Practical Null Steering in Millimeter Wave Networks

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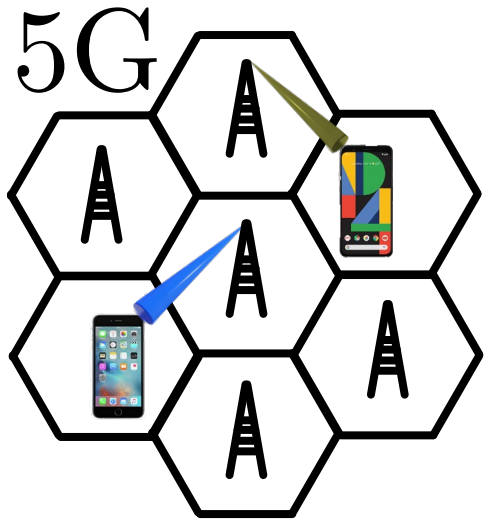
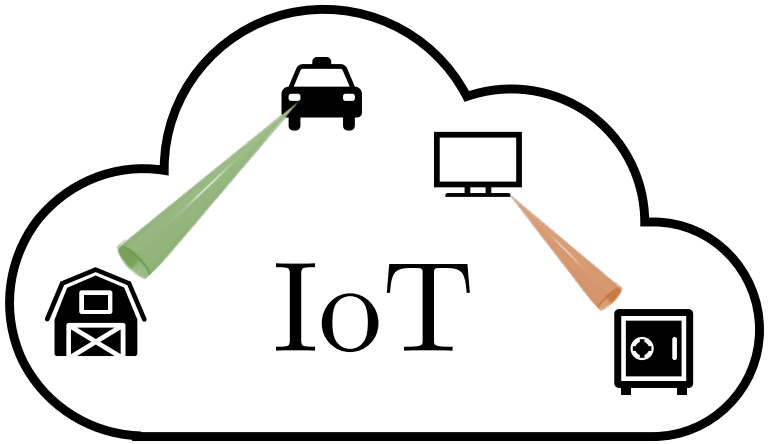
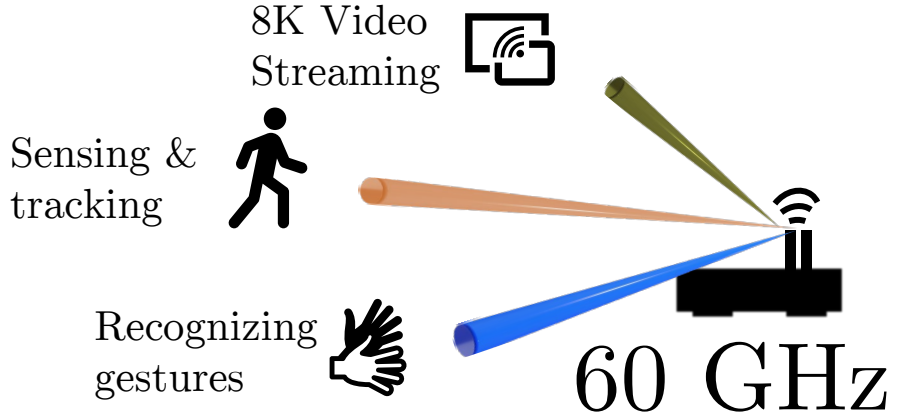
Millimeter Wave

High Frequency > 24 GHz, Huge Bandwidth





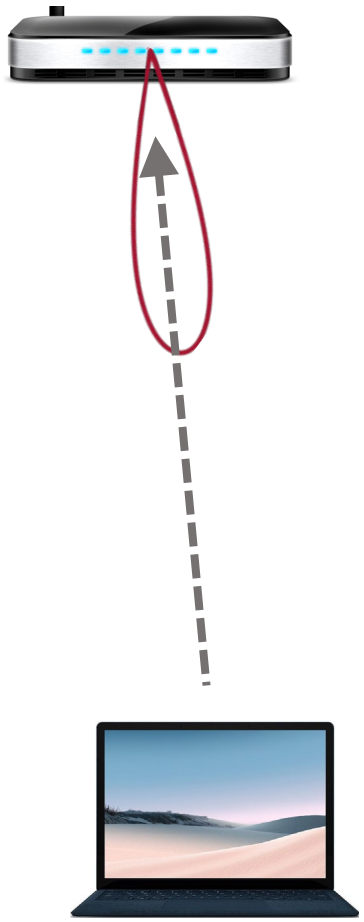


Virtual Reality

Connected Vehicles

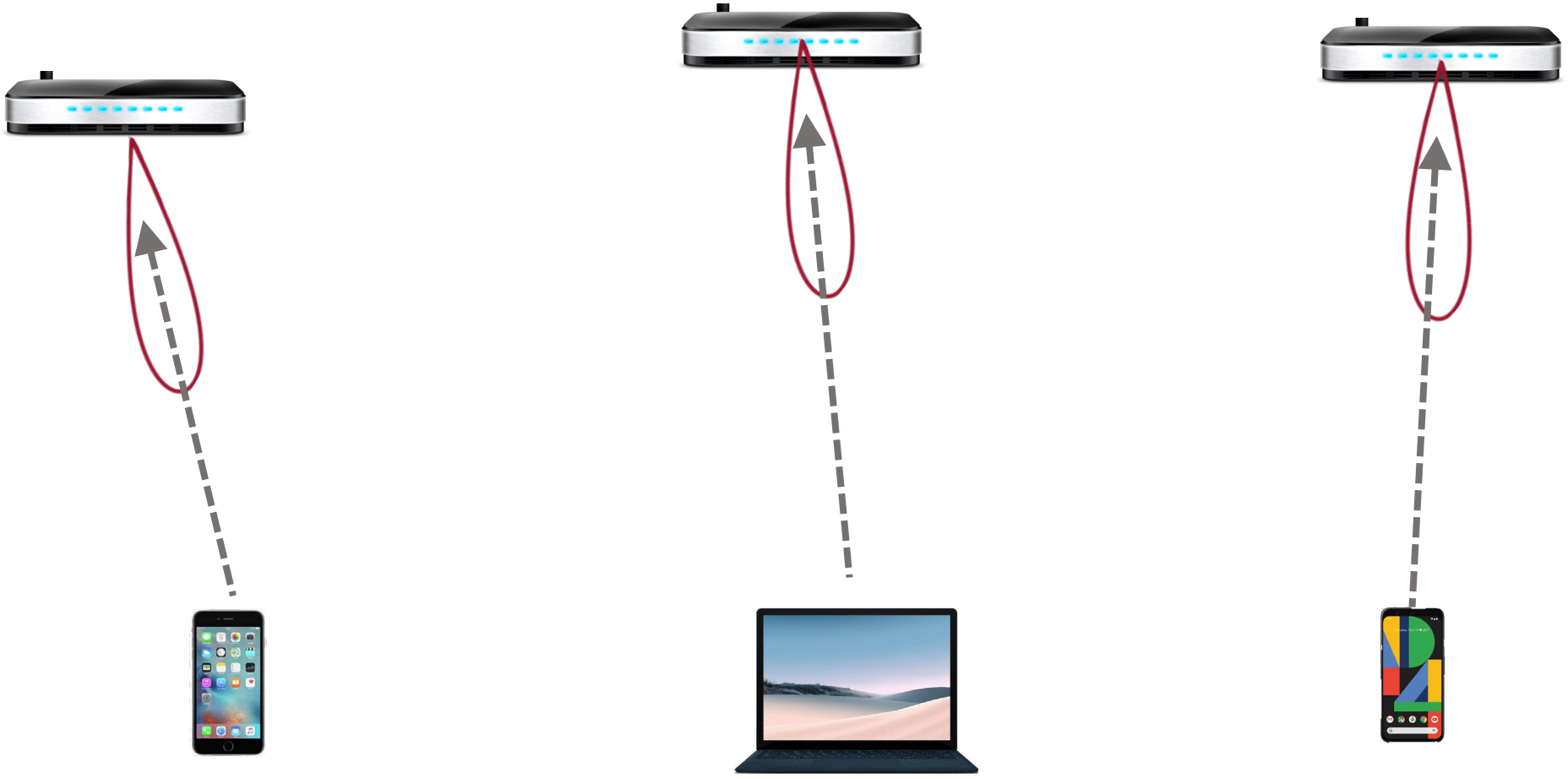
Millimeter Wave Networks

Use Directional Narrow Beams



Millimeter Wave Networks

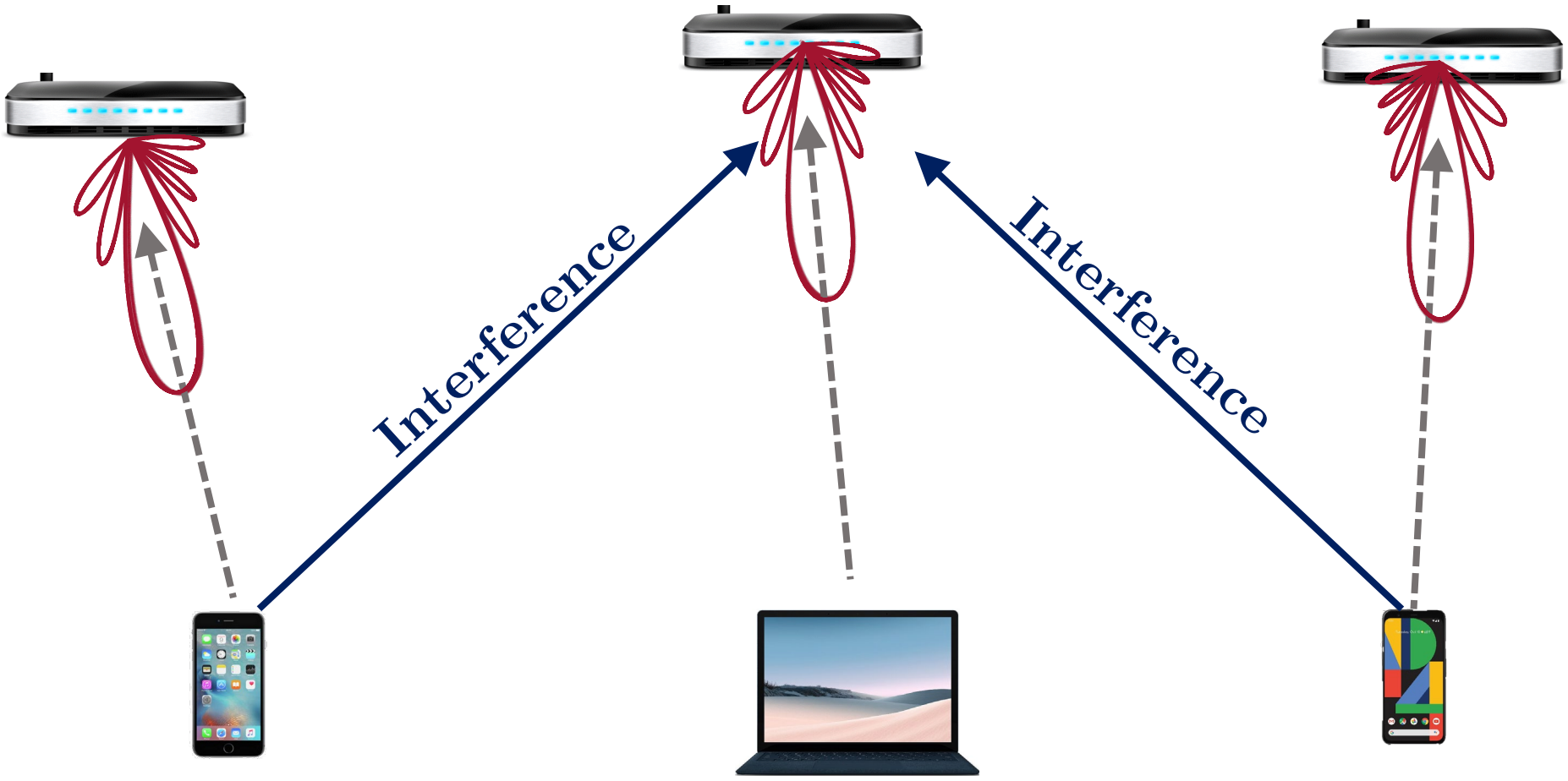
Use Directional Narrow Beams $\longrightarrow$ Multiple Links operate concurrently



Millimeter Wave Networks

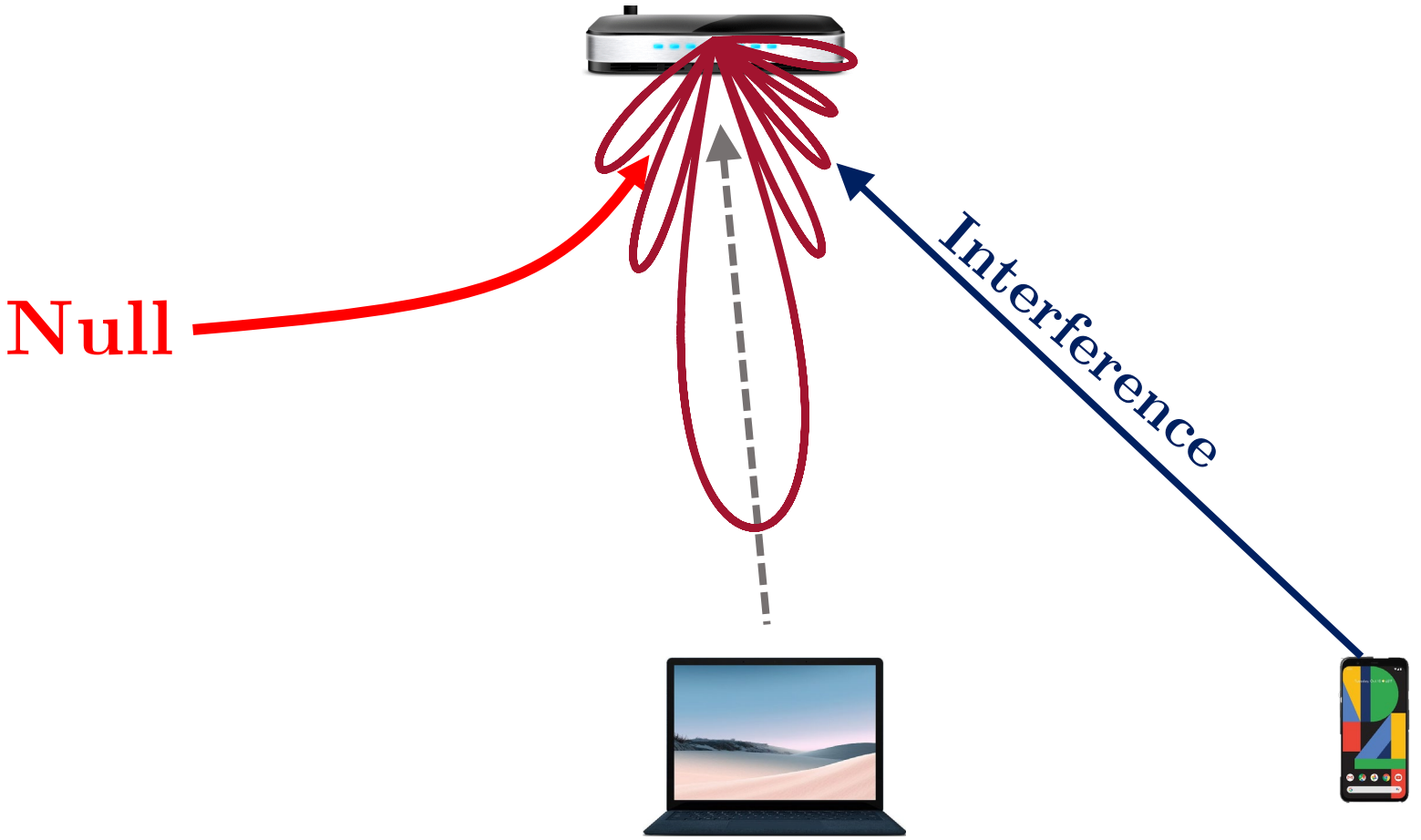
Use Directional Narrow Beams  Multiple Links operate concurrently

Interference



Millimeter Wave Networks

Nulls: Directions with no signal power.



