Tag Antenna Structure Calibrated Backscattering Signal Detection

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Introduction

Backscatter-Assisted IoT Network for 6G

- The advent of 6G networks necessitates **massive IoT nodes** deployment for enhancing service capabilities
- Conventional wireless communication technologies are **power-intensive and costly** to integrate into IoT nodes
- *Backscattering* emerges as a promising **sustainable** solution for data transmission, offering cost-effective deployment of massive IoT

Advantage of Passive Backscattering

✓ *Low-cost & Small Form Factor*

- Backscatter Communication (BackCom) **eliminates** active RF components & batteries, simplifying tag circuitry

✓ *High Energy Efficiency & Sustainable*

- Utilizing backscattering reduces overall energy consumption, promoting Green Communication and sustainability goals

Motivation

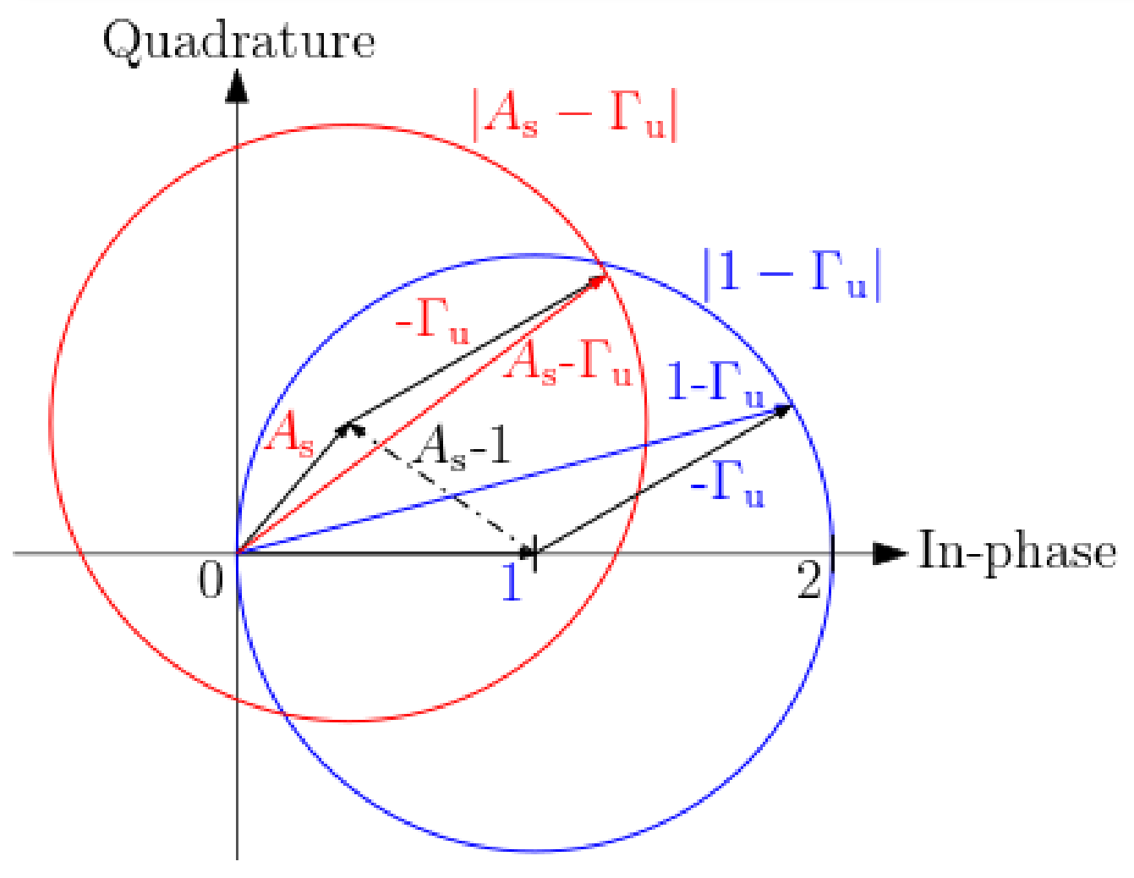


Fig. 2: Complex plane for $A_s - \Gamma$

- The widely used Minimum Scattering Antenna (MSA) assumption, A_s =1, is **impractical**
- For given unit $|\Gamma_u|$, the surface area enclosed by red (blue) circle representing feasible A_s-Γ (1-Γ)
- Amplitude and Phase of backscattered signal is influenced by A_s

