

THE TRIODE THAT PREDATED DE FOREST: ROBERT VON LIEBEN AND THE LRS RELAY

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INTRODUCTION

A triode amplifier tube with alkaline-earth oxide emitter, patented before de Forest's Audion detector tube? An amplifier tube in production before Western Electric made any of Arnold's improved high-vacuum triodes? This is the story of the von Lieben or LRS tube, which performed both of these remarkable feats. The man responsible, the evolutionary steps, the surrounding circumstances, all join in the story of a development deserving to be known far better in North America.

The electron-tube industry sprang from three design directions that formed the basis of early production. They were: 1912-20, the von Lieben mercury-vapor triode; 1913+, the de Forest/Western Electric/General Electric vacuum triodes; 1915-23, the French military "TM" high-vacuum triode.

Robert von Lieben obtained German patent DRP Nr. 179,807 for a triode amplifier device. His application was filed on March 4, 1906, and the patent was published November 18, 1906. By contrast, Lee de Forest's Audion did not operate in his laboratory until December 30, 1906. His famous patent application, filed January 29, 1907, was issued as U. S. Patent 879,532 on February 18, 1908.

Unlike de Forest, von Lieben continued major development work which resulted in commercialization in 1912 of a structure far different from that of 1906. Von Lieben's tube performed as an amplifier from the very start. The interests, and hence the goals, of the two inventors were markedly different. Von Lieben had no contact with wireless, only with wire telegraphy and telephony. Only amplification was required. In contrast, de Forest was thoroughly immersed in wireless in all its phases. Consequently it is astounding that he and others neglected his "detector" audion for six years before attempting to develop its other characteristics as an amplifier and oscillator.

There were fundamental differences between the von Lieben and de Forest tubes. Advocates of either type might well cry out: *vive la différence!*

Figure 1 illustrates the initial commercial form of the LRS tube in 1912. It was about 17 inches (43 cm) high. The bulb, pinched in at its center, confined the planar woven-wire mesh grid. In operation the tube was spectacular: The bottom half glowed red from the large-area oxide-coated platinum filament; the top half was filled with a sky-blue glow of ionized mercury vapor.

THE MAN

Robert von Lieben was born on September 5, 1878. He was not the usual penurious inventor living in a garret. His father, Leopold, was a wealthy banker

