



Audio-Beamformer

Thierry Schwaller

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Einführung

Idee

Akustik

Direktiver Lautsprecher entwickeln

Arrays

Design

Audio Beam Steering

Evaluation

Fazit

Einführung

Konzept

Akustik

Arrays

Klassisches Lautsprecher Array

Design

Parametrisches Lautsprecher Array

Evaluation

Fazit

Einführung

Akustik

Arrays

Design

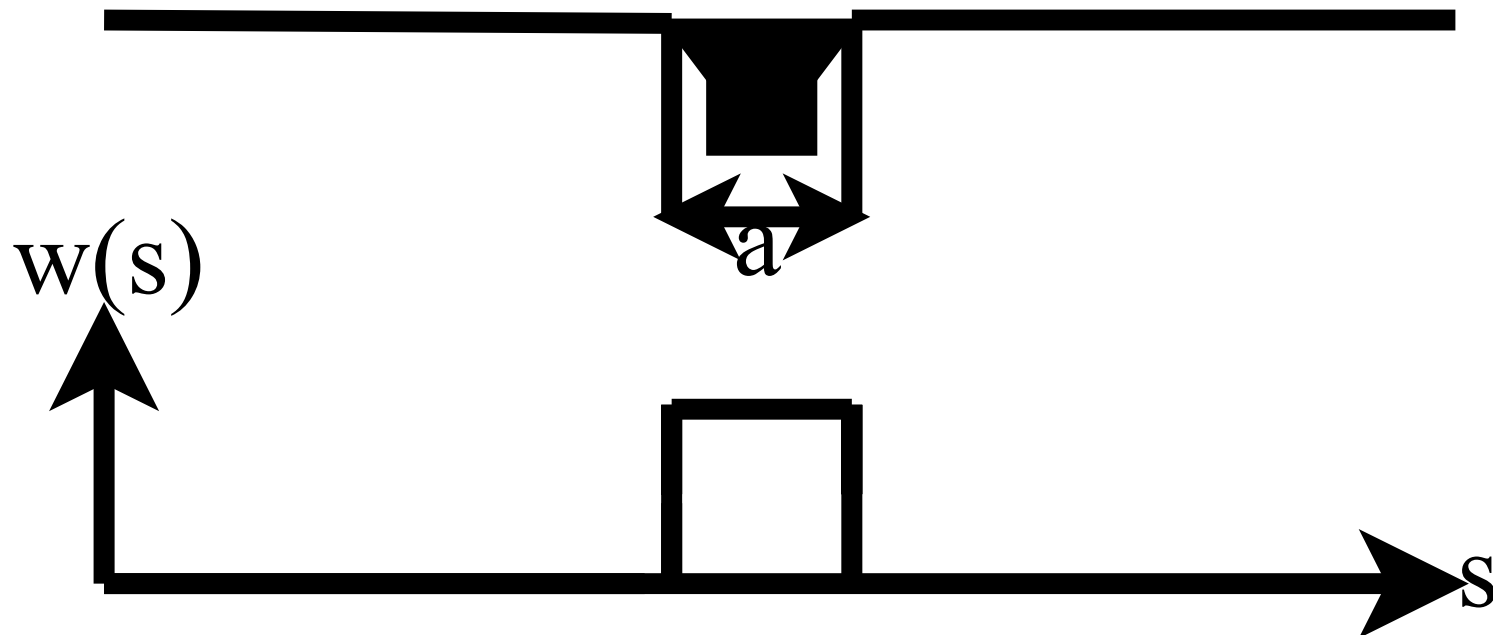
Evaluation

Fazit

Direktivität

Akustische Direktivität

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



Einführung

Akustik

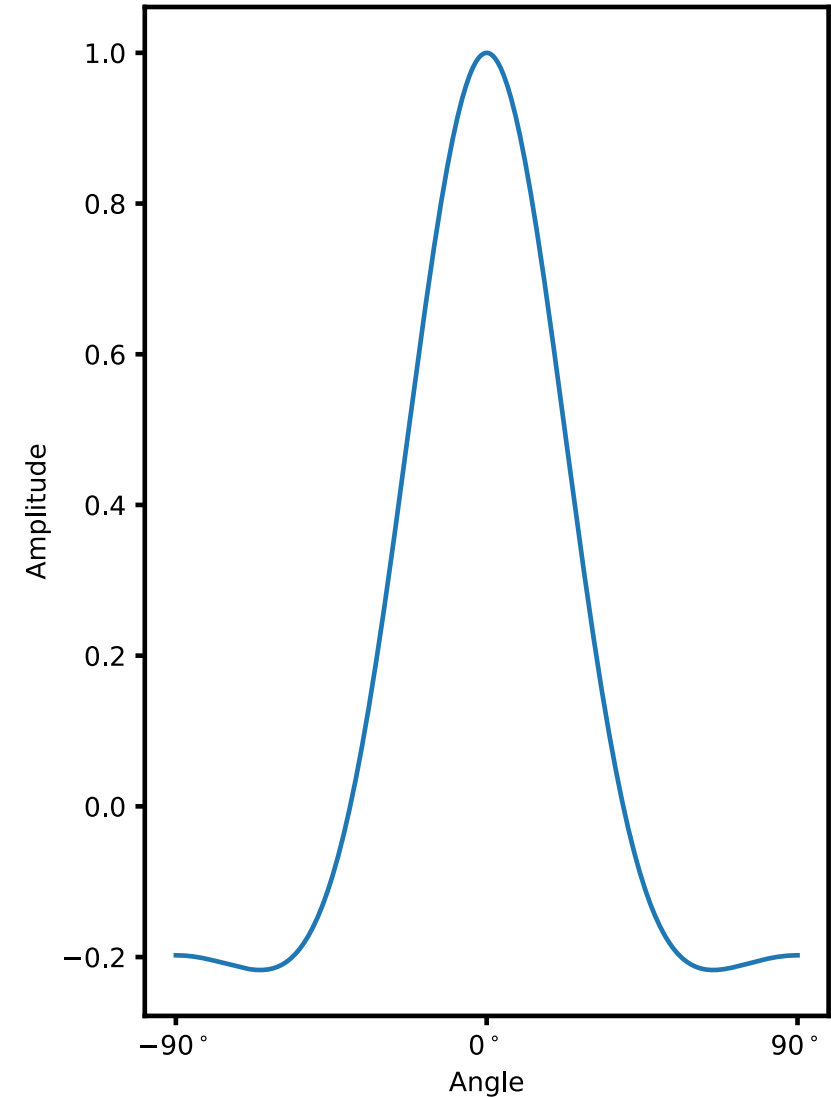
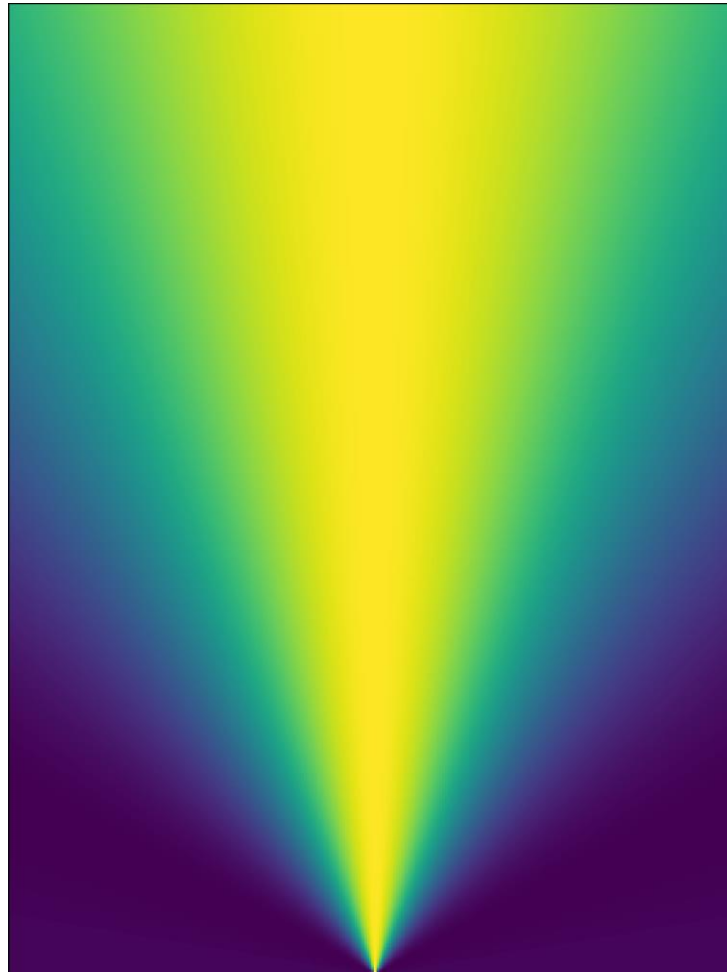
Arrays

Design

Evaluation

Fazit

Direktivität $a = \lambda / 2$



Einführung

Akustik

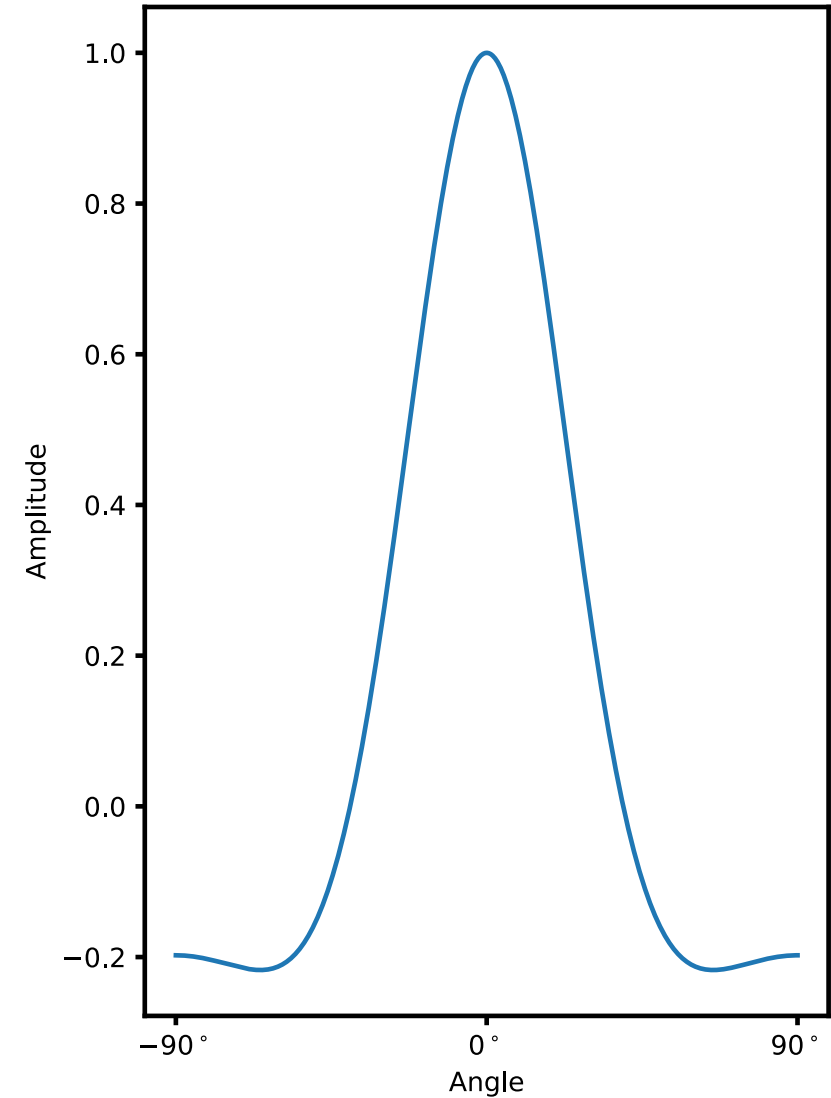
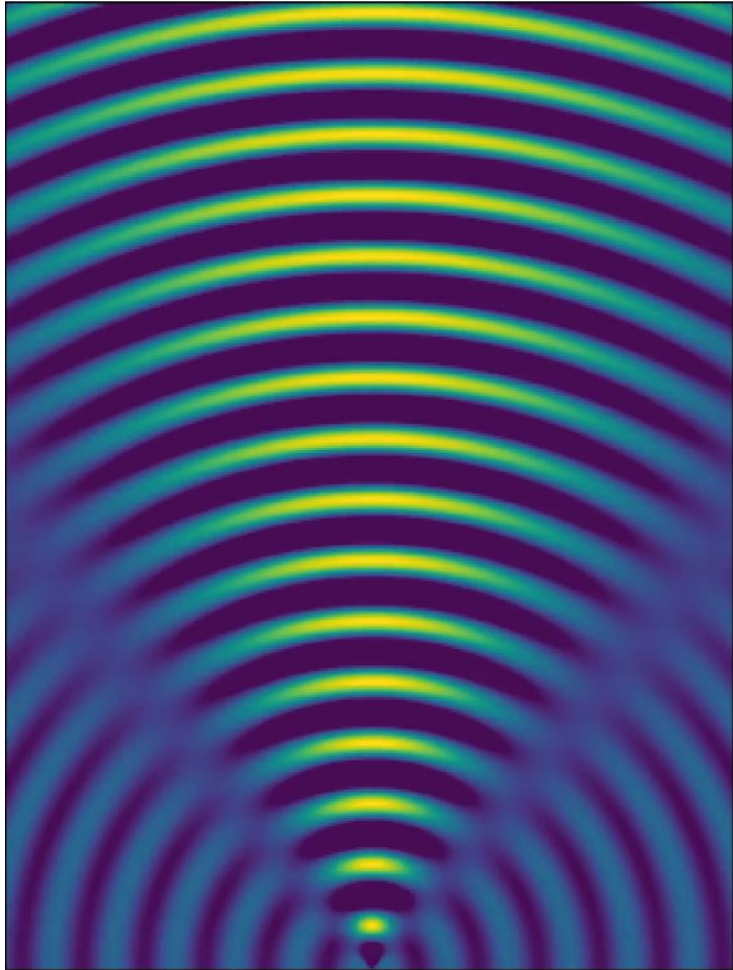
Arrays

