

The role of the First World War in the rise of the electronics industry

by Frederik Nebeker

The First World War, sometimes called the ‘war of invention’, brought technology to the attention of everyone and played a major role in establishing the electronics industry. It brought about mass production of electron tubes, especially for use in wireless telegraphy and telephony, and revealed how versatile the new technology was, as dozens of new applications emerged. Because of these applications, large numbers of people were trained in the technology, and many of these people continued to work with tubes after the war.

Electronics dominates modern economies. The production of electronics hardware is the largest branch of the manufacturing sector, and all sectors of the economy make great use of electronics, especially in the form of communications and computing. At the beginning of the twentieth century, however, there was no electronics industry. World War I played a huge role in creating that industry.

World War I is one of the clearest turning points in all of history. It brought four empires (Hohenzollern, Habsburg, Romanov, and Ottoman) to an end and created the modern map of Europe. It terminated the colonial era. It was the first total war, with mobilisation of entire economies, and it was nearer a global war than anything earlier, with armies on several continents and naval conflicts on most seas. It may also be considered the first technological war: during the war itself there was a struggle for technological superiority, with each of the major belligerents organising efforts, involving thousands of people, to achieve technological advance.

These efforts, as we will see, greatly benefited the new technology of electronics. Electronics may be defined as the study, design, and application of devices involving electron tubes and transistors, that is, devices involving electron flow through vacuum, gas, or semiconductor. Traditional electrical engineering exploits the flow of electrons in conductors—dynamoes, power lines, and motors—and control is exerted by mechanical means, such as switches and potentiometers. Electronics was a new realm. Its basic idea was to set electrons free in a vacuum in order to control them more precisely and rapidly. A crucial point is that the control was achieved

electromagnetically, without mechanical action.

The birth of the electronics industry might be thought of as occurring in four steps:

- (a) Invention or discovery. In the 19th century physicists invented electron tubes in the course of studying electrical discharges.
- (b) Application. In the years around 1900 engineers recognised that tubes could perform useful functions.
- (c) Technological advance. Engineers found how to improve the performance of tubes through better design, better materials, and better construction-techniques.
- (d) Commercialisation. Companies mass-produced tubes and devices containing tubes.

These four steps may provide a fairly general model for the emergence of a new technology. In the first step—the discovery or invention step—a physical phenomenon or physical effect is discovered or created. Here the physical effect was electrical discharge in an evacuated tube. In the second step—the application step—someone sees that the physical effect might be exploited. Initially, tubes were used for displaying rapidly changing electrical currents and for detecting wireless signals. The third step is one of technological advance. Getting something to work in the laboratory is not the same as making a practical device. Many improvements were necessary in order for tubes to perform consistently. Large design-changes created new tube-types. Steps two and three often formed a positive-feedback loop: it was found that an existing

tube could be used in a new way, then that a modified tube would perform that new function even better, then that the modified tube could be used in still another way. These are the two legs of the biped of technological advances:

- recognition of a new application of a device and
- improvement of the device itself.

The fourth step is commercialisation or, more generally, the large-scale adoption of the technology. (Some technologies become widely used in the government or military without ever becoming a commercial product.) A market of some sort must be found or created. Mass production requires both standardisation and the development of manufacturing techniques. There is also positive feedback from step four to step two. Some potential applications are not reached because of an economic barrier; mass production lowers the economic barrier. Of these steps, the first was taken before the war, the next two had just begun their feedback loop at the outbreak of war, and the fourth was taken by the end of the war.

Pre-war electronics

For much of the 19th century physicists, in laboratories in many countries, experimented with electrical discharges in glass vessels. The purpose was to understand electricity and gases. In 1838, for example, Michael Faraday studied the passage of current through a tube containing rarefied gas, which then became luminous. In 1879 William Crookes demonstrated that a magnetic field deflects 'cathode rays', the discharges from negative electrodes. The most famous 19th century experiment on electrical discharges was what is now regarded as the discovery of the electron:

