phase delay is changed at one frequency in such a case, almost invariably, no audible changes are introduced. In other words, a phase-sensitive signal can be made phase-insensitive by adding the effect of room reverberation to it.

In anechoic listening to buzzy signals, minimal changes in group delays may be audible. This has already been demonstrated with a sawtooth wave, modified by a group delay smooth with frequency, but containing local abrupt change. In the top-left and top-right cases in Figure 11.11, the amplitude spectra are otherwise equal, but the phase of one harmonic has been reversed. This corresponds to applying a group delay of only 0.32 ms at 3100 Hz and none at other frequencies, making that frequency much louder. Such frequency-dependent variations in an otherwise smooth group delay can thus have a large effect during anechoic or headphone listening.

11.6 Psychoacoustic Concepts and Music

Music is a form of art which is composed of sound and silence. It is an art communicated through hearing, and the relations of musical sounds to psychoacoustics are interesting here. The sounds used in music have diverse dimensions, and many of these dimensions are related to psychoacoustics and to the theory of hearing. Some of the phenomena in music can be directly explained by results obtained from psychoacoustics.

This section contains a discussion on two psychoacoustic views of music in two specific perspectives: melody and harmony, and rhythm. Note that in music, terms like consonance, dissonance, and rhythm are very complex and depend on the style of music, and the discussion in this book is therefore limited to only a 'sensory' perspective.

11.6.1 Sensory Consonance and Dissonance

A musical note, simply a 'note' in the following, is defined as a sound that evokes pitch and has a defined duration. This is a somewhat restrictive definition, since it excludes, for example, drum sounds. However, for simplicity, a note is here defined to be a complex harmonic tone