6.3 - Velocity Modulated Tubes: Magnetron Tubes

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History and operating principles of magnetrons are given in the appendix C. The collection includes over 90 types of magnetrons, among which:

- **British S-band early pulse magnetrons, including the first GEC 8-cavity prototype.**
- **Early X-band magnetron types, British, US and German types.**
- **Other wartime pulse and CW magnetrons, including rarest German multi-cavity types.**
- **After-war magnetrons, including pulse, CW, FM, VTM types**

6.3.1 - British and Canadian S-band early pulse magnetrons.

- Left, the first GEC developmental prototype of 8-cavity E-1189, likely operated in July 1940, before the Tizard Mission even began. Right, E1189 was standardized by Admiralty as NT98 from 1941. Click to enlarge

GEC delivered its early prototype of the 10-cm multicavity power magnetron with oxide coated cathode and six cavities in June 1940, under the experimental code E1189. The design was modified to 8-cavity to operate more efficiently in the field of a standard 6 lbs magnet. In August 1940 the first production unit of the modified design, the sample No. 12, left GEC to be brought to America by the Tizard Mission. E1189 was used from 1941 in the transmitter of the Naval radar Type 271, standardized as NT98 and its Canadian equivalent **3D**. The same basic design was retained for the E1198, a frequency variant operating at 9.1 cm. E1198, intended airborne radar sets, was standardized as CV38 and as **3C** by Canadian REL.

The construction details of the sample brought to America by the Tizard Mission were disclosed to MIT Radiation Lab. and to vacuum tube industries, among which Western Electric and Raytheon. Both were asked to build copies of the submitted design in order to qualify alternate sources for military needs of Great Britain and even to spread samples through the research American centers involved in the development of radar. Eventually the sample No. 12 was left in Canada at REL, a productive branch of Canadian Research Council. The sample No. 12 originated then the many and many types appeared in US from the late 1940 and even the Canadian types. The response of American industries, coordinated by the MIT Radiation Lab., was impressive. Within few months Raytheon introduced so many changes and improvements to the original design and to the manufacturing processes to be able to reach the impressive production level of 2.400 magnetrons per day. Just to give an idea of how astonishing this figure can be, the entire production of NT98 and CV38 in England, by the two firms GEC and BTH, was of about 2000 units through the entire 1941. In the meanwhile Western Electric, already involved in the design of complete radar sets, introduced in 1941 a wide variety of types, ranging from 700 MHz to the S-band, being also involved in the development of higher frequency types.

Fixed tuning types were followed by tunable ones, to reduce handling of spare parts. Packaged magnetrons, complete with magnet, were introduced to facilitate field maintenance operations. Even due to the improvement of the strapping, first proposed in England by James Sayers, peak powers raised from the original 5 or 10 kW to hundreds of kilowatts or even to megawatts.

Canadian REL was directly involved in the production of NT98 and of CV38 as alternate source for the British manufacturers. They even used these magnetrons, respectively coded as 3D and 3C, in their own radar sets. Even if 3D and 3C are badged as REL their production was run outside by Northern Electric, the Canadian sister company of Western Electric. So the copies of the GEC E.1189, made by Western Electric in 1940, led to volume productions in Canada.

