THALES
Building a future we can all trust

Development of High-Power Pulsed Traveling Wave Tubes at Thales

IVEW 2024
Session L2.1-4

Philip Birtel, Wolfgang Dürr, Erdogan Cakir, Klaus Zimmermann

www.thalesgroup.com

Thales Open

DEVELOPMENT OF HIGH-POWER PULSED TRAVELING WAVE TUBES AT THALES
-OUTLINE-

- Motivation
- Baseline TWT design and heritage
- Development efforts and prototype results

Template: 87211168-DOC-GRP-EN-007

Motivation

> Earth observation missions: High-power Ka-Band radar satellites

> NASA Earth Systems Explorer Mission candidate ODYSEA[1]

- 400W Doppler Ka-Band Scatterometer
- 3-fold increase in resolution compared to Ku-band

> ESA COPERNICUS Sentinel 3-NG[2]

- 1000W Ka-Band Altimeter candidate

> On-going effort by Thales to provide 400W and 1000W pulsed Ka-Band TWTs

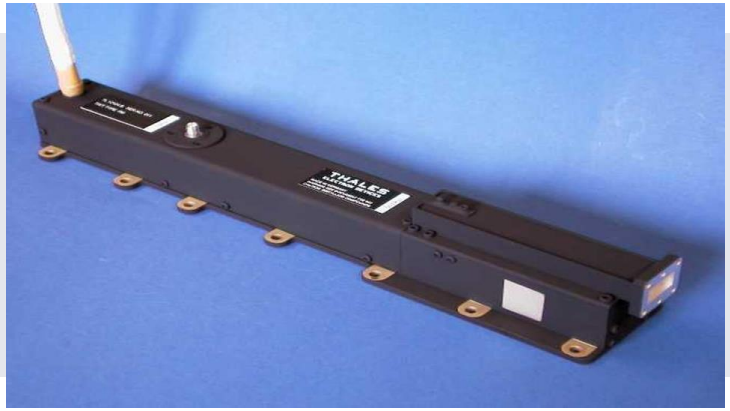
QuikSCAT Scatterometer satellite, www.wikipedia.com

1: https://odysea.ucsd.edu/

2: https://www.esa.int/Space_in_Member_States/Germany/Copernicus

Template: 87211168-DOC-GRP-EN-007

Thales Radar Heritage



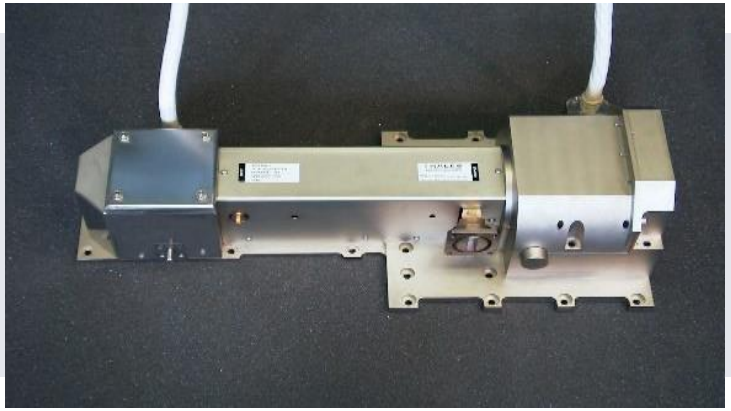
> Medium-power Ku-Band

- SAR/Scatterometer (space)

> 120W @ 13GHz

- Duty cycle 40% continuously
- Efficiency 57%

> Heritage: >21 flight units



> High-power X-Band

- SAR (space)

> 4kW @ 9GHz

- Duty cycle 4% continuously
- Efficiency 40%

> Heritage: >30 flight units

> High-power Ka-Band

- RADAR (airborne/ground)

> 800W @ 35GHz range

- Duty cycle customer specific
- Efficiency 28%

> Heritage: ~10000 flight units

Template: 87211168-DOC-GRP-EN-007

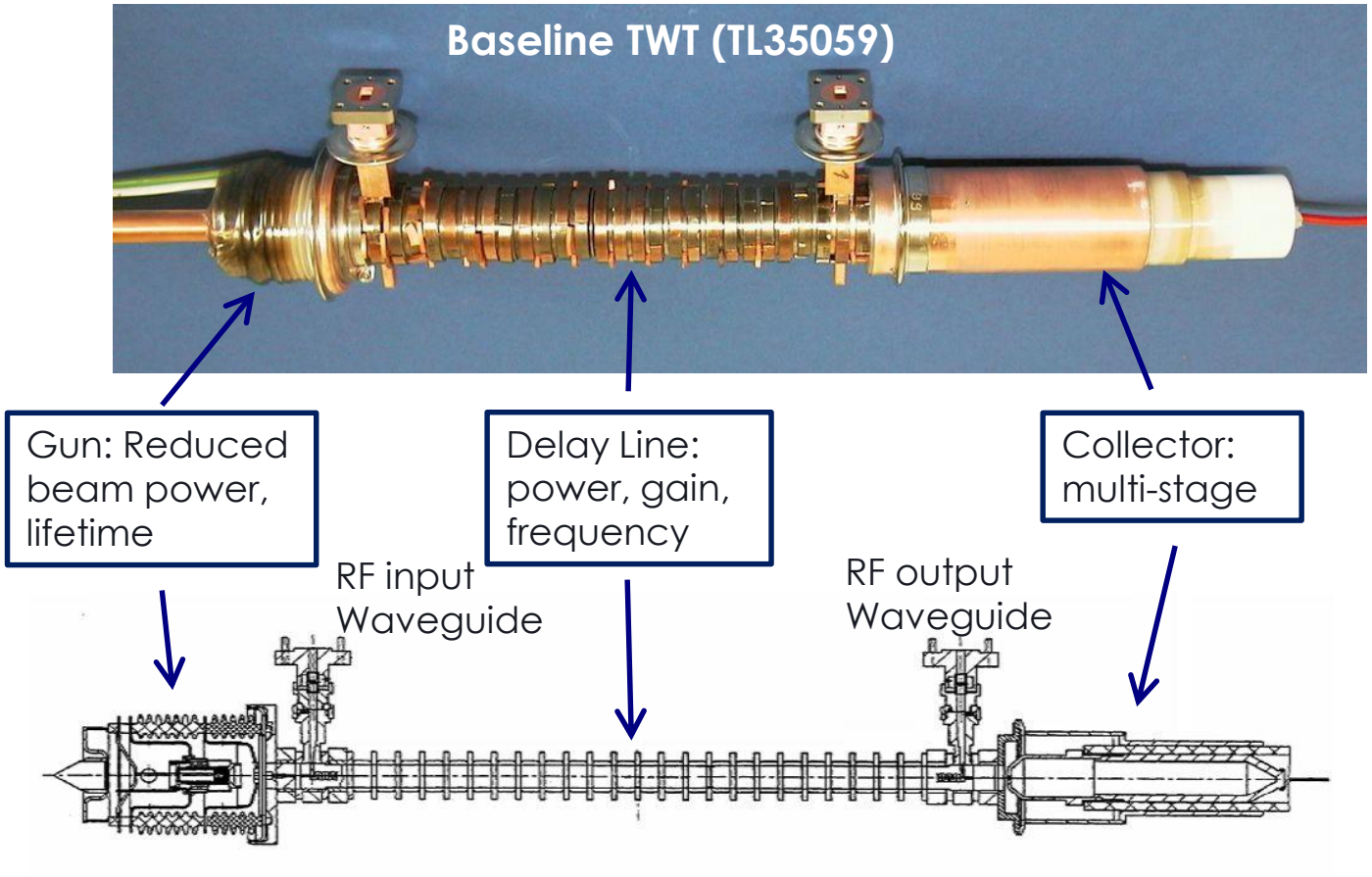
TWT Adaptation for Earth Observation

> Earth Observation TWT req.:

- 400W/1000W peak power @ 35.75GHz
- Small bandwidth (30MHz / 200MHz)
- 120W average output power
- ~8 years mission lifetime
- Reduced DC power consumption

> Baseline TWT:

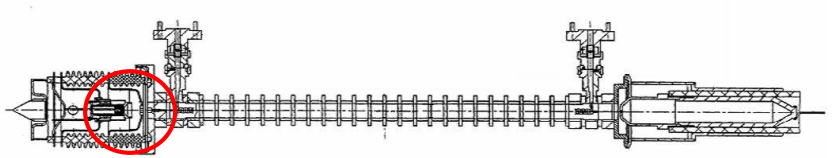
- 1000W peak power @ 35GHz
- ~3% bandwidth (~1GHz)
- 110W average output power
- (some non-space-qualified materials)



