Brussels, 23 June 2017

COST 031/17

DECISION

Subject: **Memorandum of Understanding for the implementation of the COST Action "European Network for High Performance Integrated Microwave Photonics" (EUIMWP) CA16220**

The COST Member Countries and/or the COST Cooperating State will find attached the Memorandum of Understanding for the COST Action European Network for High Performance Integrated Microwave Photonics approved by the Committee of Senior Officials through written procedure on 23 June 2017.

MEMORANDUM OF UNDERSTANDING

For the implementation of a COST Action designated as

COST Action CA16220
EUROPEAN NETWORK FOR HIGH PERFORMANCE INTEGRATED MICROWAVE PHOTONICS (EUIMWP)

The COST Member Countries and/or the COST Cooperating State, accepting the present Memorandum of Understanding (MoU) wish to undertake joint activities of mutual interest and declare their common intention to participate in the COST Action (the Action), referred to above and described in the Technical Annex of this MoU.

The Action will be carried out in accordance with the set of COST Implementation Rules approved by the Committee of Senior Officials (CSO), or any new document amending or replacing them:

a. “Rules for Participation in and Implementation of COST Activities” (COST 132/14);
b. “COST Action Proposal Submission, Evaluation, Selection and Approval” (COST 133/14);
c. “COST Action Management, Monitoring and Final Assessment” (COST 134/14);
d. “COST International Cooperation and Specific Organisations Participation” (COST 135/14).

The main aim and objective of the Action is to shape and bring together the IMWP community supporting coordination and networking actions to consolidate this ecosystem. It will provide exchange of knowledge, ideas, deliver a portfolio of technological benchmarks to establish performance indicators and define future technological requirements in high performance scenarios such as 5G, automotive and aerospace technologies. This will be achieved through the specific objectives detailed in the Technical Annex.

The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 80 million in 2016.

The MoU will enter into force once at least five (5) COST Member Countries and/or COST Cooperating State have accepted it, and the corresponding Management Committee Members have been appointed, as described in the CSO Decision COST 134/14.

The COST Action will start from the date of the first Management Committee meeting and shall be implemented for a period of four (4) years, unless an extension is approved by the CSO following the procedure described in the CSO Decision COST 134/14.

TECHNICAL ANNEX

OVERVIEW

Summary

Next generation global telecommunication platforms and emerging massive take-up applications in radar, communications and space industries will require entirely new technologies to address the current limitations of electronics for massive capacity and connectivity. Multigigabit-per-second 5G wireless communications, the Internet of Things, the upcoming Smart Car scenarios and satellite payloads will require a full convergence between optical fibre and wireless segments.

Microwave photonics (MWP) combines RF and photonics and is the best positioned technology to carry out this convergence. Current MWP systems, however, are fiber and discrete-component based, which limits energy-efficiency, flexibility and scalability, and, as a result, high volume application. Integrated Microwave Photonics (IMWP) seeks to address these limitations by incorporating these systems into photonic integrated circuits (PICs). IMWP is still at its infancy and a considerable body of knowledge, technical and scientific roadmaping and interactions between industry academia need to be developed during the next years.

The European Network for High Performance Integrated Microwave Photonics (EUIMWP) Action aims to shape and bring the relevant IMWP community supporting coordination and networking actions to consolidate this new IMWP ecosystem, providing exchange of knowledge, ideas and delivering a portfolio of technological benchmarkings to establish performance indicators defining future technological requirements in high performance scenarios such as 5G, automotive and aerospace technologies.

The action brings together groups from academia, industry and transnational organizations with complementary competences and on a global scale including PIC and MWP experts, microwave system application designers and end-users to fully develop the synergies required by this new paradigm.

Areas of Expertise Relevant for the Action	**Keywords**
● Electrical engineering, electronic engineering, Information engineering: Electrical and electronic engineering of semiconductors, components, systems ● Electrical engineering, electronic engineering, Information engineering: Communications engineering and systems (select for additional explanation) ● Electrical engineering, electronic engineering, Information engineering: Sensors and sensor systems ● Electrical engineering, electronic engineering, Information engineering: Micro-electronics, optoelectronics for electrical and electronic engineering ● Nano-technology: Electro-optics for nano-technology applications	● Integrated Microwave Photonics ● Advanced radio acess networks ● Photonic aided radar systems ● Aerospace systems ● Internet of Things

Specific Objectives

To achieve the main objective described in this MoU, the following specific objectives shall be accomplished:

<u>Research Coordination</u>

● Promote the exchange of knowledge, information and personnel between the main stakeholders in the IMWP field, namely PIC designers, RF designers, manufacturers, photonics researchers and end-user industries as well as other communities engaged in IMWP.

● Provide a set of metrics and benchmarks to drive research efforts in IMWP for application in 5G, automotive industry and space communications.

● Define a consensus IMWP evolution roadmap on its main relevant anticipated high performance applications with the help of the outcomes of the different WGs and by involvement of industrial stakeholders .

● Support end-user industry in the uptake of IMWP technologies and with solutions in their strategic

applications.
● Provide the necessary components to facilitate the uptake of IMWP (building blocks process design kits, models, libraries etc.)
● Promote the WG roadmaps as well as the consensus roadmap among relevant stakeholders, such as GFMs, end-user industry, research policy decision makers on European and national level.
● Provide to IWMP community an easy access to relevant research facilities by consolidating and supporting widely recognized initiatives to establish integrated Pan-European networks of facilities open for testing, developing and prototyping IMWP innovative systems.
● Involve industry, especially GFM, software providers PIC manufacturers and end-users in the areas of 5G, automotive and space applications for the definition of IMWP requirements and application scenarios.
● Provide input to the relevant standardization and regulatory bodies on IWMP matters.

Capacity Building
● Promote collaborative research actions across different IMWP stakeholders such as PIC designers, RF designers, manufacturers, photonics researchers and end-user industries.
● Foster a generation of ECIs with a unique (and, currently, extremely rare) set of competences ranging from PIC technologies, mm-wave/sub-THz engineering, IMWP, system engineering skills and enhanced technological transfer expertise
● Support new and incipient research networks between ECIs and young innovators to stimulate the identification of opportunities leading to the creation of spin-off companies in the IMWP area.
● Deliver training schools and MOOCs on the main fundamental aspects and applications areas on IMWP to make this field known by application engineers.
● Facilitate the participation of ITC countries in consortia and research programs related to IMWP and to the broader field of MWP

1) S&T EXCELLENCE

A) CHALLENGE

I) DESCRIPTION OF THE CHALLENGE (MAIN AIM)

Microwave photonics (MWP) has evolved over the last 30 years to the point where it shows strong potential as a key enabling technology in fields such as optical fibre and wireless communications, automotive and aerospace engineering and bio-medicine. Highly demanding applications such as 5G are spurring the continued evolution of MWP, driven by ever increasing requirements in capacity and performance in terms of timing jitter, bandwidth, in addition to reduction of size, weight and power consumption (SWaP), and low-cost implementation. Current MWP systems, however, are fibre and discrete-component based, which limits energy-efficiency, flexibility and scalability, and, as a result, high volume application.

Photonic integration is emerging as a promising solution for providing compact and scalable photonic systems with the potential for implementing high bandwidth, fast and complex functionalities in an efficient way. This technology is driven by high bandwidth optical communications and massive deployment of low-cost optical interconnects for datacom. Photonic integration allows for low-cost, small footprint, reproducible and energy-efficient devices, which can be manufactured using generic foundry models (GFM) and multi project wafer runs (MPW). It is only natural then to consider the application of photonic integrated circuits (PICs) in the field of MWP. This approach creates a new paradigm for MWP: ubiquitous deployment combined with unsurpassed bandwidth. Known as Integrated Microwave Photonics (IMWP), this field has emerged during the last few years and is now experiencing rapid growth.

