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Proof-of-Concept: Integrating low capacitance measurement into ATE

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Contents

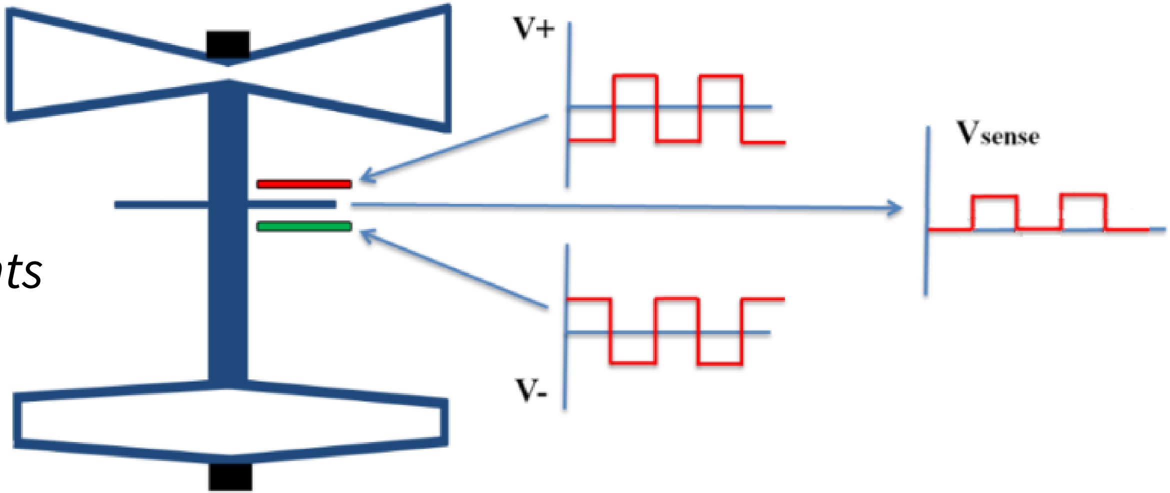
1. Introduction

Introduction

- The use of MEMS is growing.
- One of the biggest applications: Sensing.

$$C = \frac{\varepsilon_0 A}{d}$$

Capacitive Read-out offers:



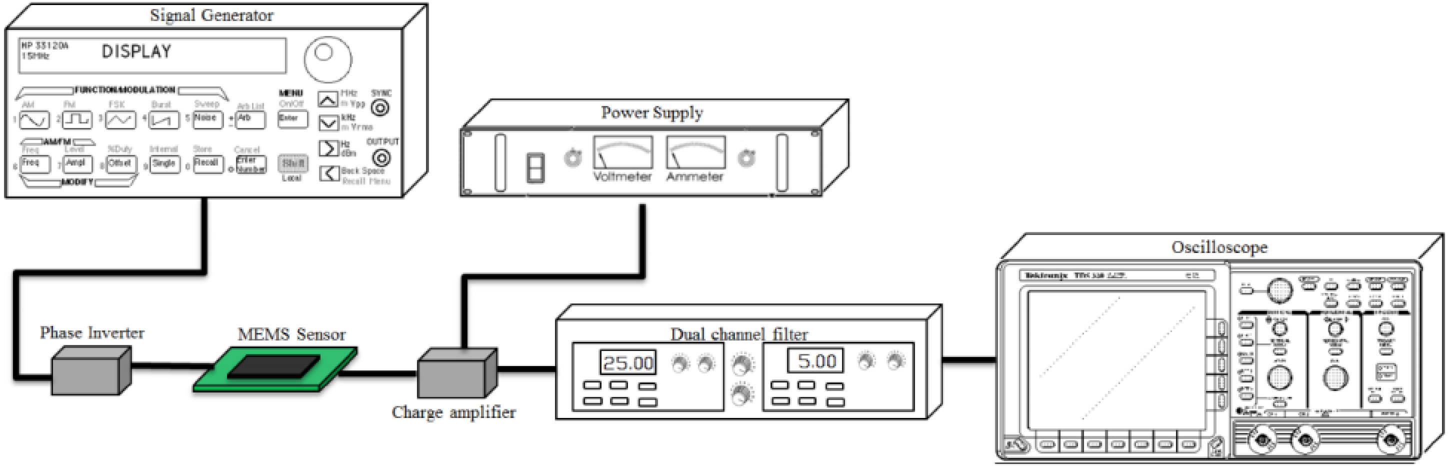
Low

- ➢ *Temperature Coefficients*
- ➢ *Power Dissipation*
- ➢ *Noise*
- ➢ *Fabrication Cost*

2. Motivation

Our motivation

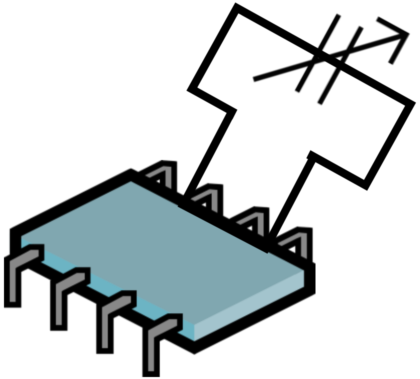
- Due to the advantages and widespread use of Capacitive read-out, we want to create a measurement system that is:
  - ▶Accurate
  - ▶Repetitive
  - ▶Small footprint



