The Rise and Fall of the Vacuum-Tube

H. J. Schmitt, RWTH-Aachen

The Museum of communication techniques and tubes of the Aachen University of Technology (RWTH) was founded by Professor Aschoff (CT) and Professor Doering (Tubes) in 1952. With over 1000 exposition items it reflects the dramatic development of these technologies from their historical beginning to their modern status.

The invention of the Vacuum Tube is seen here stimulated and embedded in the requirements of electronic communication – with a social impact comparable to the development of automotive traffic, air transportation etc. in about the same period of time.

Early communication in the 18th century was essentially based on optical techniques. Examples of optical „telegraphs“ are found in France, Germany and GB, **Fig. 1**, leading a. o. to the interesting (and lasting) development of different signalling codes [1].

Fig. 1: Optical Telegraph, UK 1795 - 1814

Fig. 2: Aachen Railway Telegraph 1843

The optical area was followed by various developments of wired telegraphy systems. A simple example for a limited number of „commands“ is the „Aachen Railway telegraph“ (1843), **Fig. 2**. It served to signal just a few commandos to clear the rail etc. and is prominent particularly due to its originator – Wheatstone. Simple optical and wire signalling with few commands still prevail e. g. in modern traffic systems.

While long distance telegraphy was possible, its extension to more demanding voice telephony and ultimately picture transmission required higher sensitivity than available with magnetic, chemical detectors or coherers used so far and new more powerful transmitters. For this problem vacuum technology became the decisive „new" solution.

Although cathode rays in evacuated tubes were studied in various physics laboratories, the development of electron tubes really startet with Edison 1883 and his observation of a shadow zone of the general blackening of his light bulbs behind the positive pole, **Fig. 3**. Obviously there was a transport of negative charges to the more positive part, and Fleming – who saw this at an exhibition – and being employed at that time by Marconi had the brilliant idea that this could be the basis for a more sensitive rectifier/demodulator for signal transmission. The year 1904 is noted (and celebrated) as the invention of the „Fleming Diode".

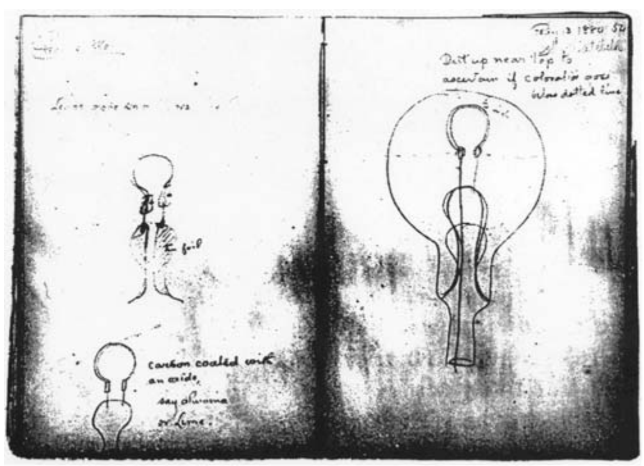


Fig. 3: Edison effect 1883

Once the nature of the electronic phenomenon was better understood, it was logical to look into the possibility of controlling the electron flow. External means (a la cathode ray tubes) were already known, but more practical means were found to steer the current density by means of an intermediate grid. De Forest – who had previously used the Fleming-diode as an „Audion" claimed this „Triode" invention (1907) [2] more or less simultaneously with von Lieben in Austria. The discussion of the patent situation lasted for years. A copy of the original von Lieben Tube of 1909 given to the Museum by Philips is shown in **Fig. 4**.

Fig. 4: Replica of v. Lieben tube, 1908

The Triode opened the way to electronic amplification, to long distance telephony and ultimately early Radio distribution. There remained the problem of life time because the early tubes still contained some residual gas and lasted only some 100 hours. This problem was solved 1914 by Langmuir (who got his PhD in Göttingen 1906 with Nernst) by perfecting high vacuum using the now available molecular pumps.

High-vacuum tubes began to be produced commercially – early receivers built for the beginning public radio distribution with one or two tubes as shown in **Fig. 5** in a true „audion“, model of 1919 with variometer coupling to the antenna.

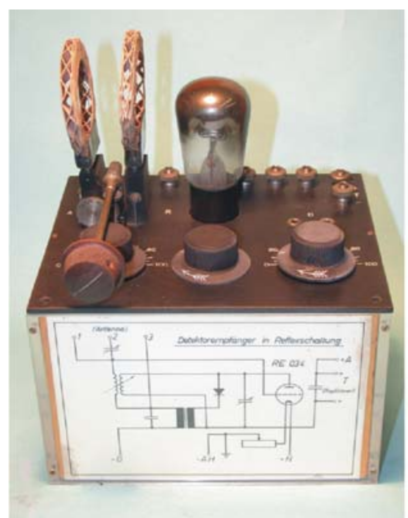
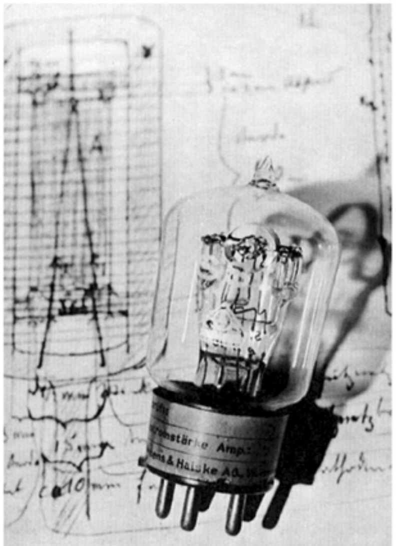


