

# CRUCIBLE OF COMMUNICATIONS: HOW AMATEUR RADIO LAUNCHED THE INFORMATION AGE AND BROUGHT HIGH TECH TO LIFE

## PART 1: THE BIRTH AND BREADTH OF THE HAM RADIO HOBBY

### INVITED ARTICLE

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### ABSTRACT

The hobby of amateur radio, or “ham radio” as it is commonly known among its 3 million global practitioners, has been at the vanguard of electrical and computer engineering since a young Italian inventor, Guglielmo Marconi, first demonstrated wireless at his summer home in Bologna in 1894. Ever since that fateful discovery, amateur radio has played vast and vital roles in capturing the imagination of inventors, spawning new technologies, fueling the global engineering work force, and fostering friendship and international goodwill. This three-part series of articles chronicles the historical evolution of amateur radio, and shows the astounding impact that the ham radio hobby has made on both the engineering profession and the world.

### INTRODUCTION

Since the beginning of the 20th century, the hobby of amateur radio (or “ham radio” as it is affectionately known) has incubated a global arsenal of trained technical experts, and has served as the world’s proving ground for wireless communications technologies. The hobby has also provided a unique social melting pot for people from all walks of life — from ages 5 to 109 — to share in the passion of wireless communications and experimentation [1, 2]. The avocation of ham radio allows one to tinker with communication systems, software, electronics, and antennas, facilitating a very strong intuitive understanding of fundamental principles of science, technology, engineering, and math (STEM). At the same time, practitioners of ham radio develop social skills and self-confidence by sharing and learning their craft with others, and gain access to a global network of friends, colleagues, and mentors through their pursuits of the hobby.

Using tiny slivers of licensed radio frequency bands throughout the entire electromagnetic spectrum, amateur radio operators around the world are granted access to the airwaves through the Radio Regulations of the International Telecommunication Union — Radiocommunication Standardization Sector (ITU-R) [3]. Ham operators are licensed by their own country’s government, assigned a unique call sign identifier for communicating throughout the world, and are permitted to operate their own hobby radio stations for the purposes of two-way communications, experimentation, and enjoyment. More than a dozen shared ham bands are available and harmonized across the globe, from the lowest carrier frequency of 136 kHz (the 2200 meter band, with a 1 W power limit) to the highest band of 47 GHz in the millimeter-wave regime.

The term “ham” is believed to have originated from wireline telegraph operators who used the word to denigrate other operators who did not receive Morse code accurately, or who had poor or unintelligible sending styles (e.g., bad fists). In G.M. Dodge’s 1903 book, *The Telegraph Instructor*, a “ham” is described as a poor operator, a “plug.” It seems that early professional wireless operators brought that pejorative from their wireline practice to describe the non-paid hobbyists who were building their own radio stations and were causing radio interference, but the hobby embraced the label from the onset.

Hams design, build, or buy a wide range of transmitters, receivers, amplifiers, antennas, audio and radio frequency filters, comput-

er controllers, switching systems, and other gadgets in a constant quest to improve their stations or to enhance operations for a particular facet of the hobby that most intrigues them. Using their personal radio stations, which they call “rigs,” hams engage in experimentation and discovery, enjoy leisurely conversations with other hams, try out new modes of digital and analog communications, and pursue personal interests among the many varied aspects of the hobby, such as long-distance (DX) communications, contesting, emergency preparedness, moon bounce, satellite communications, model airplane remote control, and county hunting, just to name a few. Many ham operators have “the gift of gab” and enjoy the art of “rag chewing,” a good-natured term for describing an extremely long conversation with other hams over the air.

Each country provides its own licensing structure to allow citizens to gain their amateur radio license, offering different classes of license that incentivize and reward applicants to attain greater demonstrated levels of technical knowledge and operating proficiency in exchange for greater access to the amateur radio spectrum. Maximum station transmitter power is limited to about 1 kW, depending on country, the class of license, and particular frequency band. As part of the ITU spectrum allocation, there is international agreement that amateur radio frequencies are provided strictly for hobby use, and must be open for anyone to intercept and eavesdrop over the air to promote self-policing, although some modulation and coding methods make eavesdropping more technically difficult. Using ham radio to bypass commercial communication networks is prohibited [4].

