Early microwave magnetrons

The trajectory of electrons, moving under the effect of an electrostatic field, is affected by superimposed magnetic fields. The combined effect of electric and magnetic field on electrons had been exploited in a variety of unconventional vacuum tubes, commonly referred to as ‘magnetrons’ by their designers.

Tyne gives several examples of early experiments on tubes where magnetic fields generated by solenoids control electron flow. De Forest and Von Lieben patented some kinds of such electron devices and Moorhead sold the A-P solenoid tube for a while.

The first description of the static characteristics of a device called magnetron was described by A. W. Hull in 1921. The tube had a linear filament in a coaxial cylindrical plate. The plate cylinder was surrounded by a winding, used to generate a magnetic field. The radial electric field and the superimposed magnetic field forced electrons to follow circular orbits before reaching anode. If the magnetic field was raised, the radius of the orbits became smaller and smaller until electrons could not reach the plate, so causing a cut-off condition in the anode current. Hull also noted that just on the border between conduction and cut-off, adding a resonant tank circuit, the tube could sustain self-oscillations.

Split anode magnetron designs had been approached since 1924, in order to reach more stable oscillations at higher frequencies. In this case, the LC resonant circuit was placed between the two anodes. From 1934 to 1935 K. Posthumus at Philips developed a four segment magnetron; he also left a theoretic treatment of the rotating electron clouds, which gave the relations between the tube geometry, as the number of anodes, and the intensities of electrical and magnetic fields. In 1936, Cleeton and Williams reached the upper frequency of 47 GHz with a split anode structure. Multi-cavity devices, forerunner of the high power magnetrons in use since WWII, had been proposed by Samuel of the Bell Telephone in 1934. Multi-cavity magnetrons were subsequently developed in Russia and in England.

The first high power microwave multicavity magnetron, suitable for radar applications, was assembled by J.T. Randall and H.A.H. Boot at Birmingham University. The prototype, sealed by wax, operated while continuously connected to the vacuum pump on 21st February 1940. RF bursts of about 500W were generated at about 3 GHz. GEC, which had been asked for its industrialization, assembled the E1188 prototype, with the typical glass spacers for the filament and for the RF output and the thin copper end seals. Shortly later the design was modified, using an oxide coated, indirectly heated cathode, according to the draft E1189. On 17th July a prototype of E1189 gave 12KW peak output pulses at 9.5 cm wavelength. The early prototypes all had six cavities, the anode block being machined using a Colt revolver drum as drilling template. In August 1940 the design of E1189 was modified with 8 resonating cavities all around a larger cathode cylinder, giving the same output power with a small 6-lbs. permanent magnet.

Mechanical drafts and a picture of the E1189 are given in the following figure.

