- PhD Proposal – Academic year 2023-2024

Enhancing Radomes functionalities and active antennas performances for millimeterwave reconfigurable multibeam solutions using additive manufacturing & flex technologies

Laboratory: Lab-STICC UMR 6285 – www.labsticc.fr

Financial support: Projet PEPR 5G – Financement DGE / BPI France

PhD Supervision:
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Keywords in English: Design and synthesis of multi-beam antennas, active antenna, millimeter antennas, 3D integration technologies, electromagnetic modeling, integrated antennas, electromagnetic coupling, radome, holograms, metasurfaces

1. Context

This project is part of the framework of the Acceleration Strategy on 5G and networks of the future, and more specifically on the development of advanced technologies for 5G systems. Their development induces numerous scientific and technological challenges to be addressed in the coming years. Digital technologies offer the possibility to develop flexible and agile network architectures, with convergence of networks, distributed cloud, sensing structures and advanced applications. Both terrestrial and non-terrestrial systems will cooperate to provide such news services, through interoperability and aggregation of heterogeneous systems, for customers experience benefit. Quality of services, latency, multi-gigabit-per-second data rates, connectivity everywhere as well as energy consumption and environment impact minimization remain key challenges.
Consequently, 5G imposes major technological and architectural innovations, notably radio access based on beamforming for spatial diversity and communication capability. In addition, spectrum resources will be highly solicited for providing enhanced bandwidth over wider frequency ranges, with consequently new expectations regarding millimeter wavelengths.

Development of smart antennas capable of adapting their beams according to the channel within multiple bands requires going beyond conventional antenna design methods, but also to develop an electronic front-end capable of probing the immediate electromagnetic environment and controlling the antenna pattern. Advanced beamforming systems, combined with massive MIMO techniques and intelligent RF front-ends are fundamentally expected and considered as technology breakthroughs.

2. Ambitions for mmwave antennas – Objectives

Exploiting mmWave frequencies for future 5G networks appears as a fundamental ambition, bringing scientific challenges and issues regarding both new design concepts for antennas architectures and technologies toward agile and low power consumption solutions critical for the development of future mmWave communication networks
The main challenges in the millimeter band lie in the design of energy-efficient systems inducing co-designed RF circuits and antennas. The objectives are to create reconfigurable antenna solutions with beamforming and multi-users MIMO capabilities, and to design advanced digital processing techniques to manage these systems.

A high-gain and wideband antennas remain mandatory at mmWave frequencies to exploit efficiently the huge available spectrum. Array solutions including thousands of elements guarantee the required power budget specifications in terms of realized gain and EIRP (Effective Isotopically Radiated Power), as well as sectorization possibilities through individual amplitude/phase controls.

Nevertheless, specific investigations have to be done regarding spatial feeding techniques to achieve extremely energy efficient solutions, while preserving flexibility on multibeam radiation patterns possibilities. In particular, individual amplitude-phase planar array excitation modules have to be ideally suppressed to reduce feeding module losses.

Emerging concepts are addressed by this thesis, considering new combinations of low-profile transmit-array or flat-lens architectures with alternative beamforming approaches exploiting either holographic techniques or artificial beamforming through surface impedance modulations. Indeed, a spatial surface impedance modulation controlled through holographic techniques or metamaterial structuration can be exploited to transform a reference excitation mode to guided surface mode and then to a desired radiation pattern through an appropriate controlled nearfield illumination. A near-field illumination of the planar array can be ensured through 3D multi-materials-based radome-likely functionalities using additive manufacturing, eventually combined with flexible technologies to report tuning components for holographic mode control.

3. Methodology - Study approach

- First, an analysis of the literature will be done to position the subject in the context of millimeterwave antenna arrays, in particular with a specific attention to the generation of multiple beams, and the co-integration capacity of MIMO (Multiple Input-Multiple Output) solutions. The work will also aim to identify competing solutions such as RIS structures (Reconfigurable Intelligent Surfaces), and to assess the potential of hybrid approaches based on holographic techniques.

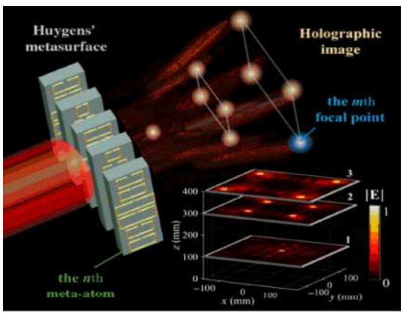
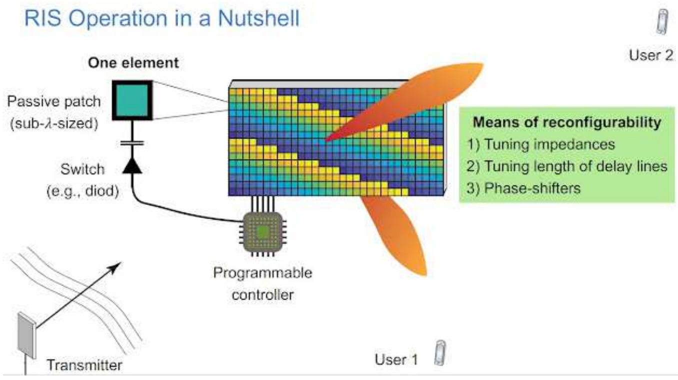