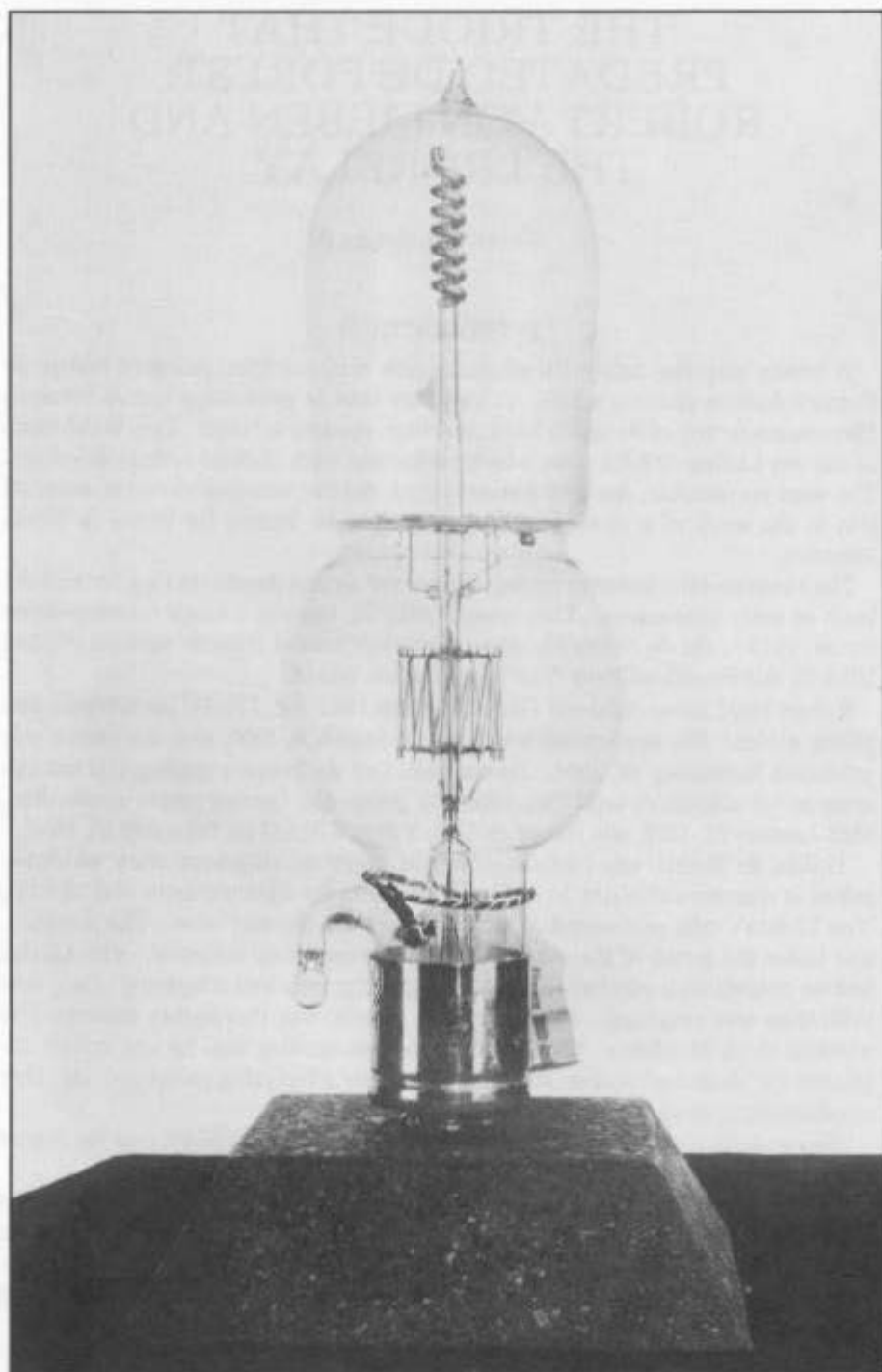


Fig. 1. LRS Relay, ca. 1913

Photo: Lauren Peckham

and long-time president of the Vienna Stock Exchange, at that time at the peak of the power and influence of the Austro-Hungarian Empire. As with Marconi, Robert's parents provided ample financial support, which later enabled him to maintain his own private laboratory, starting in his home.

He inherited his bent for things scientific from his uncle Adolph, a distinguished chemist at the University of Vienna. Another uncle, Richard, contributed to the financial and business acumen of the family.

Robert was not outstanding at school, for his independent spirit rebelled at the enforced discipline of the schoolroom. Nevertheless, he progressed through the Academic Gymnasium, and through the Reale Schule on the Hessegasse. Following the "middle school" he volunteered to serve in the elite Uhlan cavalry. Unfortunately, after but a few weeks he was thrown from his horse and impaled on a picket fence. This left him with a pierced lung, which did not heal properly. It gave him constant pain throughout his life, which ended when he was but 35 years old.

One might say that von Lieben was self-educated. He obtained practical shop experience through a year of manual work with Siemens in Nürnberg. He also audited courses in experimental physics at the University of Vienna.

In the spring of 1899 he went to Goettingen for a year of study under the brilliant Professor Walter Nernst. At that time Nernst was only 35 years old, yet had already achieved wide fame. The two men became fast friends, and their chemistries matched - as one might say today, they were able to "relate" to each other. Nernst had a strong effect upon von Lieben, and influenced his life and technical activities in later years.

At Goettingen, von Lieben devised an electrochemical phonograph which was demonstrated under the friendly eyes of his mentor. In 1903 he published a paper concerning polarization of X-rays. This was but eight years after Roentgen's discovery of these rays. In those days X-rays were generated in gaseous-discharge tubes. Thus, in his researches von Lieben obtained experience with the phenomena of discharges in gases and with cathode rays, all of which served him later on. These were the building blocks which he was destined to fit together into his successful telephone relay and radio amplifier.

Opening his own laboratory in his father's home furnished an outlet for von Lieben's energies. They were not needed in a daily race for survival, but had to be consumed in some useful manner, such as the science which he loved so much. "Germany made science a business, whereas other countries gave science the status of a hobby for rich men" [1]. Von Lieben combined the best of both definitions.

In appearance he had finely molded, almost girlish features, with dark Oriental eyes. One would have thought him to be a dreamer. He was inordinately shy, a trait emphasized when with strangers. But in his work, and with friends or in the laboratory, von Lieben became completely self-confident and intense, concentrating upon the subject at hand. He would immerse himself and work endlessly until the wee hours of the morning. He wished to see new ideas carried out promptly. He would adjourn with his associates for detailed postmortems of the work. These sessions were generally held in the nearby Hotel Bristol, which he favored for its fine food. At other times he would convene symposia with other prominent scientists, always over a table laden with good food.

Several illustrations indicate the breadth of von Lieben's technical interests and mechanical skills. While still a schoolboy he built an electrical generator and lighting system for his father's summer villa south of Vienna, at a time when such a system was a real rarity. He made improvements upon agricultural machines. Later he developed apparatus for photographing the human eye. He tackled the problem of an electromechanical coupling for the power train of a gasoline engine (which had first been put into automobiles only between 1897 and 1900). Later, during a visit to Paris he saw a Wright Brothers airplane. Fascinated, he purchased one of the machines, conceived improvements, modified the plane, and then presented it to the Austrian military (rather an inconceivable happening in 1990!).

Von Lieben appeared to be excited by the latest technical developments. As with so many other scientists, once they are bitten by an idea, the concept rules their lives until success is achieved [2]. "Lieben followed all progress in physics and chemistry with eagerness and perseverance, almost as an noble sport!" [3]. Then the idea of amplifying telephone signals captured his imagination. It did not leave him until his death.

