PLatter: On the Feasibility of Building-scale Power Line Backscatter

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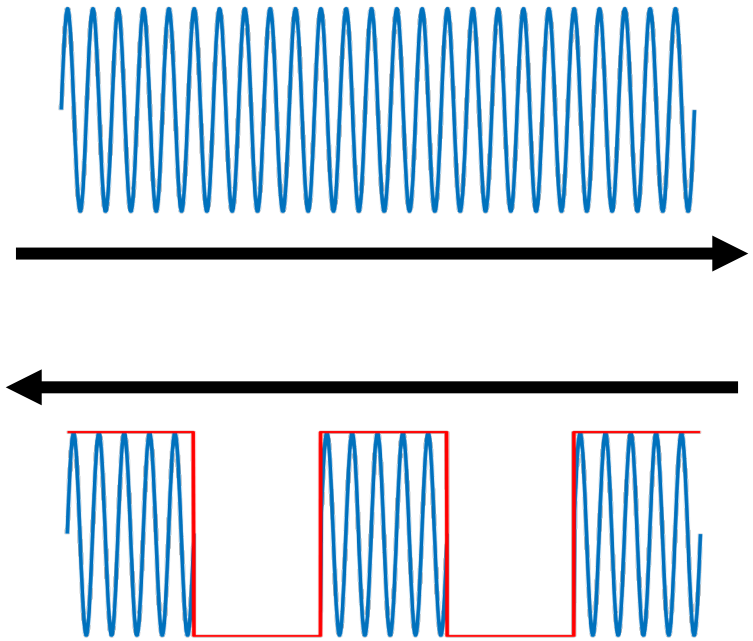
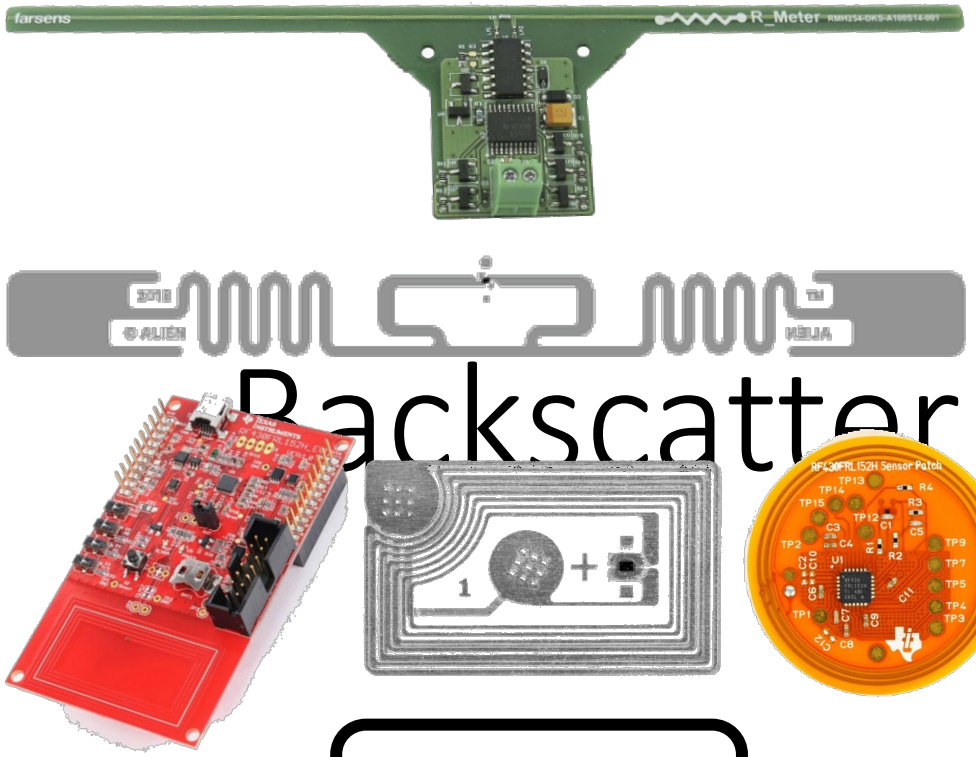
Carnegie Mellon University

Electrical & Computer ENGINEERING

WiTech





Backscatter

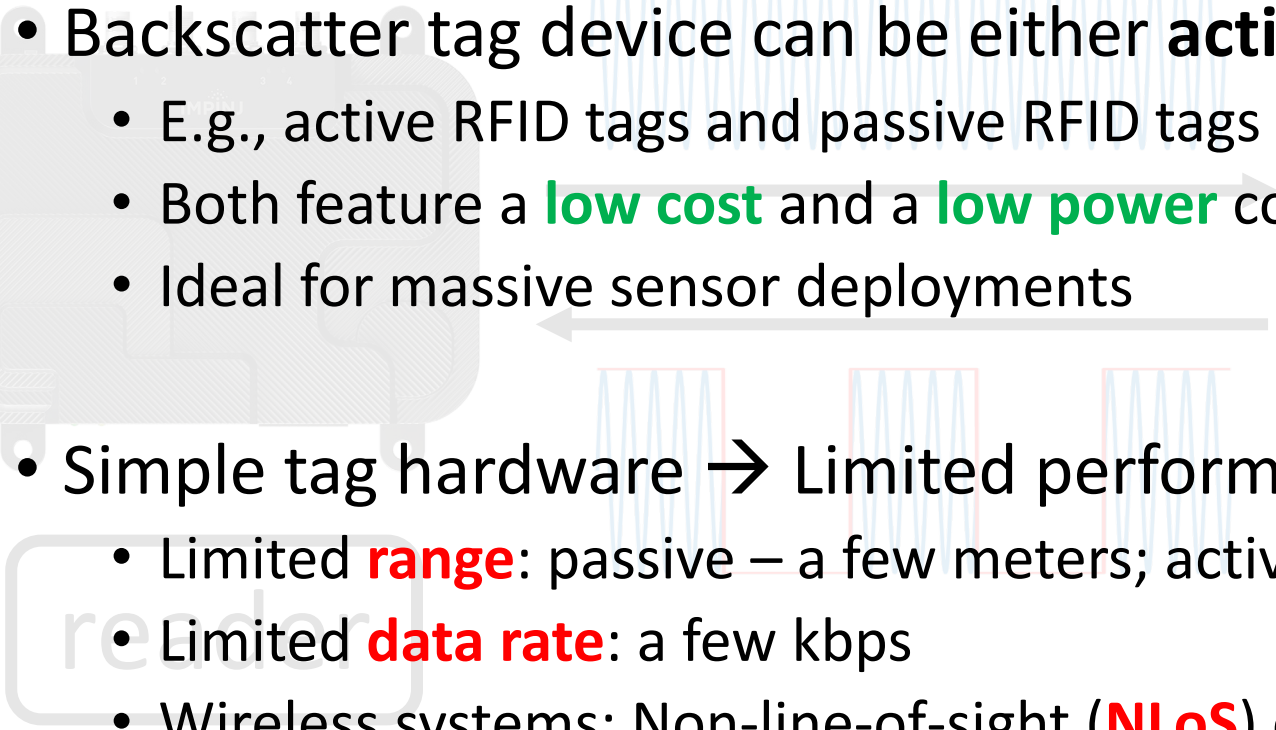
reader

tag

Device picture sources:
https://www.atlasrfidstore.com/impinj-r700-RAIN-rfid-reader/
http://www.farsens.com/en/products/rmeter-ma10/
https://www.atlasrfidstore.com/alien-squiggle-rfid-white-wet-inlay-aln-9940-higgs-9/
https://www.ti.com/tool/RF430FRL152HEVM
https://www.atlasrfidstore.com/smartrac-midas-nfc-wet-inlay-nxp-ntag213/
https://www.ti.com/tool/TIDM-RF430-TEMPSENSE

Backscatter

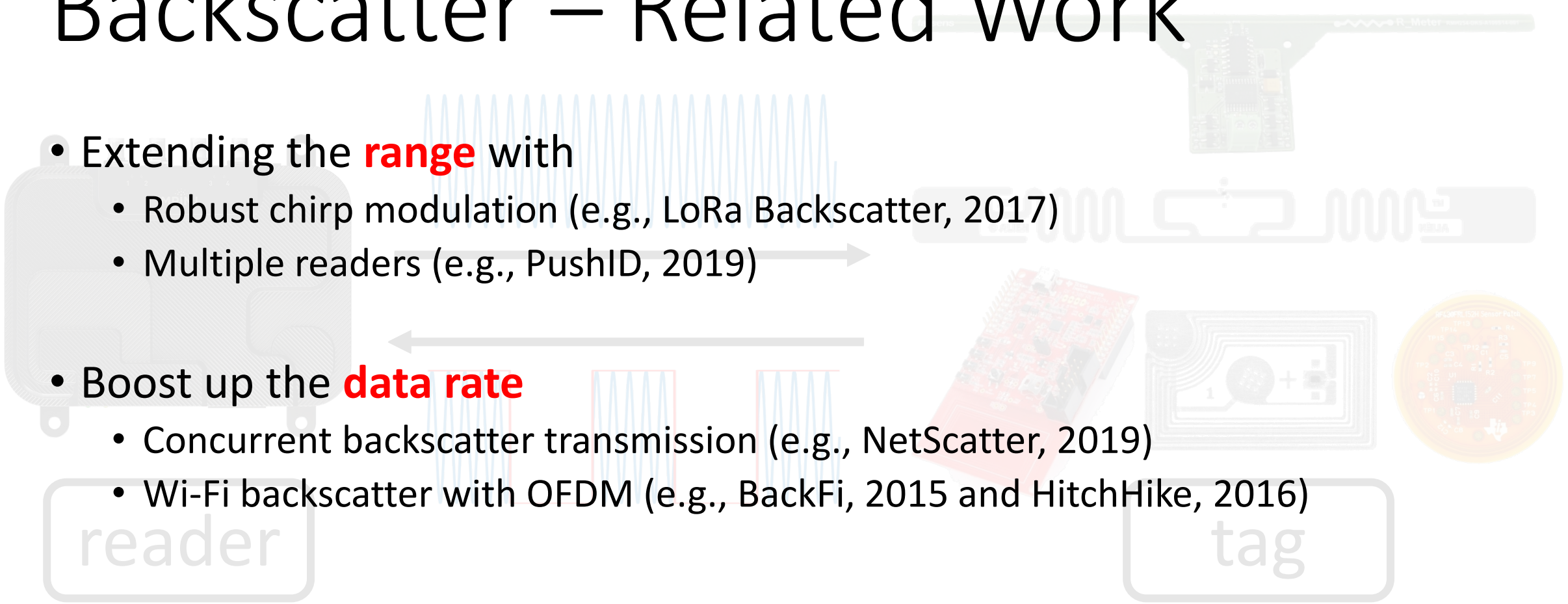
- Backscatter tag device can be either **active** or **battery-free**
  - E.g., active RFID tags and passive RFID tags
  - Both feature a **low cost** and a **low power** consumption
  - Ideal for massive sensor deployments



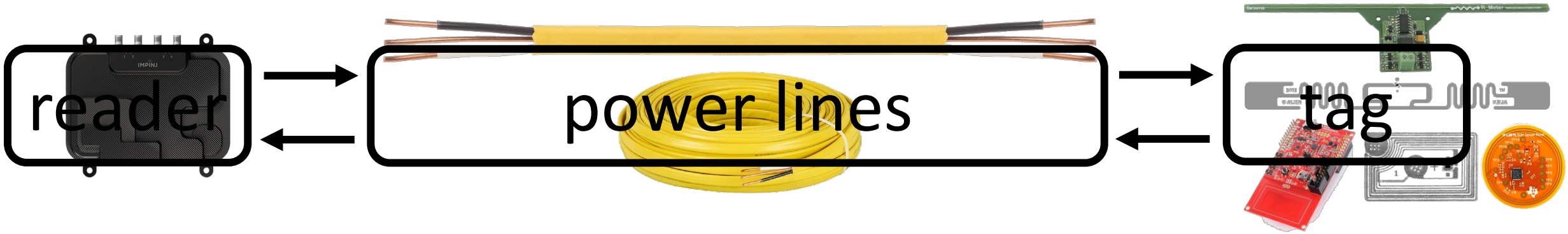
- Simple tag hardware → Limited performance
  - Limited **range**: passive – a few meters; active – a few tens of meters
  - Limited **data rate**: a few kbps
  - Wireless systems: Non-line-of-sight (**NLoS**) challenges

