Over 100 Years of the IEEE Medal of Honor

With Foreword by K. J. Ray Liu, 2022 IEEE President & CEO and Asad M. Madni, 2022 IEEE Medal of Honor Recipient
Over 100 Years

OF THE

IEEE Medal of Honor

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The profession of engineering has a long, rich, and significant history, bringing science and technology together to improve the lives of individuals and provide substantial benefits to humanity. Therefore, it is essential that the stories of pioneering technological developments and discoveries, and the people behind them, are preserved for generations to come.

IEEE roots go back to the time when electricity and telegraphy first began to have a major influence in society with the 1884 founding of the American Institute of Electrical Engineers (AIEE). Within 30 years, another technical revolution began with the birth of radio and vacuum tube electronics, and in 1912 the Institute of Radio Engineers (IRE) was founded. On the first of January 1963, the AIEE and the IRE came together to form the current IEEE.

Today, IEEE reflects on the progress of 138 years at the forefront of revolutions in energy, communications, and computing, the underlying disciplines in hardware and software that have supported these technological advances, and the many fields of application in industrial activities, consumer products, transportation, medicine, and many other domains that have shaped our modern standard of living.

As the largest technological association in the world, it is our responsibility to preserve the legacy and heritage of IEEE, its members, their related professions and technologies, and to champion the importance of engineering to future generations.

The Medal of Honor, sponsored by the IEEE Foundation, is the IEEE’s most prestigious award for an exceptional contribution or an extraordinary career in the fields of electronics and electrical sciences and engineering. Since 1917, the most important contributors to these fields have received the IEEE Medal of Honor in recognition of their critical roles in laying the foundations of the modern electric world.

Our IEEE Medal of Honor recipients and their collective accomplishments exemplify the tremendous progress achieved in electronics and electrical science over more than a century. As a result, the Medal of Honor is a living testament to the lives and careers of these major contributors to our modern world. At IEEE, we focus on what’s next—enabling innovation and the creation and delivery of new technology solutions. Much of the work being done today is inspired and built on the foundational deeds of our IEEE Medal of Honor recipients.

The IEEE Medal of Honor is widely considered to be equivalent to the Nobel Prize in the Field of Electronics and Electrical Sciences and Engineering. The Nobel Prize, awarded in many disciplines, seeks to recognize an individual’s contributions to humanity as an ideal. Similarly, the IEEE Medal of Honor celebrates outstanding accomplishment of both excellence and personal contributions to engineering, science, and technology. It is a celebration of the accomplishments and lasting societal impact of some of the greatest minds of our time.

Within these pages you’ll find legendary trailblazers and innovators. Their contributions are evident in the technologies we use every day to communicate, work, travel, stay healthy, and entertain ourselves. Their endeavors have helped accelerate the pace of technological change, often building on each other, to evolve large and small advances to even greater heights. We are thrilled to have recognized such a diverse roster of award recipients from around the world and across the broad spectrum of engineering disciplines. And to provide an opportunity for aspiring pioneers, thinkers, and makers to learn from these far-reaching journeys, innovations, and insights.

We hope that you will enjoy celebrating more than 100 years of Medal of Honor history embodied by the visionary leaders — our members and colleagues — profiled in the following pages. Their achievements serve as an inspiration to the next generation of technologists.

The Medal of Honor recipients featured in this book are a remarkable group of individuals who have made enormous contributions to science, technology, the engineering profession, and the IEEE — our professional home. Through their influential efforts, they have helped IEEE foster the creation of new technologies for the benefit of humanity.

K. J. Ray Liu
2022 IEEE President & CEO

Asad M. Madni
2022 IEEE Medal of Honor Recipient
IEEE is the world’s largest technical professional society and serves professionals involved in all aspects of the electrical, electronic, and computing fields and related areas of science and technology that underpin our modern civilization. And it serves the general public as well, as a driving force in supporting and stimulating the technological progress that underpins economic growth and improves standards of living and well-being around the world.

IEEE members — more than 400,000 technologists in over 160 countries — drive technological innovation and excellence for the benefit of humanity every day. IEEE inspires a global community to innovate for a better tomorrow through its highly cited publications, conferences, technology standards, and professional and educational activities.

IEEE members are technical professionals united by a common desire to continuously learn, interact, collaborate, and innovate. They are at the forefront of life sciences and biomedical engineering, robotics, artificial intelligence, machine learning, photonics, computers, software, hardware and chip design, microwave theory, aeronautics, the Internet of Things, cellular communications, power and energy, remote sensing, and cybersecurity, among other cutting-edge technologies.

At IEEE, the professional home for the engineering and technology community worldwide, we know that the advancement of scientific and technical knowledge has always been the engine that drives the quality of life for every citizen of this planet and for improving global conditions.

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For the full story of the IEEE Medal of Honor, its origins, connections to other major awards, and its legacy of esteem, please visit https://ethw.org/IEEE_Medal_of_Honor.
History of the IEEE Medal of Honor

To explore the history of the IEEE Medal of Honor is to explore the history of IEEE itself. The roots of the modern-day Medal of Honor trace back to 1917, when the Institute of Radio Engineers (IRE) established the IRE Medal of Honor to recognize key advances and achievements in radio technologies. At first, the Medal could only be earned by a person who, within the prior two calendar years, had publicly debuted the greatest advance in radio communication, which also needed to be both operational and described in a scholarly journal of note. Within two years, however, there were changes to these requirements, and recipients were no longer bound by limits on publication or time.

The IRE Medal of Honor, designed by noted sculptor of the era Edward Field Sanford Jr. of New York, was first awarded to Edwin H. Armstrong for his work on the audion. Though the award was earned in 1917, it was not presented until 1919, a delay due in large part to World War I. Since then, the Medal of Honor has been awarded nearly every year (no awards were presented in 1925, 1947, 1965, and 1976) to some of the most significant figures in engineering history.

Guglielmo Marconi earned his IRE Medal of Honor in 1920. Alfred N. Goldsmith, a key figure in the creation of the IRE, as well as standards development, earned his Medal of Honor in 1941. An impressive IRE Medal of Honor winner from those early decades was Professor Michael I. Pupin, who not only earned IRE’s top accolade, but also received the American Institute of Electrical Engineers’ (AIEE) Edison Medal in 1920, the American Association of Engineering Societies’ (AAES) John Fritz Medal in 1932, and served as a Fellow and a president of both the IRE and AIEE. In addition to those accomplishments, Professor Pupin mentored no less than five future Nobel Prize winners. In all, to date, seven Medal of Honor recipients have earned Nobel Prizes in fields ranging from radio wave propagation to the invention of the transistor.

In 1963, AIEE and IRE merged to form the IEEE, weaving together rich tapestries of engineering history and accomplishment. Consolidating two such exceptional organizations was challenging; the logistics of meshing together awards processes was no exception. The resolution proved simple, yet elegant—award inaugural IEEE Medals of Honor to two exceptional candidates, John H. Hammond Jr., an inventor with more than 700 inventions,
and George C. Southworth, a research engineer at Bell Telephone Laboratories.

The 1963 merger brought with it the merging of fields of interest as well, broadening the pool of exceptional candidates for recognition. Following the merge, the IEEE Medal of Honor would be earned by mathematical theorists like Claude E. Shannon (1966), by laser pioneers like Charles H. Townes (1967), and by Charles F. Quate, the pioneer of magnetic resonance imaging (1988).

Today, the IEEE Medal of Honor is presented for “an exceptional contribution or an extraordinary career in the IEEE fields of interest.” The IEEE Medal can only be earned by an individual, and those who earn it become ineligible to earn any other IEEE institute-level medal or recognition, including technical field awards. It is the only major award in engineering not named for an inventor or scientist.

Since the turn of the 21st century, IEEE Medal of Honor recipients have included engineering giants like Gordon E. Moore (2008), Andrew J. Viterbi (2010), John L. Hennessy (2012), and Mildred Dresselhaus (2015). While much has changed since its 1917 genesis as the IRE Medal of Honor, much remains the same for the IEEE Medal of Honor. Today, the Medal ranks among the preeminent accolades for engineering, honoring the work of those whose efforts have advanced technology and done so in benefit to humanity, a legacy with roots that extend back more than a century to the work of the IRE.

Theodore von Karman once remarked that a scientist studies what is, while engineers create what never was. For IEEE Medal of Honor recipients, there is perhaps no greater summation of what sets them apart from the exceptional caliber of engineers working in IEEE’s fields of interest. The IEEE Medal of Honor recipients have dared to envision something new, something revolutionary, and then worked tirelessly to achieve it. They are giants, and the engineers of today can and will stand upon their shoulders, seeing further... and one day achieving even more.
Vinton (Vint) G. Cerf was born June 23, 1943, in New Haven, Connecticut. He received the B.S. degree in Mathematics/Computer Science from Stanford University in 1965 and the M.A. and Ph.D. degrees in Computer Science from the University of California at Los Angeles in 1970 and 1972, respectively. He is known as one of the “Fathers of the Internet.” As early as 1969 Dr. Cerf and his colleague, Robert E. Kahn, were already working on the U.S. Defense computer network, ARPANET. In 1972, Dr. Cerf joined the faculty of Stanford University. With Dr. Kahn, he conceived the Transmission Control Protocol/Internet Protocol (TCP/IP) suite, the key technical innovation that permitted the transformation of the original ARPANET into today’s Internet. In 1974, they outlined the design of the internetwork protocols in a paper entitled “A Protocol for Packet Network Intercommunications,” which was published in the IEEE Transactions on Communications. While the details of the protocols have changed to some extent, the essential concept was fully articulated in that first paper and remains viable today.

Dr. Cerf played a major role in managing the development of Internet-related data packet technologies and network security programs while with the U.S. Department of Defense’s Advanced Research Projects Agency from 1976 to 1982. It was during this time that he formed the Internet Configuration Control Board (ICCB), which evolved into the Internet Architecture Board (IAB), the body responsible today for technical oversight of the Internet architecture and standards process.

Between 1982 and 1986, he served as vice president of MCI Digital Information Services, where he led the engineering of MCI Mail, the first commercial e-mail service to be connected to the Internet.

As Corporate Vice President of the Corporation for National Research Initiatives, he was responsible for managing the National Digital Library and packet network research projects. He conducted national research efforts on information infrastructure technologism, co-inventing knowledge robots (mobile software agents used in computer networks) with Dr. Kahn.

Dr. Cerf returned to MCI Corporation as Senior Vice President of Internet Architecture and Engineering in 1992. He was responsible for the development of MCI’s Internet network.

In the 1990s, Vint Cerf, Robert Kahn, and others co-founded the Internet Society in aid of standards and policy development for the Internet. In the 2000s, he promoted the Internet Corporation for Assigned Names and Numbers (ICANN), a non-profit that helps to ensure a stable, secure, and interoperable global Internet, and served as its chairman from 2000-2007.

Dr. Cerf is an IEEE Life Fellow and has received many other accolades for his work on the Internet, including the US National Medal of Technology, the US Presidential Medal of Freedom, US National Medal of Technology, the Queen Elizabeth Prize for Engineering, the Japan Prize, the Charles Stark Draper Award, the ACM Turing Award, and more.
Born on 8 September 1947, in Mumbai, India, Asad Madni received the B.S. and M.S. in Electrical Sciences and Engineering at the University of California, Los Angeles (UCLA) in 1969 and 1972 respectively, the Ph.D. in Engineering from the California Coast University in 1987, and the Senior Executive Program post graduate credential from MIT Sloan School of Management in 1990.

Madni served as President, COO, and CTO of BEI Technologies Inc. from 1992 until the completion of its US$600M acquisition to Schneider Electric in 2006. Prior to BEI, he was with Systron Donner Corporation for 18 years in senior technical and executive positions, eventually as Chairman, President, and CEO. There he made seminal and pioneering contributions in the development of radio frequency (RF) and microwave systems and instrumentation which significantly enhanced the capabilities of the US Tri-Services and allies. He is currently an Independent Consultant, Distinguished Adjunct Professor and Distinguished Scientist at UCLA ECE Department, Faculty Fellow at the UCLA Institute of Transportation Studies and Connected Autonomous Electrical Vehicle Consortium, and Executive Managing Director and CTO of Crocker Capital.

From automobiles to airplanes and spacecraft, the sensor innovations developed by Madni have revolutionized navigation and stability in aerospace and automotive systems, helping to keep people safe around the world. He led the development and commercialization of the GyroChip®, resulting in a solid-state six degree of freedom microelectromechanical system (MEMS) inertial measurement unit, which required convergence of micromachining, advanced signal processing, and mixed signal integrated circuit design to provide orders of magnitude improvement in size/cost and reliability over prior technologies. It is in use worldwide in over 90 types of aircraft including the active control electronics pitch stability control system of the Boeing 777, as the yaw damper for over 3,000 Boeing 737s; in most business jets as a sensing element in leading attitude control and reference programs; and for guidance, navigation, and control in major U.S. missile, drone, underwater autonomous vehicle, helicopter, and space programs, including the Mars Rover Sojourner and NASA’s AERCam Sprint autonomous robotic camera. It is also used in the ARCHER airborne hyperspectral imaging system used by the U.S. Civil Air Patrol in search and rescue and disaster management missions.

Madni’s leadership was instrumental in transitioning the GyroChip® technology from the aerospace and defense sectors to the automotive and commercial aviation markets. He led a miniaturization effort resulting in significant sensor size reduction while increasing performance and was chief architect for signal processing techniques. These breakthroughs dramatically reduced the cost of the GyroChip® and facilitated unprecedented acceptance by the automotive industry for use in over 80 models of passenger cars for electronic stability control and rollover protection systems.

In 1977, Madni [seated, center] discusses the communications-line analyzer he developed for the U.S. Navy

For pioneering contributions to the development and commercialization of innovative sensing and systems technologies, and for distinguished research leadership.
His innovations also resulted in performance, reliability, and cost advantages for MEMS accelerometers; linear/rotary position sensors; and torque, pressure, and embedded sensors/actuators for the automotive industry. These technologies and the GyroChip® became the foundation of vehicle dynamic control and helped realize the dream of autonomous vehicles through capabilities including electronic stability control, rollover prevention, lane change assist, autonomous cruise control, navigation, drowsy-driver detection, drunk-driver detection, child seat detection, memory seat sensing, self-maintenance, and other key features without which autonomous vehicles would not be a reality today.

Additionally, Madni also led the development of the control system for the Hubble Space Telescope’s Star-Selector, which is still in use today. It has provided the Hubble with unprecedented pointing accuracy and stability, resulting in over 1 million truly remarkable images that have enhanced our understanding of the universe, such as the discovery of Pluto’s moons and the formation of galaxies thousands of light years away.

Madni made seminal and pioneering contributions in the development of intelligent systems and instrumentation that significantly enhanced U.S. combat readiness and provided the Department of Defense the ability—not possible with prior art—to simulate more threat representative ECM environments for current and future advanced warfare training. He also led the development of an adaptive control system for a minimally invasive endometrial ablation system, which represented a major advance in the treatment of abnormal uterine bleeding, a condition known as menorrhagia. The system is used to eliminate the tissue responsible for menstrual bleeding by endometrial ablation and allows gynecologists to perform ablation under direct visualization on an outpatient basis under local anesthesia.

His current research focus is on the development of ultra-high data throughput and wideband instrumentation for the detection of rare events, including cancer cells in the bloodstream. He is also guiding research in the area of demand/response techniques for smart grid and electric vehicle applications, wearable sensors, computational sensing, as well as a revolutionary single-shot network analyzer with orders of magnitude improvement in bandwidth and data throughput rate.

Madni is an IEEE Life Fellow, an Eminent Member of the IEEEEta Kappa Nu honor society, and has received numerous other awards over the years. They include the 2022 Royal Academy of Engineering Prince Philip Medal, the 2020 American Society of Mechanical Engineers Soichiro Honda Medal; the 2019 IEEE Frederic Philips Award; a 2016 Ellis Island Medal of Honor; the 2012 IEEE Aerospace and Electronic Systems Society’s Pioneer Award; the 2015 Institution of Engineering and Technology J.J. Thomson Medal and a 2005 Achievement Medal; the 2010 IEEE Instrumentation and Measurement Society’s Career Excellence Award; and an IEEE Millennium Medal. He has been elected to several academies and professional societies including, U.S. National Academy of Engineering, U.S. National Academy of Inventors, U.K. Royal Academy of Engineering, and Canadian Academy of Engineering. He has also been awarded six honorary doctorate degrees and six honorary professorships.
An international icon of information theory, Jacob Ziv’s innovative tools for practical data compression enable the fast and efficient transfer of files over the Internet we now take for granted and revolutionized how we store information.

Ziv is best known for his development, with Abraham Lempel, of the Lempel-Ziv (LZ) algorithms. The LZ algorithms changed the way communications and data storage, and processing systems are conceived and have had an immense impact on the daily lives of computer users and on the operations of commercial electronic products worldwide. The advancements in computing and communications technology continuously pose extremely severe demands on storage, bandwidth, and transmission speed. LZ compression has played a pivotal role in meeting these demands and making the use of lossless data compression pervasive in day-to-day computing.

Prior to the LZ algorithms, data compression methods were centered on communication sources with known stochastic structure. However, in the real world, communication channels and sources often fail to have such structure. The first practical error-free compression algorithm, the Huffman code, was not computationally efficient and required knowledge of the statistics of the data to be compressed, which prevented real-time processing. Ziv’s algorithms allowed for data compression and channel coding without a known probabilistic structure. Rather than trying to measure the source statistics of a given source sequence, and then encoding both the measured statistics and the actual sequence, the LZ algorithms encode the source sequence directly in a way that automatically compresses where possible. This would become central to what is now called universal compression, and Ziv’s accomplishments spurred much subsequent research on universal algorithms.

When the LZ algorithms were developed, their practical impact was not felt right away because there was no real need for data compression for communication. They were used in the late 1970s for magnetic decoding, but it wasn’t until the Internet began to emerge that their importance was realized. LZ is now an integral part of the classical communication algorithms.

Ziv has also made seminal contributions to lossy compression—most notably his 1976 work with Aaron Wyner in which they established the optimal rate for lossy compression with side information at the decoder. It is considered a standard tool in multiterminal information theoretic models spanning beyond source coding, for example, communications aided by relays. Other classical contributions relate to performance bounds, such as the Ziv-Zakai bound on the minimum mean square error, which is one of the tightest to date, decades after its original derivation. He also has made notable contributions addressing basic theoretical problems of practical importance, such as classification problems and universal procedures in source and channel coding/decoding. His recent contributions have focused on different aspects and fundamental ingredients of classification and universal data compression.

Ziv has been a leading figure in the Israeli engineering and scientific community, including at the Technion - Israel Institute of Technology, where he assembled one of the world’s top faculties in the information sciences. He has also served as president of the Israel National Academy of Sciences. In addition to his many research contributions, Ziv has mentored countless young researchers in many fields, both at the Technion and through the IEEE Information Theory Society, serving as a source of wisdom and common sense cherished by so many.

An IEEE Life Fellow and Foreign Associate Member of both the U.S. National Academy of Engineering and the U.S. National Academy of Science, Ziv is the Andrew and Ema Viterbi Faculty of Electrical Engineering Distinguished Professor Emeritus at the Technion - Israel Institute of Technology, located in Haifa, Israel. Ziv served as president of the Israel Academy of Sciences and Humanities from 1995 to 2004.

Ziv was born in Tiberias, Israel, on 27 November 1931. He received the B.S. in engineering and M.S. in electrical engineering from the Technion Israel Institute of Technology, Haifa, Israel, in 1954 and 1957, respectively, and the Ph.D. from MIT in 1962.
Chenming Hu’s pioneering achievements regarding transistor models and novel transistor structures have enabled the continued scaling of semiconductor devices that enable production of the smaller yet more powerful and cost-effective computers and electronic devices proliferating society today.

In the mid-1990s, it became clear that two-dimensional, planar metal oxide semiconductor field-effect transistors (MOSFETs) could not deliver continued performance improvements as dimensions were scaled down due to current leakage in short channel length transistors. This slowed channel length scaling and threatened to end the continuation of Moore’s Law. Moore’s Law is the concept that the number of transistors in compact integrated circuits doubles approximately every two years, enabling the personal electronics we continue to take for granted. To overcome this anticipated roadblock in scaling, Hu led the development of a revolutionary three-dimensional transistor structure known as the fin field-effect transistor (FinFET), named so because its thin vertical fin shape resembles a shark’s dorsal fin. By reducing the thickness of the fin, etched out of the surface of a silicon wafer, the transistor channel length can continue to be scaled proportionally.

Intel began using the FinFET for mass production of computer processors in 2011 and called it the most radical shift in semiconductor technology in 50 years. Hu’s FinFET innovation enabled the 22-, 16-, 14-, 10-, 7-, and 5-nm technology nodes, which were unthinkable not long ago. Today, practically all high-end computers, smart phones, and communications devices use FinFET technology, and it may add decades to furthering the state of the art in electronics evolution.

Also important to the continued advancement of semiconductor technology, has been Hu’s contributions to device modeling. In 1996, Hu’s breakthrough BSIM (Berkeley Simulation) transistor model was chosen as the first industry standard for linking the transistors/manufacturing and circuits/computer-aided-design aspects of semiconductor technology. BSIM models use original mathematical formulas based on transistor physics research. BSIM replaced dozens of in-house models because it’s extremely accurate and highly computationally efficient. It can be used to simulate circuits containing hundred-millions of transistors. BSIM also enables higher level computer-aided design tools to achieve first-silicon success without redesign. Hu has provided all the BSIM series of standard models to the semiconductor industry royalty free, and most integrated circuits created after 1996 have been designed using BSIM models. Hu and his students continue to develop new BSIM models today.

Hu also made pioneering contributions to IC reliability modeling and design. His Berkeley Reliability Tool (BERT) allowed engineers for the first time to design for reliability so that manufacturers and IC design companies can be confident that what they produce will not fail in the field. The descendants of his original models are now embedded in integrated circuit design simulator tools, which has been integral to producing smaller yet more reliable and higher-performance integrated circuits.

An IEEE Life Fellow and recipient of the 2014 U.S. National Technology and Innovation Medal, Hu is the TSMC Distinguished Professor Emeritus with the Department of Electrical Engineering and Computer Sciences at the University of California, Berkeley. Hu was born on 12 July 1947, in Beijing, China. He received his B.S. in electrical engineering at National Taiwan University in 1968, and his M.S. and Ph.D. in electrical engineering and computer science at the University of California, Berkeley in 1970 and 1973, respectively.

For a distinguished career of developing and putting into practice semiconductor models, particularly 3-D device structures, that have helped keep Moore’s Law going over many decades.

Chenming Hu
(12 July 1947)
Over the past six decades, the raw processing power of computers has increased by six orders of magnitude while cost has dropped by three orders of magnitude. Computers have become ubiquitous, invisibly embedded in everyday items, such as mobile phones, cameras, automobiles, and entertainment systems.

By comparison, in the early 1950s, only the largest firms and institutions could afford a computer. Leasing for about US$200,000 per month in inflation-adjusted 2010 dollars, a large-scale computer occupied roughly a hundred square meters, used thousands of vacuum tubes, consumed over a hundred kilowatts, and needed a full-time operating and maintenance staff.

In order to broaden the market, vendors endeavored to offer computers to replace the punched-card equipment widely used by businesses and institutions for over half a century.

Early medium-scale computers

By the mid-1950s, over a dozen intrepid vendors worked to deliver inexpensive vacuum-tube computers. Limited in their capabilities, none were shipped in quantities of more than a hundred or so.

While IBM developed large-scale computers in its laboratory in Poughkeepsie, New York, engineers in its upstate Endicott laboratory designed a medium-scale computer based on a rotating magnetic drum for memory. Delivered in 1954, the IBM 650 Magnetic Drum Data Processing System targeted scientific, engineering, and business applications. Like the large-scale computers, it supported magnetic-tape drives and also offered a scientific floating-point arithmetic option. A usable entry configuration leased for US$4,000 per month (US$32,000 inflation adjusted). Using vacuum tubes for control circuits, the 650 offered 2,000 words of 10 digits or five alphanumeric characters each on a 10-cm diameter drum spinning at 12,500 revolutions per minute.

A few years later at IBM’s new laboratory in San Jose, California, engineers pioneered a computer based on the world’s first moving-head magnetic disk drive. Delivered in 1956, the IBM 305 RAMAC (Random Access Method of Accounting and Control) targeted business applications such as inventory, billing, accounts receivable, and transaction processing. The entry configuration leased for US$3,200 per month (US$25,000 inflation adjusted). The 305 used vacuum tubes and a plugboard control panel and could execute up to 200 instructions from a small magnetic drum memory. The RAMAC stored up to 5,000,000 characters on a stack of 50 61-cm diameter disks spinning at 1,200 revolutions per minute.
By 1956, a computer census reported that three-quarters of the world’s 1,100 computer installations were IBM 650s, making it by far the most popular computer at the time. Its numbers later peaked at 1,800 installations. The IBM 305 RAMAC was nearly as successful, with over 1,000 delivered before its withdrawal in 1961.

Although the IBM 650 and 305 cost less than one fifth that of a large-scale computer, many small businesses still found them too expensive, with a monthly rental exceeding that of their typical assortment of punched-card machines. During this time, computer designs normally targeted either scientific or business applications, but not both. In general, scientific and engineering applications benefited from the fastest possible arithmetic calculations, whereas data processing applications did not benefit from processing speeds faster than the input/output data rates of peripheral devices. A design focused on business data processing applications, together with less expensive circuits, was required before the economic needs of the small-business punched-card marketplace could be met. This suggested a cost target close to the US$2,500 monthly rental for a small business’s typical assortment of punched-card equipment.

**Early solid-state computers**

With magnetic-core memory and transistors in widespread production, the 1960s witnessed a dramatic increase in the number of computers, with deliveries tripling every year.

Philco was one of the first out in 1958, with its all solid-state, large-scale, scientific S-2000 Transistorized Automatic Computer. Using its innovative high-speed surface-barrier transistor, it competed with IBM’s later large-scale scientific 7090 Data Processing System. The Electrologica company in the Netherlands also delivered its medium-scale, solid-state, scientific X1 computer that same year.

Although the IBM 1401 Data Processing System was not the earliest solid-state commercial computer, it rapidly became the world’s most widely used and held that distinction through most of the 1960s. The story behind the 1401’s success is explained in part because it targeted the small-business punched-card user marketplace while leveraging IBM’s mass-production capabilities and worldwide customer support organization.
Kurt E. Petersen's foundational work on microelectromechanical systems (MEMS) helped unify and provide direction for the field, and his commercialization of MEMS technologies has continued to transform the field to realize the many applications we take for granted today. MEMS involve miniature mechanical and electromechanical elements, such as sensors, actuators, and other microelectronics, merged onto a common silicon substrate along with integrated circuits. MEMS-based devices provide important functionality in today's smart phones, medical devices, and smart automotive and smart human-machine interface applications. It was Petersen's 1982 seminal review paper, "Silicon as a Mechanical Material", that helped lay the foundation for future MEMS research. It summarized all the mechanical properties of silicon as well as mechanical devices made on silicon chips at that time and also anticipated future devices. Prior to this work, MEMS research consisted of many unconnected and unrelated efforts. Petersen's paper provided the diverse group of MEMS researchers with a unified vision and a sense of community in which to develop the MEMS industry as we know it today. Petersen was also instrumental in establishing forums for the MEMS academic, industrial, and government communities to share and discuss their work. In 1984, he served as the first program chairperson for the biennial Solid-State Sensors, Actuators, and Microsystems regional workshop. In 1987, he was the first co-chairperson of the yearly International Conference on MEMS.

Petersen has played a significant role in developing innovative MEMS tools, co-founding six companies to commercialize his ideas. At NovaSensor as co-founded in 1985, Petersen led the development of a disposable pressure sensor for blood pressure monitoring during and after surgical operations. NovaSensor was also the first to commercialize the revolutionary silicon fusion bonding (SFB) and deep reactive ion etching (DRIE) fabrication processes. Practically all of today's MEMS high-volume products use a variation of these processes. In 1996, he co-founded Cepheid, where he developed a totally automated, microfluidic system to test for anthrax in the U.S. mail system. Other MEMS diagnostic tests commercialized by Cepheid have transformed the molecular diagnostics industry using microfluidics and the polymerase chain reaction. Petersen became the founding chief executive officer of SiTime in 2004. SiTime commercialized MEMS devices that outperform quartz crystal oscillators for timing applications, and its products can be found in many consumer mobile devices. Petersen co-founded both Profusa and Verreon in 2008. Profusa's small, flexible hydrogel implant for glucose sensing is causing the medical industry to change how it thinks about measuring chemicals in the body. Projects at Verreon were focused on the development of MEMS sensors and actuators on glass substrates instead of silicon to take advantage of cost efficiencies and the potential for use in the flat panel display industry. In 2011, Petersen joined the Silicon Valley Band of Angels, which is an investment group comprised of former and current high-tech executives that funds and mentors early stage, high-tech start-up companies. Petersen is an IEEE Life Fellow and member of the U.S. National Academy of Engineering.

Petersen was born on 13 February 1948, in San Francisco, California. He obtained a B.S. cum laude from the University of California, Berkeley in 1970, and a Ph.D. from MIT in 1975, both in electrical engineering.
Bradford W. Parkinson
(16 February 1935)

For fundamental contributions to and leadership in developing the design and driving the early applications of the Global Positioning System.

A visionary leader in academia, industry, and the U.S. military, Bradford W. Parkinson’s role in developing and advancing the Global Positioning System (GPS) has provided the world with technology we now take for granted and that impacts virtually all aspects of modern living. GPS has become an engine of economic development and the basis for countless applications that rely on accurate positioning and timing information. Parkinson was the chief architect of this satellite-based navigation system that works in any weather condition, anywhere in the world, 24 hours a day, to let us know precisely where we are—whether on land, at sea, or in the air.

As a Colonel in the U.S. Air Force in 1973, Parkinson led the efforts to gain government approval of GPS and served as the first director of the GPS Joint Program Office. While GPS was originally funded solely by the military, Parkinson insured that certain GPS signals would be freely available for civil applications. Under his leadership, the GPS satellites were produced and launched in 44 months. Simultaneously, a ground control system was developed and deployed to upload the satellites. Also developed were eight different kinds of user equipment to demonstrate the capabilities of the new system, and Parkinson led extensive tests to confirm that GPS could meet its goals.

As a professor at Stanford University, Parkinson participated in the development of many innovative applications for GPS while leading a research group within the Center for Positioning, Navigation, and Time. His group successfully modified a commercial Boeing 737 for robotic aircraft landings. In 1992, this plane made 110 fully blind landings using GPS alone. They also developed the first precision robotic farm tractor controlled to an accuracy of approximately two inches on a rough field, initiating the era of autofarming. The group also created the Wide Area Augmentation System (WASS) intended to enable aircraft to rely on GPS for all phases of flight, including precision approaches to any airport within its coverage area. WAAS can also improve accuracy of personal GPS devices. Parkinson also served as coprincipal investigator and program manager of the NASA/Stanford Relativity Gyroscope Experiment, which validated Einstein’s general theory of relativity using orbiting gyroscopes. With GPS providing precision orbit control and measurement, the experiment verified two effects of general relativity never before tested with a mechanical apparatus.

Parkinson’s technical, program management, and political expertise made the initial configuration of GPS a reality. He then worked tirelessly to ensure that GPS remains an effective and reliable military capability as well as a precise and reliable international utility supporting an ever-increasing array of civil applications. Today’s mobile Long-Term Evolution (LTE) communications technology is essentially dependent on high-precision GPS timing for its operation. GPS is also integral to providing emergency services; marine, air, and automotive navigation; weather forecasting and tracking; and surveying and mapping applications.

An IEEE Life Fellow and co-recipient of the 2003 Charles Stark Draper Prize, and recipient of the 2019 Queen Elizabeth Prize for Engineering, Parkinson is the Edward C. Wells Professor of Aeronautics and Astronautics Emeritus at Stanford University, in Stanford, California.

Parkinson was born on 16 February 1935, in Madison, Wisconsin. He was a distinguished graduate of the United States Naval Academy, graduating in 1957 with a B.S. in engineering.
Aerospace, Satellites, & Navigation

The Global Positioning System or GPS is a great technological success story. Developed in the 1970s and 1980s by the U.S. Department of Defense (DoD), the system was primarily intended for the U.S. military. It was successfully used in the U.S.-Iraq War (1990-1991) and U.S. interventions in Kosovo (1999) and Afghanistan (2001-2002). Non-military use was a secondary objective, and throughout the 1990s, civil users were limited to a purposefully degraded subset of the signals broadcast by GPS. Despite these limitations, civil applications of GPS grew at an astonishing rate. Applications unforeseen by the designers of the system are now thriving, and many more are on the way. Through applications in land transportation, civil aviation, maritime commerce, surveying and mapping, construction, mining, agriculture, earth science, electric power systems, telecommunications, and outdoor recreational activities, GPS has become an essential part of the commercial and public infrastructure.

The baseline GPS constellation comprises 24 satellites arranged in six orbital planes (lettered A-F). Each plane is inclined at 55° from the equatorial plane and the orbital period is 12 hours.

The principle of satellite navigation is very simple: your position can be determined if you can measure your distance from each of three objects whose positions (i.e., coordinates in a well-defined reference frame) are known to you. In order to implement a global navigation system based on this principle, GPS has fielded a constellation of 24 satellites in medium-earth orbits with a 12-hour orbital period. These satellites are the objects at known locations from which a GPS receiver measures ranges. The satellites are moving in space at a speed of about 4 kilometers (about 2.5 miles) per second, but the position of each at any instant can be estimated from its broadcast message with an error no worse than a few meters. The distance between the user and a satellite is measured in terms of the time it takes a radio signal to travel from the satellite to the user. Precise measurement of transit time is accomplished by transmitting signals with precision in accordance with nearly perfectly synchronized clocks carried aboard the satellites.

In order to measure the true transit time of a signal from a satellite to a receiver, it is critical that the clocks in the satellite and the receiver be in sync. Fortunately, this tough requirement is easily sidestepped, allowing use of inexpensive quartz oscillators in GPS receivers. The bias in the receiver clock, the amount by which the receiver clock is out of sync at the instant of the measurements, affects the transit times for all satellites equally. The corresponding measured ranges are thus all too short (or too long) by a common amount.
These biased ranges are called pseudoranges. The receiver clock bias thus becomes the fourth unknown to be estimated, in addition to the three coordinates of position. A user, therefore, needs a minimum of four satellites in view to estimate a four-dimensional position: three coordinates of spatial position, plus time.

GPS can determine a three-dimensional position instantaneously, continuously, and globally with an accuracy of several meters. Due to precise and ultra-stable clocks carried aboard the satellites, an inexpensive GPS receiver can also serve as a precise clock and keep time with an accuracy of about 0.1 microsecond. In fact, GPS has become a true global time reference for commercial and scientific activities. GPS users the world over have become accustomed to such accuracy in specifying position and time. The only requirement is for the receiver antenna to have a halfway clear view of the sky to be able to see a minimum of four satellites.
Regarded as the most prolific contributor to the world’s consumer electronics of the late 20th century, Kees Schouhamer Immink fueled the big bang of digital electronics with pioneering coding techniques that have provided the foundation for all generations of optical storage media, from the compact disc (CD) to the Blu-ray disc (BD). A multitalented pioneer in technical areas ranging from coding theory and practice to electronics, mechanics, and optics, Immink has inspired generations of theorists and engineers and has made a lasting impact on how we handle data. Immink established the area of constrained codes as an important subfield of information and coding theory, and his myriad of practical coding constructions have accelerated the development of digital data storage technology. Immink’s eight-to-fourteen modulation (EFM) technique for digital recordings improved playing time and was more robust to dust, fingerprints, and disc damage such as scratches, leading to the creation of the CD. The introduction of the CD in 1982 marked the beginning of the change from analog to digital sound technology. It quickly revived a sluggish music industry and essentially replaced the traditional music delivery methods of vinyl records and cassette tapes. This optical storage technology also provided low-cost, high-capacity, flexible data storage exceeding what computer hard drives could accommodate at that time. Building on his EFM technology, Immink developed an advanced channel coding method called EFMPlus, which was integral to the design of the digital versatile disc (DVD). Offering higher storage capacity than the CD, but at the same dimensions, the DVD is able to store any kind of digital data from computer software to video programs. Upon its introduction in 1995, the DVD became the fastest adopted consumer electronics product and generated billions of dollars for the film industry. While the DVD was quickly replacing traditional video cassettes, Immink was already working on further advancements to his original inventions by developing an even higher-density optical disc format. This work evolved into the BD, which can handle high-definition content suitable for feature films and video games. Immink was also among the first engineers to conduct experiments with optical recordable and erasable media, bringing the mini disc, CD-R, DVD-R, and BD-R formats into the homes of consumers. He also added to realizing broadcast-quality recording products for consumers with his contributions to the digital video camcorder. With approximately 500 billion CDs, DVDs, and BDs estimated to be in use, Immink’s inventions have impacted people all over the world. As recognition of Immink’s role in the digital media revolution, his honors include an Emmy award from the U.S. National Academy of Arts and Sciences, induction into the Consumer Electronics Hall of Fame, and knighthood by Queen Beatrix of The Netherlands.

An IEEE Life Fellow, foreign member of the U.S. National Academy of Engineering, and recipient of the 1999 IEEE Edison Medal, Immink is president of Turing Machines, Inc., Rotterdam, The Netherlands.

Immink was born in Rotterdam, the Netherlands, on 18 December 1946. He earned a B.S. from Rotterdam Polytechnic and M.S. and a Ph.D. at the Eindhoven University of Technology.
In a career spanning more than 50 years, G. David Forney, Jr. has influenced virtually every major advance in the field of coding theory, providing practical solutions that have enabled high-speed data communications for systems ranging from wired to wireless and from electrical to optical. Forney introduced concatenated codes in 1965 as error-correcting codes constructed of two or more simpler codes to achieve good performance with reasonable complexity in detecting and fixing errors during data transmission. His concatenated method became widely used for space communications, and the approach is widely practiced today for satellite communications, mobile telephony, and digital video broadcasting. Forney joined Codex Corporation to develop practical implementations of coding theory, where he designed the first coding system to go into space—a convolutional code with sequential decoding for a NASA Pioneer deep-space mission in 1968.