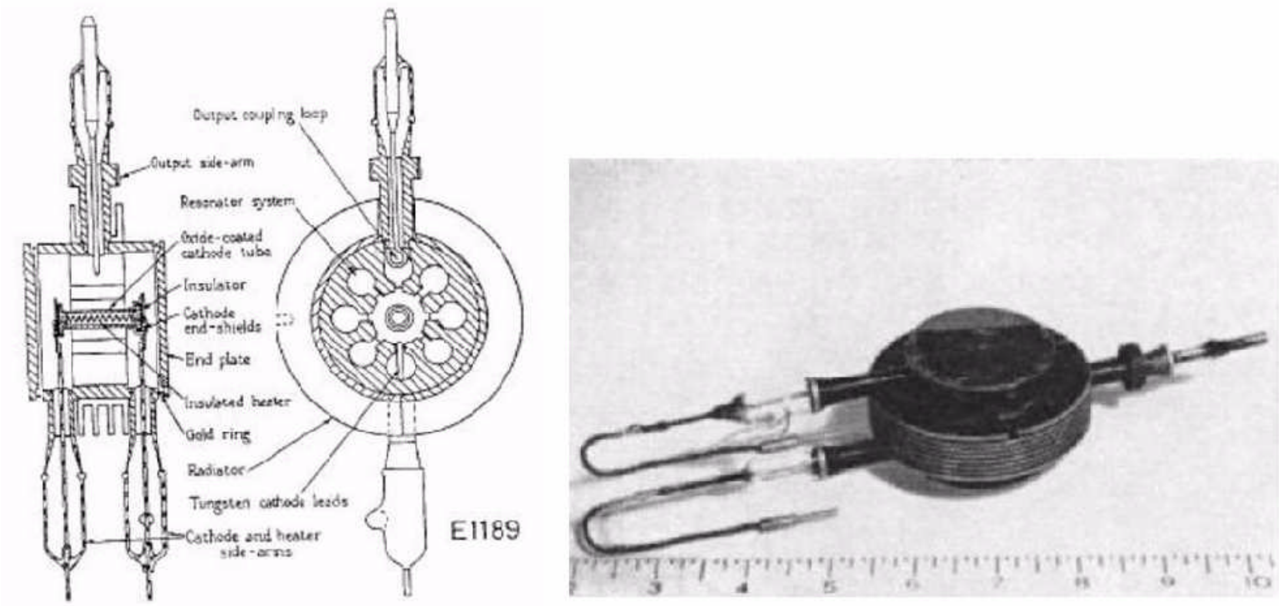

Fig. 1 - Left, original drafts of the E1189, the first S-band power magnetron produced by GEC. Right, a picture of the E1189 brought to North America by the Tizard mission.

One of the eight cavities E1189, the sample No. 12, was brought to the North America by the Tizard mission. Its design details were transferred to Western Electric, to Raytheon and to the Radiation Lab at MIT, in U.S., and to R.E.L. in Canada. REL was the radar-manufacturing arm of the Canadian National Research Council. The sample was X-rayed and eventually left in Canada. In U.S. the Radiation Laboratory at MIT controlled the development of new radar equipment and components, including magnetrons. The development also continued in England, pushed by military. At the very beginning magnetrons operated well beyond the limits of conventional electron tubes, as microwave high-power pulse generators, but evidenced many troubles. Its operation was quite critical and frequency spectrum generated was influenced by unwanted modes of operation. The glass spacers and the thin copper sealing plates were delicate: many magnetrons were damaged by improper handling when attempting to replace them in the field.

The strapping technique, connecting the cavities according to some schemes, prevented modes of oscillation different from the pi fundamental one. Strapped magnetrons were soon available, capable of generating clean pulses of several tens to hundreds kilowatts. The close co-operation among manufacturers, research laboratories and users of the three countries, Great Britain, U.S. and Canada, resulted in a very fast improvement of the early magnetron types, with everyday introduction of high performance devices for every application and, virtually, for every new radar equipment.

In the next pages some of British and U.S. early S-band pulsed magnetrons are shown. Their look closely recalls the E1189 prototype. U.S. magnetrons evolved with the addition of mounting brackets and of a rugged glass boot over the filament connections.

