5. High-frequency space charge tubes

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This section shows the techniques developed in the years to increase the operating frequency of space charge tubes. The family includes both transmitting types and low-power ones in which, due to considerably lower operating voltages and dissipated power, smaller and closely spaced electrodes are used. Anyway the boundaries between the two families are not well defined and sometimes we see that tubes originally designed for use as local oscillator in superheterodyne receivers were also used to generate pulses in the order of kilowatts.

Space charge 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, then just experimental in the largest countries and later referred to 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 45 MHz, while RCA operated its vision antenna on the Empire State Building at 54 MHz. Articles on propagation of UHF signals, so were defined radio waves above 30 MHz, 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 on propagation of radio waves from 50 to 150 MHz.

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 probably the most powerful UHF tube was the WE 316A, capable of generating about 6W at 500MHz. An 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. Another set generating 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 and 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, as tantalum or molybdenum, capable of operating at very high temperature and hence of 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 were widely used in allied VHF/UHF radar sets at least until the late 1942 and even later in radar jammers and navigation sets. 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.

- Low power: acorn and other VHF tubes

We see that the first attempts to reduce parasitic capacitance and transit time led to small tubes, usually designed scaling down cylindrical electrode systems, with well spaced connections to outside. Even the suppression of the usual bakelite base contributed to a further reduction of parasitic parameters.

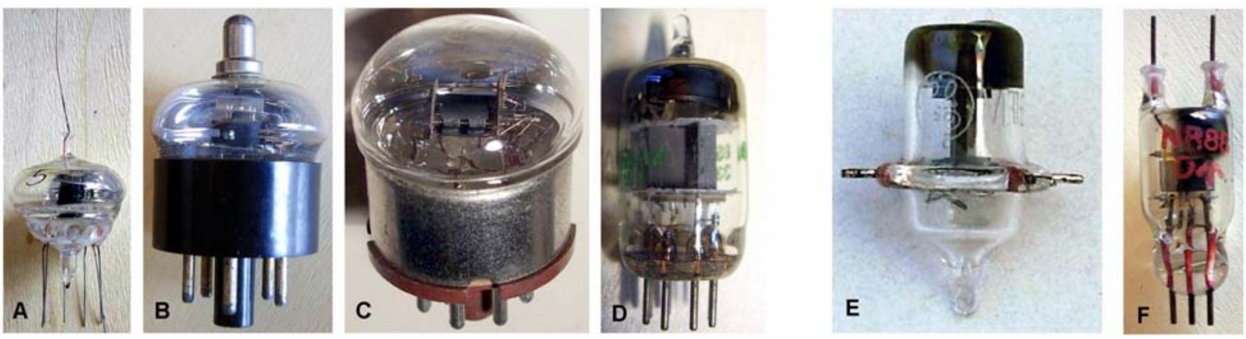


Fig. 5.1 - Simplest high frequency tubes were designed scaling down ordinary electrode systems. A) The flying leads 384A, one of the early VHF amplifiers by WE, was only 27 mm high. B) 387A was derived from 386A, a slightly improved 384A, adding the octal base and a cap. C) The VHF amplifier 717A, 'mushroom' due to its look, was a single-sided and based variant of 384A. D) The industry standard 6AK5 derived from the 717A, moving its electrode assembly in a miniature 7-pin glass envelope. E) RCA introduced its 'acorn' family around the mid thirties. The 955 above was rated for operation as amplifier or oscillator in the UHF region, up to 600 MHz. F) NR88 was the European answer to the complex manufacturing processes of acorn tubes. Its body measures 36 by 15 mm. (Click on image to enlarge)

A new non conventional approach to the amplification of VHF signals came in the late thirties with the introduction of secondary emission amplifiers. Here the amplification derived from electron multiplication due to secondary emission effect by intermediate electrodes, called dynodes. More or less in the same years other non conventional tubes referred to as ‘deflectrons’, based upon the bouncing of an electron beam between two anodes, were proposed as oscillators or mixers in the VHF region. The collection includes samples of these families and even a rare prototype of a secondary emission amplifier, the R-1790, used in the receiver front end of early radar SCR-270 and later superseded by the 1630 ‘giant acorn’.

