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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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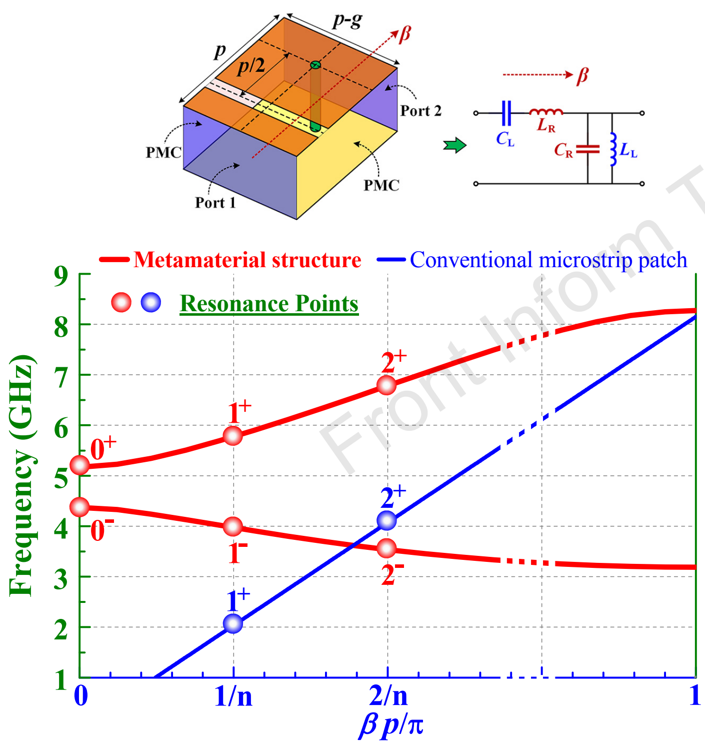
Motivation

- **Enhance the bandwidth of low-profile microstrip patch antennas**
  - Traditional patch antennas requrie thick low-permittivity substrate
  - Using dispersion-engineered metasurfaces as radiators
    - Engineering dispersion relation
    - Electrically thin substrate
    - Applicable to relatively high permittivity

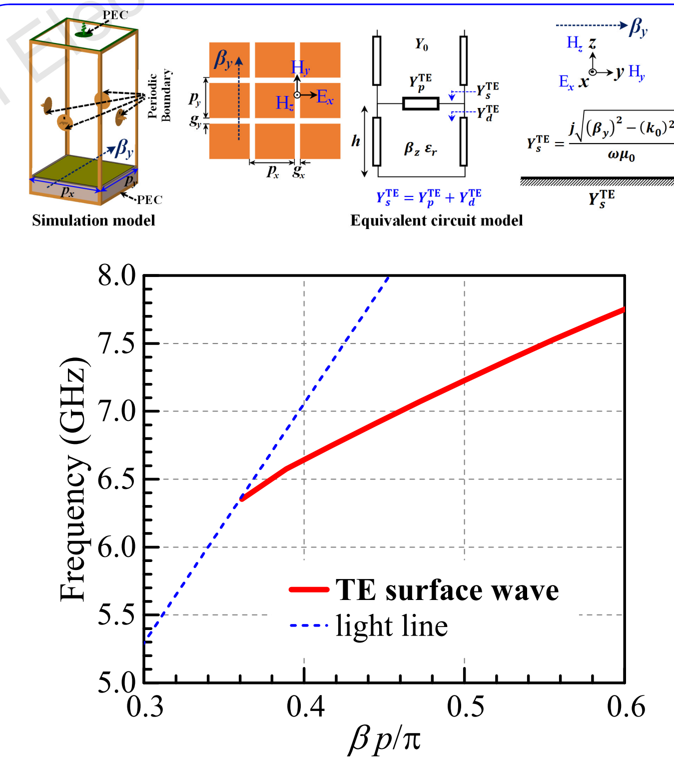
- **Engineering dispersion of metasurface to improve antenna performance**
  - Reduce Size: Volume/Aperture/Profile
  - Enhance Radiation: Directivity/Gain/Efficiency
  - Widen Bandwidth: Impedance/Gain/Pattern/CP/RCS
  - Enhance Beam-Scanning Capability
  - Mutual coupling, beamwidth, …

