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Review:

Dispersion-Engineered Wideband Low-Profile Metasurface Antennas

Key words: Metasurface antenna, dispersion engineering, composite right/left-handed (CRLH), guided wave, surface wave, wideband, low profile

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Motivation

❖ Enhance the bandwidth of low-profile microstrip patch antennas

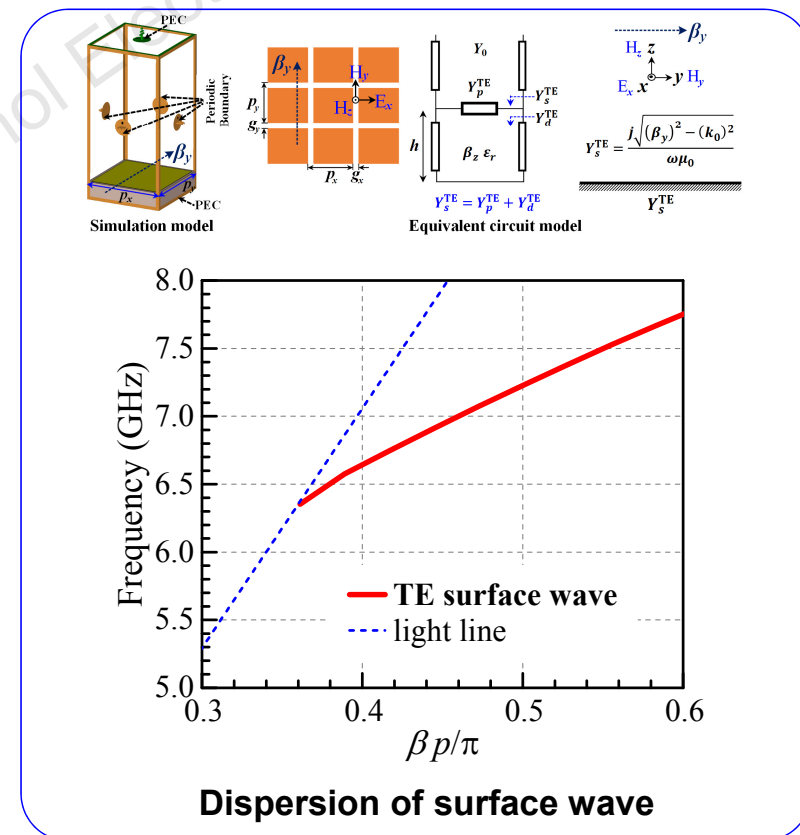
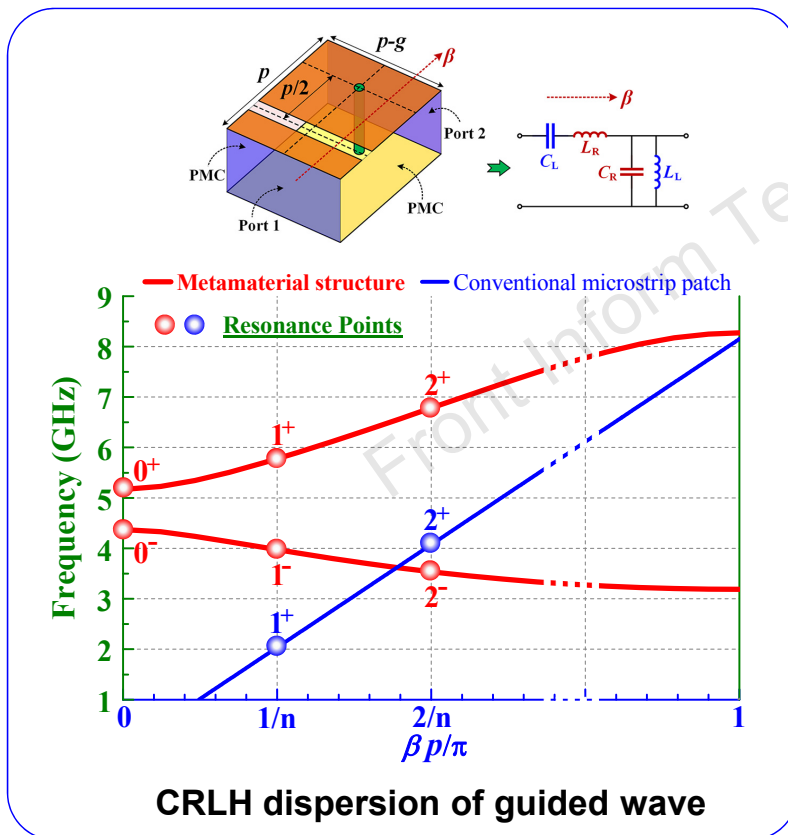
- ❑ Traditional patch antennas require **thick low-permittivity** substrate
- ❑ Using dispersion-engineered metasurfaces as radiators
 - Engineering dispersion relation
 - Electrically thin substrate
 - Applicable to relatively high permittivity

❖ Engineering dispersion of metasurface to improve antenna performance

- ❑ Reduce Size: Volume/Aperture/Profile
- ❑ Enhance Radiation: Directivity/Gain/Efficiency
- ❑ Widen Bandwidth: Impedance/Gain/Pattern/CP/RCS
- ❑ Enhance Beam-Scanning Capability
- ❑ Mutual coupling, beamwidth, ...

