

#### Innovative Motion Control



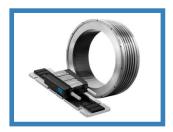
# MATLAB Helps Save Time and Effort by Streamlined Commissioning of the QuiET System

Ralph Coleman Senior Researcher Advanced development



#### Outline

- Company presentation
- Product development workflow
- Active isolation systems
- Commissioning tool
- Results
- Conclusion



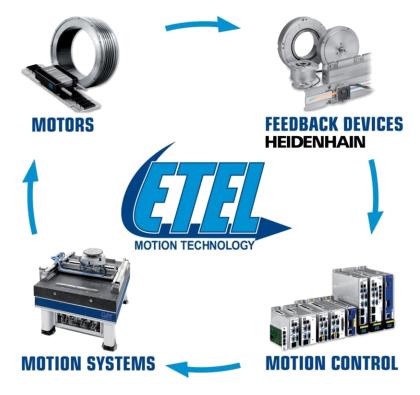






### **ETEL** product range

A comprehensive motion control solution





### The company

#### General data 2015

Headquarters: Môtiers / Switzerland

• Capital: 17.8 million CHF

Net sales: approx. 60 million CHF

Building area:

• Môtiers – 14'700 m<sup>2</sup>

Couvet – 1'660 m<sup>2</sup>

Worldwide employees: 349





### **ETEL** forward integration

From components to advanced motion systems

**MOTION SYSTEM** 

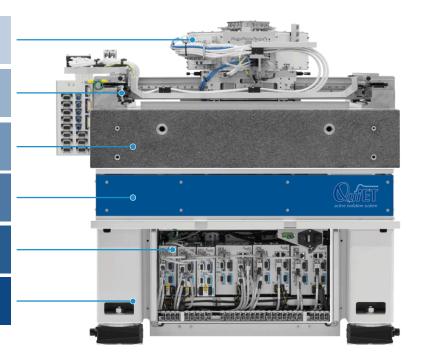
**MOTORS** 

BASE

**ACTIVE ISOLATION SYSTEM** 

**MOTION CONTROL** 

**FRAME** 







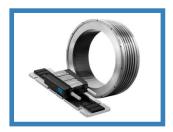
 Reduce the development time of control algorithms by around 40% by using high-level programming in MATLAB and Simulink

- Software tools:
  - Developed simultaneously by using the same interface with Simulink Real-Time & stand-alone products
  - Deployed with small changes only to avoid error-prone implementation



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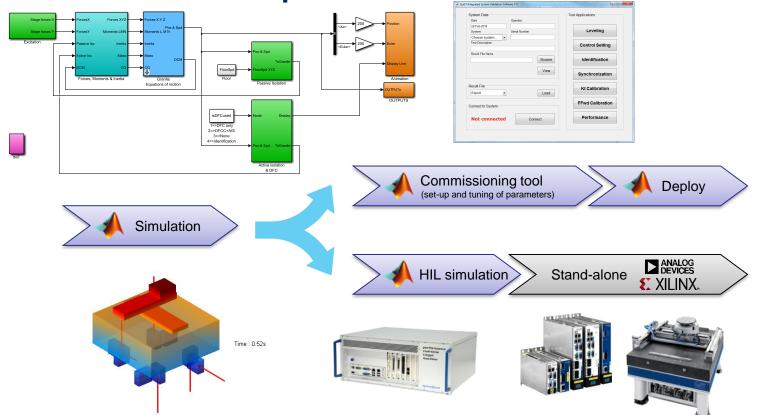








