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Envision Mission – Ka-Band TWT

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

ESR - Executive Summary Report

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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. OVERVIEW

This study is inserted in the frame of the preparatory activities for the "Development of $120\,W$ $32\,GHz$ TWT for Payload Data Transmitters" for EnVision mission. EnVision is proposed as a joint mission with NASA, with payload elements funded by the ESA Member States. 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. This calls for vacuum tube high power amplifier technology, namely Travelling Wave Tubes (TWT). The $120\,W$ $32\,GHz$ TWT is intended to be part of the Ka band communication subsystem that includes two Ka band TWTs.

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 the klystron for the Metop_SG program.

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 $31{,}8 \div 32{,}3\,GHz$ with $120\,W$ saturated RF output power, $200\,MHz$ instantaneous bandwidth and 60% overall efficiency (at saturation).

Moreover, margin of safety on critical aspects that may affect reliability have been considered by analysis and tests.

Furthermore, in order to verify that the TWT is free from multipactor phenomenon in the range $31{,}8 \div 32{,}3\,GHz$, verification by simulation has been carried out of the more sensitive regions of the structure. The simulation has been carried considering $9\,dB$ margin respect to saturated RF output power level as per the applicable ECSS-E-20-01A rev.1

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

Starting TRL was assumed "3" because there was not any proven prototype.

A BB model has been designed and tested in laboratory environment to verify the main electrical performances. A revision of the design followed the test activities on the BB to arrive to the EBB that has been tested in laboratory environment to verify the electrical performances.

Output TRL is "4" since the EBB demonstrates the electrical requirements in laboratory environment.

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.

The development activity, according to the SOW [A1], has been organized in five "Tasks", briefly described in the following paragraphs.

4. DEVELOPMENT TASKS

4.1 TASK 1 – Market/Literature Survey and Preliminary Analysis

The aim of the market survey was to assess the today available TWT potentially suitable for the intended application.

Considering the variety of Ka-band products available on the market using CW amplifier, the focus has been put on communication and data transmission equipment for military and civil, i.e. scientific projects, space applications.

It has been evidenced also that the today technology of Solid-State Ka-band does not allow to reach, in a reliable way, the required power level, the limiting factor being the RF power semiconductor devices, therefore the evaluation has been mainly concentrated on the tube technologies and the already available products.

From the survey, it has been drawn the conclusions that the TWT closest to the requirements for Envision mission was from USA market, and that in any case it required heavy modifications to satisfy the requirements. Therefore, it was pointed out the opportunity, or even the necessity, to develop a European device as the baseline for such application.

Furthermore, the result of the survey has been the basis for technological solutions trade-off and for review of tube target specification.

From the market survey, from literature examination and from Leonardo heritage it came out that the TWT to be developed has to implement four major technical solution:

- Electron gun with focus electrode control configuration: for better electron beam quality.
- Insulated anode: for cathode current adjustment.
- Collector configuration with four stages at least: for high efficiency.
- Reduced RF losses helix: for reduce thermal stress and improve efficiency.

4.2 TASK 2 – TWT Building Blocks Proof-of-Concept: Design, Manufacturing and Verification

At the end of the Task 1 preliminary TWT baseline solutions have been identified and proposed; the successful Preliminary Analysis Review meeting allowed to pass to the Task 2. In this frame the design, electrical and mechanical, has been finalized and the TWT ET3706 BB has been manufactured and tested.

A brief description of the main building blocks is given here below.

Electron gun

The electron gun generates the electron beam that is focused to the desired diameter in order to be injected into the helix structure, it is designed once the interaction structure is defined since this one dictate electron beam operating voltage, current and diameter. Compression of the beam to the required diameter is achieved by an electrostatic optics.

The most appropriate optics configuration is the Pierce optics with focus electrode since it is capable to produce the suitable laminar electron beam.

