5. High Frequency Tubes

Conventional tubes intended for operation at very high frequency depart for shapes, connections and electrode structures from the low-frequency ones. The same concept of high frequency evolved in the years. Until WWII the research for vacuum tubes capable of operating at very high frequencies was essentially pushed by communication markets. Military carefully watched at new high-frequency tubes usable for radio localization sets, just experimental in several countries and later known as radar. Anyway we must consider that before WWII, with few exceptions, the early advanced television transmitters used frequencies just above the limit of short waves. In 1939 B.B.C. started its experimental high-quality transmission at 45MHz, while RCA operated its vision antenna on the Empire State Building at some 54MHz. Articles on propagation of UHF signals, so were defined radio waves just above 30MHz, were worthy of publication in the advanced press. In January 1939 Proceedings of I.R.E. published ‘A study of ultra-high frequency wide-band propagation characteristics’ by R.W. George from RCA., while in September 1939 Proceedings of Radio Club of America gave the article ‘Ultra-high-frequency propagation’ by M. Katzin, a study on propagation of radio waves from 50 to 150MHz.

RF power in the order of a few hundreds watts was hardly obtainable at these frequencies and power dropped sharply to few watts at higher frequencies. In 1937 one of the most powerful UHF tube was the 316A, made by Bell, which was capable of generating about 6W at 500MHz. The alternate solution was the use of power transmitting triodes with positive grid, in the circuit configuration devised by Barkhausen and Kurz. A 462 MHz transmitter, designed by RCA for two-way telephony between Rocky Point and Riverhead, used two UX-852s operating as push-pull Barkhausen oscillator to generate a mere 6 W RF and another set giving 115 W at 411 MHz used two water-cooled 846s, wasting some 1200 W just for filaments.

The design of high frequency tubes required difficult compromises among antithetical choices. In order to reduce parasitic capacitances, electrodes and their connections had to be well spaced. But to reduce the transit time, electrodes has to be very close to each other. A possible compromise was to reduce both spacings and electrode surfaces, using small bulbs with well spaced connections, as in the ‘acorn’ tubes. Unfortunately this solution greatly limited the power that could be handled. The power-versus-frequency limits were evident even in the more powerful ‘doorknob’ shaped tubes. Power increase was possible by the introduction of new plate materials, capable of operating at very high temperature and dissipating heat by radiation.

External anode solutions, although very difficult to manufacture, also offered excellent heath transfer to external radiators. ‘Micropup’ triodes were introduced by British GEC from 1939 and widely used in allied VHF/UHF radar sets at least until the late 1942 and even later in radar jammers and navigation sets even later. Micropups were capable of delivering peak power in the order of several kilowatts at wavelenghts down to 25 cm.

Planar electrode shapes favored the realization of vacuum tubes with closely spaced electrodes, capable of operation well beyond 1 GHz. ‘Rocket’, ‘lightouse’ and ‘oil can’ were the most popular families, so called from their shapes. The upper limit of the most successful planar designs was only slightly increased after the war, refining materials and processes and approaching 10 GHz.

Here the most relevant families.

5.1 - Acorn and secondary emission tubes

Probably the ‘acorn’ type was the first standard envelope specifically designed for higher frequency applications. All-glass body, well spaced pins, small electrode structures and short leads were the solutions condensed in these tubes, to reach operating frequencies up to about 1000 MHz. Introduced in 1934 by RCA, acorn tubes were intended for low-level applications, even if some of them were used in pulsed operations to generate power in the order of one kilowatt.

Acorn tubes were difficult to manufacture and required special ceramic or porcelain sockets.

Fig. 5.1 – A 6F4 ‘acorn’ triode.

In the late thirties, secondary emission amplifiers were even investigated as front-end in high frequency receivers, to increase the overall RF gain. VHF amplifiers based upon secondary emission were attractive, since granted high transconductance figures. Indeed, the very early VHF secondary emission amplifiers introduced by RCA around 1939 used a big 12-pin ‘acorn’ envelope. The collection includes one very early developmental prototype and production samples of this giant acorn, as well as other post-war secondary emission amplifiers.

