Idiosyncrasies of TWT Amplifiers

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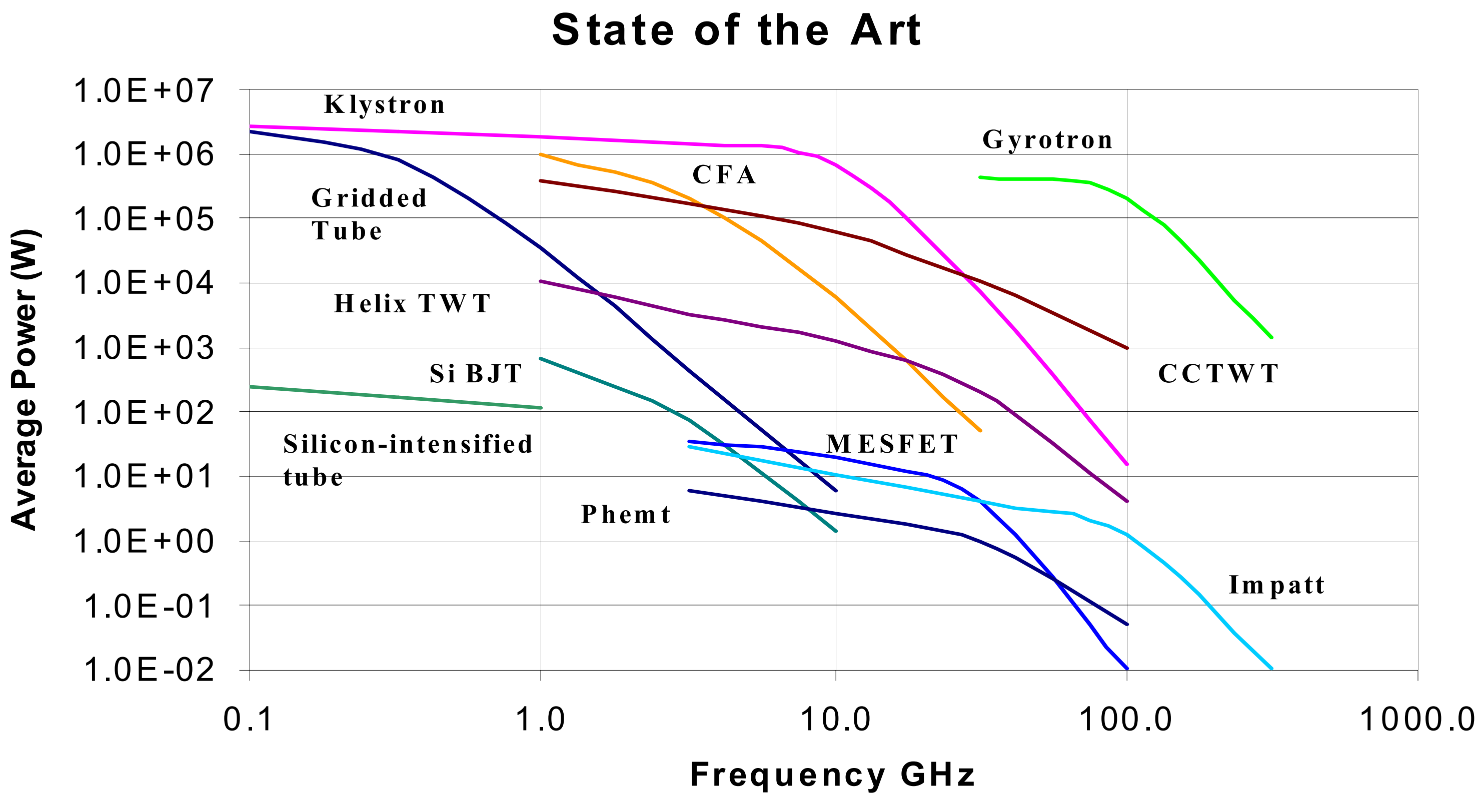
Introduction to the Traveling Wave Tube (TWT)

- The traveling wave tube (TWT) is an electron tube used for amplification at microwave frequencies – generally identified as frequencies between 500 MHz and 300 GHz or to wavelengths measured from 30 cm to 1 mm.
- The TWT is not a new device. Its remarkable capabilities and some of its potential applications have been known for nearly 60 years.
- It was invented during the latter part of World War II by an Austrian refugee, Dr. Rudolf Kompfner, while working on microwave tubes for the British Admiralty.
- Power generation capabilities range from watts to megawatts.
- For helix TWTs, bandwidths may be as high as two octaves or more and power levels of tens to hundreds of watts
- For coupled-cavity TWTs, bandwidths in the 10 – 20% range are common with power levels in the megawatt levels.

