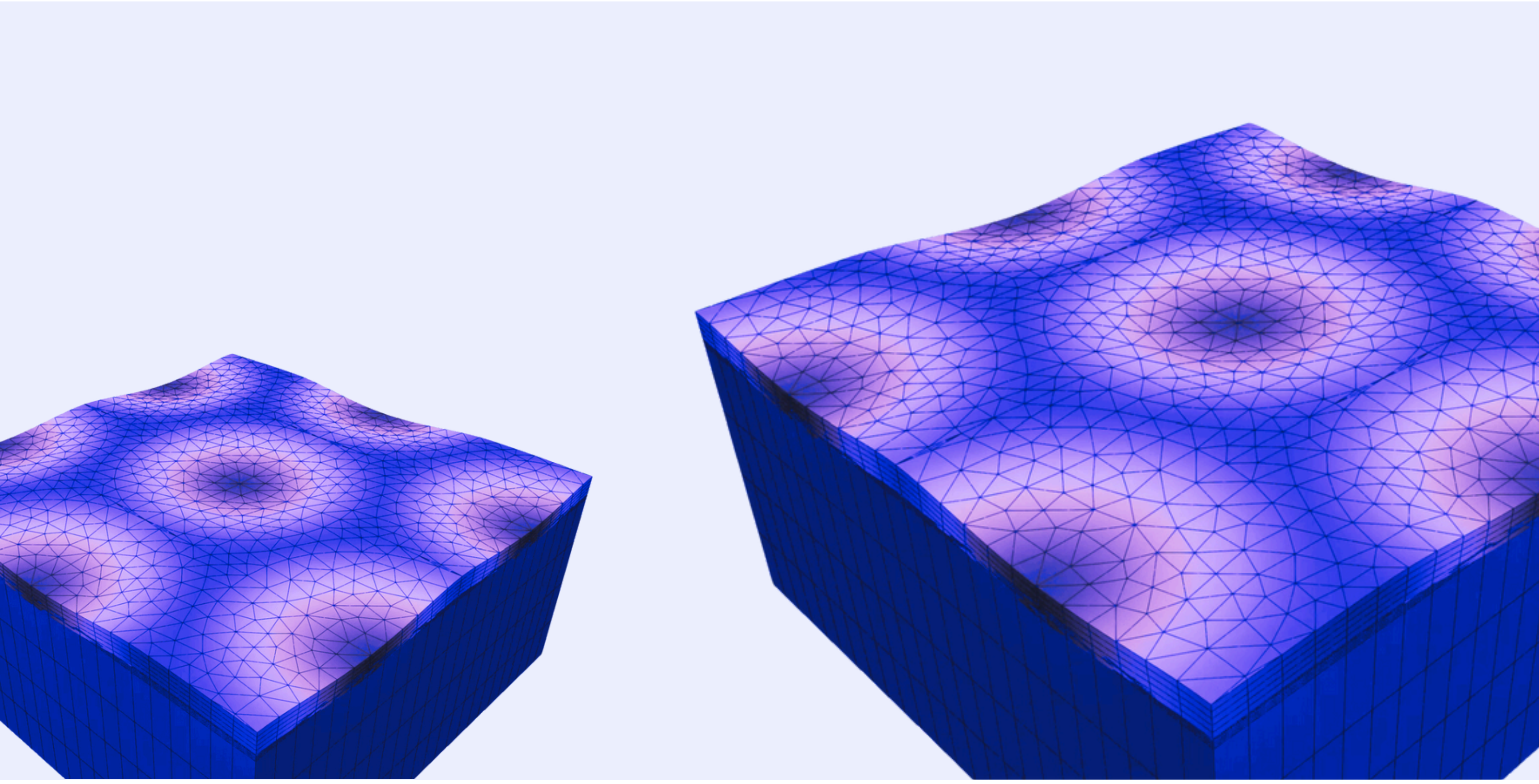
QUANSCIENT



Quanscient Webinar 17th Dec 2024 | Executive summary

Analyze your MUT design with cloud-based multiphysics simulation

Explore a wider design space and optimize the performance of your CMUT and PMUT devices with Quanscient Allsolve

Contents

Overview

This document summarizes the "Analyze your MUT design with Quanscient Allsolve" webinar, which explored the challenges of simulating complex MUT arrays and demonstrated how Allsolve leverages cloud computing and advanced numerical techniques to provide efficient and accurate solutions.

The summary includes case examples showcasing Allsolve's capabilities in simulating both PMUT and CMUT devices, along with key takeaways and answers to questions received during the live event.

About the technical speaker

Dr. Andrew Tweedie

UK Director, Co-founder

Dr. Andrew Tweedie, our UK Director, was leading the technical discussion in this webinar. Dr. Tweedie has extensive experience in the ultrasound industry, where he led research and development activities, including the development of new modeling and manufacturing processes for ultrasonic devices.

Introduction to Quanscient Allsolve
A cloud-based multiphysics simulation software

Through cloud computing and the advanced numerical techniques such as the Domain Decomposition Method (DDM), Quanscient Allsolve enables

Speed: Reducing runtime from weeks to hours, and days to minutes

Flexibility: Python scripting interface enabling customization, unlimited number of users with every plan with the hardware and all features included, and a usage-based pricing structure

Scalability: Thousands of simulations in parallel with zero added computational time enabling optimization studies, parameter sweeps, and manufacture-aware design

Automation: Programmatic control of simulations, proprietary design workflows, removing lengthy manual setups and repetitive tasks

Overall, Quanscient Allsolve enables increased simulation throughput and more reliable designs through the ability to run more simulations faster with more accurate results.

Trusted in both industry and academia

UK Atomic Energy Authority · Infineon · Massachusetts Institute of Technology · Proxima Fusion · imec · Paul Scherrer Institut

Challenges in MUT design with traditional tools

Designing and simulating micromachined ultrasonic transducers (MUTs) presents several challenges for traditional simulation tools:

Complex geometry
MUTs have intricate structures with many small features and layers, making it difficult to create accurate simulation models.

Transient analysis
MUTs typically operate in a broadband frequency range, necessitating transient analysis, which is more computationally intensive than steady-state analysis.

Large arrays
MUT arrays often comprise thousands of elements, leading to large problem sizes that can exceed the capacity of traditional simulation software.

High Degrees of Freedom (DoF)
Accurately capturing the complex geometries and multiphysics interactions in MUTs can result in models with millions of degrees of freedom, pushing the limits of traditional simulation tools.

Multiphysics nature
Simulating MUTs requires considering multiple physical phenomena, such as structural mechanics, acoustics, and piezoelectricity, which can be computationally demanding.

CMUT complexities
Capacitive micromachined ultrasonic transducers (CMUTs) introduce additional challenges due to their non-linear behavior, requiring specialized simulation techniques.