Considered the founder of the modern modem, in 1970 Forney brought quadrature amplitude modulation (QAM) to the marketplace by designing the first high-speed 9,600 bits per second (bps) QAM telephone-line modem. This became the foundation of Codex’s commercial success, and it revolutionized the industry, providing the foundation for the international V.29 9,600 bps modem standard. Forney also introduced the now universally used concept of trellis diagrams to describe the Viterbi algorithm, and he is considered the first to recognize the Viterbi algorithm as an optimum sequence detector rather than just a proof technique. His Forney algorithm (FA) is employed by all practical decoders for Reed-Solomon (RS) codes for computing error values after error locations in a received code word have been determined. The FA continues to be widely used in many physical-layer transmission systems and optical/magnetic storage devices, which employ RS coding for outer-layer error control.

Another important contribution by Forney is the minimum-phase whitened matched filter for maximum-likelihood sequence decoding of modulation symbols in the presence of intersymbol interference and noise. When turbo codes were introduced in 1993, Forney demonstrated that they could be described as codes on graphs. In 2001, with what are now known as Forney-style factor graphs, he showed that one graph can simultaneously describe both a code and its dual, which provides for new, efficient decoding algorithms. Forney continues to contribute to error-correcting coding techniques with recent work focusing on tail-biting trellis realizations using Forney-style factor graphs.

Forney is an IEEE Life Fellow and member of the U.S. National Academy of Engineering and U.S. National Academy of Sciences. Forney is adjunct professor emeritus with the Department of Electrical Engineering and Computer Science and the Laboratory for Information and Decision Systems at MIT. Forney was born in New York, New York, on 6 March 1940. He received the B.S. in electrical engineering from Princeton University in 1961, summa cum laude, and the M.S. and Sc.D. in electrical engineering from MIT in 1963 and 1965, respectively.
With innovations that have helped mold the history of advancements in science, technology, and education in the United States and around the world, Mildred Dresselhaus paved the way for the rise of nanotechnology and blazed a path for women in science and engineering. Known as the queen of carbon science based on her lifelong research into the properties of graphite and carbon-based materials, the era of carbon electronics can be traced back to her tireless research efforts.

During the 1960s, Dresselhaus was a pioneer in researching carbon, one of the most abundant elements, and its thermal and electrical properties. She used magnetoreflection spectroscopy to determine the graphite band structure, which led to the currently accepted band model for graphite. Her insights regarding the composition, structure, and properties of graphite have encouraged bold new research into single-atom-thick graphene. Graphene has potential practical applications in high-speed electronics circuits and systems. In the late 1970s, she made important contributions to understanding the structure of graphite intercalation compounds. The work of her group on fullerenes and carbon nanotubes began in the early 1990s before these structures were well known. She also demonstrated the symmetry of single-wall nanotubes and how one could calculate their electronic structure. Her work on nanotubes includes the important contribution of the measurement of Raman spectroscopy on isolated single-wall carbon nanotubes. Her work on the semiconductive properties of carbon nanotubes has opened new possibilities in nanotechnology.

Dresselhaus’ public advocacy for women in engineering and science began in the mid-1970s, when the number of American women seeking undergraduate degrees in engineering began to rise. Recognizing this as an issue of great importance for the profession, Dresselhaus began actively speaking out in favor of women’s access to careers in technology and science. Her unquestioned accomplishments in the laboratory and classroom gave her an unparalleled credibility in this national dialogue. Her 1975 article, “Some Personal Views on Engineering Education for Women” (IEEE Spectrum cover)
Transactions on Education) remains an immensely valuable and accurate account of the psychological and social challenges facing women in a male-dominated field. The article also stressed the critical importance of role models for women engineering students, which Dresselhaus herself certainly served as through mentoring, formally and informally, countless young women across the United States and around the world.

An IEEE Life Fellow and member of the U.S. National Academy of Engineering, Dresselhaus received numerous awards including the U.S. Presidential Medal of Freedom in 2014. At the time of her death, she was an institute professor of electrical engineering and physics with MIT.

Dresselhaus was born Mildred Spiewak in Flatbush, Brooklyn, New York, on 11 November 1930. Dresselhaus graduated from Hunter College in New York with her undergraduate degree in liberal arts in 1951. She carried out postgraduate study at the University of Cambridge on a Fulbright Fellowship and Harvard University, where she received her M.A. from Radcliffe College. She received the Ph.D. from the University of Chicago in 1951.
B. Jayant Baliga is considered the world’s preeminent power semiconductor scientist. His development of the insulated gate bipolar transistor (IGBT) transformed the way we utilize power and has improved the comfort, convenience, and health of billions of people around the world while reducing environmental impact. Baliga’s invention of the IGBT in 1979 and subsequent development and commercialization while with General Electric led to the world’s most important semiconductor switch. Baliga combined the physics of bipolar and metal-oxide semiconductor field-effect transistor (MOSFET) technologies to create a device far superior to both, resulting in lighter and more efficient power converters. His leadership and perseverance in convincing General Electric to continue investing in IGBT development and his ability to address and overcome design and technology challenges were critical to the IGBT’s successful commercialization. IGBT enabled the creation of cost-effective and efficient automobile electronic ignition systems that have reduced gasoline consumption by an estimated 1.1 trillion gallons, resulting in reduction of carbon dioxide emissions by 22 trillion pounds. IGBT also made possible the adjustable speed motor drives for refrigeration and air conditioning and the miniature electronic ballast in energy-saving compact fluorescent bulbs. The improved efficiency of these devices due to IGBT has resulted in a reduction in energy usage of over 50,000 terawatt hours and 56 trillion pounds in carbon dioxide emissions. IGBTs are also an essential component of compact and lightweight portable defibrillators used to control the shock delivered to victims of cardiac arrest and save the lives of hundreds of thousands of people each year. All commercially available electric and hybrid vehicles use IGBTs to control the transfer of power from the battery to the electric motors. IGBTs are also important in wind- and solar-power generation stations, converting electricity to power suitable for consumer and industrial use.

Baliga’s pioneering contributions include the Baliga Figure of Merit for evaluating the pros and cons of materials and devices operating in high-frequency circuits. He was able to demonstrate that wide bandgap semiconductors such as silicon carbide (SiC) and gallium nitride (GaN) could provide significant performance improvements over silicon for power electronics. His SiC power device innovations have been commercialized since 2005 by numerous companies for use in solar inverters and motor control applications. Baliga is also responsible for four successful spin-off companies from his research at North Carolina State University. Inventions that have been commercialized by these companies include the TMBS rectifier used as bypass diodes for solar panels, the super-linear RF silicon power MOSFETs used in cell-phone base station amplifiers, and MOSFETs used to deliver power to microprocessors and graphics chips in laptops and servers.

An IEEE Life Fellow, Baliga received the 2010 National Medal of Technology and Innovation from President Barrack Obama, the highest honor conferred by the U.S. government to an engineer. He was inducted into the National Inventors Hall of Fame in 2016. Baliga is the Progress Energy Distinguished University Professor at North Carolina State University located in Raleigh.

Baliga was born in Madras, India, on 28 April 1948. He received his B. Tech. in electrical engineering from the Indian Institute of Technology, Madras, in 1969. He received the M.S. and Ph.D. from Rensselaer Polytechnic Institute in 1971 and 1974.
Irwin M. Jacobs
(18 October 1933)

For leadership and fundamental contributions to digital communications and wireless technology.

A pioneering engineer and visionary business leader, Irwin Mark Jacobs has played a central role in advancing modern digital communications with revolutionary innovations critical to the development of today’s wireless communications systems. From his beginnings as a communications theorist, Jacobs’ success lies in his ability to take ideas that advance digital technology from theory to practice and successful commercialization. As a co-founder of technology companies that have provided important innovations, Jacobs played a key role in the shift from analog to digital communications experienced during the past 50 years. Jacobs co-founded Qualcomm, Inc. in 1985 and grew it from a small technology firm to a Fortune 500 company. He helped lead revolutionary developments such as the Code Division Multiple Access (CDMA) technology that greatly improved cellular communications efficiency compared to analog systems. Jacobs overcame the initial skepticism and controversy involved with introducing the new technology and guided CDMA to successful implementation and standardization. CDMA would become the foundation of third generation (3G) wireless systems. Jacobs was also instrumental in Qualcomm’s development of a satellite communications and tracking system for the trucking industry. Using spread-spectrum technology, advanced signal processing, and innovative antenna designs, the system provided the first two-way communication and positioning system for fleet management. Known commercially as OmniTRACS, the system is still in use around the world today. Prior to Qualcomm, Jacobs co-founded LINKABIT Corporation in 1968, which provided innovative semiconductor technology and programmable devices that were important to the development of satellite-to-home television services.

While at MIT, Jacobs co-authored, with John Wozencraft, Principles of Communication Engineering (Wiley, 1965), which is considered one of the best communications theory textbooks ever. An IEEE Life Fellow, former chairman of the U.S. National Academy of Engineering, and Fellow of the American Academy of Arts and Sciences and American Association for the Advancement of Science, Jacobs’ many honors include the U.S. National Medal of Technology (1994) and the inaugural IEEE Vehicular Technology Society Hall of Fame Award (2009). Jacobs is founding chairman and chief executive emeritus of Qualcomm, Inc.

Jacobs was born on 18 October 1933, in New Bedford, Massachusetts. He received the B.S. in 1956 from Cornell University and the M.S. and Sc.D. in electrical engineering from MIT in 1957 and 1959, respectively.

View Irwin M. Jacobs’ recipient speech | See supplemental content
One of the world’s top leaders in computer engineering, John L. Hennessy’s pioneering work at Stanford University as one of the early proponents of the Reduced Instruction Set Computer (RISC) architecture helped revolutionize how computing is performed. At a time when the industry favored the Complex Instruction Set Computer (CISC) architecture, Hennessy assembled a team of researchers in 1981 at Stanford to focus on the RISC architecture. He thought that computing would be more efficient with a simpler instruction set that could be processed in one clock cycle compared to the many clock cycles required for CISC. He created his MIPS (Microprocessor without Interlocked Pipestages) processor, which was well liked by academics but did not gain interest from industry, which was attached to CISC.

To help RISC fulfill its potential and transfer the technology to industry, Hennessy took a sabbatical from Stanford University to found MIPS Computer Systems (now MIPS Technologies) in 1984. By the end of the 1990s, seeing MIPS’ success, most major microprocessor companies introduced RISC-based products of their own. MIPS would become one of the top computer processing architectures in the world and it is used in nearly all of today’s mobile applications as well as in gaming consoles. A member of Stanford’s faculty since 1977, and having held positions including provost and dean of the School of Engineering, Hennessy was named Stanford University’s 10th president in 2000. As the first engineer to hold the position, Hennessy expanded university programs related to the environment, energy, and human health. He strived to bring important research to realization and make it accessible to those who will benefit from it. In 2005, he was named the first holder of Stanford’s Bing Presidential Professorship. An IEEE Fellow, Hennessy is president emeritus of Stanford University and was the recipient of the 2022 Charles Stark Draper Prize.

Hennessy was born on 22 September 1952, in Huntington, New York. Hennessy earned his B.S. in electrical engineering from Villanova University and his M.S. and Ph.D. in computer science from the State University of New York at Stony Brook.
Morris Chang
(10 July 1931)

For outstanding leadership in the semiconductor industry.

Morris Chang’s visionary leadership shaped the technology policy for an entire nation and revolutionized how the semiconductor industry does business around the world. With pioneering concepts such as the dedicated integrated circuit (IC) foundry and fabless IC design and virtual fabrication services, he revolutionized Taiwan’s semiconductor development and impacted the global semiconductor industry.

Chang was recruited by the Taiwan government to help strengthen its semiconductor industry and became president of Taiwan’s Industrial Technology Research Institute in 1985. He founded the Taiwan Semiconductor Manufacturing Company (TSMC) in 1987 as the world’s first dedicated IC foundry company. By focusing on manufacturing other companies’ ICs, TSMC met the needs of chip manufacturers requiring outside contractors for overflow and specialty work and provided services for companies lacking the resources to do their own fabrication work. While there was skepticism concerning the viability of such a business model, Chang was persistent and was able to demonstrate its advantages. TSMC became the template for fabrication houses that followed, and through Chang’s leadership it developed into the largest silicon foundry in the world. The creation of TSMC sparked the development of fabless IC companies during the 1990s. Dedicated foundries reduce the cost of entry for these companies by manufacturing their chips but without competing with them. Utilizing the strengths of the foundry concept, Chang’s virtual fab service model incorporates cutting-edge information technology to provide companies with the same benefits and convenience as if they had their own dedicated IC fabs, while still maintaining confidentiality. However, the virtual fab reduces the burdens of capital investment, research and development and intellectual property efforts normally required. While at Texas Instruments (TI) during the 1960s and 1970s, Chang managed TI’s TTL electronic logic circuit was established as the standard logic family, TI’s calculator ICs fueled the growth of the pocket calculator market and TI became a leader in metal-oxide-semiconductor memories. TI also introduced the innovative Speak & Spell handheld educational device under Chang’s management.

An IEEE Life Member, Chang was born on 10 July 1931, in Ningbo, Chekiang, China. Chang earned his B.S. and M.S. in mechanical engineering from MIT. In 1964, he received the Ph.D. in electrical engineering from Stanford University.

IEEE Spectrum cover

View Morris Chang’s recipient speech | See supplemental content
Andrew J. Viterbi
(9 March 1935)

For seminal contributions to communications technology and theory.

As developer of the Viterbi Algorithm and co-founder of Qualcomm Incorporated, Andrew J. Viterbi’s contributions to communications technology have impacted people’s lives throughout the world. There is a Viterbi detector in practically every disk drive and high-capacity MP3 player, images transmitted from deep space are made possible by the Viterbi algorithm, and third-generation mobile telephones employ one or more of Viterbi’s systems. He developed the Viterbi Algorithm in 1967, which was a breakthrough in wireless technology that separated information (voice and data) from background noise. Fundamentally changing how digital communications are processed, the algorithm is used in most digital cellular phones and satellite receivers as well as in such diverse fields as magnetic recording, voice recognition, and DNA sequence analysis.

Viterbi co-founded Qualcomm Incorporated in San Diego, California, with Irwin Jacobs in 1985. His vision and technical leadership at Qualcomm pioneered the revolutionary Code Division Multiple Access (CDMA) system as a more efficient method for digital mobile communications. Utilizing spread-spectrum technology, CDMA allows many users to occupy the same time and frequency allocations. It provides more efficient use of power and bandwidth, enables more calls in the same geographic region and emits a lower level of radiated power in the phone/device.

An IEEE Life Fellow, Viterbi holds memberships in the National Academy of Engineering, the National Academy of Sciences and the American Academy of Arts and Sciences. He has received the National Medal of Science in 2008 from U.S. President George W. Bush as well as several IEEE awards and honors from other international organizations. The University of Southern California (USC), Los Angeles renamed its school of engineering the Viterbi School of Engineering in 2004. Viterbi is currently president of the Viterbi Group, San Diego, California, which invests in startup companies in the wireless communications and network infrastructure sectors, and he also holds the titles of Presidential Chair Visiting Professor at USC and Distinguished Visiting Professor at the Technion, located in Haifa, Israel.

Viterbi was born on 9 March 1935 in Bergamo, Italy. Arriving in the U.S. in 1939, he received the B.S. and M.S. in electrical engineering in 1957 from MIT and the Ph.D. in electrical engineering in 1962 from the University of Southern California.
Robert H. Dennard has been a pioneering figure in the semiconductor industry. His invention of one-transistor dynamic random-access memory (DRAM) and contributions to principles of scaling MOS devices brought about far-reaching and fundamental changes in science and technology, impacting a broad range of industries from aviation to telecommunications. He was granted a patent for DRAM in 1968, and it first began to appear in products in the 1970s. Now used by all computer component and system manufacturers, DRAM requires less power and costs much less than previous magnetic memory and also is less complex and, therefore, denser than the other semiconductor memory cells previously developed. At the time of its development, the largest memory configuration in a computer was 1 MB, requiring several kilowatts of power, while today 1 to 2 GB of DRAM is common, requiring only a few watts of power. Dennard’s development of scaling theory has also been a driving force in microelectronics.

Along with fellow researchers, Dennard developed a concept of MOS transistor and circuit scaling that provides for systematic reduction of MOS integrated circuit dimensions and predicts the benefits of such reduction in improved circuit performance, lower power and greater density. They showed how to design devices and highly integrated circuits at the micrometer level at a time when device fabrication was at much larger dimensions. In the 1980s, he generalized the original work to show how to design devices down to submicrometer dimensions with further improvements in performance and density. The scaling concept led the way from the 5-µm devices of the early 1970s to today’s 0.045-µm devices used in Gigabit memory chips and powerful microprocessors.

Dennard’s research career spans over 50 years and includes 52 U.S. patents and many awards and recognitions, including the IEEE Cledo Brunetti Award, the IEEE Edison Medal, the National Medal of Technology, and induction into the National Inventors Hall of Fame. In 2009, Dennard was named recipient of the Charles Stark Draper Prize. An IEEE Life Fellow, Dennard is an IBM Fellow at the IBM T.J. Watson Research Center in Yorktown Heights, New York, where he continues to investigate the limits of scaling and future evolution of microelectronics.

Dennard was born in Terrell, Texas, on 5 September 1932. He received his B.S. and M.S. in electrical engineering from Southern Methodist University, located in Dallas, Texas, in 1954 and 1956, respectively. He earned a Ph.D. from Carnegie Institute of Technology in Pittsburgh, Pennsylvania, in 1958.
Communications
Telegraph, Wireless Telegraphy, & the Telephone

Telegraph & Wireless Telegraphy

The electrical telegraph grew out of advances in electrical science between about 1800 and 1840, particularly the discovery of galvanic electricity by Luigi Galvani, the invention of the electrical battery by Alessandro Volta around 1800, and research into electromagnetism by Hans Christian Ørsted, Andre-Marie Ampère, Joseph Henry, and Michael Faraday during the 1820s and 1830s. The first two telegraph lines opened in Great Britain in 1837 and the United States in 1844. The telegraph was the only form of electrical communication until the invention of the telephone in 1876, and it remained the mainstay of rapid long-distance communication until the development of practical long-distance telephony after 1900. After 1920, as long-distance telephone rates dropped and many countries introduced airmail service, telegraphy’s share of the long-distance communications market entered a long decline. By 1970, the overland telegraph industry in the industrialized world was dead or dying. Submarine telegraphy survived longer; it was the only medium for rapid overseas communications until the advent of transatlantic radiotelephony in 1927, and it remained the cheapest and preferred medium until the installation of undersea telephone cables in the 1950s. After 1980, other technologies, such as facsimile and electronic mail, took over the role of long-distance record communications formerly supplied by the telegraph.

In 1844 Samuel Morse used this telegraph key to send the message “What hath God wrought” on the experimental line between Washington, DC and Baltimore, Maryland. Courtesy: Smithsonian Institution

In technological and scientific terms, the telegraph was important for three major reasons. First, telegraphy was the first major application of discoveries in electrical science, and it was one of the first technologies with a firm scientific foundation. Second, telegraph electricians during the mid-19th century helped to establish the discipline of electrical engineering. Finally, technical problems, especially in submarine telegraphy, stimulated major advances in physics, oceanography, marine engineering, and electrical engineering.

Telegraphy was the first technology to sever the connection between communication and transportation. Because of the telegraph’s ability to transmit information almost instantly, it affected many aspects of society, culture, politics, international relations, and economics after 1840. It helped to
create integrated national and international markets, accelerated the dissemination of news, provided a model for new literary forms, aided Western imperialism, and spurred national governments to develop telecommunications and technology policies.

In England, Guglielmo Marconi began his wireless experiments in 1895, and on 2 June 1896, he filed his provisional specification of a patent for wireless telegraphy. He demonstrated the system to the British Post Office in July. The British patent was accepted on 2 July 1897, and the US equivalent on 13 July 1897. In March 1896, Alexandr Popov demonstrated a similar wireless system in Russia, having demonstrated a more rudimentary system a year earlier.

Telephone

Along with telephone transmission and switching, the telephone instrument—the user interface—is one of the three major subsystems that make up a telephone network. To a substantial extent, the history of innovations in telephony is an American story, in part because as late as the 1950s, the U.S. had more than half of the world’s telephones, and in part because AT&T, operator of the Bell System and its research arm, Bell Telephone Laboratories, played a dominant role in telephone innovation. Over the century following the beginning of telephone service, the instruments evolved in ways that improved their quality, efficiency, reliability, and ergonomics, keeping in step with advances in transmission and switching.

Below is a timeline that provides insight into the development of the telephone:

- 1861: Phillip Reis demonstrates and names a telephone, which transmits sound
- 1875: Alexander Graham Bell succeeds in transmitting speech sounds
- 1876: Bell succeeds in transmitting intelligible speech and received his patent
- 1877: Thomas Edison, Emile Berliner, David Hughes, and Henry Hunnings invent solid variable-resistance transmitters
- 1878: Francis Blake invents a variable resistance solid carbon transmitter that Bell adopts
- 1878: Thomas Watson receives patents for the magneto and the ringer
- 1886: Edison invents the granular carbon transmitter
- 1890: Anthony White develops the solid-back transmitter
- 1892: Lars Magnus Ericsson of Sweden introduces the first widely used handset telephone
- 1896: Alexander Keith, John Erickson, and Charles Erickson invent the dial telephone
- 1896: First common battery telephones go into service in Worcester, Massachusetts
- 1927: First combined handset telephone installed in the Bell System

- 1937: Western Electric introduces the Model 302 desk telephone with an improved handset
- 1949: Western Electric Model 500 introduced; kept in production until 1986
- 1956: Ericsson Ericofon, the first one-piece, modern phone marketed on the basis of style
- 1962: Gerhard Sessler and James West of Bell Labs invent the foil electret microphone
- 1963: Touch Tone dialing introduced by AT&T
- 1977: Consumers in the U.S. could own rather than lease phones; other countries follow
Gordon E. Moore, co-founder and chairman of the board, emeritus, of Intel Corporation, is one of the pioneers of semiconductor and microprocessor technology. He is the namesake of Moore’s Law, one of the guiding principles of the global semiconductor industry. Introduced in 1965, Moore’s Law stipulated that the number of transistors on a silicon chip would double each year for 10 years. In 1975, he revised the theory, stating that the complexity of chips would double every two years. Moore’s Law remains an industry guidepost today for a US$200 billion per year industry that feeds a trillion dollar a year electronics industry.

In addition to his engineering contributions, Moore is among those responsible for the formation of two of the semiconductor industry’s best-known companies – Intel Corporation and Fairchild Semiconductor. Moore was among a group of eight scientists and engineers that founded Fairchild in 1957, to develop and manufacture a diffused silicon transistor. As head of Fairchild’s research and development department, Moore led the creation of the first family of integrated logic circuits. Capitalizing on the almost simultaneous inventions of the integrated circuit and the MOSFET (Metal Oxide Field Effect Transistor), Fairchild became the leading producer of bipolar integrated logic circuits and was responsible for much of the device understanding for MOSFETs, which are used in most microprocessors. To manufacture integrated circuit memories using the MOSFET transistor, Moore left Fairchild in 1968 with Robert Noyce to co-found Intel Corporation. Moore later led Intel from being simply a memory company to one focused on microprocessor development. Under his leadership, Intel produced a number of products based on LSI technology, including the world’s first microprocessor. The development of the microprocessor is considered among the most significant developments in all of technology, and Intel’s success in this area has made it the largest semiconductor company in the world.

An IEEE Life Fellow and member of the National Academy of Engineering, Moore has received numerous awards, recognitions, and honors, including the IEEE Founders Medal, the U.S. National Medal of Technology, and the Presidential Medal of Freedom, America’s highest civilian honor. In 2000, Moore and his wife created the Gordon and Betty Moore Foundation to focus on the environment, higher education and science, and the San Francisco Bay Area.

Moore was born on 3 January 1929, in San Francisco, California. He holds a B.S. in chemistry from the University of California, Berkeley, and a Ph.D. in chemistry and physics from the California Institute of Technology.
In a career spanning more than 50 years, Thomas Kailath distinguished himself with significant accomplishments as a scholar, academic, and entrepreneur. Kailath is a respected leader in digital signal processing and system theory. In addition to influencing modern work in semiconductor manufacturing and wireless communications, he has also mentored and personally trained several generations of electrical engineers and applied mathematicians.

Dating back to his early writings in the late 1950s, Kailath recognized that engineering theory would play a critical role in meeting technological challenges in the disciplines of communication, computation, control, and signal processing. Since then, his theoretical work has led to fundamental breakthroughs in communications, information theory, signal detection and estimation, sensor array signal processing, VLSI architectures for signal processing, and semiconductor manufacturing. He also contributed to probability and statistics, linear algebra, and matrix and operator theory. He has written several books, authored or co-authored over 300 journal articles and papers, and shared in the development of 13 patents. Specific contributions by him and his over 90 Ph.D. students and postdoctoral scholars include algorithms for feedback communications, universal estimator-correlator detector structures for random signals in noise, and the concept of displacement structure leading to fast algorithms in many fields, such as estimation, control, direction of arrival estimation, adaptive filtering, channel identification and equalization, VLSI systems for signal processing, matrix theory, and linear algebra. Much of his early work outpaced what could be implemented at the time. As technology advanced, Kailath and his students were able to successfully address industrial issues in areas such as optical lithography and multiple antenna wireless communication.

An IEEE Life Fellow, he is past president of IEEE Information Theory Society and a recipient of its Shannon Award. Other honors include the IEEE James H. Mulligan Jr., Education Medal, the IEEE Jack S. Kilby Signal Processing Medal, Guggenheim and Churchill Fellowships, and an election to the National Academy of Engineering, the American Academy of Arts and Sciences, the Indian National Academy of Engineering, the Silicon Valley Engineering Hall of Fame, and IEEE’s Etta Kappa Nu. He is currently the Hitachi America Professor of Engineering, Emeritus, at Stanford University in California.

Kailath was born on 7 June 1935, in Poona, India. Kailath received his B.S. from College of Engineering in Pune, India, and M.S. and Ph.D. from MIT.
During his career as a scientist, educator, and high-level technology executive, James D. Meindl, director and Pettit Chair Professor of the Joseph M. Pettit Microelectronic Research Center at Georgia Institute of Technology in Atlanta, has logged a string of exceptional accomplishments.

Early in his career, Meindl developed micropower integrated circuits for portable military equipment at the U.S. Army Electronics Laboratory in Fort Monmouth, New Jersey. He then joined Stanford University in Palo Alto, California, where he developed low-power integrated circuits and sensors for a portable electronic reading aid for the blind, miniature wireless radio telemetry systems for biomedical research, and non-invasive ultrasonic imaging and blood-flow measurement systems. Meindl was the founding director of the Integrated Circuits Laboratory and a founding co-director of the Center for Integrated Systems at Stanford. The latter was a model for university and industry cooperative research in microelectronics.

From 1986 to 1993, Meindl was senior vice president for Academic Affairs and provost of Rensselaer Polytechnic Institute in Troy, New York. In this role, he was responsible for all teaching and research. He joined Georgia Tech in 1993 as director of its Microelectronic Research Center. In 1998, he became the founding director of the Interconnect Focus Center, where he led a team of more than 60 faculty members from MIT, Stanford, Rensselaer, SUNY Albany, and Georgia Tech in a partnership with industry and government. His research at Georgia Tech includes exploring different solutions for solving interconnectivity problems that arise from trying to interconnect billions of transistors within a tiny chip.

Over his career, Meindl has supervised over 80 Ph.D. graduates at Stanford University, Rensselaer Polytechnic Institute, and Georgia Tech, who have gone on to have a profound impact on the semiconductor industry.

An IEEE Life Fellow, Meindl was the recipient of the Benjamin Garver Lamme Medal of the American Association for Engineering Education, the J.J. Ebers Award of the IEEE Electron Devices Society, the IEEE Education Medal, and the IEEE Solid State Circuits Award.

Meindl was born on 20 April 1933, in Pittsburgh, Pennsylvania. He received his B.S., M.S., and Ph.D. in electrical engineering from Carnegie-Mellon University in 1955, 1956, and 1958, respectively.
James L. Flanagan profoundly influenced our understanding of how humans speak and hear. A pioneer in the areas of speech analysis, speech transmission, and acoustics, his early research led to increased understanding of how the human ear processes signals and the development of advanced methods to assist hearing and improved voice communication systems. These achievements, which are in addition to his primary telecommunications work, include an electronic artificial larynx, playback recording techniques for the visually impaired, and automatic speech recognition to help the motor impaired.

Formerly director of the Information Principles Research Laboratory at Bell Laboratories in Murray Hill, New Jersey, Flanagan was one of the first researchers to see the potential of speech as a means for human-machine communication. He contributed to current techniques for automatic speech synthesis and recognition, and to signal coding algorithms for telecommunications and voice mail systems, including voicemail storage, voice dialing, and call routing. He also created auto-directive microphone arrays for high-quality sound capture in teleconferencing, and he pioneered the use of digital computers for acoustic signal processing. As vice president for research and director of the Center for Advanced Information Processing at Rutgers University in Piscataway, New Jersey, he was a leader in the development of global systems for human-computer interfaces that are actuated by speech and that incorporate sight and touch modalities.

An IEEE Life Fellow, Flanagan was a former president of the IEEE Signal Processing Society and received its Achievement Award. He was also the recipient of the IEEE Centennial Medal, the U.S. National Medal of Science, was a member of the U.S. National Academy of Engineering and the U.S. National Academy of Sciences.

Flanagan was born 26 August 1925, in Greenwood, Mississippi. He received the B.S. in electrical engineering from Mississippi State University in 1948, and the M.S. and Sc.D. in electrical engineering from MIT in 1950 and 1955, respectively. Between periods of educational training, he served in the U.S. Army (1944-1946), and as assistant professor of electrical engineering at Mississippi State University (1950-1952).
Tadahiro Sekimoto contributed significantly to the enormous growth of NEC Corporation and Japan’s electronics industry. Highly successful in developing commercial applications, his seminal work in digital and satellite communications formed the cornerstone for modern communications systems. His push to integrate computers and communications, an idea proposed in 1977 by then-chairman Koji Kobayashi, helped to establish the information technology industry and a worldwide information society. From 1948 to 1965, Sekimoto developed innovative communications technology at NEC’s Central Research Laboratories in Tokyo. He designed early pulse-code modulation equipment as well as coding and decoding circuitry. During the late 1960s, he developed a time-division multiple access system and automatic routing system that had a huge impact on satellite communications. These technologies also formed a foundation for cellular telephony decades later.

During a two-year assignment at COMSAT in Washington, D.C. from 1965 to 1967, he led the development of single-channel-per-carrier pulse-code-modulation multiple-access demand-assignment equipment (SPADE). Commercialized by Intelsat in the early 1970s, SPADE made it economically feasible for developing countries to participate in worldwide satellite communications networks. Sekimoto was elected to NEL’s board of directors in 1974 and appointed president in 1980. He guided the company’s colossal sales growth from 893 billion yen (US$4.7 million) in 1980 to 2,899 billion yen (US$30.5 million) in 1993. During his tenure, the company consistently ranked among the top five worldwide in communications, computer, and semiconductor sales. NEC also established three overseas laboratories and 33 plants in 16 countries, as well as basic research facilities in Tsukuba, Japan, and Princeton, New Jersey. Named chairman of the board in 1994, Sekimoto was also chairman of the Institute for International Socio-Economic Studies, an NEC think tank subsidiary.

An IEEE Life Fellow, Sekimoto was a foreign associate of the U.S. National Academy of Engineering. His awards include the IEEE Alexander Graham Bell Medal, the IEEE Communications Society’s Edwin Howard Armstrong Achievement Award, the American Institute of Astronautics and Aeronautics’ Aerospace Communications Award, and the Emperor of Japan’s Grand Cordon of the Order of the Sacred Treasure. The author of numerous technical publications and seven books, Sekimoto also held 35 Japanese patents and five patents issued overseas.

Sekimoto was born on 14 November 1926, in Hyogo, Japan. He received the B.S. in physics and the Ph.D. in engineering from the University of Tokyo in 1948 and 1962, respectively.

For contributions to digital satellite communications, promotion of information technology R&D, and technical and corporate leadership in computers and communications.
Hailed as the father of semiconductor light emitter technology in the western world, Nick Holonyak, Jr. is commonly credited with inventing the light-emitting diode (LED) and the first semiconductor laser to operate in the visible spectrum. Light sources based on his work dominate the optical communications and home entertainment industries. As the John Bardeen Chair and professor at the Center for Advanced Study at the University of Illinois at Urbana-Champaign, Holonyak and his students made seminal contributions to quantum well lasers. Virtually all semiconductor lasers today use quantum wells for fiber-optic communications, compact disk and digital video disk players, medical diagnosis, surgery, ophthalmology and many other applications. In the early 1980s, Holonyak’s group introduced impurity-induced layer disordering, which converts layers of a semiconductor structure into alloy electrical properties. The discovery of this alloy solved the low-reliability issues previously plaguing lasers. With this technology, lasers exhibit higher performance and durability, making them ideal for DVD players and other optical storage equipment.

Holonyak began his distinguished career at Bell Telephone Laboratories in Murray Hill, New Jersey, in 1954, where he helped develop silicon-diffused transistor technology. He joined General Electric’s Advanced Semiconductor Lab in 1957, where he developed thyristors, the basic electronic elements in household light-dimmer switches, and the first visible semiconductor laser and visible LED. Holonyak holds four patents and has published numerous papers.

An IEEE Life Fellow and a Fellow of the American Academy of Arts and Sciences and the Optical Society of America, he also is a member of the U.S. National Academy of Engineering and National Academy of Sciences. His honors include the IEEE Jack A. Morton Award, the IEEE Edison Medal, the U.S. National Medal of Science, the Charles Hard Townes Award of the Optical Society of America, the National Academy of Sciences Award for the Industrial Application of Science, the American Society for Engineering Education Centennial Medal and the Japan Prize, and was the recipient of the 2015 Charles Stark Draper Prize for Engineering.

Holonyak was born in Zeigler, Illinois, on 3 November 1928. He received the B.S., M.S., and Ph.D. in electrical engineering from the University of Illinois in 1950, 1951, and 1954, respectively. As a Texas Instruments Fellow in Semiconductor physics at the University of Illinois (1953-54), he did graduate work under the direction of John Bardeen.
Herbert Kroemer is a true pioneer in the field of physics and in the technology of semiconductors and semiconductor devices. His work in heterostructure-based transistors has furthered the development of the cell phone and other wireless communications technologies.

When Kroemer applied the heterostructure principle to semiconductor lasers, it allowed them to operate continuously at room temperature. This advance paved the way for the development of the semiconductor lasers used in CD players, fiber optics and other applications. It also is central to non-laser light-emitting diodes (LEDs), now found in most new U.S. traffic signals. He received the 2000 Nobel Prize in Physics. His winning work was published in a 1963 paper, “A Proposed Class of Heterojunction Injection Lasers,” in the Proceedings of the IEEE.

Kroemer originated the concept of the heterostructure bipolar transistor in the mid-1950s while with RCA Laboratories in Princeton, New Jersey. From 1959 to 1966, his work with Varian Associates, located in Palo Alto, California, yielded the invention of the double heterostructure laser and his seminal paper on the topic. He also worked on microwave device problems, and, in 1964, was the first to publish an explanation of the Gunn Effect. Since 1976, he worked at the University of California, investigating molecular beam epitaxy, materials research, and solid-state physics.

He is a Fellow of the IEEE and the American Physical Society, and a Foreign Associate of the U.S. National Academy of Engineering. He has received numerous awards, including the IEEE J.J. Ebers and Jack Morton Awards. A native of Germany, he received a Ph.D. in physics from Germany’s University of Gottingen, and holds honorary doctorates from the Technical University of Aachen, Germany; the University of Lund, Sweden; and from the University of Colorado. In 2001, he received Germany’s Bundesverdienstkreuz (Order of Merit). Kroemer is the author or co-author of more than 280 publications.

Kroemer was born in Weimar, Germany, on 25 August 1928.
Herwig Kogelnik’s groundbreaking work in photonics and optical communications has revolutionized modern light wave communications technology. He is credited with helping to revolutionize global information movement and management.

In 1961, Kogelnik joined Bell Laboratories, located in Holmdel, New Jersey, where he served as director of both the Electronics Research Laboratory and the Photonics Research Laboratory. His research focused on optics, electronics, and communications, including work on holography, photonics, laser resonators, and Gaussian beams.

Along with C.V. Shank, Kogelnik pioneered the distributed-feedback (DFB) laser in 1971. Additionally, his leadership in the development of practical wavelength division multiplexing (WDM) led to a groundbreaking dense WDM system, further revolutionizing light wave communications by expanding capacity and lowering costs.

In the area of photonic switching, Kogelnik’s research with R.V. Schmidt led to the development of the reversal directional coupler wavelength switch, a mainstay of experimental photonic switching systems, and a necessary component in ultra-high-speed optical networks. Under his leadership, the Photonics Research Laboratory developed many other fundamental components of optical communications, including high-speed avalanche photodiodes, tunable semiconductor lasers, photonic integrated circuits, and high-capacity amplified transmission systems.

Kogelnik has earned 34 patents through his career and is the author of 85 articles. He is a Fellow of both the IEEE and the Optical Society of America, which he served as vice president in 1987 and president in 1989. He is also an Honorary Fellow of St. Peter’s College at Oxford University. Kogelnik has received numerous awards, including the Optical Society of America’s Frederic Ives Medal in 1984, the IEEE David Sarnoff Award in 1989, the Joseph Johann Ritter von Prechtl Medal from the Technical University of Vienna, Austria in 1990, and the 1991 IEEE Lasers and Electro Optics Society Quantum Electronics Award. He was elected to the U.S. National Academy of Engineering in 1978, and the U.S. National Academy of Science in 1994.

