6. Velocity Modulated Tubes

Even if magnetron structures were described since the twenties, the investigation on velocity modulated or VM tubes started around the second half of the thirties, to overcome the severe frequency limitations due to the transit time of electrons in conventional space charge amplifiers. These vacuum tubes include several families, differing from each other for their operating principle, or better for the way to exchange energy from the input port to electrons and back, from electrons to the output port. Basically we have Heil tubes, klystrons, magnetrons and traveling wave tubes, also known as TWTs.

Heil tubes and klystrons appeared shortly before the outbreak of WWII. Magnetrons were already known, but their diffusion outside the laboratories of the major physics institutes had to wait until 1940, when the first high-power multi-cavity magnetron was assembled at Birmingham University. TWTs appeared later, as the many derivatives and hybrid designs.

6.1 - Heil tubes and Klystrons

The little known Heil tubes and the klystrons are all velocity modulated (VM) tubes, intended to operate in the microwave region. Operating principles and summarized history of Heil tubes can be read in the **appendix A**.

The collection includes some Heil oscillators made by British STC in the fifties.

Fig. 6.1 – Some STC Heil tubes. From left: V233A/1K, V239C/1K, V241C/1K, V24£A/2FS, V247C/1K.

Operating principles and historical outlines of klystrons are given in the **appendix B**. The collection includes several klystrons, almost exclusively American and British types, that can be dated from WWII up to the sixties. Among the others, some of the early British devices, a Canadian REL-8B very early copy of the Sutton oscillator, a couple of rare Western Electric types, the 402A linear beam and the reflex vapor-phase cooled 459A, and some klystrons intended for operation in the millimeter range. Even British EMI is well represented by several nice samples.

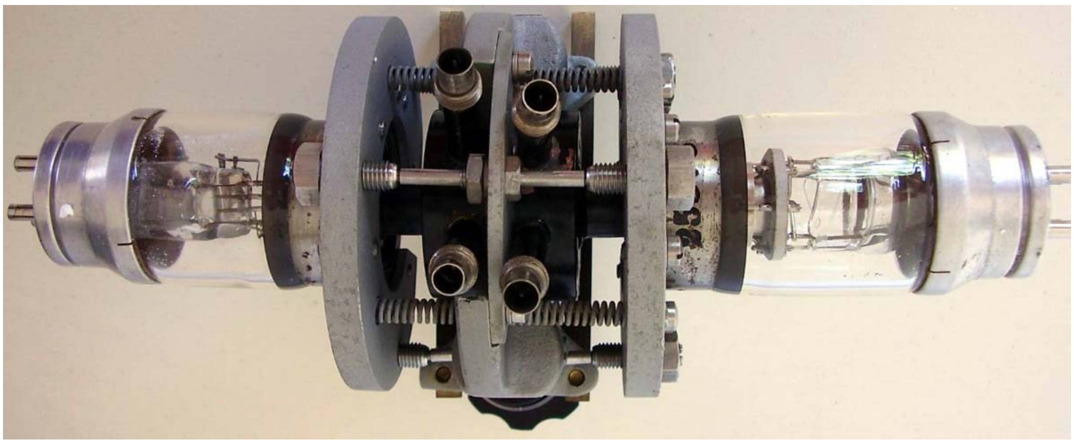
6.2 - Klystron Tubes

Fig 6.2 - Some of the early klystron designs introduced in the WWII. From left:

- **A) The British CV35, one of the S-band factory-tuned types derived by the Sutton prototype; late 1941**
- **B, C) The Canadian derivative of the Sutton early klystron still retains its geometry. Here the photos of the REL 8B and of the bulb inside.**
- **D) The 2K28 derived from the 707A, the early WE type designed for S-band local oscillators.**
- **E) The WL-417A is one of the many variants derived from the original Sperry design.**
- **F) WE 402A is one of the few linear beam klystrons built in limited quantities and developed during WWII as experimental type 1436.**

Fig. 6.3 – Shapes of some U.S. klystron tubes

Fig. 6.4 – Some shapes of British klystrons. Only few of them look similar to U.S. types.



6.4.1 - One of the very early [Sperry prototype](), about 1939 or 1940.

6.3 - Magnetrons

History and operating principles of magnetrons are given in the **appendix C**. The collection includes a wide variety of magnetrons, among which:

- British S and X bands early pulse magnetrons.
- Canadian copies of the very early British S-band magnetron.
- U.S. pulse magnetrons
- Multicavity CW magnetrons
- Split-anode CW types
- Voltage tunable magnetrons, including FM CW types

Multi-cavity magnetrons for pulsed operation, usually designed for use in radar transmitters, are well represented with over than 50 different types. Exhibits include small power types intended for beacons or missile guidance systems. Remarkable some British and Canadian early magnetrons.

