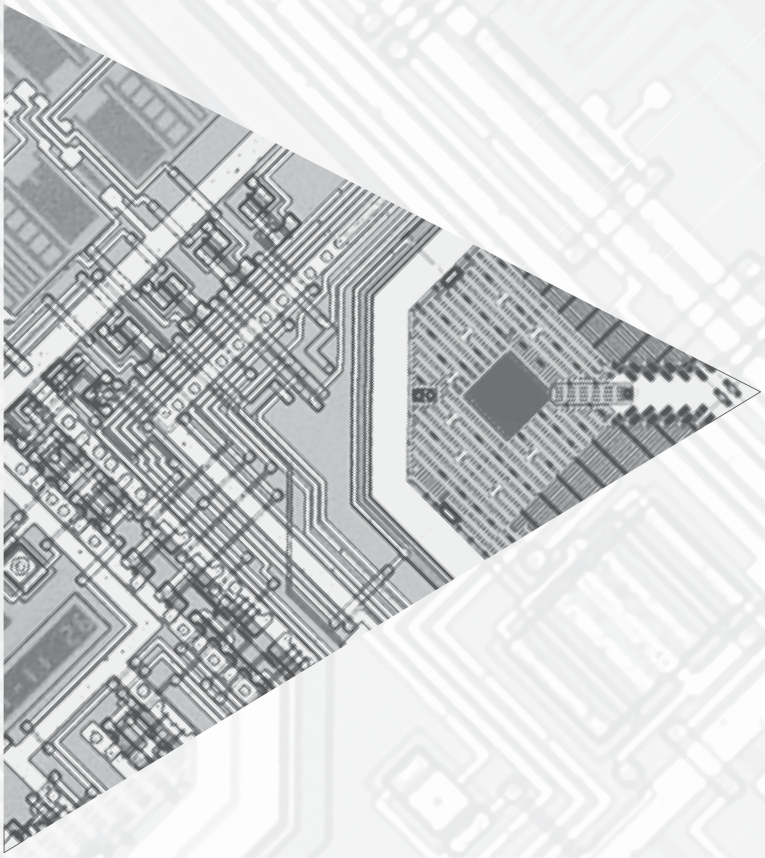

The Innovation Engine

THE FIRST 50 YEARS OF ANALOG DEVICES


Three Technology Way
ANALOG DEVICES
Celebrating 30 Years in Signal Processing
Happy 50th

The Innovation Engine

The First 50 Years of Analog Devices

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This book, like our company, has been a team effort. Ray Stata devoted significant time to share his memories and retell much of the story of ADI. Journalist Tam Harbert researched the history of ADI and the electronics industry and interviewed more than 100 current and former employees, business partners, educators and friends. While not everyone interviewed is quoted by name, they all shaped the narrative by contributing colorful detail, anecdotes and memories. Thanks to the editorial board: Barrie Gilbert and Dave Kress, for their archives and their willingness to stay the course through this multiyear effort; Peter Real, Bob Adams and Sam Fuller, who provided guidance, reviewed chapters and shared important detail; and Mark Skillings, who tracked down the facts and many of the artifacts that appear throughout the book. Many people gave their time and in some cases donated mementos so that ADI's first 50 years would be well represented, and we have done our best to include them in the acknowledgments section. A special thank-you to Vince Roche for his support and encouragement in documenting the history of ADI. It has been an honor and a privilege to be part of ADI and to bring this story to you.

Maria Tagliaferro

Editor-In-Chief
The Innovation Engine: The First 50 Years of Analog Devices

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Foreword

When Matt Lorber and I started Analog Devices (ADI) in 1965, I never dreamed it would survive, let alone thrive, for 50 years. We started out with the modest ambition of becoming the leaders in the emerging market for modular operational amplifiers, a goal we achieved in just four years, against other startups with a head start. Then, year after year, decade after decade, we listened to our customers and expanded our product portfolio to meet their needs and ended up becoming the market leader in high-performance analog and mixed-signal ICs.

In the history of business, few companies survive for 50 years. For technology companies, such longevity is even more rare. By its very nature, the tech business changes quickly and often dramatically. In Darwinian fashion, companies must either adapt or die. To sustain long-term success, ADI became a learning organization, developing an ability to sense changes in the environment and to learn, adapt and change.

As described in the pages to follow, ADI has changed dramatically over its 50-year history, from transistor modules to ICs, from low-volume to high-volume markets, from components to system solutions, and from a small tiger team to more than 15,000 employees. But what has not changed are our core values and fundamental beliefs. Tolerance for risk, along with a commitment to innovation and excellence, are embedded in our culture. Most importantly, we believe that employee satisfaction is the cornerstone of business success. Talented employees drive customer satisfaction through innovative and continuous improvement. Satisfied customers in turn generate sales growth and profit, increasing stockholder value as well as the means to ensure employee satisfaction—a virtuous win-win cycle for all.

With a positive view of human nature, we believed that people were honest and trustworthy and, that for their own self-esteem, they would want to do the best job possible and develop their full potential if given encouragement and support. Therefore, we emphasized positive leadership that respected and trusted people, gave them challenging work and a say in how they did it, recognized and rewarded their accomplishments, and accepted mistakes as a source of learning. These ideals were embedded in ADI's DNA and created a motivating, satisfying work environment.

As we look to the future, our success will continue to depend on our ability to identify and respond to changes in the environment, to select the right opportunities in which to invest and to execute with excellence. But that alone will not be enough. It will also take an entrepreneurial spirit with passion, ambition, courage, determination, perseverance, creativity and lots of hard work.

In my vision of ADI's future, every employee will think and act like an entrepreneur, taking responsibility for their own happiness, success and self-esteem in whatever role they play, working collaboratively with others to achieve success for the company. Leaders will set an example by living the values and virtues that have made ADI successful. I envision ADI as a community of like-minded people with mutual respect, shared values and aspirations, and a collective ambition to make a difference in the world. In this community, each of you will take pride in being a part of ADI.

The purpose of this book is to describe the origins of the company and the steps along the way that created this remarkable success story. Its goal is to highlight the core values, beliefs and strategies that drove our decisions in the hope that they may serve as guideposts for ADI's continued success. Will ADI exist 50 years hence? I hope so. And if it does, it will be because it remained true to its core values and continued to learn, adapt and innovate.

This book is dedicated to employees of ADI, past, present and future. I would especially like to thank long-tenured employees for their vital role in making ADI a special place to work. You were the ones who led by example, who set the tone and culture of the place, who carried the folklore and stories, who have led us through many technology, market and organizational transitions, and who shared the knowledge, expertise and wisdom to help ADI capture the great opportunities ahead.

My thanks to all who came and stayed and who created ADI's success. And a special thank-you to your loved ones and families who have supported you in your careers at ADI.

Ray Stata

Ray Stata
Co-Founder and Chairman of the Board, Analog Devices
2018

50 Years of Innovation

In January 1965, two graduates of the Massachusetts Institute of Technology (MIT) sat in their apartment in Cambridge, Massachusetts, preparing to file papers to launch their startup. They had what they believed was a golden opportunity.

Ray Stata and Matt Lorber were on the cusp of the electronics revolution. Their new company would make operational amplifiers, a ubiquitous building block for analog products and systems. But as they filled out the paperwork for incorporation, they struggled with what to call their new venture.

They listed the names of companies they thought were relevant. At the top of the list was Digital Equipment Corporation (DEC), founded in 1957 and one of many successful technology companies taking root along Massachusetts' Route 128. However, their company would focus on analog, not digital, technology. What about Analog Equipment? That wasn't quite right. They would be making components, not equipment. Farther down the list, another company—Data Device Corporation—caught their eye. Yes, op amps were devices. The combination of those two phrases described what the company would make, so they wrote "Analog Devices" in as the name of the corporate entity.

Stata and Lorber never dreamed that their new venture would grow over the next 50 years into a multibillion-dollar Fortune 1000 company. Analog Devices Inc. (ADI) would survive the ups and downs of the electronics industry, even while other famous New England giants (including DEC) stumbled and fell. ADI would become one of the few semiconductor companies to not only keep making its own chips (and in the United States, no less) but also to stay on the East Coast. As digital technology proliferated, analog was considered antiquated technology. Nonetheless, ADI stubbornly refused to change its name or even its logo, a simple triangle designed in 1965.

This is a technology as subtle and complex as the world itself. It deals with turning physical phenomena into electrical signals and processing these signals to get useful information. Humans experience the world through their senses: seeing with their eyes, hearing with their ears, feeling temperature and pressure with their skin. The range of values that these "human sensors" detect—across light, frequency and temperature—consists of infinite shades of gray. Analog circuits are the "analog" of these real-world signals. They detect, measure and process the varying shades of these physical phenomena.

"The speed at which an organization learns is its only sustainable competitive advantage."
RAY STATA

ADI has stuck to its knitting because, from day one, it realized the importance of analog technology. Although the spotlight shifted to digital technology in the 1980s and '90s, the show could not go on without the critical role analog played behind the curtain. Consumers marvel at the magic of modern technology, including smartphones. They sit securely in the safety of cars with air bags and advanced driver-assistance systems. None of these conveniences would be possible without analog technology.

Digital technology, on the other hand, deals with numeric representations of analog values. A digital value is made up of ones and zeroes. Although people often refer to the world becoming digital, analog technology is the bridge between physical and digital.

ADI has built a consistently profitable business based on that fact. It grew from a fledgling startup that barely scraped by in 1965 to a company with sales of $3.4 billion by its 50th year. That is an

MIT graduates Matt Lorber and Ray Stata founded Analog Devices in Cambridge in 1965.

incredible feat, especially in an era when the average life span of S&P 500 companies is shrinking. A Yale University study found that the average company life span decreased from 67 years in 1920 to just 15 years in 2015. The reason? It's getting more difficult for companies to adapt to rapid changes in technology and markets.

> **"Many of the innovations that are foundational to the future sit at the intersection of the physical and digital worlds, essentially in our wheelhouse."**
>
> **VINCE ROCHE**

Throughout its history, ADI has done just that. This book tells the story of how this tenacious and creative company rode wave after wave of change in technologies and markets. It describes the characteristics of a powerful corporate identity that enabled a startup to reach the age of 50. These qualities are essential, enduring principles that make up ADI's heart and soul. They are the keys to ADI's continued success.

This book is organized into four sections, each of which delves into principles that guide the company and how they have influenced its direction. These principles are: organizational learning, innovation-driven business success, unconventional thinking and maintaining a strong corporate identity. In between each section are profiles of the three CEOs who served ADI over its first 50 years. Each of them emphasized these core principles while using his unique talents to improve the company. Stata established the culture, early structure and successful strategy of the company. Jerry Fishman, CEO from 1996 to 2013, turned ADI into a well-tuned, reliable operational and financial engine. Vince Roche, elected CEO in 2013, Is leading ADI into a new era and a new world of opportunity.

Organizational Learning

ADI never stops learning. Stata's commitment to organizational learning enabled ADI to avoid the innovator's dilemma. Described by Clayton Christensen in his 1997 book, this dilemma is an unwillingness of successful companies to abandon tried and true ways of doing business, even when the landscape shifts and those ways are no longer effective.

Despite its success, ADI has never remained comfortable with the status quo. By remaining open to new ideas, technologies and markets, the company recognized and successfully adapted to three tectonic shifts over its first 50 years: from modules to ICs, from low-volume to high-volume markets, and, most recently, from components to system solutions for signal processing. Each of these transitions prompted major changes in company strategy, organizational structure, technology, product development and manufacturing. As Stata frequently reminded the company: "The speed at which an organization learns is its only sustainable competitive advantage."

Innovation-Driven Business Success

The success of ADI's business is driven by innovation—in process technology, circuit design, manufacturing methods and more.

It starts with innovative people. From ADI's earliest days, Stata recognized that the success of the company depended on the success and satisfaction of its people. In the beginning, much of the innovation came from individuals. More recently, ADI has innovated by fostering more collaboration—across technology disciplines and product groups, and between ADI and its customers.

Such innovation has led to products that command some of the highest profit margins in the industry and steady, strong revenue growth. Unlike many startups in the modern era, ADI had to focus on profits from the start. To get funding in 1965, Stata and Lorber struck an unusual deal with the bank. For every dollar of profit ADI earned, the bank would lend it an additional dollar. ADI has been profitable in all but one of its 50 years. In turn, the company has continued to invest a hefty portion of those profits back into research and development.

Unconventional Thinking

ADI has often taken smart, calculated risks, going against conventional wisdom. Even in the face of adversity or short-term losses, the company persists when it believes that a new technology or business can make money in the long term and sustain ADI's leadership in the industry. This willingness comes directly from Stata, who early on insisted that ADI get into the business of integrated circuits.

ADI has been unconventional in many ways. From day one, it took a broad, worldwide view. It established its own direct sales offices around the world rather than going through distribution—an approach unprecedented for a semiconductor company. It reached beyond its shores for engineering talent and manufacturing sites. Rather than staffing overseas plants with expats, ADI nurtured local talent and encouraged their autonomy.

> **"In technology companies, it's all about transitions. Transitions in leadership, transitions in technology, transitions in markets. How you manage across those transitions separates the companies that are going to last from those that don't."**
>
> **JERRY FISHMAN**

In sales and marketing, ADI eschewed the hard sell and adopted an educational approach, with comprehensive data sheets, application notes and its highly respected technical journal, *Analog Dialogue*.

Strong Corporate Identity

ADI expanded from its initial product base by following the signal chain. As it entered new product categories and developed new technologies, its core identity remained consistent but gradually broadened. It started with operational amplifiers. As analog signals needed to be converted to digital, and vice versa, the company added data converters. Eventually, customers wanted to process these signals digitally. Thus, ADI entered the digital signal processor (DSP) market. As wireless communications became prevalent, ADI built strong capabilities in radio frequency (RF) technology. It also evolved from selling components to partnering with customers on signal processing systems design.

The next phase calls for ADI to evolve its identity further. As billions of sensor-laden devices are connected to the internet, ADI's technology is more relevant than ever. "Many of the innovations that are foundational to the future sit at the intersection of the physical and digital worlds, essentially in our wheelhouse," Roche said. These trends are moving ADI's technology from the periphery of information and communications to the fulcrum of the next technology wave.

ANALOG DEVICES

ANALOG DEVICES

ADI's logo has remained largely unchanged since 1965, reflecting the company's ability to maintain its core identity and values.

The extent of ADI's success in this new hyperconnected world depends on its ability to continue to learn, evolve and adapt while maintaining its core identity and values. The coming transition will challenge the engineering prowess, adaptability, management talents and business models of companies across all industries. Such an inflection point often spells trouble for existing companies, which can be weighed down by their past, and creates opportunities for nimble startups.

Fishman put it well in an interview with *Electronic Business* magazine: "In technology companies, it's all about transitions. Transitions in leadership, transitions in technology, transitions in markets. How you manage across those transitions separates the companies that are going to last from those that don't."

ADI has a long track record of navigating transitions successfully. As it enters a new half-century, the company has the technology and leadership to capitalize on the changes that lie ahead. At ADI, the future is already in progress.

Organizational Learning

Key to ADI's success and longevity is its ability to continue to learn and adjust to changes in the environment. Throughout its history, the company strove to avoid the "innovator's dilemma," first described in a book by Clayton Christensen. The company has weathered three major transitions. As a startup, the company was highly successful in its first product category, op amp modules, but Ray Stata wouldn't let ADI rest on its laurels. Recognizing the importance of integrated circuit (IC) technology, he pushed the company into IC design and manufacturing. When the digital revolution created new markets for sophisticated analog-to-digital conversion, ADI diversified into converters. When growth slowed in its traditional low-volume, high-performance markets in aerospace, defense and instrumentation, the company targeted high-volume consumer and communications markets. Most recently, the company responded to its customers' need for more than components and expanded its expertise to system-level ICs and software.

The First Transition

From Module Startup to IC Powerhouse

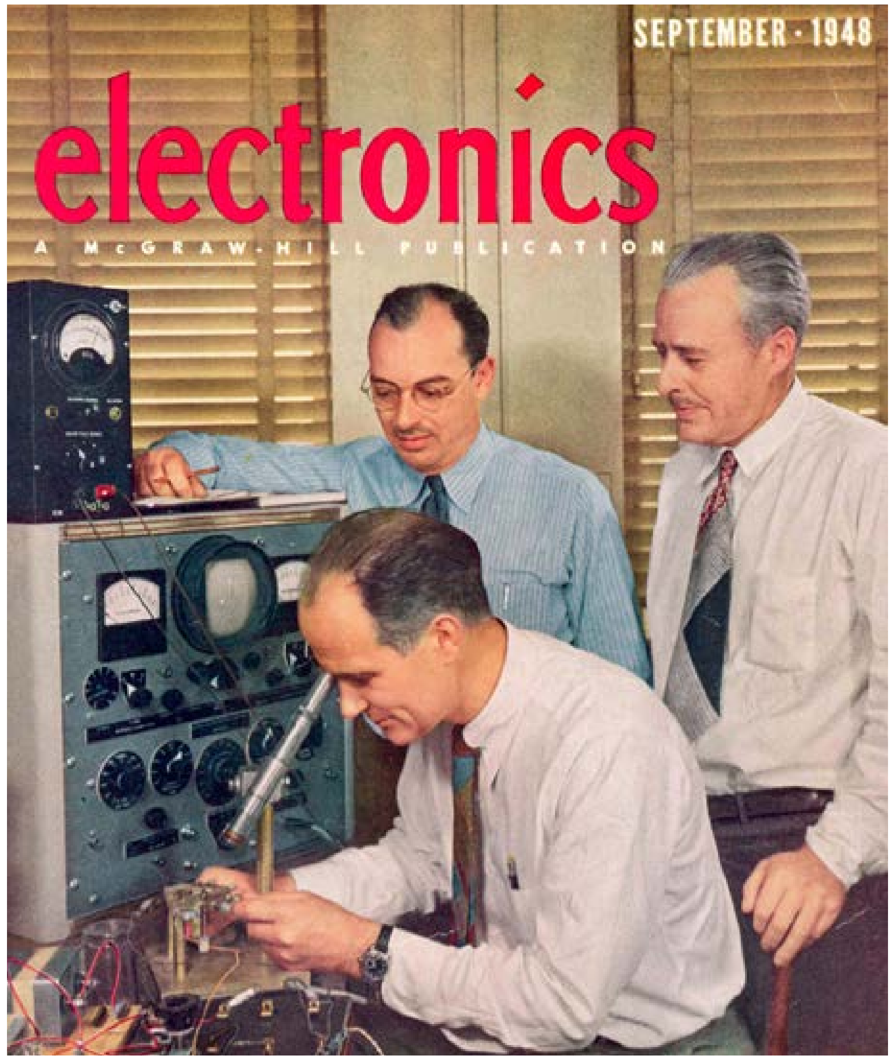
In the 1950s, Massachusetts was on the cusp of an electronics boom. The bipolar transistor, invented in 1947 at Bell Labs, was spurring innovation at universities, research labs and major corporations.

The Cold War drove the U.S. government to pour vast amounts of money into defense research, much of it in the Boston area. The subsequent explosion of technology created a rich mix of electronics companies along a recently built highway ringing Boston, called Route 128. Raytheon, based in Waltham, had become the world's leading producer of transistors. Sprague Electric manufactured high-frequency surface barrier transistors in North Adams under license from Philco. Then there were Clevite Transistor in Waltham, Transitron in Wakefield, Sylvania Electric Products in Woburn and Unitrode in Watertown. Most of these early IC pioneers would fade as, inexorably, Silicon Valley took over.

One company, however, would not only survive but thrive. ADI, originally founded to make op amp modules, would in its first four years go public, enter the IC market and expand its product line to data converters. It would learn to design and manufacture ICs in its own facilities and build an incredible team of engineers for whom nothing seemed impossible.

The Birth of Analog Devices

Ray Stata graduated from the Massachusetts Institute of Technology (MIT) in 1958 with a master's degree in electrical engineering and a dream of launching his own company. He recognized that achieving his goal would require more than engineering



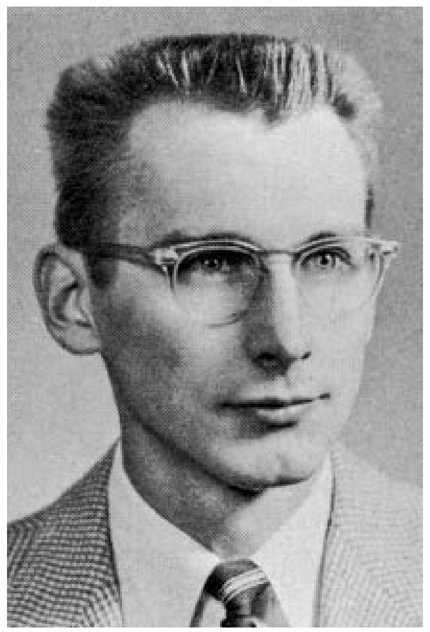
From top left: The inventors of the transistor, John Bardeen, Walter Brattain and William Shockley (seated), appeared on the cover of *Electronics* magazine in September 1948.

knowledge, so he got a job with one of the most renowned technology companies of that time: Hewlett-Packard Company (HP). While at HP, he learned about business, the instrumentation market and especially the "HP Way"—a management style that stressed respect for the individual. "HP was like a mini-MBA for me, where I learned the basics of business," Stata said. "More importantly, I learned that commitment to employees—to their welfare and the development of their full potential—are cornerstones to building a successful company."

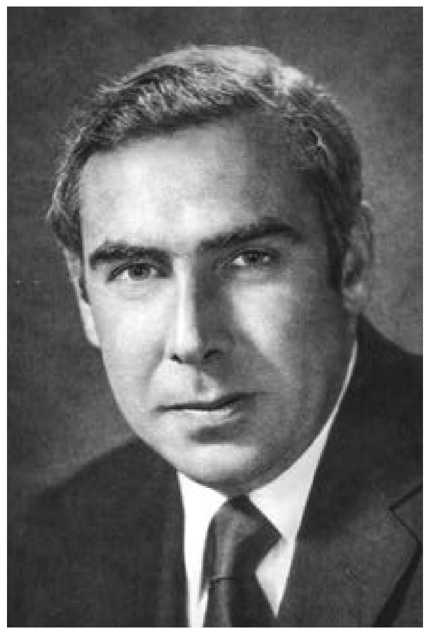
Many entrepreneurial graduates, then and now, started their businesses on or near MIT's campus in Cambridge.

After four years with HP, part of which he worked as HP's sales representative in New England, Stata was ready to try his entrepreneurial wings. He and Matt Lorber, an MIT acquaintance with whom he shared an apartment, pooled a few thousand dollars and founded their first startup, Solid State Instruments (SSI), together with a third MIT colleague, Bill Linko.

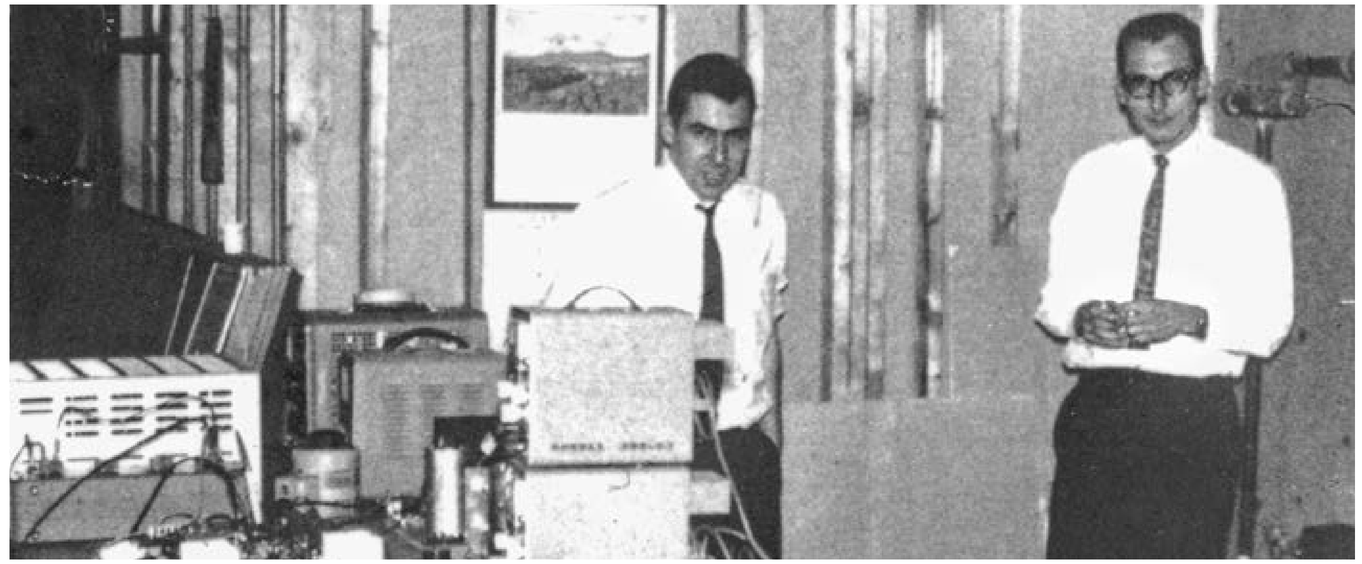
"By any standards, SSI was an ill-conceived venture," Stata said. "We had no strategy, no plan and very little money. All we had was an urge to start a company." To generate cash, Stata brokered a deal with a contract manufacturer to provide power supplies to a high-volume customer. SSI used this money to develop its first product, a rate table to generate precision angular rates as a test platform for gyroscopes. The rate table used direct drive motors and tachometers from the Kollmorgen Corporation, known for its innovative technological platforms that supported motion control and electro-optical systems. Founded in 1916, Kollmorgen supplied periscopes and related equipment for U.S. Navy submarines. Lorber had used motors from Kollmorgen in his work at his previous employer, MIT's Instrumentation Lab, which developed the navigation system for the Polaris submarine. During the rate table development work, Kollmorgen was so impressed with the team that it decided to buy SSI to develop electronic controls to complement its motors. As part of the deal, which was $50,000 in stock for



Ray Stata graduated from MIT with bachelor's and master's degrees in electrical engineering, then worked at Hewlett-Packard, where he learned the business basics that shaped the development of ADI.



Matt Lorber also graduated from MIT with bachelor's and master's degrees in electrical engineering. He founded two companies with Stata: SSI in 1962 and ADI in 1965.



Matt Lorber and Ray Stata (circa 1962) in the utility space of their Cambridge apartment building. The co-founders launched Solid State Instruments and then went on to launch their second venture, Analog Devices.

each of the SSI founders, Stata, Lorber and Linko agreed to stay on for two years.

Most instrumentation companies in the early '60s, including SSI and Kollmorgen, designed and built their own electronics, including operational amplifiers (op amps). During their work at Kollmorgen, Stata and Lorber began to understand how the supply chain was forming in the electronics industry. Rather than designing their own op amps, Stata and Lorber decided to buy standard op amp modules from several startups, including Burr-Brown, George A. Philbrick Researches and Nexus Research Laboratory. The pair perceived a trend that would become a driving force in the electronics industry: As technology advanced, many customers would want to buy functional circuits rather than build their own. Why waste time and effort designing all their circuits from scratch? It made more sense to buy quality standard components. It would save in development costs and speed their time to market.

Stata and Lorber became convinced they could build better products than what was available. Just a few days after their contract with Kollmorgen was up, on January 18, 1965, they founded a company to do just that, naming it Analog Devices Inc.

The first version of ADI's logo. While it has changed in color and style, the logo 50 years later still featured prominently the triangle and square.

From their posts at Kollmorgen, Stata and Lorber surveyed the suppliers of op amps and became convinced they could build better products than what was available. Just a few days after their contract with Kollmorgen was up, on January 18, 1965, they founded a company to do just that, naming it Analog Devices Inc. To finance it, the two men borrowed against the proceeds of the SSI sale: $100,000 in Kollmorgen stock. In a deal with the First National Bank of Boston that would be unheard of a few decades later, ADI borrowed a dollar for every dollar of profit ADI made. "We had to kill to eat," Stata said. This arrangement set a standard of profitable growth at ADI for many years.

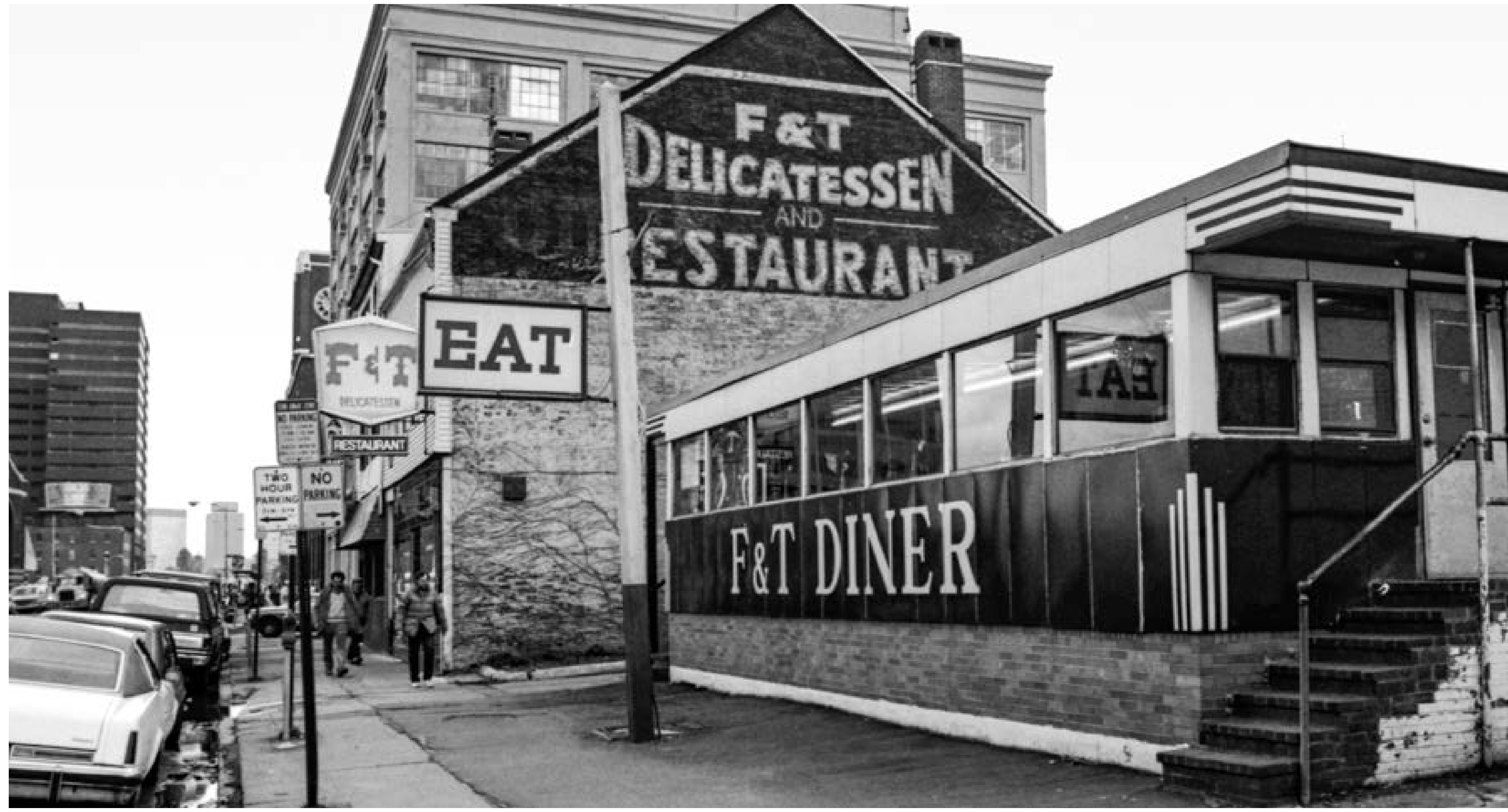
ADI's first markets were aerospace, defense and instrumentation. Among its first customers were university research labs, small companies and military contractors, all of which built instruments and systems that needed high-performance op amps. These organizations had no interest in designing and building their own op amps and were willing to pay a hefty price to buy these components. Because op amps were a fundamental component in analog products, this business brought ADI in touch with thousands of customers and a growing universe of applications.

ADI got off to a fast start. While still working at Kollmorgen, Lorber and Stata engaged Richard Burwen, a truly brilliant engineer who worked as a consultant. The startup was greatly assisted by the technical expertise of Burwen, who designed ADI's first op amps: Model 101 was general-purpose, Model 102 was high-speed and Model 103 was high-accuracy. So ADI was ready to start selling and shipping product in small quantities shortly after opening the door and essentially broke even in its first year of operation. In January 1968 (three years after incorporation), ADI published its first catalog, which listed 45 op amps—the broadest selection among its fledgling competitors. Sales were growing at 80 percent per year. In just four years, ADI became the market leader in modular op amps with sales of $8.7 million in fiscal year 1969.

Several factors accounted for ADI's early success. First, it had attracted a team of excellent designers who created a broad selection of products, with many that provided the highest performance available. Second, based on his experience at HP, Stata's aggressive mass-marketing approaches to reach thousands of customers around the world were more effective than those of his competitors. By the third year, ADI had a mailing list of thousands of engineers, to which it continuously mailed product announcements, tutorial information, application handbooks and a technical publication, *Analog Dialogue*. Third, unlike its competitors, ADI placed heavy emphasis on penetrating the global market. In its very first year, the company set up international direct sales offices with local inventory and logistics support. Finally, as an additional factor, Teledyne's Amelco division in 1966 acquired and integrated two ADI competitors in the Boston area, Philbrick and Nexus, giving ADI the opportunity to lure away some of their talent. Teledyne's bureaucratic approach to managing these startups failed, so these competitors quickly went out of business.

ADI's first offices were at 221 Binney St., at the corner of 5th and Binney in Cambridge.

The company's first location was in Cambridge, Massachusetts, at Fifth and Binney streets near MIT, in a rundown area of old industrial buildings with inexpensive rents. (That area later came to be known as Kendall Square.) The only way to enter ADI's "executive" office was a fire exit along the outside of the building, an idiosyncrasy that spooked potential employees.



The F&T diner was about the only eatery near ADI's first office, in an area of Cambridge now known as Kendall Square.

But those who ventured into the building became a tight-knit group of entrepreneurs. Alumni of those early days tell stories of its familial atmosphere. Sally Snyder, an elderly woman who packed and shipped products, played a motherly role. She insisted that Stata and Lorber eat lunch and often made them sandwiches. She was also an entrepreneur, selling sandwiches to other employees during the lunch hour. According to company lore, one of these sandwiches found its way into a shipment to a customer in Germany. In response, ADI received a Telex: "Thank you for the amplifiers. They arrived in good working order. Thank you also for the chicken sandwich. It did not."

When they weren't buying Snyder's sandwiches, the staff sometimes grabbed lunch at the F&T Restaurant, a diner located at the spot that became the Kendall Square subway entrance for the inbound Red Line subway train.

Jim Maxwell remembers a particular lunch shortly after he was hired in 1968. His manager, Ed Grokulsky, had invited Stata to join them at the F&T. Maxwell was excited about the opportunity to learn from a founder of the company in person. Instead, "Ray started grilling me and Ed, asking us what was going on in sales and in engineering. All through lunch, he drilled us with question after question," Maxwell said. Stata wanted to hear what the two men were learning from customers. "I was surprised and impressed because this guy, a founder, thought I knew something important. He thought I had something valuable to contribute." That accessibility, curiosity, valuing of employees and attitude of continuous learning were characteristics that influence ADI culture to this day.

In 1969, the two founders decided to part ways. Already married and settled, Stata wanted to grow the company.

Lorber, still a bachelor, wanted to cash out. "I knew I'd been lucky," Lorber said. "I didn't know how many more times I could gamble and win in this business." It turned out to be several. Lorber went on to establish three other companies. The most successful was Copley Controls, which he founded in 1984 and sold in 2008.

Taking the company public would satisfy both men. ADI debuted in over-the-counter trading in March 1969, offering shares at $16 each to raise nearly $1 million. Stata got the capital he wanted to expand the business. Lorber

The first modular op amps produced by ADI in 1965.

A Short History of the Analog-to-Digital Converter

In the days before digital computers, real-world analog signals such as sound (music), images (TV), voice (telephone) and physical phenomena like pressure, temperature, motion and even radar were acquired, measured and processed in the analog domain by circuits such as op amps and analog computers. But as digital computation emerged, the industry saw that there were advantages to processing analog signals in the digital domain. This created a need for a new category of circuits called analog-to-digital converters.

In the instrumentation market, the new devices were called data converters because they converted analog data (measurements) to a digital format. The digital voltage meter was an early example of data conversion. But the biggest advantages of processing analog signals in the digital domain were in high-speed applications like guidance systems in aerospace and defense applications and analyzing the dynamic structural performance of airplanes. More applications emerged over time, such as digitizing voice signals for telephony and converting music from analog records to CDs.

The successive approximation register (SAR) converter was an early approach to converting high-speed signals that was invented by Bernie Gordon, the founder of Epsco and later Analogic. Pastoriza Electronics, and subsequently ADI, built its converter business on SAR converters. As ever higher speed converters were required, ADI acquired Computer Labs, which had been founded by John Eubanks and Robert Bedingfield to exploit the pipelined converter techniques invented at Bell Labs. Sigma-delta conversion, also invented at Bell Labs, then became the most commonly used technique since this converter architecture was easily integrated with digital circuits. Because of the cost benefits resulting from Moore's Law, integration of converters with digital circuits, especially to enable wireless communications, became ubiquitous.

While not the first to introduce sigma-delta converters, ADI engineers Bob Adams, Richard Schreier and many others contributed significantly to advancing the performance of these converters for ever more demanding applications. ADI leadership in the converter market has been and continues to be a key driver of the company's success.

sold a significant number of his shares in the IPO and stepped back from the company, although he remained on the board of directors for several years.

Expanding into Converters

Having achieved leadership in the fast-growing modular op amp business, Stata began to think about what other product categories ADI could introduce into its global sales and marketing machine. To find the answer, he turned to ADI's op amp customers, which now numbered in the thousands, asking what other products they would rather buy than build. The overwhelming response was data converters. In 1965, Digital Equipment Corp. had launched its landmark PDP-8 minicomputer, triggering explosive growth in minicomputers. ADI's customers were using these computers to automate instrumentation, so they needed to translate analog signals from the instruments into the binary language of minicomputers. They needed analog-to-digital converters (ADCs).

There was just one problem: ADI didn't know how to design converters.

Fortunately, Stata found someone who did. Jim Pastoriza, a designer for Philbrick in the early '60s, had founded his own company to pioneer the development of converter modules. It was just down the road from Cambridge, off Route 128 in Newton, and had just reached $1 million in sales. In 1969, ADI bought Pastoriza's firm and entered the converter market.

Early modules were manually trimmed to improve precision and reduce cost. This photo depicts the module before and after encapsulation.

> "Each year [the ICs] got better and they were an order of magnitude cheaper. I concluded that we had to take bold steps to learn how to design and manufacture ICs, or our success would be short-lived."
>
> **RAY STATA**

It was a natural expansion. Op amps and converters used the same primitive hand-assembly manufacturing process in the company's new headquarters in Norwood, where ADI moved when it outgrew its Cambridge space. Production testing of converters was much more complicated than the testing of op amps, but the test equipment was not expensive and the skills required for testing both product categories were similar. Both op amp and converter modules were encapsulated in black plastic, which led to the nickname "hockey pucks." The DAC modules were typically 2 inches square, while the majority of ADCs were 2 inches by 4 inches. The op amps had many more variations in size, from 1 inch square to rectangular shapes.

Entering the IC Age

Both types of modules were selling well, but Stata observed that some companies had started buying a new technology, integrated circuit op amps. Although ADI's hand-tweaked modules consistently outperformed these IC devices, "each year [the ICs] got better and they were an order of magnitude cheaper," Stata said. "I concluded that we had to take bold steps to learn how to design and manufacture ICs, or our success would be short-lived."

Since ADI was now a public company, Stata had to sell his board of directors on the idea. The board balked, and for good reason. It seemed a crazy and unnecessary risk. The module business was highly successful. Modular op amps typically sold for $10 to $20, with the highest-performance types selling for as much as $200. IC op amps, on the other hand, sold for a couple of dollars. Some of ADI's design engineers thought ICs would never meet the performance levels that ADI's instrumentation customers required. The company didn't have the money to invest in expensive semiconductor manufacturing equipment. Plus, large companies like Fairchild and National were already way ahead of the game. Finally, ADI had no knowledge or experience in designing and manufacturing ICs.

But the persistent Stata would not be denied. Convinced that ICs were the future, he borrowed against his ADI stock and personally invested $2 million to fund a startup, named Nova Devices, to design and manufacture ICs that ADI then marketed and sold under its own brand. Within two years, it was clear Stata had made the right call. ADI bought Nova in 1971 (with no gain to Stata), and it became Analog Devices Semiconductor (ADS) Division. By 1979, ICs would make up more than half of ADI's revenue.

It was among the first of many moves that showed Stata's ability to see potential where others could not. "Ray was able, almost before anybody else, to clearly see how modules would dwindle down to almost nothing and ICs would take over," said Modesto "Mitch" Maidique, who was part of the founding team at Nova Devices. "He had this ability to see the future."

Nova, Analog: integrated circuit winners

By Donald White
Globe Staff

Integrated circuits? Ugh!

Everybody knows they are bad news, right?

Consider the evidence. Only the other day General Electric announced it had dropped the manufacture of i/cs on which it had spent an estimated $50 million over four years but had achieved less than $5 million in annual sales.

Sylvania, Philco and United Aircraft have all quit the i/c business in the past year. A good business to be from, quite obviously.

You will get an argument, though, from the entrepreneurs at Nova Devices, Inc. in Wilmington which is not only new to the i/c game, but profitable.

Nova has become profitable at a pace that is somewhat dazzling for the electronics industry. The reason is probably its association with Analog Devices, Inc. of Norwood.

It was largely Analog money that helped seed Nova two years ago and yesterday Analog said it has acquired all of Nova's outstanding stock.

Ray Stata, Analog's president, who also has a private financial stake in Nova, said Analog's 1972 sales will probably exceed $16 million and a substantial part of the firm's growth will come from Nova. Analog's sales for fiscal 1971 (year ending Oct. 31) will be about $12.5 million.

With Analog providing much of the support — money, management, marketing — that many start-up firms find exceedingly burdensome, Nova was able to concentrate on technology and production techniques. Its founders feel that they have enough savvy in both sectors to make Nova just about the only successful new i/c operation in the East.

As Stata explains, i/c manufacturers in the East such as Transitron, Sprague, RCA and others progressed to manufacture from more modest transistor design and fabrication. And in any case Nova does not regard such firms as competition.

The i/c business, according to Stata, is split 80/20. The 80 percent group make the type of product that has been clobbered by price erosion. The other, smaller group produces esoteric, more expensive devices.

Most new i/c companies are located on the West Coast in a Bay area known as Silicon Valley. They are there because that is where the technology is and because of it, the Nova team say, there can be no such thing as proprietary information or a trade secret.

Peterson and Stan Harris, marketing manager, are Transitron alumni. Modesto Maidique, a Ph.D. who is vice president and engineering manager, is from MIT. They head an operation with 70 employees in 12,000 square feet of new space. By February they will have taken on another 12,000 square feet in the same building.

Nova's products closely parallel, and in some cases are counterparts of, the amplifier and computer-interface modules that Analog makes in discrete component form. They are sold by Analog's sales network.

The company is staking much on its ability to innovate in products and manufacturing.

Peterson, Harris and Maidique feel so confident that they have stolen a march on the industry that they are talking of doubling the workforce in the next year. Stata is confident enough to be talking about Nova in terms of "making a more than usual contribution" to Analog earnings next year.

Analog, which earned 17 cents in the third quarter (versus 18 cents for the whole of last year), will probably wind up this year with 30 to 35 cents a share.

The *Boston Globe* reported on how Nova Devices succeeded in ICs even as other local IC makers failed. ADI acquired the startup, which was backed by Ray Stata, in 1971.

> **"Ray was able, almost before anybody else, to clearly see how modules would dwindle down to almost nothing, and ICs would take over. He had this ability to see the future."**
>
> **MITCH MAIDIQUE**
> **Co-founder of Nova Devices**

Mitch Maidique co-founded Nova Devices in 1969. He joined ADI in 1971, when ADI acquired the startup.

Nova Devices

When Nova Devices was launched in September 1969, however, success was far from certain. The company started with a group of linear IC engineers who had left Transitron: Maidique, Robert Peterson, Doug Sullivan and Stan Harris. (Another engineer who got his start at Transitron, Robert Swanson, had left the company several years earlier to work for Fairchild and then National. He would go on to found a major competitor of ADI, Linear Technology.) After temporarily setting up shop in Woburn, Massachusetts, they leased 10,000 square feet of space in a flimsy building in the woods of Wilmington, a Route 128 suburb north of Boston. In 2015, ADI still owned and used that building, which became 831 Woburn St. Across the street from it, ADI built a sprawling campus of four ADI buildings, including a fab that occupied hundreds of thousands of square feet.

"It looked like some cheesy diner, with this thin veneer of paneling that you'd cringe at if you saw it in someone's house because you know there's nothing but architectural problems behind the paneling," said Dave Kress, who joined ADI in 1972.

ADI had already been selling rebranded ICs. The performance of off-the-shelf IC op amps was not adequate to meet the requirements of its demanding instrumentation customers. So ADI bought IC op amps from the likes of Intersil, Transitron and Harris, temperature-tested and graded them and then resold the highest-performing parts at a premium. IC op amp manufacturers published only typical specifications. By more extensively testing over temperature, ADI published minimum and maximum specifications that instrumentation companies could rely on.

The ADS Division's goal was to design and manufacture its own ICs and to figure out how to improve performance to meet requirements of its modular op amp customers. Initially the focus was on IC op amps because they were fairly simple products. But it was not long before ADI's engineers began to think about how to design the more complex data converters as ICs. To achieve its goal, ADS recruited and hired engineers with analog IC design and manufacturing expertise. Despite the fact that such skills were rare, the combined entities of Nova/ADS and ADI managed to hire a cadre of talent that became key to ADI's long-term success, including analog IC design pioneers Paul Brokaw and Barrie Gilbert. "When you have a young company in the technology industry, the most important thing is to get the best minds in the industry," said Maidique, who went on to serve as president of Florida International University. "We did that with Brokaw and Gilbert. These guys just went to town and designed great circuits."

The talent went beyond just two engineers. The company developed a deep bench of design engineers with a thorough understanding of transistor physics and analog circuit architectures; manufacturing engineers with a knowledge of materials and process technology; technical sales and marketing engineers with the applications knowledge to teach and support customers; and executives skilled in mapping out a strategy that would make ADI a leader in analog ICs.

"The talent pool there was startling," said one early employee. "There were more

Nova's microcircuit manufacturing facility in Wilmington, 1971.

Thin-film resistors are deposited on silicon wafers by radio frequency sputtering, 1971.

Engineers in the lab at Nova Devices.

brains per square inch in that place than I had ever seen. . . . Wilmington was destined to produce circuits that were legitimate landmarks in the industry." The circuit architectures and products not only met customer needs but also laid the foundation for advanced analog IC design and established ADI as an innovator and leader in high-performance analog ICs.

It was a period of tough challenges, great accomplishments and much fun in Wilmington. Brokaw and Gilbert set a tone of strong, sound vetting at the technical level. The degree of scrutiny in both interviewing candidates and reviewing technical designs meant ADS was no place for the thin-skinned. Brokaw's interviewing technique was legendary.

"Paul Brokaw was the definitive technical interviewer," said Fellow Dave Robertson, who joined ADI in 1985 and experienced Brokaw's technique firsthand. "Rather than ask you about his circuit, Paul would get you to talk about your own thesis project or circuit design. He'd start in your comfort zone, then keep asking different questions until he got you to the point where you'd have to say, 'I don't know.' That was when the real interview started." In 2015, that interviewing technique was still being used, Robertson said. "We look for people who can operate very creatively, people who can solve problems when they are in situations where nobody knows the answer. If you're innovating, you can't look it up in a textbook."

Such probing sometimes produced surprising hires. Mike Libert was still working as a short-order cook, paying his way through electronic technician school, when Brokaw spotted a jewel in the rough. "He knew the difference between what he knew about and what he understood," Brokaw said. "I try to interview by guiding the candidate to the edge of something he or she claims to understand to see how far they can extend their knowledge on the spot." Libert was the type of person

Circuit Layout in the Rubylith Age

The process of laying out circuits in the early days of IC production required careful attention to detail and much arduous labor. In the earliest days of IC production, a layout engineer could transfer a circuit's schematic, showing the connections between a circuit's components, by cutting directly onto thick Mylar sheets called Rubyliths. Each sheet corresponded to one mask layer for exposing a silicon wafer.

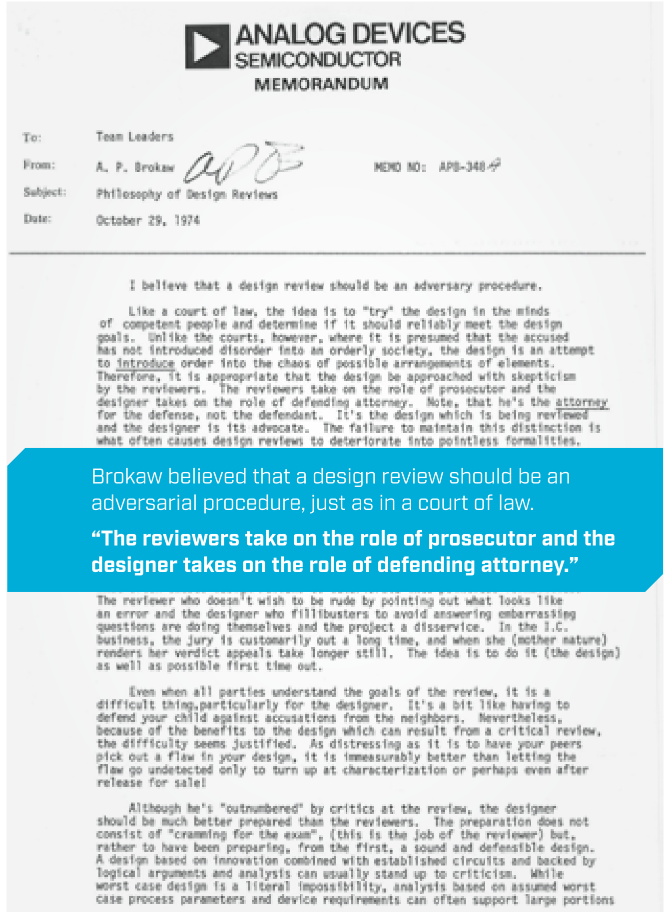
An engineer hand-cuts IC designs onto a Rubylith.

"In the mid-1960s, Rubys—coated with a thin layer of red plastic—were as large as 4 feet square," Barrie Gilbert said. "After creating the translucent drawing of the layout on Mylar from the designer's schematic, it was placed on a light table and overlaid with a blank Ruby, and their alignment was secured.

"Using a metal ruler and X-Acto knife, the layout designer cut with surgical precision rectangular outlines in the red plastic layer over certain areas of the drawing, each of which corresponded to a specific step in making the IC," Gilbert said. "These areas were later peeled off the Ruby. Many of the holes were less than a quarter-inch square and could be easily overlooked. The only way to check them was to produce smaller colored transparencies of all the several layers, align them as best we could and staple them at an edge. These were held up to a window while we scanned diligently for misalignments and missing openings. Just one error of this sort was all it took for the entire IC to fail."

By the 1970s, specialized equipment made the job easier. One company developed a light table specifically for cutting Rubys. "The table had a gear-driven digital micrometer accurate to within one-thousandth of an inch over the entire surface, so that the cutting knife could be positioned with very high repeatability," Dave Kress said. "The layout drawing was hung on the wall next to the machine, and measurements from it were dialed into the micrometer, avoiding the need to manually align the cutting knife over the layout. The Rubys, at that time up to 1,000 times the actual size of the components on the chip, were then photographed by a huge camera. These images were used to make a set of glass plates, called masks. Through the process of photolithography, these masks were used to create the circuit on the actual silicon wafer. Ultimately, the entire mask-making process was automated."

Wafers in the 1960s and '70s were about 2 inches in diameter; the early ICs required only six or seven masks. By 2015, wafers were 12 inches across and used as many as 40 different mask layers. While the layout of digital-circuit subsystems is now highly automated, the work of laying out analog circuits—which nonetheless are often highly complex—remains largely a manual process, requiring highly skilled layout engineers.



ANALOG DEVICES
SEMICONDUCTOR
MEMORANDUM

To: Team Leaders
From: A. P. Brokaw
MEMO NO: APB-348
Subject: Philosophy of Design Reviews
Date: October 29, 1974

I believe that a design review should be an adversary procedure.

Like a court of law, the idea is to "try" the design in the minds of competent people and determine if it should reliably meet the design goals. Unlike the courts, however, where it is presumed that the accused has not introduced disorder into an orderly society, the design is an attempt to introduce order into the chaos of possible arrangements of elements. Therefore, it is appropriate that the design be approached with skepticism by the reviewers. The reviewers take on the role of prosecutor and the designer takes on the role of defending attorney. Note, that he's the attorney for the defense, not the defendant. It's the design which is being reviewed and the designer is its advocate. The failure to maintain this distinction is what often causes design reviews to deteriorate into pointless formalities.

The reviewer who doesn't wish to be rude by pointing out what looks like an error and the designer who fillibusters to avoid answering embarrassing questions are doing themselves and the project a disservice. In the I.C. business, the jury is customarily out a long time, and when she (mother nature) renders her verdict appeals take longer still. The idea is to do it (the design) as well as possible first time out.

Even when all parties understand the goals of the review, it is a difficult thing,particularly for the designer. It's a bit like having to defend your child against accusations from the neighbors. Nevertheless, because of the benefits to the design which can result from a critical review, the difficulty seems justified. As distressing as it is to have your peers pick out a flaw in your design, it is immeasurably better than letting the flaw go undetected only to turn up at characterization or perhaps even after release for sale!

Although he's "outnumbered" by critics at the review, the designer should be much better prepared than the reviewers. The preparation does not consist of "cramming for the exam", (this is the job of the reviewer) but, rather to have been preparing, from the first, a sound and defensible design. A design based on innovation combined with established circuits and backed by logical arguments and analysis can usually stand up to criticism. While worst case design is a literal impossibility, analysis based on assumed worst case process parameters and device requirements can often support large portions

Brokaw believed that a design review should be an adversarial procedure, just as in a court of law.

"The reviewers take on the role of prosecutor and the designer takes on the role of defending attorney."

Memo No: APB-348
Page Two

of a design. This work is part of the normal design process, and the results can handle many of the routine questions which will arise. The more difficult areas will involve design tradeoffs and value judgements. In these areas, the designer should be prepared to offer technical arguments based on analysis, experiment, and prior experience, which are sufficient to convince reasonable, but skeptical, devils advocates. He should also be prepared for the possibility that the design can be improved upon (or even that it must be). In fact, when there are areas of the design which the designer feels are weak, he should point them out ahead of time so that the reviewers can put extra effort in these areas to come up with recommendations.

The reviewers should also prepare carefully, though not necessarily at great length. Questions which may require detailed answers should be asked in advance so that answers can be prepared. Reviewers should have many questions ranging in scope from general circuit concepts to "nit-picking" questions about specific values and arrangements. It will generally develop that the designer will be so well prepared in most areas, that many of the questions will have obvious answers and need not be asked. In other areas, where a weakness appears, reviewers should zero in and make certain that the design is at least adequate, or that the designer is made aware of deficiencies or probable loose ends. Where you suspect an unresolved difficulty, try to prepare a solution or alternative in advance. Come equipped not only with questions, but, wherever possible with answers in the form of synthesis methods, alternate configurations, or relevent technical papers.

The review process can and should also go on continuously and informally with designers and team members sharing ideas. It is important to recognize that weakness in a design should be given wide exposure (in our technical circle) in hopes that someone will come up with a better answer.

The idea of the design review is to improve the design. All the participants should prepare with the impersonal passion with which they would undertake a chess tournament. Design reviews should be a game of wits, where the designer prepares a strong design with an impenetrable defense and the reviewers make a tactical attack prepared to expose any weaknesses. In this game, however, both participants can win by helping to make sounder and more efficient designs.

