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# First Year Report

## Summary ESR Reports (MS6)

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# 1. INTRODUCTION

This 1st year report is an evaluation of the first-year research results for all TESLA ESRs by their respective supervisors and these results have been published in an almanac accessible through the project website. Despite some delays in the recruitment for some of the ESRs, this milestone has been reached and in these cases the supervisor has based their evaluation on the months that the ESR has been working on their project. The report will be updated at Milestone 10 and the end of the second year.

# 2. SUMMARY REPORTS

## ESR1 Yifang Wei (HWU)

| Project Information | |
|---|---|
| Name of fellow | Yifang Wei (ESR1) |
| Host Research Department | Department of Electrical, Electronic and Communications Engineering. Heriot-Watt University (HWU) |
| Supervisor 1 name and host | Prof. Jiasheng Hong (HWU) |
| Supervisor 2 name and host | Dr. Christian Arnold (TESAT) |
| Supervisor 3 name and host | |
| Start Date | 01/07/2019 |

**Summary Report**

For this project, the target is to design an elegant beamforming network based on active phased array which is capable of feeding massive antenna elements for several 100s. Combined with the commercial "core chip" with phase shifter and gain control section, the beamforming network also consists of antenna array elements with high performance which are convenient installed.

For commercial considerations, analogue or hybrid beamforming is used in this design due to the digital beamforming has drawbacks on high power consumptions and cost of digital to analog (D/A) and analog to digital (A/D) conversion which will become limitation for massive MIMO (multiple input multiple output) system applications. Although digital beamforming system has excellent flexible on angle of freedom and controlling without analogue phase shifter and gain control section, the analogue beamforming is used in this project because of the massive beam numbers and antenna elements.

To compare with the existing products and applications in recent year, the wide frequency bandwidth on K/Ka band and the MIMO network with more input beams and antenna elements are the challenges which are also the targets for this project. The targets now are that: 16 inputs and 512 outputs, wide band around 20 GHz and 30 GHz to achieve 2-3 GHz bandwidth and elegant and convenient structures.

During this year, the design and testing process of unit wide band power divider has completed. The designs and simulation results of basic MIMO structure of 4-input-16-output network is achieved by simulation software AWR and CST. For 4-16 network, the S11 from 19 GHz to 20.5 GHz is below-24 dB, from 29 GHz to 30.5 GHz is also around -24 dB. Next step is to continue to optimize the performance in simulation, to fabricate and test step by step for the 2-2, 4-4, 4-16 networks to show the performance of the operations. The investigation of power divider with load will also be start next to compare and analyze for a power without load.

Concerning the active antenna are usually used for the "user beam" which serve the end user and mobile device. The transmit and receive parts (Rx and Tx) are usually separated. Especially the beamforming network system in this project which will have intersatellite links and gateway beams.

The novel structures of waveguide transition are designed for the beamforming system with separate Rx and Tx in this project to connect PCB (printed circuit board) and PA/LNA (power amplifier/low noise amplifier) and antenna array. It will reduce cost on fabrication and simplify steps on installation. Additionally, it will make the system have multiple functions by just replace the waveguide part and PA/LNA parts. Because if the feeding networks with waveguide transitions has two separate size and structures, it is difficult to be applicable on both Rx and Tx on one system.

The basic designs of the SICL (substrate integrated coaxial line) to waveguide with ridge stepped transform and the SICL to ridge waveguide transitions are completed in simulation software CST. The performance of return loss will be expected better than 26 dB, now some performances of designs still need to optimize and improve. Some novel structures such as a replaceable waveguide transition by using multi-layer patches is also investigating now.

Considering the tolerance and fabrication will also be next step works to have better performance and valid results for applications and research.

## ESR 2: Abdul Sami (UPNA)

| Project Information | |
|---|---|
| Name of fellow | Abdul Sami (ESR2) |
| Host Research Department | Department of Electrical, Electronic and Communications Engineering. Public University of Navarre (UPNA) |
| Supervisor 1 name and host | Miguel A. G. Laso (UPNA) |
| Supervisor 2 name and host | Dr. Iván Arregui (UPNA) |
| Supervisor 3 name and host | |
| Start Date | 01/09/2019 |

**Summary Report**

Abdul started his PhD in September 2019 at the Microwave Component Group (MCG) in Public University of Navarre (UPNA) under the supervision of Prof. Miguel Laso and Dr. Ivan Arregui. The title of his PhD is "Microwave and millimeter-wave components for easy fabrication".