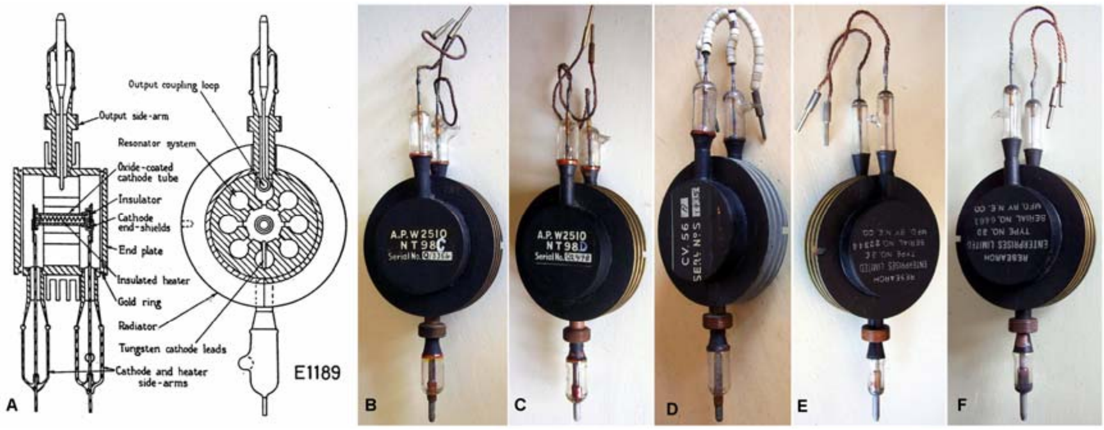

Fig. 6.3.2 - Early British and Canadian S-band magnetrons. A) Draft of the GEC E1189 eventually approved as A.P. W2501 or NT98. B) NT98 was the early multicavity magnetron used in the Naval radar Type 271. Early tests started in March 1941 on the battleship Orchis. NT98C was one of the available frequency selections, 2980 to 3005 MHz. B) NT98D is another frequency selection, 2940 to 2980 MHz. D) The strapped type CV56 began to replace NT98 from the end of 1941. By the introduction of this magnetron a tenfold increase of the pulse power, from about 10 kW to about 100 kW, was obtained. Collection also includes frequency selections CV56A, CV56B and CV56C. E) Canadian REL 3C, manufactured by Northern Electric, was equivalent to British CV38, used in airborne AI Mark VII radar. F) REL 3D was equivalent to NT98. (Click on image to enlarge)

6.3.2 - Early X-band magnetron types

Development of centimeter X-band magnetrons started before the summer of 1941 both in England, involving BTH and GEC under the supervision of Birmingham, and in America under the direction of MIT. The first American type to go into production was the 2J21, a twelve slot design. Developed with the support of M.I.T. by Westinghouse, 2J21 was quite unstable, operating in modes different from π one and generating about 15 kW with an efficiency lower than 15 per cent. It was used only in the airborne radar set AN/APS-3. Western Electric developed its 725A as plug replacement for 2J21. A special long-life cathode was devised, made by an oxide-impregnated nickel mesh welded on the surface of a nickel cylinder. Anode block contained twelve strapped resonators. Both vane-type and hole-and-slot type anodes were manufactured. 725A could generate typical pulses of 50 kW and up to 150 kW at low p.r.r., with efficiency as high as 50%. 725A became an industry standard with a production exceeding 250.000 units during the war, some 90.000 units being delivered to England and even to Russia under the Lend-Lease Act. 725A was also the forerunner of many variants, among which the 730A, 2J49 and 2J50.

The basic anode structure of 725A was retained in the development of the tunable X-band magnetron 2J51. This was a packaged magnetron, complete then with its magnet, designed to be compatible with 725A. Magnetic shunts were supplied to adapt 2J51 to different pulse voltage and current levels. 2J55 and 2J56 were fixed frequency variants of 2J51, retaining the packaged style and resulting much lighter than the 725A plus its associated magnet.

British developments proceeded in parallel with American ones. A first type with twelve slots went into production, selecting the best design among the ones submitted by GEC and BTH. The magnetron approved as CV108 was a 12-slot design, comparable as per performances to the 2J21.

Even if manufacturing of the slotted anode block was greatly simplified by the use of gear cutting tools, we can assume that production output from BTH and GEC could hardly cover in 1943 the demand, limited to few selected combat units then still experimenting X-band sets. In the meanwhile British firms which had received design details of WE 725A, BTH and GEC, started their own independent designs of strapped types. BTH delivered samples of its MX52 for tests since June 1943. Iron polepieces were added to operate as plug-in replacement for CV108 and this variant was approved as CV209. GEC completed the development of its E1487 in August 1943. The magnetron, operating with efficiency around 30%, was fitted with a single iron polepiece to operate in the same permanent magnet used for CV108. It was approved as CV208. Production started at the end of 1943, followed by the CV214 fitted with waveguide flange and glass boot on cathode stems as the 725A. Anyway thousands of American radar sets and about 90.000 units of 725A magnetrons were already on their way to London under the Lend and Lease Act.

