TWTs and BWOs

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TWT (Traveling Wave Tube) appeared in 1946, thanks to the work of Rudolf Kompfner at the Clarendon Laboratory, Oxford. Kompfner moved to the Bell Telephone Laboratories where the device was further improved by John R. Pierce, who also left a simplified theory. TWT uses the interaction between electrons moving in a linear beam and the signal propagating along a transmission line, usually a helix. Its internal schematic is given in the following figure.

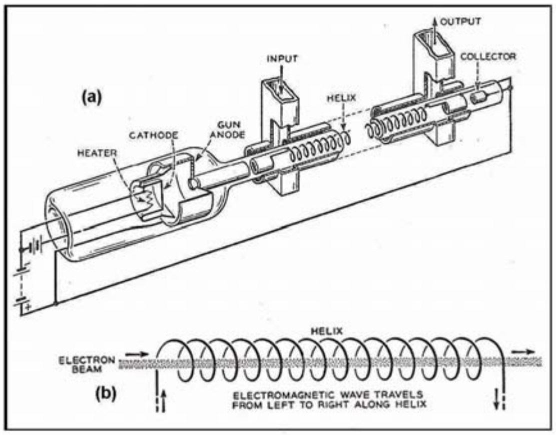

Fig. 6.4.1 – The TWT in the figure has the electron gun on the left. The generated electron beam travels to the collector through the helix, terminated at both sides by short coupling probes. The beam is then captured by the collector at the extreme right. Signal propagates in the same direction of the beam through the helix at the same velocity of electrons, as in the draft 1(b), so that additive interactions between the signal and electrons occur turn after turn for the entire length of the helix.

The figure above shows one of the very early models, with a beam of about 8 mA through the helix up to the collector. An external magnetic field parallel to the beam is applied to keep it focused throughout the length of the helix. Input and output probes are coupled to input and output waveguides. The signal propagates from the input probe through the helix up to the output coupler as in any transmission line. Depending upon the geometry of the line, usually many wavelengths long, we can imagine several signal maxima and corresponding minima moving forward along the helix in a movement that recalls the advancing of a cork-screw. The functions corresponding to the bunching and the catching of a klystron here are more or less continuous over the length of the tube. At any bunching around slow-moving electrons, some energy is lost by the beam and is transferred to the propagating signal. Bunches progressively increase as the signal does, moving in the direction of the output coupler.

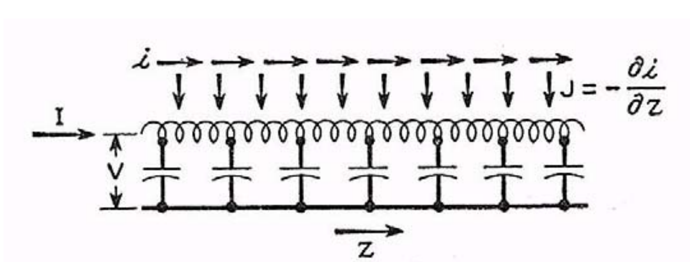

Fig. 6.4.2 – TWT model proposed by Pierce. The helix is here represented as a lumped-constants line and the signal moves forward in the direction z; successive arrows, indicated as i, represent the convection current of the electron beam. The current (J) impressed from electrons to the propagating signal is given by the relation on the right.

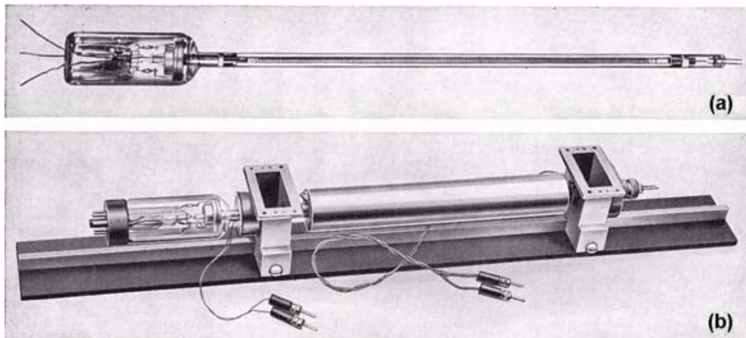

Fig 6.4.3 – Early TWT prototypes at Bell Telephone. The lower tube is mounted into the waveguide input and output transitions, with the focusing coil between them.