At the start he had a meeting with his supervisors in which they told him about their previous works, taught him some basic concepts and guided him as to how he would pursue his PhD. At the beginning, he studied papers on waveguide filters based on step-impedance resonators (SIRs) published by MCG and learnt basic techniques. Then, he reproduced those results using CST microwave studio to learn design procedure. Afterwards he started actual work by designing narrow bandpass filter using step-shaped geometry (varying height) with constant widths employing non-standard ports for Q-band satellite applications. This was a reference filter (as this topology was already implemented), with low-pass response and was not our targeted design. Our target was to implement a novel filter topology with suppressed low-pass response, relax fabrication and employing standard ports to avoid use of transformers to reach standard ports. For that purpose, firstly a novel filter topology with varying heights and widths was implemented to suppress low pass response and then the filter was redesigned with standard ports keeping in mind the minimum mechanical gap criteria and to avoid glitches in bandpass. Finally, the design parameters were slightly optimized for better return loss. Sensitivity analysis of all design parameters of the optimized filter was performed for the worst-case error and compared with classic inductive iris filter of same specifications. The fabrication yield was 84% for the novel filter while it was 12% for the inductive iris filter. In the meanwhile, a new analytical formula to calculate the heights of the filter with varying width was also developed to reduce the use of simulation tools. A final prototype is fabricated, tested and the results are in good agreement. A first draft of manuscript has been written based on the results mentioned above where it will be further processed on the suggestions of the supervision team. After the approval, this manuscript will be submitted to IEEE regular journal.

One other novel design technique for suppressing lowpass response is under process and has not yet been finalized. Moreover, a compact lowpass filter for Ku-band satellite applications was analysed for high power handling capabilities. Although the filter has a compact profile, but it has a minimum mechanical gap equal to 3.2445mm which is good for high power handling capabilities. The multipactor breakdown analysis was performed at different frequencies in the passband using SPARK3D. The minimum threshold input power of the proposed filter is estimated to be more than 20 kW at 11.7 GHz which is the maximum frequency of the passband. An abstract was written based on this work and submitted to MULCOPIM 2020 but unfortunately the conference has been delayed until next year due to the coronavirus pandemic. Abdul has withdrawn his abstract from this conference and will submit it to a relevant conference as soon as possible.

## ESR 3: Jabir Hussain (UPNA)

| Project Information | |
|---|---|
| Name of fellow | Jabir Hussain (ESR3) |
| Host Research Department | Department of Electrical, Electronic and Communications Engineering. Public University of Navarre (UPNA) |
| Supervisor 1 name and host | Miguel A. G. Laso (UPNA) |
| Supervisor 2 name and host | José M. Lopetegui Beregaña (UPNA) |
| Supervisor 3 name and host | Israel Arnedo Gil (UPNA) |
| Start Date | 01/09/2019 |

**Summary Report**

A summary of the technical findings under the project geared towards a PhD thesis titled "New design techniques for telecommunication payloads of space systems suitable for additive manufacturing in the context of large platforms" is briefed below:

1. An in-depth study of the coupled-mode theory was made to familiarize with the concept of modelling the electromagnetic behaviour of smooth-profiled rectangular waveguide devices in terms of coupling coefficients and then relate the coupling coefficients to the physical parameters of the device.
2. A study of inverse-scattering synthesis techniques was also performed to calculate the coupling coefficients from a target frequency response and subsequently the physical dimensions of the device.
3. Here, coupled-mode theory for rectangular waveguide devices having variations only along height was considered. The inverse scattering synthesis method was based on layer peeling and the zero-order approximation of the iterative solution of Gel'fand–Levitan–Marchenko (GLM) equations. With this new inverse scattering method microwave and millimeter wave filters with very high rejection levels can be synthesized.
4. Using mathematical modelling software (MATLAB), the theoretical concepts were formulated for various calculations and evaluation; following which simulation using 3D-EM simulation software (CST) was done and any mismatch from expected behaviour was noted.
5. In this case, a mismatch of scaling along the frequency was observed, and appropriate correction was applied. Steps to further improve the scaling factor using an appropriate electromagnetic modelling of the effect have been identified.
6. The performance of the smooth rectangular waveguide filter in terms of power handling and insertion loss with the constraints on minimum gap and length of the filter was performed. However, consistent results are yet to be obtained.

An investigation on the marketability of the end-product of the project was performed; fabrication using metal additive manufacturing techniques can be a bottleneck to reach higher Technology Readiness Level (TRL). Reduction of insertion loss by silver-plating must be performed at its current state-of-the-art

## ESR 4: Abhishek Sharma (UPV)

| Project Information | |
|---|---|
| Name of fellow | Abhishek Sharma (ESR4) |
| Host Research Department | Universidad Politécnica de Valencia (UPV) |
| Supervisor 1 name and host | Prof. Vincente Boria (UPV) |
| Supervisor 2 name and host | Dr. Santiago Cogollos (ITEAM-UPV) |
| Supervisor 3 name and host | Prof. Michael Höft (CAU) |
| Start Date | 12/09/2019 |

**Summary Report**

This report summarizes Abhishek Sharma's PhD research progress from September 2019 to June 2020. This time corresponds to the first year of his PhD candidature. As explained in his Career development plan, his work is concentrated on exploring the novel reconfigurable/tunable topologies in cavity waveguide filters.

