

1-Bit Pre-phased Reconfigurable Intelligent Surface for Single/Multi-Beam Scanning

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Reconfigurable Intelligent Surface (RIS), a type of metasurface composed of sub-wavelength-sized unit cells that manipulate phase, amplitude, and polarization, is a device designed to redirect signals from transmitters, such as base stations, to selected receivers. Especially multi-beam RIS, which adds multi-beam capability to beam scanning, can maximize coverage expansion under power-constrained conditions. Multi-beam RIS presents a promising solution for wireless communication systems by providing virtual line-of-sight in multiple directions simultaneously and improve system's quality of service.

To realize multi-beam RIS, Amirmasood Bagheri et al. and Yongji Chen et al. used analog and 2-bit control, respectively. However, due to concerns such as power consumption, system complexity, cost, and scalability, 1-bit control is preferred for RIS. Though, traditional 1-bit control produces quantization lobes that create unintended communication links in undesirable directions leading to security and interference issues. Additionally, the low bit quantization makes it difficult to implement sophisticated phase adjustments required for multi-beam scanning. Shengguo Meng et al. applied the ABC optimization to phase quantization for a 1-bit RIS with a size exceeding $700\lambda^2$, enabling multi-beam scanning. However, bulky RIS sizes can be impractical in densely packed environments or below upper-mid band where wavelengths are not particularly short. And the algorithm with high computational complexity must be conducted whenever the positions of the transmitter or receiver change. The pre-phase method allows single-beam scanning 1-bit RIS without any optimization, but it has not yet been explored for multi-beam.

In this study, we propose a 1-bit pre-phased RIS design that can form single/multi-beam scanning with a small aperture size operating at 3.8 GHz. This design approach also facilitates the adaptation to larger RIS sizes and higher frequencies as needed, thanks to the high scalability of 1-bit digital control. The designed unit cell in Figure 1(a) achieves the desired pre-phase by adjusting the Tx-line length at the bottom. A p-i-n diode, inserted in the middle of the Tx-line, ensures a 180-degree phase shift depending on the unit cell's on/off state. Four unit cells are designed to have pre-phases of 0° , 45° , 90° , and 135° , respectively and arranged to mimic a spherical wave incident. The RIS is composed of a 16×16 element array, resulting in an aperture size of $28.44\lambda^2$. The performance of the RIS in single and multi-beam scanning under normal incidence of a plane wave is validated through simulations, as shown in Figure 1. (b) and (c), respectively. The designed RIS reduces quantization lobes in both single beam and multi-beam scanning with 1-bit control and also achieves low SLLs of below -10 dB and -7.5 dB, respectively.

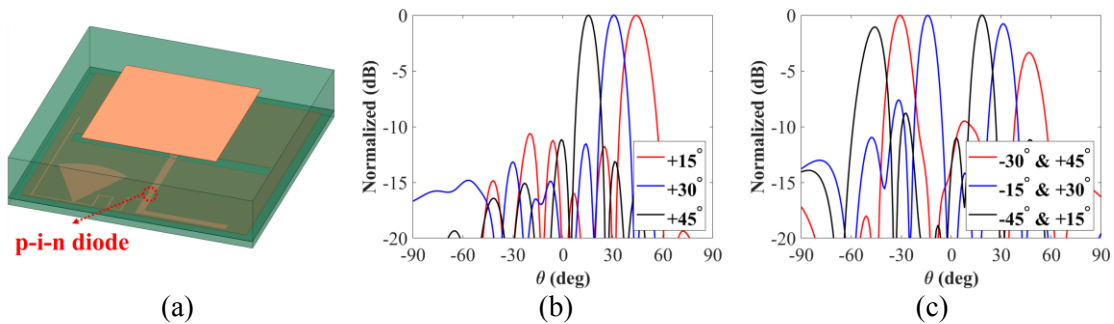


Figure 1. (a) Unit cell structure, and simulation results for (b) single beam and (c) multi-beam scanning.

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