A detailed study of variation in screen printed resistors on plastic

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NRC·CNRC

A Detailed Study of Variation in Screen Printed Resistors on Plastic

Neil Graddage, Christophe Py, Heping Ding, James Lee, Ye Tao

Industrial Partners
Jones Packaging, Caledon Controls, XRCC

Smart Packaging for Pharmaceutical Applications

This work has been performed as part of the Smart Packaging for Pharmaceutical Applications project within the Printed Electronics Program at NRC.

Project is led by Jones Packaging.

- Packaging design and production company.
- Specialists in pharmaceutical packaging.

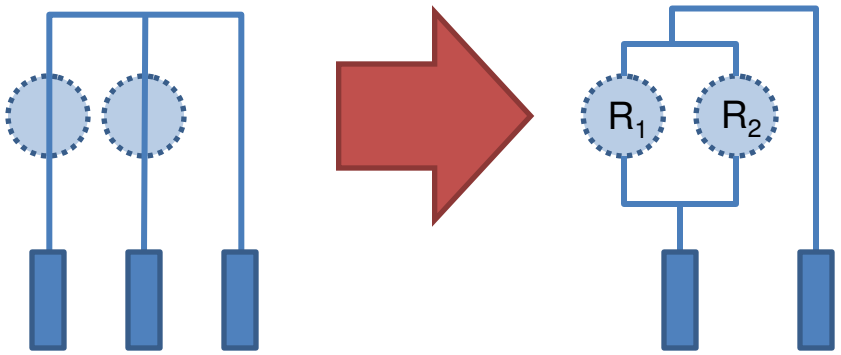
Other partners in the project include

- Caledon Controls Ltd.
- Xerox Research Centre of Canada

Resistor based multiplexing

- The project aim is to print smart drug packaging
  - Monitor removal of medication from a blister by the breaking of a conductive trace
- Current solutions require one connection for every blister.
- We wished to multiplex this by use of resistors in series with each blister.
- This technique is limited by the variation of the printed resistors.

Source: MTS Medication Technologies



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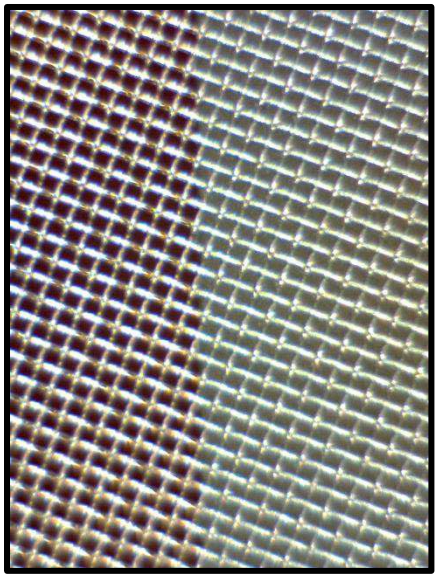
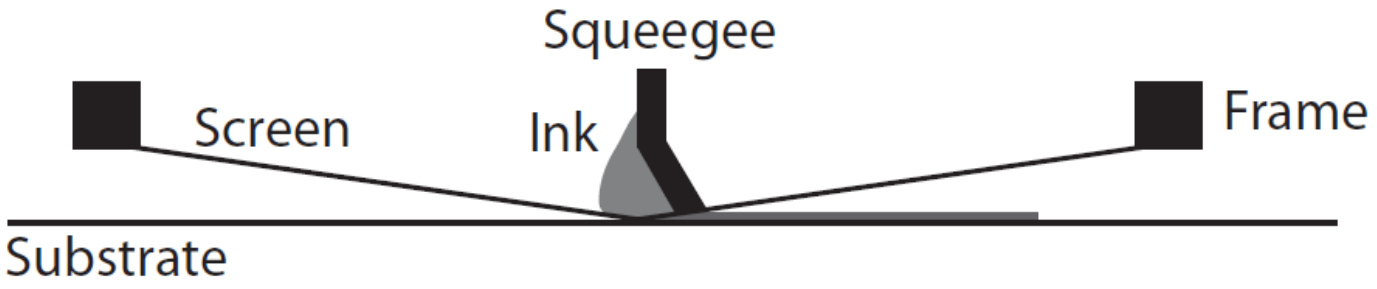
Screen Printing

