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On the Shoulders of Giants: Reflections on the Creators and Uses of Radio

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(Special Editorial Paper)

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"If I have seen further it is by standing on the shoulders of Giants"
Isaac Newton

ABSTRACT This preface-style article contains a brief account of the creators of radio – Lee de Forest, inventor of the triode; Edwin Howard Armstrong, inventor of regeneration, the superheterodyne, and wide-band FM; and David Sarnoff, head of RCA and champion of electronic television – their influences, and the digital age they helped to bring about.

INDEX TERMS History of radio, radio pioneers, wireless communications.

I. PRELUDE

On July 27, 2012, James Bond and Queen Elizabeth II boarded the Queen's helicopter on the grounds of Buckingham Palace for a flight to the London Stadium in East London. The Queen wore a peach dress, appropriate to her 86 years; Mr. Bond, as she called him, wore his signature black tuxedo. On the way the helicopter flew over crowds of waving Brits, even Winston Churchill standing on his statue's pedestal in Westminster raised his hand and smiled. When they arrived over the stadium, the pair leapt from the helicopter and parachuted 800 feet onto the roof. Shortly after landing, Queen Elizabeth II took her seat beside Prince Philip to preside over the opening ceremony of the Olympic Games.

Of course, the episode was a clever television sleight of hand. A real Daniel Craig playing the real James Bond, as genuine as a fictional hero can be, arrived at Buckingham Palace to meet the real Queen Elizabeth for their helicopter journey. But stunt men, one trussed into a peach dress, parachuted into the stadium. The 80,000 spectators watching understood it was a spoof of Bond films and, with the exception of two American television commentators who believed *the* Queen was descending in a parachute, so did viewers across the globe. Television reviewers thought the trick a light-hearted and fitting way to celebrate Britain and begin the games, which over the next two weeks attracted an estimated 3.6 billion viewers.

The London Olympics became known as the first "social media Games," that moment when electronic technology enabled people across the world to take in the events on a combination of televisions, computers, and mobile devices. They could comment upon their experience on Facebook and Twitter, replay highlights, and look up information about the contenders on a special website (london2012.com). A vast "converged communications network" that combined voice, broadcast, data, mobile, and wireless internet carried as much as 60 gigabits of information a second to 80,000 connections. In just two weeks the infrastructure accommodated an average of 9.5 million global browsers on the internet each day; there were 4.73 billion webpage views, and 1.3 petabytes (quadrillion) of information were downloaded; the BBC offered 24 high definition and 24 standard definition television channels over satellite and cable; and the Olympic Park where the athletes lived and performed was a true global village, the largest public WIFI network in the world.

Editor's Note: This article was solicited from noted author Tom Lewis, whose historic account of the development of radio *Empire of the Air, The Men Who Made Radio* (1991), will be republished by Cornell University Press in a thirtieth anniversary edition later this year. Lewis and Ken Burns turned the book into a PBS documentary film in 1992 and David Ossman made it into a radio drama the same year. The current article serves both as a preface to our technical manuscripts on 5G, as well as to the re-release of *Empire of the Air* later this year. The Editor-in-Chief hopes this slight diversion from our usual research focus will help lend some historic context and perspective to the microwave field, and highlight how far we have come since the early days of wireless communications.

The Games signaled a remarkable moment in the evolution of communication. In less than a century humans had moved beyond the limits of newspapers and books, print technology that informed individual readers in a small region, to radio broadcasting that reached millions of listeners collectively and transcended the confines of geography, to a time when billions of viewers receiving information from low orbiting satellites above the globe, could, if they wished, pass on what they received to others.