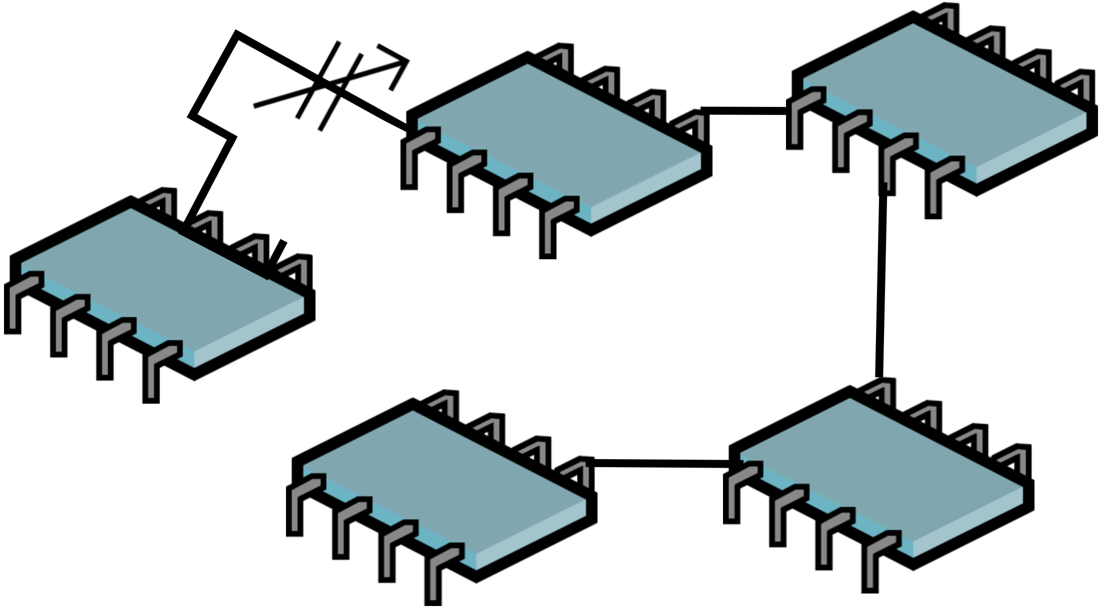
3. Design

The design options

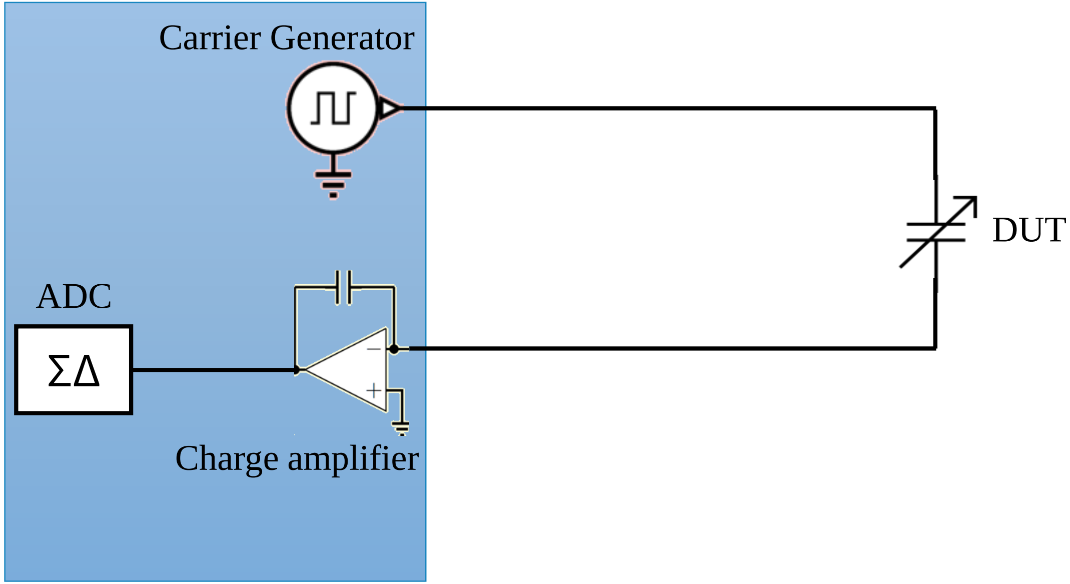
- *Single chip*



- *Multichip*

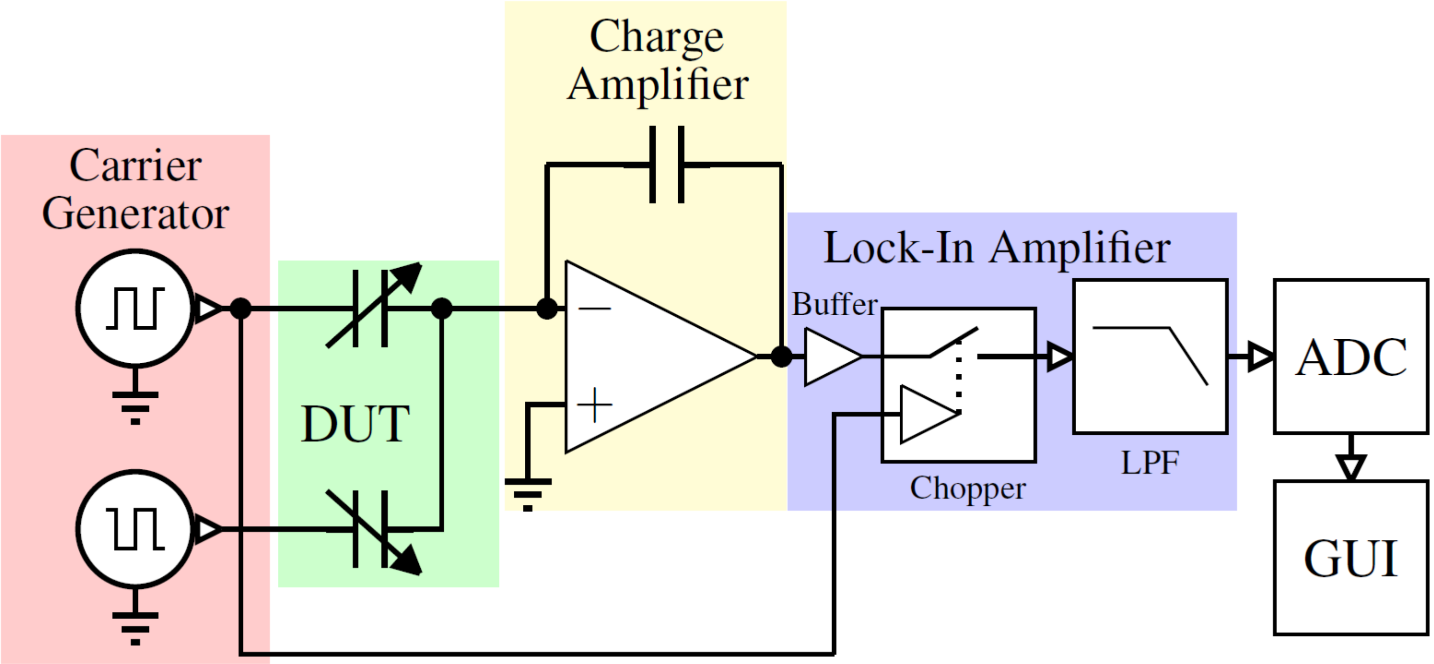


Single Chip Design Overview



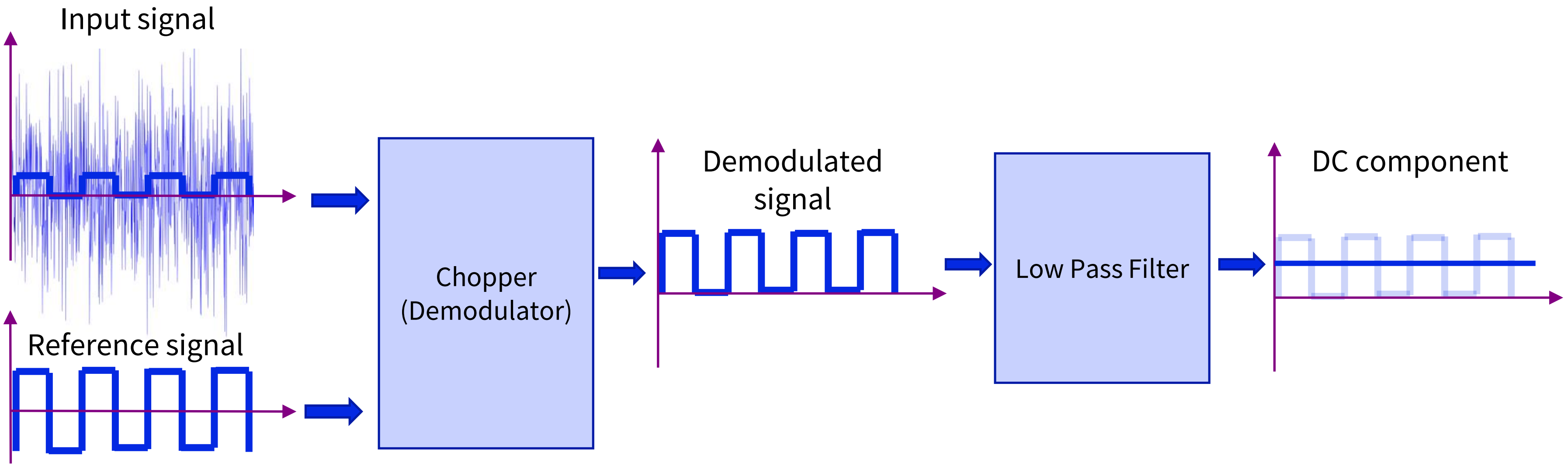
Block diagram showing the main components of the *single chip* capacitance measurement system.

Multichip Design Overview



Block diagram showing the main components of the *multichip* capacitance measurement system.

Lock in amplifier



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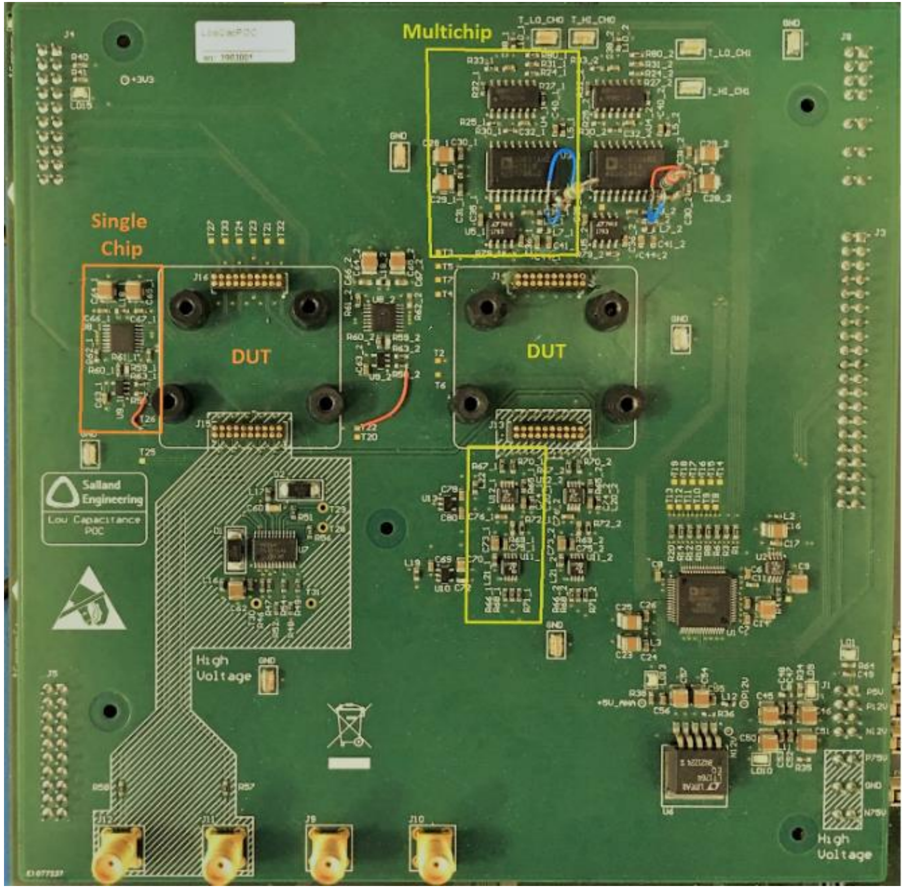
PoC PCB

- PCB with 2 single-chip channels, 2 multi-chip channels and a high voltage MEMS driver.



4. Specifications

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Salland's Low Capacitance Measurement solution

Target Specifications

- Target to a 8-16 channel Low capacitance PXIe instrument
  - ▶ Range: sub pF (extendable to nF)
  - ▶ Accuracy: ≈ fF, Resolution: aF
  - ▶ Frequency up to 2MHz (extendable to higher frequencies)
- Suitable for high volume
  - ▶ High parallel => many channels, small =footprint, "immune for long wires"
  - ▶ Efficient => Fast measurements and high Parallel efficiency
- Develop the technology to use it in several formats
  - ▶ PXIe (8-16 ch), Modules, ATE, etc.
  - ▶ MEMS, IoT Market, etc.

