The Sutton tube, the first reflex klystron oscillator

Early in 1940 British had taken the decision to build radio-localization sets operating around 10 cm. At Birmingham a group of scientist leaded by Professor Mark Oliphant was working since 1939 on power transmitting klystrons, based upon information and prototypes of the velocity modulated tube recently devised by Russell and Sigurd Varian at Stanford. In February 1940 Randall and Boot successfully operated their first prototype of multi-cavity magnetron. It was time to move to microwaves.

Quite early in 1940 Robert W. Sutton of the Signal School group at the Bristol University started developing a tunable single resonator klystron for the local oscillator of the receiver. Klystron was promising over other microwave sources, magnetrons or Heil oscillators, because of its predictable low noise, due to the loose interaction with the shot noise of the electron beam and to the high ‘Q’ of the output resonator. A CRT electron gun subassembly was used to generate the higly focused electron beam. To keep the noise low, the resonator iris of the interaction gap was quite large, about 5 mm. Two deep drawn copper discs formed the horned interaction gap, connecting it to the external cavity through a glass-to-copper seal process recently developed at GEC. The reflector was cup shaped, likely to keep the beam still focused in its backward travel. The shape of the internal horns was likely inspired to the Hansen’s rhumbatron resonators and anyway similar solutions can be found in parallel developments, as the linear klystrons made at Bell in the early forties.

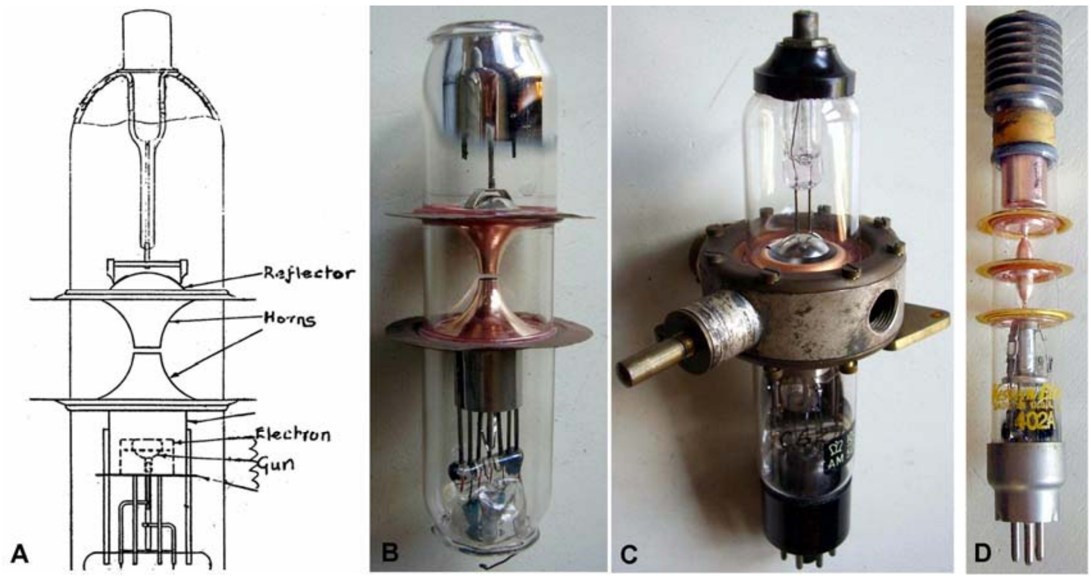

Fig. 1 - A) Draft of the Sutton tube bulb. B) A bulb believed to come from the Bristol Signal School, likely used to test suitable external cavities. C) Complete AM 10E/501, S/N 062. D) A sample of the Western Electric 402A, one of the many linear beam amplifiers experimented at Bell. Click to enlarge.

According to Callick, the first ‘Sutton tube’ operated in September 1940 with 3% tuning range. Development of the external cavity, including the coupling to the copper discs of the bulb and a low-noise tuner, was completed by December 1940. Approved as Admiralty NR89, it gave 10 mW in output at 10 cm over its 8% mechanical tuning range.