Fixing a date when a technology begins is often problematic. In the case of our current technology, certainly Heinrich Hertz's proof of the existence of electromagnetic waves in 1887, Guglielmo Marconi's demonstration of wireless in 1894, Joseph Thompson's discovery of the electron in 1897, Reginald Aubrey Fessenden's development of the heterodyne in principle in 1902, and John Ambrose Fleming's invention of the thermionic valve in 1904 are significant. These men built upon prior work and theories of Michael Faraday, Joseph Henry, and James Clerk Maxwell among others. At the beginning of the twentieth century three Americans employed the knowledge of the past to create the foundations for modern electronics and our digital age: Lee de Forest who invented the three element vacuum tube; Edwin Howard Armstrong, the genius who discovered the fundamental circuits that made broadcasting and receiving possible and whose invention and experiments with wide band FM laid the groundwork for world communication; and David Sarnoff, not an inventor but a sagacious entrepreneur who as head of RCA and NBC was at the forefront of technical development and broadcasting for half a century.

De Forest, Armstrong, and Sarnoff were each self-assured and headstrong in ways that often brought them into a prolonged and hostile drama more worthy of a classical writer like Aeschylus or Sophocles. Still, it was a twentieth-century American drama, played before a backdrop of change that included the expansion of wealth, the rise of corporations, the development of mass culture, and war. And these protagonists possessed all the qualities of character the ancients understood so well: virtue and vice, integrity and fraud, honor and greed, idealism and ambition, jealousy and envy, pride, and genius.

II. THE PLAYERS

Lee de Forest, the first character we encounter in this drama, possessed all the dreams and vices of an incurable romantic. Son of a stern Congregationalist minister, the boy was filled with passionate and often conflicting desires–to do good, to make a fortune, to improve the world, to become famous. He duly recorded in a voluminous diary he kept, of his yielding to impulses of cynicism and callousness, distrust and jealousy. First exhibited in his youth, these characteristics remained with him through his life. At times in his erratic career, he was a willing partner in deception and fraud. Each of de Forest's nearly twenty radio telephone companies ended in bankruptcy and sometimes their officers faced criminal charges. Still, his dreams and aspirations were often prescient. One of the earliest to envision what he called a "radio telephone," a prototype of today's radio receiver, de Forest broadcast opera and music from his laboratory in New York City as early as 1907. His desire to find a new way to capture sound on radio waves led him to create the three-element radio tube, what he called the "Audion." Though he stumbled upon his discovery and did not fully comprehend its operation, Lee de Forest's "Audion" remains the key invention underlying the modern electronic circuits that are part of our daily lives.

Edwin Howard Armstrong possessed the force of genius in his understanding of electromagnetic waves. His discoveries unleashed the potential of electronic communication to the world. Understanding the properties of de Forest's Audion tube which had eluded its inventor, Armstrong created a circuit that turned it into a powerful instrument of receiving *and* transmitting radio waves. He created a novel way of tuning that is the basis of every radio and television today. And above all Armstrong created an entirely new type of broadcasting system, wide-band frequency modulation, which listeners would come to call FM. His inventions made him the largest shareholder in the Radio Corporation of America at one point and brought him additional millions from other companies. Though endowed with a remarkable ability for creative thinking and for challenging accepted beliefs and assumptions about the new science, he was hobbled, and fatally so, by his aloof manner, his contempt for charlatans, and his inflexible will. His scorn for de Forest's inability to understand how his radio tube worked drew him into protracted and exhausting legal battles that he ultimately lost in the Supreme Court. His intransigence and unwillingness to recognize the realities of modern law and American corporations in the twentieth century forced him into another protracted legal battle with RCA over the rights to FM, a struggle which ultimately bankrupted him and led to his death.

David Sarnoff possessed the energy, ability, shrewdness, and determination to be ranked with the most powerful and successful business entrepreneurs in the twentieth century. No fiction celebrating the American dream could quite equal Sarnoff's life story. A poor Jewish emigrant from the Pale of Russia, he landed with his family at the age of nine into the Dickensian poverty of a New York tenement. In thirty years, he became president of Radio Corporation of America, the largest radio manufacturing and broadcasting company in America. More than any other person in America, Sarnoff understood the meaning and impact of the new technology of radio. Initially his proposal in 1916 for a "radio music box" and broadcasting met with little interest from his superiors who saw wireless only as means of transmitting and receiving telegraph messages. A decade later RCA was selling a variety of radios featuring de Forest's tubes and Armstrong's circuits and was broadcasting to them over NBC, the first national radio network. As head of RCA he pioneered and promoted electronic television and later color television, when few saw its potential. For nearly five decades, the names RCA and NBC–along with Sarnoff's own–were synonymous with American electronics and broadcasting. He fiercely guarded what he thought of as *his* company and would let nothing and

no one get in the way of RCA's success. Yet these achievements came at a steep price. Personal relationships suffered or ended in enmity as they were always sacrificed to the corporation.

