Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: Simple Wireless System Simulation with Characteristics of 3D-Printed THz Metasurfaces

Date Submitted: January 2025

Source: Akifumi Kasamatsu, Tatsuo Hagino, National Institute of Information and Communications Technology (NICT), 4-2-1 Nukuikita-machi, Koganei, Tokyo, 1848795, Japan
Yuttana Intaravanne, Nantarat Srisuai, Patharakorn Rattanawan, Paramin Sangwongngam, Noppadon Nuntawong, Mati Horprathum, National Electronics and Computer Technology Center (NECTEC), 111 Thailand Science Park, Phahonyothin Road, Khlong Nueng, Khlong Luang, Pathum Thani 12120, Thailand
E-Mail: kasa@nict.go.jp, yuttana.intaravanne@nectec.or.th

Re: N/A

Abstract: Metasurfaces have become crucial in advancing THz technology for development of compact, planar, and lightweight devices. In this work, we have proposed and demonstrated 3D-printed THz metasurfaces by using a 3D printer with digital light processing technique, and simple wireless simulation with S-parameter characteristics of the metasurface devices designed for some variations of beam direction.

Purpose: Information document for IEEE 802.15 SC THz

Simple Wireless System Simulation with Characteristics of 3D-Printed THz Metasurfaces

Akifumi Kasamatsu, Tatsuo Hagino
National Institute of Information and Communications Technology (NICT), Japan

Yuttana Intaravanne, Nantarat Srisuai, Patharakorn Rattanawan, Paramin Sangwongngam, Noppadon Nuntawong, Mati Horprathum
National Electronics and Computer Technology Center (NECTEC), Thailand

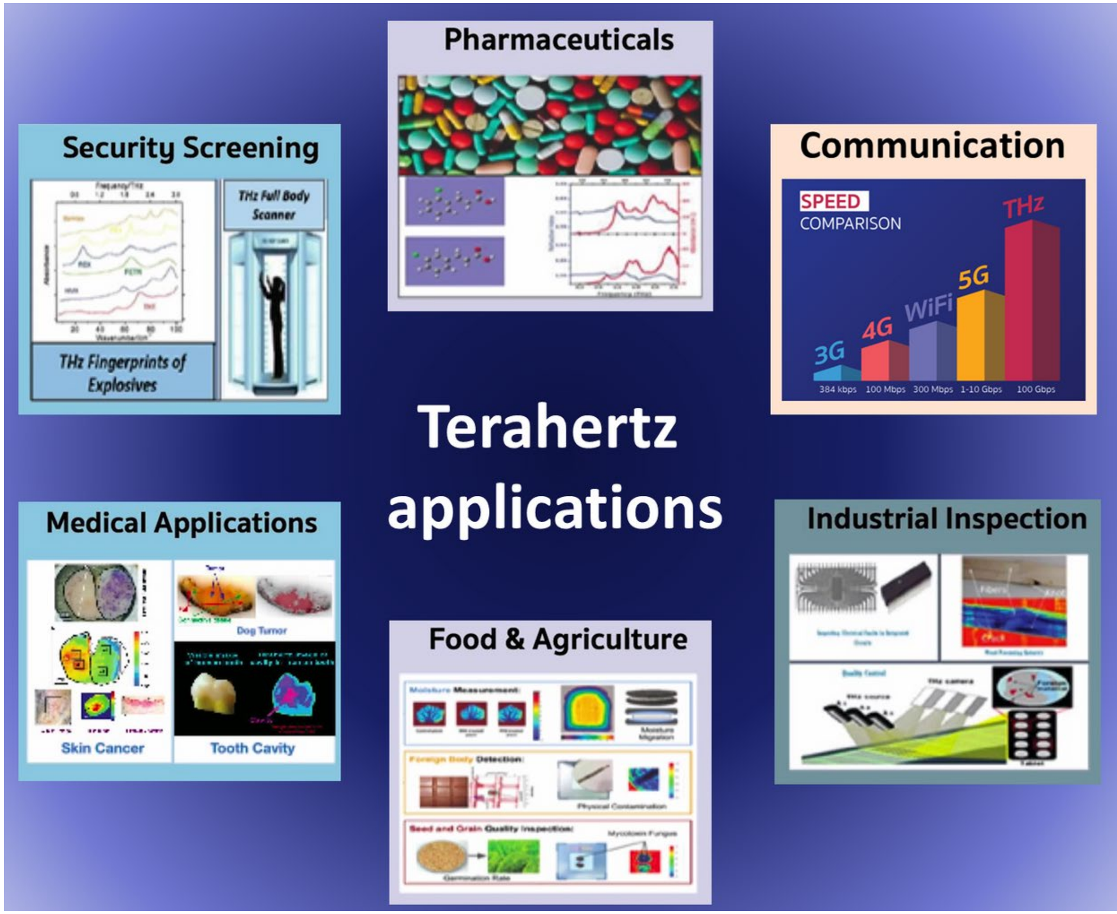
Motivation and Outline

- Terahertz Metasurface Devises (NECTEC)
  - Technology for development of compact, planar, and lightweight devices
  - 3D-printed metasurfaces with digital light processing technique: faster and cheaper than traditional photolithography
  - Available to vary the beam direction by metasurface design
- Wireless System Simulation (NICT)
  - Basic wireless system simulation using S-parameter characteristics of metasurface devices designed by NECTEC
  - Using frequency bands assigned for IEEE802.15.3d
  - Observing EVM for several beam directions

