# Phased Array Probes for Non-contact Air-coupled Ultrasonic Testing

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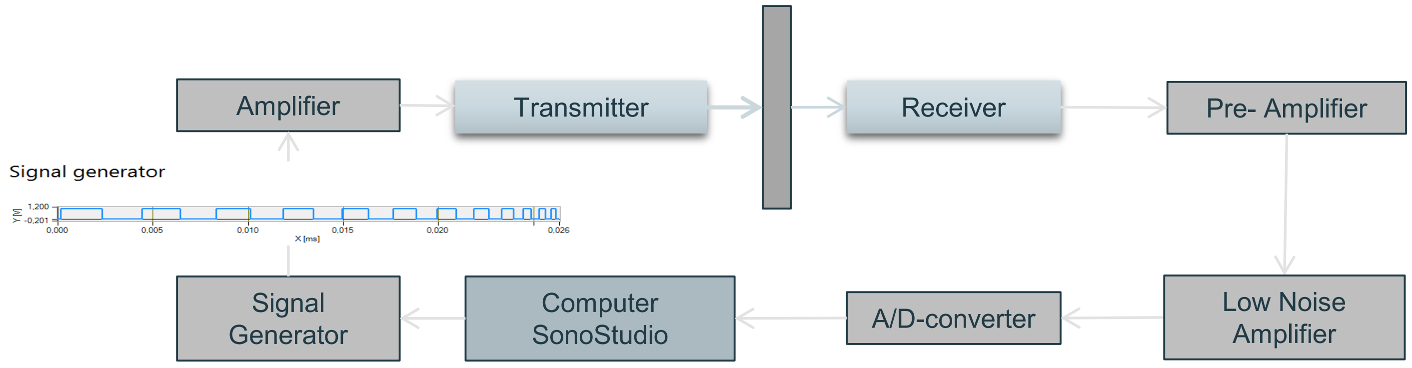
# Air-Coupled Ultrasonic Testing system – SONOAIR


- Non-contact air-coupled non-destructive testing system
- Sending-receiving configuration, having the test item in between 2 transducers which are sitting opposite to each other
- Evaluated is the sound damping between sender and receiver at a specific point (point measurement)
- The testing of an area is only possible by multiple measurements or manipulation of the transducer position
- A system with up to 4 measurement channels measuring at the same time is available
- A good/bad rating is only possible by comparison

## System Setup

- High-end 4-channel ACUT system:
  - Powerful transmitter with up to 400 V (4 kW)
  - Freely programmable signal generator (50 – 750 kHz)
  - High range low-noise amplifier up to 120 dB at 1 nV / √Hz
  - Customizable software
  - Full data access
- Multi-channel digitizer with up to 100 MSps
- Data storage and viewer

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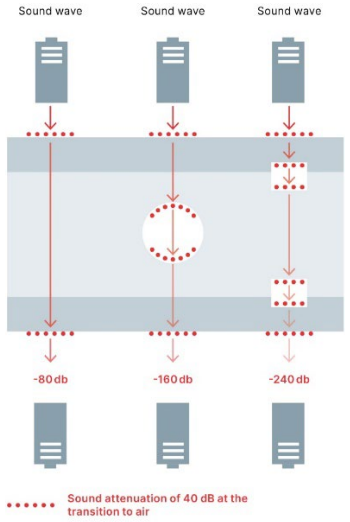
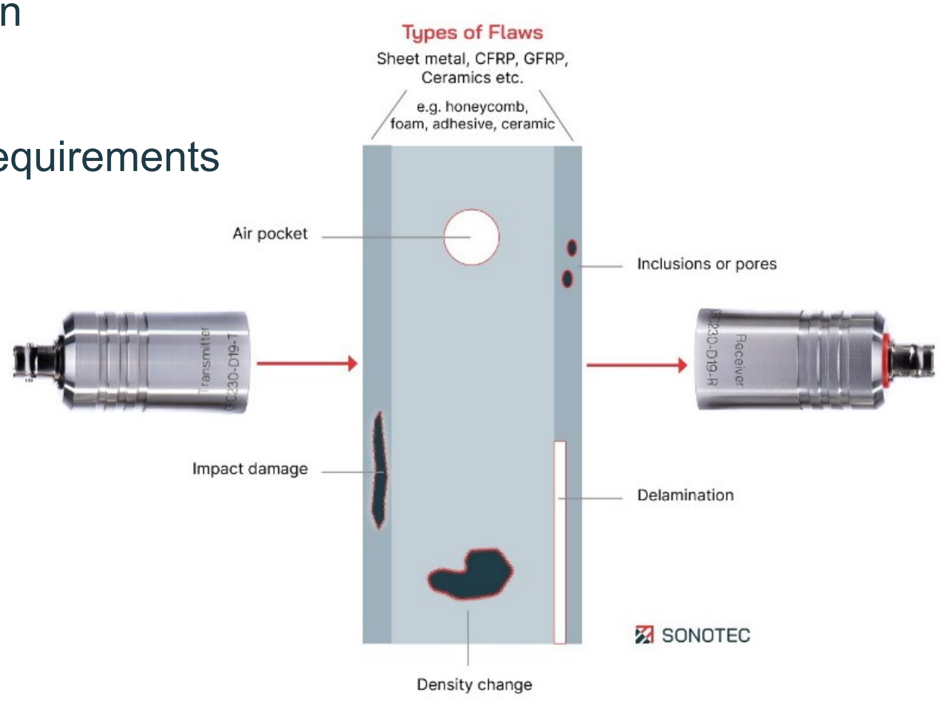
# Air-Coupled Ultrasonic Testing – Probes

