

Introduction

Science or Magic?

How did the human race develop palm-sized devices that enable people to converse and exchange text messages worldwide, snap and upload pictures, download music and videos, and determine their precise locations?

I've been interested in the history of technology for a long time, having worked in the high-tech industry for 30 years; I specifically wanted to know more about the evolution of wireless, and I was surprised that I couldn't find a comprehensive history. There are many books on key figures and time periods in the history of wireless, but none that explain how we got to where we are today. So I decided to write such a book.

The following pages trace the entire journey—from the discovery of fundamental scientific effects to the development of next-generation wireless standards.

Arthur C. Clarke said that a sufficiently advanced technology is indistinguishable from magic. But most magic is just sleight of hand. Drawing back the curtain reveals the true sources of advanced wireless technology: brilliant science, ingenious products, and innovative business models.

Science rarely progresses in a straight line. Nor is there a single correct way of doing science. The history of wireless technology shows that the clash of opposing philosophies of science can be a catalyst and even a necessary ingredient for progress.

The history of wireless technology cannot be separated from the history of wireless business. Technology harnesses science to create valuable products and services. Business delivers those products and services to customers. Before a technology comes to life, someone has to determine who needs it and what they're going to do with it. It's also business's job to figure out how best to package and distribute technology—how to get it in the hands of as many people as possible in a form they can use.

The story of wireless is fascinating and inspiring, and the technology should be celebrated. Great technology is every bit as creative as great art. While we can often perceive the creativity in a work of art directly, we usually need to know the story behind a technology to fully appreciate the creativity that went into its development.

No one has figured out how to bottle and sell creativity, but the history of wireless provides important clues about its sources. There are lessons about persistence; luck and preparedness; synthesizing ideas; challenging common assumptions; and more.

The first decision for anyone writing history is deciding where to begin. A history of wireless communications could begin with the first person to commercialize the technology, Guglielmo Marconi. Or it could start with Heinrich Hertz, the first scientist to create and detect radio waves. Why not go back further? After all, Hertz was only verifying James Clerk Maxwell's theory of the electromagnetic field. The dilemma is that there would not have been a Marconi without a Hertz, nor a Hertz without a Maxwell, nor a Maxwell without a Faraday.

I chose to start with the debate between Luigi Galvani and Alessandro Volta that led to the invention of the battery. (Galvani actually witnessed wireless communications but did not understand its significance.) Once investigators were armed with a source of continuous current, the discovery of electromagnetism became almost inevitable.

The narrative proceeds to Michael Faraday, the great experimentalist who added more to our knowledge of magnetism and electricity than anyone before or since. Faraday laid the foundation for James Clerk Maxwell, who translated Faraday's observed facts into the symbolic language of equations and assembled them into a comprehensive theory of electromagnetism—an achievement that, ironically, might have been disowned by the strict empiricist Faraday.

A note about terminology: most early scientists were known as "natural philosophers." That term is used here, as well, because that's what investigators such as Michael Faraday wanted to be called. Faraday detested the word "physicist." I've also kept the jargon to a minimum; however, some of it is unavoidable. Most concepts are explained in place and reviewed in the Glossary.

Faraday did science in the laboratory; Maxwell did science in his head. Heinrich Hertz proved that Maxwell's fertile imagination produced something concrete. There really are electromagnetic waves that propagate through free space.

Next the journey takes us on an important detour. Wireless communications is technology for conveying human intelligence. There would be no wireless telegraph without Samuel F.B. Morse's wired telegraph and there would be no wireless telephone without Alexander Graham Bell's wired

telephone. The stories behind these two great inventions are essential to the history of wireless.

The idea seems obvious today but taking wireless out of the laboratory, fashioning it to serve specific applications, and offering it for sale initially faced tremendous resistance. With the telegraph going great guns, Guglielmo Marconi struggled to build the first wireless business. He built it around a technology—spark transmission—that would prove a dead end. (At least, temporarily; more than a century later a technology called ultra wideband is emerging that uses spark-like signals.)

That brings us to several lesser known names: the people who put wireless on the right technological footing. Reginald Fessenden and Edwin H. Armstrong led the way. Fessenden understood that wireless needed to be based on continuous waves rather than sparks. Armstrong took the vacuum tubes invented by John Ambrose Fleming (the valve) and Lee de Forest (the Audion) and built vastly superior transmitters and receivers. Amateur radio operators—Armstrong was one of them—contributed numerous refinements.

