Use of Microwaves for the Detection of Corrosion Under Insulation: The Effect of Bends

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Outline

- Motivation
- Principle of Detection
- Waveguide Excitation
- Water Detection
- Effect of Insulation
- Bends

Situation

Some pipelines are insulated and this insulation is protected by cladding.

Problem

Damaged cladding allows water ingress

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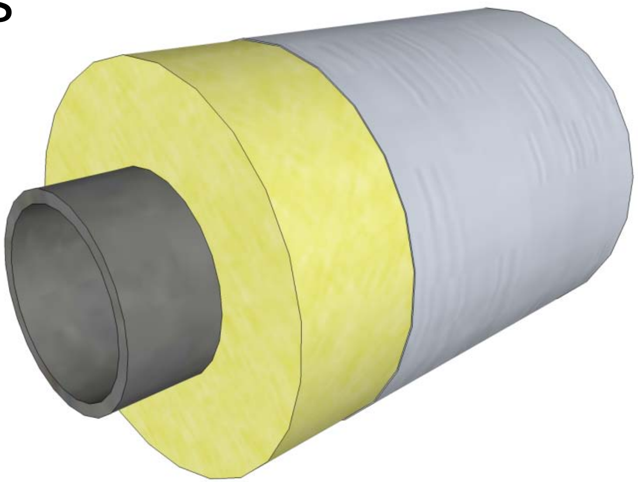
Insulation traps water next to pipe

⇩

Accelerated corrosion initiates

⇩

Inspection requires insulation removal

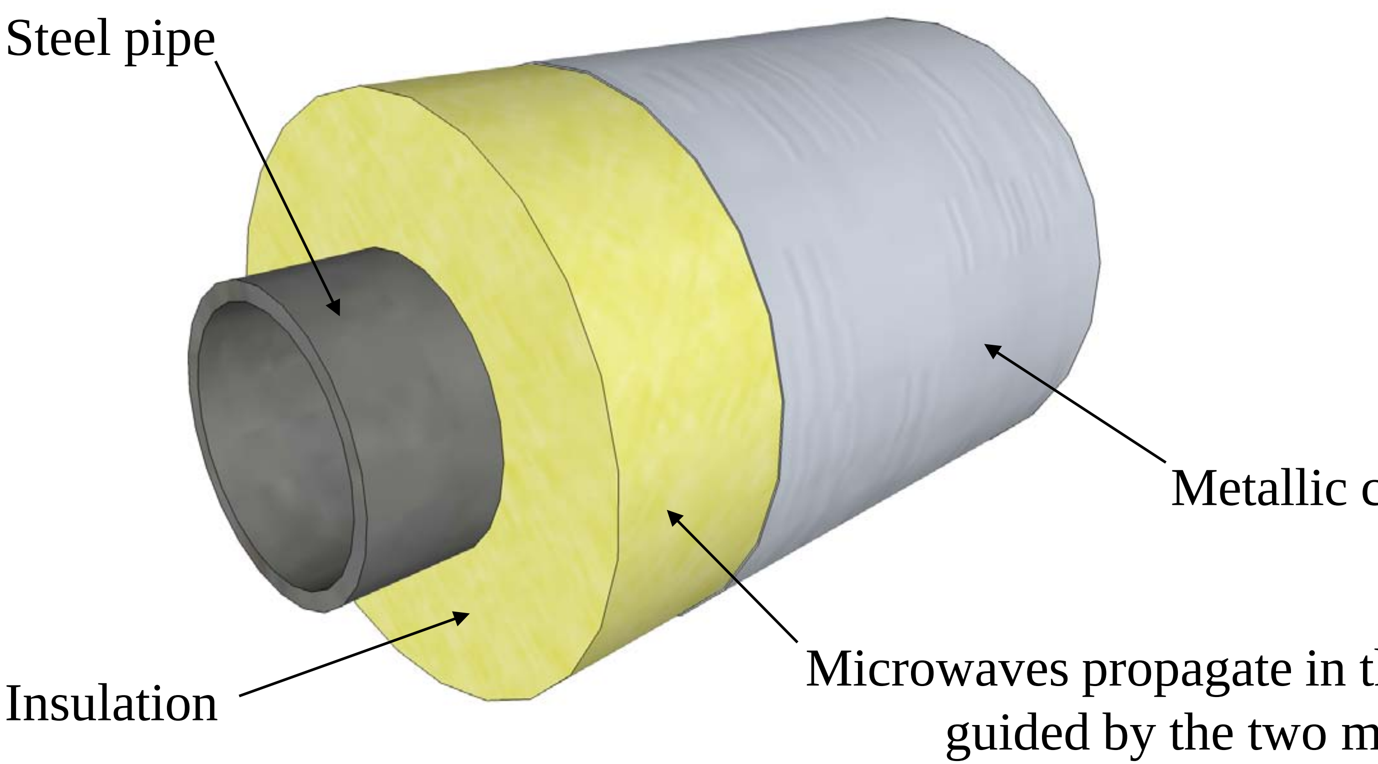


The Coaxial Waveguide Idea

An insulated pipeline will act as a coaxial waveguide, supporting electromagnetic wave propagation.

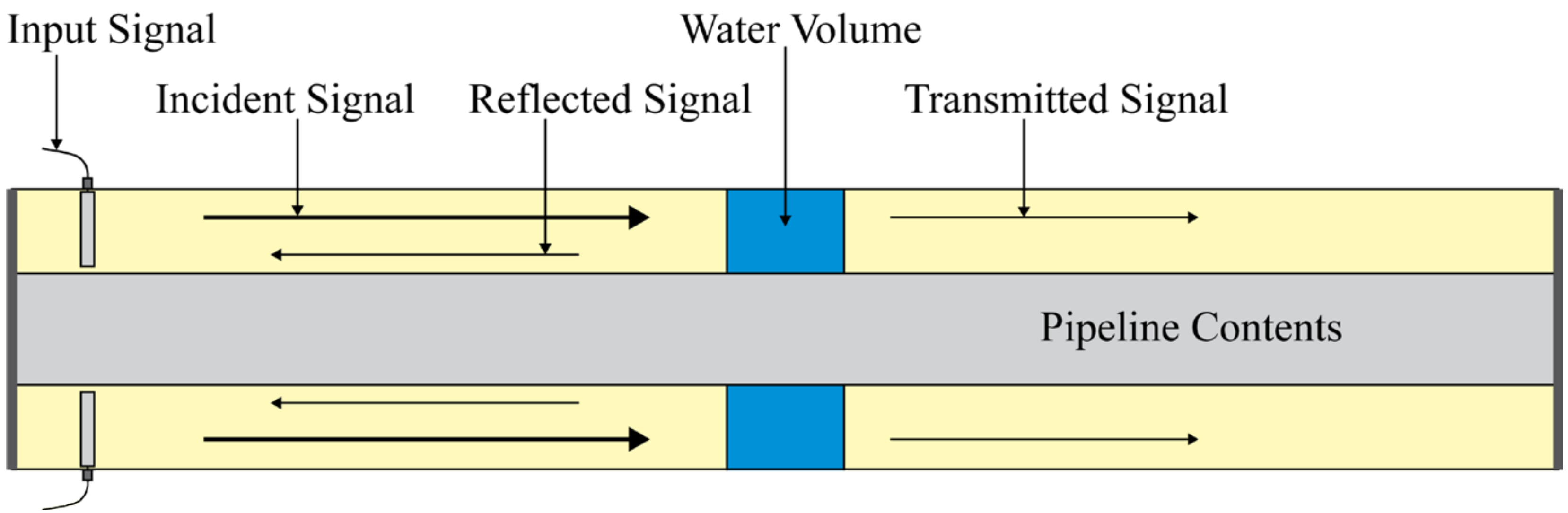
Interested in microwave frequencies because:

- Water has a high dielectric constant at these frequencies
- Insulation is transparent at these frequencies

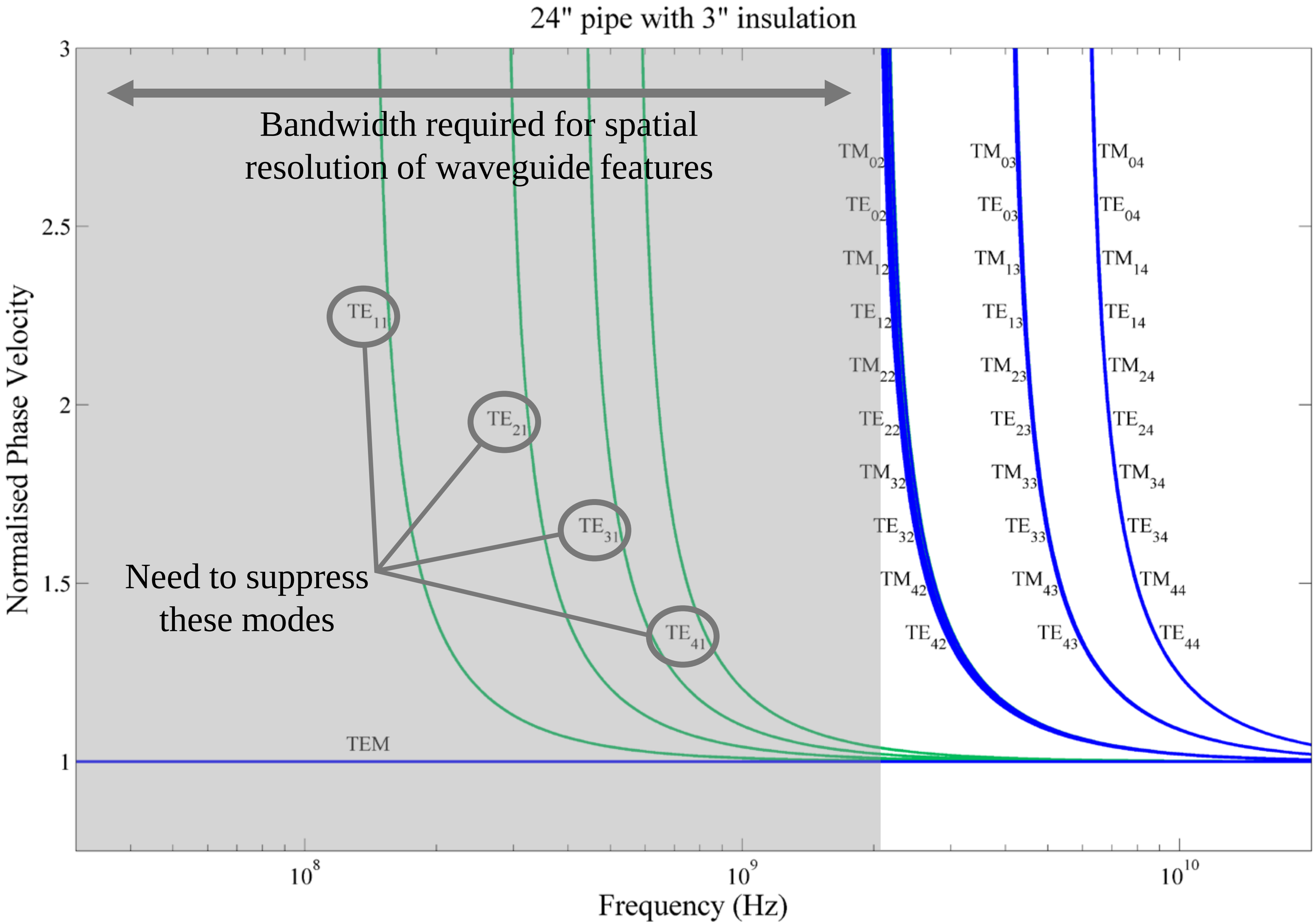


Principle of Detection

- Antennas used to excite microwave propagation
- A water patch acts as an impedance discontinuity
- Microwave signal undergoes a partial reflection
- Pulse echo reflections used to locate water

