# Security in Terahertz WLANs with Leaky Wave Antennas

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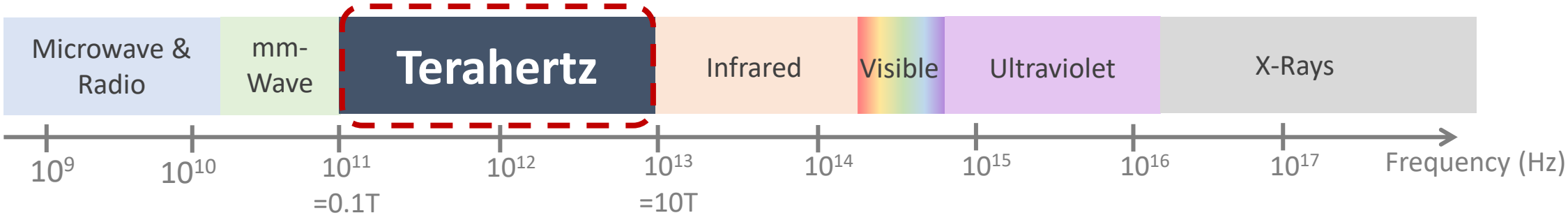
# Opportunities and Challenges in Terahertz

⊕ Large bandwidth ⇨ High data rate

⊖ High pathloss ⇨ Directional transmission required



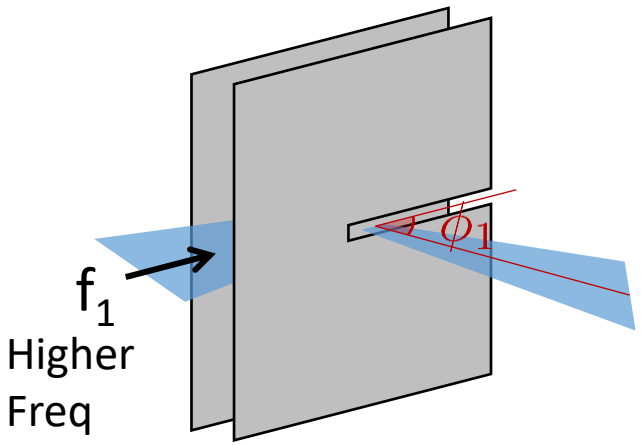

Terahertz antenna design is challenging

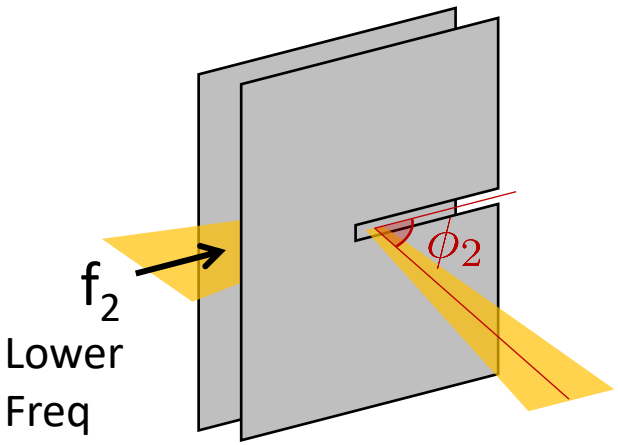
- High operating frequency, large bandwidth
- Directional, steerable

➔ Explore different THz antennas

# Advantages of Leaky-Wave Antenna (LWA)

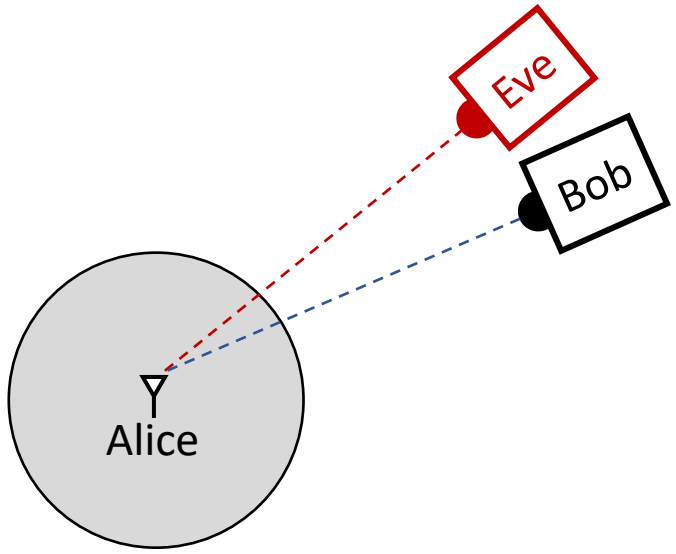
- High operating frequency, large bandwidth
- Controllable directional link via frequency-angle coupling



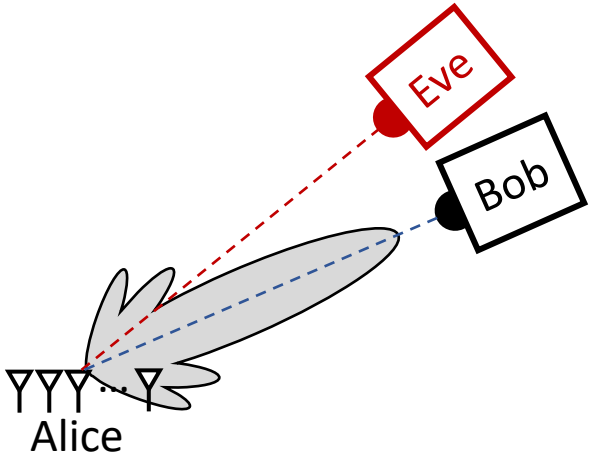
# Different Antennas, Different Eavesdropping Scenarios