Apparently he divided his time between Goettingen and his Vienna laboratory. By that time his mind was concentrating upon the telephone-amplifier problem and its solution.

TUBE DEVELOPMENT

About 1904, with financial backing from his father, von Lieben purchased a small manufacturer of telephone equipment, located in Olmutz, Moravia, now part of Czechoslovakia. A good deal of his time must have been expended in commuting the several hundred miles among the factory, the University and home. Railroads were the best available means of transportation in those days. He altered the name of the firm to Telephon und Telegraphenwerke Robert von Lieben - Olmutz-Wien. The business prospered and grew to employ several hundred men. It was during this period that former school teacher Dr. Eugen Reisz and engineer Sigmund Strauss joined the staff. Strauss came from Berliner Aktiengesellschaft (AG).

Von Lieben did not care for strictly regulated business life. He was happiest in his laboratory, where he could follow his own ideas freely. Consequently, he eventually sold the plant about 1909 to Berliner AG but retained rights to the partially developed relay. Strauss remained with him.

Before then, however, all the building blocks from various technologies were at hand. The telephone-equipment company brought the need for an amplifier forcibly to his mind. It was quite apparent that electromechanical devices could not follow weak telephone signals with the required accuracy, sensitivity and speed. In 1905 all the elements of the enigma suddenly fell into place. An amplifier, employing the control of cathode rays, was visioned, attempted, and found to work!

From the start of tube development, platinum ribbon coated with alkaline-earth oxides was employed as the electron emitter. This is truly startling, since Professor Wehnelt had published his work on the emitting properties of such oxides only as late as 1903-4 [4]. Von Lieben made use of these emitters almost

Fig. 2. First concept of von Lieben amplifier tube: a high-vacuum device with the beam defocused magnetically by the input signal. (Adapted from DRP Nr. 179, 507.)

at once (1905-6). Their advantage lay in the greatly reduced heater power required, as well as cathode rays being generated with but 200 volts on the anode. It is interesting to speculate how such rapid transfer of this brand-new technology could have occurred. One clue lies in the fact that both Wehnelt and Nernst were specialists in electrochemistry and in cathode rays. Their relation must have been close for the new development to be transferred to a favored student so promptly.

Once the original invention had been shown to work, it was obvious that much development effort would be required to convert it into a commercial reality. Consequently, von Lieben established an independent Vienna laboratory. Partly this was to give recognition to his two loyal co-workers. Partly his inherent shyness caused him to withhold his name from that of the laboratory. Further, the illnesses and related pain from the cavalry accident forced him to remain abed, absent from work for longer and longer periods of time. Much of the work thus fell upon the shoulders of Reisz and Strauss. Until that time the commercial success of the project was felt to have low probability. Nevertheless, von Lieben provided ample financing for operation of "Laboratorium Reisz und Strauss," in short, LRS. At first located at Hofzeile 21, it later moved to Vegagasse 21.

Reisz has written about von Lieben with admiration and respect. "I worked closely with von Lieben during the entire development period. It was unusual the manner in which he cooperated when difficulties arose. In the late evening hours he might modify the complicated high-vacuum apparatus, and would not rest until our research could be resumed, following the new methods and without further problems. At daybreak he then accompanied me home, all the while discussing every detail of the test results" [5]. These discussions were an important part of his own scientific work.

This was only the beginning of six years of arduous labor. In contrast, de Forest allowed his Audion to remain unchanged for the five years before Arnold assumed the conversion of that tube into a high-vacuum practicality with long life and widespread new applications.

Figure 2 is a sketch from the original concept, which resulted in issuance of DRP Nr. 179,807, "A Cathode-Ray Relay." This was an electromagnetically controlled high-vacuum version. Applied for on March 4, 1906, the patent was issued November 19th. One must recall that de Forest's rather gassy triode did not operate in his laboratory until the very end of 1906. His patent was filed for in January, 1907, but was not issued until early 1908. Thus, in Europe von Lieben is credited with the invention of the triode tube, having beaten de Forest to a patent office by almost a year, and with an issue date 15 months earlier.

In Europe, von Lieben had close competition. Max Dieckmann and Gustav Glage filed for a cathode-ray relay tube on November 10, 1906! While roughly similar to von Lieben's, it was sufficiently different to be patentable. The work of von Lieben is mentioned in their application. (As an aside, Dieckmann came very close to obtaining a fundamental patent some years later for a television imaging tube. He lost out to Philo T. Farnsworth by a close margin. Unfortunately second place does not pay off!)

The combined talents of the inventor and his patent attorney resulted in an exceptionally broad basic claim, which reads: "A cathode-ray relay for signals up to the *highest frequencies* [emphasis added] characterized by the well known fact

that electron beams emitted from concave, oxide-coated cathodes are influenced by signals of increasing frequency so that the output frequencies are the same but with greater amplitude. * * * The use of this relay could be highly advantageous for many problems in telephony such as the transmission of speech over long distances by cable and by wireless. This relay could be useful in amplification of speech and music and for many problems associated with the transmission of photographs."