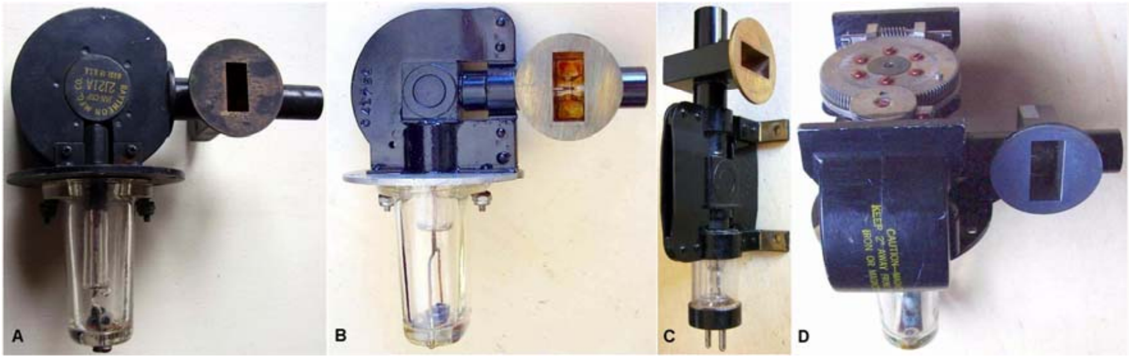

Fig. 6.3.3 - The development of X-band magnetron in US. A) 2J21 and 2J21A were the first unstrapped X-band magnetrons. B) The strapped Western Electric 725A was the most successful type, with almost 300.000 units manufactured only during the war. Its design originated several variants. C) 730A was a mechanical variant of 725A, with cathode leads rotated by 90 degrees and with a bi-pin base. D) 2J51 was the tunable and packaged version of 725A. It also originated fixed-frequency variants, as 2J55 and 2J56. (Click to enlarge)

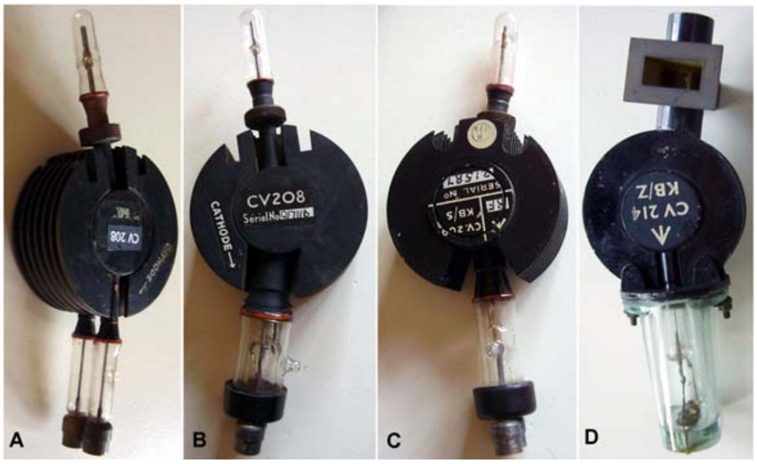

Fig. 6.3.3A - British X-band magnetrons. A) Early samples of GEC CV208, about August 1943, were characterized by double stem connections to heater. B) The single stem CV208 was interchangeable with the BTH CV209 (C) and both could replace the quasi-experimental unstrapped CV108. D) CV214 was a variant of CV208 with glass boot and waveguide interface, used in Naval radar sets. (Click to enlarge)

6.3.3 - Other wartime pulse and CW magnetrons

The rapid diffusion of radar applications during WWII led to the development of many CW and pulse magnetron designs, for frequencies from hundreds megacycles to more than twenty gigahertz and for output powers up to megawatts. Germany developed small power CW magnetrons as microwave oscillators instead of klystrons in communication equipment or instrumentation. They learned of the British magnetron from a captured set and designed their multi-cavity magnetrons too late to use them out of experimental sets. The collection includes some extremely rare samples.

Fig. 6.3.4 - Three German magnetrons in excellent conditions are the rarest of the whole collection. A) One extremely rare sample of the X-band 12-cavity LMS 12, used in the very late Berlin D radar sets. Only few tens of units made before the end of war. D) The 18 GHz version LMS 13 remained in the evaluation stage. This is the only sample still intact to survive. E) Even more rare this RM 4025, a split-anode self-contained-resonator pulse magnetron in a developmental stage at Siemens. 5 kW pulses at 10 GHz. (Click to enlarge)

6.3.3A - CW magnetrons

Here we find some samples of low power British and German split-anode magnetrons. Some were used approximately from the mid thirties in early experiments on microwave propagation or radio-localization. Other were designed for microwave instrumentation or communication equipment.

