SWTEST
PROBE TODAY, FOR TOMORROW
2025 CONFERENCE

Wafer Level MEMS Testing

Challenges and Solutions for high-yield manufacturing

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Overview

Introduction

1. MEMS PROBING
   - Best probing choices for accurate measurements
2. MEMS TESTING
   - Advanced static and dynamic sensor drive for wafer test
   - High Accuracy measurement with high parallelism
3. RESULTS IN INDUSTRIAL ENVIRONMENT
   - Three axis dual proof mass low g accelerometer case study

RAY

Introduction

MEMS Wafer-Level Test Challenges

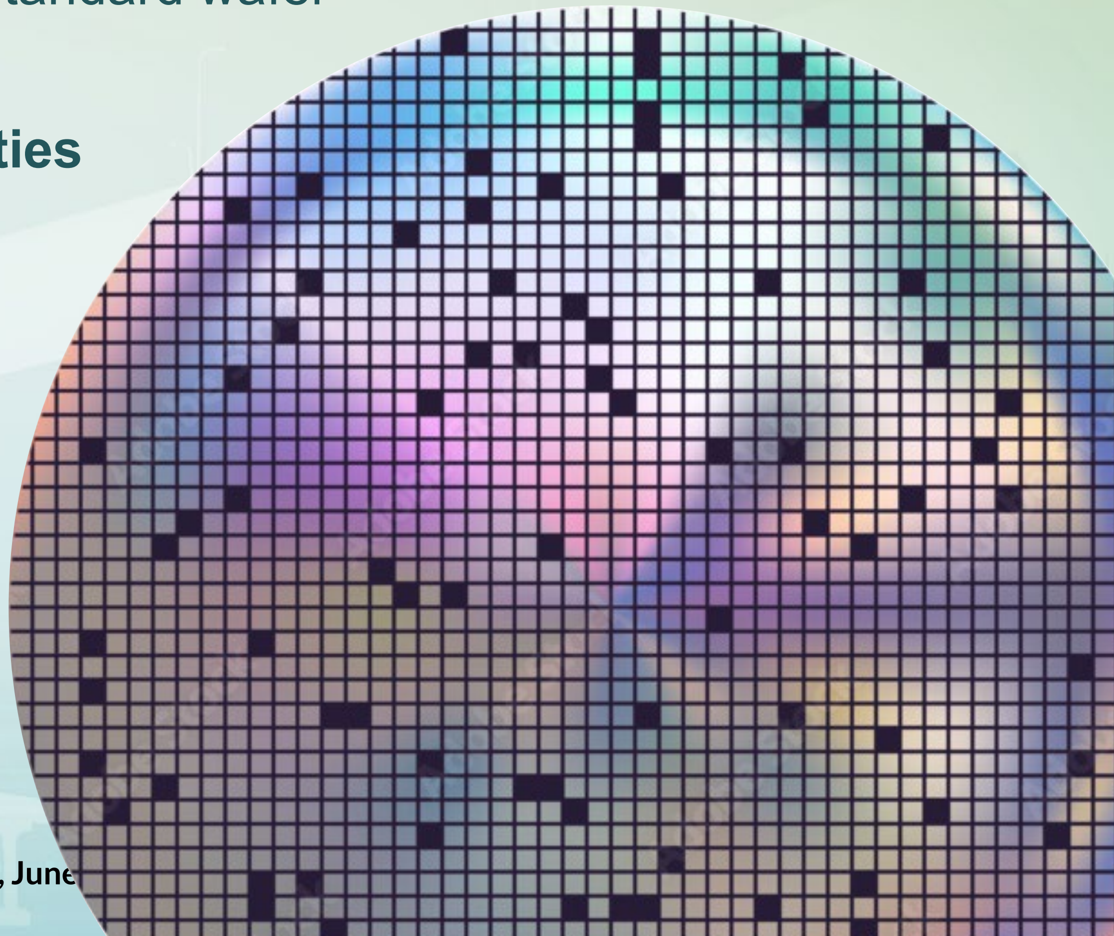
1. Stimulate **MEMS with electrostatic stimulation** on standard wafer probers
2. Reach high throughput with high parallelism **capabilities**
3. Ensure short development time **to production**
4. Perform **high-accuracy, repeatable**

   Measurement: Capacitance, Spring Constant

   C to V curve, and Frequency resonance, 2 GOhm

   leakage

   A reliable probe technology is required!



Section 1

MEMS PROBING

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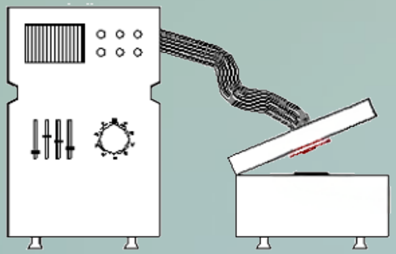
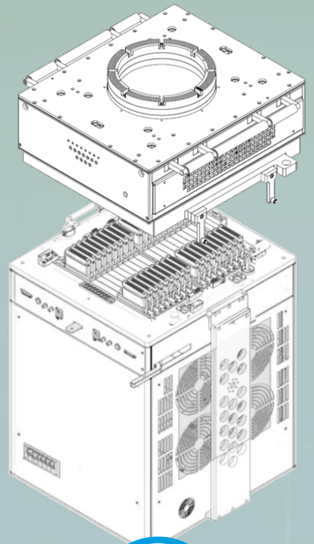
Tester Docking Setup Evolution



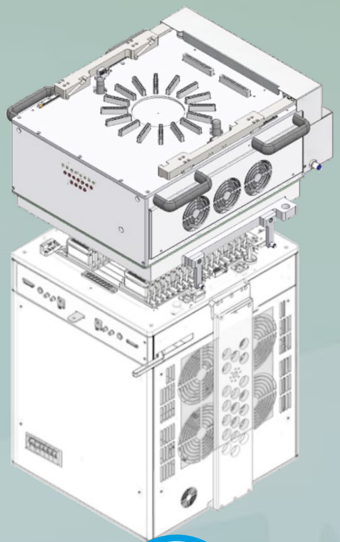
0

TRADITIONAL PROBING APPROACH



1

DOCKING WITH SVM UNIT AND POGO TOWER



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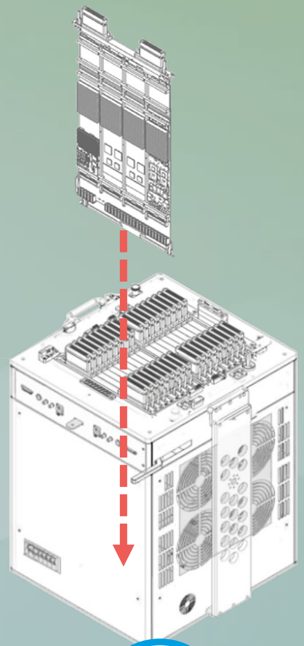
DIRECT DOCKING WITH SVM UNIT



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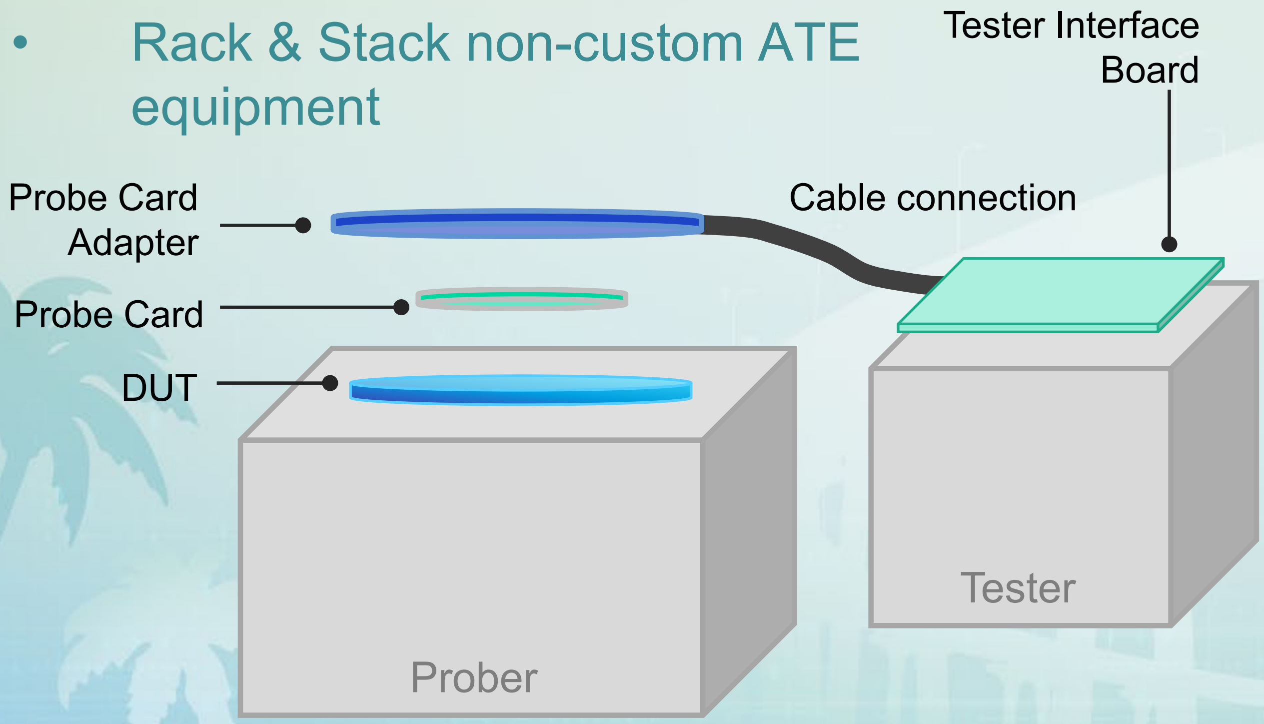
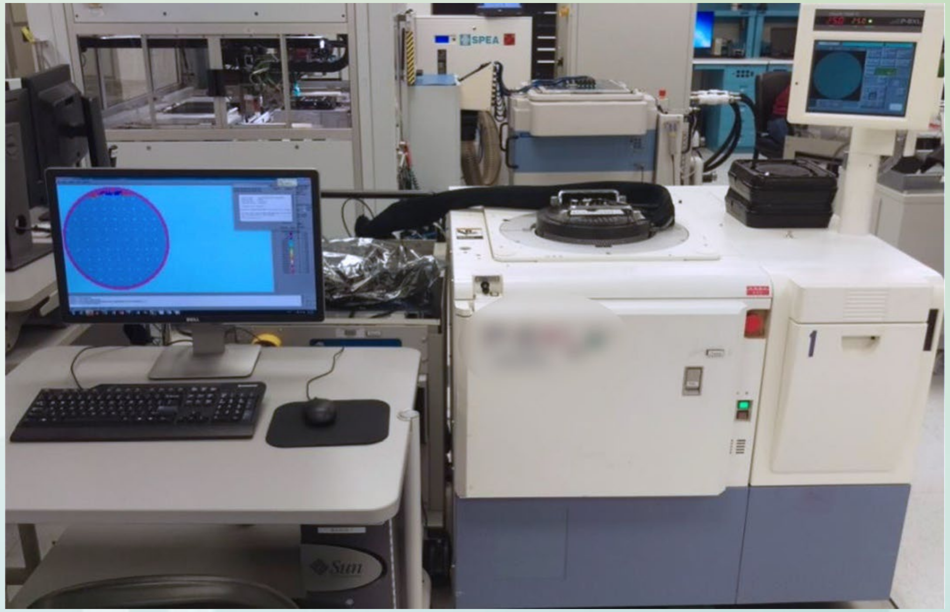
DIRECT DOCKING WITH IN-TESTER SVM