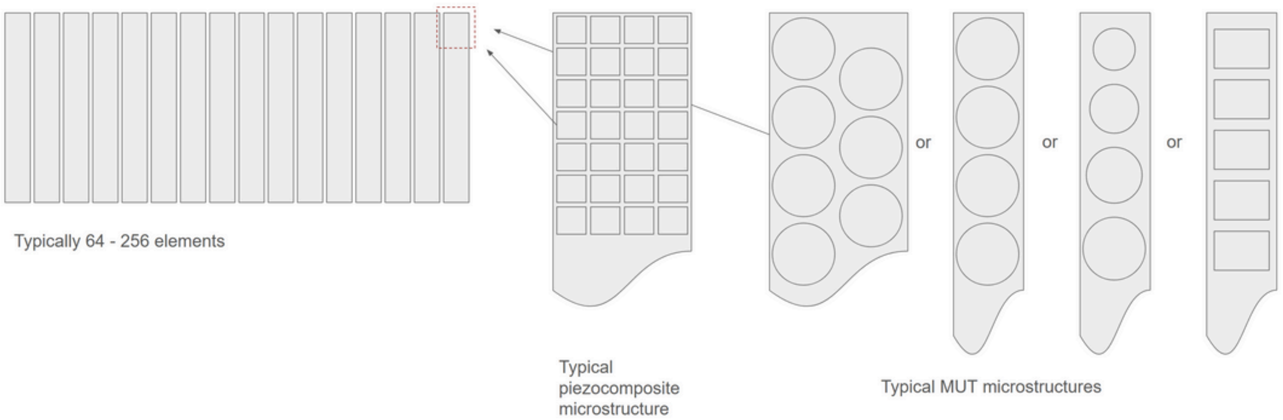
These challenges highlight the limitations of traditional tools in effectively simulating MUTs. Traditional software often requires simplifications, compromises on accuracy, or long runtimes, hindering the design and optimization of high-performance MUT devices.

Array structures and simulation approaches

Traditional simulation tools struggle to capture the complexity and scale of MUT arrays

MUT arrays used in diagnostic imaging, such as linear phased arrays, typically consist of 64 to 256 elements. These arrays can be constructed using various technologies, including piezocomposites and MUT structures (CMUTs or PMUTs).

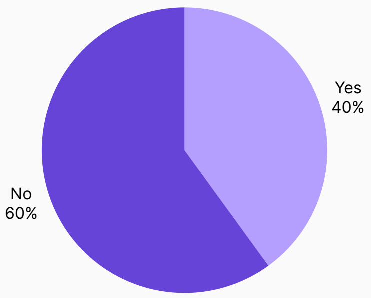
Simulating these large arrays presents challenges due to their complexity and the number of elements involved. Traditional simulation approaches often start with a simplified "unit cell" representing a small section of the array. This provides basic insights into the design and behavior of individual elements.



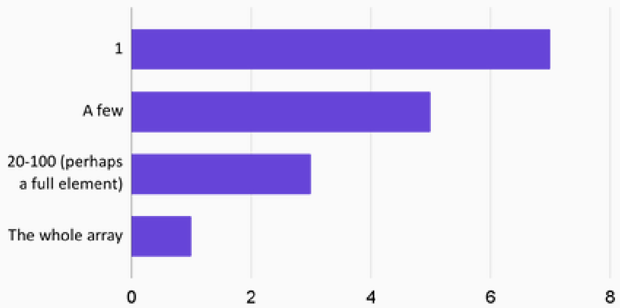
Webinar poll: MUT simulation practices

A live poll revealed that most participants were not currently utilizing simulation, and those who did typically simulated only a few cells.

Do you currently use simulation for designing MUTs? (n=25)



If yes, how many cells do you typically simulate? (n=17)



Array structures and simulation approaches

Quanscient Allsolve enables efficient simulation of large 3D sections of MUT arrays

However, to accurately capture the performance of the entire array, more comprehensive simulations are needed. Different cross-section approaches (elevation and azimuthal) can be used to analyze specific aspects of the array, such as beam patterns and crosstalk.

Ideally, large 3D sections of the array should be simulated to gain a complete understanding of the array's behavior and imaging performance. Quanscient Allsolve enables this by providing the computational power and scalability needed to handle these complex simulations.

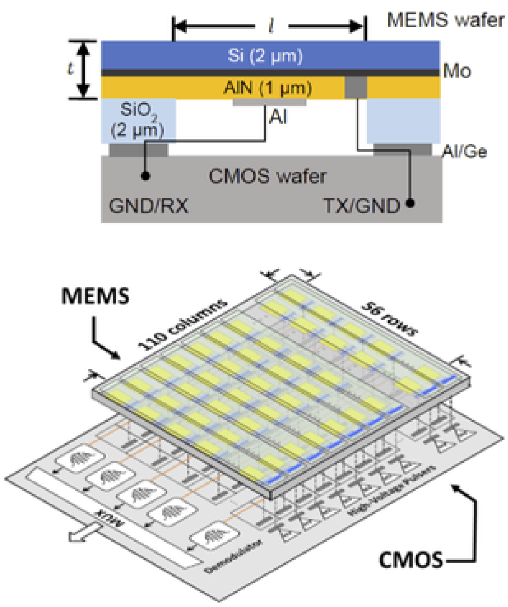
- Unit cell
  - Good for evaluating fundamental MUT design
  - Impedance, surface displacement
- Elevation cross section
  - Typically ¼ or ½ element depending on symmetry
  - Elevation beam pattern and array impedance
- Azimuthal cross section
  - ½ or 1 cell in vertical, depending on symmetry
  - Azimuthal beam pattern, crosstalk, element impedance
- Full 3D section
  - Typically ¼ or ½ symmetry
  - Excellent prediction of array imaging performance

Case examples and results
Simulating PMUT arrays with Quanscient Allsolve

This section presents a series of simulations performed on PMUT arrays using Quanscient Allsolve. We begin with a basic unit cell model and progressively increase the complexity, culminating in a full 3D simulation of a large array section. Each simulation explores different aspects of PMUT behavior, including transient response, harmonic characteristics, crosstalk, and far-field beam patterns. These examples demonstrate how Allsolve can be used to analyze and understand the performance of complex PMUT designs.

PMUT reference design: 110x56 cell array

Our analysis utilizes a 110x56 element PMUT array design from the BSAC group at UC Berkeley. While originally intended for fingerprint sensing, we adapt this array for diagnostic imaging, simulating its performance as a linear array operating into a water load.

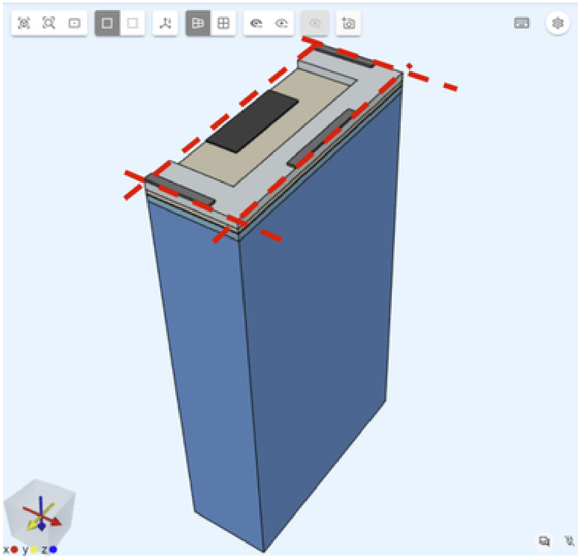


Example PMUT array for fingerprint imaging showing PMUT stack (top) and array layout (bottom)

Case examples and results
Unit cell analysis

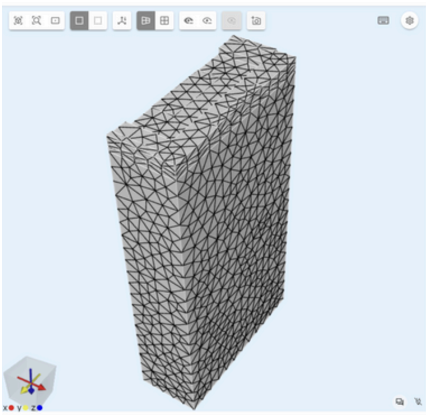
Unit cell simulation: Fundamental MUT analysis

The analysis begins with a unit cell, the smallest repeating element of the array. This simplified model, with symmetry applied along the boundaries, allows for efficient extraction of fundamental performance characteristics. Despite its simplicity, the unit cell provides valuable insights into the behavior of individual PMUT elements.