So far IMWP has been an effort of individual research groups, which often cannot cover the whole spectrum of competence from system level down to radiofrequency (RF) integrated circuits (ICs) and PIC design and fabrication capability. Therefore, it would be ideal to bring together groups with such complementary competences for the first time, and on a global scale including PIC and MWP experts, microwave system application designers and end-users to fully develop the synergies required by this new paradigm. The European Network for High Performance Integrated Microwave Photonics (EUIMWP) Action aims to shape and bring the relevant IMWP community supporting coordination and networking actions to consolidate this new IMWP ecosystem, providing exchange of knowledge, ideas and delivering a portfolio of technological benchmarks to establish performance indicators defining future technological requirements in high performance scenarios such as 5G, automotive and aerospace technologies.

Funded by the Horizon 2020 Framework Programme of the European Union

II) RELEVANCE AND TIMELINESS

Next generation global telecommunication platforms and emerging applications in radar, communications and space industries will require entirely new technologies to address the current limitations of electronics for massive capacity and connectivity. For example, multi-gigabit-per-second 5G wireless communications and the Internet of Things (IoT) will require a full convergence between the optical fibre and wireless segments. IMWP combines RF and photonics and is the best positioned technology to carry out this convergence. 5G communications will demand agile broadband fibre-wireless interfacing chips and front-ends both at the central office (COs) and Base Stations (BTs) to extend the operating spectrum to the millimetre bands (24 GHz – 90 GHz). In the automotive sector, the upcoming Smart Car scenarios demand flexible solutions combining reliable car-to-car and car-to-roadside communication with radar systems, both for blind spot detection (mostly @24 GHz) and for autonomous cruise control functionalities (mostly @77 GHz). IMWP can provide a solution capable of integrating both communications and radar with unprecedented flexibility. Compact high-frequency beam-steered systems based on IMWP technologies can be envisioned here. Future radar systems will require a wider spectral bandwidth (>40 GHz), lower timing jitter (<15 fs), and real-time signal processing during the next decade. That implies the need for photonic-enabled radar implementation through IMWP technologies. The space sector calls for cost-effective and low-SWaP telecommunications satellite payloads, which is a clear opportunity window for MWP. The European Space Agency (ESA) and the main satellite Primes in Europe and the US have a Roadmap that foresees the substantial introduction of Photonics by 2020. ESA, for example, is currently supporting the introduction of discrete-component MWP systems in their payloads and through the latest 'Invitations to Tender' has signalled the evolution to IMWP, for further SWaP reduction. Hence, IMWP is a key enabler of MWP for all these demanding applications and offers additional advantages of robustness and compactness, reduced phase noise, and potentially lowered costs.

Since 2004 PIC technology and eco-system development have been driven and supported in Europe by the European Commission (EC) leading to several platforms providing generic PIC foundry processes, based on material platforms like Indium Phosphide (InP), Silicon-On-Insulator (SOI) and Silicon Nitride (Si_3N_4). Some initial projects were established to use this technology for IMWP. However, first IMWP outcomes showed that further progress is required to be competitive with incumbent microwave technologies. The main causes were: a) no single PIC technology clearly addressed all the IMWP performance requirements, b) the lack of maturity of GFMs and c) a non-existent evolution roadmap to overcome these limitations. These factors were instrumental in the partial disintegration of the potential networking framework that could have been established between academia and end user stakeholders on MWP research, with the subsequent loss of the momentum in Europe, thus hindering the development of IMWP for emerging markets.

However, two factors bring back IMWP on the map. The first one is the advent of the abovementioned "killer applications", with expected massive take-up, that have extremely challenging performance and scalability requirements. The second is the outstanding progress in PIC technology in terms of standardisation and quality of manufacturing processes. These can enable IMWP again to tackle these demanding challenges. Hence the EUIMWP Action is very timely and relevant for the main European academic and end-user stakeholders, since it aims at creating a cohesive framework to share knowledge and expertise in the field of IMWP. EUIMWP will define an IMWP evolution roadmap towards the anticipated high-performance applications by providing a set of metrics and benchmarks to drive research efforts and influence user-industry about IMWP technology for their future strategic applications. EUIMWP will achieve the targets through the Action members' unique combination of broad knowledge and multidisciplinary expertise in IMWP, PIC, high performance MWP-driven components, systems and applications.

B) SPECIFIC OBJECTIVES

I) RESEARCH COORDINATION OBJECTIVES

The objective of the research coordination in EUIMWP is to foster an exchange of knowledge between the main stakeholders in the IMWP field (academia, research institutions, industry and end-users) to accelerate the collaboration and cross-fertilisation between them, with the scope to finally enable the IMWP field to reach the stage of maturity needed in applications.

This will be carried out by exchange of information and personnel, and through comparative studies and quality assessment processes. The successful implementation of the EUIMWP roadmap, will show the feasibility of IMWP for the selected high-performance applications. To achieve this ambitious objective, EUIMWP will focus on three strategic applications areas:

- 5G wireless communications: Next generation (5G) wireless communication systems will require 1,000 times more capacity then current networks. Access to mm-wave and sub-THz spectrum is a key requirement for reaching the required 100s Gb/s data rates. MWP techniques have already shown the potential for highly efficient mm-wave signal generation, distribution through optical fibres and direct fibre-wireless conversion at chip-scale level. A work group (WG3) will work on the definition of the requirements for the critical components/subsystems needed for fibre-wireless interfacing at chip-integration scale. These will address efficient mm-wave and sub-THz carrier generation, energy efficiency, smaller SWaP and unprecedented bandwidths for the wireless links (10s to 100s Gb/s) for access networks and backhauling. From them a specific IMWP roadmap for 5G systems will be produced.
- Aerospace systems and applications. Highly flexible and reconfigurable satellite payloads are required for future satellite-based telecommunication systems. IMWP techniques are being considered as a possible low-SWaP alternative to digital systems for space-borne switches and transceivers. A work group (WG4) will define the potential IMWP solutions for specific aerospace and satellite applications leading to reduced SWaP, enhanced functionalities and robustness and low phase noise for on board LO generation. From them a specific IMWP roadmap for aerospace systems will be devised.
- Automotive: in the automotive field the convergence of communication and radar functionalities is highly desirable for reducing the SWaP and cost of the system. Moreover, frequency agility in radar can improve the localization efficiency. IMWP can facilitate the combination of these two functionalities, with the sharing of the same hardware and the reduction of SWaP and cost, and it can provide an extreme frequency agility that allows adapting the localization system to the specific traffic situation, improving its performance. The use of photonics also allows for an easy distribution of the RF communication and sensing signals enabling a coherent ground network of communication/radar antennas for an enhanced distributed localization system that support the car-to-car communication and sensing system. PIC technologies will be evaluated with the aim to providing both functionalities with a special emphasis on enhancing radar system performance in terms of target recognition, robustness and classification precision, and low power consumption. A work group (WG5) is defined to tackle this challenge. These requirements will set the specific roadmap for IMWP (sub)systems for automotive systems.