Kogelnik was born in Graz, Austria, on 2 June 1932. He received his Dipl. Ing. from the Technische Hochschule Wien, Vienna, Austria in 1955, and a doctorate in 1958, also from the Technische Hochschule. In 1960, he received a Ph.D. from Oxford University.
Beginning in the 1960s, Andrew S. Grove repeatedly made fundamental contributions to semiconductor devices and technology. His early research helped create stable MOS devices, and improved the reliability of all silicon semiconductor devices, which touched off the explosion of the MOS-based IC industry.

Throughout that industry’s dramatic growth, Grove has demonstrated uncommon leadership and vision, especially in his many roles at the helm of the Intel Corporation. In 1968, he helped found Intel Corporation. He became Intel’s president in 1979, served as CEO, and then served as chairman of the board from 1998 until his retirement in 2005. His responsibilities ranged from overseeing technology and product development to steering Intel deftly into new areas, making it one of the largest and most successful businesses in the world. He is recognized worldwide as an expert of both technology and management.

Grove wrote more than 40 technical papers and held several patents on semiconductor devices and technology. His four books have all been very well received, and his 1967 Physics and Technology of Semiconductor Devices is considered the seminal work in the field.

Grove lectured at universities all over the world, and was a featured speaker at virtually every major electronics conference. For six years he taught a course in semiconductor device physics at the University of California, Berkeley. He also lectured at the Stanford University Graduate School of Business.

Highlights of Grove’s many honors include the AEA Medal of Achievement, the Heinz Family Foundation Award, and being named Man of the Year, Technology Leader of the year, CEO of the Year, Statesman of the Year, and Distinguished Executive of the Year by various organizations.

He was a Fellow of the IEEE and the Academy of Arts and Sciences, as well as a member of the National Academy of Engineering. IEEE recognized him repeatedly, beginning in 1966, when he won an Achievement Award, which was followed by the J.J. Ebers Award, the Engineering Leadership Recognition Award, and the Computer Entrepreneur Award.

Grove was born in Budapest, Hungary, on 2 September 1936, and died at home in Los Altos, California on 21 March 2016. He earned a B.S. in chemical engineering from the City College of New York and a Ph.D. from the University of California, Berkeley in 1963.
Charles Concordia was born on 20 July 1908, and grew up in Schenectady, New York. An excellent student, Concordia went straight from high school to work at the General Electric Company. Although he continued his studies part time at Union College in these early years, he earned his first degree, an honorary D.Sc. from the college in 1971, and later received an honorary D.Sc. from Iowa State University.

For his first few years at GE, Concordia worked on early television research and then joined the company’s test program, an advanced engineering course, graduating in 1934. His work gravitated to systems engineering and electric utility, and he became GE’s consultant to public utilities, advising on system protection and reliability. During World War II, he worked on generators and turbines for naval destroyer propulsion, researched superchargers for airplanes, and helped develop ships’ electrical drives. In the 1940s, he chaired AIEE’s subcommittee on large-scale computing devices and continued his consulting work after the war. He retired from GE in 1973 and continued independent consulting for clients such as Westinghouse and power companies in Taiwan and Hong Kong. He also served on the Advisory Panel to the Federal Power Commission as it dealt with the after-effects of two blackouts and served internationally as a blackout consultant.

His accomplishments made him well-known as a power systems engineer and in the expanding field of planning, operation, and security of extended power systems. His theory of electric machines and his work on the dynamic analysis of interconnected electric power systems, electrical machinery, and automatic control systems all made significant impressions on the field. In the 1940s, he pioneered the idea that synchronous machines’ voltage-regulator characteristics affect their stability. In 1951, he wrote *Synchronous Machines -Theory and Performance*, which became a well-known text. By the end of his career, he had accumulated six patents and published over 130 papers.

A Fellow of the IEEE, ASME, and AAAS, Concordia was a member of the NAE and NSPE. He was chairman of the IEEE Research and Transfers Committee, as well as a member of the IEEE Publications and Spectrum Editorial Boards, and the Power System Engineering Committee. He helped start and then chaired the first committee on computing devices at the AIEE. He was chairman of the International Study Committee on Power System Planning and Operation of the International Conference on Large Electric Power Systems (CIGRE) for nine years, and was a founder and National Treasurer of the Association for Computing Machinery.

Among the many awards bestowed upon him by the IEEE and the AIEE are the Lamme Medal, the Centennial Medal, and the Power-Life Award. He also won the Philip Sporn Award from CIGRE and both the Coffin Award and the Steinmetz Award from the General Electric Company.

Charles Concordia
(20 June 1908 – 25 December 2003)

For outstanding contributions in the area of Power System Dynamics which resulted in substantial improvements in planning, operation and security of extended power systems.
As its name suggests, a generator generates electricity. Michael Faraday’s discovery of electromagnetic induction demonstrated a way to construct a simple generator, but there was little need for such a device until commercial technologies that used electricity, such as lights, appeared. The earliest commercial uses of electricity, such as telegraphy, arc lighting systems, and metal electroplating used batteries as their power source. This was a very expensive way of generating electricity.

In the 1860s and 1870s, many inventors sought ways of using Faraday’s induction principle to generate electricity mechanically. Two kinds of generators emerged. The first was a generator of direct current (DC) electricity. The second was a generator of alternating current (AC) electricity. In truth, a DC generator could generate AC current, but it contains a simple device called a commutator to turn AC into DC. A commutator reroutes the flow of electrons inside the DC generator, so that the energy that appears at the output is a pulsing direct flow. An AC generator does not need a commutator and generates AC directly.

One of the most important inventors of generators was German Werner von Siemens, who designed improved DC generators and called them dynamos. An even better generator was introduced by French Zénobe-Théophile Gramme in 1867, which produced substantially higher voltages than previous attempts. In 1871, he demonstrated a working model and began manufacturing them with Hippolyte Fontaine. Grammé’s dynamos generated AC current and were widely used in arc lighting systems. In 1872, however, von Siemens reemerged and invented what is essentially the modern type of dynamo, referred to as the drum armature type of machine, which was a more efficient design.

AC and DC generators were both used from the 1870s on. For example, AC generators were used in a type of outdoor arc lighting known as the Jablochkoff Candle. However, in the late 1870s when Thomas Edison devised his highly successful electric lighting system, he used DC generators. A major reason for this choice was that Edison wanted to use electric power both for lighting (for which AC was fine) and for running electric motors. At the time, there was no good AC electric motor available, so DC was the only option. In 1882, Edison installed DC generators at the Pearl Street station facilities in New York City, one of the earliest commercial power generating plants.
As electric lighting and centrally distributed power began to achieve commercial success in the 1880s, inventors began looking for ways to distribute central-station power over longer distances. Edison’s DC system was poorly adapted to this, because he had chosen to use 120-volt bulbs and motors. A much higher voltage would have been easier to transmit down long wires, because at a low voltage, so much energy is lost as heat. Edison stations, such as that at Pearl Street, could be no more than about a mile from the customer. AC offered an alternative: a way to generate at a low voltage, “step up” the voltage for transmission using a simple device called a transformer, and then “step down” the voltage at the customer premises. The only remaining problem, though, was the lack of a suitable AC motor design.

Nikola Tesla, an immigrant to the United States, devised an improved AC generator as well as a practical AC motor. Tesla’s system used polyphase AC, in which the generator produced several different AC flows that were combined or superimposed onto one another to create a single polyphase AC output, with the component currents “out of phase” with one another. The Tesla motor, introduced in 1887, was designed so that the peaks of this polyphase current supplied power at just the right moment in the rotation of the motor, and the resulting induction motor, as he called it, ran smoothly. With a practical AC motor and generator in hand, along with transformers to raise and lower voltage, Tesla’s system could be used by power companies to create ever-larger networks of power distribution using massive power plants, such as the Niagara Falls hydroelectric plant built in the 1890s. Larger power systems helped lower costs, which stimulated demand for electricity, especially in homes.
Donald O. Pederson was born on 30 September 1925, in Hallock, Minnesota, and died on 25 December 2004, in Concord, California. He received a B.S. from North Dakota State University in 1948, and both an M.S. and Ph.D. from Stanford University in 1949 and 1951, in electrical engineering.

In 1955, he joined the University of California at Berkeley, where he became a professor in the Department of Electrical Engineering and Computer Sciences. Throughout his 50-year teaching and research career – more than half of it at the University of California at Berkeley – Pederson concentrated on the design and performance of electronic circuits. His work on circuits began with those using vacuum tubes as the active devices, then transistors and finally large-scale integrated circuits, with special attention to new and improved design technologies.

The development of SPICE (Simulation Program with Integrated Circuits Emphasis) was a major achievement in combining software engineering, numerical analysis and modeling of transistors for integrated circuit implementation. Since then, SPICE has been the standard means of simulating circuits at the transistor level. Pederson’s research efforts have been reported in more than 100 technical publications, while his teaching influenced countless graduate students. Before his retirement in 1991, he was the inaugural E.L. and H.H. Buttner Professor of Electrical Engineering.

Pederson was elected a Berkeley Fellow in 1995. He has an honorary Ph.D. from the Katholieke Universiteit in Leuven, Belgium, and was a Fulbright Lecturer in Ireland.

Named a Fellow of the IEEE in 1964, and a Life Fellow in 1991, he received the IEEE Education Medal in 1969, the IEEE Centennial Medal in 1984, and the IEEE Solid-State Circuits Council’s Outstanding Development Award in 1985. Pederson was a member of the National Academy of Engineering and the National Academy of Sciences and a Fellow of the American Association for the Advancement of Science and the American Academy of Arts and Sciences. Industry has recognized his achievements as well, honoring him with the Semiconductor Industry Association’s inaugural University Research Award, the Phil Kaufman Award from the Electrical Design Automation Companies, and, as co-recipient, the 1996 Computer & Communication Promotion Prize.
George H. Heilmeier was born on 22 May 1936, in Philadelphia, Pennsylvania. He received the B.S. in electrical engineering with distinguished honors from the University of Pennsylvania, Philadelphia, and the M.S.E., M.A., and Ph.D. in solid state materials and electronics from Princeton University located in New Jersey.

At RCA Laboratories, he did original work in parametric amplification, tunnel diode down converters, millimeter wave generation, ferroelectric thin film devices, organic semiconductors, and electro-optics effects in molecular and liquid crystals. He was appointed head of solid state device research in 1966 and head of device concepts research in 1969. In 1968, he received international recognition for his discovery of several new electro-optic effects in liquid crystals, making possible for the first time, the electronic control of the reflection of light. This led to the development of the first liquid crystal displays for calculators, watches, and instrumentation.

Heilmeier was selected by U.S. President, Richard Nixon to be a White House Fellow for the year 1970-1971, serving as special assistant to the Secretary of Defense. He was appointed assistant director for Defense Research and Engineering, Electronic and Physical Sciences, in September 1971. In this position, he was responsible for all Department of Defense research and exploratory development in the areas of electronics and physical sciences.

In 1975, he was appointed the director of the Defense Advanced Projects Agency (DARPA) and initiated major efforts in space-based lasers, stealth aircraft, space-based infrared technology, and artificial intelligence applications. In December 1977, he was named a vice president of Texas Instruments, and, in February 1983, he was promoted to senior vice president and chief technical officer, responsible for all TI research, development, and engineering activities.

Heilmeier held 15 U.S. patents and was a member of the National Academy of Engineering, the Defense Science Board, and was chairman of the Technical Advisory Board of Southern Methodist University. He has received many major awards, including the IEEE David Sarnoff Award, the IEEE Frederik Philips Award, the Secretary of Defense Distinguished Civilian Service Medal twice, and the 26th Arthur Flemming Award as the Outstanding Young Man in Government.

View George H. Heilmeier’s recipient speech | See supplemental content
Robert M. Metcalfe was born on 7 April 1946, in Brooklyn, New York. He received a B.S. in electrical engineering from MIT, and a B.S. from the MIT Sloan School of Management in 1969. He received an M.S. in applied mathematics from Harvard University in 1970. In 1973, he received a Ph.D. in computer science from Harvard for research done at MIT’s Project Mac on packet switching in the ARPA and Aloha computer networks.

In 1972, Metcalfe went to the Computer Science Laboratory at the Xerox Palo Alto Research Center (PARC) to join in the early development of personal computing. In 1973, he invented Ethernet, the local-area networking technology on which he shares four patents.

In 1976, Metcalfe moved to Xerox’s Systems Development Division to manage microprocessor and communication developments that led, long after he left, to the Xerox Star workstation. While at PARC he began eight years of part-time teaching at Stanford University, finishing as a consulting associate professor of electrical engineering with a new course on distributed computing.

Metcalfe left Xerox in 1979 to promote personal computer local-area networks (PC LANs), especially Ethernet. He acted as a broker in bringing together Digital Equipment, Intel, and Xerox Corporations to promote Ethernet as a standard. Now an international computer industry standard, Ethernet is by far the most widely installed LAN, with connected computers numbering 50 million.

Also in 1979, Metcalfe founded 3Com Corporation in Santa Clara, California, a Fortune 500 computer networking company, where he held various positions. He retired from 3Com in 1990. Afterwards, he took up writing for InfoWorld.

Among many other awards, Metcalfe received the 1980 Grace Murray Hopper Award from the Association for Computing Machinery (ACM), and the 1988 IEEE Alexander Graham Bell Medal. His publications include the often cited “Ethernet: Distributed Packet Switching for Local Computer Networks,” with David Boggs in the Communications of the ACM, July 1976, and “Local Networks of Personal Computers,” at the Ninth World Computer Congress in Paris in 1983. He served on the Office of the President’s Advisory Committee on Information Networks, the National Research Council’s Computer Science and Technology Board, and as chair of the Corporation for Open Systems, promoting worldwide computer and telephone networking standards. Metcalfe was a visiting Fellow at Wolfson College in the Computer Laboratory of the University of Cambridge, England in 1991-1992. In 1995, Metcalfe was awarded a prize for his journalism from the San Francisco Exploratorium. In 2003, Metcalfe received the National Medal of Technology from U.S. President, George W. Bush, and was inducted into the National Inventors Hall of Fame in 2007.
Lotfi A. Zadeh was born on 4 February 1921, in Baku, Azerbaijan. He studied at Alborz College, an American Presbyterian Missionary School in Teheran, Iran, and later at the University of Tehran, from which he received the B.S. in electrical engineering in 1942. Zadeh traveled to the United States in 1944 to pursue graduate studies, and received the S.M. in electrical engineering from MIT in 1946. Subsequently, he joined the faculty of Columbia University as an instructor in electrical engineering, where he earned the Ph.D. in 1949 and was appointed assistant professor in 1950. He was promoted to the rank of professor in 1957. At Columbia University, Zadeh taught courses in electromagnetic theory, circuit analysis, system theory, information theory, and sequential machines. His doctoral dissertation initiated a new direction in frequency analysis of time-varying networks.

In 1959, Zadeh left Columbia University to join the faculty of the electrical engineering department at the University of California, Berkeley. He was named chairman of the department in 1963. During his five-year tenure as chairman, the name of the department was changed to electrical engineering and computer science. Zadeh became professor emeritus in 1991 and continued to do teaching and research at Berkeley in his capacity as director of the Berkeley Initiative in Soft Computing.

In 1950, he co-authored, with Professor J.R. Ragazzini, a seminal paper on an extension of Wiener’s theory of prediction. In 1952, he co-authored, also with Professor J.R. Ragazzini, a paper on sampled-data systems that led to the widely used method of $z$-transformation. After moving to Berkeley, Zadeh focused his attention on linear systems and automata theory. This work led to his collaboration with Professor Charles Desoer on a text on linear system theory entitled *The State Space Approach*, which laid the foundations for the modern approach to systems analysis and control.

In 1965, Zadeh authored his seminal paper on fuzzy sets. This landmark paper initiated a new direction which, over the past three decades, has led to a vast literature and a rapidly growing number of applications ranging from consumer products to subway trains and decision-support systems. In the future, the impact of fuzzy set theory—or fuzzy logic, as it is commonly referred to today, is likely to be felt not only in the realm of products and manufacturing, but also in the basic sciences and especially in mathematics, physics, and chemistry.

Zadeh was a Fellow of the IEEE and a recipient of the 1973 IEEE Education Medal, the 1992 IEEE Richard W. Hamming Medal, and an IEEE Centennial Medal. He was a member of the National Academy of Engineering and a Foreign Member of the Russian Academy of Natural Sciences. Among his other awards are the Ronda Prize, the Grigore Moisil Prize, the Kampe de Feriet Medal, and several honorary doctorates.

Lotfi A. Zadeh was a pioneer in the field of fuzzy logic, which has had a profound impact on various disciplines and industries. His contributions have not only advanced the field of computer science and technology but have also influenced fields such as mathematics, physics, and chemistry. Zadeh’s legacy continues to be celebrated through various awards and recognitions, including the IEEE Lofti A. Zadeh Award for Emerging Technologies.
Alfred Y. Cho was born on 10 July 1937, in Beijing, China. He received the B.S., M.S., and Ph.D. in electrical engineering from the University of Illinois in 1960, 1961, and 1968, respectively. He was the director of the Semiconductor Research Laboratory at AT&T Bell Laboratories, Murray Hill, New Jersey.

In 1961, Cho was a member of the engineering staff at Ion Physics Corporation in Burlington, Massachusetts, a subsidiary of High Voltage Engineering Corporation, where he studied charged micron-sized solid particles in intense electric fields. In 1962, he joined TRW Space Technology Laboratories in Redondo Beach, California, and engaged in research in high current density ion beams. He returned to the University of Illinois in 1965 to pursue doctoral studies and, in 1968, joined Bell Laboratories as a member of Technical Staff. He was promoted to department head in 1984 and to director of the Materials Processing Research Lab in 1987.

Cho’s many significant research accomplishments include the development of molecular beam epitaxy (MBE), which has the ability to deposit single crystal structures one atomic layer at a time creating materials that cannot be duplicated by nature or fabricated using any other known technique. This precise crystal growth method is used for the fabrication of quantum structures, and electronic and optical devices. He fabricated the first MBE artificial superlattice, the first MBE hyper-abrupt junction varactor, IMPATT diode, mixer diode, field effect transistor operating at microwave frequencies, and the first MBE double-heterostructure laser operating cw at room temperature. Most of the semiconductor lasers used in today’s compact disc players are manufactured using MBE material. The impact of MBE fundamental science has been at least as dramatic as its impact on semiconductor technology. It brings experimental quantum physics to the classroom and most major universities throughout the world have MBE systems.

Cho has published over 400 papers in surface physics, crystal growth, and device physics and performance. He holds 46 patents on crystal growth and semiconductor devices related to MBE. Cho has received many awards, including the National Medal of Science, presented by U.S. President, William Clinton in 1993. He is a Fellow of the IEEE, and the American Academy of Arts and Sciences. He is a member of the Academia Sinica (Taiwan), U.S. National Academy of Engineering, and National Academy of Sciences.

Alfred Y. Cho
(10 July 1937)

For seminal contributions to the development of molecular beam epitaxy.
Karl Johan Åström was born in Östersund, Sweden on 5 August 1934. He received the M.Sc. in engineering physics and the Ph.D. in automatic control and mathematics from the Royal Institute of Technology (KTH), Stockholm in 1957 and 1960, respectively. In 1987, he was awarded the Docteur Honoris Causa from l'Institut National Polytechnique de Grenoble.

From 1955 to 1960, Åström held teaching appointments at different departments at KTH, at the same time he worked on inertial guidance for the Research Institute of National Defense in Stockholm. He joined the IBM Nordic Laboratory in 1961 to work on theory and applications of computerized process control. He worked on optimal and stochastic control as a visiting scientist at IBM Research Laboratory in Yorktown Heights, NY and San Jose, CA in 1962 and 1963. Upon his return to Sweden, he was responsible for modeling, identification, and implementation of systems for computer control of paper manufacturing machinery. In 1965, Åström was appointed chair of automatic control at Lund Institute of Technology/University of Lund, Sweden. He held visiting appointments at many universities in the USA, Europe, and Asia.

Åström has been vice dean and dean of the Department of Engineering Physics and chairman of the computing board at Lund University. He has been a consulting editor for the IEEE Transactions on Automatic Control and was an editor of Automatica and many other journals.

Åström’s interests cover broad aspects of automatic control, stochastic control, system identification, adaptive control, computer control, and computer-aided control engineering. He published five books, among them Adaptive Control, co-authored by B. Wittenmark. He contributed to several other books, authored many papers, and holds three patents. For his paper, “Theory and Application of Adaptive Control,” Automatica 75 (1983) 471-486, Åström received the Automatica Prize Paper Award. He was awarded the 1987 IEEE Donald G. Fink Prize for his paper “Adaptive Feedback Control,” Proceeding of the IEEE 75 185-217. He has supervised 40 Ph.D. students and numerous M.Sc. students.

Åström is a Fellow of the IEEE, a member of the Royal Swedish Academy of Sciences, and a vice president of the Royal Swedish Academy of Engineering Sciences (IVA). In 1990, he received the IEEE Field Award in Control Systems Science, and Engineering.
Amos Edward Joel Jr. was born on 12 March 1918, in Philadelphia, Pennsylvania. He obtained the B.Sc. in electrical engineering and M.Sc. in electrical engineering from MIT in 1940 and 1942, respectively. He spent his entire professional career, from July 1940 to March 1983, with Bell Telephone Laboratories, starting as a member of the technical staff. There, Joel’s efforts were devoted to the study, design, and evaluation of telephone switching systems, a field in which he has made many contributions.

During World War II, Joel designed early general-purpose digital computers and cryptanalysis machines. Following the war, he conceived and taught the first course on switching system and circuit design and went on to design the first automatic telephone billing equipment (AMA).

A pioneer in the development of electronic switching systems, Joel started fundamental engineering studies in 1948 that later became the basis for his many contributions. He supervised development planning for the Bell System’s first electronic telephone switching systems, and played a major role in establishing the concepts of electronic switching now employed throughout the world.

From 1961 to 1967, Joel was responsible for the design of two systems used to improve operator services: one for 0 and 0 + calls that require operator services (TSPS), and the other that announces telephone number changes (AIS). Versions of both systems are in service throughout the nation.

Joel received a basic patent for his early studies of the switching aspects of cellular mobile radio service. More than 70 other U.S. patents have been issued for his work, including the largest ever U.S. patent for his work on AMA. He has authored and co-authored several books and numerous papers on switching. He has been the co-recipient of the New Jersey R&D Council’s Outstanding Patent Award, 1972; and the IEEE Alexander Graham Bell Medal, 1976. He has been recognized for his work in switching with the Franklin Institute Stuart Ballantine Medal, 1981; the International Telecommunication Union Centenary Prize, 1983; the Genoa, Italy Columbian Medal, 1984; and in 1989 the Kyoto Prize of the Inamori Foundation of Japan, and the New Jersey Inventors of the Year Award by the New Jersey Institute of Technology.

Joel was active in the AIEE and then IEEE since his student days serving on many committees and boards, as chairman of the New York Section and president of the Communications Society. He was a member of the AAAS, ACM, Sigma XI, and the National Academy of Engineering, and a Life Fellow of IEEE.
Leo Esaki was born on 12 March 1925, in Osaka, Japan. He is one of only three Japanese physicists ever to receive the Nobel Prize. Interestingly enough, all three attended the Third High School (equivalent to the present junior college) in Kyoto, which may be no more than just coincidence or proof of the importance of an educational environment in developing scientific talent.

Esaki went on to major in physics at the University of Tokyo because he wanted to understand nature in a most fundamental way, but credits the war-time psychology as also having an effect on him, especially after the war. It was then that he decided to go into industrial research, in order to participate more effectively in the process of rebuilding war-torn Japan. He joined Sony Corporation, and it was there in 1957 that he discovered the tunnel diode, the first quantum electron device, for which he received a Ph.D. in physics.

In 1960, motivated by his curiosity about American ingenuity and perhaps the American dream, he came to the U.S. and joined IBM Research. An offer from IBM to become a resident consultant extended what was to be a one-year visit into a stay that has lasted 31 years. In 1967, he was named an IBM Fellow.

For more than 20 years, Esaki’s work at the IBM/T.J. Watson Research Center has focused on man-made semiconductor structures such as superlattices and quantum wells. The origins of such structures date back to seminal papers by Esaki and Raphael Bu, published in 1969 and 1970. They asserted that semiconductor structures of extraordinary electronic properties could be designed using the principles of quantum theory and synthesized with the advanced techniques of epitaxy do-it-yourself quantum mechanics, or band structure engineering. A variety of engineered structures have demonstrated intriguing characteristics, including nearly ideal resonant tunneling. Activities in this new frontier of semiconductor science have given immeasurable stimulus to device design, leading to unprecedented electron-transport and optoelectronic devices for applications.

In recognition of his pioneering role in opening up this new field, known as semiconductor quantum structures, Esaki shared with his two colleagues the 1985 International Prize for New Materials of the American Physical Society.

Esaki is a Fellow of the American Academy of Arts and Sciences, and a Foreign Associate Member of both the National Academy of Sciences and the National Academy of Engineering. In addition to his scientific achievements, Esaki has also helped interpret Japan for the West and vice-versa. Through his witty essays, he has helped bridge the gap between the two cultures that he, as a scientist with a foot in each, has managed to span. In 1998, he was the recipient of the Grand Cordon of the Order of the Rising Sun.
Robert G. Gallager was born in Philadelphia, Pennsylvania on 29 May 1931. He received the B.S. from the University of Pennsylvania in 1953, and the S.M. and Sc.D. from MIT in 1957 and 1960, respectively, all in electrical engineering.

Following two years at Bell Telephone laboratories and two years military service in the Signal Corps, in 1956 he joined the department of electrical engineering and computer science at MIT. He was the Fujitsu Professor of Electrical Engineering, co-director of the Laboratory for Information and Decision Systems, and co-chairman of the Department Area I (Control, Communication, and Operations Research).

Gallager’s early work on information theory focused on the reliability function of noisy channels, i.e., the exponential rate at which error probability can be driven to zero with increasing code length. The resulting paper, “A Simple Derivation of the Coding Theorem and Some Applications,” won the 1966 IEEE Baker Prize, and contributed to many later developments in coding. His book, Information Theory and Reliable Communication (Wiley, 1968) generalized these earlier results along with many new results. The book remains the standard graduate text and reference work for the field. Gallager’s later information theory work focused on multiaccess communication.

In the mid-1970s, Gallager’s research focus shifted to data networks. He is well known for his work on distributed algorithms, routing, congestion controls, and random-access techniques. Data Networks (Prentice Hall, 1988), co-authored with D. Bertsekas, helped provide a conceptual foundation for this field. Gallager was involved in the founding of Codex Corporation in 1962. His fundamental studies on quadrature amplitude modulation and detection led directly to the 9600 bps modems that provided Codex’s commercial success. His inventions in coding and modulation led to four patents.

Gallager was on the IEEE Information Theory Society’s Board of Governors from 1965 to 1970 and 1979 to 1988, and was its president in 1971. He was elected an IEEE Fellow in 1968 and a member of the National Academy of Engineering (NAE) in 1979.
C. Kumar N. Patel was born in Baramati, India on 2 July 1938. He received the B.E. from the College of Engineering in Poona, India and the M.S. and Ph.D. in electrical engineering from Stanford University in 1959 and 1961, respectively. Patel joined the Bell Laboratories in Murray Hill, New Jersey in 1961. Patel’s discovery, in 1963, of the laser action on the vibrational-rotational transitions of carbon dioxide and his invention, in 1964, of efficient vibrational energy transfer between molecules, led to his series of experiments which demonstrated that the carbon dioxide laser was capable of very high cw and pulsed power output at very high conversion efficiencies. No other laser has made a greater impact on society.

In 1966, Patel began pioneering studies which created a new field of infrared nonlinear optics which led to his 1969 invention of the spin-flip Raman laser, a class of tunable infrared lasers and the first tunable Raman laser in any wavelength region. Using this laser, he carried out very high-resolution spectroscopy of both ground and vibrationally-excited states of molecular gases, resulting in his contribution to the problem of atmospheric pollution detection. In 1970, he developed a tunable laser opto-acoustic measurement technique for extremely small concentrations of pollutant gases. In 1973, he carried out the first measurements of the temporal variation of concentration of nitric oxide in the stratosphere, which provided crucial data bearing on the problem of ozone depletion by man-made nitrogen oxide emission from sources such as the SST. His opto-acoustic spectroscopy studies of cryogenic liquids and solids, begun in 1980, are providing crucial data in understanding these materials and have culminated in the first observations of high vibrational over-tone absorption of molecular hydrogen in solid hydrogen. Patel’s current research interests include spectroscopy of highly transparent liquids and solids, and surgical and medical applications of carbon dioxide lasers.

Patel has received numerous awards, including The Optical Society of America’s Adolph Lomb Medal (1966); Coblentz Prize (American Chemical Society, 1974); Association of Indians in America’s Honor Award (1975); IEEE Lamme Medal (1976); National Academy of Engineering’s Zworykin Award (1976); OSA Townes Medal (1982); New Jersey Governor’s Thomas Alva Edison Science Award (1987); Hon. D.Sc., New Jersey Institute of Technology (1988); George E. Pake Prize of the American Physical Society (1988); and the OSA Frederic Ives Medal (1989).

Patel is a Fellow of the IEEE, the American Physical Society, the Optical Society of America, the American Academy of Arts and Sciences, the Association for Advancement of Arts and Sciences, the Laser Institute of America, and the American Society of Laser Medicine. He is a member of the National Academy of Engineering and the National Academy of Science.
Calvin F. Quate was born on 7 December 1923, in Baker, Nevada. He received the B.S. in electrical engineering from the University of Utah in 1944, and the Ph.D. from Stanford University in 1950. In 1949, he joined the technical staff at Bell Telephone Laboratories, located in Murray Hill, New Jersey, and soon became department head and then associate director of electronics research. He transferred to Sandia Corporation in Albuquerque, New Mexico, in 1959. In 1960, he was appointed vice president and director of research.

Quate joined Stanford University in 1961 as professor of applied physics and electrical engineering. He has served as chairman of the applied physics department, as acting chairman of the electrical engineering department, and as associate dean in the School of Humanities and Science. Presently, he holds the Leland T. Edwards Chair in Engineering at Stanford, and since 1984 has been a Senior Research Fellow at Xerox Palo Alto Research Center (PARC).

Quate worked on acoustic amplifiers, interaction of acoustics with semiconductors, and acoustic correlators, all of which have become important fields of research. His early work led to an understanding of noise space charge waves on electron beams, practical systems of periodic focusing of electron beams, coupled helixes in traveling wave tubes, and the design of practical microwave amplifiers and oscillators.

He initiated the activity on acoustics that led to the scanning acoustic microscope, which has resolution exceeding that of optical microscopes. It sharply reveals structure in optically opaque or even transparent materials. One can see things with sharp contrast that are not easily seen with optics and can examine sub-surface structures in integrated circuits that is not at all visible with optics.

Quate’s judgment and enthusiasm was infectious and has led many of his colleagues to work in acoustics and related fields. His work on electron tunneling microscopy revealed the atomic scale structure of crystalline substances.

Quate has served on several government committees, including the Defense Science Board. He was a Fellow of the IEEE and member of both the National Academy of Engineering and the National Academy of Sciences. In 1981, he received the Morris N. Liebmann Award of the IEEE, and later the Ultrasonics, Ferroelectrics, and Frequency Control Society’s 1986 Achievement Award. In 1982, he received the Rank Prize for Opto-electronics from the Rank Prize Funds of the Royal Society of London for his work on the scanning acoustic microscope.
Paul C. Lauterbur was born 6 May 1929, in Sidney, Ohio. He received the B.S. in chemistry from Case Institute of Technology in 1951. Between 1951 and 1953, he worked as a research associate at the Dow Corning Labs at the Mellon Institute where he was involved in the studies of organosilicon chemistry, vulcanizing systems and reinforcing fillers of silicone elastomers. It was at that time he was introduced to nuclear magnetic resonance (NMR).

In 1953, Lauterbur was drafted into the U.S. military and served two years in the Army Chemical Center Laboratories working on the biological testing of chemical warfare agents and studies on aerosols. While he was at the Army Chemical Center, he also set up the nuclear magnetic resonance laboratory and began research on NMR spectroscopy.

Lauterbur returned to the Mellon Institute in 1955, working part time towards his Ph.D. in chemistry, which he received from the University of Pittsburgh in 1962.

Upon receiving his degree, Lauterbur joined the faculty of the State University of New York at Stony Brook where he served as a professor in the departments of chemistry and radiology. He was named as university professor in 1984, and continued to hold the position of adjunct university professor at Stony Brook even after he left in 1985 to join the faculty at the College of Medicine and in the department of chemistry of the University of Illinois at Urbana-Champaign. At the University of Illinois, he held the post of director of magnetic resonance imaging research.

It was during his tenure at Stony Brook, and his sabbatical at Stanford University that Lauterbur accomplished much of his work on NMR spectroscopy, furthering his inquiry into its applications to the studies of the structures of molecules, solutions and solids. He also extended his NMR studies to applications in biochemistry and biophysics when he discovered nuclear magnetic resonance imaging. His work at SUNY Stony Brook laid the foundations for the field of nuclear magnetic resonance zeugmatography, or nuclear magnetic resonance imaging, commonly referred to as MRI. The breakthrough, though now a commonplace medical diagnostic instrument with this name, is built upon his work, and his discovery provided a new field of endeavor for physicists, engineers, and clinicians.

Lauterbur published more than 110 scientific articles regarding various aspects of NMR and its applications. Lauterbur received many honors and awards, including an honorary Ph.D. from the University of Liege, Belgium, the 1982 Gold Medal of the Society of Magnetic Resonance in Medicine, the 1984 Albert Lasker Clinical Research Award, the 1986 European Magnetic Resonance Award, the 1987 National Medal of Science (USA), the 1987 Roentgen Medal, the 1987 Gold Medal of the Radiological Society of North America, the 1992 International Society of Magnetic Resonance in Medicine Award, the 1994 Kyoto Prize for Advanced Technology, the 1999 Gold Medal of the European Congress of Radiology, and the 2001 NAS Award for Chemistry in Service to Society. In 1985, he was honored with membership in the National Academy of Sciences. In addition, in 2003, along with Sir Peter Mansfield, he won the Nobel Prize in Medicine.
Biomedical

**CAT Scan, MRI, and Ultrasound**

Doctors have used x-rays to see inside the body for more than a hundred years. But this technique has many limitations. X-rays can’t show features of soft tissues, which make up most of the body. In the 1960s and 1970s, it was still very common for doctors to perform so-called exploratory surgery in order to investigate parts of the body for disease or injury. Today, however, new techniques of imaging can often take the place of exploratory surgery. Three extremely important techniques for looking inside the body are computer assisted tomography (CAT), magnetic resonance imaging (MRI), and ultrasound imaging.

A CAT scan is a cross-sectional image created by taking traditional x-ray images from many different directions and then using a computer to calculate the shapes and positions of objects blocking the x-rays. CAT scans were impossible before the availability of the modern computer. David Kuhl and Roy Edwards built a transmission CT (computer tomography) scanner. Their CT scan of a patient on 14 May 1965, was possibly the first ever made. In the 1960s, Allan Cormack in the United States did important work on a scanning method that projected gamma rays (which is electromagnetic radiation of shorter wavelength than x-rays) through an object on a rotating platform. In the early 1970s in England, Godfrey Hounsfield developed a CT scanner and produced medical images. Within a few years, there were hundreds of CAT scanners throughout the world, and in 1979 Cormack and Hounsfield shared the Nobel Prize in Medicine for their work in developing computer assisted tomography.

MRI, or Magnetic Resonance Imaging, takes advantage of the fact that different chemical elements respond in various ways in rapidly changing magnetic fields. Depending on the chemical element and its association with different tissues in the body, it is possible to form medical images. Because this technique requires high-intensity magnetic fields, the equipment is large and expensive. The basic idea was first demonstrated in the 1940s by Felix Bloch at Stanford and, independently, by Edward Purcell at Harvard. It was not until the 1970s, however, that the technique became practical for human use. One of the leading developers, Raymond Damadian formed a company to produce MRI machines and began taking orders in 1980. By the end of the decade, thousands of MRI machines were in use in hospitals worldwide.

Did you know that ultrasound imaging grew out of submarine technology? The threat of submarines during World War I and World War II led to a great deal of research into what became known as sonar. Sonar works by sending out pulses of sound and detecting the echoes when the sound is reflected back by objects. In the 1940s and 1950s, a number of engineers worked to adapt sonar to medical use; among the most influential were George Ludwig at MIT, John Julian Wild and John M. Reid in Minnesota, and Douglass Howry at the University of Colorado. In the early 1960s, a number of products reached the commercial market, and doctors soon found many uses for ultrasound imaging, including gathering images during a pregnancy.

**Pacemakers**

An interest in the interaction between living organisms and electricity dates back to the beginnings of electrical science. Luigi Galvani’s anatomical experiments in the late 18th century led him to observe that an electric spark could cause the muscles of a dissected frog to twitch. The growing knowledge of the human body led to experimentation on a wide range of electrotherapies by pioneering scientists and physicians. These techniques employed both
direct current and static electricity. It was already known that the heart responds to mechanical blows to the chest with a fist, a technique now known as percussive pacing. It soon became clear that the heart was an organ especially sensitive to electricity as well. As early as 1788, attempts were made to treat irregular heartbeats with an electric shock, and in 1872, T. Greene in England published an important but sometimes overlooked paper showing that electric shock could restart a stopped heart. By 1878, Munich surgeon Hugo Wilhelm von Ziemssen discovered that periodic pulses of DC current applied to the chest could cause the heart to accelerate until its beat coincided with the external stimulus. Then, in 1889, John Alexander McWilliam proposed that small, regular electric pulses could be used to treat conditions where the heart was beating irregularly or at the wrong rate. Subsequently, in 1899, he published key experiments demonstrating his thesis that regular heart rhythm could be evoked by applying regular impulses.

Did you know that ultrasound imaging grew out of submarine technology? The threat of submarines during World War I and World War II led to a great deal of research into what became sonar.