Like the more difficult parts of a circuit design, this philosophy is an expression of judgement as much as completely supportable fact. Like an apathetic design review it will probably not have served its purpose unless it provokes some comment. Please take some time to see if you have a philosophy in this area, and to try to improve mine for our mutual benefit.

djk

cc: P. Holloway
W. Maxwell

"Design reviews should be a game of wits, where the designer prepares . . . an impenetrable defense and the reviewers make a tactical attack prepared to expose any weaknesses."

Paul Brokaw's influential memo on "Philosophy of Design Reviews," 1974.

who could extend his knowledge. He taught himself how to draft circuit layouts by watching and asking the regular layout draftsmen and eventually ran that group.

Then, there were candidates who couldn't extend their technical knowledge contemporaneously. Brokaw typically walked candidates through a circuit diagram, asking them to explain how the circuit worked. One candidate famously replied, "It beats the shit out of me." That was Jerry Fishman, who was hired in 1971 as a product marketing manager in Wilmington and became CEO in 1996.

It was rarified air. "We used to refer to going to work as going down the rabbit hole—a reference to *Alice in Wonderland*—because magical things happened," said Peter Holloway, who was hired in 1974. "There was a sense that we could do anything."

"Companies would pay billions of dollars to re-create the atmosphere we had in Wilmington then," Kress said. "We had these super guru designers and process experts. When you had a question, you could go right to the person who could give you the definitive answer."

Great atmosphere notwithstanding, in the early years, ADS had difficulty manufacturing ICs profitably. Yields were abysmal until Maidique hired several people who had run a wafer line at Sprague Electric. Jody Lapham was one of them. "When I came in, they were using a mix of 1½- and 2-inch wafers, and they were counting broken wafers to get their yield numbers up," he said. "At the end of the line, if they needed a higher yield, they just smashed a few."

Lapham's group was able to improve those yields legitimately. "We started seeing yields increase, from just a few percent to 30 percent and higher," Maidique said. "Within a short time, we were making money hand over fist."

By the end of 1972, ADI was one of the only profitable open-market semiconductor businesses on the East Coast. Sylvania, Philco and United Aircraft had all quit the business.

Looking to the West Coast

Meanwhile, Stata had his eyes on developments on the West Coast. He tracked down two people at a scrappy competitor, Zeltex: Hank Krabbe, a talented engineer who had been designing modular op amps that were superior to ADI's, and Keith Rutherford, who was sales vice president of Zeltex. Over dinner and several bottles of Krabbe's favorite wine, the expensive Bernkasteler Doctor, Stata and Mel Sallen, ADI's first sales manager, persuaded both to join ADI. Krabbe would move to Boston while Rutherford remained for a time in California, where he set up direct sales offices in the state's northern and southern regions.

As ADI got deeper into IC converters, Krabbe urged Stata to look into complementary metal oxide semiconductor (CMOS) process technology for converter products. Krabbe agreed to go back to California to set up a joint venture with Micro Power Systems Inc. to design and manufacture the industry's first CMOS converters. A custom semiconductor maker, Micro Power was founded by John Hall, who had previously co-founded Intersil with Jean Hoerni, the inventor of the planar process for manufacturing integrated circuits.

CMOS had advantages over bipolar in several respects. Inherently lower in cost, CMOS was better suited for

The Vanishing Op Amp, by ADI Fellow Barrie Gilbert

The key idea out of which the op amp developed was that of using feedback around an otherwise general-purpose, high-gain amplifier to create an overall function that is defined almost completely by components in the (specialized and sometimes complicated) feedback network. The idea of forcing a function to be defined by an accurately controllable set of components arose during World War II and is usually attributed to Harry Black, born in Leominster, Massachusetts, in 1898. While working at the Bell Telephone Labs, Black realized the potency of the "feedback idea" in a 1927 paper.

Black's objective was to reduce the distortion in amplifiers used in telecommunications. But its stronger promise was yet to be understood. This was the realization that by designing special amplifiers for use in this way, having very high internal gain and then adding an external network that feeds some of the output back to the input, their internal distortion, variations in gain and other characteristics over time, temperature and aging would be almost fully eliminated. That meant the function was determined by the feedback network. In most respects, the op amp vanished from the designer's concern.

A simple example of this idea was the exact control of the gain of an audio amplifier, using various different op amps, whose "open-loop gain" at low frequencies was as high as a million and as low as 100,000. If a designer used a network consisting of just two resistors, connected to the amplifier output and arranged to send, for example, one-hundredth of that output back to the input of the op amp in a particular way—known as "negative feedback"—so as to always keep the amplifier's input to a very small value, then the "closed-loop gain" would be accurate to within -0.01 percent for the higher-gain samples of op amp and still to within -0.1 percent for an op amp having the lower gain.

Over the years, hundreds of types of op amps have performed scores of amazing tricks; they refuse to be outdated by advances in digital technology. In 2015, minuscule op amps were fabricated using processes originally developed and optimized for digital applications and thus unfavorable for analog design. Yet their performance has improved in numerous specialized ways, and cost has dropped to the point where one can add an op amp to a large-scale mixed-signal IC (handling both analog and digital signals) for much less than a penny's worth of silicon—roughly one-thousandth the cost of a typical modular op amp when ADI was founded.

The world of electronics in the service of humankind would be impossible without the use of op amps in every conceivable system.

Analog Devices Inks ICs Deal

By MARTIN GOLD

NORWOOD, Mass. — Analog Devices has signed a long-term development and production contract for integrated circuits with recently-formed Intersil spinoff Micro Power Systems, Inc., Santa Clara, Calif. (EN, Nov. 15.)

The deal calls for Micro Power to manufacture and process C/MOS analog switches, dual-junction field effect transistors, and eventually monolithic digital-to-analog and analog-to-digital converters which Analog would design and market.

ADI signed a long-term IC development and production contract with Micro Power Systems in 1972 and jointly designed the industry's first CMOS 10-bit DAC, the AD7520.

the implementation of switches, high-density logic and digital interface circuits, which were important in converter products. It wasn't long before Krabbe designed the industry's first complementary metal oxide semiconductor (CMOS) 10-bit digital-to-analog converter (the AD7520) using the Micro Power process. "We have thus become one of the first manufacturers of integrated circuits to take advantage of the possibilities which CMOS technology offers to analog product design," ADI's 1973 annual report stated.

Analog Devices was among numerous businesses that sprouted up along Route 128, an area that became viewed as Massachusetts' version of Silicon Valley.

Micro Power founder Hall was a pioneer in the use of a technology for generating accurate and highly stable thin-film resistors, which could be added to a silicon circuit at the wafer level. Nova Devices had also developed thin-film technology tuned to improve the performance of analog circuits. ADI enhanced the performance of its op amps and other precision linear products using thin film and then went on to develop technology for trimming the thin-film resistors on the chip with a laser, one of ADI's first and most important process innovations. It was a breakthrough that brought the company a significant and lasting competitive advantage. (See Laser-Trimming: A Unique ADI Core Competence, page 71.)

In the 1970s, ADI grew from a startup into a well-established public corporation. By the end of the decade, it had $135 million in revenue and 2,700 employees. It had navigated a transition into the IC business, which by the end of the decade brought in half the company's revenue. ADI continued to grow its highly profitable module business as well, especially for more complex converter products; in fact, the profits from the module business funded the IC development work that produced those breakthroughs.

Meanwhile, the number of electronics companies along Route 128, a road that would soon be called "America's Technology Highway," continued to grow. By one count, there were 1,212 firms in the area in 1972. In the 1980s, the Massachusetts economy would boom, and state politicians would talk about the "Massachusetts Miracle." But the miracle would start to fade in the mid-1980s, as U.S. defense spending slowed dramatically. This would bring ADI to another important crossroad.

The Second Transition

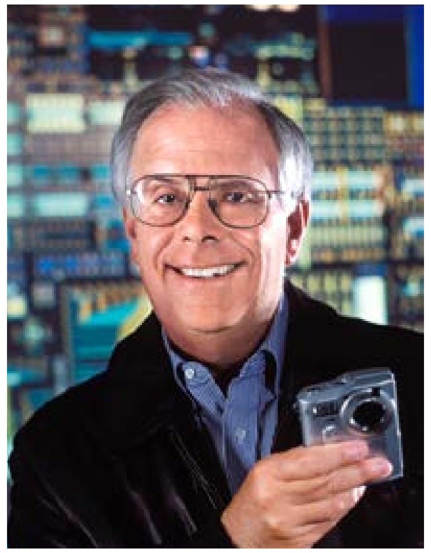
Extending From Low to High Volume, From Industrial to Consumer Markets

From 1970 to 1985, ADI sales grew at a compound annual rate of more than 27 percent. The markets the company served—defense, aerospace and instrumentation—were hungry for high-performance analog products. The year 1984, which was met with some trepidation because of George Orwell's dystopian novel, was actually ADI's most successful up to that point, with revenues of $313 million, nearly $100 million more than the previous year. Management predicted that the company would reach $1 billion in sales by 1988.

That was not to be, however. The ever-cyclical semiconductor industry took a dive in 1985. Sales grew a meager 3 percent to 4 percent for the next two years, and ADI's net income dropped by half, from $37.4 million in 1984 to $18.7 million in 1987. More worrisome was the big picture: Long-term growth in the defense and aerospace markets was slowing. The West had won the Cold War, a victory punctuated by celebratory Germans tearing down the Berlin Wall in 1989 and the collapse of the Soviet Union two years later. But defense and aerospace, which made up 17 percent of semiconductor industry sales in 1975, would drop to 7.5 percent by 1985 and to just 1 percent by 1995. Defense spending would remain an important market for ADI, but it would not be a growth driver for the semiconductor industry nor ADI for the long term.

"The handwriting is on the wall," declared *Electronic Business* magazine. "The U.S. Congress is paring down defense programs, and the message to an army of military electronics suppliers is clear: It is time to find new business for growth."

The instrumentation market was slowing as well because a large part of it supported the defense and aerospace industries. Meanwhile, the consumer, computer and communications markets were taking off. The companies that made those products started turning to ADI for high-performance analog ICs, especially converters, where ADI had built a leading franchise. Management knew these customers would be different, but just how different they were would lead to a second major transition and a reinvention of the company's organization and culture.



Jerry Fishman, who was hired in 1971 and rose to become CEO in 1996, oversaw much of ADI's transition to high-volume and consumer markets.

> **"We found ourselves in a position with the very best technology in a market that was growing very slowly, or in some cases shrinking. A shift to these faster-growing markets would require a whole new way of thinking about the world."**
>
> **JERRY FISHMAN**

In the 1990s, the company's marketing material began to highlight digital cameras, CD players, computer peripherals, mobile phones and other consumer electronics.

"We found ourselves in a position with the very best technology in a market that was growing very slowly, or in some cases shrinking," said Jerry Fishman, who had risen to general manager of Analog Devices Semiconductor Division (ADS) in 1979 and executive vice president in 1988. ADI certainly had great products. What it did not have was the right mindset, Fishman said. "A shift to these faster-growing markets would require a whole new way of thinking about the world."

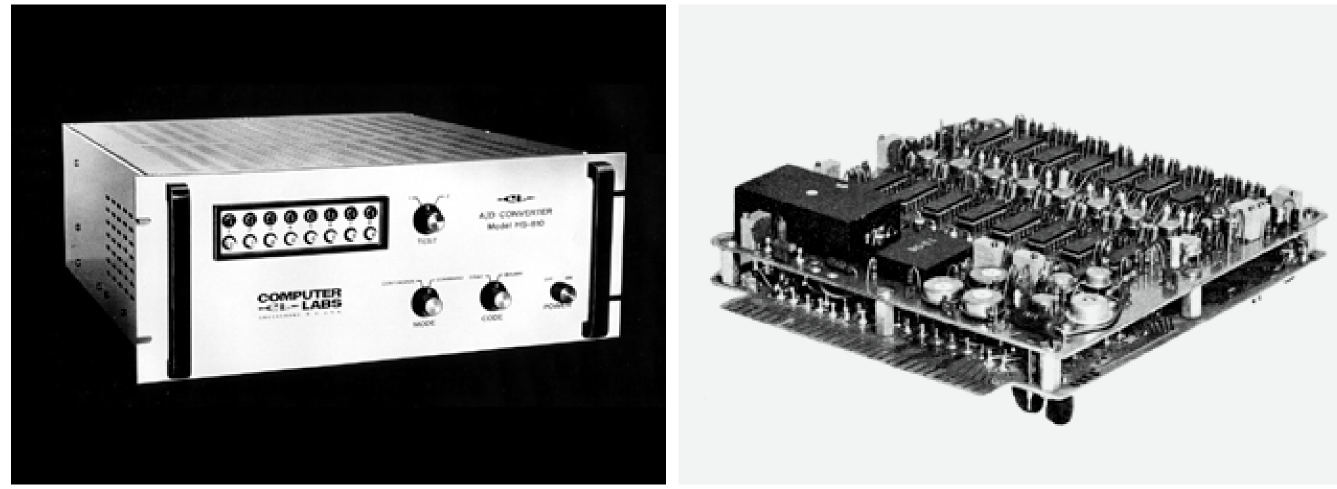
The Strength of Converters

During the 1970s and '80s, ADI had doubled down on converters, investing in every possible technology to design and manufacture them. In addition to converter modules built in Norwood, Massachusetts, and bipolar converters fabricated in Wilmington, Massachusetts, ADI had launched a new fab in Limerick, Ireland, to build CMOS converters.

Then, in 1978, ADI bought Computer Labs, a company in Greensboro, North Carolina, that specialized in very high-speed converters. Computer Labs had been founded 10 years earlier by John Eubanks and Robert Bedingfield, engineers who pioneered the development of high-speed data conversion at Bell Labs. This breakthrough, which at the time was achieved through a mixture of module and hybrid technologies, would prove vital as ADI later expanded its business in wireless communications and learned to manufacture complex circuits with IC technology.

"It wasn't clear which technologies and applications would win out, so we bet across the board," Ray Stata said. Each geographic location focused on its own technology and products, fostering close collaboration between circuit design and process design. That strategy created the best environment for innovation. Each location could independently exploit each technology. Through this collection of diverse, independent technologies, ADI achieved leadership in almost every segment and application of converters.

The strategy also had created an organizational structure based on technology and, by extension, location. It nurtured independence and creative freedom—key aspects of ADI's culture. Design groups were co-located and worked autonomously within their technology area. Individual engineers and project groups were free to innovate. In terms of business, each geographic location was a division that operated as an independent unit, with its own design, marketing and



Computer Labs, which ADI acquired in 1978, designed and manufactured rack-mounted systems (left), converter cards (right) and converter modules (not shown).

manufacturing. Each was responsible for its own profits and losses. "We tolerated and even encouraged internal competition among the various locations and technologies in order to drive innovation and provide the best solutions for the market," Stata said. It was not unusual for marketing and design engineers from different ADI divisions to show up at the same time to visit the same customer in an effort to understand future requirements and compete to win sales. "It was a little crazy, but it worked remarkably well," Stata said, "at least until the mid-'80s." That's when several trends converged. Growth shifted to high-volume markets, process technologies started to converge (companies were starting to combine bipolar and CMOS) and ICs replaced modules and hybrids. To meet the challenges of this new landscape, ADI had to dramatically change its structure and its beliefs about what was important to success.

ADI Manufacturing Crosses the Pond

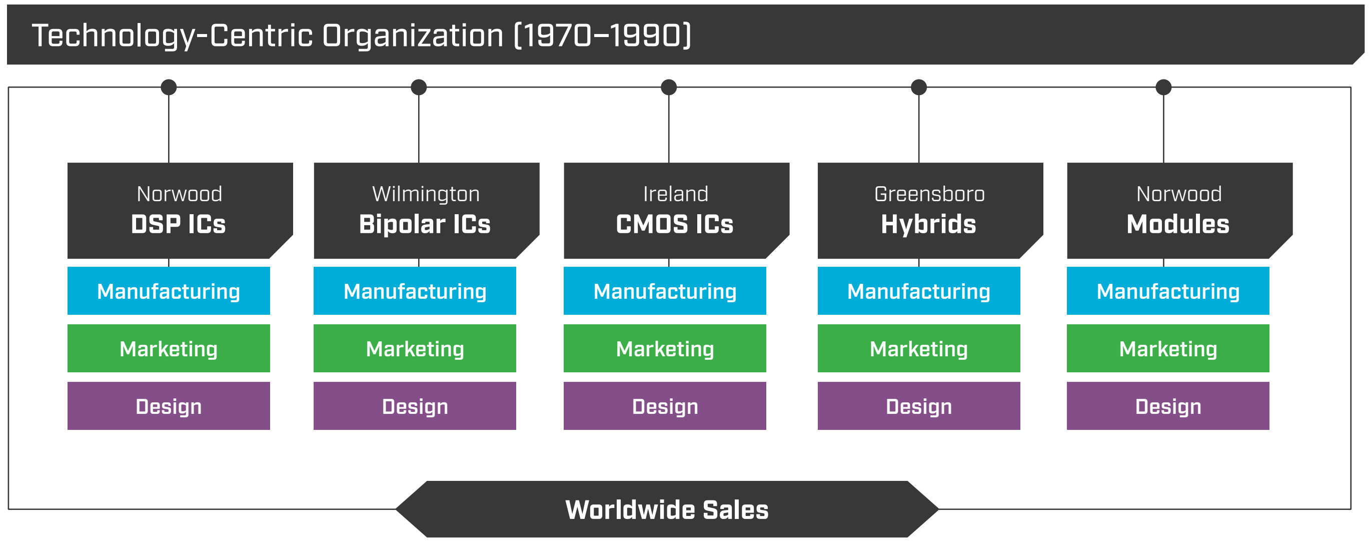
A confluence of technical and economic forces led ADI to establish a new IC fab in Limerick, Ireland, in the mid-1970s.

The popularity of a circuit that Hank Krabbe designed using Micro Power's analog CMOS confirmed the promise of CMOS technology for converters. The AD7520 was the industry's first CMOS monolithic 10-bit multiplying DAC using CMOS current switches and logic circuits. However, ADI's Wilmington fab was equipped to build only bipolar current switches and logic, which made inefficient use of silicon, and Micro Power's fab was too small and focused on custom circuitry.

If ADI was going to start making CMOS chips, it would need a new fab.

The company investigated various locations, looking for governments that would offer financial incentives. In Ireland, the Industrial Development Authority (IDA Ireland), a government agency focused on attracting multinational companies to the island nation, which at the time suffered from an unemployment rate of 20 percent or more, offered a tax holiday until 1989. It also offered hefty capital grants and subsidies for startup costs, R&D and training, as well as industrial buildings ready for build-out.

In January 1976, ADI reached an agreement with the Irish government to set up a plant in Limerick. Krabbe agreed to relocate to Ireland and bring with him ADI engineers Bill Breckenridge and Jerry Whitmore, who joined ADI in 1972 and 1973, as well as several consultants. Their charter: Set up the plant, transfer the technology, hire their replacements and leave within three years. While some team members elected to stay on beyond the initial setup period, the team did indeed meet its goals and, in the process, launched a facility that has been instrumental to ADI's success in many ways.



ADI operated as a technology-centric organization from its inception through 1990. By extension, this meant each geographic location operated as an independent business unit, except for sharing sales resources. Each division had its own products optimized for its particular technology. The arrangement stimulated healthy internal competition, particularly for converters, until the company's entry into high-volume markets necessitated the centralization of manufacturing and the creation of worldwide product groups.

High-Volume Markets

ADI's strength in converters—it had 40 percent of the market and advertised that it had the highest performance and broadest selection of converters in the industry—proved to be key to entering high-volume markets. ADI hardly had to go looking for these new customers. Often, they came to ADI. Many consumer products were in transition from analog to digital technology. These mainstream products sometimes sold millions of units. Converters, in particular, were required to translate between real-world (analog) signals and the digital domain. CD players had started to replace analog audio cassette tapes and vinyl records, and IC technology was allowing them to get cheaper and smaller. Sony introduced one of the first portable CD players, called the Discman (later to be rolled up under the Walkman name), in 1984. Minicomputers gave way to even smaller personal computers that sat on individual workers' desks. Early personal computers fascinated hobbyists, but when IBM introduced its first PC in 1981, corporate America started to notice. Intel's relentless advances in microprocessor performance made IBM PCs, and compatible clones, powerful enough to become the principal tool of office workers for the next 30 years. The mobile phone, designed by Motorola's Martin Cooper back in 1973, had the appearance and weight of a brick. But by the mid-'80s, a network for mobile telephony was being introduced in the United States and Europe, and companies were designing ICs into the first mobile handsets that could truly be held in the hand.

Martin Cooper (left), pictured with the Federal Communications Commission's Benjamin Hooks, designed the first mobile phone, the Motorola DynaTAC phone, in 1973. By the mid-'80s, a cellular network for mobile communications ushered in the first truly hand-held mobile.

It was a huge growth opportunity, but to be successful, ADI had to learn the requirements of these new markets, which turned out to be the polar opposite of ADI's traditional customers. Since its early days, ADI had sold standard components in small quantities to thousands of different customers, which designed them into many different end products. ADI had mastered the "long tail," a strategy of selling a broad selection of unique items with relatively small quantities sold to each customer, decades before Chris Anderson of *WIRED* magazine coined the term in 2004. ADI's traditional customers placed a high value on the technological sophistication and high performance of ADI parts and were willing to pay a high price for them. Gross profit margins on these parts were typically greater than 65 percent. The customers' products took years to design, but they had long life cycles. Once ADI's components were designed in, ADI could count on those sales sometimes for a decade or more.

"The culture around the company was that it didn't matter how long it took to develop products as long as they were the best," Fishman said. "It didn't matter how much the products cost as long as they performed well, and it didn't matter if we delivered them on time because the customer would wait."

However, consumer, computer and communications markets (and later the automotive market) were different. These customers sometimes wanted components optimized for their applications. Called application-specific standard products (ASSPs), these chips were designed for a particular type of application, industry or sometimes a single customer. Rather than selling a broad selection to many different customers, ADI needed to develop more specialized chips that would be sold to a narrow range of customers. If the product into which the chip was designed was a hit in the market, sales could skyrocket and ADI would need to quickly ramp to high-volume chip production. If the product reception was lackluster, ADI would not see much return on its R&D investment. The initial price of the chip might be high, but customers expected that price to drop in response to the rise in production volumes. That meant yields had to be high if ADI hoped to earn a solid profit.

These customers not only demanded high volumes but also required consistently high quality, reliability and on-time delivery. They wanted defect levels of less than 100 parts per million, which was unprecedented at that time. Many of them had adopted just-in-time manufacturing and needed parts delivered on a strict schedule.

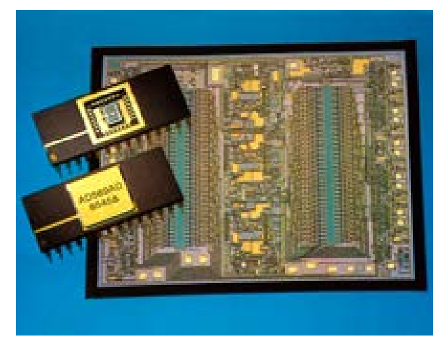
Different Markets, Different Business Models

Defense / Aero / I&I	Consumer / Communications
General-purpose parts	Application/industry-specific ICs
Low volumes	High volumes
High price	Low price
10- to 15-year life cycle	< 2-year life cycle
Engineering sale	Strategic/management sale
Technology-driven	Customer-driven
Diversified, low-risk	Concentrated, high-risk

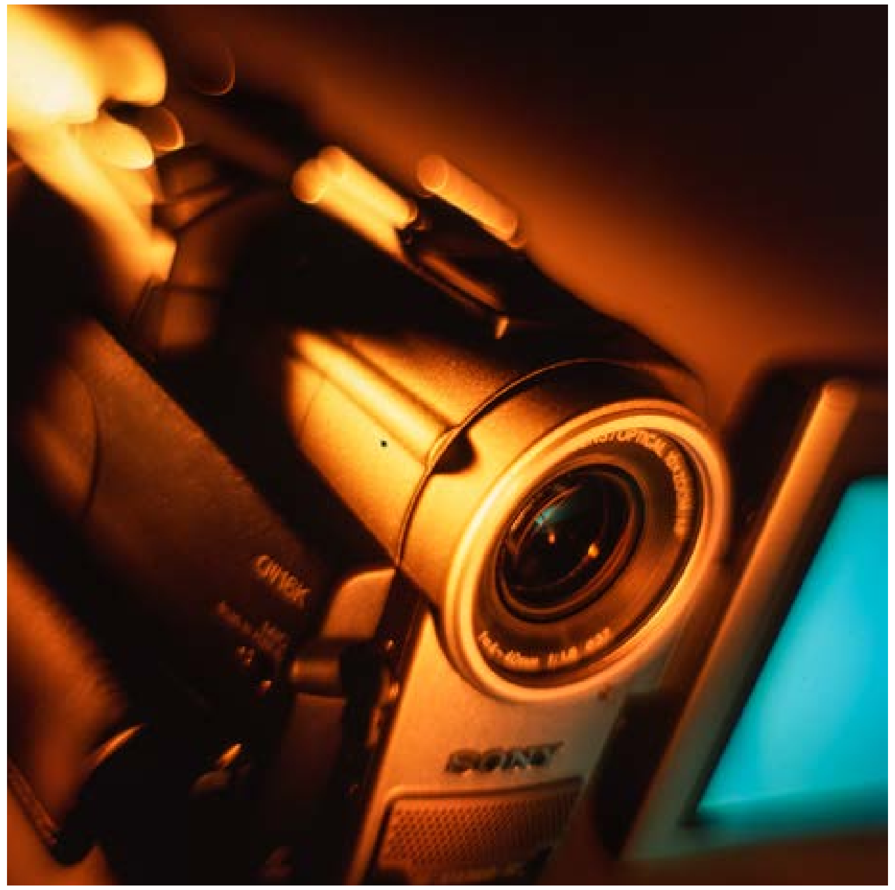
Entering new markets prompted ADI to develop new customer-driven business models and diversify its product portfolio.

Navigating Consumer Markets

The first sign that a fundamental shift was underway came in the mid-1980s. Sony, the Japanese consumer electronics company, needed a 16-bit digital-to-analog converter (DAC). The AD569, designed



The AD569 was the first ADC inherently monotonic to 16 bits, making its performance attractive in the nascent digital audio market.



Digital photography and videography relied on ADI converter technology. ADI achieved an estimated 60 percent market share for analog front ends of digital cameras by 1999.

> **"The Sony experiences were an enormous education for the company at all levels. They made us perform better than we thought we could on every single front, including design, manufacturing, quality and customer service."**
>
> **CHRIS MANGELSDORF**

by engineer Peter Holloway, was a good choice. It was inherently monotonic. In other words, its analog output moved only in the direction that the digital input moved. This characteristic, highly valued by the industrial control customers for whom the part was designed, was also useful in audio because it reduced certain types of distortion. Sony wanted better digital-to-analog conversion and needed monotonic performance for a CD player it was developing. The price it wanted, however, shocked ADI. The AD569 sold for more than $15; Sony wanted a version that could be sold for a few dollars. ADI declined to bid, but Burr-Brown, an early competitor, accepted the challenge. Within a short time, Burr-Brown was cranking out millions of these DACs with a different and cheaper design, and making a profit. This experience served as a canary in the coal mine.

"It was the first of many data points that led us to understand that there needed to be a significant change in the cost picture," said John Hussey, who joined ADI in 1982 and headed the converter operation.

Several years later, Sony came calling again, this time looking for a CMOS analog-to-digital converter (ADC) for its Handycam, an early digital video camera. When Fellow Chris Mangelsdorf (who joined ADI in 1984) saw the performance and price points Sony wanted, he threw the request for quote in the trash. But Hussey encouraged him to try, and eventually Mangelsdorf designed the AD875, a 10-bit CMOS ADC that met the requirements and the price goal. Although the AD875 was designed for Sony, ADI designers quickly followed with a derivative standard part, the AD876. In future generations, other CMOS circuits in the camcorder were integrated with it to provide a complete analog front end. "The system we gave them came in at half the power of Sony's previous bipolar system, and the image performance was actually better," Mangelsdorf said. ADI ended up capturing a large portion of the market for converters in video camcorders. Eventually, the analog front end was modified for use in digital still cameras, color scanners and digital copiers. In fact,

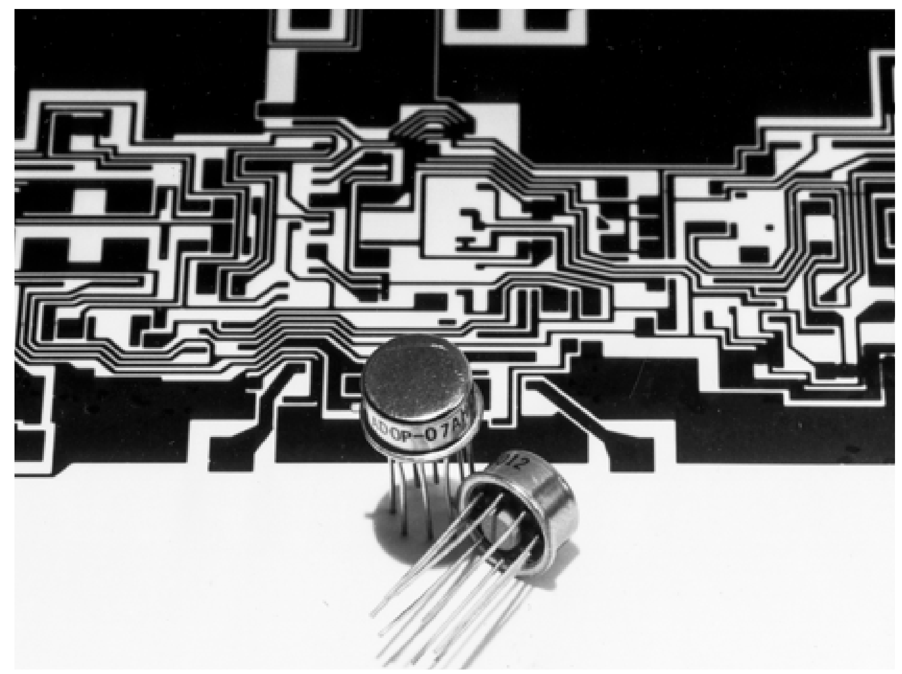
ADI Fellow Chris Mangelsdorf (left) was encouraged by John Hussey (right) to design a CMOS ADC that helped ADI capture a large portion of the market for converters in video recorders.

by 1999, ADI converters could be found in 60 percent of all digital cameras.

The Sony experiences were "an enormous education for the company at all levels," forcing ADI to up its game, Mangelsdorf said. "They made us perform better than we thought we could on every single front, including design, manufacturing, quality and customer service." One of the biggest lessons was how to effectively leverage R&D investments, Hussey said. ADI learned how to exploit standard products to develop ASSPs, which subsumed other circuits for a particular application. For example, the analog front end was sold to other customers making the same or similar products. Thus began a virtuous cycle that would expand ADI's aftermarket for decades. Standard products got ADI in the door. After learning what the customer needed, ADI would develop an ASSP, which in turn was used to improve the performance of new standard components or, in the case of Sony, new, improved converter products or integrated subsystems. "We learned how to leverage core technology through that progression quickly," Hussey said.

By the 1990s, ADI's converter portfolio led in most market segments, and competitors were realizing how important and valuable converters had become. One company in particular, Precision Monolithics Inc. (PMI) in Santa Clara, California, had become a thorn in ADI's side. PMI was building some of the same circuits as ADI (referred to as "second sourcing") and undercutting ADI's prices in the process. More importantly, PMI was developing a line of converters that was viable competition.

PMI had been founded in 1969 by Marv Rudin and Garth Wilson, two linear circuit designers from Fairchild Semiconductor. The founders soon hired George Erdi, who had designed the first high-precision amp at Fairchild Semiconductor. Erdi also had designed PMI's industry standard OP07, introduced in 1975, the first op amp to use an offset trim technique called "zener zapping." (Zener zapping was an alternative to ADI's laser-trimming technology that produced similar



The PMI OP07, which became the AD OP07 following the acquisition, was the first op amp created through zener zapping.

advantages for op amps and converters. However, laser-trimming ultimately proved to be the most cost-effective approach for most applications.)

PMI had talented engineers and great products. Then one of its initial investors, a private company called Bourns, bought complete ownership. When Bourns did not invest enough for PMI to keep pace with its competitors, the astute Stata saw an opportunity. He knew that if ADI didn't acquire PMI, then one of its competitors would, which could be a serious threat to ADI's converter franchise. In fact, Linear Technology was also trying to buy PMI, "but ADI came in and had more cash than I did," said Robert Swanson, Linear Technology co-founder and CEO. In 1990, ADI bought PMI for $60.5 million plus warrants. The move not only eliminated a low-price competitor but also gave ADI a substantial presence in Silicon Valley and access to its engineering talent.

George Erdi designed many op amps that became industry standards, including the PMI OP07 in 1975. Erdi left PMI in 1981 for Linear Technology.

DEAL LETS ADI MOVE INTO SILICON VALLEY

Analog Devices acquires PMI for $60M

BY MARTIN GOLD

Norwood, Mass. — Analog Devices Inc. last week completed the acquisition of Precision Monolithics Inc. (Santa Clara, Calif.) from Bourns Inc. for $60.5 million in cash. Bourns also gets warrants to purchase 1 million shares of ADI common stock at $10 per share.

PMI becomes a division of ADI, enabling Analog Devices to broaden its base into the Silicon Valley. Alan King, formerly president of PMI, will be vice president and general manager of the new ADI division, reporting to Jerry Fishman, executive vice president of ADI.

PMI's sales organization will be combined with that of Analog Devices', which reports to Doug Newman, ADI's vice president of sales and marketing. An ADI spokesman said it's too early to comment on how many people would he affected by merging the companies.

The final selling price was lower than what was asked for when the negotiations between the companies began last spring (see April 23, page 14.) The original asking price was $80 million.

'The acquisition makes Analog Devices the second-largest nonconsumer analog IC supplier.'
—*Ray Stata, ADI*

But Bourns was given the option to buy Analog stock. "We decided to lease the PMI facility rather than buy it. The adjustment was also due to evaluating the asset values," explained the ADI spokesman.

"The acquisition makes Analog Devices the second-largest nonconsumer analog IC supplier," according to Ray Stata, Analog's president and chairman, referring to National Semiconductor. "We now have the people and resources to become the world leader in this market, and that is our goal." The acquisition adds close to 850 people to ADI's head count, bringing the total to approximately 5,900 people.

Expansion planned

"We already have several major thrusts to expand into new segments of the analog IC market, including computer peripherals and telecommunications equipment," Stata noted. "A reallocation of resources in the combined companies will allow us to fund these new initiatives while expanding market share in our traditional markets."

The combined sales of Analog Devices and PMI are currently running at an annual rate of about $540 million.

An article in *Electronic Engineering Times* reported that by acquiring PMI in 1990, ADI became the second-largest non-consumer analog IC supplier in the world.

Creating the "New Analog"

PMI was ADI's largest acquisition up to that point. The need to integrate its staff and operations, combined with the shift to high-volume markets, the merging of process technology, and the growing dominance of ICs threw the inadequacy of ADI's structure into stark relief. Management had already been considering changes; now, it realized it needed to completely redesign and rebuild the company for the second time in its history.

"Many of our most sacred beliefs had to change," Stata said. For example, division managers believed that they couldn't be held accountable for profits unless they controlled manufacturing. And design managers believed they couldn't manage engineers unless they were within walking distance of their desks.

Rather than having independent divisions with their own manufacturing and other functions, ADI needed centralization and efficiencies of scale. Disparate design and manufacturing locations and methods could not reach the volume or quality levels required. Now, ADI needed centralized and standardized manufacturing that could produce high volumes of components cost-effectively and at high levels of quality and reliability. The internal competition among technologies had outlived its usefulness and had become divisive and wasteful. ADI needed to reorganize and consolidate design and marketing teams into worldwide product strategy groups.

So ADI launched a campaign called "Creating the New Analog." The reinvention would affect nearly every part of the company. ADI would consolidate its independent operating divisions that were based primarily on technology and location. Where Wilmington and Limerick converter groups had competed against each other before, now engineers from both locations were pulled together into worldwide converter product groups focusing on high-speed and high-resolution products and markets. To emphasize the importance of the new strategy, in 1994 Stata and Fishman brought hundreds of managers to a hotel ballroom near Norwood and pronounced the "death of the divisions."

For the first time, ADI would have a worldwide head of IC manufacturing: Tom Urwin, formerly general manager in Limerick. His mission was to standardize manufacturing processes so that products designed in various locations could be manufactured in one of three fabs, or even in external foundries, which the company started using in the early 1990s. For the first time, design engineers were separated geographically from manufacturing engineers, to the distress of both. The ability of the two groups to work side by side had been one of ADI's greatest competitive advantages. Now, out of necessity, they had to learn to collaborate across great distances. The move of assembly and subsequently testing to a central location in the Philippines was met with similar apprehension. But the centralization, along with a laser-like focus on quality, increased yields and reduced defect levels dramatically, setting the company on a path to world-class levels. By the turn of the century, yields were consistently high, defect levels were far less than one part per million and costs were in line with those of higher-volume analog manufacturers.

The company centralized, consolidated and improved many other functions, including sales, marketing, finance and order processing. Reorganizing European sales was particularly important because of the formation of the European Union. Brian McAloon, who had joined the company in 1987 and ran the Limerick operation, was named head of European sales. He was put in charge of bringing independent offices in a dozen European countries, each with its own language, culture and habits, into one sales organization with common business processes. They would all report to McAloon.

Long Live the New Analog

When ADI created the "New Analog," it was changing more than just the corporate organizational structure. It had to change the culture as well.

As the company had grown and added new locations over the previous 20 years, each division had developed its own subculture and ways of doing things. ADI's hands-off management traditionally respected such independence and individuality. It even tacitly encouraged various groups to compete with each other. "The attitude of management seemed to be that such internal competition would keep us keen," Chris Mangelsdorf said. "The message was: Competition breeds strength, so let the best team win."

But that wouldn't work for the New Analog. Several divisions defined by technology location were being reorganized into product-centric divisions. Rather than each location being responsible for all aspects of its own products, from design to manufacturing to marketing, these functions would now be centralized. It was a huge cultural shift, and management wanted to send its message as emphatically as possible.

So Ray Stata and Jerry Fishman staged a funeral for the old way of doing things. In a meeting near Norwood of senior managers, they officially buried the old divisions. A slide showed each division as a coffin. In the back of the room, a trumpeter played taps.

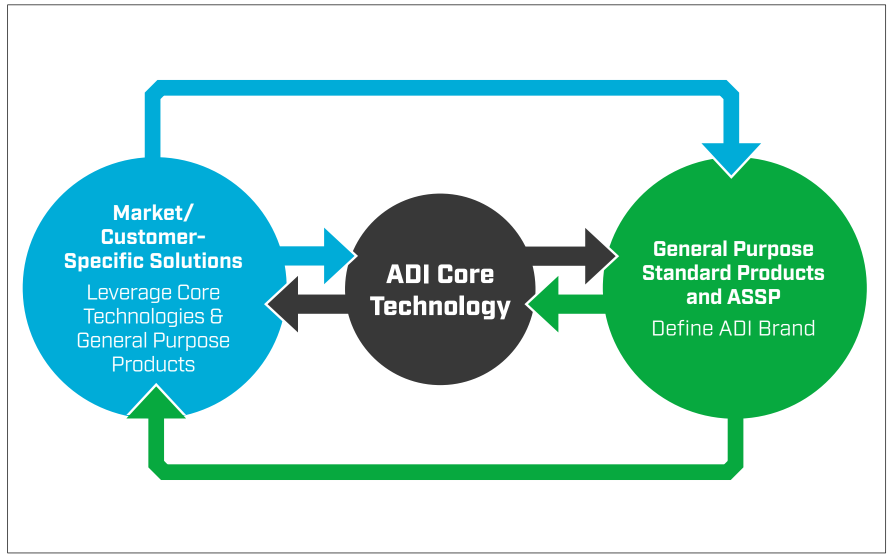
"That ceremony marked the official end of the divisions competing with each other and running themselves as separate businesses," Fishman said. Although the managers laughed at the campy drama, they realized the seriousness of the moment. The old Analog was dead. Long live the new Analog.

Costs in ADI's finance department were higher than they were at many companies, largely because of the profusion of different financial systems used by the divisions, according to Joe McDonough, who joined ADI in 1983 and was chief financial officer from 1991 to 2008. ADI consolidated staffs, picked the best financial system and implemented it company-wide. That cut the amount of time needed to close company books each quarter from 11 to seven days, and significantly improved planning and forecasting.

Gerry Dundon, another executive in Limerick who had joined ADI in 1977, headed the effort to consolidate order management, logistics and distribution. Each location in Europe had its own warehouse and order management system. There were nine order-processing systems in Europe, a different one in the United States and yet another in Japan. "And none of those

Joe McDonough, CFO from 1991 to 2008, oversaw the standardization of ADI's financial systems.

Developing an Ambidextrous Organization



ADI evolved into an ambidextrous organization, leveraging and strengthening its core technology portfolio by selling standard products to low-volume markets and application-specific solutions to high-volume markets.

systems talked to each other," Dundon said. Over the next several years, ADI would implement one worldwide planning and order-processing system. For the first time, various geographies would be able to see orders, as well as inventories, and thus be able to quote reliable delivery dates to customers.

Total Quality Management

The entire reinvention brought an increased emphasis on Total Quality Management (TQM), a discipline that Stata had been promoting within the company for years. Now, he pushed it harder. Employees throughout the company learned TQM techniques and how to apply them in their particular area, which led to improvements across the board.

"We shifted our emphasis from 'what we do best' to 'what can we improve?'" said Mark Skillings, who joined ADI in 1972 and served as marketing manager of business development.

By adopting TQM, the company reduced manufacturing costs, improved efficiency and produced better-quality components.

Despite the huge push by management and the immediate drastic organizational changes, it took a decade for ADI to fully make the transition. Even after it was complete, the company continued to learn lessons from high-volume markets. One of the key lessons was figuring out when ADI could profit from a high-volume market and when it could not. Sometimes differentiation and high performance would win the order but not at a sustainable price, resulting in profit margins getting too slim.

It was a tricky balance. The diversity and complexity of ADI's technology gave

it the ability to play in many different markets. Participating in some markets offered valuable lessons even if ADI ultimately exited. "Technology doesn't recognize market boundaries," said Dave Robertson. "The consumer market can be an invaluable proving ground for new technology." The key was to know exactly when to leave a low-margin market and take the technology developments into a more profitable market.

It took many years for ADI to learn how to make this distinction. For example, in the mid-2000s, it used its micro-electromechanical systems (MEMS) technology, originally developed for the automotive market, to make micro-phones for computers and mobile phones. The iPhone, first introduced in 2007, used ADI's MEMS microphones in some of its early versions. Apple had told ADI that it valued innovation and superior performance, Stata said, "but superior performance is a subjective evaluation when it comes to sound."

By 2012 it was clear that Apple's requirements were changing along many dimensions beyond pure technical performance. ADI learned it had to be sure that its customers' products would continue to require innovation, which is where ADI excelled. If innovation was not valued, then the component commoditized and margins dropped.

In 2013, the company sold the micro-phone business to InvenSense for $100 million, and ADI increased its focus on inertial MEMS sensors for industrial, automotive and emerging drone

Early models of the Apple iPhone, unveiled by Steve Jobs, used ADI's MEMS microphones.

and robotic applications, areas where it could provide unique capabilities and get a better return on investment.

By 2015, ADI took a highly disciplined approach to high-volume markets. "We are going to fund [only] those products that are highly differentiated, and where we think we can maintain that differentiation over multiple generations," CTO Peter Real, who joined ADI in 1981, told analysts. The company wanted to work with customers that valued, and were willing to pay for, ADI innovation.

"We will carefully select the most attractive opportunities in the consumer market," said Vince Roche, who was named CEO in 2013. "These will be areas with higher barriers to entry where we can achieve higher and more sustainable growth and returns."

Meanwhile, the company continued serving its traditional markets. The long tail of sales in low volumes to a vast collection of industrial and instrumentation customers created a stable, long-term revenue base that helped fund the company's investments in new markets and new technologies. Just as it continued building modules as it ventured into ICs, ADI kept selling to low-volume markets while it generated new growth in the high-volume ones. The challenge was to achieve the latter while retaining its original culture of innovation in high-performance, technologically sophisticated analog products.

Ultimately, this came to be referred to as an ambidextrous strategy, a term coined by Michael Tushman and Charles O'Reilly in their book *Winning Through Innovation*. This strategy would evolve for ADI, providing a new direction by which management would steer the company in the next leg of its journey.

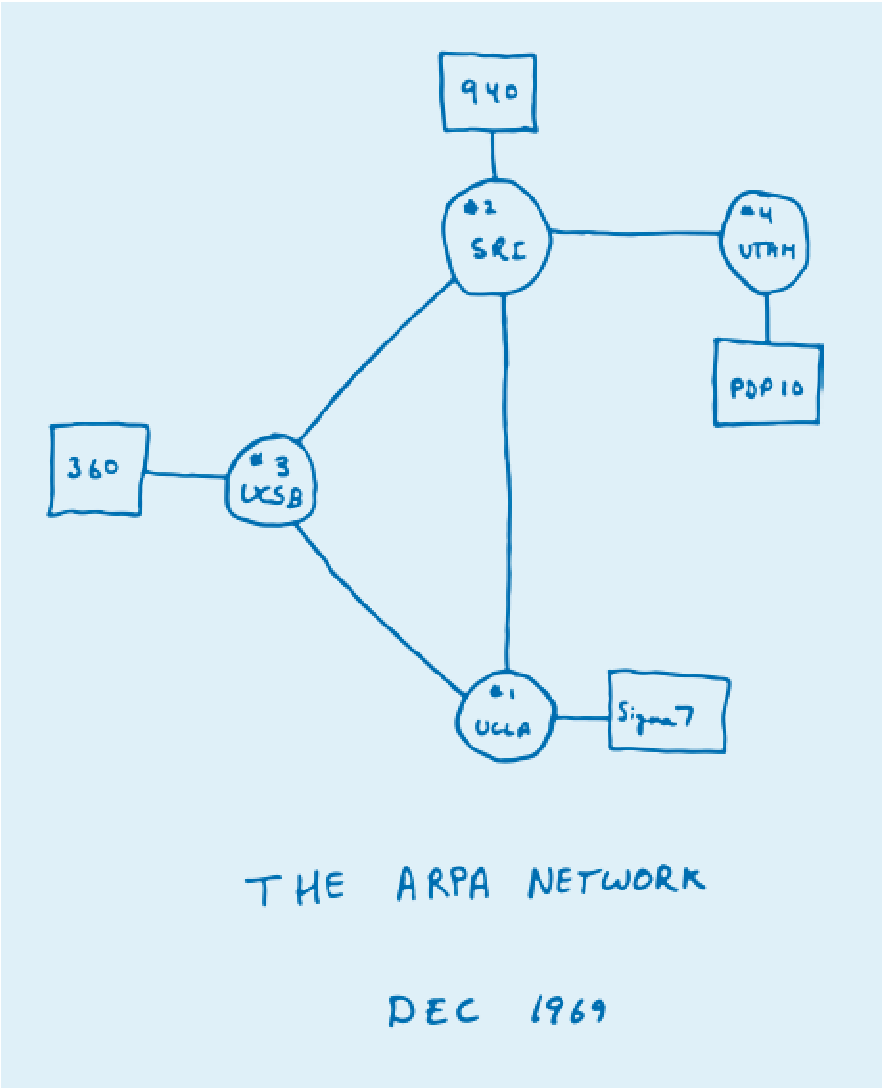
The Third Transition

From Components to Systems

At the turn of the millennium, the technology industry was again booming. An obscure network started by the U.S. Department of Defense in 1969 had grown into the World Wide Web. Growing traffic on the information superhighway created a hunger for fast connections as well as new business opportunities, which drove a frenzy of investment. All manner of companies flocked to the internet, and it seemed like any startup with ".com" in its name could attract venture capital, regardless of its business plan or revenue.

Increasingly, analog information was being digitized so it could be distributed over the internet. Music, for example, went from vinyl records to CDs to MP3 files. Apple introduced the iPod and the iTunes Store in 2001, which eventually led to the decline of retail record stores. The same thing would happen to books, photographs, movies and newspapers over the next 15 years. Meanwhile, the number of transistors that could be packed onto digital chips using complementary metal oxide semiconductor (CMOS) technology continued to grow exponentially, leading to smaller, less expensive and more powerful electronics of all sorts. Computers continued to shrink, to laptop and then tablet size. Cellular phones became thin and lightweight, ubiquitous and smart.

ADI was well positioned to capitalize on these trends, having expanded from its traditional focus in industrial, aerospace and defense, and instrumentation applications to also serve the burgeoning market for high-performance analog technology in consumer, computer, communications and automotive applications.



In 1969, the creation of the Advanced Research Projects Agency Network (ARPANET) laid the technical foundation for the internet. Shown here are the first four switches of the network—the physical Interface Message Processor (IMP) —as drawn by Alex McKenzie, an engineer at Bolt Beranek and Newman (BBN). In the 1970s, BBN developed the first host-level protocols, person-to-person network email and other central pieces of the modern internet.

According to ADI's annual report, "2000 was by every measure the best year in ADI history." Revenue had jumped 75 percent in one year—from $1.45 billion in 1999 to over $2.57 billion in 2000.

Then came the dot-com crash. Virtually all tech companies' revenues and stock prices plunged. ADI's sales dropped to $1.7 billion by 2002. However, ADI weathered the downturn better than most. Jerry Fishman, who became CEO in 1996, had kept a tight rein on finances. With more than $2 billion in cash and short-term investments on its balance sheet, ADI had the wherewithal to not only get through some tough years but also continue a healthy level of R&D investment.

Changing Semiconductor Dynamics

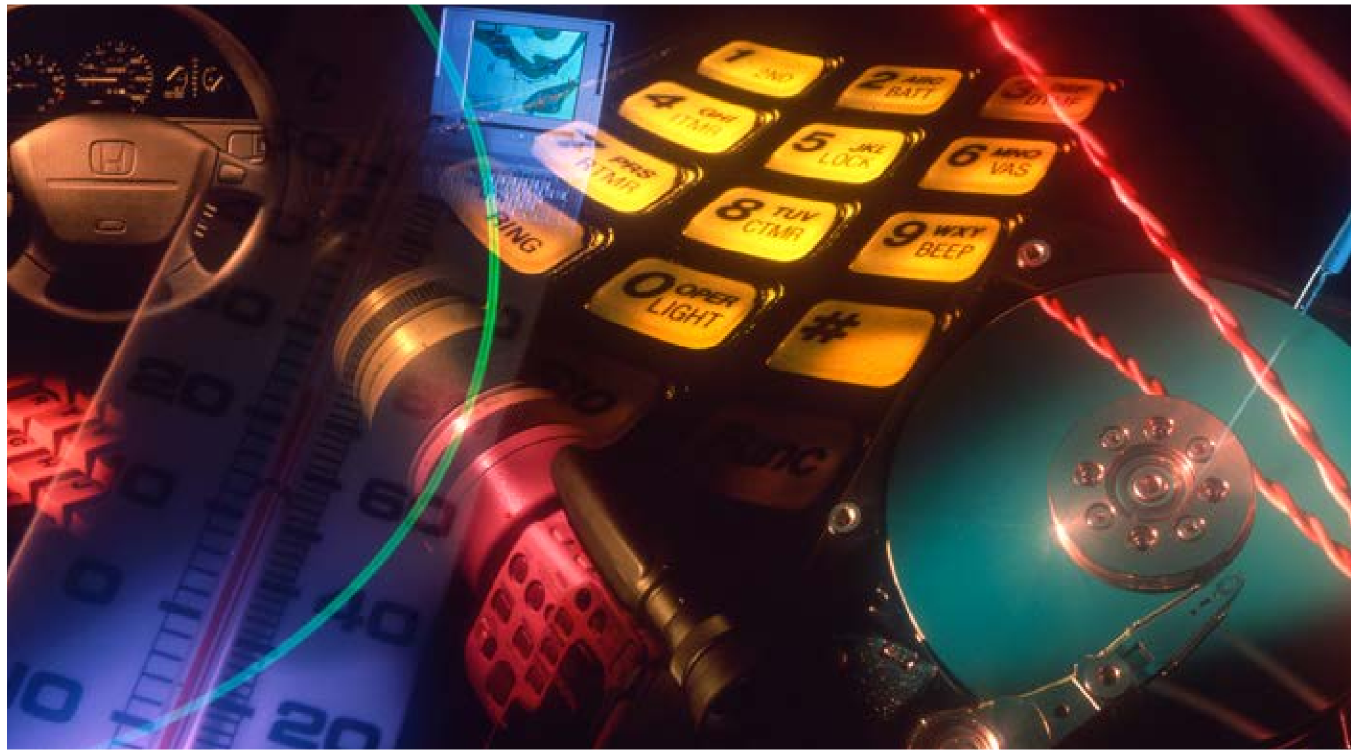
Despite the dramatic financial ups and downs, technology continued to advance at a breakneck pace. The dynamics of the semiconductor industry were changing. On the digital side, complex high-volume components like microprocessors and memory were taking advantage of Moore's Law, increasing dramatically in processing performance and storage capacity while dropping in price. These devices had standardized on CMOS process technology, which allowed for the use of standard CAD tools and design methodologies. These advantages made higher levels of integration technically and economically feasible.

Furthermore, customers in high-volume markets such as consumer, computer and communications wanted general-purpose components such as converters to be fine-tuned to their requirements. They wanted to integrate many different functions—digital signal processor (DSP), converters, amplifiers, sensors and power management—together to create a subsystem solution. And they didn't want to do the design and integration themselves. Not only would they incur high engineering costs, but few had the expertise to design these complex chips. Instead, most outsourced to their chip suppliers, who were more experienced and efficient in chip design and could spread development costs across multiple customers.

As customers outsourced more system design, they looked for semiconductor companies that deeply understood application requirements and were organized internally to coordinate the integration of the broad range of functions that were often required. ADI's roots in materials processing, device structures and circuit design were deep, and for nearly 40 years, those innovations had been its chief competitive advantage. It had some of the best engineers in analog circuit design and process technology and produced some of the highest-performing analog components in the world. However, the company had been organized to sell components to customers, who then designed their own board-level systems.

This is where ADI's product-centric organization proved inadequate. Incorporating system-level design and innovation was a significant challenge. To adjust to the new reality, the company had to again make massive changes in its organizational structure, business processes and beliefs about what constituted success. This was the third major transition at ADI: from a component-centric to a system-centric business. Describing the shift, Ray Stata often quoted an axiom attributed to Russell L. Ackoff, a professor at the University of Pennsylvania's Wharton School who was a pioneer in systems thinking and engineering: "The performance of systems depends much more on how well the parts work together than how well they work

> **"The performance of systems depends much more on how well the parts work together than how well they work separately."**
>
> **RUSSELL L. ACKOFF**
> Professor, University of Pennsylvania
> Expert on organizational theory



By the mid-2000s, customers in every market segment were demanding more complete system solutions.

separately. If you optimize the performance of the parts, you systemically sub-optimize the performance of the whole." The axiom had twofold implications: It applied to how well components had to work together in a system and how well divisions had to work together in a company.

"Historically, ADI was structured to optimize the performance of the organizational parts, sometimes at the expense of the company as a whole," Stata said. "We had always believed that the growth and the profits of our product groups were the most important measures of success." The approach had worked for decades. But now ADI had to figure out how to collaborate across product groups for the benefit of its customers and how to measure organizational performance in new ways. "We had to think and act as one company, as opposed to a collection of separate product lines," Stata said.

The Expansion From Components to Systems

The trend toward greater integration and applications specialization had been persistent at ADI for years, as the company followed the lead of its customers. Its experience designing a CMOS converter for Sony, for example, had shown how it could profitably design, sell and leverage application-specific standard products (ASSPs). (See The Second Transition, page 31-33.) But the responsibility for the design of ASSPs was still carried out in product groups like amplifiers or converters. That organizational structure, centered on product groups with their respective profit and loss centers, worked well enough. ASSPs were treated as components, and the model for doing business did not change.