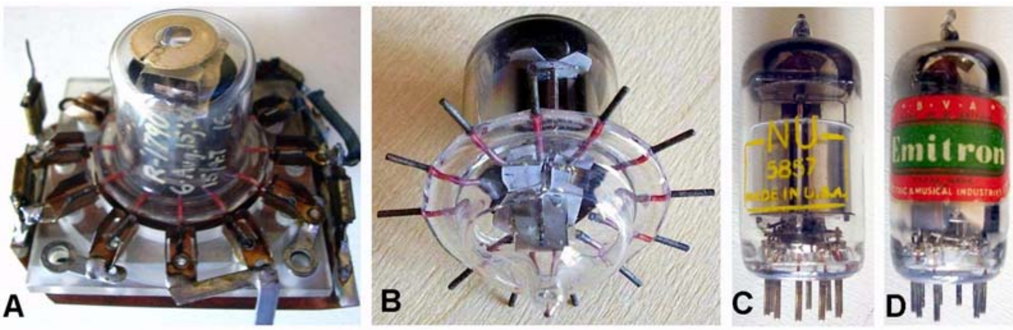
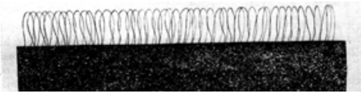


Fig. 5.2 – From left, the developmental R-1790, fig. 5.2-A, evolved in the 1630, fig. 5.2-B. After the war, National Union registered this miniature 5857, 5.2-C. The CV2276 was a British amplifier, developed by GEC as Z319.

5.2 - Door-knob tubes

Probably these tubes were first introduced by Western Electric around the mid 1930s as transmitting triodes for frequencies up to about 600 MHz. Electrodes were mounted close to the base in a domed all-glass envelope. To enhance high frequency performances, very small and closely spaced electrodes were used. Cathode was a filament of tungsten, for the minimum section. Anode was carbonized and finned metal or graphite, for better power dissipation. Grid was made of tiny tungsten loops clamped between the folded ends of a metal plate, as in the detail below:



In some types, rods supporting anode and grid came out even from the top, for easier connection of the tube in the middle of Lecher resonating lines.

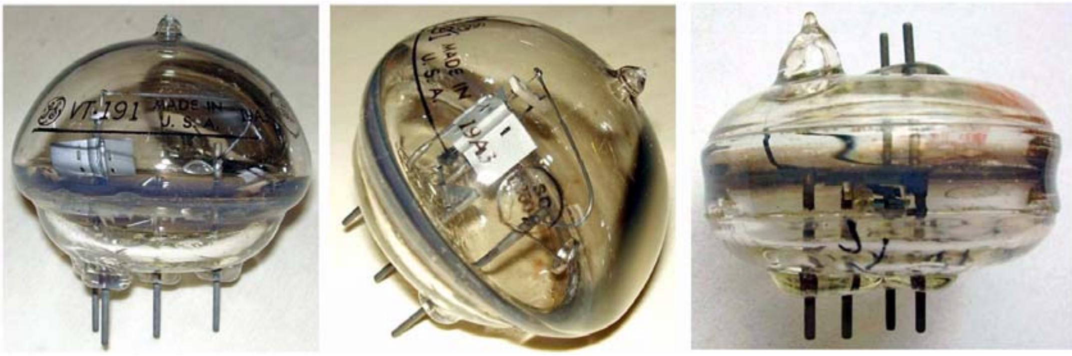


Fig. 5.3 – Left, two views of a VT-191 'door-knob' single-ended UHF transmitting triode. Right, a WE 368A, with anode and grid connections both from base and from top.