The timeline below outlines the advancement of technologies leading to the modern pacemaker:

- 1788: First attempts to treat irregular heartbeats with an electric shock
- 1872: Green successfully uses electric shock to start a stopped human heart
- 1878: Von Ziemssen discovers response of heart to regular electrical stimulation
- 1889: McWilliam experiments with electrical impulses applied to the human heart
- 1899: Defibrillation published in seminal paper by McWilliam
- 1928: Physicist Eugene T. Booth and surgeon Mark C. Lidwell revive a still-born infant
- 1932: Arie Hyman invents a hand-cranked device and coins the term artificial pacemaker
- 1950: Toronto team employs an AC-powered, external device using vacuum-tube technology
- 1952: Paul M. Zoll keeps a patient alive for 52 hours, following which the patient survives for 6 months
- 1957: Earl Bakken and Clarence W. Lillehei apply a wearable transistorized pacemaker external to the body
- 1958: First use of a fully implantable pacemaker by Rune Elmqvist and Åke Senning
- 1959: First use of temporary transvenous pacing for patients awaiting an implanted pacemaker
- 1960: Wilson Greatbatch and William Chardack employ an improved implantable pacemaker
- 1962: Greatbatch’s U.S. patent #3,051,356 is issued and licensed to Medtronic, Inc.
- 1970: Medtronic produces an improved pacemaker that becomes a de-facto industry standard
- 1972: First lithium iodide battery powered pacemaker and first hermetically sealed pacemaker
- 1973: Cordis releases the Omni series, the first externally programmable implantable pacemaker
- 1982: Anthony Rickards introduces rate-modulated pacemakers that adapt the heart rate to demand
- 1988: Raúl Chirife implants first rate responsive pacemaker using a hemodynamic sensor
- 2005: Biventricular pacing for Cardiac Resynchronization Therapy (CRT) introduced
Jack Kilby was born on 8 November 1923, in Missouri. His father was an executive with the Kansas Power Company. Kilby traveled with his father during vacations and learned that cost was an important variable in engineering solutions, a lesson he kept with him all his life. Aware that he wanted to be an engineer by the time he was in high school, he studied engineering at the University of Illinois. His college studies were interrupted by military service during World War II, during which he worked in an Army radio repair shop in India. After returning to the United States, he graduated from college. He received his B.S. in electrical engineering from the University of Illinois at Urbana–Champaign in 1947. He earned his M.S. in electrical engineering from the University of Wisconsin–Milwaukee in 1950, while working at Centralab, a division of Globe-Union Corporation in Milwaukee.

Kilby began to think about making all of the individual components of a circuit out of a single block of material. When he first started working at Texas Instruments in 1958, the company had a policy of a company vacation in July, when everyone with vacation time took it and the company essentially shut down for a few weeks. As a new employee, Kilby had no vacation time coming. He used the time alone to think about more efficient engineering of the miniaturized circuits he had been hired to develop. He designed an integrated circuit out of a single unit of silicon. As a semiconductor allowing electricity to pass through it, silicon could contain within it all the parts and connections of a circuit. Although the semiconductor material might be more expensive than the materials usually used for parts other than the transistors, the end result of integration would be far less expensive than having to set up separate production processes for all the component parts. Other engineers were also working on integrated circuits, and Kilby shared the honors of co-invention of the microchip with Robert Noyce of Fairchild Semiconductor.

Kilby built the first computer using integrated circuits at Texas Instruments in 1961. Six years later, he and two co-workers invented the first pocket calculator to show how useful integrated circuits would be in daily life, not just for powerful government or military applications. By the time Kilby left Texas Instruments in 1970 to become an independent inventor, he was widely recognized for his engineering knowledge and creative inventions. In 1978 he became a professor at Texas A&M, retiring in 1984. Kilby held more than 60 patents on various inventions. In 1982, Kilby was elected to the National Inventors Hall of Fame. He received the National Medal of Science in 1970, the National Medal of Technology in 1990, and the Nobel Prize in Physics in 2000. Kilby’s work and contributions inspired the IEEE to name one of their most prestigious awards, the IEEE Jack S. Kilby Signal Processing Medal, after him. The award is given to those who, like Kilby, make outstanding contributions to the field.
John R. Whinnery

(26 July 1916 – 1 February 2009)

For seminal contributions to the understanding and application of electromagnetic fields and waves to microwave, laser, and optical devices.

Born in Read, Colorado on 26 July 1916, John R. Whinnery was an innovator in the field of electromagnetism and communication electronics. He received both his B.S. and Ph.D. in electrical engineering from the University of California, Berkeley, in 1937 and 1948, respectively. From 1937 to 1946, he helped develop velocity modulation tubes with W.C. Hahn at the General Electric Company in Schenectady, New York, where his work on problems in waveguide discontinuities, microwave tubes, and applications to radar aided in the war effort. During that period, he was active in war training classes, and from 1945 to 1946, held a part-time lectureship at Union College in Schenectady.

Upon returning to Berkeley in 1946, Whinnery joined the faculty as a lecturer and, upon completion of his doctorate, became first an associate professor and then a full professor. During his long tenure at the university, Whinnery held several leadership positions, including director of the Electronics Research Laboratory (1952-1956), chairman of the Department of Electrical Engineering (1956-1959), and dean of the College of Engineering (1959-1963). He retired as professor emeritus in 1987.

Because the teaching load at Berkeley left little time for pure research, Whinnery accepted an offer from Simon Ramo, who was then heading research and development at Hughes Aircraft Company, to take a leave from the university and join his growing R&D operation. This move led to an 18-month collaboration with Andrew Haefl, of the Radio Corporation of America (RCA) fame, in his new Electron Tube Laboratory, where Whinnery led microwave research focused on traveling wave tubes.

His career also included a research stint in quantum electronics at Bell Laboratories in New Jersey (1963-1964), visiting professorships at the University of California Santa Cruz and Stanford University, and a 1959 Guggenheim Fellowship at the Swiss Federal Institute of Technology (ETH Zurich).

His research led to innovations in microwave amplifiers such as triodes and traveling-wave tubes, including the backward-wave amplifier, which is still used in radar and satellite communications. After becoming interested in the emerging field of lasers and laser applications, Whinnery and his students produced advances in ultra-short optical pulses, which can be used to study fast processes in materials and chemical reactions. He was recognized as one of the country’s top experts on the fundamentals of quantum electronics.

In addition to his research, Whinnery is widely credited with helping to bring the study of applied electromagnetic theory to a broader audience with the pioneering textbook, Fields and Waves in Modern Radio, which he co-authored with Simon Ramo in 1944.

In 1992, Whinnery’s research contributions, excellence as an educator, and record of service earned him the National Medal of Science, the nation’s highest scientific honor bestowed by the President of the United States. He was a Fellow of the IEEE and of the Optical Society of America. In addition to the IEEE Medal of Honor, he was the recipient of many other awards, including the Founder’s Award of the National Academy of Engineering, the Lamme Medal of the American Society for Engineering Education, the Berkeley Citation, and the Distinguished Engineering Alumnus Award. He also earned the uncommon distinction of being elected to both the National Academy of Sciences and the National Academy of Engineering. He served on NASA’s Science and Technology Committee on Manned Space Flight for the Apollo Space Program. Whinnery earned a national reputation in matters of engineering education and played a key role in the creation of the Commission on Engineering Education. In 1994, the John R. Whinnery Chair in Electrical Engineering and Computer Sciences was established at Berkeley.
Norman Foster Ramsey was born in Washington, D.C., on 27 August 1915. Ramsey was educated in the United States and England; he earned five degrees in physics including the Ph.D. from Columbia University in 1940, and the D.Sc. from Cambridge University in 1964.

Ramsey's scientific research focused on the properties of molecules, atoms, nuclei, and elementary particles and included key contributions to the knowledge of magnetic moments, the structural shape of nuclear particles, the nature of nuclear forces, the thermodynamics of energized populations of atoms and molecules; for example, those in masers and lasers, and spectroscopy.

Ramsey not only contributed basic advances in the theoretical understanding of the physics involved in his research, but he also made pioneering advances in the methods of investigation; in particular, he contributed many refinements of the molecular beam method for the study of atomic and molecular properties, he invented the separated oscillatory field method of exciting resonances, and, with the collaboration of his students, he was the principal inventor of the atomic hydrogen maser. The separated oscillatory field method provides extremely high resolution in atomic and molecular spectroscopy, and it is the practical basis for the most precise atomic clocks. Likewise, the atomic hydrogen maser made even higher levels of spectroscopic resolution possible, and it also functions as the basis for atomic clocks having the highest levels of stability for periods extending to several hours.

During World War II, Ramsey joined the MIT Radiation Laboratory where he headed the groups that developed the first three-centimeter wavelength magnetrons and the related radar systems. Later, he became a group leader at the Los Alamos Laboratory. After the war, Ramsey returned to Columbia University until 1947 when he joined the faculty at Harvard University, where he became Higgins Professor of Physics in 1966.

Ramsey was the executive secretary of the group that established Brookhaven National Laboratory and he became the first chairman of the Brookhaven physics department. He served as the first science adviser to the Secretary General of NATO from 1958-1959. He was a founding Trustee of Universities Research Association for the construction of the 200 Gev accelerator at Batavia, Illinois, and he served as president of the Association from 1966-1972. He was president of the American Physical Society from 1978-1979.

Ramsey’s contributions have been recognized by many prestigious awards including the Presidential Certificate of Merit (1947), the E.O. Lawrence Award (1960), the Davisson-Germer Prize (1974), and the Columbia Award for Excellence in Science (1980). He is a Fellow of the American Physical Society and is a member of the National Academy of Sciences. Ramsey wrote and published five books and he authored or co-authored more than 300 scientific papers.
Nicolaas Bloembergen was born in Dordrecht, the Netherlands, on 11 March 1920. He obtained the Phil. Cand. and Phil. Dr. at the University of Utrecht in 1941 and 1943, respectively. Following World War II, he came to America in the spring of 1946, walked into Professor Edward Purcell’s office at Harvard University and requested the opportunity to do graduate work in the emerging field of nuclear magnetic resonance. This fateful step started a lifelong association with the university. It also set the future pattern for his scientific work, which began with magnetic resonance and evolved in a natural way in quantum electronics, non-linear optics, and lasers.

Bloembergen returned briefly to the University of Leiden in Holland to defend his thesis and receive the Ph.D. in 1948. His Ph.D. thesis, “Nuclear Magnetic Relaxation,” investigated what controlled the shape of spectral lines, which can occur when atoms in their excited state emit radiation. This research was used to write what became the classic Bloembergen, Pound, and Purcell paper (BPP) published in the Physical Review in 1948. A measure of the continuing influence of his Ph.D. thesis is that it was first published as a book in 1961, 13 years after he graduated.

Bloembergen spent more than 40 years at Harvard University and was considered the father of nonlinear optics, which investigates how electromagnetic radiation interacts with matter. In 1949, Bloembergen returned to Harvard as a Junior Fellow of the Society of Fellows. He became associate professor of applied physics in 1951, Gordon McKay professor in 1957, Rumford Professor of Physics in 1974, Gerhard Gade University Professor in 1980, and emeritus in 1990. After retiring from Harvard, in 1991, he relocated to Tucson, Arizona, and became affiliated with the University of Arizona, College of Optical Sciences.

Bloembergen’s work in electron spin resonance led to his invention of the three-level solid-state maser in 1956. This found use as a microwave amplifier and was a forerunner of the subsequent laser developments which rely most heavily on the three-level pumping system. Primarily in recognition for this work, he shared the Morris Liebmann Memorial Award of the Institute of Radio Engineers for 1959 and the Stuart Ballantine Medal of the Franklin Institute in 1961.

The rapid evolution of quantum electronics into the optical region led Bloembergen into the field of nonlinear optics of which he is one of the founders. The last two decades of his scientific work emphasized laser spectroscopy and laser interaction with matter.

His excitement with science and his productivity continued at the same high level from the time he was a young scientist to the end of his career. His magnetic resonance work was recognized by the Oliver E. Buckley Prize for Solid State Physics awarded by the American Physical Society in 1958. In 1974, he was awarded the National Medal of Science by the president of the United States for pioneering applications of nuclear magnetic resonance. His other awards include the 1979 Frederic Ives Medal of the Optical Society of America for contributions to nonlinear optics and the 1981 Nobel Prize in Physics for his contributions to the development of laser spectroscopy.
John Wilder Tukey was born in New Bedford, Massachusetts, on 16 June 1915, the only son of the two top 1898 graduates of Bates College. While his father taught Latin in New Bedford, Tukey was largely educated by his mother at home. He later obtained the B.S. and M.S. in chemistry from Brown University in Rhode Island, and a Ph.D. in mathematics from Princeton University in New Jersey.

Tukey’s diverse talents allowed him an eclectic career. In 1939, he began teaching at Princeton University and eventually rose to the position of chairman of the Department of Statistics. He also worked with Bell Laboratories for decades. During World War II, Tukey helped create the U-2 spy plane. In the 1950s, he was part of a committee that reviewed the value of the Kinsey Report, and, in the process, he often argued with its creator. In the 1970s, he asserted that aerosol cans were detrimental to the ozone layer. He also worked on the polls used by NBC television broadcasting company to predict elections and served as a consultant to the Educational Testing Service.

Tukey was noted for his contributions to the theory and application of Fourier methods. His work on the cepstrum, with B.P. Bogart and M.J.R. Healy, was influential in vocoder development and other areas and gave the profession such Tukeyisms as quefrency, gamnitude, and saphe. His gift for language also had broader impact; he is credited with coining the terms bit and software.

Finally, his development of the Fast Fourier Transform Algorithm, published jointly with J.W. Cooley, revolutionized the application of Fourier methods. It drastically altered the economics of frequency domain versus time domain approaches to problems and digital versus analog implementation, and was the major stimulus for the rapid, subsequent development of digital signal processing.

Tukey was the father of modern exploratory data analysis. He was honored many times for his contributions to statistics and to science. In 1965, he was named the first recipient of the S.S. Wilks Award of the American Statistical Association. He received the National Medal of Science in 1973, and the Shewhart Medal of the American Society of Quality Control in 1977.
Sidney Darlington was born in Pittsburgh, Pennsylvania, on 18 July 1906. He received a B.S. in physics, magna cum laude, from Harvard University in 1928, a B.S. in electrical engineering from MIT in 1929, and a Ph.D. in physics from Columbia University in 1940. Professors George W. Pierce of Harvard and Ernst A. Guillemin of MIT instilled in him a lifetime fascination with theoretical aspects of communication engineering.

In 1929, Darlington became a member of technical staff at Bell Laboratories in Murray Hill, New Jersey, where he remained until he retired as head of the circuits and control department in 1971. At Bell Labs, Darlington was ranked alongside his colleague Claude Shannon for breakthroughs in communication networks that foreshadowed the integrated circuit and in turn computers and modern communications. Darlington’s discovery of ways to custom-design circuits using precise mathematical specifications, a specialty now called network synthesis theory, made him the leading authority in electronic circuits for decades.

At a chalkboard at Bell Labs, with three or four other rocket guidance experts, Darlington scrawled equations that became the basis for guiding the Air Force Titan I, the Thor-Delta, and dozens of other rockets. His rocket guidance formulas could instantly plug in the information from several sources, including the trajectory designed to launch a satellite, the data from radar that tracked the rocket, and the instruments in the rocket itself, and could then return a flow of commands to the rocket.

Always a tinkerer, in the 1950s, Darlington spent a weekend at home playing with a new gadget, the transistor. Trying to get more gain from an amplifier the size of a kernel of corn, he found a way to combine two or more transistors in one chip, an idea that became the Darlington type of Compound Chip and pointed the way toward integrated circuits. He patented the idea and lived to see the Darlington chip become required study for electrical engineering students everywhere.

Darlington also made advances in radar, inventing the pulse compression (chirp) radar in 1947. This approach, using several frequencies to lower the demands for high peak power, made possible the antiballistic missile defense system.

Darlington was an IEEE Life Fellow, an Associate Fellow of American Institute of Aeronautics and Astronautics (AIAA), and a member of the National Academies of Engineering and Science. For many years, he was active in the IEEE Circuit Theory Group and in the International Union of Radio Science (URSI) where he served as a delegate to several URSI general assemblies. He received the Prize Paper Award of the IEEE Circuit Theory Group in 1972, the IEEE Edison Medal in 1975 for basic contributions to network theory and for important inventions in radar systems and electronic circuits. In 1945, he was awarded the Presidential Medal of Freedom, the highest civilian honor in the United States, for his contributions during World War II.

Sidney Darlington
(18 July 1906 – 31 October 1997)

For fundamental contributions to filtering and signal processing leading to chirp radar.
William Shockley gained fame and shared a Nobel Prize for his development of point-contact transistors, work that provided the basis for one of the sweeping technological revolutions of the 20th century. His junction and field-effect transistors became workhorses of the electronics industry. In later years, he would gain notoriety for his views on eugenics. In sum, he was a brilliant, pivotal, and controversial figure, stimulating to work with but often difficult to work for. But even his failures could catalyze important change: the men who fled his autocratic management of Shockley Semiconductor Laboratory founded key companies in the integrated circuit revolution, qualifying Shockley at the very least as the grandfather of Silicon Valley.

Shockley was born in London on 13 February 1910, to American parents. His father was a mining engineer, and his mother was one of the first women surveyors in the United States. During his early childhood, his family moved around a great deal, and his parents educated him at home until he was eight years old. He received his B.S. from the California Institute of Technology in 1932. Soon thereafter, pursuing a fascination in the new European theories of quantum mechanics, he traveled east to attend graduate school at MIT. There, he was noticed by physicist Phil Morse, who would lead Shockley to Bell Telephone Laboratories and later to wartime advisory groups. Shockley received his Ph.D. in 1936, and that same year joined the technical staff at Bell Labs.

One of his early accomplishments at Bell Labs was to design, with colleague James Fisk, the world’s first nuclear reactor. Intrigued by advances toward fission by European scientists, Bell gave the two researchers a small room and lab equipment. The resulting reactor design was forwarded to Washington, which promptly classified it and denied Fisk, Shockley, and the labs any patent. Only after the war, and after having duplicated his concept, did the Manhattan Project physicists learn of Shockley’s work.

The same year of his graduation, he joined Bell Telephone Laboratories, working in the group headed by D.J. Davisson and remaining there until 1955. It is here that he began the development of the transistor, a fundamental technology that brought the world into a new era of modern-day electronics. However, during WWII he had to interrupt his time at Bell Telephone Laboratories to serve as the research director of the Anti-submarine Warfare Operations Research groups. Afterwards, he served as an expert consultant in the office of the Secretary of the War. Working as a military researcher, he was able to calculate the statistical improvement of air power, and advised the US Air Forces on how to increase the efficiency and accuracy of its bombing campaign. He also influenced the U.S. Navy’s ability to better target German U-boats, which were a danger to Atlantic trade between the U.S. and Britain. During World War II, on leave of absence from Bell, he developed operations research techniques for the Navy’s Anti-Submarine Warfare Operations Research Group (ASWORG).

Shockley foresaw the commercial potential of transistors as the nerve cells of computers. In 1954, Shockley was named director of transistor physics research at Bell, but left Bell Laboratories in 1956 to join Beckman Instruments, Inc. and establish the Shockley Semiconductor Laboratory in Mountain View, California, for research, development, and production of new transistor and other semiconductor devices. This became the Shockley Transistor Corporation, a subsidiary of Beckman Instruments, in 1958. The firm was the first to work with silicon as a semiconductor.

In April 1960, Shockley Transistor Corporation was acquired by the Clevite Corporation, and Shockley continued as a consultant to the Shockley Laboratories of Clevite Transistor until its sale to International Telephone and Telegraph in 1965. In 1965, Shockley renewed his association with Bell Telephone Laboratories in the capacity of executive consultant. He retired from this position in February 1975.
Richard Bellman was born in Brooklyn, New York, on 26 August 1920. He received the B.A. from Brooklyn College in 1941, and the M.A. in mathematics from the University of Wisconsin in 1943. As part of his service in the U.S. Army, he spent two years at Los Alamos National Laboratory in a theoretical physics division group. Leaving Los Alamos in 1946, he entered Princeton University and completed his work toward the Ph.D. in just three months.

In the immediate postwar years, Princeton University was a center of defense-motivated research activity in non-linear differential equations. As a graduate student there, Bellman became a member of an inner circle of young mathematicians led by Professor Solomon Lefschetz. His doctoral research under Lefschetz resulted in his first major work, Stability Theory of Differential Equations (1946) subsequently published as a book in 1953, and regarded as a classic in its field. He served on the faculty at Princeton University until 1952.

Bellman joined the newly established Rand Corporation in Santa Monica, California, in 1952. At Rand, he became interested in the theory of multistage decision processes, then emerging as an important problem-area in the control of both small- and large-scale systems.

His invention of dynamic programming in 1953 was a major breakthrough in the theory of multistage decision processes—a breakthrough which set the stage for the application of functional equation techniques in a wide spectrum of fields extending far beyond the problem areas which provided the initial motivation for his ideas.

This work marked the beginning of a new era in the analysis and optimization of large-scale systems and opened a way for the application of sophisticated computer-oriented techniques in a wide variety of problem areas ranging from the design of guidance systems for space vehicles to pest control and network optimization.

In addition to his fundamental and far-ranging work on dynamic programming, Bellman made a number of important contributions to both pure and applied mathematics. Particularly important was his work on invariant imbedding, which by replacing two-point boundary problem with initial value problems makes the calculation of the solution more direct as well as much more efficient. His work on quasi-linearization and its applications to system identification led to many results of a practical nature in the study of nonlinear systems. In the later part of his career, Bellman’s research focused increasingly on the application of mathematics to medicine and biological sciences. He was the founder of the journal Mathematical Biosciences, and the co-author of the book Mathematical Models in Medicine. Bellman left the Rand Corporation in 1965 to join the faculty of the University of Southern California, where he held a joint appointment as professor of mathematics, electrical engineering, and medicine.

A prolific writer, he authored over 600 published research papers, 35 books, and seven monographs. Over the course of his career, Bellman received a number of honors for his work, including First Norbert Wiener Prize in applied mathematics, awarded in 1970 jointly by the American Mathematical Society and the Society for Industrial and Applied Mathematics; First Dickson Prize, Carnegie-Mellon University, 1970; and John von Neumann Theory Award, awarded in 1976 jointly by the Institute of Management Sciences and the Operations Research Society of America. He was elected as a Fellow of the American Academy of Arts and Sciences in 1975, and to membership in the National Academy of Engineering in 1977.
Robert N. Noyce
(12 December 1927 – 3 June 1990)

For his contributions to the silicon integrated circuit, a cornerstone of modern electronics.

Robert Noyce helped create the first integrated circuit, the forerunner of the microprocessor. Noyce also co-founded two companies, Fairchild Semiconductor, and Intel, that helped usher in the era of Silicon Valley.

As a child growing up in Iowa, Noyce showed an early interest in tinkering and figuring out how things work. This interest deepened when Noyce enrolled at Grinnell College in 1946. Noyce took his degree in physics, but he also demonstrated great talent for engineering. At Grinnell, he was introduced to the transistor, which had been invented by a team headed by William Shockley at Bell Labs in 1947. Noyce was fascinated with the new device.

After college, Noyce earned a doctorate in physics at MIT in 1953, and a few years later, he joined Shockley’s new company, Shockley Semiconductor Laboratories in Palo Alto, California. Noyce was attracted to Shockley Semiconductor because of Shockley’s reputation of genius. In 1957, Noyce and a group of others left Shockley Semiconductor to branch out on their own. The group, known as the Fairchild Eight, obtained funding and set up their own company, Fairchild Semiconductor, in Mountain View, California.

At the time, making silicon transistors was an arduous process. They had to be wired together by hand. Noyce and Fairchild co-founder, Gordon Moore, began looking for a better way of connecting transistors. They came up with the idea of combining transistors in a solid block of silicon. This was the integrated circuit. As fate would have it, another inventor named Jack Kilby was working on the same problem in Texas. Noyce and Kilby came up with the same solution at virtually the same time. For that reason, they share credit for the invention.

In 1968, Moore and Noyce left Fairchild Semiconductor with the dream of creating a company that specialized in developing integrated circuits for the computer industry. They called their venture Integrated Electronics, which is now more commonly known as Intel. At Intel, engineers developed a microchip that could store computer language (ones and zeroes) and introduced its first random access computer (RAM) memory chip in 1970. After that advancement, the first microprocessor quickly followed. Noyce also made his mark as an innovative manager with an easygoing style that encouraged creative solutions to problems.

Noyce was richly rewarded for his accomplishments. In addition to acquiring great wealth, he held 16 patents, and received many awards, including the National Medal of Science, the National Medal of Technology, and the Charles Draper Prize of the National Academy of Engineering. Noyce was highly regarded by his peers who respected his technical brilliance and admired his gracious personality.
H. Earle Vaughan was born on 3 February 1912. He began his long Bell System career in 1928 as an assistant in Bell Laboratories. He was promoted to the position of technical assistant and while working in this capacity, he attended Cooper Union College in New York City, receiving his B.S. in 1933.

Vaughan was responsible for the planning and development of Bell Laboratories No. 4 Electronic Switching System (ESS) for long-distance telephone traffic, one of the largest and most complex undertakings in the history of the company. As director of the No. 4 ESS Switching System Laboratory, Vaughan coordinated efforts leading to the January 1976 cutover in Chicago, Illinois, of the first No. 4 ESS, which was able to connect up to 550,000 telephone calls an hour.

Prior to 1940 and through the war years, Vaughan worked on a variety of transmission and signaling projects, including some related to defense. In 1945, he undertook research work on an experimental Electronically Controlled Automatic Switching System (ECASS), a high-speed system using cold cathode gas tubes, reed switches and a special telephone set. This project was followed a few years later by work on another experimental switching system, the Drum Information Assembler and Dispatcher (DIAD). This magnetic drum-controlled system, which used vacuum tubes and semiconductor diodes, explored for the first time the use of memory and scanning techniques in switching.

In 1952, Vaughan became a supervisor in the switching research department, where he conducted studies on the uses of transistor, ferroelectric, and magnetic core memories for use in logic systems. In 1955, he was appointed head of the switching research department. His previous work on ECASS, DIAD, and other experimental switching systems paved the way for significant work on an Experimental Solid-State Exchange (ESSEX), which began in 1955. This system, using solid-state devices, was based on a concept of integrated time-division switching and transmission. It employed pulse-code modulation to convert analog signals into digital signals in remote line concentrators, and also used a central time-division switch.

Vaughan was appointed director of the Systems Research Center in 1958, and he assumed responsibility for four departments involved in digital circuitry research. In 1962, Vaughan transferred to the Switching Systems Development Area to serve as director of the Electronic Switching System Center. In this position, he was responsible for system and software design for No. 1 ESS, the first major commercial electronic switching system introduced into service in 1965. In 1968, Vaughan assumed overall responsibility for planning and developing of No. 4 ESS. He retired in March, 1976, completing a telecommunications career of more than four decades, more than half devoted to the conception and development of advanced telephone switching technology and systems.

Vaughan was a IEEE Fellow and served on several Institute committees. In 1944, he received the Naval Ordinance Award for his computer work. Vaughan held 27 patents and published 13 articles related to several areas of electronics and telecommunications technology, including electronic circuits, signaling systems, and call-switching systems.
Integrated Circuits

An integrated circuit (IC) is a thin slice of silicon or sometimes other material that has been specially processed so that a tiny electric circuit can be etched on its surface. The circuit can have many millions of microscopic individual elements, including transistors, resistors, capacitors, and conductors, all electrically connected in a certain way to perform some useful function.

The first ICs were based on the idea that the same process used to make clusters of transistors on silicon wafers might also be used to make a functional circuit, such as an amplifier circuit or a computer logic circuit. Slices of the semiconductor materials silicon and germanium were already being printed with patterns, the exposed surfaces etched with chemicals, and then the pattern removed, leaving dozens of individual transistors, ready to be sliced up and packed individually. But wires, a few resistors, and capacitors would later connect those same transistors to make a circuit. Why not do the whole thing at one time on that slice of silicon?

The idea occurred to a number of inventors at the same time, but the first to accomplish it were Jack Kilby of Texas Instruments and Robert Noyce of Fairchild Semiconductor Incorporated. The idea caught on like wildfire because the IC had many of the advantages that made the transistor attractive earlier: small size, high reliability, low cost, and small power consumption. However, these circuits were difficult to make because one faulty component within a chip ruined the whole. As engineers became more proficient at squeezing more transistors and other components onto a single chip, the problems associated with making these chips increased. When the transistors were reduced to microscopic size, even the smallest bit of dust could ruin the chip. That’s why today, chips are made in special clean rooms where workers wear the bunny suits that we often see on TV.

Compared to the original IC, which was a simple device with just a few components, the number of components on today’s ICs is amazing. In the 1960s, an engineer named Gordon Moore predicted that the number of elements on a chip would double every year (later revised to every two years) into the foreseeable future. Moore’s Law has held true so far. By the beginning of the 21st century, the Intel Pentium chip had over 100 million transistors on it, the total number of components including resistors, capacitors, and conductors being even larger.
Why Integrate a Circuit?

An integrated circuit (IC) and the computer have evolved hand-in-hand for over 30 years. Why is the relationship between the two so close? Partly because the computer, unlike many other electronic systems, demands an incredibly large number of components to function. You can build a functional transistor radio from five transistors, but even in the early days of computers, thousands or tens of thousands of switches, relays, electron tubes, or transistors were needed just to make a computer that, today, would be outperformed by a hand-held calculator. ICs offered a way to make more complex circuits that were much smaller than circuits made with individual or “discrete” components, because an IC can have many millions of microscopic individual elements, including transistors, resistors, capacitors, and conductors. Just as importantly, they require much less electricity, so they don’t overheat or gulp enormous amounts of energy.

Why do computers require so many components? Because the heart of computers—their logic and memory functions—are made up of thousands or even millions of nearly identical sets of simple circuits, and each of these circuits requires one or more transistors. Computer logic consists of simple “gate” circuits that process information in the form of pulses of electricity representing ones and zeroes. Everything a computer does—displaying information, calculating the path of a computer game’s ammo, sending an email—is controlled by a program that consists of instructions, translated into “binary” numbers: ones and zeroes. Actions such as keystrokes, mouse clicks, etc., are the “input” to the program. The circuits in a computer deal with the program instructions and the input data by adding or subtracting ones and zeroes, changing zeroes to ones, or comparing numbers to determine if they are alike or different. All that happens inside electronic circuits called gates, which are made up of transistors.

If it’s still unclear how combinations of gates turn 0s and 1s into information displayed on a screen, don’t worry. Study computer science in college and you’ll eventually understand. Complex computer operations require many, many tiny logic decisions to perform the simplest functions, and thousands of simple functions have to be performed simultaneously to do something as complicated as play a game or view a movie. Using the most popular type of construction, each logic gate requires up to four transistors. You can imagine how these add up and why it takes millions of transistors to make even one microprocessor chip.
John Robinson Pierce made many important contributions to microwave and communications technology during his long career at Bell Laboratories, as well as to the development of microwave electron tubes such as the traveling-wave tube. Pierce is also remembered for naming an amplifying device developed by some of his Bell Labs colleagues—the transistor.

In the late 1950s, Pierce was an early and enthusiastic promoter of communications satellites and played a pivotal role in the development of two of the earliest, Echo I and Telstar.

Pierce was born on 27 March 1910, in Des Moines, Iowa. Pierce obtained both a B.S. and a Ph.D. from the California Institute of Technology in 1933 and 1936, respectively. Shortly after earning his doctorate, Pierce joined Bell Telephone Laboratories in New York City, where he worked on various problems concerned with electron-tube design.

During World War II, this experience proved valuable when Bell Labs made the transition to microwave research in support of the U.S. radar development effort. Pierce helped develop an improved type of reflex klystron tube, which was used in radar receivers.

In 1951, Austrian Rudolf Kompfner joined Bell Labs and began work on a new type of microwave amplifier called a traveling-wave tube. At the time, there were almost no practical electronic devices that could amplify microwaves in a broad range of frequencies. Pierce and Kompfner, working with other Bell Labs colleagues, developed a tube that amplified microwaves by making the waves slow down enough to be in step with an electron beam, which transferred its energy to the waves. The traveling-wave tube proved to be valuable for the construction of microwave communications relay stations both on the ground and later in orbiting communications satellites.

As early as 1954, Pierce advocated using satellites for communications between widely separated points on the ground. Following the Soviet Union’s launch of the first artificial satellite, Sputnik I, in 1957, the U.S. government increased its own efforts to launch satellites. Pierce supported the idea of launching a 100-foot (30-meter) aluminum-covered balloon to serve as a passive reflector of microwaves from one ground station to the other. Named Echo I, this satellite was launched in 1960 in cooperation with NASA and the Jet Propulsion Laboratory. In addition to relaying the words of President Eisenhower from the West Coast to the East Coast of the U.S., Echo I’s highly visible presence in the night sky advertised the fact to millions around the globe that the U.S. could orbit satellites too. With Pierce’s involvement, Bell Labs also developed an active communications satellite called Telstar I, which carried a miniature microwave relay station on board. Telstar enabled the first intercontinental television broadcasts to take place in 1962.

During his career, he wrote several books on communications technology for popular audiences, including *The Theory and Design of Electron Beams*, *Traveling-Wave Tubes, Electrons, Waves and Messages*, *Man’s World of Sound* with E.E. David, Jr., and *Symbols, Signals and Noise*. He also wrote an autobiography and several science-fiction stories for magazines. The latter were published under the pseudonym J.J. Coupling.

In 1948, he received the Institute of Radio Engineers (IRE) Fellow Award for his many contributions to the theory and design of vacuum tubes. He was the recipient of the IRE Morris Liebmann Memorial Prize for 1947. In 1960, he received the Stuart Ballantine Medal. Pierce was a Fellow of the IRE, the American Physical Society, the Acoustical Society of America, and the British Interplanetary Society, and a member of the National Academy of Sciences.
Rudolf Kalman was born in Budapest, Hungary, on 19 May 1930. The son of an electrical engineer, he decided to follow in his father’s footsteps. He immigrated to the United States and obtained a B.S. and M.S. in electrical engineering from MIT in 1953 and 1954, respectively. He continued his studies at Columbia University where he received his Sc.D. in 1957 under the direction of Professor John R. Ragazzini.

From 1957 to 1958, Kalman was employed as a staff engineer at the IBM Research Laboratory in Poughkeepsie, New York. During that period, he made important contributions to the design of linear sampled-data control systems using quadratic performance criteria, as well as in the use of Lyapunov theory for the analysis and design of control systems. He foresaw at that time the importance of the digital computer for large-scale systems.

In 1958, Kalman joined the Research Institute for Advanced Study (RIAS). Between 1958 to 1964, he made some of his truly pioneering contributions to modern control theory. His research in fundamental systems concepts, such as controllability and observability, helped put on a solid theoretical basis some of the most important engineering systems structural aspects. He unified, in both the discrete-time and continuous-time case, the theory and design of linear systems with respect to quadratic criteria. He was instrumental in introducing the work of Caratheodory in optimal control theory and in clarifying the interrelations between Pontryagin’s maximum principle and the Hamilton-Jacobi-Bellman equation, as well as variational calculus in general. His research not only stressed mathematical generality, but was guided by the use of the digital computer as an integral part of the design process and of the control system implementations.

During his stay at RIAS, Kalman also developed what is perhaps his most well-known contribution, the so-called Kalman filter. He obtained results on the discrete-time (sampled data) version of this problem in late 1958 and early 1959. He blended earlier fundamental work in filtering by Wiener, Kolmogorov, Bode, Shannon, Pugachev, and others with the modern state-space approach. His solution to the discrete-time problem naturally led him to the continuous-time version of the problem and in 1960 to 1961, he developed, in collaboration with Richard S. Bucy, the continuous-time version of the Kalman filter.

The Kalman filter, and its later extensions to nonlinear problems, represents perhaps the most widely applied by-product of modern control theory. It has been used in space vehicle navigation and control in the Apollo vehicle, radar tracking algorithms for ABM applications, process control, and socioeconomic systems. Its applications popularity is due to the fact that the digital computer is effectively used in both the design phase as well as the implementation phase. From a theoretical point of view, it brought under a common roof related concepts of filtering and control, and the duality between these two problems.

In 1964, Kalman moved to Stanford University where his research efforts shifted toward the fundamental issues associated with realization theory and algebraic system theory. He opened up new research avenues in a new and basic area and his contributions helped shape a new field of research in modern system theory.

In 1971, Kalman was appointed graduate research professor at the University of Florida in Gainesville. He became director of the Center for Mathematical System Theory, and his education and research activities involved the departments of electrical engineering, industrial engineering, and mathematics. He also acted as a scientific consultant to research centers in the Ecole des Mines de Paris, France.

Kalman not only shaped the field of modern control theory, but was instrumental in promoting its wide usage. Kalman published more than 50 technical articles, co-authored the book Topic in Mathematical System Theory (McGraw-Hill, 1969), and delivered numerous lectures. He was a member of many professional societies and served on the editorial board of numerous journals. He became a Fellow of the IEEE in 1964.
Rudolf Kompfner was born in Vienna, Austria, on 16 May 1909. Various circumstances impelled him to study architecture at the Technische Hochschule in Vienna, where he received his Diplom Engineer in 1933. He then moved to England, where he served with Philip D. Hepworth as an architectural apprentice from 1934 to 1936, and as an architect with Franey and Sons, Builders from 1936 to 1941.

Although trained as an architect, Kompfner’s heart was given to physics, especially to electronics. While working as an architect, he read intensively in the library of the British Patent Office. During this period, he invented a split beam oscilloscope tube and he learned about new microwave devices and velocity modulation from the technical literature.

A brief internment as an enemy alien early in World War II enabled Kompfner to pursue studies in physics with interned German physicists. He was then released, and more or less drafted to the physics department of the University of Birmingham, where the British Admiralty had set up a secret tube-research center under Professor M. L. Oliphant. Kompfner was assigned to develop a low noise klystron amplifier. He spent two discouraging years building klystrons before he invented the traveling-wave tube in 1943. In all, Kompfner served with the Admiralty from 1941 through 1950, as principal scientific officer, and as distinguished scientist from 1946. From 1950 to 1951, he was employed at Oxford and as a consultant to the English Electric Valve Company. He received his D. Phil. in physics from Oxford in 1951.