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**



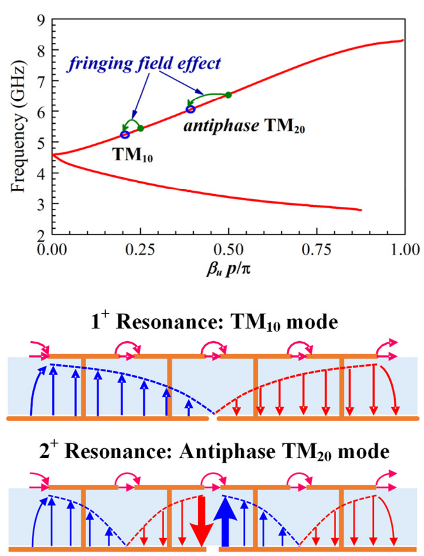
CRLH dispersion of guided wave



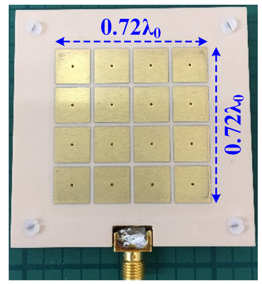
Dispersion of surface wave

CRLH MTS Antennas

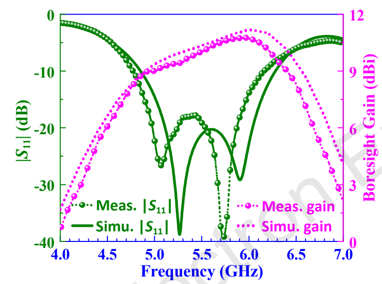
Open-Ended CRLH MTS Antennas

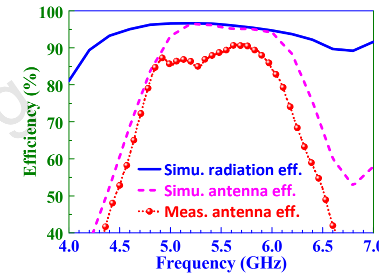


Thickness: 0.06 λ_0 • Bandwidth: 4.77-6.16 GHz, 26% • Gain: 8.7-10.8 dBi

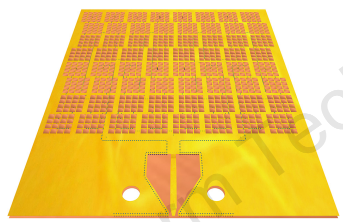


ε_r = 3.38, 0.06λ_0-thick

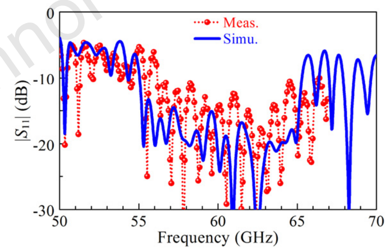


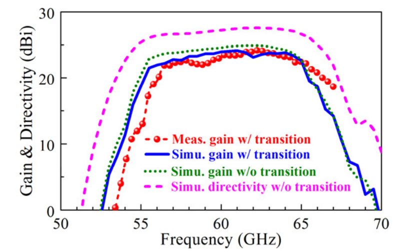


