Towards Dual-band Reconfigurable Metasurfaces for Satellite Networking

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LEO Satellite Communication

Low Earth orbit (LEO) satellite networks (LSNs) aim to provide global low-latency connectivity

2200 satellite as of May 2022

600 satellite as of Feb 2019

1600 satellite as of May 2022

LEO SatCom has various challenging use cases

Complex beam-alignment, tracking, and handover

Transportation

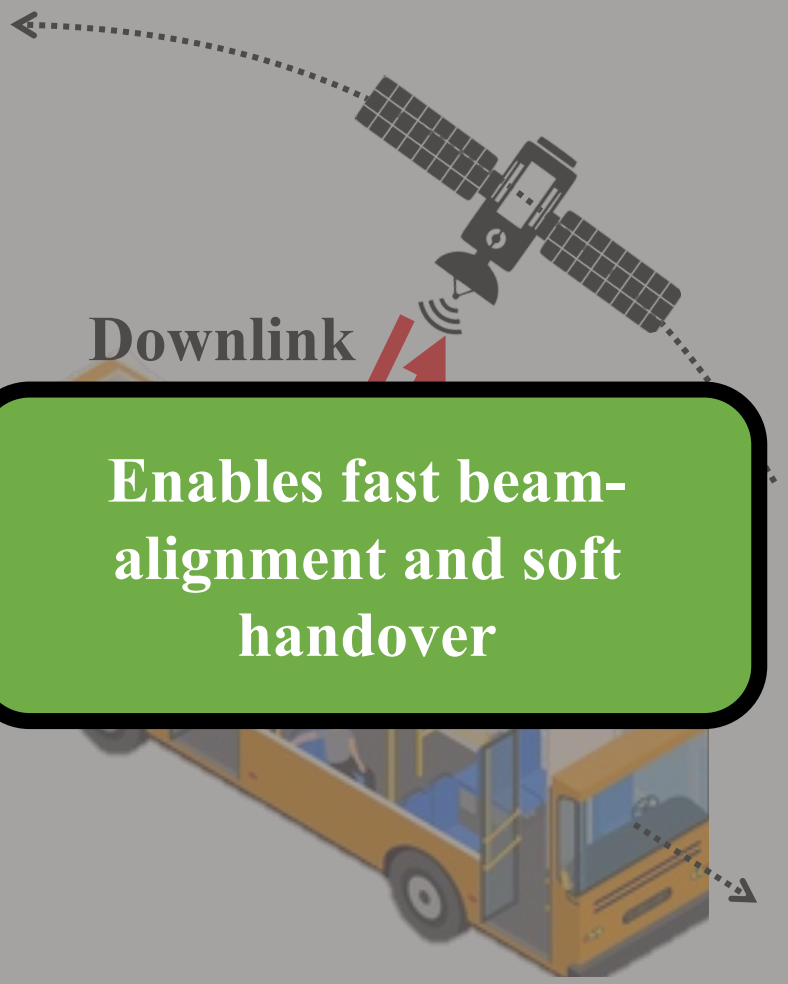
LoS blockage

Urban Canyon

Requires power consuming and expensive antenna dish

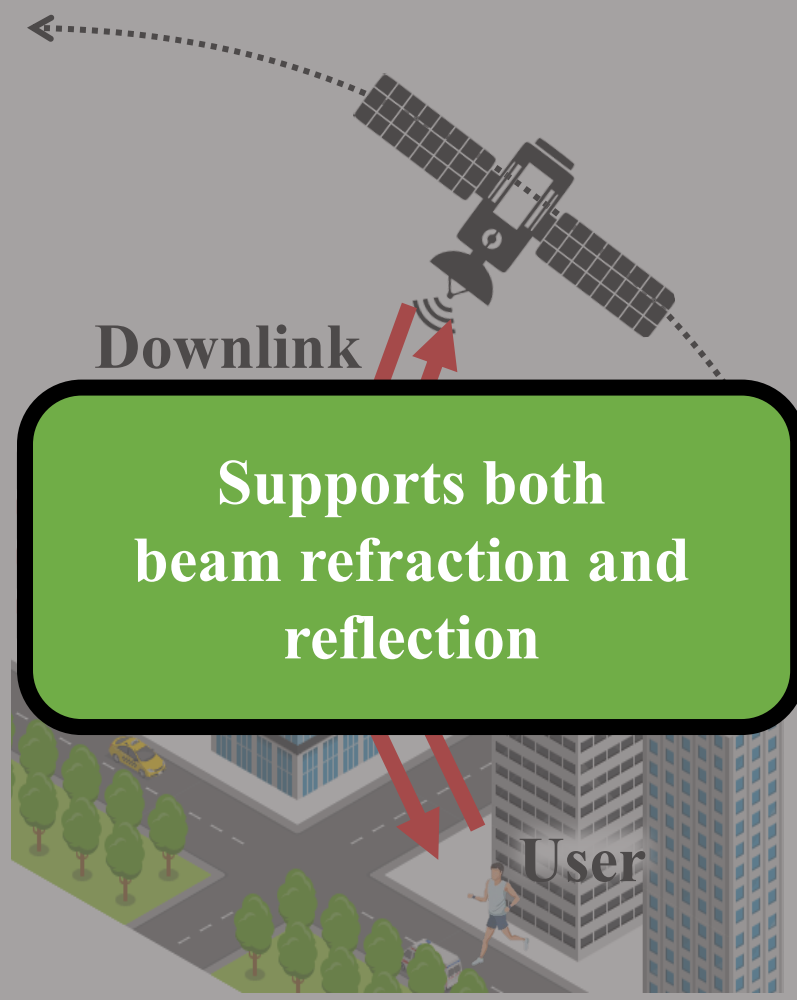
Rural

Our solution: intelligent reconfigurable surfaces



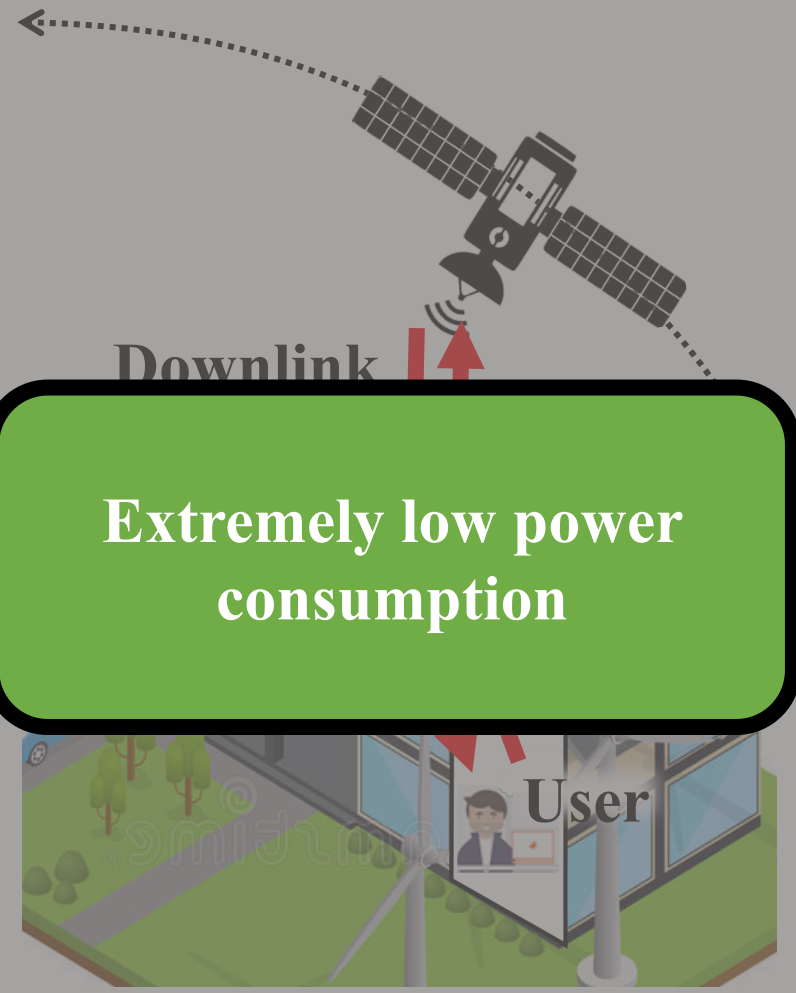
Enables fast beam-alignment and soft handover

