7.1 - Radar Tubes: Pulse Modulator Switches

> **Back to main index** < > **Go to the modulator switch index** <

This family includes tubes designed or selected for medium and high power pulsers used to operate radar transmitters. Most of these tubes are used to generate peak pulses of tens or hundreds of kilowatt and even of megawatts, to drive the magnetron. Basically three different types of switches were commonly used for the purpose, spark gaps, gridded vacuum tubes, triodes or tetrodes, and high-speed thyratrons.

7.1.1 - Spark gap tubes, trigatron tubes

Sealed spark gaps were used in early radars to operate as switches. They derived from rotary spark gaps, in attempt to stabilize the firing point at different pressure levels encountered in airborne sets and to prevent corrosive effects of ozone, typical of sparks in open atmosphere. Spark gaps were uses to discharge a charged line through the magnetron, so generating the high-power radio frequency pulses. Spark gaps were also used as protective devices to prevent excessive voltage build-up in the modulators or even as gas switches in antenna duplexers, just as TR switches. Since no heater is present, efficiency is very high. The major drawback is an appreciable variation of the firing voltage through the life, mainly due to the erosion of electrodes. When used as pulse generators in radar modulators, a moderate jitter in the firing timing can be espected. Spark gaps made for radar modulators were capable of handling peak currents of hundreds amperes. Tipically two or three devices were used in series connected circuits, the discharge being triggered shorting the lower gap. When fired, total voltage drop was as low as one hundred volts even with peak currents in the order of some hundreds of amperes. Pulse repetition rate in the order of 2000 pps was obtainable.

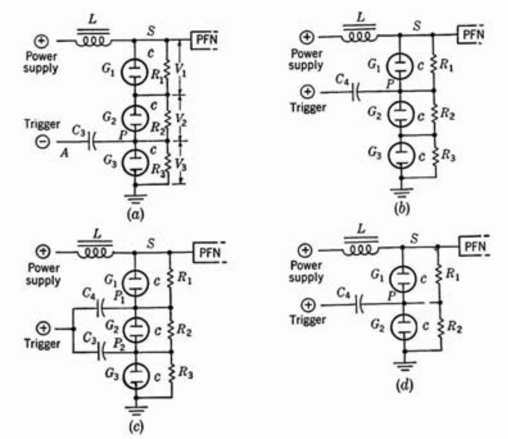

Fig. 7.1.1 - Typical circuits for series connected spark gaps to discharge the pulse forming network, PFN. (Click on the image to enlarge)

This section includes most of the American two-electrode types described by Glasoe, in his ‘Pulse Generators’, including the mercury-filled iron-sponge 1B42. The development of spark gaps for pulse generators in Western Electric is described in this article from BSTJ.

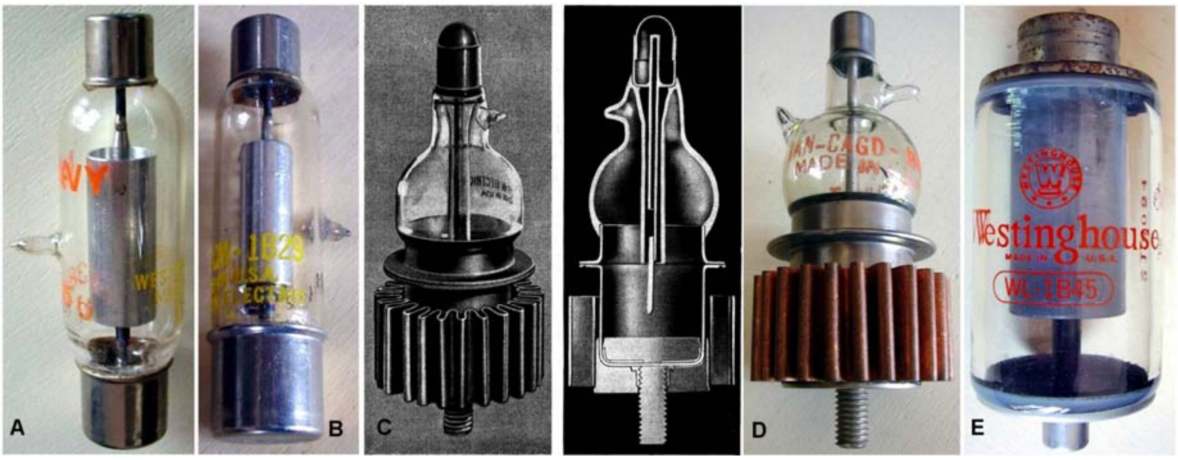

Fig. 7.1.2 - Two-electrode spark gaps commonly used in many of the early American radars. A) 1B22 was an argon-hydrogen filled spark gap used in the modulator of AN/APS-4 to drive the 725A magnetron. B) 1B29 was a scaled-down 1B22, rated for 30 A. C - D) 1B42 was rated for 80 to 300 A pulses. Cathode was formed by liquid mercury immobilized in a cup-shaped iron sponge. Mercury evaporating due to sparks returned into the sponge so to always leave a fresh electrode surface. E) 1B45 was a high-power spark gap, capable of switching 450 A at 15 kV. (Click on the image to enlarge)

