

Audio-Beamformer

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Idee

Einführung

Akustik

Arrays

Direktiver Lautsprecher entwickeln

Design

Audio Beam Steering

Evaluation

Fazit

Konzept

Einführung

Akustik

Arrays

Design

Evaluation

Fazit

Klassisches Lautsprecher Array

Parametrisches Lautsprecher Array



Einführung

Akustik

Arrays

Design

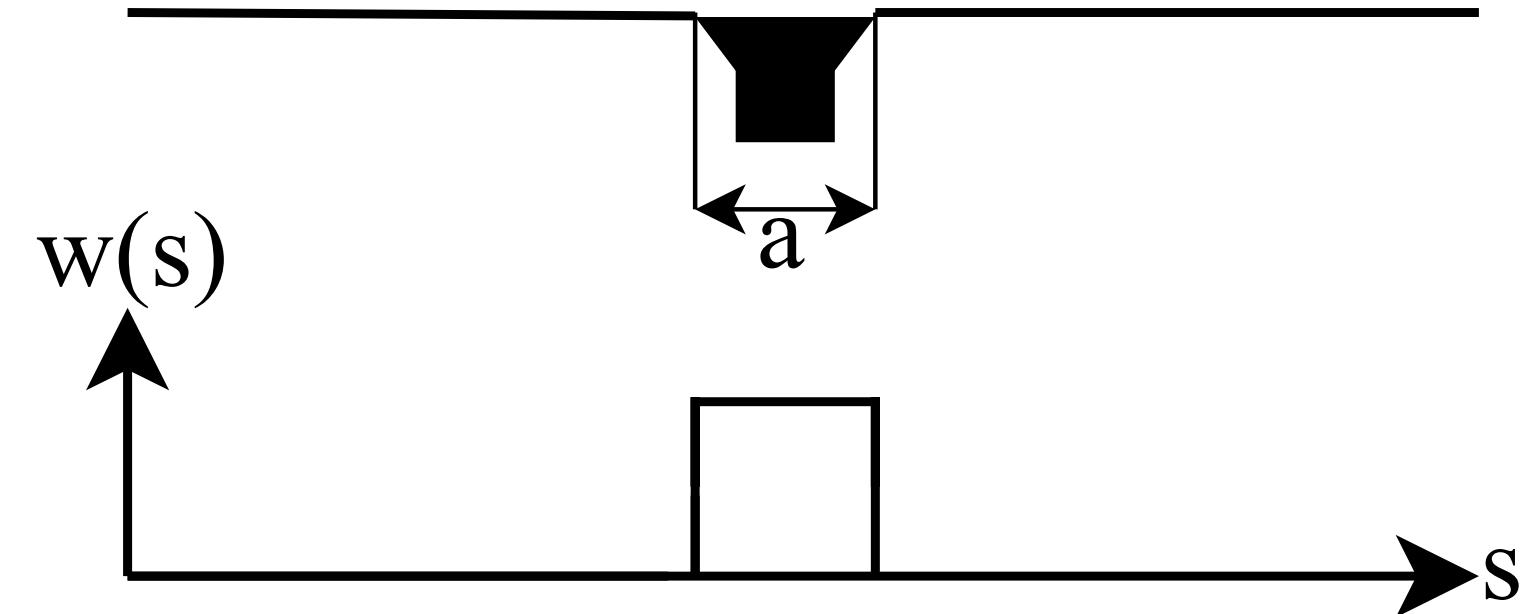
Evaluation

Fazit

Direktivität

Akustische Direktivität

$$D_T(\varphi) = \frac{\sin \frac{\omega a \sin \varphi}{2c}}{\frac{\omega a \sin \varphi}{2c}}$$





Einführung

Akustik

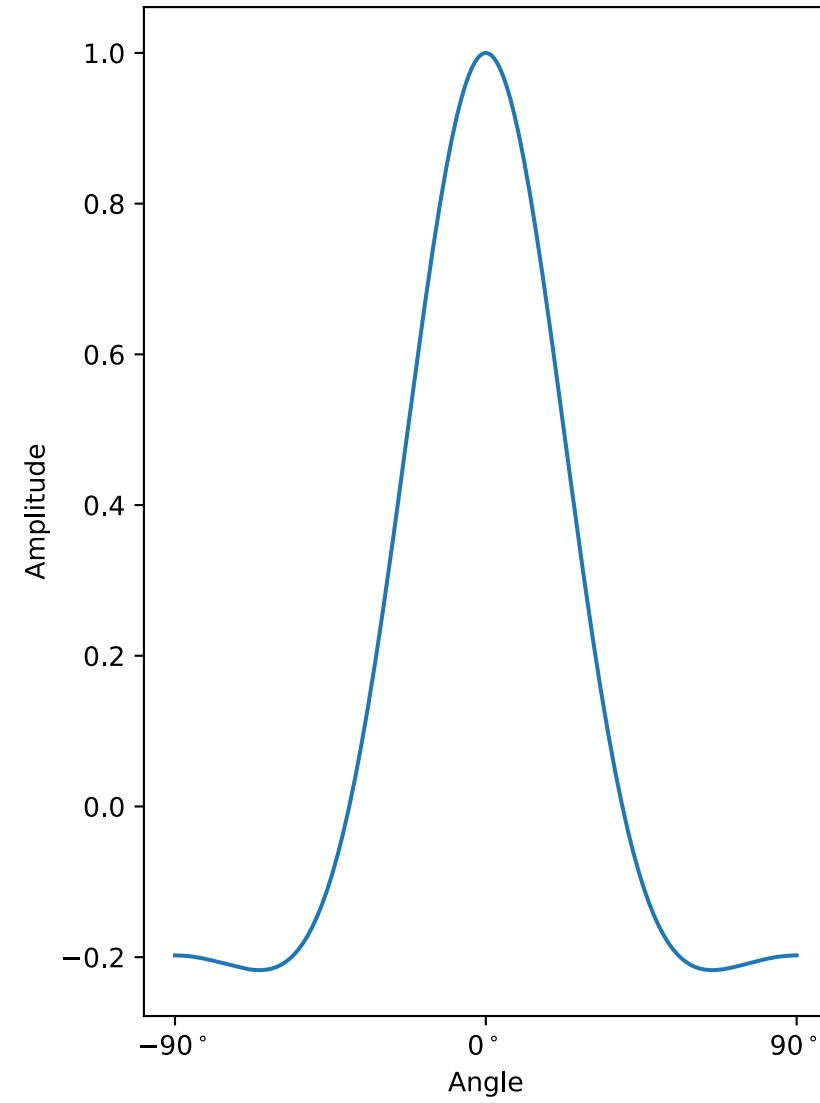
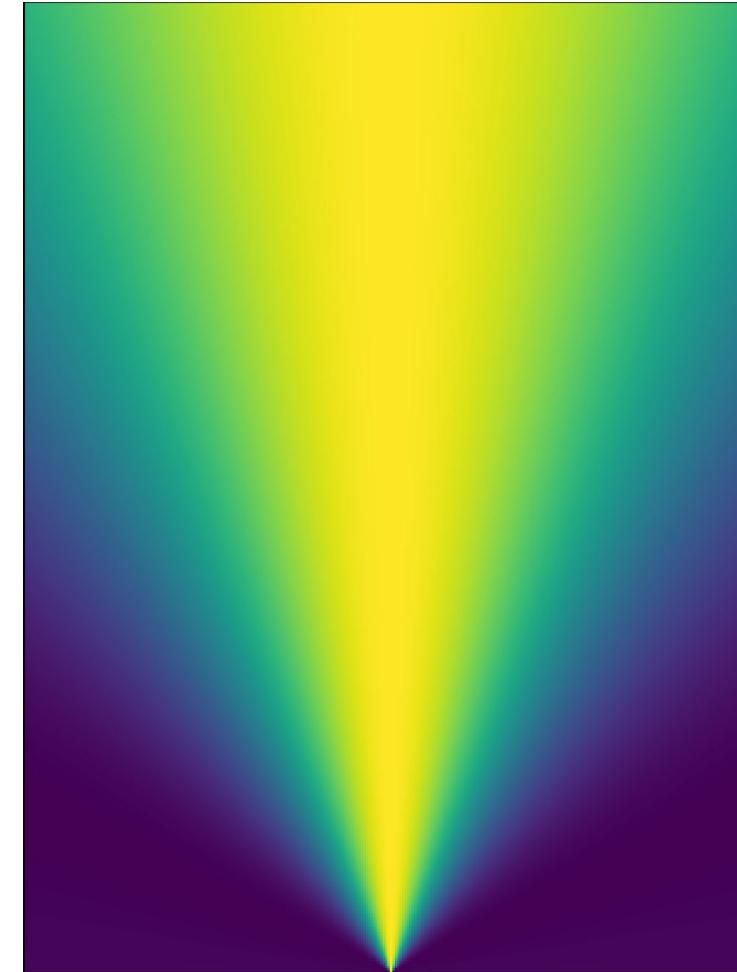
Arrays

Design

Evaluation

Fazit

Direktivität $a = \lambda / 2$



Einführung

Akustik

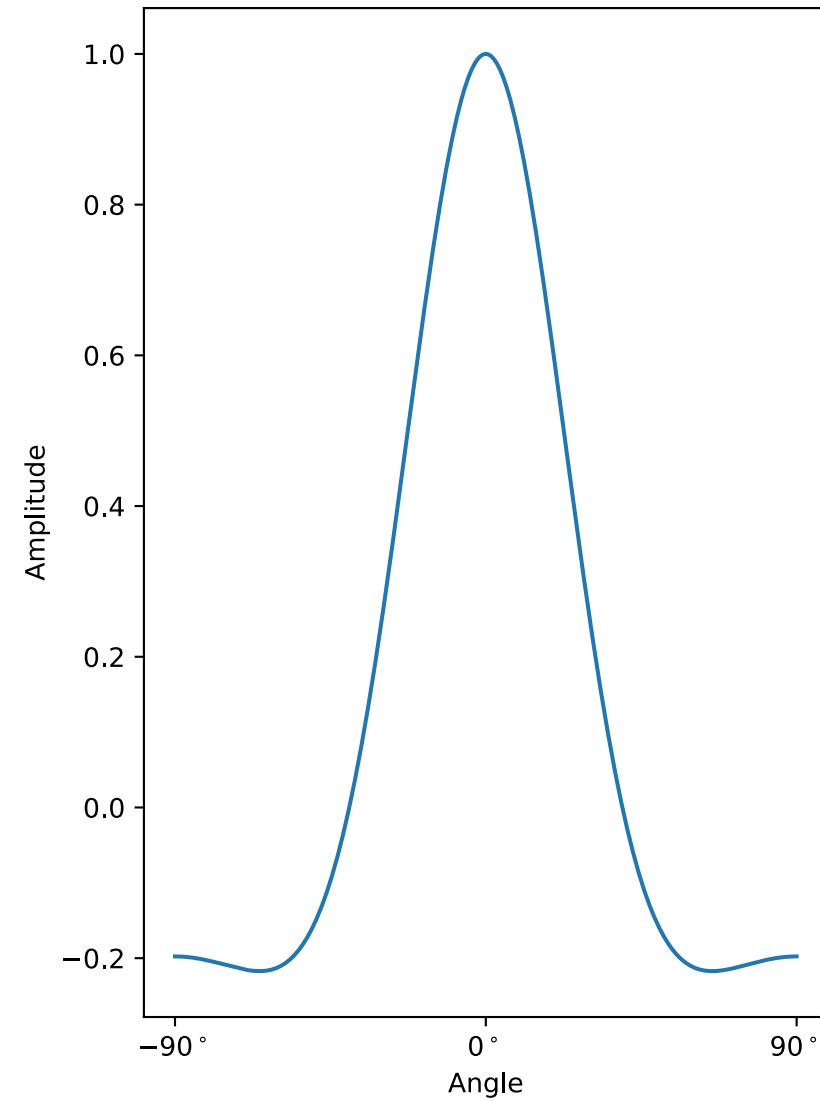
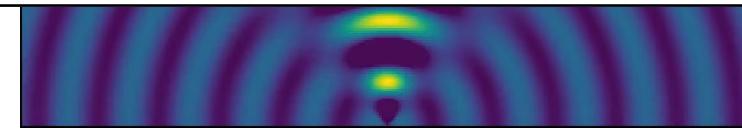
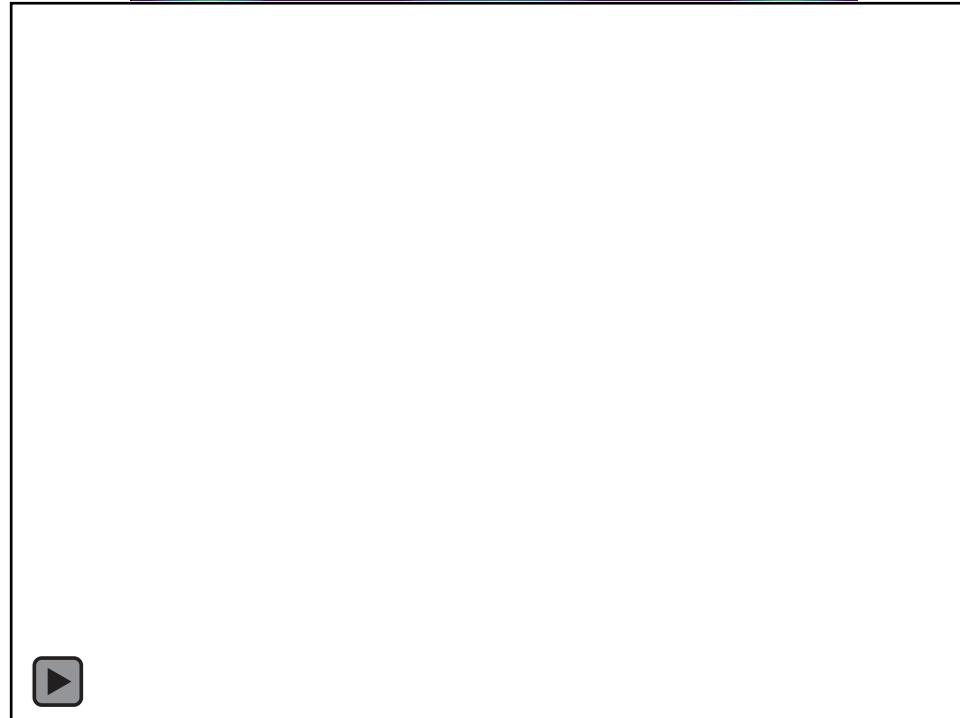
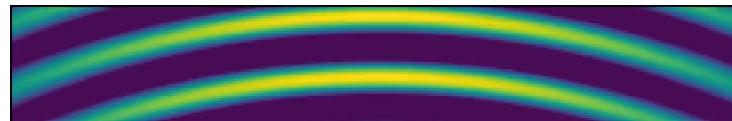
Arrays