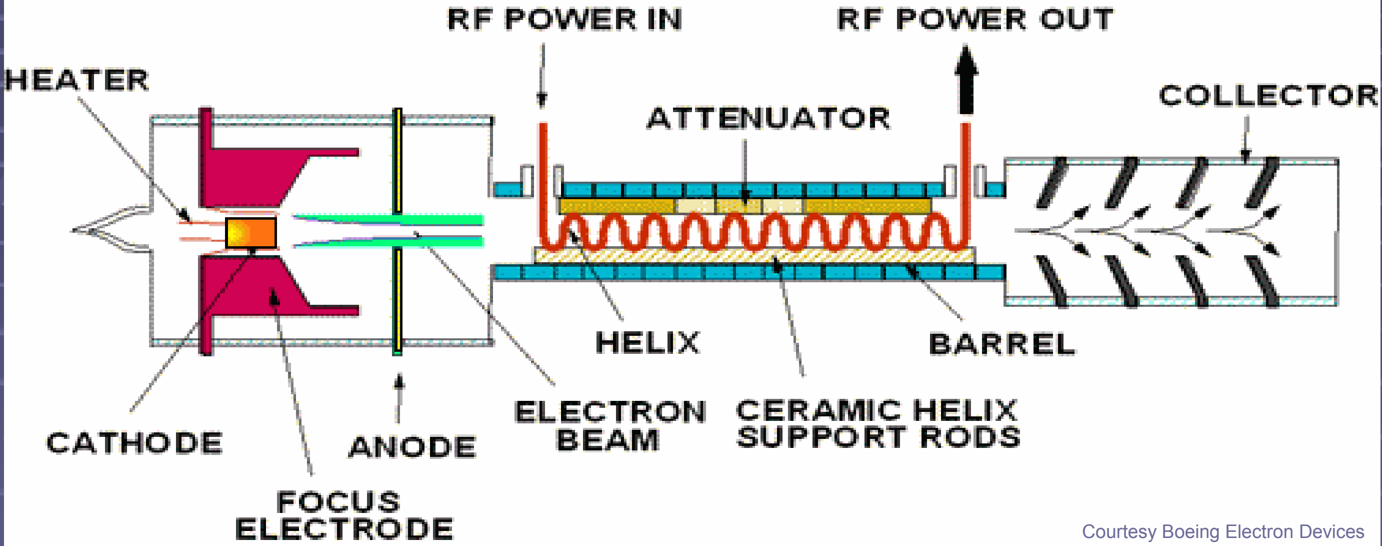
Tube Output Power



Specific Applications and TWT Design Trade-Offs

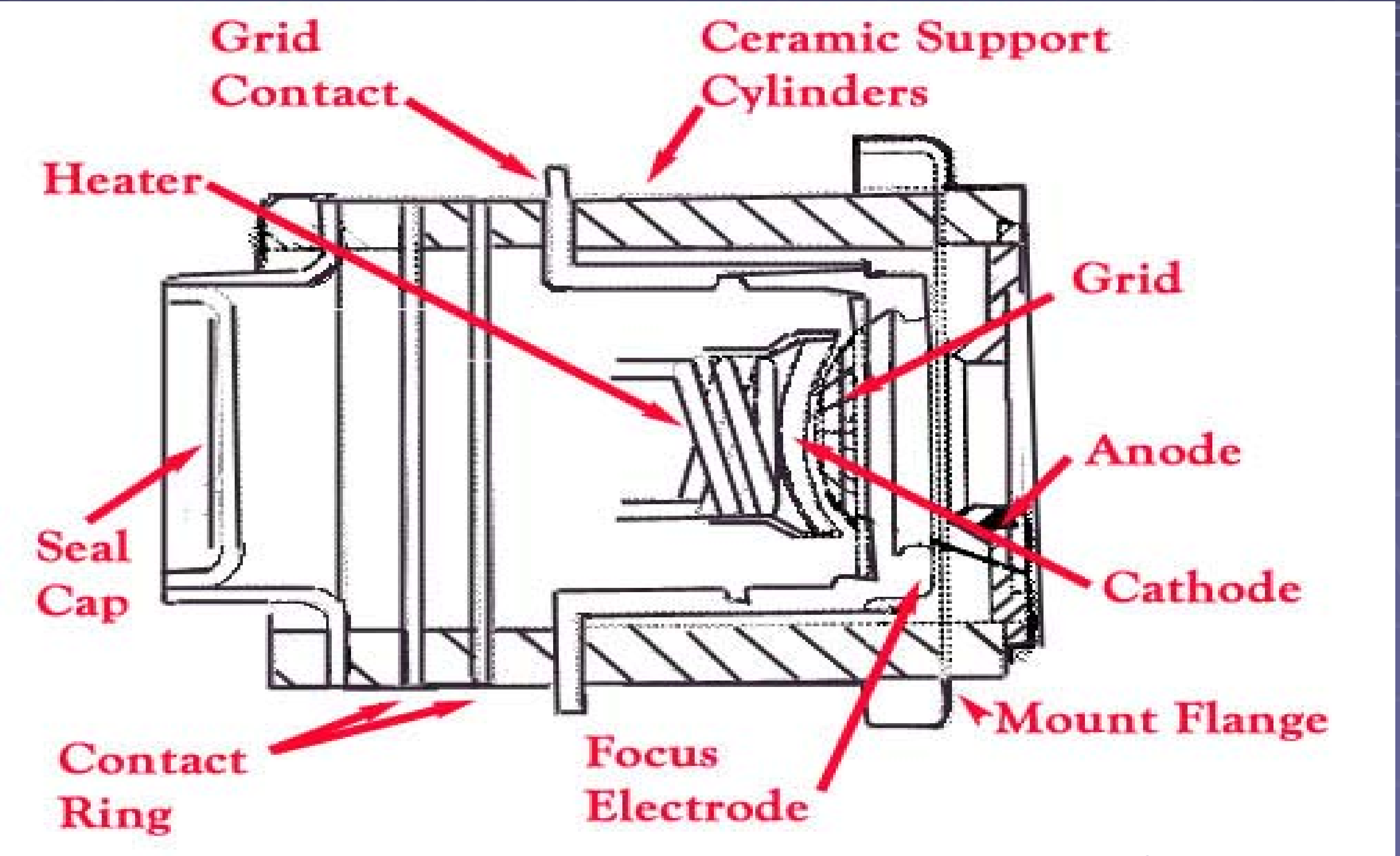
- The design of a TWT originates with the requirements to provide certain amounts of gain and power over a certain frequency band
- These considerations lead to trade-offs that affect each of the major subassemblies of the TWT. Those considerations include:
  - Type of slow-wave circuit to be used in meeting the power and bandwidth requirements, including the selection of cathode voltage and current to be used in meeting those requirements. It is important to note that the higher thermal dissipation capability in coupled-cavity TWT circuits can provide two orders of magnitude and greater power output capability than available from TWTs having helix circuits, at the penalty of increased size and weight;
  - Method to be employed for focusing the electron beam;
  - Method to be used for varying the beam current, including the method used for turning the TWT on and off as well as any modulation required during TWT operation;
  - Operating life requirements;
  - Environmental conditions under which the TWT will operate (ambient pressure, ambient temperature, shock and vibration levels, etc.);
  - Type of cooling available;
  - Size and weight limitations;
  - Cost.