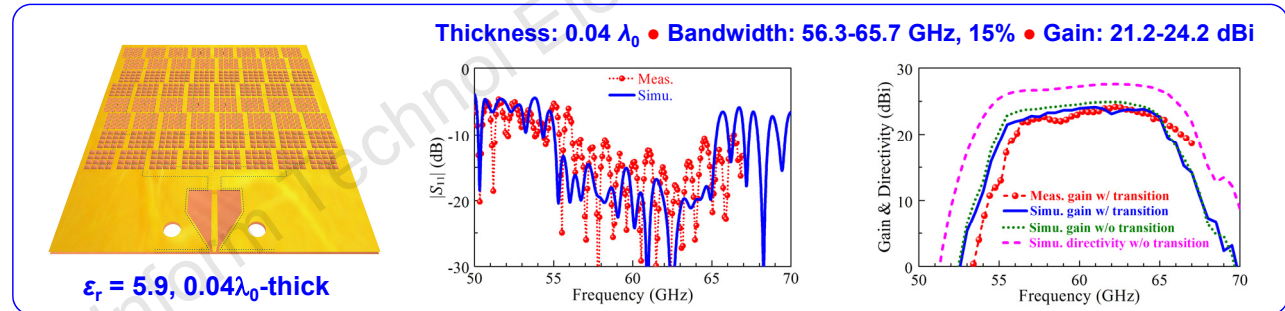
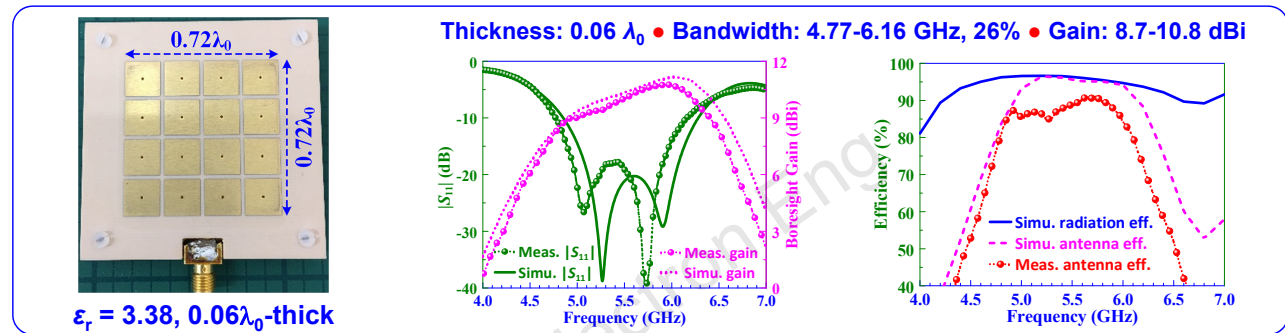
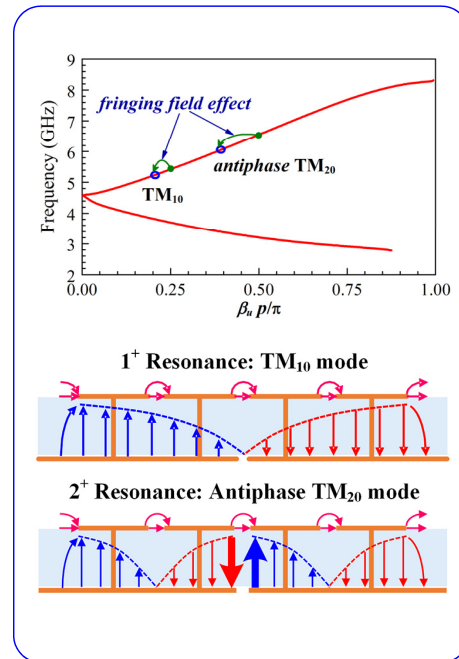
Dispersion-Engineered Metasurface (MTS)

- ❑ Engineering the dispersion of guided/surface waves with MTS
 - More resonances occurring in the same fractional bandwidth
- ❑ Multiple operating modes for desired radiation
 - Setting particular boundary conditions
 - Using proper excitation schemes

