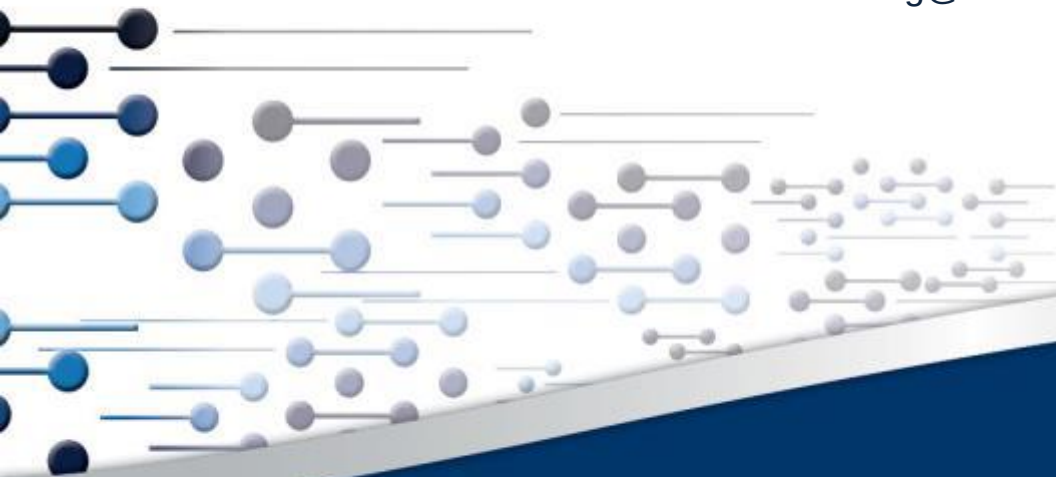


Overview of Guided Wave Ultrasound for Non-Destructive Evaluation

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Contents

- Wave propagation basics
- Vibration and modal analysis
- Conventional ultrasound in NDE
- Guided wave ultrasound
 - Advantages / selling points
 - Disadvantages / challenges
 - Application examples

Wave Propagation Basics

The Wave Equation

$$\frac{\partial^2 w}{\partial t^2} = c^2 \frac{\partial^2 w}{\partial z^2}$$

Any function of the form:

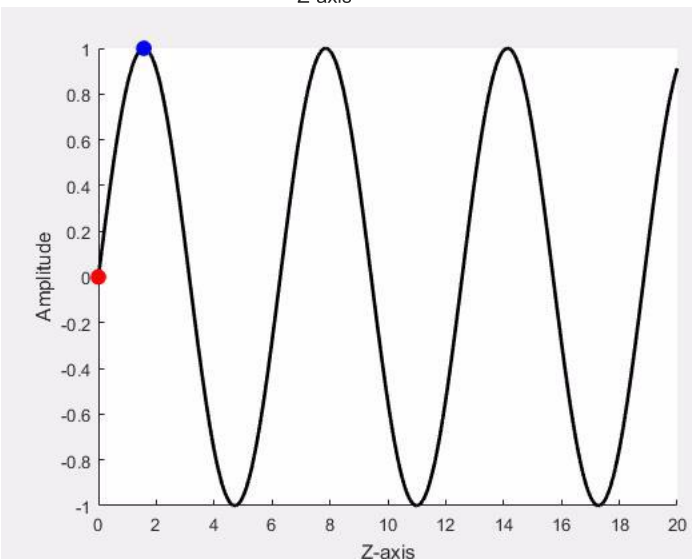
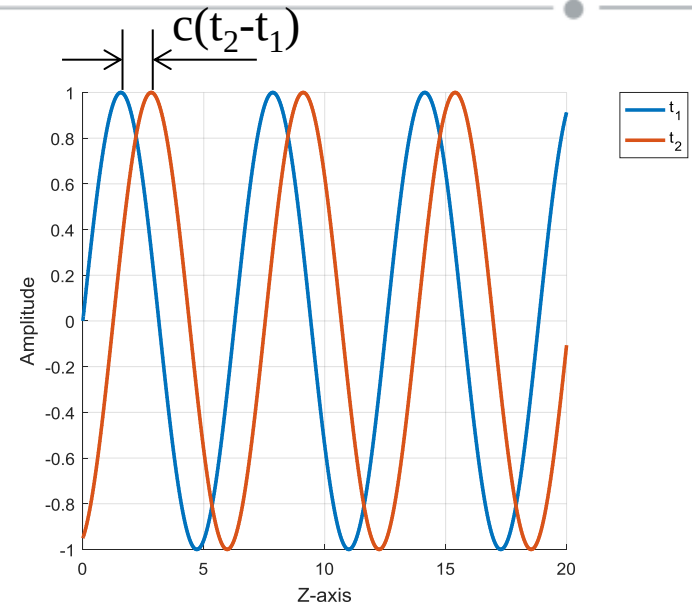
$$w(z, t) = f\left(t \pm \frac{z}{c}\right)$$