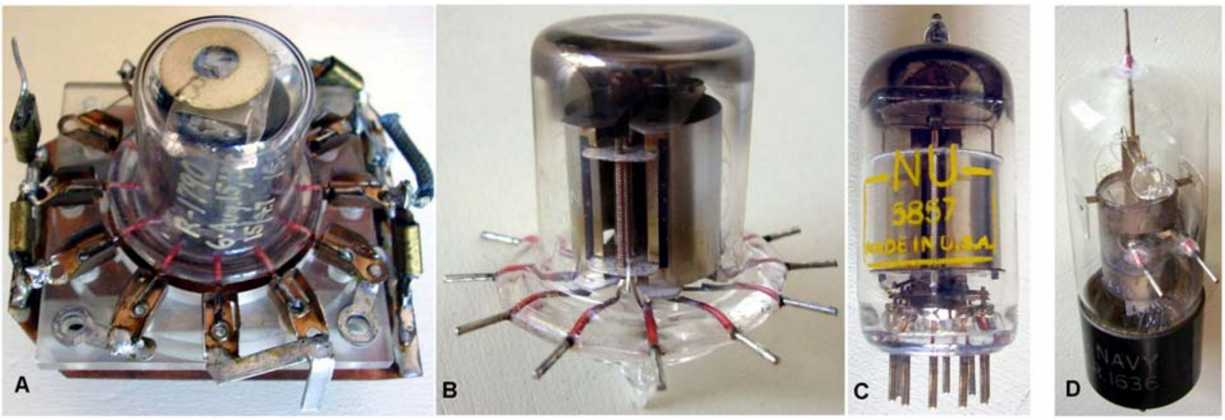
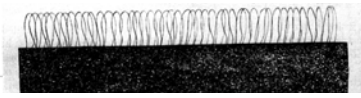


Fig. 5.2 - Samples of secondary emission amplifiers and of a beam deflection mixer. A) R-1790 is a rare RCA prototype of VHF secondary emission amplifier used in the early receiver of the SCR-270 radar set, 1939. B) A sample of the 1630 ‘giant acorn’ which went soon later in production. C) National Union 5857 was one of the few secondary emission amplifiers appeared in US and in England after the war. D) 1636 was a beam deflection mixer used in the receiver of the AN/TPS-18 radar set. (Click on image to enlarge)

- Doorknob tubes

The doorknob family was introduced in the mid thirties by Bell Telephone to generate power in the UHF region. It concentrated innovative solutions to keep size and spacing of electrodes as small as possible, also reducing the inductance of connections. For a while these tubes were considered to be the most powerful RF sources available over 200 MHz and were used in the early development of VHF radar sets in America and in Great Britain.



Enlarged view of the grid of a doorknob tube. The tiny tungsten wire loops are supported by the side cooling fin.

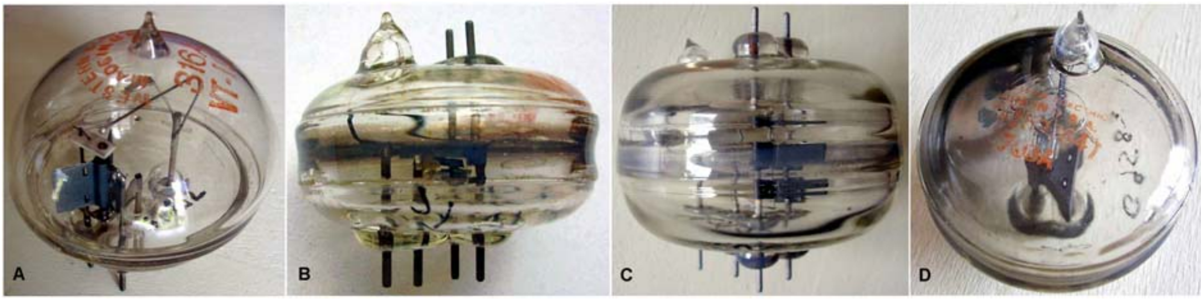


Fig. 5.3 - To keep connections as short as possible, the same rods which supported electrodes extended as pins to the outside of the short hard-glass envelope, that looked like an old porcelain doorknob. Electrodes were very small and mounted close to each other. A tiny thoriated-tungsten filamentary cathode was surrounded by the grid made by small tungsten loops attached to a cooling fin. Anodes were made by graphite blocks, later replaced by metal types with three large cooling fins.
A) The 316A was capable of delivering 30 W at 500 MHz anc could be operated up to 600 MHz. B) 368A was double-ended to be mounted in the middle of a resonating line. Introduced in 1934, it could be operated up to 1750 MHz. It was also made in the single-ended version 368AS. C) The double-ended 388A had graphite anode to withstand 50 W plate dissipation. D) The 703A can be found either with metal or with graphite anode. It was rated for 20 W plate power dissipation and could be used as amplifier, oscillator or mixer up to 1500 MHz.
(Click on the image to enlarge)

