18TH CENTURY TECHNOLOGY FOR MODERN MEDICAL IOT

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According to science lore, Luigi Galvani (Figure 1) accidently discovered the underlying concept of today's battery. Galvani was actually a surgeon and while in his lab dissecting a frog he and his lab assistant noticed that when his copper and zinc probes bracketed a nerve on the frog's leg, the leg began to twitch. He wrote up a paper in 1790 on this phenomenon, calling it "animal electricity." Maybe this was a precursor to the phrase "animal magnetism?"

Figure 1: Luigi Galvani, discoverer of animal electricity.

In 1791, Alessandro Volta (Figure 2) replicated the work of Galvani, but replaced the frog with brine-soaked paper to show that animals or any other biological matter was not necessary to get the same results. It is not clear why there was a battle between scientists about whether biological matter was important or not. Fans of electronics history might also know that Volta established the law of capacitance $C = Q/V$ and in 1799, he created the voltaic cell, which was a milestone event that ultimately lead to today's electronic batteries. But at the time, neither Galvani nor Volta understood why electric current was possible with metal-to-metal probes connected through an electrolyte material.

Figure 2: Alessandro Volta took biological matter out of the equation.

Along came one of the big figures in the history of electronics and chemistry around 1840 - Michael Faraday (Figure 3). He applied real theory to the voltaic cell and he invented the terminology key to describing a battery, including the electrode, electrolyte, and ion. Faraday codified the idea that electro-motive force is caused by a chemical reaction between two electrodes (of different materials) through an electrolyte.

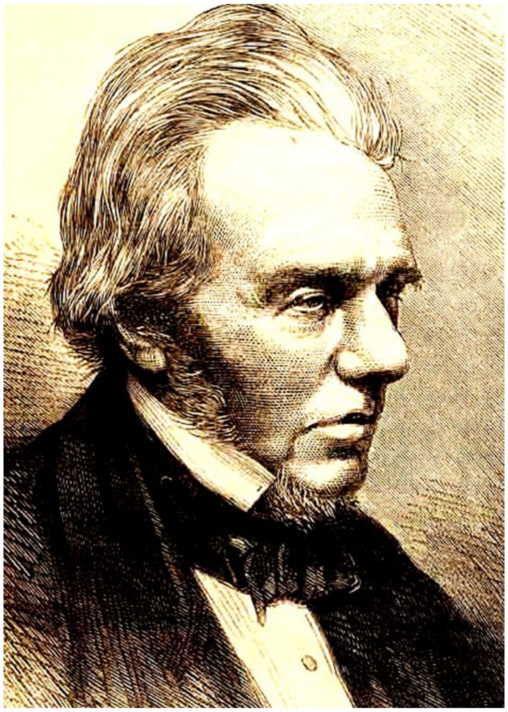

Figure 3: Michael Faraday puts science to the phenomenon.

As with many discoveries in electronics, a phenomenon is observed and it takes time before the proper theory is developed and the entire concept of how it all works is discovered. But what a discovery it was. The concept of the voltaic cell is sometimes revealed in grade school science class, where children are delighted to see that a potato can power a clock.

In simple terms, a voltaic cell (Figure 4) creates energy due to a chemical process. The zinc atoms in contact with an acid dissolve, causing electrons to separate from the atoms. The negatively-charged electrons cannot travel through the acid, so they travel down the wire connecting the two electrodes because they are attracted to the positive ions on the copper side.

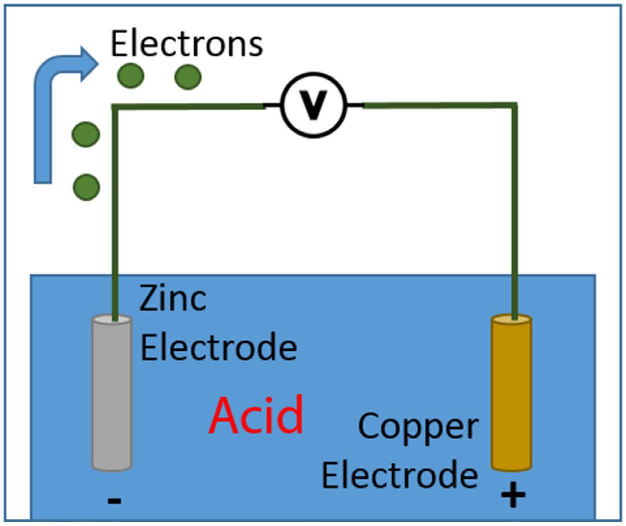

Figure 4: A simple voltaic cell.