Components of a TWT



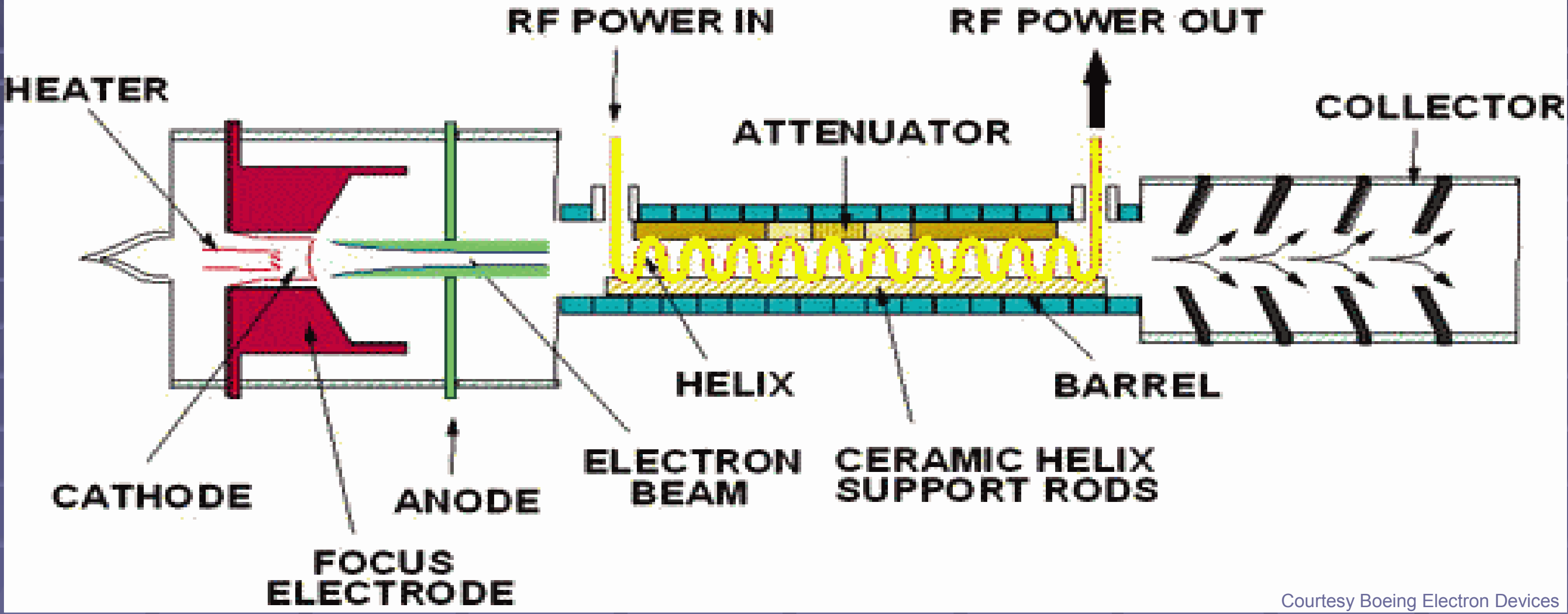
- At the left of this diagram is an electron gun assembly.
- The cathode, when heated, emits a continuous stream of electrons.
- These electrons are drawn through an aperture in the **anode** and are then focused into a well-defined cylindrical beam by a magnetic field.
- The beam is thereby caused to travel inside the slow-wave circuit for the length of the tube.
- The electrons are finally collected and their kinetic energy is dissipated in the form of heat in the **collector**.

Typical TWT Gun



Courtesy Boeing Electron Devices

Wave – Beam Interaction



- At the same time that the cylindrical electron beam is moving along the length of the tube axis, the RF signal to be amplified is fed into the slow-wave structure consisting, in this case, of a coiled wire called a **helix**.
- The RF energy travels along the **helix wire** at the velocity of light. However, because of the helical path, the energy progresses along the axial length of the tube at a considerably lower axial velocity, determined primarily by the pitch and diameter of the helix

TWT Parameters Affecting Performance

- Power vs. Frequency
- Efficiency
- Harmonics
- Intermodulation Distortion
- Gain Flatness, Phase Linearity, and Group Delay
- Noise Figure
- Noise Power Output and Carrier–to–Noise Ratio
- Dynamic Range for Linear Operation

Noise Figure

$$F(dB) = 10 \times \log_{10}\left[\frac{S_i / N_i}{S_0 / N_0}\right] = 10 \times \log_{10}\left[\frac{N_a + G_a N_i}{G_a N_i}\right]$$

- Noise figure (F) is the degradation in the signal-to-noise S/N ratio
- S_i and N_i are the input signal and noise levels
- S_0 and N_0 are the output signal and noise levels
- Na is the noise added by the amplifier and G_a is the gain of the amplifier
- Since the input noise level is usually thermal nose, the primary source of noise in a TWT is related to the density and electron velocity variations with the electron beam.
- The level of the noise power is related to the number of electrodes in the gun, the size of the electron gun, and its beam optics.