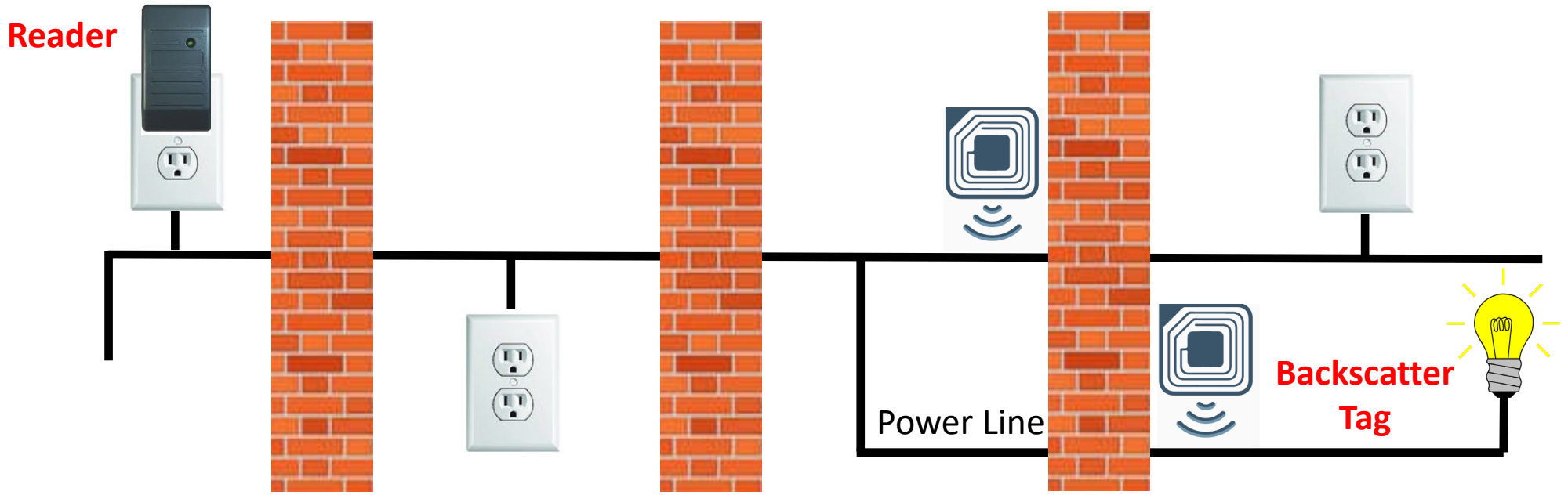
Backscatter – Related Work

- Extending the **range** with
  - Robust chirp modulation (e.g., LoRa Backscatter, 2017)
  - Multiple readers (e.g., PushID, 2019)
- Boost up the **data rate**
  - Concurrent backscatter transmission (e.g., NetScatter, 2019)
  - Wi-Fi backscatter with OFDM (e.g., BackFi, 2015 and HitchHike, 2016)



PLatter – Power Line Backscatter





PLatter – Power Line Backscatter

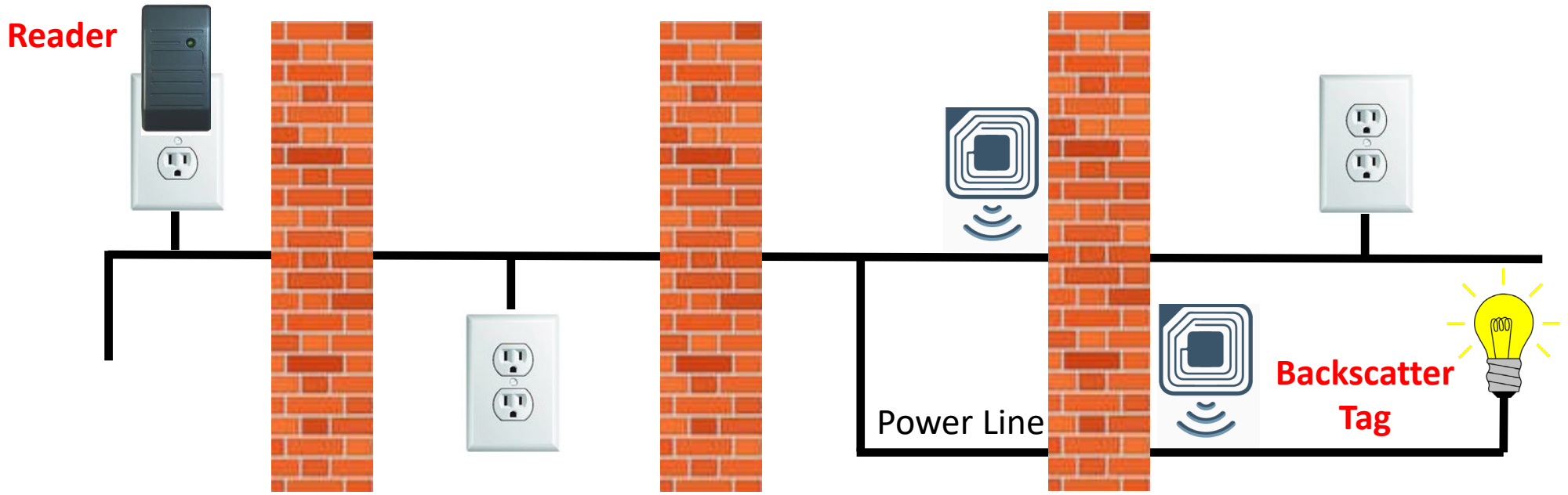
Such a design features:

- Indoors/NLoS applications
- Building-scale communication with existing infrastructure

Our prototype system shows:

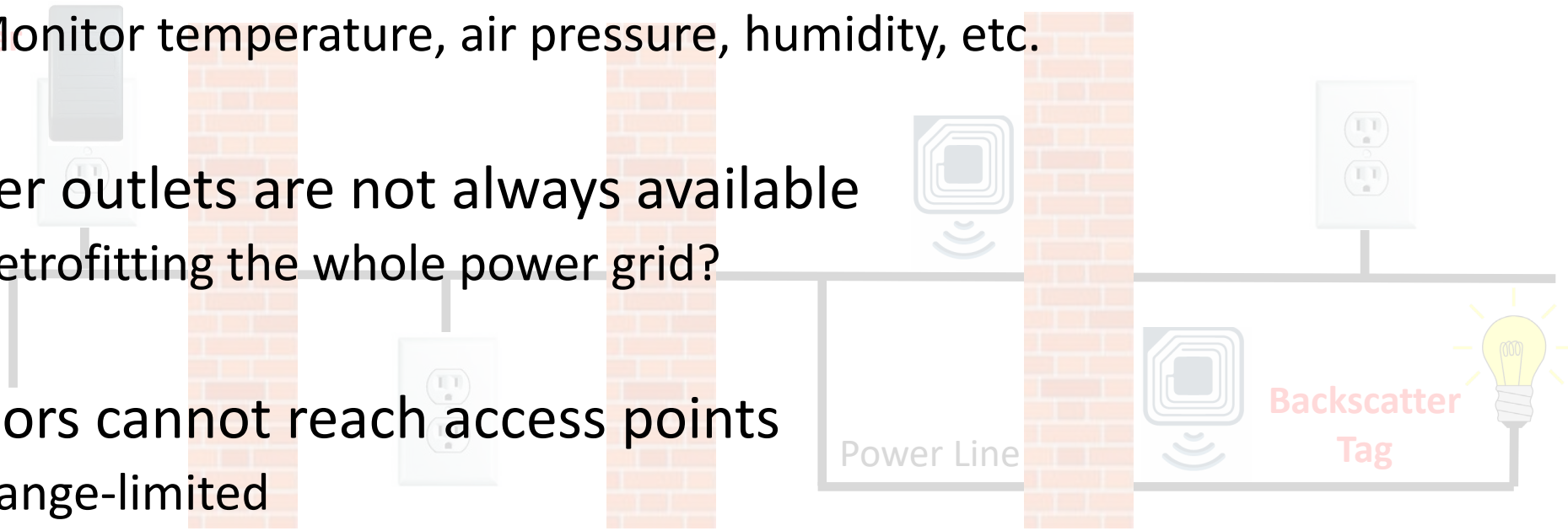
- Up to 300-ft (~91 m) range
- Up to 4 Mbps data rate

We choose **13.56 MHz** as our operating frequency



How Does PLatter Work?

- As an industrial manager, you want to improve your factory…
  - Monitor temperature, air pressure, humidity, etc.
- Power outlets are not always available
  - Retrofitting the whole power grid?
- Sensors cannot reach access points
  - Range-limited



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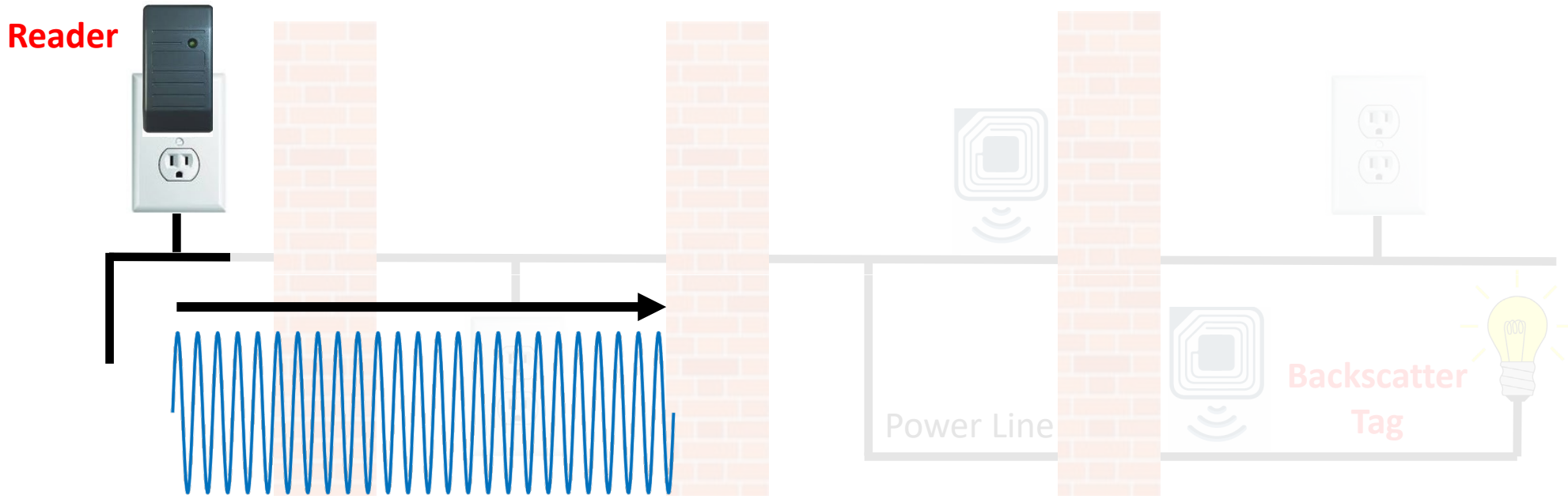
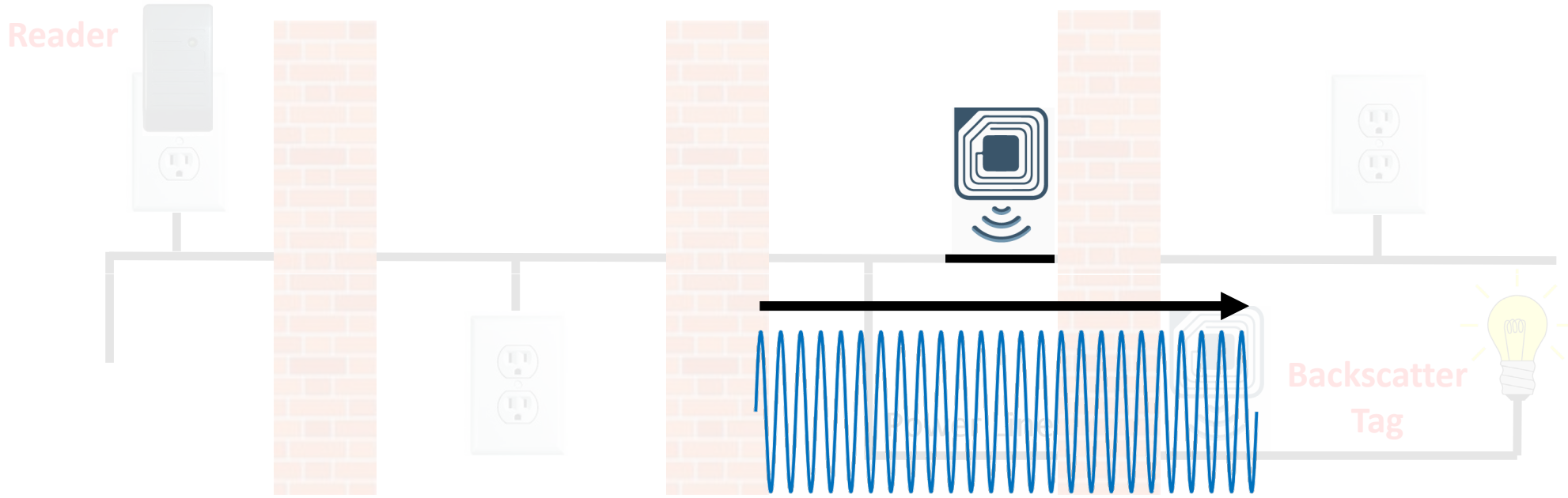


How Does PLatter Work?



