Active Reconfigurable Intelligent Surface Aided Wireless Communication Prototype

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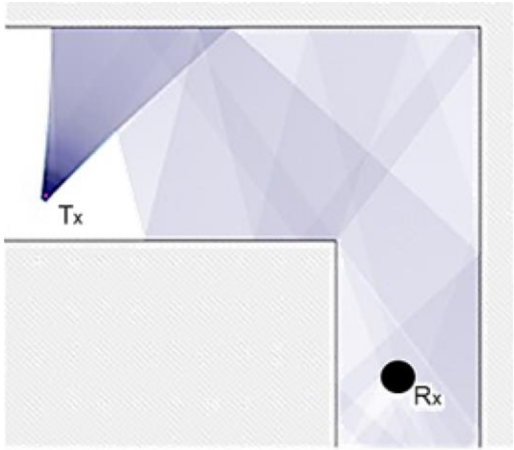
Outline

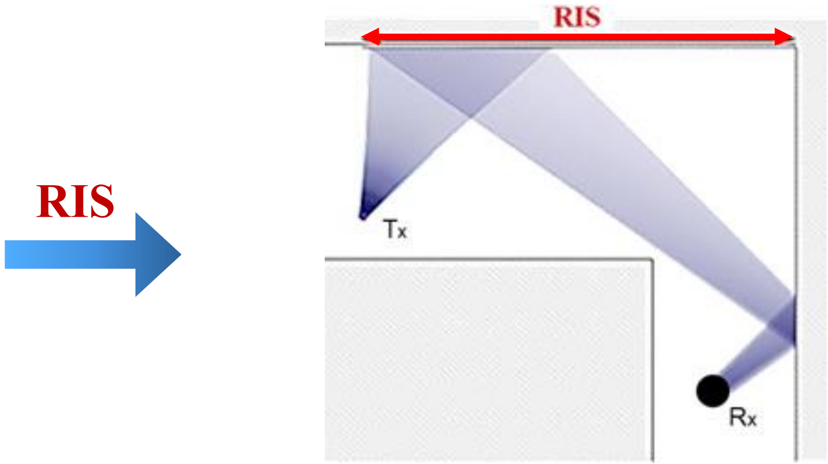
- Basics of RIS
- Existing passive RIS
- Developed active RIS
- Conclusions

Basics of RIS

- A surface of reconfigurable metamaterials
- Control the propagation of electromagnetic wave
- Manipulate the channel to improve the signal quality



Traditional wireless communications:
Heavily rely on the environment



RIS-aided wireless communications:
Control the environment

Outline

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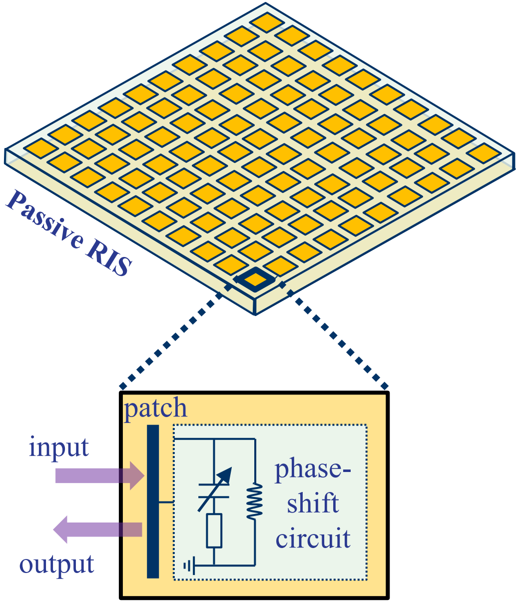
Realization of passive RIS

- RIS consisting of a large number of passive elements
- Negligible thermal noise, low cost, low power consumption

