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# The Tesla Genius:

## Part 2: Inventions and innovations—Visions of electric fires

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The higher a man's status, the more he is under the sway of daemons
and he must always be on his guard lest he be diverted from the main course he has set for himself.
—Johann W von Goethe, 1829

For the past fifteen years, I have pursued occasional research of Nikola Tesla, which includes performing various Tesla Coil experiments (3–15kW class). During that time, I have defended Tesla when I thought credit was due him, and I have tried to refute some of the fringe-science misconceptions about him. My satisfaction in writing this series of articles is to construct a balanced view of the life and work of Tesla and to debunk some of the misconceptions about Tesla that have prevailed since his death.

As a review, in the first article (*AJNP* Vol. 1, July 1987, 3–10) I briefly outlined a biography of Tesla. I defined three periods in his life that chronologically reflected his work, reputation, and important people involved with him at each of those stages: From Tesla's birth to his arrival in America, I called the Constructive period, which is characterized by his family life, education, and engineering work (in Budapest and Paris). The next phase of Tesla's life was the Productive Period, which is characterized by his prolific and profitable inventive activity after he arrived in America. This period lasted approximately two decades, ending before World War I. I showed that the Period of Decline overlapped the Productive Period—this final period starting with the 1895 New York laboratory fire. This period is further characterized by Tesla's onerous financial problems, his floundering reputation, and his obsessive caring for pigeons. This article will not, however, present Tesla's inventions in chronological order.

Nikola Tesla was described by Hugo Gernsback, noted science-fiction writer, as "the greatest inventor that ever lived." Many biographers and science writers have liberally expressed these sentiments on many occasions (Cheney [1981] 1983, 239; Hunt and Draper [1964] 1981, 222). What did Tesla invent to earn such accolades? What quantity and quality of inventiveness did he exhibit? By what standards shall we measure Tesla's works? What things were unique about the age that allowed him to thrive and, ultimately, to fail? I will define three categories of the work accomplished, attempted, and attributed to Nikola Tesla that will help answer these questions.

The first category of Tesla's inventions is what I call the Manifested Technologies; it is characterized by those inventions and technological systems which found profitable markets for Tesla and his backers. The second category I call the Prototype Technologies; it includes those inventions and systems that never came to fruition. The reason for these failed products was primarily due to poor capitalization. In other instances, the support technologies didn't as yet exist. At other times the problem was that the newly competing material or technology was not sufficiently superior to existing ones to warrant expensive industrial conversions. The third category I call the Speculative Technologies, featuring Tesla's speculations for technological utopias. These technologies are documented by his writings to specific people or companies and by his general articles written for public reading.

## Manifested Technologies

One can't deny that Tesla was one of the most prolific inventors that America has ever seen. I believe he was second only to Edison for the number of patents filed by an individual. We must credit Edison for the higher profile of all his patents, each of which was already a significant part of a marketable or marketed product. Nearly half of Tesla's patents were never developed into products or realized in the marketplace. However, Tesla's innovations were quite insightful; his inventiveness outclassed Edison's work in one area in particular: Tesla's alternating-current theories and technologies changed the modern world tremendously. These technologies are the apex of his Manifested Technologies.

### *War of the Currents*

Known historically as the "War of the Currents," the battle for the choice between AC and DC during the period from the late 1880's to the early 1890's realized the completion of the greatest of Tesla's achievements. Consider the following developments that set the stage for the AC verse DC conflict: various inventors in America and Europe were scrambling to apply the emerging electrical sciences and technologies in all manner of novel ways. The most common application for electricity at the time was to operate electric motors, which operated industrial machinery. The new electric light bulb offered profound new applications for electricity. (Yes, Edison gets the credit this time.) The fast-spreading technologies of the telephone and telegraph required easily sustainable sources of electricity to thrive. Electric motors were becoming sophisticated and powerful enough to employ them as the motive source for elevators, urban trains, and small vehicles. The only two common sources of constant electricity were batteries and dynamos. But as the reader knows, batteries are expensive and short lived. And though the dynamo had been developed around 1830, it had found little industrial use before 1850, and was a constant maintenance problem for the thirty years preceding Tesla's arrival in New York in 1884.

The War of the Currents was a clash between two ideologies. Edison with his financial backer J.P. Morgan was pitted against Tesla with his two financial backers George Westinghouse and A.K. Brown (of the Western Union Telegraph Company). Morgan consolidated Edison and several other companies (such as Thompson-Houston) into a large holding company then named General Electric. Considerable investments were made in setting up DC as the dominant form of electricity for eventual world-wide use. In the same way that he had gained control of the steel and railroad industries through his financial trusts, Morgan was determined to control the emerging electrical utilities. These investments required the placement of the DC generators in the proximity of the customer. AC, on the other hand, requires only one alternator to serve many customers, and the cost of the distribution network is dramatically cheaper than multiple generators on every block. Thus, the capitalization of DC power required the resources of a man like Morgan. He could influence politicians and universities, print propaganda against AC, and secure the backing of several eminent engineers and scientists such as Edison and Lord Kelvin.

The principal financial resource for AC research was George Westinghouse. He was clearly the underdog against Morgan's financial empire, but he believed in the superiority of alternating current. He was able to gain the support of several university scientists and electrical engineers who recognized the value of the AC system. Two supporters were Michael Pupin and William Anthony. It was Anthony that won for Tesla an invitation to lecture the American Institute of Electrical Engineers (AIEE) on May 16, 1888. Tesla's apologetics for AC is a classic. Thus, the opening salvos in the War of the Currents were fired by Tesla, and he won the AIEE's support for the campaign to come (Cheney [1981] 1983, 39 ff ).

*DC and AC technology*

To more fully appreciate Tesla's insights into AC generation, let's first review the state of electrical power generation just prior to Tesla's contributions to it. Of course there were batteries for generating near steady DC power, but they were not versatile for practical use. There were also devices called dynamos for mechanically generating DC, and alternators for mechanically generating AC. The basic principle that both of these devices operate on is called *electromagnetic induction*, which applied to practical generators at that time can be stated as the production of a current in a conductor (in our case a conducting wire by moving the conductor through a magnetic field. Now since the strongest part of a magnetic field of a magnet is localized near the magnet itself, then one good way to move the wire through its field ought to be to form it into one or more loops, fix the loops to an axle, and then spin the axle near the strongest part of magnet's field. This loop-and-axle configuration is referred to as a rotor (see Fig. 1). (It's important to note that direct current does not mean that the current is constant—it means that the current circulates in one direction only, though its current strength may vary.)

