Photonically Enabled Metasurfaces for 5G

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Outline

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- Metasurface Design
- Optical Control
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- Acknowledgments

Motivation

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- Newly emerging technologies, such as 5G communications, require a large number of mm-wave circuits with increased functionalities in a compact volume.
- Millimeter-wave systems
  - Require efficient, reconfigurable, tunable devices to be used in multiple applications.
  - Improving the size, functionality, complexity, and cost.
- On-the-move connectivity requires:
  - radiators
  - beam steering capabilities
  - high-gain link

5G Antenna Array

Motivation

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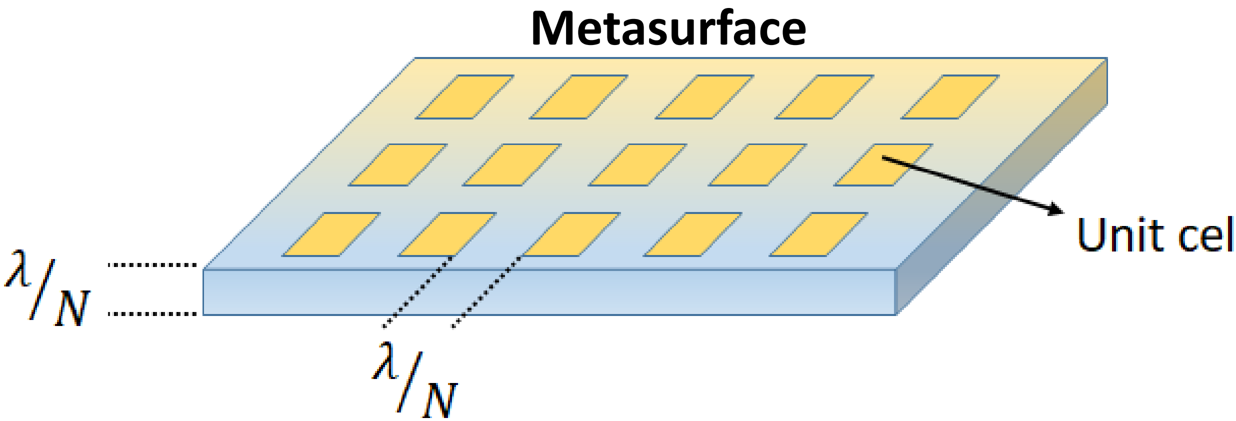
- Metasurfaces (MSFs) → two-dimensional counterparts of metamaterials consisting of a finite number of unit cells
- Reconfigurability of MSFs → switching mechanism → redistributes the currents → alters the electromagnetic fields
- Electronic switches:
  - Active biasing
  - Bulky circuits
  - Complex design



- Optically controlled switches:
  - Do not require bias-lines
  - Large bandwidth
  - Immunity to electromagnetic interference