Thickness: 0.04 λ_0 • Bandwidth: 56.3-65.7 GHz, 15% • Gain: 21.2-24.2 dBi

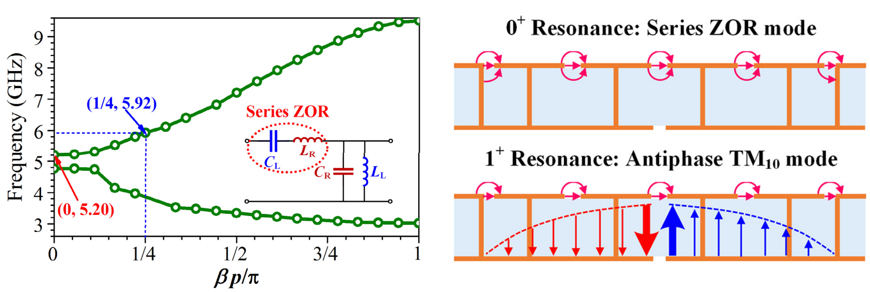


ε_r = 5.9, 0.04λ_0-thick

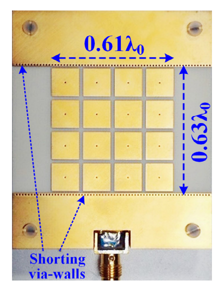


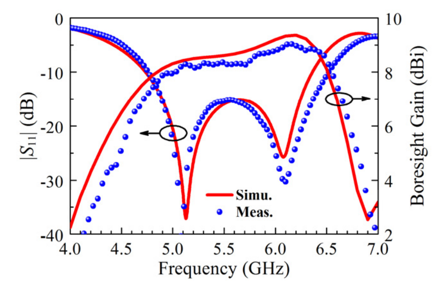


Short-Ended CRLH MTS Antenna



Thickness: 0.06 λ_0 • Bandwidth: 4.74-6.36 GHz, 29% • Gain: 7.5-9.4 dBi

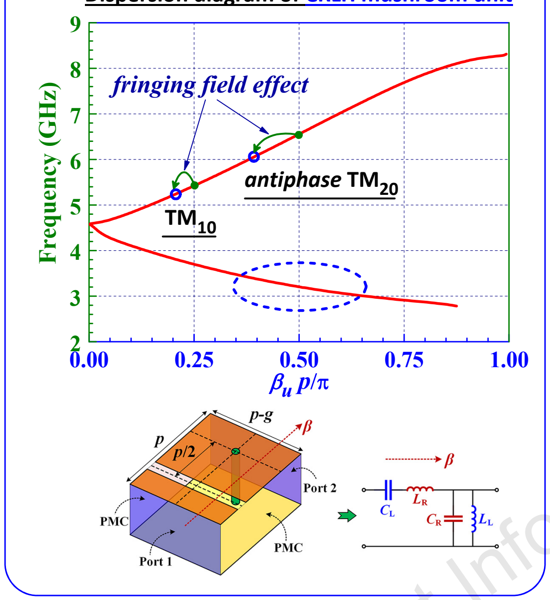




ε_r = 3.55, 0.06λ_0-thick

RH MTS Antenna

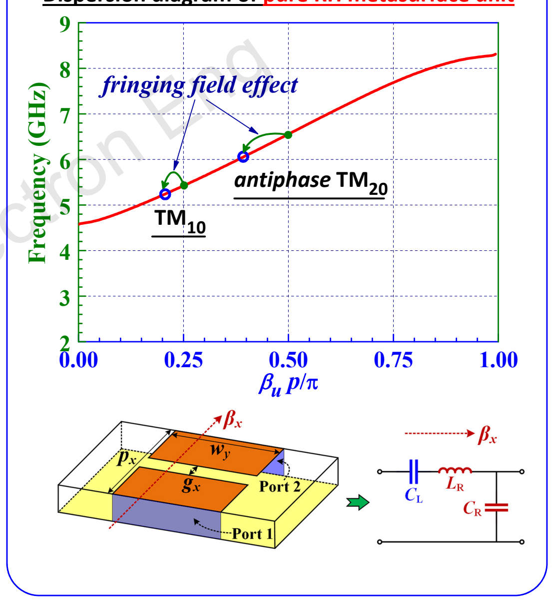
Open-Ended RH MTS Antenna



Dispersion diagram of CRLH mushroom unit

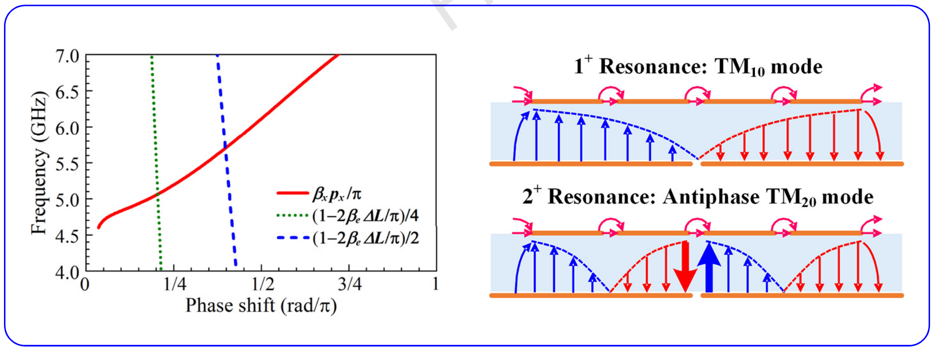
Two operating modes on RH dispersion branch

