LISA\textsubscript{ES} – EVALUATING LIQUID CRYSTALS AS PHASE SHIFTERS IN A DIRECT RADIATING HORN ARRAY ANTENNA (ISL K\textsubscript{A}-BAND)

Alexander Hoehn\textsuperscript{1}, Matthias Tebbe\textsuperscript{1}, Norbert Nathrath\textsuperscript{2}, Michael Trümper\textsuperscript{2}, Ralf Gehring\textsuperscript{3}, Helmut Wolf\textsuperscript{4}, Christian Weickhmann\textsuperscript{4}

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Investigations for electric beam forming / steering of the LISA lightweight intersatellite link antenna

Baseline: LISA\textsubscript{MS}
Mechanical antenna steering
Incl. 2-channel, low loss waveguide rotary joint

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Vision: LISA\textsubscript{ES}
Electrical steering through beam forming using liquid crystal phase shifters

8x8 LEO horn array antenna, septum OMT (LHC, RHC), low loss waveguide / rotary joint, mechanical / fast 2-axis steering

6x16 GEO horn array antenna, septum OMT (LHC, RHC) und 512 LC-phase shifters

Dynamic +/- 11° electric beam forming

Liquid crystal (LC) -- based phase shifter (P/S - working principle:
• Controlled LC-orientation (E-field or H-field) affects \( \varepsilon_r \)
• Phase shift of \(~400°/10\) cm LC-cavity
• Individual phase shifters in each waveguide pathway to each horn
• Using film electrodes (\( \pm 165\) V AC) to generate variable E-field direction within P/S

Obtaining required phase shift for GEO to LEO (\( \pm 11° \)) application:

\( \Rightarrow \) Need approx. 2,700° phase shift for 40 x 40 cm LISA array in Ka-band

\( \Rightarrow \) With only \(~400°/\) per P/S, use multiple phase numbers (7–8)

Phase Shifter Characterization:

<table>
<thead>
<tr>
<th>Phase shift (steady, dynamic) vs. applied voltage</th>
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<tbody>
<tr>
<td>Losses and rate of change of phase shift vs. voltage and temperature</td>
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<tr>
<td>'phase number jump' optimization: modelled losses during GEO satellite tracking without (top)</td>
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</tbody>
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Losses with 'jump' optimization during GEO Lite distinguishes

L\<sub>ISA</sub>\textsubscript{ES} LC-phase-shifter based steering status:

• Fundamental manufacturability and functionality demonstrated
• Complex and high risk integrated phase shifter manufacturing challenges remain (vacuum, thermal expansion, robustness)
• Large number of components (16 x 16 array = 512 P/S for two polarizations)
• Still high losses in E-field electronics (power electronics) and phase shifters (RF-power)
• Slow rate of change due to required phase 'jumps', partially compensated due to optimization strategies

L\<sub>ISA</sub>\textsubscript{ES} - additional publications and information:

- Electronic Letters 2013: Recent measurement of compact electronically tunable liquid crystal phase shifter in rectangular waveguide topology.

P/S components:
• LC-cavity (Rexolite) with thermal expansion / fill ports
• Two (top, bottom) 50 \( \mu \)m Kapton film electrodes with high impedance Titanium-electrodes, each with two supply wires and internal voltage divider
• Used in split block (testing) or integrated with electroplated skin and flanges

4x4 Array Demonstrator (w/o phase shifters)

RF-pattern test with 4x1 horn row and 9° commanded shift