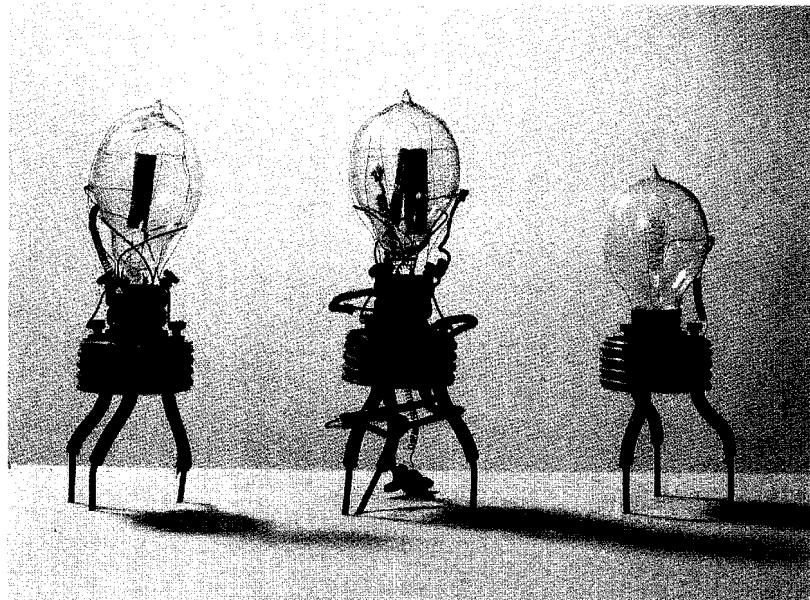
in 1897 J. J. Thomson, on the assumption that the cathode rays were streams of particles, measured the charge-to-mass ratio of the particle by balancing electrostatic deflection and magnetic deflection.

In the years around 1900 several people found that an electrical discharge in a vacuum might make a useful device. In 1895 Wilhelm Röntgen, studying cathode rays, discovered X-rays. In 1897 Karl Ferdinand Braun constructed a cathode-ray tube as a means of studying variable electric currents. In 1904 John Ambrose Fleming, knowing about the effect discovered two decades earlier by Edison that current would flow in one direction between a heated filament and a second electrode, invented the diode as a detector of radio waves. And in 1906 came two milestone events: Lee de Forest in the United States invented the triode as a detector of radio waves, and Robert von Lieben in Austria invented a 'cathode-ray relay' as a telephone repeater.

What was the situation in 1912? X-ray tubes were being manufactured for medical diagnosis. A few people were experimenting with cathode-ray tubes. Von Lieben's tube showed promise as a telephone repeater, but was not yet in use. Both Fleming's diode and de Forest's triode were being used, in modest numbers, as detectors of radio waves, but for this purpose other devices, notably crystal detectors and electrolytic detectors, were more reliable and often more sensitive. Indeed, in 1912 a US court condemned de Forest for 'abuse of trust on the basis of valueless patents, in particular a three-electrode lamp called an "audion" which has been proved to be without any interest whatsoever!'

In 1912 and 1913, however, the picture changed. Most important was the discovery by a number of people (including de Forest, Fritz Loewenstein, Edwin Howard Armstrong, Otto von Bronk, Alexander

An experimental lamp (right) used by John Ambrose Fleming (1849–1945) for his wireless detector, together with early oscillation tubes (c. 1903) (Courtesy of Science Museum/Science and Society Picture Library)





Telephone communications section of the Austrian General Staff (c. 1918) (Courtesy of Hulton Archive)

Meissner, Charles S. Franklin, and Henry J. Round) that the triode could be an amplifier and an oscillator. Second, a number of large companies began to devote resources to making the triode into a practical device. In the United States, AT&T (and its subsidiary Western Electric) wanted a telephone repeater, and General Electric wanted a high-frequency oscillator; both companies began development of electron tubes.

The electron-tube telephone repeater is a clear instance of market pull. The desire to extend the range of telephony led to the use of heavy-gauge conductors and to inductive loading. The practical limits of these methods stimulated the invention of various types of repeaters that were partly mechanical, such as that devised by S. G. Brown in Great Britain¹. The electron tube solved the problem.

Most important was the move from the 'soft' tube, containing gas at low pressure, to the 'hard' tube, with the enclosed space at high vacuum. De Forest had believed the gas necessary for the tube's operation. De Forest and others were misled by the fact that, when used strictly as a detector of radio waves, the 'soft' tube was indeed more sensitive than the 'hard' tube. For the tube to function effectively as an amplifier or oscillator, however, a high vacuum was necessary. To solve the numerous problems in turning a hand-crafted laboratory device into a reliable and manufacturable product required the resources of a large company, and the people—like Langmuir, Meissner, and Round—who made the greatest contributions worked in industrial research laboratories.