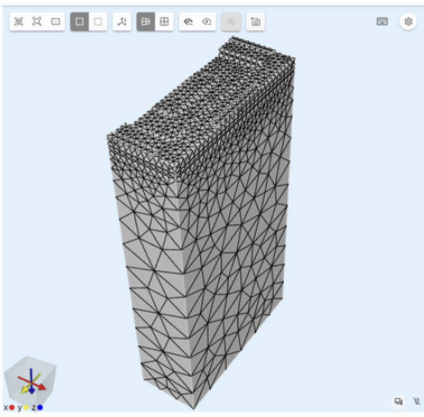


Unit cell mesh: Flexibility over meshing & element order

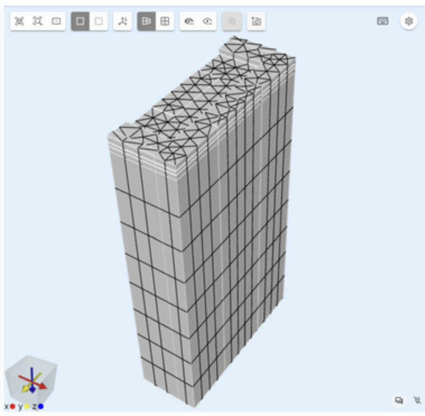
Quanscient Allsolve offers a high degree of flexibility in meshing. Users can employ structured, unstructured, or hybrid meshes and refine specific areas as needed. A mesh convergence study on this unit cell model is recommended to determine the optimal mesh density for accurate and efficient simulations.



5 um order 2 mesh



10 um order 2 mesh, refined to 2 um on MUT structure



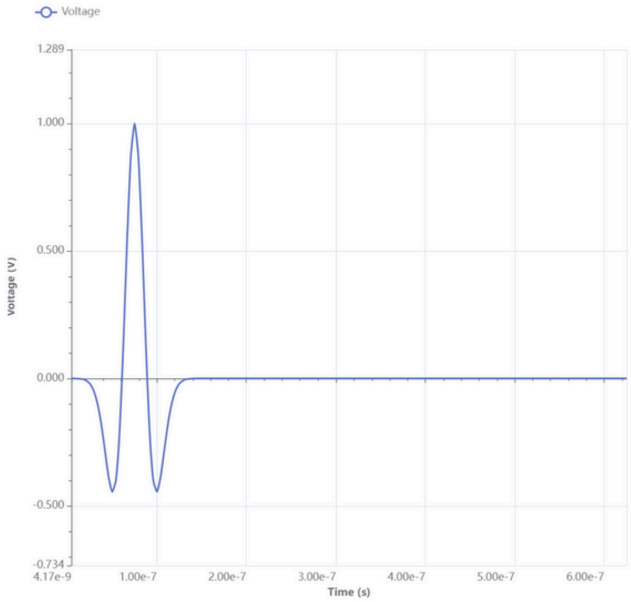
5 um order 2 mesh, extruded in z axis

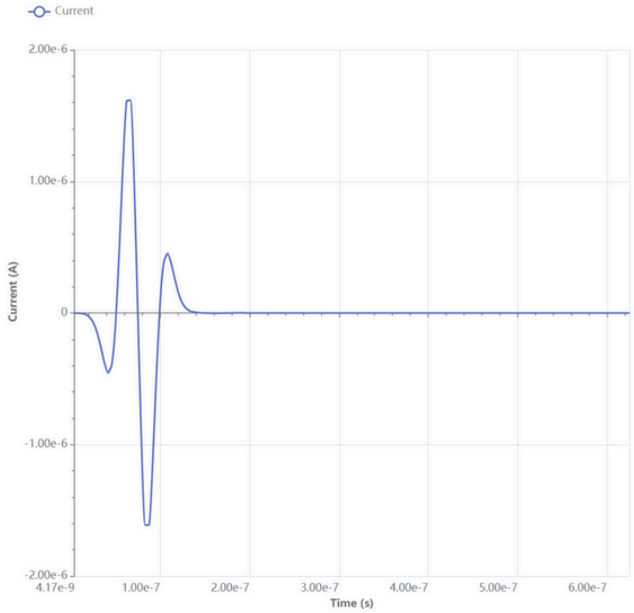
Case examples and results
Unit cell transient simulation results

Voltage and current

Transient simulations on the unit cell, driven by a short voltage wavelet, reveal key performance aspects. The simulation results include the electrical current flowing through the PMUT and visualizations of the membrane displacement and pressure wave propagation in the water load.

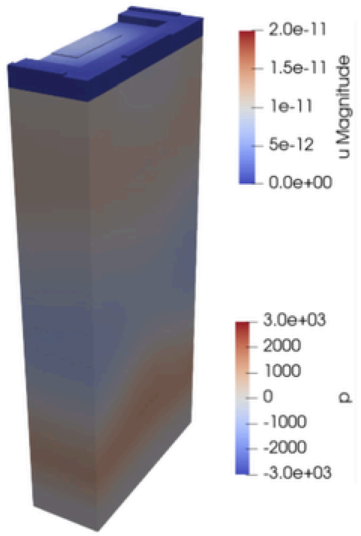
35k	1	0.8	0.02
DoFs	Core	Minutes	Core-hours





Case examples and results
Unit cell transient simulation results

Displacement & acoustic field



35k
DoFs

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Minutes

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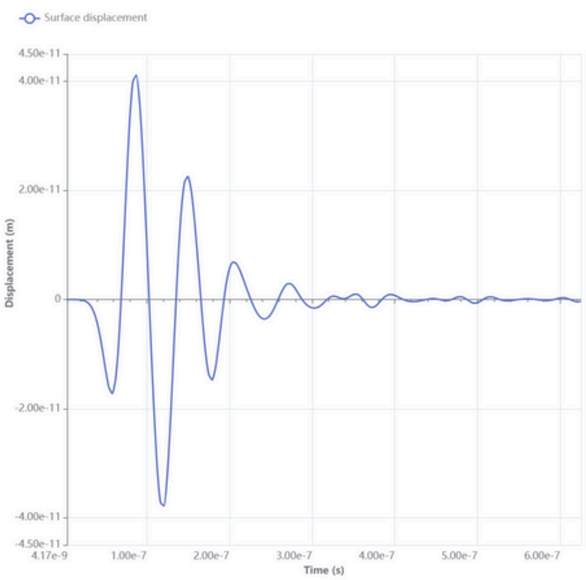
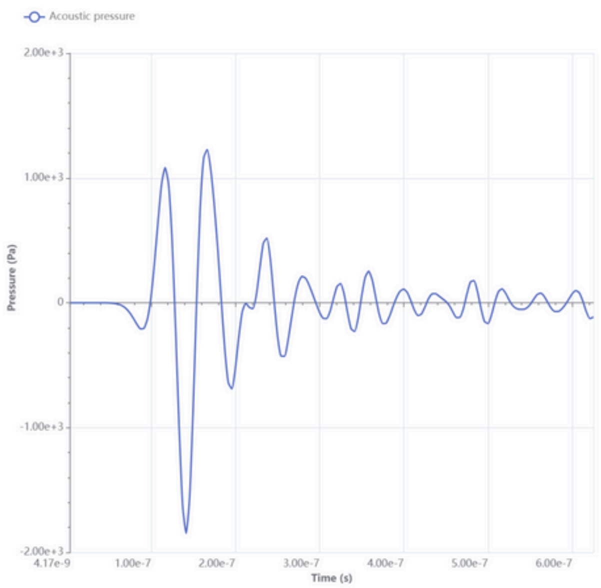
Core-hours

