DOCUMENT NUMBER: **PAR7064443**

DOCUMENT REVISION: **A**

DATE: **May 19, 2023**

CAGE CODE: **N/A**

Customer: European Space Agency

Envision Mission – Ka-Band TWT

120W 32 GHz Helix TWT ET3706A for Payload Data Transmitters for EnVision mission

FP - Final Presentation

CDRL No.: N/A

Contract N.: 4000130150/20/NL/HK

Nr. of pages	Classification
4	UNCLASSIFIED
0	UNCLASSIFIED CONTROLLED
0	RESTRICTED
0	CONFIDENTIAL
0	SECRET
4	**Total nr. of pages**

Document Authority

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REVISION RECORD

Rev.	Modification N.	Date	Description	Author/s
A	N/A	May 19, 2023	First Issue	R. Martorana A. Mendolia Calella

INDEX

1. APPLICABLE DOCUMENTS

Ref.	Identifier	Title
A1	ESA-TEC-TDE-T206-015ES Issue 1, Revision 1 22/08/2019	Statement of Work Development of a 120 W 32 GHz TWT for Payload Data Transmitters
A2	4000130150/20/NL/HK	ESA Contract for 120 W, 32 GHZ TWT for Payload Data Transmitter

2. ACRONYMS

Acronym	Description
CW	Continuous Wave
EBB	Elegant Breadboard
RF	Radio Frequency
SOW	Statement of Work
SWS	Slow-wave Structure
TWT	Travelling Wave Tube

3. FINAL PRESENTATION

LEONARDO

Leonardo Electronics – Microwave Power Solution

Ka-Band TWT 120W 32 GHz Helix TWT ET3706A
for
Payload Data Transmitters
for
En Vision mission

ESA Contract 4000130150/20/NL/HK

FP – Final Presentation

PAR7064443 rev. A

Palermo

May 19th, 2023

Electronics

Helicopters

Aircraft

Cyber & Security

Space

Unmanned Systems

Aerostructures

SUMMARY

- Overview
- Main Performance Requirements
- Market: SSPA vs TWT
- TWT Design, Manufacturing and Verification
- Design Improvements
- Margin verification

Overview

This study is inserted in the frame of the preparatory activities for the “Development of 150 W 32 GHz TWT for Payload Data Transmitters” for EnVision mission.

The baseline launch date is in 2032, with a backup in 2033. The requirement for the Envision mission is to provide a high-power RF source in Ka band.

The development has been grounded on Leonardo know how and heritage on vacuum tubes design, technologies and production of microwave tubes for the airborne and military applications and the experience previously gained with the development, under ESA contract, of:

- C Band klystron for the Metop/SG program
- X Band 4 kW 10 % duty cycle Helix TWT for cSAR application.

The objective of this activity has been to design, develop, manufacture and test an Elegant Breadboard (EBB) capable to demonstrate the feasibility of a TWT operating in the frequency range 31,8 ÷ 32,3 GHz with 150 W saturated RF output power, 200 MHz instantaneous bandwidth and high overall efficiency.

The activity started with the design and test of a TWT BB with entry TRL 3 to reach TRL 4 with the TWT EBB.

In the frame of margin verification an electron gun test vehicle, reproducing the same electron gun adopted in the TWT has been designed, three assemblies have been manufactured and subjected to cyclic heater ON/OFF to verify experimentally its capacity to survive the induced thermal stresses.

Main Performance Requirements

PARAMETER	Min	Max	UoM
Frequency range	31,8	32,3	GHz
Rated output power	150 (51,8)	–	W (dBm)
Gain at saturation	50	–	dB
Efficiency at saturation	60	–	%
Gain flatness	–	0,2	$dBpp$
Noise Figure	–	35	dB
Spurious output ratio	–	−60	dBc
Second harmonic output ratio	–	−30	dBc