Radio and the war

In war, communications is of supreme importance, allowing one to solicit and receive information and to direct forces on land and sea. For example, the dispersion of an army along a front several hundred

kilometres wide became practical only through the use of the telegraph. The immense size of armies in World War I, with chains of command having a dozen or so links, and the need to co-ordinate infantry, artillery, tanks, and aircraft made extreme demands on communications capabilities.

The telegraph and the telephone were the mainstays of military communications. An indication of the volume of telegraph traffic is the estimate that the wired network built by the US army in Europe carried more than five million telegraph messages in the last year and a half of the war, an average of 10 000 messages a day². Telephony was especially important at the front as it connected forward units to command posts and artillery observers to those directing the guns. In the final year of the war the US Signal Corps strung approximately quarter of a million kilometres of telephone wire and set up 273 telephone exchanges³.

Early in the war, however, it became clear that wired communications would not suffice, as at the March 1915 Battle of Neuve Chapelle. It began with a 35-minute 'hurricane bombardment' that was one of the first demonstrations of the unprecedentedly intense use of artillery that became characteristic of the war. This opening barrage carried more shells than had been fired in the whole of the Boer War, fought from 1899 to 1902.⁴ The Germans likewise made heavy use of artillery. One unforeseen result was an almost complete disruption of telegraph and telephone communications, even though signalmen worked constantly to mend line breaks and repeatedly laid new line. So although British units broke through the German line, the lack of communication—laterally at the front, between advancing units and commanders trying to co-ordinate actions, and between guns and observers—precluded exploitation of the initial successes. According to one historian, 'it was glaringly obvious that the breakdown in communications, the

British troops using a French ground-telegraphy system, which did not rely on wires that could be cut by shell fire (Courtesy of Imperial War Museum)



inevitable lack of speedy reaction to the situation at the front, the shattering of the telephone lines between observers and the guns, had been almost wholly responsible for the frustrations and delays⁵. The Germans succeeded in reforming their trench line just a thousand yards or so further back.

The vulnerability of telegraph and telephone lines to artillery fire continued throughout the war. Even along stationary lines enormous numbers of shells were fired, and an assault could be preceded by a barrage of a million rounds. On one occasion on the Western Front, an artillery barrage caused 350 breaks in a one-kilometre line⁶. A contemporary assessment was that, in the forward zones of warfare, 'the intense effect of modern artillery fire has practically ruled out the use of wired communications⁷.

Because the existing alternatives to wired communications, such as couriers and messenger dogs or pigeons, were slow and extremely limited in range, the war saw the rapid development of three electronic means of instantaneous communication without wires: ground telegraphy, radio telegraphy, and radio telephony. The first of these, though widely used during the war, is forgotten today.

Engineers had long known that electric impulses could be detected after travelling several hundred metres through the ground. The French engineer Gustave-Auguste Ferrié recognised that the newly available electron tube could significantly extend the range of this technique. He made improvements in the signal generator and in the receiver—notably by the use of a triode amplifier—and achieved a usual range of several kilometres. These devices began to be used in large numbers in 1916, and by the end of the war the French had produced almost 10000 of them for use by the Allies. The Germans also deployed a system of ground telegraphy⁸.

As important as ground telegraphy was, the other electronic means of wireless communications—wireless telegraphy and wireless telephony—were vastly more important. Wireless was crucial for very-long-distance communication, replacing telegraph cables (in many cases out of necessity, as land lines and submarine cables were cut). Wireless was crucial to the navy, as it became a necessity of fleet operations. Wireless was crucial to the army, supplementing wired communications and creating new communication possibilities, as when used in vehicles (and wireless in tanks contributed greatly to their effectiveness). And wireless was crucial to the air force, air-to-ground links making aircraft surveillance vastly more valuable and air-to-air telephony allowing co-ordinated fighting by airplanes. An indication of the importance of radio is the wartime production of the French company, the Société Française Radio-électrique: 63 permanent wireless stations, 300 ship stations, 18000 airplane stations, and 12500 mobile stations⁹.

It was indeed radio that created by far the greatest need for electron tubes. They were used as rectifiers (detectors), oscillators (both for transmitting and for heterodyne receiving), amplifiers (at both audio and radio frequencies), and as modulators (impressing an audio signal on a radio-frequency carrier wave). And it was for radio that most improvements in tube design were made. Tubes were specialised for function, power level, frequency level, and durability. For example, for use in aircraft, ships, and other places where mechanical shocks and vibrations were common, 'ruggedised' tubes were designed. Two examples of specialised tubes are a tube (the EVN129) designed by Telefunken as a heterodyne oscillator and a tube (the Type E) designed by Western Electric for transmitters in airplanes.