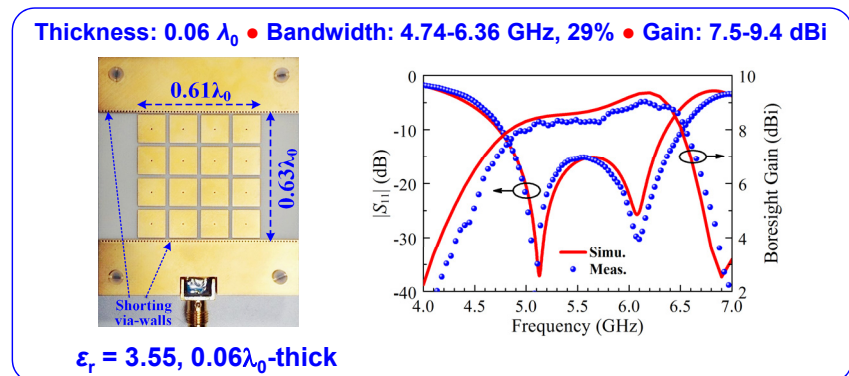
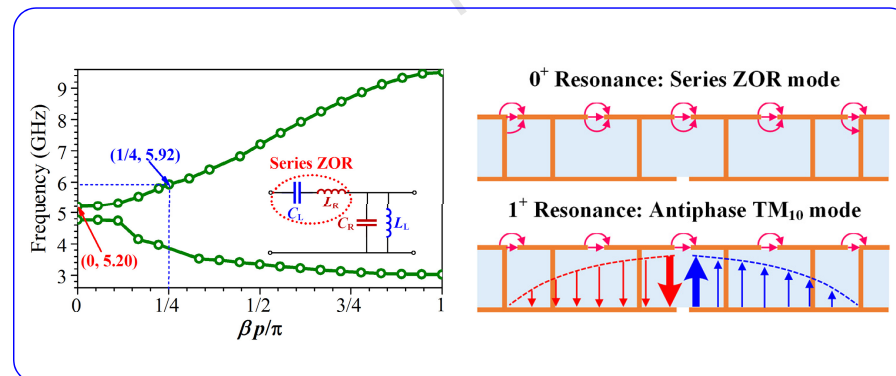


CRLH MTS Antennas

Open-Ended CRLH MTS Antennas

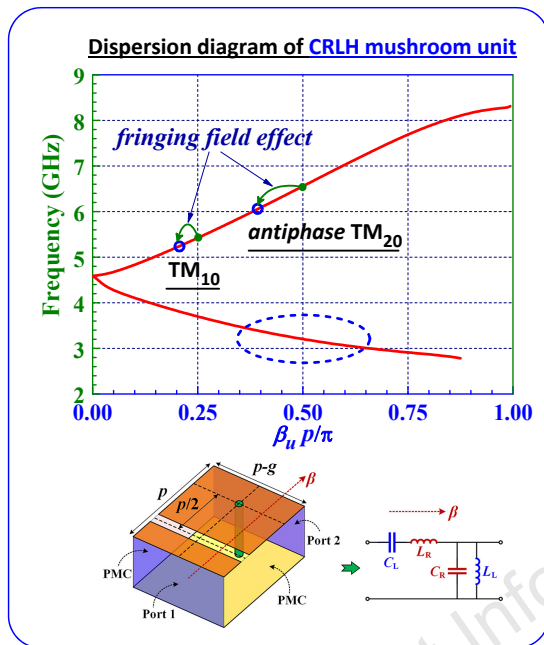


Short-Ended CRLH MTS Antenna



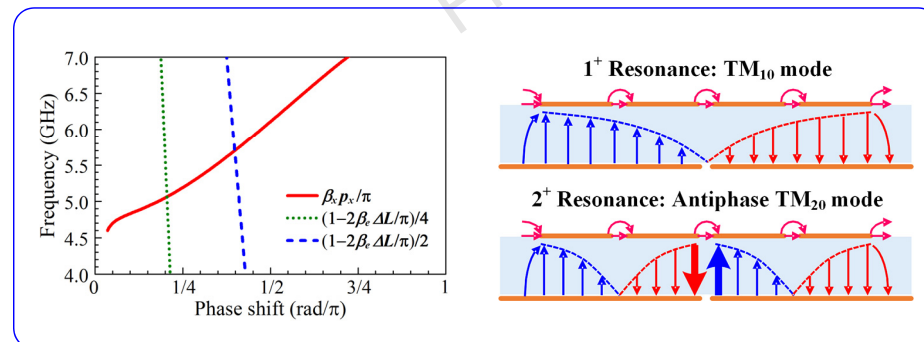
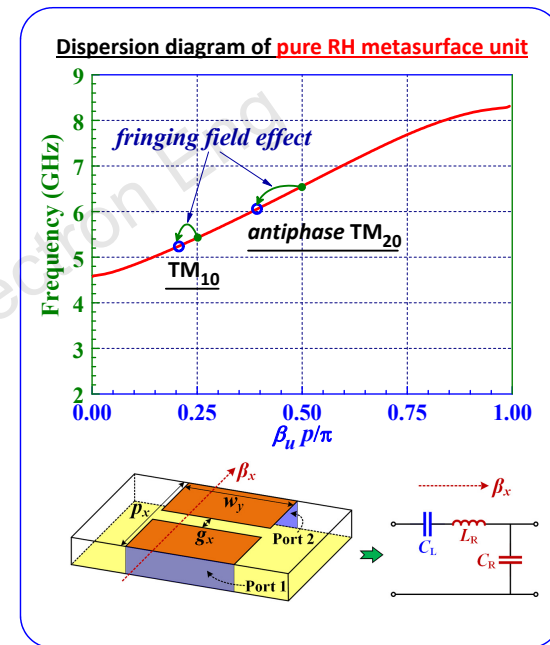
RH MTS Antenna