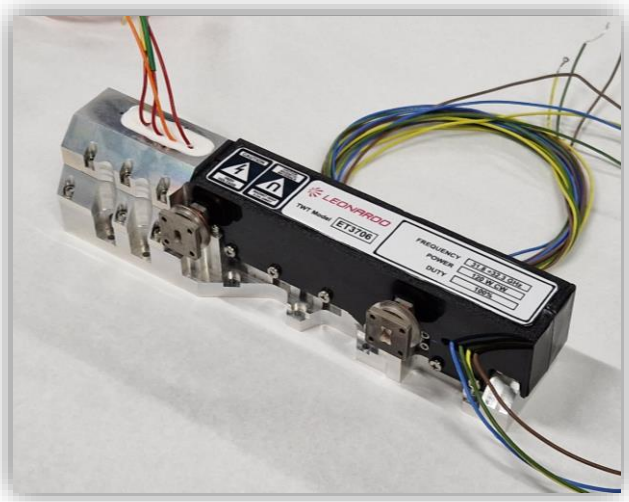
Market: SSPA vs TWT

Solid State Amplifier

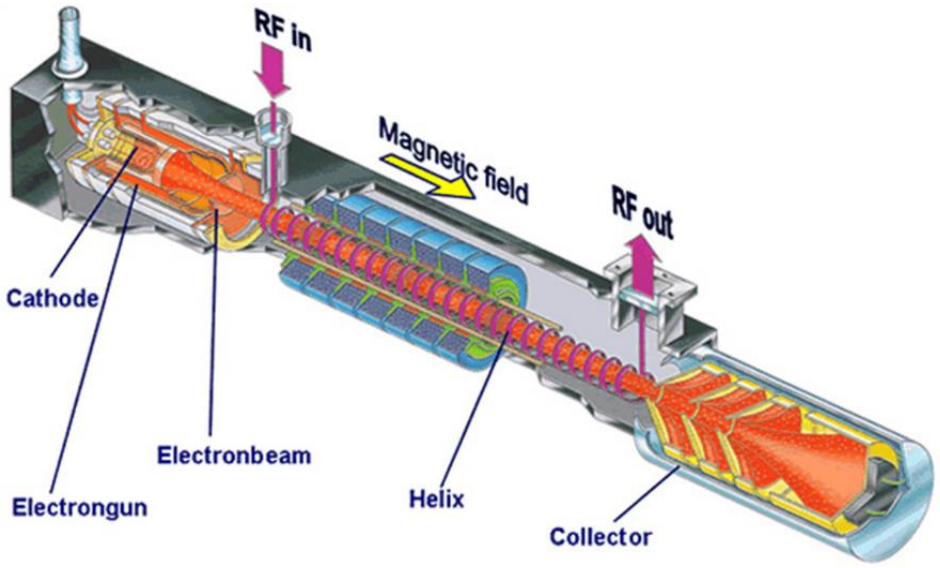
50 W Ka Band CW

Vacuum Tube

150 W Ka Band CW



TWT Design, Manufacturing and Verification



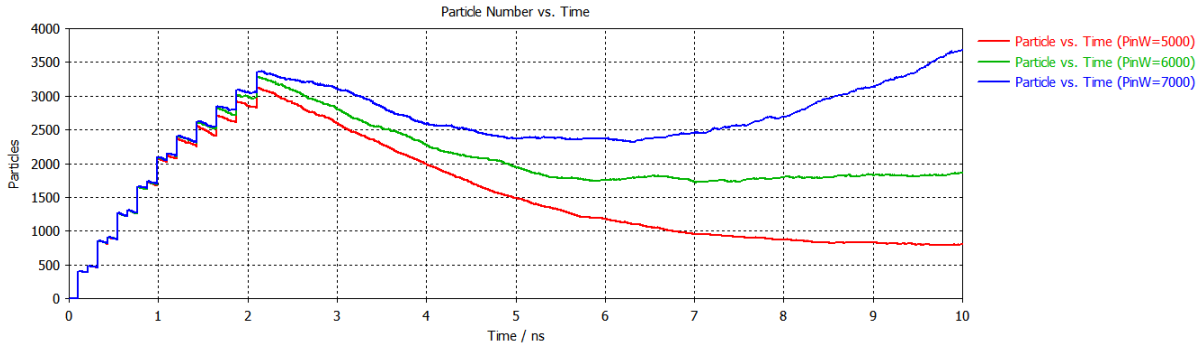
Building Blocks Description for TWT ET3706			
Block	**Technology & Requirement**	**BB**	**EBB**
Electron Gun	Configuration		
	Modifications	*The optics have been modified improving electron beam divergence and laminarity*	
	Design Maturity	**Medium**	
Interaction Structure	Configuration		
	Modifications	*None*	
	Design Maturity	**High**	
I/O Ports	Configuration		
	Modifications	*None*	
	Design Maturity	**High**	
Magnetic structure	Configuration		
	Modifications	*None*	
	Design Maturity	**High**	
Four-stages Collector	Configuration		
	Modifications	*The geometry of the stages has been modified*	
	Design Maturity	**Medium**	