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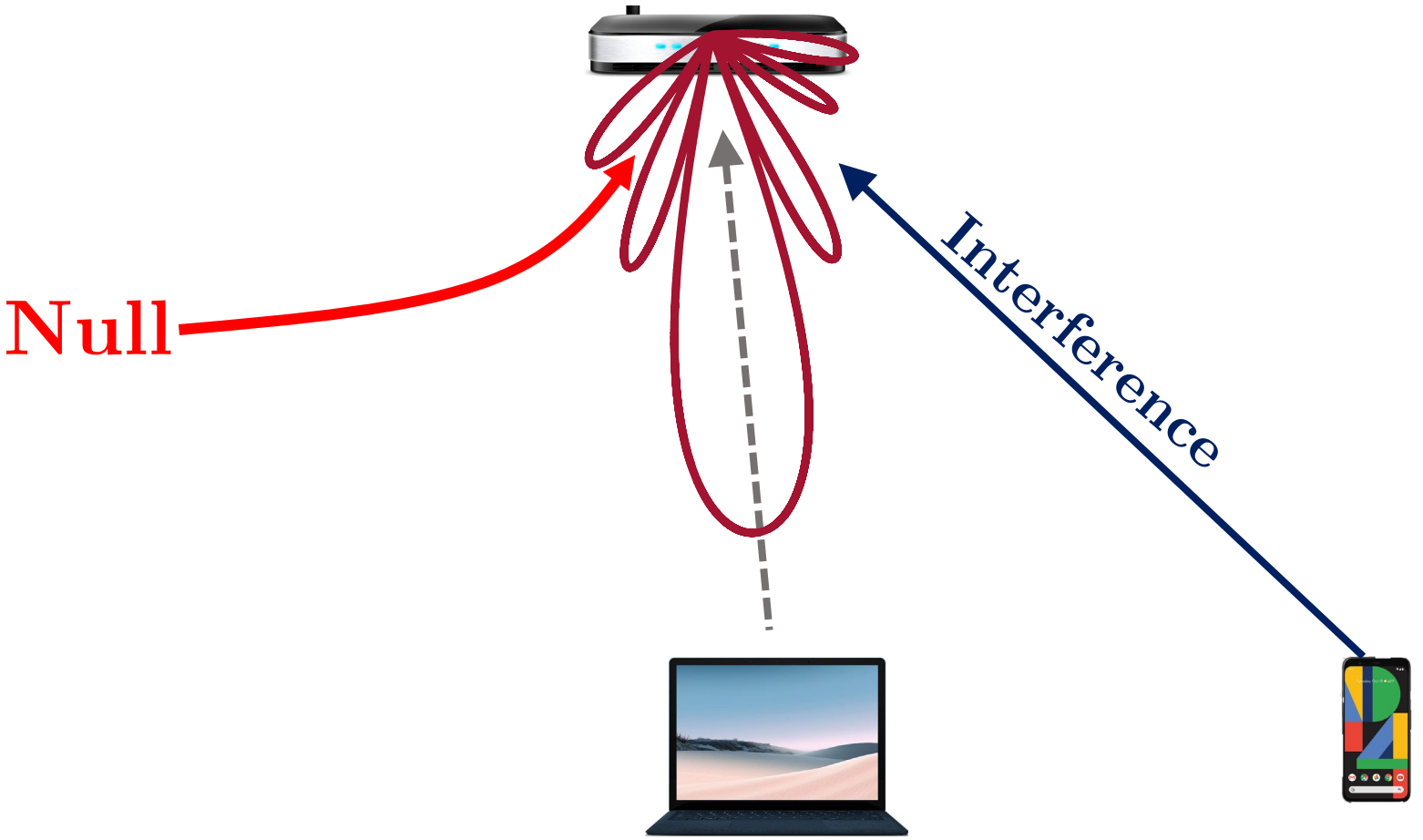
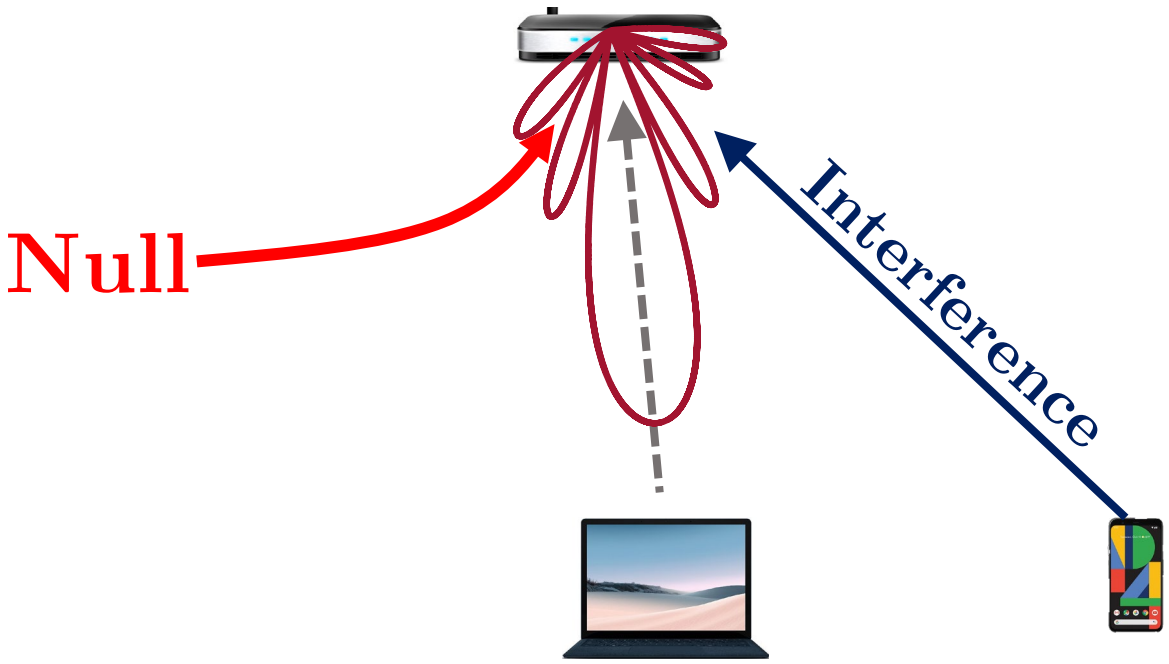


Millimeter Wave Networks

Nulls: Directions with no signal power.

Can we align a null towards the interferer while preserving the main beam?



Creating Nulls in Practice is Challenging

Network-Level

Need Fast Null Steering

Quickly find the direction of interferer

Need Wide Nulls

Direction of interferer not accurate!

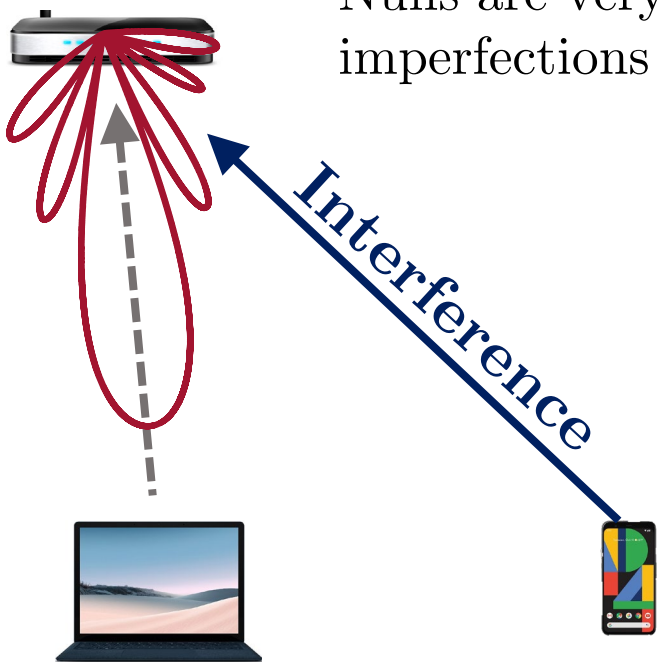
Hardware-Level

Limited Control Over Hardware

e.g. 802.11ad 60 GHz radios offer only 2 bits of control

Hardware Imperfections & Errors

Nulls are very sensitive to hardware imperfections



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Need to Align Multiple nulls

Multiple interferers and multipath

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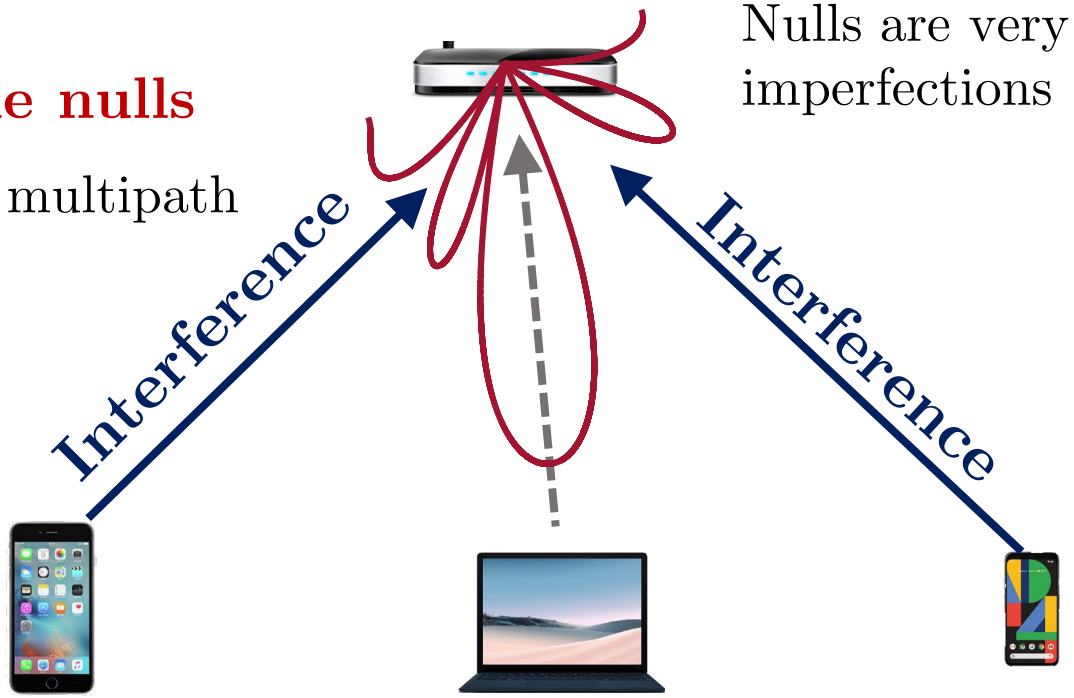

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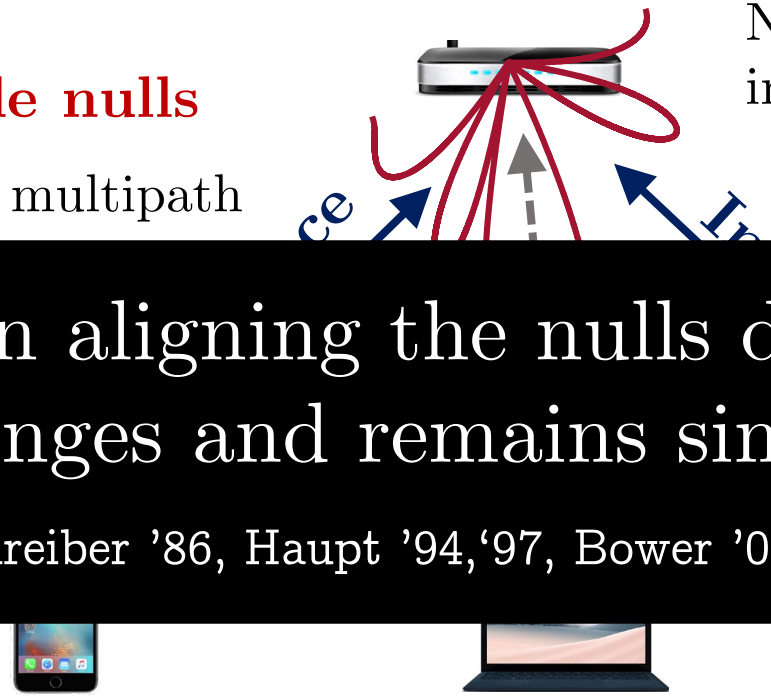

Past work on aligning the nulls does not address these challenges and remains simulation based.

[Steyskal '82, '83, Schreiber '86, Haupt '94,'97, Bower '01, Day '07,'09, Haupt 2010]

Nulli-Fi

First practical mmWave null steering system that addresses both hardware and network level challenges.

Nulli-Fi is implemented on commercial mmWave radios and can find interference directions in less than 300 ns and suppress them by 15 dB.

