Carnegie Mellon University

Electrical & Computer ENGINEERING

Ingestible Electronics: Microelectronic System for a Smart Pill

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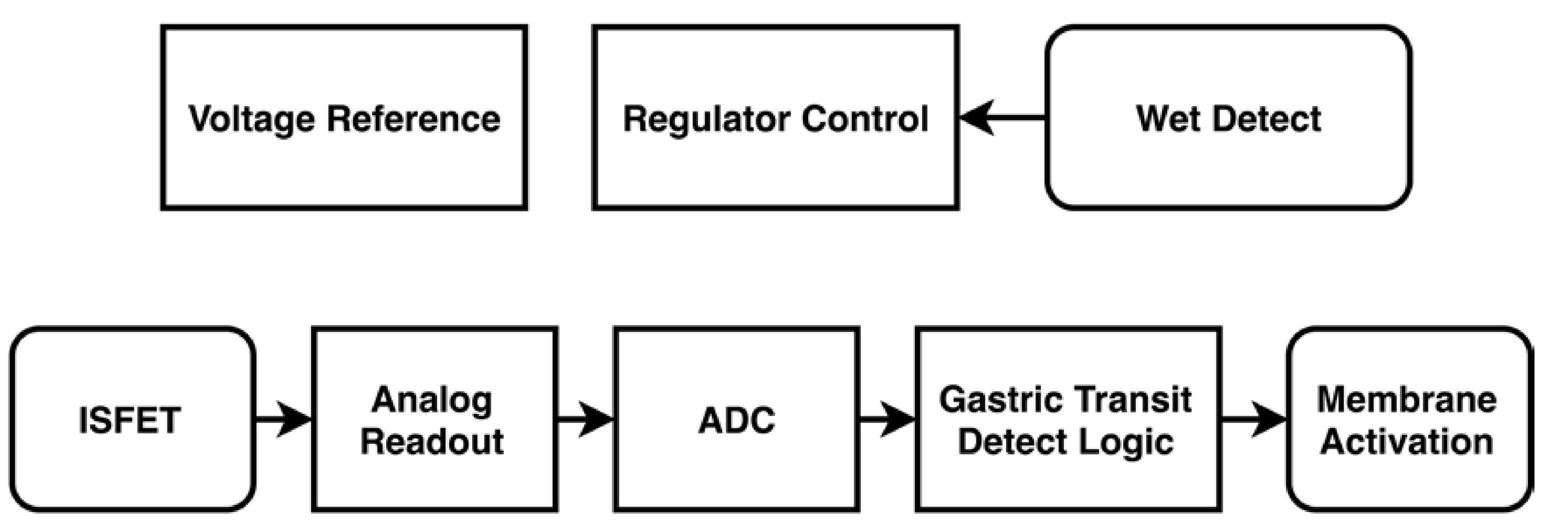
Introduction

An advancement in biocompatible batteries creates new applications in medicine. Materials scientist Chris Bettinger has created biocompatible batteries which pose little risk when ingested. This technology enables the development of so-called ingestible electronics. There is a whole class of therapeutics which are effective with bolus delivery of a known amount to a specific location. This includes vaccines, IBS treatment, and microbiome payloads. Traditionally, a controlled release of drugs means a sustained release, relying on passive polymeric materials which disintegrate in the digestive system. The need for an acutely targeted release motivates the creation of a smart pill, a tablet with integrated sensors, electronics and a drug reservoir. These modules may be implemented on an IC to reduce cost and size.