Transportation



Supports both beam refraction and reflection

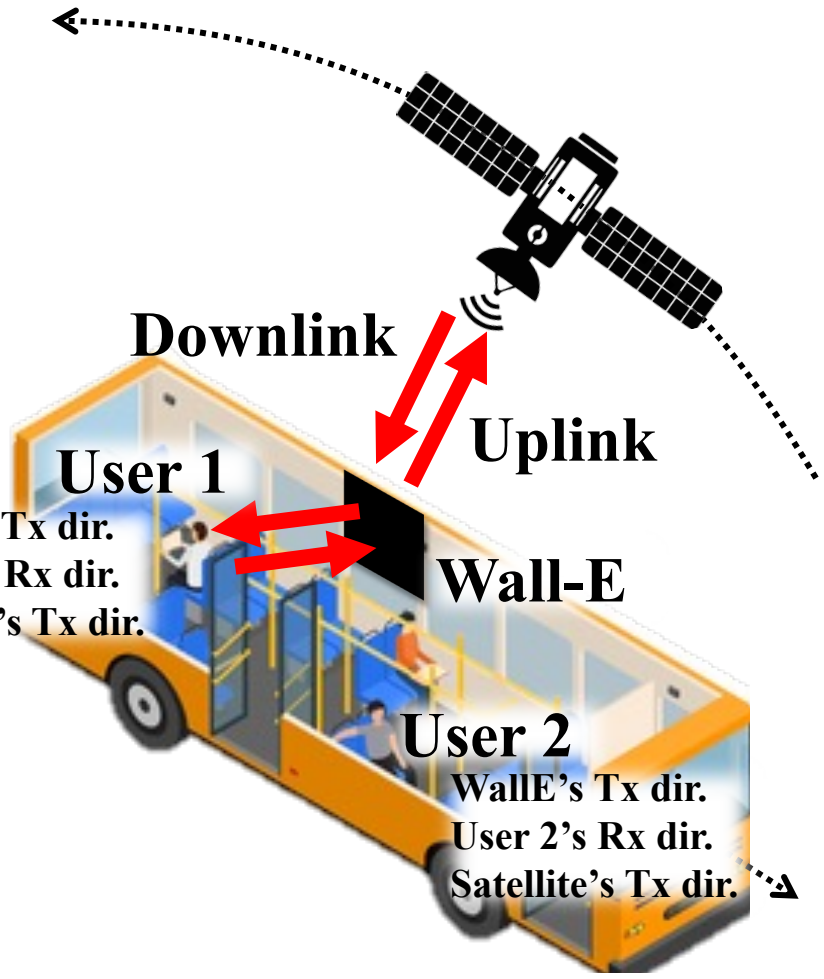
Urban Canyon



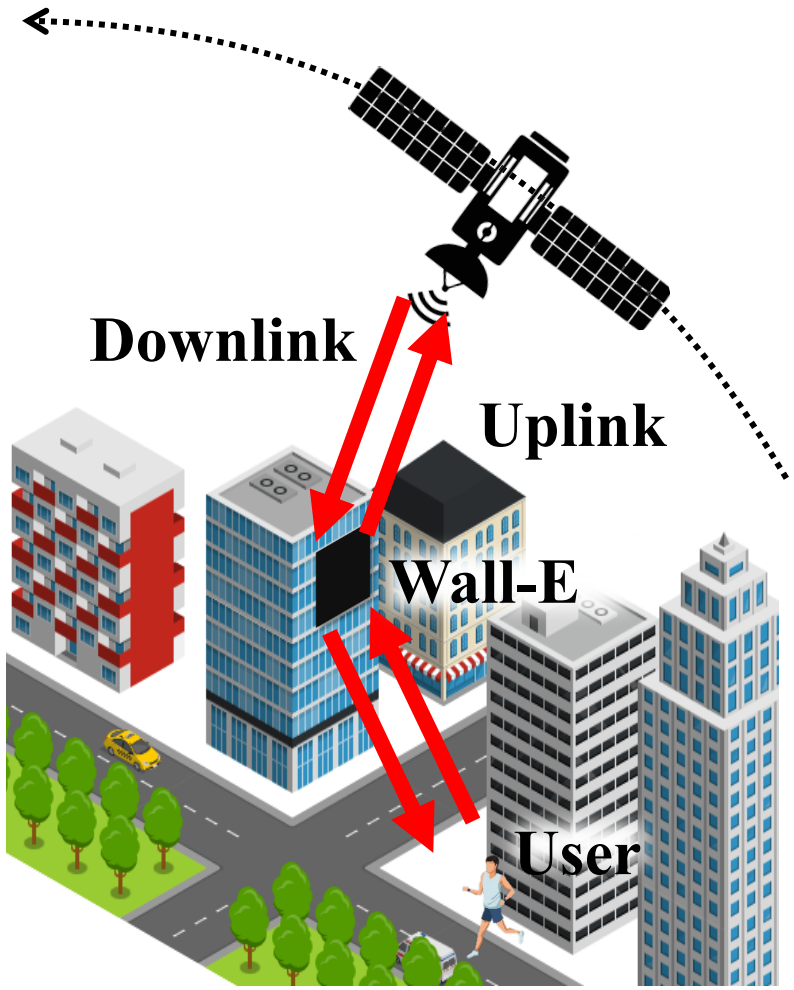
Extremely low power consumption

Rural

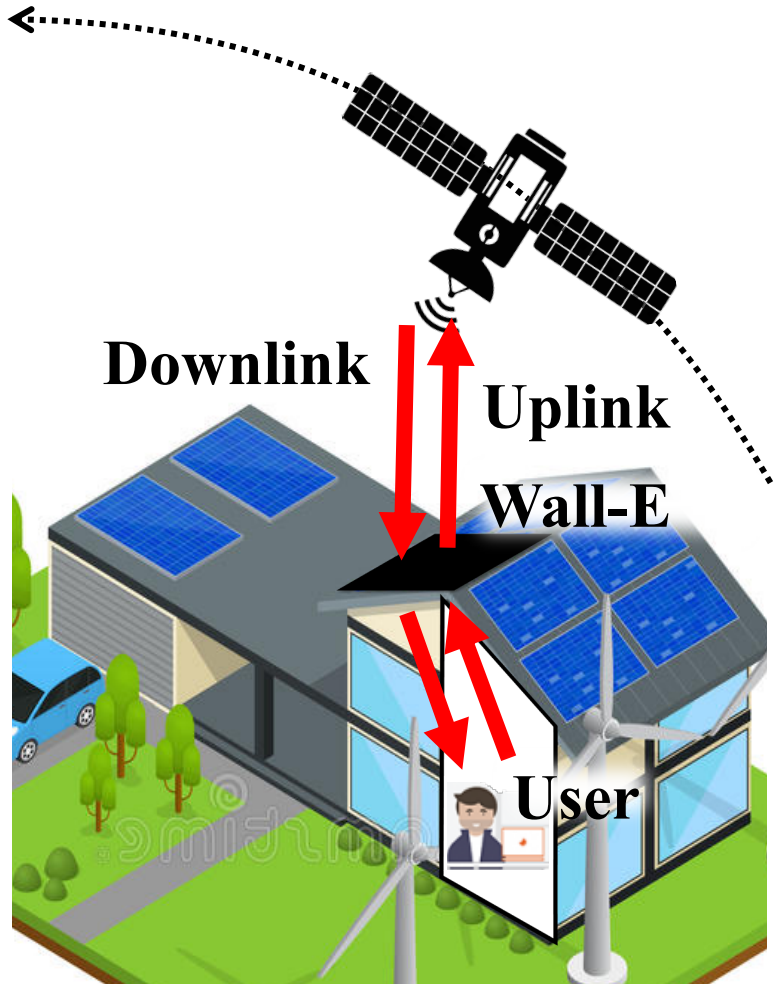
Our solution: intelligent reconfigurable surfaces