In December 1951, Kompfner went to Bell Laboratories. For a number of years, he worked chiefly on microwave tubes, including traveling-wave tubes and backward wave oscillators, which he conceived independently of others. Later, his interests broadened. He had a leading role in initiating and carrying through the Echo Satellite experiment, and he directly supervised the group who built the east-coast terminal (which also found use in the Telstar experiment).

Kompfner made original contributions in a number of fields, including antennas, and was deeply involved, among other things, in optical communications. He was an associate executive director of research and communication sciences at Bell Labs from 1962 until his retirement in 1973. Afterward, he held teaching positions in applied physics at Stanford University and engineering sciences at Oxford University.

He was the author of many publications and held more than 55 patents. He won the National Medal of Science in 1975. He was awarded the Duddell Medal of the Physical Society of England in 1955, the David Sarnoff Award of the American Institute of Electrical Engineers in 1960, and the Stuart Ballantine Medal of the Franklin Institute in 1960.
Jay W. Forrester was born 14 July 1918, on a cattle ranch 20 miles from the nearest town of Anselmo, Nebraska. He received the B.S. electrical engineering from the University of Nebraska in 1939 and S.M. from MIT in 1945. Initially at MIT, he also served as a research assistant, being engaged in teaching and in the development of high-voltage electrostatic generators. In 1940, he was a cofounder of the Servomechanisms Laboratory at MIT and spent the war years in the development of hydraulic servomechanisms for gunfire and radar antenna control.

From 1944 to 1951, Forrester was associate director of the Servomechanisms Laboratory at MIT. Late in 1944, he was in charge of a project to develop a real time simulator of flight behavior of multi-engine aircraft. Originally, the simulator was conceived in terms of analog technology but early in this work, Forrester perceived that design limitations would prevent the achievement of adequate dynamic accuracy of the simulator and the program was switched to an investigation of digital technology. Within just a few years, the work became fully committed to digital technology and the aircraft simulator project emerged as a digital computer for real time simulation.

In 1951, Forrester founded the Digital Computer Laboratory at MIT, which he directed until 1956. During this period, he was one of the outstanding pioneers in the formative period of digital computer art. Although his best-known contribution is the invention and development of coincident-current, magnetic core memory, he made many other fundamental contributions to the organization, design, reliability, and the use of digital computers. In 1951, Forrester became head of the division of newly-formed Lincoln Laboratory at MIT which was responsible for the design of the SAGE air defense system. As such, he was again a pioneer, but this time in the use of the new digital computer as the fundamental element in a large scale, real-time information processing system. He and his group made many contributions to the art of system design, software development, and test and evaluation, as well as to the continued improvement of computing hardware, displays, and communications.

In 1956, Forrester returned to the academic staff of MIT as professor of industrial management in the Sloan School. His major interests were in the application of feedback theory, information systems, and digital simulation and modeling to the understanding and design of social systems. He was the author of numerous books, including *Industrial Dynamics* (MIT Press 1961), *Principles of Systems* (Wright-Allen Press 1968), *Urban Dynamics* (MIT Press 1969), and *World Dynamics* (Wright-Allen Press 1971), which indicate the scope and importance of his work.

Forrester was a Fellow of the IEEE, the American Academy of Arts and Sciences, and the Academy of Management, and a member of the National Academy of Engineering and numerous other professional societies. Among his honors are honorary doctorates from the University of Nebraska (1954), Boston University (1969), and Newark College of Engineering (1971); the Inventor of the Year Award from George Washington University (1968); and the Valdemar Poulsen Gold Medal of the Danish Academy of Technical Sciences (1969).
John Bardeen was born on 23 May 1908, in Madison, Wisconsin. An extraordinary student, he advanced from third grade directly to junior high school. He started college at the University of Wisconsin, where he earned both his B.S. and M.S. in electrical engineering, in 1928 and 1929. For three years, Bardeen worked as a geophysicist at Gulf Research Laboratories, in Pittsburgh. In 1936, he earned a Ph.D. in mathematical physics at Princeton University.

During World War II, he worked at the Naval Ordnance Labs to help design defense systems against magnetic mines and torpedoes. After the war, he accepted a generous offer from William Shockley to work at Bell Labs. He worked especially well with Walter Brattain, another member of Shockley’s research group. In 1947, Bardeen and Brattain developed the point-contact transistor, which was based on the insight that electrons behave differently at the surface of metals. In June 1948, the invention was announced, and its first commercial use would be on telephone switching equipment four years later. Shockley quickly made improvements on the transistor design and developed the junction transistor. The three shared the 1956 Nobel Prize in Physics.

In 1951, Bardeen quit Bell Labs to take an academic position at the University of Illinois where he studied superconductivity and developed a theory about how extremely cold metals function as such good conductors. From 1954 to 1957, he served on the Council for the American Physical Society, and was president from 1968 to 1969. In 1954, Bardeen was elected to the National Academy of Sciences, and then the National Academy of Engineering in 1972. In 1972, he was awarded a second Nobel Prize for this work on the BCS (Bardeen, Cooper, and Schrieffer) theory; he would share this award with fellow colleagues Leon Cooper, J. Robert Schrieffer, and Bob Schrieffer. Bardeen consulted for Xerox, General Electric, and other companies interested in applying theoretical physics to technology. He was a founding member of the Commission on Very Low Temperatures of the International Union of Pure and Applied Physics, serving as chairman from 1969 to 1972. He remained active at the University of Illinois for the rest of his career and was still involved in the scientific community when he died in 1991.

Bardeen also served on the President’s Science Advisory Committee from 1959 to 1962, and on the White House Science Council in the early 1980s. His honors included the Stuart Ballantine Medal in 1952, the Buckley Prize in 1954, the John Scott Medal in 1955, the Fritz London Award for low temperature physics in 1962, the Vincent Bendix Award of the American Society for Engineering Education in 1964, National Medal of Science in 1965, the Medal of Honor of the Institute of Electrical and Electronic Engineers in 1971, the James Madison Medal of Princeton University in 1973, the Presidential Medal of Freedom in 1976, and the Lomonosov Prize from the Soviet Academy of Sciences in 1987. He received 16 honorary degrees and was elected to the National Academy of Sciences, the National Academy of Engineering, and the American Philosophical Society. In 1990, Bardeen was one of 11 recipients of the Third Century Award, honoring exceptional contributions to American creativity. He was also named by Life Magazine as one of the 100 most influential people of the century.
Dennis Gabor was born in Hungary on 5 June 1900. He studied electrical engineering first in Budapest, later in Berlin, where he finished his academic education with the award of Dr. Ing. in 1927, with his thesis on “The Recording of Transients in Electric Circuits with the Cathode Ray Oscillograph.” In this work, he was the first to use an iron-shrouded magnetic lens, and a bistable electronic circuit for the self-recording of transients. The last part of this work was done in the German Association for High Voltage Networks. Afterward, he joined the Siemens & Halske A. G. Berlin, where he started his long list of investigations on gas discharges and plasmas. The most far-reaching result of his six years with Siemens & Halske was his invention of the molybdenum tape seal, which is used to this day in high-pressure quartz-mercury lamps.

In 1934, Gabor left Germany. He went to the British Thomson-Houston Co. Research Laboratory (BTHCo) in Rugby, England, first on an inventor’s agreement, later as a member of the research staff. He spent 14 fruitful years at the laboratory. The low-pressure gas discharge lamp with a positive characteristic, which could be operated on the mains like an incandescent lamp, with which he started his work, was not a success, as it had insufficient life, but he was luckier with other inventions, such as a cathode ray tube with a memory, and finally with holography.

Holography is a photographic technique which creates a three-dimensional image. It was born as an attempt to improve the electron microscope. It was well known since 1936 that the resolving power of electron microscopes had to stop tantalizingly short of resolving atomic lattices, because the aperture of electron objectives could not be increased beyond a certain limit, owing to the spherical aberration which could not be corrected. Gabor considered the possibility of taking a bad picture first and correcting it by light-optical means. But in an ordinary electron microgram this is not possible, because one-half (the more important half) of the information has dropped out: the phase of the electron waves. Gabor thought, “of course the phase has dropped out, because there was nothing to compare it with. Let us see what happens if we put in a known wave, as a phase standard.” A little mathematical analysis showed that this would indeed work, one has only to superpose on the bad image, which is entirely unlike the true image, a coherent background, nowadays called a reference wave. Now, if one illuminates the bad picture with the coherent background, or a light-optical simulation of it, the true image will come out, because the original wavefront is reconstructed. Gabor termed the bad image a hologram, from the Greek holos or the whole, because it contained all the information. He then verified the theory, in 1948, by light-optical experiments with coherent light. These classic holograms are now well known and have been often reproduced.

Other work by Gabor during his time with the BTHCo was his theory of communication, which is now known as structural theory as distinguished from the Shannon-Wiener statistical theory. One result was what Gabor called the complex signal which has the same relation to the real signal as the phasor to a sine wave.

In 1949, Gabor joined the Imperial College of Science & Technology, first as a reader and associate professor of electronics, later as a professor of applied electron physics until 1967. During this time, he carried out nearly 20 mostly experimental investigations with his Ph.D. students. They cleared up the Langmuir Paradox, the surprisingly fast apparent establishment of Maxwellian distributions of electrons in a low-pressure plasma, which had worried Gabor for 25 years.

Though Gabor was always a passionate scientist and inventor, he was almost equally interested in social problems, and he was one of those people who could not help looking into the future. In his spare time, he wrote the book, Inventing the Future (1963) which has been translated into seven languages and influenced numerous futurologists. Gabor emphasized the normative approach; instead of extrapolating from present-day trends, which when continued long enough, are almost certain to lead to tragic conflicts. Instead, he hoped people would invent in broad lines as possible and desirable future and steer towards it.
Transistors & Semiconductors

Transistors

Today, when we refer to electronics, we are usually referring to things containing transistors. Transistors are devices that switch electric currents on and off or amplify electric currents. They use specially prepared substances to do this, and are used individually or in clusters of up to several million on integrated circuits. The transistor got its start in the 1940s, when engineers began looking for a replacement for the electron tube, an earlier device for amplification and switching. The electron tube was based on the light bulb, so it was large, fragile, and created excess heat.

The inventors of the point-contact germanium transistor were John Bardeen and Walter Brattain, who worked under William Shockley, at Bell Telephone Laboratories in New Jersey. In 1939, Brattain and Shockley worked together on an electron tube replacement made of the chemical element germanium, a semiconductor. Germanium and other semiconductors had been used for many years in point-contact diodes, which consist of a small sample of semiconductor crystal with a permanent electrical connection at one end and an adjustable connection at the other. When the “cat's whisker” is adjusted correctly, the diode acts as a one-way valve for electric current. Brattain and Shockley believed that they could modify the diode and regulate the current similar to how the grid in an electron tube regulates current. The device did not work, however Brattain and Bardeen returned to the idea in the mid-1940s, finding a new way to connect the germanium crystal to a circuit that allowed it to amplify current.

After a little brainstorming and an office poll, the new device was named the “transistor,” which was short for “transfer resistor.” The point-contact transistor, as it was called, worked, but not very well. It was difficult to make and the early models often failed unexpectedly. Shockley suggested a new design almost immediately, which became known as the junction transistor. A junction transistor consists of a single piece of semiconductor crystal, into which chemical impurities have been introduced to create three chemically different regions. The transitions between the regions are known as junctions. The impurities and junctions change the way the crystal conducts electricity. By sandwiching the three different layers, the middle layer can be electrically stimulated so that it affects the flow of electricity from the top to the bottom layers. It acts like a tiny hand on an electrical spigot. The first germanium junction transistors were introduced around 1950, and engineers quickly developed many different ways of making them so that they were less expensive, more useful, and easier to make in large quantities.

The military began using junction transistors almost immediately in airplanes and missiles, where engineers were trying to squeeze in complicated communication and guidance systems. Transistors were perfect for these military systems, because they were much smaller and used much less electrical current than vacuum tubes. Soon, they were used in hearing aids, portable radios, and all sorts of other electronic devices.

Bardeen, Brattain, and Shockley were awarded the Nobel Prize in Physics in 1956 for their groundbreaking work. Shockley went on to become an entrepreneur in the transistor manufacturing business, while Bardeen...
Semiconductors have a unique atomic structure that allows their conductivity to be controlled by stimulation with electric currents, electromagnetic fields, or even light.

Semiconductors

The semiconductor is one of the most common—but least understood—terms in the tech world. Simply defined, semiconductors are generally certain elements (such as silicon) and chemical compounds (such as lead sulfide) that allow but still resist the flow of electricity. Somewhere between good conductors, such as copper, and poor conductors, such as glass, lie semiconductors, which are just fair conductors. So, why is it important?

Semiconductors have a unique atomic structure that allows their conductivity to be controlled by stimulation with electric currents, electromagnetic fields, or even light, making it possible to construct devices from semiconductors that can amplify, switch, convert sunlight to electricity, or produce light from electricity.

In electronics, the usefulness of semiconductors stems from the structure of the atoms that make up semiconductor crystals. For example, a silicon atom has four electrons in its outer orbital (the top “shell” of orbiting electrons). When heated to the melting point and refrozen, silicon atoms tend to form organized crystal structures or lattices. In a process called doping, phosphorus or arsenic atoms are mixed into the silicon. This disturbs the silicon’s structure, giving the resulting crystal extra electrons. The crystal is changed from a fair conductor to a good conductor. Since electrons carry a negative charge, this type of crystal with extra electrons is known as an N-type or N-doped semiconductor.

Doping the crystal with boron or gallium also turns the crystal into a conductor, but doing so results in a shortage of electrons. Physicists say the crystal has holes, which make the crystal positive or P-type. When N-type and P-type crystals unite, the junction acts as a barrier to the flow of electricity in one direction but presents almost no resistance in the other direction. This one-way valve can be used in an electronic device called a diode. A diode is like a door that only swings one way—you can go out, but you can’t go back in.

Around the middle 1950s, engineers discovered that junction diodes made from a material called gallium arsenide emitted light (although it was only much later that usable lasers and LEDs were made this way). Free electrons traveling through a semiconductor crystal have a fairly high level of energy, so they are said to be in the conduction band. When an electron meets a hole in the crystal (where an electron would normally be), it tends to stay there. When a free electron “falls in,” it releases energy in the form of a photon of light. When the energy difference or band gap between the high conduction band state and the lower state is small, as it is in silicon, the light is released at the invisible infrared frequencies. When the band gap is large, the emission is visible light. This happens in all types of diodes, but in an ordinary silicon diode, the silicon itself absorbs most of the light. Light emitting diodes are constructed so that most of the light radiates outward. The device is usually mounted in a small reflector cup to help direct the light, and the whole assembly is packaged in translucent plastic.

A semiconductor laser diode, like the kind in a DVD, uses much the same principle, but with special materials to create a larger band gap. A laser diode uses heterostructure, junctions of two different types of semiconductor materials, chosen so that the band gap is very large. The device also uses mirrors and other means to reflect light emitted from the junctions in order to stimulate the laser effect.

While a semiconductor diode is the simplest type of electronic device, semiconductors are also used to make transistors, integrated circuits, and many other types of electronic devices.
Edward L. Ginzton
(27 December 1915 – 13 August 1998)

For his outstanding contributions in advancing the technology of high power klystrons and their application, especially to linear particle accelerators.

Edward L. Ginzton was born on 27 December 1915, in Russia. He emigrated to California from China in 1929, a refugee from the Russian Revolution. He was 13 years old, could not speak a word of English, and had only one year of formal schooling.

During the next eight years, he completed a curriculum that began with the first grade and culminated with a B.S. in 1936 and a M.S. in 1937, both in electrical engineering from the University of California at Berkeley. He continued his studies with graduate work at Stanford University in electrical engineering in 1938 and a Ph.D. in physics in 1940. It was during this latter period that he met the Varian brothers, inventors of the klystron amplifier tube. The Varian brothers and Professor William W. Hansen asked him to work in the physics department to help explore the characteristics of the new tube and determine the range of its usefulness, as well as to develop methods of making microwave measurements.

With the Varian-Hansen group in 1941, Ginzton joined the research laboratories of the Sperry Gyroscope Company in Garden City, New York, where he remained throughout the war, successively becoming an assistant project engineer and research engineer in charge of microwave research, from 1942 to 1945, and head of microwave research and tube research laboratories from 1945 to 1946.

In 1946, Ginzton returned to Stanford University where he became professor of applied physics and electrical engineering. He developed klystron tube technology to the point of obtaining millions of watts of pulsed power, and this led to what is probably the outstanding accomplishment in his career. The first tube operated successfully in 1949, developing 25 million watts of pulsed power at a wavelength of 10 centimeters. For his work in this field, Ginzton was awarded the Morris Liebmann Memorial Prize in 1957. From 1949 to 1959, he was director of the university's microwave laboratory.

In parallel with the klystron work, Professor Hansen developed the theory of the electron linear accelerator and proposed construction of a billion volt version, 220 feet in length, powered by 22 of the high power klystrons. Hansen died before this project was started and it became Ginzton’s responsibility to complete the work, which was done in 1952. Perhaps the greatest demonstration of usefulness of this accelerator was its use by Professor Robert Hofstadter in measuring the size and charge distribution of a number of nuclei, the work for which Hofstadter was awarded the 1961 Nobel Prize in Physics.

In addition to teaching and other academic responsibilities, Ginzton supervised the construction of other microwave linear accelerators. In 1956, he became director of a group of Stanford physicists and engineers who began to study the practicality, usefulness, and costs of an accelerator two miles in length. Under his supervision, the preliminary design of the accelerator was completed, and the project received U.S. Congressional approval in 1961. The two-mile device at the Stanford Linear Accelerator Center (SLAC) was completed in 1966 and is being used for research as the highest energy electron accelerator in the world.

Prior to Congressional approval of the two-mile accelerator, Ginzton was asked to become chairman of the Board of Varian Associates. Two years later, in 1961, with approval of the project assured, he chose to continue his work at Varian and left the Stanford project. In 1965, Ginzton was elected to the National Academy of Engineering and in 1966 he was elected to the National Academy of Sciences. Ginzton wrote many papers in the field of electronics and microwaves, and published a text in his field. He was the sole or joint holder of approximately 50 patents in the field of electronics and microwave devices.
Gordon Kidd Teal was born in Dallas, Texas, on 10 January 1907, and educated in the Dallas School System. He earned the B.A. in mathematics and chemistry with honor at Baylor University in three years. He then entered Brown University for graduate study leading to the M.S. and Ph.D. His thesis involved studies and investigation of the chemical-electrical properties of germanium.

In 1930, Teal began his career of creative research and innovation at Bell Telephone Laboratories at the invitation of Drs. R.R. Williams and Robert M. Burns. His personal research resulted in 45 patents and a number of key papers on the preparation and control of electronic materials in order to achieve and understand reproducible physical properties of scientific and technological significance. He is best known for the results of his research in germanium and silicon and in particular for the preparation of the first high-purity, high-perfection, single-crystalline germanium for transistor use. He was a co-developer of the first junction transistor. As stated by William Shockley (Nobel Laureate, 1956), “There was probably no more important scientific development in the semiconductor field in the early days following the announcement of the transistor than the development of high-quality single crystals of germanium at Bell Telephone Laboratories.”

During the depression years from 1932 to 1935, Teal took advantage of the reduced hours at Bell to become research associate to Harold C. Urey (Nobel Laureate in Chemistry) at Columbia University. One of the results was a review of all research on heavy hydrogen published with Urey.

In 1953, Teal joined Texas Instruments (TI) partially to return to his hometown and partially to found and build TI’s Central Research Laboratories. Best known developments under his direction are the first commercial silicon transistor (1954) and a chemical reduction process for ultra-pure silicon (1957). According to opinions summarized in Fortune (November 1961), “The silicon transistor was a turning point in TI’s history. TI sales rose almost vertically; the company was suddenly in the big leagues.” Other developments included digital signal processing for oil exploration and infra-red detectors. These were of major importance to the nation’s economy and security as well as TI’s economic welfare. Teal was particularly proud of the outstanding talent recruited and developed and their subsequent impact on TI. Teal became international technical director for TI during 1963 and 1964 thereby fostering their growth as an international company. He resided in England, France, and Italy and was most active in their scientific and industrial life.

In 1965, Teal took a leave of absence from TI to become the first director of the National Bureau of Standards Institute for Materials Research in Washington, D.C. He introduced an imaginative and lively interpretation of government’s planning system (PPBS) as applied to science, and took unique steps to expose the managerial talent under him to high level personnel in successful U.S. corporations.

Teal resumed his position at TI and was vice president and chief scientist for corporate development from 1968 until 1972, the year he retired. Afterward, he served as a consultant.

Teal held most chairs at the Institute of Radio Engineer (IRE) Dallas Section and helped create DIRECTION Magazine. He was a major contributor to the merger of the American Institute of Electrical Engineers (AIEE) and IRE. He served as a director and president of Texas Academy of Science and as chairman of the board of the Council of Scientific Societies of Dallas-Fort Worth area which he was instrumental in creating.
Charles H. Townes
(28 July 1915 – 27 January 2015)

For his significant contributions in the field of quantum electronics which have led to the maser and the laser.

Charles Hard Townes was born in Greenville, South Carolina, on 28 July 1915. He attended Furman University in Greenville, where he completed the requirements for the B.S. in physics and the B.A. in modern languages, graduating summa cum laude in 1935, at the age of 19. Physics had fascinated him since his first course in the subject during his sophomore year in college because of its "beautifully logical structure." He was also interested in natural history while at Furman, serving as curator of the museum, and working during the summers as a collector for Furman’s biology camp. Townes completed work for the M.A. in physics at Duke University in 1936, and then entered graduate school at the California Institute of Technology, where he received the Ph.D. in 1939 with a thesis on isotope separation and nuclear spins.

A member of the technical staff of Bell Telephone Laboratories from 1933 to 1947, Townes worked extensively during World War II in designing radar bombing systems and has a number of patents in related technology. From this, he turned his attention to applying the microwave technique of wartime radar research to spectroscopy, which he foresaw as providing a powerful new tool for the study of the structure of atoms and molecules and as a potential new basis for controlling electromagnetic waves.

At Columbia University, where he was appointed to the faculty in 1948, he continued research in microwave physics, particularly studying the interactions between microwaves and molecules, and using microwave spectra for the study of the structure of molecules, atoms, and nuclei. In 1951, Townes conceived the idea of the maser, and a few months later he and his associates began working on a device using ammonia gas as the active medium. In early 1954, the first amplification and generation of electromagnetic waves by stimulated emission were obtained. Townes and his students coined the word maser for this device, which is an acronym for microwave amplification by stimulated emission of radiation.

In 1958, Townes and his brother-in-law, Dr. Arthur L. Schawlow, showed theoretically that masers could be made to operate in the optical and infrared region and proposed how this could be accomplished in particular systems. This work resulted in their joint paper on optical and infrared masers, or lasers (light amplification by stimulated emission of radiation). Other research was in the fields of nonlinear optics, radio astronomy, and infrared astronomy. He and his assistants detected the first complex molecules in interstellar space and first measured the mass of the black hole in the center of the galaxy.

Having joined the faculty at Columbia University as associate professor of physics in 1948, Townes was appointed professor in 1950. He served as executive director of the Columbia Radiation Laboratory from 1950 to 1952 and was chairman of the physics department from 1952 to 1955. From 1959 to 1961, he took a leave of absence from Columbia University to serve as vice president and director of research for the Institute for Defense Analyses in Washington, D.C., a nonprofit organization which advised the U.S. government and was operated by 11 universities.

In 1961, Townes was appointed provost and professor of physics at MIT. In 1966, he became institute professor at MIT, and later in the same year, resigned from the position of provost in order to return to more intensive research, particularly in the fields of quantum electronics and astronomy. He was appointed university professor at the University of California in 1967. During 1955 and 1956, Townes was a Guggenheim Fellow and a Fulbright Lecturer, first at the University of Paris and then at the University of Tokyo. He was National Lecturer for Sigma Xi and also taught during summer sessions at the University of Michigan and at the Enrico Fermi International School of Physics in Italy, serving as director for a session in 1963 on coherent light. In the fall of 1963, he was Scott Lecture at the University of Toronto. He was the Karl Schwarzschild Lecturer in Germany and the Birla Lecturer and Schrodinger Lecturer in India.

In addition to the 1964 Nobel Prize in Physics, Townes has received the Templeton Prize, for contributions to the understanding of religion, and a number of other prizes as well as 27 honorary degrees from various universities.

Townes served on a number of scientific committees advising governmental agencies and was active in professional societies. This includes being a member and vice chairman of the Science Advisory Committee to the president of the U.S., chairman of the Advisory Committee for the first human landing on the moon, and chairman of the U.S. Department of Defense’s committee on the MX missile. He also served on the boards of General Motors and of the Perkins Elmer Corporations.
Claude Elwood Shannon’s realization that all information could be transmitted in a series of 1s and 0s laid the foundation for a revolution in the spread of information. He developed the mathematical theories and techniques that made possible the analysis of switching circuits, computers, and communications.

Shannon was born 30 April 1916, in Petoskey, Michigan, but grew up in Gaylord, Michigan, where he worked as a Western Union messenger boy while in high school, an educational step he took in three years.

At the University of Michigan, he did work in both electrical engineering and mathematics and received the B.S. in both fields in 1936.

During summers while in college, he repaired radio sets in a Gaylord department store.

At school, he joined the Army Signal Corps Reserve Officers Training Corps and soon found himself busy developing new Army instruments, including a modulation meter, a code speed meter, and networks having any desired frequency-impedance characteristic. When he graduated, however, he was not yet 21 and had to wait to receive his Signal Corps reserve officer commission.

Shannon spent 1936 to 1940 at MIT, where, among other activities, he worked as a research assistant in the Department of Electrical Engineering in charge of operating the Bush mechanical differential analyzer, the precursor of modern analogue computers. In 1940, Shannon took his S.M. in electrical engineering and his Ph.D. in mathematics, both from MIT, both simultaneously again. In a master’s thesis which has proven critically important, he demonstrated that Boolean logic could be worked with electrical switching circuits. This thesis was meant to help the telephone industry move from human operators to complex switching circuits. However, the theory it expressed has been foundational to modern computing.

After receiving his Ph.D., he spent the next year at the Institute for Advanced Study at Princeton, then joined Bell Telephone Laboratories at Murray Hill, New Jersey, in what became a most fruitful and dynamic association. While he was often solitary in performing his own work, he was an invaluable help to colleagues when they faced challenges. He remained at Murray Hill until 1956 when he returned to MIT, first as visiting professor and, a year later, as professor of communications science. He was a member of both the Department of Mathematics and the Department of Electrical Engineering.

His most significant piece of work was “A Mathematical Theory of Communication,” published in two parts in the Bell System Technical Journal in 1947-1948. With this paper, Shannon laid down the theoretical foundation for communications engineering, a kind of thermodynamics of communications which, up to that time, had been missing. In opening a new mathematical field for engineering applications, Shannon’s work compares only to that of Norbert Wiener in the theory of time series and to that of Von Neumann and Morgenstern in the theory of games. Of equal importance was the impact of Shannon’s definitions, his model of the communications process, and his theory on scientists and engineers concerned with human communications. He was a principal pioneer in information theory and deserves much of the credit for the digital communication which is fundamentally important in our information age.

This mathematical theorist also found joy in creating mechanical automata. "I’ve always pursued my interests without much regard for financial value or value to the world," Shannon once told the IEEE Spectrum. “I’ve spent lots of time on totally useless things.” His rambling home overlooking Mystic Lakes in Winchester, Massachusetts, abounded with the products of his gadgeteering to the delight of young and old alike. In the living room was a player piano programmed with randomly cut music and supervised by a fully clothed department store mannequin. Also, there was the mouse that learns, a mechanical creature that, with the aid of a small computer, could find its way through a maze to a brass cheese. Outside were a host of mechanical devices, gadgets, and conveyances, including a camping bus, a complete bicycle shop, and a chair lift to carry visitors from the house down a steep embankment to the edge of the lake.
Electric Light

Since Edison’s invention of a practical incandescent bulb in 1879, electric lighting has been part of popular culture. For example, it was one of the great attractions of the world’s fairs in Chicago in 1893, in Buffalo in 1901, and in St. Louis in 1904. Electric lighting made cities inviting in the evening hours, giving Broadway the moniker the Great White Way. And it made homes brighter and livelier. Not surprisingly, in the early decades of the century, pop culture references to electric lighting were almost always positive. Take, for example, Charlie Chaplin’s 1931 movie City Lights, which celebrated electric lighting both indoors and outdoors.

Despite its popularity, the incandescent lamp was quite inefficient, so engineers sought alternatives. Work in the 1920s led to two new types of lamps that were significantly more efficient—the high-pressure mercury-vapor lamp and the low-pressure sodium-vapor lamp. Both lamps were especially suitable for street lighting, and both became widely used in the 1930s. So-called discharge lamps, their electric current flows from one electrode through a gas or a metal vapor to another electrode. The mercury-vapor lamp produced a bluish light, whereas the sodium-vapor lamp emitted a monochromatic, orangish light. The latter was more efficient and enjoyed widespread adoption in Germany and the Netherlands. In other countries, including the United States, England, and France, mercury-vapor lamps were preferred. The distaste for the poor color rendering of the sodium lamp was so great in the United States that some states outlawed its use for street lighting.

Neon lights, another type of discharge lamp, also became common in the 1930s. Movies have portrayed neon both positively and negatively. For example, in The Postman Always Rings Twice (1946) and On the Town (1949), neon lights are seen as modern and attractive, while in It’s a Wonderful Life (1946) and From Here to Eternity (1953), they are associated with tawdry and decadent parts of town.

Just before World War II, still another type of discharge lighting—fluorescent lighting—appeared. Researchers had long known that discharge lamps often emitted ultraviolet light. They also knew that certain minerals converted ultraviolet light to visible light in a process called fluorescence, the re-emission of light at lower frequencies. Many attempts to develop a practical lamp—placing fluorescent materials in reflectors behind the discharge tube, in a coating inside the tube, in a coating outside the tube, or within the glass itself—came to naught. Success finally came in the late 1930s, with improved lamp design and the discovery of fluorescent materials from which one could obtain white light—light having a distribution of frequencies similar to sunlight. Fluorescent lighting was featured at the 1939 New York World’s Fair. Fluorescent lights appear in movies from the 1940s on, but are seldom remarked upon, though they receive negative mention in Goodbye, Columbus (1969) and Clerks (1994).

For the past 70 years, incandescent and fluorescent
Since Edison’s invention of a practical incandescent bulb in 1879, electric lighting has been part of popular culture. Not surprisingly, in the early decades of the century, pop culture references to electric lighting were almost always positive.

Lights have dominated electrical lighting. The introduction of the compact fluorescent bulb in the 1970s was notable because it could be used in sockets designed for incandescent bulbs. And at the end of the century, an entirely new type of electrical lighting became economically important. Light-emitting diodes (LEDs) were invented in 1962, and soon found use as indicator lights and for instrument and computer displays. Great advances in LED technology in the 1990s led to their widespread use in large video screens and for lighting. Many movies, such as Hackers (1995) and Spider Man (2002), feature the huge video-screens in New York City’s Times Square. In the first years of the 21st century, LEDs began to be used in traffic lights, automobile taillights, and flashlights. In turning electricity into light, LEDs are significantly more efficient than incandescent bulbs. As the manufacturing cost of LEDs continues to decrease, they are increasingly replacing incandescent lights.
A native of Minnesota, Harold Alden Wheeler was born in St. Paul on 10 May 1903. His family lived in Mitchell, South Dakota, for some years, then in Washington, D.C. He graduated in 1925 from George Washington University with the B.S. in physics, and followed this with further studies at Johns Hopkins University until 1928.

During his early college years, Wheeler also engaged in part-time work at the Radio Laboratory of the National Bureau of Standards. Following this, he became associated with Professor Hazeltine at Stevens Institute of Technology in the development of the Neutrodyne receiver, which came into general use in the mid-1920s. In 1924, he was one of the original employees of the Hazeltine Corporation.

In 1925, Wheeler made the first receiver with diode automatic volume control and linear detector. This feature was rapidly adopted for general use. He was employed by the Hazeltine Corporation, Little Neck, New York, from 1924 to 1946, advancing to vice president and chief consulting engineer. From 1930 to 1939, he was in charge of the Hazeltine laboratory in Bayside, Long Island, engaged in the development of improvements in broadcast radio receivers for various manufacturers. From 1939, when the laboratory moved to Little Neck, Long Island, Wheeler was then concentrating on the problems of frequency modulation and television receivers. This work was recognized in 1940 by the Morris Liebmann Prize of the Institute of Radio Engineers (IRE).

During World War II, his principal responsibility was radar Identification Friend or Foe (IFF) equipment for the U.S. Navy; for this work he received the Navy’s Certificate of Commendation. Beginning in 1947, his principal occupation became president of Wheeler Laboratories, Inc., Great Neck, New York. The company was active in the development of microwave circuits and antennas, particularly for tracking and guidance radar in missile systems. The organization contributed particularly to the design of large phased-array antennas. In 1959, Wheeler’s company became a subsidiary of Hazeltine Corporation, and he was elected a director and vice president of the parent company, which was a major manufacturer of electronics equipment for military applications. Wheeler directed Hazeltine Corporation’s Great Neck and Smithtown laboratories, specializing in microwave and antennas.

After 1950, Wheeler served the government in various capacities as an expert consultant, and then as a member of the Defense Science Board. In addition, in his 40 years of activity in the radio engineering profession, Wheeler presented numerous scientific papers and published many articles in scientific periodicals, especially the *Proceedings and Transactions of the IRE*. He was awarded 180 U.S. patents and many foreign patents. In recognition of his inventions, he received one of the Modern Pioneer Awards from the National Association of Manufacturers in 1940.

A member of the IRE since 1927, Wheeler was promoted to Fellow in 1935, and a member of the Board of Directors in 1934 and again from 1940 to 1945. He was also promoted to Fellow in the American Institute of Electrical Engineers in 1946. He was the second chairman of the IRE Long Island Section, an associate member of the IET, a Fellow of the Radio Club of America, and a member of Sigma Xi and Tau Beta Pi.
The Merger of AIEE and IRE

The American Institute of Electrical Engineers (AIEE)

The International Electrical Exhibition hosted by The Franklin Institute was scheduled to take place in Philadelphia, Pennsylvania in September, 1884. Nathan S. Keith, an inventor and electrometallurgical engineer, wanted American professionals to form their own organization so that they could participate in the Exhibition on an equal footing with their international peers. Keith, along with Thomas Edison, Elihu Thomson, Edwin Houston, Edward Weston, and 20 other prominent leaders in the American electrical sciences, issued three published “calls” to create a national organization. Keith organized a formal meeting on 13 May 1884, at the American Society of Civil Engineers, the oldest American professional society founded in 1852, to “unite those involved in the art of producing and utilizing electricity.” The attendees drew up a charter and named themselves the American Institute of Electrical Engineers (AIEE). The first technical session of the newly formed AIEE was held at The Franklin Institute during the 10-day Exhibition. By far, the largest numbers of new members were inventor-manufacturers and corporate managers, but electrical engineers, electricians, professors, and instructors were well represented. Nine future presidents of the AIEE were among the Exhibition’s 89 American representatives.

Although early topics included telegraph and telephone communications, the challenges of electric power generation and the design of electric motors soon dominated the interests of the AIEE. The standardization of electrical units, definitions, and nomenclature were also top priorities. Edison’s legendary battle with Nikola Tesla and George Westinghouse regarding alternating versus direct current technologies grabbed headlines and fostered scientific research. Increasingly, communications technology was relegated to a secondary concern of the society.

The Institute of Radio Engineers

The creation of the world’s first professional association of radio engineers came just a few weeks after the historic sinking of the RMS Titanic on 14 April 1912. Radio signals carried the distress calls that saved more than 700 lives in the tragedy, and radio was now a hot topic. Efforts to form a new independent professional society serving radio engineers culminated on 23 August 1913 when the Institute of Radio Engineers (IRE) incorporated under the laws of New York. Robert H. Marriott became the first President. The first IRE meetings were held at Sweet’s Restaurant on Fulton Street in New York within blocks of at least 10 prominent radio companies. Membership in the new IRE quickly grew from 46 in May 1912 to 231 by January 1914. By the next year, 83 members were registered from foreign countries.

Merger of the AIEE and IRE

Through the help of leadership from the two societies, and with the applications of its members’ innovations to industry, electricity wove its way more deeply into every corner of life, through television, radar, transistors, and computers. Increasingly, the interests of the societies overlapped.

Membership in both societies grew, but beginning in the 1940s, the IRE grew faster and in 1957 became the larger group. On 1 January 1963, the AIEE and the IRE merged to form the Institute of Electrical and Electronics Engineers, or IEEE. At its formation, IEEE had 150,000 members, 140,000 of whom resided in the United States. The IRE’s former Medal of Honor, its highest award, was selected to be IEEE’s highest award in the field of electronics and electrical engineering. The IEEE also continues to present the Edison Medal, which remains the oldest award in the field of electrical engineering.

IRE Dinner at Luchow’s Restaurant in New York City in 1915.
Radio waves are said to be electromagnetic waves because they consist of variations in electric and magnetic fields. Electromagnetic waves can travel through the air, as they do when radio and television signals are broadcast, for example, or even in a vacuum. Electromagnetic waves can also travel along an electric wire. That’s what happens with telephone lines. There is a third and completely different way of transmitting electromagnetic waves: the waveguide. The person most responsible for developing waveguides was Bell Labs engineer, George Clark Southworth.

Southworth was born on 24 August 1890, in Little Cooley, Pennsylvania. He studied physics and received the B.S. from Grove City College in Pennsylvania in 1914, and did graduate work at both Columbia University in New York City and Yale University in New Haven Connecticut. Prior to World War I, Southworth began experimental work at Grove City College, and during the war, continued with research work at the National Bureau of Standards and at Yale University. He spent approximately one year working at the radio section of the National Bureau of Standards, and then in 1918, he became an instructor at Yale University. He studied radio waves of very short wavelength at Yale, completing a Ph.D. in 1923.

