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The Proliferation of Tube Types

Paper for the IEEE Conference on the History of Electronics 2004 at Bletchley Park

In this paper the tube development and the growth of thermionic tube types in the 1920's will be described for the application field of radio receivers.

Start of the Radio Era

At the beginning of the 1920's tubes were established components in the field of wireless telegraphy and telephony application as well as for amplifying purposes in telephone systems. A lot of theoretical work had been done thanks to Richardson, Langmuir, Schottky, van der Bijl, Barckhausen and others. The military demand during World War I had led to a tube manufacturing industry which produced e.g. the VT1 in the United States, the R.E.11 in Germany or the TM (also designated as „R") in France, maybe the best tube construction of that time. These „three electrode tubes" or „triodes" were general purpose tubes which were used in nearly all stages of the equipment.

These tubes had either a cylindrical or a parallel plane construction with tungsten or oxide coated filament. They had a glass bulb evacuated to a high degree. (The forerunners, i.e. the tubes of de Forest and von Lieben, were gaseous tubes). Their electrical data were similar.

Fig.1: Examples of the State of the Art at the End of WW1
From left to right: VT 1 (USA), R.E.11 (Germany), R (TM) (France)

First Radio Era Tubes:

The radio era started – e.g. in the US in about 1921, in Germany in 1923 - with tubes for general application according to the state of the art, which means they had either pure tungsten or oxide coated filaments and a system either tubular or more plane. This results in basically four types. Fig. 2 shows examples of the Radio Corporation of America

Fig. 2: Examples of the Beginning of the Radio Era Tubes

Left: UV 200 (tungsten filament), right: WD11 (oxide coated filament)

The UV 200 is a gaseous type with a little amount of argon gas, which has in general a higher value for mutual conductance due to what is called gas amplification. This results in higher sensitivity when used as detector, providing the tube is kept in a proper operating point. On the other hand this kind of tube shows a strong dependence on temperature and a somewhat erratic function. The construction was the same as used in the UV201, which was the high vacuum version.

(It was known since Langmuirs work that a high vacuum tube is more constant and reliable in function. Therefore gaseous tubes were basically behind the state of the art. Despite of this there came up occasionally some new gaseous types, like in Germany tubes of the brandname „Ultra“ or – intended as tubes for mains operation- the Telefunken bar tubes Arcotron 201 and 301 as late as 1929)

Technical Motivation for type Variation

Thoriated Tungsten Filament („Dull Emitter“)

The power consumption of the tungsten filaments of tubes like UV 201 was very high, resulting in a short duration of the A-battery (filament battery). Tungsten filaments needed temperatures like incandescent lamps, and they gave a bright shining light when operated. They were called „bright emitters“.

In about 1922 an improvement came up:
For metallurgical reasons (prevention of recristallisation) the tungsten for filaments of incandescent lamps was mixed with a small percentage (some 0.7%) of thoria, a process patented the by Westinghouse in 1910 [1]. It was observed that tubes with these filaments sometimes had a very high electron emission even at lower temperatures. The special process steps needed to ensure this high electron emission were investigated [2] and improved (resulting among others in a thoria percentage of about 1.4%). The result was called the thoriated tungsten filament or „dull emitter“, because the reqired temperature now was lower, giving a dull yellow light. In this way the power consumption was reduced to less than one half.
The active layer of the thoriated filament is a mono atomic layer of metallic thorium on the surface of the tungsten, which is extremely sensitive to residual gases, especially oxygen. In consequence the vacuum of these „new“ tubes had to be much higher. This very high degree of vacuum was ensured by a process of „gettering“, which is the binding of residual gases to the surface of evaporated metal inside the glass bulb of the tube. The first getter metal used was magnesium which was evaporated by induction heating from the outside of the bulb after the pumping process. The magnesium deposit gave a mirror-like shining layer on the inside of the glass bulb.
At first the new dull emitter type tubes had the same mechanical construction as their predecessors and can easily be recognized by the mirror-like shining glass bulb. Fig. 3 shows examples of the Radio Corporation of America.

Fig. 3 Pure Tungsten filament versus Thoriated Tungsten Filament
Left: UV 200 (Tungsten filament), right: UV 201A (same construction, but high vacuum, thoriated tungsten filament and magnesium getter mirror)

Different Electrical Functions

The early radio receiver had basically three stages of different function: Radio (High) frequency amplifier, Audion (Detector) and Audio (Low) frequency amplifier. These three stages could by principle be operated with general purpose tubes, but these tubes were not optimized for the different electrical requirements, e.g. impedance matching or capacitances.

