# Radar tube development

**Go to Radar Tube Index**

The overview is focused on tubes specifically designed during the early development and the wartime evolution steps of British and American radiolocalization sets. The reason why these tubes are so interesting stays in their fast evolution, due to the many applications of the radar in WWII. Very early radar experiments started around 1935, intended for ground or naval early warning equipment, capable of detecting approaching airplanes or ships. Frequencies under 100 MHz were used because of the relative immunity obtainable against fog or rain and even because this was the limit of the best components readily available at the time from electronic market. Great Britain played a leading role in the definition of the major architectures, introduced even hefore the war, and in the development of their basic components. Military schools, universities, British scientists and industries worked together under the co-ordination of ad-hoc committees to investigate all the solutions potentially suitable to fill the blocks of any radar set. As we will see, they built different devices for each function and selected the right one after careful evaluation of merits and defects. In a few years they set the new standards for low-frequency and microwave radars, with the introduction of external anode triodes up to about 1 GHz and of the magnetron in the microwave region for the transmitter, of the reflex klystron and of the crystal diode mixer in the receiver, of special tubes to pulse modulate the transmitter, up to the T/R switch in the antenna diplexer and the long persistence CRT screens for PPI presentation.

## Low frequency British systems

British Chain Home system operated at frequencies between 20 and 55 MHz. 20 µs pulses were used, peak power raising up to 1 MW. Peak emission capacity was the main limiting factor in the transmitting tubes, by far more severe than plate power dissipation. Special silica tubes, the NT57 and the improved NT57D, with short anode and twin tungsten hairpin filament capable of 5A emission, were probably the early tubes specifically designed for radar applications, since 1936. NT57s were also used in mobile ground MB1 and MB2 radar systems and in GL1 and GL2 gun-laying systems. A push-pull of self-oscillating NT57s was used in the transmitter section of early Type 79 shipborne radar set, delivering about 15 kW at 40 MHz. From 1939 NT57 was replaced by NT57T, with thoriated-tungsten filament and increased emission. The collection also includes the CV14 silica valve with three hairpin filaments, developed around 1940 and presumably capable of over than 50 A peak emission. Despite of the impressive increase of the emission current over just few years of evolution, silica valves were not the solution. Their manufacturing was a painstaking job and their production was too low to support the wartime demand.

An effective replacement for silica valves came from the external anode GEC VT58, with pure tungsten filament and derived from ACT10 television transmitting triode. Delivery of VT58 started in 1938. Early batches were used in prototypes of CHL VHF radar system, operating at 200 MHz. Then VT58 advantageously replaced NT57 in MB2, GL1 and GL2 systems. By November 1939 VT58 was superseded by VT98, same shape but with thoriated-tungsten filament and increased emission. As REL type #5, VT98 was also manufactured in Canada and used in the transmitter section of SCR-588 for the CHL system installed in 1941 to protect the Panama Channel.

At low-frequency bulky directional antenna arrays were required to obtain information about the position of targets. Higher frequencies were required to design accurate or airborne radar sets. Other countries assumed that frequencies around 500 MHz were the highest obtainable with best triodes. On the contrary British evaluated correctly the need for microwaves, and planned at least four evolutive steps at 1.5 meters, followed by 50, 10 and 3 centimeters. Their policy was simple: when prototypes of any step were just released for early operational tests, their scientists and industries were already developing components for the next step. In this way they were years ahead other countries, until America got into the field, building components and systems even for British.

## Airborne VHF and UHF British systems

The very early airborne radar set, known as RDF 1.5, was first tried in the autumn of 1936 at Bawdsey Manor. Operating at 45 MHz it was based upon a ground based transmitter and a TRF receiver, sold by EMI for their television service, installed with a CRT display on the aircraft. In March 1937 a compact airborne transmitter was built, using one of the new Western Electric 316A doorknob tube at 45 MHz.

In August 1937 a new prototype operating at 1.25 meters was ready. Two 316As in push-pull were used in the transmitter and RCA 955 acorn triodes converted the received echoes at 45 MHz, ahead of the EMI TRF receiver, used as IF strip. Test flights proved that a small decrease of the frequency to 200 MHz resulted in improved overall system sensitivity with peak pulse power in the order of 1 kW. By the end of 1946 two airborne systems, the AI (Air Intercept) and the ASV (Air to Surface Vessel), were defined. Collection includes samples of 316A and of equivalent tubes made by STC and by Mullard, plus a developmental high-emission LWG5 doorknob.

Since 1938 doorknob tubes were replaced by 4304 triodes, so increasing the output power to about 2 kW and the useful range to about 15 miles. The improved ASV set was also modified for use as CD or Coastal Defense radar, later also coupled with Coastal Artillery Batteries.

In 1939 the EMI IF module was replaced with a lighter and more efficient PYE chassis, even this one made for television, based upon the recently released VHF pentode EF50 which became a British radar workhorse through WWII.

In 1939 the 4304 VHF transmitting tubes were replaced by the new GEC VT90 ‘micropups’ in the AI Mark II and in the ASV Mark I. Doorknobs entered in the black list for new designs. Transmitter based upon VT90 tubes generated 5 kW pulses at 200 MHz. The same basic architecture was retained until the delivery of early microwave types, fitted with magnetrons operating at 10 cm. The most relevant upgrade was the replacement from 1941 of VT90 with the more compact and sturdy NT99, capable of operation at 600 MHz. In AI and ASV at 200 MHz a couple of NT99s generated 100 kW pulses, while in AMES11 mobile radar they operated at 600 MHz. Until 1942 NT99 was the standard micropup for British radar transmitters equipped with space charge triodes.

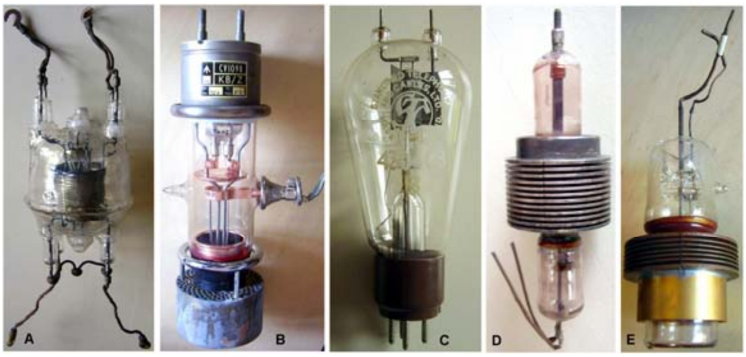


**Fig. 1 - British transmitting tubes for VHF radar sets. A) The quasi-experimental CV14 silica valve. B) VT98, standardized as CV1098. C) 4304 VHF triode. D) VT90 and E) NT99 micropups. Click to enlarge.**

Waiting for the development of microwave sets, micropup based ASV was also adopted by US military forces. About 18.000 units were built in America by Philco and by Canadian REL during 1941. VT90 was manufactured among the others by RCA, Amperex and National Union as 8011, by Western Electric as 710A and as Type #1 by Canadian Northern Electric for REL. The other workhorse, NT99 standardized as CV92, was manufactured in America under the code 8026 by RCA, 4C27 by National Union and by Central Electronics and Type #7 by Canadian Rogers for

REL. By the way micropups were also used in several Canadian designs, as in the REL CSC marine radar prototype, the marine surface warning radar sets SW1C, SW2C and SW3C, the 281 air warning sets, the Type 286, 290 and 291 marine sets, derived from ASV.

