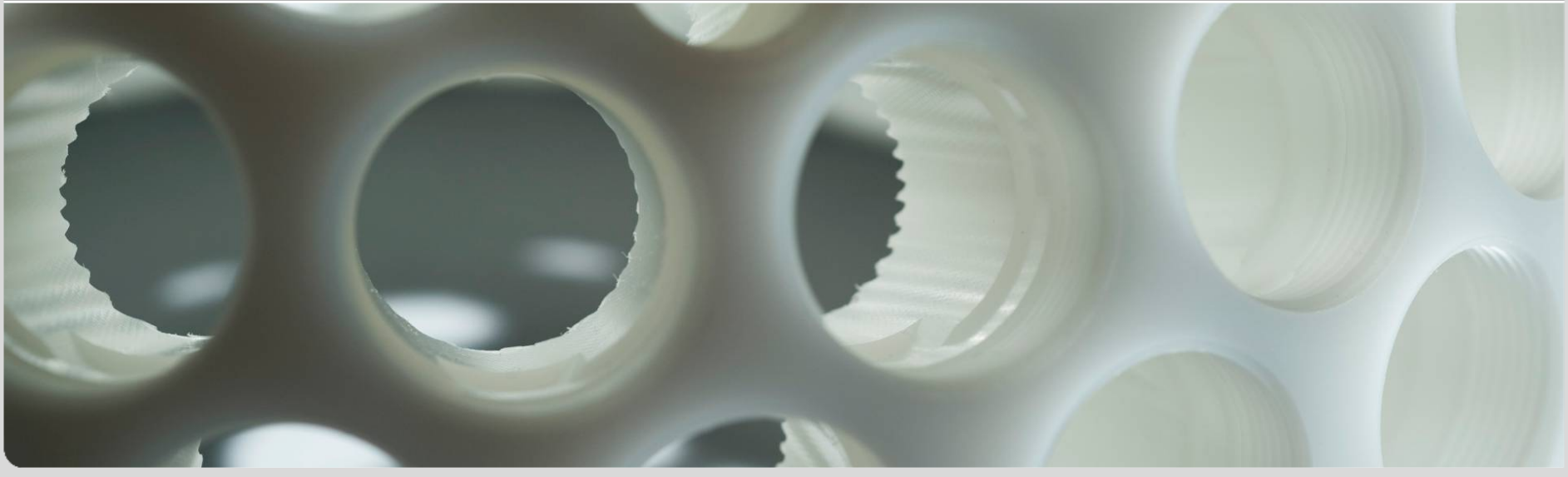
Second generation Piezo composite based single fibre transducers for a 3D USCT system

M. Zapf[1], K. Hohlfeld[2], P. Pfistner[1], S. Gebhardt[2], K. Schlote-Holubek[1], C. Imbraccio[1], K. v. Dongen[3], H. Gemmeke[1], N.V. Ruiter[1]

Karlsruhe Institute of Technology, Institute for Data Processing and Electronics, Karlsruhe, Germany[1]
Fraunhofer Institute for Ceramic Technologies and Systems, Dresden, Germany[2]
TU Delft, Delft, The Netherlands[3]

INSTITUTE FOR DATA PROCESSING AND ELECTRONICS



KIT 3D USCT

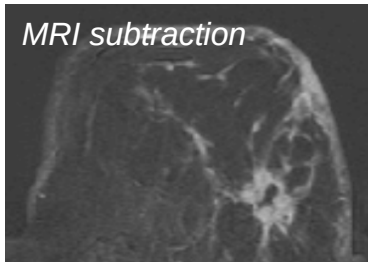
3D Ultrasound Computer Tomography
for early breast cancer diagnosis …

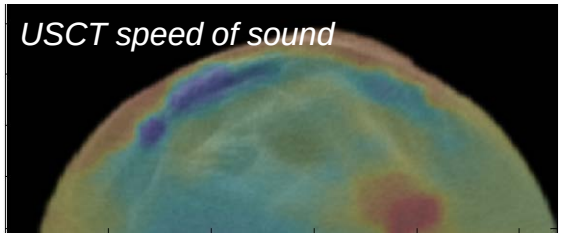
- as harmless as diagnostic ultrasound
- as economical as X-ray mammography
- as sensitive as MRI (long term goal)

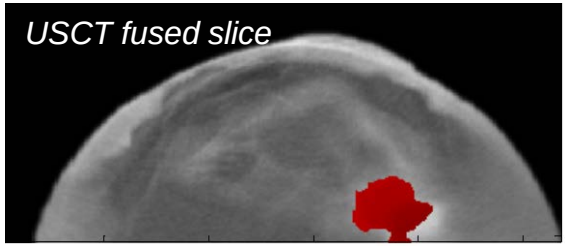
Current stage:

- pilot study 2012-13,
  University Hospital Jena
- study with 200 patients 2015-2017,
  University Hospital Mannheim

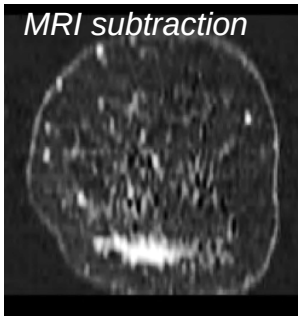
Clinical Trial Jena

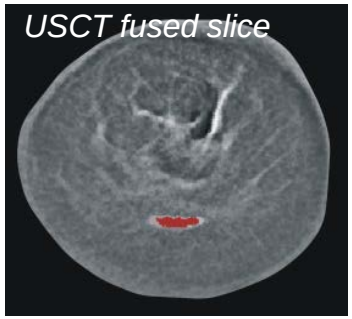




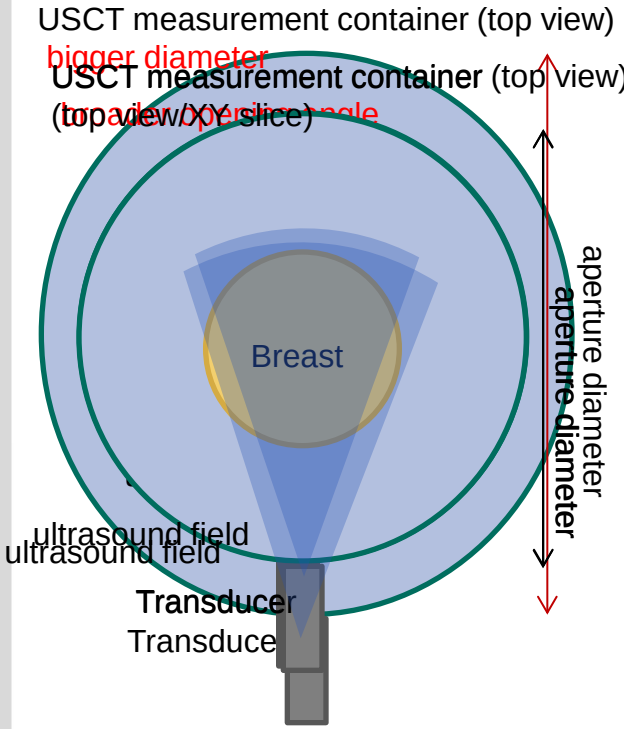


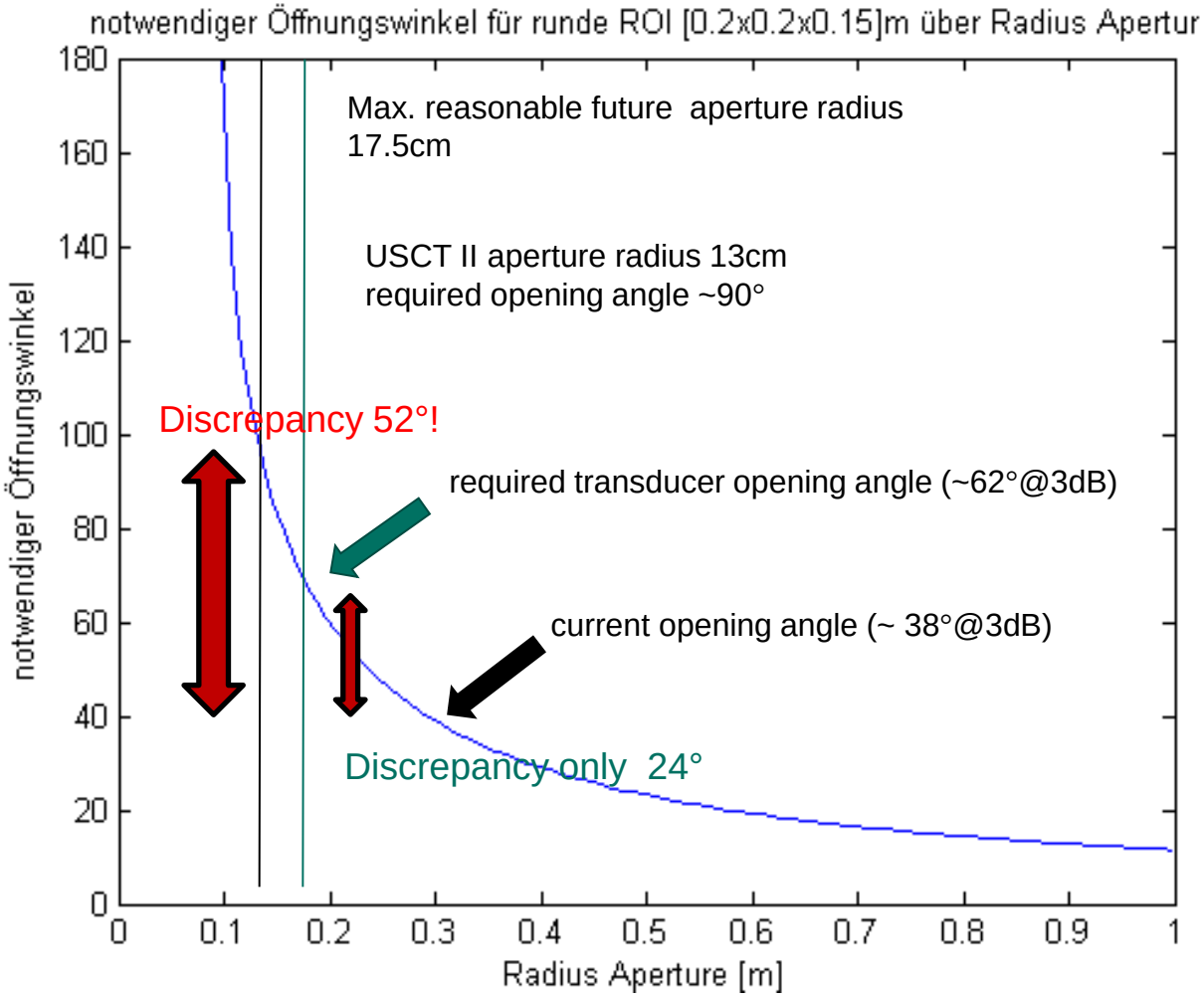
- One conclusion from the Jena Study:
  - ROI to small, several patient breasts are not well „illuminated“
- Objectiv for improved imaging: new transducers with greater opening, random element distribution & good bandwidth





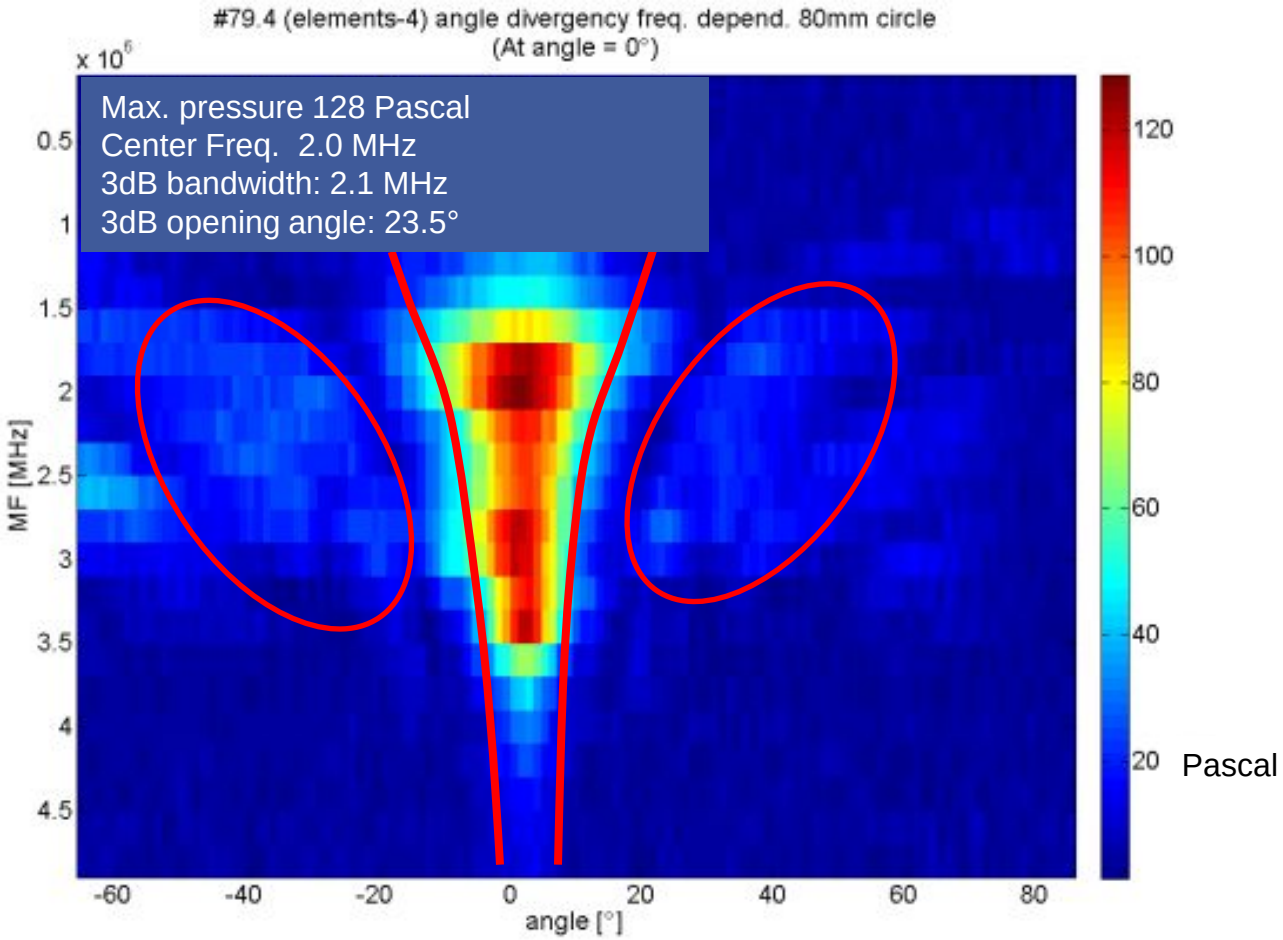
Motivation: Relation object size to transducer divergancy / opening angle





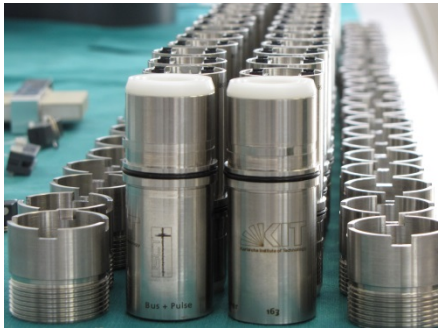
- Better imaging: increased opening angle required additional to increased aperture radius

USCT 2.0 transducer performance: Pressure over frequency and angle

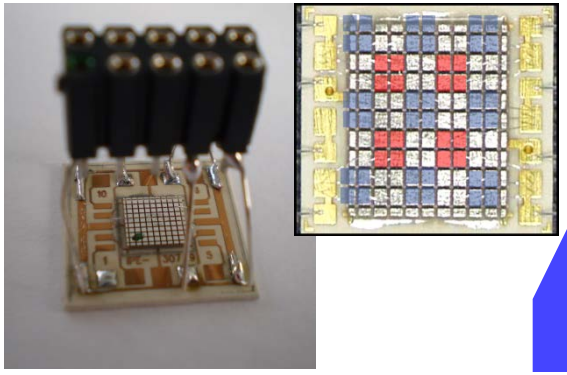


Transducer 79.4 4: 900µm wide rectangular piezo, 4x substructured, dice-and-fill

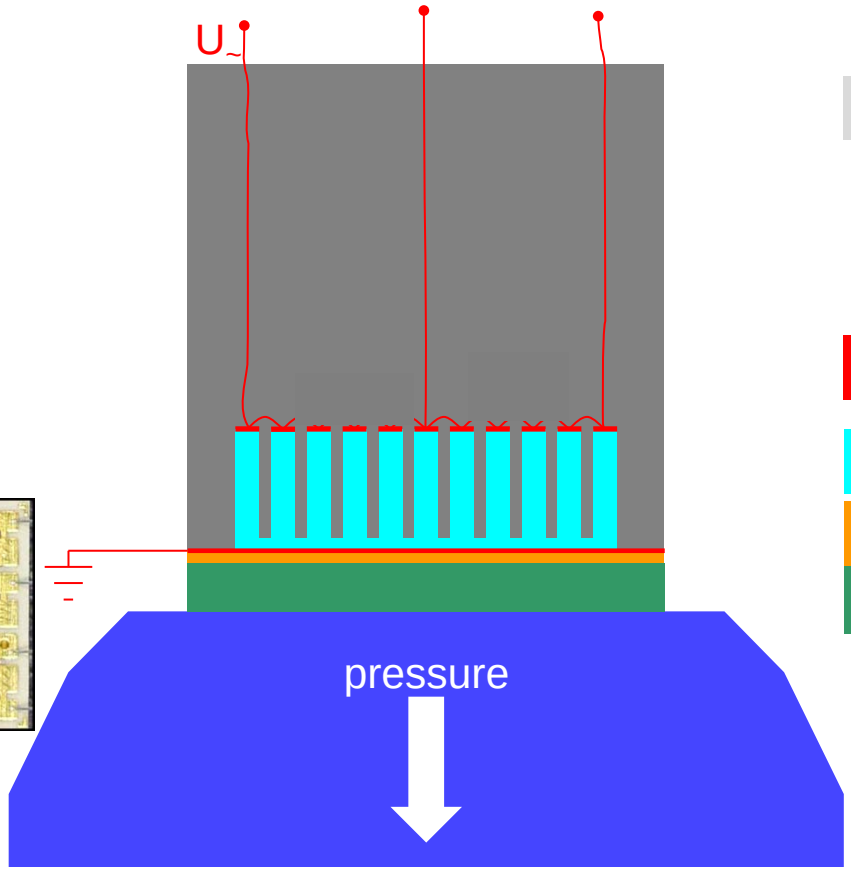
USCT II Transducers



3D USCT II transducers



„Raw“ transducer
without Polyurethane



Scheme: vertical cut

Backing / Filler

Electrodes

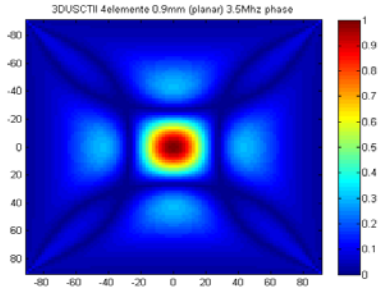
Piezo – ceramic

Glue

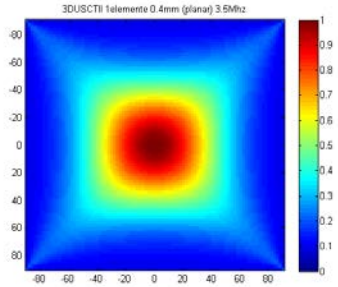
Matching layer

Water

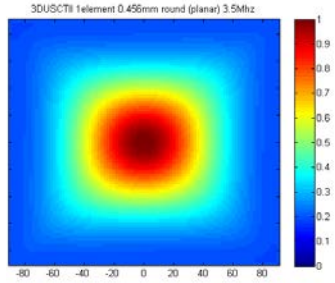
Design and specification



Transducer rectangular (0.9mm x 0.9mm)



