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The History of Wireless Telegraphy at the Eiffel Tower

Ted Simpson and Bill Liles

Long after Gustave Eiffel's famous tower had been built to celebrate the first century of the Republic, many Parisians were still offended by this *tour de fer* and sought its removal. Eiffel argued against this, saying that the unique advantages the tower's elevation offered for scientific research justified its permanence; the height was particularly important for the transmission of the newly discovered Hertzian waves carrying telegraphic signals *sans fil* (without wires). But it was still the age of machines. Steam power and electric lights were common. Vacuum tubes were yet to come. Here we review an array of devices used to generate and detect these invisible waves. With this new mode of communication, ships at sea were no longer bereft of news from distant ports or other ships; the French military posts on distant shores were kept in constant contact. Time signals from the Paris Observatory could be shared with anyone possessing a simple antenna and crystal receiver. Here we look back at the rapidly developing state of the art in antennas and transmitters and the people involved in this exciting era. We summarize the early stages of wireless technology from a French perspective.

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INTRODUCTION

About the same time that Gustave Eiffel [1] launched the design of his iconic tower in Paris in 1887, Heinrich Hertz [2] began a series of experiments in Karlsruhe, Germany, which in turn led Guglielmo Marconi [3] to attempt to span the oceans with wireless telegraphy. Who would have guessed that these events would lead to the creation of one of the most powerful radio stations in Europe?

The Eiffel Tower stands today as a treasured monument to French ingenuity and artistic spirit. But it was not always so; there were serious misgivings about the appearance of this huge iron tower. Many felt it was an unwelcome addition to the skyline. There were questions about its long-term usefulness. Since that time, it has become the symbol of Paris and of all things French. Here we look back to see how Eiffel countered the early criticisms with words and deeds as well as by personally financing experiments with the new wireless telegraphy from the vantage point of the tallest of existing man-made structures.

THE FIRST DEMONSTRATION OF WIRELESS TELEGRAPHY IN FRANCE

Nine years after the French Exposition of 1889 closed, Eiffel, seeking scientific uses for his great tower to thwart the efforts of many to tear it down, invited Eugène Ducretet [4], a famous French instrument maker, to use the platform outside his office atop the tower to demonstrate this new wireless communication. Ducretet brought equipment of his own design, a large induction or Ruhmkorff coil, to excite a thin-wire antenna suspended from the tower's top, as shown in Figure 1, and a coherer detector [3] to receive signals exchanged between himself and an associate similarly equipped high in the Panthéon.

High on that windy perch on 5 November 1898, Ducretet caused a sensation in France with a public demonstration of wireless communication between the Eiffel Tower and the Panthéon 4,000 m away. This was done in the presence of representatives of the Académie des Sciences. The era of wireless communication in France was launched!

A BASE-DRIVEN TEST ANTENNA

Eiffel then contacted Captain Gustave Ferrié with the French military and offered him the use of his tower as a support for an experimental wireless station. In 1903, after much delay, Eiffel proposed to place his tower at the disposal of the military engineers for new experiments in wireless telegraphy, writing [1] "I also offer to bear all the costs

EDITOR'S NOTE

The membership of the IEEE Antennas and Propagation Society (APS) History Committee has remained the same for the last three years. Expressions of interest of potential new committee members are welcomed. As well, the committee welcomes the comments and participation of all Society members in its activities. The "Historically Speaking" column is one of the activities undertaken by this committee. We encourage submissions on all relevant topics in the field of interest of the APS.

This month, we have a fascinating overview article by Ted Simpson, the Society's historian, and Bill Liles, a committee member, on the role the Eiffel Tower played in the development of wireless communications. It has been 102 years since regular broadcasts began from the Eiffel Tower. However, before that the tower was used as an antenna mast for early propagation experiments with the then newly developed radio equipment.

Now an important symbol of Paris and France, it was not always so accepted. At the time of its construction in 1887, many Parisians were against building an iron tower in the center of Paris. Some expressed their concern through the press, for example, in a letter titled "Artists Against Mr. Eiffel's Tower," stating that the tower was a threat to the aesthetic beauty of Paris. A skeletal iron tower or "beffroi" (a skeleton of a church bell tower) in the center of Paris was considered to be in sharp contrast to the refined nature of the city.