Motivation

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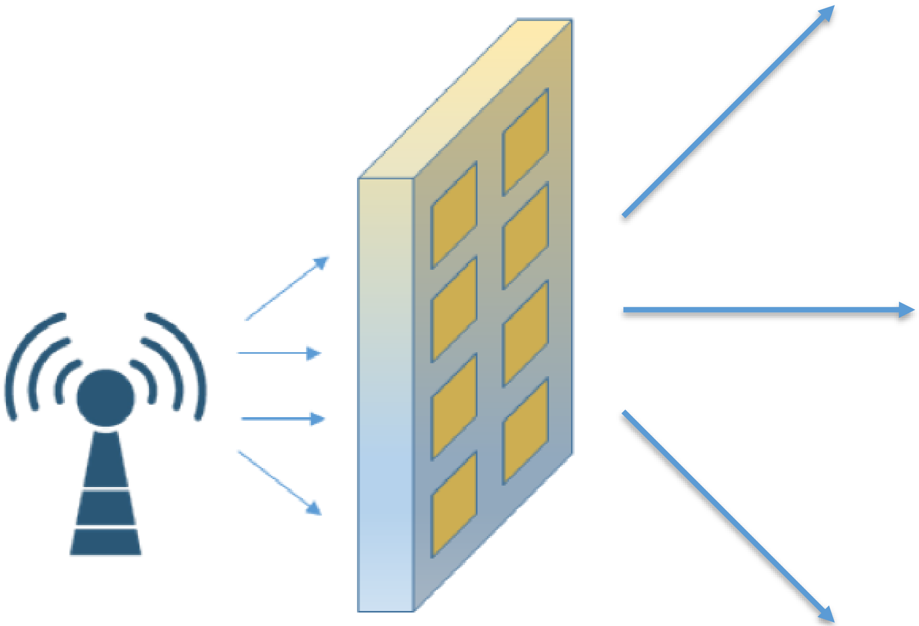
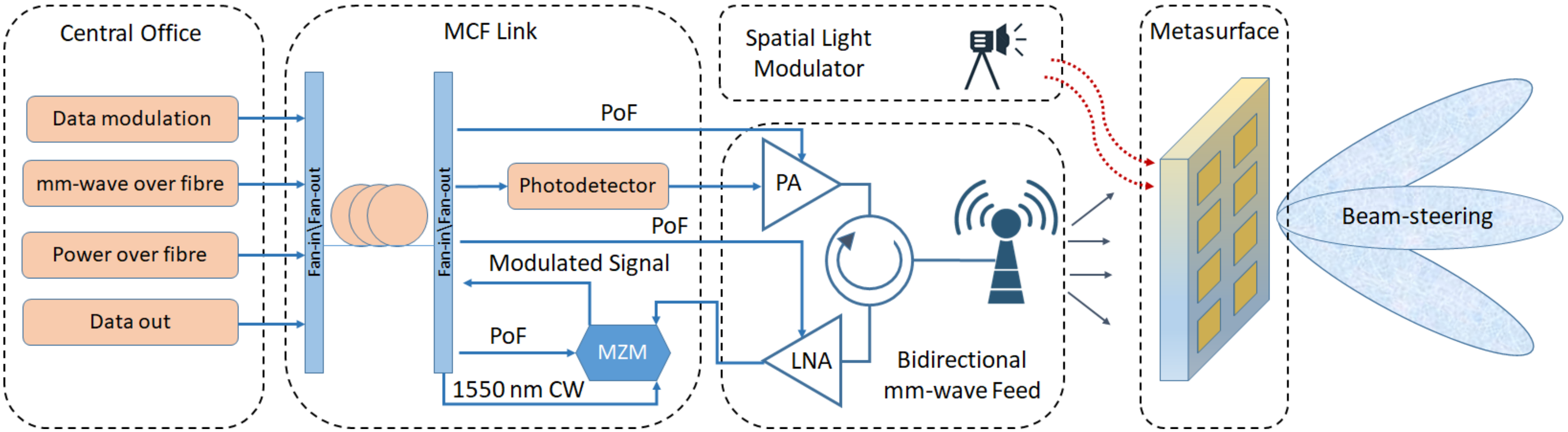
- In this work, we propose the design and fabrication of a MSF-based radiator that will enable the beam steering of an antenna fed through a multi-core-fibre (MCF) link.

- The MSF will be optically reconfigurable using a spatial light modulator (SLM), which will alter the properties of optically-dependent switching components embedded within the design.