Comparison to equipment available in the market

	Target	**Analog Output**	**Salland** (Single chip)	**Salland** (Multichip with current design)
Capacitance Range	±4pF	0.25pF to 10pF	±4pF	±7.5pF (0fF to 7500 fF differential)
No. of Ranges	1	1	1	1
Settling time	-		65ms (min 11ms max 110ms)	3ms
Sensitivity	4fF		4fF	2fF~4fF
Resolution	24 bit	4aF/√Hz	24 bit (4 aF)	18 bit (≈ 200 aF)
Carrier Frequency	-	100kHz	20kHz or 10kHz	100kHz to 300kHz
Carrier Amplitude		2.25 V	3V	1.8V
Noise			±1fF	±4fF

5. Results

Accuracy of low capacitance meter

Measured Capacitance	Single Chip		Multichip		Noise Multichip (fF)
	Ch1 (fF)	Ch2 (fF)	Ch1 (fF)	Ch2 (fF)	
0.0pF (Open circuit)	0.4	0.4	-2.35	-0.15	±3
0.47 pF ± 0.25pF (N_Inv)	-	529.29	-	527.37	±2
0.56 pF ± 0.25pF (Inv)	-	-604.71	-	-600.96	±2
0.47pF - 0.56pF	-	-73.06	-	-71.83	±3
1pF ± 0.25pF (N_Inv)	1006.12	-	1007.30	-	±4
0.82pF ± 0.25pF (Inv)	-821.42	-	-816.93	-	±4
1pF-0.82pf	186.64	-	192.62	-	±3
0.47pF – 0.47 pF	-2.21	-	-1.99	-	±1
1.2pF ± 0.25pF (N_Inv)				1153.12	±4

Measurements of known capacitance on DUT board.

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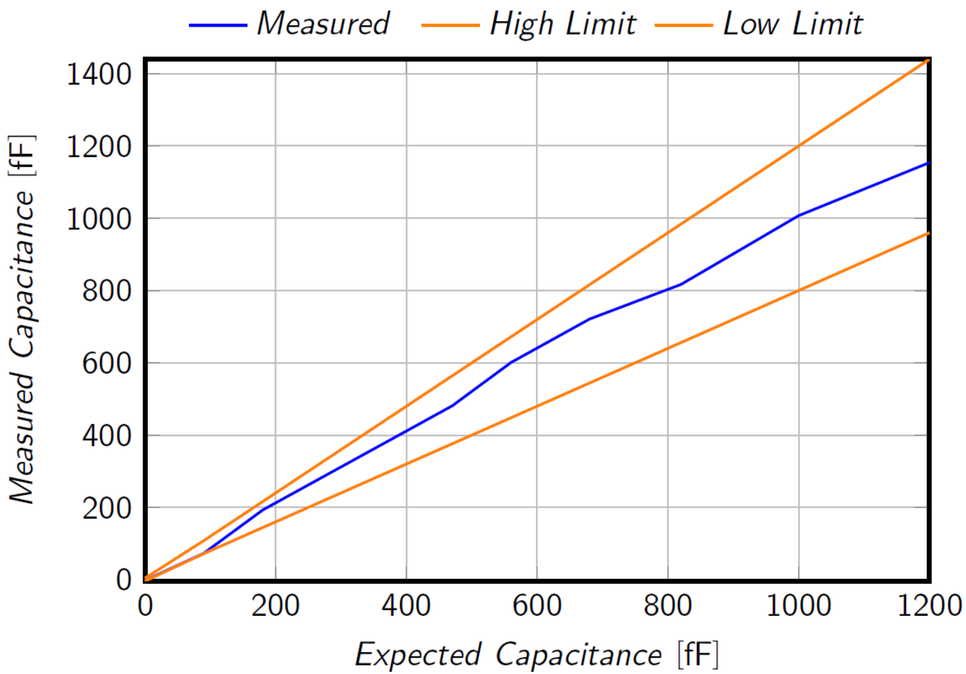
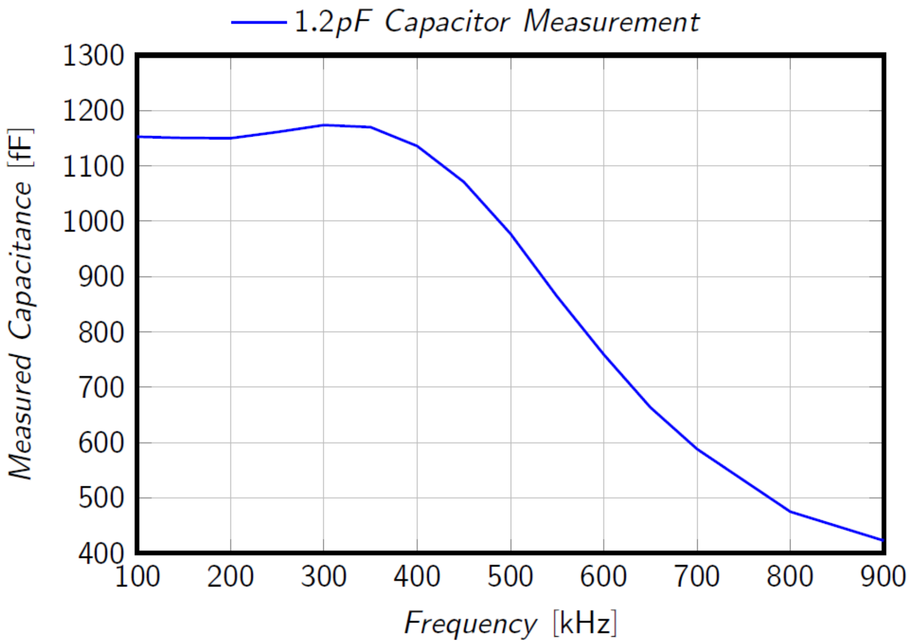
Accuracy of low capacitance meter

- The expected capacitance is measured from capacitors with ±20% tolerance.
- Measurements executed on 0, 90, 180, 470, 560, 680, 820, 1000 and 1200fF.