In 1923, he began his career with the Bell System, working for AT&T where he came to specialize in the transmission of very high frequency electromagnetic waves. He worked on transoceanic radio telephony and later with the early development of microwave techniques. It was for transmitting microwaves that Southworth developed waveguides. With transmission through the air, as in radio broadcasting, there is considerable wasted energy because the waves necessarily spread out to some extent. With transmission through wires there are significant losses, especially at the higher frequencies of microwaves. But a waveguide, essentially a hollow metal pipe, channels the microwaves effectively and reduces transmission losses by a factor of five or so.

The waveguides of Southworth became very important in radar systems during World War II. For his work in waveguides, he received the Morris N. Liebmann Prize of the Institute of Radio Engineers (IRE) in 1938, and the Stuart Ballantine Medal of the Franklin Institute in 1947. He received the Louis Levy Medal of the Franklin Institute for his work on microwave radiation from the sun in 1946.

In 1963, the IRE merged with AIEE, forming the IEEE. As the IRE and AIEE had each already selected recipients for their own awards, the 1963 Medal of Honor was given to both candidates. It was the only time that two Medals of Honor were given in one year.

George C. Southworth
(24 August 1890 – 6 July 1972)

For pioneering contributions to microwave radio physics, to radio astronomy, and to waveguide transmission.
John H. Hammond, Jr.
(13 April 1888 – 12 February 1965)

For pioneering contributions to circuit theory and practice, to the radio control of missiles, and to basic communication methods.

John H. Hammond, Jr. was born in San Francisco, California, on 13 April 1888. His father was a mining engineer whose work took him to South Africa, England, and several parts of the United States. Hammond frequently traveled with his father and also, through him, met such leading engineers as Thomas Edison, Guglielmo Marconi, and Alexander Graham Bell. While much of his education took place outside of formal setting, Hammond attended the Lawrenceville School in New Jersey, where he invented a circuit breaker that allowed him to duck the school's lights-out rules. He completed his formal education with a B.S. from Yale University in 1910. Hammond was given an honorary Sc.D. from George Washington University in 1919.

He started his career by working at the Patent Office in Washington, D.C. Interested in remote control, and possessing good access to start-up money, he founded the Hammond Radio Research Laboratory soon afterward. From 1912 until 1928, the Hammond Laboratory was in a building above the rocky Gloucester coastline in Massachusetts, where much pioneering work in radio was accomplished. Hammond received over 420 U.S. patents, which underlie much of modern electronic technology.

Hammond did extensive work for the U.S. military services starting in 1912 when the chief of Coast Artillery for the Army witnessed the successful radio control of a boat from shore in Gloucester. During both World Wars, the Hammond group developed radio and other remote-control systems applicable to waterborne and airborne missiles.

However, Hammond did not only work in remote control. Love of music fostered his experiments in the application of electronics to various other fields. In communications, the Hammond group contributed to development of the triode for amplification purposes, the i-m principle for selectivity, and of f-m techniques for broadcasting and telephony. Well known are the dynamic amplifier for expansion, compression, and noise reduction in audio systems; the accentor for improving the tonal performance of pipe organs; and the telespot for the momentary injection of a high-speed confidential facsimile service into a television channel with automatic reception, recording, processing, and display.

The value of Hammond’s inventions was well recognized. The U.S. government acquired rights in over 90 of these for radio-dynamic purposes and Radio Corporation of America (RCA) acquired rights in over 160 for radio-electronic purposes. Hammond’s interests beyond engineering both supplemented and intertwined with his scientific work. From 1928 on, Hammond worked at the Hammond Castle, a medieval castle-museum, complete with a moat, drawbridge, and towers that he had erected on his Gloucester coastline property. In the great hall of the castle is the magnificent 10,000-pipe organ designed by Hammond and built over a period of 20 years. The great hall has been used for recordings by some of the major record companies, and some of the greatest organists in the world have played there. The Hammond Castle also houses his impressive collection of art.

The list of Hammond colleagues, correspondents, and consultants over the years reads like a roster of the radio-electronic pioneers to include Lee de Forest, Nikola Tesla, George W. Pierce, Irving Langmuir, David Sarnoff. Harvard’s Dr. E. Leon Chaffee became a consultant to the Hammond Laboratory as early as 1918.
Edward V. Appleton was born on 6 September 1892, in Bradford, England. He studied under Sir J.J. Thomson and Lord Rutherford at St. John’s College, Cambridge University. After participation in World War I, he returned to Cambridge and devoted himself to research on radio waves. In 1920, he was appointed assistant demonstrator in experimental physics at the Cavendish Laboratory. Two years later, he became sub-lector at Trinity College. He received the D.Sc. from the University of London and became Wheatstone Professor of Physics there in 1924. In 1936, he returned to Cambridge as Jacksonian Professor of Natural Philosophy and, in 1939, was appointed to the post of secretary of the Department of Scientific and Industrial Research, the senior British Government post concerned with physical science.

In 1924, Appleton began a series of experiments which proved the existence of the ionosphere, a layer in the upper atmosphere. With the cooperation of the British Broadcasting Corporation (BBC), he applied FM to the Bournemouth transmitter and observed a beat between the signal reflected from what he later called the E layer and the outgoing signal, thus proving conclusively the existence of the ionosphere, as well as measuring its height. In 1926, he discovered an upper layer which he subsequently called the F layer, or Appleton layer. It is this layer, unaffected by atmospheric conditions, that allows the transmission of short-wave radio around the world.

Appleton’s findings had direct value to the British military during World War II. In a famous publication in 1932, he set forth the now classical magneto-ionic theory which quantitatively describes radio-wave propagation in the ionosphere. Further research provided the basis of the technique developed for aircraft detection. Sir Robert Watson-Watt has stated that, but for the scientific work of Appleton, radar would have come too late to have been a decisive influence in the Battle of Britain.

Even through the administrative phase of his life, Appleton continued to perform ionospheric research and to publish frequent accounts of new work. He produced more than 100 contributions to the literature on the ionosphere, not to mention numerous contributions in other fields, and was the editor of the Journal of Atmospheric and Terrestrial Physics. He retired from the secretarship of the Department of Scientific and Industrial Research in 1949 to return to the academic field, as principal and vice chancellor of the University of Edinburgh, a position he held for the rest of his life.

Appleton was the recipient of numerous awards, including the Nobel Prize in Physics, the U.S. Medal of Merit, the Norwegian Cross of Freedom, and appointment to the French Legion of Honor and to the Pontifical Academy of Science. He was a Fellow of the Institute of Radio Engineers.
Ernst A. Guillemin was born in Milwaukee, Wisconsin, on 8 May 1898. He received the B.S. from the University of Wisconsin, Madison, in 1922, and the S.M. in 1924 from MIT, both in electrical engineering. In 1926, he received the Ph.D. from the University of Munich, Germany, on the Saltonstall Traveling Fellowship. He returned to MIT as an instructor, becoming assistant professor in 1928, associate professor in 1936, and professor of electrical communications in 1944. He helped build his department’s communications program and taught linear, passive, lumped, finite, and bilateral networks. In 1941, he took on the administrative responsibilities of the communications option for the Department of Electrical Engineering. He was appointed to the Edwin Sibley Webster Chair of Electrical Engineering in 1960 and held the position until his retirement in 1963.

Guillemin was an excellent teacher. He had a gift for presenting even complex material to students and thus was able to bring subjects often saved for graduate study into undergraduate classrooms. He inspired many students who did well in their own right, including Sidney Darlington, William Hewlett, and Robert Fano. His lectures were famously interesting and his textbooks well written. He was the author of the volumes, *Communications Networks*, *Introductory Circuit Theory*, *Synthesis of Passive Networks*, and a reference work entitled, *The Mathematics of Circuit Analysis*.

Like many other engineers of his generation, Guillemin also helped with war efforts during World War II. In 1940, Guillemin was appointed consultant to the Microwave Committee of the National Defense Research Committee (NDRC). In this capacity, he devoted approximately half of his time to consultation with various groups in the Radiation Laboratory at MIT, on problems dealing with the design of electrical networks for special applications. Guillemin was awarded the President’s Certificate of Merit for his outstanding wartime contributions in 1948.

Guillemin was a member of the American Society of Electrical Engineers and a Fellow of the American Institute of Electrical Engineers and the American Academy of Arts and Sciences.
Harry Nyquist
(7 February 1889 – 4 April 1976)

For fundamental contributions to a quantitative understanding of thermal noise, data transmission and negative feedback.

Harry Nyquist was born on 7 February 1889, in Nilsby, Sweden. He moved to the United States in 1907. He attended the University of North Dakota, Grand Forks, from 1912 to 1915, and received the B.S. and M.S. in electrical engineering in 1914 and 1915, respectively. He attended Yale University in New Haven, Connecticut, from 1915 to 1917, and was awarded the Ph.D. in 1917.

From 1917 to 1934, Nyquist was employed by the American Telephone and Telegraph Company in the department of development and research transmission, where he was concerned with studies on telegraph picture and voice transmission. From 1934 to 1954 he was with Bell Telephone Laboratories, Inc., where he continued in the work of communications engineering, especially in transmission engineering and systems engineering. At the time of his retirement from Bell Telephone Laboratories in 1954, Nyquist was assistant director of systems studies.

During his 37 years of service with the Bell System, he received 138 U.S. patents and published 12 technical articles. His work ranged from thermal noise to signal transmission. The Nyquist sampling theorem postulates that the sampling rate must be at least twice the highest frequency in the sample in order to reconstruct the signal. His mathematical explanation of the thermal noise has also kept his name closely connected with the phenomenon. His work laid the foundation for modern information theory and data transmission, the invention of the vestigial sideband transmission system now widely used in television broadcasting, and the well-known Nyquist diagram for determining the stability of feedback systems.

After his retirement, Nyquist was employed as a part-time consultant engineer on communication matters by the Department of Defense, Stavid Engineering Inc., and the W. L. Maxson Corporation. Before his death in 1976, Nyquist received many honors for his outstanding work in communications. He was the fourth person to receive the National Academy of Engineer’s Founders Medal, in recognition of his many fundamental contributions to engineering. Nyquist was also awarded the Stuart Ballantine Medal of the Franklin Institute in 1960 and the Mervin J. Kelly award in 1961.

Nyquist paper in AIEE Transaction; Certain Topics in Telegraph Transmission Theory

Graphical interpretation of thermal noise in data transmission, Adobe Stock
Emory Leon Chaffee was born in Somerville, Massachusetts, on 15 April 1885. He received the B.S. in electrical engineering in 1907 from MIT. He then attended the Graduate School of Arts and Sciences at Harvard University where he received the M.S. in 1908 and the Ph.D., both in physics, in 1911.

In 1910, during his doctoral research, Chaffee discovered a method of producing the first coherent continuous electrical oscillations from 1 to 100 or more megacycles and applied them to radiotelephony. For this work, he was awarded the Bowdoin Prize at Harvard and the Longstretch Medal of Merit of the Franklin Institute.

He remained on the faculty of Harvard University until his retirement in 1953. Appointed instructor in electrical engineering in 1911, he progressed to assistant professor of physics in 1917, associate professor of physics in 1923, and professor of physics in 1926. He was appointed as Rumford Professor of Physics in 1940, and Gordon McKay Professor of Applied Physics in 1946. These last two appointments were continued as emeritus professorships after retirement.

His work also had concrete practical applications. In the 1920s, he had airplanes release charged grains of sand to disperse clouds over Washington, demonstrating weather control. During World War II, he directed research that resulted in better radar equipment and led a Harvard program.

During his 42 years of active research, Chaffee served as director of Cruft Laboratory from 1940, co-director of the Lyman Laboratory of Physics from 1947, chairman of the Department of Engineering Sciences and Applied Physics 1949-52, and head of wartime Pre-Radar Training Course for Officers of the three services.

He was awarded the honorary degrees of Doctor of Science from Harvard in 1944, and Doctor of Engineering from Case Institute of Technology in 1955. An early researcher in the theory of vacuum tubes, he published many papers in electronics, physics, and biophysics. He was author of two books and co-author of another.

Chaffee served as vice president of the Institute of Radio Engineers (IRE) in 1922. He was Fellow of the American Academy of Arts and Sciences, the American Physical Society, and the IRE.
Albert W. Hull was born on a farm in Southington, Connecticut, on 19 April 1880, and graduated from Yale University, where he majored in Greek and took one undergraduate course in physics. He taught languages at Albany Academy for a time before deciding to return to Yale, where he earned a Ph.D. in physics. He then taught physics for five years at the Worcester Polytechnic Institute while doing research on photoelectricity. He joined the staff of the General Electric Research Laboratory (GERL) in Schenectady, New York in 1914, remaining there until his retirement in 1949.

During 1916, Hull began experiments on the use of magnetic control of vacuum tubes as an alternative to grid or electrostatic control. In the 1918 issue of the Proceedings of the IRE, he published a paper on a vacuum tube which he had invented called the dynatron. The dynatron had three electrodes: a thermionic cathode, a perforated anode, and a supplementary anode or plate. In normal operation, the plate was maintained at a lower positive potential than the perforated anode. Hull explained that secondary emission of electrons from the plate caused the dynatron to behave as a true negative resistance. Thus, the tube could be used as an amplifier or could generate oscillations over a wide range of frequencies. If a control grid were added between the cathode and the perforated anode, the device became what Hull called a pliodynatron. In addition to grid control, he had tested successfully magnetic control by applying a magnetic field parallel to the axis of the tube. Initially, Hull's work on these novel electron tubes was part of an effort at General Electric to develop amplifiers and oscillators that might be used to circumvent the vacuum-tube triode patents of Lee de Forest and Edwin Armstrong.

By 1920, this research led to his invention of the magnetron, which took the form of a coaxial cylindrical anode and cathode with an axial magnetic field produced by an external coil. The Hull magnetron was tested as an amplifier in radio receivers and also as a low-frequency oscillator. It was reported in 1925 that a magnetron made at GERL could generate a power of 15 kW at a frequency of 20 kHz. At the time, Hull anticipated that the magnetron would find greater use as a power converter than in communication applications.

Hull also was a key participant in the development of gas-filled electron tubes at the GERL during the 1920s. In 1927, he discovered how to protect thermionic cathodes from rapid disintegration under ion bombardment. This enabled the successful development of a variety of hot-cathode thyratrons (gaseous triodes) and phanotrons (gaseous diodes). These devices were employed in such applications as synchronous torque amplifiers, thyratron motors, control of guns and machine tools, and direct-current power transmission.

Hull became assistant director of the GERL in 1928 and was known for his collegial management style with minimal interference with the research agenda of his staff members. He was elected a member of the National Academy of Sciences and served as president of the American Physical Society in 1942. He did consulting work and served on an advisory committee of the Army Ballistics Research Laboratories after retirement from General Electric.
Julius A. Stratton
(18 May 1901 – 22 June 1994)

For his inspiring leadership and outstanding contributions to the development of radio engineering, as teacher, physicist, engineer, author and administrator.

Born in Seattle, Washington, on 18 May 1901, Julius A. Stratton attended the University of Washington for one year until he went to MIT to obtain his B.S. in 1923 and M.S. in 1925. He then did graduate study in Grenoble and Toulouse, France, and the Technische Hochschule of Zurich, Switzerland, awarded him the degree of Doctor of Science in 1927. During the following year, he studied under a traveling scholarship from MIT, chiefly at Munich and Leipzig, Germany. Stratton joined the staff of MIT in 1928 to serve in the electrical engineering and physics departments for 20 years. In 1945, he was appointed director of the Research Laboratory of Electronics. He was named provost of MIT in 1949, and in 1951, he became vice president as well. In 1956, he was named to the newly created post of chancellor. As chancellor, Stratton administered the academic program of the institution, acted as deputy to the president, and served as general executive officer.

During World War II, he served as an expert consultant in the Office of the Secretary of War and was awarded its Medal for Merit in 1946. Stratton was a Fellow of the American Institute of Physics and the American Academy of Arts and Sciences, and a member of the American Philosophical Society and the National Academy of Sciences. He is an appointed trustee of the Ford Foundation, and one of the nine-member National Science Board of the National Science Foundation.

Stratton was the author of numerous technical papers and books on theoretical physics, especially electromagnetic theory. His many activities included membership on the Defense Science Board, the National Science Foundation Advisory Committee on Government-University Relations, and the Naval Research Advisory Committee.

He became an Institute of Radio Engineers (IRE) member in 1942, and a Fellow in 1945. He served on the Board of Directors from 1948-1951, and again in 1954. He headed the Radio Wave Propagation and Utilization Technical Committee from 1945 to 1948.

An anechoic shielded chamber used in electromagnetic experimentation, Adobe Stock
In 2009, the renowned classical music radio station, WQXR, which was the last commercial classical music radio station in the New York City area, sold its frequency and became part of the public radio network at a new frequency and at one tenth its former signal strength. Among WQXR's founders was former Institute of Radio Engineers (IRE) president John Vincent Lawless Hogan. Hogan was not only a prolific inventor who presided over some important developments in radio and facsimile, he was also a crucial early leader who shaped the IRE, and thus IEEE's, institutional history.

He was born in Philadelphia, Pennsylvania, on 14 February 1890, and was raised in New York, where he attended the Horace Mann School. As a teenager, he was a radio amateur and worked as an assistant to Lee de Forest. He studied electrical engineering at Sheffield Scientific School at Yale University, where he earned honors in physics and mathematics, and in 1909 became a telegraph engineer for Reginald Fessenden’s National Electric Signaling Company. He was the chief of the operating, erection, and inspection department of the company during the extremely important long-range radio tests using the U.S. Navy’s then new Arlington wireless station and the cruiser USS Salem, which were carried out during the winter of 1912-1913. The Salem sailed from the Delaware River east across the Atlantic Ocean to Gibraltar. The transmitting station at Arlington possessed high-power spark-gap as well as electric-arc dischargers, and it sent test messages to the ship alternately using one type then the other. By the time the Salem reached a distance of 1,200 miles (1,920 km), signals from the arc were beginning to be stronger than the ones from the spark. Moreover, the messages sent via arc could be heard at Gibraltar, 6,400 km away, during the hours of daylight. The experiments confirmed the Austin-Cohen formula for radio wave propagation and showed the feasibility of continuous wave transmission over very long distances.

Hogan had been a founder of the Society of Wireless Telegraph Engineers, and he helped preside over its merger with the Wireless Institute in 1912. This was the merger which formed the Institute of Radio Engineers (IRE), one of IEEE’s predecessor bodies. Hogan went on to become a Fellow of the IRE, and in 1920, became its president. During the 1920s, he experimented with television, radio, and facsimile transmission. In 1921, he went into business for himself as the president of Hogan Laboratories, Inc., a consulting firm advising on the construction of radio stations and inventions in radio and facsimile. He developed a facsimile transmission system for a four-column newspaper page, with illustrations, at a rate of 500 words per minute. During World War II, Hogan served as special assistant to Vannevar Bush, head of the Office of Scientific Research and Development. He worked on communications for the National Defense Research Committee and the Army Signal Corps, principally with radar, guided missiles, and proximity fuses.
Harald T. Friis was born on 22 February 1893, in Næstved, Denmark, and graduated in electrical engineering from the Royal Technical College in Copenhagen in 1916. He then spent about two years at the Royal Gun Factory in Copenhagen. In 1919, he received a fellowship which enabled him to come to the United States where he studied radio engineering at Columbia University under John H. Morecroft. In 1920, Friis joined a research group headed by Edwin H. Colpitts at the Western Electric Company, a group which became part of Bell Laboratories in 1925.

Friis initially was assigned to investigate radio reception from ships at a station in Elberon, New Jersey. He designed a double-detection superheterodyne receiver and undertook a long series of measurements of field strength and noise over a wide range of frequencies. He developed techniques to compensate for signal fading and used oscillographs to determine phase differences and other propagation phenomena. He and two colleagues published an important Institute of Radio Engineers (IRE) paper on radio transmission measurements in 1923. They stressed the need to measure signal to noise ratio rather than field strength alone and discussed how to achieve satisfactory radio communication while minimizing equipment cost.

Friis published further results of his research in his December 1925 IRE paper on directional antennas, in a 1926 paper on the static recorder in the Bell System Technical Journal, and in a May 1928 IRE paper on oscillographic observations.

Friis assisted in the design of the receiving system used by his colleague, Karl Jansky, to detect and record galactic radio noise in the early 1930s. These observations launched the new science of radio astronomy. Friis and Edmond Bruce were co-inventors of the rhombic antenna which came into wide use as a shortwave antenna. Friis subsequently designed a multiple-unit steerable antenna (MUSA), which employed an array of rhombics and was altered for optimum reception of shortwave signals. He received the Morris N. Liebmann Award of the IRE in 1939 in recognition of his many contributions to radio science and engineering.

In 1938, Friis became the director of a research team at the Holmdel laboratory facility of Bell Labs with the mission of developing microwave systems. He and a colleague, Alfred C. Beck, designed a horn-reflector antenna which became widely used. The Holmdel group went on to develop both microwave radar and communication equipment used by the military during World War II. Friis invented an ingenious rocking horse mechanical scanner for a radar set used to locate enemy mortars. In a May 1946 IRE paper, he disclosed a radar transmission formula which had proven useful to the group at Holmdel. A microwave relay network based on their work was installed for commercial use in the U.S. soon after the war.

Friis was also widely recognized for his leadership skills. He did not seek attention and thus often did not gain acclaim for his own important work. He was a more natural collaborator and his assistance to others was deeply appreciated. His work as a teacher and supervisor was seen as invaluable; conversations with Friis frequently helped other engineers sharpen their work and make great progress.

In 1954, Friis received the Valdemar Poulsen Medal of the Danish Academy of Sciences. He also received the Ballentine Medal from the Franklin Institute in 1958 and the Mervin Kelly Award of the IEEE in 1964. He retired from the Bell Labs in 1958 but continued work as a research consultant to the Hewlett-Packard Company for the next decade. His autobiography, entitled Seventy-Five Years in an Exciting World, was published by the San Francisco Press in 1971.
William Litell Everitt was born on 14 April 1900, in Baltimore, Maryland. During World War I, he served in the U.S. Marine Corps from 1918 to 1919. At the war’s conclusion, he matriculated at Cornell University, where he taught electrical engineering from 1920 until he received the E.E. degree in 1922. In that year, he joined the North Electric Manufacturing Company of Galion, Ohio, as engineer in charge of the design and development of their relay automatic public switchboard exchanges.

He left North Electric Manufacturing in 1924 to teach electrical engineering at the University of Michigan. In 1926, the year in which he received the M.A. from Michigan, he transferred to Ohio State University to take charge of their communications engineering staff in the capacity of assistant professor. During the summers from 1925 to 1930, Everitt served with the Department of Development and Research of the American Telephone and Telegraph Company.

Joining the Institute of Radio Engineers (IRE) as an associate member in 1925, he became a member in 1929, and also was elevated to the rank of associate professor at Ohio State in that year. In 1933, he received the Ph.D. and was promoted to a full professorship. At Ohio State, he originated and directed the annual Broadcast Engineering Conference, in which the IRE participated. He became a Fellow of the IRE in 1938.

In 1940, Everitt was appointed a member of the Communications Section of the National Defense Research Committee. Two years later, he took a leave of absence from the university to serve as director of operational research with the U. S. Army Signal Corps.

He was appointed head of the University of Illinois electrical engineering department in absentia 1943, and at the war’s conclusion he took up his duties there. He was dean of the University of Illinois’ engineering college from 1949 until 1968. His interest in and accessibility to students was much praised by colleagues. At the time of his retirement, a teaching award was named in his honor. He was the first recipient.

Everitt was the author and editor of numerous texts and articles on electrical engineering, including the widely used *Communications Engineering*. Everitt consulted for various broadcast stations and radio manufacturing companies. He also invented several devices, including a radio altimeter and automatic telephone equipment. He was president of the IRE in 1945.

In 1954, Everitt was appointed 2.5 million for his distinguished career as author, educator and scientist; for his contributions in establishing electronics and communications as a major branch of electrical engineering; for his unselfish service to his country; for his leadership in the affairs of The Institute of Radio Engineers.
John Milton Miller was born in Hanover, Pennsylvania. He graduated from Yale University in 1915 with a Ph.D. in physics. From 1907 to 1919, Miller was a physicist with the National Bureau of Standards, and from 1919 to 1923, a radio engineer at the Radio Laboratory, Air Station, Navy Department in Washington, D.C. He then joined the Naval Research Laboratory (NRL) in the Office of Naval Research, as a radio engineer. During the period from 1925 to 1936, he was in charge of radio receiver research at the Atwater Kent Manufacturing Company in Philadelphia, Pennsylvania, and from 1936 to 1940, he was assistant head of the research laboratory for the RCA Radiotron Company.

Returning to NRL in 1940, Miller subsequently became superintendent of Radio I Division in 1945, was named associate director of research in 1951, and then was appointed scientific research administrator in 1952. During this latter period, he continued to act as superintendent of Radio I Division at the laboratory. Miller has served as a patent expert with the government and has been issued more than 20 patents of his own in the radio field. His inventions include fundamental circuits for quartz crystal oscillators. He collaborated in the perfecting of crystals cut to have zero temperature coefficient, and the designing of the first high-powered crystal-controlled radio transmitter. Miller was awarded the Distinguished Civilian Service Award in 1945 for initiation of the development of a new flexible radio-frequency cable urgently needed in radio and radar equipment which solved a desperate material shortage in the United States during World War II, a well-deserved honor.
Walter Ransom Gail Baker was born in Lockport, New York, in 1892. He received his B.S. in 1916, and M.S. in 1919, both in electrical engineering from Union College in Schenectady, New York.

He took a job with General Electric (GE) in 1916, and worked on radio apparatus for military applications during the first World War. As a member of the radio engineering department at GE during the early 1920s, he contributed to the design of radio broadcast transmitters including station WGY in Schenectady. In 1929, he was selected to be production manager for a Radio Corporation of America (RCA) manufacturing plant in Camden, New Jersey, but he returned to GE in 1935 as the manager of its radio-television facility in Bridgeport, Connecticut. He was named a GE vice president in 1941.

Baker served as director of the engineering department of the Radio Manufacturers Association (RMA) in the 1930s. The RMA established two television committees to prepare reports on standards and frequency allocation for FCC hearings held in June 1936. Donald G. Fink has described the work of these two committees as being “the first major step in television standardization in the United States.” Several of their recommendations, including those for channel width, aspect ratio, and frame rate, survived as part of the National Television System Committee (NTSC) standards adopted in 1941. The 441-line picture recommended by the RMA committee in 1936, however, was changed upward to 525 lines by the NTSC.

In the face of disagreement among RCA and its competitors, including Zenith, Philco, and Dumont, over proposed standards, the Federal Communications Commission (FCC) in May 1940 announced that it would be prepared to authorize full commercialization of television “as soon as the engineering opinion of the industry is prepared to approve any one of the competing systems of broadcasting as the standard system.” After a meeting with the FCC chairman, James L. Fly, Baker agreed to organize and chair the NTSC in an effort to reach a consensus. Over the next several months, 168 members devoted 4,000 hours to meetings and compiled 600,000 words of reports and minutes. At its final meeting on 8 March 1941, the NTSC changed its recommendation on the number of lines from 441 to 525. This was a compromise between the 441 lines favored by RCA and 800 lines preferred by the Philco Corporation. The NTSC standards became the basis for an explosive growth in the industry after World War II, and there were approximately 31 million monochrome television receivers and 416 transmitting stations in the United States by November 1954.

Baker served as president of the Institute of Radio Engineers (IRE) in 1947 and then chaired the second NTSC from January 1950 until its final meeting in July 1953. The FCC adopted this committee’s recommended standards for compatible color television and authorized commercial broadcasting under these standards beginning in January 1954. Baker became interested in the educational potential of television and published a paper on the subject in 1954. He contended that the pace of technological change had tended to overwhelm the educational system and that television might be used to facilitate learning because of its visual impact.

The War Department cited Baker for his assistance in the design and production of radio and radar equipment. He also worked with the military during the Korean War. He was awarded the Army Medal of Freedom in 1953.

Baker served as president of the Electronic Industries Association, which in 1953 voted him its Medal of Honor. An IRE Fellow, he served on many IRE and technical committees. He received the IRE Founders Award, which is given only on special occasions to outstanding leaders in the radio industry, in 1958. Baker, the fourth winner of this award, received it for outstanding contributions to the radio engineering profession through wise and courageous leadership in the planning and administration of technical developments which have greatly increased the impact of electronics on the public welfare.
By the 1970s, the oft-called Father of Television, Vladimir Zworykin had parked his 21-inch RCA TV in the corner of a room and rarely turned it on. He was not fond of the shows. But without him, we would not have TV as we know it today. In 1924, he created the iconoscope, the first practical, all-electronic television camera tube. In 1929, he invented an important part of the receiver called the kinescope, a cathode-ray picture tube. Zworykin’s work moved television away from mechanical systems and his contributions to electronic television are immense.

Zworykin was born in Russia on 30 July 1889. He was interested in television his entire career. As a young engineering student, he worked for physicist Boris Rosing who was trying to send pictures through the air. In 1919, following the Russian Revolution, Zworykin moved to the United States. He worked at Westinghouse Electric Corporation in Pittsburgh, Pennsylvania. In 1929, when Zworykin didn’t get the support or encouragement he needed to build electronic televisions, he moved to RCA. With the strong support of RCA’s head David Sarnoff, another Russian immigrant, Zworykin continued developing electronic television. His all-electronic television system was introduced to the public at the 1939 World’s Fair in Queens, New York.

Zworykin’s and RCA’s work was directly challenged by the patent claims of Philo T. Farnsworth who also worked on electronic television. Farnsworth won a major patent suit against RCA in 1939 and Zworykin’s designs for electronic TV would not be considered the first. Despite the legal battle, Zworykin’s contributions to television were great. And while some may have called him the Father of Television, Zworykin always said that television was the creation of hundreds of inventors and researchers. Zworykin’s own contributions were recognized by the AIEE who awarded Zworykin its Edison Medal in 1952, for outstanding contributions to the concept and design of electronic components and systems.
Frederick E. Terman is viewed as one of the founding fathers of Silicon Valley. He is also the author of *Radio Engineering*, which would become an important textbook for the profession.

Born in English, Indiana, on 7 June 1900, Terman was educated at Stanford University, where he received the B.A. in chemistry in 1920 and M.S. in electrical engineering in 1922. In 1924, he was given the D.Sc. in electrical engineering by MIT, where he studied with Vannevar Bush. It was only the eighth Ph.D. awarded at MIT.

Terman joined the electrical engineering faculty of Stanford in 1925 as an instructor and by 1942 had become full professor and executive head of the electrical engineering department. Some of his most notable achievements came as an educator and administrator, though his work as a researcher in radio engineering was also very successful. During this early part of his career at Stanford, he taught David Packard and William Hewlett and encouraged them both in their research and in their desire to start a business together.

In 1932, Terman published the seminal textbook, *Radio Engineering*. There were four editions of this textbook. It would become the bible for the profession. In 1943, he followed the success of this work with his publication of a handbook for radio engineers.

At the outbreak of World War II, Bush asked Terman to come work in Massachusetts. From 1942 to 1945, he directed the Harvard University Radio Research Laboratory, which was associated with MIT’s Radiation Laboratory. The main work of the laboratory was research and development of radar countermeasures and it had a staff of 800, though it also worked closely with industrial contractors. Terman’s efforts to support war efforts led to his being decorated by the British government and receiving the Presidential Medal of Merit in 1948.

Returning to Stanford in 1945, he was appointed dean of the School of Engineering. After the war, he took steps to unite Stanford’s interests with those of private companies. When Stanford set up some vacant land as an industrial park, he courted technology corporations as tenants, hoping to assist Stanford graduates in finding jobs. Hewlett-Packard, General Electric, and Kodak moved in and made Stanford Research Park one of the most successful such sites in the world. As a result, Terman is viewed as one of the founding fathers of Silicon Valley.

Terman also continued to actively support research work at the university. While he was there, Stanford became involved in investigations with traveling wave tubes and emerged as a leader in academic work in electronics. Terman advanced through the ranks at Stanford. Upon his retirement in 1965, he was provost and vice president.

The president of the Institute of Radio Engineers (IRE) in 1941, Terman was also a member of the American Institute of Electrical Engineers (AIEE), the American Physical Society, the American Society for Engineering Education, and the National Academy of Sciences. He was one of the 25 founding members of the National Academy of Engineering in 1946. Terman was the author of a number of books and technical papers on radio. His son, Lewis Terman, was 2008 IEEE President. The Termans are the only father-son pair to serve in the Institute’s highest volunteer role.

Terman received honorary doctorates from Harvard University, University of British Columbia, and Syracuse University. In 1956, the AIEE awarded him its first Education Medal. In 1963, he made a memorable speech before the IEEE annual banquet entitled “Impossible Except for Electrical Engineers.”
Ralph Bown focused on improving long-distance communication, and he led the press conference that announced the invention of the transistor.

Bown was born in Fairport, New York, on 22 February 1891. He received an M.E., M.M.E., and Ph.D. from Cornell University, where he also taught in the physics department. He then served as a captain in the Signal Corps in World War I. In 1919, he joined the development and research department of the American Telephone and Telegraph Company. With that department, he went to the Bell Laboratories in 1934.

Much of Bown’s work was concerned with various aspects of radio broadcasting and ship-to-shore and overseas telephony. His efforts to improve long-distance communication resulted in many communications patents. As Bell research director in 1948, Bown led the press conference that announced the invention of the transistor. Bown’s service to the company was recognized when he was appointed vice president of Bell Telephone Laboratories before his 1956 retirement.

Bown also used his talents to assist the military. He was a division member and consultant of the National Defense Research Committee, specializing in radar, and in 1941, visited England to study radar operations under combat conditions. He also served as an expert consultant to the Secretary of War.

Bown was internationally recognized for his pioneering research and development work in the field of communications engineering. He received the Institute of Radio Engineer’s (IRE) Morris Liebmann Memorial Prize in 1926 and served as president of the Institute in 1927.
Lawrence C. F. Horle’s work centered around the standardization of terminology and ratings. His most important contributions to radio were in the field of standardization of terminology and ratings.

Horle was born on 27 May 1892, in Newark, New Jersey. He received his degree in mechanical engineering from the Stevens Institute of Technology in 1914. Following graduation, Horle became a member of the faculty of the physics department of Stevens, where he remained until 1916, devoting a large part of his time to investigations of vacuum-tube characteristics and development of vacuum-tube circuits. In 1916 and 1917, he was a design engineer for the Public Service Corporation of Newark.

During World War I, he served as an expert radio aid for the U.S. Navy, in charge of the radio development laboratory at the Washington Navy Yard. Following his Naval service, he became chief engineer of the de Forest Radio Company and remained in this capacity until 1921. From 1921 to 1924, he was consulting engineer for the Department of Commerce Radio Laboratories at the National Bureau of Standards, in Washington, D. C. In 1924, he became associated with the Federal Telephone and Telegraph Company as chief engineer, becoming vice-president in charge of engineering in 1927. He became a practicing consultant in 1929, specializing in industrial standardization in the communications field. Starting in 1941, he as civilian consultant to the Army Communications and Coordination Board of the Chief Signal Officer, United States Army.

Lawrence C. F. Horle
(27 May 1892 – 29 October 1950)

For his contributions to the radio industry in standardization work, both in peace and war, particularly in the field of electron tubes, and for his guidance of a multiplicity of technical committees into effective action.

Horle was elected to Associate membership in the Institute of Radio Engineers (IRE) in 1914, transferred to the Member grade in 1923, and to Fellow grade in 1925. He has served on various committees and was president in 1940. In addition to his long-standing affiliation with the IRE, Horle was chief engineer of the Radio and Television Manufacturers’ Association. He was a Fellow of the American Institute of Electrical Engineers and of the Radio Club of America.

Standardization made vacuum tubes an essential component in the 20th Century; electronics revolution, Adobe Stock
Ralph V. L. Hartley, inventor of the electronic oscillator circuit that bears his name, was born in Spruce, Nevada, on 30 November 1888. He graduated with the A.B. from the University of Utah in 1909. As a Rhodes Scholar, he received the B.A. in 1912 and the B.Sc. in 1913 from Oxford University. Upon returning from England, Hartley joined the Research Laboratory of the Western Electric Company and was given charge of radio-receiver development for the Bell System’s transatlantic radiotelephone tests of 1915. He invented his oscillating circuit during that time and also invented a neutralizing circuit to eliminate triode singing resulting from internal coupling.

During World War I, Hartley worked out the principles that led to the development of sound-type directional finders. After the war, he worked at Western Electric and later at Bell Laboratories, doing research on repeaters, and voice and carrier transmission. During this period, he formulated the law that the total amount of information that can be transmitted is proportional to frequency range transmitted and the time of the transmission.

Illness kept Hartley away from research for about 10 years, but in 1939, he returned to Bell Labs as a consultant, and during World War II, he was particularly involved with servo problems. He retired from Bell Labs in 1950. He was a Fellow of the American Association for the Advancement of Science.
Harold H. Beverage supervised the development of receivers for transoceanic communications at the Radio Corporation of America (RCA), which led to a patent for the Beverage Antenna. Beverage was born in North Haven, Maine, on 14 October 1893. As a teenager, he built a home-made wireless set through which he picked up signals from the Carpathia, the ship that rescued the Titanic survivors. At that time, he had already developed a lifelong interest in radio technologies. Within a few years of the Titanic disaster, he graduated from the University of Maine in 1915.

Upon graduation, Beverage went to work for General Electric Company as a radio-laboratory assistant. During the World War I, he worked on radio transmission technologies for naval applications and on adaptations for voice transmission. He studied the effects of extremely long antenna wires through a variety of experiments in 1919. In 1920, he was placed in charge of developing receivers for transoceanic communications at RCA. This work led to what is still referred to as the Beverage Antenna. In 1921, he received his first patent for the wave antenna which would become a standard for long-wave receiving. As his career progressed, his work extended to ultra-short-wave equipment as well.

