Medical Diagnostic Ultrasound:
The transducer and its sound field

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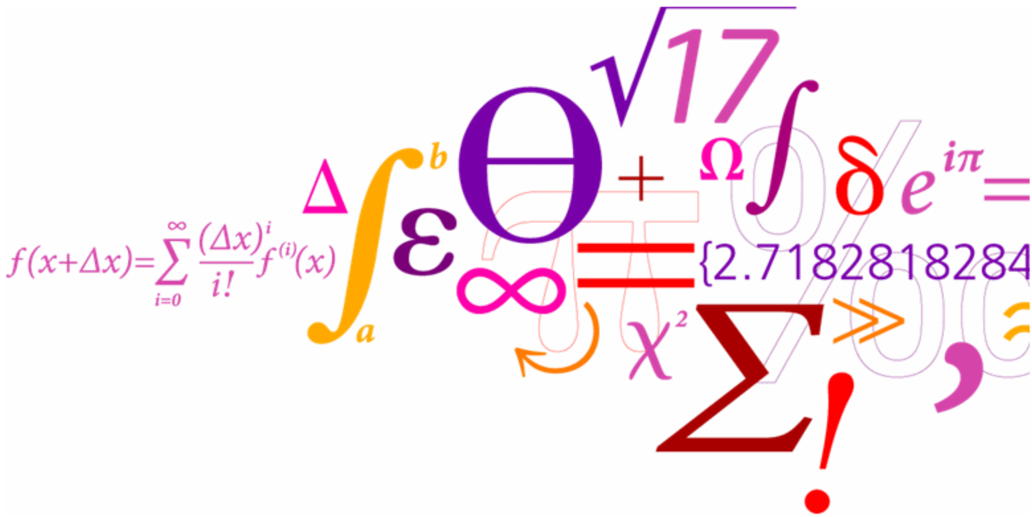

Content

- Introduction
- Wave propagation
- Generation of ultrasound
  - The transducer
  - The field
- Generation and reception of ultrasound

What is ultrasound?

- Sound with frequencies above the audible range (>20 kHz)
- Mechanical energy that is transported in a medium (do not propagate in vacuum)
- At high frequencies, the sound can be "formed" to beams
- The sound can be generated and recorded with a *transducer*, that interchangeably works as a loudspeaker and a microphone

History

- The existence of ultrasound has been known for 200 years, since Spallanzoni understood that bats use ultrasound for navigation and prey detection
- The discovery of piezo-electricity provided the basis for emission and reception of ultrasound 100 years later
- First application was detection of submarines during first WW
- 1935 first therapeutic application
- 1950 echography (diagnosis)

Italian insight

When a drop hits the surface of water, circles are build around the point of impact.

The sound of a voice causes the same phenomena, but the waves travel further.

The glow [of fire] reaches even further.

And longest flies the thought in the universe, but because the thought is final, it never reaches infinity.

Leonardo da Vinci, 1452 - 1519

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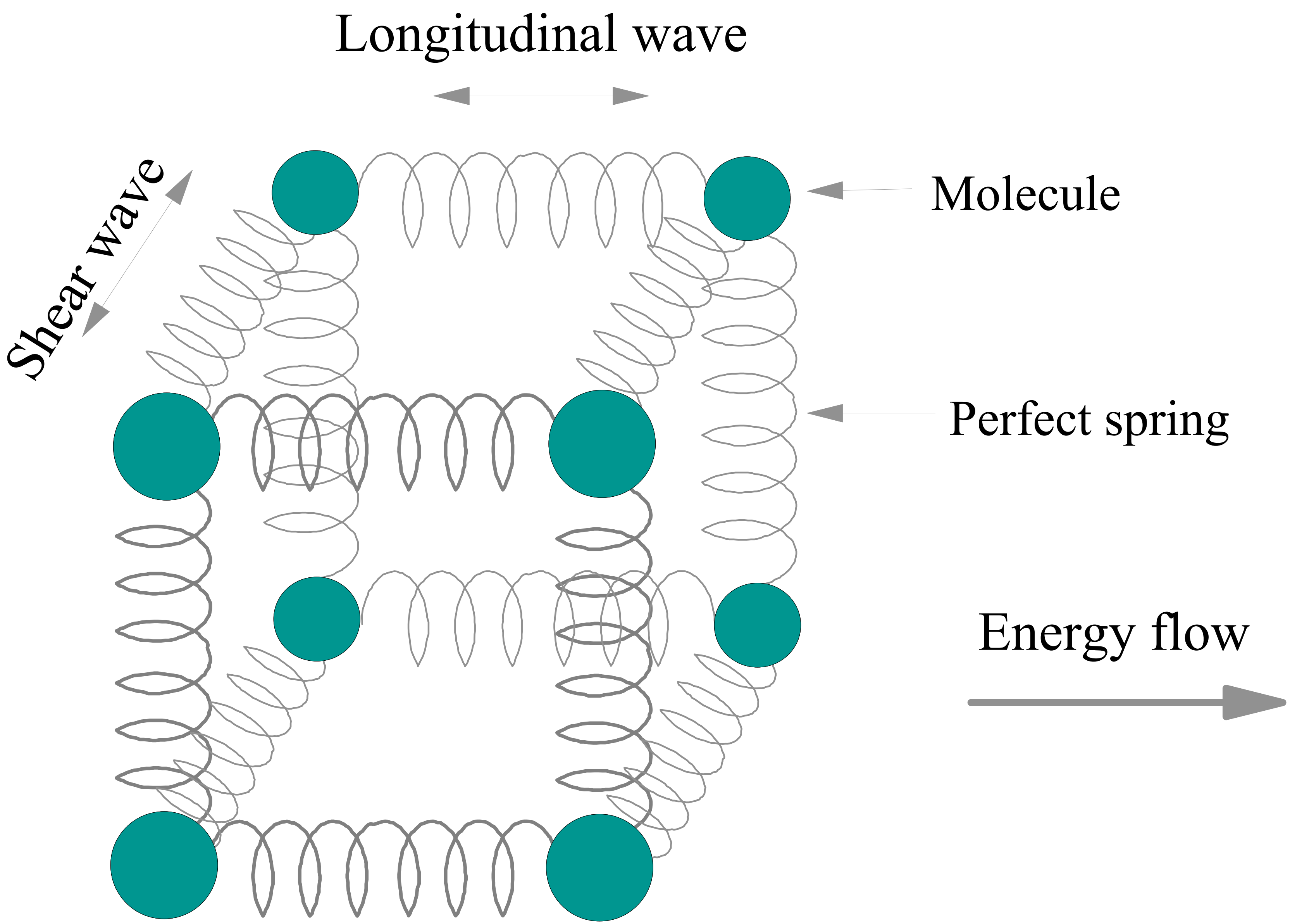
Mechanism behind propagation



Frequency, sound speed and wavelength

$$f = c_{medium} / \lambda_{medium}$$

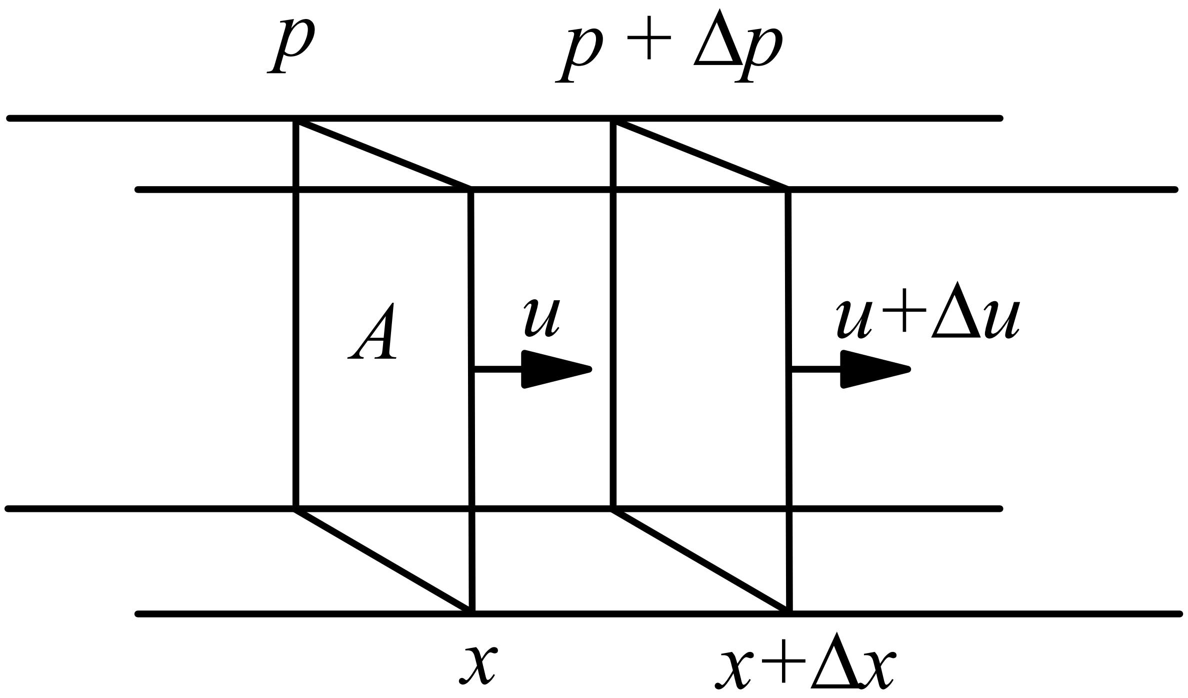
Frequency, sound speed and wavelength

$$f = c_{medium} / \lambda_{medium}$$

Intensity (energy)?