Use of NR89, and of its Air Ministry frequency variant 10E/501, was difficult due to the high resonator voltage, about 1700 V, and to the critical operation through the tuning range. The very long drift space originated unpredictable mode jumping during tuning and at fluctuations of the operating voltages. Yet the ‘Sutton tube’ was the only microwave oscillator suitable for the purpose, at least until November 1941, when the improved EMI designs, approved as CV35 and CV36, were released for production, soon followed by the Western Electric low-voltage type 707A.

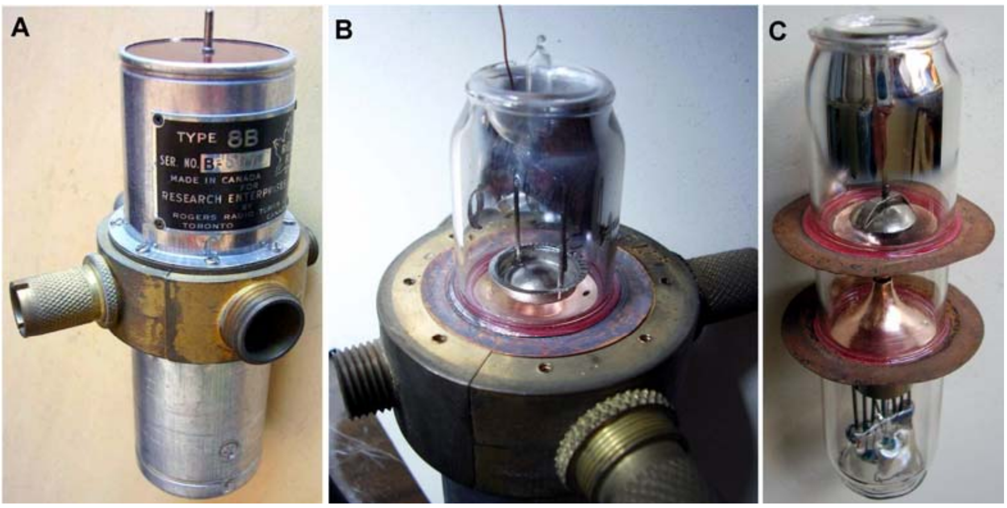

Fig. 2 - The Type 8 Canadian reproduction of the Sutton tube, made by Rogers for REL. The external resonator looks quite simpler than in the original version and supported by two aluminum half cans. The variable tuner has been removed, replaced by factory tuned plungers. Four frequency variants were made, identified by suffixes A to D. In B one sample of REL 8 with top can removed, to show the cup-shaped reflector over the deep drawn upper horn. In C the bulb of the original Sutton tube, to observe the small differences, mainly in the support of the reflector. Click on image to enlarge.

We know that British released preliminary specifications for a GL microwave radar to Canadian REL. E1189, made as REL Type 3D by Northern Electric, was indicated in the transmitter and a Bell 1020Y local oscillator with a crystal mixer to be released soon, was listed in the receiver front-end. Details of the Sutton oscillator were certainly known at Bell, where it was also X-rayed. Unfortunately, at least in the first half of 1941, Bell was unable to deliver its own local oscillator and all the early radar experimental sets had to rely upon the British Sutton oscillators, with the only exception of the Canadian variants made by Rogers for REL. To prevent the criticism of the variable mechanical tuning, the REL Type 8 klystron was factory pre-tuned to fixed frequencies, with four frequency suffixes, A to D. Type 8 was ruggedized, with two aluminum half cans supporting the resonator. It was used among the others in the Canadian REL GL3 set, delivered to Great Britain from Autumn 1941 under the Lend and Lease Act.

From the start the Sutton's design suffered from two major drawbacks, the high reflector voltage and the critical tuning. Therefore other devices were investigated between 1940 and 1941 as alternatives for local oscillator. STC owned the proper experience to propose the little known velocity modulated oscillator devised few years before by Oskar Heil and his wife and referred to as Heil oscillator. Even if efficiency of Heil tubes was very low, they operated at low resonator voltage, down to 215 V. We found samples of undocumented Heil oscillators designed to operate at 10 cm and even at 3 cm. According to Callick in 1941 both STC and GEC ran tests on planar triode structures which could operate as local oscillators, or maybe as mixers too, in the receiving section. Electrodes and their spacings in early British planar triodes were quite inaccurate, due to the use of established technologies in their construction. Anyway early in 1941 General Electric had introduced its lighthouse design with the ZP-446 prototype, evolved in the 2C40. Tubes of this family could operate at 3 GHz and beyond, since planar electrodes were accurately positioned very close to each other by glass spacers.

