TABLE S_1: Band- and application-resolved quantitative summary for representative static phase-control mechanisms. Efficiency types: R = reflection; T = transmission; FE = focusing efficiency; AE = aperture efficiency; n.r. = not explicitly reported.

Band	Application	Mechanism	Phase Range	Efficiency	3-dB BW	Reference
Microwave band						
Microwave	GRIN lens / focusing	Propagation (GRIN)	Full 0–2π	$>50\%$ (AE at center frequency)	65% (gain)	[1]
Microwave	GRIN lens / focusing	Propagation (GRIN)	Full 0–2π	Max 67% (AE); $>50\%$ over X-band	66% (impedance BW)	[2]
Microwave	Beam steering / nonreciprocal	PB (magneto-optical)	Full 0–2π	Up to 96% (1st-order diffraction, forward)	n.r.	[3]
Microwave	High-efficiency lens	Huygens	Full 0–2π	$>86\%$ (T)	15–20%	[4]
Microwave	Full-space bifunctional (CP-decoupled R/T)	PB + Propagation	Full 0–2π	$\sim 83\%$ (co-pol T, 9 GHz)	n.r.	[5]
Microwave	Independent CP reflection	PB + Propagation	Full 0–2π	$>90\%$ (co-pol R)	$>40\%$ (fractional BW)	[6]
Optical band (Visible)						
Visible	Anomalous reflection	Resonant (plasmonic)	Up to $\sim 2\pi$	$\sim 85\%$ (R)	$\sim 85\%$	[7]
Visible	Metalens	Propagation (dielectric)	Full 0–2π	Up to $\sim 90\%$ (T)	n.r.	[8]
Visible	Metalens	Propagation (dielectric)	Full 0–2π	$>95\%$ (T)	n.r.	[9]
Visible	PB metalens	PB (dielectric)	Full 0–2π	66–86% (FE)	n.r.	[10]
Visible	PB wavefront shaping	PB (plasmonic)	Full 0–2π	$\sim$ 13–23% (T)	n.r.	[11]
Visible	Achromatic metalens	PB + Resonance	Full 0–2π	$\sim 40\%$ (T)	49%	[12]
Optical band (NIR / Telecom)						
NIR	Phase-gradient control	Resonant (plasmonic)	$\approx$ 0–2π	$\sim$ 40–50% (R)	few %	[13]
NIR	Analog optical computing	Resonant (GSP)	0–2π	Up to $\sim 80\%$ (R)	$\sim$20%	[14]
NIR	Metalens	Propagation (dielectric)	Full 0–2π	$\sim$ 60–80% (FE)	n.r.	[15]
Telecom	Holography	Huygens	$\sim$ 0–2π	82% (T)	40 nm	[16]
NIR	Pulse shaping	Huygens	Full 0–2π	$>90\%$ (T)	n.r.	[17]

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TABLE S_1 – continued from previous page

Band	Application	Mechanism	Phase Range	Efficiency	3-dB BW	Reference
NIR	Spin multiplexing	PB + Resonance	Discrete 0–2π	$\sim$ 25–30% (R)	25%	[18]
NIR	Waveguide metalens	Propagation + Resonant	Full 0–2π	$\sim$ 16% (FE)	n.r.	[19]

TABLE S_2: Band- and application-resolved quantitative summary for representative *active* phase-control mechanisms. Insertion loss/efficiency metrics are reported as stated in the cited works (e.g., reflection magnitude, diffraction efficiency, or insertion loss in dB). "n.r." denotes not explicitly reported.

Band	Application	Mechanism	Phase Range	Insertion Loss / Eff.	3-dB BW	Special FOMs	Ref.
Microwave / RF band							
Microwave / RF	Programmable coding (R)	PIN diode switching	2-bit (4 states, $\sim$90° step)	$\sim$3 dB (R mag., all states)	$\sim$15–20% (per band)	Dual-band (C/Ku); $\sim$90° $\pm$ 15° spacing	[20]
Microwave / RF	Beamforming antenna	Varactor tuning	Continuous $\sim$150° (per element)	Max AE $\sim$11%	$\sim$4% (9.6–10 GHz)	2D steering: $\pm$50° (az.), $\pm$70° (el.)	[21]
Microwave / RF	Beam steering (R)	Varactor tuning	$\sim$330° (near 2π)	1.5 dB (unit-cell R loss)	$\sim$300 MHz (per state)	Full Ku coverage by retuning	[22]
Microwave / RF	Independent phase & amplitude (R)	Varactor + PIN	0–180° (varactor)	$\lvert R\rvert \approx$ 0.3–0.8 (amp. tuning)	$\sim$100 MHz ($\sim$2.2%)	$\Delta\lvert R\rvert < 22.2\%$; phase var. $< \pm 9°$	[23]
Microwave / RF	1-bit coding (R)	PIN diode switching	180° $\pm$ 20°	$<$ 0.9 dB (ON), $<$ 0.2 dB (OFF)	$\sim$8.2%	Energy conv.: $>$ 79.4% (ON), $>$ 94.4% (OFF)	[24]
Microwave / RF	Resistive coding (R)	Graphene gating	Binary π (1-bit)	$\lvert R\rvert \sim$ 0.33 (at resonance)	$\sim$5% ($\sim$500 MHz)	R_s: 2500–580 Ω/sq (tuned)	[25]
Microwave / RF	Independent phase & amplitude (R)	PIN coding + graphene gating	Binary π (PIN)	$\lvert R\rvert \sim$ 0.35–0.75 (tunable)	n.r. (functional: 5.2–5.6 GHz)	R_s: 290–1600 Ω/sq (tuned)	[26]
Terahertz band							
THz	Beam steering (deformation)	Liquid-crystal elastomer (opto-thermal)	Static 0–2π; dynamic steering via bending	Low–moderate (CSRR loss)	n.r. (functional: 0.48–1.1 THz)	Max steering tuning $\sim$22° at 0.68 THz	[27]
THz	Beam steering / focusing (R)	PCM (GST) switching	Abrupt $\sim \pi$ (state switching)	High reflectance (ground-backed)	n.r.	State change: amorphous $\leftrightarrow$ crystalline	[28]