Terahertz properties and applications

THz properties

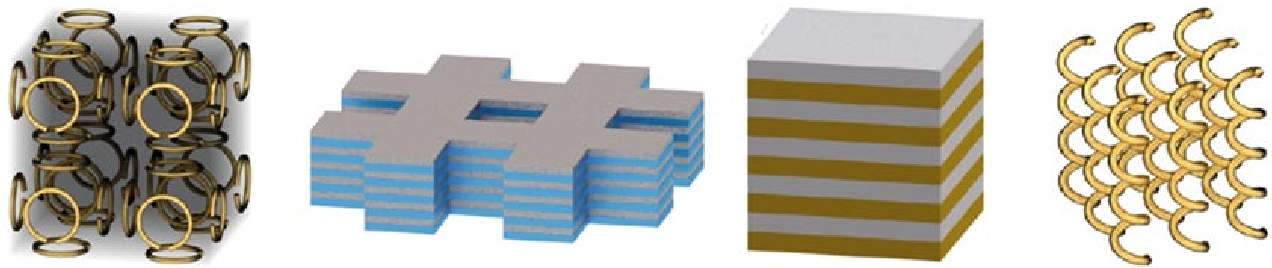
- Easily passes through non-polar materials.
- Absorbed by polar materials.
- Non-ionizing then safe for human.
- Reflected by metals.
- spectral fingerprints for Bio-molecules



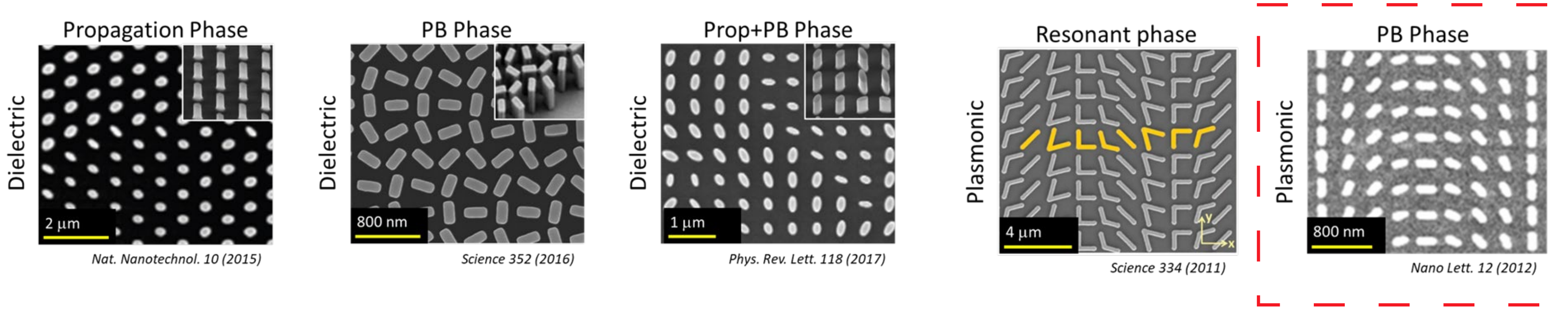
Reference: Kamonchanok Duangkanya, et al., "Development of 3D-Printed THz Metasurfaces with Digital Light Processing Technique," The 2024 International Conference on Photonics Solutions (ICPS), Dec. 2024

What are Metasurfaces?

Metamaterial



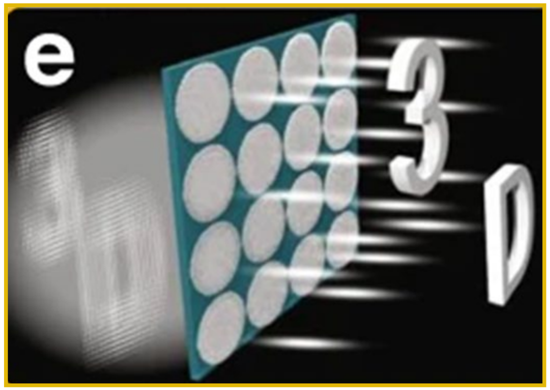
Metasurface



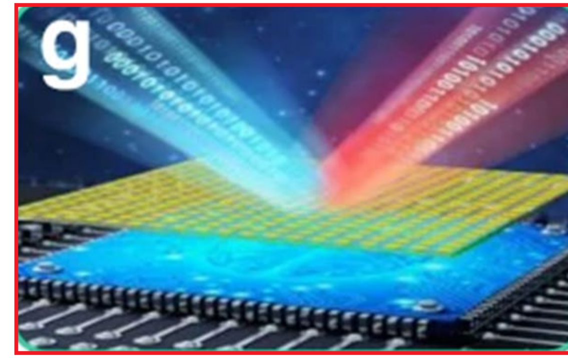
Reference: Kamonchanok Duangkanya, et al., "Development of 3D-Printed THz Metasurfaces with Digital Light Processing Technique," The 2024 International Conference on Photonics Solutions (ICPS), Dec. 2024

Metasurfaces applications

Imaging systems



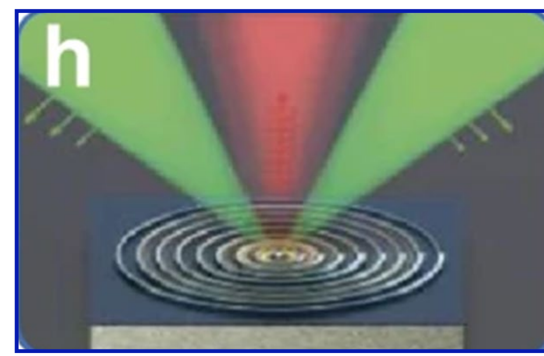
Radar systems



Metasurfaces applications

Communication systems

Quantum optics



ref.: https://www.nature.com/articles/s41377-023-01218-y

Reference: Kamonchanok Duangkanya, et al., "Development of 3D-Printed THz Metasurfaces with Digital Light Processing Technique," The 2024 International Conference on Photonics Solutions (ICPS), Dec. 2024

