Klystron Tubes

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The principle of velocity-variation, first used in Heil oscillators, was also used in other microwave amplifying and oscillating tubes. The application for klystron with integral cavities is usually credited in the early 1939 to Hahn and Metcalf and to Russell and Sigurd Varian, two brothers that worked for a while at the Stanford Physics Department with Professor Bill Hansen. Hansen had developed the theory of resonant cavities, named ‘rumbatron’, essential for the klystron operation. Sperry Gyroscope Company, interested in a blind-landing system, financed its initial development.

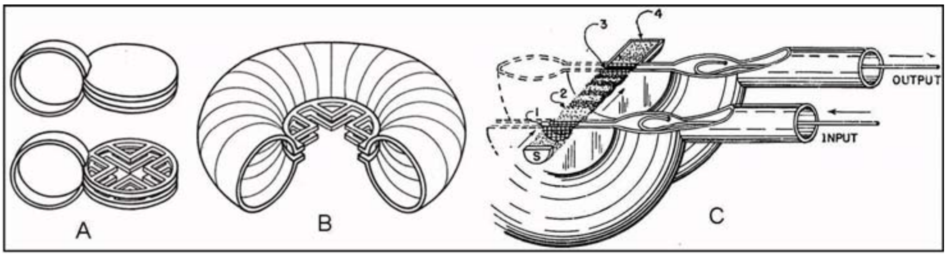


Fig. 1.1 – A and B show how the single turn LC resonator evolved in the ‘rumbatron’. The cavity may be considered as the result of many elementary sections, each being similar to A, all parallel connected. This connection results in very low inductance value. The shape of the capacitor in the middle of the cavity easily interacts with an electron beam. Q of this kind of resonator is very high. The early form of klystron amplifier is represented in C. Here the stream of electrons coming out from the source S crosses the short gap (1) of the first resonator. When passing through the gap, also referred to as buncher, electrons are subjected to acceleration depending upon the instantaneous value of the electric field between the capacitive rings. As result of the impressed acceleration, some electrons speed-up while other slow-down, to form bunches of electrons in the drift space (2) where no external field is impressed. The electron beam, whose density is now modulated by the input signal, crosses the second gap (3), also known as catcher, delivering energy to the cavity and to output. Electrons are then captured by the collector (4).

The linear beam klystron

Two forms of such a device, also called ‘linear beam klystron’, are given in the following figure.

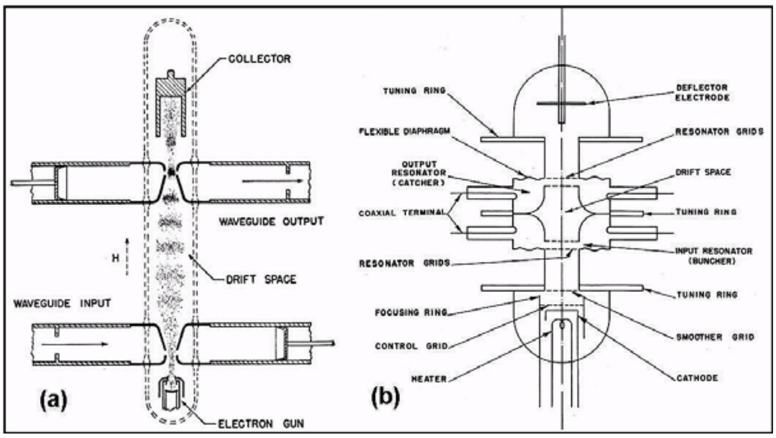


Fig. 1.2 – Left, draft of a linear beam klystron with external resonating cavities, in this case part of input and output waveguides. Right, in this early Sperry design the resonating cavities are embedded in the tube itself and flexible diaphragms allow some tuning. The collection includes a sample of this very early structure.

In fig. 1.2(a) the tube has four copper rings, the solid black sections, which form the capacitive gaps inside the glass body and connect to the waveguide resonating chambers outside. In the second example, the body of the klystron, from the upper to the lower tuning rings, is all metal with two flexible diaphragms to tune the two internal cavities. Domed glass seals support the electron gun, cathode and focusing grids, and the collector, here referred to as deflector. In both cases geometry and operating conditions are selected to have optimum bunching just at the catcher gap.