In order to achieve the above targets, EUIMWP will be structured into six specific research Working Groups (WGs): WG1: Fundamentals of PIC for MWP, WG2: Subsystem Development through IMWP for wireless communications and radar functionalities, WG3: IMWP for 5G; WG4: IMWP for aerospace; WG5: IMWP for automotive; WG6: Roadmap definition of the IMWP-based systems and coordination group. WGs 1 & 2 will explore the fundamental PIC technologies and subsystems development concepts for application to the challenges set by applications considered in WG3-WG5. Hence, WG1 through 5 will interact among them and with a sixth WG, having the specific task to produce the EUIMWP global roadmap, which will be the cornerstone for the evolution of IMWP in the near/middle term future. WG6 will also have a catalysing role towards the exchange of knowledge between the WGs.

EUIMWP addresses explicitly the request for inclusiveness that is at the heart of COST. The Network of Proposers (NoP) includes a number of the COST-identified ITC, specifically Hungary, Poland, Slovenia, Ireland, Greece, Czech Republic, Portugal, and Cyprus. The EUIMWP network will facilitate the participation of such countries in the consortia and research programs related to IMWP and to the broader field of MWP. This is particularly relevant for those ITC countries that currently do not play leading roles in European PIC foundries programmes. The identification of clear collaboration needs within the field of IMWP will allow the formation of relevant consortia to apply for top research projects funded by H2020 and other international agencies, e.g., ERC. The knowledge exchange enabled by EUIMWP will foster and actively encourage the formation of new generations of Early Career Investigators (ECIs) and innovators on IMWP technologies. The Action will deliver Training Schools (TSs) on the main applications areas on IMWP, providing free-access to massive open access online courses (MOOCs) on IMWP in order to promote education, training and skill development.

II) CAPACITY-BUILDING OBJECTIVES

EUIMWP will provide a unique one-stop marketplace for the next years where industry and academia can build a strong and coordinated capacity in research. The major capacity building objectives of this Action is the promotion of collaborative research actions across different stakeholders such as PIC designers, RF designers, manufacturers, photonics researchers and end-user industries. Thus, EUIMWP will be fostering a generation of ECIs with a unique (and, currently, extremely rare) set of competences ranging from PIC technologies, mm-wave engineering, IMWP, system engineering skills and enhanced technological transfer expertise. The Action will also be supporting new and incipient research networks between ECIs and young innovators. The Action aims to consolidate and support widely recognized initiatives to establish integrated Pan-European networks of facilities open for testing, developing and prototyping IMWP innovative systems. The definition of the roadmap will serve as a catalyst to position the Action as a unique forum, which brings the most relevant players together to discuss IMWP technologies strategies beyond 2020. During its lifetime, it will be fully open to the incorporation of new partners from all COST member countries and other cooperating states as well as recognized international experts in the field.

C) PROGRESS BEYOND THE STATE-OF-THE-ART AND INNOVATION POTENTIAL

I) DESCRIPTION OF THE STATE-OF-THE-ART

IMWP has to face many challenges from the technology and application points of view. EUIMWP is focused on wireless communications, radar and aerospace ecosystems, which are the most demanding application scenarios. To justify this statement, a brief review of the state-of-the-art of each of these strategic applications is indicated. PIC Technologies for MWP: To date, only three material platforms: 1) Indium Phosphide (InP), 2) Silicon Nitride (Si_3N_4-SiO_2) and 3) Silicon Photonics Si-Ph have reached the required maturity to be considered viable for the implementation of complex MWP circuits [1]. None of them offer so far IMWP Basic Building Blocks (BBBs) adapted to the current state-of-the-art GFM Models [2]. IMWP subsystems development: The activity in IMWP to date has focused on Application Specific Photonic Integrated Circuits (ASPICs) designed to perform a particular MWP functionality. ASPICs demonstrated so far implement very simple, low-end functionalities (filtering, arbitrary waveform generation, optoelectronic oscillation, phase shifting and delay lines) with moderate performance metrics and no multifunctional or programmable ability. Co-integration of photonics and RF parts has not yet been reported with the exception of very basic schemes

[2]. More complex or high-end subsystems such as those needed for applications combining communications and radar will require higher performance in terms of very stable radiofrequency (RF) sources, and very precise signal detection and digitization. Multifunctional radar systems also require the development of reconfigurable and software-defined MWP subsystems, capable of producing wideband waveforms over carriers ranging up to the millimetre waveband, above 30 GHz, while maintaining the phase stability necessary for coherent pulse-Doppler processing, target imaging, and clutter rejection [3]. The direct generation of modulated RF signals by means of direct digital synthesizers (DDSs) with acceptable stability is limited to a few GHz, and the necessary process of multiple up-conversions worsens the generated signals phase noise [4]. Similarly, the precision of analogue-to-digital converters (ADCs) drops with increasing input bandwidth and sampling speed [5]. Photonics enables a new concept of multifunctional MWP systems that can manage in the same system several applications such as meteorology, environment monitoring, target detection and communications [6] by providing in a single chip several functionalities such as Photonic-based RF generation, beamforming and filtering. However, it is necessary to look forward towards photonics integration in order to reduce the SWaP of these photonics-based radar sub-systems. Wireless Communications: 5G communications imply a gigantic step forward compared to 4G and 3G. To briefly summarize, 5G targets extremely ambitious goals in terms of coverage and mobility (global & ubiquitous), number of connected users (over 100), maximum speed per user (10 Gb/s), spectral efficiency, latency and energy efficiency [7]. Meeting these targets will require a host of new technologies such as full duplex, device-to-device communication, MIMO, large number of small cells and the usage of the mm-wave and sub-THz spectrum (30 GHz to 300 GHz) [8,9]. Given the small cell sizes that are likely to be adopted in 5G, there will be a requirement to produce versatile and tuneable RF-photonic components (both for the central office and remote antenna units) in relatively large numbers and at low cost per unit. Current MWP systems are limited in their SWaP, making them unsuitable for large-scale use. There is therefore a motivation to employ IMWP in order to meet the required SWaP specifications for 5G [7,8]. Focusing on pico-cell wireless communications applications for 5G the operation beyond 50 GHz (E, W, D bands) offering links with data rates up to 100 Gb/s and flexible and reconfigurable RF-photonic front ends will be needed. When moving to higher frequency carriers the phase noise of the radio-frequency oscillator becomes a critical component that is challenging to integrate into MMIC technology platforms. However, generating the microwave and THz signals by photonic means provides not only inherent compatibility with fibre-optic communication systems but also the possibility to achieve extremely low-phase noise at the high-frequency carrier [9]. In terms of capacity-enhancement and energy-reduction the advantages of Radio-over-Fibre-fed pico-cells for 5G scenarios can be improved further by means of radio beam steering within each cell, which effectively partitions each cell dynamically into smaller cells via space division multiplexing. For operation at high data rates, beam steering of wide-spectrum signals is needed, which requires so-called true-time-delay (TTD) techniques to drive the phased array antenna's (PAA) elements. Implementations of such TTD techniques by means of integrated tuneable optical resonator rings or by means of wavelength-selected delay lines have been reported [10,11]. The automotive communications for smart self-driving car scenarios and cooperative driving scenarios have attracted the attention of photonic technologies [12, 13]. Since the mutual positioning of the roadside terminal with respect to the car (or of the car with respect to other cars) is changing quickly, narrow fast steerable radio or optical beams are needed to convey the information in the limited time window available. Solutions may be devised based on integrated PAAs with a relatively high number of antenna elements in order to yield a narrow beam, and TTD-enabled beam steering to create a large bandwidth [14]. Therefore, to deal with the future 5G connectivity based on small-cells for high-density user numbers or high-speed mobility scenarios it is necessary to address the full photonics integration challenges of those subsystems. Aerospace communications and applications: The impact of photonics technologies is studied for aerospace technologies for many applications. In the case of satellite payloads, the programme ARTES has provided a sort of studies that have identified segments on telecommunications satellite payload to be replaced with photonics technologies.