III. THE INFLUENCE OF RADIO

The interweaving of the peculiar personalities and temperaments of de Forest, Armstrong, and Sarnoff converged with the dawn of the electrical era, a heady time when developers began to apply the unfolding principles of electricity to new discoveries which would alter human conduct. Their early years coincided with the developments and discoveries taking place across the world. De Forest was born in 1873, three years before Alexander Graham Bell created his telephone, and seven years before Thomas Edison patented his incandescent lamp. Armstrong's birth in 1890 and Sarnoff's in 1891, followed Heinrich Hertz's proof of electromagnetic waves and preceded Guglielmo Marconi's demonstration of wireless.

Just as de Forest, Armstrong, and Sarnoff were growing in the excitement of their life's work, the importance of radio communication was growing in American consciousness. With demonstrations of primitive transmitters and receivers at expositions, including de Forest's at the St. Louis World's Fair in 1904, radio intrigued the public as a novelty. In 1912 when Sarnoff helped relay news of the survivors of the *Titanic* disaster from a station he operated in a New York City department store, people thought of its practicality. Half a decade later, as soldiers fought in towns and trenches across much of the world, nations began to rely upon it as a necessity. During World War I, Howard Armstrong installed a working radio system for the French, placed radio sets in army air corps planes, and invented a way to detect enemy communications. Lee de Forest sold radio sets to the navy. And David Sarnoff, working for the Marconi Company, supplied radio equipment to navy ships.

After the War radio broadcasting came of age at the very time of America's increasing power and influence in the world. In the 1920s Sarnoff was present at the inception of RCA, a corporation that gathered in de Forest's and Armstrong's patents, along with those of other inventors. Combining these inventions enabled the new medium of radio broadcasting that Sarnoff had long championed to spread across the continent. Its significance cannot be understated. Now the words of one person standing before a microphone could shape the thoughts of millions listening around the nation, and the world. The metaphor was appropriate, too. In the nineteenth century farmers spoke of broadcasting to describe the way they spread seed in all directions across their fields. In the twentieth engineers adapted the farmers' word for spreading music, drama, news, and ideas across the land. Broadcasting quickly transformed the business of telegraph operators and the hobby of amateur enthusiasts into a fixture of the American home. Radio became the first modern mass medium, one that knew no geographic boundary, and excited the imaginations and minds as well as the ears of listeners.

What began in the fall of 1920 as a few broadcasts (including the returns of the Harding-Cox presidential election) from a single station in Pittsburgh, became by 1923 the fastest growing industry in the United States. There were 618 stations by the end of the decade, all operating on the system of amplitude modulation or AM, and many affiliated with three radio networks that spanned the nation. Their broadcasts were heard in 12 million houses–more than 40% of American households. Over the next decade that number would grow to 28 million–more than 80% of American households. Broadcasting had become what de Forest called "an Empire of the Air." It had made America into a land of listeners. It entertained and educated, angered and delighted, and joined every age and class into a common culture. Radio opened American living rooms to the wider world.

Radio first flourished at a time when many Americans were showing less interest in public affairs both abroad and at home and wished only to return to, as the cliché of the day said, "normalcy." Isolation, especially from European affairs, ruled the minds of many who had become disillusioned by the recent world war and the world-wide flu pandemic of 1918 that took about 700,000 American lives. Apathy also ruled. The percentage of voting age Americans who cast ballots in the 1924 presidential election was lower than at any time since 1828. For a time, radio offered listeners a chance for new entertainment. Instead of parties organized around a record player, they gathered before the radio to listen first to classical music and lectures, and later to be audio witnesses to public spectacles like Lindbergh's return to the United States after his historic flight across the Atlantic, and sporting events like baseball and boxing.

