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一种多波束可旋转的金属波导太赫兹阵列天线

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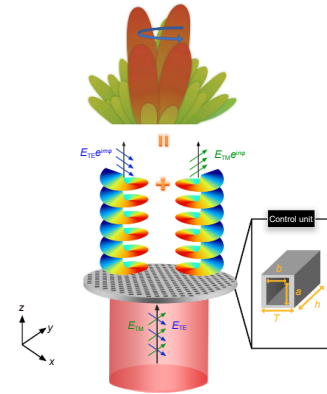
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摘要: 随着移动通信的高速发展和通讯环境的日益复杂, 多波束天线在多目标雷达、卫星通信以及多点无线通信等领域有着广泛的应用需求。轨道角动量是电磁波的基本属性之一, 它具有螺旋形波前, 可独立于振幅、相位、偏振等基本属性, 能为电磁波提供新的复用维度。基于亚波长金属波导阵列对电磁波优异的调控能力, 我们设计了一种多波束可旋转的太赫兹 (THz) 阵列天线, 通过调控入射波两正交偏振分量的相位分布, 可将其分别转化成强度分布一致、阶数相反的涡旋波束。通过改变两分量的相位差, 可实现 45° 偏振方向上波束的干涉图样发生旋转。此外, 该阵列天线还展现出了高增益 (31 dBi) 和宽带宽 (61 GHz) 的特性。该工作可为基于多波束阵列天线的方位角测量提供新的思路, 对丰富 THz 频段的阵列天线设计具有重要意义。

关键词: 太赫兹波; 涡旋波束; 多波束天线; 方位角测量

中图分类号: O441.4

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A multibeam rotatable metallic waveguide terahertz array antenna

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Abstract: With the high-speed development of mobile communication and the increasingly complex communication environment, multibeam antennas are widely required in the application fields of multi-target radar, satellite

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communication, multi-point wireless communication, etc. Orbital angular momentum is one of the fundamental properties of electromagnetic waves. It has a spiral wavefront and is independent of basic properties such as amplitude, phase, and polarization. It can provide a new multiplexing dimension for electromagnetic waves. Based on the excellent electromagnetic control capability of the sub-wavelength metal waveguide array, we designed a multibeam rotatable terahertz (THz) array antenna. By adjusting the phase distribution of two orthogonal polarization components of the incident wave, they can be transformed into two vortex beams with the same intensity distributions and opposite orders. The interferometric patterns in the 45° polarization direction can be rotated by changing the phase difference between the two components. Moreover, the array antenna also shows the performance of high gain (31 dBi) and wide bandwidth (up to 61 GHz). This work can provide a new way for azimuth measurement based on multibeam array antennas and is of great significance to enrich the design of array antennas in the THz band.

Keywords: terahertz wave; vortex beam; multibeam antenna; azimuth measurement

1 引言

为了提高频谱资源的利用率, 增加信道容量, 能够同时产生多个独立波束的多波束天线被越来越多地应用在各个领域^[1-4], 如多目标天线雷达^[5-7]、卫星通信^[8-10]以及无人驾驶设备^[11]等。太赫兹 (THz) 波具有丰富的频谱资源, 可以大幅度提高通信带宽, 实现超高速无线通信, 可以满足通讯信息量迅速上涨的需求, 相比于传统天线, THz 天线具有频率更高、带宽更宽、波束更窄的特点, 这些特点赋予了 THz 天线巨大的应用潜力^[12]。涡旋波束因为携带了轨道角动量而在天线通信系统信道容量、提升信号传输速率方面有广泛的应用前景^[13-16], 利用涡旋波束的干涉特性实现多波束旋转为完成对目标方位角的测量提供了新的思路。