One obvious problem with this arrangement is the removal of the generated current from the rotor, a process called commutation in the case of direct current. After all, we can't simply dangle the ends of the looped wire out of the rotor, for in just a few rotations the wires would be wrapped-up on the axle. One solution is to solder the ends of the looped wired to isolated conducting insulated contacts that are fixed to the axle, and then to remove the current out of the rotor by touching conducting "brushes" to the contact strips but allowing the brushes to slip freely as the axle rotates. (The brushes for industrial use are usually just conducting metallic graphite.) The commutation of direct current is represented in Fig. 2.

The first inefficiency in this attempted solution arises because of the inefficient contact of the brushes on the slip rings from each winding as the rotor turns. Another source of inefficiency results from the process of producing a steady dynamo output current. Many independent windings are placed on the rotor at regularly varied angles. From the laws of physics it is known that as a winding rotates within a magnetic field, with each rotation there comes an instant at which the winding develops its maximum current. The slip contacts are so positioned that when a winding is producing its maximum current, the brushes can complete the circuit and thereby route this current for useful power. Each winding will, on its turn, present its maximum current to the brushes as the rotor continues to rotate in the magnetic field. But because the windings are only allowed to conduct during the time its current is near or at its maximum, then more than fifty percent of the available energy from the winding can go unused. By the time of Tesla's contributions, capacitors and other means were used to filter-out the variations, so that the dynamo could maintain a steady output current. Now, while an alternator can produce more current and sustain longer brush life than a dynamo for a given size and mass, the world of the latter nineteenth century couldn't do very much with AC except to light electric lamps. The opportunity and timing for Nikola Tesla could not have been better.

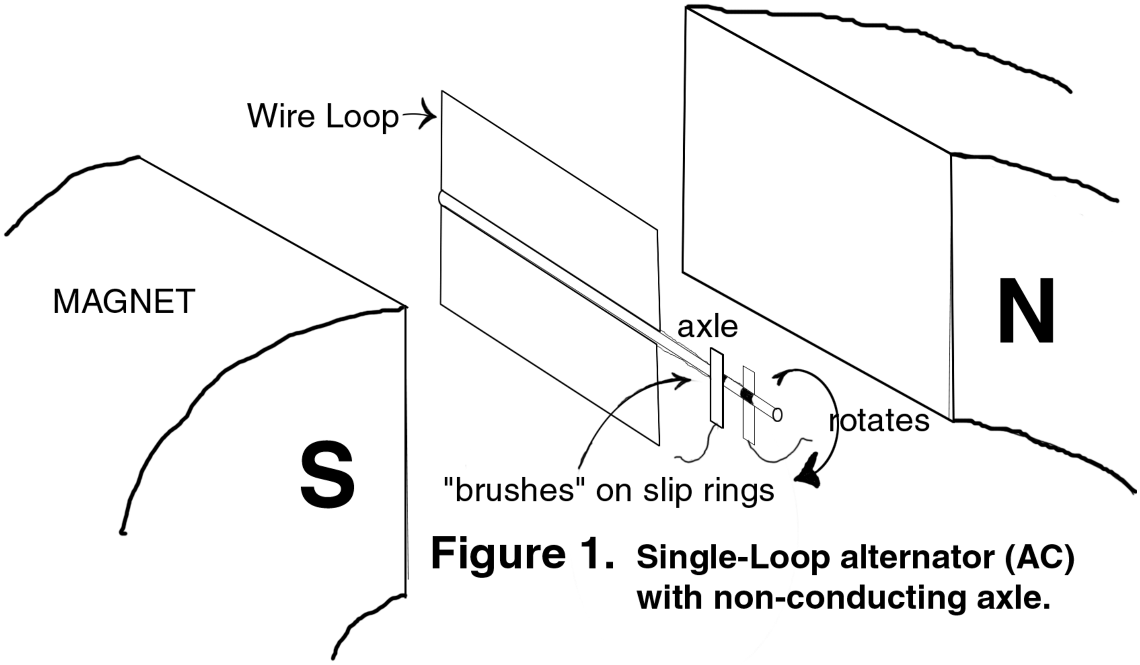


**Figure 1.** **Single-Loop alternator (AC) with non-conducting axle.**

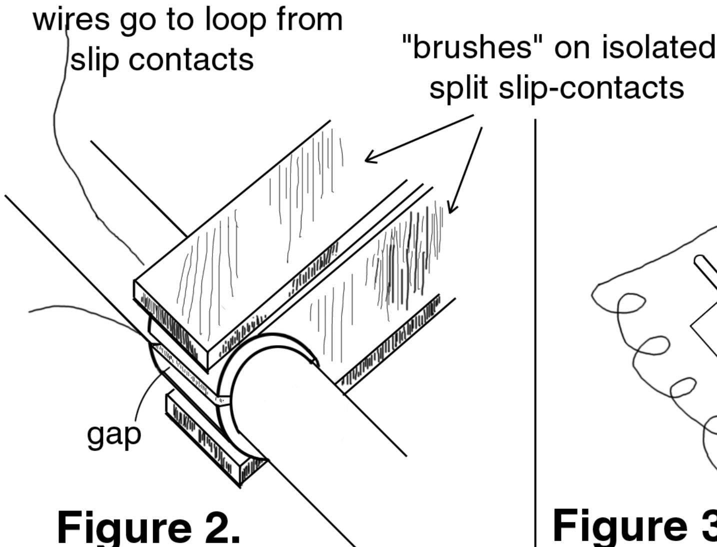


**Figure 2.** **Single-loop commutator for DC.**

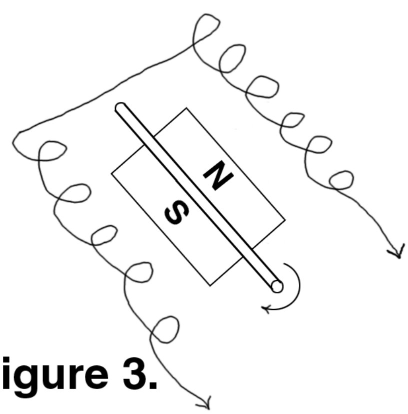


**Figure 3.** **Tesla's alternator -- Only the magnet "moves" (rotates)**

Tesla's genius in AC technology started while he was still in college. In a series of remarkable insights and visions, he realized that only relative motion between the windings and the magnetic field is needed to produce alternating current. He reasoned that if the magnet is rotated within stationary windings, alternating current can still be produced without having to use slip rings and brushes. (See Fig. 3.) His insights also included how to use the current more effectively. Tesla conceived of a vastly improved transformer for AC use. While others at the time had some moderate success with building AC transformers, Tesla's innovations were to be the standards of AC transformer design. Tesla also applied his AC induction theory to producing an efficient AC motor which was more than a match for its DC industrial rival. At the same time, he figured out how to convert AC to DC without the use of rectifiers, by using a scheme of synchronous motor activity to extract the desired current. Tesla had, therefore, solved all three problems with AC: how to generate it, transmit it, and use it.