What is 3D Printing

3D Printer

3D Print

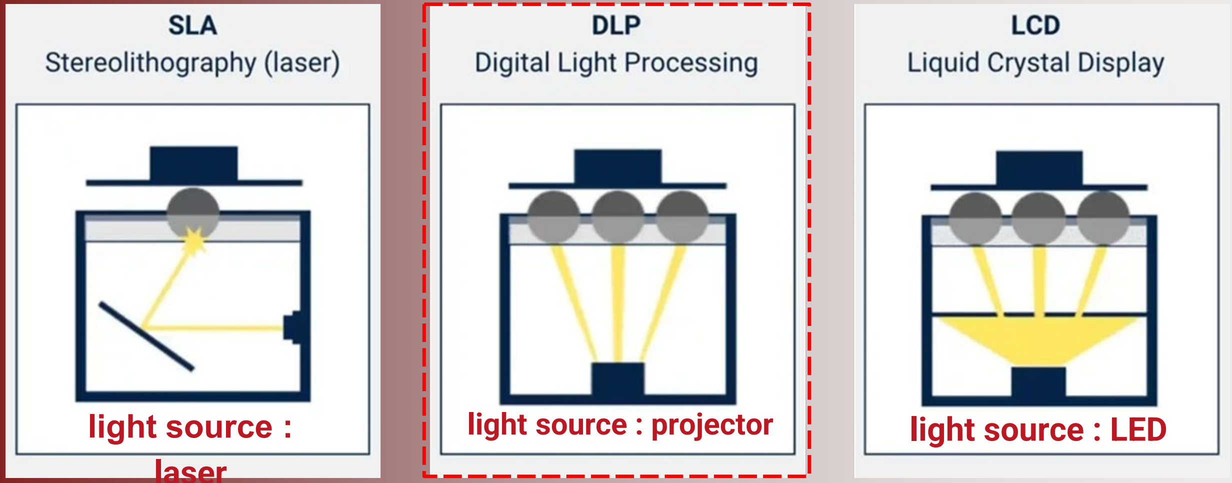
https://www.print3dd.com/what-is-3d-printer/?srsltid=AfmBOopLFWxR2opd1IKYka63-gAHktHCMtbyK8uQoviZxOh3dpclwVY0

3D printers : the printing process and materials.

1) Plastic injection system.

2) Powder melting system.

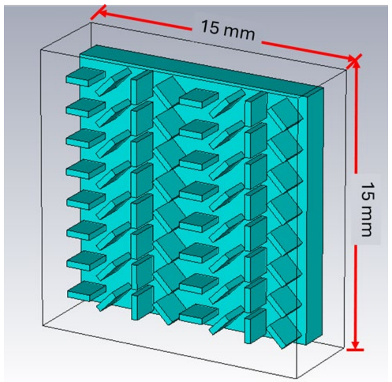
3) Resin tray system.



https://3mash.com/en/blog/3d-printing-technologies--sla--dlp--and-lcd

Reference: Kamonchanok Duangkanya, et al., "Development of 3D-Printed THz Metasurfaces with Digital Light Processing Technique," The 2024 International Conference on Photonics Solutions (ICPS), Dec. 2024

3D printed metasurface device



3D model from SOLIDWORKS program

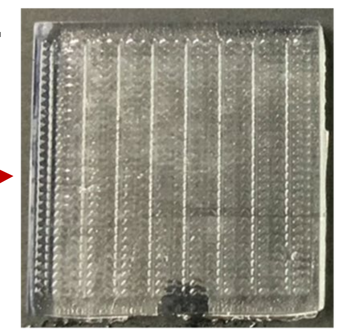
Printing conditions

Fix parameters : Phrozen Sonic Mini 4K
Resione G217

Vary parameters : Printing speeds from
30, 90, 120, 150
and 180 mm/ min.

SEPTILLION

Phrozen Sonic Mini 4K



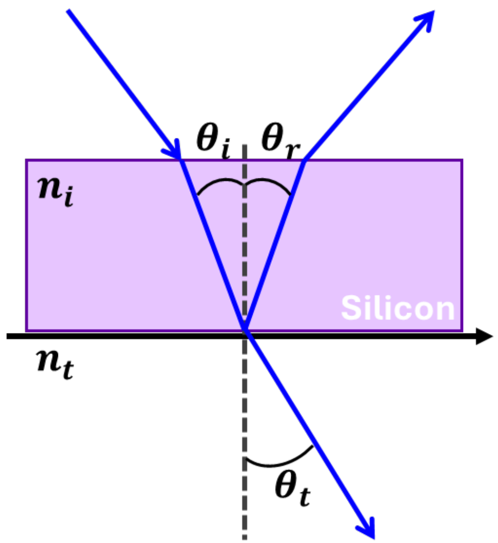
THz metasurfaces sample

Reference: Kamonchanok Duangkanya, et al., “Development of 3D-Printed THz Metasurfaces with Digital Light Processing Technique,” The 2024 International Conference on Photonics Solutions (ICPS), Dec. 2024