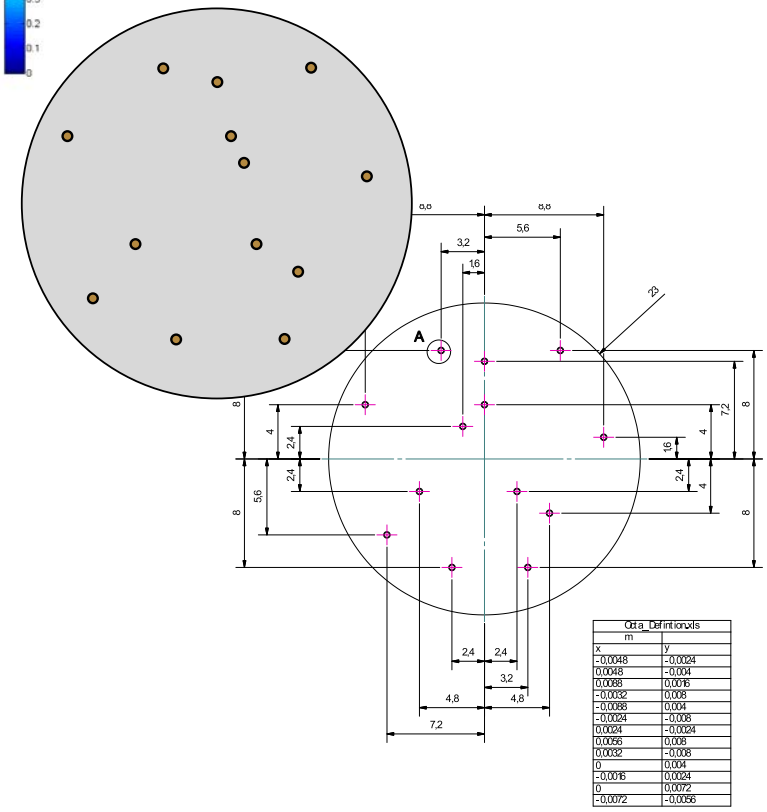
Transducer rectangular (0.4mm x 0.4mm)



Transducer round (diameter 0.456mm)

Opening angle for f_{max} (3.5MHz) receiver*emitter	20% drop	50% drop	Sound pressure
3DUSCTII Transducer (0.9mm, rect)	14°	22°	100%
Transducer 0.902mm round	16°	28°	100%
Transducer 0.4mm rect	30°	54°	25%
Transducer 0.4561mm round	**33°**	**58°**	**25%**

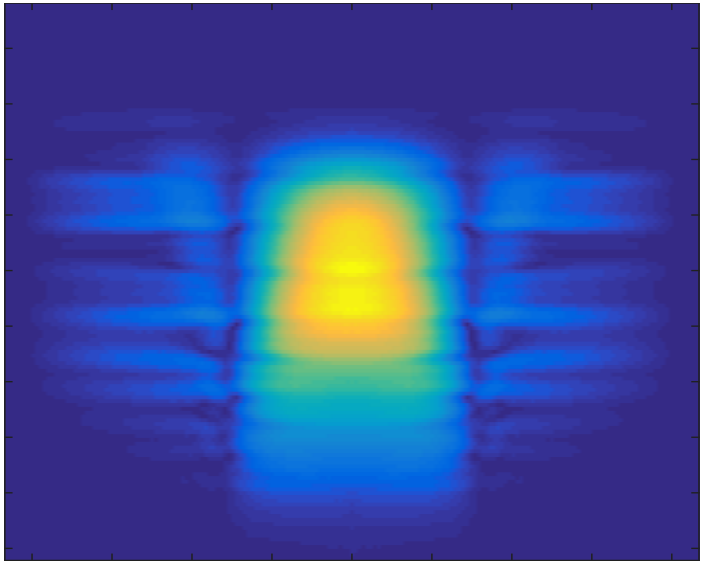
13 exactly positioned, round piezofibres of 460µm

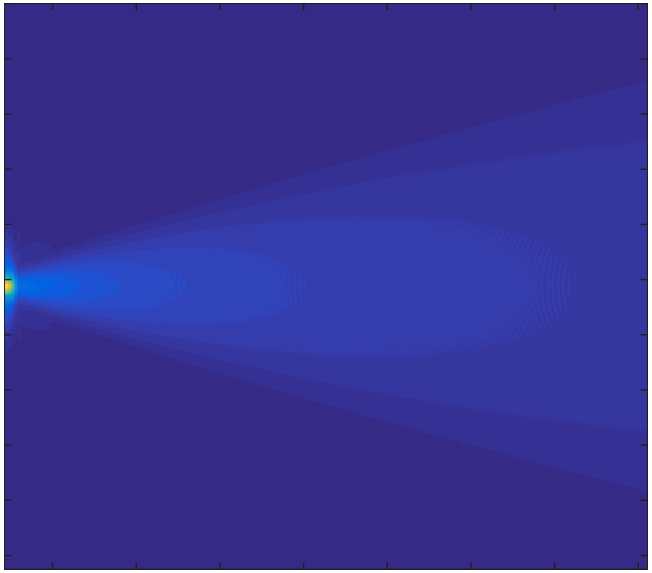


Transducerarray specification

Design and simulation II: Finite element

red: Backing + filling PU + Tungsten (12 MRayl)
red + bright blue: Piezofaserkompositscheibe
(CeramTec Sonox 505 14.2 MRayl)
grey: Matching (TMM4 ca. 6.3 MRayl)
Blue: Water (1.5 MRayl)

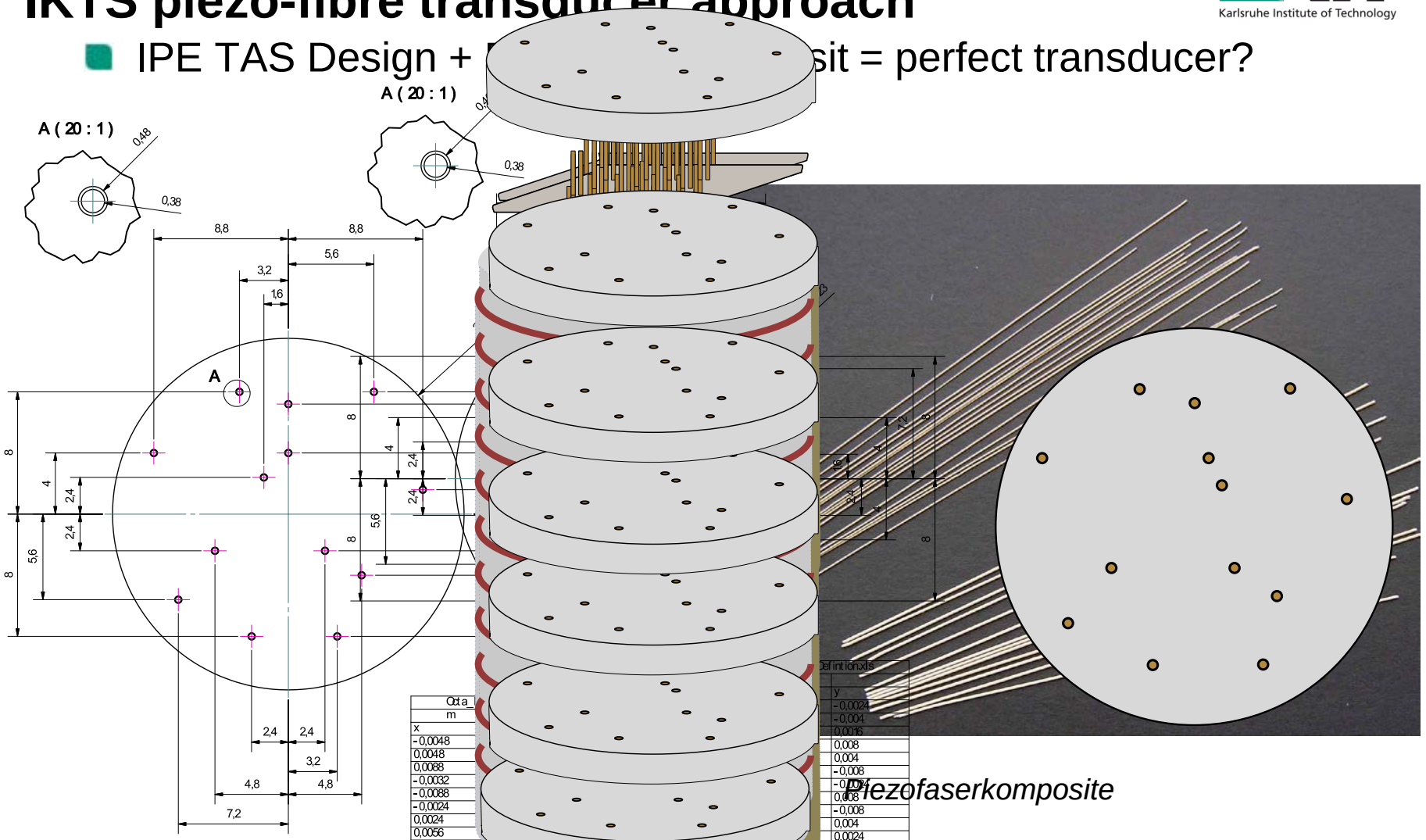




(in 1cm distance)

IKTS piezo-fibre transducer approach

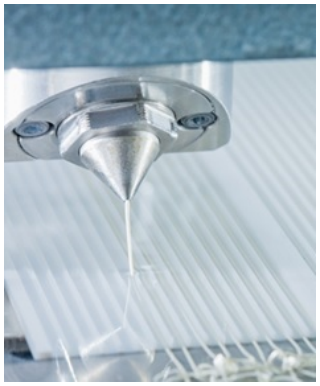
- IPE TAS Design + [illegible]sit = perfect transducer?

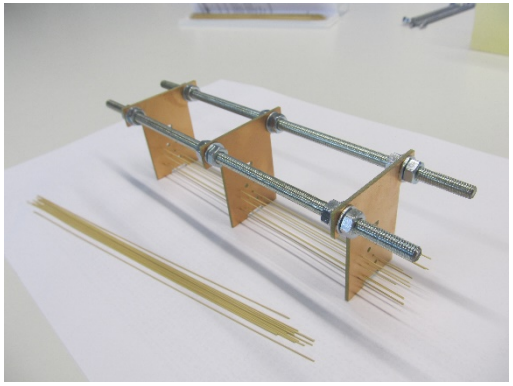


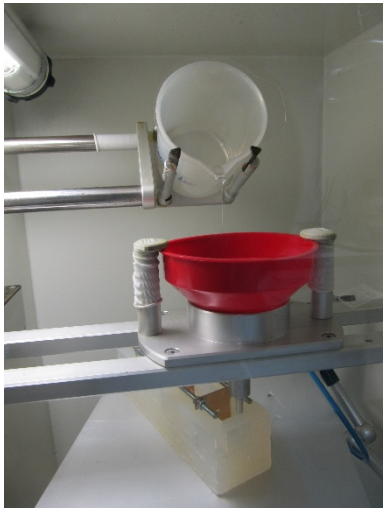
Piezofaserkomposite

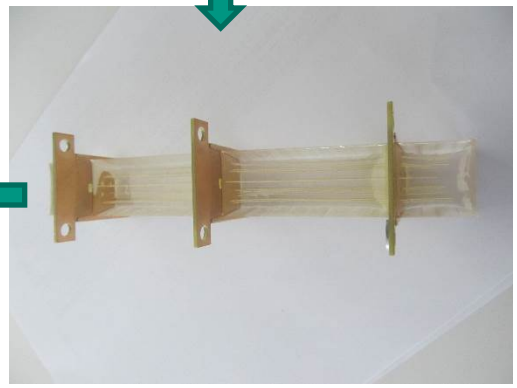
IKTS production of piezo fibre discs

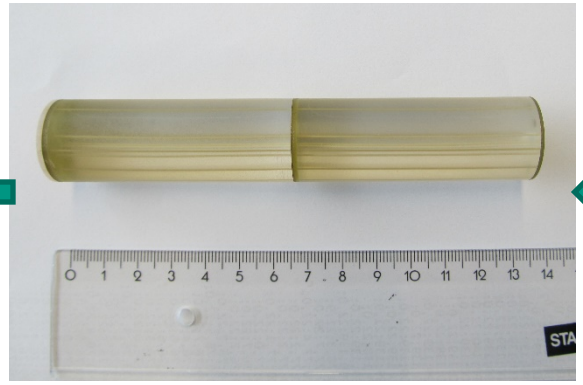
- PZT fibres Ø 450 µm
- Composite discs Ø 23 mm, thickness 0.40 to 2.05mm

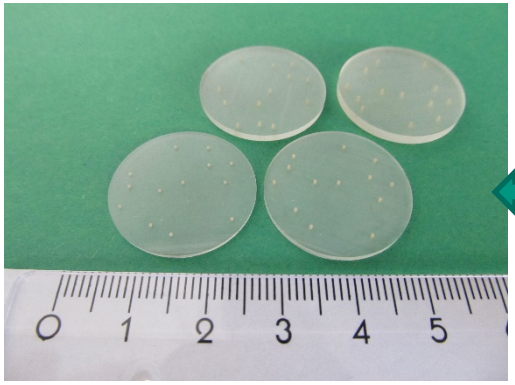












2nd iteration Piezofibre Transducers

- First batch had great variability of individual fibre performance[1]

- Second batch of fibres with improved production process, significantly improved reliability

- 4x discs for six thicknesses
  - 400µm, 550µm, 750µm, 1050µm, 1450µm, 2050µm
  - Corresponding to 1 to 4 MHz

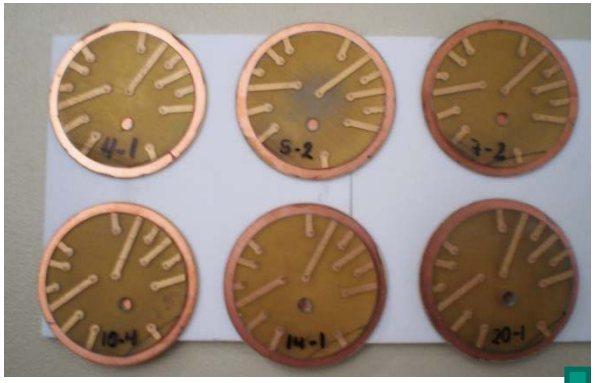
Produced 24 piezofibre discs from one batch of fibres and moulding

Selected discs for prototypes

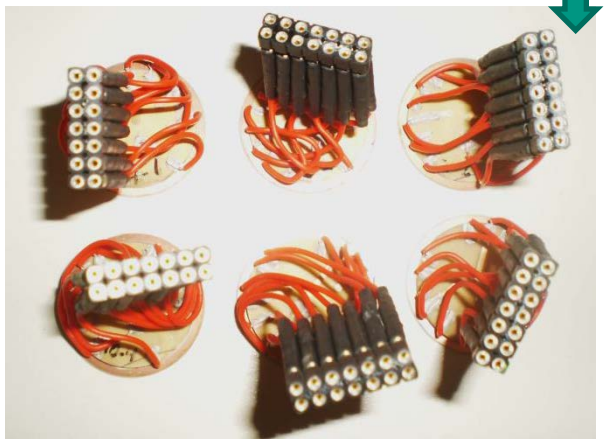
[1] see IEEE IUS 2015 paper “Evaluation of composite fibres for USCT”
[2] see SFB/TRP report K04 21.2.17