Tubes as the acorn triodes or even the same EF50 pentode designed for television use operated quite satisfactorily at low frequency. Over 200 MHz receiving sections of radar sets moved to grounded-grid triode amplifiers in the RF front-end, this solution granting the full separation between input and output circuits, no unwanted feedback, and then the highest gain. New planar triodes were designed at STC Ilminster, with grid wires welded to a copper disc, mounted close to the cathode surface for the maximum transconductance. S25A, standardized as CV16, was introduced in 1941. It was followed by S28A, standardized as CV88 and usable up to 1 GHz, and by the simplified design S26A or CV53, suitable for receivers operating at 200 MHz. CV82 was a variant of CV53 with internal feedback loop introduced to operate as oscillator. Other popular UHF tubes were the NR88 tiny triode and the CV58 planar diode, usable as mixer up to 1 GHz. UHF power diodes, as the CV8 and later the CV94, were developed for use as TR switches.

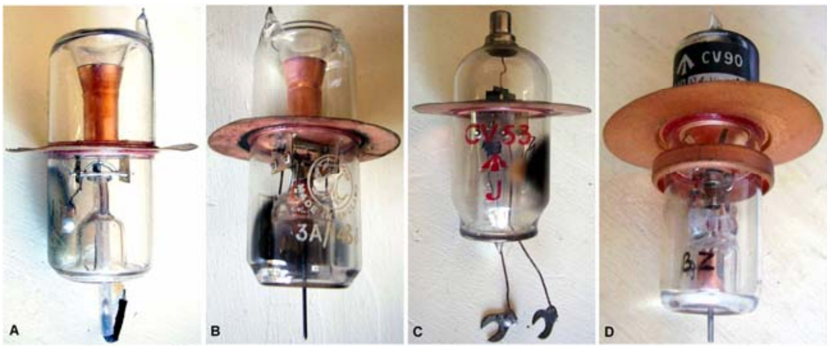


**Fig. 2 - Samples of British planar receiving tubes. A) CV16 early planar triode. B) CV88 was designed to operate up to 600 MHz. C) CV53 was a simplified variant usable up to 400 MHz. D) CV90 was capable of operation up to 3 GHz. It was the forerunner of 'rocket' tubes, so called for their shapes. Click to enlarge.**

# US ground and naval systems

One of early US radar set, operative by May 1937, was the SCR-268, designed at the Signal Corps Laboratories, Fort Monmouth, New Jersey. Intended as aircraft warning and searchlight director it operated at 205 MHz, the transmitter generating 75 kW pulses. This exceptional result, requiring current emission in the order of 10 A, was obtained using 16 special tubes connected in a ring oscillator, to prevent the parallel of input and output capacitances. More or less in the same days US Navy started testing its own 'XAF' 200 MHz prototype. XAF evolved in the CXAM, intended for battleships and carriers, and in the simpler SC and SK used in small vessels.

Special tubes were designed for the transmitting sections. As general rule American designers did not use external copper anode, as British did. They preferred small structures with tantalum anodes, capable of operating also as getters at cherry red temperature, in compact hard-glass bulbs. Sometimes grids were made of platinum, to prevent emission under high-power pulses. Early types, derived from the electrode assembly of the transmitting type 100T, were characterized by side grid and anode double connections. The collection includes an undocumented sample of an early 227, replaced by the 227A and used in SC-1 and SK systems. There is a rare sample of 327A used in SC-2, in the early version with platinum grid and single top plate contact. Available samples of 127A, also known as VT-127A and used in SCR-268, and a sample of the powerful VHF triode 527A capable of 60 A emission.

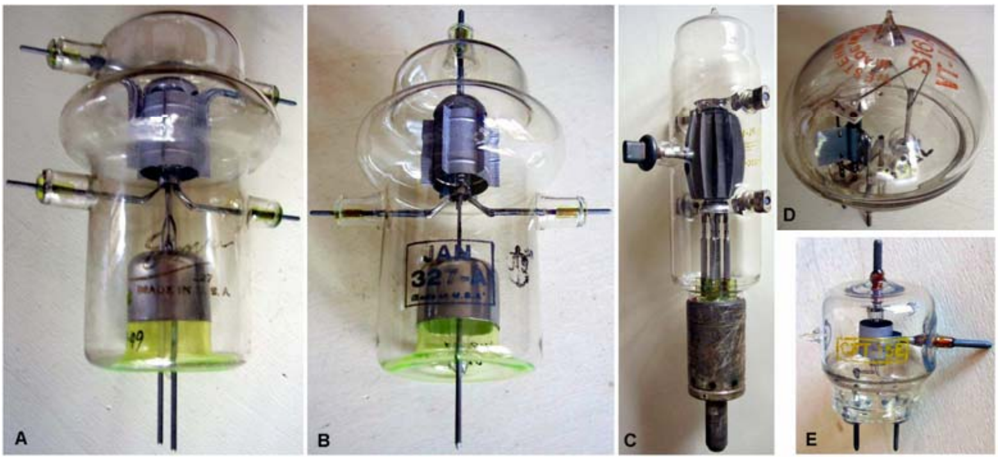


**Fig. 3 - American VHF/UHF transmitting triodes. A) 227, as the little brother 53A, has double grid and plate side pins. B) In the 327A plate has a single top contact. C) The powerful 527A is 13-inch high. D) 316A was the first doorknob, also used in the early British AI prototypes. E) 15E could operate at 500 MHz. Click to enlarge.**

To better detect ghost echoes, the anode voltage of ring oscillators was usually pulsed at variable pulse repetition rate, around 4098 pps, and pulse duration from 3 to 9 microseconds. One of most common pulser tube was the 304TL, eight tubes being operated in parallel in the SCR-268. Six 100THs were used in the prototype of the CXAS modulator, replaced in the successive production by six WE 356As.