Design and methods

Traditional optics

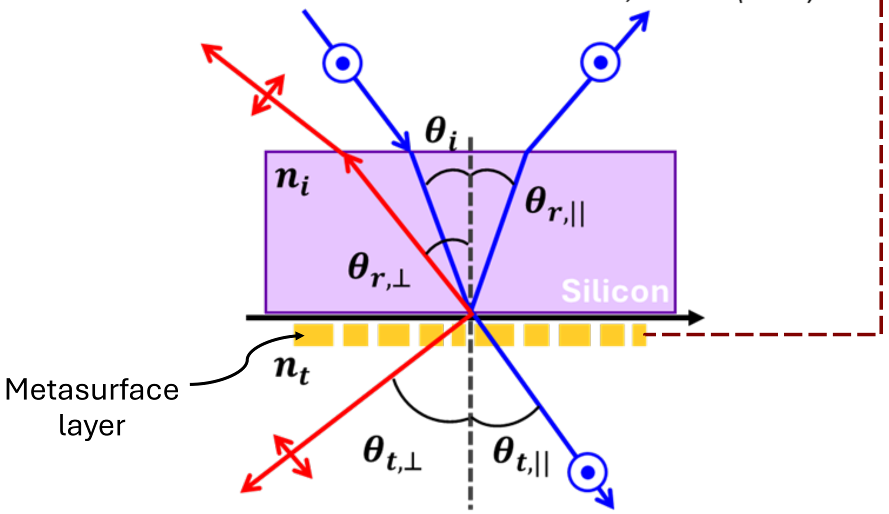
$$n_t \sin(\theta_t) - n_i \sin(\theta_i) = 0 \quad \text{...... (1)}$$



Metasurface optics

$$n_t \sin(\theta_t) - n_i \sin(\theta_i) = \frac{\lambda_0}{2\pi}\frac{d\Phi}{dx} \quad \text{...... (2)}$$

N. Yu et al, Science (2011)

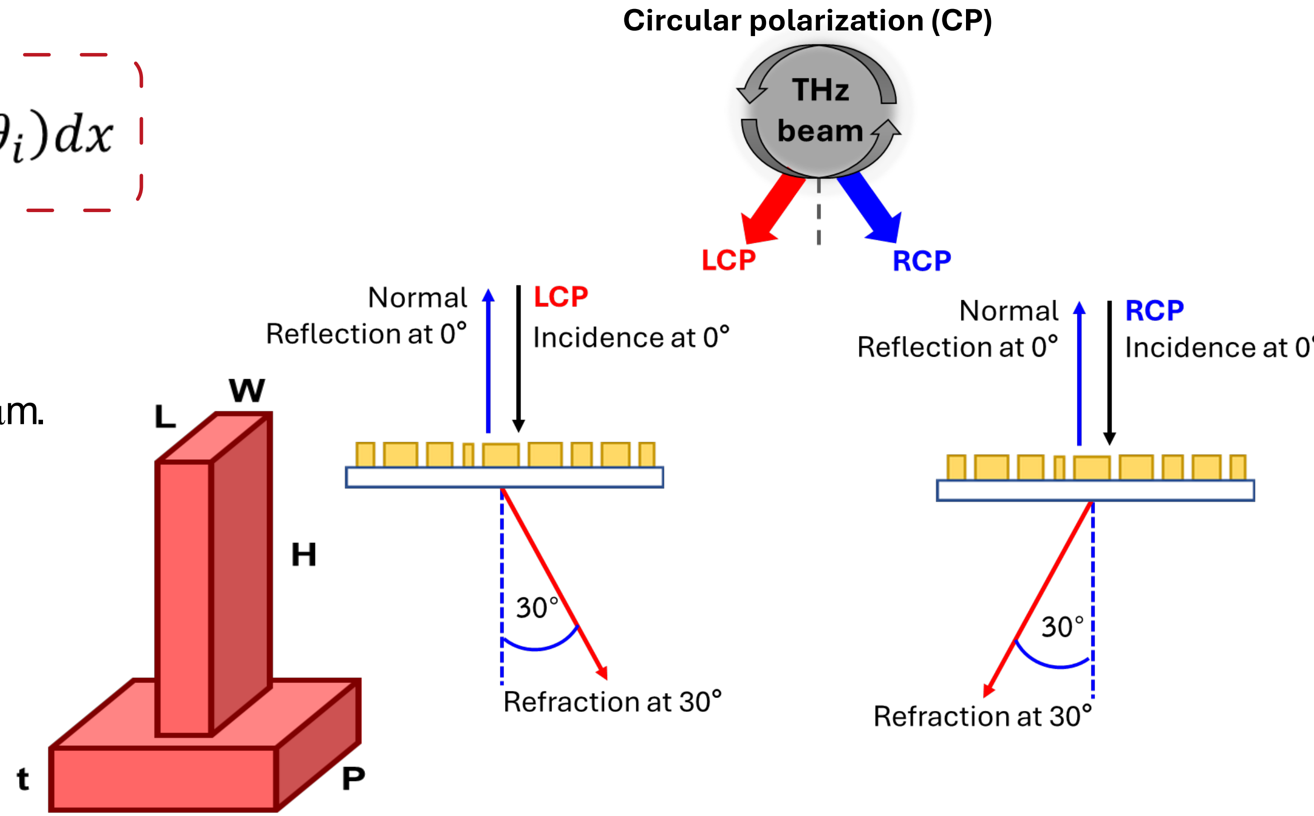


Reference: Kamonchanok Duangkanya, et al., "Development of 3D-Printed THz Metasurfaces with Digital Light Processing Technique," The 2024 International Conference on Photonics Solutions (ICPS), Dec. 2024

Design and methods

$$d\varphi = \frac{2\pi}{\lambda_0}(\sin\theta_r - \sin\theta_i)dx$$

dx is the size of a unit cell or **P**.
θ_i is an incident angle = 0°
θ_r is a refraction angle = 30°
λ_0 is a THz wavelength = 1000 μm.