- Common printing process
- Ink is displaced through a mesh stencil
- Mesh is under tension in a frame
- Ink is drawn across the screen by a polymer blade (squeegee)





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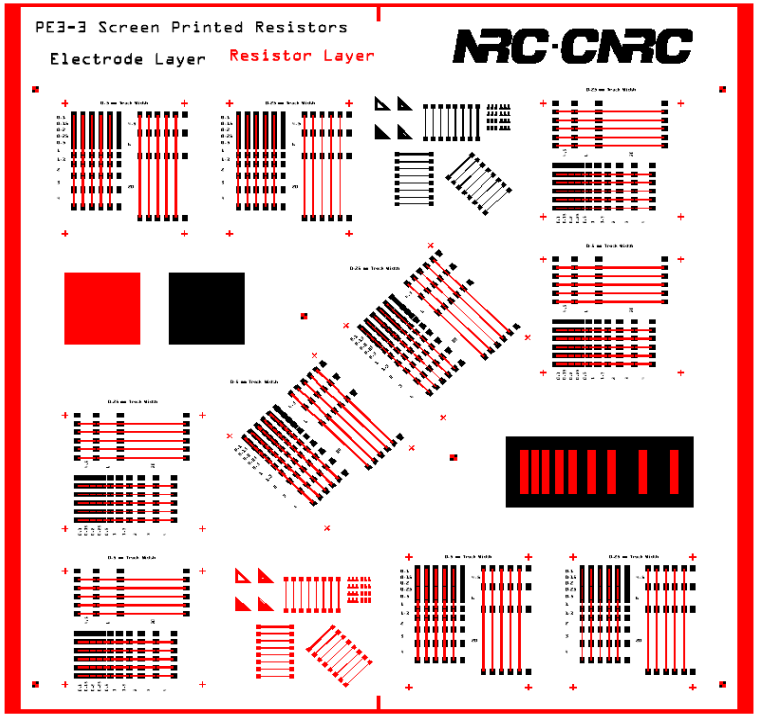
Screen Printed Resistors 1

- Comprehensive testing performed to assess capabilities of screen printing.
- Focused on variability rather than absolute values.
- Electrodes were silver.
  - DuPont 5025
- Resistors were carbon.
  - DuPont 7082
- Printed resistors of width 0.25 and 0.5 mm.
- Printed a range of resistor lengths between 0.1 and 20 mm.



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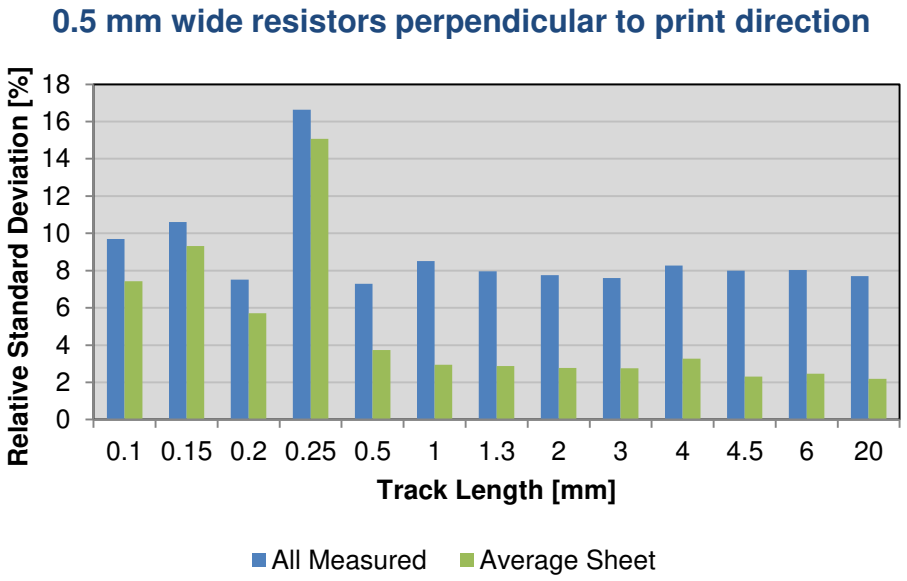
Screen Printed Resistors 2