Nulli-Fi

Creating nulls in the beam pattern

Nulling Algorithm

Initialize

Discrete Optimization Framework

Steering the null towards the interferer

Fast null steering protocol

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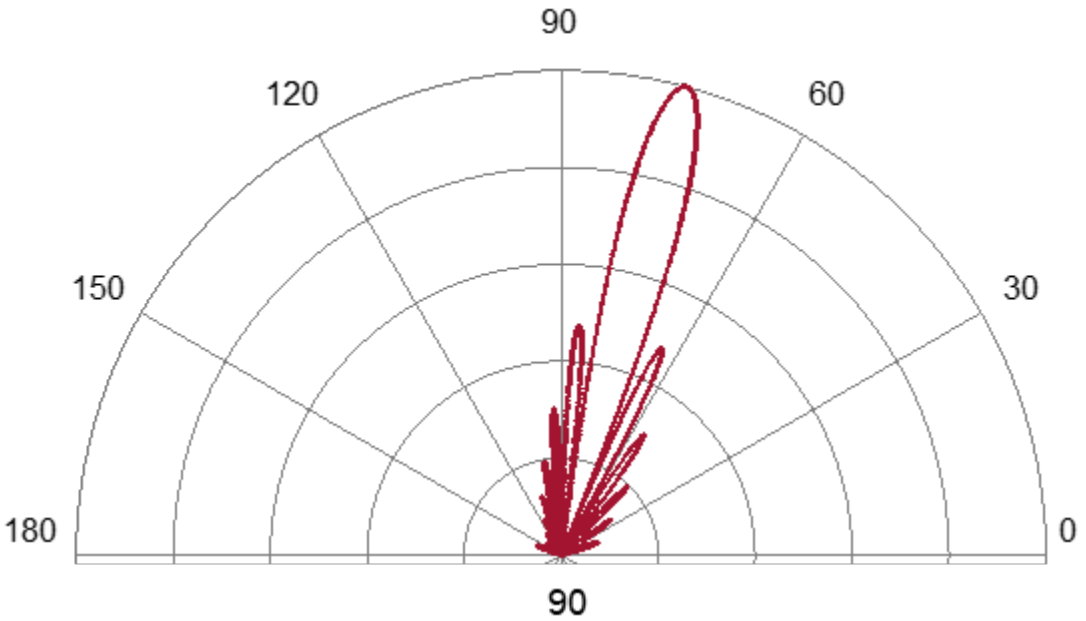
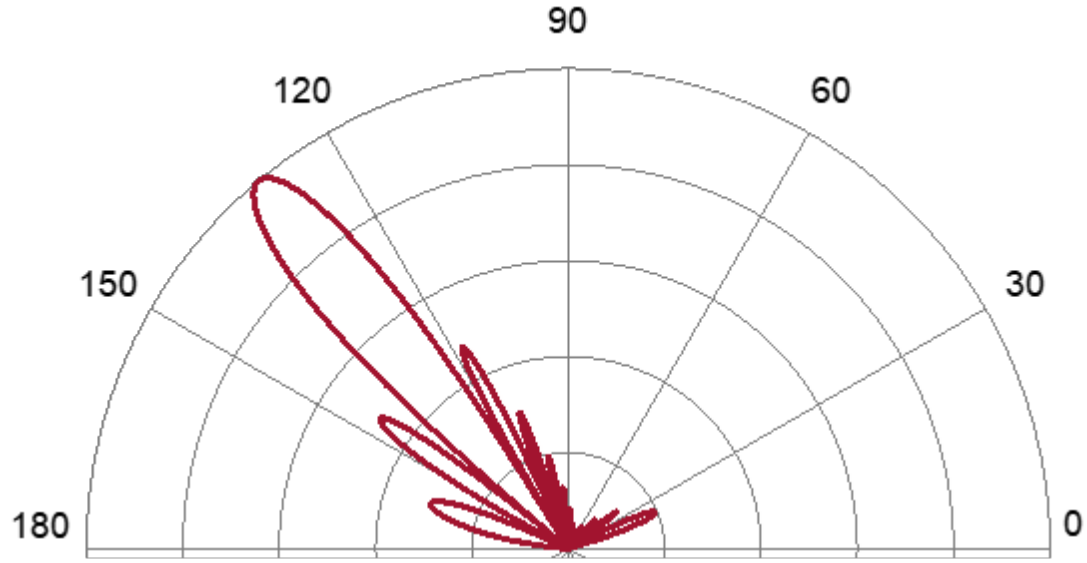
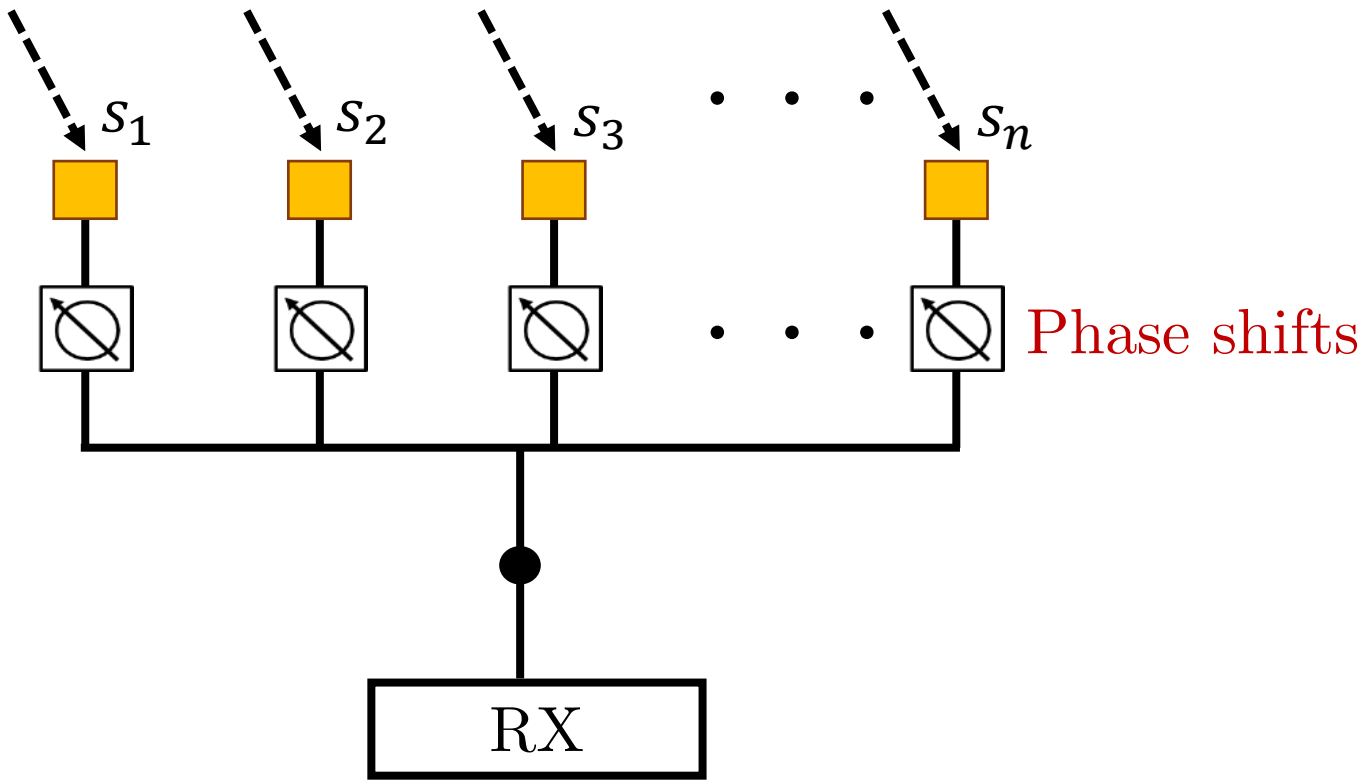
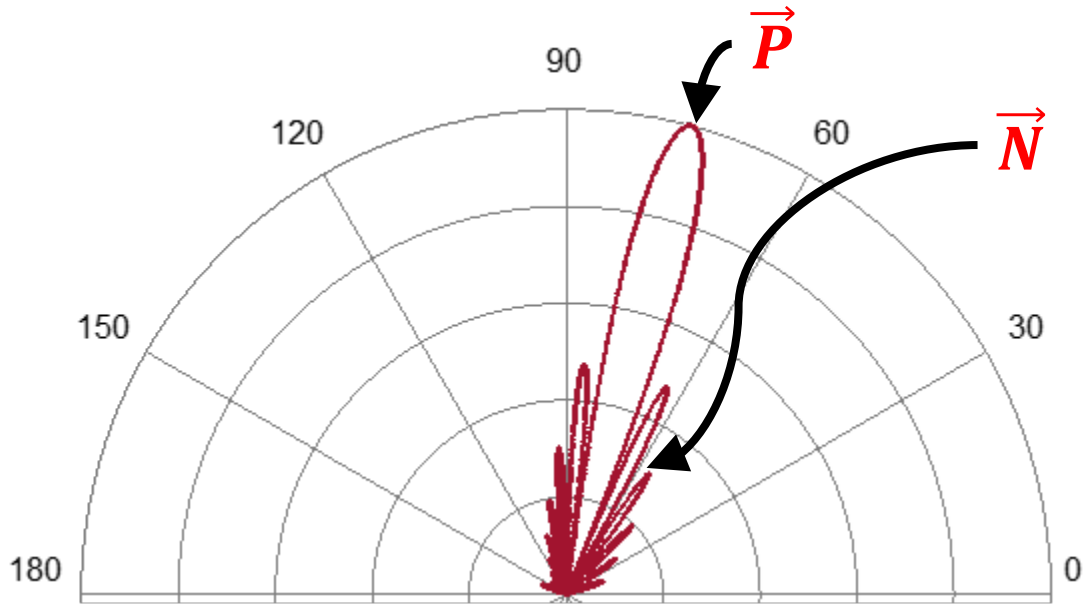
How to control the beam pattern?



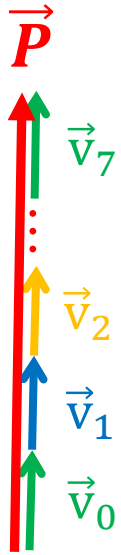




Representing Signals as Vectors

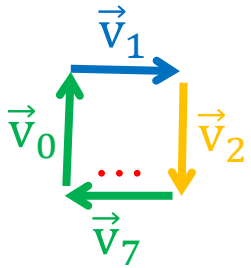


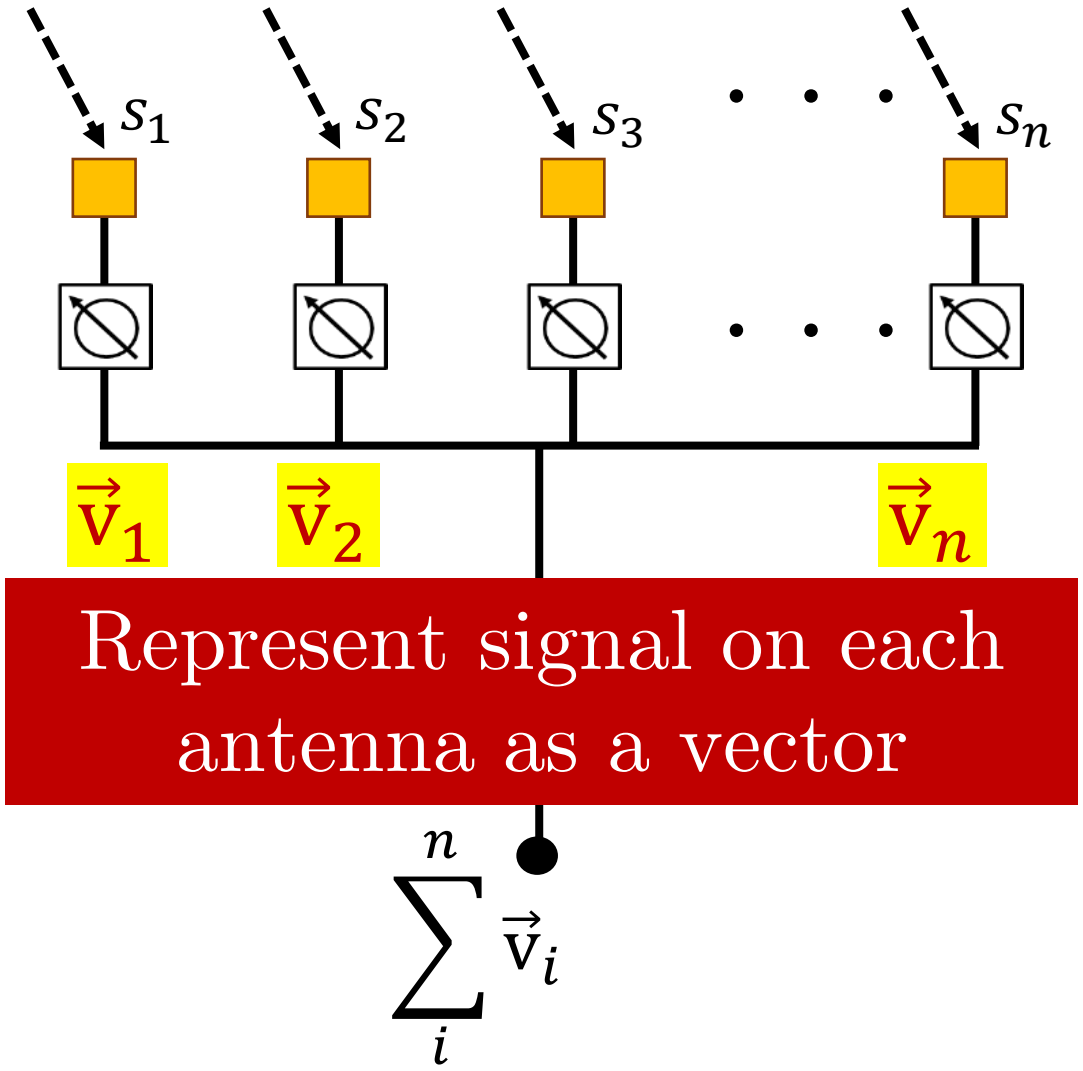
At the main lobe



At a null

$\vec{N} = 0$

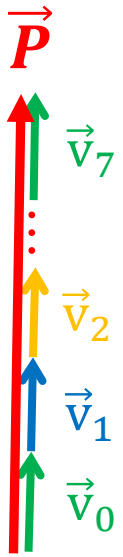




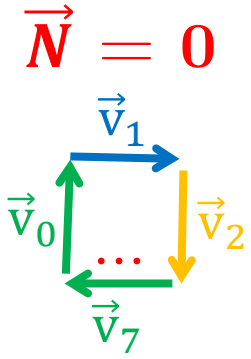
Nulli-Fi's Algorithm

Key Observation:

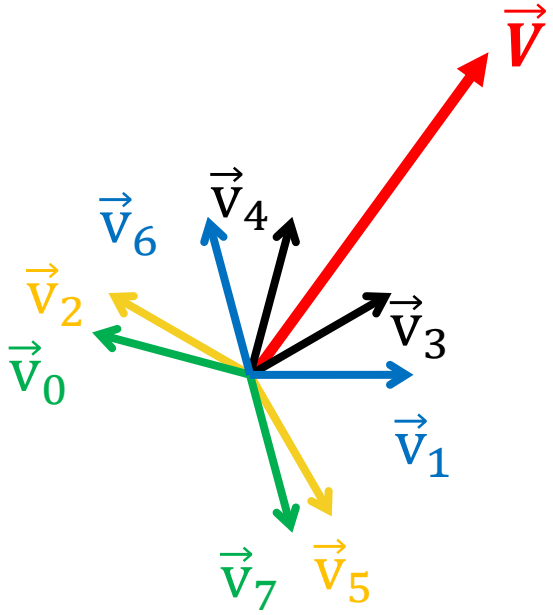
> At any angle, the vectors summing up to the signal V come in *symmetric pairs* around V.



At the main lobe

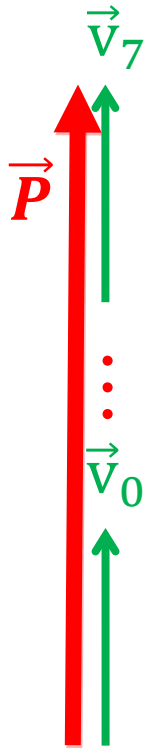


At a null

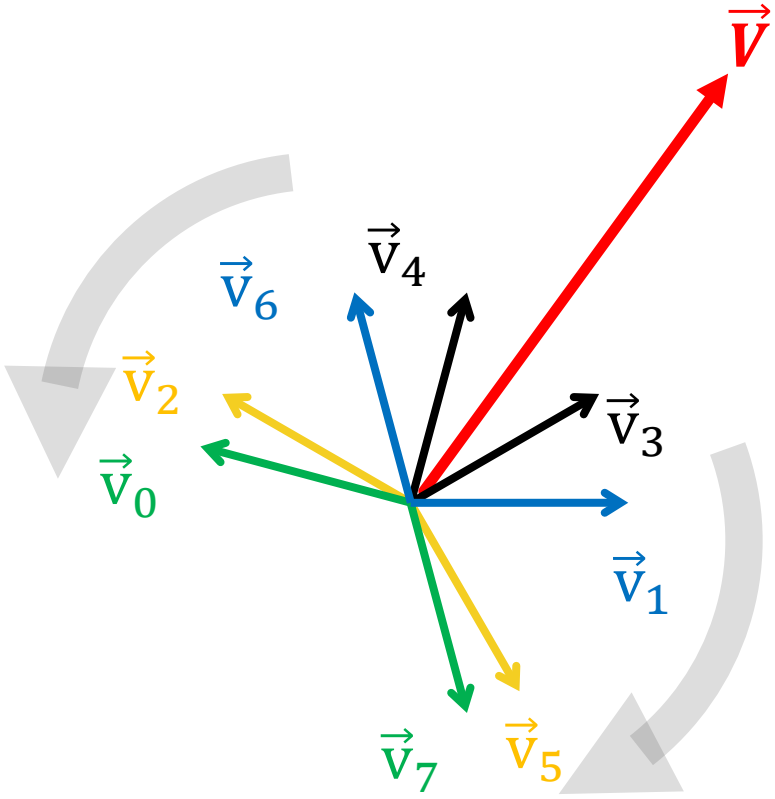


At any angle

Nulling Example



At main lobe (90°)



At null point (ϕ)

Restrict maximum phase shift on each antenna to $\pm\alpha$ to keep the main lobe intact.