Omni-Directional



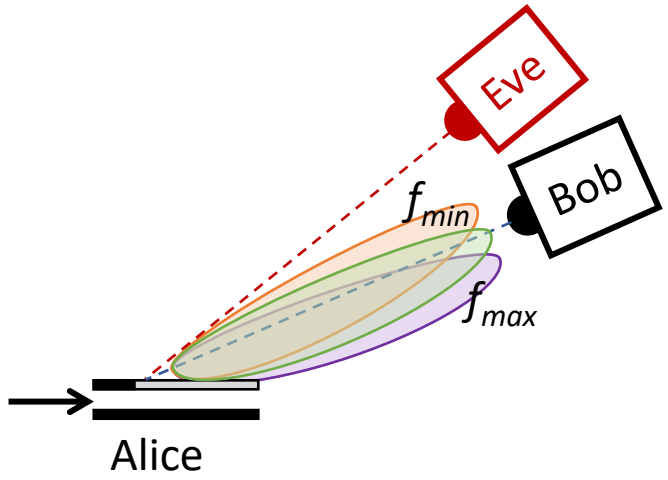

Depend on distance

Directional




Further depend on angle

LWA Directional Link

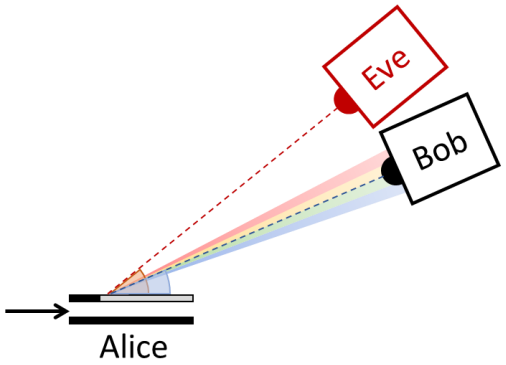



Further change across frequencies

# Project Goal: Threat Assessment

## Examine Secrecy of LWA Links under Eavesdropping

Modeling

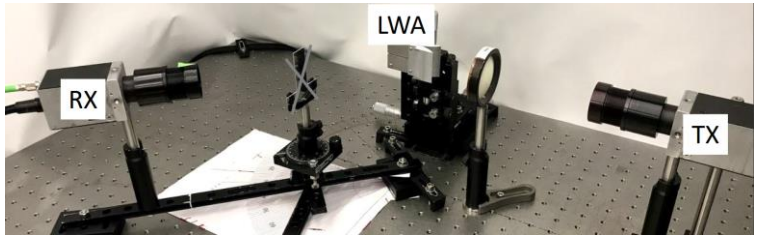



Security Properties

Frequency?

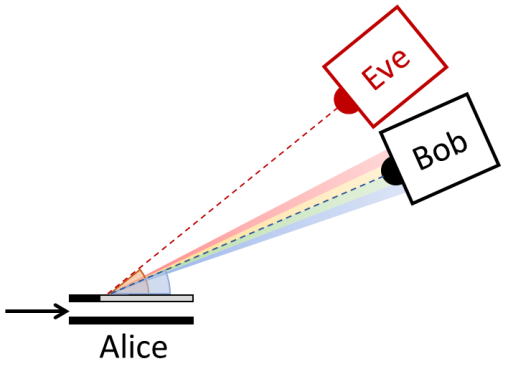
Bandwidth?

Experimental Validation




>> Future Work: Countermeasure Design

## Modeling

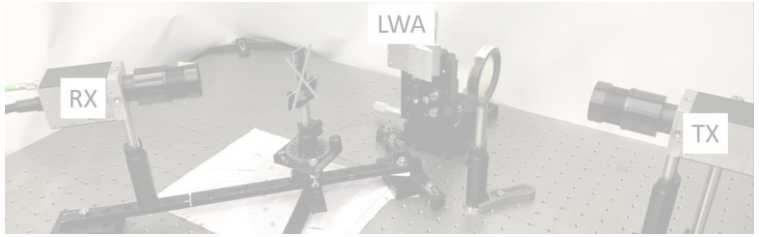



## Security Properties

Frequency?

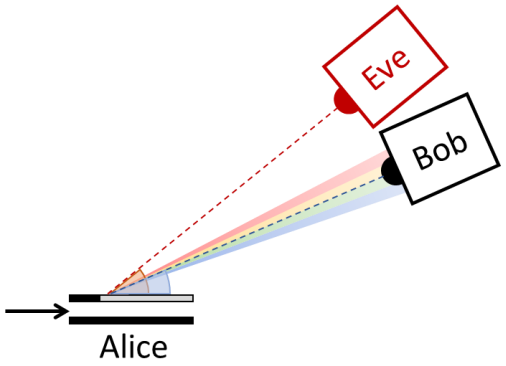
Bandwidth?

## Experimental Validation



# Goal: Flexibility to Explore Important Parameters

Modeling



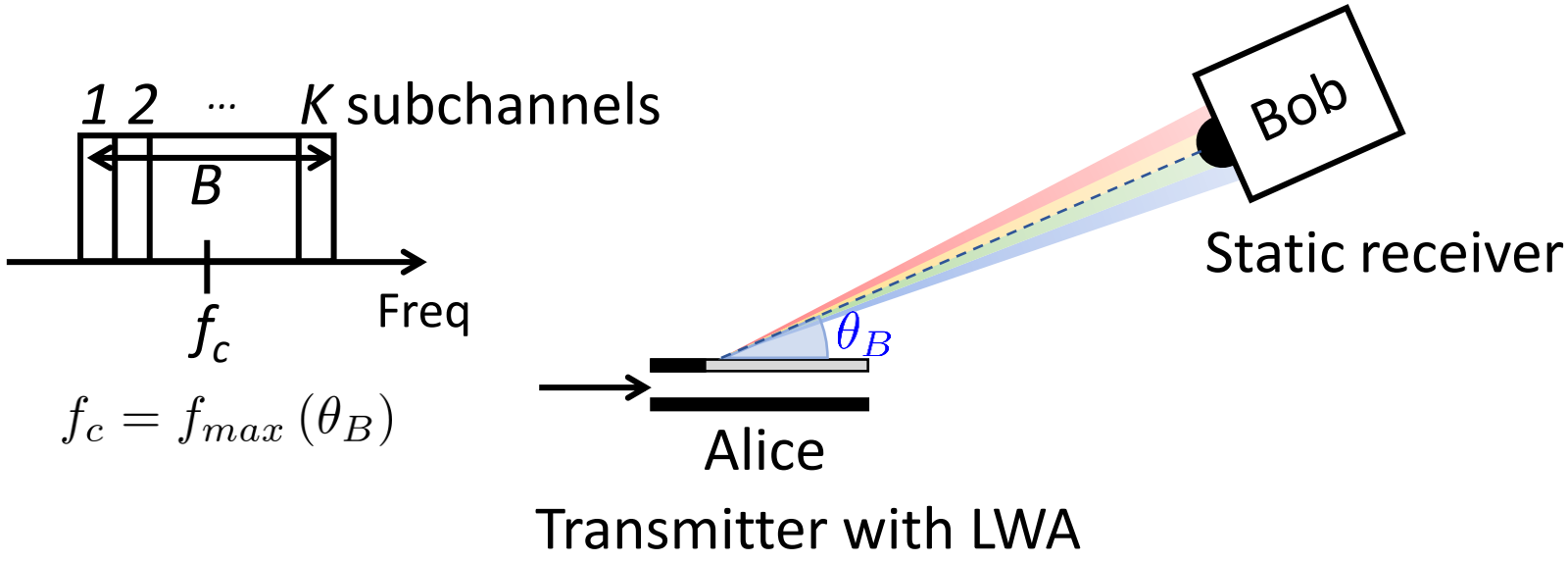

System Model
(Alice-Bob)