Design

Evaluation

Fazit

Schallausbreitung



Einführung

Akustik

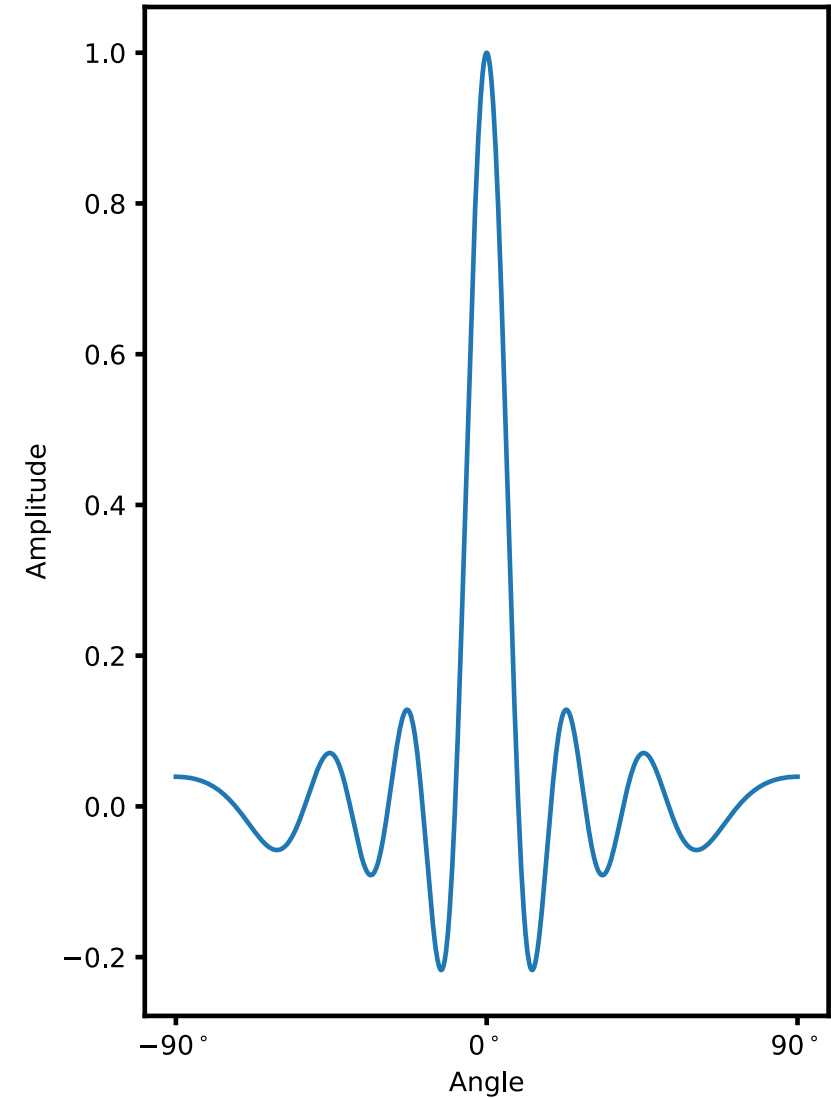
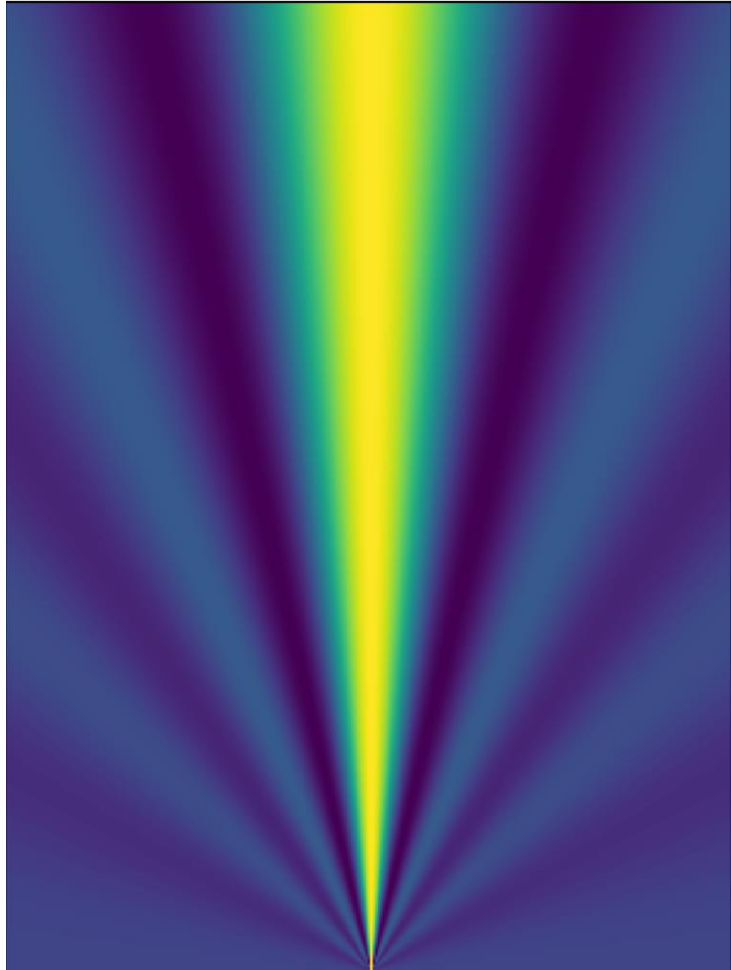
Arrays

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Fazit

Direktivität $a = 2\lambda$



Einführung

Akustik

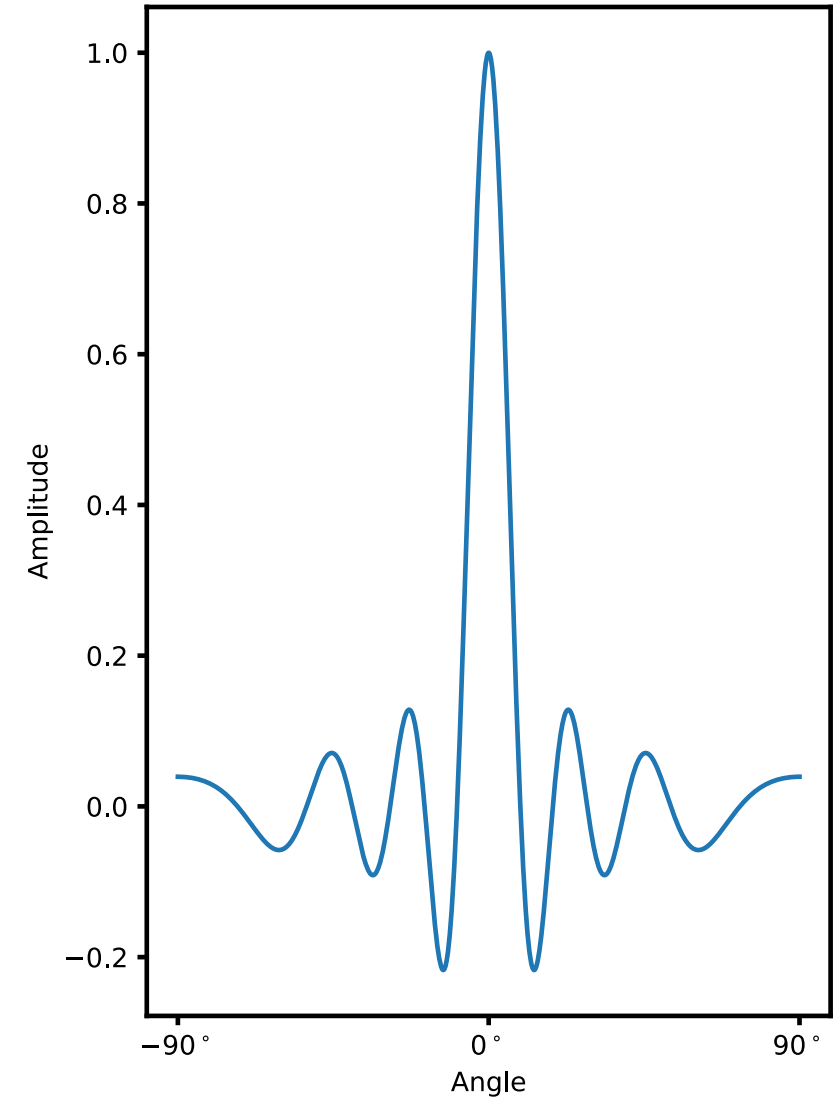
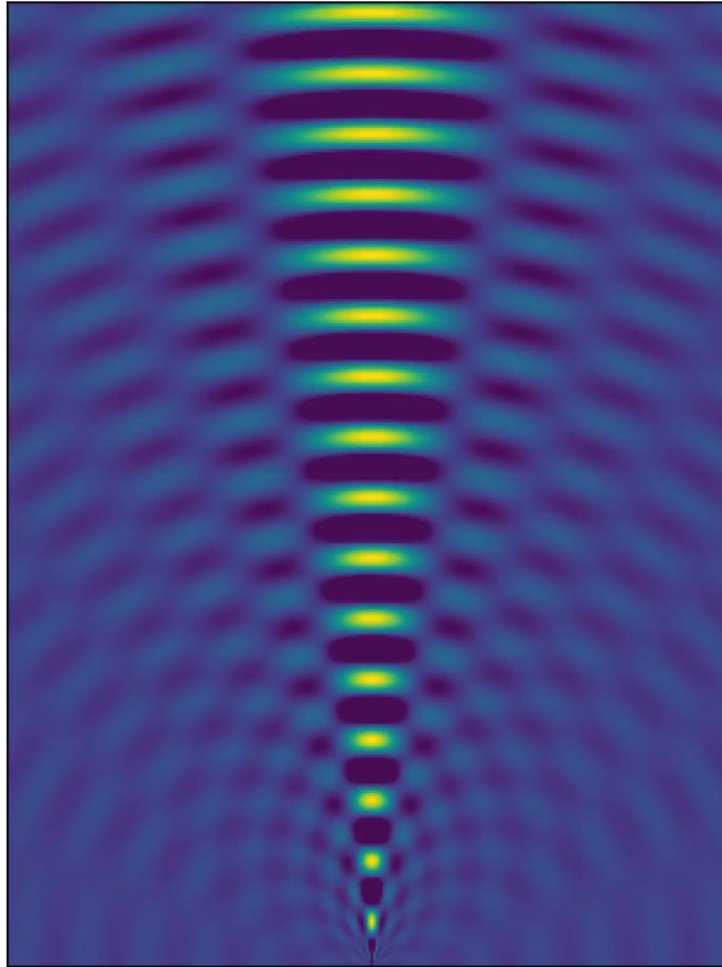
Arrays

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Schallausbreitung



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Sound from Ultrasound

Demodulation in der Luft

Demodulation

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

Zweite Ableitung führt zu Hochpass

Ideale Umhüllende

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

Amplituden Modulation

Einführung

Akustik

Arrays

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Evaluation

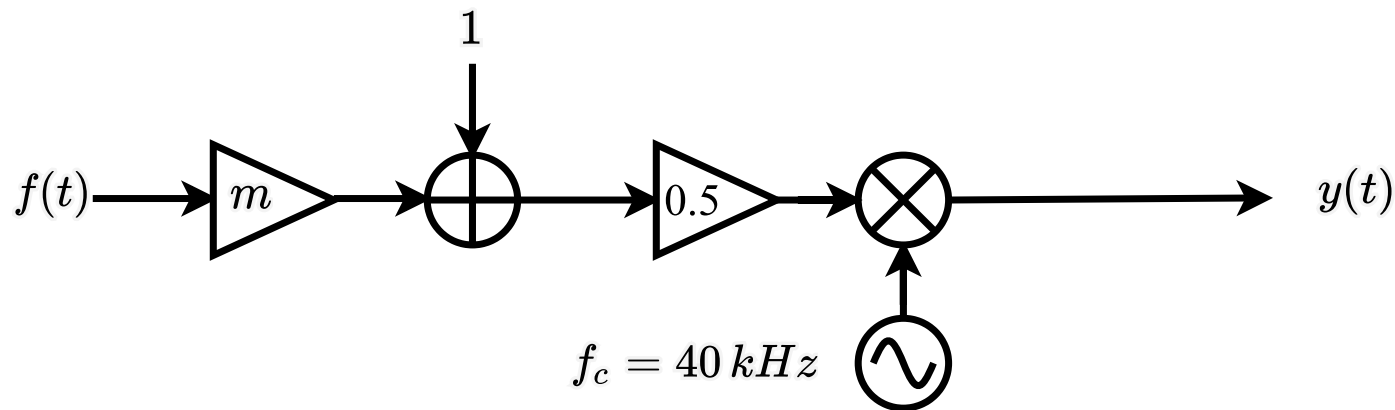
Fazit

Umhüllende

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

Hörbares Signal

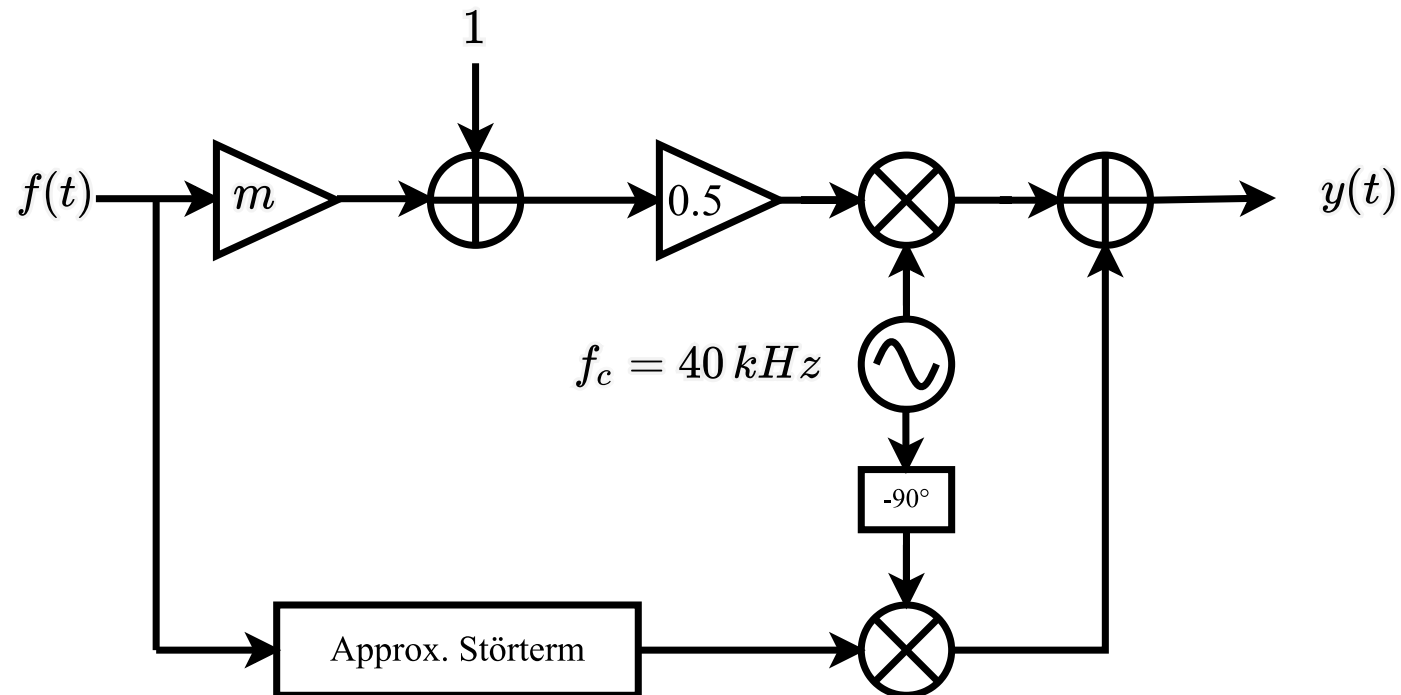
$$f_{RX}(t) = mf(t) + \frac{1}{2}m^2f^2(t)$$



Modified AM

Ähnlicher Aufbau wie QAM

Störterm-Unterdrückung



Einführung

Akustik

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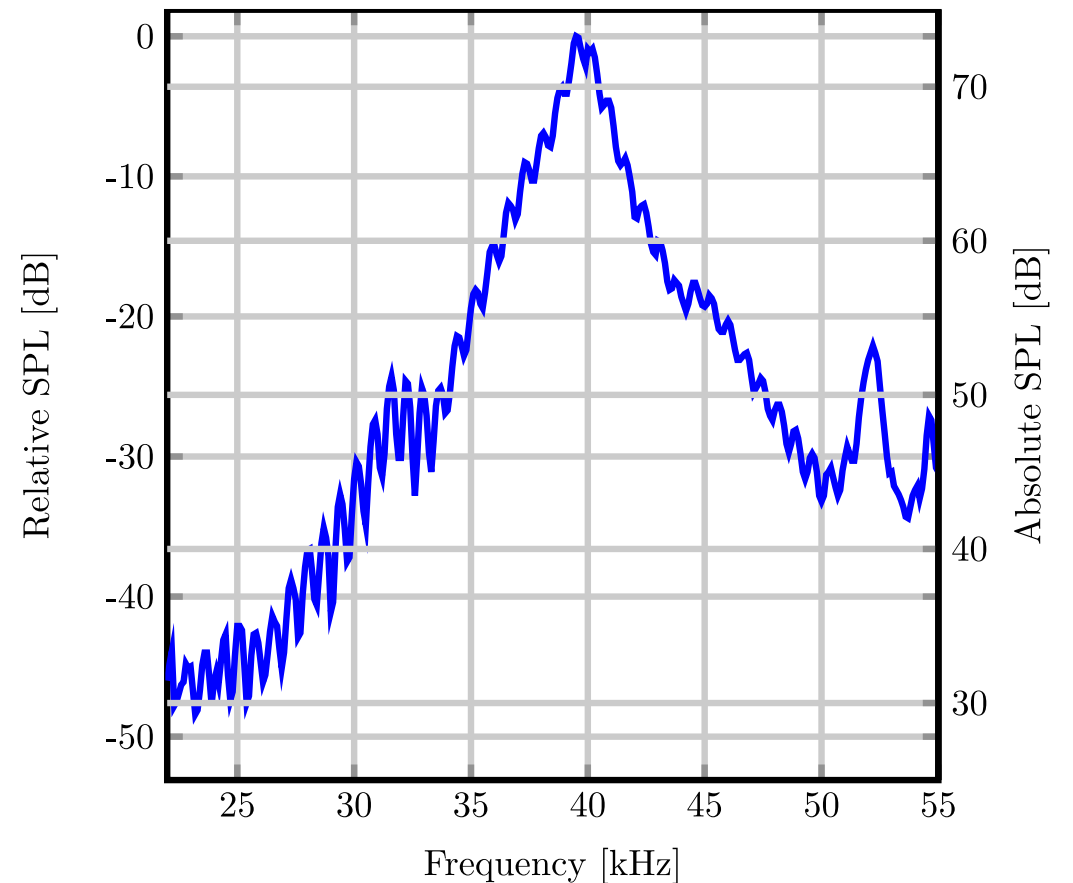
Fazit