It was in the nineteen thirties–years marked by the crisis in financial markets and capitalism, and the consequent strain on America's social fabric–that world events began to intrude and radio showed its power to influence. The influence might be malign like the populist Father Charles Coughlin's weekly *Hour of Power* program broadcast nationally from his National Shrine of the Little Flower Church in Royal Oak, Michigan, to an estimated 30 million people over the Columbia Broadcasting System (CBS). Coughlin, who began broadcasting catechism lessons to Catholic children in 1926, soon turned to crude nationalism and populist antisemitism. In his imposing voice, appropriately sonorous and trilling, he attacked usury, "modern Shylocks," Franklin Roosevelt, and the New Deal, among others; he praised isolationists who wanted to keep the nation out of the entanglements of a European war, and sympathized with Fascists and Nazis, even justifying *Kristallnacht* as a righteous retribution for the Jewish persecution of Christians in the first century. In a memorable song line Woody Guthrie said the radio preacher suffered from "Gas on his stomach and Hitler on the brain." Though CBS dropped his weekly program early in the decade, Coughlin forged his own group of sixty independent radio stations that reached the major cities across the country, until he was finally silenced by the Catholic Church.

Radio's influence could be unifying, as Franklin Delano Roosevelt showed in his periodic evening broadcasts to the nation, "Fireside chats." Having first honed such talks when governor of New York, Roosevelt exploited the potential of the new medium to connect with the people directly rather than through newspapers whose editorial pages were often hostile to his plans. With his patrician and confident manner, plain language, simple sentences, and easily grasped analogies, he created an imagined intimacy with his audience. And *he* imagined them, Americans in their living rooms, sitting around the family radio struggling to understand the remarkable changes taking place across the world. Witnesses to the president delivering his chats on Sundays at 10:00 PM before a bank of microphones in a small office in the White House, reported that he would often nod and gesture with his hands just as though the audience was sitting there with them. The president was careful not to wear out his welcome into American homes, he gave just 30 chats over twelve years to an audience estimated to be between 50 and 60 million listeners. He kept his chats short, too, most under a half hour and some just 13 minutes. But they were effective. Listeners responded by flooding their representatives and senators with letters supporting his proposals.

Beyond their immediate and pragmatic purpose to change the votes of sometimes reluctant legislators, Roosevelt's chats sought to dispel fear, explain America's place in world affairs, and affirm a positive future for the nation. While Coughlin excoriated bankers for their alliance to the wealthy, their greed, and their religion, Roosevelt said succinctly that banks used "your money to work to keep the wheels of industry and of agriculture turning around." While Coughlin glibly praised isolationists who wanted to ignore the Nazi assault on Great Britain, Roosevelt soberly declared that the United States, "must be the great arsenal of democracy." Malign or not, the power of radio to influence could not be denied. "We are living in an age when communication has achieved fabulous importance," the playwright Robert Sherwood wrote to Roosevelt, "There is a new decisive force in the human race, more powerful than all the tyrants. It is the force of massed thought–thought which has been provoked by words, strongly spoken."

But most of the time radio offered escape and fantasy to listeners caught up in economic peril. It provided a chance to reaffirm cultural values that were being challenged by the vast influx of immigrants from southern Europe, the population movement from farms to cities, and Great Migration of six million blacks from the rural south to northern cities. Comedy shows, variety sketches, and soap operas often tacitly affirmed the home as a moral anchorage, a feminine domestic haven which intersected with the more masculine affairs of the world. More often than not the inhabitants were average folks and working class, with whom audiences could relate, or at least aspire to. Frequently the plots of the shows and sketches centered on such real world challenges as financial stress, business schemes, romantic difficulties, and complicated relations with relatives and neighbors.