Fig. 5: Early Audion, 1919

Significant further progress was made by introduction of an additional 2. Grid at positive potential – the „Tetrode“ first suggested by Schottky (1916), **Fig. 6**. Some problems of current flow due to secondary emission of electrons from the anode could be solved by



TETRODE, SCHOTTKY 1916

introducing one more grid at 0 (or slightly negative) potential – the „Pentode“ by Tellegen 1926 – a tube offering much higher amplification than a triode. Already 1932 Philips alone had produced over 100 Millions tubes for the rising communication/radio market [3].

An interesting special development represents the so called „Loewe-Mehrfachröhren“ – the attempt to put serval (up to 3) tubes in one bulb and „integrate“ all passive components-resistors, capacitances etc. into the tube. This started in 20‘s and continued into the 30‘s. De Forest tells of a meeting 1934 with Loewe (who later emigrated to England for political reasons). The „Loewe tubes“ may be considered first IC’s although still macroscopic. They were not really successful on the market, **Fig. 7**.

Fig. 7: Loewe “Mehrfachröhre” 1930

With rapid multiplication of radio stations higher selectivity became important – which led to the development of the superheterodyne system – mixing the received signal down to an intermediate frequency convenient for amplification, followed by demodulation. For this purpose a very useful combination of tube systems e. g. a „Hexode“ for multiplicative mixing and a Triode for generation of the tunable local oscillator signal was developed, **Fig. 8**. A typical superheterodyne (tube) radio of the 50's is shown in **Fig. 9**. It also includes the „magic eye“ based on a small fluorescent fan used for accurate tuning.

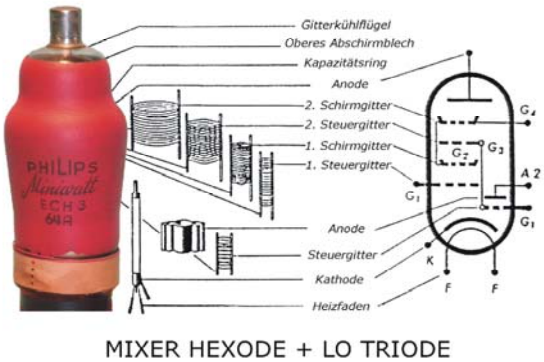


Fig. 8: Hexode-Triode combination for superheterodyne technique, 1935

Fig. 9: Superhet-radio with magic eye, 1950

Tube radios usually had 4 – 6 tubes – later development of TV (widespread starting in 40‘s / 50‘s) had 20 – 30 tubes, and with the onset of computers numbers rose up to 18000 tubes for the ENIAC, with 18 kW power consumption and related heating, burn – out and service problems.

The widespread tube area ended with the onset of transistors (invented 1948, Bell, Germanium) and commercially widespread in the 50‘s, with the development of Si-technology and IC’s at TI and Bell. There are reported 100 Millions transistors/head of world population in use today.

As of 1955 the classical radio tubes almost vanished. Some still believe in the so called "tube sound“ based presumably on a slight inherent non-linearity particularly important for „Guitar-amplifiers“ to recreate the same sound as in vintage recordings from „pre transistor“ days.

Fig. 10: Early CRT, 1930


Fig. 11: LCD-display, 2002

Other vacuum tubes which had a somewhat longer dominance are display CRT’s. They started actually earlier with investigations of cathode rays. Braun developed „methods to present rapidly varying phenomena“ long before the turn of the 19th century – received the Nobel price 1909 – together with Marconi, **Fig. 10**. The picture tube was the basis of common TV from the beginning around 1940 till roughly today, with changes to present colour and changes in format – from round to 4:3 to 16:9 etc. Right now it fades out as consumer TV and computer monitor – rapidly being replaced by flat screen devices based on liquid crystals, plasma etc., and surviving for the time being only for cost reasons in low price applications, **Fig. 11**.

The Museum also presents vacuum-devices for other purposes – e.g. x-ray technology. This in a way is even older than most other applications: Again working on cathode rays Röntgen observed strange fluorescence of materials (particularly salts) in his laboratory (1883) and for his outstanding work received the Nobel – price in 1901 – the very first Nobel price of all! Today high power tubes are based on rotating anodes, **Fig. 12**, to avoid damages of the high energy beam on the anode material. In his early work Röntgen already took pictures of body-interiors. The first are of a hand with ring (**Fig. 13**) – it is said he took his wifes hand first – for safety reasons!