Piezoelektrischer Ultraschall-Transducer

Hohe Güte

$$f_R = 40 \text{ kHz}$$

Schmale Bandbreite



Vorteile von Arrays

Einführung

Akustik

Arrays

Design

Evaluation

Fazit

Höherer Schalldruck

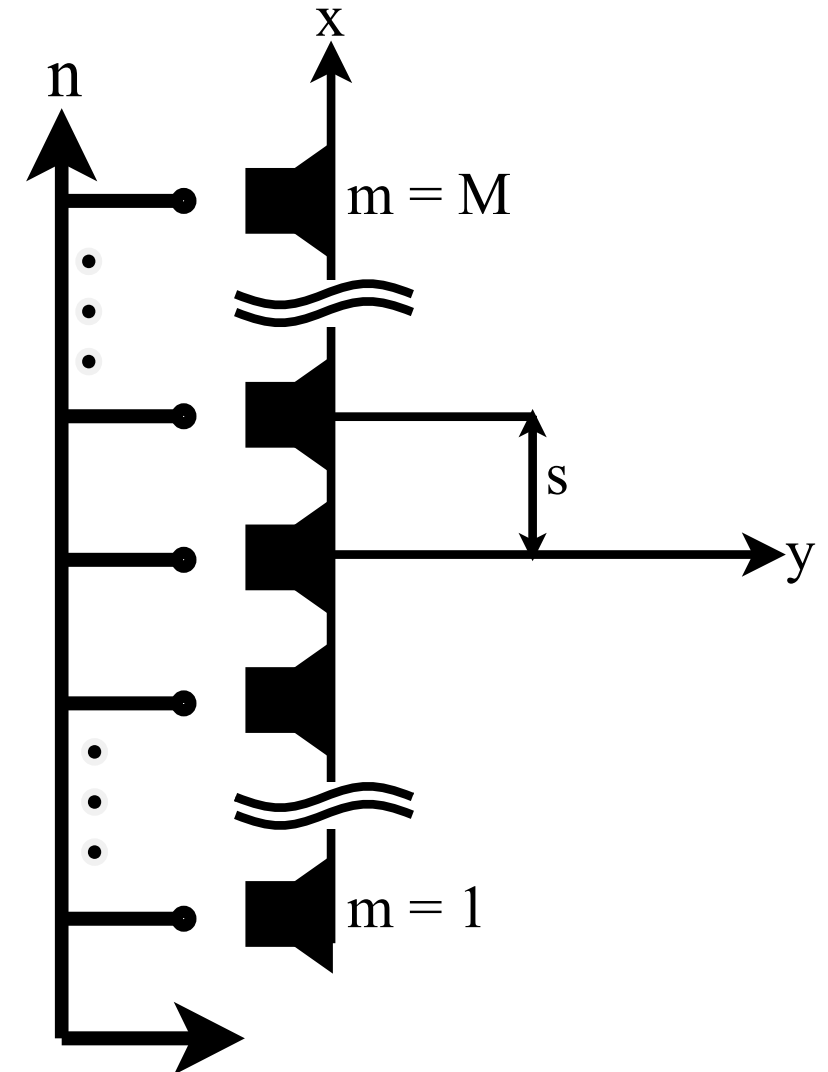
Verstärkung der Richtcharakteristik

Ermöglicht Beamforming

Richtcharakteristik

Richtcharakteristik

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



Einführung

Akustik

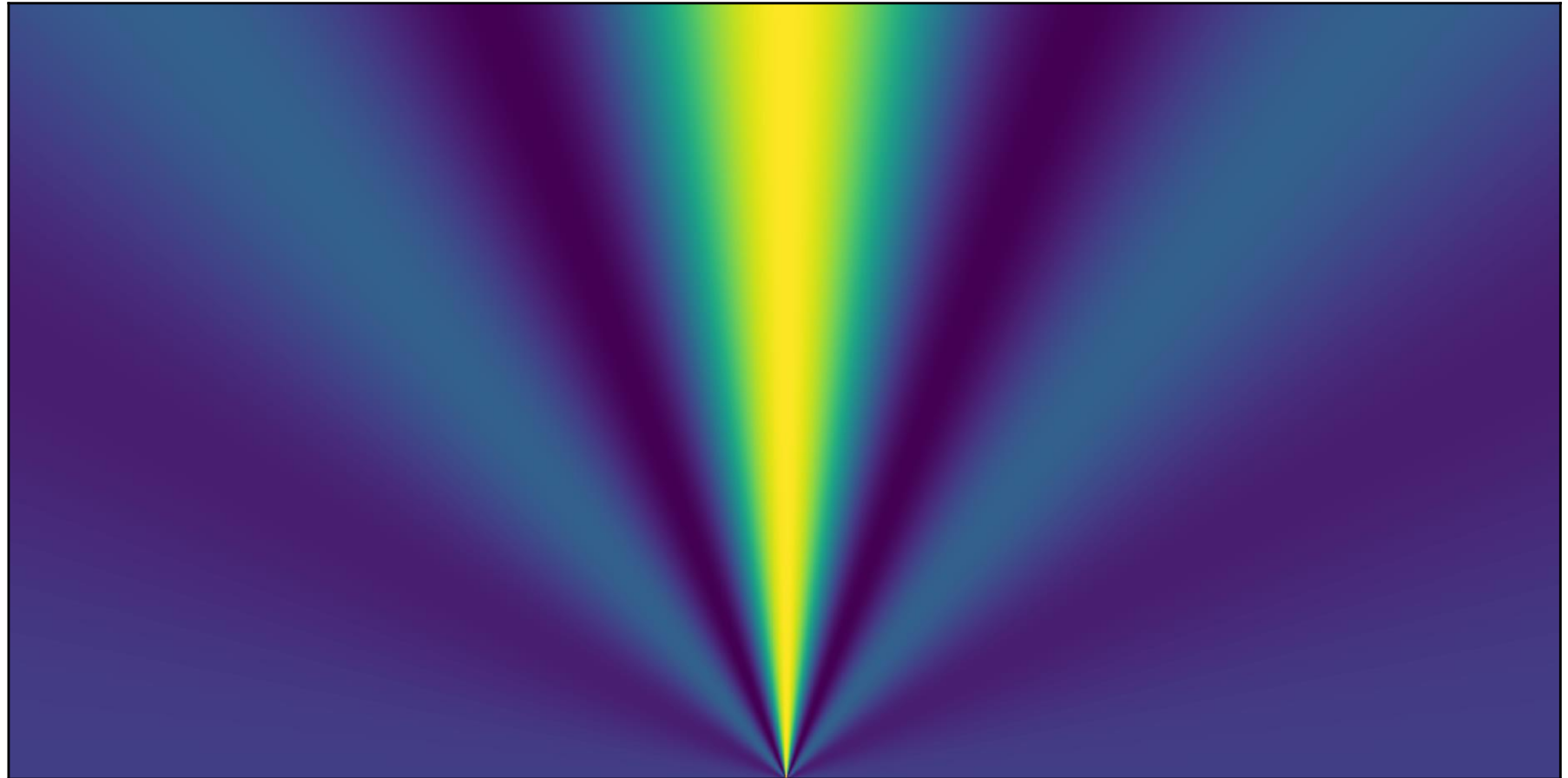
Arrays

Design

Evaluation

Fazit

Richtcharakteristik $M = 5$



Einführung

Akustik

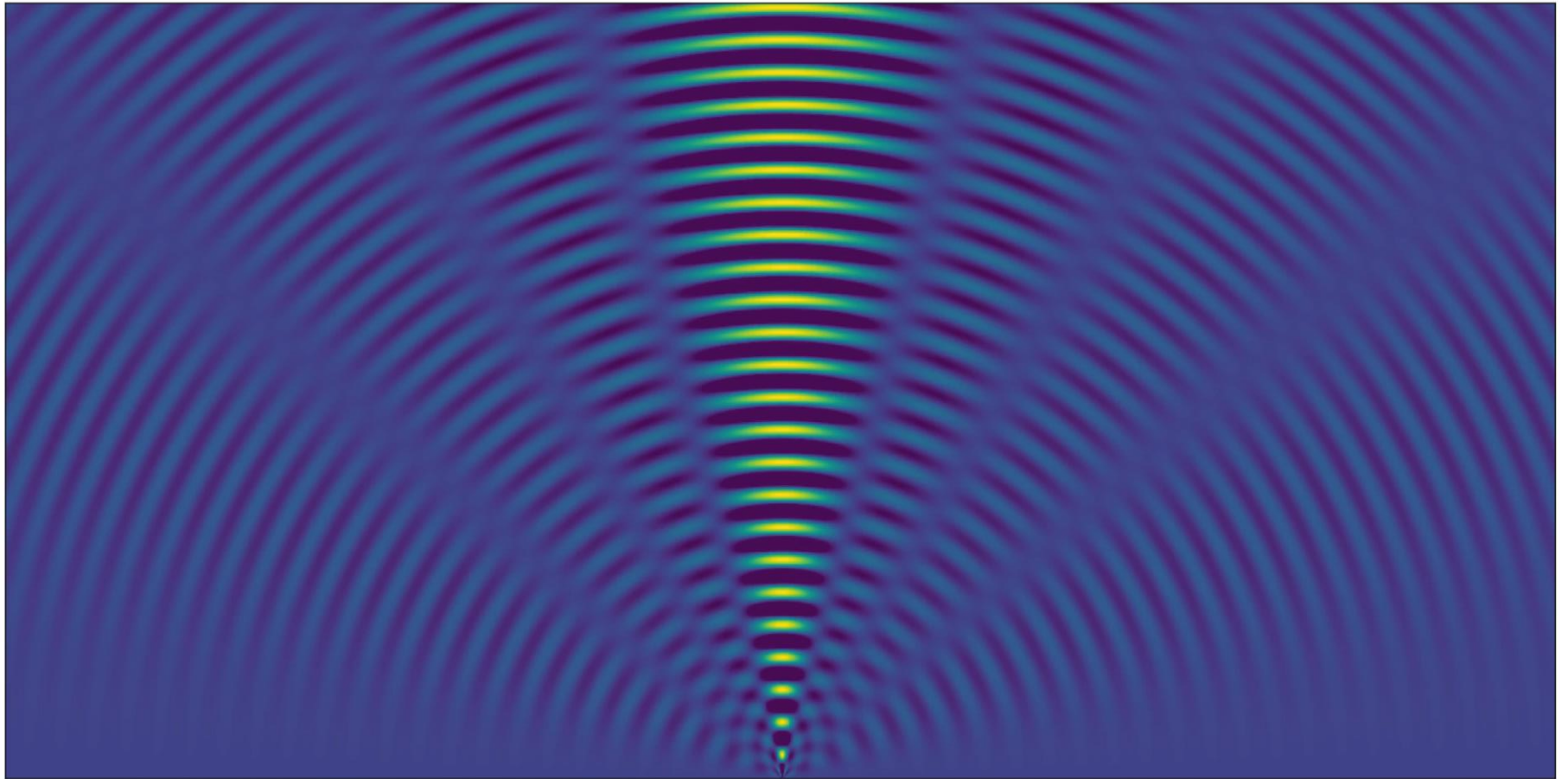
Arrays

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Richtcharakteristik



Einführung

Akustik

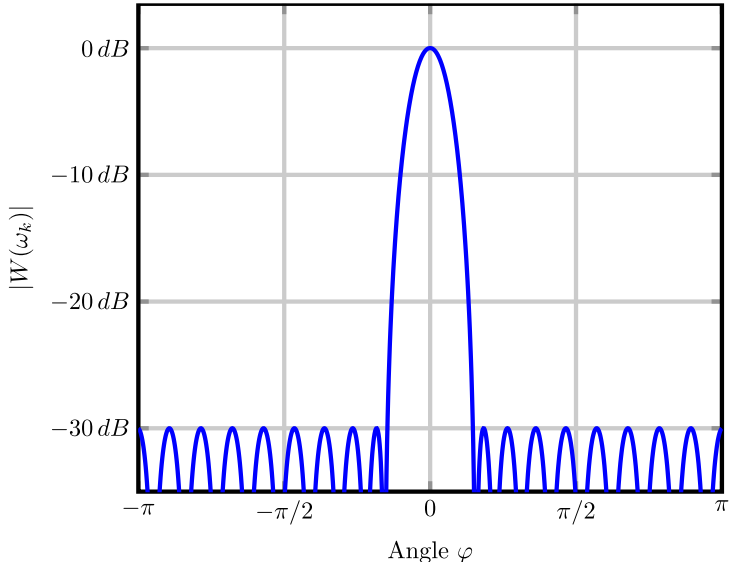
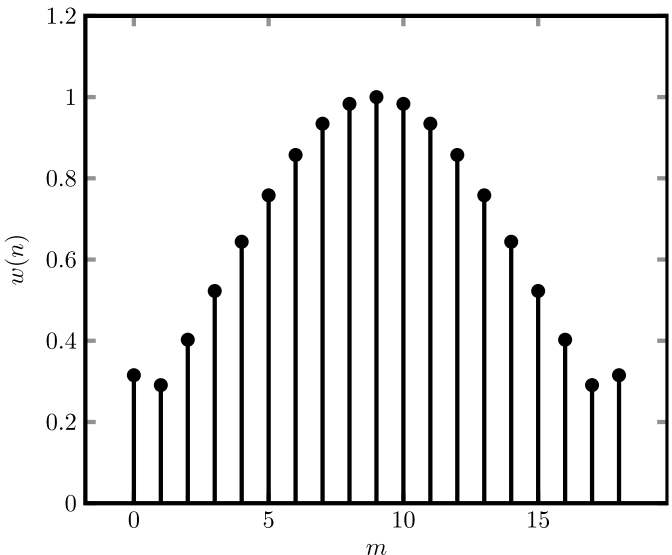
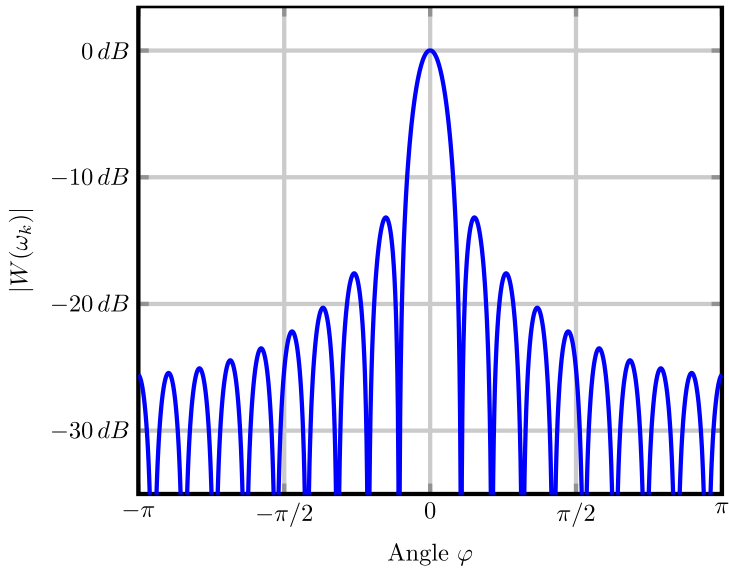
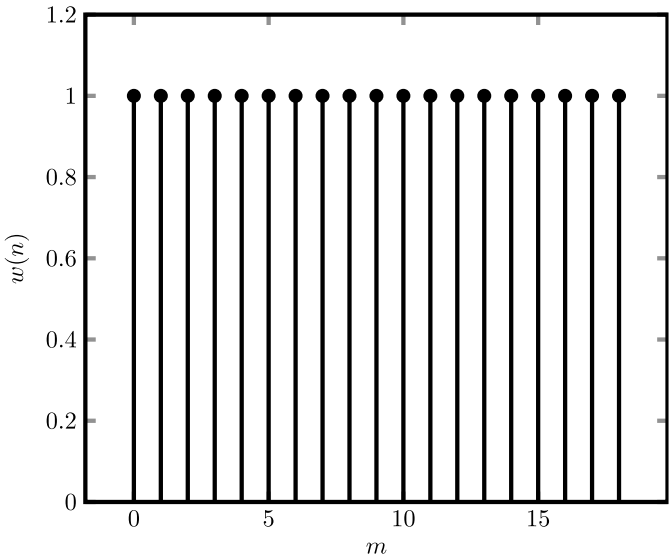
Arrays

