ECE 463: Digital Communications Lab.

Lecture 12: IoT II: Backscatter

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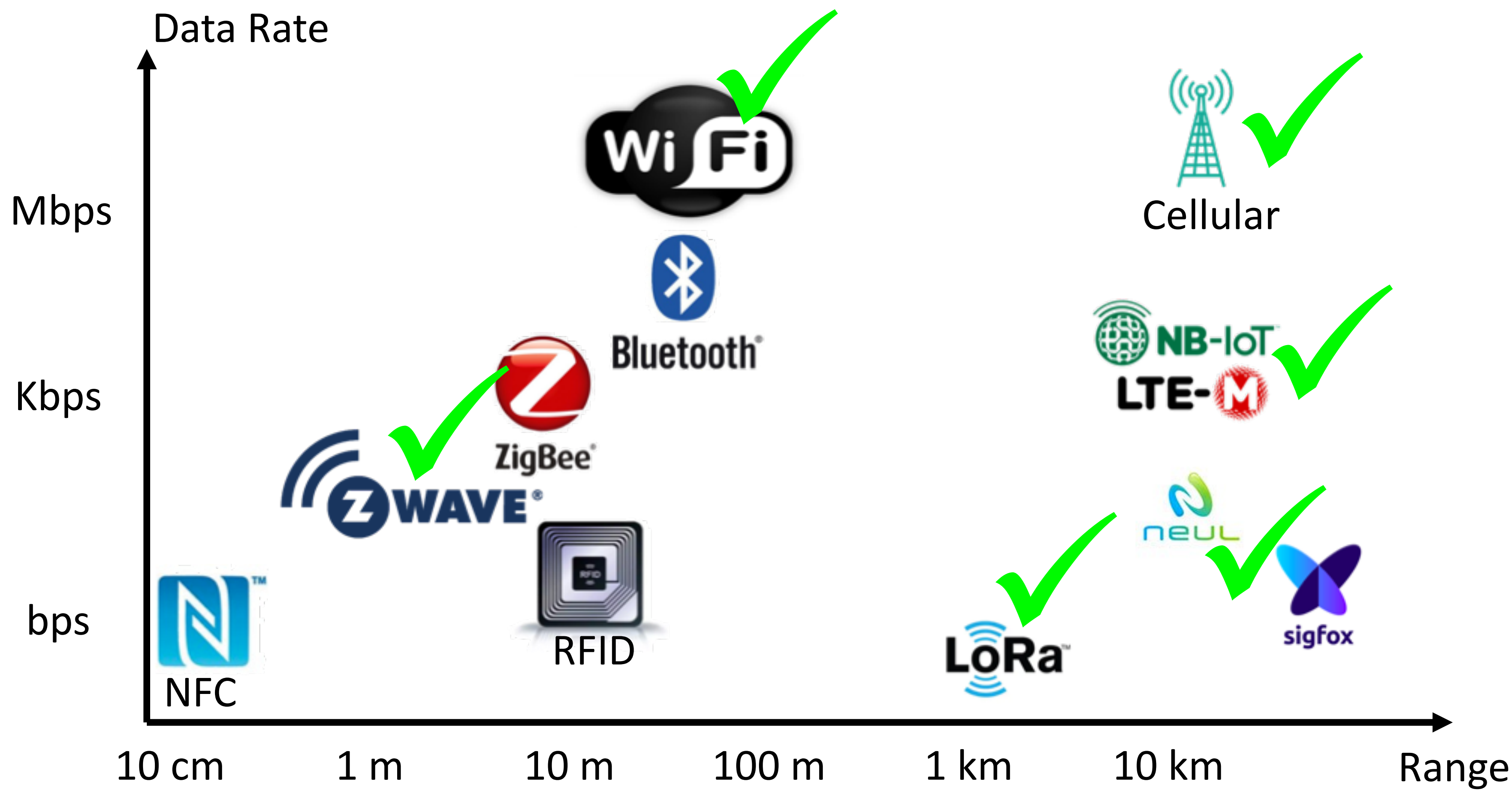
Previous Lecture:

- ✓ IoT Intro.
- ✓ Spread Spectrum
- ✓ Chirp Spread Spectrum
- ✓ Low Power Wide Area Networks

This Lecture:

- ❑ Backscatter Communication
- ❑ RFIDs
- ❑ NFC

IoT Technologies



IoT: Backscatter Communication

- Low power: No Battery
- Low cost: 10 cents
- Low range: 10 – 15 meters
- Low Data rates: 10Kbps – 640 Kbps

RFID: Radio Frequency IDentification

Active RFID

- Has battery
- Longer range
- Shorter life span
- Transmits its own signal using OOK

Battery Assisted RFID

- Has battery
- Battery used from computation & sensing but not communication
- Backscatters a reader's signal using OOK

Passive RFID

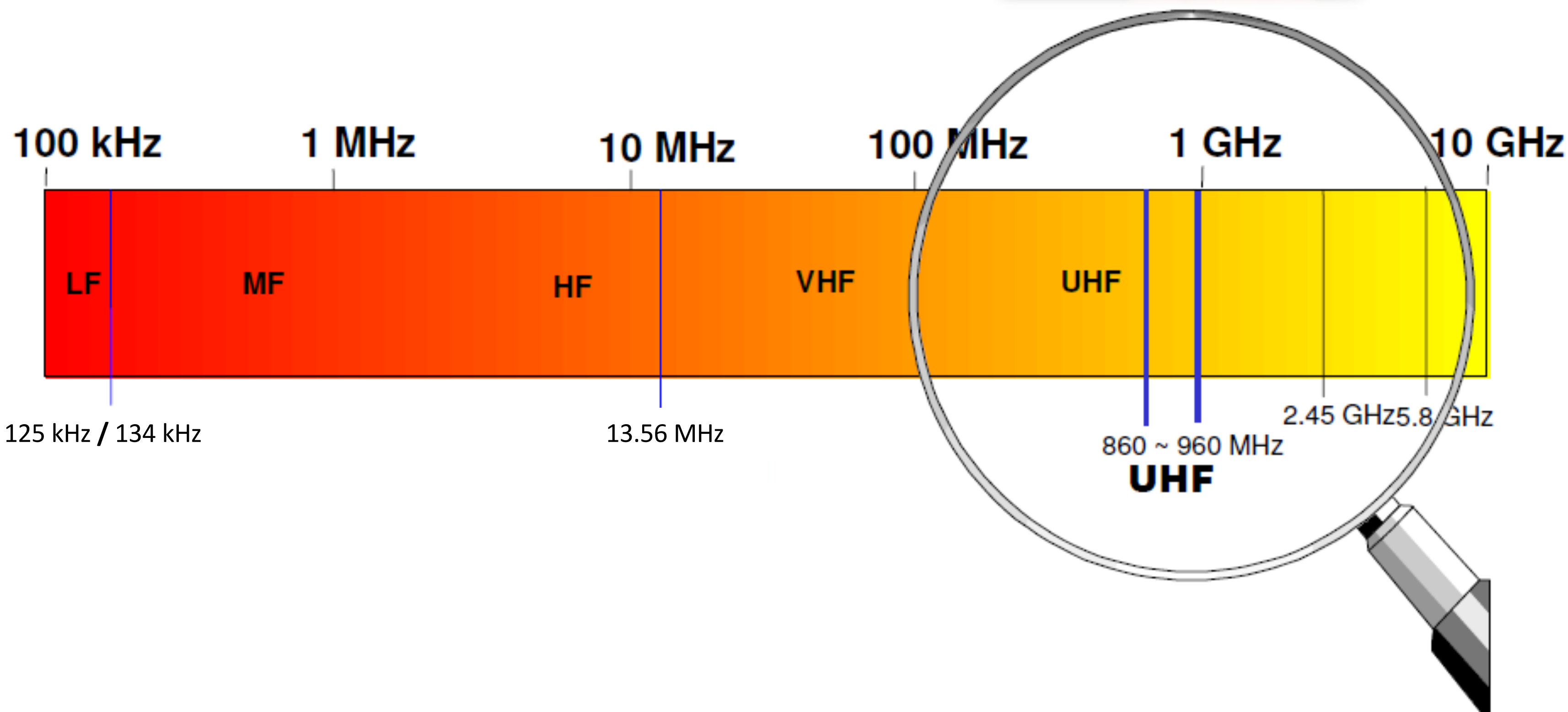
- No battery
- Short range
- Long life span
- Backscatters a reader's signal using OOK