The building blocks on EO and OE converters, photonics down/up conversion stages, analogue optical links, optical switches and photonic frequency generator units were identified. The uses of this bulky photonics devices save considerably in terms of power consumption, mass and units into telecommunication payloads. However, the introduction of PIC technologies to further reduce SWaP adding flexibility to the telecommunications payloads in terms of frequency adaptation to accommodate one payload to different missions have not been reported [15]. As mentioned previously to meet satellite payload scenarios in order to extent operational life of the mission the compactness and reduced SWaP characteristics of IMWP technologies are required.

II) PROGRESS BEYOND THE STATE-OF-THE-ART

The aforementioned strategic applications face common challenges towards their realization in an integrated platform. The main one is how to achieve a monolithic PIC integration approach that will combine, on a single platform, the different critical sub-systems identified on each application with sufficient performance. At this stage, in fact, there are a number of different material platforms (InP, silicon photonics, silicon nitride and lithium niobate) each with different desirable performance metrics, and it is not yet clear which one will eventually provide the best solution for IMWP applications, as a considerable number of trade-offs that need to be considered exist. Besides, these are not only relevant from a technology point of view but also from the performance requirements of MWP systems. To date, hybrid integration approaches are commonly employed to combine the advantages of several platforms and reach the required system-level specifications. Overcoming the actual limitations of the state of the art requires working along the following lines:

PICs and subsystems for IMWP: Definition of the characteristics of the current GFM for IMWP technologies. i) Definition of a set of common photonics building blocks (BBs) and process design kits (PDKs) to IMWP, ii) Definition of MPW to host the integration and implementation of IMWP requirements, iii) Dynamic and update portfolio of key capabilities to perform high performance behaviour and how to define them according to available PIC technology and iv) design of complex and multifunction software-defined IMWP chips.

Wireless Communications applications: - Definition of critical subsystems to be integrated under PIC platforms for the *5G application scenarios* of pico-cell wireless communications. In particular, i) Low-phase noise sub-THz carrier frequency generation and agile tuneable multiband/multifunction MWP front-ends (e.g. for filtering, beamforming), ii) Broadband photodetection beyond D band, iii) 2D beam steering and co-integration with tuneable laser diodes for enhanced resolution and fast tuning. - Identify the monolithic PIC large-scale platforms and their requirements that fit under the defined critical subsystems. - Settle the bounds that limit the integration of the identified subsystems under IMWP to establish a specific technological roadmap.

Radar applications: - Definition of the critical subsystems to be deployed on PIC platforms with the performance required by radar applications, especially automotive scenarios. In particular, i) tuneable high-Q optical filters for mode selection and sideband/carrier filtering, ii) high-linearity phase and amplitude modulators for electrical-to-optical conversion, iii) low-noise and high-responsivity photodetectors for optical-to-electrical conversion. - Monolithic approach of PIC integration to minimize SWaP and cost where a single technological platform is used for the fabrication of all the required optical components.

Aerospace Applications: Definition of the IMWP technologies available to integrate critical photonics subsystems with potential benefits towards future satellite payload systems. i) sub-THz Photonics sources (Q/V band) on a chip compared with actual bulky fibre-based lasers, iii) PIC integration of key telecommunications payload segments based on IMWP blocks of combiners, dividers and phase modulators. – Requirements of the integration of telecommunications satellite payloads under IMWP technologies.

Furthermore, the **definition of a general roadmap for IMWP** from the specific evolution roadmaps of the three application fields is expected to act as the key to its future successful exploitation. The use of GFM according to each IMWP technology will help to lower the fabrication costs and bring benefits derived from the economies of scale as they will become ready to use and to discuss for the end-user industry.

III) INNOVATION IN TACKLING THE CHALLENGE

In order to provide a common interface for the challenges on IMWP devised by the three selected strategic application scenarios, an innovative research approach in terms of networking is required. The novel networking approach among researchers in photonics technologies, integrated devices and applied systems enabled by EUIMWP is fundamental. This synergy between a broad range of multidisciplinary competences will allow to gather the different knowledge backgrounds and expertise to address the complex challenge of bringing IMWP technologies closer to commercial reality. This will be done by making it ready to meet the specification rules set by foundries and by developing specific building blocks, design kits and libraries ready for external use. In addition, other innovative approaches will allow new research angles and results:

- Each targeted strategic application needs to define new methods to validate the proposed requirements. All of them will share a common background on IMWP technologies that offers different capabilities, but they need to be able to compare their advantages to provide a comparable library of behaviours. New metrics for simulation accuracy are needed, which could be user-oriented (design or device), or application specific. The Action brings an opportunity for the formation of new experts by teaching PIC design to researchers with a background related to the application.
- A new approach to provide a clear definition of the application in terms of IMWP technologies is envisaged. New photonics BBs and PDK will be added to the software designers' libraries reflecting those applications requirements, easing the adoption of reliable IMWP technologies based on PIC designs through simulation and testing.
- The Action will work jointly with PIC foundries and software providers to develop novel libraries of component models or complement existing ones to include metrics relevant to analogue applications, e.g. including nonlinear behaviour of photonic components. This capability is needed to estimate some performance parameters (e.g. spurious-free dynamic range) that are critical for analogue applications and to allow accurate simulation of system-level MWP functions before fabrication. This result will be made available to the photonics community as a whole and is expected to be beneficial for wider field of applications.
- The definition of a roadmap motivated by the applications and supported by IMWP technologies will be crucial. It is necessary to define and validate the application requirements under IMWP, in order to develop high performance applications including 5G, automotive and space technologies.

Action participants will provide access to experimental facilities in a coordinated way. Partners will have access to foundries facilities and designer's libraries on different PIC technologies. Such a holistic approach cannot be achieved by paper and simulation studies alone; test beds and experiments are needed to gain new insights and to validate new IMWP technologies.

D) ADDED VALUE OF NETWORKING

I) IN RELATION TO THE CHALLENGE

EUIMWP is the added value tool to bring different research communities under photonics technologies (1) to tackle the gap between the research outcomes and the end-user requirements (2) to push the technological readiness level of IMWP one level higher from technological concepts (Technology Readiness Level (TRL) 2-3) to its possible validation (TRL 4-5) in order to meet the requirements of next-generation of innovative and high-performance systems in communications, radar and space. In particular:

Scientific networking: Excellent science based on a high quality interdisciplinary research approach that will combine the expertise from user-industry, foundries, photonics designers, research centres and academia. The Action will provide the opportunity for high-quality research initiating future collaboration towards key scientific and technological advances on IMWP.

Innovative networking: The Action aims to build the IMWP value chain (vertical) with the added value that: 1) future target metrics for IMWP applications become clear to the (academic) researchers and 2) end users (industry) become aware of the potential of IMWP as a novel technology.

Inter-disciplinary networking: IMWP is inherently multidisciplinary and requires thorough knowledge of material science (material nonlinearities), photonics, electronics, and integration technologies, all at the same time. Knowledge of PIC simulation and PDK design tools are required, as well as fabrication technologies and characterization techniques. Knowledge of applications is required when PICs and systems are designed. EUIMWP provides these inter-disciplinary approach as a unique opportunity for training the new generations of ECIs to provide them with the tools to face the future societal challenges with IMWP.

Open and new networking: IMWP is a new field with potentially novel applications that are maybe unforeseen. Therefore, new players need to be added when these opportunities arise during the Action and new Working Groups will be created to consider them.

II) IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

This Action within the COST framework is totally different from others research initiatives carried within EU, e.g., H2020 CSA. In fact, this Action will be open for collaboration with other parties and stakeholders without any burden of partnerships or legal bounds. Therefore, it facilitates the access for researchers that are not capable to join such initiatives on PIC and IMWP due financial issues and allows the participation of wider audience. There are efforts at the European level targeting research on PIC and IMWP as well as at the international level. Specifically, it is worth to mention that EU ACTPHAST project offers a free prototyping service to SMEs on seven photonic technology platforms, among which the JePPIX platforms for InP and TriPleX technology, EU coordinate and support action (CSA) LightJumps and the national Dutch programme MEMPHIS II. The EU CSA LightJumps aims to accelerate and support business development of photonics SMEs, by means of high level business mentoring and business planning. The EU CSA PICs4All stimulates interest in photonic integration; increases the number of specialized scouts in the photonic integration field, and enhances introduction of ASPICs at the industrial level. On the other hand, it is worth pointing the FIWIN5G MSCA training network that pursuits to produce the training of ECI on the area of 5G high-speed wireless internet and beyond. On a global basis, the Ministry of Science and Technology of China supported photonics integrated projects under the National Basic Research Program or 973 Program. In USA, the recent American Institute of Manufacturing for integrated photonics is focusing a relevant and unique national effort on this area supported by US government. Differently from those efforts, which are addressing pre-defined agendas, this Action can freely explore new topics and ideas about IMWP, using the networking outcomes coming from its participants, and join the effort of mixing the various competences identified above.

EUIMWP Action will be capable to provide technical inputs to many of the world standardisation and regulatory bodies, e.g., IEEE, APT and ITU-T. The Action will collaborate with those aforementioned projects in order to cross-fertilise the networking and allow a major participation to discuss common topics to foster future projects. Moreover, the value of the networking of researchers provided by Actions is recognised by the international community, since colleagues from other regions (e.g., America and Asia/Pacific) have been asking to join several Actions, namely those in the area of photonics and communications.

This global dimension of an Action enables a better exchange of results (at the various levels, i.e., theoretical, experimental, measurement, simulation, and so on), a wider assessment of models (contributing to a better acceptance of the resulting models), and a "faster" path to contributions to common ground of standardisation bodies (given the full international dimension of the supporting institutions). This is not a new experience in COST, as many of Actions have provided inputs to the above-mentioned entities on behalf of COST.

2) IMPACT

A) EXPECTED IMPACT

I) SHORT-TERM AND LONG-TERM SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS

In what follows, EUIMWP's key impact goals are summarized, showing how they relate to the expected ones (indicating in between parentheses the contribution to short- and long-term impacts –(ShT) and (LoT)– in scientific, technological, and socioeconomic components –(SiC), (TeC) and (SoC):

IMWP roadmap: EUIMWP aims to influence on the future of mainstream high-performance applications sectors, specifically Space, 5G Wireless communications and automotive through IMWP technologies. The EUIMWP IMWP roadmap pursues a twofold-objective. Firstly, the definition of a common framework to identify and validate which are the key requirements imposed to IMWP technology by the selected applications (specific roadmaps). Then, these roadmaps will be integrated into a general one that shall provide the envisioned capabilities of the multidisciplinary IMWP technological approach. EUIMWP will give this vision on an evidence-based manner and with a comparative assessment between technologies. Thus, clarification of capabilities of each PIC material platform and application requirements may lead to a reduced uncertainty for potential industrial inversion. (ShT, LoT, SiC, TeC, SoC)

PIC as Key Enabling Technology: EUIMWP Action aims to impact the main industry and investor perception on integrated photonics technologies as the key enabler asset for their applications "beyond 2020". On the long-term EUIMWP will define the foundations and requirements of fully integrated PIC solutions for each strategic application benefiting the active companies (manufacturers, end users) participating in the Action since, this information is strategic to gain competitive advantage. On the short-term the definition of novel IMWP-specific BBs, PDKs and validation models over the existing generic PIC solutions for each key component will provide immediate impact on available technology. Companies (design houses, design software, foundries) with activity on integrated optics participating in the Action will immediately benefit as this will allow them to expand their business model to embrace IMWP. EUIMWP networking will provide new methods and solutions not available today from IMWP. (ShT, LoT, SiC, TeC, SoC)

Spreading Excellence European front-end knowledge area: EUIMWP NoP is geographically diverse, includes most of COST member countries and Inclusiveness Target Countries (ITC). It provides a unique opportunity for effective inclusiveness and widened participation in European science, promoting scientists in IMWP and empowering new actors on the stage of the scientific and technological areas tackled by this Action. This fact, together with the open and bottom-up spirit of COST, is a key factor for spreading knowledge over every region in Europe, and to give research centres and institutions in ITCs the opportunity to link to the major players in the H2020 framework. (ShT, LoT, SiC, TeC, SoC)

Fostering the young talent: The young innovators and ECI's participants at EUIMWP will be working in topics that are the basis for the future photonics technologies. As a consequence of the COST networking they will be able to access a unique platform of PIC facilities and interact with the world-leading IMWP expertise provided by the Action NoP (ShT, SiC).

Moreover, that interaction will facilitate being in touch with upcoming research projects in the H2020 program and build connections to the most relevant industries and institutions on this field. This will provide them with knowledge and experience and will equip them with the breadth of intellectual and management skills that will be required for future technological leadership.(LoT, TeC)

Addressing the Societal challenges: The ICT is transversal to the societal challenges that have been identified by the EC for the H2020 framework. Photonics technologies are the key enabling components to develop ICT in order to address societal challenges. For instance, for the challenge imposed by inclusive, innovative and secure societies, the use of IMWP will increase information access for all citizens, through the development of the future Internet infrastructure with multi-Tb capacity, while reducing the networks' carbon footprint and the overall cost per bit. Those envisaged IMWP-based products will enable the development of future smart cities, smart home, remote health, smart mobility to impact on all areas of the society. (LoT, SiC, TeC, SoC)

From COST to beyond 2020: EUIMWP developed expertise will put their members in an excellent position to provide expert advice to government, industry and standardization bodies on potential applications and worldwide trends in this technology, adding considerably to the EU's competitiveness in emerging IMWP technologies. The EUIMWP Network of Proposers (NoP), together with their institutions, gathers many of the academic and industrial researchers in the area, and brings previously established links to international standardization bodies and industry groups, namely ETSI, 3GPP-RAN4 (Radio Access Network), CTIA (USA), 5G-PPP (EU) and the Photonics21 PPP (EU). In particular and from the production of a roadmap of requirements and recommendations EUIMWP will draft White Papers and submit recommendations to theses standardization bodies, potentially impacting some decision makers and strategies for "beyond 2020" on 5G and integrated photonics. (LoT, TeC)

B) MEASURES TO MAXIMISE IMPACT

I) PLAN FOR INVOLVING THE MOST RELEVANT STAKEHOLDERS

In the area of IMWP technologies more specifically in the area of PIC, communications. automotive, radar and space technologies one can identify a number of institutional stakeholders, as follows: universities (UNIs), institutional research centres (IRCs), and End User Solutions vendors (EUVs), PIC manufacturers, designers and integrators (PICs), SMEs in the various technological areas related to the sector (SMEs), regulators (REGs) and policy makers (POMs). EUIMWP plans to involve these key stakeholders to participate, in a number of actions listed below (indicating in between parentheses the corresponding stakeholders):

- The EUIMWP's NoP already includes many stakeholders in the area, encompassing all key institutions and organizations (UNIs, IRCs, EUVs, PICs, SMEs).
- Members of EUIMWP's NoP have significant links to industry. On top of those already involved in the NoP, others will be invited to join and form an advisory Committee (EUVs, PICs, SMEs).
- EUIMWP will establish and invite to join a list of the research groups in Europe with activity in the area of the Action (UNIs, IRCs, EUVs, PICs, SMEs).
- EUIMWP will establish a list of the Graduate Schools (i.e., universities awarding a Ph.D. degree) in Europe with activity in the area of the Action, so that the Action can reach Ph.D. students for its TSs (UNIs).
- Researchers from outside Europe involved in previous Actions and projects in the area (e.g., USA, Canada, Brazil, China, Japan and Australia) will be invited to continue their involvement on specific topics of the Action and join an Advisory Committee (UNIs, IRCs, EUVs, PICs).