Integrated Circuit System Diagram

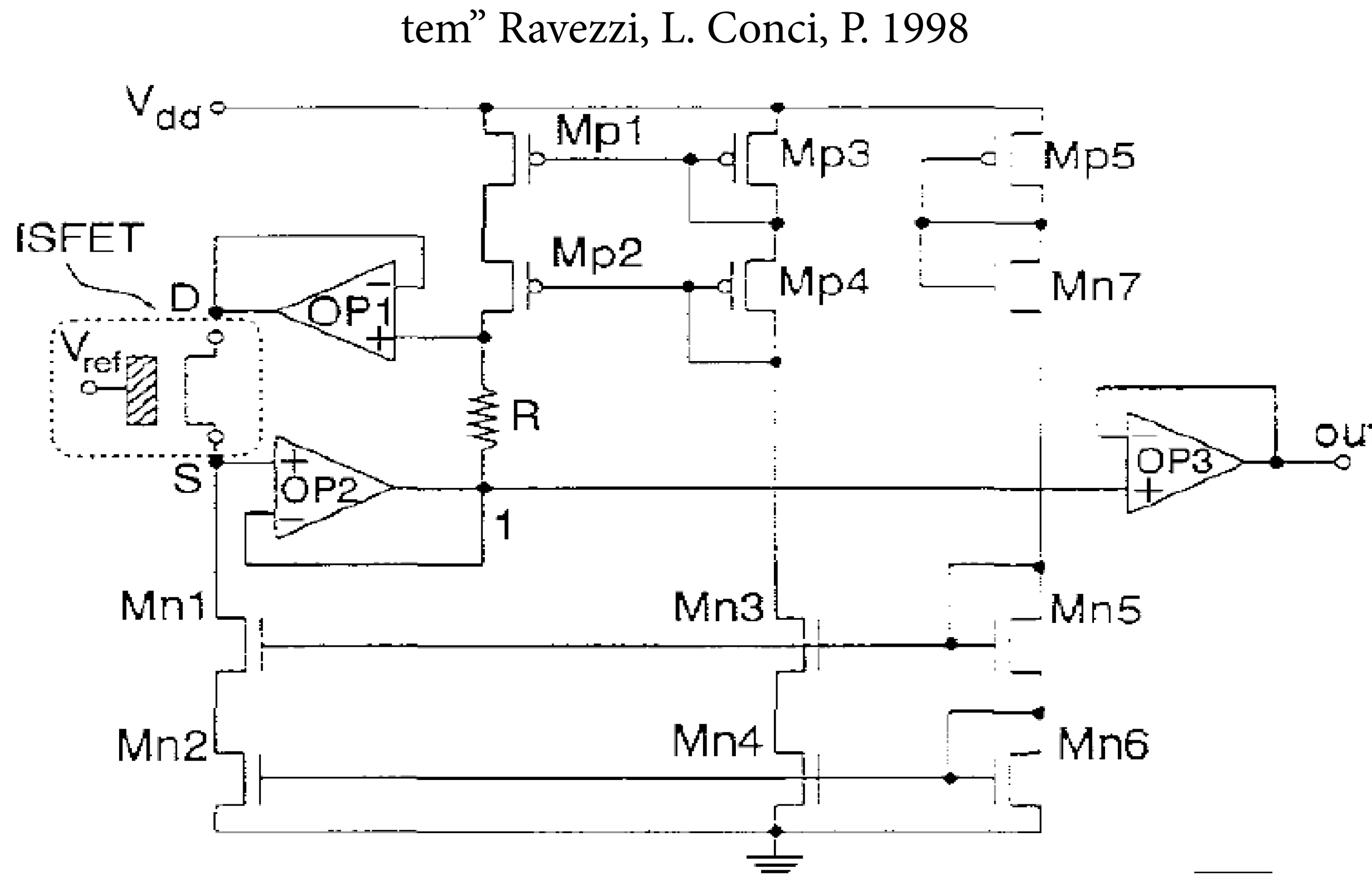


ISFET pH Sensor

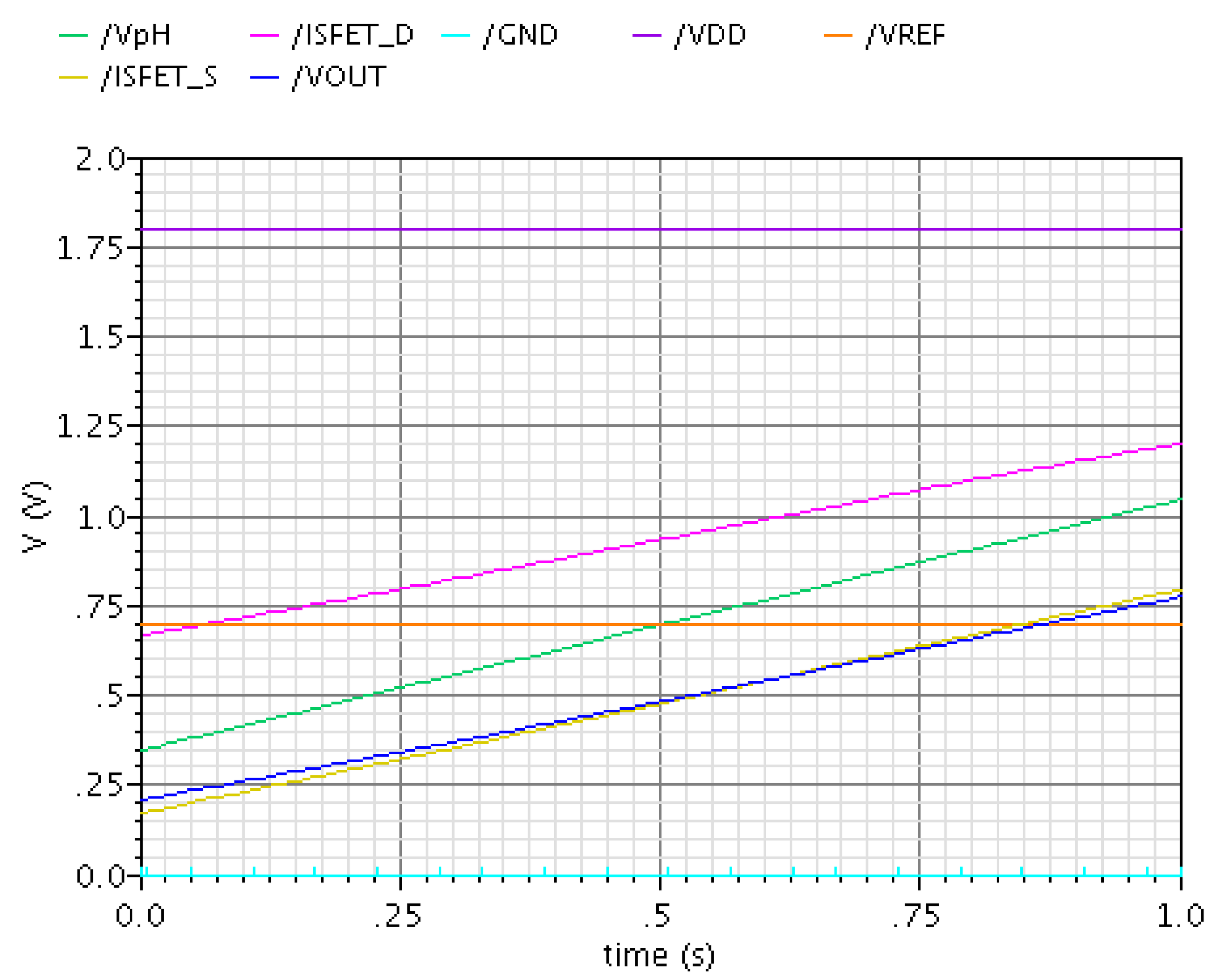
pH may be used to localize the smart pill within the digestive tract. The Ion Sensitive Field Effect Transistor provides multiple advantages over conventional pH sensors. Namely, it is compatible with the CMOS process, and it avoids the bulky glass electrode. The ISFET combines a MOSFET with a ion sensitive insulator attached to the gate. Fluctuations in pH linearly affect the threshold voltage of the MOSFET. By selecting the Silicon Nitride passivation layer for the ion sensitive layer, additional process steps are avoided. The sensor achieves a sensitivity of up to 58mV/pH [1].

The floating gate electrode presents a challenge, as it may obtain a charge during manufacturing, modifying threshold voltage at pH=7 [2]. A solution may be UV treatment. A single ended analog readout circuit for the ISFET has been simulated, that applies constant current and voltage to the device.