- Value of A_s has no effect on the differential radar cross section, which depends on $|\Gamma_1 - \Gamma_2|$, but it significantly changes the magnitude of the backscattered signal
- Selecting the same Γ for complex A_s and A_s =1 leads to different outcomes, resulting in inaccurate predictions of backscattered signal characteristics

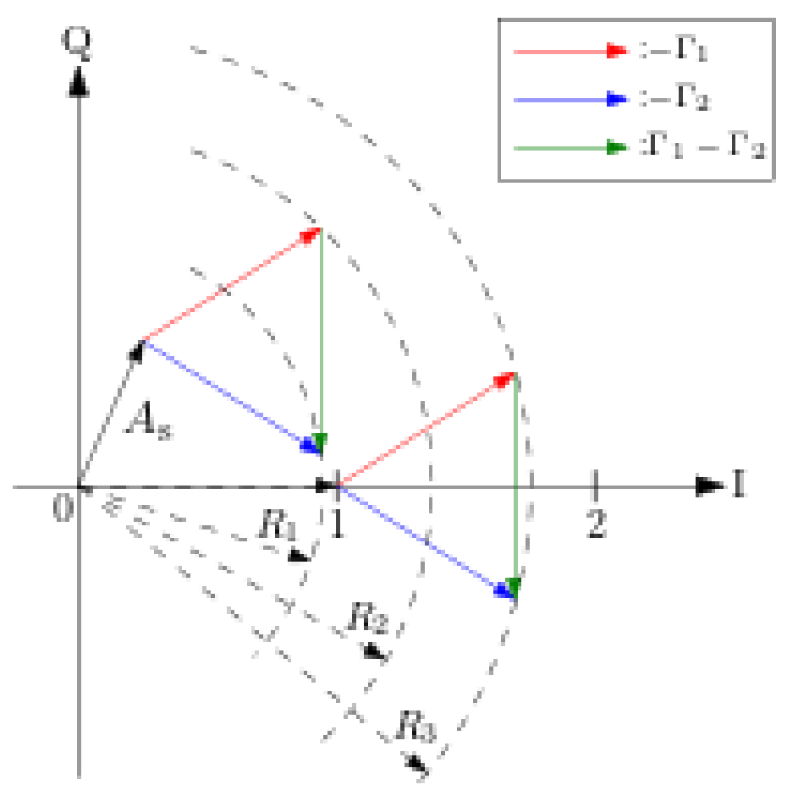


Fig. 3: Impact of A_s on $|A_s - \Gamma|$

Background & System Model

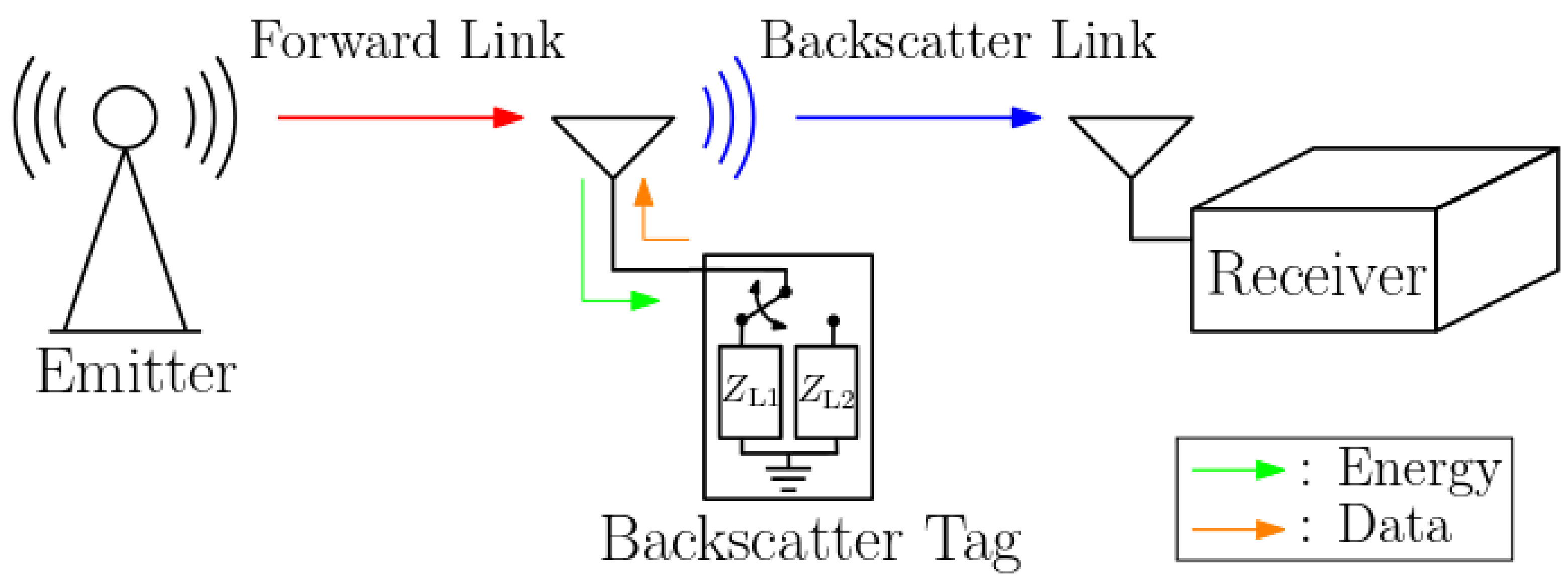


Fig. 1: Bistatic BackCom system with binary load modulation

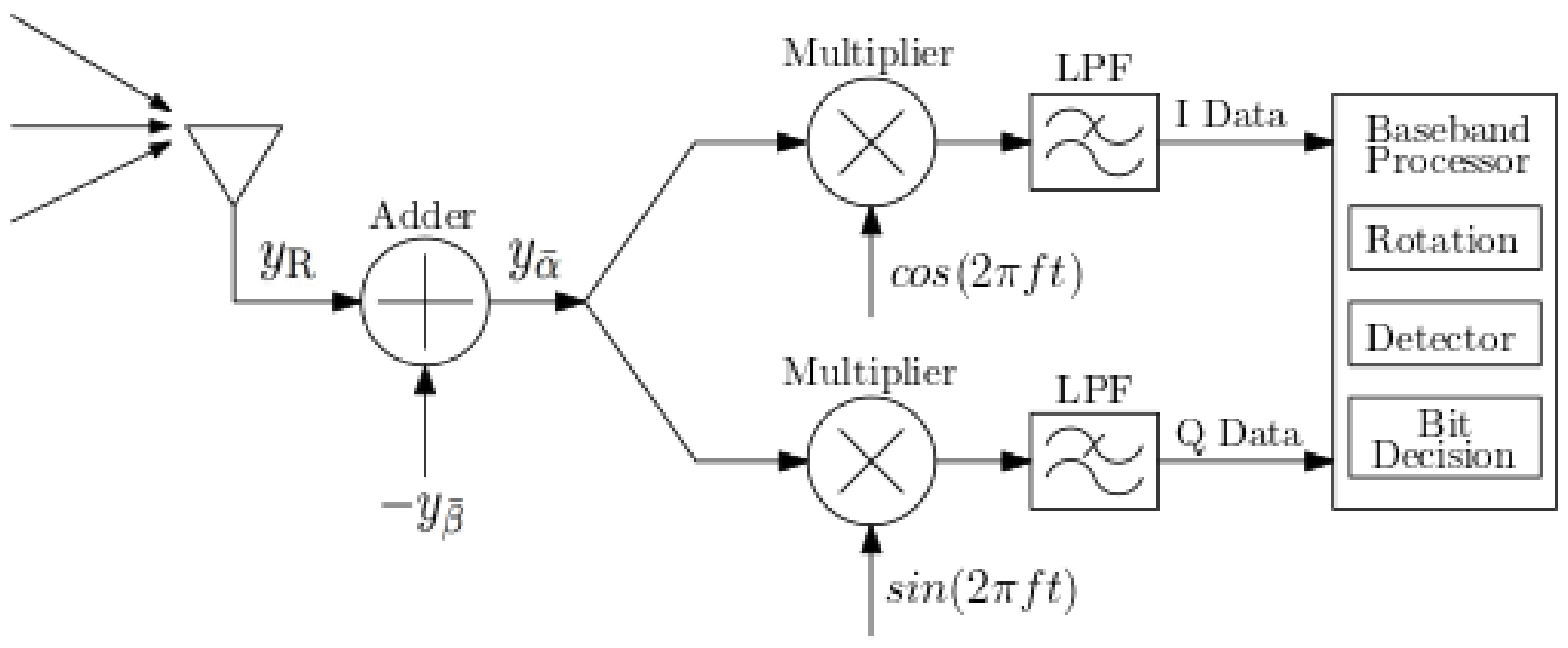
BackCom System and Theory:

- In the forward link, the emitter continuously transmits RF carrier
- When the RF carrier impinges the tag's antenna, part of the power is harvested, and the remaining power is 'reflected' back
- The backscattering field is given as: $\vec{\boldsymbol{E}}_\mathrm{b} \triangleq \frac{\vec{\boldsymbol{E}}_\mathrm{a}}{I_\mathrm{a}} I_\mathrm{m} \left(A_\mathrm{s} - \Gamma\right)$
- $\vec{\boldsymbol{E}}_\mathrm{a}$: Backscattering field when tag's antenna current is I_a , I_m : Matched load current, A_s : Structural mode scattering dependent term, Γ: Reflection coefficient
- Tag modulates backscattered signal with data by varying the current flow of its antenna by switching load impedances (Z_{L1}, Z_{L2})

Backscattering Field

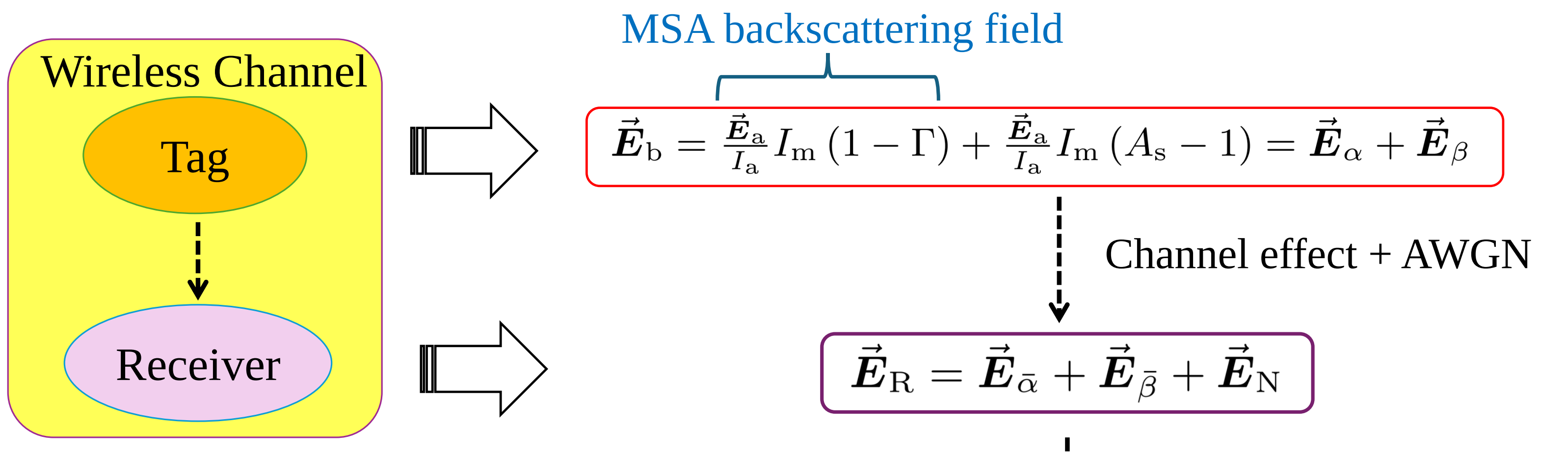
Structural Mode Scattering (A_s) + Antenna Mode Scattering (Γ)

