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1 (Coordinator)	TTI Norte, S.L.	TTI	Spain
2	Airbus Defense and Space SAS	AIRBUS	France
3	Universita degli Studi di Roma Tor Vergata	UNITOV	Italy
4	Fundación Tecnalia Research & Innovation	TECNALIA	Spain
5	OMMIC SAS	OMMIC	France

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Abbreviations and Definitions

Acronym	Description
5G	Fifth Generation
ADS	Advanced Design System
CAPEX	Capital Expenditures
CM	Control Module
CW	Continuous Wave
dB	deciBel
DC	Direct Current
DLV	Deliverable
DRC	Design Rule Checking
ECSS	European Cooperation for Space Standardization
EEE	Electrical, Electronic and Electromechanical
EM	Engineering Model
EM	ElectroMagnetic
EMC	ElectroMagnetic Compatibility
EPC	Electrical Power Conditioning
EU	European Union
FLEXGAN	Ka-band GaN-based SSPA for FLEXible payloads and multicarrier operations for 5G satellite concept
GaN	Gallium Nitride
GBPS	GigaBit Per Second
GEO	Geostationary Earth Orbit
GHz	Giga Hertz
HPA	High Power Amplifier
HPS	High Power Section
HTS	High Throughput satellite
MEC	Mechanical and Thermal System
MMIC	Monolithic Microwave Integrated Circuits
OPEX	Operational Expenditure
ORL	Output Return Losses
PA	Power Amplifier
PAM	Product Assurance Manager

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PAP	Product Assurance Plan
PAE	Power Added Efficiency
PCB	Printed Circuit Board
PSU	Power Supply Unit
RC	Radial Combiner
RF	Radiofrequency
RFT	Radio Frequency Tray
RMS	Root-Mean-Square
S/S	Subsystem
SME	Small and Medium Enterprises
SPC	Spatial Power Combiner
SSPA	Solid State Power Amplifier
TRL	Technology Readiness Level
TWTA	Traveling-wave Tube Amplifier
VHTS	Very High Throughput Satellite
W	Watt
WP	Work Package

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PERIOD REPORT

Grant Agreement number:	821830
Project Acronym:	FLEXGAN
Project Title	Ka-band GaN-based SSPA for FLEXible payloads and multicarrier operations for 5G satellite concept
Start date of the project:	01/11/2018
Duration of the project:	36 months
Period covered by the report:	From 01/11/2018 to 31/10/2019
Version:	1.0
Project website address:	www.h2020-flexgan.eu

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1. Summary for Publication

1.1. Summary of the Context and Overall Objectives of the Project

FLEXGAN is a European research project co-funded from EU H2020 programme funds. The project Ka-band GaN-based SSPA for FLEXible payloads and multicarrier operation for 5G satellite concept (FLEXGAN) aims at designing, developing and testing, in a representative space environment (TRL5), a low cost high power and efficient Ka-band Gallium Nitride (GaN) Solid State Power Amplifier (SSPA) with RF output power varying capability (flexible SSPA), with high innovative & low loss recombination schemes and with the ability to operate in multicarrier operation mode for highly flexible payloads for 5G satellite applications. The operational frequency band is 17.3-20.2 GHz and the objective output power is 125 W CW.

5G demand requires the deployment of very High Throughput Satellites (vHTS) than can satisfy the expected needs implying a growth opportunity for GEO satellites. This kind of spacecraft offers high capacity, large number of users and communication volumes (1 Terabit/s per satellite), with lower cost per GBPS, increasing the flexibility since the satellite capacity is allocated where it is needed. Future vHTS satellites will make use of Ka/Q/V gateways where the forward payload link will operate in K-band. Traditionally, demand for power at high frequencies has resulted in Travelling Wave Tube Amplifiers (TWTAs) as the logical amplifier of choice; this is due to the fact that traditional Solid State Power Amplifier (SSPA) technology was unavailable at similar performance levels. However, technological advancements such as linearization, miniaturisation, and the use of different materials such as Gallium Nitride (GaN), have levelled the playing field for SSPAs. GaN SSPAs employ more units with less power leading to a better agility, less redundancy, generic and reconfigurable payloads.