Challenge in air-coupled ultrasonic testing

- → Large interface losses (over 99% per interface)
- → Frequency dependent attenuation in air of up to 40 dB/m @ 400 kHz
- → High lateral resolution @ low frequencies for defect detection
- → Frequency dependence of axial resolution
- → Due to a large variety of possible defects, different sensor requirements are needed



## Air-Coupled Ultrasonic Testing – Probes

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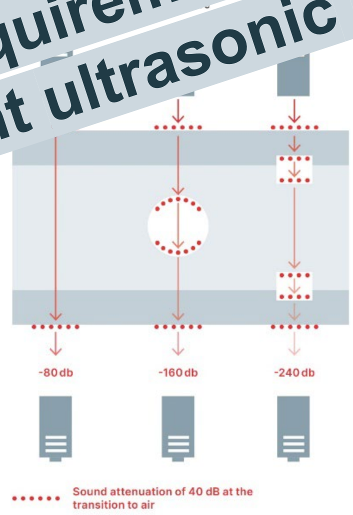
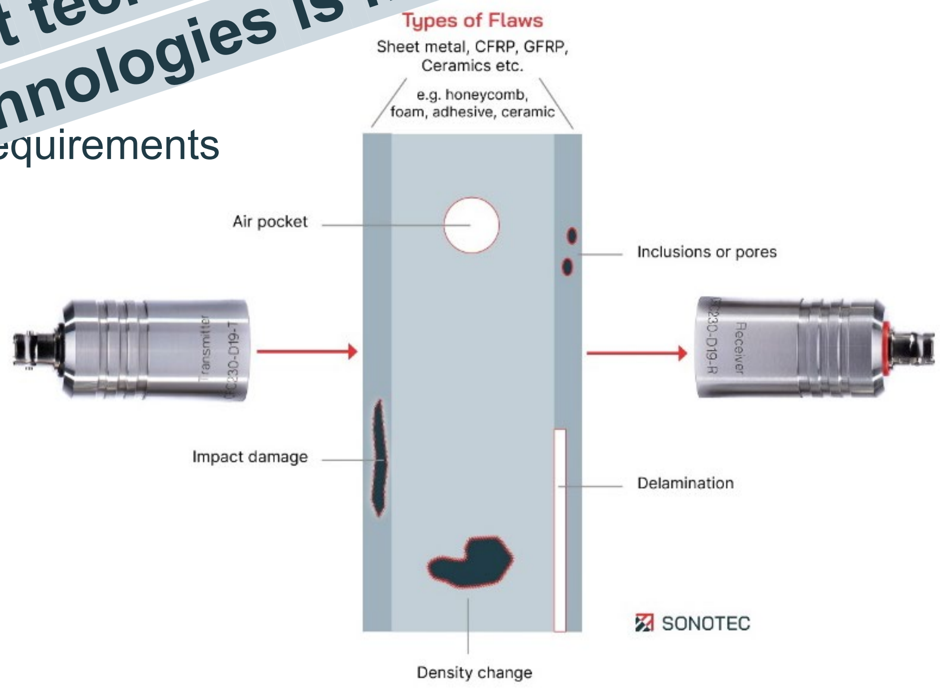
**To fulfill the requirements for the best technical solution the use of different ultrasonic probe technologies is necessary!**

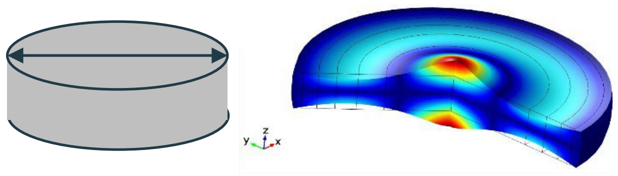


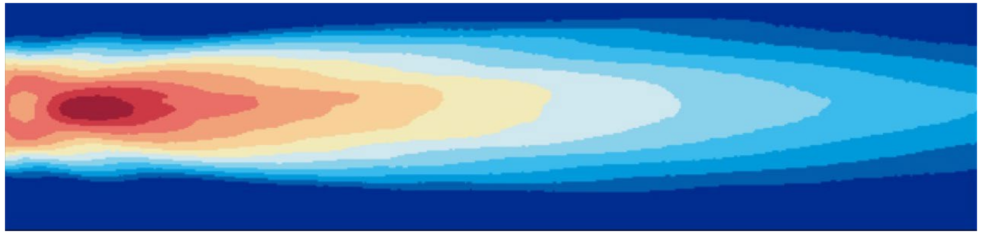
# Air-Coupled Ultrasonic Testing – Piezoceramic Probes

Acoustic parameters – SONOSCAN CF series

- Radial vibration modes
- Frequency range from 50 kHz to 300 kHz
- Frequency dependent aperture size
- Mechanically robust design



Sound field of CF050



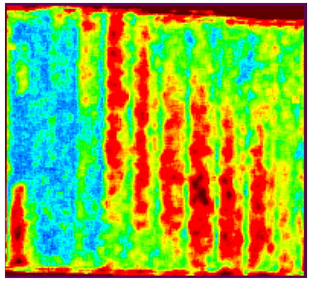
| Frequency | Aperture size |
|---|---|
| 50 kHz | Ø 45 mm |
| 75 kHz | Ø 30 mm |
| 125 kHz | Ø 19 mm |
| 200 kHz | Ø 11 mm |
| 300 kHz | Ø 7 mm |