Today, amateur radio uses analog transmissions such as Morse code (CW), single sideband (SSB), and frequency modulation (FM), and a wide range of digital modulations such as frequency shift keying (FSK), phase shift keying (PSK), and 8-GFSK (Gaussian FSK) for radio teletype (RTTY), amateur slow scan television (ATV or SSTV) and weak signal Joe Taylor (WSJT) applications such as meteor scatter, moon bounce, propagation sounding, or other types of weak signal work. Morse code is still a very popular communications mode in ham radio, despite the fact that most countries removed the code proficiency requirement for licensing decades ago. A computer communications mode known as FT-8 has become extremely popular in recent years and is used for DX computer communications with very modest stations or when propagation is marginal [5]. Casual over-the-air listening (e.g., tuning of the bands) quickly reveals that rig styles vary widely, from antique tube radios to ultra-modern direct conversion software defined radios (SDR) that hams build from scratch (e.g., home brew), purchase in kit form and assemble, or purchase from a wide range of international vendors. Hams design and deploy their own antennas for their rigs, and operate from a wide range of locations. Antennas run the gamut from simple indoor wire dipoles for apartment dwellers, to whip antennas on vehicles, to massive towers with rotatable yagi beams erected on large seaside lots or mountaintops. Some hams operate large stations remotely by logging in from anywhere via the Internet.

### IN THE BEGINNING

At the dawn of wireless, none of today’s modulations existed. There was only the spark gap transmitter and the coherer receiver, and only Morse code telegraphy could be used, since Prof.

Reginald Fessenden had not yet stunned and amazed the world with his transmission of sound. In 1899, Prof. Jerome Green of Notre Dame published "The Apparatus for Wireless Telegraph" in the July edition of *American Electrician*, where he provided the reader with very modest but detailed circuitry using commonplace electronics to transmit up to two miles [6]. At that time, radios were constructed on blocks of wood with hand wound coils, crudely built capacitors (condensers), and batteries, as can be seen in Fig. 1 from Marconi's original wireless set from 1894.

Professor Green's paper launched the hobby of ham radio by igniting the imagination of experimenters through the magic of wireless (Fig. 2), and that magic continues to fuel the hobby to this day. As shown in this article, governments had to quickly catch up to encourage but manage the use of this new thing called "radio spectrum," as more and more experimenters began to build transmitters to tinker with wireless communications. As discussed subsequently, the sinking of the Titanic in 1912 brought the entire world together with the realization that it was in the public's best interest to encourage all possible development in wireless communications.

The growing fascination with and interest in amateur radio was not just due to the birth of wireless and the development of affordable electronics alone. The Wright Brothers' first flying machine, demonstrated in 1903, followed by their successful airplane flight of 1905, further fueled intense interest in wireless. Now, hobbyists with an inclination for understanding how things worked (e.g., those interested in engineering) could simultaneously experiment with small model airplanes as well as wireless sets, and many hobbyists realized that wireless could eventually be used to control airplanes and other remote devices.

These early tinkerers, the first amateur radio enthusiasts, operated in an unregulated world without any channelized spectrum, no standards, and no licenses, just wide-open opportunities to experiment, transmit, receive, and tinker with the crude electronics of the day. Anyone was able to communicate with anyone else who happened to also be using the radio waves at the same time, despite the public's perception that wireless telegraph was private [7]. A 1907 article in *Electrician and Mechanic* taught readers how their amateur stations could be expected to perform, based on the particular circuitry, antenna, and detector they chose to use (Fig. 3). See Table 1 From 1907 *Electrician and Mechanic* (From: [8]).