- All glass VHF-UHF power tubes

The simplest solution to increase the operating frequency was the suppression of the base and the use of short, well spaced connections from electrodes to external resonating circuits. The doorknob tubes were excellent examples of this approach. Nevertheless many and many shapes were devised, depending upon the frequency, the power, the possibility of adapting already proven solutions and even the integration into some external mechanical, thermal and electric design. Most of the tubes listed in this section are also listed in the transmitting types. For this reason here we will show just few more types of relatively small power, maybe just used in microwave instrumentation.

Fig. 5.4 - Shapes of all-glass VHF / UHF tubes. A) 15E was very small, with thoriated-tungsten filament, squirrel cage grid and tantalum anode. Four tubes were used at 500 MHz in the ring oscillator in the Navy ASB radar. B) 592, also known as 3-200A3, was intended for RF heating up to 200 MHz. C) The British GEC CV52 was capable of operating as oscillator up to 1200 MHz. The large pin is connected to the grid, presumably a squirrel cage one. D) The German RD12Ta operated up to about 600 MHz. (Click on the image to enlarge)

- Micropup tubes

This family was devised by British GEC as an improved replacement of WE doorknobs in the VHF transmitter of the early radar sets. The external cylindrical anode was sealed at both ends to glass domes, the lower one supporting the heater and cathode assembly and the upper one supporting a thick rod which terminated in a parrot-cage-shaped grid. Soon later the structure was stiffened by shortening the grid supporting rod. This led to new designs with tighter tolerances and closely spaced electrodes, capable of operation at frequencies exceeding 1 GHz.

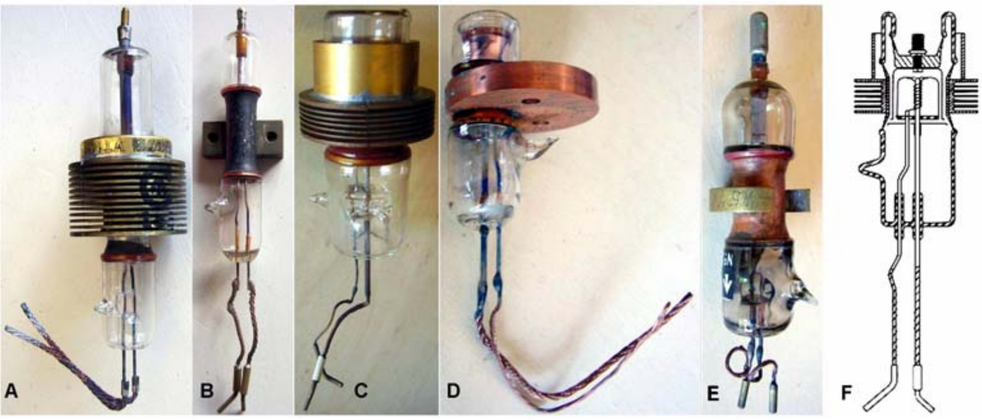


Fig. 5.5 - When introduced in 1939 by GEC micropup tubes were the most advanced and compact sources of VHF power. Most of the British and Canadian and a large number of American radar sets used them at least until the late 1941, when superseded by S-band magnetron oscillators. A) VT90 was the first micropup tube introduced in 1939 for the aircraft radar under development. In the photo a Canadian equivalent, the REL 1, manufactured by Northern Electric, B) CV15 was the conduction cooled version of VT90. Two tubes in push-pull were used in early ASV radar transmitters, delivering 10 kW at 200 MHz. C) NT99, approved as CV92, appeared around the mid 1941. Its new design included a larger cathode emitting surface, a stiffened structure and closer electrodes. Peak emission greater than 40A and operating frequency over 600 MHz were achieved. CV92 gave origin to the selections CV199 and CV1256, depending upon emission. D) CV55 'millimicropup' was designed to operate up to 1.2 GHz. E) CV8 was a power diode designed to operate as TR switch. F) Section of a CV92 micropup. (Click on the image to enlarge)