However, by the mid-2000s, the trend toward more complete system solutions, which integrated multiple functions from across product lines on a single chip, became more pronounced. This required more collaboration across product groups, which led to conflicts over investment priorities and the allocation of engineers. These conflicts slowed the decision process and made dealing with ADI more difficult for customers.

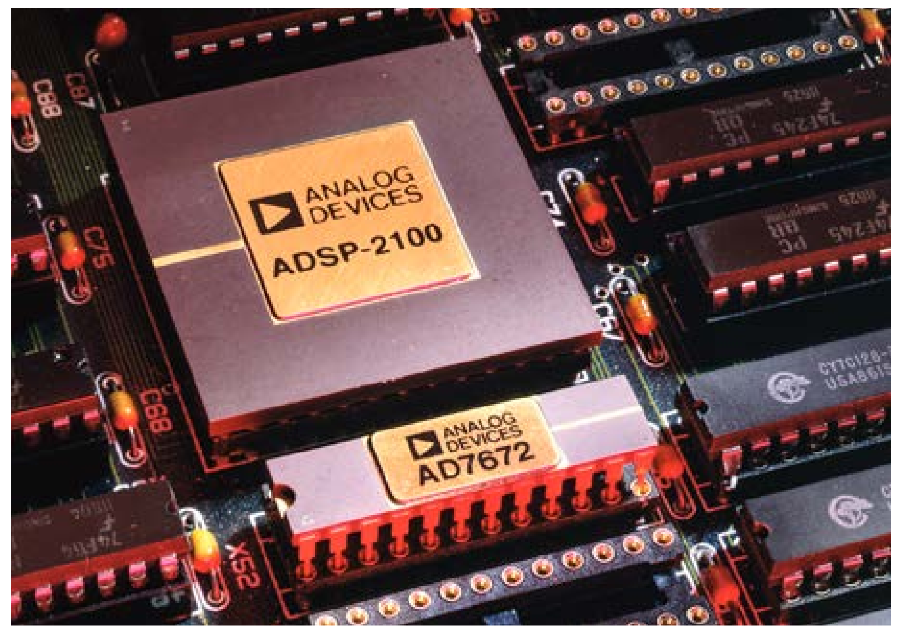
The factors that motivated higher levels of integration and system solutions were many. First, cost benefits in high-volume markets from more integration became even more important as price declines for customers' products put greater pressure

on their costs. It was not just the cost of silicon but also the mounting engineering expenses to design these complex system chips. Chip suppliers were more experienced and efficient in silicon chip design and could spread the development costs across multiple customers. But even more fundamentally, few customers had the expertise to design complex silicon chips. They were forced to outsource system design to silicon chip suppliers.

> "We had to think and act as one company, as opposed to a collection of separate product lines."
>
> **RAY STATA**

Another factor that came into play was that rapid advances in process technology, design methodology, test and packaging made the integration of more complex multifunction system chips technically and economically feasible, although still challenging. Standardized CMOS process technology and CAD tools, plus the advantages of smaller size and lower costs, made ever higher levels of integration a relatively easy decision.

But the advantages of analog integration were not always so obvious. While Moore's Law in digital ICs had conditioned customers to expect more integration, leading to "smaller, faster, cheaper" solutions, the rule didn't always translate easily to analog ICs, which required a combination of digital CMOS and proprietary analog process technologies. ADI pioneered the use of CMOS for analog designs, but it required clever circuit design innovation to realize the cost and power advantages of CMOS process technology in analog circuits. The system-level CAD tools for analog were insufficient, and test automation was more challenging. Nonetheless, ADI learned to design and manufacture these complex system ICs.



ADI introduced the ADSP2100 fixed-point DSP in 1986.

ADI's early work in DSPs laid groundwork that ultimately helped the company move toward systems solutions. In the early 1980s, before customers were even thinking about asking suppliers for ASSPs and systems designs, Stata had spotted a hole—and an opportunity—in ADI's product portfolio. Customers had begun processing analog signals in the digital domain. ADI supplied the analog-to-digital (ADC) and digital-to-analog (DAC) converters, but it offered nothing that processed the digital signals. When Hank Krabbe returned from Greensboro, North Carolina, in 1981, he formed a small group to work on digital signal processing.

As DSPs gradually became the engines around which some systems were designed, this work helped ADI nurture a system mindset. It was in digital signal processing, for instance, where the company started to offer software and development tools for systems. In 1986, ADI introduced the ADSP2100 fixed-point DSP. That part, along with voice coding algorithms developed by the DSP team, got the attention of the cellphone companies. Meanwhile, ADI had been successful

"What's an Analog Company Doing in Digital Signal Processing?"

When ADI decided to create a digital signal processing business in Norwood, Massachusetts, in the early 1980s, that was the question on the minds of many employees. ADI was an analog company. Entering the DSP market seemed sacrilegious.

But it made perfect sense to Ray Stata. ADI made analog-to-digital converters (ADCs) to translate real-world signals into digital form. It also made digital-to-analog converters to translate digital data back into analog signals. That left a big hole. DSP was the next place to go to compete in the signal-processing chain. This broadened the vision of opportunity from data acquisition to real-world signal processing, a phrase coined by ADI to describe a new category of products in which ADI was the leader.

Nevertheless, Stata knew ADI would be up against stiff competition. "Stata sees DSP as both a risk and an opportunity for his company," *Electronic Business* magazine reported in 1985. "On the one hand, he says, DSP is an open window into many lucrative markets. . . . On the other hand, it pits Analog Devices against a host of companies with similar ambitions; not only AMD, TI and TRW but also brash newcomers, such as Integrated Device Technology and Weitek Corp. and Japanese powerhouses, such as Fujitsu Ltd. and NEC Corp."

The long journey in DSPs helped ADI learn how to adapt to the evolving needs of its customers.

Developing a DSP product platform required much more money than developing an analog component, with R&D expenses wiping out a hefty portion of operating profits. In fact, the DSP division lost tens of millions of dollars annually for many years. Wall Street questioned the strategy. Employees on the analog side of the house (which was most of them) resented the DSP division for diverting precious R&D dollars and for the negative financial impact, because profit-sharing was tied to the overall performance of the company, not individual divisions.

DSP didn't always have the full confidence of senior management, either. CEO Jerry Fishman sometimes expressed skepticism. "It took us a decade to understand the DSP business," said Fishman in describing the business in a case study by the Tuck School of Business at Dartmouth. "Instincts that had served us well for over 30 years took us in the wrong direction."

The long journey in DSPs helped ADI learn how to adapt to the evolving needs of its customers. Along with increased analog and mixed-signal integration, DSPs helped the company think in terms of systems and software, rather than just components. Also, through DSP, ADI developed digital expertise that would be important to future systems business.

For example, DSP emphasized the importance of design tools. SigmaDSP, developed for the mid-range automotive audio market, was a case in point. Programming DSPs was complicated, and customers didn't want to deal with complexity. Recognizing this, ADI created SigmaStudio design software for the SigmaDSP. The design team, led by Fellow Bob Adams—who joined ADI in 1989—focused more on ease of use than on the performance of the hardware. "We realized that our automotive customers were looking for simplification," Adams said. "The engineers [designing with the part] were very busy. They needed to get their jobs done quickly, and they didn't want to have to train themselves on some complicated new programming language." SigmaStudio was a software program with a graphical user interface that made designing the part into a system simple. SigmaDSP incorporated "hooks" for the SigmaStudio software. "The innovation was in how the hardware and software worked together," Adams said.

The team that developed the AD7001 baseband converter for cellphones, pictured in the employee newsletter, included future CEO Vince Roche (background center).

in getting its converters designed into an emerging cellphone standard in Europe called global system for mobile communications (GSM). ADI engineers had developed specialized analog baseband solutions for cellphones such as the AD7001 and AD7002 baseband converters, utilizing CMOS TXDAC technology for the transmission path and sigma-delta ADC technology for the receive path, together with fully integrated GSM analog and digital channel filters. This led to the AD7015, an industry breakthrough in terms of performance, achieving the highest level of integration seen for an analog baseband and voice-band codec solution in a single IC. The device complemented the digital baseband solutions ADI had developed through its DSP expertise.

Early in the evolution of the GSM standard, ADI engineers found that similar analog baseband technology could be tailored to support the infrastructure side of the cellular network. They began to develop products, including radio frequency (RF) technology, for both ends of the network.

In the mid-1990s, recognizing the burgeoning market for communications products, ADI established a dedicated Communications Division with the purpose of delivering more application-specific solutions. Initially, discrete RF products were developed for both the cellular handset and infrastructure markets, but the skyrocketing sales of cellphones soon created extraordinary pressures to quickly integrate more functions and reduce costs. While ADI continued to sell more discrete and performance-leading application-specific solutions in the cellular infrastructure market, the company had to do something radical if it was to continue to compete in the handset market.

This press release photo highlighted the revolutionary AD7015 codec, which integrated mixed-signal components into a single IC for GSM handsets, complementing ADI's digital baseband solutions.

The pace of change in the handset market, including the emergence of new radio standards and the proliferation of frequency bands, drove ADI to strengthen its position with the acquisition of Mosaic, an RF company in the United Kingdom. The team at Mosaic, leaning heavily

In the early 1990s, ADI tailored analog baseband technology to support the infrastructure side of 2G GSM cellular networks.

on ADI expertise in data converters, synthesizers, amplifiers and mixers, architected the first direct-conversion RF transceiver for GSM handsets. This transceiver, called Othello, was a major industry breakthrough: Direct-conversion transceivers could very efficiently and effectively support the rapidly proliferating number of cellular standards and associated operating frequency bands. Othello achieved unprecedented levels of RF integration, fitting a quad-band radio in a 30 percent smaller area and using 75 percent fewer components than competing designs, which translated into significant cost reductions for customers' handset designs.

The cellphone market marked ADI's first exposure to the demand for complete solutions, including RF front ends, analog and digital baseband solutions, and software protocol stacks for specific end markets to support customers.

Parallel with this effort, teams at ADI continued to drive mixed-signal baseband and RF innovations, including a line of frequency synthesizers based on BiCMOS technology. It thereby established a leadership position with cellular infrastructure customers, essentially developing higher performance and more discrete versions of the same core building blocks that were being used in handset applications. The infrastructure market pushed the performance of a portfolio of core technologies in a coordinated way across ADI, including high-speed converters, amplifiers, mixers, modulators, demodulators, clocks, synthesizers and power detectors. Many of these initiatives were new categories for ADI. The standard products developed in these areas, while directly beneficial to the infrastructure market, seeded new business opportunities in many other application areas such as satellite communications; industrial, scientific and medical (ISM) band transceivers; and wireline communications. Teams supporting the handset and infrastructure end markets continued to share techniques, intellectual property and resources where appropriate.

Experience and learning in the communications market, which demanded ever higher levels of integration and systems solutions, set the stage for a pervasive transition to the systems business and opened doors to significant new opportunities for growth.

By the mid-2000s, however, it had become apparent that differentiation in the standards-based cellular handset communications market was limited. ADI would have to significantly scale up its investment level to continue to compete. Rather than take this step, the company decided to sharpen its focus on the communications infrastructure, turn its attention to improving the user interface in smartphones, and exit the handset radio and baseband business. The cellphone communications strategy just wasn't working. To be successful, ADI would have to make massive

ADI Fellow Paul Ferguson joined ADI in 1986 and was a member of the handset team, which was acquired by MediaTEK. Ferguson would eventually return to ADI along with several other members of the team.

Wireless Communications: An Early Driver of Systems Solutions

ADI's entry into the cellular handset radio and baseband business was one of its earliest moves into highly integrated systems solutions. It also served as a cautionary tale about what it takes to compete in fast-paced, fast-growing markets.

With the standardization of wireless communications protocols, the mobile handset market exploded. In 1990, there were only about 12 million cellphone users worldwide. Within a decade, more than a million phones were manufactured every day, and the market was led by Nokia and Motorola. By 2015, the market had grown to more than a billion units annually and market leadership had shifted to Apple and Samsung.

Mobile handsets needed ADI's high-performance analog, DSP and RF circuits to support telecommunications standards that differed from region to region and were evolving from generation to generation, but they needed them at ever lower costs and in a constantly shrinking form factor.

ADI's handset business found its greatest traction in the early 2000s in China. These customers were attracted to ADI's solution for the ease of design afforded by the highly integrated radio and baseband signal chain solution, which included software. By 2006, ADI's handset group had designed several generations of radio and baseband chipsets and subsystems and had brought numerous innovations to market. Despite solid growth and a good position in China, however, sales did not generate sufficient scale to support the R&D investment necessary to keep pace with competitors and evolving standards.

ADI decided to sell. In 2007, MediaTek, a Taiwanese company, paid ADI $350 million for the cellular handset radio and baseband business.

It was a difficult decision for CEO Jerry Fishman. "I've divested businesses before," he said, "but this one was particularly tough. I knew the handset team well; they were some of our sharpest and hardest-working. Nonetheless, sometimes you can have great people doing great work and still the fundamental economic forces of a business are too much to overcome." As it turned out, ADI's timing was excellent. By selling when it did, the company recovered much of its investment, preserved jobs for the team and secured a supply for its customers.

additional R&D investments that would have detracted from investments in other diverse and lucrative businesses. Plus, ADI management worried that standards would ultimately turn handset ICs into low-priced commodities. Indeed, cellular carrier promotions already were turning the phones into something "given away" with subscription contracts.

The move proved prescient, as the prices on handset chips plummeted. "Ray and Jerry did exactly the right thing in getting out of the handset market when they did," said Fellow Paul Ferguson, who joined ADI in 1986 and was a member of the handset team. "There were a lot of companies that didn't exit the handset market, and later wished they had."

Nevertheless, a great deal had been learned about how to organize teams to innovate at the system level and ADI had developed a trove of core technology for communications. ADI continued to focus its RF and mixed-signal efforts on more fragmented, more profitable applications where it could add value and achieve leadership. The key RF initiative in the handset business, namely the development of Othello, carried forward in the infrastructure work at ADI and directly led to the development of a family of infrastructure-grade direct-conversion transceivers such as the all-CMOS Catalina (AD9361) and Clemente (AD9368) RF transceivers.

ADI experience in the communications market, which demanded ever higher levels of integration and systems solutions, set the stage for yet another pervasive transition, this time to the systems business, and opened doors to significant new opportunities for growth.

Breaking Down the Silos

Initially, there had been debate about whether the systems business was a good strategy for ADI. Some thought that ADI should stick to components and leave the systems business to others. But as more major customers turned to systems solutions, it became clear that ADI's component-centric organizational structure was not working for the systems opportunities the company was pursuing. When customers wanted ADI to take responsibility for system design and the integration of products from different groups—as chipsets or multichip packages or as monolithic integration—no one person or group had the responsibility or authority to make decisions. This delayed decisions and compromised execution. ADI faced another fundamental transition in the nature of its business.

As an initial step to experiment with new organizational structures before making wholesale changes, Pat O'Doherty, who joined ADI in 1981, was appointed in 2008 to head a cross-disciplinary, cross-functional team dedicated to medical electronics. Rather than selling components, O'Doherty's team focused on building relationships with healthcare leaders and innovators, and understanding the systems challenges and the market

Pat O'Doherty led ADI's Healthcare Segment—a cross-disciplinary, cross-functional team dedicated to medical electronics innovation.

dynamics. It was not just circuit and systems innovations that were important but also innovations in packaging. The group was intentionally named the Healthcare Segment, as opposed to medical electronics, to emphasize the purposeful change underway in this new organizational approach.

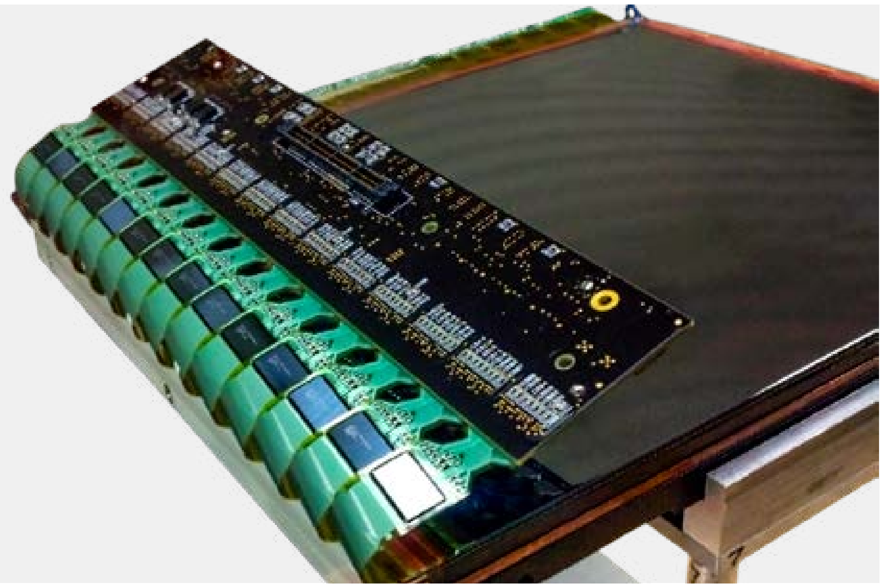
An early success was in digital X-ray machines. ADI developed a front end (ADAS1256) for these machines that integrated current-to-digital data conversion for photonic sensors on a flexible substrate, which enabled versatile systems packaging. The product ultimately ended up leading the digital X-ray market and enabling a family of solutions that could support radiography, fluoroscopy and mammography imaging systems in portable and dental applications with the same platform. "It was a breakthrough in terms of the amount of integration on a chip, and it was a breakthrough in terms of the value that it provided to our customers," O'Doherty said.

The ADAS1256 medical imaging solution was developed by a global team that successfully integrated current-to-digital data conversion for photonic sensors on a flexible substrate. Members of the team are pictured after receiving an award from Jerry Fishman and Vince Roche during the 2010 GTC.

Another product, the ADAS1150, combined a photo diode array with four 128-channel ADCs in an innovative packaging scheme that provided an unprecedented reduction in size and cost of X-ray detection in CT scanners. The new 256-slice CT scanners required over 250,000 channels of ADCs, made possible by 512 of the ADAS1150 modules.

The Healthcare Segment team's increasing ability to think in terms of systems rather than components also helped ADI win business from a company it had long wanted as a customer: Roche Diagnostics, a leading provider of diabetes patient monitoring systems. Roche Diagnostics supplied glucose meters for home use. By pricking a finger for a drop of blood, placing the drop on a test strip and inserting the strip into the meter, diabetics could monitor their glucose levels regularly. ADI felt its chances were slim, however, because Roche Diagnostics was the largest medical customer of one of ADI's top competitors. Unseating this entrenched competitor was not likely unless the sales team could find the right opportunity, which meant solving an important problem no one else could.

In 2010, ADI saw an opportunity. Roche Diagnostics was redesigning its meter to reduce costs, improve accuracy,



The X-ray panel of a digital X-ray machine, which used the ADAS1256 front end. This development was an early success for working across product groups and disciplines to design a systems-level product for a specific vertical business, in this case healthcare.

decrease test time, increase battery life and make it easier for patients to use.

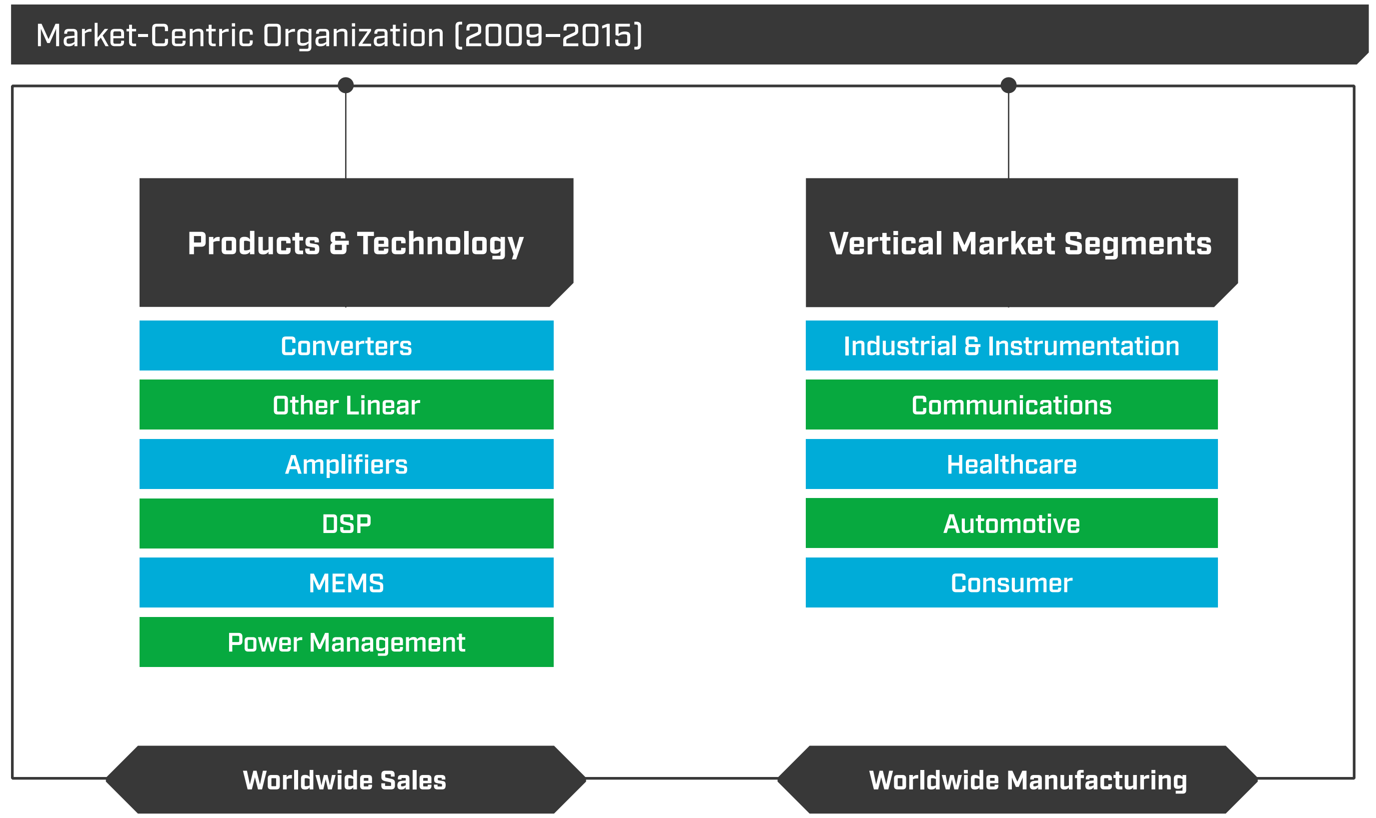
As part of the redesign, Roche Diagnostics developed a new test strip that replaced costly materials while improving performance and size. But successfully extracting a glucose measurement from the new strip was far more complex and heretofore impossible for Roche Diagnostics. The ADI sales team, working with the Healthcare Segment, was able to open the door at Roche Diagnostics by showing them how to solve this complex analog problem. ADI's analog expertise was crucial, but Roche Diagnostics clearly wanted a semiconductor company that would take responsibility for the system design. ADI met regularly with Roche Diagnostics for months before bids were due in order to learn as much as possible about the design challenge. "We treated it as if we'd already won the business," said Mike Riley, who joined ADI as a field sales engineer in 2009 and was later promoted to global account manager. "We worked as if we were an extension of Roche Diagnostics' R&D team."

By the time bids came due for the business, ADI had developed a 1,000-page spec to submit, showing how its technology could meet Roche Diagnostics' design criteria. ADI even solved a signal impedance issue that had been a nagging problem in earlier designs. It was a convincing case, and ADI won the business. Weekly meetings continued over the next four years, as a multidisciplinary team of more than 50 ADI staff worked with Roche Diagnostics to develop the product. The ADI team combined disciplines across linear, converters, DSP, software, packaging and manufacturing, at 11 different locations. "One Roche Diagnostics executive told us that if it wasn't for the Irish accents (much of the ADI team was from Limerick), you couldn't tell who worked for ADI and who worked for Roche Diagnostics," said Riley. The system on chip (SOC) they developed, the ADuMC350, comprised functions that previously required three chips.

"The fact that we were able to win this major piece of business over a long-standing incumbent supplier at Roche Diagnostics validated our market segment organization structure as a significant competitive advantage," said O'Doherty.

Success in the Healthcare Segment and earlier in the wireless communications

Working closely with Roche Diagnostics' R&D team for more than four years, ADI developed a system on chip (SOC) solution that integrated the functions of three chips in the Accu-Chek glucose meter.



ADI transformed into a market-centric organization to provide customers with complete system solutions that cut across product groups. Vertical market segments were created to understand customer requirements and to coordinate ADI's response. Planning and profit-and-loss responsibility were shared between the product and market organizations.

sector had clearly demonstrated how ADI could not only continuously extend innovation in its traditional components business but also become a leader in innovation for systems solutions. But it would require deeper understanding of the customers of ADI's customers, as well as new competencies in system engineering and software. For the glucose meter, for example, ADI had to develop an even deeper understanding of the product's end use, including electrochemical reactions for blood analysis. That was far beyond the typical applications know-how needed for a component-level product approach. But the impact was undeniable, and the healthcare organizational experiment would be expanded.

Creating the New Analog, Again

By 2009, ADI's management was ready to take the plunge into another major reorganization. The new structure would retain innovation in the company's core products and technologies—converters, linear and RF, micro-electromechanical systems (MEMS) sensors, power management and DSP—while creating a parallel organization to integrate those technologies in five market segments: communications, industrial, consumer, healthcare and automotive.

The company also rebalanced R&D to emphasize the performance of the enterprise as well as the performance of product groups. The direct sales force would continue to have account responsibility, coordinating the interactions between the company and customers, but the market segment teams would play a greater role in coordinating interaction between the product groups. The overall goal was to move the complexity of navigating ADI's broad portfolio of products away from the customer and to more effectively coordinate ADI's experts and expertise to serve customers' needs.

Systems solutions required a different sales strategy as well. ADI's broad range of signal processing technologies gave it an advantage over many other companies when it came to design and integration. As a result, many large industrial companies like GE, Honeywell, Raytheon and Rockwell wanted to work with ADI. But these were high-level partnerships. These customers weren't buying components from a catalog. Rather, they sought a semiconductor company that would partner with them to optimize their entire system.

That meant that the choice of semiconductor supplier was now a strategic decision made by executives, not just by design engineers. That, in turn, made the sales cycle longer and more complex. Rather than quoting the speeds and feeds of technical specifications to the engineers, ADI's sales team had to explain to management how and why ADI's technology, design and integration expertise was the right choice as the heart of their product.

Fortunately, Vince Roche, who had risen through the ranks on the marketing and business development side of ADI, had the right mindset for systems development and selling. Roche had joined the company's Limerick operation in 1988 and worked his way up to the position of vice president of worldwide sales by 2001. "I'm less interested in the pieces. I'm more interested in the whole," Roche said. "When I joined ADI, I saw a very sophisticated treasure trove of pieces of technology that were very, very important to the intersection between the physical world and the digital world. I saw an opportunity to start combining the pieces together in new ways. That was a huge attraction for me."

Developing ADI's systems capability was an ongoing process. Roche fine-tuned the strategy when he was named CEO in 2013, putting even more emphasis on bringing ADI's technology to bear on specific market needs.

Particularly in communications and automotive, the semiconductor business was becoming more and more customized, Roche said. The challenge was not only to integrate technology; ADI had to be clever in partitioning so that parts of the design could be reused (and the R&D costs amortized) by more customers. Software—both within the design and as design tools—was becoming more and more important. Implementing functions by using algorithms, for example, made solutions "sticky" for individual customers while allowing ADI to repurpose the core underlying hardware in other areas. And providing rapid prototyping kits that included things like programmable gate arrays and easy-to-use design software made it easier for customers to choose ADI and more rapidly develop very complex products and product platforms.

"What we deliver outside the chip is becoming as important as what we deliver inside the chip," Roche said. "We need to provide product development scaffolding: signal chain development platforms, web-based GUIs and complementary alliances to support our customers' product evaluation and design processes."

But it remained a complex balancing act. On one hand, a large proportion of ADI sales still went to a broad mix of customers who relied on the technical superiority of its components, so ADI needed to continue to innovate in component technology. On the other hand, it needed to combine those technologies and make them easier for customers to use. "ADI has many customers, many products and many markets," Roche said. "We need to maintain ADI's diversity and yet focus it more productively. We are technology-driven, market-focused and systems-inspired."

ADI was not the only semiconductor company facing the challenge of evolving into systems solutions, Stata believed, but meeting the challenge would be the key to ADI's continued prosperity. "In the future, competitive advantage will be closely linked to how successfully companies embrace systems thinking," he said. "Combining the very different cultures of a components and a systems company into an ambidextrous organization is a huge challenge, which many semiconductor companies have not yet fully addressed." ▶

Triumph Through Transitions

Throughout its history, ADI sensed and adapted to changes in technology and markets while retaining its core innovation and creative, independent culture.

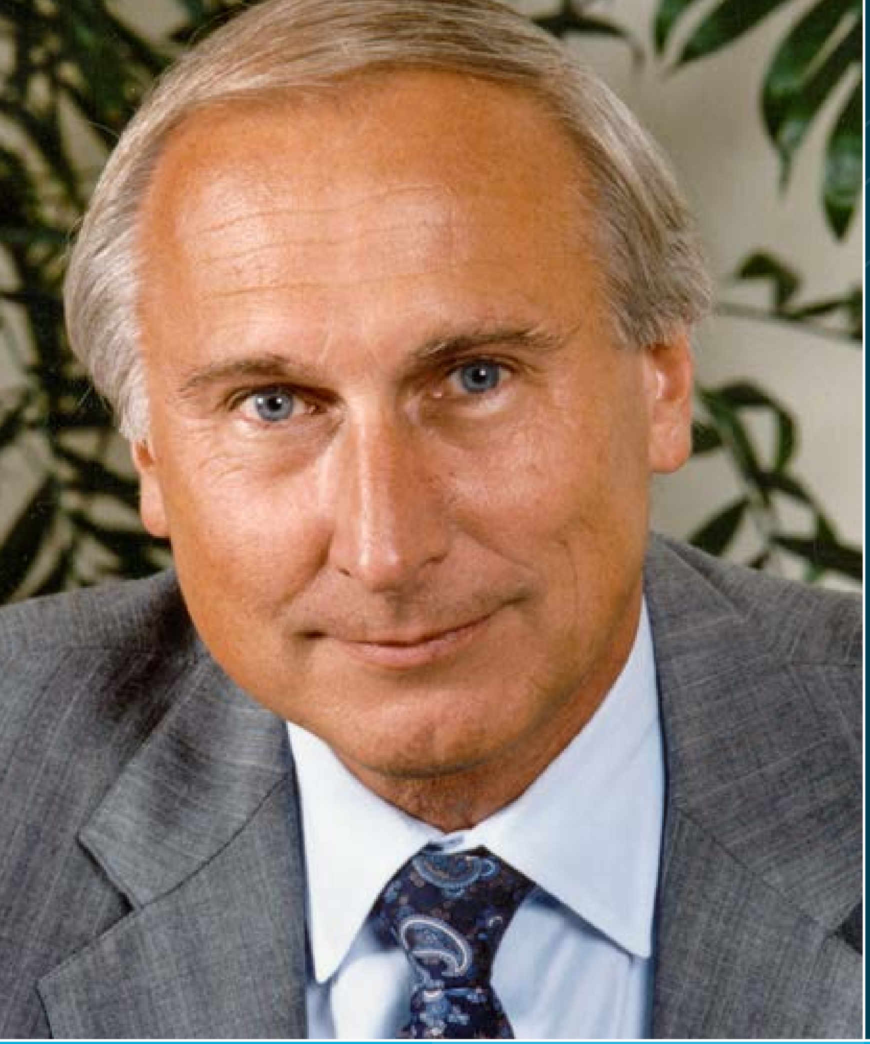
When IC technology revolutionized the nature of the electronics industry, ADI embraced it even as the module business continued to provide a path for growth and profits, especially for high-performance converter products. When new high-volume markets emerged, ADI shifted its market focus and upgraded its manufacturing capability but continued to serve established low-volume customers. When ADI's customers needed more integration, systems solutions and software, the company stepped up its game and learned new skills while continuing to innovate in process technology and circuit design.

This ability to continually learn and adapt has created a diverse, multifaceted company. Management often describes it as ambidextrous. "We are a company of 'both' and 'and,'" said CEO Vince Roche. "Both general-purpose and application-specific products, both large and small customers, both vertical and horizontal markets, both exploiting existing technology and exploring new technology, both growth and profits."

It's also both following the voice of the customer and leading customers to new possibilities. ADI listens carefully to understand customers' needs but also leads by creating new technologies and products to solve problems in ways customers never thought possible. "The best, most innovative products we've launched have been the result of collaborative innovation with our customers," Roche said. "Applying the best technologies imagined by our engineers toward solving customers' most critical challenges. We are careful to strike a balance between being customer-centric and technology-forward."

> "The best, most innovative products we've launched have been the result of collaborative innovation with our customers."
> **VINCE ROCHE**

By remaining open to new ideas, new technologies and new markets; by being willing to change its organizational structure to meet the shifting needs of both its customers and its business; and by retaining the best of the old while embracing the best of the new, ADI will continue to be a leader in the semiconductor industry for years to come.



CEO SPOTLIGHT

Stata Built an Enduring Foundation for Long-Term Success

As founder and CEO, he established ADI's core values and meritocratic corporate culture.

1934	1965	1971–1996	Since 1973
Born in Oxford, PA	Co-Founder	President	Chairman of the Board

RAY STATA co-founded ADI in 1965 and led the company through its first 30 years, a tenure attained by very few technology CEOs. Even fewer founders stay actively engaged with their companies for 50 years.

During Stata's tenure as CEO, revenue grew to $1.2 billion by 1996. In the early years, he established ADI's core values of organizational learning, innovation-driven business success, a commitment to excellence, tolerance for risk and dedication to employee welfare. Ensuring not only ADI's survival but also a thriving long-term future, Stata led the company's transition from hand-assembled transistor modules to integrated circuit semiconductor technology and guided its entry into high-volume communications and consumer markets. He also continuously pushed the company into new technologies, and from the very beginning, he oriented the company to take a global view of business opportunity.

Beginnings

Stata was born in a rural farming community southwest of Philadelphia. The family moved so frequently that before high school Stata spent every grade in a different school, including first grade in a one-room school with one teacher serving eight grades. In 1949, the family returned to their hometown of Oxford and put down roots. Attending Oxford High School gave Stata access to a library for the first time and the opportunity to participate in sports. He lettered in basketball, soccer, baseball and track. His leadership ability began to emerge, as well; he was elected class president.

As he pondered his future, Stata was certain of only two things: He would be the first in his family to attend college, and he would be his own boss. Perhaps because his father was self-employed or perhaps because of the entrepreneurial spirit he saw in the farmers around him, Stata had a strong streak of self-reliance and a desire to be in control of his destiny. The idea of someday starting his own company was already in his mind even in high school.

His interest in science led him to consider pursuing a technical career. The laws of physics came to life when Stata slammed into a wall during a basketball game. The collision injured his neck, and he spent a week in a hospital in traction. As fate would have it, an elderly man in an adjacent bed was an engineer. "It was the first time I ever talked to an engineer, so I asked him lots of questions about technology and a technical career, and especially about which were the best engineering schools." The man said Massachusetts Institute of Technology was not just the best but the only school to consider. "Set your sights on MIT," he told Stata. "You'll never regret it." When Stata left the hospital, he began to learn more about MIT and became determined to go there.

Stata won a four-year Naval Reserve Officers Training Corps (NROTC) scholarship. MIT didn't have an NROTC program, but Rensselaer Polytechnic Institute did, so he had to make a choice. "I would have never had the courage to turn down that scholarship had the old man's admonition not been ringing in my ears," he said. Fortunately, "MIT had a need-blind admissions policy. If you were willing to take on debt and work during school and the summers, you could swing it—and I did. As the old man foretold, I never regretted it."

In addition to studying science and engineering, Stata got significant exposure to the humanities. MIT required 25 percent of a student's course hours to be in humanities, with subjects including the history of Western civilization and exposure to great thinkers from Plato and Aristotle to the modern day. "These courses opened my eyes to a part of the world I knew nothing about," he said. "This experience started me on a lifelong journey of continuous learning about the nature of human beings, their aspirations and what a work environment should do to address their needs."

With the goal of starting a business after graduation, Stata took a job at Hewlett-Packard, the premier instrumentation company at that time. Stata's time at HP helped shape his views about a culture that would attract exceptional people and motivate them to achieve extraordinary results. Within four years, he launched his first startup, Solid State Instruments, with MIT peers Matt Lorber and Bill Linko. The company was sold to Kollmorgen Corporation in 1963, less than a year after its founding. Two years later, Stata and Lorber started ADI with the nest egg they received from the sale. Their idea was to participate in the emerging new market for operational amplifiers.

Management Style

In the early years, Stata and the ADI team focused on building the organization, getting products designed and manufactured, and winning customers. The values of the organization were implicit in his day-to-day interactions with employees and by the decisions taken by the company. As the company grew larger, Stata cultivated a culture that was centered on learning, innovation, excellence, a tolerance for risk and a dedication to employee success and well-being. He found that most talented people valued the opportunity to follow their instincts, to be bold and take risks without fear of failing. Stata embraced a positive view of human nature and believed that people wanted to do the best job possible and to develop to their full potential if given the encouragement and support.

Stata believed that employee satisfaction and well-being were the cornerstones for the company's success. Even after taking the company public, contrary to conventional wisdom, Stata was very clear that the path to creating stockholder value started with employee satisfaction. Talented, committed employees would drive customer satisfaction through

Stata in the Community

Stata lived the tenet of ADI's corporate philosophy "to be an asset to every community in which ADI operates by providing stable employment and supporting worthy causes." Stata contributed his time by playing a key role in promoting and improving technical education. In 1977, he was among the founders and the first president of the Massachusetts High Tech Council, a group of CEOs who worked to make Massachusetts a more attractive place for employees to live and work and for companies to grow businesses. The organization focused on improving the quality and quantity of technical graduates, strengthening ties between universities and industry, boosting the quality of science and math education in elementary and secondary schools and encouraging business-friendly government policies. In 1982, he co-authored (along with James Botkin, Dan Dimancescu and John McClellan) the book *Global Stakes: The Future of High Technology* in America, urging improvements in U.S. engineering education. Later, with the same co-authors, Stata wrote *The Innovators*, an early articulation of the impact of innovation on economic development and job creation.

Among his largest financial contributions was $25 million in 1997 to MIT for the development of the Center for Computer, Information and Intelligence Sciences, an iconic building designed by Frank Gehry. He also contributed $10 million to the Boston Symphony to name the chair for the music director.

Ray Stata presented a copy of his book *Global Stakes* to President Ronald Reagan in 1983 at a roundtable with technology executives.

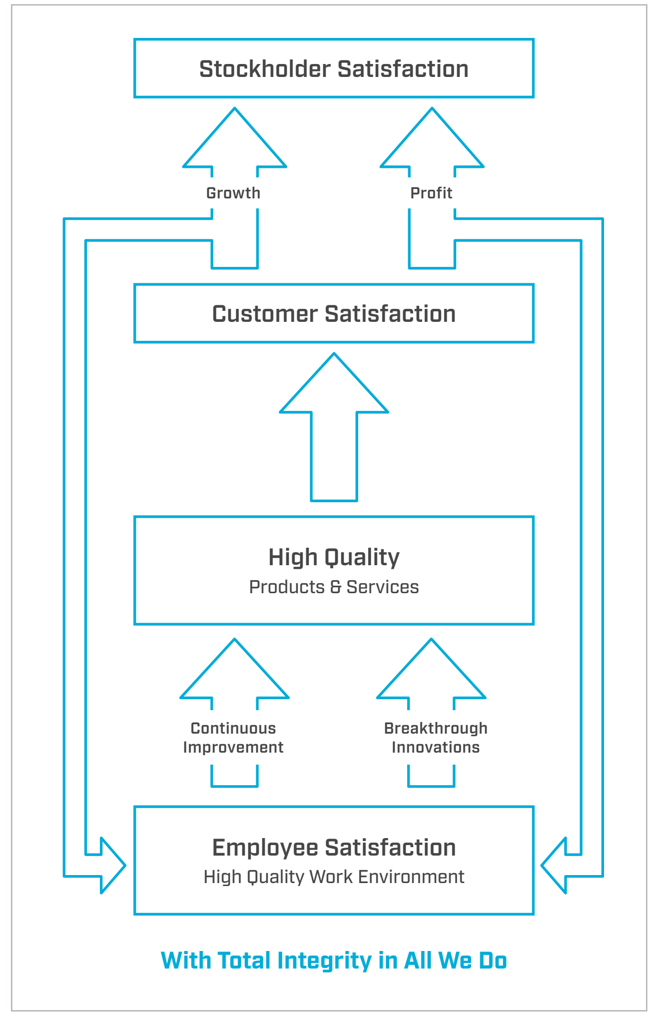
innovation and continuous improvement. Satisfied customers in turn would generate growth in sales and profits, which would create stockholder value as well as the means to share success with employees who made it possible. ADI created a work environment that attracted the best engineers, gave them the freedom to follow their muse, recognized and rewarded their contributions and honored the most outstanding innovators as Analog Fellows from whom others could learn.

Stata was sensitive to the fact that everything has life cycles—technology, products, markets and ultimately companies themselves. He saw his role as sensing the points of inflection in the environment and then motivating the organization and its leaders to respond. His goal was to create a learning organization that could adapt to change, often dramatic change, like the shift from modules to ICs. He was also an early adopter of management innovations like total quality management and systems thinking, and he continually encouraged employees to learn new skills and behaviors.

Stata's management style made for a particularly even-keeled company. When the semiconductor industry went through a particularly severe recession in the mid-'80s, ADI continued to invest in R&D, "That's largely to the credit of founder Ray Stata, who really believes—and applies—all those uplifting theories so popular in business schools about taking the long view, creating an informal, democratic culture, and putting the interests of employees and customers ahead of those of stockholders," stated a December 23, 1985, article in *Fortune* magazine.

Stata had a quiet, reserved manner and rarely if ever lost his temper. "He would get his point across if there was something that he was upset about, but I never saw him fly off the handle," said Joanna Montalbano, who was Stata's executive assistant for 27 years. He preferred asking questions to answering them, which could frustrate people trying to read him. When he did answer questions, it was with a transparency and lack of ego that was uncharacteristic of technology CEOs. "I would not represent myself as an innovator or a great engineer," he said. "But I have the entrepreneurial instincts to learn from others." "He's a shy fellow who listens a lot and doesn't like to say much about himself," the *Fortune* article said. Although ADI had made him rich, he never moved far from his roots.

Model for Analog Devices
"Being the Best"



Stata believed that employee satisfaction and well-being led to high-quality products and services, which in turn increased customer and stockholder satisfaction.

Innovation-Driven Business Success

Innovation in all areas has driven ADI's business success. That means hiring innovative people, developing and adapting innovative technology, and ensuring one has an innovative organization. All of these are woven throughout the fabric of ADI's corporate culture. The company hires the most talented engineers in the industry and retains them by providing challenging and rewarding careers. It encourages creative thinking in developing technology and products. It combines technical, process and organizational innovation to solve its customers' problems.

Hire Great People, and Stay Out of Their Way

Ray Stata's philosophy on how to run a business was simple: "I've always believed that a company's purpose was to meet the needs of people—specifically, three groups of people: employees, customers and investors." And the best way to satisfy the latter two groups was to make sure ADI did a good job with the former. To that end, ADI hired top talent and created an environment that enabled them to do great work.

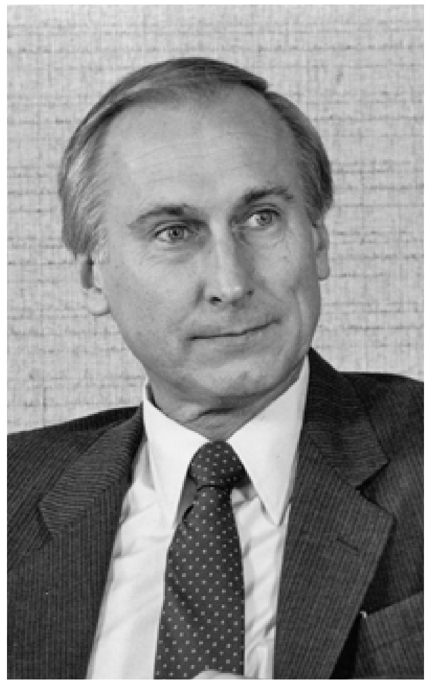
"You can't have an innovative company unless you have great innovators," said Stata.

Stata built a culture that nurtures employees, reveres and rewards engineers, and tolerates different personalities, conflicting views and constructive failures.

He believed that most people were honest and hardworking and would do their best, given the right environment. Sometimes, however, too many corporate rules and too much hierarchy stifled enthusiasm and creativity, Stata noticed. He was determined that would not happen at ADI. "Hire great people, and stay out of their way" became his motto. He built a culture that nurtures employees, reveres and rewards engineers, and tolerates different personalities, conflicting views and constructive failures.

From early on, Stata demonstrated a knack for identifying and hiring talented people.

In 1969, a California startup named Zeltex introduced modular op amps that outperformed some of ADI's key products. Stata went on the hunt to find out who was behind these designs and discovered Hank Krabbe. Stata and Mel Sallen, ADI's sales manager, flew to the West Coast to check out this pesky competitor. By the end of that trip, they had hired two of Zeltex's most valuable employees: Keith Rutherford, vice president of sales, and Krabbe, vice president of engineering. Rutherford was instrumental in building ADI's sales organization over many decades. Krabbe turned out to be one of the most valuable employees in the history of ADI.



Ray Stata pursued key innovators as a means of building an innovative company. These people had a lasting influence on ADI and the generations that followed.

ADI also hired Barrie Gilbert and Paul Brokaw, two of the best analog circuit designers in the industry. The recruitment of Gilbert shows how far Stata would go to hire great people. In 1972, Stata approached Gilbert, who had already invented the Gilbert Cell, one of the most widely used circuit architectures for modulation or mixing. Gilbert needed to stay in England to care for his ailing mother, so with Stata's backing, Gilbert set up a one-man design center in his home.

"We set up operations in my three-storied home," Gilbert said. "One upper room became a well-equipped electronics lab, another my office and layout facility. It was ADI's first remote design center." A few years later, Gilbert moved to Oregon and rejoined former employer Tektronix. But by 1979, Stata persuaded him to come back to ADI and again set up a remote design center, this time in Oregon. That eventually became ADI's Northwest Labs.

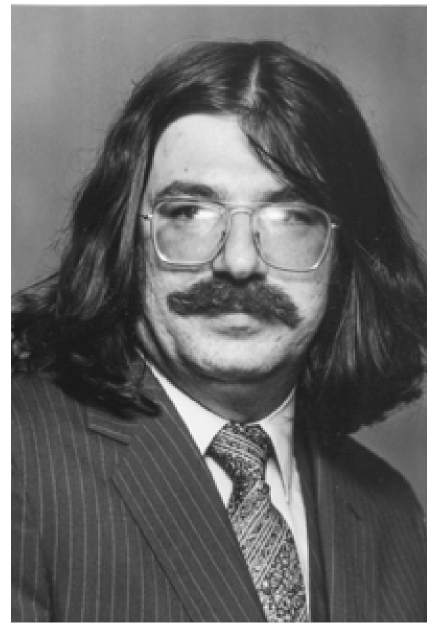
Back in Massachusetts in 1971, Mitch Maidique, who joined ADI through the acquisition of Nova Devices, brought Brokaw into the fold. Brokaw had been working as a board-level designer but wanted to learn to design ICs, so he answered a Nova Devices employment ad. Before mailing in the application, Brokaw's wife noticed that the name in the ad matched the name of the person living in the house next door in Woburn. So Brokaw walked over, knocked on the door and left his application with Maidique's wife. He got the interview, and the job. "About halfway through the interview, I realized that Paul knew a lot more about circuit design than I did," Maidique said. "I was like some minor composer interviewing Beethoven."

Talented module designers working at ADI, such as Lew Counts and Jack Memishian, soon also learned to design ICs and joined the growing ranks of world-class IC designers in Wilmington, Massachusetts.

In 1971, Maidique also hired Jerry Fishman for the marketing department. Fishman's brash and aggressive manner, somewhat atypical for ADI, caught Stata's attention. "He was the kind of person who is hard to ignore," Stata said. "He was not afraid to challenge the CEO and top management." Beneath the rough exterior, however, Stata spotted a keen intellect and insightful thinker whom he thought could help ADI navigate the future. Fishman quickly ascended the executive ladder. He was promoted to head of Analog Devices Semiconductor (ADS) Division in 1979, to group vice president in 1982, to president and COO in 1991 and to CEO in 1996.

Stata and Fishman became the yin and yang of ADI. Stata was gentlemanly and professorial. He spoke softly. He empha-

Lew Counts joined ADI in 1968 as a module designer and then transitioned to IC design in Wilmington in 1974.



Jack Memishian, hired in 1973 to design modular converters, later transferred to IC design in Wilmington.

Hank Krabbe: Renaissance Man

Hank Krabbe re-created the ADI culture at the new Limerick division and inspired the staff with his enthusiasm, charismatic personality and management style.

Both a talented engineer and a skilled leader, Hank Krabbe was among the most influential employees in ADI's history. At 6 feet 6 inches tall, he was often called "the gentle giant." But it was his larger-than-life personality that charmed nearly everyone who met him.

Krabbe grew up in Germany and immigrated to the United States as a young adult, earning an electrical engineering degree by attending night school. Stata hired him from Santa Clara-based Zeltex in 1969, and within a year, Krabbe became ADI's director of engineering. After a brief stint in Norwood, Massachusetts, Krabbe returned to California to collaborate with Micro Power to explore the use of CMOS technology for converter products. A team overseen by Krabbe designed the AD7520, the industry's first 10-bit CMOS monolithic DAC. The part became an industry standard.

Having proved the advantages of CMOS converters, Krabbe needed a CMOS fab to scale manufacturing beyond the limited capacity of Micro Power. ADI didn't have the financial resources to build another fab, so Krabbe negotiated a deal with the Industrial Development Agency (IDA Ireland) to fund the first IC fab in Ireland. With a small team of engineers, he moved to Ireland to build the facility and the business. "Consider the challenge of setting up this multifaceted project in a country that had no wafer fabrication engineers, no IC designers and no professionals skilled in marketing semiconductors," said Pat Cunneen, the first Irish employee, who was hired as human resources manager in 1976. "This was a country where even the technical community spelled MOS with two S's."

Krabbe inspired the Limerick staff with his enthusiasm, charismatic personality and management style. He re-created the ADI culture at the new division; there was little hierarchy. "It was very pluralist, very open," Cunneen said. Krabbe worked closely with the newly established National Institute of Higher Education (later renamed the University of Limerick) to develop courses that would help educate and train engineering talent for the new facility. He helped develop the curriculum, supervised projects and tutored students. In 1998, the university conferred upon him an honorary doctorate degree.

Krabbe also designed circuits. When the facility was being built, government inspectors requested a special process monitor circuit be made as a part of the approval of its fabrication process. "It normally takes several months to design such a circuit, but Hank could not wait that long," a publication by the University of Limerick reported. "After the inspectors left the factory on Friday afternoon, Hank went home and arrived at the factory early on Monday morning with a completed design. The inspectors who returned later in the week were dumbfounded."

Krabbe was proud of his contribution to building the Limerick operation. "The odds were pretty much stacked against us, and it was a hell of a lot of work," Krabbe said. "But it was also extremely rewarding."

In 1979, Krabbe returned to the United States. The following year, he worked in Greensboro, North Carolina, with the recently acquired Computer Labs. He then became vice president of new business development, responsible for investigating and defining new business opportunities. He started the DSP Division and was its first general manager.

Krabbe retired in 1989. "It's difficult to imagine what ADI would be like today without the many significant contributions Hank made during his 20 years at Analog," Stata said.

After Krabbe's death in 2008, ADI established a scholarship fund in his honor at the University of Limerick.

sized bold, innovative engineering and risk-taking. Fishman was blunt and demanding. He swore. He emphasized operational excellence, the bottom line and profits. The men argued often, but it was nearly always a constructive dialogue that produced good decisions for the company. Moreover, they modeled the kind of free thinking, open expression and constructive criticism that was encouraged throughout the company.

Jerry Fishman and Ray Stata became the yin and yang of the company.

"It's OK to Be a Rebel"

Individual freedom and autonomy were key ingredients for ADI, Stata believed. "The importance of the individual and the freedom to make decisions and to take initiatives at the local level is a cornerstone of our value system," he said. "It is individuals who think and act, who create and lead, who add value and make improvements." Stata wanted to make sure that the management style would not unnecessarily inhibit individuals. Although ADI had a management structure, in practice there was little hierarchy. In fact, Stata initially prohibited the publication of organization charts because he thought they oversimplified how a company actually operated, particularly when the company was small.

In 1989, for example, new hire Ira Moskowitz was astonished when he could find no organization chart. "I had just started my job at ADI, and I asked somebody for an org chart because I wanted to understand how the company worked. But there was none. It didn't exist." Moskowitz, who eventually became vice president of manufacturing for North America, had previously worked at a large, bureaucratic technology company. Every time he asked someone to explain ADI's organization, they would draw something on a whiteboard that looked more like a network diagram than an org chart.

Employees were encouraged to think creatively and take reasonable risks rather than censor themselves for fear of punishment. "We place more emphasis on developing people's judgment than on enforcing rules and regulations," Stata told employees during one orientation. In practice, that meant employees were not afraid to speak their minds and engage in healthy debate at all levels.

Ira Moskowitz, who joined ADI from a large tech firm, was pleasantly surprised by ADI's emphasis on individual autonomy and lack of bureaucracy.

"There is an unusual degree of freedom and an understanding that it's OK to be a rebel," said Gilbert, no shrinking violet in expressing and defending his opinion. Employees never out-and-out rebelled, but they sometimes followed directions somewhat selectively, achieving technical breakthroughs by following their own instincts. "The trick was always to look for product ideas that nobody even thought possible, then pursue them relentlessly regardless of what others believed," said Gilbert. "Naysayers would be politely but firmly ignored."

Often, engineers intuitively anticipated what customers needed before the customers themselves knew they needed it. Mike Timko, who joined ADI in 1970, had an idea for a temperature sensor design that would be much simpler than other ways of measuring temperature, such as thermocouples,

The ADI Philosophy

In the late '70s, ADI published two documents that spelled out Ray Stata's ideas about the purpose of the company and its policies. Titled *Human Resource Philosophy* and *The Corporate Objective*, the booklets encapsulated key parts of ADI's culture.

"At ADI, we view business as a human process, the ultimate goal of which is to satisfy the needs and aspirations of the people associated with the firm—primarily our employees, our customers and our stockholders," Stata wrote.

Key human resources beliefs

- People are honest and trustworthy. They are most satisfied when working to their fullest potential and want to be held accountable.
- People learn and develop judgment by making mistakes and will run the risk of being wrong if they know that a reasonable level of mistakes is considered natural and healthy.
- Individual judgment is generally more reliable than rules and regulations.
- ADI stresses individual freedom and autonomy. It welcomes discussion and tolerates conflict when goals are being developed, but once agreed to, it expects individuals to support these goals.
- The success of the company depends on its ability to attract capable and talented people. The emphasis is on promotion from within.
- In order to encourage technical staff to fully develop their careers, ADI provides opportunity, recognition and rewards commensurate with those in management.