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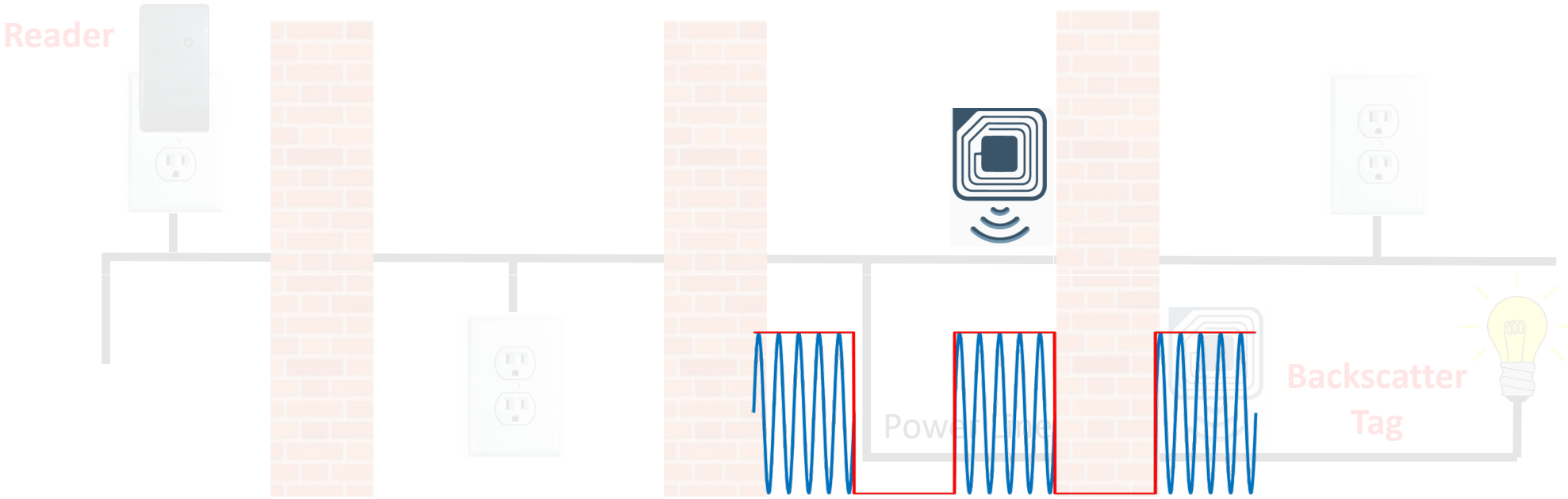

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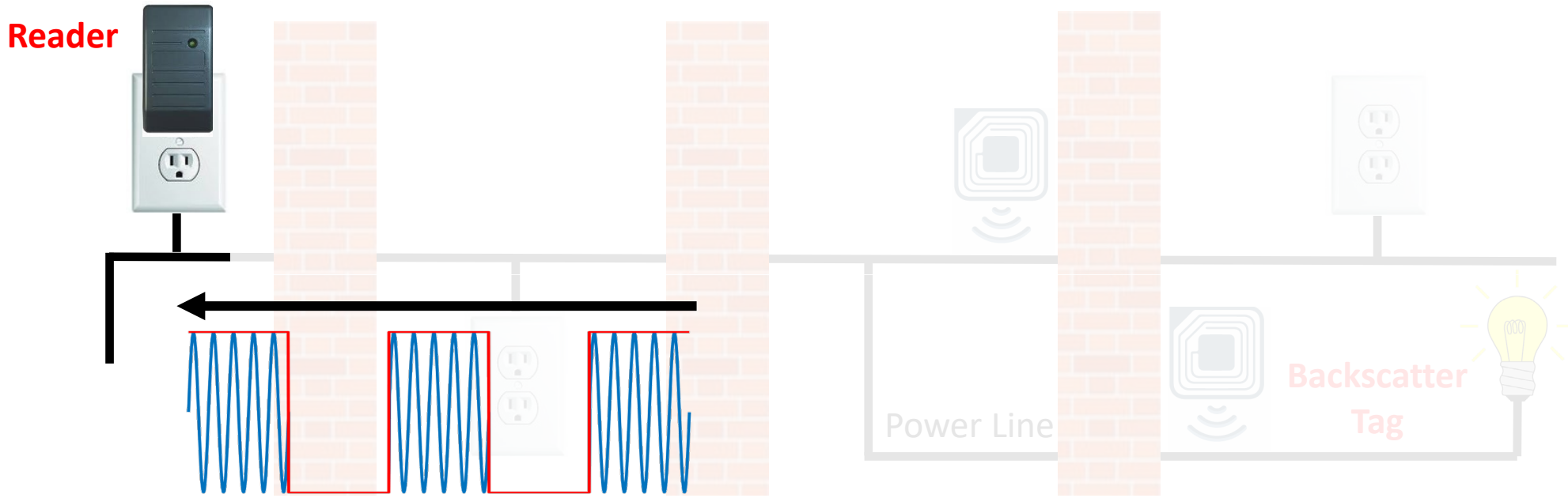

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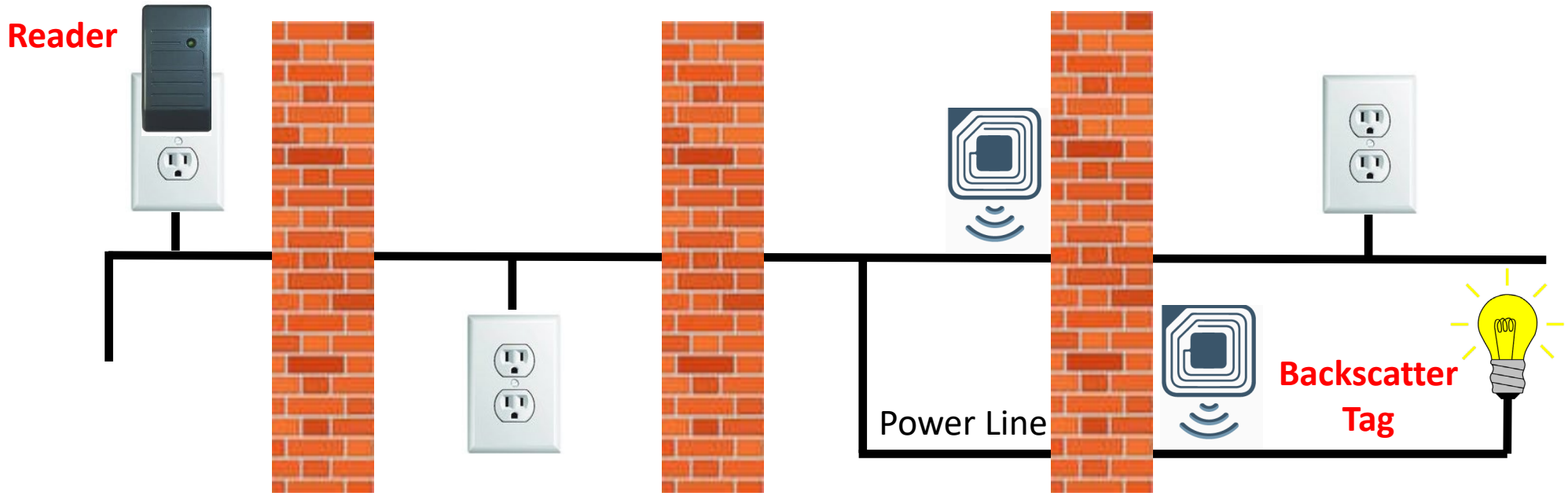
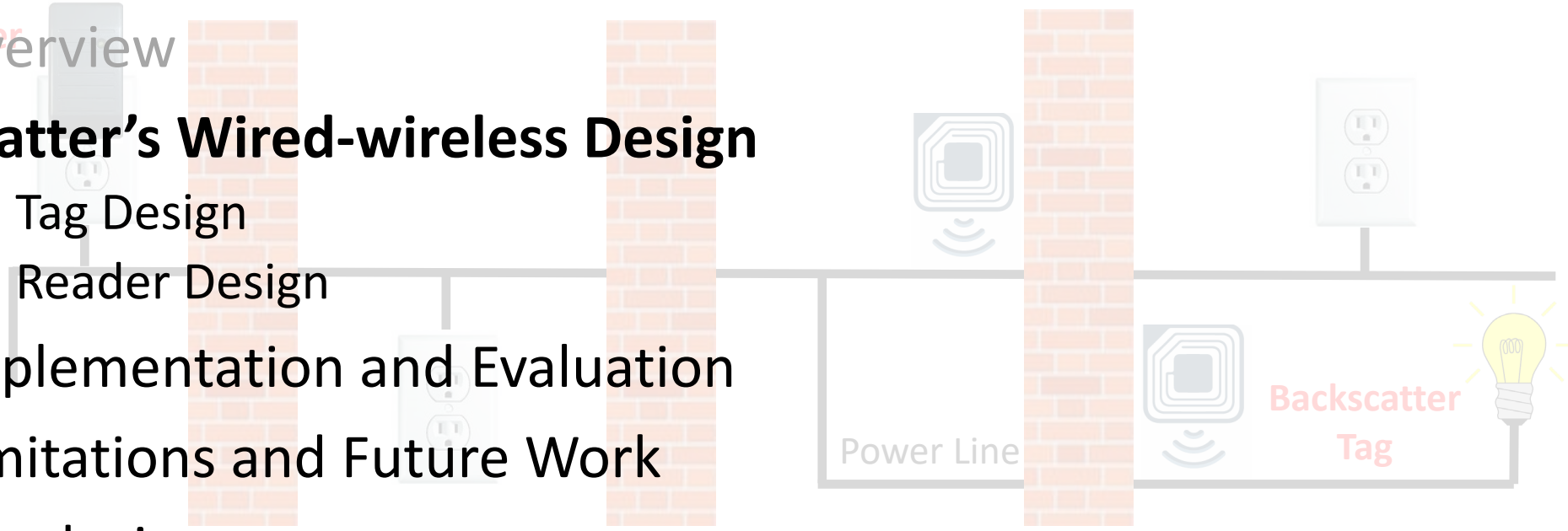
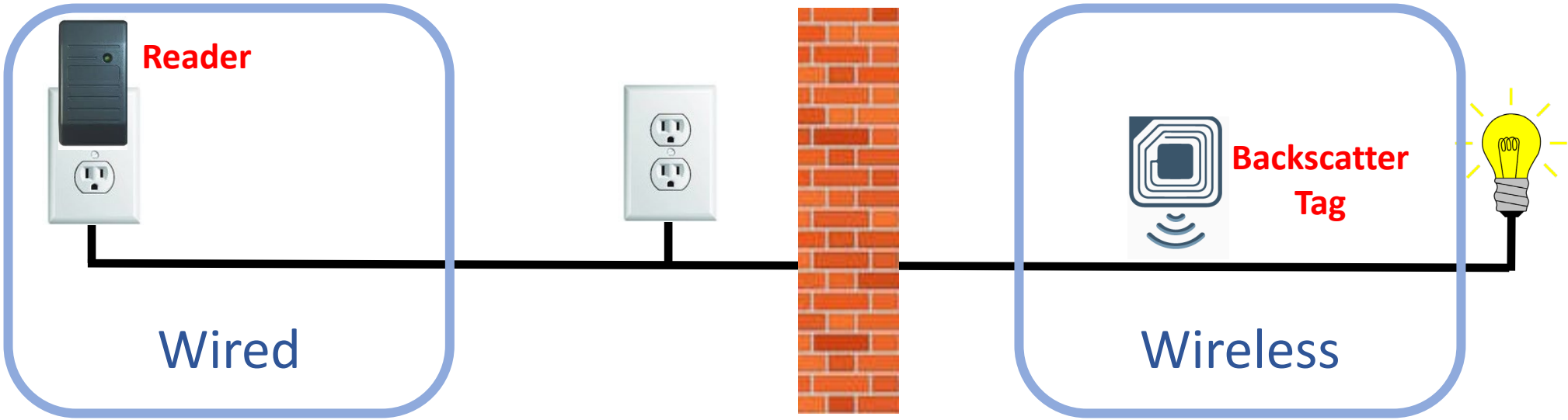


Content

1. Introduction and Related Work
2. Overview
3. **PLatter's Wired-wireless Design**
    1. Tag Design
    2. Reader Design
4. Implementation and Evaluation
5. Limitations and Future Work
6. Conclusion



