Electronic Testing of the Droplet Presence

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LIRMM

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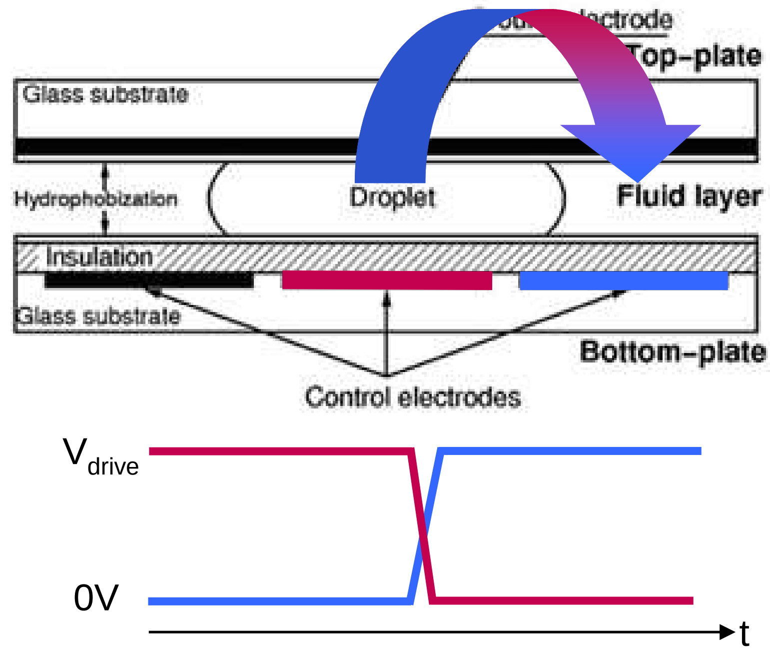
* Duke University: F. Su, S. Ozev and K. Chakrabarty, "Ensuring the operational health of droplet-based microelectrofluidic biosensor systems", IEEE Sensors, vol. 5, pp. 763-773, August 2005

Introduction

- Testing principle : based on using a test fluid and verifying the droplet motion when V_{drive} is applied



- Catastrophic fault = fluid motion inhibition

- Droplet motion could be detected by measuring the capacitance between top and blue electrodes ⇨ on-chip electronics

State of the art

Fault classification: catastrophic faults

- Catastrophic faults
  - Dielectric breakdown of the hydrophobic insulator
    - short circuit between droplet and electrode
    - no charge can be stored at the interface
    - no electrowetting mechanism
  - Short between adjacent electrodes
    - lead to a larger electrode
    - droplet is not large enough to overlap the 2 electrodes
  - Degradation of the electrode
    - fragmentation of the droplet
    - no motion due to the variation of surface tension forces
  - Open in metal interconnections
    - failure in charging electrode

Fault classification: parametrics faults

- Parametric faults lead to variations of the droplet velocity (u)

given by the balance between the work done by the surface tension gradient and power dissipation*:

$$\frac{\varepsilon_0 \varepsilon_R}{2d} V_{drive}^2 \quad - \quad F_T \quad = \quad \mathrm{B}\,\gamma_{LM} \left(\frac{\mu_D u}{\gamma_{LM}} \right)^{0.3} \quad + \quad \left(\frac{mL}{h} + s \right) \mu_0 u \quad + \quad \zeta u$$

external force (per unit length) — **threshold initiation force** — **viscous dissipation** — **viscosity of the filler fluid** — **friction fluid/ insulator**

$\varepsilon_0 \varepsilon_R$: insulator permittivity

γ_{LM} : liquid-medium interfacial tension constant

μ_D , μ_0 : viscosity of droplet and filler fluid

B, m, s, ζ : fluidic constants

d: insulator thickness

L : electrode length

h : capacitor height

* H. Ren, R.B. Fair, M.G. Pollack, E.J. Shaughnessy, Sensors and Actuators B 87 (2002) 201-206.

