point.one

MEMSLand

Cost Effective MEMS to Develop a Sustainable High Tech Business

Fulfilling the promise of RF-MEMS

EPCOS

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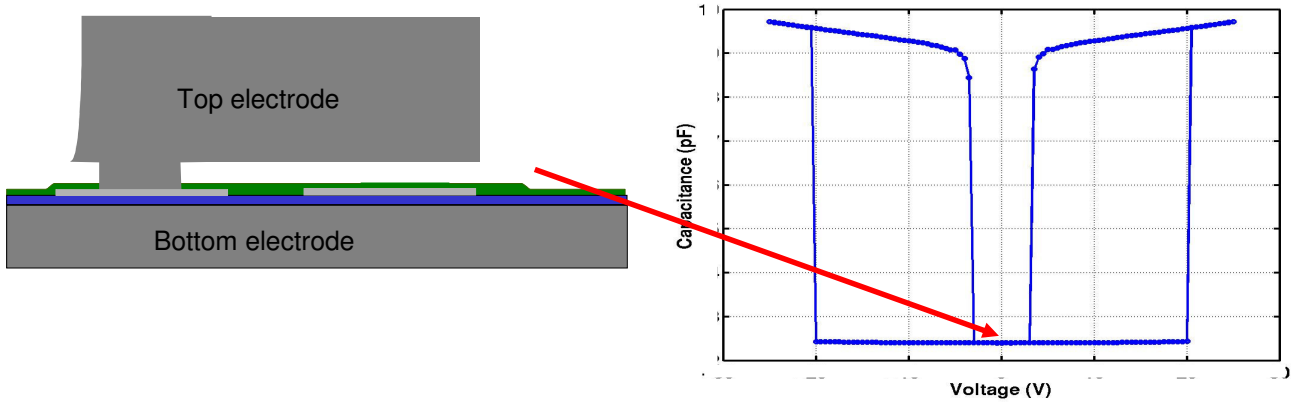
RF-MEMS switch

- The RF-MEMS is a variable capacitor with a moveable top electrode.



- The RF-MEMS switch has excellent RF-performance:
  - High Con/Coff ratio
  - Low losses
  - High power handling
  - Very low harmonic & intermodulation distortion

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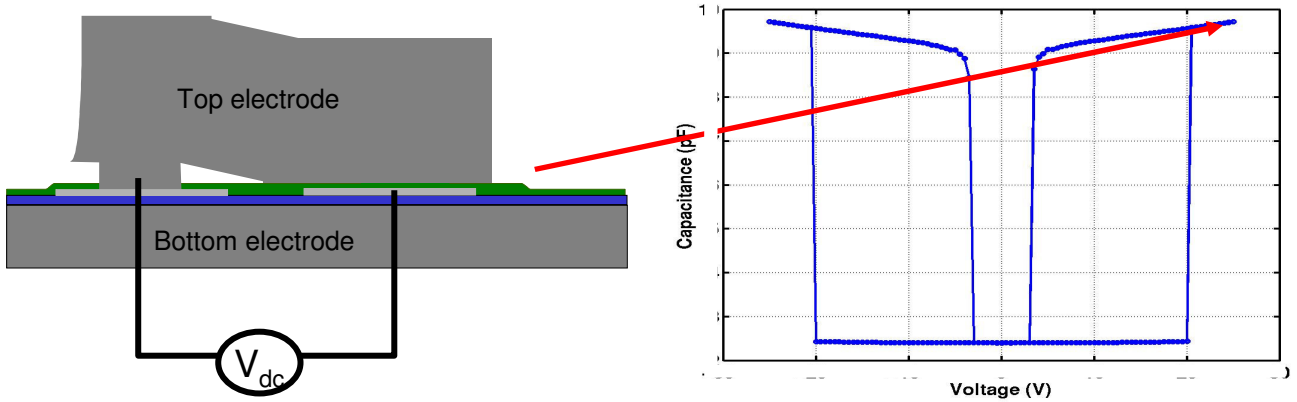