0 - Traditional probing approach

- soft docking
- I/V and C/V converters on probe card
- C load drivers on probe card
- remote test station
- Low parallelism
- Rack & Stack non-custom ATE equipment





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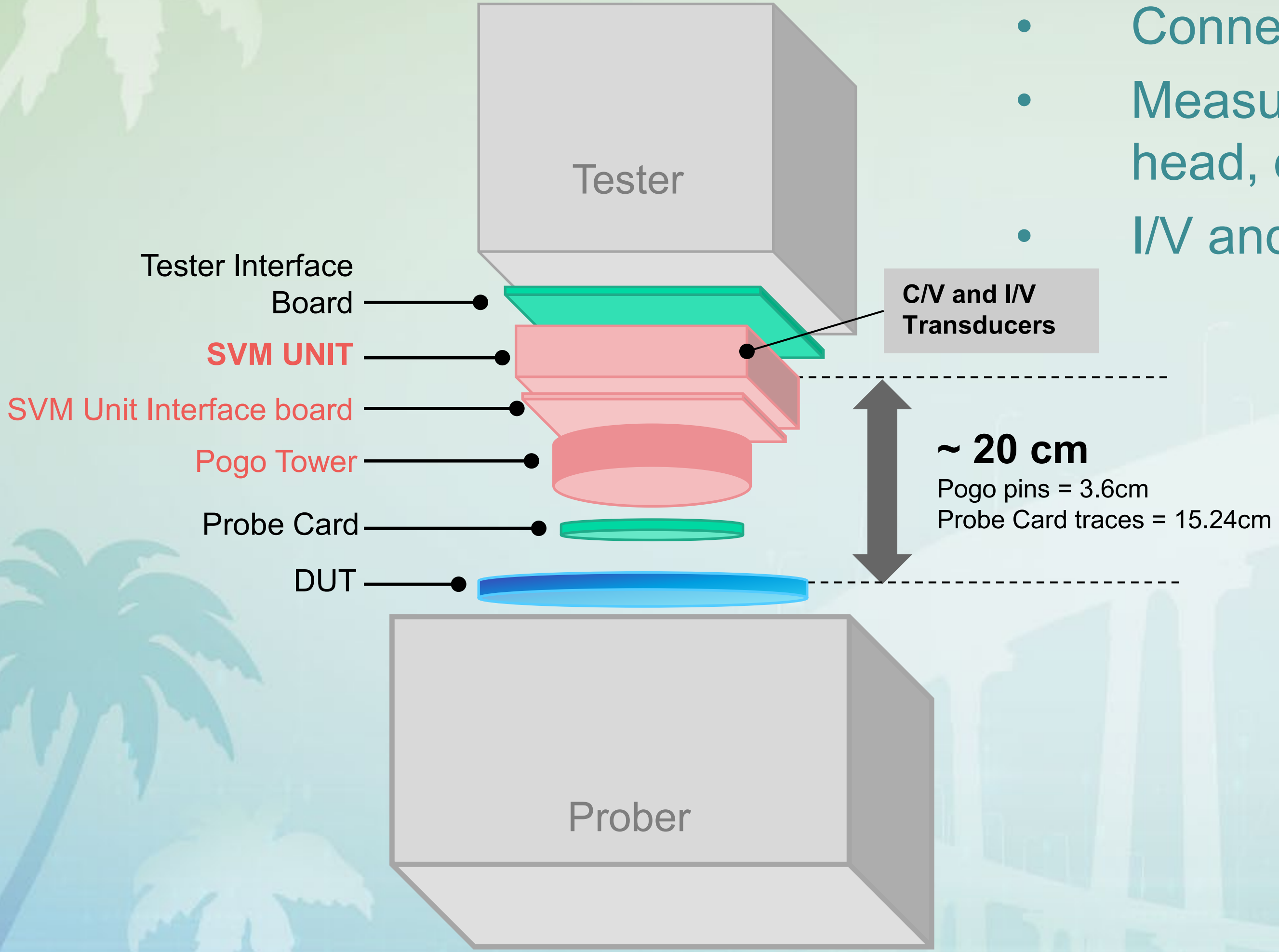
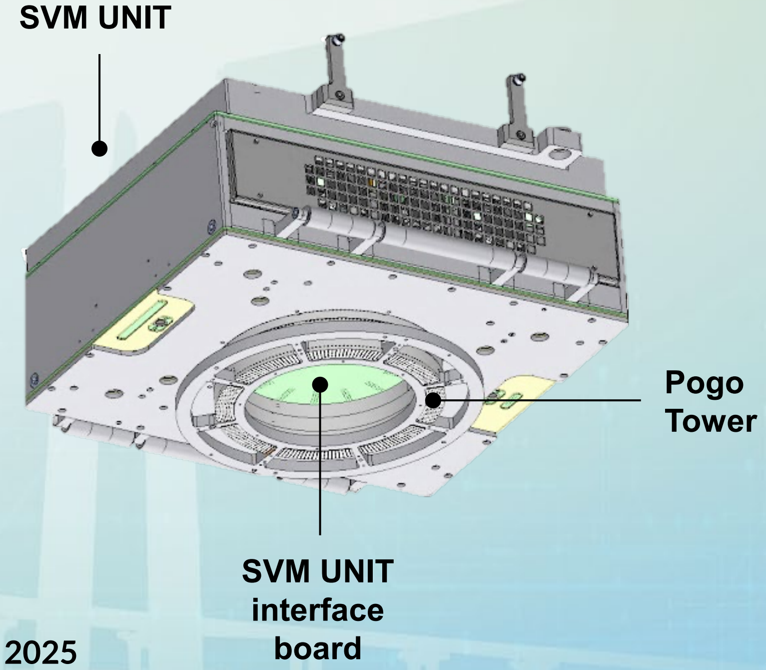
1 – Docking with SVM Box and pogo tower