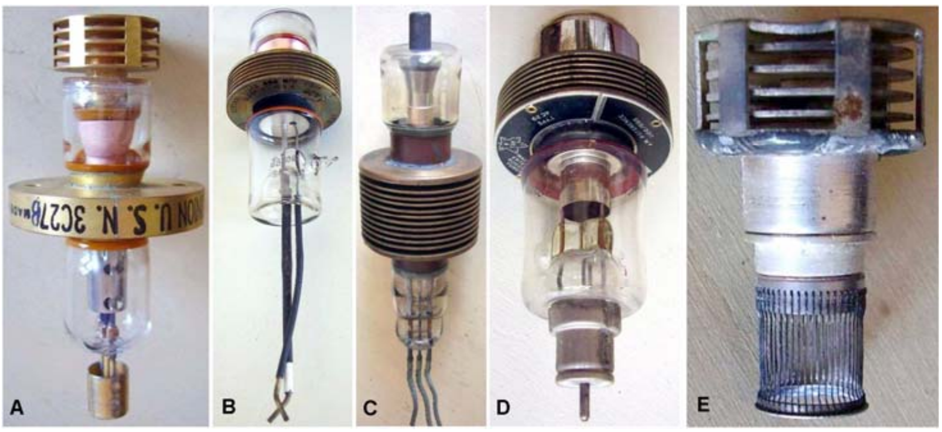


Fig. 5.6 - Micropup tubes developed in America. A) National Union 3C27 was a design presumably derived from British CV55. It evolved into the 3C27B, with the grid radiator, and eventually in the 3C37. B) During WWII RCA developed the 4C28 from the British derived 4C27 for use in its Shoran navigation system. C) After the war RCA announced the powerful 7C24 and the lower power 8014A as VHF oscillators also suited for industrial heating. D) The Canadian REL 4C29 was registered as 'secret' during WWII. It was still in production for Canadian Air Force in the mid fifties. E) Grid assembly of a 3C37 showing the parrot-cage grid welded all around the short copper rod terminated in the finned radiator. (Click on the image to enlarge)

- Rocket tubes

Rocket tubes were so called because of their shape. The family evolved duuring WWII, and even later, probably from the British design carried out at STC Illminster for the front end of early radar receivers. The early design was quite crude, with parts derived from normal receiving tubes, but it worked properly at about 200 MHz and soon evolved into refined solutions capable of operation even beyond 3 GHz. The collection includes samples of successive developments in England and in America.

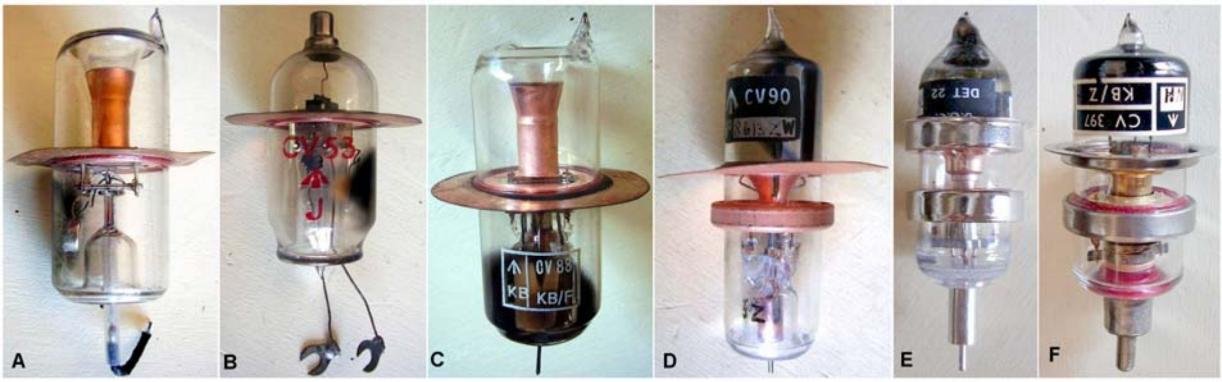


Fig. 5.7 - Samples of British VHF/UHF planar triodes. A) STC S25A, introduced in early 1941 and approved as CV16, was desiged to operate as amplifier around 200 MHz. B) The design was simplified adopting a nickel boxed anode: CV53 was considerably easier to produce and operated satisfactorily up to 600 MHz. C) In the S28A, approved as CV88, the visible improvement is the coaxial heater-cathode connector. Tighter tolerances raised the usefulness of this amplifier to 1 GHz. D) CV90, available since 1943, had an internal feedback probe to operate as oscillator up to 3 GHz. It can be considered as the first 'rocket' shaped tube. E) DET22, approved as CV273, replaced CV90 from 1945. F) DET24 / CV397 was a later power variant of CV273. (Click on the image to enlarge)

