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MILCOM 2011
Networks... Attaining the Value

Spatial focusing and nulling of RF signals using time-reversal

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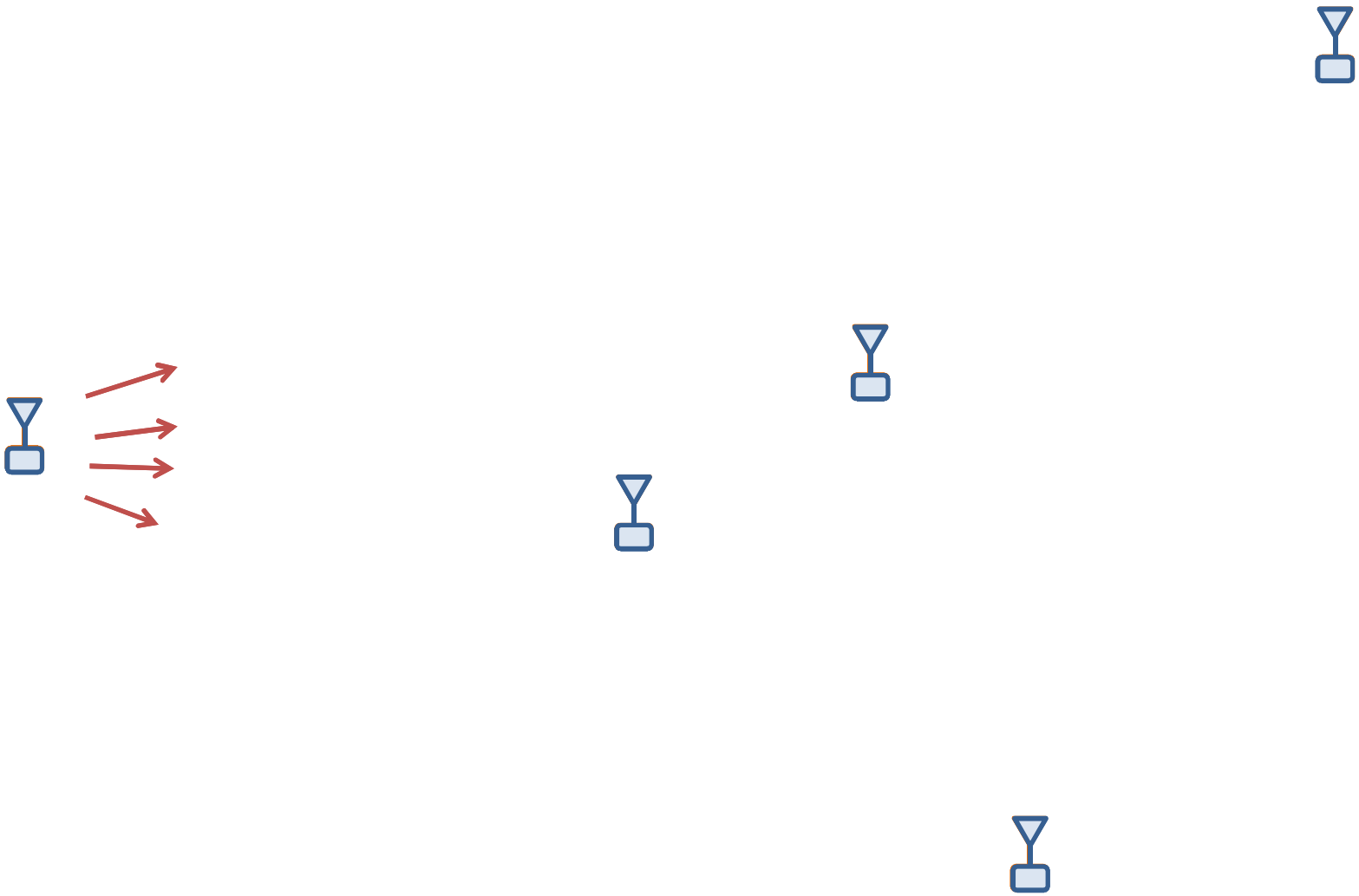
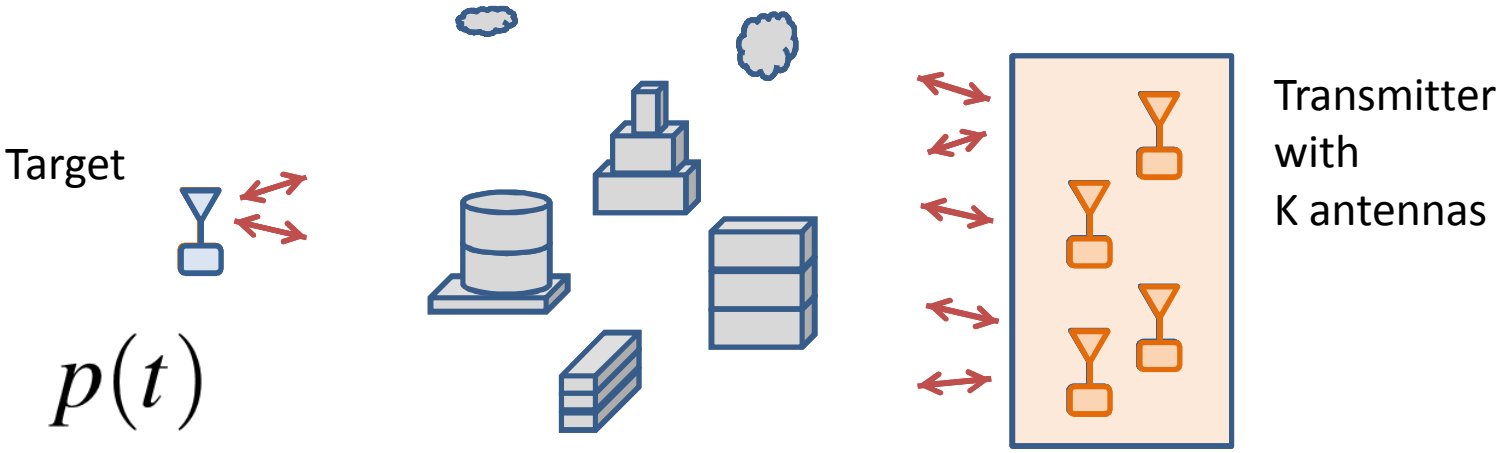
Time-Reversal ?