### Product development workflow

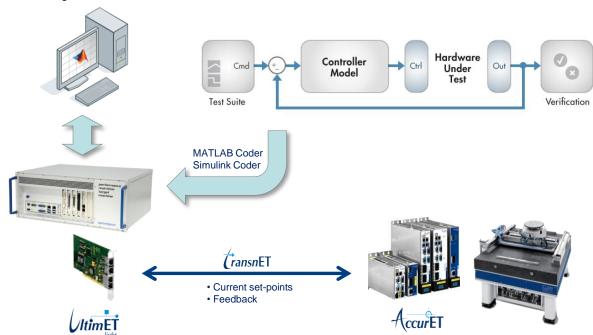




### HIL for development of control & commissioning

Simulink Real-Time used to accelerate development

- Controller in Simulink
- · Commissioning software in MATLAB OOP





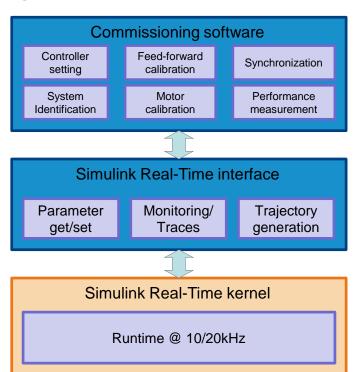
### Software structure during development

Interface with Simulink Real-Time











#### Switch over to stand-alone system

MATLAB Compiler used to create stand-alone application

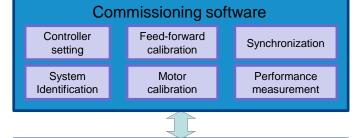




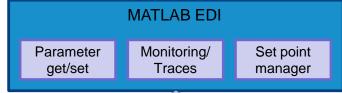
### Software structure when deployed

Interface through EDI library

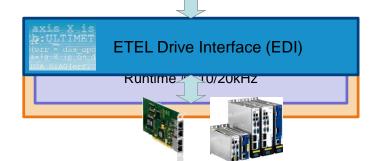










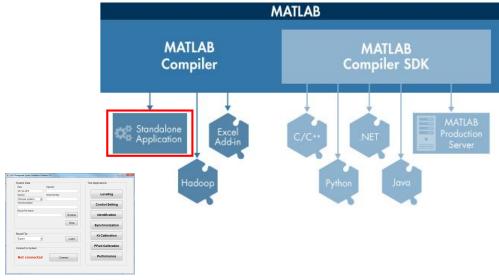






### Stand-alone application

Currently investigating the creation of plug-ins for ComET

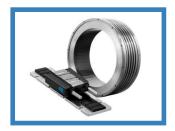


Stand-alone commissioning tool





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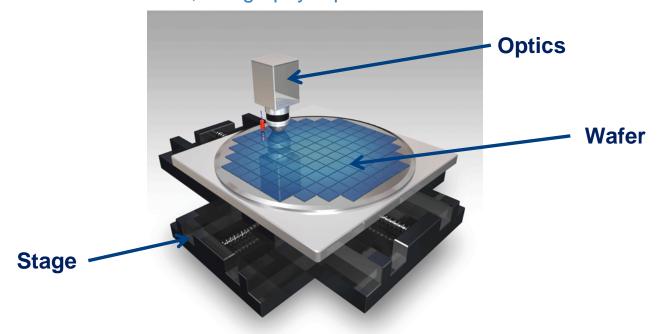






### Isolation systems

Motivation: Semiconductor market, lithography & process control



The relative position between optics and wafer should be stable to obtain a focused image



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Motivation: Semiconductor market, lithography & process control

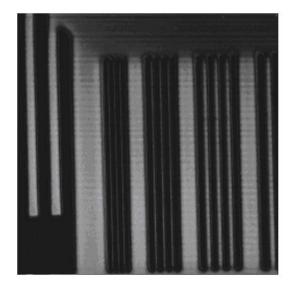


Image with poor position stability

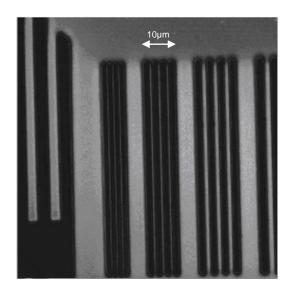
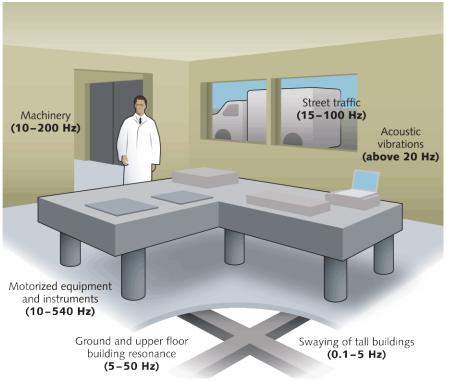