利用亚波长尺度单元阵列构成的调控器件如超表面^[17-18]等, 可实现对 THz 波的灵活操纵和调控。本文所用的金属矩形波导是波导系统中一种常见的波导结构, 其波导壁由金属材料制成, 具有规则的矩形截面、腔体内可填充电介质 (一般是空气) 的特征^[19]。它能像传输相位型超表面一样通过电磁波在传输过程中产生的光程差来实现相位调控, 根据矩形波导理论, 每个矩形孔支持两个正交偏振态的基模 (TE_{01} 模和 TE_{10} 模), 因此与电介质超表面相比, 这种金属波导单元对电磁波的控制主要依赖于垂直于偏振方向孔的尺寸, 单个矩形孔可以实现两个正交偏振波的独立控制^[20]。更重要的是, 相位延迟与空穴尺寸之间的解析关系可以清晰地表达出来, 更方便我们控制单元的选择。此外, 由于异常透射效应^[21]的存在, 该亚波长金属矩形孔有着异常高的透射率, 便于器件的设计与实际应用。

在本文中, 我们提出了一种基于金属波导阵列的多波束可旋转 THz 天线。通过设计单元的结构尺寸, 可以同时且独立调控其所传导的两种正交模式在 $0\sim 2\pi$ 范围内的相位延迟。进而通过设置一系列金属波导单元的排布, 可将入射波两正交偏振分量转化为阶数相反的涡旋波束。由于这两束波的偏振方向相互正交, 因而无法直接干涉, 但其在其它偏振方向如 45° 方位角上的投影分量可以发生干涉。而干涉增强 (或减弱) 的方位角与入射波两正交分量的相位差成正比, 因此可通过改变该相位差, 使得干涉波束发生旋转, 从而实现利用两正交分量的相位差对旋转波束方位角的调控。所设计拓扑阶数为 $m = \pm 1$ 的涡旋阵列天线可产生双波束远场辐射图样, 其远场增益为 31 dBi, 其 3 dB 带宽高达 61 GHz (114~175 GHz, 相对带宽 42.2%)。通过采用更高拓扑阶数的涡旋波束进行干涉, 还可以产生更多的波束。所提出的多波束旋转可控的 THz 阵列天线可为雷达天线的方位角测量提供新的思路, 对丰富 THz 频段的阵列天线设计具有重要意义。

2 原理与理论模拟

2.1 设计原理

图 1 展示了一个基于金属波导的多波束可旋转 THz 阵列天线示意图。所用的控制单元是内部为空气的亚波长矩形金属孔, 如插图所示, 其可看作是一种金属波导。基于波导理论, 当内部孔的尺寸大于半波长时, 可以支持两种具有正交偏振态的基模 TE_{01} 和 TE_{10} 模, 金属波导单元对电磁波的调控主要依赖于垂直于偏振方向上孔的尺寸, 其可实现对 THz 波两个

正交偏振分量的独立控制。将一系列金属波导单元按一定规律进行排列, 可将入射平面 THz 波的两正交偏振分量分别转化成 ± 1 阶涡旋波束。这两束波的振幅分布相同、涡旋相位变化方向相反。由于这两束波的偏振方向相互正交, 因而无法直接干涉, 但它们在其它偏振方向如 45° 方位角上的投影分量可以发生干涉, 两正交偏振波的相位差与干涉增强的方位角有直接对应关系, 即^[22]:

$$\theta_d = \frac{\Delta\varphi - n\pi}{2m} \begin{cases} \text{当 } m \text{ 为奇数时, } n \text{ 为奇数} \\ \text{当 } m \text{ 为偶数时, } n \text{ 为偶数} \end{cases}, \quad (1)$$

