CV150 Power Klystron and Oboe Mk IIB, 1942

'The EMI team wisely decided to build their development model and get it operating in a coach at Hayes. They drove this coach with the klystron version of H2S to Hurn airport on 14 May.': Sir Bernard Lowell in his 'Echoes of War' tells us his history of an obscure yet extremely advanced British achievement at the beginning of microwave airborne radar era, the Oboe Mark IIB fitted with the CV150 pulse power klystron in its TR3539 transmitter.

In the first half of 1941 early microwave airborne radar sets were designed for AI use aboard of night fighters and for ASV, to patrol Atlantic convoys. Terrain mapping by metric radio-localization sets, investigated years before by the same Bowen, barely allowed seeing the coastline. In the second half of 1941, due to the improved resolution of microwave sets, new tests were made to take advantage of them in terrain guidance. Late in 1941 it was decided to design a self-contained system to guide heavy aircraft of the Bomber Command over their targets in enemy territory. In November 1941 the very early H2S was born: an AI Mk VII system modified with a fixed angle scanner returned echoes of the Southampton town from 5.000 ft. A variant, based upon a high-power pulsed klystron, was approved few days later. The decision for the klystron was taken for political rather than for technical reasons. Magnetron was considered a vital secret to be carefully preserved. Therefore no authority was given to fly magnetron sets over continental Europe, fearing that its secret could fall in enemy hands. The capture of a klystron transmitter would have address German developments towards a predictable dead end. We know that klystron had been thoroughly investigated in England as microwave power source until the mid 1940, when early GEC cavity magnetrons started delivering thousands of kilowatts. On 23 December 1941 a contract was placed with EMI Hayes to design the power klystron itself and to build 50 radar sets fitted with the klystron transmitter. Preliminary specifications of the system and of the klystron itself were presumably derived from those of the AI Mark VII, based upon the CV38 unstrapped magnetron: 10 kW typical output pulses. EMI designed its PK150, approved as CV150, capable of delivering 15 kW with 4 µs pulses and up to 30 kW at lower duty.

The images given by Lowell of a coach with strange antennas on the roof, running round the EMI plant, through London suburbs and bringing super-secret equipment to Hurn airport on 14 May appear like part of the deception that the British were preparing against Germany: a representation to fool possible German spies and confirm the use of the klystron as source of RF power.

First trials of the magnetron H2S on heavy bombers were made on the Halifax V9977, arrived at Hurn on 27 March 1942. A second Halifax, the R9490, arrived on 12 April 1942. It was fitted with the EMI variant to run comparative tests. Several scanners were tried in the first months of 1942. Lowell tells of the several little improvements of the magnetron version and even of disappointing results in his flight in V9977 Halifax on 22 May. Nevertheless '*The same old succession of aerial troubles -that is gaps and fades and poor range*' was even found in the EMI version on 2 June. In chapter 13 Lowell tells of remarkable differences between the magnetron and the klystron versions. This can be explained with the increased power of the first equipment. Magnetron version was continuously improved. By March 1942 the new AI Mark VIII with CV64 strapped magnetron gave 40 kW pulses at the same input of CV38. Its power would rise over than 100 kW as soon as the new modulator with the CV125 trigatron was available.

Unfortunately the entire EMI design staff and the magnetron H2S prototype went lost on Sunday 7 June in the crash of the V9977 Halifax during a test flight. The death of Blumlein and his team caused the subsequent cancellation of the power klystron and of any further developments on klystron radars. Nevertheless the CV150 power klystron was another very important British achievement. Maybe it was too advanced for its time, anyway it was forerunner of the many high power klystrons developed years later at Stanford and elsewhere.