# Air-Coupled Ultrasonic Testing – Piezoceramic Probes

Application parameters – SONOSCAN CF series

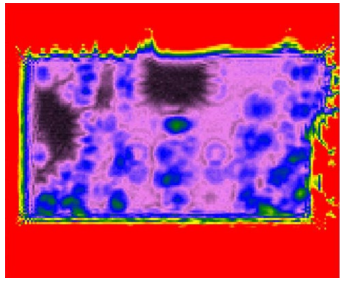
- → Highest sensitivity
- → Narrowband
- → Aperture size and therefore lateral resolution is frequency dependent
- → Suitable for the measurement of strongly attenuating materials like

SONOSCAN CF050
50 kHz



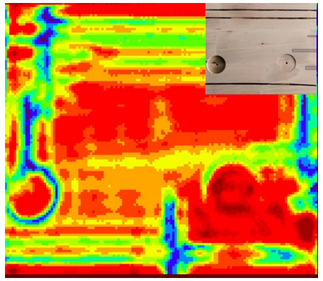
Steel plates with 100 mm foam core and delamination

SONOSCAN CF200
200 kHz



Electronic circuit board with delamination after reflow process

SONOSCAN CF200
200 kHz

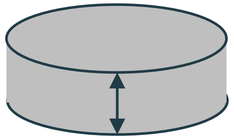


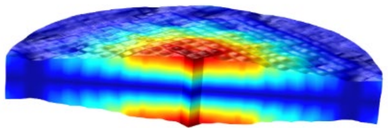
Glued beech wood with flat bottom holes

# Air-Coupled Ultrasonic Testing – Piezocomposite Probes

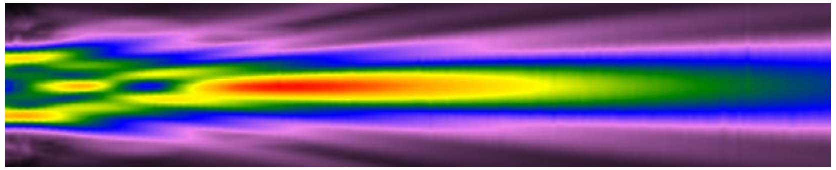
Acoustic parameters – SONOSCAN CFC series

- → Axial vibration modes
- → Two different technologies available
- → Frequency range from 50 kHz to 2 MHz
- → Different aperture sizes for each frequency available
- → Beamforming by mechanical focusing

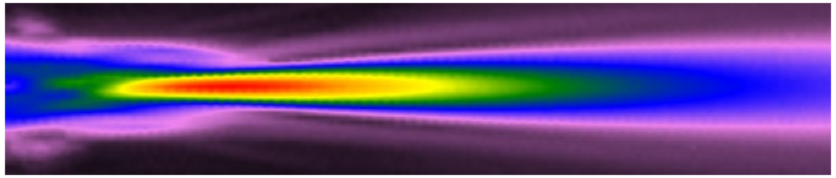




CFC230-D25 unfocused



CFC230-D25 focused



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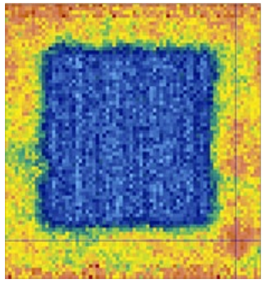
# Air-Coupled Ultrasonic Testing – Piezocomposite Probes

Application parameters – SONOSCAN CFC series

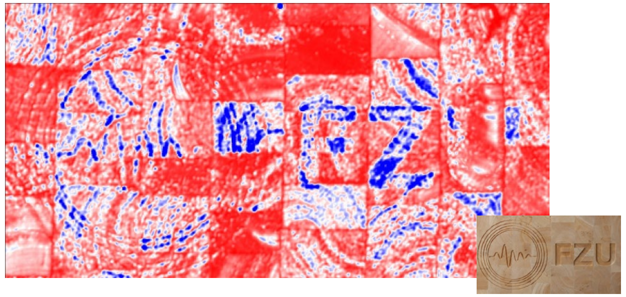
- High sensitivity
- Broadband – bandwidths with up to 30%
- Aperture size and therefore lateral resolution frequency independent
- Very suitable for aplications with high resolution and accuracy requirements

SONOSCAN CFC230
230 kHz



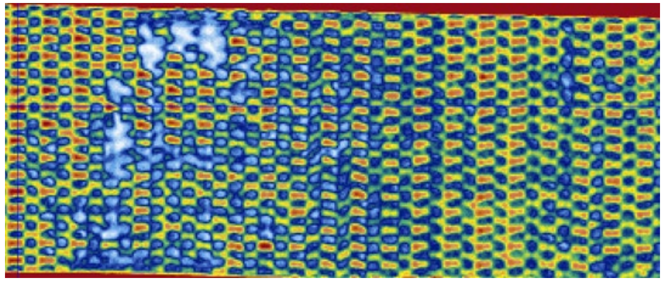
CFRP plates with foam core and air pocket