Production of prototypes

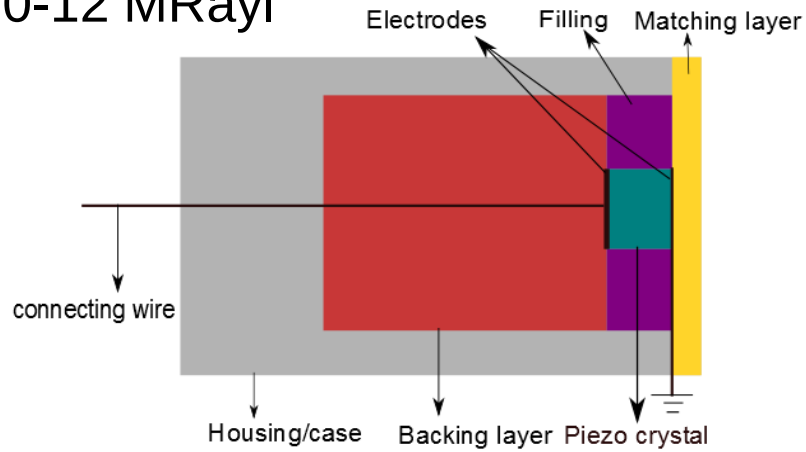
- Matching TMM4: ~370µm, ~6-7 MRayl
- Backing PU+Tungsten: 1cm thick, ~10-12 MRayl



Ground side surface covered with conductive silver glue Heraeus PC3000



Wires connected with Heraeus PC3000 (100°C curing)

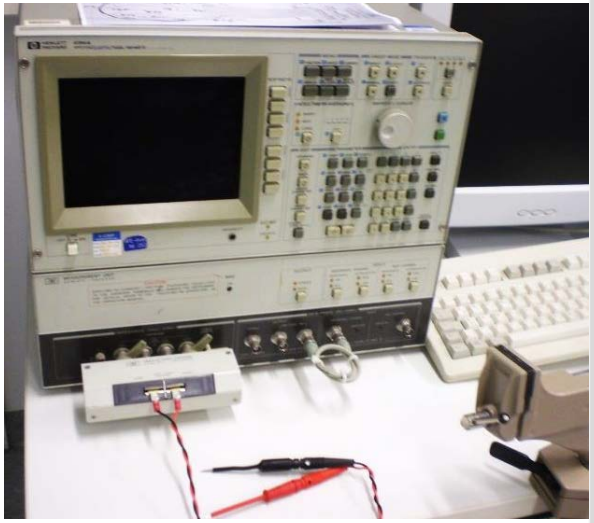


Set of 6 prototypes

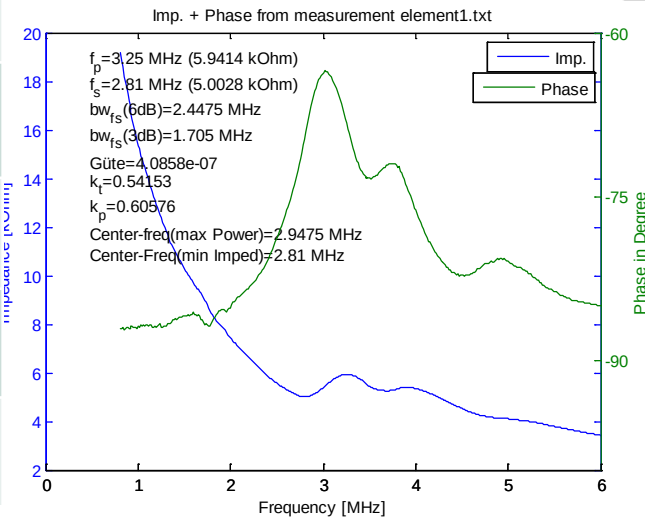
Impedance-Phase characterisation

- quality control and reproducability check

Thickness of disc (in µm)	Center freq. (in MHz @max. Power, mean/std.)	BW (max. Power@ 3dB/6dB)	Phase (in degree@ max. Power)	Kt (mean/ std.)	Working (kt >0.1)
400	3.01 (0.24)	1.69 / 2.34	-69.98°	0.56 (0.17)	**11/13**
550	2.54 (0.07)	1.57 / 1.99	-72.24	0.84 (0.06)	**12/13**
750	2.06 (0.11)	1.23 / 1.34	-74.53	0.90 (0.01)	**13/13**
1050	3.56 (1.29)	0.17 / 0.17	-85.08	0.91 (0.03)	**4/13**
1450	3.34 (0.07)	1.62 / 2.54	-85.22	0.11 (0.24)	**1/13**
2050	2.53 (0.04)	1.25 / 1.73	-85.30	0.00 (0.00)	**1/13**



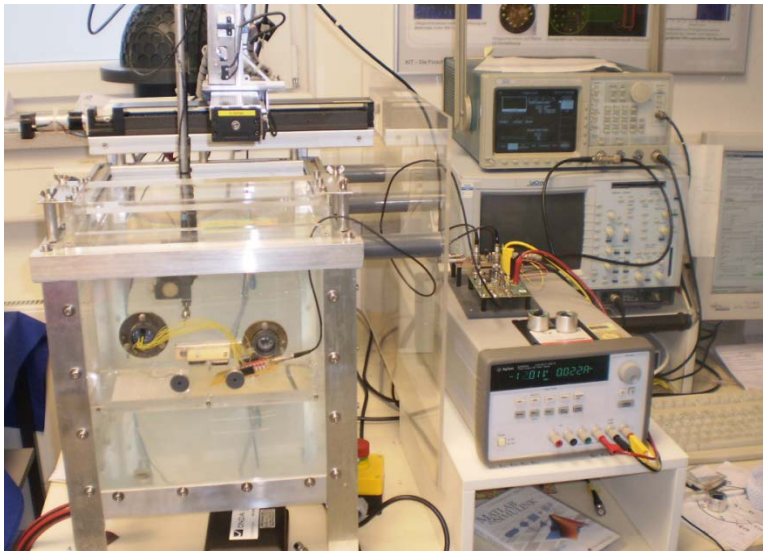
HP4194A characterisation station



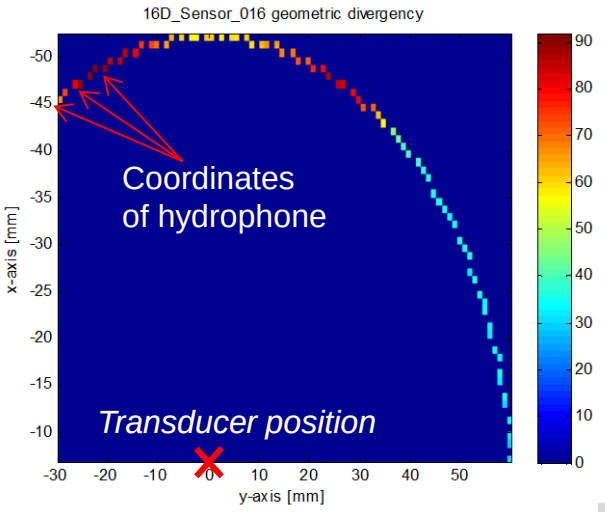
Example impedance curve

Acoustical characterization

- 3-axis US characterization station
- Setup and parameters
  - Self-built system
  - Excitation voltage +-/100Vpp
  - Freq.-sweep with Chirps: 0.5MHz to 5.5MHz in 250kHz steps
  - Calibrated Onda HNC-400 hydrophone (up to 10MHz) + 20dB pre-Amp.
  - 16x averaging (4x SNR gain)
  - Digitization 400µs, 20MHz
  - Semicircle profile, measurement time ~ 6 hours

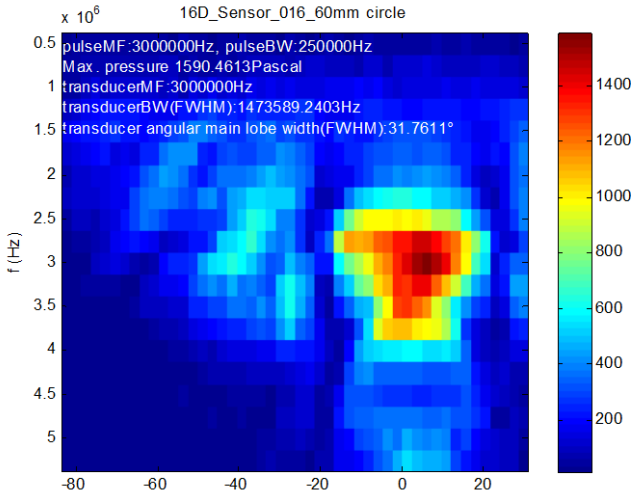


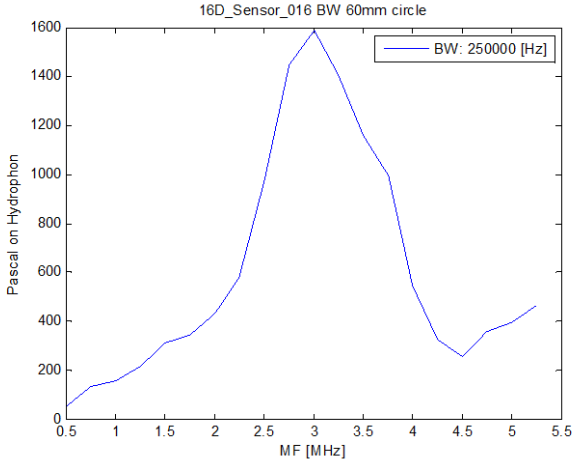
Left: acoustical pressure measurement container + (30 x 30 x 50 cm), right: AWG, Amp., DAQ, Osci, control PC



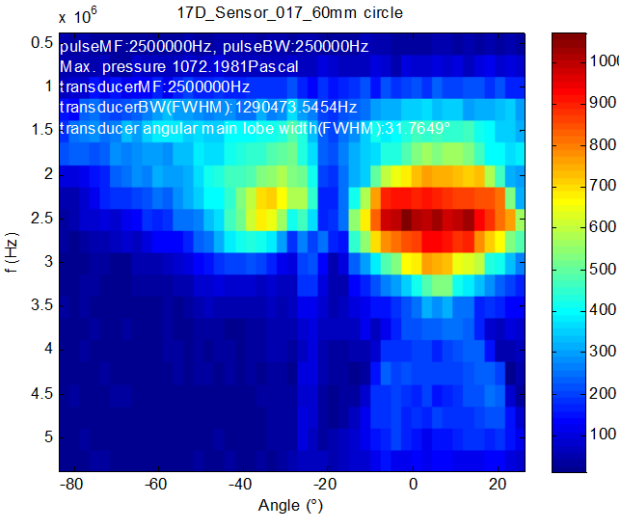
Transducer Prototypes

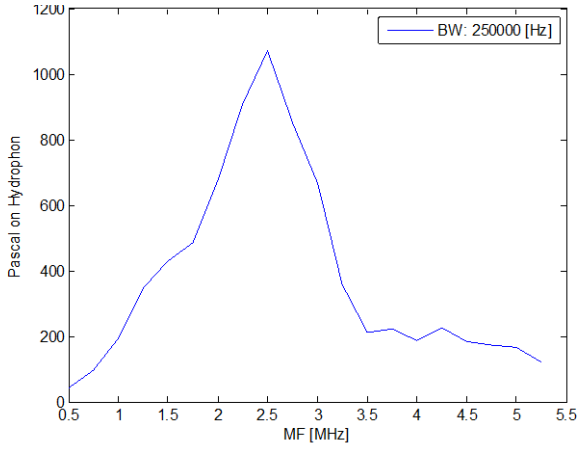
- 400µm (ele. 1)



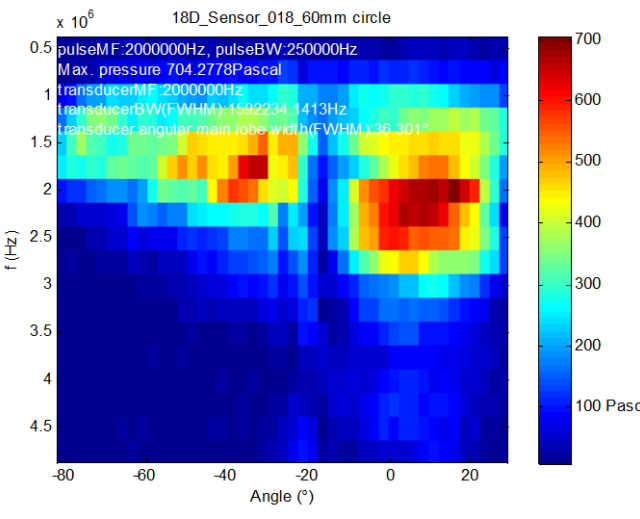


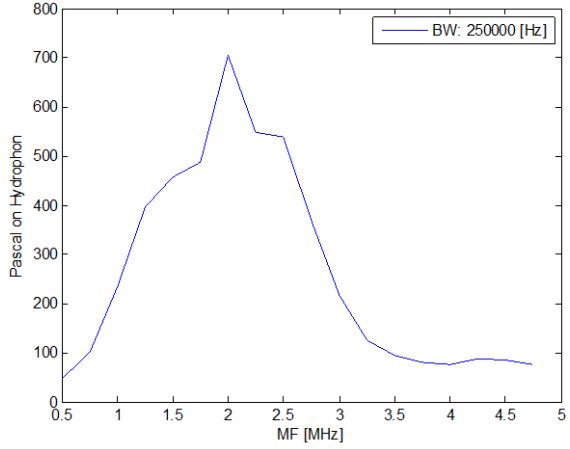
550µm (ele. 4)





750µm (ele. 1)

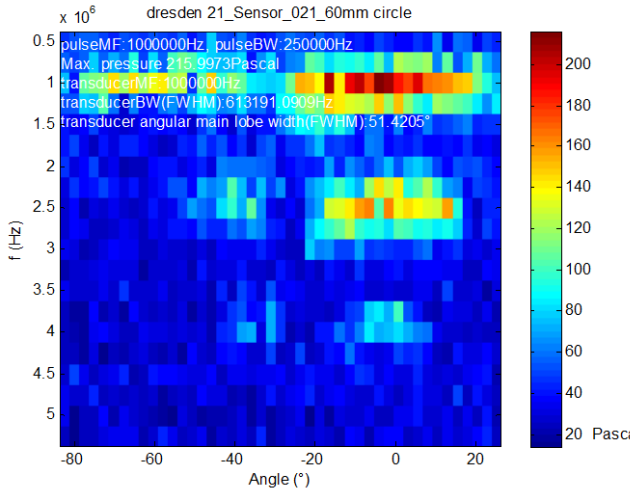




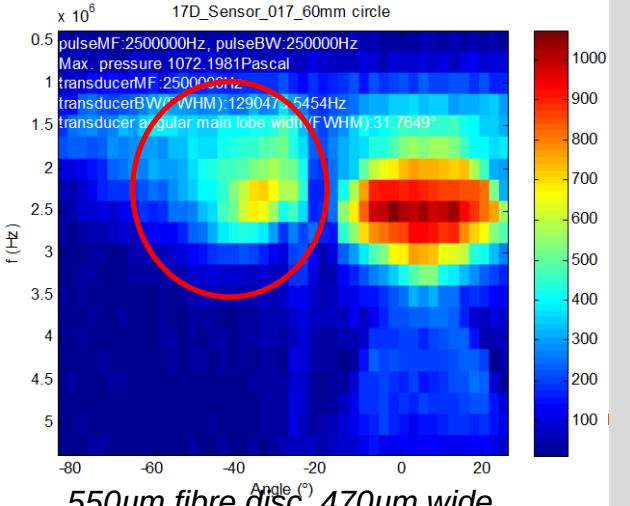
Discussion & Results

- Reliability
  - Secondary resonances dominate discs beyond 750µm: excluded
  - Reliablility of fibre disc production:
    kt > 0.1: **92%** for 400, 550, 750µm
  - Reliability of transducer prototypes:
    peak pressure < 0.3kPa @6cm): **65%** (13/20)

- Performance
  - Separation of side lobe is concern: phase inversion? Usable?
  - 400, 550 and 750µm most interesting thicknesses for the application: expected pressure (~ 1-2kPascal@6cm), good bandwidth (~ 2MHz @6dB) & acceptable opening angle



2050µm fibre disc, 470µm wide

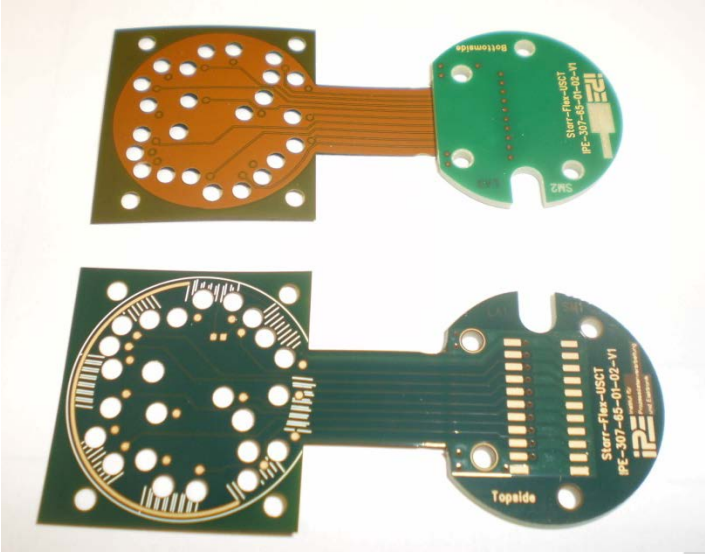


550µm fibre disc, 470µm wide

Next Steps and outlook

- Connectivity & Integration with electronics
  - Sputter process: Au and Cr/Au-layers (Adhesive improvment)
  - PCB design ready
- Substructuring (100µm fibres)
  - Ongoing work, bundleing questions open
- Improved substrate material
  - Tungsten filled ?