Early British S-band magnetron tubes

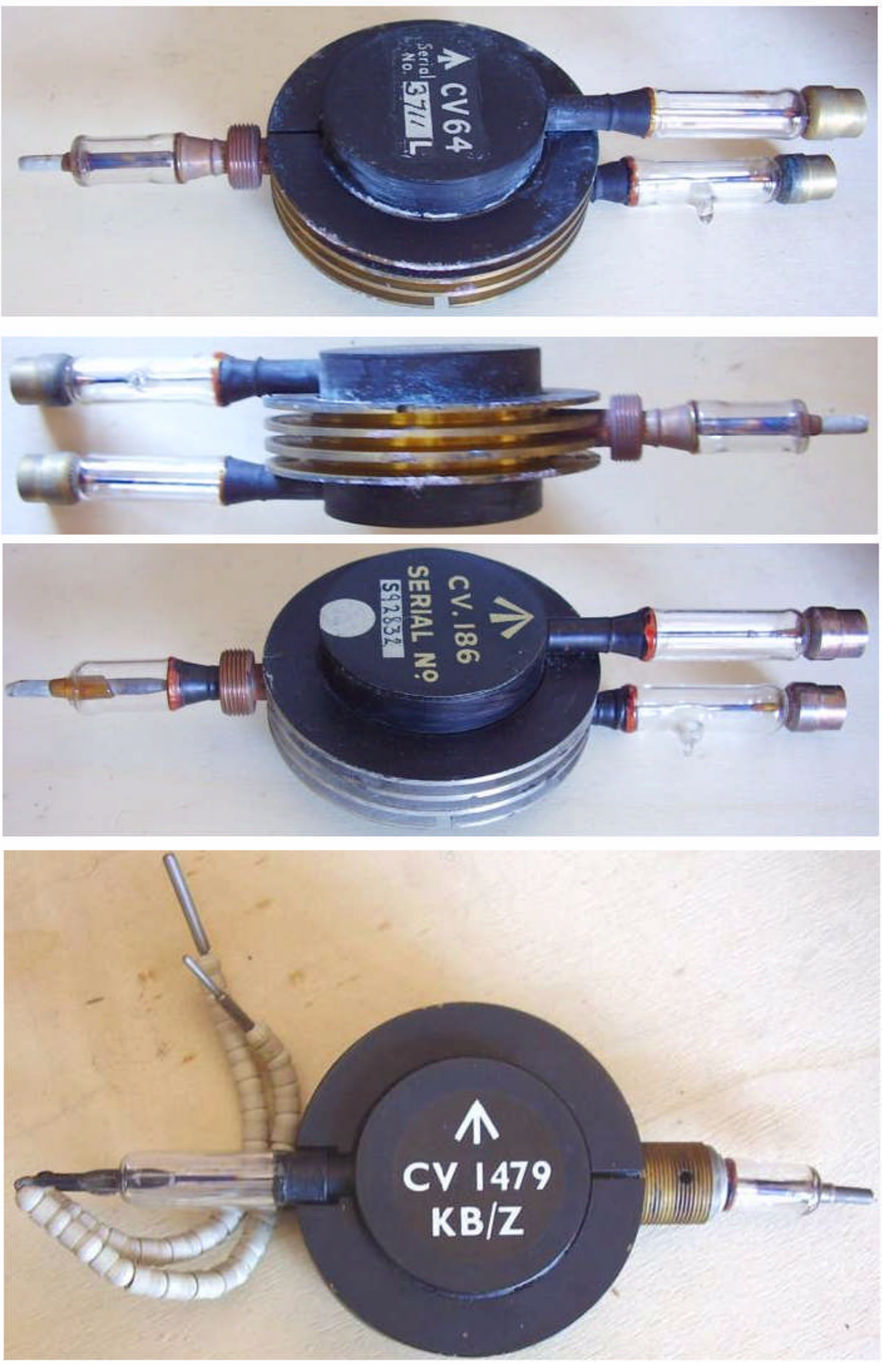

Fig. 2 – CV64 was the first echelon strapped magnetron, 40KW-pulse power at 3300MHz. CV186 was very similar, 35KW at 3320MHz, for use in Lancaster bombers turret gun laying radar system. CV1479 delivers 450KW pulses at 3045MHz.