Use of the tube as an amplifier was not only envisioned but demonstrated several years before de Forest was able to do so. The German courts considered it to be a "pioneering invention." There were many patent cases, but the Leipzig court held in favor of von Lieben, and no appeal was ever taken from that decision.

It is interesting to consider why the concept of an inertialess electronic amplifier required such a long time before it was pursued by other investigators. George A. Campbell, in the Boston laboratories of AT&T, recognized the need as early as 1907. The ensuing depression of that year prevented active work on the concept. This same depression arrived in England in time to stop British tube development at the Post Office Research Station in 1908. Fortunately, the financial resources at the disposal of von Lieben did not curtail his efforts.

In 1910, Dr. Frank B. Jewett, then at engineering level with Western Electric's laboratories in New York City, gave recognition to the problem in his well known letter to Professor Robert A. Millikan, at the University of Chicago, which resulted in the recruiting of Harold D. Arnold and later of Hendrik J. van der Bijl. Dr. Jewett's letter stated in part [6]: "Such a device, in order to follow all of the minute modulations of the human voice, must obviously be practically inertialess, and I don't see that we are likely to get such an inertialess moving part except by the utilization somehow of electron streams which you have been working with in Physics for the past ten years."

It seems that von Lieben initially was interested as much in the pure-science aspects of his relay as in its commercialization. He wanted very much to publish scientific papers in the *Physikalische Zeitschrift*. It remained for Reisz and Strauss to urge him in the direction of a product which might give a financial return.

Strauss described the first demonstration of the relay in his paper as follows [3]: "In 1907 Lieben demonstrated the relay to his friends. This was in his private laboratory in the Opelsgasse #6 in Vienna. Through his relay a telephone conversation could be amplified with perfect clarity. Dr. Richard Leiser assisted with these experiments. His contributions were primarily concerned with obtaining a more uniform and longer-lived oxide coating. Also, engineer Eugen Reisz was an assistant. Reisz had abilities far above the average. He was rich in ideas, and was most clever with experiments." (Might not Dr. Leiser be termed the first tube engineer to battle low emission, hence deserving of the understanding sympathies of following generations of factory process engineers?)

Evolution of the practical tube design required several well-defined steps. Just to mention them by title will be sufficient to conjure visions of endless experiments, failures, argumentative discussions, and plodding advances in the minds of tube engineers from later years.

1. Change in the emitter design permitted reduction in current required from

20 to two amperes.

2. Improved pumping and maintenance of the vacuum which was so essential was achieved only after hard work over a long period of time.

3. An arc developed frequently near the anode, which would completely block tube operation. One attempt to eliminate the arc was to place a woven-wire mesh between cathode and anode. "It was similar to the screen used in Davy's safety lamp." (This should be considered a most significant statement, leading to the concept of the grid structure.) The mesh, plus a series current-limiting resistor in the anode circuit, completely eliminated the arcing.

4. It was observed that the input signal could be connected to the mesh. External magnetic coils were no longer necessary. Electrostatic control replaced electromagnetic! The dimensions of the mesh "grid" were found to control tube characteristics. By necking at the mid-point of the bulb, and extending the mesh completely across the narrows, it became possible to achieve even greater signal amplification. (In later patent applications statements were made which evidenced knowledge of de Forest's work with a triode grid.)

5. When attempts were made to seal the tube from the pumping stand, failures occurred at unpredictable times. Observation showed there were changes in the color of the ionized gas. Hundreds of tubes were made and discarded. The trouble ultimately was traced to low mercury pressure. Originally the tubes had been attached for long periods of time to Gaede mercury pumps. Backstreaming of the mercury vapor had fortuitously allowed vapors to enter the tube. After tip-off the gas "cleaned up" to a hard vacuum. This altered properties of the discharge in the tube. A droplet of mercury was purposely introduced into the bulb. Eureka - good tube life and uniform operation resulted - *success!*

Several additional patent filings were necessary due to the major alterations in design. Also, other investigators had been active in the field. The literature shows such names as Dieckmann, Glage, Otto von Bayer, W. J. Milham, C. Giesel, and Jonathan Zenneck. Thus, the von Lieben trio filed for a patent on September 4, 1910. This was published on July 11, 1911, as DRP Nr. 236,716. The more important patent was applied for on December 20, 1910. It was issued on July 12, 1912, as DRP Nr. 249,142, "Relay for Varying Currents."

During five years of development, the tube was so altered in structure as to be almost unrecognizable. Figure 3 shows the sketches from the later patent; it should be compared with the sketch shown in Figure 2 for the 1906 design. The photograph of Figure 1 corresponds with the tube design placed in production in 1912. As usually happens during manufacture of any product, there were further modifications. One of the forms taken by the tube during the WW I era or shortly thereafter is pictured in Figure 4. A design closer to conventional European triodes was employed, somewhat similar to the French TM receiving tube but significantly larger. It is unknown how this design compared in performance, or for what application it was intended.