The Eiffel Tower was built to commemorate the 100th anniversary of the French Revolution in 1789. A competition was organized to "build on the Champ-de-Mars an iron tower with a square base, 125 meters wide and 300 meters high" [S1]. Out of the 107 proposals submitted, the proposal by the well-known entrepreneur Gustave Eiffel was chosen. He led a team of engineers, including Maurice Koechlin, Emile Nouguier, and architect Stephen Sauvestre. Eiffel had already made a reputation for himself in the world of steel construction, as both an engineer and a contractor.

The Eiffel Tower was designed to reduce wind resistance as much as possible by offering a light and open structure. As Eiffel himself explained: "All the cutting force of the wind passes into the interior of the leading-edge uprights. Lines drawn tangential to each upright with the point of each tangent at the same height, will always intersect at a second point, which is exactly the point through which passes the flow resultant from the action of the wind on that part of the tower support situated above the two points in question. Before coming together at the high pinnacle, the uprights appear to burst out of the ground, and in a way to be shaped by the action of the wind" [S1].

Eiffel was born in 1832 in Burgundy, where his mother was a coal merchant. His family was originally from the Rhineland and had the surname Boenickhausen. The family took the name of Eiffel in 1879 to honor the hills in its homeland region.

The assembly of the tower itself—amazingly—took only two years. Although drawings were commenced in 1884, construction work began only in January 1887. The first stage was finished in April 1888. The second stage was completed in August of the same year, and the third and final stage in March 1889. In its final bare form, the tower stood 312 m high.

The Eiffel Tower was inaugurated on 31 March 1889, when Gustave Eiffel walked to the top of the tower and hoisted the French flag to its summit. From then on, Eiffel looked for uses of his tower. He had obtained a 20-year concession from the city of Paris to use the land on which it was built. This meant that after 1909 its future would be uncertain and would depend upon the Paris City Council's decision [S2].

Despite initial opposition, within 10 years, the tower entered popular culture, perhaps because of the huge success of the 1900 Paris Exposition and the positive outlook for the new century. In this spirit, the French Aero Club offered a prize of 100,000 ₣ for the first airship to complete the journey from the club's headquarters to the tower and back within 30 min. On 12 July 1901, the renowned Brazilian aviator Alberto Santos-Dumont made three separate balloon flights over Paris, managing to reach the tower and round it on the third attempt. But he was forced to land in a nearby garden because of rudder problems. The next day, he succeeded in flying his hydrogen-filled airship around the Eiffel Tower and back in 40 min—too long to earn the prize. Always persistent, Santos-Dumont eventually succeeded in taking the prize on 19 October 1901.

The tower offered a host of other scientific possibilities, such as those involving the newly developed Hertzian waves and meteorological and gravitational experiments. Eiffel had the names of 72 scientists carved along the edge of the first floor to honor them and to symbolically put the tower under their protection. Additionally, Eiffel established a meteorological station for himself on the third floor [S2].

There is much to tell about the use of the tower for wireless transmissions that is relevant here. This is where Ted Simpson and Bill Liles take up the rest of the story. Please enjoy reading this wonderful history.

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which may result from these experiences and the installation of a special post … I would be very happy if my offer could be profitable to the important service of our Military." This generous offer apparently tipped the scales, and work began.

In 1905, the antenna Ferrié set up for this experimental station consisted of a single wire suspended from an insulator attached to the top floor of the tower and driven from a small wooden building at the tower's base, as shown in Figure 2. it was excited, as before, by an induction coil triggered by a Morse code key. Using this rudimentary setup, communication was established with Belfort, where a post had been established by Captain Paul Brenot [5]. These tests confirmed

FIGURE 1. Eugène Ducretet transmitting the first wireless signal to the Panthéon in 1898 from the top of the Eiffel Tower. (Source: [4].)

that the influence exerted by the tower was not very pronounced if the antenna was pulled away from the tower.

The little Champ-de-Mars post received perfectly all of the communications exchanged by the English stations. It was already sufficient to link Paris to the borders and to maintain relations between the armies in the field and the capital.

Elated at the modest success of a single-wire antenna, the military engineers decided to expand the station to enable longer range and greater reliability. To increase the surface area of the antenna, the number of wires was to be increased, and to generate a better signal, direct excitation of the antenna's terminals was to be replaced by excitation through transformers supplied by the ac of the Left Bank Sector. Experiments with equipment continued for many years as new equipment became available.