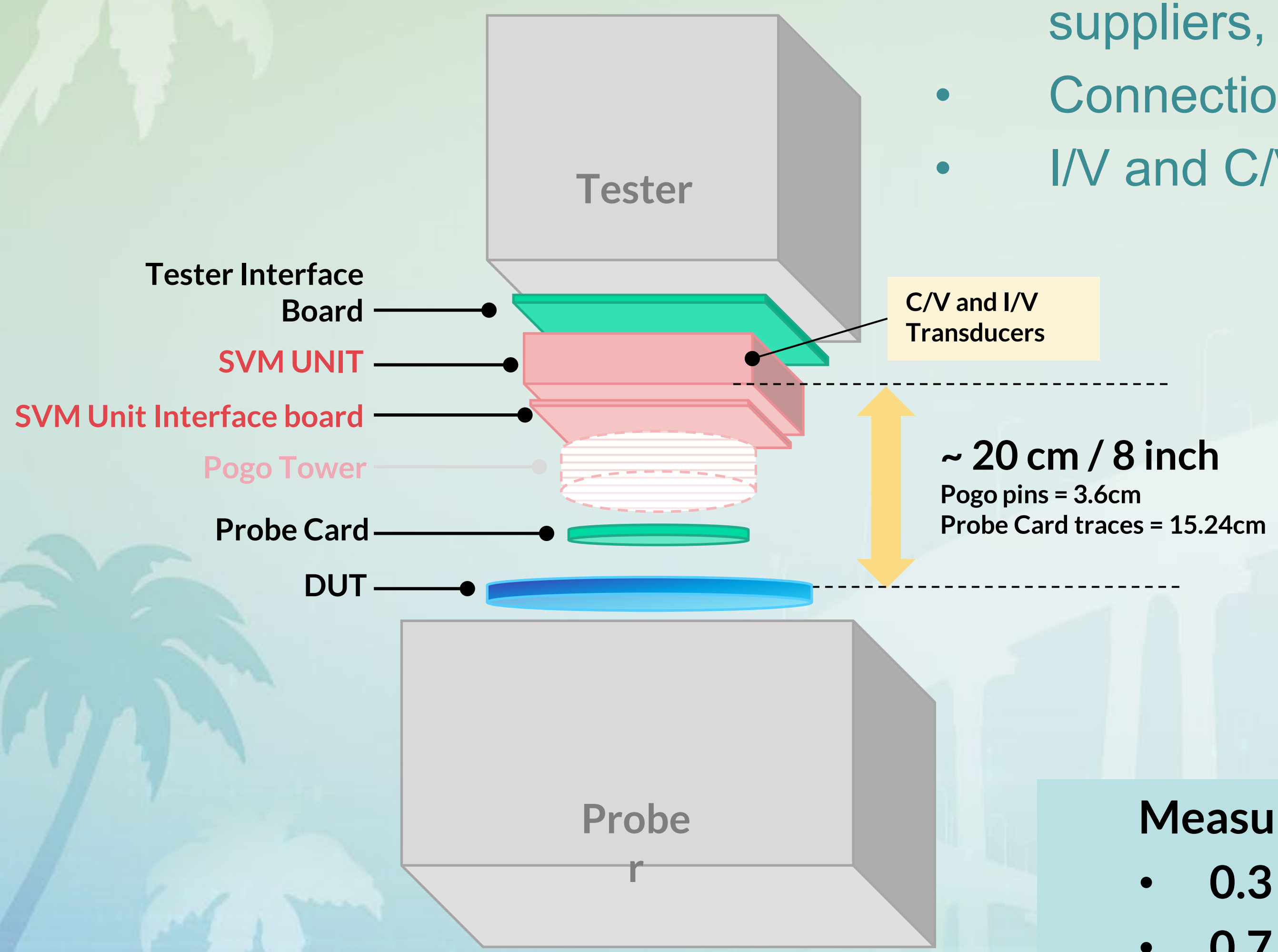
- Pogo tower docking
- Connection ensured by the pogo pins of the Interface
- Measurement tools have been moved inside the test head, closer to the DUT
- I/V and C/V Transducers inside the SVM Unit





2 – Direct Docking with SVM Box

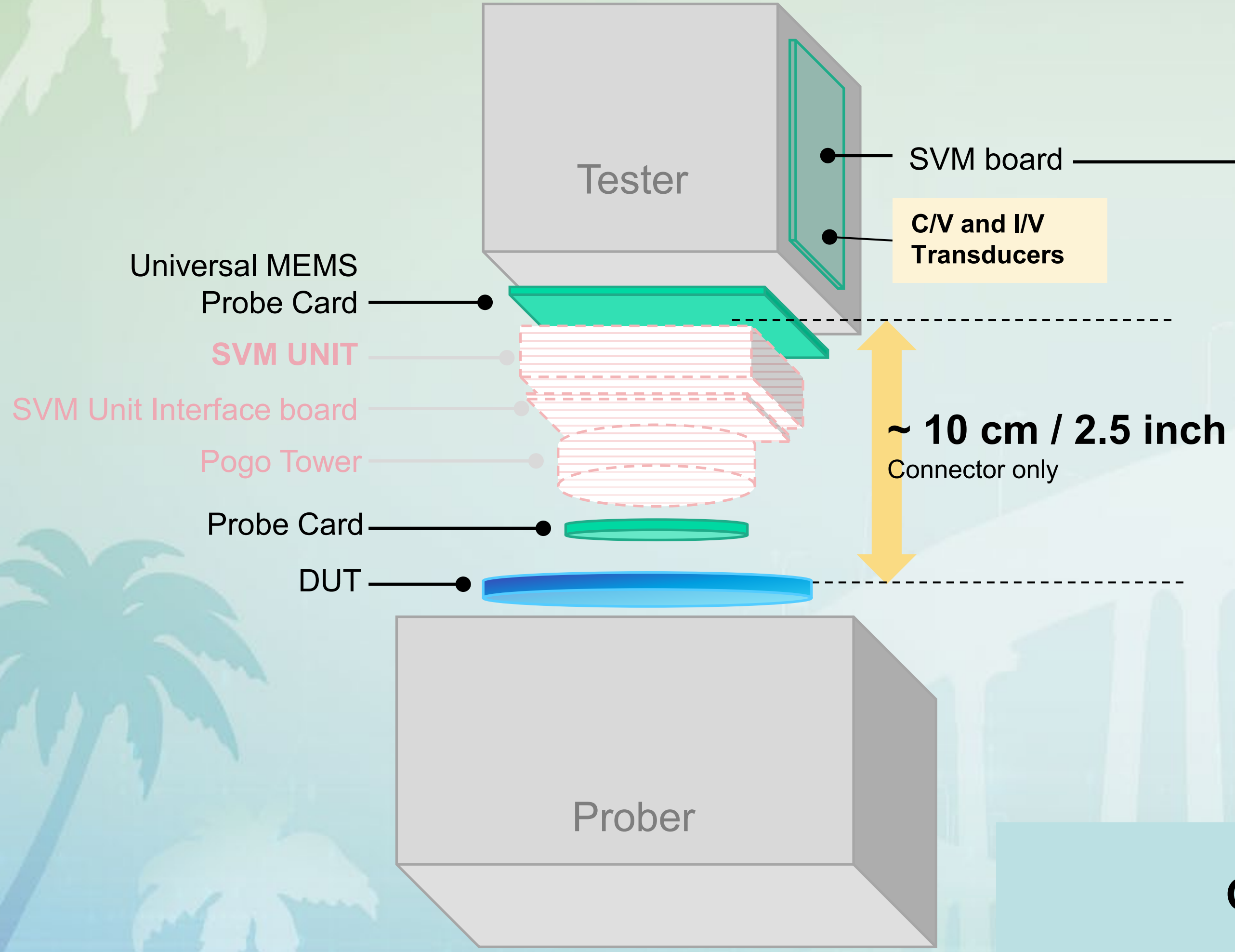
- Direct docking (compatible with all major prober suppliers, like Accretec, TEL, …)
- Connection ensured by the pogo pins of the Interface
- I/V and C/V Transducers inside the SVM Box

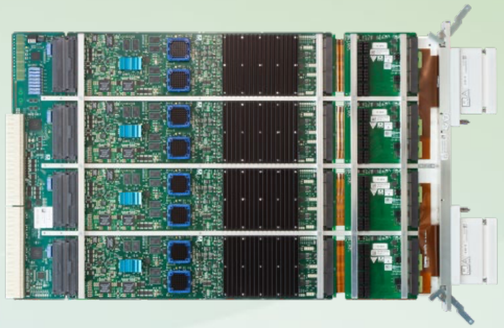


Measurement accuracy in this setup is:

- **0.3 fF @ range 5 pF for the capacitance measurements**
- **0.7 pA @ range 100 pA for the current measurements**

3 – Direct Docking with In-Tester SVM (on-going)





- Direct docking minimizes connection length and number of interconnections
- No additional hardware on probe cards: both the boards are just point-to-point connections
- Integrated C/V and I/V transducers on SVM board, inside the tester

Capable of reaching std deviation of 300 aF

Probing Technology Requirement

- Vertical probing is required due to automotive application
- There is a proprietary zero calibration method prior to testing
- To qualify probe card must pass high insertion for about 2 Million mechanical cycle
- Pass GRR of less than 10%
- Mechanical CPK must be higher than 1.67
- Capabilities to probe dual layer Shield Vs Pad

Universal probe card design

- Standardized card design with replaceable contactor pins
- Economic benefits:
  - Reduced development time and cost.
  - Increased flexibility and scalability.
  - Simplified maintenance and troubleshooting.

