# Keeping Technology Cool

## Solving the Power Dissipation Challenge

### By Nina Morrison

Intel co-founder and multi-billionaire Gordon Moore affected the lives of legions of future gamers and gadget-freaks - many of whom had not yet been born - when he published an article in *Electronics Magazine* on April 19, 1965. The magazine, which incidentally claims to have invented the word "electronics," is best known for this 1965 article.

The article in question was called "Cramming More Components onto Integrated Circuits," and it reads like a prediction for the future by a young man brimming over with enthusiasm for the burgeoning semiconductor industry. ("Integrated circuits will lead to such wonders as home computers," the article announces).

But what was so groundbreaking about this particular article? Dr. Hamid Mahmoodi, a professor of computer engineering at SFSU, has based most of his research on the theories that the article proposed, as well as its unintended side effects and challenges.

"Moore's Law," as Moore's article eventually became known, suggested that the numbers of transistors that can be integrated on a single chip will double every eighteen months. These microchips are the same size, so they take up the same amount of space when "crammed" into a microprocessor. The microchips and the microprocessors may look more or less the same, but every eighteen months they operate with twice as much sizzle and zap as their predecessors. What was in 1965 a bunch of prediction and speculation has burst forth into "law."

Today's computer engineers ensure that this doubling of transistors (a kind of basic building block of the circuitry that makes up the insides of our computers) and their integration (or "cramming," according to the original article) onto a computer chip does happen about every eighteen months. The doubling of integration density in computer chips is achieved by reducing transistor sizes in each new generation of the technology. Early transistors had dimensions around 100 micro-meter (the same size as the thickness of human hair), and modern transistors have dimensions of about 100 nano-meter (size of AIDS virus). Hence, the modern chip manufacturing technology is regarded as a class of nano-technology. Early computer processor chips had a few hundred transistors in them and modern processor chips have a few billion transistors in them. What Dr. Mahmoodi does is try to solve a resulting challenge of all this doubling – overheating. He does this through better design, including by designing chips to dissipate as little energy as possible for a given operation.

In the early stages of the integrated circuit industry, "power dissipation wasn't that much of an issue," Mahmoodi says, "because in early computers the integration density was not that high compared to computers today." In 1965, the idea that microprocessors would be filled with dozens of computer chips covered from top to bottom with transistors was just an abstraction. However, by 2007, these super-hero microprocessors have become the standard. As computing power increased, so did the associated design problems.

One of the problems that computer designers are faced with is excessive heat. Heat is generated when the switch-like components of information inside a computer chip turn on or off - a process called binary switching, which refers to the way computers do their work. The electrical energy dissipated by the binary switching is transformed into heat energy, which results in a temperature increase. If the temperature increases too much, the computer chip ceases to function properly, and at about 120 degrees Celsius will actually begin to malfunction or even burn.

The smaller "nanoscale" dimensions of all the transistors, jam-packed on to so many chips and busily switching on and off, have made it more difficult for engineers to ensure that all of these tiny parts are in working order. Overheating and transistor functionality can wreak havoc on two very important factors: stability and reliability. If a chip gets too hot, it stops its binary switching and starts malfunctioning and even burning.

Mahmoodi creates new designs for integrated circuitry in nanoscale technology in order to compensate for these modern problems. This particular field of specialty did not exist until recently - only in the last few years computers have become so powerful that specially trained engineers are needed to manage the design problems they pose. Dr. Mahmoodi sees a challenge in the balance between power and performance, and specializes in trying to figure out how to make increasingly powerful machines operate more reliably. As the applications become more and more complicated, the circuitry tends to break down. "This is by no means acceptable," he said, and it's true. A powerful computer that doesn't work reliably isn't really a powerful computer at all.

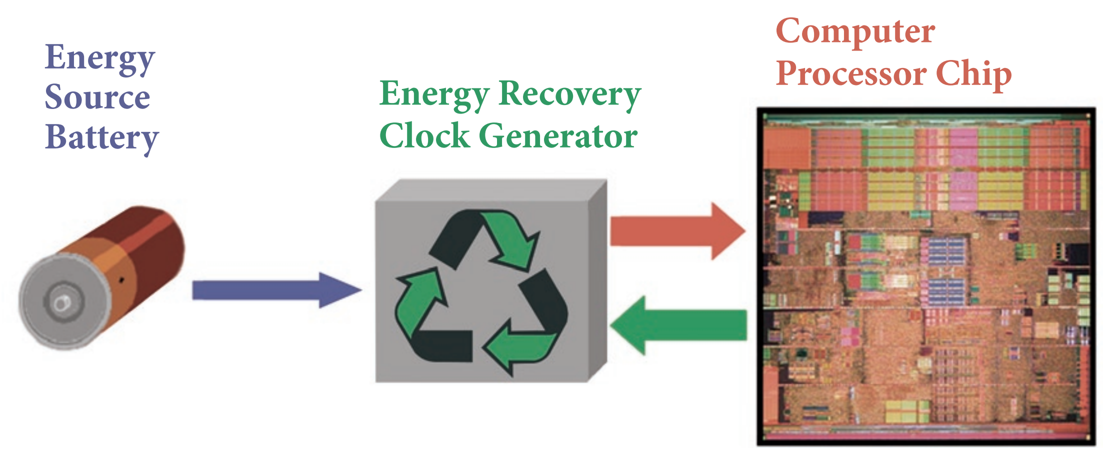
The increased performance of these chips over the last ten years has sparked a phenomenal boom in technology. The time frame mentioned by Moore in his original article, eighteen months, has become almost a given in the field of electronics. In 1965 Moore was simply writing about his observations and forecasts, but we have come to expect things to improve, or "double," about every eighteen months. We are perfectly comfortable with replacing our cell phones, PDAs, even our iPods, about every eighteen months—because a better model will most certainly be available.

