Politecnico Di Torino
Department of Electronics and Telecommunications Engineering

PhD Program in Electrical, Electronics and Telecommunications Engineering

# Thesis Abstract

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**Thesis Title:** Bi-anisotropy, Non-Locality and Theory of Electromagnetic Multipoles for High Performance Smart Electromagnetic Skins (SES)

## Abstract

Physical layer of 6G systems is envisaged to provide communication, sensing, localization and computing in a programmable and cooperative Smart Radio Environment (SRE). This requires ultra-broadband connectivity, low latency and seamless coverage. Sub-THz/mm-wave bands have the potential to achieve these goals. Although it meets the performance requirements but it suffers from major draw-backs of strong free-space attenuation, high building penetration loss, strong features interaction during propagation and strongly degradation in coverage outside Line-of-Sight of Base Station (BS) antenna. For an implementation that maintains low complexity, environmental sustainability, and operational efficiency, adding new BSs to the SRE is not feasible. To overcome this drawback and as an alternative to BSs, suitable, *ad-hoc*, active and passive devices, collectively referred to as Smart Electromagnetic Skins (SESs) can be introduced.

SESs provide a cost-effective and efficient alternative to increasing the number of BSs to improve the performance of next-generation communication networks and concurs to the implementation of SREs. SES can be seen as a generalization of the concept behind a ReflectArrays (RAs), as they are generally designed to redirect the incident field in a direction that is not specular with respect to the direction of incidence. As the diversity between the pointing direction and the direction specular to the incident field increases (commonly referred as high deviation angle scenario), specular and parasitic radiations arise, which affect the radiation pattern, energy efficiency, and pointing direction of SESs. Parasitic radiations can also arise in high deflection angle scenario (large difference between incident and pointing direction) which increase the count of possible mode coupling channels. The techniques generally adopted for SES design, such as phase gradient or meta gratings that are based on homogenized-effective-medium model, are unable to overcome this drawback efficiently. Efficiency of phase gradient method reduces with increasing deviation angle and meta grating method is in-efficient in parasitic modes suppression in high deflection angle scenarios.

In this work, SES designs using multi-resonant bi-anisotropic unit cells based on the array phase method are utilized which suppress parasitic radiations with wide bandwidth and good pointing direction accuracy but are unable to overcome issue of parasitic radiations efficiently as angular differences increase. An innovative inverse unit cell topology is introduced that

exhibits a novel hybrid bianisotropic response, arising from the structural inversion of conventional unit cell topology. It consists of a fully metallic top layer with an aperture with suitable shape, showing inside one or more further metallization. The proposed configuration then gives rise to a concurrent omega-type and chiral-type bianisotropic coupling within a single planar unit cell, without requiring 3D structure or mirror asymmetry or geometric handedness. This hybrid bianisotropic behavior, not previously reported in the literature, outperforms conventional unit cell in parasitic radiation suppression in high deflection angle cases, however it is not as effective in high deviation angle scenario. Bi-anisotropic unit cells using Phase Gradient (PG) effectively overcome specular radiations for high deviation angle scenario but do not address non-specular parasitic radiations.

To address this second problem, another solution is proposed using Theory of Electromagnetic Multipoles, which defines radiation mechanisms of a structure by considering the role of volumetric charge-current distributions and Toroidal Dipoles (TDs) in addition to conventional Electric Dipoles (EDs) and Magnetic Dipoles (MDs). Starting with initial SES design based on the Phase-Gradient (PG) approach, formation of TDs and anapole is demonstrated for first time ever in an SES/RAs. By combining both local and non-local approaches in super-cell design, higher-order symmetry-breaking of unit cells and the addition of a MD is utilized to exploit anapole formation as a parasitic mode suppression method. This enables incorporating bi-anisotropy with both local and non-local characteristics within a single gradient period, to convert the PG super-cell into a composite meta-molecule. Numerical analysis of SESs with increasing size confirms the effectiveness of the proposed approach, which allows for a drastic reduction in parasitic modes while leaving the performance of the desired mode unchanged. Adopting a multipole perspective enhances understanding of the radiation mechanisms of SESs, unlocks their latent performance potential, and opens new opportunities for multifunctional design.