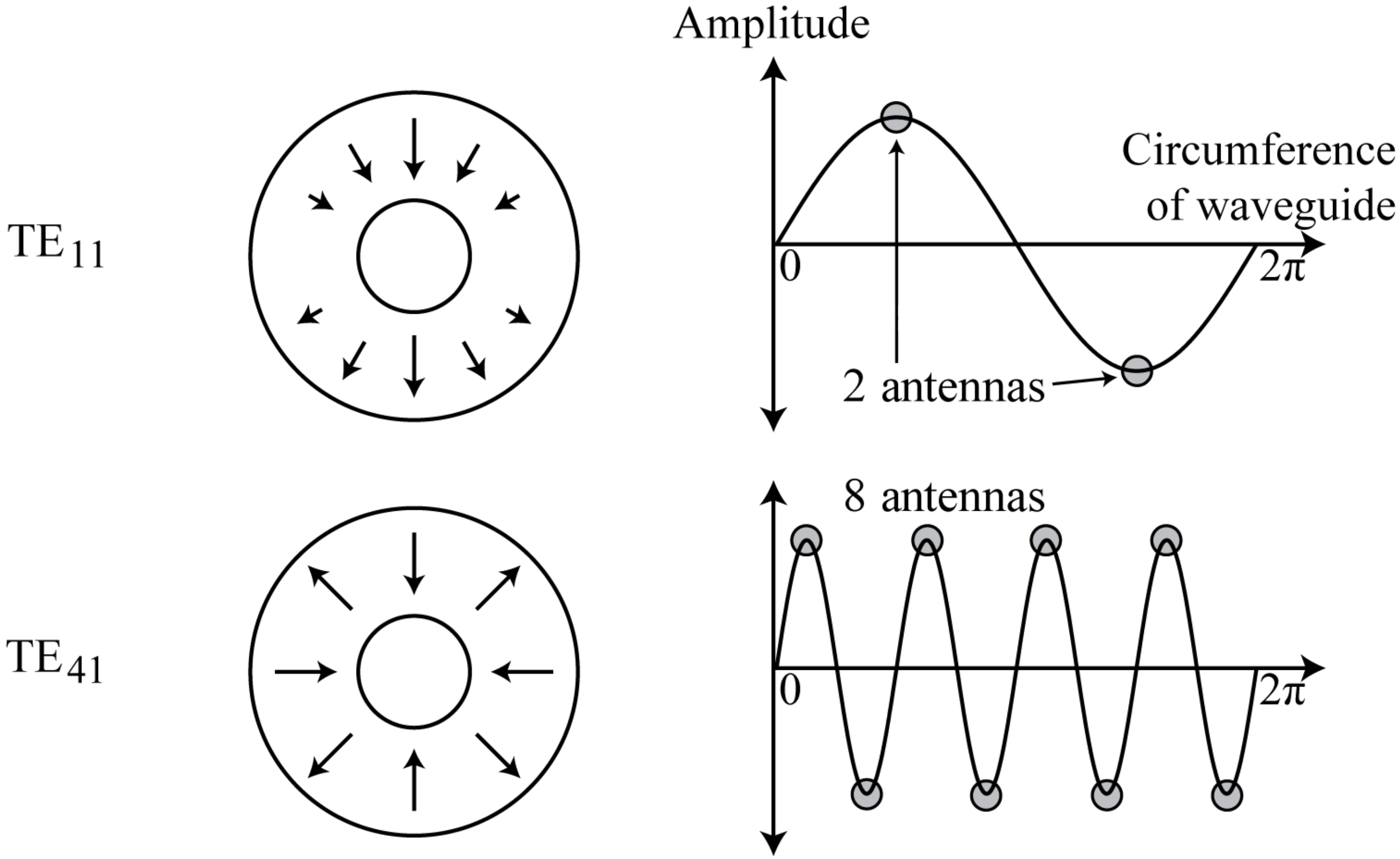


Dispersion Curves

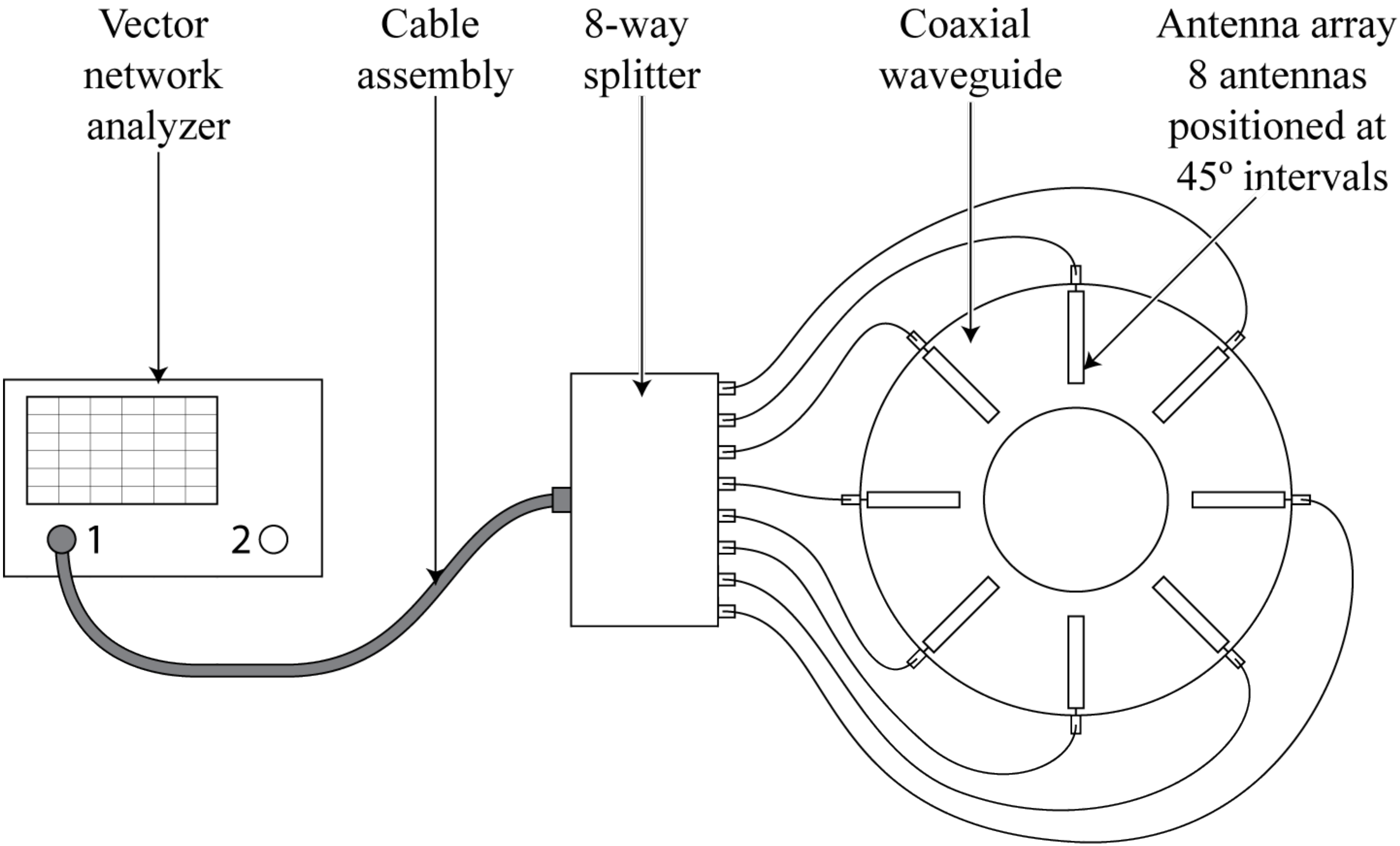


Antenna Array for Pure TEM Excitation

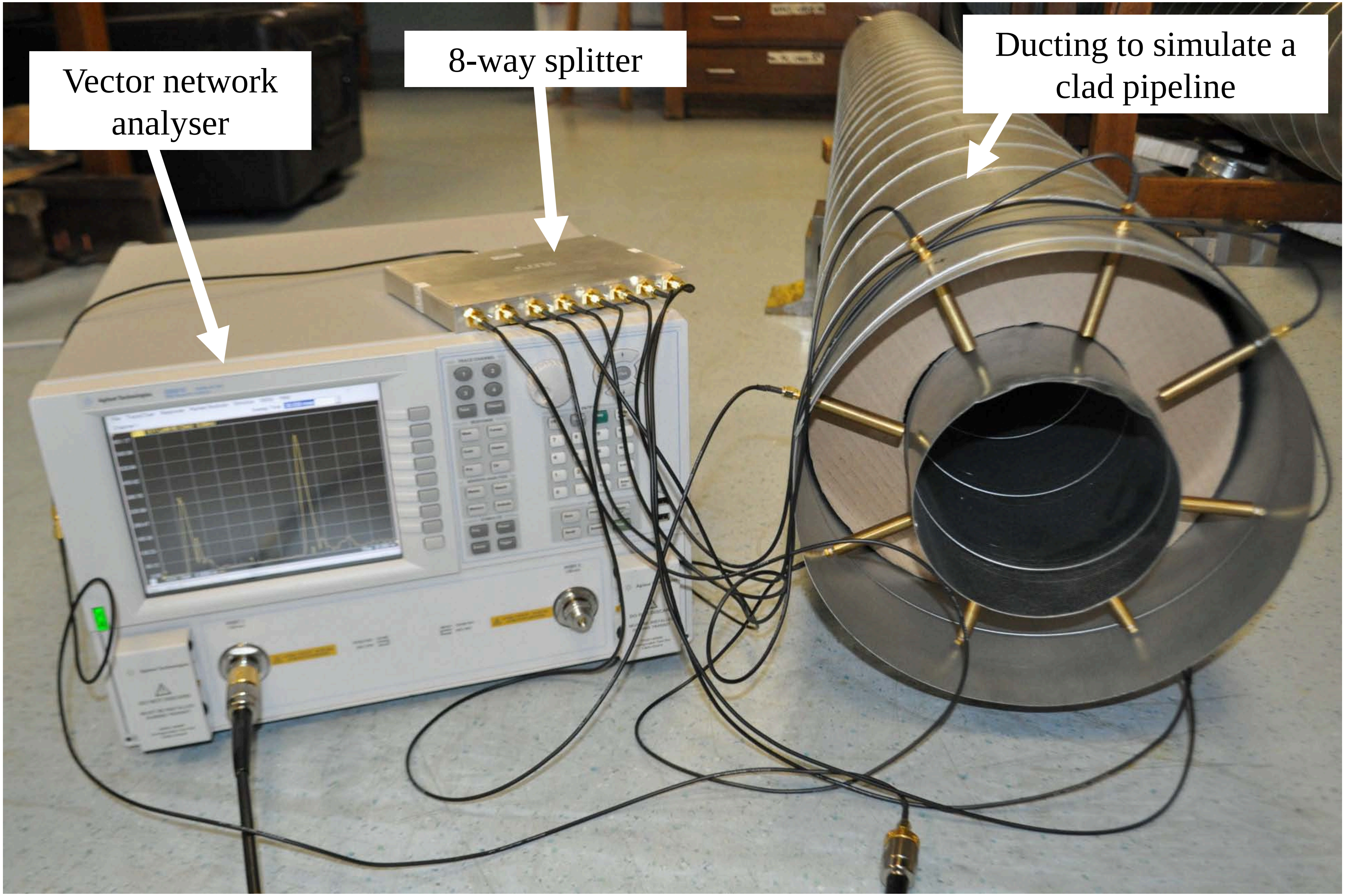
- Use two antennas per wavelength to filter out the non-axisymmetric modes.
- Highest mode from the TE_{p1} family that can propagate in the 6" pipe waveguide is TE_{41} therefore need 8 antennas.



