Software-Defined Metasurfaces: The VISORSURF Project Approach

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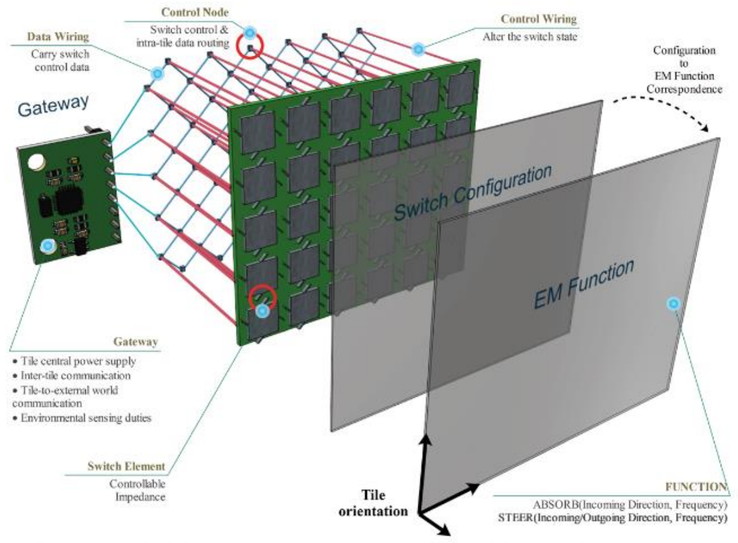
Introduction

We present the concept and electromagnetic aspects of Hypersurfaces (HFSs), artificial, ultrathin structures with software controlled electromagnetic properties. The HFSs key unit is the metasurface, a plane with designed subwavelength features whose electromagnetic response can be tuned via **voltage-controlled continuously-tunable electrical elements** that provide **local control of the complex surface impedance** and advanced functionalities, such as tunable perfect absorption and wavefront manipulation. A **nano-network of controllers** enables software defined HFSs control related to the emerging Internet of Things paradigm.

The Visorsurf project

METASURFACE HYPERVISOR

A Hardware Platform for Software-Driven Functional Metasurfaces



"To control electro-magnetic interaction via software"

Objectives..

- Design, build and demonstrate **software-defined metasurfaces (SDMs)** that achieve **end-to-end** functionality
- **Analyze** and **extend** each H/W and S/W layer of the SDMs
- Develop **technologies utilizable** by applications and services

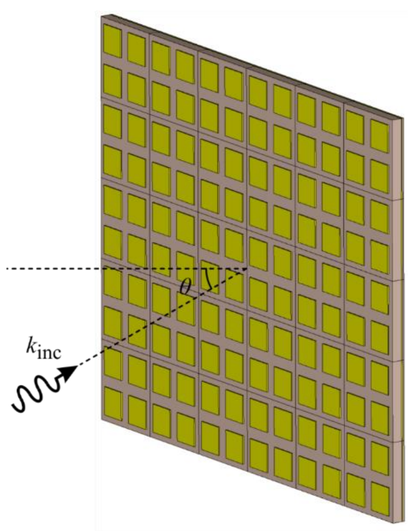
A novel hardware platform (prototype) for software programmable metasurfaces, named Hyper-Surface (HSF)

➢ combines classic **metasurfaces** with small-scale, networked electronic controllers, commonly referred to as **nanonetworks**

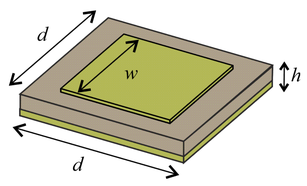
➢ software-defined HSFs naturally provide **adaptive** electromagnetic behaviour

Enables the translation of advanced concepts of Physics in software

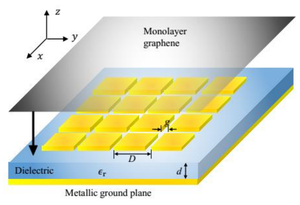
The Metasurface Unit Cell Prototypes



Switch fabric metasurface (GHz)

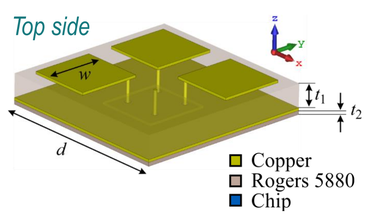


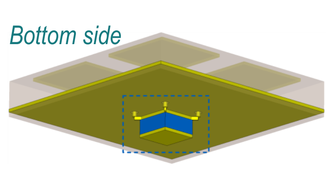
Graphene-based metasurface (THz)



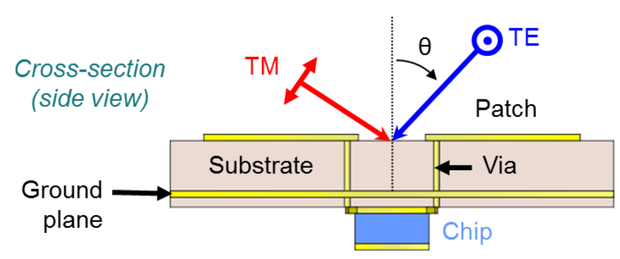
Contoller (chip intergration)