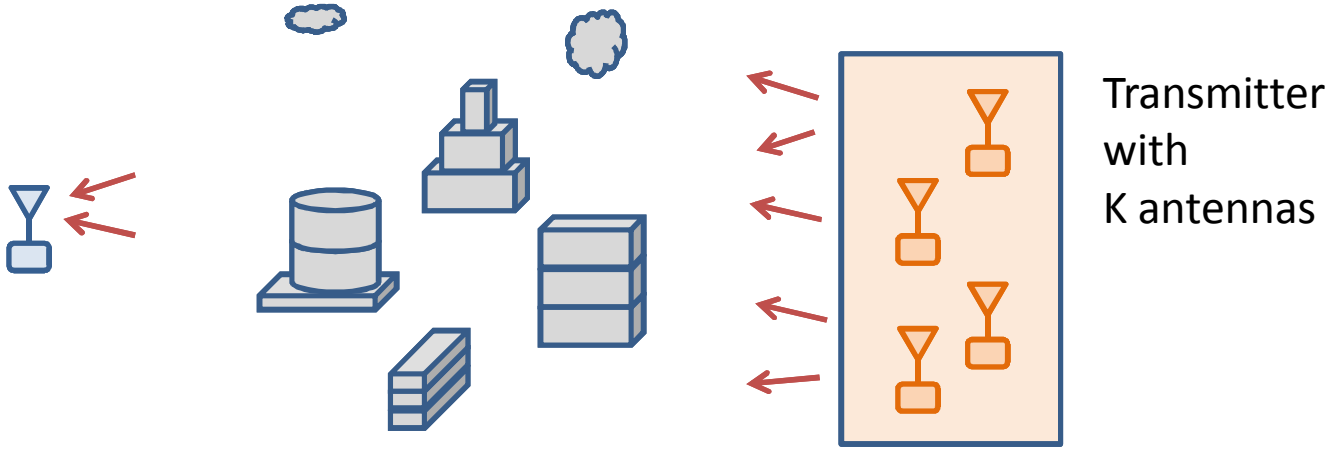


Application



$$\mathbf{y}(t) = p(t) * \mathbf{h}_m(t)$$

Application



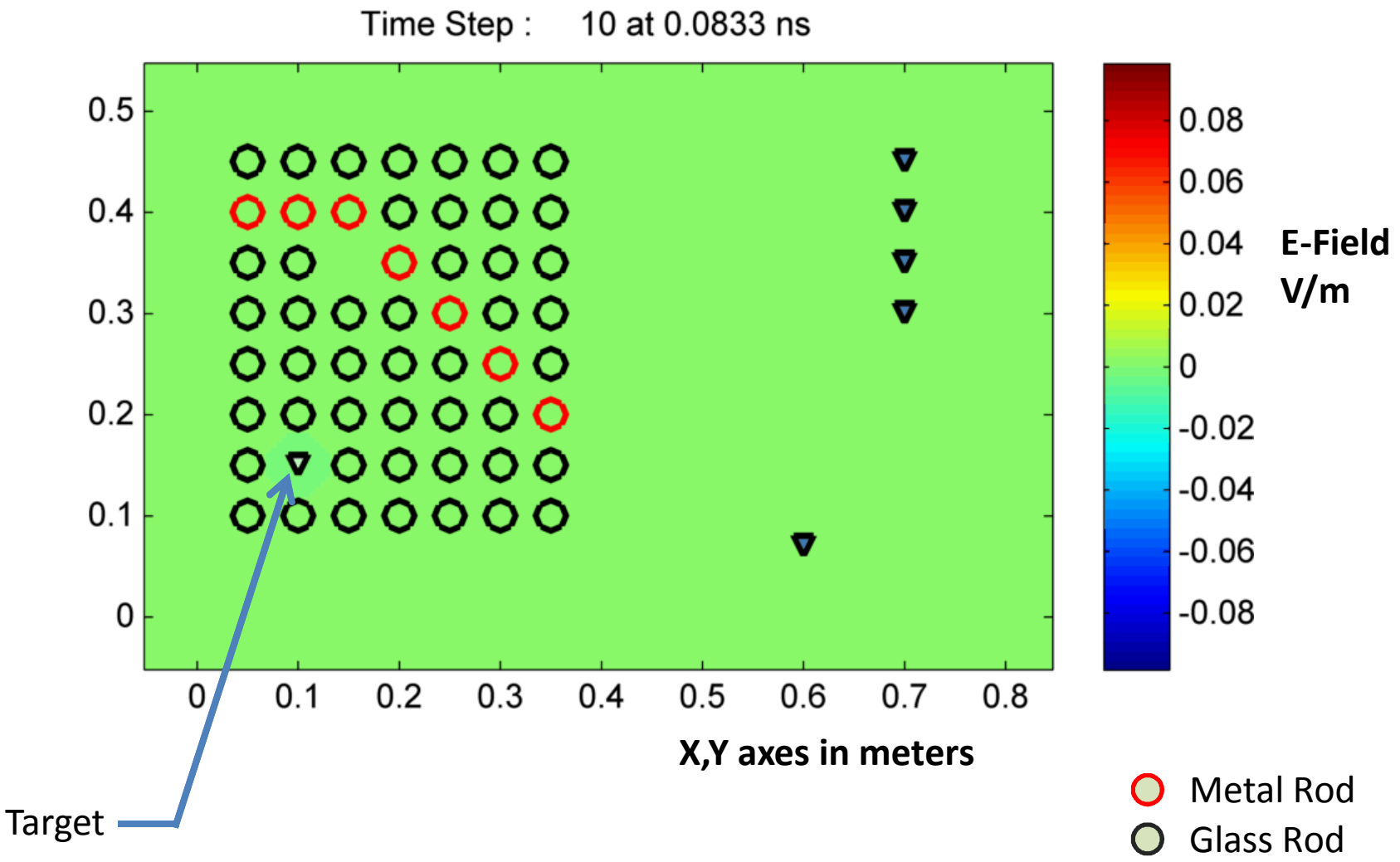
$$z(t) = \sum^{K} \mathbf{y}_{tr}(t) * \mathbf{h}_m(t)$$