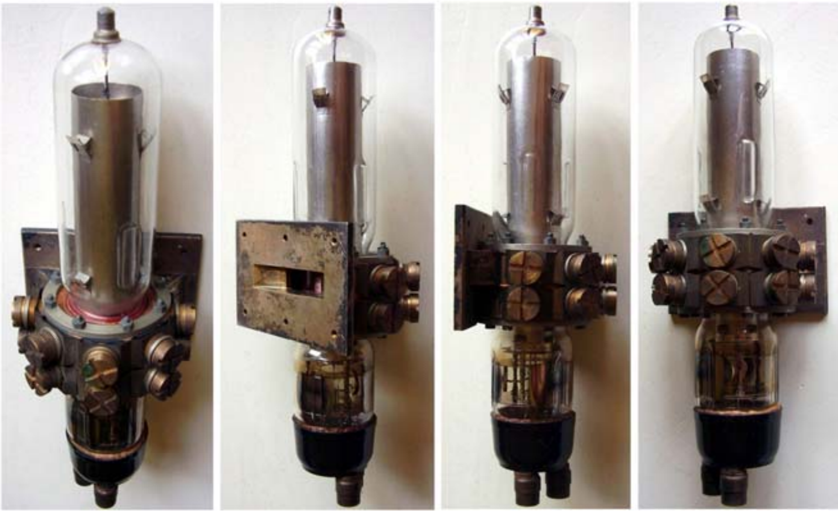

Fig. 1 - Views of the CV150 pulse power klystron. Click to enlarge.

We must assume that late in 1941, when EMI started developing its PK150 design approved as CV150, its goal was a power output comparable with that of CV38: 10 kW typical output pulses at about 100 kW in input. It is not easy today to compare performances of the two solutions, since power of magnetron transmitters progressively increased by November 1941, when early samples of the strapped CV64 began to be available. We can say that RF power output of CV150 well exceded values given for CV38:

- **Peak input power 150 kW. 80 W maximum mean input power**
- **Peak output power 18 kW typical, up to 25 - 30 kW obtainable at lower duty**
- **Cathode voltage pulsed to -12.5 kV**
- **Peak collector current 6 amps**
- **Peak resonator current 6 amps**
- **Wavelength centered at 9.4 cm, adjustable plus or minus 2.5 mm**
- **RF pulse build-up in the order of 100 ns.**

Waiting for the new Oboe modulator, latest tests were arranged with a Type 64 modulator, modified for 1 µs pulse length. A special pulse transformer was added to raise the voltage from 7.8 kV to 12.2 kV. The TRE report underlines that, taking into account the overall conditions of tests, results were consistent with expectations: 15.2 kW were measured in the water calorimeter at center frequency. CV150 then gave power enough to compete with the unstrapped magnetron. Looking at the high value of the resonator current, about one half of the cathode emission, we observe that the same device had margin enough for further power increases by improved focusing of the electron beam. Unfortunately, after the crash of the Halifax V9977, the entire project was canceled and the same power klystron was shelved for the rest of the war. Attempts to use the CV150 in other applications, as in the 'Lucero' navigation system, never got beyond the prototype phase.

The memory of such a device was frozen thanks to its unique design, very impressive for solutions and performances, into the diary of Ed Ginzton, Professor in Physics at Stanford and cofounder of Varian. His notes, after a trip to Britain early in 1944, are reported in the historical background of the paper 'HIGH-POWER KLYSTRONS: THEORY AND PRACTICE AT THE STANFORD LINEAR ACCELERATOR CENTER' by George Caryotakis. Ginzton's notes are today one of the few available sources of information about the tube and its performances.

"*…I saw a klystron of a remarkably simple design which produced 20,000 watts of power, well beyond any klystron made in the United States at that time. The fact that it was so simple and so beautiful impressed me enormously, and led me to develop a still bigger tube a few years later.*

A two resonator klystron, using grids, and operating 12,000 volts has been designed and built for 9.1 cm. It was intended for an airborne system but due to changing circumstances will probably not be used. It differs from other pulsed klystrons developed in Britain in that it uses a very large beam cross-section, a very large current density and grids to improve the modulation coefficient of the gaps. Although the grids are large in diameter, the RF losses in these are made small by using large grid spacing. The effect of the latter are made small by the high acceleration voltage. As such, this tube represents the furthest deviation from standard klystron design that I have ever seen. The cathode focusing and/or grid interception losses are poor.