Threat Model
(Eve)

LWA Model
(Freq-Ang)

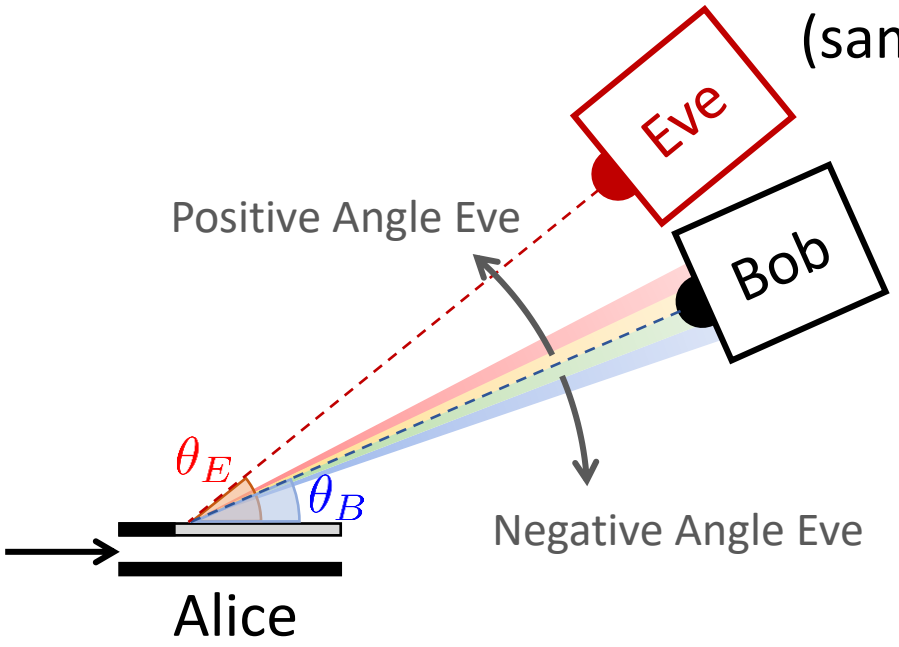
Security Metric
(For Each Freq)

# System Model (Alice-Bob)

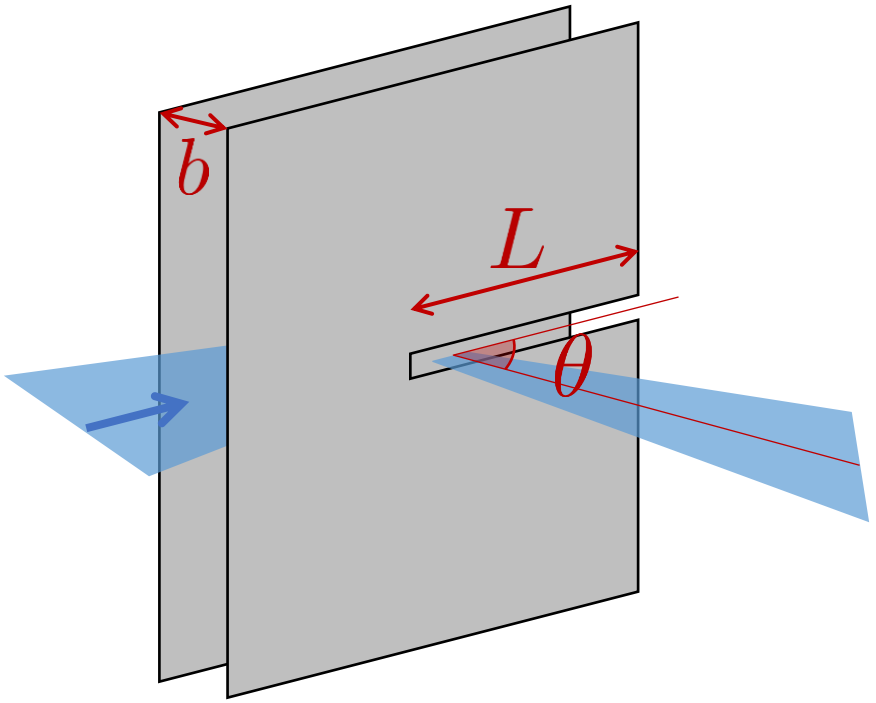


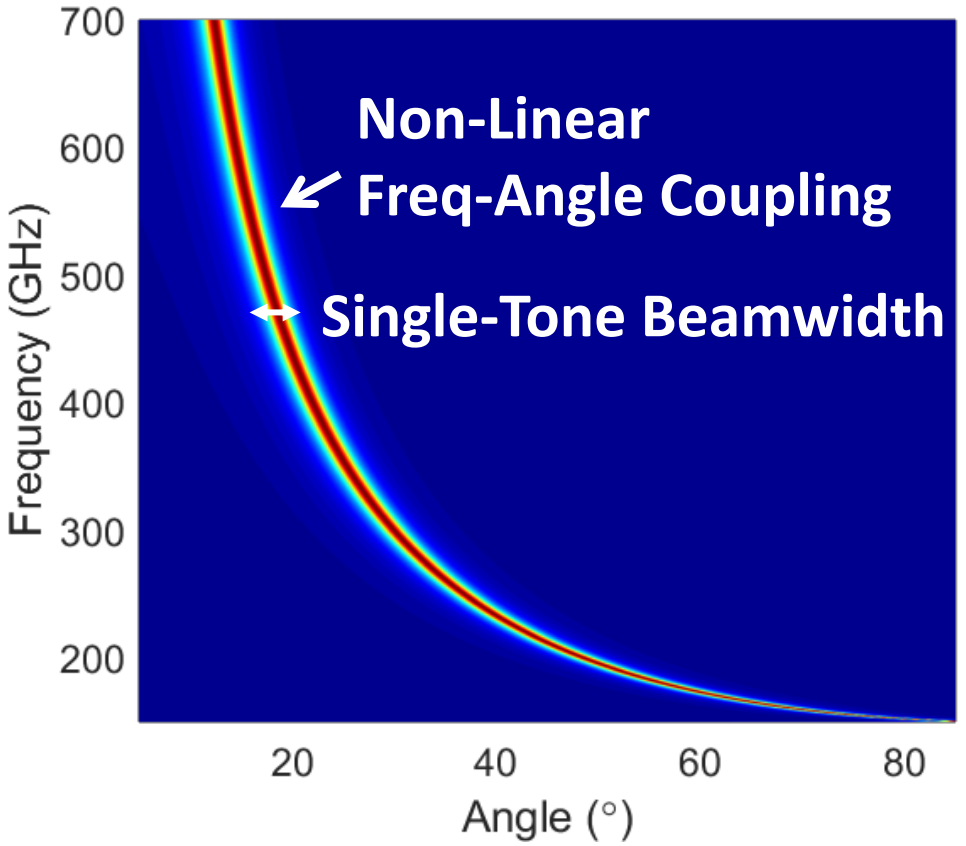
# Threat Model (Eve)