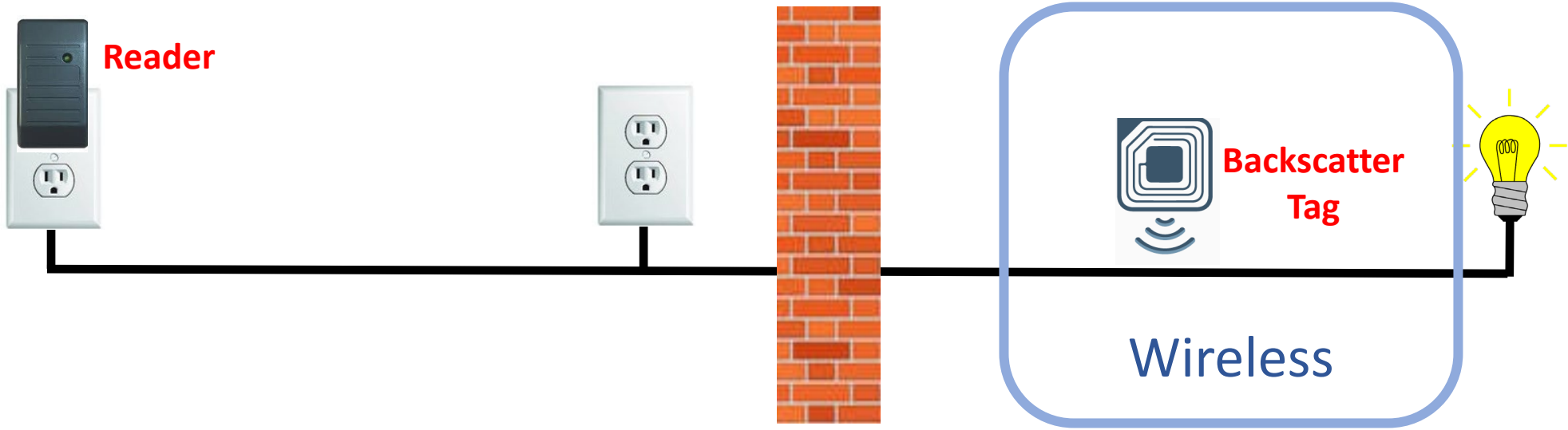
PLatter's Wired-wireless Design



PLatter's reader design

PLatter's tag design

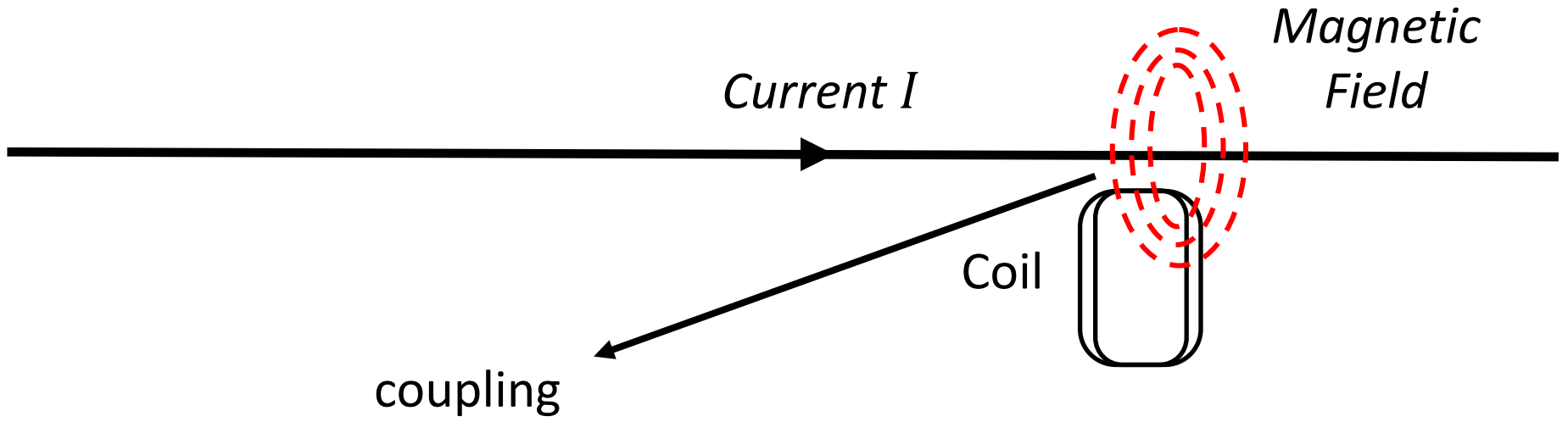
Tag Design



Power lines are wire conductors

PLatter's tag design

How does the tag backscatter?



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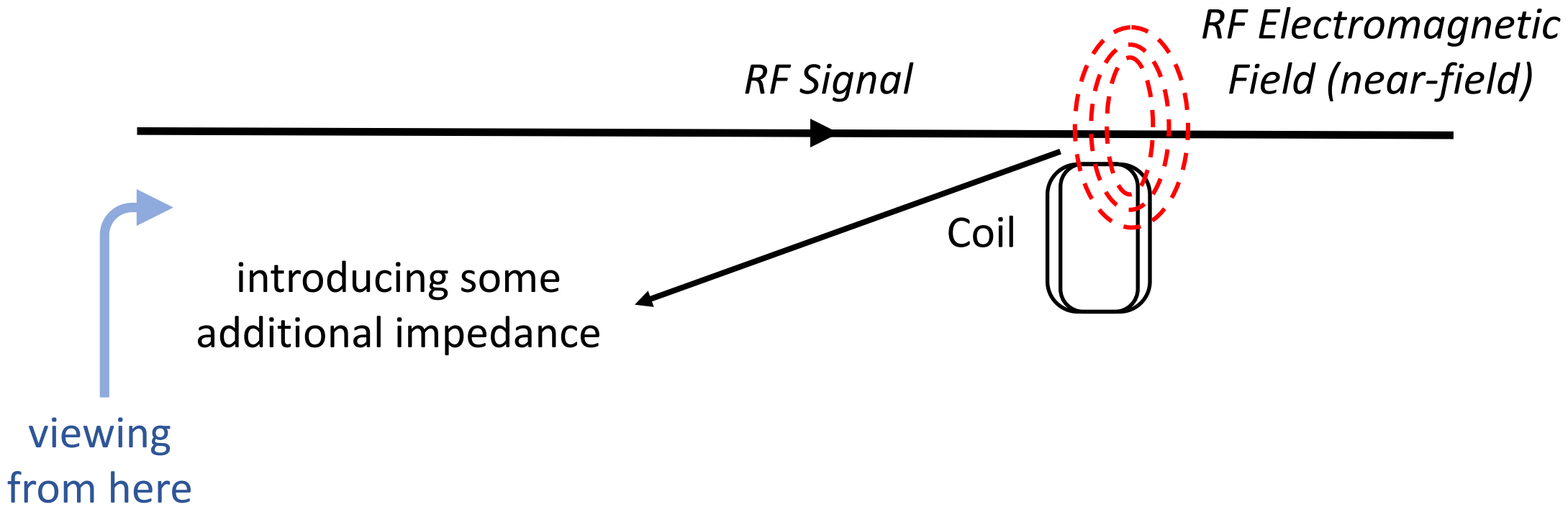

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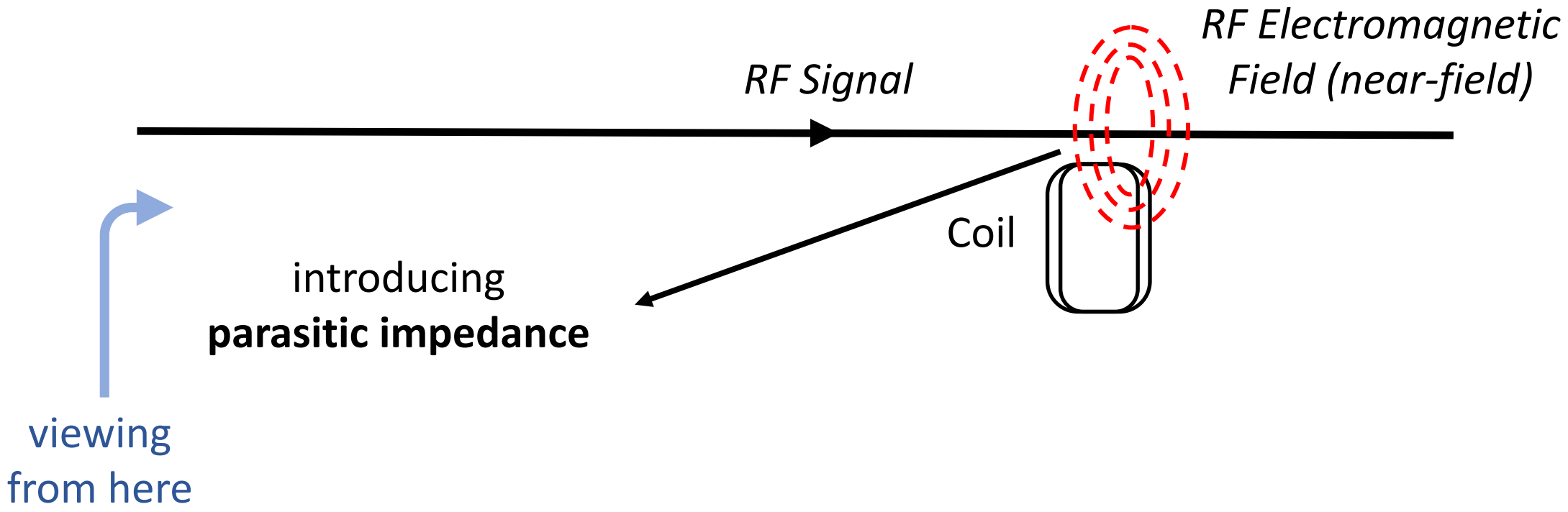

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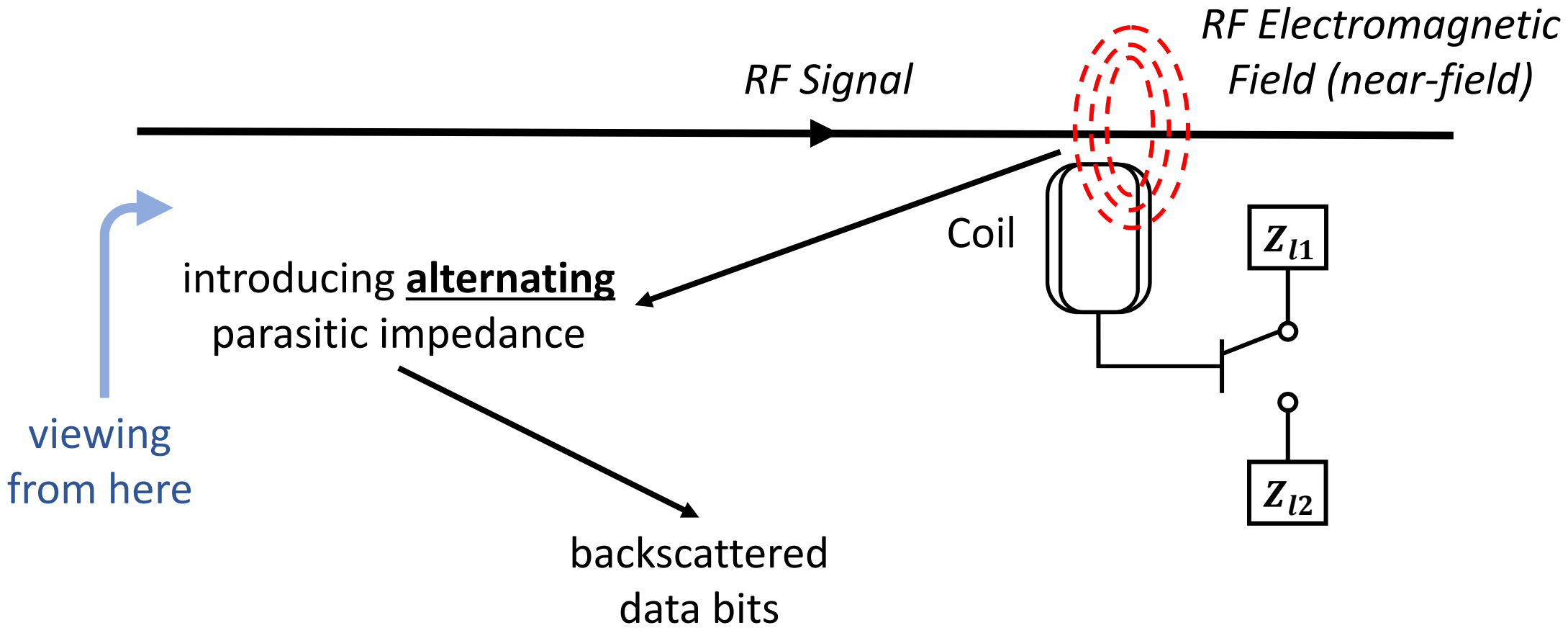
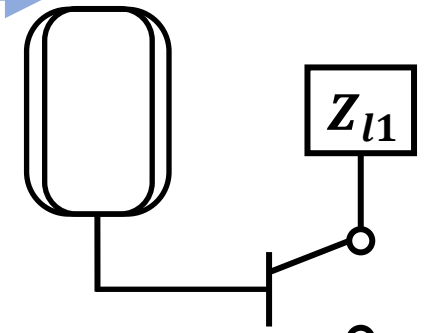


