Metasurface Based Reconfigurable Beamforming/Beam-Steering for Sub-MillimeterWave and THz Communications
Xiaomin Meng (xm51@sussex.ac.uk), Maziar Nekovee (m.nekovee@sussex.ac.uk)
University of Sussex, School of Engineering and Informatics, Richmond, Brighton, UK

MOTIVATION
As we step up in the frequency spectrum for wireless communication, resolving high free-space wave loss and providing optimum propagation direction become of critical importance. Traditional phased array don’t scale well - a 28GHz 5G transmitter may integrate 1024 antennas to achieve 1 Gbps data rate over 200m e.g. for fixed-wireless access, while a 300 GHz 6G transmitter would require 100,000 antennas in order to achieve similar communication range, assuming same output power.

In this work we explore alternative beam-forming and beam-manipulation approaches based on reconfigurable meta-surfaces. We investigated reflect array solutions based on either PIN-diode and liquid crystal approaches, with the liquid crystal offering a more promising solution.

LIQUID CRYSTAL
Liquid crystals (LC) that are in the nematic phase, which consist of thread-like molecules, possess an anisotropic dielectric property. The anisotropy comes from the molecular realignments to an applied bias voltage, causing a permittivity variation $\Delta \varepsilon_r$ between ON and OFF state. It is the $\Delta \varepsilon_r$ that causes a resonance variation between ON and OFF state of our unit cell, which is analogous to a drive or lag in the antenna response, giving rise to the phase difference in reflected signal.

\[ \varepsilon_r = \varepsilon_{r,\perp} \]
\[ \varepsilon_r = \varepsilon_{r,\parallel} \]

<table>
<thead>
<tr>
<th>LC Type</th>
<th>Freq</th>
<th>$\varepsilon_{r,\perp}$</th>
<th>$\varepsilon_{r,\parallel}$</th>
<th>$\tan\delta_{r,\perp}$</th>
<th>$\tan\delta_{r,\parallel}$</th>
<th>$\Delta \varepsilon_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT3-23001</td>
<td>19 GHz</td>
<td>2.5</td>
<td>3.3</td>
<td>0.0143</td>
<td>0.9983</td>
<td>0.8</td>
</tr>
</tbody>
</table>

THEORETICAL FAR-FIELD AND FUTURE WORK
The main contributions to the far field approximation lies in the summation of distance terms between unit cell and observer ($r_{m,n}$), and phase difference terms of ON and OFF states ($\varphi_{m,n}$). For future research, we will optimize the matrix $\varphi_{m,n}$ with machine learning algorithms (such as genetic algorithm) to achieve desired beam functions.

\[ F_{m,n} = f(\theta, \phi) \sum_{m=1}^{M} \sum_{n=1}^{N} e^{ik_0 r_{m,n}} e^{ik_0 r_{m,n}} \varphi_{m,n} = \begin{bmatrix} 1/0 & \cdots & 1/0 \\ \vdots & \ddots & \vdots \\ 1/0 & \cdots & 1/0 \end{bmatrix} \]

REFERENCES

SIMULATION RESULTS
Unit cell of the LC patch antenna. Periodicity $D = 2\text{mm}$, patch dimensions $L_x = 1.134\text{mm}$ and $L_y = 0.747\text{mm}$, substrate permittivity modelled as $\varepsilon_r = 2$ in OFF state, $\varepsilon_r = 4$ in ON state.

Ideal operating frequency at 94.6GHz, where the reflected amplitude of ON and OFF elements are equal, also coinciding with high (~200deg) phase difference.

Green block for ON, red for OFF state of the LC unit cell. The “checker board” (top left), “stripes” (top right) and all ON (left) configuration have been previously studied, our results confirm with the pattern presented in other papers, which mainly come from devices that use PIN diodes[2] and operate at <10GHz frequencies.