Fault classification: parametrics faults

- Variation of one of these parameters will impact the droplet velocity by changing the external force or a dissipation term
- Particule contamination (dust particle, foreign fluid droplet) : reduce the droplet velocity and change the cell capacitance
- Defect in the temperature controller during a biological/chemical reaction: impact on fluid viscosity and then on fluid velocity
- Voltage supply: modify external motion force

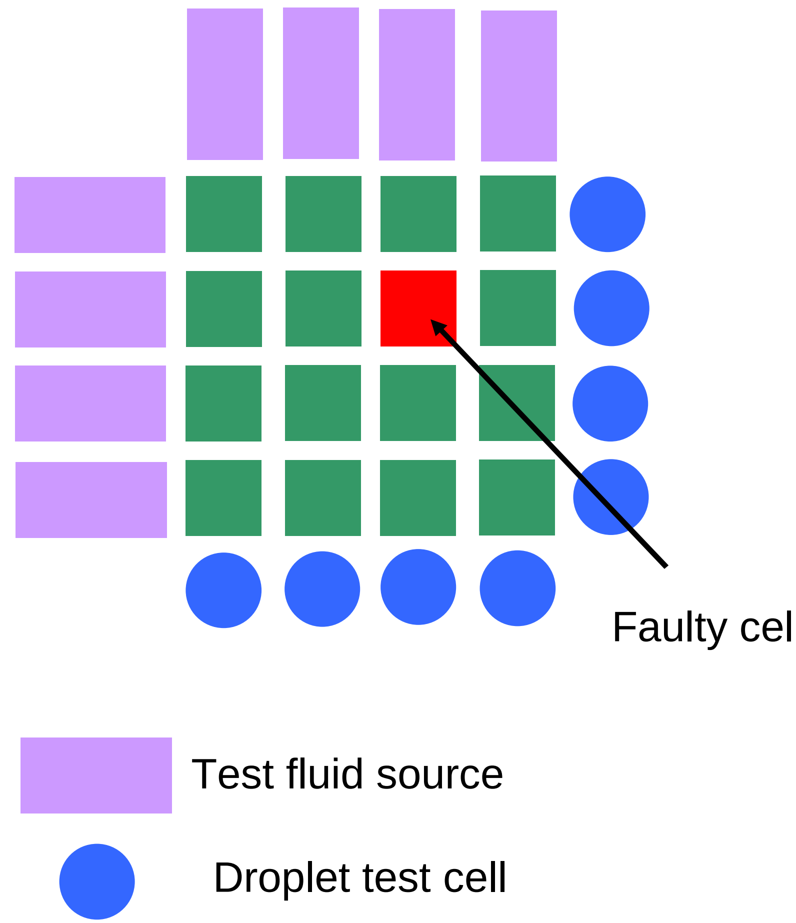
⇨ verification of the droplet velocity permits to detect all these parametric faults

Test of catastrophic faults

- First method proposed by Duke: very simple to implement
  - first, droplets are driven along the x axis and are detected at the end of the row by the droplet test cells if there is no faulty cell on the row
  - second, same operation is done along the y axis

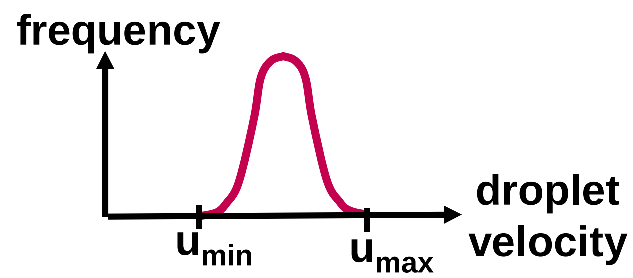
  ex: no droplet is detected for the row 2 and the column 3 due to the faulty cell

  ⇨ using more complex algorithms, method can be extended for detecting multiple faulty cells or for on-line monitoring



