28 GHz Phased Array-Based Self-Interference Measurements for Millimeter Wave Full-Duplex

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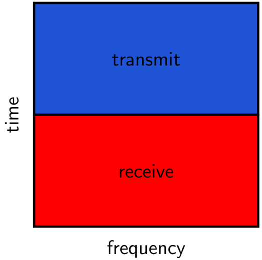
Self-Interference Measurements at 28 GHz

For the past century, devices have not been able to transmit and receive information simultaneously using the same frequency spectrum.

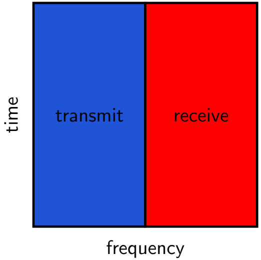
"half-duplex" operation

Self-Interference Measurements at 28 GHz

Half-duplex operation is a wasteful use of spectrum and introduces delays in communication.



(a) Time-division.

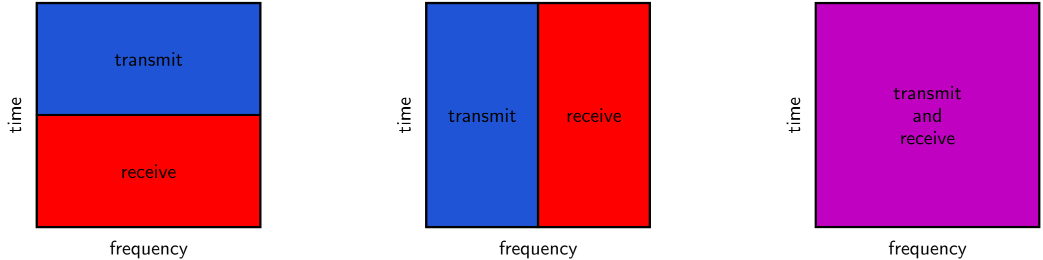


(b) Frequency-division.

Self-Interference Measurements at 28 GHz

What if devices could transmit and receive
at the same time using the same frequency spectrum?

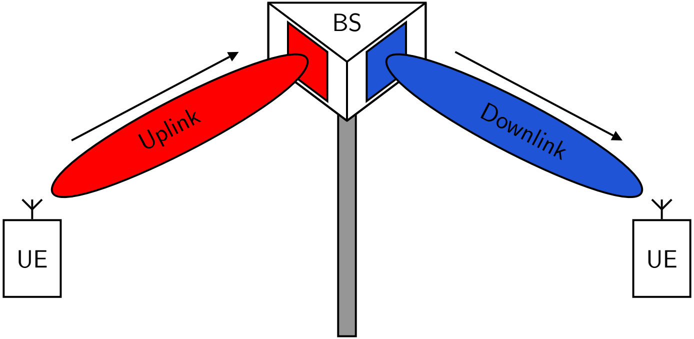
"full-duplex" operation



(a) Time-division. **(b)** Frequency-division. **(c)** Full-duplex.

Self-Interference Measurements at 28 GHz

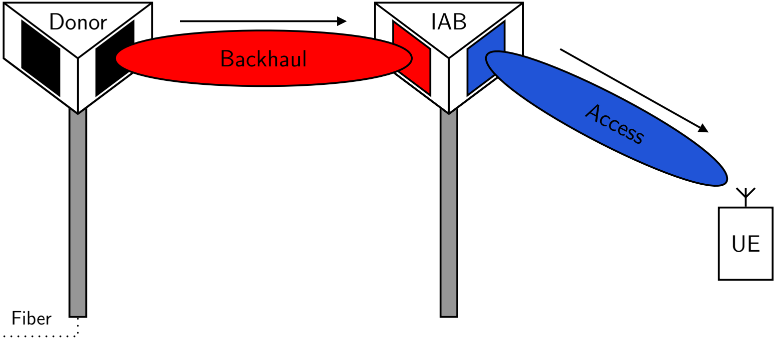
Full-duplex would transform wireless communications on multiple fronts.