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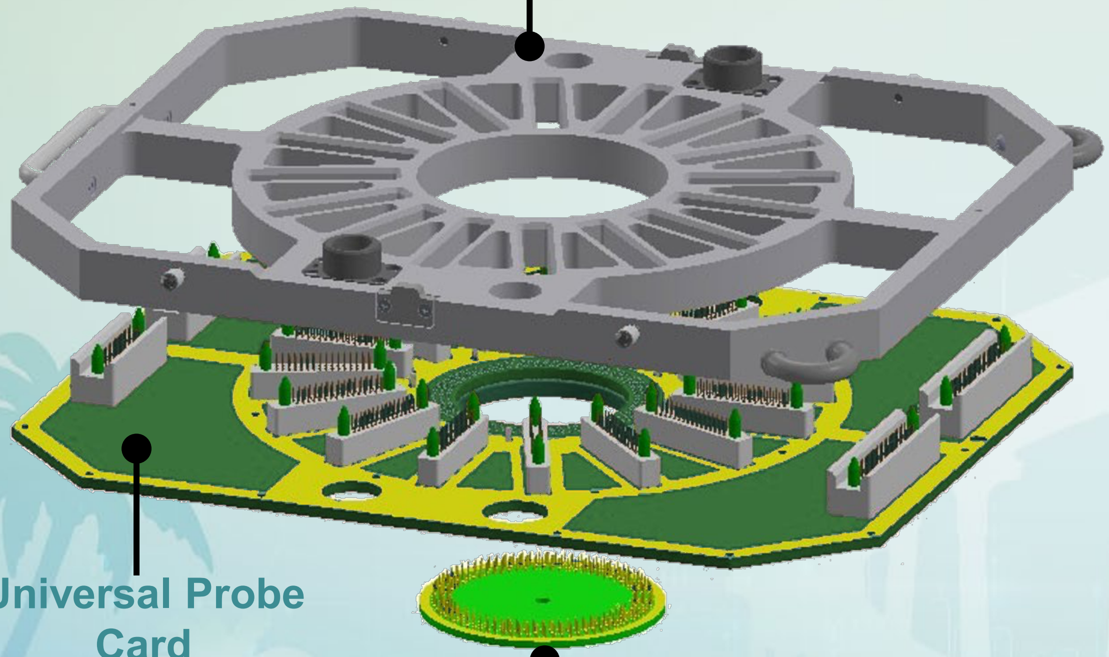
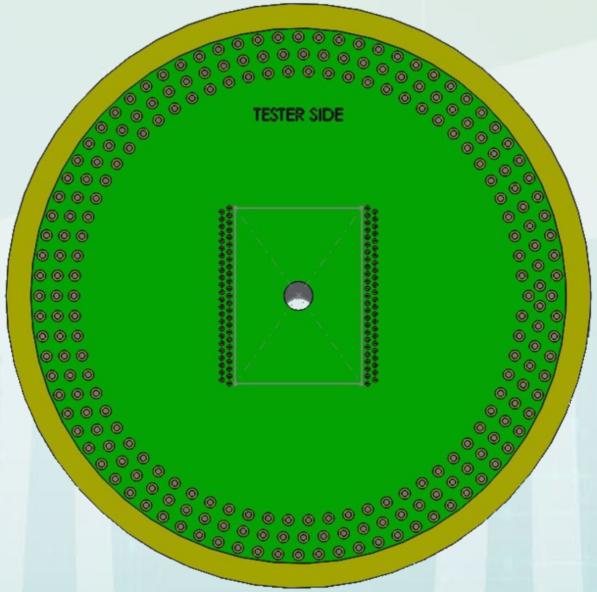
Universal MEMS Probe Card

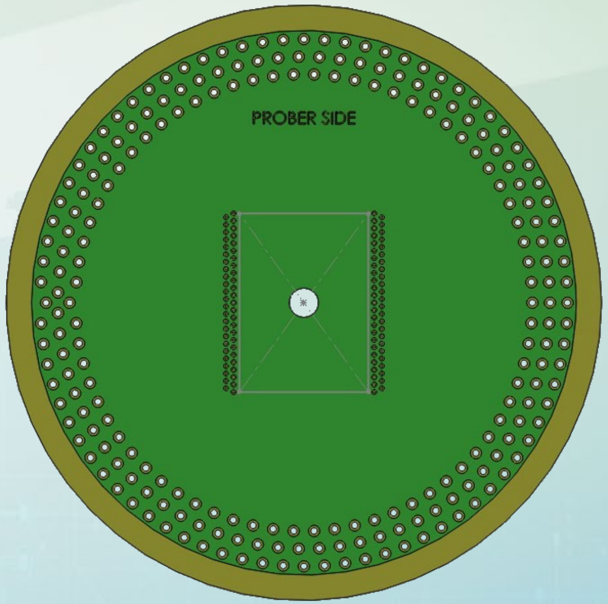
A universal probe card can be used for different projects, just replacing the contactor block.



Probe card PCB
Tester Side



Probe card PCB
Prober Side



This small PCB is the only application-dependent element

Section 2

MEMS TESTING

Measurement Challenges

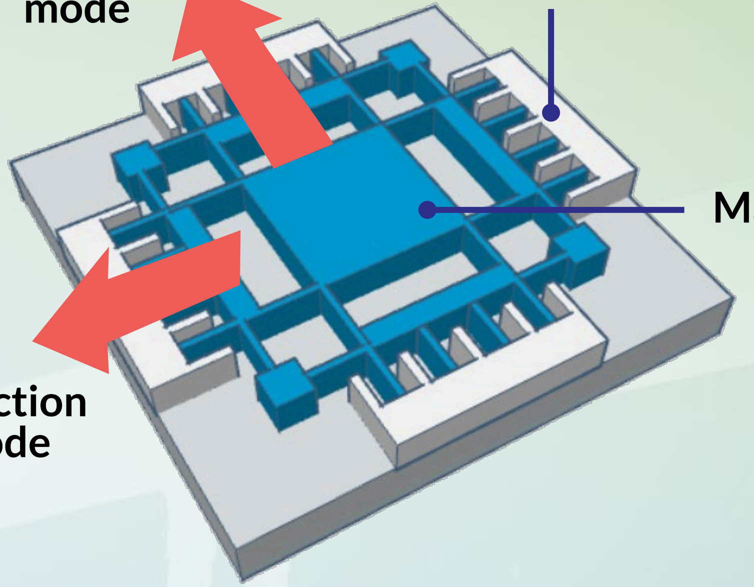
- Stop using home-made custom rack & stack equipment
- Start using standard prober and ATE (Automatic Test Equipment)
  - Measurement of MEMS using standard ATE
    - What type of MEMS: accelerometers, gyroscopes, pressure, magnetic sensors
    - This presentation will cover three-axis accelerometers
    - Perform high-accuracy, repeatable Measurement: Capacitance, Spring Constant C to V curve, and Frequency resonance, 2 GOhm leakage

Section 2.1

ELECTROSTATIC STIMULATION

MEMS Sensor - Electrostatic Actuation

- **MEMS accelerometers use a mobile proof mass that changes the distance between capacitor plates.**
- **When the accelerometer experiences acceleration, the proof mass moves, altering the capacitance.**
- **During wafer testing, we cannot physically move the device to simulate acceleration.**



ELECTROSTATIC STIMULATION

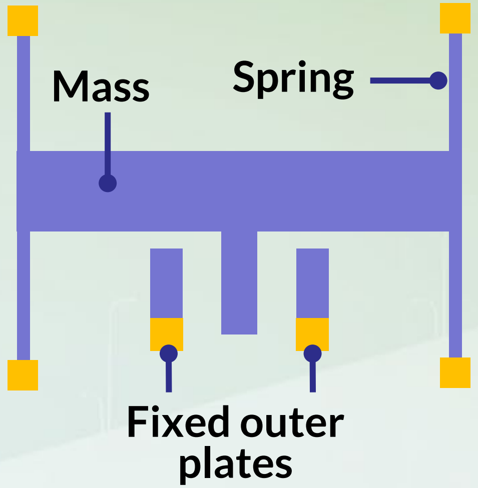
- We apply a DC voltage to fixed electrodes to attract or repel the proof mass.
- This electrostatic force causes a change in capacitance, mimicking the effect of acceleration.
- By measuring this capacitance change, we can determine the accelerometer's the change in capacitance creating a C/V curve and calculation of spring constant

LUCA

Principles of Electrostatic Actuation

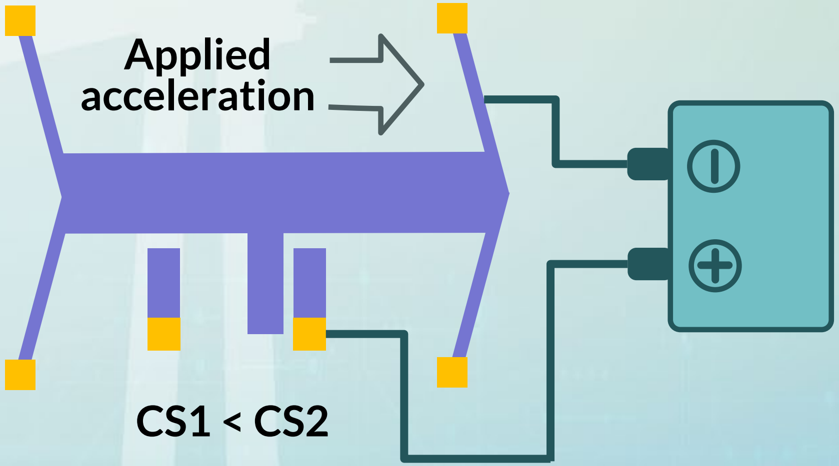
Force Generation: Voltage applied to electrodes creates electrostatic force. $F=\epsilon A(V^2)/2(g^2)$

- F: Electrostatic Force
- ϵ: Permittivity
- A: Electrode Overlap Area
- V: Applied Voltage
- g: Gap Distance



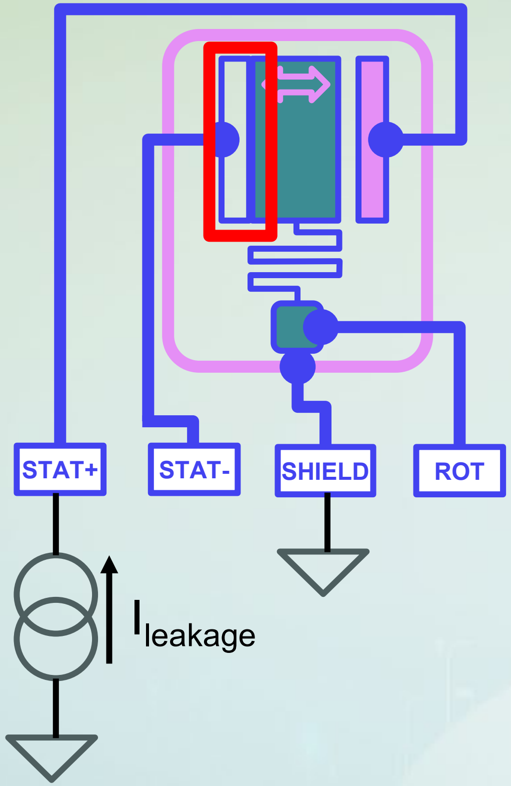
DC Stimulation: Applying a DC voltage attracts or repels the mobile parts, changing the capacitance. This allows us to measure parameters like stiffness and the gap between structures.