1D Acoustic Wave

Elemental volume in a 1D sound wave in liquid



u: Speed of elemental volume

A: Cross-sectional area perpendicular to energy flow

p: Total pressure (both dynamic and static) = "force per area"

1D Acoustic Wave equation

Elemental volume in a 1D sound wave in liquid

Mass of elemental volume:

$$\rho A\Delta x$$

Newton's second law:

$$-A\Delta p = \rho A\Delta x \, du/dt$$

or after $\Delta \rightarrow d$

$$dp/dx = -\rho \, du/dt$$

1D Acoustic Wave equation

Elemental volume in a 1D sound wave in liquid

Likewise:

$$du/dx = -\kappa\, dp/dt$$

κ: Compressibility factor

1D Acoustic Wave equations

Sound wave in lossless (homogeneous) liquid

$$dp/dx = -\rho \, du/dt$$

$$du/dx = -\kappa \, dp/dt$$

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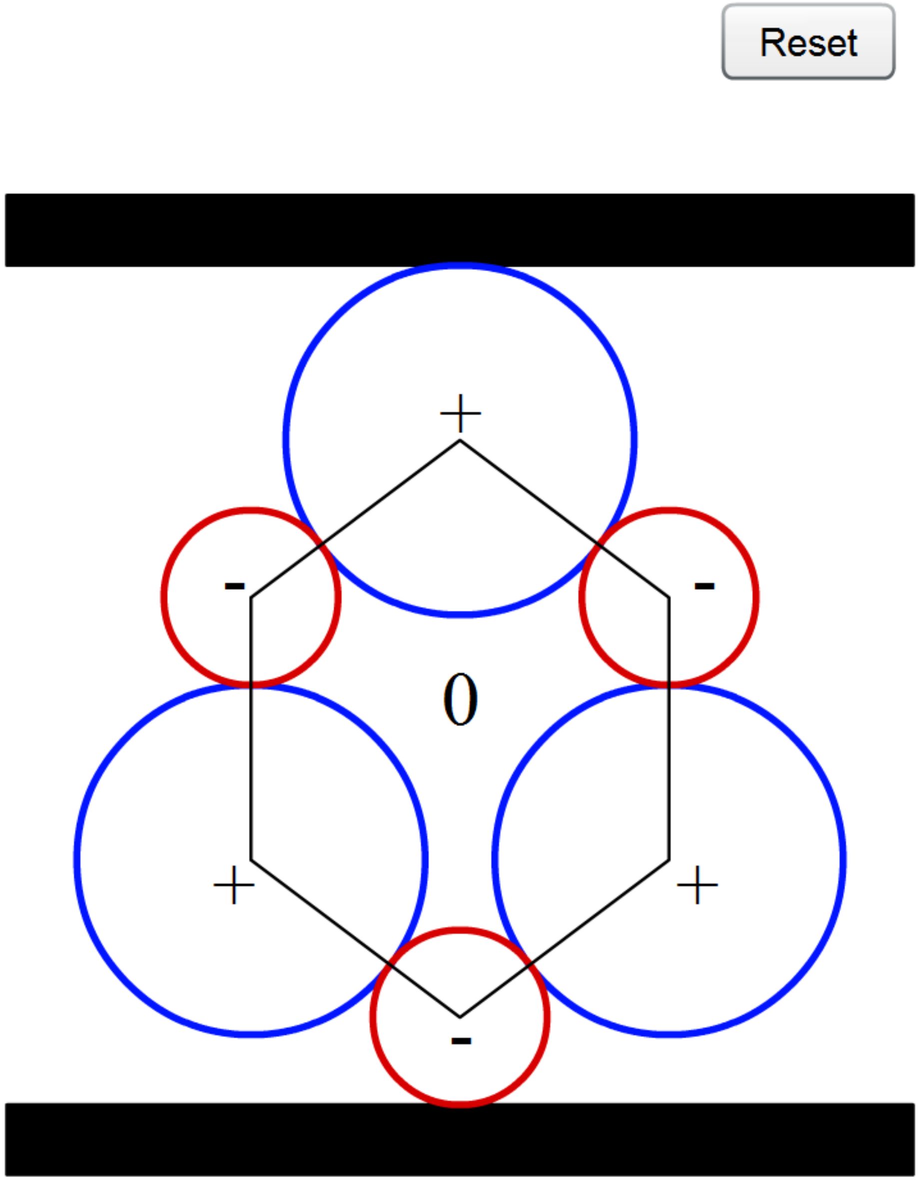
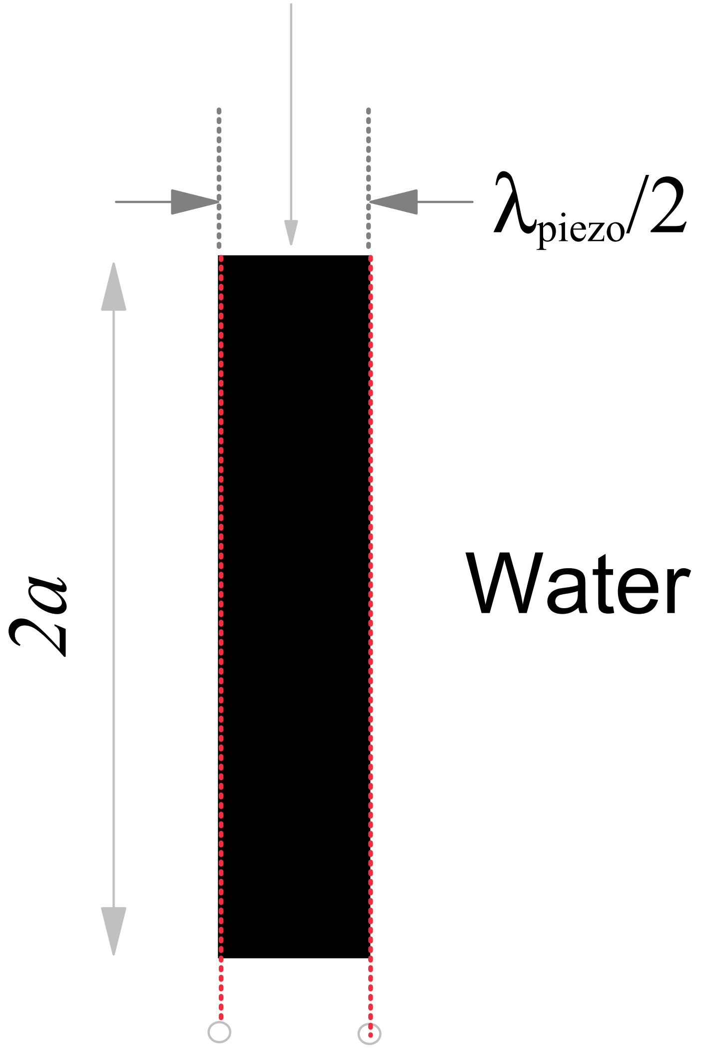
2D model of quartz



Flat single element transducer

(μ problem)

Disk of piezo-electric material



$$g_e(t) = A\sin(2\pi f_0 t + \varphi)$$

If

$c_{water} = 1\,480$ m/s

$c_{piezo} = 2\,250$ m/s (PVDF)

Thickness of disk = 0.5 mm

What is the wavelength in water?