Electron Gun: Lifetime and Grid Configuration

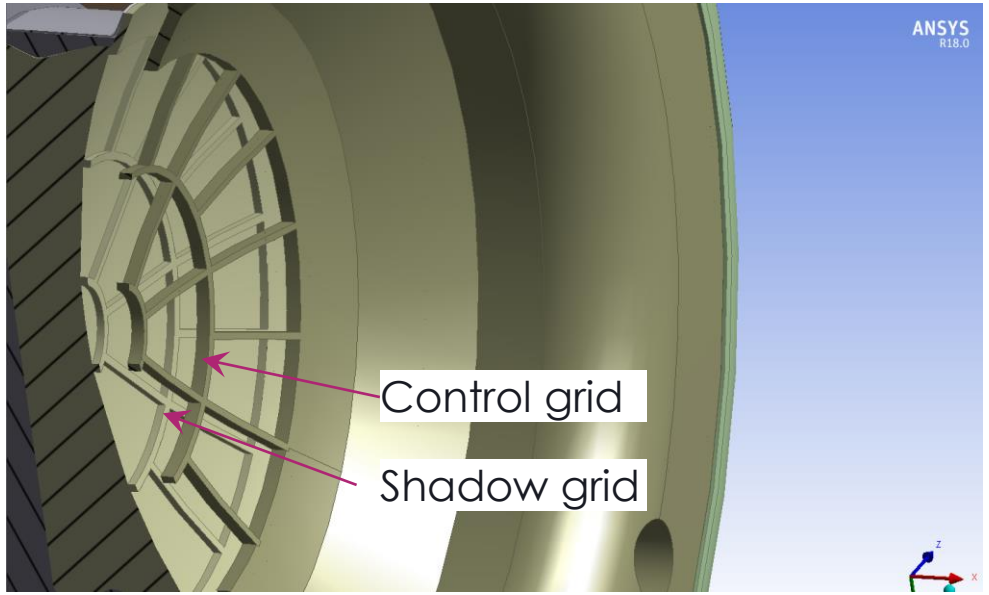
> Removal of shadow grid (no experience over multi-year missions)

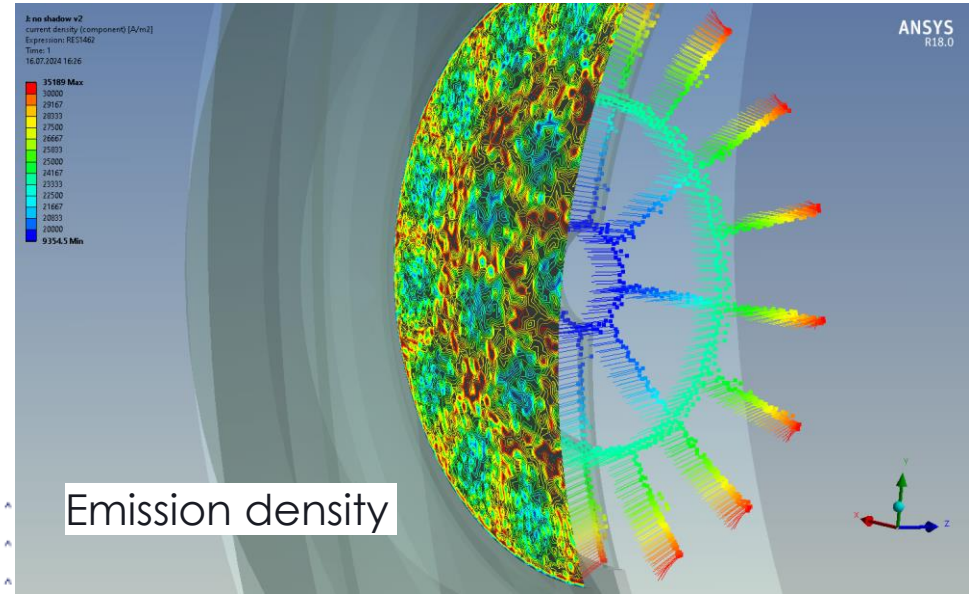
- Control grid interception current, but managable