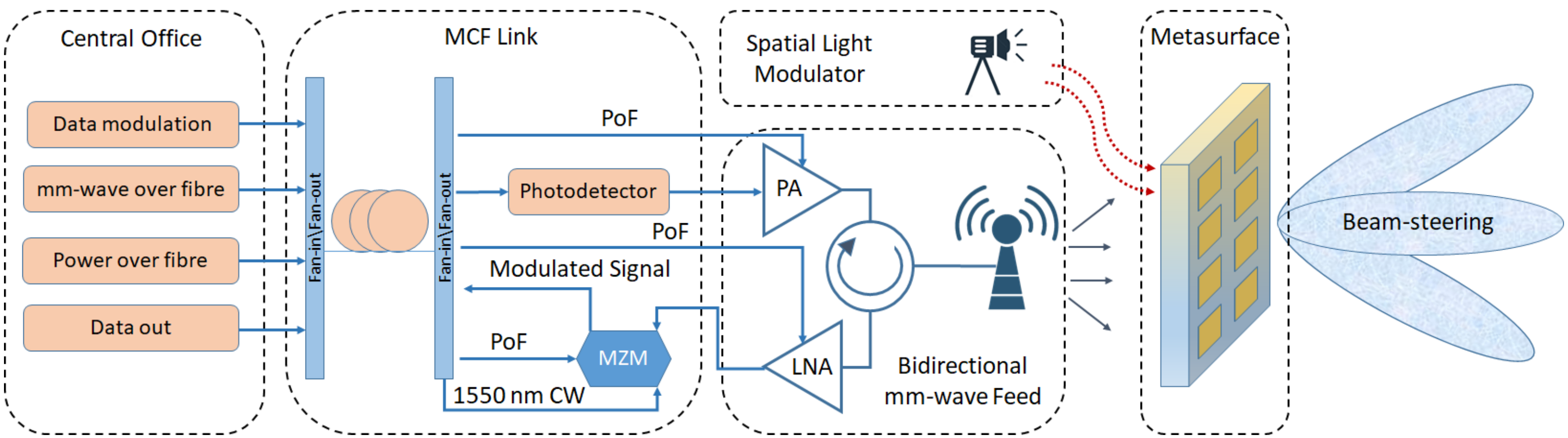
System Design

- System
  - Central office (CO)
  - MCF Link
  - mm-wave feed
  - Metasurface



System Design

- Photonic control:
  - the need for a mm-wave feed network is eliminated
  - losses incurred by the mm-wave signals are reduced significantly
  - increases the efficiency and reduces the upfront and operating costs of the remote antenna units.
- The proposed MSF will be capable of providing beam steering and control of parameters such as beam width and sidelobe level.
- The MSF will be linked by multi-core fibre links to a central office, providing an uplink via optical heterodyning and a down-link via external modulation, along with power over fibre.

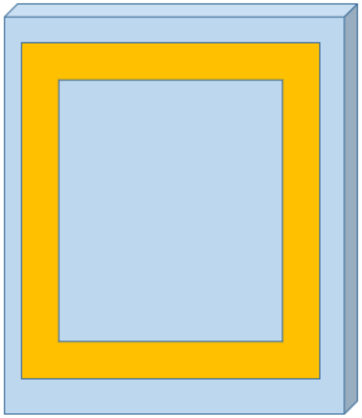


Metasurface Design

- MSFs have the ability to tailor electromagnetic (EM) waves by introducing abrupt phase changes. Their unit cells can be considered as an origin of tangential field discontinuities, and can be patterned by a distribution of electric and magnetic surface currents according to Huygens’ field equivalence principle.

- The metasurface induces surface currents that produce the required tangential fields on both sides of the interface.

- The required magnitude of the current is produced by implementing sub-wavelength inductive (e.g. loaded wires) and capacitive (e.g. loaded loops) elements within a metasurface unit cell.



Single MSF square ring-shaped unit cell

Metasurface Design

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- The MSF can be characterised by its surface impedance (Z_{ms}) and admittance (Y_{es}), which can simplify the design using simple circuit models. The impedance is directly extracted from the complex reflection (R) and transmission (T) coefficients, which can be related to Z_{ms} and Y_{es} of a periodic metasurface for a normally incident plane wave using,

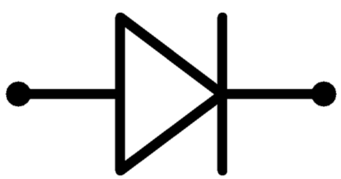
$$Z_{ms} = \frac{2\eta(1 - T - R)}{1 + T - R} \qquad Y_{es} = \frac{2(1 - T - R)}{\eta(1 + T + R)}$$

where η represents the free space wave impedance.