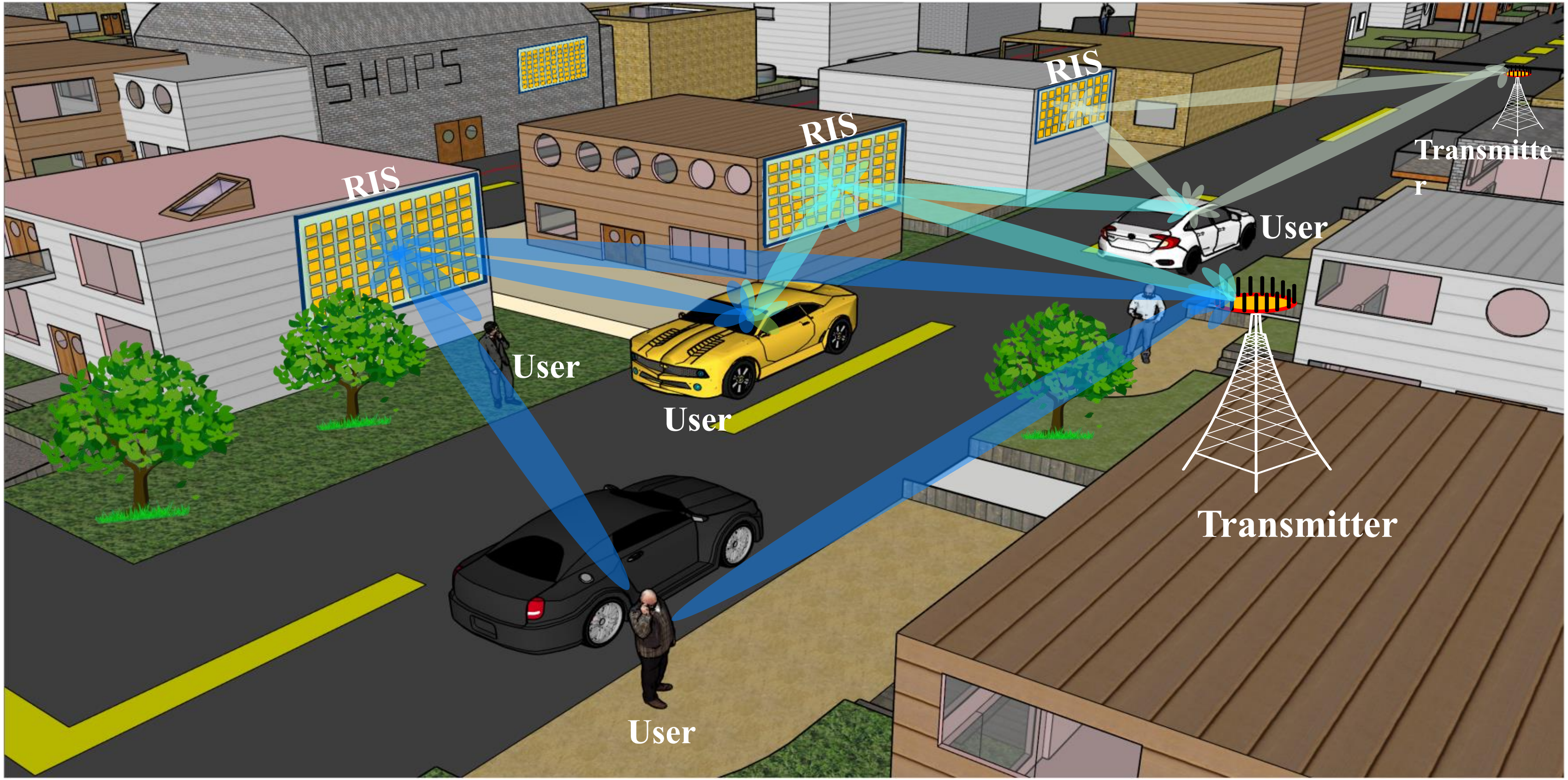


Passive element

RIS-aided commutations@2.3 GHz

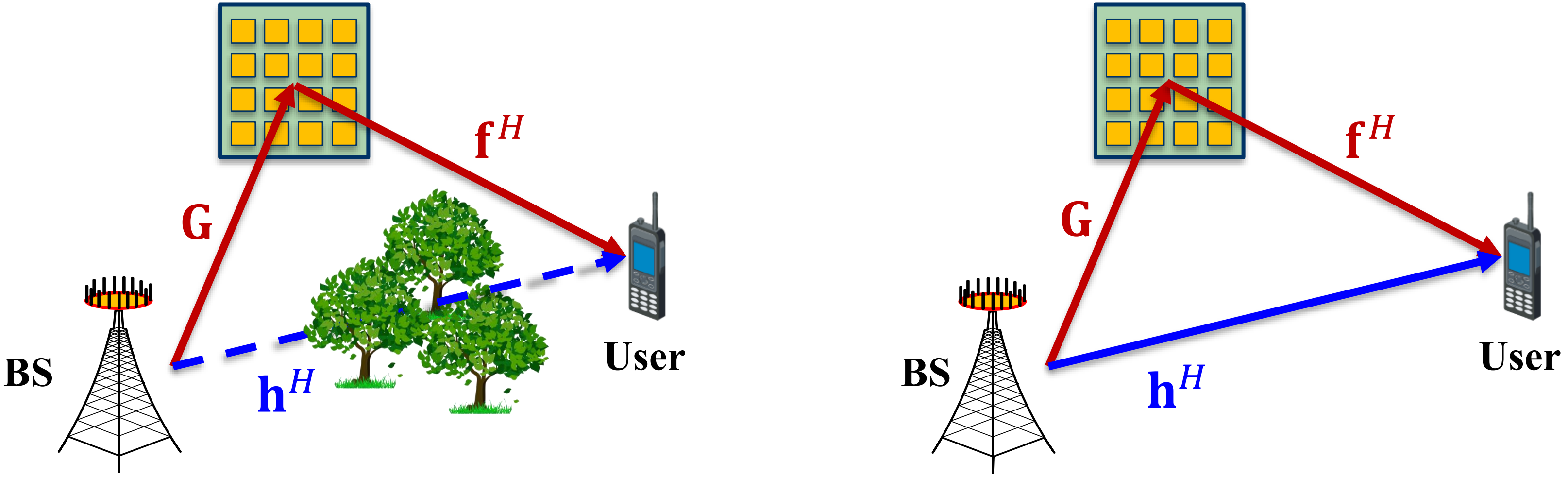
RIS-aided commutations@28 GHz

Application of passive RIS



"Multiplicative fading" effect

- The RIS-aided reflection link suffers large-scale fading twice



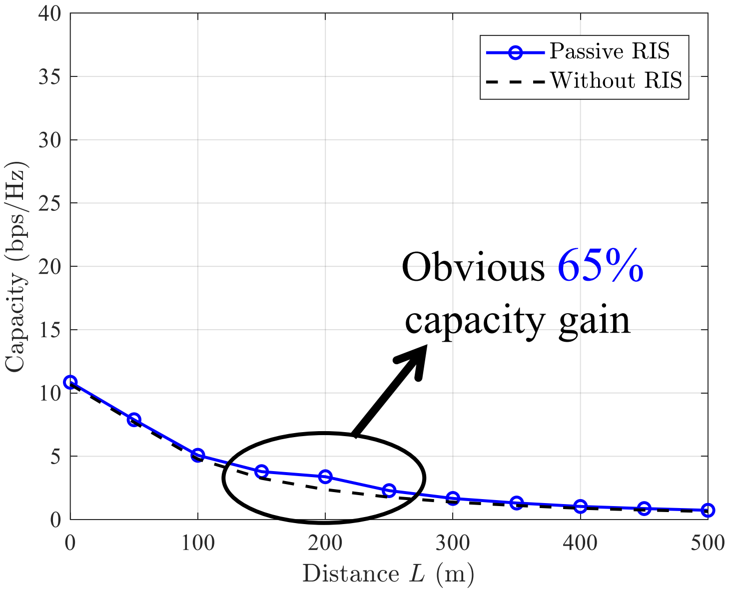
(a) Atypical scenario (b) Typical scenario