The research progress done so far in this project is divided into three phases that were carried out:

The first phase started with a review of the research papers related to the numerous types of cavity filters. A report was drafted with the outcomes of this review. Besides, the complete design procedure of cavity filters using a full-wave Computer-Aided Design (CAD) tool was followed (and learnt at the same time); the waveguide filters were designed from the scratch specifications using AWR software, and this work was further extended to simulation and optimization of the same topologies in FEST3D software Platform for the validation purpose. In this task, the filters of order three, five and eight were demonstrated.

Once got the preliminary idea on the waveguide cavity filters design, the second phase started with designing the combline filter topology on the CST studio, as per the prescribed specifications that were further optimized to obtain the final geometry. Alongside, the more focused review of the papers related to tuning / reconfigurable topologies in cavity filters was carried out, and it was prepared a detailed report on the outcomes. For the sake of refining the present design flows, the group delay method is further adopted for refining the design of the comb-line filter. Once done with the refined design of in-line combline filters, this work was further extended to design a folded topology of combline filters. First, electric cross-coupling was implemented using capacitive probes, in order to impose the transmission zeros in both the upper and lower sides of the passband. Secondly, the same topology was implemented using irises as capacitive cross-couplings. For this purpose, a new cavity size was discovered by several iterations to comply with the required filter specifications.

Furthermore, a review focused on the Galileo Positioning System was done. A research of the frequency band allocation and 5G spectrum allocations in the European area was carried out and compiled within a report. Also, few cavity filters models available in the European market were added to complete the report.

A separate investigation on the papers related to the variable inductors and patents in the domain of cavity filters was carried out, and a report was drafted with useful conclusions.

Furthermore, several experiments to find out the tuning capability of the cavity filters have been investigated, by incorporating the metal coarse tuning screws and adopting the dielectric material for fine tuners. The tuning ranges are compared by conducting various experiments, which are still in progress.

Alongside the above tasks, Abhishek attended the following events as a part of TESLA network:

1. FIMU4SPACE on Microwave filters and Multiplexing Networks for space communication system held in UPV campus at Valencia.
2. Innovation triangle event organized remotely by the Public University of Navarra.

## ESR 5: El Mehdi Messaoudi (UPV)

| Project Information | |
|---|---|
| Name of fellow | El Mehdi Messaoudi (ESR5) |
| Host Research Department | Universidad Politécnica de Valencia (UPV) |
| Supervisor 1 name and host | Prof. Vincente Boria (UPV) |
| Supervisor 2 name and host | Jorge D. Martínez (UPV) |
| Supervisor 3 name and host | Prof. Cristiano Tomassoni (UNIPG) |
| Start Date | 17/09/2019 |

**Summary Report**

El Mehdi Messaoudi started his participation in this project on 16 September 2019. His university education was based on low frequency analog electronics, and analog circuit devices. Initially, therefore, in parallel with his university research project, he carried out in-depth studies on the area of filters for space applications. In addition to reading individual papers and recommended by his mentor, he has also taken the following courses at the Universitat Politècnica de València:

- Design of passive components for high frequency communication system (3 ECTS)
- Space communication systems (3 ECTS)
- Seminar: Command and control systems for emergency management
- Seminar: Theoretical and experimental characterization of mobile radio channel
- Seminar: New technologies for vehicle networks and services for intelligent environments

In addition to individual study and the university courses, the courses taken within the TESLA network were also very useful, such as the one-week intensive course at UPV (FIMU4SPACE 2019). Finally, the European conference in Paris helped him to understand how his technical work should be presented to the scientific community.
As for the research project carried out, he has designed and simulated two filters using Ansys HFSS software that are now ready for manufacturing. Unfortunately, with the situation created by the COVID-19 health emergency, the fabrication has been delayed. Both filters are two different versions to comply with very stringent specifications for space applications.

The main goal of this Project consists on demonstrating the possibility of implementing miniaturized band-pass filters based on substrate integrated quasi-lumped elements using multi-layer technologies. One of the main challenges of this work is to envisage a way for implementing strong magnetic and electric couplings in order to design wide-band band-pass filters, while introducing transmission zeros in order to enhance the selectivity at the lower and upper frequency bands. These filters are of great interest for intermediate- / radio-frequency (IF/RF) up- and down-converters for flexible payloads in space applications. To keep a compact RF chain, miniaturization of these filters with footprints below 7x7 $mm^2$ are absolutely required.