Image with good position stability



### Isolation systems

#### Typical floor vibration sources







A brief introduction

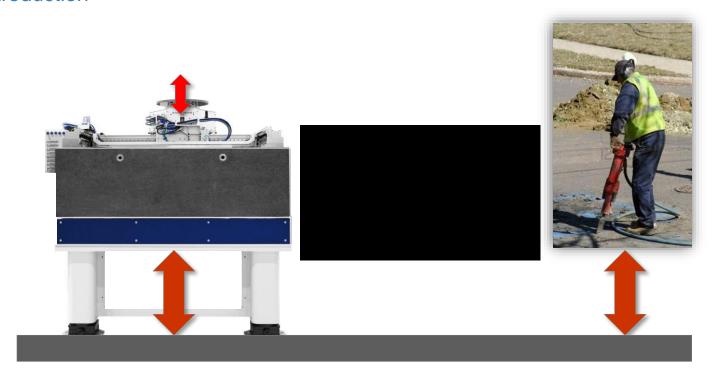






#### QuiET – Floor vibration isolation

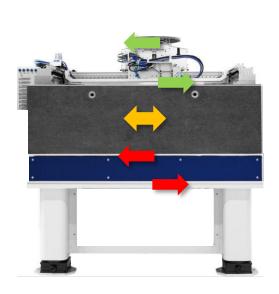
#### A brief introduction

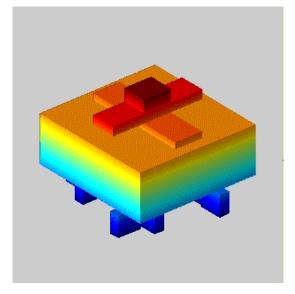




### QuiET – Stage movement compensation

#### A brief introduction

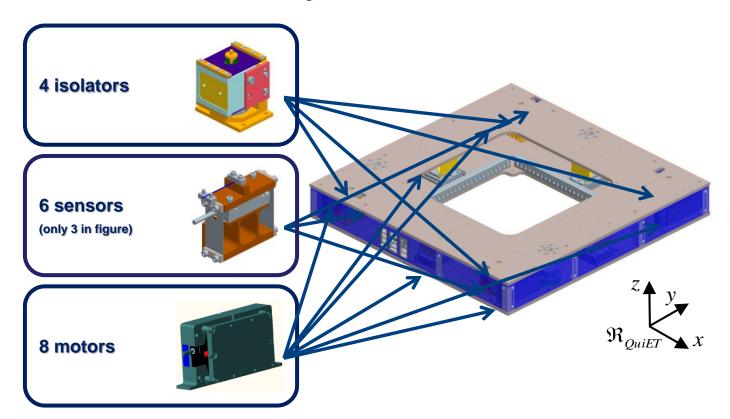




Simulation with badly tuned parameters and base movements magnified x200

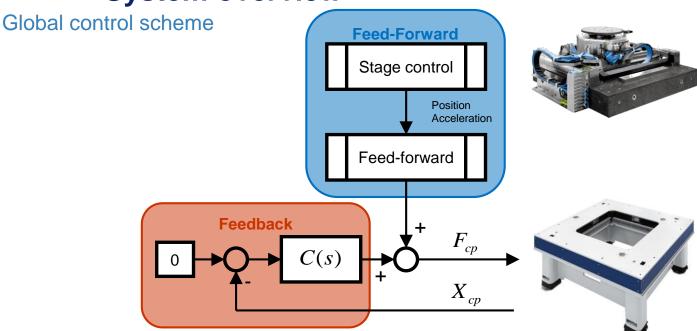


### Mechanical assembly





#### System overview

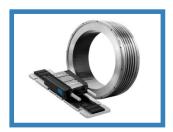


- → 6 Degree-of-Freedom (DoF) systems are tough to get up-and-running
  - All calculations with matrices
  - Inter-axis communication issues