Same radius as Bob
(same channel gain)



# Leaky Wave Antenna Radiation Model



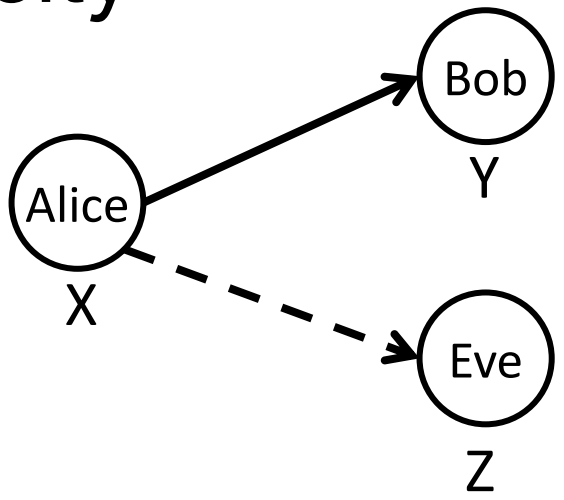

LWA Far-field Radiation Pattern [1]

$$G(f,\theta) = L\,\mathrm{sinc}\left(\left[\beta(f) - j\alpha - k_0\cos\theta\right]\frac{L}{2}\right)$$

Plate separation $b$ = 1 mm
Slot length $L$ = 3 cm

[1] Gross, Frank. *Frontiers in antennas: next generation design & engineering*. McGraw Hill Professional, 2010.

# Security Metric: Secrecy Capacity




- Maximum achievable secrecy rate based on information theory

$$C_S = \max_X I(X;Y) - I(X;Z)$$

- Subchannel secrecy capacity
  (Approximation: assume frequency-flat within the subchannel)

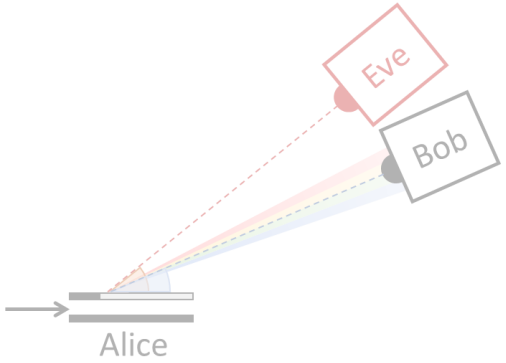
$$C_S^k = \frac{B}{K}\left[\log_2\left(1+\mathrm{SNR}_k^{Bob}\right) - \log_2\left(1+\mathrm{SNR}_k^{Eve}\right)\right]^+$$

Bob's channel capacity  Eve's channel capacity

- Total secrecy capacity: summation of each subchannel

$$C_S = \sum_{k=1}^{K} C_S^k$$

Modeling

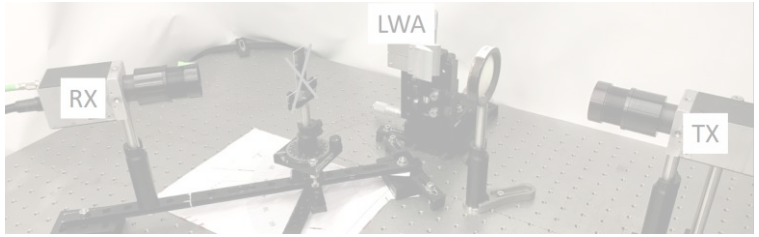



Security Properties

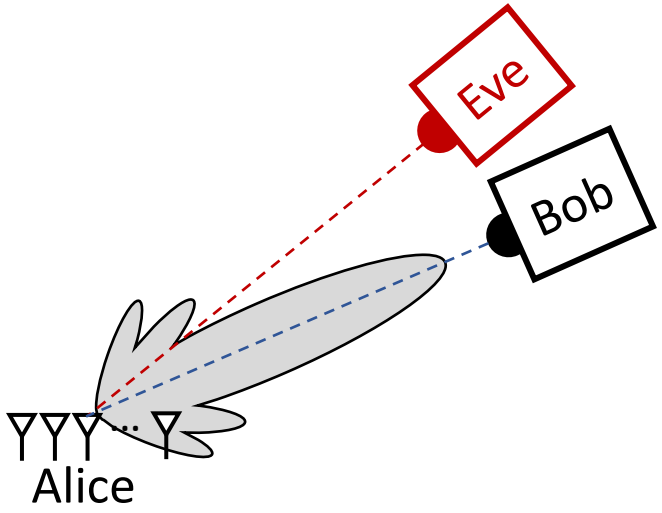
Frequency?

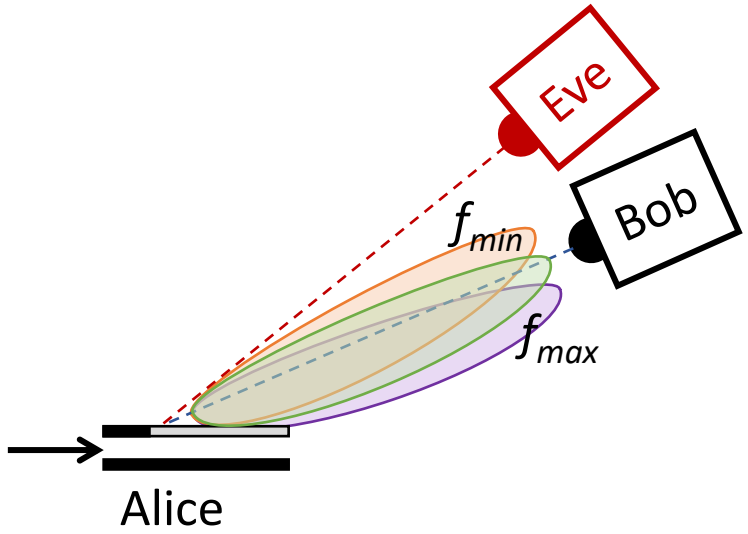
Bandwidth?