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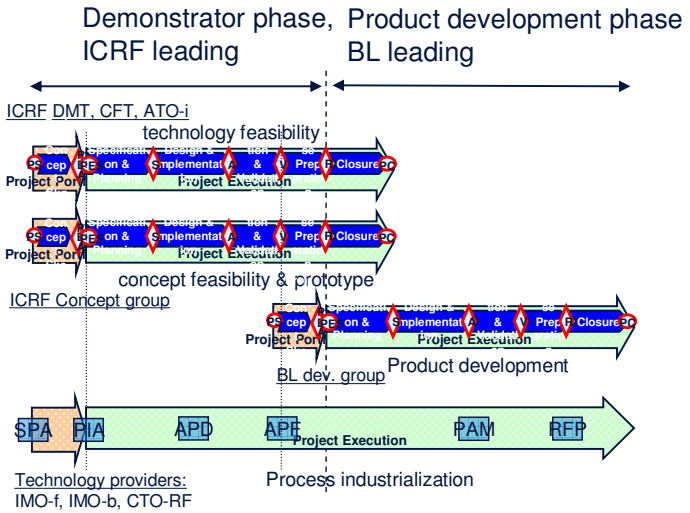
According to the initial plan we're done...

PHILIPS

RF-MEMS plan, two phases envisioned

Phase 1: Demonstrator
Q3 2005 – Q2 2007

- Device specifications met
- Manufacturability proven
- Transfer process to ICN 6"
- Engineering samples



Phase 2: Product development
Q3 2007 – Q2 2008

- Adaptive MEMS component ready for system integration