- **Thanks for your attention!**



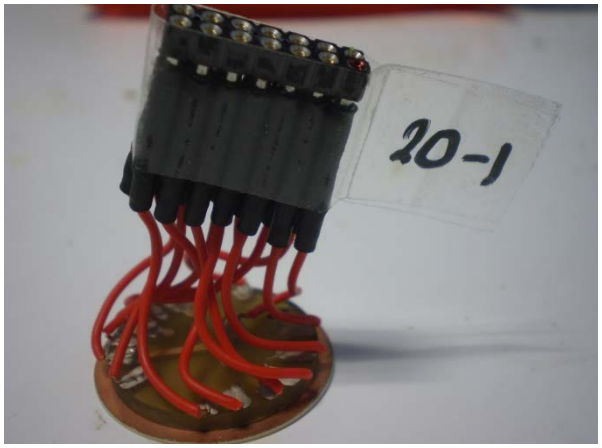
Flex print PCB for integration of discs into electronics and housing

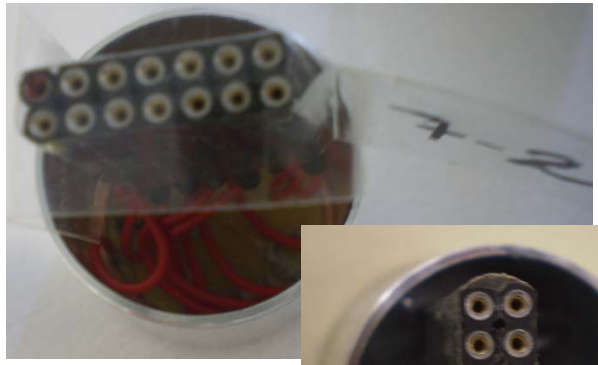
Ongoing work…

This project was partly funded as Sonderforschungsbereich/Transregio 39 »PT-PIESA« SFB/TR 39 as subproject K04.