RFID: Radio Frequency IDentification

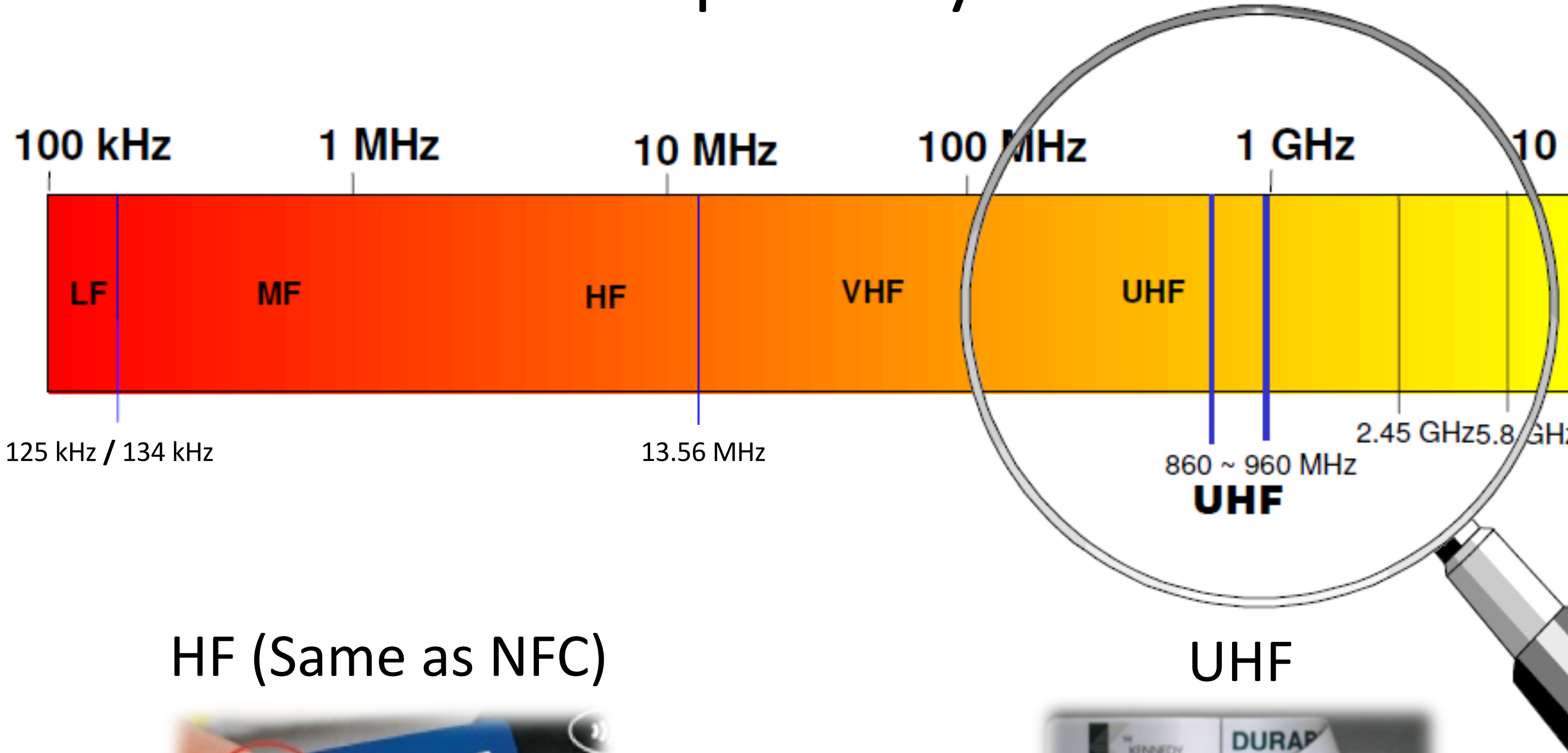
Passive RFID

HF (Same as NFC)

UHF



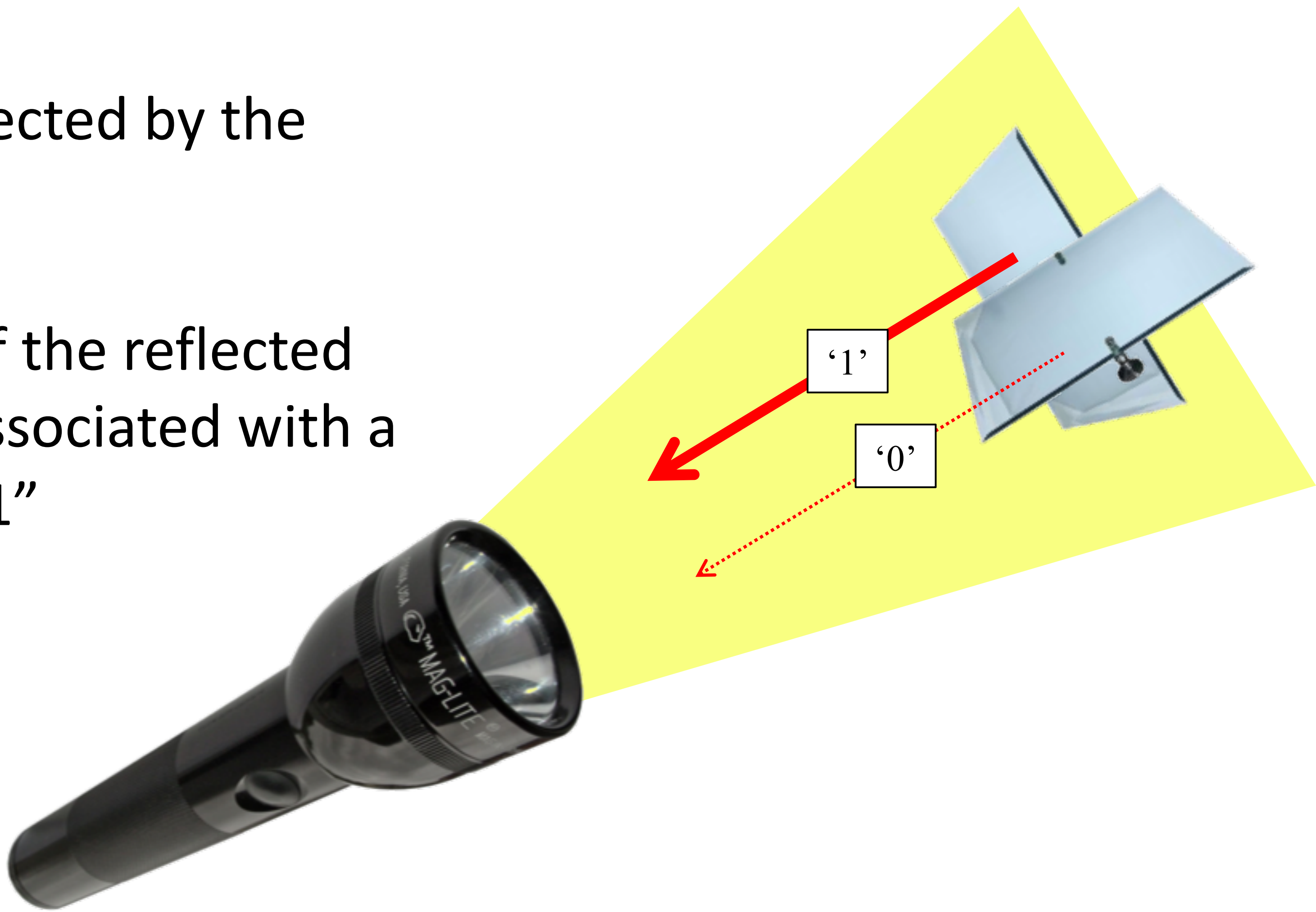
RFID: Radio Frequency IDentification



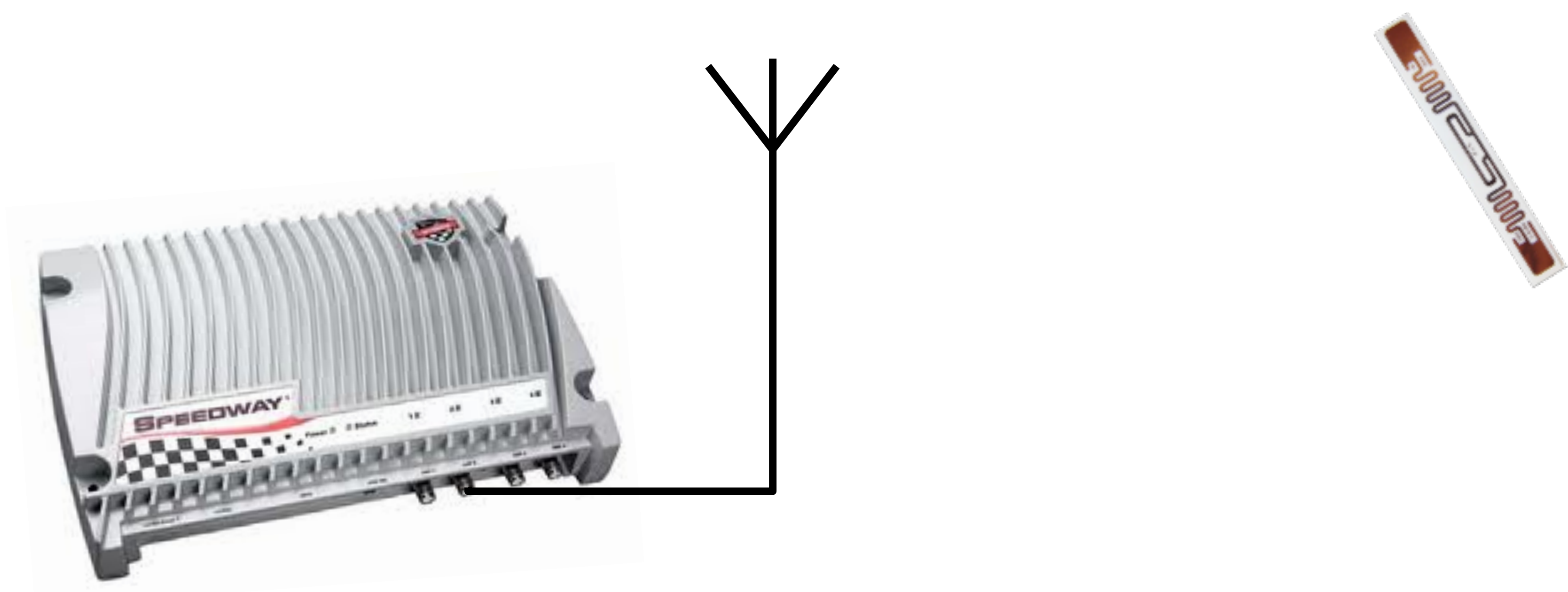
	HF (Same as NFC)	UHF
		
Range:	< 1cm	Few meters
Data Rate:	bps to few kbps	100s kbps
Technology:	Backscatter over Inductive Coupling	Backscatter over RF

Backscatter Communication

- A flashlight emits a beam of light
- The light is reflected by the mirror
- The intensity of the reflected beam can be associated with a logical “0” or “1”