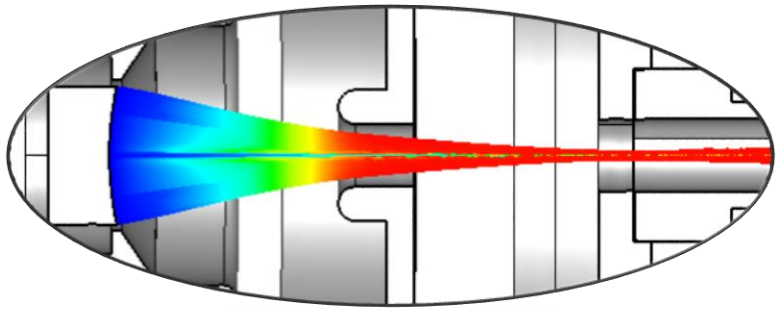
TWT Design, Manufacturing and Verification

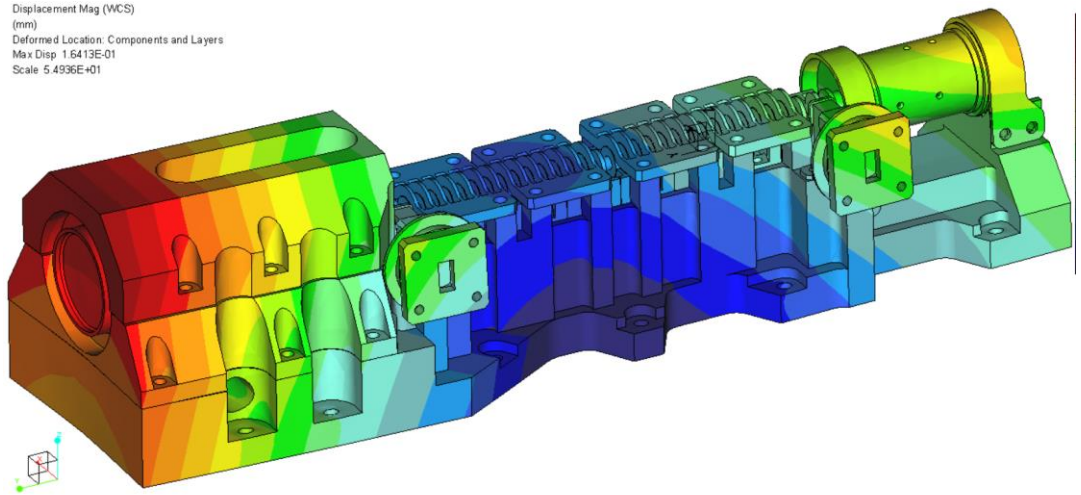
TWT EBB Detailed Design

The simulation software **CST** has been used for the TWT design to demonstrate compliance with the RF specifications and Multipactor margin verification.

Ansys Mechanical has been used to demonstrate compliance with the thermal and mechanical requirements and to verify the Margin of safety compliance with respect to ECSS-E-ST-32C.