High efficiency GaN SSPAs can replace TWTAs in high power and high frequency payload applications if technology at MMIC level is able to provide the required RF power in Ka band with the efficiency that the system needs. Furthermore, in space applications the size and weight are also limited resources which directly affects the satellite launch cost.

The impact of GaN technology in space-borne units is now a priority concern due to the different applications in which it can be used. There are some initiatives to develop GaN MMICs and low power GaN based HPAs. However, it has not identified any project or development in Ka-band for the development of high power GaN based SSPAs due to the challenge in the design of the efficient combination of several GaN devices at Ka-band frequencies whereas the size and weight is kept as low as possible. The main technology innovations that FLEXGAN brings are:

1. Bring known terrestrial technologies by TTI to space
2. SSPA able to provide the required output power maximising the power added efficiency to compensate the downlink fading losses
3. SSPA able to transmit in multicarrier mode w/o memory effect
4. Implementation of highly innovative linearization techniques
5. Use of lightweight composite structures to decrease the weight of the overall SSPA
6. Employment of low loss combination technique.
7. Design, develop and test of a Ka-band HPA Monolithic Microwave Integrated Circuit (MMIC) based on D01GH technology from OMMIC to have a 100% European SSPA

FLEXGAN will develop a high power GaN based SSPA with the design challenge of the efficient combination of several GaN devices at Ka-band whereas the size, weight and power consumption are kept as low as possible.

There are several important efforts in Europe focused on demonstrating the capabilities of GaN technology applied to HPA for space segment. Despite of the promising results, there is still some uncertainty in the

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aerospace market to introduce a new technology by replacement of another (TWTAs) that has demonstrated its validity during years. FLEXGAN will allow reinforcing and corroborating the use of GaN technology for space applications.

FLEXGAN Consortium members have a wide experience in the design of Ka-band GaN based SSPAs for satellite communications in the ground segment. However, a scenario for space hardware is quite different and more challenging from ground hardware. Some of the critical challenges are: the on-board DC power generation, the thermal management, the multipaction and corona effects due to vacuum operation, the ionizing radiations, the availability of space qualified component, the reliability guidelines, etc. Therefore, this project will bring known terrestrial technologies to space.

Apart from the innovations above mentioned, FLEXGAN also will:

- Allow to reinforce and corroborate the use of GaN technology for space applications.
- Bring known terrestrial technologies to space.
- Create new business opportunities around space market.
- Stimulate the integration of space into European society and bring benefits to European citizens:
- Provide 5G satellite connectivity and resilience:
    - Wide connectivity: anywhere/anytime
    - Cost per bit reduction
    - Security union
    - Reduction of OPEX and CAPEX in the 5G radio networks
- Promote jobs creation: qualified employment
- Contribute to European research and technology ecosystem
- Participate in climate resilient future: FLEXGAN as a “Green technology”

Considering that this equipment is a category D unit according to the definition in ECSS standards, certain design margin is included in the RF power capability with respect to values required by the satellite. In a first phase of the project it will be developed:

- High power & high efficiency combination techniques
- A complete EM of an SSPA (EPC, RFT, thermal & control) based on non-EU technology and on high efficiency combination techniques. This SSPA will be functionally and electrically tested, as well as temperature tests will be accomplished.
- A MMIC based on GaN EU technology with 10 W of output power, complying space de-ratings and with similar requirements in terms of output power to the 10 W HPA MMIC based on non-EU technology with the objective of replacing it.

In a second phase of the project, the developed EM will be upgraded by replacing the GaN power module based on a non-EU technology with the EU-MMIC designed and realized with OMMIC technology. The EM developed in the phase 1 of the project will be used to benchmark the results obtained in phase 2. This second EU-SSPA will be functionally and electrically tested, as well, and submitted to environmental and mechanical tests in such a way that the developed amplifier will be tested and characterized in a relevant environment (TRL 5).

The concrete objective of FLEXGAN are:

- Objective 1: Establish specific requirements for the design and development of a GaN based SSPA suitable to operate in satellite networks operating in Ka-band for future 5G connectivity.
- Objective 2: Design, develop and test an EM SSPA based on non-EU technology. The idea is to have in a first phase a SSPA that could be fully characterised and useful to demonstrate key challenging aspects of the design of an EM SSPA that is fully representative of a FM configuration. In this way as

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output of objective 2 aspects such as multipaction, corona effects, thermal dissipation, output power flexibility and high efficiency combination at Ka-band will be fully designed and tested in the phase 1 of the project.