SONOSCAN CF400
400 kHz




Laminated, stuctured cork plate

SONOSCAN CFC230-D25-P50
230 kHz

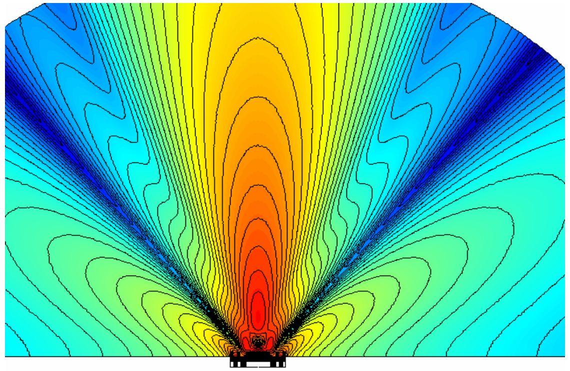


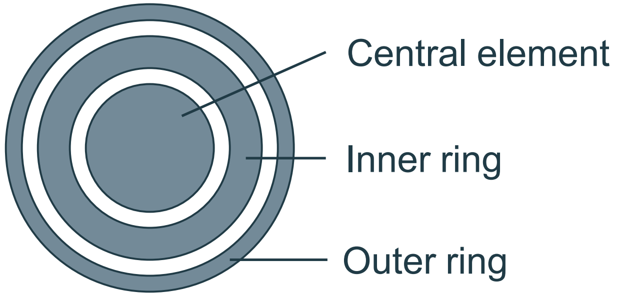
Thermoplastic GFRP with honeycomb core

## Phased-Array Probe Design

3-channel annular array transducer SONOSCAN CF 400-3E

- → Piezocomposite transducer
- → 3 elements
- → Equally sized
- → Structured electrode
- → Annular array







SONOSCAN CF400 3E

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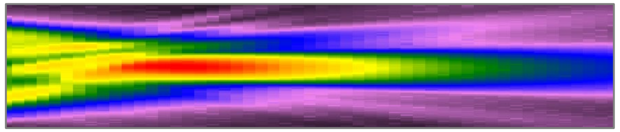
# Air-Coupled Ultrasonic Testing – Multi-Element Probes

Application parameters – SONOSCAN CF400-3E Multi-Element

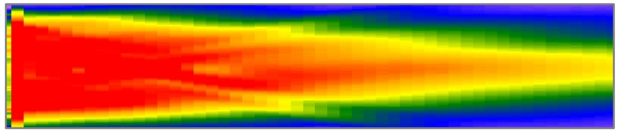
→ High resolution/high sensitivity

→ Focusing on very short distances

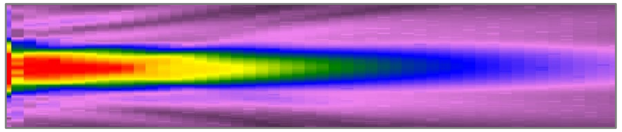
→ Avoiding side lobes



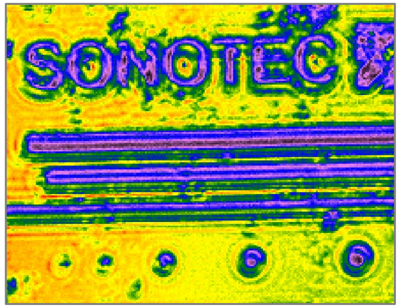
Soundfield – Conventional focused probe



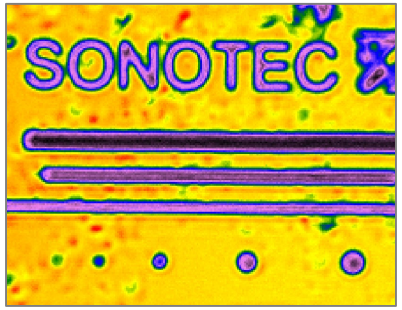
Soundfield – unfocused Phased-Array probe



Soundfield – focused Phased-Array probe




Conventional probe
(gap 20 mm)

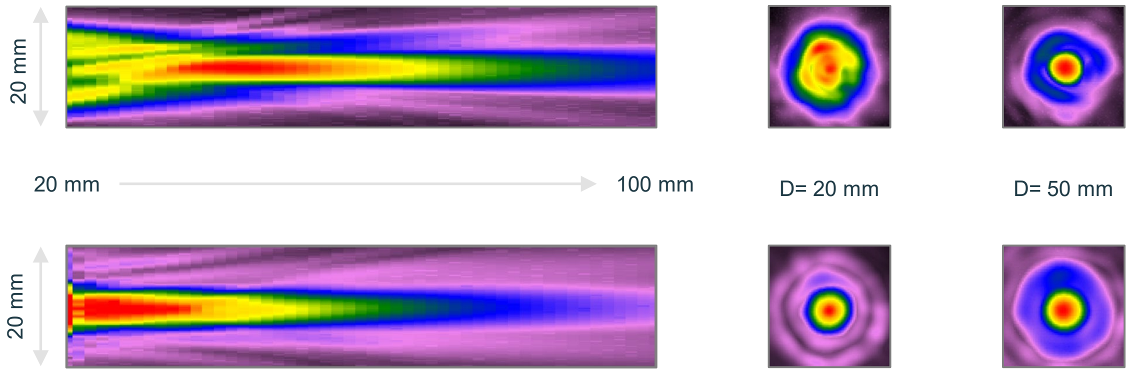



Phased-Array probe
(gap 20 mm)