Crystal oscillates (best) at:

Wavelength in water is:

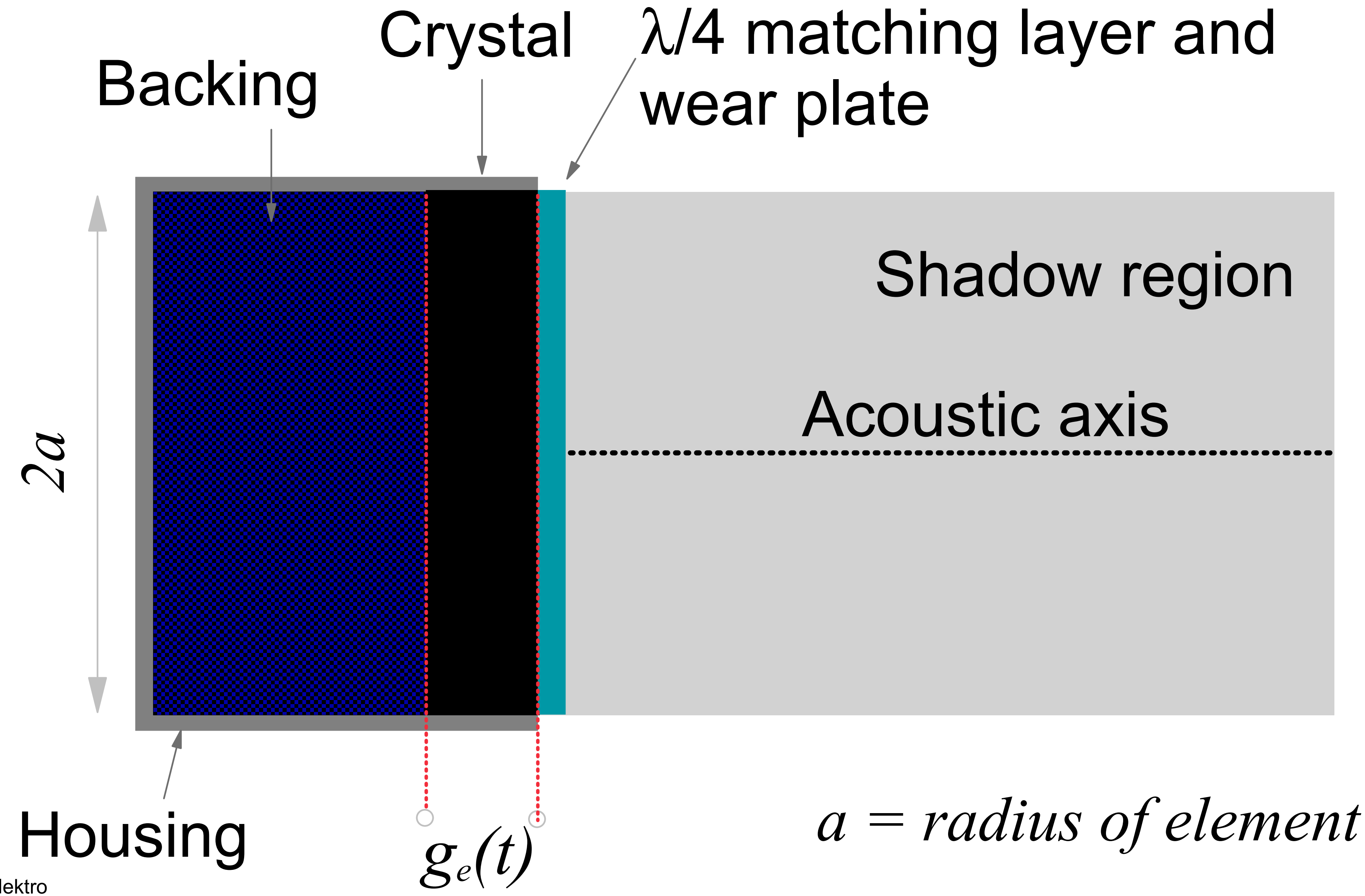
Flat single element transducer
(alternative view)

Disk of piezo-electric material

Water

Disk of piezo-electric material	Water
c	c
λ	λ
f_0	f_0

Cross-sectional view of flat single element transducer



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Calculation of pressure field

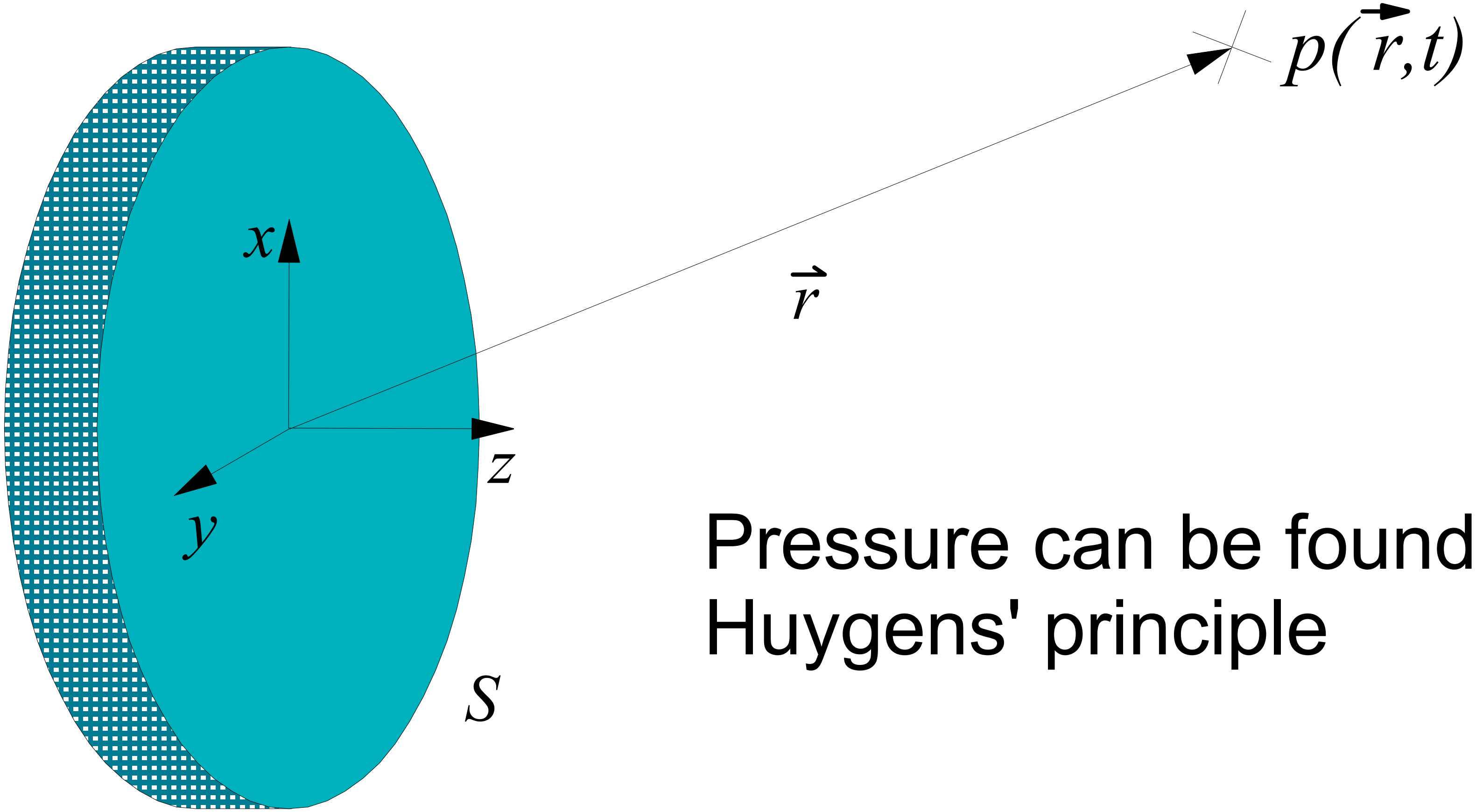
Transducer surface

How can the pressure field in front of the transducer be calculated?

Assume that:

- the transducer surface is located in an infinite baffle
- the piston surface moves with a velocity perpendicular to, and constant over, the surface

Calculation of pressure field:

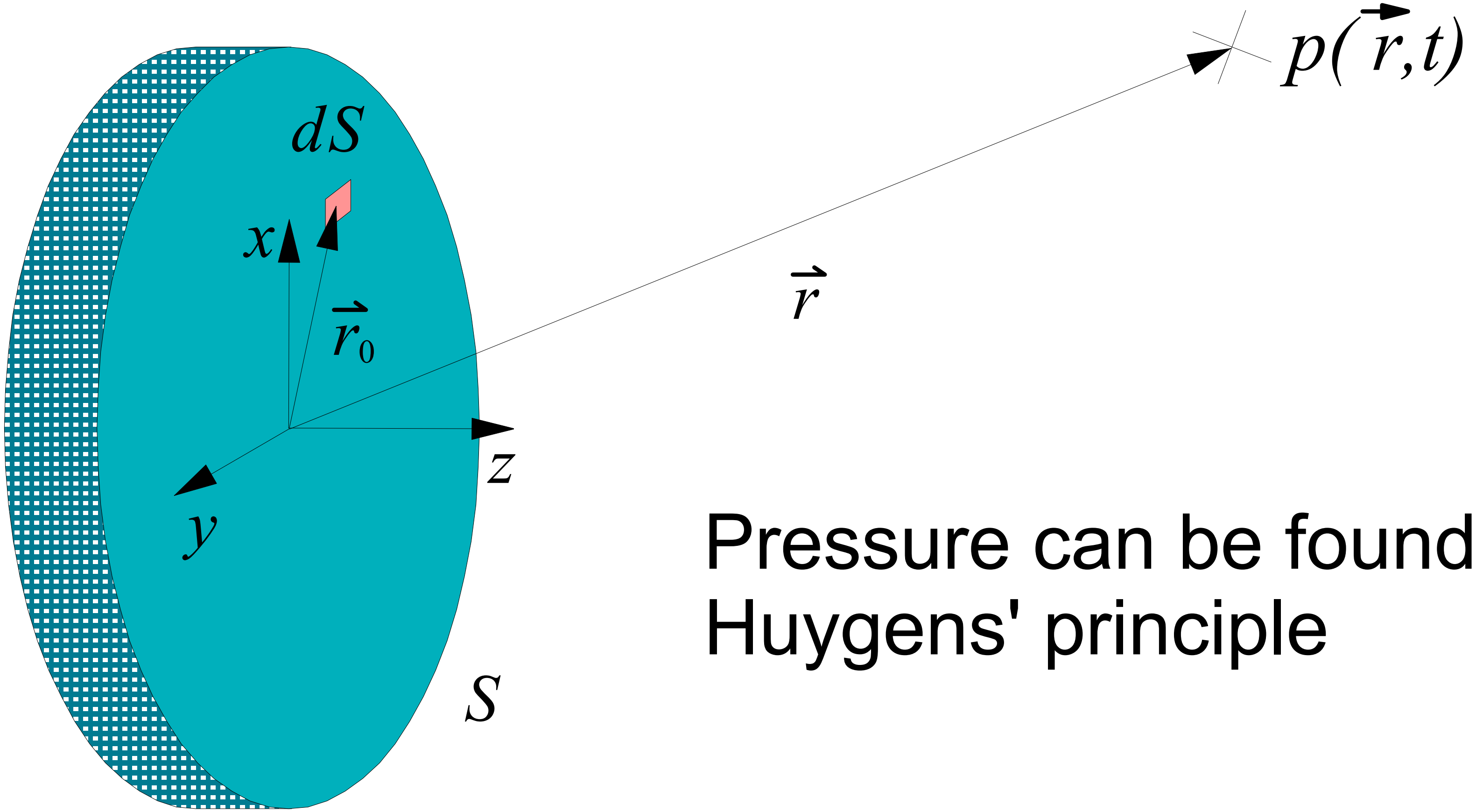


Pressure can be found with Huygens' principle

Transducer surface

Calculation of pressure field:

the surface consists of many small sources

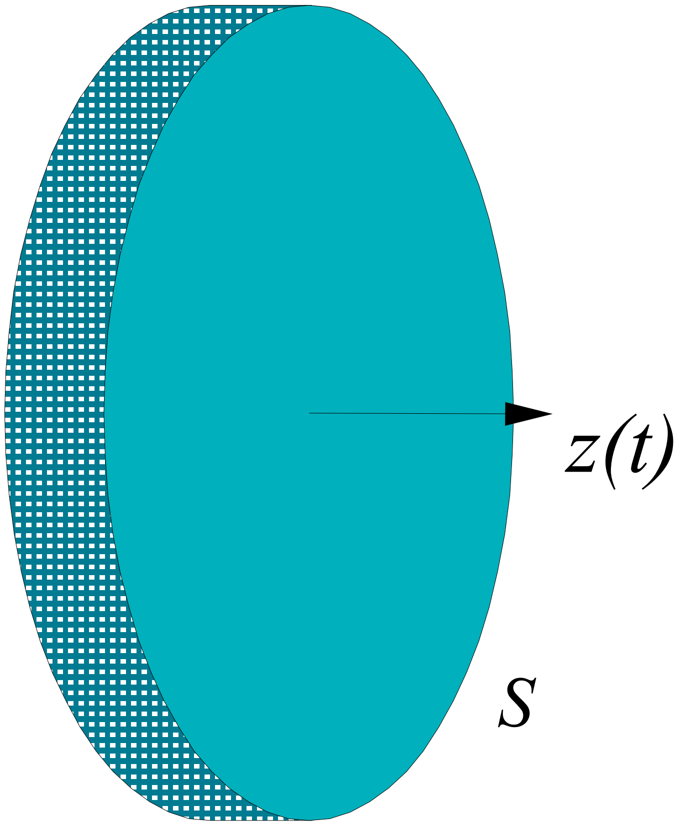


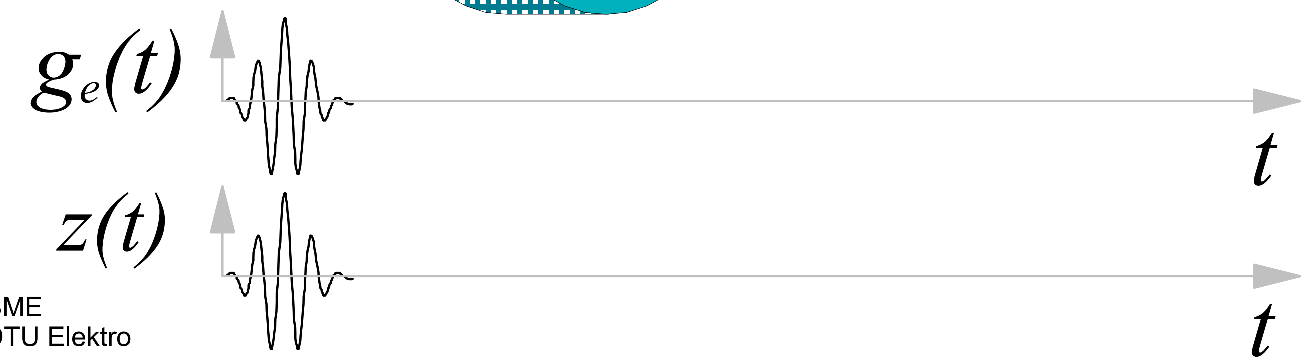
Pressure can be found with Huygens' principle

Transducer surface

Calculation of pressure field, $p(\vec{r},t)$

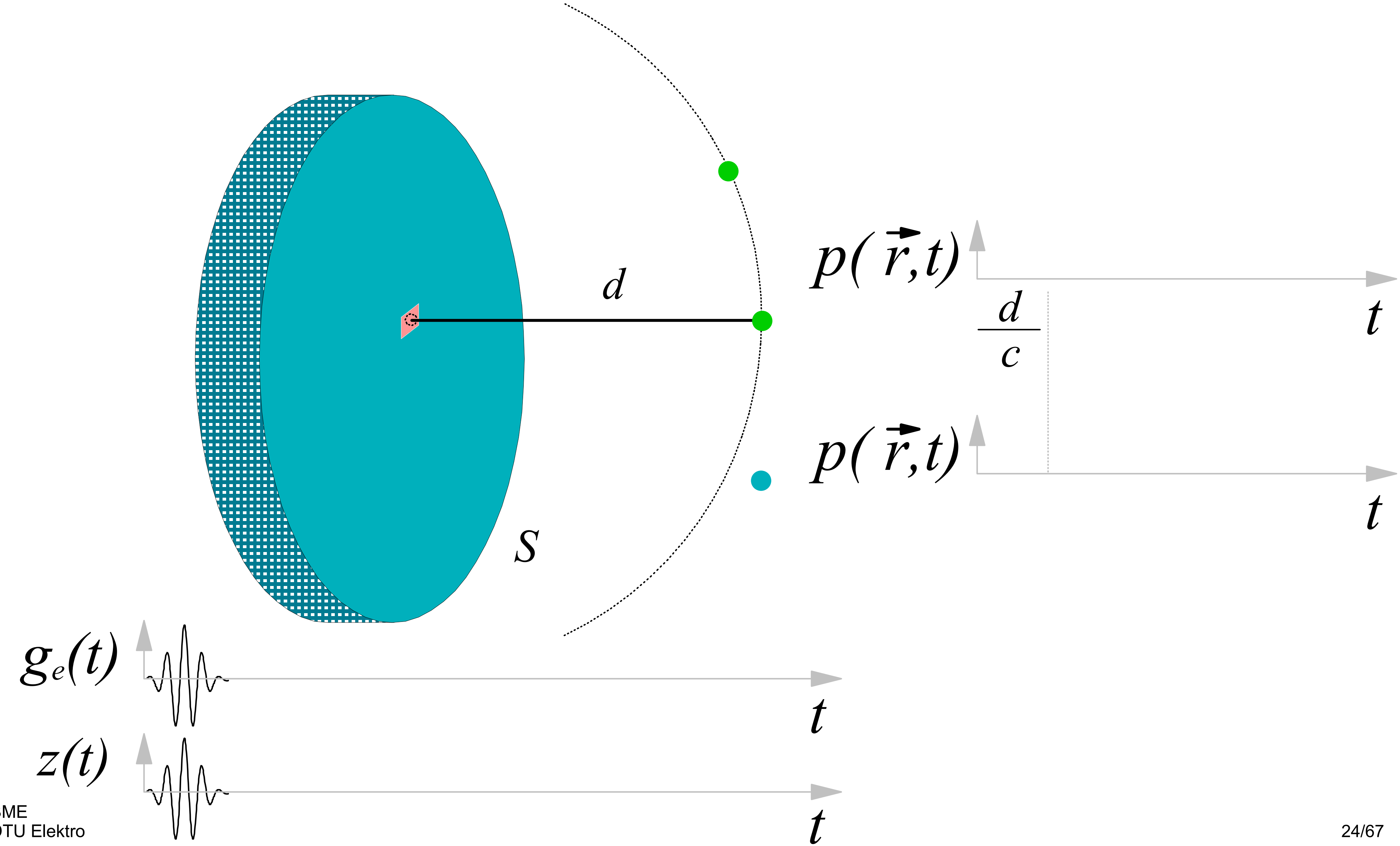
the electrical signal and the surface velocity



