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Photonically Enabled Metasurfaces for 5G

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Abstract

An optically reconfigurable metasurface is proposed for use as an antenna radiator at 28 GHz. The metasurface is transmittive and is fed through a horn antenna connected to a multi-core-fibre link, significantly reducing the losses compared to a mm-wave feed. In the proposed system, radiated beams will be photonically controlled using a spatial light modulator, thus not requiring the use of optical fibers. For optical reconfigurability the switching component will be based on silicon instead of photodiodes and varactors, eliminating the need for an active biasing network.

1 Introduction

Newly emerging technologies, such as fifth-generation (5G) communications, require a large number of mm-wave circuits with increased functionalities in a compact volume [1]. These mm-wave systems will need efficient, reconfigurable, tunable devices to be used in multiple applications, but without compromising the size, functionality, complexity, and cost. Designing a highly-directive, low-profile and compact radiator to be used in emerging technologies, requires narrow and focused beams, which continues to be a major challenge for front-end unit microwave engineers. In addition, on-the-move connectivity offered by many communications applications, needs radiators that should also feature beam steering capabilities to maintain a high-gain link with other radiators.

Metasurfaces (MSFs), which are the two-dimensional counterparts of metamaterials, have been considered as potential candidates to address many of the aforementioned challenges in future communication systems. Reconfigurability is normally achieved using a switching mechanism, that redistributes the currents and hence, alters the electromagnetic fields. However, most electronic switches require active biasing. This problem can be solved by using optically controlled switches, which do not require bias lines. Further advantages of photonic switches are the large bandwidth and the immunity to electromagnetic interference.

Here, 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. In addition, the MSF will be optically reconfigurable using a spatial light modulator (SLM), which will alter the properties of switching components embedded within the design. The following sections outline the system design and optical control aspects of our concept.

2 System Design

The schematic diagram of the proposed system is shown in Figure 1, consisting of the central office (CO), the MCF Link, the mm-wave feed and the metasurface. By providing photonic rather than mm-wave control of the radiated beams from the metasurface, the need for a mm-wave feed network is eliminated, and the losses incurred by the mm-wave signals are reduced significantly. This in turn increases the efficiency and reduces the upfront and operating costs of the remote antenna units. The proposed metasurface will be capable of providing beam steering and control of parameters such as beam width, sidelobe level and elimination of reflected waves. 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 [2].

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 [3]. The metasurface induces surface currents that produce the required tangential fields on both sides of the interface. These magnetic and electric surface currents along the interface can be achieved in a passive manner by creating a distribution of miniature electric and magnetic dipoles [4]. 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. 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) coef-

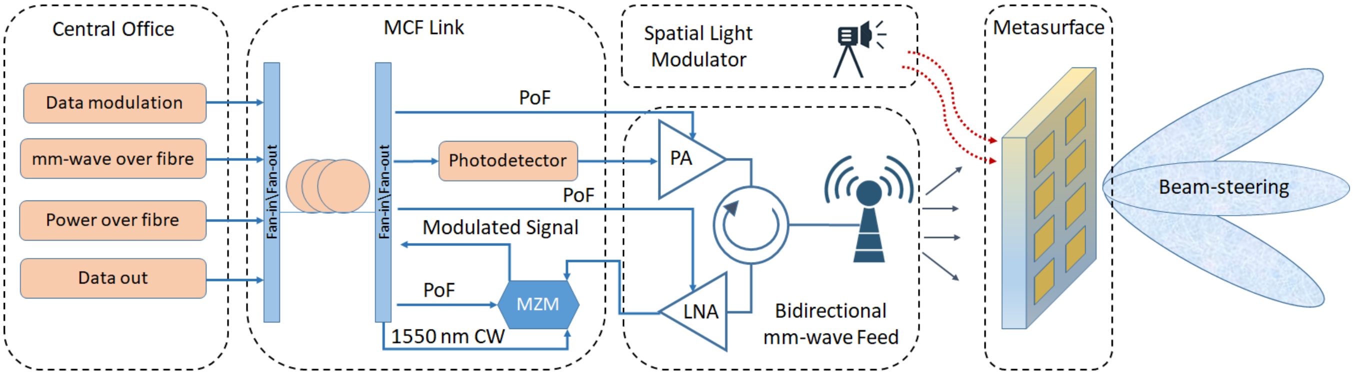

Figure 1. Proposed schematic diagram of the measurement set-up used to photonically reconfigure a metasurface, which is fed through a multi-core fibre.

ficients [5], which can be related to Z_{ms} and Y_{es} of a periodic metasurface for a normally incident plane wave using,

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

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.

3 Optical Control

To achieve beam-steering a reconfigurable element is required since the metasurface itself does not allow for active control of the reflected or transmitted fields. 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. Some of the limitations of using such components are low switching speeds, bulky biasing networks, limited switching states, and undesirable losses. To overcome these limitations the designed metasurface will be optically reconfigurable, enabling low loss and low power consumption, due to the linearity of the optical devices and the absence of biasing networks [6]. The optical control of the MSF will be provided via a spatial light modulator, thus enabling a potentially cost-effective approach. Furthermore, the use of the SLM allows unprecedented levels of rapid reconfigurability for the surface and also excludes the use of optical fibres connected directly to the metasurface. Photodiodes, photovaractors and silicon dies are potential candidates to be used as the optically reconfigurable switching elements on the metasurface.

Silicon dies have been exploited in microwave applications due to their optically dependent conductivity [7]. When illuminated by light, electron-hole pairs are created, shifting silicon's insulator state to a near conducting state. For enough electrons to be promoted from the valence to the conduction band the photons incident upon the silicon must have sufficient energy. Commonly, light in the near infrared range is used, as it 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.

4 Conclusions

We have proposed the conceptual design of a metasurface to be used as a reconfigurable antenna radiator in order to provide beam-steering capabilities at 28 GHz. The switching elements embedded within the metasurface will be controlled optically using a spatial light modulator. 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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