By the end of 1910 the tube could be shown to operate as planned, with an acceptably long life and uniform characteristics. It could be cloned with assurance of success. During the early months of 1911 a great deal of thought must have been expended as to how to attract support from large organizations such as Siemens and Allgemeine Elektrizitäts Gesellschaft (AEG). Professor Nernst can be presumed to have been the pivotal contact for his former student and

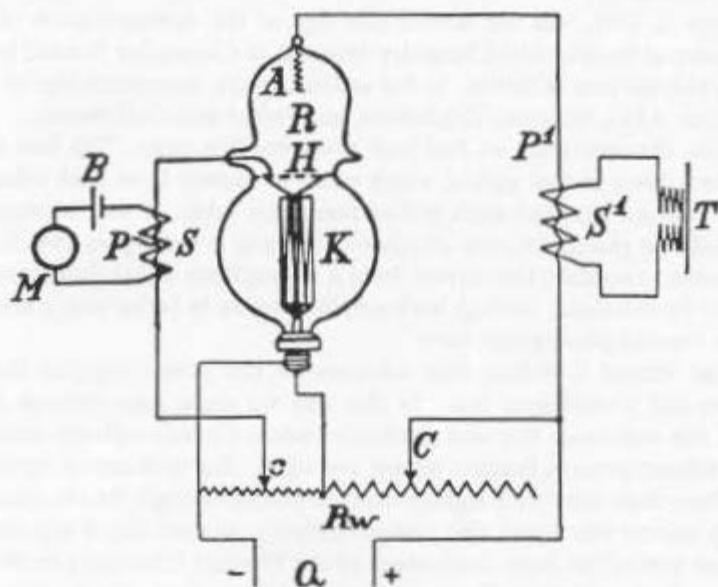


Fig. 3. Evolution to 1910: a gaseous device with the beam controlled electrostatically. (Adapted from DRP Nr. 249,142.)



Fig. 4. The final commercial form, with concentric elements. (Reproduced from Archiv Geschichte Mathematische Naturwissenschaften Technische 1930-31, 13.)

close personal friend. The climax of all the planning can best be described in the words of Strauss [3]:

"August 3, 1911, was the memorable day of the demonstration of the von Lieben tube at the Physical Chemistry Institute of Chancellor Nernst, located on the Dorotheenstrasse in Berlin. In the audience were representatives of the great companies: AEG, Siemens, Telefunken, and Felten und Guilleaume."

"For this demonstration we had built two travelling cases. The first contained two Lieben tubes of that period, which could be viewed from both sides, in conjunction with an iron-hydrogen ballast resistance tube. It was arranged so the tubes could be placed into the circuit by means of a multi-pole switch. Thus it was possible to conduct the current from a microphone either directly to a head-phone, or by switching, through both amplifier tubes in series with a loudspeaker having a wooden phonograph horn."

"In the second travelling case we installed the power supplies for the microphone and a resistance box. In this way we could pass through the many steps of the resistance box and gradually reduce the microphone current from normal volume so as to become almost inaudible. But with use of the multi-pole switch these inaudible voice signals were amplified through the two tubes. Then suddenly speech was heard with complete clarity, so loud that it was understood in the last row of the large auditorium of the Physical Chemistry Institute. The demonstration made a terrific impression. All those present were amazed - one might even say they were beside themselves!"

"At that time it was thought that the Lieben tube would be of use only as a voice amplifier. However, at once the large companies wanted a method which would permit simultaneous two-way telephonic communications. Obviously it was felt that many years would be needed to find such a solution. Fortunately by the Fall of 1911 we had arrived at a tentative solution which proved to be quite satisfactory."

The active participation of Robert von Lieben was becoming more and more curtailed due to his failing health. It is best to continue here with the narrative of the remaining 18 months of his life.

In 1927 Eugen Reisz wrote that during von Lieben's later years he was intrigued by the structure of the atom. "It is my memory distinctly, that his thoughts and ideas at that time were in exact agreement with the scientific experiments that have been made up to this time" [5].

Strauss wrote [3]: "In the summer of 1911 von Lieben married the beautiful actress Anny Schindler, the granddaughter of the famous poet Julius von der Taun. She had been appearing in the well known Burgtheater in Vienna. Thus, he then stood at the peak of his life, having found a beautiful wife, and having achieved success in his work. Then shadows began to fall across his path. A tumor formed in his chest, probably resulting from the riding accident sustained many years earlier. X-rays were used, and for a while gave him some relief from the increasing pain. Despite the best of care, Robert von Lieben died on February 20, 1913. He had lived long enough to see the acceptance of his work, but not the triumphs which were to follow."

Following his death eulogies were given by the outstanding playwright Hugo von Hofmannsthal, and by such outstanding scientists as Nernst and Einstein.

TUBE PRODUCTION AND APPLICATIONS

Demonstration of the LRS tube in August 1911 was the first time that a tube had ever been shown as an amplifier, capable of filling an auditorium with sound. The audience had been selected to include technical men as well as members of management who could make major decisions. Wilhelm von Siemens was present, and was thenceforth a strong advocate pushing formation of the Consortium that followed.