The electron gun is usually of convergent type, to have enough current density in the beam. The most common type is the 'Pierce gun', from the name of its designer, J. R. Pierce of Bell Telephone. Because of the repelling forces existing in dense electron beams, high power klystrons usually require some focusing systems. The ion-focused beam is commonly used in klystrons for TV repeaters: here a small flux of positive ions counteracts the repelling forces, being captured by an ion trap before they could strike the cathode surface. Also electrostatic or magnetic focusing are widely used. To improve efficiency, since interactions with gaps take place in the outer zone of the beam, Sperry devised a cathode capable of generating a hollow-beam.

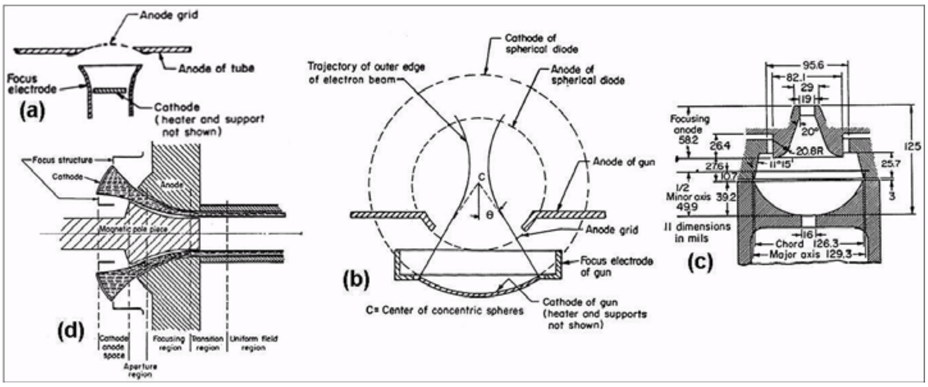


Fig. 1.3 – 3(a) shows the empirically designed gun used in the [2K25](2K25). 3(b) shows the Pierce gun, part of a spherical diode with a focusing electrode, while in 3(c) is given the section of a gun devised by O. Heil at Bell System. 3(d) shows a Sperry gun for generating hollow beams.

In a linear klystron the second cavity, corresponding to the catcher, may be tuned at a given harmonic frequency of the input signal and in this case the tube operates as frequency multiplier. Of course the catcher gap also remodulates crossing electrons in time-quadrature with respect to the residual modulation. In dual gap structures, as those of fig. 1.2, electrons are captured by the collector and no use is made of the secondary modulation. But cascaded structures can be built at no extra cost along the same beam when higher gain is required: here additional gaps take advantage of the secondary modulation.

Cascaded klystron tubes are in common use as output amplifiers in high power transmitters, as TV repeaters, fed by relatively low power frequency multiplier and driver stages. In the following picture there are some of early external cavity klystron tubes developed by Bell Labs. also including cascade types. In these tubes details of the internal electrode structure are well visible.

Fig. 1.4 – Linear beam klystron tubes developed by Bell Laboratories. 4(a), 4(b) and 4(c) are very early prototypes developed prior to WWII. 4(b), 4(f) and 4(g) are cascade types.

