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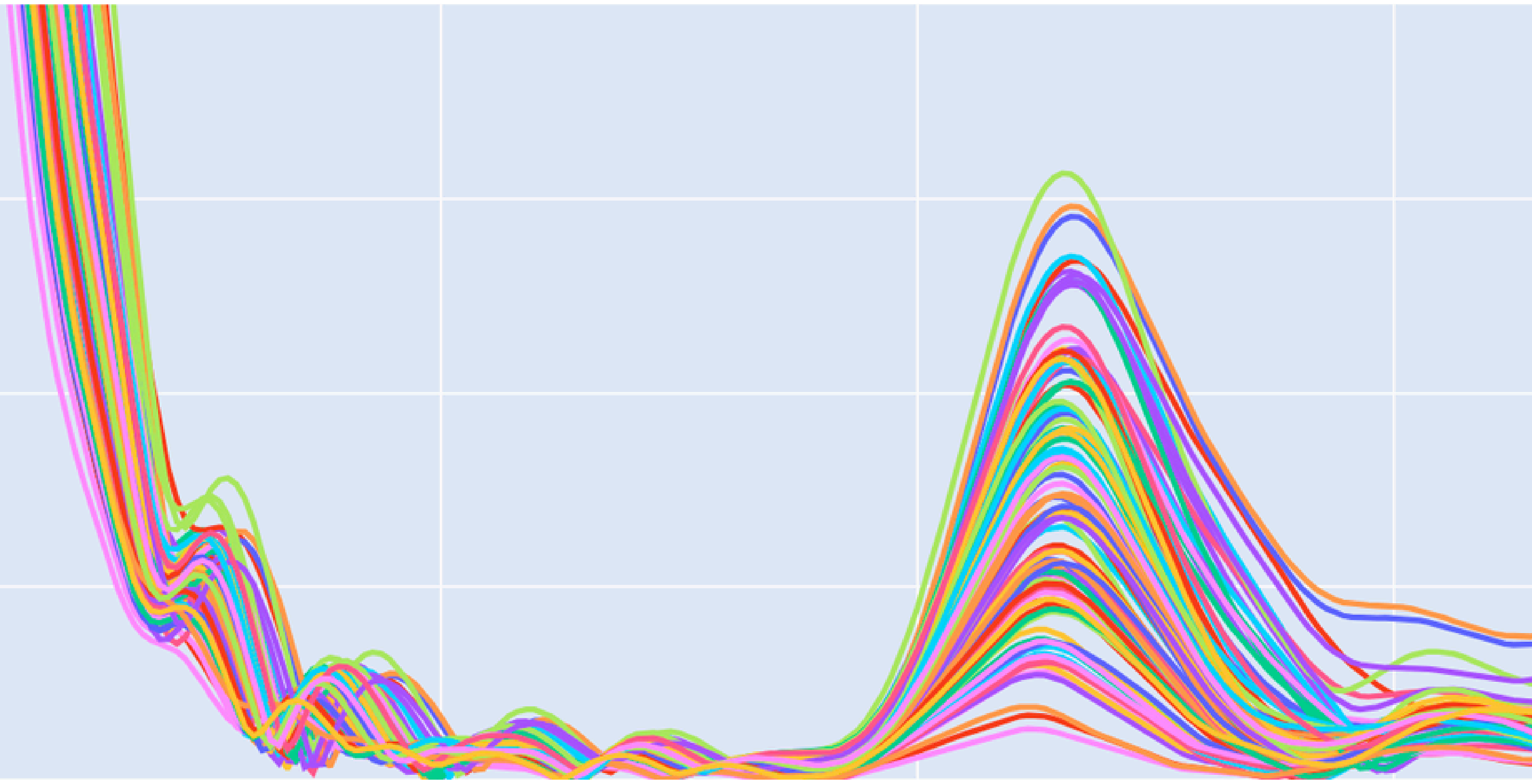


Quanscient Webinar 18th June 2024 | Executive summary

Faster and more reliable MEMS design with cloud-based multiphysics simulations

See how engineers are leveraging cloud computing for faster design cycles and increased product reliability in MEMS design

Contents

Overview

This webinar highlighted how cloud-based multiphysics simulation software, Quanscient Allsolve, addresses challenges in MEMS design, such as slow prototyping cycles, limitations in simulating complex multiphysics interactions, and restricted design exploration due to computational constraints. The webinar detailed how Quanscient's cloud-based platform overcomes these issues through cloud computing, enabling faster design cycles and increased product reliability.

A live demonstration showcased Allsolve's capabilities in setting up and running a microspeaker simulation, including meshing, parameter sweeps, and results analysis. Guest speaker **Dr. Andrew Tweedie**, CEO of Kogsys, presented real-world examples of how Allsolve has been used to simulate large-scale PMUT arrays and optimize complex MEMS designs for manufacturability, resulting in reduced development time and increased product reliability.

WATCH THE WEBINAR RECORDING →

About the speakers

Dr. Andrew Tweedie

CEO of Kogsys

Dr. Tweedie has an extensive background in MEMS design and experience working with clients in the MEMS industry, helping them leverage Quanscient Allsolve to tackle design challenges.

Dr. Abhishek Deshmukh

Team Lead - Application Engineering, Quanscient

Abhishek has more than nine years of experience in computational fluid dynamics (CFD) research and software development, especially for applications in high-speed compressible flows, turbulence, multiphase flows, and combustion.

Challenges faced with simulations in MEMS design

Slow prototyping and extended lead times

Traditional software and limited computing power often necessitate extensive physical prototyping to validate designs.

This process is time-consuming and expensive, delaying product launches and hindering rapid response to manufacturing or reliability issues.