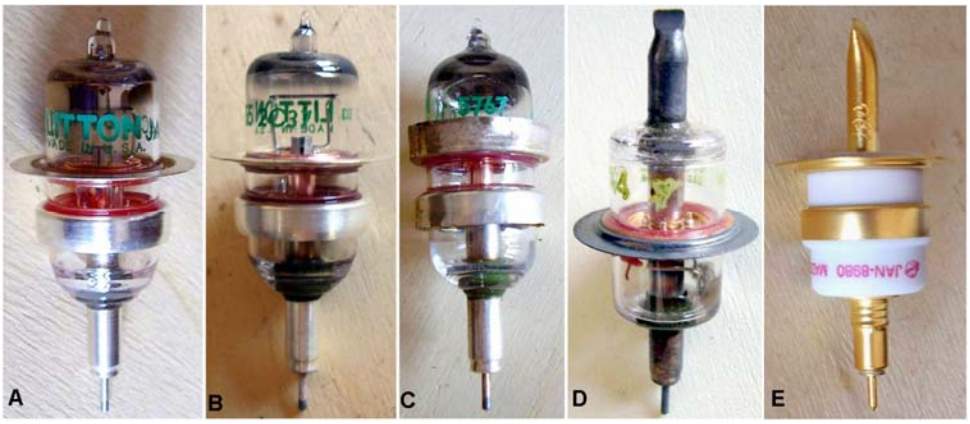


Fig. 5.8 - Rocket style tubes made in US were all derived from the Sylvania experimental SB-846A developed during WWII. Here is a Sylvania catalog of rocket types.
A) 2C36, registered to Sylvania in June 1946, came with an internal feedback probe to operate as oscillator up to 5 GHz. B) The developmental SB-846A was registered after the war as 2C37, capable of operating as amplifier or oscillator up to about 3.3 GHz. C) 5767 was one of the shape variants of SB-846A, its folded anode ring being designed to fit a coaxial mount as the one in the SG-24/TRM-3 FM signal generator. D) In the early fifties 6BA4 and the similar 5768 were proposed by Sylvania as RF front end in UHF television tuners. E) The Eimac 8980 was produced in the late seventies as maintenance part to replace the obsolete 2C36 in military test sets. (Click on the image to enlarge)

- Lighthouse tubes

Tubes of this family developed by General Electric, were considered ‘secret’ during WWII. These planar tubes were designed to operate inside coaxial cavities and were referred to as lighthouse because of their shape. The family includes few devices, usually low-power triodes, capable of operating in some cases over 3 GHz in continuous or in pulsed mode.

Fig. 5.9 - Lighthouse tubes were designed during WWII by General Electric. A) Construction details of a 2C40, showing the planar electrodes held in place by the two glass spacers. B) 2C40 could be used up to 3.75 GHz. As oscillator in pulsed operation it could deliver 300 W. C) Larger cathode surface and electrodes were used in this 2C44 to generate more powerful pulses, up to 1.4 kW. D) The 2B22 planar diode was intended to operate as detector, mixer or TR switch up to 1.5 GHz. E) 3C22 was the most powerful device in the family, capable of dissipating 125 W with forced-air cooling. (Click on the image to enlarge)

- ‘Oil-can’ tubes

These tubes, so called for their shapes, derived from the early L-14 experimental tube, designed during WWII by General Electric. Lighthouse tubes had proven their effectiveness in the UHF region. Unfortunately their power dissipation was very poor because of the small size of the plate and of its associated heat radiator, the plate cap. In the oil-can tubes the section looks someway reversed and the plate is the largest electrode, usually terminated in a finned radiator. The GE bulletin ETX-110 covers disc seal tubes, both lighthouse and oil-can types.