Proposed Method



$\mathcal{Y}_R$: Received backscattered signal
$\mathcal{Y}_{\bar{\alpha}}$: Signal dependent on $\vec{\boldsymbol{E}}_\alpha$
$\mathcal{Y}_{\bar{\beta}}$: Signal dependent on $\vec{\boldsymbol{E}}_\beta$

Fig. 4: Receiver with Signal Subtraction Technique



MSA backscattering field

$$\vec{\boldsymbol{E}}_\mathrm{b} = \underbrace{\frac{\vec{\boldsymbol{E}}_\mathrm{a}}{I_\mathrm{a}} I_\mathrm{m} \left(1 - \Gamma\right)} + \frac{\vec{\boldsymbol{E}}_\mathrm{a}}{I_\mathrm{a}} I_\mathrm{m} \left(A_\mathrm{s} - 1\right) = \vec{\boldsymbol{E}}_\alpha + \vec{\boldsymbol{E}}_\beta$$

Channel effect + AWGN

$$\vec{\boldsymbol{E}}_\mathrm{R} = \vec{\boldsymbol{E}}_{\bar{\alpha}} + \vec{\boldsymbol{E}}_{\bar{\beta}} + \vec{\boldsymbol{E}}_\mathrm{N}$$

Transform into signal quality

$$y_\mathrm{R} = y_{\bar{\alpha}} + y_{\bar{\beta}} + n_\mathrm{R}$$

Subtract $\mathcal{Y}_{\bar{\beta}}$ & assume n_R is negligible

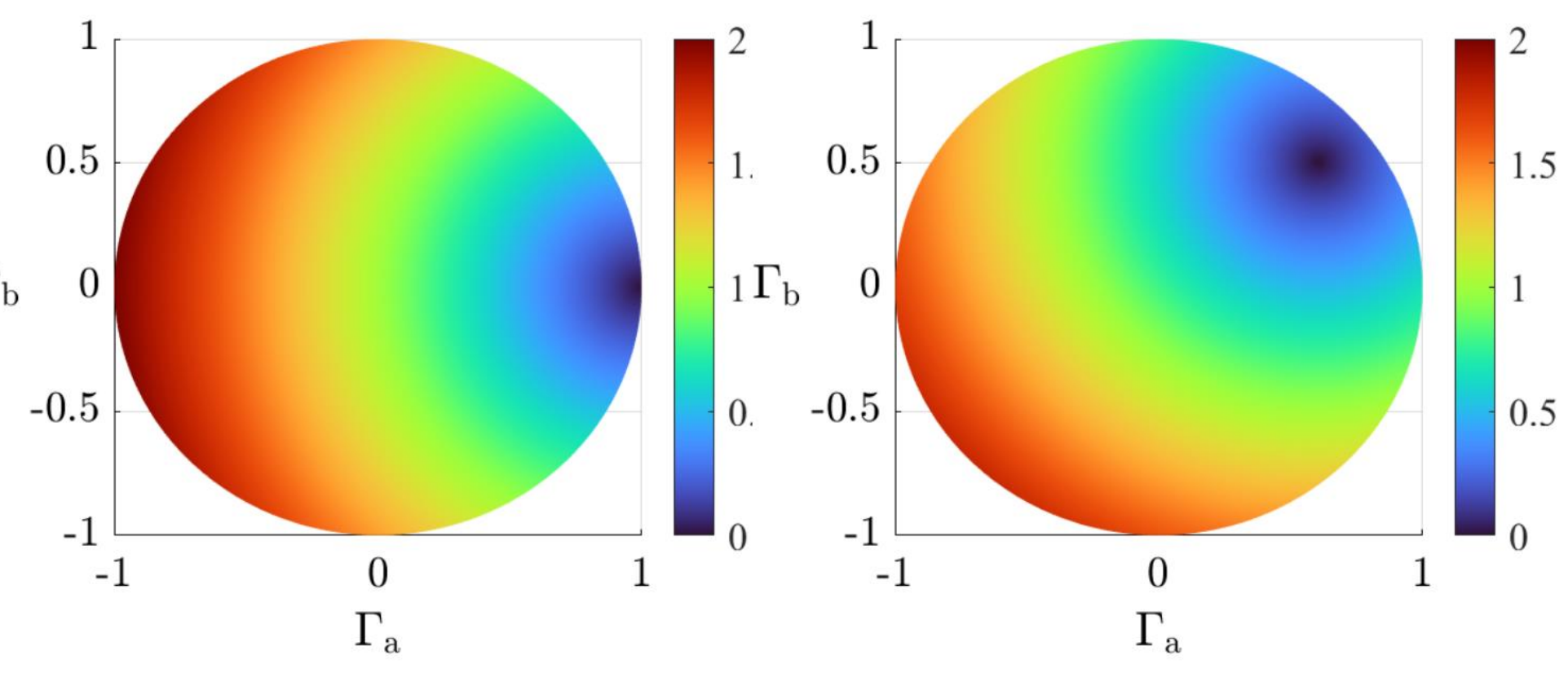
$$y_\mathrm{R} = y_{\bar{\alpha}}$$

Signal Subtraction Technique (SST)

- $\mathcal{Y}_{\bar{\beta}}$ is a constant and can be acquired during training overhead period
- After applying SST, $\mathcal{Y}_R$ is equivalent to the signal backscattered from the tag equipped with MSA

