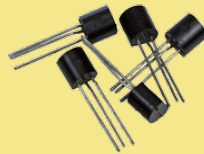
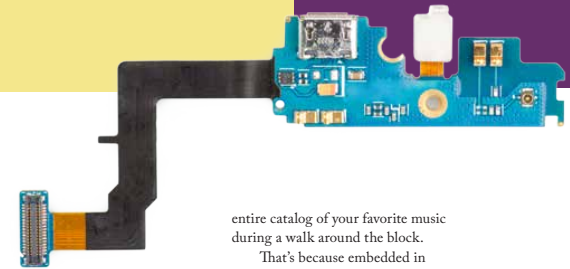
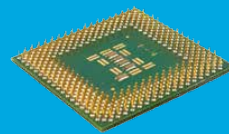


BUILDING BLOCKS

How Caltech breakthroughs in technology have led to advanced communications for the world's use.

by Cynthia Eller & Katie Neith



In today's world, cell phones—and, in particular, their multifaceted brethren, smartphones—are nearly ubiquitous. In no small part, these palm-sized computers have revolutionized the way we communicate, learn, and live in the 21st century, replacing not only our landlines but our alarm clocks, books, cameras, calendars, and more. And that pocket full of powerful technology that most folks can't leave home without—and may even be reading this magazine on—is chock full of Caltech innovations.

"Caltech has always played a role in cutting-edge technologies that are game-changers," says Vice Provost for Research Morteza Gharib (PhD '83), who has served on the Institute's faculty since 1993. "The work that's been done here has taken those room-sized original computers and turned them into an iPhone."

PIONEERING THE BASICS

The smartphone is a marvel of miniaturized engineering. And at its most fundamental level lives the integrated circuit—or chip—which acts as a central hub that connects with and feeds power to all the other components in the phone.

Behind that chip, says Gharib, is Caltech alum Gordon Moore (PhD '54). "Gordon Moore is responsible—more than any other single individual—for putting a silicon chip in every personal computer worldwide," Gharib says.

It began when Moore co-founded Intel in 1968, where he led the development of the chips that began powering microcomputers in the early 1970s. This set of electronic circuits on a tiny piece of silicon is still the central technology that enables you to download and save a book for a subway ride or pull up an

entire catalog of your favorite music during a walk around the block.

That's because embedded in the circuits of each chip are a bunch of transistors, coined by another Caltech alum, William Shockley (BS '32), who went on to win the 1956 Nobel Prize in Physics with his co-creators for their innovation. These devices are used to manipulate electronic signals and are essential to modern electronics. They provide the power a smartphone needs to perform the calculations that enable a quick check of the weekend weather forecast or the ability to find the best route home during rush hour.

Transistor technology grew by leaps and bounds in the post-WWII era so that, as predicted by Moore in his eponymous law, the number of transistors in an integrated circuit have indeed doubled approximately every two years over the past four decades.

It was Caltech's Carver Mead (BS '56, MS '57, PhD '60)—now the Gordon and Betty Moore Professor of Engineering and Applied Science, Emeritus—who kept Moore's law on track during those boom days by pioneering what is called the very-large-scale integration (VLSI) design methodology in the 1980s. Mead's set of tools and standards enabled scientists to place at first thousands and, today, literally billions of transistors on a single chip. He also shared those tools

with the world, coauthoring a VLSI textbook and thus helping to build an industry where others could learn the technique quickly and design even more powerful chips.

"Suppose I had the magical power to go back and remove Carver Mead's work on VLSI from history," says Gharib. "This smartphone in my hand would not be here."

CAPTURING A MOMENT

When JPL's engineers first developed its so-called camera-on-a-chip technology, they were clearly not aiming at a proliferation of "selfies" posted to Instagram and Facebook. Instead, the Lab's Center for Space Microelectronic Technology was charged with miniaturizing the camera systems located onboard interplanetary spacecraft.

Originally, the plan was to take existing digital camera technology and find ways to make it smaller. But Eric Fossum, JPL physicist and engineer, had a better idea: he invented the active pixel sensor (APS), the camera-on-a-chip technology that could be integrated onto a complementary metal oxide semiconductor (CMOS) chip along with the other circuits required by a cell phone.