> Cathode emission density inhomogeneous under control grid bars

- Alternative: MMC chrome cathode

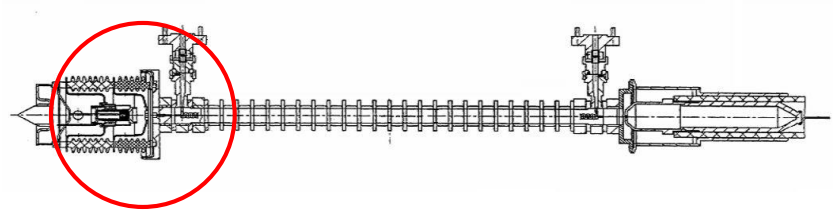




Thales Open

Template: 87211168-DOC-GRP-EN-007

Electron Gun / Focusing System



> **Removal of shadow grid no significant effect on beam focusing**

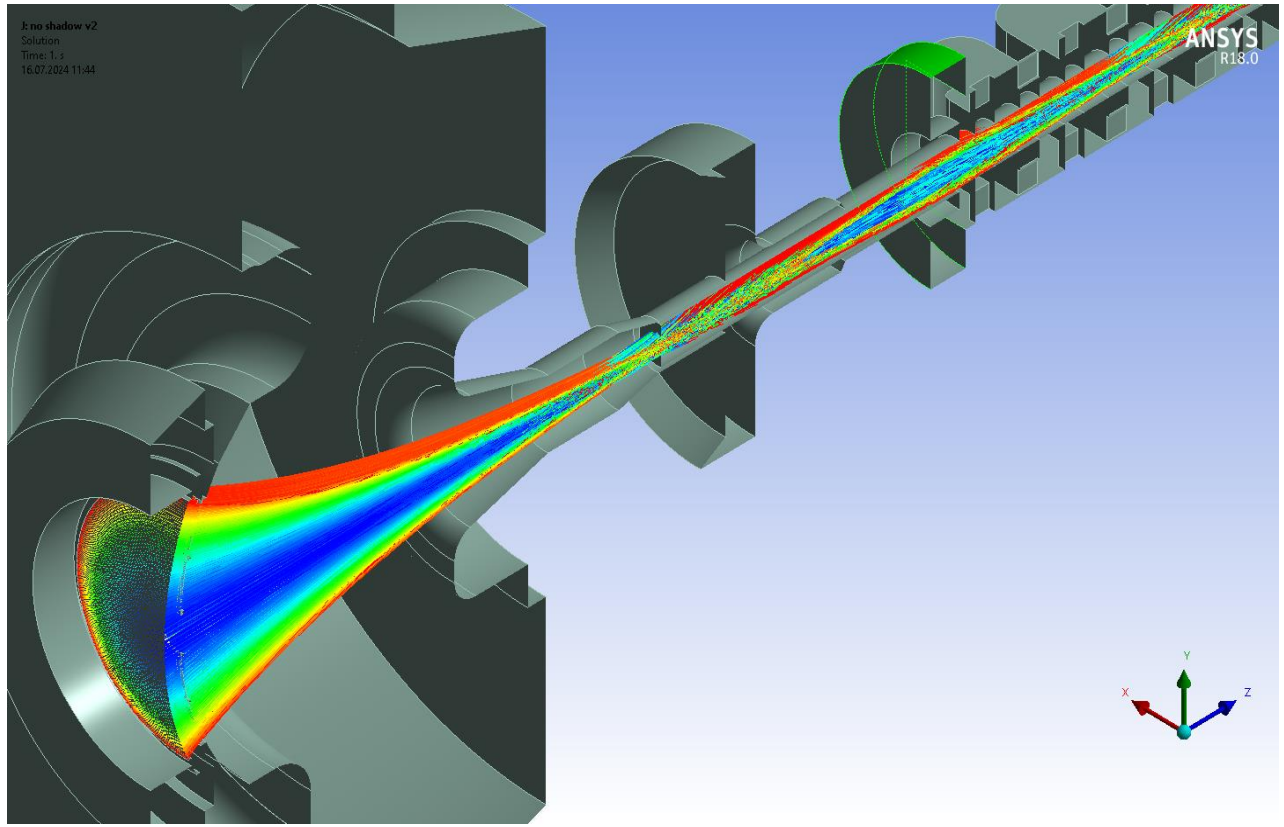
> **1000W: no large changes necessary**

> **400W 1st prototype: beam tunnel radius reduced by 10%**

- Even though simulation predicted problems…

> **Beam focusing has large impact on TWT efficiency**

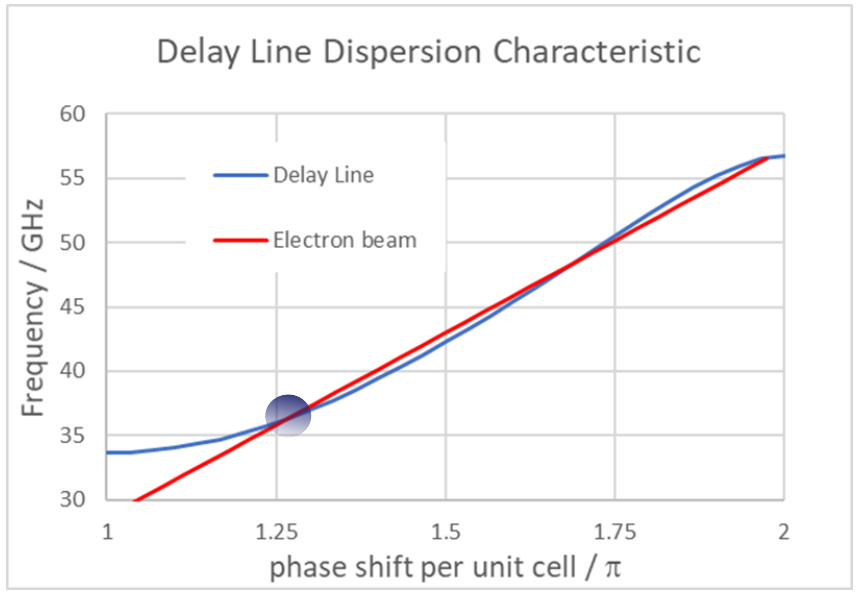
- 5% beam transmission loss as large as 60% RF power

