Instabilities in Helix Traveling-Wave Tubes

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7th ITG International Vacuum Electronics Workshop, Bad Honnef
Oral Session 7 (IVEW): Traveling-Wave Tubes, 10:20-11:50 AM - May 28, 2020

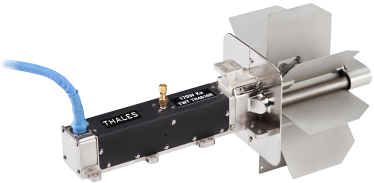
TUHH THALES

Traveling-Wave Tubes

DLR Small-Geo, ESA, P. Carril

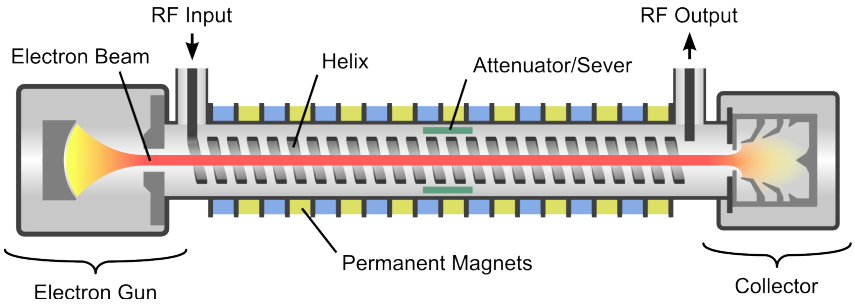
RF Power Amplifier

- High output power and gain
- Large bandwidth
- Efficiency
- Robustness



Thales, TH4816RC

Helix Traveling-Wave Tubes



Project SINATRA (2017-2021)

TUHH

SINATRA: Fully Cascaded **Sim**ulation of Instabilities and **Na**rrowband Phenomena in Helix **Tra**veling-Wave Tubes

Cooperation (since 2005):

THALES

TUHH
Technische Universität Hamburg

- Simulation, prediction, and analysis of
  - Backward-wave oscillations (✓)
  - Power holes (✓)
  - π-mode and drive-induced oscillations (X)
- Expand functionality of proprietary simulation tool (✓)

Funding:

DLR

Research Contract 50YB1712

Outline

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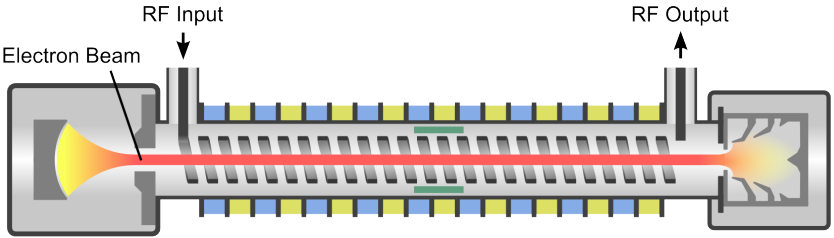

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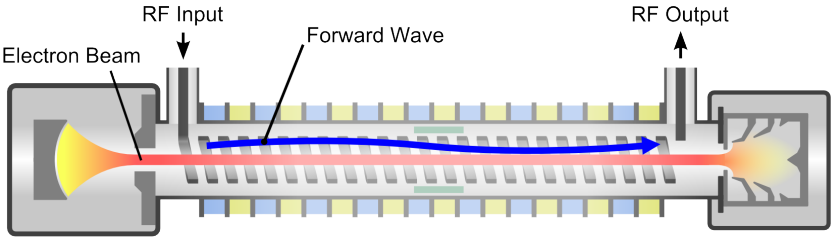

- Amplification of forward-traveling RF wave

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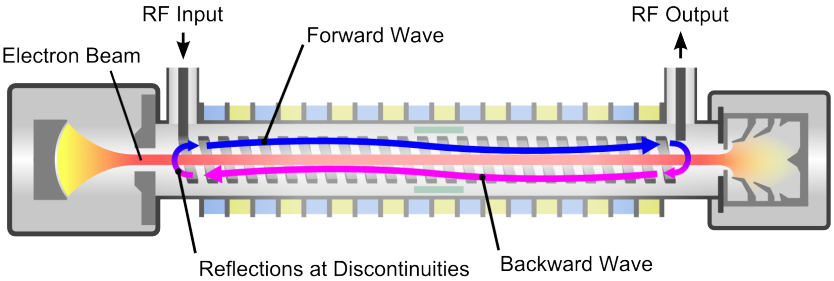