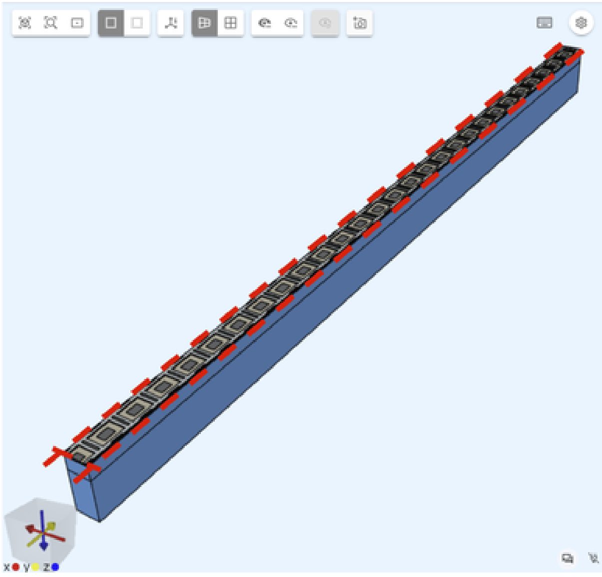




Case examples and results
Cross-sectional analysis

Elevation cross section: Elevation beam pattern

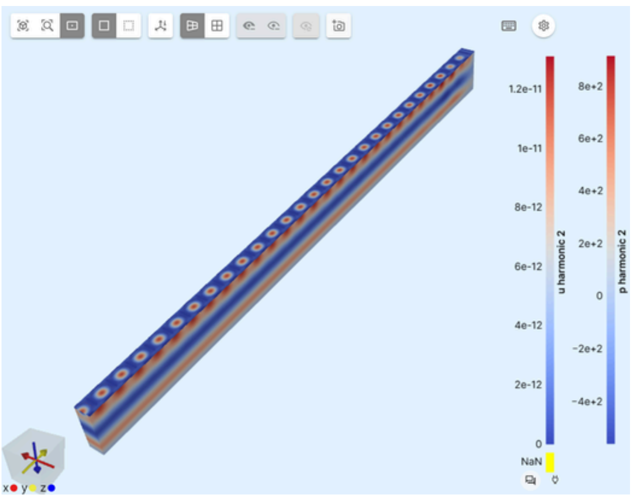
To analyze the elevation beam pattern, a cross-section of the array is simulated. This model, comprising 55 elements with symmetry applied, effectively represents an infinite array. By driving all elements in phase, the resulting acoustic field and beam pattern in the elevation direction can be accurately captured.

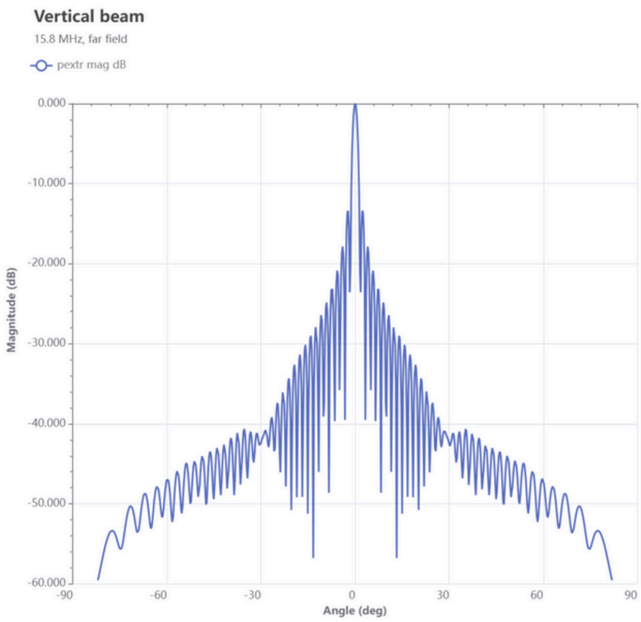


Elevation harmonic simulation results: Displacement, pressure and far field beam pattern

Harmonic analysis of the elevation cross-section at 15.8 MHz provides insights into the steady-state behavior of the array. The simulation results illustrate the surface displacement of the PMUT elements, the acoustic pressure field in the water, and the resulting far-field beam pattern. The narrow beam pattern observed is consistent with the broad dimensions of the array relative to the operating wavelength.

2.3M DoFs | **16** Cores | **0.8** Minutes | **0.2** Core-hours

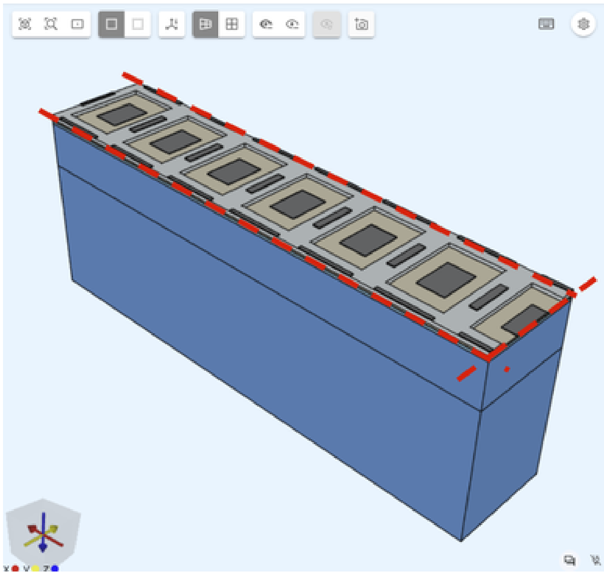




Case examples and results
Cross-sectional analysis

Azimuthal cross section: Simulating crosstalk

An azimuthal cross-section is used to investigate crosstalk between elements. This model includes a central driven element and six passive adjacent elements, with symmetry applied to represent an infinite array. Analyzing this model helps quantify the level of crosstalk and its potential impact on array performance.