Appendix

Build up



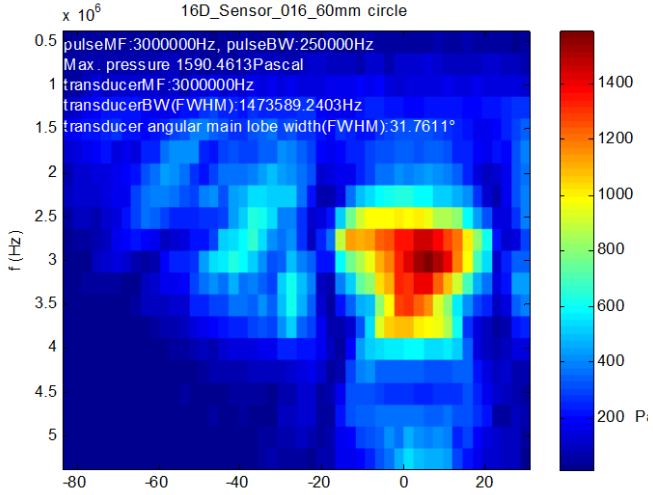


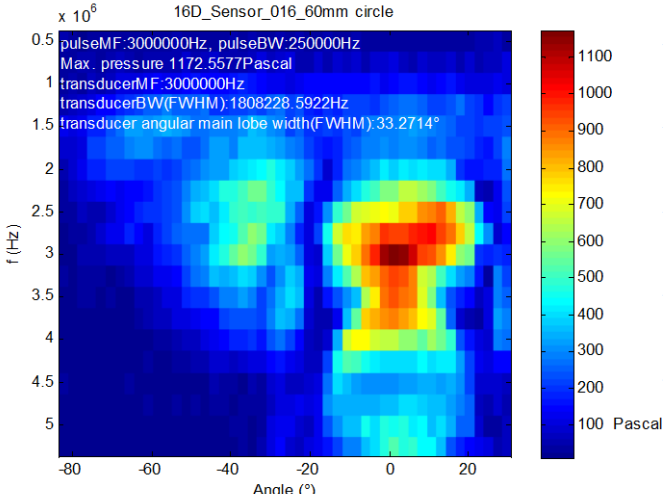
400µm Transducer Prototype

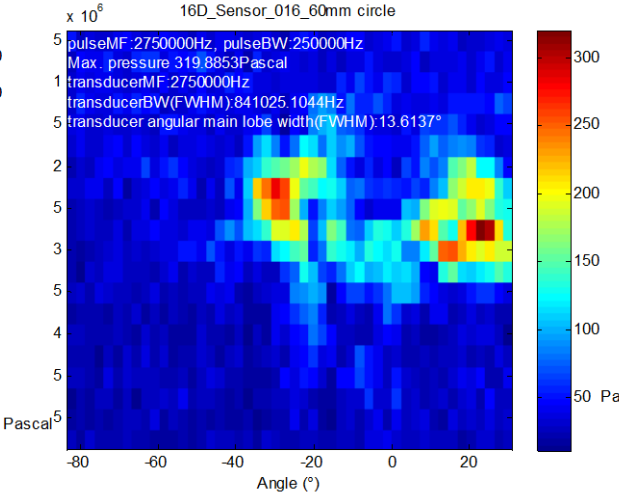
- Element 1

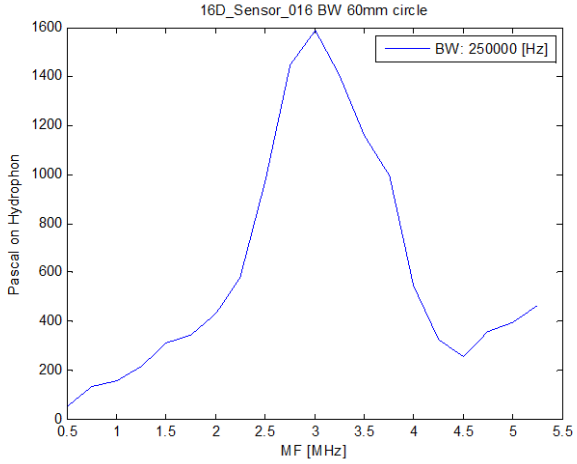
Element 3

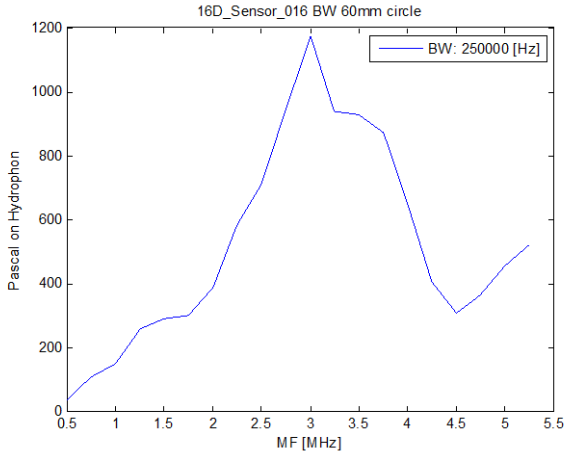
Element 4

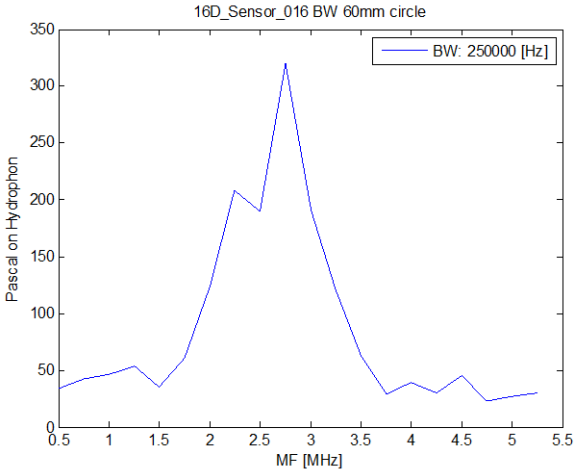






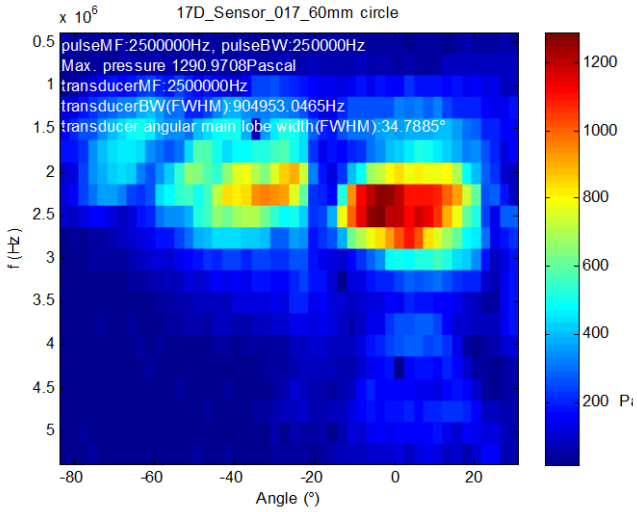


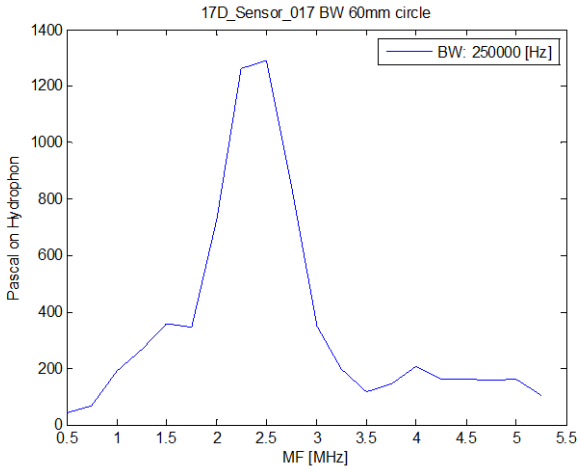




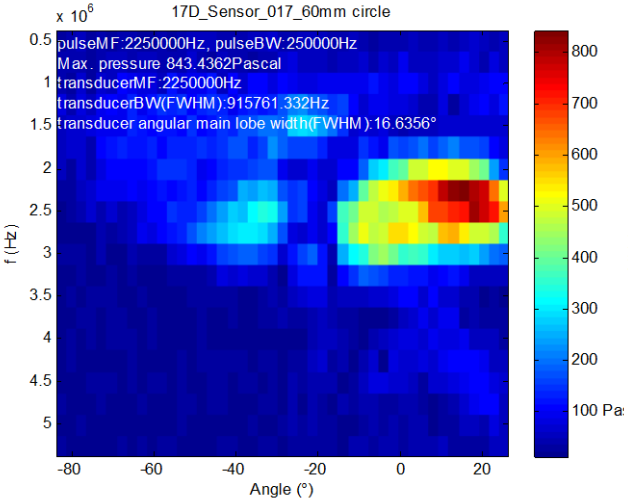
550µm Transducer Prototype

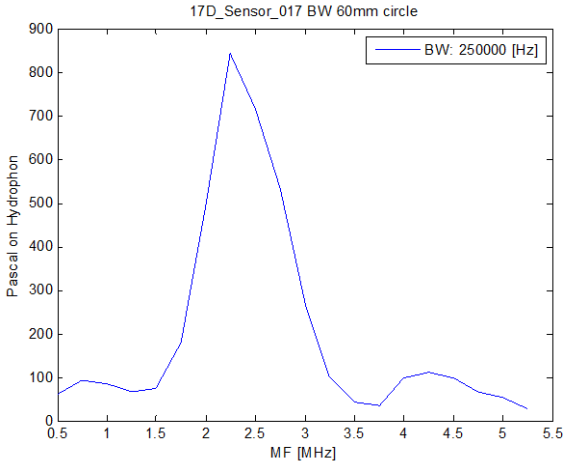
Element 1



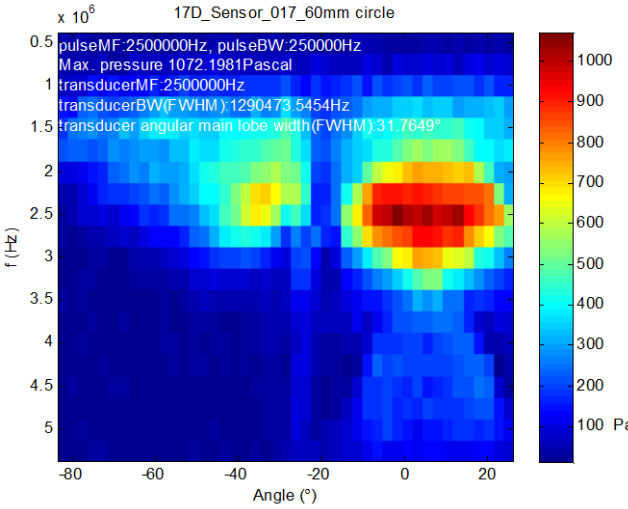


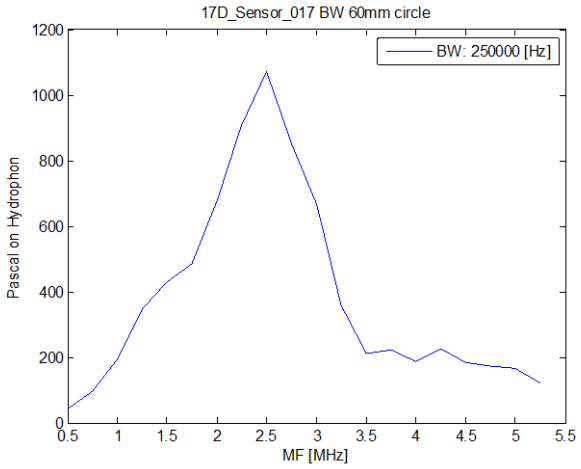
Element 3





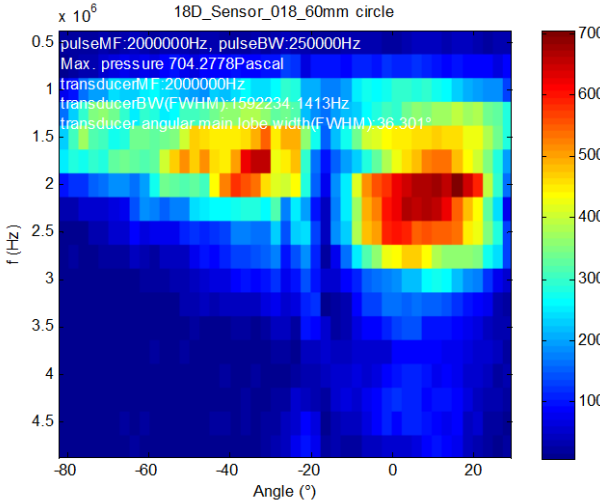
Element 4

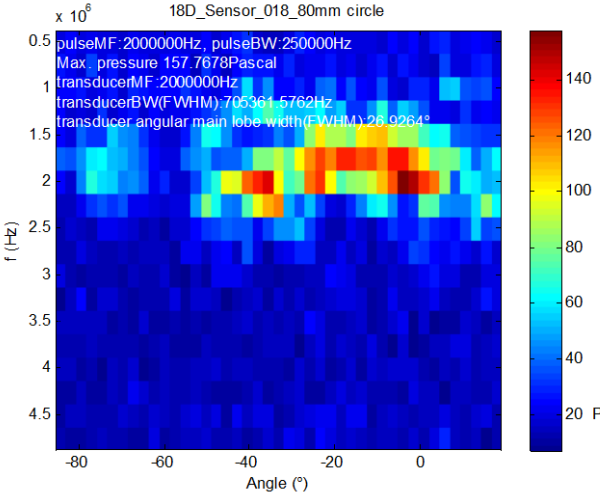


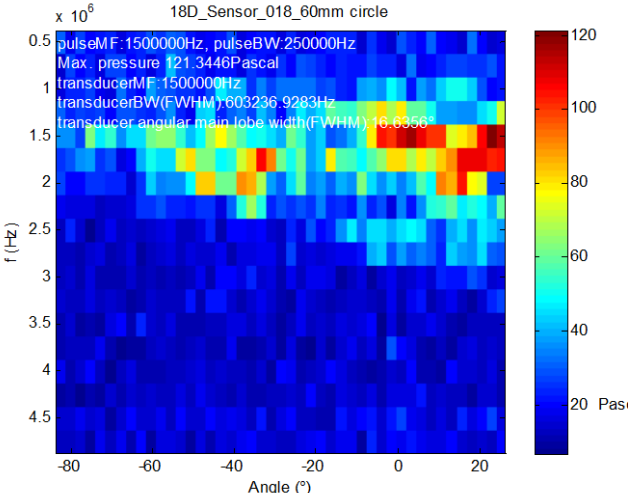


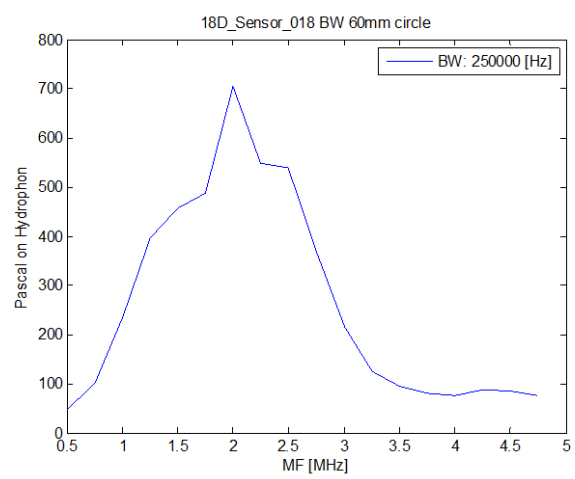
750µm Transducer Prototype

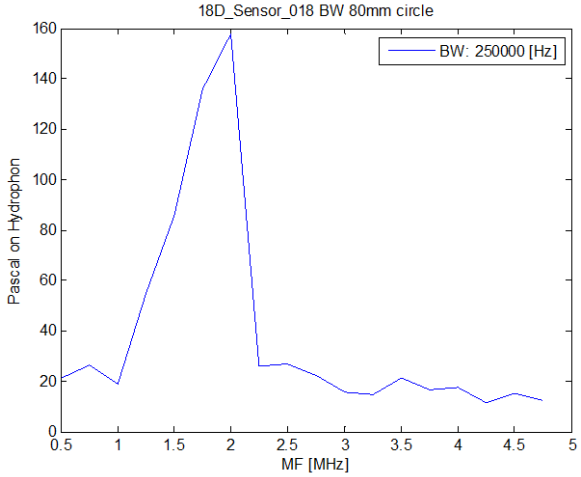
- Element 1
- Element 3
- Element 4

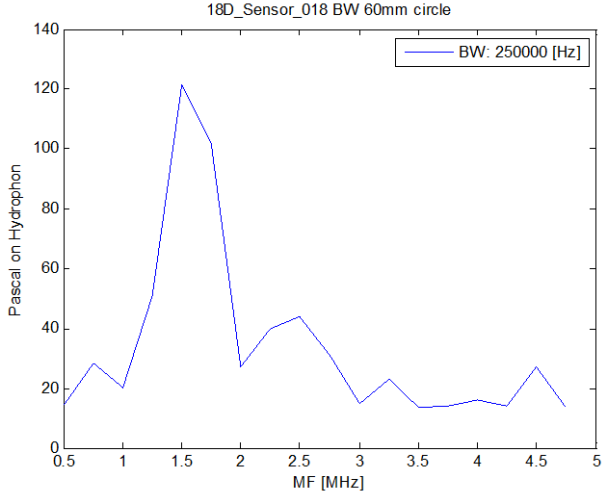










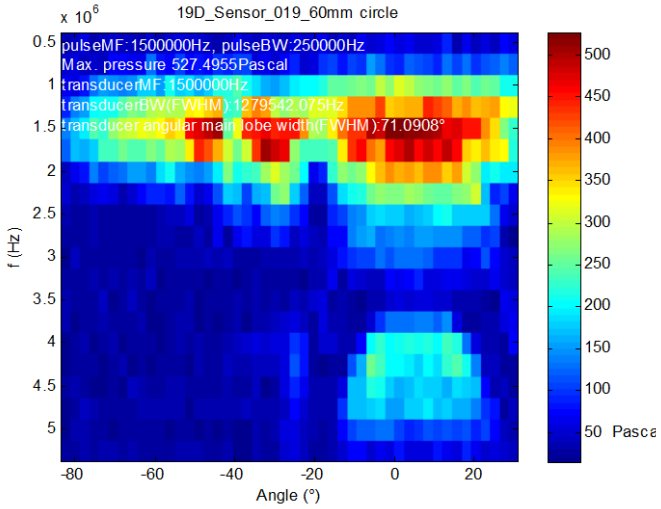


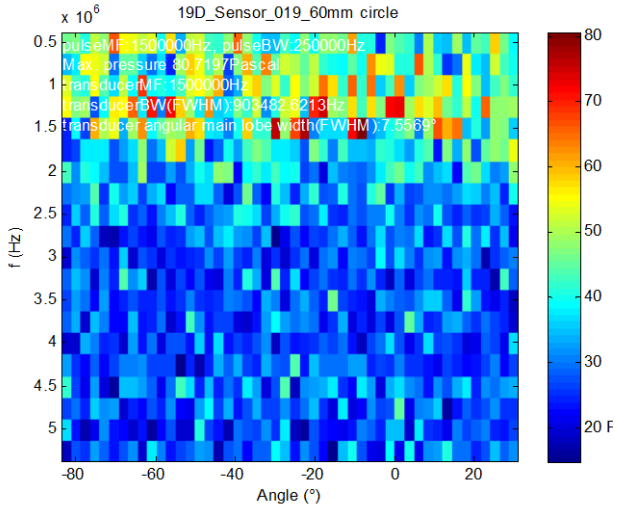
1050µm Transducer Prototype

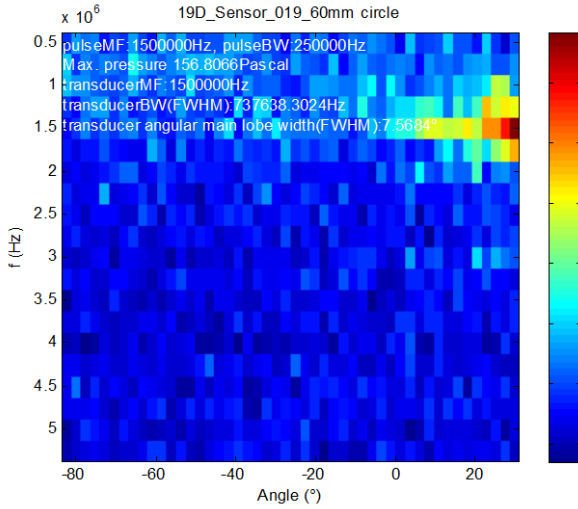
- Element 1

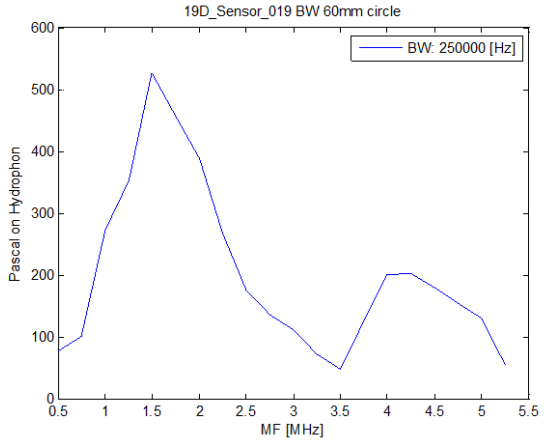
Element 3

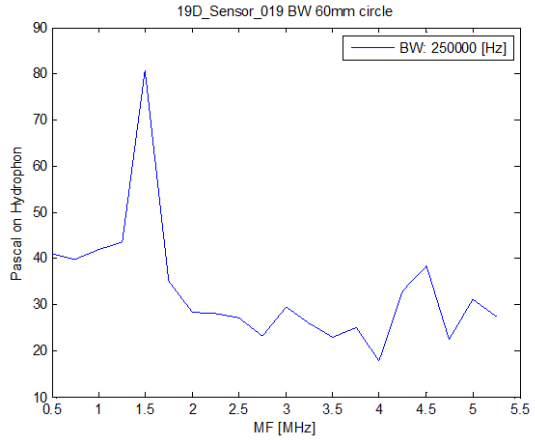
Element 4

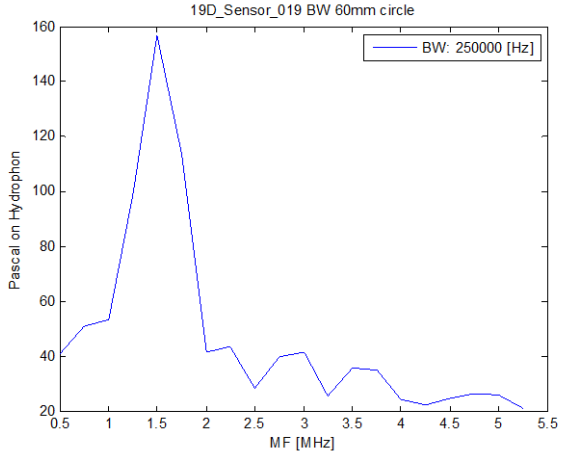








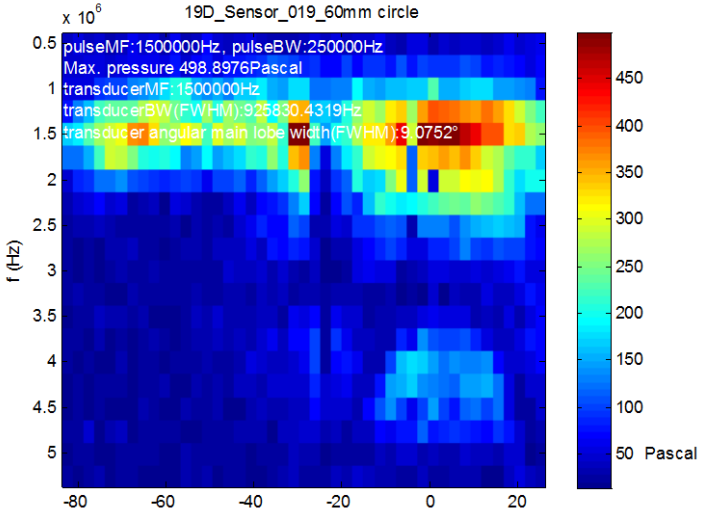


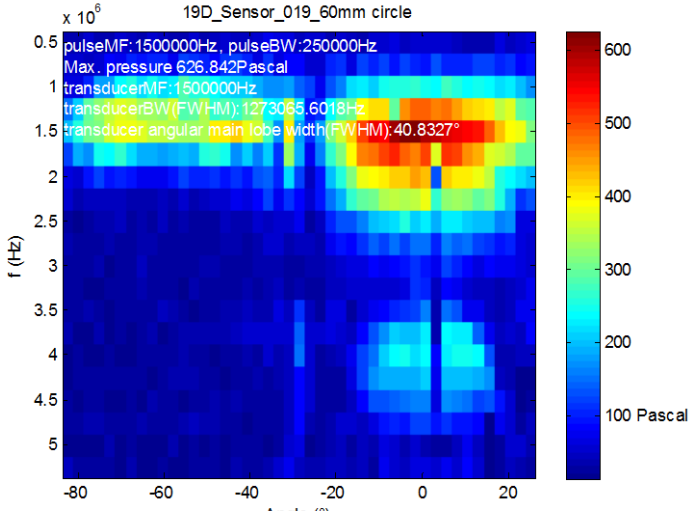


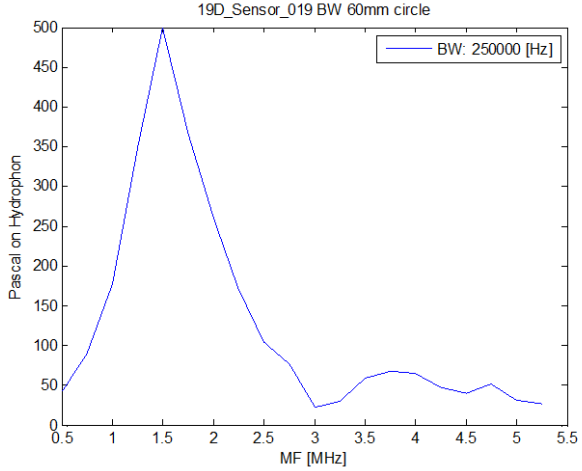
1050µm Transducer Prototype II

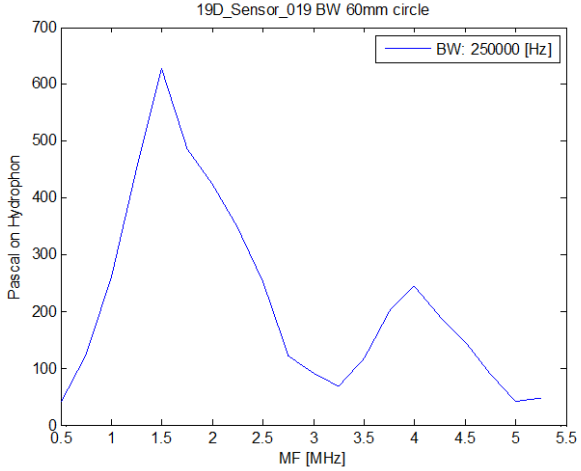
- Element 5

Element 6







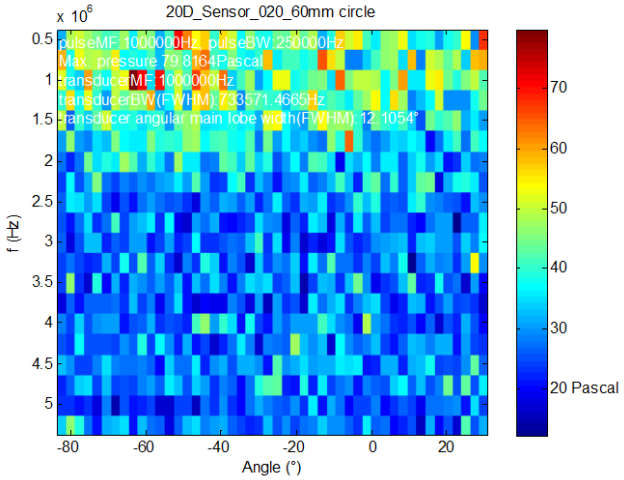


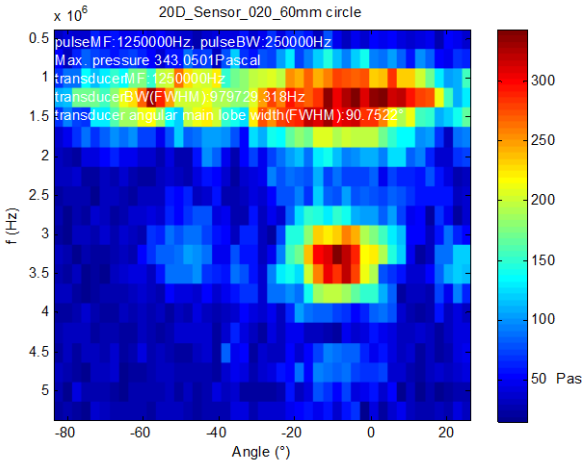
1450µm Transducer Prototype

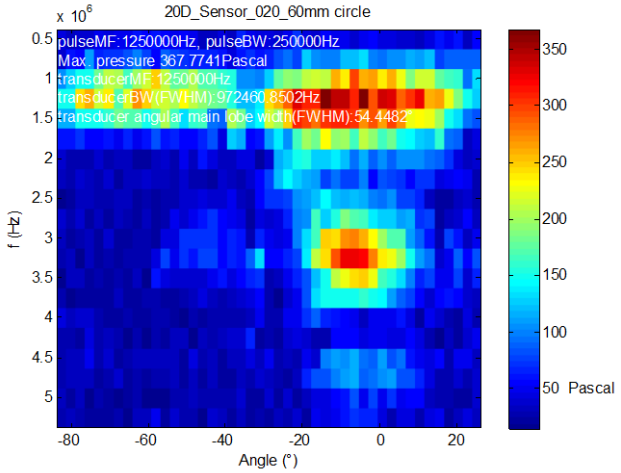
- Element 1

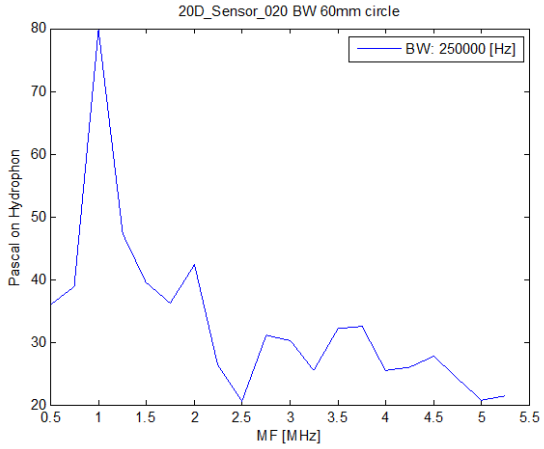
Element 3

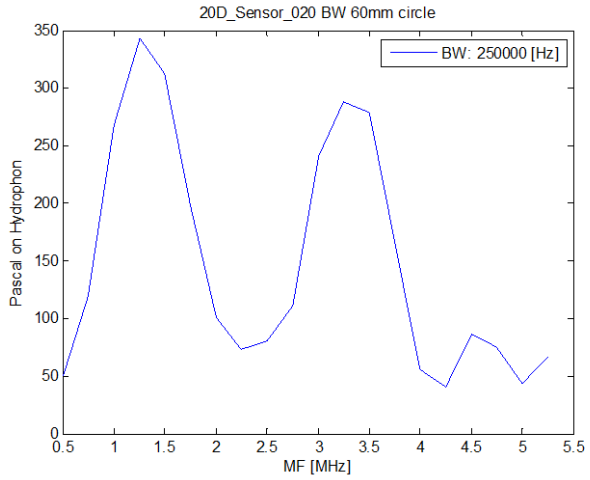
Element 4

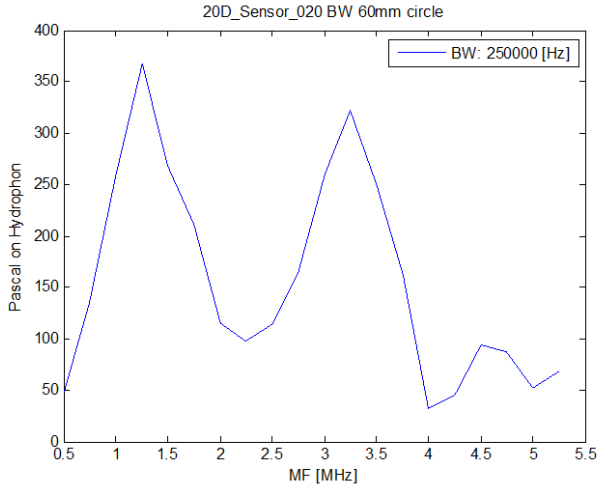