US early S-band magnetrons

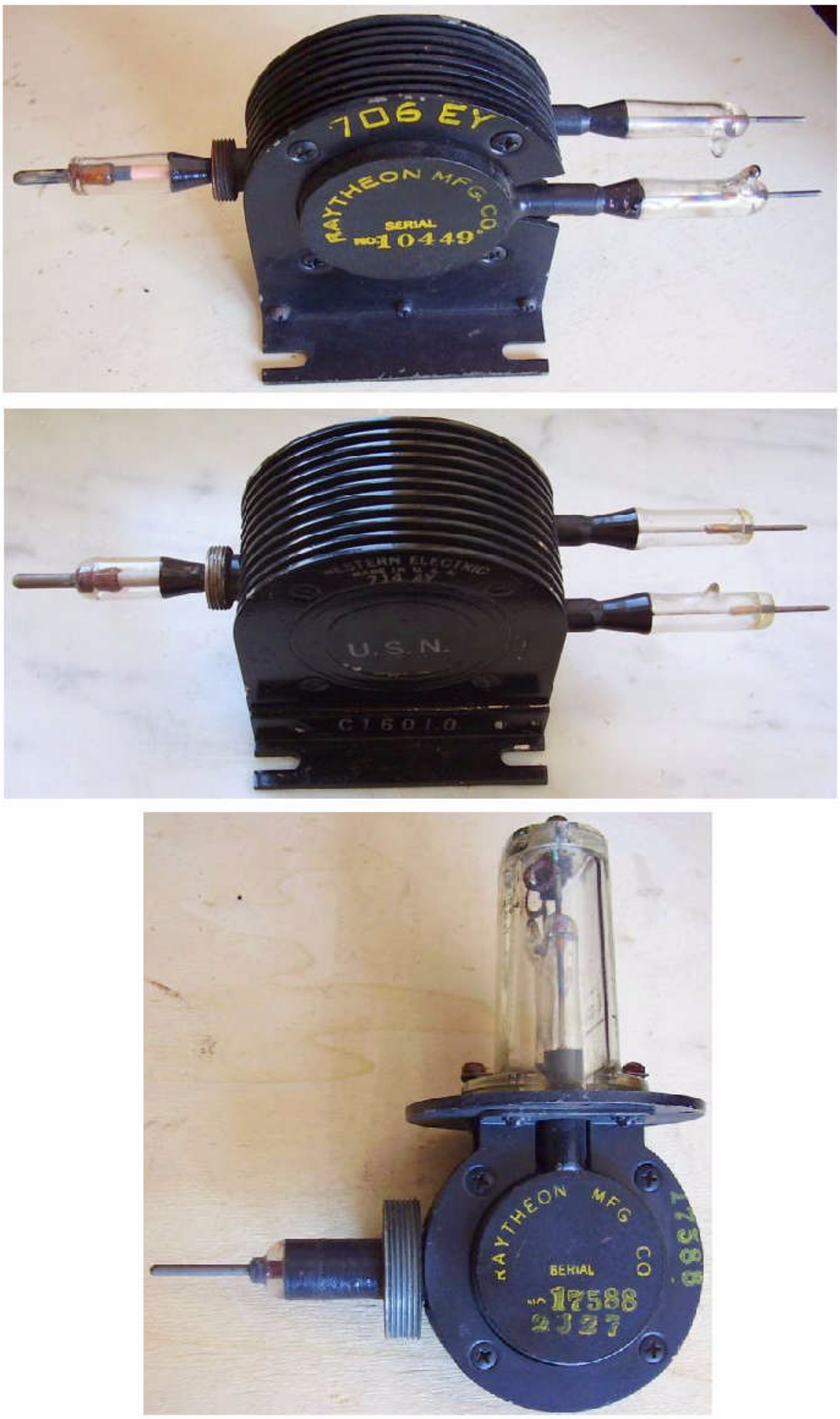

Fig. 3 - Some of the early U.S. S-band magnetrons. Western Electric 706A to 706C were fixed frequency cavity magnetrons inspired to the E1189 brought by the Tizard mission; shortly later they were replaced by the 706AY to 706GY version, capable of 200KW output pulses. WE 714AY gave 125KW pulses. Raytheon 2J27, capable of 265KW output pulses; although retaining the same basic structure of other similar magnetrons, its design included several improvements, such as the glass boot to protect the filament seals and the thick mounting flange.

The X-band evolution

Once the radar sets based upon S-band magnetrons had become operative, British and U.S. researches moved to the next border: the development of multicavity magnetron capable of operation in the X-band region. In this band a better resolution was expected, the radar sets being compact enough to be easily installed even in small combat airplanes, as night fighters.