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Fazit

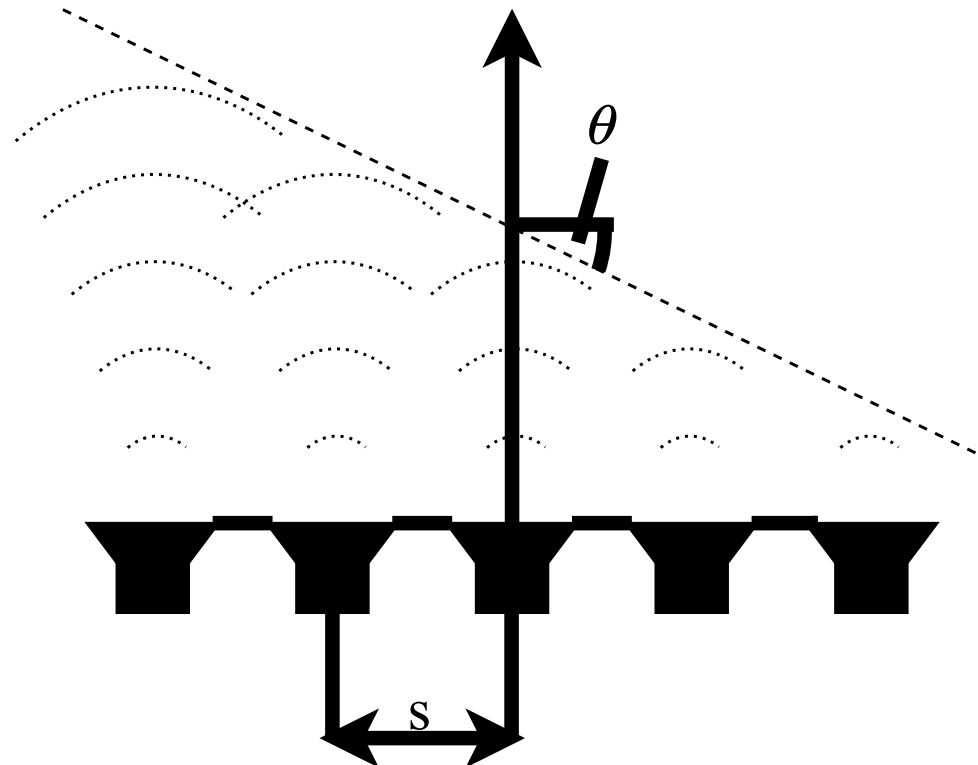
Dolph-Chebyshev Window



Beamsteering

Unterschiedliche Verzögerungen

Wellenfronten ergeben Winkel



Einführung

Akustik

Arrays

Design

Evaluation

Fazit

Einführung

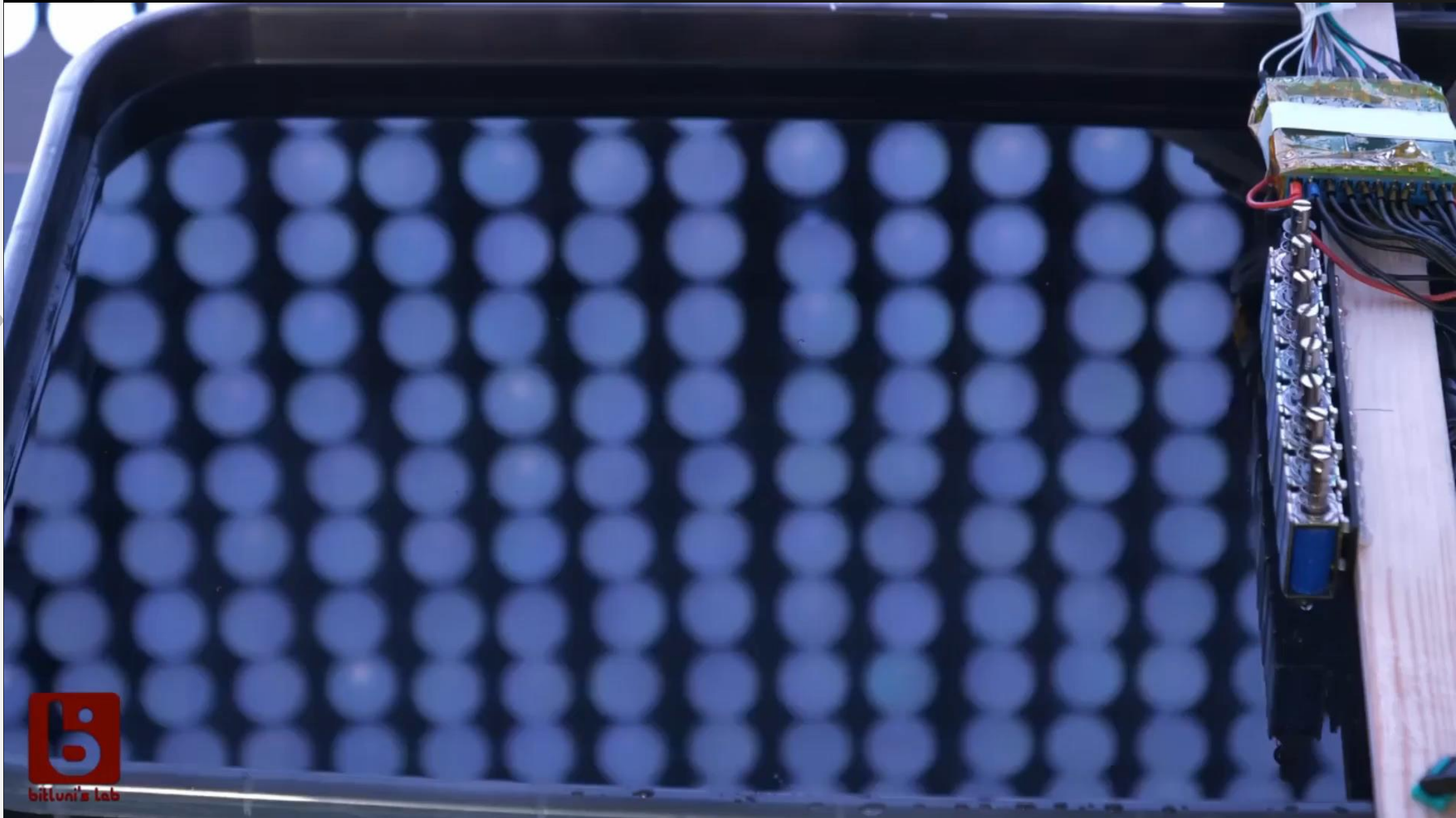
Akustik

Arrays

Design

Evaluation

Fazit



Quelle: bitluni (<https://youtu.be/z4uxC7ISd-c>)