Open-Ended RH MTS Antenna

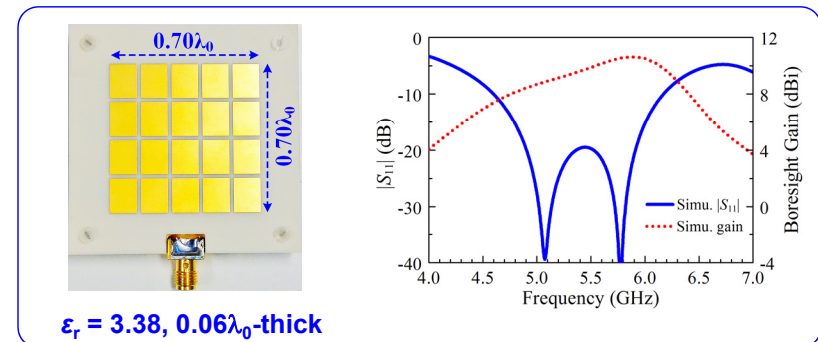


Two operating modes on
RH dispersion branch

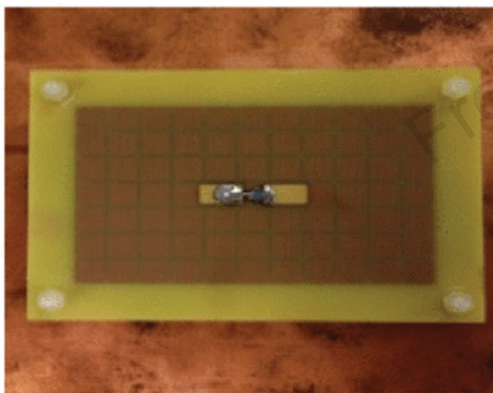
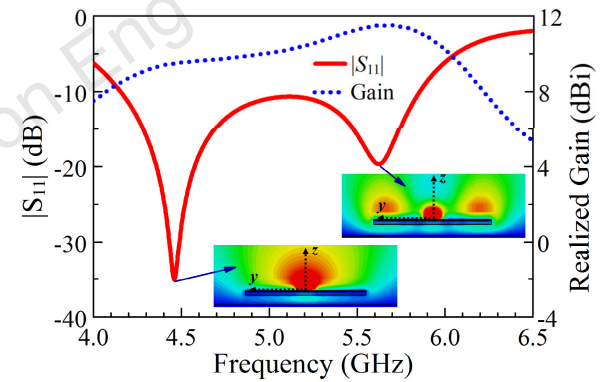
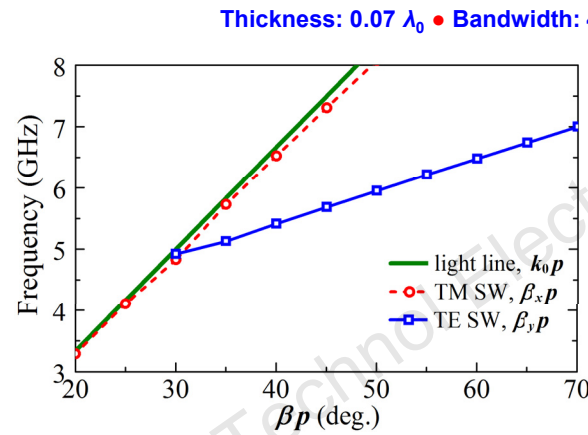
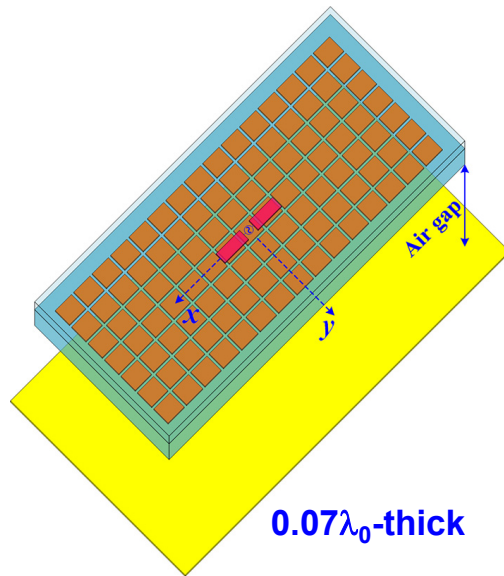
LH dispersion branch
is NOT necessary



Thickness: $0.06 \lambda_0$ • Bandwidth: 4.60-6.17 GHz, 29% • Gain: 7.4-10.6 dBi



SWR (Surface Wave Resonance) MTS Antenna



TE surface wave
resonance mode

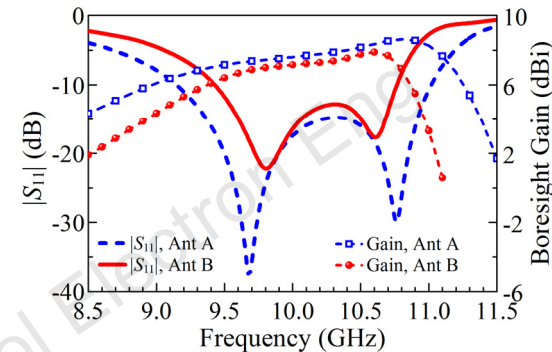
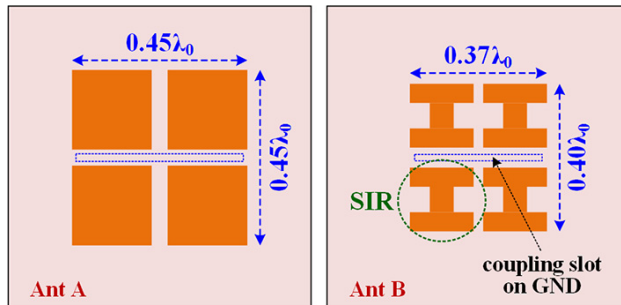
Dipole mode