Nulli-Fi's Algorithm

Theorem:

Given an angle ϕ, a beam pointing towards θ, and a restriction of $\pm\,\alpha$ on the phase shift, the algorithm creates the best possible null along ϕ while ensuring the loss in the main lobe is at most $\sin^2 \alpha$.

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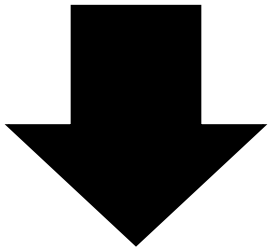
Fast Null Steering Protocol

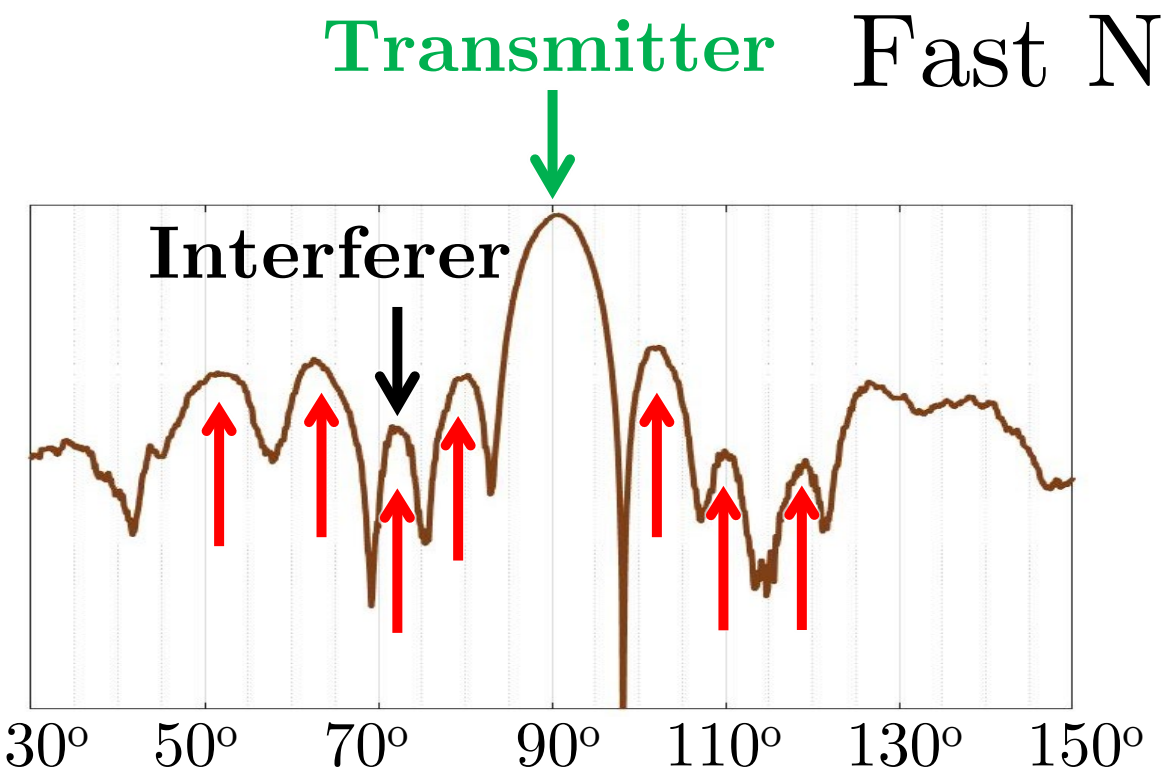
Key Idea:

Interference is likely coming from a side lobe.



No need to scan all possible directions looking for the interferer.

Fast Null Steering Protocol



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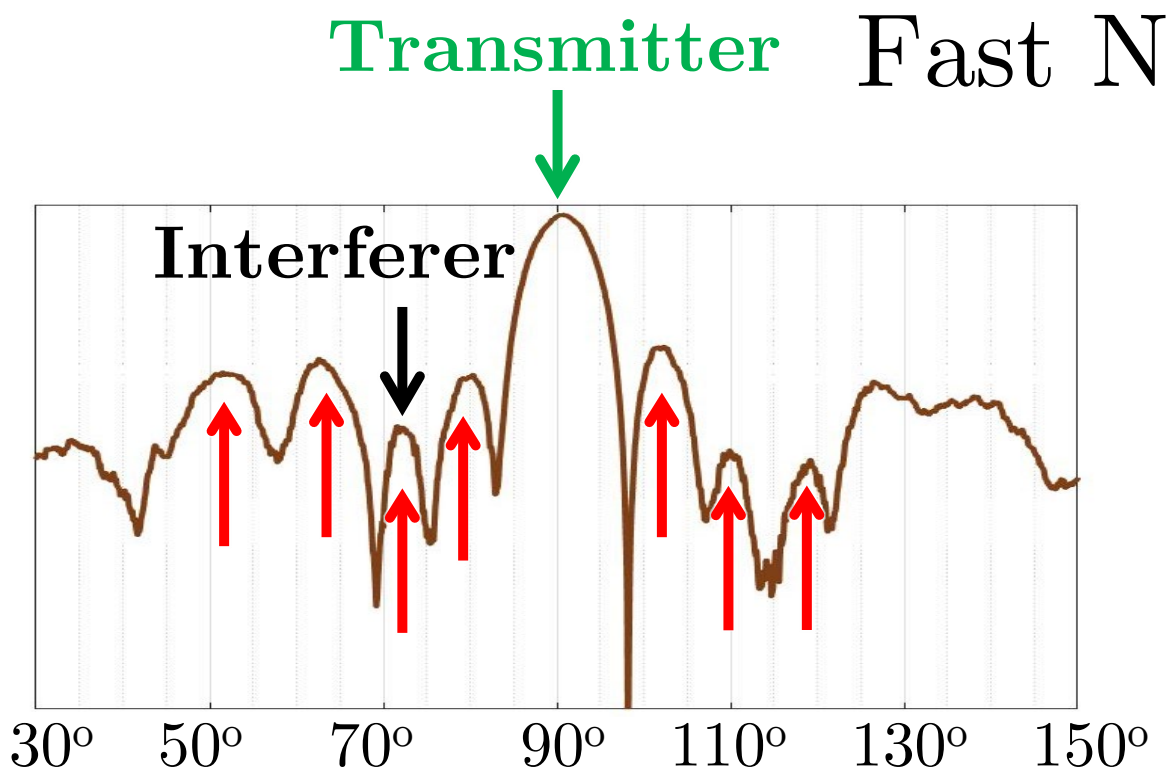
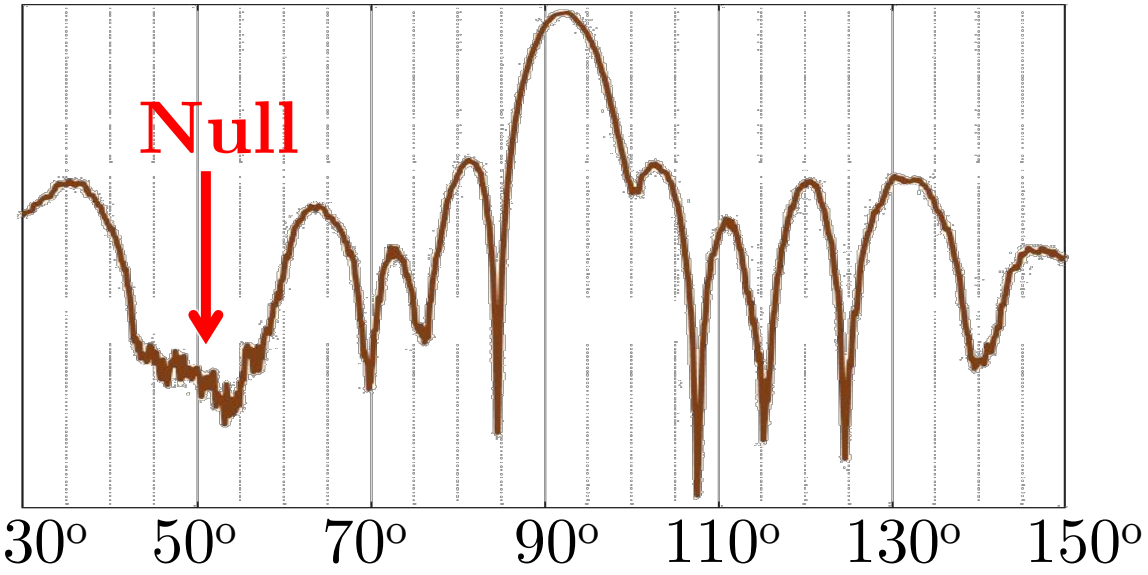
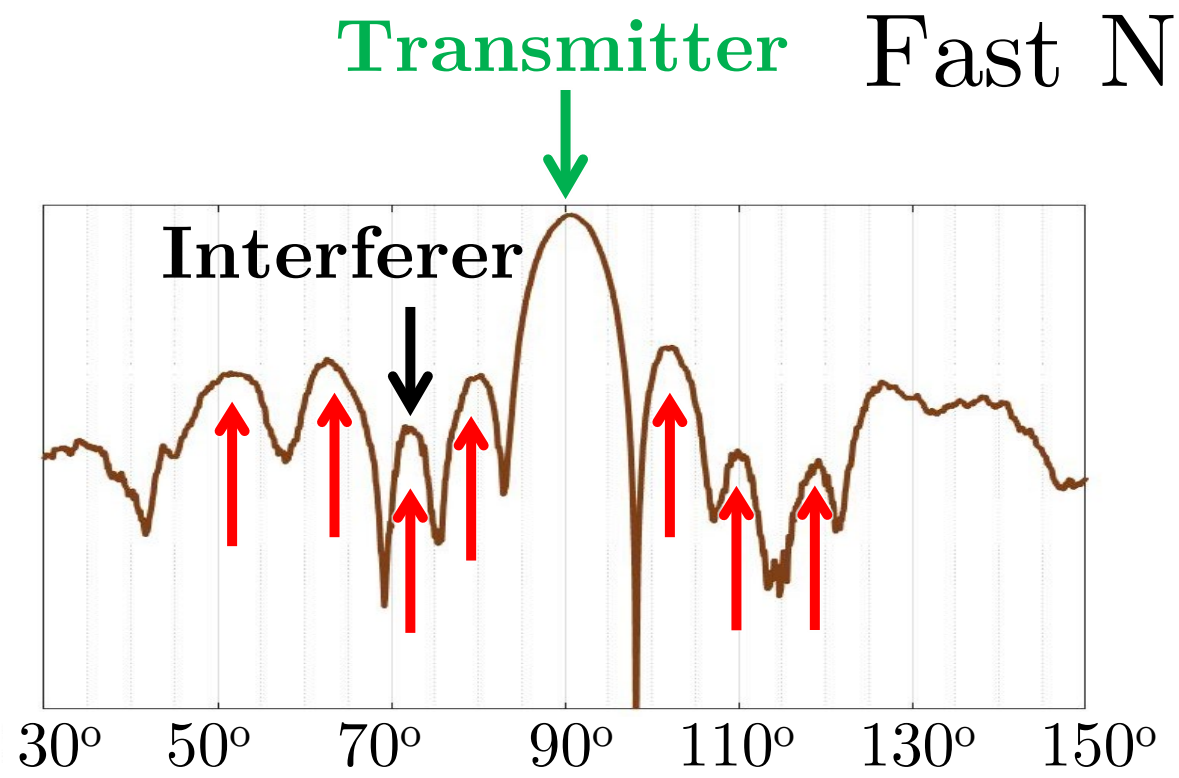


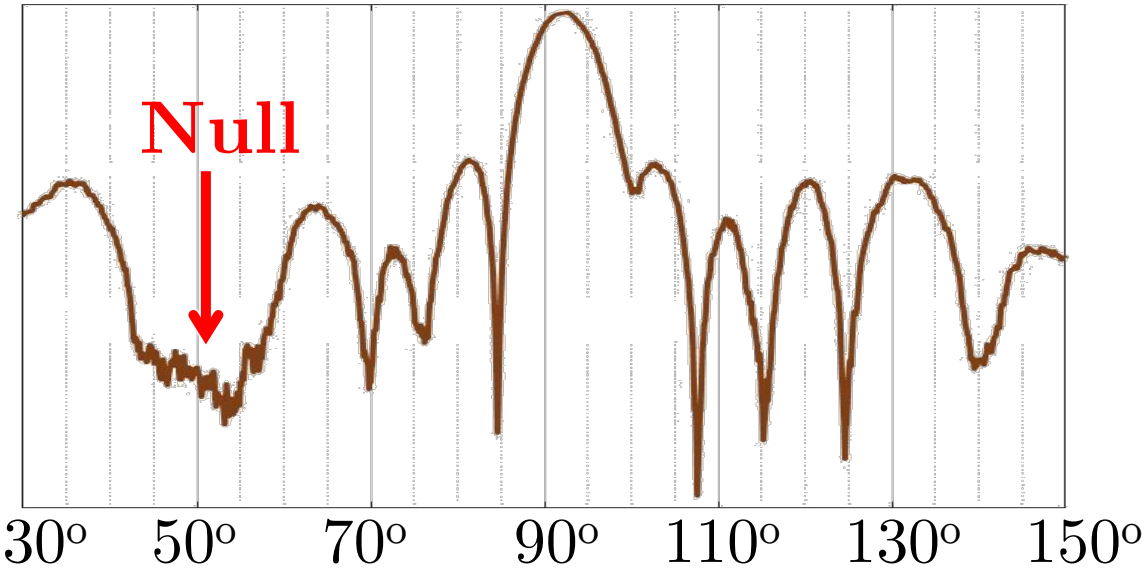


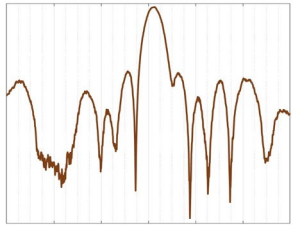
Interference

Signal

Fast Null Steering Protocol







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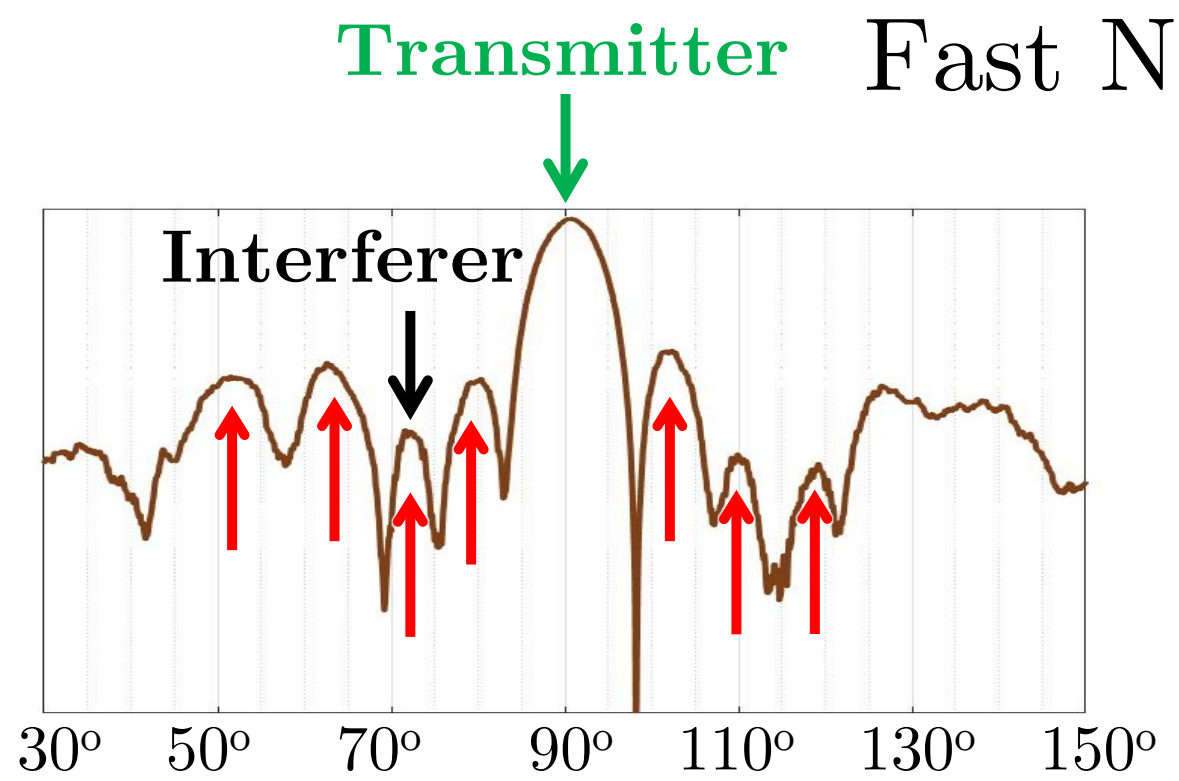