is a solution. So, for example:

$$w(z, t) = \sin\left(t - \frac{z}{c}\right).$$

Note:

- Negative indicates forward propagation.



Wave Propagation Basics Cont'd

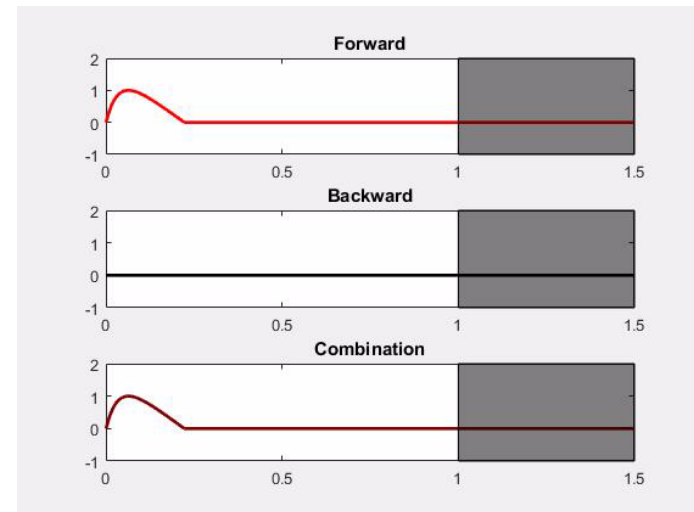
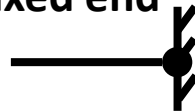
Reflections and Boundary Conditions

For forward and backward propagation:

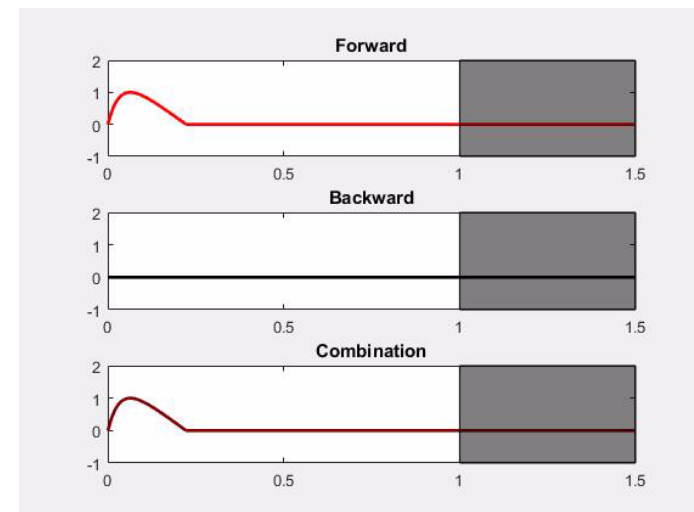
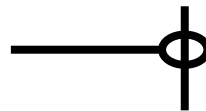
$$w(z, t) = f\left(t - \frac{z}{c}\right) + g\left(t + \frac{z}{c}\right)$$

Consider what happens at the boundary...