Low-frequency radars were mainly intended to operate as early warning and searchlight director sets, or even to operate as precision range finders in fire control. Nevertheless higher frequencies were required for radar to give accurate angular data from the antenna array, replacing optical range finders. The highest frequency possible in 1938 was somewhere between 500 and 700 MHz. The CXAS prototype used four giant doorknob tubes, likely derived from 388A, in the RF section to generate 2 kW pulses. Two 388As were used in the driver stage. About ten units of CXAS were built coded as Mark 1. But just in those days Western Electric had been involved in the design and production of British E.1189 multi-cavity magnetrons. The radar design was soon converted to the use of the early magnetron designed by WE, the 700A.

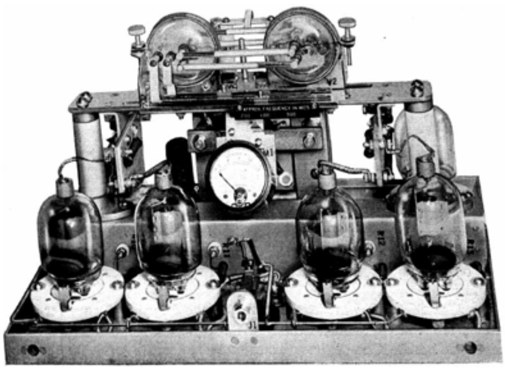

**Fig. 4 - The transmitter module of CXAS. Click to enlarge.**

Moving to airborne ASV and AI sets, as said before US bought some 18,000 units made to British designs. In addition to these other sets were designed to be installed on lighter airplanes. US Navy ASB used four 15E triodes in the ring oscillator of its transmitter operating at 500 MHz.

In the receiving section UHF vacuum tubes as acorns were used whenever possible as amplifiers and mixer. Special tubes were also introduced to enhance the receiver front-end. Among these we see the secondary emission hexode designed by RCA for the receiver of the SCR-270 radar. Samples of giant acorn 1630 and of a rare early prototype, plus samples of the early secondary emission amplifier EFP60 are available in the collection. Other innovative UHF tubes were the lighthouse planar types introduced by General Electric, as 446A, 2C40A and other types.

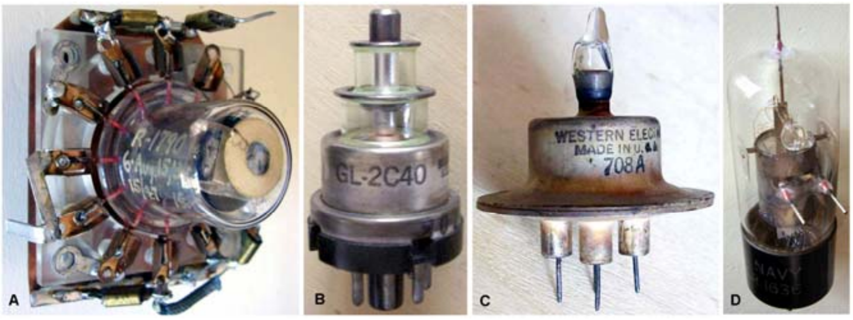


**Fig.5 - VHF/UHF amplifier tubes. A) R-1790 is an early prototype of the 1630 'giant acorn'. B) 2C40 is one of the lighthouse planar tubes. C) WE 708A was designed to operate as UHF grounded-grid amplifier. D) 1636 was a beam-deflection heptode intended as mixer at 600 MHz. Click to enlarge.**

Vacuum tube mixers were capable of withstanding high-energy pulses coming from the transmitter, provided that suitable lengths of transmission lines were inserted, to result in high-impedance input when the grid was driven positive by the signal.

British and American solutions differ considerably in many respects and almost always the British ones look more elegant, advanced and efficient. American UHF receiving tubes were based upon miniaturized electrode assemblies, as the acorn 955 or the WE 384A. The best ones available in 1940 probably were the RCA 1630 and the WE 708A. A quite wide family of UHF triodes with planar electrodes, forerunner of the many planar devices listed in the UHF section of the catalog, were developed at the British STC from 1939.

American VHF/UHF transmitting tubes were usually characterized for their hard glass bulb, hence for a preponderance of radiation-cooling, and for their filamentary cathode. Only at the very beginning British followed similar guidelines, with their silica bulbs and attempts to build their own variants of WE doorknobs. By 1938 GEC had developed the external anode VT58, replaced by the improved VT98 in 1939, which outperformed most of the previous tubes. By 1939 other compact transmitting triodes were introduced by GEC: the micropup family, among which the VT90 and the NT99, soon followed by milli-micropup triodes, as the CV55, capable of operation at 1200 MHz. Micropup triodes reached some popularity in America and were manufactured by several firms, as RCA, Amperex, National Union, WE and by Canadian Rogers for REL. Even some proprietary deviced were developed by these firms. It is the case of RCA 4C28, designed for their SHORAN navigation system, or of the National Union 3C37 or even of the REL 4C29. Due to their heavy external radiator and hence to their intrinsic capability of withstanding impedance mismatches, RCA proposed some micropup triodes even for industrial heating, as the 6C24 or the 8014A.

# German tubes for radar sets

German radar sets were more or less similar as per performances and operating frequencies to British and American pre-war types. Frequencies from about 110 to about 600 MHz were used through the war, the highest ones being approximately the upper limit of space-charge power triodes not using planar electrodes. Anyway we see the lack of evolution of German vacuum tubes during the war, probably because of the severe shortage of many strategic materials. Some high-frequency tubes were derived from pre-war American designs, as acorns or doorknobs. A jumbo doorknob, the TS6, was designed for the Seetakt sets operating under 400 MHz.

The collection includes some German and Japanese power triodes capable of operation up to UHF region, to appreciate their internal structure. Usually heat is dissipated by radiation from darkened or finned anodes. Electrodes are short, about 1 cm, closely spaced. Construction details can be appreciated in the LD5 and LD15 smaller triodes and in the higher power LS180, used in the transmitter of Würzburg radar. See also the external anode Toshiba RT-323.