This work is based on a novel approach based on the use of lumped-elements and multi-layer embedded couplings incorporated into substrate integrated structures. The main objective is to apply this solution for implementing a C-band wide-band bandpass filter, with high selectivity at the passband edges while keeping a very small footprint. A co-simulation approach was employed for the design and optimization of the filter, by means of 3D EM (Electromagnetic) simulations of the multi-layer structures coupled to circuital simulations of the lumped-element equivalent circuits.
As already said, two filter prototypes are ready to manufacture, and the simulated results obtained are very promising. In addition to the simulation of the proposed structure, a tolerances study has also been carried out using 3D EM simulation.
Next step will be to do research on this topology to implement reconfigurable filters using MEMS (microelectromechanical system) tuning elements.

## ESR 6: Chad Bartlett (CAU)

| Project Information | |
|---|---|
| Name of fellow | Chad Bartlett (ESR6) |
| Host Research Department | Chair of Microwave Engineering – Kiel university |
| Supervisor 1 name and host | Prof. Michael Höft (CAU) |
| Supervisor 2 name and host | Dr. Christian Arnold (TESAT) |
| Supervisor 3 name and host | Prof. Joachim Oberhammer (KTH) |
| Start Date | 01/09/2019 |

**Summary Report**

The key objective of this research project is to introduce novel W-band cavity-based filter designs for satellite applications. Throughout the first year of the project, the student has built a good background in filter theory as well as gained experience in several manufacturing techniques such as high-precision milling, FDM and SLA 3D printing, as well as their possible applications to W-band filters.

The student has moved into the simulation and testing of various complex filter designs as well as a novel miniaturization technique for low-pass filter design. This included a two-month research secondment at Tesat Spacecom – Germany to learn about high frequency filters for space applications. Following, the secondment, a filter using the novel design technique has manufactured which is to be tested, while at the same time, a patent document has been agreed upon between CAU and Tesat that will be submitted to corresponding legal departments for review. The student continues to investigate novel filter designs that maybe applicable to stringent satellite applications.

The student has also participated in a several of webinars hosted by external organizations such as “Advanced manufacturing for millimeter-wave and Sub-THz space payloads” by CNR-IEIIT and “Silicon-micromachined THz systems enabling the large-scale exploitation of millimeter and submillimeter-wave frequencies” by KTH. Also, the student participated in different TESLA workshops and summer schools: The Innovation Triangle Initiative (IΔI) organized by Navarra university – Spain, and summer school on “Additive manufacturing of RF components" organized by the university of Limoges – France. The student has also participated in the most prestigious European conference in the field; the 49$^{th}$ European microwave conference in Paris – France.

The second stage of the student’s industrial secondment begins at Spinner Gmbh to collaborate on a novel additive manufacturing technique which has been aimed to be partnered with CNE-IEIIT and Fraunhofer IFAM**.**

## ESR 7: Abdulrahman Widaa (CAU)

| Project Information | |
|---|---|
| Name of fellow | Abdulrahman Widaa (ESR7) |
| Host Research Department | Chair of Microwave Engineering – Kiel university |
| Supervisor 1 name and host | Prof. Michael Höft (CAU) |
| Supervisor 2 name and host | Prof. Cristiano Tomassoni (UNIPG) |
| Supervisor 3 name and host | Dr.-Ing. Holger Maune (TUD) |
| Start Date | 01/09/2019 |

**Summary Report**

The key objective of this research project is to introduce new competitive designs of tunable filters suitable for the increasingly developing space industry including next-generation flexible satellites. Throughout the first year of the project, the student has built a good background and experience on filters in general and more particularly on tunable filters. Firstly, the student has reviewed and investigated all the related state-of-the-art designs available in the literature. Also, the student has received very good knowledge in filters by taking the TESLA-wide available course of “Microwave Filters” at Kiel university.

Then, the student moved to the investigation and simulation of various proposed solutions and techniques. This also included a two-month research secondment at the Institute of Microwave and Photonics – Technical university of Darmstadt – Germany to benefit and learn from their broad experience in tunable devices and components. Following, the student has proceeded to the next step of realizing and fabricating various prototypes for testing.

The student has also participated in a couple teaching and course activities and received a competitive student grant. The student took a part in teaching microwave technology and electromagnetic compatibility laboratory course at Kiel university. Also, the student participated in different TESLA workshops and summer schools: The Innovation Triangle Initiative (IΔI) organized by Navarra university – Spain, and summer school on “Additive manufacturing of RF components" organized by the university of Limoges – France. The student has also participated in the most prestigious European conference in the field; the 49$^{th}$ European microwave conference in Paris – France, and also received a competitive student grant to participate in the coming 50$^{th}$ European microwave conference in Utrecht – Netherlands.