Siemens und Halske AG was prominent in telegraph and telephone systems in Germany and other parts of Europe. It had the technology needed for tube work through its dominance in the incandescent-lamp industry. Von Siemens immediately saw the solution for the needs of long-distance communication.

AEG and Telefunken were leaders in Germany in wireless communications and equipment manufacture. At that time they were engaged in a duel with British Marconi, attempting to break the near-monopoly held by Marconi on maritime wireless. Telefunken could see that early acquisition of the von Lieben patent could provide an advantage through protection in the manufacture of tubes, as well as in making and selling apparatus for wireless transmission and receiving, whether aboard ships or across the oceans. They recognized that further circuit development would be necessary.

Felten und Guillaume apparently were desirous of augmenting the business of their equipment manufacturing division, predicting a wide new market for equipment containing electron tubes.

To this time there had never been seen or heard amplification based upon so much development work in depth by one small group, especially by a man with such excellent scientific backing and credentials. Germany felt fortunate that this occurred within her boundaries.

How did this compare with tube work in other countries at that time? In England, some of Fleming's diodes were being used as wireless detectors. But they were not favored by marine operators, in comparison with improved crystal detectors, due to noise and instability induced by gas content. There had been some tube work at the laboratories of Marconi, as well as the British Post Office. In 1908 Captain H. J. Round was working with poorly outgassed "soft valves." The depression of 1907-8 curtailed his project, and only low-level effort was expended until 1914.

A few "soft" tubes had been made in France but there seems to have been no real direction, goal, or centralization of effort. It remained for then-Colonel Ferrie to galvanize France into tube activity with the start of WW I in 1914.

In the United States, de Forest and his companies had bought about 700 Audions, made by McCandless, during the three years 1909-1911 (1909, 440; 1910, 214; 1911, 45) [7]. In that period all other customers had purchased but 228. Obviously this was but a low-level effort with the inventor. Practically all those tubes were used in detector sockets. To that time no one had found their amplifier or oscillator characteristic. De Forest had made *no* improvement over his 1906 design; he was deeply engaged in other wireless matters.

It would be another year (1912-13) before H. D. Arnold and his Western Electric associates would initiate their development work, which would convert the Audion into a "hard vacuum" triode, thus opening up entirely new vistas for

tubes and their applications. Tube work in any other country, if any, was confined to academic research.

The Consortium formed to exploit the von Lieben patents was of a restricted nature among AEG-Telefunken, Siemens und Halske, and Felten und Guilleaume Carleswerke AG. It was signed February 19, 1912. Exclusive rights to the von Lieben group patents were assumed by the four companies [8]. The agreement was limited to sharing costs and benefits among the participants on a 45%-45%-10% basis respectively. Basic research would be performed at a laboratory established in the AEG Oberspreewerke. Development and manufacture of tubes and equipment were to be performed by the member best suited for that work.

Much work was needed to adapt the radical new active component to practical and useful circuits. Fortunately Reisz, Alexander Meissner, and others soon devised the needed circuits, as shown by ability to use the amplifier in two-way telephone repeaters. Development of radio equipment for military use became very important, as evidenced by the large production volumes during the war by the TeKaDe equipment division.

In what manner did the von Lieben group participate in the Consortium, and how were present and future patent rights assigned to the Consortium or its members? What financial rewards were arranged or paid with the von Lieben group? None of the references available make any mention of these problems or their resolution. Written requests to the companies have drawn no response. The passage of 80 years of time, the intervention of two destructive wars and a great depression, and corporate reorganizations have militated against ever finding answers.

It is known that Reisz moved to Berlin and headed the laboratory at the Oberspreewerke. Strauss remained in the Vienna laboratory to be in close touch with von Lieben, who was confined to his bed for longer and longer periods.

Felten und Guilleaume promptly changed the name of the Carleswerke division to reflect its planned new products better. The name became Suddeutsche Telephon Apparate, Kabel, und Drahtwerke AG (South German Telephone Apparatus, Cable, and Wire Works Co.). The patented trademark was k_d , later known as TeKaDe. Manufacture of equipment for telephone central offices was a major product, along with wire and cable for communications and power distribution. Siemens was the major customer.

Volume production of the tube was assigned to Siemens-Osram Plant A on Sickingerstrasse, Berlin, with Dr. Pirani in charge of the project. (In 1915, Pirani invented the vacuum gauge which bears his name and which was used universally for many years.)

It was already known that a constant mercury-vapor pressure was essential for stable tube operation. Its control was attempted in two ways. Some tubes have a vertical millimeter-type scale etched into the bulb just above the plane of the grid mesh. This was to indicate the optimum height of the dark space which was present beneath the blue ionized gas. The second was enclosure of the tube in a chimney to provide a cooling air current by stack action. Here, too, a vertical scale could sometimes be found as an indicator of the optimum operating condition.

Efforts to control the tube and improve it were not lacking. Bulb height was

reduced to about seven inches. Various mesh sizes and perforated metal sheets were used at the grid plane to provide different amplification and current-controlling conditions.

Data for an early production LRS tube are of interest [5]:

Overall length	8.7 in. (22 cm)
Overall diameter	4.15 in. (10.5 cm)
Amplification	3.5-4.0
Life expectancy	400 hours.