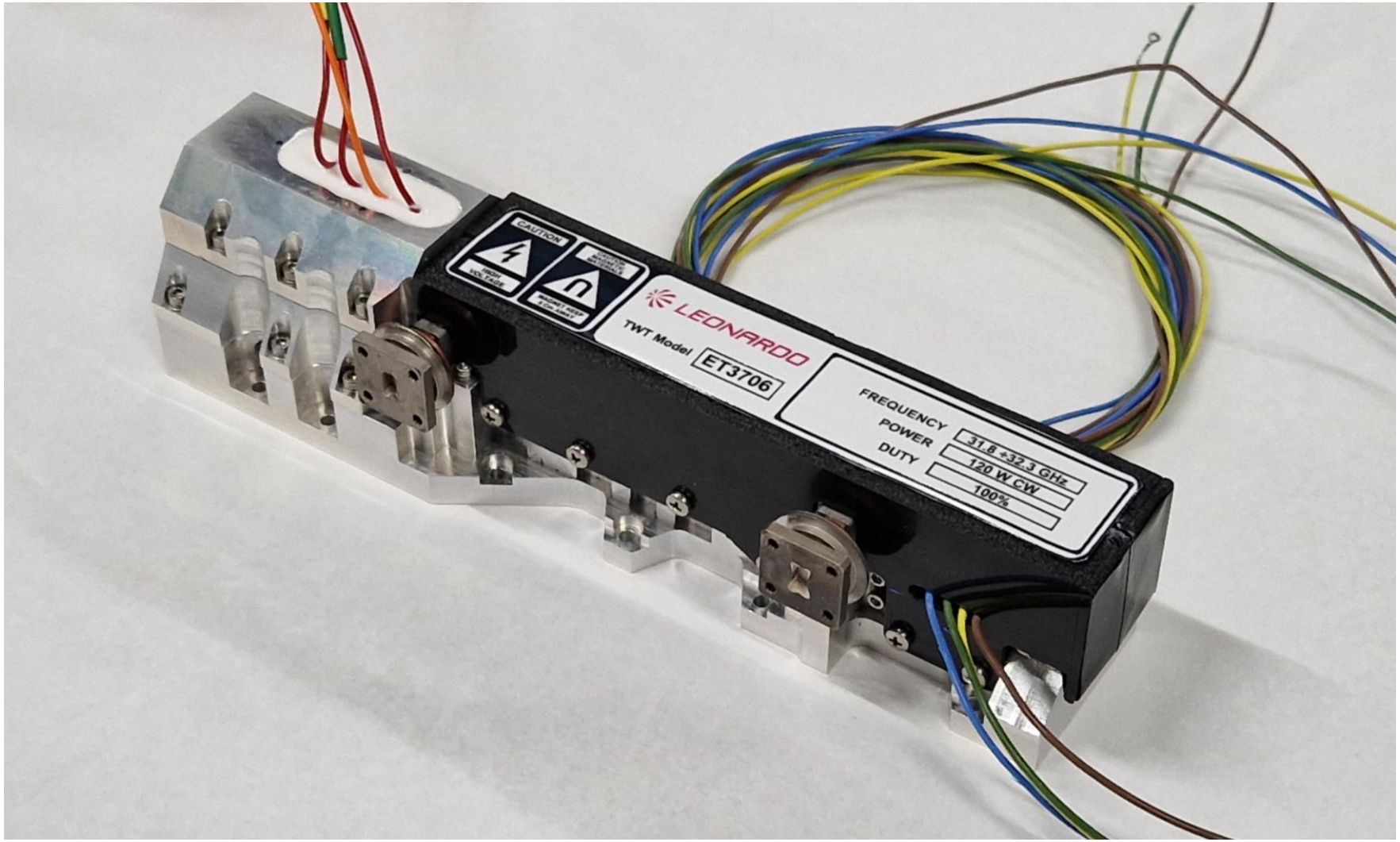


TWT Design, Manufacturing and Verification

TWT EBB Manufacturing

Fabrication of the TWT has been accomplished in accordance with the established manufacturing and assembly flows, using the Leonardo approved processes and procedures

The manufacturing has been straightforward without significant issues.



TWT Design, Manufacturing and Verification

TWT EBB Testing – Operating Conditions

SYMBOL	PARAMETER	Min	Max	UoM	EBB Measurements
	Warm up time	–	3	min	3
E_F	Heater voltage	4	6	V	5,18
I_F	Heater current	–	1,5	A	1,09
E_K	Cathode voltage	-10	-8	kV	$-9{,}2$
I_K	Peak cathode current	–	150	mA	145
I_h	Helix current with RF	–	5	mA	4
E_{FE}	FE ON voltage	-20	0	V	-1
I_{FE}	FE current	–	1	mA	0
E_A	Anode voltage	0	1.000	V	0
I_A	Anode current	–	1	mA	0
	Collector voltage:				
E_{C1}	- first stage	$35\%\ \lvert E_K\rvert$	$39\%\ \lvert E_K\rvert$	V	$37\%\ \lvert E_K\rvert$
E_{C2}	- second stage	$23\%\ \lvert E_K\rvert$	$27\%\ \lvert E_K\rvert$	V	$25\%\ \lvert E_K\rvert$
E_{C3}	- third stage	$21\%\ \lvert E_K\rvert$	$25\%\ \lvert E_K\rvert$	V	$23\%\ \lvert E_K\rvert$
E_{C4}	- fourth stage	$7\%\ \lvert E_K\rvert$	$11\%\ \lvert E_K\rvert$	V	$9\%\ \lvert E_K\rvert$
	Peak collector current:				
I_{C1}	- first stage	–	50	mA	74
I_{C2}	- second stage	–	50	mA	36
I_{C3}	- third stage	–	100	mA	21
I_{C4}	- fourth stage	–	150 $(NO\ RF)$	mA	77
–	Duty cycle	–	100	%	100