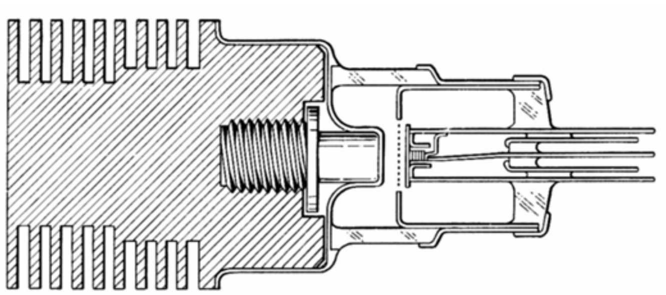


Fig. 5.10 - Section of the L-14 experimental triode developed during the war at General Electic. The anode stud is screwed into the finned radiator at left

Oil-can tubes soon gained popularity for their compact size, their relatively simple construction and tho outstanding performances obtainable. Anode power dissipation in the order of 100 W could be easily obtained with a moderate air flow across the fins of the radiator and frequencies in excess of 3 GHz could be attained. In pulsed operation, as in the case of many navigation transponders, they could deliver 3 kW RF power. The early types gave origin to countless variants, even conduction-cooled types, and improvements. Until the late fifties productions had retained the original glass spacers, later replaced by ceramic ones. Improved high-rel variants were developed for commercial airlines, suffix AL, still in use in DME transponders at the end of last century.

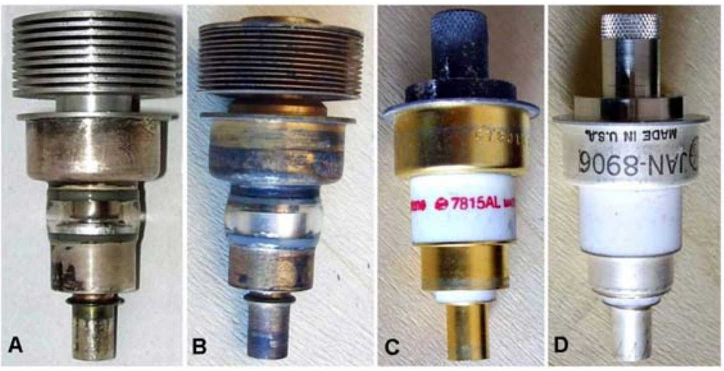


Fig. 5.11 - Samples of oil-can UHF transmitting tubes, their body measuring about 77 mm in height. A) 2C39 was among the early types introduced since the end of WWII, even if it was registered in 1946. B) 322 was a gridless variant of 2C39, proposed as modulation-clipper diode at frequencies up to 1500 MHz. C) 7815, registered in the sixties, featured several improvements over the 2C39 prototype. The extended ceramic spacers offered enhanced insulation at high altitude operation. The matrix type cathode surface could withstand high voltage surges without damages. The above image shows a conduction cooled 'AL' selection, qualified for use in airline navigation equipment. D) 8906, registered in the early seventies, has an improved high-emission matrix cathode. It can be operated up to 3 GHz and can generate pulses up to 3 kW. (Click on the image to enlarge)

- Pencil tubes

These UHF tubes were introduced by RCA in the late 1949. The family takes its name from the shape of the tubes, just ¼-inch diameter and hence thin as a pencil.

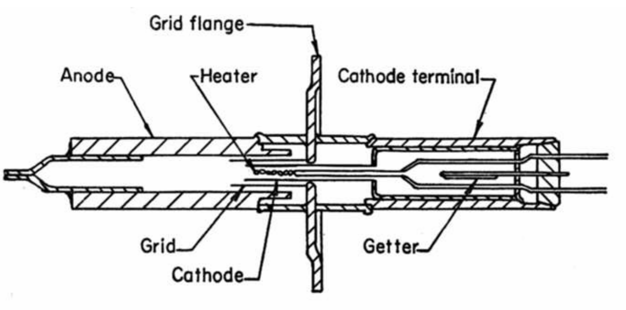


Fig. 5.12 - Section of a pencil triode showing the internal electrode structure.

For their structure, with a large grid flanged termination, these tubes were intended to operate in low-power grouded-grid circuits at frequencies uo to 3 GHz. The family also includes some factory-assembled oscillators, listed in another sub-section. Even if these tubes were used in some UHF generators and test equipment, the never gained popularity because of the strong competition of other families, as the rocket one.