Dr. Mahmoodi's interest in digital and integrated circuits formed when he was young. "I used to break them apart, actually," he says, laughing, "and look inside to see and figure out what is there."

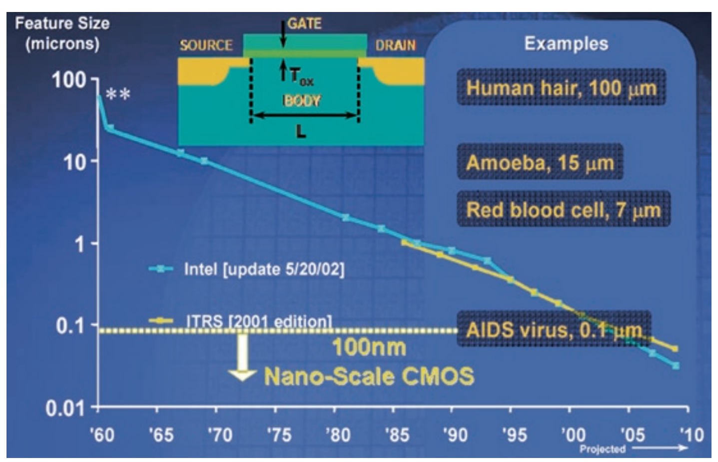
Mahmoodi became fascinated by the "power dissipation challenge," a specialization in the computer engineering industry which he refers to as a "frontier challenge." Power, in this context, refers to the rate of energy usage - the amount of energy used per unit of time. Dissipation refers to energy loss over time. With computers, this lost energy, or, dissipation, converts into heat. Most of us are at least somewhat familiar with overheated hard drives on PCs and Macs. It can be annoying, and it can raise our energy bills a bit, but for larger corporations it necessitates loud, elaborate fans and cooling systems for servers and entire computer systems, which can be very expensive. Another side effect of excessive power dissipation is reduce battery life-time in portable electronic devices such as cell phones, laptops, PDAs, ect. What we want computers to do is to perform well (and perform, in this context, refers to the speed of running applications). This challenge that Mahmoodi is interested in is being able to "find the right balance between power and performance." His low-power, high performance digitally integrated circuitry designs reduce power and improve speed.

A computer's circuitry needs to "dissipate the least amount of power for the performance that is needed," Mahmoodi says. One of the approaches he has taken to reduce power

Dr. Hamid Mahmoodi



dissipation is called "energy recovery from the clock network of a chip." Because such a significant amount of power is dissipated over clock networks - signals that synchronize the actions of circuitry inside a microprocessor - a low-power clocking network could be a way to reduce power dissipation without losing speed (performance). In order to recover energy from the clock network, Mahmoodi creates different types of flip-flops, which are electronic circuits that can retain a logical state and also switch back and forth from one state to another. These flip-flops, which serve as bits of memory, use up power as they change states. Mahmoodi proposed four different types of flip-flops that would operate more efficiently and dissipate less power. The proposed flip-flops operate with an unconventional kind of clock network called a *sinusoidal clocking network* - which uses a different type of waveform to function. The flip-flops, when tested, used up about 46% less power than regular flip-flops.




There is plenty of interest in Mahmoodi's low-power, high-performance integrated circuit design ideas. The semiconductor industry, a behemoth that employs about 225,000 people in the United States according to the Semiconductor Industry Association's website, is very, very interested. "Private industry is the main point of contact for this field" Mahmoodi says. But government agencies such as DARPA (Defense Advanced Research Projects Agency), which is the research and development branch of the Department of Defense, are also interested. NASA's space missions also "suffer from limited battery life times for their electronics, so they also have great interest in low-power design," Mahmoodi says.

In addition to the interest from organizations such as DARPA and NASA, the work that Mahmoodi is involved in helps generate advanced cell phone features like voice-recognition programs, camera and video capabilities, document readers and email and Internet functions.

Video games have also been well-served by the trend towards smaller, faster, more powerful circuitry design. Gamers who once played a ridiculous-looking amusement called 'Pong,' which consisted of two bars smacking a ball across the screen, might find the "graphically intensive video games" (as Mahmoodi describes them) of today nearly unrecognizable. The games that are currently out on the market are extremely sophisticated applications that feature animation, sound effects, and the occasional celebrity cameo appearance, such as Ray Liotta's turn as the voice of Tommy Vercetti in *Grand Theft Auto: Vice City*.