- Resistors below 0.25 mm were not reliable due to limits of screen printing.
- Best case was nominally 0.5 mm wide resistors of length over 1mm
  - Average relative standard deviation of 8%
  - As low as 3.7% for > 1mm long resistors within a set.
  - Printed perpendicular to squeegee print direction.



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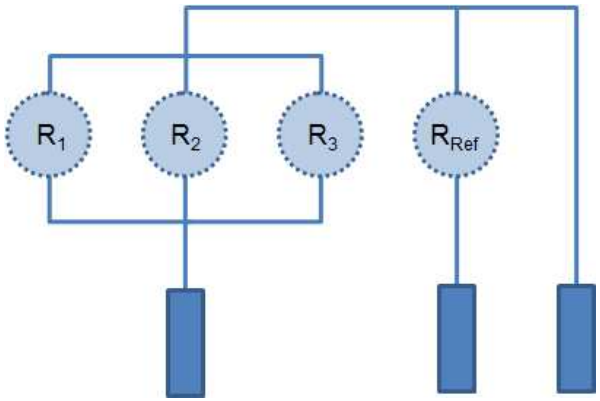
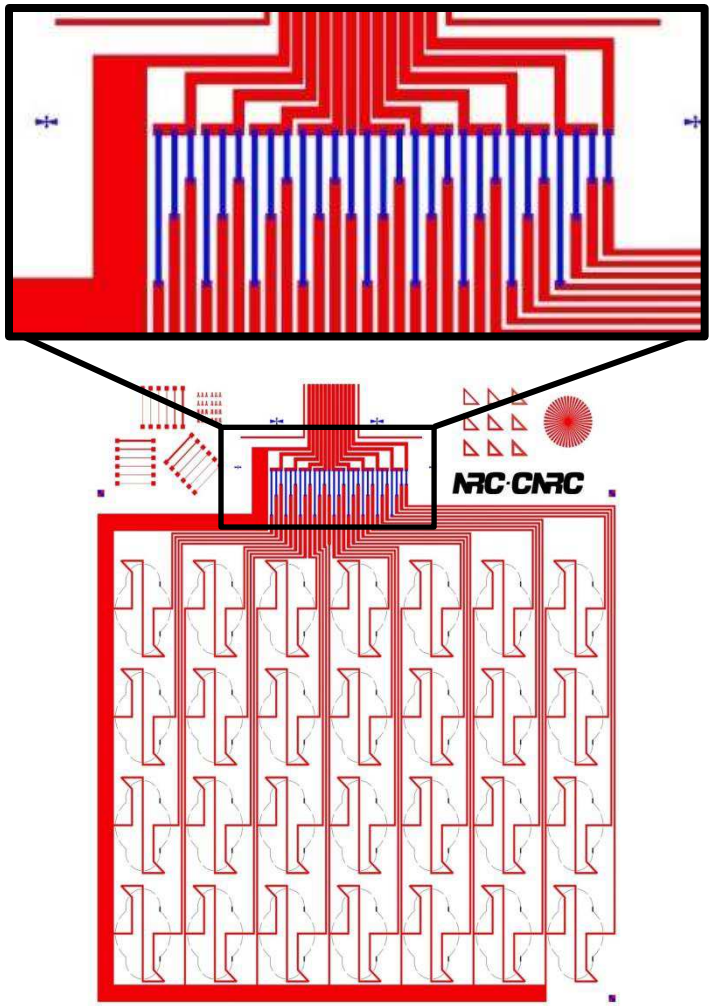
M=3 Demonstrator Production – Relative Referencing