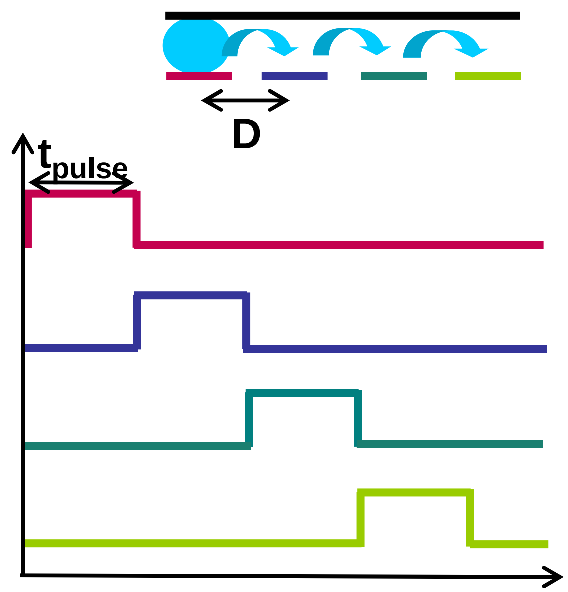
Test of parametric faults

- Monte-carlo analysis:
  - standard deviation of all the parameters
  - ⇨ deviation of droplet velocity



- Test based on pulse duration:
  - if $t_{pulse} = D/u_{min}$: motion should always be detected (pulse is large enough for moving slowest droplets)
  - if $t_{pulse} < D/u_{max}$: no motion should be detected

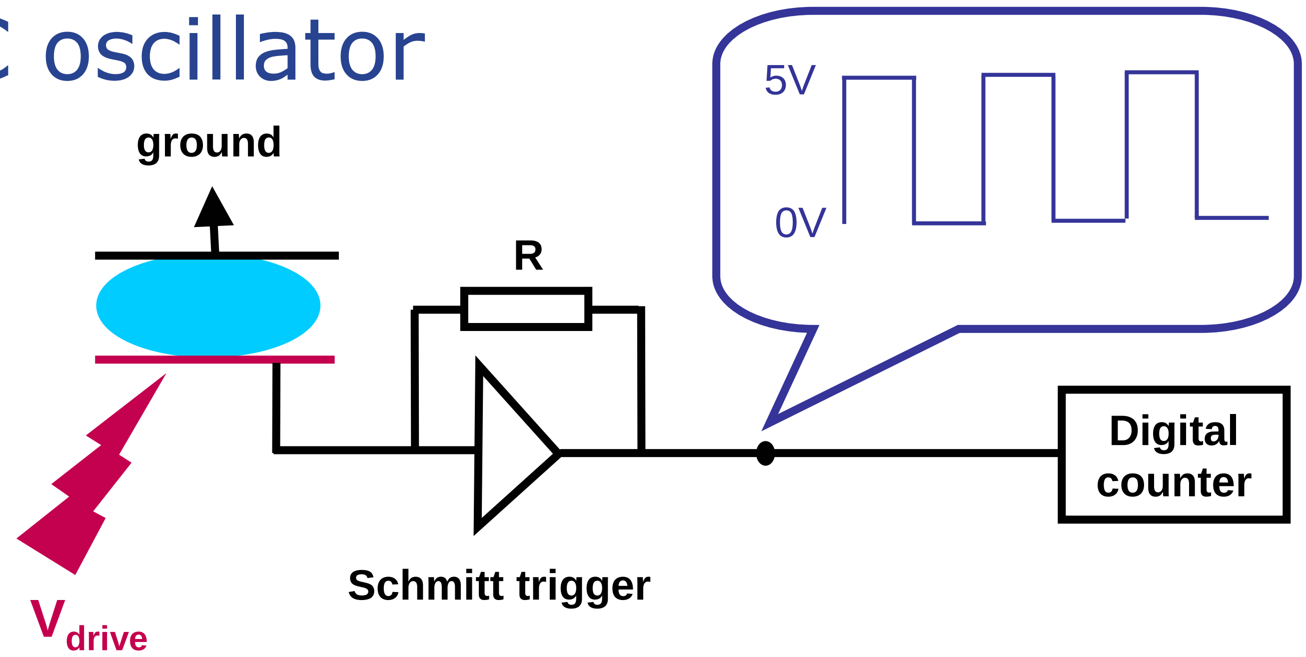
⇨ For parametric or catastrophic fault testing, on-chip electronics detection of the droplet is necessary