Azimuthal harmonic simulation results: Crosstalk and far field beam pattern

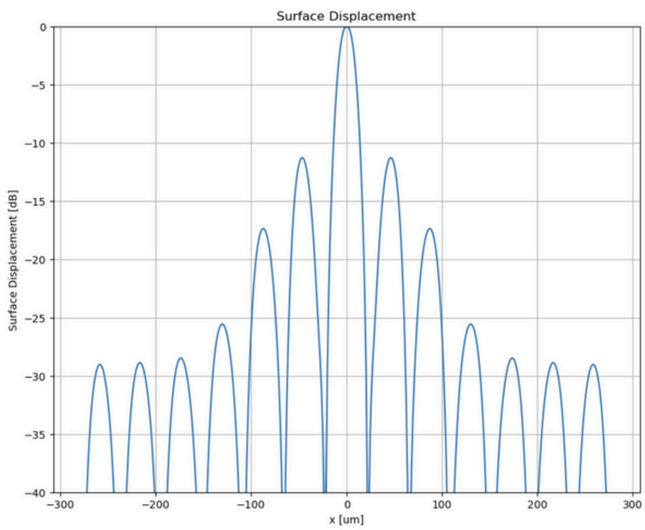
Harmonic analysis of the azimuthal cross-section provides a quantitative measure of crosstalk. The simulation results show the crosstalk levels across the 13 elements and the azimuthal far-field beam pattern. While a relatively wide beam is achieved, some ripple is observed, suggesting potential crosstalk effects that might need mitigation for high-fidelity imaging and beam steering applications.

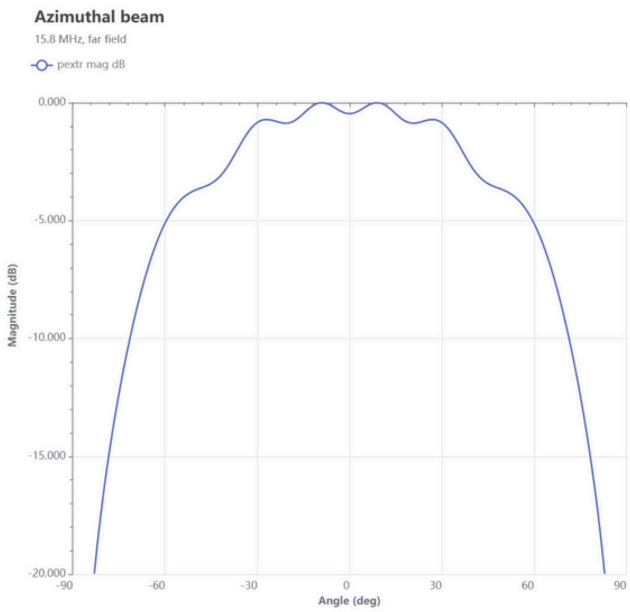
557k DoFs

1 Cores

3.7 Minutes

0.06 Core-hours

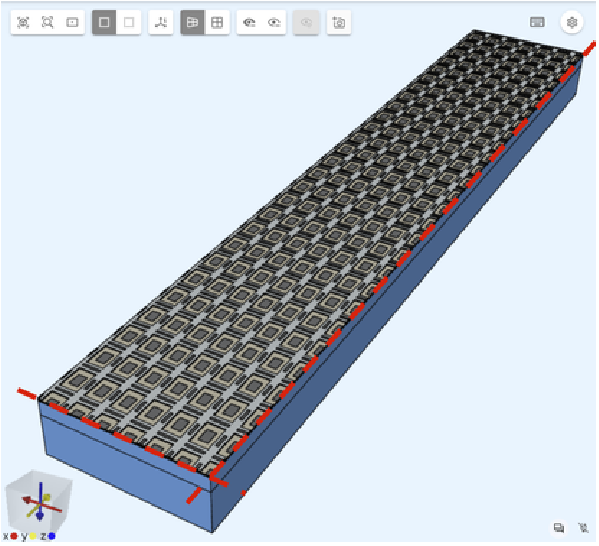




Case examples and results
Full 3D array simulation

Full 3D section: Geometry

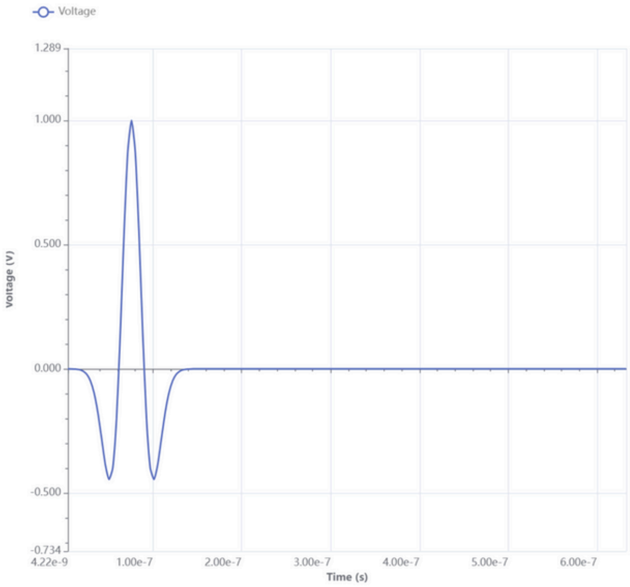
To achieve the most comprehensive understanding of the array's behavior, a full 3D section of the array is simulated. This model encompasses 13 elements in the azimuthal direction and 55 elements in the elevation direction (effectively 715 cells with symmetry). This large-scale simulation captures the complex interactions within the array and provides detailed insights into its performance.

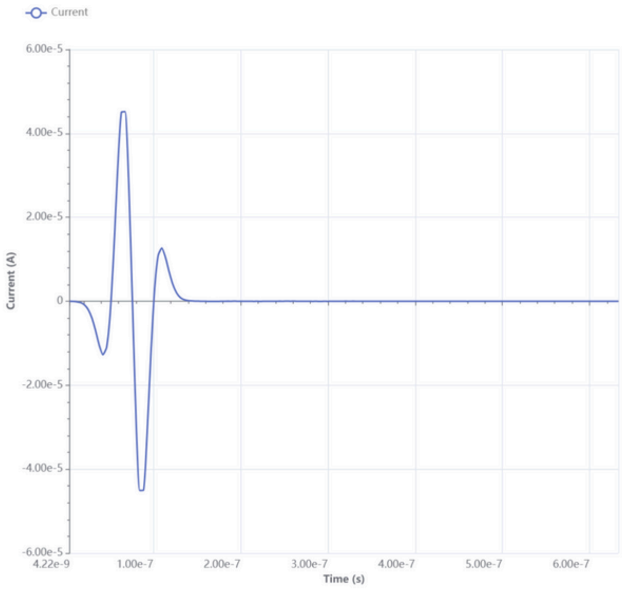


5.3M	32	14.5	7.7
DoFs	Core	Minutes	Core-hours

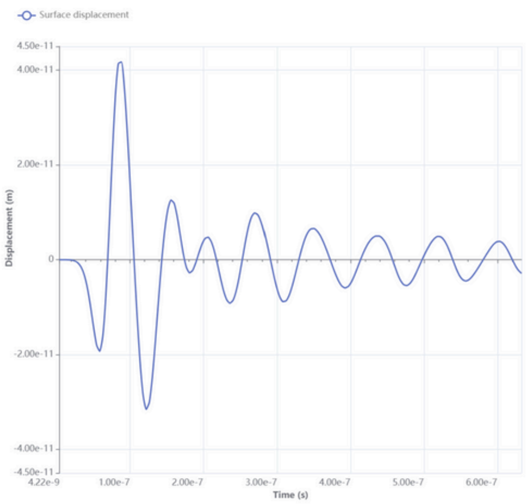
Full 3D transient simulation results: Drive voltage and current

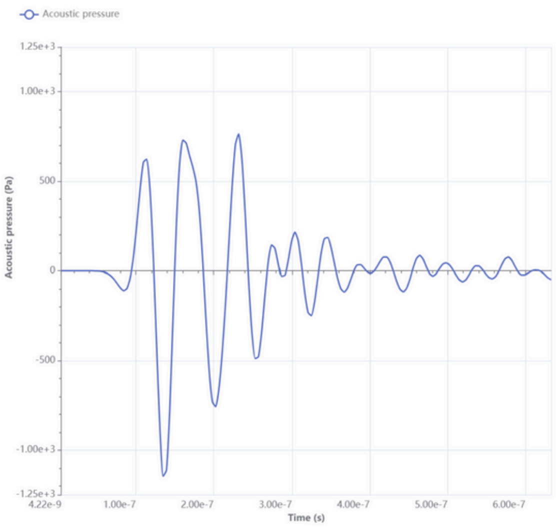
The transient simulation results also show the surface displacement of the driven elements and the acoustic pressure propagating into the water load. These visualizations illustrate the complex wave patterns and interactions within the 3D array structure.