So why is AC, rather than DC, the preferred means of transmitting electrical power? From the laws of physics we know that the resistance of a wire is not ideally zero, and that the power loss over a length of wire is described by

$$\text{Power Loss} = \text{Current}^2 \times \text{Resistance}$$

The longer the wire, the higher the resistance to both alternating and direct current. Since both types of current experience equal loss under the same resistance and average current, why is AC better for transmission than DC? Because the *Total Power* developed by a generator is Current $\times$ Voltage, one can reduce the current in the wire and maintain the same power by dramatically increasing the voltage. So, a given long length of wire will be much more efficient at transmitting power at high voltage, which reduces the power consumed by the resistance of the wire. Physicists and engineers knew this principle at the time of Tesla's activity, so why was Tesla so opposed? The answer hinges on the prevailing technologies of his time.

Edison had only low-voltage DC motors, generators, and other devices for industrial and consumer use, which he intended to power by placing generators on every block and in every factory. Although Edison could raise the DC voltage to allow placement of the generator far away from where the current was going to be used, the power loss to line resistance would be excessive. Most of the power generated would be lost in the transmitting wires, before the appliances, lights, or whatever could use it. Therefore Edison would have to supply his thousands of customers with thousands of generators to reduce the distances between the generators and consumers. And he actually intended to pursue this scheme. Before Tesla, there was no known effective way of transforming either AC or DC up to a high voltage for transmission to the user, and then reducing it efficiently for the user's appliances to operate. With the AC technology that Tesla designed, AC could be produced far away from the consumer, and efficiently shipped to the consumer by increasing the transmission voltage quite high by transformers (which only work with AC). Near the consumer, the high-voltage AC is reduced to usable lower voltages by another transformer, while maintaining virtually the same power transfer levels. Finally, the cost of the AC distribution systems would be much less than constructing a myriad of DC generators for thousands, even millions, of users.

In terms of daily usage and civilized living, the ubiquitous electric outlet is as indispensable as the automobile. Life would be radically different if modern civilization weren't able to plug-in its electrical appliances. What would be the prevailing form of transportation if there were no cars as they exist now? Just as we can lay the prevalence of the automobile at the feet of men such as Henry Ford, we can lay the form of prevailing electric power at the feet of Nikola Tesla. Even the sixty-Hertz frequency that the modern power grid oscillates at is Tesla's idea. The structure of the power grid—with its centralized, distantly located power generating stations supplying power over long distances—is a manifestation of Tesla's genius. (The Edison alternative would require a generator on virtually every block.) Part of the durability of the AC power grid is its flexibility: Originally, the standard low-voltage AC value meant for consumer use was to be 100 volts. As subsequent years have passed, the demand for more electric power for individual consumer use, and demand for power in terms of the vast number of new customers has over a period of time, required the low-voltage standard to creep upward from time-to-time. First, it was 100 volts; then around 1925, the standard was 105–7 volts; sometime around World War II, the consumer needed a standard of 110 volts. By the middle of the sixth decade, 115–7 volts became the standard. More recently, 120 volts became the standard. As this is written, some experts that I know are talking about 123-5 volts as a coming standard. Tesla's scheme for our AC power grid is quite durable and has survived the test of time well.

*Tesla's other important inventions*

This structure that Tesla conceived long before coming to America is the height of his Manifested Technologies. There were about forty patents alone, which applied to every aspect of AC power generation and use. Directly following the sale of his AC patent rights and royalties to Westinghouse, Tesla financed many new products, many of which became successful in the marketplace. One of the early inventions to help Tesla gain a reputation in America was his new and improved arc light, on which he posted seven patents. To reduce the resistance of the wire used in his high-voltage experiments, he also invented the so-called Litz wire (stranded bundles of insulated wires) for his Tesla Coils. This, like many of Tesla's ideas, is simple and elegant. Litz wire has a lower overall resistance (reactance) to the energies and frequencies than a single wire of comparable size and bulk. This is because the surface area of conduction in Litz wire is many times that of ordinary wire. One must realize that Tesla was operating his famous Tesla Coils at radio frequencies, which induces current mainly on the surface of a conductor (Cheney [1981] 1983, 61).

Around 1890, Tesla built his high-frequency generators. Operating up to 33kHz, these electro-mechanical devices were Tesla's first attempts at building radio-frequency generating apparatus. He quickly realized that the frequencies developed were not high enough to be useful, and soon afterwards, he built the forerunners of what are now the nefariously electrifying, though very useful, Tesla Coils. These devices were able to generate radio frequencies up to several megahertz. By far the most spectacular Tesla Coil system was built by Tesla himself at Colorado Springs in 1899. As the Tesla Coil is a resonant auto-transformer, its principle application is in modern electronics. The basic circuit that Tesla developed used transformers and capacitors to resonantly tune the primary and secondary circuits to each other. Since the primary and secondary windings frequently shared a common current (depending upon the design and application), this arrangement is called an *auto-transformer*. These resonant auto-transformers are used as high-voltage power supplies in television sets, while radios use the basic circuit in matching radio-frequency circuits.

A couple other practical inventions serve to show the range of Tesla's genius. Shortly after leaving the employ of Edison, he developed an automatic-feeding arc light. It was marketed and its success helped him to meet Westinghouse. Most people are unaware that Tesla built and patented an automobile speedometer (Cheney [1981] 1983, 219).

## Prototype Technologies

Probably the broadest range of inventive activity that Nikola Tesla was involved with were the Prototype Technologies. In researching a broad range of Tesla's developments and inventions, I found that most were never placed on the market by Tesla. For a variety of reasons Tesla couldn't gain sufficient capitalization. Actually, he wasn't too interested in marketing some of his inventions; furthermore, the support technologies of his day were often too backward to allow him his desired goals. Tesla was interested in everything, and he dabbled with all kinds of engineering disciplines. Whereas Edison would experiment with something only if he knew that there was a market ready for the invention, Tesla tended to experiment first and look for a market later.