其中: θ_d 为干涉增强的方位角, m 为涡旋波束的拓扑荷数, 当 $m = 1$ 且 $n = 1$ 时, 式 (1) 可以写为:

$$\theta_d = \frac{\Delta\varphi - \pi}{2}. \quad (2)$$

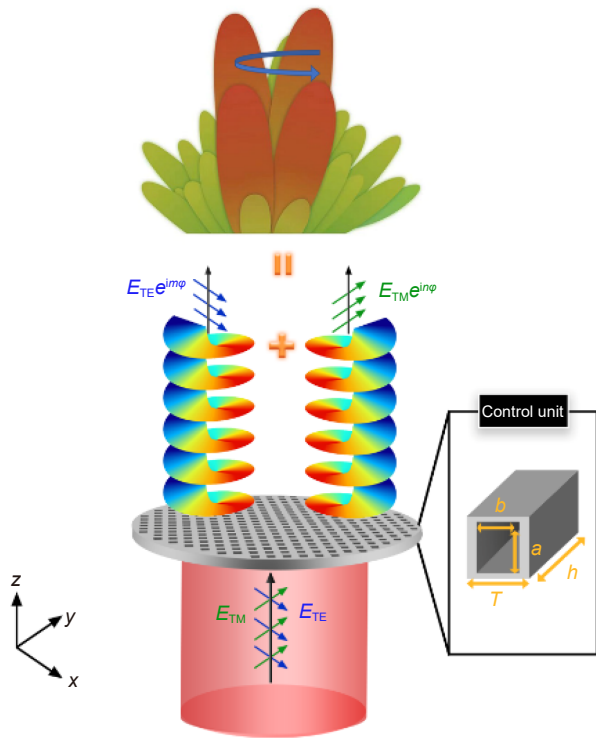


图 1 基于金属波导的多波束可旋转 THz 阵列天线示意图
Fig. 1 Schematic diagram of a multibeam rotatable THz array antenna based on metallic waveguides

由式 (2) 可知, 干涉增强的方位角 θ_d 与入射波两正交偏振分量的相位差 $\Delta\varphi$ 存在线性关系, 这意味着可通过改变相位差 $\Delta\varphi$ 实现 45° 偏振方向上干涉图样的方位角 θ_d 的变化, 即干涉图样的旋转。

涡旋波束是一种具有螺旋相位波前的特殊光场, 相位分布中含有 $\exp(im\theta)$ 项, θ 为螺旋形相位的方位角, 在传输过程中每绕光轴转一周, 波前的相位就改变 $2m\pi$, 其携带的相位可以表示为

$$\varphi(x, y) = m\theta. \quad (3)$$

2.2 调控单元的选择

所采用的工作频率为 0.14 THz, 调控单元中所用金属为 Al, 其相对介电常数可通过 Drude 模型计算得到^[23]。铝孔中的电介质是空气, 其折射率 $n_0 = 1$, 所设计调控单元的周期 $T = 2 \text{ mm}$, 厚度 $h = 6 \text{ mm}$ 。在工作频率下, 但金属为完美电导体时, x 偏振的 THz 的传播常数可以写为^[20]

$$k_x = \sqrt{n_0^2 k_0^2 - (\pi/b)^2}, \quad (4)$$

同理, y 偏振的 THz 的传播常数可以写为

$$k_y = \sqrt{n_0^2 k_0^2 - (\pi/a)^2}, \quad (5)$$

其中 $k_0 = 2\pi/\lambda$ 为波数, n_0 为金属波导单元中介质的折射率, a 为金属波导单元在 x 方向上的尺寸, b 为在 y 方向上的尺寸。当 THz 波通过厚度为 h 的金属波导单元后, 累积的相位延迟分别为 $\Phi_x = k_x h$ 和 $\Phi_y = k_y h$, 因此可以知道金属波导单元对电磁波的调控主要依赖于垂直于偏振方向上孔的尺寸, 其可实现对 THz 波两个正交偏振分量的独立控制。式 (4) 与式 (5) 明确了相位延迟与尺寸 (a, b) 的解析关系。通过商用软件 COMSOL 模拟, 也同时可以计算得出相位延迟与结构参数的关系, 与解析关系较为吻合。我们选取了 64 个金属波导调控单元, 用于完整覆盖 x 偏振分量与 y 偏振分量 $0 \sim 2\pi$ 的相位延迟, 且相位变化间隔均为 $\pi/4$ 。由于异常透射效应的存在, 这 64 个调控单元中的绝大多数透射率都大于 90%, 这为实现高增益提供了有利的前提条件, 其具体尺寸如表 1 所示^[22]。