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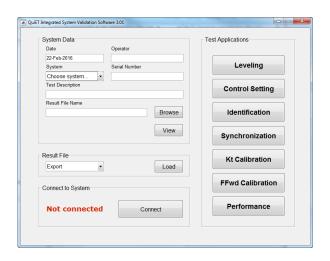




### Commissioning tool general overview

#### Available features by user

Feature	Customer	Internal use
Leveling	✓	✓
Controller setting	✓	✓
Transmissibility measurement	✓	
System Identification		✓
Synchronization		✓
Motor calibration		✓
Feed-forward calibration	✓	✓
Performance measurement	✓	✓

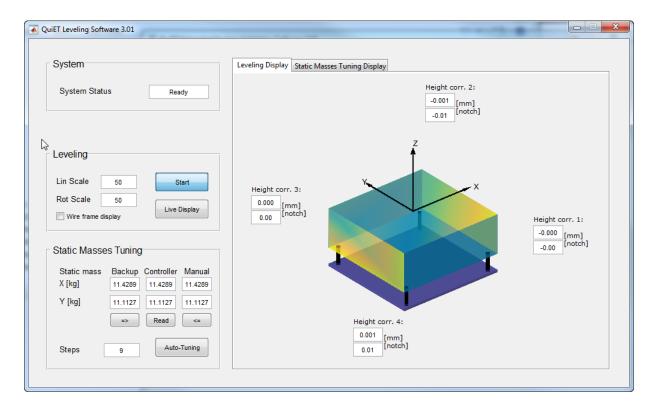


→ Deployed as stand-alone application using the MATLAB Compiler for customers and internal use



### QuiET Commissioning Tool

#### Leveling

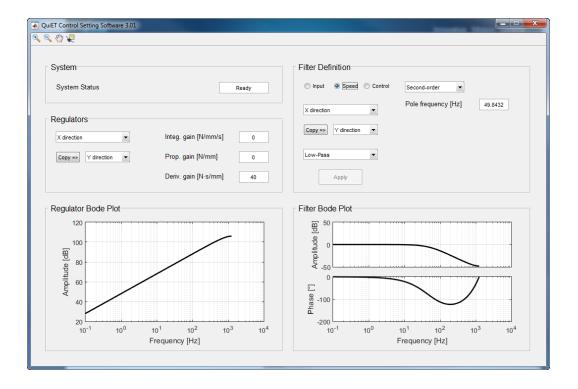




### QuiET Commissioning Tool

Feedback controller setting

This tool is used to set the PID controllers and the filters

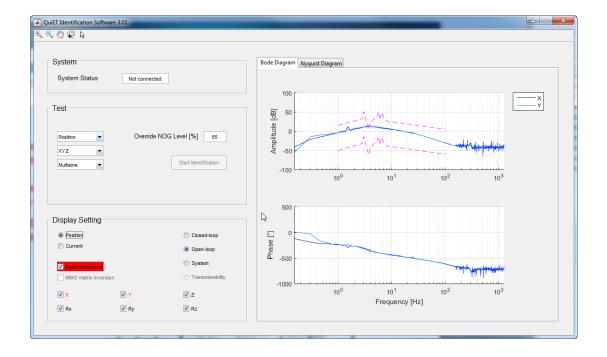






#### System identification

- This tool is used to identify all transfer functions in 6 DoF
- Intensive use of the Control System toolbox