Anforderungen

Einführung

Akustik

Arrays

Design

Evaluation

Fazit

Stand-Alone

Easy to use

Professional

Einführung

Akustik

Arrays

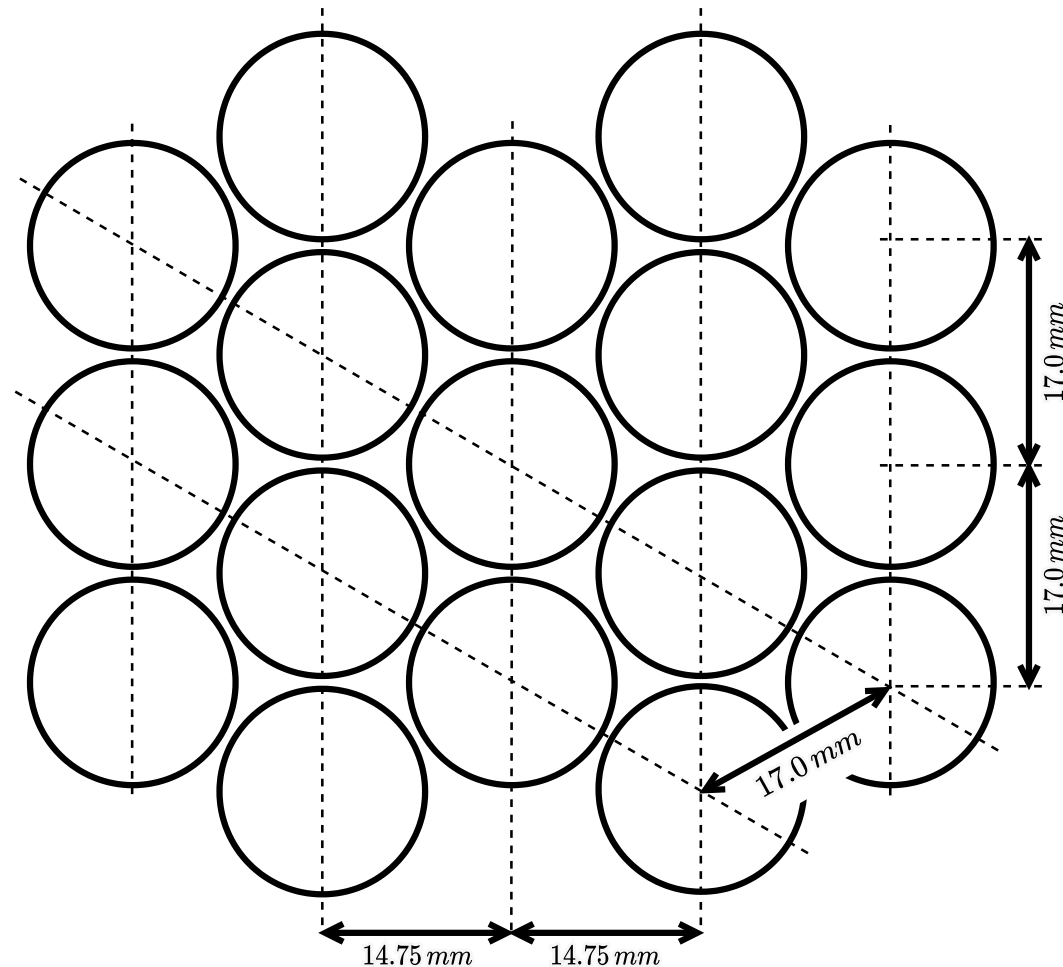
Design

Evaluation

Fazit

Aufbau Array

Hexagonale Anordnung



Einführung

Akustik

Arrays

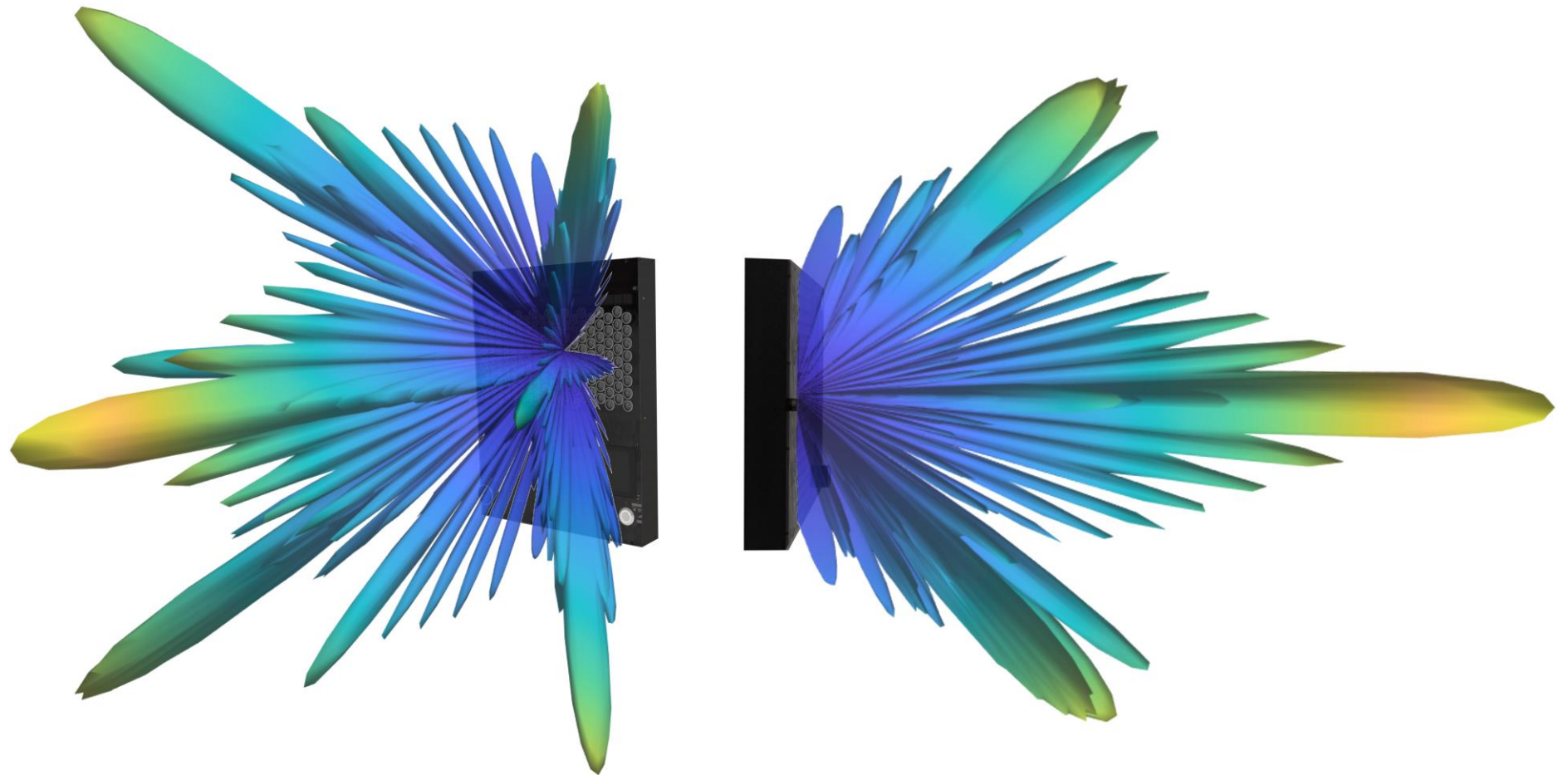
Design

Evaluation

Fazit

Aufbau Array

Matlab Simulation



Einführung

Akustik

Arrays

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Evaluation

Fazit

Signalfluss

Einführung

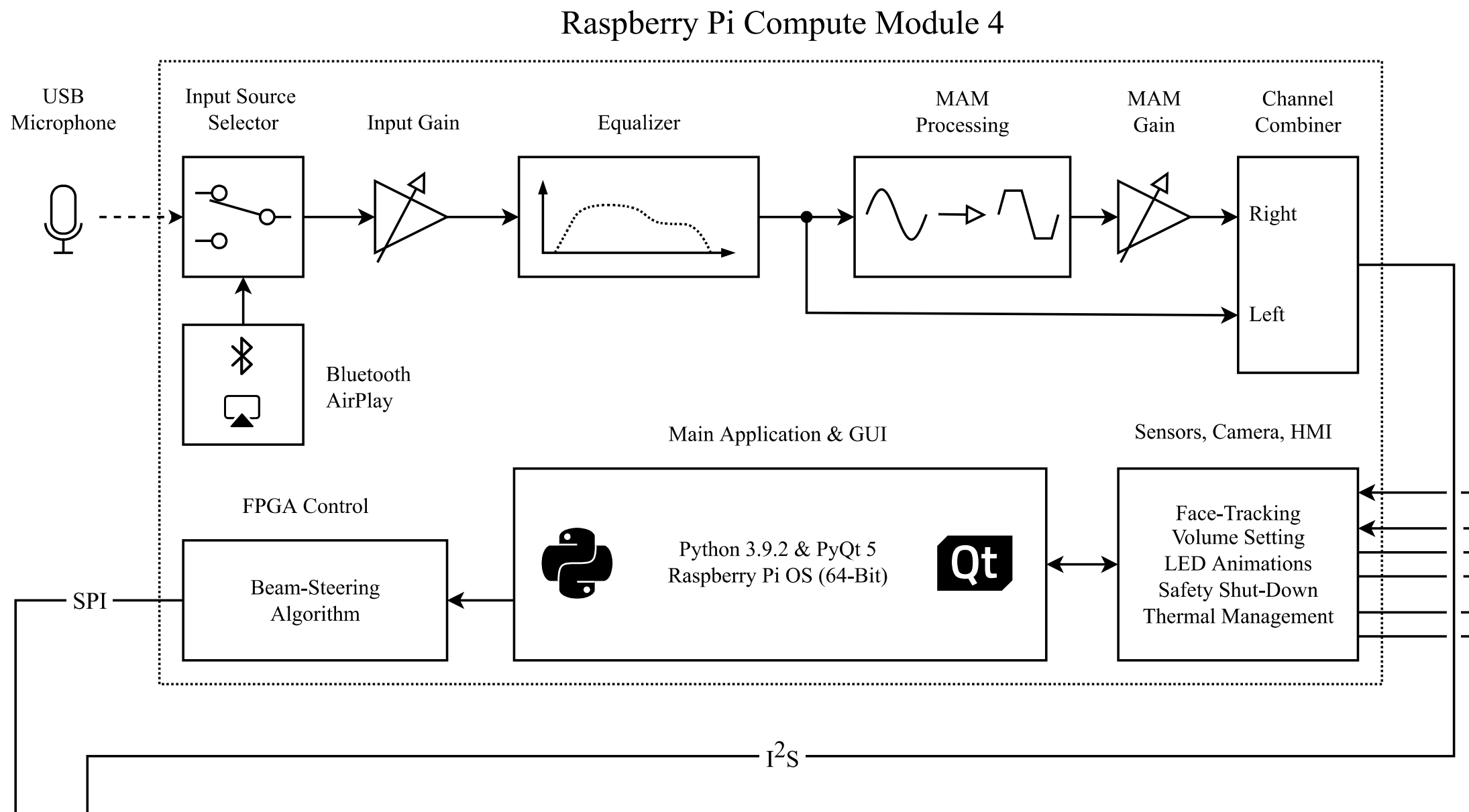
Akustik

Arrays

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Evaluation

Fazit



Einführung

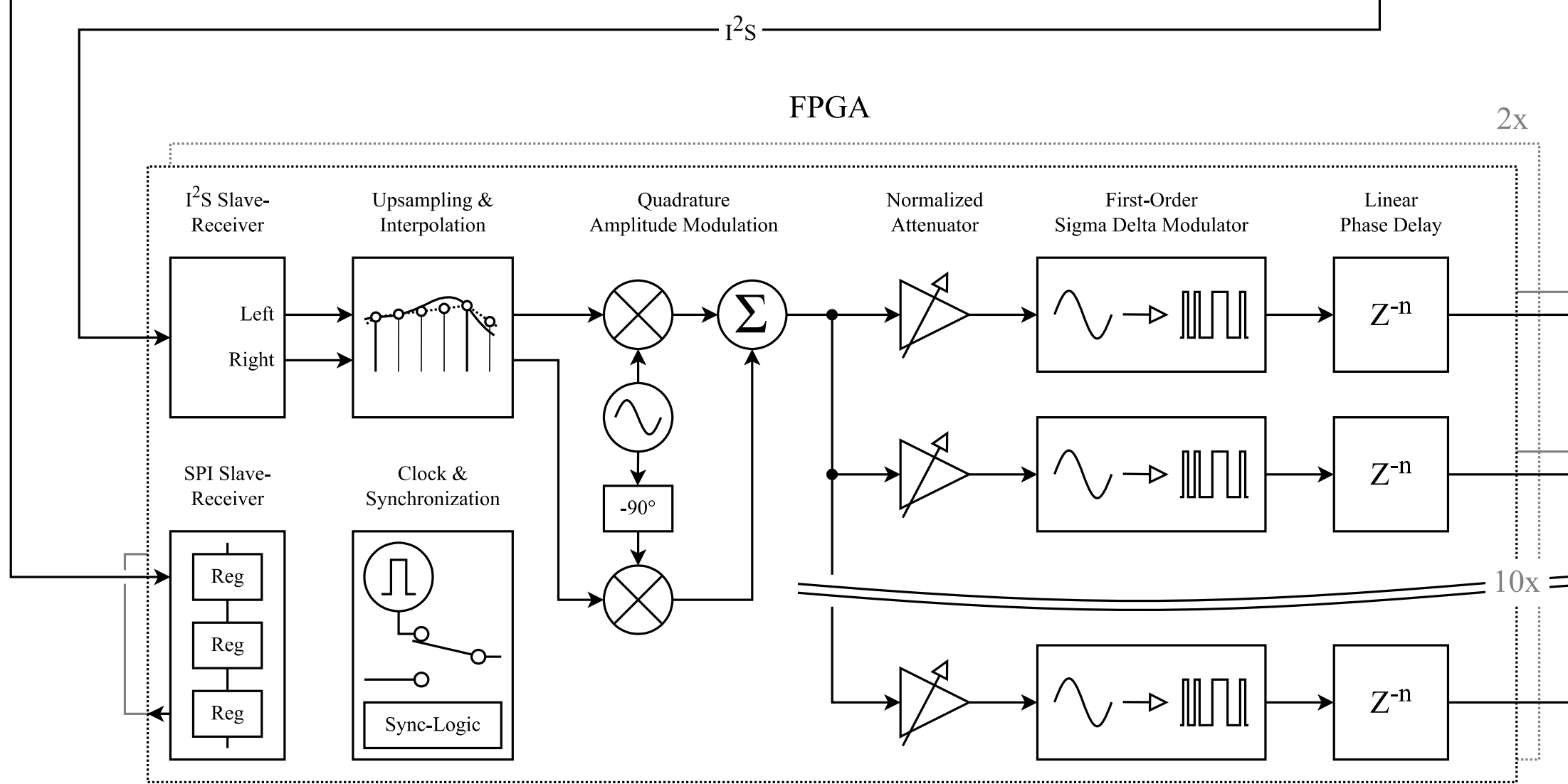
Akustik

Arrays

Design

Evaluation

Fazit



Einführung

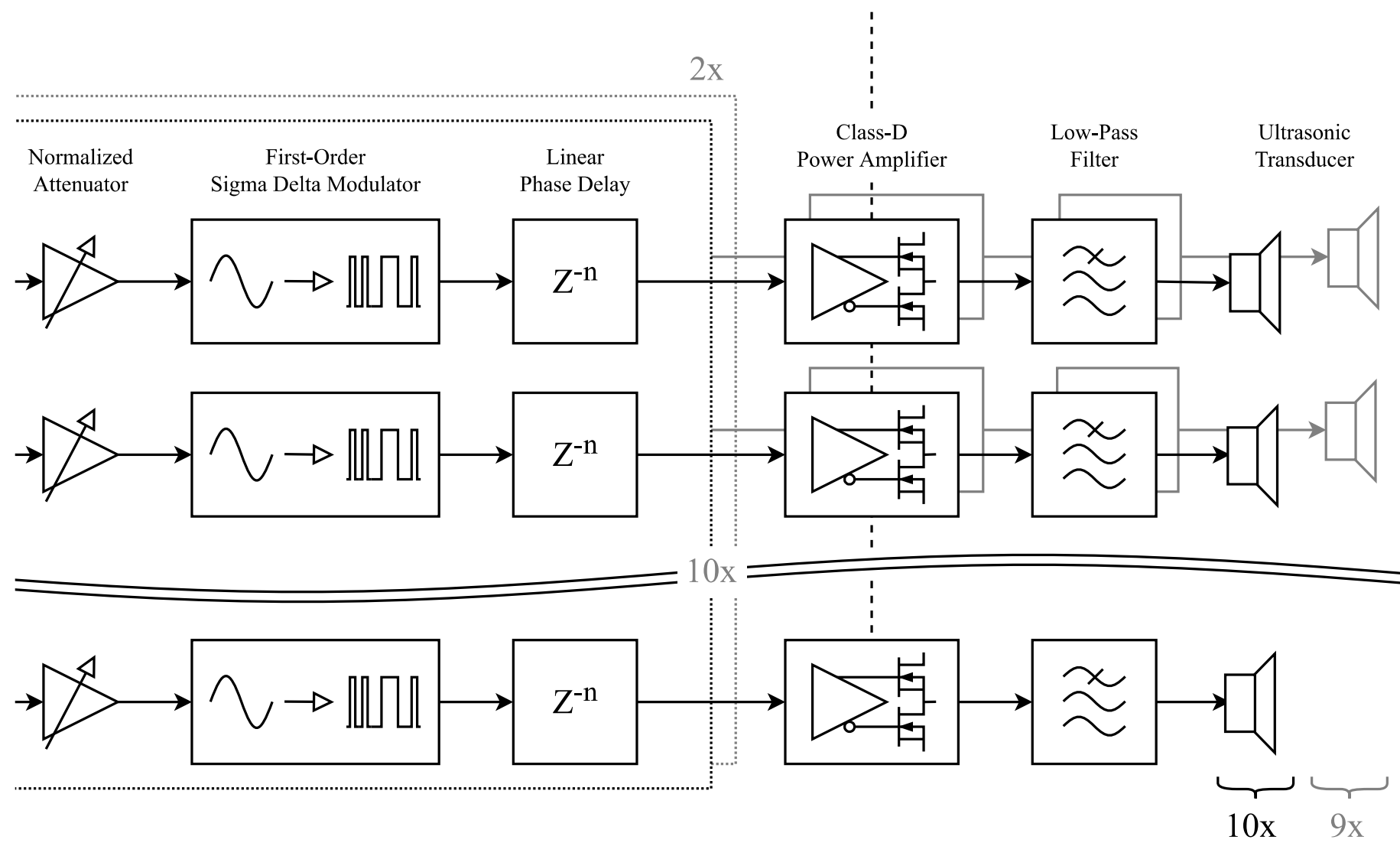
Akustik

Arrays

Design

