

Final publishable summary report

Project acronym: ORF4AUTO

Project title: *“New organic printable materials for large scale/low cost integrated RF systems onto automotive elements.”*

Project duration: 11/2012 - 11/2014

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Declaration by the Project Coordinator (as stated above)

I, the project coordinator, declare that all consortium partners have approved the content of this report and released it for publication and dissemination unless otherwise stated.

29/06/2015

Date



Signature

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1. Final publishable summary report

Executive Summary

This project has focused on the common objective of the partners involved, in investigating the application of conductor ink (inorganic and organic) printing technology to current automotive antenna and telematic products, creating the first telematic unit with an operative antenna printed directly on its plastic enclosure.

Due to the confidential nature of the technology, processes, and images of circuitry dealt with in this project from both largest partners, FICOSA and Intrinsic Materials, this publishable final report has been written taking into account the confidentiality of industrial knowledge from all partners. A higher detail, confidential version final report is available upon request.

To reach this point, this project has generated advances in both the synthesis and printing techniques of organic and nano-particle based inks, investigated in the context of seeking the optimal ink configuration for printing an antenna and passive components directly on plastic.

Combining these technologies has proven the industrial opportunity to increase added value and competitiveness to current designs by allowing smaller PCBs (hence device overall size) in telematic units, yet potentially yielding a high gain from printed antennas, by taking advantage of the larger enclosure area. The prototype was created by modifying an existing telematic product, however this technology can be applied to numerous automotive communications applications, as well as other industries

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Project context and objectives

The automotive industry is currently experiencing a boom in connectivity requirements, for both infotainment and user communications (V2X, 4G, Bluetooth, Wifi, GPS, Assisted navigation) and emergency call and localization (e-call) whilst the industry demands increasingly non-visible antennas and maintaining high performances (hence high antenna gains) with increasingly lower costs.

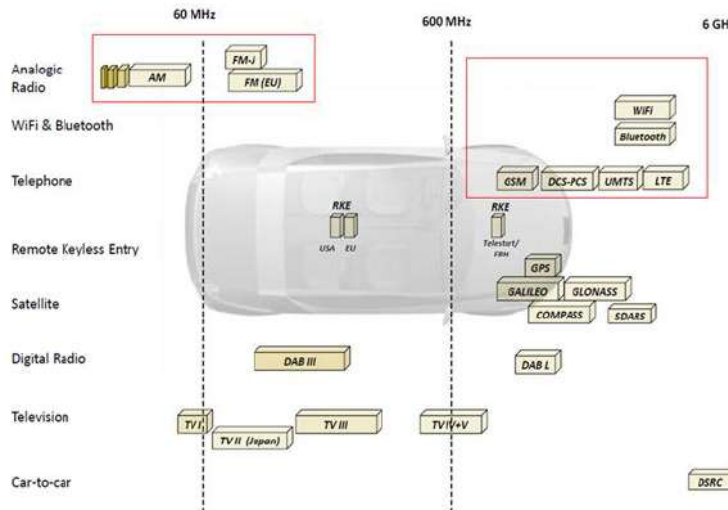


Figure 1: Current bands used in vehicular communications

In parallel to this evolution, new research fields have been created following new advances in conductive organic polymers and metallic nano-particle technology, also investigating printing and curing techniques on diverse surfaces. Hence, this project has allowed the combination of RF and automotive industrial knowledge from Ficosa- Advanced Communications, with new research performed by Intrinsic Materials, Leitat, and The University of SouthHampton, advancing in the synthesis of both organic and non-organic printable conductive inks, and innovative printing techniques allowing the printing of high accuracy patterns (such as Ficosa patented fractal antenna designs, and passive component designs) directly on plastic enclosures.



Figure 2: Current FICOSA Telematic Unit, Adapted prototype with a printed antenna, and a printed inductor sample, created by the Orf4Auto Project

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The prototype demonstrator produced by this project has confirmed the viability of antenna printing on the protective plastic casing, and the added competitiveness that this could add:

- Overall PCB dimensional reduction, due to the liberation of board area by the printed antenna if printed on the cover instead.
- Increased antenna performance by allowing to increase the available antenna aperture area. (Particularly relevant with the increasingly important, longer wavelength LTE-700 band).