- ❖ Wideband operation
- ❖ Boresight radiation

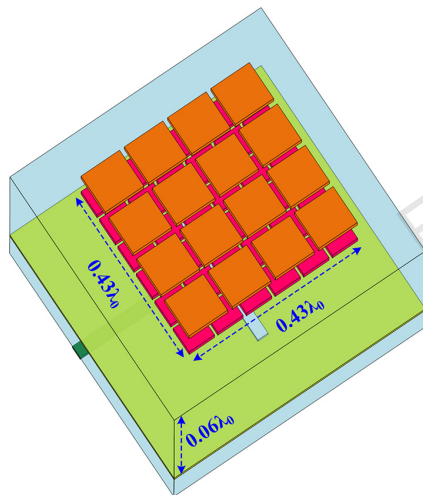
Miniaturized MTS Antennas

SIR (Stepped Impedance Resonator) MTS Antenna

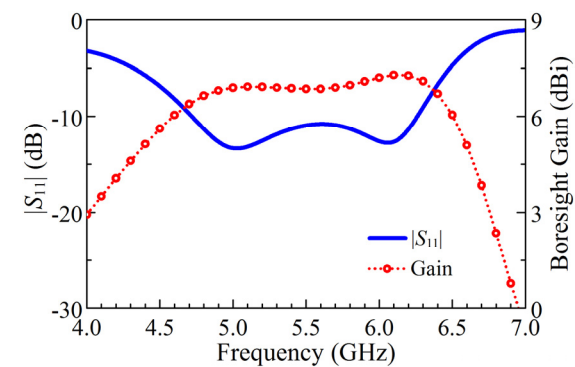
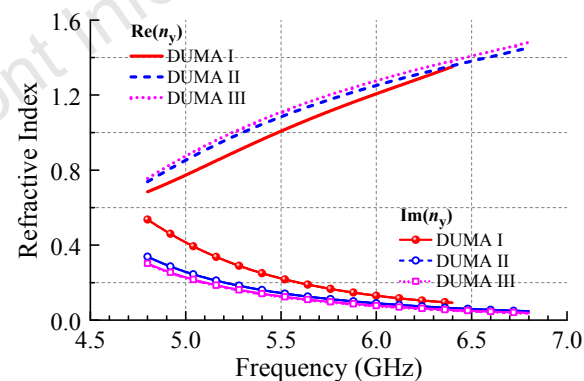
Aperture Size: $0.40\lambda_0 \times 0.37\lambda_0 \times 0.05\lambda_0$ • Bandwidth: 9.43-10.77 GHz, 13% • Gain: 6.4-7.9 dBi



Dual-Layer Overlapping MTS Antenna



Aperture Size: $0.43\lambda_0 \times 0.43\lambda_0 \times 0.06\lambda_0$ • Bandwidth: 4.72-6.26 GHz, 28% • Gain: 6.4-7.3 dBi



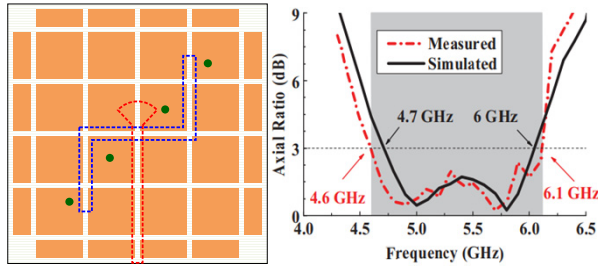
Further enhance capacitive coupling with
dual-layer metasurface

Higher effective refractive index

Miniature Antenna

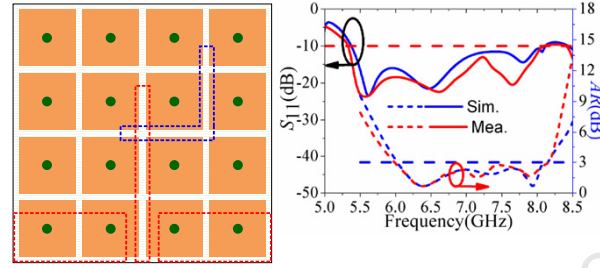
Circularly Polarized MTS Antennas

Z-slot + MTS



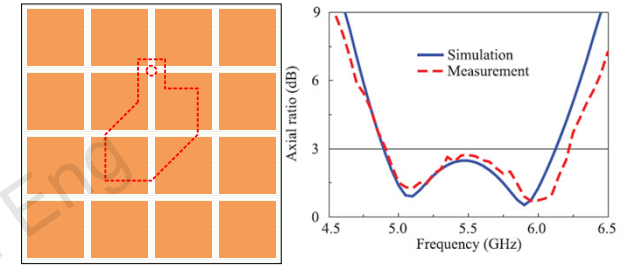
Lin et al., 2015, APCAP
ARBW = 24.3% $\epsilon_r = 3.38$
MTS: $0.80 \times 0.80 \times 0.058 \lambda_0^3$