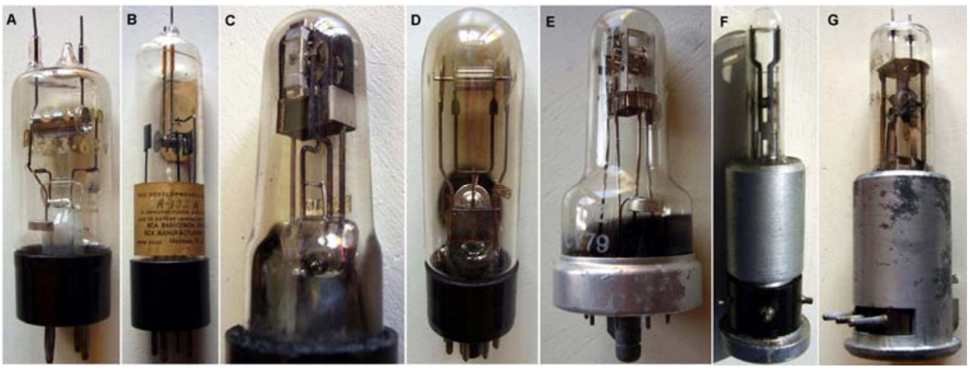

Fig. 6.3.5A - Low-power CW magnetrons. In these tubes anode is split in two half sections or even in fingers, alternately connected to one of them. A) British CW10 is a rare split-anode magnetron which can be dated around 1935. Used in the very early experiments on UHF radio-localization. B) RCA A-103A is a very rare prototype of split-anode magnetron with self-contained resonator, operating around 3 GHz. C) GEC interdigital 8-segment prototype. D) 12-segment GEC interdigital prototype. E) CV79 was one of the British interdigital types in production late in the war for use in a microwave relay system. F) German RD2Mh was a small-power magnetron, 300 mW around 5 GHz, used in microwave test generators. G) German RD4Ma delivered 12 to 15 W at frequencies around 1.5 GHz. It was used in a microwave communication link. (Click on image to enlarge)

6.3.3B - Power split-anode magnetrons

Early split-anode types gave origin during the war to improved designs, with build-in sections of the resonant line. They were used in ECM equipment intended to VHF and UHF radars. Capable of generating hundreds of watts at frequencies up to about 1.000 MHz, they were developed during the war by the Radio Research Laboratory of Harvard University together with General Electric.

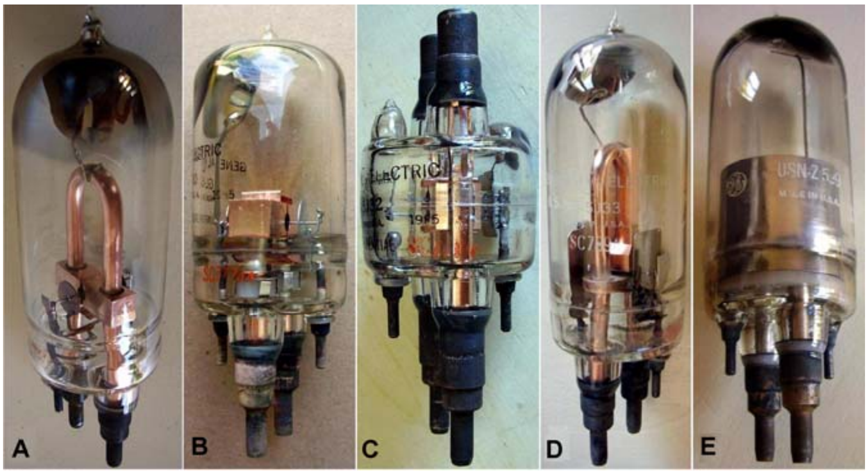

Fig. 6.3.5B - During the war split-anode magnetrons originated a line of liquid-cooled CW devices used to jam VHF and UHF German radar emissions. They were so secret that their classification 'Secret' was etched on the bulb. A) 5J29 could be tuned by an external line between 350 and 770 MHz. B) 5J30 could oscillate between 150 and 385 MHz. C) 5J32 was mounted in the middle of the resonating line, 350 to 750 MHz. D) 5J33 had a third anode tied to the center of the resonator, 750 to 1150 MHz. E) ZP-599 has an internal shield, 90 to 300 MHz. (Click on image to enlarge)