At first tubes suited for a special application were selected from a whole batch by measurement and then marked by colour. Fig. 4 shows an R.E.84 by Telefunken, marked with red colour (which meant best suited for detector application) and a Cossor P2, marked with red colour too (which meant best suited for high frequency stages [3])

Fig. 4: Selected Tubes with Colour Markings

Left: Telefunken R.E.84 (selected for detector use), right: Cossor P2 (selected for high frequency amplification)

Later, tubes were constructed to be specialized for specific applications. Basically there were tubes with low amplification factor for transformer coupling between stages. These were tubes like the old ones, e.g. R.E.11, R etc. Then there was a need for tubes with low capacitance values and high plate resistance, which were suited for high frequency anplification. Tubes suited for detector operation should have a high value for mutual conductance and meet special requirements for the grid characteristic. Since 1925 the resistor-capacitor-coupling between stages came into use, which needed tubes with a high value for plate resistance.

A good example of this tube specialization is given by tubes of an at that time small German company, the „Radio Röhren Fabrik", later a Philips subsidiary called „VALVO". Their first tube was called „Normal", which means „standard". The electrical data - filament rating 3V/0.5A, Amplificaton factor 8 and mutual conductance 0.2mA/V – were typical for a tungsten-filament tube. This tube could be used in all stages of a good receiver of that time: Audion and one to two LF stages, giving power for a set of headphones or poor loudspeaker operation. The low frequency interstage coupling then was done by transformers, requiring tubes with a low amplification factor.
(Comparable types were e.g. the „UV 201" by Radio Corporation of America, the D II by Philips, the R5 by Societe Francaise Radioelectrique or the A.R. by Ediswan)

Fig. 5 Specializing of Tubes According to Circuit Demands

From the left: Radioröhrenfabrik „RRF" Oekonom, Oekonom H, Oekonom N (not shown: Oekonom W)

The first improvement of the „Normal" was the **„Oekonom"**, which means „economic".In this tube the tungten filament was replaced by one of thoriated tungsten, so the filament supply was more „economic".

In the next step this tube Model was adapted to the above mentioned three basic application fields. In consequence we find an **„Oekonom H"**, suited for **h**igh frequency amplification, an **„Oekonom N"** for audio (**N**ieder-) frequency amplification using transformer coupling of stages and finally an **„Oekonom W"** for audio amplification using resistor (**W**iderstands-)-capacitor-coupling.

Table 1 gives data of all RRF (since 1926 called „Valvo“, since 1927 a Philips subsidiary) radio tubes of the year 1926.

Betriebsdaten der VALVO-Empfängerlampen

TYPE	Telegr.-Wort	Heiz- strom in Amp.	Heiz- spannung In Volt	Zulässige A.-Spannung in Volt	Durchgriff in %	Steilheit i. mA/Volt	Innerer Widersl. in Ohm	Verwendungsbereich *)
Valvo-Normal	Valvo	0,45—0,5	3—3,5	20/100	12	0,2	ca.42000	H.A.N.
Valvo-Reflex	Valre	0,3—0,35	1,5—2	10/100	24	0,5	„ 8500	H.A.N.
Valvo Ökonom H	Valha	0,05—0,06	3,0—3,5	20/100	10	0.6	„ 16000	H.O.
Valvo Ökonom N	Valko				17	0,5	„ 12000	A.N.
Valvo Ökonom W	Vawev	0,04—0,05	1,8—2	20/200	4	je nach äuß. Widerstand	„ 50000	A.W.
Valvo Lautsprecher 201 B**)	Vabau	0,3—0,32	3,5—4	10/150	17	1	„ 5800	A.N.E.
Valvo Oscillotron**)	Varos	0,3—0,32	3,5—4	50/250	9	1,2	„ 9500	H.A.N.O.
Valvo Telotron	Vatel	2,0	5,5	200/700	8	1	„ 10000	O.E.

*) H. = Hochfrequenz, A. = Audion, N. = Niederfrequenz, O. = Oscillator, E. = Endverstärker, W. = Widerstandsverstärker.
**) Diese Röhren werden auf Wunsch mit 5,5—6 Volt Heizspannung und 0,25—0,27 Ampère Heizstrom-Verbrauch, bei sonst gleichen Daten, angefertigt. Anfertigungsdauer 8—10 Tage vom Eingang der Bestellung, soweit nicht vorrätig.