It was also in 1907 that the U.S. Navy became particularly bothered by two teenagers, Henry C. Heim and Alfred Wolf, who listened in to the wireless telegraph transmissions between a fleet of naval vessels off the shore of Alameda, California. The boys heard messages and compiled a book of the "choicest confidences" between sailors, officers, and people on land, and then provided the most embarrassing messages to the *San Francisco Examiner*. The boys even went so far as to spoof an Admiral, using their clandestine transmitter to delay the departure of a naval ship [9]. These types of incidents gave early amateur operators a bad name, and created deep mistrust among naval and commercial operators while the hobby was in its infancy. However, even with such occurrences, the public's growing interest in radio could not be squelched. The ability to create one's own equipment to navigate the invisible airwaves fueled further interest in this fascinating hobby [10].

It was the dual and near-simultaneous discoveries of practical wireless communications and airplanes that motivated a small group of teenagers from New York City to transform their Aero Club to the Junior Wireless Club in January 1909. This group of teenaged and pre-teen boys, led by honorary president E. Lillian Todd (the world's first woman aircraft designer) and advisor Prof. Reginald Fessenden, eventually became the Radio Club of America, the world's oldest radio society [8]. The title of "first wireless society in the world" is sometimes contested by the Australian Institute of Wireless, founded in 1910 as the Wireless Institute of New South Wales, later becoming the Wireless Institute of Australia. The Wireless Association of America, an hon-



FIGURE 1. The author with Guglielmo Marconi's original wireless set as preserved from 1894 at the Marconi museum in Villa Griffone, Balogna, Italy (photo taken in October 2013 at the Marconi Society board meeting).

orary club founded in 1909 by Hugo Gernback, who published *Modern Electrics* (the world's first magazine to cover strictly radio topics), was launched just weeks after the Junior Wireless Club, and boasted 10,000 members by late 1910. Local wireless clubs sprang up all over the world in the 1909–1912 timeframe, providing the hobby with enough "grass roots" to influence governments and the public about the coming age of wireless communications and the need to foster the amateur radio hobby.

As just one example of the influence of the very earliest of amateur radio enthusiasts, the Junior Wireless Club (later known as the Radio Club of America) was a driving force that caused the U.S. Congress to reject Senator Depew's 1910 proposed legislation that would have completely prohibited amateur radio operators in favor of purely commercial and military (e.g., Navy) spectrum use. The lads went to Washington, DC to testify before a senate subcommittee to plead their case for the importance of amateur radio spectrum [11, 15], and other radio societies lobbied elected officials in force [8]. Students at universities across the world were beginning to build amateur radio sets, while naval officials, upset with the amateurs, complained at congressional hearings that "it was quite common with youths living in the bay cities to play with wireless telegraphy, having aërials and receiving apparatus by which could be read government wireless messages" [9]. It was clear that military and commercial interests were dead set on prohibiting amateur radio operators from ever accessing or listening in to the radio spectrum. Bill after bill in Congress was proposed from 1909 through 1912, only to be rejected by elected officials who were bombarded by the impassioned pleas for spectrum access by members of fledgling wireless clubs across the country.

The sinking of the Titanic on April 14, 1912 was the watershed moment for amateur radio. The Marconi telegraph was credited for saving over 700 people at sea, and all of humanity could now see the importance of wireless and the concurrent need to cultivate expertise in the field of wireless. This event drove Congress to modify their legislative approach. Instead of banning amateur operators altogether, the legislators agreed to finally set aside dedicated radio frequencies for experimentation and hobby use, knowing full well that the spectrum being allocated to the hams was far beyond the realm of usefulness for the technology used at that time. When President William Howard Taft signed the Radio Act of 1912 on August 17, amateur radio operators finally had a law to permit their operation, but they were relegated to the very upper, unexplored reaches of the radio spectrum — the wavelengths of 200 m and smaller — which had yet to be understood or harnessed for use [8, 11]. This model of free, protected radio spectrum for amateur hobbyists was first implemented in the United States, and was eventually adopted worldwide, leading to today's ITU global allocations and protections for the amateur radio service, despite



