The development of the British reflex klystron as local oscillator in microwave radar receivers

We know that British carefully planned all the developmental steps for their radar sets, including the use of microwaves when elsewhere the upper limit of usable frequencies was around 500 MHz. For each step, or frequency band, they settled the basic architecture and the standards which were universally accepted, remaining basically unchanged until today.

In 1939, when they decided to have radar sets operating at 10 cm wavelength, everything needed for the purpose, components as well as instrumentation, had yet to be invented. One year later, in the summer 1940, the E.1189 magnetron outperformed any other known transmitting tube, generating pulses in excess of 10 kW at 3 GHz. For the local oscillator of the receiver the decision had been taken of using a reflex klystron, because of its predictable low noise level, due to the presence of the high Q cavity at the output loosely coupled with the electron beam. Basing upon information on devices built in the US, the development was undertaken by Robert Sutton of the Signal School group at the Bristol University. According to Callick, he took advantage of a new copper-to-glass seal process developed at GEC to extend the internal resonator gap to an external tunable cavity.

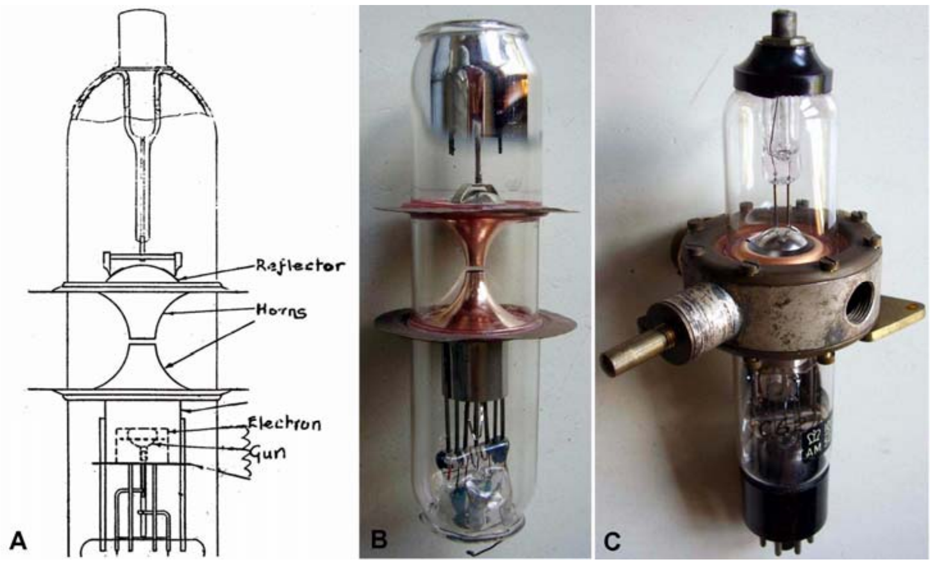

Fig. 1 - A) Drawing of the Sutton tube with the electron gun, the two horn-shaped resonator terminations and the cup-shaped reflector. B) One of the very early bulbs of Sutton tube, likely coming still unbased from the Bristol Signal School where it was used in the developmental job of adapting an external cavity. C) A complete NR89 reflex klystron: this sample for Air Ministry is labeled as 10E/501, S/N 062. Click on images to enlarge.

The internal electrode arrangement of the tube is given in the drawing of fig. 1A. Sutton used a CRT electron gun to generate a focused electron beam. The horn-shaped resonator terminations likely ensured uniform acceleration of electrons to the interaction gap. The top reflector was cup-shaped to help maintaining the beam still focused after the reflection. The design of the bulb was completed by September 1940, when the first ‘Sutton tube’ started to oscillate, but the complete design of the NR89 with its external cavity was released for production only in December.

NR89 required about 1700 V resonator voltage to deliver 10 mW at about 3 GHz, with just 3% tuning range. All the voltages, including that of the electron gun, had to be well regulated. Tuning was very difficult. The excessive drift space, due to the long distance between the resonator gap and the reflector, caused the tendency to mode jumping which had to be corrected by frequent adjustments of the focusing voltage.