Fixed end



Free end



Wave Propagation Basics Cont'd

Wavenumbers and Dispersion Curves

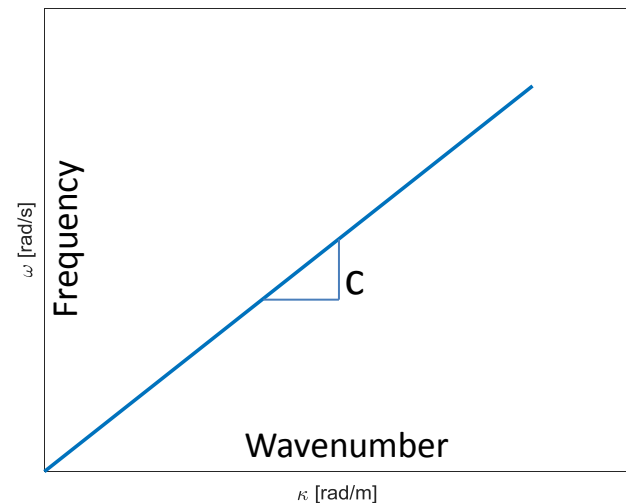
Assume that wave speed (c) is the same at all frequencies, and define:

$$c = \frac{\omega}{\kappa},$$

The previously defined solution form can be written as

$$\begin{aligned} w(z, t) &= f\left(t - \frac{z}{c}\right) = f\left(\omega\left(t - \frac{\kappa}{\omega}z\right)\right) \\ &= f(\omega t - \kappa z) \end{aligned}$$

$$\omega = \frac{2\pi}{T} = 2\pi f, \text{ and } \kappa = \frac{2\pi}{\lambda}$$



Vibration and Modal Analysis

Standing Waves

Standing waves can be seen as the sum of two waves propagating in opposite directions:

For forward propagation, we had:

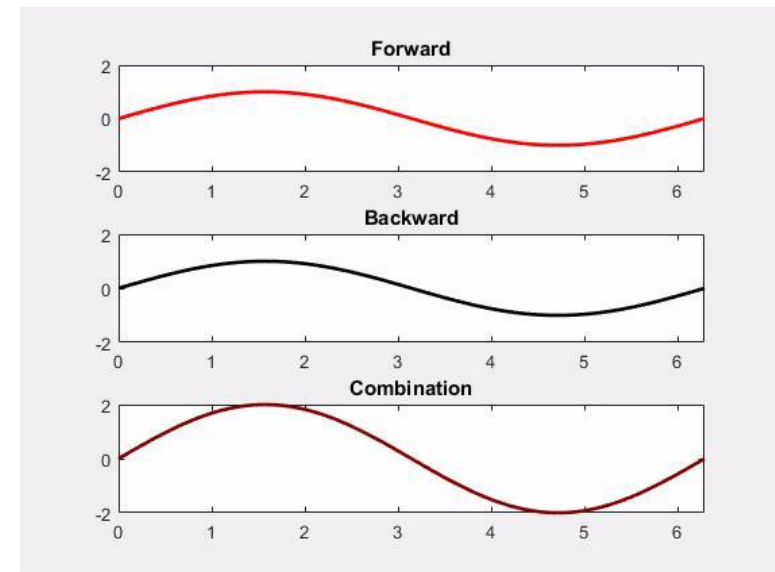
$$w(z, t) = \sin(\omega t - \kappa z)$$

and recall

$$\kappa = \frac{2\pi}{\lambda} \quad \text{and} \quad c = \frac{\omega}{\kappa}, \quad \text{so} \quad \omega = \frac{2\pi c}{\lambda}$$

Boundary conditions fix “ λ ”, and “ c ” determines the “ ω ” of the vibration.

This “ ω ” is called the **natural frequency**. If excited at or close to the natural frequency, we will observe **resonance**.



Vibration and Modal Analysis Cont'd

Modal Analysis

- If a structure is damaged the natural frequency and/or mode shape will change.
- Structure excited by operational loads, hammer (instrumented) or actuators.
- Mode shape and natural frequencies can be measured using accelerometers, strain gauges or laser vibrometer.
- Frequencies are typically low Hz / kHz range.
- Finite element modelling can be used to design the measurement.