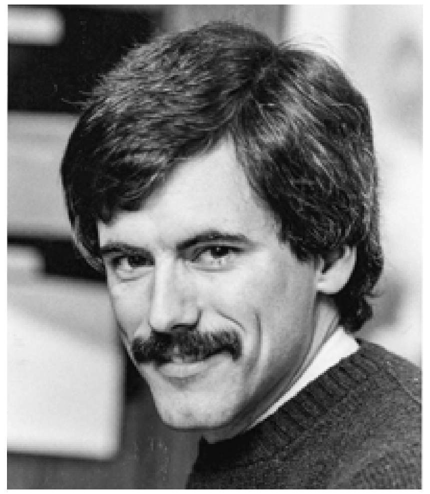
Key corporate objectives

- To search continuously for opportunities to make unique or valuable contributions to the development and application of analog and digital signal processing technology.
- To share the company's success with its employees.
- To work hard to understand customers' businesses so that ADI can anticipate customer needs and enhance their effectiveness.
- To provide for stockholders a secure and liquid investment with an attractive rate of return.
- To treat suppliers as partners in ADI's effort to fulfill customer needs. As such, ADI should be open and frank about its plans as they affect suppliers.
- To be an asset to every community in which ADI operates by providing stable employment and supporting worthy causes.
- To be the best at what we do individually and collectively and thus obtain the largest market share in every market segment ADI serves.
- To dependably deliver high-quality products and services to ensure customer satisfaction.
- To continuously improve quality in every area of the company, including marketing, customer service, finance, human resources, manufacturing and engineering.

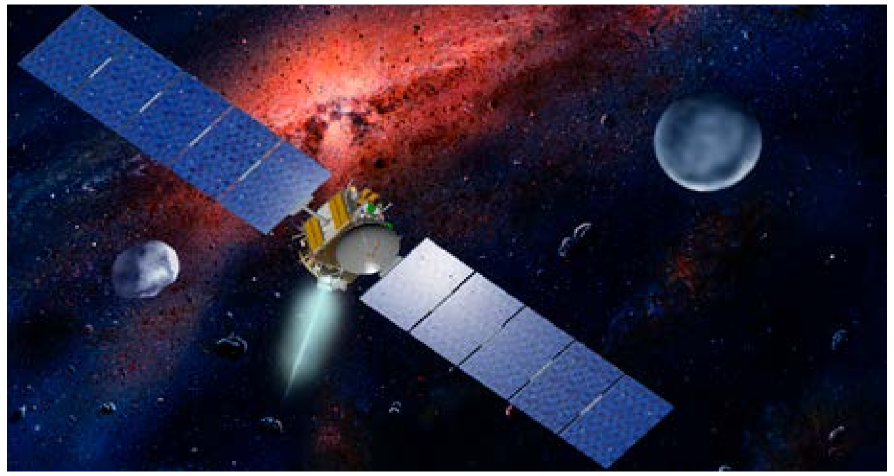
thermistors and resistance temperature devices (RTDs). He showed the design to Maidique, who said to drop it. "He said the company was still trying to figure out how to sell op amps," Timko recalled. "He thought we couldn't afford to spend any marketing time learning how to sell temperature sensors, which were a totally different market."

Timko, who was drafted during the Vietnam War, kept noodling on the idea while in the service. When he returned to ADI several years later, he found that his new boss, Paul Brokaw, had independently come up with a similar idea. Together, the two approached marketing once again with the idea but were told that there was no customer demand for such a part.

Convinced the idea had merit, Brokaw and Timko developed the sensor as a skunk works project. When a competitor introduced a three-terminal thermometer, Timko and Brokaw suddenly got funding to move the project to the front



ADI Fellow Mike Timko, pictured, and Paul Brokaw kept working on the AD590 temperature sensor as a skunk works project despite a lack of enthusiasm from marketing.



NASA used the AD590 in the Dawn space probe and many other missions.

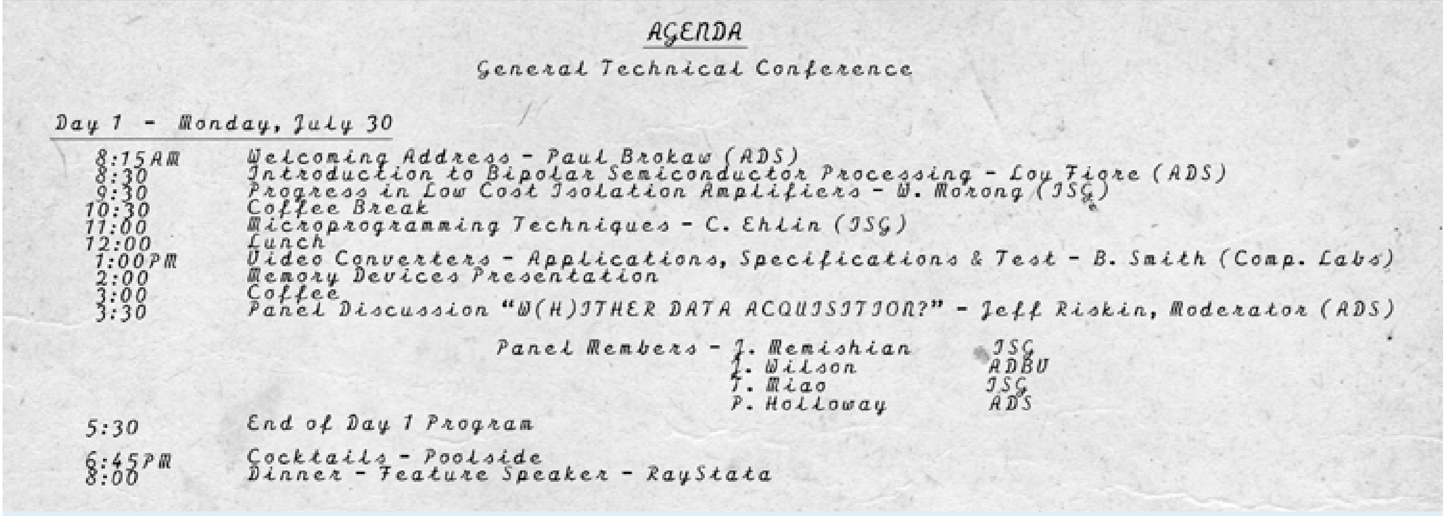
burner. The advertisement for the part was written by none other than Fishman, who shared an office with Brokaw. Introduced in 1977, the AD590 temperature sensor was an immediate hit. Its simplicity and ruggedness led NASA to use the part in countless spacecraft, including missions to Mars. More recently, the AD590 was used in the Dawn spacecraft that orbited the dwarf planet Ceres. As of 2015, 38 years after its introduction, the AD590 had cumulative revenues above $300 million and was still selling.

The AD590 was an early example of how ADI's culture led to prescient innovation. The attitude of asking "what if?" continued as a strong thread in ADI culture. Engineers listened carefully to customer requests but also tried to move beyond them to propose solutions that customers might not have believed possible. Engineers were constantly imagining what ADI technology was not only doing then, but what it could do in the future.

In the late '70s, designer Peter Holloway was working on something he called a DACport. He envisioned a digital-to-analog converter (DAC) with a microprocessor interface that would make it easy for digital engineers to incorporate converters in their designs. There was a great deal of resistance from managers, who didn't think there was a market. "I disagreed," Holloway said. He secretly kept at it. It wasn't out of disrespect, Holloway noted. Rather, the culture encouraged people to have the courage of their convictions, a courage that Stata himself exemplified. "I would have never taken such a strong position if Ray hadn't shown that same quality when he stood up to the board and invested in Nova Devices," Holloway said. "The environment encouraged people to stick their neck out. If you lost, you lost, but you got to play another day. If you won, great things happened."

In fact, the DACport, officially named AD558, became quite popular. "People hadn't realized how much of a barrier there was to incorporating analog-intensive ICs into digital systems," Holloway said. The part went on to be featured in an *Electronic Engineering Times* article that showcased products

GTC: A Celebration of Innovation and Learning



AGENDA

General Technical Conference

Day 1 - Monday, July 30

8:15AM	Welcoming Address - Paul Brokaw (ADS)
8:30	Introduction to Bipolar Semiconductor Processing - Lou Fiore (ADS)
9:30	Progress in Low Cost Isolation Amplifiers - W. Morong (ISG)
10:30	Coffee Break
11:00	Microprogramming Techniques - C. Ehlin (ISG)
12:00	Lunch
1:00PM	Video Converters - Applications, Specifications & Test - B. Smith (Comp. Labs)
2:00	Memory Devices Presentation
3:00	Coffee
3:30	Panel Discussion "W(H)ITHER DATA ACQUISITION?" - Jeff Riskin, Moderator (ADS)
	Panel Members - J. Memishian ISG J. Wilson ADBU T. Miao ISG P. Holloway ADS
5:30	End of Day 1 Program
6:45PM	Cocktails - Poolside
8:00	Dinner - Feature Speaker - Ray Stata

The Day 1 agenda for the first GTC.

The technical highlight of the year at ADI is the General Technical Conference (GTC), an internal conference for engineers throughout the company. The conference has become a celebration of ADI innovation, which emphasizes interaction and learning.

The first GTC took place in 1979 and was organized by Paul Brokaw, Jack Memishian, Phil Burton, Jody Lapham and Ivar Wold. It was held at the Sheraton Boxborough Hotel in Massachusetts and drew 100 attendees. The main presentation room was an indoor tennis court. Presenters were encouraged to use overhead transparencies rather than 35 mm slides. The transparencies could be projected onto the wall and scribbled upon with wax pencils as the presenter explained his design.

By 2015, attendance had grown to more than 2,000. The conference included multiple tracks for presentation of technical papers, poster sessions, roundtable discussions, design workshops and product demonstrations. The event was videotaped and archived for access by those who could not attend. ADI's CEO typically delivered an opening address on the first day. The CTO gave the closing address. Other company executives also speak about the company's accomplishments and challenges.

The event became a platform from which to announce new ADI Fellows and to bestow awards for patents granted. Starting in 2015, it also featured the "Ahead of What's Possible" awards, given to teams who had come up with a breakthrough technology or product that captured system-level value and extreme competitive advantage for ADI. Winning teams' work contributed demonstrably to profitable growth for the company, created a differentiated experience for customers and improved quality of life.

The GTC often hosted an outside speaker at its main banquet. Speakers have included Lester Thurow (1989), an economist and former dean of the MIT Sloan School of Management; Carver Mead (1996), a pioneering engineer in VLSI circuit design and education; Tim Berners-Lee (2001), credited with inventing the World Wide Web; Robert Langer (2014), a pioneer in the biomedical field; and Morris Chang (2015), chairman and founder of Taiwan Semiconductor Manufacturing Company.

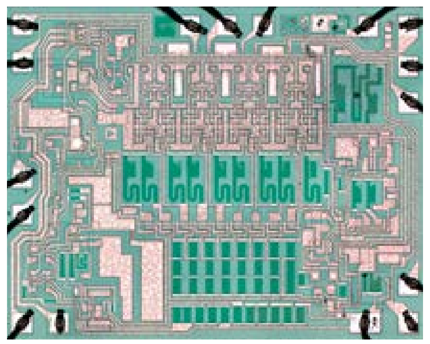
Learning and sharing remained at the center of the GTC. Over the years, in addition to the technical paper presentations, the conference incorporated a vast array of interactive activities. In 2015, there were more the 70 hands-on demonstrations of products, ideas and tools. GTC 2015 also hosted the first ADI Technical University sessions. These sessions were designed to increase continuous learning within the ADI engineering community by creating, identifying and promoting engineering engagement.

Peter Holloway, shown here on the bottom right with the AD558 design team, joined ADI in 1974. The company's culture encouraged him to continue developing the AD558 in spite of management resistance.

its editors thought would be launching pads for future innovation.

The same culture existed in Limerick. The predominant attitude was: It's better to ask for forgiveness than permission. In 1984, ADI was constructing a second building at the Limerick site. There were no plans for a second fab, but two Limerick executives, Pat Quinn and Rob Marshall, hoped that someday there would be. Without telling management in the United States, Quinn and Marshall specified that a basement should be included in the new building. A basement would be needed if a second fab were built, according to Eamon Ryan, who joined ADI in 1981 and became director of Limerick manufacturing operations. Within a year, ADI decided to build a new fab in Limerick. The fact that the building already had a basement saved six to nine months of permitting and construction time, Ryan said.

New hires were often impressed by the amount of freedom and latitude they



The AD558 DACport achieved instant popularity after its launch in 1980.

were given, even if it was their first job out of school. "The engineer is king here," said Tracy Keough, head of human resources from 2003 to 2006. "Young engineers get a tremendous amount of responsibility at a very young age. They feel like they will have a chance to innovate."

Chris Mangelsdorf, who was hired in 1984 while still working on his Ph.D. at MIT, tasted that freedom. "They gave me a lot of space," he said. "Initially, my boss wanted me to work on amplifiers, but I was obsessed with converters." So he was allowed to hand off the amplifier work to another designer. "They let me thrash around and work on all kinds of creative stuff. I was really surprised."

Recruiting newly minted Ph.D.s, as well as graduates and undergraduates studying engineering, math and science, fueled the company's talent pipeline. While these recruits were first attracted by ADI's reputation and the opportunity to learn alongside many of the industry's leading innovators, it was the environment that kept them at ADI, oftentimes for their entire careers. This environment allowed independence and freedom but balanced it with collaboration. Working at ADI meant solving complex problems that were interesting and challenging, and that advanced science and technology. Engineers could experiment and explore in ways that not only satisfied customers but sometimes amazed them.

Stata's philosophy, combined with the fact that different divisions of the company were run independently during ADI's first 25 years, created a confederacy of innovation, according to Dave Robertson. "ADI never had a central research group," he said. Instead, different people in different parts of the company were free to develop their own ideas. The result was the kind of bottom-up engineering that allowed small, agile teams to develop technologies and applications without a lot of top-down approvals.

Elevating Engineers: The Parallel Ladder

The company's success depended on creative technical minds. However, as the company grew, engineers moving up the ladder frequently accumulated managerial responsibility by default, whether they wanted it or not. This aspect of the corporate organization frustrated those who wanted to continue to focus on their creative technical work.

Brokaw, in fact, nearly left the company because of it. When he complained about not getting enough layout resources, Maidique made him manager of the emergent layout department. When Brokaw said ADI needed to focus on developing more new products and not just improving existing ones, Maidique made him head of that effort. Before long, Brokaw had wafer test and trim reporting to him as well. Managing people took up all his time when what he really wanted was to design circuits. He planned to leave ADI and told Maidique so.

However, since Brokaw didn't have another job lined up, he agreed to stay long enough to hand off his responsibilities in an orderly way. Maidique hired a managerial replacement, and Brokaw transferred the management work. Then he decided to stay a bit longer to finish up some of his design projects. The result: "I just never got around to leaving," Brokaw said. He was back doing the type of work that he enjoyed and was best at.

To reduce the risk of losing such talented engineers, Stata created a parallel ladder program in 1978. The program was designed to give engineers the option to continue as individual contributors rather than having to go into management in order to progress in responsibility, stature and pay. The parallel track meant engineers could keep doing what they did best—innovating, developing professionally and increasing their technical contributions to the company—without penalty.

To recognize the most creative engineers, the company established the ADI Fellows program. It was the top rung of the technical ladder, constituting less than 1 percent of all ADI engineers. Fellows, through their accomplishments, earned respect and status in the company and were allowed more freedom to follow

Criteria for ADI Fellows

Current Fellows are responsible for electing new Fellows based on two primary criteria, while taking into account a number of secondary factors. The chairman and the CEO make the final choice. *For a full list of ADI Fellows, see page 166.*

Primary criteria

Innovator: Accomplished in creating and marrying new technology to market opportunity to generate substantial growth potential. The technical contribution brings new and innovative ideas, resulting in a product that defines the state of the art.

Revenue Contributor: Has been a leader in creating products that result in substantial revenue and profits for ADI.

Secondary criteria

Mentor: Recruits and develops talent.

Entrepreneur: Generates or brings together ideas and resources that result in new business and product opportunities.

Consultant: Helps others outside of his or her area of responsibility to solve difficult technical problems.

Engineering Manager: Directs and develops a small engineering staff based on knowledge and expertise in a specific technical area.

Organizational Bridge: Takes initiative to cross organizational lines to transfer technology and ideas and to stimulate cooperation between different groups.

Teacher: Keeps abreast of evolving technical knowledge and teaches others.

Publisher: Has a successful record in writing and publishing technical articles and presenting at industry conferences.

Gatekeeper: Brings important new ideas into the company and forges strong relationships with industry researchers, educators and consultants.

Ambassador: Represents the company on industry, education and community committees.

their muse. Managers were expected to honor the status of Fellows. "We wanted Fellows to be empowered to speak up and be heard for their personal views and as representatives of the technical community," said Stata.

In 1978, Stata named Brokaw and Gilbert as the first two Fellows. Through the program, ADI recognized and rewarded engineers not only for breakthrough ideas but also for the commercial success of products based on these ideas. These two requirements for promotion to Fellow were spelled out explicitly. (See criteria for ADI Fellows, page 65.)

Being named a Fellow was a recognition of past achievements, yet Fellows could not sit back and relax. They were expected to serve as role models for the type of innovation that made ADI successful. They were expected to continue to advance the technical frontier, deliver superior products and enhance their contribution to the company in other ways, such as mentoring younger engineers. Although there was no specific job description for Fellows, "you've proven yourself capable of doing some pretty unusual work," Gilbert said. "So you are expected to inculcate those around you with the same skills that have helped you."

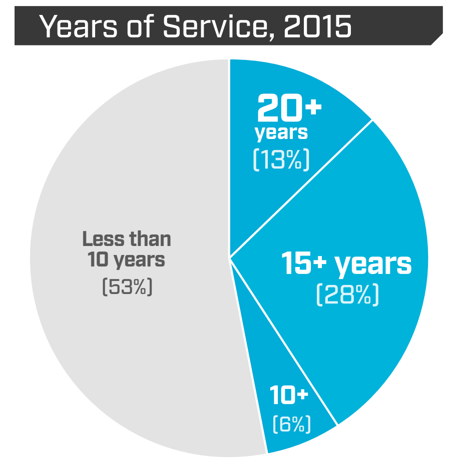
Stata hoped that the Fellows would play a significant role in the technical guidance of the company, and they did so by their individual insights and influence. But Fellows rarely reached consensus. Instead, they became known for their strong opinions and lively debates. As a group, they exemplified the tolerance of free thinking, even contrariness, inherent in ADI culture. "There's recognition that high levels of creativity and eccentricity sometimes go hand in hand," said Bob Adams, himself a Fellow. "If we were not willing to embrace a wide range of different personality styles, we probably wouldn't have a very creative company."

ADI's record of hiring and retaining top engineers created a virtuous cycle. ADI developed a reputation as a great place for engineers to work. Analog pioneers like Gilbert, Brokaw, Memishian, Counts, Timko and the many others who followed drew younger engineers who wanted to learn from the analog masters.

More Than a Job, a Career

The company's reputation spread across the industry, not only in the engineering community. When Bill Matson was considering joining ADI as vice president of human resources in 2006, he applied his due diligence. "I found that ADI was considered the gold standard when a customer was trying to do something difficult," he said. One top semiconductor executive "waxed eloquently about the things that he had seen from Analog Devices, how sticky the technology was and what a great reputation the company had."

Employees often stayed at ADI for decades. Of the 9,000 people ADI employed worldwide in 2015, 47 percent had been with the company more than 10 years, 28 percent for more than 15 years, 13 percent for more than 20 years and a dozen for 40 or more years.



Employees stay at ADI for many years, some even their entire careers.

In a 2015 survey, 88 percent of employees said they were proud to work at ADI and would recommend it as a good place to work. "Such numbers were unheard of," Matson said. "These numbers showed that this was just a very different, very special place."

ADI's ability to hire great people, nurture their creativity and development, appreciate their innovative thinking, and reward their good work became more and more important. "We've always attracted people over the years who want to do extraordinary things," said Vince Roche in a 2013 GTC speech. "What's more, customers increasingly want more direct interaction with ADI's engineers. They want ADI to become partners in their designs. The increasing frequency and intensity of engineering interactions bodes well for us as we bring to bear the full breadth of our technology and expertise to solve our customers' toughest challenges."

Two ADI Engineers Who Defined the Industry

ADI hired two analog pioneers early in its history: Paul Brokaw in 1971 and Barrie Gilbert in 1972.

Paul Brokaw became famous for inventing the Brokaw bandgap reference. "In the old days, if you wanted a voltage reference, you had to come up with at least 7 volts that would light up a zener," Brokaw said. That meant a lot of power overhead, which could be a problem when making low-voltage regulators.

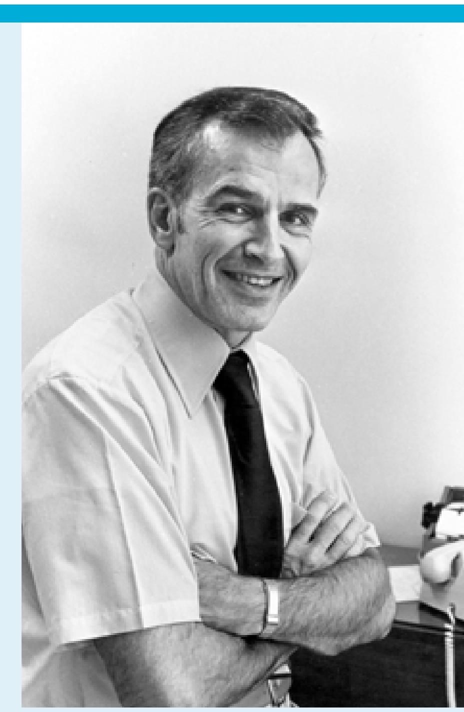
Brokaw had heard analog pioneer Bob Widlar describe a bandgap reference at a seminar, so he decided to try to design a simpler one. The result was a two-transistor bandgap circuit with an output voltage of around 1.25 volts with extremely low drift over a wide range of temperature.

The first in a long series of products to use the Brokaw bandgap was the AD580, which became an industry standard. It remains firmly seated in the ADI catalog, which offers among the broadest range of voltage references in the industry. Beyond that, the Brokaw cell was embedded in countless ADI products (and those of other companies throughout the industry) and is found in every textbook on IC analog design principles.

A Life Fellow of the Institute of Electrical and Electronics Engineers (IEEE) with over 100 patents, Brokaw made many contributions to the industry and to ADI. Several notable product achievements that were the first of their kind include the AD590 2-terminal temperature transducer, the AD571 (8-bit) and AD573 (10-bit) analog-to-digital converters (ADCs), the AD22100 voltage output temperature sensor with signal conditioning, and the AD594/595 thermocouple amplifiers with cold-junction compensation.

Barrie Gilbert became famous for the Gilbert Mixer, a linearization technique used in all sorts of communications systems, including base stations and cellphones. The mixer is actually a class of versatile cell topologies used as basic analog function blocks based on the translinear principle, which was discovered and popularized by Gilbert.

The Gilbert Mixer became one of the most widely cited inventions in the electronics industry, with billions of this mixer circuit in use. At ADI, Gilbert's considerable contributions included the industry's first high-performance analog IC multiplier, the AD534; the first RMS to DC converters, the AD536 and AD636; the first multistage, RF logarithmic amplifier, the AD640; the first voltage-to-frequency converter, the AD537; and numerous other seminal integrated circuit products for which Gilbert, a Life Fellow of the IEEE, received more than 100 patents.



Paul Brokaw was working on board designs when he answered a Nova Devices ad for an IC designer in 1971.

Barrie Gilbert initially worked out of his home in England and then later moved to Oregon and established what eventually became ADI's Northwest Labs.

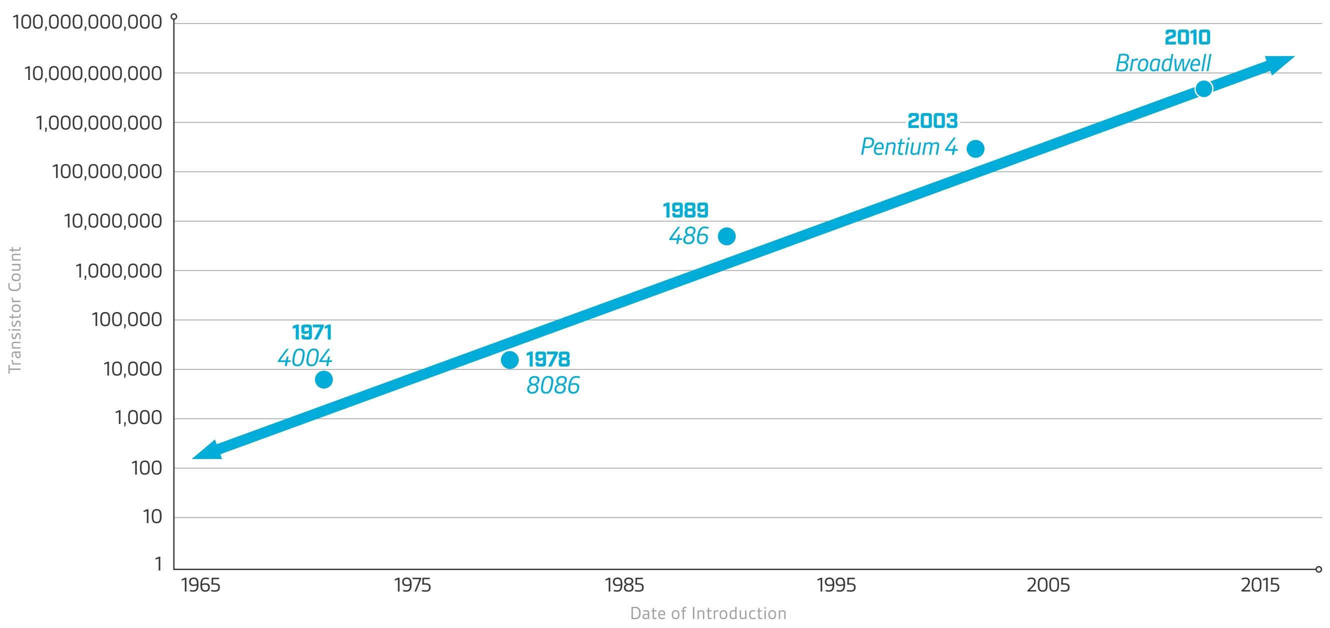
Push the Limits of Process Technology and Manufacturing

Through a combination of talented engineers, skilled managers, dedicated employees and dogged persistence, ADI became a semiconductor innovator, developing its own circuits, proprietary process technologies, manufacturing advances, design software and packaging.

When Moore's Law began to dictate pace across much of the semiconductor industry, the company figured out how to take advantage of what the law offered, while never abandoning its own analog process development. That combination provided the company with the best of both worlds. With its own processes, ADI offered products with performance advantages difficult for other companies to match. Through its partnership with the largest foundry in the world, it leveraged the benefits of Moore's Law.

Moore's Law predicted that the number of transistors per chip for digital complementary metal oxide semiconductor (CMOS) would double every 18 to 24 months. By focusing both commercial and government research on industry-standard digital CMOS process technology, as well as standard design tools and test equipment, the semiconductor industry continuously reduced cost, lowered power consumption, increased operating speeds, and expanded the capability to design and manufacture ever more complex chips. For example, by 2015—the 50th anniversary of Moore's Law—one of Intel's processors contained multiple cores and over 5.5 billion transistors.

Microprocessor Transistor Counts & Moore's Law



In 1965, Intel co-founder Gordon Moore predicted that the number of transistors in an integrated circuit would double every two years. Moore's prediction became a self-fulfilling prophecy that has driven technological breakthroughs for more than 50 years.

However, Moore's Law applied exclusively to digital CMOS. ADI initially exploited the increased digital CMOS transistor density to reduce cost and improve performance in digital signal processors (DSP). But the benefits of Moore's Law to ADI's high-performance analog strategy were somewhat limited: Some aspects of analog circuit performance actually degraded as transistors got smaller. In addition, unlike digital circuits, which could be manufactured on the same process technology, the application requirements for analog circuits were so varied that no single process technology was adequate. In fact, many analog companies, including ADI, exploited various process technology recipes in hundreds of combinations and flows to differentiate their products and domains of applications.

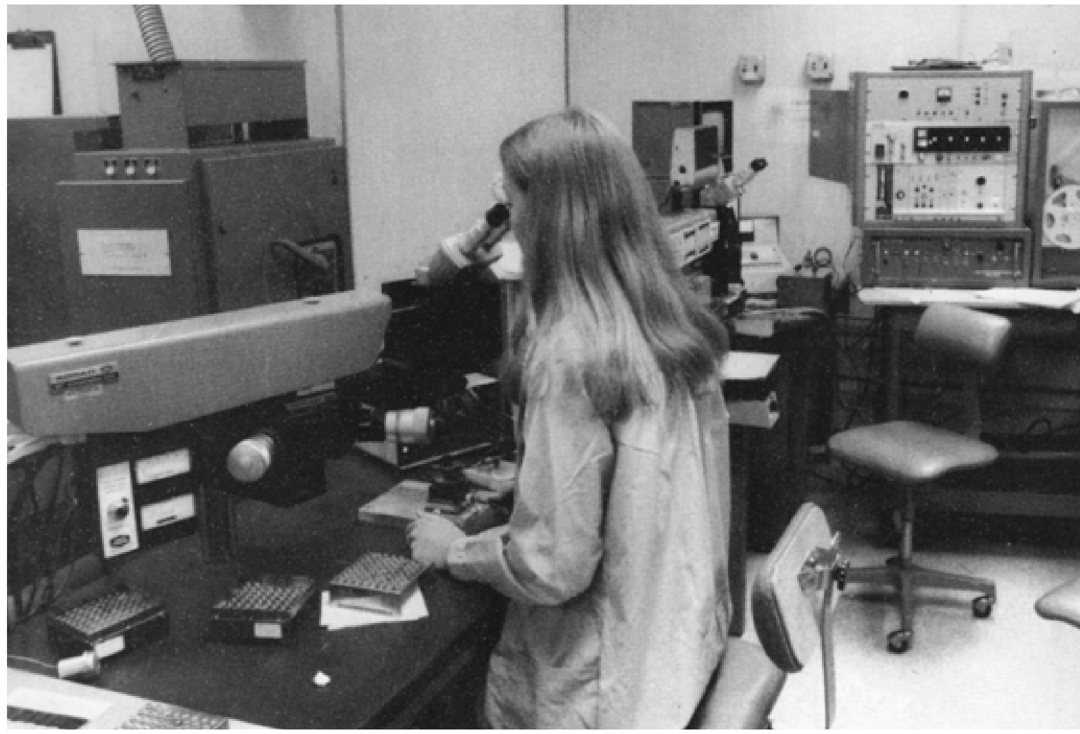
Over the years, ADI developed a range of process technologies that few semiconductor suppliers could match, from variations and combinations of bipolar, CMOS, radio frequency (RF) and microelectromechanical systems (MEMS) to exotic processes that could fabricate chip-scale transformers for isolation amplifiers. But the cost structure of devices manufactured using these internal, fragmented, low-volume processes was too high for the consumer, computer and communications markets that ADI entered in the '90s. The challenge was to learn how to leverage digital CMOS processes used in foundries, where unit volumes were much higher and unit costs much lower than ADI's fabs. This was achieved in large part by collaborating with Taiwan Semiconductor Manufacturing Company (TSMC) to modify its process slightly to produce analog CMOS and, later, BiCMOS processes using silicon-germanium and insulating substrates.

Early Process Technologies

Nova Devices, acquired by ADI in 1971, began by adapting existing bipolar processes in Wilmington, Massachusetts. There, Nova Devices developed thin-film resistor technology, which was substituted for diffused resistors in the bipolar processes. Thin-film resistor technology provided stable precision resistors for applications requiring very high accuracy. ADI engineers soon figured out how to actively laser-trim these thin-film resistors on the wafer. This capability enabled ADI to become a leader in both high-performance op amps and converters. ADI designers and process engineers improved the bipolar processes by working hand in glove, tweaking processes to meet a particular set of application requirements. This led to a proliferation of recipes and process flows, very much different from rigidly standardized digital CMOS processes.

Bipolar was well-suited to op amps and other analog circuits, enabling ADI to develop some of the highest-speed, highest-accuracy analog products of the day. However, as ADI's product portfolio expanded into converter ICs, it bumped up against the limits of bipolar technology, which was not well suited for switching and logic circuits required in converters. For those, CMOS technology was more promising.

To explore the use of CMOS technology for converters, ADI struck a joint venture



In the early 1970s, ADI developed technology to actively laser-trim thin-film resistors on the wafer, providing customers with stable precision resistors.

In early op amps modules, operators manually selected and trimmed resistors to reduce voltage offset during the manufacturing process. With ICs, this trimming was done automatically using lasers.

with Micro Power Systems. The CMOS process for converters was modified from CMOS for digital circuits. Among other things, it required higher operating voltages and the incorporation of thin-film resistors that, like analog circuits, were laser-trimmed to achieve the required accuracy. The plan was to develop the technology and then transfer it to a new fab that ADI was building in Limerick, led by Hank Krabbe and a team of five engineers from California.

"The challenge was to figure out how ADI could exploit CMOS technology, first for converter ICs but eventually for other mixed-signal ICs as well," said Ray Stata.

Calling the Irish venture a challenge was an understatement. ADI knew little about CMOS technology. It was starting a fab in a country with virtually no experience in IC technology or manufacturing. The Limerick team struggled to get an early 12-micron CMOS process to work on 3-inch wafers. Ralph Eckels, a process engineer from Micro Power, set up the process relying on memory and "essentially some cryptic notes," said Dennis Dempsey, who was hired in 1977 in Limerick. "There was no structure to it. There was no documentation. . . . It was just horrendous." The team struggled for months, trying to get decent yields on some of the industry's first CMOS converters.

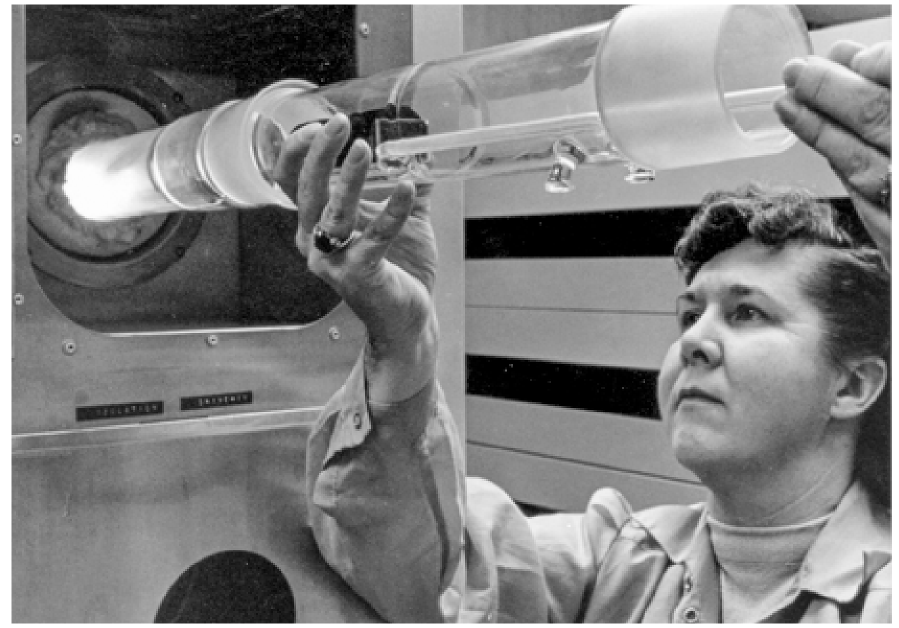
When Krabbe hired Europeans with semiconductor experience, notably Tom Urwin (a British national with experience at a Signetics fab in Scotland and a Philips fab in the Netherlands) and Pat Quinn (a Scotsman with experience at the Signetics fab), things began to turn around. Urwin was rather shocked to see the manufacturing shortcomings. "Those early days were a bit unnerving," he said. Even after 18 months, Limerick didn't have a fully developed and repeatable process. The beloved Krabbe had many great qualities, "but manufacturing really wasn't his thing," said Barry Macken, who was hired by Krabbe in 1977. "When Tom Urwin and Pat Quinn arrived, manufacturing became a big deal." Soon the Limerick team mastered the CMOS process and continued to improve the performance and feature size steadily over time.

Tom Urwin (left) and Barry Macken joined ADI's operation in Limerick and the quest to build high-performance converters using CMOS process technology.

The Emergence of BiCMOS

It turned out that neither bipolar nor CMOS processes alone were adequate to manufacture more accurate and more integrated converters. Both were needed: bipolar for the analog input/output circuits, and CMOS for logic functions and interfaces with the microprocessors and other digital circuits that were becoming more and more prevalent.

So it wasn't long before ADI fabs on both sides of the pond started combining bipolar and CMOS into processes generically called BiCMOS. At that point in ADI history, strong competition between the two fabs for both resources and converter



A fab technician in the Analog Semiconductor Division in Wilmington loads 2-inch wafers into the diffusion furnace, circa 1970s.

Laser-Trimming: A Unique ADI Core Competence

One of ADI's first process innovations was the development of laser-trimmed thin-film resistor technology to reduce voltage offset and drift over temperature.

In the early days, when ADI made modular op amps, the company manually matched the characteristics of discrete transistors and manually selected resistors during the manufacturing process to reduce voltage offset and drift over temperature. The need to adjust resistor values became even more important as the company moved into ICs and converters. In the early 1970s, ADI improved on a thin-film silicon chromium resistor material developed by Micro Power and started using lasers to adjust the value of the thin-film resistors incorporated in the silicon circuit design.

Initially, ADI would trim each individual part before putting the lid on the ceramic dual-in-line package. Later, the company learned to laser-trim directly on the wafer before it was sliced into individual die.

The AD506 op amp was the first laser-trimmed product manufactured at the Nova Devices facility. It was followed by the AD532, which was initially laser-trimmed in the package and later on the wafer. That part, in turn, was followed by the AD534 multiplier, designed by Barrie Gilbert to be laser-trimmed on the wafer.

The exact composition of ADI's thin-film resistor material "remained as secret as the recipe for Coca-Cola," Gilbert said. The technique would enable analog and linear products that significantly outperformed competitors. It would be applied to converters, as well, leading to high accuracy—initially for 12 bits of resolution and then extended to 16 bits—launching ADI as a powerhouse in data conversion technology.

ADI was not the only company to do this, but it did it better than anyone else. "The large companies were not motivated to develop thin-film, laser-trimming technology since the market for high-performance analog ICs was too small," Ray Stata said. "By the time they figured out it was a good idea, we were miles ahead of them. This capability established our technology leadership and differentiated us from other companies in the market, especially in converters."

market share made collaboration unlikely. So each fab worked toward BiCMOS from a different starting point. The Limerick fab, which made only CMOS at the time, started to investigate the possibility of adding bipolar. The Wilmington fab, which focused on pure bipolar processes, began exploring CMOS. The perceived duplication of effort turned out to be serendipitous. Having the two teams work on BiCMOS at the same time accelerated innovation, since there was stronger competition inside ADI than from other companies at that time.

However, as an analog company, ADI at first resisted the use of CMOS processes, especially in Wilmington. There were ongoing discussions in Wilmington over how much ADI should invest in CMOS processes. Several processes were being considered, but ADI could only afford to invest in one. This was complicated by the fact that analog circuits of the era had to operate on 30 volts, but CMOS and digital circuits were already migrating to lower voltages of 12 or 5 volts.

Limerick 3-inch fab, 1978

By the late 1970s, the company had to choose which technology Wilmington would pursue. Two camps—the Linear Operating Group (LOG) and the Converter Operating Group (COG)—debated for months about the choice. Finally, Jerry Fishman, then head of Analog Devices Semiconductor Division (ADS), threatened to decide for them, knowing that the engineers would likely do anything to keep such a technical decision out of management's hands. An arduous, daylong meeting spilled into the night at the home of Paul Brokaw. The LOGs, responsible for developing op amps and other all-analog circuits, clamored for a high-precision complementary bipolar (CB) process based on an innovative idea proposed by Barrie Gilbert. Following the example of the CMOS, Gilbert proposed making a complementary NPN and PNP bipolar process. The COGs, who needed logic and digital switches in a smaller area than ADI's bipolar processes could achieve, argued in favor of what they called BiMOS, which would add NMOS, a forerunner of CMOS technology, to an all-NPN bipolar process.

Each side was a passionate proponent of its view, but in the end, they came to a decision: Wilmington would develop BiMOS (and eventually BiCMOS). There were no hard feelings, especially because it wasn't long before Wilmington invested in CB as well, in order to stay ahead of competition in the analog market. To help drive home the need for both processes, Lew Counts, who joined in 1968 and by this time was the LOG design manager, pushed through first-generation CB amplifiers as fast as possible, even forgoing design reviews, which he feared might derail the development.

The Great Debate: Bipolar or CMOS?

As the semiconductor industry realized the advantages of CMOS process technology, ADI engineers had to not only learn a new technology but also change a mindset.

Coming from a background of high-precision analog, many ADI circuit designers had both feet firmly planted in the bipolar camp. Over two decades, they had been widely respected for their ability to coax the best performance out of bipolar process technology. CMOS represented a culture change. It opened the door to outsourcing chip fabrication to foundries. That broke the bond (and the advantages) of circuit designer and process engineer working side by side.

Culture change always requires a champion—someone who can promote the new attitude, open up minds and convince doubters by presenting a sound rationale for the change, all without tempers flaring. To encourage ADI engineers to share their ideas on CMOS in a relaxed atmosphere, Chris Mangelsdorf started the NBD seminar series. NBD stood for No Bipolar Devices or No Big Deal, depending on whom you asked.

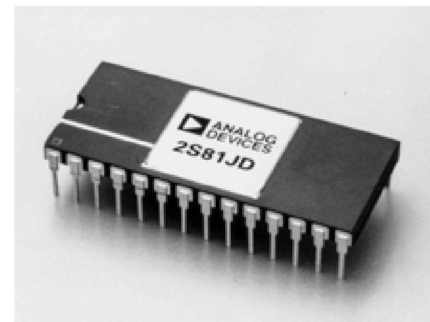
CMOS advocate Chris Mangelsdorf dressed as the superhero character Captain CMOS, with his sidekick Double Polly, at a Halloween party.

Mangelsdorf was a CMOS advocate, but he tried to keep things lighthearted. At one Halloween party, he dressed as a superhero named Captain CMOS. His date and Captain CMOS's sidekick, Double Polly, sported a sandwich-style costume representing the polysilicon capacitor structure that ADI used at the time. The costume was such a hit that Captain CMOS showed up again on GTC panels, discussing the benefits of CMOS versus bipolar process technologies.

In 1971, ADI's first linear bipolar process went into production and was used for op amps, references, comparators, temperature sensors and the AD561 digital-to-analog converter.

Beyond BiCMOS

Complementarity, the ability of a circuit to both push and pull a load or process a signal without wasting power is an extremely powerful concept in many engineering fields. The digital world had gained huge advantages in moving from NMOS technologies to the symmetrical CMOS. But the power of complementarity was far less obvious in the analog domain. Gilbert's idea of boosting the performance of PNP transistors to be on par with NPN transistors turned out to be one of ADI's most significant process innovations, increasing both speed and precision. Fellow Jody Lapham, who joined in 1973, worked with designers, including Fellow Wyn Palmer and Doug Mercer, to apply Gilbert's game-changing idea for complementarity, and helped put ADI ahead of the competition in high-performance analog circuits. The first generation of ADI's CB process produced amplifiers that were up to 10 times faster, with the same power consumption as earlier IC amplifiers.



BiMOS II went into production in 1985 and was used for products such as the 2S80 series of resolver-to-digital converters and the AD569 digital-to-analog converters.

In the 1980s, the company continued to develop bipolar processes to achieve ever-higher-speed circuits. Lapham and a talented young engineer he hired from MIT in 1987, Susan Feindt, extended the CB process by pioneering the development of silicon on insulator technology, or bonded wafers, together with trench isolation, to provide multiple benefits of dielectric isolation. Dubbed extra fast complementary bipolar (XFCB) and introduced in the early 1990s, the process was more reliable and increased speeds while lowering power consumption. XFCB enabled an additional tenfold increase in speed over earlier CB. Further enhancements included the addition of self-aligned architectures and

ADI Fellow Jody Lapham was instrumental in the development of ADI's first CB process. He worked with circuit designers to develop amplifiers that were up to 10 times faster without increasing power consumption.

silicon germanium, providing several generations of industry-leading precision analog processes.

Around the same time, ADI acquired Precision Monolithics Inc. (PMI), which had a fab in Silicon Valley. With the acquisition came Mohammad Nasser and his team, who had successfully combined CB and CMOS to produce the industry's first CBCMOS process, capable of operating at up to 30 volts. After the acquisition, the Silicon Valley team developed successive generations of CBCMOS to reduce feature size and increase speed.

Ultimately, the Wilmington team added CMOS to XFCB in order to facilitate the design of very high-speed RF and converter circuits required for base stations in the rapidly growing wireless communications infrastructure market. Products based on the third generation of that bipolar process (XFCB-3) increased speeds 1,000 times over the initial process, enabling ADI to lead the base station market.

Embracing the Emerging Foundry Model

TSMC, founded by Morris Chang in 1987, was a new type of semiconductor company with a new business model; it had no products of its own but rather planned to offer wafer fabrication services to others in the semiconductor industry, a model that came to be called the foundry business. Initially some semiconductor executives were skeptical, leading to the infamous quote from Jerry Sanders, then CEO of Advanced Micro Devices: "Real men have fabs." But ADI and other midsize semiconductor companies could not afford the capital investments and process R&D to keep pace with TSMC and other emerging foundries in digital CMOS. Nor could they compete on price against large-scale manufacturing facilities. ADI realized that by partnering with TSMC, it could gain access to the benefits of Moore's Law without having to make a large investment. ADI quickly became one of TSMC's top five customers. In the early 1990s, ADI relied on TSMC as the sole source of wafers for its DSPs.

A deep trust blossomed between the two companies, and they explored ways they could exploit their respective digital and analog technology expertise. Their goal was to achieve a process technology

Wilmington wafer fab Module B, circa 1988

Limerick 8-inch fab diffusion area, 2012

Morris Chang and the ADI-TSMC Relationship

Ray Stata first met Morris Chang in 1986. Chang had left Texas Instruments after a 25-year career in which he had risen to the level of group vice president for semiconductors. ADI's vice president of finance, Joseph M. Hinchey, had worked with Chang and recommended Stata consider him for ADI's board.

TSMC and ADI developed a symbiotic relationship and pushed the limits of technologies and business models. Pictured here: Ray Stata and Morris Chang.

Chang recalled the interview as pleasant enough, but nothing happened immediately. "I thought maybe he changed his mind," said Chang. But the following year, Stata invited Chang to join the board, beginning a long and fruitful relationship between the two men.

In 1987, Chang had just launched a new venture, the Taiwan Semiconductor Manufacturing Company (TSMC), based on a novel idea: The company would manufacture ICs for the industry. "The only problem with our business model, frankly, was that there was no market," said Chang. "Everybody in those days had their own fabs." Chang and TSMC were pioneering the fabless model, which eventually caused a sea change in the industry, enabling chip companies to prosper by designing their own chips but hiring third-party foundries to manufacture them. By 2014, foundries would produce 37 percent of the total semiconductor industry output, according to the Global Semiconductor Alliance. TSMC would lead the foundry business, with over 50 percent of the market and revenue of more than $25 billion in 2014.

In the 1980s, no one could foresee how successful the foundry model would become. But Stata and Chang saw that they needed each other. TSMC needed customers and analog know-how. ADI needed digital CMOS for its DSP products but had no dedicated CMOS fab and didn't want to build one.

ADI taped out its first product at TSMC in June 1990 and within three years became one of TSMC's top customers. The relationship blossomed in the 1990s and became a major source of innovation for both companies. "We began to build a deep and trustful relationship that promised to mature and endure over the next 30 years," said Stata. "It was as if we were part of the same company as we began to explore ways to exploit our respective digital and analog technology expertise."

Together, the companies pushed the limits of technologies and business models. "What made this effort so remarkable was that there was no real template, no rules and no existing measure of success of how to make this work," said Chang, "just a desire to make it happen."

According to TSMC, by 2015 ADI had taped out more products, on more processes, than any other customer in TSMC history. The joint process development with TSMC, in both analog CMOS and very high-speed silicon germanium CMOS, was an important source of innovation for ADI.

In 2015, ADI awarded its Founders Innovation Award to Chang. In bestowing the award, Stata said Chang's vision in creating the fabless semiconductor industry was "second only to Moore's Law in amplifying the pervasive impact that semiconductor technology has had on our society."

suitable for low-cost, high-volume manufacturing of high-speed analog circuits, essentially reproducing the benefits that digital circuits got from digital CMOS. If TSMC could add highly linear capacitors to its CMOS process, then ADI's analog design engineers could create high-performance converters and other analog circuits on these much lower cost wafers.

The resulting process came to be known as Analog CMOS and was a key enabler of ADI's entry into the high-volume consumer, computer and communications markets. In addition, the new process was perfect for a new type of converter called sigma delta. This converter excelled at translating analog signals (like audio) to and from digital with low noise and distortion, and was less susceptible to interference from on-chip digital processors. This combination allowed manufacturers of consumer products to integrate high-performance converters and digital functionality on the same chip, and drove the cost of audio converters down by more than an order of magnitude.

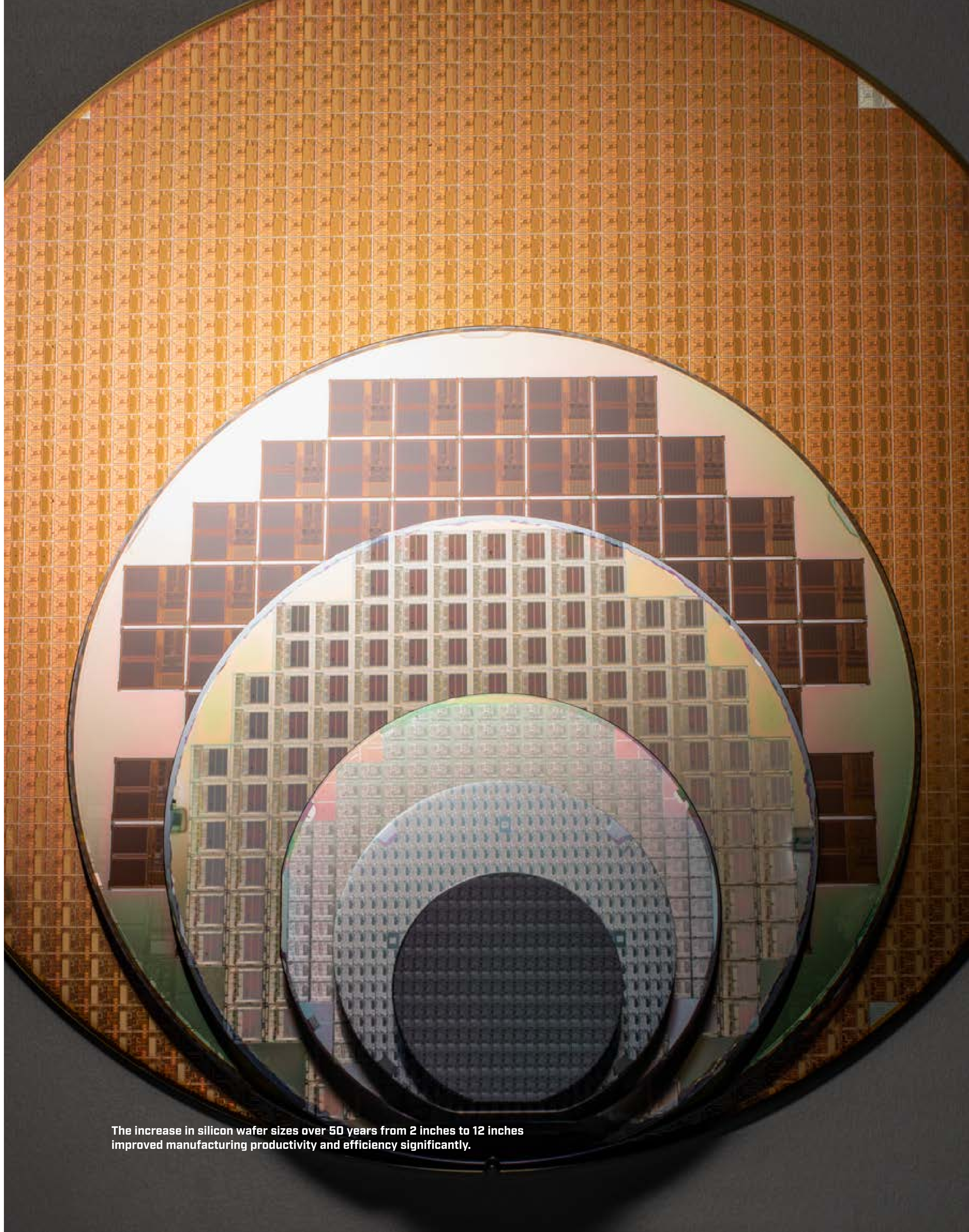
The two companies then developed a version of BiCMOS to support ADI's mobile phone business. ADI transferred bipolar technology to TSMC, while TSMC transferred several generations of its CMOS processes to ADI. Both companies ran the same BiCMOS process. TSMC supplied wafers for high-volume markets; ADI supplied wafers that had other features for the higher-performance, low-volume markets.

With each technology transfer, the two companies learned more about one another's skills, technologies and people, paving the way for even closer collaboration—developing a 0.18-micron process technology for analog ICs. Unlike previous process transfers, these next-generation, high-speed BiCMOS processes required intensive co-development between ADI and TSMC engineers. TSMC agreed that these processes would remain exclusive and proprietary to ADI.

Meanwhile, the base station market, which had been using XFCB-3, also needed CMOS to achieve more highly integrated solutions. The lithography required for high-density CMOS circuits was beyond the 0.35-micron technology running in the Limerick fab, and ADI decided against the substantial investment it would have taken to advance beyond the 0.35-micron node internally. Instead, it decided to work with TSMC to develop bipolar silicon germanium (SiGe) CMOS. This development required ADI to share its most prized process technology with TSMC. But the trust that had developed between the companies gave ADI the confidence to do so. The XF3C process, the first XFCB joint development with TSMC, was released to production in

ADI realized that by partnering with TSMC, it could gain access to the benefits of Moore's Law without having to make a large investment.

A Wilmington fab operator loads 8-inch wafers into the diffusion furnace.



The increase in silicon wafer sizes over 50 years from 2 inches to 12 inches improved manufacturing productivity and efficiency significantly.

2013, and the companies continued to collaborate on even higher-performance variations for the future.

The decision to outsource some analog circuit wafer fabrication was controversial within ADI, primarily because it was perceived as breaking the close collaboration between ADI's circuit designers and process technology developers. "It's important to tailor the process for the circuit. That's what has made us so successful in the process area," said Feindt. "When going to a foundry, you lose the close interaction between circuit designers and process developers."

So, ADI cautiously maintained in-house process technology development and manufacturing for many of its products, while outsourcing manufacturing of high-volume processes to take advantage of Moore's Law. Joint process developments with TSMC achieved the best of both worlds. It was a delicate balancing act between keeping ADI's competitive advantage with proprietary processes and meeting the need for greater capacity and lower cost, said Jerry Fishman in his 2011 General Technical Conference speech. "These foundry processes are becoming more attractive because of advanced lithography requirements and also the increasing capability of foundries to offer many processes that are similar to boutique processes at ADI." He added, "I believe our internal fabs can continue to be a competitive advantage if we figure out new processes that are truly unique."

And ADI repeatedly did just that. For instance, Wilmington developed variations of XFCB, upgrading to a double-polysilicon emitter process called RF-25. This process enabled designers to apply analog circuit design techniques to RF signals to achieve high-performance RF ICs. RF-25 produced products whose improved reception and transmission of mobile phone signals helped ADI gain market share with base station equipment makers. "The RF-25 process not only provided the platform for important RF products, but it also provided the bipolar technology for ADI's high-speed BiCMOS process, which became a very important platform for several generations of breakthrough high-speed data converters," said Dave Robertson.

ADI continued to innovate both internally and in partnership with TSMC. Nasser was responsible for developing proprietary BiCMOS and processes with DMOS structures that could handle very high voltages. This capability was particularly important in automotive and industrial applications. Later, he also worked with TSMC to develop low-cost process variants and new devices with TSMC's existing recipes. Both approaches created proprietary advantages for ADI.

ADI Fellow Susan Feindt joined ADI in 1987 as the process development team was pioneering silicon on insulator and trench isolation. The team's discoveries led to ADI's XFCB process technology, which increased speeds tenfold while lowering power consumption.