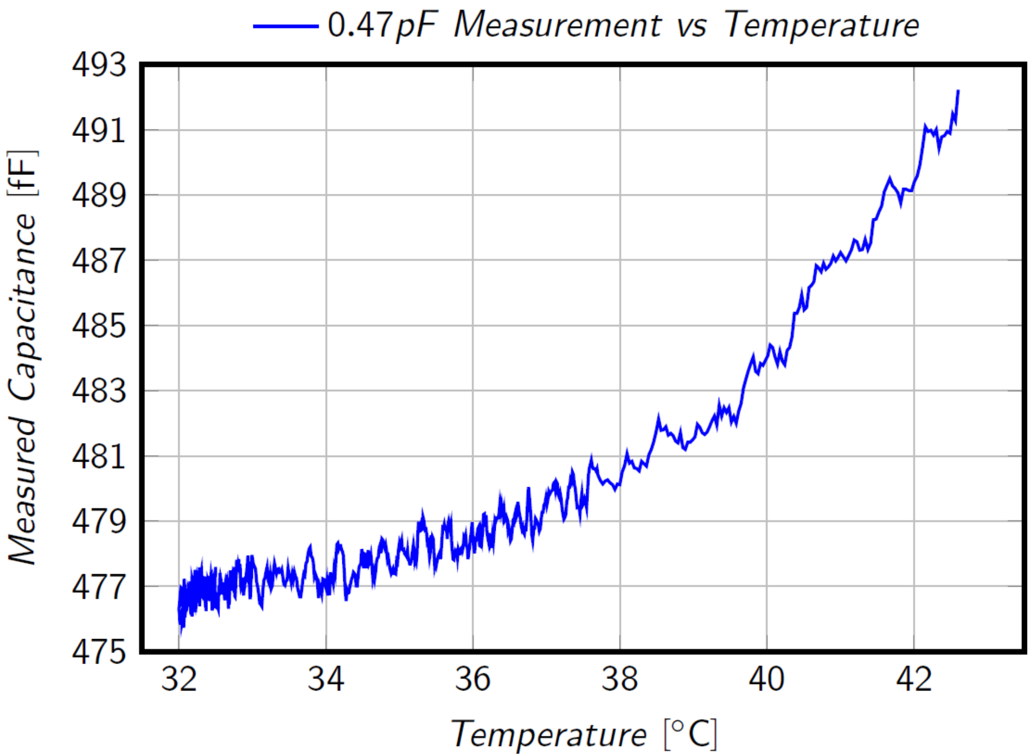


Effect on measured capacitance from carrier frequency

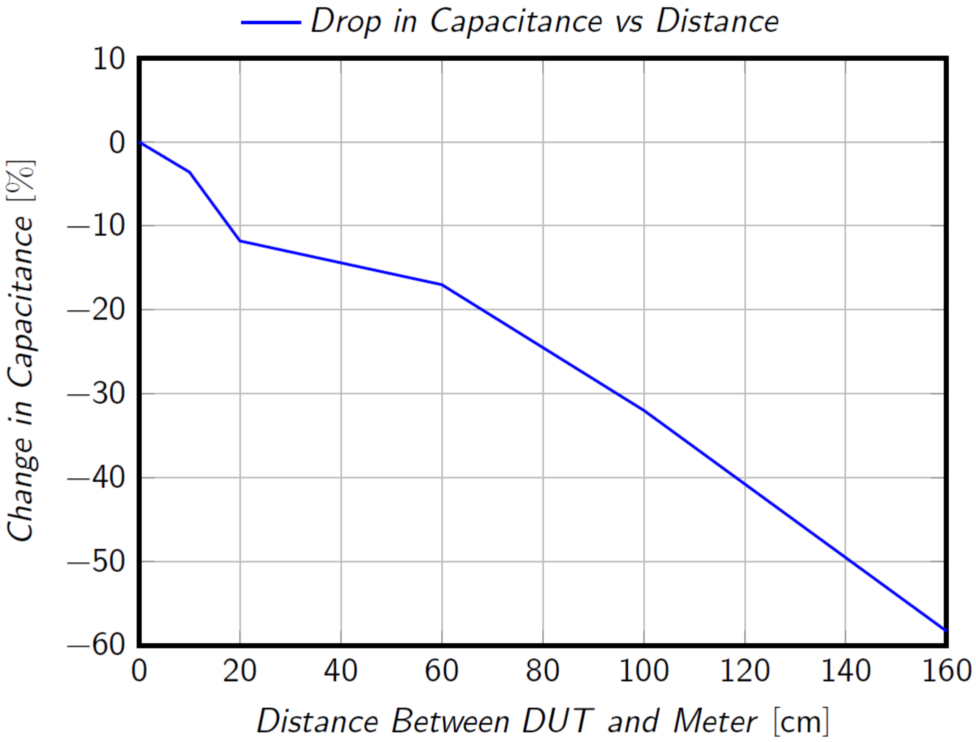
- These measurements where taken with the current hardware of the Low Capacitance POC.
- The bandwidth of the system can be increased by changing some components.



Temperature influence in capacitance measurement



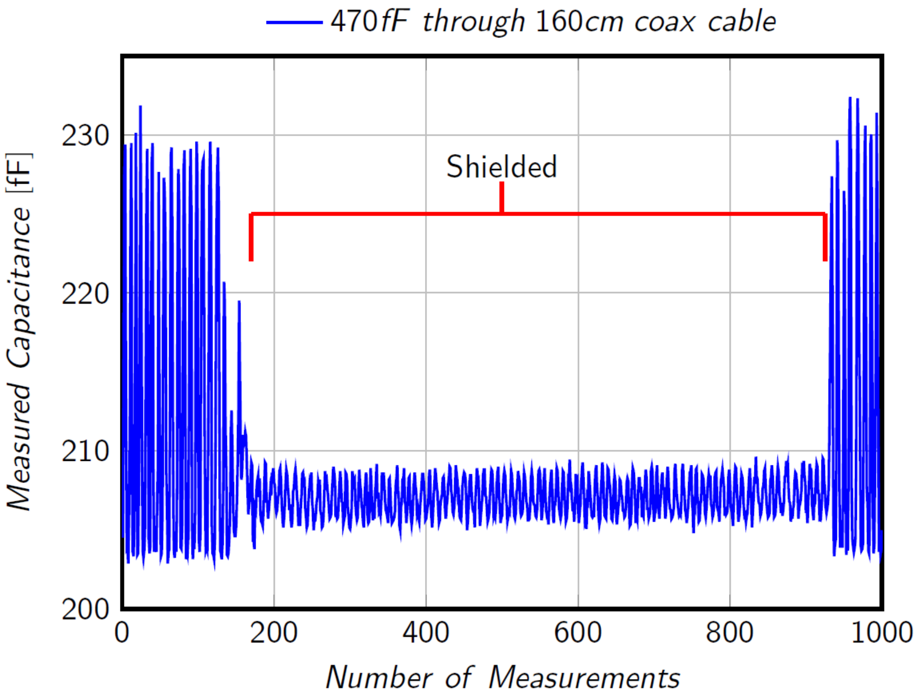
Influence of distance from DUT to readout circuit.