## ESR 8: Mohammad Mehrabi (KTH)

| Project Information | |
|---|---|
| Name of fellow | Mohammad Mehrabi (ESR8) |
| Host Research Department | Micro- and Nanosystems, KTH |
| Supervisor 1 name and host | Prof. Joachim Oberhammer (KTH) |
| Supervisor 2 name and host | Dr. Oleksandr Glubokov (KTH) |
| Supervisor 3 name and host | Dr Janne Lathinen (Harp Technologies) |
| Start Date | 19/08/2019 |

**Summary Report**

During 10 months at KTH, Mohammad has been working on micromachined filters with high quality factors and has completed two PhD courses on MEMS technology (Hands-on MEMS) and radar systems.

Through the radar course, he has learned principles of design and operation of radars, including application of filters in radar systems; in the Hands-on MEMS course, Mohammad has theoretically and practically learned fabrication processes, techniques and materials utilized for micromachining at KTH. He has gained practical experience of fabrication in KTH clean room, has designed, and measured several test devices. Mohammad's experience in the courses allows him to take part in teaching the radar course next year and help some TESLA researchers, who will come to KTH for secondments, with the Hands-on MEMS course.

Mohammad has designed several novel filters with high quality factors at sub-THz frequencies. He has investigated a novel concept to implement high-Q resonators through silicon micromachining, their utilization in narrowband bandpass filters, including analysis of achievable internal and external coupling coefficients. Mohammad has found several fundamental limitations in the designs and successfully investigated ways to overcome them. He has designed several filters, a transition for simplified excitation of the filters, as well as a calibration kit for the measurements. Mohammad has gained practical knowledge of assembly and measurements of fabricated microchips with filters and has been working on implementation of his designs through preparing the necessary photomasks and corresponding process flow.

Mohammad has attended several conferences, workshops, and courses. He took part in the European Microwave Conference in Paris, including the TESLA meeting, where he attended several sections and a workshop on tuneable filters; during the filter course at UPV in Valencia, he has learned various design techniques for implementation of filters and multiplexing networks for space applications; in the Innovation Triangles Initiative, Mohammad has learned important marketing aspects of his project and presented his triangle together with the expected product; during the UNILIM Summer School, he has learned advantages and disadvantages of various 3D printing fabrication methods, which can be used for implementing filters for space applications in future.

## ESR 9: Armin Karimi (KTH)

| Project Information | |
|---|---|
| Name of fellow | Armin Karimi (ESR9) |
| Host Research Department | Micro- and Nanosystems, KTH |
| Supervisor 1 name and host | Prof. Joachim Oberhammer (KTH) |
| Supervisor 2 name and host | Dr. Oleksandr Glubokov (KTH); Dr. Umer Shah (KTH) |
| Supervisor 3 name and host | Dr Janne Lathinen (Harp Technologies) |
| Start Date | 25/11/2019 |

**Summary Report**

During his incomplete year (7 months) at KTH, Armin has been working on several research problems and has taken two PhD courses on antennas and microsystem technology.

During the antenna course, he learned design foundations of various antenna types, including micromachined waveguide antennas to be used in the switchable frontend he will be developing during the next years at KTH. In the microsystem technology course, Armin has learned MEMS manufacturing processes which will be required for implementation of his future designs.

Armin has been working on his research project on MEMS reconfigurable frontend for future space applications. He has designed and optimized a compact switching network for the frontend, which included individual designs of several mm-wave components, such as couplers, T-junctions, antennas, and MEMS switches, as well as arrangement and optimization of the entire assembly. Armin has started implementation of the designed structures by micromachining through drawing photomasks for the first fabrication run.

Armin has attended a workshop at Chalmers University of Technology (Gothenburg, Sweden), where he expanded his network by interaction with several experts in microfabrication. He also has participated in two online conferences, including the Innovation Triangles Initiative and UNILIM Summer School (TESLA events), where he successfully presented results of his work to international audience for the first time. Armin has also prepared two posters for internal KTH and TESLA events.

## ESR 10: Luke Robins (TU GRAZ)

| Project Information | |
|---|---|
| Name of fellow | Luke Robins (ESR10) |
| Host Research Department | (TU GRAZ) |
| Supervisor 1 name and host | Dr. Reinhard Teschl (TU GRAZ), Prof. Wolfang Bösch (TU GRAZ) |
| Supervisor 2 name and host | Dominik Brouczek, MSc. (Lithoz), Dr. Martin Schwentenwein (Lithoz) |
| Supervisor 3 name and host | |
| Start Date | 01/09/2019 |

**Summary Report**

Within the TESLA framework, Luke Robins (ESR10) investigates ceramic additive manufacturing technologies with the focus on non-planar passive RF-components. Ceramics exhibit properties that are especially advantageous in extreme ambient conditions and thus for space applications. First, their thermal expansion coefficient is generally low, leading to small distortion values with respect to temperature changes. Moreover, ceramics can withstand high temperatures and due to their considerable relative dielectric constant, ceramics structures are used for miniaturisation of components like RF-filters and antennas. One disadvantage of many ceramics, however, is their low thermal conductivity, hindering the dissipation of heat that calls for customization and optimization of ceramic material for high power components.