- Objective 3: Design and test a MMIC based on European D01GH GaN technology from OMMIC.
- Objective 4: Upgrade the EM SSPA (objective 2) using the MMICs from OMMIC (objective 3) and perform environmental tests in order to have at the end of the activity a TRL5 SSPA. All the research findings and results of FLEXGAN that don't compromise the future exploitation activities will be disseminated and communicated to the scientific and industrial community as well as to the general audience.

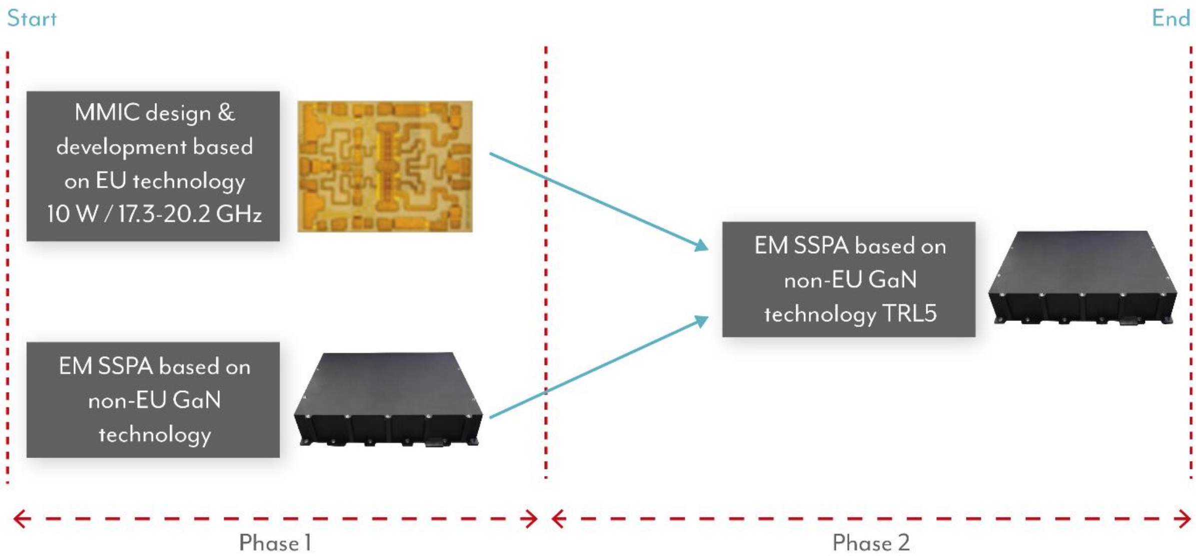

FIGURE 1. FLEXGAN Phases

FLEXGAN Consortium is comprised by five partners from three European countries: TTI leading the project and TECNALIA from Spain, AIRBUS and OMMIC from France and UNITOV from Italy. The Consortium includes industrial partners TTI (SME), OMMIC (SME) and AIRBUS, as well as one academia partner from one university, UNITOV, and from one research organization, TECNALIA.

As can be seen in next diagram, the Consortium is well balanced and covers all the supply chain needed to develop the project with success: from the GaN European manufacturer (OMMIC) and requirements identification of final user (AIRBUS), passing through modules design (UNITOV, TTI and TECNALIA), development and SSPA integration (led by TTI), up to TRL5 verification activities (TECNALIA).

FLEXGAN project was divided into two reporting periods. The first one from M1 until M18, i.e. from 01.11.2018 till 30.04.2020, and the second one from M19 till the end of the project in M36. This document details the work carried out during the first year of FLEXGAN and it is not linked to a reporting period.