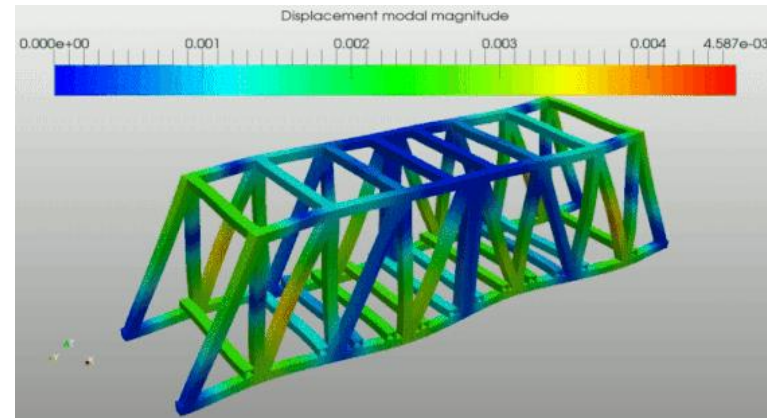
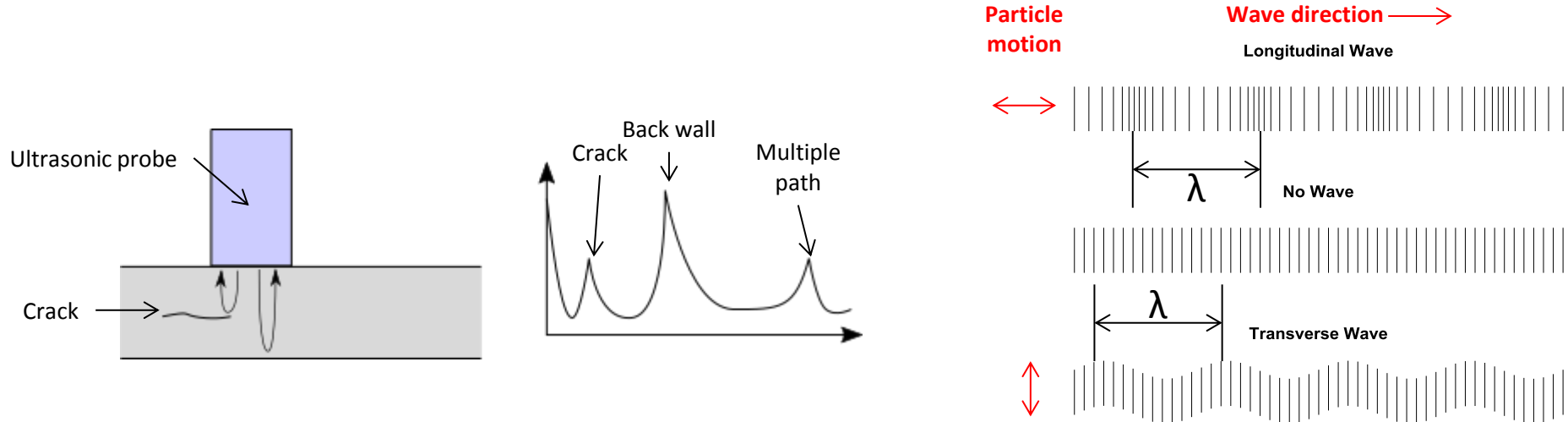


Figure from <https://commons.wikimedia.org>



Conventional Ultrasound



- Frequencies typically in 1-15 MHz range (λ 5-0.3 mm in steel)

Material	Longitudinal [m/s]	Transverse [m/s]
Aluminium	6320	3130
Steel	5890	3240

Speeds of sound (approximate)

Conventional Ultrasound Cont'd

Other Types of Waves

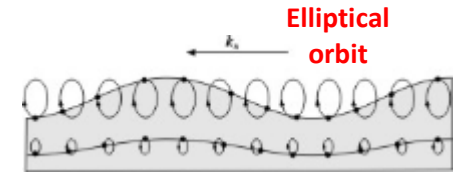
Besides longitudinal and transverse waves, other common waves types include:

Surface (Rayleigh) waves:

- Combination of longitudinal and shear waves, with amplitude that decreases with thickness.