There are many good examples of inventions that Tesla built to serve some useful application for himself; yet, it was others who came after Tesla that found a marketable product in what he had done first. Artificial lighting in the form of fluorescent tubes, neon lights, etc are good examples. Shortly after Tesla started building his high-voltage, high-frequency machines, he found that rarefied gases inside glass tubes emitted light when electrically excited. It's curious to me that he never sought to market these new lighting systems. But hindsight is perfect they say. The most novel of Tesla's artificial lights was the carbon-button lamp: Inside a mostly-evacuated glass bulb was a small disk of hard carbon suspended by a wire. When the lamp was placed inside a strong high-voltage, high-frequency field, the ionized gas inside would oscillate with the field. This created friction with the carbon, thereby heating it up to incandescence. Witnesses observed that the light emitted was pure white. But for Tesla, the carbon-button lamp wasn't a grand enough development to consider selling. Maybe Tesla was aware of some formidable problems with it as a viable product; but if that is so, he never told anybody. Tesla's demonstrations with lighting tubes in the early 1890's were the triggers for other engineers to duplicate the work. What we now use as fluorescent lights were developed by D. McFarlane Moore at Sylvania, based on his observations of Tesla's demonstrations at the 1893 Columbian Exposition in Chicago. There are numerous ways that tube lights with rarefied gas are excited to emit light. Tesla used both high-voltage transformers and radio-frequency fields to operate his rarefied gas (e.g., neon, mercury vapor, air) lights. Yet, some of Tesla's artificial lights have never been developed outside his laboratories. In several instances, the light is well documented, such as the carbon-button lamp, yet has not found commercial or consumer use today (Cheney [1981] 1983, 90; Hunt and Draper [1964] 1981, 89; O'Neill [n.d.] 1981, 46–49, 146–149).

Some of the more dynamic opinions for or against Tesla were formed during Tesla's involvement with x rays. Most of the early x-ray research was done around 1890, involving a group of about a dozen scientists on both sides of the Atlantic. X-ray effects were being discovered and studied by these scientists for nearly a decade, especially as higher and higher voltages were available. Although Wilhelm Roentgen is credited with the discovery of x radiation, Tesla and several other scientists were trailing Roentgen's research by only a matter of weeks, or even days. As noted in the video teaching series *The Mechanical Universe* (Goodstein 1985, part 1), the scientist or explorer gets the credit for a discovery because he identifies and documents the discovery so that it never needs to be rediscovered. The example used in *Mechanical Universe* to clarify this discovery/credit phenomena is that of Columbus in 1492. While settlers, raiders, fishing fleets, and other explorers from Europe had encountered the Americas in previous centuries, it is to Columbus that we credit the discovery of America because no other Europeans needed to rediscover it. The same phenomena generally holds true for pioneering scientists and engineers. Roentgen consolidated his observations and experiments, and he theorized the nature of what he called "X Radiation." His announcement, in January 1890, touched off parallel research but also claims of prior discovery. Tesla acknowledged the value of Roentgen's work and claims, even though he had already exceeded the sophistication of Roentgen's experiments. Tesla didn't claim prior discovery though, since, by his own admission, he didn't recognize the significance of his results (Cheney [1981] 1983, 101).

However, Michael Pupin did not react to Roentgen's claims as magnanimously as Tesla had. Pupin was also a Serbian immigrant, having arrived in America fifteen years before Tesla. He was an early supporter of Tesla's alternating current scheme. In fact, Pupin jeopardized his faculty position at the then recently-formed Columbia University electrical engineering college by breaking with the vested DC interests there. The question of who really discovered x rays caused Pupin to diverge from Tesla. Ultimately, a number of other differences arose between Pupin and Tesla, which led Pupin to side with Marconi against Tesla's claim to being the originator of radio. Pupin asserted to have discovered x radiation before Roentgen. He said that he had x ray shadow photographs made at the same time as Roentgen's. That may very well be, but Roentgen published his results two weeks before Pupin. Now Tesla didn't endear himself to Pupin any by producing two-year old x-ray photographs of his friend Mark Twain. No matter which way Pupin turned to show that his work predated Roentgen's, Tesla could easily show that his own experiments not only predated Pupin's but that they were much more advanced. Tesla had undermined every one of Pupin's claims about having first discovered x rays and their properties (Cheney [1981] 1983, 100-101). Nearly every research laboratory on both continents, it seems, jumped into x-ray research during the ensuing years. Tesla's experiments led him to speculate that x rays were particles. The x-ray experiments on biological organisms (including people) led him to warn of their detrimental effects on living tissue. In 1897, Tesla was the first to call for some regulation of exposure and uses of x rays. So Tesla's contribution to the x-ray industry was in the form of introducing safety measures, not in pioneering x-ray machines or realizing a profit from his own research (Cheney [1981] 1983, 105).

*Tesla's radio pioneering—"fatherhood" and fiasco*

The wireless—or what we now call radio—was one of Tesla's more controversial projects. By the time Tesla arrived in America, many scientists had been working with the theory of electromagnetism: The mathematical basis for which had been codified by James Clark Maxwell about twenty-five years earlier. And at about the same time that Tesla decided to study the wireless, Heinrich Hertz, in 1888, demonstrated that a spark transmitter could induce a spark in a nearby receiver. Tesla determined that an electro-mechanical, high-frequency alternator would be the basis for his radio technology. These devices were built during the early years that Tesla was in America. It wasn't long, however, before Tesla decided that the frequencies developed by these machines were too low to be useful. This challenged him to conceive the quintessential contribution to radio technology—the so-called "tank circuit." This circuit is a parallel arrangement of capacitor and inductor to form a resonant, high-Q circuit. Tesla went on to use this circuit, fed by other resonant transformer circuits, to generate for the first time manmade high-frequency electromagnetic energy. Some of the basic alternators of the time could generate up to around 30kHz, but by feeding the tank circuits with those alternators, Tesla could achieve frequencies up to ten times greater.

During the early years that Tesla spent lecturing to scientists and engineers about the value of AC, he described and demonstrated his wireless apparatus. He also published his ideas, drawings, and possible uses for the emerging technology. Fully intending to develop the wireless as a marketable, profitable system, Tesla centralized his research in his New York laboratory. It appeared that Tesla's scheme of combining the wireless as a means of transmitting information (by telegraphy, voice, etc) and as a means of transmitting electric power was progressing quickly; he expected to see fruition within a decade. Accounts of the various activities (including the wireless) in the New York laboratory captured public fancy. It was during this time that Tesla perfected his now famous Tesla Coils, which utilize the tank circuits. However, independent of Tesla, enough scientists around the world were working with the same technology based on Tesla's, Maxwell's, and Hertz's earlier developments. The race was on, and Tesla was the odds-on favorite to win. Then, in 1895, Tesla's lead was lost because of a disastrous fire that destroyed his New York laboratory. It took two years of recovery for Tesla to file just several patents for wireless technology. In any case, there was a philosophic chasm between Tesla and the other radio investigators around the world that left him in isolation.