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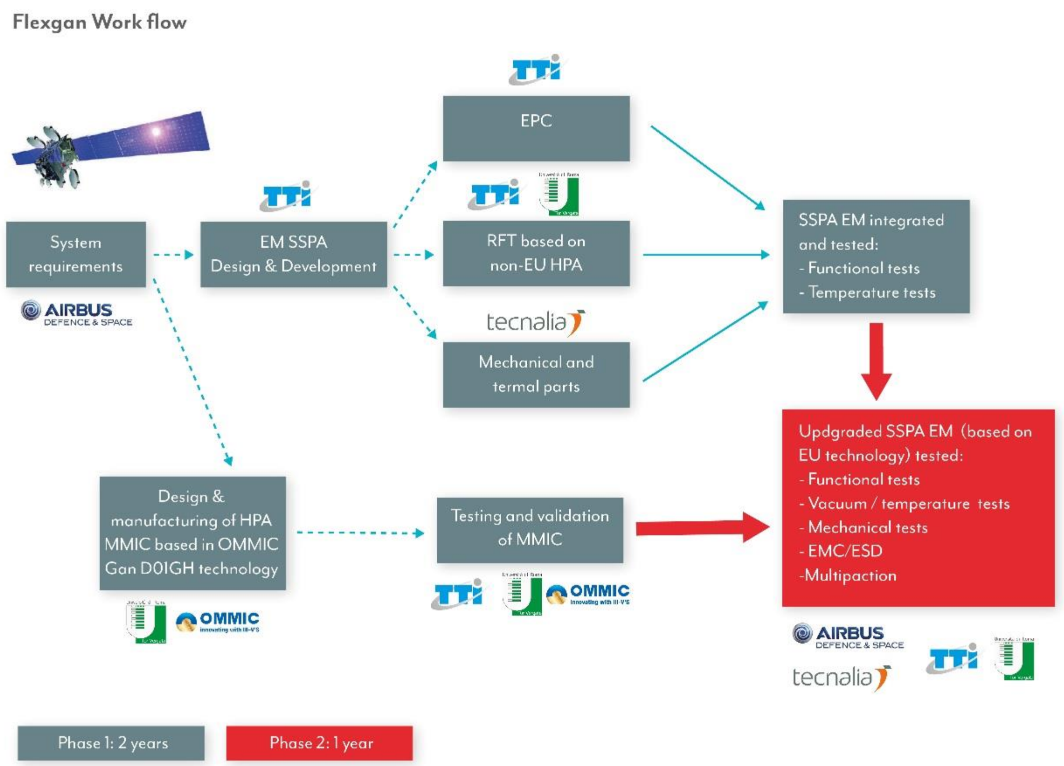

FIGURE 2. FLEXGAN consortium

1.2. Work Performed from the Beginning of the Project to the End of the Period Covered by the Report and Main Results Achieved So Far

As aforementioned, this report covers the work performed during the first year of the project (first project period), from 01.11.2018 till 31.10.2018. The technical activities developed within this period have been focused on:

- Defining, implementing, maintaining and controlling the overall FLEXGAN Product Assurance Programme.
- Establishing the specific requirements for FLEXGAN SSPA and provision of up to date usage cases for SSPA.
- Defining FLEXGAN baseline architecture.
- The design and development of HPA GaN MMIC based on D01GH GaN technology from OMMIC (1st iteration)
- The design, development and test of highly efficient combiner techniques
- The preliminary SSPA design.
- The design of the power module based on the non-EU MMIC and on the MMIC based on OMMIC technology.
- Working on the detailed design of the EM SSPA based on non-EU GaN technology.
- Defining, implementing and controlling the Innovation Management plan.
- Establishing a preliminary business plan.
- Defining an initial exploitation plan.
- Carrying out different dissemination and communication activities.

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FLEXGAN Product Assurance plan has been prepared and established as a mandatory basis for the entire project development. FLEXGAN Product Assurance plan has been defined according to ECSS standards by adapting them to the scope and timeline of the project. FLEXGAN PAP establishes the basis of quality assurance, risk management, dependability, EEE components, materials, mechanical parts and processes, safety and FLEXGAN cleanliness & contamination control plan. Critical aspects and procedures relative to the product assurance during design phase have been identified and set. Special product assurance templates have been generated, being established as a basis in the design assurance.