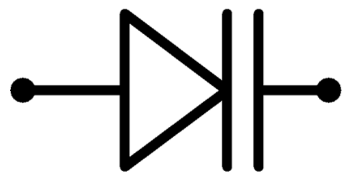
- The MSF will be designed using ANSYS HFSS, using a low-loss microwave substrate. A 28 GHz horn antenna will be used as a source for the metasurface, and the MSF will be fabricated using a high-precision LPKF ProtoMat milling machine for subsequent testing in an anechoic chamber.

Optical Control

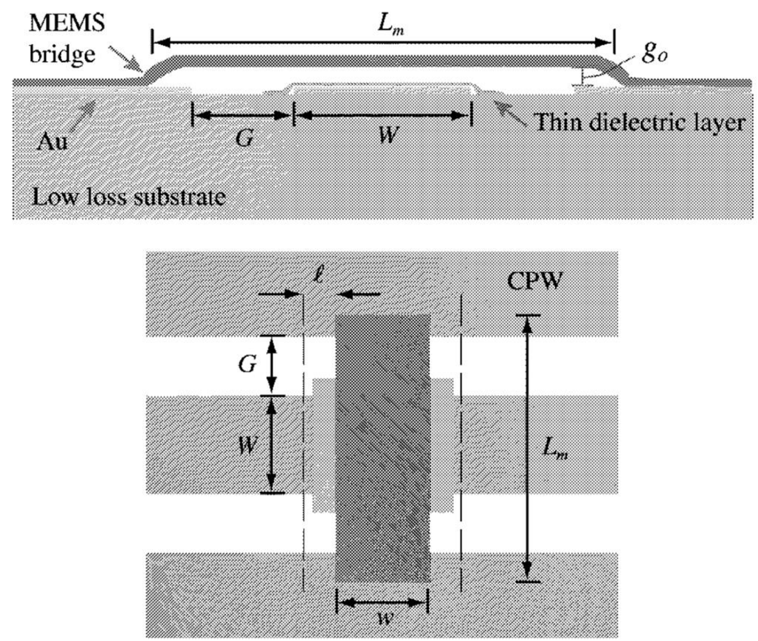
- Beam-steering → reconfigurable element is required.
- Several reconfigurable methods have been reported to date, such as those based on mechanical, electrical, optical and material change techniques. Most commonly, electrical techniques have been exploited using PIN diodes, RF-MEMS and varactors.



PIN Diode



Varactor



RF-MEMS

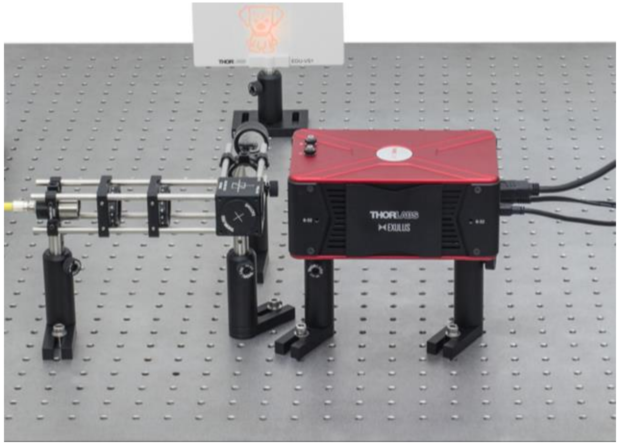
- Limitations of using such components
  - low switching speeds
  - bulky biasing networks
  - limited switching states
  - undesirable losses