The lifetime was considered quite good for such an early stage of development. Later tubes had higher gain and longer life.

Table I lists the chronology of many events which transpired in rapid succession after 1911. Study of this table tells a great deal about the importance attached to the LRS tube in Germany. Note that the public demonstration of the tube was carefully scheduled after patent protection had been assured to the von Lieben group. Further, the Consortium became a legal entity only six months after the demonstration. This is a remarkably short time when one considers the number of groups involved, their spatial separation, and the time usually required by legal departments to draw up the necessary contractual terms. This certainly indicates the importance attached to the project. Note further that the technical staff had the OSW laboratory in operation only two weeks after the contracts were signed.

In 1912 an international conference was held in London concerning regulation of wireless telegraphy. Its importance was underlined by the recent sinking of the Titanic and loss of life, which would have been less had there been greater use of wireless on ships. There needed to be coordination among the communications companies. At that time Marconi held almost a monopoly and there was a great deal of conflict between the companies of other countries.

Telefunken was able to display new equipment developed through the rapid circuit work of Meissner and others, which included the LRS tube. The tube was even used as a table decoration, proudly displaying the red of the filament area, and the blue of the ionized mercury. This greatly strengthened the hand of the Germans. Thus, just a few months later Marconi and Telefunken signed an agreement concerning tube and equipment development. Captain Round of Marconi was to concentrate upon development of receiving valves. Telefunken would concentrate on evolving transmitting valves. (This agreement did not last long, due to the outbreak of WW I.)

Tube processing was all done on stationary or "trolley" exhaust positions. Rotary or semiautomatic pumping stands were still years away. Tubes with greater power-handling capability were needed, as well as smaller ones for portable military apparatus. The glass bulbs, stem-making, and bulb sealing required the services of skilled glass workers. Metal parts, even the anode, used wire. The grid was usually a woven-wire mesh, the production of which was a specialty of German industry.

AEG built the first telephone repeaters using LRS tubes and submitted them to the Reichspost for approval. This was obtained at the end of 1912. Each fresh application of the tube required circuit development and new equipment designs to accommodate the new component. Innovative uses needed "selling" to potential customers - not difficult at that time, since the Consortium members

TABLE I
CHRONOLOGY OF THE VON LIEBEN TUBE

<u>1910</u>	
Sept. 4	Patent application filed.
Dec. 20	Patent application filed.
<u>1911</u>	
July 11	Patent DRP Nr. 236,716 published in response to Sept. 4 filing.
Aug. 3	LRS tube demonstrated in Berlin at Nernst's Institute.
<u>1912</u>	
Feb. 19	Consortium agreement signed by the four companies.
Mar. 1	AEG-OSW Lieben-tube development laboratory in operation.
July 9	F & G Carleswerke reorganized and renamed.
July 12	Patent DRP Nr. 249,142 published in response to Dec. 20, 1910, filing.
Aug. 2	Name of F & G's new division registered: TeKaDe.
Oct.	LRS tube and transmitter displayed at London conference.
Oct. 15	Telefunken files for a patent on base and socket for LRS tube (DRP Nr. 264,554, Sept. 26, 1913).
<u>1913</u>	
Early	Dr. Pirani starts commercial production of LRS tube at Osram Werke A.
Feb. 20	Robert von Lieben died.
Feb.-Apr.	Reisz and Strauss meeting with AT&T to sell LRS license.
<u>1914</u>	
Aug. 1-3	F & G purchases Wolfram-Lampen AG, Augsburg. WW I begins.
<u>1915</u>	
	Production of LRS tube by Consortium in Berlin.
<u>1916</u>	
	TeKaDe required to assume production.
<u>1917</u>	
Mar. 21	Fire destroys tube and lamp plant.
<u>1918</u>	
Summer	TeKaDe resumes production of LRS tube but for only a few years.

and the military were the chief users. With the staff of excellent circuit engineers assigned to the project, there was rapid progress.

Soon two danger signals appeared. First was an investigation for Siemens by the tube laboratory of Akkumulatorenfabrik AG, a Berlin manufacturer of storage batteries and mercury rectifiers. Their investigations of mercury vapor showed that the tube would be inherently noisy and that maintenance of the optimum vapor pressure would be almost impossible, since environmental temperature would need accurate control. Second, work at General Electric and Western Electric in the U. S. with an improved vacuum, using the recently introduced Gaede pump, showed great promise. Consequently, AEG concentrated on the new high-vacuum approach for tubes, while Siemens continued development of the LRS tube for a while longer.

On April 10, 1913, Dr. Meissner of Telefunken applied for a patent using the LRS tube in a transmitter. On June 21 he was able to conduct a radiophone conversation between Berlin and Nauen, a distance of about 25 miles (40 km). It demonstrated the use of the tube as an oscillator and modulator. For those days, with the low power of the LRS tube, that was a remarkable feat.