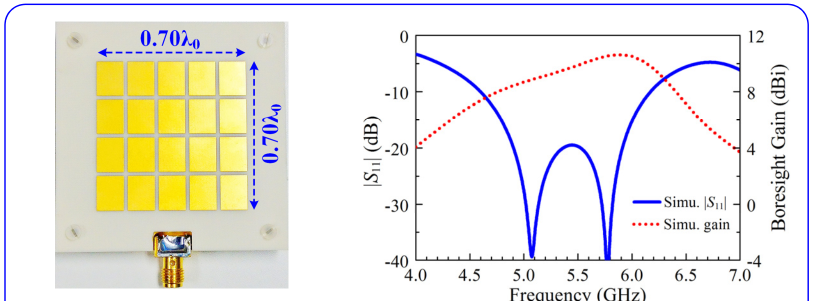
LH dispersion branch is NOT necessary



Dispersion diagram of pure RH metasurface unit

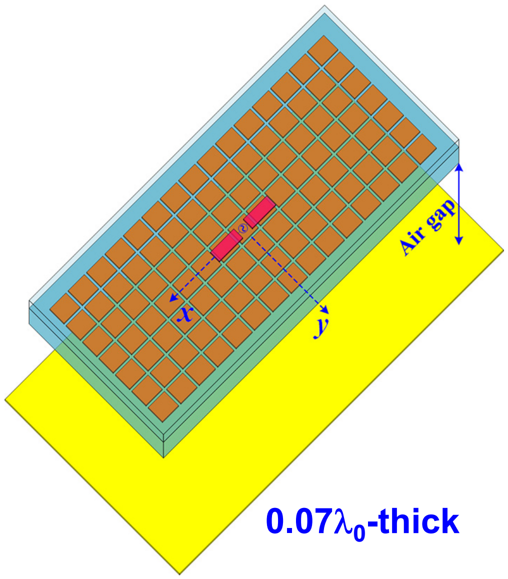
Thickness: 0.06 λ_0 ● Bandwidth: 4.60-6.17 GHz, 29% ● Gain: 7.4-10.6 dBi



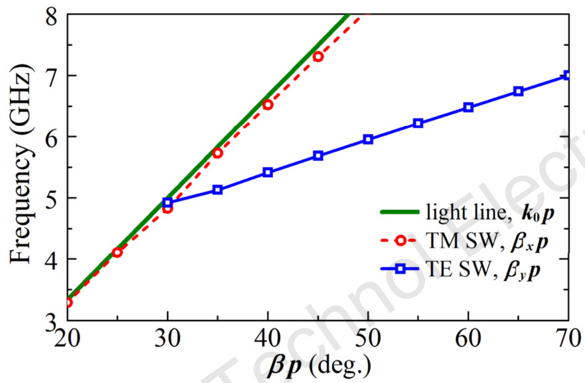


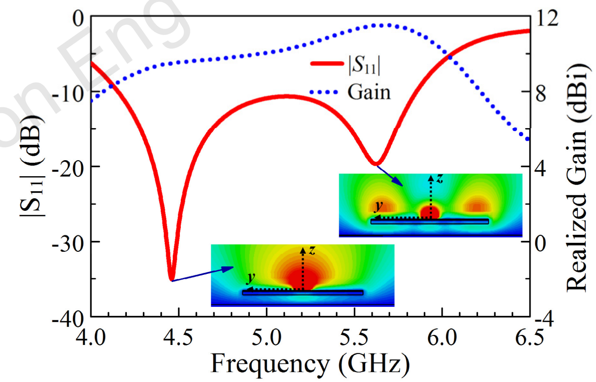
ε_r = 3.38, 0.06λ_0-thick

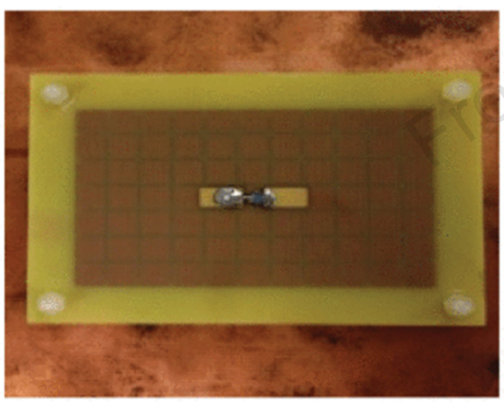
SWR (Surface Wave Resonance) MTS Antenna



Thickness: 0.07 λ_0 • Bandwidth: 4.15-5.85 GHz, 33.6% • Gain: 8.5-11.5 dBi







TE surface wave resonance mode

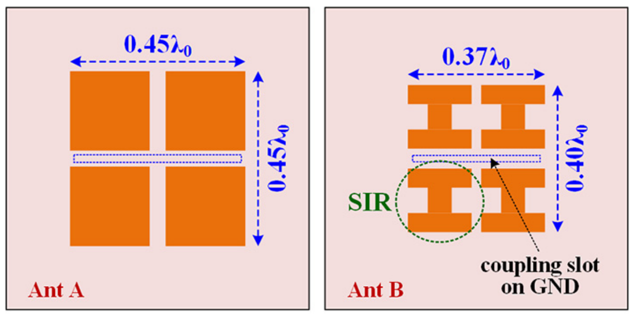
Dipole mode

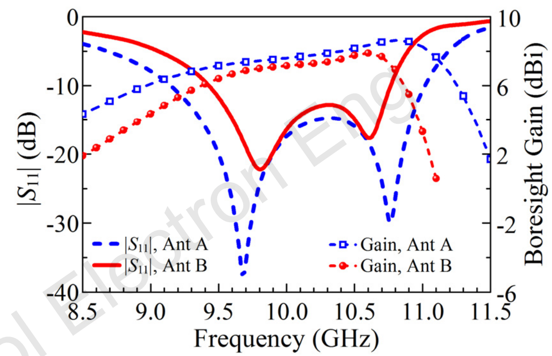
- Wideband operation
- Boresight radiation