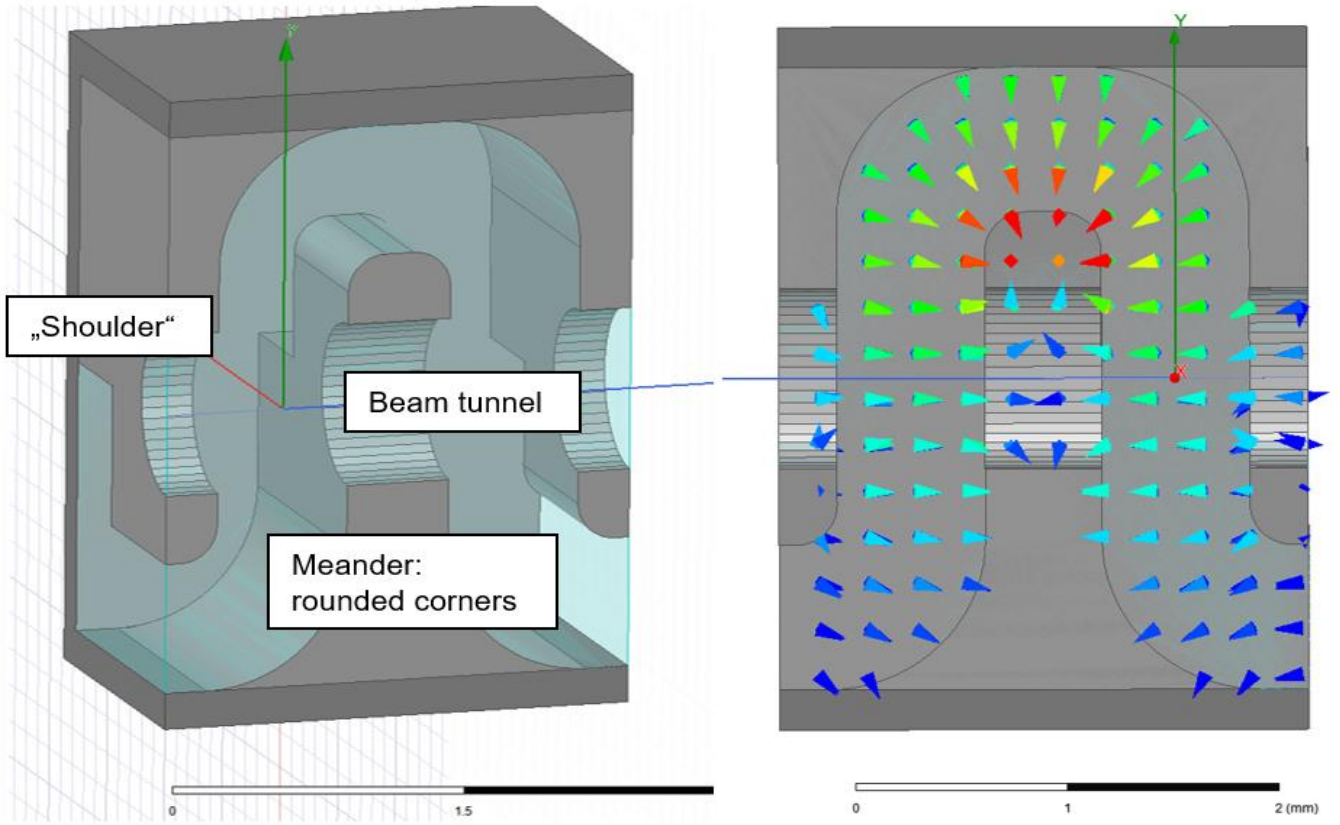


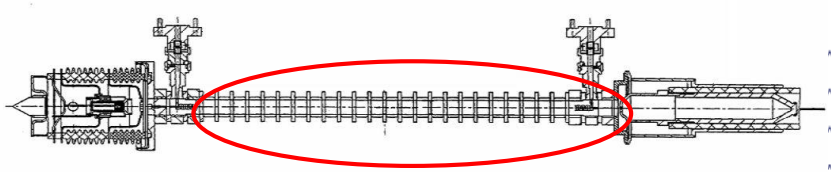
Delay Line

> „Double Comb“ Folded-Waveguide delay line

- „Shoulders“: compact structure

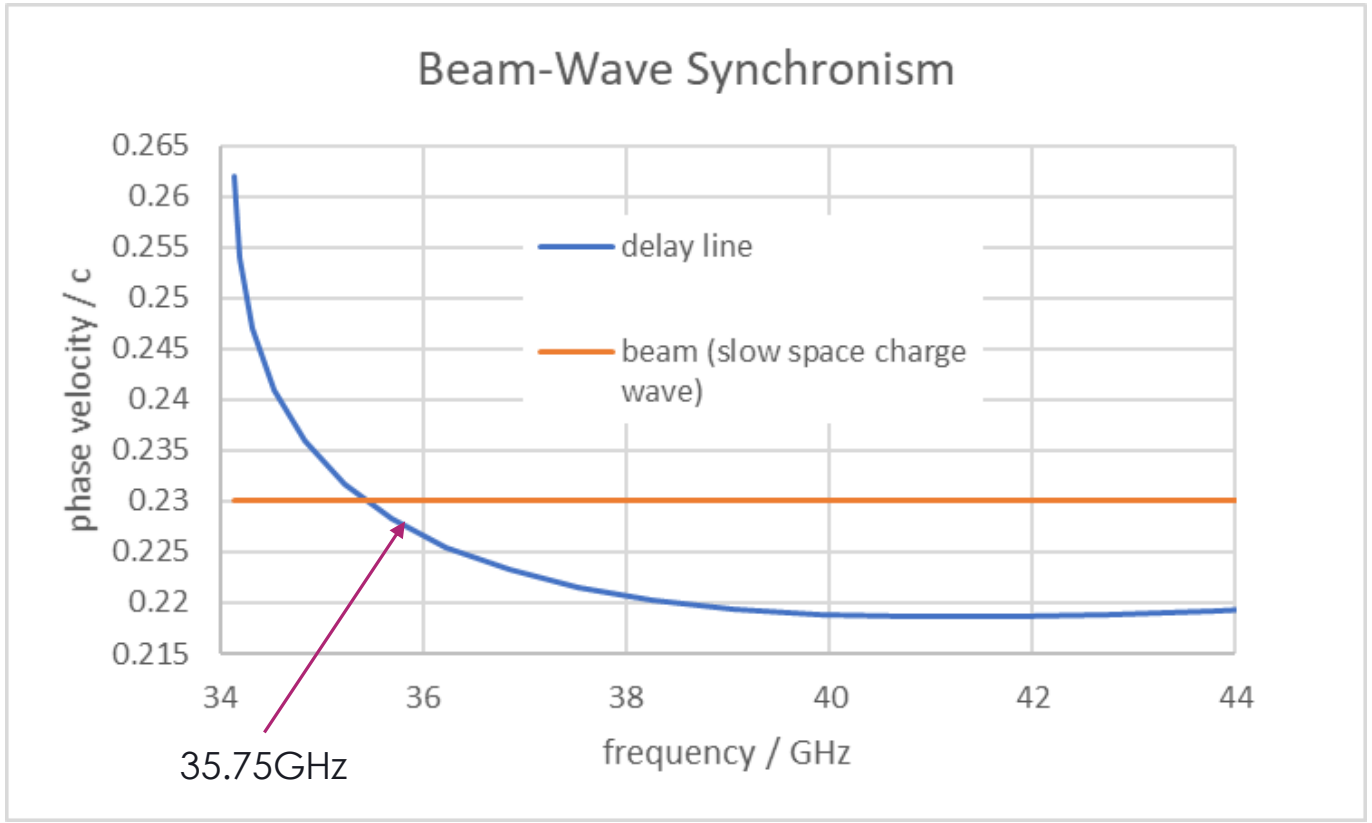






Bandwidth Considerations

- Phase velocity of delay line almost constant > 36GHz
- Good potential for „large“ bandwidth (>10%)
- Not required for this application
- Operation close to cut-off frequency to increase coupling impedance and beam efficiency

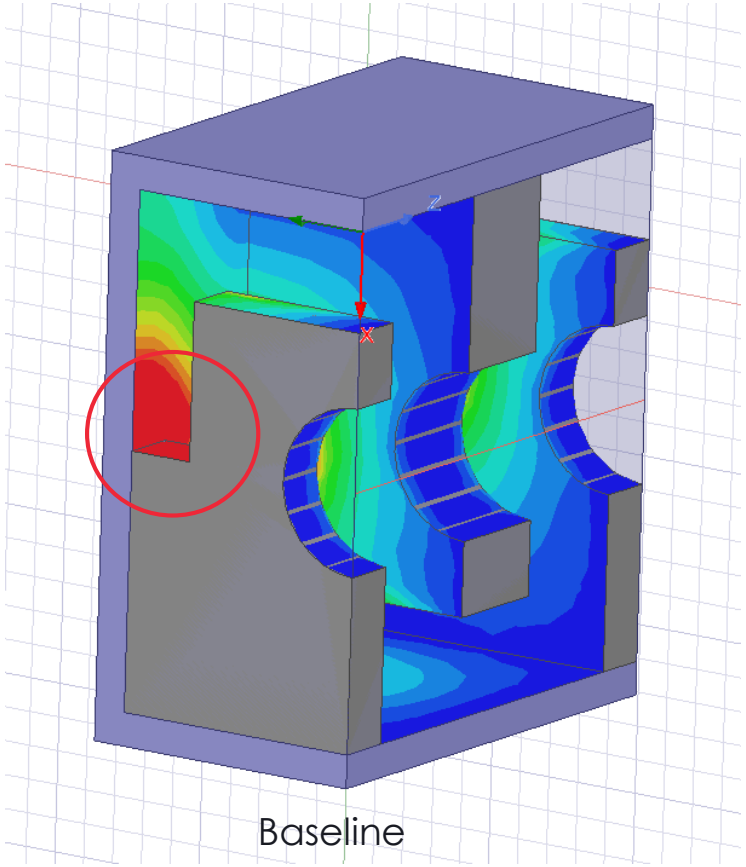


Thales Open

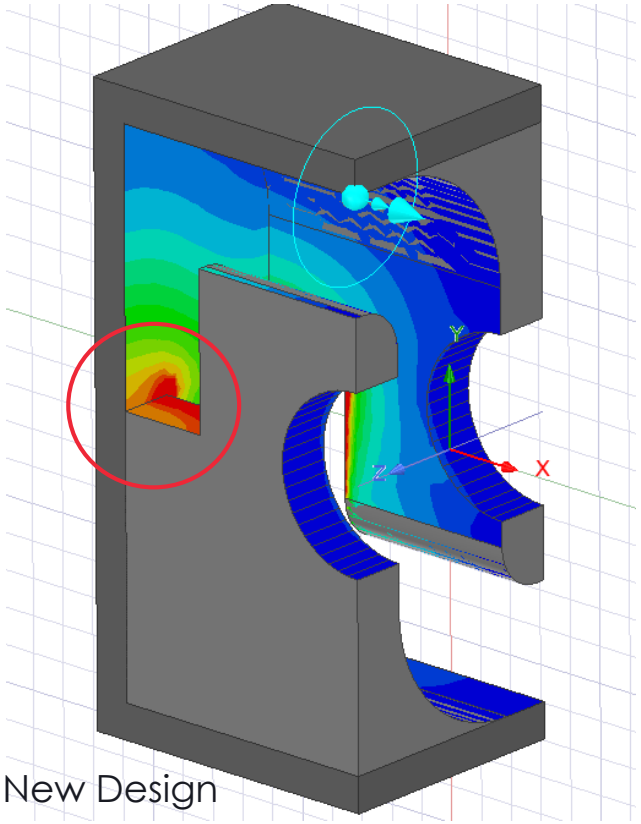
Template: 87211168-DOC-GRP-EN-007

Delay Line Losses

- Surface current concentration in „shoulder“ cut-outs
- RF loss reduction by extending shoulders