A base station could transmit and receive simultaneously.

Self-Interference Measurements at 28 GHz

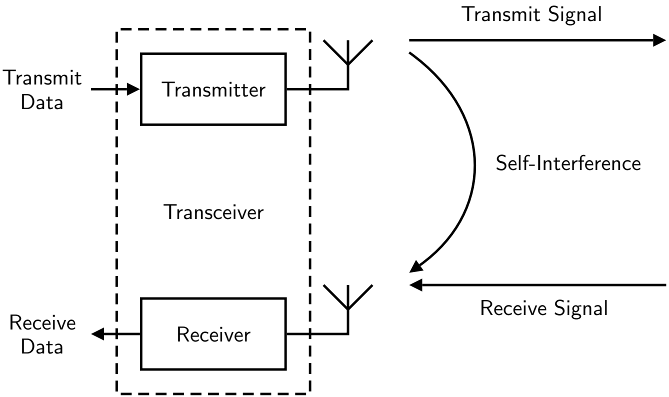
Full-duplex would transform wireless communications on multiple fronts.



It would facilitate the deployment of low-latency, multi-hop networks.

Self-Interference Measurements at 28 GHz

Why don't devices operate in a full-duplex fashion?



Why Measure Self-Interference at 28 GHz?

The research community lacks a good understanding of self-interference in full-duplex millimeter wave (mmWave) systems.

- Current models are sensible but have not been verified by measurements.
- Existing measurements are extremely limited.[1]
- Valid question: "Is self-interference negligible when using highly directional beams?"

As a result of this uncertainty:

- We cannot accurately evaluate full-duplex mmWave systems.
- We cannot develop practically sound solutions for full-duplex mmWave systems.

We have conducted the first extensive measurement campaign and characterization of self-interference in full-duplex mmWave systems.

[1] S. Rajagopal et al., "Self-Interference Mitigation for In-Band mmWave Wireless Backhaul," IEEE CCNC, 2014.

Why Measure Self-Interference at 28 GHz?

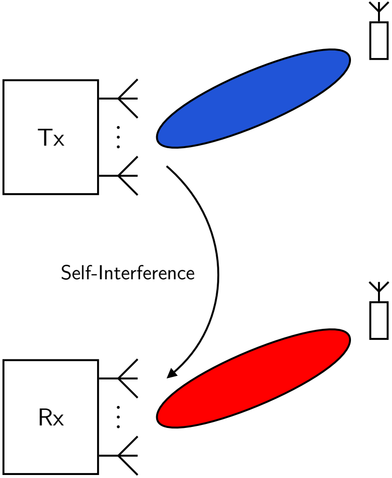
Self-interference depends on:

1. transmit beam
2. receive beam
3. self-interference channel

Could compute self-interference if all three are known (in theory).

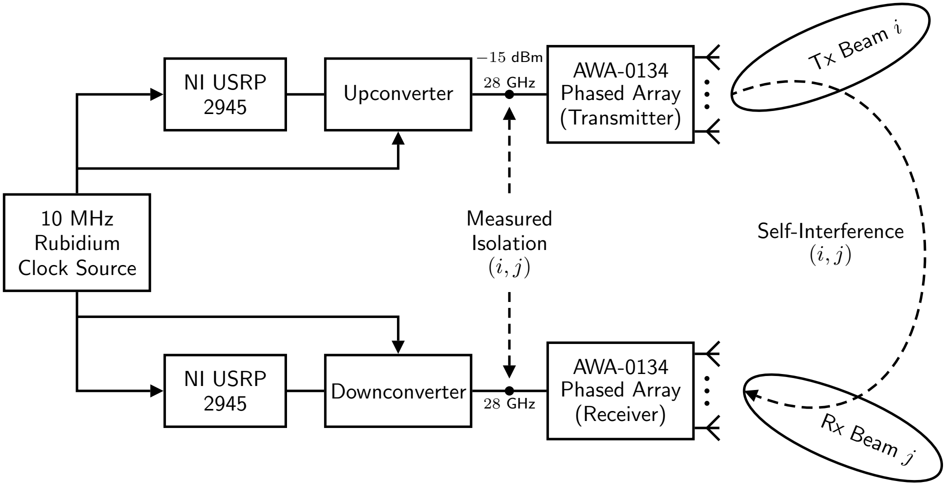
- not possible to inspect the channel directly
- no measurement-backed models exist for the channel (near-field? far-field? both?)