6.3.4 - Other magnetrons

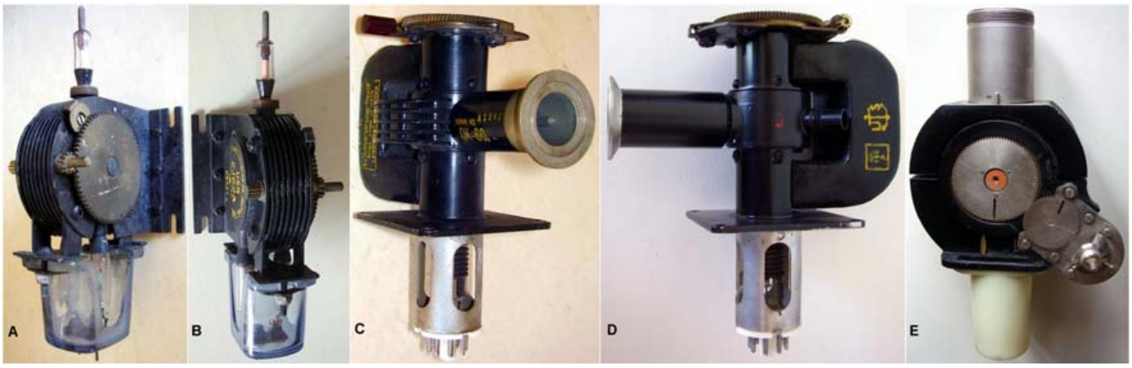

Fig. 6.3.6 - A selection of American wartime tunable magnetrons. A) 2J61 and B) 2J62 were tunable pulse magnetrons intended to replace the entire family of S-band fixed frequency types 706AY to 706GY. C) QK60 / 4J61 and D) QK62 / 4J63 were tunable CW magnetrons used in radar jammers. E) 5J26, a 700 kW L-band pulse magnetron, was designed to replace a family of fixed frequency types, 4J21 to 4J30 and was still in use some sixty years later. (Click on image to enlarge)

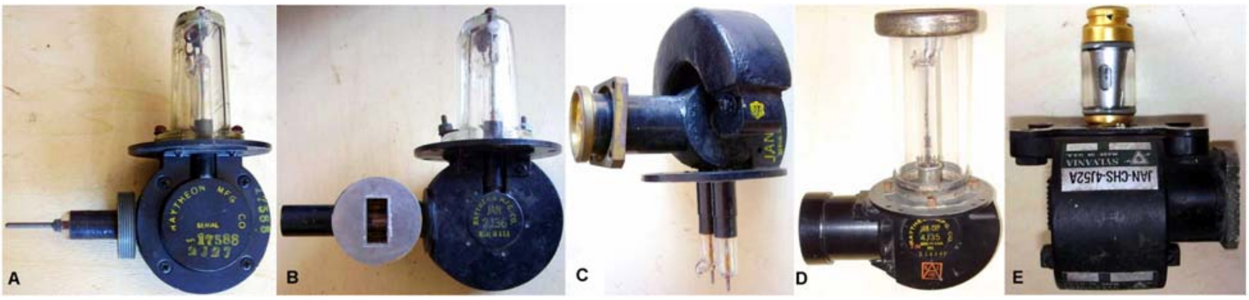

Fig. 6.3.6A - Wartime pulsed magnetrons. A) The Raytheon family [2J22 to 2J29](#) was derived from the original British design, rotating by 90° the coaxial output. Raytheon also greatly simplified the manufacture of precision cavities into the copper anode block, by die-cutting anode segments from copper foil and then silver-brazing several discs within a support template, to obtain the wanted anode thickness. B) [2J36](#) was a still unstrapped Raytheon variant of the early X-band 2J21. C) [2J39](#) and the similar [2J38](#) were small power, under 10 kW, pulse magnetrons for radar beacons. D) Conversely [4J35](#) was one of the most powerful S-band magnetron, 750 kW typical. E) [4J52A](#) was a packaged replacement for 725A, giving about 100 kW pulses. (Click on image to enlarge)