The know-how produced by this project directly increases the design options of future versions of FICOSA’s telematic units, with which FICOSA plans to penetrate potential new markets, while increasing current antenna production volume, thus increasing its customer base of advanced communications products.

Although this project is initially based on this product, applied to vehicles for the automotive market (passengers, commercial, trucks) that does not mean that the new product is to be used exclusively in this sector. The objective markets can be found also in the more general transportation markets, including military and defence applications, and aeronautic sector.

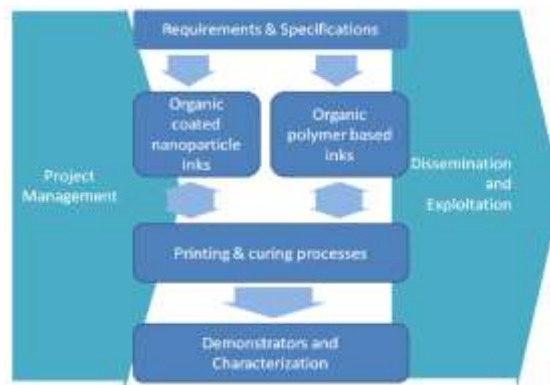


Figure 3: Research flows between defined workpackages of the Orf4Auto Project

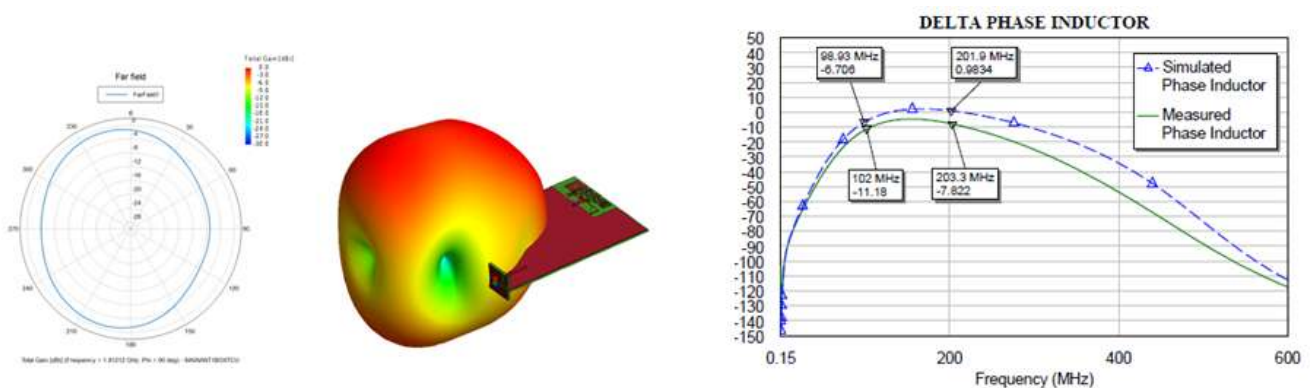


Figure 4: Simulated field patterns of the RF compensated printed fractal antenna, and phase measurements of a printed inductor sample

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Main S&T results/foregrounds

The research flow executed for this project was centralized at FICOSA, focusing on the final application and purpose of the project: integration of a new printed-on-plastic antenna onto an existing FICOSA automotive telematic unit, currently in production and being integrated in various vehicle models.

The following research flow diagram illustrates how the results developing in parallel from work packages 3, 4, and 5, focusing on the development organic and metallic nano printing technology, where aligned and validated at FICOSA for viability analysis taking into account electrical, material and the other design constraints.