Operators monitor SVG/Thermco vertical reactors, 2000.

ADI's internal fabs continued to be a driving force of innovation.

> "I believe our internal fabs can continue to be a competitive advantage if we figure out new processes that are truly unique."
> **JERRY FISHMAN**

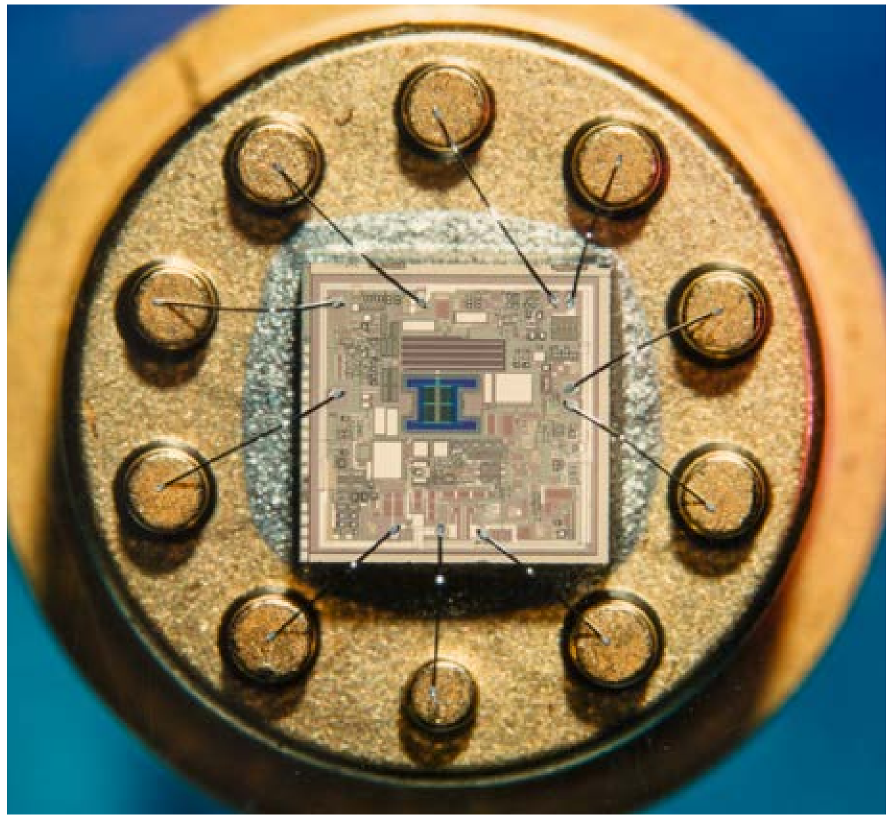
The MEMS Challenge

Meanwhile, ADI was developing processes that went beyond conventional integrated circuits. In the 1990s in Wilmington, the company developed micro-fabrication techniques that combined tiny mechanical structures with electronics. One of the first challenges for this MEMS technology was to produce accelerometer sensors for automotive airbags. Initially, MEMS opened the automotive market for ADI but led to other lucrative markets, as well. For example, MEMS advancements enabled six degrees of freedom motion sensors needed for guidance in drones, which ranged from inexpensive consumer toys to multimillion-dollar defense systems.

Another process developed at Wilmington incorporated photonics. Shrenik Deliwala, hired in 2003, worked for over a decade designing devices that combined microelectronics and photonics. ADI's first attempt at manufacturing photonics was in 2000, when its MEMS fab worked on an optical MEMS device. Although photonics technology was very different from ADI's traditional analog and digital offerings, Stata was convinced of its potential and sponsored a small team in Wilmington to bring it to market. ADI also joined MIT's Microphotonics Center, which led to the integration of a germanium photodiode with a high-speed silicon process, producing the industry's first commercially available integrated optical receiver.

ADI gained a deeper understanding of optical devices and systems that, coupled with advances in system in package (SIP) manufacturing, led to several innovative healthcare solutions. For example, one product integrated a large area of photodiode arrays with high-performance analog-to-digital converters (ADCs) in a single module to improve the quality of medical computed tomography (CT) images. The photodiodes used "through silicon via" (TSV) technology that was first used by ADI in its MEMS manufacturing. ADI also used photonics in products that detected heart rate and blood oxygen levels and in gesture sensors for robotics applications. In addition, packaging innovation that combined photodiodes, signal processing, optical filters and light sources enabled devices for many wearable applications.

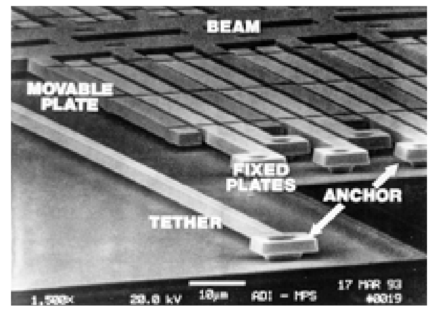
This work depended upon ADI's tradition of very close collaboration among designers, manufacturing engineers and process technology engineers, as well as the unique capabilities of ADI's fab, Deliwala noted. "This is something you can do only if you have a fab that has the flexibility to experiment with new



The ADXL-50 was the industry's first surface micro-machined accelerometer to include signal conditioning on chip.

approaches," said Deliwala. "We could go after these markets in a way that other companies often could not."

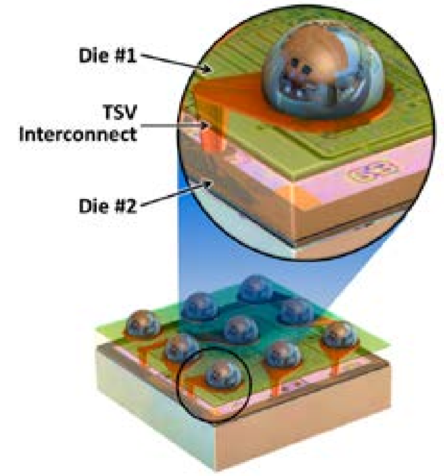
The Limerick fab was also building on its historic capabilities to develop new processes. It continued to manufacture high-performance BiCMOS-based products in its main fab, but in 2011 it focused on new processes and innovation by creating a smaller, more flexible facility for manufacturing devices using exotic materials, such as gold, nickel and iron, that could not be used in a traditional fab because of contamination. The initial idea was to place solder bumps on circuits and do back-end finishing, said Fellow Denis Doyle, who joined ADI in 1991 and became vice president of manufacturing, but Limerick soon saw more opportunities. "The Orange Fab" (so named because workers wore orange bunny suits instead of the traditional white suit) started to manufacture transformer-based isolators as alternatives to opto-couplers. The isolators, which the company called iCouplers, had been developed by Fellow Baoxing Chen, hired in 1997, but the company had not been able to find a fab suitable for manufacturing them.



ADI entered new markets in the 1990s by developing processes that went beyond integrated circuits, including MEMS technology to produce automotive sensors.

"It turned out that what we needed to make these isolators was electroplated gold and some dielectrics called polyimides," said Bill Lane, who had been hired in Limerick in 1987 from the National Microelectronics Research Centre, part of University College Cork that later became the Tyndall Institute. Successfully manufacturing the isolators helped to establish a mindset that the Orange Fab could do "more than Moore," meaning that it could create value by discovering and taking advantage of a variety of materials beyond traditional silicon, as well as advanced packaging.

"Once we got the isolators up and running, we looked for other products we could manufacture in that fab," Lane said. Among them were digital isolators for automotive applications (for shaft rotation, position control and engine management), medical applications such



Stacked die and TSV Interconnect, originally developed for ADI MEMS manufacturing, were combined with packaging innovation to enable a number of breakthrough solutions for wearable applications.

as smart catheter positioning, a magnetometer that enables location-based applications used in smartphones, and a MEMS RF micro-switch. The latter—a switch made of gold with a MEMS moving beam—had been invented 15 years earlier but had languished because it could not be made in a traditional fab. ADI

Simulation, Analog Design and ADICE

As the industry entered the IC era, design became the bottleneck to progress. With large-scale integration of circuits, the design process had to become more automated. Several companies began to offer CAD tools, but strictly for digital design. There were few tools to aid analog design. Researchers at the University of California, Berkeley, developed one tool, called SPICE, that analog designers began to use. SPICE (simulation program with integrated circuit emphasis) was a general-purpose, open-source analog electronic circuit simulator. Just as it had with process technologies, ADI would adopt SPICE and then also develop its own tools.

ADI started using SPICE, tweaking it for its own needs, in the mid-1980s and ultimately developed its own version, which it called Analog Devices Integrated Circuit Emulator (ADICE). The software included its own programming language, so ADI engineers could develop their own specific transistor models and simulate how circuits behaved on ADI's proprietary processes. "We didn't have to be compatible with other processes, so we could customize the models to our own processes and the requirements for analog circuits," said Dave Smart, a Fellow who joined the company in 1988.

The flexibility and sophistication of ADICE grew over time. It was collective innovation as the world's best analog designers contributed to features and performance.

As mixed-signal ICs gained popularity in the mid-1990s, Smart continually updated the ADICE system so it could be used to simulate both digital and analog circuits. Eventually, commercial CAD vendors introduced similar design tools. ADI further modified ADICE so that its engineers could work with both industry-standard design tools and with proprietary ADICE tools. Over decades of circuit design, ADI engineers programmed custom instructions into the software that take advantage of ADI's proprietary processes. "Engineers would use the ADICE programming language to code the way they wanted to analyze designs," said Smart. "Now that is part of the internal intellectual property of the company. It's embedded in these simulation setups."

ADICE was one way ADI retained its intellectual property and continued to take advantage of the valuable symbiosis between its designers and process technologists, even when outsourcing manufacturing. After 30-plus years of

Reddy Penumalli (left) and Dave Smart discuss ADICE upgrades, circa early 1990s.

modeling and simulating ADI designs, ADICE contained hooks that enabled ADI to "turn the knobs," even as it worked with foundries.

Thus, ADICE played a major role in ADI's success by enabling engineers to create many of the analog industry's most innovative products.

engineers believed they might be able to manufacture it in the Orange Fab.

Past attempts to make MEMS switches ran into three challenges: The switch contacts degraded (a function of the material used to make the contacts); materials like gold tended to relax when the switch was held in the "on" position for a long time, which meant the switch would not turn off when the voltage was removed; and the parts tended to have charging and leakage currents. Once the process was brought to the Orange Fab, ADI solved all three challenges. Engineers used a hard-wearing refractory metal that would not degrade to make reliable switch contacts, and they redesigned the gold beam to enable years of "on" time without failing. A team of designers and process engineers worked together, modifying

The isolated cleanroom in Limerick used exotic materials and came to be known as "the Orange Fab" after the operators' brightly colored cleanroom suits, or bunny suits.

Manufacturing and Advanced Packaging

The number and variety of packaging technologies started exploding in the early 2000s. Among the most significant developments was chip-scale packaging (CSP) technology, meaning the package was no bigger than the chip itself, as small as 1 mm by 1 mm. As of 2015, ADI had 186 different packaging styles, most of them various types of CSP.

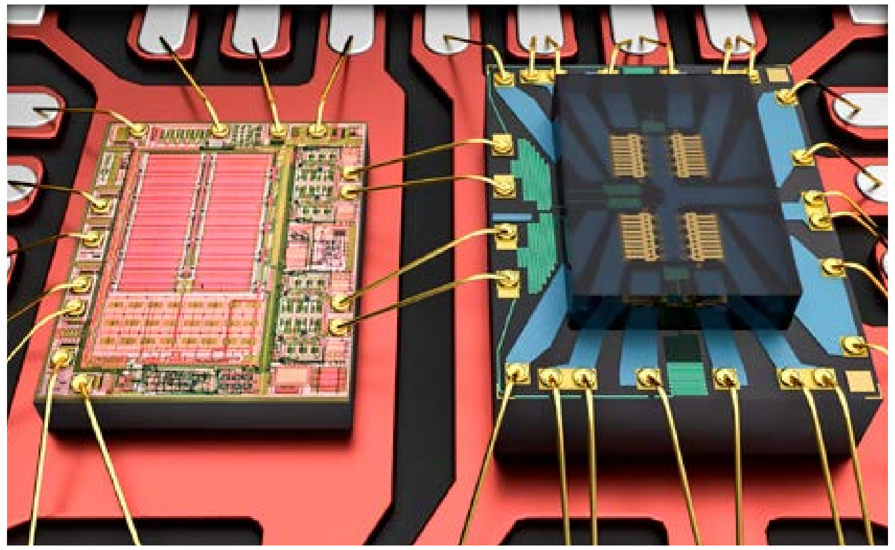
Even when functions could be integrated onto one chip, it did not always make sense to do so. Sometimes, performance could be improved by combining ICs made with different process technologies and other devices in a system in package (SIP).

CSP and SIP technologies became key capabilities in providing the system-level solutions ADI customers increasingly wanted. For example, for an integrated photonics vital signs monitoring healthcare product, ADI combined MEMS sensors, LEDs and application specific ICs (ASICs) in a 2 mm by 3 mm clear laminate package.

As packaging became more complex and more important, teams of specialized engineers were dedicated to developing advanced assemblies and ways to test them, working at Wilmington and Limerick as well as at ADI's test and assembly facility in the Philippines and with strategic subcontractors elsewhere in Asia. ADI also amassed considerable intellectual property and trade secrets related to testing complex, three-dimensional SIP system solutions, which also required an entirely different approach in order for ADI to live up to its reputation for high-quality, high-reliability products.

the design and re-engineering the process, to solve the charging problem. In addition, a silicon-capping technology developed for inertial MEMS parts was transferred from Wilmington to Limerick. In 2015, the first MEMS RF micro-switch was released, featuring lower parasitics and capacitance than a CMOS semiconductor switch, making it perfect for the high-end instrumentation market.

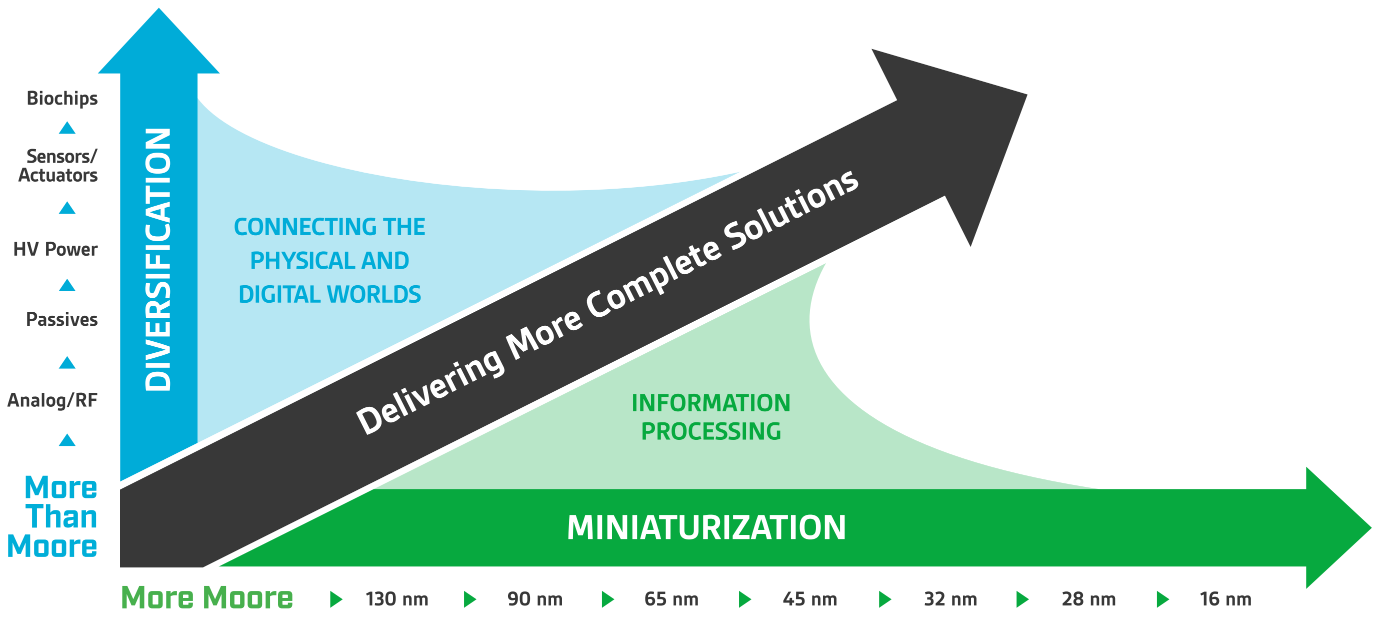
"The MEMS RF micro-switch is a good example of how proprietary process development continues to play a role at ADI in developing new business opportunities," said Stata.



A MEMS RF switch, shown with a drive IC (left) and a MEMS switch die (right) mounted on and wired to a metal lead frame, illustrating ADI's exotic materials processing and packaging capability.

Indeed, the evolution of process development at ADI was one of relying on historical strengths while continually experimenting to find, enable and exploit new technologies. The company depended upon its internal, proprietary processes and internal fabs for many of its innovations, while also working with outside foundries—specifically TSMC—to take advantage of Moore's Law and outside expertise in digital CMOS processes. ADI continued to leverage its own history of innovations while remaining open to technological and manufacturing developments happening in the broader semiconductor industry. By combining both, it continued to produce some of the highest-performance, most technically sophisticated products in the world.

"More Than Moore" Adds Unique Value



As the challenges and opportunities associated with connecting the real world to the digital world grew, combining different technologies (analog, digital, photonics, MEMS, etc.) into modules and stacked die along a More Than Moore trajectory became as important as increasing the density of transistors in monolithic ICs.

Create More Value Through Collaboration

As ADI continued to extend its capability from components to systems, Ray Stata continued to remind his company of Ackoff's axiom (from Wharton School business professor Russell L. Ackoff): System performance depends more on how well parts work together than how well each individual part works separately. This axiom applied to products, as the semiconductor industry advanced to higher levels of integration and ADI evolved from its traditional focus on components to a far broader systems perspective. It also applied to the company's organizational structure. Enhancing innovation through collaboration between product lines and divisions meant another shift in corporate culture. Instead of focusing within a particular technology or design discipline, engineers with different specialties had to figure out how to make the parts work better together than individually. As CEO Vince Roche described it, "Increasingly, solving our customers' most important challenges will require solutions that are technology-led, market-focused and system-inspired."

> **"Increasingly, solving our customers' most important challenges will require solutions that are technology-led, market-focused and system-inspired."**
>
> **VINCE ROCHE**

Although collaborative skills were important, ADI did not want to dampen the creativity of individual engineers. The company needed to maintain autonomy and creativity but also foster more collaboration that would lead to better solutions for customers. Even as ADI passed its 50th anniversary, the company was still navigating this balance.

"It sounds simple, but changing our beliefs about what is important is the most difficult part," Stata said. "Learning how to manage the trade-offs to optimize the performance of ADI as a whole is a new challenge."

In ADI's early days, internal collaboration came quite naturally. Designers, process technologists and test engineers were all in one location, at times even in the same office. "If an operator was having trouble running tests, she'd just come into my office and tell me things weren't working, and I'd have a look," said Dave Kress. "We took care of it in five minutes."

As ADI grew, collaboration became more difficult. The company had created independently operated divisions in different parts of the world, some of which even competed with each other. The rivalry between converter designers in Wilmington, Massachusetts, and Limerick, Ireland, for example, was constantly simmering. But it was precisely at the time when products, technologies and the company became more complex that collaboration became essential to maintaining the pace of innovation. Engineers had to develop skills to work in teams across product groups and disciplines. ADI needed to start collaborating and learning outside of its walls as well, something that Roche stressed after he was named CEO. "Complexity is likely to increase at an exponential rate in the coming years," he said. "And our entire organization needs to be much more externally focused."

At the 2005 GTC, CEO Jerry Fishman celebrated the company's 40th anniversary by recognizing the top-selling products and the people whose individual and collective contributions made these innovations possible.

It was yet another balancing act between a heritage that focused on technology-driven innovation and a future orientation that would emphasize more system-impacting innovation. "On the one hand, we must continue thinking and dreaming about how to make a massive impact with our technology," Roche said. "On the other hand, we must marry that technology and the real world in a much, much more aggressive way than we have over our history."

From One to Many

ADI's culture had been defined by individual freedom and autonomy. This worked well early in analog design, when a creative idea from one talented designer could lead to a best-selling circuit. That model set the tone for the company. "In the old days, outrageously talented individual contributors could invent whole products, even whole industries, pretty much by themselves," said Fellow Bob Adams, who joined ADI in 1989. But the emphasis on systems required a team-based approach, which required more top-down management. The trick was to figure out how to do that without quashing individual creativity. "It's a matter of finding the right balance between keeping what works well about the old way and the need for a higher degree of organizational coordination," Adams said. As in any balance, however, there was tension. Some engineers wondered why managers didn't just let them pursue new designs. But they also saw the big picture: The designs customers were demanding often required diverse interdisciplinary teams, and that required more management.

The autonomous culture manifested in a confederacy of individual "fiefdoms" that coexisted within the corporation,

ADI Fellow Bob Adams, who joined ADI in 1989 as senior staff designer, recalled that the transition from components to systems required ADI to find the right balance between organizational coordination and individual autonomy.

a structure that had its advantages but also hampered communication and collaboration. Shrenik Deliwala, a native of India who joined ADI from a startup, likened ADI's culture to that of his home country. "If you ask somebody to define an Indian, it's impossible," he said. "India has 400 languages, including 24 official ones. It's the same way at ADI." In other words, the company had lots of different people in different areas, with different viewpoints, speaking different languages. This cacophony was vital to the creative process but potentially damaging to the execution process.

Parts of the company even used different business models. "Some groups are focused on consumer markets and are shipping millions of units a week at 50 cents apiece," said Dave Robertson. "Other groups are doing a million units a year at $10 apiece. There are some markets where the product lifetimes are two years, others where they are 25 or more years." This tremendous breadth and depth was both ADI's great strength and a potential weakness, he said. "It's a matter of getting the right portion of the population to work across boundaries," Robertson said.

The culture of individual empowerment also meant that employees were used to having their say. That slowed decision-making, a growing disadvantage in an age when agility could make the difference between success and failure. "The negative side of that [culture] was that everything

ADI Fellow Dave Robertson recalled that the tremendous breadth and depth of the company's businesses were both great strengths and potential weaknesses.

took too long to get resolved," said CEO Jerry Fishman. "Anyone could get in the way of anything for whatever reason. . . . With the sanctity of the individual, we forgot the second half, which is that eventually somebody has got to decide, and once they decide, everybody better line up behind that decision."

That meant being willing to make hard decisions about which products and technologies to develop and which to cancel. Roche emphasized this philosophy. "We can't tolerate harmony at the expense of candor," he said. The key, he explained, was to fully resource the projects that would create the most value for customers and have the agility to change course when circumstances changed.

Balancing Individual and Group Innovation

The evolution of several ADI businesses illustrated how the company could combine and balance, over a period of decades, the creativity of individuals, the breadth and depth of its technology, broad collaboration, and business discipline in order to produce innovation in the market.

Technology developments in areas as diverse as amplifiers, optical sensors, process technology, packaging and

Creativity, collaboration and discipline were key ingredients in evolving ADI's businesses early in the 21st century.

ADI Fellow Katsu Nakamura, who served as chairman of the GTC from 2013 to 2017, led the team developing ultra-low-power technology.

low-power design, for example, were championed by individuals; when combined, they produced innovative solutions such as tracking fitness and health using smartwatches.

In the first decade of the 2000s, individuals within ADI made significant advancements in their respective areas of expertise. Fellow Scott Wurcer developed the ADPD221x, a low-noise amplifier for optical applications. Deliwala developed photo diodes and worked with the Wilmington fab to fine-tune a silicon photo-diode process technology to manufacture them. Meanwhile, Katsu Nakamura, also a Fellow, and his team developed ultra-low-power technology, particularly well-suited to sensors. Then, in 2010, ADI started to see a market developing for devices that monitor health vital signs using smartwatches and wristbands. The healthcare group was able to bring together a team to combine all this technology, enabled by a breakthrough in system in package (SIP) capability, into a product that was both technically superior and economical. Samsung incorporated the product, the ADPD142, into both its phones and watches.

"All of these components had been developed for other purposes," said general manager Tony Zarola, who was director of vital signs monitoring in the healthcare group and joined ADI in 1988. "We needed only to make minor changes to adapt the existing components for vital signs monitoring solutions, meaning we avoided the costly, time-consuming process of developing new silicon and could bring a complete solution to market much more quickly." Customers were interested because ADI took a systems view. "When we visited customers, we barely referenced the silicon," said Zarola. Rather, ADI stressed its value as a strategic partner that understood the market, had superior technology and knew how to integrate that technology into systems.

How Collaboration Leads to New Products

Even within traditional component businesses, collaboration was spurring creativity. Jen Lloyd, vice president of Healthcare and Consumer Systems, joined ADI as a college hire in 1997 and was general manager of the Linear and Precision Technology organization when it realized the value of collaboration. "The linear designers worked in close proximity to one another in San Jose and Wilmington, yet many of the innovations were from designers working alone," she said. "We had great success with this and drove performance leadership at the component level, but we needed to move our scope to the signal chain in order

Tony Zarola and his vital signs monitoring team adapted existing components to develop custom SIP solutions more quickly.

ADI Fellow Bill Hunt's team in Limerick spearheaded the development of PLLs and other standard RF components together with ADI's Northwest Labs.

Jen Lloyd (right), vice president of healthcare and consumer systems, achieved higher levels of growth and customer partnership in precision linear devices and converters by challenging her team to think about innovation in signal chains and systems in addition to the core component technology.

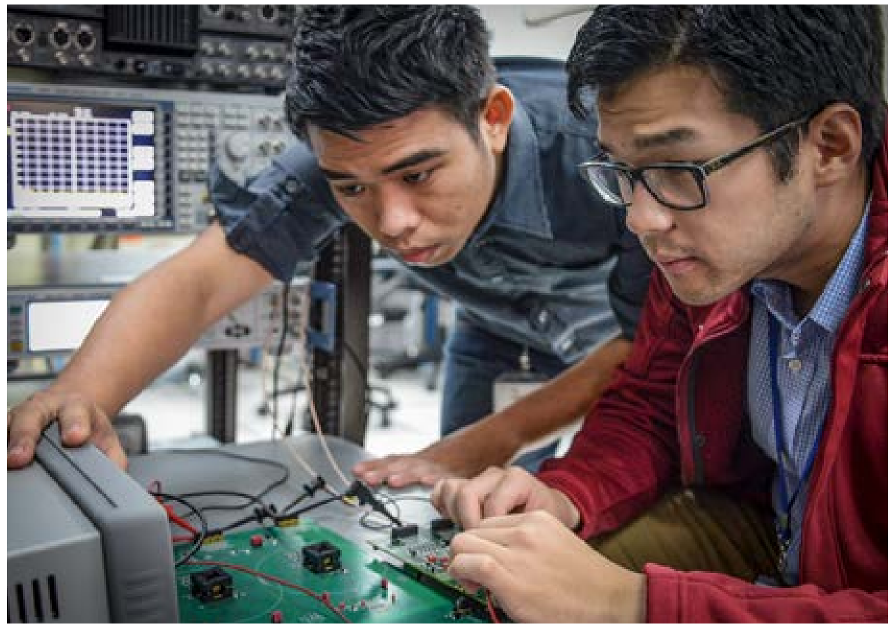
to have a stronger impact on customer applications. This required learning and collaboration across the organization, engaging with customers at a new level and shifting from component to system level thinking. This shift in mindset resulted in valuable innovations and higher growth for the business."

In automatic test equipment, to address growing challenges from customers over the complexity and performance of their designs, interdisciplinary teams worked alongside customers such as Teradyne and Advantest to innovate at the system level. Pin driver, power management unit and comparator technologies were combined on a proprietary process node, which enabled system-level impact and simultaneously created an easy-to-use, small-footprint solution. "The team not only solved the problem, the success of the business helped change long-held beliefs about how to innovate," said Lloyd.

The breakthroughs continued in areas such as battery formation and test applications, where ADI simplified the customers' circuit design, improved performance, and dramatically improved power efficiency and density. "We achieved the innovation by bringing together know-how from across ADI, including technology expertise in precision measurement, power management, process and assembly technology, as well as field applications insights from our global sales team."

ADI combined individual with group innovation in the communications market as well. Barrie Gilbert, founder and director of ADI's Northwest Labs in Oregon, described his affinity for radios. "Radio systems have always been an intimately conversant part of my life, which is why I always felt ADI should be involved in such matters," Gilbert said. In the early days, ADI was focused on making ever more precise op amps, data converters and non-linear ICs, but not radio frequency (RF) parts. That didn't stop Gilbert from designing several innovative RF power detectors and other functions for radio, including the AD640, the first monolithic multistage log amp, and the AD607 superheterodyne receiver for cellphones. During that period, both the Northwest Labs and a Limerick team led by Bill Hunt, who joined ADI in 1979, continued to focus on standard RF components.

The Limerick team developed phase-locked loops (PLLs), key components in advanced radios. By the late 1990s, the PLLs and other RF components—including mixers, modulators and detectors from Northwest Labs—were designed into equipment for wireless infrastructure where the emphasis was on very high performance, said John Cowles, general manager for amplifier



Interdisciplinary teams began to develop system-level solutions in addition to creating new components.

and radar integrated products, who joined ADI in 1998 and later became design manager for the Northwest Labs. "These two groups were a team spearheading RF in terms of standard [component] products," he said. "We built up the franchise with a small team."

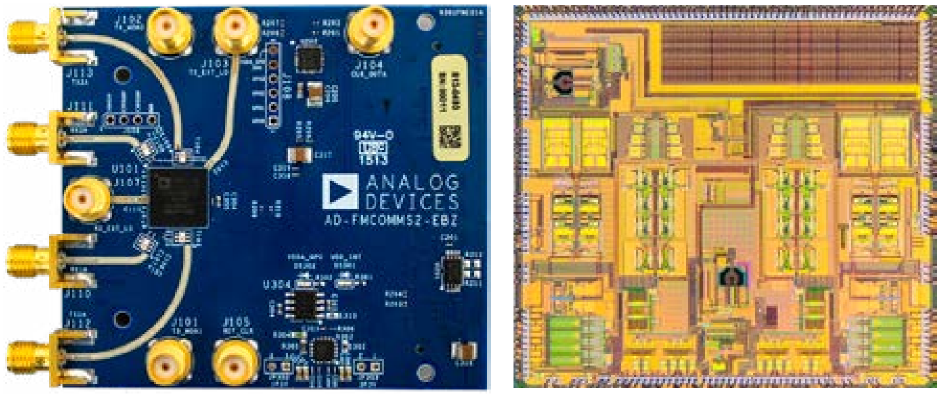
Meanwhile, ADI brought together a multi-disciplinary team of engineers to focus on providing communications solutions for the wireless handset market. In the mid-1990s, dozens of companies were designing cellphones, and high-speed and precision converter and linear functions were in high demand, so ADI created a communications division to focus on challenges such as integrating various functions into one handset-ready device. This was one of the first areas where ADI successfully used an interdisciplinary team of engineers from various product groups, including converters, RF and DSP. Their comprehensive knowledge of the system led not only to components that significantly enhanced cellphone performance but also to the design of a system-oriented, integrated baseband chipset and direct conversion radio for global system for mobile communications (GSM) phones.

ADI would eventually decide to sell the handset baseband and radio portions to MediaTek in 2007. But it had learned valuable lessons about the creativity of individuals, the integration of inter-disciplinary product development, and collaboration across teams that extended from Ireland to both coasts of the United States, namely Oregon, North Carolina and Massachusetts.

ADI's focus turned increasingly to the infrastructure sector of the communications market, where sales to base-station customers exceeded $200 million in 2007. Fellow Tony Montalvo, who joined ADI in 2000, worked on handset chipsets and remained with the company in Raleigh, North Carolina, after the divestiture to MediaTek. He had been pondering how to tailor RF ICs for particular markets. Montalvo had also been involved in developing application-specific standard product (ASSP) transceivers for worldwide interoperability for microwave access (WiMAX), a wireless standard that never developed into a market. "The transceiver team had been stung by the rather expensive failure in WiMAX, and so they were determined to reduce exposure to single markets and to single customers," said Peter Real, who joined ADI in Limerick in 1981 and rose to become chief technology officer. The technology at the time limited RF products to fairly narrow applications or customers, which meant ADI had to find markets big enough to amortize the development cost of the parts, but not so big that the parts were commodities.

Montalvo and a team of 50 engineers dared to take advantage of a new, 65-nanometer CMOS process to design

After developing handset chipsets for GSM and ASSP transceivers for WiMAX, ADI Fellow Tony Montalvo and his team designed Catalina (AD9361), a software-reconfigurable radio that could be used in a broad range of markets.



The AD9361 RF Agile Transceiver, also known as Catalina, was enabled by the combination of 65-nanometer CMOS process technology, radio circuit design expertise and wireless infrastructure systems understanding.

a software-reconfigurable radio that could be useful for a broad range of markets. The product, called Catalina (AD9361), was a hit in the wireless infrastructure market; it surpassed $100 million in revenue and led to several generations of products all based on the same platform.

The development of Catalina was informed by ADI's experience developing components for specific markets and customers. It was partly derived from a key RF initiative in the handset business called Othello. And it was inspired by examining business and market issues. "I was included in discussions with the business people," Montalvo said. "As a technologist, I typically would not have been exposed to the commercial issues, but the fact that I had that experience was the impetus behind this product. This technology was a solution to a business problem." The resulting RadioVerse™ platform supported not only products for the wireless infrastructure market but also many industrial applications, including autonomous machines. The platform complemented ADI's portfolio of more discrete RF solutions. The combination meant that ADI could sell to a broad range of wireless infrastructure and communications applications.

Montalvo's group set an example of excellent interdisciplinary teamwork within ADI. Key to the team's effectiveness, he said, was the fact that many of the engineers understood both systems and silicon. "Senior people, in particular, were expected to be curious about the systems we were targeting with our designs," he said. "In time, they actually became part-time system engineers, which created a more direct connection between system requirements and silicon." That, in turn, allowed the team to make trade-offs between internal blocks while still meeting system-level requirements.

Such multidisciplinary teams with broad skills examined problems from a variety of perspectives. "It's been said that innovation is about connecting the dots," said Real. "Expose teams of creative people to more dots, and good things happen."

Catalina was the foundation for a family of transceiver solutions and led to the 2016 launch of RadioVerse, a technology and design ecosystem for wireless infrastructure and many industrial applications, including autonomous machines.

Multidisciplinary teams with broad skills became the key to innovation, said CTO Peter Real.

"It's been said that innovation is about connecting the dots. Expose teams of creative people to more dots, and good things happen."

PETER REAL

Points of Inspiration: Connecting the Dots

In the broader perspective of ADI's culture, the combination of creative autonomy, teams that understood systems and silicon, business discipline, and a bit of serendipity were all dots that connected when the market for wireless infrastructure exploded in the first decade of the 21st century.

As teams experienced the excitement of winning customers and gaining market share through collaboration, connecting the dots inspired creative autonomy as well, Montalvo said. "All it takes is a few people modeling the desired behavior, and having fun doing it, and it catches on." For example, customers used digital pre-distortion (DPD) in macro cell base stations to reduce power dissipation dramatically. However, the digital pre-distortion itself drew too much power for small cell base station applications. On their own, and without telling anyone, team members Chris Mayer (a Fellow in Norwood, Massachusetts) and Martin McCormick (who joined ADI from Lyric Semiconductor Inc., a Cambridge, Massachusetts, startup that ADI acquired in 2011) worked together on a DPD solution. "They developed a small-cell-optimized DPD algorithm and implemented it in a block that draws very little power and adds virtually no area to the die size," Montalvo said. They secretly implemented it in the RF transceiver. "When they finally came clean—just weeks before tapeout—they were afraid that there would be repercussions. While some were taken aback, I celebrated their initiative and their close collaboration."

Roche celebrated it, too, in a speech delivered at the General Technical

A new culture of teamwork—including some off-the-record innovations—was a game-changer for ADI in the 21st century.

Conference in 2015. The algorithm meant that ADI "will be able to extract significant incremental revenue from every sale without additional manufacturing cost," he said. "What a great example of cross-functional collaboration. . . . This is only the first proof point that customers want—and will pay for—more than silicon, if we provide them with an easy-to-implement solution that solves a difficult problem."

Another example of enhancing innovation through collaboration was the development of the AD6676 data converter, code-named Ocelot. The project began with the inspiration of an individual designer. Richard Schreier, a Fellow in Toronto who joined the company in 1997, had worked on a research project in which he developed a prototype of a configurable converter. The original market for which it was designed never materialized, but Schreier had kept working on the project. When Gabriele Manganaro joined ADI as design director of high-speed converters in 2010, he thought Schreier's design was potentially useful for Ericsson, a key infrastructure customer. While Ericsson liked the idea, it wanted many changes, including much higher performance. So Manganaro formed a cross-functional team that spanned three sites (Toronto, Wilmington and Beijing) to develop Ocelot. The converter eliminated the need for several components—including a filter, a driver and a clock—thus reducing cost, size and power consumption. Ocelot found broad acceptance in the market.

While the genesis of Ocelot was one designer, the expansion into a broad, multidisciplinary team meant that people from different locations with many different skill sets were learning from each other as well as from the customer, Manganaro said. "In the past, we had lots of small, isolated teams working concurrently, sometimes independently solving the same problems in different ways without learning from each other," he said. "There was lots of internal reinvention."

Ocelot used a completely new way to do analog-to-digital conversion, which meant even product characterization needed to be transformed. Product engineers and IC designers collaborated to figure out which parameters to measure and how. Application engineers became involved in product development, weighing in on how to test the parts and what to test for. Half of the software development was done in Wilmington and half in Toronto. Schreier himself, heretofore a self-described pure analog IC designer, ended up writing some of the software, Manganaro said.

Collaboration broadened everyone's perspective, enabling talented employees across ADI to combine their individual creativity to solve customers' problems in new and compelling ways.

In the automotive industry, for example, an automaker wanted ADI to design better noise cancellation for an audio system. The customer approached ADI with the idea of increasing, to eight or more, the number and location of microphones in the car, but the ADI team reconsidered the problem. By then, ADI's Automotive Group was well established, with strong relationships and intimate knowledge of the industry—from the customers, to their customers and suppliers, to the regulatory environment.

Collaboration broadened everyone's perspective, enabling talented employees across ADI to combine their individual creativity to solve customers' problems in new and compelling ways.

Ocelot showcased ADI's ability to enhance innovation through cross-functional collaboration and to quickly achieve broad market acceptance.

A Supply Chain That Runs Like Clockwork

Nothing quite equals the collaboration that makes ADI's manufacturing and supply chain run like clockwork. Over the years, ADI has embraced total quality management (TQM) and developed highly integrated manufacturing and planning systems to manage an incredibly complex process.

In 1982, when John Hassett joined ADI's Limerick operation, the company had thousands of customers and shipped thousands of units per day. Each manufacturing site handled its own operations. Wafer manufacturing could take up to 13 weeks. Assembly took about two weeks, and package options were usually limited to either plastic or ceramic dual inline packages (DIPs). Testing could take another two weeks. Then products were boxed and hand-carried in a shipment at the end of each quarter across the Atlantic to the distribution center in Norwood. By 2015, it was "a very, very different type of operation," said Hassett, who by then had risen to senior vice president of global operations and technology in charge of manufacturing worldwide.

During the 1980s, it became clear that ADI, along with the rest of the U.S. IC industry, had to up its game. The Japanese semiconductor industry had taken over the memory chip business, producing high volumes of high-quality, low-cost DRAMs and delivering them "just in time" to their customers. It prompted many companies, ADI among them, to embrace TQM techniques, pioneered in Japan, to increase quality and efficiency.

As management reviewed the company's operations, Ray Stata realized ADI had a challenging task ahead of it. In 1985, ADI was late in delivering 40 percent of its orders. In Wilmington, outgoing defect levels were as high as 12,000 parts per million. Yields for some challenging products were only 15 percent good parts. "We realized just how much we had to improve to meet our customers' expectations and how little time we had to do it," he said.

In 1986, Stata hired ADI's first vice president of quality and productivity improvement, Art Schneiderman, who set up a system for identifying and correcting quality problems. ADI's early quality improvement program was one of its first efforts to collaborate across disciplines and divisions. It elevated teamwork as a virtue in the manufacturing culture.

The company intensified its quality improvement efforts in the early to mid-1990s as ADI moved into high-volume markets and centralized its manufacturing, logistics and ordering processes. With Rob Marshall assuming responsibility for worldwide manufacturing and Gerry Dundon leading the supply chain planning, ADI put sophisticated IT systems in place. Centralized enterprise resource planning (ERP) and order management systems used hard data, intelligent business rules and algorithms to make accurate assessments and forecasts.

When John Hassett joined ADI in 1982, each manufacturing site handled its own operations.

By 2015, the size, scale and agility of ADI's worldwide operations were staggering. The company had a portfolio that included over 20,000 product models and was shipping billions of units to some 40,000 locations in 80 different countries. Half of ADI's revenue was from products that were designed, developed and manufactured at external fabs on external processes, and half in ADI's Wilmington and Limerick fabs using internal processes, some of which used hundreds of different process variations. Products were then shipped to any of several third-party packaging and assembly houses in Asia as well as ADI's facility in the Philippines. And despite all of this complexity, 96 percent of all orders were delivered within six weeks with only one defect per million units shipped.

ADI sustained the leading market share position in digital cameras thanks to the insight and execution of the Digital Imaging Systems (DIS) team, several of whom are pictured here receiving an award from Jerry Fishman. They pioneered a platform approach, not just out of necessity, given the pace of change in the consumer electronics market, but also to leverage their game-changing core technology time after time.

Adding more microphone components meant a larger, more elaborate wire harness, adding weight and complexity. Instead, Martin Kessler, an applications engineering manager who joined ADI full time in 1994 and had worked as a co-op student before that, suggested an integrated solution that reduced the number of connections required, thus reducing the amount of wiring in the vehicle. The team developed the AD2410 and the automotive audio bus (A²B) solution to distribute audio and control data together with clock and power over a single, unshielded, low-cost, twisted-pair wire.

Mark Gill led a team that concluded the products with the greatest return on investment were the ones where engineers balanced listening with challenging the client.

"The real differentiation for the customer happens if you've got people who understand the problem sufficiently well that they can challenge some of the customer's traditional assumptions," said Mark Gill, who joined ADI in 1989 and rose to vice president of the automotive business. "By doing that, we end up creating a different value proposition." Gill led a team that reviewed a series of products and found that those with the greatest return on investment were the ones where "our engineering teams not only listened, but we were able to balance listening with challenging, to get in the middle of this area, which we call insight."

ADI gradually elevated a culture that used to rely on the innovation of individual engineers, broadening it to synthesize ideas from different minds and perspectives to produce solutions for its customers.

"By working together across perceived boundaries at ADI, we can apply our imaginations to solve even more difficult problems," Roche said during his 2015 speech at the GTC. "And with the insights we bring through knowledge of our domain and understanding of markets and customers, we challenge each other and push the edge of what's possible."

The Definition of Innovation Expands

From the beginning, ADI success was based on innovation. The company's people, technologies and organization have all contributed to this innovation. Staying at the forefront of the industry requires ADI to continue innovating in each of these areas and also to take a broader perspective.

While Stata's philosophy of hiring great people and then getting out of their way remains, "systems thinking has taught us that there is more to it than just focusing on the individual," Stata said.

"Customers increasingly value our ability to engage in conversations about the possible and to think beyond components in order to deliver whole product solutions that will shorten their design cycles and get them to market faster," Roche said. "Our unique culture of self-initiative, inventive entrepreneurship and excellence, coupled with a spirit of collaboration and teamwork passionately focused on our customers, produces a virtuous cycle of innovation that will continue to serve us well."

CEO SPOTLIGHT

Fishman Left Legacy of Financial Excellence

As ADI's second CEO, he significantly strengthened the company's operations and its balance sheet.

1945	1971	1991	1996–2013
Born in New York City	Joined ADI	President	CEO

JERRY FISHMAN, ADI's second CEO, was about as different from Ray Stata as a person could be. Where Stata was soft-spoken and polite, Fishman was outspoken and assertive. Stata symbolized technology and engineering; Fishman symbolized business and profits. Stata wanted to take calculated risks; Fishman wanted to protect ADI's bottom line.

"Stata and Fishman were enormously different in everything except their devotion to ADI," said John Doyle, who served on ADI's board from 1987 to 2011. "They both valued the things that mattered most: people and innovation."

Fishman got noticed soon after he joined ADI as a product marketing engineer in 1971. He was not afraid to say what he thought, even to the CEO. "A lot of people were extremely deferential to Ray. I just was never one of them," said Fishman. "If I thought he was wrong, I'd just tell him, and I'd be blunt. What people always failed to recognize about Ray was that that's what he wanted."

Fishman wasn't shy about his ambition, either. He looked for opportunities to demonstrate his talent. "He sort of lived beyond his job responsibilities," said Stata. "His orientation was to look up a few levels beyond where he was in the organization to understand what the company was trying to achieve in the broader context." Stata got to know Fishman and started to see his leadership potential as they worked together to grow the semiconductor business and establish a fab in Ireland. He promoted Fishman to general manager of the semiconductor division in Wilmington in 1979, to vice president of the division in 1980, and then to group vice president and head of semiconductor operations worldwide in 1982. However, "I always had some reservations about how far he could go in ADI, because in some respects,

he was antithetical to the values that I espoused, at least on the surface," said Stata.

But as he watched Fishman handle greater and greater responsibilities, Stata gained more confidence in Fishman's capabilities and realized that he must clear a path to the top, or else Fishman would go elsewhere. He also realized that Fishman shared his values, including respect for people and innovation as the core of the company's success. He promoted Fishman to president and COO in 1991, and then to CEO in 1996.

During Fishman's tenure, revenue grew from $1.2 billion in 1996 to $2.6 billion in 2013. He was in on the ground floor of ADI's first major transition, the semiconductor business, and played a major role in ADI's transitions into high-volume markets and the evolution to system solutions.

Beginnings

Fishman was tough. He had to be. Born and raised in Flushing, a rough neighborhood in the Queens borough of New York City, he woke up every day ready to fight. "If you were not in somebody's face, they were in yours," he said. "It was just a question of survival." He developed a rough, intimidating exterior.

He was also smart. His father, an Eastern European immigrant who worked in the Garment District, preached education as the way out of poverty and encouraged Fishman to excel in school. But when he won a scholarship to the tony Phillips Academy in Andover, Massachusetts, Fishman wouldn't go. He compromised with his father by going to the best school that was close to home and free: the Bronx High School of Science. The trip to school took an hour and 45 minutes—each way—but he stubbornly stuck it out. "Once I start things, I really hate to give up," he said.

Fishman went on to earn four college degrees: bachelor's and master's degrees in electrical engineering, an MBA, and a law degree. But he never put much stock in all that education. He was simply casting about trying to find a profession, he said. He credited the street smarts developed while growing up in New York as his best training for business.

Management Style

When Fishman took over leadership of the company, it was an adjustment for employees. Unlike Stata, he was neither polite nor diplomatic. In fact, he liked to play devil's advocate to test people's character and intelligence. "Woe to the person who came to a meeting unprepared," said Vince Roche, who would succeed Fishman as CEO.

Unsuspecting job candidates got the same treatment. Marnie Seif, hired in 2006 as ADI's general counsel, recalls her interview with Fishman. "He takes me into the chapel and holds up my resume by its corner like it smells so bad he can't bear to hold it in his hands," she said. "'It says here that you went to Brown as an undergraduate,' he said. Then he throws it across the table and says, 'Why the hell did you do that?' That's how the interview started."

But there was a warm heart under that brash exterior, which Fishman showed more of as the years went by. The combination meant people both respected him as a leader and felt they could talk with him about problems. "On many occasions, I saw people seek out Jerry's counsel on very personal matters," said Colleen Donham, Fishman's assistant for 12 years. He would shut his door and talk with them for as long as they needed.

He had a wicked sense of humor that he used to either put people at ease or make them uncomfortable, as the situation required. He also used it to make a point. Maria Tagliaferro, who joined ADI in 1994 and became head of corporate communications, recalled that Fishman liked to lighten up his speeches with humor. During one GTC speech, as he described a difficult decision to reorganize the DSP group, he noted that successful gamblers know when to cut their losses. "We at ADI need to follow the gambler's creed," he said as Kenny Rogers' song "The Gambler" began to play. As the lyrics came through the speakers—"You've got to know when hold 'em, know when to fold 'em"—a screen behind Fishman showed the famous tableau of poker-playing dogs around a table.

"Working on the GTC keynote was always an adventure," said Tagliaferro. "Poker-playing dogs, Tinker Bell, Frankenstein and bobbleheads all showed up, and I bet most people could tell you the message behind each one. Jerry knew how to break the ice with a good a laugh, but mainly he knew how to make his point."

Although he valued technology and innovation, Fishman always emphasized that ADI was a business. Historically, the company operated as if great technology would always generate great profits. "It turns out, that's only half true," he said. "You have to do the right things technologically, and you have to decide to make money. You don't automatically make money even if you do the right things."

One of his biggest achievements was building up the company's balance sheet. He was fiscally conservative; his philosophy was to "capture the upside while protecting the downside," said Roche. Fishman did just that when the internet bubble powered an unsustainable bull market and raised company valuations, particularly tech stocks, into the stratosphere. The Dow Jones Industrial Average rose from around 2,600 at the start of 1991 to 11,500 in January 2000. ADI's stock price went from around $1.30 in 1991 to $100 in August 2000, splitting several times along the way. As COO, Fishman used those salad days to strengthen the balance sheet, raising cash reserves from $16.5 million in 1991 to $300 million by the time he was named CEO in 1996. By 2000, the balance sheet included $1.7 billion in cash and short-term investments. It was as if he foresaw the bursting of the bubble and subsequent crash of the stock market, which fell back to 7,300 by late 2002. The semiconductor industry experienced a severe downturn. Even though ADI sales plummeted from $2.6 billion in 2000 to $1.7 billion in 2002, the cash cushion Fishman had built enabled the company to weather the storm. It continued investing in R&D and maintained its profitability through it all.

Fishman had a screen in his office that tracked the share prices of ADI and its competitors in real time. He had a bell he would ring whenever the stock hit a new high, said Jim Fishbeck, head of investor relations. Fishman dedicated time to building relationships with Wall Street analysts and institutional investors, sometimes unexpectedly jumping onto Fishbeck's phone conversations with them. Suddenly, the investor found himself talking directly to the CEO. "He could do that because he had such a sharp mind," said Fishbeck. "He never had to look up facts. He knew them all."

Fishman's fatal heart attack in March 2013 shocked every employee at ADI. But the crisis did not extend to ADI's business operations. "We did not miss a step," said Donham. "That was because Jerry ran such a tight ship."

He would have been proud of that. "In technology companies, it's all about transitions," said Fishman. "Transitions in leadership, transitions in technology, transitions in markets. It's how you manage across those transitions, I think, that more than anything separates the companies that are going to last from those that don't."

How "the Chapel" United Two Voices

When Stata named Fishman president and chief operating officer in 1991, a special conference room was built between their offices in Norwood. The room had soundproof walls and one window, made of stained glass. They called it "the chapel." But the two men did more yelling than praying in it.

"We built it to be a place where Ray and I could go to iron out our differences in private," said Fishman. "Nobody in the company would know what went on in that room, and when we emerged, it would be with one voice."

After Fishman was named president and COO in 1991, ADI built a soundproof conference room between Stata's and Fishman's offices in Norwood that became known as "the chapel" due to its stained-glass window.

Their personalities were—at least on the surface—incompatible. Stata was a studious engineer, inherently interested in exploring technology; Fishman was a hard-nosed businessman who was more interested in profits. While Stata would push ADI technically, Fishman would push back financially. "Ray, we can't make any money on that!" was a frequent refrain.

Stata liked to get into the weeds. Even at annual meetings, he insisted on incorporating technical information like block diagrams and schematics into his presentations. Fishman avoided getting too technical and stressed more of the financial—tailoring his presentations for investors.

Although the quiet one of the two, Stata was more daring. "Ray was ever the entrepreneur," said Robbie McAdam, a 30-year employee who rose to become executive vice president of strategic business segments. "His natural inclination was to take risks." Fishman was careful, conservative and skeptical. He was rarely in favor of any acquisitions, for example. "The seller always knows more than the buyer," Fishman said.

But the two men were able to compromise in ways that strengthened the company. "There is no end of companies on the trash heap of history that had only the technological innovation or only the business discipline but not both," said Dave Kress. "The balance between Stata and Fishman really worked well and benefited us all."

As the years went by, the two men found they needed to use the soundproof room less and less for its original purpose. The chapel was dismantled in 2013.

Unconventional Thinking

Throughout its history, ADI has been willing to take the road less traveled (or in some cases not even paved). Ray Stata set the tone early on by forging ahead with his plan to make ICs, even when ADI's board of directors believed the company was doing just fine in modules.

Such willingness to break the mold was not limited to technology or business strategy. It also applied to marketing, sales and distribution. From its earliest days, the company established business units, sales offices and distribution across the globe. Even as most U.S. electronics companies kept their most important operations in the United States, ADI was planting seeds around the world, establishing significant manufacturing, design, assembly and test operations in places like Ireland, the Philippines, China and India. Unlike most multinationals, ADI gave foreign divisions a high degree of autonomy and encouraged them to develop high-level engineering skills. In sales and marketing, the company chose to educate customers rather than hard-sell them. Stata believed that if he gave customers accurate information, thus earning their trust, the sales would come. Whether it was through its "paper salesmen"—printing and mailing high-quality data sheets, application notes and the highly respected tech journal *Analog Dialogue*; through face-to-face seminars and meetings; or through its online community EngineerZone, ADI strove to be a learning resource for customers. It even eschewed third-party distribution for its first 25 years, preferring instead to deal directly with customers.

Global From the Start

From the beginning, ADI looked beyond its U.S. shores, both for markets and for innovators. The company recognized that its business was a global one and that it needed to be close to customers and sources of new engineering talent. Within a year of its founding, the company opened its first international sales and logistics office and ultimately expanded all over the world.

The selection and development of major international locations was guided by ADI's strategy of closely coupling product marketing and design with process development. It chose regions that had a motivated labor pool and excellent educational resources. It tapped into areas around the globe that gave it access to graduates from top engineering schools, which remains a key way ADI finds and develops technical talent. In addition, nearby universities meant employees could easily continue education throughout their careers, upgrading their skills as work and technology evolved. "We wanted to push our employees up the technology curve," said Ray Stata.

Unlike most multinationals, ADI gave foreign divisions a high degree of autonomy and encouraged them to develop high-level engineering skills.

Ireland

For ADI's first large-scale international expansion, it took a leap of faith into the land of the saints and scholars: Ireland. In the mid-'70s, the company was looking to build its second fab and scale up the manufacturing of CMOS converters that had been developed by Hank Krabbe's team at Micro Power's CMOS prototype fab in California. (See ADI Manufacturing Crosses the Pond, page 29.)

As the company searched for sites, Ireland caught its attention. The country was aggressively courting industry. Ireland had one of the highest unemployment rates in Europe and had experienced a mass exodus of population over the previous two decades. Thus, to bolster the economy and create jobs, the government had created the Industrial Development Agency (IDA Ireland). This agency offered rich incentives to attract companies: a subsidy of 40 percent of capital costs, employee training and a tax holiday until 1989.

The downside was that the country had little experience in semiconductor manufacturing, no infrastructure and no trained workers. Although GE had a facility near Galway that manufactured diodes, Ireland had no IC fabs. ADI would be the first.

Stata and Krabbe flew over to have a look. A team from IDA Ireland led them on a tour of possible sites, answering their questions and trying to assuage their concerns. David Hanna, who worked at IDA Ireland at the time, remembered having dinner with the two men. "One of the things that impressed me about Ray was his focus on the relationship between academic institutions and industry," said Hanna. Stata wanted close cooperation between his company and the academic world.

