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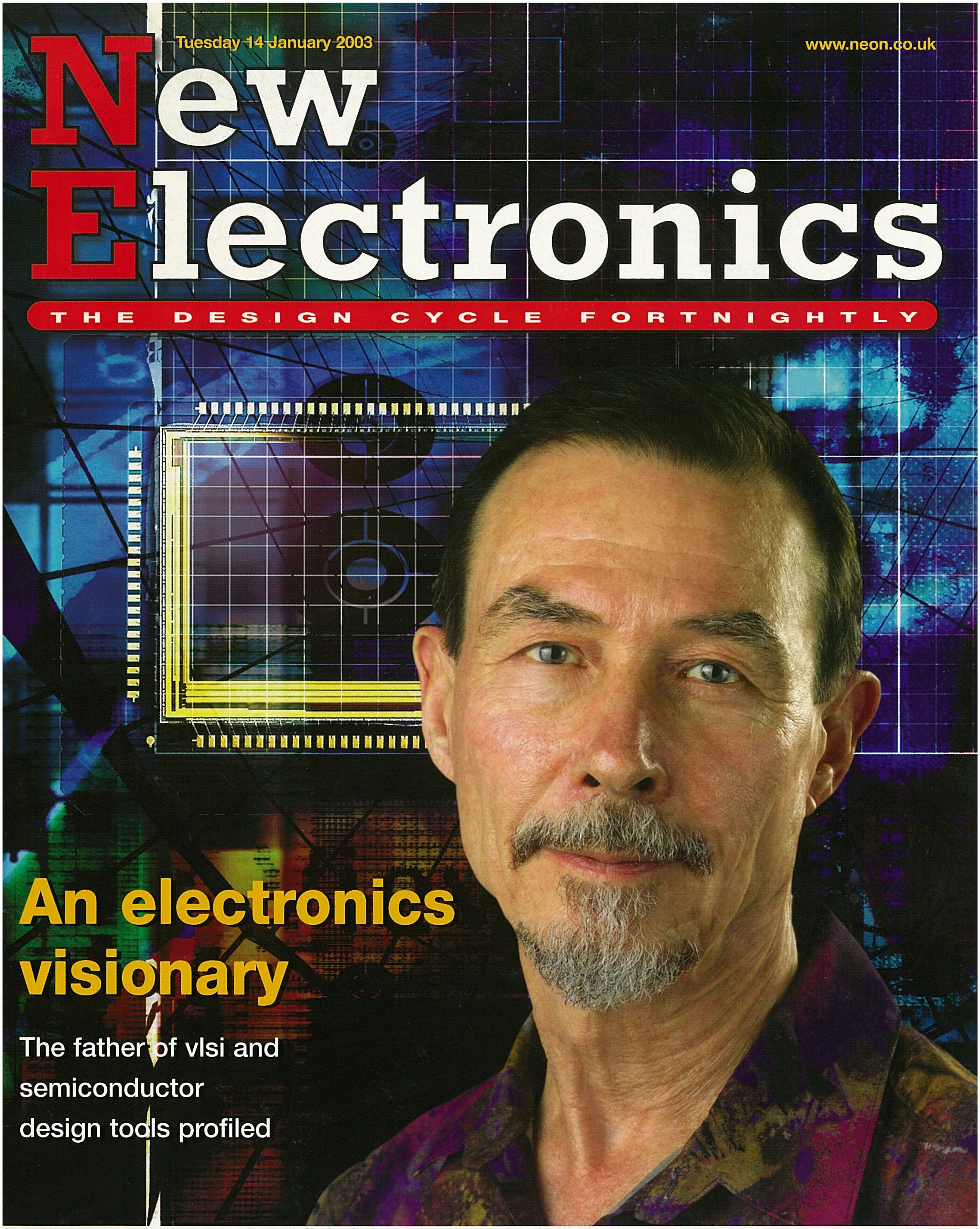
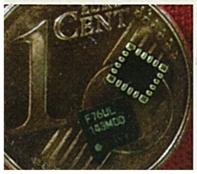
New Electronics