Experimental Validation



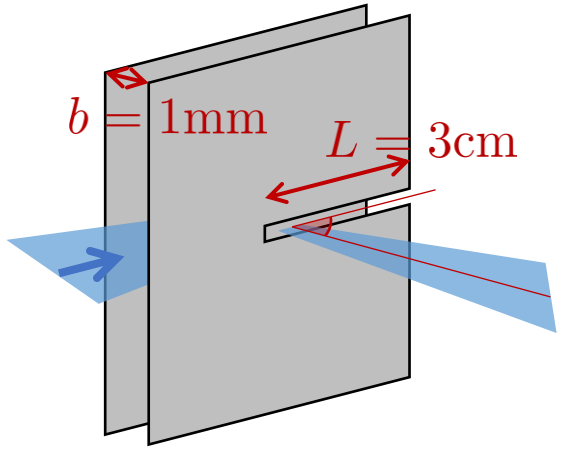
# Conventional Directional Link vs. LWA Link

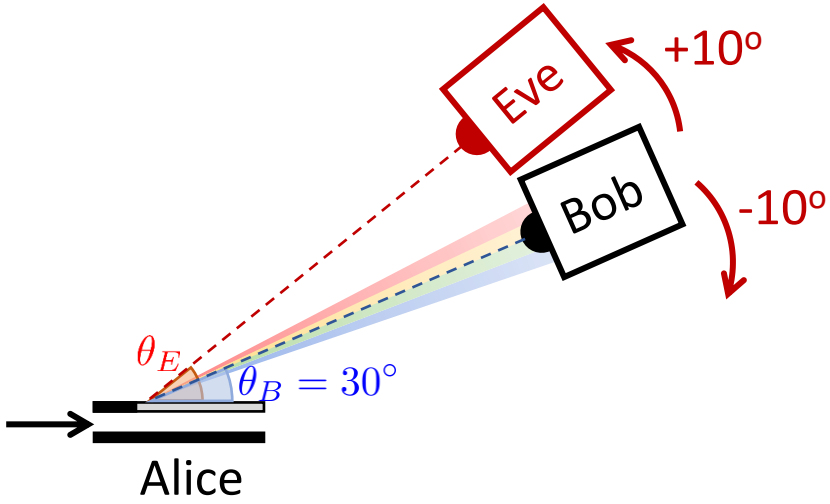



- Uniform secrecy across subchannels → Vulnerable but complementary edge Frequencies
- BW and beamwidth are decoupled → BW and beamwidth are naturally coupled
- A wider beam is less secure → LWA link maintains certain secrecy level despite increasing beamwidth

# Numerical Example Scenario

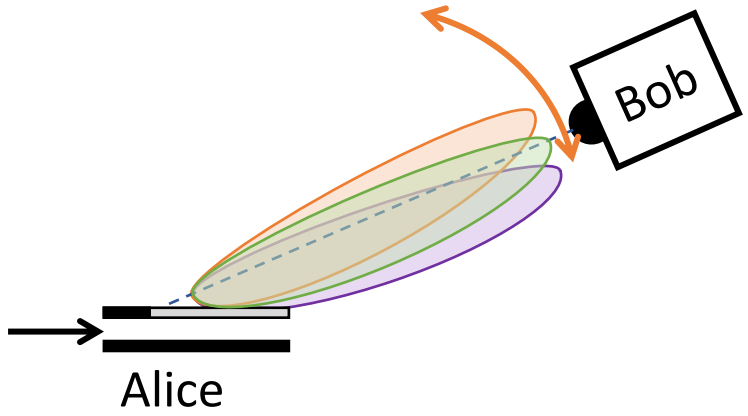



- LWA parameters
  - Plate separation $b$ = 1 mm
  - Slot length $L$ = 3 cm
  - Attenuation constant $\alpha$ = 50 rad/m
- Alice-Bob Link
  - Bob at 30°
  - fc = 300 GHz
  - Bandwidth = 27 GHz
  - 9 subchannels, each with 3 GHz
- Eve at [-10°, 10°] to Bob

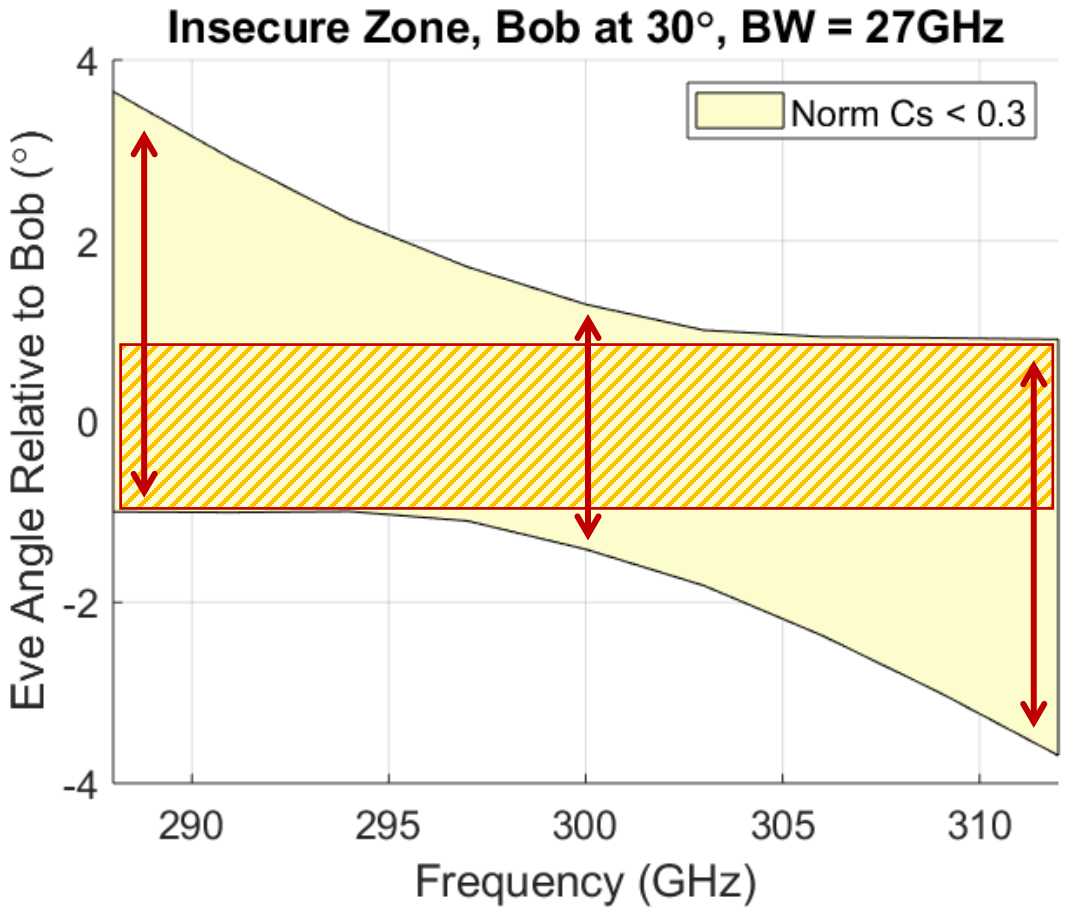
# Insecure Zone

- When Eve locates within this angular region, the secrecy level of that subchannel is below a certain threshold