Table 1: Radio Receiving Tubes of Valvo Company (former RRF) of the year 1926
Reproduced from a Valvo Catalogue of 1926

Here we find the types mentioned above and some additional ones. Of special interest is the Valvo Lautsprecher (loudspeaker) 201 B, which is an output tube, developed from the RCA-type UV 201A. This leads over to the next group, the output tubes.

Output Tubes

The upcoming desire for loudspeaker operation (instead of the annoying earphones) required output tubes. At that time an output tube was a tube able to deliver an output power of more than 100 Milliwatts.

Even in the early times – that is, in the time of tungsten filament – we find output tubes. Fig. 6 gives two examples.

Fig. 6: Early Output Tubes with Tungsten Filament

Left: Philips Type „E“, right: Lorenz (a German company) Type LV 3,5/220

The further development of output tubes followed the path to thoriated tungsten filaments. Fig. 7 gives examples of some tubes of this kind.

Fig. 7: Output Tubes with Thoriated Tungsten Filament

From the left: Telefunken „RE 209“, Cossor „Stentor two“, Valvo „201B“

Screened Valves or Tetrodes

We have seen that special electrical qualities make the tube able to meet special circuit reqirements. In the case of high frequency amplification a tube with very high amplification factor and high plate resistance would be able to give useful voltage amplification by a factor of several hundreds instead of about tens when using a tube of the type descibed above. So the sensitivity of a receiver could be remarkably increased.
The means to do so was basically known since WW1, it is the use of a second grid, called the screen grid. This second grid is located between the standard (control-) grid and the plate. It screens the control grid from the plate voltage and the result is a very high amplification factor.
The better the separation of control grid from the plate, the higher the amplification factor will be.

One early construction of a screened tube (1926) is the type S 625 made by Marconi-Osram. In order to get a very good separation, the thoriated tungsten filament an the control grid are connected to one base, whilst screen grid and plate are connected to a second base opposite to the first one.
This construction, though very good from the electrical point of view, caused mechanical problems to the setmakers due to the double ended construction.
Fig. 8 shows this tube and a somewhat later American construction with an indirectly heated cathode designated UX224, this one made by Rogers in Canada.

Fig. 8 Screened Valves („Tetrodes")
Left: Marconi-Osram S 625 (thoriated tungsten filament), right: RCA UY224 (indirectly heated cathode)

Fig. 9 Tube with electrostatic shielding
by Conductive Metal Paint

The high amplification made possible by using tetrodes caused an old problem to newly appear in severe form: the problem of self-oscillating. This could be solved only by thoroughly shielding the input of the amplifier stage from the output and shielding of the tube itself. In consequence the tubes were electrostatically shielded. This was done mostly by spraying the tube outside with a conductive metal paint (see Fig. 9), but there were also wire mesh shieldings or sheet metal shieldings in use.

Barium Evaporated Filament (Dark Emitters)

The last filament improvement during the 1920's was the barium evaporated filament. In this process, introduced in 1927, metallic barium is deposited on the (surface oxidized tungsten) filament. An amount of barium, deposited in a barium pocket (see Fig.10, right tube) and evaporated by means of induction heating from the outside of the bulb. The result was a deposit of metallic barium on the filament, causing a very high specific electron emission. The reqired filament temperature was very low now, one could see only a dark red glowing („Dark Emitter")

The surplus amount of barium gave a barium deposit inside the glass bulb on the places oppssite to the openings of the electrode assembly (Fig.10), acting as the getter. So dark emitter tubes can be recognized by this new getter look.

Fig. 10 Dark Emitter Output Tubes

Left: RE134 (Telefunken), right: RE 604 (Telefunken), note the barium pocket on the anode

In consequence there was designed a whole new set of tubes with dark emitters according to the different electrical requirements mentioned above.

Output Pentodes

The year 1927 was a very important year for tube development. In this year came up the barium evaporated filament, the indirectly heated cathode (to be dicussed later) and, last but not least, Philips introduced the B443, the first output pentode. This is a screened tube with an additional grid, the suppressor grid. This third grid suppressed the secondary electrons which were hit out of the anode metal. The result was an output tube which had a very high amplification factor and thus required less preamplification.

The electrical improvement can be seen from Fig.12, giving a comparism between different output tubes. Since this picture is taken from a German book, it is showing Telefunken types of the years 1928 to 1938.

Since the B443 came up with dark emitter filament, the tube looks similar to the dark emitter tube given in Fig.10, having a little thicker bulb than the RE 134 shown and an additional side screw contact.