- Transfer of package process to IMO-b assembly site
- Ramp-up to meet customer volumes

Development flow

- Product specifications
- Product design
- MEMS technology specifications
- MEMS device design
- MEMS process
- MEMS characterization
- MEMS reliability evaluation
- Product characterization
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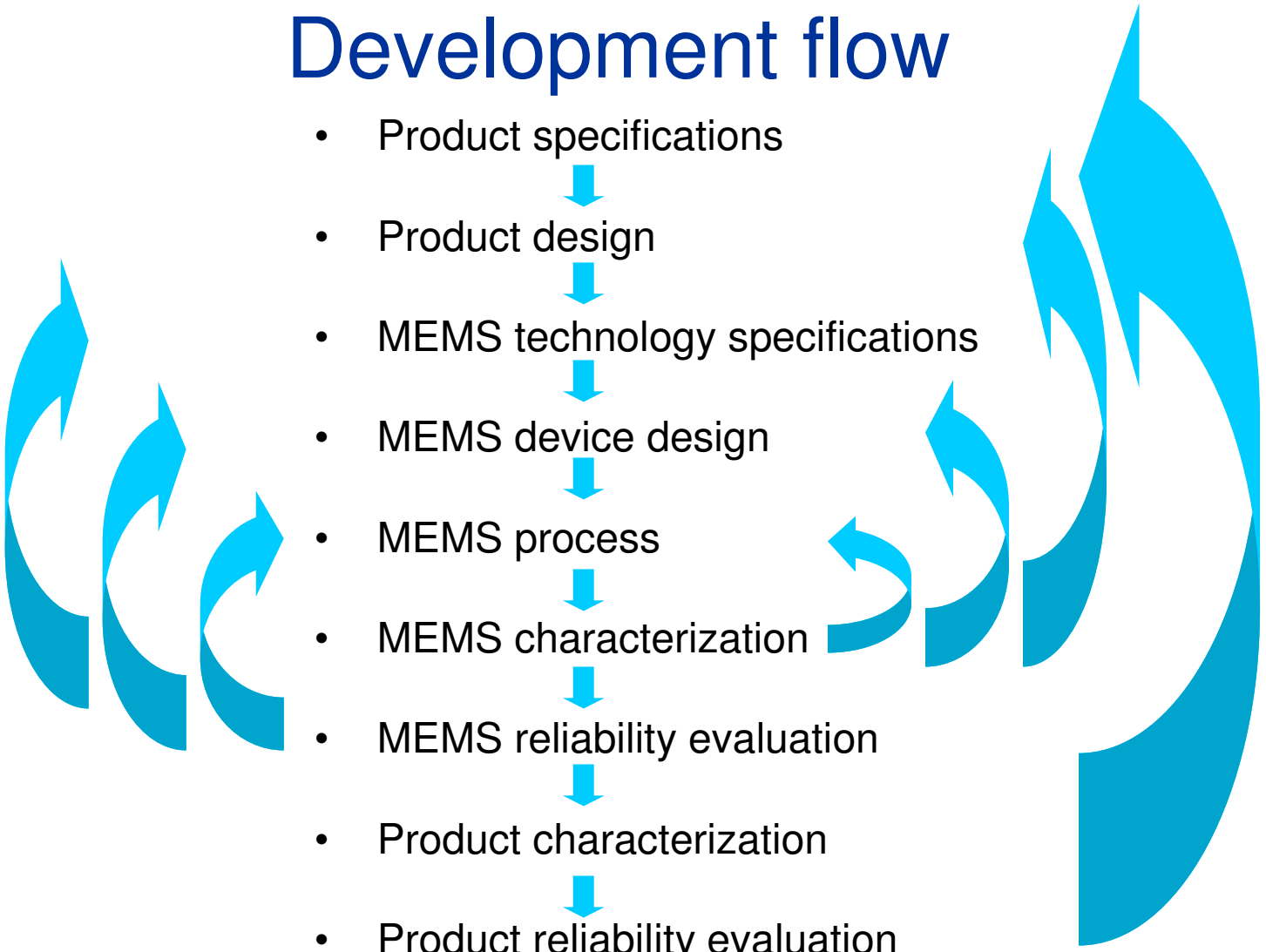