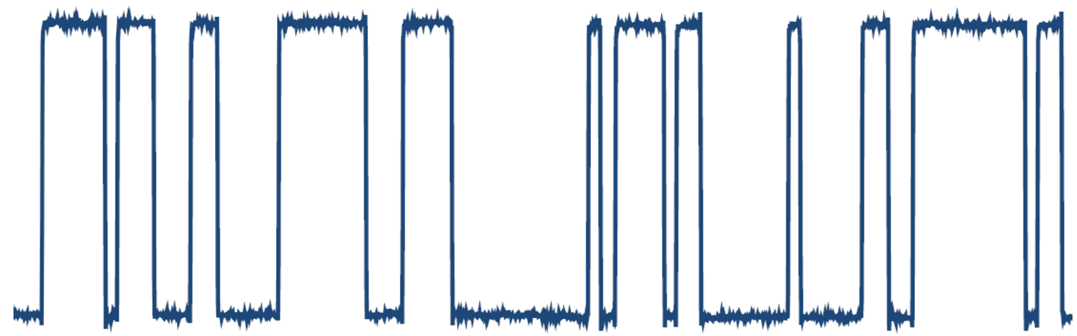


Backscatter Communication

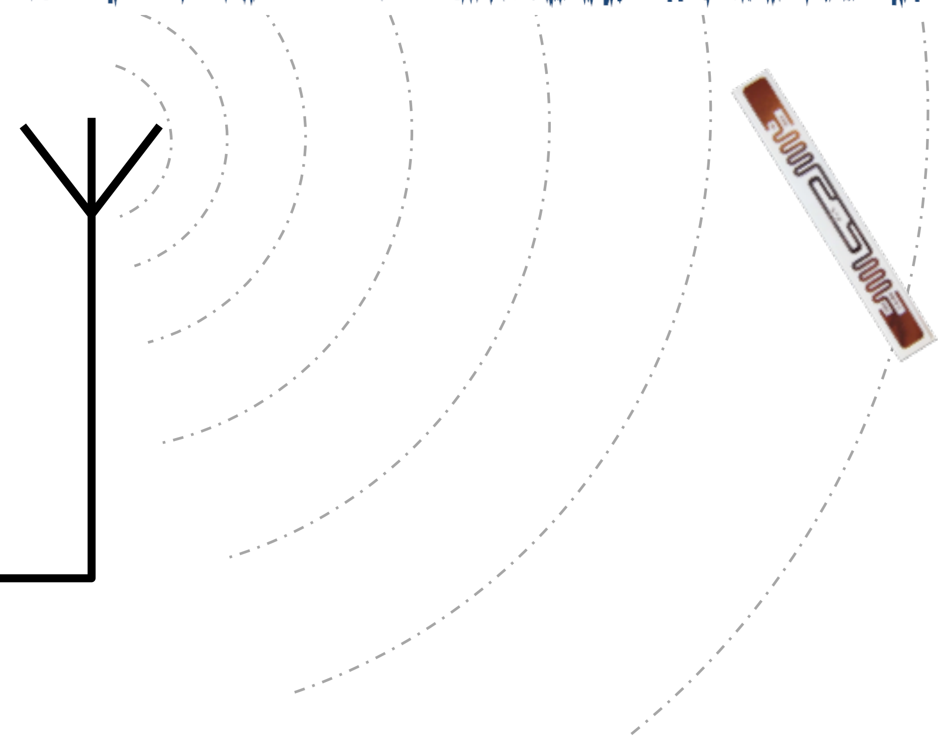


Backscatter Communication

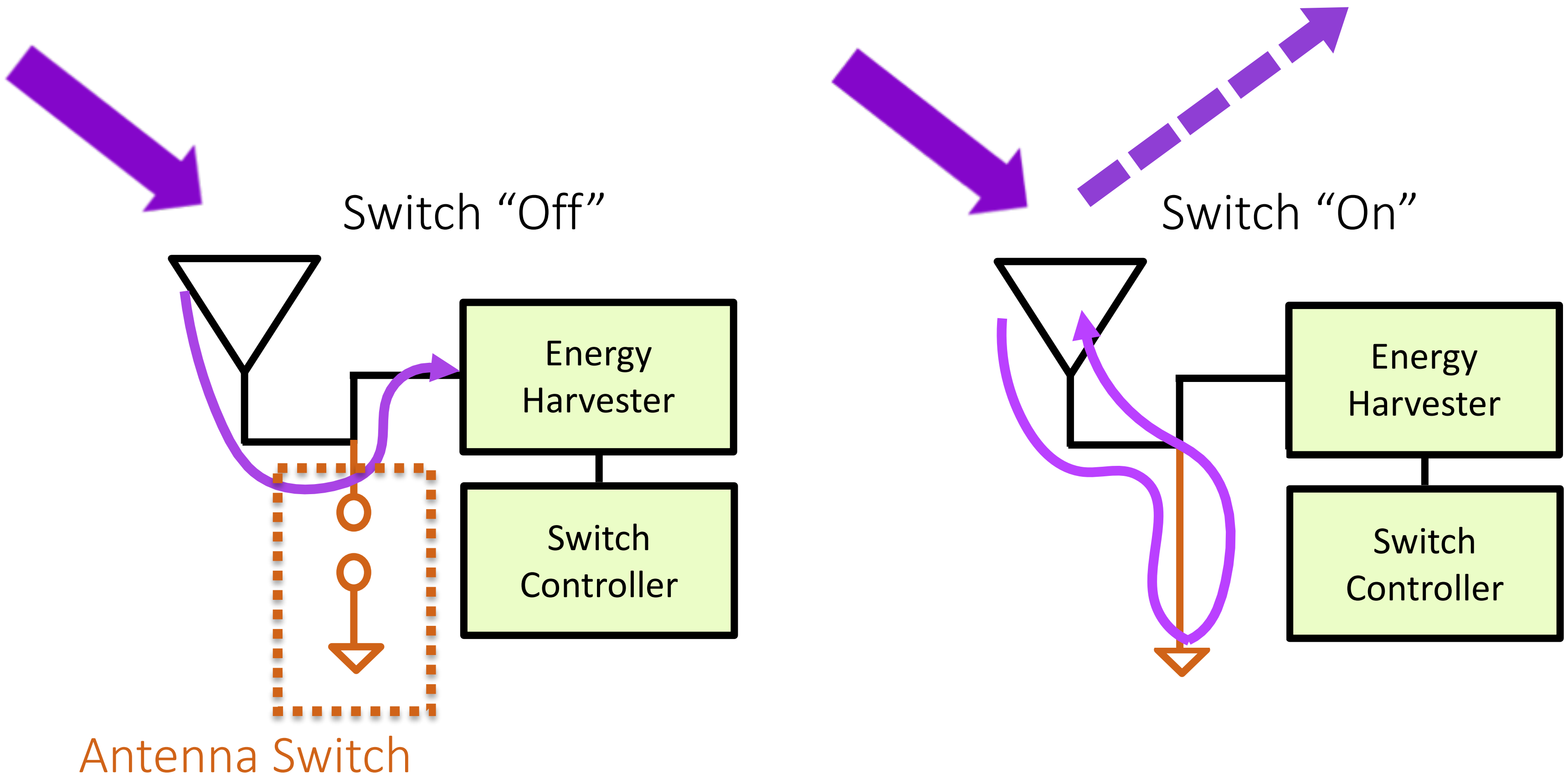
Tag reflects the reader's signal using ON-OFF keying



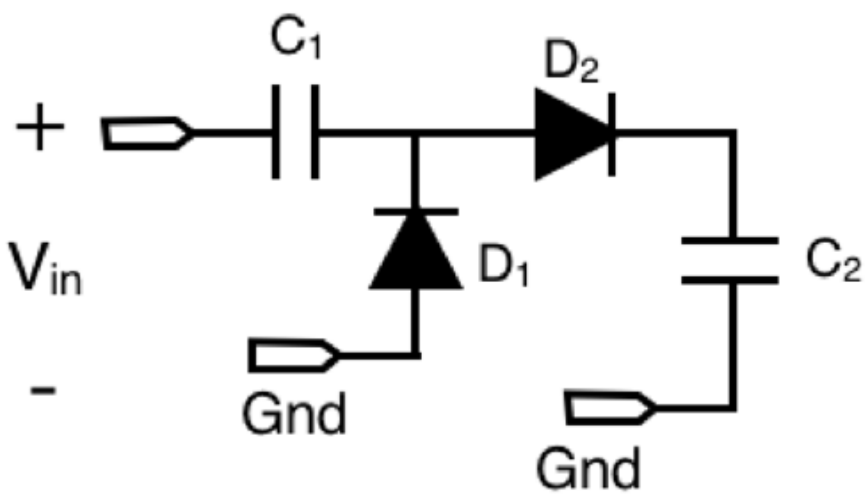
Reader shines an RF signal on nearby RFIDs



Backscatter Communication



RFID: Energy Harvester



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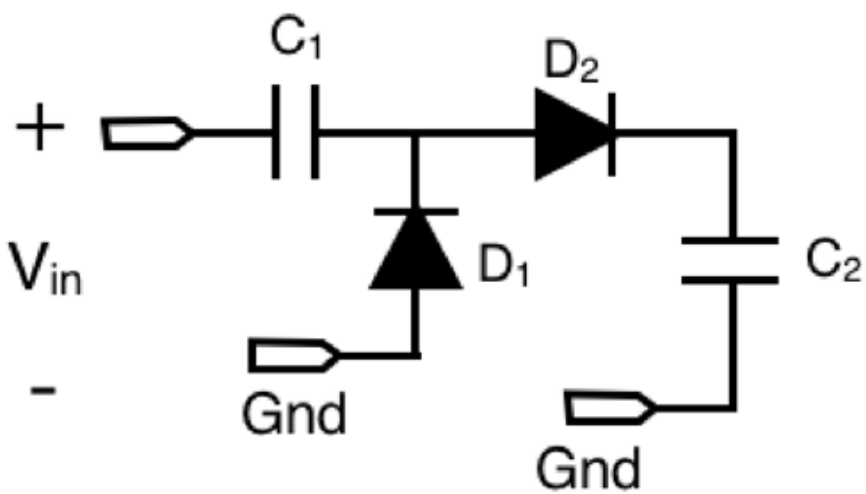