Fig. 12: X-ray tube with rotating anode

Firg. 13: Early X-ray of Mrs. Röntgen

The future of x-rays is also questionable: other techniques, NMR (2003 again honored by Nobel-price), ultrasound imaging, PET represent alternatives under rapid development – and some without potentially harmful side-effects.

The only area where vacuum devices survive for the forseeable time are „high power and high frequency“ applications. The Museum has a particular emphasis on these elements – being the prime research area of its Founder [4].

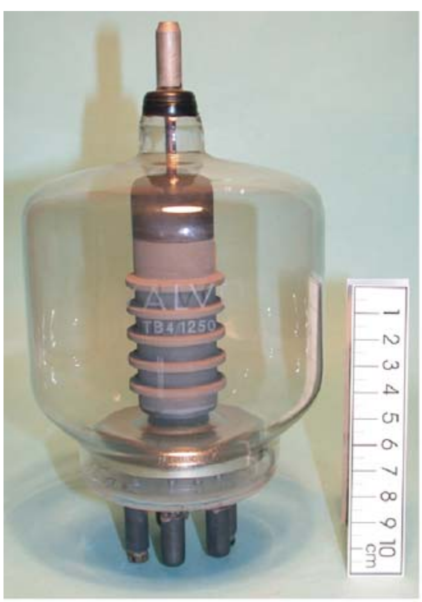


Fig. 14: High power transmitter Triode, 875 W, 1980

Conventional Triodes, designed for kW-power transmitters usually operate with water cooling, **Fig. 14**, shows a Triode for 875 W outputpower- and many more large Triodes, Tetrodes, Pentodes still used commercially are exhibited. With increasing frequency in the range above some 100 MHz to the GHz range problems arise due to delay effects in the e-beam control and the contacting. Contacting problems could partially be avoided in so-called sealed-disc-triodes immediately fitting to coax-lines.

Electron-beam delay in turn is made use of in other special tubes: In Klystrons the e-beam is velocity modulated in passing a central grid zone, bunches after a certain drift and is either reflected (low power Reflex-Klystron, **Fig. 15**) or collected after passing one or more additional cavities inducing a powerful amplified signal in the final output cavity. The Museum shows many multi-cavity Klystrons developed in the second half of the 19th century. **Fig. 16** shows the latest addition, a 5 m long water-cooled 4 cavity Klystron (plus a 5th one for harmonic suppression) as used for electron accelerators. It operates at 500 MHz with output power of 600 kW and there are even larger ones in production for other particle accelerators.

Fig. 15: Low power Reflex-Klystron, 1944

Fig. 16: 600 kW multi cavity Klystron, 500 Mhz

Another MW-power tube based on e-density bunching is produced in millions: the Magnetron with 1 – 2 kW for conventional Microwave ovens and higher power types for Radar. Attempts to replace these by solid state have so far been unsuccessful largely for cost reasons. Also broadband Travelling-Wave-Tubes are produced in limited numbers for Satellite Communication.

A rough graph of historical development of vacuum-devices and their demise is shown in **Fig. 17**. There are „technology – waves“ every 50 to 100 years. Presently culminating technologies may be replaced in time by nano-devices, single electron elements and communication via quantum states.

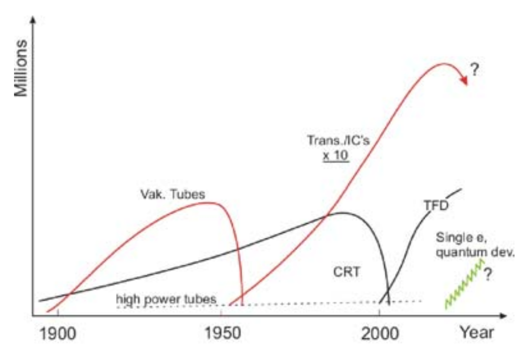


Fig. 17: Historical trends

But predictions are always difficult, as shown by one made by one of the greatest of Vacuum-Technology, Lee de Forest half a century ago: „I refrain from the unbased belief that each individual on earth may some day „wireless“ to any other. I recognize the electromagnetic laws – and the FCC!“ This was well before the „handy-cult“!

Although out-dated, the role of tubes in history remains with the development of Radio, TV, Radar, Computers and the whole world of communiation, and instrumentation. As G. C. Lichtenberg (1780, Göttingen) said: „Alles Wichtige im Leben geht durch Röhren...“

References:

[1] V. Aschoff, „Geschichte der Nachrichtentechnik“
Bd. 2, Springer 1995

[2] Lee de Forest, „Father of Radio“
Wilcox + Follett, 1950

[3] „Philips Honderd“, Philips 1991

[4] H. Döring, „100 Jahre Elektronenröhren“
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