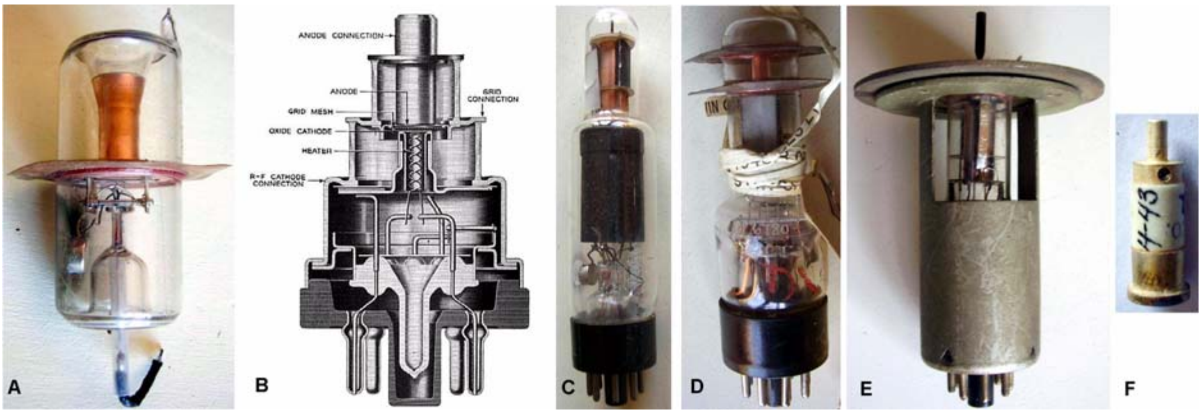

Fig. 3 - Overview of tubes investigated for use as local oscillatro in the receiver through the development of microwave radar sets between 1940 and 1941. A) CV16 was the first planar triode designed by STC Ilmore, soon followed by improved types, oscillating up to about 750 MHz. B) In February 1941 General Electric introduced its improved line of lighthouse planar triodes capable of operation up to 3 GHz and over. Glass spacers ensured very close spacings between electrodes and tight tolerances. C) The group of Fremlin at STC designed a series of Heil oscillators capable of operating down to 3 cm. The otherwise undocumented DV27 could operate at 10 cm. D) DV57 is described in the attached label as a 3 cm version of a DV55. E) CV230 is another 10 cm Heil oscillator with conductive probe protruding from the top of the bulb. F) The mixer silicon diode, proposed by Oliphant and first made at TRE by Skinner, was improved at BTH with a ceramic spacer, becoming a worldwide industry standard. Here a 1N22 made by Western Electric to the original BTH design.

Eventually reflex klystrons derived from the early Sutton tube were universally accepted as local oscillators over any other solution, from the 10 cm band down to millimetric waves.

10 cm reflex klystron: the race between England and America

Early in 1941 the Sutton tubes, the NR89 and its frequency variant 10E/501, were the only tubes usable as local oscillators in microwave radar receivers. Anyway the search for better klystron devices was active on both sides of Atlantic.

The REL type 8 was just a ruggedized variant, its electrode structure being identical to the original one. In 1941 in England EMI started improving the Sutton design, reducing the diameter of the interaction gap to 2 mm and using a much smaller reflector placed very close to the resonator, to minimize the tendency to mode jumping. According to Callick, the experimental work was completed in June 1941 and first samples of the frequency variants CV35, CV36 and CV67 were released by November. The new oscillators were much more stable, even if still requiring resonator voltage of about 1400 V to operate.