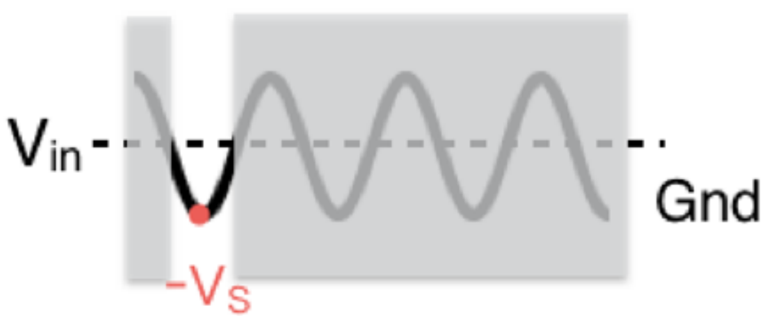

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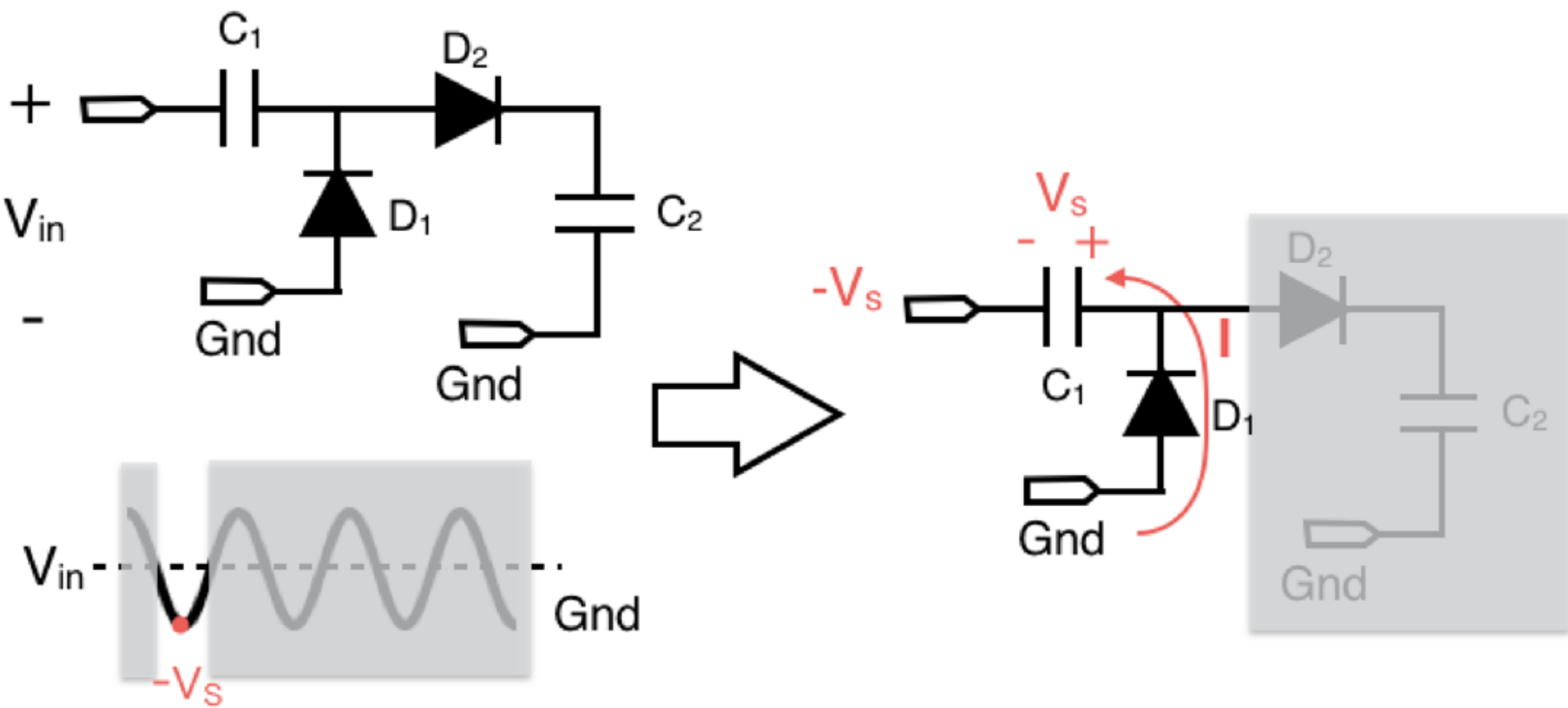

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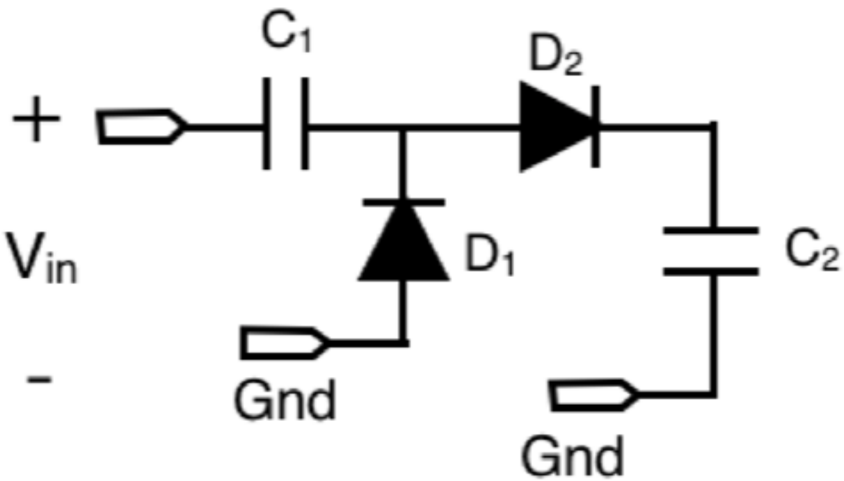

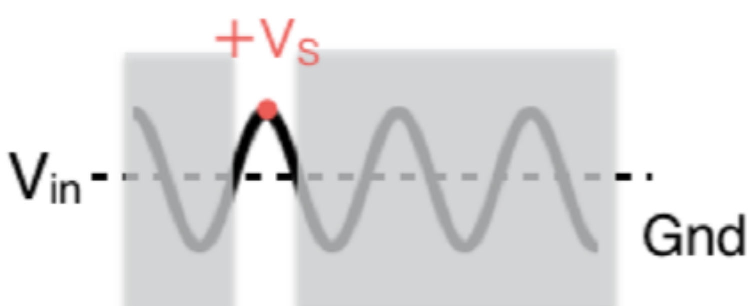

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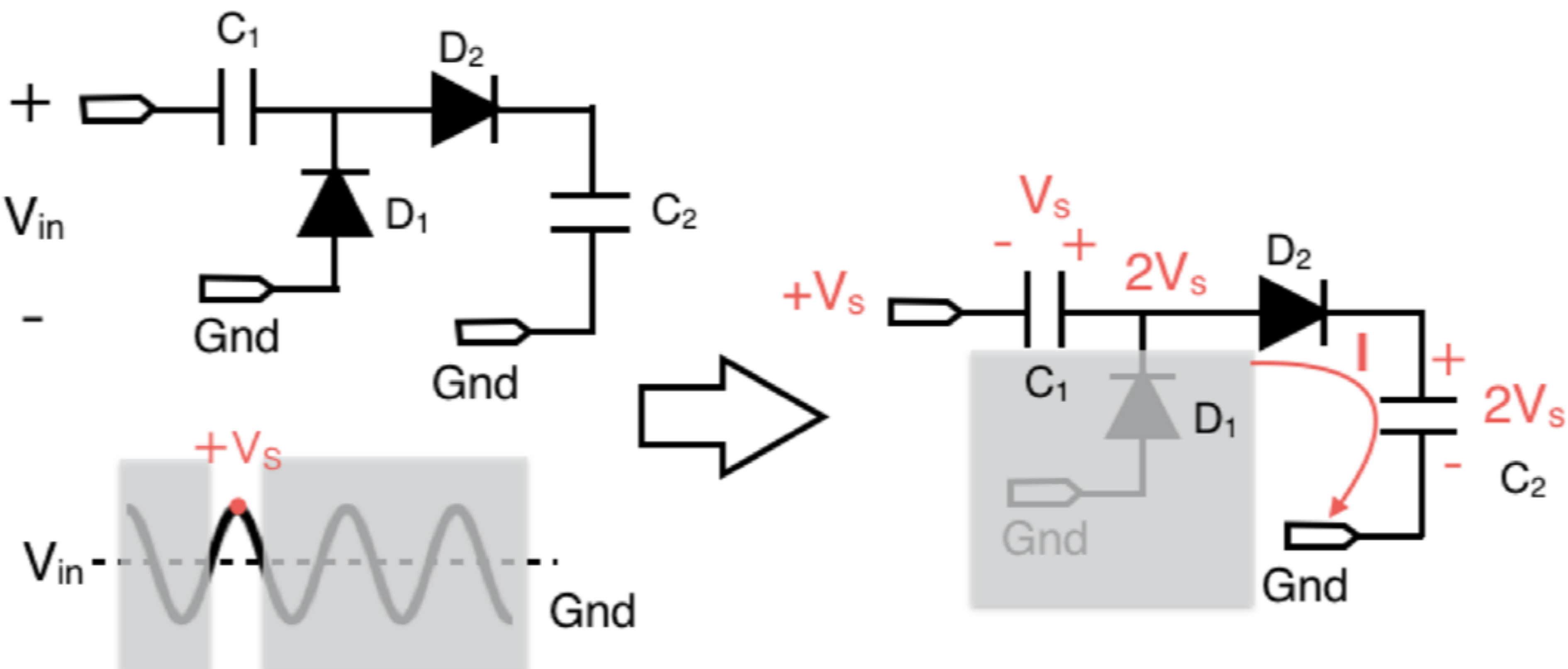