Limited design exploration

Due to time and cost constraints inherent to physical prototyping and the limited computational resources, engineers are often unable to fully explore all potential design possibilities.

This can lead to suboptimal designs that fail to maximize yield, reliability, or performance.

Limited multiphysics capabilities

MEMS devices involve complex interactions between multiple physics domains (mechanical, thermal, electrical, fluidic).

Traditional software can struggle to accurately simulate these multiphysics interactions, requiring simplified models or separate simulations for each domain.

This can lead to inaccurate results and potential oversights in the design process.

Meshing complex geometries

Traditional software may struggle to create accurate simulation meshes for the intricate details of MEMS devices.

This can lead to simplified models that do not fully capture the real-world behavior of the device, resulting in less accurate simulation results.

How cloud-based software addresses these challenges directly

Accelerated design cycles and reduced reliance on physical prototypes

Cloud-based simulation platforms offer powerful solvers and virtually unlimited computational resources.

Engineers can test and validate design variations with faster speed and increased accuracy, reducing the need for extensive physical prototyping.

This enables shortened development timelines and faster time-to-market.

Comprehensive multiphysics simulations

Cloud-based software can enable accurate and efficient simulation of complex multiphysics interactions through natively coupled multiphysics algorithms.

This eliminates the need for simplified models or separate simulations for each domain, resulting in more comprehensive and reliable design validation.

Optimized design exploration

With access to extensive computational resources and faster simulation times, engineers can explore a wider range of design possibilities within the same timeframe.

This allows for a more thorough optimization process, leading to designs that maximize yield, reliability, and performance.

Accurate meshing of complex geometries

Cloud-based simulation platforms can leverage powerful computing capabilities to generate high-quality meshes for even the most intricate geometries.

This ensures that simulations accurately capture the real-world behavior of the device, leading to more reliable results.

Other benefits of cloud-based simulation software and their business impact

No user limits

Flexibility for teams: Any number of engineers, researchers, or collaborators can access Quanscient Allsolve within your chosen plan, facilitating seamless teamwork regardless of your organization's size.

No barriers to access: Users don't need specialized hardware. The cloud-based nature of Allsolve means simulations can be set up and monitored from any device with a web browser.

Easy sharing: Collaboration becomes as simple as sharing a link. Team members can work on simulations concurrently, review results, and provide feedback in real time.

Python scripting interface

Automatically generated Python script: Allsolve automatically generates Python scripts that fully define your simulation setup.

Extensibility for unique physics: If the GUI doesn't directly support certain physics, users familiar with FEM weak-form equations have the flexibility to add them using Python.

Accessible knowledge base: The extensive multiphysics script libraries provide a valuable resource, offering pre-built simulation examples and templates to accelerate your work.

Usage-based pricing

Predictable costs: Quanscient Allsolve's pricing is based on actual simulation runtime. You are not charged when simulations are idle, ensuring you only pay for the computational resources you use.

Scalability for all: This model enables organizations of all sizes to access powerful simulation capabilities without large upfront investments in hardware and software licenses.

Support and materials

Expert assistance: Directly contact Quanscient's simulation experts for technical support and guidance whenever you need it.

Self-paced learning: Access a comprehensive library of resources, including tutorial videos, documentation, and user guides to quickly learn the software and expand your simulation expertise.

Live demonstration
Microspeaker design with Quanscient Allsolve

Dr. Abhishek Deshmukh
Team Lead Application Engineering, Quanscient

Objective

Showcasing the design parameter sweep capabilities of Quanscient Allsolve for the simulation of electrostatically actuated silicon-based microspeakers using the harmonic balance method for strongly coupled multiphysics

Process

1. Walking through the setup of a basic building block of the microspeaker in the GUI

2. Explanations of the couplings between different physics, namely, solid mechanics, electrostatics, laminar flow, and mesh deformation for large displacement

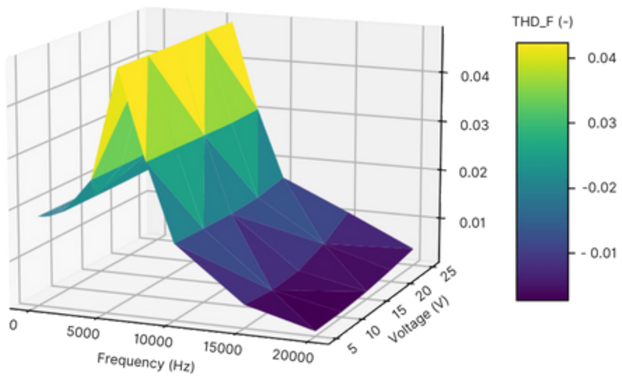
3. Setting up a two-parameter sweep (frequency and voltage) as the design parameters

4. Modification of the autogenerated script for post-processing of the simulation output to obtain the value of the quantity of interest, in this case, total harmonic distortion of the displacement

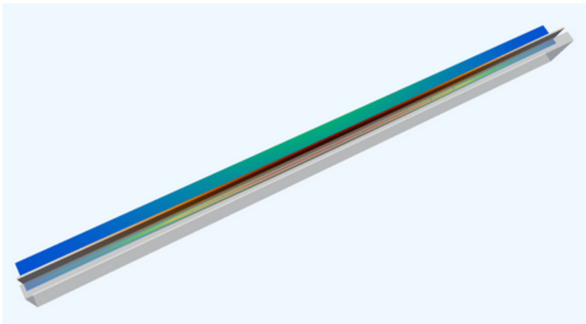
Results

Parameters

Frequency: 20 - 20,000 Hz
Voltage: 5 - 25 V



The response surface for the total harmonic distortion of displacement from the 75 simulations that characterizes the behavior of the microspeaker over the chosen frequency and voltage ranges



Qualitative comparison showing contour plots of displacement and fluid velocity

Key benefits demonstrated

1. Ease of setting up of parametric sweeps for the complex multiphysics simulation

2. Parallel simulation sweeps enabling efficient exploration of the MEMS design space, providing a comprehensive response surface for design of experiments within the runtime of a single simulation

Real-world success with Quanscient Allsolve

Dr. Andrew Tweedie

CEO, Kogsys

Kogsys provides consultancy services across a wide range of application areas. In this webinar, founder and CEO, **Dr. Andrew Tweedie** presents some of the ways that Kogsys uses Allsolve for MEMS simulations, taking PMUT fingerprint arrays as an example.