THE DESIGN CYCLE FORTNIGHTLY



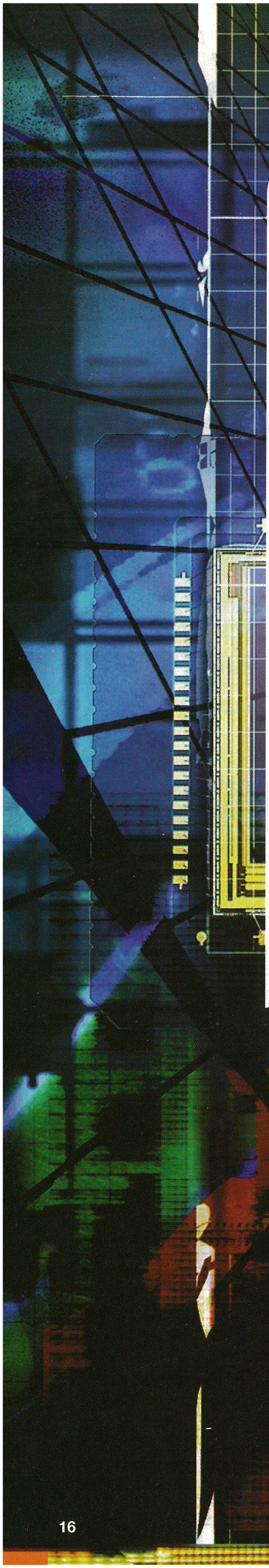
An electronics visionary

The father of vlsi and semiconductor design tools profiled



Special report: IC Fabrication

Plus: Embedded memory controllers • Handing off motor control tasks • Optimised power scaling • Antenna developments • Laser etched circuits



An electronics visionary

Founding father of vlsi, pioneer of semiconductor design tools and a passionate advocate of analogue electronics. It can only be Professor Carver Mead, says David Boothroyd.

For decades, Professor Carver Mead has been a charismatic figure in the global electronics industry; someone who genuinely deserves the title 'visionary'. Now approaching 70, Mead recently retired from his full time academic position – Professor of Engineering and Applied Science at the California Institute of Technology (Caltech) – where he had taught for more than 40 years.

His achievements go back to the late 1960s, when he was one of the first to look into the future of the semiconductor industry and consider how small a functioning transistor could be (his answer: 0.15µm). He forecast that, within 15 years, millions of transistors would fit on a single chip – at the time, a revolutionary idea at which many scoffed, but one which played an important part in setting the electronics industry on its dramatic course to vlsi technology.

Other specific innovations include the high electron mobility transistor, or hemt, now the standard amplifying device for microwave communication systems, and used widely in satellite, fibre optic and mobile telephones. In the design field, Mead developed the foundations for vlsi with his structured custom design approach, used throughout the semiconductor industry. His 1970s book '*Introduction to VLSI Systems*' is seen as the field's classic textbook. He is also credited with pioneering the idea of the silicon foundry.

Engineering honours

Not surprisingly, his achievements have been widely recognised. During his career at Caltech, he received more than a dozen microelectronics and engineering honours, including the 1999 annual Lemelson-MIT prize worth $500,000. He holds more than 50 US patents and has contributed to more than 100 scientific publications.

"Carver has demonstrated a unique ability to identify areas of developing importance in electronics and jump in at the right time to accelerate progress," says another electronics industry great, Intel's Gordon Moore. "His contributions to vlsi design trained a generation of engineers that has driven the semiconductor industry and his work on electronic analogue and biological systems has advanced both neural networks and our understanding of how our eyes and ears process information."

Microsoft's Bill Gates has said of Mead: "Nobody ignores Carver Mead. He catches your attention and makes you say Wow!"