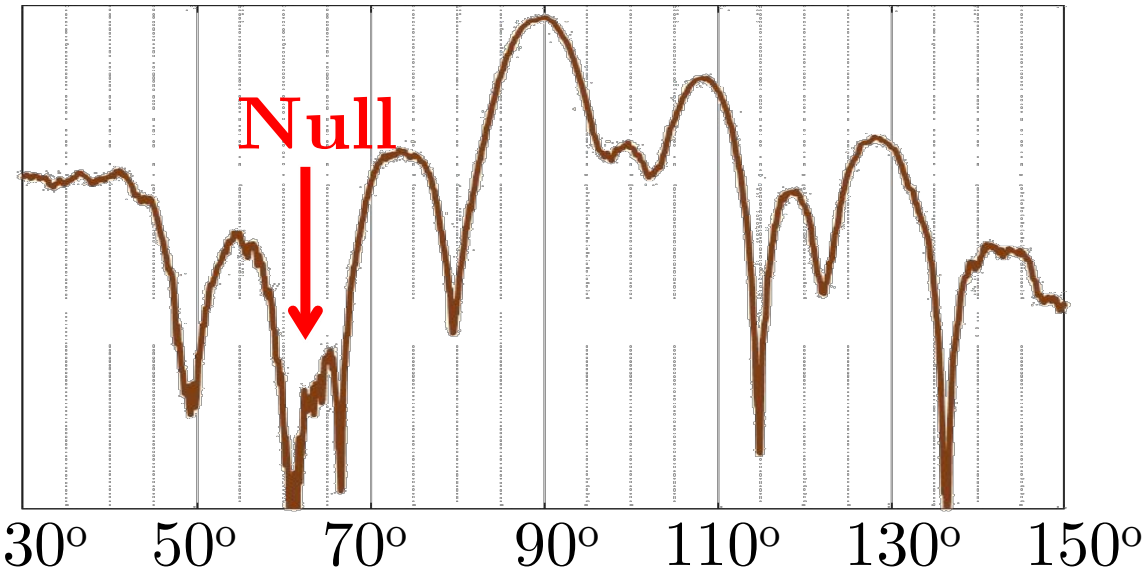

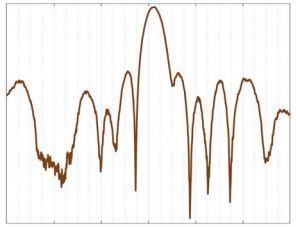

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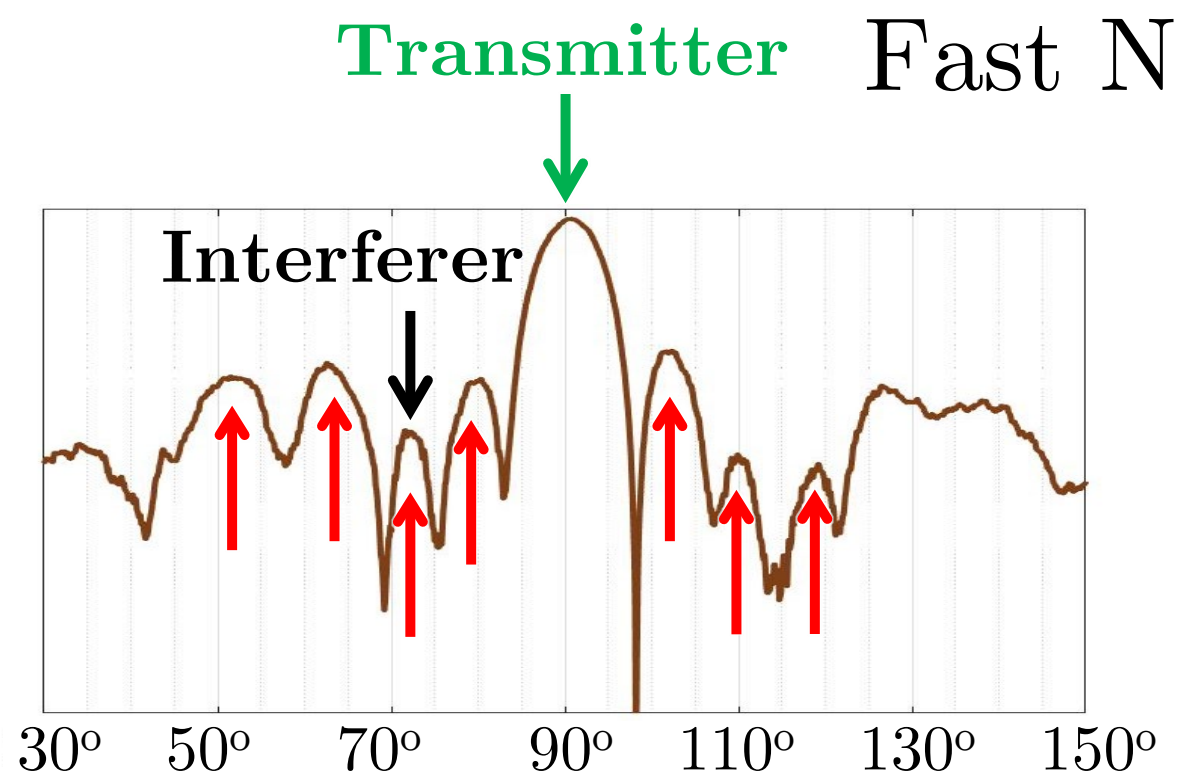

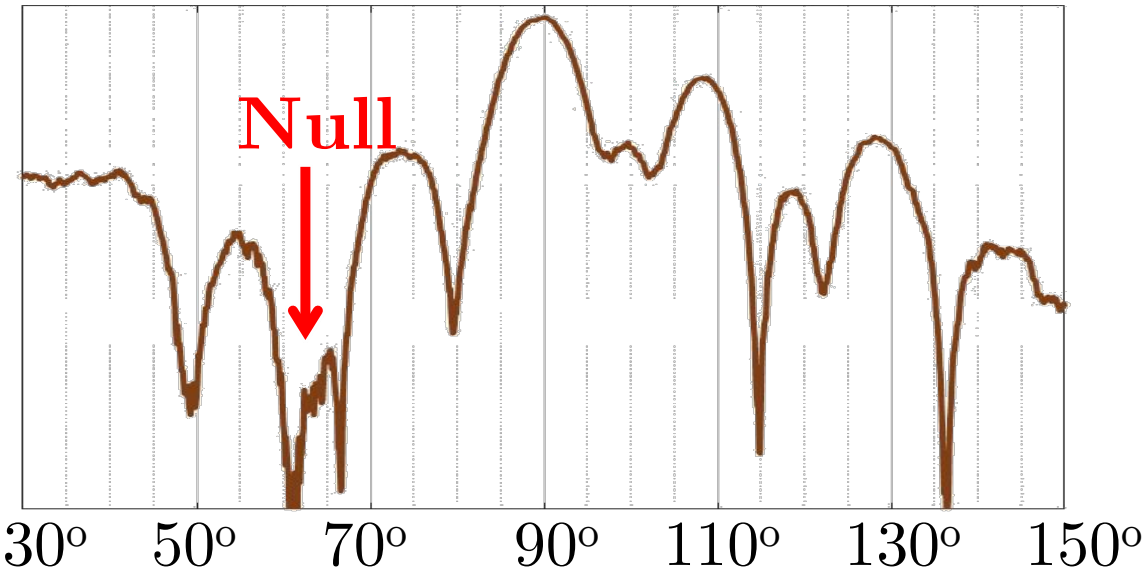

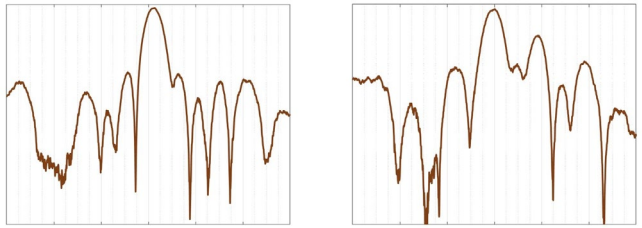

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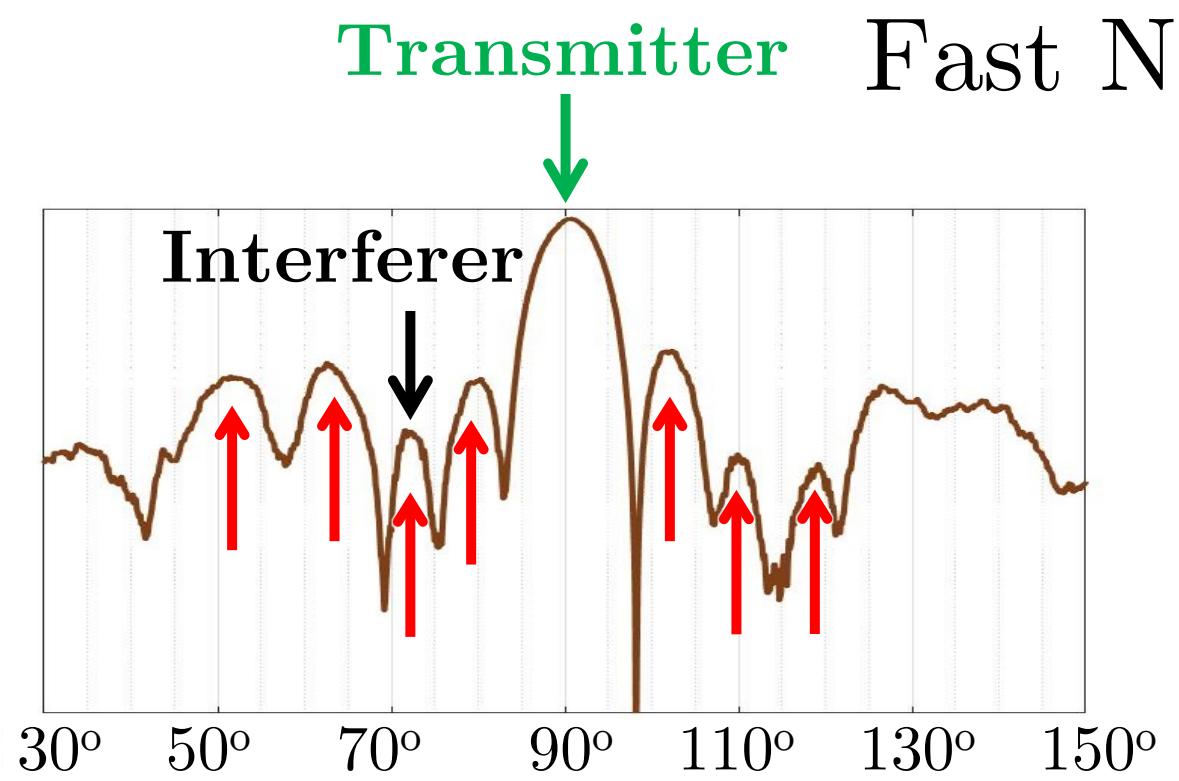

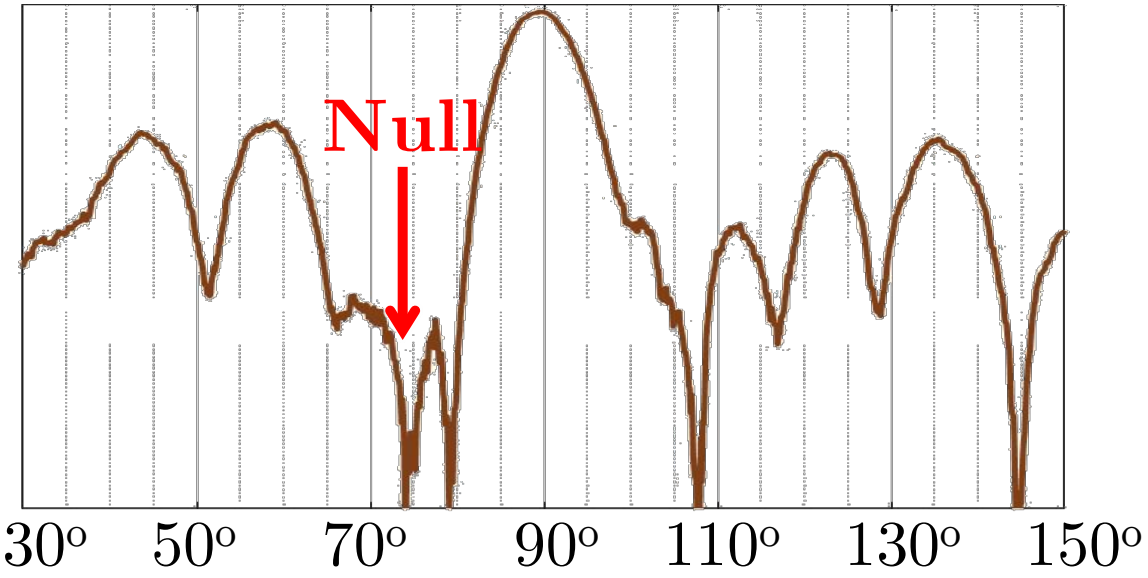

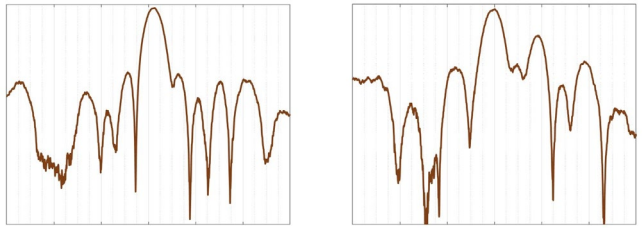

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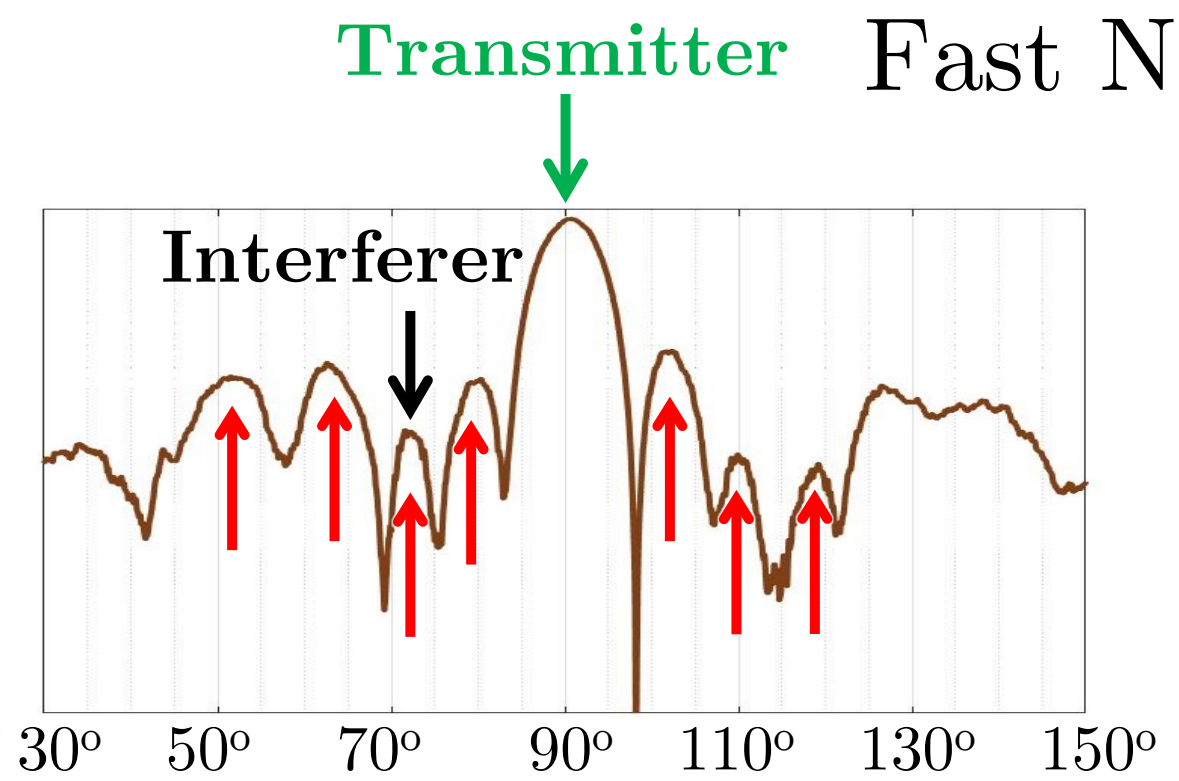