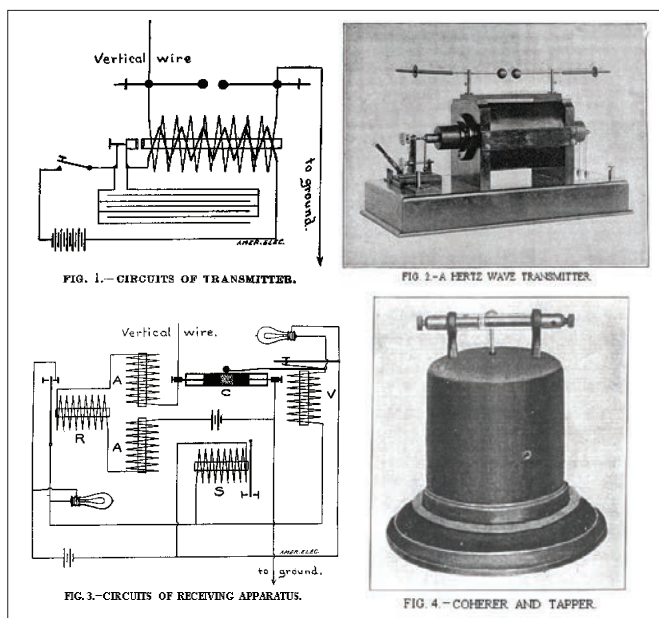


FIGURE 2. Circuitry published by Prof. Jerome Green in the July 1899 issue of *American Electrician* [6]. The circuits were able to cause the coherer to ring a bell using wireless transmissions over a distance of 2 miles on the campus of Notre Dame. <https://earlyradiohistory.us/1899nd.htm>.

Spark Coil	Antenna Height	Type of Detector
		Coherer Liquid Detector or Barretter
1/2 inch	35 feet	1/4 mile
1	40-45	1/4 to 1/2 mile
2	50	5 to 10
4 <sup>1</sup>	75	10 to 20
6 <sup>1</sup>	100	15 to 30
10 <sup>1</sup>	150	50 to 75
15 <sup>1</sup>	180	75 to 100

FIGURE 3. A table from the *Electrician and Mechanic* in 1907 teaches readers what type of range can be expected when constructing their home brew wireless transmitter and receiver system [8].

overwhelming commercial and military interests in radio spectrum.

This type of story, where hams have been the very early adopters — the first tinkerers and the ones to push the envelope of a new technology, often before they become adults — has played out time and time again since the dawn of wireless, and continues today. As shown in this series, from the dawn of the information age, from the early days of talking movies, through the golden age of AM and FM broadcasting, through the advent of television, satellites, cellular telephones, packet radio, and the Internet, hams have always been at the very cutting edge, and have in many cases been responsible for creating the continuing advances in communications. Given the heritage of ham radio operators as early adopters (and in many cases the inventors) of new technologies and communication modes, it should come as no surprise that vendors with pioneering ideas often target the amateur radio market before investing and growing product lines for government and commercial marketplaces. As described in this series, it is the ham radio community's spirit of tinkering with, improving, and socializing each new communications technology that has brought high tech solutions to the world at large.

## THE HAM SPIRIT: A GLOBAL FELLOWSHIP

The ham radio hobby has an incredibly strong “esprit de corps,” since licensed amateurs throughout the world realize their good fortune of having free access to the very precious resource of spectrum that is usually licensed to commercial interests to generate revenues for government coffers. From this sharing of the “radio commons,” a genuine comradery and deep respect