Reference: Kamonchanok Duangkanya, et al., "Development of 3D-Printed THz Metasurfaces with Digital Light Processing Technique," The 2024 International Conference on Photonics Solutions (ICPS), Dec. 2024

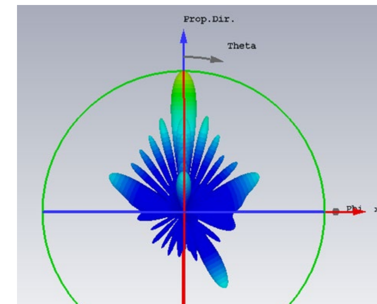
Design and methods

TDS

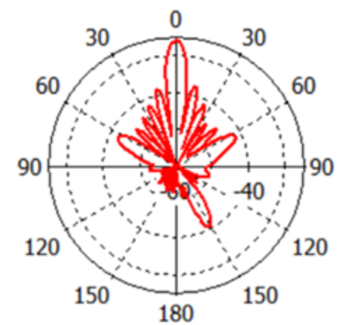
Resin Properties :
n = 1.7 , ε = 2.89

CST MICROWAVE STUDIO

Incident : LCP , RCP
Frequency (f) : 300 GHz



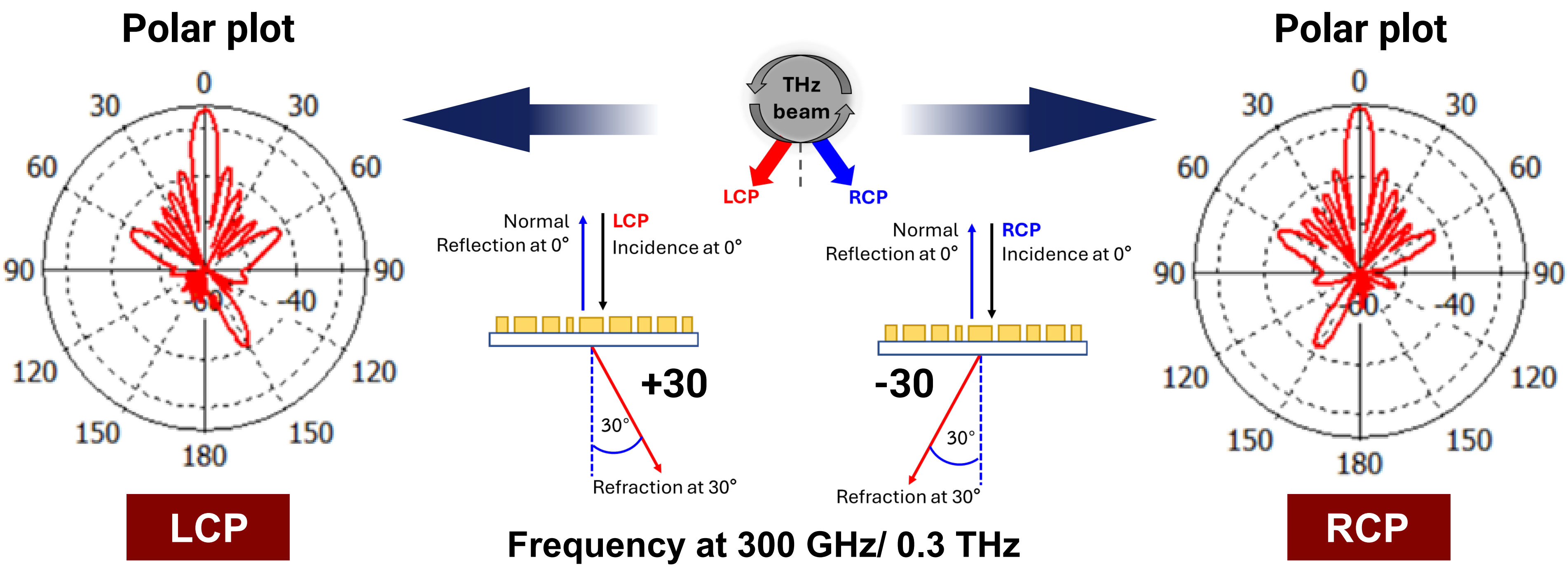
3D plot



Polar plot