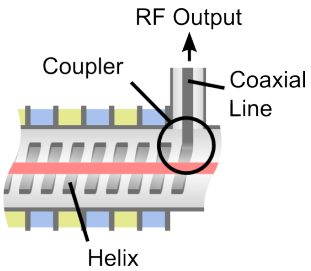
- Amplification of forward-traveling RF wave
- Reflections at discontinuities

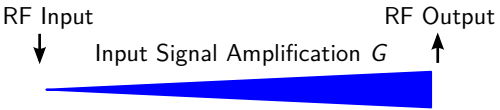
$\rightarrow$ Feedback loop

$\Rightarrow$ Risk of oscillations from multi-reflections

Internal Feedback Loop

- Discontinuities cause reflections of RF waves
  - Mainly at input and output coupler
- Oscillation arises from noise, if loop gain $G \cdot \Gamma^2 > 1$





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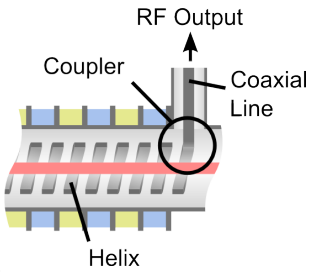

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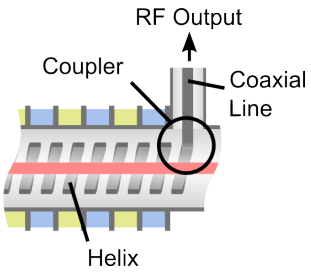

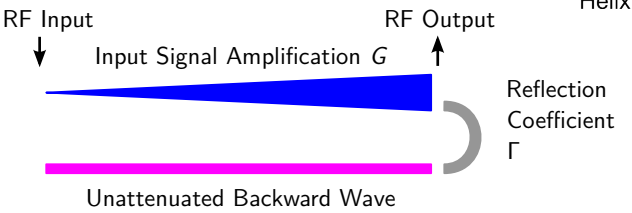

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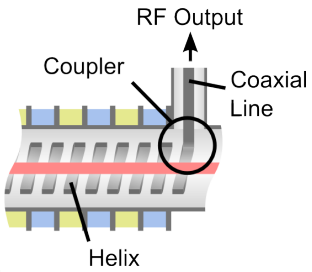

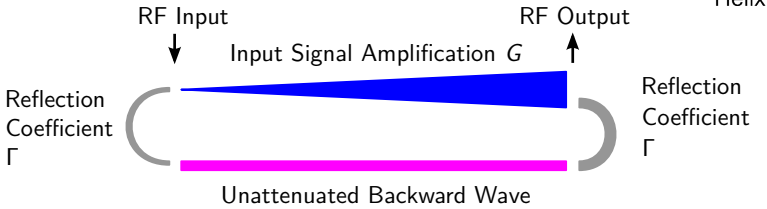

Oscillation Suppression

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- Example: amplification $\approx 60\,\mathrm{dB} \rightarrow \Gamma < -30\,\mathrm{dB}$ for stability $\rightarrow$ hardly feasible

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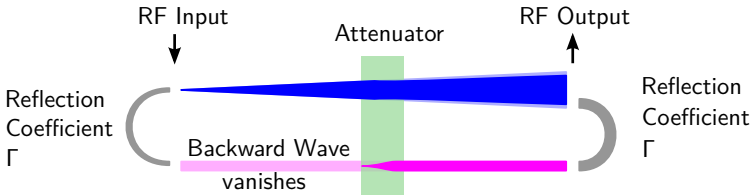
- Introduction of attenuators/severs into the tube
  - Small forward-wave attenuation (modulated beam is not disturbed)
  - Strong backward-wave attenuation



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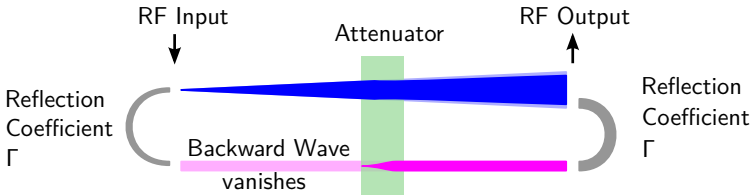
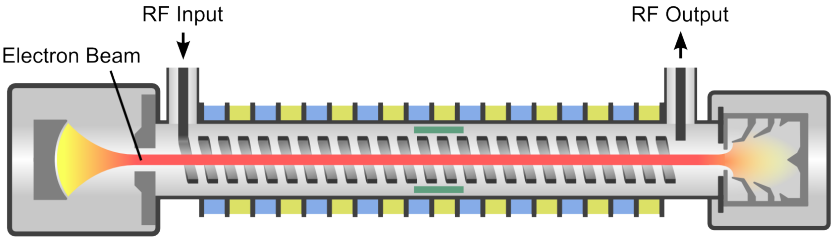