A brief set of requirements for the TWT ET3706 EBB are presented in the following table.

TWT Design, Manufacturing and Verification

TWT EBB Testing – Main Performances

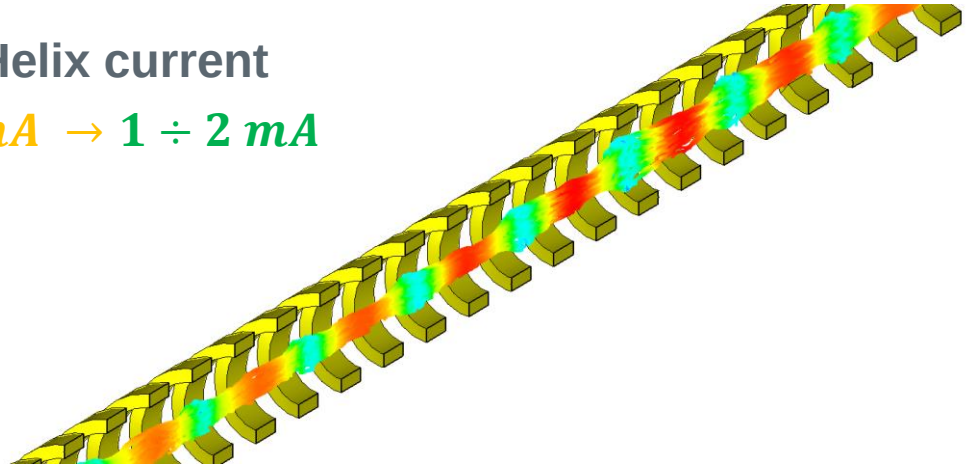
PARAMETER	Min	Max	UoM	EBB Measurements
Frequency range	31,8	32,3	GHz	$31,8 \div 32,3$
Rated output power	150 (51,8)	–	W (dBm)	170 (52,3)
Gain at saturation	50	–	dB	47
AM/AM curve	Monotonic		–	Monotonic
Efficiency at saturation	60	–	%	44
Gain flatness	–	0,2	$dBpp$	0,2
Noise Figure	–	35	dB	34,7
Spurious output ratio	–	−60	dBc	< -60
Second harmonic output ratio	–	−30	dBc	< -30
AM/PM curve	Monotonic		–	Monotonic
AM/PM conversion	–	5	$°/dB$	4,9
Electronic Efficiency	–	–	–	13

Design Improvements

The current TWT design has demonstrated, either by simulation prediction or by test, to fulfill most of the requirements in terms of margin of safety and performances. TWT assembly has not shown critical issues but nevertheless, some activities could be carried on to reduce the helix current and to increase the gain and the overall efficiency.