Dynamic Characterization: AC stimulation enables resonance and Q-factor measurement.



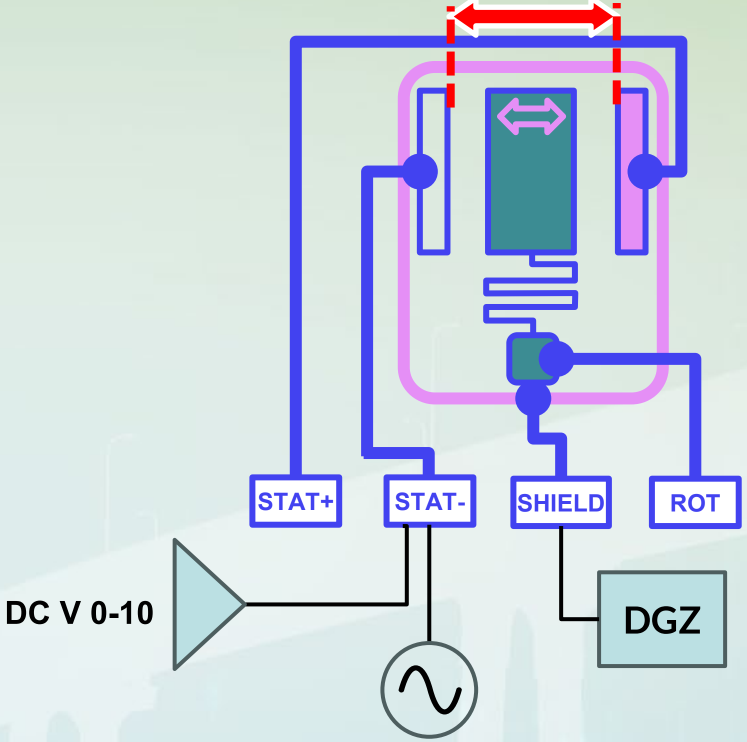
C-V: Measuring how the capacitance changes with the applied voltage (Capacitance-Voltage or C-V measurement) provides information about the displacement of the MEMS structure.

Defects Found for Each Test



LEAKAGE (CURRENT)

One of the 2 plates (or both) in contact with the central mass

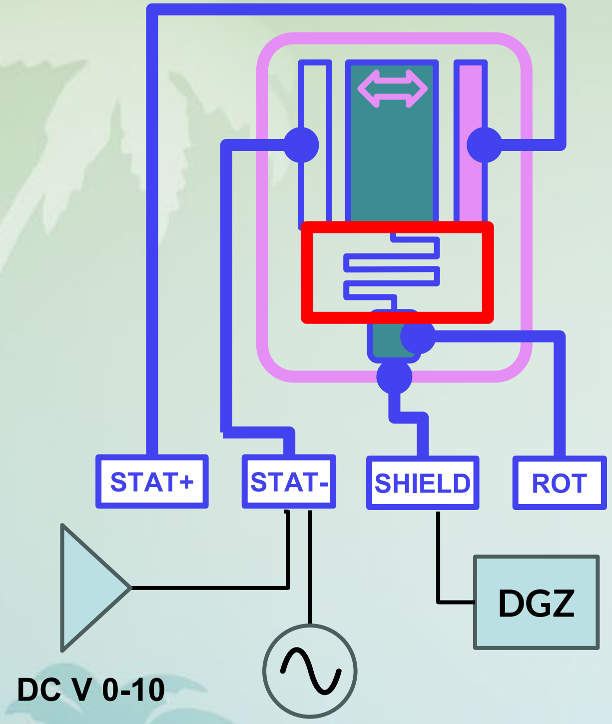


AXIS CAPACITANCE:

Defect on the distance between mass and 2 plates:
Far plate = lower capacitance
Near plate = higher capacitance

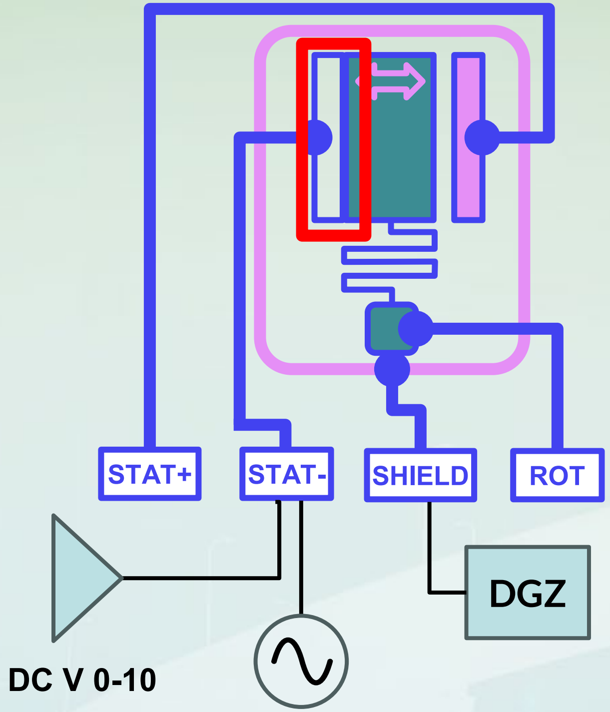
Defects Found for Each Test

LUCA 2



AXIS CAP DELTA
(C@0V-C@10V)

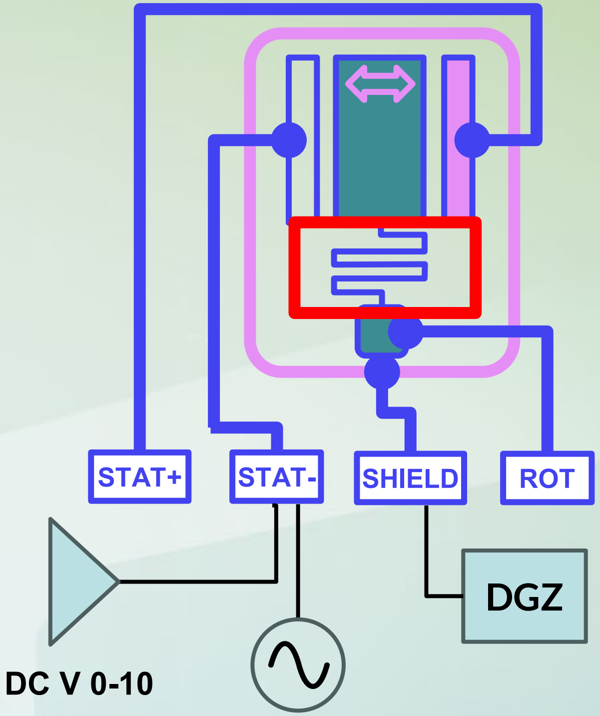
Sensor with an incorrect elastic constant (DC makes it move away or closer)



AXIS HYSTERESIS

Device that was damaged during the test

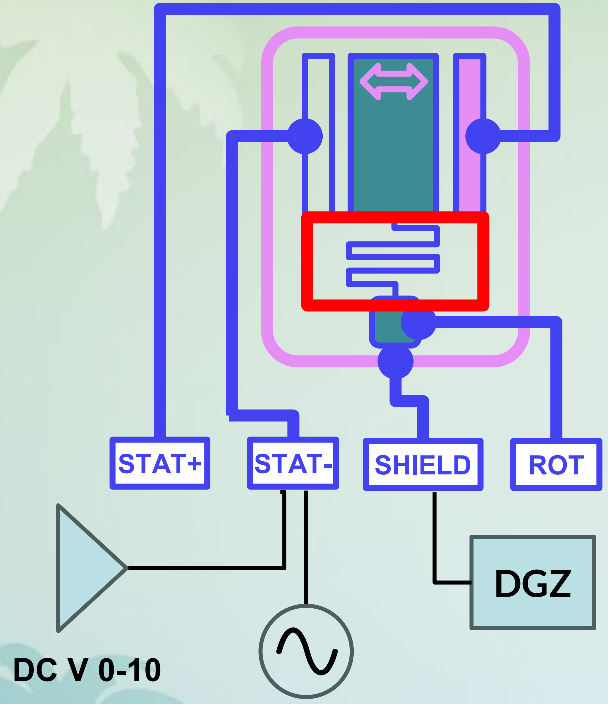
- 0V DC (initial position)
- 5-10V DC
- 0V DC (final position: same as initial)