$\Rightarrow$ **Oscillation suppression**

Outline

Instabilities in Helix Traveling-Wave Tubes



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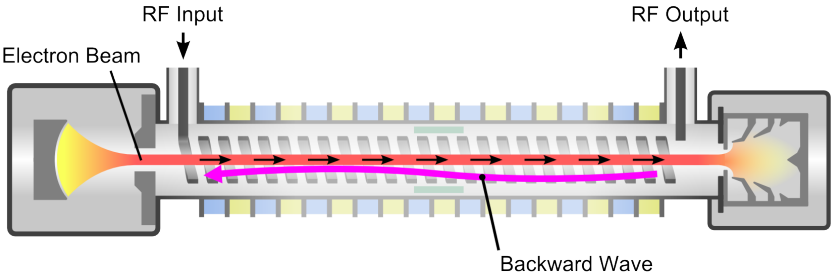
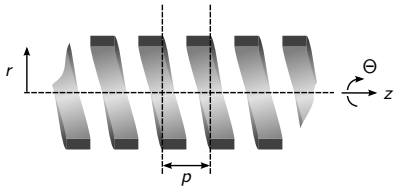
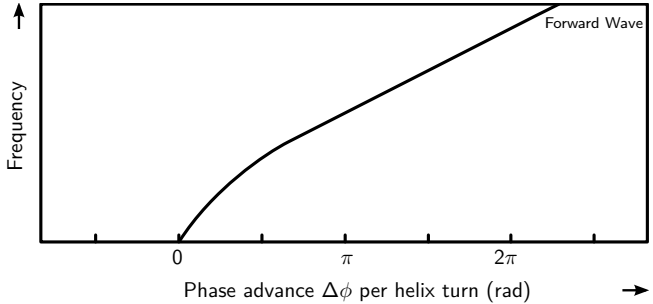


- Forward-traveling electron beam
- Backward-traveling RF wave
- Beam-wave interaction similar to "stroboscope-effect"

$\rightarrow$ Risk of backward-wave oscillations

Beam-Wave Interaction in Helical Delay Lines





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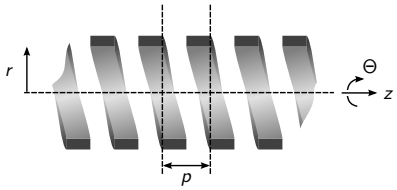

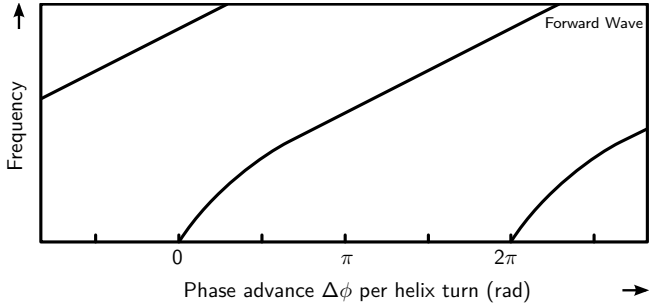

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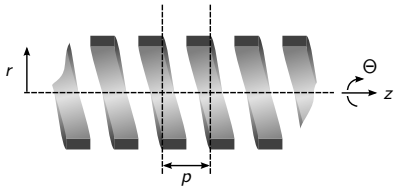

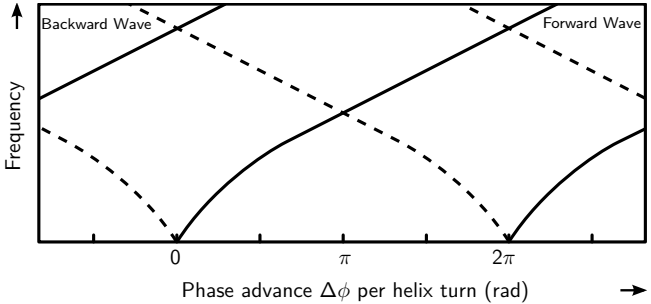

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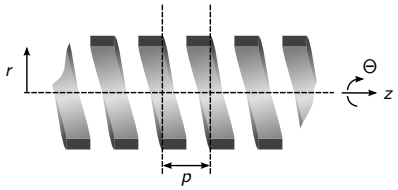