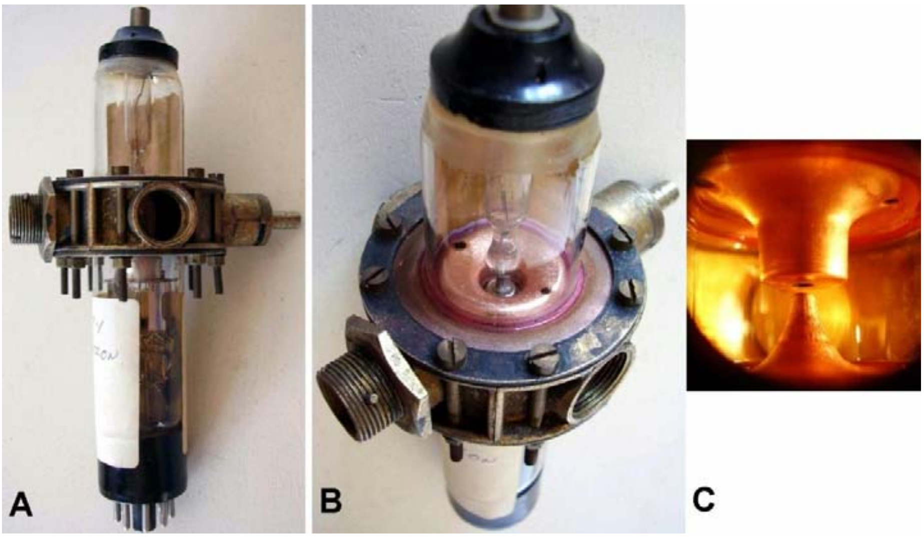

Fig. 4 - Images of an early version of CV35, still with bakelite top spacer. In B) can be observed the small size of the reflector, deeply penetrating into the top end of the resonator. In C) a close-up view of the electrode shapes at the interaction gap.

By the middle 1941 McNally at Bell Labs had built samples of low voltage klystron tubes. The new design approach took advantage of mesh grids to increase coupling between the resonator system and the electron beam. Grids became bright white in operation, but the tube oscillated at 300 V. Samples of the WE 707A, complete with suitable external resonators, were released by the end of 1941, almost at the same time of the renewed EMI klystrons. The announcement of the low-voltage WE klystron certainly caused considerable disappointment in England

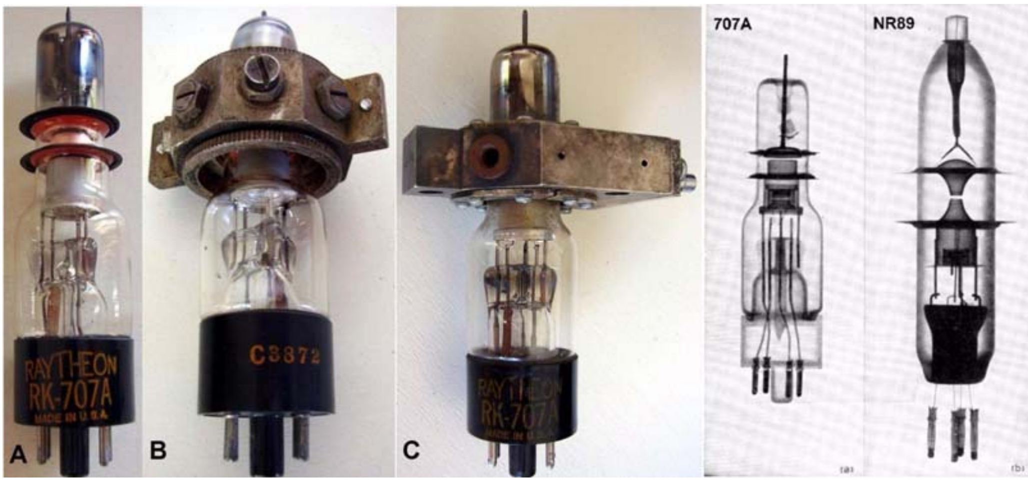

Fig. 5 - Samples of 707A, two of which with different resonating cavities installed. On the right the X-ray photo of the WE 707A compared to the one of the British NR89. (Source Bell Labs.)