Mead's work has ranged from fundamental semiconductor work to original design philosophies. But perhaps the single most important theme underpinning his whole approach – certainly in the latter years – has been the belief that the use of analogue techniques and the physics of cmos vlsi technology represents, by far, the best chance of creating 'machines' that might eventually rival the performance of neurobiological processing. A corollary of this view is that conventional digital electronics is highly unlikely ever to do that.

This approach – presented in Mead's book '*Analogue VLSI and Neural Systems*' – has spawned a new field of study called neuromorphic engineering (NME), a term he coined. It aims to build working pieces of technology, in which the design is far more closely modelled on biological systems than anything done previously. Examples include the human iris, or the auditory system, or a microrobot that can fly – like a fly.

In electronic terms, NME aims to create analogue circuits that mimic neurobiological architectures. Rather than implementing abstract neural networks remotely related to biological nervous systems, NME chips aim to directly exploit the physics of cmos vlsi technology to implement at least some of the physical processes that underlie real neural computation. Why has Mead been so convinced that this radically different approach to conventional electronics has so much potential?

"Biological information processing systems operate on completely different principles from those with which most engineers are familiar. For many problems, particularly those in which the input data are ill conditioned and the computation can be specified in a relative manner, biological solutions are many orders of magnitude more effective than those we have been able to implement using digital methods."

This advantage stems principally from the use of elementary physical phenomena as computational primitives, and to the representation of information by the relative values of analogue signals, rather than the absolute values of digital signals. This approach requires adaptive techniques to mitigate the effects of component differences.

"This kind of adaptation leads naturally to systems that learn about their environment. Large scale adaptive analogue systems are more robust to component degradation and failure than are more conventional systems, and they use far less power. For this reason, adaptive analogue technology can be expected to utilise the full potential of wafer scale silicon fabrication."

Mead modestly puts the originality of his ideas down to a simple attitude he has had all his life.

"At any point in time, there always seemed to me to be things that were limiting what we could do, presenting a potential brick wall to further development, but most people weren't paying attention to that. So I would try to find out what we could do about it. I've always tried to ask, is there something we should be thinking about that no one is?"

The answer has, invariably, been yes.

"For example, how were we going to make devices ever smaller without them melting? Then, when we saw we could make devices with millions of active components in them, how were we going to handle the design of such things? Nobody knew how to do that. Then there is the question: is the standard computer architecture the right approach when you have millions of active devices?"

Design tools done badly?

Despite its dramatic success, by going down the route it has, has the electronics industry also failed in some sense? Mead thinks so.

"I believe the whole space of design tools has been done very badly – and still is. People may think about a design from a higher level but, when it comes to implementing it, it's very difficult to impose a strict discipline – like a timing discipline, or an architectural one – on the entire design. So you end up tackling problems such as timing when the chip comes back and this is making the production of today's large chips extremely difficult."

Mead is certain this has already had the effect of applying a brake to electronic development.

"You can see this in the development of low power devices, which has not proceeded very well. Power dissipation levels have come down a bit, but there has been no fundamental breakthrough. There are some very good potential approaches to achieving this that are understood by a very few people, but it hasn't penetrated the industry yet."

Extremely low power operation is just one of the attractions of neuromorphic engineering.

"Biological systems achieve their low power performance through the use of massive parallelism, which is something we have never been able to understand well enough to make it work. We have made small steps, such