Design

Evaluation

Fazit

Schallausbreitung





Einführung

Akustik

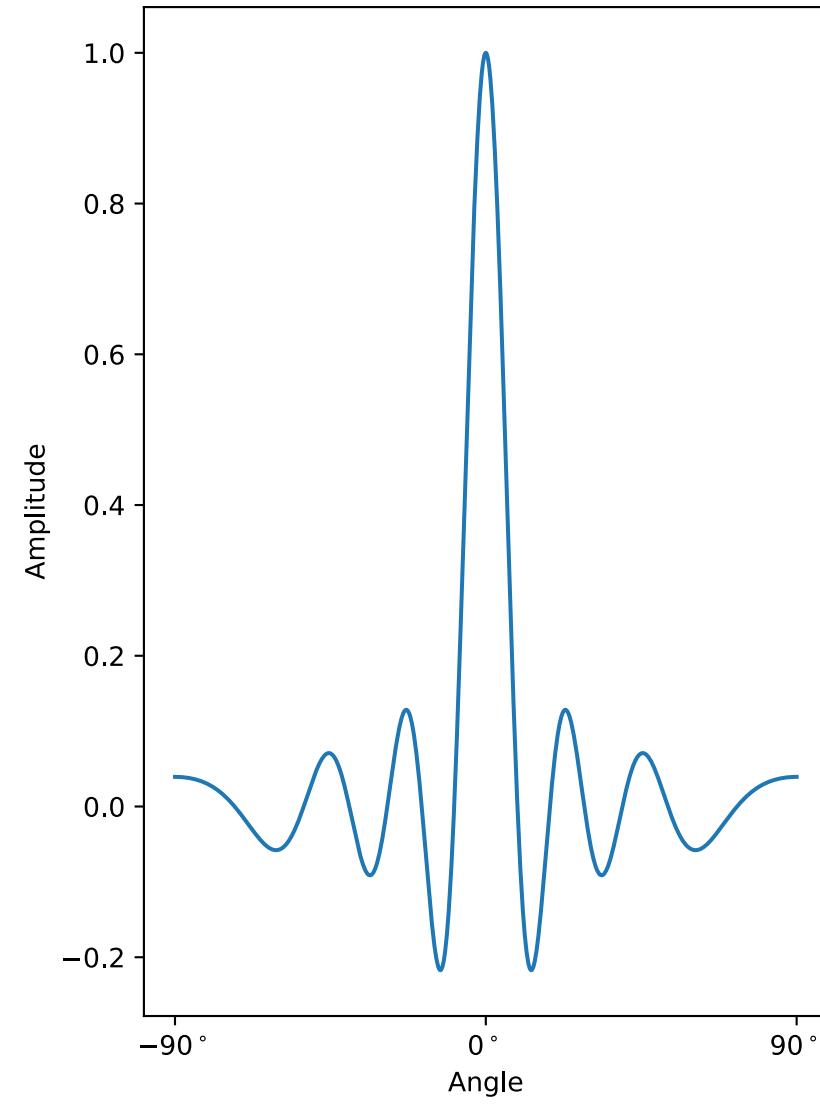
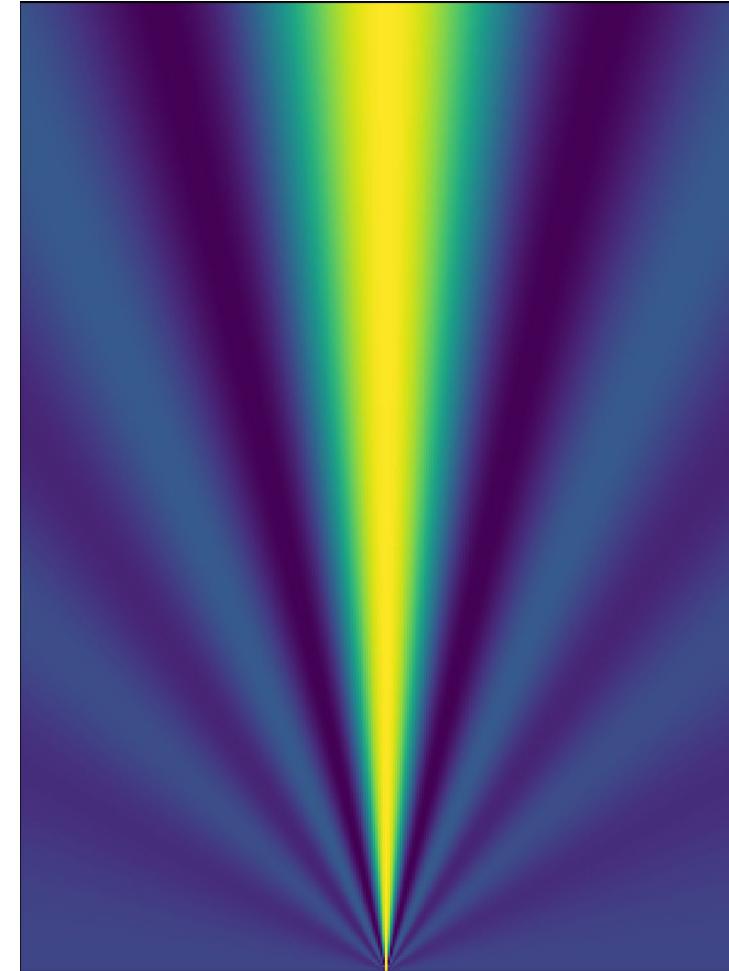
Arrays

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Fazit

Direktivität $a = 2\lambda$





Einführung

Akustik

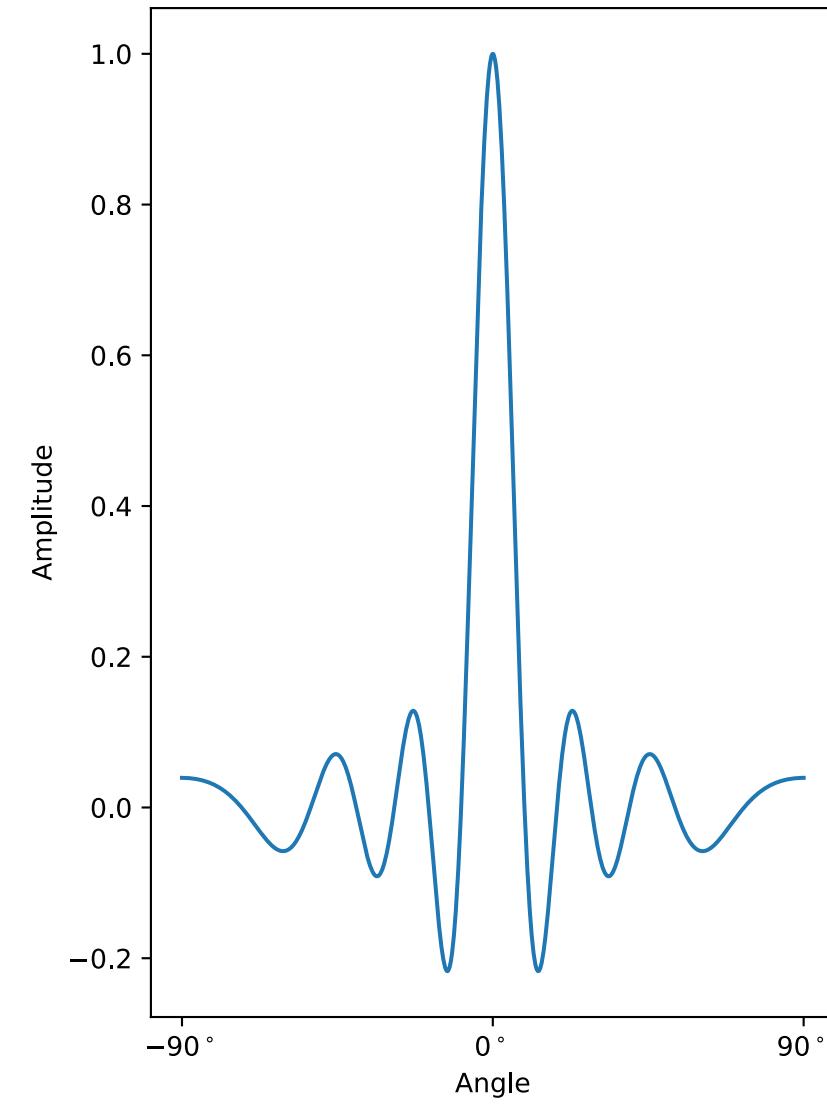
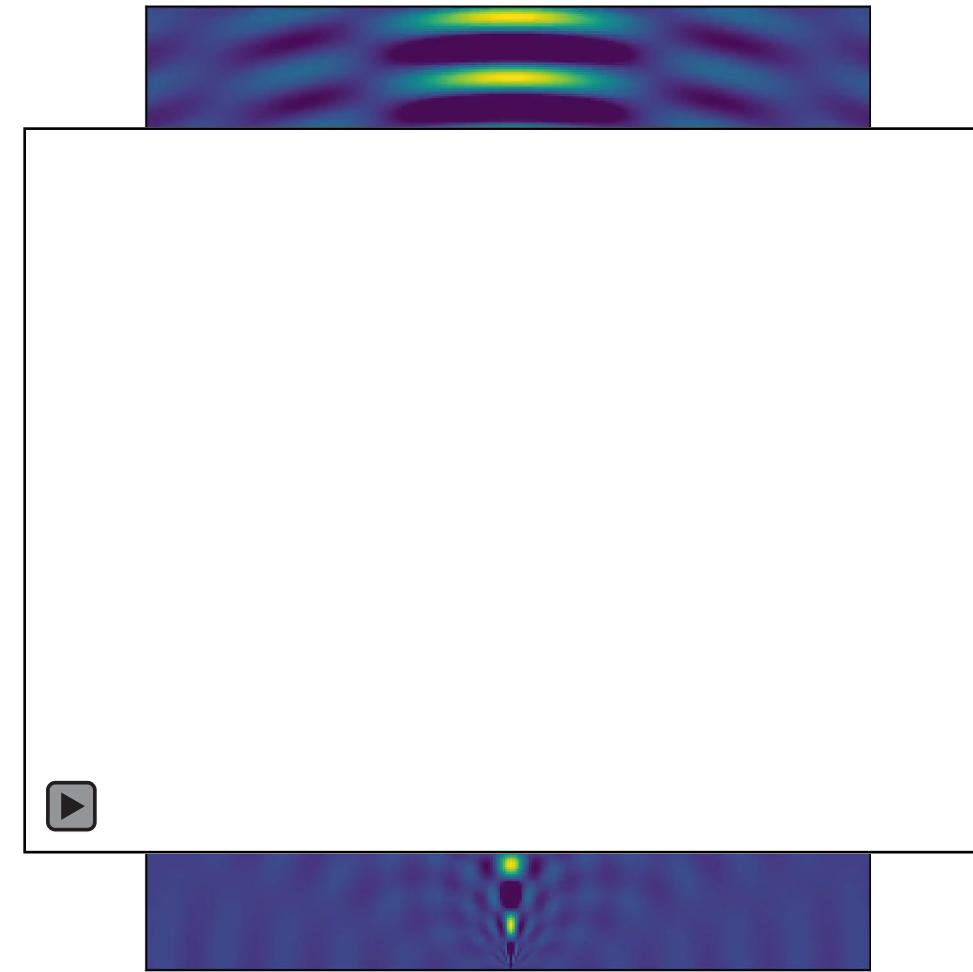
Arrays

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Fazit

Schallausbreitung





Einführung

Akustik

Arrays

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Evaluation

Fazit

Sound from Ultrasound



Einführung

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Demodulation in der Luft

Demodulation

$$p \propto \frac{d^2}{dt^2} E^2(t)$$

Zweite Ableitung führt zu Hochpass

Ideale Umhüllende

$$E(t) = \sqrt{1 + m \int \int f(t) dt^2}$$



Einführung

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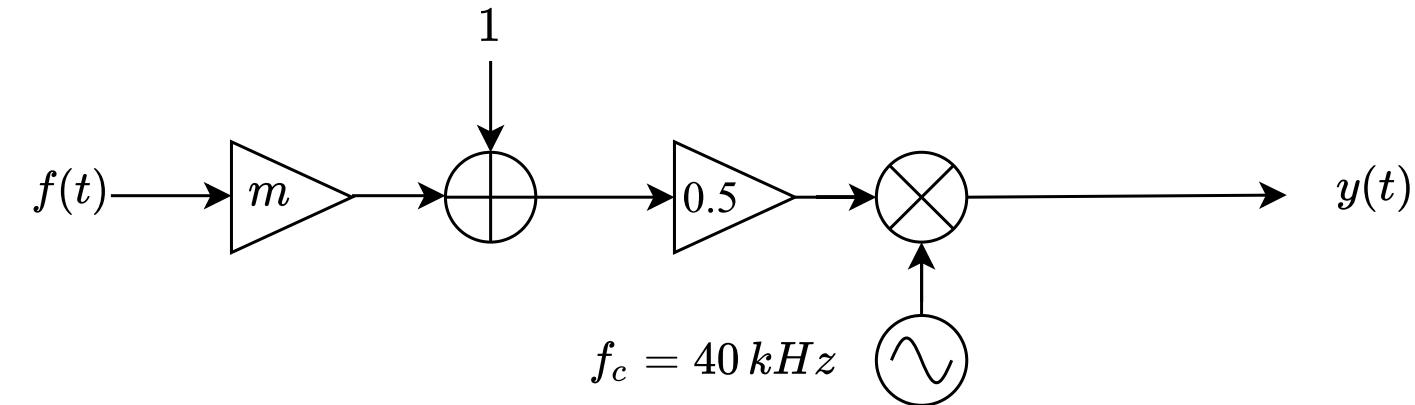
Amplituden Modulation

Umhüllende

$$E(t) = \frac{1}{2} (1 + mf(t))$$

Hörbares Signal

$$f_{RX}(t) = mf(t) + \frac{1}{2}m^2f^2(t)$$





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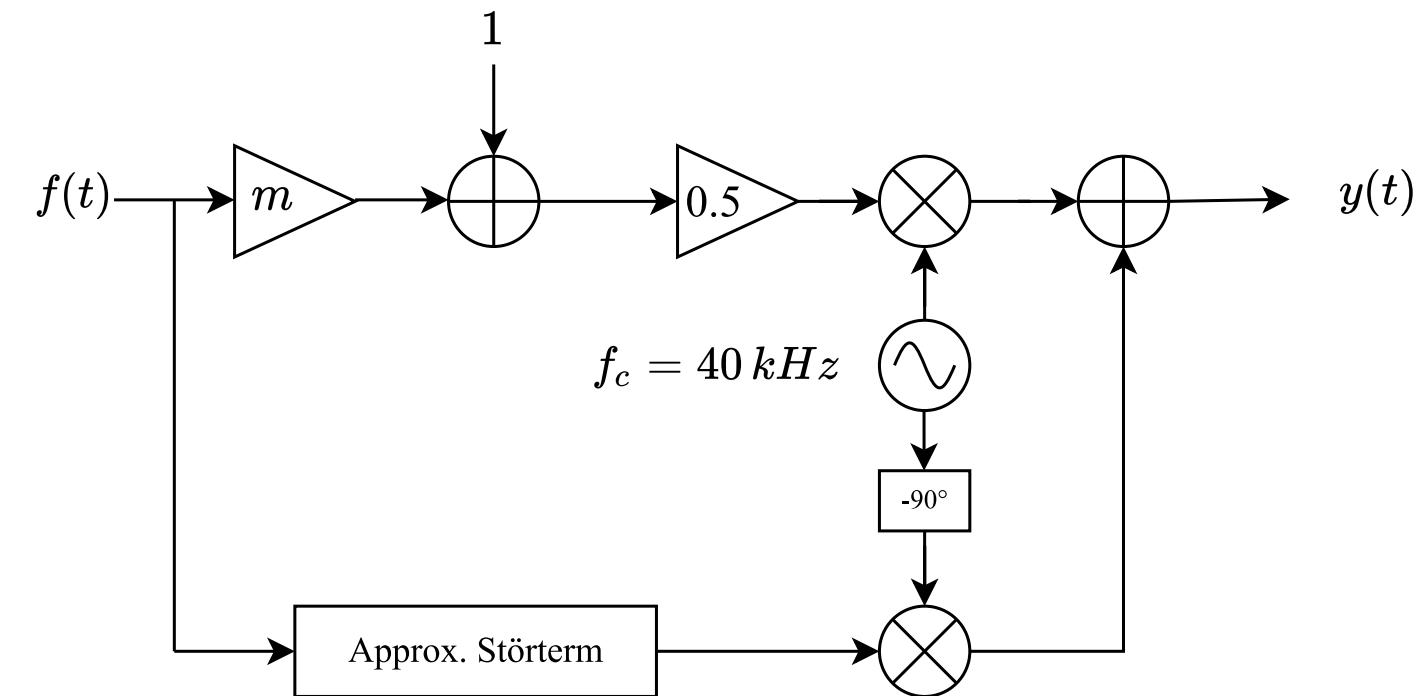
Evaluation