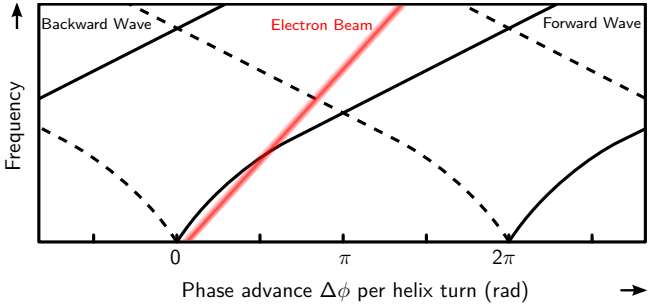

→ $v_{\mathrm{ph}} = \frac{\omega}{\beta} = \frac{2\pi f}{\Delta\phi/p}$

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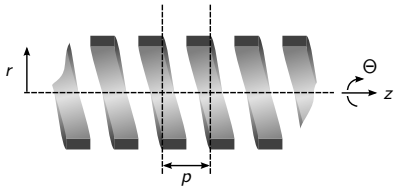

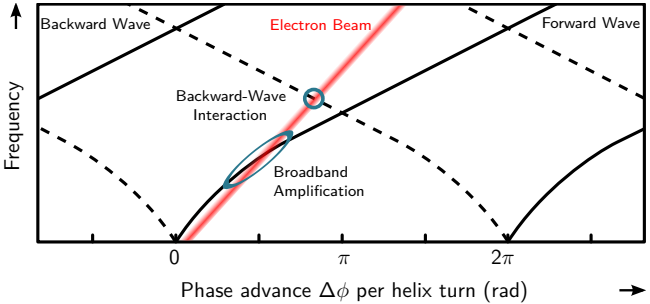

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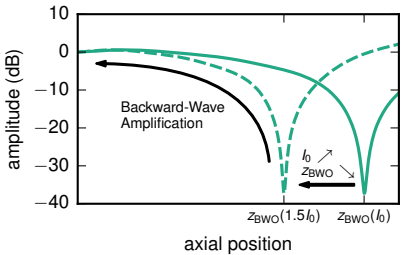
Phase synchronism $\rightarrow$ beam-wave interaction:

- Broadband drive-signal amplification
- Backward-wave interaction
  - $\rightarrow$ Risk of oscillations

Backward-Wave Oscillations

Amplitude of backward RF-wave



- Infinite amplification after length z_{BWO}
  - $\rightarrow$ Any noise rises up to an oscillation
- Inherent problem in helix TWTs
- Limits output power and gain

Outline

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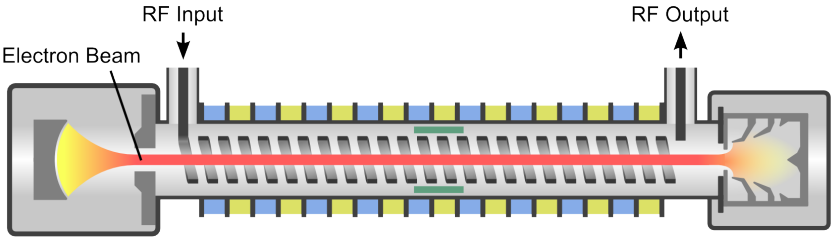

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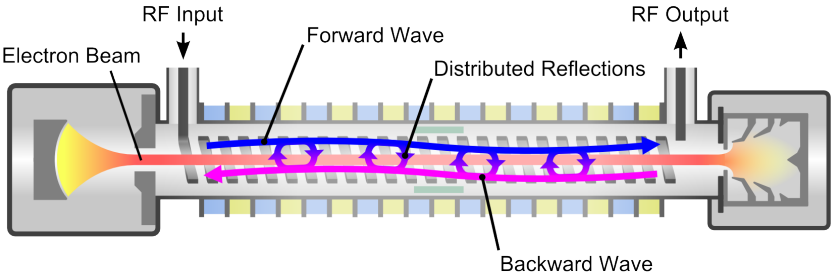


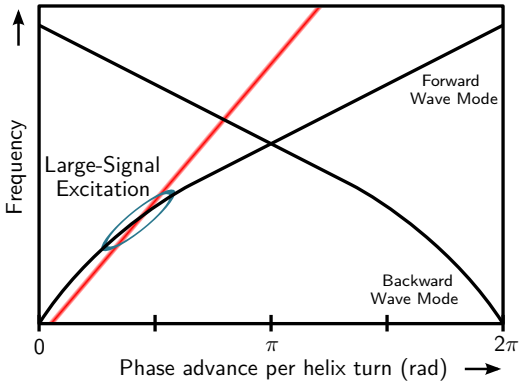
- Distributed reflections caused by asymmetries (imperfections)
- Multi-coupled system with increased risk of oscillation

