CLAIMS:

1. A 2-bit phase-quantized unit cell of a reconfigurable intelligent surface for manipulating a received electromagnetic wave comprising a multi-mode vortex beam, the 2-bit phase-quantized unit cell comprising:

an antenna provided on a first surface of the unit cell;

a quadrature phase shifter circuit provided on a second surface of the unit cell and communicatively connected to the antenna through a via, the quadrature phase shifter circuit being configured to selectively provide a phase shift of 0-degrees, 90-degrees, 180-degrees, or 270-degrees to the electromagnetic wave received by the antenna based on control signals received from a control module and provide a phase shifted electromagnetic signal to the antenna to be re-radiated,

whereby the control signals were computed based on a phase compensation factor of a transmitter that transmitted the electromagnetic wave at the unit cell, a beamforming factor of the transmitter at the unit cell and a conversion compensation factor of the unit cell,

whereby the conversion compensation factor of the unit cell is computed based on a mode number of the multi-mode vortex beam transmitted by the transmitter and an azimuth angle of the unit cell as computed based on an axis perpendicular to a plane of the first surface of the unit cell.

2. The 2-bit phase-quantized unit cell according to claim 1 wherein the quadrature phase shifter circuit comprises:

a first delay line having an end coupled to the via and another end coupled to a first switch, a second switch and a third switch, the first delay line being configured to provide a 0-degree phase shift to the electromagnetic wave received by the antenna;

a second delay line having an end coupled to the first switch and having a section coupled to a first control line, the second delay line being configured to provide a 90-degree phase shift to the electromagnetic wave received by the antenna;

a third delay line having an end coupled to the second switch and having a section coupled to a second control line, the third delay line being configured to provide a 180-degree phase shift to the electromagnetic wave received by the antenna; and

a fourth delay line having an end coupled to the third switch and having a section coupled to a third control line, the fourth delay line being configured to provide a 270-degree phase shift to the electromagnetic wave received by the antenna.

3. The 2-bit phase-quantized unit cell according to claim 1, whereby the phase compensation factor of the transmitter to the unit cell is computed based on a wave vector k of the multi-mode vortex beam transmitted by the transmitter and a distance d_{T-RIS} between the transmitter and the unit cell.

4. The 2-bit phase-quantized unit cell according to claim 1, whereby the beamforming factor of the transmitter at the unit cell is computed based on the wave vector k of the multi-mode vortex beam transmitted by the transmitter, a spatial location of the unit cell on the reconfigurable intelligent surface, and a direction of a modified electromagnetic wave as re-radiated from the antenna of the unit cell.

5. A reconfigurable intelligent surface system for wireless communication, the system comprising:

a layer comprising a plurality of 2-bit phase-quantized unit cells that are each configured to receive electromagnetic waves from a transmitter, wherein each of the received electromagnetic waves comprises a multi-mode vortex beam;

a control module communicatively coupled to each of the plurality of 2-bit phase-quantized unit cells, the control module configured to:

for each of the plurality of 2-bit phase-quantized unit cells,

compute a phase shift to be provided by the unit cell based on a phase compensation factor of the transmitter at the unit cell, a beamforming factor of the transmitter at the unit cell and a conversion compensation factor of the unit cell, whereby the conversion compensation factor of the unit cell is computed based on a mode number of the multi-mode vortex beam transmitted by the transmitter and an azimuth angle of the unit cell as computed based on an axis perpendicular to a plane of the first surface of the unit cell, and

provide control signals to the unit cell such that the unit cell is triggered to provide the computed phase shift to the electromagnetic wave received by the unit cell, and re-radiate a phase shifted electromagnetic signal.

6. The reconfigurable intelligent surface system according to claim 5, whereby each of the 2-bit phase-quantized unit cells comprise:

an antenna provided on a first surface of the unit cell,

a quadrature phase shifter circuit provided on a second surface of the unit cell and communicatively connected to the antenna through a via, the quadrature phase shifter circuit being configured to selectively provide a phase shift of 0-degrees, 90-degrees, 180-degrees, or 270-degrees to an electromagnetic wave received by the antenna based on control signals received from the control module.

7. The reconfigurable intelligent surface system according to claim 5, whereby the phase compensation factor of the transmitter to the unit cell is computed based on a wave vector k of the multi-mode vortex beam transmitted by the transmitter and a distance d_{T-RIS} between the transmitter and the unit cell.