- **Metasurface unit-cell:** 2x2 metallic patch, metal-backed
- **Chip**: **voltage-controlled microwave network** (an IC) supplying the desired complex impedance values (both *R* and *C*) at its output ports
  - Frequency band: 4-6 GHz
- Chip ports **connected** to unit-cell patches **using through vias**
  - Via position is critical
  - Chip "behind" the ground plane





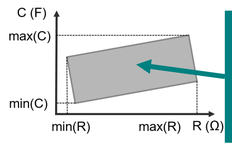
Decoupling of metasurface & chip (design and operation)



Continuous complex-impedance tuning

- Chip = **varistor** (R) & **varactor** (C) fine-tuned by two voltages
  - **Range limits:** Frequency, dimensions, parasitics, fabrication (technology)

Finite RC area → *Finite Tunability*

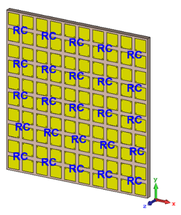


Optimize unit-cell (metasurface-side) for given tuning range

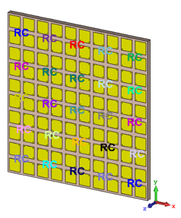
Global and local tuning

- Chip-network provides the **same or different** RC values in each unit-cell → **local or global tuning** of the metasurface response

Global tuning



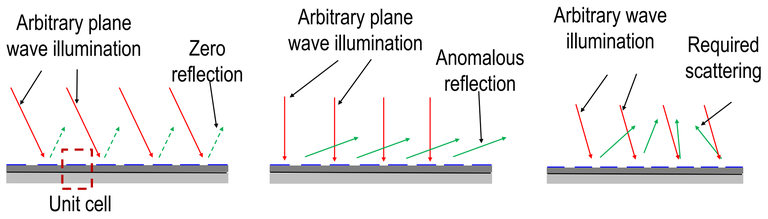
Local tuning



Tunable Electromagnetic Functions

The response of the metasurface depends on the impinging wave, that is, ***frequency, polarization, angle of incidence***; for a given wave it is adjusted by the controller chip to provide the requested electromagnetic function:

- ❑ Tunable perfect absorption for different incidence angles
- ❑ Tunable anomalous reflection
- ❑ Tunable scattering (focusing, beam splitting, etc)



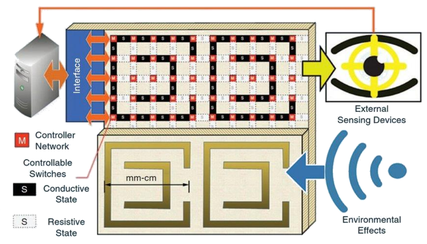
- Zero reflection
- Near-unity reflection
- Wide phase span
- Free control of reflection amplitude and phase

Each function deployed in the same metasurface on demand by programmatic control

HyperSurface software aspects

- **Software-Defined Metasurfaces** are structures whose properties can be **programmatically controlled**: Reprogrammed, adapted.
  - Interface w/ computer
  - Intergrated Controllers
  - External stimuli sensors (incident wave sensing, feedback)
  - Network / interconnections

Internet of Materials

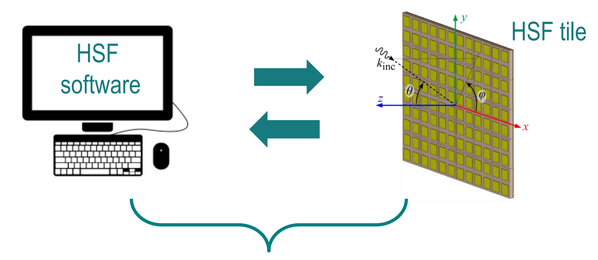


Basically, two modules:

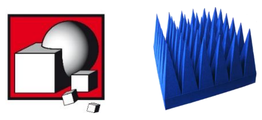
- **API** (Application Programming Interface)**:** What a (non-specialist) end-user employs to interact with a HSF.
  - For all practical purposes: a GUI.
  - **Compiler:** Translates high-level requests to controller (chip) directives
    - ❖Software provided by the HSF designers
    - ❖Relies on database and acceleration/optimization algorithms

Deployable to both simulated & fabricated ("real") prototypes

- **Simulated:** Software hooked on a computer cluster
- **Fabricated:** Software hooked on automated measurement setup



Simulated model (e.g. on CST)



Actual device (e.g. in anechoic chamber)

Selected publications

- F. Liu, O. Tsilipakos *et al.*, "Intelligent metasurfaces with continuously tunable local surface impedance for multiple reconfigurable functions", Phys.Rev. Appl., vol. 11, 044024, 2019.
- O. Tsilipakos, F. Liu, *et al.*, "Tunable Perfect Anomalous Reflection in Metasurfaces with Capacitive Lumped Elements", in *Proceedings Metamaterials 2018*, pp. 392-394.
- A. C. Tasolamprou, A. Pitilakis, *et al ., "*Exploration of intercell wireless millimeter-wave communication in the landscape of intelligent metasurfaces", IEEE Access, vol. 7, pp. 122931-122948, 2019.
- F. Liu *et al.*, "Programmable metasurfaces: State of the art and prospects, in *IEEE International Symposium on Circuits and Systems (ISCAS) 2018*.
- S. Abadal *et al.*, "Computing and Communications for the Software-Defined Metamaterial Paradigm: A Context Analysis", IEEE Access, vol. 5, pp. 6225–6235, 2017.

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