The networks presented over 200 different programs in the nineteen thirties in addition to lectures, interviews, readings and programs that local stations arranged. The offerings of comedy, soap operas, variety, mystery, have lived on in the refulgence of time as radio's "Golden Age." Many like *Just Plain Bill, Backstage Wife, The Goldbergs, Jack Benny, Gang Busters,* and *Amos 'n' Andy,* were wildly popular and lasted for decades beyond the nineteen thirties; some made the transition to television. Many served as audio novels that often featured ordinary people lending a voice to listeners' personal expectations, imaginations, problems, and desires. Bill Davidson, the barber and wise man in the fictional town "Hartsville," encountered "people who might be your own next door neighbors"; Mary Noble, "a little Iowa girl," had adventures in New York as the backstage wife of "a matinée idol of a million other women" often involved jealousy, blackmail, and even rage, before gliding to an implied, if tense, understanding–until the next episode; Molly Goldberg, matriarch of a striving Jewish family, sought to maintain its traditions in a world of assimilation; Jack Benny offered music, banter with the announcer or guests, and animated light comedy; famous FBI cases like John Dillinger and Baby Face Nelson were brought to life by the gang busters; two white actors out of the minstrel tradition put on radio blackface to portray Amos and Andy's preposterous and often bumbling adventures in Harlem.

While the programs brought Americans together by reflecting their aspirations and fears, and offered them a few minutes of relief from personal and national cares, they often tacitly underscored American prejudices, especially racism. The voices of Amos and Andy, complete with "colored" inflection, foolish phrases, and fractured grammar, reinforced a racist stereotype, as did the empty-headed plot lines. Blackface minstrel shows filled with banjo strumming, ballads, and comedy delivered in a stereotypical black dialect were a staple of national and local radio schedules throughout the nineteen twenties and thirties. Comedy routines often mocked women and reinforced fixed images of shiftless blacks whose predilections included gambling, theft, and drink. Still other blackface actors like Moran and Mack, who also called themselves "Two Black Crows," were frequently guest acts on popular variety shows. Blackface, not black actors, was the rule. With the exception of "Rochester," Jack Benny's valet, blacks seldom appeared on programs. One popular show, *Beulah*, whose lead character was modeled in part on Aunt Jemima, featured a white man voicing the part of a black maid.

By the third decade of the century many Americans considered their radios as important as food and shelter. Radio allowed everyone, even those with little money or power, an escape from reality and worry into another world. Researchers found that in the average house the radio was on for four hours a day. Censorious critics condemned it as passive and unwholesome entertainment. But broadcasting was a force that could not be stopped. "When they say 'The Radio,'" E. B. White wrote in 1933, when the unemployment was nearly 25 percent, "they don't mean a cabinet, an electrical

phenomenon, or a man in a studio, they refer to a pervading and somewhat godlike presence which has come into their lives and homes."

IV. GLOBAL REACH

All those radios both reflected and amplified changes that were taking place in America. Mass communication of broadcasting had brought mass consumption to a new level. Prior to radio, companies faced the challenge of selling their products to more than 100 million people spread over 160,000 square miles of the 48 states. Now radio joined with advances in transportation and mass production, pioneered by Henry Ford for his Model T in 1914, to bring forth mass consumption. After the austerities imposed by the World War, there was an extraordinary expansion of wealth and material progress in the nation and Americans were ready to consume as never before. Though the economic contraction of the Depression had dampened the public's ardor for goods, it did not stop it. A 1935 survey found that close to 70 percent of American homes still owned a radio, including 50 percent of families whose annual incomes were under $1,000.

Commercial sponsors discovered the power of the new medium, which meant gold for the network coffers. When Sarnoff began NBC, he hadn't wanted advertising on his network, as he regarded the programs as a public service and a way to sell RCA radios. But he quickly adapted to the enhanced revenues that satisfied the corporation's shareholders. Lee de Forest, who had taken to calling himself the "Father of Radio," deplored "the insidious influence of the avaricious advertiser." Other critics decried the emphasis on profits, one calling the programs "a new and noisy method of letting peddlers into your home," But the lure of relatively easy riches proved irresistible and most listeners accepted commercials thinking them a small price for the number and variety of programs they were offered. Indeed, a number of companies including Atwater Kent Radio, A & P grocery stores, Fleischmann's Yeast, and Texaco gasoline added their names in the titles of the programs they sponsored. Sarnoff himself created and sponsored the *NBC Symphony Orchestra*. Throughout the Depression revenues from advertising sales increased yearly, from under 5 million in 1927 to over 215 million in 1940. Sarnoff would let nothing challenge NBC's commercial radio profits. He rejected Armstrong's revolutionary FM radio, because it would make 40 million AM radios–and his network–obsolete. He needed the money from NBC, along with revenue generated by RCA's radio equipment sales, to support the development of a new technology, electronic television.