8. A method for manipulating received electromagnetic waves using a 2-bit phase-quantized unit cell of a reconfigurable intelligent surface, the method comprising:

receiving an electromagnetic wave comprising a multi-mode vortex beam using an antenna provided on a first surface of the unit cell;

selectively providing, using a quadrature phase shifter circuit provided on a second surface of the unit cell and communicatively connected to the antenna through a via, a phase shift of 0-degrees, 90-degrees, 180-degrees or 270-degrees to the electromagnetic wave received by the antenna, based on control signals received from a control module and providing a phase shifted electromagnetic signal to the antenna to be re-radiated,

whereby the control signals were computed based on a phase compensation factor of a transmitter that transmitted the electromagnetic wave at the unit cell, a beamforming factor of the transmitter at the unit cell and a conversion compensation factor of the unit cell, and

whereby the conversion compensation factor of the unit cell is computed based on a mode number of the multi-mode vortex beam transmitted by the transmitter and an azimuth angle of the unit cell as computed based on an axis perpendicular to a plane of the first surface of the unit cell.

9. The method according to claim 8, whereby the quadrature phase shifter circuit comprises:

a first delay line having an end coupled to the via and another end coupled to a first switch, a second switch and a third switch, the first delay line being configured to provide a 0-degree phase shift to the electromagnetic wave received by the antenna;

a second delay line having an end coupled to the first switch and having a section coupled to a first control line, the second delay line being configured to provide a 90-degree phase shift to the electromagnetic wave received by the antenna;

a third delay line having an end coupled to the second switch and having a section coupled to a second control line, the third delay line being configured to provide a 180-degree phase shift to the electromagnetic wave received by the antenna; and

a fourth delay line having an end coupled to the third switch and having a section coupled to a third control line, the fourth delay line being configured to provide a 270-degree phase shift to the electromagnetic wave received by the antenna.

10. The method according to claim 8, whereby the phase compensation factor of the transmitter to the unit cell is computed based on a wave vector k of the multi-mode vortex beam transmitted by the transmitter and a distance d_{T-RIS} between the transmitter and the unit cell.

11. The method according to claim 10, whereby the beamforming factor of the transmitter at the unit cell is computed based on the wave vector k of the multi-mode vortex beam transmitted by the transmitter, a spatial location of the unit cell on the reconfigurable intelligent surface, and a direction of a modified electromagnetic wave as re-radiated from the antenna of the unit cell.

12. A method for wireless communication using a reconfigurable intelligent surface system comprising a layer having a plurality of 2-bit phase-quantized unit cells and a control module communicatively coupled to each of the plurality of 2-bit phase-quantized unit cells, the method comprising:

receiving, using the plurality of 2-bit phase-quantized unit cells, electromagnetic waves transmitted from a transmitter, wherein each of the received electromagnetic waves comprises a multi-mode vortex beam;

for each of the plurality of 2-bit phase-quantized unit cells,

computing, using the control module, a phase shift to be provided by the unit cell based on a phase compensation factor of the transmitter at the unit cell, a beamforming factor of the transmitter at the unit cell and a conversion compensation factor of the unit cell, whereby the conversion compensation factor of the unit cell is computed based on a mode number of the multi-mode vortex beam transmitted by the transmitter and an azimuth angle of the unit cell as computed based on an axis perpendicular to a plane of the first surface of the unit cell, and

providing, using the control module, control signals to the unit cell such that the unit cell is triggered to provide the computed phase shift to the electromagnetic wave received by the unit cell and to re-radiate a phase shifted electromagnetic signal.

13. The method according to claim 12, whereby each of the 2-bit phase-quantized unit cells comprise:

an antenna provided on a first surface of the unit cell,

a quadrature phase shifter circuit provided on a second surface of the unit cell and communicatively connected to the antenna through a via, the quadrature phase shifter circuit being configured to selectively provide a phase shift of 0-degrees, 90-degrees, 180-degrees, or 270-degrees to an electromagnetic wave received by the antenna based on control signals received from the control module.

14. The method according to claim 12, whereby the phase compensation factor of the transmitter to the unit cell is computed based on a wave vector k of the multi-mode vortex beam transmitted by the transmitter and a distance d_{T-RIS} between the transmitter and the unit cell.

15. The method according to claim 12, whereby the beamforming factor of the transmitter at the unit cell is computed based on the wave vector k of the multi-mode vortex beam transmitted by the transmitter, a spatial location of the unit cell on the layer, and a direction of a modified electromagnetic wave as re-radiated from the antenna of the unit cell.