Isfet Readout Circuit -"ISFET Sensor Coupled With CMOS Readout System" Ravezzi, L. Conci, P. 1998



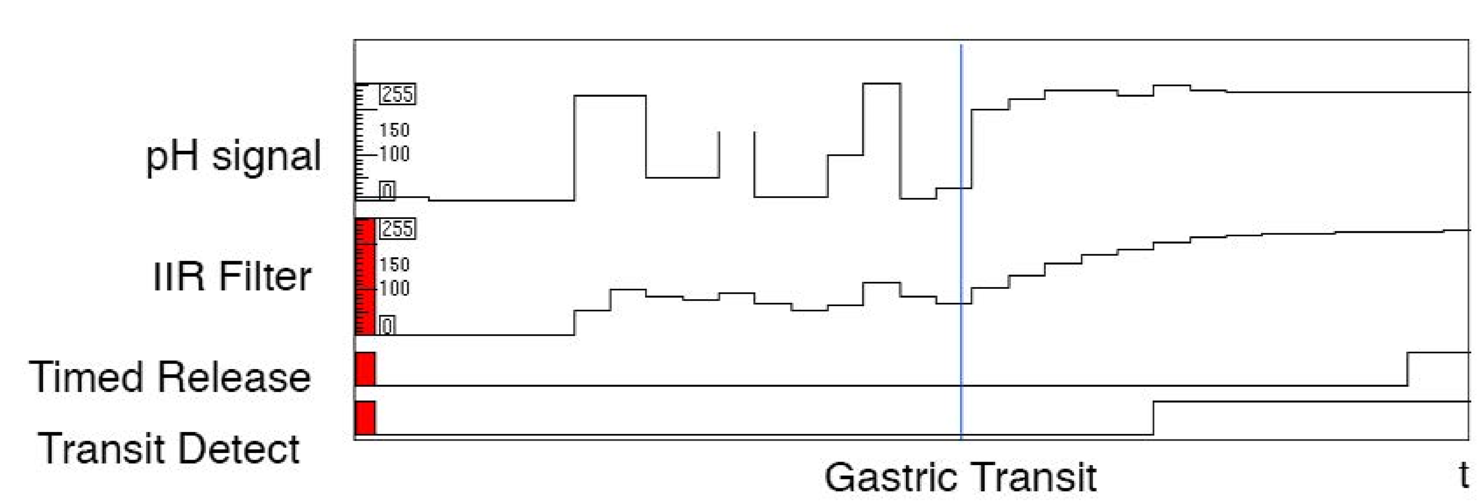
ISFET Analog Readout Simulation



Gastric Transit Detection

Throughout the gastrointestinal transit, pH fluctuates widely. There is a sharp up swing in pH between gastric emptying and cecum arrival, which may be used to locate the smart pill in the digestive system [3]. Digital logic has been simulated which detects this transition, delays to allow for partial passage through the intestines, then activates drug release.

Gastric Transit Detection Logic



Power

The miniature size of the smart pill places constraints on the power consumption of the device. Gastric transit can take three days or more, during which the pill must be sampling pH. A 3 gram melanin battery with two cells in series provides 25mAh at 1V nominal. A low-quiescent charge pump boosts the voltage to 1.8V. Additionally, the smart pill must be shelf stable for multiple years. In order to conserve the battery before the pill is taken, the pill remains off until saliva causes conduction between electrodes on the pill surface, starting the clock and charge pump.

Selected References

[1] L. Ravezzi and P. Conci, "ISFET sensor coupled with CMOS read-out circuit microsystem," Electron. Lett., vol. 34, no. 23, p. 2234, 1998.

[2] P. a. Hammond, D. Ali, and D. R. S. Cumming, "Design of a single-chip pH sensor using a conventional 0.6-uM CMOS process," IEEE Sens. J., vol. 4, no. 6, pp. 706–712, 2004.

[3] J. Shimizu and H. Zou, "Gastrointestinal Transit of IntelliCap Bioteleme try Device in Yucatan Miniature Pigs," p. 10510, 2011.