Fazit

Modified AM

Ähnlicher Aufbau wie QAM

Störterm - Unterdrückung





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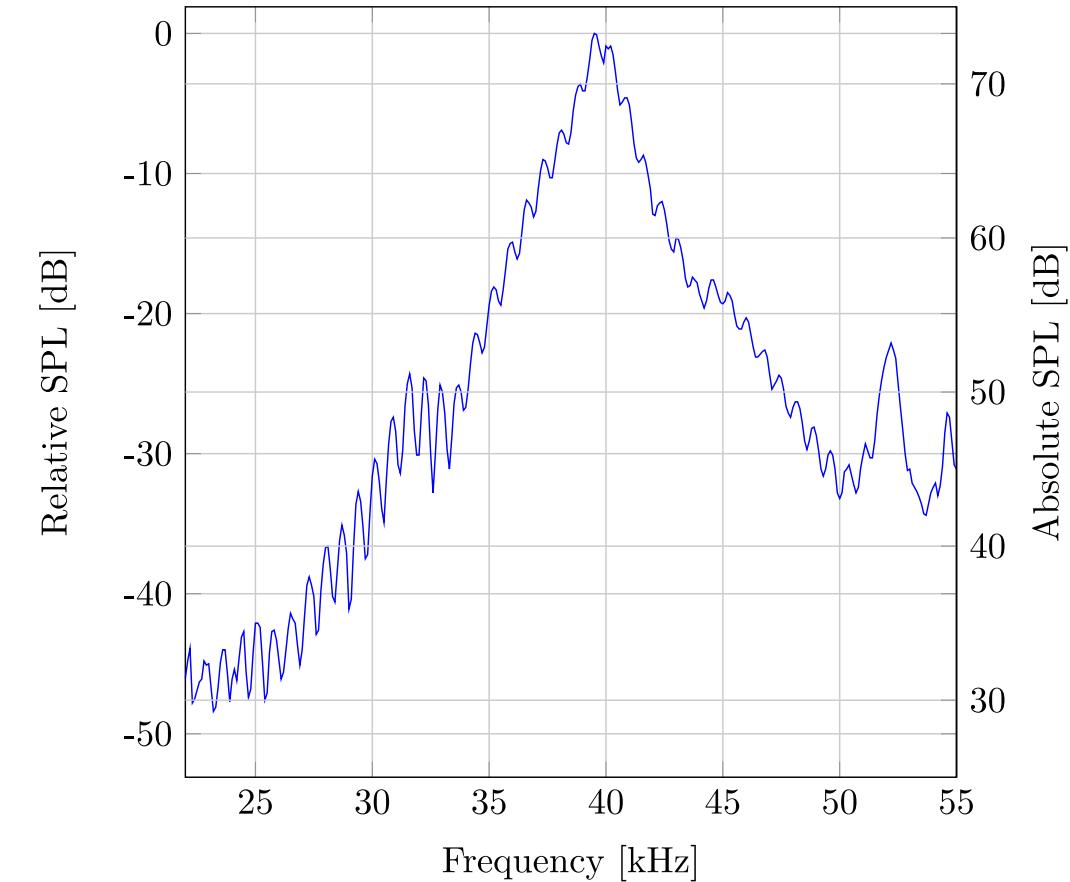
Piezoelektrischer

Ultraschall-Transducer

Hohe Güte

$f_R = 40 \text{ kHz}$

Schmale Bandbreite





Einführung

Akustik

Arrays

Design

Evaluation

Fazit

Vorteile von Arrays

Höherer Schalldruck

Verstärkung der Richtcharakteristik

Ermöglicht Beamforming



Einführung

Akustik

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Design

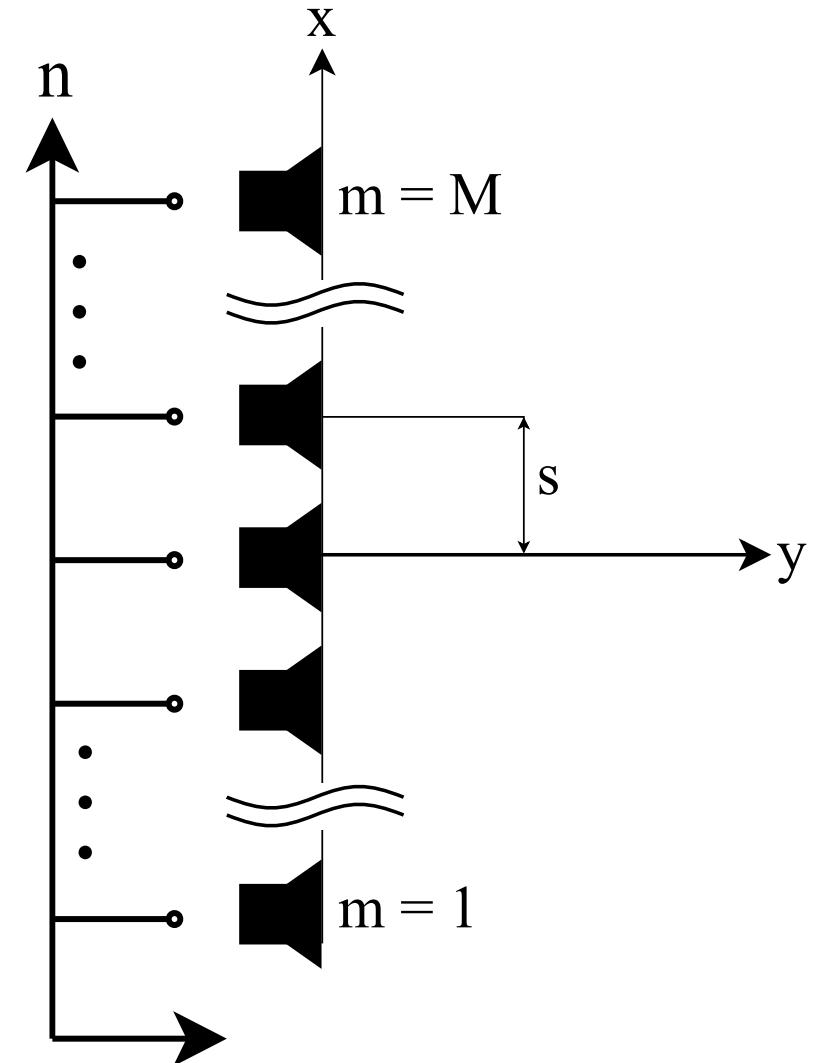
Evaluation

Fazit

Richtcharakteristik

Richtcharakteristik

$$D_A(\varphi) = \frac{\sin \frac{Mks \sin \varphi}{2}}{M \cdot \sin \frac{ks \sin \varphi}{2}}$$





Einführung

Akustik

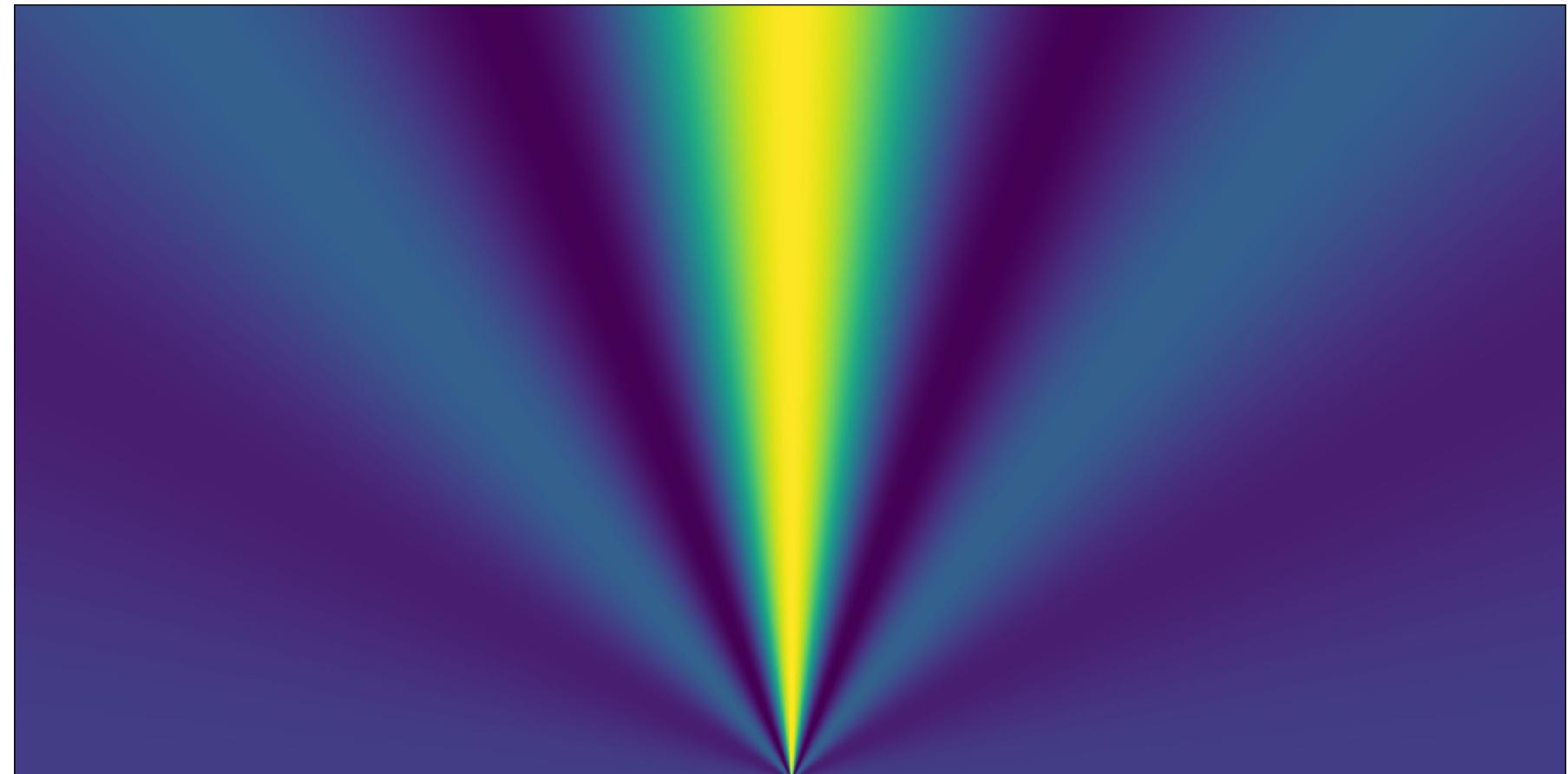
Arrays

Design

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Richtcharakteristik $M = 5$



Einführung

Akustik

Arrays

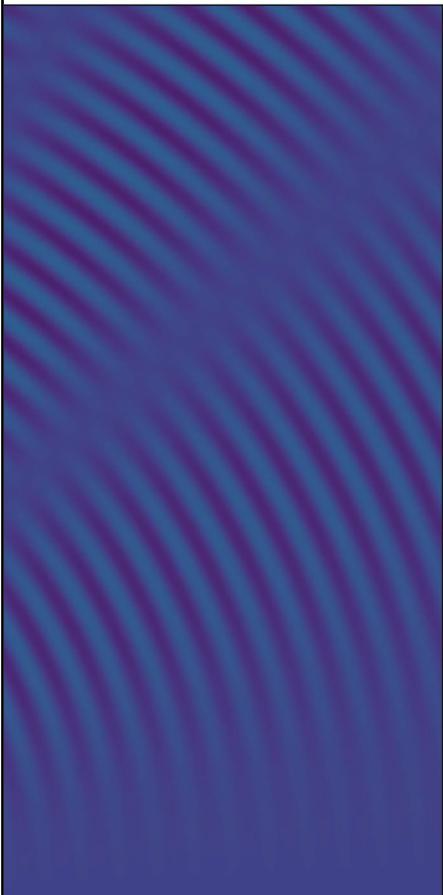
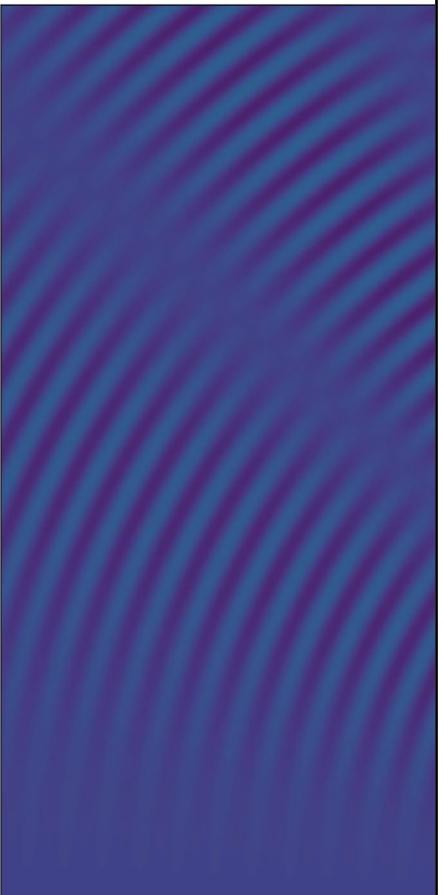
Design