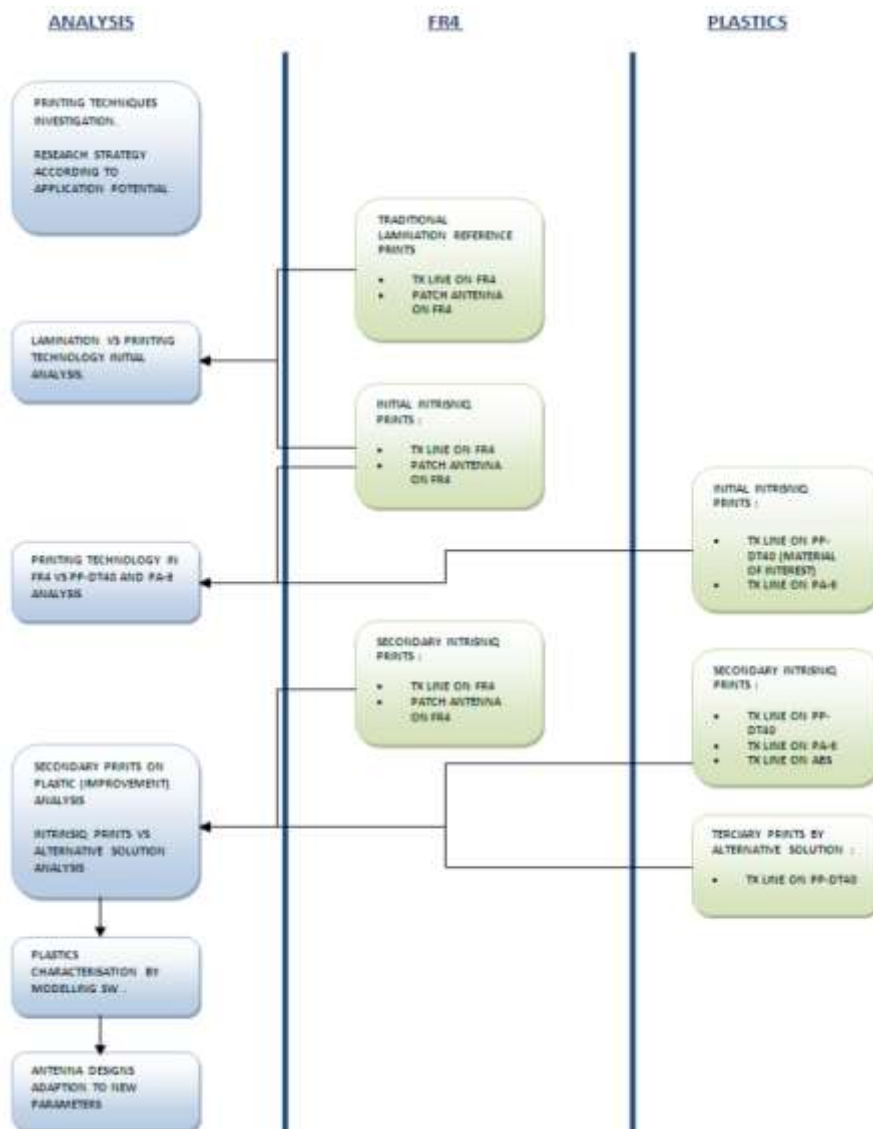


Figure 5: Following, the summaries of the objectives and results of the work packages performed by the partners of this project

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WORKPACKAGE 3: ORGANIC COATED NANOPARTICLES INK INVESTIGATION

(Lead by IML)

The objectives of work package 3 were defined as:

- Synthesis of base materials including metallic nanoparticles using IML proprietary plasma technology.
- Formulation of metallic nanoparticle's based inks for inkjet and screen printing.
- Printing Processes Investigation
- Study and definition of organic coatings for metallic nanoparticles to control oxidation levels of the final printed conductive structure.
- Techniques investigated to improve resistivity.
- Characterization of resulting inks/pastes.

Workpackage Results Summary

As a first step, it has been confirmed that the plasma process (researched by IML) still offers the most cost effective solution in comparison with other techniques available today (cost being a definitive factor in automotive electronics).

Numerous test cycles were performed in order to achieve the optimal configuration for the ORF4AUTO requirements, such as adhesion and conductivity, the latter being highly dependent on inter-particle cohesion and the non-formation of copper oxides.