$$z(t) = \sum^{K} p(-t) * \mathbf{h}_m(-t) * \mathbf{h}_m(t)$$

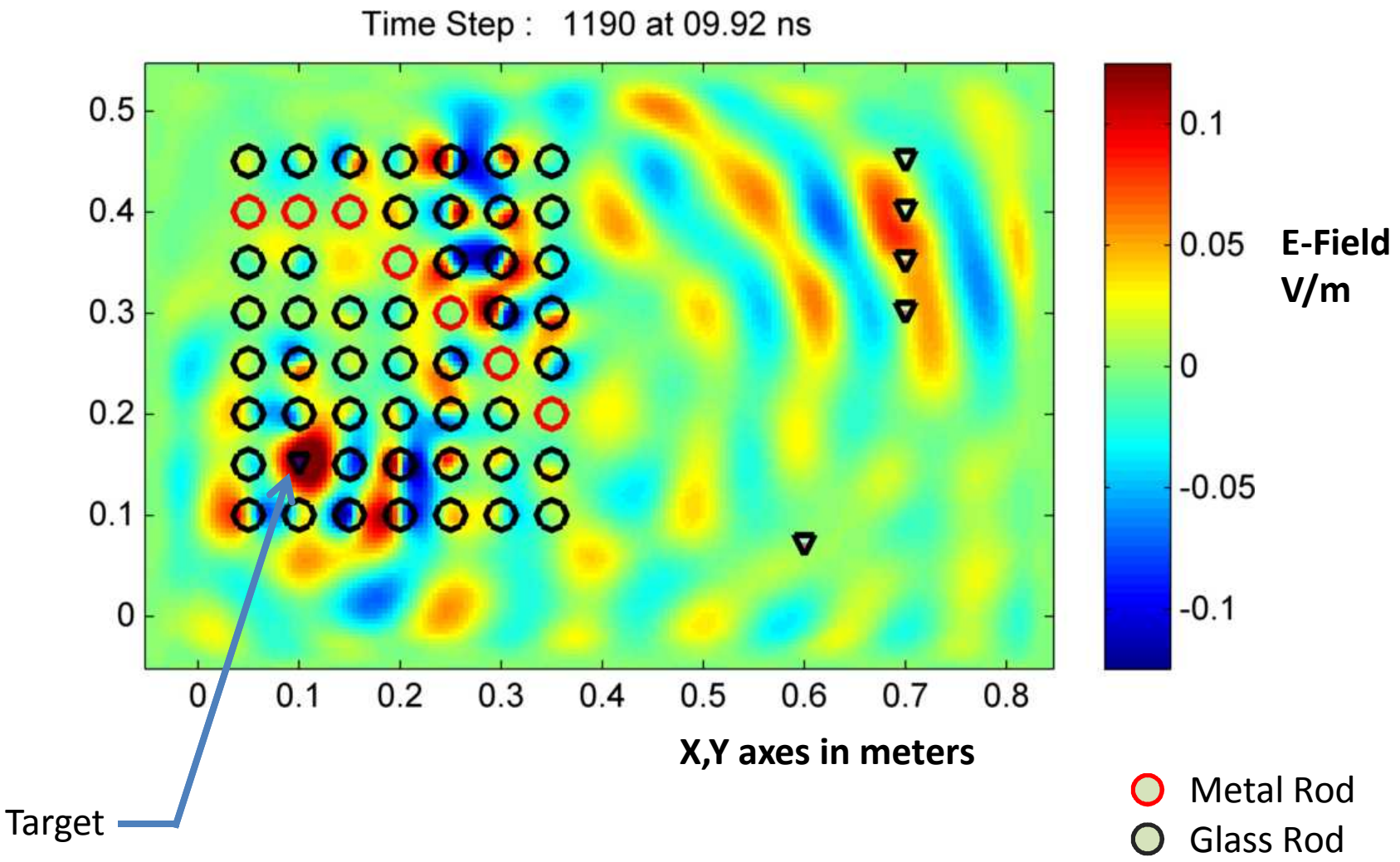
Convergence in Time

and in Space

Illustration



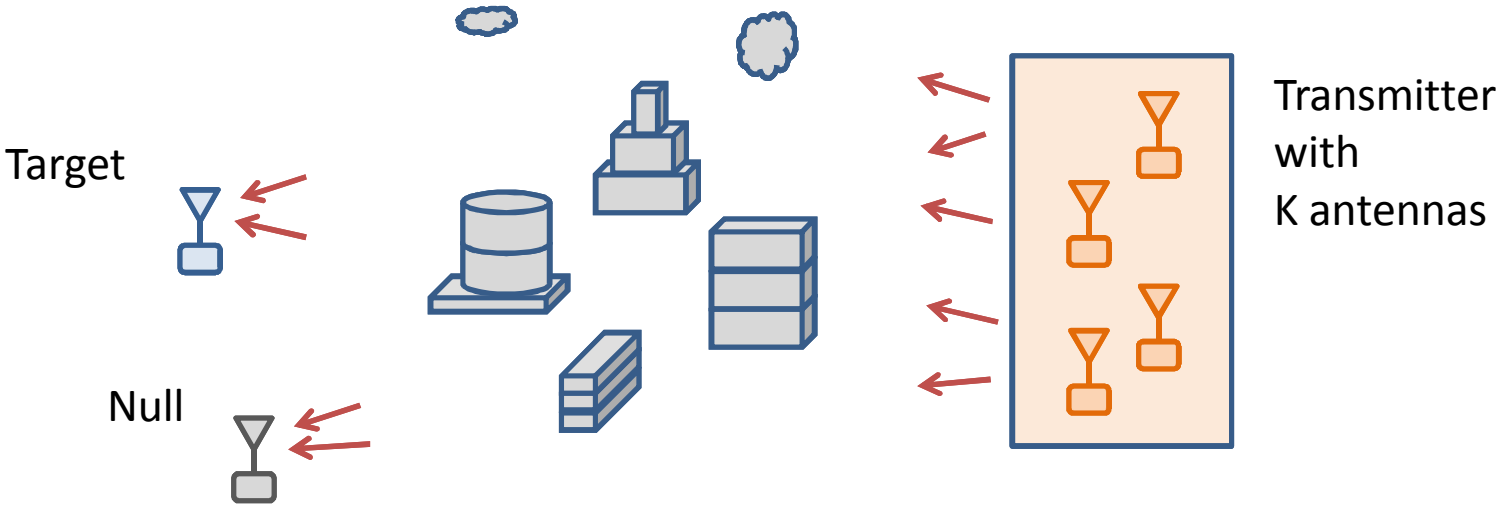
Illustration



Why?