As soon as news and likely samples of the new 707A arrived in England, TRE requested the development of a new family of oscillators capable of operation under 300 V. The design of KR6 family was carried out by EMI with assistance from the group of Signal School at Bristol. Moving from samples of WE 707A, the group built intermediate experimental units, one of which is in the figure below. They devised a grid made of thin corrugated tape, about 1 mm high, welded to the internal ribs of the resonator. The tape mesh offered the minimum impact surface to electrons, while giving the best interaction with them.

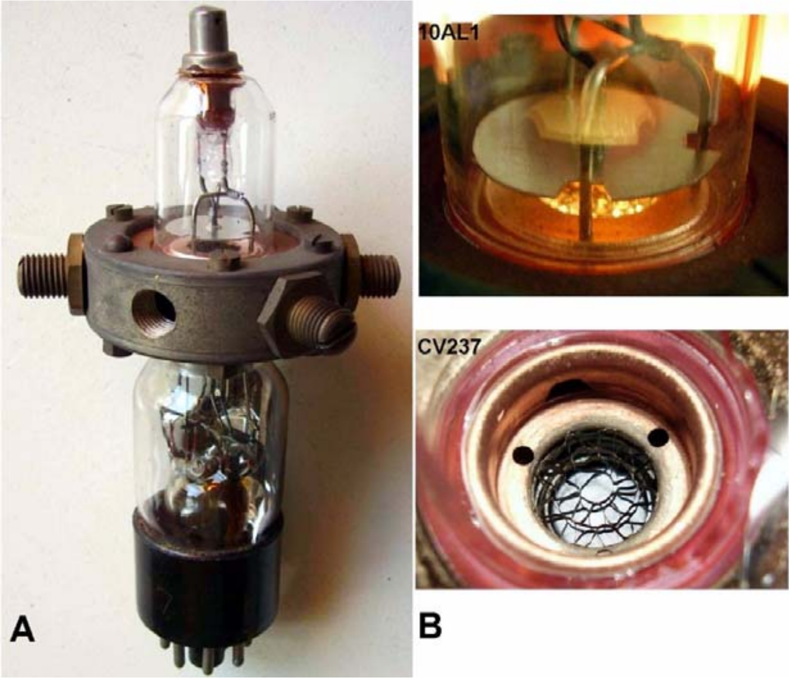

Fig. 6 - A rare sample of an experimental klystron built at Bristol during the development of the low voltage EMI KR6 family. The shape of the tube recalls that of a 707A. The grid of the prototype, made of corrugated tiny ribbon, can be barely seen in the photo at top right. On the bottom, the grid of a production klystron, the CV237.

The new KR6 design led to the frequency variants, CV116, CV237, CV238 and CV272. They well outperformed the American design, being considerably smaller in size and operating at 230 V resonator, the same supply voltage of the IF section. They also facilitated the field replacement, since all the British klystrons came with factory installed and pre-tuned resonator system.

