# A Multi-Step Multi-Sample μNMR Relaxometer Using Inside-Magnet Digital Microfluidics and a Butterfly-Coil-Input CMOS Transceiver

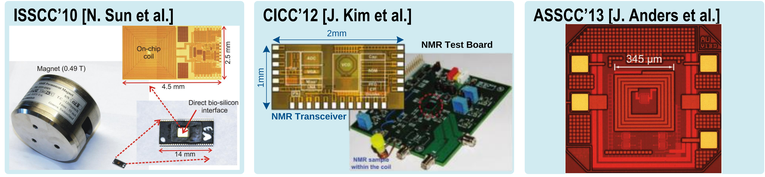
Ka-Meng Lei, Pui-In Mak, Man-Kay Law, and Rui Martins[1]

State-Key Laboratory of Analog and Mixed-Signal VLSI, University of Macau, Macao, China, 1- also with Instituto Superior Técnico, TU of Lisbon, Portugal

## Research Background

**Nuclear magnetic resonance (NMR):**

- A novel and tantalizing tool
- Non-invasive and target-specific
- Several CMOS NMR systems have been reported
- Sample management poses a great challenge




**Challenges on Multi-Sample Multi-Step Experiments**

**System Highlights:**

- Co-integration of **microelectronics** and **digital microfluidics** technologies
- Sample manipulation (and sensing) **inside portable magnet** (1.2 kg, 0.5 Tesla)
- Cross-domain optimized **Butterfly-coil** to expand the effective electrodes

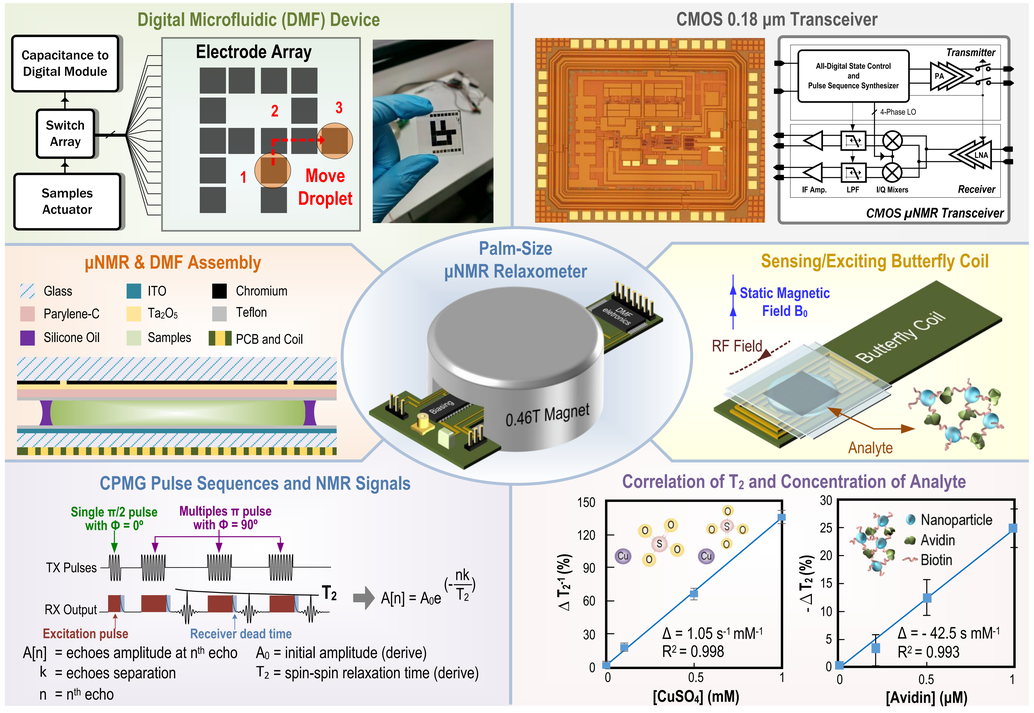
**Result Highlights:**

- **World-first electronic-automated μNMR relaxometer**
- **Multi-step multi-sample chemical/biological assays**
- **Unprocessed targets can be quantified by spin-spin relaxation time ($T_2$)**
- **Auto-handling and recognition of 2 biological samples with pre-designed probe**
- **Flexible route projection and optimization at software level**