Signal model: $y = (\mathbf{h}^H + \boldsymbol{\theta}^H \mathrm{diag}(\mathbf{f}^H)\mathbf{G})\mathbf{w}s + z$

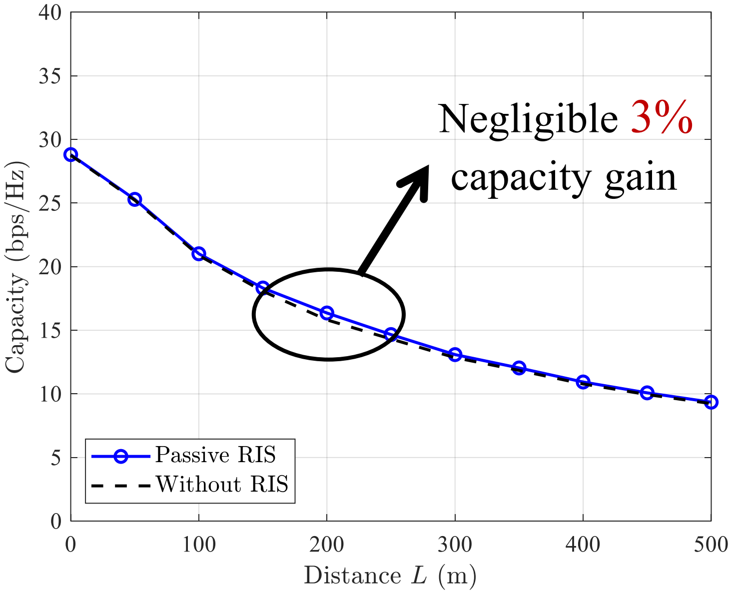
Product instead of summation

Example

- Passive RIS can only achieve negligible capacity gain in typical communication scenarios



(a) Atypical scenario



(b) Typical scenario

Outline

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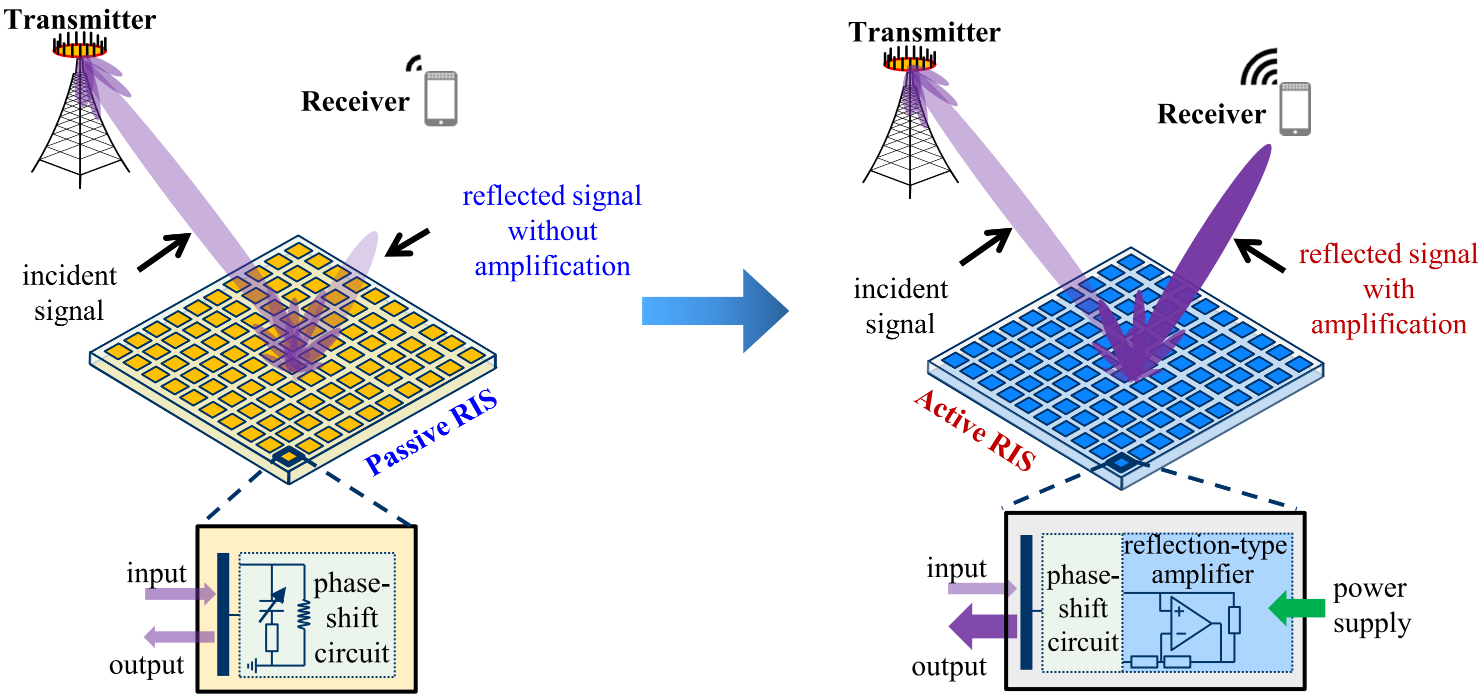
Concept of active RIS