Miniaturized MTS Antennas

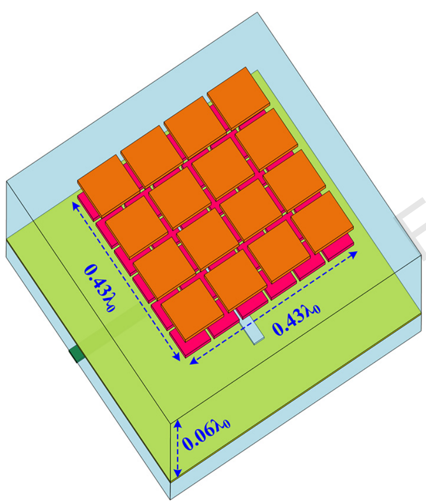
SIR (Stepped Impedance Resonator) **MTS Antenna**

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

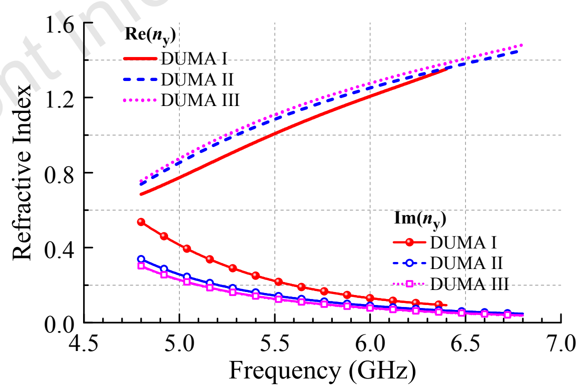


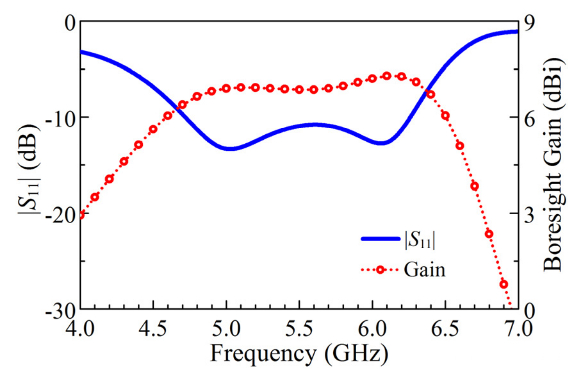


Dual-Layer Overlapping MTS Antenna



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

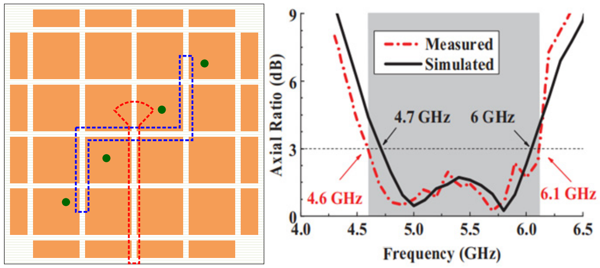




Further enhance capacitive coupling with dual-layer metasurface → **Higher effective refractive index** → **Miniature Antenna**

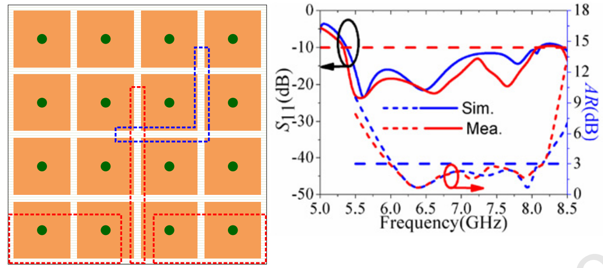
Circularly Polarized MTS Antennas

Z-slot + MTS



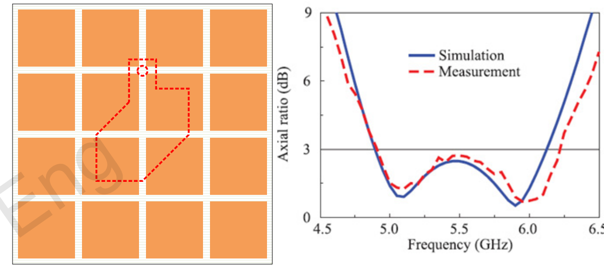
Lin et al., 2015, APCAP
ARBW = 24.3% $\varepsilon_r = 3.38$
MTS: $0.80 \times 0.80 \times 0.058\ \lambda_0^3$