It just so happened that the new National Institute for Higher Education (NIHE) had opened in 1972 in Limerick. Its founder and first president, Dr. Ed Walsh, had taught at U.S. universities and wanted to replicate the cooperative engineering education approach he'd seen there. He saw that ADI could be a linchpin in that effort. If Limerick could land ADI, it would be a boon to NIHE, the local economy and even the national industrial environment because it would show that Ireland could attract sophisticated, high-tech industries.

Walsh invited Stata and Krabbe to visit NIHE in October 1975. "Ray told me bluntly that most colleagues advised him that Ireland could not yet provide the expertise and infrastructure for the manufacture of such a sophisticated product," Walsh wrote in his book *Upstart: Friends, Foes and Founding a University*. Yet after touring the facilities and talking with faculty and students, Stata was impressed. Stata asked Walsh if he would be willing to make changes in the curriculum to include certain textbooks—one on advanced materials and the other on electronics. "Without too much hesitation, [we] agreed to do as Stata requested, with the proviso that Analog Devices located in Limerick," said Walsh. Thus began a long and fruitful relationship between the company and the NIHE, which in 1989 would become the University of Limerick. (See ADI and the University of Limerick, pages 106-107.)

"The goals of NIHE and its commitment to strongly supporting ADI were the major reasons we selected Limerick over other locations," said Stata. Yet colleagues in the U.S. electronics industry thought it was a crazy bet, noting that Ireland had neither the infrastructure nor the technical manpower for IC manufacturing. In looking back, Stata said, "Our decision to locate in Limerick was the second-riskiest decision in ADI's history, after the decision in the late 1960s to enter the IC business. But it was also one of the most important factors in ADI's success."

ADI set up the Limerick plant in 1976 as a self-contained autonomous subsidiary with R&D, marketing, applications engineering and all other business functions except sales on site.

Ireland had deeply rooted traditions, which included blessing the building during the dedication ceremony of ADI's Limerick facility in May 1977.

In January 1976, ADI signed an agreement with the Irish government to set up an IC manufacturing plant in Limerick. The facility was dedicated during a ceremony held in May 1977.

Maintaining its penchant for the unconventional, ADI set up the Limerick facility not only as a manufacturing location but as a self-contained autonomous subsidiary. In addition to manufacturing, the site had its own R&D, marketing, applications engineering and all other business functions except sales. "We were very much in control of our own destiny," said Gerry Dundon, who graduated in NIHE's first class and joined ADI in 1977. "If things went wrong, we had only ourselves to blame. There was no real tight control from the U.S."

And that suited the Limerick employees just fine, for they were a scrappy lot of talented adventurers. (See "Tops of the Town" Showcased Limerick Talent, page 104.) They were eager to prove how valuable they could be to ADI, and fearful that the company might not stay. Limerick employees breathed a sigh of relief in 1984 when ADI decided to upgrade the facility from 3-inch to 4-inch wafers because it demonstrated the company's commitment to invest in the facility for the long term, said Bill Hunt, who was hired in Limerick in 1979.

The locals could be forgiven their insecurities. With a population of about 60,000 in the mid-1970s, Limerick was a mixture of agriculture and early industrial activities, such as garment making and flour milling. The decline of traditional enterprise left behind ramshackle buildings and high unemployment. In his office, the city manager had an aerial view of the town, showing scores of collapsed roofs, according to Walsh. When he was recruiting faculty for the NIHE, Walsh tried to bring them from the airport to the campus without seeing too much of the dereliction of Limerick. It was so bad that one American job candidate remarked that he had no idea Ireland had been bombed so extensively during World War II. It hadn't.

ADI's move to Limerick turned out to be good for both Ireland and ADI. The company's business success in Ireland became a showcase for IDA Ireland, helping the agency to lure other technology companies from abroad. Intel was persuaded to build a major fab in Dublin. "Every time a company was thinking of Limerick, we would run them over to ADI and introduce them to Hank," said Hanna. ADI's presence helped establish IC design expertise in Ireland as well as attract a range of related support industries. By 2016, ADI employed approximately 1,100 people in Limerick, mostly engineers, and contributed significantly to the local economy.

Irish Minister for Industry John Bruton opened the Limerick extension building in 1984.

As ADI started its Limerick operations, NIHE's first class was graduating, and the company hired at least four from the class of 1976, including Dundon, Mary Holmes, John Sullivan and Paul Egan. It was the start of a long symbiotic relationship between ADI and the institution. The ADI facility gave locally grown engineers—specifically the new graduates from NIHE—a ready-made employer. Several of NIHE's early graduates went on to become senior executives at the company, including Vince Roche, John Hassett, Rob Marshall, Robbie McAdam, Brian McAloon, Dick Meaney and Peter Real.

One of the first Irish nationals hired in Limerick was Pat Cunneen in June 1976. His initial assignment was to recruit top management and manufacturing talent to replace the startup team, which was to return to the States by 1979. Because there were no experienced IC people in Ireland, Cunneen reached out to other European locales to hire semiconductor expertise. These early hires included Tom Urwin, a Briton, and Pat Quinn, a Scot. In 1983, Rob Marshall and Robbie McAdam were hired from General Instrument in Scotland and a GE plant in Dundalk, Ireland, respectively.

"Tops of the Town" Showcased Limerick Talent

Limerick, indeed Ireland, is a small place where people who work together often play together as well. Rather than going straight home from work, many Limerick staff used to gather at Patrick Punch's bar in Dooradoyle, just a couple miles down the road from ADI's facility. A group known as "Mahogany Row," led by managing director Pat Quinn, would play pool against "Mulcahy's Maulers," led by Bill Mulcahy, the head of maintenance, according to Pat Cunneen, who was human resources manager at the Limerick plant for many years.

The Limerick employees were competitive in many ways. And when they were the newest division of ADI, they sensed that they had to be bold. "Being from a small, emerging island country, we were out to prove ourselves to the world," said Vince Roche, another NIHE graduate who joined the Limerick operation in 1988 and rose to become CEO of the company in 2013. The philosophy was "it's better to ask forgiveness than permission."

Camaraderie and collaboration were fostered in Limerick during work and after hours, transforming a "ragtag bunch of people" into a cohesive and highly productive team. Employees competed in a televised talent contest called "Tops of the Town" for several years. In 1985, ADI won the nationwide competition.

But the Limerick staff's most ambitious competition had nothing to do with business or technology. Rather, it was a nationwide talent contest called "Tops of the Town." Sponsored by the John Player cigarette company, various community groups and other organizations across Ireland competed by writing and performing their own one-hour variety shows. The final competition was held at The Gaiety Theater in Dublin and televised nationally. It was one of the most popular events on Irish TV.

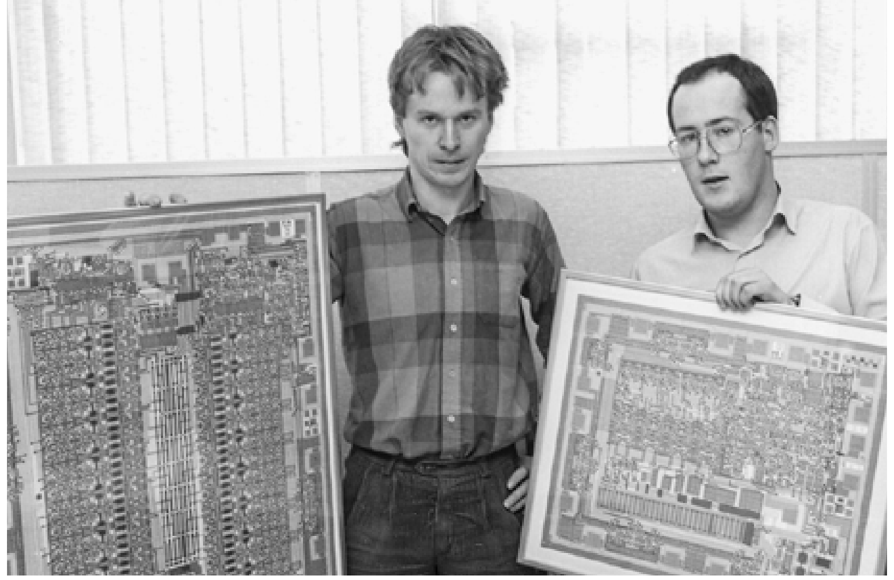
For several years running in the 1980s, ADI staff competed in "Tops," with Cunneen serving as musical director. One year, they placed second. Then, in 1985, the ADI team won the national competition, beating Digital Equipment Corporation, which assembled computers in Ireland.

"For me, 'Tops' was always a microcosm of what was special about ADI Limerick," said Cunneen. "The performances were a glittering showcase of the talent that lies deep in the roots of the Analog community in Limerick."

Meanwhile, the timing was phenomenal for the new NIHE graduates. "There weren't an awful lot of technologists around who knew the industry, and therefore if you showed any initiative at all, you got some brilliant breaks," said Dundon, who at age 28 became operations manager of the plant. "We were a ragtag bunch of people who really didn't know the semiconductor industry, but we learned quickly from a few experts and became a cohesive group."

It was more than just starting an IC plant in virgin territory. And it was more than just bringing up a new process technology. "It was a big challenge to get the right materials, including the raw silicon and gases," said Marshall. "This was an industry in its infancy. In many cases, you were doing your own thing in isolation. There were no other facilities around on which you could benchmark."

But Limerick eventually turned the corner. It was one of the first units of the company to effectively implement the total quality management principles Stata espoused in the early 1980s. Urwin and Quinn launched quality circles in 1982, educating employees on quality and world-class manufacturing standards. "When Quinn was manufacturing manager, this plant was leading the corporation in on-time delivery and quality," said Barry Macken, who was hired by Krabbe in 1977. "Urwin, Quinn and Marshall drove manufacturing excellence."



Both Dick Meaney (left) and Peter Real (right) joined ADI upon graduation from NIHE and went on to become senior executives. Meaney displays the AD7820 8-bit flash ADC and Real the AD7575 8-bit SAR ADC. Both products leveraged the process technology developed in Limerick.

Robbie McAdam (left) and Rob Marshall (right) helped navigate ADI's transition into high-volume markets.

When Brian McAloon became managing director in 1987, he brought "entrepreneurial flair" to the organization, helping expand its focus and identify emerging market opportunities, said Cunneen. "He would never accept that something couldn't be done," said Mike Britchfield, who joined in 1986. "He brought a 'can-do' attitude into the organization." Largely because of McAloon's management style, Limerick targeted new and unconventional markets for high-performance analog in the early '90s, moving into hard disk drives, mobile phones and video for PCs.

Meanwhile, ADI did not limit its university partnerships to just one. It developed a relationship with Gerard

Led by managing director Brian McAloon, Limerick expanded its focus and targeted new and unconventional markets for high-performance analog in the late 1980s and early 1990s.

ADI and the University of Limerick

ADI and the University of Limerick helped each other to take root and grow, a symbiotic relationship that continues to benefit both organizations to this day.

In the 1960s, Ed Walsh had come to the United States from Ireland to go to school, studying nuclear engineering and electron physics and then teaching at Iowa State University and Virginia Tech. In so doing, the Irishman developed an appreciation for the U.S. model of land-grant universities and cooperative education. When he returned home to found the National Institute of Higher Education (NIHE), he hoped to stimulate economic and social development by using the same approach.

Walsh learned that several multinational corporations in Shannon, about 11 miles from Limerick, had to import experts in such areas as electronics, advanced materials and business management because they couldn't find the high-skilled labor in Ireland. At that time, engineering education focused on the needs of traditional industry. In contrast, NIHE would offer degrees in electronics and computer systems. As for materials, "I think there was one metallurgist in the country with a doctorate, but no one with expertise in polymers," he said. "So a degree in advanced materials, including semiconductors, was a no-brainer." NIHE also offered degrees in business, management, marketing and European studies.

But Irish academia and the political establishment looked with disdain upon Walsh's ideas. In the 1970s, European universities were still classic ivory towers of academia. "Those who graduated from the universities had wonderful mathematical abilities and scientific knowledge but little understanding of or interest in the needs and opportunities associated with Ireland's emerging high-tech sector," said Walsh. "The ethos of the universities gave little encouragement to those who were interested in understanding and addressing the needs of the technological sector."

The World Bank, however, favored the U.S.-inspired model and agreed to help fund the institute. It understood "that we were also in the business of creating a new generation of young people who would be in a position to make things happen in Ireland," Walsh said.

Conversations with Ed Walsh, the founding president of the University of Limerick, persuaded ADI to build its new fab in Limerick.

The first class of University of Limerick students in 1972, when it was known as the National Institute for Higher Education (NIHE). ADI quickly developed a symbiotic partnership with the university. Hundreds of UL graduates found jobs at ADI; several of them rose to the executive level.

When Walsh met Ray Stata and Hank Krabbe, it was clear that NIHE was offering the kind of educational resources they were looking for, even if ADI's choice of Limerick would be seen as counterintuitive.

"Ray told me his colleagues thought he was rather daft because he was looking at Ireland," Walsh recalled. For NIHE, having ADI locate the first chip-manufacturing operation in the country in Limerick would signal that the region and Ireland could support the most sophisticated high-tech manufacturing. "It would trigger a wave of more advanced and high added-value investment that would not only create jobs but prosperity and wealth," Walsh said.

Once ADI arrived, Barry Macken, the head of NIHE's electronics department, invited Krabbe to help revise the curriculum. "So, this man who was so busy setting up this complex operation, he came regularly to our monthly meetings," said Macken. "He would comment on the curriculum. He would meet with students. He would help with their lab work. He was wonderful."

And of course, ADI got to pick out the cream of NIHE's crop. Many students spent time at ADI through cooperative education programs, "and when they graduated, they were recruited in such numbers that they formed the core of Analog's operation in Europe," said Walsh. In fact, ADI recruited more than just students. It also hired both Macken and Phil Burton, a senior member of the electronics engineering faculty, away from the institute.

"We wondered if that was going to sour the ADI-NIHE relationship," said David Hanna, who worked at IDA Ireland. "But Ed Walsh was a bigger man than that." Besides, having its faculty raided showed just how good the NIHE was. By hiring the NIHE's best and brightest, ADI was demonstrating that Limerick could supply the talent a tech company needed to be successful not only in manufacturing ICs but in designing them, as well.

In 2015, the University of Limerick opened the Analog Devices Building as part of a project to build a world-leading research center that integrated biological, chemical and environmental sciences with electronics engineering. Pictured: Ray Stata, UL Foundation Chairman Loretta Brennan Glucksman, Vince Roche and former UL President Don Barry.

Over the years, ADI continued to support the institute, which later became the University of Limerick. Burton returned to the institute in 1981, being named chair of a research professorship funded by ADI. Scholarships were established by ADI at the University of Limerick in honor of Krabbe in 2008 and in honor of Robbie McAdam in 2015. Also in 2015, the University of Limerick opened the Analog Devices Building, which housed an interdisciplinary program that brought pharmaceutical science, materials science, biomedical materials and engineering, and energy and sustainable environmental research together. The program and building were part of the €52 million Bernal Project, which focused on applied sciences and engineering.

Wrixon, a professor at University College Cork, about 50 miles south of Limerick. Wrixon founded the National Microelectronics Research Centre at the university in 1981. Now known as the Tyndall National Institute, this organization became a rich source of both process technology research and talent for ADI. Bill Lane, who was hired in 1987 and became Limerick's director of development, and Denis Doyle, who was general manager of Limerick manufacturing, both graduated from that institute.

When ADI acquired Hittite Microwave in 2014, it expanded its presence in Cork to include about 100 people.

ADI's venture in Ireland was one of the company's most important success stories. "It demonstrated ADI's tolerance for risk and willingness to blaze new trails," said Stata. "It was through self-determination, autonomy and the fierce commitment of the workforce in Ireland that ADI overcame the many unforeseen obstacles and emerged as the worldwide leader in the rapidly growing CMOS converter market."

Building upon its successful partnership with the University of Limerick in the 1970s, ADI partnered with the National Microelectronics Research Centre (later renamed Tyndall National Institute) at University College Cork in the 1980s.

The Philippines

Another bold international expansion occurred in 1982, when ADI established an IC assembly center in the Philippines. To compete against other semiconductor companies, ADI needed to lower costs and planned to move labor-intensive assembly operations offshore. It focused on the Philippines not only because of the cost of labor but also because it had native English speakers, a culture of solving problems and good engineering educational institutions, among them the University of the Philippines, Mapua Institute of Technology, De La Salle University and the University of Santo Tomas. For a location, ADI chose Cavite, a province on the southern shore of Manila Bay, just a few miles from the capital city.

In 1985, Ed Fortunado became the managing director of ADI's Philippine operation.

Most of the multinational companies with operations in the Philippines installed their own expats to run the operations, and Stata was strongly advised against hiring a local manager. Initially, he followed that advice. ADI hired George Leonard, an American working in Southeast Asia, to be managing director.

"Yet in every other country where we built an operation, we always went with the locals," said Stata. So when Leonard returned to the United States in 1985, ADI decided to offer the position to Philippines native Ed Fortunado, whom Leonard had hired as engineering manager. Fortunado had previously worked for Interlek Semiconductor Inc., ADI's subcontractor in the Philippines. He was not only knowledgeable about ADI's products but also familiar with the challenges the Filipino work culture presented, such as getting workers to use the right tools for the job. "At that time, resources were in short supply in the Philippines, so the mindset was to make things work with whatever you had on hand," Fortunado said. "MacGyver [a fictional secret agent in a U.S. TV series who solved complex problems using common materials and his Swiss army knife] was a hero for most people in the Philippines." Workers would use adjustable wrenches rather than the special tools designed for the delicate assembly work. Rather than machining parts to the proper level, they might use epoxy, which caused variations in the process. "That was the biggest challenge we had when we first started,"

ADI opened a test development lab at Mapua Institute of Technology in 2016. Manny Malaki, director of product test engineering, and Doc Reynaldo Vea, president of Mapua Institute of Technology, had the honor of cutting the ribbon.

The Philippines: Islands of Problem-Solvers

The Philippine culture is one of industriousness, dedication and creative problem-solving, which made for a perfect match with ADI's corporate culture. It made ADI Philippines a showcase for a variety of programs—some corporate and some grassroots—aimed at solving social and environmental problems.

In establishing ADI's first Leadership in Energy and Environmental Design (LEED) Gold-certified building, ADI Philippines renovated an existing building and recycled many of its structures and materials, including 60 percent of walls, 35 percent of floors, 88 percent of metal roofing and 100 percent of roof deck. The building was designed to collect rainwater, water rejected from the facility's water-treatment system and condensation from air conditioning. This water was enough to meet 100 percent of the facility's requirements for non-potable water, such as landscape irrigation.

When Typhoon Haiyan hit the Philippines in 2013, ADI's employees and facilities were not directly affected. However, the storm—which was reported to be the strongest recorded storm ever to make landfall—did affect many of their friends and families. ADI Philippines staff held a series of fundraising activities, which contributed to an overall donation of $180,000 from ADI and its employees worldwide. The money was donated to Habitat for Humanity, and many ADI Philippines employees volunteered to help Habitat rebuild and repair shelters.

ADI Philippines also ran many small grassroots programs to help the community. Once a year, for example, it brought in medical professionals such as optometrists and dentists to provide free eye and dental screenings to the local population. There were also many one-time programs designed to meet a specific need. In 2014, for example, it launched a program to help local school libraries. Employees donated almost 1,000 books, and the company donated equipment such as bookshelves, TVs and DVDs. Other programs included health and safety seminars for schoolchildren and parents, visits to orphanages and the homes for the aged, and environmental activities such as tree planting, cleanup of rivers and seminars on proper disposal of waste. ADI Philippines received the Philippine Economic Zone Authority Hall of Fame award for its work helping the community address these challenges.

After Typhoon Haiyan devastated the Philippines in 2013, ADI employees volunteered with Habitat for Humanity and collected $180,000 in donations through a series of fundraisers.

said Fortunado. But their culture of resourcefulness also made the Filipinos an excellent fit for ADI.

The workers learned, and the facility grew. By 1988, most of ADI's assembly and test operations from around the world had been transferred to the Philippines. As the company centralized manufacturing as a part of its "Creating the New Analog" strategy in the 1990s, the Philippine facility embraced total quality management (TQM) processes. Over the years, the staff increased its capabilities to include new product qualification. At Mapua Institute of Technology, ADI established a test development lab and took on that responsibility for many products. By 2004, the facility was working with designers at various sites around the world to develop the hardware and software to test increasingly sophisticated products. This synergy helped ensure that products were designed so that they could be thoroughly, efficiently and cost-effectively tested.

As more functions were centralized at the Philippine facility, its staff required ever closer collaboration with ADI engineers around the world. To forge those relationships and help ease the transition of certain functions, Filipino engineers moved to locations like Wilmington and Limerick to work with their counterparts for periods ranging from six months to over a year. "It was key to understanding how things were done," said Fortunado.

The Philippine location gradually evolved to become an important engineering hub for ADI. It established capabilities in design and layout as well as product applications. The company consolidated printed circuit board design and fabrication in the Philippines. As it moved up the learning curve, local educational resources were critical. In 2005, the University of the Philippines launched a master's program in microelectronic design. In 2010, ADI sponsored a professorial chair at the university, collaborating with the institution on wireless sensor node and energy-harvesting technologies, focusing specifically on power distribution and grid monitoring. And in 2013, ADI established an IC design lab at the university.

Although the university produced a steady stream of engineers with master's degrees, many of them left the country in search of opportunities to apply their microelectronics design skills, said Fortunado. Because most of the local semiconductor companies were strictly manufacturing, there just were not many design jobs. But in 2010, the Philippine staff started doing design and layout work with the university. Graduates went through ADI's immersion program, which provided training and development, collaboration and mentoring with a variety of assignments at sites around the world.

In less than five years, this design team grew from six to 50 engineers and went from block designs to full IC designs.

ADI has supported the master's program in microelectronic design at the University of the Philippines since 2005. The company established the Microelectronics Design Professorial Chair in 2010 and an IC design lab in 2013.

With more than 3,800 employees, the Philippine operation is ADI's largest single site in the world.

They started with power management switches, multiplexers and precision digital-to-analog converters. By 2015, the team was involved in advanced technology development and breakthrough designs, including a medical body area network (MBAN) radio project to provide vital-sign monitoring in health care applications.

The company also established a shared services center in the Philippines. In 2009, its call center began fielding employee relations questions and has since evolved to handle other functions as well, including information systems support and customer returns.

According to John Hassett, ADI senior vice president, global operations and technology, by 2015 80 percent of all ADI customer returns were serviced out of the Philippines. "The Philippines has grown from being a small, fledgling assembly operation in 1982 to being a very important contributor, not only to our manufacturing strategy but also in terms of servicing the overall needs of ADI's customers," he said. "The staff developed proprietary test algorithms and processes as well as factory floor and system management utilities that enable the facility to flex and support a high mix of products at world-class levels. The operations at Cavite are a key differentiator for ADI."

As of 2016, with more than 3,800 employees, the Philippine operation had become ADI's largest single site in the world. Over 33 years as head of ADI's Philippine operations, Fortunado led this transformation and impressive growth.

"Ed Fortunado has been a distinguished leader at ADI," said Stata. "He deserves tremendous credit for guiding the facility up the learning curve, in terms of quality levels and the technical sophistication of the work performed in the Philippines. It's an incredible success story." And another great example of the rewards along the road less traveled.

Designing Around the World

As the semiconductor industry grew, ADI expanded its design activity worldwide. In the 1990s, ADI's centralization of manufacturing along with the increasing capabilities in design software meant that circuits could be designed anywhere—in theory. In practice, however, shared values and a strong corporate culture were the true success factors when it came to globalization of engineering and design teams. The criteria for establishing a design center included the availability of specialized design expertise, proximity to great engineering schools as a long-term source of engineering talent and, in cases like India and China, a presence in significant emerging markets. ADI's first international design center was Barrie Gilbert's one-man band, set up in his U.K. home in the 1970s. Gilbert later moved to Oregon, where ADI established Northwest Labs, which became the model for design centers. By 2015, ADI had design centers around the world.

As of 2015, ADI operated design, development and field application engineering centers in more than 30 cities around the world.

India

In 1995, the company opened a product development center in Bangalore, India, with a staff of about 10 engineers, led by Reddy Penumalli, who left his role as CAD manager in Wilmington to return to India. ADI tapped the engineering expertise of India's technical universities, including graduates from the famous Indian Institutes of Technology. "We forged long-term relationships with the universities and the faculties to build up our talent base," said Dick Meaney, senior vice president of the industrial and health care business group.

Karthik Sankaran, who joined ADI in India in 1999, served as managing director of the India center for several years and by 2015 was general manager of embedded system products and technology. The team cut its teeth on a product that would push the state of the art in digital signal processing cost and performance. The first India-developed SHARC was the highest-performance floating-point digital signal processor (DSP) at the time and cost less than $10, which enabled ADI to enter consumer and automotive processor markets, Sankaran said.

With digital signal processing, ADI India led the company's transition from the handcrafted layouts it had used in analog design to modern, fully synthesized designs and quickly became a center of excellence for digital design, according to Stata. As their skills grew, Indian designers enhanced the SHARC architecture and built a strong design verification capability. The center also added product test engineering, applications, software and algorithm teams. In 2015, the Indian team designed the highest-performance processor ADI had ever developed, the ADSP2158x SHARC.

Allocating resources to build world-class digital design expertise was both unconventional and risky. Although other multinationals had designers in India, they limited the work to low-level design. But ADI encouraged its designers to fly as high as their wings could take them. "The concept of ownership exists here," said Sankaran, who previously worked at other chip vendors' India facilities. In other centers, designers often lacked the big picture and were doing bits and pieces of a design or software in isolation, he said. "The ADI India team develops the whole product. We try to understand the customer and market needs, define the product, develop it, support customers and then take the product forward to the next generation."

ADI India gradually moved beyond DSP chips to software, mixed-signal products and embedded microcontrollers. By 2015, it was bringing products to market for nearly every one of ADI's technology segments—from converters and linear to RF components and sensors. In fact, Stata considered ADI India to be leading the way in ADI's move to complex systems solutions. Its early work on DSPs led ADI India to adopt a systems perspective in chip architecture, software and algorithms. "In many ways [ADI India is] a microcosm of the third transition now underway at ADI," he said. "ADI India has been ahead of the wave in anticipating the shift to systems solutions by becoming a center of excellence for software and by providing algorithms and tools for audio, video and automotive applications." By 2016, the Bangalore center had grown to nearly 400 people, and plans were underway to double the staff in the next five to seven years.

> **"ADI India has been ahead of the wave in anticipating the shift to systems solutions by becoming a center of excellence for software and by providing algorithms and tools for audio, video and automotive applications."**
>
> **RAY STATA**

Analog Devices plans IC unit at Bangalore

K.C. Krishnadas
BANGALORE 16 SEPTEMBER

ANALOG Devices Inc. (ADI), the US $ 567-million American company and one of the major players in Digital Signal Processing (DSP) technology, may set up its integrated circuit (IC) design centre at Bangalore.

Speaking to *The Economic Times*, Mr Ray Stata, chairman and chief executive officer, ADI, said while Bangalore offered tremendous opportunities in software, a final decision has not yet been taken. The project is the fifth IC design project outside the United States, the other four being — Ireland, England, Japan, and Germany.

ness development, South East Asia and the rest of the world.

ADI would interact with local companies here to make sure the silicon used in the design is appropriate for future design projects. "We are looking for a software-silicon synergy," says Mr Mikhael Haidar. ADI is also tying up with Infosys, a Bangalore-based software firm.

However, industry-watchers ascribe the presence of such a top-heavy delegation at Bangalore to the likelihood of Bangalore being the most preferred choice for the IC design plant. With this tie-up, ADI would have a total of seven alliances with Indian companies which include BPL Systems and equipment to the IISc.

Mr Mikhael Haidar said the visit to Banaglore was to meet partners and explore opportunities including that of the location of the IC design centre. He said Indian companies can benefit by taking advantage of reference designs to meet specific needs of the Indian market.

This is because India has never had electronics' companies known abroad except in software. The work done by Infosys, according to Mr Stata, had brought the company tremendous recognition within ADI and demonstrated that Indian companies had design capacity and not just software talent.

ADI also has an alliance with an

In 1995, ADI opened an IC design center in Bangalore, India, to focus on DSP chip design.

Karthik Sankaran, general manager of the India Product Design Center, led the team that developed cutting-edge SHARC processors and forged ADI's transition from handcrafted layouts to fully synthesized digital design.

Vince Roche and Ray Stata joined employees celebrating 20 years in Bangalore in 2015.

China

ADI officially launched a design center in China in 2000. Its roots, however, go back to 1978; following U.S. President Richard Nixon's opening of relations with China, the Chinese government invited ADI to give product seminars in four cities. Through his relationships, Stata learned about a small digital design house in Beijing, launched by Ed Lien, called BIEC. "We used this company as an adjunct to one of the divisions, to do bits and pieces of designs as opposed to taking on broader responsibilities," Stata said. In 2000, ADI bought BIEC and it became the basis for ADI's first China design center. By 2002, the Beijing center had designed its first product, a 24-bit data acquisition system on chip, the ADuC834 precision analog microcontroller.

"ADI was one of the companies that got involved with customers in China early, particularly in the telecom and energy space," said Dave Robertson. "The emphasis for the China design centers was access to top talent—there are some great engineering universities in China. Of course, one of the important side benefits was that it allowed us to more effectively engage engineer-to-engineer with our customers in China."

The company also launched joint labs at six Chinese universities, including Tsinghua and Fudan, to recruit grads. As of 2015, ADI had joint labs with over a dozen universities in 19 locations throughout China and a second design center in Shanghai. ADI acquired a third design center, in Hangzhou, when it bought Linear Technology Corporation in 2016.

China had become one of ADI's largest and fastest-growing markets, especially in automotive, healthcare and wireless communications. As of 2016, revenue was growing in the double digits. The company's local design and application resources were particularly key to penetrating the China market. By being geographically close, ADI forged deep engagements with key Chinese customers and collaborated on technology road maps and products.

ADI's Asia headquarters expanded with the opening of the new Pudong location in January 2014.

A World of Talent

ADI continued to have active cooperative education programs with many universities around the world. If a university produced particularly high-quality engineering students, ADI sometimes established a design center nearby.

That was the case in Valencia, Spain, according to Meaney. ADI was hiring talented graduates from two nearby universities—Polytechnic University of Valencia and the University of Valencia—to work in the Limerick facility. But several engineers wanted to eventually return to Spain, so rather than taking the risk of losing the talent, ADI established a design center in Valencia.

One of the factors that enabled ADI to design products at so many different locations was its increasing use of CAD tools and shared libraries of design elements and process characterization, some of which included proprietary technology. In some projects, ADI staff "chased the sun" in their development of products. "Work being done in the Philippines, for example, could be handed off to somebody in Wilmington, who handed it back to the Philippines 12 hours later," said Hassett.

Employees gathered for the dedication of ADI's European Research and Development Centre in Limerick, which became the first building in Ireland to achieve Platinum LEED certification.

ADI's early decision to develop ADICE, its own version of a simulation program with integrated circuit emphasis (SPICE); its disciplined development of detailed models to simulate mixed-signal designs; and its purposeful application of industry-standard CAD tools turned out to be huge assets for the company. The tools allowed designers to handle more complexity and enabled groups worldwide to work on designs collaboratively. "It's a great way for design centers to build up their competency so they can one day be able to do full designs themselves," said Meaney.

Regardless of location, engineers could successfully design products even if they didn't have experienced process engineers on site, he said. "The CAD tools have captured enough of the variables of the process to allow the remote design center and people without hands-on experience in process technology to be successful."

ADI's investments around the world showed no signs of slowing down. ADI's 2014 acquisition of Hittite Microwave added several new design locations, including Cairo and Istanbul. In 2015, the Philippines opened a new 280,000-square-foot building and Limerick opened a 140,000-square-foot European R&D Centre. The centre incorporates fab engineering, product engineering, customer applications and R&D teams, enabling innovation and collaboration across technologies and disciplines.

From Paper Salesman to Online Engineer

Sales did not come naturally to Ray Stata.

"I'm basically an introvert and a nerd at heart," he said in a 2009 interview with *The Newsletter of the Center for Ethics and Entrepreneurship* at Rockford College. But in his first job—as a Hewlett-Packard (HP) salesman in the early 1960s—Stata was forced out of his comfort zone. The results surprised him.

"The particular style by which I engaged with people worked remarkably well," he said. He was sincere, knew his products and listened carefully to his customers. He built relationships with them based on trust, honesty and reliability. So when he explained how HP products could solve their problems, he often closed a sale. "I learned that you really don't sell technology-intensive products," said Stata. "You basically facilitate buying decisions."

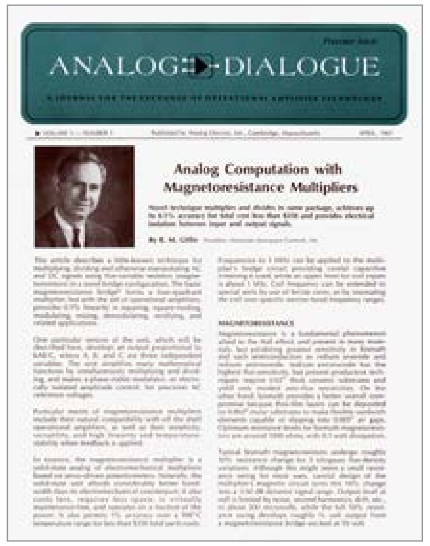
That lesson became the foundation of ADI's sales, distribution and marketing strategy. Rather than a "hard sell," an approach based on education and customer service worked well for ADI. The company was creating a market for new types of components based on innovative technologies, such as data converters and analog ICs. If engineers were to buy, they needed to understand what the products were, how they worked and how they could be used to solve their problems. Uncharacteristic for a small company, ADI had a broad and varied customer base. It wasn't too long before dozens of different products were being sold to hundreds of customers. And then hundreds of different products sold to thousands of customers, all buying in relatively small quantities. How could a small sales organization reach so many customers?

The Paper Salesman

For the first couple of decades of ADI's history, the answer was "the paper salesman." ADI reached most customers through high-quality printed information. It paid special attention to publishing detailed data sheets and application notes that contained realistic specifications, which customers appreciated. Whereas ADI's competitors quoted "typical" specifications, ADI quoted "minimum" and "maximum" specifications based on testing every component and verifying that performance was within the specifications, an ADI practice that continues to this day. Ten-page data sheets were not unusual. By 2015, some data sheets had grown to more than 100 pages, more akin to a reference manual, in order to define and characterize the performance of complex application specific ICs (ASICs).

"The mantra was: 'There is no such thing as too much technical information,'" said Dave Kress, who worked in marketing. Such information included diagrams of sample circuits and illustrations of how to use the new technology.

"The reason ADI put such a tremendous amount of effort into characterizing the products was so that when we delivered the product, the answers to the first questions the customer would have were right in front of them," said



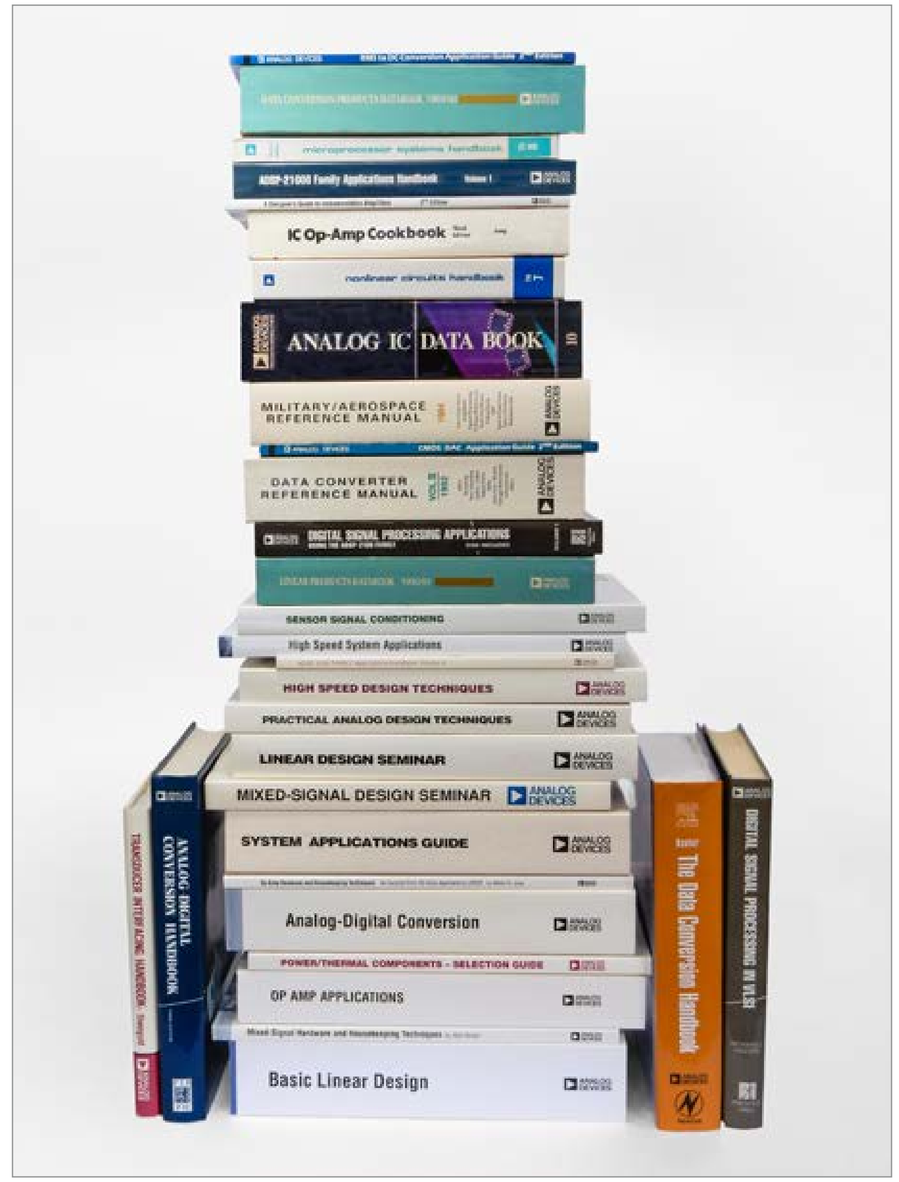
Analog Dialogue, **first published in 1967, is the longest-running in-house publication in the electronics industry. Written by ADI engineers for engineers, the articles provide insights related to circuits, systems and software for real-world signal processing system design.**

Stata, who also called the approach the "augmented" product. "They didn't have to call us. They had what they needed to know to get their job done."

Stata believed educating the customer was the best way to not only win a design for ADI products but also to build ADI's brand and create loyalty with customers. Central to this strategy was *Analog Dialogue*. In 1967, Stata launched the technical journal and made it available free to subscribers. The first issue contained three articles, including one by Stata on "Operational Integrators." The final page of the issue listed other publications worth reading, including from ADI competitors Philbrick Researches and Burr-Brown Research Corp. At the top of the list was the 1965 Philbrick *Applications Manual for Computing Amplifiers*, which was described in the list as a book that "every op amp user should own." The manual, which remained a classic, was edited by Dan Sheingold.

Sheingold had joined Philbrick in 1949 and had a variety of responsibilities. "I did drawings. I did testing, just about everything that George [Philbrick] didn't want to do," said Sheingold. He was there when Philbrick designed the first commercial op amp, the K2-W, in 1952. He also edited Philbrick's newsletter, *The Lightning Empiricist*. "But mostly I was going out in the field, talking with customers and teaching them how to use these things because analog was always sort of mysterious, and still is."

But by the mid-1960s Sheingold had become an engineer without portfolio.



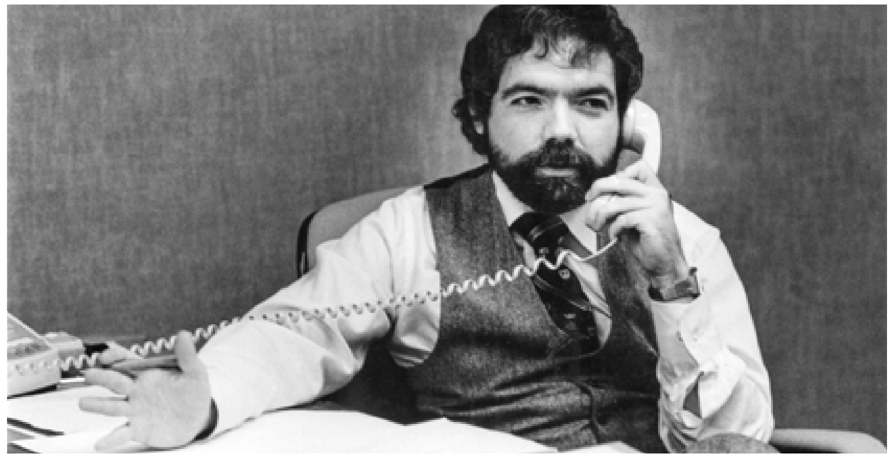
ADI's technical publications, which became known collectively as "the paper salesman," provided customers with detailed information about product specifications and performance. Many were edited by Dan Sheingold.

Teledyne had acquired both Philbrick and Nexus Research, and the resulting staff shuffle made Sheingold "a staff consultant where basically I didn't have to do anything," he said. Yet he was still collecting a handsome salary. "I used to go down to Norwood Airport and take flying lessons."

Stata had already lured several sales and marketing people away from Philbrick when he invited Sheingold to dinner at Jimmy's Harborside Restaurant in December 1968. ADI needed a talented editor to take over *Analog Dialogue*, Stata told Sheingold, a task that Stata had shouldered to that point. He also wanted Sheingold to write an applications manual for data converters, which at that time were as foreign to most engineers as op amps had been many years earlier.

Stata knew Sheingold was the man to explain what converters were and how to use them. After 19 years at Philbrick, Sheingold went to work for the upstart ADI in early 1969.

For 44 years, Sheingold edited *Analog Dialogue*, setting "the gold standard of analog circuit prose" and making it the longest-running in-house publication in the entire electronics field. (See The Gold Standard of Analog Circuit Prose, page 127.) ADI published Sheingold's *Analog-Digital Conversion Handbook* in 1972. Sheingold edited several other classics, including *Non-Linear Circuits Handbook* and *Transducer Interfacing Handbook*.

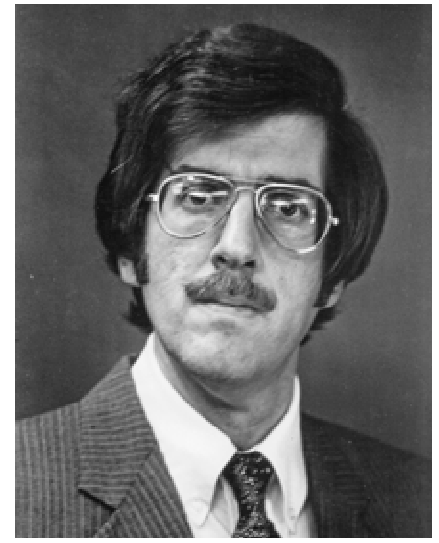


In the mid-1970s, Dave Kress and other ADI employees answered customers' questions over the phone and led education seminars for customers around the world.

The paper salesman—which included *Analog Dialogue*, honest and thorough data sheets, detailed application notes, catalogs and handbooks—worked amazingly well. In fact, the company was sometimes surprised by orders from far-flung organizations that had somehow gotten hold of a catalog. In 1978, for example, a half-million-dollar order came in over the transom from a company in China. "We have no salesmen over there," Stata told *The Boston Globe*. "The order came out of the blue."

The high-quality publications also opened doors for the small sales team. "Marie Etchells ran the graphics department, and she assembled these enormous data books," said Jim Fishbeck, who joined ADI in 1972 and rose to director of corporate communications by the time he retired in 2002. "The salesmen liked those because that was one way they could get in to see the customer. They could call and say, 'Hey, Bill, I've got the new data book. Can I come and see you today?'"

Equally important was ADI's technical support hotline, which was started by Jeff Riskin, an engineer and journeyman problem-solver who, during ADI's early years, tackled management and technical challenges. ADI offered technical and applications support by telephone starting in the mid-1970s. Initially, two engineers fielded these calls, speaking engineer-to-engineer with customers, trouble-shooting issues, and writing and editing data sheets. As the company grew and expanded into semiconductors, call volume expanded significantly—by the mid-1990s, ADI would field 200 calls a day. The applications support team grew along with it, serving as a training ground for salespeople and eventually feeding into a nascent group of field applications engineers. ADI began to gather information from application support calls, which enabled the company to identify trends and product opportunities.



Jeff Riskin led ADI's technical support hotline, which established engineer-to-engineer communications for customers on demand.

As products became more complex, and the need for customer support expanded, ADI provided more opportunities for face-to-face education,

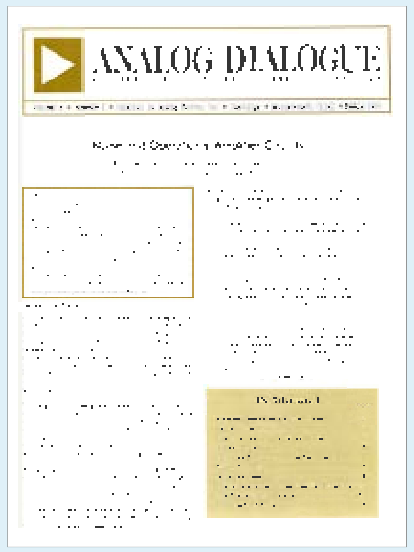
Analog Dialogue Chronicles Industry's Evolution

When ADI published the premiere issue of *Analog Dialogue* in 1967, the cover tagline said it was "A Journal for the Exchange of Operational Amplifier Technology." How the tagline changed over the company's first 15 years illustrated how quickly ADI, and the industry, developed.

While the tagline changed, the mission of *Analog Dialogue* remained the same: to deliver in-depth engineer-to-engineer technical articles addressing tough, real-world design problems. As ADI's product portfolio expanded, so did the spectrum of article topics contained in *Analog Dialogue*.

1969

"A Journal for the Exchange of Analog Technology."



The tagline dropped "op amps" after ADI acquired Pastoriza Electronics. ADI's business was starting to shift toward data conversion and mixed-signal processing.

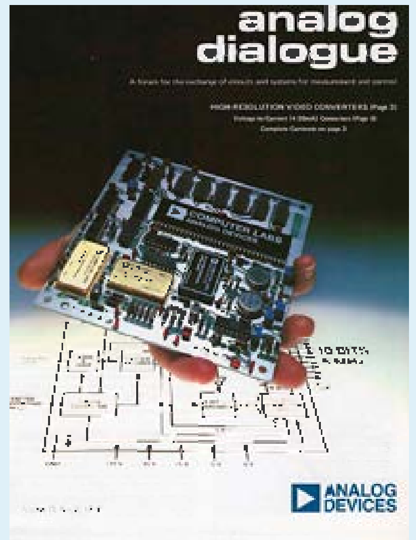
1971

"A Forum for the Exchange of Circuit Technology: Analog and Digital, Monolithic and Discrete."

The tagline changed again after ADI entered the IC business. Between 1971 and 1979, ICs would grow to be more than half of ADI's revenue.

1979

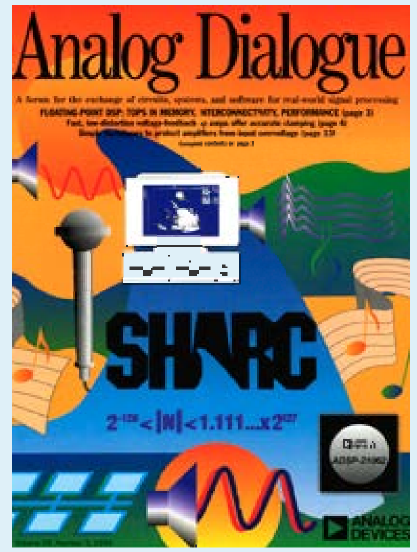
"A Forum for the Exchange of Circuits and Systems for Measurement and Control."



The new tagline reflected the fact that ADI offered more complete printed circuit and systems products before systems-on-chip were possible.

1984

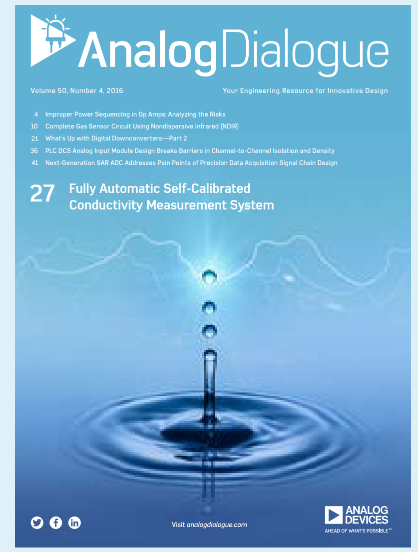
"A Forum for the Exchange of Circuits, Systems and Software for Real-World Signal Processing."



ADI was entering digital signal processing and positioned itself as the expert in real-world signal processing. The tagline remained the same for the next 31 years.

2016

"Your Engineering Resource for Innovative Design."



The new phrase tied the company's past to its future, with its focus on technical innovation enabling customers to do things that they had never done before.

launching its next unconventional marketing tactic—a worldwide seminar program for customers. Starting in 1976, Kress, Paul Brokaw, Fishbeck and others spent much of their time on the road. "We would see thousands of customers around the world over the course of six or eight months," said Kress. The seminars provided such great information (and a lighter promotional touch than most vendors) that engineers flocked to them for decades, until the ubiquity of the internet changed how engineers learned and researched.

Early Emphasis on Selling Direct

While data books and educational seminars reached a large number of ADI's customers, the company also built a direct sales force that focused on education, customer service and applications engineering. In 1966, Stata hired Mel Sallen, who had a master's degree in engineering from MIT, as ADI's first sales manager. One of Sallen's first tasks was building a direct sales force, domestically and internationally. He helped establish ADI's first international sales subsidiary, in London. Within three months, that office was generating profits. ADI then quickly established sales subsidiaries in Germany (1968), France (1969) and Japan (1970).

"Setting up these direct sales operations internationally, for a company our size, was unheard of," said Stata. Most electronics companies used manufacturer's reps for foreign sales and distributors for their domestic sales to small customers, focusing their direct sales and support on major high-volume

Kozo Imai established ADI's sales subsidiary in Japan with Mel Sallen in 1970.

customers. But since most of ADI's sales came from many customers buying relatively low volumes, ADI assumed the distributor function itself. "This paid off tremendously because we did a better

Franz Donaubauer, Val O'Donohue, Marie Etchells and Keith Rutherford (front row from left) and other sales reps attend the 1980 International Sales Conference. By bucking the conventional wisdom of using distributors and setting up direct sales operations internationally, ADI seized a competitive advantage in fragmented markets.

Mel Sallen: An Engineer's Salesman

Mel Sallen, ADI's first sales manager, set the foundation of ADI's sales organization.

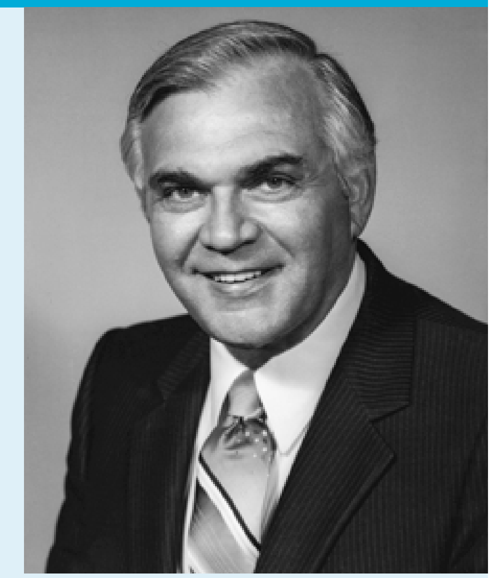
His hiring in 1966, however, was inauspicious. In the early days, Stata was less than forthright with prospective hires about ADI's headquarters in a rundown area of Cambridge, Massachusetts. ADI's executive offices were in the basement of an old brick building. "When you looked out the windows, you saw the hubcaps of cars in the parking lot," said Stata. So when he recruited Sallen, Stata met him for lunch at the swank Sonesta Hotel on the Charles River.

After joining, Sallen was shocked at the company's austere digs. But the bad conditions produced a good result for the head of sales: Rather than stare at hubcaps, Sallen hit the road to visit customers. Sallen had a master's degree in engineering from MIT and had worked as an engineer before getting into sales, so he could talk with customers about technical issues. He doubled sales and profits in his first year with the company and proved to be such an effective salesman that ADI staffers nicknamed him "Mel Sell 'Em."

He established international subsidiaries in London, Germany, France and Japan in his first four years with the company. The Japanese subsidiary came about when he was approached by Kozo Imai, who worked for a Japanese distributor. Imai, who spoke very little English, kept saying he wanted to form a "ja-benture," Sallen recalled. "It took me three days to figure out that he meant 'joint venture.'" Sallen told Imai that ADI did not do joint ventures but offered him a job that led to the creation of Analog Devices Japan Inc.

He was a fearsome negotiator. Stata took advantage of Sallen's skills to buy a home in Brookline in 1972, asking him to negotiate a deal while Stata and his family were on vacation. When they returned, "we owned a 7,000-square-foot Tudor on 3.5 acres of land for only $200,000, which was a lot less than we were willing to pay." Sallen was similarly aggressive in getting good deals for ADI as well. But once a deal was struck, Sallen made sure that ADI held up its part of the deal.

In fact, beyond building sales, Sallen's most lasting impact on the company was his advocacy for the customer. "He



Excellent sales skills earned Mel Sallen the nickname "Mel Sell 'Em."

understood that the purpose of the company was to satisfy customers when, under the stress of growth, many others were preoccupied with internal problems and turf wars," said Stata. "Mel was both respected and feared for his avid support of the customer's position."

For example, he would return from sales trips with a pocket tape recorder full of memos he had dictated about customer complaints and problems. His administrative assistant would type up memos based on the tapes, and engineers cringed when they received them.

"We didn't necessarily like Mel's post-trip memo blasts, but we understood what he was doing," said Jim Fishbeck. "Taking care of the customer was of paramount importance. Even at his most bombastic, the attacks were never personal. They were always aimed at doing the best job he could for ADI's customers."

"Mel was both respected and feared for his avid support of the customer's position."

RAY STATA

job of working with our customers than distributors and representatives could at the time."

International sales skyrocketed, rising to 43 percent of total revenues by 1975. By 1995, they were 56 percent of revenues, and by 2015, they constituted 61 percent.

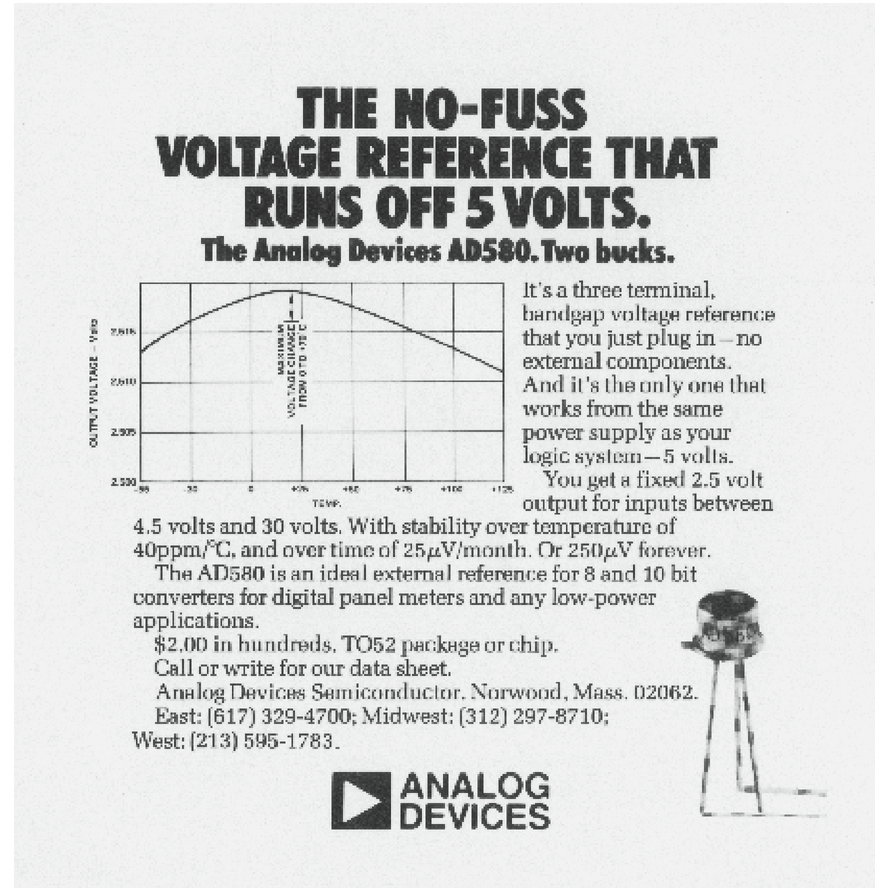
Although ADI was bucking the conventional wisdom of using distributors, there was a method behind the madness. Given ADI's customer base and the degree of education and technical support required, distribution made no sense, Stata figured. Distributors typically stocked only the parts with the highest turnover. If a customer ordered a part the distributor did not have in its warehouse, it would have to turn around and order from ADI. Because of the nature of ADI's customers, that would happen frequently. Why not just serve these customers directly? It would reduce delivery times and save margin, Stata reasoned. Plus, it maintained a direct relationship with customers. So, both domestically and abroad, ADI stocked and shipped its own parts, regardless of the quantity ordered. "This strategy of forgoing distributors was unique in the history of the semiconductor industry," he said. "It definitely gave us an advantage over our competitors in these fragmented markets."

