19th INTERNATIONAL CONGRESS ON ACOUSTICS
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"Acoustics for the 21st Century"

Low Frequency Limits of Reflector Arrays

Measurements and theory on flat, thin panels

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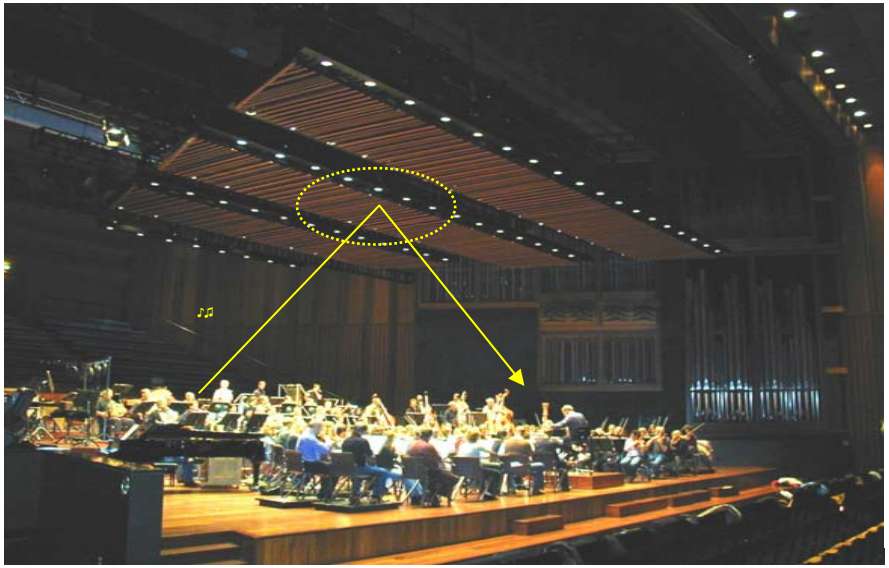
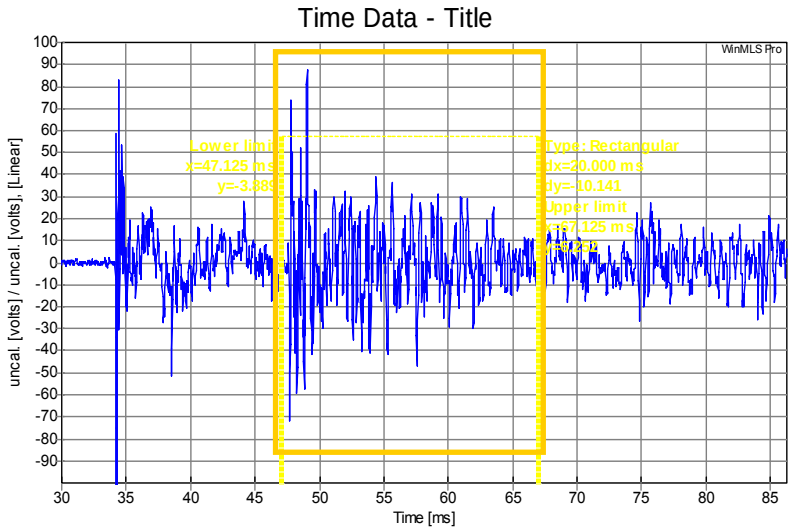
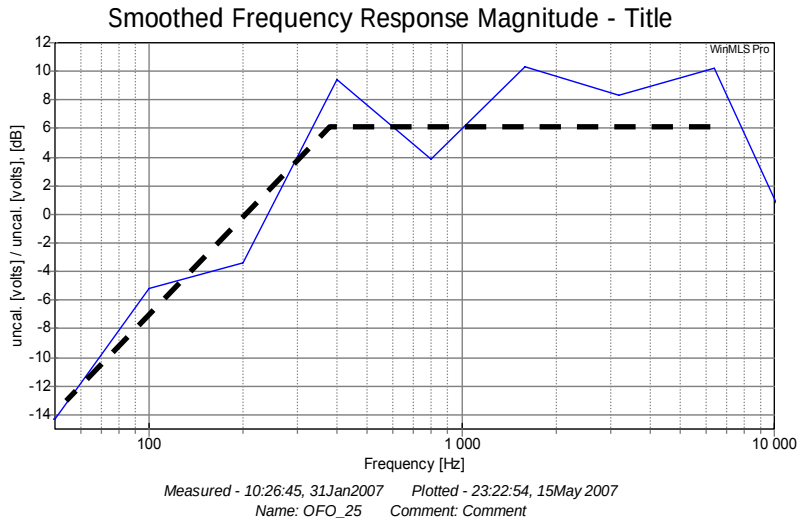
Background: Orchestra Canopy