among fellow hams permeate the hobby, transcending language barriers, socioeconomic status, religion, level of education, profession, or country borders. Women and young people (teenagers or younger) are especially encouraged and welcomed both on the air and at local in-person monthly meetings held at the tens of thousands of community amateur radio clubs throughout the world. But the hobby realizes it must do more to bring in underrepresented citizens. In a February 2022 opinion article, David Minter, the Chief Executive of the American Radio Relay League (ARRL), one of the world's largest national amateur radio organizations, made a call for an increased push to increase the diversity of the hobby in the face of an anemic 1 percent annual growth rate for U.S. amateur licensees [12]. Today, about 15 percent of licensed ham operators are female, and many males are aging out of the hobby. With the great need to increase access and diversity in STEM, efforts are underway worldwide to increase underrepresented groups. Within the past few years, the hobby has seen rapid growth of licensed amateur radio operators in Thailand, China, and Indonesia, which bodes well for the international growth of the hobby.

Hams are never strangers to one another — there is most often an instant bond when fellow hams meet for the first time, whether in person or on the air — and life-long friendships across the world naturally evolve through shared interests in the hobby. Ham operators who talk with each other over the radio may exchange electronic or paper QSL cards commemorating on-air contact, although most QSLing today is done through the Internet, using applications such as the Logbook of the World developed by the American Radio Relay League (ARRL).<sup>1</sup>

Hams enjoy meeting over the airwaves, but also often meet in person for technical interchanges or to simply rag chew about their stations, recent contacts, or matters entirely unrelated to ham radio. Such meetings are usually over a meal, and when such a meeting occurs in person, as opposed to over the air, it is called an “eye-ball QSO.” It is not uncommon for hams to talk with each other over the air for years, perhaps never meeting in person, or perhaps meeting their invisible ham friend in person years or decades later, at a distant club meeting or “hamfest.”<sup>2</sup>

Many life-long, deep personal and professional linkages are formed between fellow hams that typically transcend the hobby, leading to planned family vacations, job opportunities, technical innovations, and business ventures, all while creating a vast citizenry with core competencies and vital expertise that propels the entire electronics communications complex in peace time, or the military complex during war time. It is not an exaggeration to state that ham radio was the world's first global social network.

## SOME FAMOUS AMATEUR RADIO OPERATORS

The ranks of radio amateurs are filled with women and men who have shaped our civilization from all walks of life. While it is impossible to list the enormous number of hams who have made history, a small sampling will motivate the reader to see how the hobby involves people from many different backgrounds. For example, famed Austrian-born movie actress Hedy Lamarr (Fig. 4) invented frequency hopping spread spectrum and created underwater missile guidance systems while dabbling in amateur radio before World War II [13].

<sup>1</sup> The international amateur radio community uses Q-signals and other abbreviations for common messages. For example, a radio contact is called a QSO, a ham's location is called their QTH, and a station may make an open call to solicit a radio contact on any frequency by calling CQ, (abbreviation stemming from “seek you”).

<sup>2</sup> Hamfests are large gatherings of amateur operators and non-licensed radio enthusiasts that are held over a weekend and include technical talks, social outings, swap meets, vendor exhibitions, and flea market equipment sales. The world's largest hamfests often have more than 30,000 attendees and are held annually in Dayton, Ohio in May, Central Florida in February, Friedrichshafen, Germany in June, and Tokyo in October, with thousands of other smaller hamfests held throughout the world each year.

Other notables such as Rajiv Ghandi (Prime Minister of India, VU2RG), King Hussein of Jordan (JY1), King Juan Carlos of Spain (EA0JC), King of Thailand Bhumibol Adulyadej (Rama IX, HS1A), King Hassan II of Morocco (CN8MH), the Sultan of Oman, Qaboos bin Said al Said (A41AA), Carlos Saul Menem (President of Argentina, LU1SM), U.S. Senator Barry Goldwater (K7UGA), movie actor Marlon Brando (FO5GJ), Yuri Gagarin (the Russian astronaut who was the first human in space, UA1LO), Owen Garriott (first ham radio astronaut to transmit from space on the space shuttle, W5LFL), Mamoru Mohri (the first Japanese space program astronaut, 7L2NJY), Helen Sharman (the first British astronaut in space, GB1SS), Kathy Sullivan (the first NASA astronaut to walk in space and to dive to the deepest part of Earth, N5YYV), aviation magnate Howard Hughes (W5CY), Jon Sculley (former president of PepsiCo and CEO of Apple, K2HEP), Alex Comfort (the author of *Joy of Sex*, KA6UXR), and baseball great Joe Rudi (NK7U) are or have been licensed hams. Many famous musicians and recording artists are or were amateur operators, including Jim Croce, Burl Ives, Joe Walsh of the Eagles, teenage idol Donnie Osmond, Patty Loveless, Chet Atkins, Ronnie Milsap, Larnelle Harris, and Larry Junstrom. Even the wife of Elvis Presley, Priscilla Presley, is a ham radio operator, while the legendary country music star Johnny Cash was a highly skilled Morse code interceptor in the U.S. Air Force before he became a country music icon.