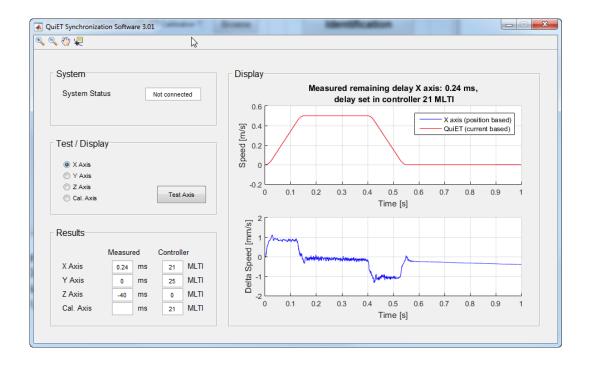




#### **Synchronization**

#### **Exact delay compensation required**

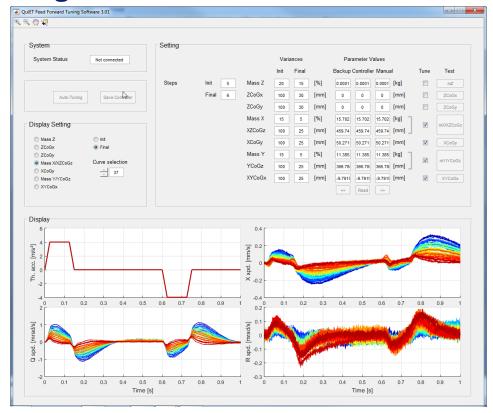
 Deterministic motion control architecture crucial for performance





### QuiET Commissioning Tool

Feed-Forward calibration







#### **Tuning**

#### Model

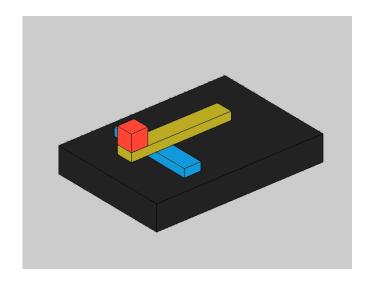
- · X, Y stage, X at the top
- · Parameters to determine
  - Levers
  - Masses

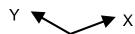
#### **Example**

- M<sub>x</sub> and Xcog<sub>z</sub>
- Stage movement in X and monitor X and Ry of base

$$\begin{bmatrix} F_{x} \\ F_{y} \\ F_{z} \end{bmatrix} = \begin{bmatrix} m_{dx} \cdot \ddot{x} \\ (m_{dx} + m_{dy}) \cdot \ddot{y} \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} = \begin{bmatrix} -\left(m_{dy} \cdot Y cog_z + m_{dx} \cdot X cog_z\right) \cdot \ddot{y} \\ m_{dx} \cdot X cog_z \cdot \ddot{x} \\ m_{dy} \cdot Y cog_x + m_{dx} \cdot (x + X cog_x) \cdot \ddot{y} - m_{dx} \cdot (y + X cog_y) \cdot \ddot{x} \end{bmatrix} + \begin{bmatrix} (m_{sx} + m_{sy}) \cdot y \cdot g \\ -m_{sx} \cdot x \cdot g \\ 0 \end{bmatrix}$$

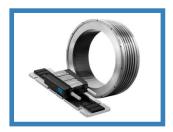






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#### Performance : Qualitative

No QuiET (passive isolation only)

 $p = 0.04 \, \text{m}$ 

v = 1 m/s

 $a = 1.2 \text{ m/s}^2$ 





#### Performance : Qualitative

QuiET with 99% of force/torque cancellation

 $p = 0.2 \, \text{m}$ 

v = 1 m/s

 $a = 6 \text{ m/s}^2$ 







#### ETEL gains

#### **High-level programming in MATLAB and Simulink:**

- Test many options before selecting a hardware & communication architecture
- Engineers focus on their core competence
- Use all powerful mathematical tools required for 6 DoF control
- Number of iterations between development teams reduced by around 80%

## Common software interface with Simulink Real-Time and stand-alone products and deploying with MATLAB Compiler:

- Debug of commissioning algorithms during the development phase
- Avoid error-prone re-implementation





#### Things to remember for the future

#### Use software modeling (e.g. UML) from the start:

- Use OOP to enable seamless interface swap
- Use a software architectural pattern (e.g. Model-View-ViewModel MVVM) to clearly separate the view (GUI) from the model

#### **Automatic code generation for the controllers:**

- Avoid error-prone re-implementation
- Avoid issues with quantization effects, etc.



### Questions