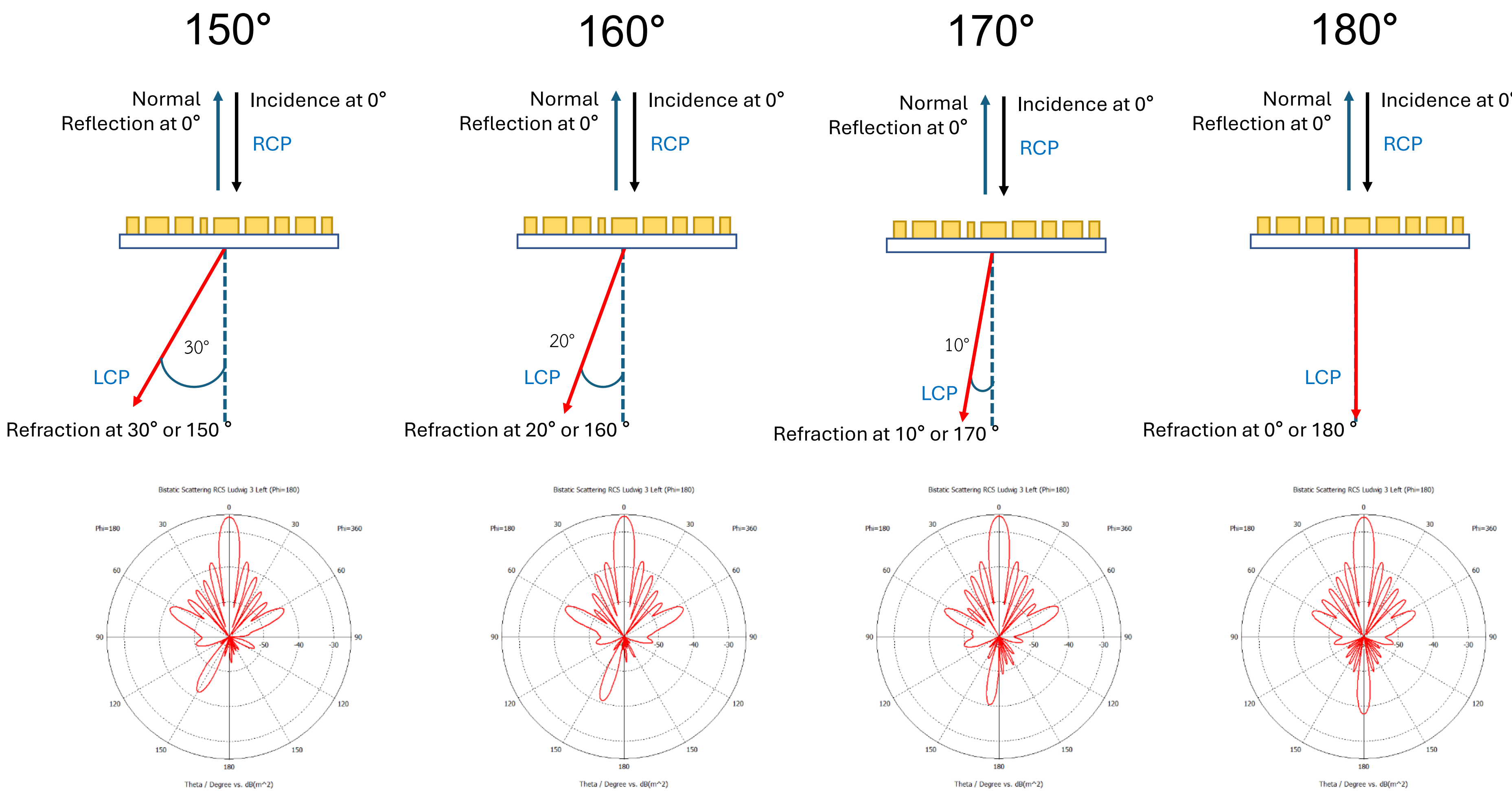
Reference: Kamonchanok Duangkanya, et al., "Development of 3D-Printed THz Metasurfaces with Digital Light Processing Technique," The 2024 International Conference on Photonics Solutions (ICPS), Dec. 2024

Example of simulation result

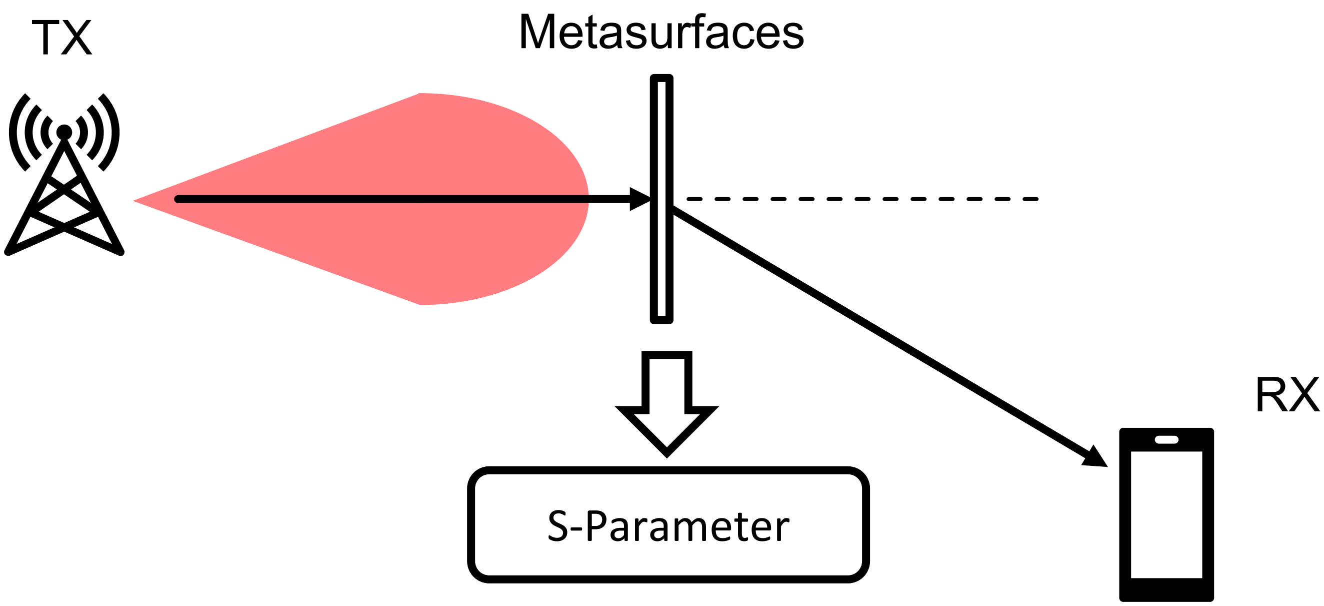


Reference: Kamonchanok Duangkanya, et al., "Development of 3D-Printed THz Metasurfaces with Digital Light Processing Technique," The 2024 International Conference on Photonics Solutions (ICPS), Dec. 2024