Based on AIRBUS relevant experience and developments, AIRBUS has determined use cases for GaN SSPAs. Furthermore, considering the actual role of AIRBUS as end user of SSPAs in flexible and high throughput satellites, AIRBUS has provided relevant and detailed specifications at different levels: equipment definition, electrical, mechanical, operability, EMC, pre-launch, launch and in-orbit environment and product assurance requirements. These specifications are aimed at guaranteeing the development and production of an SSPA adapted to the space 5G market. These requirements were critically assessed by the other partners, based on initial analysis and previous background, and discussed internally. Finally, the specifications for FLEXGAN have been established in agreement between all the members of the project.

Baseline SSPA architecture has been defined to meet system requirements and challenges established at system level. The main subsystems and their different stages have been identified, their requirements established and the interfaces between modules detailed. Three main subsystems have been defined and their main functions and characteristics described: Radiofrequency Tray (RFT), Electronic Power Conditioner (EPC) and Mechanical and thermal subsystem (MEC). FLEXGAN RFT is mainly formed by a Gain Control Unit, a Linearizer, a Medium power module and a High-Power Section (HPS). RFT architecture has been established based on power balance estimations, the main RFT components have been identified, as well as, the characteristics to be fulfilled by them have been specified. In addition, EPC architecture has been configured to meet system requirements and to give response to the RFT needs. EPC is composed by two subsystems: PSU and CM. A microcontroller is stated as core of the control module, the software and hardware requirements to be demanded to the CM have been determined. The power supply unit has been sized considering the SSPA DC power supply necessities. Furthermore, each of its stages has been identified and their main characteristics set. Preliminary selection of the 'key' EPC components was carried out taking into account the existence of a space qualified version and identifying both components. A very preliminary thermal study at high-level (architecture) were performed. The thermal requirements for mechanical system have been established for most demanding configurations of the HPS. Possible solutions to improve heat transferred from GaN chips to the cooling base (satellite panel) were studied at system level in a preliminary analysis.

The GaN MMIC design has been carried out during this period to meet the challenging requirements on output power while targeting the efficiency and linearity performance as high as possible. To mitigate risk, three different MMICs have been designed (named as HPA1, HPA2 and HPA 5). Two of them share the same architecture, power budget and active periphery but different passive structure whereas the third one is based on a balanced structure with Lange couplers, and different power budget. Even though no loop stability issues have been appeared in the simulations of these designs, in order to further reduce risks, additional modifications have been introduced. Shunting balance resistances have been inserted in the internal loops of the three MMICs to prevent possible odd mode oscillation, obtaining almost the same simulation results than before. Finally, 6 different MMICs designs have been realized. Circuit, Electromagnetic, Monte Carlo, small and large signal stability simulations have been carried out for all proposed MMIC solutions. Attending to the simulation results, the designs meet the specifications. After performing the DRC of the Gds files, reticule was arranged and approved, and finally, the wafer manufacturing started. During this period the wafer has been manufactured. Different steps have been taken for successful manufacture of the wafer (e.g.: mask making, stabilization baking, back side

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processing, etc.). The on-wafer tests began at the end of the reporting period, a complete test campaign is planned for month 13 of the project. Promising results have been obtained in the preliminary tests, in-line with the expected from the simulations.

Two highly efficient combiners have been selected as the most suitable for FLEXGAN, the Radial Combiner (RC) and the Spatial Power Combiner (SPC). Both structures have been completely designed: Electromagnetic, thermal and mechanical designs have been performed. Passive versions of both solutions have been manufactured, assembled and tested. Good matching between measurements and simulations has been achieved in both cases. Finally, a thorough assessment of the advantages and disadvantages of both combiners for the FLEXGAN SSPA has been carried out. Considering the point of view of the end user (AIRBUS), the FLEXGAN consortium has decided to use RC as a baseline for FLEXGAN, but also to develop SPC as a backup solution (contingency plan).

Power module based on non-European GaN MMIC has been designed. The aspects faced in the power module design were: the hermeticity of the module, the employ of waveguide ports, ensure low size and light weight, the selection of low outgassing and high thermal conductivity substrate and the guarantee that not voltage breakdown will be produced due to multipactor effect. Although this project aims to achieve a TRL5 solution, it has been decided to face the design of the power module as a hybrid module following standard ECSS-Q-ST- 60-05C (for future Flight model version). This ambitious objective has conditioned the design of power module with the mentioned design issues. This power module has been manufactured and assembled in two versions: one in coaxial form and the other one with waveguide ports. Preliminary measurements of both power module have been carried out during this period.