Plate (Lamb) waves:

- Similar to surface waves but generated in structures with thickness $O(\lambda)$.
- Propagate parallel to the surface and sensitive to frequency and thickness.
- Can travel several meters.



Figures from <https://commons.wikimedia.org>

Rayleigh Wave

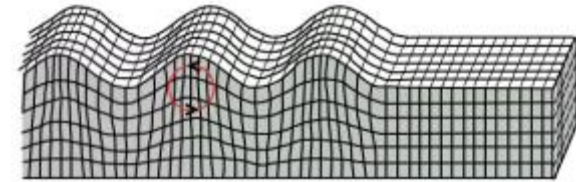


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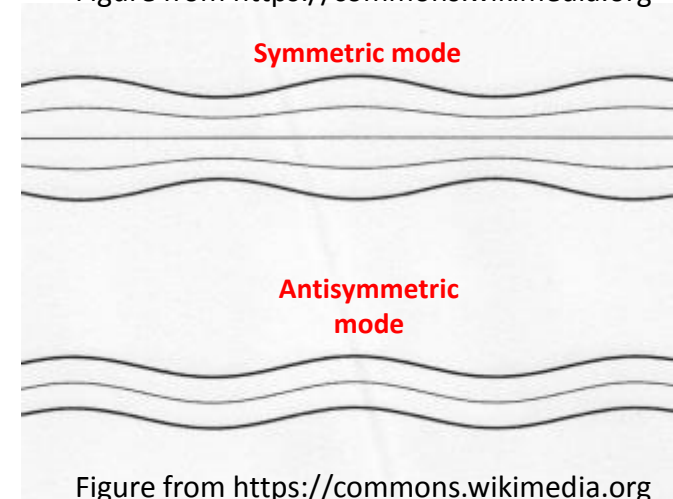
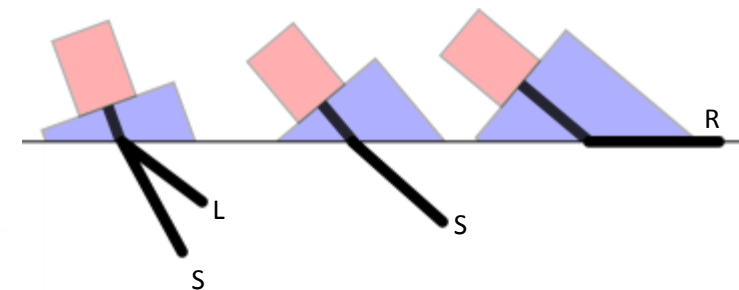
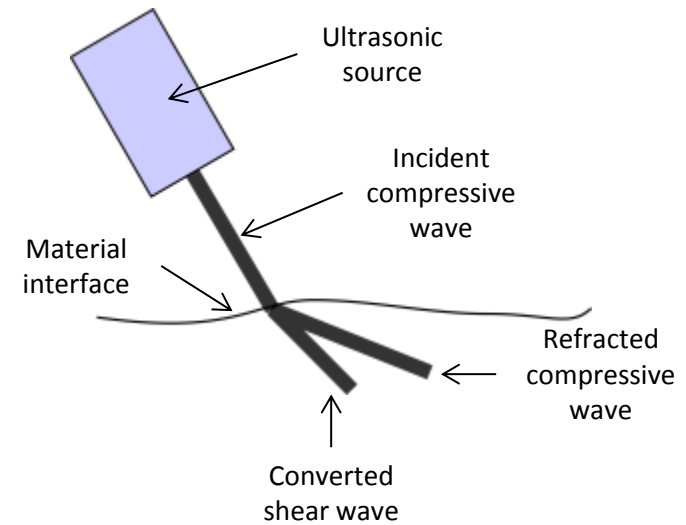
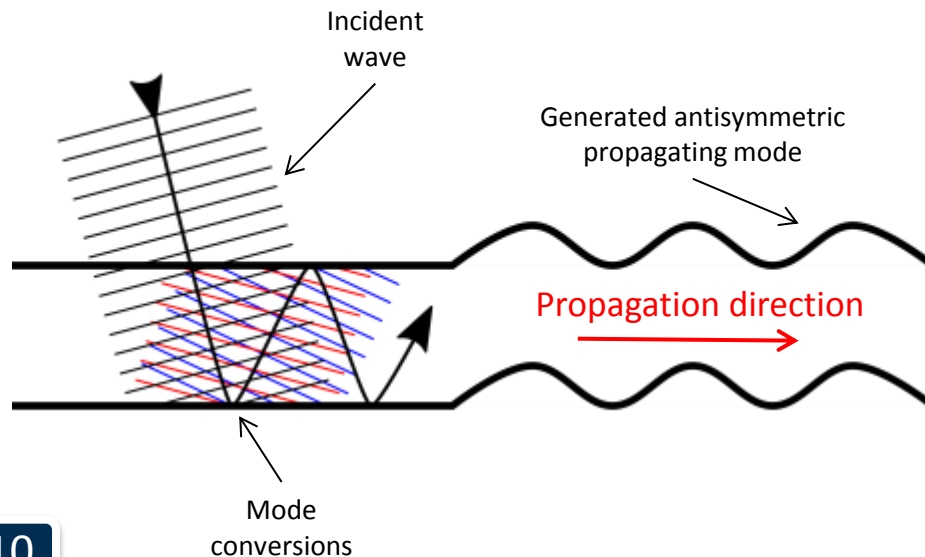