Preliminary Study with VNA

VNA measures the impedance of the power line

100-ft NM-B 14/2 cable

8 cm distance

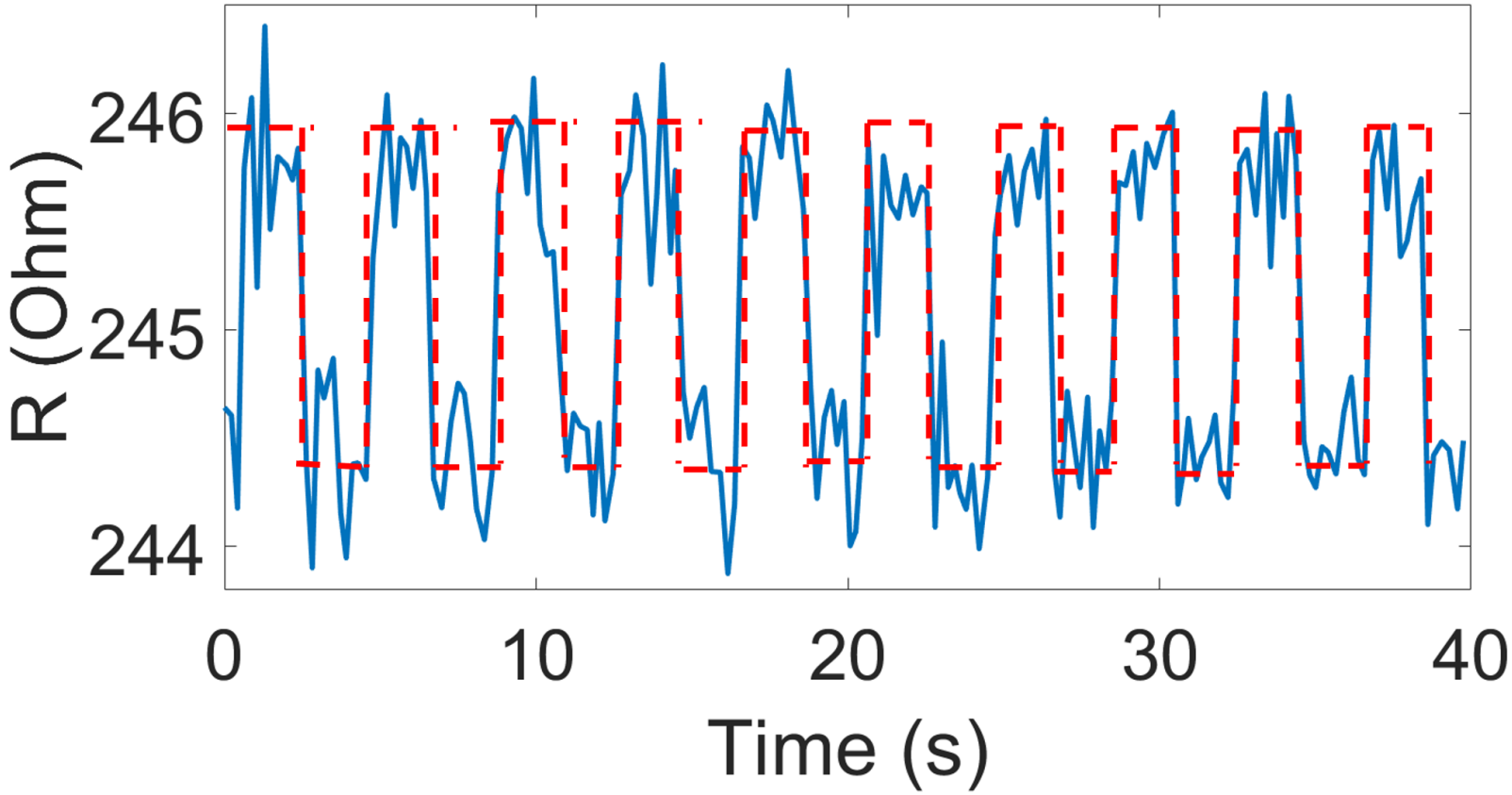


simple coil antenna toggling between two loads

standard “open” cap as termination

Device picture sources:
https://www.keysight.com/us/en/product/N9916A/fieldfox-a-handheld-microwave-analyzer-14-ghz.html
https://www.amazon.com/gp/product/B07DGMW7YS/ref=ox_sc_act_title_1?smid=A2VJNLBJK43X0O&psc=1

Preliminary Study with VNA



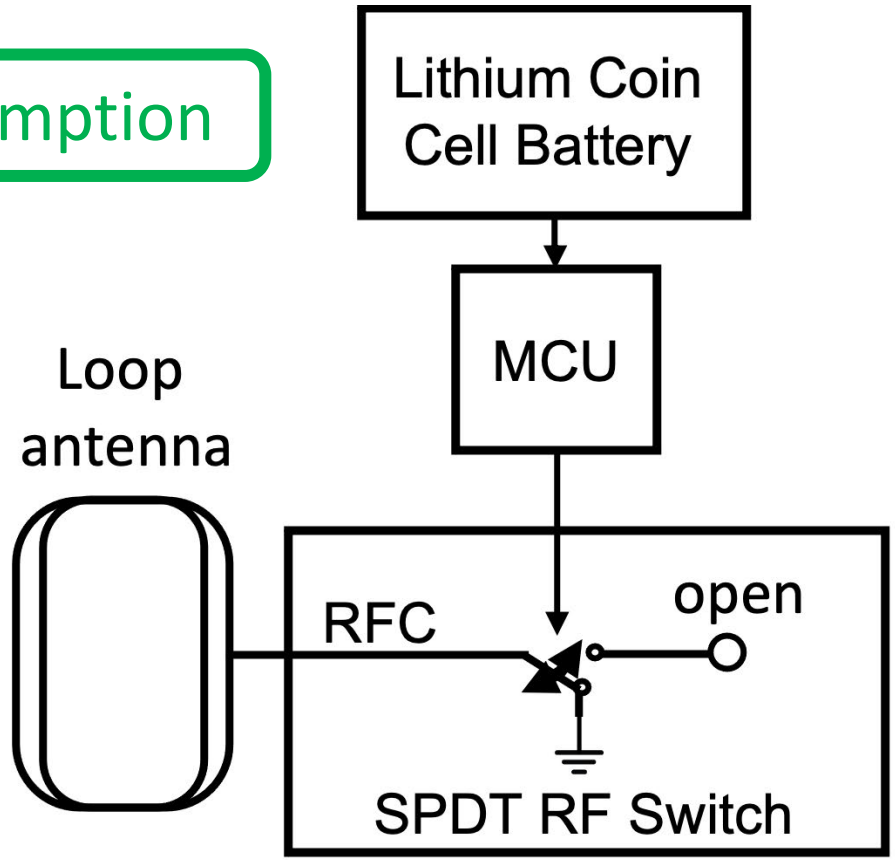
We use ***Parasitic Impedance Amplitude Modulation*** to enable a **uni-directional communication** from the tag to the reader.

PLatter's Tag Design

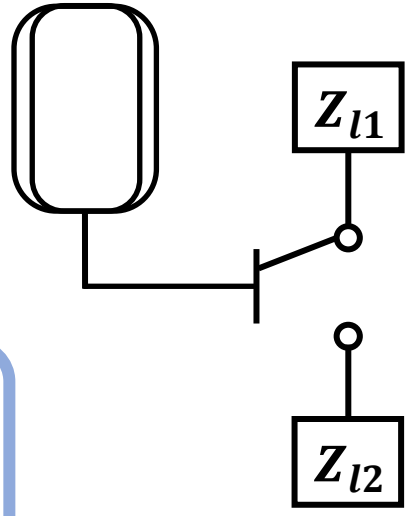
4.95 μW power consumption

More design details in paper!

- Channel coding
- Power calculation
- …

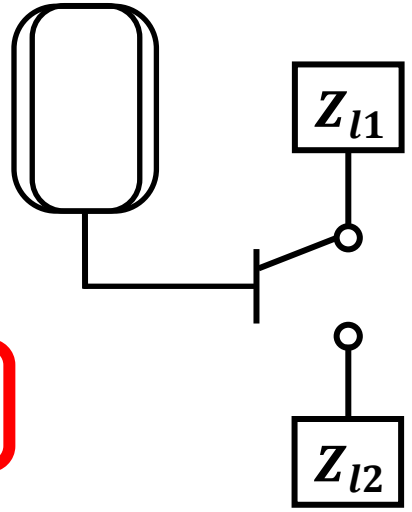


One Question Remaining



How to guarantee that the RF carrier signal can successfully enter the power lines?

One Question Remaining



Impedance Mismatch!

Impedance Mismatch

Radio-frequency Signal

50/60 Hz AC Signal

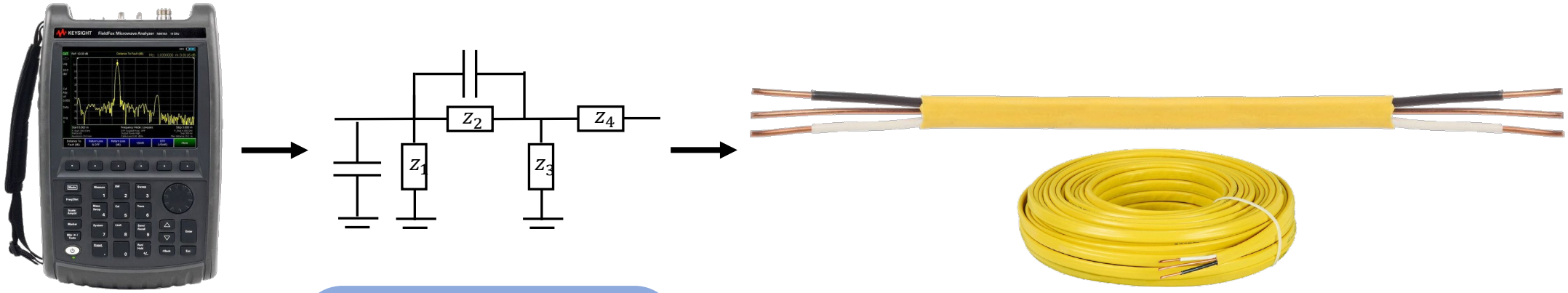
Cable picture sources:
https://www.grainger.com/product/ROMEX-Nonmetallic-Building-Cable-4WZT5
https://www.amazon.com/gp/product/B07FC8PVZS/ref=ox_sc_act_title_1?smid=A1TE63QTMAEOQO&th=1

Impedance Mismatch

RF Signal

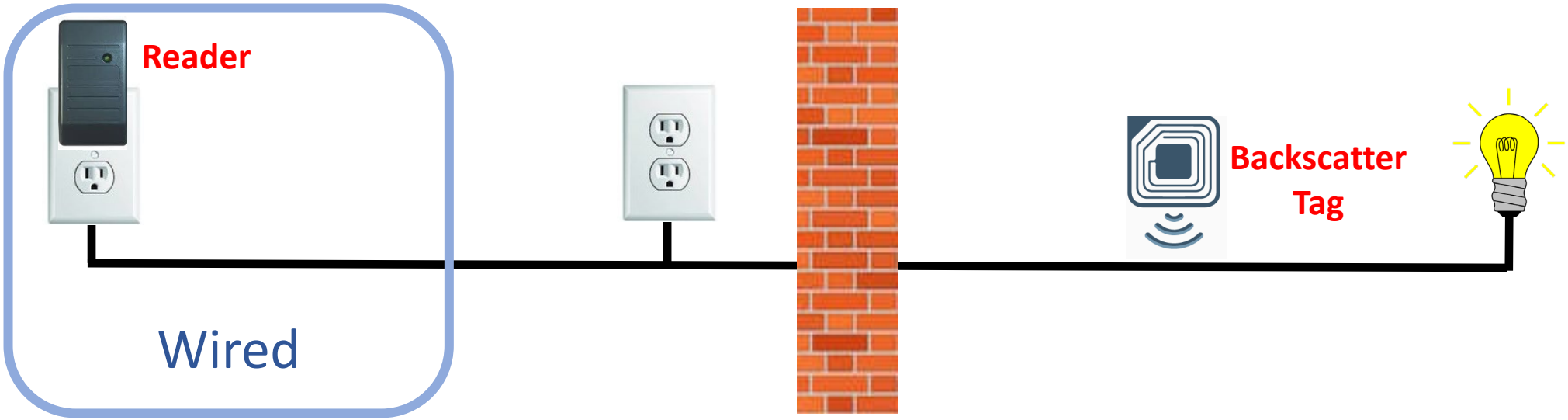
huge reflection at the reader-cable interface