This isolation ultimately lost the race for Tesla, but he didn't go down without a fight. While other researchers were perfecting wireless technology for information transmission, Tesla, on the other hand, tied-in his scheme of electric power transmission with information transmission. This was apparently the tactical error which cost him any supremacy in radio technology. By not seeing the transmission of information as the immediate goal of wireless technology, Tesla had to spend greater amounts of time and money to pursue his research, allowing other scientists and engineers to catch up to and then surpass his state of research. As the description of the historical events will shortly demonstrate, Tesla's stubborn insistence that all wireless technology be able to transmit electric power placed him outside the mainstream of prevailing scientific and engineering thought about the uses of wireless technology. Though Tesla eventually won the court battle to prove his priority of investigation, he lost the war for the fortunes of radio.

Tesla was quite sure of his preeminence in wireless technology as he arrived in Colorado Springs, Colorado in May of 1899. Most of what developed from the Colorado Springs experiments are better discussed later, but his experiments in wireless transmission of information and electric power are properly dealt with here. The Colorado Springs laboratory housed the largest Tesla Coil built until Robert Golka's experiments during the late 1970's. "The remaining space was filled with dynamos, electric wires, switches, generators, motors, and every conceivable gadget known to electricians" write Hunt and Draper ([1964] 1981, 114). Tesla had maintained for some time that the earth was an efficient conductor, suitable for all-points transmission of electric power. His tests, in early July, with the giant Tesla Coil (which he called his "Magnifying Transmitter") seemed to support his theory of the conducting earth. Now, ever since I first heard of Tesla, I was told that Tesla succeeded in transmitting power efficiently over a distance of about 20 miles, and lighting up a 20kW load (or variations thereof). The following is a typical example: "In actuality, he lighted more than 200 incandescent lamps 26 miles away" (McBirnie 1987, 2). So, it would seem that Tesla successfully tied together the transmission of information and electric power from one station. However, it's time to burst the apocryphal bubble that supports this legend. In all my research of this matter, I have not find any definitive evidence to support the assertion that Tesla had in fact performed this demonstration. Cheney ([1981] 1983, 148–149) offers the best explanation of what may have actually happened:

> It has been reported by various writers that during his power transmission experiments in Colorado, Tesla succeeded in lighting up a bank of two hundred 50-watt incandescent lamps wirelessly, at a distance of twenty-six miles from his station. In his own writings, however, no such claim was ever made, nor is there other evidence that he did so.

Though Tesla thought that he had passed a current around the earth capable of lighting 200 incandescent lights.

It is likely that Tesla really didn't demonstrate the viability of transmitting power and information while he was in Colorado. Furthermore, he didn't produce any new marketable inventions from the Colorado experiments. But his letters to financiers and entrepreneurs promised fortunes from the wireless technology based on these experiments. Unfortunately for Tesla, the rest of the pioneering radio engineers had caught up with him. As he was seeking funds for his "World Broadcasting" center, Guglielmo Marconi made world headlines by wirelessly transmitting telegraphy across the Atlantic in December 1901. But Marconi used Tesla's descriptions of the wireless published during the early 1890's, which the courts later decided was an infringement on the patents filed by Tesla in 1897. In other words, Marconi used Tesla's patented designs to steal Tesla's preeminence in wireless technology. Nevertheless, Marconi does deserve credit for developing a practical wireless system—a system which Tesla wouldn't have bothered to work-out the details. Even when radio broadcasting became widespread some two decades later, Tesla still insisted that his system, fully developed, would have been superior. Convinced that Marconi's feat was only an insignificant stunt, and having finally managed to gain financial backing, Tesla embarked on the second phase of his grand plan. But Tesla had compromised by accepting the backing of J.P. Morgan—the man he distrusted most in business dealings.

In his hurry to compete with other researchers, Tesla was almost frantic while building the Wardenclyff transmitter site. He insisted that the rash of successful wireless demonstrations following Marconi was superfluous and misdirected at best. Wardenclyff was to show the world what the proper use of wireless technology should be, and all other wireless experimenters would therefore have to fall in line. But Tesla was hampered by the poor flow of incoming money, and he had to make many compromises in its construction. Most of the work was done over a two year period, but still the project wasn't finished. For a number of years following, Tesla tried to get Wardenclyff operational, but more and more, assistants left and creditors demanded their due. After learning that no more money would come from the Morgans, Tesla fired up the transmitter that night, giving New Yorkers a grand display in what was, ironically, Wardenclyff's death knell. For several more years it stood mute on Long Island, until, at the onset of World War I, it was torn down. In the meantime, wireless systems had proliferated all over the world. Defeated, Tesla never again participated in wireless technology.

The balanced view of Tesla's work on what we now know as radio technology acknowledges his pioneering ideas, yet notes that he spent too much time and money pursuing projects that never yielded the desired results or fortunes for Tesla. Even while Tesla strove to get Wardenclyff operational, Lee DeForest invented the triode vacuum tube amplifier (used for voice modulation). Quite sensitive regenerative radios were beginning to be used around World War I. Yet, Tesla still thought in terms of telegraphy and mega-power levels. If Tesla had spent his time pursuing low-power, narrow-band wireless applications, who knows what form the early radio industry would have taken? Posthumously, Tesla won a U.S. Supreme Court decision against Marconi and others, essentially declaring Tesla the "father" of radio. But it was some forty years too late for Tesla. Even if the decision had occurred on a timely basis, the Serbian-born genius would have pursued his own goals all the more furiously, even though it was already apparent that the world wanted something else from the fruits of his genius.