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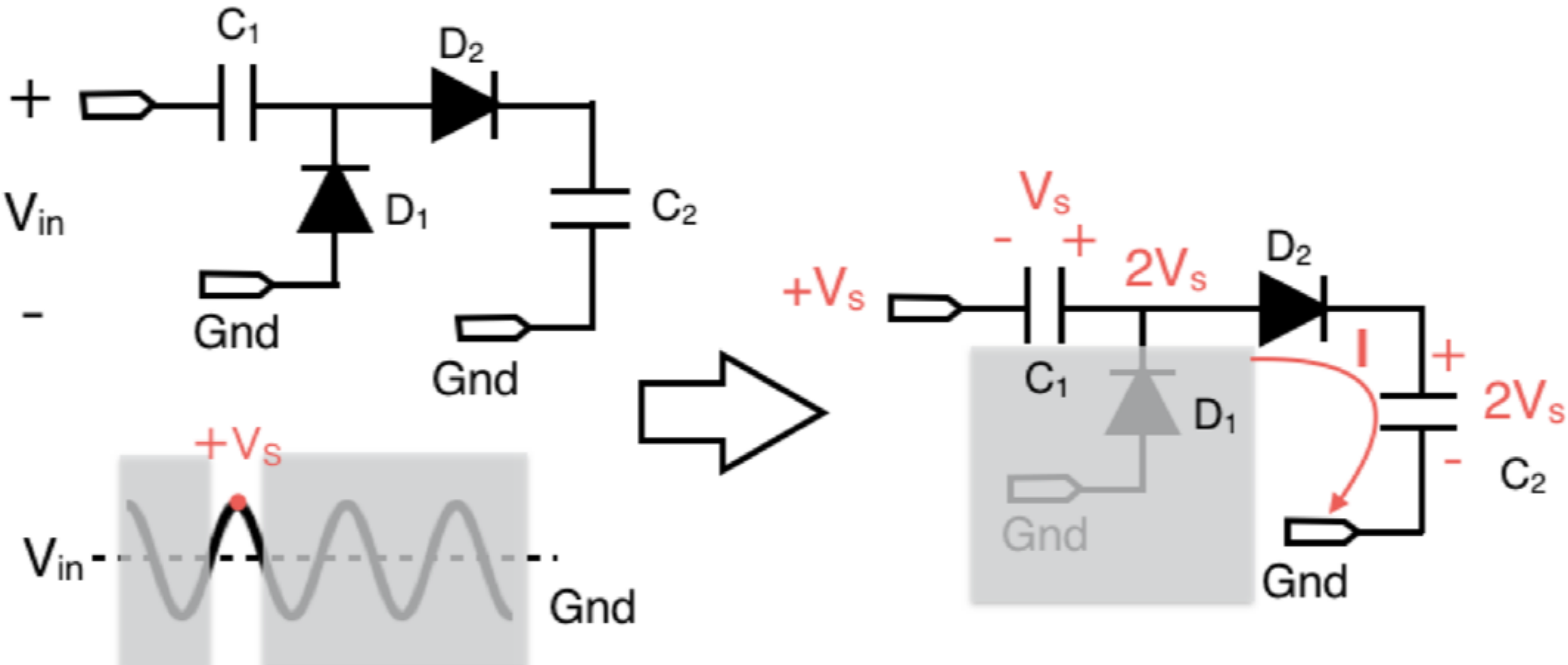


Multi-Stage Energy Harvesters can be used to amplify the voltage. (N stages → NVs)

Backscatter Communication

- Reader Transmits Continuous Sine Wave

$$x(t) = \cos(2\pi f_c t)$$

- Tag either reflect or doesn’t reflect the signal

$$s(t) = \begin{cases} \alpha \cos(2\pi f_c t) & bit = 1 \\ 0 & bit = 0 \end{cases}$$

- α is reflection coefficient $\alpha \ll 1$

- Reflection can be 70dB to 90dB weaker than transmitted signal.

Backscatter Communication

- Reader Receives

$$y(t) = h_s x(t) + h_t s(t)$$

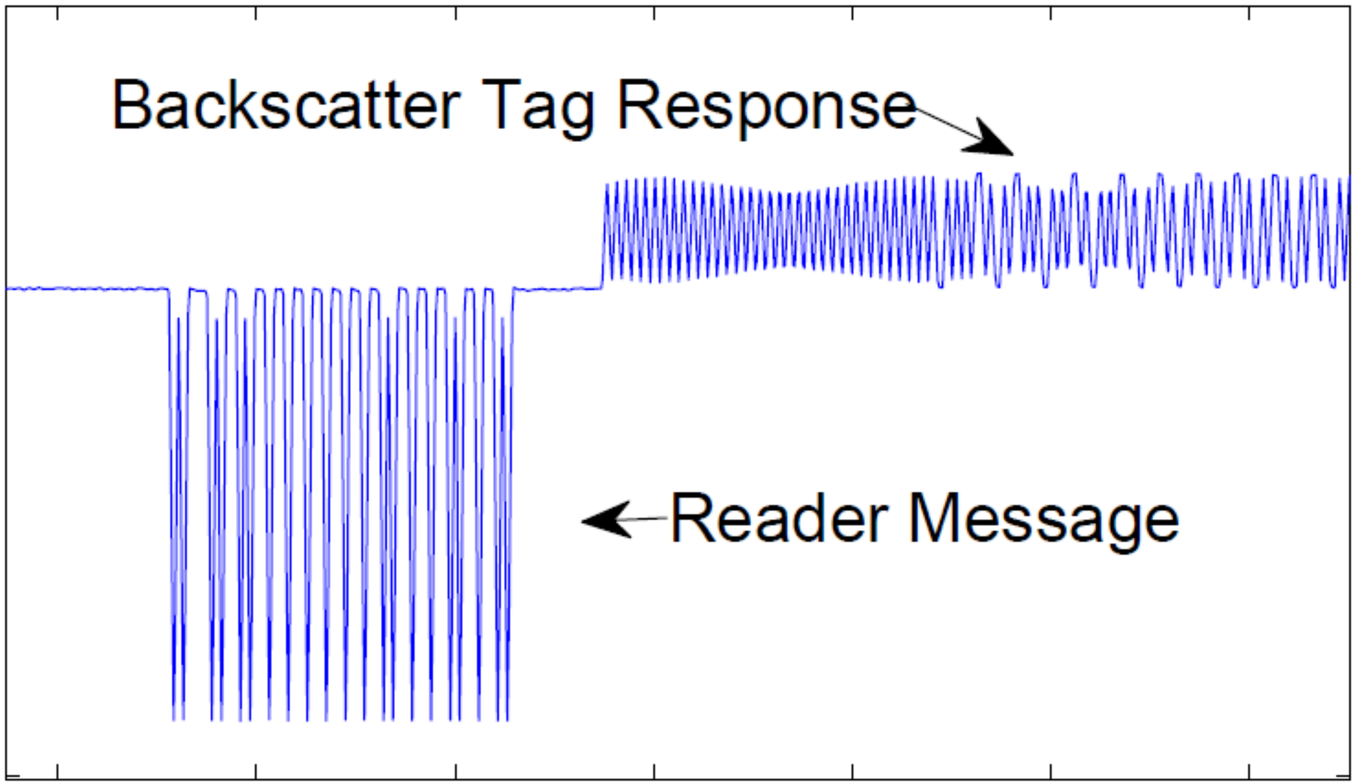
- h_s is self-interference channel
- h_t is composite channel (Reader-to-Tag and back Tag-to-Reader)

$$y(t) = (h_s + b\alpha h_t)\cos(2\pi f_c t)$$

Backscatter Communication

- Reader Receives

$$y(t) = (h_s + b\alpha h_t)\cos(2\pi f_c t)$$



Backscatter Communication

- Reader Receives

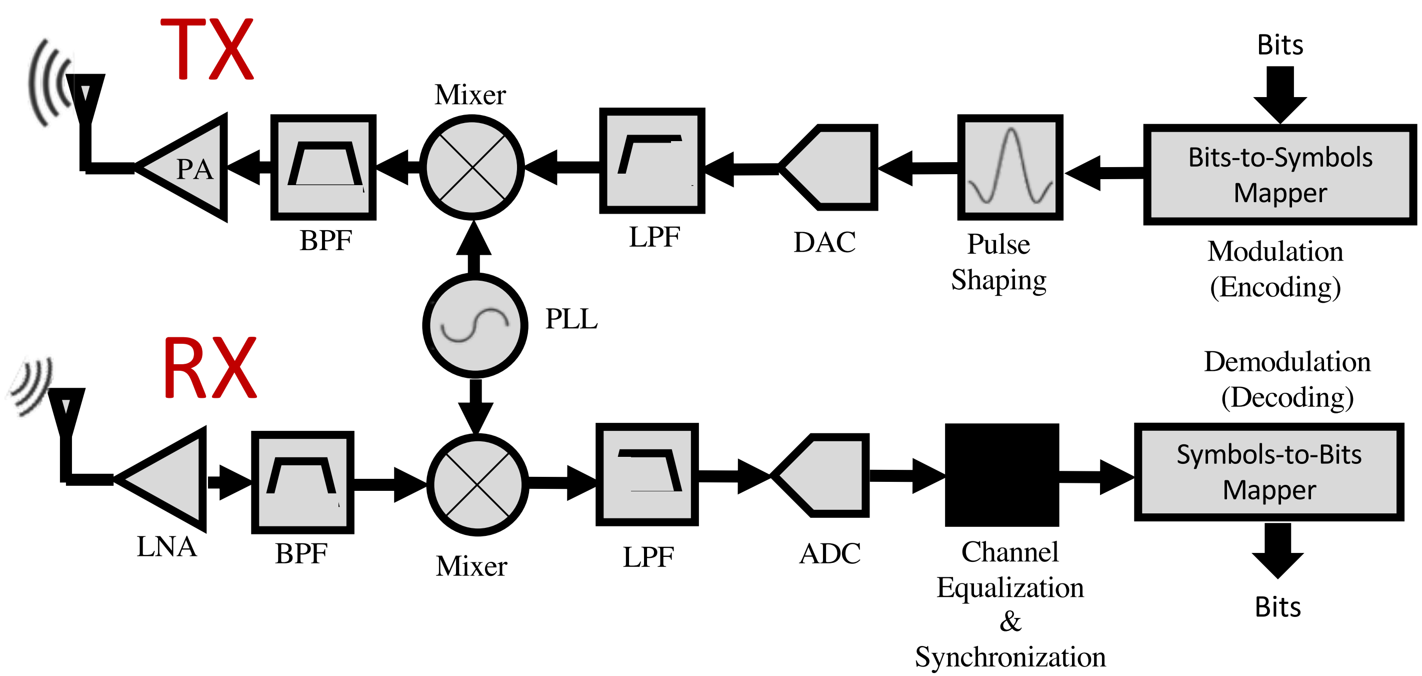
$$y(t) = (h_s + b\alpha h_t)\cos(2\pi f_c t)$$

- Reflection can be 70dB to 90dB weaker than transmitted signal.
- Reader must cancel self-interference to be able to decode.
- Reader uses a full-duplex radio
  - Can transmit and receiver at the same time!
  - Cancels Self-Interference Signal

$$y'(t) = b\alpha h_t \cos(2\pi f_c t)$$

Full Duplex Radios

- Radios are typically half duplex: Cannot transmit and receive at the same time



What happens if we transmit and receiver at the same time?