Electronic architectures for testing the droplet motion

Duke University architecture

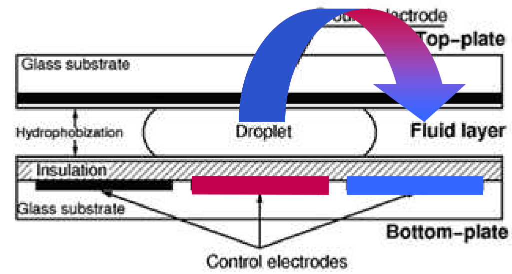
- RC oscillator

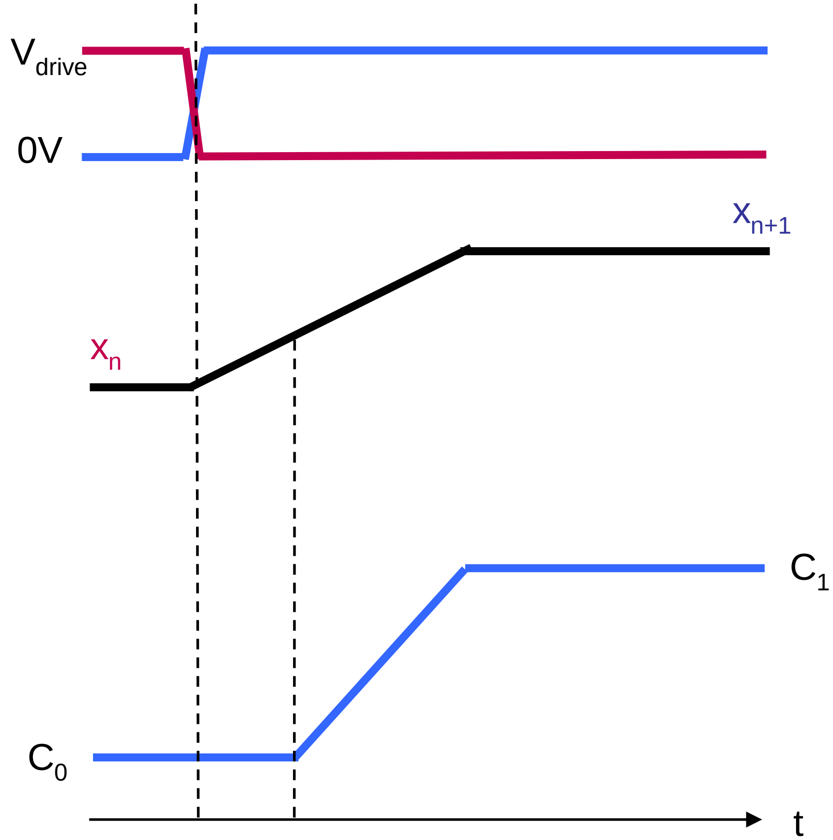


- only used to detect the droplet presence (simple pass/fail criteria)
- no information about high voltage decoupling: no effect on oscillator operating ?