Evaluation

Fazit

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Einführung

Akustik

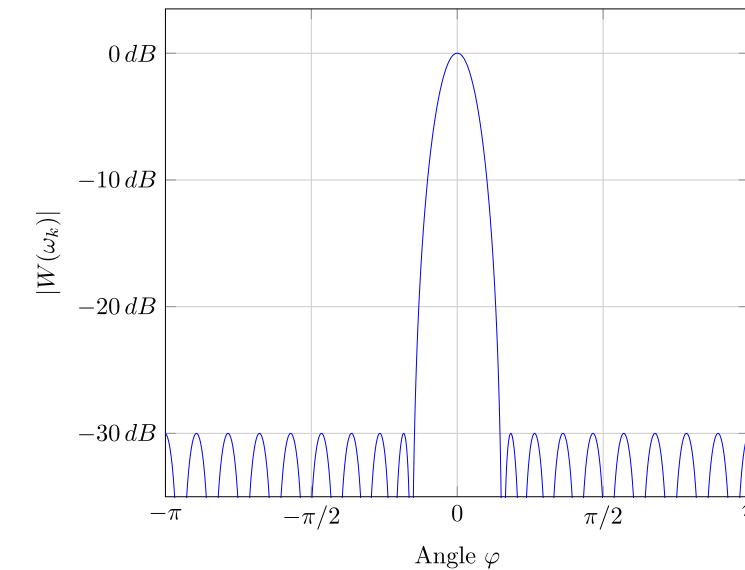
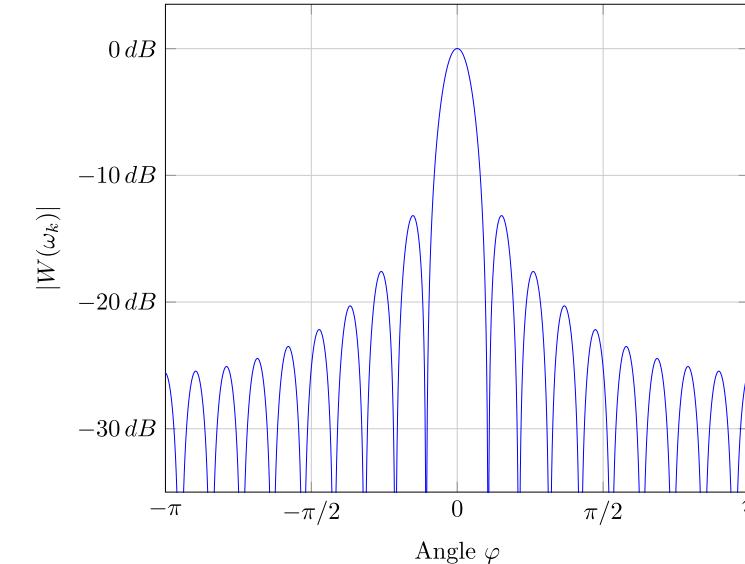
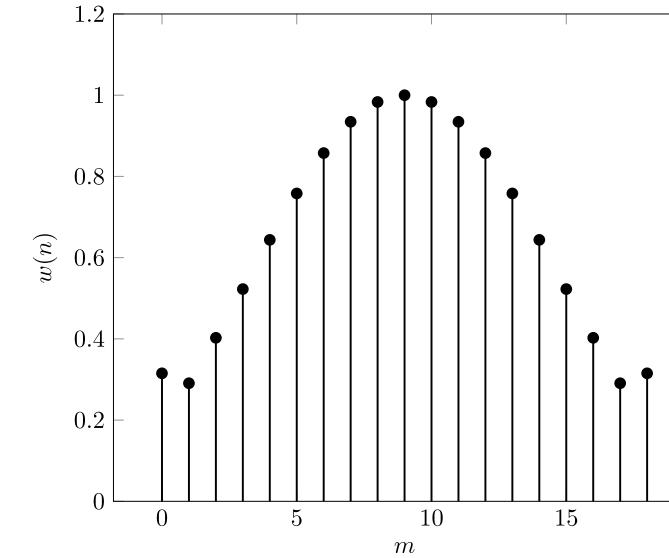
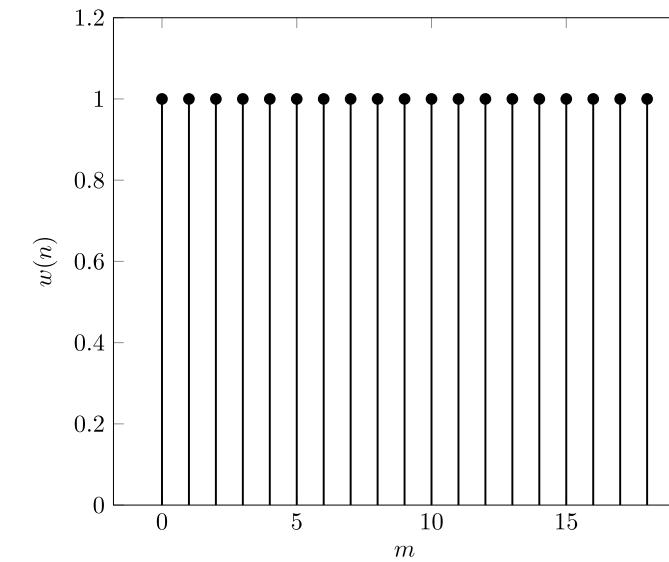
Arrays