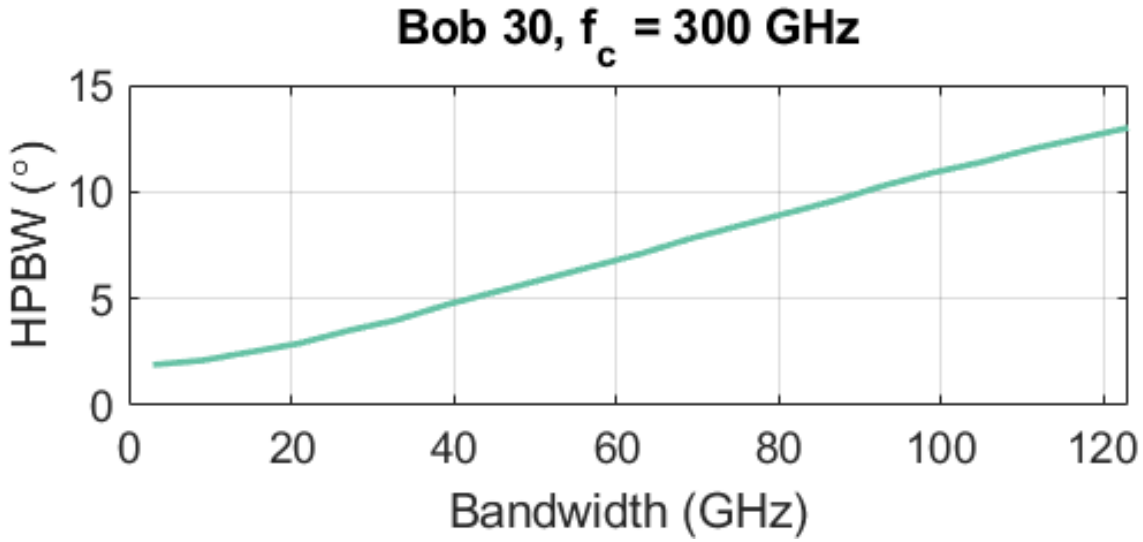

- Normalized subchannel secrecy capacity
  - $C_{S,\mathrm{norm}}^{k} = \dfrac{C_S^k}{\frac{B}{K}\log_2\left(1+\mathrm{SNR}_k^{Bob}\right)}$
  - Value between 0 and 1

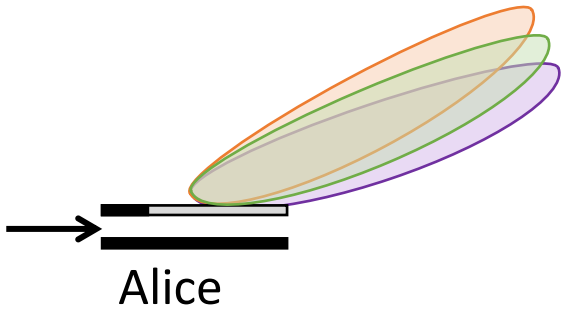
# Vulnerable but Complementary Edge Frequencies




- Close Eve, no frequency achieves the target secrecy
- Vulnerable edge frequencies (in spatial domain)
- Complementary edge frequencies (insecure zones of the two edge frequencies fall in different regions)

# Bandwidth and Beamwidth Coupling



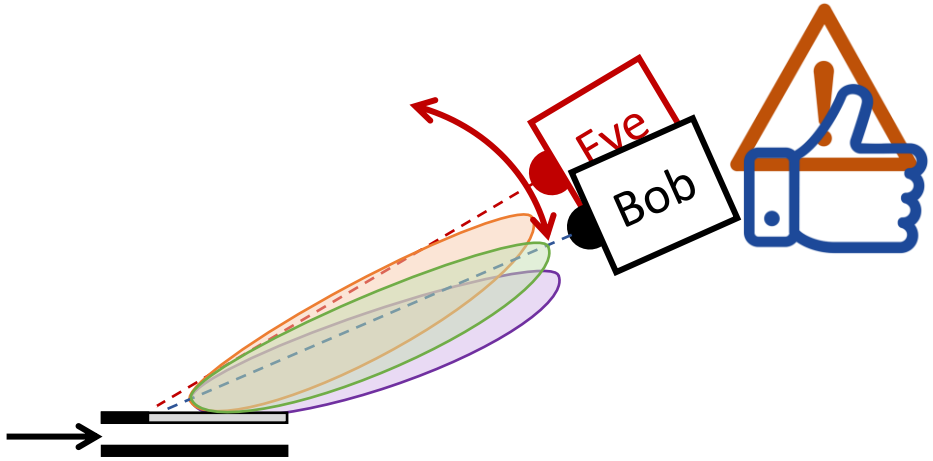




- Beamwidth increases with bandwidth for LWA link
- Different from conventional links
- Large bandwidth (higher data rate) ⇔ narrow beam (better security resilience)?