Transportation

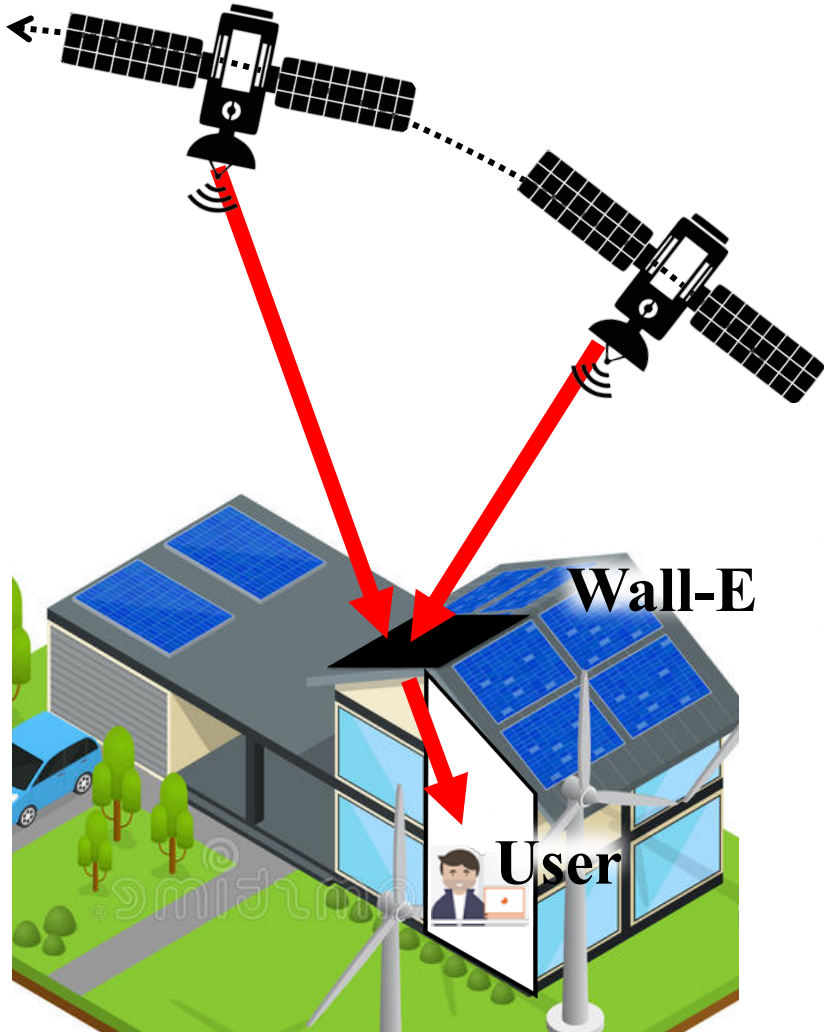


Urban Canyon

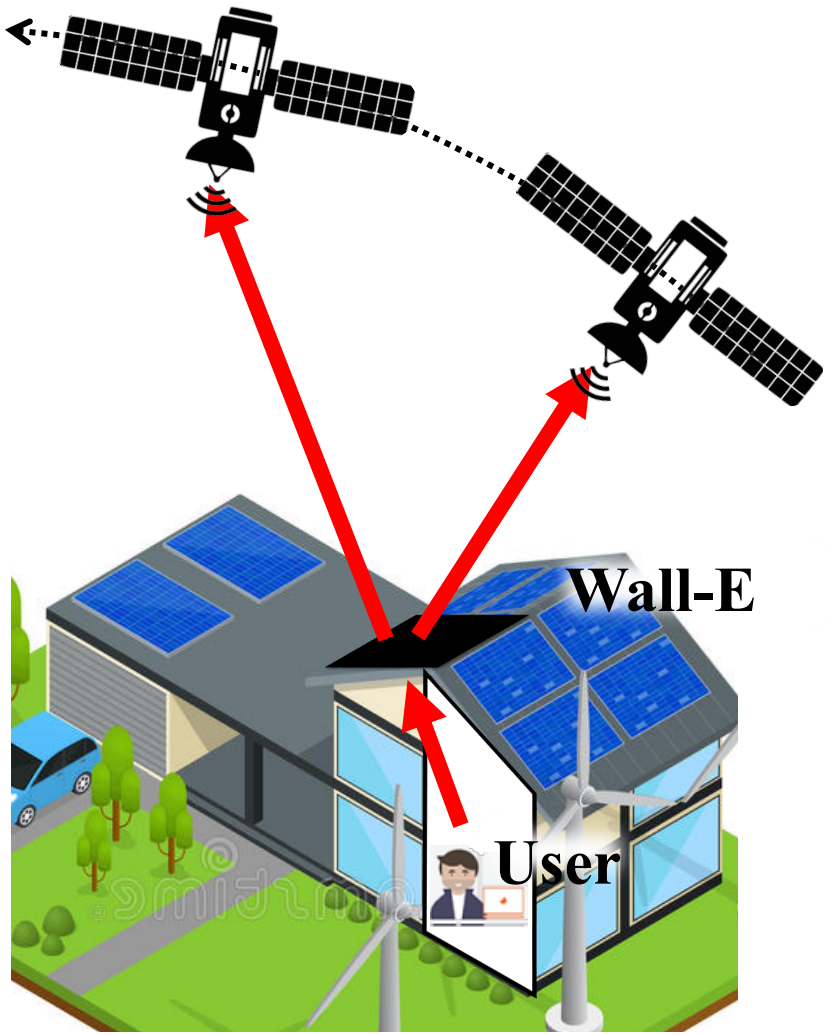


Rural

Enhancing Satellite-Satellite Handover

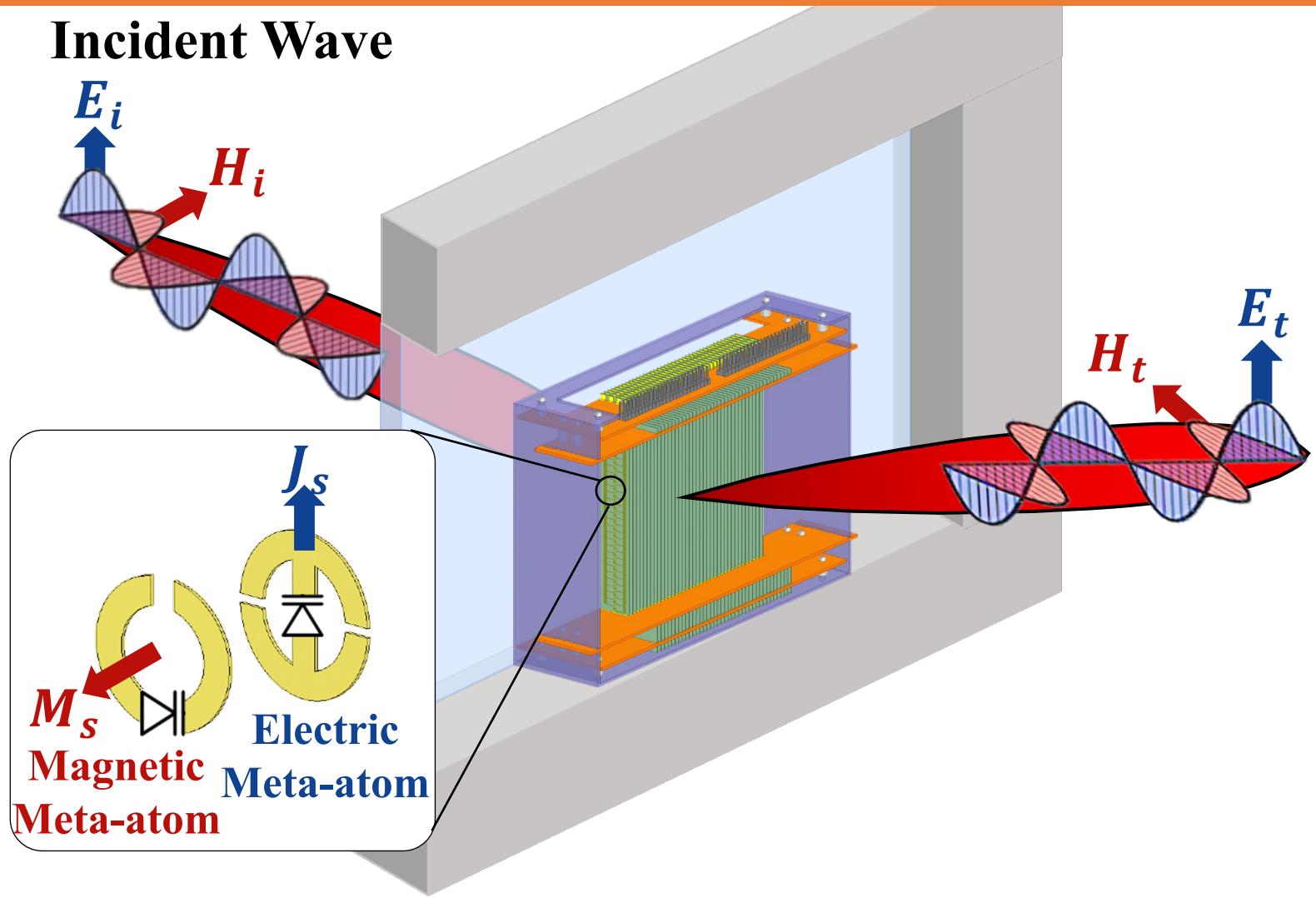


Beam Combining



Beam Splitting

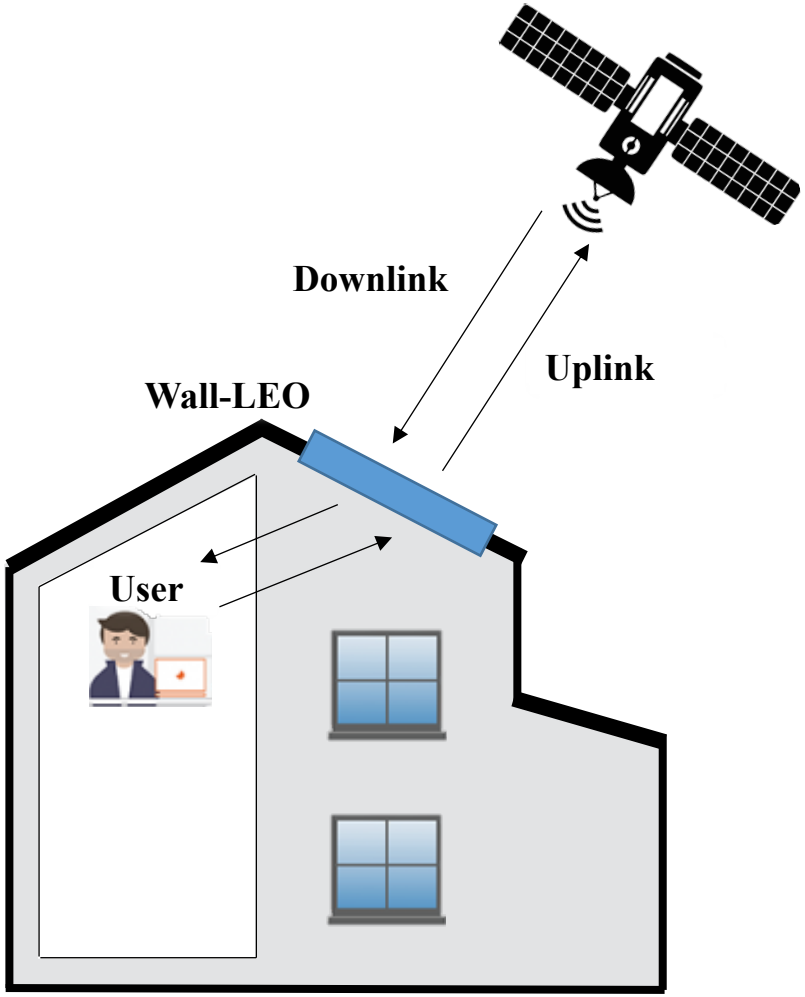
Principle: Huygens Metamaterial Surfaces [1,2]



But: Unit cells **resonate at only one frequency!**

[1] Cho, Kun Woo, et al. "mmWall: A Steerable, Transflective Metamaterial Surface for NextG mmWave Networks." *20th USENIX Symposium on Networked Systems Design and Implementation* (NSDI'23).
[2] Cho, Kun Woo, et al. "mmWall: A reconfigurable metamaterial surface for mmWave networks." *Proceedings of the 22nd International Workshop on Mobile Computing Systems and Applications*. (HotMobile'21).

However, LEO uses FDD communication



Surface has to work at both Lower Ku + Upper Ku !

	Downlink Frequency	Uplink Frequency
Starlink (Ku+Ka Constell.)	**Lower Ku (10.7 – 12.7 GHz)**	**Upper Ku (14 – 14.5 GHz)**
OneWeb (Ku+Ka Constell.)	Lower Ku (10.7 - 12.7 GHz)	Upper Ku (12.75 - 14.5 GHz)
TeleSat (Ka Constell.)	Lower Ka (17.8 - 20.2 GHz)	Upper Ka (27.5 - 30 GHz)

How to design a surface for FDD?

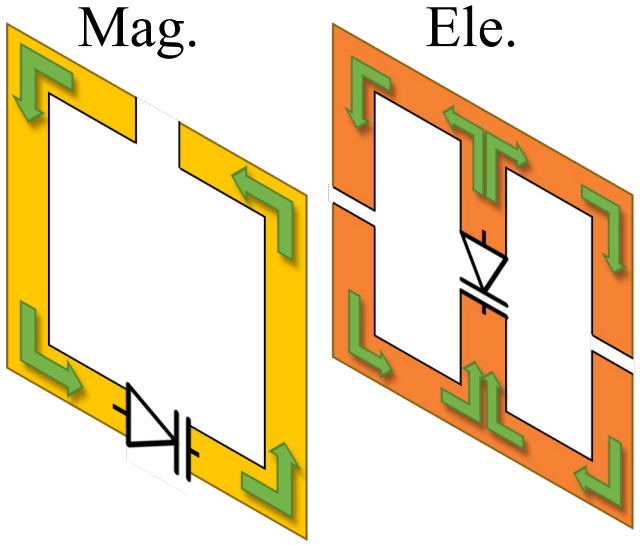
1. Two single-band RISs (one for uplink and one for downlink)
   → demands **separate beam training**, doubling the overall delay

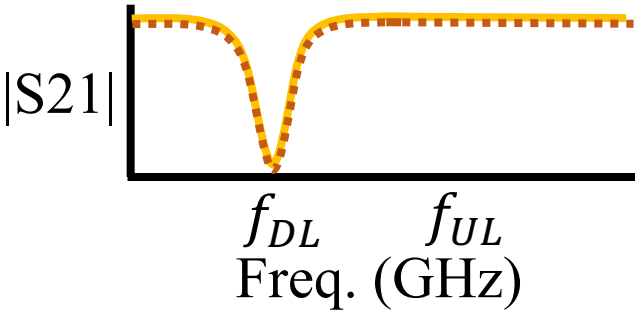
2. **Partitioning the surface** into two subsets, each resonating at a different frequency
   → useful surface elements **halved,** reducing directivity gain