"A key aspect of our business was the direct interface with our customers in terms of technical information and application assistance," said Stata. "In many respects, we were selling not only the hardware but also service in terms of the proper solution and application of this hardware. You really couldn't accomplish satisfactory service to customers in the foreign markets through representatives alone. You had to know your product."

> **"You really couldn't accomplish satisfactory service to customers in the foreign markets through representatives alone. You had to know your product."**
>
> **RAY STATA**

ADI differed from competitors in its pricing strategy, as well. Traditionally, component companies charged a higher per-piece price for small quantities of parts. If the component vendor won the design and production order, it would grant a steep discount on the price, depending on volume.

In the early years, when ADI was fighting to get recognition and market share for its module business, Stata decided ADI would set a lower price than competitors for small quantities. The strategy was to seed the market, to encourage engineers to buy ADI parts and play with them. Stata knew that getting his parts into more engineers'



Product ads complemented the detailed technical information ADI offered customers through "the paper salesman."

Making the Sales Call, Circa 1980

A photo from ADI's 1980 annual report shows sales engineer Max Snapp making his weekly sales call at Beckman Instruments, a diversified manufacturer of analytical instruments and health care electronics.

Salesmen like John Gasking and Max Snapp were the friendly faces of ADI as the company evolved its sales strategy in the 1970s and '80s. A feature in the 1980 annual report, excerpted here, painted a portrait of the ADI salesman as a force of nature: a nimble, knowledgeable, boots-on-the-ground figure doing what Gasking called "providing maximum application support."

The grey Cortina station wagon pulls into the visitors' entrance of the mammoth Marconi Avionics facility very early most Thursdays. Sales Engineer John Gasking comes prepared with a trunk filled with catalogs, application guides and data sheets, from which he will fill a large briefcase.

Gasking chooses to spend one full day a week at Marconi, a diversified manufacturer of aircraft equipment for both commercial and military use. His first stop is Engineering, where three senior design engineers have questions about an intricate new assembly for a NATO project. For the next two hours, he will answer complex technical questions about the design features and limitations of the device.

"It's a pleasure to work with engineers who want to be challenged," he says. "These engineers are restless; they won't settle for the way things were done last year."

His next stop is the quality assurance lab, where a problem has arisen. A lid has come detached from a hybrid converter, and it has technicians worried that a similar fate may await other units in the lot.

"One of my jobs is to troubleshoot field problems," Gasking says over his lunch of soup and tea. "I try to protect Analog's reputation, while looking out for the best interests of my customers. If I shrug off a problem now, it could have far worse repercussions down the line."

The balance of the day is spent in Marconi's two purchasing operations. Analog has several sizeable orders pending on the military side, and Gasking is anxious to see what has cleared.

He will spend nearly an hour explaining pricing structure, all the while listening for clues as to what quotes may have been offered from competitors. Satisfied he has left everyone with a thorough understanding of his quotation, he closes his briefcase. It is after 6 p.m.

Gasking's long hours and perseverance will pay off in many ways. In addition to a substantial order volume from Marconi's Rochester facility, Gasking has established a reputation for service which earns Analog Devices additional business when engineers, technicians and managers relocate to other jobs.

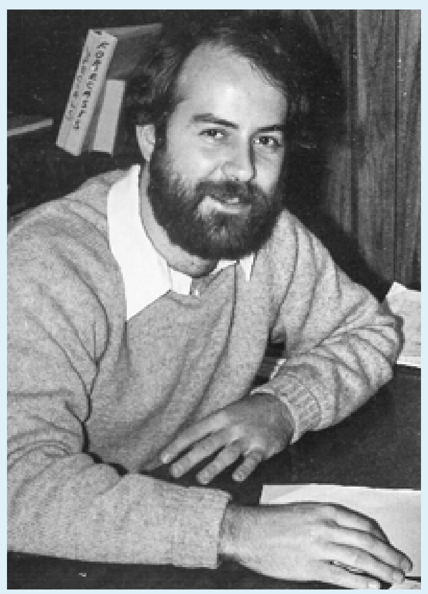
"It's a satisfying career," Gasking concludes over a glass of beer. "The sense of accomplishment is there. I wouldn't want it any other way."

Marketing Paints Small Details Into Big Picture

Being an engineer-centric company, both in its own culture and in its outreach to customers, ADI's marketing and PR approach sometimes seemed dry, low-key and overly technical, at least to non-engineers. For example, a columnist in the newspaper *Mass High Tech* once bemoaned the lack of attention ADI got from the press. Arguing that the company deserved more attention, the writer implied that ADI could do a little more to sex up its communications.

"Analog Is Everywhere" represented a radical departure from ADI's previous corporate branding campaigns.

"The typical Analog release reads something like this beauty from last week," the column said. "'Analog Devices has introduced the ADE7757, a high-accuracy electrical metering IC with an on-chip oscillator and direct stepper motor drive capability.' Woo-hoo!"



Mark Skillings, who joined ADI in 1972, was marketing director during the seminal "Analog Is Everywhere" campaign.

Such an information-packed sentence may not have impressed journalists, but it was information that ADI customers wanted. In fact, most analog companies' advertising was based on speeds and feeds. "The heart of each [marketing] campaign is an emphasis on product capability," explained ADI's 1980 annual report. "Specification detail, price, application potential and availability are routinely incorporated in all copy on the premise that the ultimate buying influence is the system designer."

That's why for much of ADI's history, advertising and marketing "was all about blocking and tackling," at least for analog technology, said Mark Skillings, who joined ADI in 1972 and who led marketing for the analog business. "Everything was at the component level and was about technology superlatives such as 'fastest' or 'lowest power.' These were important facts but not very sexy."

In 2005, ADI started to buck convention with a corporate branding campaign called "Analog Is Everywhere." It was a radical departure. "Since it was a diversion from superlatives-based advertising, I knew we would have critics," said Skillings.

But marketing conducted customer research that convinced management to approve the campaign. "It helped bring to life the concept that analog was becoming more important even as the world was said to be going more digital," Skillings said. And through the double entendre of analog the industry and Analog the company, "it emphasized that Analog Devices was the company most capable of doing analog successfully."

hands was critical to get design-ins. But there was another, more important, reason. By charging less than competitors for small quantities, ADI created an impression that its overall prices were lower. While they were lower when an engineer bought a few parts, ADI's volume prices were comparable to the competition, Stata said. "That discount pricing strategy turned out to be a big deal in terms of early market penetration," he said. And since ADI didn't incur the expense of distributors for small quantities, it could afford a lower price.

It wasn't until 1990, when ADI sales had reached $600 million, the company had acquired Precision Monolithics Inc. and it was beginning to sell to high-volume customers, that ADI shifted a portion of sales to distributors in the U.S. market. By that time, its direct sales team needed to focus on larger customers.

ADI's sales and support teams met the evolving needs of customers in the 1980s by making its popular selection guides available on floppy disks.

Listening to the Customer

ADI always took its cue from the customer. When Stata was trying to figure out how to expand beyond op amps, for example, he surveyed his existing customers. The results clearly indicated ADI should move into data converters, and the company went on to lead that market.

ADI hired engineers for its sales and marketing staff because it wanted people who could listen to, and understand, customer needs in depth. "By learning the customer's products and where they wanted improvements, we were able to identify new product opportunities and even whole new product lines," said Stata. Such engagement led to many innovative ADI products, including radio frequency (RF) components, isolation amps and synthesizers.

Later, as total quality management and "Creating the New Analog" initiatives took hold, ADI took listening to a new level by using voice of the customer (VOC) techniques in order to uncover latent customer needs while reining in the temptation to add unnecessary bells and whistles that could increase complexity and cost. Specifically, the techniques helped ADI to differentiate between the must-haves and the nice-to-haves, thereby identifying which features would actually add value for the customer. The first product upon which ADI applied VOC, AD676, was highly successful, and VOC became ingrained as part of ADI's product-definition process in horizontal markets.

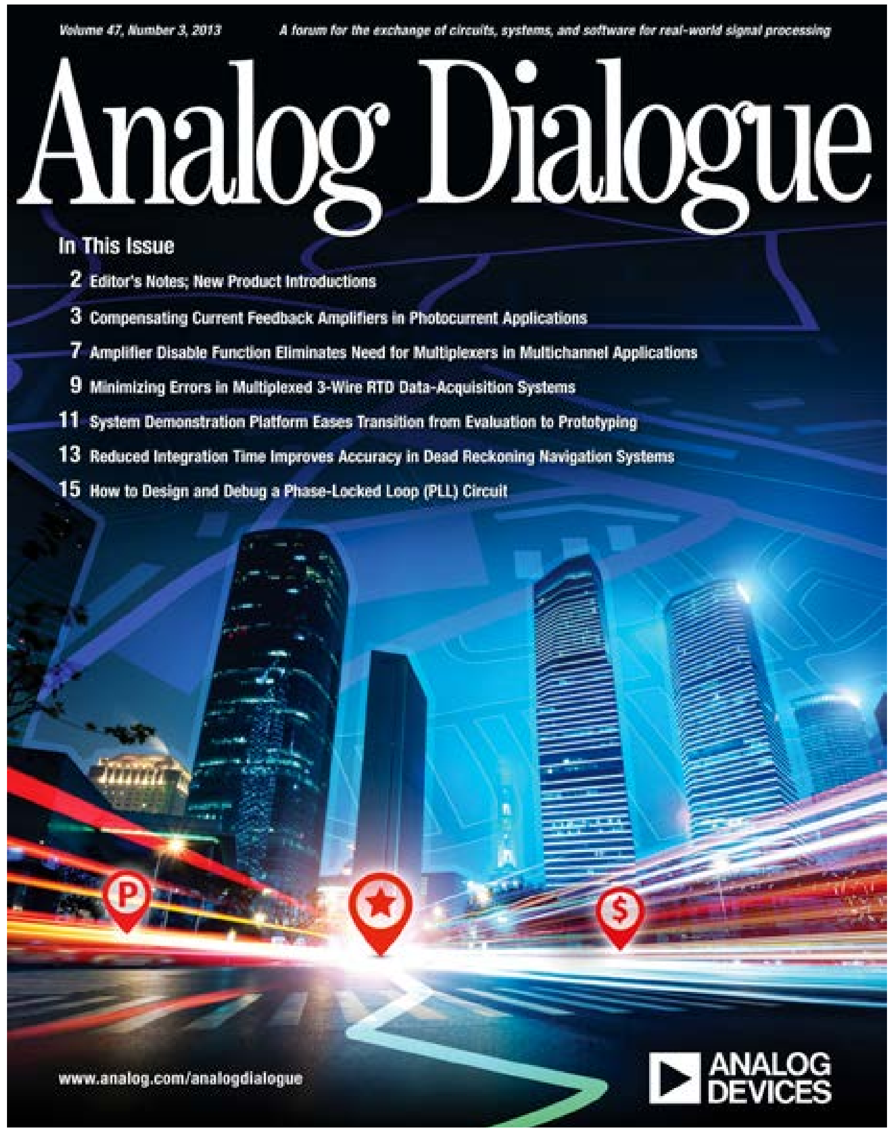
As the electronics industry evolved, customers became more interested in systems solutions than separate components.

This trend started in the PC business in the 1990s and gradually extended to other vertical markets. PC makers originally built their own motherboards and add-on boards. For example, there might be more than 30 engineers working on just a computer audio subsystem. Over time, semiconductor companies developed reference designs and provided the drivers. The 30-plus engineers at the PC vendor were reduced to one person, who managed the subsystems design. "Over the last 20 years, that has happened in almost every vertical segment, including aerospace and industrial," said David Babicz, who joined ADI in 1992 and rose to become the company's director of global alliances. "Customers now expect us to provide more of the subsystem, the design services and the software," Babicz said. "We're shaving six months off of their design cycle because we're doing a significant portion of that upfront work."

Scott Wayne worked with Dan Sheingold for many years and succeeded him as editor-in-chief of *Analog Dialogue* in 2013.

New Ways to Augment the Product

In the 21st century, the "augmented product" started including more than data sheets, application notes and a technical journal. "*Analog Dialogue* is still part of it, but by 2015 the complete product means not only technical documentation but also software, evaluation boards, simulation models and things like that," said Scott Wayne, who joined ADI in 1979 as an analog designer, worked with Sheingold on *Analog Dialogue* and became editor-in-chief after Sheingold retired in 2013.



Under Scott Wayne's editorship, *Analog Dialogue* continued its evolution to include more complete solutions, including platforms, systems and services.

As of 2015, ADI had 100,000 active customers, and if the smallest sales and customers were counted, that number rose to more than 220,000, said Thomas Wessel, vice president of worldwide sales, who joined the company in 2003. The many elements of the augmented product formed a strong foundation to engage and support ADI's diversity of customers and enable designs early in the decision-making process, he said. "We constantly aim to reach further into the customer base to control our

The Gold Standard of Analog Circuit Prose

"When I worked at ADI, every new engineer received a package of materials on his first day of work. The package included several books edited by ADI's Dan Sheingold—*Data Conversion Handbook*, *Non-Linear Circuits Handbook*, and later *Transducer Interfacing Handbook*—plus the most recent issues of *Analog Dialogue*."

Dan Sheingold served as *Analog Dialogue* editor from 1969 until his retirement in 2013.

That is how Doug Grant, who worked at ADI from 1976 to 2008, opened an article he wrote about Sheingold's retirement in 2013. Sheingold's long career and exemplary writing style influenced generations of analog engineers, said Grant. "To quote Dave Kress, Sheingold 'taught so many of us that writing about very technical information does not provide an excuse for bad writing; rather, good writing does a better job of engaging the reader and conveying the technical information you are presenting.'"

Sheingold's one-page poster showing every op amp configuration needed for a proper analog circuit design, which he created while working at Philbrick Researches, was often found taped to the wall in offices of analog engineers, said Grant.

Before joining ADI in 1969, Dan Sheingold edited *The Lightning Empiricist* newsletter at Philbrick Researches.

Sheingold said that he learned much about good technical writing from his days at Philbrick. What he'd learned in school was "very stiff. It was always in passive voice," he said. But George Philbrick "wrote fluently and creatively. I liked his writing style and tried to emulate it in my career," he said. It was a style that was more readable and distinctive than most technical writing, and often more persuasive.

Sheingold edited *Analog Dialogue* for 44 years, chronicling ADI's (and the industry's) technological transitions "from assembled discrete op amp modules and converter modules to monolithic amplifiers, analog multipliers and function circuits, converters, and onward into power management, RF and DSP," said Grant.

own destiny, direct through partners, alliances, and tools and services," he said. The elements included reference designs, global field application engineering centers, an ecosystem of third parties and industry alliances that worked with ADI to supply complete solutions, and a strong online presence, including ADI's website (one of the largest business-to-business sites in the industry) and its online design community, EngineerZone.

The Online Engineer

In many ways, the website analog.com was designed as a 21st-century equivalent of the paper salesman. It provided the same kind of information to ADI long-tail customers. Likewise, the engineering communities interacting online at the EngineerZone, where the main purpose was tech support, provided direct interaction in a different way than telephone support.

EngineerZone was started as a way to scale ADI's support resources across tens of thousands of customers in fragmented application areas. The goal was to offer around-the-clock global support that augmented the existing phone and online forms of support. It began within the DSP division in 2009 and was rolled out as an enterprise tool over the next three years. It served as a community where customers or potential customers asked questions of ADI engineers and received answers online. Over time it became a large repository and searchable database of technical knowledge, said Jennifer Mitchell, who started at ADI in 1998 and led the strategy and rollout of EngineerZone.

EngineerZone became a competitive differentiator for ADI. In a 2011 survey, over 90 percent of respondents said the information on the site was helpful to their design, 84 percent said using the community helped speed their design process, and 76 percent were more likely to purchase ADI products knowing that EngineerZone was available as a resource. But its most important function may be how it created a new way for customers to have ongoing discussions with ADI engineers, discussions that often led to design wins.

EngineerZone

ANALOG DEVICES SUPPORT COMMUNITY

In 2009, ADI launched EngineerZone, an online design community that enabled customers to receive technical support from ADI experts and discuss design issues directly with fellow engineers.

In many ways, the website analog.com was designed as a 21st-century equivalent of the paper salesman. It provided the same kind of information to the long tail of ADI customers.

Meanwhile, ADI continued to grow deep, direct relationships with large customers as well as the customers' customers. ADI did not sell directly to car manufacturers, for example, but it participated in programs like Audi's Progressive Semiconductor Program, which connected the carmaker with major semiconductor vendors. With such a large amount of automotive innovation based on electronics, ADI could play a key role by understanding what innovation automotive manufacturers wanted and then developing it.

Although ADI's sales and distribution strategies changed as the company, its customers and the industry grew and evolved over a half-century, ADI stayed true to the key lesson Stata took away from his early sales experience: Cultivate strong relationships with customers, listen carefully to their problems, be honest and reliable and make great products. Do that, and the sales will come.

Going Its Own Way

From its earliest days, ADI embraced the world. It sought customers around the globe and recognized the need to stay close to those customers. Within the first few years of its founding, the company opened sales offices in the United Kingdom, Germany, France and Japan—a risky strategy for the fledgling startup. Going against conventional wisdom, Ray Stata chose Limerick, Ireland, for ADI's first CMOS fab. Later came specialized centers in the Philippines, India, China and other regions.

In each case, ADI hired both management and staff locally whenever possible, and encouraged them to develop their capabilities, forgoing the expatriate management teams most corporations installed overseas. The company struck partnerships with nearby universities to help expand its talent base. Each ADI location was given the freedom to operate autonomously, with little oversight from U.S.-based management. This strategy paid off handsomely as many of these centers made substantial contributions to ADI's success.

Staying close to its customers meant selling direct for ADI's first 25 years rather than using distributors. The company built brand loyalty and forged strong relationships with thousands of customers by making clear and complete information, including detailed spec sheets and rich application notes, widely available through catalogs and seminars, and later through analog.com and EngineerZone.

Throughout ADI's journey along the road less traveled was *Analog Dialogue*, which remains the longest-published technical journal in the electronics industry, thriving while so many have vanished. The same spirit of managed risk-taking and staying ahead of trends that propelled its product and process portfolio was evident in its earliest strategies for globalization, long-tail market development and customer experience, although these terms would not be coined for decades.

CEO SPOTLIGHT

Roche Leads ADI into the Future

He took calculated risks that paid off, reinvigorating ADI's entrepreneurial culture.

1960	1988	2012	2013–present
Born in Wexford, Ireland	Joined ADI	President	CEO

VINCE ROCHE understood that ADI was historically an introspective company, focusing on innovation from its own engineers and profits from its own organic growth. Taking over as CEO in 2013, Roche wanted to broaden that perspective.

Unlike ADI's first two CEOs, Roche was not a native of the East Coast, or even of the United States. He was born in Wexford, Ireland, and graduated from the University of Limerick in 1982. So it's not surprising that he would bring a new perspective to the company.

In fact, he was an unusual hire for ADI. When he joined the company in 1988, "In the business units you tended to make your mark by being an excellent converter designer or linear technology specialist," he said. "I was neither."

Instead, he took a holistic view. "I've always tended to look at things from the outside in rather than from the inside out," Roche said. "I'm more interested in the whole system and how the pieces interact."

As Roche rose in the executive ranks—he was promoted in 2001 to vice president of worldwide sales and in 2009 to vice president for the newly created worldwide sales and strategic market segments—it became clear that CEO Jerry Fishman was grooming him as a possible successor. "Jerry would say to me, 'I know you have potential, but I don't know how much. I haven't seen your limit, so I'm just going to keep testing you,'" said Roche. Fishman named Roche president in November 2012. Just four months later, Fishman died from a massive heart attack.

Suddenly, Roche was in the spotlight as heir apparent and under intense pressure to rise to the challenge. The board immediately named him interim CEO. He was named CEO permanently just five weeks later, in May 2013. "Once he got the job, it was clear that Vince had what it takes and more," said Ray Stata.

Roche led the company as it broke revenue records, surpassing $3 billion for the first time in its history in 2015 and reaching $5 billion in 2017 (including revenue contributions from the Hittite and Linear Tech acquisitions). And Roche's external focus and customer relationships made him particularly well qualified to steer ADI through the transitions ahead.

Roche's external focus and customer relationships made him particularly well qualified to steer ADI through the transitions ahead.

Beginnings

Roche's native town of Wexford, which sits on the south-eastern coast of Ireland, was established by the Vikings in the early part of the ninth century. They named the town Waesfjord—meaning "inlet (fjord) of the mud flats" in the Old Norse language. A few centuries later, Roche's ancestors were part of the Norman invasion and established themselves in the region—hence Roche's French name.

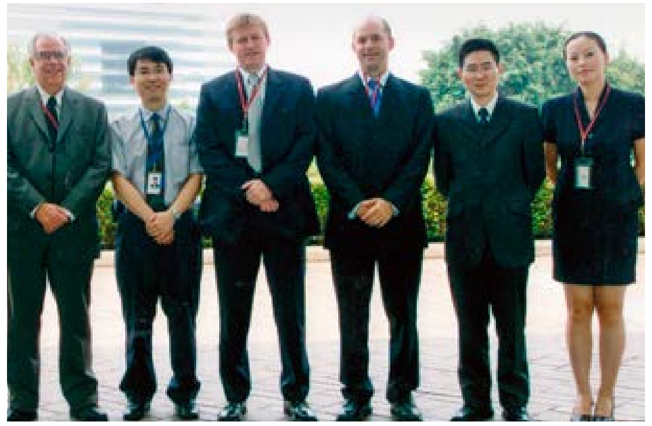
Roche's early years were immersed in the agricultural surroundings of Wexford. Generations of his family derived their livelihoods from farming. He didn't envision a life in this pursuit or in agricultural research like his father, but he was fascinated by the complex systems of the natural world.

"I enjoyed studying nature and biology, but I couldn't figure out how to build that into a career in a country that was struggling greatly economically," he said. The only path he saw was perhaps to become a biology teacher, which didn't suit him. He did see a path in engineering—DEC and Wang had recently built computer manufacturing facilities in Ireland—so he chose that as his track. "It was obvious that computing was a new wave, and I wanted to be a part of that somehow," said Roche.

By the time he graduated with an engineering degree from the University of Limerick, Roche was itching to explore far-off lands, like California. He had interned at ADI's Limerick facility, as had many of the university's students, but he had no desire to work there. "At the age of 22, Ireland was not such an exciting prospect, especially compared to Silicon Valley," he said.

So when Fairchild Semiconductor—which spun off dozens of companies (including Intel) and is often credited with creating the Valley—came to Ireland to recruit engineers, Roche jumped at the opportunity. The company hired him as an applications designer, and off he and his young family went to the high-tech mecca.

A few years later, on a trip back to Ireland to visit relatives, Roche bumped into a former college mate, Ken Deevy,



As vice president of worldwide sales, Vince Roche accompanied CEO Jerry Fishman (left) to many international sales meetings in the 2000s.

who worked as a design engineer at ADI and said the company needed someone in Limerick with Roche's Silicon Valley experience. Deevy mentioned Roche to Limerick's general manager, Brian McAloon, who in turn "tracked me down and asked me to meet him for coffee the day before I was due to fly back to California," said Roche.

> **"The technologies on which we have been innovating for the past 50 years will be even more relevant in the future."**
>
> **VINCE ROCHE**

The richness of ADI's technology, along with McAloon's charm, passion and enthusiastic vision for ADI in Limerick, convinced Roche that this was a great opportunity. He saw that combining ADI's products and technologies in new ways could lead to exciting new opportunities for the company. And he was encouraged by McAloon, who had a strong entrepreneurial bent. Roche joined ADI in 1988 as a senior marketing engineer. "Brian gave me tremendous room and support to explore new things," said Roche.

Among those things was how ADI might secure customers in the emerging digital cellphone market. Roche and engineer Bill Hunt took a different approach in that market. Rather than simply trying to get companies to buy the chips ADI was selling, they traveled around the world to learn what customers needed. Roche's marketing sense combined with Hunt's technical savvy made an effective team.

"We were a complementary pair, like PMOS and NMOS," said Hunt, who joined ADI in 1979. "We'd show them the part and describe its function, but then they would start asking us questions and telling us what they would like the part to do," said Hunt. Hunt answered their questions, often sketching out circuit diagrams on a whiteboard. Meanwhile, Roche focused on the business and technology ecosystem and asked the customers questions about their customers, the carriers they partnered with, and their business aspirations. This helped ADI understand more about the systems in which these circuits were used and served as a guide to what kind of products to develop in the future. "It helped us develop new sources of growth through architectural innovation, not just circuit innovation," said Roche.

Management Style

As CEO, Roche was less conservative and more willing to take risks than Fishman. "Jerry's strengths were in improving cost structure and building up profitability," said Stata. "Vince is more like me in that he has a strong entrepreneurial sense." Roche preferred calculated risks over certainty and predictability. He looked outside the company for new trends and opportunities rather than relying only on ideas and technologies within ADI. He spent much more time on the road talking with, and listening to, customers than either CEO before him.

After joining ADI as a senior marketing engineer in 1988, Vince Roche quickly helped the company pursue new business opportunities.

In 2017, the University of Limerick conferred an honorary doctorate on Vince Roche for his outstanding contributions to the field of information and communications technology.

Roche renewed a spirit of entrepreneurship at ADI. He encouraged adventurous thinking both inside and outside of the company, in startups, incubators and acquisitions. He spearheaded two of ADI's largest acquisitions: Hittite Microwave for $2.4 billion in 2014 and Linear Technology in 2016 for $14.7 billion.

As the third CEO in ADI's history, Roche faced the challenge of guiding ADI into the future while preserving its legacy and retaining the best of its past. The company would continue to hire and nurture great electrical engineers, for example, but it needed to hire a broader variety, including systems, algorithm and embedded software engineers. ADI would continue to embrace a diversity of products and technologies, but it needed to be more holistic in its understanding of systems and ecosystems, and build partnerships accordingly.

Roche believed that ADI was perfectly positioned for the next big era in information technology. "The technologies on which we have been innovating for the past 50 years will be even more relevant in the future," he said. "ADI has a golden opportunity to help its customers create new sources of value in this emerging age of ubiquitous sensing by leveraging all our technologies to sense, condition, convert and process real-world phenomena. The physical and digital domains are becoming ever more intertwined, and the areas where we specialize are becoming ever more critical as the bridge between these two domains. The future is completely in ADI's wheelhouse."

Strong Corporate Identity

ADI transitioned its product portfolio and business strategy over 50 years while maintaining its core identity and values. The company moved from a strictly analog and mixed-signal innovator to a leader in real-world signal processing. It expanded from providing components to also providing system solutions. The company evolved its capabilities by nurturing and maintaining an appetite for experimentation and exploration.

A willingness to open the aperture and identify new areas to explore and invest remains a vital part of ADI's identity. This ability to learn and adapt to changes in the environment is a major reason why ADI has succeeded for so long. In fact, research indicates that ADI embodies many of the characteristics that are key to long-term success. In the 1980s, Royal Dutch Shell Company initiated a study of companies that, like Shell, had survived for more than 100 years. The key characteristics these companies had in common were: a strong identity and sense of purpose, an ability to learn and adapt to changes in the environment, a tolerance for risk and unconventional thinking, and strong financial results to support exploratory investment at the periphery of the core business.

ADI's focus on solving analog challenges led it to expand its portfolio to cover the entire signal chain. This signal chain has become ever more important as sensors become embedded in many things and interconnected via wireless networks and cloud computing. But to take advantage of the growing opportunities, ADI has taken a step back in order to see the big picture. It has begun to look beyond components, beyond applications and even beyond systems, to see and understand the problems that ADI's customers' customers are trying to solve. It is reinvigorating its risk-taking culture, looking beyond ADI's walls and through different lenses to collaborate with new partners, to develop new technologies and to apply them in new ways.

The Innovation Engine

Looking back over a half-century of ADI history, Ray Stata was struck by the company's luck in selecting op amps as its first product.

"Although we didn't think of it this way in the beginning, op amps are the most universal and ubiquitous analog building blocks," he said. "ADI's success in op amps put us in touch with literally thousands of customers around the world, giving ADI a ringside seat to observe the evolution of the electronics industry, particularly as it applied to measurement and control applications."

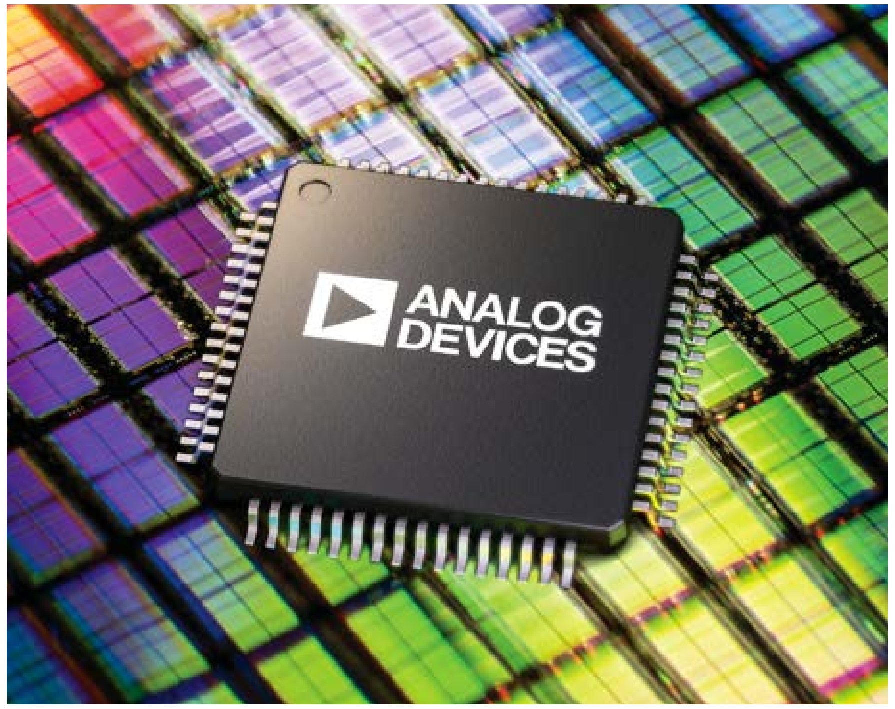
Real-World Signal Processing

It was the company's growing understanding of this evolution that led it to expand its portfolio into real-world signal processing ICs. In the 1970s, for example, ADI witnessed the impact of the booming minicomputer industry on its op amp customers as they used minicomputers to automate measurement and control. This created a need for a new analog component category, converters, to bridge the gap between analog signals and computers. So, ADI diversified into converters by acquiring Pastoriza, invested heavily in this new product category and ultimately led the converter market, reaching over 40 percent market share and $1 billion in converter sales by 2015.

ADI's entry into converters was a natural progression. Amplifiers and converters shared the same customer base and were companion products in many applications. Analog circuit design expertise and analog process technology were common to both. In fact, in many cases, op amps were used in the design of converters. Unlike amplifiers, however, converters required digital circuits.

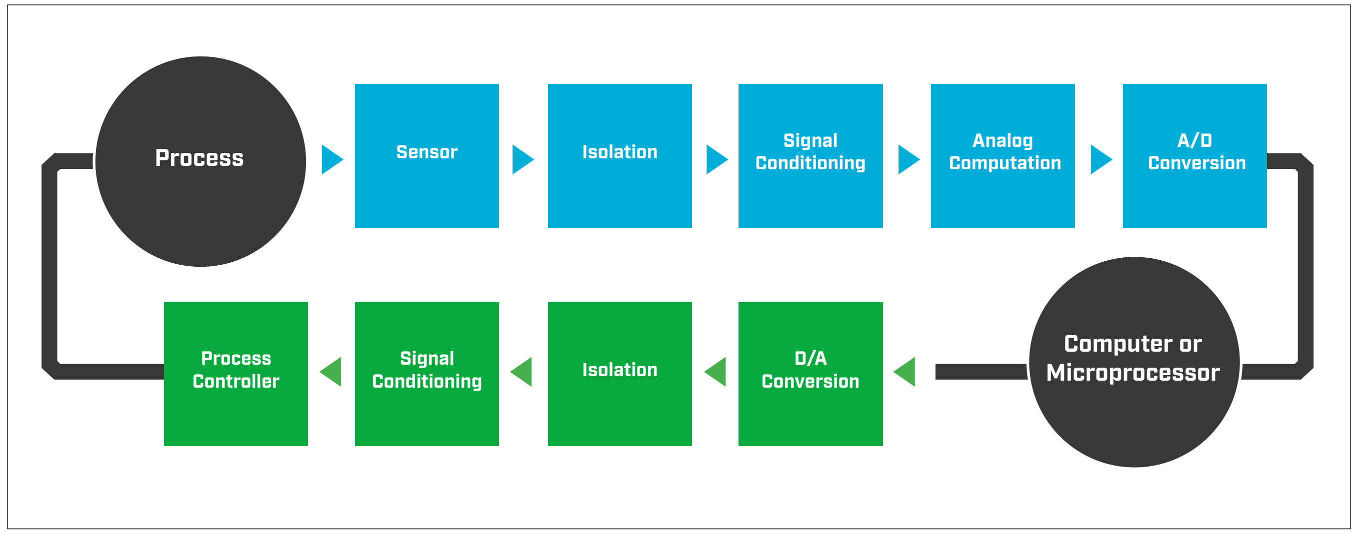
Thus began a journey in which a company whose name was Analog Devices would develop digital expertise and ultimately mix analog and digital process technology. This combined capability not only opened the door to many diverse product opportunities but also opened engineers' minds to partnering with customers on system-level solutions.

By focusing on the two product categories of amplifiers and converters—fundamental building blocks in electronics—ADI could observe where its vast and varied customers and the analog business were headed. The company made a strategic decision to focus on the high-performance segments of these categories, which provided a growing stream of reliable



ADI's core product portfolio expanded over 50 years from analog and mixed-signal components to complex system solutions for real-world signal processing.

The Measurement and Control Loop



ADI's rapid success in op amps in the late 1960s enabled the company to diversify into converters in the 1970s as op amp customers began to use minicomputers to automate measurement and control applications.

profits to fund its expansion into other closely related product categories.

Digital Signal Processing

As ADI grew its converter franchise, it saw that many customers were converting analog signals and processing them in the digital domain, which led the company into the digital signal processing market. Although it was an unpopular decision within ADI for many years, the digital signal processing business began to reshape ADI's vision of its position in the industry and guide it to new opportunities. With op amps, ADI thought of itself as an analog company. When it expanded into converters, ADI became a data acquisition company. With its move into digital signal processing, ADI was helping its customers design more complete end-to-end signal chains. That broadened ADI's identity: It became a signal processing company with all the critical components required to process signals in both the analog and digital domains. ADI coined the term "real-world signal processing" to define its business and the scope of opportunity it would pursue.

It took many years to develop the skills and technology to become a player in the digital signal processing business. This business, with its related software and development tools, was more about systems than components. "The company's experience with digital signal processing set the stage for ADI's transition to system solutions more than we could have ever imagined," said Stata.

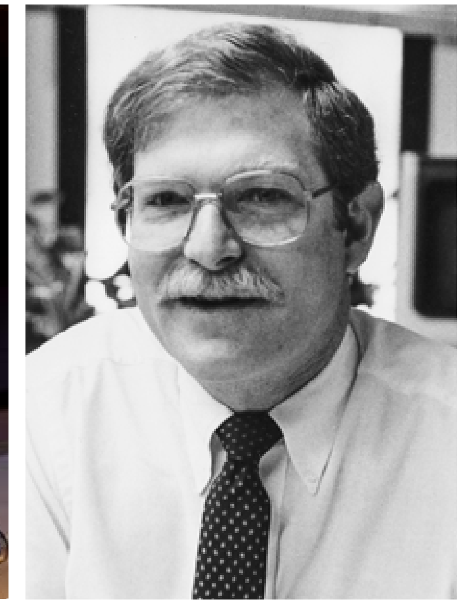
Meanwhile, ADI's desire to move into the automotive market led to an innovative and risky step to add another arrow to its technology quiver. "ADI had long seen opportunities for its analog products in automotive applications, but breaking into this market, which had a maniacal focus on quality, reliability and long-term supplier relationships, was virtually impossible," said Stata. "Existing suppliers could meet the automakers' needs."

Large automotive suppliers such as Bosch, Delphi (a subsidiary of GM) and Nippon Denso (a supplier to Japanese car companies) were building accelerometers designed to detect a crash and deploy the car's airbags. But these parts were based on bulk micro-machined sensors that were combined with sensor electronics in a vacuum package. The complex assemblies were expensive, with a selling price of about $25. ADI thought it could do much better.

When airbags became mandatory in cars in the United States in the 1980s, ADI spotted an opportunity.

Sensors

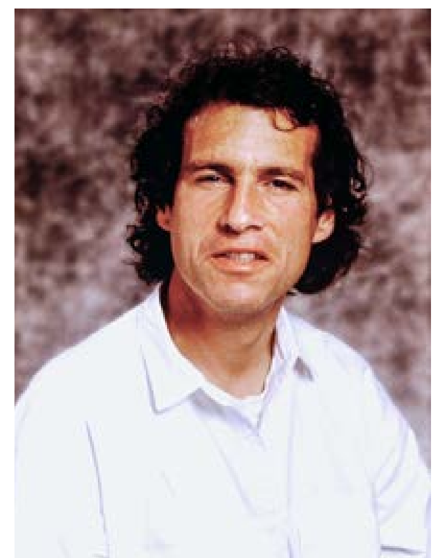
Richie Payne, who had joined ADI in 1980, and others surveyed the auto-



When airbags became mandatory in cars in the United States in the 1980s, ADI spotted an opportunity to develop a less expensive, more reliable crash-detection accelerometer. Richie Payne led the working group that developed the first MEMS accelerometer, the ADXL50.

motive market and identified the opportunity for a less expensive, more reliable accelerometer. In 1989, ADI established a group, headed by Payne, to develop a surface micro-machined accelerometer that would be compatible with standard IC processing and packaging technology. The goal was to design and manufacture a monolithic chip combining accelerometers and sensor electronics in a standard low-cost IC package. Several engineers at ADI had been working on micro-electromechanical systems (MEMS) accelerometers as a side project; Steve Sherman, who joined ADI in 1979, was the technology's strongest advocate. He and others were assigned to the project full time, and by 1992, ADI introduced its first MEMS accelerometer, the ADXL50, based on Sherman's design.

The price target of the ADXL50 was $5, an improvement in price so compelling that automakers were willing to engage with a new supplier. "I remember well traveling with Payne to Kokomo, Indiana, where Delphi designed and manufactured crash sensors, to make the pitch to senior executives," Stata said. "The lure of $5 monolithic sensors to replace their expensive hybrids at a time when volume for crash sensors was skyrocketing was so appealing that



Steve Sherman, who designed the ADXL50, was the driving force behind ADI's technology.

they agreed to be the first customer . . . if we could deliver. They even contributed to the engineering investment."

But MEMS was one of the most challenging technologies ADI had ever tackled. The engineering team had to figure out how to integrate tiny mechanical cantilevers suspended in space with sensor electronics, all on one piece of silicon. That had never been done before, and getting the manufacturing process technology right was extremely difficult. The project cost many millions of dollars per year; it took a decade before it turned a profit.

Stata had to fight efforts by management, particularly the CEO at the time, Jerry Fishman, to kill the project. In order to protect it, Stata stepped in to serve as general manager of the MEMS effort from 1997 to 2000. "Frankly, I wanted to spread myself across the door so people couldn't get in there and kill the infant," he said.

Ultimately, the effort succeeded, enabling ADI to further extend the breadth of its mastery of the signal chain and reinforcing its identity as the leader in real-world signal processing. Perhaps more importantly, it opened the door to the automotive market, which became one of the fastest-growing markets for ADI.

By 2005, ADI's MEMS business had annual sales of more than $100 million. That year, Sherman was honored for his MEMS designs with ADI's first Founders Innovation Award for significant contributions to ADI and to the semiconductor industry. In announcing the award, Stata credited Sherman as the driving force behind ADI's successful MEMS business. "It is rare that the imagination, dedication, persistence and innovative skills of a single individual would create an entire new business," he said. "[MEMS] simply would not have happened at Analog Devices if Steve did not passionately embrace this possibility, totally outside his responsibilities and outside the business of the company."

While the first product was an accelerometer for airbags, MEMS technology led ADI to develop many other products for other markets.

Extending to Higher Frequencies

Where RF was concerned, Barrie Gilbert brought a unique perspective to ADI from his experience working for Tektronix, one of the world's largest instrumentation companies, and from his personal interest in radio technology. In 1989, he designed ADI's first RF product, the AD640, the first commercial monolithic multistage RF log amp in the industry. While the part was intended for the instrumentation market, its unique design caught the eye of customers in the communications market. This led to a series of products from Northwest Laboratories.

"As our ambition grew in communications, extending the performance of components and ultimately systems would require higher frequencies," said Stata.

Guiding this ambition was the understanding that the frequency spectrum was not solely the realm of instrumentation and telecommunications applications. Medical imaging, aerospace and automotive applications were exploring how to use these technologies to detect and treat disease, for security and surveillance, and to provide contextual awareness for accident avoidance and autonomous machines, respectively. In the 2000s, many of these markets were clamoring for higher-frequency parts. Although ADI had a long history of breakthroughs in RF-to-bits technologies, higher frequency microwave and millimeter-wave electronics were rapidly advancing, and

MEMS Leads ADI into Unusual Places

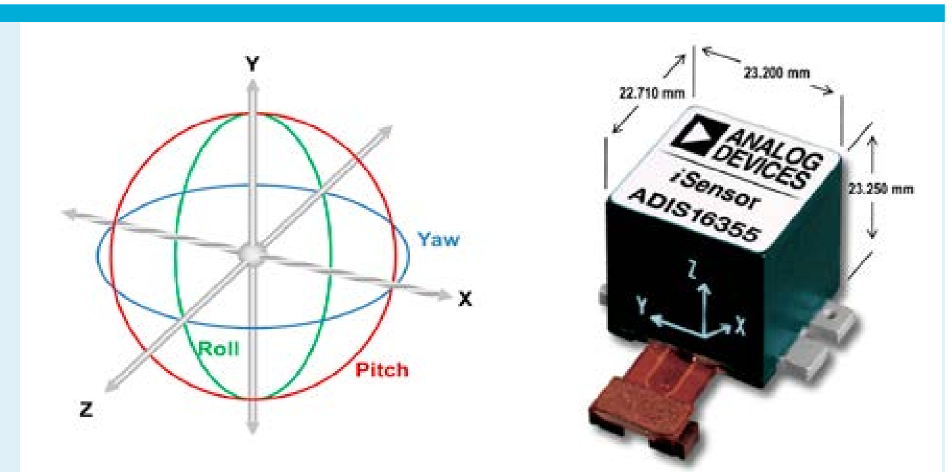
As ADI explored the markets for MEMS devices, it hit upon some rather nontraditional applications.

The controller for the Nintendo Wii video game console. ADI's ADXL330 three-axis accelerometer enabled an experience unlike anything in video game history. It was wireless and motion-sensitive, so participants could move it in any way they wanted, and the movement would be reflected in the video game. In June 2007, *Fortune* magazine named Fellow Jack Memishian to a list of top innovators for his invention of the part. "What's two millimeters square, can sense three ranges of motion (up and down, side to side, and front to back), and has caused six months of mass hysteria at electronics retailers everywhere? It's an accelerometer from Analog Devices in Cambridge, Mass.," the article stated. "Analog fellow Jack Memishian developed the breakthrough chip for unimagined hand-held devices. Then Nintendo came calling, put it into the Wii remote, and the rest is history."

In June 2007, *Fortune* magazine named ADI Fellow Jack Memishian to a list of top innovators for his invention of the ADXL330 three-axis accelerometer, which was used in the controller of the disruptive Nintendo Wii video game console.

The Celestron SkyCount was a hand-held device that identified and located more than 6,000 celestial objects viewable by the naked eye. The product "transforms the night sky into a personal planetarium using the power of motion signal processing technology," said an ADI press release. The product used ADLX322 motion sensors, along with a GPS receiver and inclinometer. The product was named among the best innovations in the personal electronics category by the Consumer Electronics Association in 2006.

Eventually, multiple MEMS sensors were integrated into one package, called an Inertial Measurement Unit (IMU). The iSensor® IMU featured multi-axis combinations of precision gyroscopes, accelerometers, magnetometers and pressure sensors. These plug-and-play solutions with full factory calibration, embedded compensation and a simple programmable interface inspired a wide range of new product ideas.



ADI integrated multiple MEMS sensors into one package, called iSensor Inertial Measurement Unit (IMU).

Joint surgery: Before knee surgery, for example, a surgeon could attach an IMU to the joint and move the knee through a range of motions. The IMU captured data that then produced the drill points for the replacement joint. The IMU system was three times more accurate than previous methods.

Location of first responders: Firefighters wearing IMUs could be tracked and located in a burning building where GPS was inoperable.

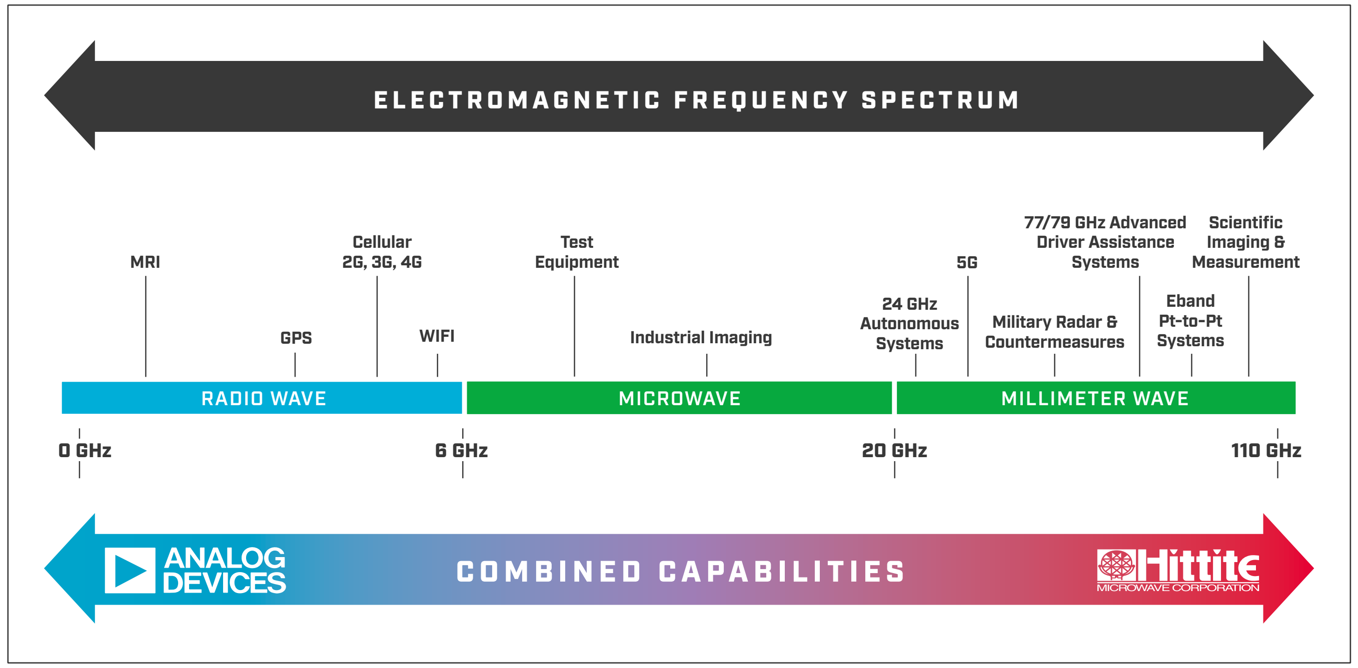
Smart agriculture: IMUs were embedded in farm equipment such as combines so they could be automatically steered to an accuracy of within a few centimeters, which was critical to saving seed, fertilizer and water. IMUs were also used in drones that fly over fields, using hyperspectral imaging to map moisture content, possible disease and other factors.

As the performance of IMUs increased, specifically as drift characteristics improved by more than 50 times, ADI found even more applications.

Autonomous driving: IMUs in conjunction with other sensors reliably guided autonomous vehicles in circumstances or environments where other sensors were compromised.

Positive train control: IMUs enabled precise train location, even when GPS was not unavailable, to support the U.S. government's mandate to outfit all trains with positive train control.

Augmented reality: Merged with visual sensors, IMUs in augmented reality headsets enabled the user to assess the status of factory equipment from a safe distance.



ADI expanded its high-frequency components portfolio by acquiring Hittite Microwave in 2014.

IC designers with such expertise were in short supply. With demand for high-frequency components growing, ADI used its financial strength to buy its way into the market. In 2014, it acquired Hittite Microwave, one of the few companies that specialized in this area. The $2.4 billion acquisition established ADI as a leader in RF, microwave and millimeter technologies.

> **“Power management was the missing link in our quest to provide customers with the complete solution.”**
>
> **RAY STATA**

Adding the Power Component

Power management was the largest segment of the analog IC market. Its size, coupled with the fact that design and manufacturing technology for power management was similar to that used for amplifiers, had always tempted ADI to compete in the business. In addition, power management had become increasingly important in high-performance analog systems. “Power management was the missing link in our quest to provide customers with the complete solution,” said Stata. ADI would try to build its power management portfolio organically over many years before it made the bold decision to acquire its rival, Linear Technology.

When ADI decided to make a serious investment in power management in the mid-'90s, the goal was to establish a broad franchise just as it had in op amps and converters. “From the perspective of an analog products company, this made a lot of sense,” said Stata. “However, we

Hittite Acquisition Expands ADI’s Antenna-to-Bits Reach

As demand for higher-frequency applications grew, ADI knew it needed to strengthen its RF product portfolio and extend its reach into the microwave and millimeter range.

The company already supplied everything in the signal chain “from antenna to bits,” up to about 6 GHz, which represented about 65 percent of the market. However, customers needed higher-frequency components to meet a growing demand for greater capacity and better accuracy in a range of applications. In the wireless communications market, for example, service providers would need to support 1,000 times more capacity in 2020 than in 2014.

Hittite company logo, 2014

ADI had been working on higher-frequency components, but progress was slow. “High-performance RF is hard to do well,” said CTO Peter Real. “It takes time to build the necessary critical engineering competence to develop industry-leading solutions which, once built, create high barriers to entry and carry high margins.”

Then, ADI spotted an opportunity to move up the spectrum through acquisition. In 2014, it bought Hittite Microwave Corporation, headquartered in Chelmsford, Massachusetts, which specialized in such high-frequency components primarily for the aerospace and defense markets. The $2.4 billion acquisition joined the two companies’ expertise, enabling ADI to provide “antenna-to-bits” solutions through to millimeter wave frequency.

The combination quickly bore fruit, with products emerging for the cellular infrastructure, automotive, aerospace and defense markets.

In the wireless base station market, ADI built an analog front end combining data converters, down converters, low-frequency amplifiers and other components into 4G and 5G receiver modules. Previously, base station customers bought the various components from different suppliers and designed the subsystems themselves. “It really changed the opportunities we have with our customers,” said Rick Hess, former CEO of Hittite, who became ADI’s executive vice president of business units.

In automotive, the company developed a 77 GHz radar for advanced driver assistance applications to detect objects earlier, more reliably, with greater precision and over much farther distances.

The acquisition moved ADI into a more strategic position in aerospace and defense as well. “Hittite sold a lot of product into aerospace and defense, but it was transactional,” said Greg Henderson, a Hittite executive who became senior vice president of ADI’s automotive, communications, and aerospace and defense businesses.

Hittite CEO Rick Hess became ADI’s executive vice president of business units after the acquisition.

Hittite executive Greg Henderson became senior vice president of the automotive, communications and aerospace and defense groups.

The combination of Hittite and ADI products, the ability to span the complete signal chain and the capability of ADI’s larger sales force meant that the company could design and optimize these subsystems like never before.

“Hittite and ADI have gone from being very potent component-level suppliers to being able to architect our customers’ RF and microwave systems,” Vince Roche said. “We’re inspired from the application level in and working to create the best technology from the component level out.”

underestimated the strength of well-entrenched competitors, including Linear Technology, National Semiconductor and Texas Instruments." ADI found it difficult to design products that offered distinct advantages over competitors. Moreover, customers didn't view ADI as a player in power management. The company's stellar reputation for technical expertise in analog design and manufacturing was not enough.

But ADI took advantage of another trend: the shift toward systems solutions in high-volume markets. Communications, computer and consumer customers looked for specialized embedded solutions for power management in the signal chain. So ADI refocused its power management R&D on this challenge.

"We became very good at integrated system-level application-specific power management," said Katsu Nakamura, a Fellow who joined ADI in 1994. The strategy included designing circuits that could not only operate with very little power but also efficiently regulate the amount of power used.

The latter capability was increasingly important in the Internet of Things (IoT). For example, a sensor monitoring the structural integrity of a bridge must operate for years and is designed to use very little power most of this time. But if the sensor detected a change that indicated the bridge may have been compromised, it needed immediate access to sufficient power to send an alert. "It's a huge challenge in terms of load regulation," said Nakamura. "The solution may need an extremely low amount of power to sustain the sensor system over very long time periods—less than microwatts or just hundreds of nanowatts—and then suddenly require many orders of magnitude more power, or tens of milliwatts of power, when it has to communicate to an external gateway."

Low-power expertise was particularly important to gain entry into wearable and embedded sensor applications in the healthcare markets, said Jim Doscher, who joined ADI in 1982 and became general manager of healthcare. "Having low-power technology gave us a reason to talk to customers developing wearables and gave us all the building blocks to provide system solutions," he said.

But embedded power management was a niche. Roche realized that power management expertise and the size and breadth of a power product portfolio would increasingly matter as major customers narrowed supplier lists and forged strategic ventures. These customers had widening gaps in analog

The Genesis of Linear Technology Corporation

For a guy who didn't know much about electronics when he graduated from college, Robert Swanson did pretty well for himself.

Swanson grew up in Wilmington, Massachusetts, and graduated from Northeastern University with a degree in industrial engineering. In 1960, he was hired by Transitron, based in Wakefield, because he was trained in statistics and the company was starting its first statistical quality control program.

It was a fortunate career move. Transitron was a pioneer in the chip business—second in size only to Texas Instruments in the early 1960s—and a seedbed for talent. Wilf Corrigan, who went on to found LSI Logic, and Pierre Lamond, who became a highly successful venture capitalist, worked there. And the founders of Nova Devices, which Ray Stata funded in 1968 and which became ADI's Semiconductor Division, came from Transitron.

Linear Technology logo, 2016

Swanson left Transitron in 1963 to join Fairchild Semiconductor and then in 1968 moved to National Semiconductor, eventually running its analog business. But as National grew to approach $1 billion in sales, Swanson and others in the analog division became frustrated. They felt the company was losing focus and becoming overly bureaucratic and political.