Other wartime uses for tubes

German U-boats posed such a threat to Allied shipping that great efforts were made to develop anti-submarine techniques. A listing of the main centres of anti-submarine research during the war includes 31 sites in Britain and 10 in the United States. And several measures were taken to facilitate co-operation between research groups in different countries.

Though attempts were made to detect submarines by their own magnetic fields or by their inductive effect on generated magnetic fields, most research aimed at means of picking up the engine noise of U-boats by hydrophones (underwater microphones). Many of the devices, some of them functioning just as a stethoscope does, were purely acoustic, that is, non-electrical. Several factors, however, led to the widespread development of electrical detectors: the sensitivity of (electric) microphones, the ability to convey an electrical signal a considerable distance (permitting the detector to be placed in locations inaccessible to a human listener), the existence of electrical filters cutting out certain frequencies, and the amplification allowed by electron tubes¹⁰. By the end of the war, about 4000 Allied vessels were equipped with hydrophones, as were a few dozen minefields connected to listening stations on shore.

A much more sophisticated and effective means of detecting submarines was sonar, or echo ranging as it was then called. In the years just before the war, several people had the idea that ships could locate objects, such as icebergs, by detecting sound reflected off them. Because of the wartime need for a means of detecting submarines, a large developmental programme for echo ranging began in France in March 1915. It, too, made use of electron tubes. In February 1918 Paul Langevin achieved a transmission range of 800 metres and, for the first time, obtained clear echoes from a

submarine; after several more months the range of detection of a submarine reached one and a half kilometres. These developments, however, came too late to play a role in the fighting.

Another electronic technology played a large part in the defeat of the U-boats: radio intelligence. The British, using direction-finding stations and listening stations, together with decryption of enemy codes by the Admiralty's Room 40, often knew exactly what U-boats were at sea and their approximate locations¹¹.

The ability to take a bearing on a radio signal made electronic navigation possible. Aviators used direction finding for navigation in two different ways. In the first, the aviator transmitted a coded message identifying himself. Direction-finding stations replied, also in code, giving the bearing of the first transmission. With responses from two or more stations, the aviator could find his position on a map. The second way had the advantage that the aviator did not need to break radio silence, but required direction-finding capability on the plane: the aviator took bearings on two or more transmitters in known locations. Many ships acquired direction-finding sets, which they used to determine their bearings relative to what might be called 'radio lighthouses', stations set up along coasts to broadcast identification signals for navigation purposes.

Electronics also made a difference in sound ranging, which was a technique to locate enemy artillery by careful determination of the time of arrival of the sound of the gun. Experiments by the French in the fall of 1914 were encouraging enough to establish a sound-ranging service, but it was not until electron tubes were used for amplification that convincing results were obtained¹².

There were some other applications of electron tubes during the war. There were a few electronic control-devices: in airplanes some generators incorporated a vacuum-tube automatic compensator that helped



Hydrophones in use at Otranto in 1917. In the right foreground a sailor is holding a nondirectional hydrophone. In the right background are two directional hydrophones suspended from a boom. On deck are boxes containing batteries and transformers. (Courtesy of Imperial War Museum)

maintain constant voltage over a wide range in speed¹³; and electron tubes were used in the guidance system of a homing torpedo built in 1914¹⁴.

There were other types of electron tubes. X-ray tubes were produced in large numbers. Rectifying tubes, such as mercury-arc rectifiers, were already being used, especially for battery charging, in 1914. There were some applications of cathode-ray tubes, such as an oscilloscope developed at the suggestion of J. J. Thomson to study underwater explosions of the sort produced by mines¹⁵.

The electronics industry

Before the war, electron tubes were manufactured by hand in small numbers. Just after the war H. J. Round wrote: 'I have mentioned that the production of valves at that time [early in the war] required special men. ... it was a terrible process. Again and again we lost the knack of making good tubes owing to some slight change in the materials used in their manufacture.'¹⁶ Yet wartime communication needs called for hundreds of thousands of tubes, and it was not simply a matter of increasing the number made. The tubes had to give consistent performance to predetermined standards, and they had to be long lived. There needed to be physical standardisation—exterior dimensions, base, and socket—and performance standardisation, insuring uniform characteristics in large numbers of tubes so that tubes would be interchangeable. To achieve this standardisation there had to be test equipment and agreed-upon test procedures.