Evaluation

Fazit



Einführung

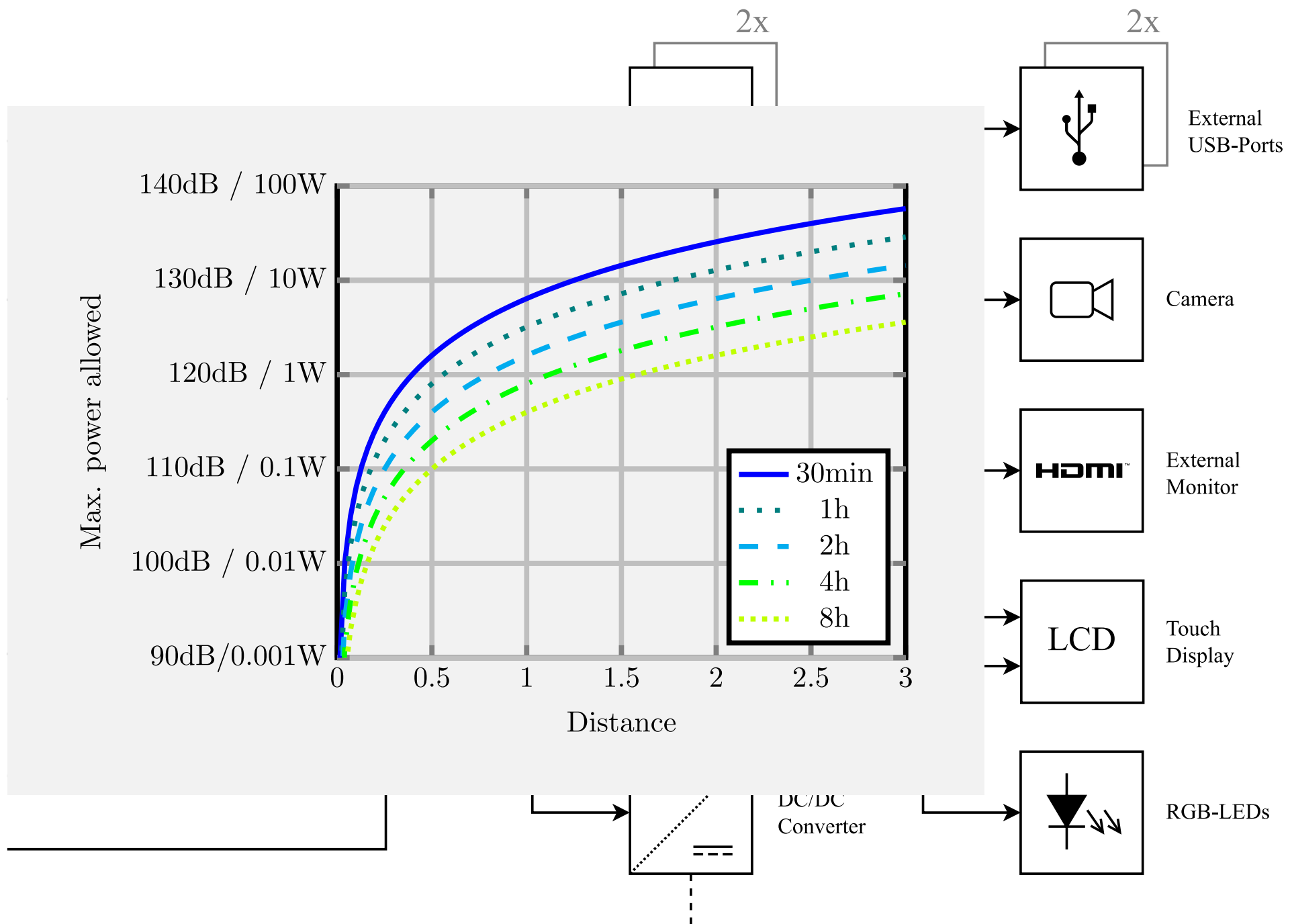
Akustik

Arrays

Design

Evaluation

Fazit



Einführung

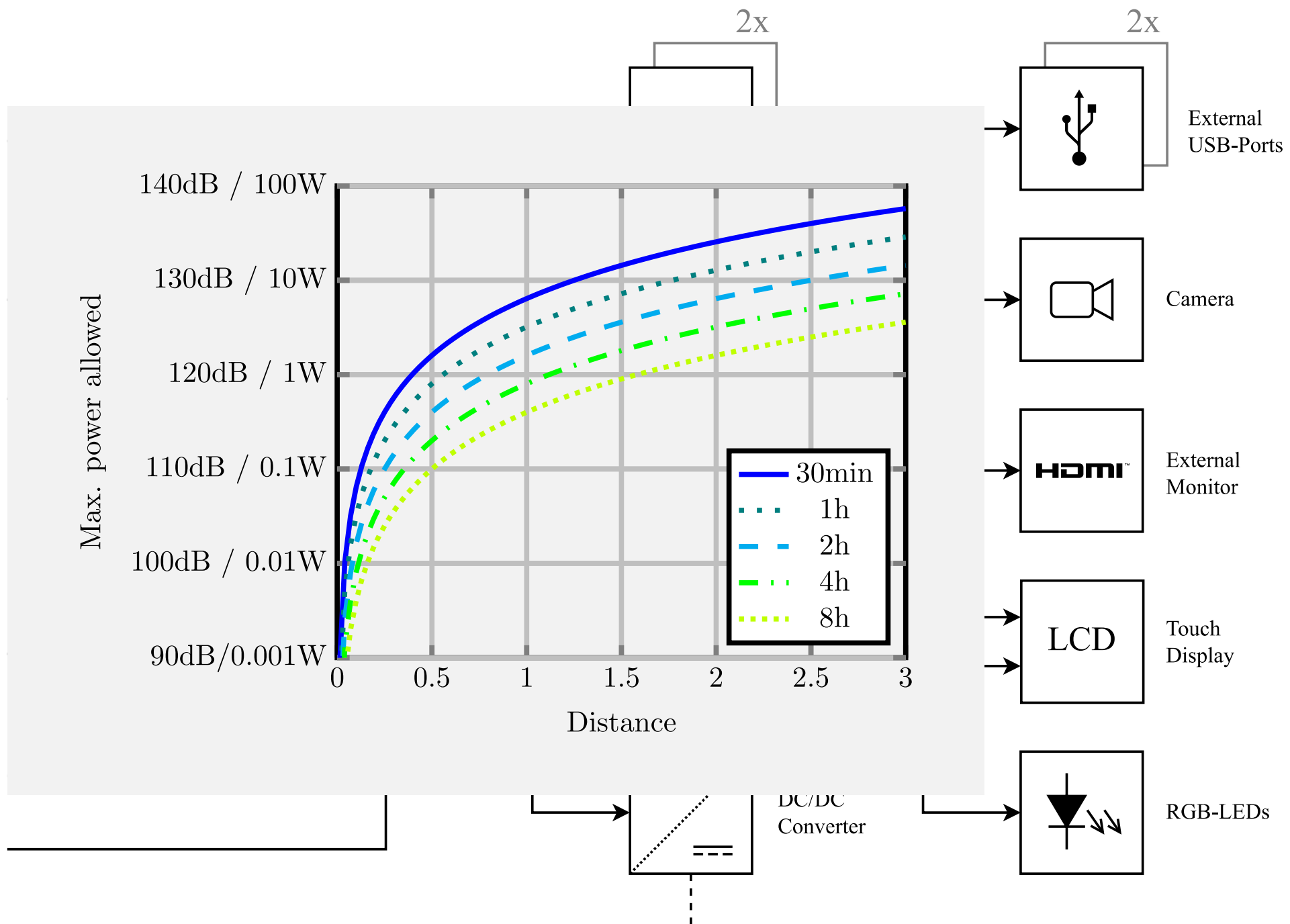
Akustik

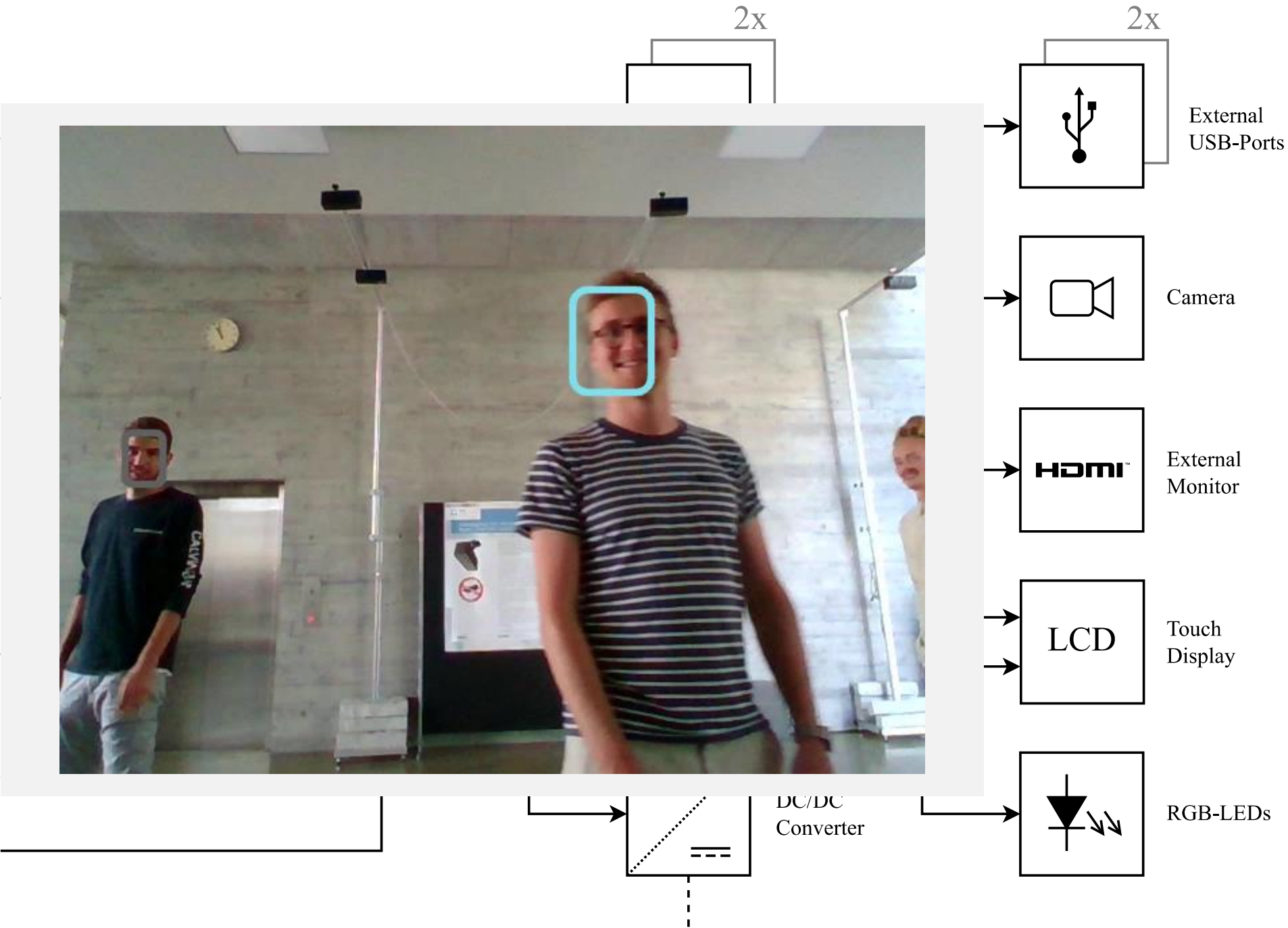
Arrays

Design

Evaluation

Fazit





Einführung

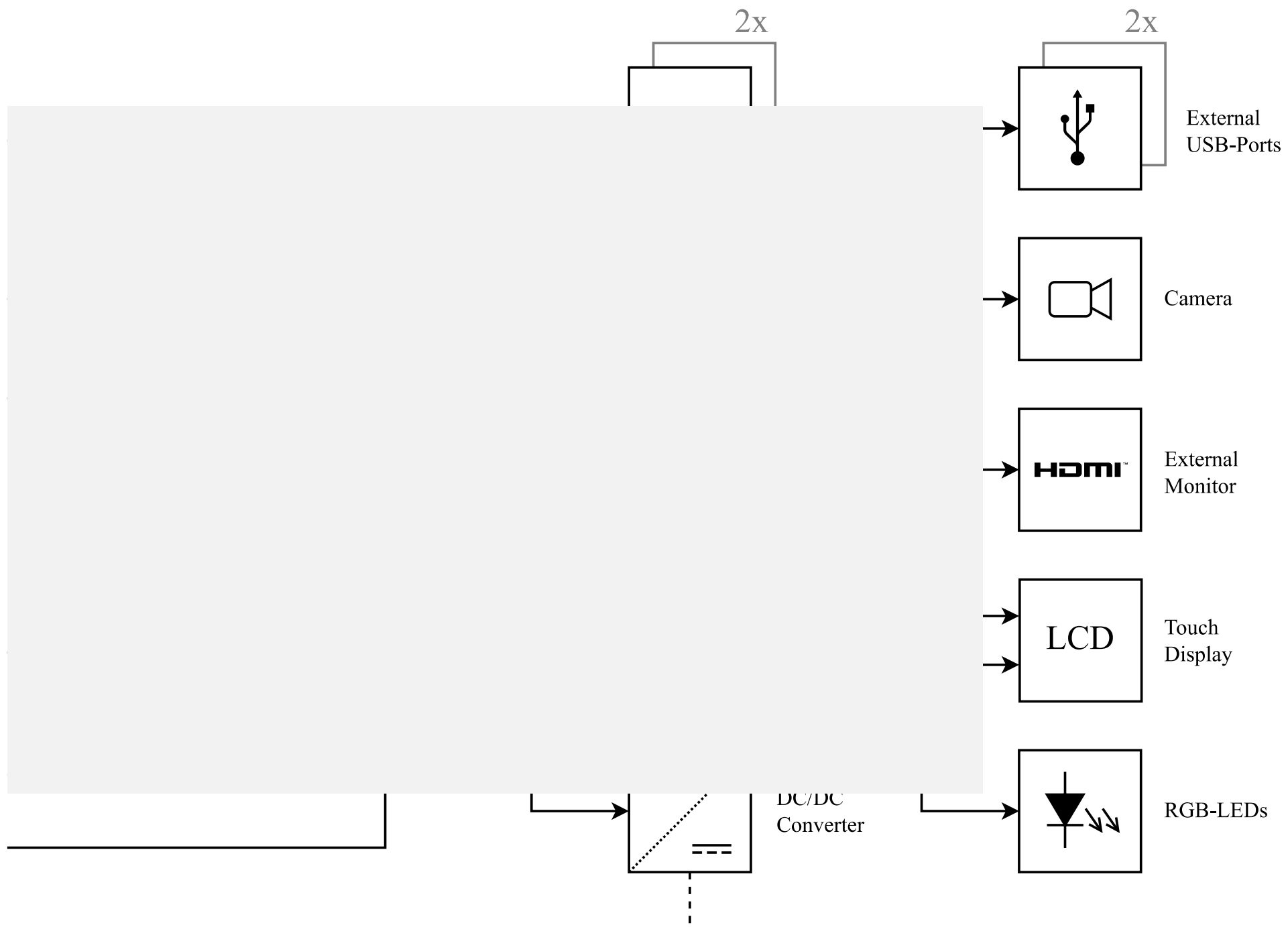
Akustik

Arrays

Design

Evaluation

Fazit



Einführung

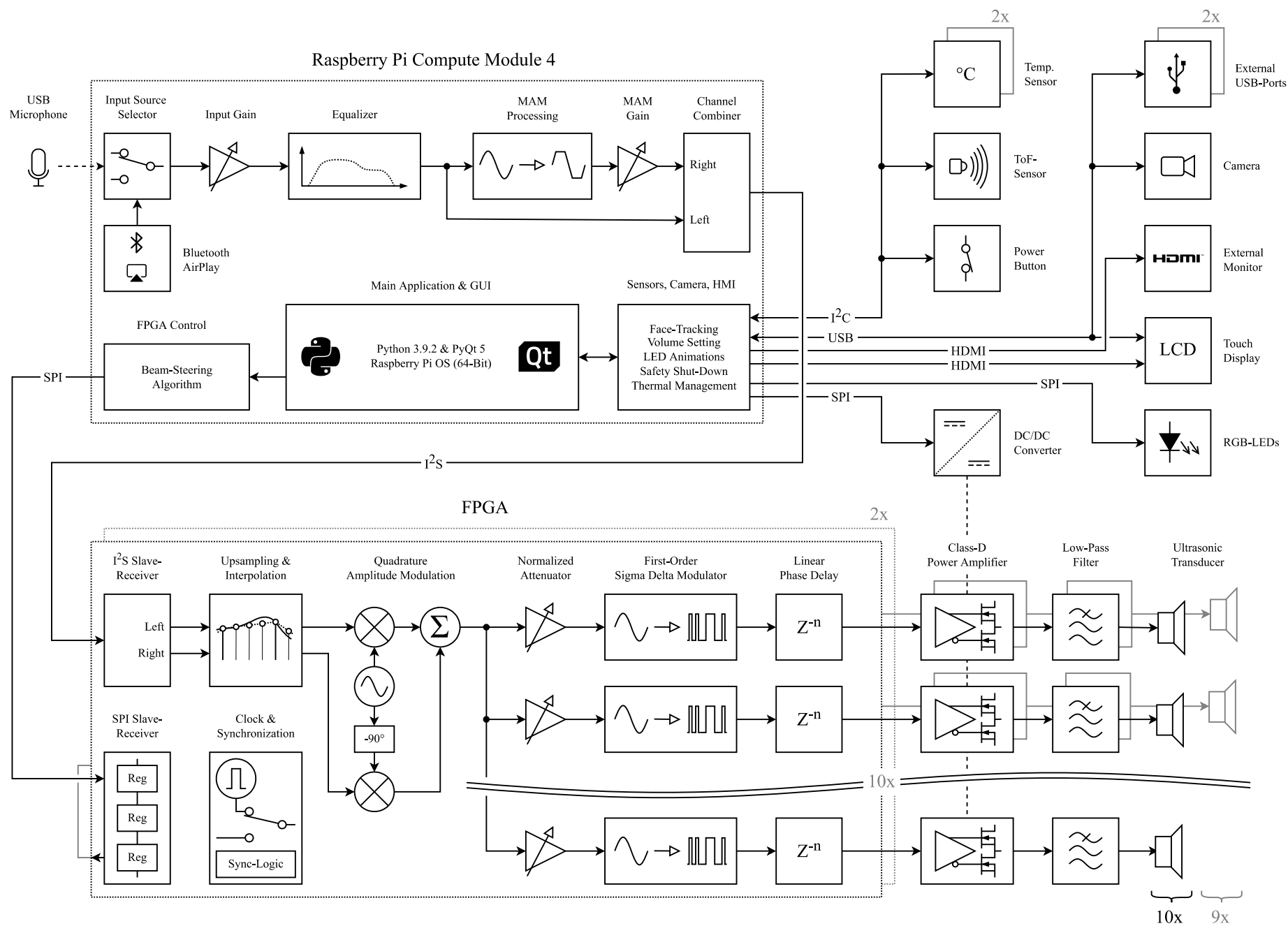
Akustik

Arrays

Design

Evaluation

Fazit



Einführung

Akustik

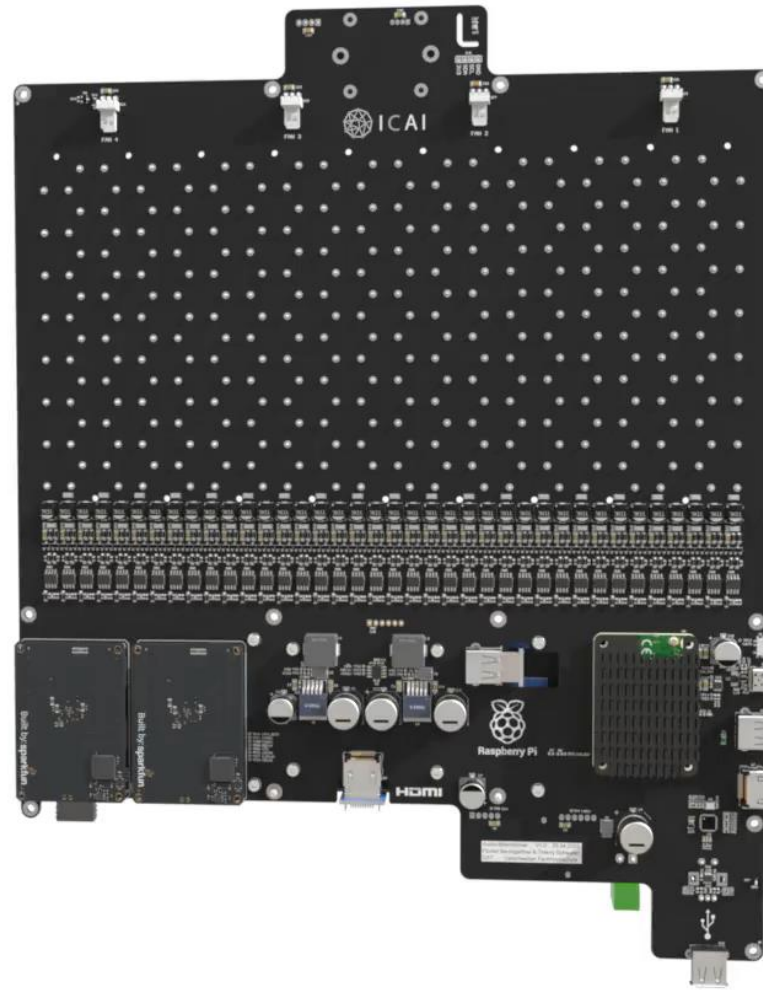
Arrays

Design

Evaluation

Fazit

PCB



Einführung

Akustik

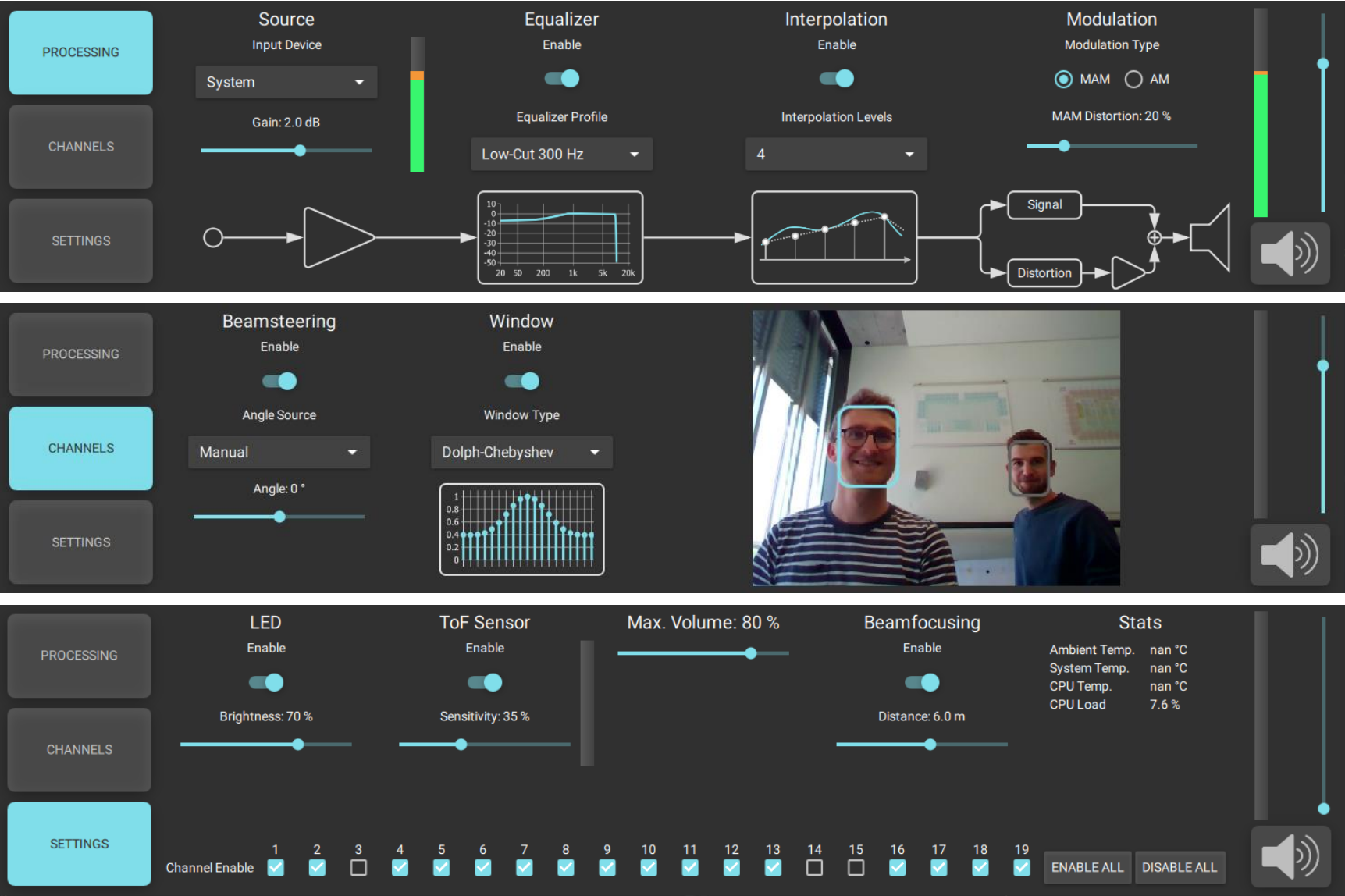
Arrays

Design

Evaluation

Fazit

GUI



Endprodukt

Einführung

Akustik

Arrays

Design

Evaluation

Fazit



Einführung

Akustik

Arrays

Design

Evaluation

Fazit

Funktioniert es?