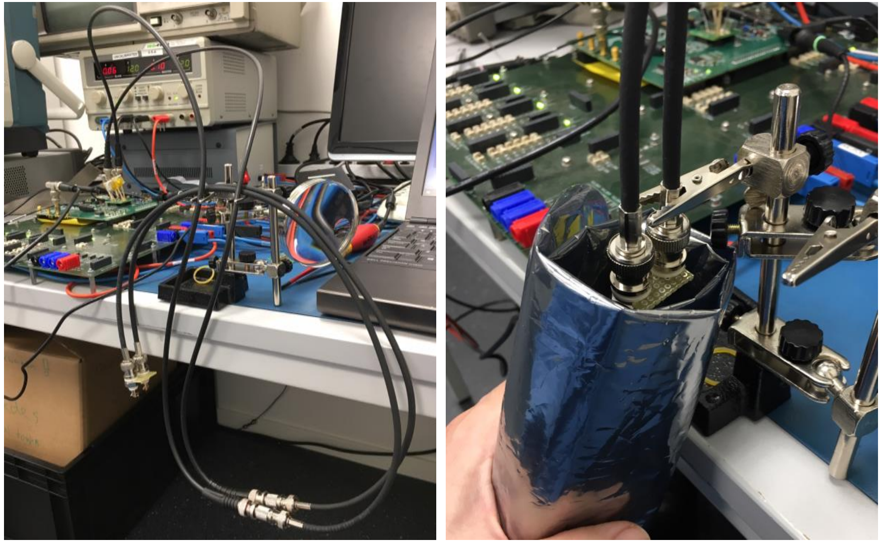


The reason of the jump from 10 cm to 20 cm and from 20cm to 60 cm is caused by using different cable types,

=> Use good cabling and connectors so that length can be compensated

EMI influence in measurements





Measurement setup with 1.6m cable between DUT and read-out circuit. DUT shielding with a rolled ESD bag.

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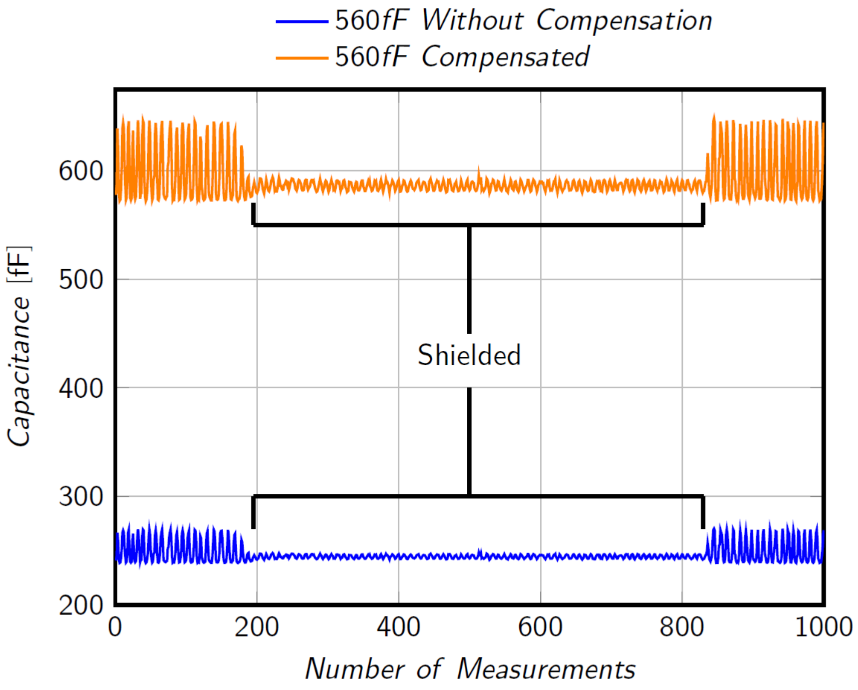
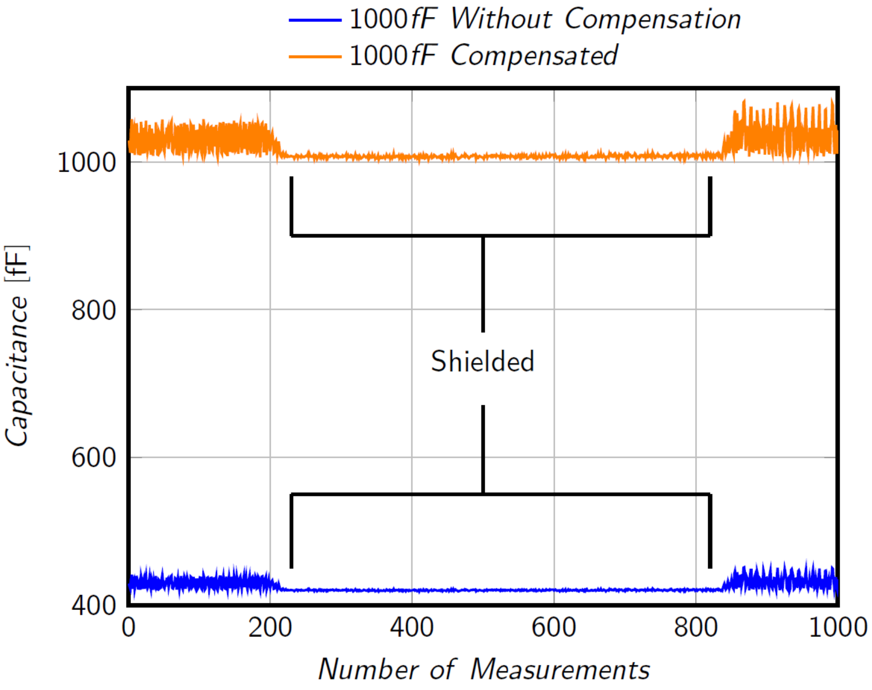
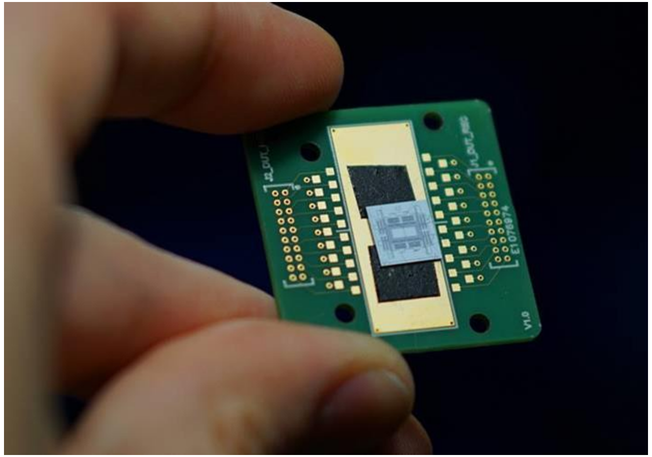
Gain compensation for measurements at long distances