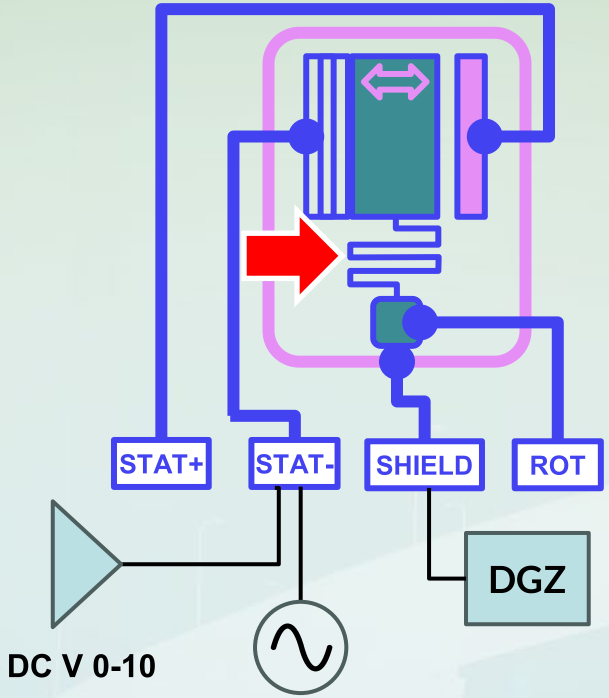


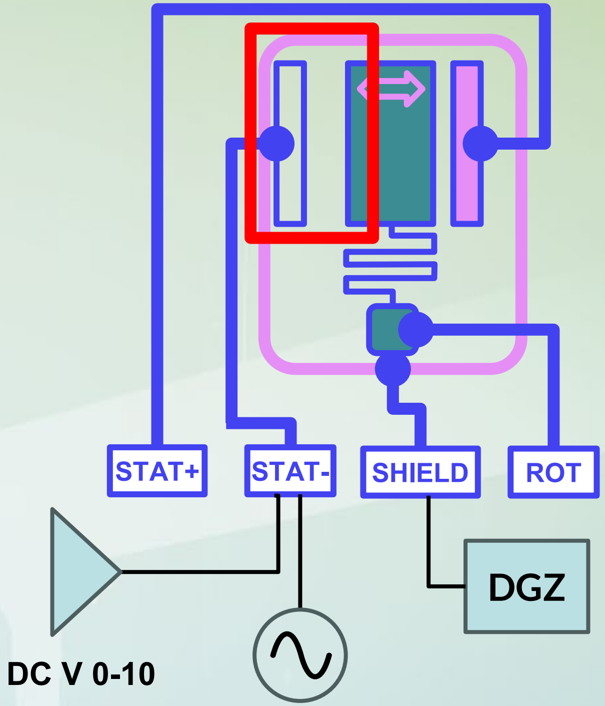
AXIS MISMATCH
(C+@0V = C-@0V)

Asymmetry in the Capacitance measurement at one sense plate+ versus the capacitance measured at the sense plate-

Defects Found for Each Test







PULL-IN

DC voltage increased until the stator is attracted in contact with the rotor:

- High voltage (device too rigid)
- Low voltage (device too flexible)

STICTION

After the pull-in test, the device may remain stuck (→ stiction)

RESONANCE/QUALITY

Wrong resonance frequency range or low quality factor indicates process issues (encapsulation)

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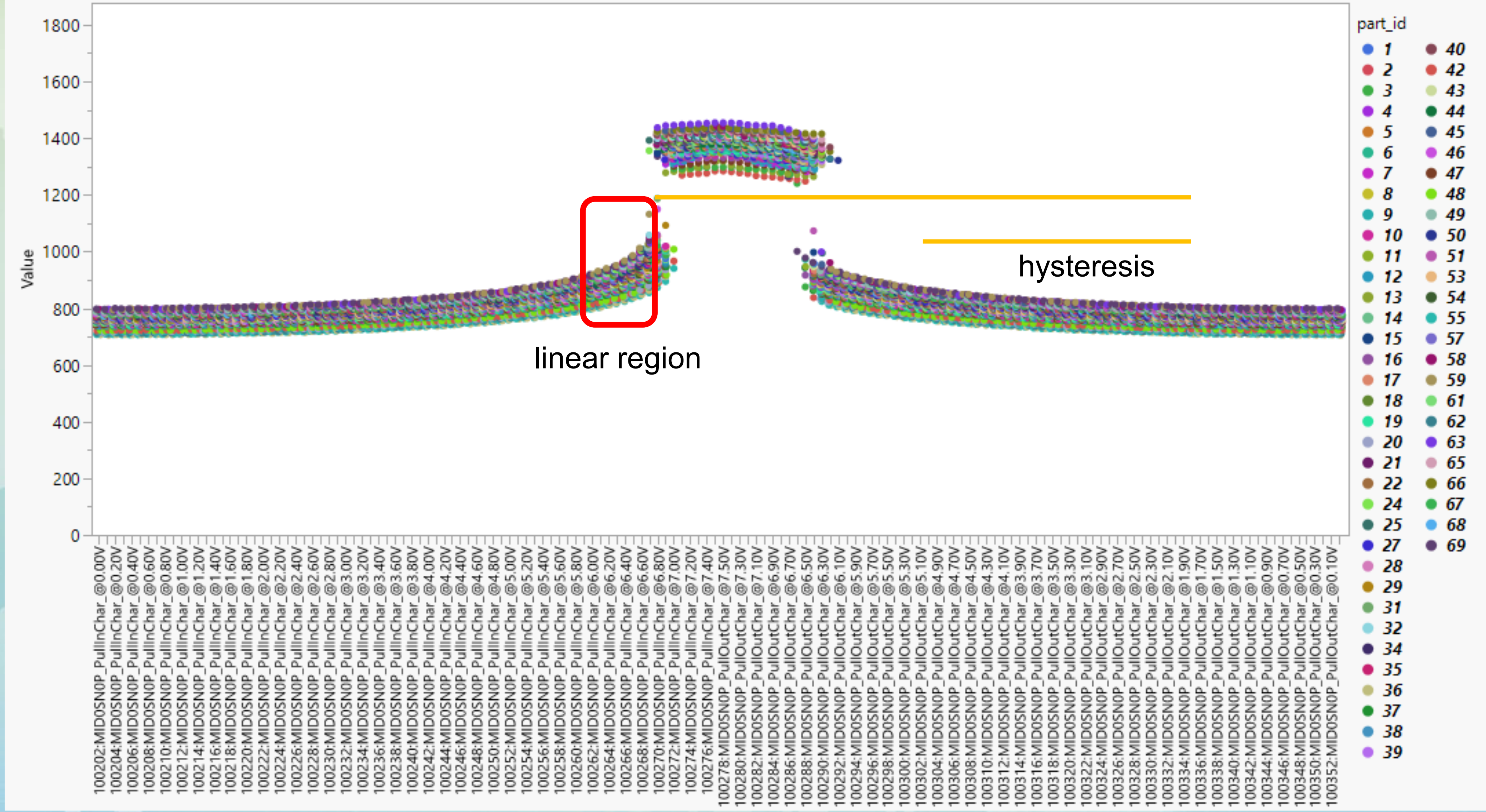
Effects of Electrostatic Actuation



Section 2.2

ACCURATE MEASUREMENTS

Precise measurements of minute parameters

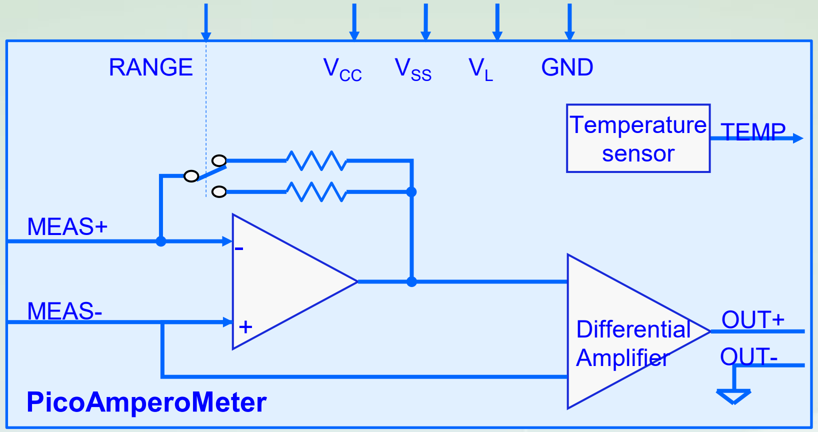
High-precision measurements are crucial to identify subtle defects:

- **fF Capacitance measurements** for determining minute changes in proof mass position
- **pA Current measurements** ensure absence of stray leakage due to physical defects in the MEMS structure
- **µV Voltage measurements** are necessary to accurately measure voltage changes in response to infrared variation on temperature sensors
- **Impedance/resistance (KΩ, pF)** are needed to identify stray series resistance in MEMS structures
- **mΩ/GΩ Resistance measurements** (4-wire configuration) are used to measure Wheatstone bridges structures in MEMS pressure sensors.