Results of a predecessor project between Lithoz GmbH and TU Graz constitute the starting point of Luke Robins' studies. During this previous study, several monoblock filters were designed, manufactured, and measured. In addition, the dielectric properties of 3D printed sample materials were characterised. The research question Mr. Robins is addressing in this context is what range of effective dielectric constants is achievable within a certain ceramic material by reducing its density (or in other words by increasing the porosity). For that purpose, Mr. Robins proposed different lattice structures in consultation with Lithoz GmbH (one of the proposed host organisations of his secondments) by taking the technical limits of the 3D printing machines, the necessary channels for cleaning and other post processing steps, as well as the shrinkage of the ceramic sample during the necessary sintering process in to account.

The evaluation of the dielectric properties of the manufactured ceramic samples took place in the lab of the beneficiary TU Graz by analysing the frequency shift of a resonant cavity when the samples are inserted. Based on the reduction of the effective dielectric constant, Mr. Robins is conceptualising a filter structure that contains areas of different relative permittivity. By applying a methodological approach containing an issue-specific review of background literature (e.g. on filter theory, satellite requirements, additive manufacturing technologies, post processing) followed by identifying critical points with regard to fabrication and assembly (sample cleaning, over-polymerisation, and metallization) and a well-structured documentation, Mr. Robins gained expertise in manufacturing of passive RF-devices and thus contributed to an EuMC-paper as co-author.

## ESR 11: Arash Arsanjani (TU GRAZ)

| Project Information | |
|---|---|
| Name of fellow | Arash Arsanjani (ESR11) |
| Host Research Department | (TU GRAZ) |
| Supervisor 1 name and host | Dr. Reinhard Teschl (TU GRAZ), Prof. Wolfang Bösch (TU GRAZ) |
| Supervisor 2 name and host | Vojislav Petrovic Filipovic, PhD (JR), Dr. Wolfgang Waldhauser (JR) |
| Supervisor 3 name and host | |
| Start Date | 03/09/2019 |

**Summary Report**

"Design of mm-wave passive components in semi-planar technology" is the working title of the project Arash Arsanjani (ESR11) is pursuing during the TESLA Innovative Training Network. The aim of this work is to develop new concepts and structures that decrease the losses of passive RF-components with respect to purely planar technologies while allowing the integration of tuning elements to obtain an adaptive response. The fabrication – especially with respect to repeatability and reproducibility – of RF-components becomes increasingly difficult with higher frequencies, moreover as additional constraints like small size and low weight arise for space applications.

Mr. Arsanjani thoroughly addressed these challenges in his first year at TU Graz. He investigated transmission line technologies that minimise dielectric losses by allowing the wave travel through air. In order that the components feature nonetheless a size reduction, Mr. Arsanjani proposed periodic structures that are capable of artificially increasing the relative dielectric permittivity. After investigating different fabrication techniques, he designed and simulated a mushroom-shaped meta-material structure. Based on this structure, Mr. Arsanjani proposed a $4^{th}$-order filter. The manuscript submitted to the European Microwave Week was accepted for presentation at the EuMC 2020.

In correspondence with his supervisors at Joanneum Research (JR) – the host organisation of his first secondment – Mr. Arsanjani arranged details of the fabrication of prototypes using metal additive manufacturing techniques. The designs exploit and exhaust the technical limits of applied production machines. Three identical parts were fabricated in the first production run to be able to evaluate reproducibility issues on the one hand and to have more options for testing surface finishing operations on them on the other. The ongoing research focuses on the improvement of the surface quality of the 3D-printed samples and the increase of the electrical conductivity to reduce the insertion loss of the filter. Therefore, Mr. Arsanjani reached out to TU Graz experts on surface analytics and structure analysis. Meanwhile he is designing a second prototype and optimizing the functional metamaterial elements with the aim of easier surface preparation, post processing and coating.

## ESR 12: Abdul Rehman (UNIPG)

| Project Information | |
|---|---|
| Name of fellow | Abdul Rehman (ESR12) |
| Host Research Department | (UNIPIG) |
| Supervisor 1 name and host | Prof. Cristiano Tomassoni (UNIPIG) |
| Supervisor 2 name and host | Dr. Eng. Antonio Alvino (SERMS) |
| Supervisor 3 name and host | Dr. Luca Pelliccia (RF Microtech) |
| Start Date | 04/03/202024 November 2021 |

**Summary Report**

The aim of this project is the study of miniaturized electromagnetic filters.