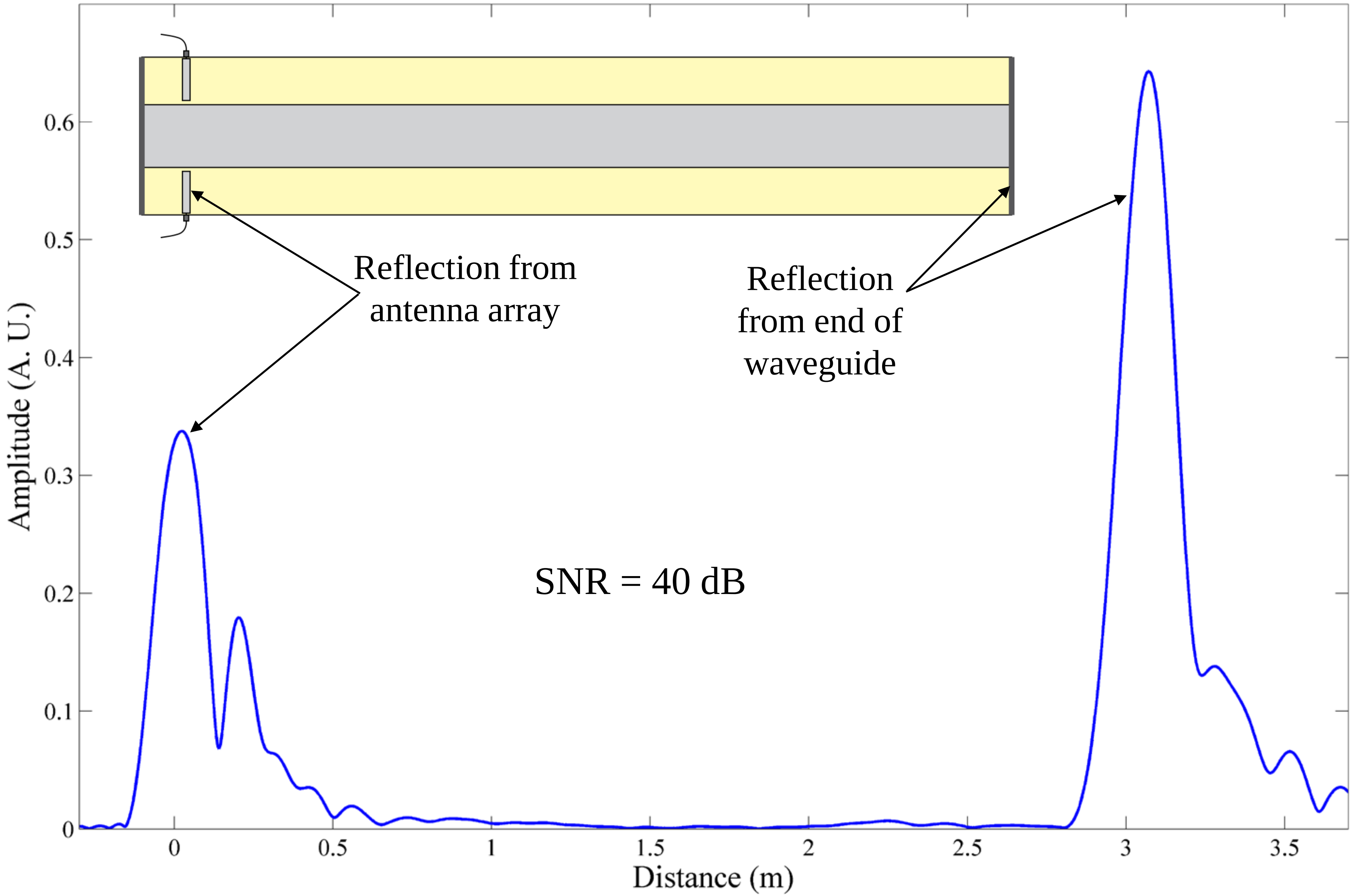
Experimental Setup for a 6” Pipe



Experimental Setup



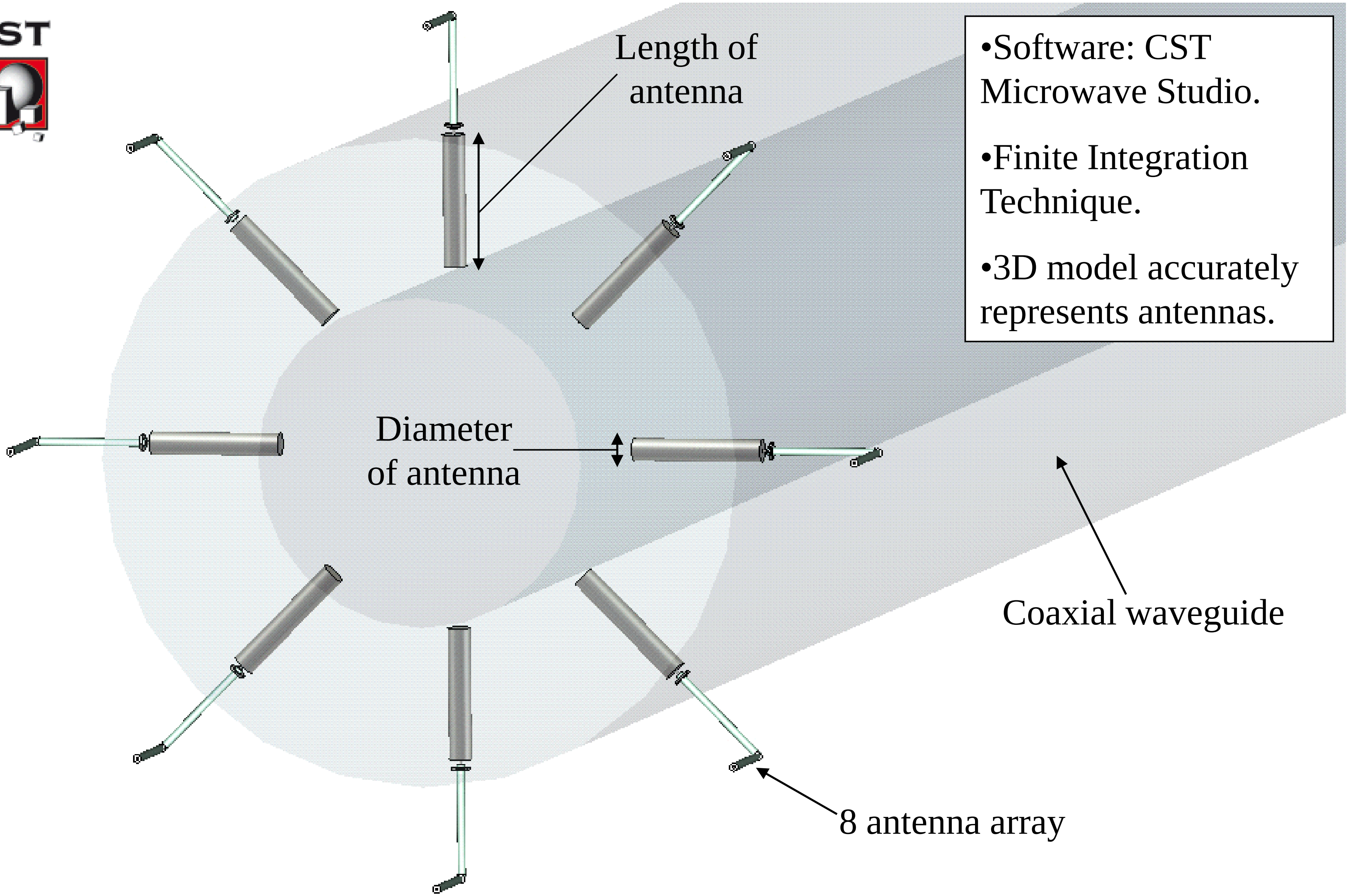
Time Domain Reflectometry Signal



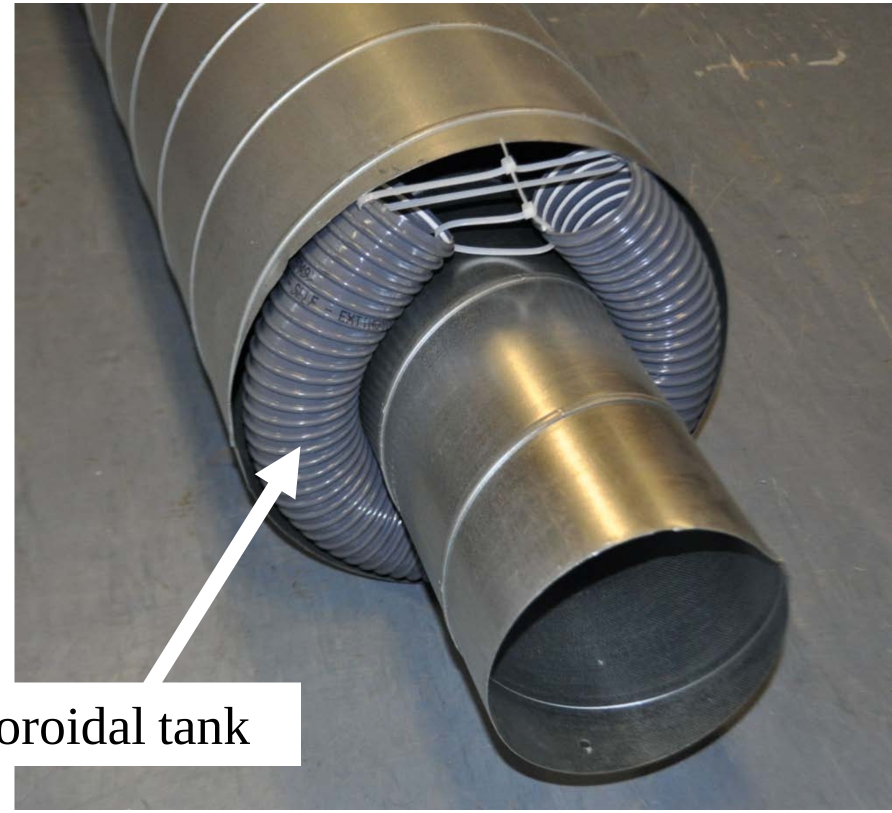
Optimal Array Design

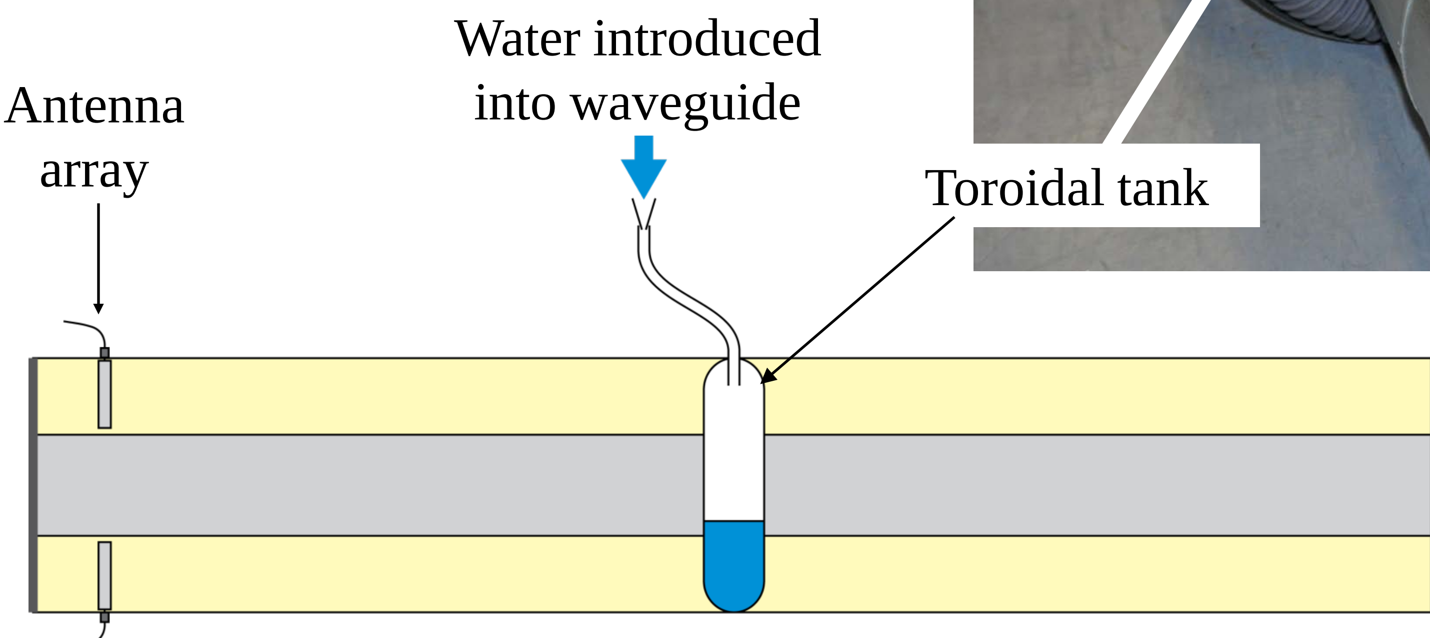
CST

- Software: CST Microwave Studio.
- Finite Integration Technique.
- 3D model accurately represents antennas.