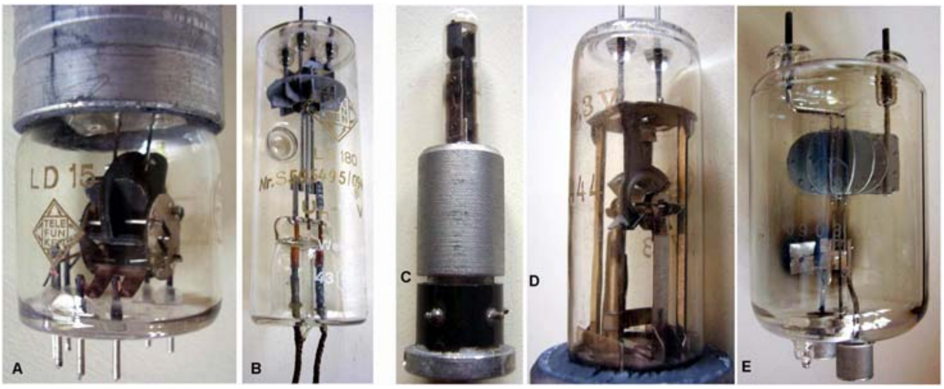


**Fig. 6 - Samples of German high-frequency tubes, all with internal anode. A) LD15 is a medium power triode generating 2.5 kW pulse power. B) LS180 was used in the Würzburg radar, 8 kW peak. C) RD2Mh magnetron was used in microwave generators. D) RD4Mh magnetron, used in communication links. E) T-310 is a Japanese triode quite similar to the German LS180. Click to enlarge**

# Microwave radars, UK

The need for smaller antenna arrays to be easily installed on aircraft pushed the research for powerful sources of RF pulses at frequencies higher than those obtainable from space charge triodes. Around 1937 in America Varian brothers were already working at Stanford University on linear beam klystrons capable of generating continuous signals of about 25 W around 3 GHz for a blind landing system financed by Sperry. One of these early klystron devices is on display in the collection. A couple of years later Randall and Boot were working at the Birmingham University at the development of a multicavity magnetron. In February 1940 a six-cavity prototype generated RF bursts of about 500 W at 3 GHz. The design of the prototype was improved by GEC, resulting in the first experimental type E1188, followed by the improved E1189, modified to indirect-heated oxide-coated cathode and soon later to eight-cavity anode. **The very first eight-cavity E-1189 prototype, presumably operated at GEC by the end of July 1940**, is on display in the collection.

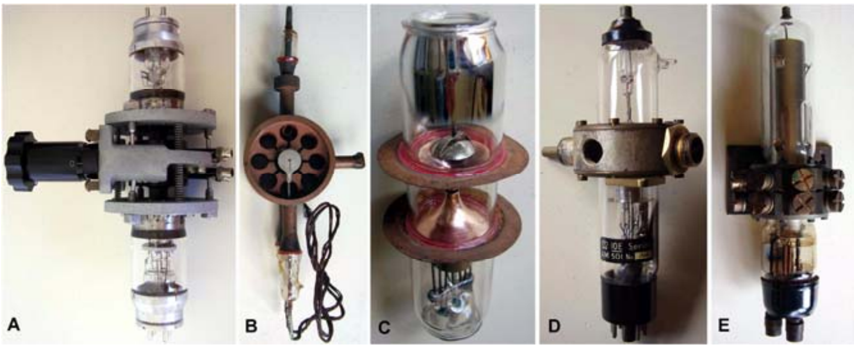


**Fig. 7 - A) An early Sperry klystron prototype about 1939. B) E-1189 prototype, very early 8-cavity magnetron, believed to be made in July 1940. C) 'Sutton tube' klystron prototype, about mid 1940. D) NR89 also coded as 10E/501 is the same klystron complete of cavity. End 1940. E) CV150 the only pulsed power klystron designed during WWII, 1942. Click to enlarge.**

E-1189 was approved early in 1941 as NT98, Admiralty Pattern W 2510, originating four frequency selections which included NT98C and NT98D. The variant for airborne radar sets was the NT89, approved as CV38. The E-1189 No. 12, brought to America in August 1940 by the Tizard Mission, gave origin to the many US and Canadian magnetron families. We will see later the US derivatives of this early magnetron sample. The sample was eventually left in Canada, originating productions fully interchangeable with British ones, REL 3D equivalent to NT98 and REL 3C equivalent to CV38.

As local oscillator in the receiver a reflex klystron was designed by Robert Sutton at Admiralty Signal Establishment, Bristol, with the support of the Clarendon University, on the information made available one year before at Stanford for the early klystron developed by the Varian brothers. The 'Sutton tube' was completed with the external cavity by the late 1940 and approved as NR89, AM reference 10E/501. A direct derivative of NR89 was the Canadian REL Type 8, with four frequency selections (A to D), external shield and 4-pin base. The collection includes samples of 8B. NR89 operated at very high resonator voltage, about 1700 volts, and since June 1941 it was replaced by the improved CV35 and its frequency variant CV67, both operating at 1200 V.

A very unique device was the CV150, a power klystron capable of pulsed operation in the S-band with peak output pulses in the order of 10 kW. This device was developed by EMI as PK150, around the late 1942 and the first half of 1943, under a contract for delivering 50 modified H2S radar sets to the Bomber Command. The order was canceled during the early test flights, even because of the death of the EMI design team in the crash of one of the two Halifax used for test. One of the rare samples of this klystron is in the collection.

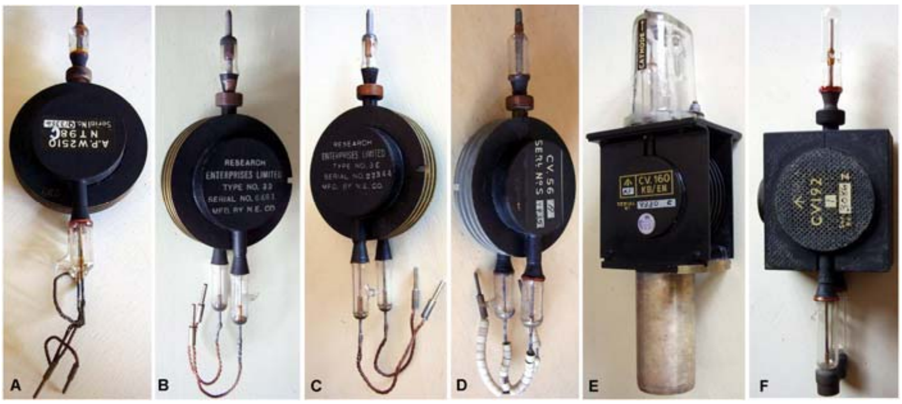


**Fig. 8 - Samples of early British S-band magnetrons. A) NT98 was the first operative magnetron from mid 1941. B) and C) Samples of Canadian REL 3D and 3C, equivalents to NT98 and CV38 respectively. D) CV56 was the first strapped version of NT98. E) CV160 was a high power variant of CV56. F) CV192 was convection-cooled through the heavy copper body. Click to enlarge.**

Back to the magnetrons, early S-band (10 cm) 8-cavity types could be safely operated at output peak power levels not exceeding about 10 kW. This because of possible mode jumping during the anode voltage build-up. The strapping technique, devised in July 1941 by Sayers at Birmingham University, overcame such a problem, forcing magnetrons to stay locked on oscillations in 'π' mode. At least a tenfold power increase was obtained by strapped magnetrons. Actually there was a delay until about the end of 1941 in their use, because of the need for new components in modulators and antenna duplexers capable of handling peak power levels in the order of hundreds of kilowatts. A sample of strapped prototype, likely built by the group of Sayers, is on display.