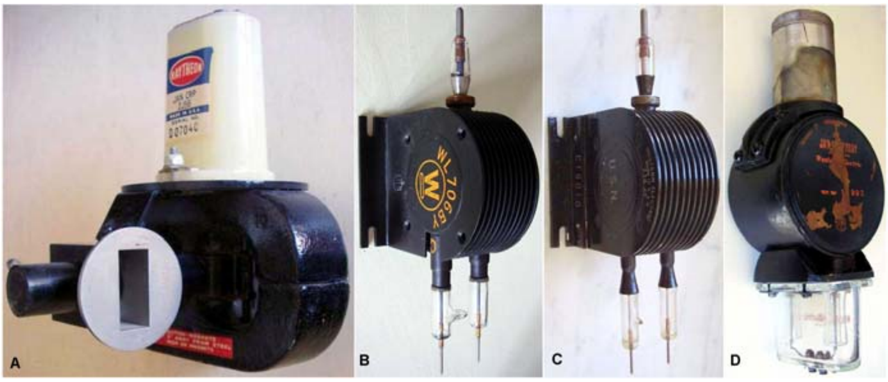

Fig. 6.3.6B - American wartime pulsed magnetrons. A) [2J55](#) and [2J56](#) in the photo were fixed frequency variants of 2J51. Weight of these types was of about 1.6 kg compared with the 5 kg of 725A and the external magnet. B) and C) The early Western Electric S-band magnetrons, directly derived from the British prototype of the Tizard Mission, were coded as [706A to 706C](#), depending upon the frequency. In the above image two strapped samples, [706EY](#) and [706CY](#), about 150 kW peak power in the S-band. D) [728DY](#) was an L-band magnetron capable of generating 400 kW pulses. (Click on image to enlarge)

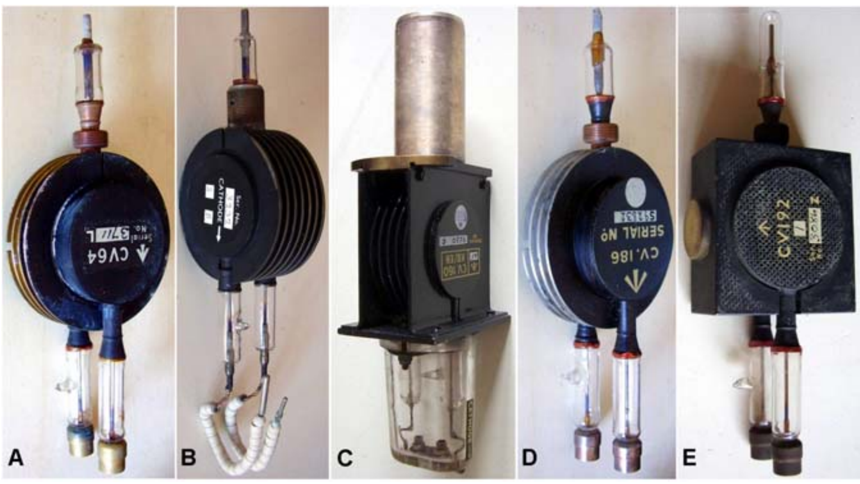

Fig. 6.3.7 - British wartime magnetrons. A) [CV64](#) was the strapped version of CV38 / REL 3C, used in AI Mark VIII and in H2S airborne radars. B) [CV76](#) was a high-power variant of CV56 used in Type 277 early warning radar since 1943. C) [CV160](#) was introduced early in 1944 as alternative to CV76. It incorporated some distinctive features of American magnetrons, as the large coaxial output connector and the glass boot over the cathode stems. D) [CV186](#) was a quite small magnetron, about 35 kW, used in the 'Village Inn' turret gun-laying radar. E) [CV192](#) is a rare example of conduction-cooled magnetron, high-power variant of CV64 intended to operate inside a pressurized box. (Click on image to enlarge)

6.3.4 - After-war magnetrons, including pulse, CW, FM, VTM types

Development of new magnetrons continued even after the end of the war. These devices had proven to be reliable and efficient sources of microwaves and their use began to spread to countless fields, as medicine, industrial heating, mapping, meteorology, maritime and air traffic control, active guidance systems, ECM, up to microwave ovens in everyday use. Here we can see a selection of types introduced in the years.