An exponential increasing of the communication market is forecast in the following years. Indeed, with the advent of Internet of Things (IoT) an incredible number of objects will be connected to the network. Part of this traffic will be handled by the space segment. The reduction of costs is of capital importance. Reduced dimensions of component results in lower cost especially in satellite technology. Indeed, volume and weight strongly influence the cost of a satellite because of the cost of the launch.

To be involved in this research activity, some basic knowledge is needed. ESR12 started to acquire such basic knowledge. Because of bureaucratical problems ESR12 arrived in March 2020. A couple of day after his arrive the lockdown for coronavirus started. However, he started his PhD course at the university of Perugia. He followed two university courses that gave him some important basic knowledge for his research activity:

1) 'Antennas'
2) 'Advanced design of microwave and RF systems'

ESR12 started his research activity studying a filter with wide spurious free band capability. The wide spurious free band are obtained by exploiting a new technique based on the use of the coupling matrix. The increasing of spurious free band does not allow a reduction of the filter itself, however it allows avoiding (or at least to reduce the dimension) of the lowpass filter used for removing the spurious frequencies, this resulting in a smaller filtering system. ESR12 designed the preliminary prototype of a 4-pole TM filter based on this new approach. The design is promising as he was able to significantly increase the spurious free band. The next steps are the design optimization and manufacturing. Furthermore, the application of this new methodology to other filter technologies will be taken into account.

## ESR 13: Enrique López Oliver (UNIPG)

| Project Information | |
|---|---|
| Name of fellow | Enrique López Oliver (ESR13) |
| Host Research Department | (UNIPIG) |
| Supervisor 1 name and host | Prof. Cristiano Tomassoni (UNIPIG) |
| Supervisor 2 name and host | Dr. Eng. Antonio Alvino (SERMS) |
| Supervisor 3 name and host | Dr. Luca Pelliccia (RF Microtech) |
| Start Date | 01/07/2019 |

**Summary Report**

The aim of this project is the study of Additive Manufacturing (AM) techniques for the electromagnetic (EM) components.

These new manufacturing technologies opened a lot of possibilities and offer potential advantages that the scientific community is still investigating. In the last decades, several AM technologies have been developed. There are technologies for the manufacturing of metal objects, plastic objects, and ceramic objects. Different technologies offer different advantages and challenges. The application of such technologies to the manufacturing of the EM components requires the development of some dedicated post processing techniques. As an example, in order to obtain low losses components, sometimes it is necessary to levigate the surface. Usually EM components are in metal. When plastic or ceramic based technology are used, it is necessary to metal plating the manufactured object. The development of the procedure allowing the improvement of the component performance is part of the research in that field. Another possible research activity related to the AM technologies is the development of new component with non-conventional geometries that cannot be manufacturing with traditional manufacturing technique. In other word the high flexibility of AM technology is used to design new class of component.

In his first year of activity, Enrique López Oliver (ESR13) started studying the problem for acquiring a basic knowledge for giving his contribution in that field. ESR13 is involved in the PhD courses of our University. During this year he followed two courses: 1) 'Antennas', 2) 'Advanced design of microwave and RF systems'.

Those two university courses gave him some knowledge about Antennas and Filters. ERS12 also followed an intensive course on microwave filters in Valencia, Spain, organized by the European Space Agency (ESA) in collaboration with the University of Valencia. The knowledge about such components is very important in the ESR13 activity, as one of the goals is the additive manufacturing of filters and antennas. In the first part of the year ESR13 also acquired some basic knowledge about AM.

His first research activity was the design of a component that exploits the high flexibility of the AM. Indeed, this component has a non-conventional geometry that would be hardly manufactured with traditional manufacturing technology. ESR13 developed a new class of filters that are similar to the classical combline filters. Combline filters consist of resonating metal cylindrical posts inside a metal cavity. The new filter class introduced by ESR13 consists instead of a conical resonating posts inside a metal cavity. This geometry allows for the realization of filter with piled cavities where the conical post of a cavity is also the housing of the conical post of the cavity below it. This new class of filters is very flexible. The main advantage with respect to the classical combline filters is that its volume is reduced of about 30%. Furthermore, they present a spurious free band larger than that of the classical combline filters. Such filter has been already manufactured by using Polyjet technology. This technology is capable of manufacturing plastic objects with very high resolution. Of course, the manufactured object needs to be metallized. The filter has been measured and results are very good. The results on that filter have been published in a conference paper (IMS2020) that is the premier event in Electromagnetics in the world. Furthermore, a paper on the Transaction on MTT (the most important journal in our field) has been submitted and it is now under review.