FIGURE 2. A wooden shack serving early wireless experiments at the Eiffel Tower. (Source: [5].)

THE FIRST PRACTICAL ANTENNA: A FOUR-WIRE FAN

By 1908 the Eiffel Tower station antenna consisted of four wires, each 380 m in length, suspended from insulators attached to a beam located at the top of the tower. It was driven through a single downlead from a transmitter located in a wooden shack near the tower's base. Insulated pull-off cables were attached to trees, as indicated in Figure 3. Today, we would say that this was an electrically small top-loaded monopole capable of an intercontinental range of coverage if driven with sufficient power.

The operation of the transmitter circuit of Figure 4 was as follows: 230-V 42-Hz power supplied at A is controlled by a Morse code key M to the primary P of a transformer; the secondary S at 40 kV charges the capacitor bank C until a discharge through a rotating spark gap E supplies impulsive excitation to the antenna through a resonating coil autotransformer. The actual switching was done by a relay triggered by the key M. Each impulse of current from the capacitor excited a transient waveform; this is illustrated in Figure 5, which shows key down for 0.4 s (dashes) and, after a pause, key down for 0.1 s (dots). These discharges made a terrific noise and resulted in destructive erosion of metal at the arc sites. This was alleviated to some extent by

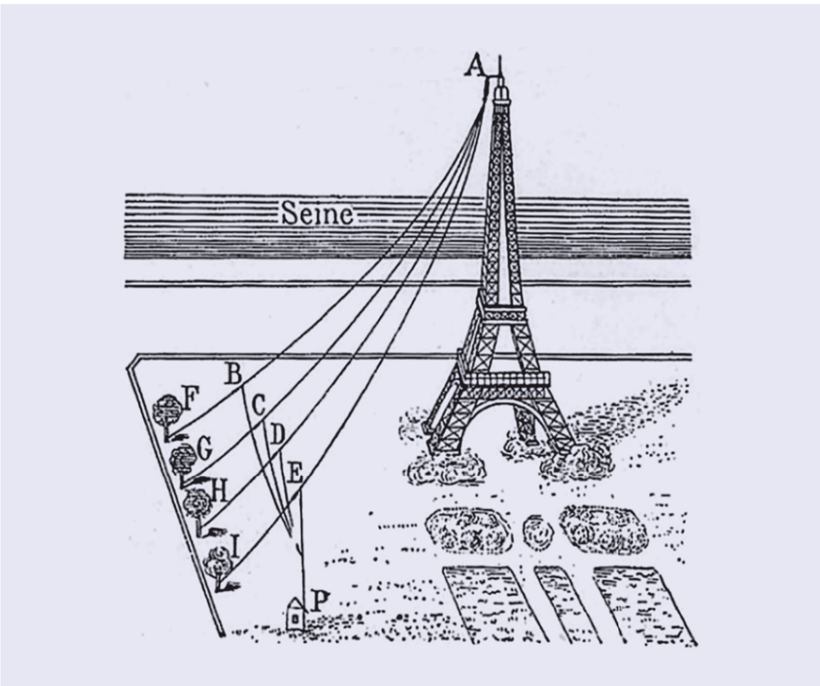

FIGURE 3. The four-wire Eiffel Tower antenna of 1908. (Source: [6].)

the use of a power blower as well as by employing rotating gaps so that the discharge site moved rapidly around the rotating electrode.

Receiving devices were crude in the beginning. Coherers were used at first but were soon replaced with more sensitive electrolytic detectors and these, in turn, with crystal detectors [6]. In operation, the crystal detector consisted of a sharp-pointed electrode that, when brought into light contact with the surface of a galena crystal, behaved as a point-contact diode.

The station grew as new equipment became available for testing. Captain Brenot remarked [5] that "the station looked like a small gypsy camp." It had grown helter-skelter into five wooden huts: one for transmission, another for reception, two used as offices for the guard officer and as shelters for the men, and the last one to house reserve equipment.

However odd this station may have appeared with its scattered wooden buildings, it allowed the French military to be in almost constant contact with its ships stationed on the North African coast. To ensure operation in case there was a loss of power from the Left Bank Sector, a not unlikely event, provisions were made to switch to a generator located in the base of the tower to continue operation.