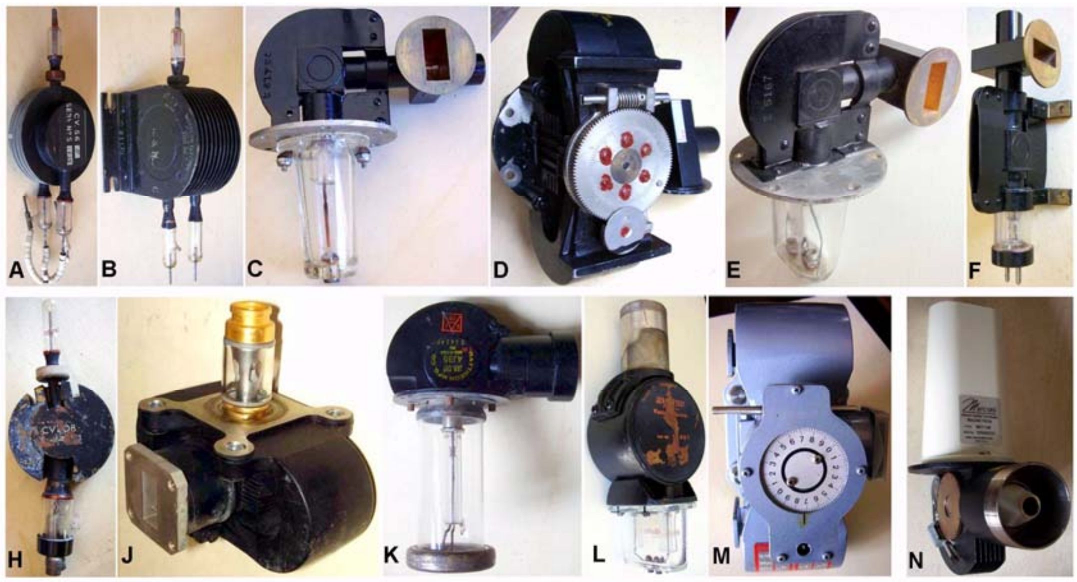


Fig. 6.5 – Some of radar pulse magnetrons in the collection.

A, British CV56, derived from the very early E1189, was the first strapped magnetron to enter in production in the late 1942, capable of delivering 100 KW typical peak power in the S-band with about 40% efficiency. In B one of the many US types directly derived from the British design, with the addition of two lateral mounting brackets. The specimen in the picture is a 706EY, capable of delivering 200KW output pulses.
In C we see the popular 12-cavity, double ring strapped X-band magnetron 725A, designed by Western Electric and built in hundreds of thousands units. It originated many variants, as the 2J50, E, or the 730A, F.
H, the same WE design also originated British variants, as the CV208, designed by GEC as plug-in replacement for CV108.
D, 2J51A is a tunable integral magnet X-band magnetron capable of generating pulses in the order of 80KW.
J, 4J52 is a fixed frequency X-band magnetron, delivering about 100 kW pulse power.
Moving to higher power types, we find:
K, 4J35, rated for over than 600 kW in S-band
L, WE 728DY, rated for about 300 kW in the L-band
M, is the ET-121, a tunable X-band magnetron made by Italian EL-TEL.
N, the Marconi M5114, rated up to 1 MW in S-band.

The collection offers a quite complete overview of the magnetron development in Great Britain and in America, from the early types up to the sixties.

Remarkable are the still unstrapped British NT98C and NT98D and their Canadian equivalent, REL 3C and 3D. All are copies of the very early E1189 prototype, serial no. 12, brought in America by the Tizard mission in 1940. They were followed by the early strapped versions, with over than ten fold increase of the pulse power. Some of the S-band types are the CV56, the CV64 and the CV76. Also available an early X-band CV208 with its RF mount.

Also present some of the early magnetron developed in U.S. by Bell Laboratories. Some were manufactured by Western Electric, other by Raytheon. This latter is well represented by a wide variety of types, including several for special applications, as beacons and jammers, and very high-power types, as the five megawatts 6410A .

Of course, in the radar development, each new magnetron asked for the simultaneous development of the associated components operating at the same frequency and capable of handling the related pulses. They included the pulser devices, the T/R switches and the same receiver front-end, local oscillator and mixer. Every effort was made to collect samples of the auxiliary components said above.

GE split anode CW magnetrons for radar jammers are also represented with several of the types described in the second volume of Very High Design Techniques, by the Radio Research Laboratories of the Harward University.