*From turbines to "atom-smashers"*

Conceived originally by Tesla when he was four, the bladeless turbine was to be his new fortune after World War I. About 1890, Tesla constructed several prototypes while in his first laboratory in New York. He didn't take this project too seriously until, in 1906, he built a ten-pound model that developed ten horsepower. After the Wardenclyff fiasco, Tesla returned to this project to help him overcome his depression. Predictably, he began to solicit new investors. The greatest financial success that the turbine brought to Tesla during this period was in prewar Europe. This invention had the ill-fated timing of gaining interest from the German navy. Despite Tesla having offered the device to the U.S. war industries first, his U.S. backers wanted to pull the financial rug out from under him. Tesla pleaded with J.P. Morgan, Jr. to maintain the funding. However, the onset of war quenched any hopes that the turbine would succeed in Europe. By 1915, an industrial model was financed for demonstration at the steam-electric plant at Waterside Station in New York. This turbine was to generate 200 horsepower. From the start, Tesla had friction with the Edison engineers that worked there. Other problems developed with the turbine operating at industrial capacity. These problems never would have exhibited themselves with the prototype models because they were not under the degree of stress developed by the industrial model. It turned out that the state of metallurgy and alloy construction early in this century could never have built a strong but light-weight alloy for the turbine that could withstand the 35,000 rpm stresses. The necessary alloys for the turbine were not available until World War II, but once again, this was too late for Tesla. Cheney ([1981] 1983, 193) notes that the Office of Naval Research in Washington, D.C., frequently receives proposals for research and development based on the Tesla turbine. These proposals will invariably be rejected until one of them offers a ten-fold improvement over the current Parsons turbine.

To be fair, Cheney cites some 1980's university scientists and alternative-energy firms that are seriously examining uses of the bladeless turbine for solutions to their own problems: Warren Rice of Arizona State University is cited by Cheney as the premier expert on Tesla's bladeless turbine and on fluid mechanics. Some incidental patents were issued to Tesla in 1916 concerning the turbine. One of them describes a valvular conduit mechanism. This device is, in reality, a fluid diode: it allows fluids to flow through it in only one direction. This device has found widespread use throughout industries dependent upon fluid dynamics, yet Tesla never earned a profit from its uses (Cheney [1981] 1383, 199 et passim). By about 1920, the continued development of the turbine was completely abandoned. Now, the reader may have noticed that I haven't attempted to describe how the bladeless turbine works. Even though I examined a copy of the patent and other sources, I couldn't figure out which were the moving parts (Tesla patent #1,061,206 [1913] 51–62).

A minor example of Tesla's Prototype Technologies is that of the *Tesla Nitrates Company.* The technique of extracting nitrogen from the air to make fertilizer was originally published in Century magazine in 1900. During World War I, Tesla formed a company to profit from this process. However, it proved to be economically unfeasible, and he made no further attempts to revive the technique (Cheney [1981] 1983, 219). A similar fate occurred to Tesla's Solar Engine: In 1898, he announced a way of producing electricity from a solarheated steam turbine—a remarkably modern idea. The idea was good, but its efficiency was no match for the conventional steam producing methods (Cheney [1981] 1983, 119–120). Cheney ([1981] 1983, 119 et passim) cites about sixty similar examples.

Some unfortunate terminology seems to be used by many Tesla biographers, and much of it relates to Tesla's experiments with vacuum tubes during the early 1890's. Several misnomers applied to Tesla's innovations include the "atom-smasher" (really just the carbon-button lamp), the point "electron microscope" (really just an electron stream in a vacuum tube), and the "cyclotron" (really just an ion stream in a vacuum tube) (McBirnie 1987, 3 et passim; O'Neill [n.d.] 1981, 152 et passim; Cheney [1981] 1983, 59 et passim; Hunt and Draper [1964] 1981, 88 et passim). While some credence may be given to Tesla for discovering some of the principles underlying these high-tech devices, he didn't develop his apparatus into the recognized modern ones.

My final example is one of the more entertaining of Tesla's successful but unmarketable developments. There were two era's in Tesla's life where he observed ball lightning. As a young boy in Croatia, and during the experiments in Colorado, Tesla had frequent occasion to observe natural ball lightning. The apparatus in Colorado was sufficient for Tesla to produce ball lightning artificially. While nothing came of those experiments during Tesla's life, a new interest in them developed during the last twenty years for nuclear fusion research. During the late 1970's, Robert Golka duplicated the Colorado Tesla Coil in Wendover, Utah to investigate the possibility that a low-energy plasma such as ball lightning could be useful in containing a fusion reaction. As of this writing, no definitive results have come from this line of research.

**Speculative Technologies**

This is the one area of any discussion about Tesla that can elicit the most fringe or mystical beliefs and self-serving opinions from people. This category embraces a wide range of Tesla's writings for public reading or otherwise about technological utopias. Tesla attempted to motivate new inventions that didn't even make it to the prototype stage, and his unsolicited letters to companies, offering solutions to an array of engineering problems, were not always welcome. Tesla's public image during his active career—and later—is in part due to the most common type of journalism of his day: It was the era of yellow journalism and sensationalism. "His own extravagant statements were grist for the mill of every sensational journalist" and "Tesla has been the victim of more forged interviews and sensational articles appearing without authority than any other inventor" report Hunt and Draper ([1964] 1981, 183) from an 1896 edition of the New York Sun. Some things that Tesla speculated about enjoyed public fancy, and in at least one case, came true. About 1890, Tesla reported that his 60-cycle frequency standard used in AC power was so stable that a synchronous motor, appropriately geared down, could run an accurate clock (Cheney [1981] 1983, 61). Tesla never built such a clock as far as I can determine, but before his death, *telechron* (brandname) movements were the operational part of all analog, motor-driven, AC-operated clocks.

*VTOLs, death rays, and "scalar electromagnetics"*

Another early speculation of Tesla's that saw subsequent fruition, was the heavier-than-air flying machine. Tesla had designed a variety of aircraft prior to the Wright brothers' successful flight in 1903. He even had one aircraft plan that he called the "Aeromobile," which was a combination car and airplane. Post Wright brothers, Tesla maintained that then-prevailing designs for airframes were always inefficient. One such advanced plan of

Tesla's was patented in 1927, a "boxlike flivver airplane" (Cheney [1981] 1983, 198). This aircraft is essentially a Vertical-Take-Off-and-Landing (VTOL) type. It was sort of a single-seated helicopter no larger than a small car. The magic property of the aircraft, which Cheney calls a "flying stove," was to be Tesla's turbine used as the motive source. But construction of even a prototype was never considered. As with a great many of Tesla's ideas, it resurfaces every so often in the popular, scientific, or engineering literature. As recently as the writing of this series, the "flying stove" concept reappeared in the September 1987 edition of Popular Science magazine. "The excellent article *X-Wing and Tilt-Rotor: Hybrid Aircraft That Get Up and Go* [July] brought to mind Nikola Tesla's 1927 patent for a vertical-takeoff-and-landing apparatus . . . Like many of Tesla's ideas, it preceded the technology that brought it to fruition by many years. —Harry Goldman" (Goldman 1987, 4). During the 1950's, Convair built and tested the *XFY-1* VTOL aircraft. It was based on the concept of the "flying stove." While they found that the *XFY-1*, nicknamed the "Pogo," experienced stability problems, needed a more powerful engine than was feasible for a small frame, and afforded the pilot a blind view of the landings, the overall idea of VTOL was feasible. Even though it was not the same machine as Tesla's—and as such, it would be unfair to compare the Pogo identically to the flying stove—the Pogo demonstrated some problems with the "flying stove" concept that Tesla could not have been aware of (Cheney [1981] 1983, 201–203).