The growth of PMUTS

The growth of academic publications on PMUTS over the last 10 years has been remarkable. As the technology has matured, it has provided a route to integrate ultrasonic technology into consumer products, which has sparked interest from major companies. (see image)

Simulation remains a huge challenge and a key area of interest for the customers of Kogsys

Why are PMUT simulations so complex?

The following aspects combine to make PMUT simulation a challenge:

- Highly complex sensor structure with many thin layers
- Arrays that can comprise many thousands of elements
- Devices typically couple into a large elastic or acoustic load
- Their broadband nature, requiring computationally demanding transient analysis
- Multiphysics simulation is essential, requiring:
  - Elastic wave propagation
  - Electrostatics
  - Piezoelectrics
  - Optionally acoustic wave propagation

1. D. A. Horsley et al., "Ultrasonic fingerprint sensor based on a PMUT array bonded to CMOS circuitry," 2016 IEEE International Ultrasonics Symposium (IUS), pp. 1-4.

As a result, simulations can easily reach 100 million degrees of freedom and require solving over hundreds or even thousands of timesteps.

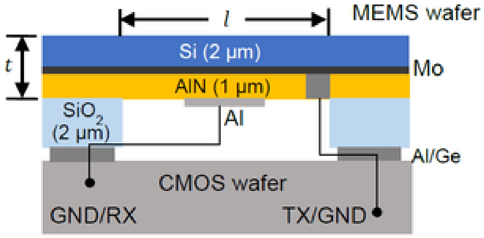
Dr. Tweedie stated that at Kogsys, they believe Quanscient Allsolve is uniquely positioned to tackle these problems.

Case example: PMUT stack simulation

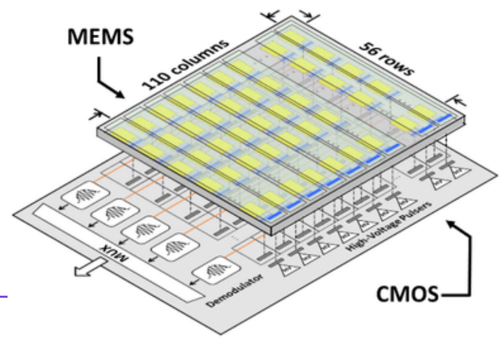
Device structure Throughout his presentation, Dr. Tweedie used the fingerprint sensing array described by Horsely et al.[1] as an example.

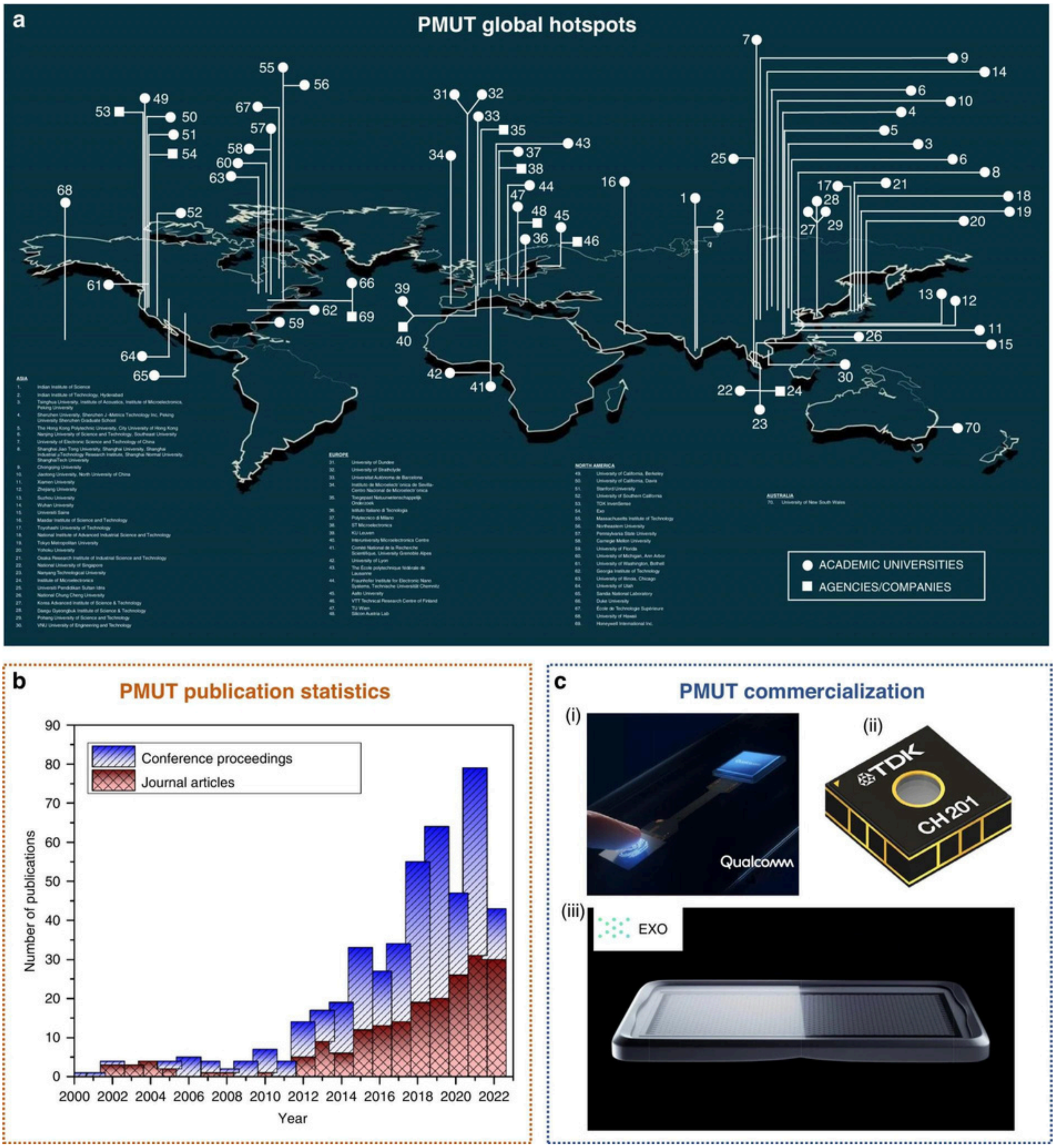
The figure below shows the structure of the PMUT stack, with the following layers:

- SiO_2 standoff
- Al drive electrode
- AlN active layer
- Mo ground electrode
- Si elastic layer



A 250 µm PDMS (Polydimethylsiloxane) layer acts as a load (not shown). The lateral pitch of the array elements is 43x58 µm, and the resonant frequency is 14 MHz. The layout of the array is shown below:





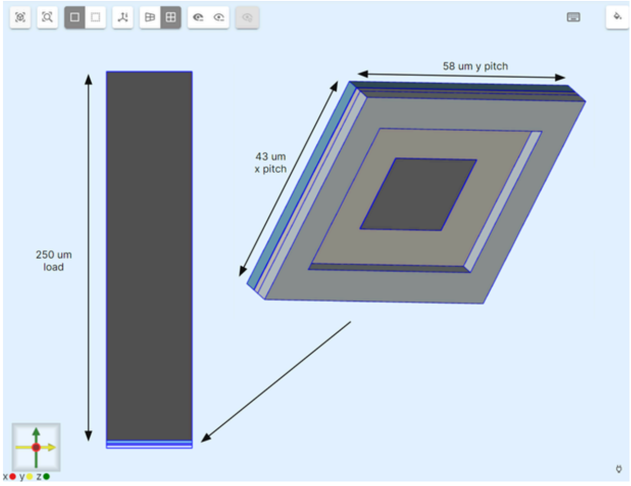
Summary of PMUT global development scenario from Roy et al. ***a*** *PMUT research locations showing the active involvement of 4 continents: Asia, Europe, North America, and Australia[2].* ***b*** *PMUT publication statistics from 2001 to 2022.* ***c*** *Major companies commercializing PMUTs. (i) 3D sonic sensor used as an in-display fingerprint sensor developed by Qualcomm Inc. (ii) CH201, which is a 5 m PMUT rangefinder commercialized by TDK Inc. (iii) Cello, which is a handheld portable PMUT based imaging probe developed by Exo Inc. All pictures have been adapted with permission*

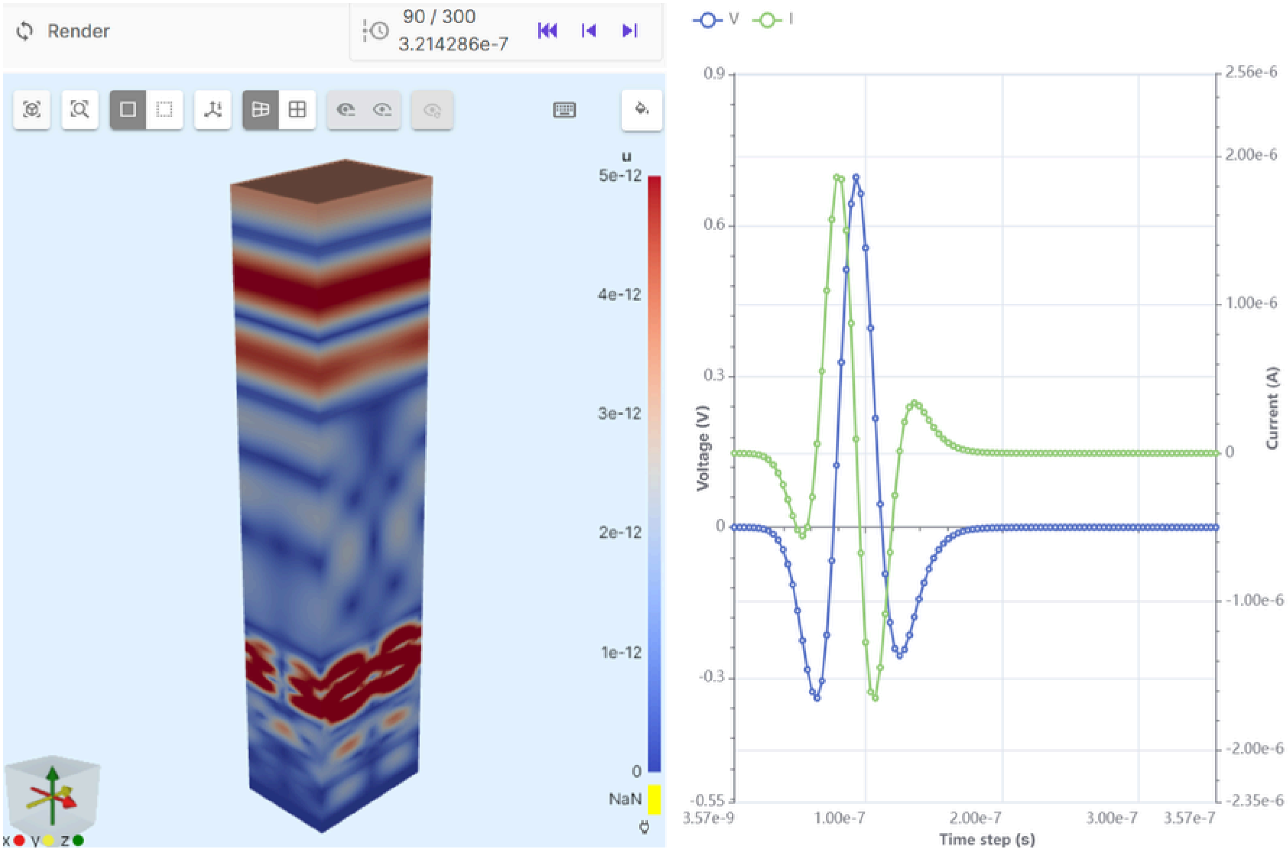
2. Roy, K., Lee, J.EY. & Lee, C. Thin-film PMUTs: a review of over 40 years of research. Microsyst Nanoeng 9, 95 (2023).