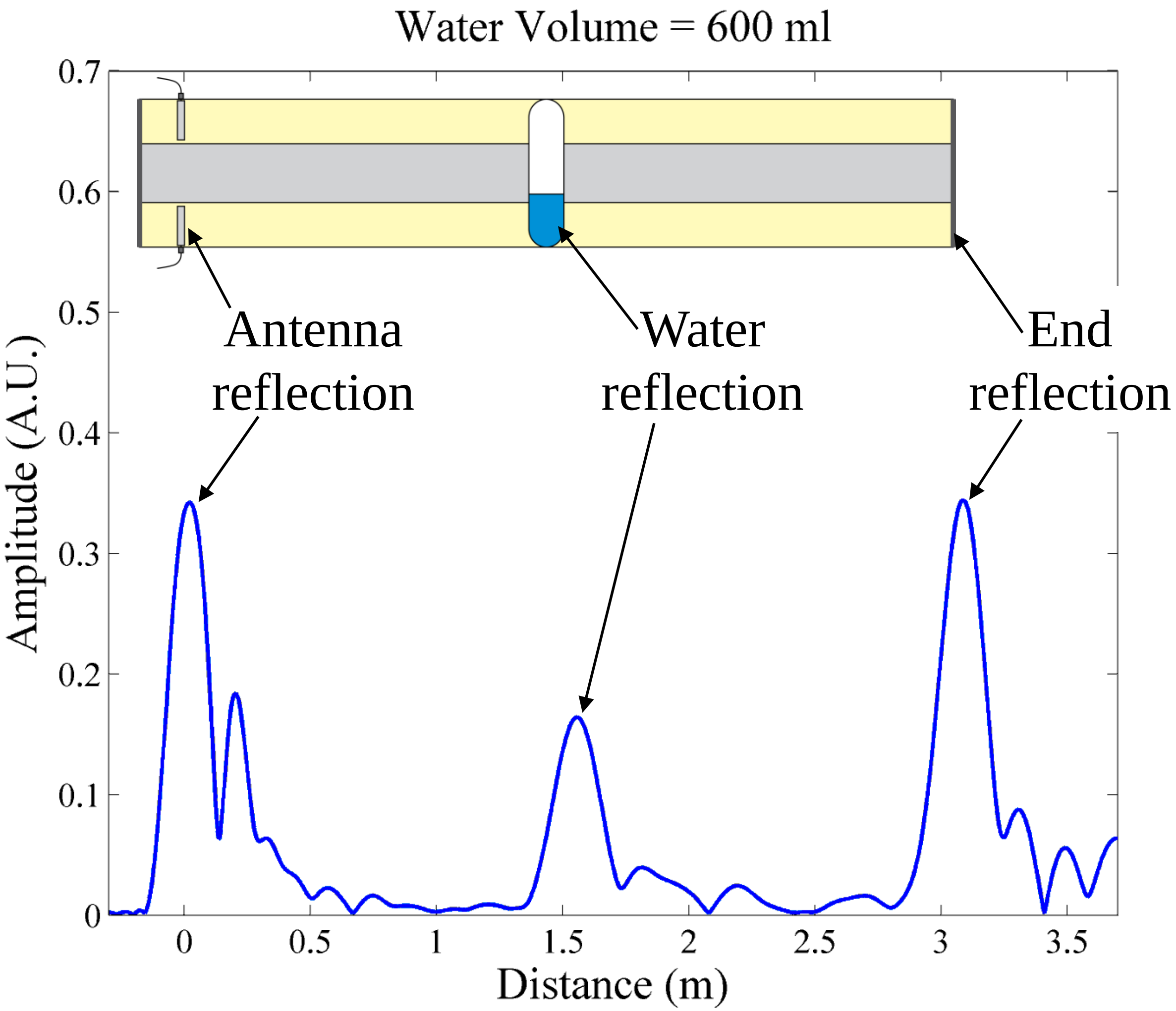


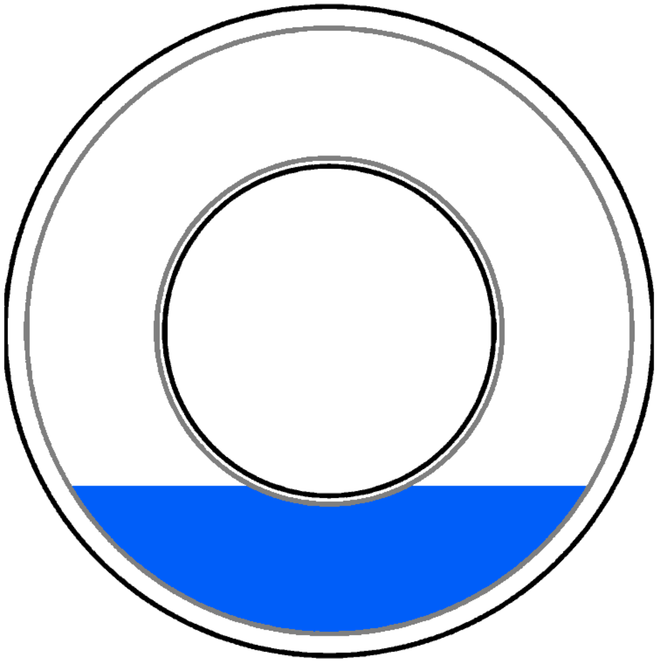
Monitor the reflection from a water defect by pouring measured volumes into a tank within the waveguide.