- Reflection
- Time window
- Freq. response



Reflector array prediction

- Fresnel-Kirchhoff (FK), Rindel (1991):

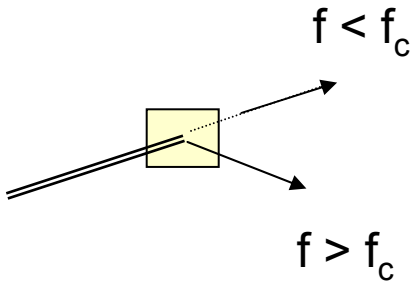
$$\mathbf{L = 20 * \log(\mu)}$$

μ = panel area / array area

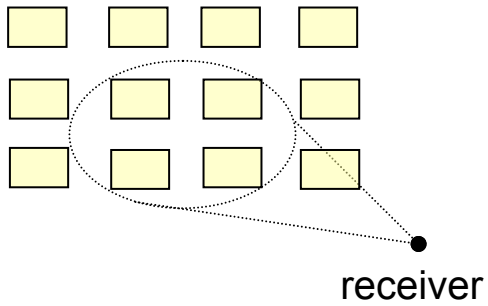
- FK assumes “perfect” reflectors
  - Sufficiently rigid
  - Large compared to wavelength: Leonard, Delsasso, Knudsen (1964)
- Reflectors are NOT perfect for **larger** λ