$\Longrightarrow$ Inspect the channel using transmit and receive beams.



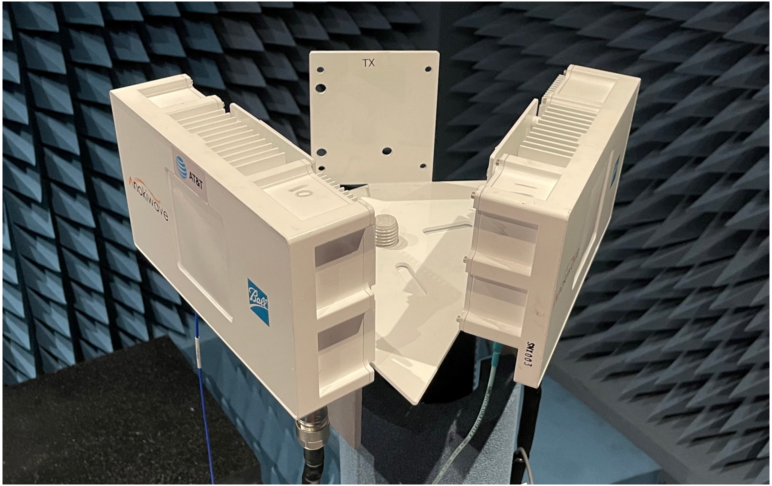
Measurement Setup and Methodology

A block diagram of our measurement setup.

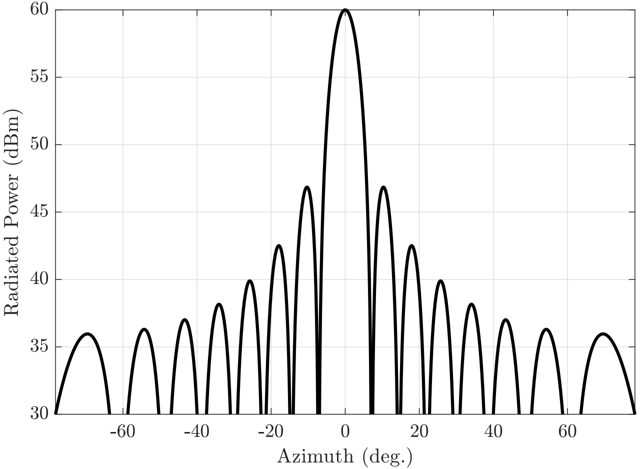


Measurement Setup and Methodology

Our measurement platform in an anechoic chamber.



Narrow beams allow us to inspect self-interference with fine granularity.



Measurement Setup and Methodology

Suppose we steer our transmit beam toward $\underbrace{(\theta_{\mathrm{tx}}, \phi_{\mathrm{tx}})}_{\text{az-el}}$ and receive beam toward $\underbrace{(\theta_{\mathrm{rx}}, \phi_{\mathrm{rx}})}_{\text{az-el}}$.

The self-interference power at the receive array output can be expressed as

$$P_{\mathrm{SI}}\left(\theta_{\mathrm{tx}}, \phi_{\mathrm{tx}}, \theta_{\mathrm{rx}}, \phi_{\mathrm{rx}}\right) = P_{\mathrm{tx}} \cdot \underbrace{\left| \mathbf{w}\left(\theta_{\mathrm{rx}}, \phi_{\mathrm{rx}}\right)^{\mathrm{T}} \mathbf{H} \mathbf{f}\left(\theta_{\mathrm{tx}}, \phi_{\mathrm{tx}}\right) \right|^2}_{\text{self-interference coupling factor}} \tag{1}$$

where P_{tx} is the power into the transmit array.