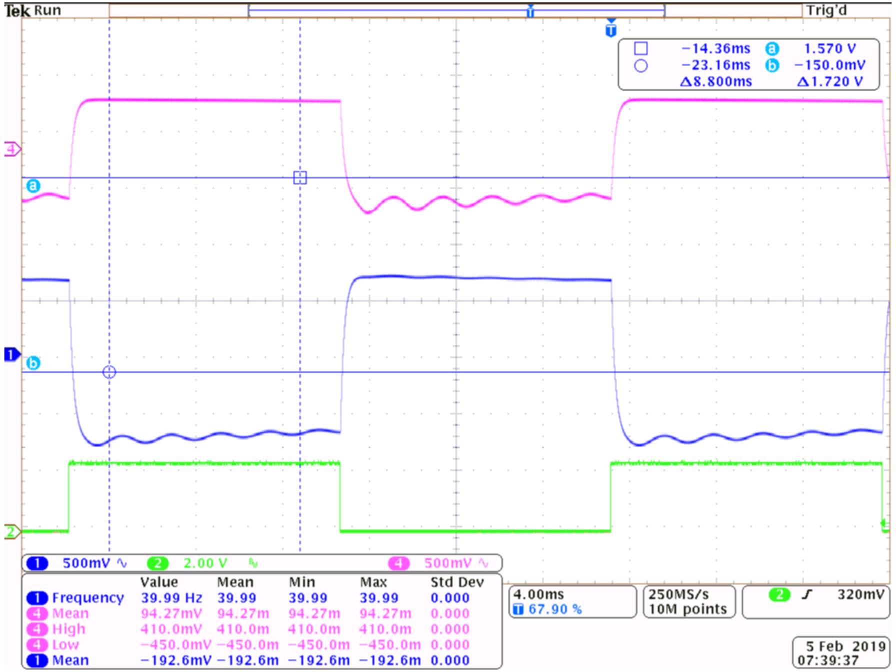


Capacitance measured through 1.6m coax cable without compensation and with gain compensation.

Dynamic measurements



MEMS Device used to test dynamic measurements of the low capacitance meter.



MEMS actuated with square wave 50V at 40Hz.

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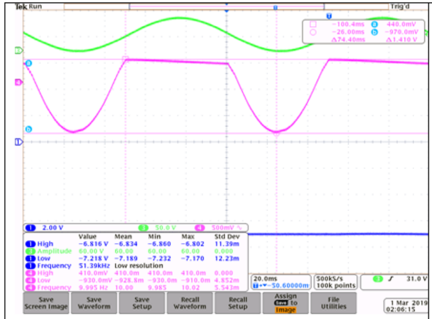
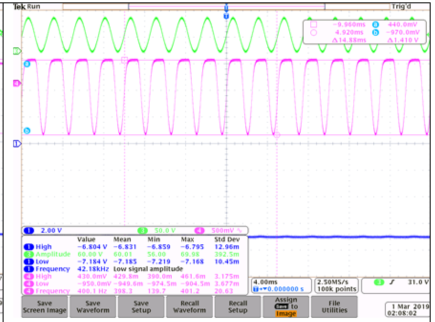
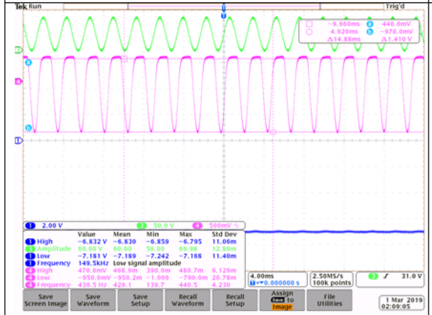
Mechanical resonance frequency



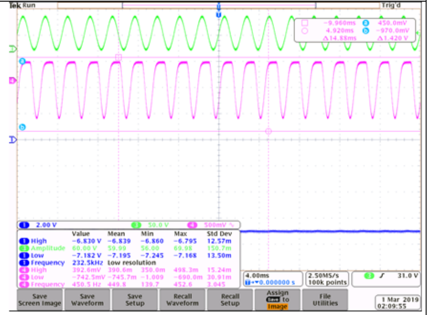
a) MEMS actuated with sine wave 60V at 10Hz.



b) MEMS actuated with sine wave 60V at 400Hz.



c) MEMS actuated with sine wave 60V at 430Hz.



d) MEMS actuated with sine wave 60V at 450Hz.

Variation of amplitude depending on frequency of actuation signal.