$\rightarrow$ π-mode oscillations

$\rightarrow$ Drive-induced oscillations

Motivation: Drive-Induced Oscillations

- Large-signal excitation at drive frequency



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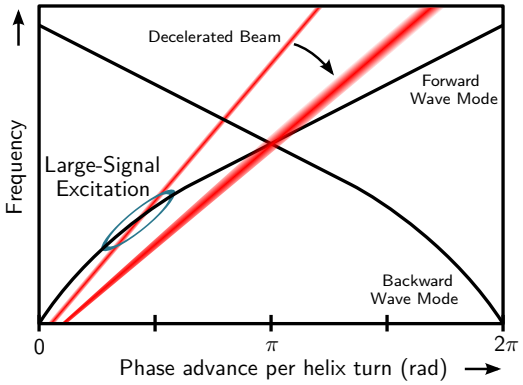
- Deceleration of electron beam
  - $\rightarrow$ Altering beam-wave synchronism
- Synchronism to π-point possible



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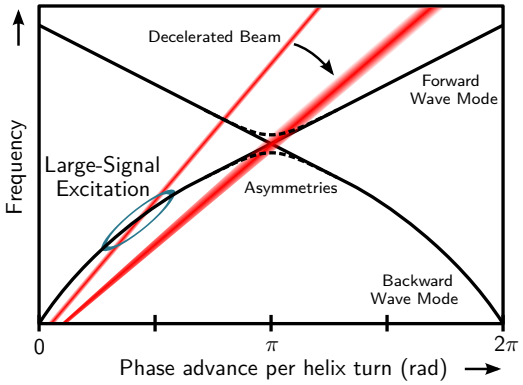

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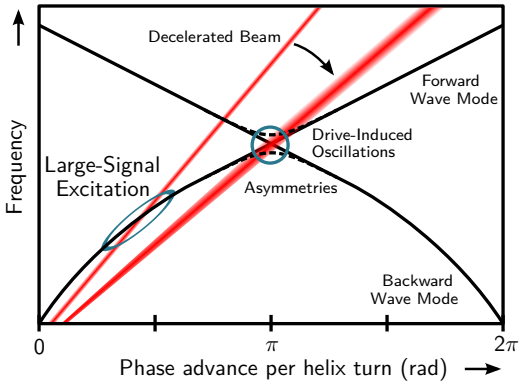
$\Rightarrow$ Drive-induced oscillations (π-mode oscillation w/o excitation)

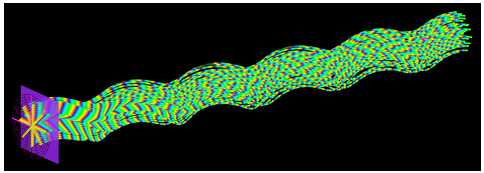


Asymmetries in Helix Traveling-Wave Tubes

Beam Asymmetries

- Shifted/tilted beam injection
- Non-ideal magnetic focusing field

$\Rightarrow$ Mixed beam modulation from forward and backward-wave interaction



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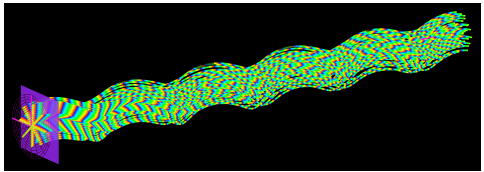
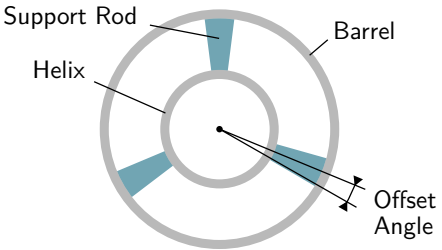


Delay-Line Asymmetries

- E.g. misaligned support rods

$\Rightarrow$ Forward-backward-wave coupling via stop band



Outline

Summary

Introduction to instabilities in helix traveling-wave tubes

- Oscillations from multi-reflections
- Backward-wave oscillations
- π-mode and drive-induced oscillations
  - Asymmetries of beam and delay-line

Project SINATRA

- Cooperation TUHH and Thales
- Simulation of instabilites

Thank you for your attention!