We will inspect the self-interference channel $\mathbf{H}$ by sweeping the transmit and receive beams and measuring self-interference power.

Measurement Setup and Methodology

The isolation L between a transmit beam and receive beam is

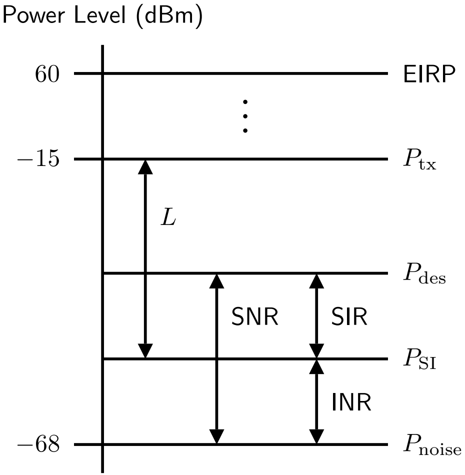
$$L = \frac{1}{\left| \mathbf{w}\left(\theta_{\mathrm{rx}}, \phi_{\mathrm{rx}}\right)^{\mathrm{T}} \mathbf{Hf}\left(\theta_{\mathrm{tx}}, \phi_{\mathrm{tx}}\right) \right|^2}. \quad (2)$$

Received self-interference power is

$$P_{\mathrm{SI}}\left(\theta_{\mathrm{tx}}, \phi_{\mathrm{tx}}, \theta_{\mathrm{rx}}, \phi_{\mathrm{rx}}\right) = P_{\mathrm{tx}} \cdot L^{-1}. \quad (3)$$

We generally desire $P_{\mathrm{SI}} \leq P_{\mathrm{noise}}$ for full-duplex.

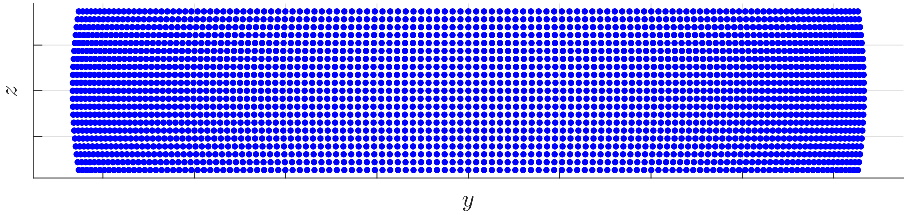
$\Longrightarrow$ We desire isolation $L \geq 53$ dB.



Measurement Setup and Methodology

For this work, our transmit and receive spatial profiles are:

- in azimuth from $-60°$ to $60°$ with $1°$ resolution (121 points)
- in elevation from $-10°$ to $10°$ with $1°$ resolution (21 points)



$121 \times 21 = 2541$ transmit/receive directions

$2541 \times 2541 \approx 6.5$ million self-interference power measurements

Measurement Results — CDF of All Measured Isolation Values

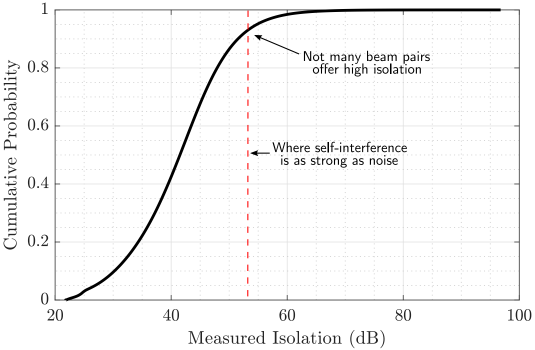
L typically ranges from 20 dB to 60 dB.

Less than 10% of beam pairs yield $L \geq 53$ dB.