Regarding the optimum particle size, It has been found that more cost effective, larger particle sizes (50-60 nm) are the most viable while still ensuring that the paste is compatible with the PP substrate.

Regarding the final ink paste formulation and printing research, it has been found that the best results were obtained with organic coated particles pastes, inkjet printed and cured by laser. Improved cohesion by other techniques (such as ultrasound) were also investigated. Numerous pastes were tested along with FICOSA, in order to fix the final paste configuration to be used for the final demonstrator. The final paste rendered, proved to be viable regarding adhesion, conductivity, and overall applicability for the Orf4Auto antenna application, although the printed paste still offers a lower conductivity value than the traditional laminated copper solutions used on FR4 PCBs today.

Planned Timing:	03/12/2012 – 02/12/2013	Executed Timing:	03/03/2013 – 02/06/2014
Resources used:	Intrinsiq Materials, Ficosa and Leitat Project Members and facilities. Ink Synthesis and printing machinery at Intrinsiq.		
Deviations:	3 month delay in workpackage official start due to administrative issues.		
Proof of Work:	Deliverables, printed samples of transmission lines and antennas on various substrates.		

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WORK PACKAGE 4: ORGANIC POLYMER BASED INKS INVESTIGATION

(Lead by LEITAT)

The main objective of this work package was the development of conductive inks for inkjet printing deposition based on organic conductive polymers. This includes the study of synthesis methods for organic conductive polymers and the needed additives for ink formulation.

The objectives of work package 4 were defined as:

- To study and define existing suitable organic conductive polymers.
- Synthesis of solutions for organic conductive polymers.
- Evaluation of different synthesis methods to define the most suitable ones according to ink requirements
- Ink formulation from synthesized organic conductive polymers solutions.
- Evaluation of resulting inks, taking into account the final application requirements.

WorkPackage Results Summary

Several organic polymer families were investigated at LEITATS chemical facilities for this project, of which the PEDOT family was pre-selected due to its lower cost and higher conductivity for in depth analysis.

Numerous PEDOT conductive inks were synthesized at Leitit in order to achieve the highest electrical conductivity possible, maintaining the appropriate physical characteristics (surface tension, viscosity). Variations in synthesis methods rendered diverse results, of which finally two formulations were selected.

The formulations proved to be suitable for inkjet printing, however the resulting prints measured much higher resistivity than the parallel investigation with metallic nanoparticle inks, hence it was concluded that organic polymers are adequate for the printing of resistors, however electrically non-viable for radiating antennas.

Planned Timing:	01/03/2013 – 02/06/2014	Executed Timing:	01/03/2013 – 02/06/2014
Resources used:	Leitit Project Members and facilities, Organic Inks Synthesis Laboratory		
Deviations:	The synthesized organic inks were not implemented in the final antenna demonstrator, as were found too resistive to be effectively used for antenna applications.		
Proof of Work:	WorkPackage Deliverables, Organic Ink Printed Samples		

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WORK PACKAGE 5: PRINTING, CURING AND CHARACTERIATION PROCESSES

(Performed by IML, FICOSA and UoS)

The objectives of work package 5 were defined as:

- Definition of printing and curing parameters for the obtained inks.
- Evaluation of the printed inks.
- Development of printed samples
- Characterization and viability analysis from FICOSA for telematic unit antenna applications.

WorkPackage Executive Summary

The printing parameters were defined for the considered ink formulations, and these were evaluated by UoS and IML. It was concluded that the nanometalic inks were more viable for antenna applications, as organic inks did not reach the conductivity levels required. Transmission line and antenna print samples were created by IML and analysed at FICOSA, electrically characterising the sample prints taking into account the current TCU plastic box material PP-DT-40. Full electrical characterisation was required for antenna adaptation and re-design taking into account the frequency bands at interest.

It was simulated that the current fractal antenna design would suffer a profile shift due to the electrical difference in the new substrate material, so the design was modified at FICOSA for IML to print an RF compensated final antenna prototypes. A semi-final antenna prototype was connected directly to the TCU PCB in order for direct VSWR measurements at the input ports, taking into account the PCB (required for accurate measurements).