Case examples and results
Full 3D array simulation





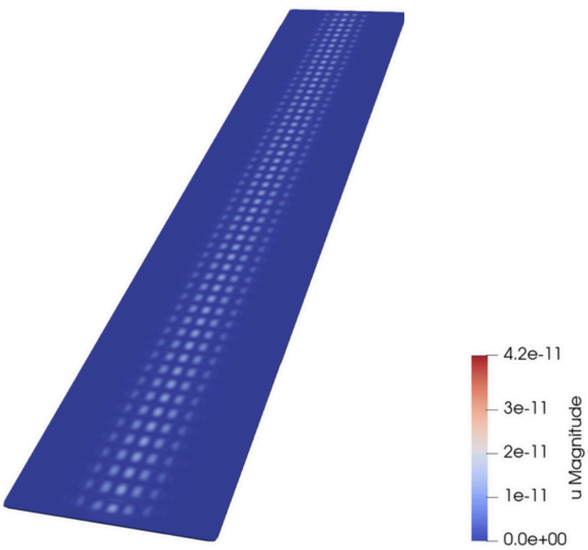
Full 3D transient simulation results: Surface displacement and acoustic pressure

5.3M DoFs | **32** Core | **14.5** Minutes | **7.7** Core-hours

The transient simulation results also show the surface displacement of the driven elements and the acoustic pressure propagating into the water load. These visualizations illustrate the complex wave patterns and interactions within the 3D array structure.

Full 3D transient simulation results: Crosstalk under pulsed excitation

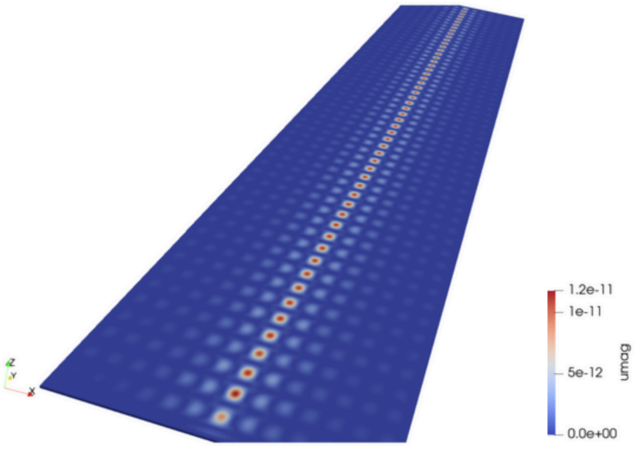
The full 3D transient simulation allows for a detailed analysis of crosstalk under realistic operating conditions. The simulation results visualize the propagation of acoustic waves and how they interact with neighboring elements, providing valuable insights into the dynamic crosstalk behavior.



Case examples and results
Full 3D array simulation

Full 3D harmonic simulation results: Crosstalk under CW excitation

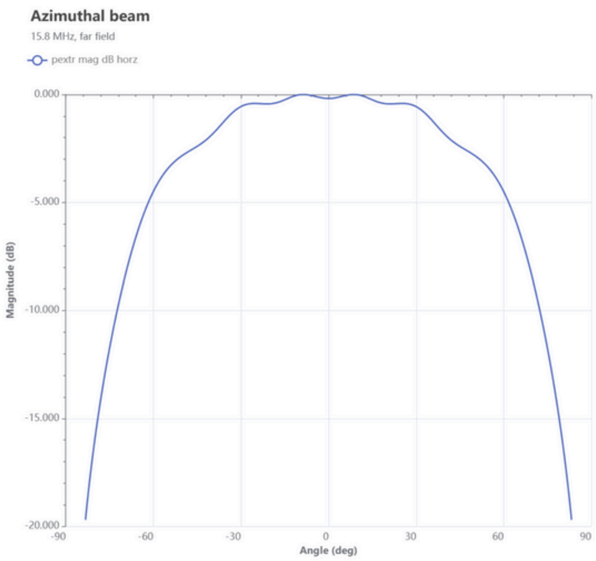
Harmonic analysis of the full 3D model provides a frequency-domain perspective on crosstalk. The simulation results quantify the crosstalk levels between elements at the operating frequency (15.8 MHz) and show how energy is distributed within the array.

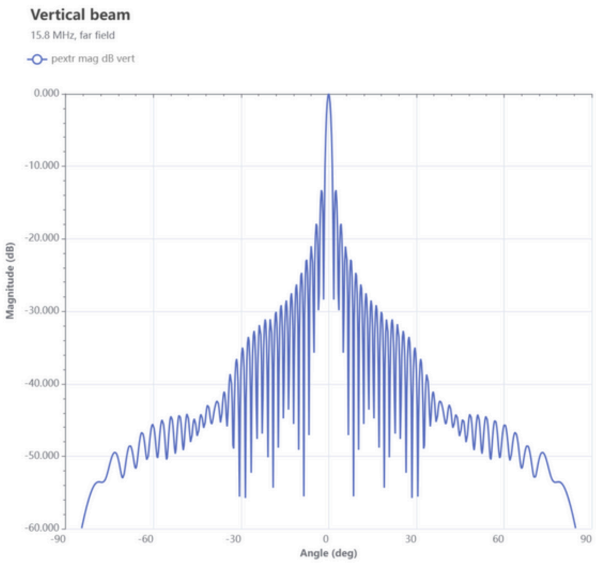


Full 3D transient simulation results: Far field beam patterns

Finally, the far-field beam patterns generated from the full 3D harmonic simulation provide a comprehensive picture of the array's acoustic performance. These patterns, encompassing both elevation and azimuthal directions, accurately reflect the combined effects of all elements and their interactions.

8.9M	32	6.7	3.6
DoFs	Core	Minutes	Core-hours





Key takeaways
Simulating large-scale PMUT arrays with Quanscient Allsolve

1 Quanscient Allsolve **efficiently simulates large, complex PMUT arrays** with hundreds of elements, capturing detailed 3D behavior

2 The software **accurately models the coupled physics involved**, including structural mechanics, piezoelectricity, and acoustic

3 Allsolve provides both **time-domain and frequency-domain** insights into array performance, including crosstalk and beam patterns

4 It enables **rapid simulation of large models**, accelerating the design and optimization of high-performance PMUT devices

In your opinion, what would be the biggest benefit from being able to accurately simulate your MUT arrays?