Impedance Mismatch

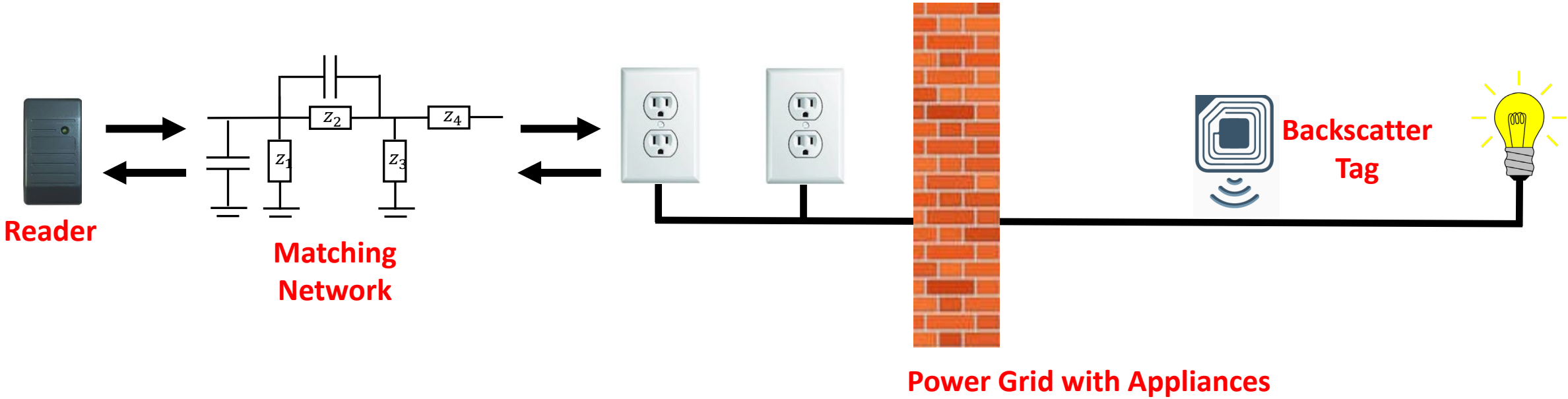


impedance matching network

PLatter's Wired-wireless Design

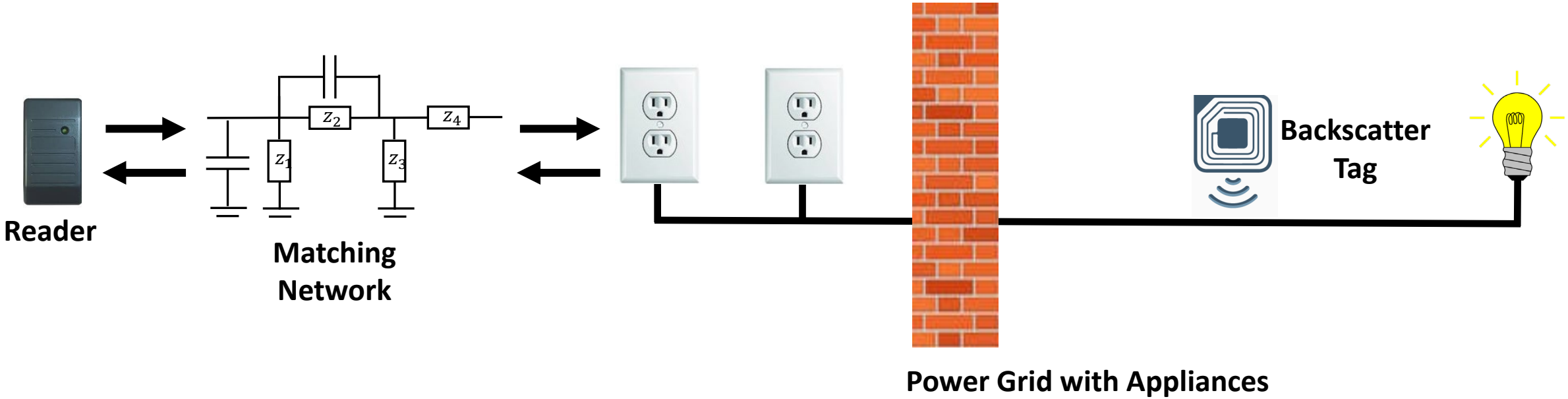


Reader Design



As long as the impedance of the power grid remains the same, our system works perfectly fine.

Reader Design



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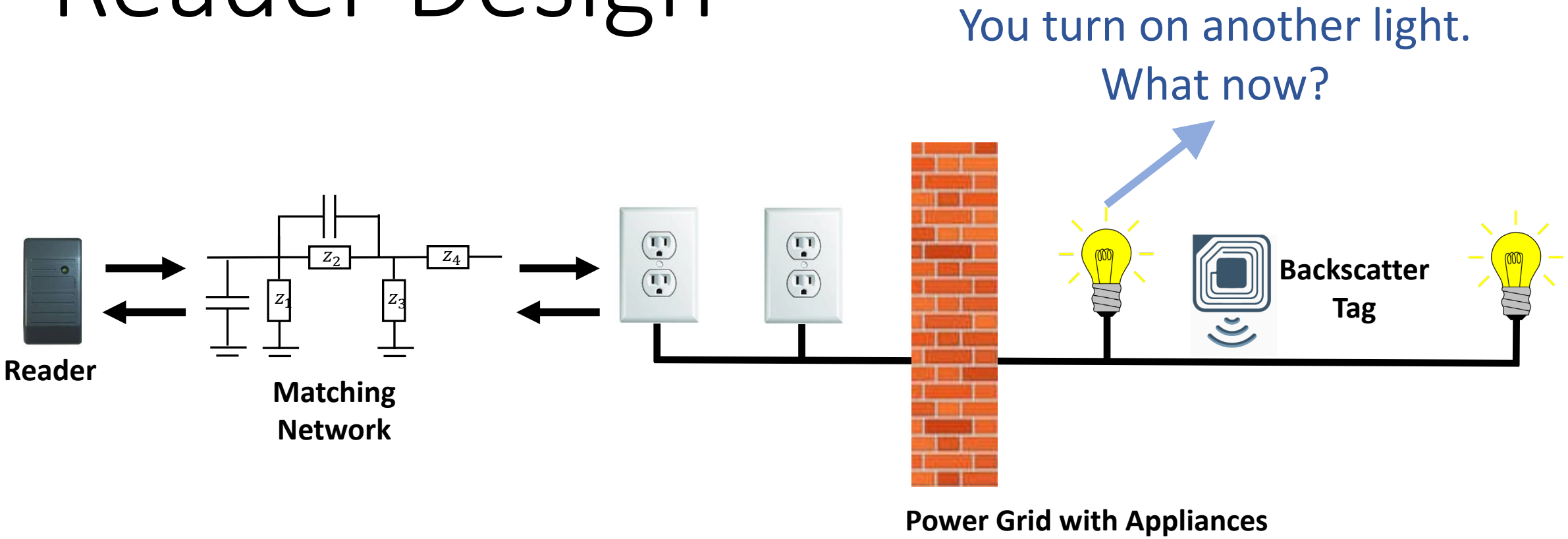

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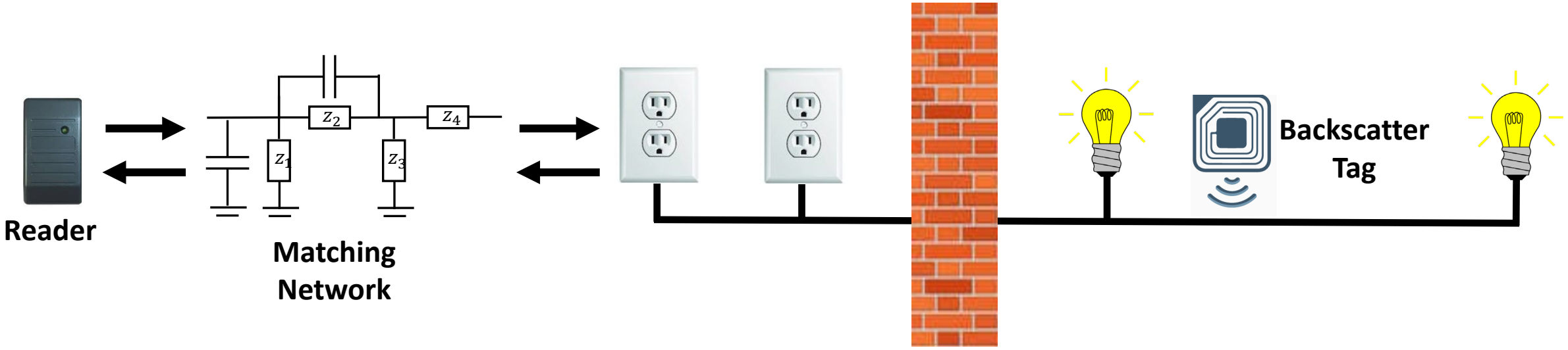
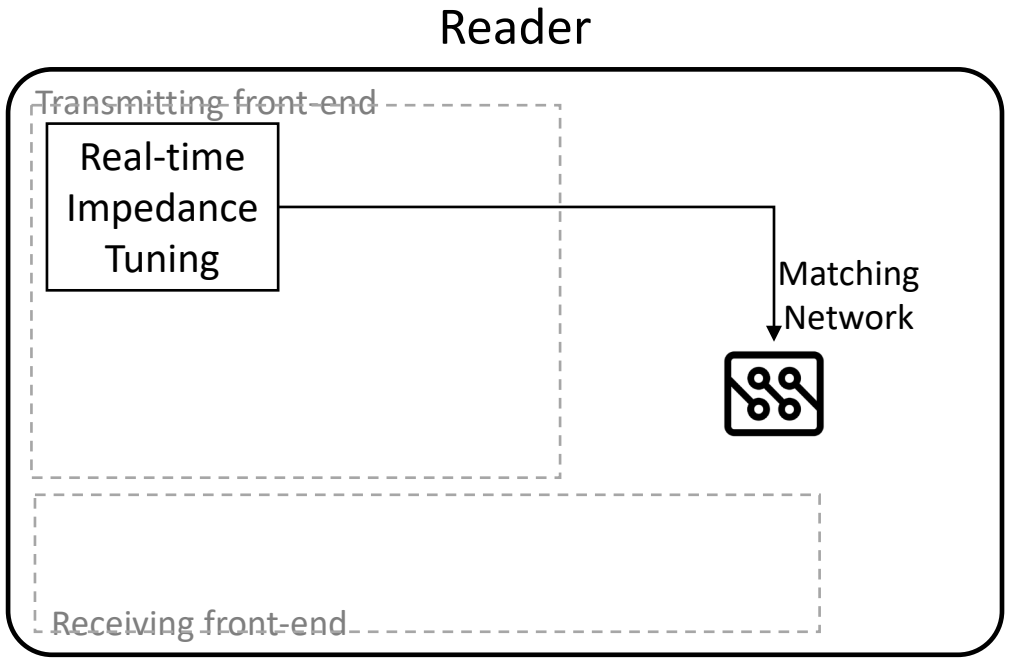
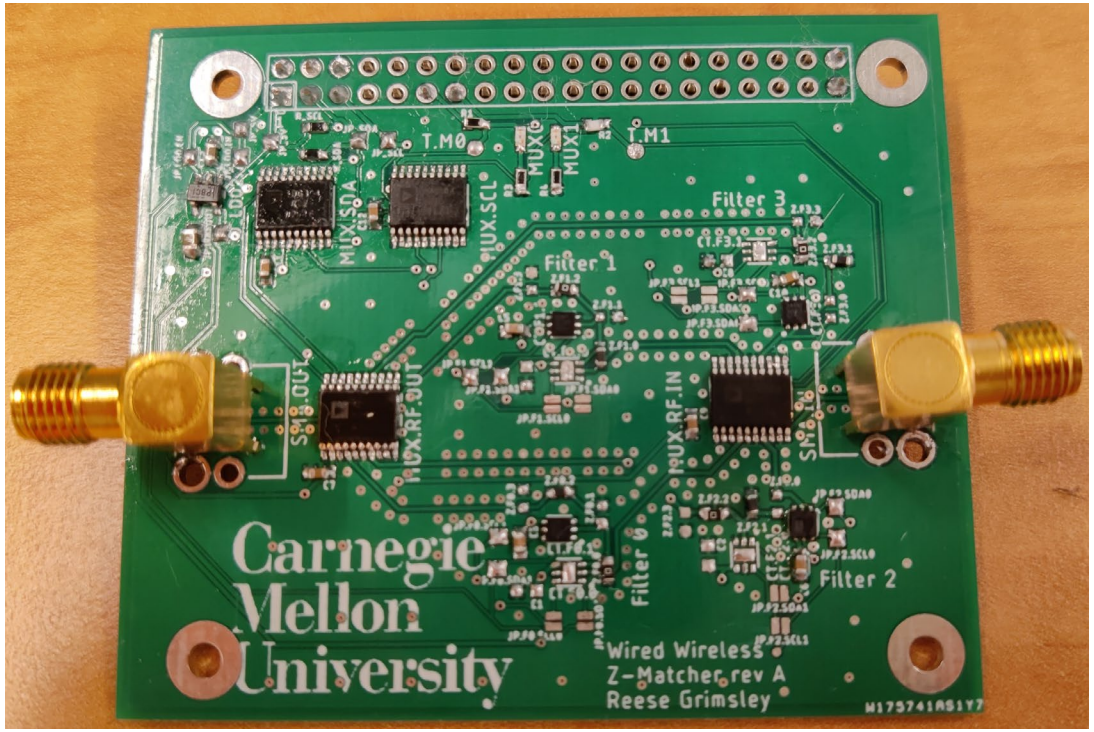


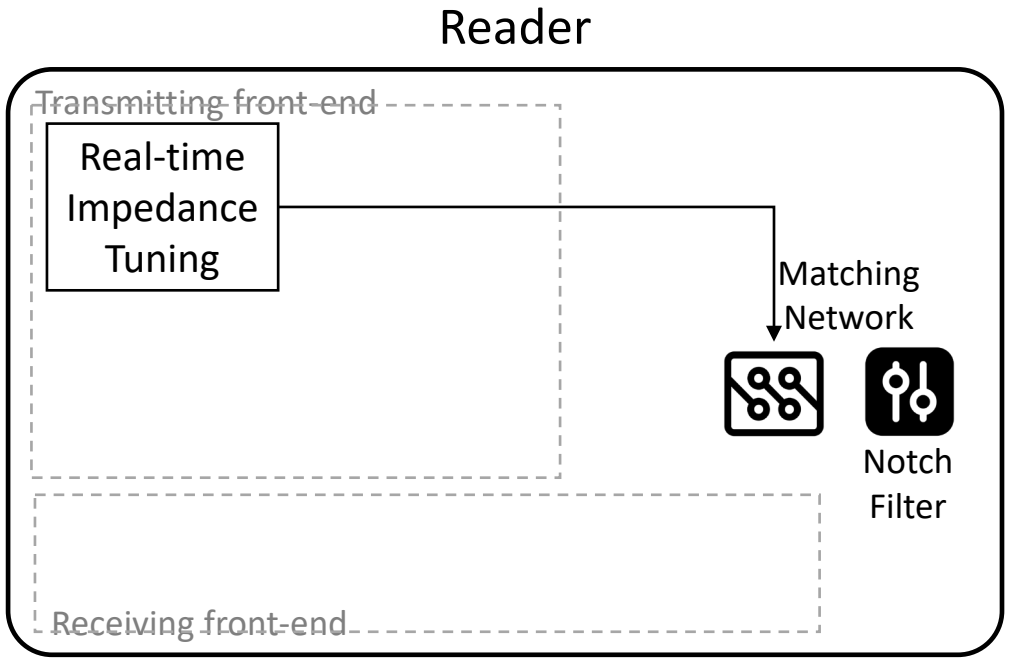
The impedance is time-varying!