David Sarnoff thought about becoming an engineer, but he ended up becoming the prototype for today's high-tech business leaders. He was a hands-on executive who understood that success requires the right technology, the right products, and the right marketing. He was also one of the first business leaders to successfully navigate the hazardous waters of intellectual property, government policy and regulation, and unscrupulous competition. During this era the word “radio” gradually replaced the word “wireless.”

Wireless underwent a dramatic transformation in the years leading up to World War II. The wireless market, once the exclusive domain of entrepreneurs and small businesses, became a playground for big corporations. New technology was developed by teams. It becomes harder to identify individual inventors, but they are still there.

The aftermath of World War II saw the commercialization of frequency modulation, mobile radio, television, and mobile telephone. Less well known, it was also the gestation period for the wideband radio technology that later (after being declassified by the U.S. government) enabled unlicensed wireless LANs, the Global Positioning System (GPS), and third generation (3G) cellular systems.

We finally arrive at the modern era of wireless. It would be difficult if not impossible to recount this part of the story without research at the frontlines of development. Fortunately, several leading actors—including Andrew Viterbi, Martin Cooper, and Donald Cox—contributed to my research.

It would be hard to exaggerate the impact of cellular telephone on culture and the global economy. Ironically, its development was largely hidden from view—and its commercialization was significantly delayed. Perhaps that explains why it has grown way beyond the most optimistic forecasts. There are well over two billion mobile phone subscribers today and the number could reach three billion by 2010.

The historic role of industry standards must also be acknowledged. A degree of conformity is required so that products from different manufacturers can talk to each other. But it would be remiss to deny the impetus of proprietary technologies and business contrarians. The evolution of wireless continues to be driven by the clash of opposing ideas.

By no means has the era of individual discoverers and inventors come to an end. The current industry is obsessed with planning, and much is already decided about the next generation of wireless technology. Or so the experts think. Even the best planning cannot prevent unexpected twists and turns in the road ahead.

The book concludes by identifying some key lessons. How did the science behind wireless technology evolve? Why did some technologies succeed and others fail? And what can scientists, inventors, and entrepreneurs learn from the history of wireless about creativity? The history of wireless provides a treasure trove of lessons about how to avoid pitfalls—and how to succeed in science and business.

PART I

Chapter One

Luigi's Dancing Frogs

On January 26, 1781 an Italian obstetrician and physiologist stumbled on a most curious phenomenon. Luigi Galvani placed a dissected frog on a glass plate at one end of his laboratory table. At the other end of the table sat a hand-cranked static electricity generator. When one of his assistants lightly touched a scalpel to the frog's inner crural nerves, the animal's legs convulsed violently. Another assistant noticed that the contractions occurred at precisely the moment Galvani's wife Lucia drew a spark from the static-making machine.

It was the first recorded example of wireless communication. The static electricity generator was the transmitter; the frog's nerves and muscles were the receiver.

Galvani is not remembered as a wireless pioneer. He did not even realize he was witnessing wireless communications. The foundation of knowledge needed to conceive of such a thing did not yet exist. Instead, he viewed the incident through the prism of 18th century science—an era dominated by Isaac Newton's theory of gravity based on unfathomable action-at-a-distance. In Galvani's eyes, sparks act on a frog several feet away just as the earth exerts its pull on an apple falling from a tree. He could easily observe the effects on the frog; understanding how the spark projected its force—and what happened in the intervening space—was beyond comprehension.

More intriguing to Galvani was the spark's ability to excite the "highly subtle fluid that exists in the nerves." He hoped the newly discovered contractions-at-a-distance would help him isolate and illuminate the operation of nerves and muscles.

Encouraged by these novel effects, Galvani performed innumerable experiments over the next several years, trying every conceivable variation. He found, for example, that atmospheric electricity from an approaching storm can trigger frog leg contractions. Then in September of 1786 he made another serendipitous discovery. Tinkering on a clear day with his atmospheric setup, consisting of a dissected frog draped over a terrace railing with an iron hook piercing its spinal chord, he observed that merely pressing the iron hook against the railing was sufficient to make the frog's legs jump. Galvani believed this corroborated his theory that the contractions were due

not to external forces but innate “animal electricity,” the delicate equilibrium of which is easily upset by nearby sparks, an approaching thunderstorm, or a suddenly completed circuit.