The British approach approximately retained the overall dimensions of S-band magnetrons, while increasing the number of cavities to operate with acceptable magnetic flux densities. A large number of cavities however resulted in a random operation, due to the increasing difficulty to avoid unwanted modes of oscillation. At the end, a 12 slot anode was selected as best compromise between performances and production easiness, being possible to accurately milling the slots with available gear cutting machines. The magnetron was approved as CV108. It looked very similar to the S-band CV64, with the exception of the output probe: a glass encased antenna, which had to be inserted into a waveguide piece.

In U.S., Western Electric followed a different design approach, scaling-down the dimensions of S-band magnetrons. U.S. advanced manufacturing processes made possible to form precise anode blocks in a single operation, starting from a cylinder of oxygen-free copper. Western Electric developed its 725A, a double ring strapped X-.band magnetron, which soon became the most popular magnetron ever made and the reference for many new design. Capable of delivering about 60KW peak power at 9375MHz, 725A had a glass boot on the filament seals and a rugged flange to be easily handled even in field service operations. Two figures give an idea of its success: some 89.480 units 725A were delivered during WWII to British Empire under the Lend-Lease Law and in the mid 950s, the same magnetron could be bought on the surplus market for as little as 4,50 USD, versus 25,00 USD asked for a 2K25 klystron.

The structure of the 725A was copied in several designs, both in U.S. and in Great Britain. 730A was a 725A with a cathode bi-pin base and the waveguide flange moved to the top. 2J21 was interchangeable with 725A and 2J48, 2J49, 2J50 from Raytheon just differed from it for their tuning frequency. British BTH designed the CV208, which was a 725A repackaged to be interchangeable with CV108.

Some pictures of X-band early magnetrons are given in the following page.