3. **Challenge: Designing a bi-resonant surface element**

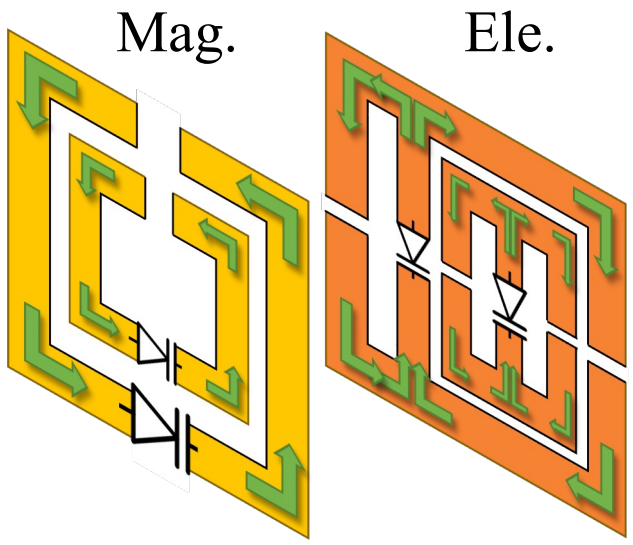
Strawman attempt #1: More varactors

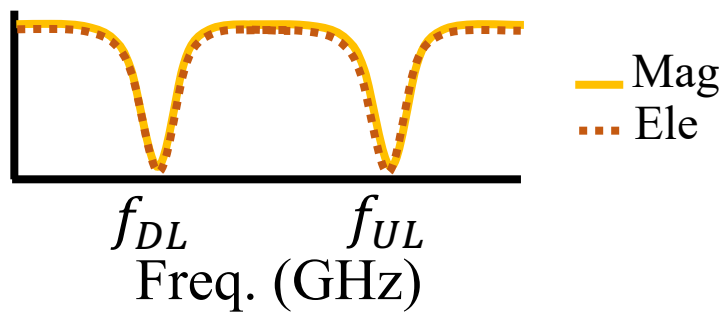
Single-band



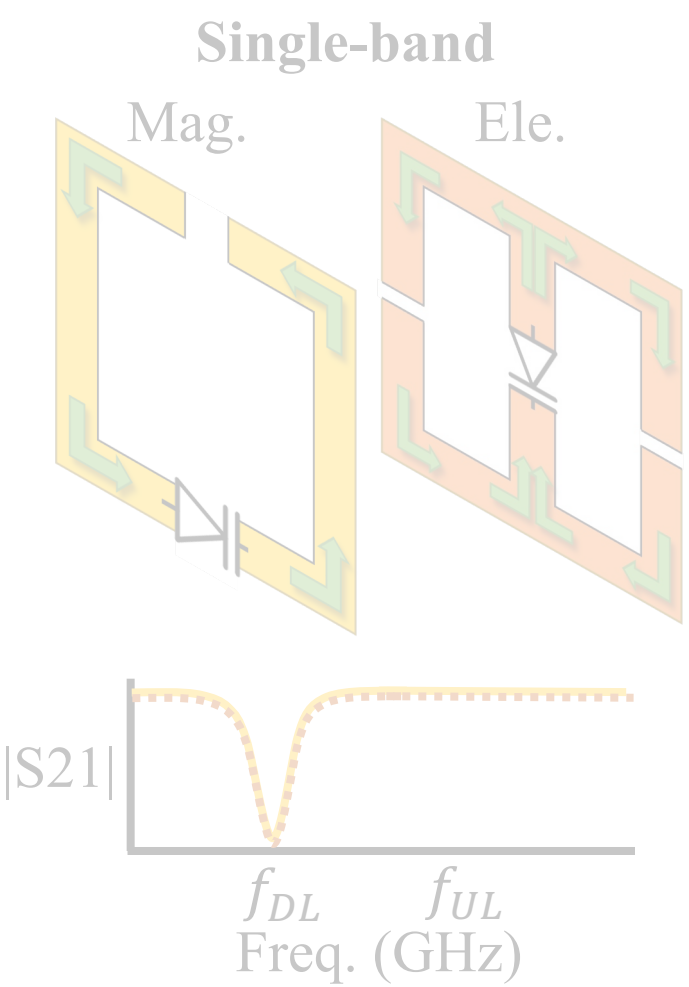


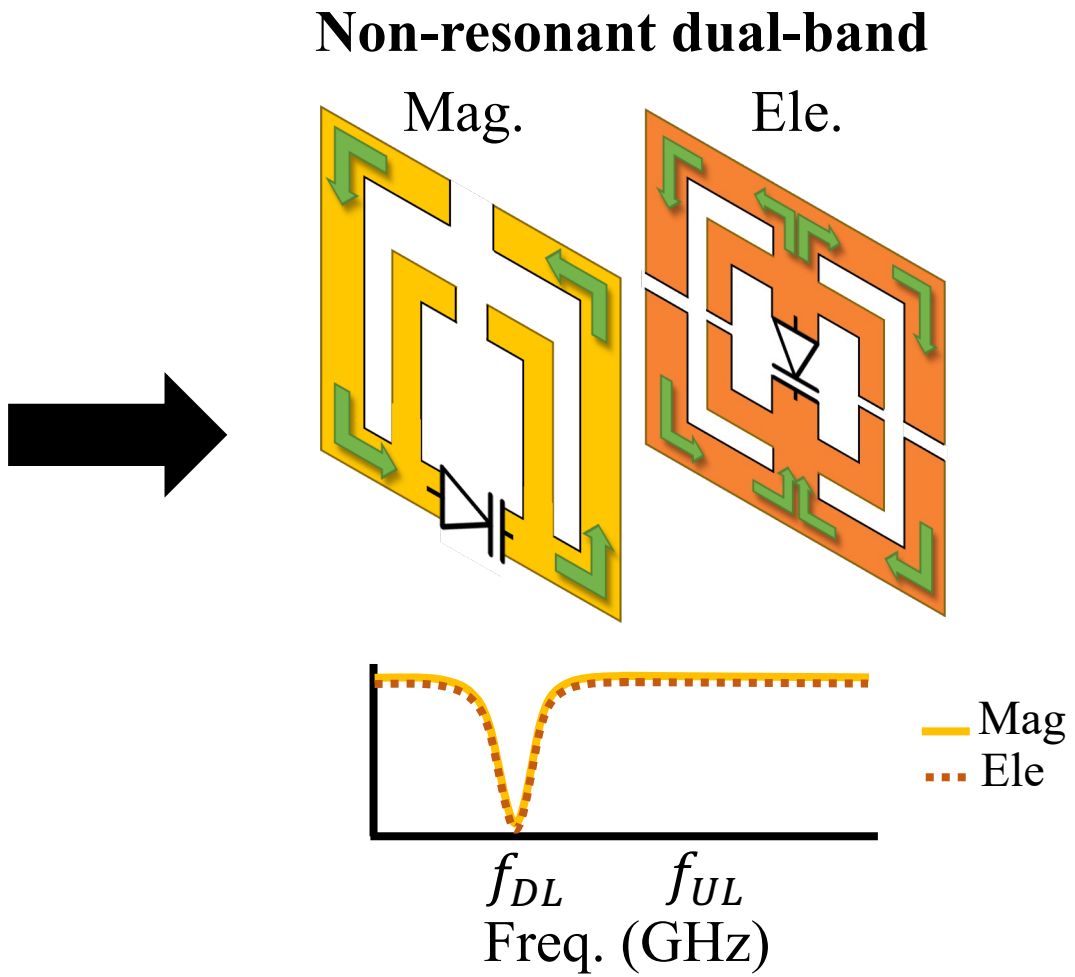
Dual-band w/ varactors





Strawman attempt #2: Overlapped rings

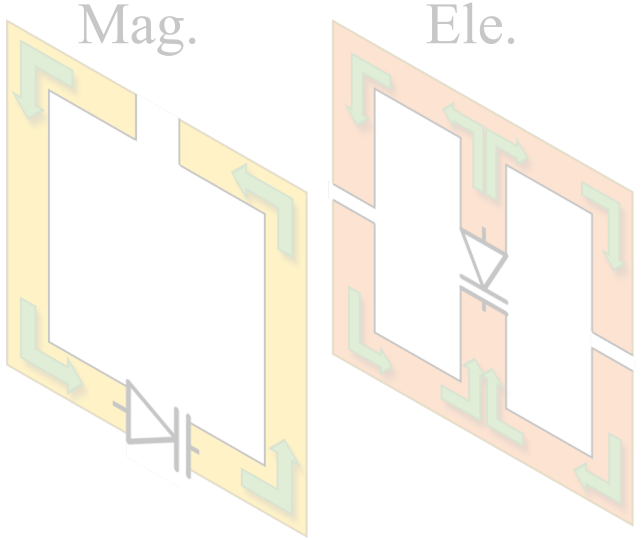


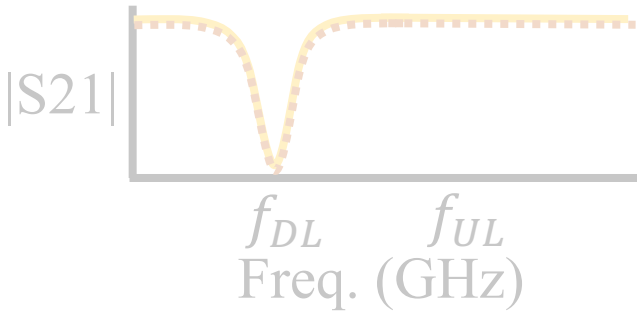


Strawman attempt #3: Inductors to Isolate

Single-band

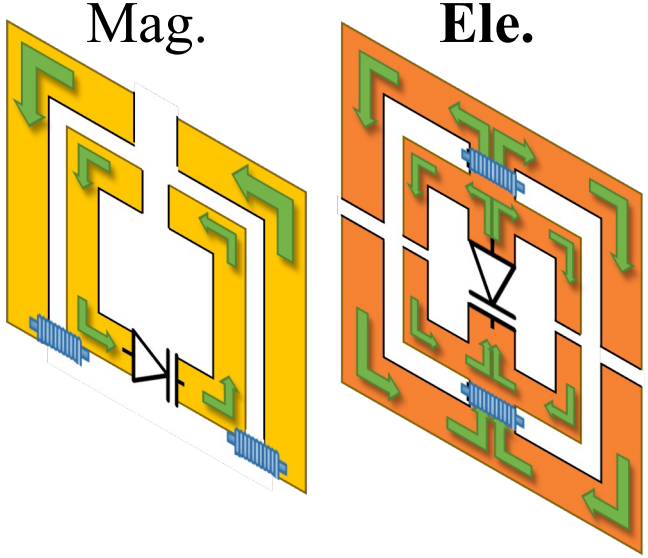
Mag. Ele.