Design

Evaluation

Fazit

Dolph-Chebyshev Window





Einführung

Akustik

Arrays

Design

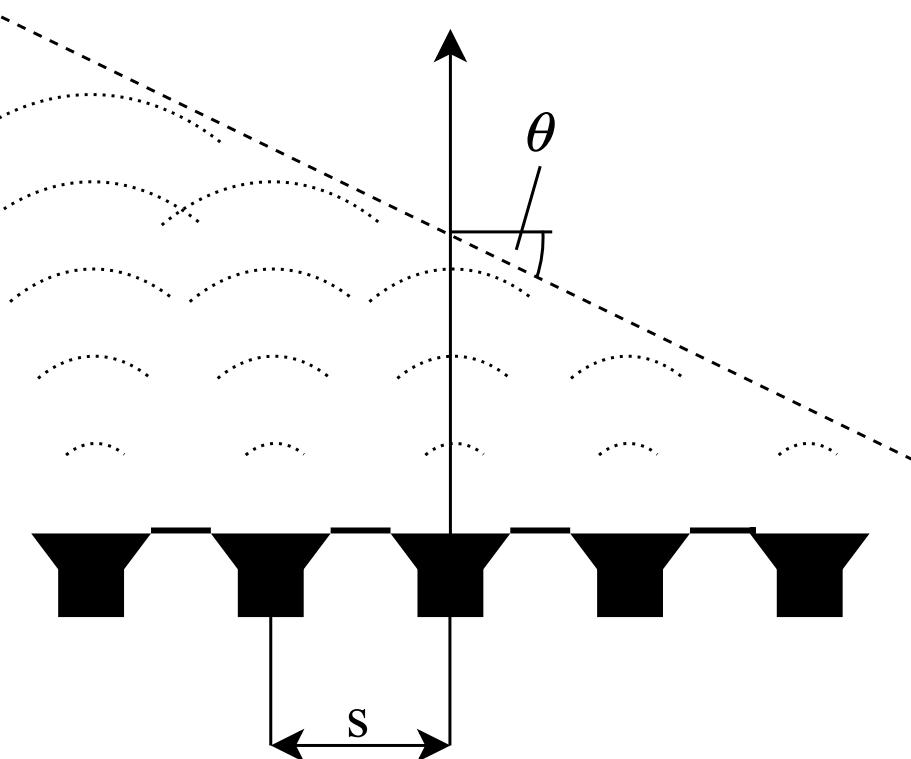
Evaluation

Fazit

Beamsteering

Unterschiedliche Verzögerungen

Wellenfronten ergeben Winkel



Einführung

Akustik

Arrays

Design

Evaluation

Fazit



Anforderungen

Einführung

Akustik

Arrays

Design

Evaluation

Fazit

Stand-Alone

Easy to use

Professional

Einführung

Akustik

Arrays

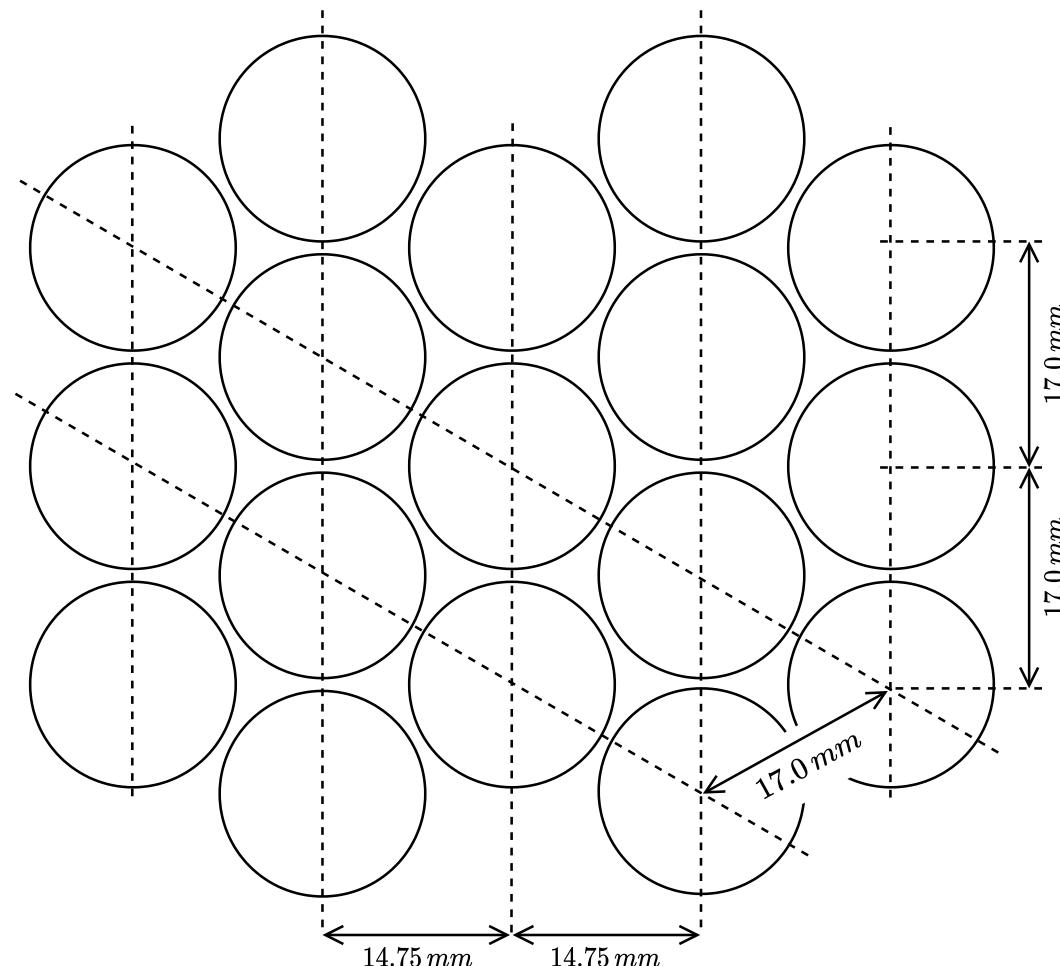
Design

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Fazit

Aufbau Array

Hexagonale Anordnung



Einführung

Akustik

Arrays

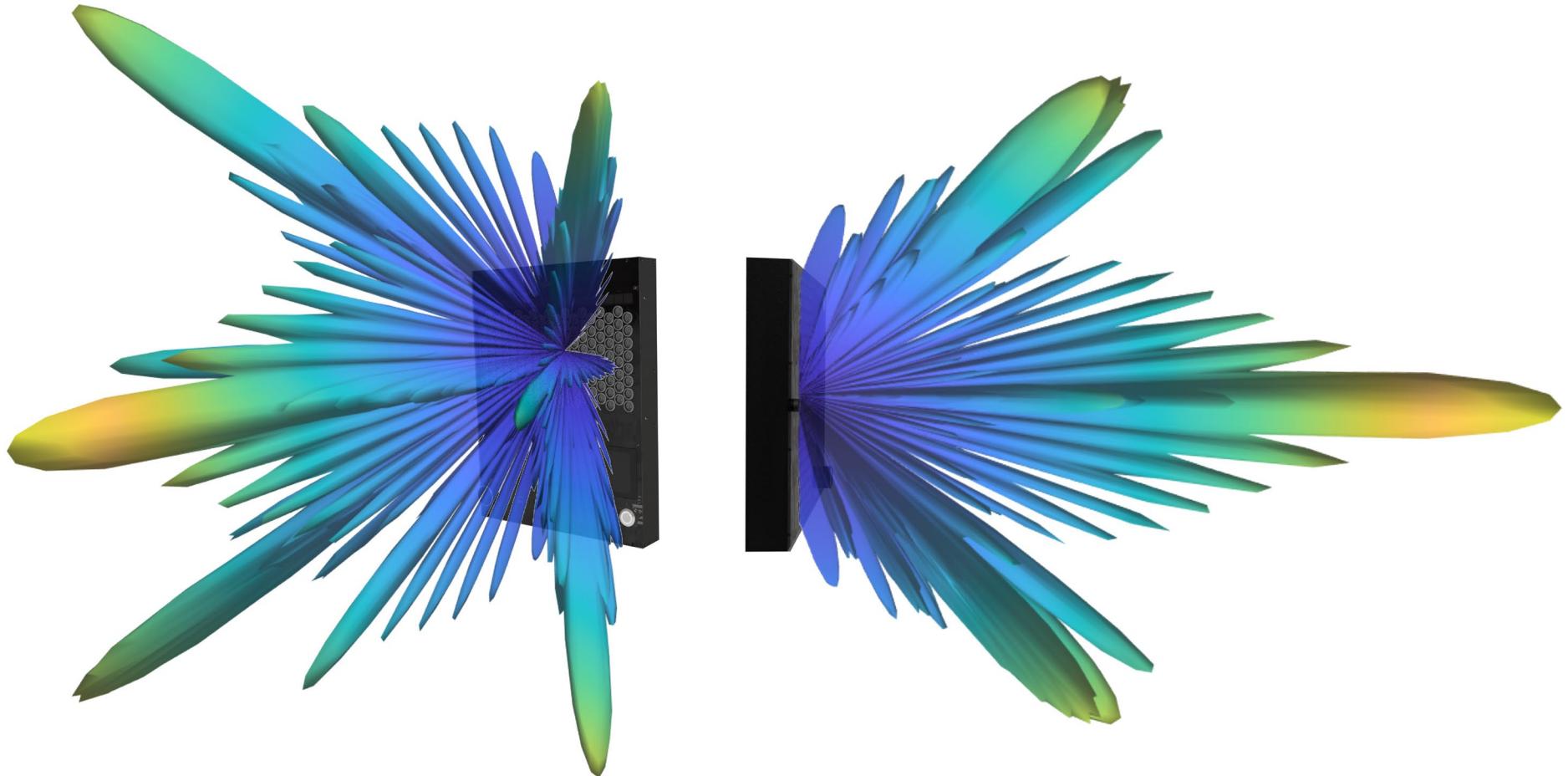
Design

Evaluation

Fazit

Aufbau Array

Matlab Simulation





Einführung

Akustik

Arrays

Design

Evaluation

Fazit

Signalfloss



Einführung

Akustik

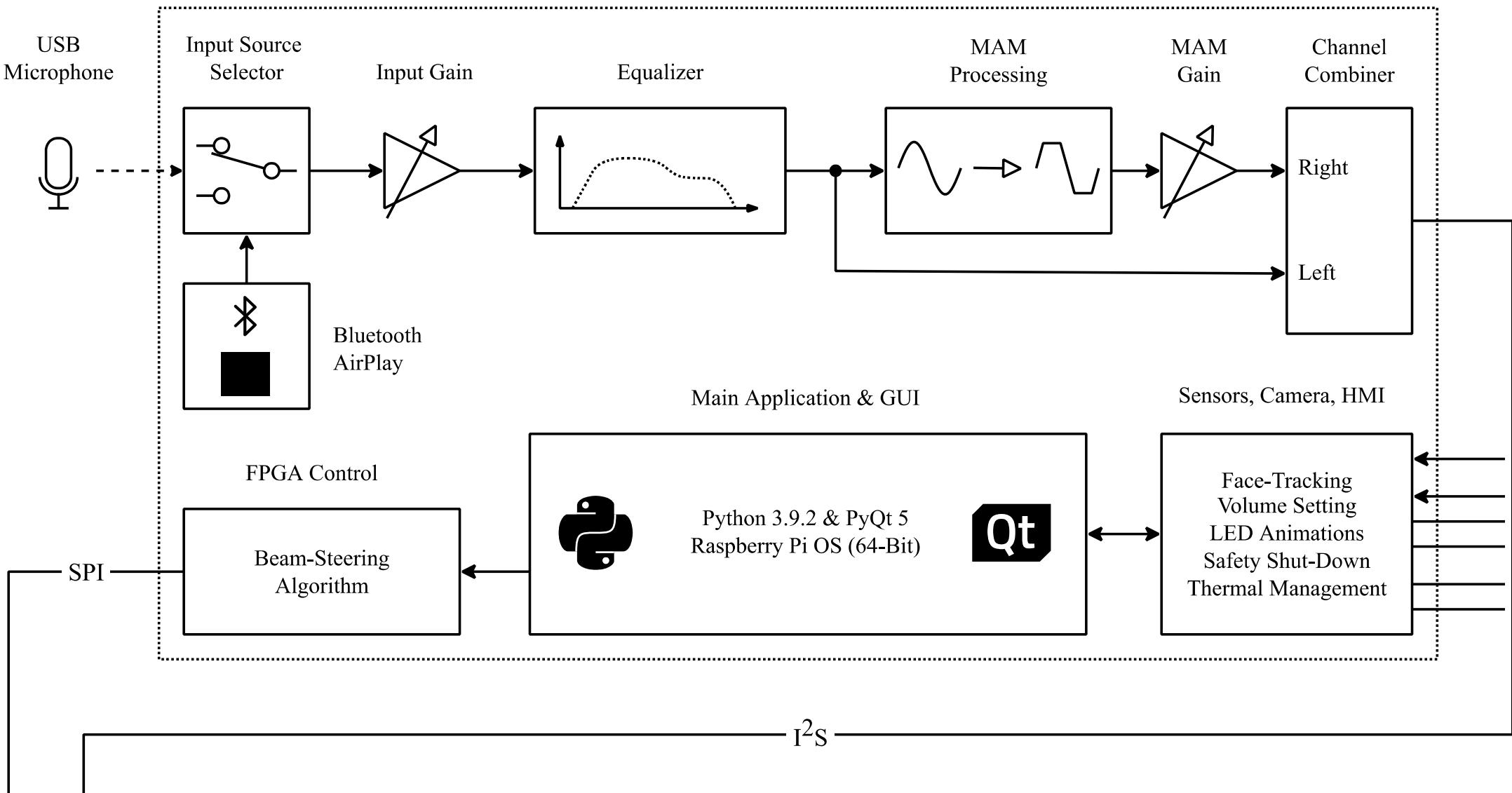
Arrays

Design

Evaluation

Fazit

Raspberry Pi Compute Module 4





Einführung

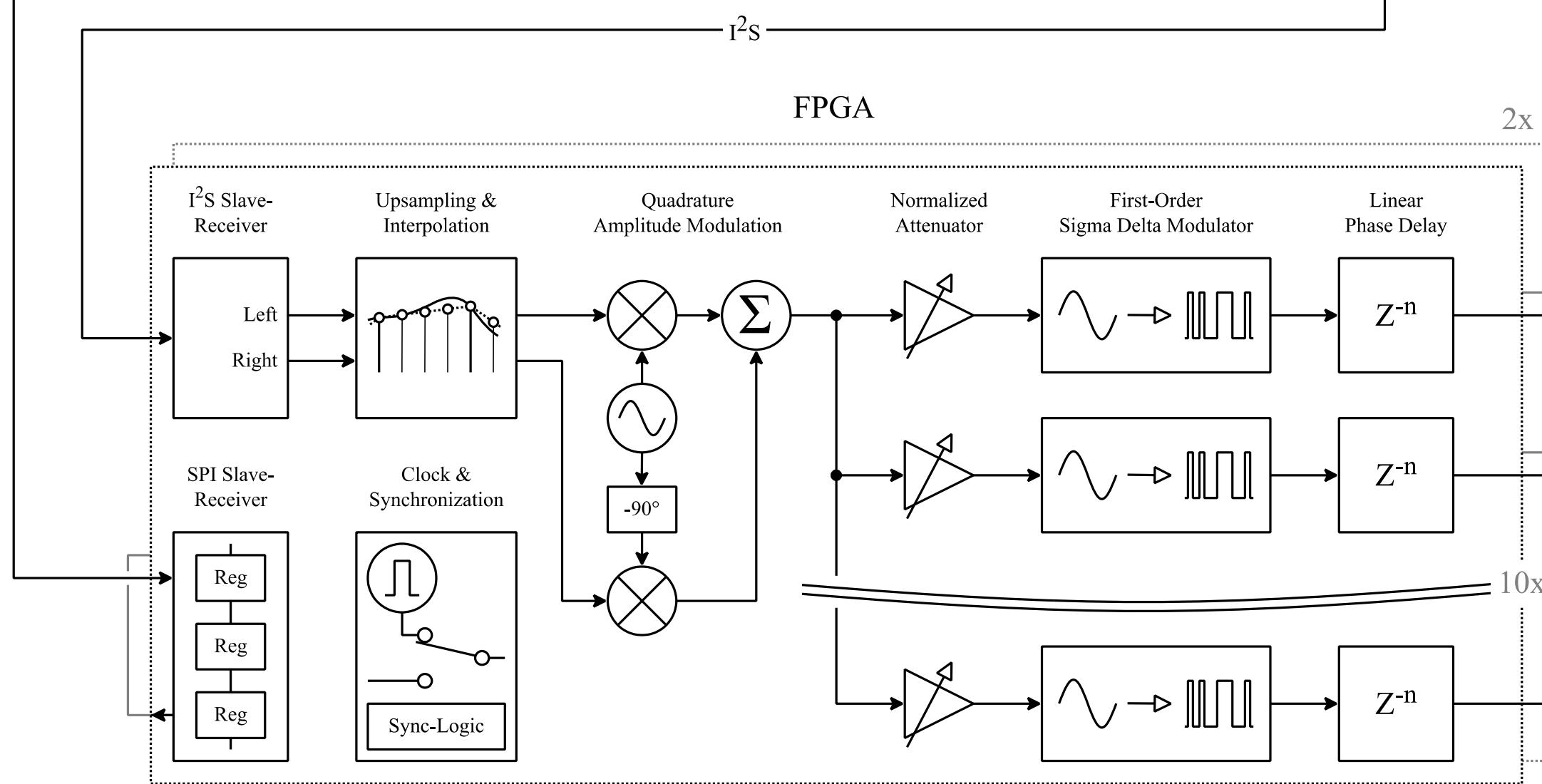
Akustik

Arrays

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Evaluation

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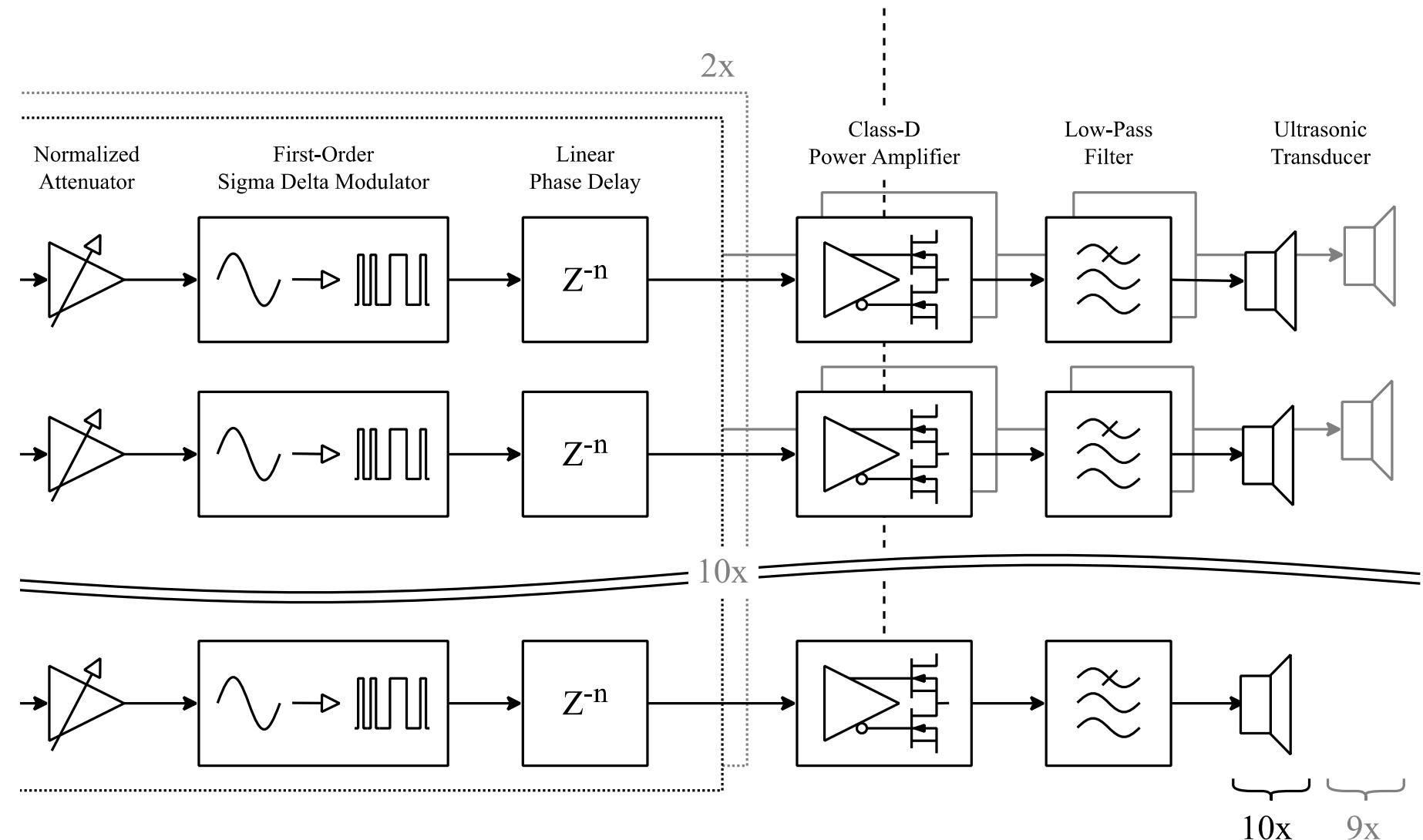
Akustik

Arrays

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Fazit



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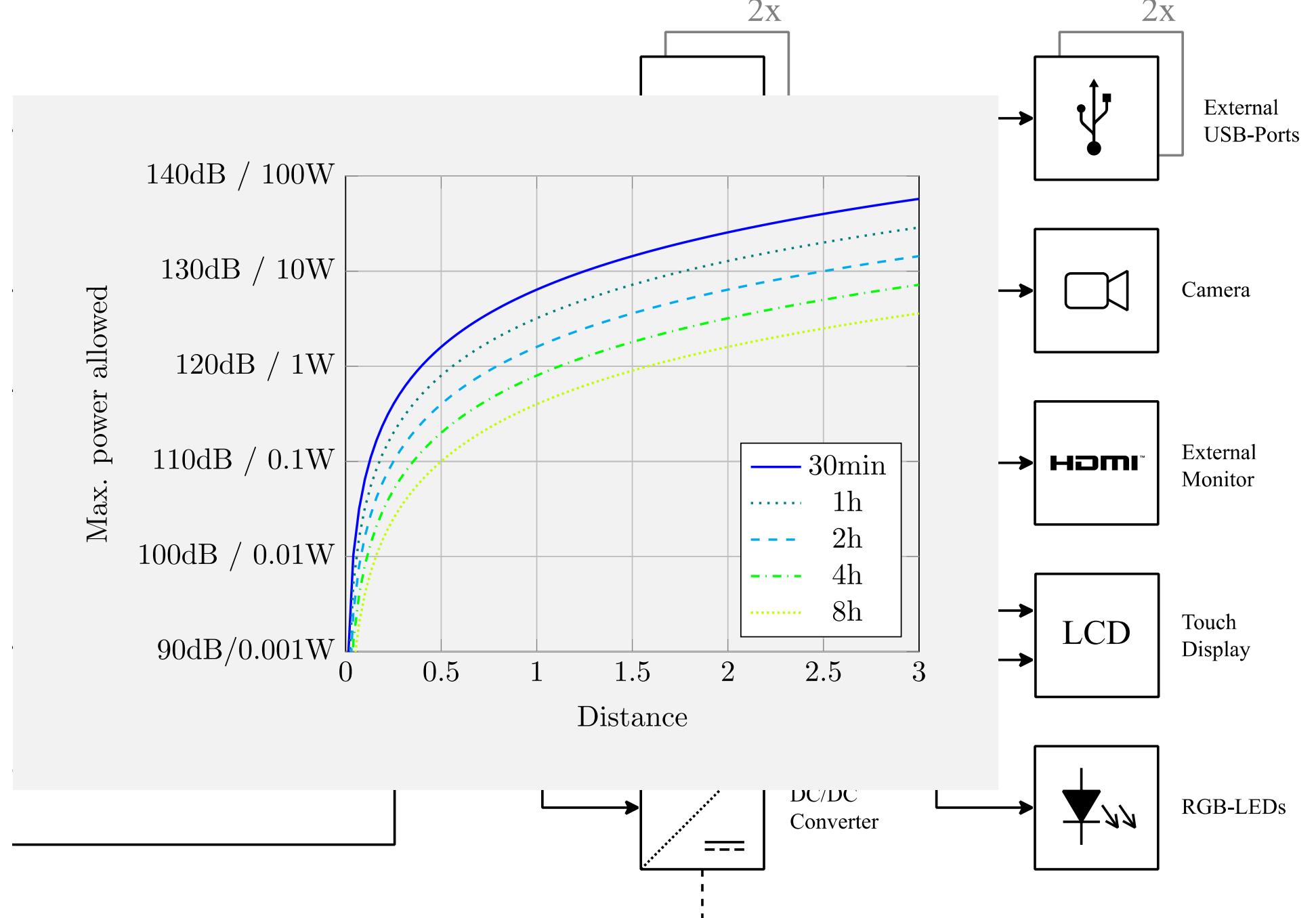
Akustik