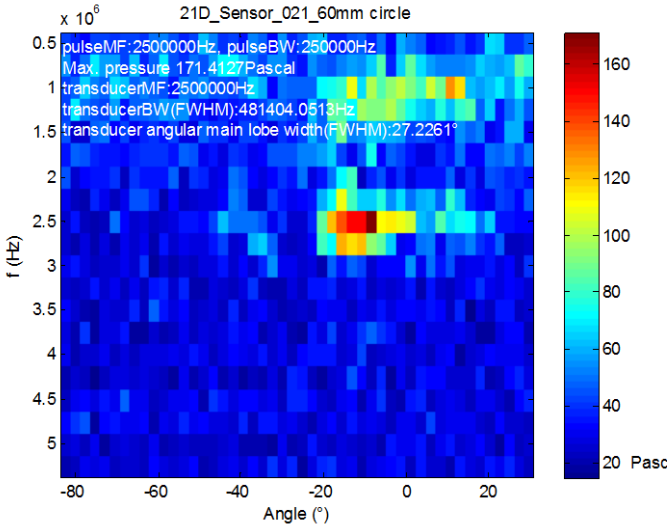


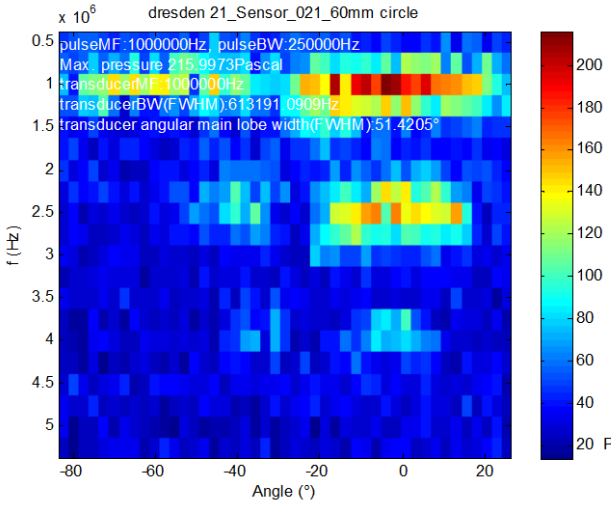
2050µm Transducer Prototype

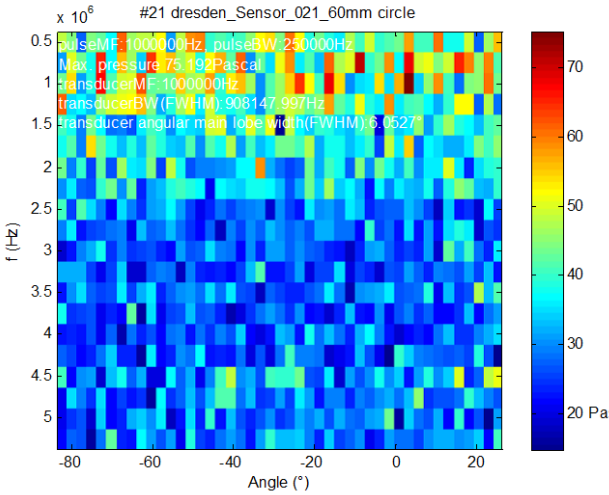
- Element 1

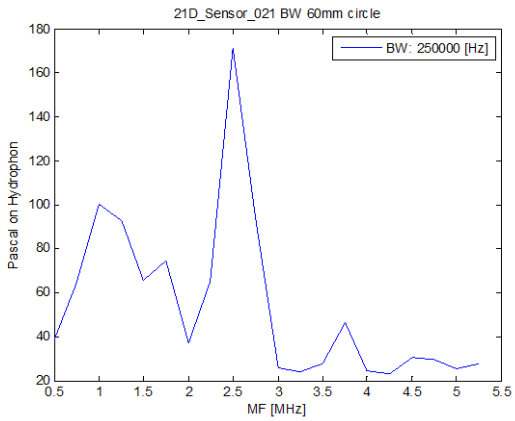
Element 3

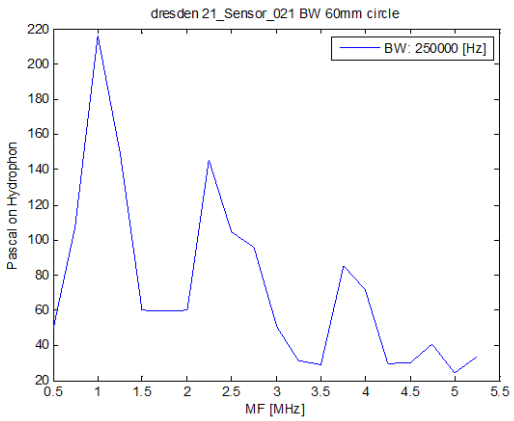
Element 4

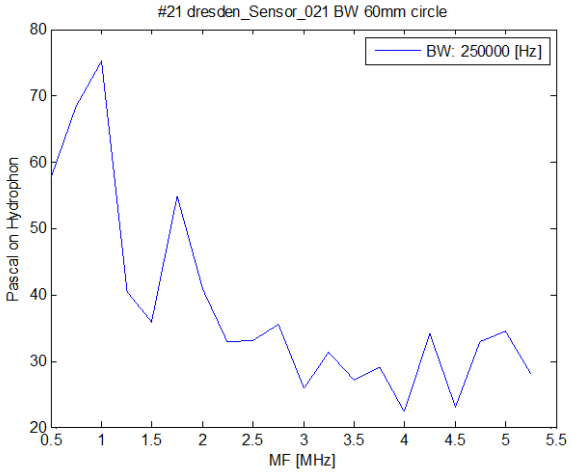








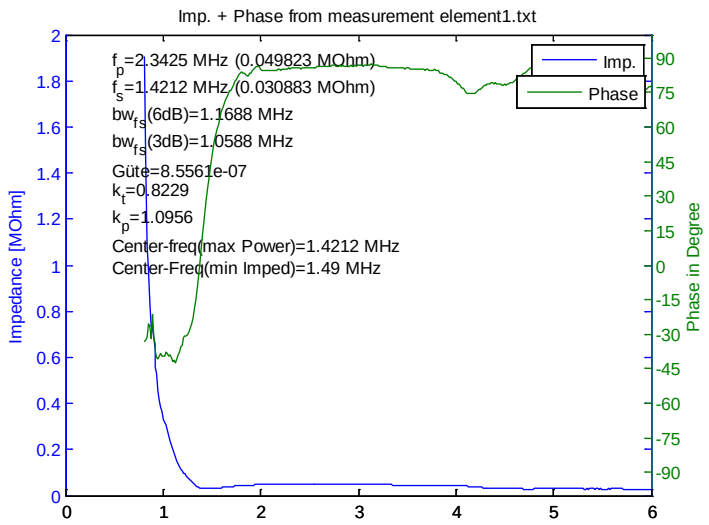


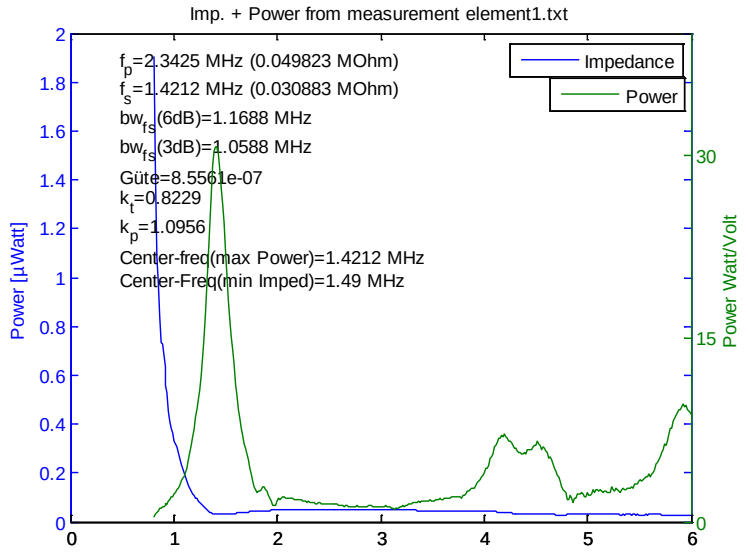


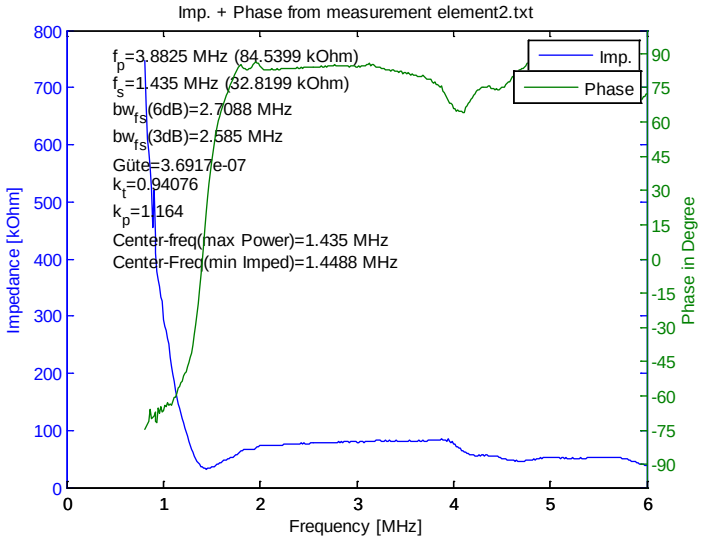
Phase 1: discs

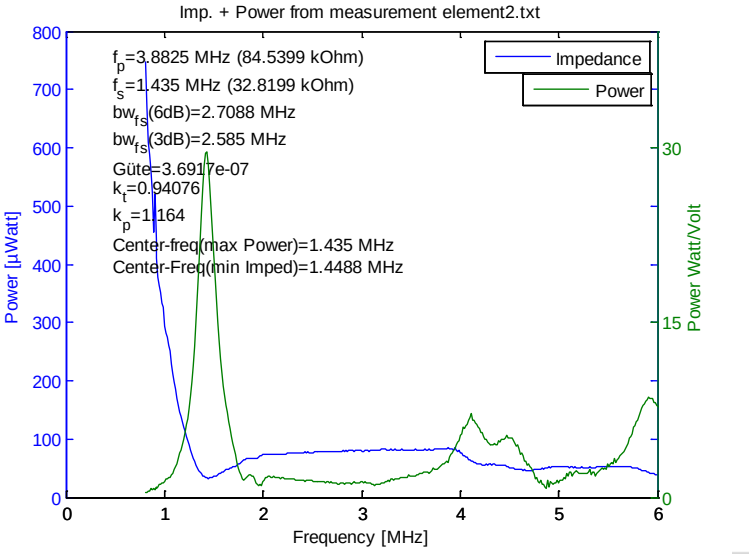
Thickness of disc (in µm)	Center frequency (MHz, max. Power, mean/std.)	Bandwidth (max. Power@ 3dB/6dB)	Phase	Kt (mean/std.)	Working (kt >0.1)
400	3.2088 (0.25724)			0.5605 (0.1706)	11/13
550	2.5530 (0.0503)			0.8438 (0.0626)	12/13
750	1.9469 (0.04931)			0.9061 (0.0149)	13/13
1050	1.4392 (0.03432)			0.9103 (0.0319)	4/13
1450	3.3209 (0.77073)			0.1193 (0.2415)	1/13
2050	2.5308 (0.03945)			0.0000 (0.000)	1/13

Phase 1:1050µm





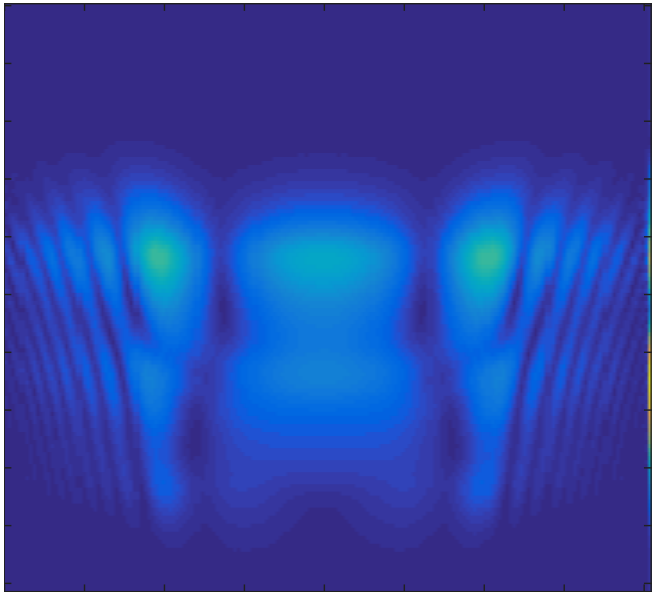


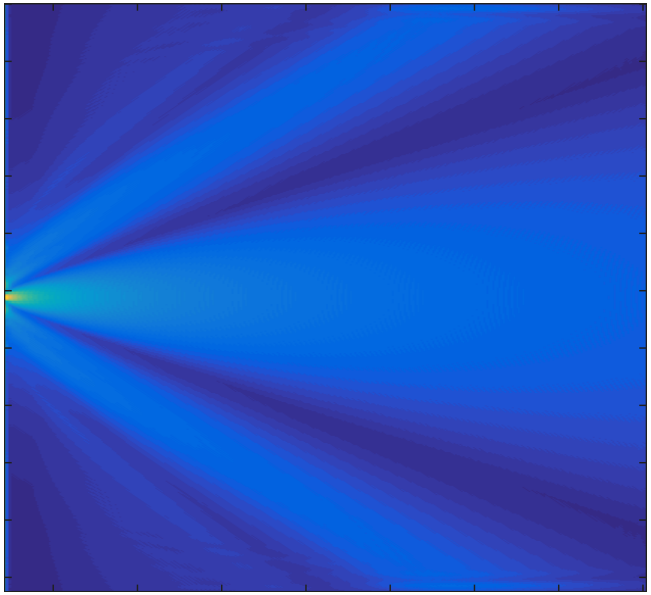


Bisherige Ergebnisse der 3. Förderperiode (Highlights)

- Auslegung und Simulation
  - PZFlex, Finite-Elemente-Simulation
  - Modell 1: Piezofaserkomposit

Rot: Backing Epoxid (EPO-TEK 301-2FL, 2,9 MRayl)
Hellblau + Rot: Piezofaserkompositscheibe
(CeramTec Sonox 505 14.2 MRayl)
Blau: Wasser (1,5 MRayl)

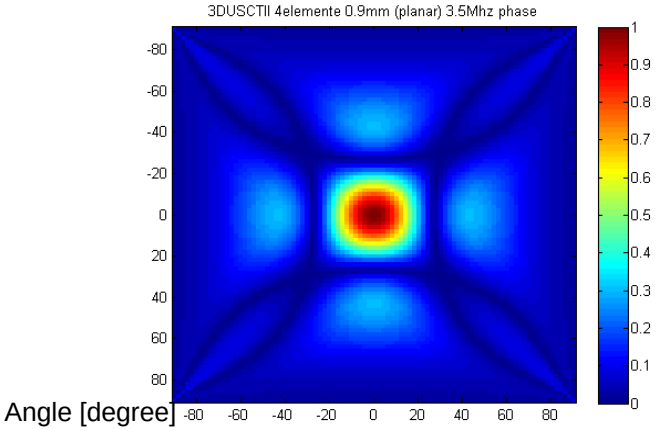




(in 1cm distance)

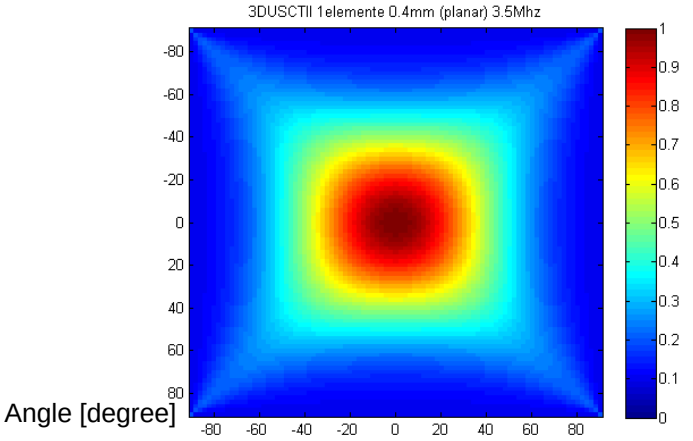
Design: Opening angle increase

- Reduced transducer surface for a ROI of 20x20x15cm³
  - Plus additional advantages

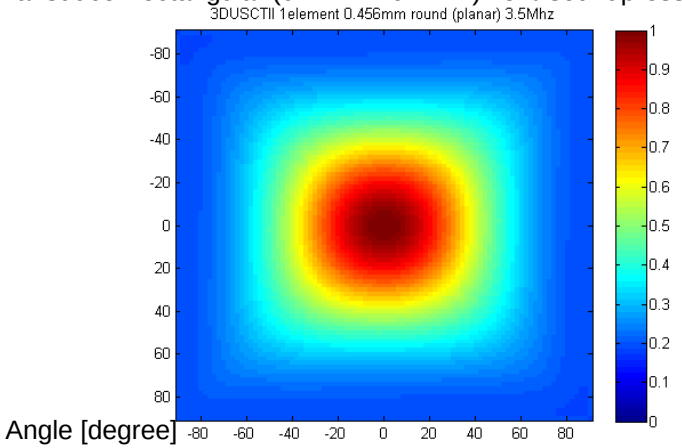


Transducer rectangular (0.9mm x 0.9mm) 100% soundpressure

Opening angle for f_{max} (3.5MHz) receiver*emitter	20%drop	50%drop	Sound pressure
3DUSCTII Transducer (0.9mm, rect)	14°	22°	100%
Transducer 0.902mm round	16°	28°	100%
Transducer 0.4mm rect	30°	54°	25%
Transducer 0.4561mm round	33°	58°	25%