Case examples and results
CMUT simulation examples with Quanscient Allsolve

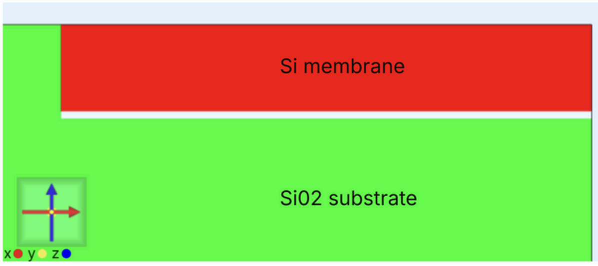
This section shifts focus to CMUTs, exploring the unique challenges they present and how Quanscient Allsolve addresses them. While sharing similarities with PMUTs, CMUTs involve different physical phenomena and require specialized simulation techniques. We'll examine a CMUT reference design, analyze its behavior through static and transient simulations, and finally demonstrate the power of Allsolve's multiharmonic solver in capturing the complexities of CMUT operation.

CMUT overview

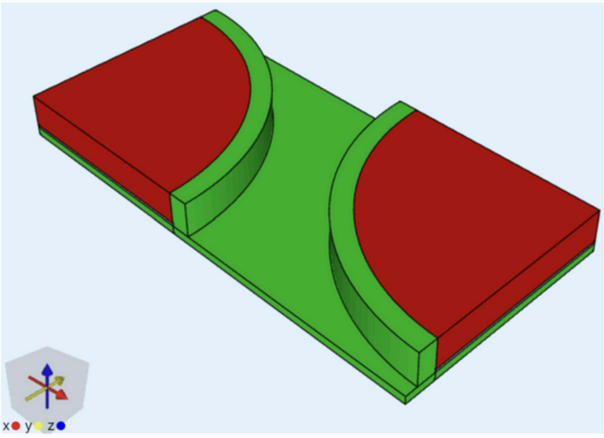
CMUTs, like PMUTs, are MEMS-based ultrasonic transducers. However, they operate based on electrostatic principles rather than piezoelectricity. This introduces complexities related to biasing, non-linear behavior, and potential contact mechanics when operating in collapse mode. These factors necessitate specialized simulation approaches to accurately capture CMUT performance.

CMUT reference design: General overview of example

The reference design used for our CMUT simulations is a simple, single-membrane structure from research conducted at DTU Nanotech in Denmark. This design, previously used to study cooling curves and transient behavior, allows us to demonstrate Allsolve's capabilities in handling the unique challenges of CMUT simulation.



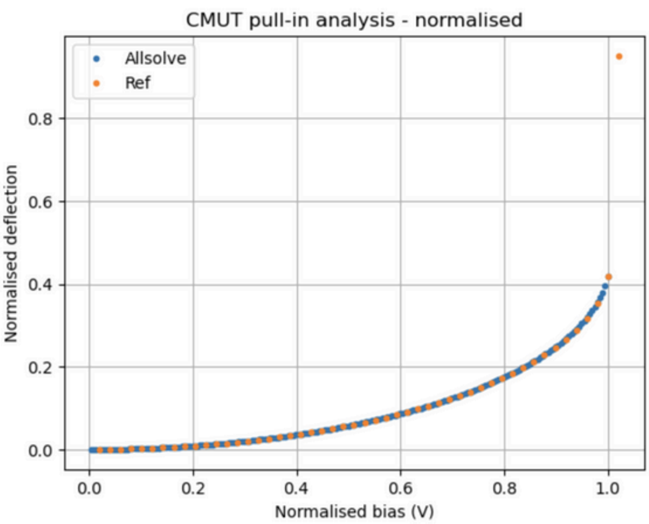
Simple CMUT structure showing cross section (top) and cutaway of unit cell pattern (bottom)



Case examples and results
CMUT static simulation results

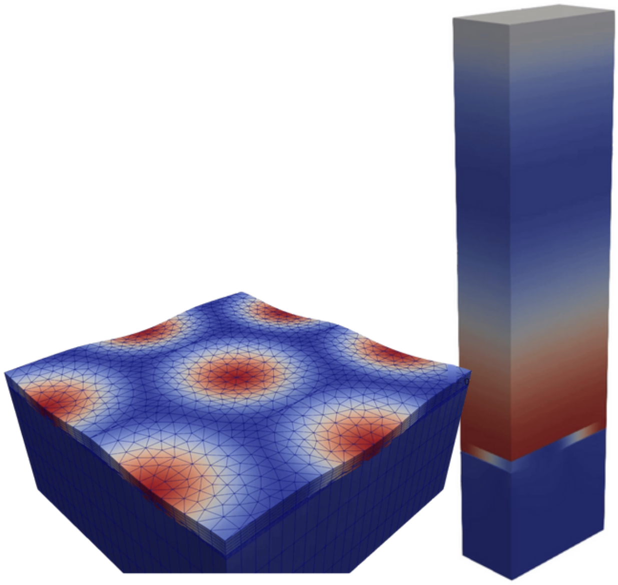
DC bias vs displacement

Before dynamic analysis, it's crucial to understand the static behavior of the CMUT under DC bias. Allsolve efficiently performs a sweep of 200 static simulations to generate a pull-in curve, plotting normalized bias voltage against normalized deflection. This curve illustrates the relationship between applied voltage and membrane displacement, a critical factor in CMUT operation.



47k	200	200	0.2	0.58
DoFs	Core	Sims	Minutes	Core-hours

Case examples and results
CMUT transient simulation results



Displacement & acoustic field

Visualization of the model

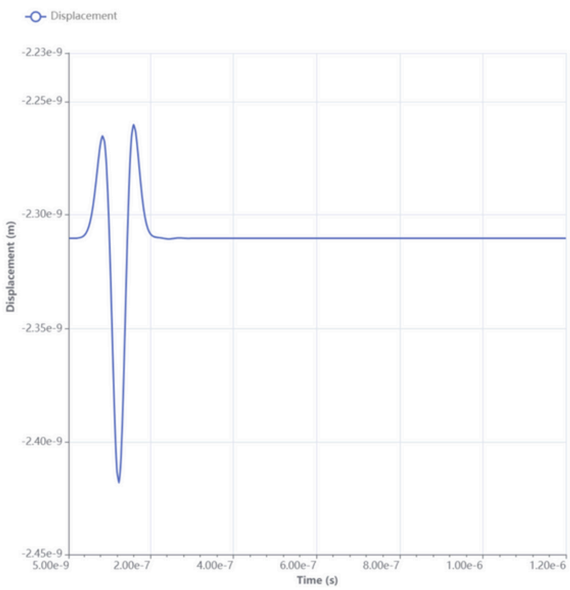
Transient simulations capture the CMUT's dynamic response to a short voltage pulse. Visualizations of the simulation results show the membrane displacement and the resulting acoustic pressure wave propagating into the surrounding medium. These dynamic visualizations provide insights into the CMUT's operational behavior.