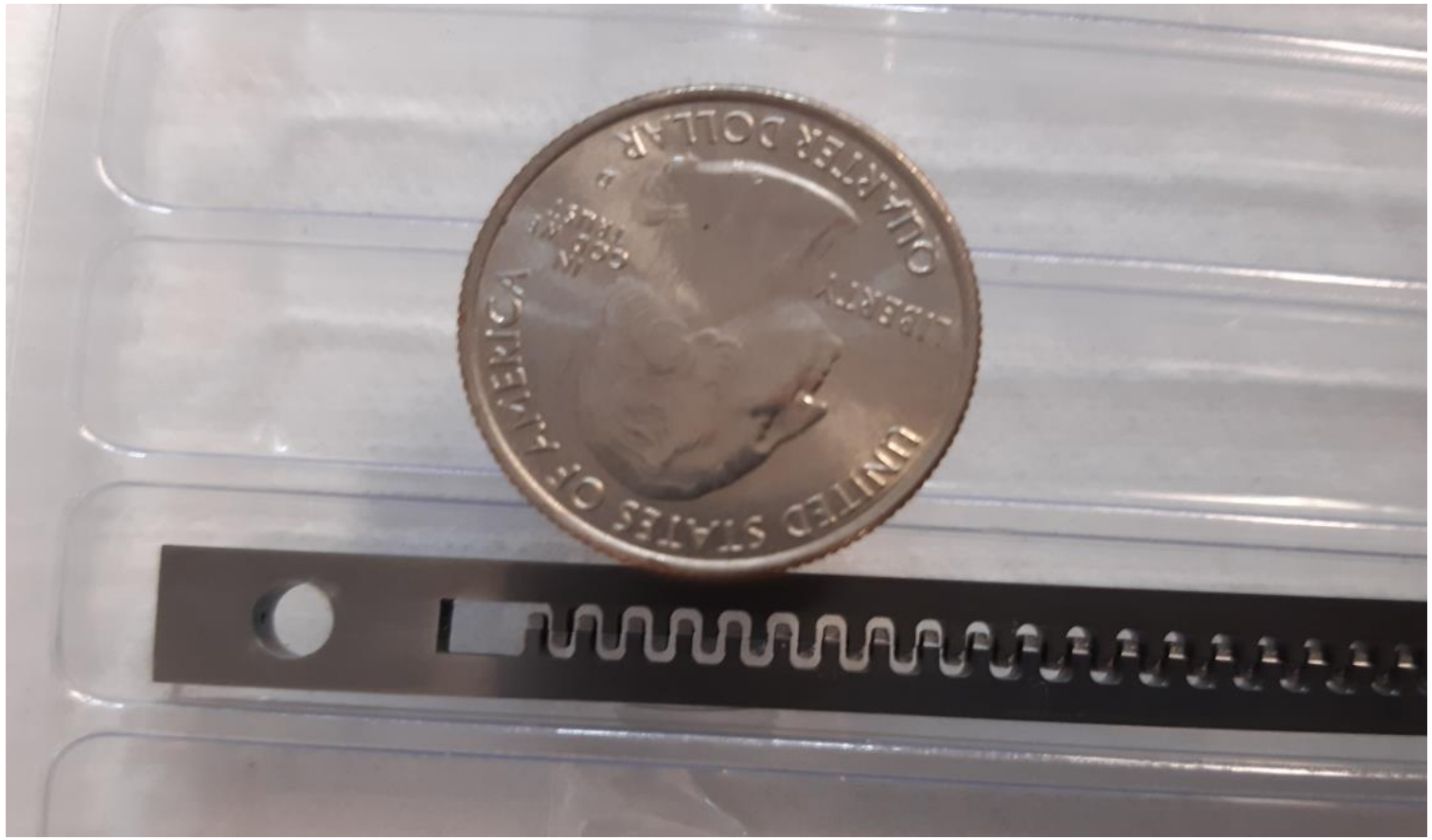


Baseline



New Design

Delay Line Manufacturing via EDM and Milling



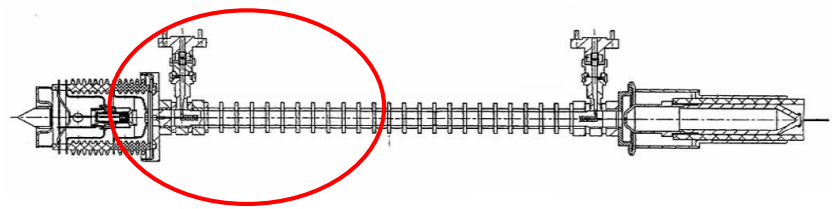
Delay Line: Passive Elements

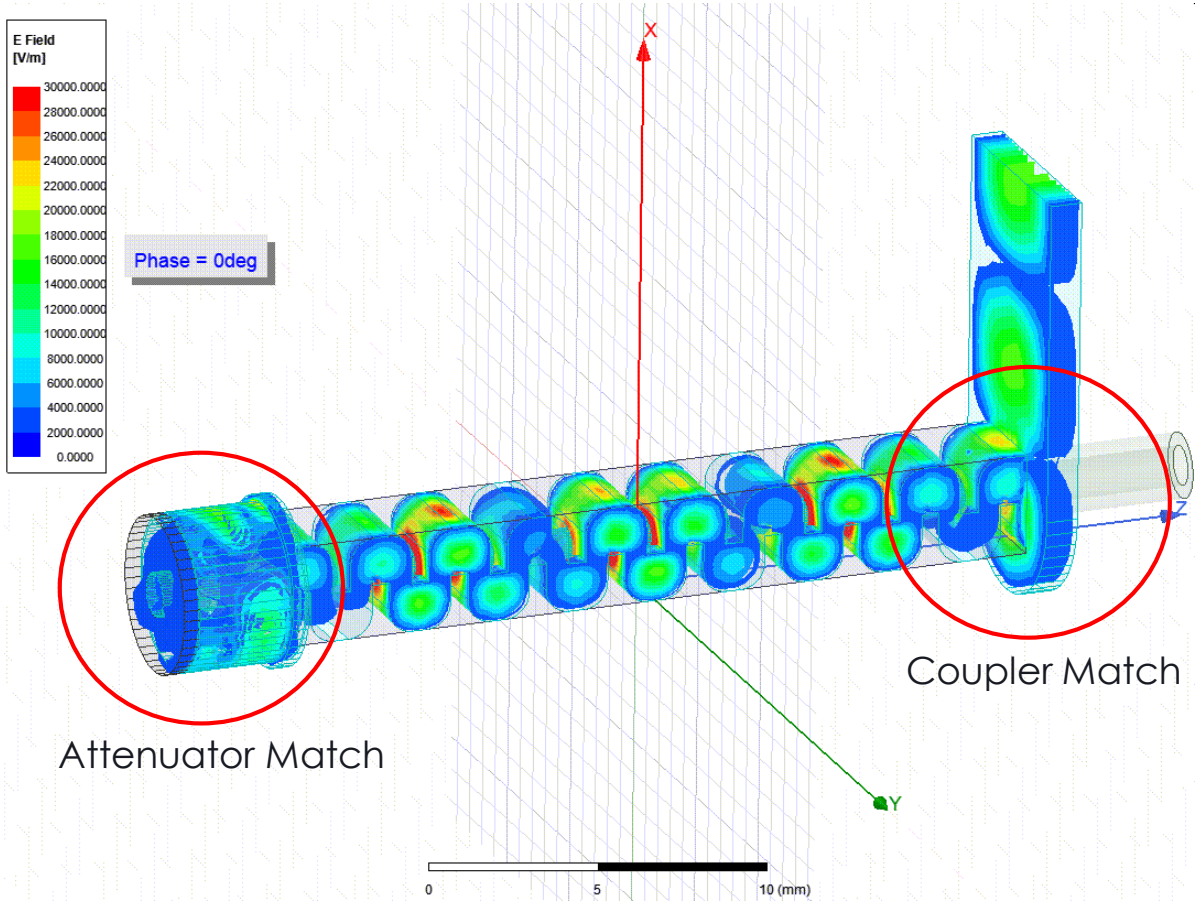
> RF Couplers

- Transition between delay line and WR28 waveguide

> Central attenuators („severs“)