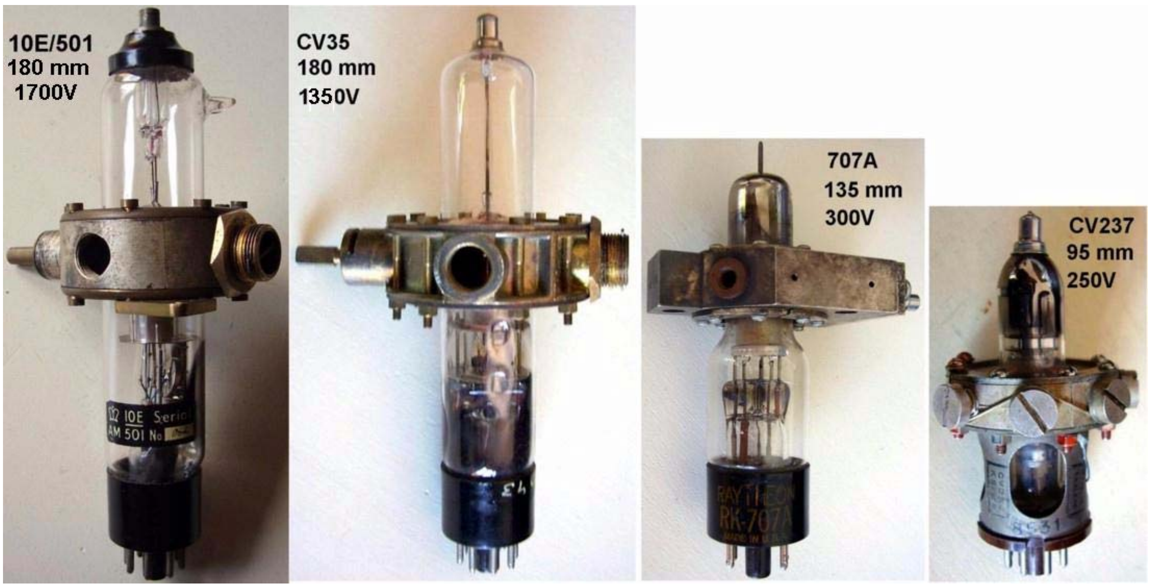

Fig. 7 - Evolution of the 10-cm local oscillator in the years from 1940 to 1943. The Sutton tube was ready by the end of 1940. The 10E/501 and its frequency variant NR89 were made through 1941. The CV35 and its frequency variants were delivered by November 1941. The WE 707A was delivered by December 1941. The CV237/CV238 are frequency variants of KR6, whose development started in mid 1942 and ended in May 1943. Click to enlarge.

The British packaged solution was appreciated by Raytheon which introduced its own 10-cm packaged oscillators, based upon their 2K28 improved variant of early 707A/B tubes.

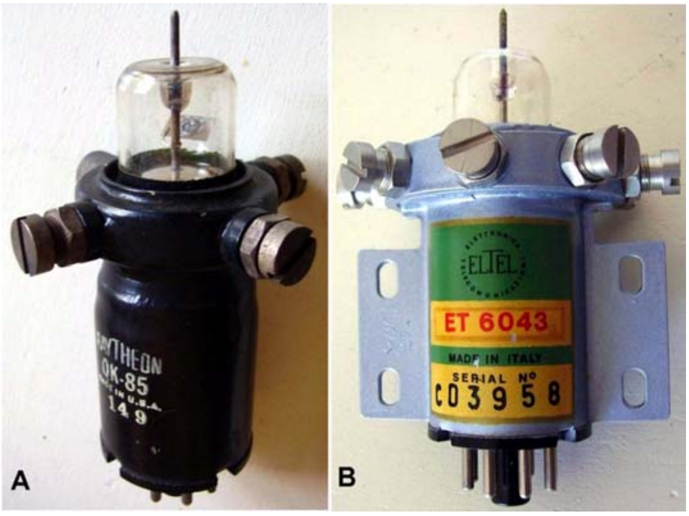

Fig. 8 - Two Raytheon packaged klystron oscillators. Both QK-85 and 6043 were variants of 2K28, with factory installed resonator. The sample in the right photo was made by ElTel, formerly ELSI which in the early sixties was a qualified Raytheon plant in Palermo, Italy.

The ‘Sutton tube’ and its Canadian direct derivatives were used through 1941, in the quasi experimental phase of 10-cm radars. About one year later, when the CV register was activated, both the early ‘Sutton’ variants, CV10 and CV11 allocated respectively to NR89 and to 10E/501, had become obsolete.