- Focus in space
- Works without line-of-sight
- Receiver location can be unknown
- Multipath is not a problem

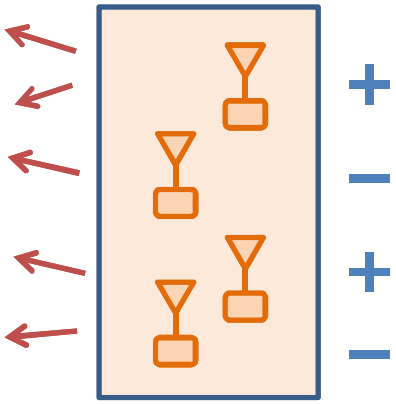
Focus at A, Null at B



- Decrease co-channel interference to other users

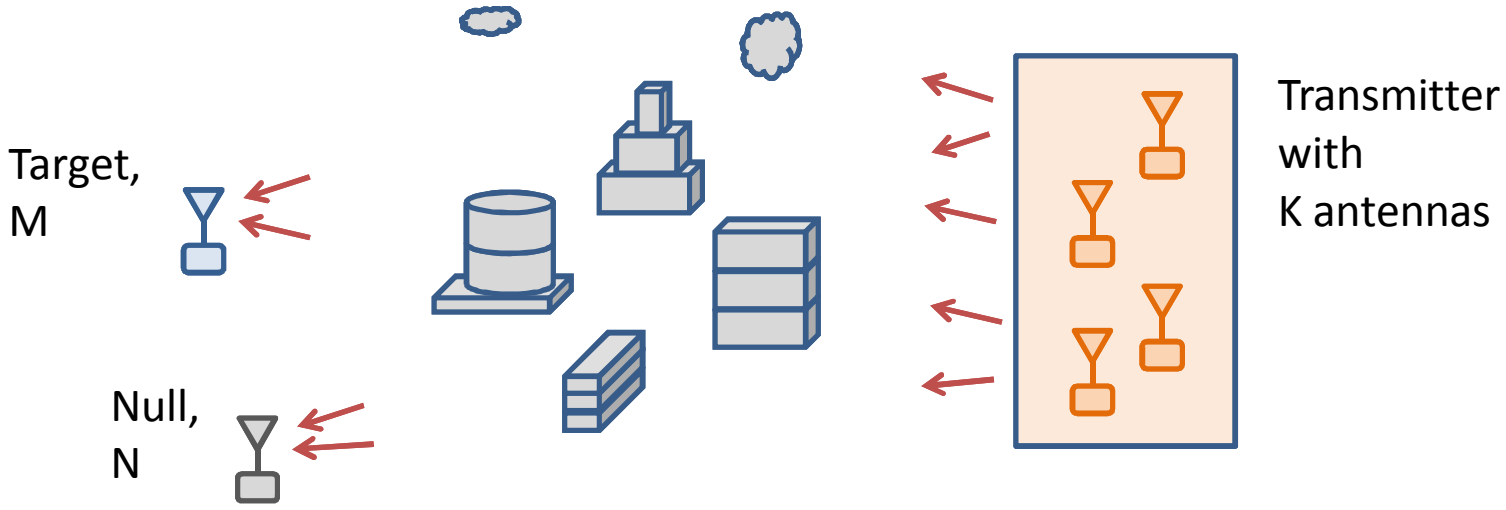
Prior approaches

1. Heuristic



2. Optimal: Complicated and requires knowledge of the channel to the null location

This work: simplified focus and null



Transmit beam-forming filter, $\mathbf{g}(\omega) = \gamma \begin{bmatrix} \frac{h_{m,1}^*(\omega)}{\|h_{n,1}(\omega)\|^2} \\ \frac{h_{m,2}^*(\omega)}{\|h_{n,2}(\omega)\|^2} \\ \vdots \\ \frac{h_{m,K}^*(\omega)}{\|h_{n,K}(\omega)\|^2} \end{bmatrix}$

This work: simplified focus and null

- Does not need full channel to the null location. Only needs PSD (easily measured without cooperation).

Transmit beam-forming filter, $\mathbf{g}(\omega) = \gamma \begin{bmatrix} \frac{h_{m,1}^*(\omega)}{\left\|h_{n,1}(\omega)\right\|^2} \\ \frac{h_{m,2}^*(\omega)}{\left\|h_{n,2}(\omega)\right\|^2} \\ \vdots \\ \frac{h_{m,K}^*(\omega)}{\left\|h_{n,K}(\omega)\right\|^2} \end{bmatrix}$