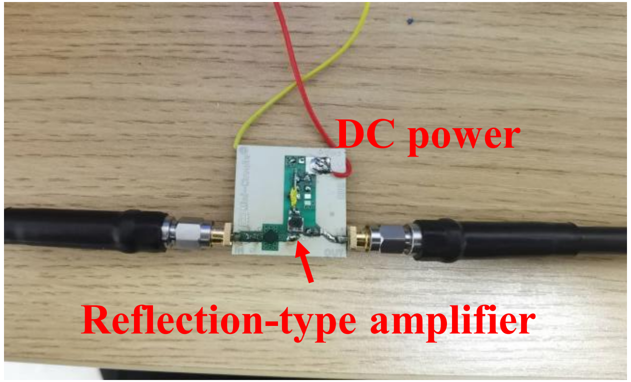
- Passive RIS: Reflect signals directionally without amplification
- Active RIS: Amplify the reflected signals using power amplifiers

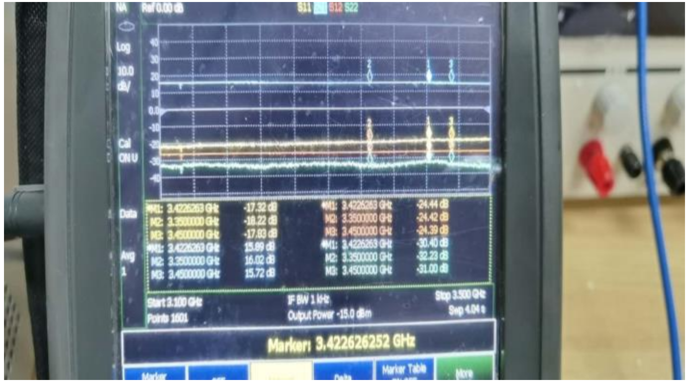


Realization of active RIS

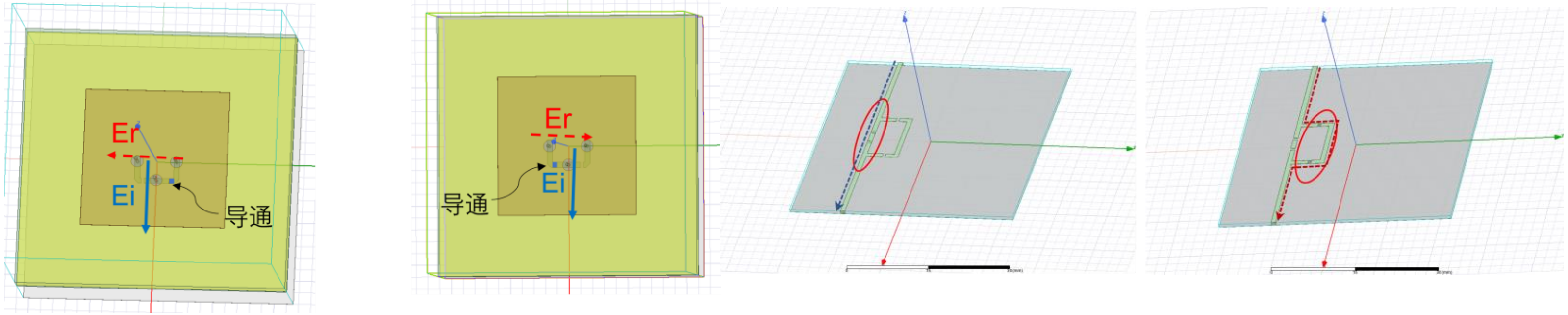
IEEE GLOBECOM®

- Reflection-type amplifier: 30 dB reflection gain



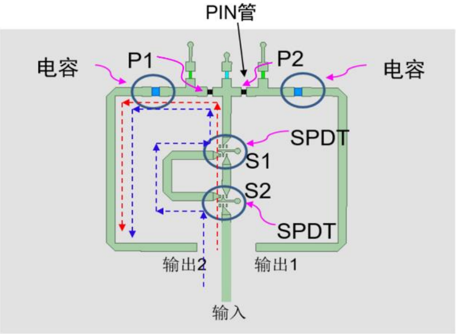


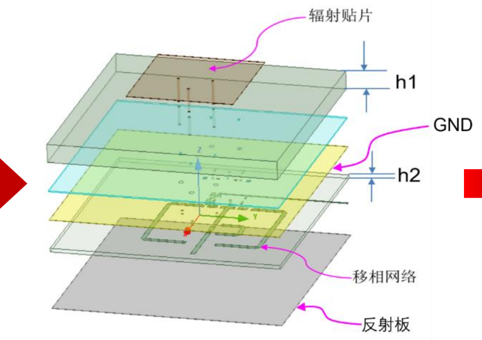
- Phase-shifting circuit: 2-bit resolution