The tools that we have come to use and depend on on a daily basis (cell phones, PlayStations) need to reliably run increasingly sophisticated applications (miniature video cameras on a cell phone, machine gun stealing in Vice City). These sophisticated applications "demand more performance from the chips that are running these applications. They need to be able to deliver reasonable speed to the customer. Those chips need to run faster—that's the demand for performance," Mahmoodi says. So while Mahmoodi has no interest in Tommy Vercetti's rise to power, he is interested in designing chips that offer higher speed and greater performance. He sees a challenge there. "There is a trade-off between power dissipation and performance," he says. "If you do something to boost the performance, typically it results in power dissipation increase. If you want (it) to run faster, typically you have to spend more energy. And also, typically if you do something to reduce energy dissipation, the system tends to get slower."

So, it's kind of a trade-off. We need the boosted performance in order to navigate Vice City, but without so much power dissipation that the console heats up and crashes half-way through the game. This is what Mahmoodi means when he speaks of "the design challenge."

Mahmoodi himself does not have much interest in video games or the latest and greatest cell phones. When asked about his favorite application for low-power, high-performance integrated circuit design, he said that his research was focused on high-speed microprocessors, the kinds that are used in laptops and desktops. He enjoys "looking inside these microprocessors" and "applying ideas wherever possible." His current project involves "new, innovative micro-architectures for high-speed microprocessors."

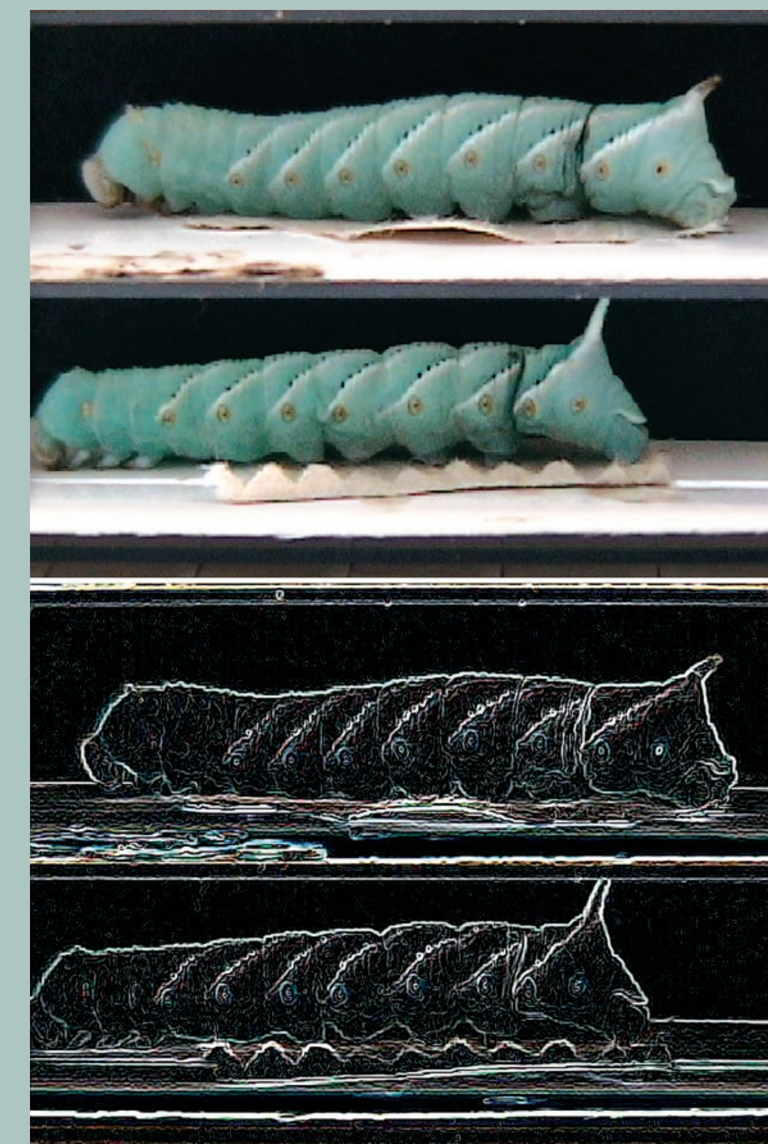
Mahmoodi says that he would like "to raise awareness about all the technological innovation that goes behind the consumer electronics that we enjoy in our daily lives." He wants the public to appreciate the processes that go into the design of such devices, even though he himself is not particularly interested in all of their applications.

"Even though I invented the technology, I personally don't follow gadgets and I'm not into that market. I'm using fairly low-tech stuff even though I design very high-tech. My cell phone is very low-tech, compared to what most other people use," he says, holding an ancient-looking cell phone (definitely more that eighteen months old).thing to reduce energy dissipation, the system tends to get slower."



# Caterpillars and pixels: a hybrid science evolves

By Denize Springer



**It used to be** that biologists and computer scientists had little opportunity for collaboration. Today, however, researchers in these fields at San Francisco State University are forging a new path by combining their distinctly different disciplines.