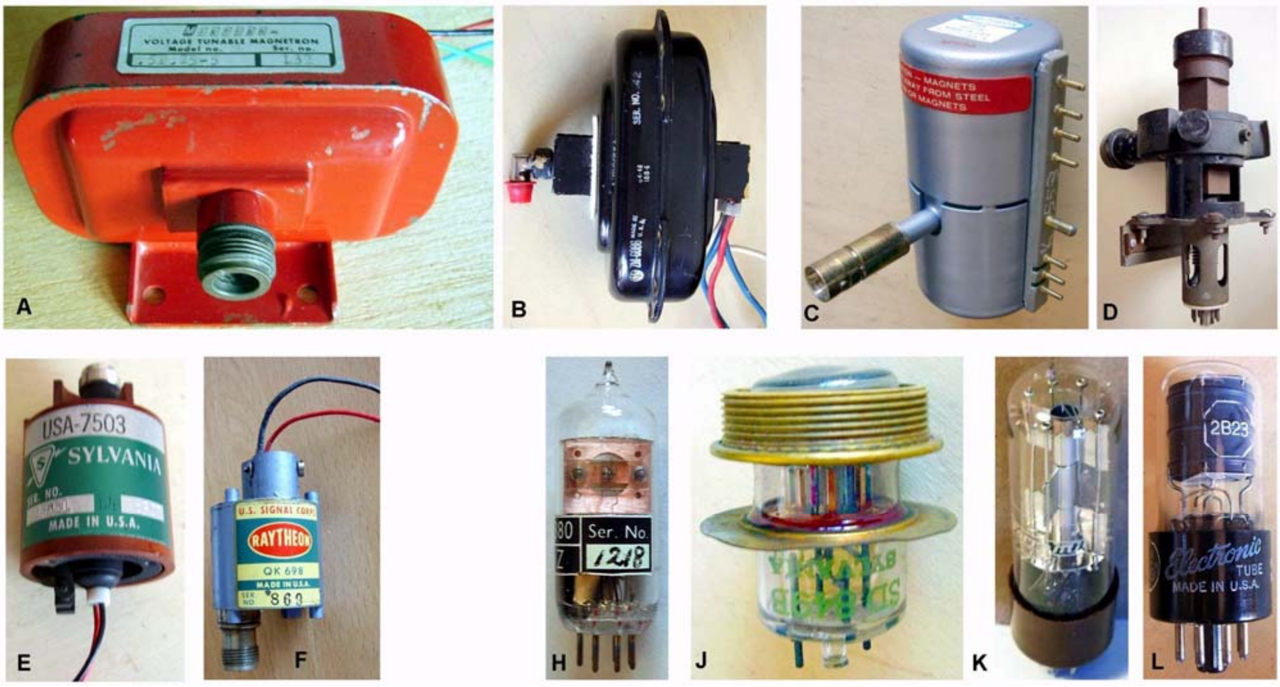
Among the others, there are several odd types. Some are low-power multicavity magnetrons for beacons or even for missile guidance. There are a couple of FM modulated types, one of which using auxiliary electron guns to electronically tune the cavity resonators. The most modern types are the voltage tunable magnetrons, or VTMs.

Many CW magnetrons were intended for radar jammers. Actally they were not used in continuous mode, but at variable pulse lenght and repetition rate. Other CW magnetrons, FM modulated, were intended for special applications, as radio-altimeter equipment.

Fig. 6.6 – Some CW magnetrons. Even if the tunable QK-60 (a) is given for pulsed operation, it can be operated at any pulse length and repetition rate. It is similar to the fixed frequency 5609 (b), 70W output at 2450 MHz, intended for RF heating. Both probably derived from the experimental CW type CM16B described by Collins. The German MG8/200 (c) is capable of delivering 250W at 2.42 GHz, while MG20 delivers 50 W at 5.8 GHz.

Fig. 6.7 – Split-anode CW magnetrons were designed during WWII to operate as RF sources for jammers in the VHF-UHF bands of German radar sets. The collection includes the four types gone in production, plus an experimental type, all described in Very High Frequency Techniques, volume II, by Radio Research Laboratory of Harward University.