Slow wave structure

The TWT slow-wave structure is made up of a helix supported by three insulating rods 120 degree apart, fixed inside the vacuum metal envelope that is part of the magnetic circuit. The helix is copper plated for reducing RF losses. The all structure is made of sections having different pitches along its length. Severed lengths are used to limit the gain of each amplifying region. SWS dimensions are such to operate at voltage below $10\ kV$.

Collector

The high efficiency requirement implies the adoption of a four stages depressed collector.

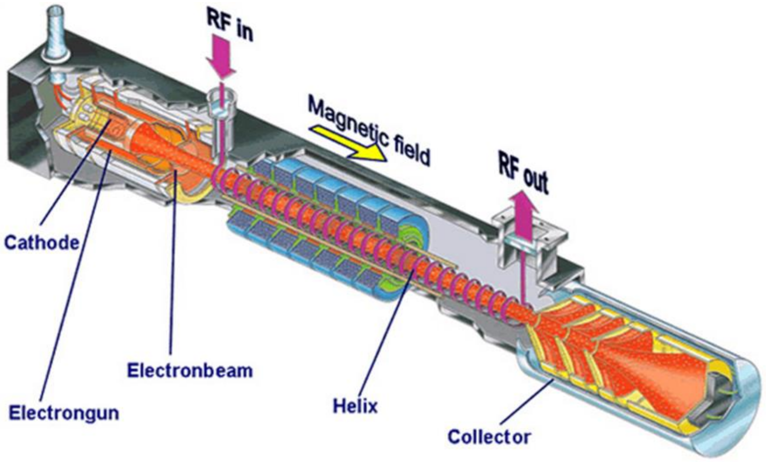
Magnetic focusing

Periodic Permanent Magnet configuration is adopted.

Housing

The major functions of this part are to support mechanically the TWT, to provide appropriate thermal dissipation and environmental strength. All of these aspects have been analyzed.

An overall picture of a TWT is shown next:



4.3 TASK 3 – TWT EBB Detailed Design and DDR Closure

In this task, a detailed design of the TWT Elegant Breadboard (EBB) has been developed, with the aim of testing RF performances and overall efficiency. According to the tests carried during the test campaign on the TWT BB, several information has been recorded and used to review the design of the TWT in order to develop the EBB model.

The simulation software CST has been used for the TWT design to demonstrate compliance with the RF specifications and Ansys Mechanical and PTC Pro-Mechanica have been used to demonstrate compliance with the thermal and mechanical requirements.

At the end of this task, a Detailed Design Review (DDR) has been held to analyze the outcome of the task and to agree on the test plan to be executed during the measurement campaign on the EBB.

Since all the work packages of the Task 3 have been verified and since all the data packages have been sent and accepted, the DDR phase has been closed.

4.4 TASK 4 – TWT EBB Manufacturing and Testing

In this task, manufacturing, assembly and testing of the TWT EBB have been carried out.

Scope of the TWT ET3706 Elegant Breadboard was to confirm the results obtained during the assembly phase of the tube in terms of baseline design, technologies and manufacturing.

At the end of the test campaign, a TRB has been held and all the results achieved in this task have been shown.

4.5 TASK 5 – Discussion of Results, Limitation and Future Work

The current TWT design has demonstrated, either by simulation prediction or by test, to fulfil most of the requirements in terms of margin of safety and performances. Nevertheless, some activities have to be carried on.

Efficiency and saturated gain are two performances to be improved; the root-cause of the misaligned results have been understood and the necessary corrective actions have been outlined.

The TWT assembly has not shown critical issues, anyway, a tight check on the dimensions of electron gun components and, more generally of the TWT assemblies, has to be accomplished in order to avoid unexpected performance results. As general concept a review for improvement will be carried on for ensuring repeatability of critical dimensions like in the electron gun where alignment in the range of $0{,}01\ mm$ is necessary to contain the helix current within 1 or $2\ mA$.

A picture of the TWT ET3706 EBB is shown below.