L-slot + MTS



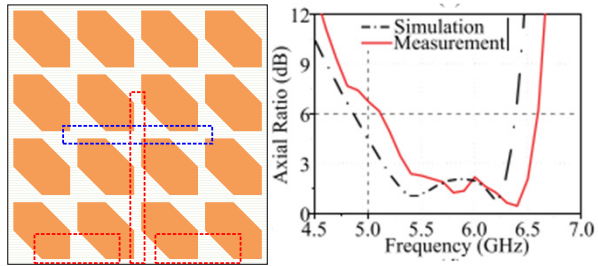
Chen et al., 2018, IEEE AWPL
ARBW = 34.3% $\epsilon_r = 2.2$
MTS: $0.90 \times 0.90 \times 0.07 \lambda_0^3$

CP patch feed + MTS



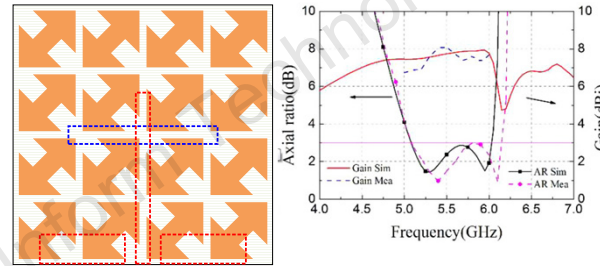
Ta et al., 2015, IEEE TAP
ARBW = 22.6% $\epsilon_r = 3.38$
MTS: $0.58 \times 0.58 \times 0.055 \lambda_0^3$

Asymmetrical MTS



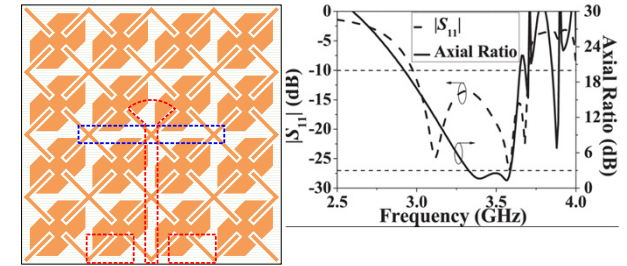
Huang et al., 2016, APL
ARBW = 20% $\epsilon_r = 3.6$
MTS: $0.75 \times 0.73 \times 0.09 \lambda_0^3$

Asymmetrical MTS



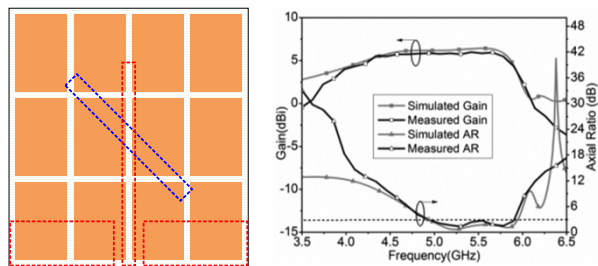
Zheng et al., 2018, MOTL
ARBW = 18% $\epsilon_r = 3.5$
MTS: $0.52 \times 0.52 \times 0.056 \lambda_0^3$

Asymmetrical MTS



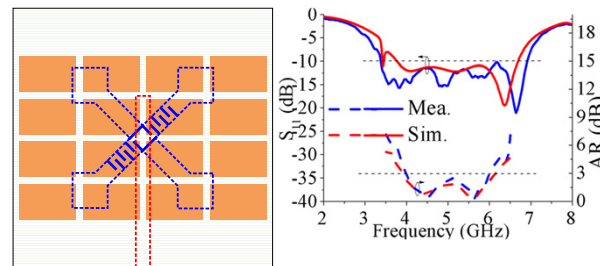
Juan et al., 2019, IEEE TAP
ARBW = 8.7% $\epsilon_r = 3.55$
MTS: $0.56 \times 0.56 \times 0.037 \lambda_0^3$

Slant slot + asymmetrical MTS



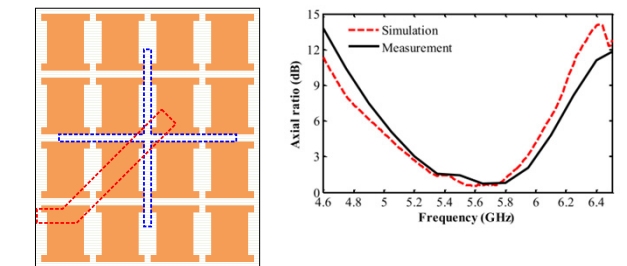
Wu et al., 2016, IEEE AWPL
ARBW = 18.5% $\epsilon_r = 4.4$
MTS: $0.62 \times 0.50 \times 0.054 \lambda_0^3$

Cross-slot with distributed circuit elements + asymmetrical MTS



Zhou et al., 2017, APL
ARBW = 44.4% $\epsilon_r = 3.66 \& 1$
MTS: $0.57 \times 0.31 \times 0.121 \lambda_0^3$