X-band Magnetrons

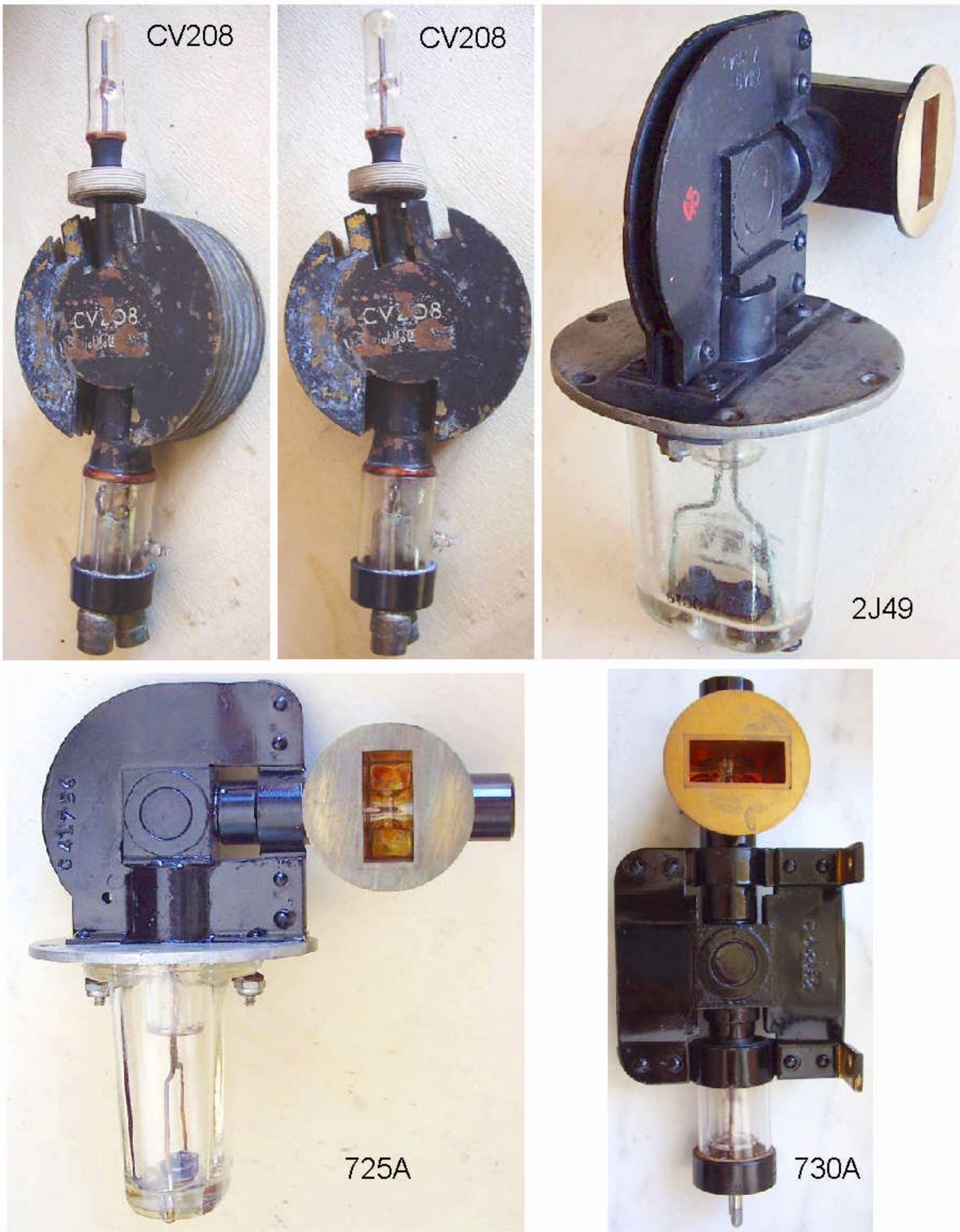

Fig. 4 – Some pictures of the early X-band pulsed magnetrons, all derived from the 725A. Top, the British CV208, with its glass encased probe to be inserted in the waveguide adapting section. CV208 had the same shape of CV108. 730A and 2J49 were U.S. variants of the 725A.

Other magnetron devices

Multicavity pulsed magnetrons became by far the most used devices in radar transmitters. But the development of this kind of velocity modulated tubes soon made available different magnetron devices for other applications.

CW multicavity magnetrons

These tubes were introduced for RF heating purpose. The most important applications were in diathermy electro-medical equipment and in microwave ovens for food heating/cooking. The principle of CW magnetrons is not different from their pulsed equivalent, but for operating parameters. Anode voltage must be limited to a safe value, within the anode dissipation capability, and the magnetic field should be accordingly low.

Fig. 5 - Telefunken MG8-200 delivers 200W at 3.3GHz. It is intended for diathermy electromedical equipment.

Split-anode magnetrons, 5J29

There are some very odd devices, designed for VHF/UHF military jammers, based upon the long time known split-anode architecture. Two fluid cooled heavy copper anodes were connected to a tuned transmission line, to generate about 150 W at frequencies from some 150 to about 900MHz.

Fig. 6 - 5J29 was the first of three split-anode magnetrons designed by General Electric for high-frequency jammers. The two anode copper blocks are internally connected by a short copper tubing which acts as shorting termination of the external tuning line, also granting inside the circulation of the cooling fluid.

5J30, Split-anode Magnetron

Fig. 7 - General Electric 5J30, split anode magnetron. Each anode block is fluid cooled through coaxial copper tubing. The two blocks are insulated from each other, the resonant line being shorted by a tuning stub on the side opposite to the magnetron. Thoriated tungsten filamentary cathode with shielding rings at each end and small shielding vanes along the filament axis.