5.3 – All glass VHF/UHF power tubes

We have already seen some samples of popular 'all-glass' VHF/UHF' tubes, with envelopes more or less standardized as 'acorn' or 'door-knob'. Nevertheless the increasing demand for high-power devices led to development of a variety of shapes and to solutions often tailored to the need of the system designer. Connections to electrodes were placed where most convenient to integrate with the resonant circuit. The use of small plates capable of high dissipation by radiation, as the tantalum ones which commonly operated at cherry red temperature, made necessary the use of high-temperature glasses, as the so called 'uranium glass', common in WWII American tubes. High operating temperatures also prevented the use of mica spacers, sometimes replaced by ceramic ones. Anyway at higher frequencies the rods connecting electrodes to outside were also used to support the same electrodes.

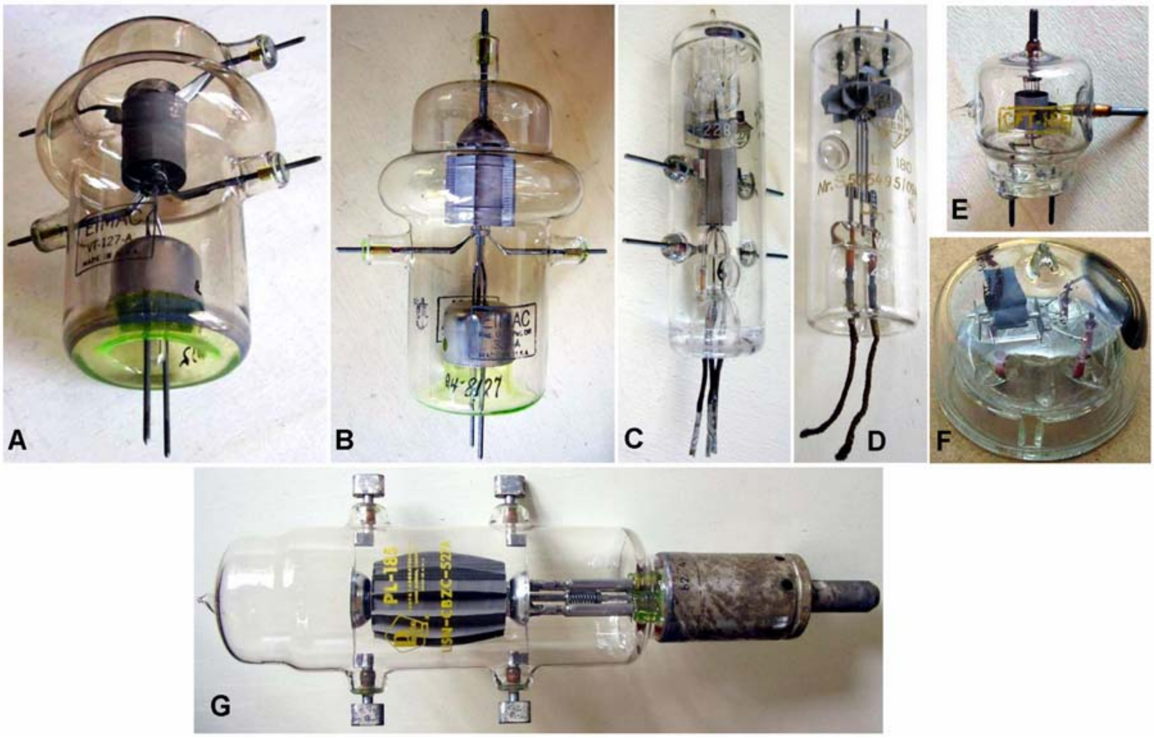


Fig. 5.4 – Some VHF/UHF transmitting tubes were designed to be mounted as direct extension of the associated resonating line.

5.3 - Micropups

This tube family was introduced in 1939 at GEC, Great Britain, with E1046 or VT90. At the time it granted the highest power at frequencies up to 300 MHz. The external anode was a short copper sleeve, usually fitted with a finned radiator, to be easily cooled by forced-air flow. Two glass domes were attached at each end. A 'parrot cage' grid, formed by molybdenum or tantalum rods, was attached to the top dome, the other one holding an oxide-coated cathode cup, with a spiralled tungsten heater inside. Their manufacture required special tooling, to hold the parts, anode and grid assembly first and then anode and cathode assembly, during the Housekeeper sealing process.