BACK TO THE FUTURE

Researchers at MIT and Brigham and Women's Hospital where trying to figure out how to power an ingestible probe for monitoring health without using a battery. Batteries in the human body might cause health concerns and they lose power over time. Perhaps remembering their potato clock experience, they considered the voltaic cell.

The key to the voltaic cell is the acid-based electrolyte. And where does the human body have its own store of acid? In the stomach (gastric acid). Gastric acid is composed of hydrochloric acid, potassium chloride, and sodium chloride and its role in digestion was discovered in the 1820's.

The research team created an ingestible device that has exposed zinc and copper electrodes connected to a temperature sensor circuit, a microcontroller, and a 900 MHz transmitter (Figure 5). In tests using pigs, the devices travelled through the digestive system and wirelessly transmitted the temperature data signal every 12 seconds to a base station 2 meters away.

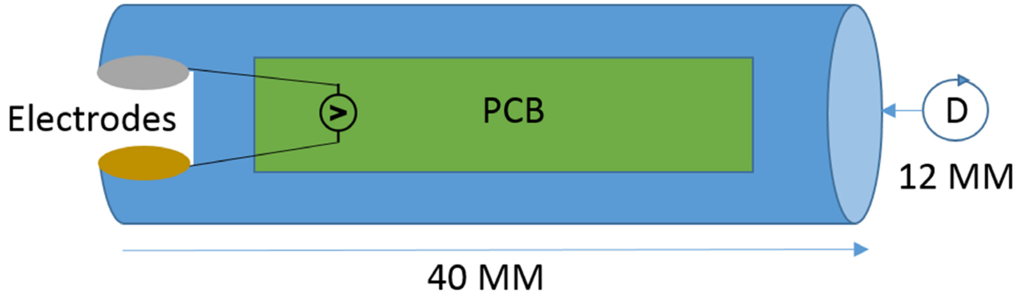

Figure 5: The ingestible device.

Interestingly, because the small intestine contains much less acid than the stomach, the voltaic cell only produced 1/100th of the energy while in the small intestine. But, power was still generated, so the system transmitted packets of sensor data at a rate of once every several minutes. This is a concept prevalent in many IoT edge devices: to conserve power, data is transmitted in bursts at optimal times in the day.

The team had leveraged a concept discovered in the 18th century to create a modern, medical IoT edge device that had almost unlimited power drawn from a biological source! The irony is that during the height of science in those long-ago times, the debate between scientists was whether or not biological matter was necessary. While the voltaic cell concept was ultimately stripped away from biological matter to prove the concept using only metals and non-biological electrolytes, we see that the biological matter is the key to this IoT solution.

SPEAKING OF THE FUTURE

It is only speculation at this point, but there are many ways that this technology could improve and become a key tool for use in medicine. For example, the team could create a device with several sensors onboard that could be used as a general platform for ingested capsules. They could use software to differentiate what data should be collected for a particular patient's issue. That data could be transmitted to a smartphone, instead of a base station, and an app could interpret the results. The data and results could be shared with a doctor using the Cloud. This ingestible technology could also be used to deliver a drug payload to a certain place within the body. Other researchers have also combined ingestible technology with a small camera for use in diagnosing internal issues.

The research team indicated that they would like to reduce the size, cost, and potentially power consumption by replacing the discrete components on the PCB with a custom IC. This is the first step to create an intelligent, sensor-based IoT edge device - employ a custom IC design and verification flow. Creating a unique footprint PCB for the custom IC and developing embedded software rounds out the solution. Mentor has a unique solution to attain the device that the researchers ultimately want to create.