Only 50% of the current passes through the short, stubby channel and one would think that this should be much better. But in spite of this, the overall-efficiency at 12kV, and 150 kW input is 20%. This means that the actual efficiency is about 40%, that being the highest efficiency for a klystron that I have ever heard of. The tube uses a slot for coupling. It has a waveguide output, and it is tunable by means of plungers over 5%. The starting time is not larger than 0.1 – 0.2 microseconds. The tube is small, light, very easy to make, is easily tunable and can be used as a power amplifier. It is this tube that makes me think that the klystron may yet rival the magnetrons.

The life of the tube seems to be about 250 hours at present. It is thought that Ba is being evaporated from the cathode which finally ruins the tube. Experiments are now being conducted with lower cathode temperatures and longer life is indicated. The tube is now in preproduction stages... "

Ginzton also left drafts of the internal electrode arrangement and of the grid shape.

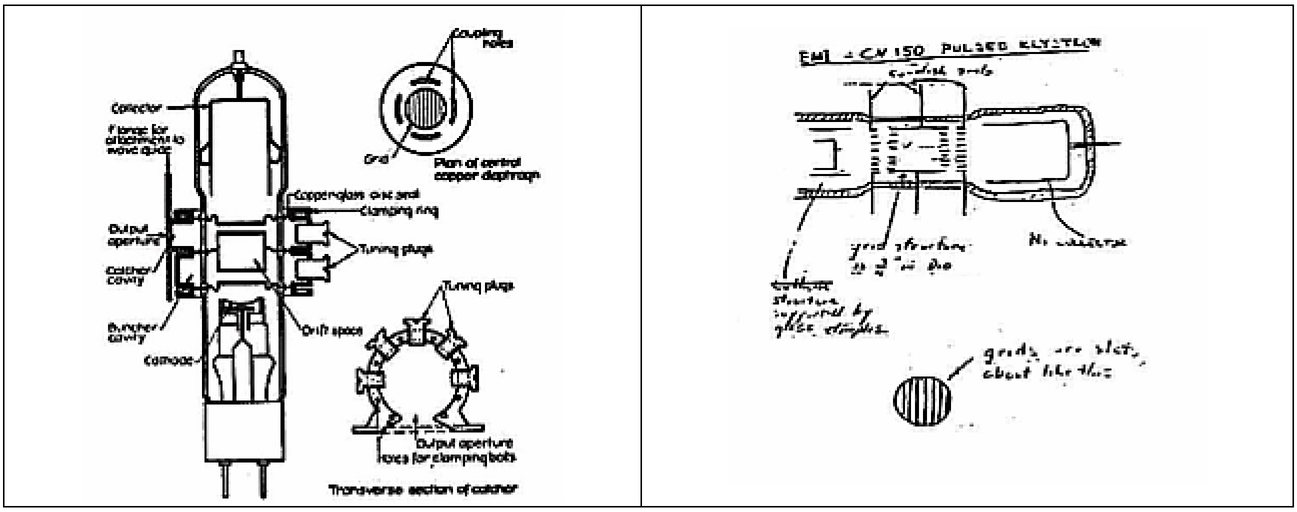

Fig. 2 - Left, sectional drawings of the klystron. Right, drafts left by Ginzton. Click on each image to enlarge

In 1948, few years after the war, Marvin Chodorow at Stanford posed near his latest achievement, the 30 MW klystron prototype MKIII, holding a sample of CV150 in his hands.