- Group resistors close together
- Design device with reference resistor in centre.
  - Measure ratio instead of absolute values.
  - Maximise multiplexing factor
  - Increase robustness





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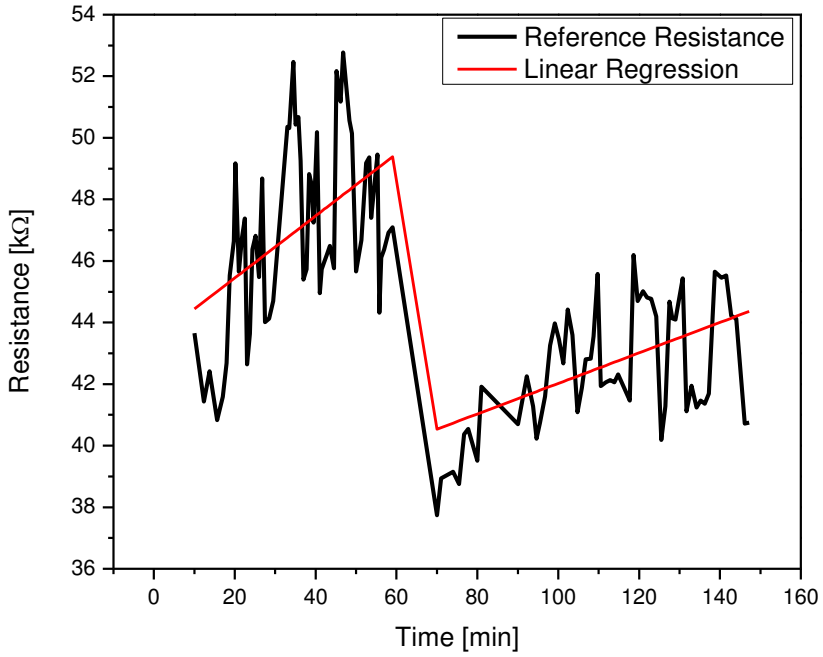
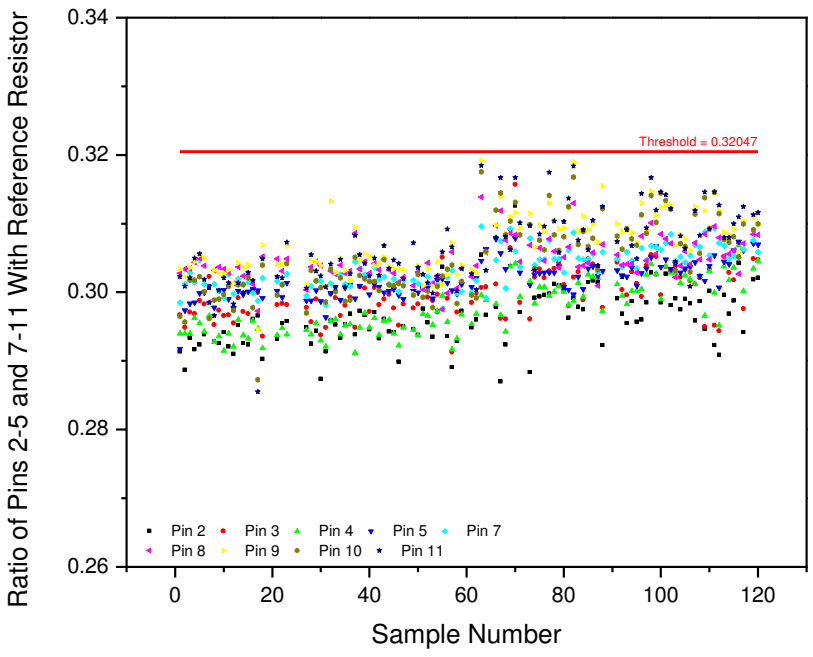
M=3 Demonstrator Printing