Galvani’s animal electricity experiments were carefully studied by Alessandro Volta, professor of physics at the University of Pavia. At first enthusiastic about Galvani’s research, Volta soon changed his mind, suspecting that in his eagerness to prove the animal electricity theory Galvani overlooked an alternative explanation: contact between dissimilar metals produces electricity.

Volta’s criticism initiated one of the most famous debates in the history of science. Did animal electricity or contact electricity cause the frog muscle contractions? The debate showed that even the most honest and meticulous scientists, when guided by divergent worldviews, may disagree about the causes of plainly observable effects. The desire for vindication drove both to further discoveries—and led one to an invention that would prove a watershed in the study and application of electricity.

Egged on by their respective supporters, each scientist sought a crucial experiment to prove his theory. Galvani struck first. He showed that contractions could be produced with a homogeneous metal arc and even with no metal whatsoever—flatly contradicting Volta’s “dissimilar metals” claim.

It was a setback for Volta and he knew it, but he refused to abandon his theory that an external source of electricity caused the contractions. Pressing on with his experiments, Volta built a columnar apparatus consisting of alternating pieces of silver and zinc separated by moistened disks. On March 20, 1800 (more than a year after Galvani’s death) Volta wrote a letter to Sir Joseph Banks, Secretary of the Royal Society in London that for all intents and purposes brought the debate to a close. He announced that by arranging specific materials in the proper order—known by posterity as the “voltaic pile”—he created a source of continuous current. Volta invented the battery.

In retrospect, neither scientist was entirely right. Galvani was correct in believing that the animal nervous system generates and uses electricity; Volta was right that different materials can be arranged to produce electricity. But Volta had tactical advantages: he outlived Galvani, excelled at self-promotion, and closed his argument by creating something other scientists could use. With the scientific community in receipt of Volta’s wonderful gift, Galvani slipped into an obscurity from which he did not reemerge for 30 years.

Volta crossed the electric Rubicon. Up to that time, knowledge of electricity was confined to static discharges—equally a subject of scientific

inquiry, parlor entertainment, and dubious medical treatment. By creating a scalable source of continuous current, Volta established the first beachhead in electronics. Easily replicated by others, the voltaic pile quickly enabled a series of discoveries in electrochemistry and electromagnetism. While the wireless incident in Galvani's laboratory is just an historical footnote, Volta's battery cleared a path to the telegraph, the telephone, and wireless.

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Prior to Volta the growth of knowledge about electricity was excruciatingly slow. Thales of Miletus (a Greek city in what is now Turkey) wrote about static electricity in the sixth century B.C., observing that amber ("elektron" in ancient Greek) rubbed with dry materials attracts straw and feather. Anyone who encountered static cling or shock knew almost as much as Thales.

As meager as that knowledge was, two thousand years passed before it was augmented. The English physician and natural philosopher William Gilbert performed the first rigorous survey of electricity and magnetism, recounted in his seminal book "On the Magnet" published in 1600. Gilbert coined the term "electricity" and described how it differed from magnetism. For example, he explained that electrified materials attract unlike materials, while "a loadstone attracts only magnetic bodies."

Further study of electricity required a means of producing static charges on demand. The German inventor Otto von Guericke rose to the challenge, constructing the first static electricity generating machine in 1663. The machine consisted of a ball of sulphur inside a glass globe rotated with a crank against a pad; the globe became electrically charged and could be removed to conduct experiments. Like other natural philosophers of his day, Guericke studied diverse areas of science, and is best known for his dramatic demonstration of atmospheric pressure. (Guericke brought together a pair of hemispheric copper bowls to form a sphere, evacuated the air within the sphere using the pump he invented, and showed that even two teams of horses could not pull the bowls apart.)

Knowledge about electricity experienced a growth spurt in the 1720s. The English chemist Stephen Gray showed that electric charges can travel 150 meters over a wet hemp line and even further over metal wire. Gray also noticed that some materials are better conductors than others, and that the earth acts as a giant receptacle for electric charges. In 1733 the versatile French scientist Charles du Fay, whose interests ranged from botany to