Following these experiments, the military engineers decided to continue the trials on an even larger scale as they discovered the advantages of wireless communication.

A DEFINITIVE SIX-WIRE ANTENNA AND A PERMANENT FACILITY

Captain Ferrié was eager to proceed and felt there should have been no delay in the construction of a new facility. But the Champ de Mars belonged to the city of Paris. Talks with the city's representatives were long and delicate because earlier plans for the creation of a public garden by the city had included the removal of the tower [5]. The city council feared that the noise of the transmitter would spoil the aesthetics of the park. Also, it was concerned for the public safety near high-voltage conductors.

The project drawn up by the military engineers to comply with the wishes of the city council included the construction of an underground station surrounded by reinforced concrete walls sufficiently thick to completely dampen the noise of the spark-driven transmitters. The new antenna, shown in Figure 6, would consist of six stranded cables, each 5 mm in diameter and 425 m in length. Tall decorative pylons were designed to anchor the insulated pull-off cables so that the presence of

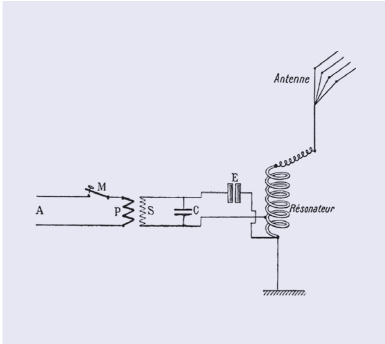

FIGURE 4. An early transmitter driven by ac through a transformer. (Source [6].)

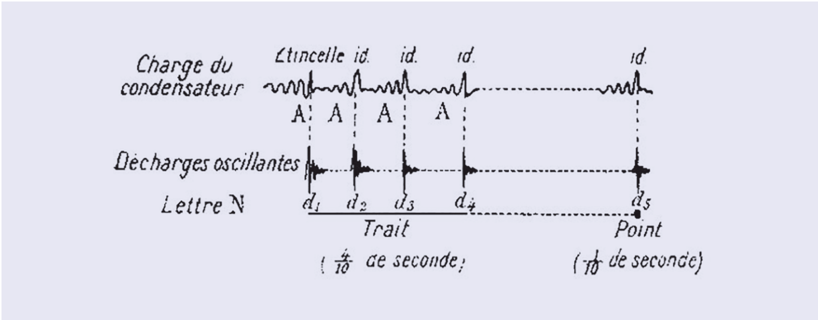

FIGURE 5. Wave shapes radiated by ac-driven transmitter sending Morse code for letter N. (Source: [6].)