The resulting profile proved efficient at GSM frequencies, although a slight distortion at 3G frequencies was found, as the LC circuit present on the PCB circuitry was pre-tuned to optimise the previous antenna. These results were however positive, as if this technology were implemented, the integrated LC circuit would be optimised for the new design to cover all desired frequencies efficiently.

Planned Timing: 01/03/2013 – 02/06/2014 Executed Timing: 01/03/2013 – 02/06/2014

Resources used: Intrinsic and Ficosa Project Members and facilities, Printing Equipment (IML), RF laboratory (FICOSA)

Deviations: The printed antenna prototypes were found to be effective up to 2.5GHz, with best matching in the GSM band, 3G frequencies were distorted by the TCU's integrated LC.

The higher V2X (6GHz) frequencies originally also included for investigation in this project, were found to fluctuate too much in performance due to minimal print differences, requiring much higher detail in print and soldering points

Proof of Work: WorkPackage Deliverables, Printed Samples for antennas and passive components

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WORK PACKAGE 6: FINAL DEMONSTRATOR VALIDATION

(Lead by FICOSA)

The objectives of the work package 6 were defined as:

- Modeling of developed materials.
- Design of RF systems with all printed passive components.
- Demonstration of obtained results.
- Validation of developed systems

Executive Summary

This workpackage details the RF modeling tasks performed by FICOSA for the RF component and antenna adaptation in this project. The printed passive components were evaluated, and a final, fully operative prototype unit was created by integrating the RF compensated printed fractal antenna printed on the units plastic cover.

This fully functional prototype was fully validated and evaluated, following standard factory test procedures, proving it's applicability for next TCU designs, with improvable points such as printing on the interior of the cover instead of the exterior (for physical protection) and improving the prints conductivity (thickness and/or formulation) as this is accountable for 1.5db less gain than it's FR4 laminated equivalent.

The final, metallic organic-covered ink configuration and printing method developed at Intinsiq materials, has been proven technically viable in the application of printed antennas and passive components, due to its strong adhesion to the current PP-DT40 plastic covers, while maintaining reasonable conductivity levels.

Printing on the cover of the unit, would allow the design of much larger surface antennas which will allow higher gains (both direct gain and diversity gain if separated to two antennas).

Planned Timing:	01/11/2013 – 02/12/2014	Executed Timing:	01/11/2013 – 02/12/2014
Resources used:	Intrinsiq and Ficosa Project Members, Printing Equipment (IML), RF laboratory (FICOSA, details in annex)		
Deviations:	Final demonstrator meets VSWR requirements in the GSM band but not fully in the 3G band due to the pre-tuned LC circuit currently in the TCU PCB.		
Proof of Work:	WorkPackage Deliverables, Printed Samples for antennas and passive components, Final Demonstrator		

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Potential Project Impact

This subsidised R&D project has given FICOSA- Advanced Automotive Antennas the opportunity to technologically expand its largest telematic project, providing new potential routes of business development that would not have been possible without the subsidy, due to current project costs and overall economic constraints.

The demonstrator has proven that printing technology can effectively be applied to improve current telematic products, increasing competitiveness by increasing antenna gain capabilities and reducing size, however remaining is one major issue to be resolved: Cost.

The automotive industry is extremely competitive in terms of cost, hence large scale industrialization viability analysis and cost reduction is required, in order to integrate this technology in current projects. If this technology was proven economically viable, and accepted by current clients, it could lead to a new generation of automotive telematic units.

Relevant Information

PROJECT WEBSITE

The following website has been created for the Orf4Auto Project:

www.olaepius.eu/projects/orf4auto/

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PARTNERS CONTACT DETAILS AND COMPANY INFORMATION

Ficosa – Advanced Communications (Automotive Sector, Catalonia)



Ficosa is an automotive multinational company based near Barcelona, funded in 1949 and currently employing approximately 8500 employees worldwide, currently holding automotive component contracts with all major western automotive OEMs.