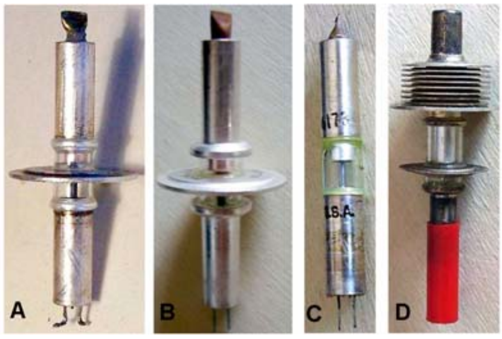


Fig. 5.13 - RCA pencil tubes were capable of operation as amplifiers or oscillators over 3 GHz. A) 4042 was a selection of EIA 5675 to HP specifications. B) 4058 was usable up to 4 GHz. As pulsed oscillator it could operate with 4 A peak emission. C) 6173 was a diode usable up to 3.3 GHz. D) 6263 and the later version 6263A were rated for 5 W CCS plate dissipation. They could operate up to 500 MHz full ratings and up to 1700 MHz at reduced ratings. (Click on the image to enlarge)

- Mixed planar tubes

Here we find high-frequency tubes which cannot be classified into the above families. Two of them were designed by Western Electric, others are part of the many and many ceramic planar tubes introduced by General Electric from the late fifties.

Western Electric UHF tubes include only two devices. The first one was a triode developed in 1940 and intended to operate as grounded-grid mixer in early US radar sets, SE, SG, SH and early Mk VIII, from about 1 to 3 GHz.

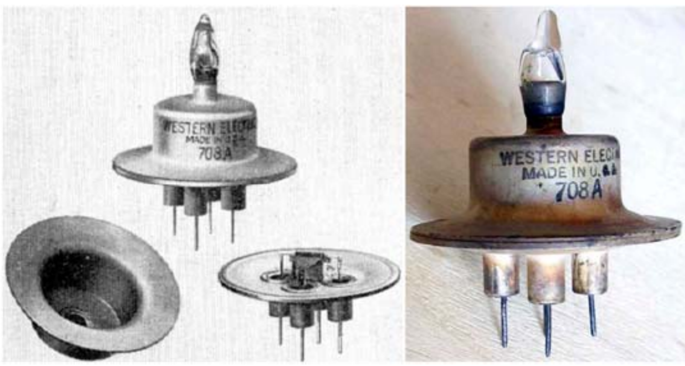


Fig. 5.14 - Left, shape and internal details of the WE 708A grounded-grid triode. Grid was welded to the steel case. Right, a sample of the tube on exhibit at the collection. Tung Sol second sourced this tube. (Click on the image to enlarge)

The second high frequency tube designed at Western Electric was the 416A, followed by the improved versions 416B, also registered as 6280, 416C with glass spacers replaced by ceramic ones and 416D with BeO spacers and increased power handling capability. This long-living triode was quite exceptional, with gain increased in the years up to 250, transconductance reaching 65 ms and 4.5 GHz useful frequency limit. As oscillator it could generate up to 5 W at 4 GHz in the D version.

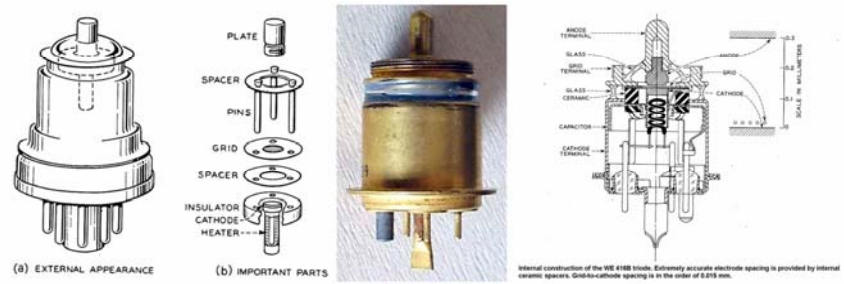


Fig. 5.15 - Left, 416A derived from the experimental triode developed at Bell, intended for operation in microwave relay transmitters and receivers up to 4000 MHz. It was designed to be mounted inside a couple of superimposed waveguides, one in input and the second in output, the grid acting as septum between the two resonators. In the middle a sample of 416B, still with glass spacers. The full development of the tube can be read at this page. Left, a sectional view of the 416B which also shows how close and precise the interectrode spacing was in this tube. (Click on the image to enlarge)