- Absorption of RF signal in a lossy dielectric resonator



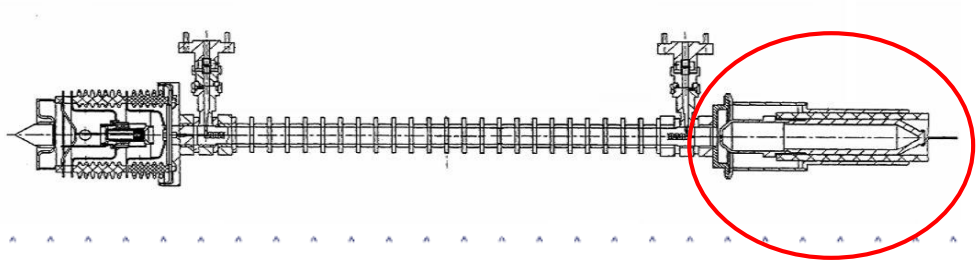


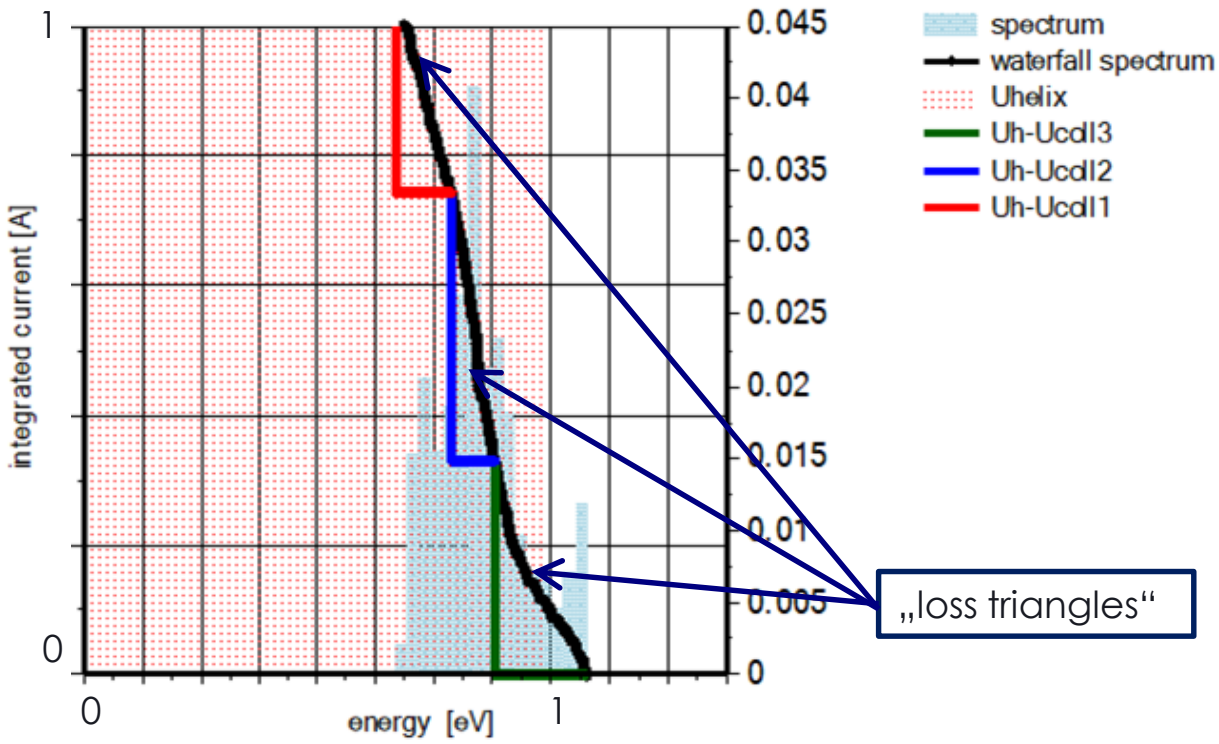
Collector: Spent Beam Energy Spectrum

> Prototypes: Single stage depressed collector

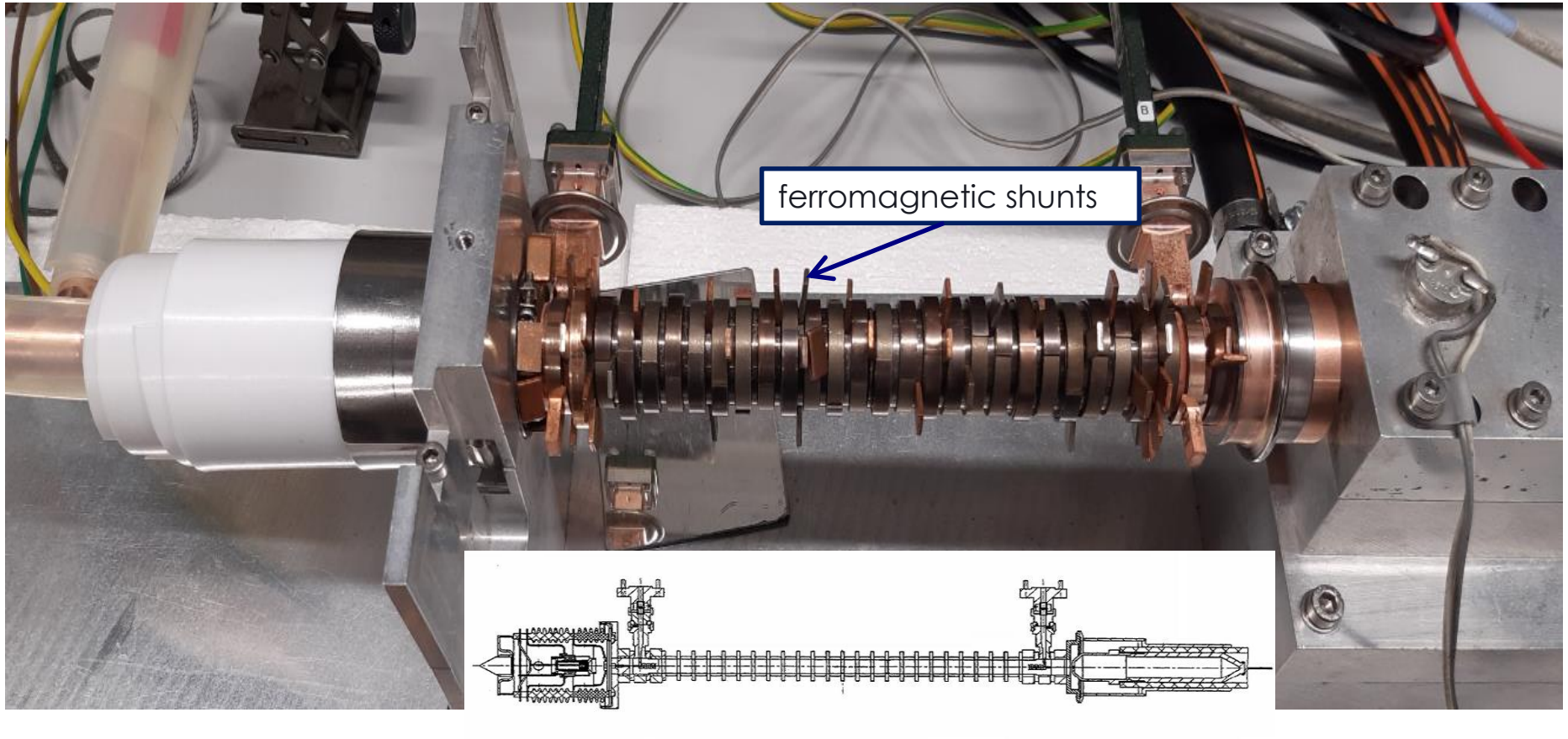
> 3-stage collector: Electro-optic and HV design available

- Dissipated power reduction expected ~33%
- Efficiency increase to ~38% (1000W) / 32% (400W)





Manufactured Prototypes (400W)



1st Prototype Results (THL 36400 A002)

> Output power very high (>450W)

> Very high gain

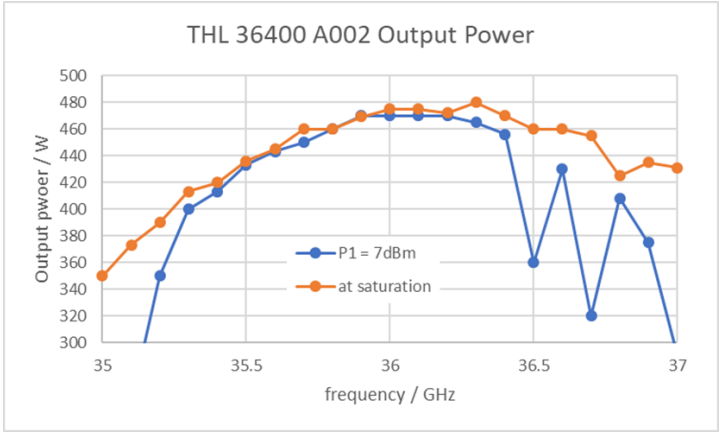
> Parasitic effects due to high gain

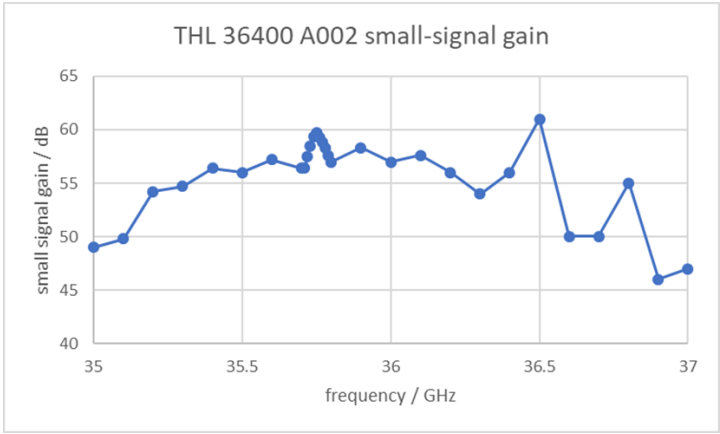
- Gain ripple
- Oscillations (if beam voltage too low)

> Beam transmission insufficient

- Decreasing the diameter of the beam tunnel was counterproductive...