We also find protective spark gaps, used to limit excessive voltage build-up across HV circuits in the radar modulators.

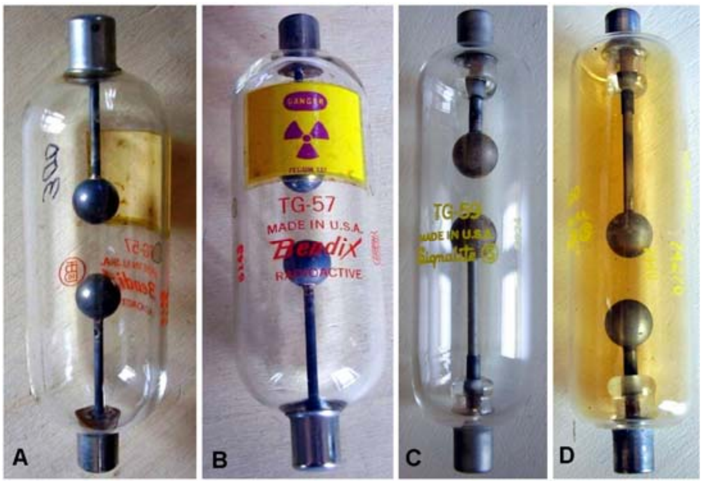

Fig. 7.1.3 - Samples of protective spark gaps. A, B) Two views of TG-57 showing electrodes and the warning label which states the presence of a radioactive activator. C) TG-59 spark gap. D) TG-60. In this sample a brown-yellow glass is used.

In WWII British used quite different types of spark gaps referred to as ‘trigatrons’. Trigatrons had a third trigger electrode in the middle of the dome-shaped cathode. A pulse transformer, oil-immersed inside the special socket, started the pilot spark from cathode to trigger pin and the ionization propagated the spark to anode. The firing was more accurate, depending upon the pulse applied to the trigger electrode. Unfortunately their life was quite short. Both British and Canadian trigatrons are in the collection.

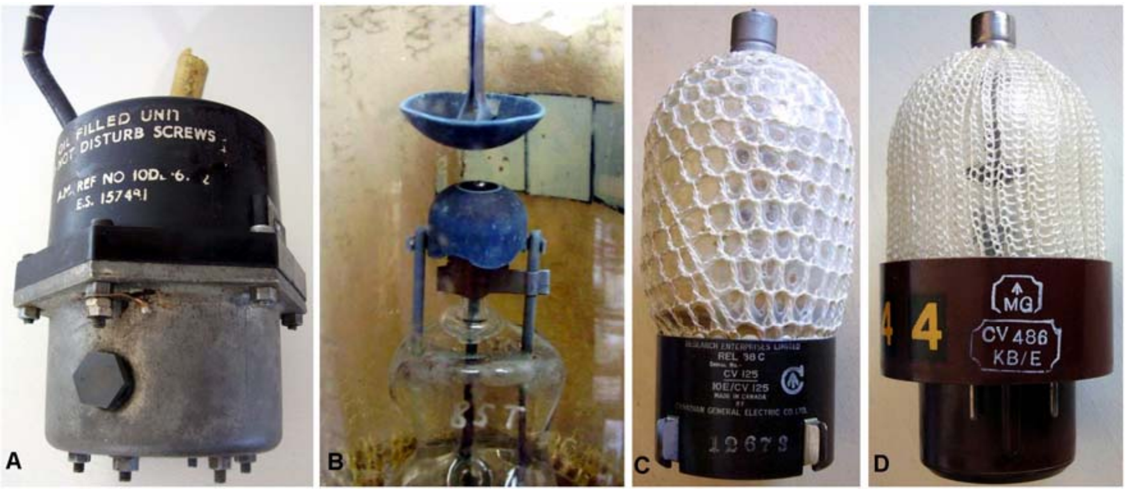

Fig. 7.1.4 - A) The special socket for trigatron tubes contains an oil-immersed pulse transformer in the lower section. B) Internal construction of a trigatron. The tip of the trigger electrode is visible in the middle of the cathode hemisphere. C) REL 38 equivalent to CV125 was rated for 530 kW pulse power at 13,3 kV. The textile sock glued to the bulb had to prevent thr scattering of glass chips all around in case of explosion. D) CV486 was quite similar to CV125 but for a B15A3 base.