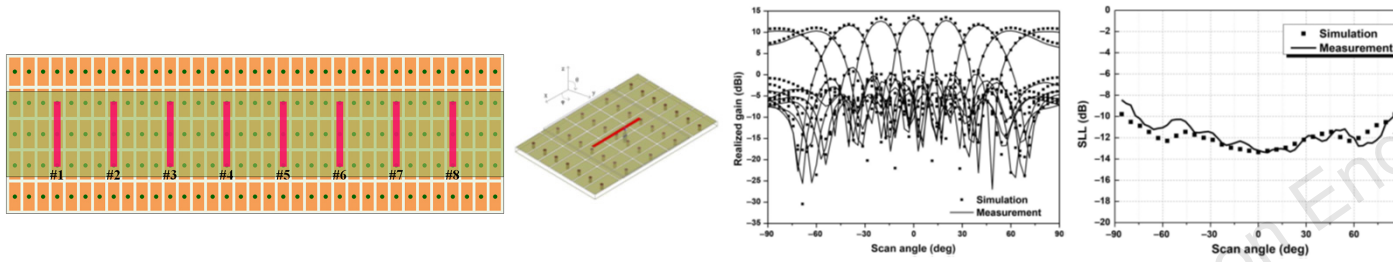
Cross-slot + asymmetrical MTS



Zhao et al., 2018, IEEE Access
ARBW = 14.3% $\epsilon_r = 3.38$
MTS: $0.73 \times 0.83 \times 0.057 \lambda_0^3$

Enhanced-Scanning MTS Phased Arrays

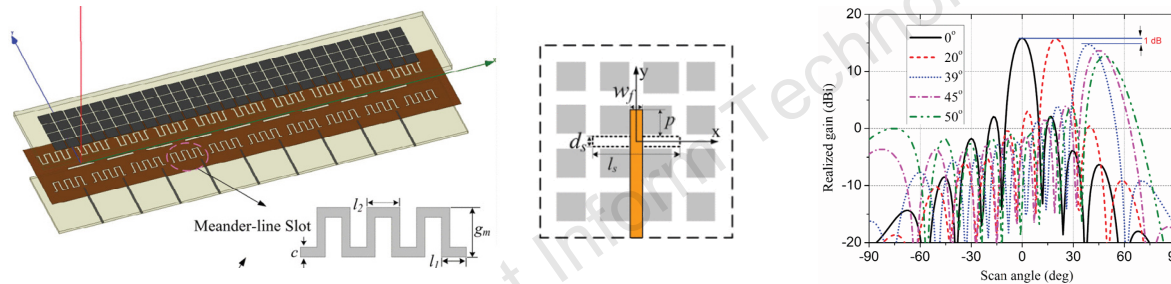
Wide-Angle Scanning Arrays Using High Impedance Surfaces



Operating in TE surface wave band

- Broad-beam radiation of each individual antenna element
- Wide scan angle up to 85° in H-plane
- SLL < -10 dB
- Gain variation: 10.1–13.1 dBi

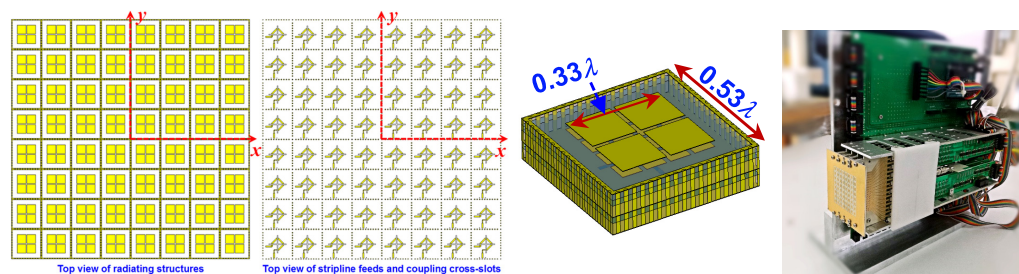
Low-Profile Broadband MTS Phased Array with Shared-Radiator and DGS



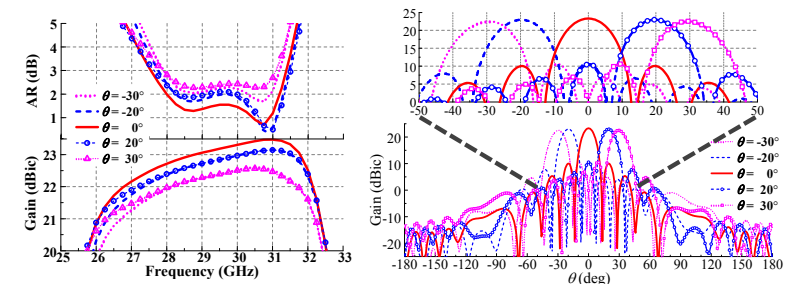
Sharing MTS-radiator + DGS

- Bandwidth: 4.6-5.8 GHz, 23.1%
- Scan angle up to 50° in H-plane
- Gain variation: 11.85–14.76 dBi