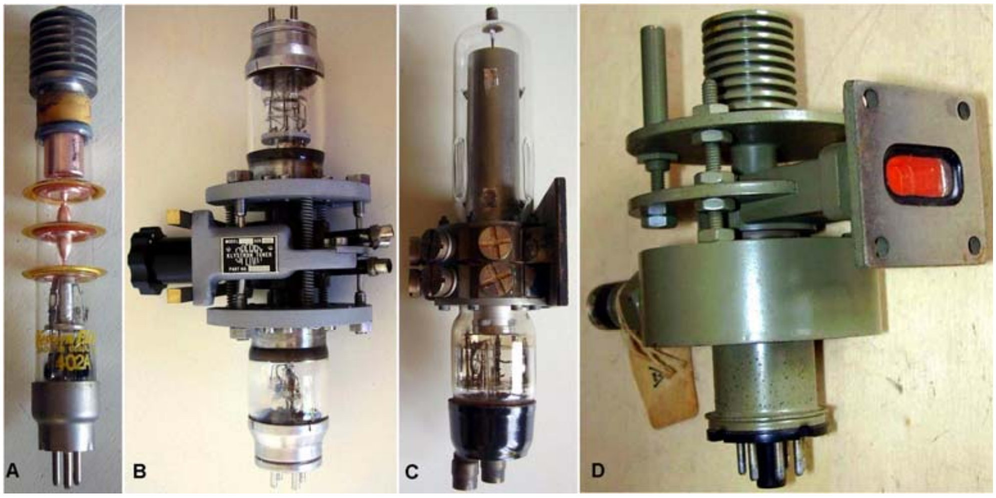


Fig. 1.5 - Linear beam klystron: A) WE 402A linear beam similar to the one identified as L.4(d) in fig. 1.4. Small production run by Western Electric. B) A sample of Sperry early type with its 11-C tuner. Likely this was the first industrialized type derived from the experiments of the Varian brothers at Stanford. Its internal schematic arrangement is given in fig. 1.2(b). C) CV150 was intended as pulse transmitter at 3 GHz. It delivered 30 kW pulses with an efficiency of about 50%. D) The Varian V-45 is a linear-beam frequency multiplier with coaxial input on the lower large resonating cavity and waveguide output. Click to enlarge.

Linear beam klystron tubes are too noisy for amplification of low level signals but have found relevant applications in high-power CW amplifiers, as television repeaters or CW radar equipment and even in microwave frequency multipliers. Below a high-power linear klystron, the F-2004.

Reflex klystrons

Any linear beam klystron may operate as oscillator adding a feedback loop between output and input cavities. Anyway when a klystron must just be operated as oscillator its structure can be simplified, leaving only one gap and negatively biasing the electrode that before was the collector. In this type of tube, referred to as reflex klystron, the negative electrode is called repeller. Electrons that have already crossed the gap, being consequently bunched, are forced by repeller to cross back the same gap that now performs the function of catcher. Philips also devised some multi-reflex structures, see A, B and C. The basic electrode arrangement of a reflex klystron is given below.

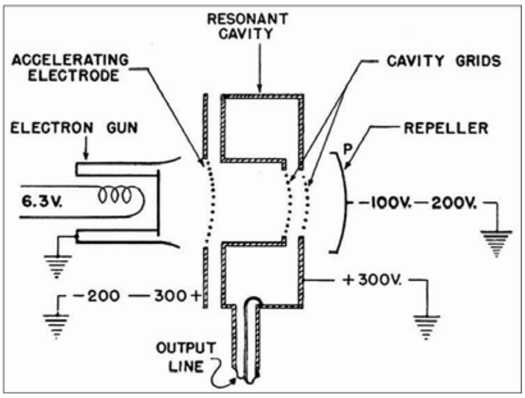


Fig. 1.6 – Draft of a reflex klystron structure, showing the repeller electrode and the single cavity with gap acting as buncher for electrons coming from the electron gun and as catcher for electrons pushed back by the repeller. Bunching occurs in the drift space, from the cavity to the vicinity of the repeller and back to resonator.

The first reflex klystron is believed to be the one designed in 1940 by Robert Sutton of the Signal School group at the Bristol University. Due to the name of its inventor, it was referred to as 'Sutton tube'. Standardized as NR89 or CV11, the 'Sutton tube' was the only device available as local oscillator for the receivers of microwave radar sets from September 1940 to the late 1941, when it was replaced by an improved EMI design. It was also copied by Rogers for Canadian REL and coded as Type 8. In the second half of 1941 even Western Electric introduced its low-voltage reflex klystron 707A.