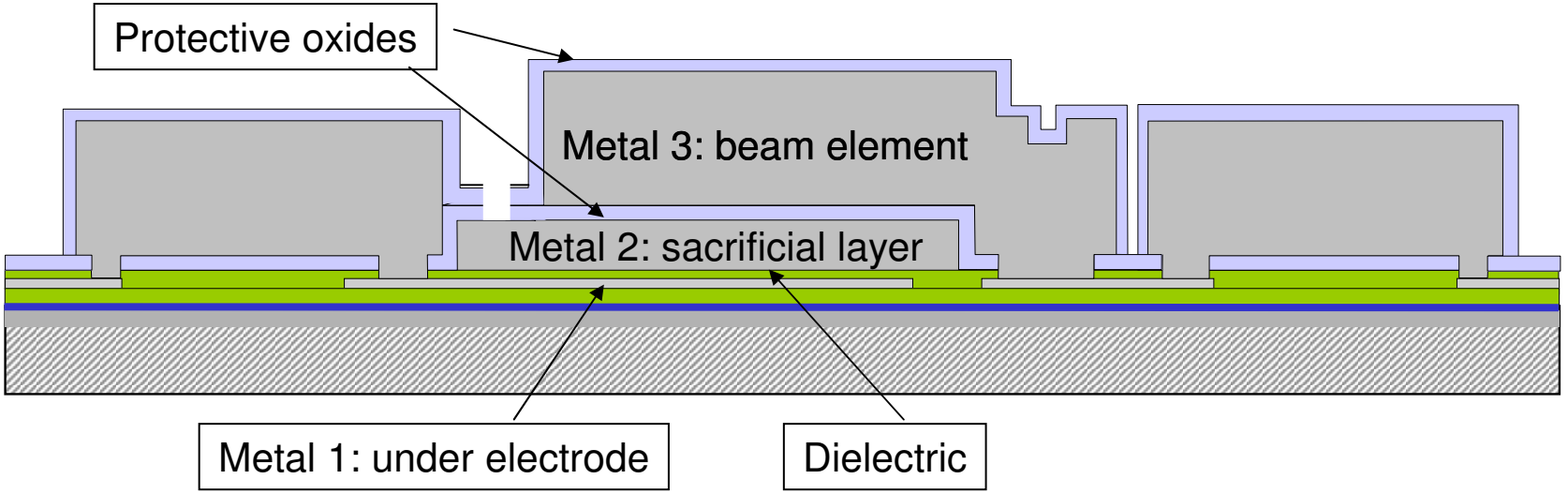
RF-MEMS process as a basis

- RF-MEMS envisioned for tunable RF for mobile
- Foreseen first products
  - Antenna tuner
  - Tunable PA match
- Products were non existing: only indicative customer specifications
- RF-MEMS process was taken as a basis
- Process was a modified version of a passive integration technology platform of Philips (NXP) running in production

2006 RF-MEMS process

CMOS compatible: low cost

- Standard materials
- Standard equipment
- Based on passive technology running in mass production



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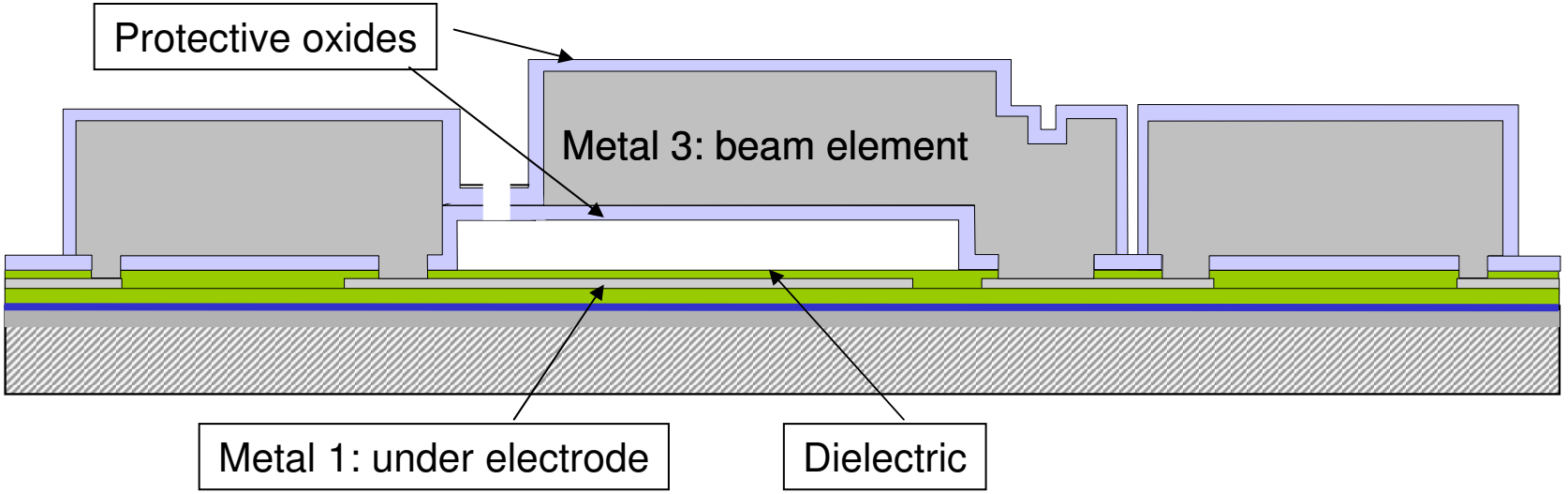