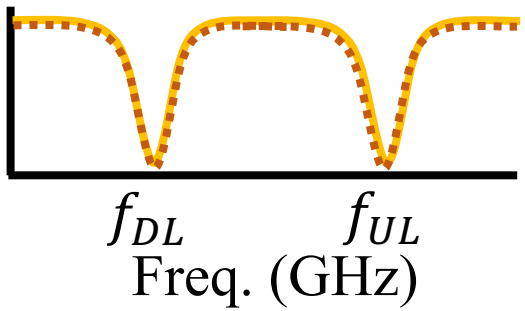




Dual-band w/ inductors

Mag. **Ele.**



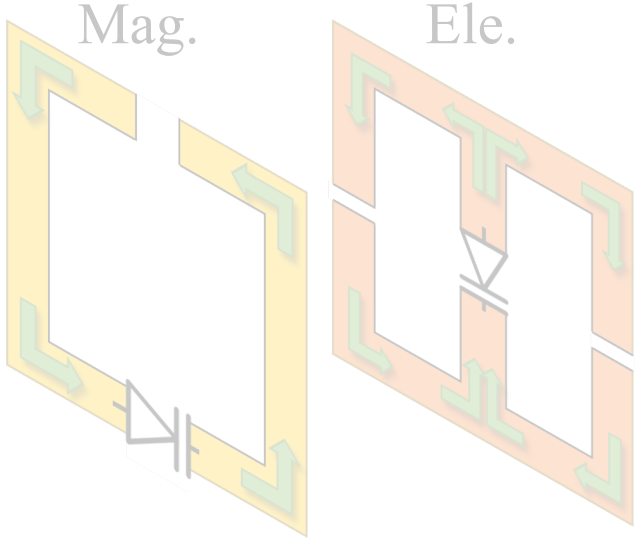


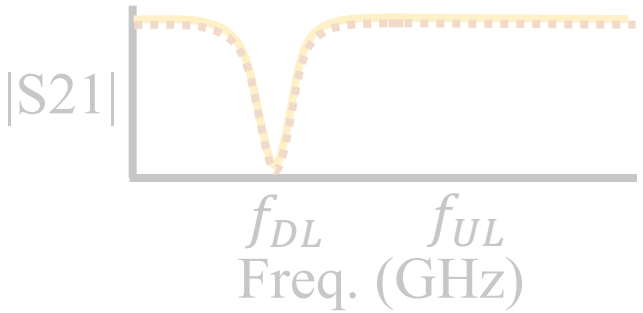
Strawman attempt #4: Meanders to Isolate

Single-band

Mag.

Ele.

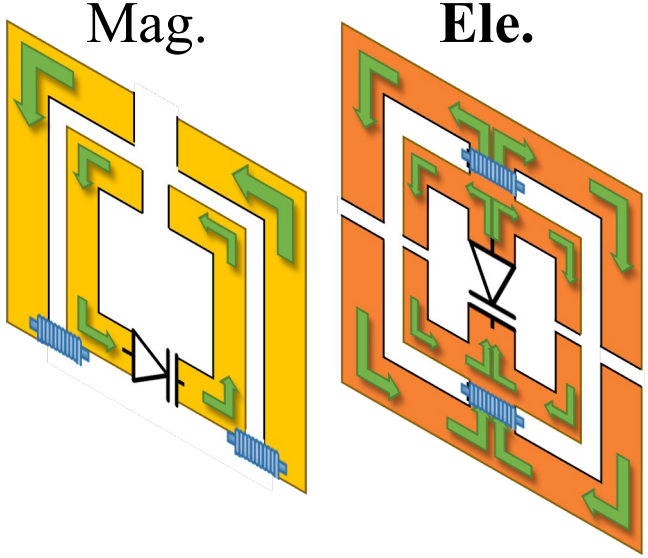


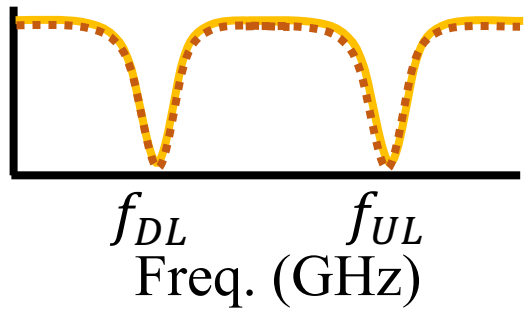


Dual-band w/ inductors

Mag.

Ele.

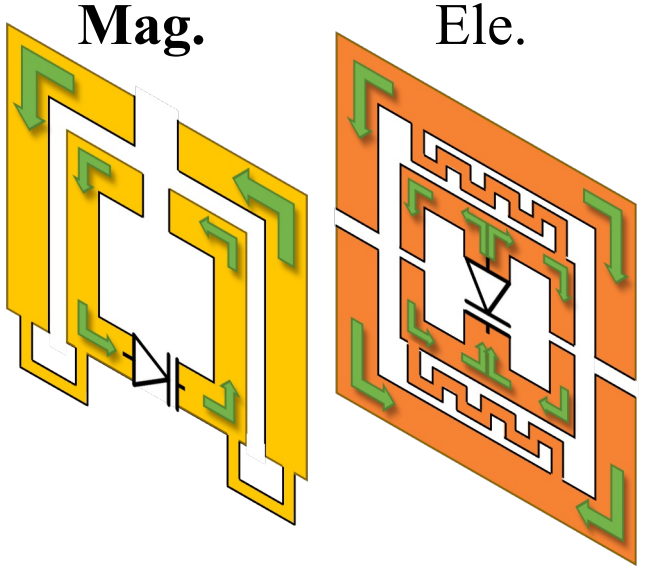


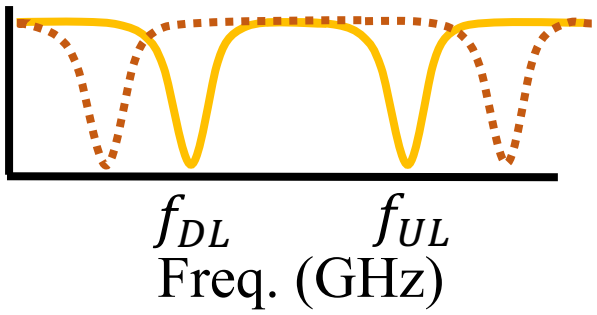


Dual-band w/ meanders

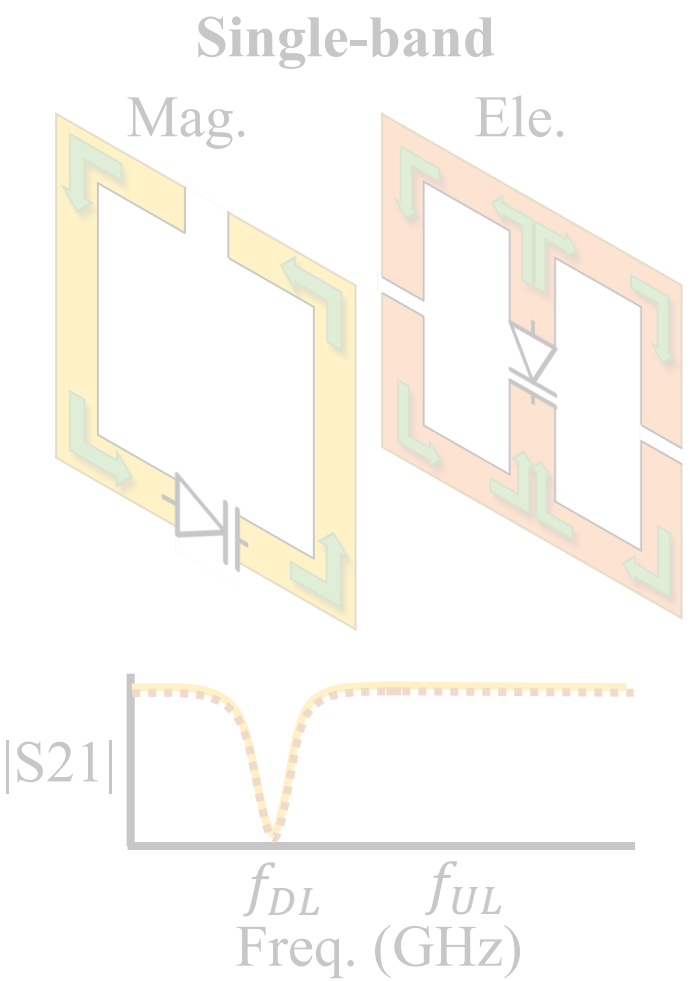
Mag.

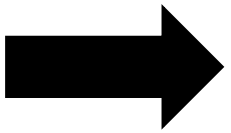
Ele.