Variation of beam direction



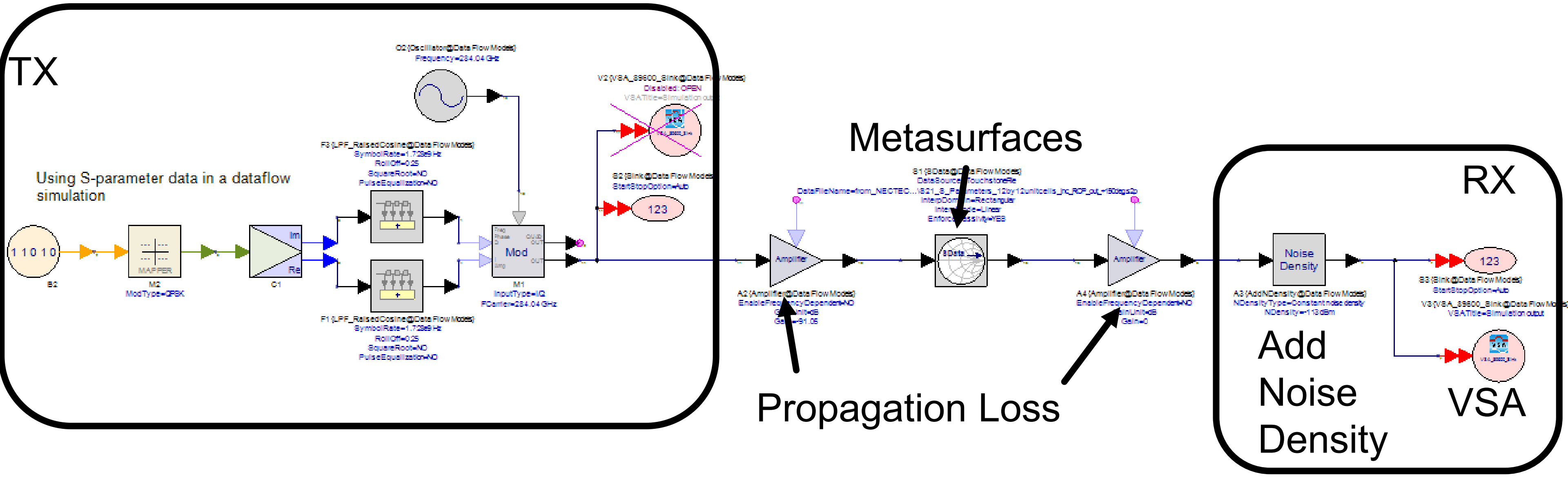
Wireless system simulation



Condition of the simulation

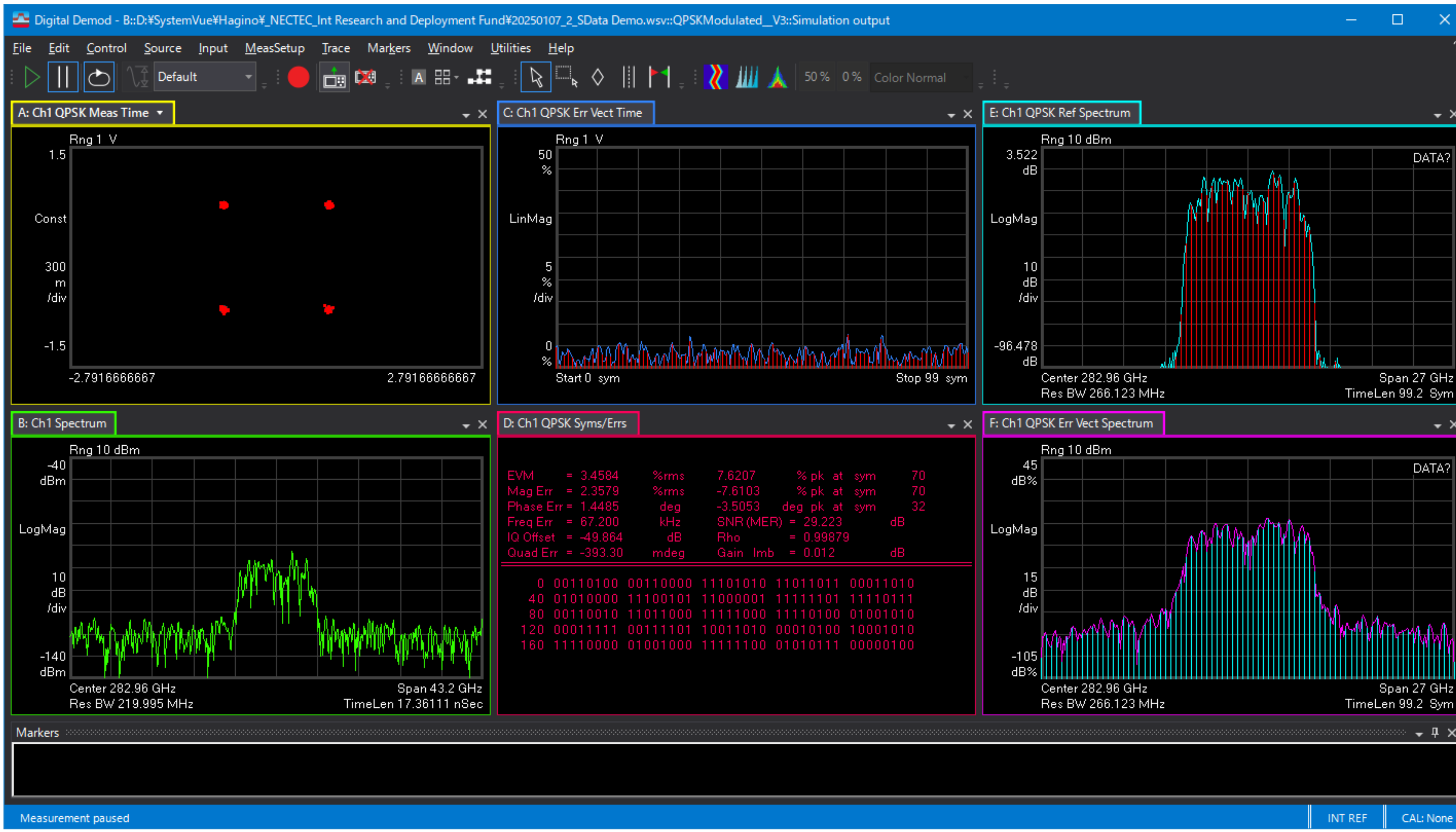
- Beam direction: +150deg, +160deg, +170deg, +180deg
- Bandwidth: 2.16 GHz, Center freq: 284.04 GHz
- Bandwidth: 8.64 GHz, Center freq: 282.96 GHz
- Mod. Type: QPSK
- TX-Metasurfaces: 1.5m ,Loss: 85 dB
- Metasurfaces-RX : 1.5m ,Loss: 85 dB
- TX PWR: 20dBm
- Adding Noise Density: -203 dBm/Hz