# Comparison Single-Element vs. Multi-Element Probe

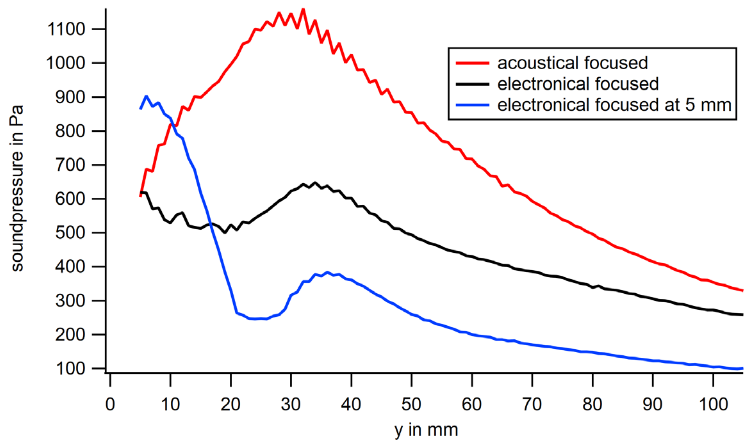
Sound field – Conventionally focused probe

- → Focal zone: 15 to 60 mm
- → Focal width: 3.6 mm




Sound field – Phased-Array probe

- → Delay law: 0 ns/900 ns/1800 ns
- → Focal zone: 5 to 30 mm
- → Focal width: 3.2 mm




Conclusion

- → Distance between probe and sample can be significantly reduced
- → Increase in sensitivity by reducing the scan distance
- → Higher resolution due to smaller focus

# Comparison of individual elements

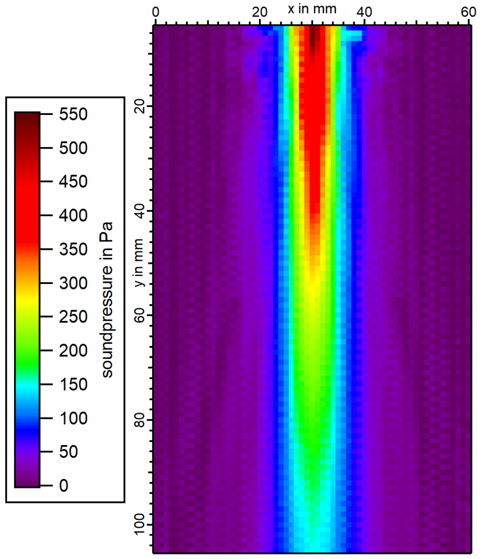
Sound field characteristic of individual elements

→ Sound pressure of individual elements significantly smaller than in combination

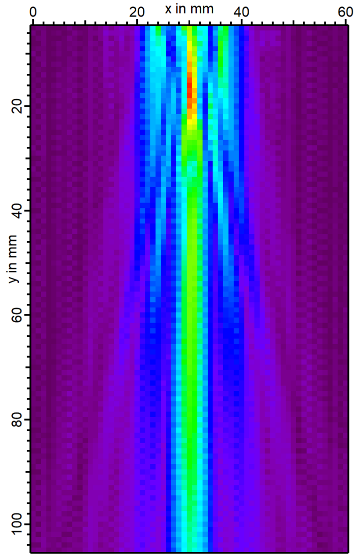
→ Main part of the sound field is generated by the central element

→ Sound fields of the inner and outer ring are highly focused with strongly pronounced side lobes

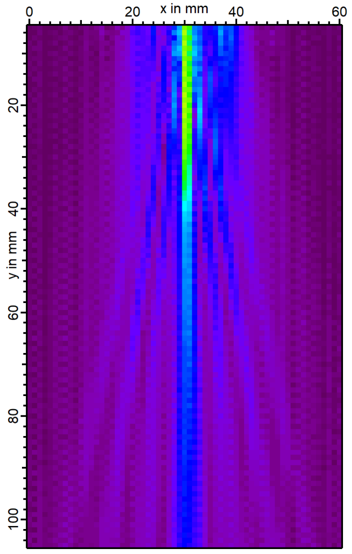
→ Excitation of all 3 elements in parallel without phase shift → sound pressure mainly defined by central element, bad lateral resolution



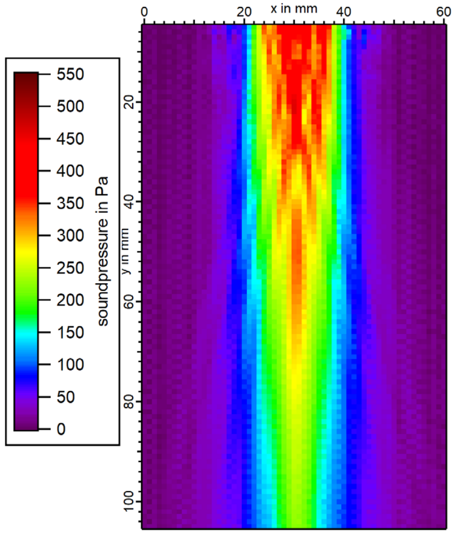
Central element



Inner ring



Outer ring



All elements parallel
no phase shift

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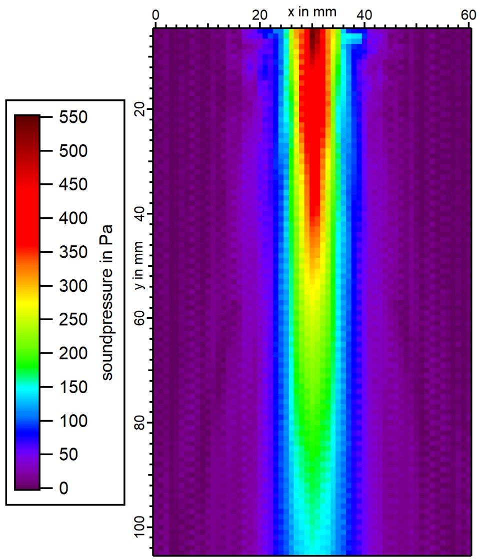
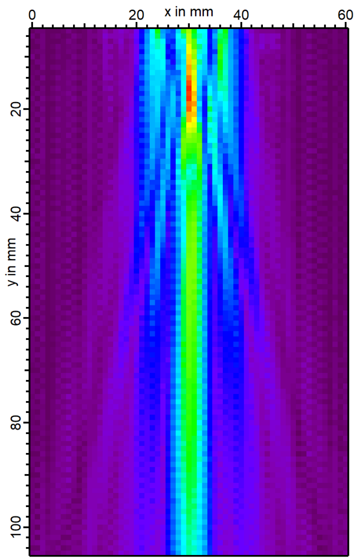
# Comparison of individual elements