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TABLE S_2 – continued from previous page

Band	Application	Mechanism	Phase Range	Insertion Loss / Eff.	3-dB BW	Special FOMs	Ref.
Optical band (Visible)							
Visible	Wavefront shaping / holography	LC tuning	Up to ~ 180–300°	$\sim$1–3 dB	n.r.	LC-overlayer dielectric metasurface	[29]
Visible	Switchable hologram / varifocal	LC + PB (TiO_2)	Full 0–2π (pol.-dep.)	$\sim$1–3 dB	n.r.	Helicity-selective intensity switching	[30]
Visible	Beam steering / holography	LC tuning (reflective)	Continuous 0–2π	$\sim$1–3 dB	n.r.	Diffraction efficiency (reported in paper)	[31]
Visible	SLM / beam steering (T)	LC-tuned Huygens	Discrete 0–2π (multi-level)	$\sim$3–5 dB	$\sim$10–20 nm	Beam steering eff. $\sim$36% (reported)	[32]
Visible	Reprogrammable holography (R)	Electromechanical MEMS (nano-kirigami)	Continuous 0–2π	n.r. (reported as high/constant)	n.r.	Pixel-addressable; voltage-driven deformation	[33]
Optical band (NIR / Telecom)							
NIR / Telecom	Wavefront modulation (resonant)	Electro-optic (Pockels, $LiNbO_3$)	Up to $\sim \pi$	$\sim$3–6 dB	n.r. (narrow)	q-BIC / QBIC resonance shift	[34]
NIR / Telecom	Wavefront shaping (resonant)	Electro-optic (Pockels, $LiNbO_3$)	Up to π	$\sim$3–6 dB	n.r. (narrow)	Static field: 2.6 kV/mm (reported)	[35]
NIR (1550 nm)	Resonant quasi-BIC EO modulation	LiNbO3 + LC (integrated)	2 (at resonance)	n.r.	narrow (high-Q)	/V 0.6 nm/V	[36]
NIR	Resonant phase-gradient (high-Q)	EO (Si-on-LiNbO3)	Resonant efficiency modulation	+1 order transmission up to $\sim 70\%$	Ultra-narrow (Q 3.1×10^4)	¿10 dB diffraction contrast	[37]
Mid-infrared band							
Mid-IR	Beam steering / phase tuning	Graphene gating (plasmonic)	Phase up to 237° (R)	$R \sim 1.5$–12% (on resonance)	n.r. (narrow)	Critical coupling; steering eff. $\sim$23% (ideal)	[38]
Mid-IR	Beam switching (discrete states)	Graphene gating (dielectric)	Discrete diffraction states (no cont. 2π)	$\sim$45–55% (diff. eff., per state)	n.r. (narrow)	Directivity $> 98\%$ (two-level), $> 90\%$ (three-level)	[39]
Phase-change materials (Optical / NIR)							
NIR	Multi-level phase modulation (R)	PCM (Sb_2Se_3)	Multi-level $> \pi$ (4-level)	$R0.5$ (typ. 0.6–0.8)	$\sim$ 42 nm (measured)	Reported: 1463–1505 nm (3 dB window)	[40]
NIR	Resonant phase tuning (R)	PCM (VO_2)	Up to $\sim 250^\circ$	Reflectance mod. $\sim$ 20–30%	n.r.	Joule heating (thermally limited)	[41]

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TABLE S_2 – continued from previous page

Band	**Application**	**Mechanism**	**Phase Range**	**Insertion Loss / Eff.**	**3-dB BW**	**Special FOMs**	**Ref.**
Telecom	Reconfigurable holography / OAM	PCM (GSST)	Full 0–2π (8-level)	Moderate (reported)	n.r.	Discrete 8 states; 1400–1600 nm operation (reported)	[42]

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