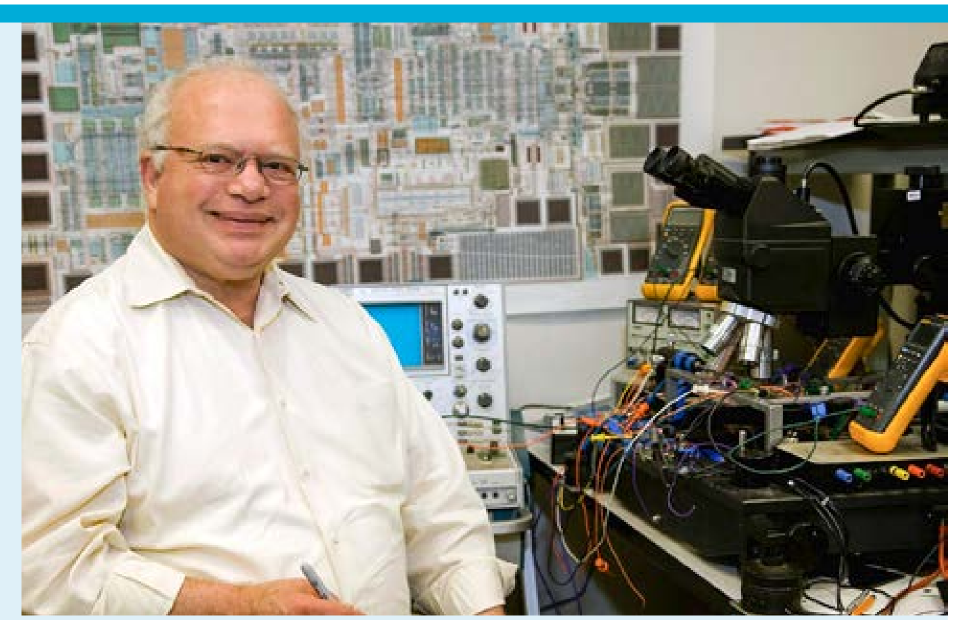
In 1981, Swanson and one of his most talented analog engineers, Robert Dobkin, left National, founded Linear Technology Corporation and quickly hired some of the best analog designers on the West Coast, including Bob Widlar, Jim Williams and George Erdi.

Linear Tech co-founder and CEO Bob Swanson earned an industrial engineering degree from Northeastern University. He worked at Transitron and Fairchild Semiconductor, and in 1968, he moved to National Semiconductor, eventually running its analog business.

"It was a maverick idea to start a company in analog because everybody was going into digital," Swanson recalled. "But that was the business I knew, and I realized that a dozen really good people could be the nucleus of a very successful analog company. That wasn't the case in the digital arena, where lots of people were making the same thing. It appeared to me that the only way you could distinguish a digital business was to make things quicker and cheaper."

But it was a hard sell in a world going crazy for logic, memory and microprocessors. Swanson recalled having to explain again and again why analog was a good business, and he pointed to ADI's success as one of his proof points.

Linear Tech went public in 1986 and never looked back, becoming one of the most successful semiconductor companies in Silicon Valley. Sales increased nearly every year, and the company was consistently profitable with some of the best gross margins in the industry. Swanson recalled Linear Tech being named to the S&P 500 Index in 2000 as a seminal moment in the company's history. Joining the S&P 500 underscored Linear Tech's role as an important American company



Linear Tech co-founder and CTO Bob Dobkin attended MIT for two years and went on to design integrated circuits at Philbrick/Teledyne until 1970, when he moved west to join National Semiconductor.

in a significant U.S. industry and marked a major turning point in Wall Street's understanding that progress in electronics was intricately tied to analog. "This was recognition that Linear Tech was a key part of the group of industries charting the country's future," Swanson said. "Moreover, it clearly articulated that analog is forever." Intel co-founder Gordon Moore was quoted at the time as saying that the dot-com boom was more about analog than it was about digital. After that, Swanson no longer needed to explain to Wall Street why analog was significant.

The company reached $1 billion in sales by 2005; by the time ADI acquired Linear in 2015, revenue had grown to $1.5 billion.

Linear Technology: Excellence in Business and Design

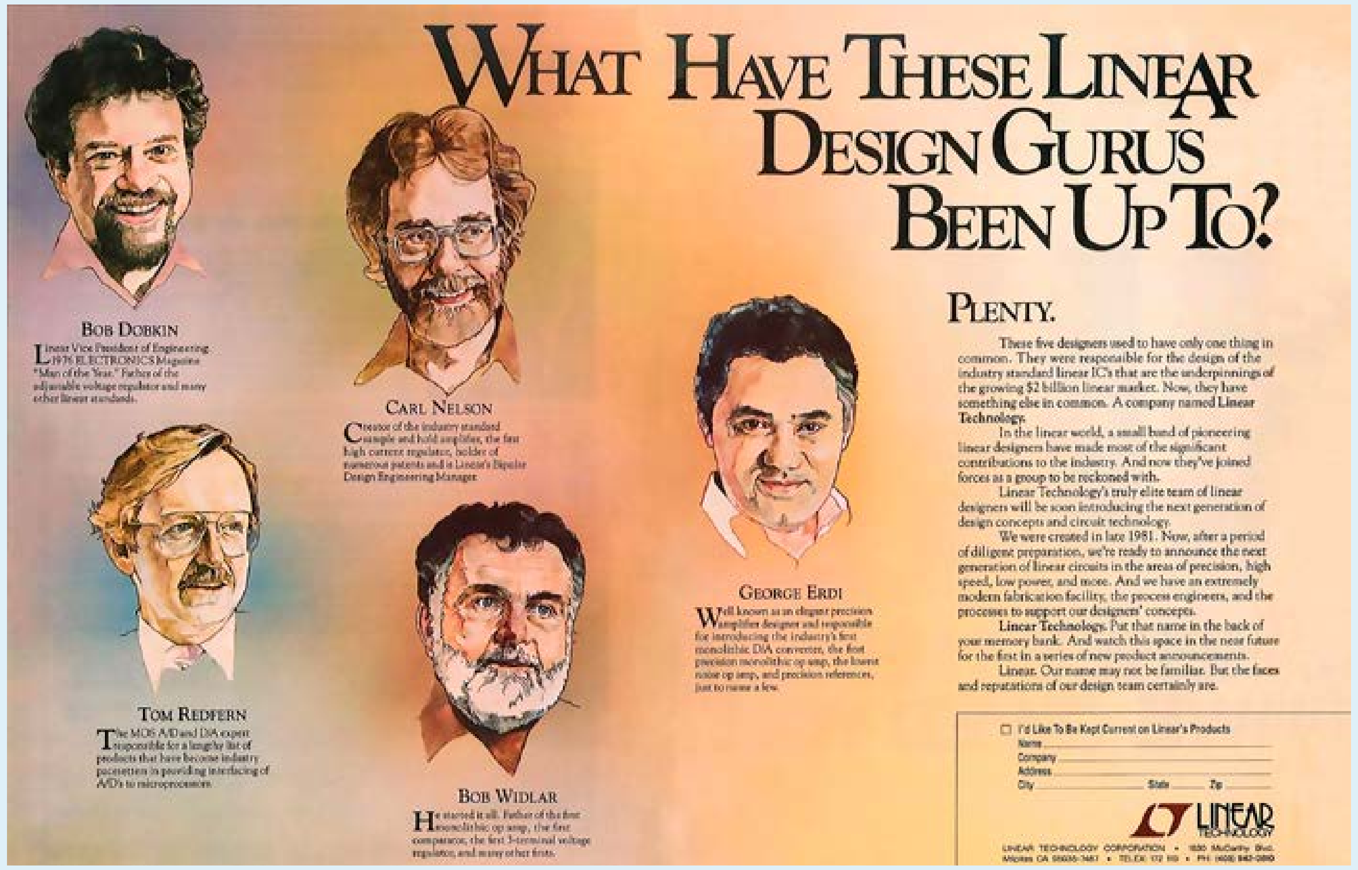
Over its 35-year history, Linear Technology Corporation became a model of both technological innovation and business savvy for the analog industry.

When Robert Swanson and Robert Dobkin founded the company in 1981, each set the culture in his respective domain. As CEO, Swanson stressed the bottom line and profits. The company's culture was based on "discipline and focus," said Swanson. "It is discipline in pricing, discipline in which markets to go after and discipline in which customers really have a strategy that's aligned with ours."

At the same time, Dobkin—serving as chief technology officer—hired and nurtured some of the best analog design talent on the West Coast, including George Erdi, Carl Nelson, Tom Redfern, Bob Widlar and Jim Williams. While stressing discipline and focus, Dobkin also gave them respect and the freedom to innovate. Once asked how he managed these pioneers, Dobkin replied: "You don't manage them. You hire them, then just let them go. You make the environment as conducive to designing and inventing as you can."

The company also encouraged engineers to anticipate what customers would need down the road, not just what customers were asking for at the time. A good example of this kind of prescient innovation was Linear Tech's burst-mode power supplies. As the first laptop computers came out, Linear Tech engineers realized customers would need a way to not only enable the laptop to go into sleep mode to conserve battery life but also to wake up quickly and efficiently to full power.

"We didn't get that idea by asking manufacturers," said Dobkin, who joined ADI as a senior vice president. "We came up with the idea that this sort of capability would be needed and then figured out how to architect it. When we put it out into the marketplace, it was quickly and widely adopted."



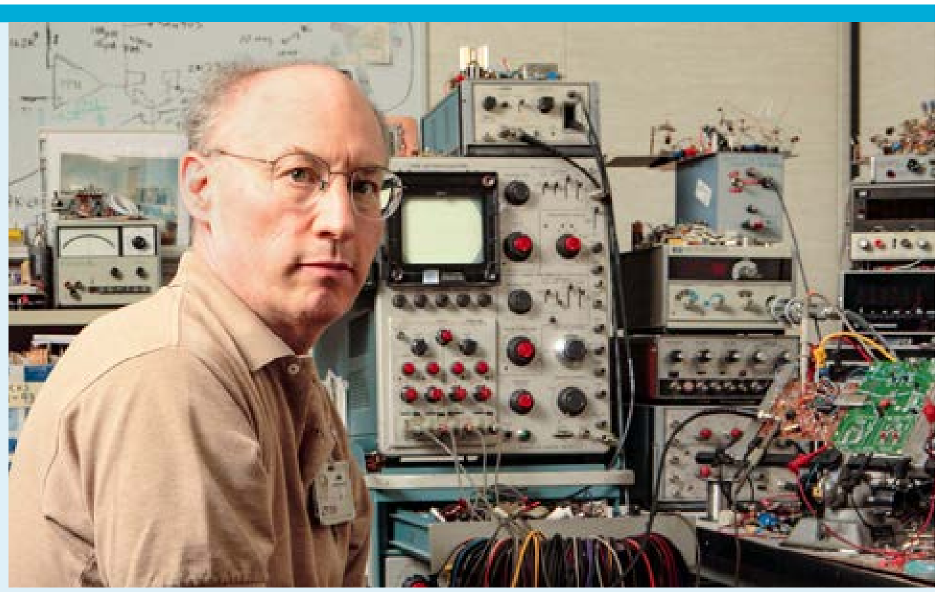
Some of the best analog design talent on the West Coast, including Bob Widlar, George Erdi, Carl Nelson and Tom Redfern, joined Swanson and Dobkin at Linear Tech. The company used this expertise as a selling point, featuring these "gurus" in a 1982 ad.

And like ADI, Linear Tech's strong culture retained talent. Staff often stayed at Linear Tech their entire careers. According to the company's 2011 annual report, 55 percent of the employees who had joined the company a decade earlier were still with Linear Tech.

Management respected engineers and paid them well. Yet Swanson and Dobkin also enforced a certain frugality. Swanson used a "scuffed desk chair from the early 1980s," according to a 2007 *Wall Street Journal* profile of the company. "He tells subordinates that they can live with worn furniture, too." Engineers were encouraged to scour electronics thrift stores to buy secondhand oscilloscopes. If equipment broke, they were expected to try to repair it rather than replace it.

Steve Pietkiewicz, an executive at Linear Tech who became a senior vice president at ADI, recalled approaching "Dobby" in search of models for a process technology he was developing. "I thought Dobby would direct me to a fellow engineer with the appropriate models," said Pietkiewicz. "Instead, he pointed to a curve tracer. The message was: You want models, go make them yourself."

Nothing illustrates how Linear Tech combined its financial discipline with



Design guru Jim Williams inspired generations of analog engineers to pursue intuitive design, emphasizing experimentation and testing over theory.

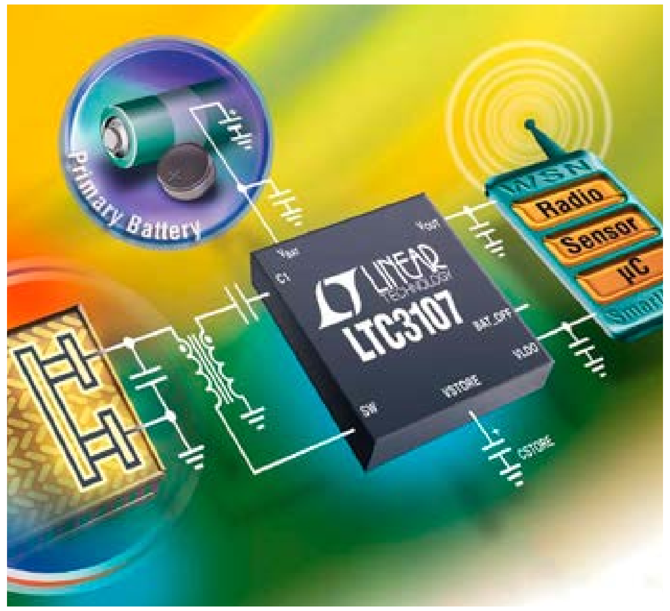
its engineering talent better than its legendary Wednesday new product meetings. When engineers proposed new products, they were expected to present the business case along with the technical advantages, including expected profit margins.

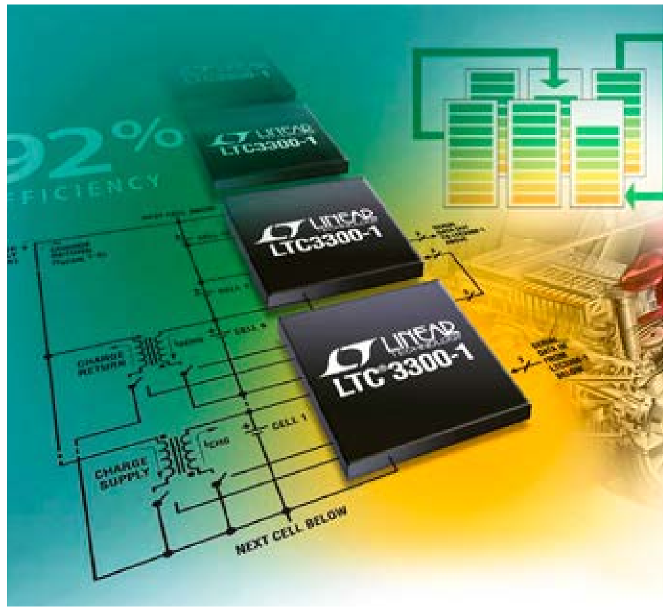
"We look at what [the function] costs if the customer goes to the competition, what it costs if they were to build it themselves and what kind of advantage we have," said Dobkin. Then, the price of the product is established based on functional value. "We don't sell our products based on some multiple of cost," said Swanson. "I know what it costs, but what is it worth?"

This pricing strategy was key to Linear Tech's stellar financial performance, said Swanson. "There's not a single customer that ever agreed to pay us a nickel more than what the product was worth to them," he said.

And it's a part of Linear Tech's culture that Swanson hoped ADI would retain. The combined companies were expected to capitalize on the fact that they had the best analog designers in the industry. "Customers are analog-challenged. The world is analog-challenged," Swanson said. "If I have a disproportionate share of analog experts, then customers can't get their product to market without us."

At the same time, ADI's focus on the signal chain and systems-level design could expand Linear Tech engineers' problem-solving skills to a broader value proposition, noted Don Paulus, a Linear Tech executive who became a vice president at ADI. Historically, Linear Tech concentrated on component-level design and performance, he said. "We have to change that mindset to focus on the overall system goal as opposed to making the very best widget in the world," said Paulus. "If we can do that, the opportunities are boundless."





Linear Tech's portfolio of power management products included energy harvesting (LTC3107) and battery management solutions (LTC3300-1).

skills. The supplier that could best fill that gap would become a strategic partner.

Roche set his sights on the ideal acquisition candidate: Linear Technology Corporation. Wall Street referred to the combination of ADI and Linear Tech as "the Dream Team." Founded in 1981 by Robert Swanson and Robert Dobkin, Linear Tech had an impressive portfolio of power management products that perfectly complemented ADI's analog and mixed-signal products.

But the merger was a hard sell. Linear Tech was fiercely independent and extremely successful. ADI made a tempting offer to Linear Tech's board and ultimately convinced them that the acquisition was good for both companies. ADI bought Linear Tech in 2016 for $14.8 billion. That was nearly 10 times Linear Tech's revenue in 2015—one of the highest multiples paid in the semiconductor industry in the previous decade and the largest acquisition ADI had ever made.

The combination created a powerhouse for innovation in every major segment of the analog semiconductor market. Combined, they had the engineering and financial resources to strengthen ADI's high-performance analog position and to explore and experiment with new opportunities for long-term growth.

"There was strong mutual respect for each company's capabilities and accomplishments," said Roche. "Together, we made a pact to reach a new record of success and leadership from which all employees would take pride."

"The importance of our power products business to the future of ADI was undeniable because bringing together ADI's signal chain capabilities and Linear Tech's power expertise created vast potential for growth," said Steve Pietkiewicz, senior vice president of power products, who joined ADI from Linear Tech. "Our two companies shared a commitment to both extend our long-standing standard product market leadership and to fully complement our signal chain and systems solutions with world class power management," said Pietkiewicz.

Linear Tech executive Steve Pietkiewicz became ADI's senior vice president of power products after the acquisition.

The acquisition also brought together many of the most talented analog circuit designers in the industry. "Our shared focus on engineering excellence and our highly complementary portfolios of industry-leading products will enable us to solve our customers' biggest and most complex challenges at the intersection of the physical and digital worlds," Roche said.

And like ADI, Linear Tech was beginning to develop system-level solutions. Among them was Linear Tech's micro-module (µModule) technology. Linear Tech had for many years focused on solving customers' complex power challenges. Now the increasing complexity of computer and communications equipment using power-hungry high-speed processors, FPGAs, and application specific ICs (ASICs) dramatically raised the stakes.

"Few customers had the design expertise to cope with high-power dissipation and currents of 100 amps in ever smaller packages. Our µModules provided a plug-and-play solution to all these problems in a small footprint," said Eddie Beville, director of power module development, who joined ADI from Linear Tech. "In addition, to succeed at the systems level, we had to extend our capabilities to fully test and verify the complete integrated power system, providing the same rigorous qualification and reliability that customers of our integrated circuits expected of us."

The µModule success led to a complete family of products tailored for a variety of systems in different markets. "They enabled faster time to market with reduced component procurement, design time and verification," said Beville.

Completing the Signal Chain

The addition of Hittite and Linear Tech filled out ADI's portfolio across the signal chain and helped the company strengthen its ability to become a systems-level collaborator with customers. "The ability to deliver a diversity and breadth of product offerings and highly innovative solutions is going to be a critical differentiator as customers carefully select their long-term innovation partners," said Roche.

A Bridge to the Future

The name Analog Devices served the company well for five decades by providing a strong sense of identity for the company and a strategic vision to guide diversification into related product categories. ADI, together with Linear Tech and Hittite, had mastered the critical building blocks in the analog sector and strengthened its ability to solve the electronics industry's toughest problems.

In short, ADI established a strong and stable platform on which to build success in new and different ways as the company entered its second half-century.

Linear Tech Innovations

1982 Industry standard precision op amps (LT1001)

1986 Highest stability precision voltage reference (LTZ1000); first 5-amp single-chip easy-to-use switching regulator (LT1070)

1987 RS232 driver/receiver with exceptional ruggedness against 10-kilovolt electrostatic discharge (LT1080)

1989 First CMOS low-power RS485 chip (LTC485)

1992 Hot Swap family (LTC1421)

1993 Burst Mode DC/DC converters (LTC1148)

1999 High-efficiency, multiphase synchronous switching regulators (LTC1628)

2001 Power-Over-Ethernet controllers (LTC4270/LTC427)

2002 First buck-boost regulators (LTC3440)

2005 High linearity active mixers with on-chip transformer (LTC5522); first high-speed 16-bit A/D converter with 100 dB spurious-free dynamic range (LTC2208)

2006 Micro-module DC/DC converters (LTM4601)

2007 First single resistor adjustable linear regulator (LT3080)

2008 First precision battery monitor device for hybrid/electric vehicles (LTC6802)

2009 Digital power system manager (LTC3108)

2010 Virtual remote sense controller (LTC4180); energy-harvesting 20-millivolt boost/power manager (LTC3108)

2011 First 18-bit, 1-mega-sample-per-second SAR A/D converter with 102-dB spurious-free dynamic range (LTC2378-18)

2013 Silent Switcher high-speed, low-noise DC/DC converters (LT8614)

A Risk-Taking Soul

In its first 50 years, ADI created a broad and cohesive range of IC building blocks to solve many of its customers' most challenging problems. These building blocks were conduits to connect the analog and digital worlds in all sorts of electronic products and systems. Now, this capability was becoming the fulcrum in a new era when sensors were being embedded in just about every physical thing, and each of those things would be connected to the IoT. To capitalize on this opportunity, ADI needed to open the aperture of its lens. It had to look beyond components, beyond silicon, and beyond applications and even systems to see the big picture. The company needed to understand the broad ecosystems in which its customers and its customers' customers operated in order to help solve important social, economic and environmental challenges.

"There's a seminal book called *The Nature of Technology*, written by W. Brian Arthur, that discusses the concept of combinatorial innovations," said Ray Stata. "With combinatorial innovation, the possibilities enabled by technology don't simply add up, they multiply. The breadth and cohesion of ADI's product portfolio gives rise to the potential for combinatorial innovations. In this sense, as we look to the next 50 years, ADI has reached a tipping point where combinatorial innovation can foster radical discontinuities that no one could have anticipated. It will take judgment and sometimes deliberate experimentation to decide which of the vast array of possible combinations will have the greatest impact on the world," said Stata.

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>
> **RAY STATA**

Arthur's book also described another dimension of combinatorial innovation. This dimension combines different perspectives, disciplines and insights from various domains and applications to create new value, said CEO Vince Roche. GE, for example, created the GE Store specifically to cross-pollinate among its many businesses. In one instance, the company used its jet engine expertise to generate power in other applications, called aeroderivative power. Similarly, Roche wanted ADI to explore ways to create more value by adding to silicon expertise and insight from different domains—such as data analytics and cloud computing—to generate new sources of value.

The proliferation of sensors, wireless connectivity and cloud computing was creating new types of companies and business models. Makers of industrial equipment, for example, could now monitor sensors embedded in their machine and notify users when maintenance was needed. Beyond that was the potential for equipment makers to switch from selling machines to selling the services those machines provide—a cloud-based "as-a-service" model that had started a decade earlier with computer software.

"With the ability to monitor machines that are in use at customer sites, makers of industrial equipment can shift from selling capital goods to selling their products as

The proliferation of sensors, wireless connectivity and cloud computing increased demand for ADI components and subsystems in applications such as smart watches, drones, autonomous vehicles and industrial robots.

services," stated a report by the McKinsey Global Institute. Sensors would transmit usage data, for which customers were charged. "This 'as-a-service' approach can give the supplier a more intimate tie with customers that competitors would find difficult to disrupt."

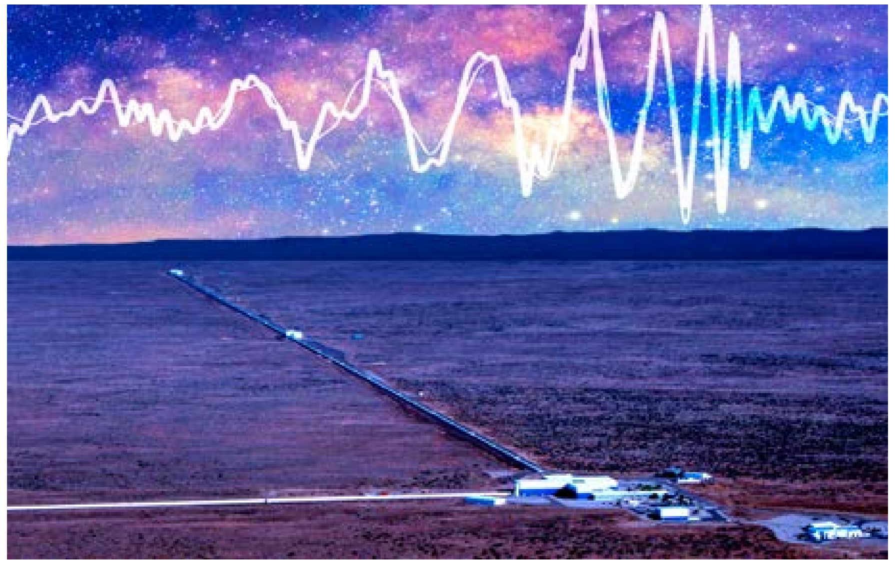
GE had moved away from just building hardware, for example. Instead, it added value from the software, data and services it wrapped around that hardware. Its lighting division sold not just lights but "energy as a service." By deploying smart lighting that collected data and then analyzing that data on its cloud platform, GE offered customers insight into how they used energy.

This was happening in many industries with many types of hardware, including cars. As ride-sharing services became available, consumers—particularly millennials—no longer needed to own a car. General Motors invested $500 million in the ride-sharing company Lyft, and GM's CEO, Mary Barra, said her company was no longer a car company but rather a transportation company.

What role would ADI play in this new world? As the company embarked on its second half-century, it faced perhaps its biggest transition yet.

ADI components and subsystems were in everything from critical healthcare devices to factory robots to the most sensitive of scientific instruments. In 2015, ADI technology enabled the Laser Interferometer Gravitational-Wave Observatory (LIGO) to record gravitational waves from the collision of two black holes more than a billion light-years from Earth.

While proud of its past success, ADI was focused on a new future. "Just as the confirmation of gravitational waves opens new ways to see the universe, we at ADI now have new ways to partner with our customers that will open new opportunities and new horizons," Roche said.



In 2015, ADI technology enabled the Laser Interferometer Gravitational-Wave Observatory (LIGO) in Hanford, Washington, to record gravitational waves from the collision of two black holes more than a billion light-years from Earth.

Three Waves of Innovation, Three Horizons of Growth

By the year 2010, the electronics industry was moving into the third wave of computing. The first wave, which began in the 1950s, was the era of centralized data and mainframes. The invention of core memory and solid-state circuits further fueled this wave. The second wave, roughly 1980 to 2010, was the personal digital era—including PCs and smartphones. Microprocessors and DRAM were key enablers of this wave. In each of these waves, network connectivity and software were also vital to invention and innovation.

By 2015, the world was well into the third wave, fueled by ubiquitous sensors and connectivity coupled with intelligent computing and abundant storage. Sensors, converters, signal processing, ultralow power and security were the enablers. In the IoT, massive amounts of sensor data would be transmitted to the cloud, and customers would need algorithms and analytics tools to draw insights from all those analog signals.

The potential seemed enormous. There were millions of mainframes in the first wave and billions of PCs and smartphones in the second. In the third wave, there could be trillions of sensor-equipped devices, and ADI could be the heart of many of them.

"With the expertise ADI has perfected over 50 years, we are moving from the periphery in prior waves to the fulcrum in the third wave of information and communications technology," said Sam Fuller, who served as vice president of R&D and CTO from 1998 to 2015. "When the combination of signal and data processing is available, the right communication technologies widely deployed and the critical software tools and applications are embraced, we have the makings of a once-in-a-generation revolution."

Vast Opportunities From Earth's Core to Outer Space

The reach and impact of ADI's technology and expertise in its first 50 years ran from measuring cosmic particles deep underground to detecting the gravitational waves that Albert Einstein predicted from the farthest reaches of space.

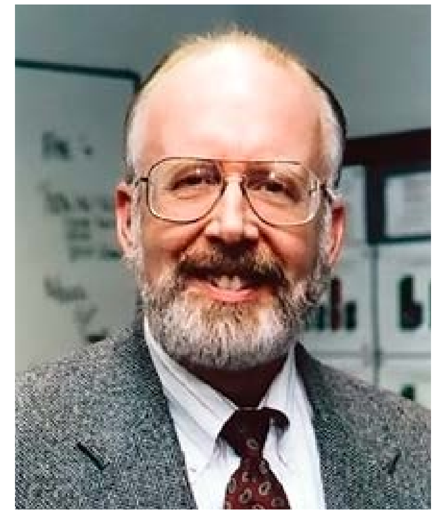
ADI was in the world's largest particle detector, called the IceCube. One and a half miles beneath the Antarctic ice, the Cube sensed and captured the collisions of neutrinos, which are invisible, chargeless and nearly weightless cosmic particles that move at the speed of light. The Cube measured the light neutrinos emit when hitting water molecules in the ice. ADI technology in the Cube's communication system digitized these signals to protect them as they traveled a mile up to the surface.

Scientists at the world's largest particle accelerator, IceCube, located in Antarctica, used ADI technology to digitize signals created by collisions of neutrinos 1 mile beneath the ice.

ADI was also in the Laser Interferometer Gravitational-Wave Observatory (LIGO), which recorded gravitational waves that traveled over 1 billion light years through space. LIGO's detectors, which sensed the ripples in the fabric of space-time, use ADI technology throughout, including in LIGO's optical measurement system. The precise measurements taken by these systems confirmed a prediction of Einstein's 1915 general theory of relativity and gave birth to an entirely new field: gravitational wave astronomy.

"Just think: ADI may help mankind 'see' back through time to the dawn of creation," marveled Roche.

> **"When the combination of signal and data processing is available, the right communication technologies widely deployed and the critical software tools and applications are embraced, we have the makings of a once-in-a-generation revolution."**
>
> **SAM FULLER**



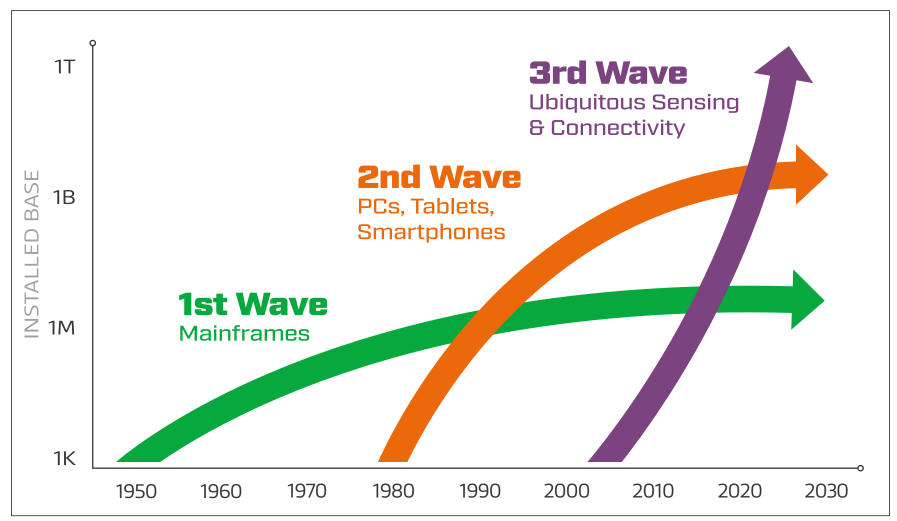
Sam Fuller, who served as CTO from 1998 to 2015, guided ADI's move from the periphery to the center of information and communications technology.

But to prosper in that revolution, ADI had to reinvigorate its risk-taking soul—to pursue and perfect new capabilities built on its critical core linear, mixed-signal and digital signal processing technologies. Management categorized ADI strategy in terms of three horizons, a concept described in a book called *The Alchemy of Growth*. The book explains how established companies maintained healthy growth by managing three horizons simultaneously.

The first horizon focuses on defending and extending the core business, which for ADI was primarily derived from semiconductor component sales. These are the bread and butter of a company, well established in the market and earning a healthy stream of revenue. "It's important that we keep funneling R&D into [core technology] to retain our leadership, because we pull on that technology to do a lot of other things," said Pat O'Doherty, ADI's vice president of emerging business. On the second horizon are emerging products that are ramping up revenue and have the potential for high growth and profits. "These may have come from ADI's core technology, but they have turned into sustainable businesses and are in their growth phase," said O'Doherty. On the third horizon are the seeds of tomorrow's business and the next generation of growth.

Roche wanted ADI to lift its gaze to find more third-horizon opportunities. "These are things that could be disruptive and might even displace our existing business," he said. Some might come from within the company, but ADI should look outward as well. "We need to discover disruptions first so that we profit rather than suffer from them. Healthy, long-term-focused companies need a mindset of perpetual novelty, openness and curiosity to push the bounds of what's possible."

Three Waves of Innovation

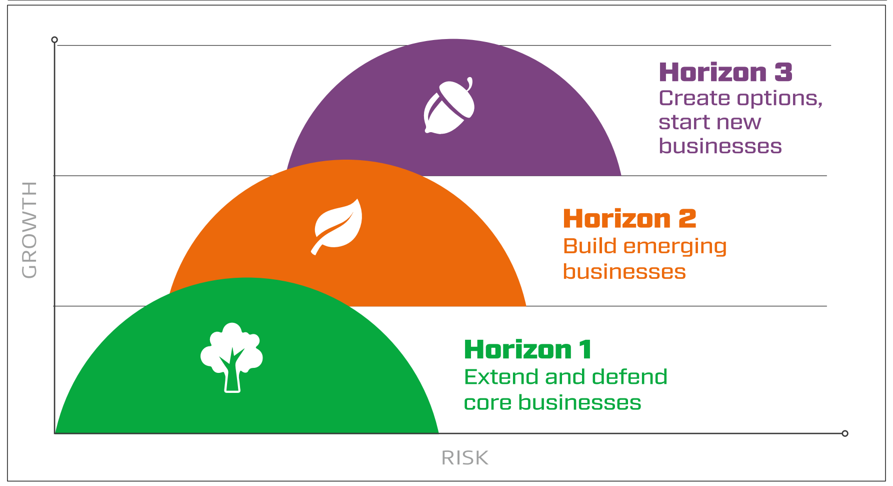


Fueled by ubiquitous sensors and connectivity, intelligent computing and abundant storage, the emerging third wave of computing created enormous potential for ADI technologies.

Analog Garage

In 2014, Roche founded Analog Garage to fund entrepreneurial activity both inside and outside of ADI. To stimulate

Three Horizons of Growth



In 2017, ADI invested about 75 percent of its R&D budget to extend and defend core business (Horizon 1), 20 percent in emerging technology and product (Horizon 2) and 5 percent on long-term investments to create options for future business growth (Horizon 3). (Diagram adapted from *The Alchemy of Growth*, by Baghai, Coley and White.)

more "intrapreneurship," ADI called on its employees to propose Analog Garage Initiatives (AGIs), ideas that are risky but also high in potential rewards.

Taking risks was certainly not new for ADI—it had always been part of ADI's culture. "When Ray took the risk on MEMS technology in the early 1990s, that was [a third-horizon] initiative," said Roche. "He had to fight tooth and nail for years to protect it from the existing businesses that wanted to kill it off." But as the company grew larger, and as the original crop of ADI engineers and managers retired, it needed to expand its options along the risk spectrum in order to stimulate fresh growth. Roche wanted to increase ADI's tolerance for risk while also managing that risk responsibly.

New AGIs would be quickly vetted and, if approved, funded. Management expected a high proportion of them to fail, but the goal was to keep up a brisk pace of new projects. "What is critical is that the learnings are captured as we exercise these initiatives," said CTO Peter Real. "To fail without learning is true failure; to fail and learn fast will be a success." Ideas that blossomed into concrete opportunities would "graduate" into the appropriate business unit, which would then take the technology to market.

To encourage ADI to look beyond its own walls and engineers, Analog Garage emphasized forging more, and stronger, relationships with universities, accelerators, venture capitalists and startups. For example, it sponsored several IoT-related projects at MIT and funded research at the University of California at San Diego on millimeter wave antenna arrays. It partnered with Greentown Labs, the largest clean-tech incubator in the world.

Analog Garage also began investing in startups. It worked with an Israeli company, for example, to develop a spectroscopy sensor-to-cloud platform. The startup had developed a hand-held instrument that could scan substances like food to identify nutritional content and medicine for chemical composition. With the partnership, ADI planned to shrink the device to a small package that could be integrated into products like smartphones and wearables.

> **"We need to discover disruptions first, so that we profit rather than suffer from them. Healthy, long-term-focused companies need a mindset of perpetual novelty, openness and curiosity to push the bounds of what's possible."**
>
> **VINCE ROCHE**

"The purpose in actively engaging with these entities is to broaden our view relative to what is going on outside of ADI and create opportunities to both learn and respond rapidly should we see software, hardware or services we're interested in," said Real.

Understanding Ecosystems

"We have the technology and systems knowledge," said Martin Cotter, ADI's senior vice president of worldwide sales and digital marketing, who joined the company in 1986. "But we need to go further to understand the ecosystems and construct go-to-market strategies that will capture more of the value we are helping create for our customers." Indeed, "in a connected, data-hungry world, the value may lie in the information as much as the silicon," added Roche.

This may lead to new sources of revenue for ADI, such as collecting a fee for each scan of the food or medicine or charging a monthly subscription, said Real. "This is where we are seeing a significant number of emerging opportunities," he said. Silicon and hardware would continue to be necessary "but not sufficient if we are to expansively and imaginatively create and capture value while leading competitively."

Martin Cotter, senior vice president of worldwide sales and digital marketing.

Analog Garage, established in 2014 to incubate technologies, capabilities and new business models, is an organic extension of ADI's risk-taking culture.

ADI partnered with Greentown Labs, the world's largest clean-tech incubator, in 2015 to help member startups bring their energy-focused inventions to market faster.

Beyond Silicon

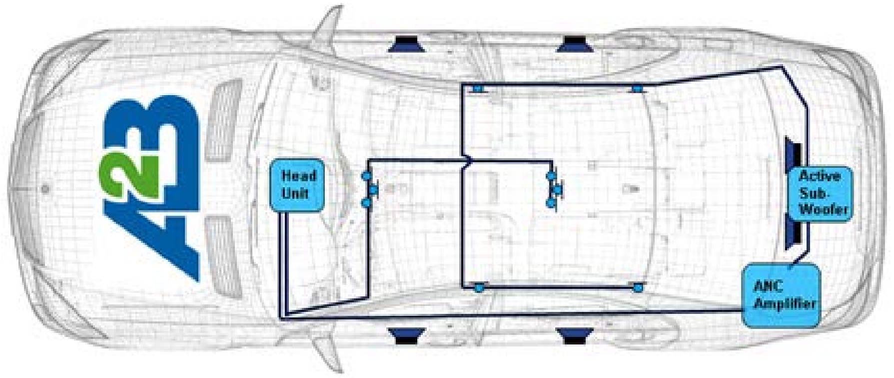
ADI's analog engineering expertise was an increasingly valuable resource to customers, and yet they wanted more. They wanted a network stack that connected to the cloud, including a layer of security atop that stack, drivers to interface to a radio, and intelligence at the node to optimize local edge as well as cloud-based processing. That meant ADI needed to collaborate more closely than ever with its customers and also with end users.

For example, the company worked with farmers to develop Crop Connect, an environmental sensing solution for agriculture. Using sensors and cloud analytics, it collected and analyzed data—including light, temperature and humidity—that can help farmers grow better crops. These collaborations helped ADI understand the conditions under which many IoT devices must operate as well as develop other sensing technologies, such as measuring moisture so farmers know exactly when and how much to water the crop and chemically analyzing the fruits to determine the best time to harvest.

"Our ambition with smart agriculture is to provide ubiquitous sensing capabilities and easy-to-understand and accurate data to growers worldwide," said Cotter. "This approach to crowd-sourced, accurate and economic data will help provide better outcomes for growers, higher-quality produce for consumers, and a socially and financially sustainable business for ADI."

Such projects also helped ADI move closer to the end customer, which helped it deepen its understanding of needs and challenges. "It is becoming increasingly important to understand not only the technology underlying [ADI's customers'] products but also their markets and the ecosystems in which they operate," said Roche.

ADI collaborated with farmers to develop Crop Connect, an environmental sensing solution to grow tomatoes more abundantly and sustainably. Here, ADI engineers use a hand-held spectrometer to check the plants.



By deepening its understanding of end customers, ADI increased the impact of its solutions. In automotive, ADI engineers developed the automotive audio bus (A^2B) to decrease the weight of cable harnesses and thus increase fuel efficiency.

Innovate With Impact

ADI's future would be about more than silicon and systems; it would be about algorithms, software, data and ecosystems. "Silicon is still the foundation and will remain so, but we have begun to extend our understanding of innovation to systems, software and business models that enable us to solve tough problems," said Roche. "Increasingly, our value may lie in producing high-quality information—not just data—that enables our customers to improve the quality of their decision-making and actions."

Value as determined by the end customer would be the driver of ADI's revenue. That meant the company must shift its perspective, from focusing on what problem its technology can solve to what problem it should solve. "We have a trove of technology and expertise and the capability to solve many problems. Our challenge is to deepen our understanding of the customer and their customers so we can anticipate which problems we should solve to have the most meaningful impact," said Roche.

For example, ADI developed a high-value solution when it looked beyond its traditional customer—suppliers of automotive subsystems—and worked directly with car manufacturers. Rather than considering only components or even subsystems, ADI engineers developed the automotive audio bus (A^2B) to distribute audio throughout the car on a twisted-pair wire, which reduced the weight of cable harnesses by up to 75 percent. A^2B solved an ongoing problem for carmakers: how to reduce weight so as to improve fuel efficiency.

By going beyond silicon, becoming a trusted partner and innovating with impact, ADI hoped to ride the third wave of information and communications technology into its next 50 years.

Analog Is Everywhere

A company that started in 1965 with the humble op amp has an opportunity to be at the center of a potential wave of technology unlike anything that has ever come before. ADI has developed some of the most sophisticated signal processing components in the industry—from op amps and data converters to DSP and MEMS, RF, power and microwave ICs. It has amassed some of the most respected analog technology companies of their era—PMI, Hittite and Linear Technology. Under the strong and consistent leadership of just three CEOs, the company has transformed from modules to ICs; expanded from low-volume industrial markets to high-volume consumer, computer and communications markets; and is evolving from designing components to developing systems. As it turns to a new half-century, it will have to evolve its culture and broaden its perspective yet again.

"Our ambition is to make sense of the bits that flow through our products in order to create useful information for our customers," said CEO Vince Roche. That will secure ADI the privileged place it has fundamentally occupied since its founding in 1965 as a complex problem-solver. More than a product supplier, ADI will be an influencer and collaborator with its customers. "The history of ADI has been all about solving the complex challenges of converting analog into digital," Roche said. "The future will be about solving the challenges of turning data into information."

Afterword

In *Reflections on the Human Condition*, the philosopher Eric Hoffer points out that "in times of change, learners inherit the earth, while the learned find themselves beautifully equipped to deal with a world that no longer exists." This is a principle that has guided much of my life and career. We are living through times of extraordinary change, and while it appears to be human nature to desire stasis in our lives, I learned early on that success lies on a different path.

That understanding played a role in my joining Analog Devices, a company that had been successful and still had a hunger to be at the epicenter of innovation. My first role back in the late 1980s at ADI was traveling the world meeting with players in the nascent cellular communications industry, figuring out the key problems ADI could solve. It was the challenge that drove us, but no one could predict the profound and far-reaching impact of our work.

In North Africa, for instance, experts credit the mobile phone with helping to improve the region's poverty rate. Cellular's impact on the reduction of information asymmetry between markets and buyers and sellers, combined with the emergence of digital payment systems, has resulted in 80 percent of regional commerce now being conducted via mobile communications. Goods from crops to crafts can now move more easily, lifting the standard of living for millions.

We suspected wireless could be a huge market, but we never dreamed of societal impacts like this. As we look to the future of 5G communications and beyond—and its potentially exponential impact on transportation, healthcare and other areas of our lives beyond traditional communications—it is clear that technology has the potential to dramatically improve our world socially, economically and environmentally.

We are at the cusp of a new age in technology, in which the boundaries between the physical and the digital worlds will increasingly blur. Powerful capabilities of electronic sensing, computing and communications are being embedded into our everyday surroundings—our homes, our cars, our offices, our factories and soon ourselves. This proliferation, along with other technologies like artificial intelligence and virtual and augmented realities, will change and reshape our world. Creative and enterprising people will invent new solutions, which, like the mobile phone, could help alleviate previously intractable problems such as poverty, hunger, and access to good healthcare, fresh water and clean air. For a company like ADI that stands at the intersection of the physical and digital worlds, this future holds almost limitless possibilities.

In this book, you've read how ADI arrived at this moment. We started with the basic component of analog technology—the humble op amp—and then expanded along the signal path to converters, digital signal processors, sensors, power and RF. Our source of innovation broadened from the ingenuity of small design teams inventing cutting-edge components to global teams collaborating to develop complete system solutions. We entered new markets as new applications for our technology emerged in new types of business.

These transitions weren't easy, but ADI faced the challenges head-on and ultimately thrived. We did so by remaining true to our core principles: staying curious and open-minded so we keep learning and adapting, thinking unconventionally rather than running with the pack, being willing to take calculated risks, and valuing innovation and innovators as the key to business success.

Moving forward, we face a far different landscape than any we've traversed before. Navigating it requires shifting our perspective and widening our aperture even more. Rather than focusing just on silicon, we are focused on fully understanding the application domain and innovating at the ecosystem level across multiple technology dimensions—from materials science to algorithms to cloud—to increasingly produce system-level solutions. We are even broadening our view of how we will more fully monetize our intellectual property, potentially creating new business and financial models with opportunities for new kinds of revenue growth and profit.

These changes are mirrored across broad swaths of the economy. Manufacturers used to just build hardware like jet engines. Today, they make as much or more revenue from embedded software, sensors, data and services than from the hardware sale. The engines do more than power jets: They produce data that, when monitored and analyzed, increase reliability and save money by highlighting when maintenance is needed and become new sources of innovation based on the learnings gained.

At least, that's the direction some industrial manufacturers are heading today. Tomorrow, a new technological breakthrough or economic shift may send the industry along a different path. If the history of the past 50 years teaches us anything, it's that no person or company knows exactly what the future holds with any level of certainty.

ADI has proved time and again how well equipped we are to adapt to whatever comes. That is the gift and the legacy of the tremendous innovators who founded and grew this company.

In our second half-century, it will be up to a new generation of ADI innovators—the talent of today and tomorrow—to write the next chapter of the ADI story. You are the key to the company's future. You have unprecedented opportunities to shape the world in ways we can't even dream of today. Your challenge, and your privilege, is to stay firmly grounded in ADI's core principles while staying ahead of what's possible. If you do that, ADI's next 50 years will be ever brighter than our first.

Vincent Roche

Vince Roche
President and CEO, Analog Devices
2018

Semiconductor Process Milestones

1970–1979

WILMINGTON

1971 Nova Devices acquisition: ADI expands into semiconductors; 12,000-square-foot operations at 831 Woburn St.

1.5-inch and 2-inch bipolar wafers; most used seven masks, but several complex products used up to 13 masks; 10 micron geometry.

The AD530, one of the first products to incorporate thin-film resistors, is manufactured on 1.5-inch wafers.

1972 ADI's space expands to 24,000 square feet for more engineering, testing and assembly.

1973 The Nova Devices group develops technology for trimming thin-film resistors with a laser on the chip. ADI improves on a thin-film silicon chromium resistor material developed by Micro Power Systems Inc. and starts using lasers to adjust the value of the thin-film resistors. Initially, ADI trims each individual part before putting the lid on the ceramic dual-in-line package. Later, the company laser-trims directly on the wafer.

Early 1970s Up to 60 tests can be accomplished in less than 500 milliseconds.

1975 Modernization of 831 Woburn St. fab to 3-inch wafers.

1976 Wilmington adds buried zener process for high-quality voltage references. This process is needed for precision DACs and ADCs at 10 bits and above. It's first used on AD561 and AD565 DACs.

1977 Bipolar process adds I2L transistors to build logic, enabling the first single chip ADC: AD571.

1978 Completes construction of new 80,000-square-foot wafer lab at 804 Woburn St. in Wilmington.

ADS begins using a CAD system for mask layout, getting away from rubyliths. ADS also installs a full mask-making facility in a separate building, which was used until the geometries became very small.

1979 Bipolar process adds BiFET transistors and allows ADI to build its first single chip FET amplifier: AD542.

Bipolar fab upgrades to 4-inch wafers from 3-inch.

LIMERICK

1976 ADI breaks ground in Limerick.

1977 Production begins in Limerick: 3-inch, 8 micron self-aligned MOS; incorporated trimmable thin-film resistors.

1978 First Irish-designed monolithic CMOS products (AD7523 8-bit DAC; AD7533 10-bit DAC; AD7541 12-bit multiplying DAC).

FOUNDRY

1972 ADI signs agreement with Micro Power Systems (MPS) to build CMOS converters and linear ICs in Santa Clara, California. CMOS and thin-film resistor technology from MPS are to be used to further ADI's digital panel meter line.

1973 Industry's first CMOS 10-bit digital-to-analog converter (the AD7520) uses the Micro Power process.

Semiconductor Process Milestones

1980–1989

WILMINGTON

1982 BiMOS process is released.

1983 Flash process, when combined with compatible precision thin-film resistors, addresses disk drive data recovery market and enables high-speed analog products.

1984 BiMOS II mixed-signal process is released; combines superior analog switching and logic density offered by CMOS with superior analog signal processing characteristics offered by bipolar and JFET.

1985 New Complementary Bipolar (CB) can achieve speeds in monolithic devices that were previously only achievable through expensive dielectrically isolated process.

LIMERICK

1982 Solid state switches manufactured using DI tubs as starting material.

1985 Linear compatible CMOS (LC^2MOS) process released. Over the next decade, LC^2MOS continued advancing with variations in geometry, voltage ratings up to +/-15 volts, LOCOS isolation technology and poly/poly caps.

1987 Transition to 4-inch wafers.

1988 World's first technology using SOI wafer and deep trenches for fault-protected switches is released. HVSDI process is still in use in 2015 on 8-inch wafer lines.

SANTA CLARA/SUNNYVALE

1988 PMI introduces industry's first CBCMOS (CBCMOS1) process capable of supporting up to 30-volt operation.

FOUNDRY

1987 ADI begins migration of ADSP-2100 to 1.0 micron from 1.5 micron.

Semiconductor Process Milestones

1990–1999

WILMINGTON

1992 XFCB extends CB by pioneering 1.5 micron Single Poly Non-Self-Aligned (SP NSA) silicon-on-insulator technology, which ADI calls bonded wafers.

1994 ADI's first double poly silicon emitter process provides 25 GHz transistors. RF25 is developed and qualified in only 14 months.

1995 Fab upgrades to 6-inch wafers from 4-inch wafers, primarily for high-speed linear products.

1996 XFCB-1.5 is released for 1.0 micron wafer production.

1998 XFCB26 1.0 micron Single Poly Non-Self-Aligned (SP NSA) releases.

1999 XFCB12 12-volt 1.0 micron.

LIMERICK

1995 Mixed-signal wafer fab is in full production.

1996 Upgrades enable 6-inch submicron production.

1997 Production begins using TSMC 0.6 micron CMOS process.

1998 Addition of thin-film resistors to 0.6 micron CMOS.

1999 First direct conversion RF chip set (Othello) is released on 0.6 micron BiCMOS process.

CAMBRIDGE

1991 ADI announces plans to build micro-electromechanical systems (MEMS) accelerometers intended for use as crash sensors in automotive airbag systems using surface micro-machine process technology.

1996 ADI signs lease for Cambridge wafer fab.

1997 6-inch wafer fab is dedicated to production of iMEMS

1998 iMEMS process is released.

SANTA CLARA/SUNNYVALE

1990 ADI acquires PMI. The Silicon Valley operation develops CBCMOS2 and CBCMOS3 processes with smaller device design rules and geometries, for 15-volt and 12-volt operations.

1996 BiCMOS and BCDMOS processes are released. Both leveraged DMOS structures to handle high voltages used in applications such as automotive and industrial controls.

1997 6-inch conversion complete running CBCMOS process.

FOUNDRY

1991 ADI signs an agreement with Hewlett-Packard that gives ADI access to HP's 0.8 and 0.55 micron CMOS and BiCMOS technologies. ADI planned to initially build products at HP fabs, with the option to transfer IP to ADI's own fabs. (No products were ever released on this process.)

1993 ADI and TSMC begin developing processes jointly. Highly linear capacitors added to TSMC standard CMOS give rise to new analog CMOS process.

1994 ADI begins working with IBM to commercialize a new SiGe bipolar process for applications requiring lowest power at speeds up to 10 GHz.

1996 ADI and TSMC expand their relationship to significantly increase standard digital CMOS wafer availability. Consumer, communications and computing market volumes necessitate transfers of process technology between Limerick and TSMC.

ADI makes equity investment in Chartered Semiconductor, whose Singapore wafer fab operates 8-inch lines.

ADI, TSMC, Altera and ISS announce joint venture. Plan an 8-inch, 0.25 micron fab in Camas, Washington, called WaferTech.

Semiconductor Process Milestones

2000–2015

WILMINGTON

2001 XFCB-2 0.6 micron.

2003 XFCB-3 0.35 micron: First SiGe Base, silicon-on-insulator shallow trench bipolar process is a joint development with TSMC.

2004 4-inch wafer lines close.

2005 XFCB18 is released.

2006 XFCB-3C 0.35 micron CMOS and SiGe.

2007 XFCB65 1.0 micron Single Poly Non-Self-Aligned (SP NSA).

2009 XFCB40 1.0 micron Single Poly Non-Self-Aligned (SP NSA).

XFCB3-OPIC: Monolithic integration of Ge photodiodes with XFCB-3.

2011 XFCB-3C 0.18 micron CMOS, 0.35 micron SiGe.

2014 8-inch wafer line added.

LIMERICK

2001 Transition to 8-inch wafers. Introduction of 0.35 micron BiCMOS.

2003 Transfer of 0.35 micron BiCMOS to TSMC to meet increased demand for Direct Conversion RF chip set.

4-inch wafer lines close.

2004 iCMOS process released: proprietary high-voltage CMOS/BiCMOS for analog components; up to 30 volts and 0.6 micron.

2005 High-voltage DMOS process released (BCDMOS).

2006 iPolar 36-volt bipolar process enabled devices that used 75 percent less silicon area than earlier bipolar processes.

8-inch wafer fab online.

2007 Development of OTP non-volatile memory using sub-micron level fuses made from thin-film resistors. Replacement of laser trim with digital calibration for high-precision DACs.

2009 Consolidation of production to 8-inch; 6-inch wafer lines close.

Initial installation of isolated cleanroom (IPD) to enable use of non-CMOS compatible materials.

2011 iCoupler process enables chip-scale transformers to isolate signals and power.

2012 EP205: ADI's first 250-volt CMOS process is released.

2014 HSCB36: 36-volt SiGe bipolar process for precision amplifiers is released.

2015 First MEMS switch using gold material is released.

New processes enable on-chip transformers with magnetic cores for power transfer, MEMS resonators, chemical and gas sensors, and energy-harvesting devices.

CAMBRIDGE

2009 Production is transferred to Wilmington; Cambridge wafer fab closes.

SANTA CLARA/SUNNYVALE

2003 4-inch wafer lines close.

2006 Fab operations close and production is transferred to Wilmington and Limerick.

FOUNDRY

2007 ADI and TSMC begin joint development of MEMS.

ADI and TSMC begin joint development of new 0.18 micron high-speed bipolar process for precision analog ICs (XF3C).

2013 XF3C (XF3 + 0.18 micron CMOS) is released at TSMC.

2014 XF4C double poly, SiGe 0.18 micron CMOS is a joint development between ADI and TSMC.

2015 XF4C BiCMOS process is released at TSMC.

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