- General Electric microwave cermet tubes

Since the second half of fifties General Electric began to introduce tiny ceramic tubes capable of extreme and hard to believe performances. Totally new materials and techniques were used in these devices to ensure the lowest attainable spacing between cathode and grid and the minimum transit time, under any kind of mechanical shock and vibration condition and over extreme temperature ranges. Grid wires were brazed to a grid washer and supported by transveral stiffening wires. In more recent tubes grid wires were welded to an etched frame. The the stiffening bars were hosted into recesses hollowed into the cathode oxide layer. Titanium anode was nickel brazed to the ceramic spacer. Cathode surface was very little to ensure very low transit time. Ceramic spacers were made of materials with temperature coefficient of expansion similar to that of titanium. Seal surfaces were diamond-lapped to ensure tight tolerances. Comprehensive description of the General Electric cermet microwave tubes and their performances are given in these notes and in this reliability report.

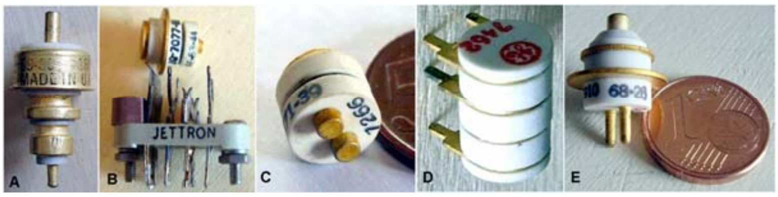


Fig. 5.16 - General Electric microwave cermet tubes. A) 6299 was usable as low-noise amplifier up to 3000 MHz. B) The 7077, here shown with its holder, could be used as low-noise amplifier up to 7.5 GHz. It was also used in a class B amplifier in the Pioneer III space probe. C) 7266 was a planar diode usable up to 7.5 GHz. D) 7462 was similar to 7077 above, but with lug terminals for PCB mounting. E) This tiny 7910 was designed to operate as plate pulsed oscillator, generating 100 W pulses and operate up to 7.5 GHz. (Click on the image to enlarge)

- Microwave modules

The development of microwave subassemblies, oscillators or amplifiers, could be a very complex issue for small industries. Then some tube manufacturers decided to offer factory assembled modules. Looking at catalogs we find standard modules built for some specific frequency and application, as the modules for radiosonde. We also read of custom design services for non standard applications.

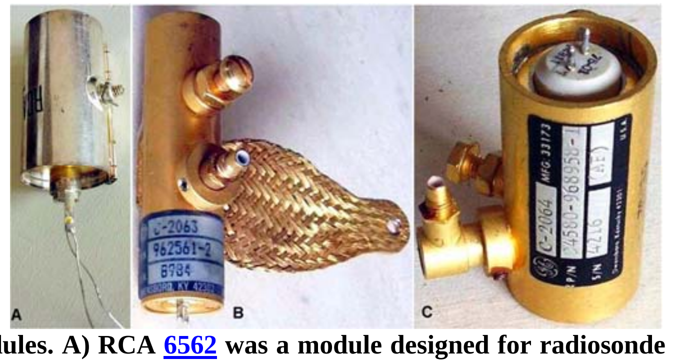


Fig. 5.17 - Microwave modules. A) RCA 6562 was a module designed for radiosonde transmitters at 1680 MHz. It used a pencil tube as oscillator. B) General Electric C-2063 was a Microwave Circuit Module, MCM, intended as local oscillator in radio-altimeter receivers. 4300 MHz center frequency. C) GE C-2064 was the transmitter MCM companion of C-2063. 4300 MHz center frequency, 70 W peak power. (Click on the image to enlarge)

- All-glass miniature planar tubes

In the fifties a few attempts were made to introduce low priced miniature tubes with planar electrodes.

Fig. 5.18 - Left, two views of the Sylvania 7245, a byproduct of a research contract with Bureau of Ships to build a fully automatic tube production plant which led to the ceramic triode SDN-1724D. Right, the British Marconi A1714, approved as CV408, capable of operating as low-noise amplifier or oscillator up to 1000 MHz. (Click on the image to enlarge)

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