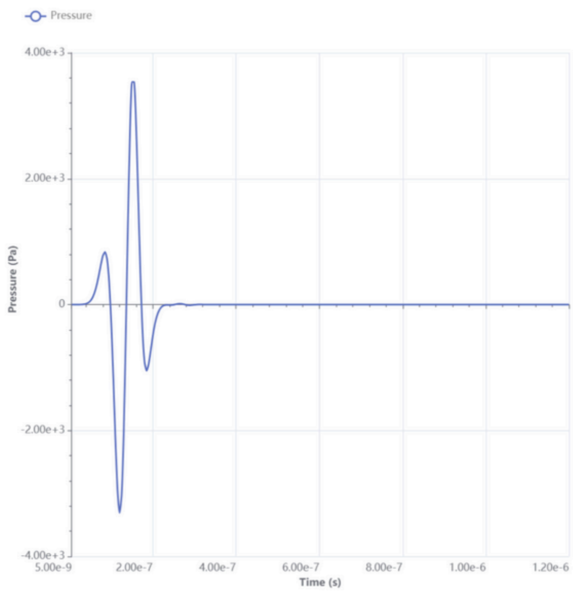
47k	1	35	0.58
DoFs	Core	Minutes	Core-hours

Result graphs

In addition to visualizations, quantitative results from the transient simulation are presented. These include graphs of the membrane displacement and acoustic pressure at specific points in the model.

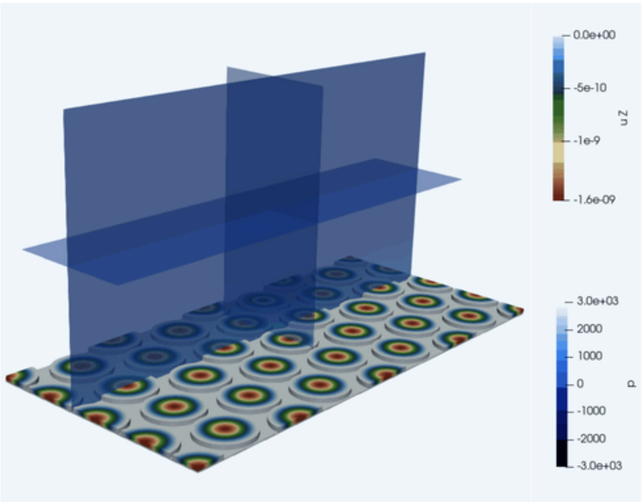
These graphs provide detailed information about the CMUT's wideband frequency response and its ability to generate acoustic waves.



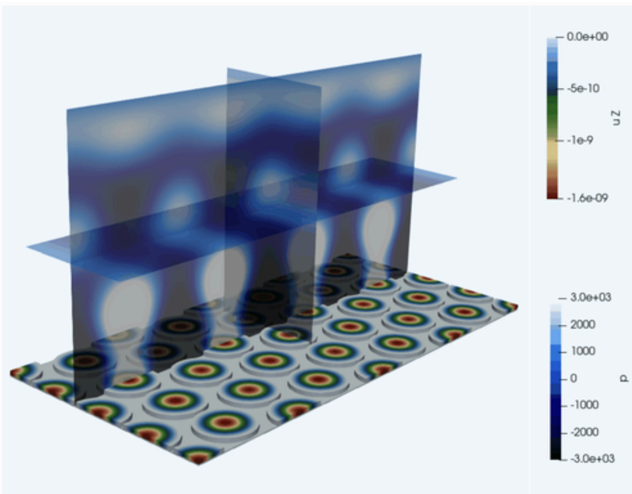


Case examples and results

CMUT multiharmonic simulation results



In phase excitation



Out of phase excitation

DC bias plus multiple harmonics in a single simulation

Allsolve's unique multiharmonic solver enables efficient simulation of non-linear effects in CMUTs. This solver considers the DC bias and multiple harmonic components simultaneously, capturing the complex interactions that arise from non-linear behavior. This capability is particularly valuable for understanding CMUT performance under realistic operating conditions, including scenarios with multiple drive frequencies.

436k	20	10	3.33
DoFs	Core	Minutes	Core-hours

Key takeaways
Simulating CMUTs with Quanscient Allsolve

1. Quanscient Allsolve accurately simulates the complex behavior of CMUTs, including nonlinearities and biasing effects, crucial for their operation

2. The software enables efficient analysis of both static and dynamic responses of CMUTs, providing insights into their performance under various operating conditions

3. Allsolve's unique multiharmonic solver captures the intricate interactions of multiple frequencies and DC bias in CMUTs, essential for understanding their behavior in real-world applications

4. By enabling rapid and accurate simulation of CMUTs, Allsolve facilitates the design and optimization of these devices for diverse applications, including medical imaging and sensing

Highlights from the Q&A

Highlights from the Q&A section of the webinar.

Q: How does Quanscient Allsolve compare to OnScale?

A: Quanscient Allsolve and OnScale differ in their fundamental approaches to simulation. Allsolve utilizes a versatile multiphysics FEM approach, accommodating a wider range of applications and offering greater flexibility in meshing and solver choices. This allows users to tailor simulations to their specific needs. OnScale primarily uses an explicit transient approach with structured meshes, which can present limitations for detailed MUT simulations, particularly in terms of meshing complexity and computational cost.

Q: What programming language is used to define models in Allsolve?

A: Quanscient Allsolve utilizes Python as its scripting language for defining models. The software features an intuitive Python interface where model setup is automatically generated as users configure their model through the GUI. This generated Python code is well-commented and easily editable, providing users with greater flexibility and control over their model definitions.

Q: What is the pricing structure for Quanscient Allsolve?

A: Quanscient Allsolve offers flexible pricing based on your modeling needs. We'll work with you to determine the appropriate plan, considering factors like the number of parallel cores and core-hours required for your simulations. You only pay for the computing power you use, as your quota is consumed only during active simulations. Every plan includes all software features, the computational resources, an unlimited number of users, and access on any device. This approach ensures you have the resources you need with a cost-effective pricing structure.

Q: Do the simulation results from Allsolve align with experimental data from published research?

A: Quanscient Allsolve utilizes well-established numerical methods, ensuring results that are generally consistent with those from other validated simulation tools. While direct comparisons to specific experimental data may require careful attention to model parameters and experimental conditions, Allsolve's ability to handle complex geometries and multiphysics interactions without simplification can often lead to more accurate results, especially for CMUTs, where capturing intricate behaviors is crucial.

Conclusion

The capabilities of Quanscient Allsolve in simulating the complex behavior of both PMUT and CMUT arrays have been demonstrated in this webinar.

Through practical examples, it was shown how Allsolve can be used to efficiently and accurately analyze these devices, providing valuable data for design and optimization purposes.

Large-scale models can be rapidly analyzed due to Allsolve's cloud-based architecture and advanced numerical methods. This accelerates the development process for engineers working with high-performance MUTs for a variety of applications.

Key takeaways

- Quanscient Allsolve can handle the complexities of large PMUT and CMUT arrays, accurately capturing their 3D behavior and multiphysics interactions
- Allsolve provides a complete picture of array performance through both time-domain and frequency-domain analysis
- A dedicated solver addresses the nonlinearities and biasing effects inherent in CMUTs
- Allsolve enables rapid simulation of large models, facilitating efficient design iteration and optimization of MUT devices
- Quanscient Allsolve offers a user-friendly, cloud-based platform with scalable computational resources to accommodate a wide range of simulation needs

Next steps

If you are interested in exploring the capabilities of Quanscient Allsolve, we encourage you to schedule a consultation with our CRO, Mr. Nikola Strah.

Schedule a 30-minute introductory call now.

Book your session now!

During this meeting, you will:

- Learn how Quanscient Allsolve can address your specific simulation needs
- Learn how to integrate Quanscient Allsolve with your existing workflows
- Discover the platform's problem-solving capabilities and explore new possibilities for your use cases

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