Transducer Current Meter

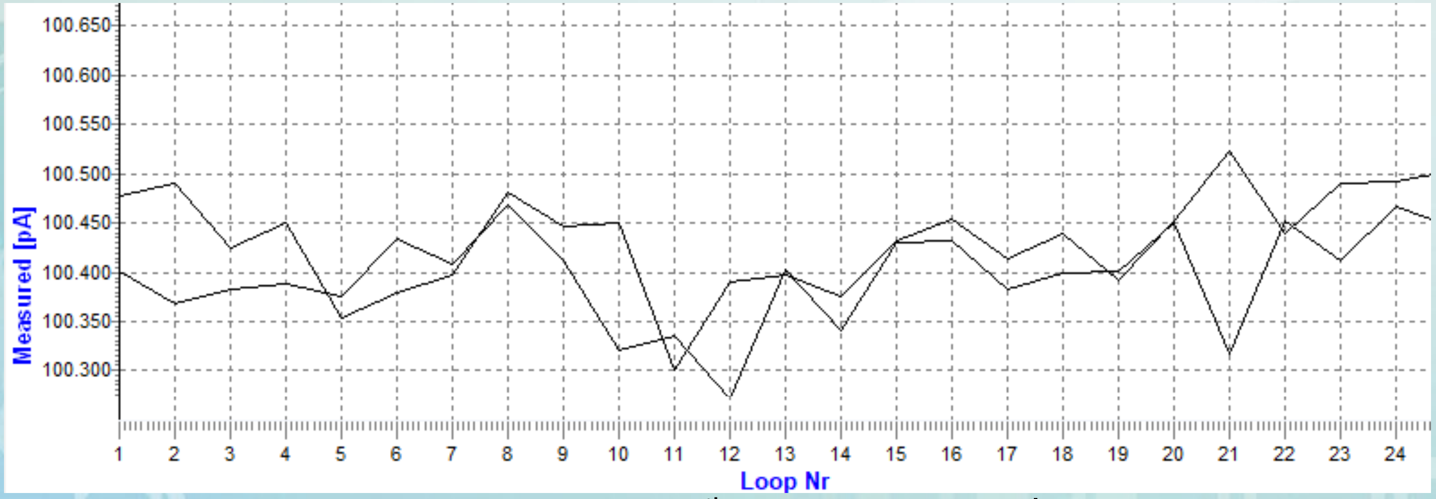
Repeatability characterization

Instrument Current Range: 100pA - 1µA



External calibration unit

REPEATABILITY @ Range 100pA (Accuracy 0.7pA)



This graph shows the repeatability of a 100pA measure.

Noise is in the order of femtoAmpere.

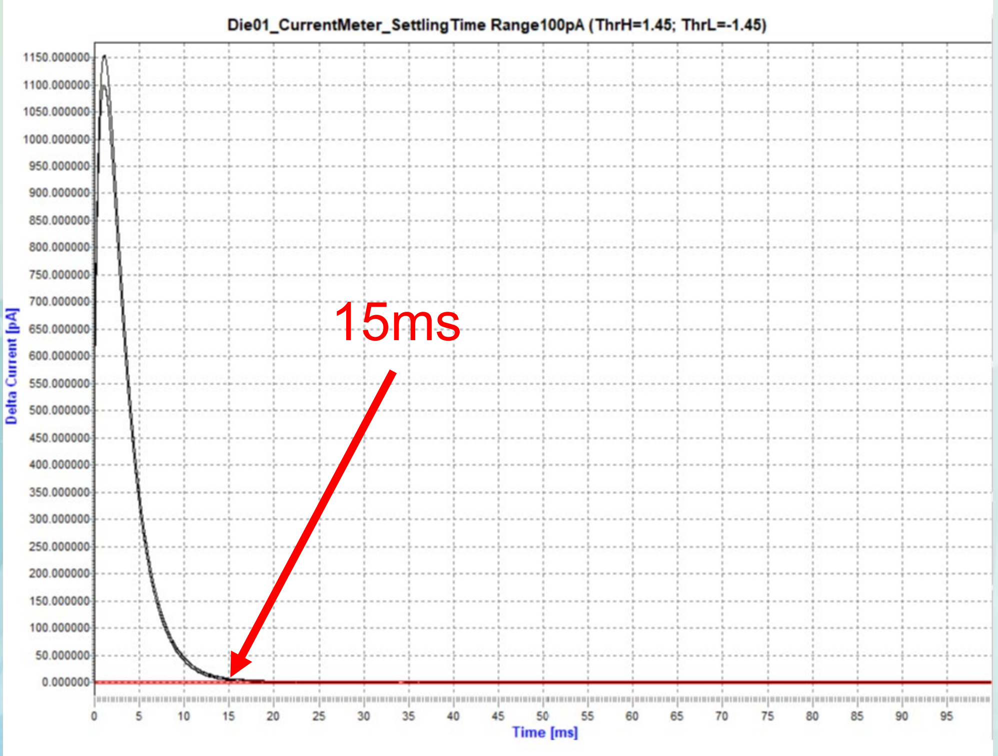
Transducer Current Meter

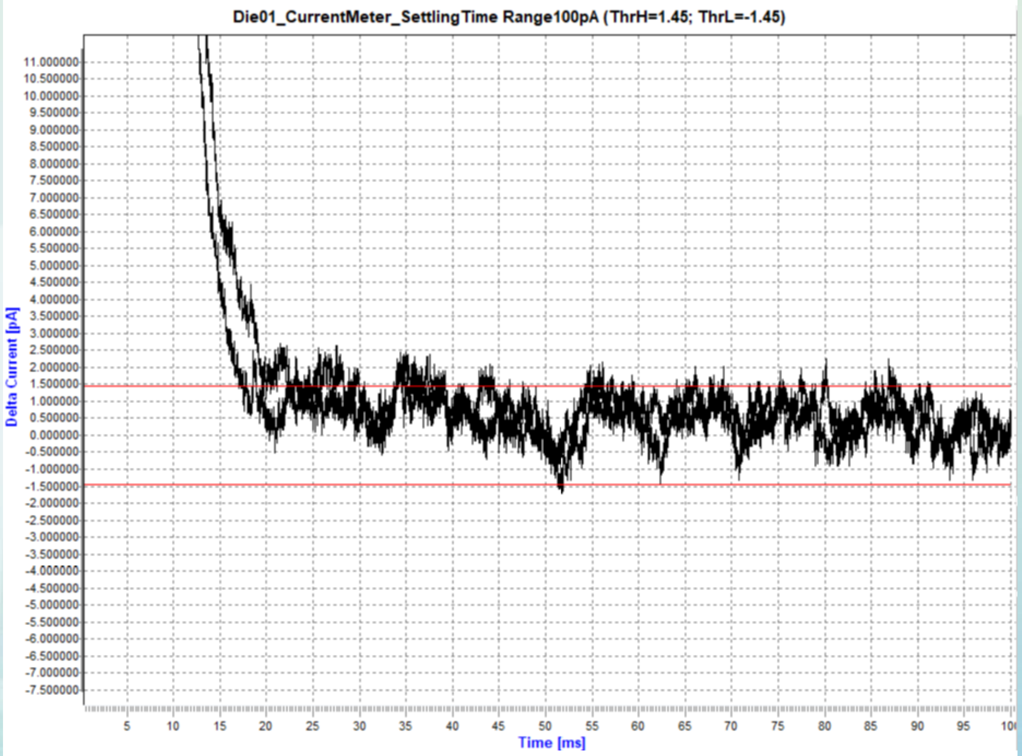
Settling Time Characterization

Since the feedback resistance of R100pA is 20Gohm the settling time is significantly large.

I.e. 1Tohm with 1V has a slew rate of 1sec if C is 1pF

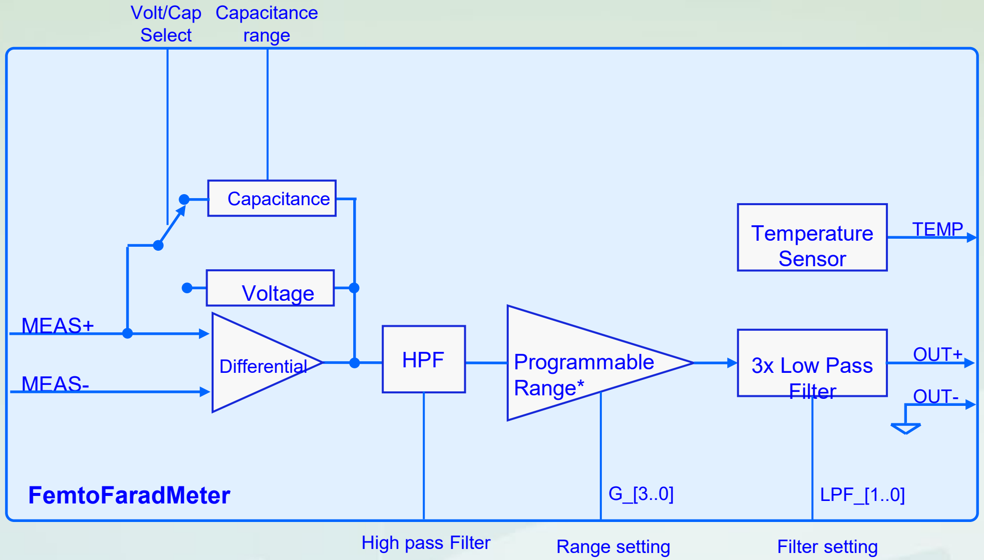
After 15ms however the accuracy is already inside the +- 1.45pA window