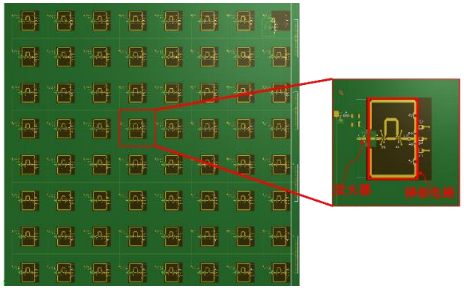


Realization of active RIS

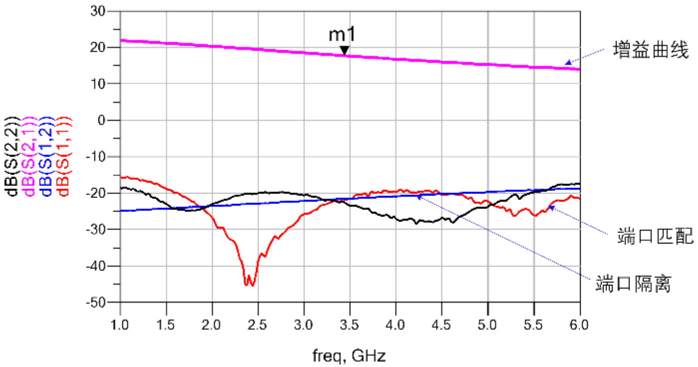
- Active RIS：Circuit -> element -> array

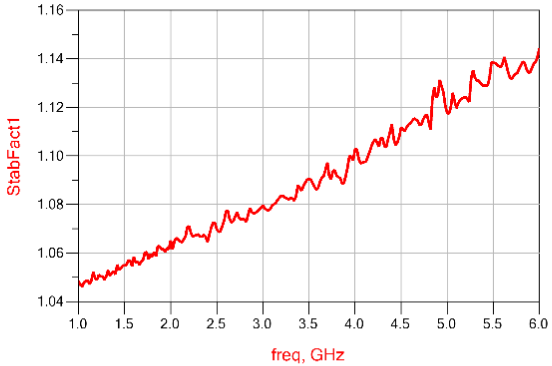






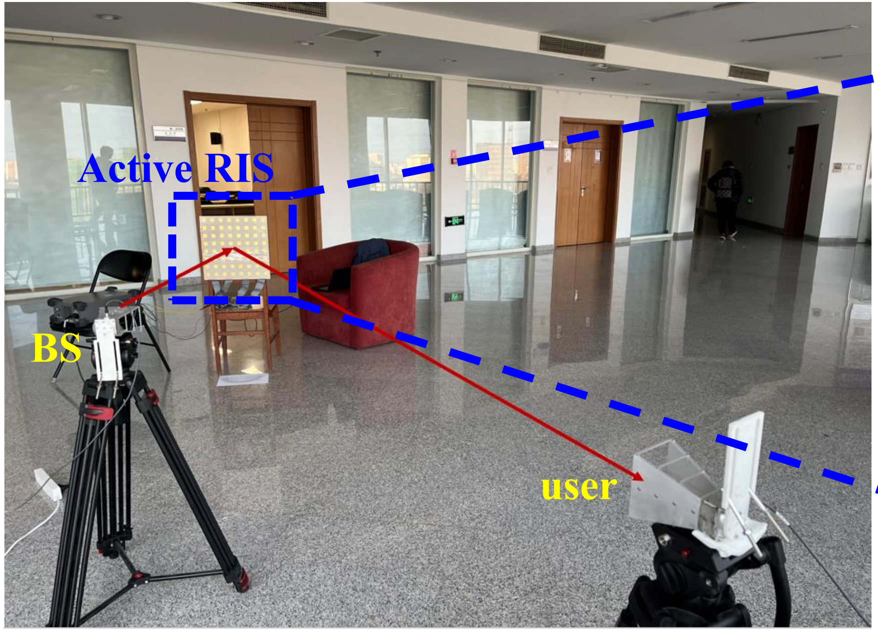
- Active RIS：Electromagnetic full-wave simulation