- Simulated volume production
  - 119 samples printed
  - Two batches
- Measured every sample using interrogator

- Initial yield of 85%
  - 3 handling errors
  - 4 electrode defects
  - 10 resistor tolerance





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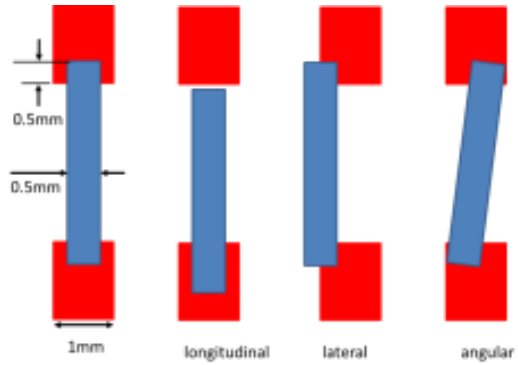
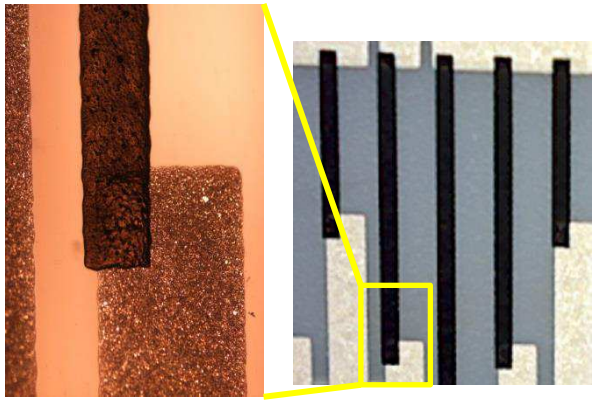
Causes of Variability 1
Misalignment

$$R = \rho \frac{l}{A}$$

- Resistor variability could be caused by:
  - misalignment;
  - cross sectional profile variation;
  - roughness (line edge and surface), and
  - variations in ink resistivity.





- Misalignment
  - Not a significant cause of variation.

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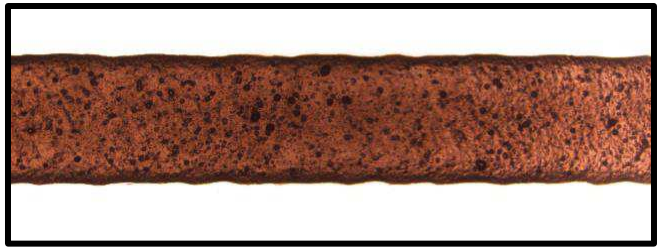
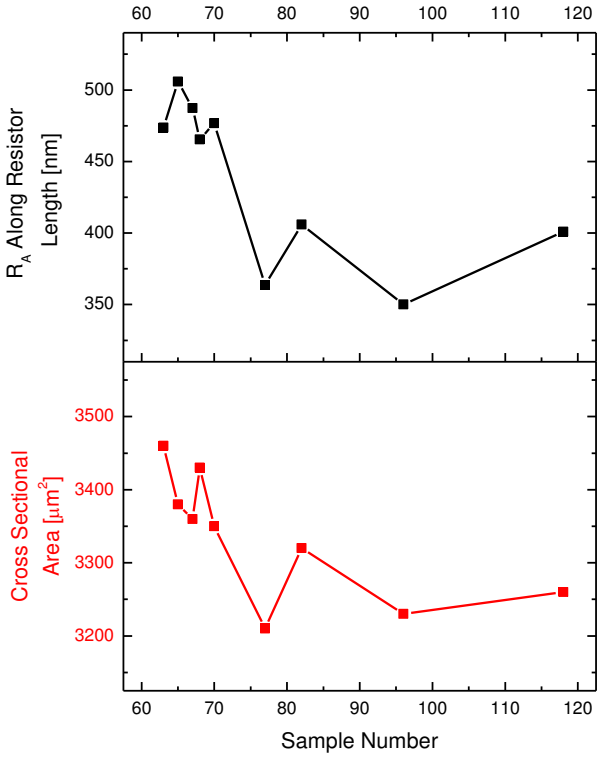
Causes of Variability 2 Roughness