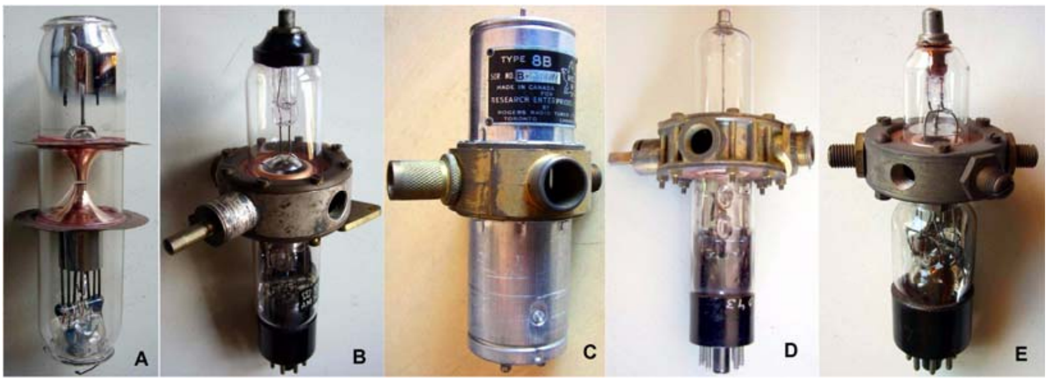


Fig. 1.7 - The story of early British reflex klystron from summer 1940 to the end of 1941. A) An unbased early sample of 'Sutton tube' likely built at the Bristol Signal School. B) A sample of NR89, with the Air Ministry code 10E/501. C) In 1941 Rogers was asked by Canadian REL to design ruggedized copies of NR89 for its microwave radar sets. The Type 8 is similar to the 'Sutton tube' with an aluminum shell and an improved tuner. D) At the end of 1941 EMI introduced an improved and more stable design which originated some frequency variants, as this CV35. E) Knowing that Western Electric had introduced the 707A low-voltage reflex klystron, in late 1941 TRE requested EMI for the development of a similar device. This 10AL1 is an experimental prototype, built to evaluate a better coupling of the resonator to the electron beam and the generated noise. The design will lead in 1942 to the introduction of a new family, including among the others the CV238, with meshes of corrugated tape brazed to the internal rim of the resonator discs.

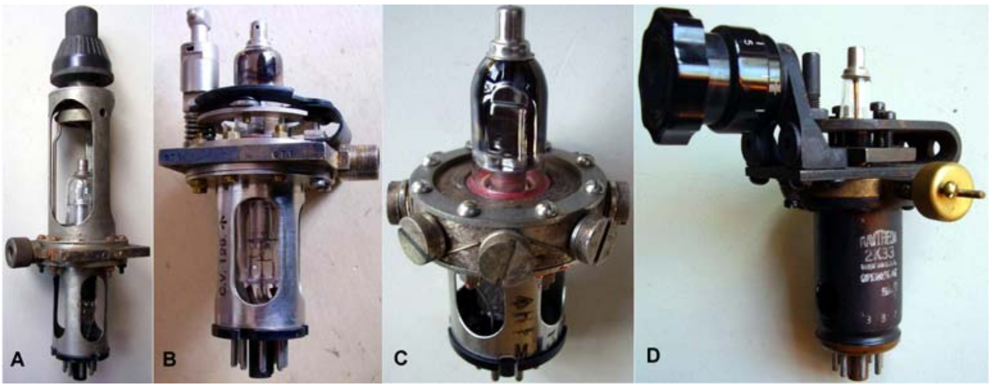
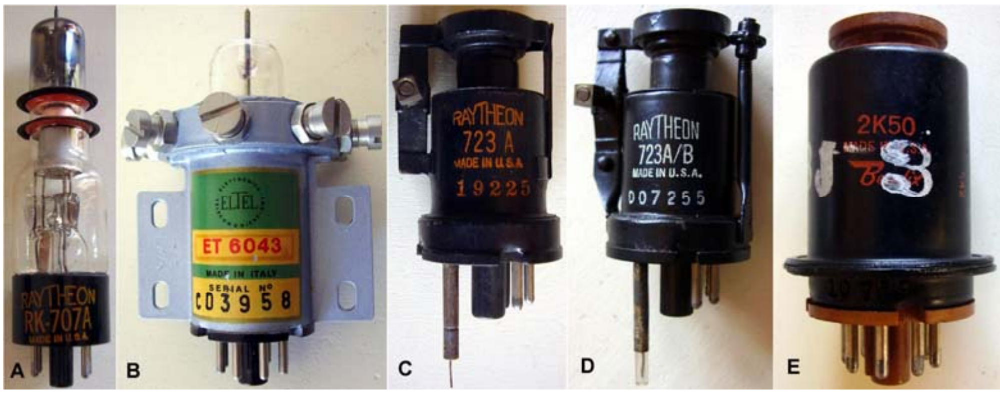