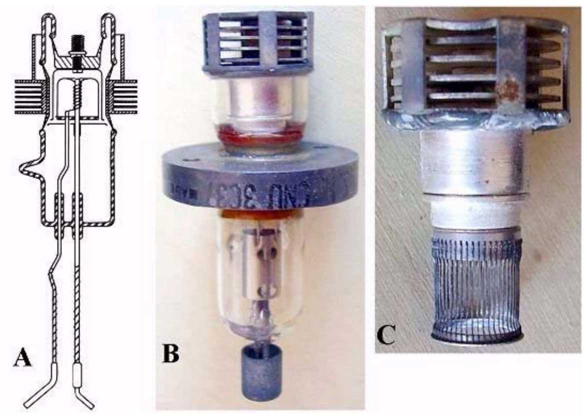


Fig. 5.5 – The cross section of a typical micropup triode on the left shows the sealed junctions of anode block in the middle to the grid and the cathode subassemblies. Right, the picture of a typical 'squirrel cage' grid.

Fig. 5.6 – Some micropup tubes. From left, the Amperex 8011, one of the many American replacements for the British V.T.90, used in pulsed operation up to 300 MHz. The British CV92, also made in United States and in Canada with different codes. The CV55, capable of operation at 600 mHz. The Canadian REL 4C29, an improved variant of the CV92.

During WWII, micropups evolved into smaller milli-micropups capable of operation over 1 GHz, such as the CV155. Other evolutions appeared in America, fitted with coaxial heater connector for easier replacement, as the National Union 3C27 and 3C37 or the Canadian REL 4C29.

Variants were proposed well in the fifties as VHF power oscillators for industrial heaters, as the 6C24.

5.4 - Rocket tubes

‘Rocket tubes’, so called for their shape, probably were the evolution of the early planar triodes developed at STC, Great Britain, as grounded-grid amplifiers for VHF signals in radar receivers. CV16, CV88 and CV53 were the very early available triodes, the latter one modified with a standard skirted top cap. The cathode was a rectangular nickel tube, with oxide coating only on the upper side. The cathode and grid assembly was common to all these types, supported by mica sheets inside the lower half of the glass envelope. The grid itself was connected to the grid copper disc by four small spring wires. All these tubes operated satisfactorily as amplifiers at 200MHz. In 1941 CV53 gave origin to a variant with an internal feedback loop, the CV82, useful as local oscillator for superheterodyne receivers up to about 600 MHz.

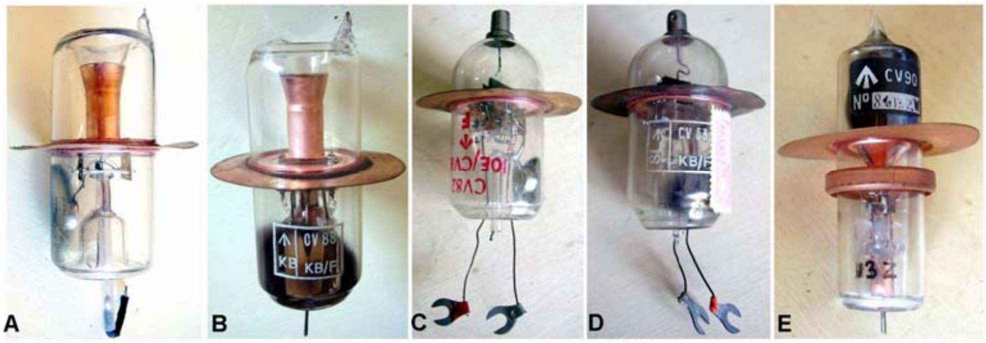


Fig. 5.7 – CV16 (A) was the first planar triode developed at STC Ilminster to operate up to about 600 MHz. The CV88 (B) was an improved version, capable of operating up to 1 GHz. A simplified design, still using the same cathode and grid assembly, led to the development of CV53 (D) and soon later of CV82 (C), with internal feedback to be used as oscillator. Moving to higher frequency, a complete redesign was needed, with closely spaced electrodes, as in the CV90 (E).