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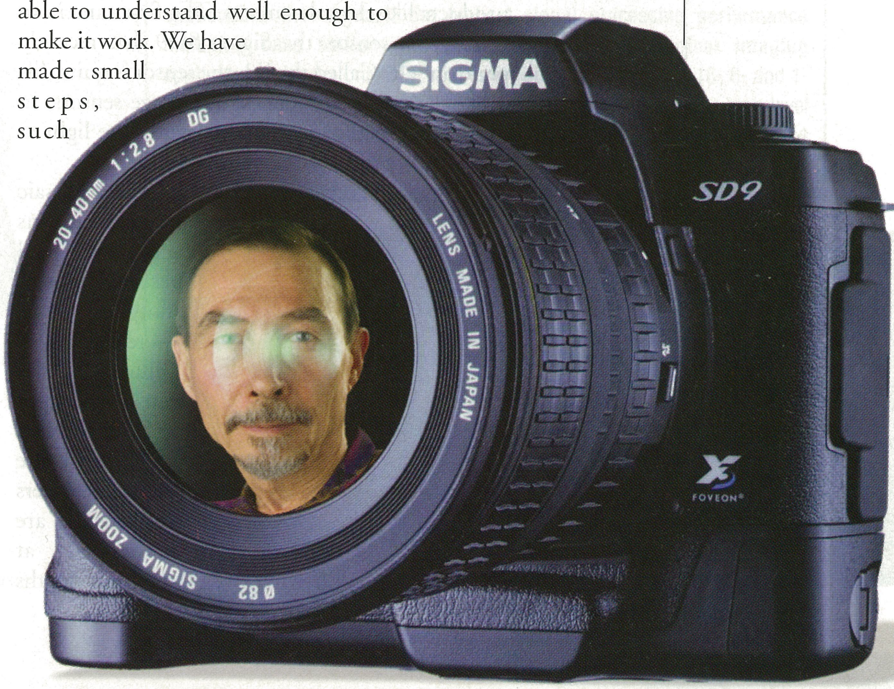
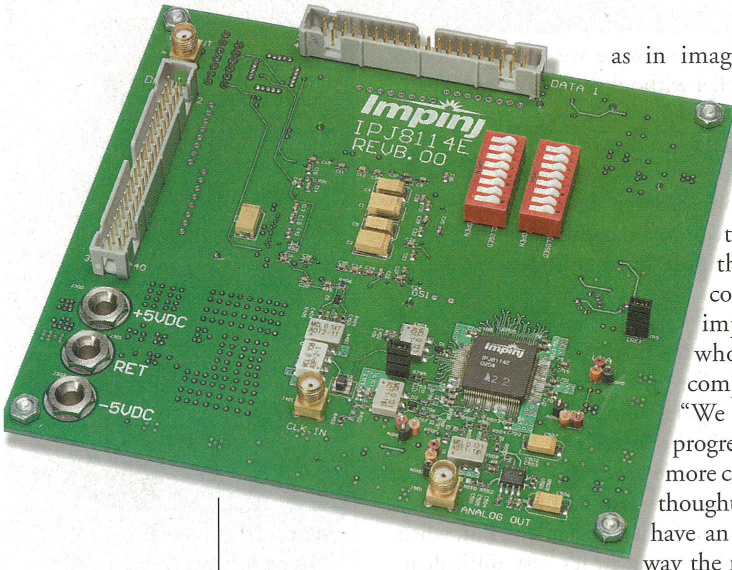
Below
Sigma's SD9 is the first camera to feature Foveon's X3 sensor. The X3 contains some 32million analogue transistors and is said to offer major improvements in image sharpness, colour detail and resistance to unpredictable colour artefacts.





Impinj's IPJ 8114E development platform, above, features a 14bit 300Msample/s d/a converter implemented in 3.3V cmos logic using Self Adaptive Silicon.
The d/a converter brings high levels of performance without the need for interpolation circuitry.

as in imaging to extract colour, using the physics of the image plane. That is a beginning of the kind of thinking that could have a huge impact on the whole concept of computing.