Evaluation by simulation

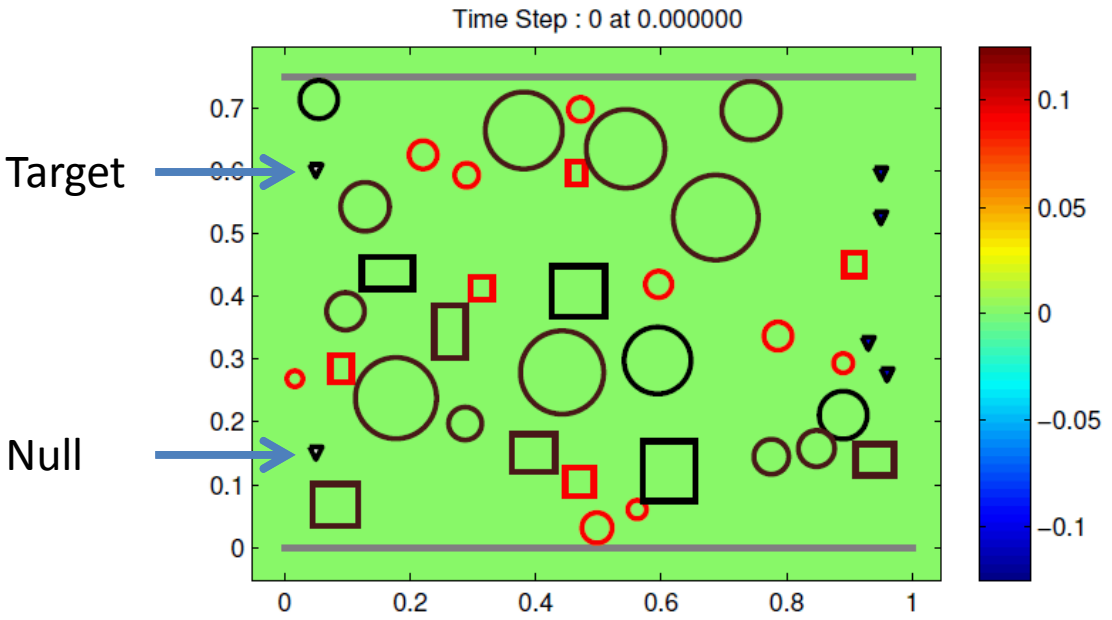
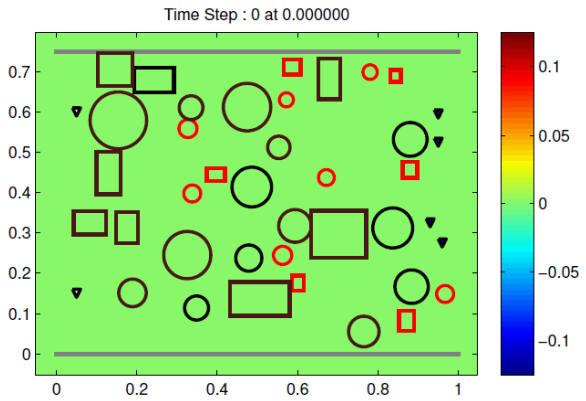
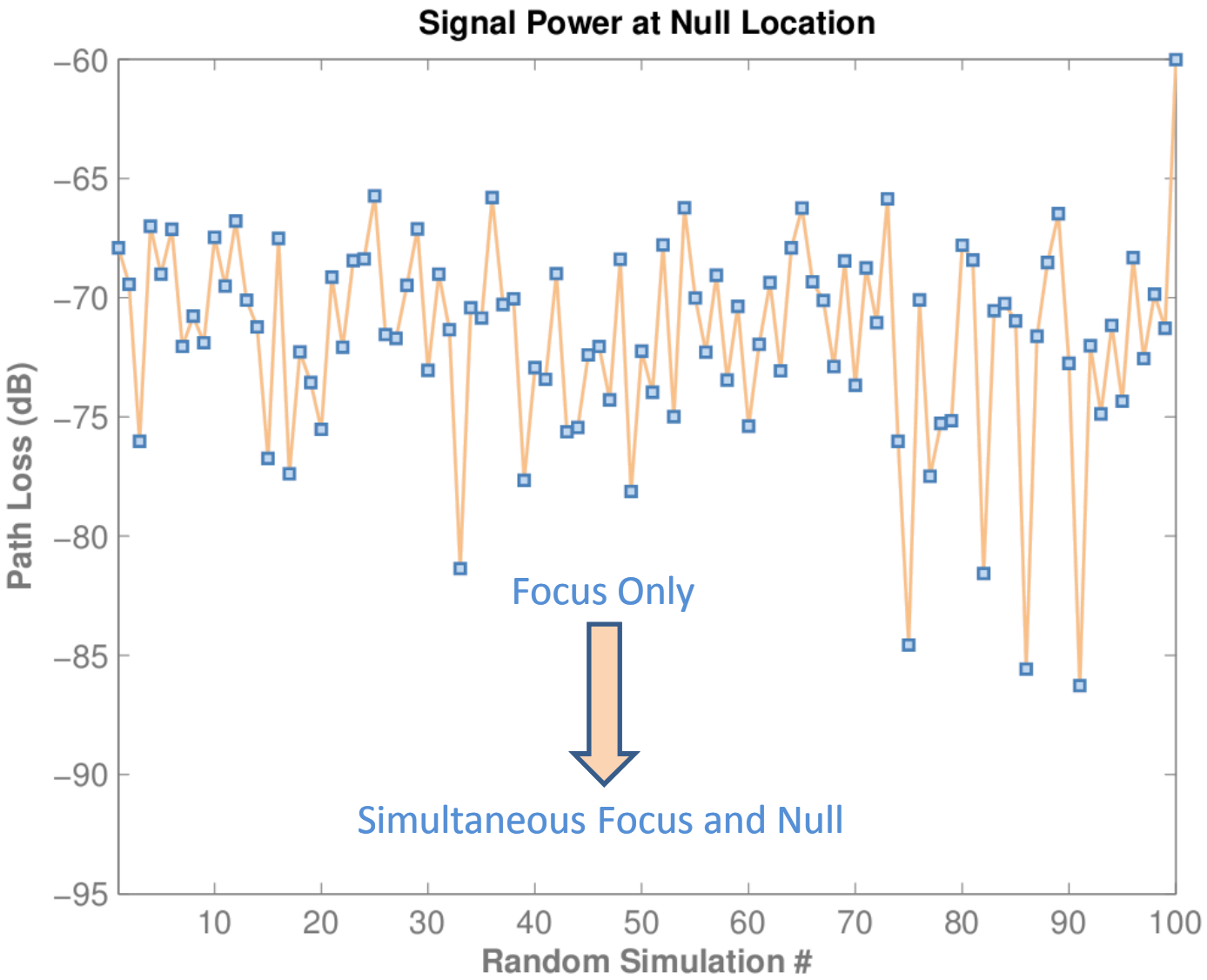