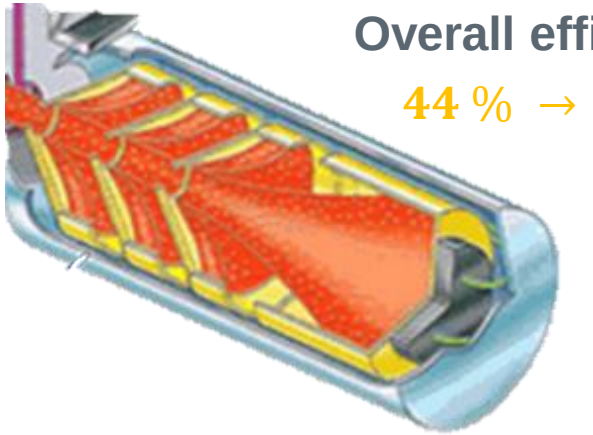
Helix current

$4\ mA \rightarrow 1 \div 2\ mA$



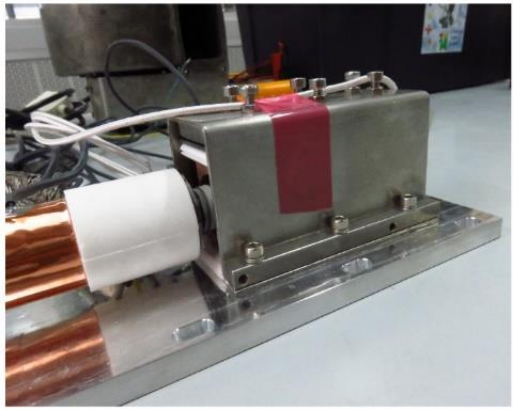
Overall efficiency

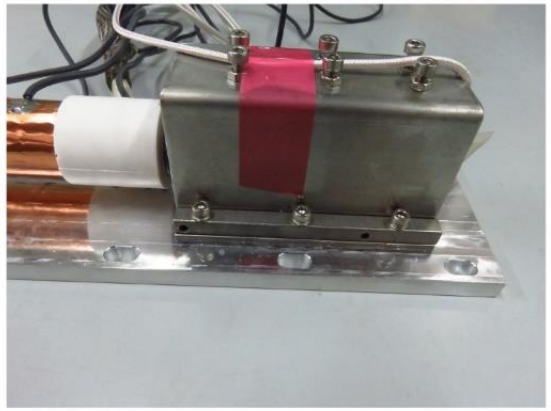
$44\ \% \rightarrow 55\ \%$

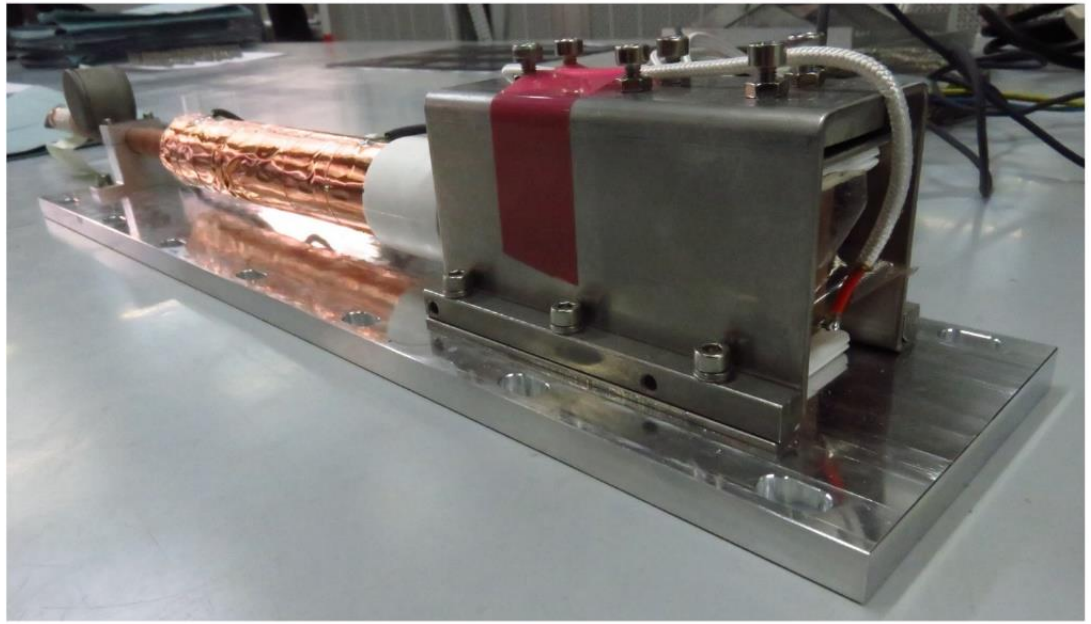


Margin verification

10.000 heater ON/OFF cycles







To demonstrate the lifetime of the heater/cathode assembly, a TV has been designed to be subjected to Heater ON/OFF cycles. The TV is made up by the same electron gun used in the TWT ET3706A and by a collector capable to dissipating the beam power during the cathode emission check.

15.000 heater ON/OFF cycles successfully performed against 10.000 cycles required.

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