Within Ficosa, the Advanced Communications department was born in the year 2001, launching its activity applying proprietary patents based on fractal antenna designs for automotive applications, allowing the miniaturization and integration of commercial radio and telephony antennas onto mirrors and other parts of new vehicles, maintaining high RF performances.

Since 2009 the Advanced Communications department has expanded its activity towards the design and production of Telematic Control Units, allowing vehicle interconnectivity for both infotainment (Internet, telephony, navigation) and emergency purposes (E-Call). Currently Advanced Communications has contracts with three major OEMs in this auto telematic sector and is pursuing new clients.

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Intrinsiq Materials (Nano metallic and printing technology, United Kingdom)



Intrinsiq Materials is a leading advanced materials company developing disruptive technology solutions. Spun out of QinetiQ PLC, Europe's largest S&T provider, their expertise lies in engineering solutions at nano-scales.

IML's current focus is on the development of conducting metal ink materials based on nanotechnology which, due to the low sintering temperature, allows these materials to be produced on low cost substrates such as PET. Their advanced products are screen and inkjet printable nanocopper based pastes and inks. With ink and paste formulation knowledge, they often develop formulations specifically around customer requirements. Due to the requirements to prevent copper from oxidising; once printed, their materials are cured either using proprietary laser systems or Xenon flash lamp systems, giving fast sintering, in air, with high performance tracks, and with no substrate damage.

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Leitat (Technological Centre, Catalonia)



Leitat is a private-non-profit Technological Research Center funded in 1906 that develops R+D activities in the areas of materials sciences, electronics, environment, biotechnologies and renewable energies with deep knowledge and experience on the technological transfers to several industrial sectors. LEITAT takes part each year in many projects financed by the regional and national government, participates in projects co-funded by the European Commission, and develops private R&D projects funded by industrial partners.

The Smart Systems research unit of Leitat develops R&D activities in new concepts of intelligent systems based on sensors and actuators networks (WSAN), wireless communications, energy harvesting for autonomous systems, and printed electronics for developing sensors, antennas and energy storage or generation devices.

LEITAT is currently involved in several regional, national and European projects related to organic electronics. Some of their most important projects in this topic are:

Microflex (FP7): Micro-fabrication on flexible substrates using printing technologies.

NANOTEG (ENIAC): Development of thermoelectric cells using printing technologies.

NANOTHERM: organic materials for thermoelectric applications.

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University of Southampton (Research on iks and printing technology, United Kingdom)



ECS, part of UoS, is the largest department of its kind in the UK and has 100 academic staff, including 36 professors plus 150 research staff and 270 PhD students. ECS, is widely recognised as being a leading centre of research in the printing of electronic functions, MEMS, sensors and nanotechnology. 65% of ECS's research was recognised as internationally leading or excellent in the most recent 2008 UK Research Assessment Exercise with the remainder being nationally excellent. ECS had led the development of sensors, intelligent materials, printing technology and printing inks for more than 20 years with hundreds of publications in the area.

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PROJECT DELIVERABLES PRODUCED

The deliverables generated by each partner are the following:

- **FICOSA- Advanced Communications, Project Coordinator (Catalonia)**



- D1.1: Project Planning.
- D1.2: Management Report
- D1.3: Periodic Technical Report
- D2.1: Definition of functional requirements for demonstrators
- D6.1: Report on printed components Modelling
- D6.2: Printed RF System Design and Simulation
- D6.3 Demonstrator Validation Report
- D6.4 Validated demonstrator
- D7.3 Exploitation Plan
- D7.4 Foreground IPR Management Report

- **Leitat, (Subcontracted by FICOSA) (Catalonia)**



- D4.1 Report on Synthesis of Organic Polymers
- D4.2 Report on Organic Polymer based Inks Formulation
- D4.3 ICP based inks and characterisation Report
- D1.4: Risk Assesment Report