Two filters

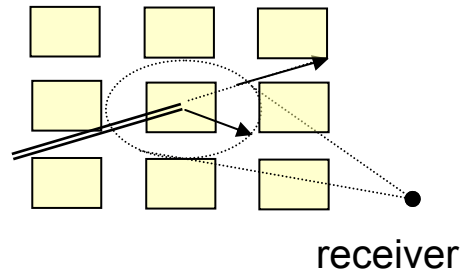
Ability to reflect sound



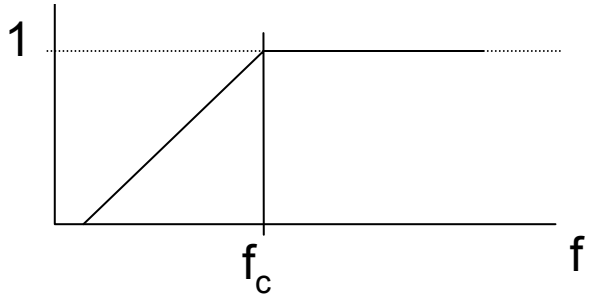
Sensitivity towards reflector



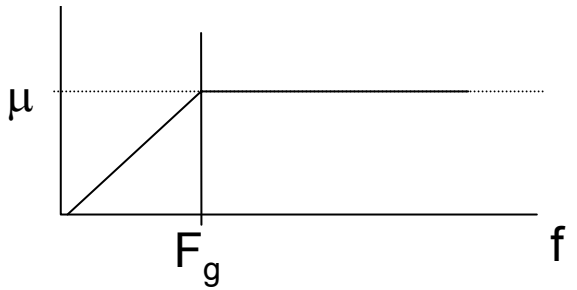
Received reflection



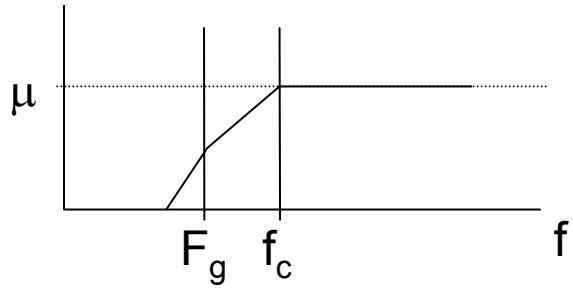
Reflection Filter +



FK-filter =



Filter SUM



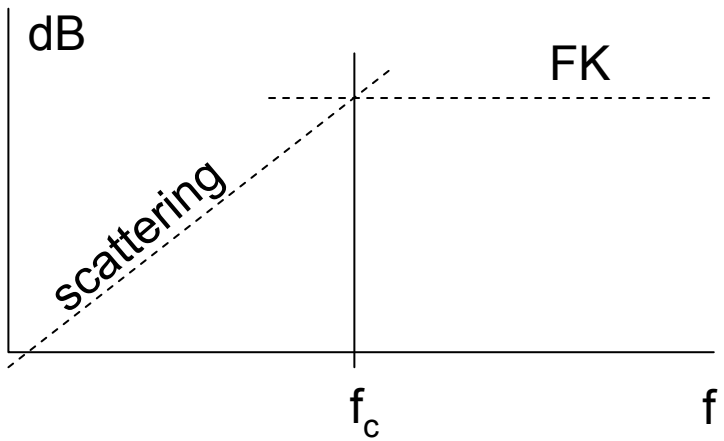
F_g by Rindel (1991)

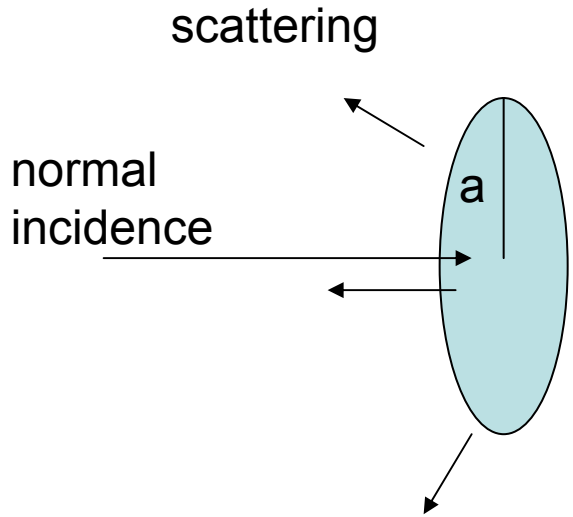
f_c = ?

Example: Disc f_c

- f <f_c asymptote: Scattering from disc, normal incidence (Pierce 1981)
- f>f_c asymptote: Fresnel-Kirchhoff (FK)