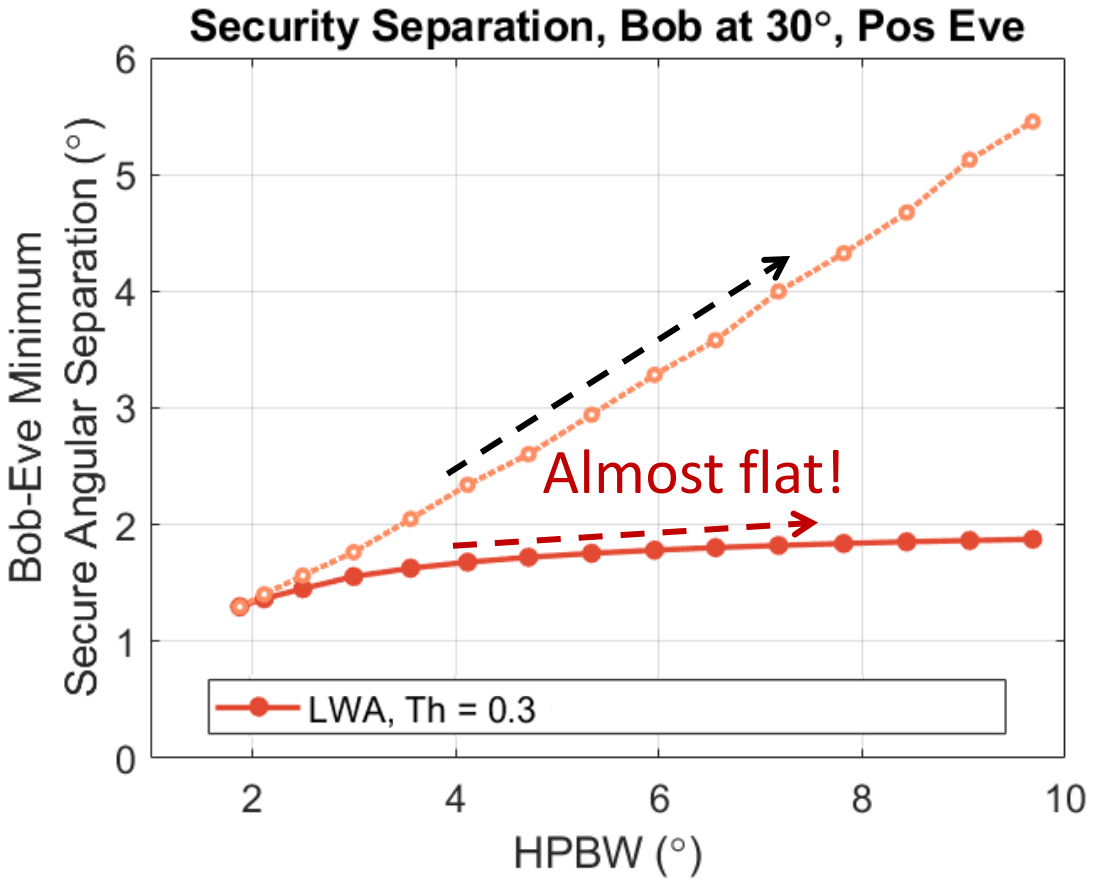
# Minimum Security Separation

- The angular separation between Bob and Eve required to achieve a certain normalized secrecy capacity

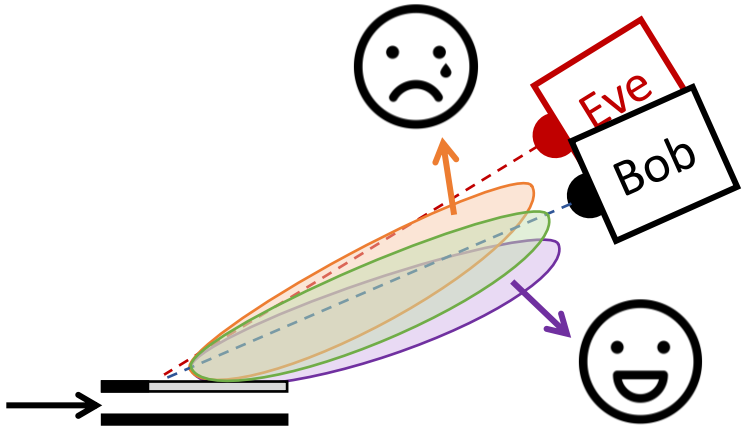
- Normalized Secrecy Capacity
  - $C_{S,\mathrm{norm}}^{k} = \dfrac{\sum_{k=1}^{K} C_{S}^{k}}{\sum_{k=1}^{K} \frac{B}{K} \log_2\left(1 + \mathrm{SNR}_{k}^{Bob}\right)}$
  - Value between 0 and 1



# Large Bandwidth Comes with Little Security Sacrifice

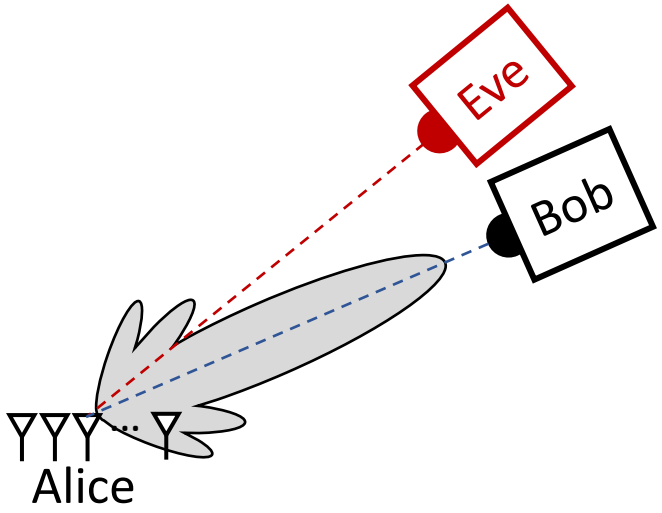


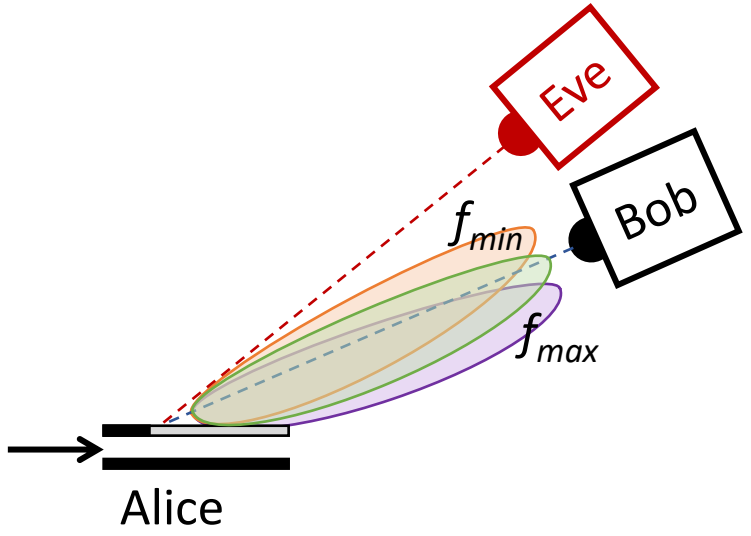

- When the targeted secrecy level is low, the security separation scales surprisingly slow
- Why?