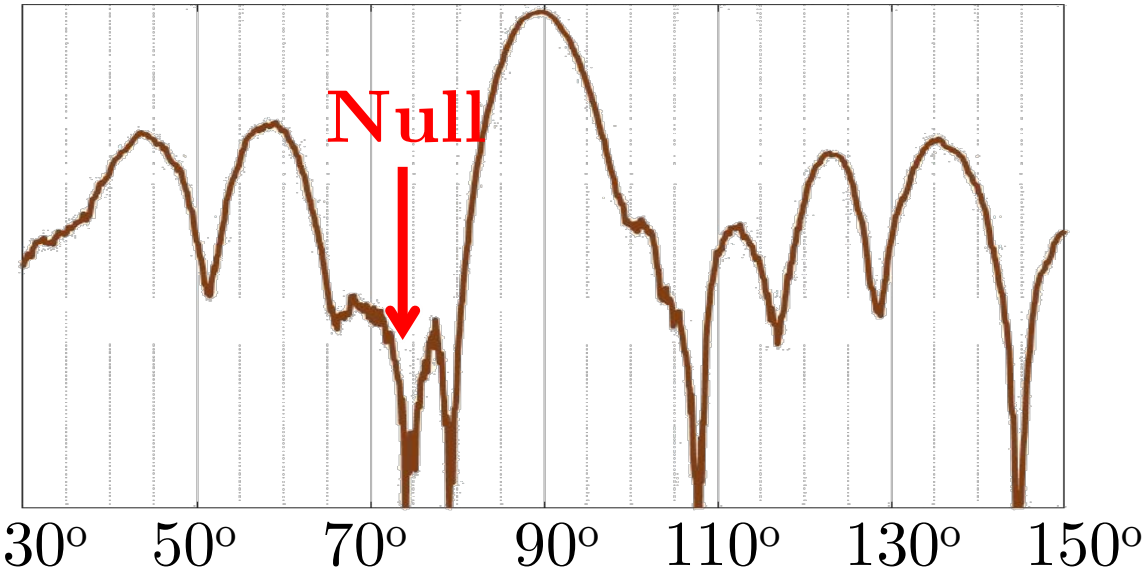

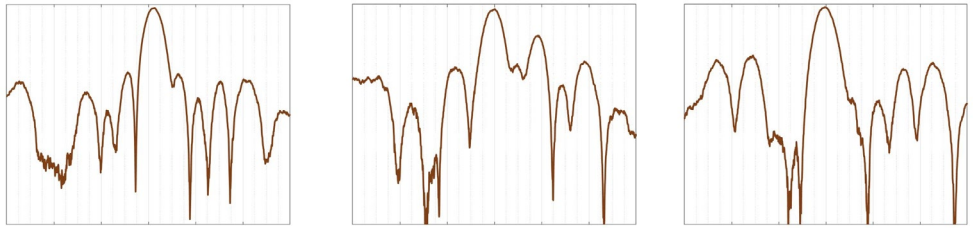

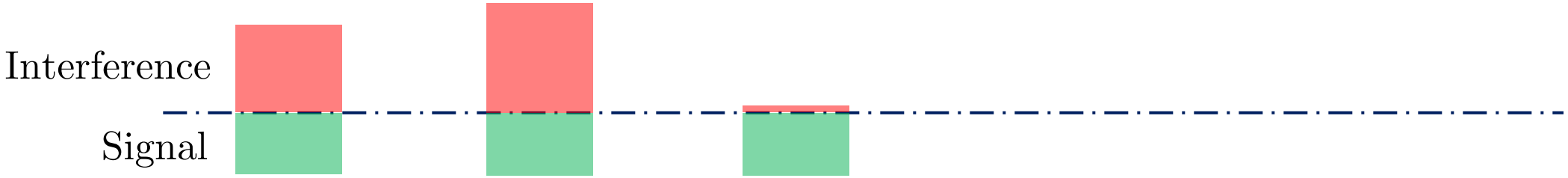

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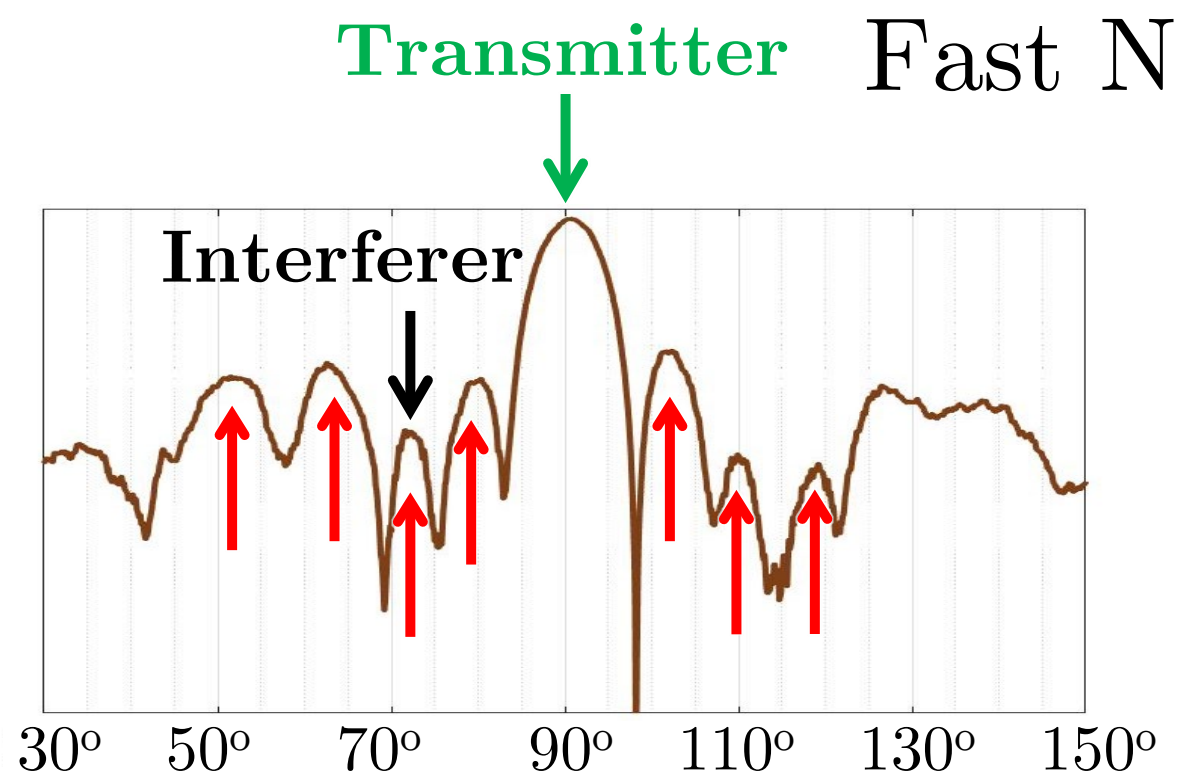