- EUIMWP has received expressions of interest from international partner countries (IPC) with active presence at standardization bodies and international RTD governmental agencies. The Action will integrate them in order to be pro-active in addressing standardisation and regulator stakeholders (at both the national and international level), by presenting Action´s outcomes on these fora and invite relevant players to events on specific topics of their interest. (EUVs, PICs, REGs, POMs).
- Members of the EUIMWP's NoP are part of many H2020 R&D projects, easily enabling the establishment of links and joint collaborations with these projects (and the other projects can be reached via the EC Coordination Meetings), e.g., for the exchange of data or for the organization of common TSs and workshops (UNIs, IRCs, EUVs, PICs, SMEs).
- Members of the EUIMWP's NoP are part of key European PPP bodies, hence, having direct access to the organizations participating in these bodies, to which the Action will be presented (UNIs, IRCs, EUVs, PICs, SMEs).
- EUIMWP Action will be involved in ECOC (European Conference on Optical Communications), the main European conference in photonics, also at EUCNC, OFC and MWP conferences, enabling direct contacts with its organizations to organize industrial-research workshops (UNIs, IRCs, EUVs, PICs, SMEs).
- The NoP is confident that with this list of Actions to actively involve the various stakeholders, the EUIMWP Action will succeed in maximizing its impact at the various levels, ranging from short- to long-terms, and encompassing the scientific, technological, and socioeconomic component

II) DISSEMINATION AND/OR EXPLOITATION PLAN

Dissemination is a key component of an Action, given its R&D dimension, together with the development of basic technology and the training of researchers. EUIMWP will target dissemination audience by a number of initiatives including:

- Organization of TS, with EUIMWP lecturers and from other Actions and H2020 R&D projects, open to the community at large, especially to ECI and ITC, with public proceedings publications.
- Participation on well- established integrated technologies TSs and doctorate programs by EUIMWP NoP, with special attention to ECI and young innovators from ITC.
- Organization of topic-specific Special Sessions and Workshops co-located in international conferences, namely ECOC and EuCNC, but extended to the IEEE MWP, CLEO, EuMW, PIC international conference, OFC or IRMMW-THz will be encouraged in order to form EUIMWP research-industry roundtable discussion groups and their reports to be published.
- Co-organization of a workshop about "Women in Photonics" with IEEE, and/or national research agencies (FECYT, EPSRC) co-located in an international conference, e.g., ECOC and OFC.
- Organization of Final Meeting (FM) event collocated with a conference in the area to be open to any professional from academia, industry and society.
- Proactive participation on COST supervised and organized events and activities and presentation of EUIMWP in EC Coordination Meetings to reach projects in the same area.
- Organization of MC meetings each 4 month, for internal dissemination.
- Production of a MOOC with EUIMWP lecturers on IMWP, by the end of the Action.
- Production of an Action Leaflet, by the beginning of activity, explaining the key aspects of EUIMWP, to be distributed to stakeholders.
- Edition of: (1) a triannual Newsletter, with key news from EUIMWP, addressing major technical and scientific developments, and announcing future activities and events; (2)

White Papers, with the views of EUIMWP on the future development and challenges for IMWP, (3) small YouTube videos, within last achievements explained to general public twice a year.

The communication strategy is essential to disseminate properly the outcome of EUIMWP to improve the public's understanding of the field through public engagement. The Action will target key stakeholders such as public authorities, private companies, foundations and at the general public at large. In addition, EUIMWP will build-up a corporative image through all the communication material. The Action website will be the core platform of the general public access to EUIMWP, complemented and linked to adequate social networks tools once the activities have started. In order to increase public awareness about the main EUIMWP outcomes the participation on public events are aimed in the Action. For instance, participation of NoP at events like “The International Science Festival Gothenburg” is essential to provide the positive attitude towards science to new generations of young scientists and general public.

Exploitation of results is also a very important component of R&D, especially in the current days, where the cycle between research and product development is shortened. Therefore, EUIMWP will enable the use of the knowledge and networking created by its members during its existence, by considering the following possibilities and actions: a) setting up consortia among the Action for the proposal of projects within the H2020 program and other research-driven funding schemes, b) developing libraries, test-beds, models, methods, PDKs, PIC building blocks, coming from the joint work developed within the Action, to be published in the proper means (e.g., scientific journals, but not exclusively), c) supporting the creation of a confederation of experimental environments in research labs, so that experimentation can be made available to other research groups (in both academia-industry) as well as SMEs (e.g., to evaluate solutions before reaching the market) within the Action, d) following, to the extent possible, gold-open access rule for the Action publications, e) fostering the conditions to submit contributions to standardization bodies, from the models, libraries, methods and outcomes jointly with industry by the conclusion of the Action and f) supporting the edition and publication of a collection of white papers by the end of the Action.

EUIMWP members shall bear responsibility for ensuring that they do not knowingly infringe third party property rights when sharing results from EUIMWP activities. In conclusion, the Action will be taking several efforts in order to ensure that a proper dissemination of its activities will reach all stakeholders in due time and with the adequate impact.

C) POTENTIAL FOR INNOVATION VERSUS RISK LEVEL

I) POTENTIAL FOR SCIENTIFIC, TECHNOLOGICAL AND/OR SOCIOECONOMIC INNOVATION BREAKTHROUGHS

On the scientific level a focus on IMPW leads to the need to develop novel components as BBs for IMWP PICs. PICs are typically optimized for telecom and data-com applications, with a focus on energy-efficiency and digital signal generation and detection. Since MWP is inherently analog, re-focusing on linearity will be key. The key research challenge is to find the optimum trade-off in a foundry-based PIC platform between high operating power, for low-noise operation, and linearity of components. Another research challenge is to interface this PIC technology with electronic microwave and antenna components. This is a major opportunity to advance the field of co-design and co-integration/packaging of microwave and high-speed photonic components, through approaches such as monolithic and heterogeneous integration and system-on-chip or system-in-package. EUIMWP will determine the best combination of integration techniques at both the PIC level and the interface with microwave components. On the technological level smaller, more robust, lower weight and lower power consumption MWP systems can be expected, as is typical for PIC-based solutions over discrete-component solutions. Compared to electronics based solutions, PIC-based IMWP allows for a far broader bandwidth. These systems can be operated at frequencies well into the 100-GHz regime, using state-of-the-art photodiodes, and into the few-THz regime, using novel photo-mixers. The advantage of using foundry-based PIC technologies means that quality monitoring, testing and testing techniques do not have to be reinvented, lowering the threshold for technology transfer out of the laboratory. Moreover, easy scaling up of production volume can be expected. Combined with a potentially low cost for IMWP systems, the socioeconomic impact will be the appearance of ubiquitous, high-bandwidth and high-resolution, implementation of beyond-state-of-the-art microwave applications. Examples include bandwidth for the future 5G network, connecting 50 billion devices by 2020, and multiple high-resolution radar systems embedded in autonomous cars and drones. The EUIMWP effort can lead to substantial returns but *it also faces some risks* inherent to its approach, where the integration of MWP functional elements, the possible poor performance of integrated chips and the failure of the Action to converge to a roadmap that provides a viable path to integration of all the various MWP functional elements with the associated electronics are identified as the principal sources. For these and other risks factors a detailed contingency and tradeoff plan is provided in section 3.4.1.