Likely Sutton used that shape of internal resonators inspired by the latest developments at Bell, some of which illustrated in the images 2A and 2B below.

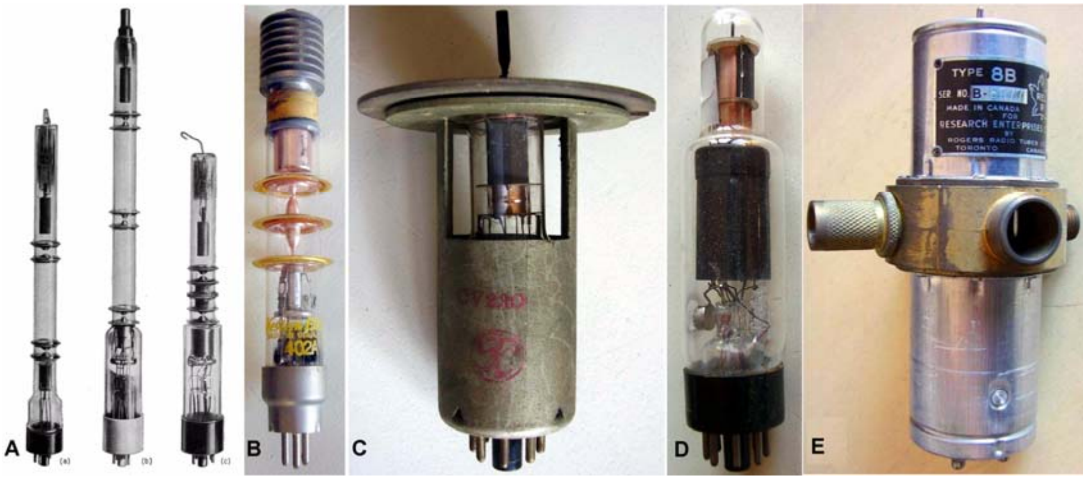

Fig. 2 - A) Experimental klystron amplifiers developed at Bell Telephone around the early 1940, all using deep drawn resonator terminations. B) The WE 402A was a linear beam klystron, using similar shapes of the internal resonator discs. C) and D) Two experimental Heil oscillators, the CV230 and the DV27 , operating in the S-band. E) In 1941 NR89 was redesigned by Canadian Rogers for REL. Type 8 mechanically ruggedized klystron was used in radar sets delivered to Britain from 1941 under the 'Lend and Lease Act'. Click to enlarge.

In images 2A and 2B we see samples of Bell linear-beam klystron amplifiers, some experimental around 1940, all with deep drawn resonator discs, which could have influenced the Sutton's design. NR89 proved to work definitely better as local oscillator than either Heil tubes developed by Fremlin at STC, CV230 and DV27, and the oscillators that Bell was developing. The Bell Labs oscillator listed in the preliminary specifications of the Canadian REL GL 3 had to be hastily replaced by the Type 8 reflex klystron, a ruggedized reproduction made by Rogers of the British 'Sutton tube'. In England NR89 was also manufactured by E.M.I. and E.K. Cole. Despite their severe drawbacks, NR89 and its Canadian reproduction were the only reflex klystrons available through the experimentation phase of S-band radar systems and anyway until the end of 1941.