3 天线仿真结果

通过式 (3) 可以获得涡旋阵列天线所需实现的相位延迟, 再根据此相位延迟对金属波导单元进行排布, 从而得到偏振复用高增益涡旋透射阵列天线。当入射波沿方位角为 45° 的方向偏振时, 该阵列天线可将入射波的两个正交偏振分量分别转化为 ± 1 阶高增益涡旋波束, 这两束波的振幅相等, 涡旋相位变化相等。虽然这两束正交偏振波无法直接干涉, 但二者在 45° 方位角方向上的投影分量可以相互干涉。当入射波两正交分量的相位差分别为 0° 、 90° 、 180° 和 270° 时, 由商业软件 COMSOL 模拟所得的三维远场辐射图样如图 2(a-d) 所示。由图可知, 当二者的相位差发生变化时, 远场多波束辐射图样也沿着 z 轴旋转, 旋转的角度与入射波两正交分量的相位差成正比, 因此可以通过改变正交偏振分量之间的相位差实现多波束的旋转。旋转角度与相位差之间的关系如图 3 所示, 其中

表 1 64 个金属矩形孔的尺寸 (a, b)

Table 1 Dimensions (a, b) of 64 selected sub-wavelength metallic holes

		Value/mm							
(a, b)	(1.8, 1.8)	(1.528, 1.614)	(1.366, 1.488)	(1.264, 1.408)	(1.729, 1.382)	(1.478, 1.311)	(1.346, 1.258)	(1.244, 1.217)	
	(1.242, 1.699)	(1.632, 1.632)	(1.437, 1.502)	(1.304, 1.413)	(1.224, 1.343)	(1.568, 1.318)	(1.407, 1.263)	(1.285, 1.22)	
	(1.283, 1.709)	(1.78, 1.652)	(1.514, 1.514)	(1.36, 1.42)	(1.258, 1.346)	(1.717, 1.328)	(1.469, 1.269)	(1.343, 1.224)	
	(1.328, 1.718)	(1.237, 1.55)	(1.616, 1.529)	(1.428, 1.428)	(1.298, 1.35)	(1.22, 1.284)	(1.557, 1.275)	(1.404, 1.228)	
	(1.382, 1.729)	(1.275, 1.558)	(1.762, 1.544)	(1.503, 1.437)	(1.355, 1.355)	(1.252, 1.288)	(1.707, 1.283)	(1.461, 1.232)	
	(1.454, 1.742)	(1.318, 1.57)	(1.232, 1.461)	(1.597, 1.445)	(1.42, 1.36)	(1.292, 1.292)	(1.216, 1.244)	(1.547, 1.236)	
	(1.543, 1.759)	(1.374, 1.583)	(1.268, 1.469)	(1.744, 1.455)	(1.488, 1.366)	(1.349, 1.298)	(1.247, 1.247)	(1.7, 1.242)	
	(1.651, 1.779)	(1.445, 1.598)	(1.301, 1.476)	(1.228, 1.403)	(1.582, 1.373)	(1.414, 1.305)	(1.288, 1.252)	(1.214, 1.214)	