Fig. 1.8 - British reflex klystrons. A) CV87 was the very early EMI design for an X-band reflex klystron to be used as local oscillator. B) EMI CV129 and its frequency variants, CV217 or CV224, were fitted with a more simple tuner. C) CV238 was one of the frequency variants originated from the experiments on 10AL1, see 1.7E above. D) Actually 2K33 was manufactured by Raytheon but it was designed at Clarendon. Click to enlarge.



Fig, 1.9 - US reflex low-power klystron intended for use as local oscillator in radar receivers. A) 707A was the first reflex klystron designed by Western Electric for the 10-cm band, Introduced in the second half of 1941, it was characterized by greater efficiency and stability against the British NR89, due to the reduced drift space and the better coupling of the gridded resonator gaps to the electron beam. B) Raytheon introduced a more compact and stable variant, the 2K28. It was followed by packaged types, complete of factory installed cavity, as the QK85 and the 6043. In the photo a sample of ET 6043, license built by Italian ElTel. C) 723A was the first reflex klystron designed by Bell for the X-band. Tuning was accomplished by bows which compressed the upper part of the tube. Its design gave origin to countless frequency variants down to about 2 GHz. D) In 723A/B tuning strut and bows were welded to the base collar, so to broaden the tuning range. 723A/B evolved in the registered 2K25, with tighter specifications. E) In the K-band 2K50 Bell used an electronic tuner. Waveguide output flange on the top. Click to enlarge.

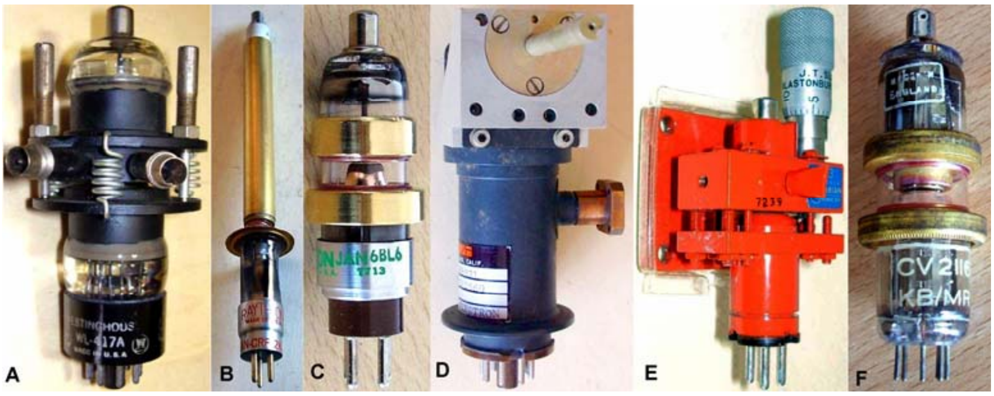


Fig. 1.10 - More reflex klystron tubes. A) 417A, registered as 2K41 was tunable around 3 GHz. B) 2K48 was designed by Western Electric to operate from 4.2 to 10.7 GHz. C) 6BL6 was widely used in signal generators, from 1.4 to 6.5 GHz. Sylvania also designed the companion 6BM6, tunable from 0.55 to 3.8 GHz. D) After the war EMI introduced a family of devices for millimetric waves. R9521 in the photo was tunable from 35 to 40 GHz. E) Varian X-13 was introduced as laboratory source for X-band microwave measurements. F) CV2116 was a British version of the US 6BL6. Click to enlarge.