- Line edge Roughness
  - Measured planar area of 50 resistors.
  - Variation appears random and small.
  - Does not correlate with device functionality.
- Surface roughness
  - Decreases through print run.
  - Correlates with decreasing cross sectional area.





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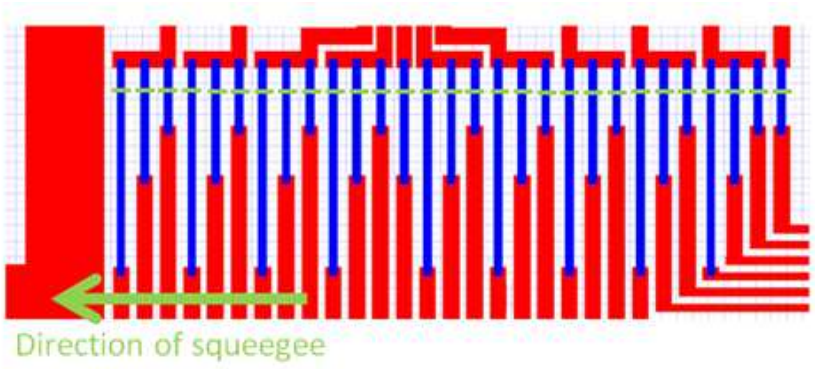
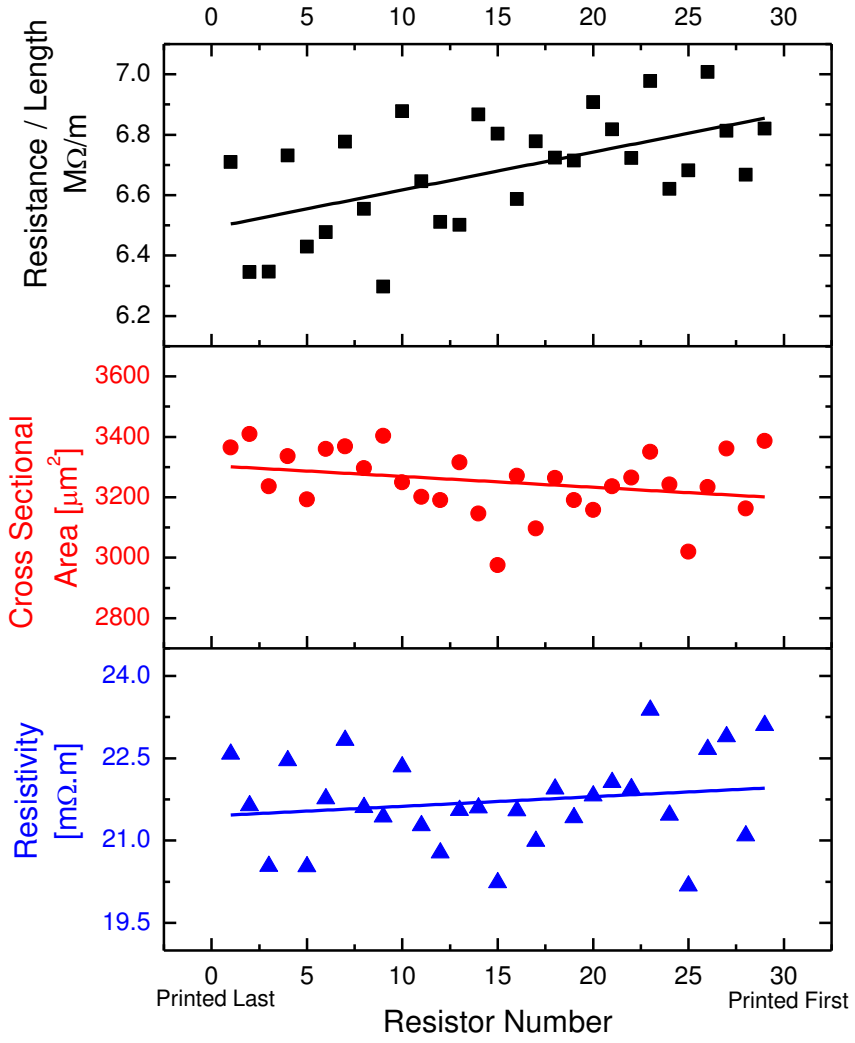
Causes of Variability 3
Cross Sectional Area and Resistivity Within a Print