Model and results

A single element model of the stack was constructed in the Quanscient Allsolve UI with the following boundary conditions:

- Lateral symmetry in x and y directions
- Voltage excitation on drive electrode with a coupled source resistance





Stack simulation outputs. Velocity field (left), voltage and current (right)

Example outputs can be seen in the plot in *Fig 4*. These single element simulations run quickly, and therefore provide an excellent platform for design studies and the Monte Carlo analysis, as will soon be demonstrated.

Simulation statistics were as follows:

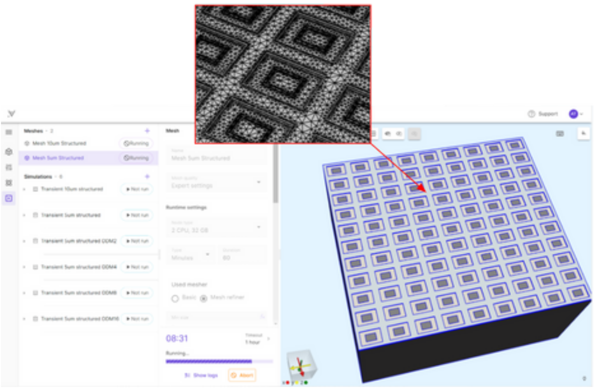
- 380k DoF
- 300 steps
- 4 min run
- 16 cores

PMUT array simulations

Simulating a larger section of the array provides more detailed insights into its performance, in particular:

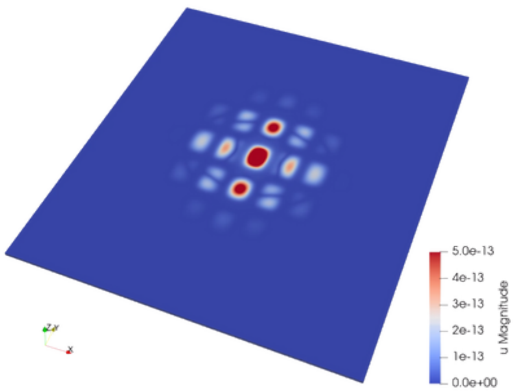
- Inter-element crosstalk
- Beam shape
- Beamforming performance

This example shows an 11x11 element section of the array. The stack design is the same as the previous example and the 250 μm PDMS load remains.

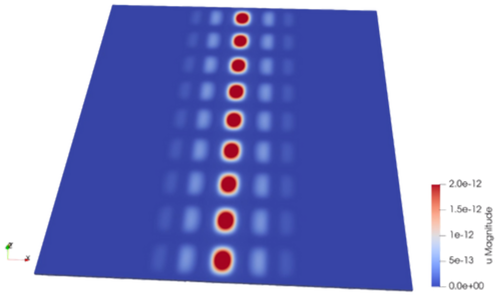


By driving a single element at the centre of the array we can see fundamental behaviour of the design:

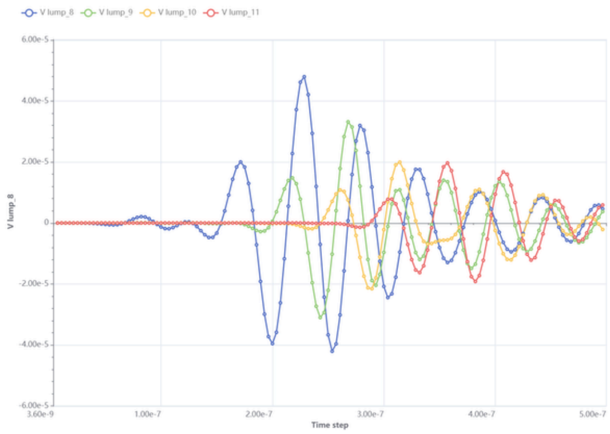
- Elastic waves propagate through the structure exciting adjacent elements
- This influences the beamwidth, bandwidth and sensitivity of the device

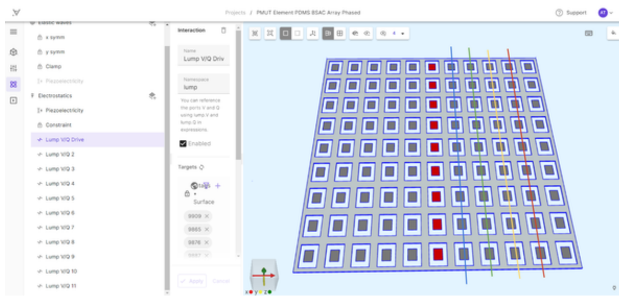


By driving a line of elements at the centre of the array we can begin to evaluate the array performance in specific beamforming scenarios. Custom drive conditions can be applied to excite a line of columns, or produce more advanced beamforming scenarios with custom element phasing.