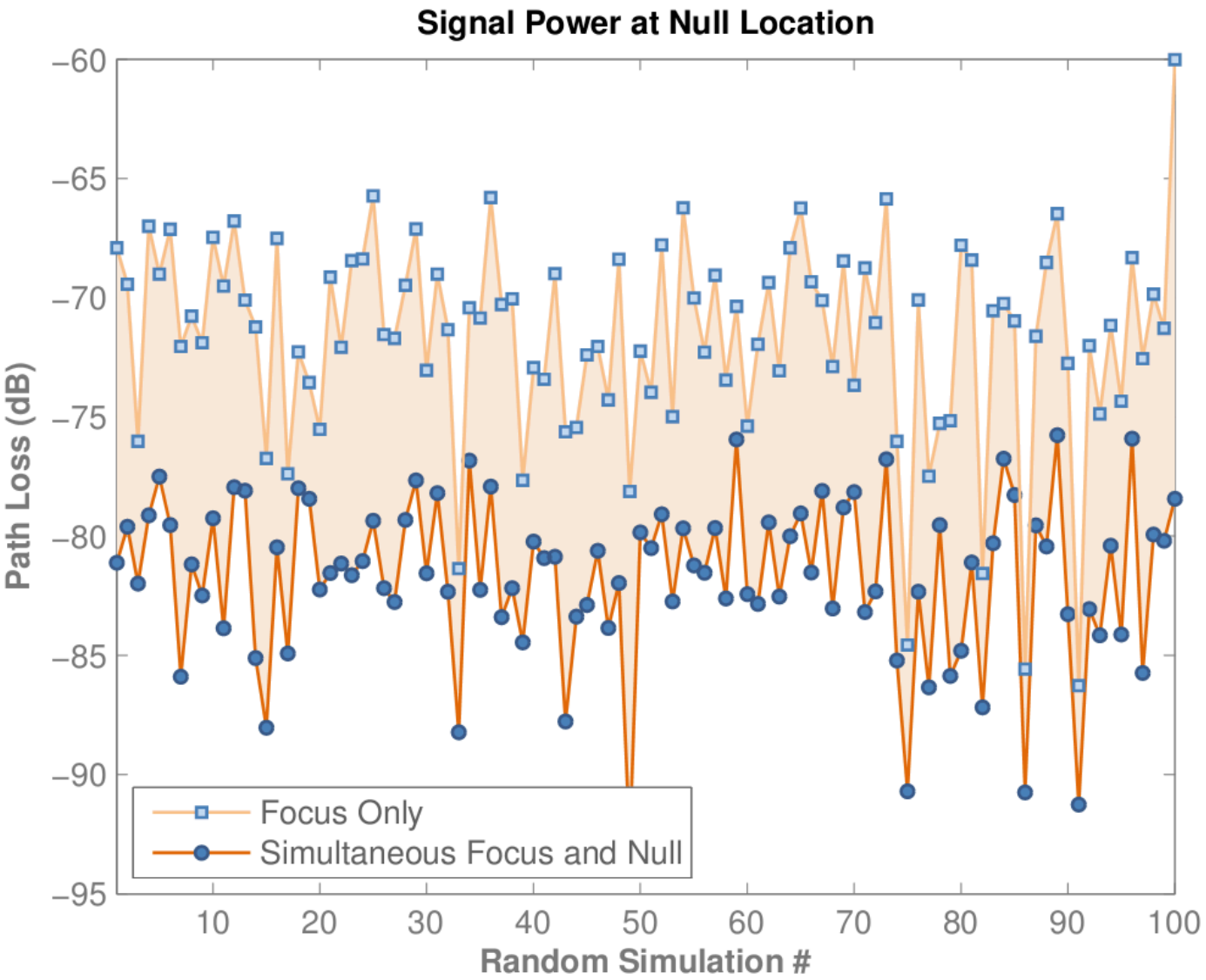
Fig. 5. Randomly created scenario for time-reversal processing. f_c = 3 GHz, BW = 500 MHz. Black objects are glass columns, Brown objects are wooden columns, Red objects are metal pipes. All axes are in meters.



Nulling


Signal Power at Null Location
Path Loss (dB)
−60
−65
−70
−75
−80
−85
−90
−95
10
20
30
40
50
60
70
80
90
100
Random Simulation #
Focus Only
Simultaneous Focus and Null