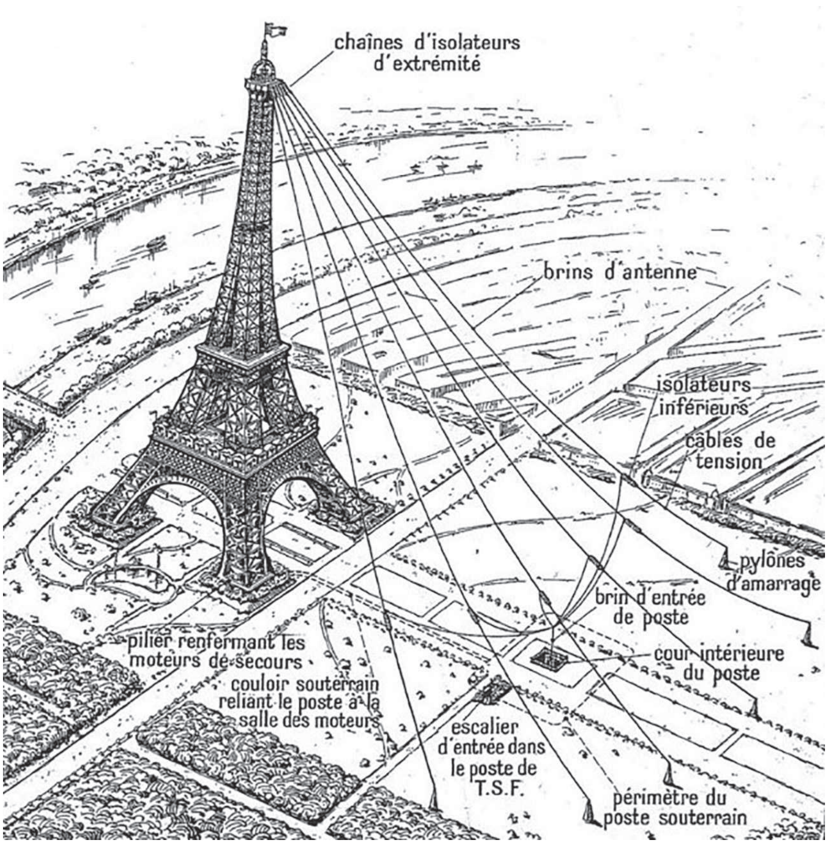

FIGURE 6. The six-wire Eiffel Tower antenna in 1910. (Source: [9].)

the elevated cables would pass almost unnoticed. It was accepted by the city of Paris, and in January 1910 the first earthworks began.

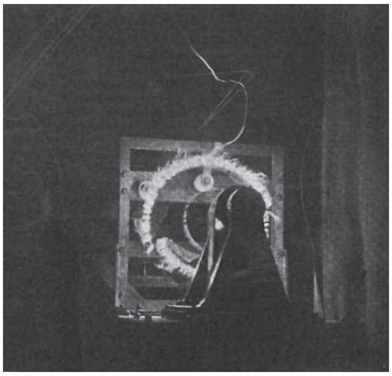

FIGURE 7. Rotating spark gap in operation. (Source: [7].)

The general installation was completed at the end of that same year and was ready to receive the equipment when disaster struck. The Seine flooded and caused damage to the equipment, requiring serious repairs. After a delay of several months, construction of a new underground station was completed and again went into operation. In this new facility, the noise from the rotating spark gap, shown in operation in Figure 7, was greatly reduced by thick concrete walls and heavy felt drapes. The station was so well hidden that an uninformed stroller could hardly find a trace of a wireless telegraphy station in the middle of this delightful park on the Champ de Mars.

Figure 8 shows the equivalent circuits for two transmitters used with the new antenna. These circuits, attributed to Oudin [6], differ from that of Figure 4 in that once the gap E arced over, it acted as a short circuit, thereby isolating the capacitor-antenna circuit. This permitted the capacitor to discharge in resonance with the antenna. In Figure 8(a) the primary P′ was loosely coupled to the secondary S′ to reduce damping and produce a longer transient wave than that obtained with the tightly coupled circuit in Figure 8(b). The choice between the two circuits was between signal length [Figure 8(a)] and signal strength [Figure 8(b)]. One can readily imagine the late nights when station operators spent hours varying capacitors and inductors while trying to contact a military post half a world away!

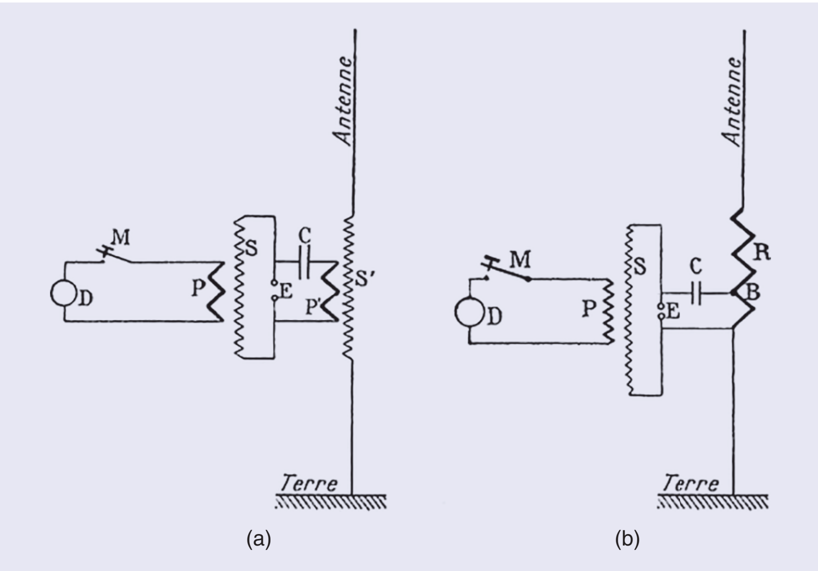

FIGURE 8. AC-driven transmitter circuits with (a) transformer coupling and (b) tapped autotransformer coupling to antenna. (Source: [6].)