7.1.2 - Hard switch tubes, triodes and tetrodes

Power triodes or tetrodes have been used as switches in radar pulsers, when flexibility, speed and precision as per pulse width, duty and pulse repetition rate were required. The major drawback was the low efficiency, due to the relevant heater power wasted to obtain the required emission and to the power needed to drive the control grid. Radar pulse modulators had to generate pulses in the order of ten kilovolts or more at currents in excess of ten amperes. Early tubes were directly derived from transmitting types, selected for their capacity to withstand required voltages and currents. Since positive ions could destroy cathode oxides when accelerated under the effect of very high electric fields, tungsten filaments were used at the beginning. Experience showed that, because of the short duration of pulses, ions could not reach harmful speeds and then the more efficient oxide-coated cathodes entered in common use. Designs of grids were improved to safely handle the positive pulses required to instantly drive the tube at full conduction.

At the very beginning transmitting tubes were just specified and tested to different pulsed operating conditions. In other cases redesigns were needed to better handle higher voltages and peak currents of the application. A comprehensive description of the development of pulse modulator tubes, from the early attempts to use off-the-shelf transmitting tubes to the development of specialized tubes with oxide-coated cathodes can be found in this article from BSTJ by C.E. Fay.

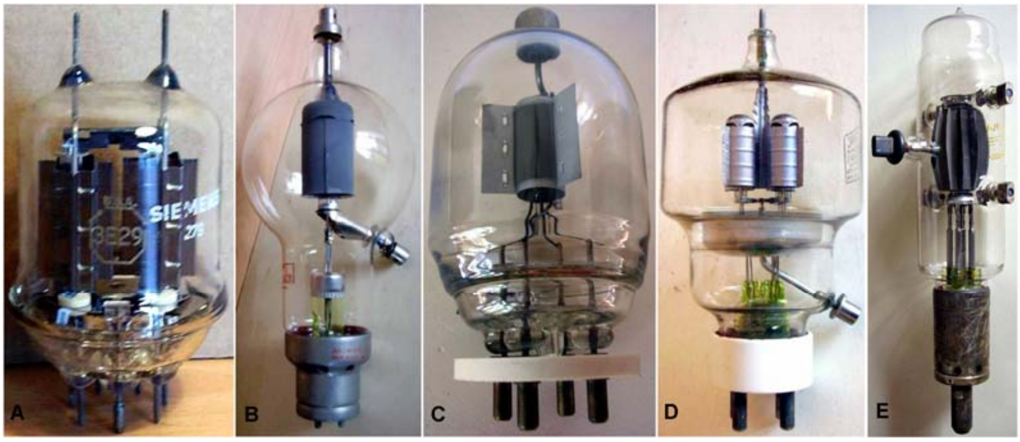

Fig. 7.1.5 - Transmitting tubes used as hard-switch pulsers. A) 3E29 was an 829B tested for 5 kV pulse operation. B) Actually 6C21 was a 1000T transmitting triode uprated to 15 A emission by raising filament voltage, from 7.5 to 8.2 V, of course at reduced life. C) Six 356A were used by Western Electric to replace six 100THs in the modulator of early CXAS and Mark 1 radar sets. The above sample is a 356B. The gridless variant 705A was one of the most diffused high-voltage rectifiers. D) 304TL was another transmitting triode used in radar pulsers. E) 527A was intended for use in 1 MW VHF ring oscillator in the transmitter of AN/TPS-18 radar. Since it was designed for high current pulse operation, 60 A, it was also used as switch in high-power radar modulators.

Fig. 7.1.6 - Vacuum tubes designed to operate as power switches in pulse modulators. A) Western Electric 701A was hastly designed to drive the very early WE magnetron, the 700A. The required emission was obtained assemblying four electrode sub-systems of the 350A power tetrode, cathode and grids, inside a cruciform plate. Grids were gold plated to decrease secondary emission at high operating temperature. B) 715A was an evolution of 701A for airborne applications. Here the four cathodes were placed side-by-side into a single plate and grid system. 715A evolved through several steps, with improvements of grid cooling and of the insulation. C) 5D21 was a further evolution during the war of 715B, with the addition of a top guard ring to prevent corona discharge at high altitudes. D) CV57 was a quite small British tetrode capable of handling 5 A pulses at 11 kV. E) Amperex AX10318-1 is a tetrode intended to operate immersed in oil to switch 5 A at 100 kV. F) ML-7003 was a screened grid triode used in pulse modulators up to 2.5 MW. It was rated for operation as switch at 40 kV, 80 A.