Figure from <https://commons.wikimedia.org>

Conventional Ultrasound Cont'd

Mode Conversion and Guided Waves

Mode conversion can occur when a wave encounters an interface between two material.



Guided Waves

Welcome to Guided Waves!

- Guides waves typically in the kHz range
- Structure are typically excited using high frequency actuators (piezoelectric), pulses (impact / laser) or operational loads.
- Waves can be measured using piezoelectric ceramics, EMATs or laser vibrometer.

Advantages:

- “Full coverage”
- Long distance propagation (up to km's!)
- Covered/buried/submerged structures

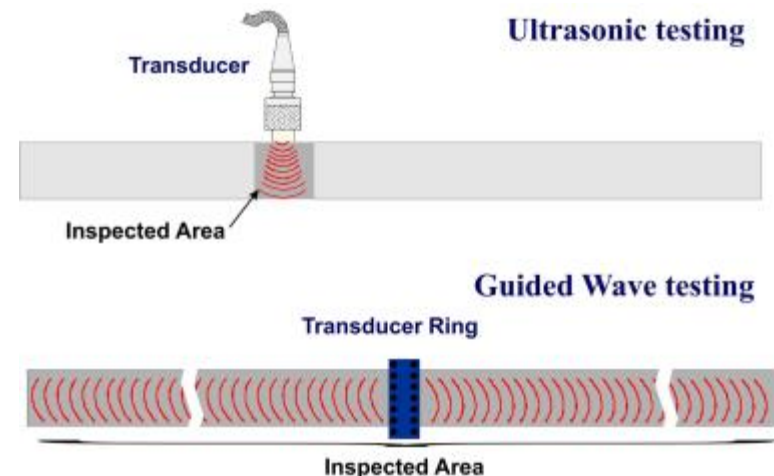


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Guided Waves Cont'd

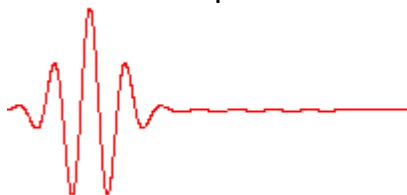
Dispersion, Phase and Group Velocities

Play additional animations...