Schematic of the simulation

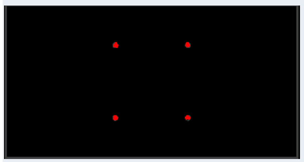
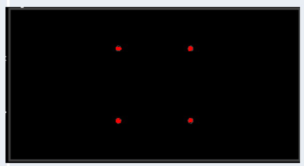
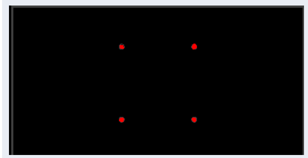
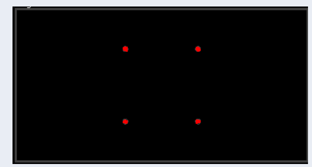
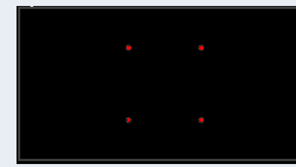
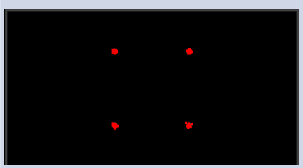
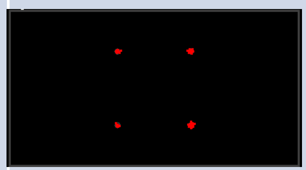
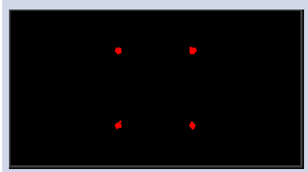
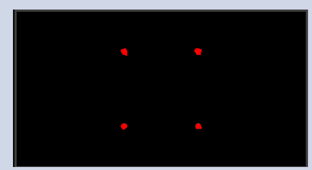
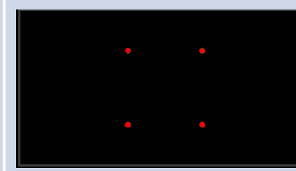


Example of the simulation results

Bandwidth: 8.64 GHz, Beam direction: 150°



Summary of the constellations

Bandwidth (GHz)	Beam direction				wo/ Metasurfaces
	150deg	160deg	170deg	180deg	
2.16					
8.64					

Summary of EVM

		EVM [%rms]				
Bandwidth (GHz)		Beam direction				wo/ Metasurfaces
		150deg	160deg	170deg	180deg	
2.16	Max.	2.3	2.0	2.1	2.0	1.3
	Min.	1.6	1.5	1.5	1.5	0.9
8.64	Max.	4.1	3.6	3.4	3.4	2.3
	Min.	3.5	3.0	3.1	3.0	1.9

- When the metasurface devices are inserted, EVM increases approximately 0.6% in 2.16 GHz bandwidth and approximately 1.2% in 8.64 GHz bandwidth.
- There is little change in EVM due to the difference in the beam direction, but the EVM deteriorates slightly only at 150 degrees.
- Overall, EVM characteristics are almost consistent with brief expectations.

Conclusion

- Terahertz Metasurface Devises (NECTEC)
  - Technology for development of compact, planar, and lightweight devices
  - 3D-printed metasurfaces with digital light processing technique: faster and cheaper than traditional photolithography
  - Available to vary the beam direction by metasurface design
- Wireless System Simulation (NICT)
  - Basic wireless system simulation using S-parameter characteristics of metasurface devices designed by NECTEC
  - Using frequency bands assigned for IEEE802.15.3d
  - Observing EVM for several beam directions

Thank you!