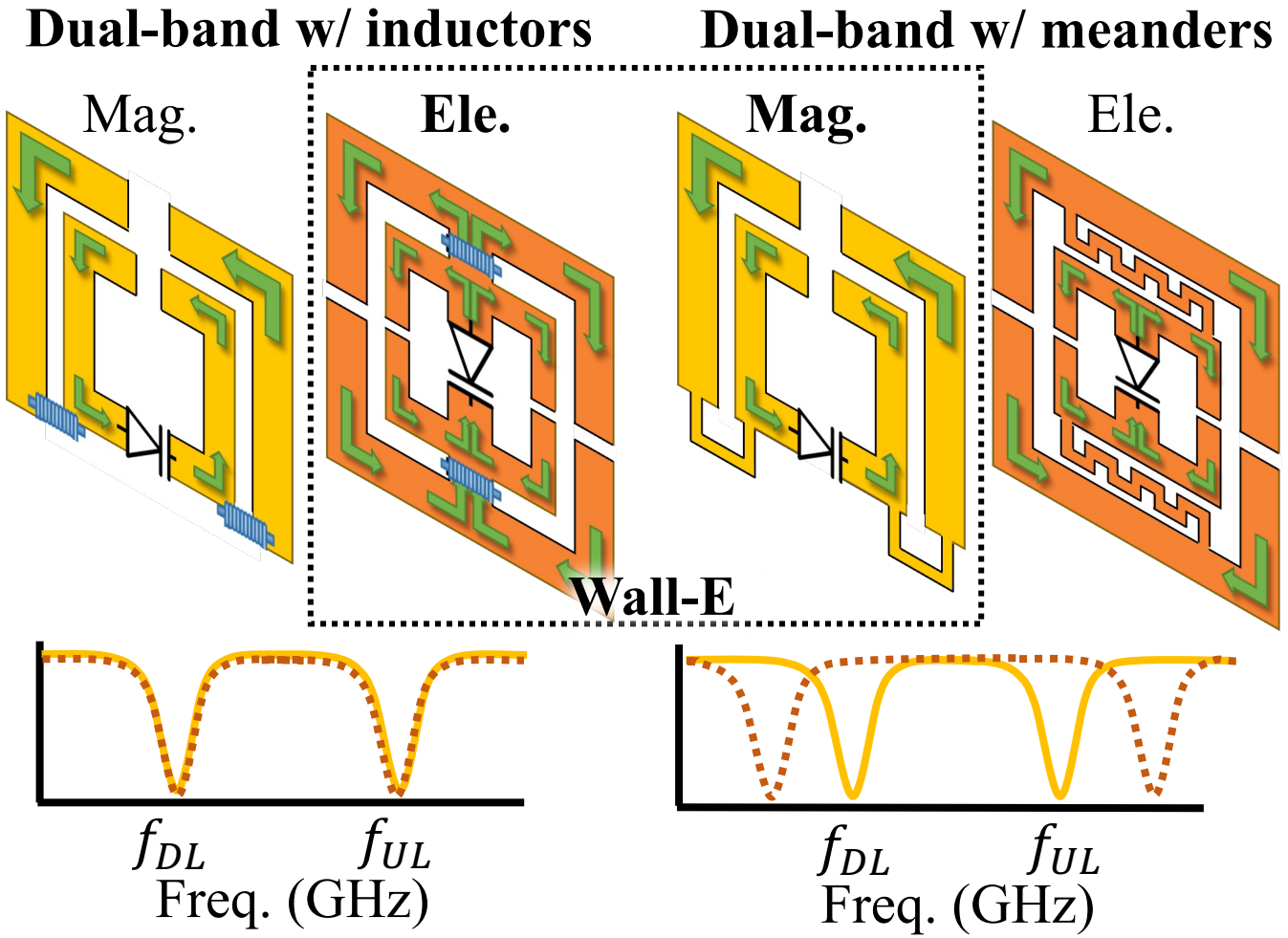




Wall-E's Design: A Combination



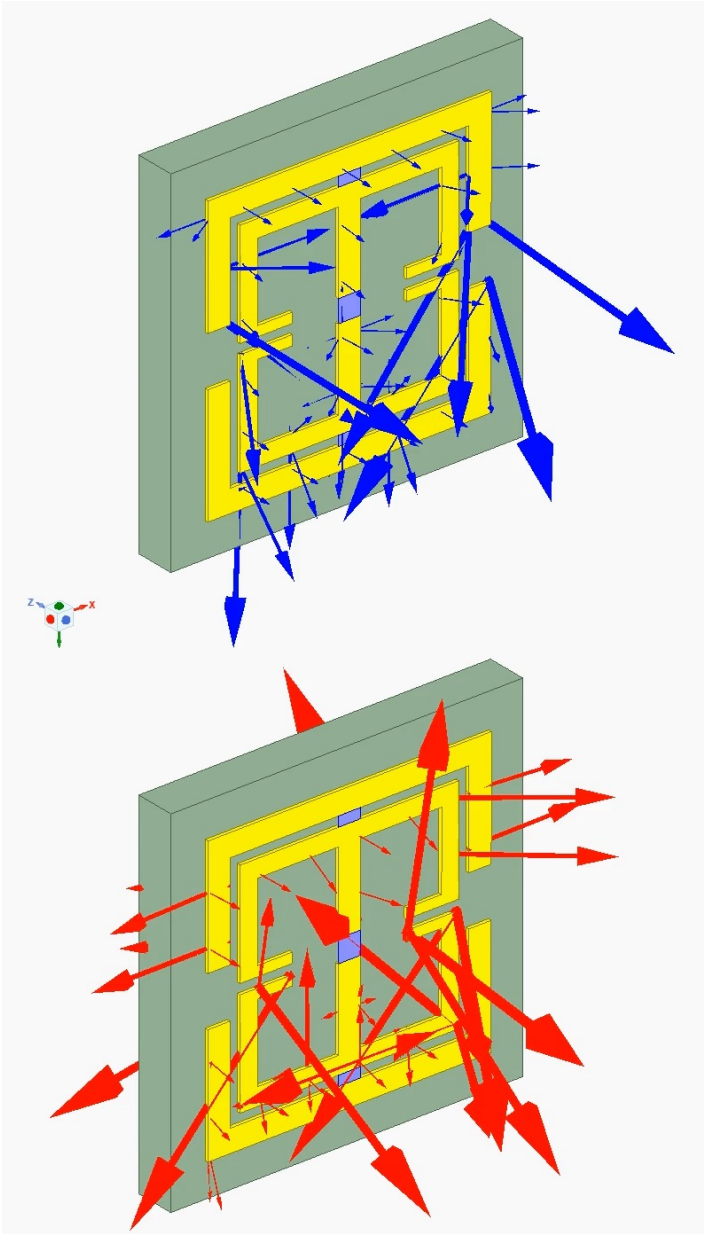


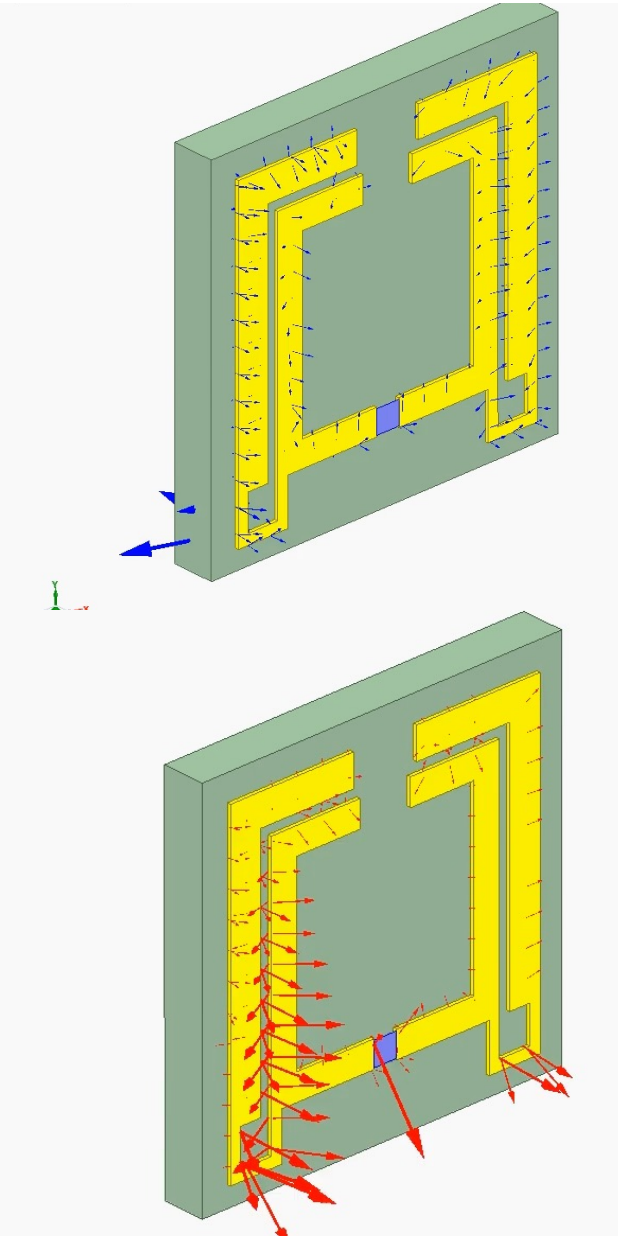


Bi-resonance Simulation

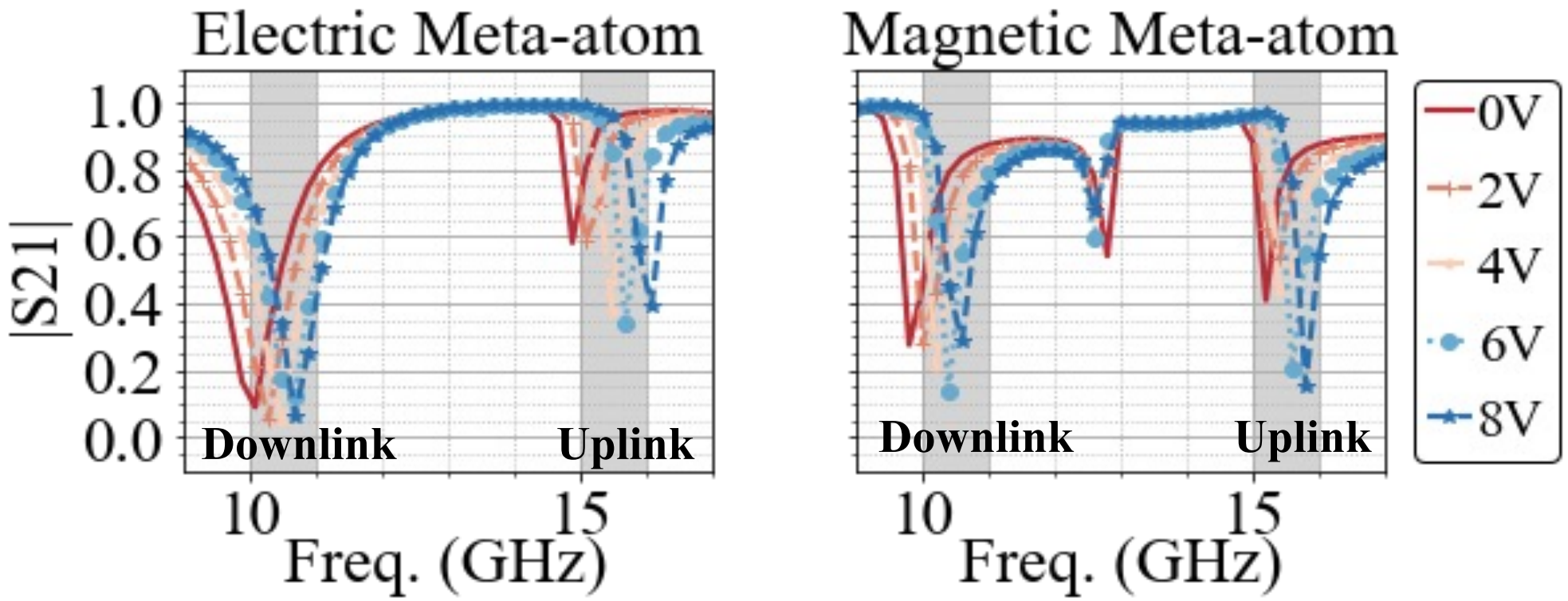
10 GHz

15 GHz

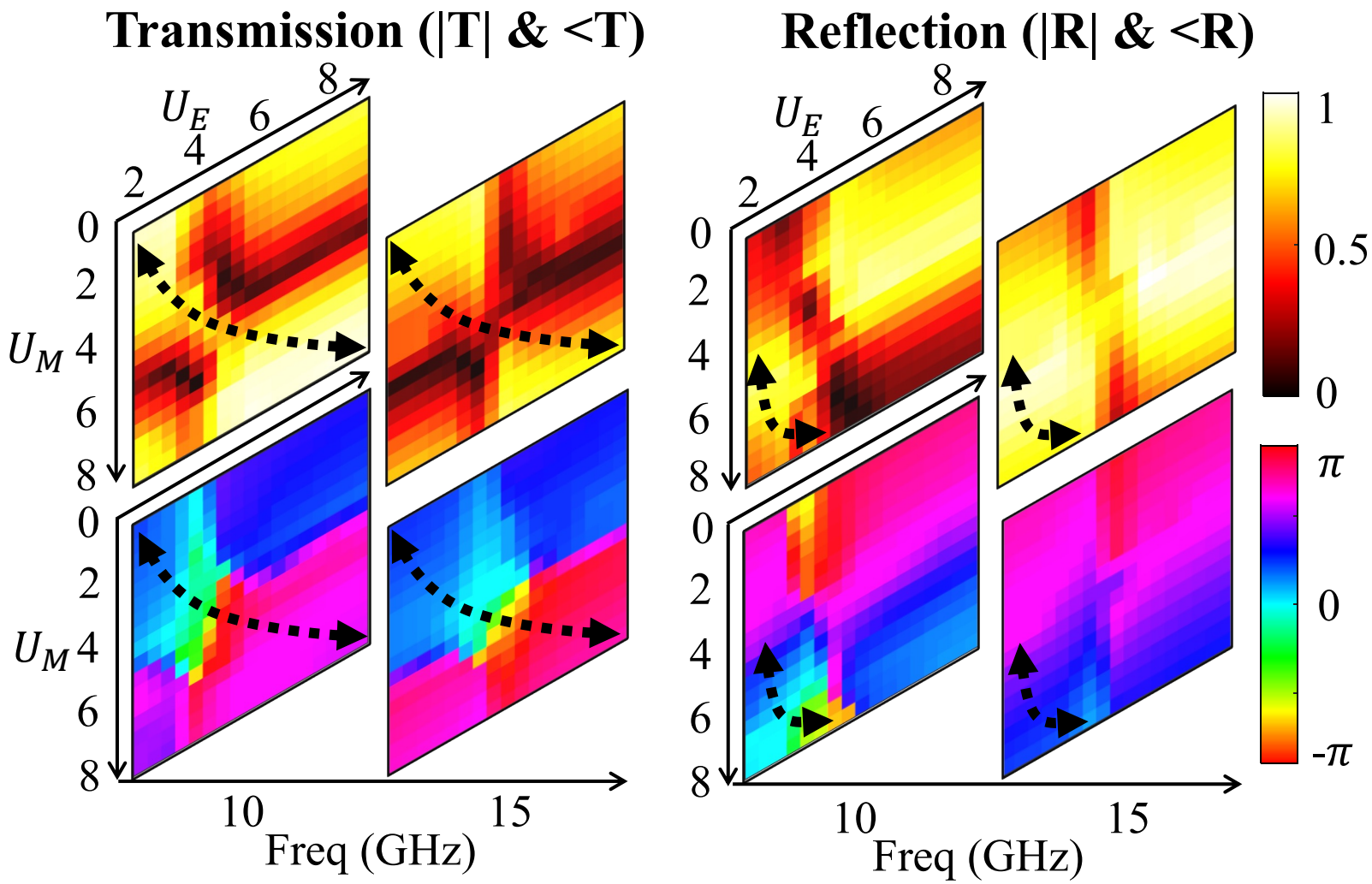




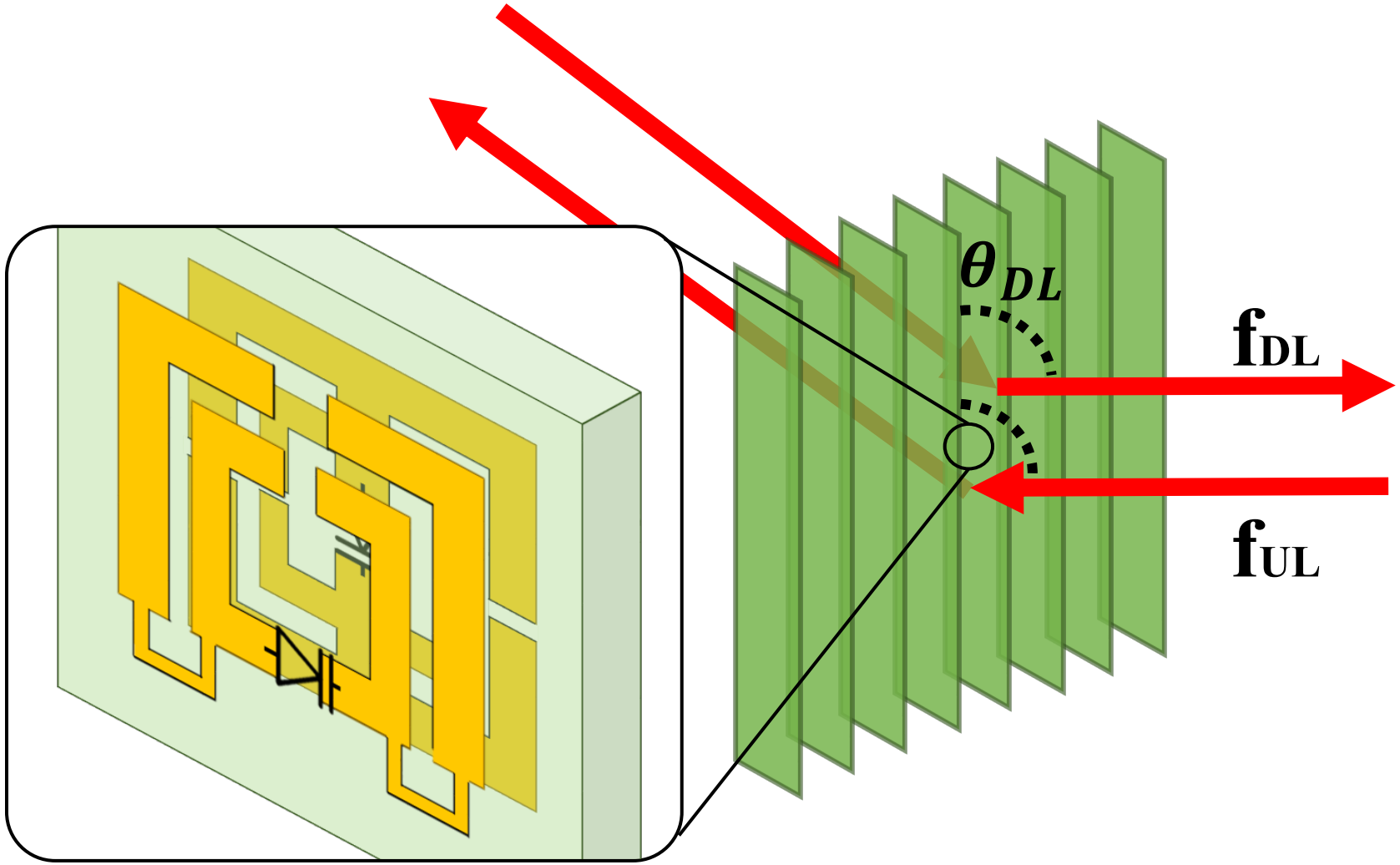
Bi-resonance Simulation



Huygen's transmissive and reflective pattern

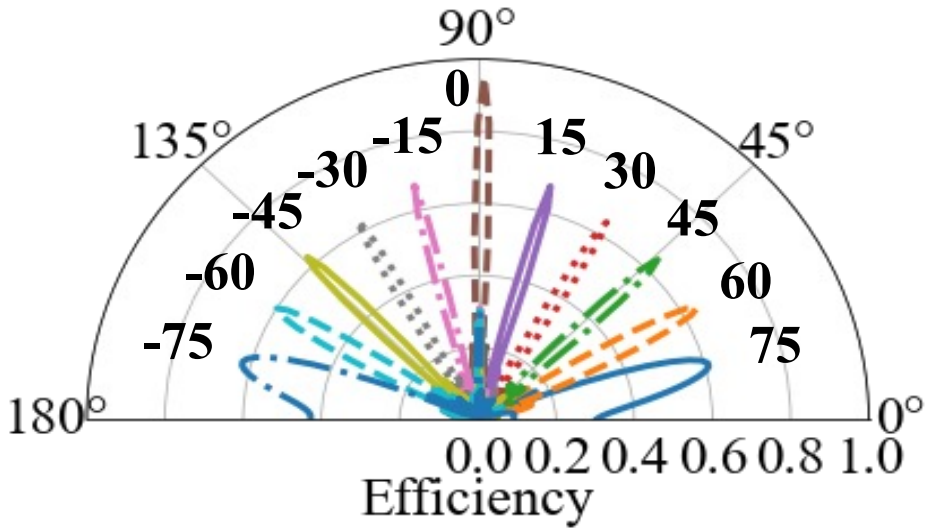