Among the British strapped magnetrons, CV56 and its frequency selections CV56A, CV56B, CV56C and CV56D replaced the NT98 family in the Type 271 naval radar, raising the minimum output power from 5 kW to 80 kW. Early in 1942 the unstrapped CV38 was replaced by CV64, the first magnetron using the echelon strapping technique, visible in this sample of CV160. With the old modulator CV 64 was capable of generating 40 kW peak power pulses, just because of its higher efficiency. When in October 1942 a new modulator became available based upon CV85 trigatron spark gap, the input power could be safely raised to 160 kW.

In 1941 the NR89 klystron evolved to the more stable CV35 and its frequency variants. In the same year, when early samples of WE 707A were made available, EMI launched a complete redesign of the S-band klystron which led to the very compact family including CV237 and CV238. A sample of a transition prototype, the 10AL1, is on display in the collection.

A high-power variant of CV64 was the CV192, one of the few magnetrons cooled by conduction. CV192 was used inside a pressurized enclosure in the airborne H2S radar set. It was necessary the development of a new trigatron switch, the CV125, to drive the magnetron at its typical 200 kW output power. Another high-power variant was the CV76, capable of handling 1 MW input pulses, was used in the Type 277 early warning ground radar. It was replaced by CV160, characterized by glass protective boot on heater stems.

Vacuum tubes were used in early radar sets to generate high-voltage pulses for modulating the transmitter. With power increase made possible by magnetrons, the more efficient solution to switch tens of amperes at tens of kilovolts was the use of sealed spark gaps, discharging a line former across the magnetron. British spark gaps were characterized by the presence of a third trigger electrode, hence the term 'trigatron'. Composition and pressure of filling atmosphere for each type was optimized to match the voltage, current and pulse characteristics of given magnetron family and application. The collection includes several trigatron samples in addition to the two said before.

To protect the point-contact silicon mixers, normally used in microwave receivers, against burn-out during the transmitter pulses, special switch devices were developed. In these devices, referred to as TR switches, the filling atmosphere must ionize under the energy of RF pulses, creating in the duplexer a momentary open path from antenna to receiver. The first TR cell was the CV43 derived from the resonators of an NR89 Sutton tube filled with low-pressure water vapour. CV43 could be used up to about 50 kW peak pulses. Other types were developed to operate with higher power pulses, as the CV193 capable of handling 100 kW. Above these levels a pre-TR was needed.

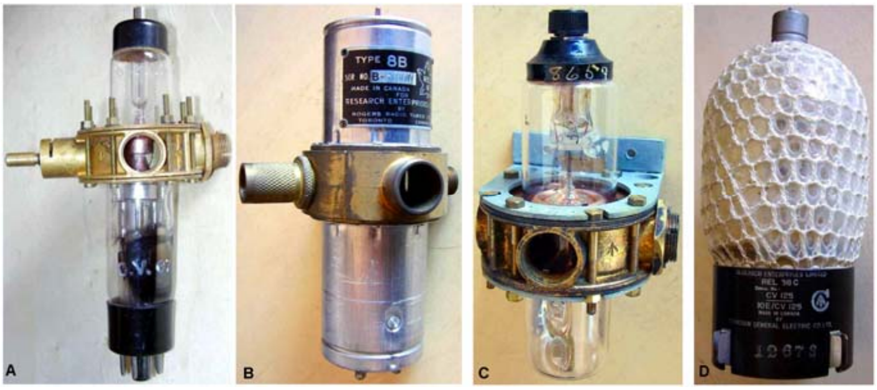


**Fig. 9 - A) CV67 is an early S-band reflex klystron. B) This Canadian REL Type 8B looks to be directly derived from the British early ‘Sutton’ klystron. C) CV43 was a TR switch designed using the resonators of the ‘Sutton’ klystron, hence the name ‘Soft Sutton tube’. D) This trigatron sample is double marked as REL 38C and CV125. Click to enlarge.**

## US S-Band development

The E1189 No.12 sample brought to America in 1940 by the Tizard mission gave a direct result with some tens of copies readied by Western Electric and Raytheon in a few weeks. Part of these copies were distributed to research centers and involved industries to let them familiarize with the new device. As said before volume productions of 3D and its variant 3C were launched from 1941 for REL by Canadian Northern Electric, sister company of Western Electric.

The two most active US companies involved in the development of multi-cavity magnetrons under the coordination of M.I.T Radiation Laboratory were Western Electric and Raytheon. As prime contractor for naval fire-control radar sets derived from CXAS, Western Electric had an immediate interest in a magnetron capable of replacing the several doorknob tubes in the transmitter. Their first product in the early 1941 was therefore the 700A to D family, capable of generating about 40 kW pulses around 700 MHz. To generate the input pulses Western Electric readily designed one of the first dedicated modulator tubes, the 701A which contains four electrode systems of 350A tetrode assembled into a cruciform anode. The TR tube for antenna duplexers operating at 700 MHz was the 702A. Following the example of the British ‘Soft Sutton tube’, the 702A was hastily designed using resonators of a linear klystrons similar to 402A. The 709A was another similar TR switch designed for slightly higher frequencies. Other WE components designed for early UHF radar service were the 704A diode, used as mixer or detector in measuring circuits, and the 705A high-voltage rectifier, a gridless 356A, soon accepted as an industry standard in radar modulator circuits. Even a special triode was introduced by WE, the 708A, intended for use as grounded-grid amplifier or mixer at frequencies in the order of 1 GHz.

WE magnetrons for wavelengths from 20 to 45 cm evolved in the 8-cavity fixed frequency families as the 728A to J, soon replaced by tunable types, as 5J26.

Moving to S-band magnetrons, early WE production through 1941 was very similar to the British E1189 prototype, just differing for added mounting brackets. Collection includes samples of the early 706 and of the frequency variant 714 families.

Late in 1941 WE also developed its own early reflex klystron to be used as local oscillator in the receiver, the 707A. It was a disc-sealed type, resembling the British shape. But, despite it was hastily designed, it was capable of operating at only 300 V resonator voltage. Quite soon 707A was replaced by the improved 707B.

The mixer was a point-contact silicon diode, as proposed by British. The collection includes several samples of early Western Electric ones. The TR switch for S-band duplexers was the 721A.