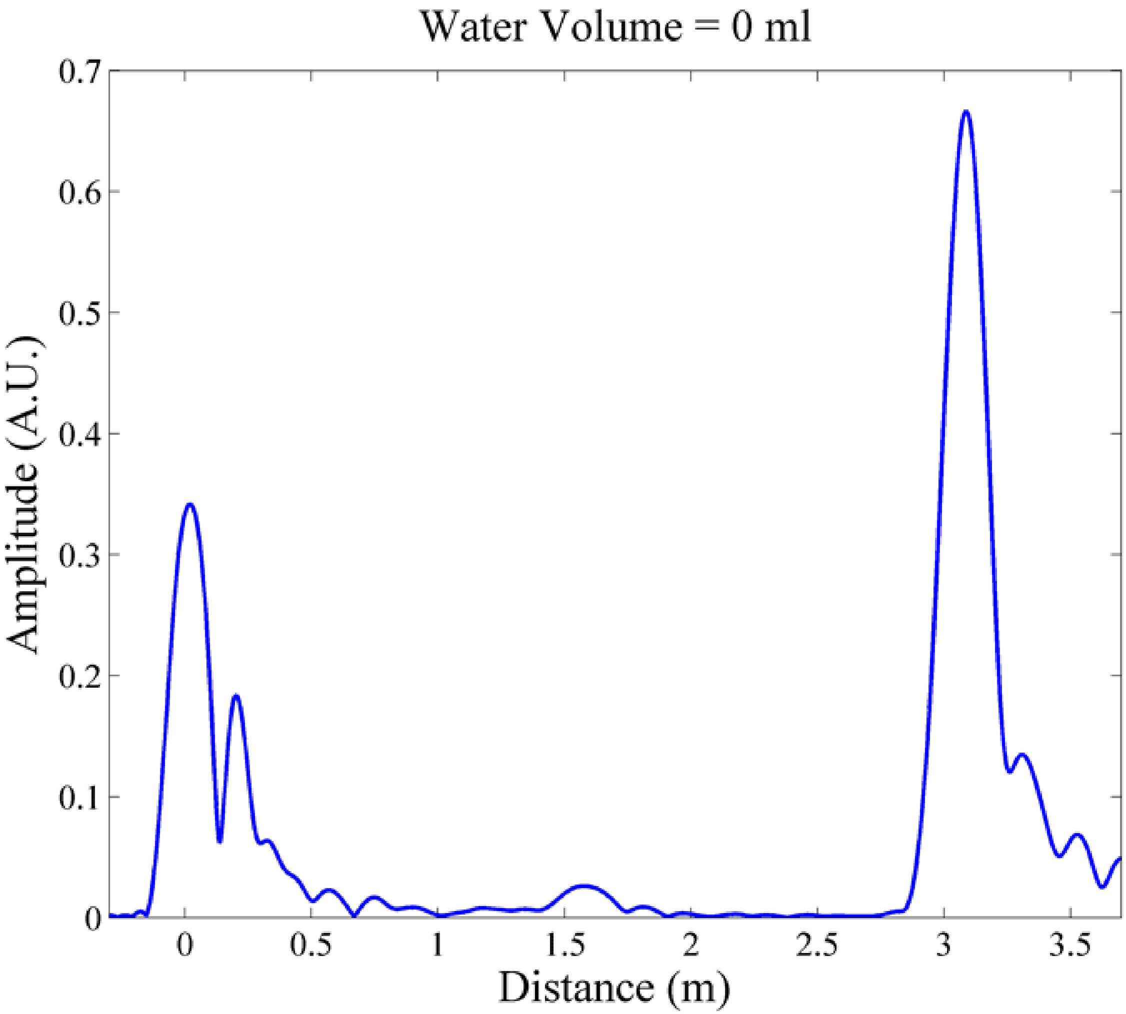


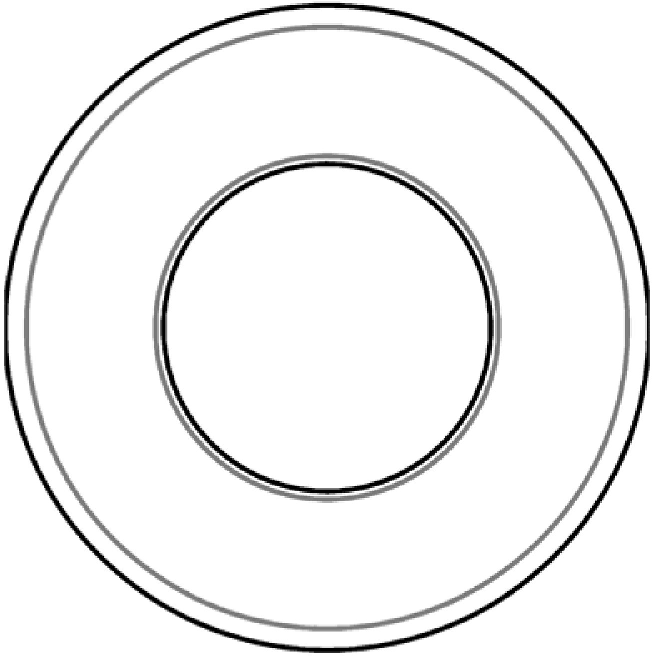
Water Detection



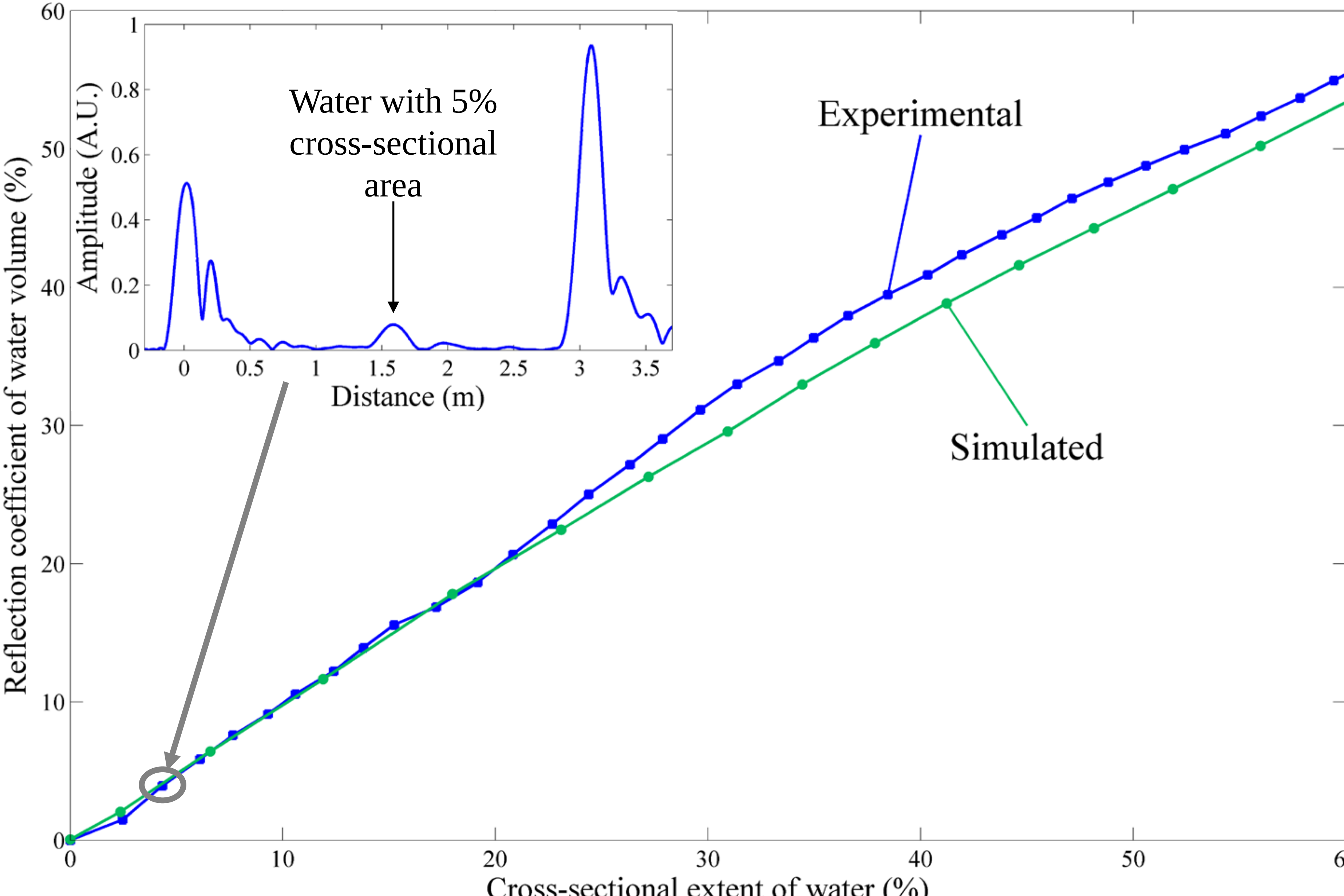


Water Detection





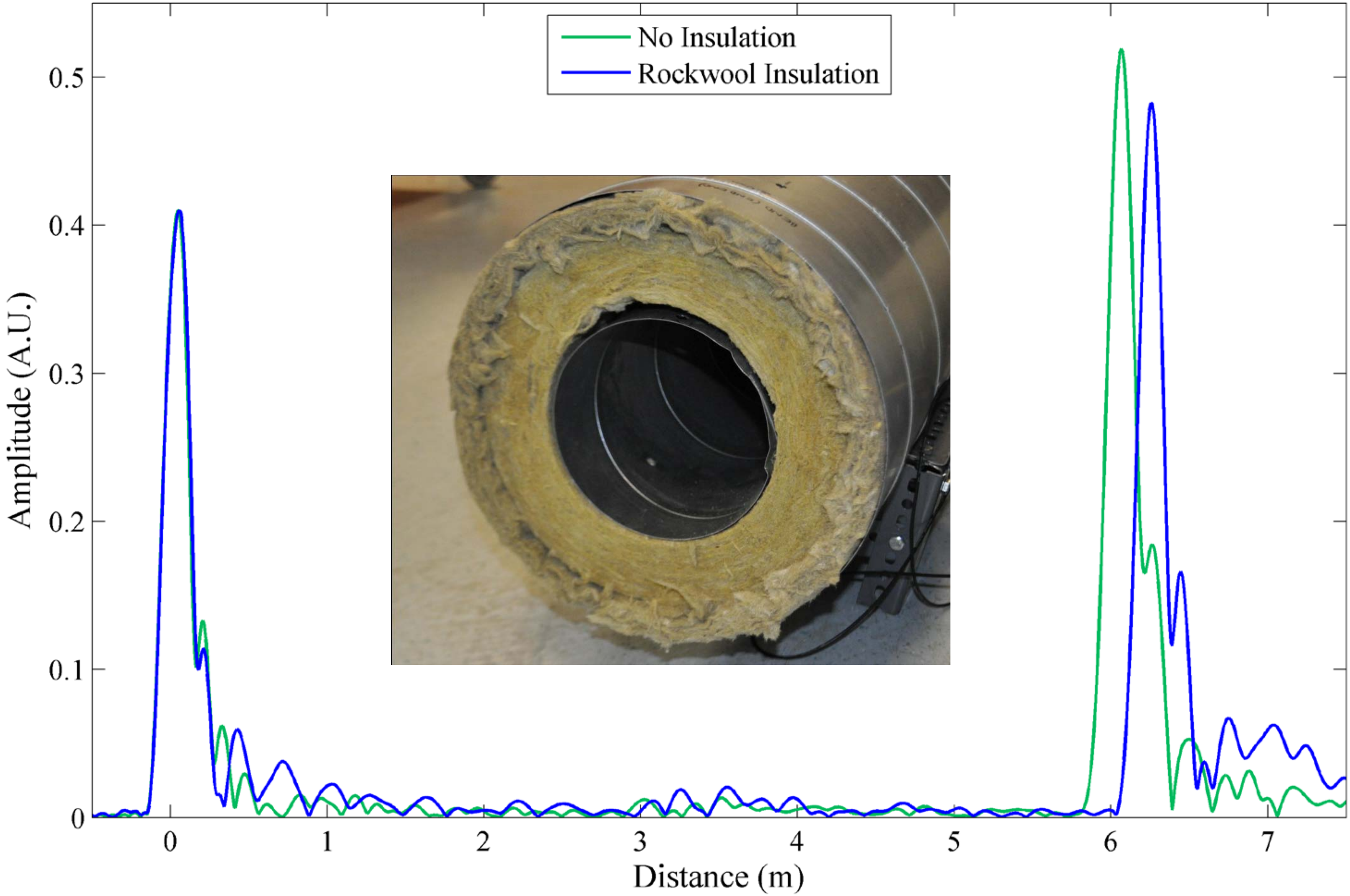
Sensitivity to Water Volumes



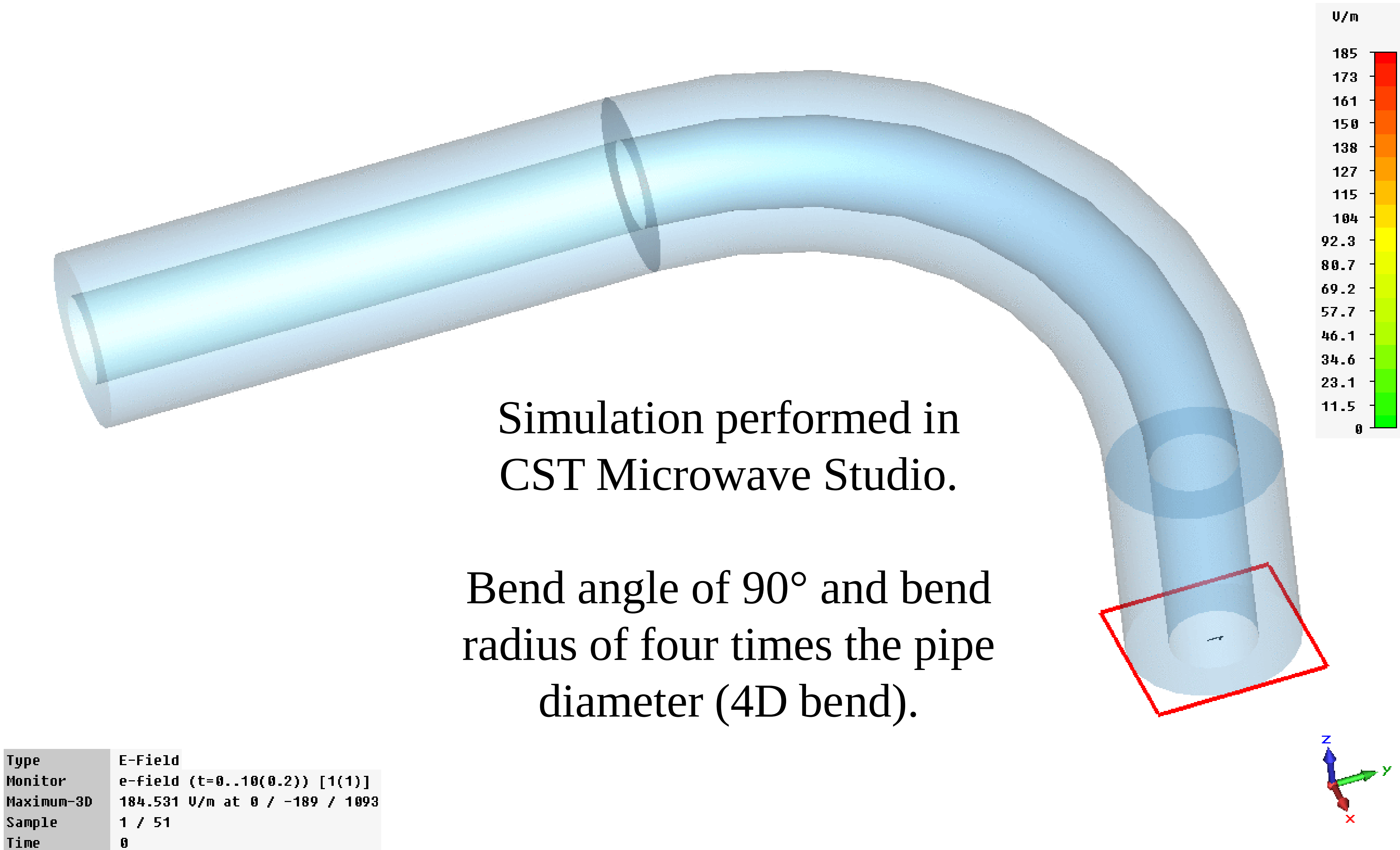
Issues of Practical Implementation

- Effect of Insulation
- Bends
- Pipe supports
- Shape of water volume
- Inspection range