$$f_c \approx 64 \cdot \frac{perimeter}{area}$$

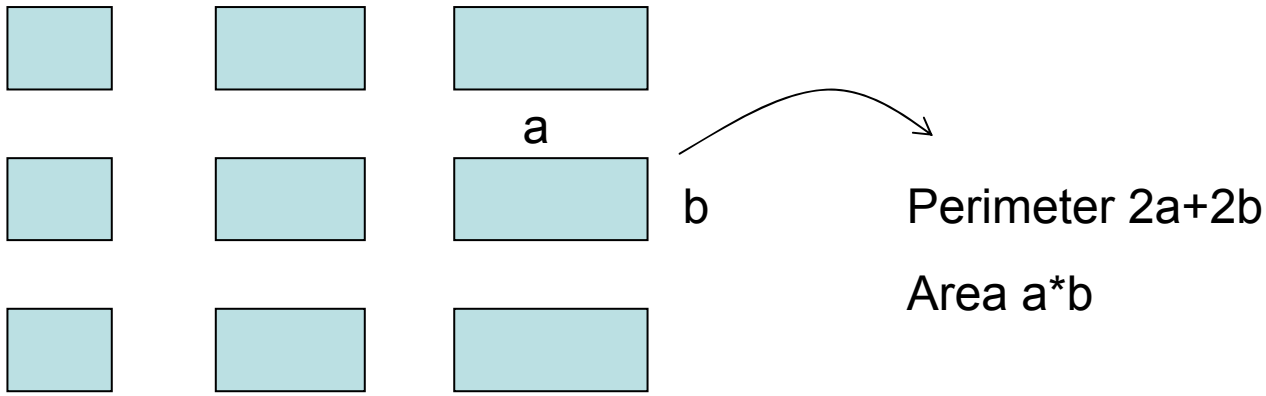




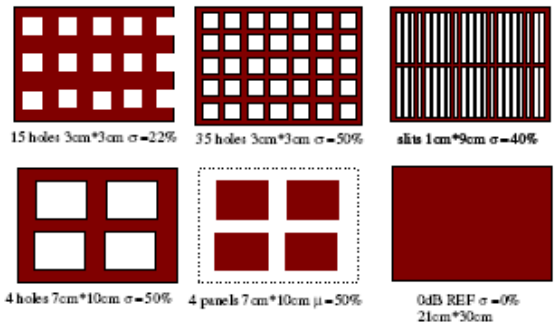
Hypothesis

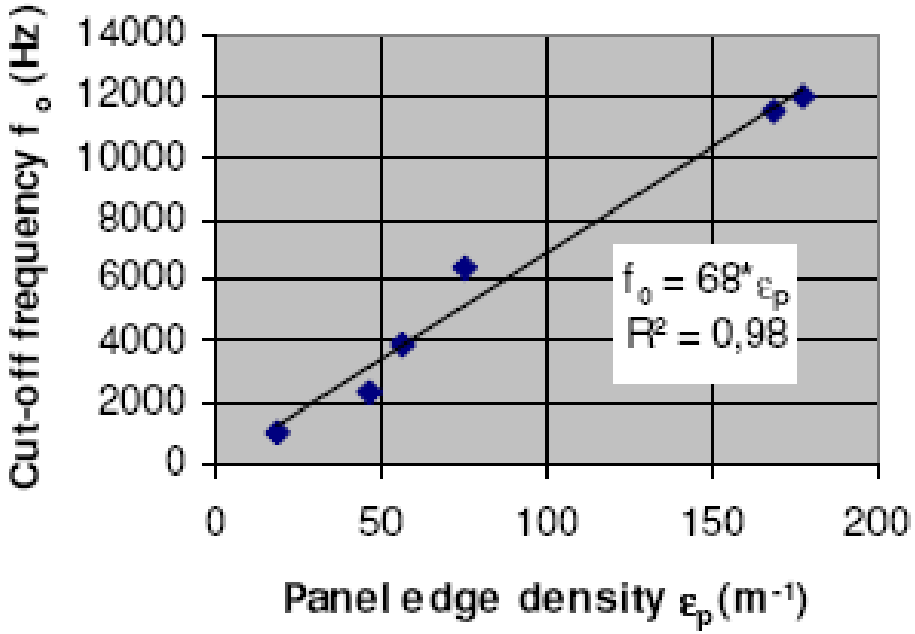
$$f_c \approx C \cdot \frac{\sum perimeter}{\sum area} = C \cdot \varepsilon$$

f_c	critical frequency of array Reflection Filter
ε	Panel Edge Density of array
C	constant to be determined



Scale model test





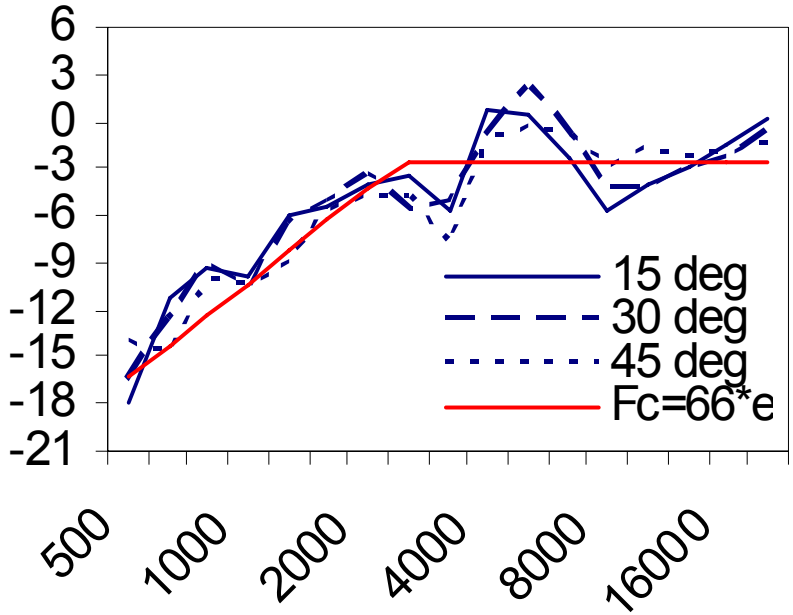
- Scale model test trend: $f_c = 68 * \varepsilon$
- $R^2 = 0.98$
- Theory on discs: $f_c = 64 * \varepsilon$