Ham radio has influenced all segments of radio and television, providing a crucible from which the personalities and technical innovations for all forms of broadcast entertainment have been hatched. Hams have ignited the world's imagination and fascination with radio since the golden age of radio in the 1920s, from the era of silent movies through the global adoption of AM and FM broadcasting, through the black and white, and then color, television era, and through the coverage of the international space race [14–16]. Walter Cronkite (a U.S. television news anchor known as the most trusted man in America, KB2GSD), space reporter Roy Neal (K6DUE), and TV humorist and producer Jean Shephard (K2ORS) molded the way content was delivered over the commercial airwaves, while Akio Morita (JP1DPJ) and Masru Ibuka (J3BB) founded Sony Corporation, Robert Moog (K2AMH) invented the music synthesizer, Ray Dolby (F5BVY) invented cinematic sound at Dolby Labs, Leo Fender (W6DUE) created the Fender electric guitar, and Nolan Bushnell (W7DUK) founded video game pioneer Atari.

Along with the large number of high-tech entrepreneurs who used amateur radio to kindle their early love for communications and electronics, the famous science fiction writer, Sir Arthur C. Clarke, conceived the notion of geostationary satellites in 1945 [17], and had personal interest and deep connections with the amateur radio community in Sri Lanka. The famous founders of Apple, Steve Jobs and Steve Wozniak, honed their high-tech computer instincts through ham radio as young boys [18, 19], where they greatly benefitted from the Silicon Valley culture inculcated by the venerable Dean of Engineering of Stanford University, Frederick Terman, who founded Silicon Valley three decades earlier. Terman was also a ham radio operator in his youth, much younger than others practicing the hobby in his home town [20], and his early experiences interacting with adults, while he himself was a child, developed both his engineering skills and confidence to later lead large teams to form companies while also creating the classic electrical engineering education textbooks of his era that impacted the entire field of engineering. Terman's students, Bill Hewlett and David Packard (also hams), founded Hewlett Packard in 1939, which became the global leader in test equipment manufacturing. The first Hewlett Packard audio oscillator was used for Walt Disney's groundbreaking movie *Fantasia* — the first movie to be shown with stereo sound — in 1940. Today's corporate giants Hewlett



FIGURE 4. Movie star Hedy Lamarr was an avid experimenter with radio and invented frequency hopping spread spectrum (Photo from <https://www.forbes.com/sites/shivaunefield/2018/02/28/hedy-lamarr-the-incredible-mind-behind-secure-wi-fi-gps-blue-tooth/?sh=4f411b1341b7>.)



FIGURE 5. Al Gross, W8PAL, the father of citizens band radio, is shown with his original walkie-talkie invention that now resides in the permanent collection of Virginia Tech [22]. (Photo from: <https://lemelson.mit.edu/award-winners/al-gross>).

Packard Enterprises, Aruba, Agilent, and Keysight Technologies can all trace their roots to the two amateur radio operators who studied under their Stanford professor who, too, was a ham.