5J32 Split-anode Magnetron

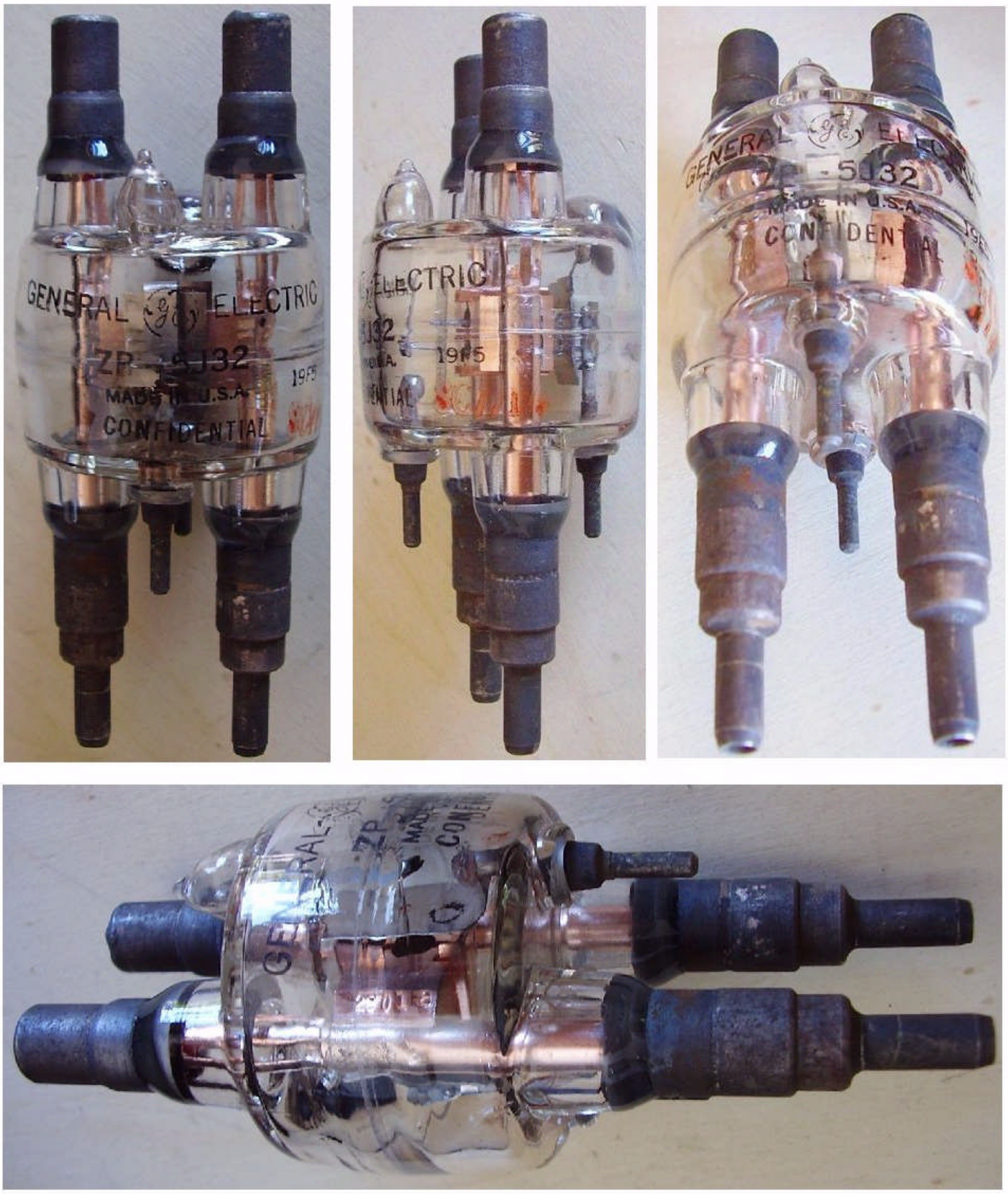

Fig. 8 - The GE variant 5J32, which differs from the 5J30 for having double-ended connections to the anode blocks.

