# A MULTI-PARAMETER LABORATORY-IN-A-PILL DEVICE WITH REAL-TIME DATA PROCESSING

**L. Wang, E. A. Johannessen, A. Bradley, S. Borthwick, J. M. Cooper, and D. R. S. Cumming**

**The University of Glasgow, United Kingdom**

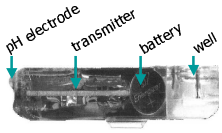
**Honeywell Automation and Control Solutions, United Kingdom**

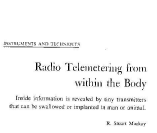


## INTRODUCTION

*An artist's impression of Laboratory-in-a-Pill*

- There has been considerable interest in the development of a miniature radio pill and a portable data receiver for non-invasive gastrointestinal monitoring.
- The location of the capsule should be tracked *in-vivo*, but the existing methods prove to be inaccurate or impractical.
- In Glasgow Univ., we prototyped a system comprising a Laboratory-in-a-pill device and a base station being capable of real-time pH, temperature and location information acquisition and data processing.



Radio Telemetering from within the Body

Inside information is revealed by tiny transmitters that can be swallowed or implanted in man or animal.

R. Stuart Mackay

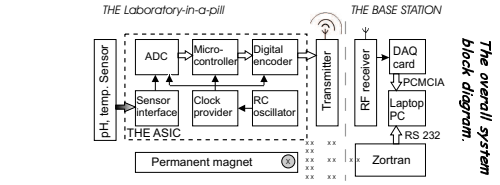
© Am. Coll. of Gastroenterology

*Mackay's First pH Sensor Radio pill in 1961*

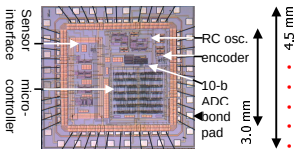
*GivenImaging's First Imaging Radio Pill in 2000.*



## SYSTEM ARCHITECTURE AND ASIC INTEGRATION




*The overall system block diagram.*

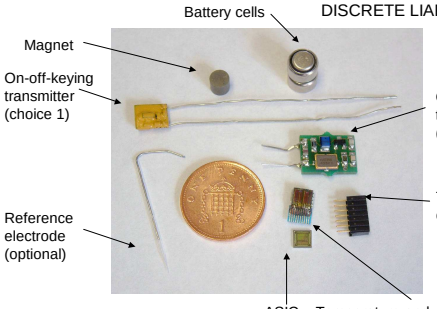



*The ASIC, an inside look*

- A compact ASIC 20 mm$^2$ in size.
- Based on AMS 0.6µm via Europractice.
- Core limited design 9 mm$^2$.
- Double pad rings for wire bonding.
- Encoded data (Manchester coding).



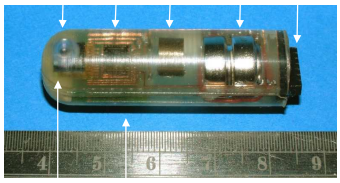
## DISCRETE LIAP COMPONENT




- The LIAP component list:
  The sensor chip
  The 433.92 MHz (ISM band) RF transmitter
  The permanent magnet (Neomag S48A from Magnequench)
  The two SR48 (70mAh each) battery cells
  The mixed-signal ASIC
  The test port connector

## COMPLETE LIAP

Access channel ASIC Magnet Battery cells Test port



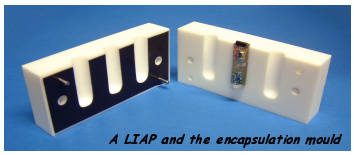
The LIAP measures 44 mm x 12 mm.

The LIAP weighs 8 grams.

Sensor chip 5mm x 5mm

Transmitter (beneath the ASIC) 6mm x 8mm x 3mm

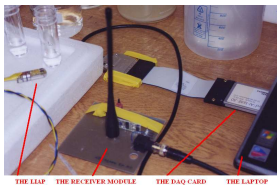
Encapsulation material using PDMS. Encapsulation process takes approx. 1 week. 5 of 6 encapsulations were successful.