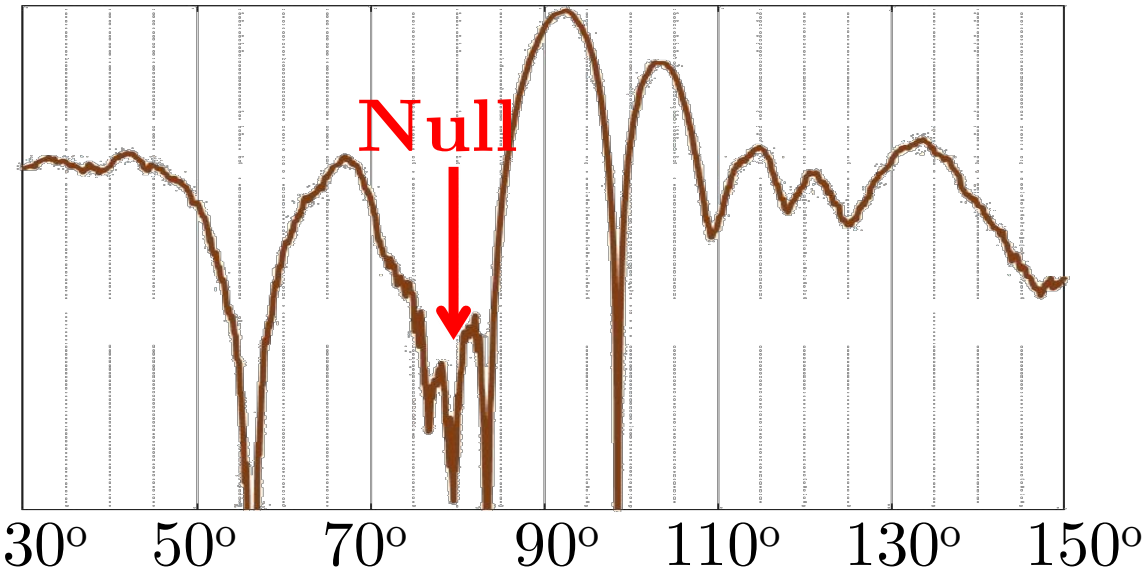

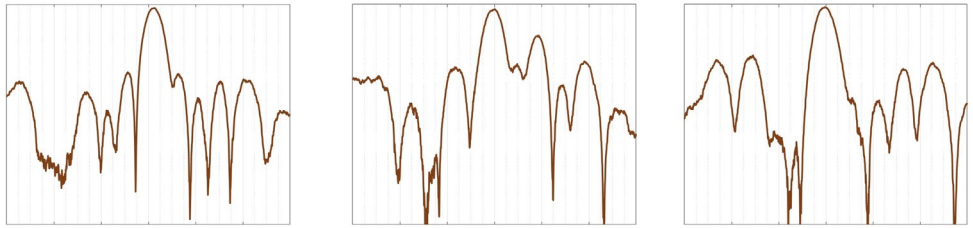

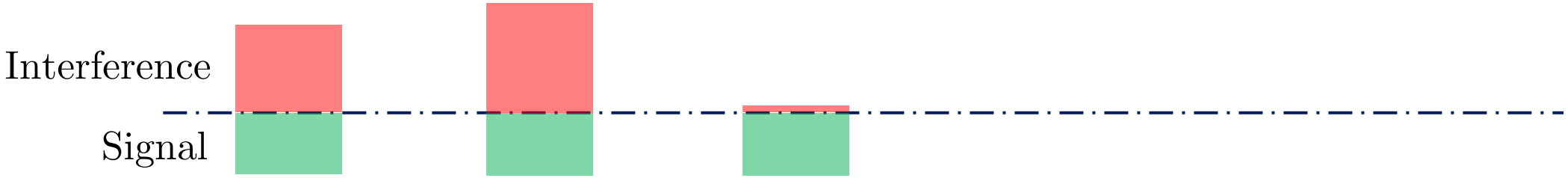

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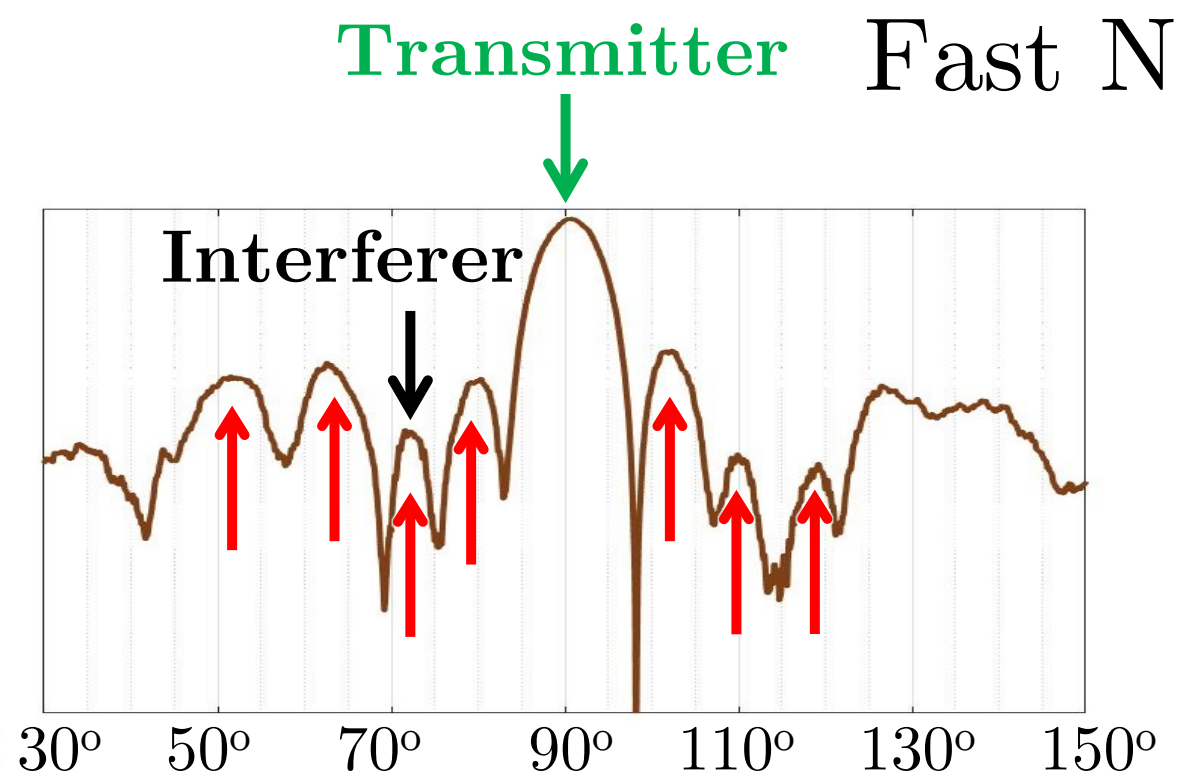
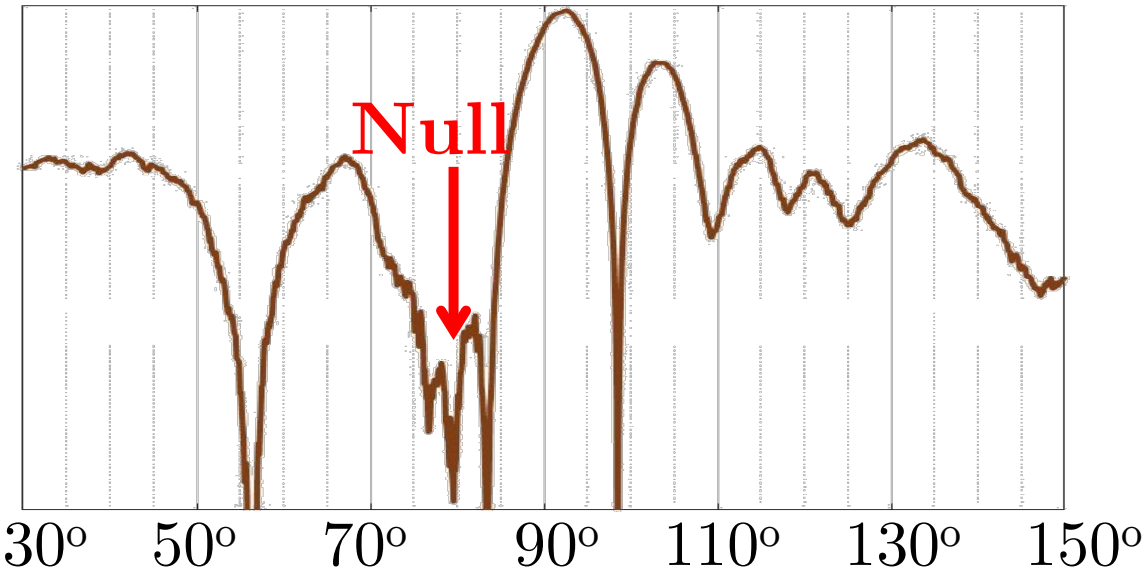
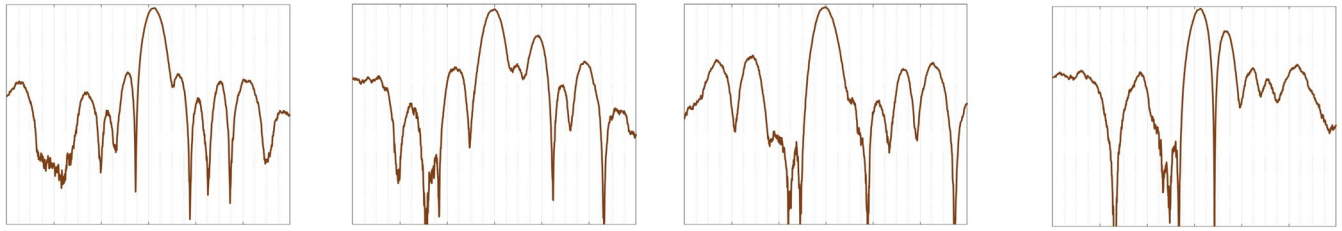
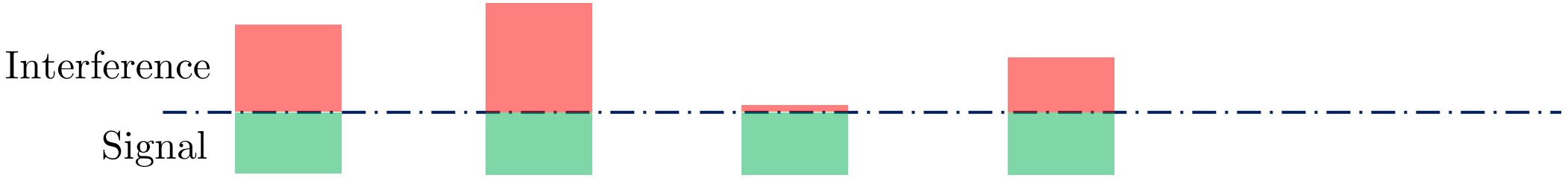
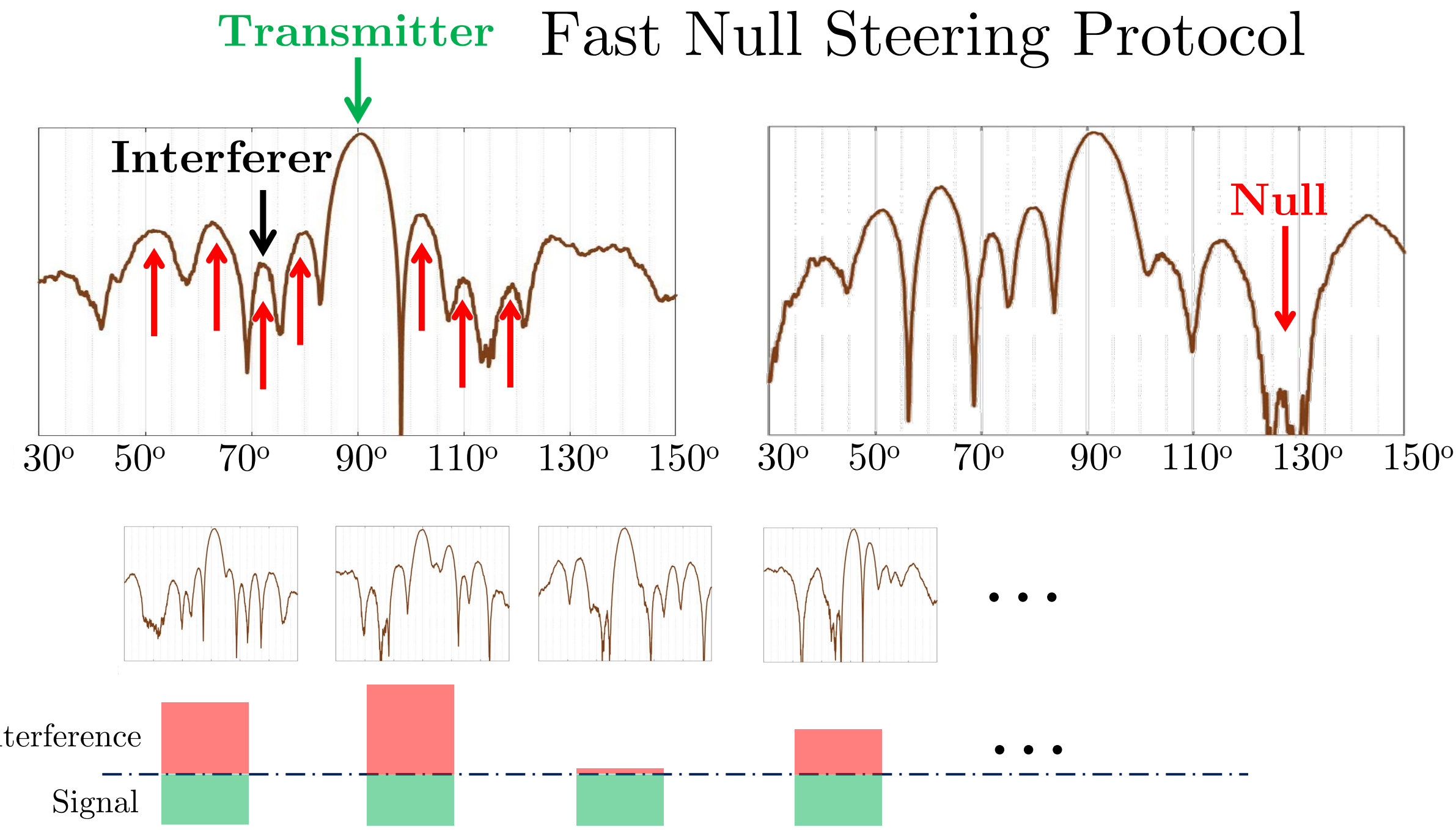




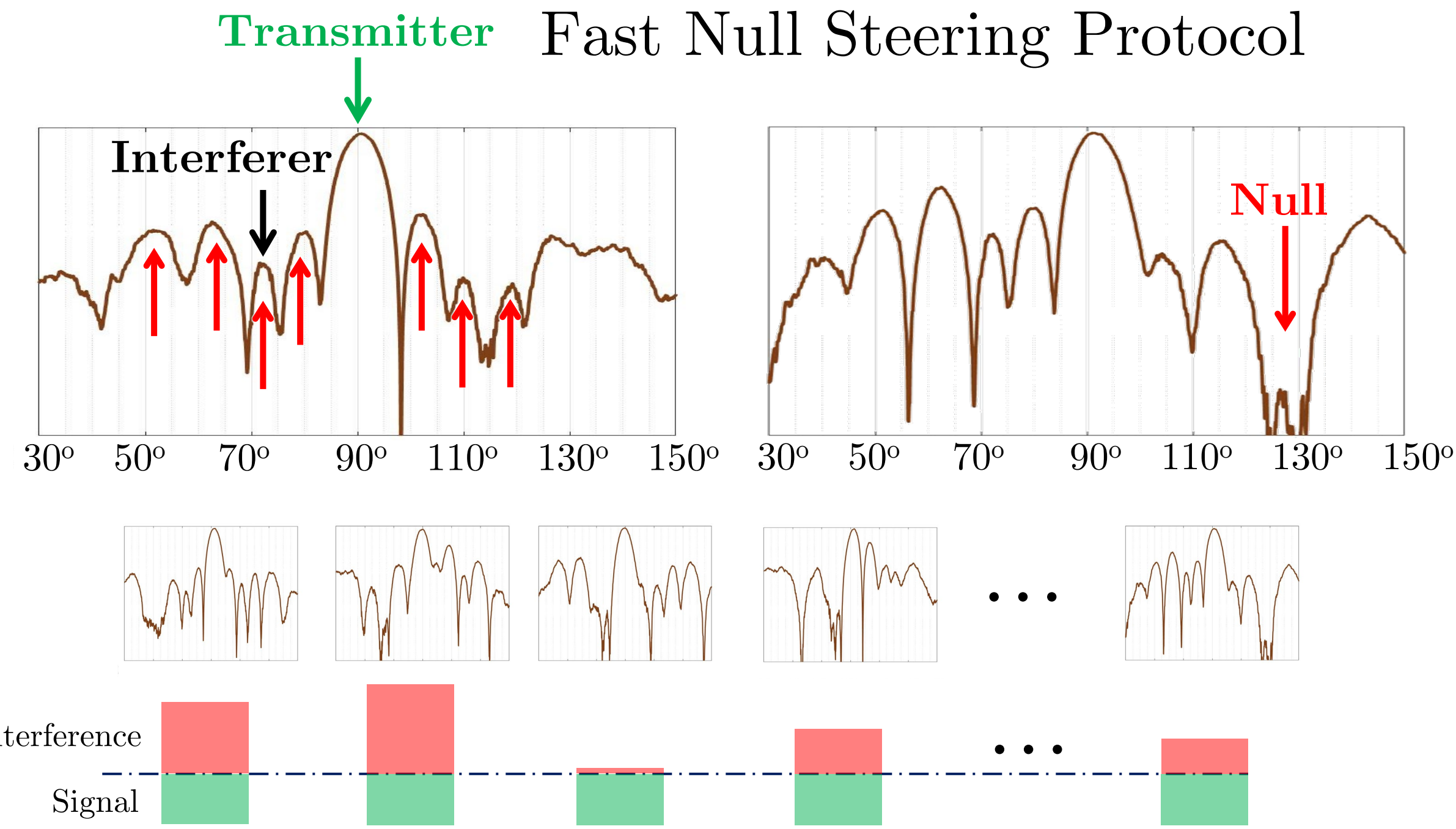




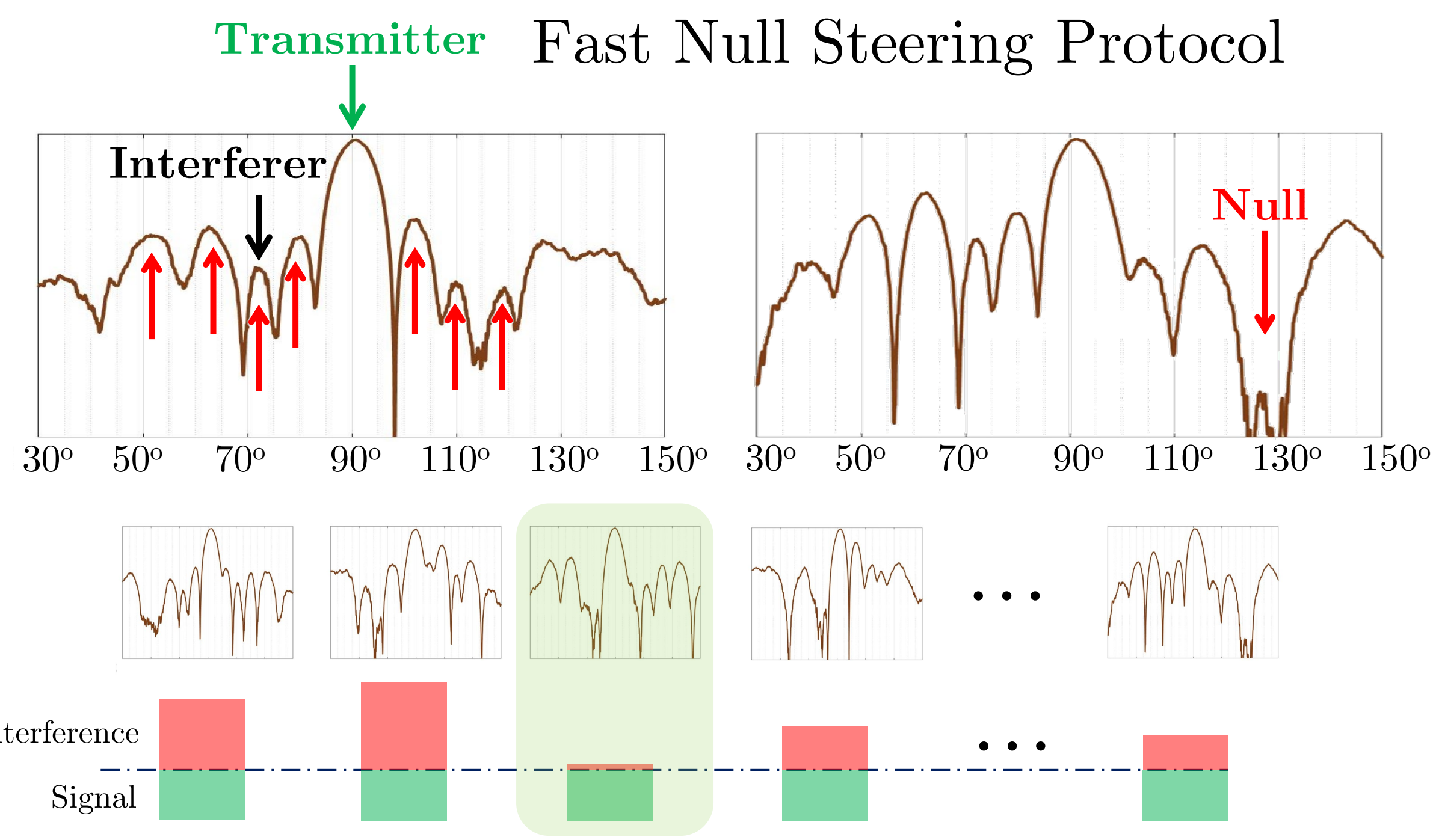
Fast Null Steering Protocol



Fast Null Steering Protocol



Fast Null Steering Protocol

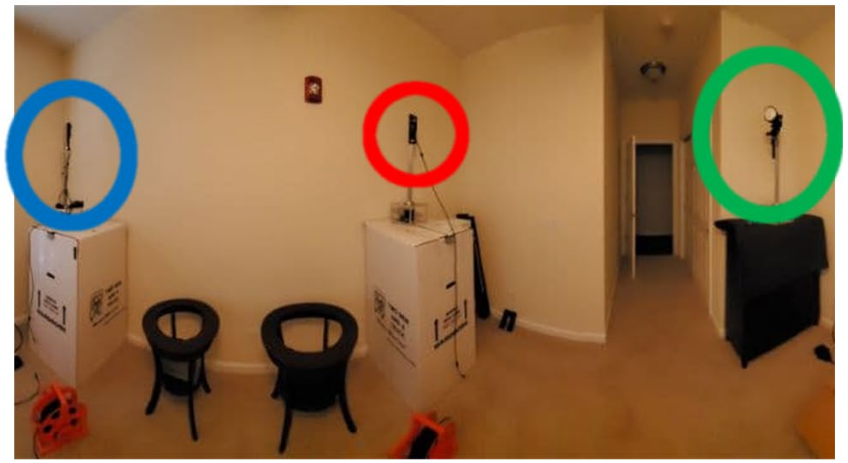


Implementation

Implemented on mmFlex: 60 GHz, 16 element antennas, sending 802.11ad packets

(a)