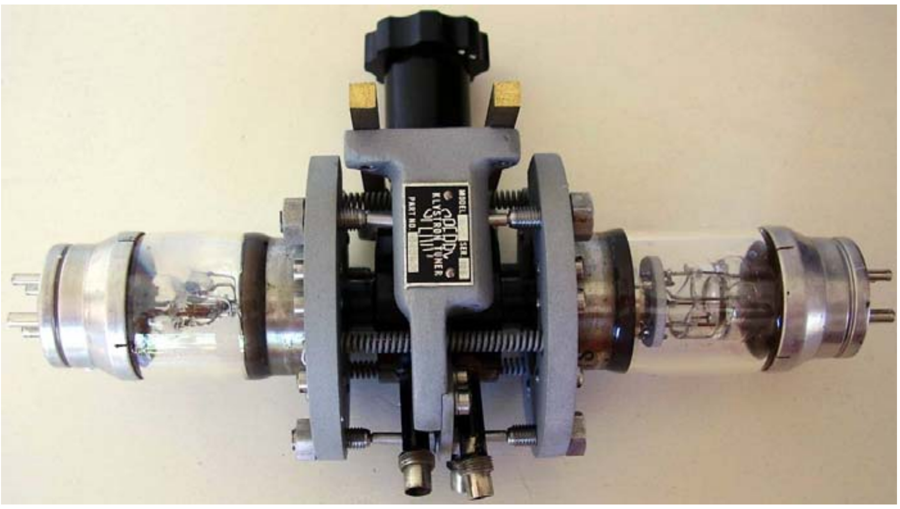

Fig. 9 - A very early Sperry linear klystron, about 1939. Click to enlarge.

The ‘Soft Sutton tube’, the first TR switch

According to Callick the first TR cell for 10 cm radar systems was designed by A.H. Cole at the Clarendon Laboratory around the mid 1941. To protect the silicon mixer diode, TR must ionize very rapidly at the magnetron pulse build-up. Then it must deionize rapidly at the end of the transmitter pulse, otherwise echoes are prevented to reach the receiver. The use of a high-Q resonator greatly improve the ionization. NR89 ‘Sutton tube’ with its ‘rhumbatron’ resonator was at the time already in production by EMI and E.K. Cole and bulbs were readily adapted to the new application. The electron gun and the reflector were removed and the bulb was filled with low pressure water vapour. Several months were required to reach reliable operation. At the end, an electrode similar to the reflector was used as keep-alive electrode, to maintain the tube near to ionization. A small quantity of argon was added to the water vapour, to obtain the required ionization and deionization time and an acceptable operating life.

Although the TR cell was approved as CV43 only at the end of 1942, its design details had been sent to America since the end of 1941. At the beginning it was referred to as ‘soft Sutton tube’ because the use of a bulb very similar to that of NR89 and of its gas filling, similarly to the use of referring to very early gas-filled triodes as ‘soft triodes’. Later versions of CV43 used different resonators, derived from improved klystron designs.

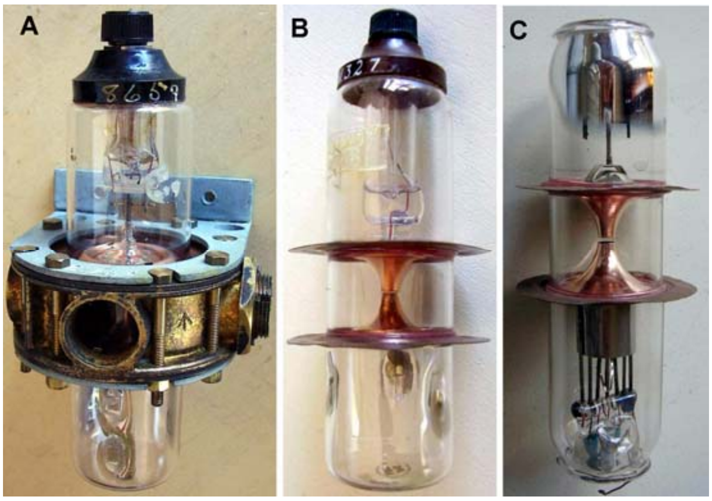

Fig. 10 - CV43 TR was also referred to as ‘soft Sutton tube’, since in it started being built around a depopulated ‘Sutton tube’ filled with water vapour. B) The glass bulb of a TR cell compared with the bulb of a ‘Sutton tube’: the electron gun is missing in the first one, while the reflector is modified to be used as ‘keep alive’ electrode. Click on image to enlarge.

Bibliography

a) **Callick, Metres to Microwaves**
b) **Hamilton et al, Klystrons and Microwave Triodes**
c) **Knowles Middleton, Radar Development in Canada**
d) **Southworth, Principles of Waveguide Transmission**
e) **Direct observations**

All the tubes in the photos are from the ase-museoedelpro collection

Last edited on 15 February 2019 by Emilio Ciardiello