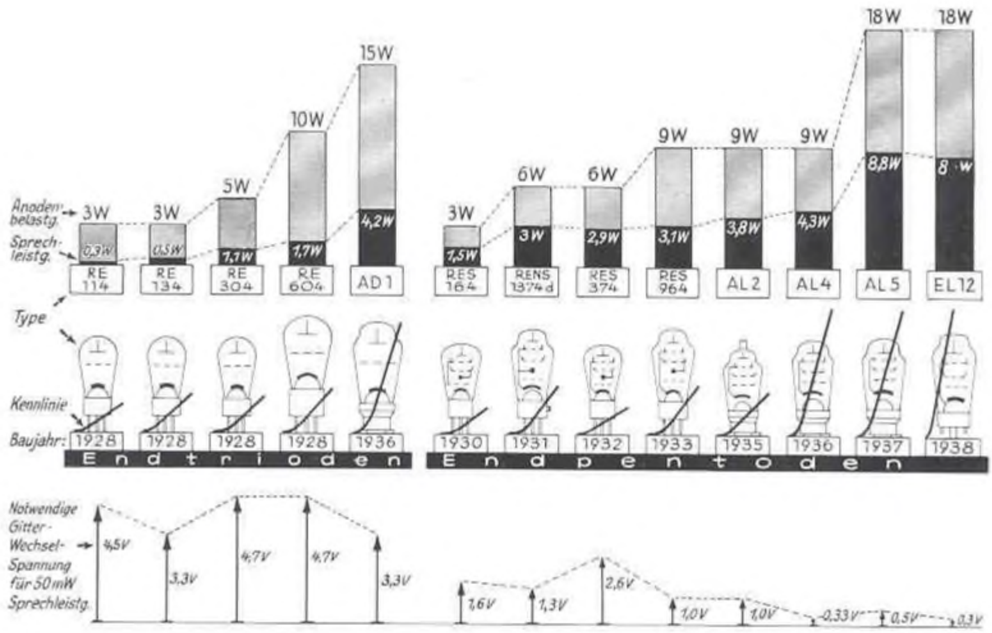

Bild 90. Die Entwicklung der Endröhren (Wirkungsgrad, Sprechleistung, Steilheit und Gitterwechselspannungsbedarf)

Fig. 11 Comparision of Output tubes (taken from [4])

The type RE 134 of Fig 11 gives half a watt output power and requires 3.3Volts RMS input voltage for 50 Milliwatts output. The RES 164, a rough equivalent to the B443, gives 1.5 watts output and requires only half of the input voltage.

Indirectly Heated Cathodes for Mains Operation

The desire to get rid of the batteries led to the development of tubes which could be heated by the mains supply. The difficulty to take filament supply from mains was the fact that mains was mostly AC-mains, causing the mains hum in the circuits. To gain freedom from hum, the electron emissive layer must be free of thermal or electrical influences of the mains frequency. The way which had to be gone to reach this goal was long (one intermediate step were the short filament tubes, one error were the Telefunken bar tubes).The final solution was the indirectly heated cathode, where the filament was only the heater for a nickel tube which was coated by the electron emissive layer, mostly a paste of barium oxide.
These tubes were introduced in 1927, too.

Fig. 12: Indirectly Heated Tubes for Mains Operation

From the left: Cardon AC-Tube (with side connections for the filament), REN 1104 (Telefunken), UY 227 (RCA)

Space Charge Grid Tubes

The last significant kind of tubes to be discussed here are the tubes with a space charge grid. It was known since WW1 that a positively charged grid between filament and control grid greatly reduced the effect of space charge around the filament, thus reducing the required amount of plate voltage. Whilst a „normal" tube required a plate voltage of some 50 to 200 Volts, a space charge grid tube could do with down to some 4 Volts, resulting in a very simple plate supply. So these tubes were widely used by home constructors.

Space-charge grid tubes were built with any type of filament and even with indirectly heated cathode. Fig. 143shows a set of these tubes.

Fig. 13: Space Charge Grid Tubes

From the left: D VI (Philips, bright emitter), Bigrille (Radiotechnique, dull emitter), DM 300 (Radio Record,dark emitter)

Commercial Reasons for Tube Type Variation

License policy and Type Designations

In the US the main owners of tube patents were RCA (GE, Westinghouse) and AT & T (Western Electric).The independent manufacturers either had to apply for licenses or to fear legal prosecution (but the US are large). Here we find the special situation, that independent manufacturers used either the same or at least similar tube designations and produced the same electrical tube types as RCA. So the total number of radio tube types in the US during the 1920's was only in the order of 10. Besides that, the US setmakers tended to use rather a tube more in their sets than using too secialized tubes.