Full Duplex Radios

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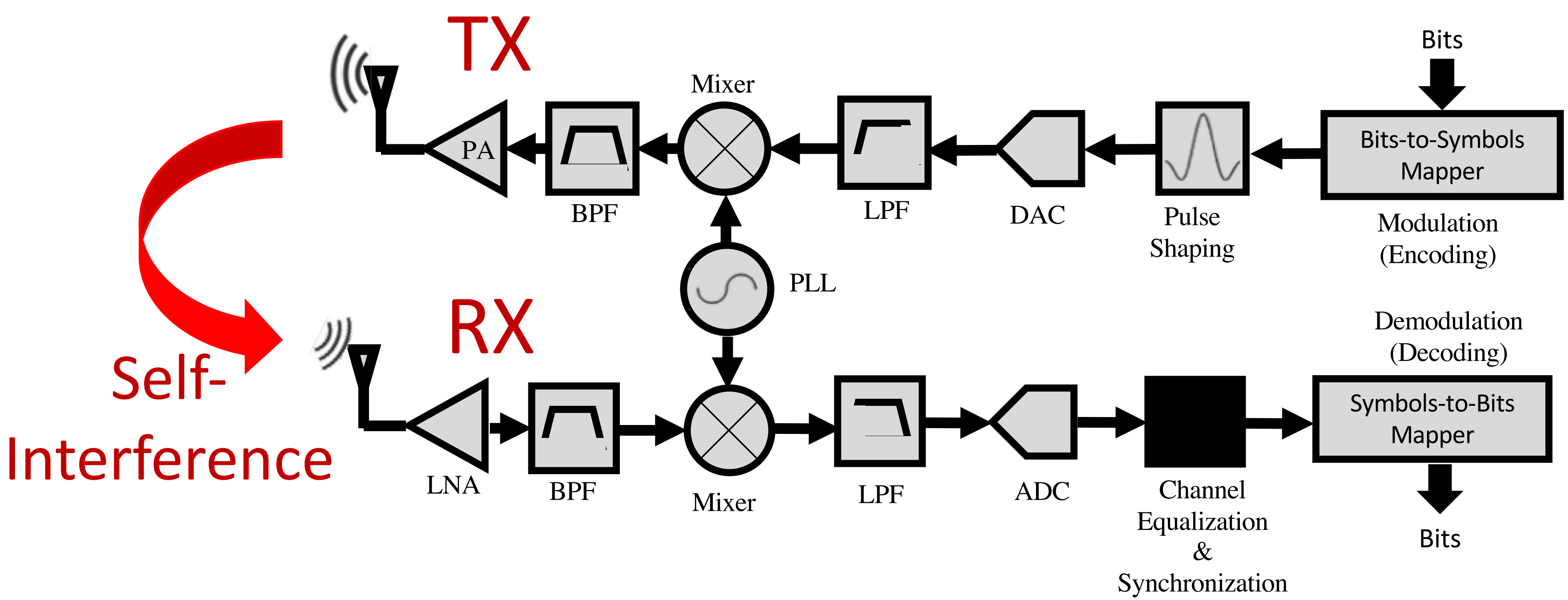

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Full Duplex Radios

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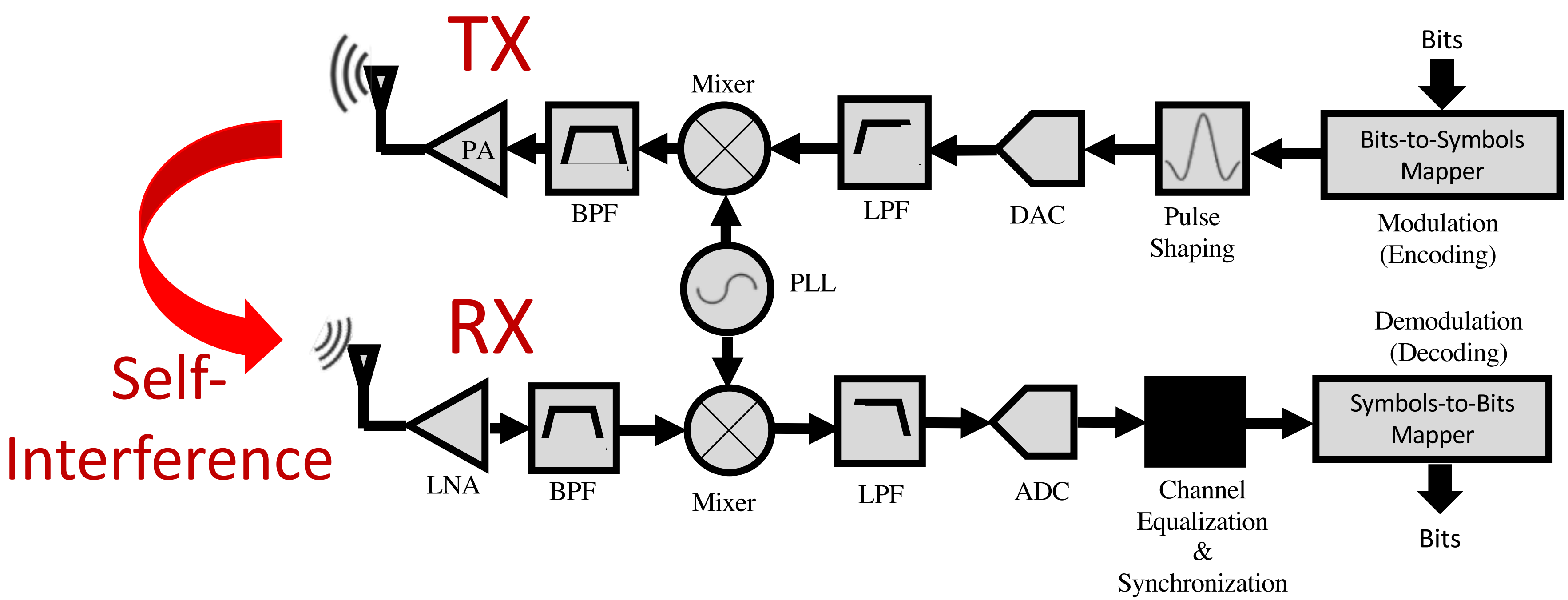
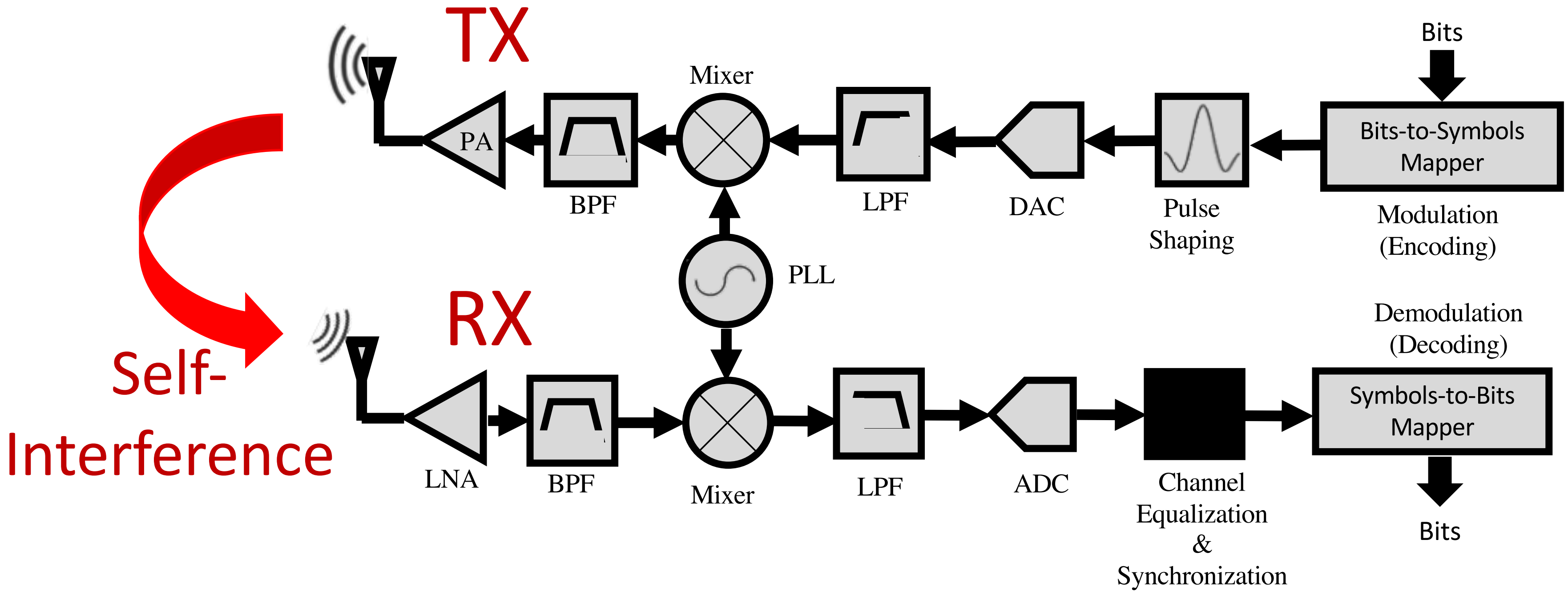


(1) Self-Interference saturates the Amplifiers & ADCs
(2) Self-Interference results in negative SINR of RX signal