6. Improvements

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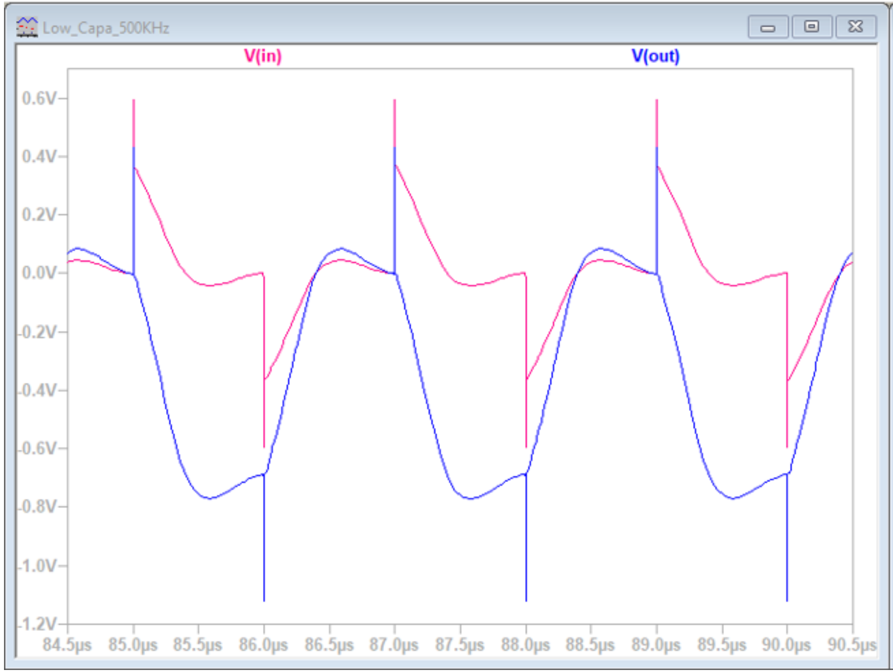
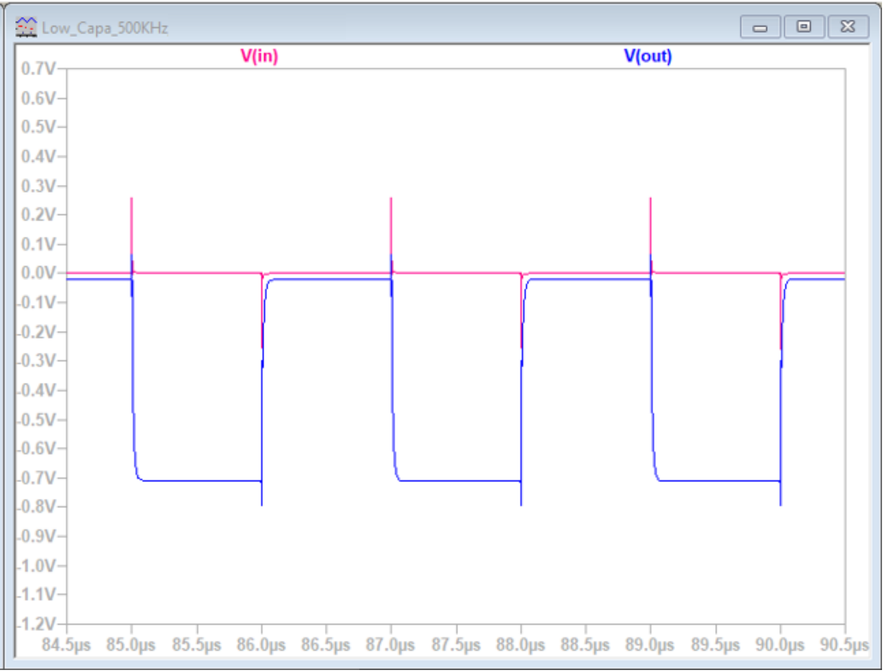
Increasing bandwidth of charge amplifier (Multichip)

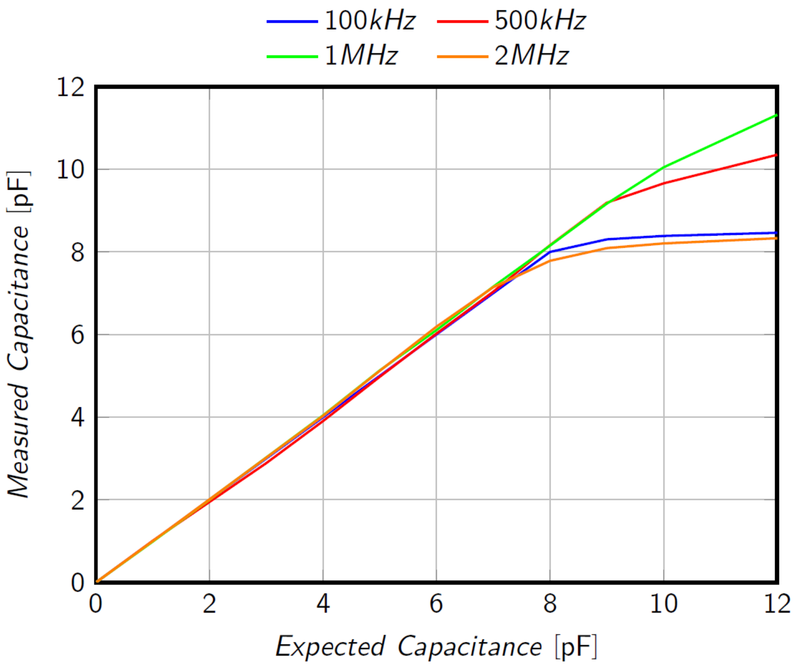


Capacitance meter using current charge amplifier with 500 kHz carrier frequency.



Capacitance meter using new charge amplifier with 500 kHz carrier frequency.

Simulation of improved hardware



Measured Capacitance vs Carrier Frequency

7. Conclusions

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Conclusions

	Multichip	Single Chip
Measurement Range	≈2 fF to ≈7500fF	0pF to ±4pF
Dynamic Range	1:3500	1:100000
Noise	±0.05 % of range*	±1fF
Resolution	200aF	10aF
Advantage summary	✓ Flexibility in Carrier frequency ✓ Avoidance of crosstalk in multichannel environment ✓ Possible to modify to have higher capacitance ranges. ✓ Faster Measurement	✓ Larger Dynamic range ✓ Lower noise

** In the worst case at ±5fF*

8. Future work

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Things to be done

- Implement proposed hardware improvements.
- Test Multichip with a know capacitance MEMS device.
- Test Multichip solution in a multi-channel implementation.
- Improve sampling rate from GUI.

Acknowledgements

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