Arrays

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Evaluation

Fazit



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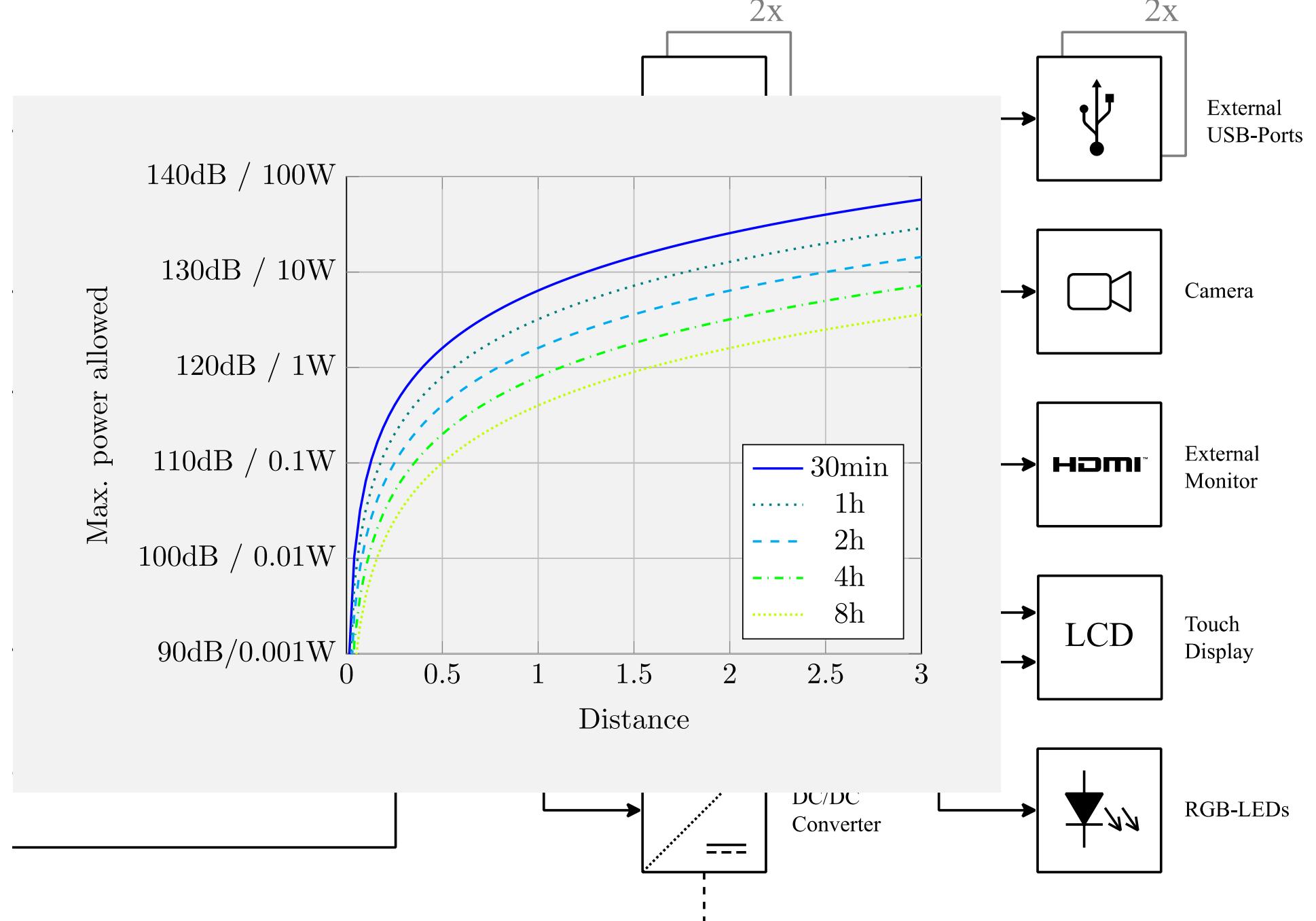
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Arrays

Design

Evaluation

Fazit





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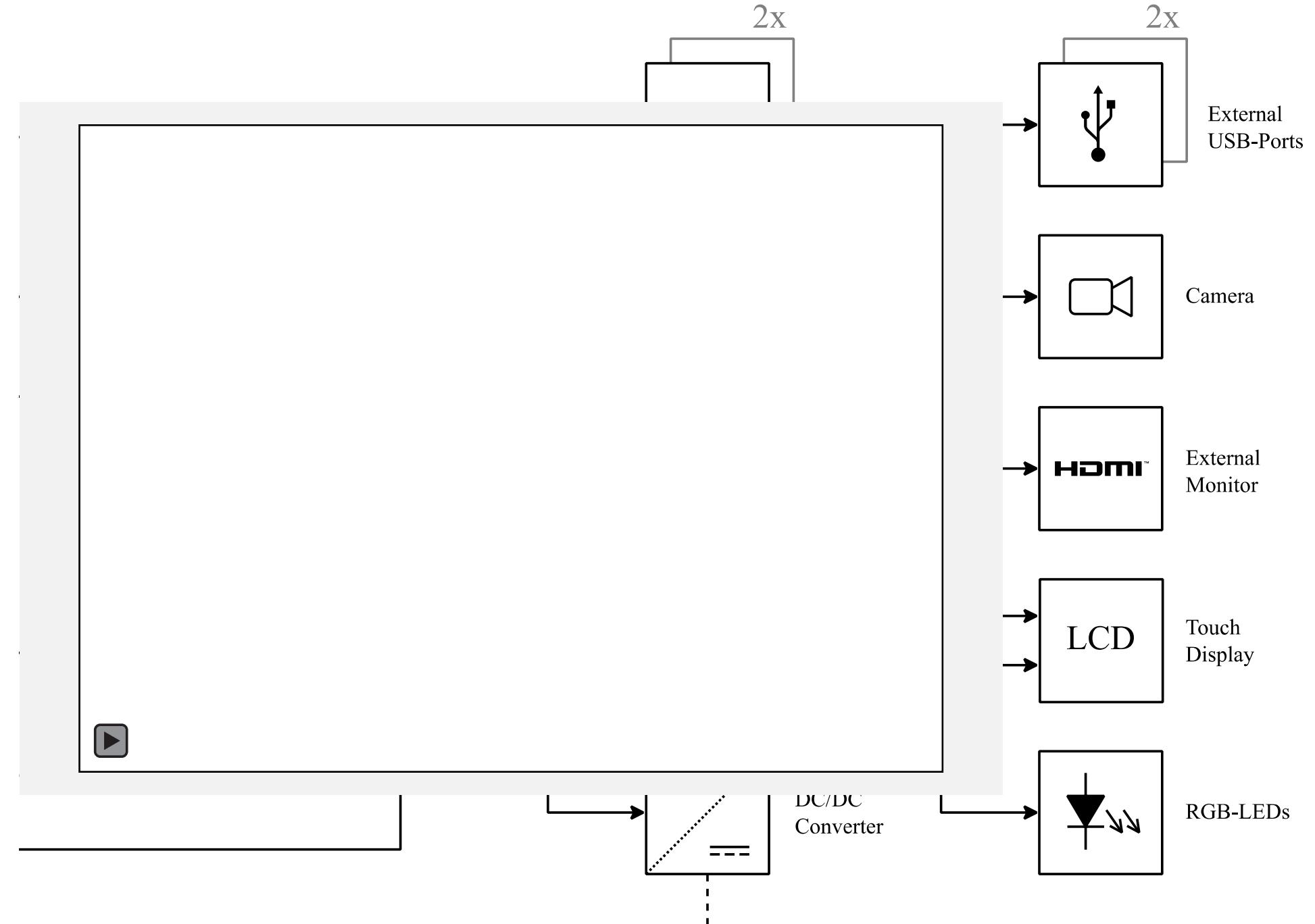
Akustik