Optical Control

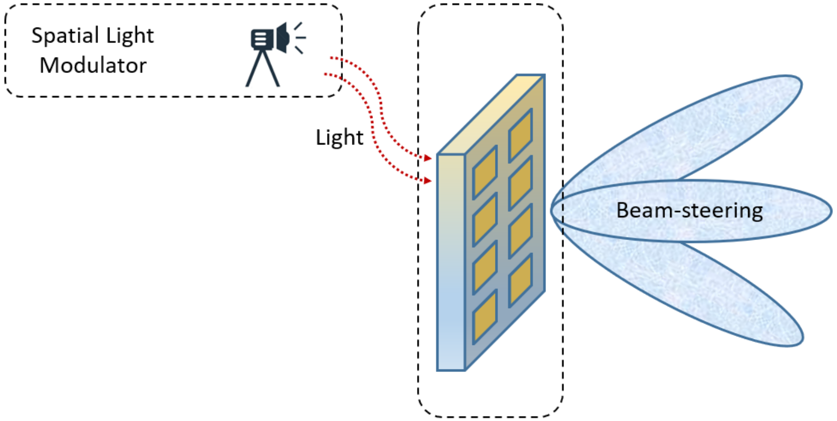
- Optically reconfigurable MSF → enables low loss and low power consumption, due to the linearity of the optical devices and the absence of biasing networks.

- Spatial light modulator:
  - enabling a potentially cost-effective approach
  - allows unprecedented levels of rapid reconfigurability
  - excludes the use of optical fibres

- Switching elements:
  - photodiodes
  - photovaractors
  - silicon dices

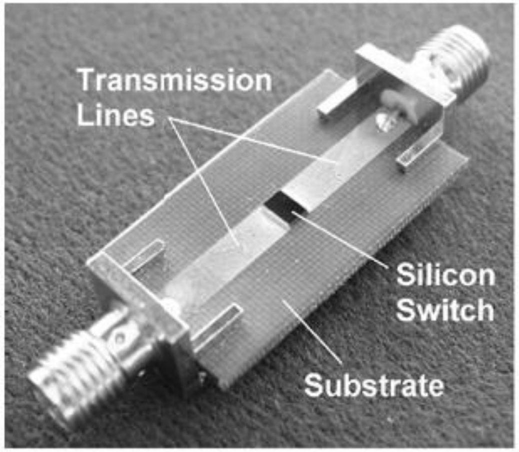


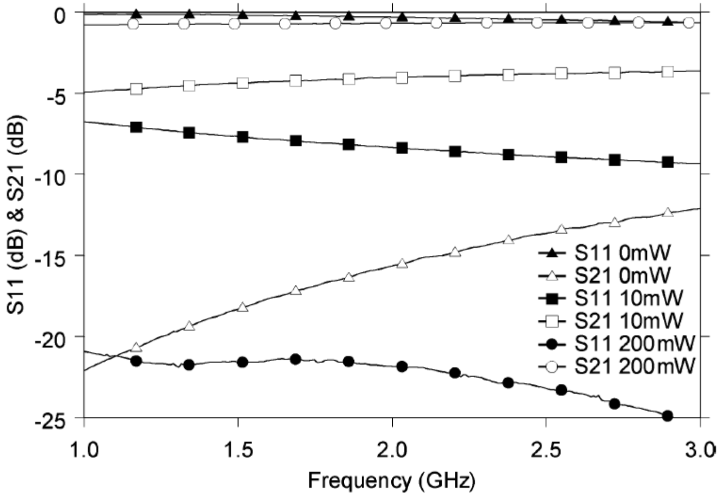
Spatial Light Modulator



Optical Control

- Silicon dices → optically dependent conductivity.
- Illuminated by light → electron-hole pairs are created → shifting silicon's insulator state to a near conducting state.
- Sufficient energy required to promote enough electrons from the valence to the conduction band.
- Light in the near infrared range → provides a balance between light penetration depth and the absorption coefficient, which are inversely proportional to each other and related to the wavelength of the light.





C. J. Panagamuwa, Frequency and Beam Reconfigurable Antenna Using Photoconductive Switches, IEEE TAP, 2006.

Conclusions

- The conceptual design of a metasurface to be used as a reconfigurable antenna radiator in order to provide beam-steering capabilities at 28 GHz was presented. The switching elements embedded within the metasurface will be controlled optically using an SLM.
- Future research will focus on designing, fabricating and embedding the metasurface with the photonic generator and this will be tested using a 5G demonstrator.

Acknowledgements

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RESEARCH & INNOVATION FOUNDATION

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