> Rework: Beam tunnel diameter increased

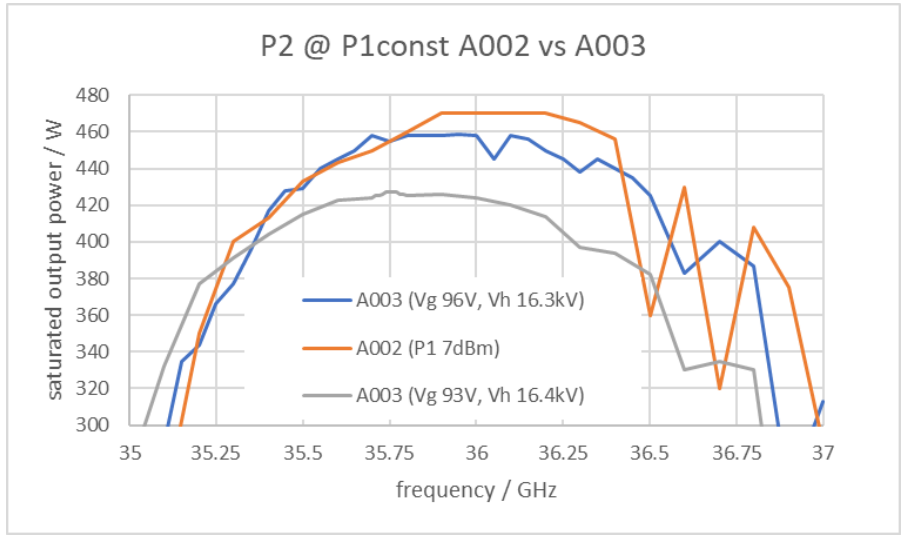


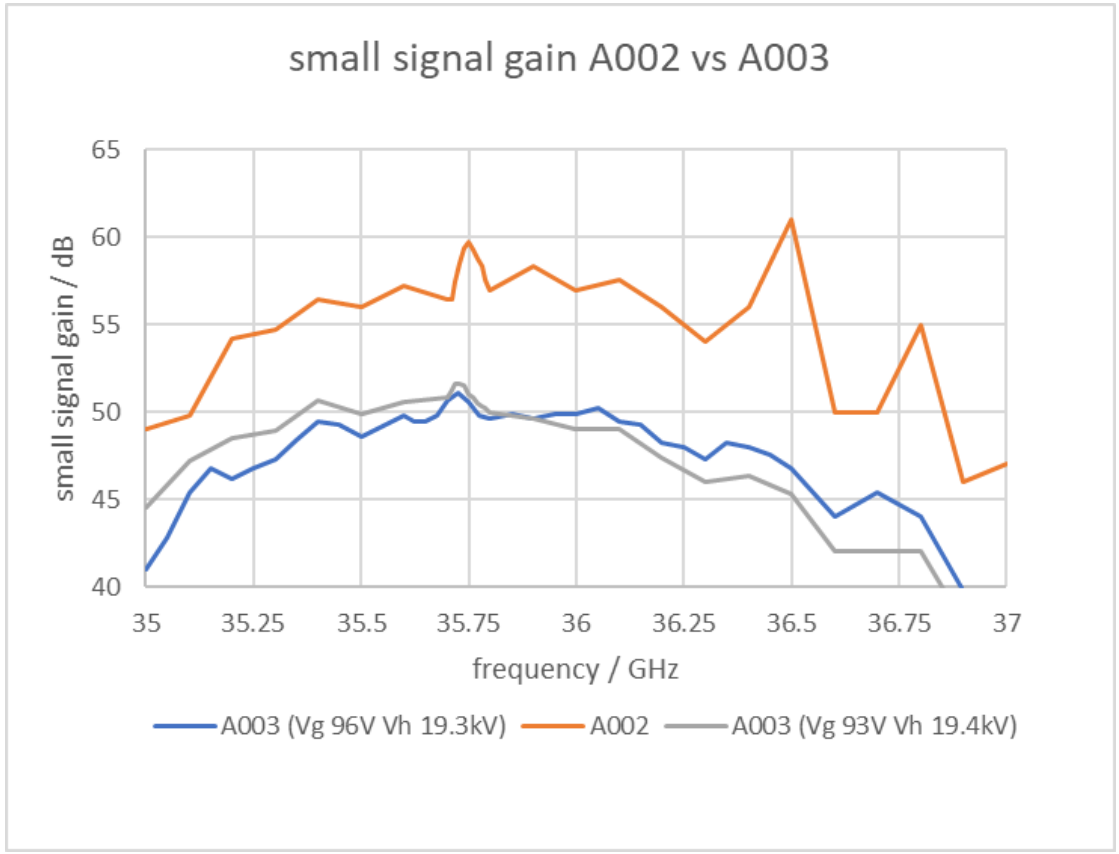


Thales Open

2nd Prototype Results (THL 36400 A003)

- Beam transmission much improved (~93%)
- Gain ripple / oscillation margin improved
- Output Power still satisfactory





Template: 87211168-DOC-GRP-EN-007

W-Band TWTs

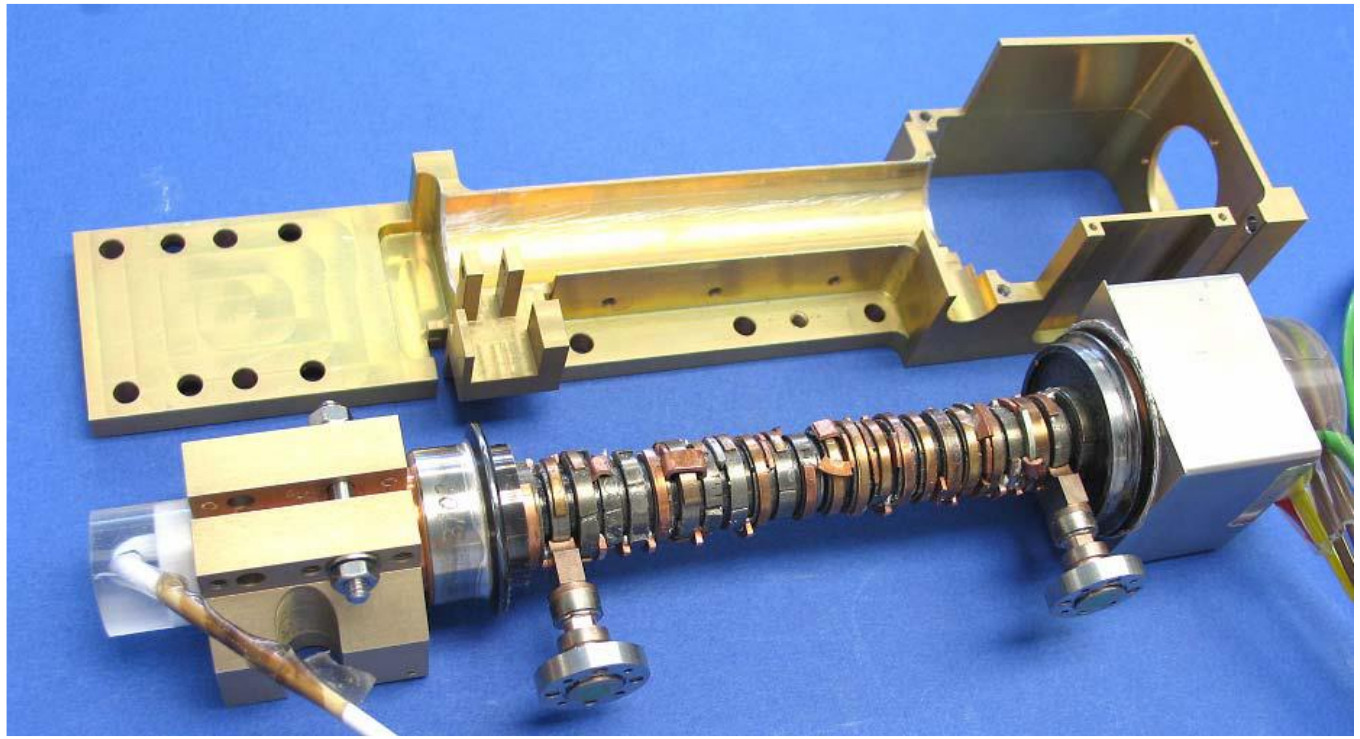
> W-Band: 94GHz, 0.5GHz bandwidth, 200W peak output power

> Development at Thales ~2000 to 2009

- Scaled Ka-band TWT

> Renewed interest:

- Spaceborne debris observation radar
- Gyro-TWT pre-amplifier



Template: 87211168-DOC-GRP-EN-007

What‘s next?

> 400W: 2nd prototype RF performance satisfactory (output power, gain, stability)

> 3rd prototype to be manufactured in Q4 2024

- Gun design without shadow grid
- Minor delay line revision (match, cut-off frequency)
- Goal: TRL 6 in Q2 2026