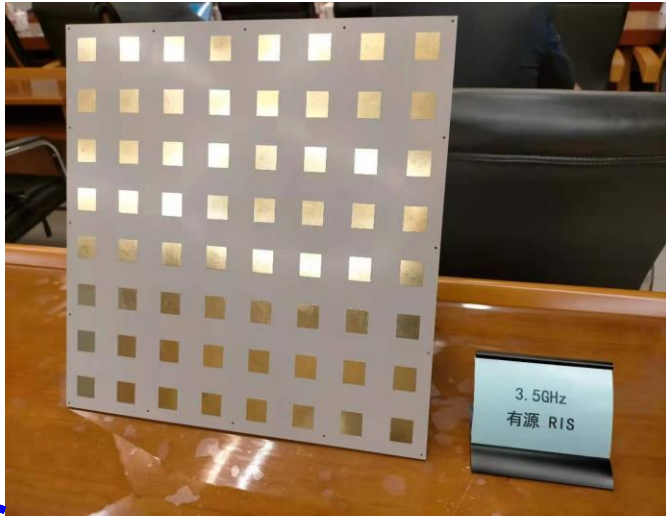




Active RIS communication prototype

- Active RIS: 3.5 GHz, 8×8 elements
- BS and user: USRP-2953R, horn antennas

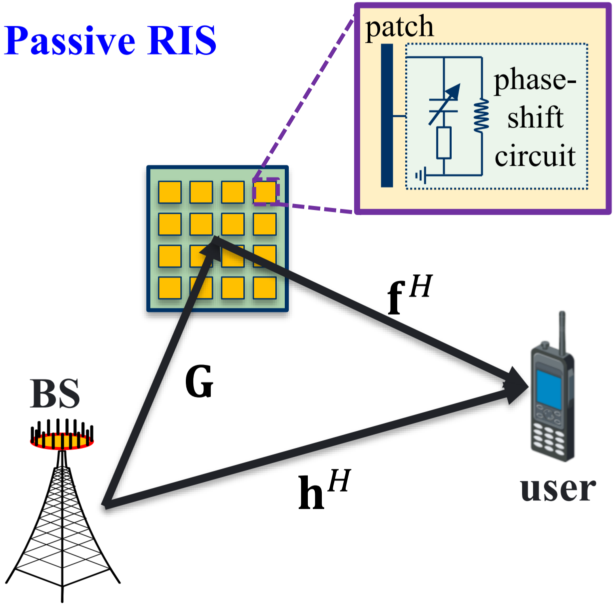




8×8 Active RIS

Signal model of active RIS

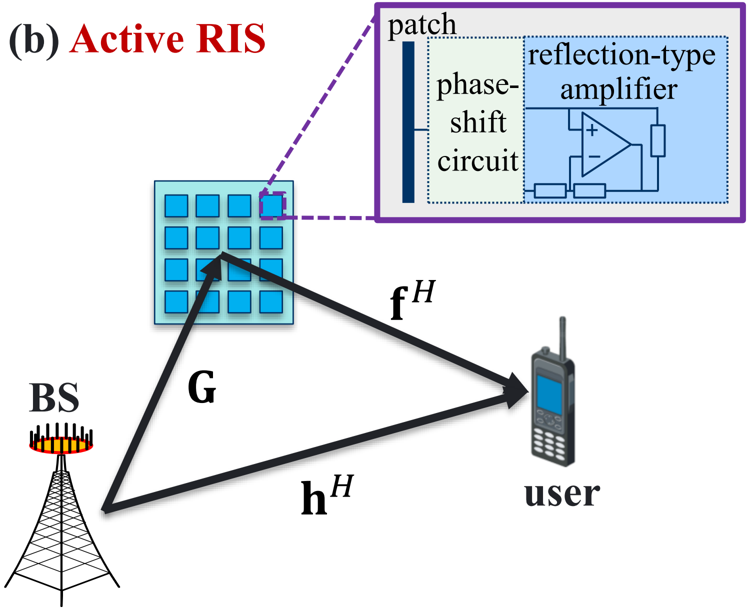
(a) **Passive RIS**



$$y = (\mathbf{h}^H + \mathbf{f}^H \mathbf{\Theta}^H \mathbf{G})\mathbf{w}s + z$$