L-slot + MTS



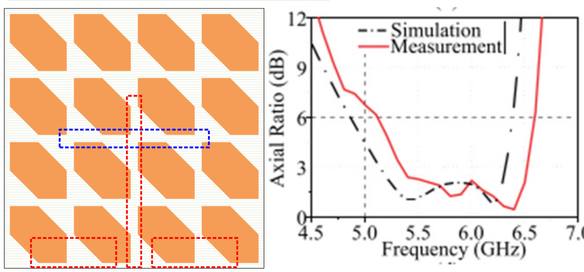
Chen et al., 2018, IEEE AWPL
ARBW = 34.3% $\varepsilon_r = 2.2$
MTS: $0.90 \times 0.90 \times 0.07\ \lambda_0^3$

CP patch feed + MTS



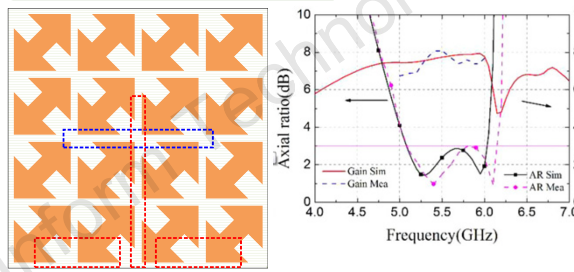
Ta et al., 2015, IEEE TAP
ARBW = 22.6% $\varepsilon_r = 3.38$
MTS: $0.58 \times 0.58 \times 0.055\ \lambda_0^3$

Asymmetrical MTS



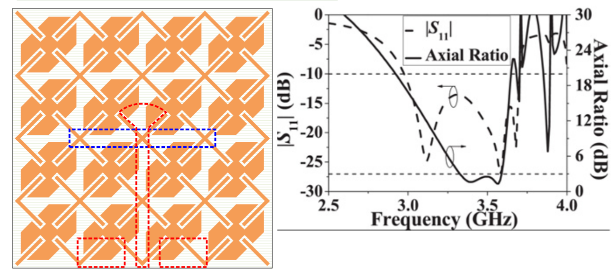
Huang et al., 2016, APL
ARBW = 20% $\varepsilon_r = 3.6$
MTS: $0.75 \times 0.73 \times 0.09\ \lambda_0^3$

Asymmetrical MTS



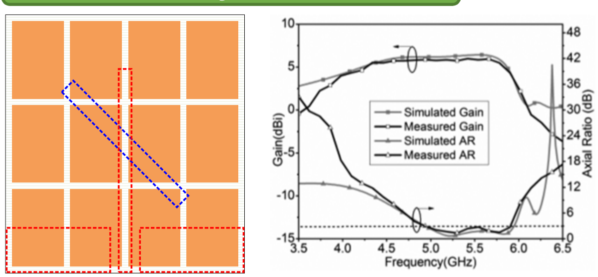
Zheng et al., 2018, MOTL
ARBW = 18% $\varepsilon_r = 3.5$
MTS: $0.52 \times 0.52 \times 0.056\ \lambda_0^3$

Asymmetrical MTS



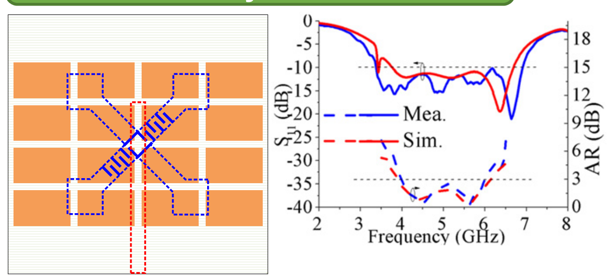
Juan et al., 2019, IEEE TAP
ARBW = 8.7% $\varepsilon_r = 3.55$
MTS: $0.56 \times 0.56 \times 0.037\ \lambda_0^3$

Slant slot + asymmetrical MTS



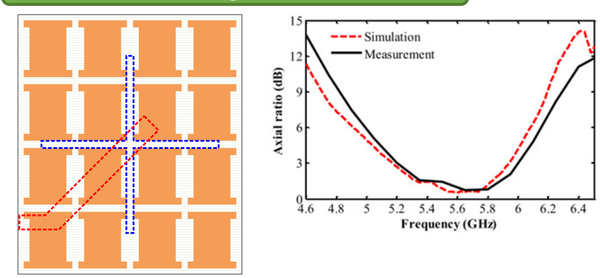
Wu et al., 2016, IEEE AWPL
ARBW = 18.5% $\varepsilon_r = 4.4$
MTS: $0.62 \times 0.50 \times 0.054\ \lambda_0^3$