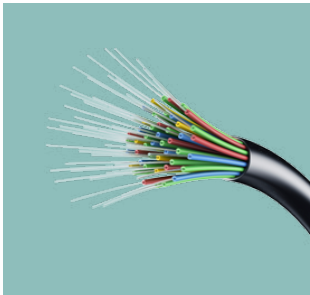
Not only are Fossum's cameras smaller, but they're higher quality, use less power—the CMOS APS

uses one-hundredth the power that previous digital camera technology required—and are cheaper than those that came before. Today Fossum and JPL's CMOS APS technology is found in everything from high-end cameras and webcams to automotive safety systems and video games.

"But it's not just a good camera," says Gharib. "It's a culture-changing technology. If you look at many events in recent years from around the world—for example in the Middle East during the Arab Spring—it has been crucial that some ordinary person who was there had a smartphone and took pictures. Easy access to cameras in phones has made societies more open. Everybody is now a journalist."

In the early 2000s, Ali Hajimiri, the Thomas G. Myers Professor of

Electrical Engineering, used inexpensive CMOS technology to develop a low-cost power amplifier that improves voice quality and increases the amount of talk time a user can get from a single battery charge. This amplifier has made possible the creation of single-chip cell phones and has cut the cost, size, and weight of the circuitry in all cell phones. Hajimiri and his research team have also combined CMOS chips with silicon chips to create an imaging system capable of seeing through objects—a system that can be used in both security programs and medical diagnostics. And they recently reported on their invention of a self-healing chip that can repair itself inside your smartphone, thereby combating extreme environmental conditions, aging, and damage.



MAKING CONNECTIONS

While the functionality of smartphones alone is impressive, speed is really the key when it comes to meeting consumer demands. For the on-the-fly information your phone provides in mere seconds or less, thanks should go to Amnon Yariv, Caltech's Martin and Eileen Summerfield Professor of Applied Physics and professor of electrical engineering. Yariv's distributed feedback (DFB) semiconductor lasers, developed in the 1970s, are still being used today to convert electrical data signals into optical lightwave signals. This allows the signals to travel swiftly through fiber-optic cables, greatly accelerating cable and high-speed Internet transmission.

In the mid-2000s, Caltech computer scientist and electrical engineer Steven Low and John Doyle, the Jean-Lou Chameau Professor of Control and Dynamical Systems, Electrical Engineering, and



Bioengineering, created a method—an algorithm called FastTCP—to speed up data transmission over the Internet even more by measuring and controlling its traffic. Computers employing the algorithm can make smarter decisions based on the data they gather, managing and unsnarling congestion so that packets of information can be sent across the network at unprecedented speeds.

As Gharib points out, such high-speed Internet communications are no longer a marvel confined to wealthier countries. With the help of sophisticated components that use Caltech innovations like Yariv's DFB, developing countries can leapfrog over earlier technologies and move directly into the 21st century.

"In Nigeria, for example, they have decided not to put in telephone lines, since most people there now have cell phones," he says. "Their country has saved billions of dollars that they would have had to put into infrastructure; they've bypassed it entirely."

TRAVEL PLANNING

Those of us who rely on the accuracy of global positioning systems, also known as GPS—the travelers, runners, and geocachers among us, for instance—are taking advantage of the work of JPL engineer Yoaz Bar-Sever, who heads

NASA's Global Differential GPS System at JPL, where a team of nearly 60 researchers work on advanced GPS applications. Among their innovations is a technique that processes cell phone data to enhance the accuracy of GPS in handheld devices.

David Rutledge, Caltech's Kiyo and Eiko Tomiyasu Professor of Engineering, is one of the researchers who have made it possible for those of us out at sea or flying cross-country to connect with friends via email or surf the Web. In 2000, Rutledge and his graduate students developed an improved transmission system for ground-to-satellite communications, an effort since commercialized through his start-up company, Wavestream. The high-power solid-state amplifiers he created provide a reliable means for bringing communication technologies to remote areas.

In fact, they have already been licensed to Southwest Airlines and deployed by the United States Army for operations in Iraq and Afghanistan. And they even provide satellite news coverage to those traveling the peaks of the Himalayas and other far-flung locations.

"Advances like these," Gharib says, "have made information available to an extent that, in the history of mankind, is unprecedented." ©:S