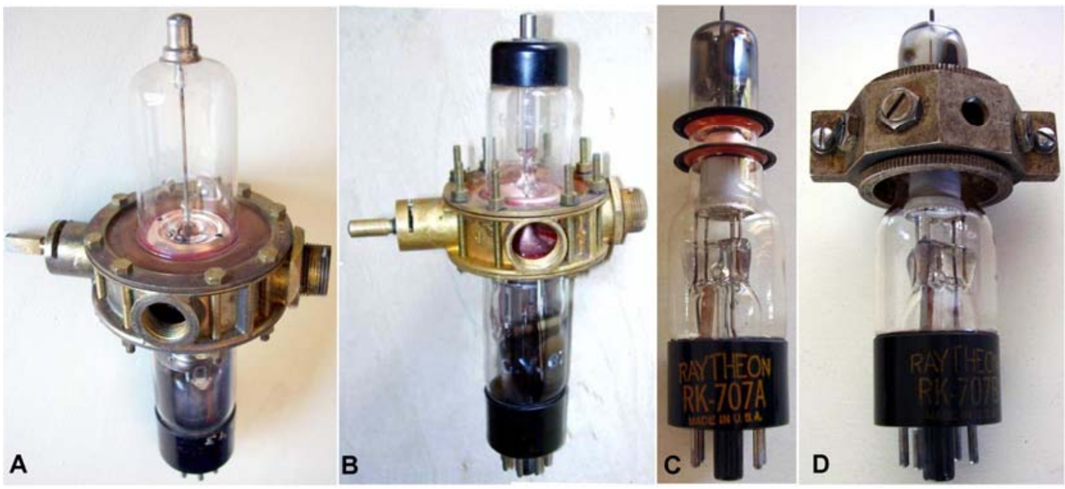

Fig. 3 - A) Sample of CV35, 100 mW minimum from 2970 to 3095 MHz. B) CV67 tuned from 3226 to 3370 MHz. Both required 1500 V resonator voltage. C) and D) For the WE design 707A the external cavity was supplied by customers at the any frequency over a range from 2.5 to 3.75 GHz. 80 mW at 300 V resonator voltage.

The design of the NR89 was deeply revised by E.M.I., reducing the iris diameter, so to increase the interaction between the resonator and the electron beam. The almost flat reflector was moved close to the interaction gap, reducing the drift time of electrons to 1½ period. Experimental work ended in July 1941 and frequency variants of klystrons made to the new design started to be delivered by

November as CV35, CV36 and CV67. As for NR89, the new devices were all supplied with factory installed resonating cavity, pre-tuned at the center of the specified frequency range. Minimum output power was 100 mW. Resonator voltage was still high, 1500 V, but not as critical as before.

More or less in the same days Western Electric was delivering samples of its own design, the 707A. It was inspired by the NR89, but considerably different. First of all only the evacuated bulb was supplied, external cavity being added by the customer to the wanted frequency. The disc rims at the gap were flat, very close to each other. Wire grids, brazed to the disc rims, improved the coupling with the electron beam. Also the flat reflector dish was mounted close to the gap. As result 707A gave 80 mW at 300 V resonator voltage, operating at any frequency determined by the external cavity, from 2.5 to 3.75 GHz.