Jack Kilby, also a ham operator who worked on early transistors, is known as the inventor of the microchip, the hand calculator, and the thermal printer while working at Texas Instruments. Kilby received the Nobel Prize in Physics. Before moving to Texas Instruments, however, Kilby worked at Centralab in Milwaukee where he collaborated with another ham operator, walkie-talkie inventor and citizens band pioneer Al Gross, to create a rugged circuit board capable of housing tubes for the world's first walkie-talkies that Gross developed and sold to the public in 1938 [21–23]. More recently, Princeton astrophysicist and Nobel Prize winner Joe Taylor (K1JT) has developed open source weak signal modulation and coding software that has caught the ham radio hobby by storm over the past decade, as it enables ham operators to make QSOs around the world using many exciting propagation channels using very modest powers and antennas with a simple sound card and computer-controlled digital modulations [5].



## CONCLUSION AND WHAT'S TO COME IN THIS SERIES

This article, Part 1 of a three-part series, has provided an introduction to the origins and current practice of the hobby of amateur radio. It should be clear that the hobby has had a great impact on the communications engineering profession, and offers a special comradery that exposes its practitioners to many social interactions and technical development opportunities with experts and enthusiasts from all walks of life. The ability to expand one's technical knowledge and interest has always been at the core of the hobby. In the coming series of articles, the historic account of how amateur radio operators and the hobby played a key role in the creation of today's information age will be chronicled.

Part 2 of this series will delve into the history of how universities facilitated amateur radio on their campuses to build up a major arsenal of technical experts who went on to develop the global radio broadcast industries, long-distance telephone, television, stereo, the walkie-talkie, and radar. The importance of amateur radio in exploring the Earth by sea, and the role of hams in World War I and World War II will also be described, as militaries relied on the skills and innovations of amateur operators to support wartime communications. A historical perspective of the growth of Silicon Valley, and other high-tech centers around the world will highlight the role that ham radio played, as these technical incubations and innovations were couched in the amateur radio spirit, with hams often being the first employees of startup companies that powered the expansion of the information age. Even during the Cold War, the history will show how amateur radio maintained international relations among ham radio enthusiasts on both sides of the Iron Curtain, even as governments were adversarial to each other.

Part 3, the final installment in this series, will offer a historical account of how amateur radio operators began learning about VHF and UHF frequencies, where they created nationwide repeater systems, often with touch-tone telephone capabilities, thereby proving the concepts and creating the global engineering talent pool needed for the fledgling cellular telephone industry. The history of the Internet would not be complete without understanding how amateur operators developed and perfected packet data communications, digital modulations, and open source circuit boards and software for nationwide computer networks that linked thousands of amateur stations across the world, decades before the Internet. The activities of pioneering ham clubs like Tucson Amateur Packet Radio (TAPR) sparked global interest in computer networking through the ham radio "packet cluster." The "big board" computers built at ham clubs across the world in the 1970s and 1980s fueled the fledgling personal computer industry. The launch of OSCAR 1 in 1961, the world's first amateur radio satellite, spawned deep technical expertise and technical know-how for the global satellite industry, leading to the creation of non-profits such as Radio Amateur Satellite Corporation (AMSAT), which sponsored rockets and built satellites that serve hams around the world. Hams of every nation participate in their country's "field day," where clubs set up stations in the wilderness over a weekend to simulate emergency communications needed in a national disaster [24]. The hobby even has its own Olympic Games. Known as the World Radiosport Team Competition (WRTC), the ham radio Olympics are held every four years around the world, and will next be hosted in 2023 by Italy in the city of Bologna (the site of Marconi's original wireless transmissions) [25]. The use of amateur radio to explore the ionosphere in new ways, and with new radio architectures and crowd-sourcing Internet-based monitoring systems like the Reverse Beacon Network (RBN), has created new fields of research, such as "space weather" to predict the upper reaches of our planet's protective layers. The final article in this trilogy shall delve into the fascinating role that ham radio has played in all of these modern advances that impact civilization, and shall conclude with a perspective on what lies ahead for the incredible hobby of amateur radio.

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## BIOGRAPHY

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