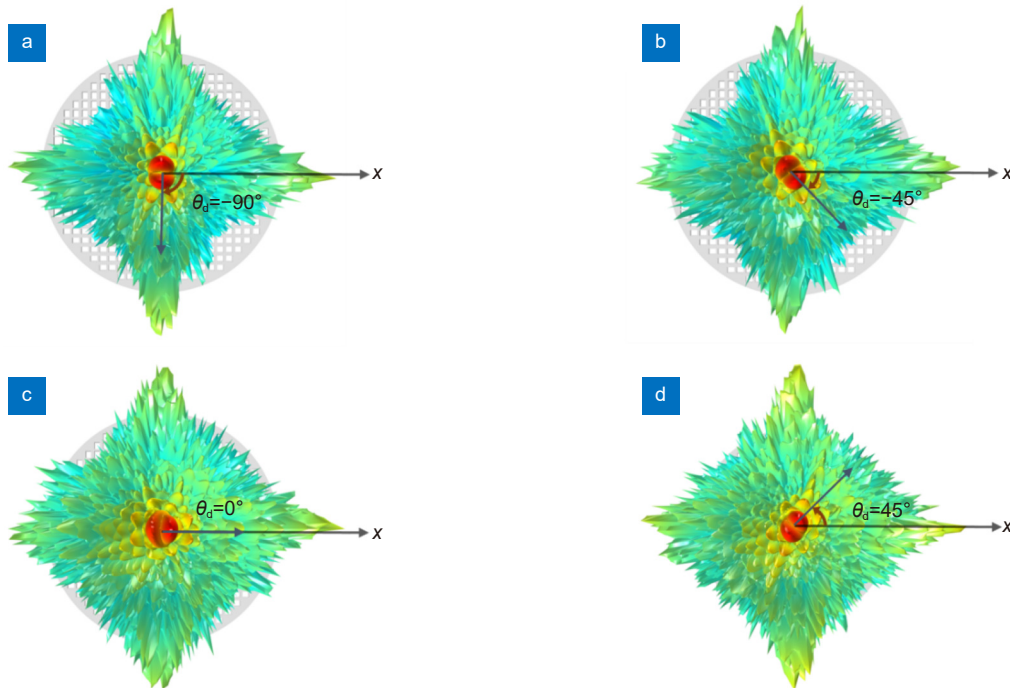


图 2 入射波两正交偏振分量的相位差为 (a) 0°, (b) 90°, (c) 180°, 和 (d) 270° 时的三维辐射图样

Fig. 2 Three-dimensional radiation patterns under the phase difference of two orthogonal polarization components being (a) 0°, (b) 90°, (c) 180°, and (d) 270°, respectively

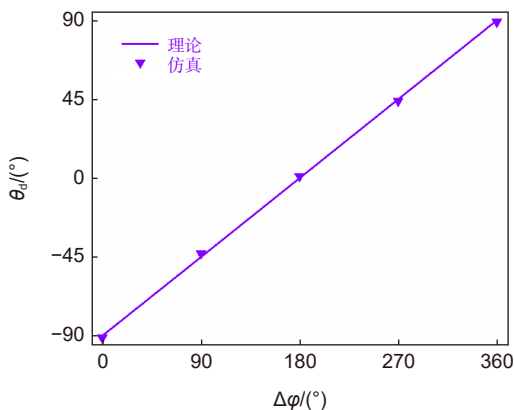


图 3 干涉增强方位角 θ_0 与两偏振分量的相位差 $\Delta\varphi$ 的关系

Fig. 3 The dependence of the interference-enhanced azimuth angle θ_0 on the different phase differences $\Delta\varphi$ between x- and y-polarized components

三角点为仿真模拟所得结果，直线是由式 (2) 所得结果。由图可见，理论与仿真结果十分吻合。

当阵列天线直径为 52 mm ($\approx 24.2\lambda$), 两正交偏振分量的相位差为 0 时, xz 平面的二维远场方向图如图 4(a) 所示, 当入射波为均匀平面波时, 两个主瓣波束的增益均为 31 dBi, 旁瓣增益比主瓣增益低 17.4 dBi, 0°方位角处增益比主瓣增益低 15.5 dB, 插入损耗仅为 1.4 dB, 不同相位差下该阵列天线的增益基本保持一致。其 3 dB 波束宽度仅为 1.98°, 这也为实现高增益提供了便利。此外, 由图 4(b) 可知, 该阵列天线的 3 dB 带宽高达 61 GHz (114~175 GHz, 相对带宽 42.2%)。其 -10 dB 反射系数带宽为 27 GHz (115~142 GHz)。因此, 该阵列天线的工作带宽极宽。