ESR13 is also working on other filtering structures. Those structures are based on spherical cavities. Spherical cavities have the advantage of very low losses. In order to exploit this capability, a metal-based AM technology has been selected. ESR13 already designed some filters based on spherical resonators from the EM point of view. Such structures however are very sensible to tolerance manufacturing. For this reason, an AM oriented design is necessary for minimizing the manufacturing tolerances. ESR13 is now optimizing the mechanical design of a four-pole filter to be manufactured (probably in the next September) by a Selective Laser Melting (SLM) machinery.

## ESR 14: Elivra Saab Llatas (UNILIM)

| Project Information | |
|---|---|
| Name of fellow | Elvira Saab Llatas |
| Beneficiary | Université de Limoges (UNILIM) |
| Host Research Department. | Institut de Recherche sur les Céramiques (IRCER) |
| Supervisors | Prof. Alexandre Maitre, Dr. Nicolas Pradeilles, Dr. Olivier Rapaud (IRCER, UNILIM) |
| Start Date | 15/11/2019 |

| Progress Report | |
|---|---|
| **Project title** | Advanced materials for high power components (ESR 14 project) |
| **Objective** | Optimize the thermal conductivity and/or loss tangent of Aluminium Nitride binary systems to specifically optimize dielectric material for high power components |
| **Methodology** | 1. Investigation of Al-N-X-O phase diagrams including AlN and sintering agents<br>2. Study of the sintering ability of AlN-based phases by coupling original additives such as RE-oxides, boron nitride and non-conventional sintering methods (HIP, SPS)<br>Study of physical properties (thermal conductivity, loss tangent, …) / microstructure correlations |
| **Period** | November 15th, 2019 – June 15th, 2020 |
| **Research** | • Literature review. Obligatory for points 1, 2 and 3 of methodology.<br>• Literature data recollection. Suitable for points 1 and 2 of methodology.<br>• Literature data meta-analysis. Suitable for points 1 and 2 of methodology.<br>• Design of experiments. Necessary for points 2 and 3 of methodology. |
| **Outreach Materials (presentation, posters, publications)** | *Research group/supervisors:*<br>• Monthly / semester presentations.<br>*University/research department:*<br>• ESR 14's project presentation for IRCER Axe 4 seminar.<br>*TESLA network:*<br>• ESR 14's project poster / outreach material.<br>• ESR 14's innovation triangle presentation for the Innovation Triangle Initiative.<br>*General public*:<br>• ESR 14's project poster (tentative). |
| **ESR 14 Training** | *Courses attended:*<br>• Introduction to the Ethics of Research.<br>*Training events attended:*<br>• Innovation Triangle Initiative<br>*Other trainings:*<br>• Compulsory NEO-CNRS's safety and laboratory risk prevention training.<br>• Equipment usage. Compulsory for points 2 and 3 of methodology.<br>  ○ Powder preparation equipment: planetary ball mill, glove box.<br>  ○ Powder and materials characterisation technics: Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD) and laser granulometry.<br>  ○ Sintering technic: Spark Plasma Sintering. |
| **Other remarks** | *Covid-19 quarantine measurements and laboratory access restrictions*.<br>Unable to perform experiments between March 15th – June 8th |

## ESR 15: Bassel Youzkatli (UNILIM)

| Project Information | |
|---|---|
| Name of fellow | Bassel Youzkatli (ESR14) |
| Host Research Department | Université de Limoges (UNILIM) |
| Supervisor 1 name and host | Dr. Nicolas Delhote (UNILIM); Dr Stephane Bila (UNILIM) |
| Supervisor 2 name and host | Prof. Vincente Boria (UPV) |
| Supervisor 3 name and host | Dr. Reinhard Teschl (TU GRAZ) |
| Supervisor 4 name and host | Dr. Martin Schwentenwein (LITHOZ) |
| Start Date | 01/02/2020 |

**Summary Report**

The PhD. program started in January 2020 at XLIM research center in the University of Limoges, France. The PhD. Title is ''Development of optimization tools for RF components position''. The main objective of this project is to design optimized passive waveguide microwave filters and components for improving their power handling, particularly increasing their power breakdown threshold for multipaction and corona within the constraints of space environment. An innovative solution is to consider the use of RF wise highly performant ceramic materials. The accomplished activities for the current period are the following:

a) Undertaking literature search and the state-of-the-art study of high-power filters for space applications, with focus on dielectric resonators filters and the dielectric materials developed so far for such applications
b) Establishing a general work plan that comprises a list of possible solutions to be investigated
c) Starting to develop some of the ideas elaborated in the general work plan, including the study of feasibility of some of the proposed solutions based on software simulations
d) Starting the RF design of some transitions from empty to filled waveguides with different materials and different geometries
e) Starting the selection of appropriate simulation software to execute high power and thermal simulations. Spark3D was chosen to realize high power breakdown simulation for components with empty or partially empty waveguides
f) Attending the first workshop of the Tesla Innovation triangle initiative
g) Elaborating the ESR Tesla project poster