When RCA created RCA Communications in 1929, Beverage became chief research engineer. By 1940, he had risen to vice president of research and development. He retired in 1958 from that position and as director of radio research but continued to work in communications as a consultant.

Beverage was recognized throughout his career. In 1923, when he was just 30 years old, he received the Morris Liebmann Memorial Prize from the Institute of Radio Engineers (IRE) for his contributions to the development of transoceanic radio. In 1937 he became IRE president. In 1938, the Radio Institute of America presented him with its Armstrong Medal for his work in the development of aerial systems. The Beverage antenna, the citation said, was the precursor of wave antennas of all types. In awarding him its Lamme Gold Medal in 1957, the American Institute of Electrical Engineers cited him for his pioneering and outstanding achievements in the conception and application of principles basic to progress in national and worldwide radio communications.
Qualifications and Today’s Award

The Medal of Honor is granted for an exceptional contribution or an extraordinary career in the IEEE fields of interest. Contributions are evaluated based on the substantial significance of achievement, originality, impact on society, impact on the profession, and publications and patents relating to the achievement. Nominations consider the candidate’s leadership in the field, breadth of work, achievement in other fields, inventive value (patents), individual versus group contributions, publications (articles, books, etc.), originality of contribution, quality of nomination, society and professional activities and honors, and the quality of endorsements.

The selection of today’s Medal of Honor recipients is governed by the IEEE Medals Council and a nine-person Medal of Honor Committee of the IEEE Awards Board. If the Medal of Honor recipient is not an IEEE member, they are automatically recommended to the IEEE Board of Directors for IEEE Honorary Membership. In conjunction with the merger of the two organizations, the design of the Medal of Honor was modified. The obverse (front) now includes the name “The Institute of Electrical and Electronics Engineers.”

The award includes a gold medal, bronze replica, a certificate, and an honorarium. The Medal may only be awarded to an individual. It is considered of such importance that recipients are no longer eligible to receive any other IEEE institute-level medal, technical field award, or recognition.
Electron (or Vacuum) Tubes

An electron tube, also known as a ‘vacuum tube’ or a ‘valve’, is a glass or metal enclosure in which electrons move through the vacuum or gas from one metal electrode to another. The vacuum tube is often used to amplify weak currents or act as a one-way valve for electric current.

Before the 1947 invention of the transistor, the electron tube was the basis of virtually all electronic devices. The simplest kind of electron tube is the diode, which was invented in 1904 by John A. Fleming. In Greek, “di” means “two.” Diodes have two electrodes inside: the negative electrode or “cathode” and the positive electrode or “anode.” Fleming’s diodes were modified light bulbs which consisted of a glass bulb with a filament inside. The filament acted as the cathode, emitting large numbers of electrons, while the anode consisted of a small metal plate mounted near the filament and connected to the outside of the tube by a thin wire.

A diode regulates the flow of electric current and acts like a one-way valve turning current on and off. When a battery is connected to the metal cathode, it heats up and electrons “boil off” from its surface. They fly around inside the glass tube and form an invisible cloud around the cathode. When the diode is placed in a circuit so that the anode is connected to the other terminal of the battery, the cloud of electrons rushes toward the anode, as do the new electrons streaming off the cathode. This flow of electrons completes the electric circuit. It is extremely difficult for electrons to flow the other way, so the diode acts as a one-way valve. Fleming invented the diode for use in radio. One of the most difficult things about receiving radio waves was “detecting” the signal. Mechanical devices were used to detect the presence of incoming radio waves, but the waves were so weak that they didn’t have enough energy to move even a very lightweight mechanical detector. With a Fleming diode and a carefully designed tuning device, radio waves could be detected when they acted on the diode.
causing it to turn on or off. The diode was a very sensitive, “electronic” type of radio wave detector.

A more versatile type of electron tube is the triode, or three-element tube, invented by Lee De Forest in 1906. His brand name for it was the Audion, but it came to be known as the triode. In a triode, a current can be all-the-way-on, all-the-way-off, or anything in between—like water coming out of a faucet. The strength of the current, like the flow of the water, can vary with the use of a tiny wire grid placed between the cathode and the anode to form the third electrode. A voltage sent to the grid—such as a radio wave or the weak signal from a microphone—controls electron flow. If the grid is positively charged, it helps accelerate the electrons across the gap between the other two electrodes. If the grid is negatively charged, it repels electrons and greatly reduces or stops the flow across the gap. The grid makes the triode a more versatile device than the diode, especially with its ability to amplify small currents. For example, whereas a Fleming diode could detect the presence of radio waves, the waves were still very weak. A triode electron tube could not only detect them, but also amplify them. That helped make it possible to transmit and receive not only the on/off signals of Morse Code, but also voice and music.

De Forest and other inventors worked for many years to improve the Audion triode. However, the amplification provided by the earliest Audions were subject to disadvantage—a loud howl known as feedback. Feedback occurs when output from the triode is unintentionally sent back to the grid, amplified again, fed back to the input, and reamplified in a repetitive pattern until it overloads the circuit. When that happens, the tube begins to generate its own waves, initiating the feedback. De Forest tried to eliminate the feedback; however, other inventors thought the feedback was valuable and searched for alternative uses. Eventually, engineers discovered that the waves generated by a triode could be used to make radio transmitters and other useful devices.

Subsequent kinds of tubes sometimes had more than three elements. A four-element tube, for example, is called a Tetrode while another famous tube used in radar is called the magnetron. Other specialist vacuum tubes are known as Travelling Wave Tubes, Klystron, Klystrode, pentode, magic eye and nixie tubes.

The electron tube was the basis of virtually all electronic devices from the early 1900s until the introduction of the transistor in the late 1940s. Today, most of the jobs once performed by the electron tube utilize semiconductor materials. Certain types of materials can act like a one-way valve just like Fleming’s vacuum tube, or the amplifier such as De Forest’s triode, but the semiconductors are more compact and rugged for some jobs. However, the electron tube is still in use, for example, in high power RF amplifiers and electronic warfare components.

The electron tube has many practical applications today. If you are using a desktop computer with a glass screen, you’re looking at a special kind of electron tube called a cathode ray tube. Many electric guitar amplifiers use electron tubes because musicians say they produce better sound and radio stations and microwave ovens usually use electron tubes to generate high-power radio waves.
Haraden Pratt was born in San Francisco, California, on 18 July 1891, and graduated from the University of California in 1914. Both his parents were telegraph operators and he learned Morse code at an early age. He worked briefly as a wireless operator on ships before entering college and during the summers while he was an undergraduate. Soon after his graduation, he joined the American Marconi Company and helped to install a transpacific station in Bolinas, California. In 1915, he left Marconi to take a job as a radio expert at the Mare Island Navy Yard. He installed radio equipment on Navy ships and installed and maintained shore stations on the West coast until 1918, when he was transferred to Washington, D.C.

In 1920, Pratt joined the Federal Telegraph Company in Palo Alto, California, and designed a system for commercial radio telegraph service. In 1926, the United States Congress passed the Air Commerce Act which provided funds for development of radio aids to air navigation. J. Howard Dellinger of the Bureau of Standards offered Pratt the opportunity to help develop a suitable system and he worked with Harry Diamond and others on the radio beacon during 1927-1928. In 1928, Pratt accepted an offer to become chief engineer of the recently organized Mackay Radio and Telegraph Company which subsequently was acquired by the International Telephone and Telegraph Company (ITT). He remained with ITT until 1951 and became a vice president and general manager.

Haraden Pratt was a division chief in the Office of Scientific Research and Development and was chairman of the Radio Technical Planning Board from 1945 to 1949. He served as telecommunications advisor to U.S. presidents Harry Truman and Dwight Eisenhower during 1951 to 1953. Pratt was a vice president of the American Cable and Radio Company from 1953 to 1958.

IEEE Harden Pratt Award

In recognition of his engineering contributions to the development of radio, of his work in the extension of communication facilities to distant lands, and of his constructive leadership in Institute affairs.
William Wilson was born in Preston, England, on 29 March 1887. Wilson was educated at the University of Manchester and at Cambridge University where he studied radio-activity under Sir Ernest Rutherford and carried on electronic investigations under Sir Joseph Thompson.

In 1912, after receiving his doctorate in science, he became a lecturer in physics at the University of Toronto and in 1914 joined the research department of Bell Laboratories where his background of training and research experience eminently fitted him for the work which was rapidly getting under way. In 1915, he was sent to San Diego to set up a radio receiving station to listen for signals from the experimental transmitter in Arlington, Virginia. After the successful completion of these tests, a program of further research was projected in which he was placed in charge of the research and development work on vacuum tube filaments.

During World War I, he had charge of the manufacture by Western Electric of vacuum tubes for the U.S. government and in 1918, he became responsible for vacuum tube research, development design, and manufacture. Continuing these responsibilities up to October, 1933, he was intimately associated with the development of high-vacuum tubes. In 1925, Wilson took charge of radio research activities of Bell Laboratories, resulting in short-wave radio telephone systems for communication with Europe and transatlantic liners and in improved ultra-short-wave systems. In 1927, he became assistant director of research. In 1934, to his duties were added the supervision of research into problems of communication by wire. He was assistant vice president in charge of personnel and publication from 1936 to his retirement in 1942.

Wilson was active in the American Institute of Electrical Engineers (AIEE), Institute of Radio Engineers (IRE), and the American Physical Society. Wilson taught in the physics department at Phillips Exeter Academy and, after his retirement from Bell Laboratories, was professor of physics at North Carolina State College.

For his achievements in the development of modern electronics, including its application to radio-telephony, and for his contributions to the welfare and work of the Institute.
Albert Hoyt Taylor was in charge of the Aircraft Radio Laboratory and later directed a radar development project for ships to use in order to detect enemy ships and aircraft.

Taylor was born in Chicago, Illinois, on 1 January 1879, and graduated from Northwestern University in 1902. He undertook his first radio investigations during 1899, which led to his first published paper in 1902. He taught at the University of Wisconsin from 1903 to 1908 before going to Germany for graduate studies. He received the Ph.D. from the University of Göttingen in 1909 with a thesis on aluminum rectifiers. He returned to the United States and became a professor of physics and department head at the University of North Dakota, where he remained until 1917. While there, he built an experimental radio station which he used in pioneering studies of wave propagation and directive antennas.

In 1917, Taylor accepted a Naval Reserve commission and was appointed district communication officer at the Great Lakes Naval station in Chicago. He established a laboratory and began research on the use of underground and underwater antennas for very low frequency radio reception. Soon afterward, he was transferred to Belmar, New Jersey, as transatlantic communications officer in charge of several high-power stations on the East Coast. In 1918, he was assigned to head an experimental division of the Naval Air Station at Hampton Roads, Virginia, where research on aircraft radio was undertaken. The following year, he became head of the Aircraft Radio Laboratory at Anacostia, Washington, D.C., with a staff of 18 people. Taylor resigned from the Navy in 1922 but remained at Anacostia as a civilian employee.

At Anacostia, Taylor studied the polarization of electric waves. During 1922, Taylor and Leo Young observed reflections of high-frequency radio waves from ships on the Potomac River as they passed between a transmitter and a portable receiver. In 1930, Taylor penned a report on radio-echo signals from moving objects which spurred the Navy’s interest in developing radio to detect enemy ships and aircraft. This led to a radar development project directed by Taylor which yielded a 200-MHz radar ready for installation on a ship by 1937. When the Naval Research Laboratory was established in 1923, Taylor became superintendent of its Radio Division, a position he held until 1945. He participated in systematic investigations of high-frequency propagation phenomena including ionospheric effects.

Taylor received the Morris Liebmann Memorial Prize of the Institute of Radio Engineers (IRE) in 1927 for his research on short waves. He served as president of the IRE in 1929 and on the Communication Committee of the American Institute of Electrical Engineers from 1936 to 1942.

On March 28, 1944, Secretary of State Cordell Hull presented Taylor with the Medal of Merit, one of the highest civilian decorations of the United States, for exceptionally meritorious conduct in the performance of outstanding services in the line of his profession as a member of the staff of the Naval Research Laboratory. Undiscouraged by frequent handicaps, Taylor labored tirelessly in the course of intensive research and experimentation which eventually resulted in the discovery and development of radar. His foresight, technical skill and steadfast perseverance contributed in large measure to the timely introduction of a scientific device which has yielded the United States Navy a definite advantage over her enemies during the present war. He retired from the Naval Research Laboratory in 1948, and wrote a book about his experiences entitled Radio Reminiscences: A Half Century.
A Sample of the IEEE Medal of Honor Recipients’ Groundbreaking Research


Alfred Norton Goldsmith was born in New York, New York, on 15 September 1888. He received his B.S. from the College of the City of New York (CCNY) in 1907, and began teaching there as an instructor that same year. He continued working there while pursuing his Ph.D. at Columbia University, where he studied under Michael Pupin and received his degree in 1911. Although he left his active appointment at CCNY in 1919, he retained a lifetime associate professorship in electrical engineering at the college.

Goldsmith began consulting to government and industry while at CCNY, first with the U.S. Department of Justice as a radio expert and with the Atlantic Communication Co. as a radio engineer in 1914. From 1915 to 1917, he consulted for the General Electric Company, and in 1917, he became the director of research for the Marconi Wireless Telegraph Company of America.

In 1919, Marconi was acquired by the newly founded Radio Corporation of America (RCA), and Goldsmith was made director of research for RCA, directly responsible to David Sarnoff. At first, he and his staff used the labs at CCNY for their research until RCA opened its first corporate labs at Van Cortland Park. Beginning with his management and oversight, the RCA labs would become one of the most important corporate research laboratories in history. He rose through the company’s ranks to the position of vice president and general manager. In 1931, he left the company, opting then for independent consulting. However, he maintained an advisory relationship with RCA for life.

Goldsmith made significant technical contributions while at RCA, making possible the first commercial radio with only two control knobs and a built-in speaker, as well as the first commercial radio-phonograph. He also developed the basic idea behind the shadow-mask color picture tube which became prevalent in commercial televisions. By the end of his career, he had received 122 U.S. patents.

Goldsmith also made his mark contributing to and shaping the professional organizations of his field. Robert Marriott appointed him to a committee to pursue a merger of his Wireless Institute with the Society of Wireless Telegraph Engineers. Their efforts were central in the formation of the resulting Institute of Radio Engineers (IRE) in 1912.

Goldsmith became first editor of the Proceedings of the IRE, and remained in that position for 42 years, elevating the journal to its leadership position. He was a sponsor and patron of the formation of the IRE Professional Group on Engineering Writing and Speech, the forerunner of IEEE’s Professional Communication Society. He was honored as a Fellow of the IRE in 1915 and served as secretary in 1918, president in 1928, and on the Board of Directors for the entire 51 years of the IRE’s independent existence. He received the Founders Award in 1954.
In 1963, the AIEE merged with the IRE to form the IEEE, wherein Goldsmith became Fellow, director, and editor emeritus. Goldsmith was the first recipient of the IEEE Haraden Pratt Award, established in 1972 to honor outstanding service to the Institute. His bequest to IEEE led to the formation of the IEEE Foundation in 1974. The Foundation’s designation of planned giving, the Goldsmith League, still bears his name, as does the IEEE Alfred N. Goldsmith Award for Distinguished Contributions to Engineering Communication.

Goldsmith’s interests went beyond radio, as well. He was a Fellow of the American Physical Society, the American Association for the Advancement of Science, the Acoustical Society of America, the Optical Society of America, and the International College of Surgeons. He served as president of the Society of Motion Picture and Television Engineers in 1932, and was a recipient of their Progress Medal Award. In 1966, he became vice president of electronics of the Pan-American Medical Association. He was a Benjamin Franklin Fellow of the Royal Society of Arts. Other awards include the 1940 Modern Pioneer Award and the 1942 Townsend Harris Medal.

Goldsmith authored a number of books, including technical texts, such as *Radio Telephony* (Wireless Press, 1918), and *The Ultra-high-frequency Domain* (Chicago: University of Chicago Press, 1936). He also authored less technical works including *This Thing Called Broadcasting*, co-authored with Austin C. Lescarboura, which considers the historical and cultural aspects of technology.
Lloyd Espenschied was born in St. Louis, Missouri, on 27 April 1889. In 1901, he moved to Brooklyn, New York, where he lived with relatives of his mother. He became an amateur radio operator in 1904 and later worked as a shipboard wireless operator for the United Wireless Telegraph Company during summer vacations. He graduated from the Pratt Institute in 1909 with a degree in applied electricity and then worked as an engineer for about a year with the American affiliate of the German Telefunken Wireless Telegraph Company. Among his assignments was the installation of the Telefunken quenched spark system on ships of the U.S. Navy.

He joined the engineering department of AT&T in 1910 and remained with the Bell Company until his retirement in 1954. He joined the Wireless Institute, which merged with the Society of Wireless Telegraph Engineers in 1912 to form the Institute of Radio Engineers (IRE). He was recorded as a discussant of the first paper published in the Proceedings as well as three other papers in the first volume. He became a Fellow of the IRE in 1924 and a Fellow of the American Institute of Electrical Engineers (AIEE) in 1930.

At the Bell Company, Espenschied worked on the design of loading coils used to enhance telephonic communication by wire, and he also was a participant in long-distance radio telephone experiments using a vacuum-tube transmitter conducted by Bell engineers during 1915. He was sent to Pearl Harbor, Hawaii, to test reception from a transmitter in Arlington, Virginia. Beginning in 1916, he worked with several colleagues, including Herman A. Affel, on a carrier multiplex system which was put in operation between Baltimore, Maryland, and Pittsburgh, Pennsylvania, in 1918. As an outgrowth of this work, Espenschied applied for a patent in 1927 on the use of piezoelectric quartz crystals in band-pass filters. He and Affel jointly received a patent on a wideband coaxial cable system of transmission which was disclosed in a prize-winning paper published in AIEE's Electrical Engineering in October 1934. This invention eventually helped make television transmission achievable.

Espenschied also contributed to the development of wire distribution of radio programming used in network radio. He patented a collision avoidance system using reflected waves for railroad trains in 1924, and later applied similar techniques for a radio altimeter for airplanes which was produced commercially by the Western Electric Company beginning in 1937.

Late in his career, Espenschied became a collector of rare books dealing with electricity going back to the 16th century, a collection now located at the Niels Bohr Library of the American Institute of Physics. He also gave numerous talks dealing with invention and the history of telecommunication. He received approximately 130 patents during his career. He received the Pioneer Award of the IEEE Aerospace and Electronic Systems Group in 1967.
Albert G. Lee entered the British Post Office Engineering Service in 1903. During his years there he was involved in the introduction of Pupin coils into cables and the design and testing of submarine and other cables. Subsequently, he spent four years on district telephone and telegraph work, and then returned to the headquarters in London where he gained further experience in different phases of telephony and telegraphy.

During World War I, Lee volunteered for service, receiving a commission in December of 1914, in the Royal Engineers (Signal Service). During the major portion of the war, he was in command of a telegraph construction company, and later took the role of officer-in-charge, General Headquarters Signal Area, and second in command of L. Signal Battalion. At the conclusion of the war, he held the rank of major. Lee was mentioned in official dispatches and received the Military Cross for his service. Lee remained in the Supplementary Reserve, where he achieved the rank of lieutenant colonel, Royal Corps of Signals.

In 1920, Lee became involved with radio work and soon became staff engineer in charge of the radio section of the British Post office. Here he was involved with the development of a coupled circuit arc, the high-power station at Rugby, and the transatlantic telephone and short-wave telephone service.

Lee was a member of the Institute of Radio Engineers (IRE) for a number of years and served as chairman of the Wireless Section in 1927-1928. He was also a member of the Committee on Admissions and was elected a Fellow in the Institute in 1929. He was a member of the Radio Research Board and chairman of the Atmospherics Committee of that board.

For his accomplishments in promoting international radio services and in fostering advances in the art and science of radio communication.
John H. Dellinger
(3 July 1886 – 28 December 1962)

For his contributions to the development of radio measurements and standards, his researches and discoveries of the relation between radio wave propagation and other natural phenomena, and his leadership in international conferences contributing to the world wide cooperation in telecommunications.

John Howard Dellinger was born on 3 July 1886, in Cleveland, Ohio. He attended Western Reserve University before receiving the A.B. from George Washington University in 1908 and the Ph.D. from Princeton University in 1913. In 1932, he was awarded the Sc.D. from George Washington University.

During the period from 1907 to 1948, Dellinger held the following successive posts at the National Bureau of Standards in Washington, D.C.: physicist, chief of the radio section, and chief of Central Radio Propagation Laboratory. During 1928 to 1929, he was chief engineer of the Federal Radio Commission. He served as a representative of the United States Department of Commerce on the Radio Advisory Committee from 1922 to 1948 and as a representative of the United States at numerous international radio conferences, starting in 1921.

Dellinger was appointed vice president of the International Scientific Radio Union in 1934. From 1950, he was chairman of Study Groups 6 on Radio Propagation of the International Radio Consultative Committee. He was appointed chairman of the Radio Technical Commission for Aeronautics in 1941, and held the same position on the Radio Technical Commission for Marine Services in 1947.

Dellinger was president of the Institute of Radio Engineers (IRE) in 1925, director from 1924 to 1927, and was chairman of the IRE Washington Section during 1932 to 1933. He represented the Institute at meetings of the American Documentation Institute during 1944 to 1948 and 1949 and on the American Standards Committee Sectional Committee on Electric and Magnetic Magnitudes and Units for 1936 and 1948.

A modern test chamber for radio wave propagation, Adobe Stock

Bell telephone magazine (1922)
Melville Eastham was born in Oregon City, Oregon, on 26 June 1885, and studied at Portland Academy. He worked for a time as electrician for a street railway company in Portland, and then moved to New York City in 1905, where he worked for the Ovington X-ray Company. In 1906, he joined J. Emory Clapp and W.O. Eddy, two other Ovington employees, in organizing the Clapp, Eddy, and Eastham Company in Boston, Massachusetts. The company became known as Clapp-Eastham following the departure of Eddy, and it manufactured radio equipment. It soon began to sell spark coils, variable capacitors, and other devices to radio amateurs. Clapp sold his interest in the company to O.K. Luscomb in 1910 and he and Eastham moved to a new site in Cambridge, Massachusetts, the same year.

In 1915, Eastham left Clapp-Eastham to form the General Radio Company which began with a capitalization of US$9,000, and with himself and a skilled machinist as the only employees. Its first products, as listed in a 1916 catalog, included an absorption wave-meter, a decade resistance box, a variable inductance, and a variable capacitor. The company enjoyed early success resulting from a strong demand for radio equipment for military communication during World War I and from the radio broadcasting boom soon after the war. By the mid-1920s, Eastham had decided to leave the radio transmitter and receiver business to others, and to concentrate on precision instruments for industry and educational institutions. Known as an engineer’s company, General Radio became known for the accuracy, durability, and craftsmanship that went into its instruments. New instruments added during the late 1920s and early 1930s included a vacuum-tube voltmeter, an impedance bridge, and an oscilloscope.

Eastham also exhibited a great interest in employee benefits and the company initiated a profit-sharing bonus plan in 1917, and began to pay the premiums for employee life insurance plans in 1918. In 1919, the company adopted a 40-hour work week and increased the number of paid holidays to nine per year. An employee stock ownership plan was implemented beginning in 1929. Eastham stepped down as president of General Radio in 1944, but retained the title of chief engineer until his retirement in 1950.

During World War II, he was in charge of a successful effort to develop the radio navigation system known as LORAN at the Radiation Laboratory at MIT. Eastham was quite active in the Institute of Radio Engineers (IRE), becoming a Fellow in 1925 and serving as treasurer from 1927 to 1940.

For his pioneer work in the field of radio measurements, his constructive influence on laboratory practice in communication engineering, and his unfailing support of the aims and ideals of the Institute.
George Ashley Campbell was born on 27 November 1870, in Hastings, Minnesota. He was one of the pioneers in developing and applying quantitative mathematical methods to the problems of long-distance telegraphy and telephony. His many contributions became essential tools for communication engineering in daily use in ever-widening fields of application.

After graduating from MIT in 1891, and receiving a master’s from Harvard University in 1893, Campbell was awarded a fellowship which enabled him to spend three years on graduate work; one year studying advanced mathematics under Felix Klein at Göttingen, one year studying electricity and mechanics under Ludwig Boltzmann in Vienna, and one year studying under Henri Poincaré in Paris.

In 1897, he joined the American Telephone and Telegraph company (AT&T). At that time, the art of telephone transmission was still in its infancy with one of the main problems being that the signal quickly became distorted as the distance between points increased. Around 1899, Campbell at AT&T and Michael Pupin at Columbia University independently discovered a way to reduce attenuation—by placing inductors, soon better known as loading coils, with known values at theoretically determined intervals along a telephone line. In doing so, they reduced to practice the theory developed earlier by Oliver Heaviside. Since inductors resist changes in current, these loading coils reduced attenuation by increasing induction. This increased the distance over which an electrical signal could travel and remain intelligible or, alternatively, allow the use of thinner and therefore cheaper copper wire on a circuit of a given length. Both men applied for U.S. patents and, rather than fight a patent interference suit after the patent office awarded the patent to Pupin, AT&T bought his patent rights. Campbell received a doctorate from Harvard in 1901 with his dissertation being on the subject of his loading coil research at AT&T.

Campbell’s career was extremely productive with discoveries, inventions, and patents. He recognized the importance of Maxwell’s capacity coefficients early on and designed his well-known shielded balance to measure direct capacities. He also invented an electric filter to avoid singing in repeater circuits. He authored numerous and influential papers, among them “Loaded Lines in Telephonic Transmission” (1903), “Cisoidal Oscillations” (1911), and the classic 1922 paper on the “Physical Theory of the Electric Wave-filter.”

George A. Campbell
(27 November 1870 – 10 November 1954)

For his contributions to the theory of electrical network.
A pioneer in the field of radio and telecommunications. Balthasar van der Pol was born on 27 January 1889, in Utrecht, Holland. He studied experimental physics with Sir John Ambrose Fleming and Sir Joseph Thompson in England, and with Hendrik Lorentz in the Conservator Physical Laboratory, Holland. He received his Ph.D. in physics from Utrecht University in 1920. He joined Philips Research Laboratories in 1921, where he worked until his retirement in 1949.

Van der Pol initiated modern experimental dynamics in the laboratory during the 1920s and 1930s, when he proposed the van der Pol oscillator. He investigated electrical circuits employing vacuum tubes and found that they have stable oscillations, now called limit cycles. When these circuits are driven with a signal whose frequency is near that of the limit cycle, the resulting periodic response shifts its frequency to that of the driving signal. That is to say, the circuit becomes entrained to the driving signal. The waveform, or signal shape, however, can be quite complicated and contain a rich structure of harmonics and subharmonics. Due to the unique nature of the van der Pol oscillator, it has become a cornerstone for studying systems with limit cycle oscillations. In fact, the van der Pol equation has become a staple model for oscillatory processes in not only physics, but also biology, sociology, and even economics.

In the September 1927 issue of the British journal *Nature*, van der Pol and his colleague J. van der Mark reported that an irregular noise was heard at certain driving frequencies between the natural entrainment frequencies. By reconstructing his electronic tube circuit, we now know that they had discovered deterministic chaos. Their paper is probably one of the first experimental reports of chaos, something that they failed to pursue in more detail.

Van der Pol built a number of electronic circuit models of the human heart to study the range of stability of heart dynamics. His investigations with adding an external driving signal were analogous to the situation in which a real heart is driven by a pacemaker. He was interested in finding out, using his entrainment work, how to stabilize a heart’s irregular beating or arrhythmias.

Van der Pol was one of the founders, and for many years, president of Het Nederlandsch Radiogenootschap and a member of the Union Internationale de Radio Diffusion, the Union Radio Scientifique Internationale, and the Royal Netherlands Academy of Arts and Sciences. He joined the Institute of Radio Engineers in 1920, and became a Fellow in 1929. He was the director of the Comité Consultatif International des Radiocommunications in Geneva, Switzerland, from 1949 until 1956.
Admiral Stanford Caldwell Hooper was born in Colton, California, on 16 August 1884. His early education was received in the public schools of San Bernardino, California, and he worked as a relief telegraph operator during his summer vacations. In 1905, he graduated from the United States Naval Academy and served on various naval vessels, having command of a destroyer during World War I. He instructed in electricity, physics, and chemistry at the Naval Academy from 1910 to 1911. From 1912, he served for two years as the first Fleet Radio Officer, resuming that post again from 1923 to 1925. For 11 years, between 1914 and 1928, he was in charge of the Radio Division of the Navy Department, as well serving as director of Naval Communications.

Hooper was a leader in developing wireless radio communications in the Navy by carrying out pioneer tests, establishing a chain of land stations for communication between fleet and land, and serving as technical advisor and head of many boards and committees dealing with communications. He suggested the position of Fleet Radio Officer as necessary to the new radio communications, and served in this post for two years. In World War I, Hooper was awarded the Navy Cross for distinguished service as commanding officer of the U.S.S. Fairfax.

After 38 years of military service, Hopper retired from the Navy in 1943, due to an injury incurred during World War II. Afterward, he was a consultant to electronic equipment manufacturers. The Franklin Institute of Philadelphia presented him the Eliot Cresson Medal for research in radio electronics in 1945. In 1948, Hooper received an honorary LL.D. from Drury College. He also received the French Legion of Honor and the Department of Navy Electronics Trophy, and is one of few to hold the Marconi Medal of Honor. In recognition of his service, a Navy vessel was renamed the Hooper in 1956.
The son of a congregational minister, John A. Fleming was born in Lancaster, England, on 29 November 1849. He received a degree in science from University College, London, in 1870, and then was a teacher until 1877, when he enrolled at St. John’s College of Cambridge University. He attended lectures by James C. Maxwell and also did research at the Cavendish Laboratory. Fleming developed a precision resistance bridge instrument given the nickname Fleming’s banjo and used it to compare resistance standards. He received the doctorate degree in 1879, and continued at Cambridge as a laboratory demonstrator until 1881, when he accepted a teaching position at Nottingham. He did some consulting for the Edison Electric Company on incandescent lamps. In 1885, he joined the faculty of University College, London, where he spent the rest of his professional career.

One of Fleming’s early investigations was concerning the Edison effect, where he studied the unilateral conductivity of a carbon-filament lamp with a metal plate connected to an external circuit. In December 1889, he presented a paper on this work to the Royal Society of London entitled “On Electric Discharge Between Electrodes Temperatures in Air and High Vacua.” He also conducted extensive research on alternating-current which led to his publication of a two-volume work, *The Alternate Current Transformer*, in 1889 and 1892. He published a number of joint papers with James Dewar during the 1890s related to the electric and magnetic properties of materials at low temperatures. Fleming was elected a Fellow of the Royal Society of London in 1892.

In April 1898, Fleming was permitted to examine Marconi’s wireless apparatus at the time it was being used to send messages for about 14 miles from the Isle of Wight. In late March 1899, Marconi demonstrated communication between England and France across the English Channel, an achievement that Fleming characterized as one of those sensational feats which at once aroused the daily press to lively comment on the matter. Fleming participated in these experiments and reported the results in a letter published by *The Times* of London. He stated that “messages, signals, congratulations, and jokes were freely exchanged between the operators” situated on opposite sides of the channel. Later the same year, Fleming gave a lecture at a meeting of the British Association for the Advancement of Science in Dover during which wireless messages were sent and received from France. In 1900, Marconi invited Fleming to help design a more powerful wireless transmitter for an attempt to send signals across the Atlantic Ocean. The transmitter, which Fleming called the first electric wave power station, was installed on the coast of Cornwall, and signals from it were reported to have been detected at a receiver in Newfoundland on December 12, 1901.

The application of the Fleming valve to wireless communication grew out of experiments carried out by Fleming during 1904, when he found that a high-vacuum thermionic diode would rectify high-frequency currents. He reported his observations in a 1905 paper published by the Royal Society of London, entitled “On the Conversion of Electric Oscillations into Continuous Currents by Means of a Vacuum Valve.” He concluded that “an ideal and perfect rectifier for electric oscillations may, therefore, be found by enclosing a hot carbon filament and a perfectly cold metal anode in a very perfect vacuum.” He suggested that the device would provide an effective means to test the performance of a wireless transmitter and determine “what changes conduce to an improvement of reduction in the efficiency of the transmitting device.” Fleming also devised a wave meter that he called a cymometer, which used the glow of a Geissler tube to indicate resonance and give a reading of wavelength on a calibrated scale.

His classic book, *The Principles of Electric Wave Telegraphy and Telephony* was published in 1906, and another book entitled *The Propagation of Electric Currents in Telephone and Telegraph Conductors* was published in 1911. Fleming retired from University College in 1926, and received the Faraday Medal of the British Institution of Electrical Engineers in 1928. He was knighted in 1929, and elected president of the Television Society of London 1930.
Radio pioneer Arthur Edwin Kennelly, the son of an Irish naval officer, was born in Colaba, India, on 17 December 1861. Educated in England and France, he left school at the age of 13 and taught himself physics while working as a telegrapher. In 1876, he left England and held various positions, including that of an assistant electrician in Malta, chief electrician of a cable repairing steamer, and, finally, senior ship's electrician. In 1887, he immigrated to the United States and became principal assistant in Thomas Edison's West Orange, New Jersey lab. Between 1894 and 1901, Kennelly worked as a consulting engineer for the Edison General Electric Company of New York. He then formed the consulting firm of Houston and Kennelly in Philadelphia, Pennsylvania, with Edwin J. Houston. In 1902, the government of Mexico retained his firm to oversee the laying of the Veracruz-Frontera-Campeche cables. Kennelly also had a career in academia. He was a professor of electrical engineering both at Harvard University and MIT and was a research associate at the Carnegie-Mellon Institute.

In 1901, Kennelly noticed that Guglielmo Marconi's reception in Newfoundland of radio signals transmitted from England was received far better than predicted by radio-wave theory. Kennelly and Oliver Heaviside, independently and at approximately the same time in 1902, announced the probable existence of a layer of ionized gas high in the atmosphere that reflected radio waves. Formerly called the Heaviside or Kennelly-Heaviside layer (now called the E region), it is one of the several layers of the ionosphere. Although short wavelength radio waves penetrate the ionosphere, longer waves reflect off it instead, a property which allows them to curve around the earth and be propagated far beyond the horizon. Kennelly is also known for the contributions he made to the analysis of alternating-current (AC) circuits with the publication of his paper, "Impedance." In that paper, he described the first use of complex numbers as applied to Ohm’s Law in AC circuit theory.

Kennelly received many awards during his lifetime. These included the Institution of Electrical Engineers (IEE) Institution Premium, the Franklin Institute Howard Potts Gold Medal, the Cross of a Chevalier of the Legion d'Honneur of France, and the American Institute of Electrical Engineers (AIEE) Edison Medal (1933). He served as president of the AIEE from 1898 to 1900 and president of the Institute of Radio Engineers in 1916.
Gustave-Auguste Ferrie was born on 19 November 1868, at St. Michel, Savoy, France. After graduating from Polytechnical School in 1891, he became an officer in the Engineers Corps of the French Army.

Ferrie headed the French Radiotelegraphie Militaire before and during World War I, a period when he made extraordinary advances in the field of radio communication. Engineers had long known that telegraph signals could travel a few hundred yards through the ground, but little use had been made of this form of wireless communication. In 1914, Ferrie recognized two things: the newly available electron tube could significantly extend the range of this technique and it might then be of enormous value in the fighting on the Western Front. Thus, was born ground telegraphy or Earth-currents signaling.

Ferrie made improvements in the signal generator and in the receiver, notably by the use of a triode amplifier, and achieved a usual range of several kilometers. The transmitter was essentially a buzzer, an electromechanical device that interrupts the circuit at a very high rate, powered by a battery. The receiver was an amplifier, employing a triode electron tube. Earth connections were usually made by driving steel pins into the ground, often a short length of insulated wire was laid along the ground and anchored at each end by a spike. These devices began to be used in large numbers in 1916, and by the end of the war the French had produced almost 10,000 of them for use by the Allies.

Ferrie became a General in 1919, and continued in the service for the rest of his life, exempted from the restrictions of the age limit ruling in accordance with a special law enacted in 1930. He received an honorary doctoral degree from Oxford University in 1919, and was a member of the Academy of Sciences starting in 1922. He was president of the International Scientific Radio Union (U.R.S.I.) and the International Commission on Longitudes by Radio, and vice president of the International Board of Scientific Unions. He became a Fellow of the Institute of Radio Engineers in 1917.

For his pioneer work in the up building of radio communication in France and in the world, his long-continued leadership in the communication field, and his outstanding contributions to the organization of international cooperation in radio.

Portable wire player recorder-available under a Creative Commons Attribution license
Peder Oluf Pedersen was born in Sig, Denmark, 19 June 1874, the only son of a farmer. He attended the village school and in 1889, sent to the King of Denmark proposals for a perpetual motion device and a calculating machine. These proposals so interested the King in his further education that he was transferred to Copenhagen where, after the necessary preparatory education, he entered the Royal Technical College, graduating with honors in civil engineering in 1897. The expense of his studies was contributed to by the King.

Pedersen soon became interested in electrical research work and in 1899, became associated with Valdemar Poulsen in his development work on the telegraphophone. He later aided in the same inventor’s development of the system for continuous wave wireless telegraphy and telephony which has become known as the Poulsen Arc.

In 1909, Pedersen was appointed assistant professor in telegraphy, telephony, and radio at the Royal Technical College at Copenhagen, becoming professor in 1912. In 1922, he was appointed principal of this college.