Sound field characteristic of individual elements

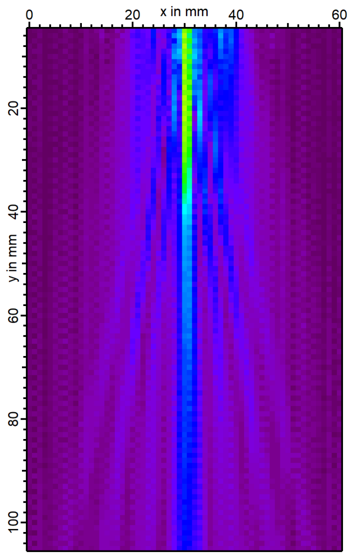
- → Sound pressure of individual elements significantly smaller than in combination
- → Main part of the sound field is generated by the central element
- → Sound fields of the inner and outer ring are highly focused with strongly pronounced side lobes
- → Excitation of all 3 elements in parallel with phase shift → focusing, high sound pressure, good lateral resolution



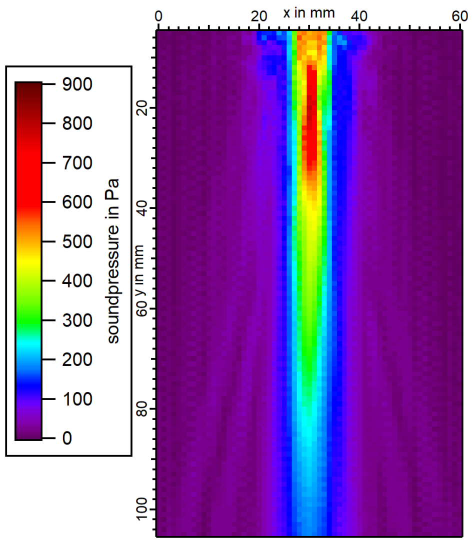
Central element



Inner ring



Outer ring



With phase shift:
focal distance 20mm

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# Comparison of different phase shifts

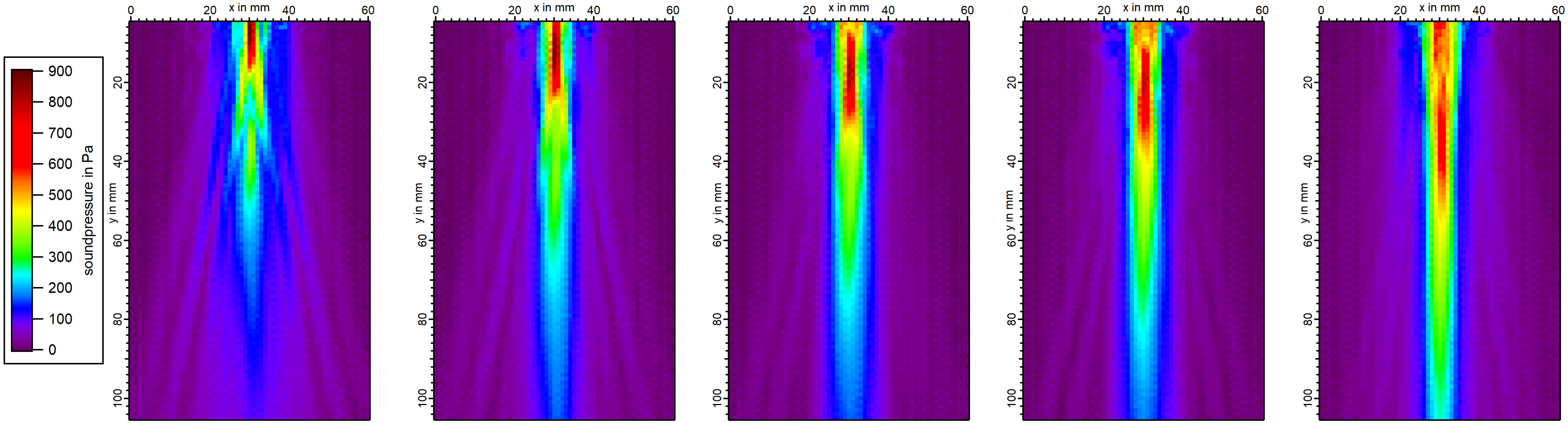
Sound field characteristic of different phase shifts between the elements

→ Studies on focusing at different distances were carried out

→ Sound field modeling to determine the phase shift between the individual elements