Nulling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−85
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10
20
30
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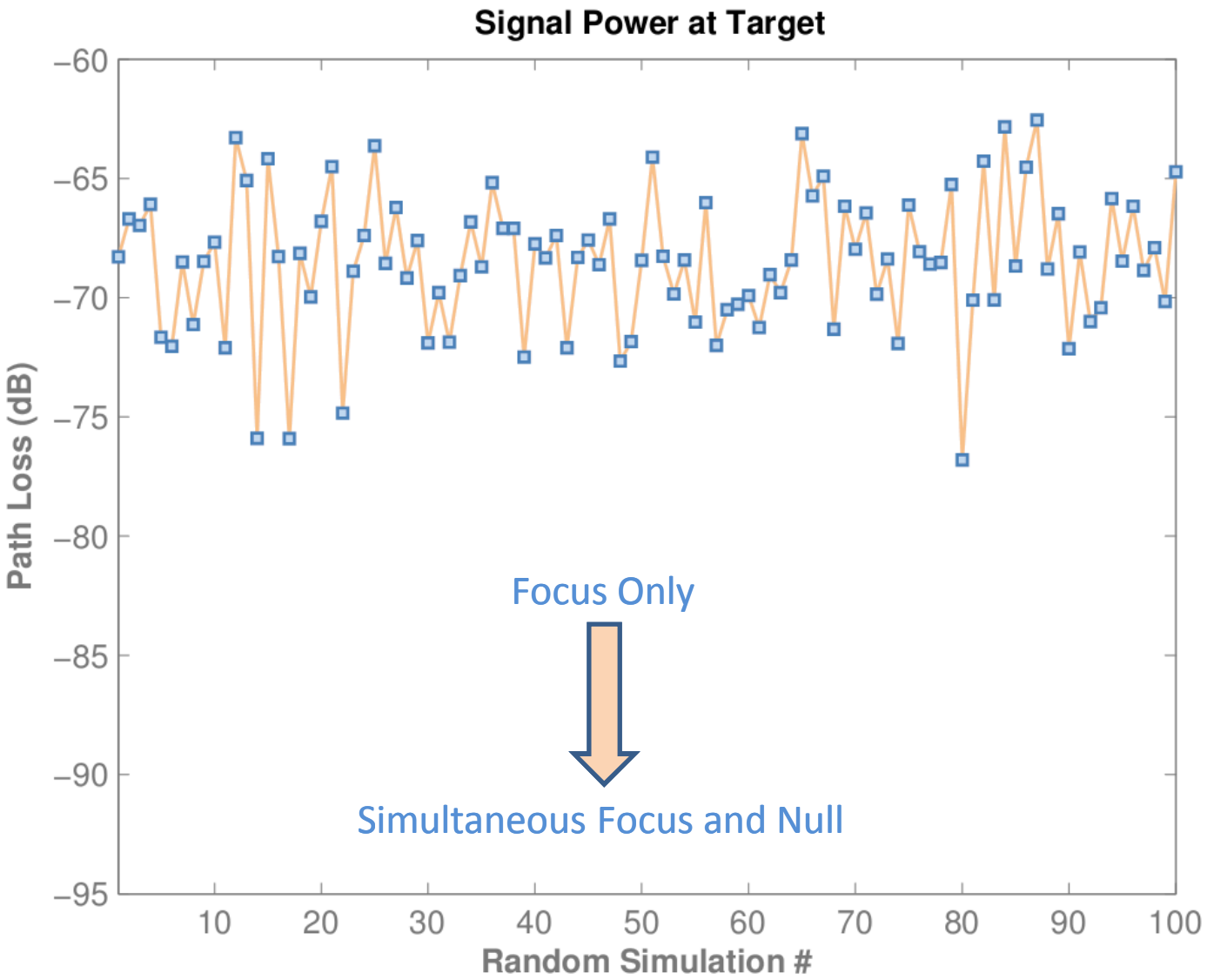
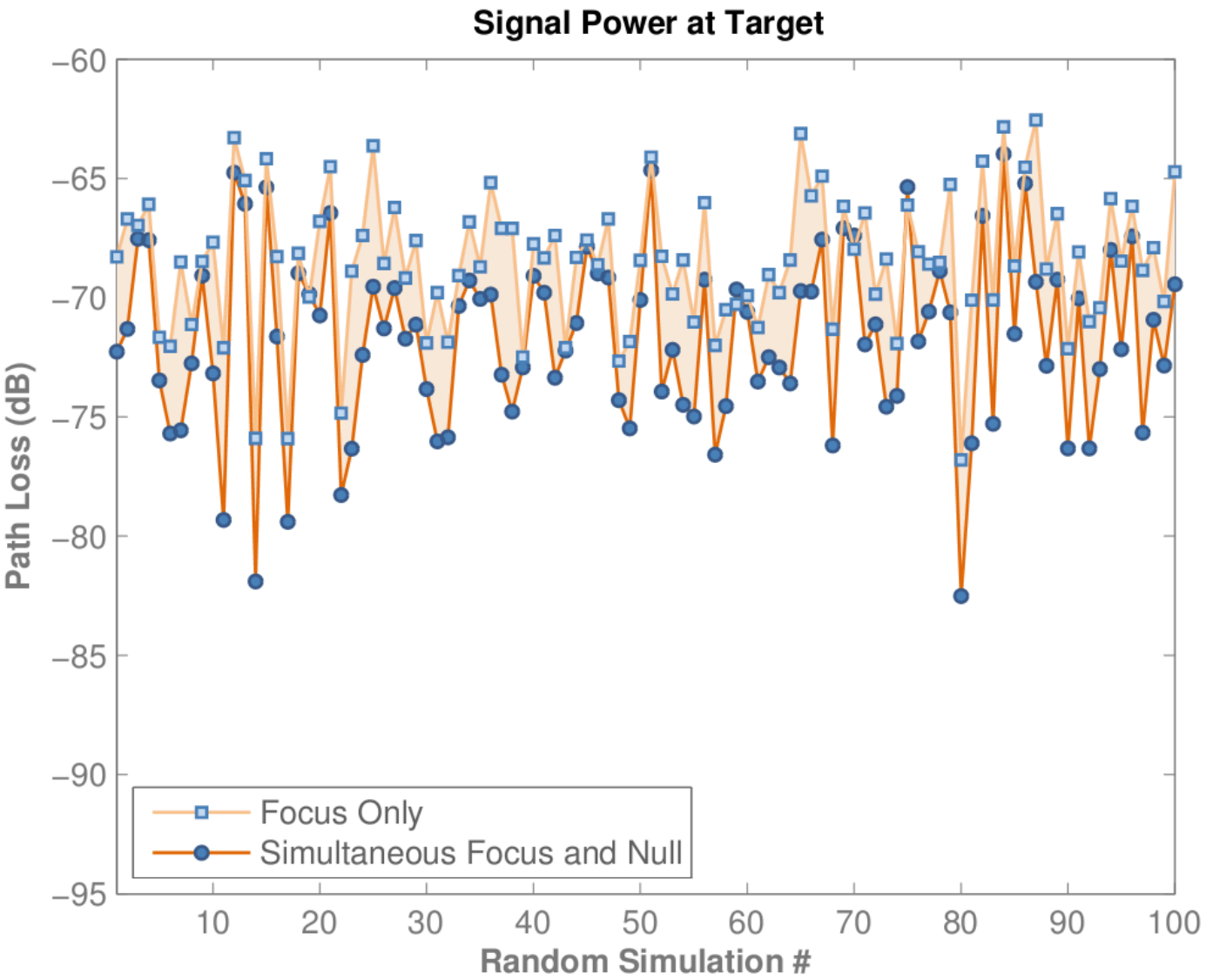
60
70
80
90
100
Random Simulation #
Focus Only
Simultaneous Focus and Null