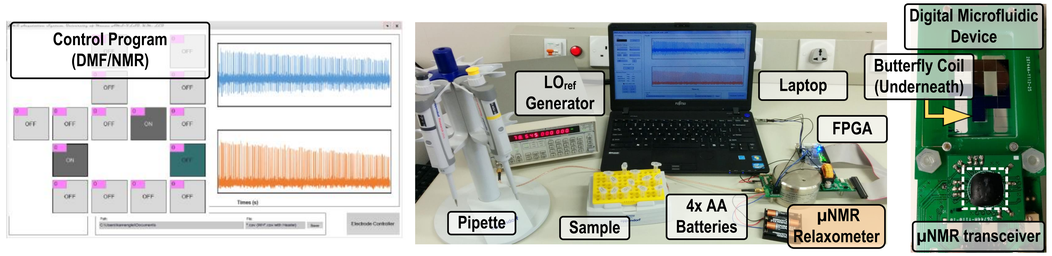
## Comparison with the State-of-the-Art

| | ISSCC '10 | CICC '12 | ASSCC '13 | This Work |
|---|---|---|---|---|
| *System Perspective* | | | | |
| **Functionality** | Relaxometry | Spectroscopy | Imaging | Relaxometry |
| **Coil Style** | On-chip spiral | Off-chip solenoid | On-chip spiral | **Off-chip PCB Butterfly** |
| **Magnet** | Portable (1.2 kg, 0.5 T) | N/A (5 T) | Large-scale (Bruker 7 T) | Portable (1.2 kg, 0.5 T) |
| **Sample Handling per Experiment** | One | One | One | **Multiple** |
| **Pre-/Post-Sample Reaction Supportability** | No (Only μNMR) | No (Only μNMR) | No (Only μNMR) | Yes (Mixing, Splitting + μNMR) |
| *Circuit perspective* | | | | |
| **Process (Voltage)** | 0.18 μm (1.8 V) | 0.13 μm (1.5 V) | 0.13 μm (1.5 V) | 0.18 μm (1.8 V) |
| **Freq.** | 21 MHz | 5-300 MHz | 300 MHz | 20 MHz |
| **Architecture** | TRx | Rx | Rx | TRx |
| **IRN (with/without coil)** | 0.93/1.26 nV/√Hz | --/3.5 nV/√Hz | 0.26/-- nV/√Hz | **0.16/0.92 nV/√Hz** |
| **Power** | N/A | 18 mW | 18 mW | 26.6 mW |

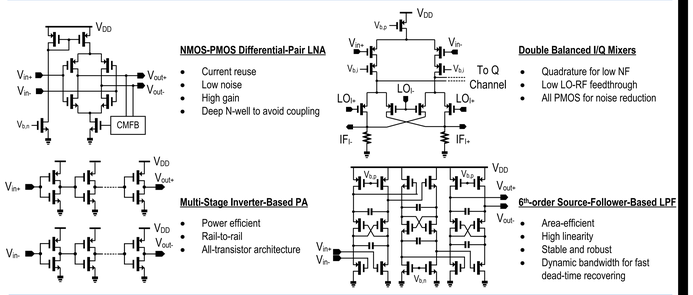
## Multidisciplinary Lab-on-a-Chip Solution



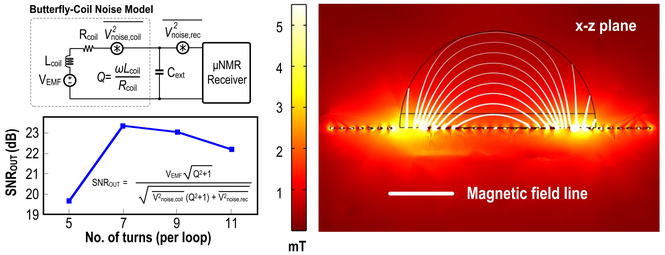

## Hardware Setup & Software Control

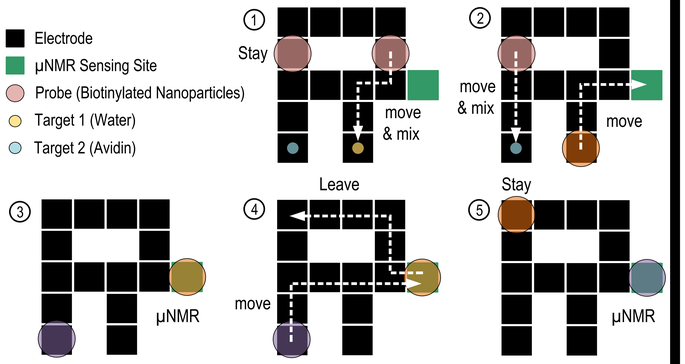



## Transceiver Schematics




## Cross-Domain Butterfly-Coil Optimization




## Multi-Sample Management