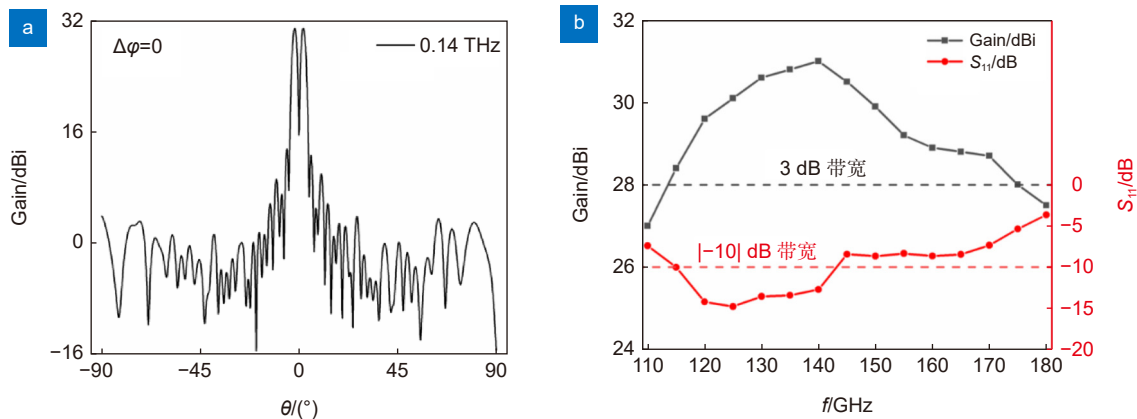


图 4 (a) 当两偏振分量相位差为 0 时在 xz 平面的二维远场方向图; (b) 增益和反射系数 S_{11} 随频率的变化曲线

Fig. 4 (a) Two-dimensional far-field radiating pattern in the xz plane for $\Delta\phi = 0$;
(b) Dependences of the gain and reflection coefficient S_{11} frequency

4 结论

我们提出了一种基于金属波导的多波束可旋转 THz 阵列天线。通过设置一系列金属波导单元的排布, 可将入射波两正交偏振分量转化为阶数相反的涡旋波束。这两束波在其它偏振方向如 45° 方位角上的投影分量可以发生干涉, 而干涉增强(或减弱)的方位角与入射波两正交分量的相位差成正比, 因此可以利用两正交分量的相位差对旋转波束方位角的调控。该阵列天线的远场增益为 31.0 dBi, 其 3 dB 带宽高达 61 GHz (114 ~ 175 GHz, 相对带宽为 42.2%), 插入损耗仅为 1.4 dB。所提出的多波束旋转可控的 THz 阵列天线可丰富 THz 频段的阵列天线设计, 能够为雷达天线的方位角测量提供新的思路。