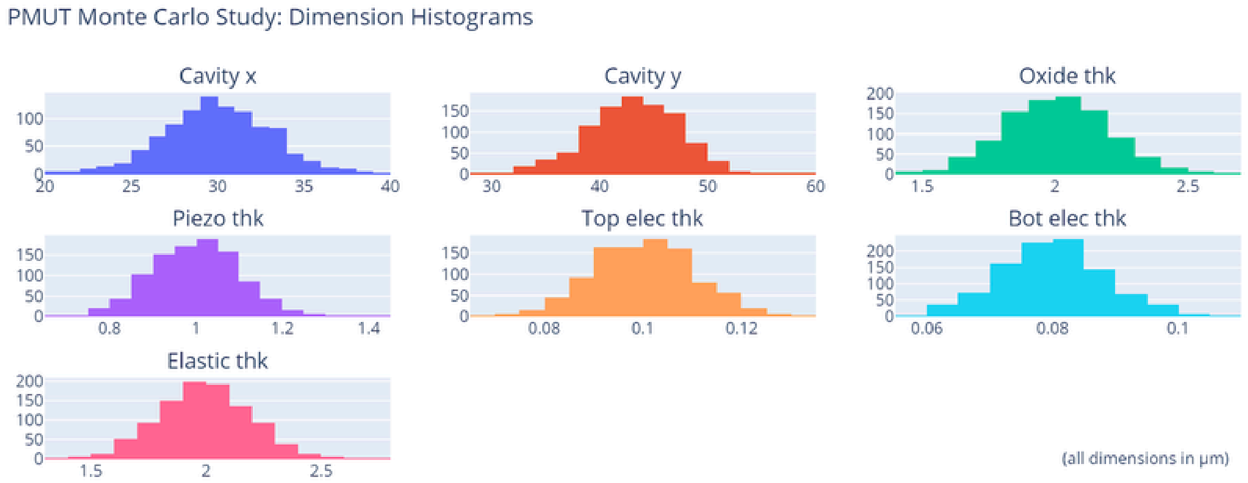
The plot below shows the voltage generated on four adjacent array elements due to crosstalk. This affects receive beamforming, and a good design seeks to reduce this as much as possible.





Simulation statistics were as follows:

- 14.5M DoF
- 200 steps
- 43 min run
- 128 cores



Monte Carlo analysis for PMUT

Manufacturing processes and material properties are always subject to variation. This means that real-world performance will always vary from theoretical results. Monte Carlo analysis allows us to simulate this effect.

This is very valuable to manufacturing engineers as it can, along with pass/fail criteria, be used to predict manufacturing yield.

We'll demonstrate this using the single element PMUT model and running 1,000 random variations to analyse the effect this will have on device performance.

Setup

The plot above shows 1,000 random variations of the single-element PMUT stack. Each key dimension is randomly altered, following a normal distribution. The distribution around the mean value can be adjusted by setting its coefficient of variation (CV)

Python scripting

Highly customized analyses, such as Monte Carlo, are set up using Quanscient Allsolve's custom Python scripting feature. Existing scripts can be modified to add custom features, such as the randomization of dimensions. This functionality has enabled the development of highly specialized models to meet specific customer requests.

The code below takes existing UI variables for the PMUT dimensions and randomises them according to a normal distribution.

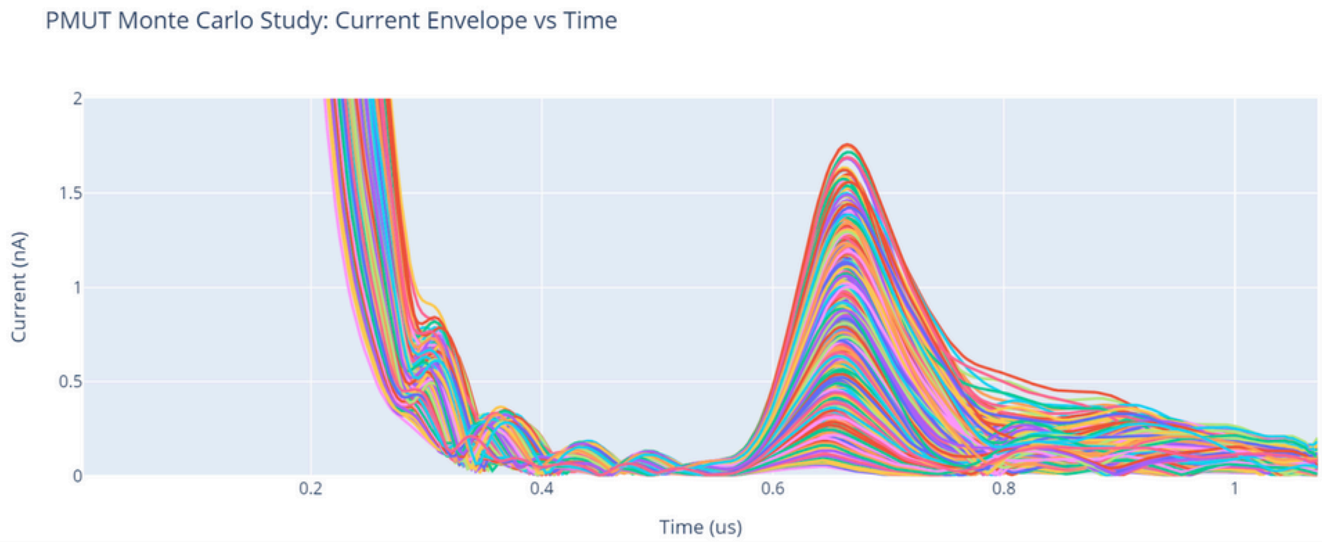
```python

# attributes to be randomised
random_vars = ["cavity_x", "cavity_y", "oxide_thk", "piezo_thk", "top_elec_thk", "bot_elec_thk", "elastic_thk"]

# if doing monte carlo randomise geometry
if expr.random_flag:

    # update attributes and log value to output
    for attr in random_vars:
        setattr(expr, attr, random.normalvariate(getattr(expr, attr), getattr(expr, attr) * expr.random_cv))