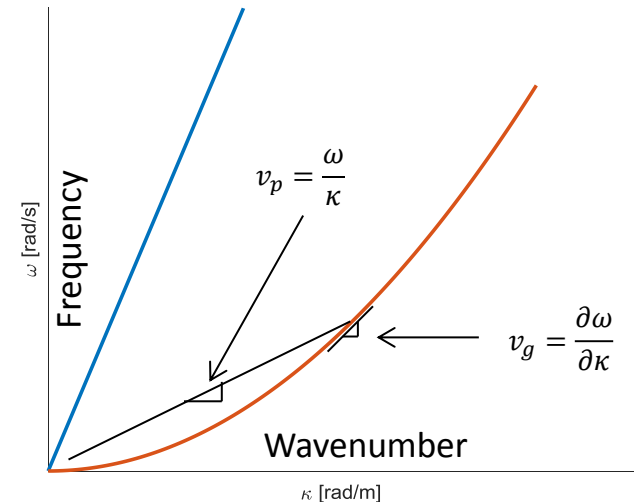
No dispersion



With dispersion



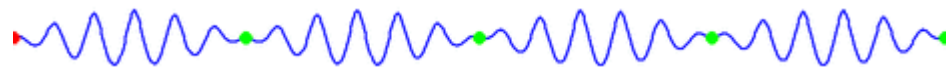
Figures from <https://commons.wikimedia.org>



No dispersion



With dispersion



Figures from <https://commons.wikimedia.org>

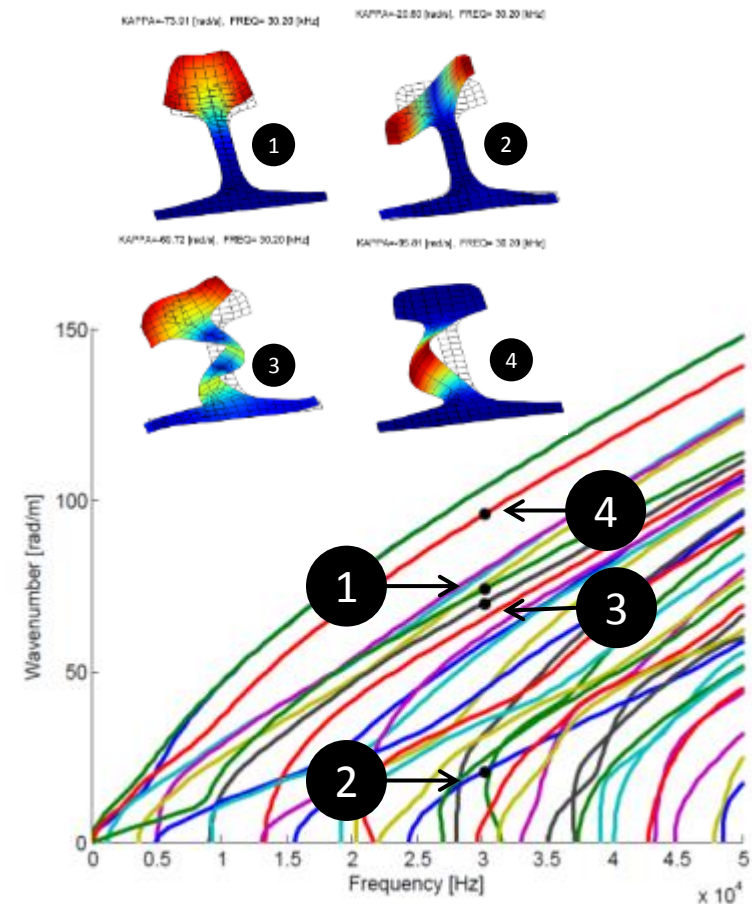
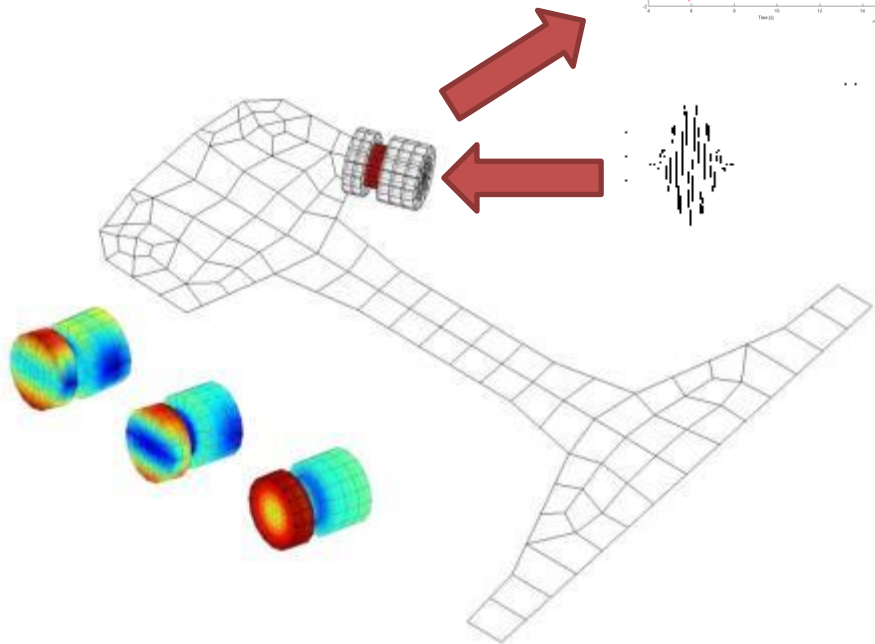
Guided Waves Cont'd