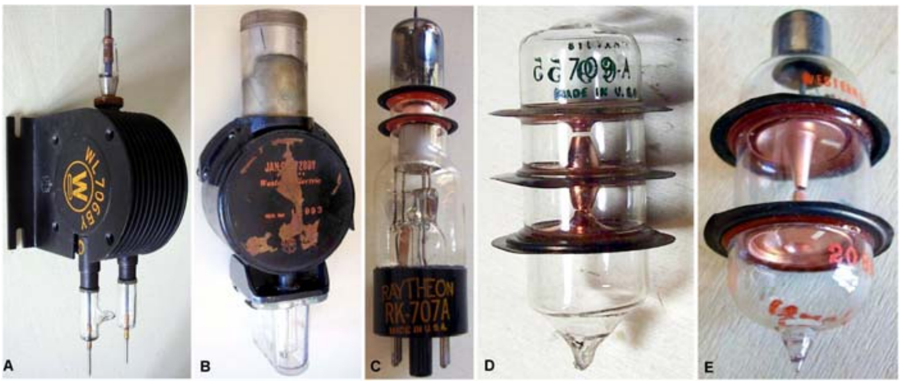


**Fig. 10 - Early radar tubes developed by Western Electric. A) 706 family was the first WE S-band design. Y suffix indicates the strapped version. B) 728 family was designed to operate around 900 MHz. C) 707A was the first S-band klystron. D) 709A was an UHF TR switch. E) 721A was the S-band TR. Click to enlarge.**

The input pulses to magnetron were generated by hard tube modulators, usually transmitting triodes or tetrodes modified for high voltage blocking capability and for high emission. Depending upon the magnetron power, several tubes were designed, as 3D21, 3E29, 715A, 5D21, 6C21 and even the 527A. Mainly in airborne applications spark gaps were used to increase efficiency. The collection includes samples of WE 1B22, 1B29 and of the mercury type 1B42. Also included some Westinghouse design types, as the 1B45 and the BL-735. High efficiency hydrogen thyratron were introduced capable of fast turnoff and quite soon they replaced any other devices in radar modulator circuits. The early types were the 3C45, the 4C35 and the 5C22.

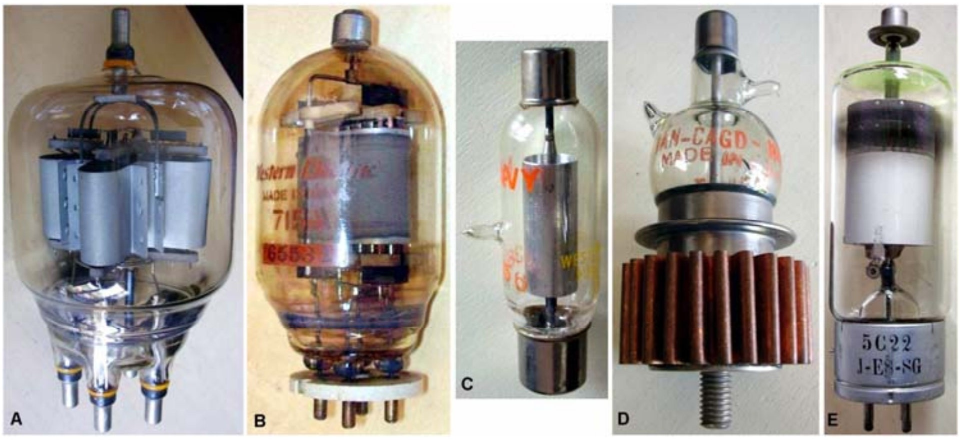


**Fig. 11 - Different tubes used in radar pulse modulators. A) WE 701A power tetrode is formed by four electrode assemblies of 350A in a single cruciform plate. B) WE 715A is the evolution of 701A, with quad-in-line cathodes in a much smaller bulb. C) WE 1B22 is an argon-hydrogen filled spark gap used in airborne radar sets. D) The WE 1B42 was capable of switching 300 A to its iron sponge filled with mercury. E) 5C22 was one of the early hydrogen thyratrons. Click to enlarge.**

Raytheon was the largest supplier of microwave tubes during the war. Original British design was deeply revised to improve overall performance and to simplify every production process. Raytheon introduced simpler sealing processes, also devising alternate manufacture of anode blocks, by silver brazing a pile of die-cut copper rings instead of machining a single copper block. As result Raytheon was capable of manufacturing about 2400 magnetrons per day. This figure can be better understood considering that the entire 1942 production of NT98 by GEC and BTH was of about 2000 units. Raytheon built some eighty percent of the entire magnetron production during the war and designed or industrialized countless new types and even entire families.

Among the production of S-band magnetrons the collection includes samples of proprietary design 2J22 and of 2J27. Low power types intended for beacons include 2J38 and 2J39. Other types were the mechanically tunable 2J61 and 2J62, which replaced groups of fixed frequency 706A to J. Other low-power tunable magnetrons were developed for use in radar jammers, as 4J61 and 4J63. High-power S-band magnetrons are represented by the 4J35.

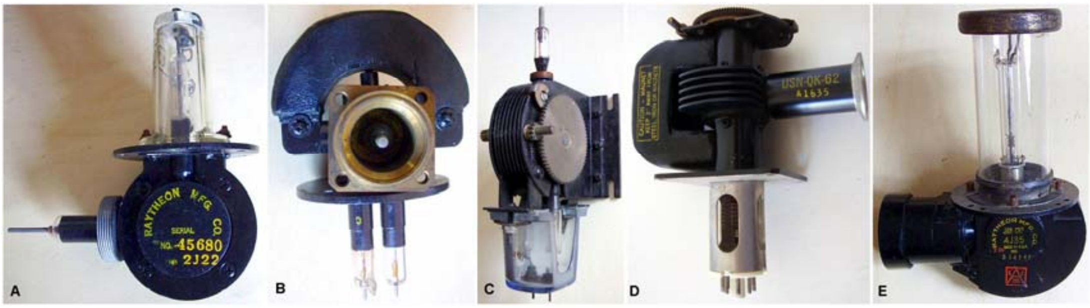


**Fig. 12 - Raytheon S-band magnetrons. A) 2J22 was one of the early types derived from original British designs. B) 2J39 was a low-power type for beacon applications. C) 2J61 and 2J62 tunable types replaced the entire WE 706 family. D) QK62 / 4J63 was a tunable CW magnetron used in radar jammers. E) 4J35 was a high-power type capable of generating 750 kW pulses. Click to enlarge.**

# General Electric CW magnetron developments

The research for improved radar performance was parallel with the development of electronic countermeasures against German radars. Under the technical direction of Radio Research Laboratory at the Harvard University, General Electric designed a family of split-anode continuous wave magnetrons covering the frequency spectrum of known German emissions, from about 100 MHz to about 1.2 GHz.

The collection includes the four types entered in volume production, 5J29, 5J30, 5J32 and 5J33, plus an unregistered type ZP-599.