One of the original 'Audion' tubes developed by Lee de Forest (Courtesy of Science Museum/Science and Society Picture Library)

The total number of audions sold before 1913 was only 750 or so; in 1913 sales exceeded 500, and the following year reached almost 6000¹⁷. By then, of course, the tube had undergone considerable development and other manufacturers had entered the field. French engineers designed an improved version of the audion (with a cylindrical, coaxial arrangement of the electrodes), known as the TM tube (the initials coming from 'Télégraphie Militaire'). Mass production began in October 1915, and by war's end more than a million had been made, most of them by Grammont and Compagnie Générale des Lampes, two incandescent-lamp manufacturers¹⁸. Because the TM tube was both effective and robust, the British mass-produced several versions of it¹⁹. By late 1918 many types of radio receiving tubes were being manufactured by several German companies, and a single Telefunken tube (the RE16) was being turned out at the rate of 1000 a day²⁰.

Western Electric developed a number of electron tubes for the US Signal Corps and the US Navy. For example, the 203A (designated the VT-1 by the Signal Corps and the CW-933 by the Navy) was a general-purpose tube, used as detector, amplifier, and oscillator²¹. General Electric was another major US supplier of tubes. GE and Western Electric had agreed to divide the task, GE manufacturing transmitting tubes, Western Electric receiving tubes²². By the end of the war, GE had supplied the military with some 200 000 tubes, and Western Electric had supplied half a million²³.

For the manufacture of electron tubes it helped enormously that light bulbs had been mass produced for many years. Both devices consisted of metal filaments, with external connections, in an evacuated or gas-filled glass enclosure. The electric-light industry emerged in the 1880s, and the standardisation of lamp types and the mechanisation of production began in the 1890s. There was a steady increase in production thereafter, with 85 million bulbs produced in the United States in 1912. The incandescent lamp industry and a variety of scientific interests (cryogenics, electric discharges in vacuum, production of X-rays) stimulated work on vacuum pumps; this work was well timed for the beginnings of the electron-tube industry²⁴.

But electron tubes were more delicate physically, and their behaviour depended sensitively upon the shape and spacing of electrodes, the precise level of vacuum, and the presence of adhering or occluded gases on surfaces within the bulb²⁵. Engineers worked out techniques for mass production at the same time as other engineers were improving tube design. At the end of the war a company was prepared 'to manufacture in quantity a certain tube in which the clearance between filament and grid is only three-hundredths of an inch, the allowable variation being of course a small percentage of this'²⁶.

England soon had some half-dozen tube manufacturers (see Table 1). In the Netherlands, NV Philips Gloeilampenfabrieken, a manufacturer of

Table 1: Some electron-tube companies and the dates they first manufactured electron tubes³²

<i>Britain</i>	
Ediswan (Edison Swan Electric Company, London)	1904
BTH (British Thomson Houston, London)	1916
Cossor (A.C. Cossor, London)	1916
Osram (General Electric Company, London)	1916
(Metropolitan-Vickers Company)	1917
Stearn (Stearn Electric Lamp Company, London)	ca. 1918
Z (Z Electric Lamp Manufacturing Company, London)	ca. 1918
<i>France</i>	
Grammont (Fotos)	1915
Compagnie Générale des Lampes (Métal)	1915
Établissements H. Pilon	ca. 1915
<i>Germany</i>	
AEG Telefunken	ca. 1912
Siemens & Halske	ca. 1912
<i>United States</i>	
McCandless	1907
General Electric	ca. 1913
Western Electric	ca. 1913
De Forest Radio Telephone and Telegraph	1914
Cunningham (Audio Tron)	1915
Moorhead (Electron Relay)	1915
<i>The Netherlands</i>	
NV Philips	1917
<i>Japan</i>	
Tokyo Denki	1917

incandescent bulbs, began producing electron tubes in 1917 and soon became an international leader in the field²⁷. In Japan the Tokyo Electric Company (which after merger with Shibaura Engineering in 1939 became Toshiba) began manufacturing three-element electron tubes in 1917, and already in early 1920 five Japanese companies were in the business²⁸.