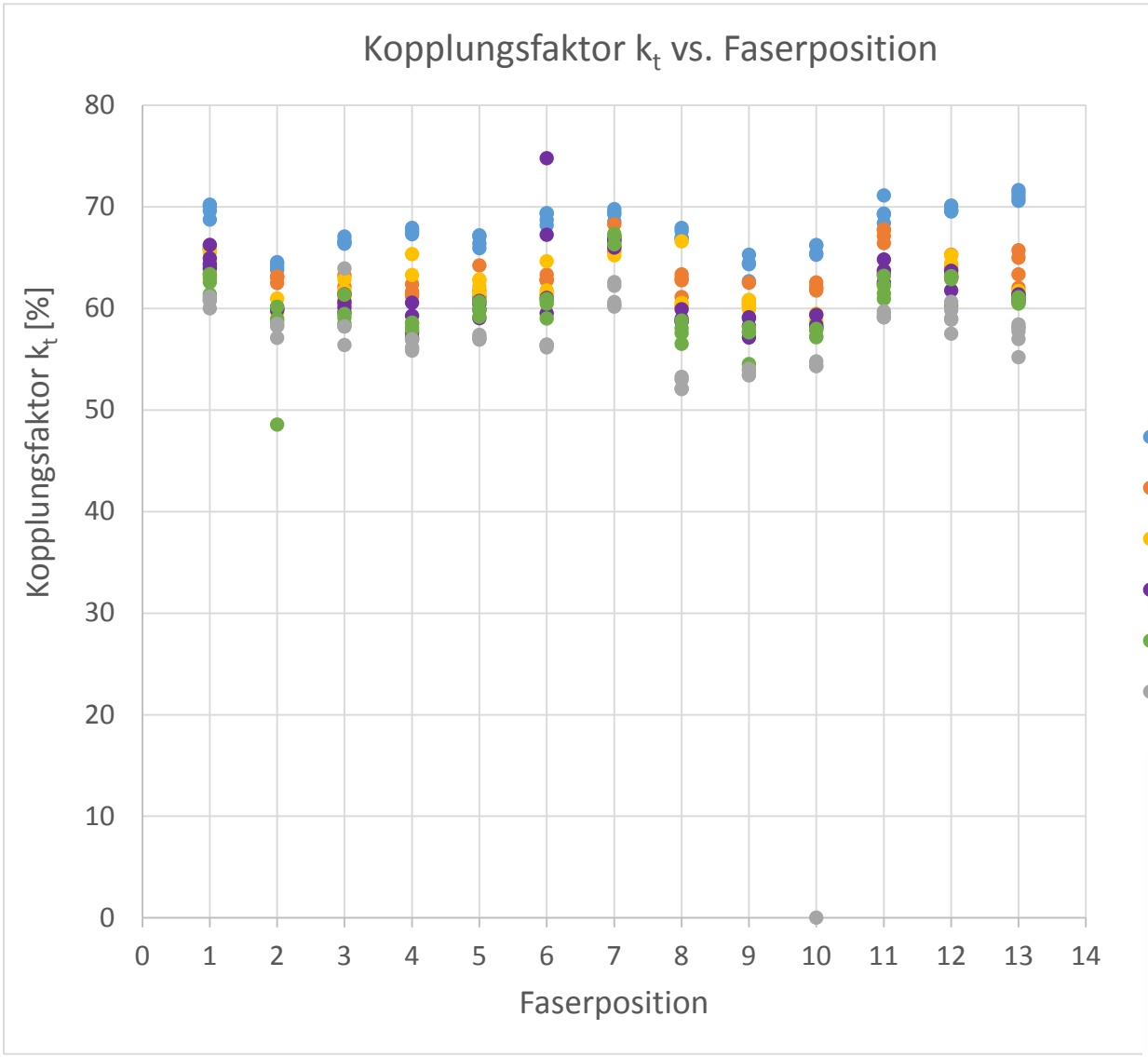


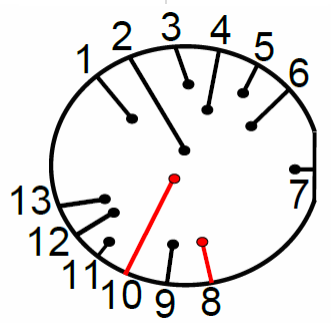
Transducer rectangular (0.4mm x 0.4mm) 25% soundpressure



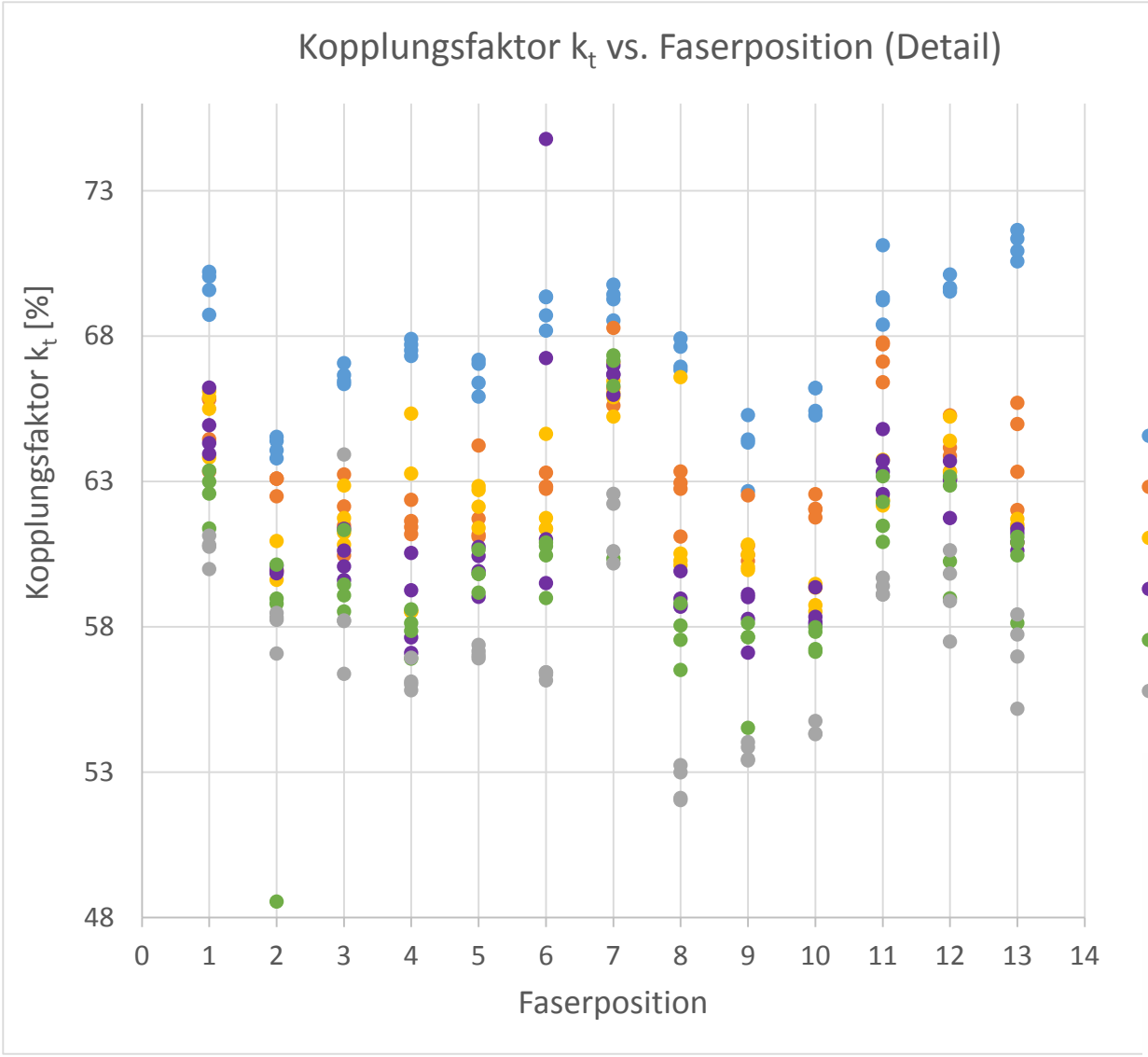
Transducer round (diameter 0.456mm) 25% sound pressure