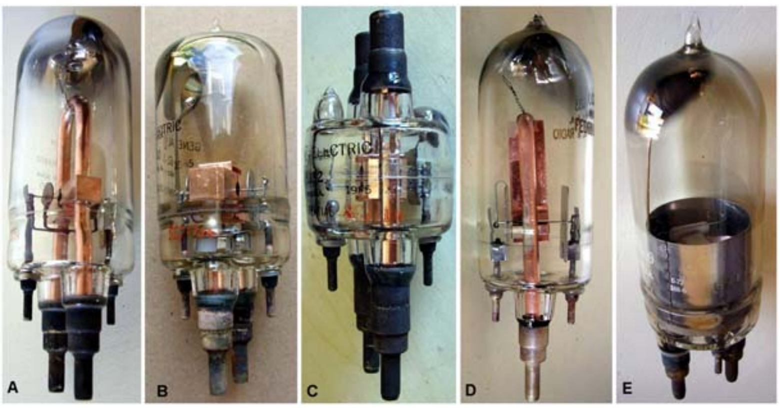


**Fig.13 - General Electric CW magnetrons. From left 5J29, 5J30, 5J32, 5J33 and ZP-599. Click to enlarge.**

# X-Band Developments

The development of X-band components, magnetrons, klystrons, TR switches and mixers started both in England and in US quite early in 1941, as soon as production details of S-band components had been released to manufacturers. An early magnetron prototype was tested at MIT in summer 1941 and later in the same year the 12-slot unstrapped 2J21 was in production, soon replaced by a more stable 2J21A. Raytheon introduced a frequency variant, the 2J36, which became very successful in short range, precision approach radars. In 1942 Western Electric designed its own X-band magnetron, the 725A. It was a strapped type well outperforming the 2J21 and making it soon obsolete. 725A was manufactured in hundreds of thousands of units, over than 90.000 pieces being delivered to Britain under the Lend and Lease Act.

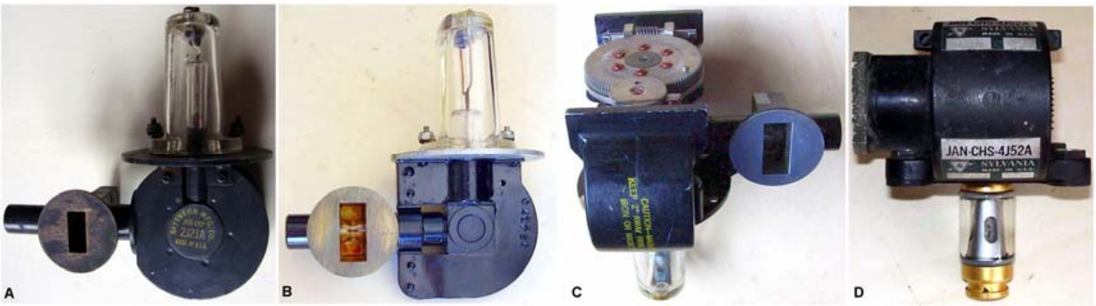


**Fig. 14 - US X-band magnetrons. A) 2J21 was the very early X-band magnetron, already in 1941. B) 725A was a true workhorse, with about 300.000 units built in WWII. C) 2J51A was a tunable packaged variant designed by Western Electric. D) 4J52 was a higher power packaged variant. Click to enlarge.**

725A gave origin to several variants, many of them as usual by Raytheon. 730A was a WE variant with waveguide flange rotated 90 degrees. 2J49 and 2J50 were simple frequency variants. A considerable departure from the basic design was the 2J51A, a mechanically tunable packaged (complete with its magnet) device which was designed to be fully interchangeable with 725A or even to be driven at higher power levels, by adding or removing magnetic shunts. Even 2J51A gave origin to variants, as the fixed frequency types 2J55 and 2J56. More powerful types were also developed, as the packaged 4J52.

As local oscillator the 723A klystron developed by Western Electric to match with the fixed-frequency 725A was soon accepted for its simple construction and its overall performances. When tunable magnetrons appeared, 723A was replaced by its variant 723A/B with extended tuning range. 723A/B was eventually superseded by the improved 2K25 which became an industry standard at least until the sixties.

Western Electric also supplied its TR switches, the 724A and then the improved 724B, some samples being displayed with their waveguide mounting. Soon other types, more reliable due to their gas reservoir and easier to use, were preferred, as the 1B24, the 1B35, the 1B37 and later the 1B63 and other types.

For a while British worked to their own X-band types, with an early unstrapped CV108. When they received design details of 725A, CV108 was readily replaced by the strapped CV208 by GEC and CV209 by BTH. CV208 was later modified to be fully compatible with CV209 and was also followed by the CV214, with integral waveguide flanged transition. X-band klystrons, CV129 and the improved CV217 were by far more complex than the American 723A/B or 2K25. The British development was slowed down when US started to delivery massive quantities of their H2X AN/APS-15 version of the British X-band H2S.

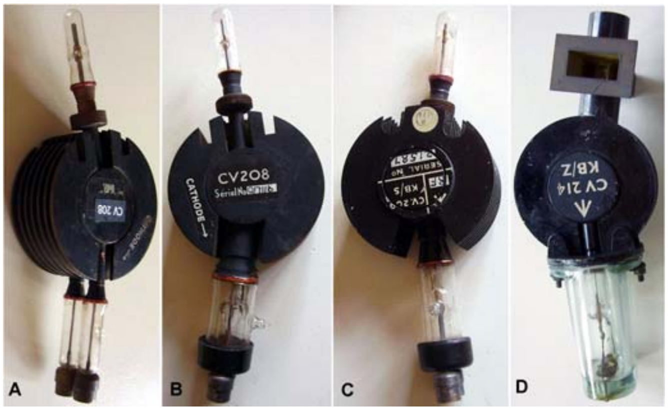


**Fig. 14b - Early British X-band magnetrons. A, B) Double and single stem versions of GEC CV208. C) BTH developed its MX57 approved as CV209. D) CV214 is an evolution for Naval radar. Click to enlarge.**

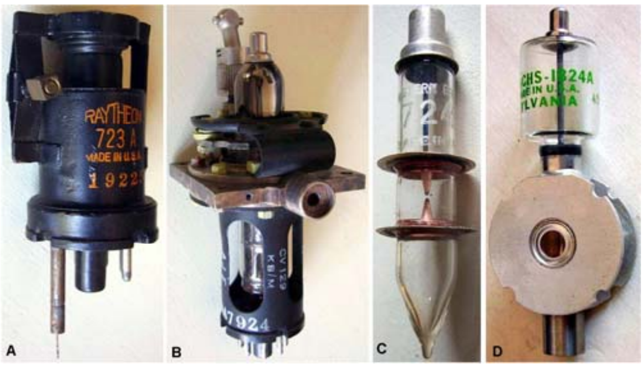


**Fig. 15 - Components for X-band. A) WE 723A was the forerunner of the industry standard 2K25. B) British CV129 was by far more complex. C) WE 724A TR switch was quite soon superseded by the tunable 1B24A (D). Click to enlarge.**