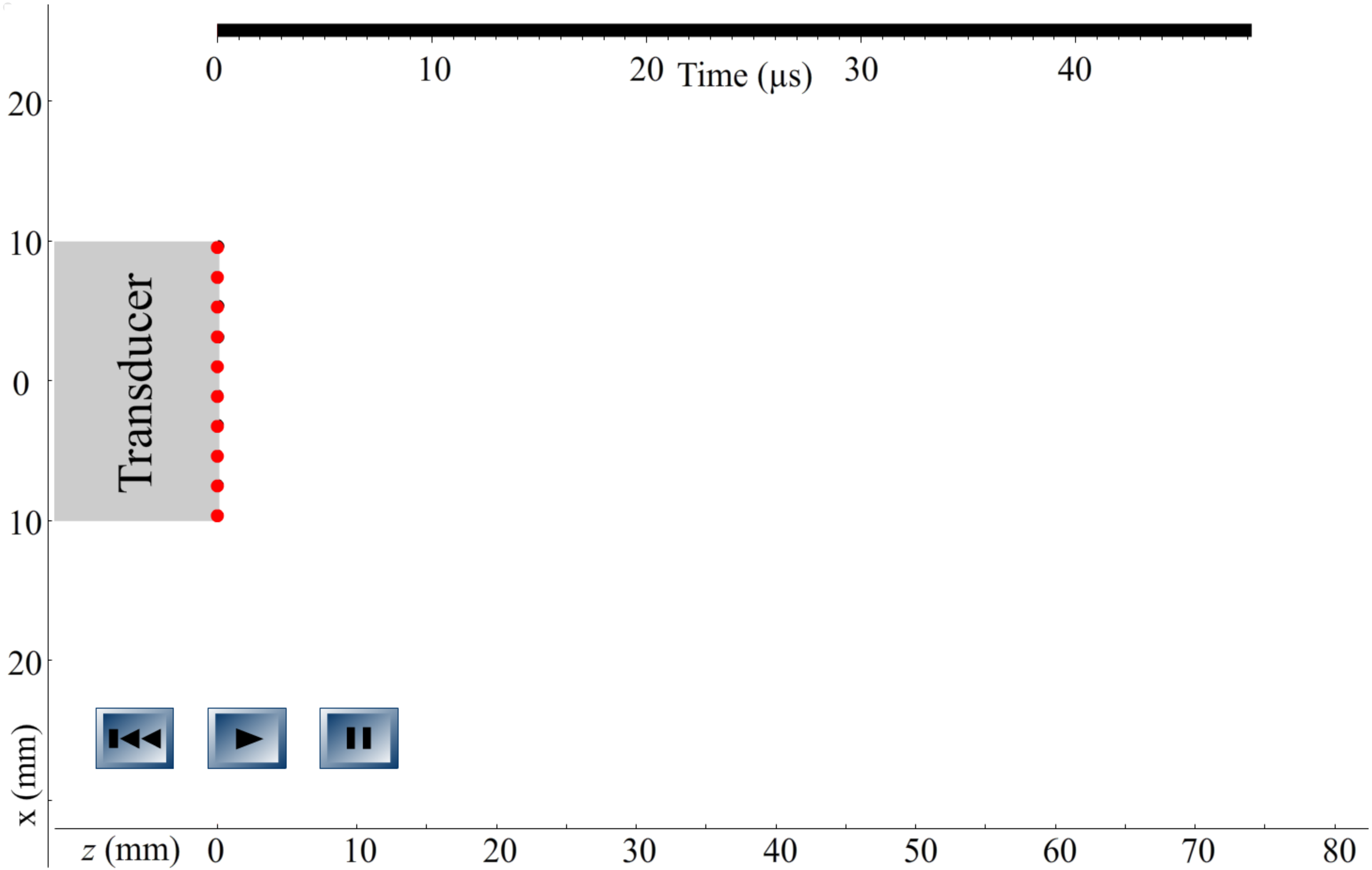


Calculation of pressure field, $p(r,t)$

looking at one source element

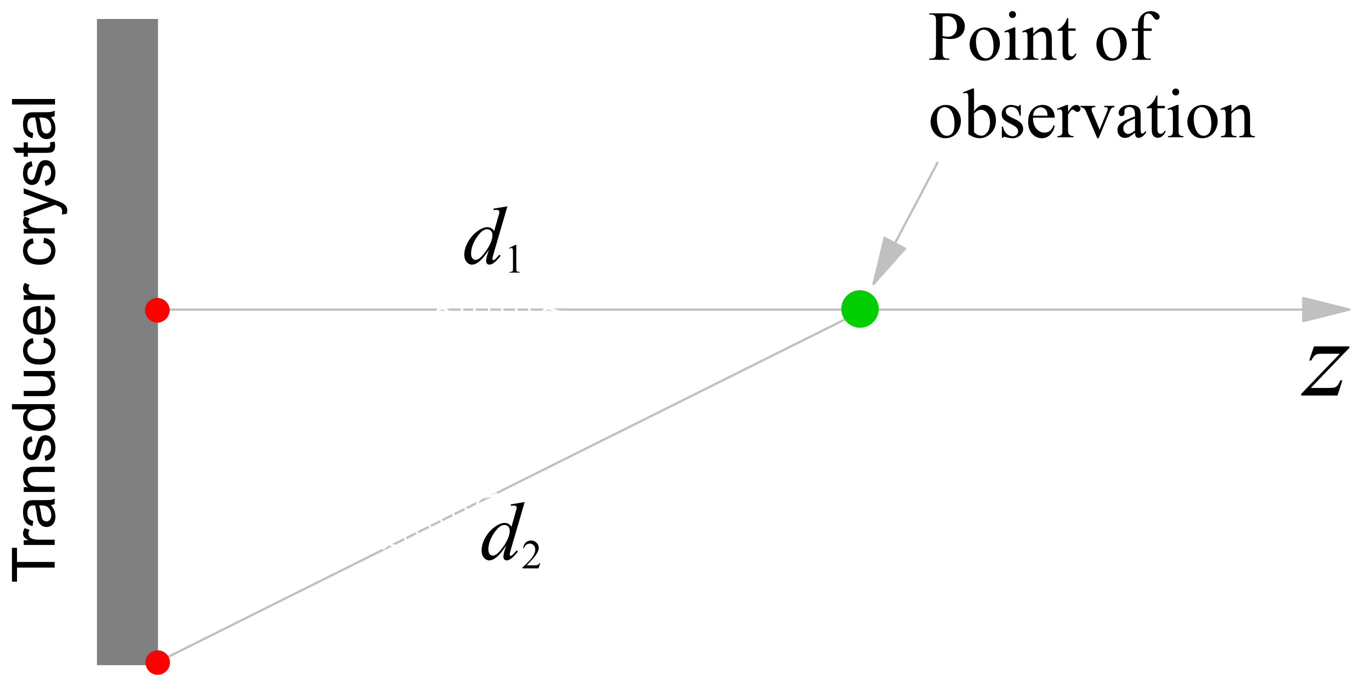


Planar transducer, sources on diameter



Different propagation paths:

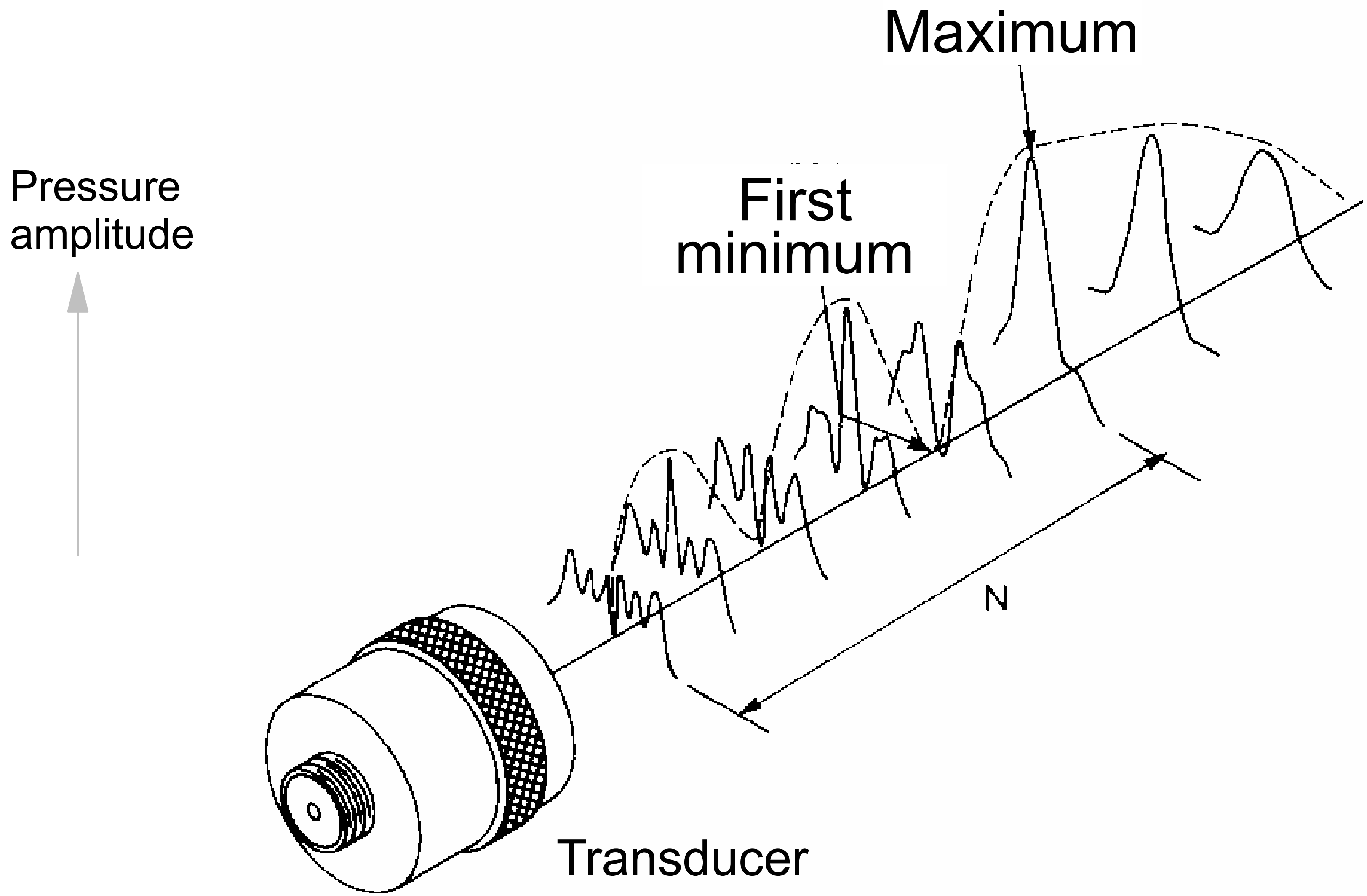
The shortest and longest



To "insure" constructive interference:

$|d_2 - d_1| < \lambda/10$

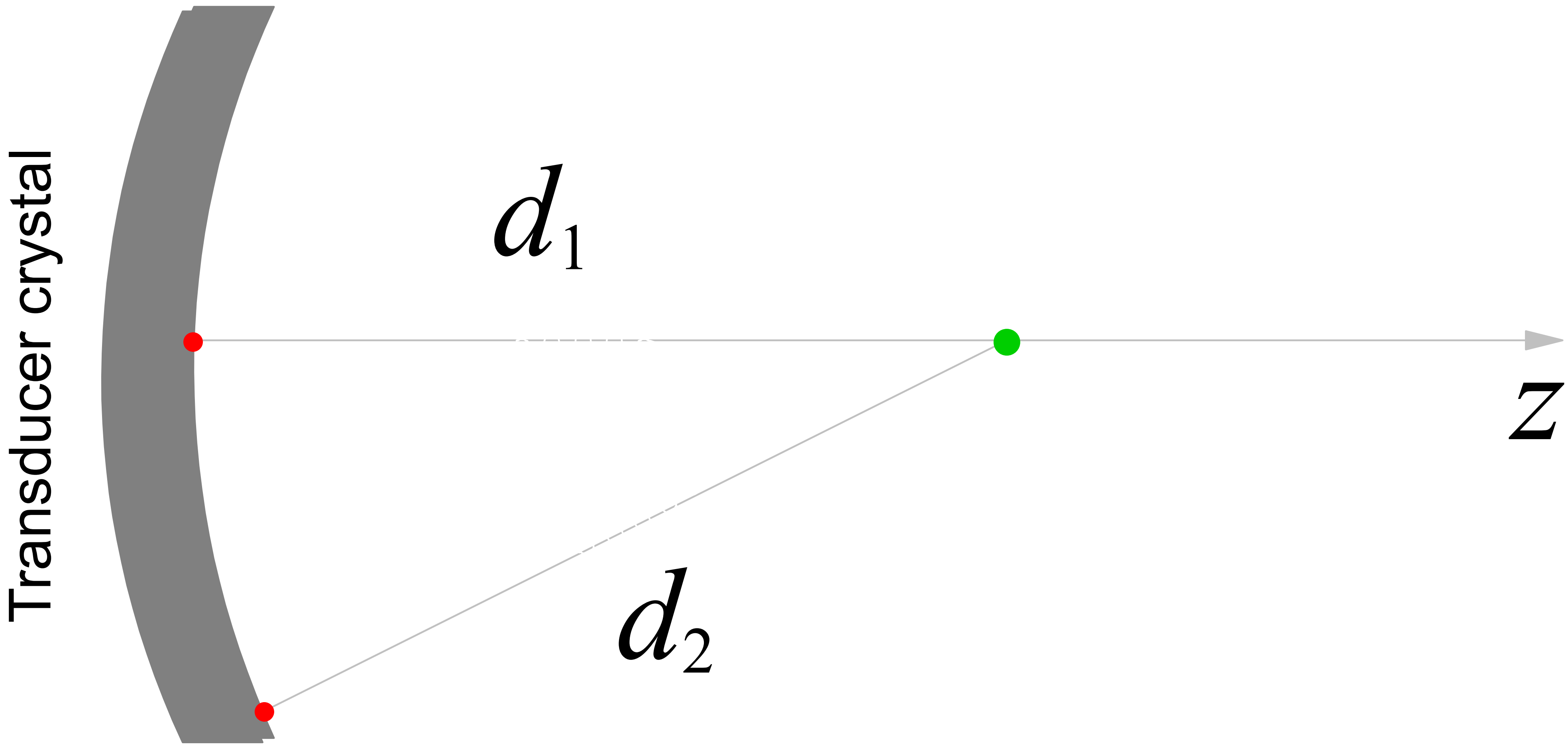
Pressure field from planar transducer (maximal amplitude of emitted pulse)