参考文献

- [1] Chen S Z, Zhao J. The requirements, challenges, and technologies for 5G of terrestrial mobile telecommunication[J]. *IEEE Commun Mag*, 2014, **52**(5): 36-43.
- [2] Chowdhury M Z, Shahjalal M, Ahmed S, et al. 6G wireless communication systems: applications, requirements, technologies, challenges, and research directions[J]. *IEEE Open J. Commun. Soc.*, 2020, **1**: 957-975.
- [3] Dahlman E, Mildh G, Parkvall S, et al. 5G wireless access: requirements and realization[J]. *IEEE Commun Mag*, 2014, **52**(12): 42-47.
- [4] Hong W, Jiang Z H, Yu C, et al. Multibeam antenna technologies for 5G wireless communications[J]. *IEEE Trans Antennas Propag*, 2017, **65**(12): 6231-6249.
- [5] Cheng Y B, Gu H, Su W M. A new method for fast multi-target localization in bistatic MIMO radar[J]. *J Electron Inf Technol*, 2012, **34**(2): 312-317.
程院兵, 顾红, 苏卫民. 一种新的双基地MIMO雷达快速多目标定位算法[J]. *电子与信息学报*, 2012, **34**(2): 312-317.
- [6] Liu C, Wang Y J. Review of multi-target tracking technology for marine radar[J]. *J. Radars*, 2021, **10**(1): 100-115.
柳超, 王月基. 对海探测雷达多目标跟踪技术综述[J]. *雷达学报*, 2021, **10**(1): 100-115.
- [7] Yi W, Zhou T, Ai Y, et al. Suboptimal low complexity joint multi-target detection and localization for non-coherent MIMO radar with widely separated antennas[J]. *IEEE Trans Signal Process*, 2020, **68**: 901-916.
- [8] Zhou L Z, Li D, Guo W J. Review of multiple-beam antennas for satellite communications[J]. *Acta Electron Sin*, 2001, **29**(6): 824-828.
周乐柱, 李斗, 郭文嘉. 卫星通信多波束天线综述[J]. *电子学报*, 2001, **29**(6): 824-828.
- [9] Yu L, Wan J X, Zhang K, et al. Spaceborne multibeam phased array antennas for satellite communications[J]. *IEEE Aerosp Electron Syst Mag*, 2023, **38**(3): 28-47.
- [10] Martinez-De-Rioja E, Encinar J A, Florencio R, et al. 3-D bifocal design method for dual-reflectarray configurations with application to multibeam satellite antennas in Ka-band[J]. *IEEE Trans Antennas Propag*, 2019, **67**(1): 450-460.
- [11] Luo Q, Gao S, Li W T, et al. Multibeam dual-circularly polarized reflectarray for connected and autonomous vehicles[J]. *IEEE Trans Veh Technol*, 2019, **68**(4): 3574-3585.
- [12] Wang S H, Xu J Z, Wang L, et al. Applications and prospects of terahertz technology[J]. *Physics*, 2001, **30**(10): 612-615.
王少宏, 许景周, 汪力, 等. THz技术的应用及展望[J]. *物理*, 2001, **30**(10): 612-615.
- [13] Lu X H, Huang H Q, Zhao C L, et al. Optical vortex beams and optical vortices[J]. *Laser Optoelectron Progress*, 2008, **45**(1): 50-56.
陆璇辉, 黄慧琴, 赵承良, 等. 涡旋光束和光学涡旋[J]. *激光与光电子学进展*, 2008, **45**(1): 50-56.
- [14] Xu J C, Guo Y X, Yang P Y, et al. Recent progress on RF orbital angular momentum antennas[J]. *J Electromagn Waves Appl*, 2020, **34**(3): 275-300.
- [15] Wang H, Li Y F, Han Y J, et al. Vortex beam generated by circular-polarized metasurface reflector antenna[J]. *J Phys D:Appl Phys*, 2019, **52**(25): 255306.
- [16] Guo Z Y, Gong C F, Liu H J, et al. Research advances of orbital angular momentum based optical communication technology[J]. *Opto-Electron Eng*, 2020, **47**(3): 190593.