Cross-slot with distributed circuit elements + asymmetrical MTS



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

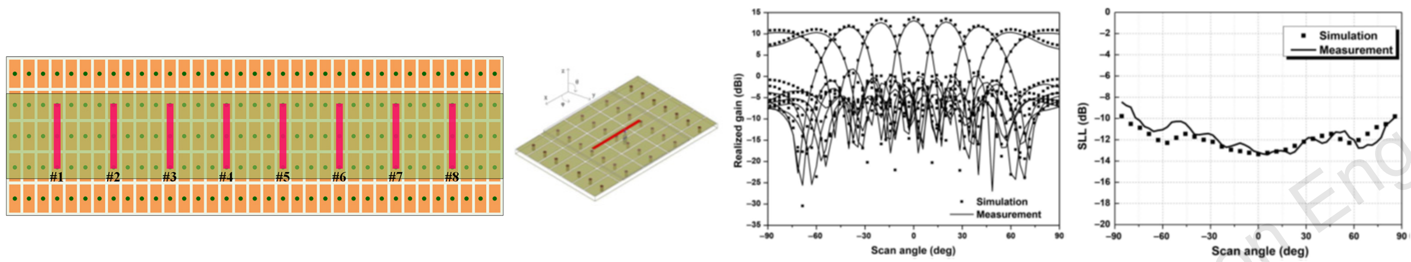
Cross-slot + asymmetrical MTS



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

Enhanced-Scanning MTS Phased Arrays

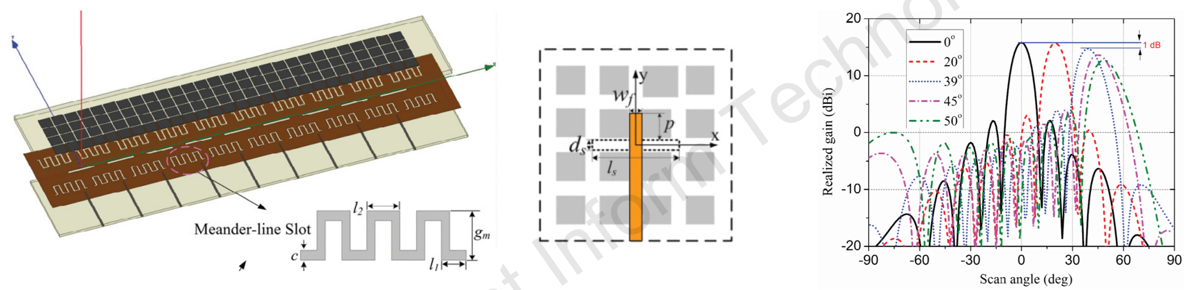
Wide-Angle Scanning Arrays Using High Impedance Surfaces



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

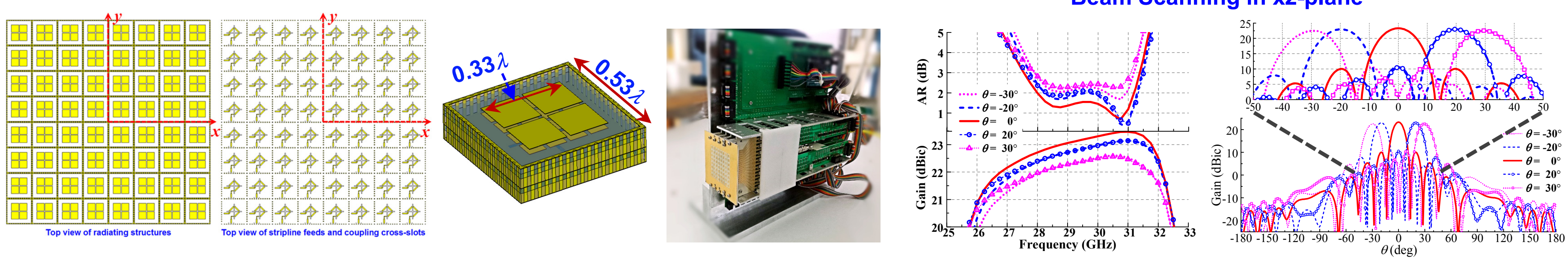


Sharing MTS-radiator + DGS

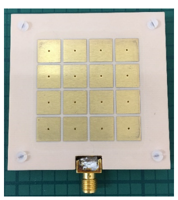
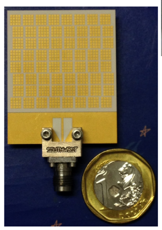
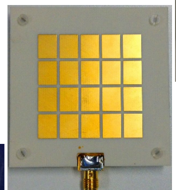
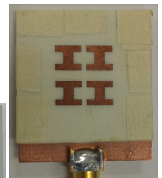
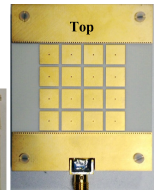
- Bandwidth: 4.6-5.8 GHz, 23.1%
- Scan angle up to 50° in H-plane
- Gain variation: 11.85–14.76 dBi