Effect of Insulation



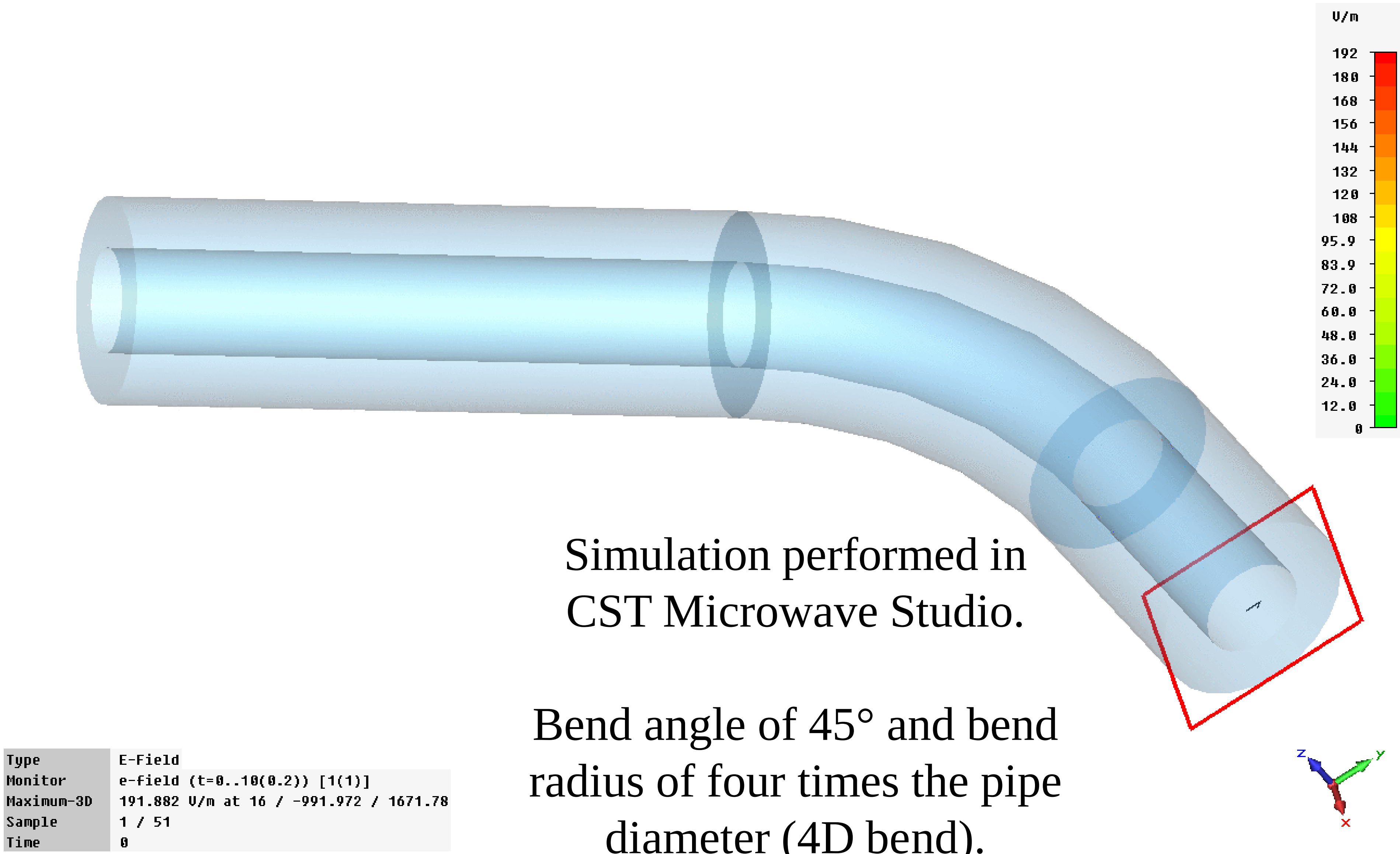
Simulations of Bends



Simulation performed in CST Microwave Studio.

Bend angle of 90° and bend radius of four times the pipe diameter (4D bend).

Simulations of Bends

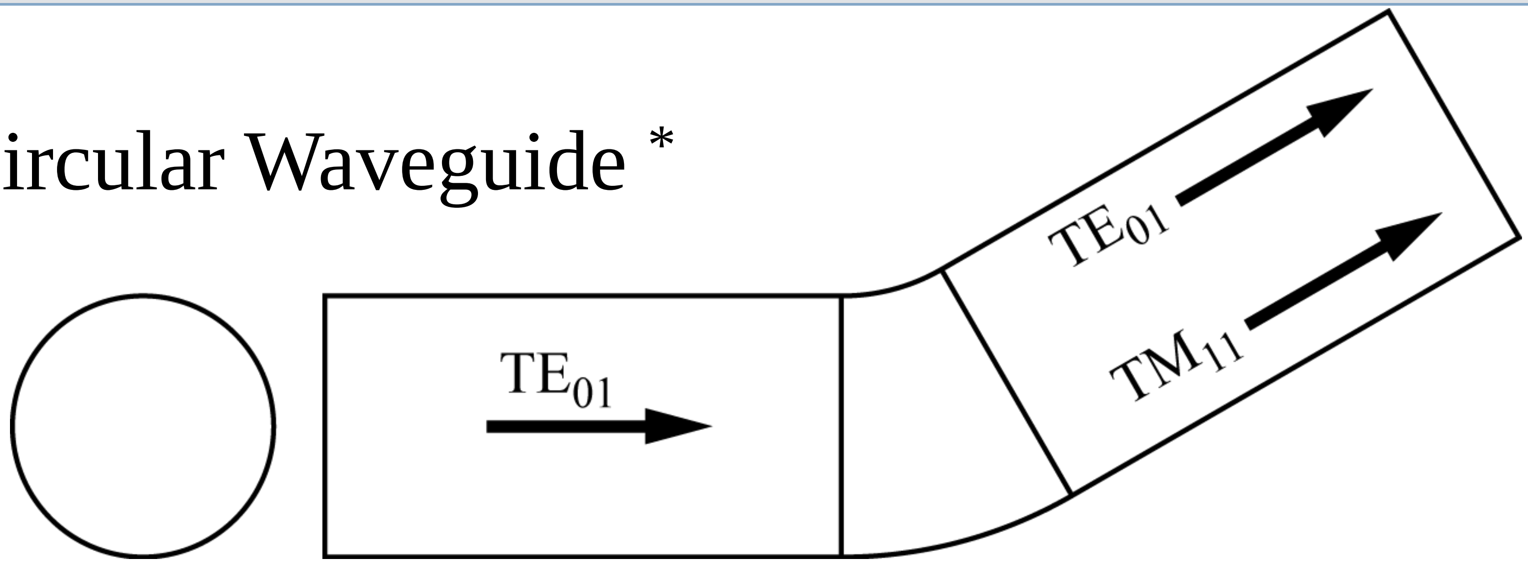


Simulation performed in CST Microwave Studio.

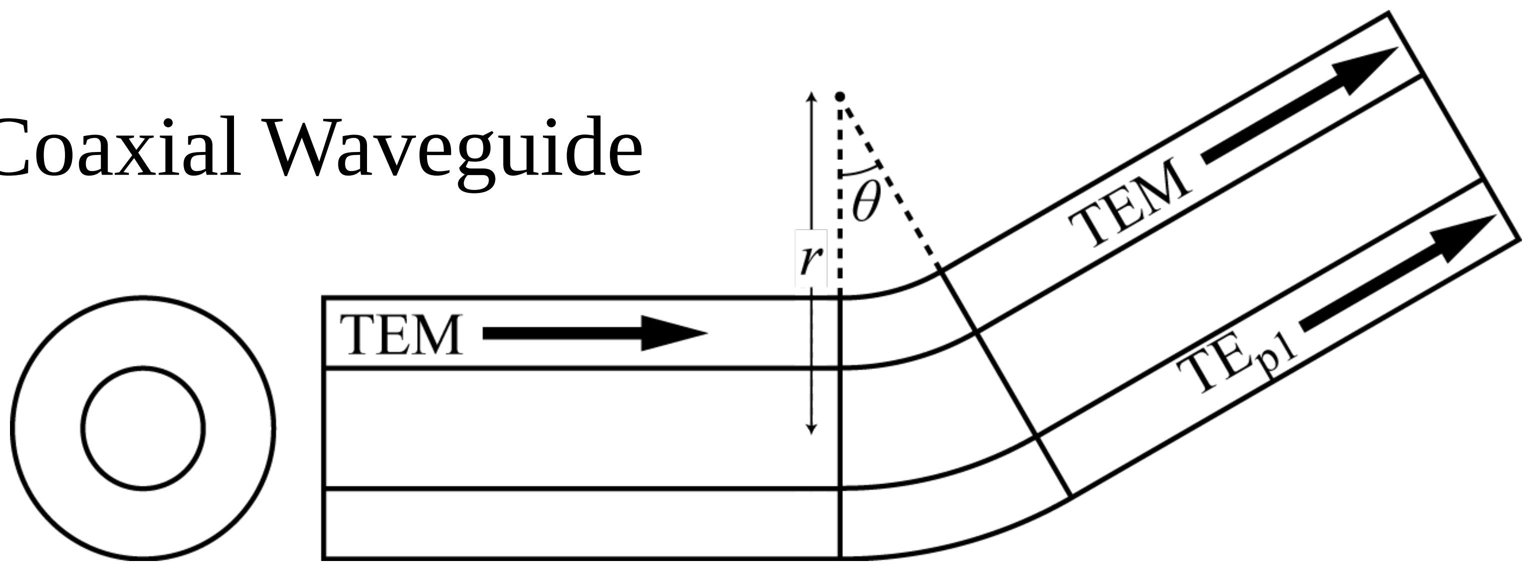
Bend angle of 45° and bend radius of four times the pipe diameter (4D bend).