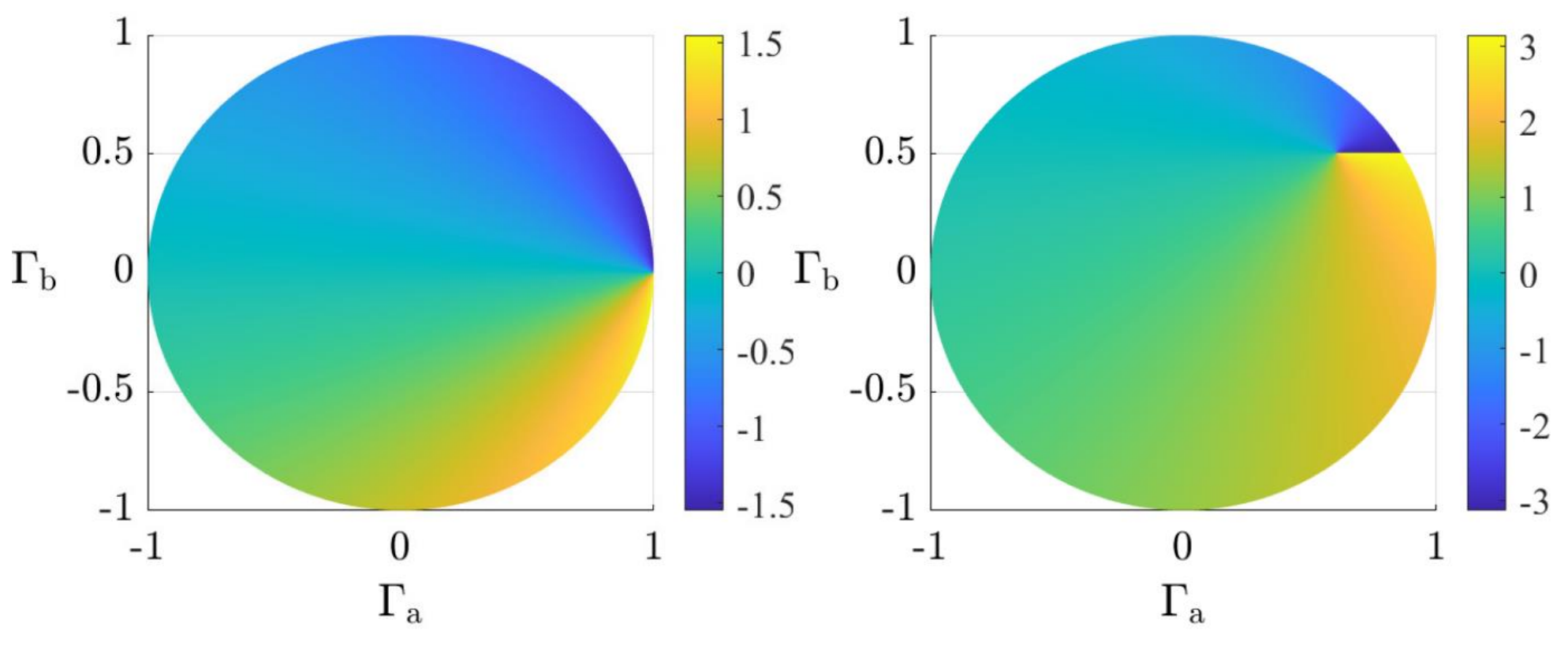
REMARK: Proposed SST effectively mitigates the challenges caused by the complex A_s, enabling the assumption of A_s=1 to be applicable across all BackCom systems

Numerical Results



(a) $A_\mathrm{s} = 1$ (b) $A_\mathrm{s} = 0.6047 + j0.5042$

Fig. 5: Impact of Γ on $\mathcal{A}$



(a) $A_\mathrm{s} = 1$ (b) $A_\mathrm{s} = 0.6047 + j0.5042$

Fig. 6: Impact of Γ on ∅

- $\mathcal{A}$ = $|A_s - \Gamma|$, ∅ = arg($A_s - \Gamma$), Γ = $\Gamma_a + j\Gamma_b$, $|\Gamma| \in [0,1]$
- The results in Fig. 5 reveal that $\mathcal{A}$ exhibits **significant** variability with Γ and A_s
- Maximum of $\mathcal{A}$ is greater when A_s =1, highlighting the **advantage** of preserving the MSA assumption
- Likewise, in Fig. 6, the phase ∅ varies with Γ and A_s, where $∅ \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$ for A_s =1, and $∅ \in [-\pi, \pi]$ for complex A_s