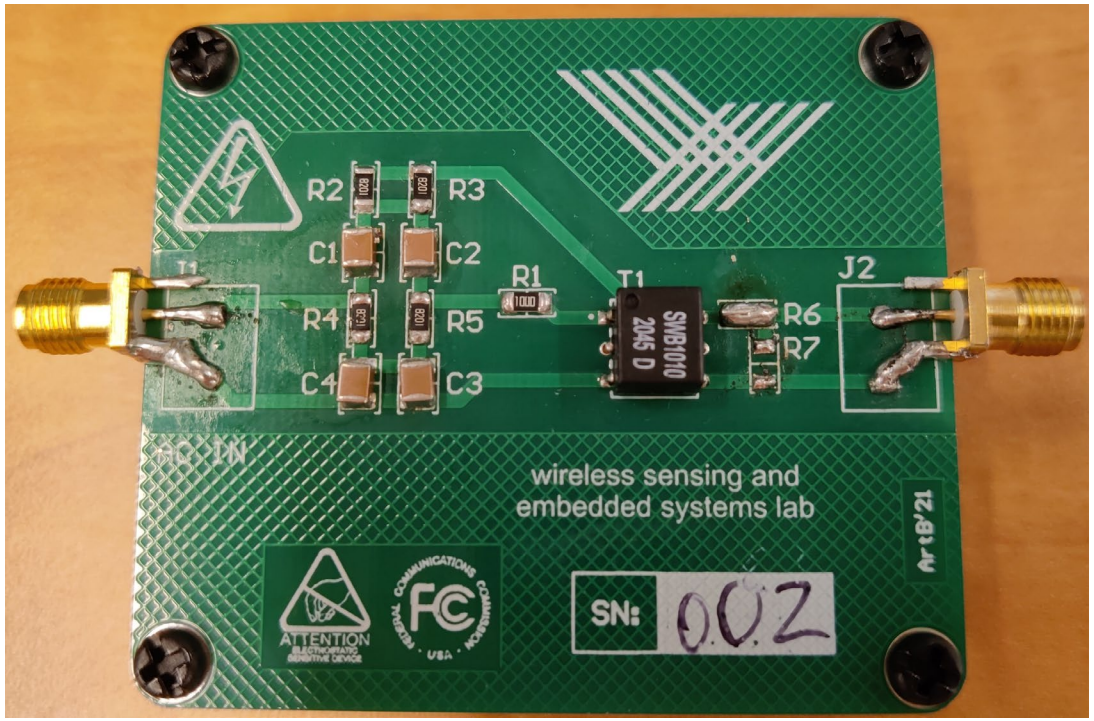




Intelligent reader design: Real-time impedance tuning

PLatter's four-channel tunable network can match a wide range of possible impedance we encounter in practice

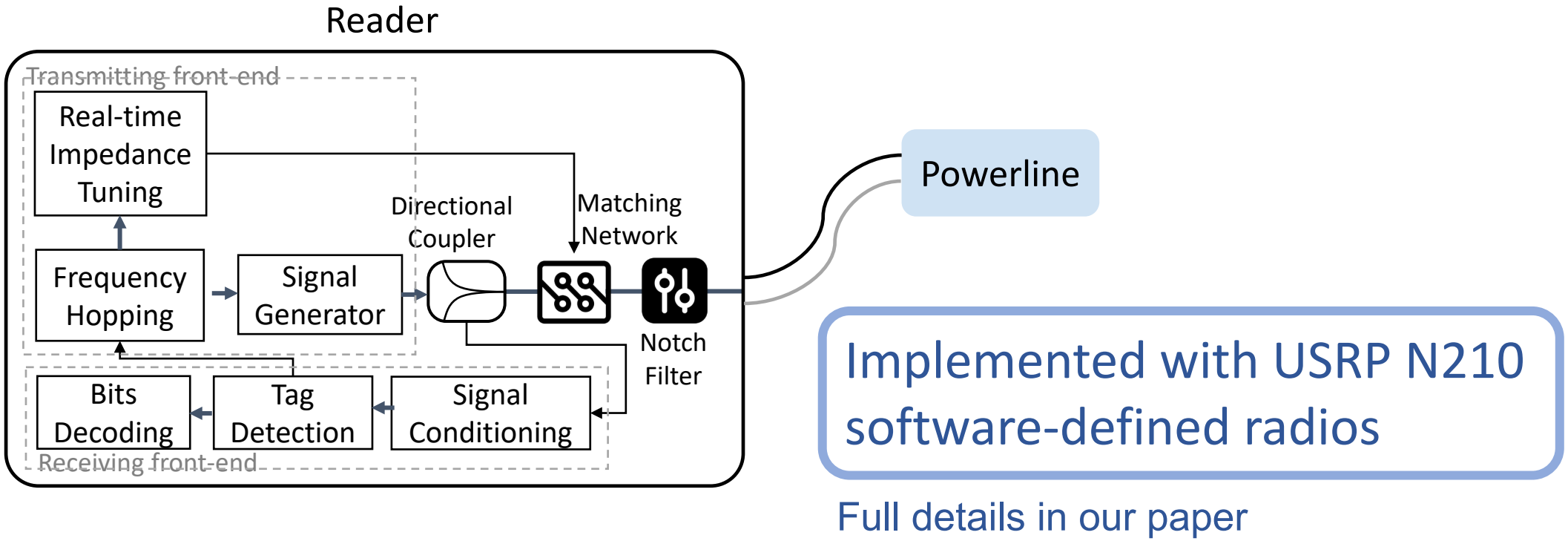




Other essential blocks:
60 Hz notch filter, etc.

Eliminating the 60 Hz AC signal so that our reader (and myself) is not burnt

PLatter's Reader Design



Implemented with USRP N210 software-defined radios

Full details in our paper

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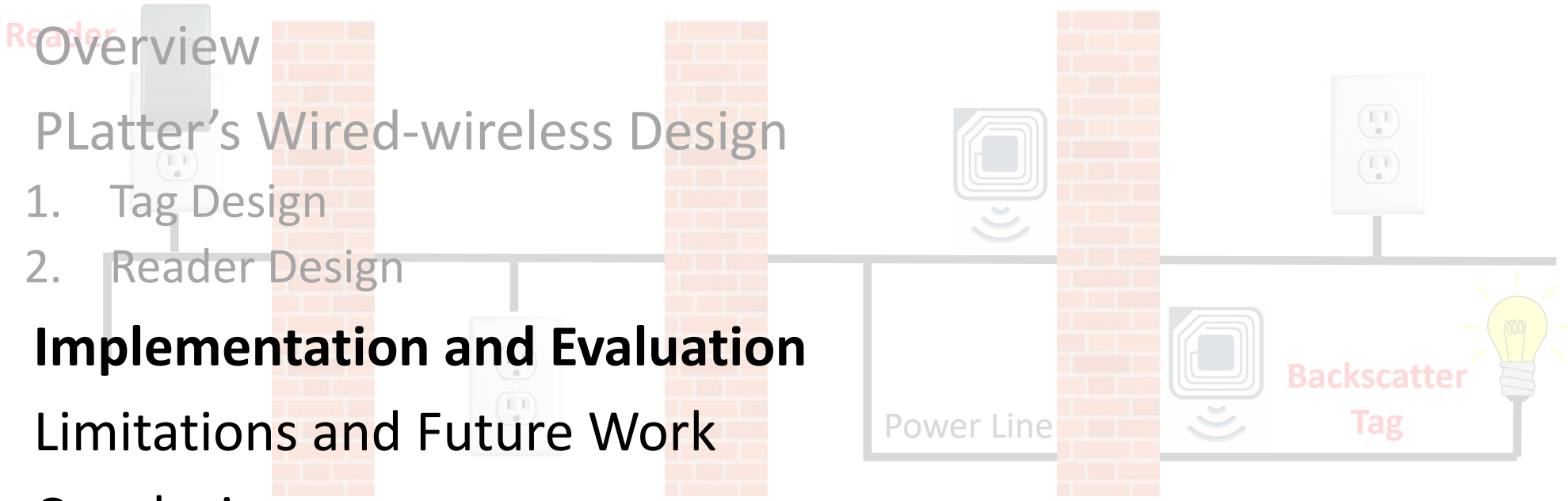
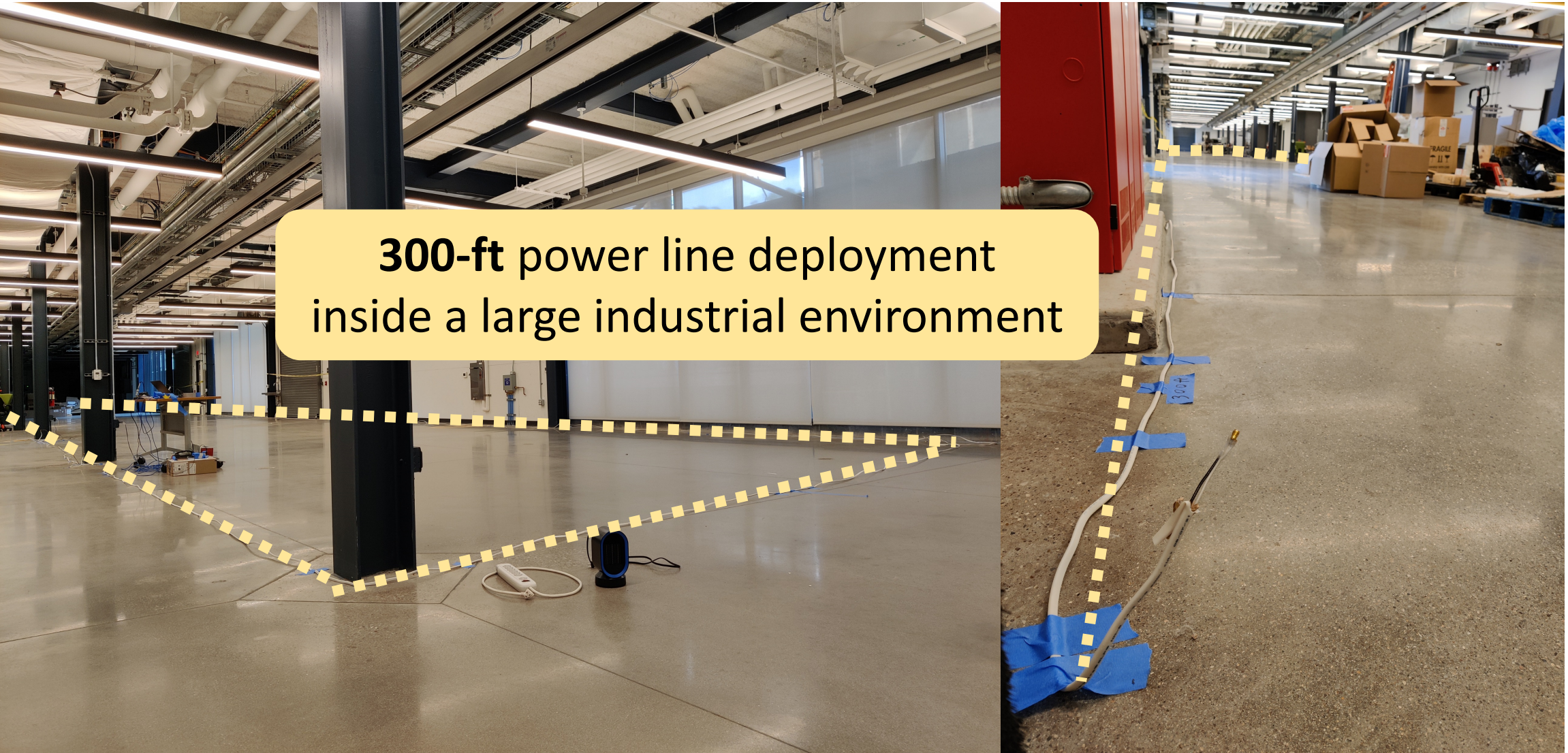