Helix is the simplest transmission line capable of interact with an axial beam, but other structures can be used to slowly propagate the signal: disk-loaded coaxial lines, helical waveguides or waveguides with transverse slots. TWT operates with no resonating cavity. It is therefore by nature a wide band amplifier. Bandwidth in the order of some gigahertz and power in the order of some kilowatts are easily obtainable from these devices. Since the mid fifties Bell claimed 500 MHz bandwidth, resulting in the capacity of amplifying and transmitting signals modulated with 11,000 voice conversations or 12 TV programs and 2500 conversations. In the late 1954 RCA announced a helix-coupled TWT with 2 GHz bandwidth. TWT amplifiers found an elective application in microwave communication links, as satellite communication, where still today are used. TWT structures were also investigated for UHF television tuners. Robert Adler from Zenith Radio proposed some miniature solutions that could operate between 100 and 1000 MHz. Their principle was anyway slightly different. Actually they looked and operated like bundled distributed amplifiers.

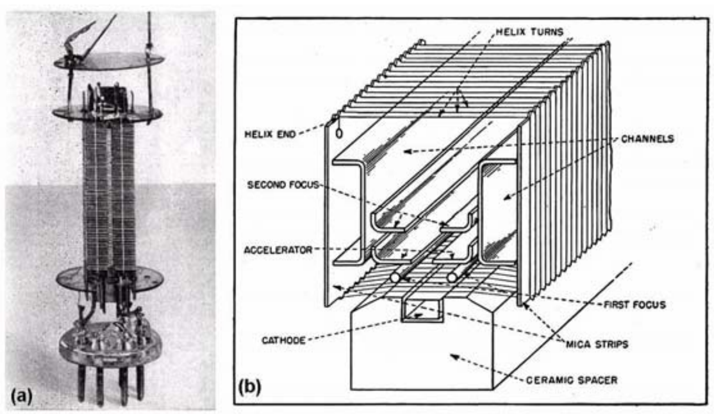

Fig. 6.4.4 – In the miniature TWT signal enters from the base, travels through the helix and is available on the top. Right, a cross-section view of electrodes. The tube operated in a magnetic field. Electronics, October 1951.

Backward Wave Oscillators (BWO)

Of course in a transmission line the RF field can propagate in either directions. The BWO uses a regressive wave, a wave moving in the opposite direction with respect to the electron beam, the operating principle being represented in the figure below.

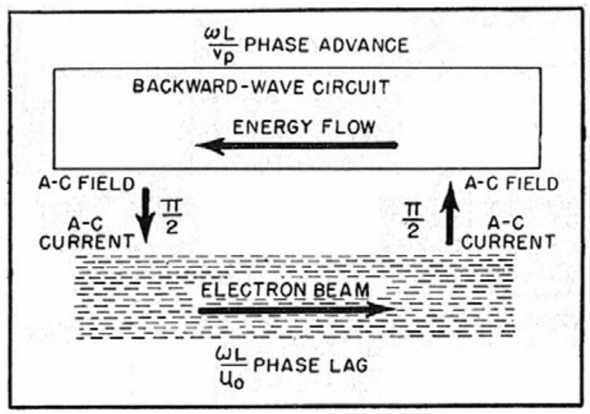

Fig. 6.4.5 – The RF field is propagated in the transmission line from right to left, with a phase velocity slightly lower than the velocity of the electron beam, which moves from left to right. On the left energy is transferred from the line to the beam, on the right it returns back to the line, each transfer adding 90-degree phase lag.

Oscillations take place when total phase shift is an integral number of cycles and loop gain equals the unity. For a given geometry, frequency is related to the velocity of the beam that depends upon the beam voltage. BWOs can be tuned over a very wide frequency range, up to three or even four-to-one ratio, just adjusting the beam acceleration voltage.

Reducing the beam current, and hence the gain, just below the oscillation start-point, the structure operates as amplifier. In this case the signal is applied to the right coupler, the one close to the collector, and the output is taken from the left coupler. Just like any other amplifier using regeneration, backward-wave amplifiers are characterized by high gain, up to 40 or 50 dB, and very-high Q.

In the next page readers can see a few samples of the TWT and BWO tubes in the collection.