In 1943 GEC introduced the CV90, an improved version of the CV82 capable of operation up to 3 GHz. The CV90 design was optimized for operating inside coaxial resonators. Both grid and plate used disk seals and the same cathode/heater assembly was terminated with a small coaxial plug. This design was replaced in 1945 by the improved CV273, that was the forerunner of a variety of rocket tubes in Europe and even in America. European types, mostly from GEC, have more or less the same shape of the original CV273. American types, from Sylvania and Litton, were made in a variety of shapes, adapted to different resonating cavities.

Fig. 5.8 – An overview of European and American rocket tubes. Starting from left, the early type, the CV273 from GEC, the EC55 from Philips, a later GEC larger power variant, the CV397. The next four tubes are American designs, including the basic 2C36, the folded grid, folded anode rings 6481, the discoidal grid 5768, also proposed as UHF television preamplifier, and the latest cermet variant, the Eimac 8980, built in the eighties as replacement for the discontinued glass-bulb 2C37.

5.5 - Lighthouse tubes

Lighthouse tubes, so called for their shape, were the RCA/GE variant of disc-sealed tubes, with simplified manufacturing processes. Here the closely spaced planar electrodes were supported by glass spacers. The major drawback of this family was the poor power dissipation, due to the small size of the anode. The only known exception was the 3C22, with built-in plate radiator.

Fig. 5.9 – From left: the section of a [2C40]() and the tube itself, a [3C22]() capable of 125W plate dissipation and the [EC157](), one of the few European lighthouses, used in UHF radio-relays.

5.6 - 'Oil can' tubes

'Oil can' types derived from the GE experimental L-14 triode. They look as upside-down lighthouses, the plate being terminated in a large finned heathsink and the cathode/heater terminating in a small coaxial plug. The most popular tube of this family is the 2C39, with countless updates and derivatives, even with conduction cooling. With proper airflow, plate power dissipation is in the order of 100 W. Maximum operating frequency is in the order of 3 GHz. These tubes were used in many power applications in communication and even as linear amplifiers for UHF television transmitters. They found an elective use in aircraft navigation transponders. Selected variants were proposed with gold finish, AL (AirLine) suffix.

Fig. 5.10 – Left to right, section of the GE experimental L-14, a [2C39](), a ceramic variant, the [7815R](), and a gold-plated conduction cooled 7815, selected for airline use.

5.7 - Pencil tubes

Pencil tubes were introduced by RCA in the late ‘40s to compete against other microwave tubes then available, as rockets and lighthouses. Pencil tubes were extremely tiny, their diameter being just one quarter of an inch, 6.35 mm, with the exception of the large grid disc. The coaxial electrode assembly, heater, cathode and grid, was housed inside the anode copper cylinder. The power dissipation was considered acceptable, due to the fair thermal conduction from the anode to an external cavity section. Some devices were also fitted with finned heathsink. Pencil tubes were useable at frequencies in the order of some gigahertz.