Phase shift matrix

(b) **Active RIS**

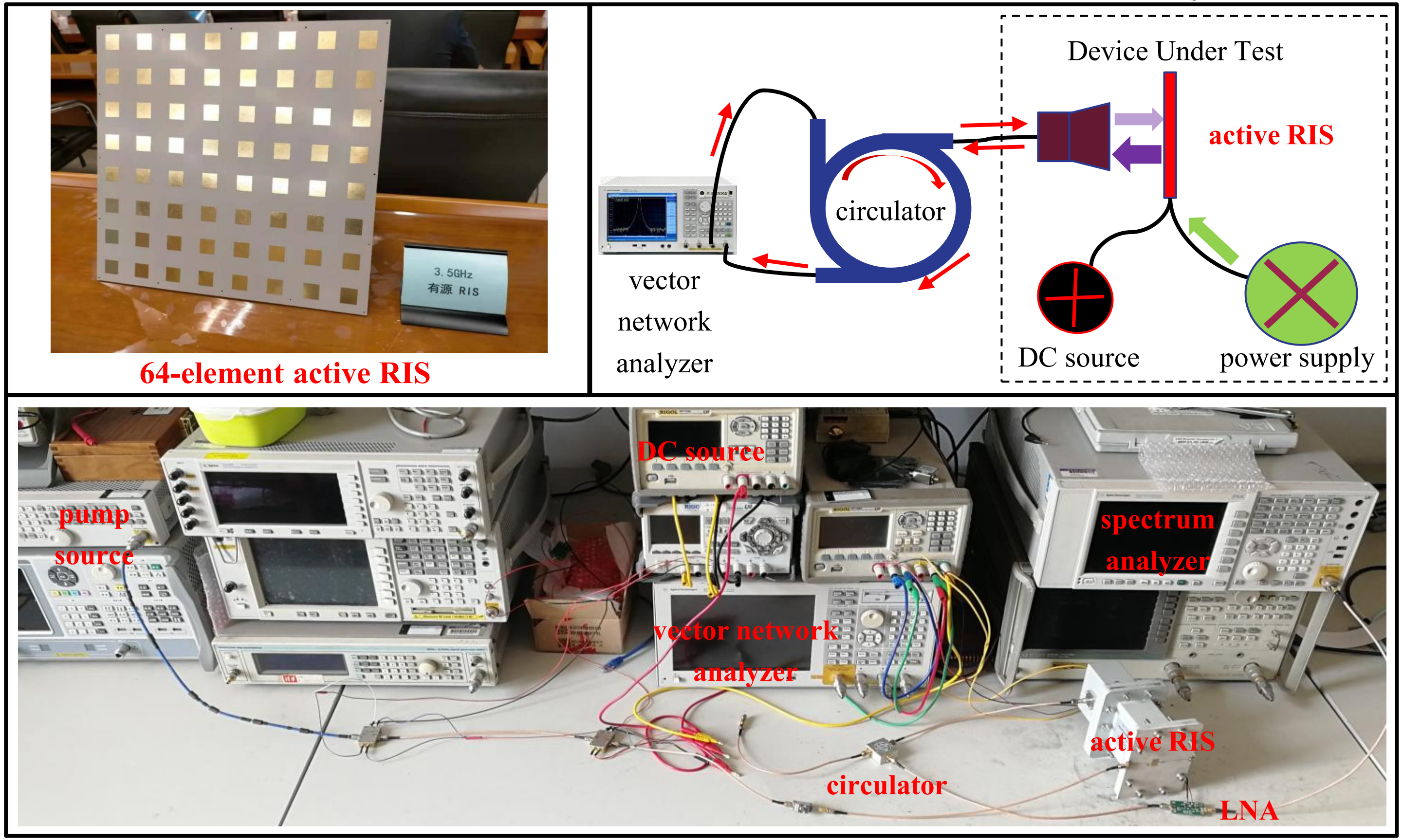


$$y = (\mathbf{h}^H + \mathbf{f}^H \mathbf{P}\mathbf{\Theta}^H \mathbf{G})\mathbf{w}s + \mathbf{f}^H \mathbf{P}\mathbf{n} + z$$

Amplification matrix

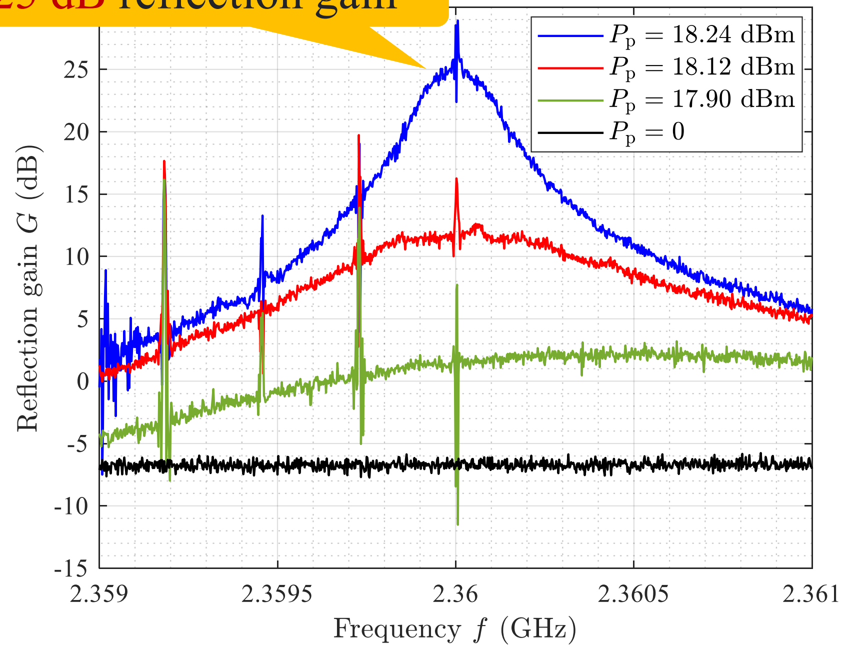
Additional noise introduced by active components