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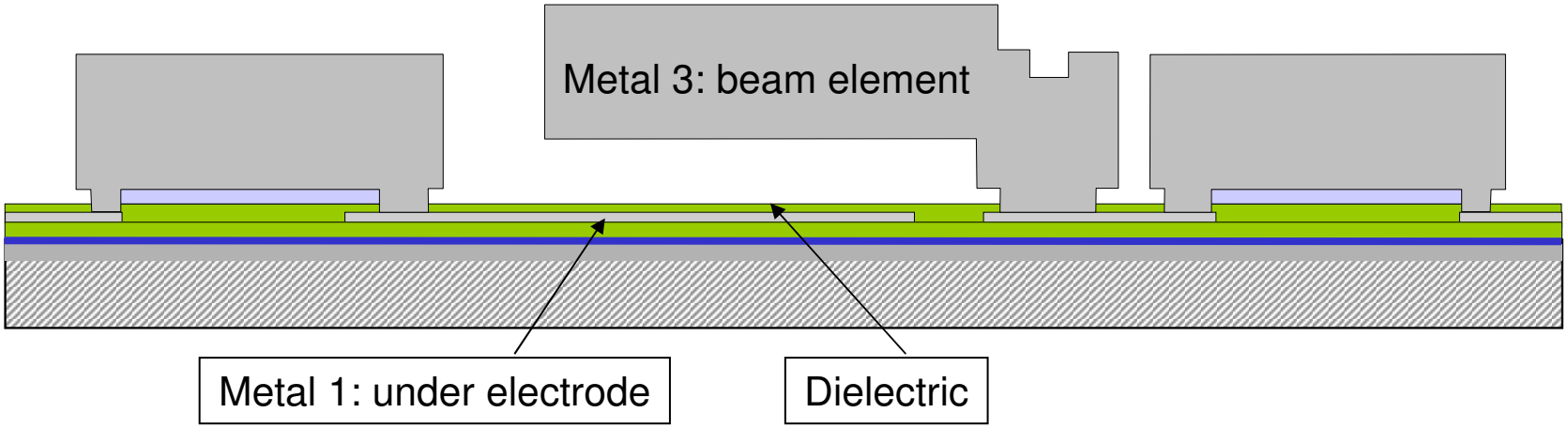
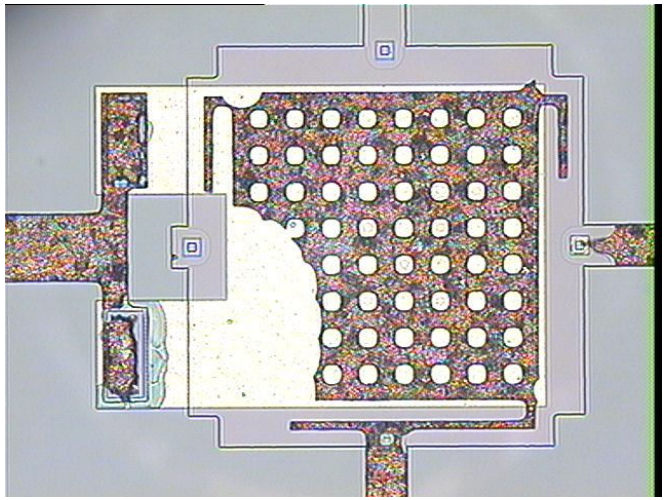


New sacrificial module required to solve fundamental issues of 2006 RF-MEMS process

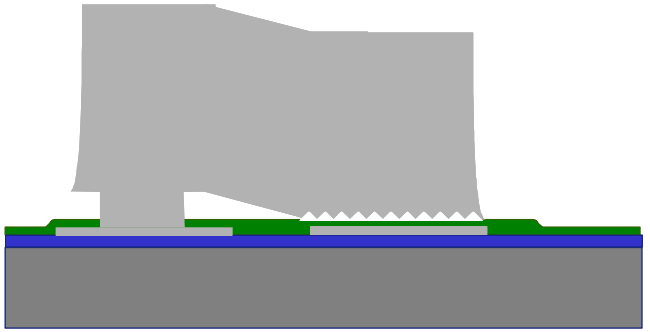
Damaged devices during release



One of the poorest devices made, showing the fundamental issue of choosing same materials for sacrificial and structural layers.

