Doppler Simulation and the Leslie

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Overview

- The Leslie
- Doppler and Leslie effect
- Leslie measurements
- Leslie effect simulation
- Doppler simulation
- Conclusions, future work.

The Leslie cabinet

- The Leslie is an audio processor used with electronic organs and other instruments.
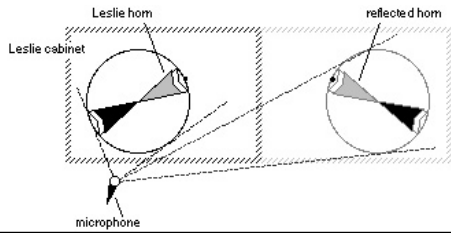

Leslie's cabinet (back)

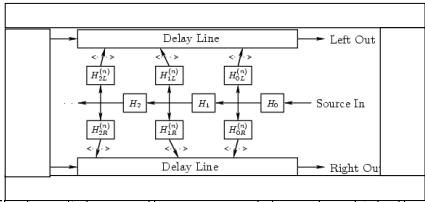
The Leslie and Doppler effect

- A moving source creates a Doppler shift.
- Multiple, differently Doppler shifted paths from the horn to the microphone.

Leslie simulation

- Block diagram of a stereo multiple-source simulation.

- The horn-listener paths are separately rendered into three components: 1) Leslie signal path equalization 2) cabinet wall reflection filtering 3) horn radiation pattern 4) time varying delay.

Leslie simulation (ctn.)

- To obtain a precise Doppler simulation, we use time-varying delay lines.
- Time varying delays simulate Doppler shift caused by motion of the source when the delay growth rate -vm/c, where vm is the speed of the source, is set to the speed of the listener away from the source, normalized by the sound speed c.
- Time varying delay lines can be easily implemented in real-time (see, for example, STK 4.0).

Doppler simulation

- The Doppler effect is simulated by using a time varying delay representing time-varying source-listener distance.

$$\dot{D}(t) = \frac{\omega_s - \omega_l}{\omega_s} = -\frac{v_{ls}}{c}$$

v_{ls} Speed of the listener
$\dot{D}(t)$ Delay growth rate
ω_s Radian frequency emitted by the source
ω_l Frequency received by the listener
c Sound speed

Source/listener motion simulation

- Moving read/write pointers simulate moving listener/source.
- Multiple moving sources/listeners are simulated using multiple delay lines.
- In general, we need as many delay lines as there are sources or listeners, whichever is smaller.

The Leslie's rotating horn

- The Leslie employs a rotating horn and rotating speakers to choralize the sound.
- Since the horn rotates within the cabinet, the listener hears multiple reflections at different Doppler shifts.

- Two horns are apparent, but one is dummy, serving to cancel the centrifugal force of the other during rotation.
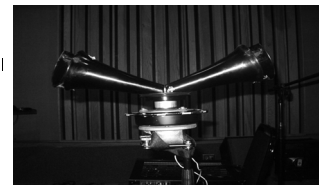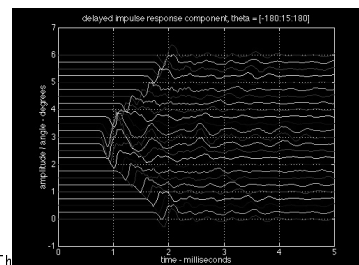

Leslie Free-Field Horn measurements

- The free-field radiation pattern of the Leslie rotating horn was measured using 2048-point-long Golay codes.
- - The horn response in the plane of rotation and along the axis of rotation was measured using a matched pair of Panasonic microphone elements mounted on separate boom microphone stands.
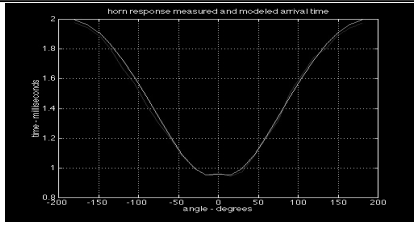

Leslie horn free-field response

Impulse responses measured using 2048-point-long Golay codes.

- Th[...] with the horn rotation.

Leslie Horn free field arrival time

- The arrival time has been measured by cross correlating the minimum phase and raw impulse responses and computed from geometry, taking horn width into account.
- Note that the asymmetry in arrival time as a function of horn angle becomes more pronounced with closer microphone placement.

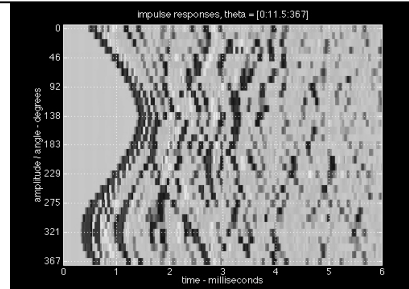### Leslie-Horn Free Field radiation pattern
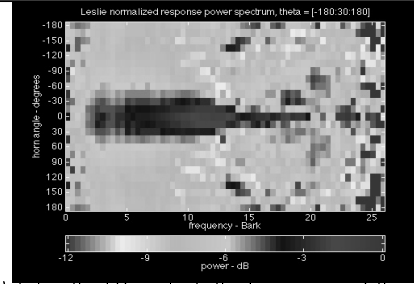
- Note how the diffuser limits the dynamic range of the radiation pattern.
- Note also how the main lobe is still present.

Leslie horn Free-Field simulation

Free-field signal

Measured response

Simulated response

Leslie cabinet response

- Note the multiple arrival times, which imply multiple Doppler shifts.

Leslie cabinet simulation

- Cabinet signal
- Measured response
- Simulated response

Summary and future work

- Measurements of the Leslie indicate that the Leslie effect may be modeled as the superposition of a set of differently Doppler shifted propagation paths.
- A method for Doppler shifting moving sources using a time-varying delay line was presented.
- Future work will focus on the wooden cabinet enclosure and rotating bass speaker port.