```

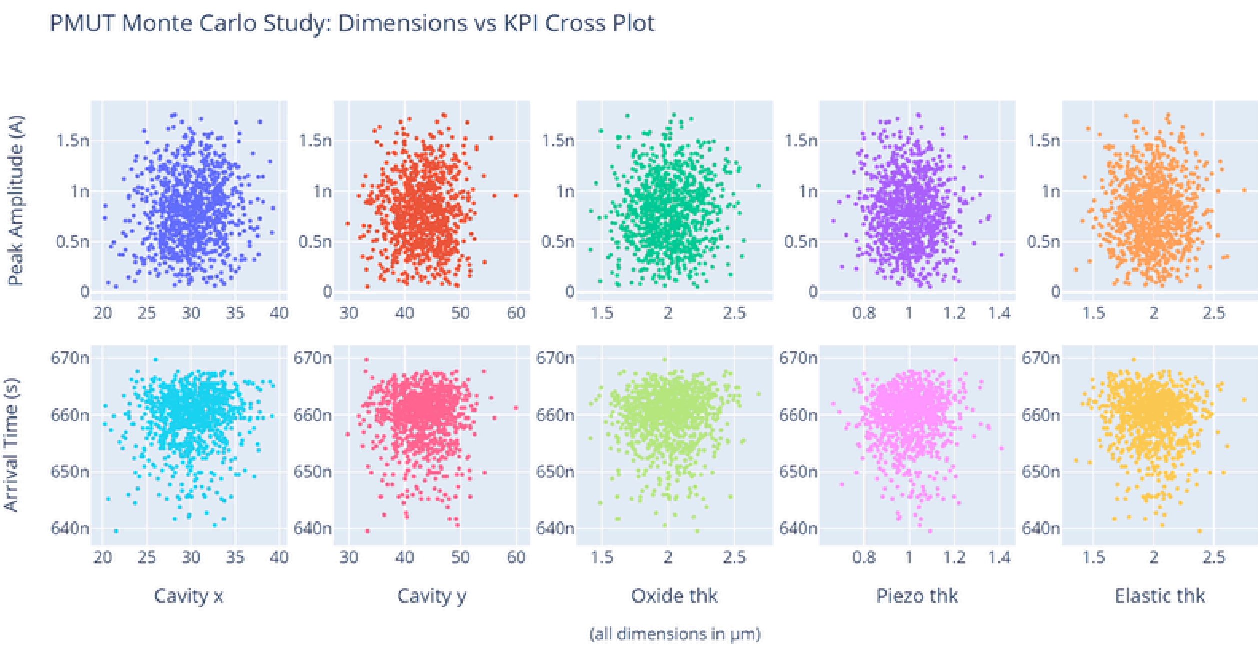


Results

The 1,000 simulations are then run in parallel. Results were downloaded to be processed in a local Python script. The received current shows a large reflection for the front face of the PDMS. However, there is a large variation in the echo signal due to the changes in device dimensions.

At this stage it is useful to process the results further to extract two key performance indicators (KPIs):

- Signal amplitude
- Signal arrival time



Once the KPIs have been extracted a cross plot can identify which dimensions strongly affect them.

The original base simulation using the design dimensions produced the following values:

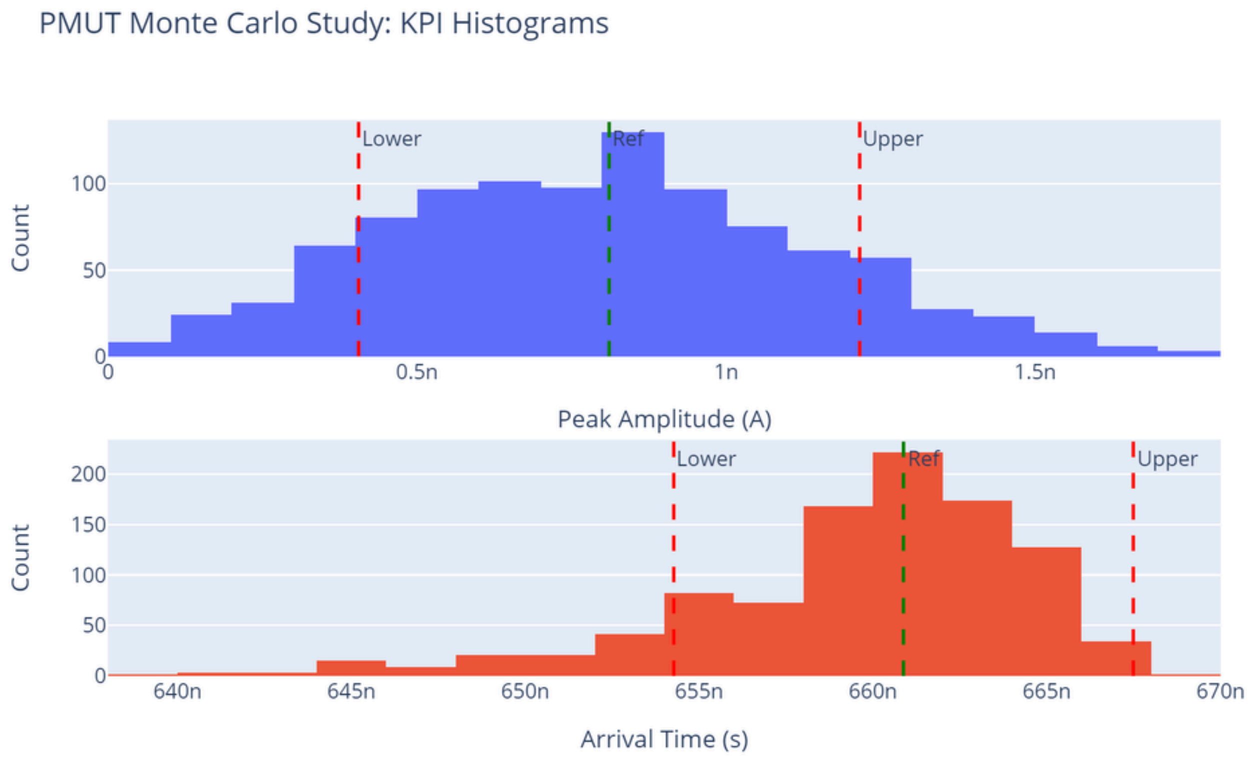
- Signal amplitude 0.8nA
- Signal arrival time 660 ns

In this plot, a straight line indicates a strong correlation, while a random distribution of points indicates low correlation. In addition, raw correlation values can be extracted for each input-output pair.

In this design, the cavity's x dimension (shorter dimension) showed the strongest correlation with outputs and had an 8x higher impact on the received signal than the y dimension.

Plotting a histogram of each KPI allows us to analyze yield.

As an example, the following pass/fail levels have been marked on the charts:
+/- 50% for amplitude
+/- 1% for arrival time



This results in the following statistics:

Total sims	1000
Amplitude fails	252
Arrival time fails	135
Total fails	281
Yield	71.9%

It can be clearly seen that this approach provides a powerful tool for understanding a design’s stability and ultimately improving manufacturing yield.

Simulation statistics were as follows:

- 1,000 simulations
- 380k DoF each
- 300 steps
- 15 min total runtime
- 1,000 cores

Highlights from the Q&A

Three questions for Dr. Tweedie were presented:

Q: From the user perspective, how do you feel about the security of a cloud-based platform?

A: "For me, the cloud has become the norm. I use it for personal banking, finances, and we even store sensitive business data on the cloud at Kogsys. I don't see it as an issue. The benefits we gain in design and manufacturing insights are a strong motivation to go into the direction of cloud technology."

Q: How easy was it to get started with Allsolve?

A: "Personally, I found it quite intuitive, especially given my background in this field. The ability to use the UI to set up an initial model and then dive into the underlying code to make any modifications was hugely beneficial. It also served as a great learning tool. For me, the learning curve with Allsolve wasn't as steep as with other tools I've used."

Q: What would you say to engineers hesitant about trying a new simulation software, let alone a cloud-based one?

A: "I understand people have limited bandwidth and can't adopt everything, but I think that traditional simulation approaches don't do enough. They don't work.

I would encourage every engineer to at least try this ability that the cloud brings to run massive design sweeps in parallel and get results very quickly.

Speaking as a company that provides consulting services, it's allowed us to turnaround projects way quicker than we could have done back in the pre-cloud days.

So, I understand people have limited bandwidth and can't adopt everything, but I think this is an area where cloud tools and particularly Quanscient Allsolve can make a huge difference."

Conclusion

We explored the common challenges in MEMS design and how cloud-based simulation software can address them.

The challenges presented:

- Slow prototyping and extended lead times
- Limited multiphysics capabilities
- Limited design exploration
- Meshing complex geometries

Through live demos by **Dr. -Ing Abhishek Deshmukh** and **Dr. Andrew Tweedie**, we saw how Quanscient Allsolve addresses these challenges and enables

- Accelerated design cycles and reduced reliance on physical prototypes
- Comprehensive multiphysics simulations
- Optimized design exploration
- Accurate meshing of complex geometries

Key takeaways

In 60-minutes, we demonstrated how a cloud-based multiphysics simulations platform, Quanscient Allsolve, enables

Faster design cycles

With virtually unlimited computational resources and parallel simulations, engineers can iterate on designs more quickly, reducing time-to-market

Increased innovation

The ability to explore a wider range of design possibilities leads to more innovative and optimized solutions

Improved collaboration

Unlimited licenses and a cloud-based platform enable seamless collaboration among team members, regardless of location

Reduced onboarding time and increased productivity

The intuitive interface allows engineers to get up to speed quickly and focus on design, not software complexities

Cost savings

Cloud-based software eliminates the need for expensive hardware and software licenses, reducing upfront costs and ongoing maintenance expenses

Get in touch

If you're considering whether Quanscient Allsolve could be a beneficial addition to your workflow, we invite you to schedule a complimentary 30-minute consultation with us. This no-obligation call is an excellent opportunity to discuss your specific needs and see how Allsolve can be tailored to meet them.

Book your session now!

Not ready for a call just yet but still curious? Fill out this form to describe your use case. Our technical team will review your information and respond within one business day.

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