IMPLEMENTING IOT EDGE SOLUTIONS

The medical IoT edge device that the researchers designed is no different than most intelligent sensor-based systems (Figure 6).

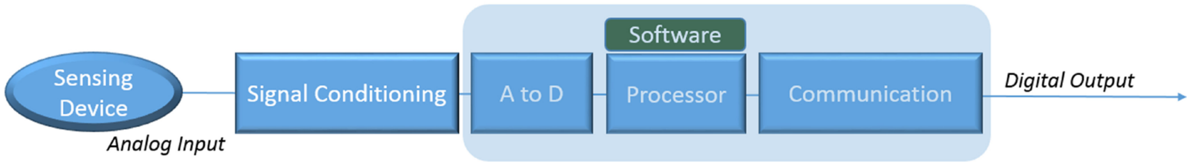

Figure 6: A typical intelligent sensor-based IoT system.

The typical intelligent sensor-based system contains:

- A sensing device that measures physical parameters from the real world, such as temperature and pressure. In many cases, this sensor is built using MEMS technology.
- A computational block, such as a processor or DSP, which processes the sensing device data signal. Bare metal or embedded software runs on this block to perform analysis or data interpretation.
- A communication block, such as a wireless transmitter, that exchanges information with a larger intelligent system, such as a smartphone.

Of course, to build a platform, the design team can add additional sensors and logic to handle these multiple input sources and build out the software to perform sophisticated analysis of the sensor data.

This typical IoT edge device points out the complexity of designing and verifying the solution: the IC team has to be proficient in digital, analog, RF, and MEMS design. Within the IC team, these domains are usually independently led by designers and consist of separate teams with domain expertise. A separate software team develops the code that runs on the processor of the IC and the PCB team creates the unique board for the IC and associated discrete elements. All of these teams exchange required information and data and the whole system needs to come together and be verified. Mentor offers a unique solution to this problem (Figure 7).

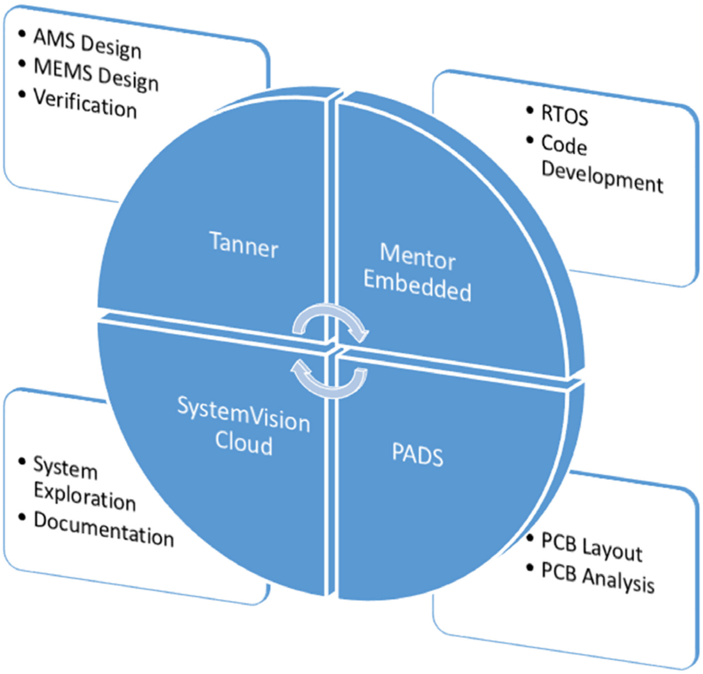

Figure 7: Mentor's complete IoT edge system solution.

Tanner provides a single, top-down design flow (Figure 8) for IoT design, unifying the analog, digital, RF, and MEMS design domains. Whether you are designing a single die or multiple die IoT device, you can use the Tanner design flow for design, simulation, layout and verification.