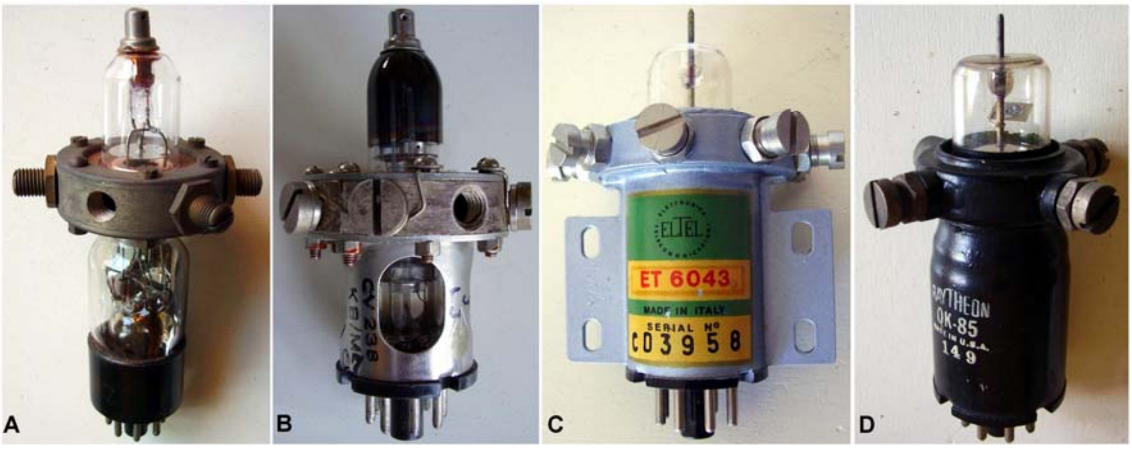

Fig. 4 - A) A British experimental prototype, likely from the Signal School at Bristol, intended to define electrode designs for a 707A-like low-voltage oscillator. Its grids are made of thin and corrugated tape, brazed to the inner rim of the copper discs. About second half 1942. B) The CV238 is one of the 10-cm klystrons derived from the previous experimentation. The family included some frequency variants of the KR6 prototype and was introduced by May 1943. It delivered 150 mW at 250 V reflector voltage in a compact and sturdy assembly. The same design approach inspired some later Raytheon designs, such as the 6043 (C) and the QK-85 (D).

British TRE, at the early news of the low-voltage 707A, asked for a new design, capable of operation under 300 V. Early development of the design was run by the Signal School group at Bristol, who also built experimental prototypes moving from available information on the American type. Grids of 707A became bright yellow in operation due to electrons striking on the wires. New grids were devised with low front section, based upon a very thin corrugated tape brazed to the inner rims of the copper discs. The new design gave origin to a family of compact and sturdy klystron oscillators, including the frequency variants CV116, CV237, CV238 and CV272. All operated at 250 V resonator voltage, with an electronic tuning range of 30 MHz and 150 mW output power. By the way, the idea of factory installed and adjusted cavities was accepted also by Raytheon, with the introduction of some proprietary designs as the 6043 and QK-85.

The ‘Sutton tube’ also originated another family of components based upon the same resonating cavity. The CV43 TR switch used the same basic resonators of the klystron. The bulb was filled with low-pressure water vapour for fast deionization, the electron gun was removed and the reflector used as keep-alive electrode, to bias the gap near to ionization. TR switch was also known as ‘soft Sutton tube’ in analogy with the soft triode detectors, filled with some gas to enhance their sensitivity, at the beginning of the radio. CV43 was soon followed by other similar TR switches designed to operate with different magnetrons and differing from each other for resonating frequency, deionization time and power ratings. The British ‘soft Sutton tube’ inspired the early WE TR switches, as the 702A, the 709A, the 721A and even to the X-band 724A. The major difference is that British TR switches were usually supplied complete with pre-tuned external cavity, while

WE supplied only the glass bulb to be mounted into any suitable cavity. Of course WE used deep drawn copper disc assemblies derived from the Bell experimental klystron line.