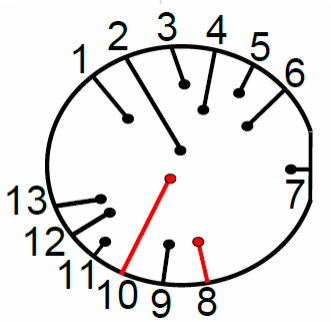
Ergebnisse Charakterisierung



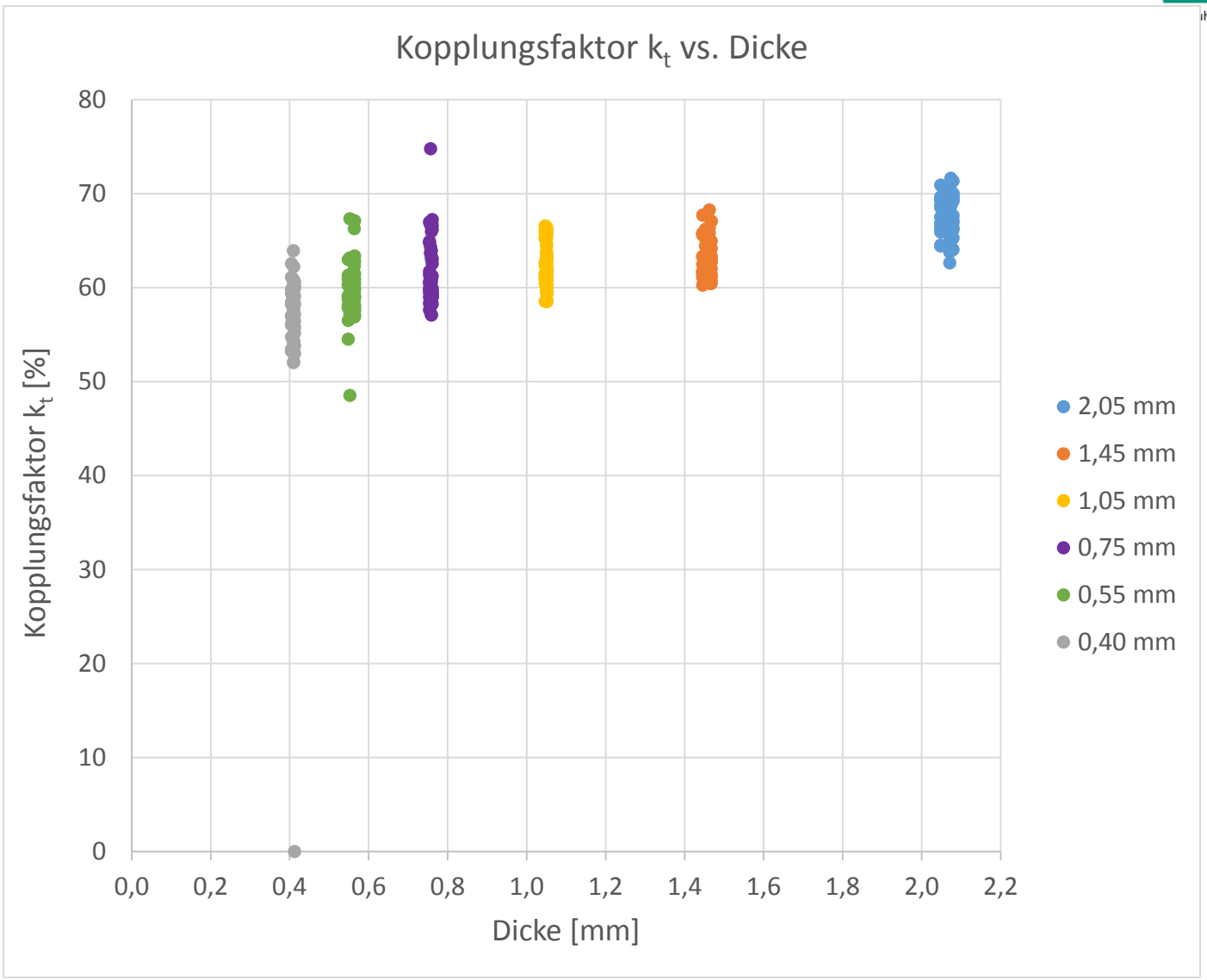


Ergebnisse Charakterisierung

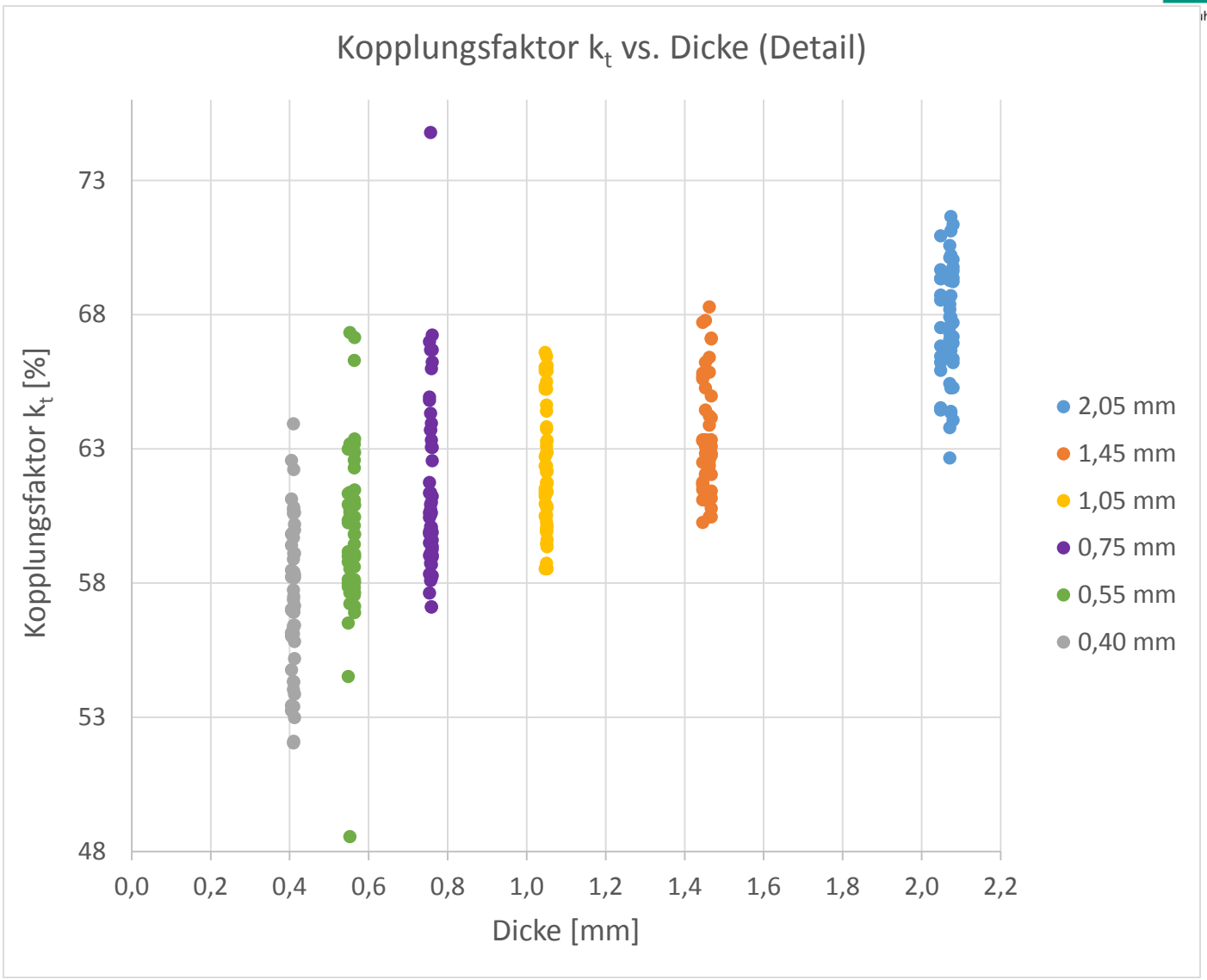




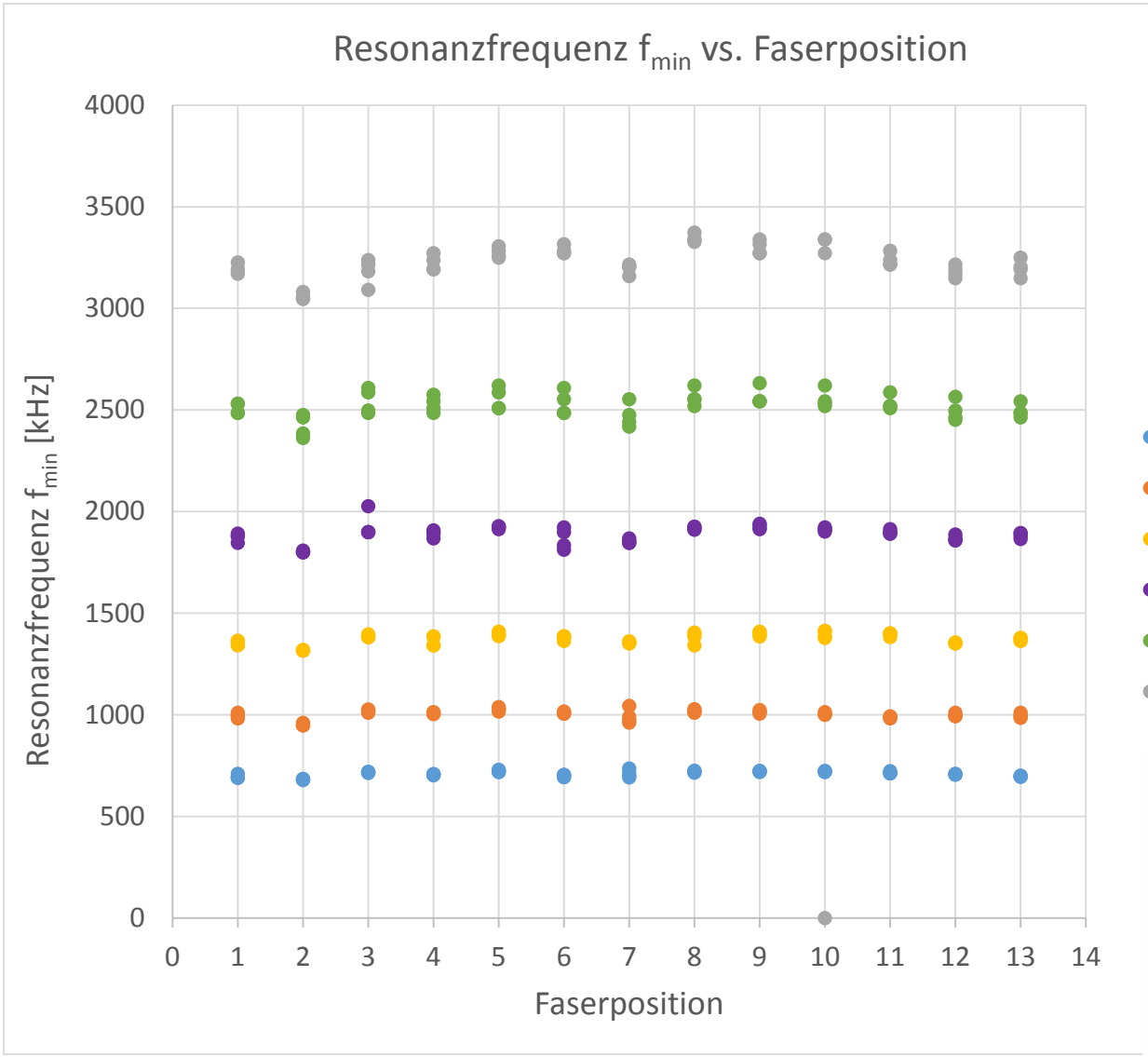
Ergebnisse Charakterisierung

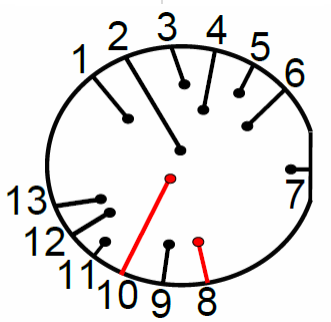


Ergebnisse Charakterisierung

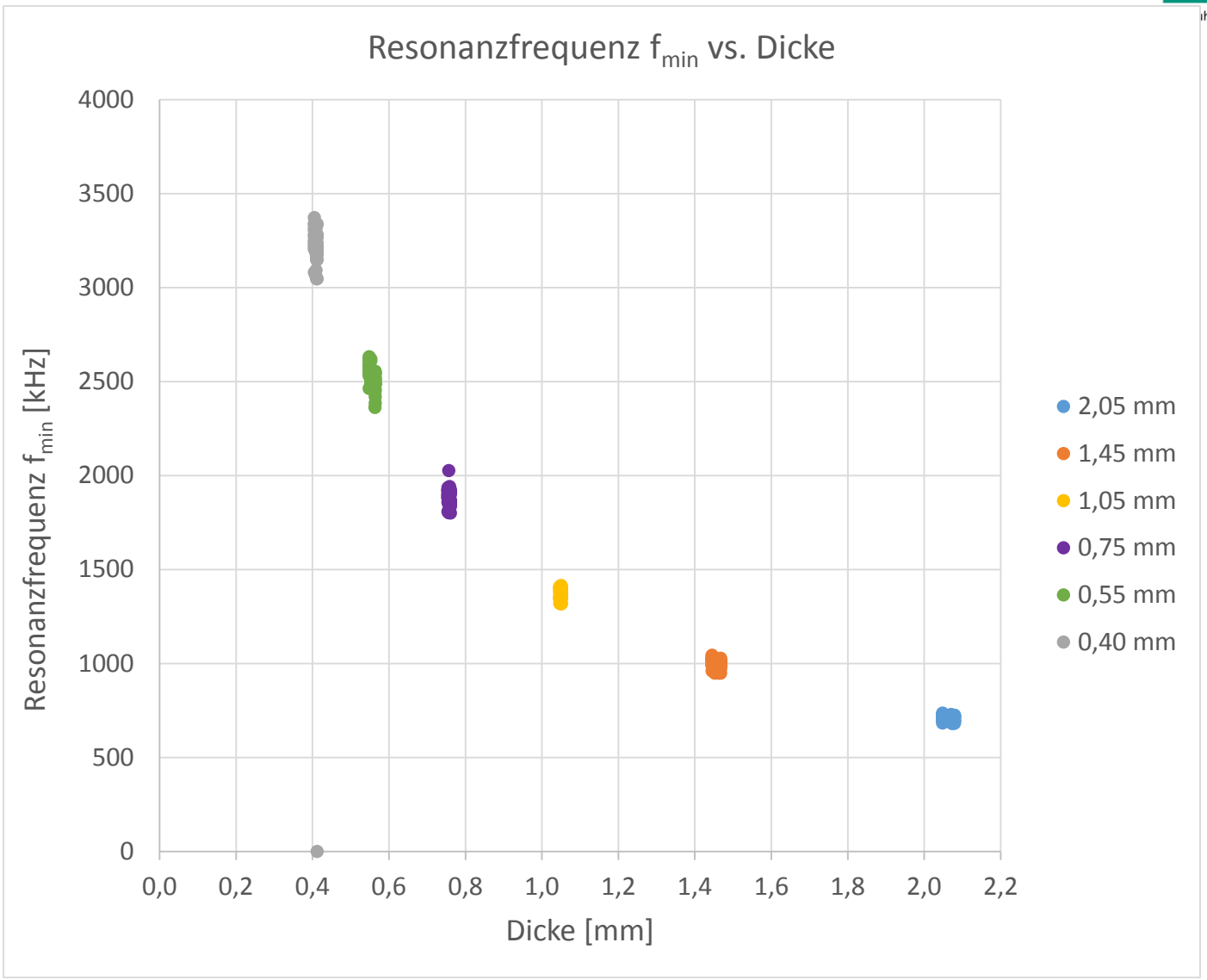


Ergebnisse Charakterisierung

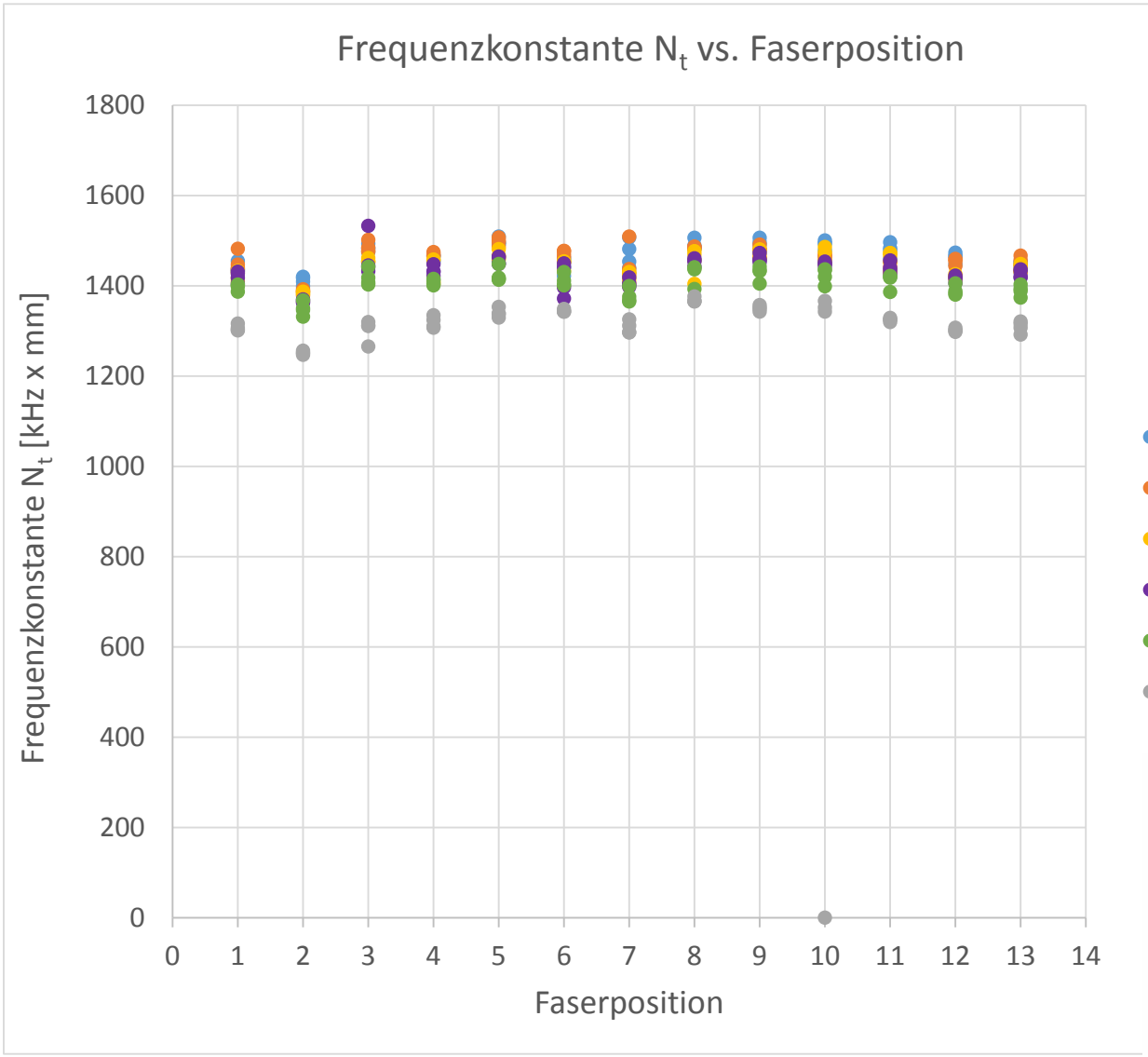


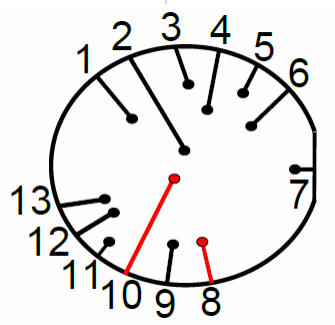


Ergebnisse Charakterisierung

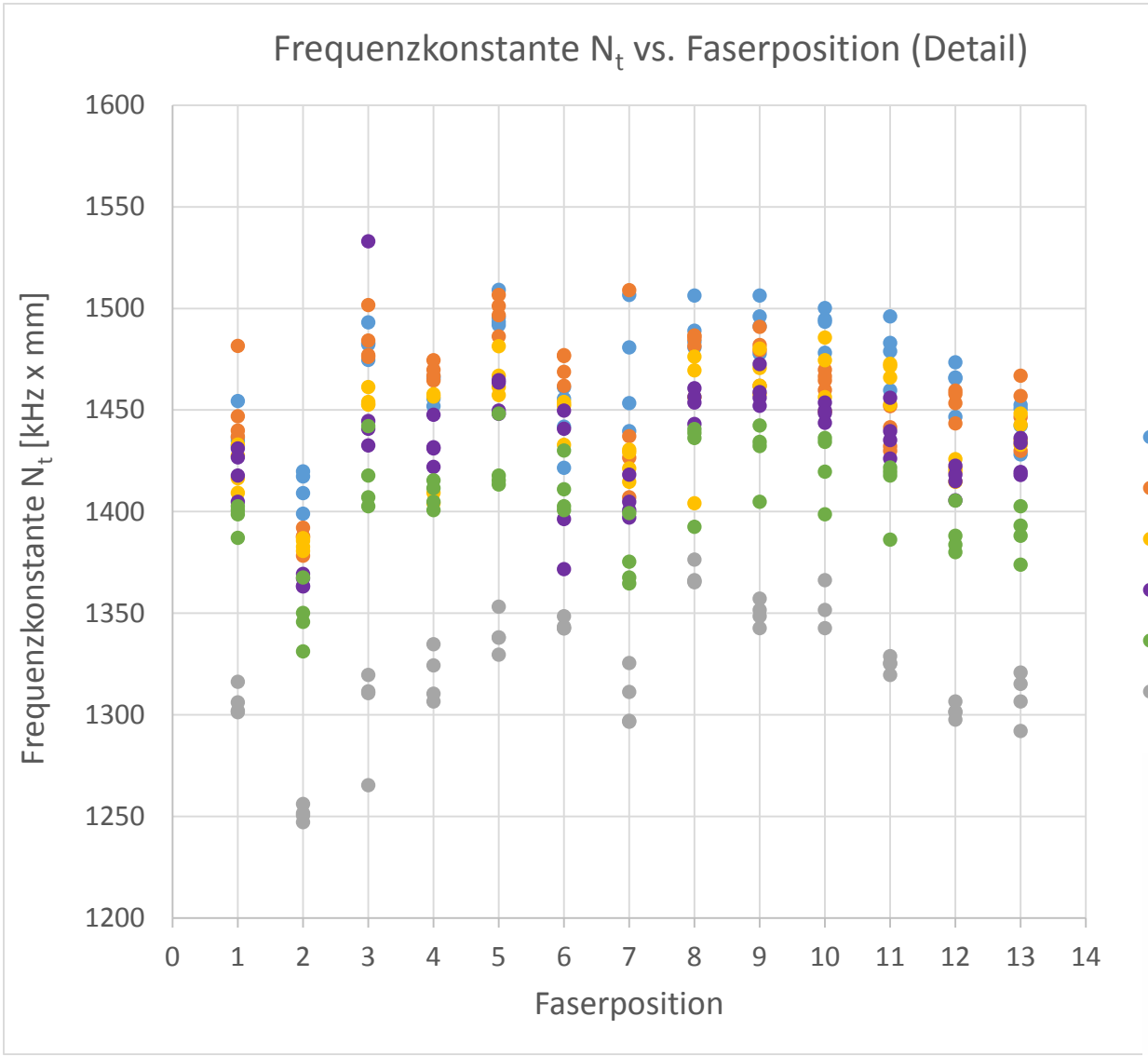


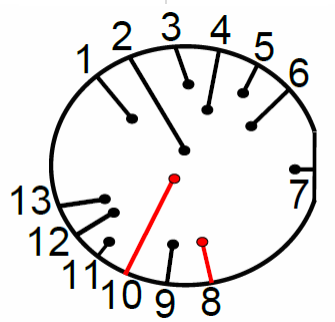
Ergebnisse Charakterisierung



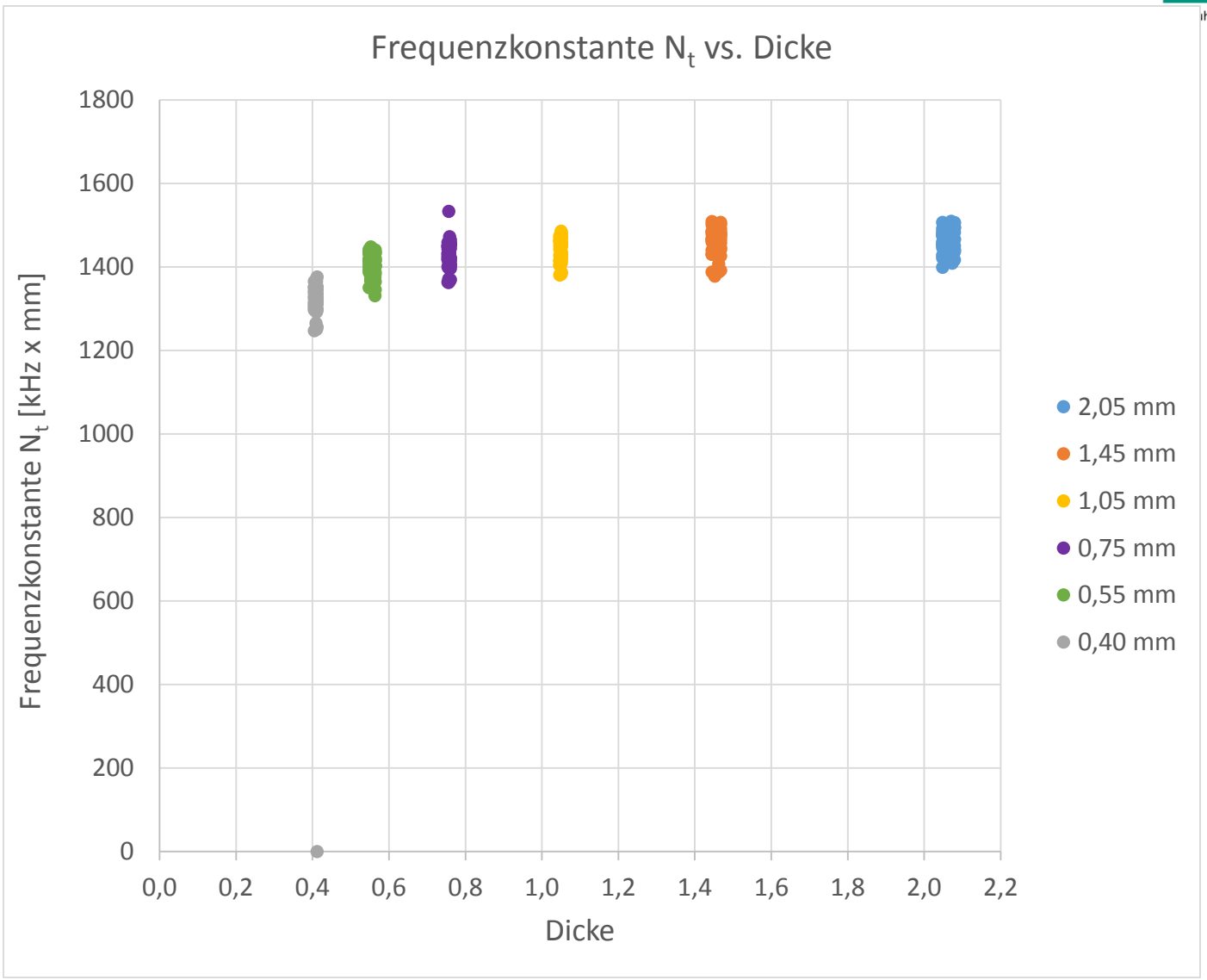


Ergebnisse Charakterisierung





Ergebnisse Charakterisierung



Dresdner Prototyp #1 II

- Stand Juli: Strang nach Vorgaben gegossen und in 450, 500, 550, 600µm Dicke Scheiben geschnitten
- Nächster Schritt Metallisierung, Polarisierung und Kontaktierung