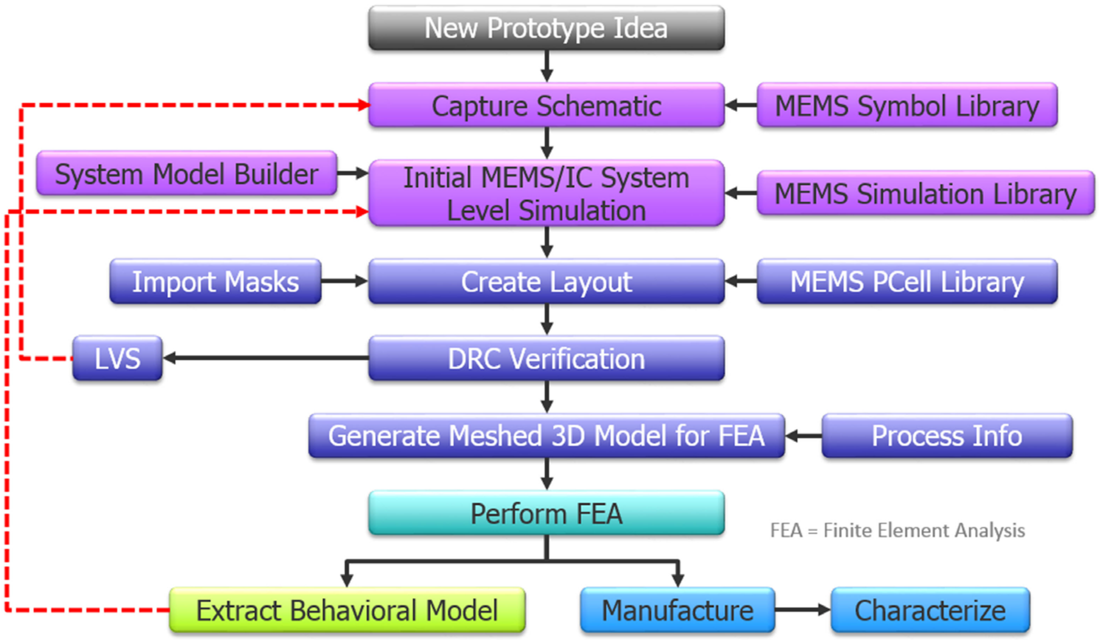

Figure 8: The multi-domain Tanner design flow.

For resource-constrained and battery-powered IoT edge devices, developers employ the scalable Mentor Embedded Nucleus® RTOS. To meet the power requirements, designers can take advantage of integrated power management that includes support for dynamic voltage and frequency scaling (DVFS), deep sleep modes, and power/clock gating.

For embedded software development, designers can use Sourcery™ CodeBench (Figure 9). This tool provides designers with open source, embedded C/C++ development tools to build, debug, analyze and optimize embedded software in heterogeneous architectures.