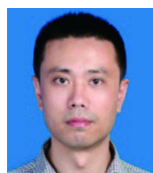
- 郭忠义, 龚超凡, 刘洪郡, 等. OAM光通信技术研究进展[J]. *光电工程*, 2020, **47**(3): 190593.
- [17] Cao T, Lian M, Chen X Y, et al. Multi-cycle reconfigurable THz extraordinary optical transmission using chalcogenide metamaterials[J]. *Opto-Electron Sci*, 2022, **1**(1): 210010.
- [18] Fan J X, Li Z L, Xue Z Q, et al. Hybrid bound states in the continuum in terahertz metasurfaces[J]. *Opto-Electron Sci*, 2023, **2**(4): 230006.
- [19] Liu X G, Guo H P. *Microwave Technology and Antennas*[M]. 2nd ed. Xi'an: Xidian University Press, 2001.
刘学观, 郭辉萍. 微波技术与天线[M]. 2版. 西安: 西安电子科技大学出版社, 2001.
- [20] Liang H W, Li J Q, Wu Z Y, et al. Metallic waveguide arrays for metasurface-like control with high simplicity in design[J]. *Adv Opt Mater*, 2020, **8**(18): 2000605.
- [21] Ebbesen T W, Lezec H J, Ghaemi H F, et al. Extraordinary optical transmission through sub-wavelength hole arrays[J]. *Nature*, 1998, **391**(6668): 667-669.
- [22] Jiang Z, Lu J H, Fan J Y, et al. Polarization-multiplexing bessel vortex beams for polarization detection of continuous terahertz waves[J]. *Laser Photon Rev*, 2023, **17**(3): 2200484.
- [23] Ordal M A, Bell R J, Alexander R W, et al. Optical properties of fourteen metals in the infrared and far infrared: Al, Co, Cu, Au, Fe, Pb, Mo, Ni, Pd, Pt, Ag, Ti, V, and W[J]. *Appl Opt*, 1985, **24**(24): 4493-4499.

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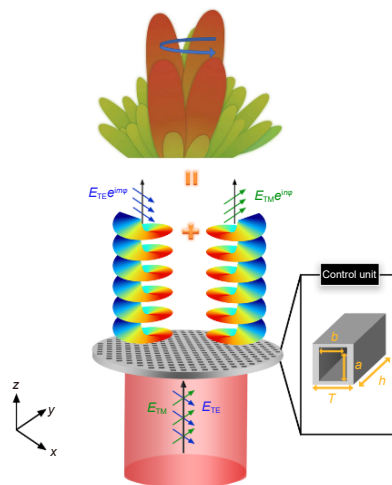
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A multibeam rotatable metallic waveguide terahertz array antenna

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Schematic diagram of a multibeam rotatable THz array antenna.

Overview: With the high-speed development of mobile communication and the increasingly complex communication environment, multibeam terahertz (THz) antennas with the characteristics of high frequency, wide bandwidth and narrow beam have great application potential in 6G wireless communication. The vortex beam carrying orbital angular momentum has a broad application prospect in enhancing the channel capacity of the communication system and improving the signal transmission rate. Using the interference of vortex beams to realize multibeam rotation can provide a new way for accomplishing the azimuth measurement of the target.

A metallic waveguide can be used as the control unit for full control of the phase, polarization, and amplitude of THz wave. In contrast to the plasmonic and dielectric metasurfaces, the phase delay of the waveguide unit is dependent and independent on the hole dimensions perpendicular and parallel to the polarization direction, respectively. Furthermore, the amplitude and polarization can be completely controlled by tuning the dimension and the orientation angle of metal holes. Notably, the analytical relationship between the phase delay and hole dimensions can be presented explicitly, which greatly simplifies the design process to select the waveguide array for a desired phase distribution. Due to the extraordinary transmission effect, the sub-wavelength metal rectangular hole can attain a very ultra-high transmittance, which is convenient for the device design and practical application. This control unit not only demonstrates a facile scheme to manipulate EM waves but also draws a promising approach to realize multifunctional devices with simplified design and high durability.

In this paper, a multibeam rotatable THz array antenna based on metallic waveguides is proposed. Thanks to the excellent control properties of the metallic waveguides, the phase delay of the two orthogonal polarization modes can be tuned in the range of $0 \sim 2\pi$ by designing the cell structure size. By manipulating the phase distribution, the two orthogonal polarization components can be transformed into vortex beams with the same intensity distributions and opposite orders. The polarization directions of the two components are orthogonal to each other, and thus they cannot interfere directly. However, their 45° polarized components can interfere, and the interferometric pattern can be rotated by changing the phase difference between the two components. Moreover, the array antenna also shows the performance of high gain (31.0 dBi) and wide bandwidth (up to 61 GHz). The proposed multi-beam rotatable THz array antenna can provide a new way for the azimuth measurement of radar antennas and is of great significance in enriching the design of array antennas in the THz band.

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