→ Focal depth can be controlled by variation of phase shift between the elements

→ Stronger focus leads to higher intensity

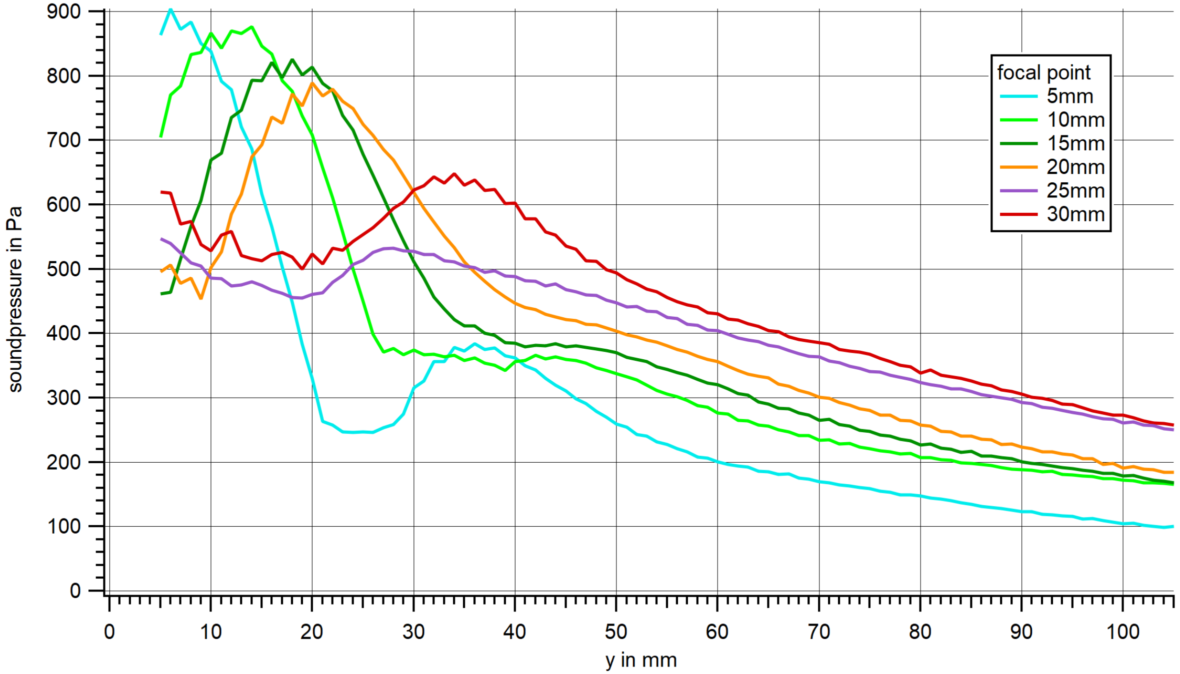



Focal distance 5 mm 10 mm 15 mm 20 mm 25 mm

# Comparison of intensity along the sound axis

Sound pressure characteristic with different focal distances

- → With increasing focal distance → intensities decrease and focal depth increases
- → A clear focus for practical measurements can be obtained with focal distance > 15 mm (last maximum clearly in the acoustic axis)
- → Focal point < 15 mm is only suitable under certain conditions



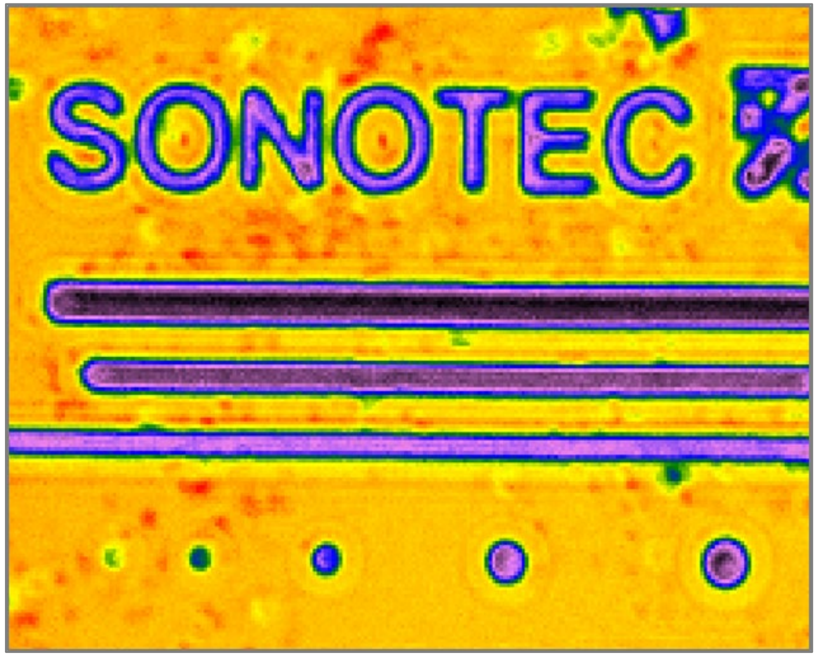
# Comparison measurement – SONOTEC reference plate

Test results:

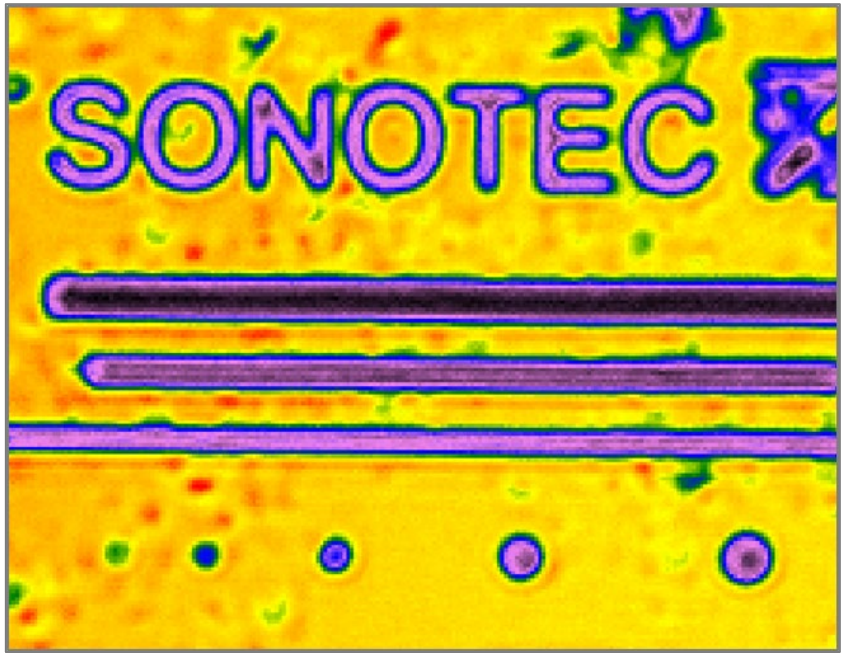
→ Comparison between CF400 and CF400-3E measurements

→ Measurement with CF400-3E has a higher resolution due to smaller focal with

→ Different interference effects at geometry edges




Conventional probe (gap 50 mm)

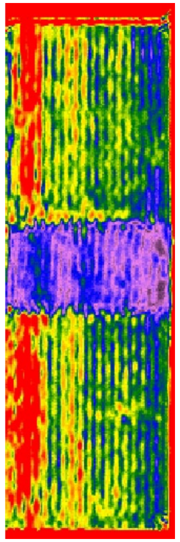



Phased-Array probe (gap 20 mm)

# Comparison measurement – Honeycomb structure

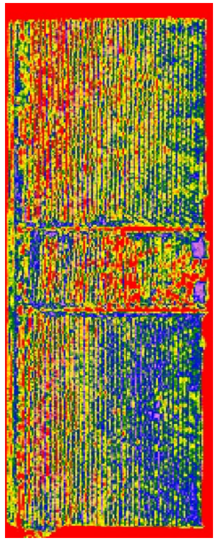
Test results:

- → Comparison measurement on a prism shaped honeycomb structure with 230 kHz and 400 kHz
- → Measurement with single element 400 kHz probe as transmitter and receiver not possible due to high attenuation
- → Measurements at 230 kHz have too low resolution
- → Combination of 400 kHz multi element transmitter with 400 kHz single element receiver gets significantly better test results



Measurement configuration:

- → Transmitter
  - → CFC230-D25-P50: Single channel probe
  - → Spherically focused
  - → Scan distance 40 mm
- → Receiver
  - → CFC230-D25-P50: Single channel probe
  - → Spherically focused
  - → Scan distance 40 mm
  - → Gain 80 dB



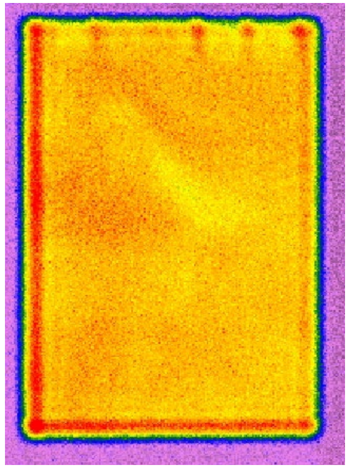
Measurement configuration:

- → Transmitter
  - → CF400-3E: 3-channel Multi-element probe
  - → Electronically focused
  - → Scan distance 10 mm
- → Receiver
  - → CF400: Single channel probe
  - → Spherically focused
  - → Scan distance 30 mm
  - → Gain 88 dB

# Comparison measurement – plastic composite material

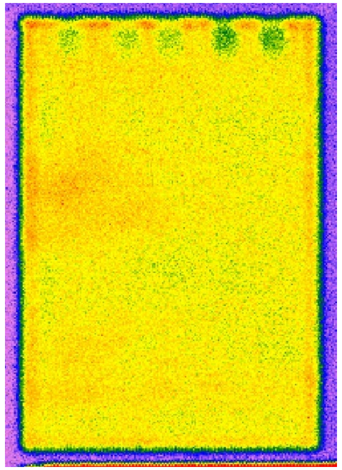
Test results:

- Comparison measurement on cuboid plastic composite sample with drilled test holes, with 230 kHz and 400 kHz
- Measurement with single element 400 kHz probe as transmitter and receiver not possible due to high attenuation
- Measurements at 230 kHz have too low resolution
- Combination of 400 kHz multi element transmitter with 400 kHz single element receiver gets significantly better test results



Measurement configuration:

- Transmitter
  - CFC230-D25-P50: Single channel probe
  - Spherically focused
  - Scan distance 40 mm
  - 400 V
- Receiver
  - CFC230-D25-P50: Single channel probe
  - Spherically focused
  - Scan distance 40 mm
  - Gain 87 dB



Measurement configuration:

- Transmitter
  - CF400-3E: 3-channel Multi-element probe
  - Electronically focused
  - Scan distance 10 mm
- Receiver
  - CF400: Single channel probe
  - Spherically focused
  - Scan distance 30 mm
  - Gain 88 dB

# Conclusion

- To fulfil the requirements for the best technical solution with air-coupled ultrasound testing, the use of different ultrasonic probe technologies is necessary
- Air-Coupled Phased-Array Transmitting is possible with linear focusing
  - Focusing in very short distances possible
  - Avoiding side lobes
  - Decreasing focal width
  - Increasing lateral resolution
- There are applications in which the use of multi-element probes can significantly improve the test result

# Ultrasound is our Strength

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