Full Duplex Radios



(1) Self-Interference saturates the Amplifiers & ADCs

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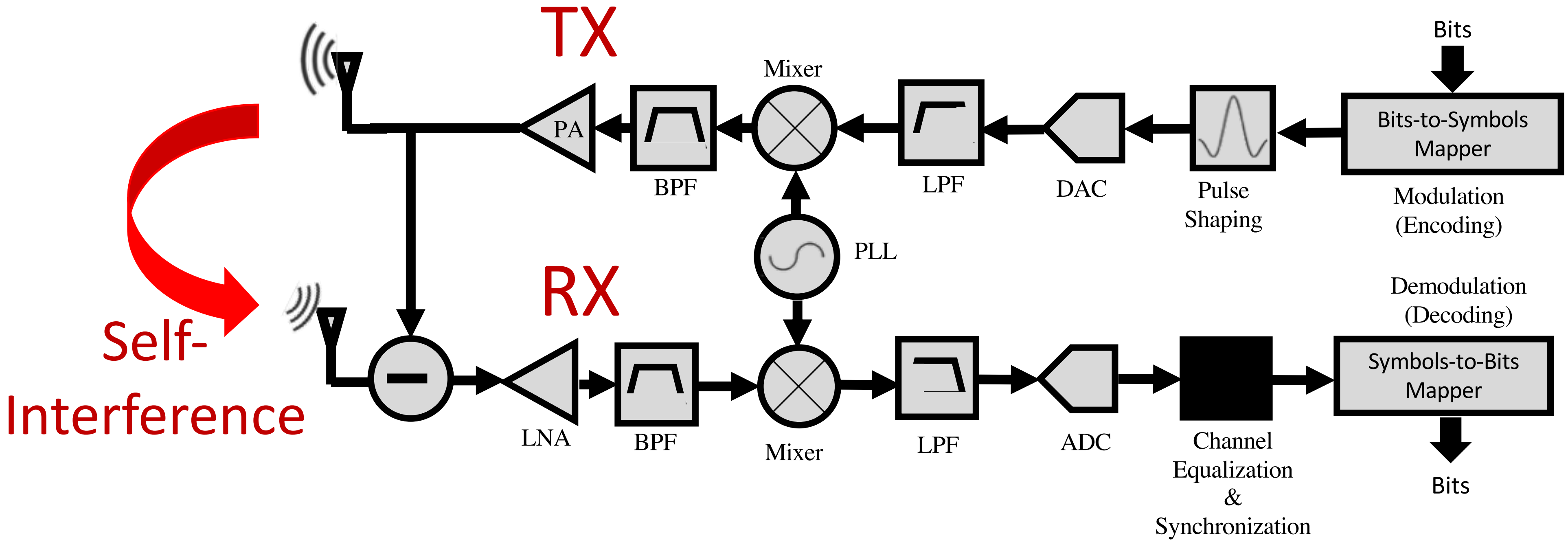
- Radio knows the self-interference signal → Can cancel it out

Full Duplex Radios



(1) Self-Interference saturates the Amplifiers & ADCs
(2) Self-Interference results in negative SINR of RX signal

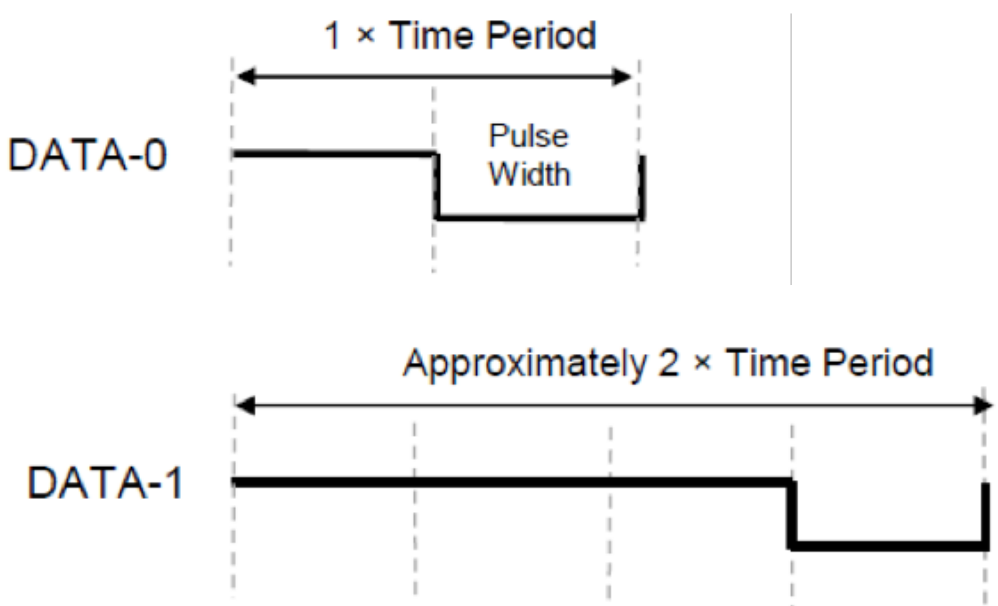
- Radio knows the self-interference signal → Can cancel it out
- For RFIDs: self-interference is a single sine wave → Easy to filter
- For Classical Radios: self-interference is wideband → Harder to cancel

Backscatter Communication

- Both Reader and Tag Use ON-OFF Keying for modulation

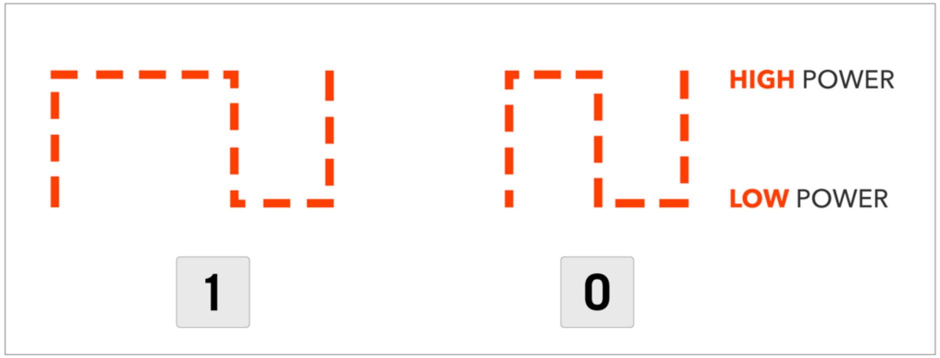
- Bit Encoding, however, can differ.

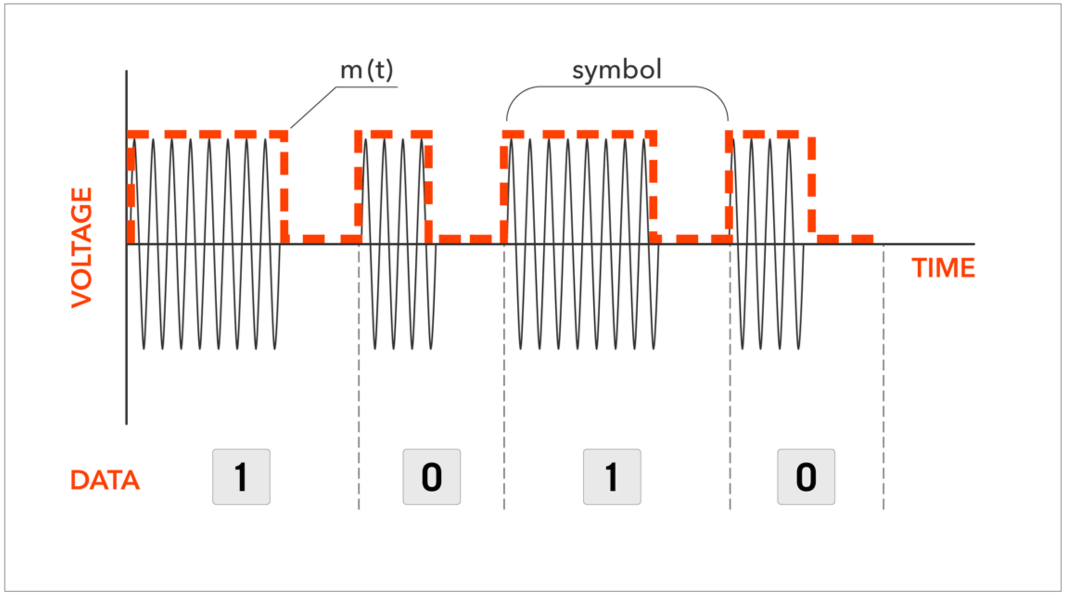
- Reader-to-Tag Encoding: Pulse Interval Encoding (PIE)



Backscatter Communication

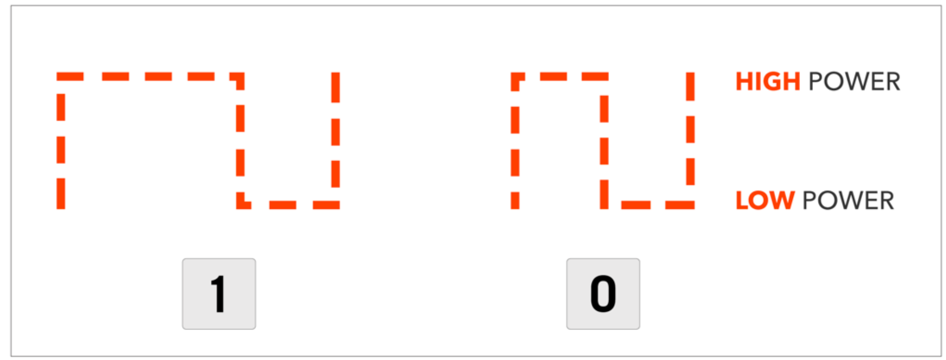
- Reader-to-Tag Encoding: Pulse Interval Encoding (PIE)





Backscatter Communication

- Reader-to-Tag Encoding: Pulse Interval Encoding (PIE)

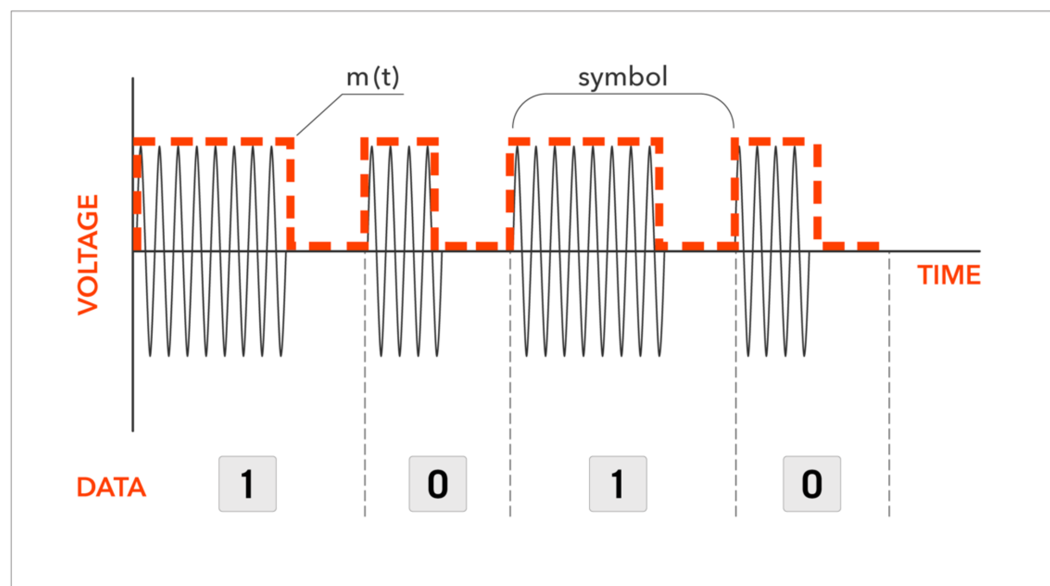


Why use PIE encoding?