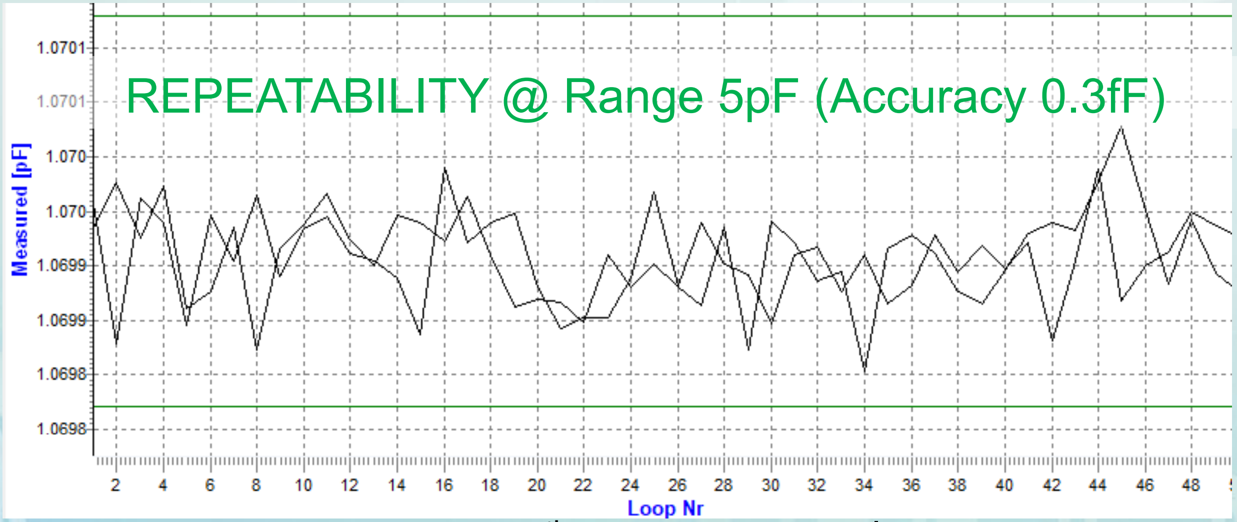


Transducer Cap/VoltMeter
Repeatability characterization

Instrument Capacitance Ranges:
0-5pF | 0-500pF



External calibration unit

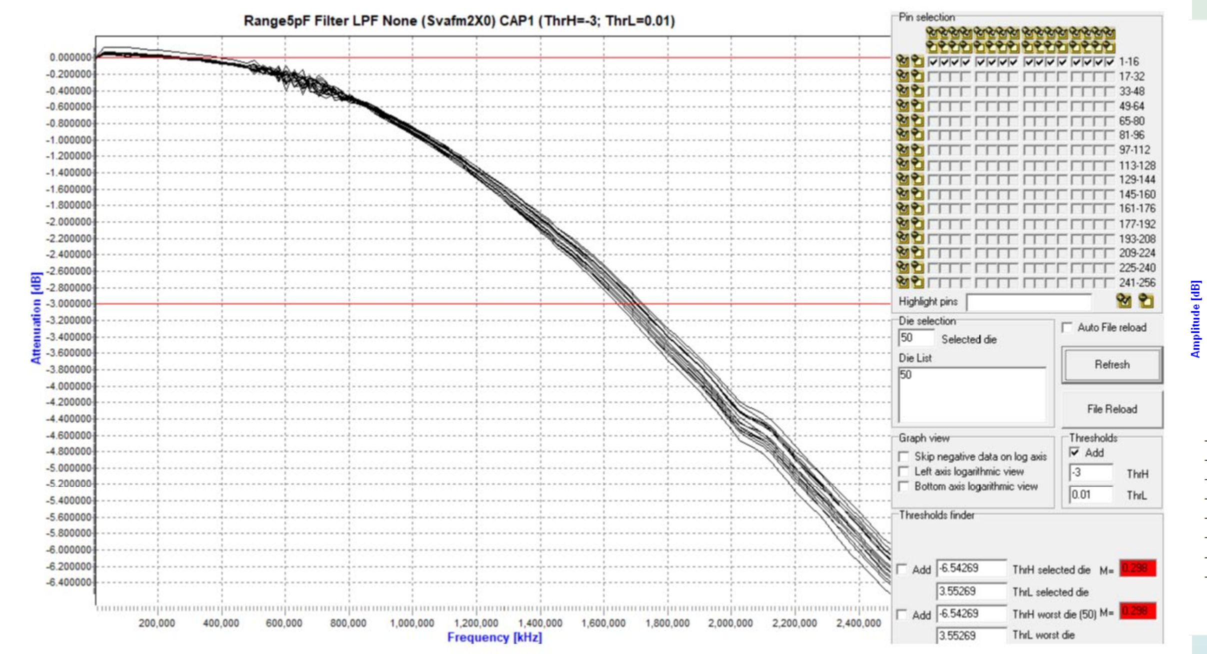


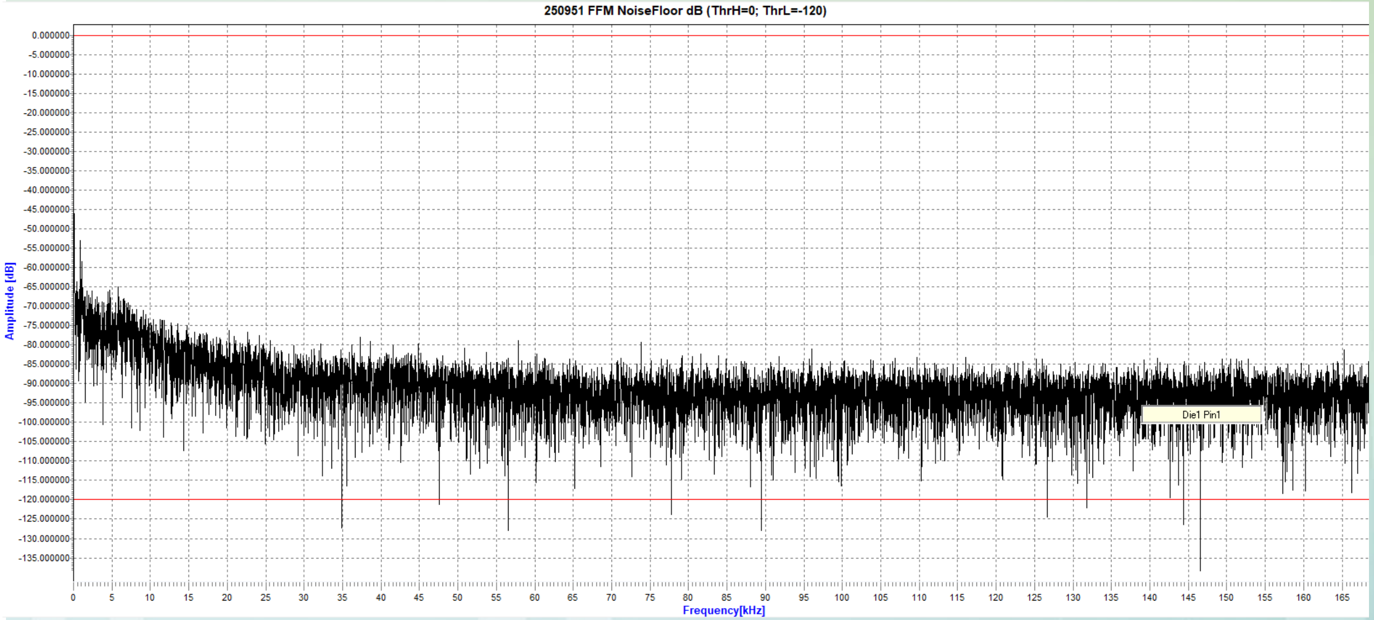
This graph shows the measurement repeatability while measuring a 1.07pF reference capacitance with the calibration unit.

Standard deviation is shown in the order of +/- 300amtoFarad.

Capacitance Meter Bandwidth

1.5MHz BW allows to perform capacitance measurements stimulating the sensor at 1MHz – Far enough from the 4-5 kHz resonance frequency for accelerometers and/or 20-30KHz resonance frequency for gyroscopes.





0.1 dB actual Bandwidth is 500kHz

3 dB actual Bandwidth is 1.5MHz

Actual noise floor is -85 dB

Section 3

RESULTS

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Case Study Results

- NXP conducted a manufacturing qualification of the test setup
- Results from the DOT800 system completed all qualification and requirements.

Qualification Requirement	Acceptance Criteria	Result	
GRR on all capacitance measurements • 3 wafers each from 3 lots • 3 repeats • 1 wafer = 13,000+ die	GRR < 10%	**PASS**	All parameters <10% GRR Worst parameter at ~6.5%
Correlation of C0 measurements on 3 total wafers, 2 lots (1 wafer = 13,000+ die)	R Square > 0.90 & P value > 0.05	**PASS**	All parameters R Square > 0.9 Worst parameter at ~0.92
Kappa, correlation of BIN performance by probe card • 1 wafer • 3 different probe card hardware	Criteria: Yield Limit: 3%	**PASS**	Yield Limit < 3% (1.26% worst case)
Kappa, correlation of BIN performance by wafer • 3 wafers each from 3 lots	Pass Bin: 3% Fail Bin: 6%	**PASS**	Worst match 2.97%
Yield (Class A) • 3 wafers each from 3 lots	Within typical range	**PASS**	Yield from 9 wafers: 85.1 +- 6.8% Yield expectation: 73.2 +- 7.7%

Conclusions

The NXP-SPEA engineering efforts produced several sensible results in:

- Improved test quality
  - GRnR <10%. Extremely desirable for automotive and consumer applications
- Direct docking advantages
  - Easier product industrialization, simpler diagnostics and calibration maintenance, and higher robustness in production environment
- Improved test coverage
  - Better pre-screen of faulty devices at wafer level, improving final test yield
- Increased test parallelism
  - Ability to increase parallelism from WTx2 (legacy platform) to WTx16 (current SPEA solution) to WTx64 (on-going SPEA/NXP project)