7.1.3 - Hydrogen thyratrons

In line-type pulsers a thyratron can be used as switch, provided that its turn-off time is fast enough to release the load and allow a complete line recharge before the next pulse occurs. Mercury-filled thyratrons could require some microseconds for the ionization to occur and hundreds of microseconds to deionize. Typical radar pulses might have about 1 microsecond duration and pulse repetition rate even over one thousand pulses per second. Mercury thyratrons are too slow to operate in most of the radar pulsers. Another problem derives from the mass of mercury ions which destroys cathode oxide coating even at low voltages. Hydrogen thyratrons proved to be fast enough to operate even at repetiton rates well in excess of 1.000 p.p.s.

Unfortunately hydrogen has some drawbacks. It reacts with cathode oxides and the temperature has to be kept as low as possible, in a narrow range over 800ºC, the lower limit for an acceptable emission. It also suffers a cleanup during operation. The gas tends to be adsorbed by materials inside the tube and to disappear. It is necessary to raise the gas pressure as high as possible and then, according to the Paschen’s curve, to decrease the spacing between the grid and the anode, to keep the breakdown voltage high enough. Typical spacing between anode and grid was around 1.5 mm and anyway below 2.5 mm. The cross-section of a typical thyratron is given below.

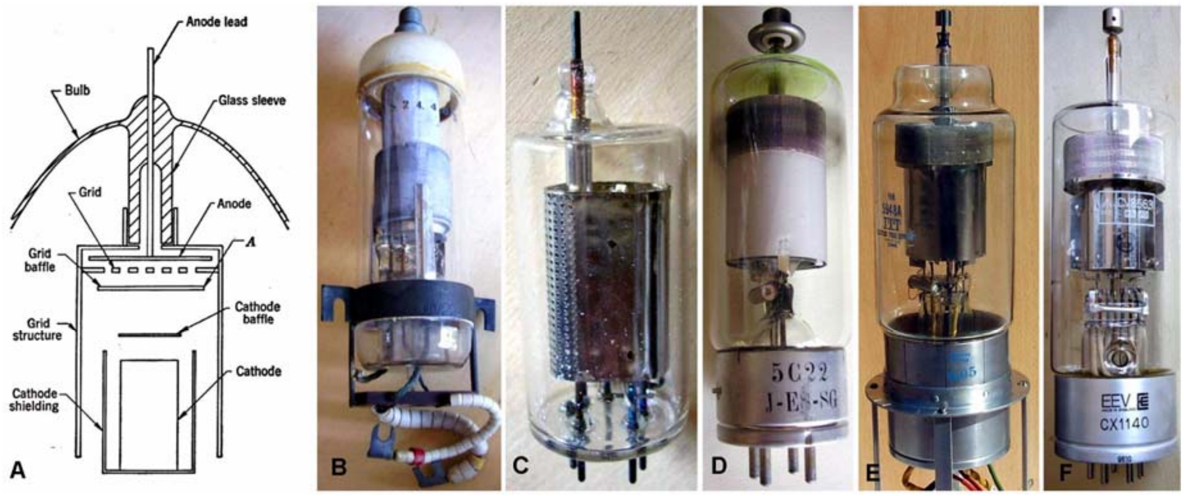

Fig. 7.1.7 - Thyratron tubes as switches for radar pulse modulators. A) Sectional drawing of a hydrogen thyratron. The grid entirely surrounds anode disc, very close to it. The anode supporting rod is fully insulated by a glass sleeve. A grid baffle (A) prevents any influence by electrostatic fields generated by anode potential in the cathode to grid region. B) CV22 was one of the few mercury thyratrons used between 1941 and 1942 in the modulator of British radars as Type 291, Type 271Q and GL3. C) 7191 miniature 7-pin hydrogen thyratron could handle 20 A peak pulses at 1.2 kV. D) For years, since WWII, 5C22 was an industry standard, used in many radar modulators. 5C22 had built-in hydrogen reservoir. The above sample was made by Italian ELSI, Elettronica Sicula, qualified by Raytheon. E) 5948 was a huge hydrogen thyratron capable of handling 12 MW pulses at 25 kV. British CX1140 / CV8563 was similar to 5948, capable of switching 12.5 MW.

> **Back to main index** <   > **Go to the modulator switch index** <