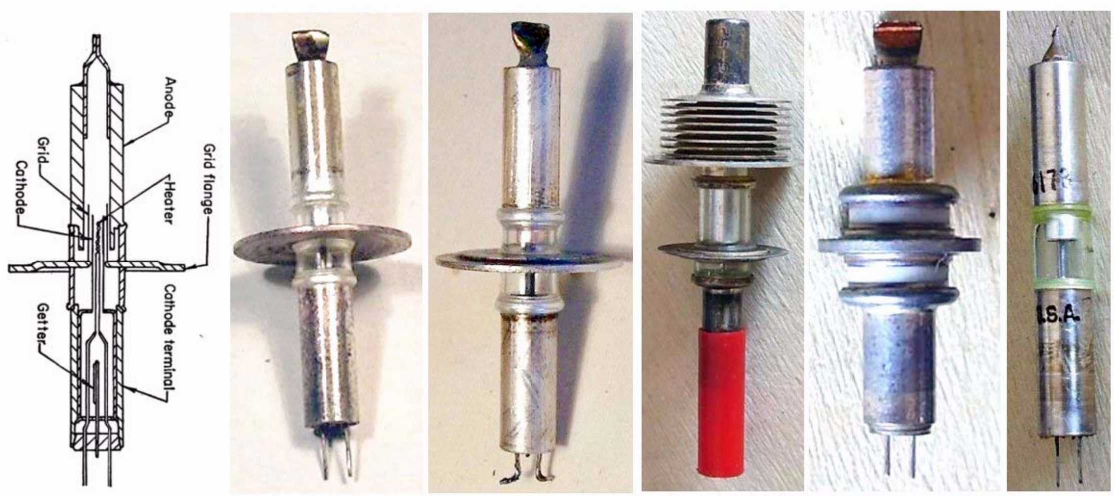


Fig. 5.11 – Left to right, the section of a pencil triode, the 5675 amplifier or oscillator up to 4 GHz, the 4042 for pulsed operation at 1.7 GHz, the 6263 rated to deliver up to 8 W at 500 MHz with forced-air cooling and the 7554, latest generation cermet pencil, capable of operation up to 5 GHz. The latest device is a pencil diode, the 6173, capable of operation up to 3.3 GHz.

5.8 - Mixed planar types

Here are grouped some different types of microwave tubes that, for shapes or for constructive designs, differ from the types already listed.

- 708A Western Electric

Fig. 5.12 - This very unique design appeared around 1940 to operate as grounded-grid amplifier/mixer in L and even in S-Band radars.

- 416A÷D Western Electric

Fig. 5.13 – This long lasting design was announced in May, 1949 as microwave amplifier for radio relay applications up to 4.5 GHz. In the years several updating were introduced to the early 416A glass spacers triode, up to the 416C and the 416D with BeO ceramic spacers and enhanced power dissipation when used as transmitter.

- General Electric Planar Cermet Types

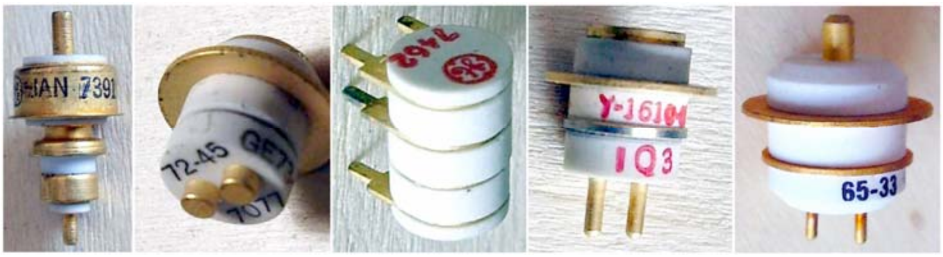


Fig. 5.14 – The latest improvements in materials and techniques led to the development of very small and light tubes usable up to almost 10 GHz and capable of operation in extreme environmental conditions, even at temperatures higher than 400 degrees or in high cosmic radiations. Several tubes of these families were used in military aircraft equipment as well in space probes.

5.9 - Microwave Modules

Fig. 5.15 - For specific microwave applications, due to the difficulties for average customers in manufacturing, assembling and tuning their own cavities, some tube manufacturers offered standard modules, built around pencil or cermet tubes. Typical applications included radiosonde transmitters, radio altimeters and other avionic equipment. The huge quantity of gold all over the surfaces of these two GE modules used in the radioaltimeter of licence built F-104G interceptor well gives an idea of their cost.

5.10 - Miniature Glass Planar Tubes

Fig. 5.16 - Even miniature glass envelopes were used for planar triodes intended to operate at frequencies under 1000 MHz. The first two images refer to the Sylvania 7245, equivalent to 6J4, while the last image refers to the British Marconi A1714, approved as CV408, capable of operating as low-noise amplifier or oscillator up to 1000 MHz. 7245 planar structure was also proposed in a ruggedized ceramic enclosure, enginered for fully automatic production.