Dispersion Curves for a Rail

Challenges with system design:

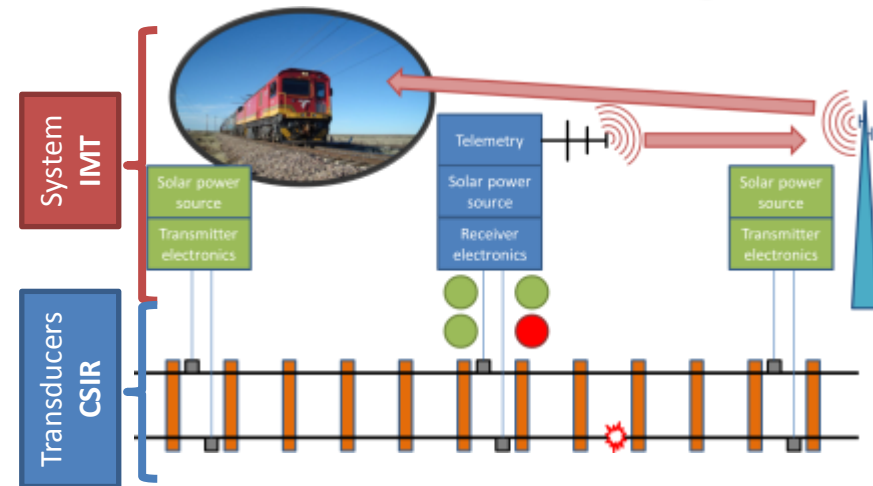
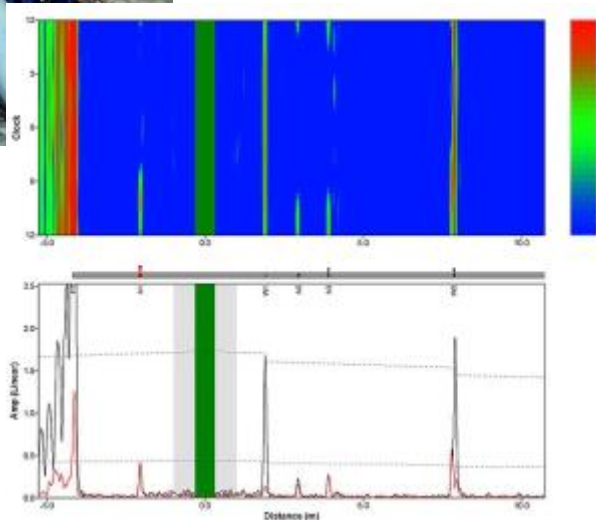
- Dispersion
- Multiple modes

Modelling required!



Guided Waves Cont'd

Application Examples



Some Final Remarks

- Monitoring vs. inspection
- GWU can be used to complement other NDE techniques

Thank you!

Questions?



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