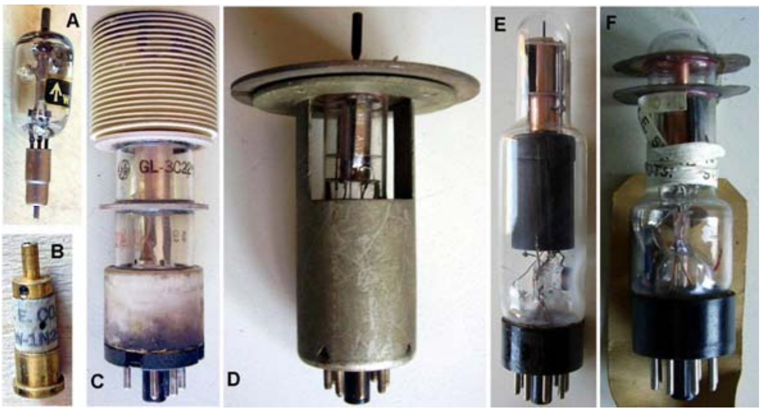


**Fig. 16 - More components related to early radar developments. A) CV58, a small diode with 0.05 mm anode-to-cathode spacing, was used as mixer up to about 1 GHz. B) Silicon point contact diode cartridges were used at higher frequencies. C) 3C22 was a power lighthouse style triode used in ECM transmitters. D, E, F) Heil oscillators, as CV230, DV27 and DV57, operating respectively on UHF, S and X bands, likely designed as local oscillators, abandoned in favor of klystron for their noise and later experimented in radar jammers. Click on the image to enlarge.**

## K-Band developments

Basically the research for K-band components started in 1942, but K-band radars were not widely diffused during the war. Today the collection includes just klystrons and TR switches of the early components developed. There are samples of 2K33 and of improved types 2K33A and 2K33B, developed at Raytheon from a Clarendon design, plus the electronically tunable 2K50, a fine Western Electric design. A 1B26 TR is also available. Other devices from Raytheon, EMI, Sperry and other manufacturers, as well as Heil oscillator, klystron, magnetron, TWT/BWO and VTM families were introduced later and are listed in their respective category index.

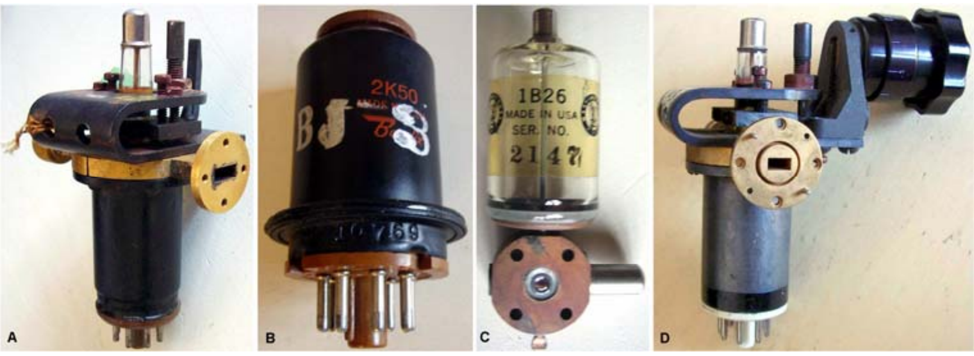


**Fig. 16 - Tubes developed for the K-band. A) 2K33 was manufactured by Raytheon, starting from a design developed at Clarendon University. B) 2K50 was a fine WE design using electronic tuning. C) 1B26 TR switch was a scaled down 1B24. D) This QK291 was one of the many frequency variants of 2K33. Click to enlarge.**

## Germany and development of VM devices

Few researches were carried out in Germany on velocity modulated tubes other than a few low-power interdigital magnetrons. These devices were intended for microwave links and sometimes in instrumentation or electronic countermeasures, instead of then unavailable klystron technologies. Quite late in the war Germany learned of British multi-cavity magnetron from captured aircraft. The attempt to fill the gap failed, due to daily bombardments of industries and to the lack of strategic materials, as the cobalt for the magnets. The few microwave sets built before the end of the war used electromagnets to operate magnetrons.

The collection includes a few exceptional samples of German magnetrons, believed to be the only ones still surviving today.


**Fig. 16b - Rarest WWII German magnetrons. A) LMS 12 magnetron was used in the few units of Berlin-D, 3 cm set, made before the end of the war. B) The 1.65 cm LMS 13 was just in the evaluation phase, as the RM4025 in C. For more information refer to the article on German WWII magnetrons. Click to enlarge.**

## Radar related equipment: IFF and navigation systems

The use of radar gave origin to several related equipment. Here we want to give a look at some tubes derived from those developed for radar applications and specialized to operate in pulsed mode for beacons, IFF transponders and navigation systems. Among the others the collection includes samples of the following families:

- All-glass UHF, among which the 826, used in the transmitter BC-1072A of the RC-148 IFF transponder associated to SCR-268 radar set.
- Micropup triodes which include 3C27, 3C27B and 3C37, presumably used in some IFF transponders, and the British equivalents CV55, CV155 and CV178. Also on display we find 4C28, used in the SHORAN navigation system, a National Union B159 prototype and 4C29, a power triode registered to REL and used by Canadian Air Force.
- Lighthouse planar types developed at General Electric, including 2C42, 2C43, 2C46 and 3C22.
- Oil-can triodes, with the 2C39 which originated countless variants, many listed in the UHF section and in use well in the eighties.


**Fig. 17 - High-frequency transmitting tubes designed during WWII for pulsed operation in IFF or in navigation equipment. A) 826 was used in the IFF interrogator of SCR-268 radar. B) British CV155 'milli-micropup' could generate 40 kW pulses at 1200 MHz. C) National Union 3C27B was an American derivative of CV155, rated for 10 kW pulse power. D) RCA 4C28 was designed for the pulse transmitter sections of the SHORAN navigation system. E) 4C29 was registered to Canadian REL and used by Canadian Air Force. Click to enlarge.**

## Cathode ray tubes

The collection also includes a few samples of early CRTs used in radar displays during WWII. Most of them were characterized by long persistence screens to continuously display echo pulses. The British also set standards for CRTs. They introduced the long persistence screens for PPI presentation and even the dark trace screen forerunner of memory CRTs. Electrostatic focus and deflection were used in small CRTs, while magnetic deflection was preferred for larger screens, 5-inch or more.


**Fig. 18 - Typical radar CRT displays used P7 phosphor type, characterized by blue trace followed by yellow persistence. Probably 5FP7 was the most diffused 5-inch CRT through the war. This sample was built by Canadian REL. Click to enlarge.**

**Last edited March 2018 by Emilio Ciardiello**

**Go to Radar Tube Index**