Near-Field Metallic Metasurfaces
for High-Performance Antenna Systems

by

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DOCTOR OF PHILOSOPHY

under the supervision of **Distinguished Prof. Karu P. Esselle**

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Certificate of Original Authorship

I, *Foez Ahmed*, declare that this thesis is submitted in fulfilment of the requirements for the award of *Doctor of Philosophy*, in the *School of Electrical and Data Engineering*, *Faculty of Engineering and Information Technology* at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Abstract

The massive demand for data rates aggravated the situation when the Coronavirus Disease 2019 (COVID-19) pandemic forced everything online. To support data-hungry wireless devices and applications, high-speed data connectivity is indispensable. Cost-effective low-earth-orbit (LEO) satellite links promise a dependable, robust, and viable solution for seamless high-speed internet connectivity, even where terrestrial technologies are ineffective. High-gain beam-steering antennas are the most crucial and costly radio-frequency (RF) technology for mobile satellite communications. Metasurface-driven antennas may offer an affordable alternative, but existing approaches often employ heavy or expensive dielectric-based metasurfaces. The weights and RF losses of dielectrics make them less attractive for practical applications. Also, they are not preferable in space due to environmental challenges (e.g., carbonization, high radiation, and cryogenic temperature). In high-power microwave systems, they can lead to dielectric breakdown. Metasurfaces built on all-metal architecture could be potential substitutes, but there is limited research, and many opportunities are yet to be explored.

The research efforts in this thesis focus on the innovative design strategy of metallic metasurfaces (MMs). The proposed approaches adopt new techniques to synthesize entirely dielectric-free, self-sustained, polarization-independent, and fabrication-friendly MMs, significantly reducing the weight and cost of low-loss dielectrics. The novel slots-in-sheets (SiS) architecture proposed in constructing MMs retains structural rigidity – a distinctive design feature from the state-of-the-art. Several antenna designs have been analyzed and tested experimentally to evaluate the efficacy of the proposed solutions. First, novel MMs are synthesized to correct the aperture near-field phase non-uniformity of shortened horns and resonant cavity antennas. The study also explains wideband gain-bandwidth improvement employing MMs thoroughly. Then, the potential research gaps are addressed by developing an entirely new dual-band phase-correcting MM and ultra-thin, single-layer dual-band metallic partially reflective surface for the first time. Secondly, the research tackles the design challenges of phase gradient MMs compatible

with the near-field meta-steering (NFMS) system. First, a wideband NFMS system with measured scanning bandwidths of at least 700 MHz is demonstrated. Further research advances the field significantly by developing a novel dual-band NFMS system of its first kind operating in full-duplex simultaneously. A methodology has been devised to design compact dual-band cells with greater freedom in tuning parameters to attain complete 360° phase shifts with excellent transmission efficiency.

Overall, the proposed antennas radically depart from traditional dielectric-based metasurfaces and exhibit excellent performance, making them expedient for modern satellite communications. They are also contenders for many cutting-edge applications, including high-power systems and deep space exploration.

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Dedication

To My Parents and Wife

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