$C_{s,norm} = 0.3$

# Conventional Directional Link vs. LWA Link

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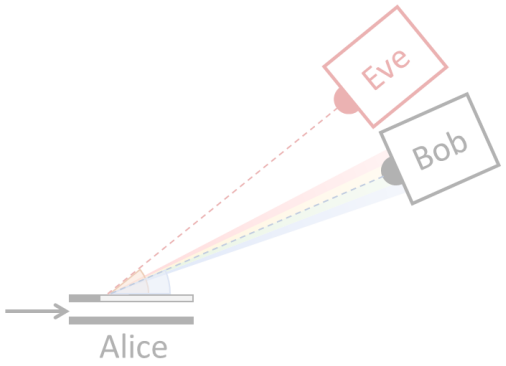
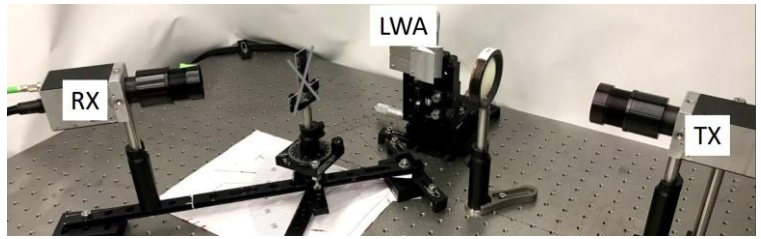
Modeling



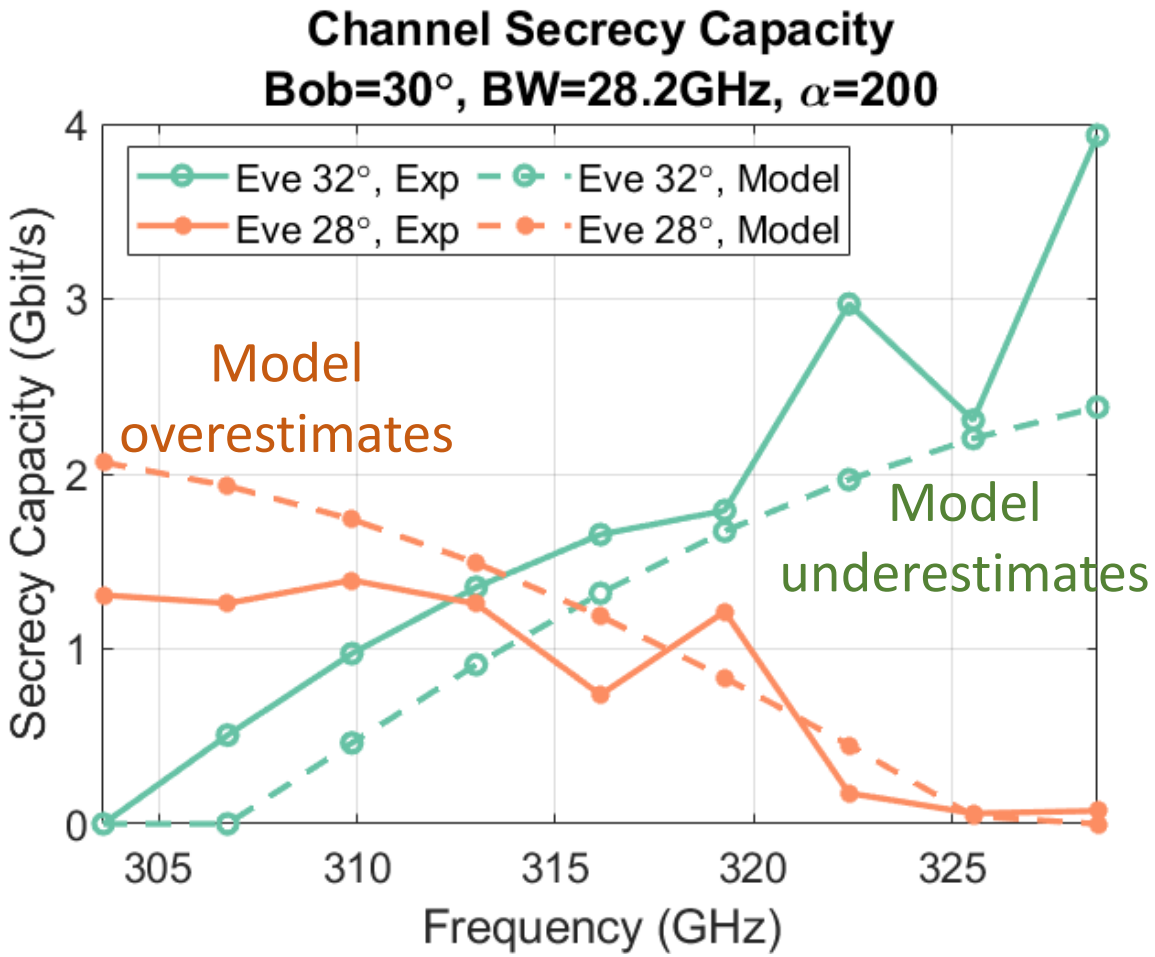

Security Properties


Experimental Validation




- Radiation pattern: measurement vs. model
- How the difference affects the security properties

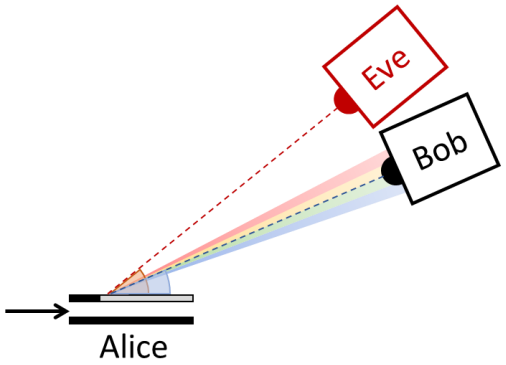
# Asymmetry of the Measured LWA Link




- The model predicts the trend
- However, model might overestimate or underestimate
- Asymmetry threat: Negative angle Eve is a more devastating

# Conclusion
## - Examine Secrecy of LWA Links under Eavesdropping

Modeling

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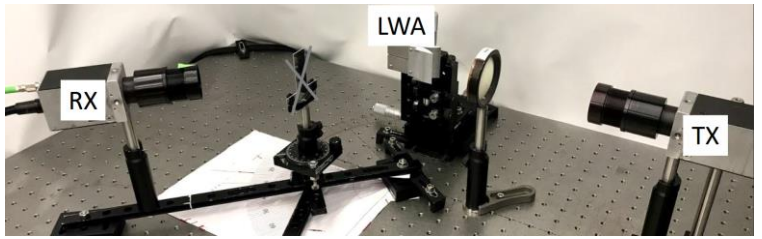


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