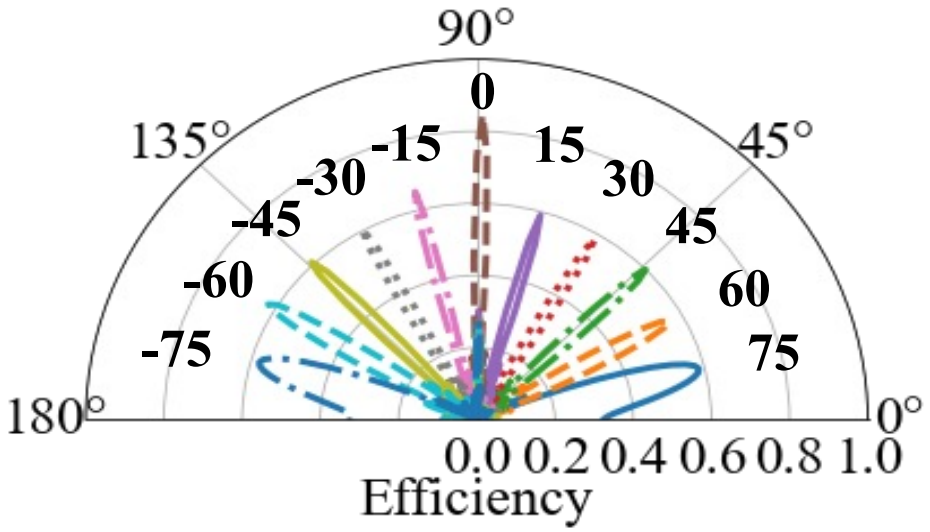
Establishing a Surface-Satellite Link



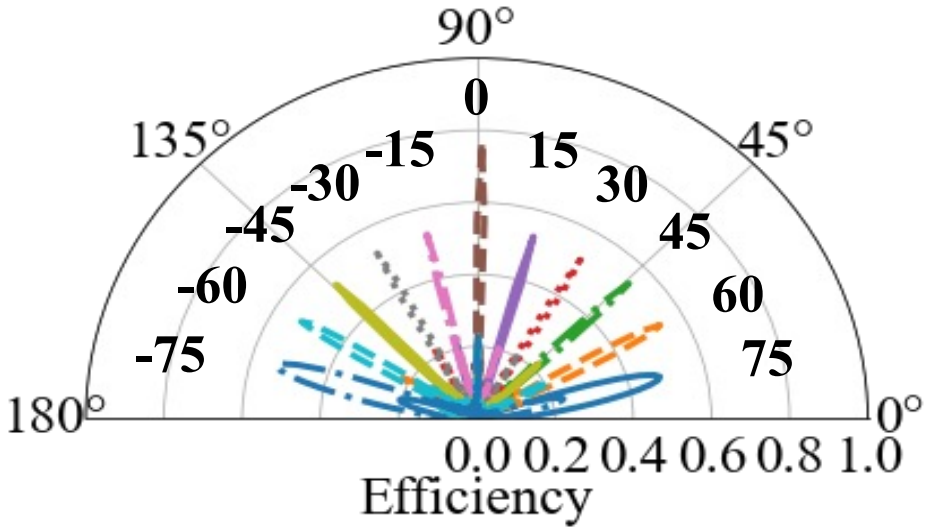
Beam Steering Simulation

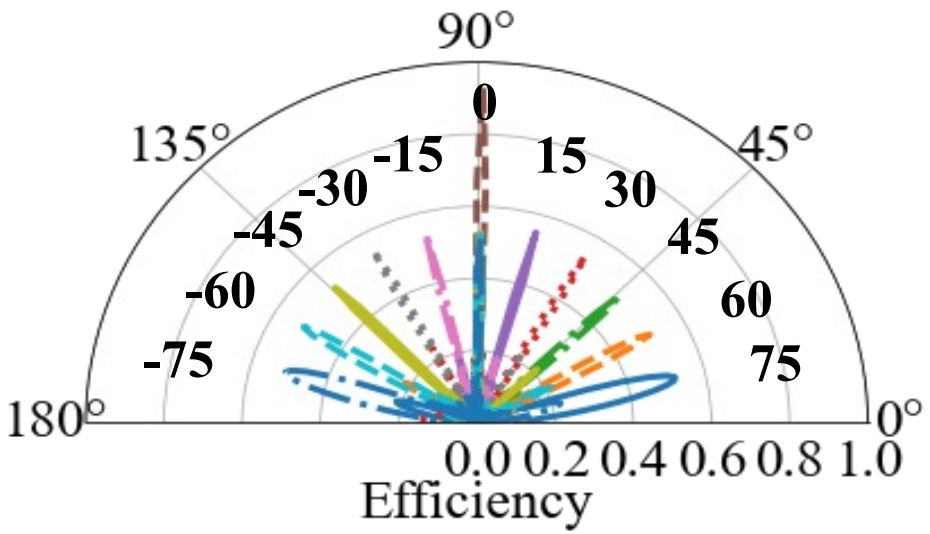
Downlink





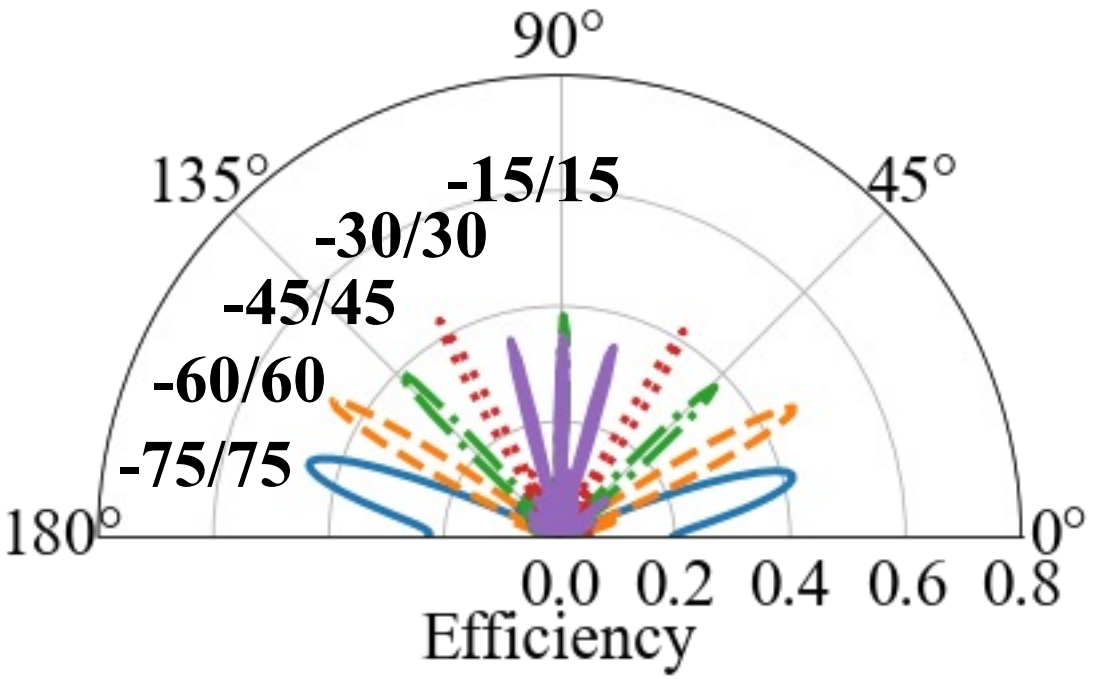
Uplink



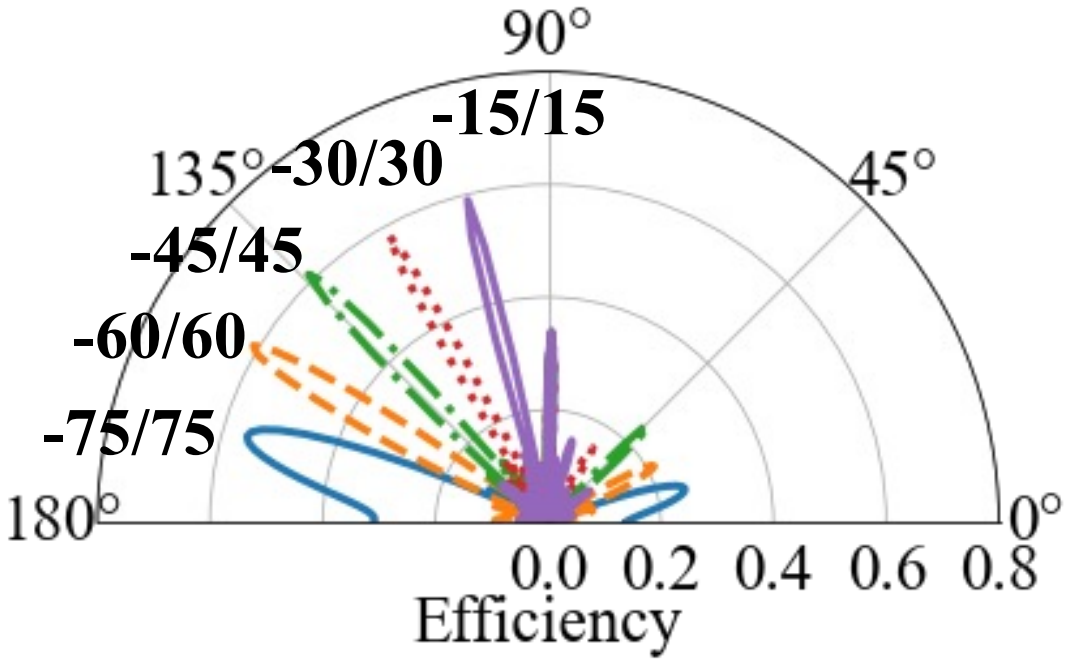


Transmission **Reflection**

Beam Splitting Simulation



Evenly distributed power split



Unevenly distributed power split

Conclusions and Future Work

- **Wall-E** for LEO satellite data networks
  - Out-to-in, indoors, outdoor applicability
  - Dual-band, steerable at almost 360 degrees, beam splitting/combining, angularly reciprocal
- First designs we are aware of that realize the potential of Huygens surfaces
  - **Overcome fundamental challenges** in satellite RF design and control

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