Though David Sarnoff had been at the forefront of broadcasting, employing the discoveries of Lee de Forest, Edwin Howard Armstrong, and others to create the most powerful network on the globe, it's doubtful that even he fully understood the ways that radio would itself become so completely intertwined with the larger movements and events that were transforming America in the twentieth century. The signs of change could be heard through radio speakers in American homes and after the introduction of the car radio in 1930, in American automobiles. Announcers brought new sounds to all parts of the changing nation. Sounds of cities and sophistication–swing! jazz! big bands!–flowed into rural ears and minds. Radio gave Americans, often separated by language, customs, religion, and history, a common denominator of entertainment. It had become the central leveling agent for American culture.

By 1940 radio technology was changing the way nations waged war. In World War II it became the standard method of communication on land and sea, and in the air. In preparation for war, Edwin Howard Armstrong pioneered the development of FM radio sets for communication in Army tanks, jeeps, and hand-held walkie talkies, and in a moment of patriotism he gave his patents, including FM, to the federal government to use for the duration of the war without royalty. Manufacturers including RCA employed his patents in the radio equipment that they manufactured and sold at great profit to the government. The inventor chose instead to devote his energy and resources to the development of technology that after the war would be used in continuous wave and pulsed FM radar, microwave (wave lengths between one meter and one millimeter) relay stations, and space communications. Now in his seventh decade De Forest created a self-directing bomb for the army, which tests proved to be unsuccessful. David Sarnoff was commissioned as a Colonel in the Army and ordered to London to design and supervise telegraph and broadcast communications for the Allied landing at Normandy. In January, 1945, he returned to RCA as "General Sarnoff," a title he guarded jealously for the rest of his life.

Recognizing the importance of promoting democracy and of its own presence in world affairs, the United States turned to shortwave broadcasting to foreign countries. After experiments in the nineteen twenties by Armstrong, Marconi, and a group of British amateurs proved that signals directed at an angle to the ionosphere could be deflected back to the earth at great distances, shortwave became the best method for very long distance radio. Other countries, including Germany, Japan, and Italy, had long used shortwaves to beam their propaganda around the world. As war grew closer, the United States took over the shortwave networks of NBC, CBS, and other broadcasters to form the Voice of America in 1942. Soon transmitters in New York and San Francisco were broadcasting over shortwave "from America to talk about the war". By the end of the conflict, Voice of America transmitters were beaming programs around the globe in 40 languages.

After 1945, the shortwave broadcasts representing American interests expanded. The Voice of America, continued to present American news, interests, and policies to scores of countries. But it was not alone. In West Berlin, Radio in the American Sector, "A Free Voice of the Free World," tailored its programs to listeners in East Germany. So popular were the programs that RIAS, as it was known, added a second channel and directed programs to target audiences that included women, youth, even East German border guards. In

1950, Radio Free Europe, began broadcasting to communist countries with more educational and didactic messages delivered by Soviet and Eastern European exiles. Funded by the CIA and private donations, it soon added a robust reports of local news, suppressed by the communists but gathered from regime opponents and defectors. A year later Radio Liberty began beaming programs with similar messages into the Soviet Union.