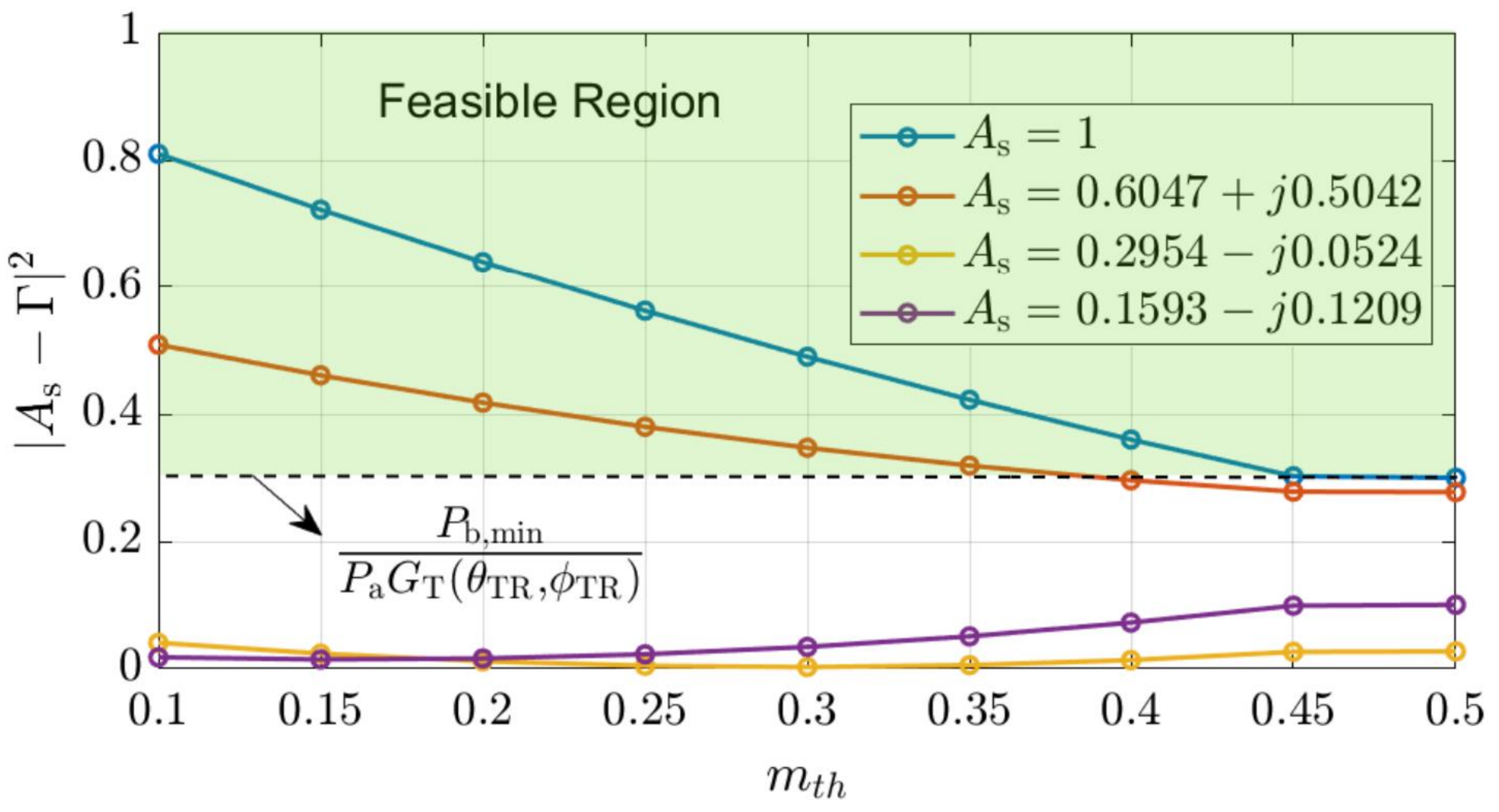


Fig. 7: Insight on $\mathcal{A}^2$ for various modulation index m_{th}

- The received signal quality **depends** on the power of the backscattered signal $P_\mathrm{bi} \triangleq S\sigma_i \propto \left|\vec{\boldsymbol{E}}_\mathrm{bi}\right|^2 \propto |A_s - \Gamma|^2 = \mathcal{A}^2$
- Higher P_{bi} **enhances** the reliability and efficiency of BackCom
- Fig. 7 shows the $\mathcal{A}^2$ for different A_s values, using the optimal reflection coefficient that **maximises** the harvested power at the ASK-modulated tag under MSA assumption
- A_s =1 results in highest $\mathcal{A}^2$ for all m_{th} and consistently remains within the feasible region ($P_{bi} \geq P_{b,min}$), where the receiver can successfully decode and retrieve the data from noise

Conclusion

✓**Analyzed** the structural mode scattering dependent parameter A_s and its impact on the BackCom system
✓Proposed an innovative signal subtraction technique to **mitigate** the discrepancies caused by the A_s= 1 assumption
✓**Acknowledge** the Australian Research Council's Discovery Early Career Researcher Award (DE230101391) for support