The preliminary design of the 5G SSPA was performed. Initial designs for each subsystem (RFT, EPC and MEC) have been undertaken based on simulations and initial analysis. The design of each part has been addressed in order to meet the requirements. Each subsystem (RFT, EPC and MEC) has been analysed with different simulation tools (ADS and Spice software programs) in such a way that the obtained results have validated the preliminary designs. Each requirement has been analysed and the first compliance matrix issued.

The detailed design of the 5 G SSPA implies a collaborative work among all the partners involved in the design of the different subsystems. To attain a feasible, reliable and optimum SSPA detailed design, an iterative and cooperative design process is required among all designs. A detailed design of different RFT stages has been performed, although it can still be refined if necessary when considering the detailed design of the other subsystems and the complete SSPA. PCB layouts, bill of materials as well as drawings of the mechanical enclosures have been made. In addition, the schematics and PCBs have been completed for the different PSU parts. A preliminary list of components of each PCB has also been defined. The key components of the PSU were established during the preliminary design, in the detailed design this list has been completed with all necessary components at each stage. As for RFT, the EPC design is not frozen and could be updated if necessary.

The different designed parts were integrated in the SSPA housing, and its preliminary footprint was obtained. Different specific connection elements (straight and bend waveguide sections) have been designed to connect the RFT parts. In addition, an output directional coupler has been electromagnetically and mechanically designed, to reduce as much as possible the insertion losses, and have the desired coupling value. The thermal viability of the complete structure is being analysed. It is necessary to ensure that the components operate within their established temperature ranges and below the maximum channel temperature according to the ECSS-Q-ST-30-11C. The preliminary results of the thermal analysis have led to the need to change the position of some parts due to the excessive heating of some components. These components are being redesigned to adapt their footprint to the available space.

Furthermore, a significant effort has been dedicated to the communication, dissemination and exploitation of FLEXGAN. The project aims to provide a strong impact through the wide dissemination of its outcomes

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and the active communication of its achievements and activities. The major aim during the first year of the project has been to make the project well-known and to achieve the largest possible audience. To this end, FLEXGAN project has been disseminated in two national magazines (ilSole24ore, Italian magazine, and Proespacio, Spanish magazine). Also, FLEXGAN project was presented at the last European Microwave Week Conference during the talk entitled "Challenges & Solutions of High Frequency and High Output Power GaN-based SSPAs". During this period, being at the beginning of the project, the already available technical results are not sufficient to produce any scientific contributions, but preliminary results are indicating that in the following months there will be enough material to start writing scientific contributions. Thus, the communication activities have been focused on the public disclosure of the project and its main objectives. Among the foreseen technology breakthroughs, significant contributions are expected in the field of GaN MMIC power amplifiers, thermal management, power combining techniques, and power supply architectures for SSPAs for next generation 5G satellites. The main communication channels established for and used by the project have been the FLEXGAN official web site and social networks. First FLEXGAN brochure has been realized with the aim to be distributed during international events, as was done in the TTI stand at IBC2019. During this period, dissemination, communication and exploitation plans have been also defined for their implementation in the incoming years of the project. These plans have been determined with the objective of establishing the strategy to efficiently communicate the project activities and also to disseminate project results and its achievements. They are mainly oriented in two different fields of application, on the one hand to the application of FLEXGAN SSPA and its results in the next space programmes and on the other hand, to the exploitation of spin-in/spin-out opportunities of FLEXGAN in non-space fields, in particular, in civil engineering applications.

From a management point of view, the work has been devoted to the coordination of the work among the FLEXGAN consortium in order to ensure the successful completion of the project objectives in accordance with its schedule.