Another magnetron family includes the so-called VTMs, voltage tuned magnetrons. Here the anode has an interdigital vane structure. Theory of operation of these devices can be found in a General Electric paper, in the appendix D. Even a couple of rare samples of CW electrically tunable magnetrons are in the collection. The 6177A, designed for FM radio altimeters, uses a voice coil to modulate the output frequency, while the QK174C, suitable for FM transmission of video signals, uses multiple auxiliary electron beams, injected in some of the cavities, to detune them and modulate the frequency. We find other exotic devices, as the tiny CV2380, a spatial resonance magnetron, in which the electron beam is coupled with the electromagnetic field of an external waveguide resonator. The Sylvania SD849B/3J22 is based upon an interdigital double anode structure. And we have some educational devices, as the GRD7, made to experiment the Hull effect and magnetic field sensors, as the GE 2B23. We will see later other devices, somehow related as operation to magnetrons, such as 'Phasitrons', used as FM modulators, and 'Trochotron' counters.



Early multicavity magnetrons in the collection

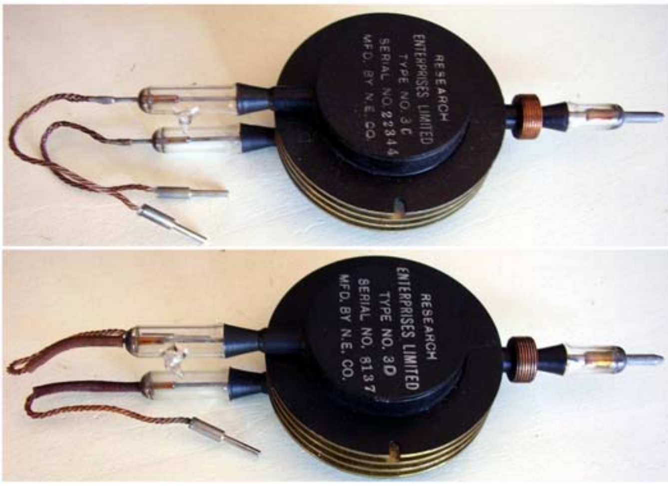


Fig. 6.8b - Canadian [REL3C] and [REL3D] are copies of the very early E1189 serial no. 12, brought in America by the Tizard mission in 1940. Still unstrapped, they operated around 3 GHz, with a peak output power in the order of 10 kW.

Fig 6.8c - Early British magnetrons directly derived from E1189 prototypes, [NT98C] and [NT98D], later approved as CV1494. These types too are still unstrapped, with output power lower than 10 kw peak at 3 GHz.

6.4 - TWTs and BWOs

TWTs (Travelling Wave Tubes) belong to velocity modulated tubes. In TWTs the microwave signal travels along a helix while exchanging energy with the focused electron beam in the middle. Principles of operation can be found in appedix E.

The collection includes several samples of TWT and BWO tubes

Fig. 6.9 – Pictures of some TWT tubes made by Western Electric and by British Standard Telephone (STC), with details of electron gun, of helix and top termination. The electron beam travels inside the helix and must be kept focused by a magnetic field generated either by a permanent magnet or by a focusing coil, depending upon the actual type.

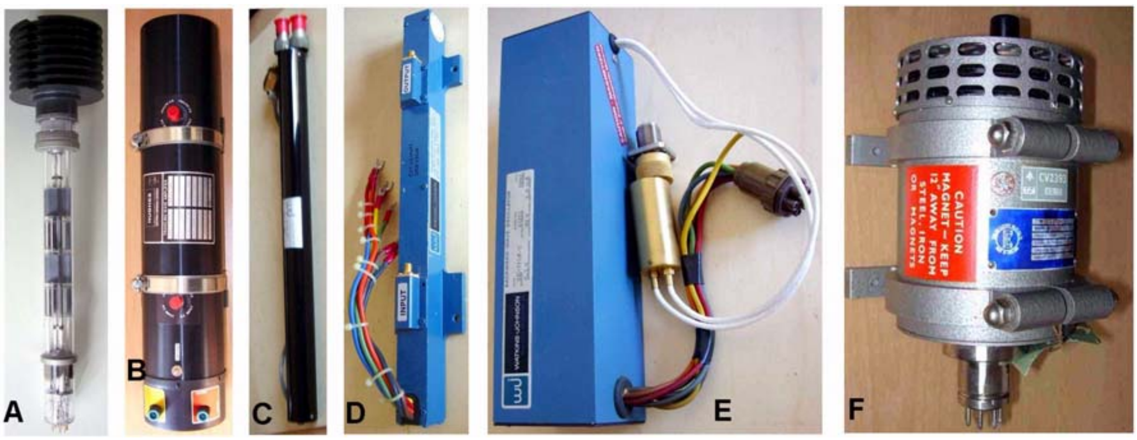


Fig. 6.10 – Some more TWTs: (A) and (C) require external focus coils. (E) and (F) are BWOs.