(b)

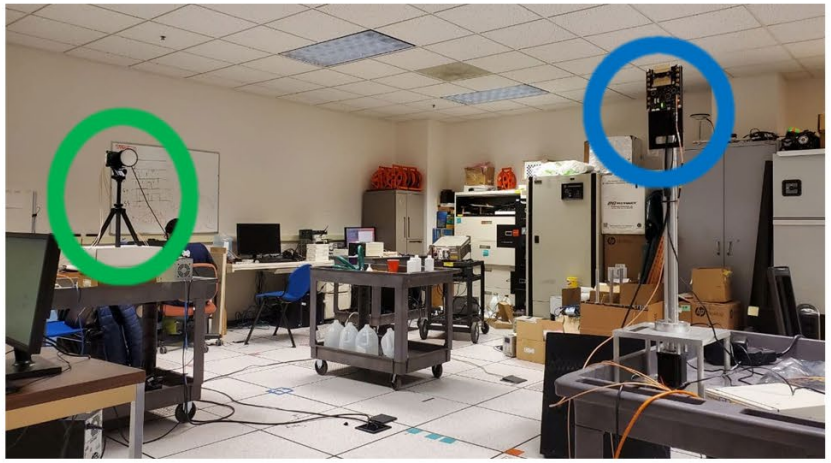


Transmitter

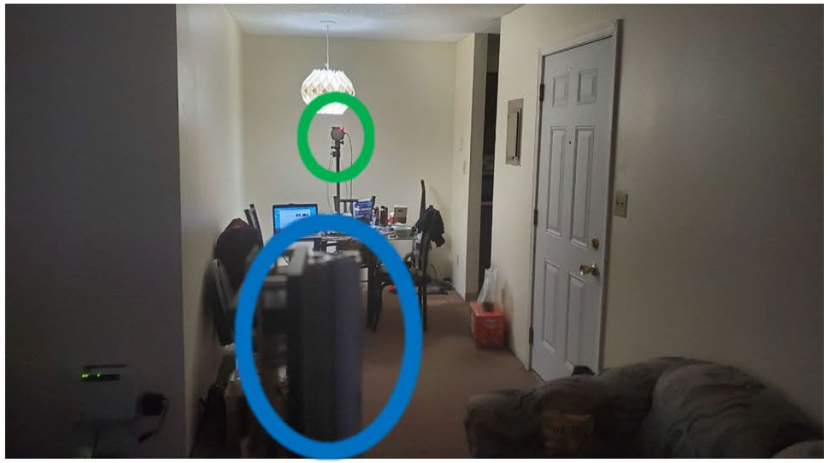
Receiver

Interference

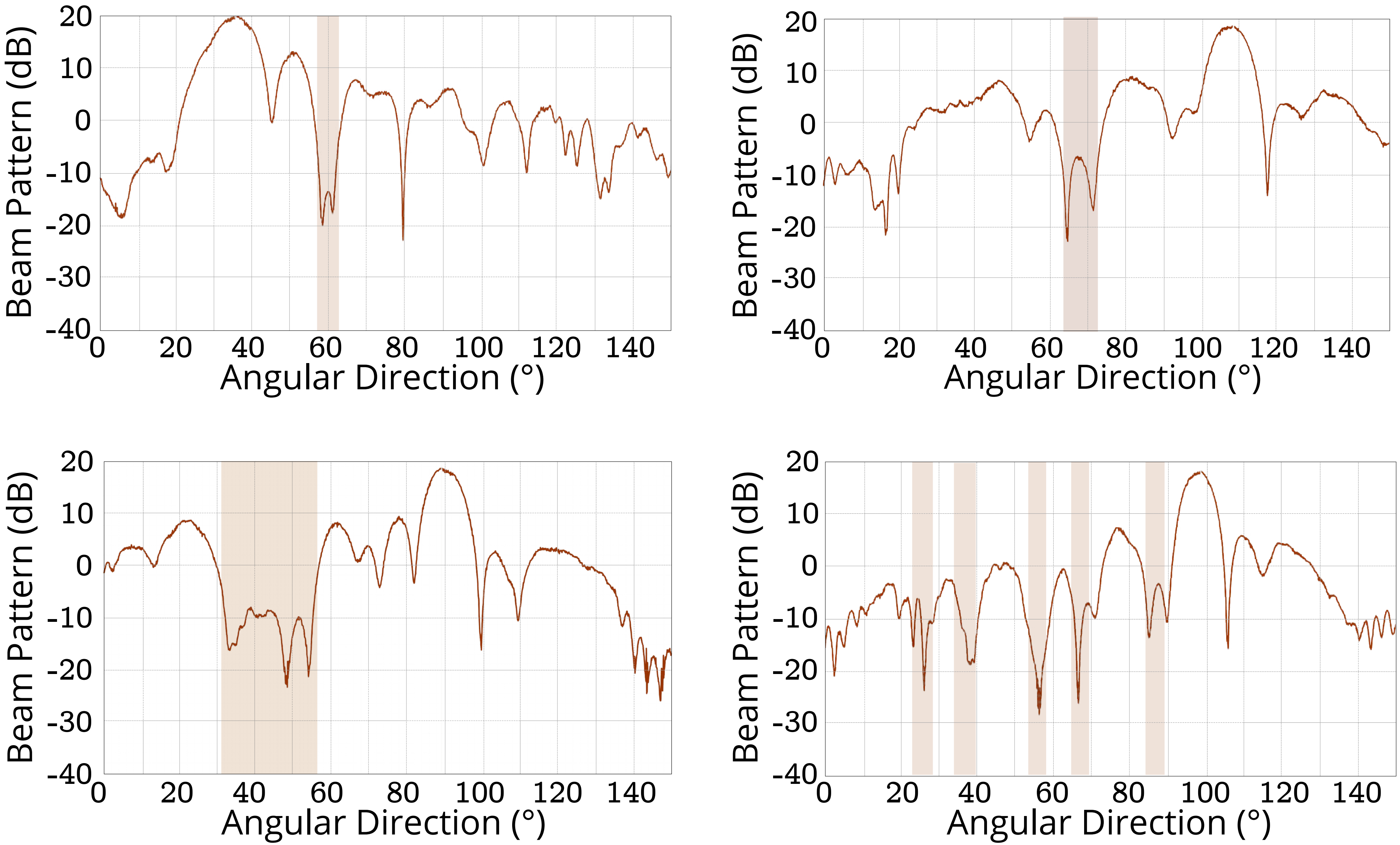
(c)



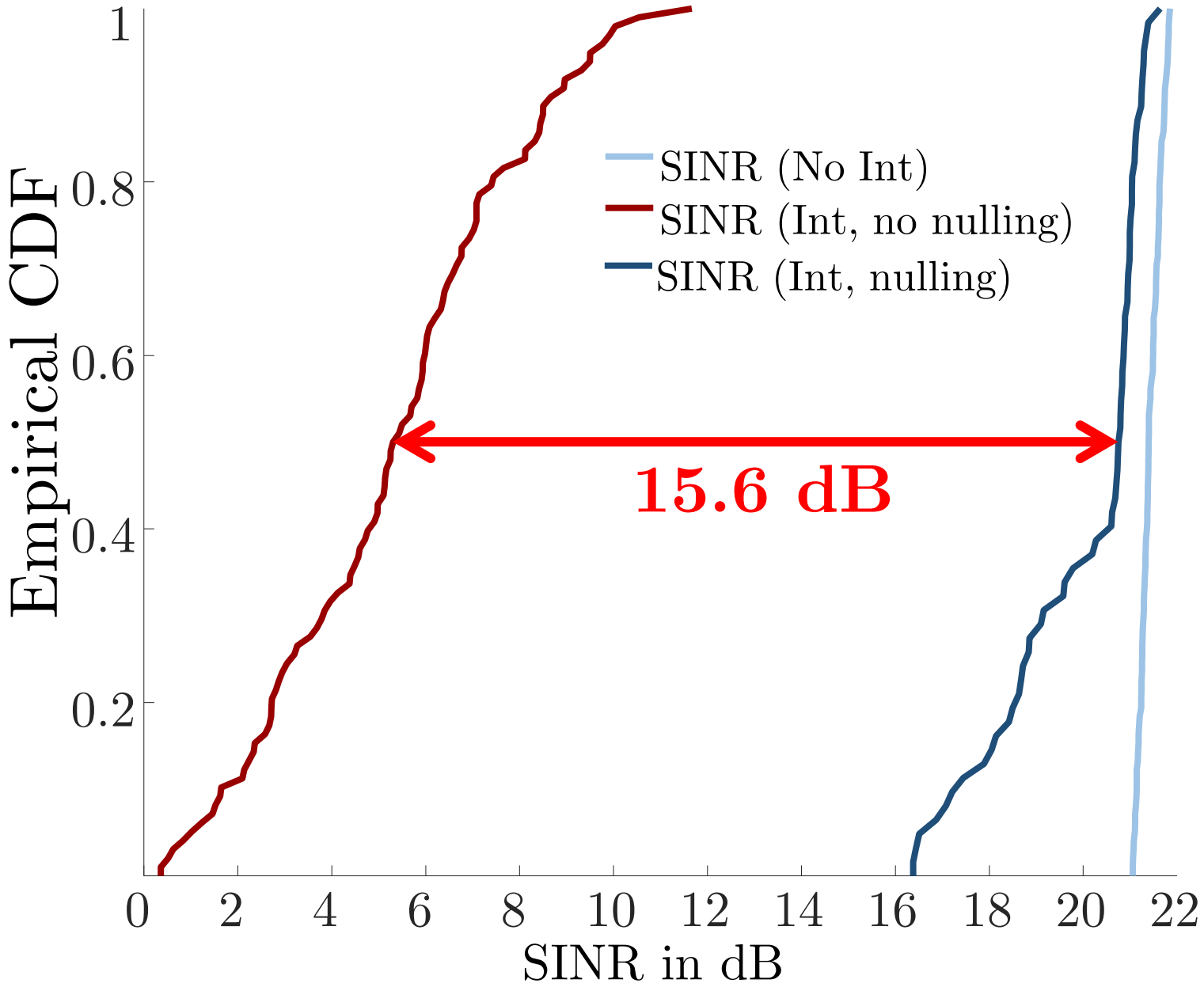
(d)



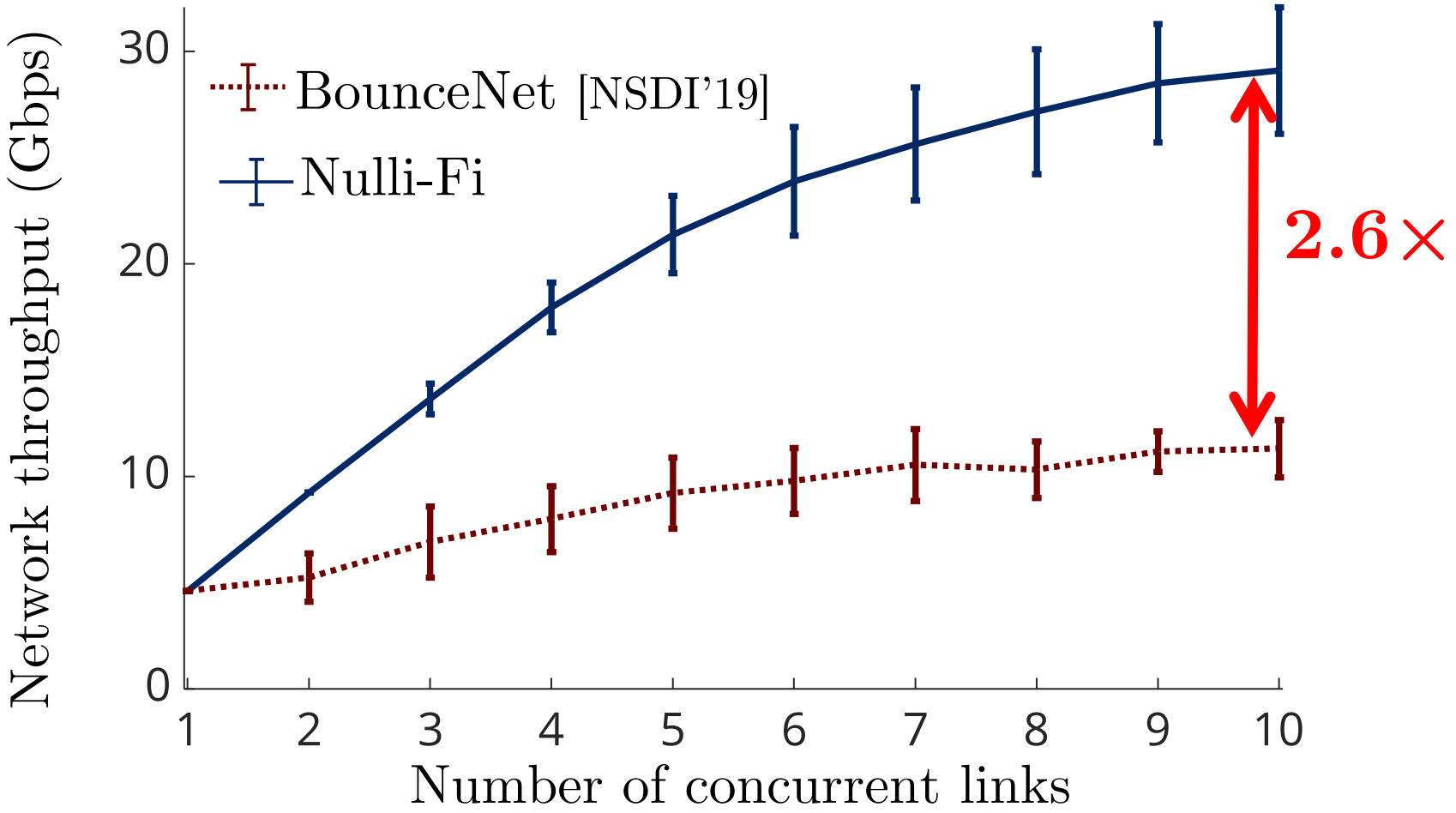
Qualitative Results



Restoring SINR using Nulli-Fi



Throughput Gains



Conclusion

- Nulli-Fi is the first practical millimeter wave null steering system.
- Millimeter wave offers a new way of interference management, opening up the opportunity of designing protocols using nulling as another primitive in our toolbox.
- We have open-sourced our algorithms on our GitLab page at https://gitlab.engr.illinois.edu/smadani2/nulling-python