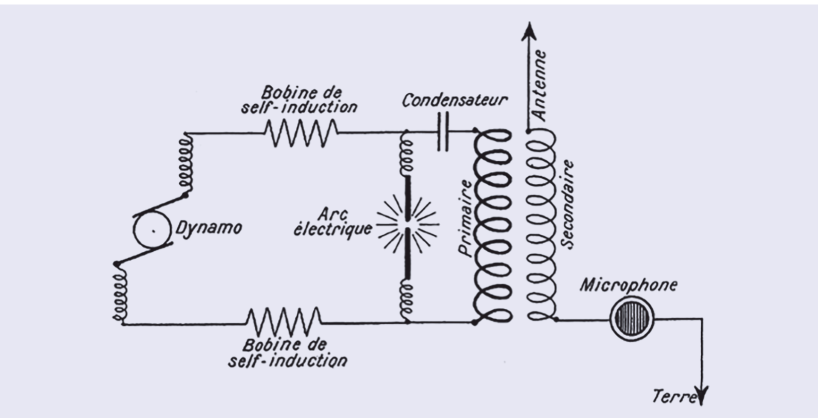

FIGURE 9. Poulsen "singing arc" continuous wave transmitter circuit with voice modulation by means of a microphone. (Source: [6].)

RADIO SCIENCE MATURES, AND TIME SIGNALS ATTRACT PUBLIC RECEPTION

During the years when it was in operation, the Eiffel Tower station served as a testing ground for both transmitting and receiving apparatus, permitting the French military to determine how best to serve its needs. At least three types of transmitters were used regularly, including the two previously discussed as well as the high-power Poulsen arc transmitter; an equivalent circuit is shown in Figure 9. This type of transmitter could provide a continuous wave signal at high power, but it required constant attention and was dangerous to operate. Voice modulation was possible, as indicated in Figure 9, using carbon-granule microphones. Since the voltage was high, several such devices were strung in series, but even then it was dangerous. On the other hand, for Morse code it was ideal; the key triggered a relay connected across a few turns of the antenna coil to accomplish a crude form of frequency-shift keying.

In a fascinating article about time signals sent by radio, Michael Lombardi wrote [10] "We live in the era of Internet FAQs [frequently asked questions], but the most frequently asked question in the real world is still

"What time is it?" Early radio stations answered this important question at regular intervals.

The Eiffel station, with call sign "FL," became the best known of the early time signal stations in Europe [10]; it was operated by the French Bureau of Longitude. The Eiffel Tower time signal broadcasts began on 23 May 1910. The frequency of the original broadcast was near 150 kHz, and the radiated power was about 40 kW. Time signals referenced to the clocks at the nearby Paris Observatory were sent twice daily. The signals spanned the Atlantic Ocean, reaching the United States and Canada and serving their intended purpose, which was to allow ships at sea to correct their marine chronometers. Soon, many others began decoding the signals to obtain the correct time, including railroad companies, clock makers, jewelers, and others. By June 1913, a regularly scheduled time service had begun. The frequency, format, and schedule for the time service were repeatedly changed, but the French somehow managed to keep the time service going through World War I and into the 1920s. Even today, the Eiffel Tower continues to be used as a mast for radio and television antennas.

CONCLUSIONS

In 1903, the French engineer Eugène Ducretet achieved a 4,000-m wireless transmission between the Eiffel Tower and the Panthéon. Thanks to this demonstration, Gustave Eiffel found a way to save his famous tower from destruction. In those days, far from being a world-famous tourist attraction, the tower was considered to spoil the scenery of Paris. It was supposed to be removed a few years after the 1889 French Exposition closed. Eiffel offered the engineer Gustave Ferrié the use of this unique site to carry out his experiments with wireless telegraphy. Ferrié eventually set up an antenna using six long cables between the top of the tower and the ground. In 1908, he was able to transmit a signal a distance of 6,000 km. The Eiffel tower subsequently became so useful as a radio station that it was saved for the benefit of Paris, France, and all those who appreciate such an extraordinary technical exploit of the time!

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WOMEN IN ENGINEERING *(continued from page 125)*

and technical strengths. We will bring more outstanding colleagues to the stage in the following two "Women in Engineering" columns of this series. Stay tuned!

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