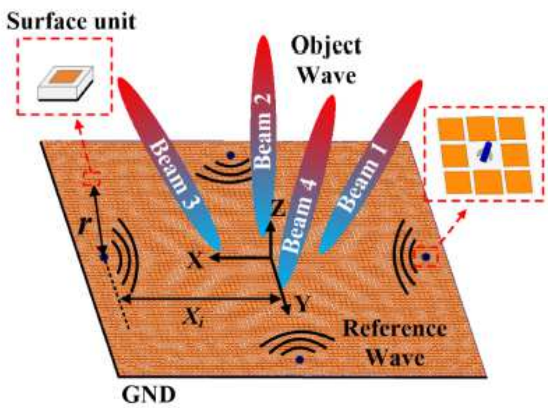
Illustration of Holographic techniques through Huygens Metasurfaces [1]



Communications Using Intelligent Reflecting Surfaces in B5G & 6G [2]

- Secondly, the effective contribution of radomes regarding conventional beam control systems will be studied. In particular, reconfigurable radome structures illuminated by a set of primary sources will be developed. The radome is likely either to act first as a guiding structure allowing the development of a directive high-gain antenna, with main-beam deviation capabilities or not. We will investigate on technological solutions and innovative topologies, in particular on the basis of flexible technologies and/or 3D printing approaches [6, 7], with the presence of dielectric/metallic/electronic structures making it possible to locally parameterize the signal in transit

- Thirdly, the generation of multiple beams, with the idea of generating multiple beam shapes by hologram reconstruction, will be addressed [3, 4, 5]. Questions regarding the generation of holograms will be examined, with again the analysis and optimization of the radome structure to contribute to this multi-spots construction. We will be able tom compare the advantages of using a near field surface controled radome with respect to holographic impedance modulated surface (HIMS) [5].



Holographic impedance modulated surface (HIMS) [5]

The work could be initiated on the basis of a projection of a first hologram controlled by a set of primary sources to generate a directional beam then a double-beam for example, before switching to a multidirectional system.

The challenge lies on the capabilities to control amplitude and phase near-fields distributions through appropriate radome structuration (composed of either dielectric/metallic structures but also active components).

References:

[1] Guanyu Shang, Zhuochao Wang, Haoyu Li, Kuang Zhang, Qun Wu, Shah Nawaz Burokur and Xumin Ding, "Metasurface Holography in the Microwave Regime", Photonics 2021, 8, 135. https://doi.org/10.3390/photonics8050135

[2] Emil Björnson, KTH university, https://github.com/emilbjornson/presentation_slides/blob/master/IRS_fundamentals.pdf

[3] Kuang Zhang et al, "Experimental validation of active holographic metasurface for electrically beam steering", Vol. 26, No. 5 | 5 Mar 2018 | Optics Express 6316

[4] Adrian Sutinjo, Michal Okoniewski and Ronald H. Johnston, "A Holographic Antenna Approach for Surface Wave "Control in Microstrip Antenna Applications", IEEE Transactions on antennas and propagation, Vol. 58, No 3, March 2010

[5] Huan-Huan Lv , Qiu-Lin Huang , Jin-Lin Liu , Jian-Qiang Hou and Xiao-Wei Shi, "Holographic Design of Beam-Switchable Leaky-Wave Antenna", IEEE Antennas and wireless propagation letters, Vol. 18, No 12, Dec. 2019

[6] Julien Haumant « Conception de composants hyperfréquences en plastique métallisé » - mars 2021, PhD Dissertation, Brest

[7] https://formlabs.com/blog/electroplating-3d-printed-parts-high-performance-antennas/

Candidacy:

Skills: Electromagnetism, Filter & Antennas – RF Design, High Frequency CAD, 3D Additive Printing Technologies

Theoretical skills: Solid background in one or more of the following domains: Theoretical and computational electromagnetics, Microwave and mm-wave antennas & components, 3D additive manufacturing techniques

Technical skills: Experience in one more or more of the following technologies/tools: CAD Tools (HFSS™, CST™, etc..), Matlab™, Python™

Profile required: Holder of a postgraduate diploma, Master of research or engineer diploma in the domains of physic, Electromagnetisms, Antennas, high frequency components design.
Fluency in English is required, a spirit of collaboration and of initiative in the face of technological challenges.

Intended starting date Dates: October 2024 or before – Duration 36 months

Modalities / How to apply:

Candidates are invited to email to Christian Person (christian.person@imt-atlantique.fr) the following elements:

- CV detailing in full your academic background including all modules & lectures
- Motivation letter
- Academic notes transcript

and optionally, letters of recommendation

Context of the thesis / Location

The research activities will be done thesis is done in the context of the laboratory Lab-STICC – UMR CNRS 6285 at IMT Atlantique (Engineering School).

The selected student will also be associated to other activities of the research group: group meetings, seminars, social events

In detail, the hosting facilities for the thesis is described below:

Establishment: **IMT Atlantique Bretagne/Pays de la Loire** (Brest campus), a high graduate engineering school (postgraduate): www.imt-atlantique.fr

Laboratory: **LabSTICC**/DH Team : https://www.labsticc.fr/en/index/

Contact

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