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• **Supplementary File** •

Design of low-profile array antenna working at 110 GHz based on digital coding characterization

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Appendix A

The geometry parameters of the antenna unit are optimized as follows: $H_s = 0.1$ mm, $H_{LC} = 0.01$ mm, $L_a = 0.3$ mm, $L_b = 0.07$ mm, $w_s = 0.025$ mm, $t = 0.002$ mm. The designed antenna unit is simulated in CST Microwave Studio and the results are shown in Fig. A1. Some details of the shear corner in the power divider network are shown in Fig. A2.

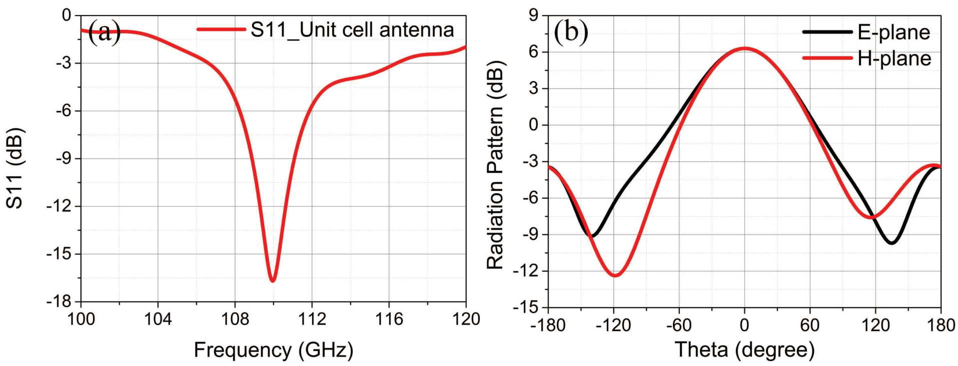

Fig. A1 Simulated results of the designed antenna unit based on NLCs. (a) The result of S-parameter from 100 to 120GHz. (b) The 2D radiation beams of the designed antenna unit at 110GHz.

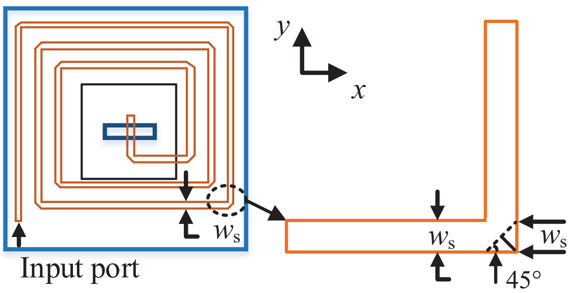

Fig. A2 Details of the shear corner in the power divider network.

Appendix B

The performance of a 1-port antenna can be partially estimated by the radiation rate, which is depicted by the S-parameter (S_{11}), as shown in Fig. B1.

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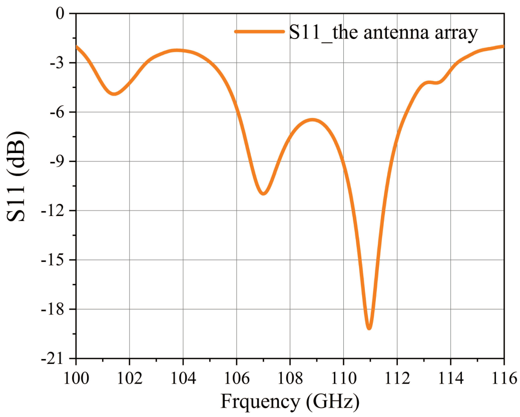

Fig. B1 S-parameter simulation results array antenna based on NLCs from 100 to 116GHz.

Appendix C

The dielectric constant of the NLCs can be roughly judged by the beam state corresponding to the 1-bit digital coding. The initial dielectric constant of the NLCs is set to be 2.4, and the corresponding phase is 0^o. When the main beam is split into two symmetrical beams, the dielectric constant of the NLCs corresponds to a 180^o coding state, that is, the beam splitting state generated when the 1-bit digital coding is satisfied. Since the phase difference varies linearly with the increase of dielectric constant of NLCs, it is possible to estimate a correspondence between the dielectric constant of the liquid crystal and phase difference. After calibrating and positioning by this approach, we can obtain these desired relationship. The scanning angles for single beam and dual beams have been shown in Figs. 1(d) and 1(e). The detailed phase differences between adjacent unit cells and the dielectric constant of the NLCs are listed in Table C1.

Table C1 The detailed phase differences between adjacent unit cells and dielectric constant of NLCs.

Scanning angle theta (°)	phase difference $\bigtriangledown\varphi$(°)	Dielectric constant of NLCs Column 1	Dielectric constant of NLCs Column 2	Dielectric constant of NLCs Column 3	Dielectric constant of NLCs Column 3
-36	-135	2.4	2.7	3	2.5
-27	-90	2.4	2.6	2.8	3
-15	-45	2.4	2.5	2.6	2.7
0	0	2.4	2.4	2.4	2.4
15	45	2.7	2.6	2.5	2.4
27	90	3	2.8	2.6	2.4
36	135	2.5	3	2.7	2.4
dual-beam	180	2.4	2.8	2.4	2.8