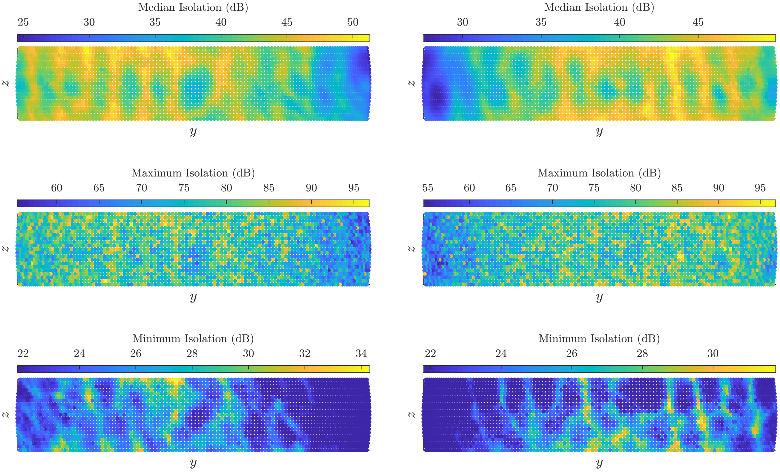
Very few beam pairs yield extremely high isolation.

Beams typically do not provide enough isolation for full-duplex on their own.

$\implies$ Need to take additional measures to mitigate self-interference.



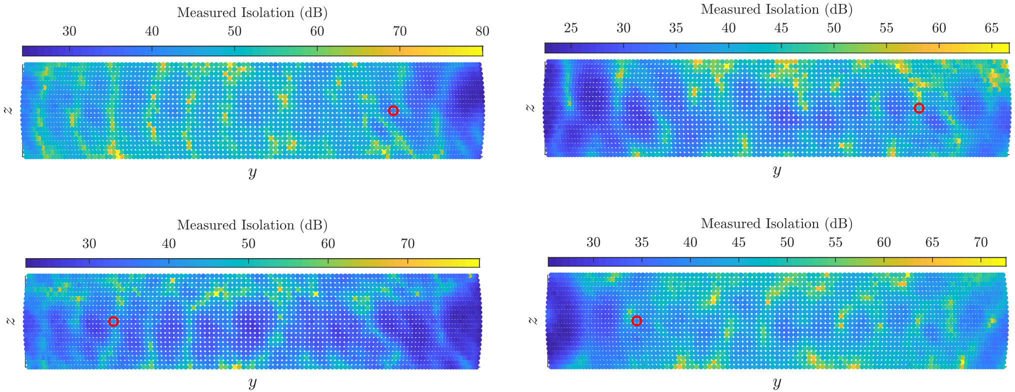
Measurement Results — Statistics Per Transmit and Receive Beam



(a) Observed by each transmit beam. **(b)** Observed by each receive beam.

Figure 1: For each transmit beam and receive beam, shown are the median, maximum, and minimum isolation across all receive and transmit beams, respectively.

Measurement Results — For Particular Transmit and Receive Beams



(a) Observed by each transmit beam for a given receive beam.

(b) Observed by each receive beam for a given transmit beam.

Figure 2: The isolation achieved across transmit and receive beams for particular receive and transmit beams (shown as red ∘), respectively.

Conclusion

Highly directional beams do not provide enough isolation for full-duplex on their own.

- Transmitting toward the receiver $\rightarrow$ typically low isolation.
- Receiving toward the transmitter $\rightarrow$ typically low isolation.

No beams provide high isolation universally.

- Isolation depends on the transmit and receive beams jointly.

Small shifts in steering direction $\rightarrow$ significant variability in self-interference coupled.

- Can this be used to our advantage to reduce self-interference?

Good topics for future work: beam selection for mmWave full-duplex, SI channel modeling, self-interference cancellation for mmWave systems.

Thank you! Questions? Feedback?

Feel free to reach out to me at `ipr@utexas.edu`.

Keep an eye out for our journal extension in *IEEE Trans. Wireless Commun.*

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