3) IMPLEMENTATION

A) DESCRIPTION OF THE WORK PLAN

I) DESCRIPTION OF WORKING GROUPS

The activities of the EUIMWP Action are organised in 6 Working Groups (WGs) that cover the foundations of PIC components and IMWP subsystems, the three selected application scenarios and the elaboration of roadmaps. The WG's thematic areas are broad, open and flexible to allow the inclusion of new members joining at a later stage or joining more than one area. The objectives of the different WGs will be achieved by including experts both from the industry and the academia. Listed tasks (Tx.y), deliverables (Dx.y) and milestones (Mx.y) by quarter (Qz), are those envisaged at this stage, however, new tasks might be added based on the interests of participants.

WG1. Fundamentals of PIC for IMWP. The goal of WG1 is to compile an accurate portfolio of requirements of PIC solutions for IMWP. T1.1) (Q2) Evaluation of current GFM for IMWP technologies; T1.2) (Q2) Definition of main PIC key components for IMWP. D1.1 (Q3) STSM Plan and content to TS1; D1.2 (Q6) Report on available IMWP PIC fabrication methods via generic photonics platforms. Content to MOOC2; D1.3 (Q8) Report on key components for IMWP. Contribution to WhP1; D1.4 (Q11) Final WG report. M1.1 (Q2) WG1 formation approval by KO and definition of WG tasks; M1.Y (Q5/8/11) Annual review. WG2. Subsystem Development through IMWP for wireless communications and radar functionalities. The goal is to define the main requirements for implementing IMWP communication and radar (C&R) subsystems in terms of PIC models and monolithic integration. T2.1) (Q2) Define actual key IMWP components for each C&R subsystem; T2.2) (Q5) Define an evaluation model for IMWP C&R transceivers; T2.3) (Q8) Evaluation of monolithic PIC integration of C&R transceivers. D2.1 (Q5) Technical report on enhanced C&R critical subsystems and PIC solutions. Content to TS2; D2.2. (Q7) Technical report on the actual IMWP components concerning high performance C&R systems; D2.3 (Q9) Technical report on modelling and methods for IMWP C&R transceiver PIC integration. Content to MOOC2 & WhP1; D2.4 (Q11) Final WG report. M2.1 (Q2) WG2 formation approval by KO and definition of WG tasks; M2.Y (Q5/7/11) Annual review. WG3. IMWP for 5G. The goal is to identify the IMWP opportunities in terms of generation, SWaP, bandwidth, and integration to unlock the future 5G communications. T3.1) (Q2) Definition of critical IMWP subsystems to be integrated under PIC platforms for 5G; T3.2) (Q5) Identify PIC large-scale platforms and their potential meeting the requirements of identified critical IMWP subsystems. D3.1 (Q5) Content contribution to TS3 and STSM plans; D3.2 (Q6) Technical report defining specific PIC models based on 5G subsystems requirements. Content MOOC3; D3.3 (Q9) Technical report on modelling and integration of

IMWP subsystem for 5G. Content WhP2; D3.4 (Q11) Final WG report. M3.1 (Q2) WG2 formation approval by KO and definition of WG tasks; M3.Y (Q5/8/11) Annual review. WG4. IMWP for Space applications. The goal is to explore the IMWP opportunities on telecommunications satellite payloads to future aerospace technologies. T4.1) (Q2) Definition of current IMWP technologies for the targeted aerospace applications; T4.2) (Q5) Evaluation of monolithic PIC approach for telecom satellite payloads; T4.3) (Q5) Evaluation of monolithic on board IMWP subsystems. D4.1 (Q5) Technical report on IMWP systems for telecomm payloads; D4.2 (Q8) Technical report on PIC components for payloads, MOOC4 and TS4 content; D4.3 (Q10) Technical report on on-board validation payloads IMWP systems. Content WhP3; D4.4 (Q11) Final WG report. M4.1 (Q2) WG4 formation approval by KO and definition of WG tasks; M4.Y (Q4/7/10) Annual review. WG5. IMWP for automotive. The goal is to identify the expected requirements for broadband fibre-wireless communication and radar systems for automotive. T5.1) (Q2) Definition of radar subsystems for automotive wireless communications; T5.2) (Q5) Identify PIC technologies meeting the requirements of enhanced subsystems. D5.1 (Q5) Report on IMWP communications subsystems and STSM plans; D5.2 (Q7) Technical report defining specific enhanced radar subsystems from IMWP components. STSM plans. Content contribution to MOOC4; D5.3 (Q9) Technical report on PIC component integration for enhanced radar IMWP subsystems. Content WhP4 and TS5; D5.4 (Q11) Final WG report. M5.1 (Q2) WG5 formation approval by KO and definition of WG tasks; M5.Y (Q4/7/10) Annual review. WG6. Roadmap definition of the IMWP-based systems and coordination group. The goal of WG6 is to coordinate and interact with the rest of WGs and the industrial stakeholders to target, identify, discuss and select IMWP and PIC key functionalities from WG outcomes. T6.1) (Q2) Report on roadmap definition of the IMWP-based systems and WG outcomes. D6.Y (Q3/6/9) Yearly report on roadmap activities and WGs identified outcomes. Contribution to MOOC4; D6.R (Q11) Report on the EUIMWP global roadmap. Contribution RM & FM event. M6.1 (Q2) WG5 formation approval by KO and definition of WG tasks; M6.Y (Q5/8/11) Annual review. SIG. Special interests' groups. The initial goal of this SIG is the production of a MOOC. New SIGs will be created in line with the interests of EUIMWP Parties during the Action. TS.1) (Q2) Production of a MOOC on IMWP. DS.Y (Q3, Q6, Q9) Yearly report on STSM plan and production of MOOC; DS.M (Q12) Inaugural opening MOOC lecture during the final meeting. MS.1 (Q2) SIG formation approval by KO; MS.Y (Q4/7/10) Annual review; MS.3 (Q11) Final review.

Dissemination and Training: Supervised by the Dissemination Manager and the Training Coordination Chair, respectively. Their tasks are summarized in Section 2.2.2 and will spread over the various WGs. Action milestones are defined below: TSx: training school; MCMx: MC meetings; FORUM: initially collocated with the first MCM after KO to present the topic to the community (external parties invited); WSx: special sessions and workshops; NLx: newsletter issues; MOOCx: planning of MOOC course (MOOC1: PIC; MOOC2: IMWP; MOOC3-4: Applications); WhPx: white paper (WhP1: IMWP subsystems, WhP2-4: Applications).

II) GANTT DIAGRAM

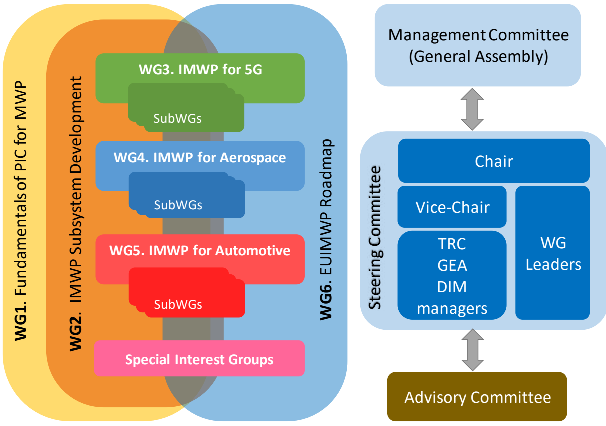
See below.