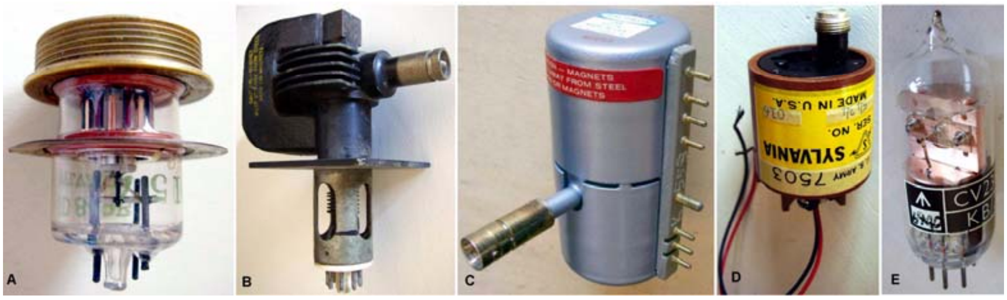

Fig. 6.3.8 - Small postwar magnetrons. A) This interdigital Sylvania experimental 3J22 could operate at 25.000 pps with 4 µs pulse duration. B) 5609 was a 70 W continuous wave type intended for RF heating. C) 6177A was a vibrating-reed FM modulated magnetron designed for radio-altimeters. D) 7503 was a tiny X-band magnetron, 200 W output pulses, for beacon applications. E) British CV2380 was an external-cavity X-band magnetron for beacons. It operated in a spatial-harmonic mode. (Click on image to enlarge)

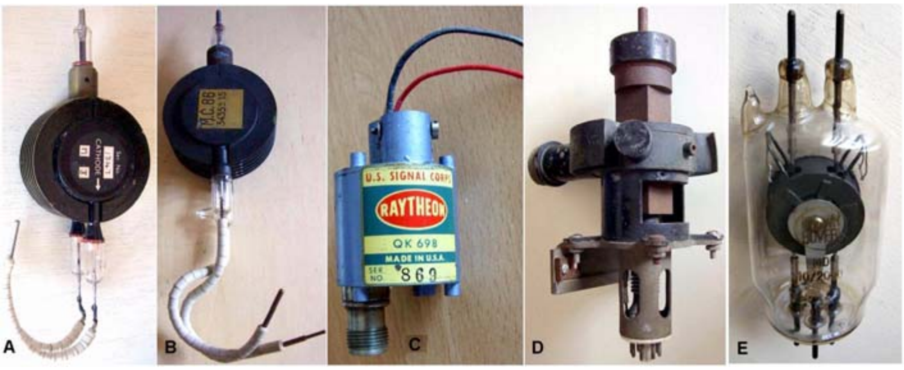

Fig. 6.3.9 - A) CV1479 to CV1482 replaced CV76A to CV76D. 450 kW out pulses. B) MC86 was a French CSF magnetron. C) QK698 was a tiny magnetron for beacon transmitters. D) QK174C is a rare sample of FM modulated magnetron intended for microwave television relays. It uses six auxiliary electron guns directed toward the resonators in order to modulate the generated frequency. E) Brown Boveri MD10/2000 Turbator includes a coaxial resonator. (Click on image to enlarge)