Dr. Hans Rukop of AEG was placed in charge of a laboratory on the Tempelhofer Ufer, Berlin, to evaluate performance of high-vacuum triodes, following the lead of Arnold at Western Electric. All these efforts benefitted from availability of the improved Gaede pump. Rukop operated his first successful high-vacuum triode at the beginning of August 1914, just as WW I was declared. Thus, the LRS tube had two years of growth without a rival. The next two years saw development of the "hard" triode to the point where Telefunken and Siemens were no longer willing to produce the LRS tube, having adopted the policy of using high-vacuum devices. Thus, they forced Felten und Guilleaume to assume production of the LRS tubes which might be needed.

Equipment using the LRS tube was not confined to telephone repeaters. Telefunken and TeKaDe assembled large amounts of other apparatus during the war. Shipboard wireless used LRS tubes in high-frequency amplifiers and heterodyne oscillators. Such equipment was found on the SS Vaterland when she was interned in New York in August 1914. In well under two years, this was truly a rapid development into commercial equipment.

It was fortunate that Felten und Guilleaume had acquired a lamp manufacturer in 1914, Wolfram Lampen AG of Augsburg. Thus facilities and technology were available when assumption of LRS production became necessary in 1916. Unfortunately, less than a year later the plant was completely destroyed by fire. Production could not be resumed until just as the war ended in 1918. It is probable that all production of the LRS tube had ceased by 1920, since high-vacuum tubes were rapidly replacing the mercury-vapor type, and were providing higher reliability, longer life, and lower cost.

Just before the major battles at the Tannenberg Marshes, the sensitive telephone equipment just recently available made it possible for General von Hindenberg's staff to eavesdrop on the Russian lines and to learn their battle plans, aiding the German victory there. Use of the LRS tubes in telephone repeaters extended voice communications from Berlin to Constantinople [Istanbul], a real necessity during the war. German Army headquarters in Luxembourg could maintain voice contact directly with both the Eastern and the Western Front.

Strauss [3] recounts that during his military service he was stationed in a remote and very hot little town in Yugoslavia, where there was one of the tube repeaters. It was not working well. Strauss was called upon to work his magic. By enclosing the tube in one of the chimney devices the temperature was reduced, and performance was again reliable.

CONTACTS WITH AT&T

Early in 1913, just a year after formation of the Consortium, Reisz and Strauss arrived in New York for meetings with AT&T. Upon arrival they received a cable telling of von Lieben's death. Presumably the mission was on behalf of, or with the knowledge of, the members of the Consortium. This trip might seem unusual in view of the close relations between Siemens and General Electric, which was also developing electron tubes. Further, the Reichspost and all the other major-country telephone companies were in close contact and presumably had patent exchanges.

Western Electric's laboratory first heard of the LRS tube through an article published in August 1912, and received by them on September 10th. Immediately the manager of the Bell Telephone Manufacturing Co. factory in Antwerp was requested to obtain and forward copies of the three pertinent patents. Thus, it is certain that Arnold was aware of the LRS tube prior to the visits.

To show just how close was the race for development and control of tubes and repeaters, consider these facts and dates:

1. Fritz Lowenstein made the unsuccessful demonstration of his "black box" to AT&T in January 1912. It was later disclosed that the box contained a de Forest Audion.

2. De Forest made his demonstration to Western Electric and AT&T on October 30-31, 1912. AT&T finally purchased certain de Forest patent rights about April 1913.

3. Arnold had been working on a mercury telephone relay. He had perfected it to the point that it was installed as a stand-by element in the event the hard-triode amplifier proved unsatisfactory during the New York-Baltimore trials in October 1913, and the preparations for transcontinental service in July 1914. This relay must have been essentially complete by February 1913, since Arnold by that time was in full pursuit of the high-vacuum triode version.

Reisz and Strauss could have known of none of these events. Consequently, they felt their reception was cavalier, and were highly disappointed that they were unable to sell the complete LRS patent rights and technology. Their sample tubes were kept by Western for six weeks of testing, without the co-developers being allowed to be present. They had felt the grid claims of the patent were outstanding, not being aware that AT&T was even then negotiating with de Forest.

There is evidence that there were legal conflicts between the de Forest and the LRS grid claims in later years. In Germany at least, they were settled in favor of von Lieben.

Arnold's mercury relay was based upon developments by Peter Cooper Hewitt with discharge tubes [9]. It is ironic that Cooper Hewitt was also thoroughly familiar with de Forest and his Audion. Their laboratories were in towers only a

few blocks apart in New York City. De Forest's wireless signals were received by Cooper Hewitt, and the two men discussed the results by phone and in person. Even more ironic, the distance from de Forest's several laboratory sites to the Western Electric laboratory was less than two miles.

SUMMARY

The von Lieben tube had a production life of only eight years. Nevertheless, it merited a prominent position in the founding of the electron-tube industry. The tube derived from the inspiration of an unusual and brilliant scientist. Not content with proving his initial idea, he spent four years developing it into a practical entity. One may well say the production of the tube in 1912 by the outstanding electrical companies of scientific Germany provided the very start of tube production which founded a fantastic worldwide industry.

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