Arrays

Design

Evaluation

Fazit



Einführung

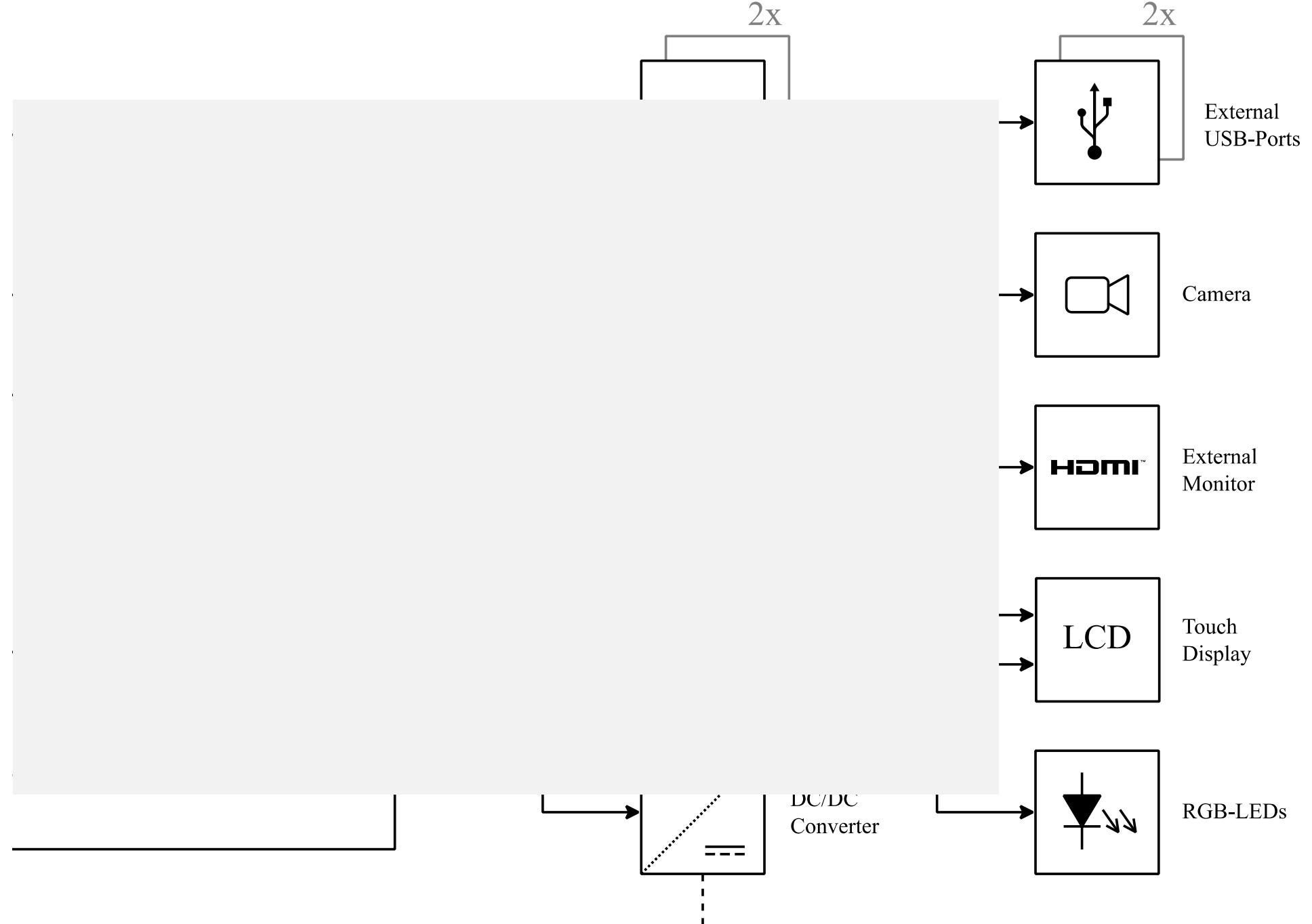
Akustik

Arrays

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Evaluation

Fazit



Einführung

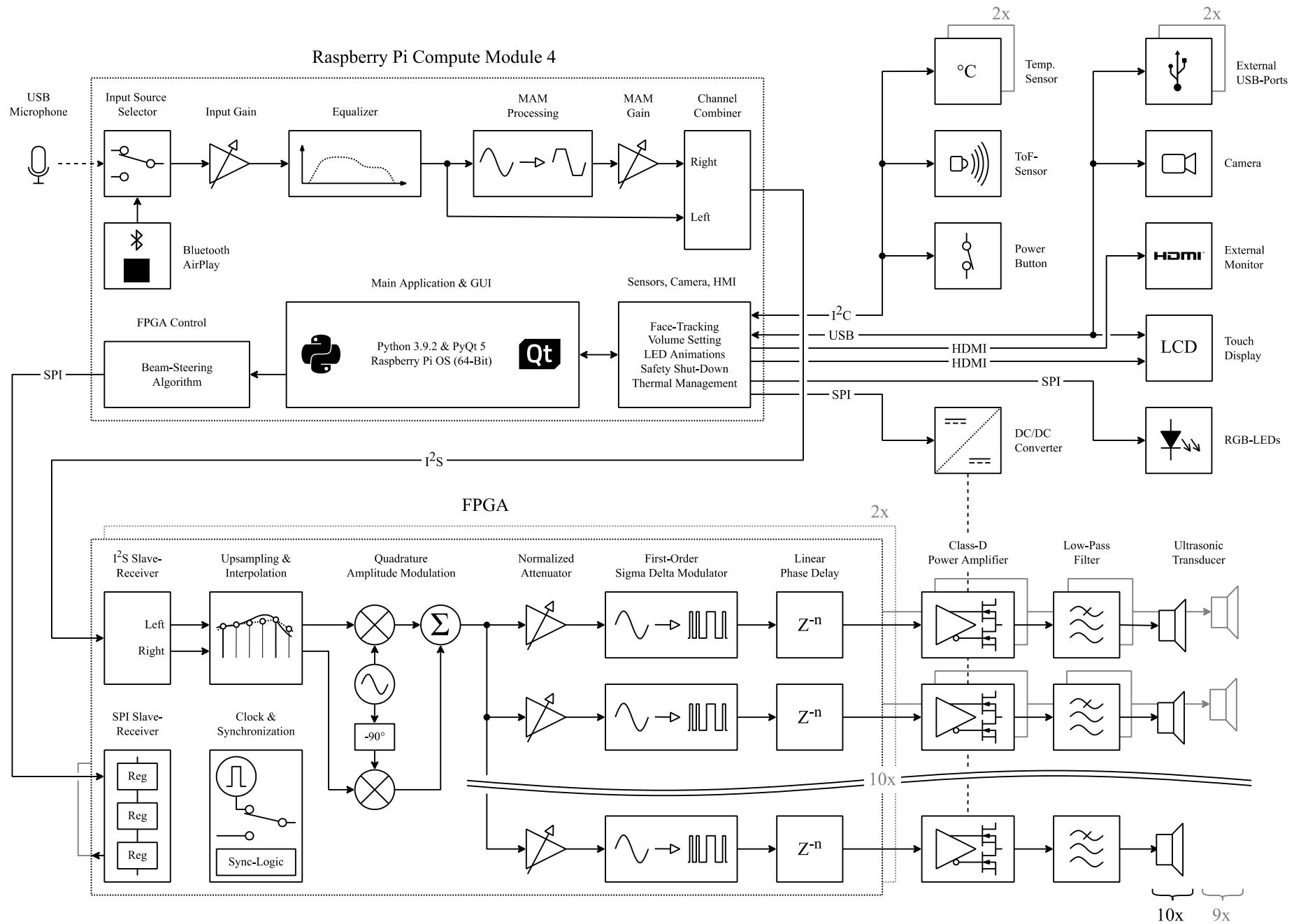
Akustik

Arrays

Design

Evaluation

Fazit



Einführung

Akustik

Arrays

Design

Evaluation

Fazit



Einführung

Akustik

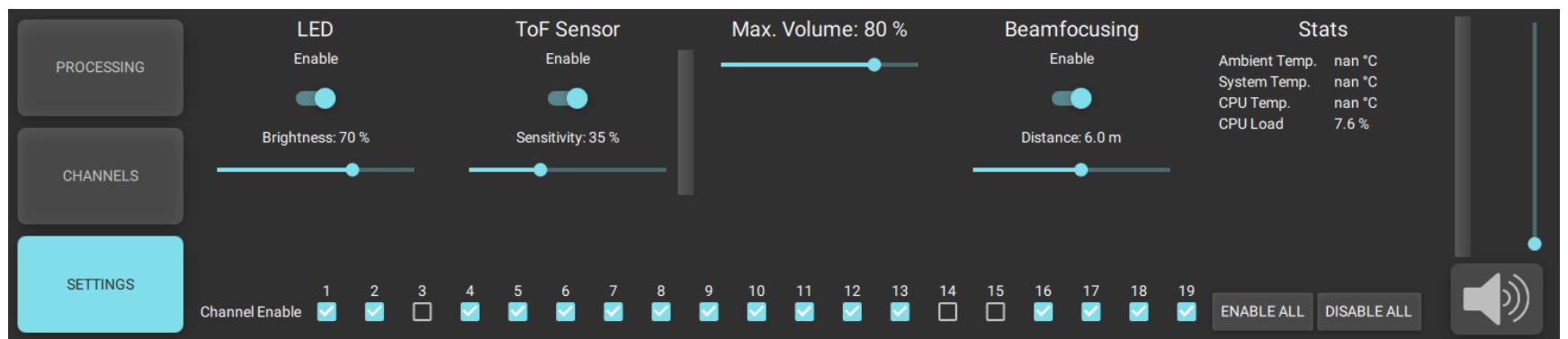
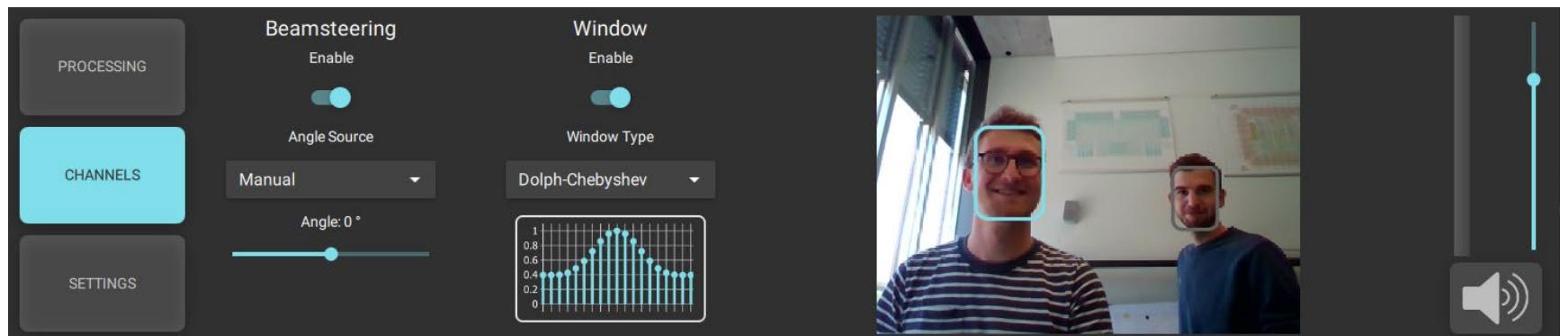
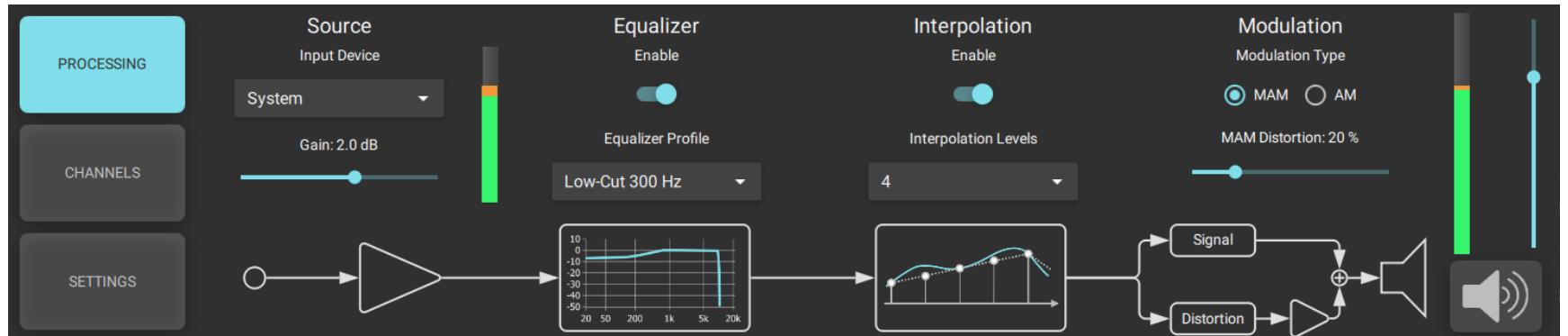
Arrays

Design

Evaluation

Fazit

GUI



Einführung

Akustik

Arrays

Design

Evaluation

Fazit

Endprodukt



Einführung

Akustik

Arrays

Design

Evaluation

Fazit

Funktioniert es?

Einführung

Quantifizierung

Akustik

Ultraschall - Messungen

Arrays

Keine Absorber - Kammer

Design

Human Expertise Test

Evaluation

17 Teilnehmer: innen
Audio Qualität
Richtcharakteristik

Fazit

Einführung

Akustik

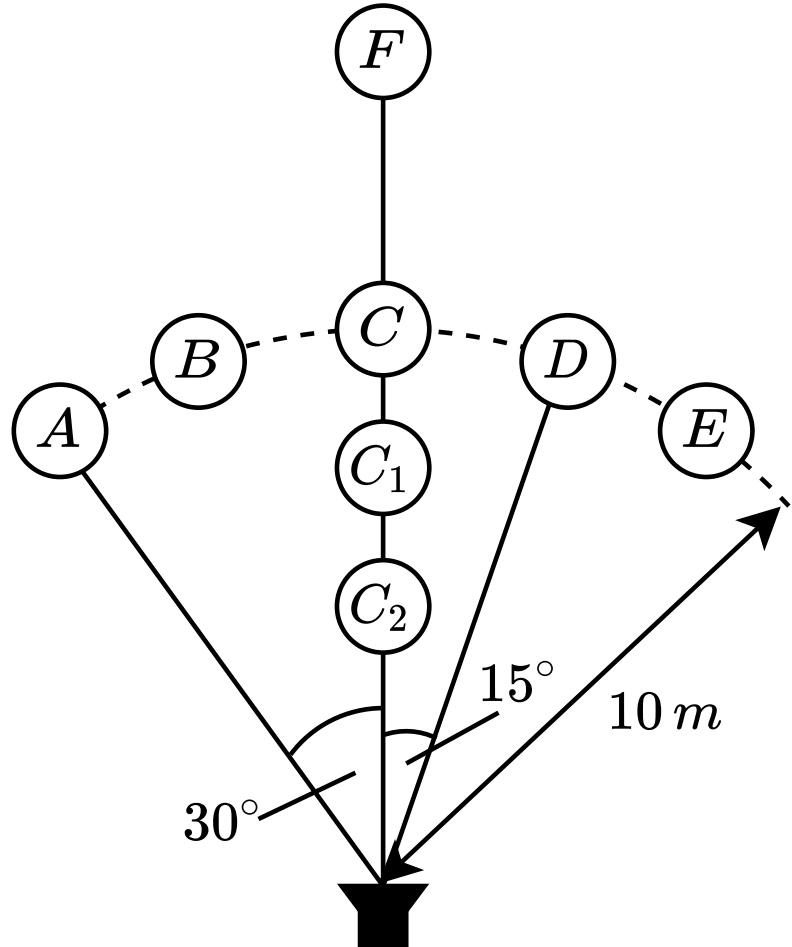
Arrays

Design

Evaluation

Fazit

Messsetup



Audio Qualität

Einführung

Akustik

Arrays

Design

Evaluation

Fazit



4

Acceptable
hearing
experience,
speech
recognizable
without effort

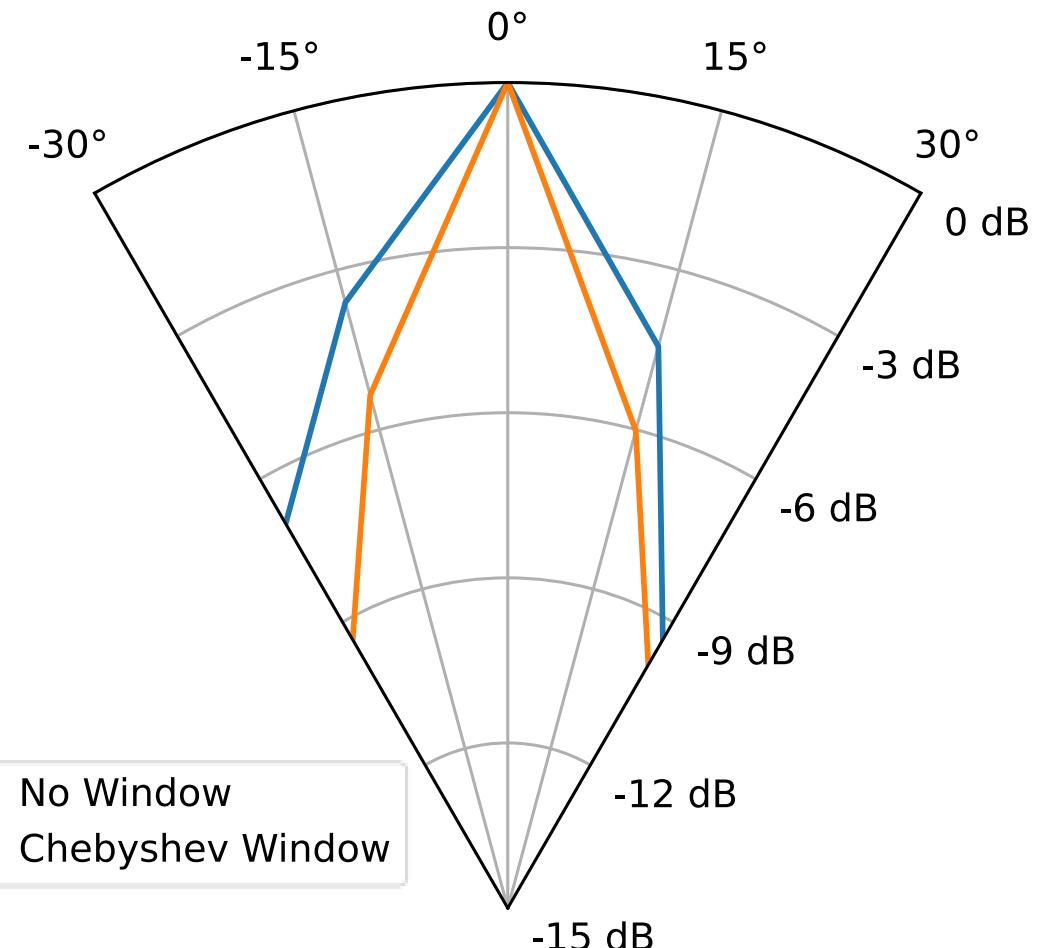
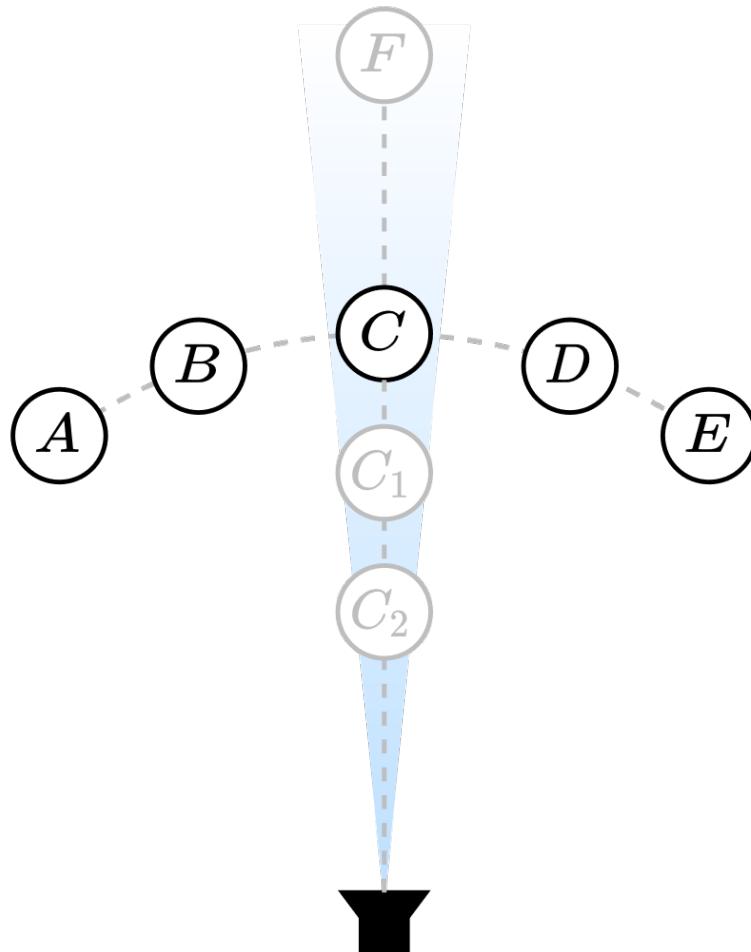
5