Lee de Forest and Edwin Howard Armstrong grew up believing in the stories of great inventors like Edison, Bell, and Westinghouse, whose discoveries in the nineteenth century helped to advance civilization. To a large degree those inventors had created companies like Edison Lamp, American Telephone and Telegraph, and Westinghouse Electric to manufacture and market their inventions. Neither de Forest nor Armstrong succeeded in creating corporations of their own. De Forest's failed for want of capital and his willingness to partner with unscrupulous and corrupt characters who led him into numerous bankruptcies and criminal courts. Armstrong's attempt to license his FM patents and start his own FM network failed because it was unequal to the phalanx of RCA's corporate lawyers whose prevarications and delays ultimately destroyed him. Though de Forest and Armstrong had created the fundamental inventions of modern radio, they failed to understand the indomitable power of the corporation in the twentieth century to subsume the individual inventor no matter how momentous the discovery.

In the end even David Sarnoff's Radio Corporation of America would succumb to the greater economic forces controlling twentieth-century America, and his power and the corporate power of RCA would prove as fleeting and evanescent as the radio waves he had harnessed so successfully. With the intention of creating a dynasty he left the company in the hands of his son, Robert in 1965. In less than a decade Robert ran it into the ground. A succession of failed leaders followed until the Radio Corporation of America was sold to General Electric in 1985. The empire of RCA that David Sarnoff had nurtured, shaped and expanded with his vision, enterprise, and will, had crumbled.

V. LASTING IMPACT

The spectators at the Olympic games in 2012 lived in a very different world than the one that Lee de Forest, Edwin Howard Armstrong, and David Sarnoff left. But it was a world they had helped to create. Many in the stadium watching the opening ceremony, including the athletes, captured the spectacle on their cell phones, that Swiss army knife of communication found in every pocket or palm, and sent them by message or email to friends and family across the globe. Others used their small computers, including iPads and tablets to access information on the internet. By 2012 the world had firmly accepted and depended upon the ever-expanding digital age.

It's fair to say that de Forest, Armstrong, and Sarnoff are the forefathers of our digital age. De Forest liked to call himself the "Father of Radio," and certainly his radio tube may be said to be the father of the transistor and the grandfather of the integrated circuit chip, the life force of today's computers. Armstrong's discoveries still help guide computer operations and his invention of and later research into wide band FM, are essential to microwave communication. In an ill-fated bid to enter computing, Sarnoff's RCA, too, produced the first commercial computer with integrated circuit chips in 1965, a half-decade ahead of IBM. Sarnoff had a prescience about the coalescence of computers and communication that few shared. In 1964 he predicted "a global communications network …[that] will instantly link man to machine." The computer would "affect man's ways of thinking, his means of education, his relationship to his physical and social environment, and it will alter his ways of living." It would be, he said, "the greatest adventure of the human mind."

On July 20, 1969, a half decade after Sarnoff's prediction, Apollo 11 landed on the moon. It was a consequential moment, the time when the inventions and the products that evolved from de Forest, Armstrong, and Sarnoff showed the world the shape of the digital future. The specially built guidance computers for the Apollo missions would use 5,000 computer chips. (The Apollo order was so large that the cost for each chip dropped from $1,000 in 1960 to $15 in 1963, $7.28 in 1965; and $1.58 in 1969.)

It was Edwin Howard Armstrong's work with continuous wave FM radar during World War II that helped to make space exploration possible. Shortly after the war in January, 1946, engineers from the Army's Signal Corps at Camp Evans in New Jersey incorporated Armstrong's equipment to send a radar pulse to the moon that bounced off the moon's surface and was captured on an oscilloscope. Traveling at the speed of light, the 477,000 mile round trip took about 2.5 seconds. Project Diana, as engineers called it, proved that microwaves could pass through the ionosphere into space. The implications were far reaching. Army engineers saw the moon bounce as a way for long distance radar to detect enemy missiles launched thousands of miles away. Astronomers saw it as a way to probe the heavens with radio waves. Air force and aeronautical engineers saw it as a way to communicate with spacecraft of the future. From that moment microwaves ruled communications between space and the earth. Soon satellites would relay messages around the globe and space exploration would be possible. On the Apollo mission data, voice, and video information was transmitted over a specially apportioned tracking and communication system of the microwave S Band. RCA's color television camera recorded the astronauts as they gave interviews while speeding to and from the moon, and engineers used RCA equipment to process the images the astronauts sent from the lunar surface to what was then the largest audience in the history of television, 600 million viewers around the globe.