Mode Conversion at Bends

Circular Waveguide *

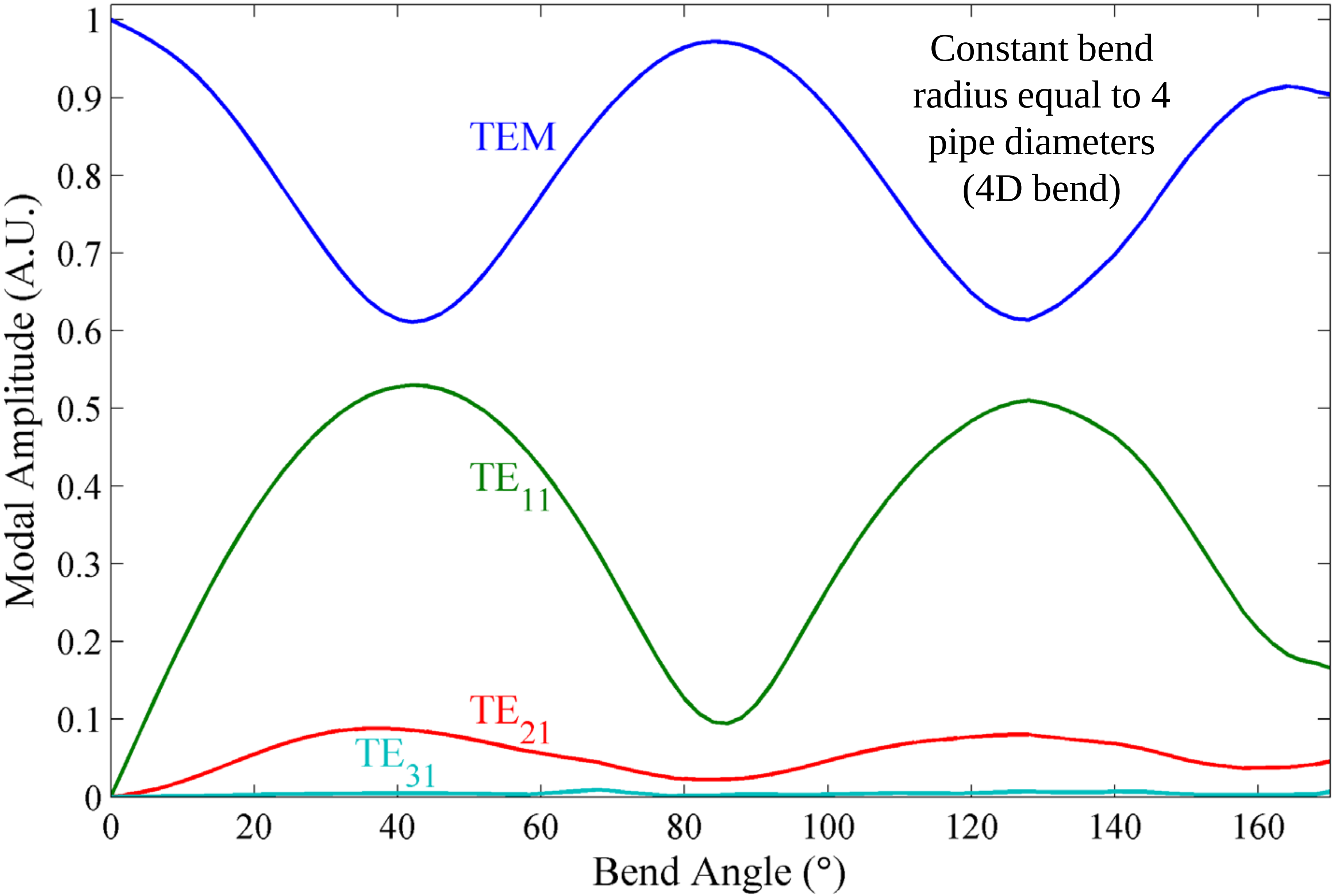


Coaxial Waveguide

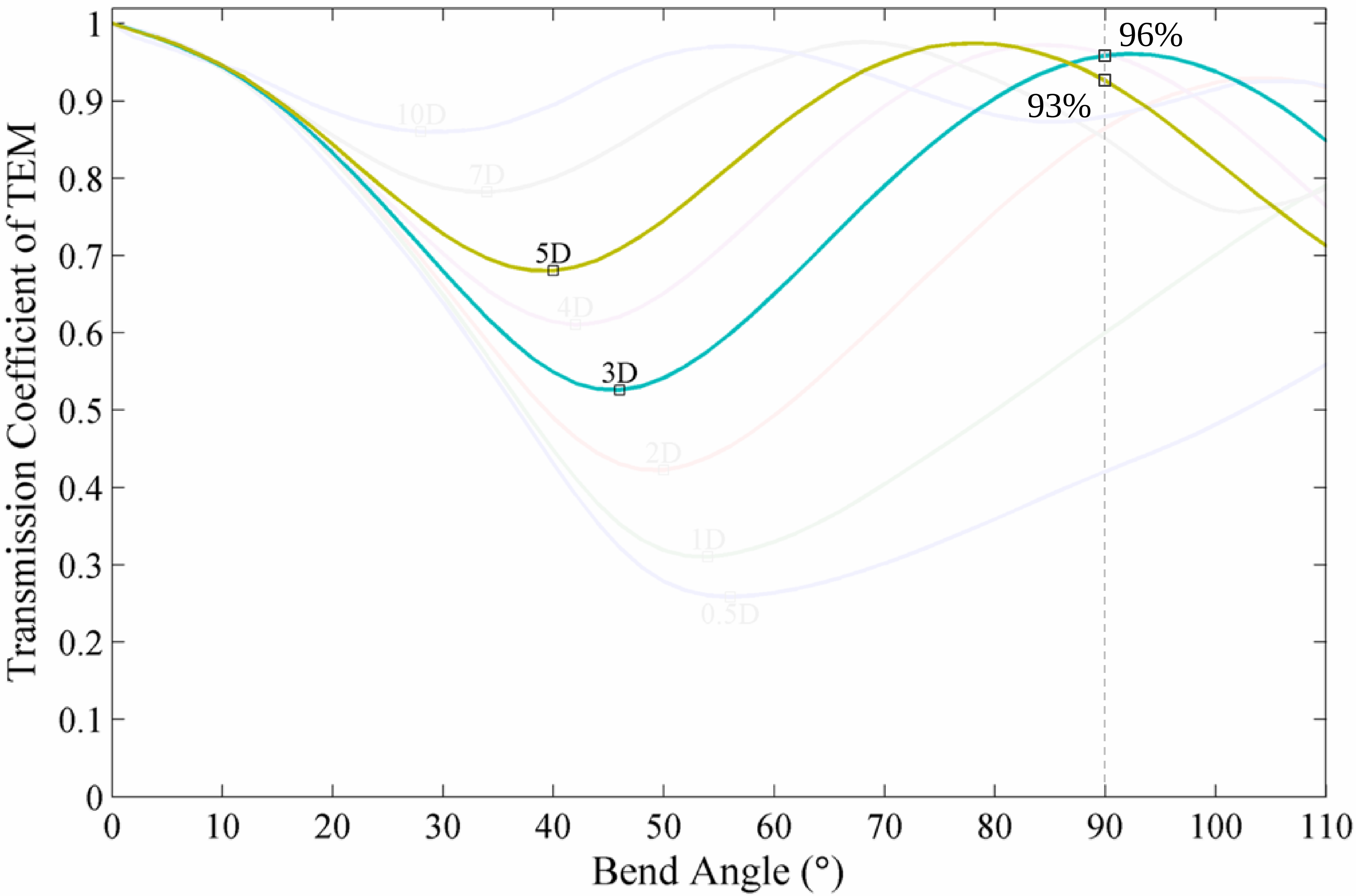


* M Jouguet, “Effects of the curvature on the propagation of electromagnetic waves in guides of circular cross-section”, Cables et Transmission, 1(2), 133-153, (1947).