X-band minimagnetron, CV2380

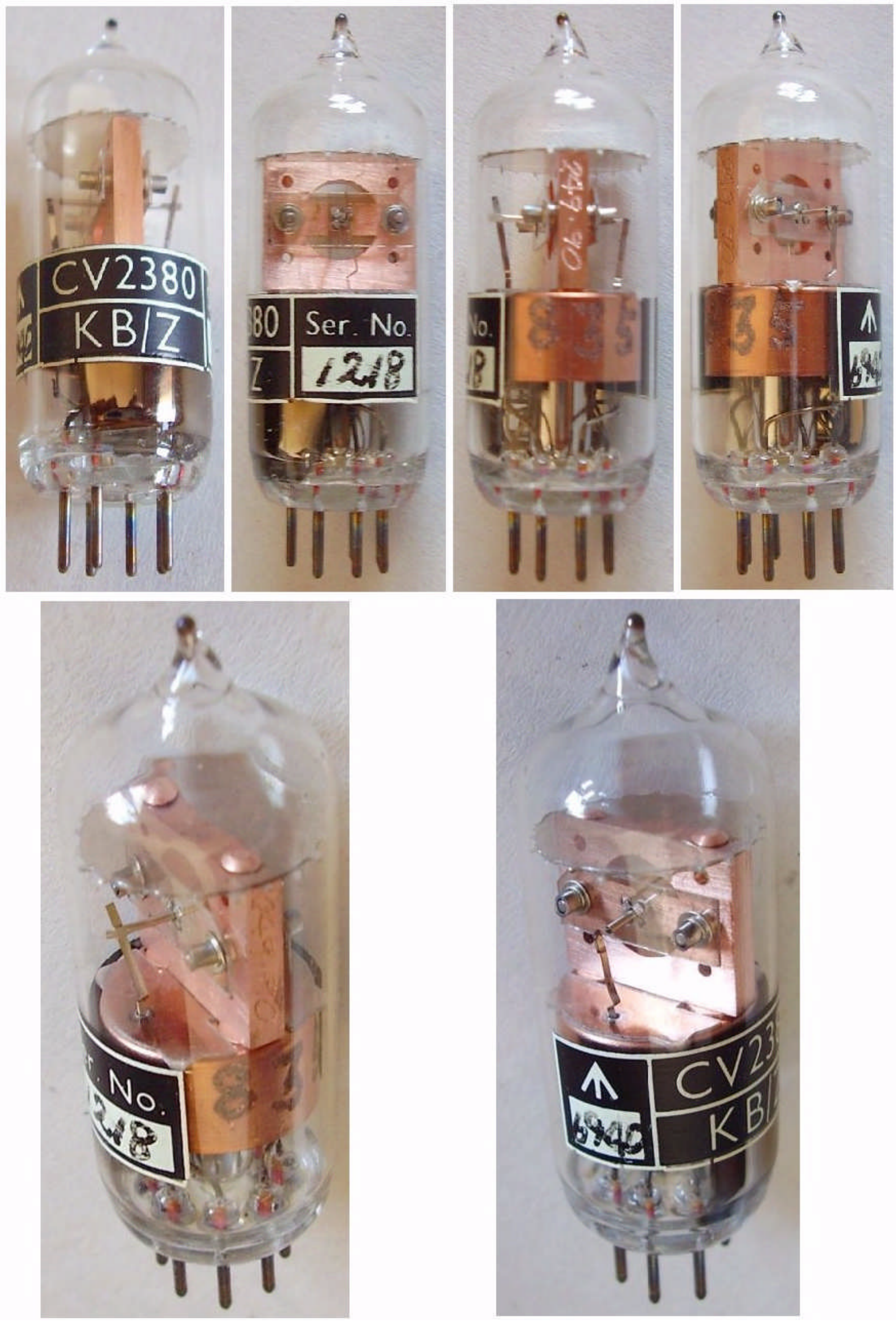

Fig. 9 – This unusual mini-magnetron can deliver about 100mW pulses at 9400MHz. It should be mounted in a special waveguide resonator, with a 2450 Oersted magnetic field.