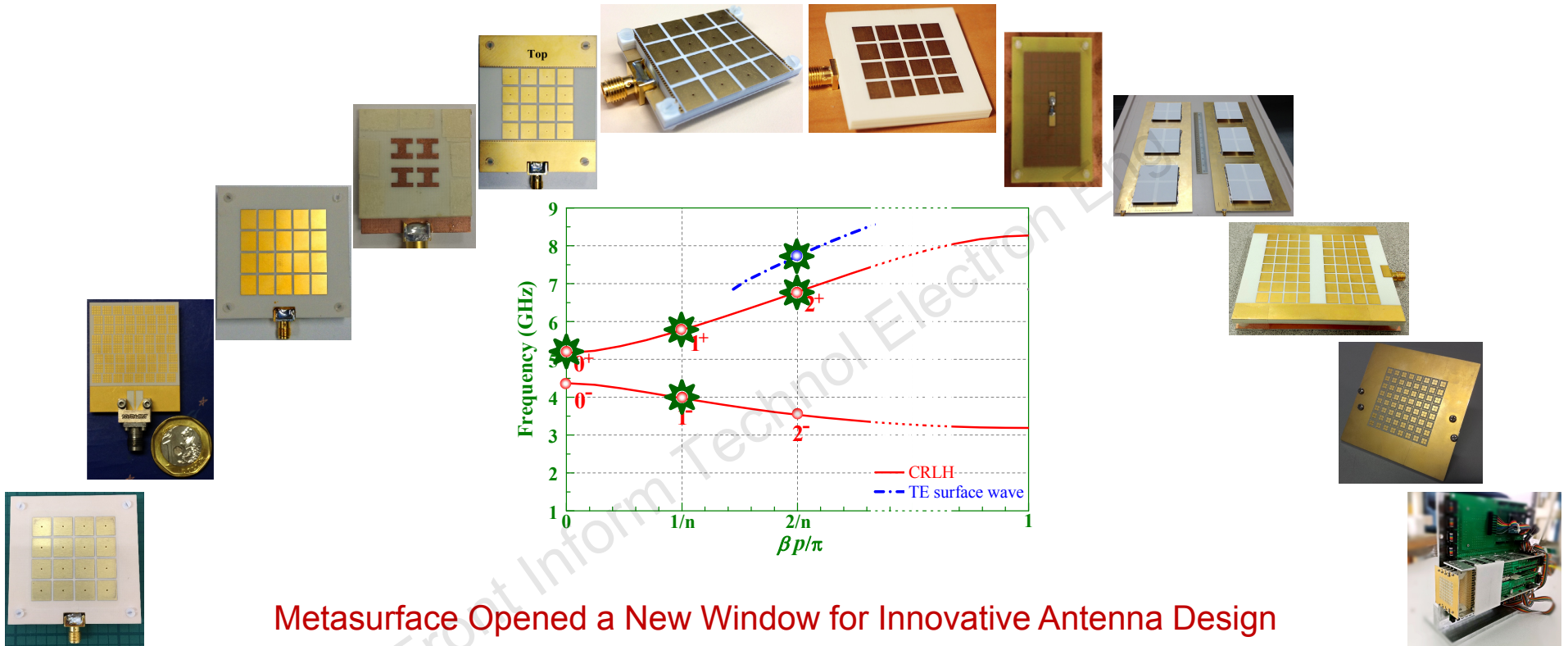
MTS-Based Wideband Wide-Scanning CP Phased Array



Beam Scanning in xz-plane



Selected Dispersion-Engineered Wideband Low-Profile Metasurface Antennas in Prof Chen's Group @ NUS



Metasurface Opened a New Window for Innovative Antenna Design

■ Unique Dispersion & Field Analysis

- Guided wave / Surface wave / Leaky wave
- Broadband / Multiband
- Miniaturization / Compact
- Beamsteering / Beamforming
- Mutual Coupling Suppression / High Isolation
- Pattern Diversity

Relevant Publication

1. W. Liu, Z. N. Chen, X. Qing, "Metamaterial-based low-profile broadband mushroom antenna," *IEEE Trans. Antennas Propag.*, vol. 62, no. 3, pp. 1165–1172, Mar. 2014.
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11. W. E. I. Liu, Z. N. Chen, X. Qing, J. Shi, F. H. Lin, "Miniaturized wideband metasurface antennas," *IEEE Trans. Antennas Propag.*, vol. 65, no. 12, pp. 7345–7349, Dec. 2017.
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13. S. S. S. Nasser, W. Liu, Z. N. Chen, "Wide bandwidth and enhanced gain of a low-profile dipole antenna achieved by integrated suspended metasurface," *IEEE Trans. Antennas Propag.*, vol. 66, no. 3, pp. 1540–1544, Mar. 2018.
14. W. E. I. Liu, Z. N. Chen, and X. Qing, "Wideband cavity backed metasurface antenna under multi-mode resonance," *Int. Symp. Antennas Propag. (ISAP)*, Busan, South Korea, Oct 23–26, 2018.
15. K. Xu, J. Shi, C. Zhang, and W. Liu, "A low-profile 1×2 filtering dipole array with small unit space and closely placed ground," *IEEE Antennas Wirel. Propag. Lett.*, vol. 18, pp. 946–950, May 2019.
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20. W. E. I. Liu, Z. N. Chen, and X. Qing, "Dispersion-engineered wideband low-profile metasurface antennas," *Frontiers of Information Technology & Electronic Engineering*, vol. 21, no. 1, pp. 27–38, 2020.