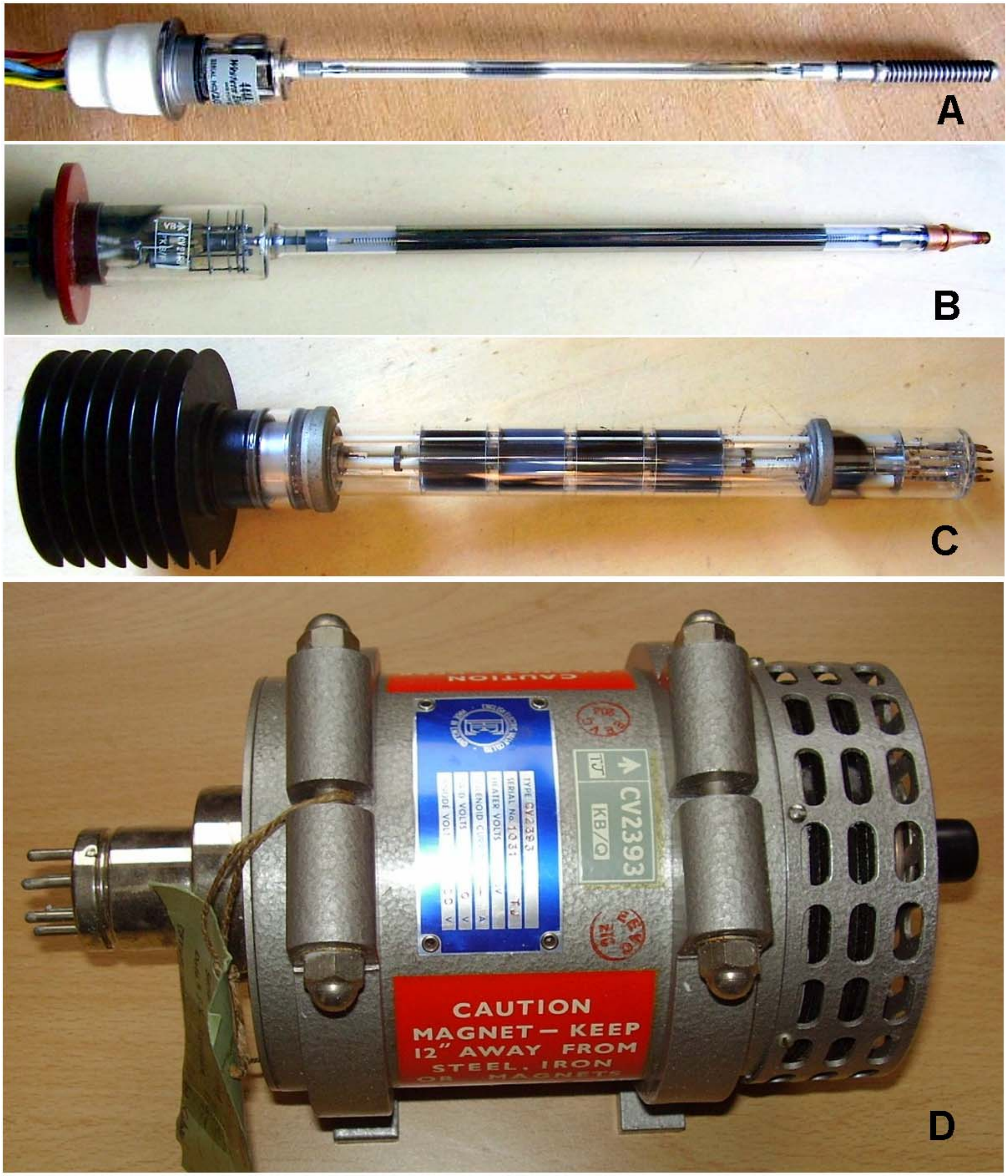

Fig. 6.4.6 - A) Western Electric 444A was one of the early TWTs in volume production for microwave radio relay transmitters. B) British STC W7/2D (CV2188), introduced in 1957, was tunable from 3600 to 4200 MHz. C) Philips 55340 gave in output 8 W typical from 3.8 to 4.2 GHz with 50 mA beam current. D) CV2393 was a backward-wave oscillator (BWO) used in electronic countermeasures, tunable from 7 to 11.5 GHz.

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