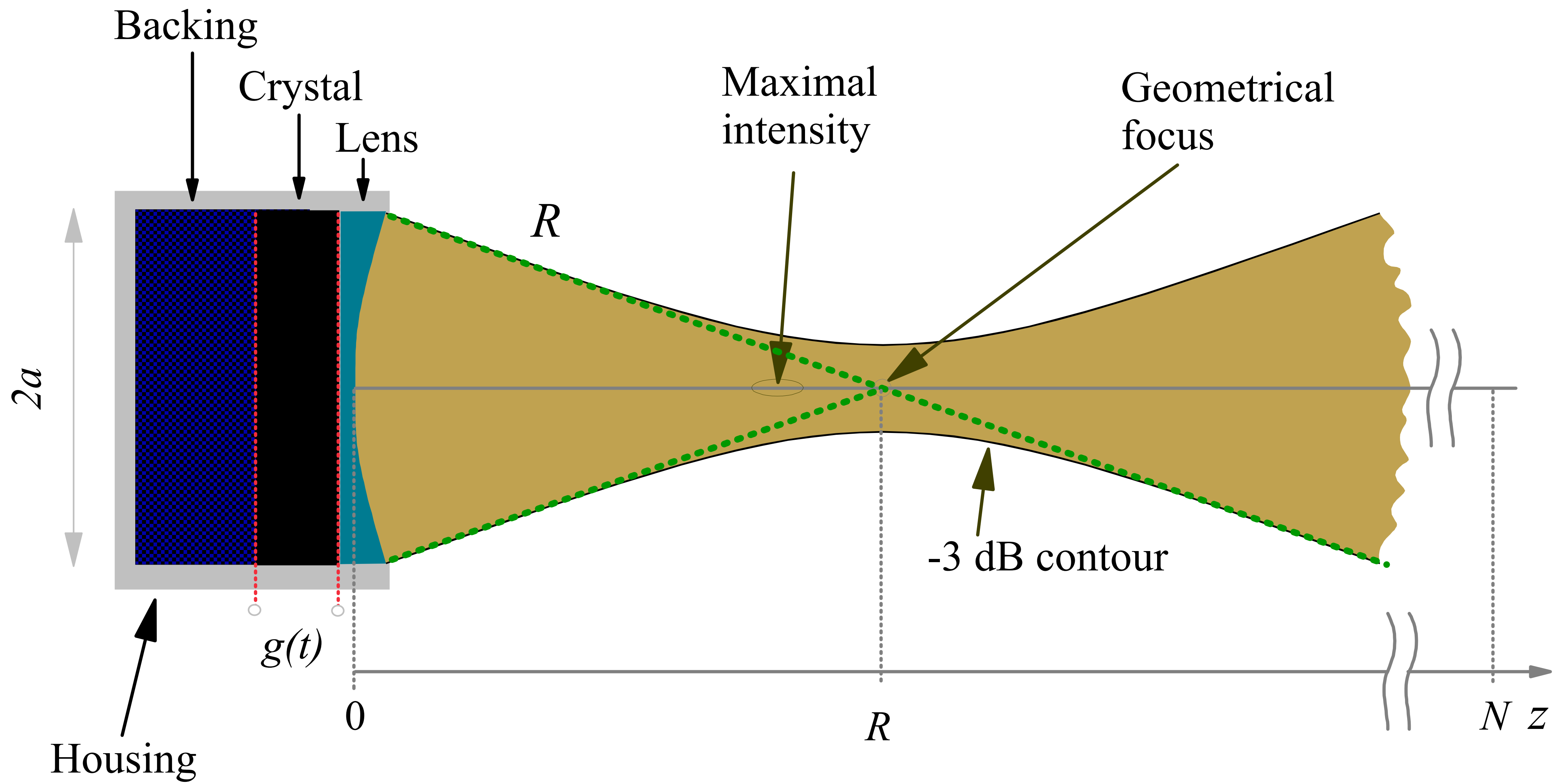
Source: Catalog of Panametrics Inc.

Same propagation paths:

Gives constructive interference at a given point

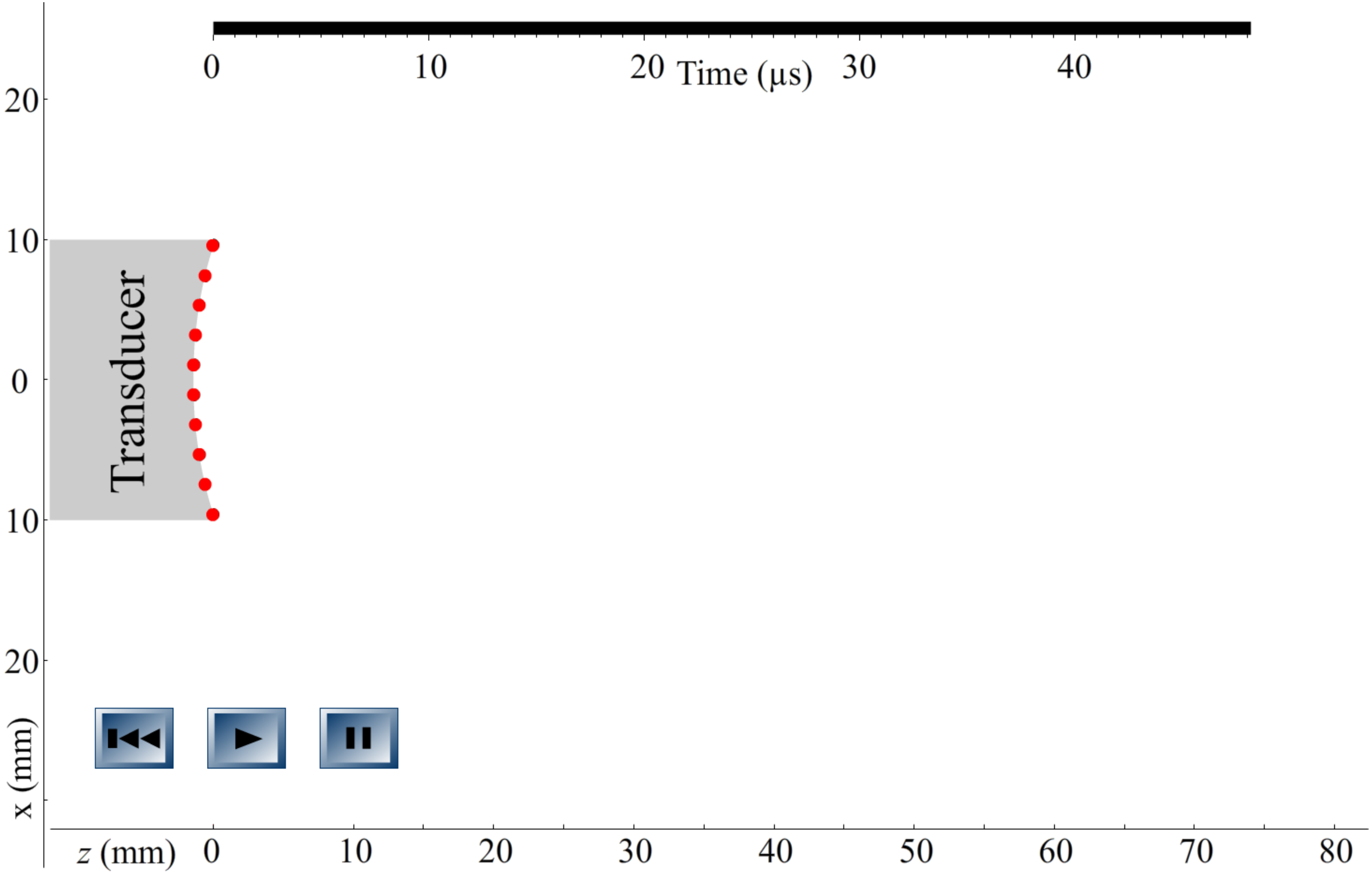


Focused single element transducer

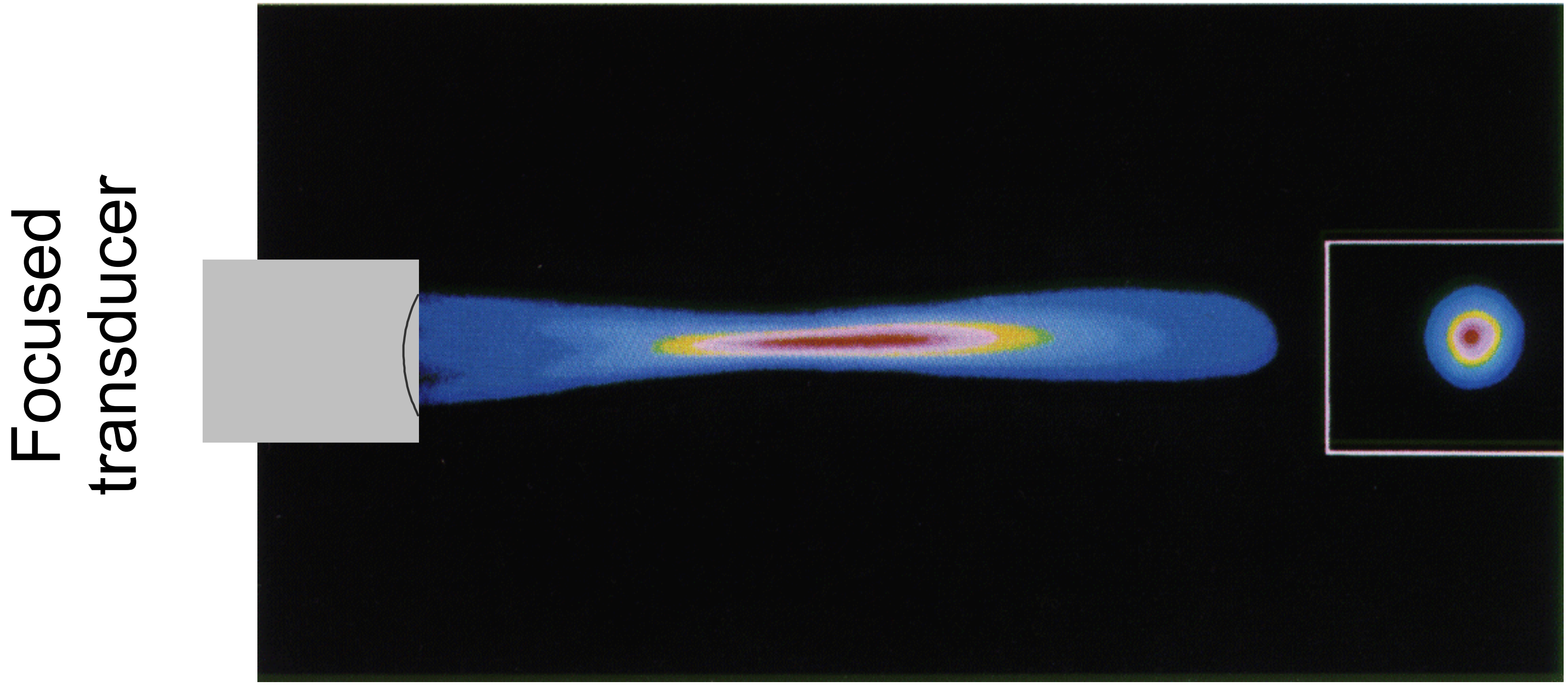


R = radius of curvature a = radius of element

Focused transducer, sources on diameter

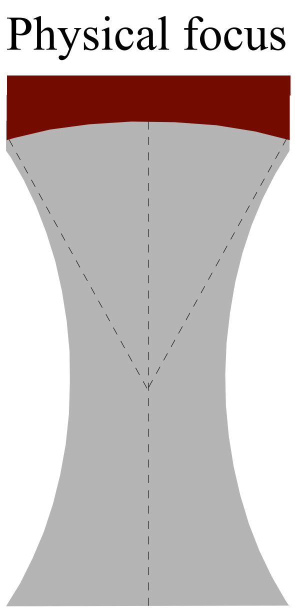


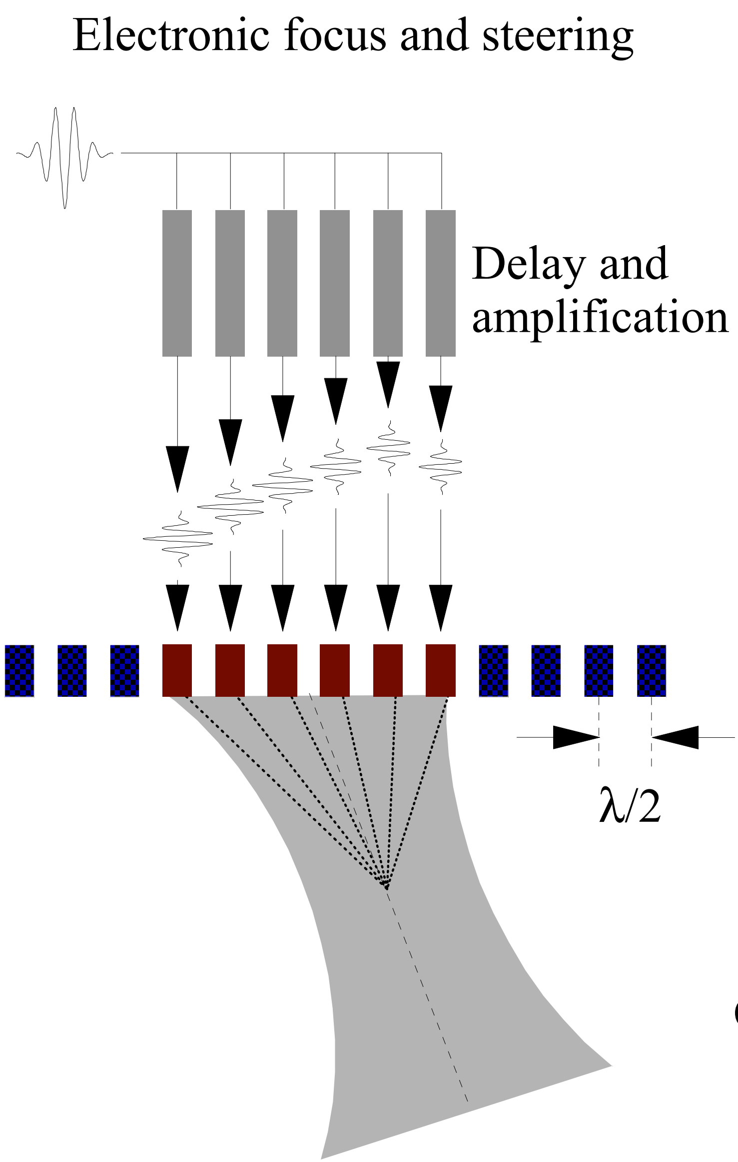
Intensity of emitted pressure field from a single element focused transducer

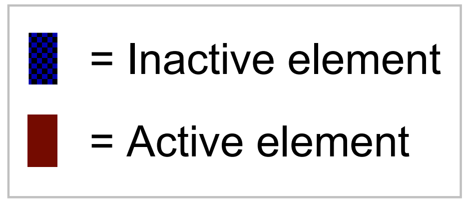


Source: Catalog of Panametrics Inc.

Electronic focusing







Observe:

- Typically, at least 32 elements
- Drawing not to scale
- Still sidelobes
- Grating lobes appear

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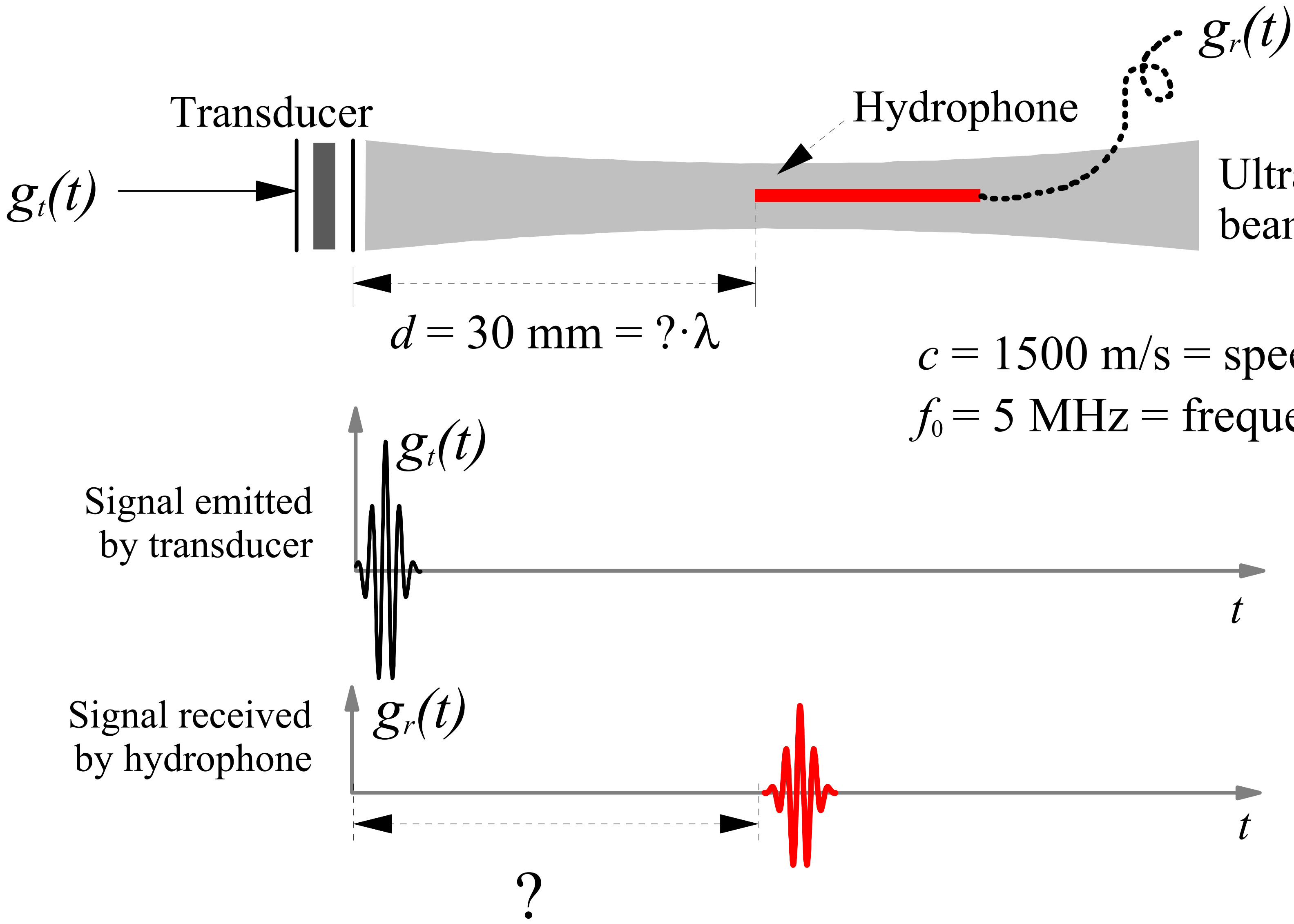
Transmission and reception:

Example



$c = 1500$ m/s = speed of sound

$f_0 = 5$ MHz = frequency of pulse