III) PERT CHART (OPTIONAL)

The PERT chart summarizes the interaction between the WGs (PIC, IMWP Applications and Roadmap) as well as the organization of the Steering Committees. As illustrated, the WG1, WG2 and WG6 are traverse to all the WGs that will contribute to roadmap definition.

GANTT Diagram

PERT Chart



IV) RISK AND CONTINGENCY PLANS

Integration of MWP functional elements and poor performance of integrated chips are the main risks elements in the Action. Fortunately, multiple foundries are currently running PIC platforms in various technologies and software vendors, design and packaging services have emerged. Therefore, the PIC eco-system is robust. Finally, the goal of delivery a useful EUIMWP roadmap needs to be assessed. The main risk factors and the envisaged mitigation plans are the following:

Risk factor #1: Integration of MWP functional elements and poor performance of integrated chips for 5G applications. Risk Level: Medium. Description: Applications like 5G communications mostly rely on the high bandwidth of IMWP systems, which is well within specifications of these PIC platforms. This is medium-risk application from a technological point of view, but IMWP approaches will have to compete with discrete-optics approaches. The NoP brings design expertise in the main three platforms InP, SOI, Si4N3) to overcome this limitation by choosing the most suitable material. Risk factor #2: Integration of MWP functional elements and poor performance of integrated chips for high dynamic range operation. Risk Level: High. Description: Applications that rely on high dynamic range are far more challenging, and include IMWP filters and oscillators. These are medium risk, as the technologies with the correct metrics do exist, but successful integration into a (hybrid) IMWP system still has to be done. Narrow-band optical filters with passbands of ~3 MHz have been reported, but integration with a laser, modulator and photodetector is required to make a functional IMWP filter, having a microwave input and output. Mitigation Plan: The NoP brings the expertise, if required, to develop new hybrid integration platforms (capable of hosting PICs and microwave monolithic ICs) and stimulating investigations into candidate materials such as silicon optical bench, polymer and glass on silicon. Risk factor #3: Integration of MWP functional elements and poor performance of integrated chips for complex systems. Risk Level: High. Description: Highly integrated and complex systems like IMWP-based radars and analog-to-digital converters are considered high risk, since many IMWP building blocks, like the oscillator, have not yet been reported with the required metrics. Moreover, electronics and RF integration is key in these applications. Mitigation Plan: The Action will propose an evolution roadmap for complex IMWP systems in successive steps involving increased degrees of complexity in terms of photonic and RF co-integration. This way the design of complex MWP subsystems can be guaranteed up to the level to which the technology development allows for while short and mid-term future evolutions will be predicted. Risk Factor #4: The threat of competing technologies. Risk Level: Low. Description: Incumbent electronic microwave technologies have matured and have clear roadmaps. It is important for IMWP to target applications well beyond the reach of the current electronics roadmap (including THz electronics) for high returns. Mitigation Plan: The EUIMWP selection of applications (WGs 3-

5) represents high gain opportunities where the inherent advantages of MWP over electronics, namely large bandwidth and tuneability can be fully exploited. Risk Factor #5: Convergence to a final EUIMWP roadmap. Risk level: Medium. Description: Identification of valuable outcomes from each WG to assure delivery of the roadmap by the end of the Action is a complex task. It needs also to be aligned with industrial expectations about product-life cycle and other. Mitigation plan: MCM will review WGs roadmap contributions yearly. The NoP brings investors and industrial key players expertise on each area of application to assess WGs roadmap progression yearly. Advisory Committee review yearly the roadmap progression to assure incremental steps on its complexity and to be aligned with industrial requirements.

B) MANAGEMENT STRUCTURES AND PROCEDURES

EUIMWP is conceived under the premise that success of COST Actions can only be achieved in a collaborative and highly interactive network where Management Committee (MC) members and experts, including a noticeable amount of ECIs, are free to discuss any activity or initiative undertaken, based on a bottom-up and open approach towards a concerted direction set up by the MC. The MC Chairperson will be elected by the MC at the kick-off among those who share this vision. The Action will divide its objectives initially into 6 technical areas organized in WGs. Each WG will have a leader and co-leader elected by the MC at the kick-off meeting (KO), preferable ECIs and women from ITCs as much as possible. Their responsibility will be to coordinate the activities of their WGs, lead scientific discussions, provide the MC with annual reports on the progress of the WG, and ensure the completion of the scientific goals of the Actions comprised on each WG. During the course of the Action, new sub-WGs and WGs can also be established depending on the needs of the parties. Among these, a Dissemination Manager (DIM), a Training Coordination Chair (TRC), a Gender-Balance and ECI Advisor (GEA) and a Secretariat for the MC will also be appointed to support the MC on the Administrative and Dissemination matters. The WGs leaders, DIM, TRC and GEA together with the Action Chair and Vice-Chair will constitute a Steering Committee (SeC). The SeC will interact more often to continuously monitor the on-going activities and report as necessary to the MC. Following the KO meeting, the MC will meet each four months. During these MC Meetings (MCM), all the issues concerning the development of the Action will be approved and discussed. The scientific progress will be monitored by the WG deliverables and milestones defined at the work plan. The MC will decide on urgent matters by electronic communication (email, virtual meetings, etc.). Annual WS and TS will be organized in parallel to each MCM. TSs will primarily focus on addressing ECI and PhD Students formation needs on PIC and IMWP and related transfer knowledge. TSs will be held on ITC as much as possible. They will be open to the entire scientific community and leading Action and invited non-NoP distinguished experts in the field will deliver these events. The TRC will coordinate TSs. The Action will promote the exchange of research students, researchers and innovators, preferable ECIs from ITCs, between the Action research centres through the STSMs. The TRC and GEA will be in charge of STSM coordination. The interaction with other COST Actions is aimed under invitation of experts to WSs and TSs. DIM will coordinate this interaction. An international advisory Committee will be placed in order to ensure that EUIMWP challenge and timeliness is been aligned with current international efforts and to provide advice on its roadmap. The advisory Committee will report to the SeC and attend MCMs annually. A website for the Action will be set up within three months from the start. This website will disseminate the outputs of the Action and will provide access for the Action members to the up-to-date information about the Action members, activities, deliverables, STSMs rules and procedures. The DIM will be responsible for the maintenance of the website.

C) NETWORK AS A WHOLE

EUIMWP’s NoP will bring together international experts in their respective fields to secure the achievement of the Action’s objectives. All major COST member countries are involved in EUIMWP and about a third of them are ITC. The NoP is formed by more than 25% of industrial and non-academic parties. The ECIs represented more than 45 % of the NoP and more than 1 of each 5 NoP are women. The NoP is also characterized by a strong expertise in the COST framework, since the key players have long experience with EU funded projects including COST Actions, CSAs and NoEs. IPCs in EUIMWP NoP are key experts in the area and they complement the work of the Network. Their inclusion also helps to facilitate possible contributions to standardization, and provides the possibility to increase the impact and visibility of the Action outside Europe. EUIMWP will continuously seek and invite new distinguished stakeholders during the Action. This balanced NoP will allow the EUIMWP Action ambition to become a leading open forum enabling direct contacts between Industry and Academia. The Action will therefore become a one-stop marketplace for international partners to learn about IMWP technologies in Europe, and in return for the Network to benefit from new knowledge and global perspectives outside Europe.

COST EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

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