Quantifizierung

Einführung

Akustik

Arrays

Design

Evaluation

Fazit

Ultraschall-Messungen

Keine Absorber-Kammer

Human Expertise Test

17 Teilnehmer: innen
Audio Qualität
Richtcharakteristik

Einführung

Messsetup

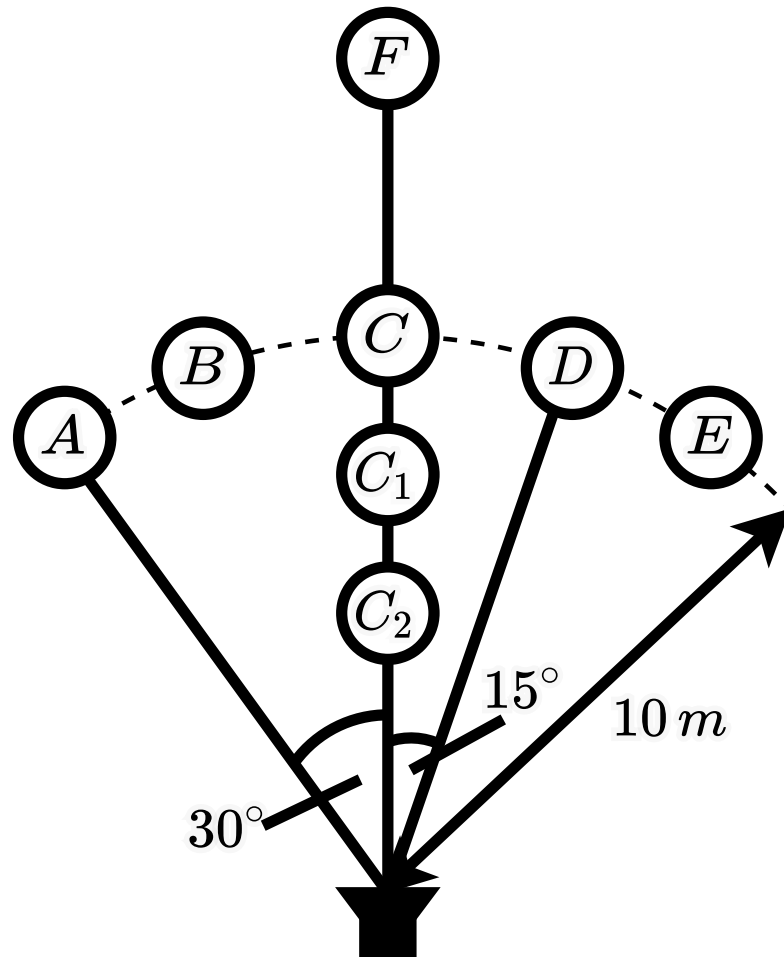
Akustik

Arrays

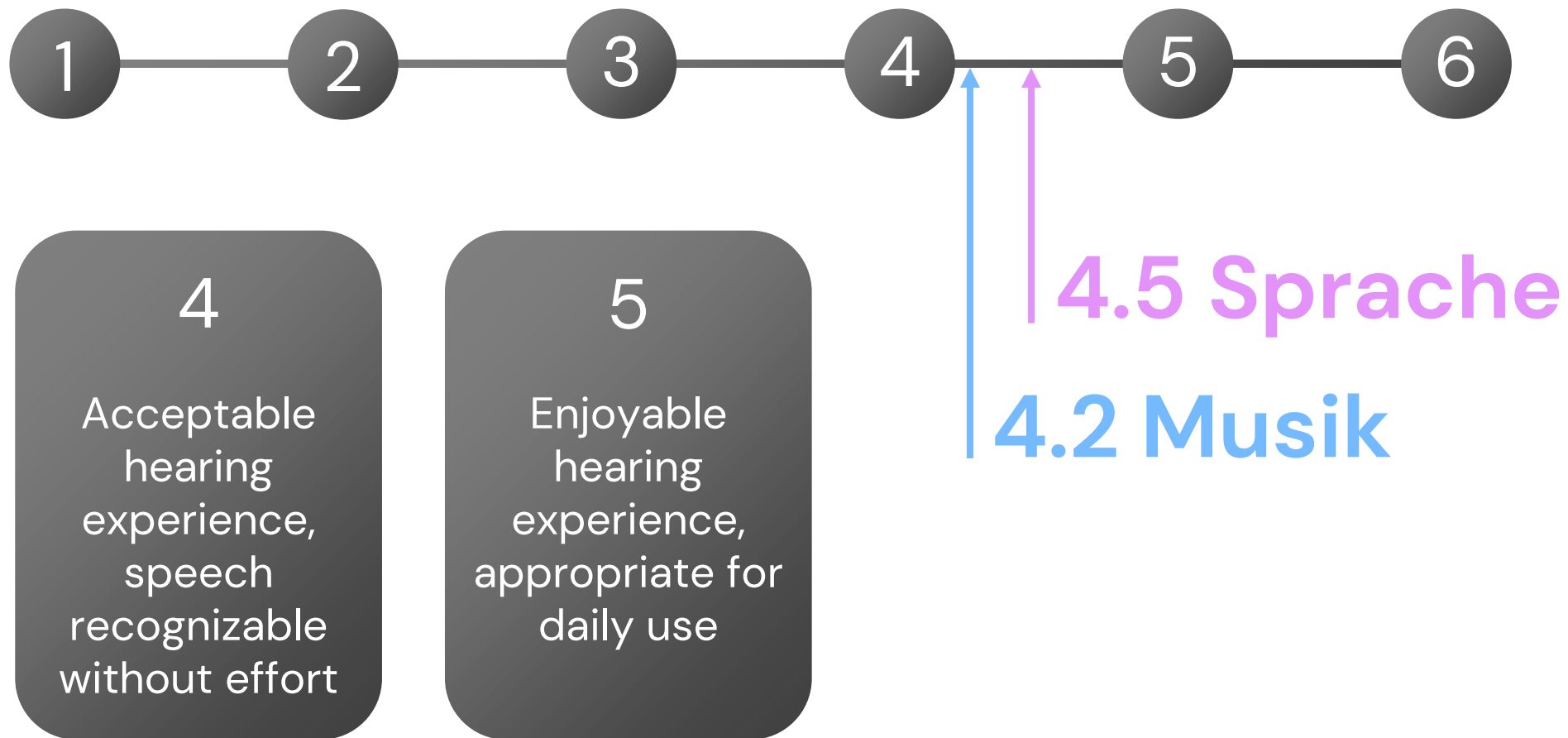
Design

Evaluation

Fazit



Audio Qualität



Einführung

Akustik

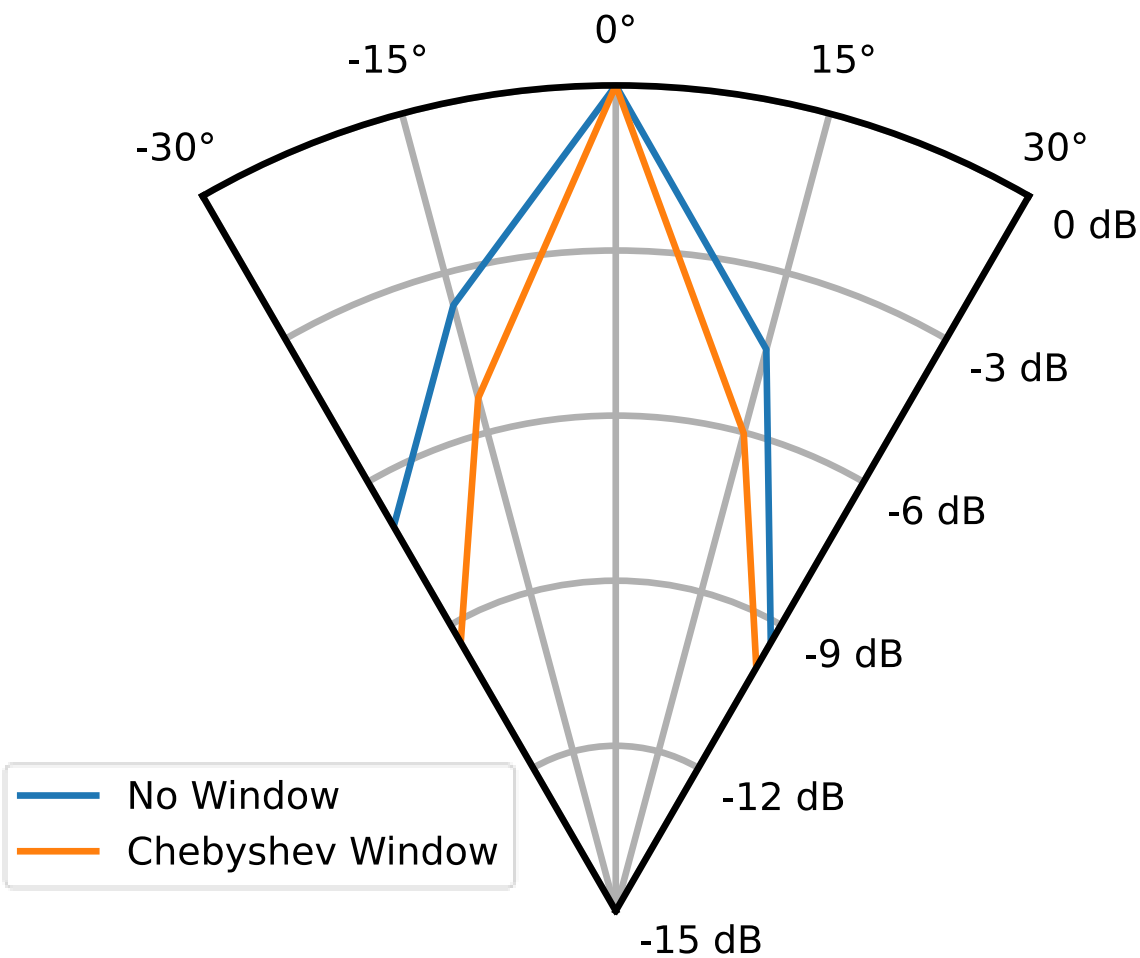
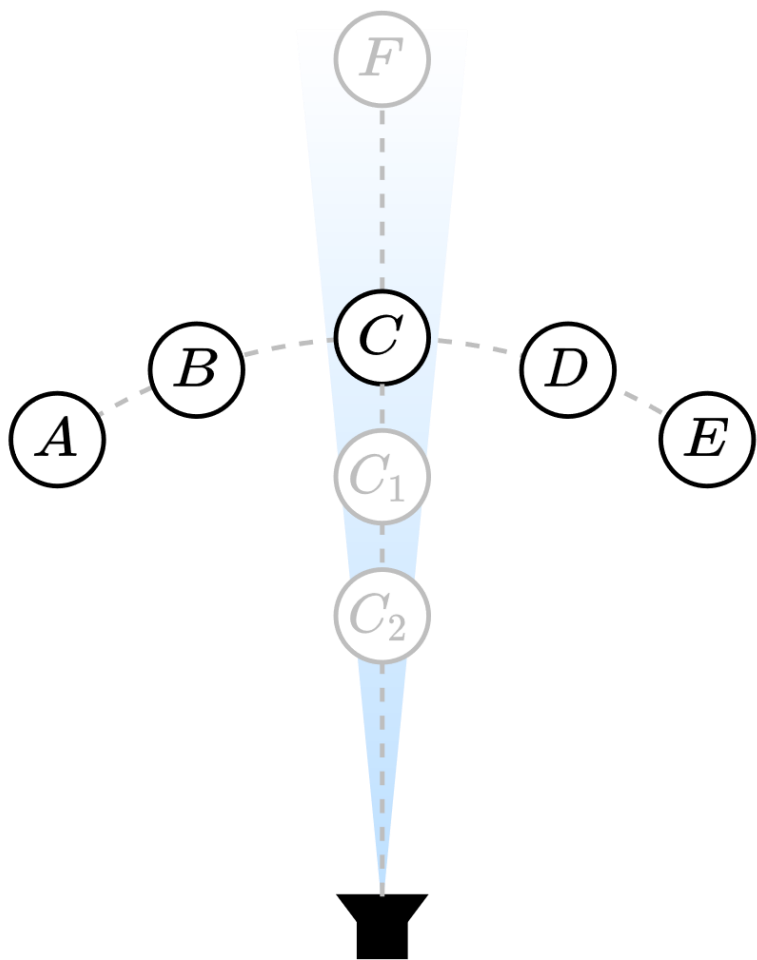
Arrays

Design

Evaluation

Fazit

Richtcharakteristik



Einführung

Akustik

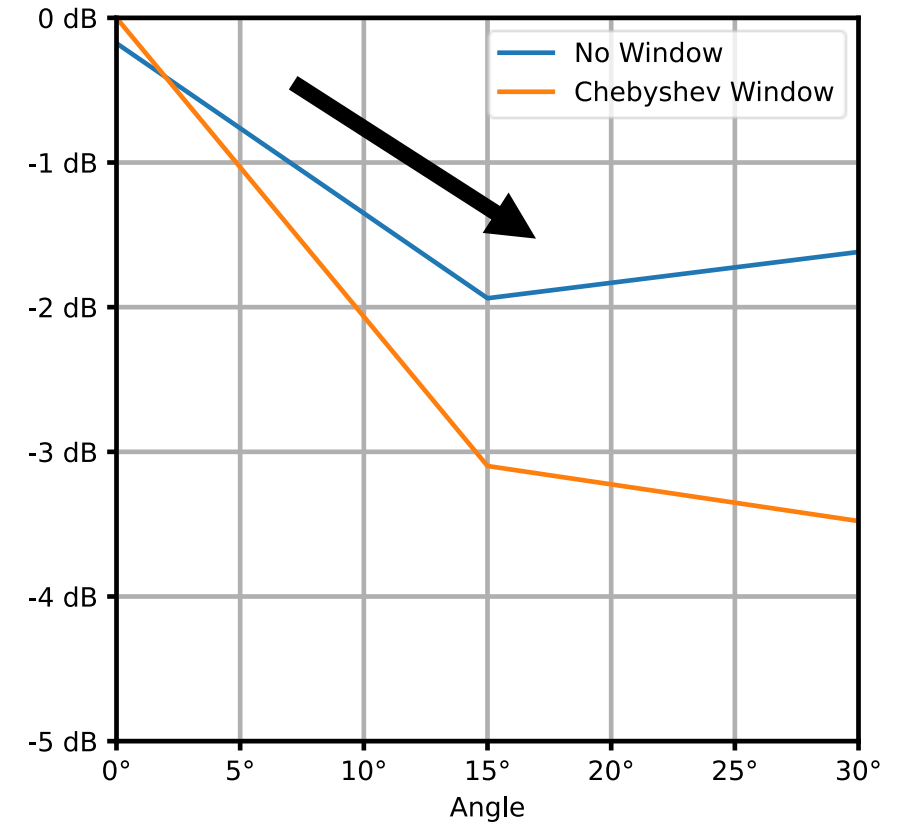
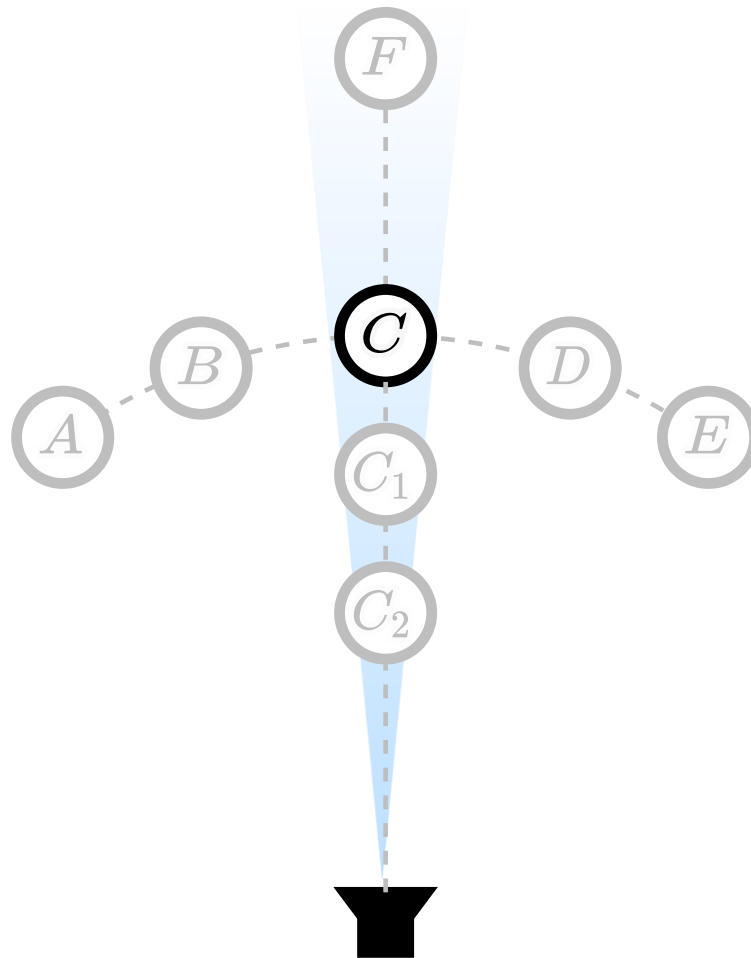
Arrays