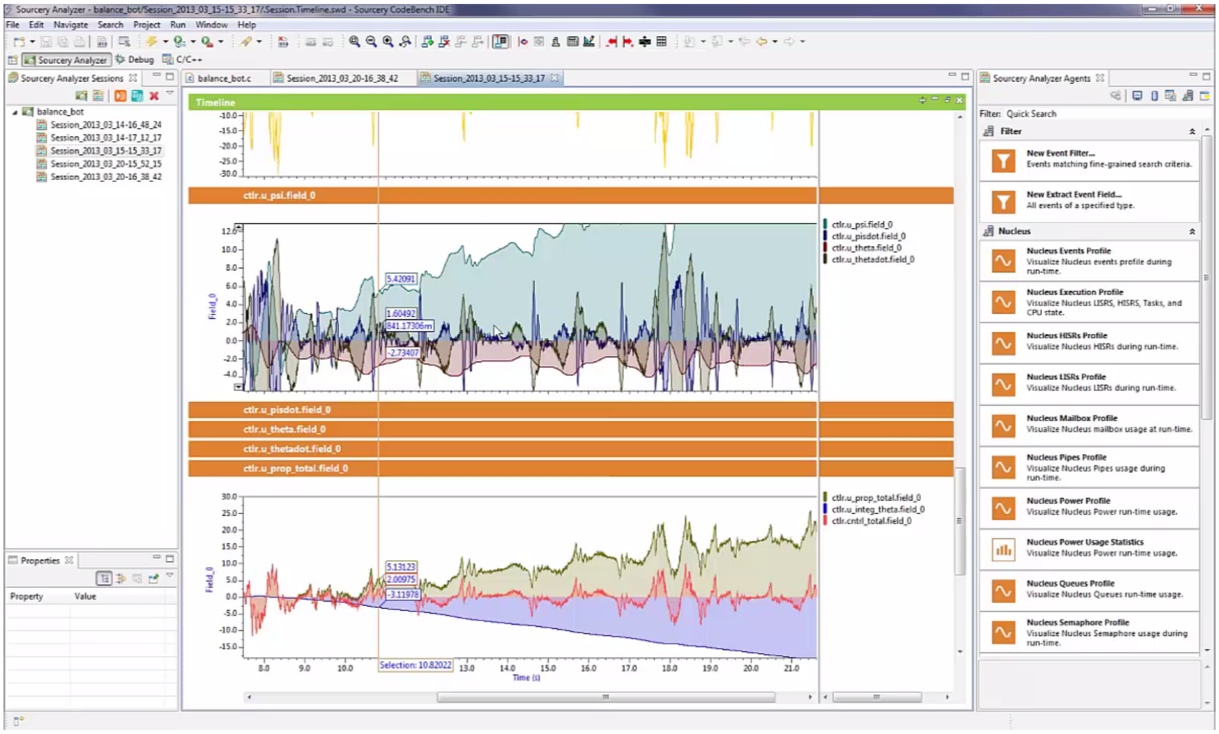

Figure 9: Using CodeBench to create and analyze embedded software.

The SystemVision® Cloud environment (Figure 10) provides an online environment to capture a system using a variety of electronic circuit and mechatronic system building-block models and then designs use state-of-art simulation technology and in-context results viewing to analyze the system.