While brilliant scientific discoveries over the last century have transformed communication, the same cannot be said for human behavior. Our digital era has given new life to the misinformed and malicious. Even before the astronauts stepped onto the moon conspiracy theorists were suggesting that the entire Apollo program was a hoax. Today the internet

offers video "proof" that the six moon landings were faked, some say in a Disney studio. Fascism, racism, anti-Semitism, sexism, and dark conspiracies, among others have all found a digital home on the net. In 2012, the firewall at the Olympics blocked 200 million malicious connection requests and two serious attacks intended to bring the entire website to its knees.

VI. EPILOGUE

"If I have seen further it is by standing on the shoulders of Giants," Isaac Newton wrote with some self-deprecation to a fellow scientist in 1676. Newton was likely referring to the centuries-old dictum that a dwarf who stands on the shoulder of a giant can see further. Of course Newton was no dwarf. Some who stand on the shoulders of giants are giants themselves. No matter their height, great philosophers and scientists always stand upon the shoulders of the greats who preceded them. They look past the present to the frontiers of ontological scientific and technological discovery. This was the case of Lee de Forest, Edwin Howard Armstrong, and David Sarnoff. They stood on giants like Heinrich Hertz, Guglielmo Marconi, and Joseph Thompson, and many others who had gone before them. They looked further and built upon the knowledge they had inherited to create a new world of radio, television, and communication. We cannot touch any of our electronic devices without being touched by one of their discoveries and creations. They were giants and they changed our lives profoundly.

VII. RECOMMENDED READINGS

For information about the London Olympic Games of 2012 see contemporary newspaper accounts, particularly the many that covered the appearance of the Queen and James Bond.

For the technology underpinning the games see:

- Jennifer Scott, "Case study: London's Olympic network from BT." *Computer Weekly,* 15 April, 2013. https://www.computerweekly.com/news/2240181706/Case-study-Londons-Olympic-network-from-BT
- Ben Rossi, "Gold for Innovation: the Technology Legacy of the London 2012 Olympics." *Inf. Age*, Jan. 2014. [Online]. Available: https://www.information-age.com/gold-for-innovation-the-technology-legacy-of-the-london-2012-olympics-123457565/

In addition to my book, *Empire of the Air,* more information about the three men I have profiled can be found in:

- J. A. Hijiya, *Lee de Forest and the Fatherhood of Radio.* Bethlehem, PA, USA: Lehigh University, 1992.
- L. Lesing, *Man of High Fidelity: Edwin Howard Armstrong.* Philadelphia, PA, USA: Lippincott, 1956.
- C. Dreher, *Sarnoff: An American Success.* New York, NY, USA: Quadrangle/New York Times Book Co., 1977.

There are many books about broadcasting history and the "Golden Age" of radio. These two offer different perspectives:

- Erik Barnouw, *The Golden Web: A History of Broadcasting in the United States: Vol. 2, 1933 to 1953.* New York, NY, USA: Oxford Univ. Press, 1968.
- Michele Hilmes, *Radio Voices, 1922-1952.* Minneapolis, MN, USA: Univ. Minnesota, 1997.

A good source of information about Project Diana is:

- "Project Diana: The Men Who Shot the Moon." Particularly useful is the "Firsthand Accounts" section. [Online]. Available: https://www.projectdiana-eme.com/image-gallery.html

There is an extensive corpus of literature on the computers for the Apollo missions. Readers might be interested in:

- David Hoag, "The History of Apollo On-board Guidance, Navigation, and Control," September, 1976, The Charles Stark Draper Laboratory, Inc. Cambridge, MA, USA. [Online]. Available: http://klabs.org/history/history_docs/mit_docs/1711.pdf
- NASA, *Computers in Spaceflight: The NASA Experience,* especially "Chapter Two: Computers On Board the Apollo Spacecraft." [Online]. Available: https://history.nasa.gov/computers/Ch2-5.html

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