Widespread use of electron tubes received a great boost from government-imposed standardisation—all tubes had to be made to the same government specifications²⁹. A British engineer commented that during the war the standard triode became ‘as much an article of consistent manufacture as a metal-filament lamp’³⁰. Among all users of tubes, telephone engineers were probably most concerned that tubes be uniform in their characteristics, stable in operation, and long lived. (A long-distance telephone connection might involve more than a hundred tubes, and failure of a single tube could break the circuit.) Bell System engineers—some of them in the engineering department of Western Electric, which manufactured tubes—brought about many improvements. In 1925 the life expectancy of a tube was fifty times that of the early tubes of 1914³¹.

Just after the war, without the pressing military needs, the number of electron tubes manufactured declined. Within a decade, however, the electronics industry had achieved a solid foundation as permanent markets for tubes were found. Most important was radio

broadcasting, which by the end of the 1920s had induced almost half of US households to purchase a radio receiver. There was heavy use of tubes in telephony, especially for carrier telephony (sending many telephone signals over the same pair of wires). In the mid 1920s came the electric phonograph, which used tubes for amplification. Sound movies and public-address systems also required tubes. And tubes found increasing use in industry. A milestone in the establishment of the electronics industry—broader than the radio industry—was the founding in 1930 by McGraw-Hill of the journal *Electronics*, which was subtitled *Electron Tubes—Their Radio, Audio, Visio and Industrial Application*.

The difference a war makes

So what did effects did World War I have? Most importantly, the war brought about mass production of electron tubes, which meant that engineers could obtain, at reasonable cost, tubes of standardised types with characteristics of predetermined values. Secondly, the war revealed how versatile the new technology was, as dozens of new applications emerged. Thirdly, because of these applications, large numbers of people were trained in the new technology, and

many of these people continued to work with tubes after the war, either in a job or as a hobby. Finally, the war showed the effectiveness of large-scale governmental and industrial support for research and development.

Called the ‘war of invention’ and ‘Krieg der Ingenieure’, it brought technology to the attention of everyone. It convinced many people that wars would henceforth be dominated by weapons and weapon-systems; in Edison’s words, ‘Modern warfare is more a matter of machines than of men.’³³ This led to enormous efforts in military research-and-development, and many of the national R&D institutions outlived the war. Industry leaders, taking note of the effectiveness of this directed research, increased their commitment to research; R&D expenses by US firms doubled in the period from the end of the war to the beginning of the 1930s, while R&D by German firms tripled³⁴.

How did it have these effects? The extreme urgency of war meant that there was abundant provision of resources, both material and human, for what were seen as vital needs, especially for military communications. The move-countermove of technological war—as, for example, eavesdropping led to frequency changing, which led in turn to rapid-search capability—required continual technological advance. There was rapid technology transfer, as patent hindrances were swept aside and companies and countries exchanged technology. In the United States,

Assistant Secretary of the Navy Franklin Roosevelt told contractors to use any patented invention required, guaranteeing them against claims for government work. The patent moratorium and the fact that almost all radio equipment was manufactured for the military caused companies to concentrate on research and development rather than litigation or marketing. Technology transfer was facilitated by collaboration by different companies on government orders and by sharing of techniques between allies. Also, the standardisation forced on manufacturers by the military probably led to more rapid adoption of tubes, as they became well-understood components of circuits.

One should, however, keep in mind that the stage was already set: there was a pre-existing incandescent lamp industry, and the technology was ready to push off just when the world war produced a prodigious swell of political, economic, and social forces that propelled the technology.

During the war the electron tube changed from an erratic device (hand made in small numbers) to a mass-produced product as reliable and as thoroughly standardised in manufacture as the incandescent lamp. Electrical technology entered decisively into a new phase of its development, as virtually all branches of electrical engineering came to adopt electronic techniques. This was perceived at the time. The journal *Electrical World* on 19th October 1918 reported: '[Vacuum] tubes have been so far improved and so much utilised for many purposes that vacuum-tube engineering seems to offer a promising new branch of electrical engineering It is clear that the essential theory and the principal working applications of vacuum tubes will have to be learned by most electrical engineering students.' Finally, the birth of the electronics industry also gave people who had suffered through the horrible destruction of war some reason to be optimistic about the future. As *Electrical World* put it on 22nd February 1919, the wartime development of the vacuum tube was 'A landmark ... for the electrical industry that will help the whole world for all time.'

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