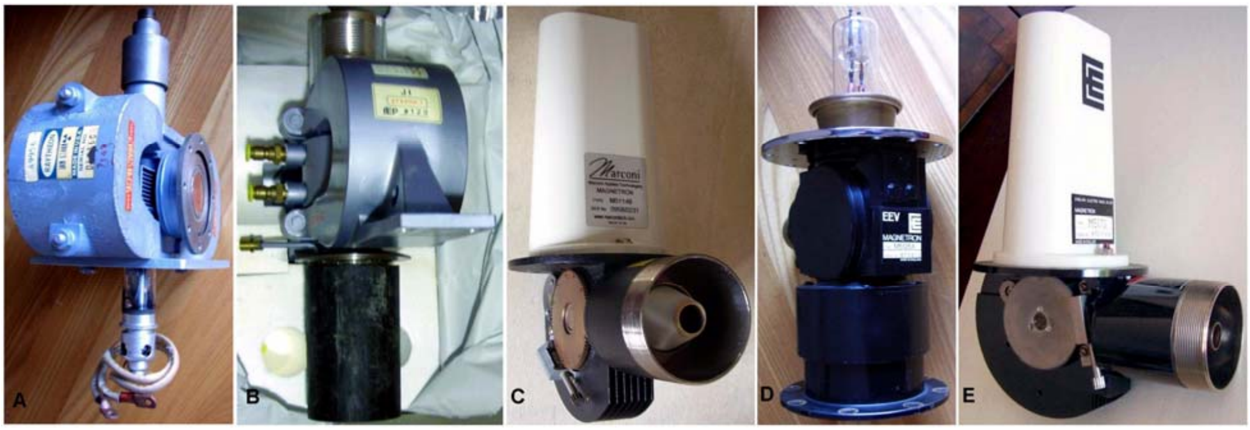

Fig. 6.3.10 - High-power magnetrons. A) 6344A is a C-band magnetron capable of generating 260 kW output pulses. B) 6410A is one of the most powerful magnetron for early warning radars, 5 MW out pulses for a weight exceeding 26 kg. This sample was made by Italian ELTEL, under Raytheon license. C) British Marconi M5114B was a tunable S-band magnetron, 1 MW out pulses. D) M5125X is a 2 MW magnetron used in linear particle accelerators, LINACs. E) M5170 is a British EEV 1 MW tunable magnetron. (Click on image to enlarge)

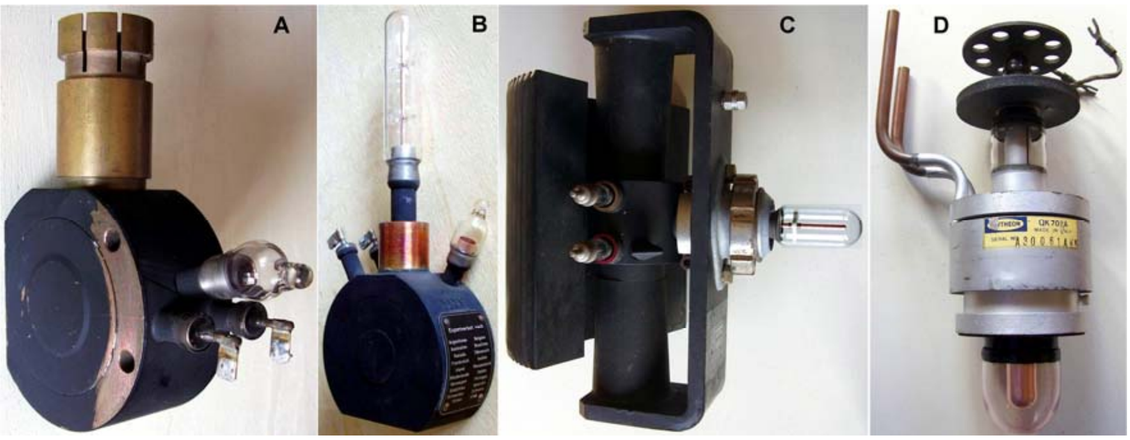

Fig. 6.3.11 - CW power magnetrons. A) Telefunken [MG20] gives 50 W at 5.85 GHz. B) [MG8] is rated for 250 W continuous at 2.45 GHz. C) Thomson-Varian [TV1022C] is a low-voltage type, capable of delivering 1 kW CW at 2.45 GHz. Forced-air cooling. D) Raytheon [QK707A] was a water-cooled 800 W magnetron, used around the late fifties in the 'Radarange' oven line. This sample was made in Palermo, in the ELSI plant. (Click to enlarge)

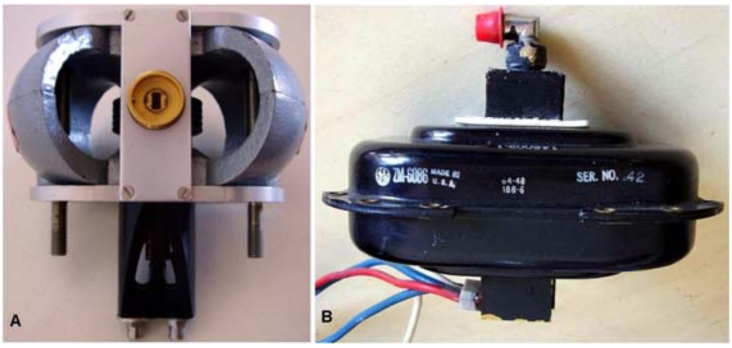

Fig. 6.3.12 - A) [M5100] is a Q-band magnetron, generating 50 kW pulses at 33 to 36 GHz. B) General Electric [ZM6086] is a voltage tunable magnetron, or [VTM]. VTMs are very special interdigital magnetrons without resonators. Useful electrons come from a virtual cathode and are deflected into spokes whose rotation speed is controlled by applied anode voltage. The above type can generate 36 mW CW from 1.420 to 2.607 MHz. (Click on image to enlarge)

Last edited by Emilio Ciardiello on 27 July 2020

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