- **Intrinsiq Materials (IML), Project Partner (United Kingdom)**



- D2.2: Definition of Technical Specifications
- D3.1: Characterization report of synthesized nano particles
- D3.2: Characterisation report of coated nanoparticles
- D3.3: Metallic nano particles ink samples and characterisation report
- D5.2: Curing Methods for metallic nanoparticles based inks
- D5.3: Curing Methods for organic nanoparticles based inks
- D7.1: Dissemination Plan
- D7.2: Report on Dissemination Activities

- **University of Southampton (UoS), Project Partner (United Kingdom)**



- D5.1: Report on Printing Parameters
- D5.4: Printed Samples and Characterisation Report

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2. Use and dissemination of foreground

Section A (public)

The following table A1, lists the publications reviewed for the Orf4Auto project as background:

TABLE A1: LIST OF SCIENTIFIC PUBLICATIONS										
	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year	Relevant pages	Permanent identifiers	Will be open access provided to this publication?
1	Low Cost Antennas using conductive plastics or conductive composites.	Integral Technologies	-	May 24, 2004	United States Patent Application	US	2004			yes
2	Transparent conductive film and preparation method thereof	Nanchang O-Film Tech. Co., LTD.	-	Jul 6, 2013	United States Patent Application	US	2014			yes
3	Flexible Board and electronic device.	Murata Manufacturing Co., Ltd.,	-	June 16, 2014	United States Patent Application	US	2014			yes
4	Broadband Planar Antennas. Design and Applications	Zhi Ning Chen and Michael Y.W. Chia	-	-			2006	pp 17-46		yes

The following table A2, lists the dissemination activities taken forward in the Orf4Auto project:

TABLE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
1	OLAE+ Conference	FICOSA	Olae + Orf4auto mid-term review	December 2014	London, England	Olae+ Project members	35 Aprox.	Various
2	FICOSA Showroom	FICOSA	Product display in company showroom	December 2014	Barcelona, Spain	FICOSA current and potential clients	-	Various
3	LEITAT Showroom	LEITAT	Product display in company showroom	December 2014	Barcelona, Spain	LEITAT current and potential clients	-	Various
4	Dissemination at DTIP 2014 (www.dtip-memes.org)	UOS	“Laser Curing of Screen and inkjet conductor on a flexible substrate”	October, 2014	England	DTIP 2014 Attendees	-	Various

Section B (Confidential or public: confidential information to be marked clearly)

Part B1

No new patents have been issued new as a direct result of this project, however the technology produced is product of several patented technologies from both Intrinsic Materials (printing techniques) and Ficosa (fractal antennas).

Part B2

The following table lists the exploitable foreground:

Type of Exploitable Foreground ⁶	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application ⁷	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
General Advancement of Knowledge	Passive component printing on plastic capability	NO	NA	Telematic Units	Automotive	2016-2020	-	FICOSA Intrinsiq Materials
General Advancement of Knowledge	Antenna printing on plastic capability	NO	NA	Telematic Units and antennas	Automotive	2016-2020	-	FICOSA Intrinsiq Materials
General Advancement of Knowledge	Electrical parameters and design restrictions of printed patterns	NO	NA	Telematic Units and antennas	Automotive	2016-2020	-	FICOSA Intrinsiq Materials

If the technology developed with this project proves economically competitive, and accepted by automotive OEMS, the foreground developed can be applied to current and future projects, increasing design options and competitive advantages over international competitors, hence increasing probabilities of new contracts, potentially increasing positive business scenarios for both FICOSA and Intriniq materials. Current telematic unit production figures at FICOSA are above 1 Million units produced per year and projected to rise.

Ficosa has commercial activities with all major automotive OEMS and presence in 19 countries in Europe, North America, South America, and Asia. FICOSA uses it's international presence and sales routes to present it's new technologies to all major OEMS. Besides this, future partners of FICOSA will allow to share worldwide sales routes in both the automotive and consumer electronics, maximising sales potential in both markets.

This technology is a product of existing patents from both FICOSA and Instriniq, application to unique patents combining both partners is a topic to be studied.

Further research applicable to FICOSA telematic projects would be related to the adaptation to the interior of the cover, increase in conductivity, and study and analysis of large scale industrialisation and cost analysis in order to lower the final per unit production cost.