> 1000W: Feasibility study concluded

> Follow-on expected in 2025

THALES
Building a future we can all trust

Thank you

www.thalesgroup.com

Thales Open

Appendix: Removal of shadow grid

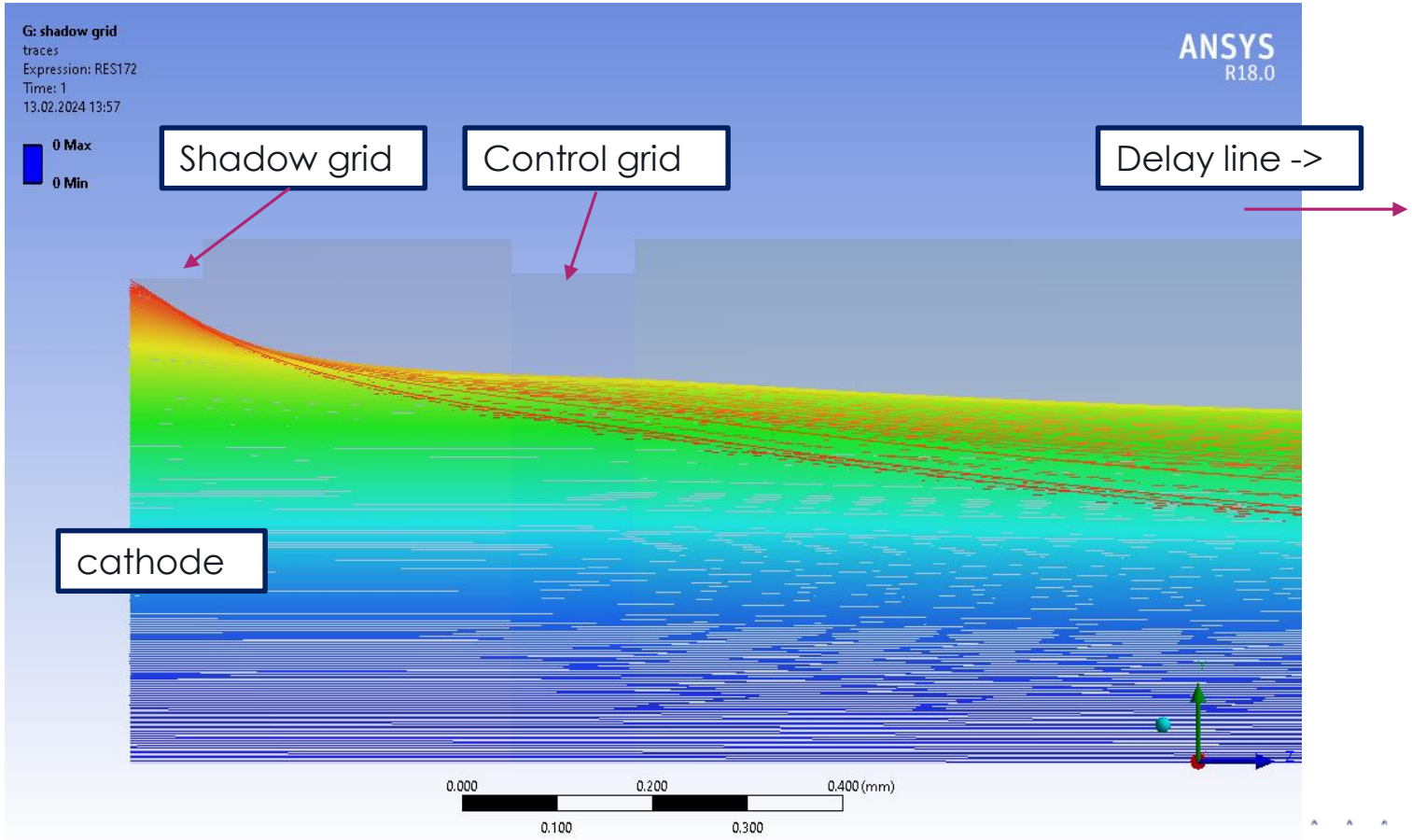
> Shadow grid: non-emissive grid fixed to cathode

- Creates „electron beam shadow“ to protect control grid

> Significant transverse velocities

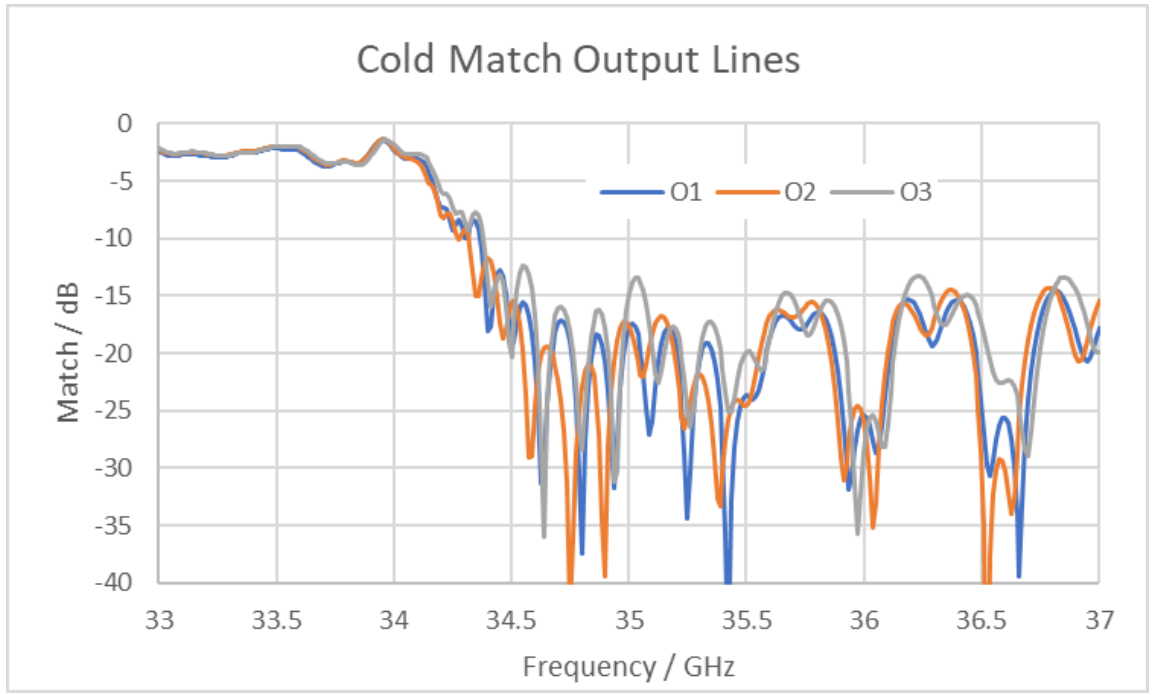
- Difficult focusing

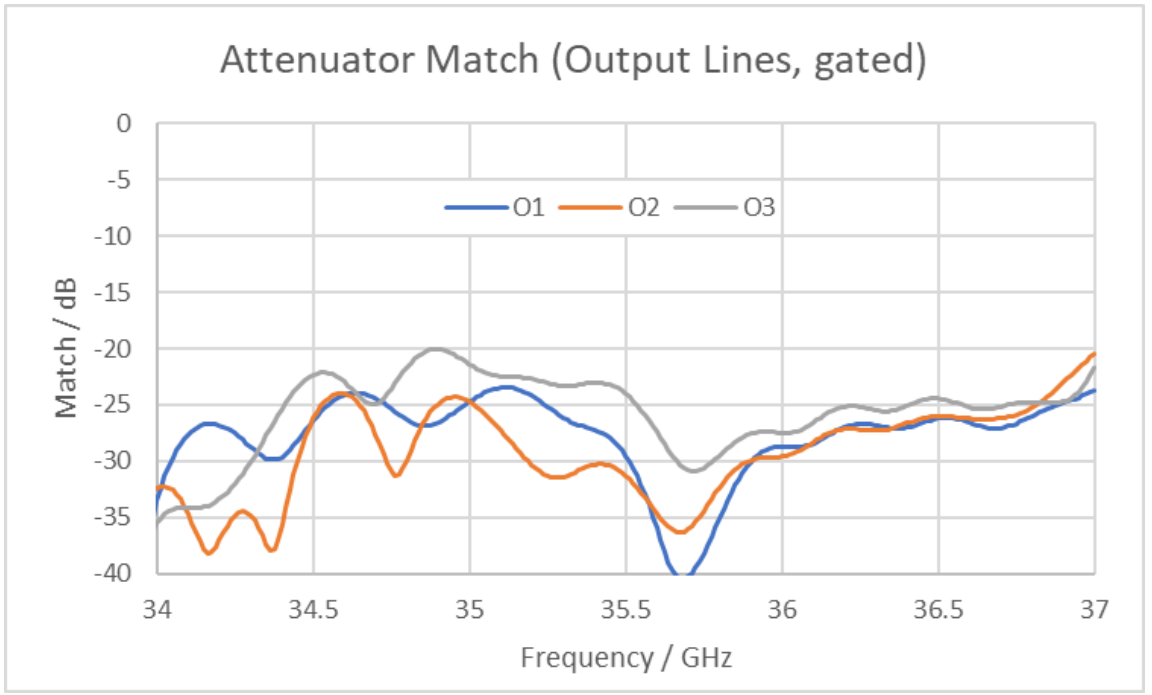
> To be removed for next prototype



Thales Open

Prototype Results (400W): Input/Output Match





> Match better -20dB in operating band (couplers and attenuators)

> Match outside operating band between -15dB and -10dB (above 37GHz)

Template: 87211168-DOC-GRP-EN-007