Signal is on for longer time

↓

Maximize energy harvesting at the tag.



Backscatter Communication

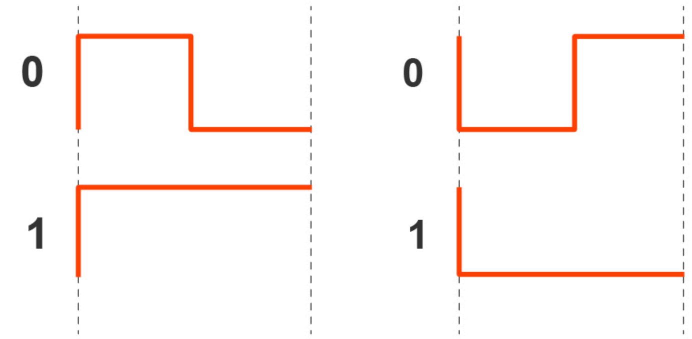
- Tag-to-Reader Encoding:
    - FM0
    - Miller Code (M=2, 4, 8)

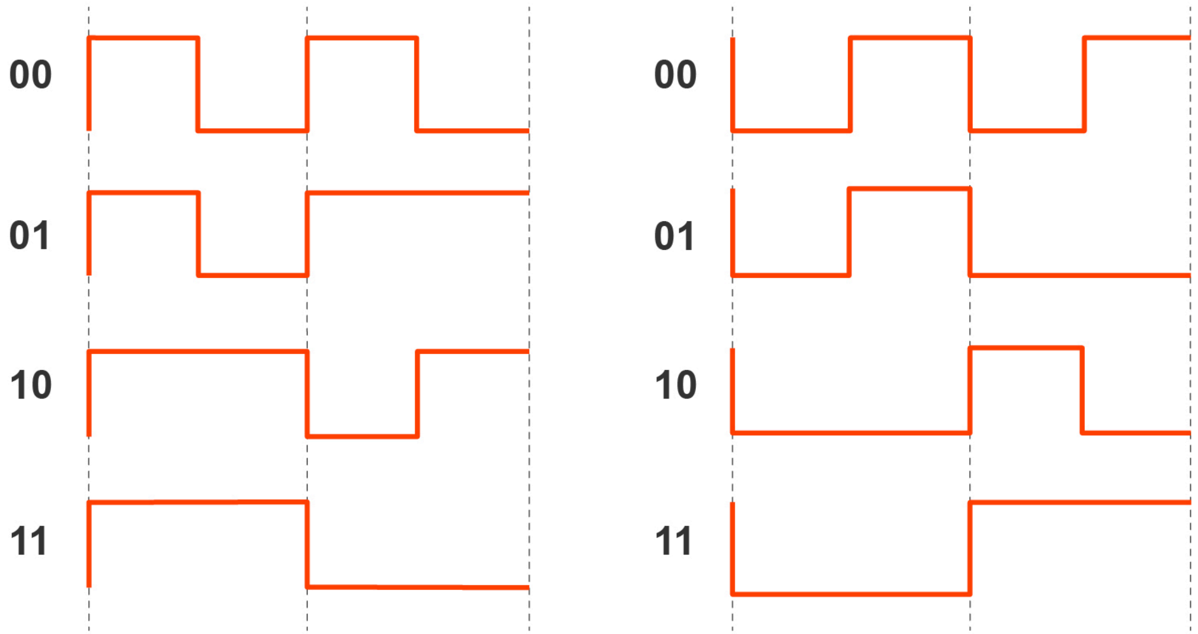
Backscatter Communication

- Tag-to-Reader Encoding: FM0

- Inverts the switch at every symbol

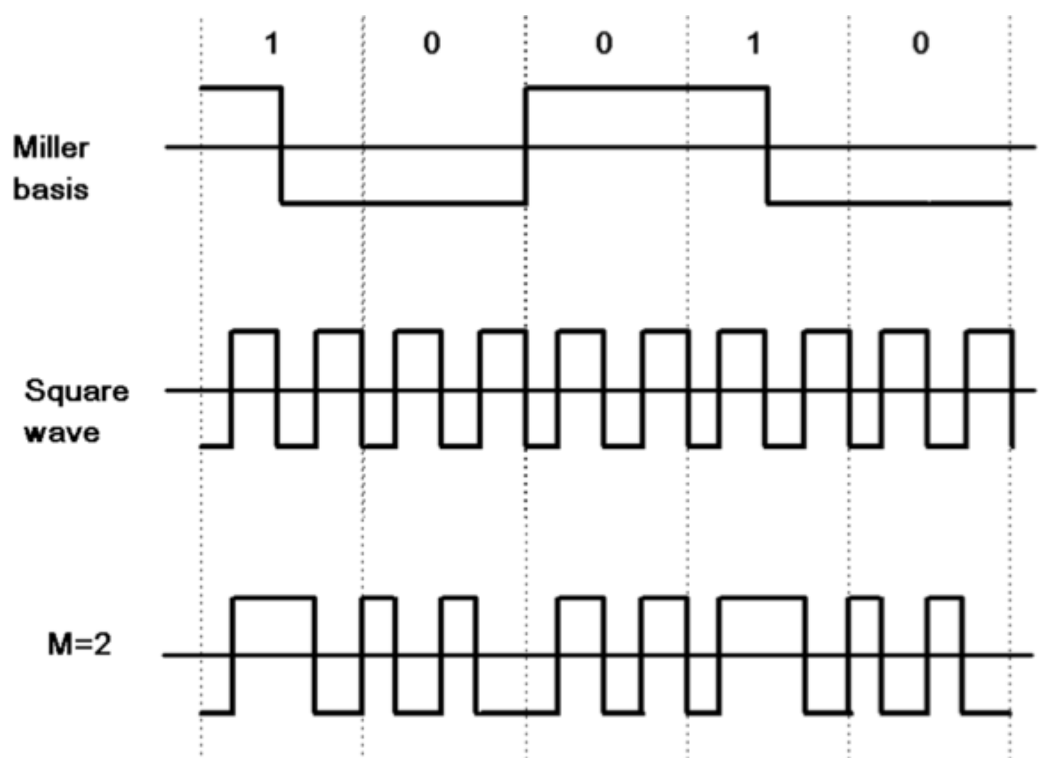
- 0 bits has extra switch mid-symbol





Backscatter Communication

- Tag-to-Reader Encoding: Miller
- Inverts the switch between two consecutive 0 bit symbols
- Inverts the switch in the middle of 1 bit symbol
- Multiple by square wave of M times symbol rate for M=2,4,8



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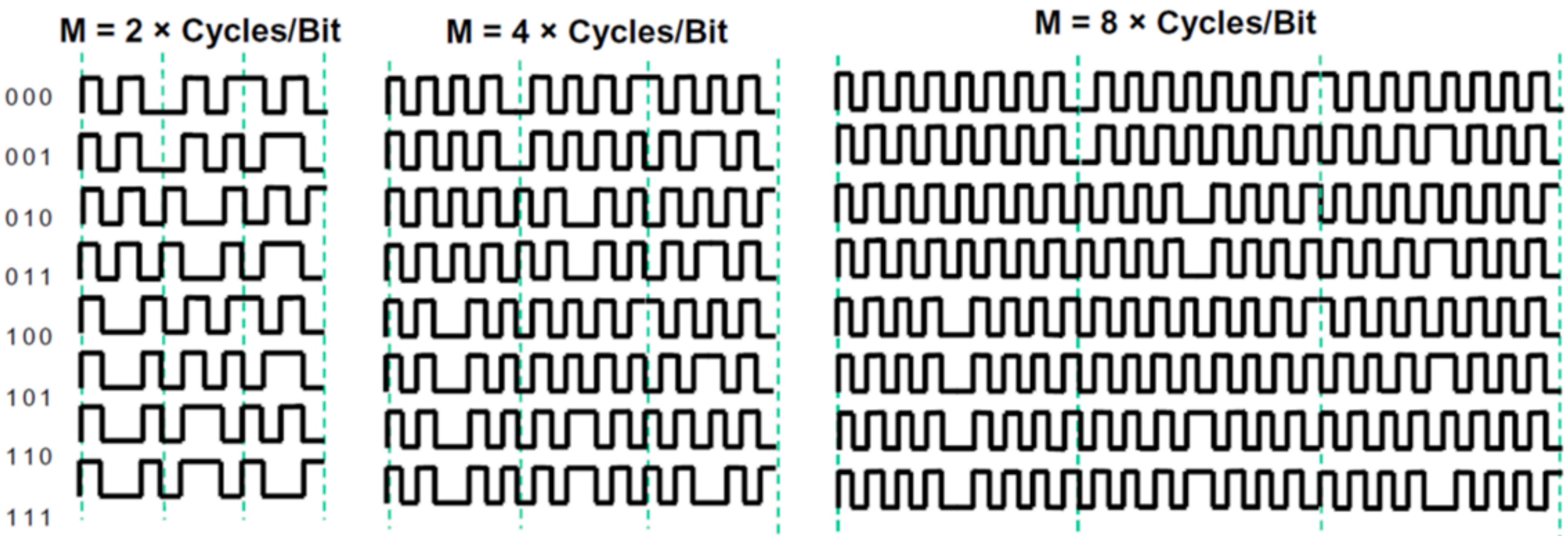

Backscatter Communication

- Tag-to-Reader Encoding:
  - FM0: High Data Rate: 40 Kbps- 640 Kbps
  - Miller Code (M=2, 4, 8)
    - Multiple switches per bit.
    - Robust to Multi-Reader, Multi-Tag scenarios.
    - Robust to noise.
    - M=2, Data Rate: 20 Kbps – 320 Kbps
    - M=4, Data Rate: 10 Kbps – 160 Kbps
    - M=8, Data Rate: 5 Kbps – 80 Kbps