Validation of active RIS signal model

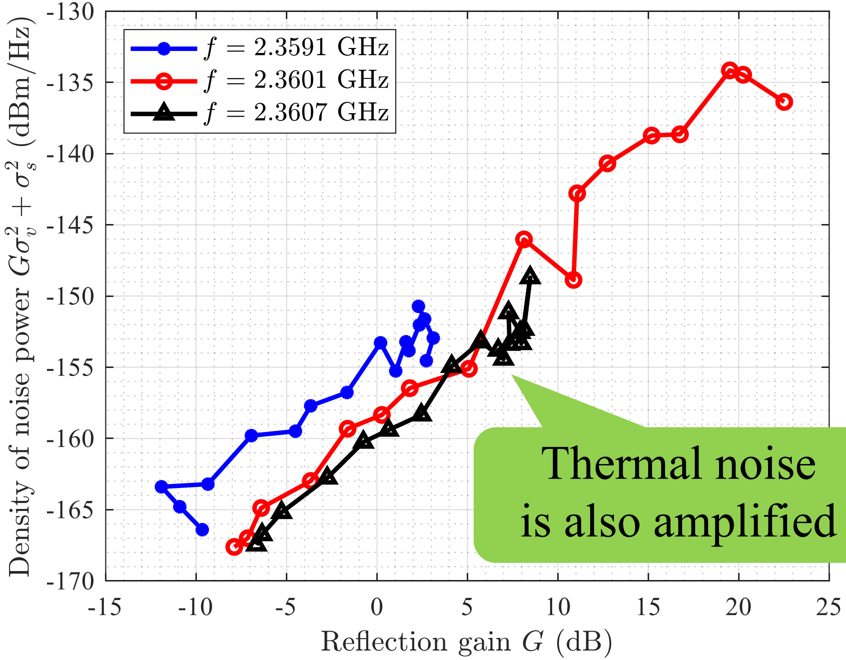


Validation of active RIS signal model

25 dB reflection gain



(a) **Reflection gain** vs. frequency



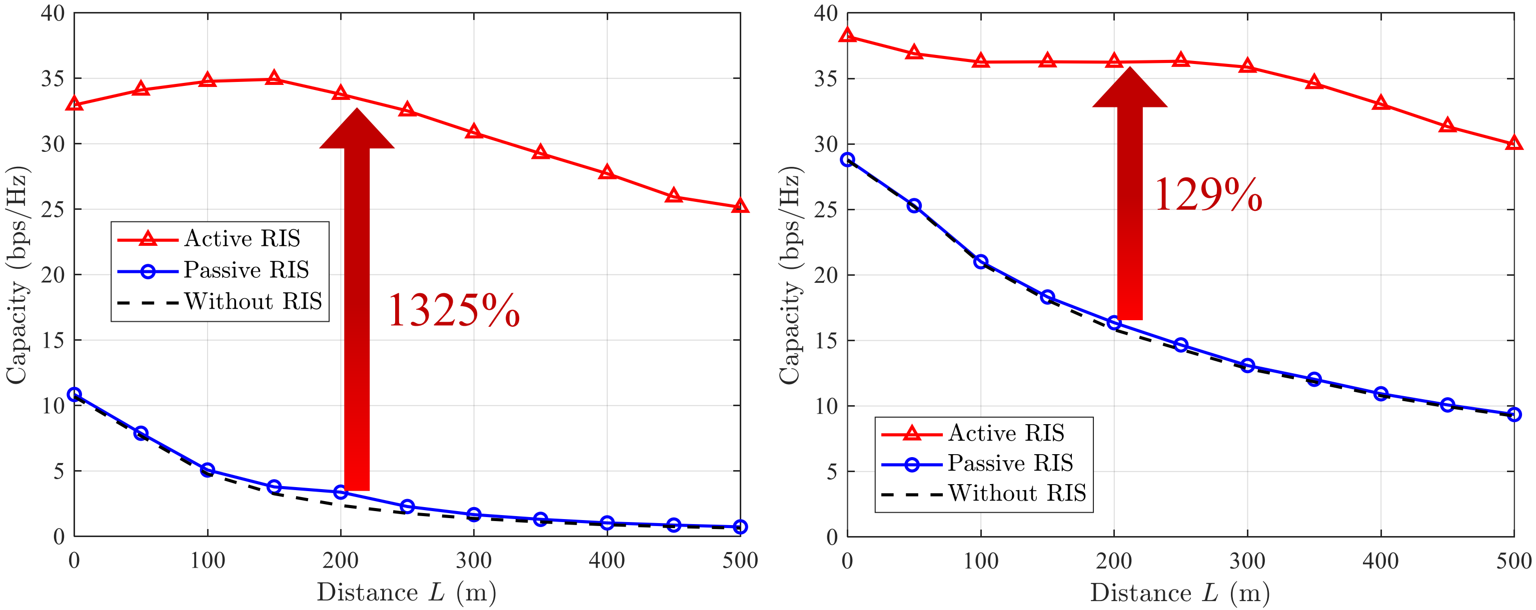
Thermal noise is also amplified

(b) **Noise power** vs. reflection gain

Signal model: $y = pe^{j\theta}x + pn + z$

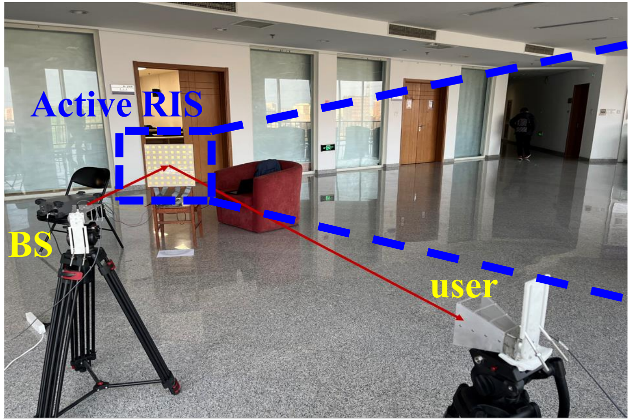
Simulation results

- Active RIS can achieve noticeable capacity gain in typical communication scenarios



(a) Atypical scenario **(b) Typical scenario**

Field test



Parameter	Setting
Frequency	3.55 GHz
Bandwidth	40 MHz
Polarization	Vertical (BS) Horizontal (user)
BS-RIS distance	2 m
RIS-user distance	3.5 m
AoA	0°

Device	Reflection AoD	Received Power	Data Rate
Metal plate	15°	-110 dBm	1.2 MHz
Active RIS		-100 dBm	28.5 MHz
Metal plate	45°	-105 dBm	1.5 MHz
Active RIS		-95 dBm	30 MHz

Conclusions

- **Basics of RIS**
  - Reconfigure the wireless environment
- **Existing passive RIS**
  - Passively reflect signals without amplification
  - Fundamental limit: “multiplicative fading” effect
  - Only achieves negligible capacity gain in typical scenarios
- **Proposed active RIS**
  - Reflect signals with amplification to overcome “multiplicative fading” effect
  - New signal model verified by experimental measurements
  - Achieves noticeable capacity gain in typical scenarios
  - Recent test results based on an 8×8 active RIS

Video Link: https://cloud.tsinghua.edu.cn/f/fd768b02984f44e398a7/

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