Design

Evaluation

Fazit

Beam Steering



Einführung

Beam Steering

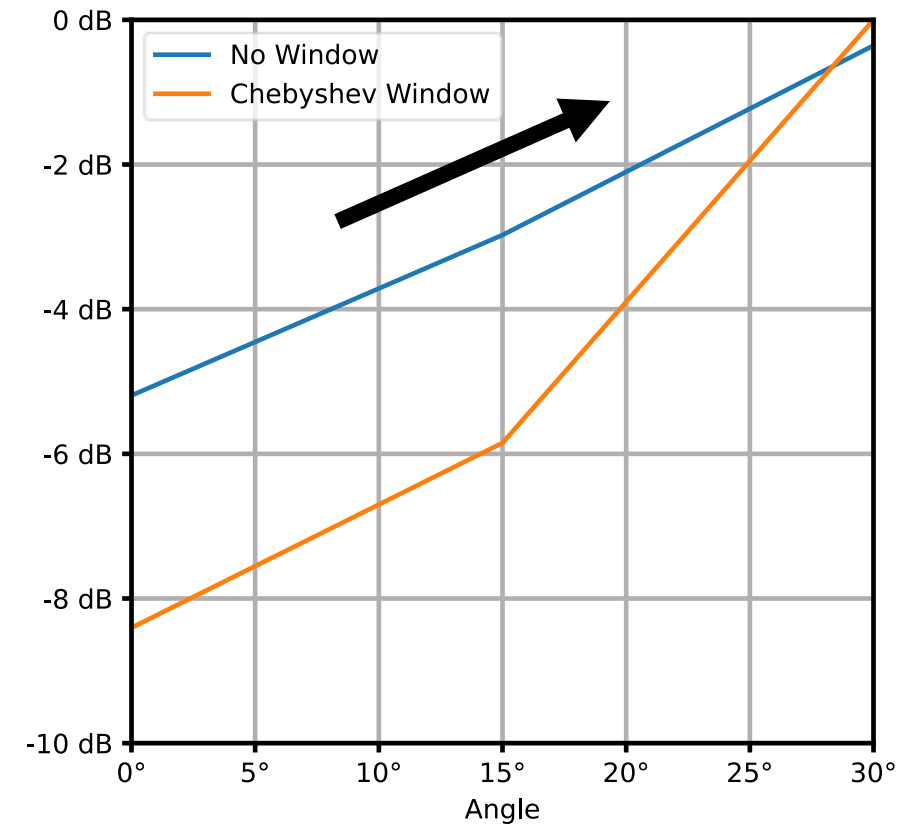
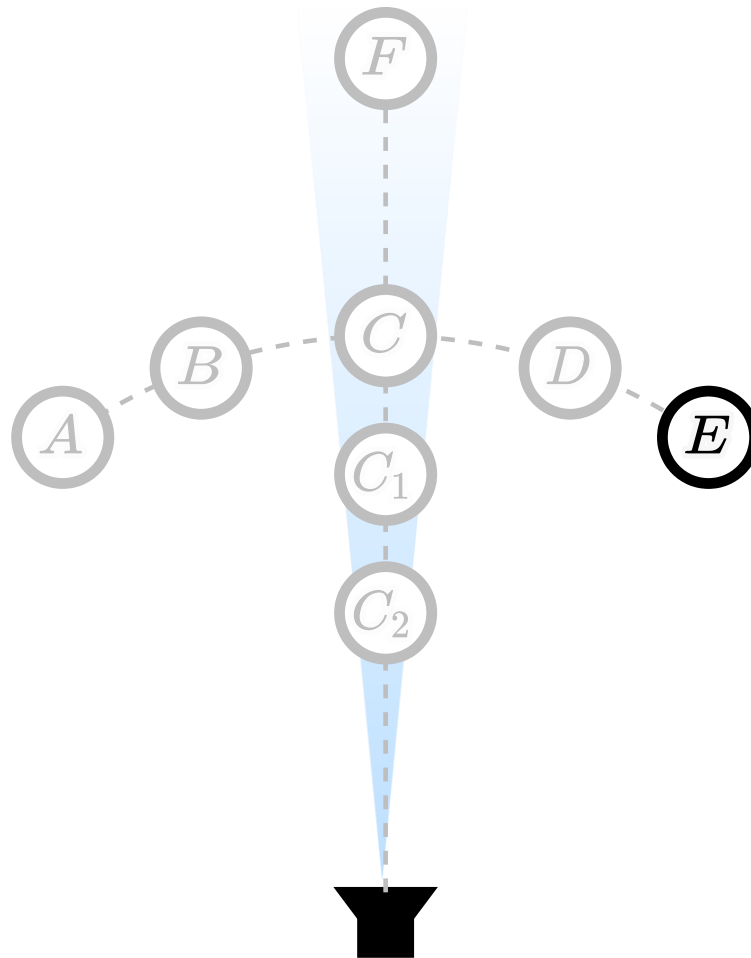
Akustik

Arrays

Design

Evaluation

Fazit



Einführung

Akustik

Arrays

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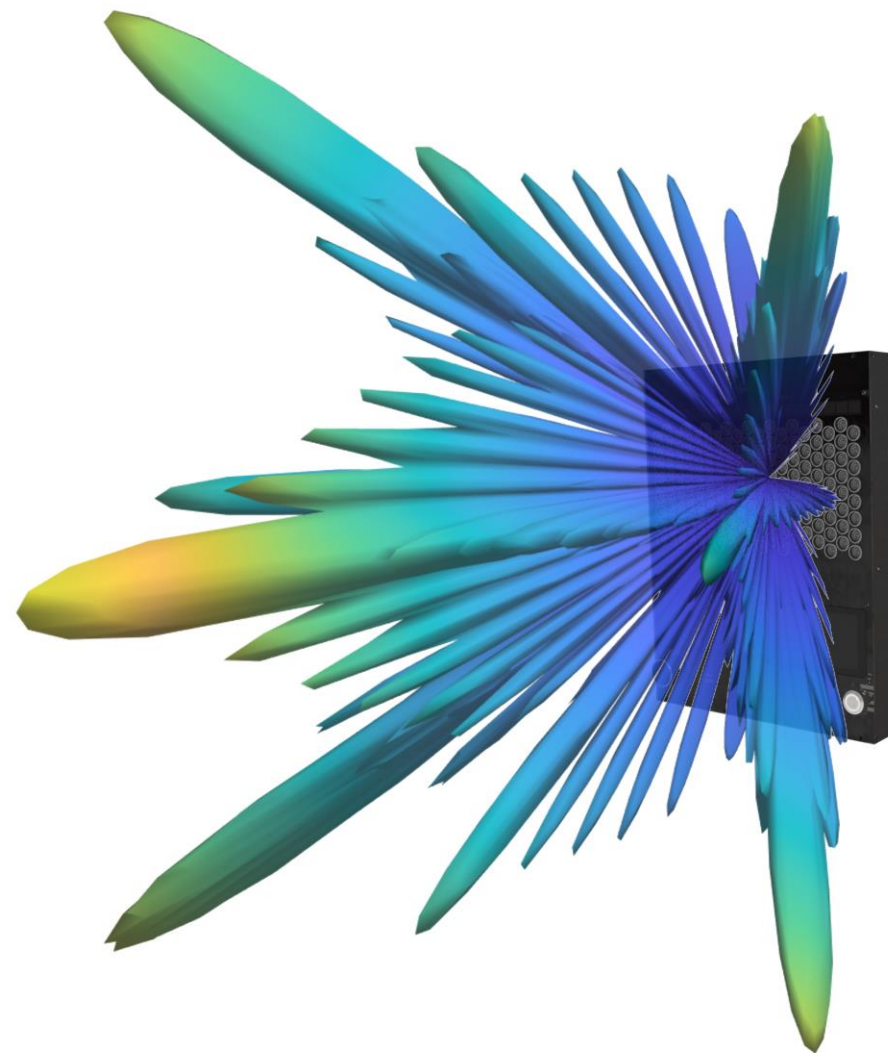
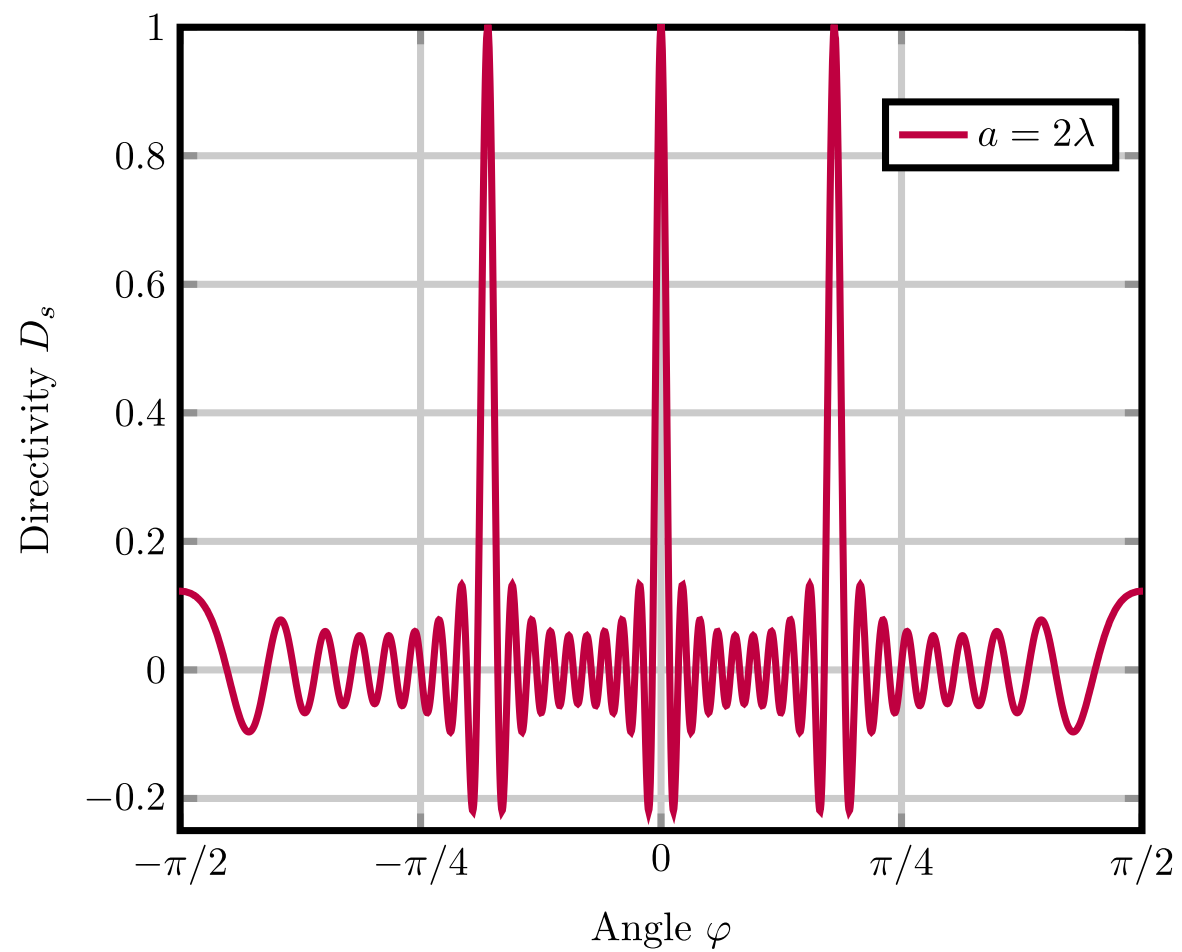
Fazit

Fazit

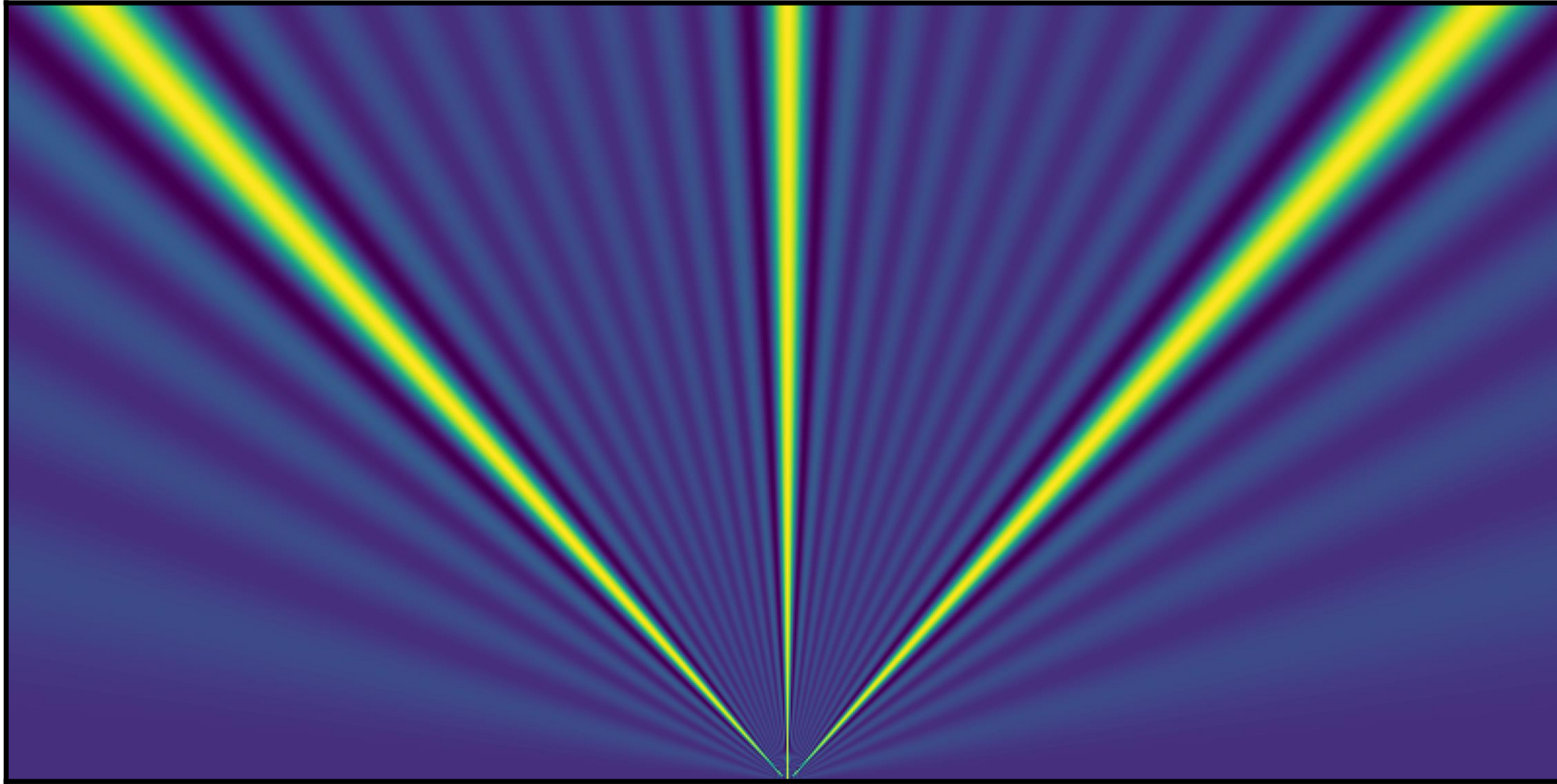
Demonstration



Grating Lobe



Grating Lobe



Min. / Max. Winkel

Minimaler Winkel

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

Maximaler Winkel

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

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

Far Field

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

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