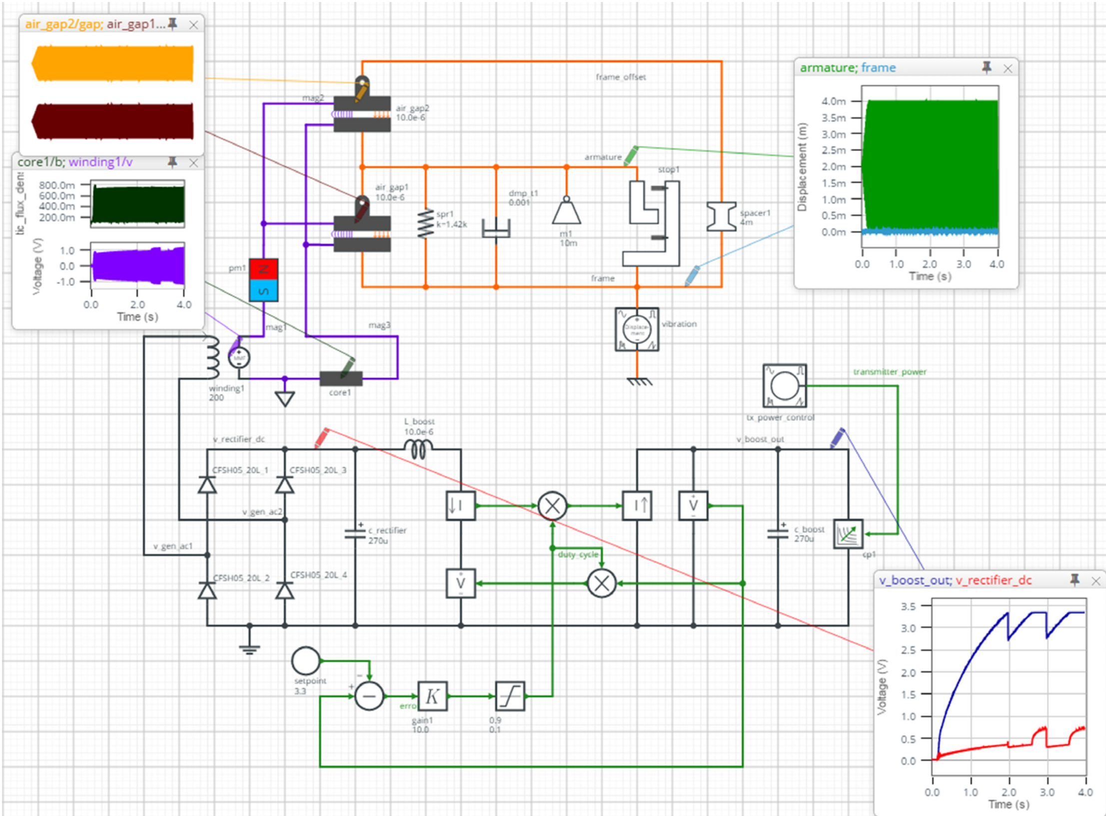

Figure 10: An energy harvesting system being verified in SystemVision Cloud.

SystemVision Cloud allows teams to embed live designs and waveform results in online documents, similar to embedding a video. The content is live, meaning it can be viewed and manipulated right in the document.

PADS® Standard (Figure 11) provides schematic capture and board layout capabilities in an intuitive and easy-to-use environment for developing the unique footprint PCBs that small IoT systems require.

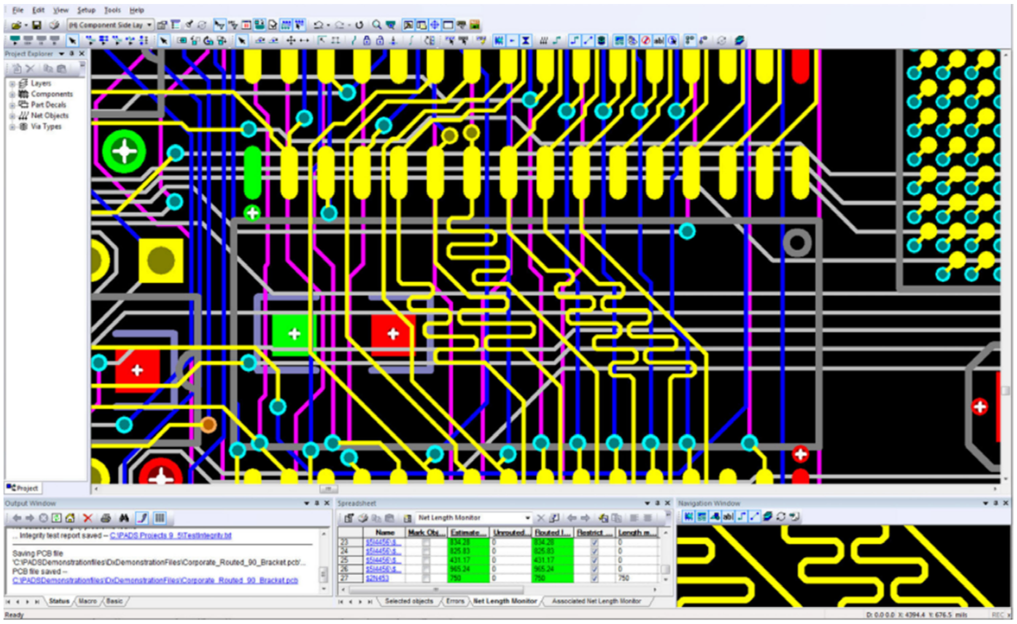

Figure 11: PCB development within the PADS environment.

THE TAKE-AWAY

As the researchers demonstrated, sometimes an ancient technology is just what is needed to power an IoT edge device. Their prototype consisted of discrete components on a PCB running software to transmit temperature data. To reach the ultimate solution, they require creating a custom IC (with multiple sensors), a unique PCB, and sophisticated software. Mentor has the tool flow to attain that solution or any other IoT edge device powered by intelligent sensors.

To learn more about creating an IoT edge device using Mentor tool flows, read this whitepaper, "Implementing an IoT Edge Device While Minimizing NRE."

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