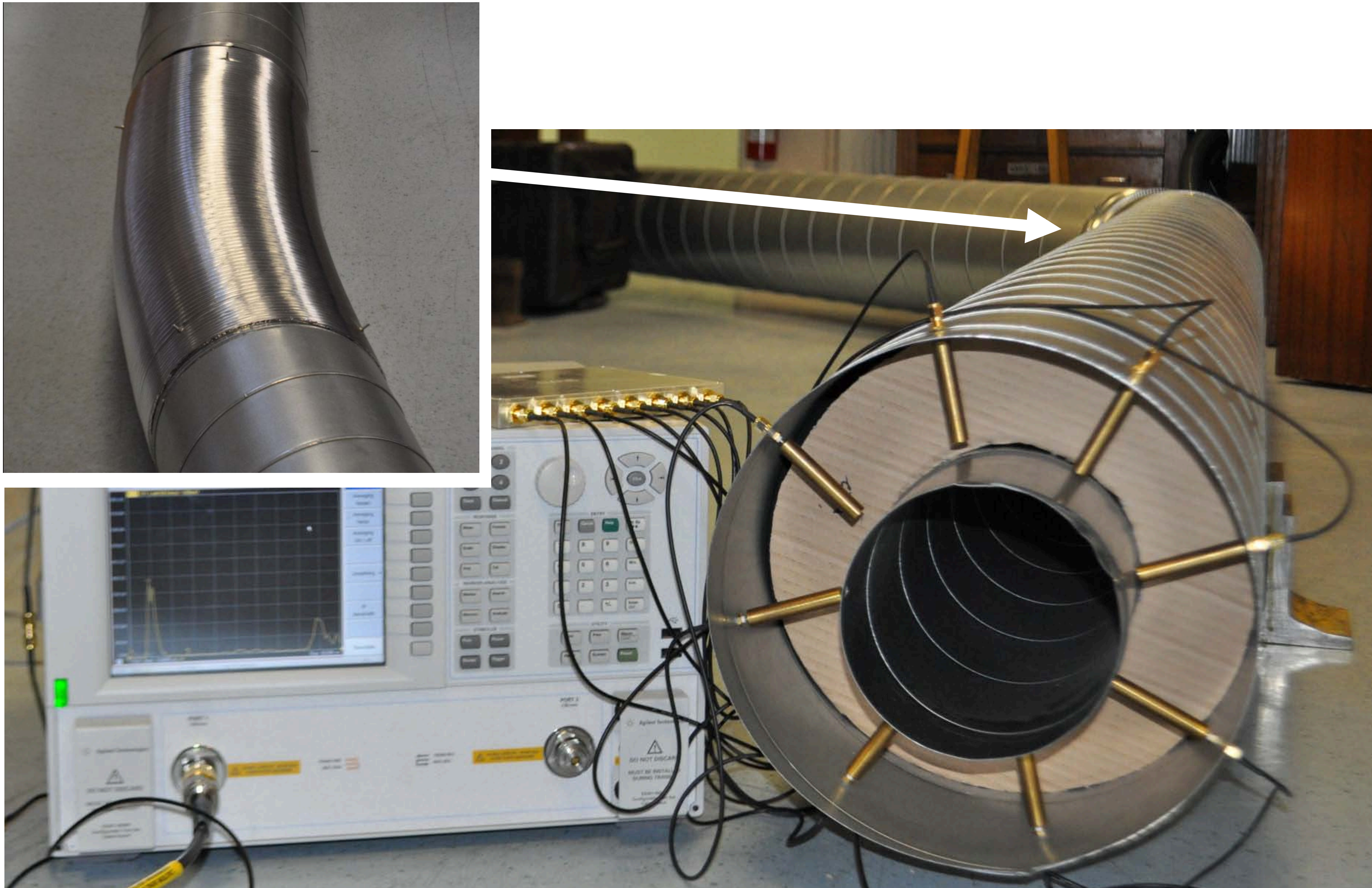
Effect of Bend Angle



Effect of Bend Radius



Experimental Setup



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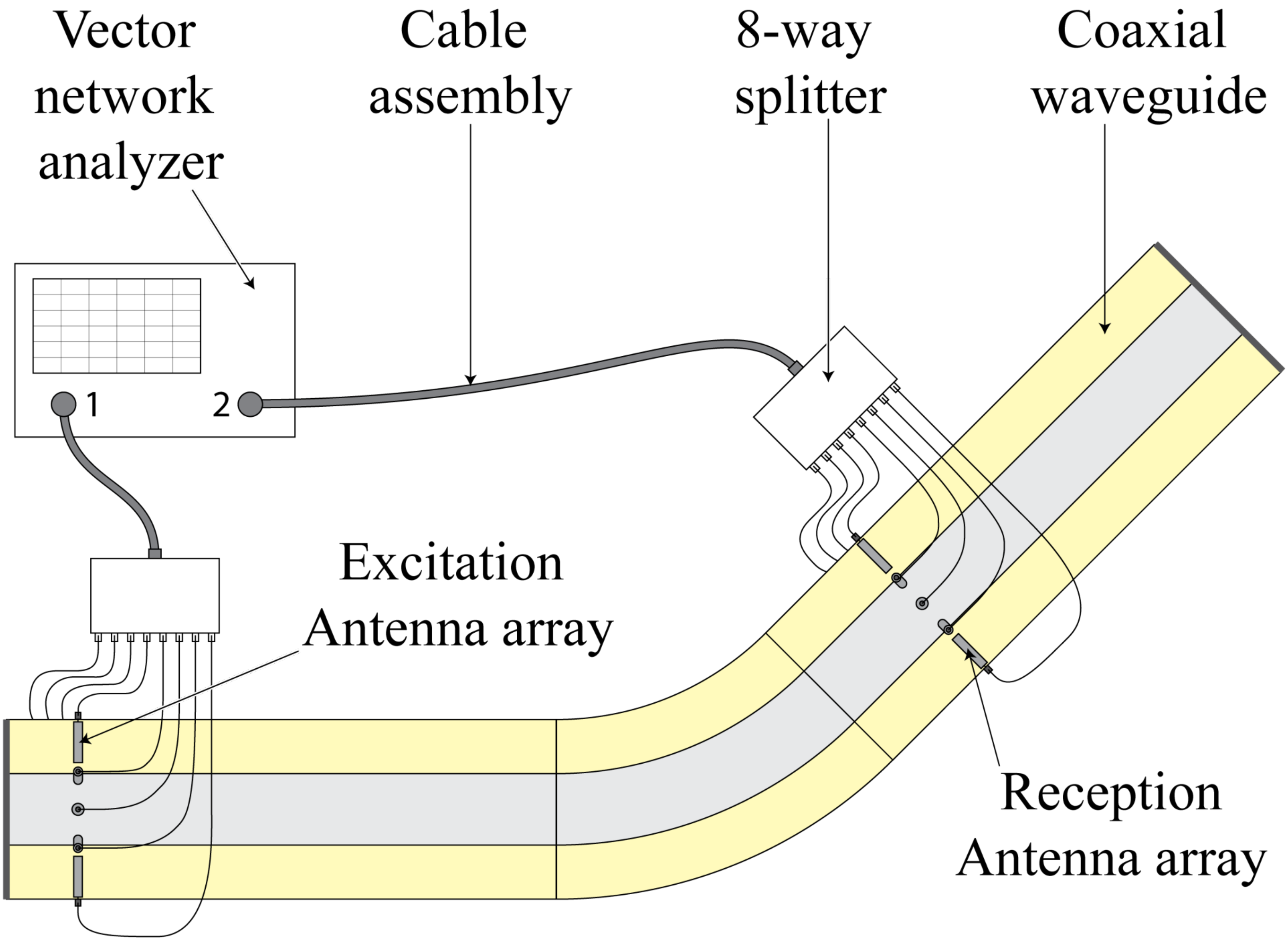
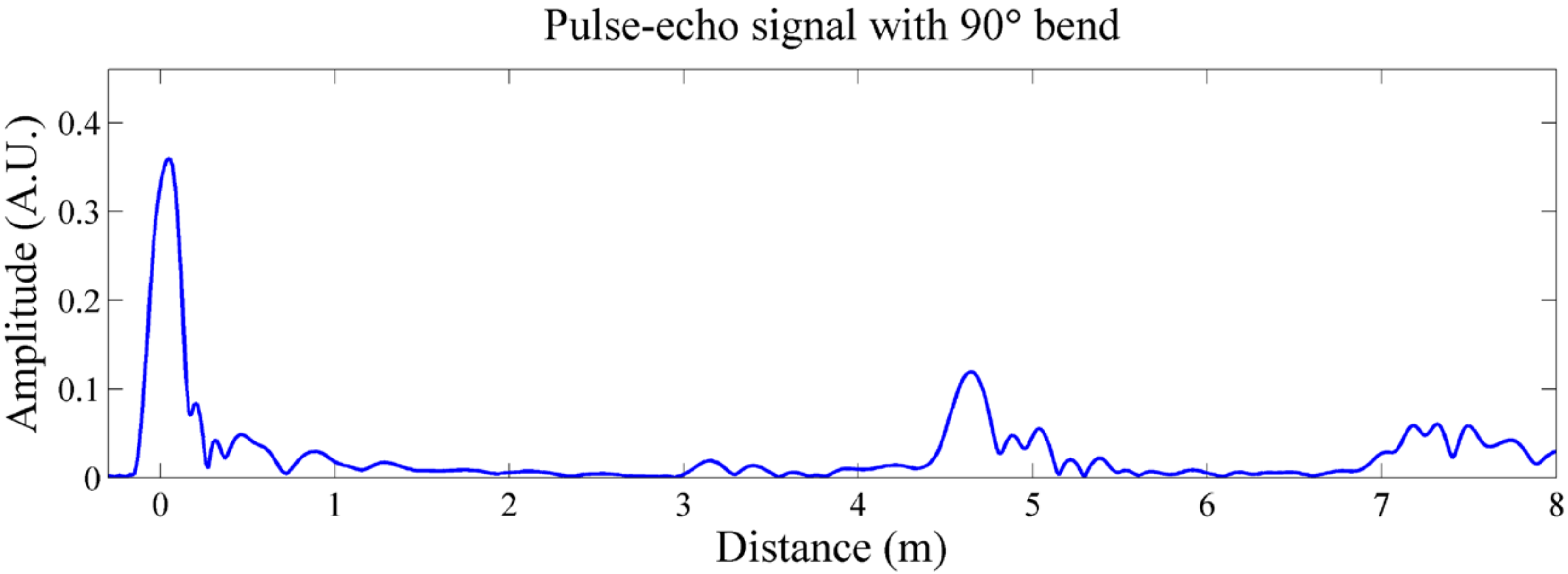
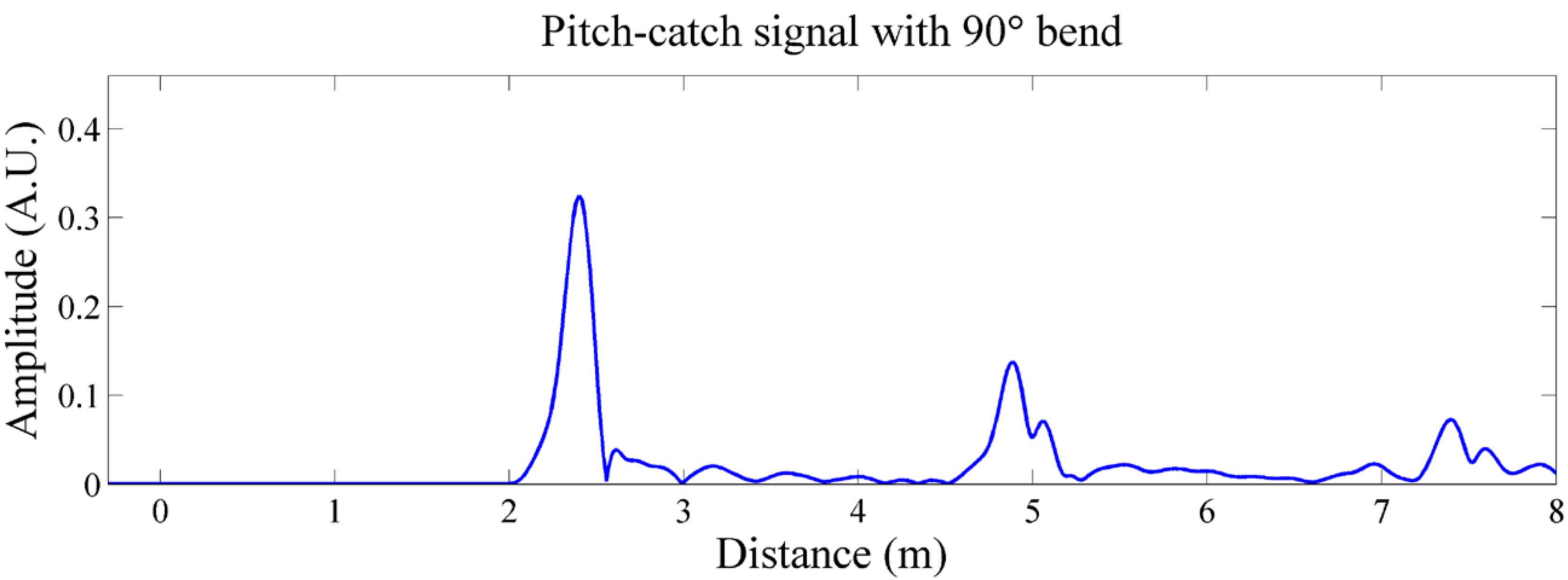
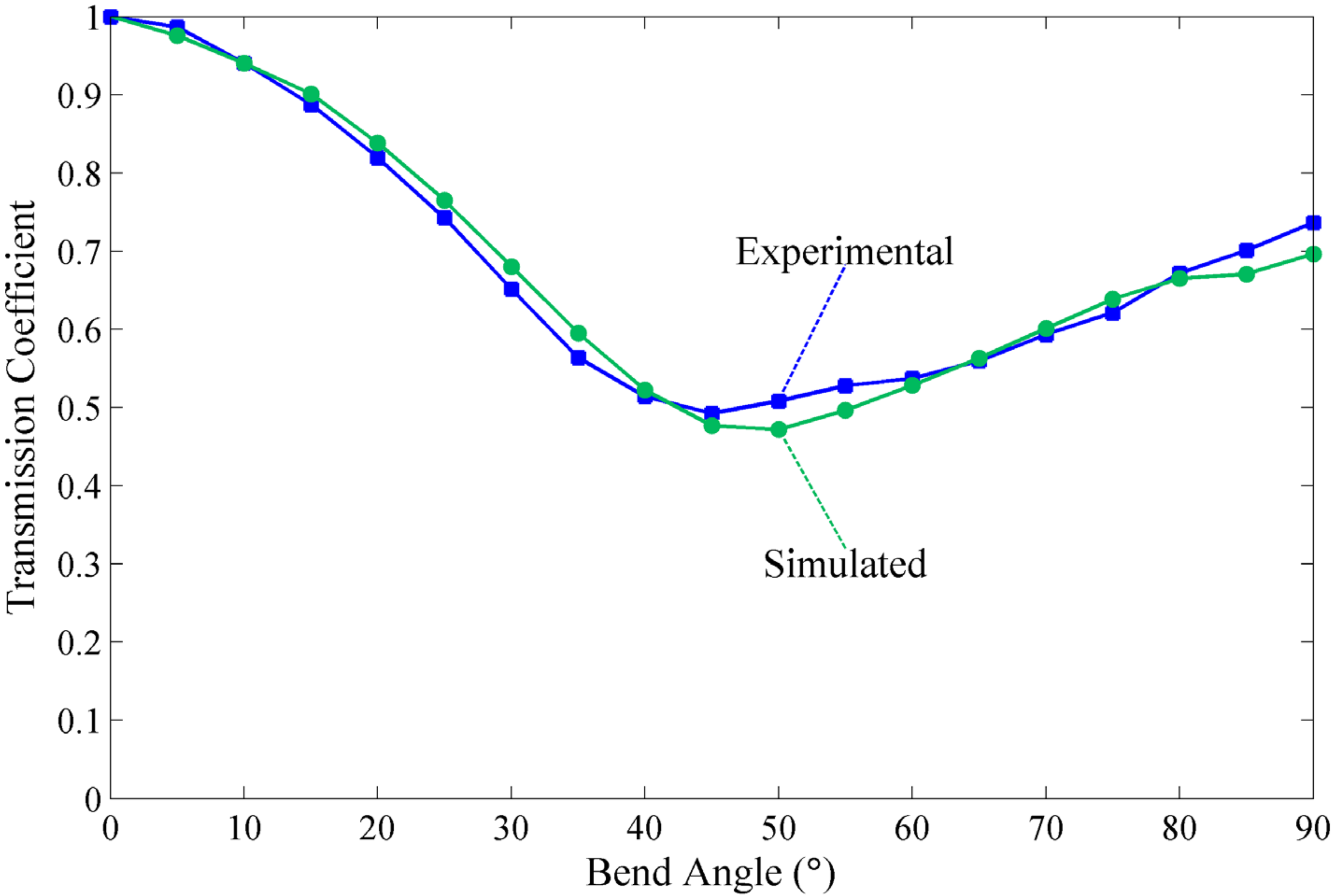


Experimental Signals





Experimental Validation



Conclusions

- Pure mode excitation with a 40dB SNR
- Highly sensitive to water volumes down to 5% cross-sectional area
- Effect of insulation is minimal
- Possible to inspect beyond a typical industrial bend

Acknowledgements

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BP

Dispersion Curves for Modes in Bends