Although much improvements were made, close to 100% yield for a good wafer, final quality /reliability could never be secured (at manageable cost)

Uncontrolled performance in down state



Cp & CpK numbers for a good batch of 23 wafers

	Vpi	Vre	Copen	Close
Cp	2.01	0.57	2.35	0.68
CpK	0.78	0.25	1.75	0.25

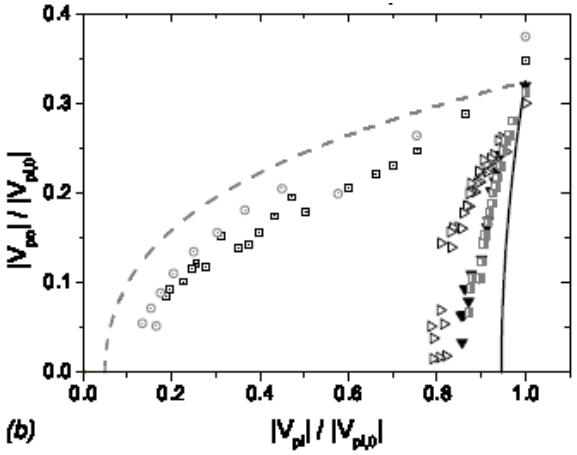
BOE etching is NOT selective to aluminum. Roughening of the aluminum by the BOE etch creates an uncontrolled additional airgap in closed state.

So we changed sacrificial module...

- Yes but not immediately, we tried but could not find a technology suiting our specs
- In hindsight this was not a bad thing as we had much more to learn
- We made devices, developed hermetic capping, made product demonstrators, tested reliability and evaluated specs
- We needed to change more...

Reliability starts day 1 of MEMS device development!

- Failure modes, testing methods, acceleration factors etc., all are not available at start
  - About 1 FTE required over entire project for testing HW & SW
- Reliability testing of early samples is key to steer the technology development
- Considerable effort was done to discriminate electrical from mechanical degradation



We had to make reliability the heart of our technology development

- MEMS device reliability in the 2006 RF-MEMS process was very good compared to literature
- Reliability was increased with several orders of magnitude, but could still not live-up to the increased specifications
- We had to change metal system to ensure good reliability
- To integrate the new metal system and new sacrificial module we also had to change our dielectric...
- Today reliability is several orders better than specified

Excellent outlook for business success

- RF-MEMS and capping processes transferred from 6” to 8” to ensure cost competitiveness
- New RF-MEMS process implemented on 8”, giving excellent reliability
- Full process release expected mid 2010

- Fully integrated closed-loop antenna tuner products available
- Experienced by top phone manufacturers as leading in upcoming market of antenna tuners

Fulfilling the promise

- Over last 15 years RF-MEMS has been a promise, that has proven to be tough to fulfill
  - Most stopped their activities, mainly due to reliability issues
- MEMSland RF-MEMS program is a success:
  - World-class modeling of RF-MEMS devices
  - Process development and integration of new sacrificial module
  - Low cost fully hermetic wafer level capping process developed
  - Fundamental R&D on materials resulting in spectacular improvement of device reliability
  - Antenna tuner topology with smart sensing and control allowing closed loop tuner products
  - And many more achievements
- Many cycles were required, some very long loops
- Programs like MEMSland are a must to manage long development times and changing business environments

For those interested in the details

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- J. Stulemeijer, J. A. Bielen, P. G. Steeneken, and J. B. van den Berg, "Numerical Path Following as an Analysis Method for Electrostatic MEMS," *Microelectromechanical Systems, Journal of,* vol. 18, pp. 488-499, 2009.
- P. G. Steeneken and J. Stulemeijer, "Path following and numerical continuation methods for non-linear MEMS and NEMS," *Arxiv preprint arXiv:0905.4653,* 2009.

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