In Great Britain the patent owners were the General Electric company (GEC) and the Marconi group. There was founded a British Valvemanufacturers Association (BVA) [5],which dominated the tube business. But these manufacturers all had their different tube designations. So we find a number of tube designations, which can be estimated from the number of tubes different due to technical reasons multiplied by the number of manufacturers.

In Germany the Telefunken Company, owned by Allgemeine Elektrizitäts-Gesellschaft (AEG), which had links to the GE in the US, and Siemens Company, was the owner not only of the tube patents, but also of most patents related to the field of radio (only TeKaDe had a share in the tube patents). The Telefunken company had a very restrictive licence policy and severely prosecuted non-licensed manufacturers. At the end of the decade Telefunken had defeated all non-licensed manufacturers. The only survivors were the Valvo company mentioned above, and a small manufacturer named Loewe, famous for its multiple tubes. [6], [7], [8], [9].
For instance Valvo, since 1927 a susidiary of Philips, was licensed in Germany only because there existed an international cross-licensing treatise between Philips, Telefunken and others.
So we find 10 manufacturers in 1925 against only 4 in 1930. Similar to the Britsh case these manufacturers had different tube designations, and so we find a lot of tube designations.

These three countries had a somewhat similar situation, because there were dominant companies having a big home market besides the export activities.

Netherlands and Hungary were the homes of two big companies: Philips and Tungsram. In these countries the home markets were too small, so these companies were extremely export oriented. Philips tended to buy local companies in other countries, like Valvo in Germany or Mullard in England (both in 1927). Tungsram tended to found own local factories using the name Tungsram, too, like Tungsram France or British Tungsram.
Philips and Tungsram made tubes according to the state of the art, sometimes even leading the state of the art; one example is the output pentode Philipps B 443 already mentioned. They had their own tube designations.

Finally there were tube factories in a lot of other countries, e.g. in Denmark (Oxytron, Manufaktur Pedersen and Elektromekano), making similar tubes by construction as dicussed above, but using different designations.

Commercial reasons for Different Tube Constructions:

Tube Bases

There were different tube bases in use, some of which for the commercial reason of making a difference to the competitors: The UV-, later the UX-base in the US, the british-french tube base already used in the R-tube (which later on - since about 1925- was standard in whole Europe) and some company specific bases, like the Telefunken base in Germany.
Consequently, tubes could be designated according to their bases. Fig. 14 shows examples of the Telefunken company, Germany.

Fig. 14: Tubes with Different Bases

From left to right: R.E.84 (Telefunken base), R.E.95 (British-french base), R.E.48 (UV-base)

R.E 84 and R.E. 95 differ only by the base, bulb and mechanical construction are basically the same.

Multiple Tubes

The last item to talk about are the multiple tubes, as they appear in Germany. As mentioned above, the Telefunken company was owner not only for the tube patents, but also for most of the other patents concerning the radio field. The German setmakers had to pay license fees to Telefunken. This fee was calculated by the number of tube sockets in the radio set. In consequence ist was good to have as few tube sockets in the set as possible.
One way to reach this goal was to build two or more tube systems into one bulb with one base. This idea led to the multiple tubes.

The TeKaDe (Telefon-Kabel- und Drahtwerke) were ownwers of tube patents too, but not of circuit patents. They constructed tubes having up to three systems inside one bulb. Fig. 16 shows a set of TeKaDe tubes.

The VT 139 has three tube systems inside, so this one tube is all one needs for a standard three tube receiver of that time (audion detector and two audio frequency stages).

Fig. 15 from left to right: VT128, VT 126, VT 139

Fig. 15: A Set of Multiple Tubes made by TeKaDe

Fig. 16: Multiple Tube 3NF Made by Loewe, containing three tube systems, condensers and resistors

The Loewe company made multiple tubes, too. This company did not only build up to three tube system into one bulb, they also includes the necessary circuit elements like resistors and capacitors. The tube shown in Fig 17 could be named the first integrated circuit, because it contained the elements for a whole standard three tube radio set. Only the coils and a variable condenser for tuning had to be added.

Conclusion

To meet the requirements of a radio set of the 1920's, which has the basic functions of high frequency amplification, audion detector, audio amplification and output stage, one needs a set of at maximum four electrically different tubes. But: Any of these tubes can be built as bright, dull or dark emitter or as indirectly heated tube. Then we have screened tubes and output pentodes, and, especially for the many home constructors, space charge grid tubes.
This manifold of tubes has (with the exception of the US) to be multiplied by the number of tube makers to get an idea of how many tube designations could be found at that time.

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The photos are taken from my private collection