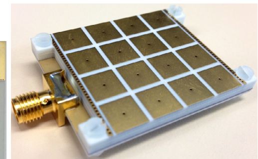
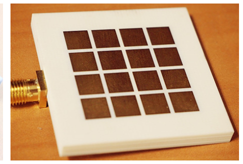
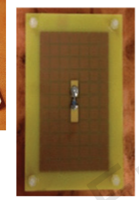
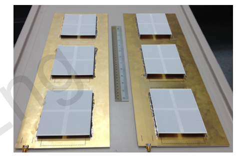
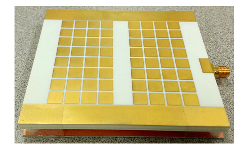
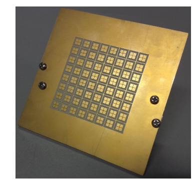
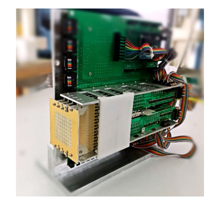
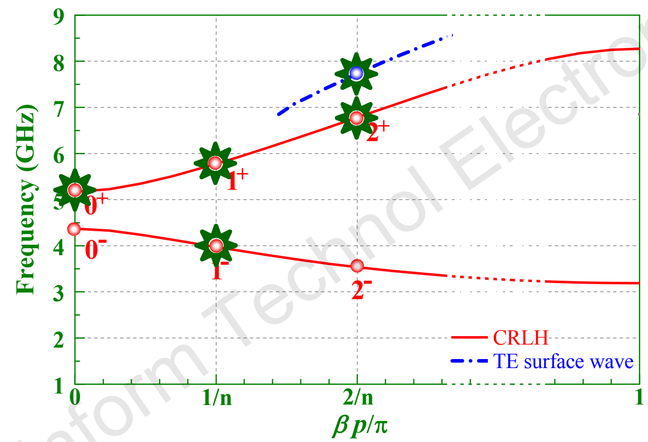
MTS-Based Wideband Wide-Scanning CP Phased Array

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.
2. W. Liu, Z. N. Chen, X. Qing, "60-GHz thin broadband high-gain LTCC metamaterial-mushroom antenna array," ***IEEE Trans. Antennas Propag.***, vol. 62, no. 9, pp. 4592–4601, Sep. 2014.
3. W. Liu, Z. N. Chen, X. Qing, "Stripline aperture coupled metamaterial mushroom antenna with increased front-to-back ratio," ***IEEE Int. Symp. Antennas Propag. (APS/URSI)***, Memphis, TN, USA, Jul. 6–12, 2014, pp. 444–445.
4. W. Liu, Z. N. Chen, X. Qing, "Metamaterial-based low-profile broadband aperture coupled grid-slotted patch antenna," ***IEEE Trans. Antennas Propag.***, vol. 63, no. 7, pp. 3325–3329, Jul. 2015.
5. T. S. P. See, X. Qing, W. Liu, and Z. N. Chen, "A wideband ultra-thin differential loop-fed patch antenna for head implants," ***IEEE Trans. Antennas Propag.***, vol. 63, no. 7, pp. 3244–3248, Jul. 2015.
6. W. Liu, X. Qing, Z. N. Chen, "Metamaterial-based wideband shorting-wall loaded mushroom array antenna," ***European Conf. Antennas Propag. (EuCAP)***, Lisbon, Portugal, Apr. 12–17, 2015.
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8. F. Lin, Z. N. Chen, and W. Liu, "A metamaterial-based broadband circularly polarized aperture-fed grid-slotted patch antenna," ***IEEE Asia-Pacific Conf. Antennas Propag. (APCAP)***, Bali, Indonesia, Jun. 30–Jul. 3, 2015, pp. 353–354.
9. W. Liu, Z. N. Chen, X. Qing, "Mode analysis and experimental verification of shorting-wall loaded mushroom antenna," ***Asia-Pacific Microw. Conf. (APMC)***, New Delhi, India, Dec. 5–9, 2016, pp. 2165–4743.
10. W. Liu, Z. N. Chen, X. Qing, "Miniaturized broadband metasurface antenna using stepped impedance resonators," ***IEEE Asia-Pacific Conf. Antennas Propag. (APCAP)***, Kaohsiung, Taiwan, Jul. 26–29, 2016, pp. 365–366.
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