Pedersen contributed a great number of papers on scientific matters in electrophysics and electrotechnics, mainly on experimental research carried out by himself. He received his Ph.D. at the University of Copenhagen in 1929. Pedersen was a member of the Royal Danish Society of Sciences, the Royal Academy of Natural Sciences (Lund, Sweden), the Academy of Engineering Sciences (Stockholm), and the Royal Society of Sciences (Trondhjem, Norway). In 1911 to 1912, Pedersen was chairman of the Danish Physical Society. In 1916 to 1920, he was president of the Danish Society of Electricians, and in 1920, he became president of the State Control Board for Licensed Telephone Companies of Denmark. From 1920 to 1923, he was president of the Society of Danish Civil Engineers. He was keenly interested in standardization work and in 1926, was elected president of the Danish Section of the International Electrotechnical Commission. He was a Fellow of the American Institute of Electrical Engineers and a member of the Institution of Electrical Engineers (Great Britain). He became a Fellow of the Institute of Radio Engineers in 1915. In 1907, Pedersen was awarded the Gold Medal of the Royal Danish Society of Sciences of Copenhagen, for a paper on an experimental investigation of the oscillations in liquid jets. He was awarded the H. C. Oersted Medal in 1927.

Poulson arc 1MW transmitter
Portable wire player recorder-available under a Creative Commons Attribution license

There was no citation regarding the specific accomplishment included for the Medal of Honor in this year.
George W. Pierce, considered one of the founding fathers of communication engineering, was born on 11 January 1872, in Webberville, Texas. He studied under Alexander Macfarlane, known for his contributions to the theory of alternating currents, at the University of Texas, where he studied physics. In 1900, Pierce earned a Ph.D. from Harvard University for his dissertation on high-frequency electromagnetic waves. He then studied for about a year at the Boltzmann Laboratory in Leipzig, Germany, before returning to Harvard where he spent the rest of his professional career.

In one of his first researches, Pierce used a high-frequency dynamometer to measure the current distribution in a loop antenna. He verified the image theory for antennas elevated above the earth as well as over artificial grounds. He also investigated the effects of both inductance and shunt capacity tuning of receiving antennas. His wave meter was used in wireless telegraphy applications. At resonance, a high-pitched signal was produced in the telephone receiver. After hearing reports of the good performance of carborundum radio detectors, Pierce carried out a long series of quantitative experiments on various minerals used as crystal rectifiers. He was one of the first to employ the Braun cathode-ray tube indicator with a camera to obtain visual images of rectification. His findings convinced him that the thermoelectric theory was not an adequate explanation of the rectification phenomenon. He used a similar experimental setup to study electrolytic detectors and found that, in sensitivity, “the best crystal rectifiers are about equal to the electrolytic detector.”

Much of his early research was reported in his classic book, *Principles of Wireless Telegraphy*, published in 1910. Pierce became the first director of the Cruft Laboratory at Harvard in 1914 and was elected a Fellow of the Institute of Radio Engineers (IRE) in 1915. He served as IRE president in 1918 and 1919. During World War I, Pierce was involved in investigating ultrasonic detection of submarines for the U.S. Navy. His second book, *Electric Oscillators and Electric Waves*, was published in 1914. He succeeded Edwin H. Hall, remembered as the discoverer of the Hall effect, as Rumford Professor at Harvard in 1921. Pierce also was elected to membership in the National Academy of Sciences. During the 1920s, he added piezoelectric crystals to his research agenda and invented the Pierce oscillator, which he patented in 1923. He also studied the magnetostriction phenomenon and received a patent on a magnetostriction oscillator in 1928.

In his later years, Pierce researched the sound of bats and insects and published *The Song of Insects* in 1948.
Jonathan A. Zenneck was born in Ruppertshofen, a small town in Wurttemberg, Germany, on 15 April 1871. In the fall of 1885, he entered the Evangelical-Theological Seminary in Maulbronn, and in 1887, the seminary in Blaubeuren where he learned Latin, Greek, French, and Hebrew. In the fall of 1889, he enrolled in the Tuebingen University in the well-known Tuebingen Seminary where he studied mathematics and natural sciences. His teacher in physics was Ferdinand Braun. In the spring of 1894, Zenneck took the state examination in mathematics and natural sciences and immediately afterwards the examination for his doctoral degree.

During the summer of 1894, Zenneck undertook zoological research at the Natural History Museum in London. From the fall of 1894 to 1895, he fulfilled the military service requirements in the First Naval Battalion (Marines) in Kiel, in which he later became a reserve officer. From 1895 to 1905, he was associated with the Physikalischen Institute in Strassburg, Alsace, first as assistant to Braun and later as assistant lecturer.

Late in 1899, Zenneck turned his attention to wireless telegraphy, conducting experiments along the lines indicated by Braun. These experiments were mainly carried on light ships in the North Sea. In the following year, Zenneck turned his attention to the many fundamental questions in wireless telegraphy which were unexplained and during the next year he turned to the theoretical and experimental explanation of the physical fundamentals of wireless telegraphy. The result of this work was the classical book *Electromagnetic Oscillations and Wireless Telegraphy*, which appeared in 1906, and which, for so many years, was the standard textbook on the subject.

In the spring of 1905, he was appointed assistant professor at the Danzig Technical High School, and a year later became professor of experimental physics in the Braunschweig Technische Hochschule. In order to take part in experiments on the fixation of atmospheric nitrogen, in 1909, Zenneck joined the staff of the Badische Anilin und SodaFabrik, one of the largest German chemical concerns.

In the fall of 1911, he returned to the Danzig Technische Hochschule as professor of experimental physics, and in 1913, he went to the Munich Technische Hochschule in the same capacity.

At the beginning of the World War I, Zenneck went to the front as a captain in the Marines. Early in December of 1914, he was sent to the United States as technical advisor for the Atlantic Communication Company, taking part in experiments with the machine senders in Sayville, and with patent processes.

After the United States entered the war, he was interned first at Ellis Island and then in Fort Oglethorpe, Georgia, returning to Germany in July 1919 to resume his duties as professor of experimental physics at the Technische Hochschule in Munich.
Louis W. Austin worked at the Bureau of Standards, where he studied radio propagation studies. He also supervised a radio laboratory at the Bureau of Standards. Austin was born on 30 October 1867, in Vermont, and graduated from Middlebury College in 1889. He continued his education in Germany where he received a Ph.D. from Strasbourg University in 1893. He taught physics at the University of Wisconsin from 1893 to 1901 and then returned to Germany, where he worked for two years at a laboratory in Berlin doing research on the properties of gases at high temperatures.

In 1904, Austin joined the Bureau of Standards, where he began the radio propagation studies that were to occupy him for the rest of his life. The U.S. Navy established a radio laboratory at the Bureau of Standards, and Austin headed it from 1908 to 1923. With a colleague, Louis Cohen, he developed what became known as the Austin-Cohen formula for predicting the strength of radio waves. Data collected during 1910 from Navy ships crossing the Atlantic provided the basis for the formula.

Austin joined the Institute of Radio Engineers (IRE) in 1913 and served as the third president of the Institute in 1914. He was a frequent contributor to the Proceedings, publishing 40 technical papers in its pages between 1913 and 1932. He served as a U.S. representative at numerous international conferences on radio and became director of a special radio laboratory at the Bureau of Standards in 1923.

Austin was described by colleagues as being warm-hearted, modest, and quiet. As he entered a hospital for surgery just before his death, he wrote a note asking that his program of radio measurements be continued in the event that “things should not go well.” Lyman J. Briggs who wrote an obituary of Austin for Science, assuring readers that his work was being continued.
Greenleaf W. Pickard received a patent for a silicon crystal detector in 1906, and he founded the Wireless Specialty Apparatus Company in order to market his detectors. Pickard was born on 14 February 1877, in Portland, Maine. Pickard attended the Lawrence Scientific School at Harvard University and also took classes at MIT. In 1899, he received a grant from the Smithsonian Institution to support his wireless research at the Blue Hill Observatory in Milton, Massachusetts. He joined the American Telegraph and Telephone Company (AT&T) in 1901, and installed wireless apparatus to report the America’s Cup yacht competition that year.

Pickard worked for AT&T to 1906. During this period, he experimented with wireless telephony and also observed some of Reginald Fessenden’s tests of a radio alternator. Pickard tested a large number of minerals in an effort to discover the most effective contact detector of radio waves. He found that a sample of fused silicon obtained from the Westinghouse Electric Company produced excellent results and he received a patent on a silicon crystal detector in 1906. Reportedly, he tested more than 30,000 combinations of materials for detectors.

In 1907, Pickard and two associates organized the Wireless Specialty Apparatus Company to market his patented detectors, one of which was called Perikon, an acronym for perfect Pickard contact. Pickard was a member of both the Society of Wireless Telegraph Engineers and the Wireless Institute when they merged to form the Institute of Radio Engineers (IRE) in 1912. He served as the second president of the IRE in 1913. During World War I, he investigated ways to mitigate static interference at a Navy radio installation at Otter Cliffs, Maine.

He published an IRE paper on the use of directional antennas to reduce static in October 1920. He speculated that much of the static was caused by solar phenomena. In his October 1925 paper, Pickard reported that he had organized an eclipse network, involving both commercial and experimental stations in an effort to measure the effects of the solar eclipse of 24 January 1925, on radio reception. Several stations had transmitted continuous wave signals at frequencies ranging from 57 kHz to 4 MHz. Observers, including Alfred N. Goldsmith, had made graphical recordings at various receiving sites.

Pickard continued to investigate propagation of radio waves and served as a consultant to the Radio Corporation of America and other clients during the 1930s. He published an IRE paper in July 1931 on the effect of meteor showers on propagation. He also explored the effect of sunspots and atmospheric pressure and temperature on reception over a wide range of frequencies. He became a Fellow of the Radio Club of America and was awarded its Armstrong Medal in 1941.
Michael Idvarskey Pupin taught mathematical physics at Columbia University. He also studied wave propagation and applied his findings to long distance telephony experiments and research. Pupin was born on 4 October 1858, in the village of Idvor, Banat, now part of Serbia. In his youth, he served as a shepherd. His parents were illiterate, but Pupin was educated at the local school in Idvor. His education progressed in Panchevo and then Prague. In 1874, with the support of his parents but with very little money, he immigrated to New York.

Like many immigrants, Pupin found that his early experiences in the United States were not easy. He drove mules, worked on farms, and was employed by a cracker factory while he learned English and saved what money he could. Making use of the resources of the Cooper Union in his spare time, he qualified for entrance to Columbia College in 1879, by passing the entrance exam with high honors. He graduated from Columbia with honors in 1883. He held the John Tyndall Fellowship at the university and was president of his class. He became a U.S. citizen the day before graduation. Pupin then spent two years at Cambridge University and continued his education in 1885 at the University of Berlin, studying and conducting research in experimental physics under Hermann Von Helmholtz. He obtained his Ph.D. in Berlin in 1889.

Pupin returned to New York that year to assume the position of teacher of mathematical physics at Columbia. He and Francis Bacon Crocker comprised the faculty of the newly created Department of Electrical Engineering there. Though the department could make no claims to having the most modern or even sufficient equipment, the laboratory building was known as the cowshed. Pupin completed some of his most important work during these early years at Columbia. In 1894, he studied wave propagation in a vibrating string, noting that these waves did not dissipate as rapidly in a string which had weights suspended from it at equal intervals as in an un-weighted string. He applied this finding to long distance telephony, ascertaining the correct spacing of inductance or loading coils along telephone lines to remove the barrier of distance from telephone communication. Other important inventions followed. In 1896, he developed a method of rapid x-ray photography that required an exposure of only a fraction of a second, rather than that of an hour or more, by placing a fluorescent substance between the photographic plate and the object to be photographed.

He remained with Columbia for life, progressing through the ranks to instructor in 1890, adjunct professor in 1892, professor in 1901, and professor emeritus in 1931. During his long career, he numbered Gano Dunn, Robert Millikan, Edwin Armstrong, and Irving Langmuir among his students. Pupin was president of the Institute of Radio Engineers (IRE) in 1917 and of the American Institute of Electrical Engineers (AIEE) in 1925 to 1926. The AIEE honored him with its Edison Medal in 1920 for his work in mathematical physics and its application to the electric transmission of intelligence. In 1915, he was made a Fellow of both the AIEE and the IRE organizations. Michael Pupin’s autobiography, From Immigrant to Inventor, won the Pulitzer Prize in 1924.
John Stone Stone invented the Stone common battery, and served as associate engineer for the American Telephone and Telegraph Company's research and development department. Born in Dover, Virginia, on 24 September 1869, Stone spent the first several years of his life in Egypt and the Mediterranean. After returning to the United States, Stone attended the Columbia University School of Mines and Johns Hopkins University. He began his career in 1890 as an experimentalist in the American Bell Telephone Company laboratory in Boston, Massachusetts. He left Bell after nine years and spent some time as special lecturer on electrical oscillations at MIT. In 1902, he became director, vice president, and chief engineer of the newly incorporated Stone Telegraph & Telephone Co., which manufactured and leased wireless telegraph apparatus. He served as president and chief engineer of the firm from 1908 to 1910. For the next 10 years, he turned to consulting and acting as an expert witness in patent cases. During this period, he wrote a defense of Nikola Tesla’s priority in *Radio and Continuous-Wave Radiofrequency Apparatus*. In 1920, he became associated with the American Telephone and Telegraph Company as associate engineer-at-large of the research and development department and remained in that position for 15 years.

Stone made many contributions to the fields of telephony and radio telegraphy. While working at Bell, he invented the Stone common battery system and assisted in developing the carrier current system of transmission over wires and methods of uniformly loading telephone cables with inductance. He held several patents, including one for a system of loosely coupled, tuned circuits for radio transmission and reception (1902), the priority of which over Marconi’s similar system was established by a U.S. Supreme Court decision after Stone’s death. He was the author of several important technical papers, including “The Practical Aspects of the Propagation of High Frequency Waves Along Wires,” for which he was awarded the Franklin Institute Edward Longstreth Medal in 1913.

He was instrumental in the founding in Boston of the Society of Wireless Telegraph Engineers (SWTE) in 1907, and served as its president until 1909. That organization originally provided a forum for the reading and discussion of technical papers for the staff of the Stone Telegraph & Telephone Co., but was then expanded to accommodate radio engineers in general. In 1912, SWTE merged with The Wireless Institute to form the Institute of Radio Engineers (IRE). Stone was a member of the Board of Directors of the IRE from 1912 to 1917, vice president in 1913 and 1914, and president in 1915. He was made a Fellow of the IRE in 1915.

**John Stone Stone**

(24 September 1869 – 20 May 1943)

For his valuable pioneer contributions to the radio art.

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**Early 4 channel tuned radio receiver of the type designed by Stone**
Lee de Forest was born on 26 August 1873, and grew up in Alabama. He became interested in machinery as a young child but repeatedly clashed wills with his father, who wanted him to study for the ministry. Desperate to convince his father to send him to the Sheffield Scientific School at Yale, he forged his father's name on a letter to Thomas Edison asking the great inventor what a man should do with a son who wanted to become an engineer. Edison never replied, but de Forest was eventually allowed to follow his scientific inclinations.

De Forest's first job was at Western Electric in Chicago, Illinois. He worked his way up to the experimental laboratory and developed a few modestly successful inventions, which spurred him to move to New York and start the De Forest Wireless Telegraph Company in 1902. In 1907, de Forest patented the Audion, a three-element vacuum tube that was a sensitive wireless receptor. He began to experiment with broadcasting speech and music and discovered that he could cause regenerative oscillation by feeding the output of the Audion back into its grid. This discovery allowed for more powerful and effective signal transmission.

De Forest was a pioneer broadcaster in addition to an inventor and engineer. He set up a radio station in the Bronx in 1916. However, his reliance on spark transmitters and inability to make radio transmission profitable excluded him from broadcast success. From this period on, de Forest was involved in several failed companies and long patent suits. One of the most famous patent battles was with Edwin H. Armstrong. Armstrong had used the Audion as a basis for his regenerative circuit, which was much more successful. De Forest won the suit, but his peers felt that the real scientific achievement belonged to Armstrong.

During the 1920s, de Forest began to work on a system for producing motion pictures with sound. The operating quality of his optical recording system was poor and failed to interest the film industry. However, when the motion picture industry later adopted the concept of sound on film, a process very similar to de Forest's was used. By the end of his career, de Forest earned more than 300 patents but never achieved the status of “Father of Radio” that he sought for himself.

He received numerous awards recognizing his contributions, including the 1946 Edison Medal from the AIEE for pioneering achievements in radio and for the invention of the grid-controlled vacuum tube with its profound technical and social consequences.

For his major contributions to the communications arts and sciences, as particularly exemplified by his invention of that outstandingly significant device: the three-electrode vacuum tube, and his work in the fields of radio telephonic transmission and reception.
The son of an Episcopal minister, Reginald A. Fessenden was born on 6 October 1866, in East Bolton, Quebec, Canada. A well-known pioneer in radio communications, Fessenden became a strong advocate of continuous-wave radio as an alternative to spark systems and he opposed excessive government regulation of the emerging industry. A prolific inventor, he introduced a number of important technical innovations. His Christmas Eve Broadcast has been dedicated an IEEE Milestone in Electrical Engineering and Computing. Fessenden graduated from Trinity College School and continued his education at Bishop’s College while teaching mathematics at Bishop’s College School. He then taught for two years at Whitney Institute in Bermuda before moving to New York City in 1886 where he worked as a tester for the Edison Machine Works on electric power distribution systems. In 1887, he joined the research staff at Edison’s new laboratory facility in West Orange, New Jersey, and worked there for about three years. He also worked for the United States Electric Company and for the Stanley Electric Company before accepting an invitation to teach electrical engineering at Purdue University in 1892. The following year, he joined the engineering faculty at the Western University of Pittsburgh where he taught and did research for the next seven years.

Fessenden and some of his more advanced students undertook research relating to wireless communication and he presented a paper on the possibilities of wireless telegraphy at a meeting of the American Institute of Electrical Engineers (AIEEE) in November 1899. He also proposed an electostatic doublet theory of atoms in solids and used it in an attempt to link data on atomic volume and spacing to properties of materials such as cohesion and elasticity. In 1900, he published a paper in the Physical Review concerning fundamental theories of matter, electricity, magnetism, and the ether. Fessenden gave up his academic position in 1900 to accept an offer from the U.S. Weather Bureau to develop a wireless network for communication with weather stations. It was during this period that he invented the liquid barretter as a wave detector which proved more sensitive and reliable than the coherer detector. The barretter employed a thin platinum wire immersed in a cup of nitric acid as a rectifier of high-frequency signals. Fessenden also conceived the heterodyne radio receiver which employed a local oscillator to mix with incoming signals. The Weather Bureau project proved unsuccessful but, in 1902, Fessenden persuaded two Pittsburgh financiers to invest in a new firm known as the National Electric Signaling Company (NESCO) to develop wireless communication commercially. The broadcasts from Brant Rock in December 1906, were part of an effort by NESCO to publicize and market the wireless system developed by Fessenden and his assistants. The Christmas Eve program as recounted by Fessenden consisted of “... first a short speech by me saying what we were going to do, then some phonograph music... Then came the violin solo by me, which I sang one verse of... though the singing, of course, was not very good”

Following disputes over marketing strategy with his financial backers, Fessenden terminated his connection with NESCO in 1911, and it soon went into receivership. He did some consulting work for the Submarine Signal Company during World War I and invented a sonic depth finder. He became involved in protracted, patent litigation with the Radio Corporation of America during the 1920s which culminated in an out-of-court settlement that enabled him to retire to Bermuda. Late in life, he became interested in ancient accounts of the lost continent of Atlantis and authored a treatise entitled The Deluged Civilization of the Caucasus Isthmus.
Early Medal of Honor History

A Design for the Medal
The Institute of Radio Engineers (IRE) awarded the task of designing its medal to the well-known sculptor Edward Field Sanford, Jr. of New York. Sanford was born in New York in 1886. He studied at the Art Students League and the National Academy of Design in 1907 and 1908, and attended the Academie Julian in Paris and the Royal Academy in Munich. Sanford’s best-known works included the Charles Francis Adams Memorial at Washington and Lee University in Lexington, Virginia, and the two colossal bronze groups for the Core Mausoleum in Norfolk, Virginia. Sanford was at the forefront of a new movement in American art during the 1920s that supported large public sculpture. He later produced many colossal Gothic figures and bronze facades for power companies, cemeteries, and courthouses, as well as the base panels of the New York State Roosevelt Memorial. Sanford also designed medallions and bronze reliefs.

Sanford’s design for the obverse or face of the IRE’s Medal of Honor was inscribed with the words “Institute of Radio Engineers” and an allegorical representation of electromagnetic waves interlinking the magnetic and electric forces in space. The reverse or back includes a laurel wreath surrounding the inscription “To___, In Recognition of Distinguished Service in Radio Communication” followed by the date.

First Recipient of the Medal of Honor
Due to the U.S. involvement in World War I, the IRE postponed its presentation of the first Medal of Honor, although it did announce that it would be presented to Captain Edwin H. Armstrong for his work on receiving apparatus. His selection was seen as an inspiration to amateur radio experimenters since Armstrong’s regenerative circuit was evolved in his amateur days. The IRE postponed the presentation of Armstrong’s 1917 Medal and did not award a Medal of Honor in 1918 due to the war. Finally, in April, 1919, the IRE announced that Mr. (now Major) Edwin H. Armstrong would receive his 1917 Medal “in recognition of his work and publications dealing with the action of the oscillating and non-oscillating audion.
Guglielmo Marconi was born in Italy in 1874. Because Marconi applied himself only in the subjects that he was fascinated by, physics and chemistry, he dropped out of several schools and was largely educated by private tutors at the family’s residences in Livorno and Bologna, Italy. In 1894, after reading articles about electromagnetic or radio waves and Heinrich Hertz’s death, he began thinking about building a device to transmit long and short bursts of radio waves over long distances. He understood that this method of communication would be faster than telegraphy and less cumbersome because no wires would be involved. His parents let him use the upper floor of their Bologna home, Villa Griffone, as a laboratory. Over the summer and fall of 1895, Marconi duplicated Hertz’s short-range experiments and then succeeded in sending signals over longer distances, he took his ideas and equipment to London, where William Preece, chief engineer of the British Post Office, supported his continuing experiments and demonstrations. Marconi eventually raised money privately and established the Wireless Telegraph and Signal Company in London. By 1899, Marconi was constructing wireless stations on both sides of the English Channel and in 1901, he installed transmitters powerful enough to send messages across the Atlantic. The following year, he established a company in New York. He lived a transatlantic existence, working in both Europe and the United States.

Marconi was widely recognized for his work in his own time. In 1909, he was awarded the Nobel Prize in Physics. Grateful Titanic survivors presented him with a gold medal in recognition of his work in radio, which helped save their lives in the 1912 disaster. Marconi and his wireless stations were illustrated on dozens of different cards sold with packs of cigarettes and he had at least two brands of cigars named after him.

Unlike many other radio pioneers, Marconi was a savvy businessman. He went to great lengths to control his own patents as well as those of others in the field. By 1912, the Marconi Company essentially controlled the global wireless communications industry. This virtual monopoly led to corruption charges in the effort to build communications networks across Europe.

Having a longtime passion for the sea and the intellectual solitude that it offered, in 1919, Marconi bought a yacht and renamed it Elettra or Amber, a natural spark generator. A state-of-the-art floating laboratory, Elettra became the site of his research breakthrough in the early 1920s on shortwave, or high frequency, radio transmission. This finally made long-distance wireless commercially competitive with cable telegraphy and greatly expanded the communications capacity of the earth’s electromagnetic spectrum. Besides his research, Marconi also hosted many parties aboard the ship, with guests ranging from laboratory assistants to royalty.

In addition to his scientific and business interests, Marconi retained his loyalty to his native country, establishing wireless networks in Italy’s imperial expansion in Libya in 1911 to 1912, and serving militarily and politically during World War I. He undertook many diplomatic missions as a government representative, serving as a member of the Italian War Commission to the U.S. government and delegate to the Peace Conference in Paris in 1919. In 1923, he became
a member of Benito Mussolini’s Fascist Party in 1923, which he supported for the rest of his life. The day after Marconi’s death in 1937, wireless operators and broadcasters around the world shut down their transmitters for two minutes of global radio silence.

Marconi was elected an honorary member of the Institute of Radio Engineers (IRE) on 14 August 1917. Among the many honors he received were the Nobel Prize in Physics in 1909, the Albert Medal of the Royal Society of Arts, and the 1932 Kelvin Medal of the Institution of Civil Engineers. The Italian government decorated him with the Italian Order of St. Maurice and St. Lazarus and the Grand Cross of the Crown of Italy. In 1915, he was nominated Senatore of the Kingdom of Italy. In the U.S., he received the Franklin Institute’s Franklin Medal and the American Association of Engineering Societies’ John Fritz Medal.

Guglielmo Marconi’s first experiments in wireless telegraphy marked the beginning of radio communication and are celebrated with an IEEE Milestone, featuring two plaque citations:

MARCONI’S EARLY EXPERIMENTS IN WIRELESS TELEGRAPHY, 1895 In this garden, after the experiments carried out between 1894 and 1895 in the “Silkworm Room” in the attic of Villa Griffone, Guglielmo Marconi connected a grounded antenna to its transmitter. With this apparatus the young inventor was able to transmit radiotelegraphic signals beyond a physical obstacle, the Celestini hill, at a distance of about two kilometres. The experiment heralded the birth of the era of wireless communication.

MARCONI’S EARLY EXPERIMENTS IN WIRELESS TELEGRAPHY, 1895 On this hill, during the summer of 1895, the radiotelegraphic signals sent by Guglielmo Marconi from the garden of Villa Griffone were received. The reception was communicated to Marconi with a gunshot. This event marked the beginning of the new era of wireless communication.

The plaques can be viewed at the two sites in which Marconi carried out his first experiments: in the garden of Villa Griffone, his family home, where Marconi transmitted his wireless signals, and beyond the Celestini hill, where those signals were received. Villa Griffone, Marconi’s family home in the second half of the 19th century, is now the site of the Guglielmo Marconi Foundation and of the Marconi Museum, which includes the young Marconi’s laboratory, on the upper floor of the villa.
Radio

For much of the 20th century, radio was one of the most popular forms of entertainment. People sat on the floor and listened to programs, much as we watch television today. Radio began in 1888, when German physicist Heinrich Hertz demonstrated the existence of radio waves (the unit of measurement for radio wave frequency was named in his honor). Radio waves, or electromagnetic waves, have the lowest frequency and the longest wavelength of any type of radiation in the electromagnetic spectrum. In a classroom experiment, Hertz made a condenser that produced these waves. Hertz didn’t think his experiment had any practical applications, but Guglielmo Marconi did.

Marconi thought to use electromagnetic waves to transmit signals. At first, Marconi was able to transmit Morse Code only a couple of miles. But in 1901, he built a transmitter strong enough to send messages across the Atlantic Ocean. This was the beginning of wireless communication. It was even faster than the telegraph and, best of all, no expensive wire or cable had to be laid. Marconi created a very successful company that utilized radio to transmit Morse Code. One of the industries to benefit most from Marconi’s work was the shipping business. Radio operators sent messages to the shore for passengers and for emergencies it could be the only hope of contacting rescue ships.

Radio transmission of Morse Code was certainly useful, even lifesaving, but others began wondering if it could be used to transmit additional sounds, such as voice. On Christmas Eve, 1906, Reginald Fessenden proved this possible when he transmitted the first music and voice program. It originated in Massachusetts and was received as far away as Virginia.

While many inventors thought of radio as a substitute for the telegraph or telephone, which transmit information from one point to another point, the fact was that anyone with a radio receiver could listen in on these “private” communications. This lack of privacy in radio became a benefit. Westinghouse, a company that manufactured radio receivers, set up its own station in Pittsburgh, Pennsylvania, to broadcast information and was granted the first U.S. broadcasting license for its station, KDKA, in October of 1920. On 2 November 1920, KDKA held the first scheduled public broadcast.
As more people began listening to radio broadcasts, inventors sought ways to design better receivers. Using electron tubes, a new technology, engineers introduced more sensitive receiver technology, such as the regenerative and superheterodyne circuits invented by American Edwin Armstrong.

In addition to being the first to transmit voice over radio, Reginald Fessenden developed amplitude modulation or AM, which was an improved way to broadcast voice and music rather than the technologies designed for Morse Code. But AM faced challenges. The receiver often encountered superfluous noise during the broadcast from sources in the atmosphere like lightning, sometimes referred to as static. American inventor Edwin H. Armstrong came up with a different system—frequency modulation or FM. By the 1930s, Armstrong was able to improve the sound quality of radio transmissions by using FM. It would be many more years, however, before ordinary people began tuning in. For the time being, AM was still king.

By the 1940s, radio broadcasting was a powerful communications tool and reached its golden age. The programming on radio was much like today’s TV, with news, sports, dramas, comedy shows, and soap operas—not to mention commercials. Just as people today spend their evenings glued to the television, people gathered in their living rooms to listen to the radio.

There were almost no portable radios, except in cars. By the 1930s, they were the single most popular item of optional equipment in cars. After the 1947 invention of the transistor, however, radios decreased in size to the point where they could truly be taken anywhere. The transistor also made it possible to combine AM and FM radios (and later tape and CD players) into a single, small package.

Despite competition from television and the Internet, radio remains a major source of information and entertainment. Some radio talk-show hosts have tens of millions of listeners, and for many people, radio remains their primary resource for music.
Ernst F. W. Alexanderson invented a self-exciting alternator. He also designed a series of high-frequency alternators for radio use. Alexanderson was born on 25 January 1878, in Uppsala, Sweden, and graduated in engineering at the Royal Technical University in Stockholm in 1900. He spent a year taking advanced studies in electrical engineering in Germany before coming to the United States. He worked for a few months as a draftsman for the C&C Electric Company in New Jersey, before joining the General Electric Company (GE) in Schenectady, New York, in 1902. One of his first inventions was a self-exciting alternator which was the subject of a paper published by the American Institute of Electrical Engineers (AIEE) in 1906. Subsequently, he devised a modified repulsion motor for electric railway use, which he described in a 1908 AIEE paper.

Beginning in 1904, Alexanderson designed a series of high-frequency alternators for use in radio as sources of transmitter power which provided an alternative to spark and arc transmitters. One of his early radio alternators was employed by Reginald Fessenden for experiments with voice and music broadcasts from a station in Brant Rock, Massachusetts, in December 1906. A later and higher-powered radio alternator capable of 50 kW output designed by Alexanderson was installed in New Brunswick, New Jersey, in 1917 and used for transatlantic communication during World War I. The first of several 200-kW Alexanderson radio alternators was located at the New Brunswick station in 1918 and served as the prototype for a long-wave radio network established by the Radio Corporation of America (RCA) following its formation in 1919. Alexanderson served as the first chief engineer at RCA and divided his time between RCA and GE for several years.

In August 1920, Alexanderson published a paper in the Proceedings of the IRE, where he noted that it already had become generally known that a new highway for world traffic has been opened up through the development of transatlantic radio communication. He commented that the most suitable band for transatlantic radio traffic was at wavelengths ranging from 10 to 20 km and this would provide room for only about 12 first class transmitting stations. He defined a first-class station as one with enough power so that its messages could be received in all parts of the world. He suggested that increasing transmitting speed, more directive antennas, and somewhat closer spacing of signal frequencies were ways to increase radio traffic in the optimum band. He provided some technical information on the 200-kW radio alternator, the magnetic amplifier, and a multiple antenna which were key elements of his long-wave system.

During the late 1920s and the 1930s, Alexanderson investigated short-wave propagation, radio facsimile, mechanical scan television, and radio altimeters. He demonstrated television in the home in 1927 using a rotating disk type receiver. He also studied and made inventions relating to electronic power conversion, direct-current power transmission, and gun-control systems. During World War II, he worked on analog computers for use with radar and developed military applications of the amplidyne.

Alexanderson retired from GE in 1948 although he continued as a consultant to the company for several more years. His numerous inventions and other achievements gained him recognition as one of the most outstanding members of the electrical engineering profession during a career of over a half century. He received more than 340 U.S. patents, with the final one issued when he was 95 years old. He was president of the IRE during 1921. He received the Edison Medal of the AIEE in 1944.
IEEE Medal of Honor
Wall of Honor

The Medal of Honor Wall Ribbon-Cutting Ceremony took place on 7 September 2017. This wall was created for the 100th anniversary of the Medal of Honor.

Two Medal of Honor recipients attended the celebration – Alfred Cho, the 1994 recipient, and Bob Dennard, the 2009 recipient. Lew and Bobbie Terman also attended the celebration. Lew’s father, Frederick Terman, was the 1950 IEEE Medal of Honor recipient.

The name of every Medal of Honor recipient is included on the wall, with room for the names of additional recipients for many years to come. There is also an interactive kiosk where users can search for more information about the recipients.

As part of the celebration, the IEEE History Center team assembled a special display case with artifacts and memorabilia from the first 100 years of the Medal of Honor, shared a brief history of the Medal with the guests, and offered a tour of the IEEE Archives.
Edwin Howard Armstrong is widely regarded as one of the foremost contributors to the field of radio-electronics. Among his principal contributions were regenerative feedback circuits, the superheterodyne radio receiver, and a frequency-modulation radio broadcasting system. He was inducted into the National Inventors Hall of Fame in 1980.

Armstrong was born on the Upper West Side of Manhattan, New York City, on 18 December 1890, the oldest child of prosperous and devoutly Presbyterian parents. Radio became Armstrong's passion when he learned that Guglielmo Marconi had invented a wireless telegraph in his backyard. Armstrong built his own station and 30-meter-tall antenna.

In 1909, he began studying electrical engineering at Columbia University under the celebrated professor Michael J. Pupin. About a year before he graduated in 1913, he devised a circuit that revolutionized radio technology. Using a triode as an amplifier, he fed back part of the output to the input, and thereby obtained much greater amplification. Armstrong made a further discovery with this circuit: just when maximum amplification was obtained, the signal changed suddenly to a hissing or a whistling. He realized this meant that the circuit was generating its own oscillations, and thus that the triode could be used as a frequency generator. The first of these discoveries of a powerful amplifier vastly increased the sensitivity of radio receivers to distant stations, while the second of an oscillator led to the use of the electron tube in transmitters and also in receivers for an added function, heterodyne reception.

In 1901, Reginald Fessenden had introduced to radio the heterodyne principle: if two tones of frequencies A and B are combined, one may hear a tone with frequency A minus B. Armstrong used this principle in devising what came to be called the superheterodyne receiver. The essential idea is to convert the high-frequency received signal to one of intermediate frequency by heterodyning it with an oscillation generated in the receiver, then amplifying that intermediate-frequency signal before subjecting it to the detection and amplification usual in receivers. RCA marketed the superheterodyne beginning in 1924, and soon licensed the invention to other manufacturers. It became the standard radio reception circuit.

In the early 1920s, Armstrong turned his attention to what seemed to him, and to many other radio engineers, as the greatest problem, namely, the elimination of static. He wrote, “This is a terrific problem. It is the only one I ever encountered that, approached from any direction, always seems to be a stone wall.” Armstrong eventually found a solution in frequency modulation, which is a different way of impressing an audio signal on a radio-frequency carrier wave. In the usual technique, known as amplitude modulation (AM), the amplitude of the carrier wave is regulated by the amplitude of the audio signal. With frequency modulation, the audio signal alters instead the frequency of the carrier, shifting it.

In recognition of his work and publications dealing with the action of the oscillating and non-oscillating audio.

Edwin H. Armstrong
(18 December 1890 – 31 January 1954)

Armstrong Lab Columbia

Armstrong on WJZ Transmitter
down or up to mirror the changes in amplitude of the audio wave. He soon found it necessary to use a much broader bandwidth than AM stations used. Today, an FM radio channel occupies 200 kHz, 20 times the bandwidth of an AM channel, but doing so gave not only relative freedom from static, but also much higher sound-fidelity than AM radio offered.

With the four patents for his FM techniques that he obtained in 1933, Armstrong set about gaining the support of the Radio Corporation of America (RCA) for his new system. RCA engineers were impressed, but the sales and legal departments saw FM as a threat to RCA and the National Broadcasting Company (NBC) relationship with AM radio stations. David Sarnoff, the president of RCA, had already decided to promote television vigorously and knew the company and the stations did not have the resources to develop or implement a new radio system at the same time. Moreover, in the economically distressed 1930s, there was even less popular demand for better sound quality, so there was not thought to be a large market for products offering it.

Armstrong gained some support from General Electric and Zenith Radio Corporation, but he carried out the development and field testing of a practical FM broadcasting system largely on his own. He gradually gained the interest of engineers, broadcasters, and radio listeners, and in 1939, about 20 experimental stations were broadcasting FM. These stations could not, according to FCC rules, sell advertising or derive income in any other way from broadcasting, but finally, in 1940, the FCC decided to authorize commercial FM broadcasting, allocating the region of the spectrum from 42 MHz to 50 MHz to 40 FM channels. In October 1940, it granted permits for 15 stations. Zenith and other manufacturers marketed FM receivers, and by the end of 1941, nearly 400,000 sets had been sold.

U.S. entry into World War II brought a halt both to the granting of licenses for FM stations and to the production of FM receivers. During the war, Armstrong experimented with the use of FM radio for radar purposes at Camp Evans in New Jersey. He modified an SCR-271 radar and created an experimental FM doppler radar system that operated on a narrow receiver bandwidth in sync with the transmitter. Although abandoning the radar to return to his battle for FM radio, his system was modified for use in Project Diana’s bounce of a radar signal off the Moon.

After the war, FM broadcasting was dealt a severe blow when the FCC moved the FM spectrum allocation to 88 to 108 MHz and thus making the 400,000 receivers obsolete. This allocation, however, allowed for two and a half times as many channels, and the FM industry slowly recovered, though it did not enjoy rapid growth until the late 1950s. In the late 1970s, FM broadcasting surpassed AM in share of the radio audience, and by the end of the 20th century, its share was triple that of AM broadcasting.

Among the many honors Armstrong received was the Edison Medal of the American Institute of Electrical Engineers (AIEE.)

“This is a terrific problem. It is the only one I ever encountered that, approached from any direction, always seems to be a stone wall.”
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The profession of engineering has a long, rich, and significant history, bringing science and technology together to improve the lives of individuals and provide substantial benefits to humanity. Therefore, it is essential that the stories of pioneering technological developments and discoveries, and the people behind them, are preserved for generations to come.”

- K. J. Ray Liu, 2022 IEEE President & CEO and Asad M. Madni, 2022 IEEE Medal of Honor Recipient