Enjoyable
hearing
experience,
appropriate for
daily use

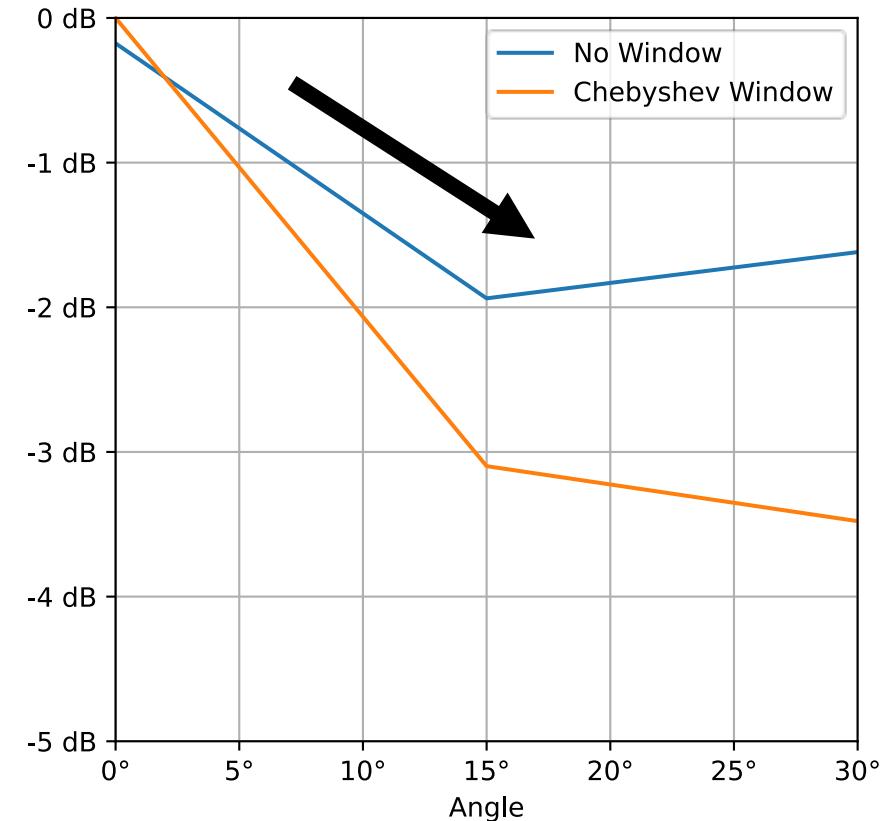
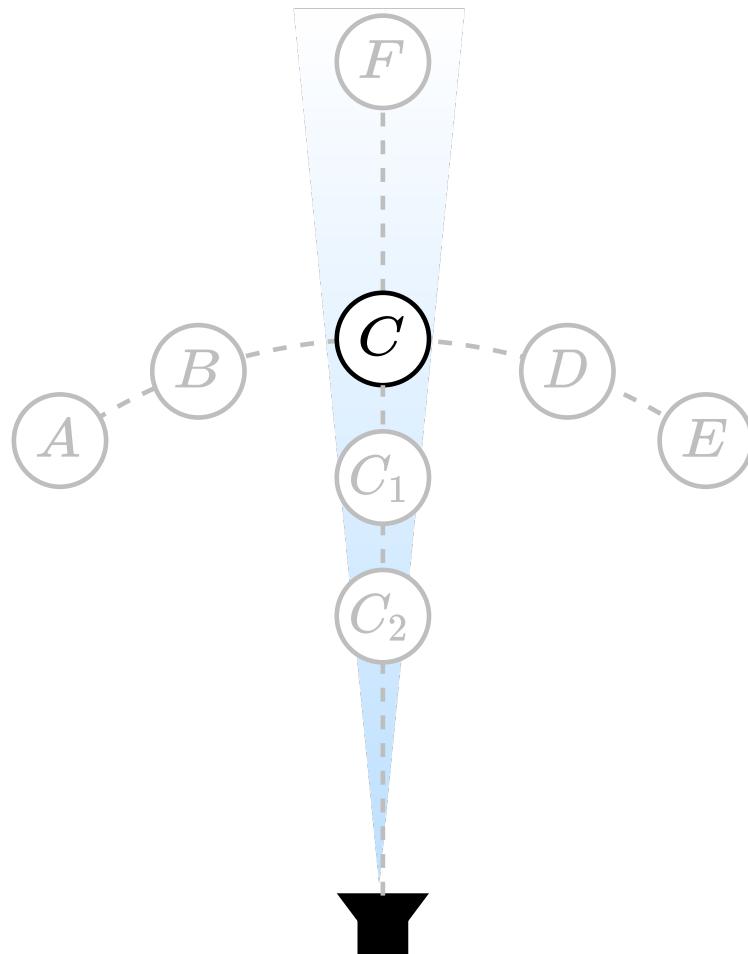
4.5 Sprache

4.2 Musik

Richtcharakteristik



Beam Steering



Einführung

Akustik

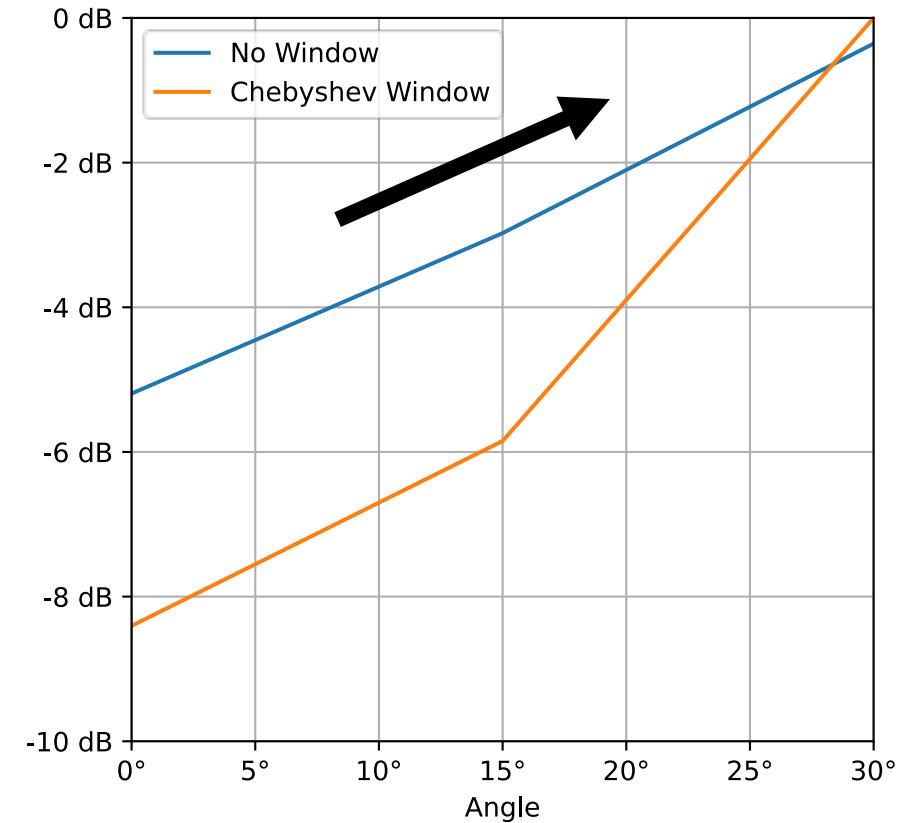
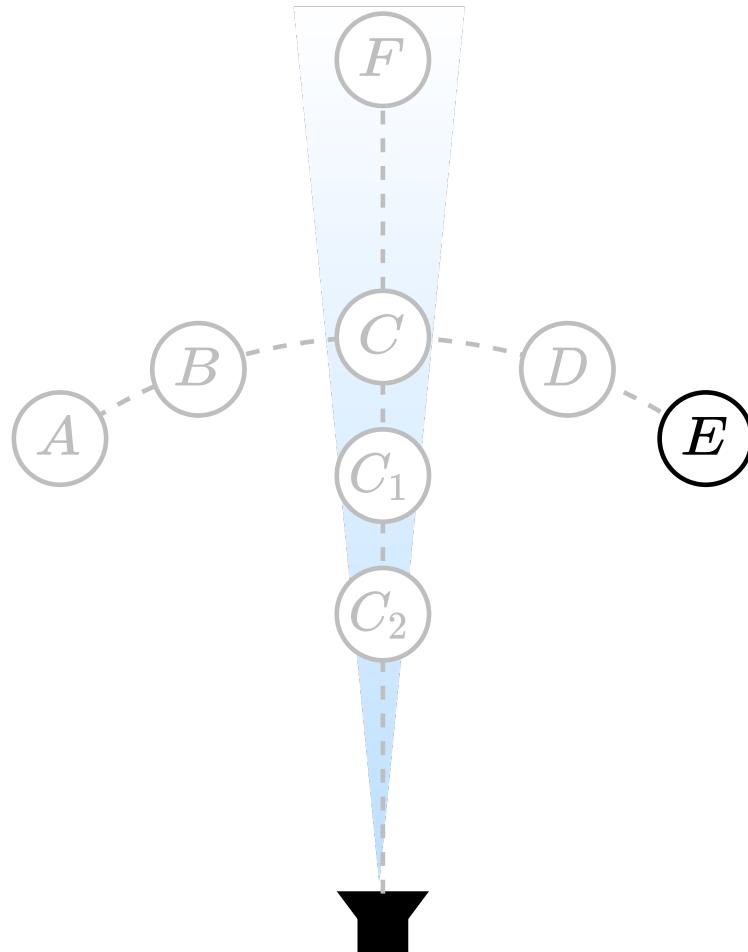
Arrays

Design

Evaluation

Fazit

Beam Steering





Einführung

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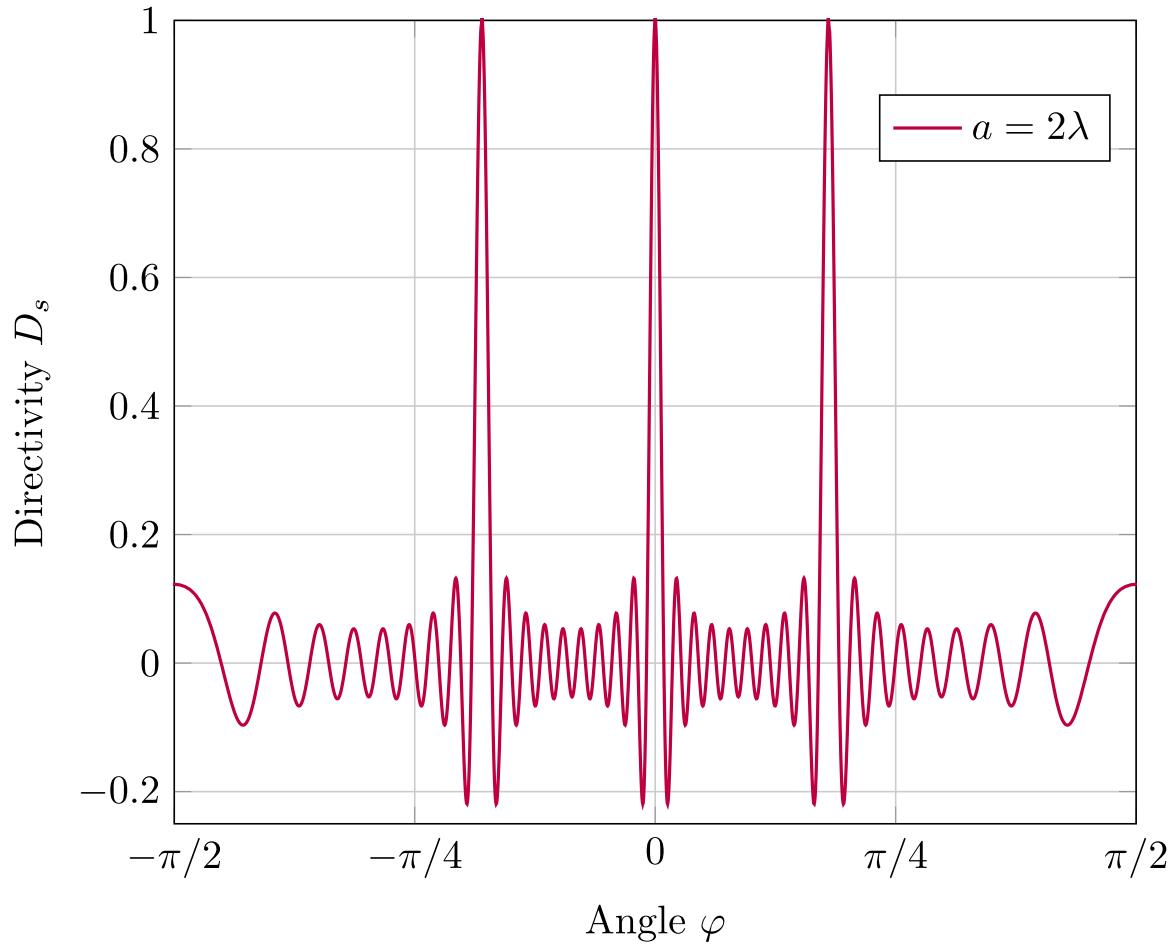
Fazit

Fazit

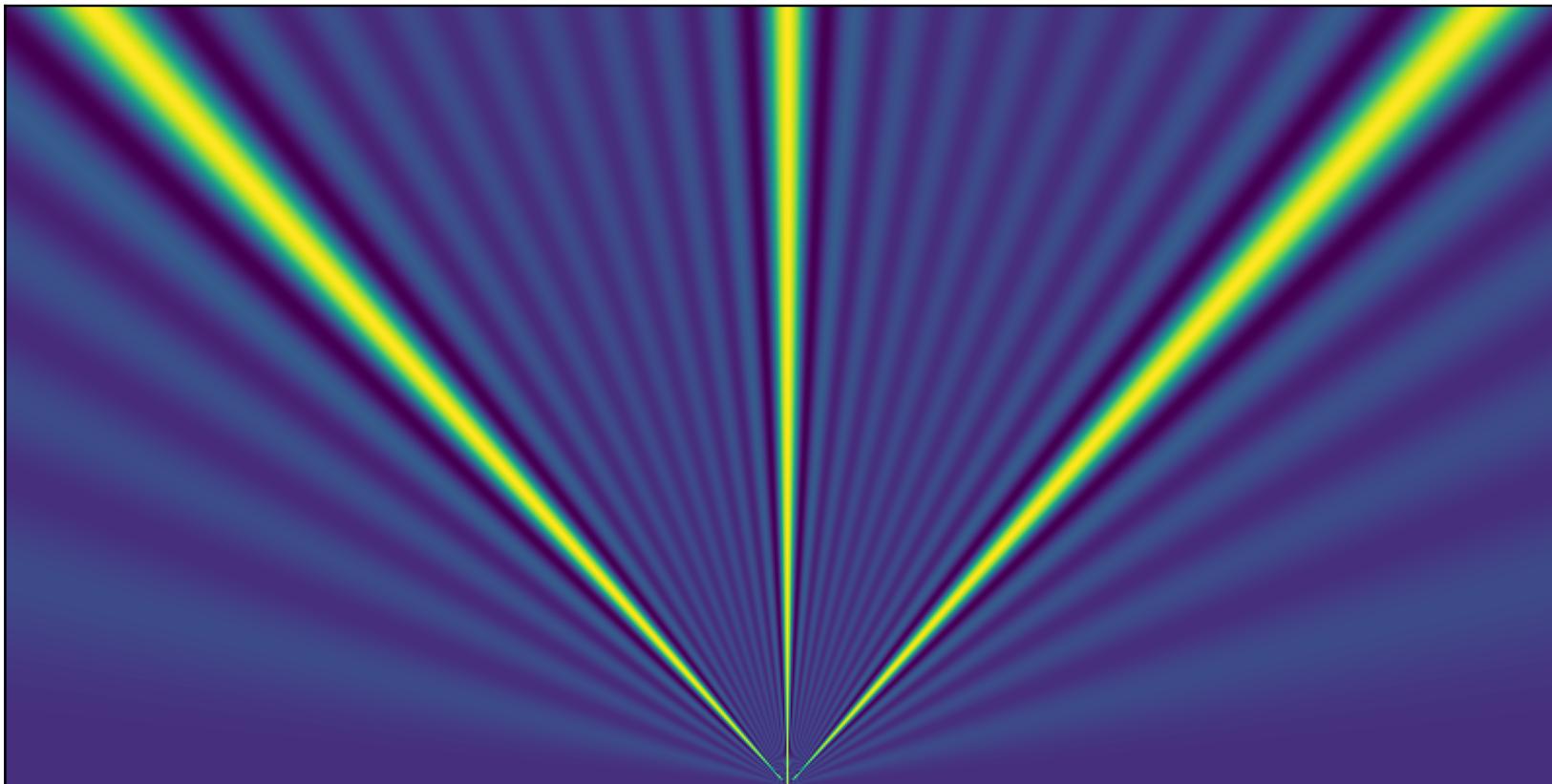
Demonstration



Grating Lobe



Grating Lobe



Min. / Max. Winkel

Minimaler Winkel

$$\varphi_{min} = \sin^{-1} \frac{\tau_{min} c_0}{Md} \approx 0.21^\circ$$

Maximaler Winkel

$$\varphi_{max} = \sin^{-1} \frac{\tau_{max} c_0}{Md} \approx 53.4^\circ$$

$$\tau_{max} = \tau_{min} \cdot N_{MC} = 320 \text{ ns} \cdot 4092 = 654 \mu\text{s}$$

Far Field

Transducer $d_T \approx 3a \approx 6.5 \text{ cm}$

Array $d_A \approx 3$ Länge Array $\approx 78 \text{ cm}$