Delay Line Structures for High-Power and High-Frequency TWTs

Philip Birtel[1], Mathias Pech[1,] Lucie Sabaut[2]
[1]Thales Deutschland GmbH, Söflinger Strasse 100, 89075 Ulm
[2]Thales AVS France, 2 Rue Marc Dassault, 78140 Vélizy-Villacoublay

philip.birtel@thalesgroup.com

Abstract

Traveling-Wave Tubes (TWTs) continue to a be competitive source of RF power, from satellite navigation in L-Band [1] to satellite-borne Radar in X-Band, to satellite communications in Ku-, Ka- and V-Band [2], [3]. TWTs provide high output power, high efficiency, resilience to environmental changes, and good bandwidth and linearity.

TWTs operate by transferring the kinetic energy of an electron beam to an RF wave, thus creating RF amplification. Unlike many other vacuum-electron devices, the exchange of energy takes place continuously while beam and RF wave travel together along a delay line. The delay line reduces the phase velocity of the RF wave to that of the electrons, typically 0.1c to 0.3c. This way, synchronism is kept between the bunches in the electron beam and the decelerating phase of the RF, which is a requirement for any continuous beam-wave interaction.

The key performance parameters for delay lines are the level of dispersion (determining the bandwidth of the TWT), the strength of the electric field in the beam tunnel (“coupling impedance”, related to the beam tunnel diameter), power handling capabilities, size, and manufacturing effort. Each delay line type also has different oscillation modes, requiring careful analysis to avoid stability problems.

Historically, there have been a large number of delay line topologies. From the 1990s, the large majority of TWTs were designed and manufactured with helical delay lines, which combine very good bandwidth with high interaction impedance and acceptable manufacturing from L-Band (1 GHz) to the lower Ka-Band (20 GHz). However, it is difficult to scale this type of delay line beyond Q-Band (40 GHz). TWT designs addressing higher frequencies, or trying to increase the output power, typically feature “Folded-Waveguide” (FWG) delay lines, which combine higher power-handling capabilities with easier manufacturing, but are generally more narrow-band and less efficient.

This contribution will compare these to types of delay lines, focusing on use-cases at Thales, particularly for high-power and/or high-frequency TWTs, and highlighting current developments and trends, such as alternative manufacturing methods.

References

[1] P. Birtel, W. Duerr and E. Cakir, "Recent Developments in High-Power Traveling-Wave Tubes for Earth Observation," *2026 17th German Microwave Conference (GeMiC)*, Karlsruhe, Germany, 2026, pp. 330-332

[2] V. Guivarch, J. Gastaud, T. Dubois and M. Kojok, "New Product Dual Ka-Band TWT THL20060D Development and Qualification," *2025 26th International Vacuum Electronics Conference (IVEC),* Rotterdam, Netherlands, 2025, pp. 1-2

[3] P. Birtel, L. Sabaut and W. Duerr, "High-Power V-Band TWT Development for Satellite Uplink Services," *2025 26th International Vacuum Electronics Conference (IVEC)*, Rotterdam, Netherlands, 2025, pp. 1-2