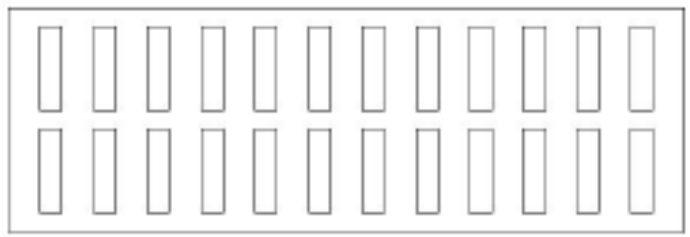
More tests

- Different shapes (normal incidence)
- 40 model arrays with different element shapes and patterns (Student project, NTNU, Trondheim):
  - Trend: $f_c = 67*\varepsilon \pm 11\%$ (disc theory $64*\varepsilon$)
  - Comment: Uneven frequency responses due to FK-effects leaves some uncertainty.

Incidence angle

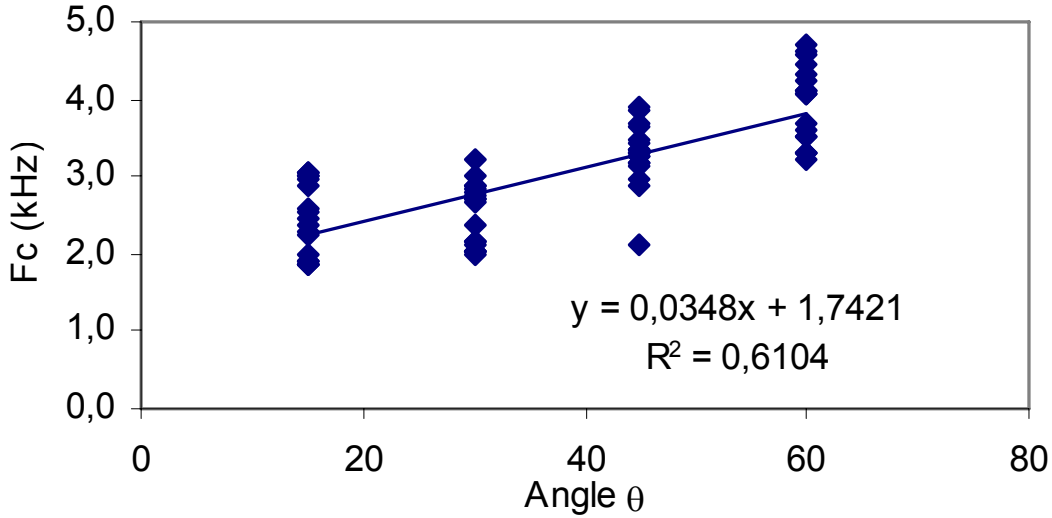
- Reflection filter “drowning” in FK-effects:
- Interference
  - Due to periodic array geometry
- Dips and peaks move with angle
- FR’s sensitive to position





Scale model measurements by Thorød, NTNU, Trondheim 2006

Incidence angle



- $\mathbf{f_c}$ correlates (R^2) only 61% with angle
- $\mathbf{f_c}$ variation can be explained by FK alone
- Hypothesis **"Reflection Filter is angle-independent"** may still hold

Further work

- $\mathbf{f_c}$ -predictor must be confirmed
  - More tests on different panel shapes
  - More tests on oblique incidence
  - More theoretical tests
- Search for array geometries with frequency responses close to ideal high-pass filter
  - To provide good reflected sound quality
  - To make $\mathbf{f_c}$-detection easier

Canopy design issues

- f >400Hz fill-in important, since through-the-orchestra path is obstructed
  - > elements must be large enough
- Smooth FR's up to 4kHz important
  - > elements must not be too large
- Higher position – wider frequency range
  - but later and weaker response
- Lower position – array should be less dense
  - to prevent stage separated from auditorium

Conclusions

$$\mathbf{f_c} = C^{*}\varepsilon$$

at normal incidence for some geometries

- C apparently in the interval ~64-68
- Must be tested for generality: Different array geometries and incidence angles
- Smooth FR's should be pursued
- 400-4000Hz important for canopies
- Canopy arrays inherently narrow-banded
- Optimum panel size and shape important

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Thank you!

- Full paper: http://www.akutek.info/Papers/MS_Array_2007.pdf
- Acoustics, research, papers, more: www.akutek.info
- ICA 2007 homepage: http://www.ica2007madrid.org/