1.3. Progress Beyond the State of the Art, Expected Results until the End of the Project and Potential Impacts (including the Socio-Economic Impact and the Wider Societal Implications of the Project So Far)

FLEXGAN supposes disruptive innovation because it changes the nature of competition in the marketplace and lead to the creation of new ventures. Current amplifying stages in satellites payloads at Ka band are based on travelling wave tubes amplifiers (TWTA), implementing low power SSPAs as driver stages. The innovation of FLEXGAN is sustained on the development of high power SSPAs based on GaN technology, which are able to provide the same services as TWTAs but improving the reliability, lifetime, noise performance, achieving a wider bandwidth and reducing the complexity. Despite the fact that TWTAs offer high power, high efficiency and well-proven flight heritage in the civil Ka frequency band, the potential benefits of SSPAs include graceful degradation, lower supply voltages, lower cost because of wider commercialization (they are suitable for use in different aerospace and terrestrial applications) and better integration in case of phased-array and multi-spot systems.

FLEXGAN project innovation relies on the development of a novel, fast and cost-effective solution based on GaN technology for onboard power amplifiers. The objective is to design, develop and test in a representative space environment (TRL5) a low cost, highly efficient and flexible SSPA at Ka band targeted to develop a future Flight model to be used in satellite payloads. It is based on D01GH OMMIC European GaN technology and implements a high innovative and low loss recombination scheme.

FLEXGAN adopts an aggressive strategy based on launching a new and better performance product (SSPA better than current TWTA) seeking to reach a leading position in the satellite market, overtaking possible competitors (SSPA manufacturers). FLEXGAN SSPA represents a new advance in the application of GaN solutions to spacecraft payloads, being conceived as an intermediate step towards the final HPA flight model from HPA ground applications. FLEXGAN will help to eliminate the gap in application

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of GaN technology to space models. FLEXGAN search from taking advantage of GaN superior properties to achieve the performance targets at a vastly improved energy efficiency.

Although FLEXGAN outcomes are susceptible to be used in aerospace (Communication, Navigation and Earth Observation missions), in airborne and in ground market segments, FLEXGAN SSPAs are specifically oriented towards a Flight model to be used onboard next generation HTS and vHTS communication satellites to be deployed in the 5G ecosystem. 5G offers faster connectivity at lower latencies and lower power consumption. That means mobile connectivity is faster than most wired broadband currently used. In fact, it could be fuel innovation in the internet of things, smart homes, augmented reality, virtual reality, health care, media, cloud services and more, which will create tremendous business opportunities across many industries. Satellite systems are key components to provide 5G services, augmenting 5G services capability and addressing some of the major challenges: increasing connectivity and reducing cost per bit. FLEXGAN SSPA will contribute to the integration of satellites communications in 5G, enabling the transmission of 5G RF signals from the satellite to the ground in a compact, reliable and flexible solution. Reliable amplification of the 5G signal within satellites is key to allow coverage reaches areas where 5G terrestrial communications fail or are not suitable, allowing broadband internet access with the associated innovative applications anywhere/anytime. Furthermore, FLEXGAN low cost SSPAs is an enabler for the cost reduction of CAPEX and OPEX in the 5G radio networks, where a cost reduction in the RF devices and modules acquisition and in the consumed energy during their operation is a key factor.

Also, FLEXGAN will contribute to increase the competitiveness of the different stakeholders in the European Space industry by the adoption of GaN technologies for on-board high power amplifiers. It will create new business opportunities around space market. Thanks to FLEXGAN achievements, the companies in the consortium will be enabled to deliver GaN-based product ready for space and ground segment in the satellite communication, Earth Observation and Navigation space markets.

As mentioned before, apart from aerospace FLEXGAN technologies could be applied to ground products in both the commercial and military markets. The technology allows spin-off products, such as SSPAs, LNAs, switches, transceivers, sensors, etc., for being installed in hub stations and user terminals. The competitiveness of project partners will be strengthened thanks to apply the novel technologies investigated and developed within FLEXGAN to other fields

Moreover, new job opportunities will be created within the project, promoting the growth of technical qualified employment. FLEXGAN will stimulate the integration of space into European society and bring benefits to European citizens. In addition, it contributes to European research and technology ecosystem.

With regards to the environmental impact, FLEXGAN SSPA will permit to reduce the emissions of the satellite launch due to the mass reduction of the payload based on FLEXGAN SSPA mass reduction. Moreover, a key advantage of GaN is its energy efficiency requiring less energy for manufacturing, system development compared to TWTA technologies or GaAs technologies. As such, it can be categorized as a ‘green technology’ in the sense that requires less energy than other alternative technologies.

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