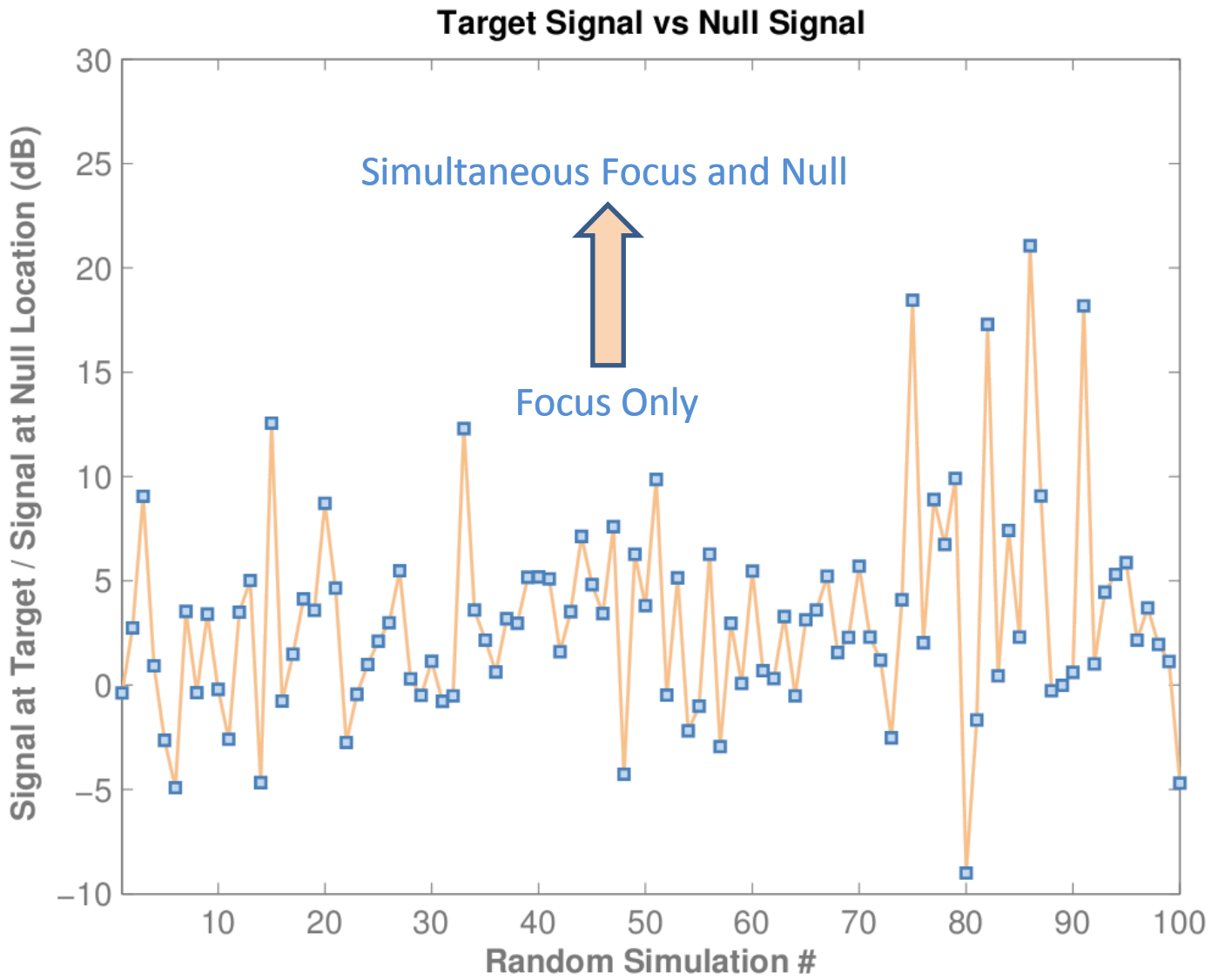
Cost


Signal Power at Target
Path Loss (dB)
−60
−65
−70
−75
−80
−85
−90
−95
10
20
30
40
50
60
70
80
90
100
Random Simulation #
Focus Only
Simultaneous Focus and Null

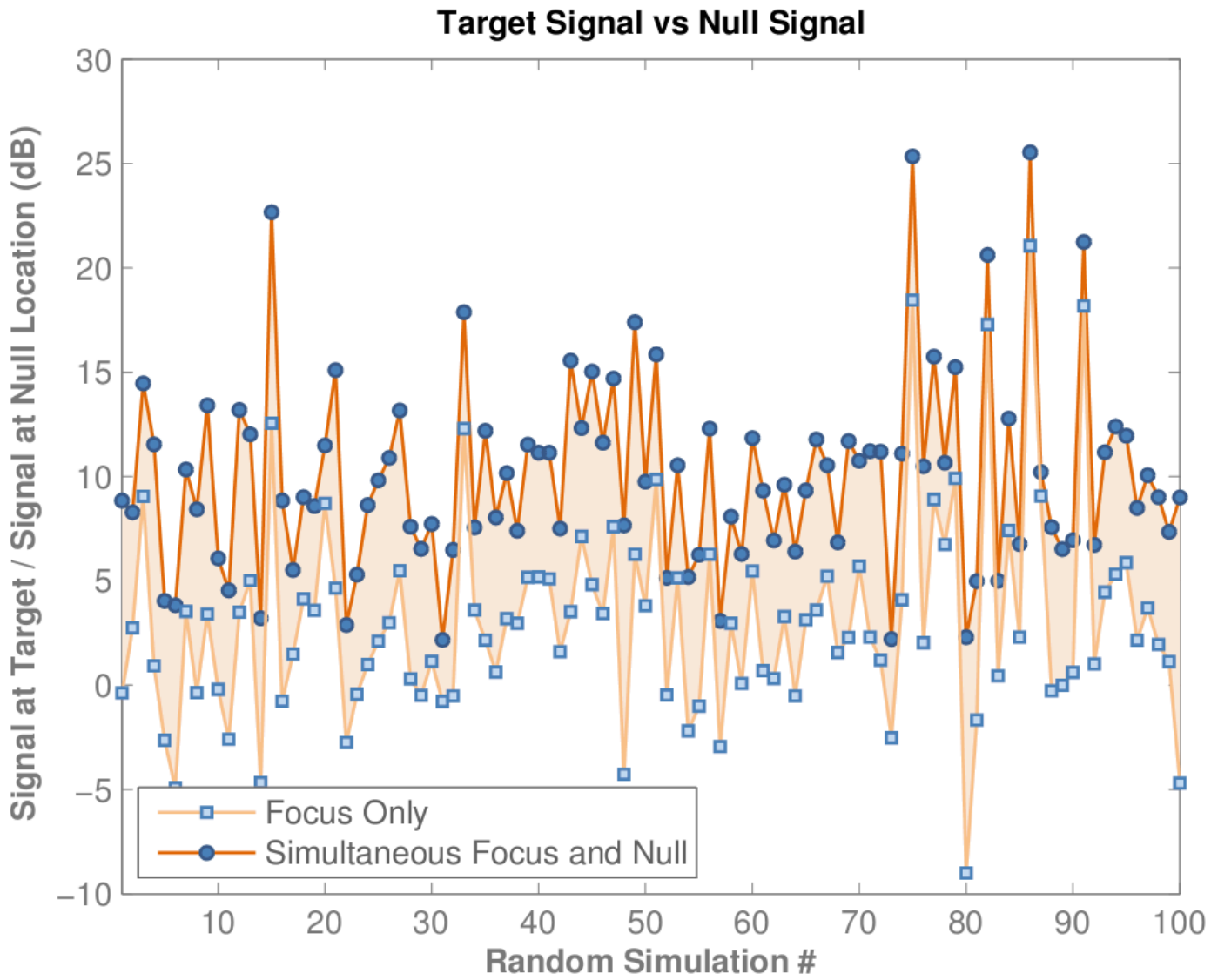
Cost


Signal Power at Target
Path Loss (dB)
−60
−65
−70
−75
−80
−85
−90
−95
10
20
30
40
50
60
70
80
90
100
Random Simulation #
Focus Only
Simultaneous Focus and Null

Target/Null


Target Signal vs Null Signal
Simultaneous Focus and Null
Focus Only
Signal at Target / Signal at Null Location (dB)
Random Simulation #
30
25
20
15
10
5
0
−5
−10
10
20
30
40
50
60
70
80
90
100

Target/Null


Target Signal vs Null Signal
Signal at Target / Signal at Null Location (dB)
Random Simulation #
Focus Only
Simultaneous Focus and Null
30
25
20
15
10
5
0
−5
−10
10
20
30
40
50
60
70
80
90
100

Experimental Results

Summary

- Radio signals can be focused at one location and nulled at a different location using time-reversal.
  - Does not need knowledge of detailed channel to null location.

- Other effects
  - number of antennas
  - bandwidth