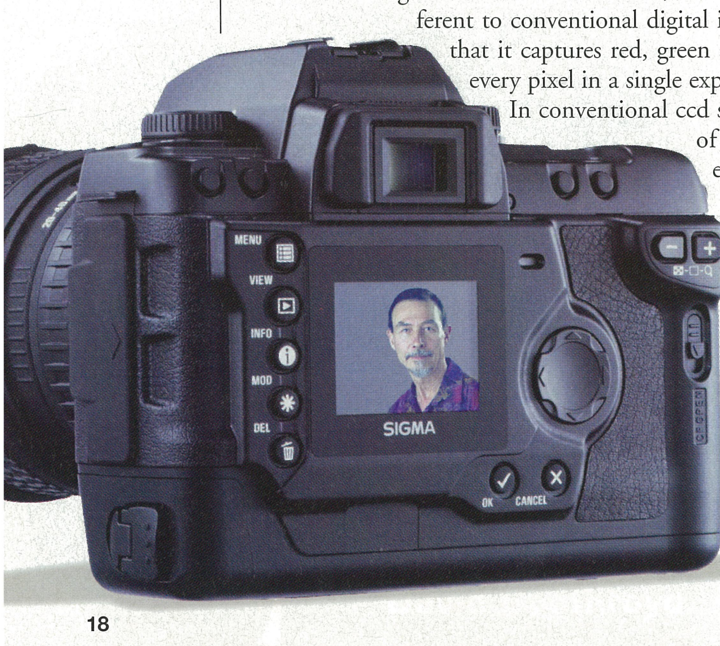
"We are making progress, but it's a lot more complex than we thought. We don't even have an idea about the way the neural substrate does a computation. The old ideas are obviously not correct and no one has come up with a conceptual view of what is going on that corresponds to the kind of problems that the brain solves, or the actual observations of signals in the brain."

Several other companies founded or cofounded by Mead are commercialising his work, such as Synaptics, cofounded with Federico Faggin in 1986. This drew on neural network research to create the computer TouchPad, featured on notebook pcs. It produces other systems, such as the TouchStyk pointing stick, ClearPad touch screen, Spiral pen input and even Chinese handwriting software.

Image guru

Another is Foveon, a joint venture between Synaptics and National Semiconductor, which is producing a radically new kind of image sensor for products like digital cameras. The first camera to feature the sensor, the Sigma SD9, has recently gone on sale. Called the X3, the sensor is quite different to conventional digital image sensors, in that it captures red, green and blue light at every pixel in a single exposure.

In conventional ccd sensors, a mosaic of filters means each pixel receives light of only one colour – red, green or blue – so the rest of the light is effectively wasted. In the X3, three layers of sensors are embedded at different depths within the silicon – registering respectively blue, green and red – because different wavelengths penetrate to different depths. The result is all the available light energy is captured.



The X3 is a remarkable chip, containing some 32million analogue transistors and is said to offer major improvements in image sharpness, colour detail and resistance to unpredictable colour artefacts. And because it uses a standard cmos process, it can potentially be made extremely cheaply. Although the Sigma SD9 is a sophisticated digital single lens reflex camera, it is already undercutting rivals from the likes of Nikon and Canon. National Semiconductor's ceo Brian Halla has said versions of the sensor could be cheap enough for use in disposable cameras.

Rethinking physics

Finally, there is Impinj, which produces so called Self Adaptive Silicon (SAS). This uses transistor physics in a fundamentally new way to make possible precision analogue and wideband rf in cmos.

SAS is a complete rethinking of the physics of floating gate p-channel mosfets (pFETs), one of the two types of transistors in cmos processing, the other being the n-channel mosfet (nFET). Floating gates are typically associated with flash or eeprom non volatile memory technology, which adjusts the electronic charge on an nFET floating gate to store one of two digital values.

SAS rethinks both the pFET physics and the floating gate physics to enable local adaptation in silicon. It differs radically from traditional floating gate technology in two ways: it fabricates floating gate devices in standard digital cmos (with no additional process masks), and the floating gate mosfet remains a fully functional transistor during memory updates, allowing precise analogue values to be stored on the floating gate.

The end result is a tuneable transistor with a non volatile analogue memory that can be used to design adjustable voltage or current sources, timing delay elements and other analogue circuits. This bring two huge improvements in analogue technology, Impinj claims that precision analogue design becomes easy because the circuits tune themselves electrically after fabrication. It adds the circuits can also continually adapt over their lifetime, maintaining performance despite temperature, supply voltage and device variations.

We may have spent the last few decades witnessing the digital revolution, but if Carver Mead's view of the future is correct, analogue electronics is in the process of staging a major comeback. NE