One of the more common of Tesla's ideas that get recycled into public awareness every so often is the so-called "death ray." I will cite one such occasion during his life. Commentary on the death ray is appropriate, as the Strategic Defense technologies sought after these days allows Tesla's ideas on this to resurface in the public mind. In 1924, newspapers announced that a death ray capable of shooting down aircraft had been invented by an Englishman—a German a Russian (take your pick). Cheney cites a newspaper in Colorado that rebuked those other news reports by pointing out that Tesla had invented such a device while in Colorado Springs in 1899. Yet, Tesla was "unusually noncommittal on the matter" (Cheney [1981] 1983, 235). Another example of Tesla's death ray speculations that captured public fancy was that of the "teleforce." On the occasion of his 81st birthday (1937), journalists heard Tesla tell of his plan to protect the U.S. coastlines with the teleforce invention. He maintained that it only needed a little more work to become operational (Cheney [1981] 1983, 255–256).

On Tesla's 75th birthday, he released plans for a geothermal steam plant, and a sea-water thermal-layer-electricity-production process. Both of these ideas have found merit in experimental research seeking alternative energy sources during the past two decades. To whatever extent that these systems are ultimately successful, we can acknowledge Tesla's visionary genius. But in no way can we say that he actually invented the alternative energy processes that may finally develop. Consider an alternative example to help clarify my point. In both the television series documentaries by Arthur C. Clarke (1983 and 1985) produced in the mid-1980's, the introductory narrative of each program gives Clarke the credit for inventing the communications satellite. Now, Clarke did write a science-fiction story in 1947 describing how such a communications network might work. It was precise in operational details, including the idea of placing the satellites in geosynchronous orbit. But Clarke did not design, build, and send up a satellite himself. The narrator's comments leave out the myriad of theoretical and applied engineering disciplines that it actually took to get the first satellites in orbit. It was major corporate entities such as RCA that placed geosynchronous communication satellites in operation during the 1970's that also share with Clark and these engineers the credit for the communications satellite.

Tesla's keen interest in flying again led him to approach the U.S. War department just prior to World War I about the construction of a remote-control dirigible that could fire torpedoes. As far as I can determine, this was the closest that Tesla ever got to actually building a prototype of one of his aircraft plans. Even with the help of John Jays Hammond, Jr., a young pioneering radio engineer, Tesla couldn't get more than a casual interest from the wartime government bureaucracy (Cheney [1981] 1983, 193). This is an example of an unsolicited innovation that Tesla promoted to a company, individual, or government. Another one was his plan to degasify copper. About 1933, he approached Dr. A.J. Phillips of the American Smelting and Refining Company (ASARCO) with a plan to degasify (or remove bubbles from) copper during the purification process. As Cheney ([1981] 1983, 248) writes, "Tesla was perfectly capable of going off half-cocked, as his forays into metallurgy (as his dissatisfaction with the metals available for use in his turbine) suggest."

One of the more amusing Tesla speculations goes back to his experiments with vacuum tubes during the early 1890's. He built a tube which contained a visible ion stream. Placing it near electric or magnetic fields would deflect the beam into all manner of interesting shapes. Tesla suggested that it would detect biological forms of life, become a medical diagnostic tool, and even detect the presence of ghosts. So far, the closest that Tesla's speculations on these matters have shown any results, have been with Kirlian photography (Cheney [1981] 1983, 93–94).

There is one other speculation on the part of Tesla that deserves mention. While in Colorado, Tesla claimed to have discovered a special class of electromagnetic phenomena which he labeled "scalar electromagnetics." For purposes of this part of the article, I don't need to go into detail of what scalar electromagnetic energies are, save that Tesla stated that such energy could transcend the speed of light—he did admitted however that this stuff was different than your run-of-the-mill transverse electromagnetic phenomena. He believed that communication with extra-terrestrial civilizations (especially with Mars) was possible by using the scalar electromagnetics devices. Tesla also believed that this class of energy could be harnessed to deliver any amount of useful electric power to anywhere in the world. Some recent allegations are that the Russians have harnessed this technology to trigger earthquakes; control weather; destroy ships, aircraft, and spacecraft including the ill-fated Challenger space shuttle (McBirnie 1987, 1 ff). This area of discussion is better dealt with in the third part in the series of articles.

*Tesla's rock-and-roll mania*

My final example of the Speculative Technologies involves the resonating earth. There are numerous times in Tesla's career where he speculated about destroying the earth by using mechanical resonant processes. My favorite episode concerning Tesla's mechanical resonance "inventions" occurred in 1898. Some parts of it strike me as apocryphal, but there appears to be one specific incident that did happen. One day Tesla tested a "tiny" (Cheney's word) electromechanical oscillator by clamping it to an iron pillar in the lab. With scientific curiosity, he proceeded to observe the effects of resonance as it became louder, various objects in the room would vibrate resonantly as the frequency of the device was changed. Unfortunately, Tesla was unaware that the vibrations were being transmitted through the building into the surrounding block. Cheney writes, "Buildings began to shake, windows shattered, and citizens poured onto the streets in the nearby Italian and Chinese neighborhoods. At Police Headquarters on Mulberry Street, where Tesla was already regarded with suspicion, it soon became apparent that no other part of the city was having an earthquake." She continues, “Two officers were dispatched posthaste to check on the mad inventor. The latter, unaware of the shambles occurring all around his building....” (Cheney [1981] 1983, 115). Tesla shut down the experiment just as the officers burst into his lab. He explained that although he had to (violently) terminate the experiment just then, he would welcome them back later that evening for another demonstration. “When reporters arrived, he blandly told them that he could destroy the Brooklyn Bridge in a matter of minutes if he felt like it,” writes Cheney ([1981] 1983, 116). I heard the same story while in high school many years ago. But the physics teacher related to me that it was a five-ton platform in the basement that Tesla set oscillating. This is more plausible to me than Tesla’s using a wind-up “chatter toy” as Cheney seems to be describing. It’s the ratio of several orders of magnitude of horsepower needed by an oscillator to move a very heavy platform over a “tiny” oscillator driving against an iron pillar that makes the earlier version of the two stories more plausible to me. Cheney ([1981] 1983, 116) quotes Tesla in an interview with a reporter, Allan L. Benson, on one other episode. She sets-up the situation first:

> “. . . he put the little vibrator in his coat pocket and went out to hunt a half-built steel building. Finding one in the Wall Street district, ten stories high, with nothing up but the steelwork, he clamped the vibrator to one of the beams. “In a few minutes, . . . I could feel the beam trembling. Gradually the trembling increased in intensity and extended throughout the whole great mass of steel. Finally, the structure began to creak and weave, and the steelworkers came to the ground panic-stricken, believing that there had been an earthquake.”