*A LIAP and the encapsulation mould*

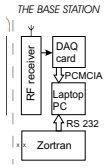


## BASE STATION

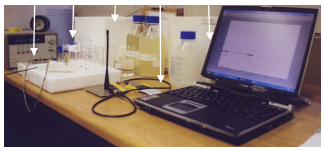



*RF signal was passed to the PC via the DAQ card.*

A MATLAB program was used for data acquisitions, digital filtering, decimation (down-conversion), demodulation and decoding operations, all executed in real-time.




Zortran LIAP RF module DAQ card pH solutions PC



*Test bench comprising of the base station and the LIAP.*

*The Zortran was initially designed to enable accurate location of central access catheters in patients' chest.*

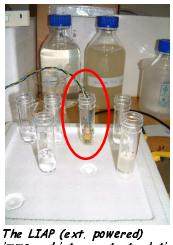



## SYSTEM TEST

- ASIC power consumption: 3.9 mW @ 3.0 V.
- Transmitter peak power (ON state): 15 mW.
- An on-capsule data compression: 70% power reduction.
- Two SR48 cells => 10h (no compression) ~ 50h lifetime.

- Detailed tests included the immersion of the LIAP in different solutions over a wide temperature range:

- pH buffer solutions pH 1, 4, 7 & 10.
- Artificial gastric & intestinal solutions.
- Artificial (high viscosity) GI solutions.
- PBS & RO water.
- Temperature ranged 10°C ~ 50°C using a feedback-controllable hotplate.

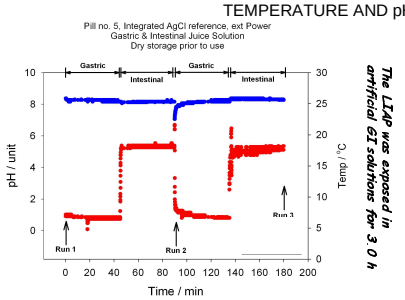


*The LIAP (ext. powered) immersed into one test solution.*

| | Buffered pH solutions | Artificial GI solutions | Artificial GI solutions (high viscosity) |
|---|---|---|---|
| pH channel resolution (pH) | 0.1 | 0.4 | 0.3 |
| pH channel response time (s) | 5.7 | 15.8 | 2400 |
| On-capsule compression ratio | 2.9 | 3.5 | 2.8 |



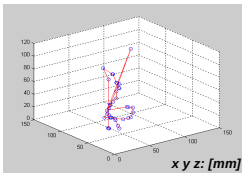
## TEMPERATURE AND pH TEST




*The LIAP was exposed in artificial GI solutions for 3.0 h*

- Blue curve: temperature channel. Red curve: pH channel.
- Artificial gastric solution pH 1.2, artificial intestinal solution pH 6.8, environmental temperature 25°C.
- Readings in intestinal solution averaged at pH 5.6 that was lower than the true pH – the deep access and deposit stuck of the access channel.

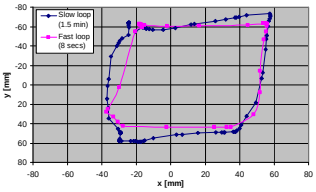
## LOCATION TRACKING TEST




*Location information displayed in real time, using the MATLAB program.*

- The magnet was moved at approximately 10 cm/min and 150 cm/min, respectively, and the position information from Zortran was presented **(below)**.
- The test also showed a location accuracy of $\pm$1 cm was achieved within 25 cm distance. For distance less than 10 cm a better accuracy of $\pm$0.5 cm was achieved.

Since the LIAP is expected to travel in the small intestine at an average speed of 2 cm/min ~ 5 cm/min, the response time of the location tracking would be sufficient.






## CONCLUSION

- *Outputs from the 8-month Laboratory-in-a-pill feasibility project:*
- *Sensors:* proven functionality within buffered and simulated GI environment.
- *ASIC*: self-timed, low power consumption, more functionalities could be added.
- *LIAP*: low cost encapsulation, size needs further reduction.
- *Base station*: being capable of real time data processing, need to be hardwared.
- *Location tracking*: there is a potential (location tracking due to a permanent magnet), but more research are required, e.g. earth field effects when ambulatory.
- *Wireless link*: an easy and cheap way to achieve a 10 kbps data link.
- *In the future:*
- Validation of the system performance in real GI tract.
- Demonstration the safety for ingestion.
- *In vivo* trials on animals.