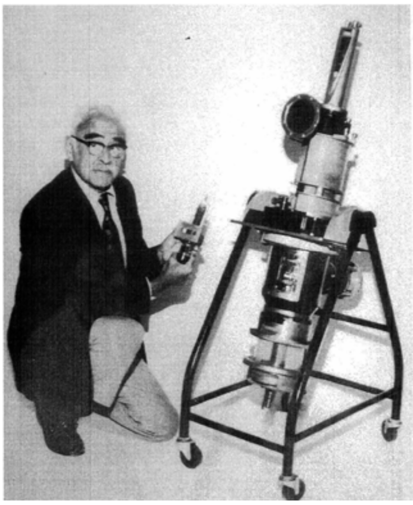

Fig. 3 - Marvin Chodorow at Stanford holding a sample of the CV150 near to the first 30 MW klystron prototype. Source: https://www.slac.stanford.edu/cgi-wrap/getdoc/slac-pub-10620.pdf

Oboe Mark IIB was the experimental set fitted with the klystron transmitter TR3539. Since the output of the power klystron was adapted to a waveguide output flange, it was necessary to design a flanged TR switch, the CV157, also used as ATR. The CV158 reflex klystron was used as local oscillator with the CV101 crystal diode as mixer.

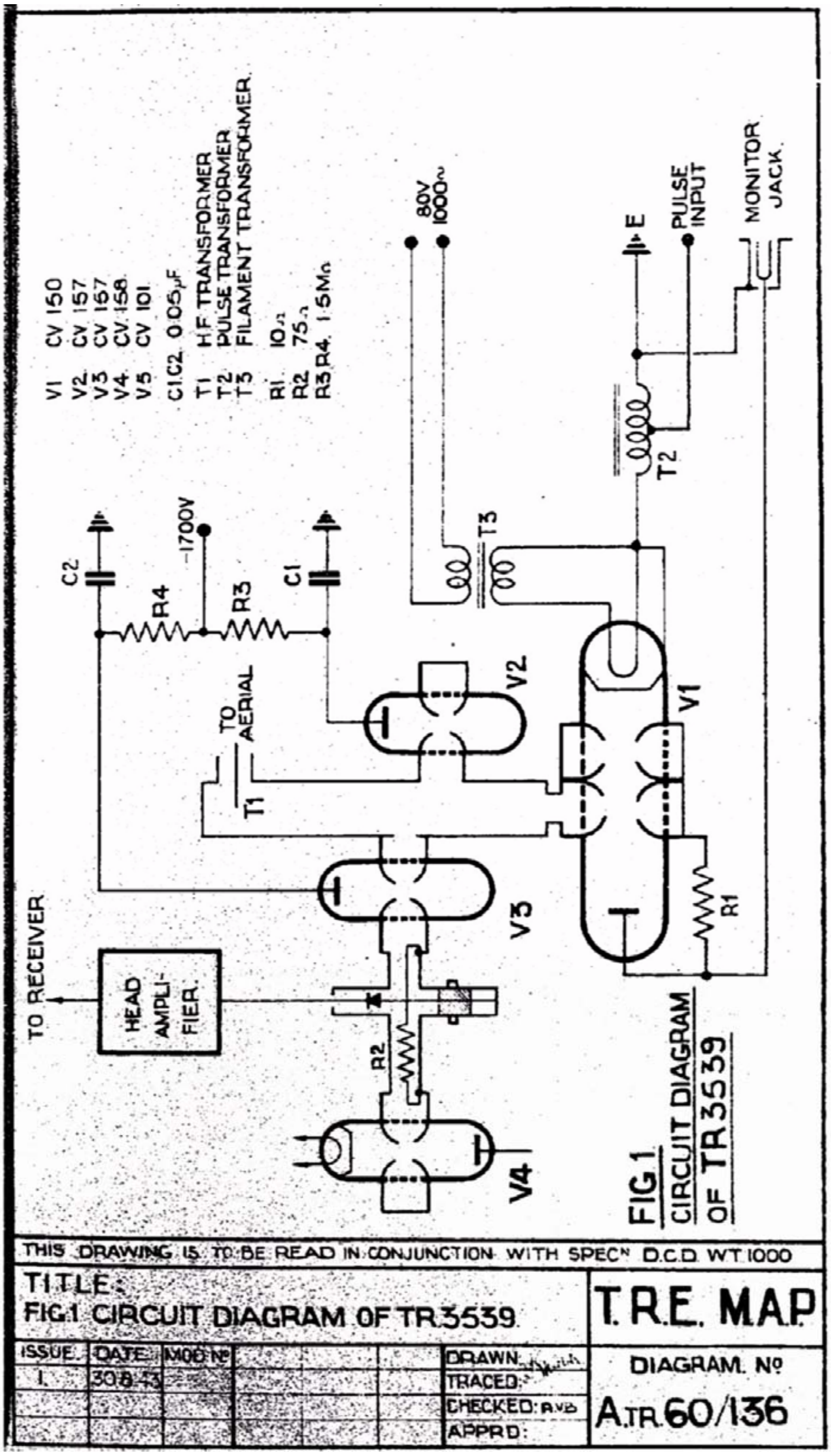

Fig. 4 - Diagram of the RF section of Oboe Mk IIB.

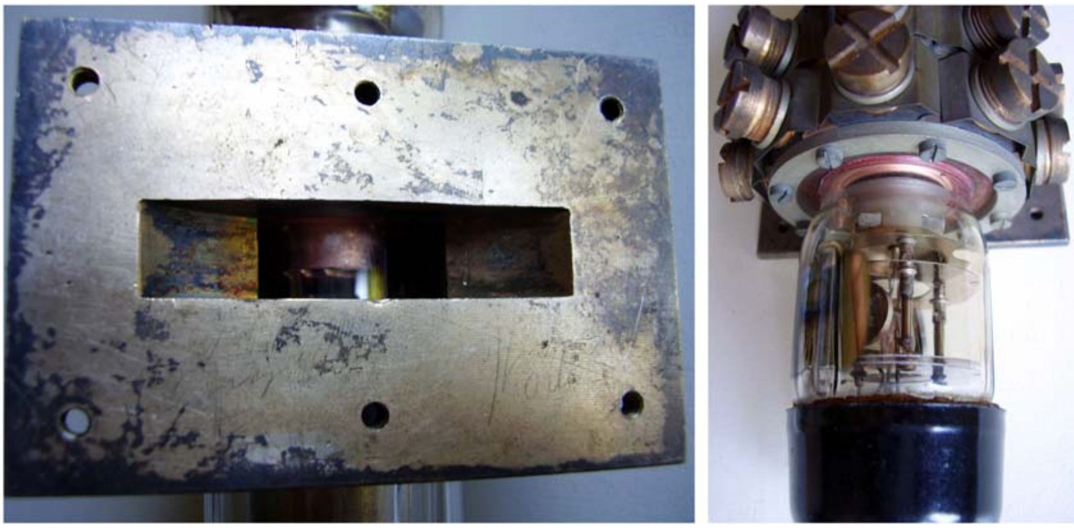

Fig. 5 - Left, the heavy and well-spaced rods of the second grid are visible from the output flange. Right, a close-up view of the large cathode. Click on images to enlarge.

We can conclude that unfortunately the decision to cancel the project to fool Germany, concentrating available resources on magnetron, delayed the use of power klystrons for several years. Luckily the same decision prevented the capture by enemy of the CV150 which, looking at the subsequent power increase of similar devices, could have led to unpredictable consequences on the development of German microwave technologies. After all, despite daily bombardments and heavy destructions, the warped CV64 sample found in the wreckage of the H2S no.6 captured near to Rotterdam led Germany in eighteen months or so to develop its own microwave technologies and its own lines of power magnetrons, still today entirely unknown.

Bibliography:

- **Echoes of War, by Sir Bernard Lowell**
- **Edward Ginzton Papers (SC0330). Department of Special Collections and University Archives, Stanford University Libraries, Stanford, Calif**
- **TRE report T1473**

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