Carrier – to – Noise Ratio

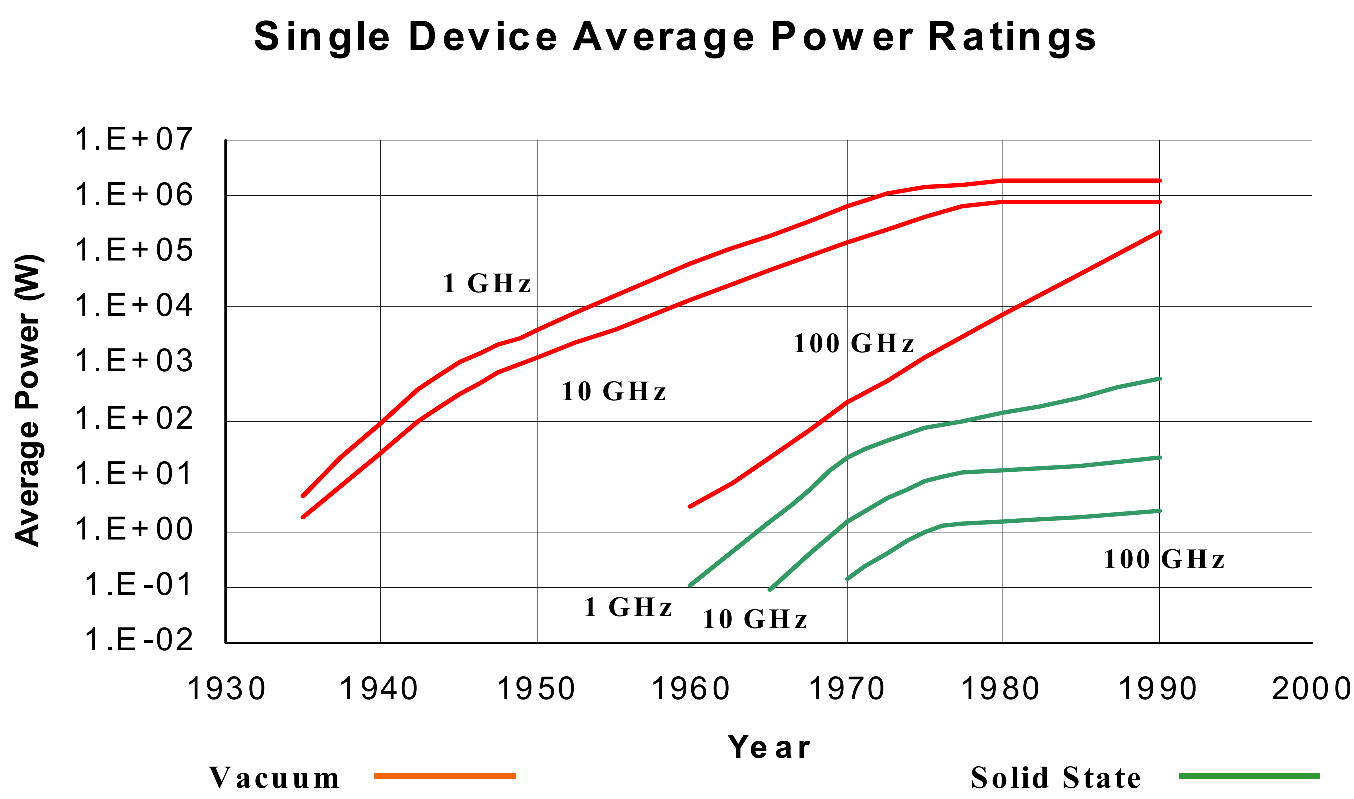
$$C/N\,(dB\cdot Hz) = P_{out}\,(dB_m) - \left[174\,{dB_m}/{Hz} + G_{noise}\,(dB) + F\,(dB)\right]$$

- Ratio of the TWT output carrier at a defined operating point (commonly saturation) and the surrounding TWT noise density.
- C/N is the carrier – to – noise ratio (dB-Hz).
- P_{out} is the single carrier output power in dBm
- F is the TWT noise figure in dB
- G_{noise} is the gain of the noise in the TWT

TWT Longevity

- Predictions have been propagating since the 1960s that microwave tubes would have to be displaced by microwave solid-state devices.
- This displacement has occurred only at the low-power and receiving circuits level of electronic systems.
- Microwave power tubes continue to perform as the only choice for high-power transmitters and are expected to maintain this dominant role throughout the next generation and beyond.
- Microwave techniques have been increasingly adopted in many electronic systems, such as airborne radar systems, space-borne military defense, missile guidance systems, and space communications links.

TWT/SSPA
Output Power Comparison



The Reality

- Vacuum Devices are:

~~Fragile~~	Robust
~~Short-lived~~	Long-lived
~~Unreliable~~	Reliable
~~Inefficient~~	Efficient