- Cross sectional area slightly increasing along print direction
- But resistance/ length decreases.
  - Also periodic with length
- Why?
  - Squeegee causing a gradient in ink composition?
  - Screen tension?
- Printing perpendicular to resistors was incorrect.





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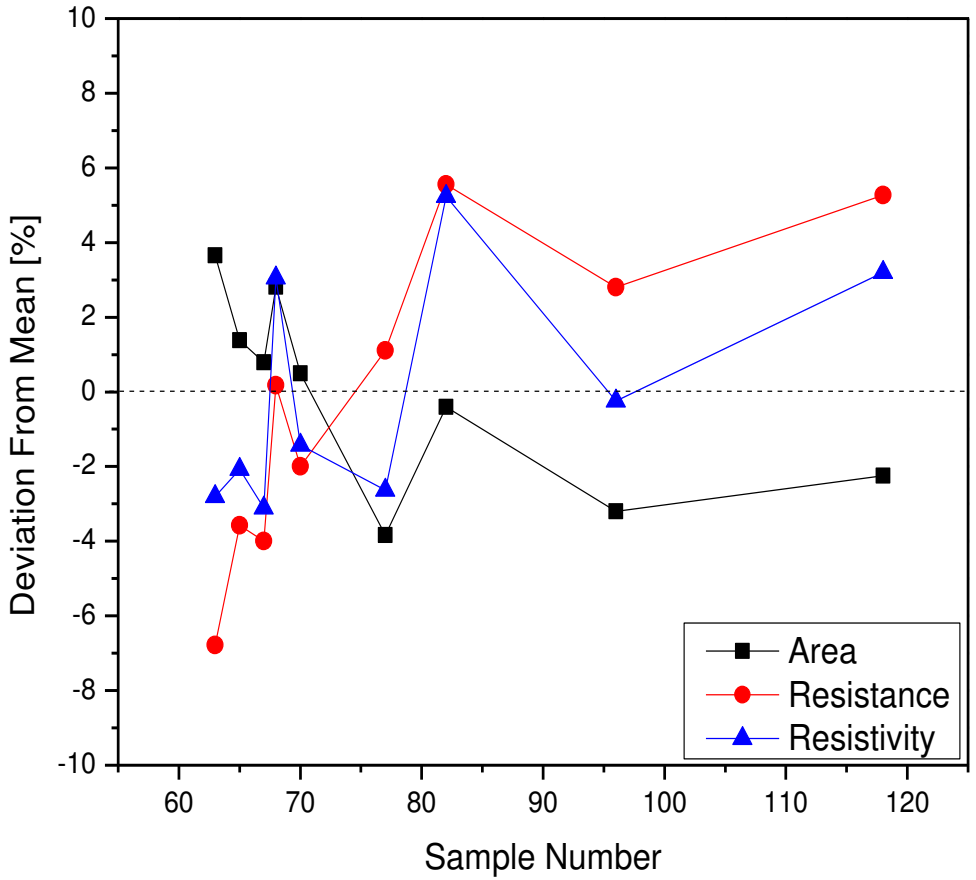
Causes of Variability 4
Cross Sectional Area and Resistivity During Batch

- Cross sectional area decreases during print run
- Resistance therefore increases.
- But increase in resistivity also observed.
- Ink evolving during printing.