Tesla continued on with the interview by declaring “that he could split the Earth in the same way—split it as a boy would split an apple—and forever end the career of man’. Earth’s vibrations, he went on, have a periodicity of about one hour and forty-nine minutes.” I find this story about the building under construction too hard to believe. The same applies to his alleged comment about the earth. What we are dealing with here is the physical property of resonance, examples of which are found in electric circuits, and with acoustic instruments. The physical resonance that Tesla was referring to was in the area of acoustic instruments: A taut string can be plucked to produce a musical note. Technically, while the string is ringing out its note, it is resonating. Any object of can be periodically “kicked” by a variable frequency “kicker” (i.e., generator) and tuned until the tested object begins to harmonize with the generator. The object then begins to resonate. Short of performing an actual test, determining whether or not an object will vibrate strongly at resonance, even under the best possible conditions, can be a very complex matter. A short, but technical, explanation of resonance should help to clarify things a bit. The best explanation of physical resonance that I have ever seen is a segment entitled “Resonance” from the television series *The Mechanical Universe*. I will abbreviate the facts presented in this segment to show why Tesla understood resonance, yet related dubious accounts to Benson.

Let $a_0$ be the amplitude of a “driving machine”—such as Tesla’s building “rocker”—and driven at frequency $\omega_0$; and let $A$ be the magnitude of vibration of the oscillator, such as Tesla’s laboratory building; then the variation of oscillation is given by:

$$A \sin \omega_0 t = \frac{a_0}{\omega_0^2 - \omega_r^2 + df} \sin \omega_0 \, t$$

As the generator frequency $\omega_0$ approaches the resonance frequency $\omega_r$ of the object, the vibration approaches its maximum. The $df$, or *damping function*, term is the fly-in-theointment for Tesla: It is determined by the physical circumstances that the object is found in. For example, a taut string that strongly resonates may not vibrate at all if placed under water. The function, when properly used, specifies a threshold magnitude necessary for the object to finally achieve resonance. It is that damping function, in my opinion, that disturbs Tesla's account of the building. A pocketsized, variable-frequency generator that Tesla is supposed to have used, could not have delivered sufficient horsepower into the building to start a resonance response. The minute energy would have been damped-out before it did anything "useful." As the *Mechanical Universe* segment relates, any building between five and forty stories is susceptible to resonant only at earthquake frequencies—i.e., between .1 to 25 Hertz, including the significant harmonics. The ten-story building that Tesla tested would have had to experienced impulses from the generator at those frequencies. And here's the rub, the energy delivered into the building by the generator would have to be of the same magnitude of energy as would be delivered by an earthquake to actually cause the building to resonate.

As for bringing down the Brooklyn Bridge, let's examine an actual example when a bridge was destroyed by resonance. On November 7, 1940, the Tacoma Narrows bridge at Tacoma, Washington collapsed from winds in excess of forty miles-an-hour. The energy delivered into the bridge structure by the cross-winds was sufficient to make the bridge oscillate violently. As the wind can be mathematically described as high-amplitude (and therefore high-energy) "pink noise" (i.e., a frequency-dependent energy density distribution curve), the frequencies within the noise band that would set the bridge into resonance would be supplied by the wind in sufficient quantity to overcome the bridge's natural damping function. Based on what actually happened, it's apparent that the wind had to supply an incredible amount of energy into the bridge to cause its destruction. This energy level is probably ten orders of magnitude over what Tesla's little generator could supply. Historically, this incident has been the only such example of a bridge collapse due to resonance. All modern bridges are designed to damp-out destructive resonance energies.

Finally, I believe that splitting the earth apart by some Tesla resonance mechanism is just about impossible. Different frequencies propagate through the earth in different layers, i.e., are ducted around the crust, mantle, etc at different rates. Tesla thought of the earth as a simple construct—a single homogenous mass. He obviously didn't stop to think of the specific order of magnitude of energy necessary to overcome the natural damping factors within the earth. Tesla thought he could do it with a ton of dynamite exploded on the same site every hour and forty-nine minutes. I maintain (without actually performing the calculations) that it would take an impact of something the size of a cometary body striking the same place on the earth at a rate of whatever the fundamental resonant frequency of the earth turns out to be.

## Conclusion

The purpose of this article was to present the real accomplishments of Tesla—especially his enormous contributions to the development of cost-effective AC technology—and to help the reader develop a sense of how to interpret Tesla's works and writings within their historical context. To simplify my presentation, I classified his inventions and innovations into three easy-to-manage categories.

The middle ground of the classification scheme which are the Prototype Technologies shows Tesla's vigor and visionary thinking that ultimately yielded fruit for others, but seemed to always evade renewed fortunes for him. Some of this was due to Tesla's inability to gauge the marketability of his "lesser" developments. Another restriction Tesla constantly contended with were the various financial and business problems that resulted from his own inability to properly plan and insure his assets and documentation. The first and foremost category of accomplishment that I defined are the Manifested Technologies. These are the most visible, demonstrable, and successful of Tesla's works. Whenever one wants to talk of the "real" Tesla inventions it's somehow much more fascinating and relevant to investigate the tangible remainders of Tesla technologies. The analysis of the rationale and intrigue surrounding the creation of the modern AC power grid is to me much more interesting than speculating on what might have been or what the Russians might be doing with Tesla technologies.

From this article and the previous one, the foundation has now been laid to examine the legacy, mysticism, and idiosyncrasies of Tesla. His technical accomplishments invite many more questions about the ripple effects he left in the vast modern sea of technology. And some of the post World War II political opinions that generated anti-Tesla writings will be examined in the coming article. Tesla continues to fascinate us; he's a model of excellence in character, determination, and inventiveness. Despite significant problems with achieving his goals, Nikola Tesla has, to this day, few rivals to his deep visionary genius.

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