Implementation



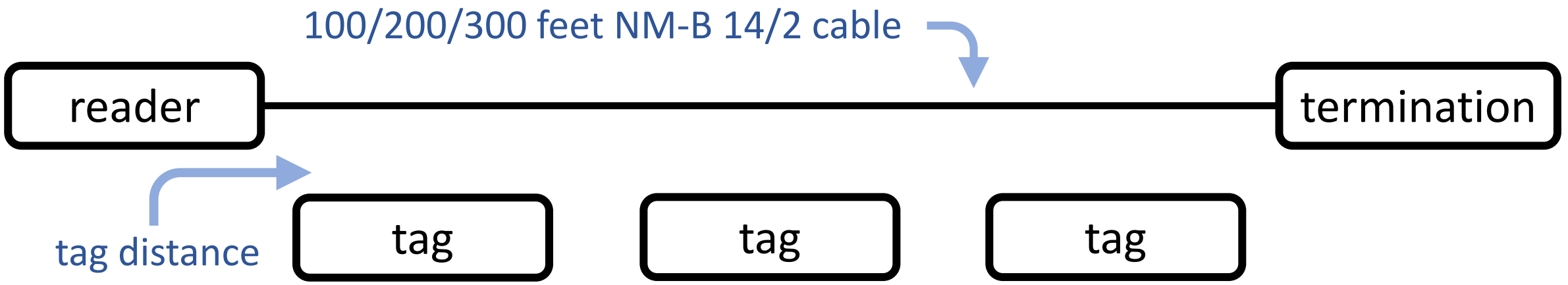
Exp

- Thoro
  - Tag
  - Cab
  - App
  - Sep
- A trac

- An end-to-end trial where the system is plugged into the **active grid**

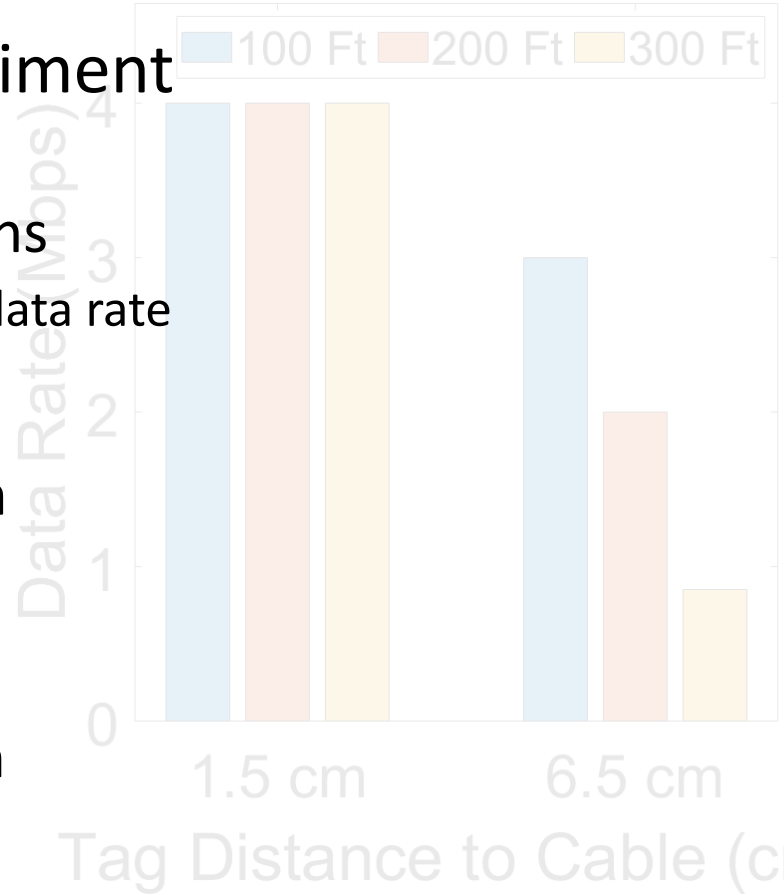
Experiment List

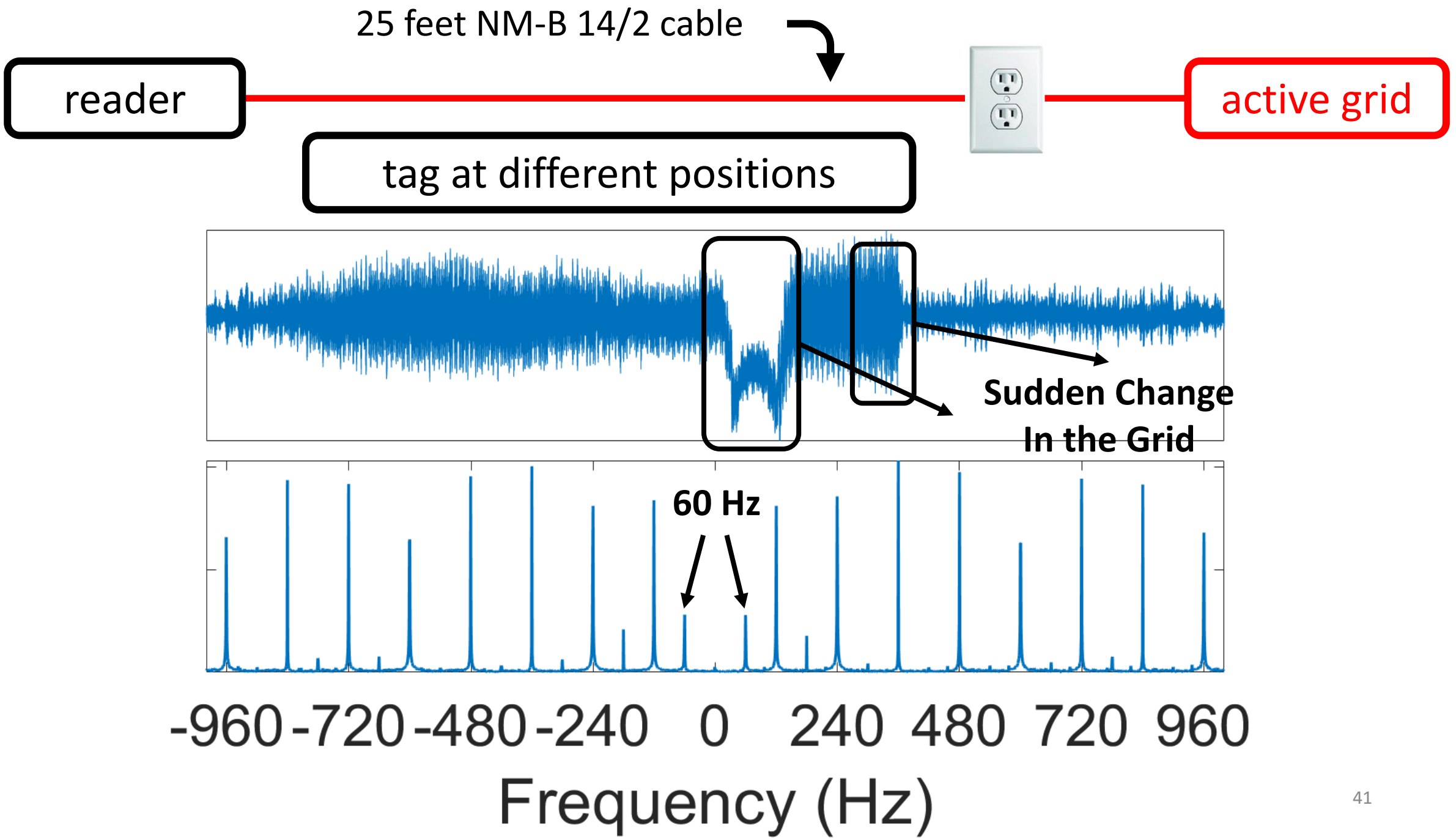
- Thorough evaluation on **static cables** to study the impact of
  - Tag position and cable length
  - Cable geometry
  - Appliance and matching circuit
  - Separating material between the cable and the tag
- A trace-driven simulation study with multiple tags
- An end-to-end trial where the system is plugged into the **active grid**



Takeaway from this experiment

1. 4 Mbps achieved under the most ideal conditions
   - Gains from coding and denoising help maintain a high data rate
2. Trade-off between tag distance and tag position
   - Farther from reader → closer to the cable
3. Trade-off between tag distance and cable length
   - Longer cable → closer to the cable

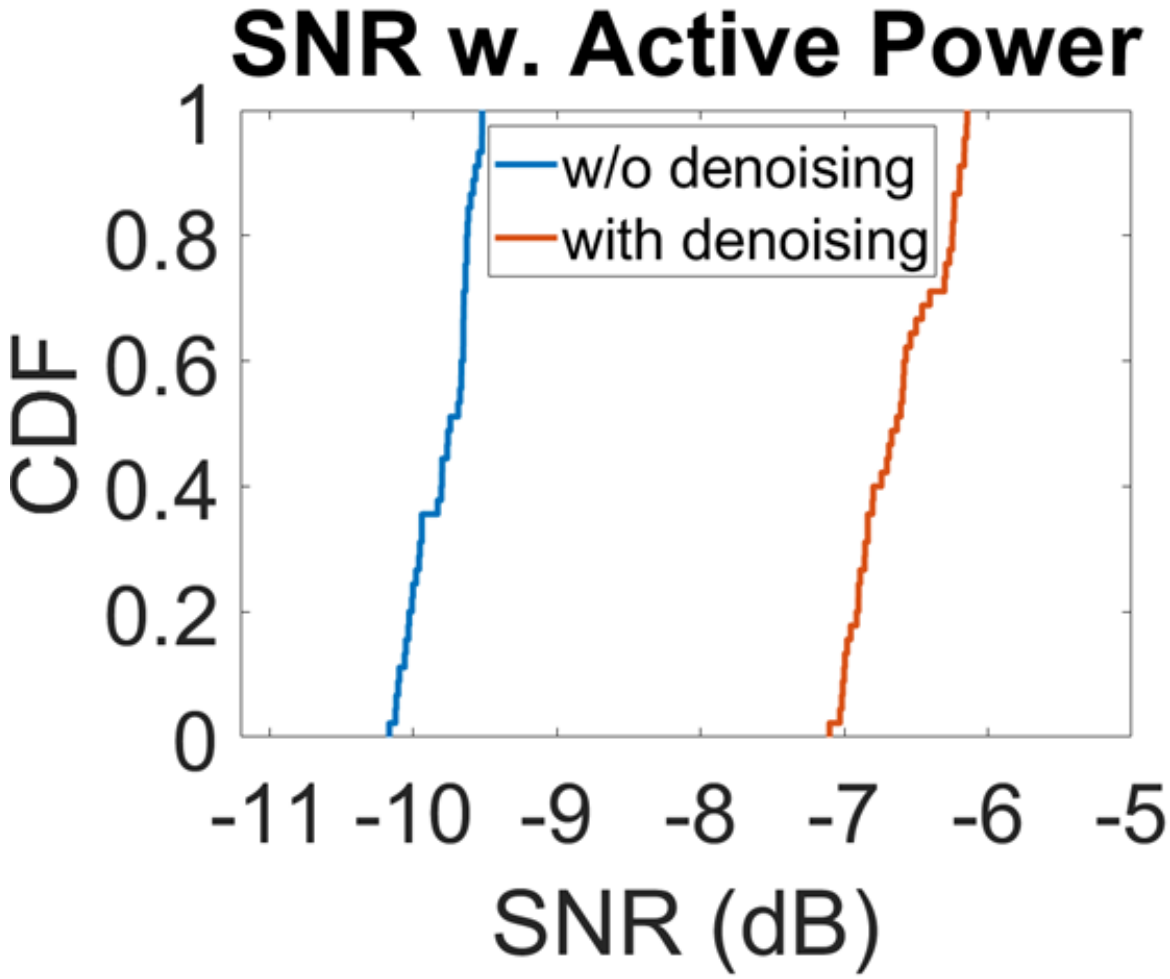



25 feet NM-B 14/2 cable
reader
active grid
tag at different positions
Sudden Change
In the Grid
60 Hz
-960 -720 -480 -240 0 240 480 720 960
Frequency (Hz)

reader

active grid

tag at different positions



Limitations and Future Work

- Tag Proximity to Cables
- Variability in Performance
- Uni-directional Communication and Tag Scalability
- …

Related Work – PLC

- Power line communication (PLC)

1. Power line as transmitting antenna (e.g., Colpitts et al, 1921)

2. Power line as receiving antenna (e.g., Cohn et al, 2010)

3. Power line as transmission line (e.g., Yonge et al, 2013)

Conclusion

- PLatter – a **building-scale backscatter communication system** leveraging existing power line infrastructure to achieve **up to 4 Mbps data rate** over **300 feet power cables**

- More details on our website:

  https://www.witechlab.com/platter.html