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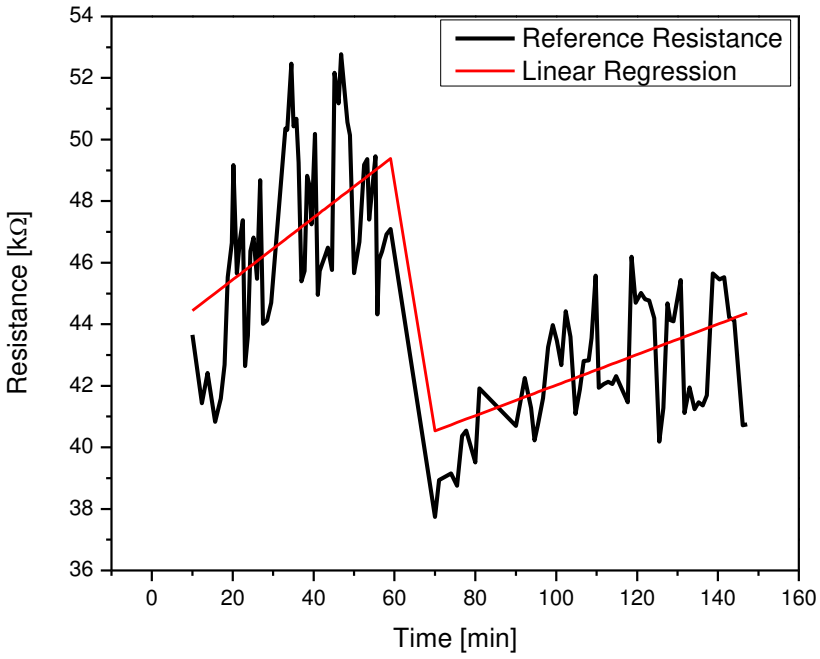
Causes of Variability 5
Ink Evolution

- Solvent evaporation causes ink to evolve during printing
  - Increases solid concentration
  - Rheology change affects transfer.
- However we would expect the rate of change to be consistent.
  - Note that the rate of change is different in each batch.
- Also variability appears to increase.
- Screen damage?
- Squeegee wear?



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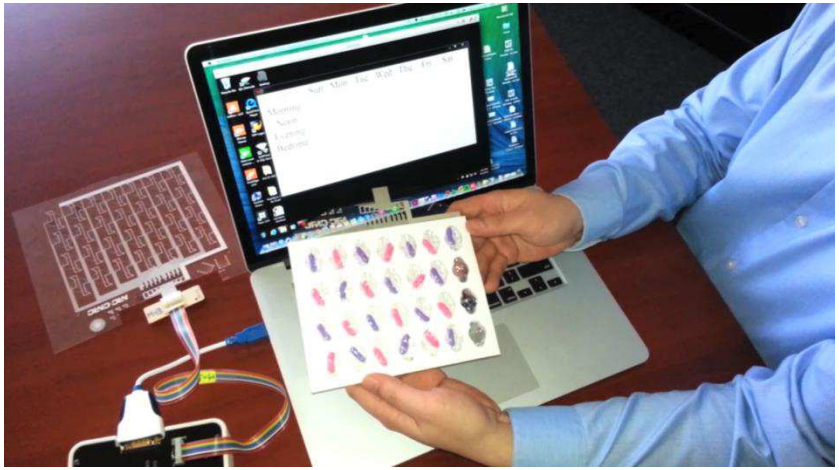
Summary

- Screen printed resistors are capable of 3.7% relative standard deviation.
- Devices should align with print direction
- Ink evolution is the major contributor to variability
  - Resistance drift through batch

- Next Steps
  - Design strategies to minimise ink evolution
  - Further examine screen and squeegee wear.



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Thank you
Any Questions / Comments?

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