LIRMM proposal

- Our aim: use the same circuit for test and measurement of:
  - capacitance value before droplet arrival (C_0)
  - capacitance value with the droplet presence (C_1)
  - droplet velocity (u)
  - capacitance value due to droplet contents (ΔC_1)

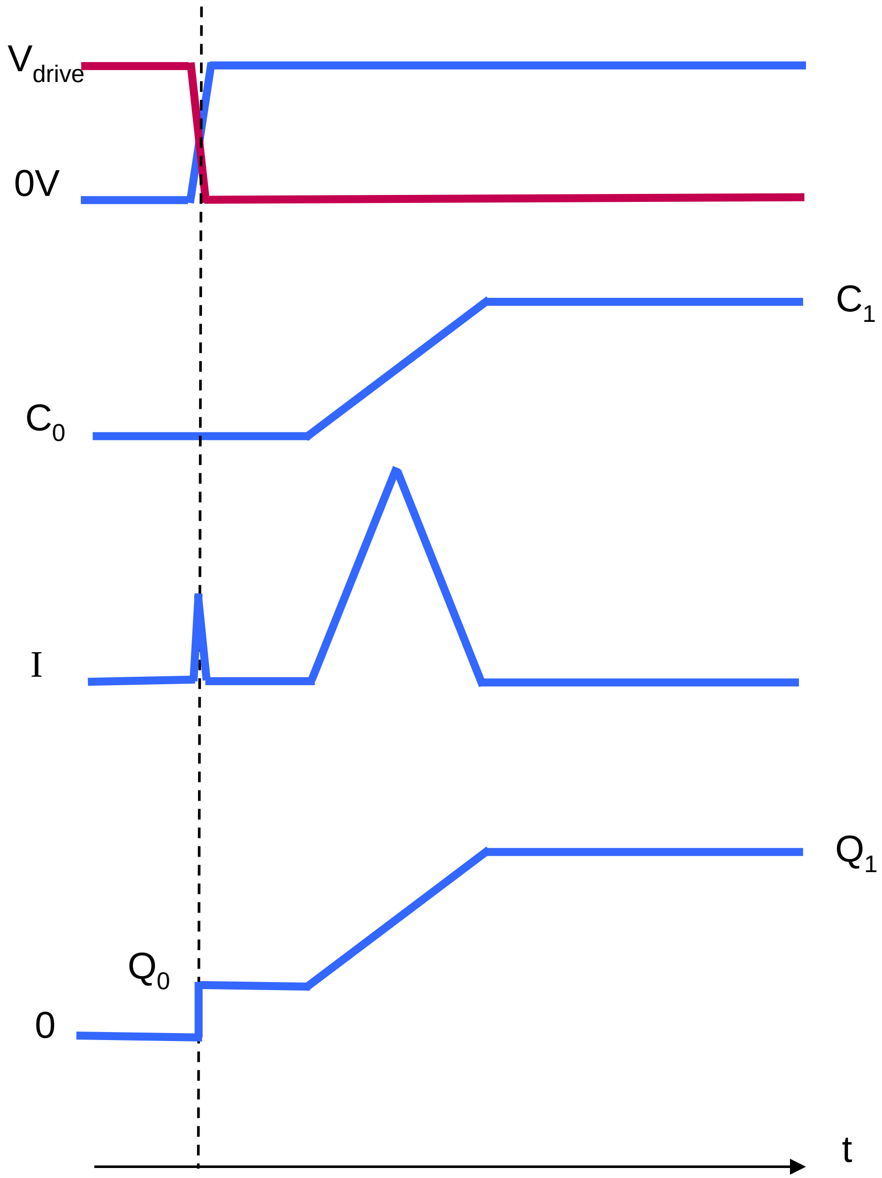




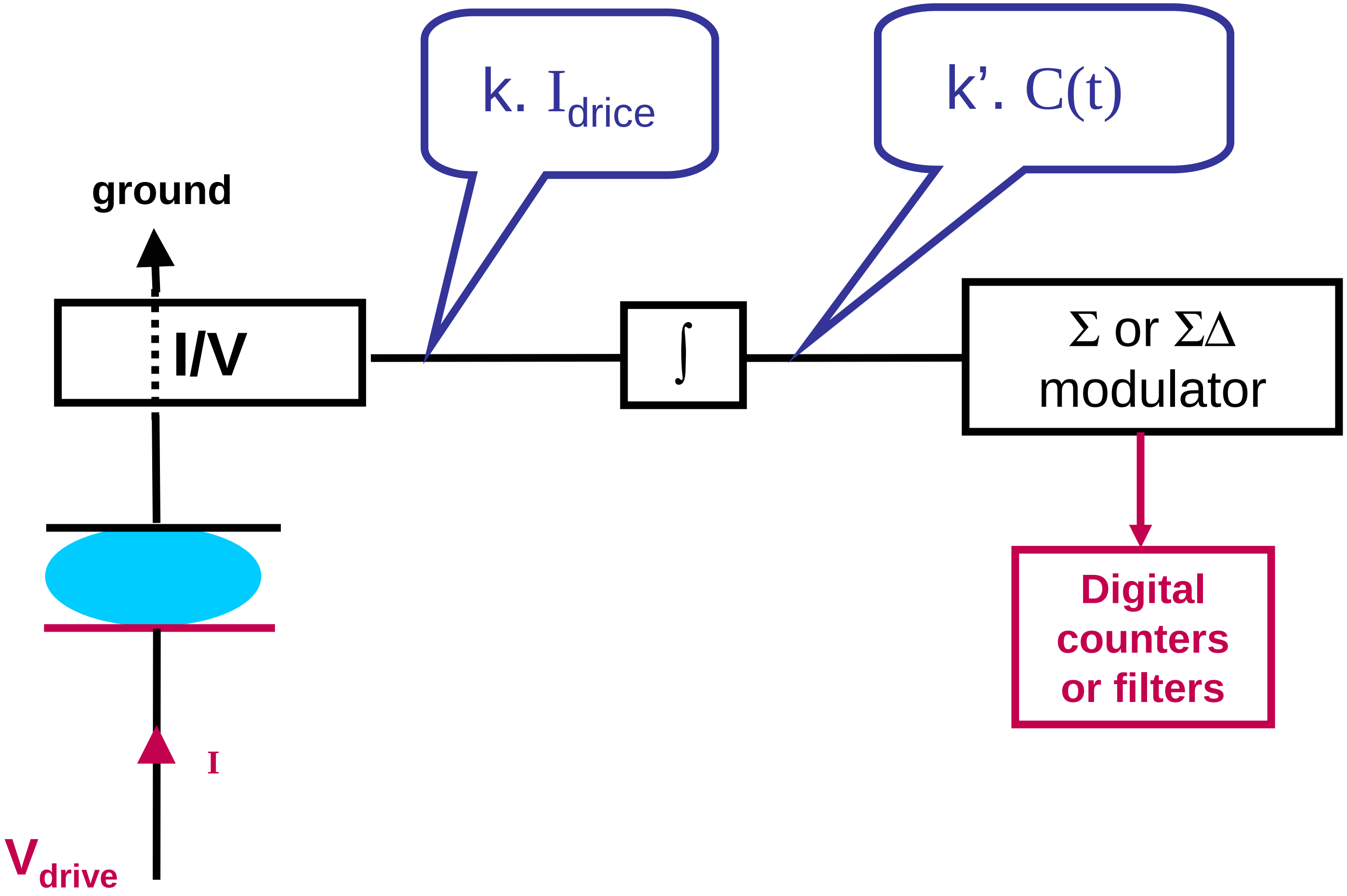
LIRMM proposal: principle

Principle:

- current tracking
- $Q = C(t).V_{drive}$
  $= \int I_{drive}.dt$



LIRMM proposal: block architecture



CONCLUSION

- Current drive tracking should allow droplet presence testing, parametric fault detection and droplet contents measurement.
- To start the circuit implementation, we need some entries:
  - design kits of the CMOS/DMOS technology
  - high voltage circuit implemented on the prototype
  - experimental or simulated values of the capacitances: C_0 and C_1
  - model for droplet transfer: C(t)
  - measurement resolution necessary for droplet contents analysis