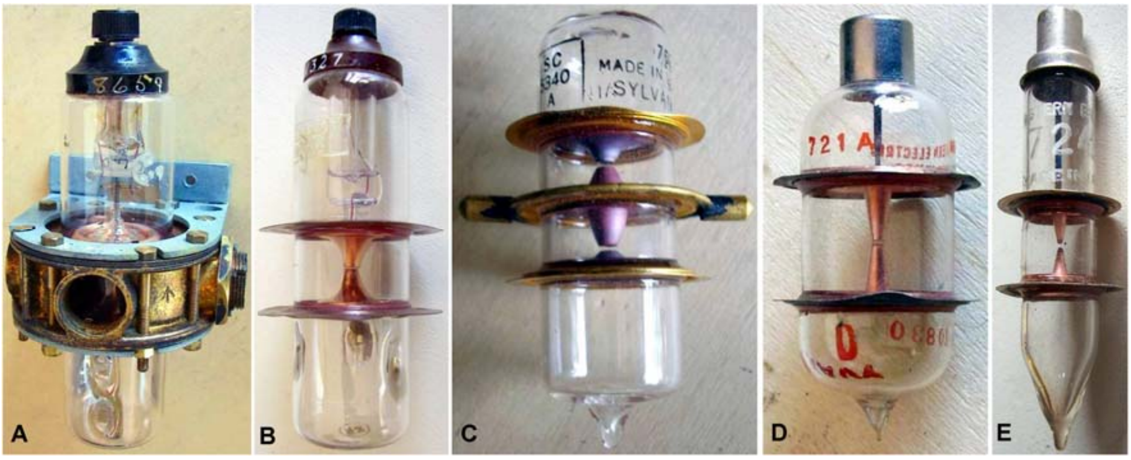

Fig 5 - A) The early 'soft Sutton tube', the CV43 S-Band TR switch. B) The internal electrode structure is visible in this CV1297. C) 702A is the first TR switch designed by WE. Its electrodes are inspired to the resonator discs of the experimental Bell klystrons of fig. 2. D) 721A is a later design used as 10 cm TR. Its gap was thermally compensated. E) 724A was a scaled down design used in X-Band antenna duplexers. Click to enlarge.

In late 1940 the Clarendon Laboratory, in close touch with E.M.I., started scaling down the NR89 design, to operate at 3 cm wavelength. The greatest obstacle arose from unacceptable losses in the glass spacer between the two resonator discs. Blumlein of E.M.I. proposed a three-quarter wave mode harmonic resonator. Glass was sealed at the nodal circle, so that the spacer had no effect on the RF path. Callick gives a detailed description of this solution. Few samples of KRN2, approved as CV87, were delivered by September 1942. Early in 1943 a simplified design, the CV129, replaced CV87. The KRN2 experimental work also originated structures with harmonic resonators operating at 24 GHz. They were later perfected by Raytheon into the 2K33 and its derivatives. Heil oscillators were also experimented in the X-band, as evidenced by the STC DV57 in fig. 6.D, but WE devices as 723A/B had already set new standards as local oscillators in radar receivers.

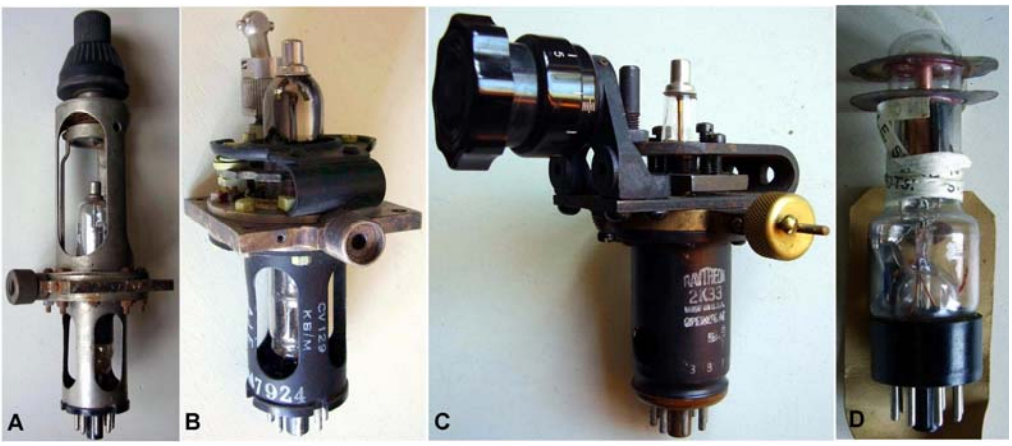

Fig. 6 - A) KRN2, approved as CV87, was the first British X-band reflex klystron. B) CV129 replaced CV87 after few months. C) Raytheon K-band 2K33, directly derived from the experiments at Clarendon on CV87. D) Also the STC DV57 Heil tube was experimented as local oscillator in X-band receivers. Click to enlarge

References:

- **Callick, Metres to Microwaves**
- **Knowles Middleton, Radar Development in Canada**
- **Southworth, Principles and Applications of Waveguide Transmission**
- **Hamilton et al, Kystrons and Microwave Triodes**

Last edited on December 30, 2017 by Emilio Ciardiello