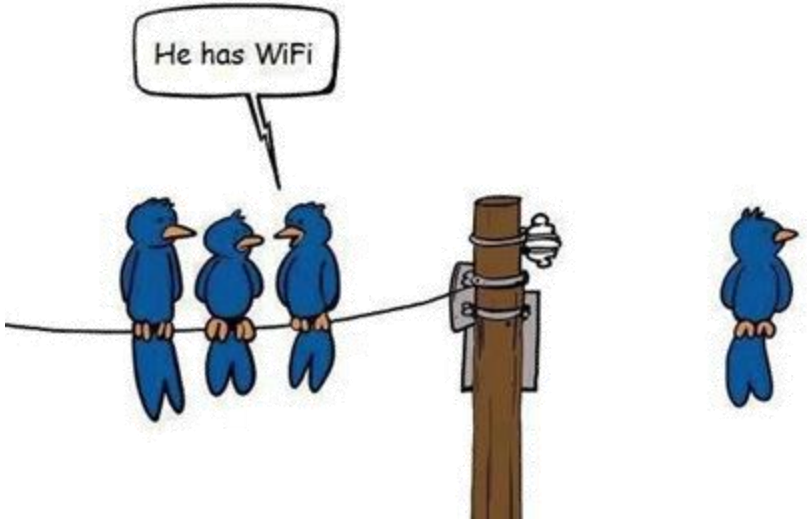
# COM-405: Mobile Networks

## Lecture 7.0: IoT Technologies

Haitham Hassanieh




EPFL

SENS
Laboratory of SEnsing
& Networking Systems

# IoT Technologies

Wi Fi

Bluetooth

NFC

RFID

Cellular

sigfox

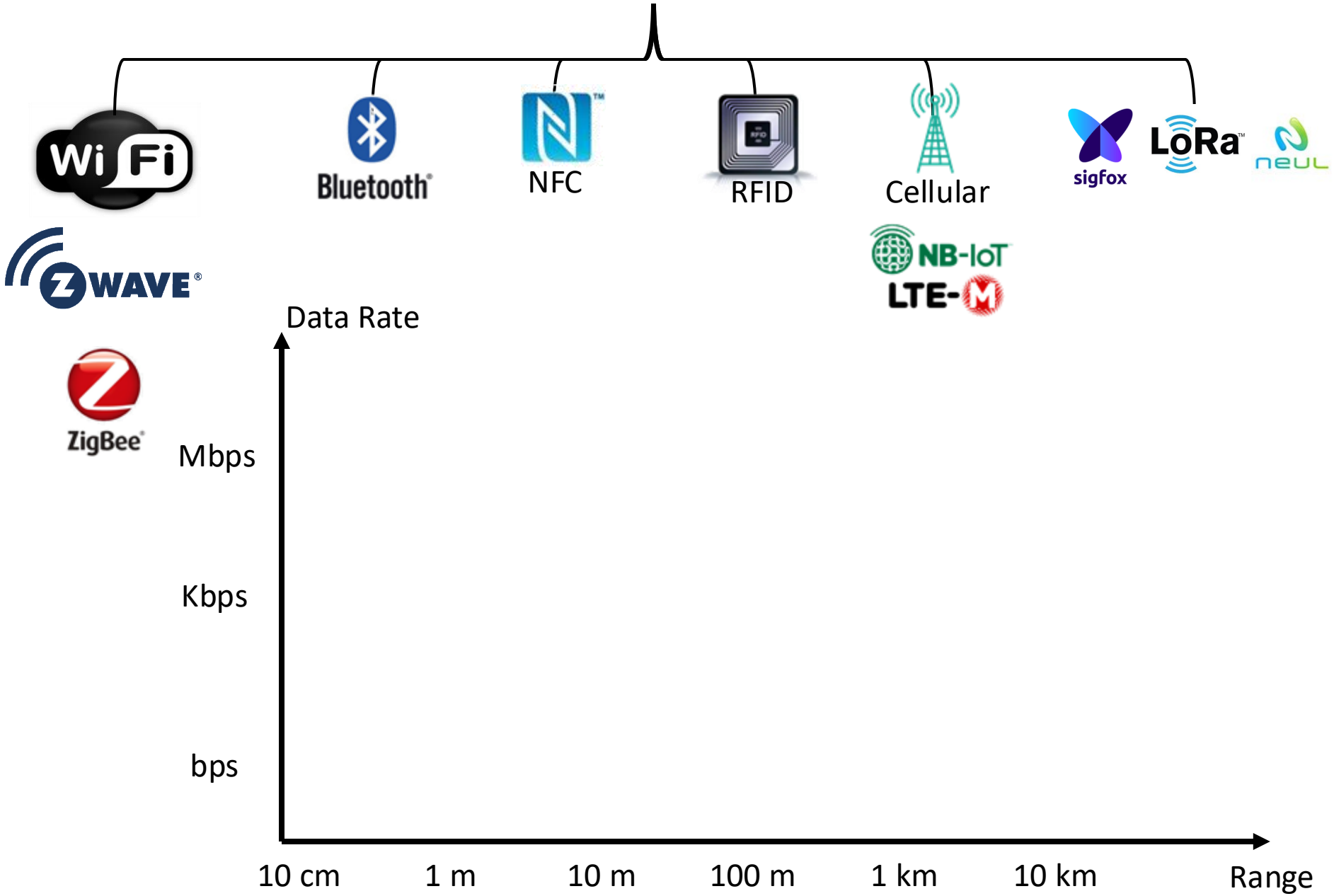
LoRa

neul

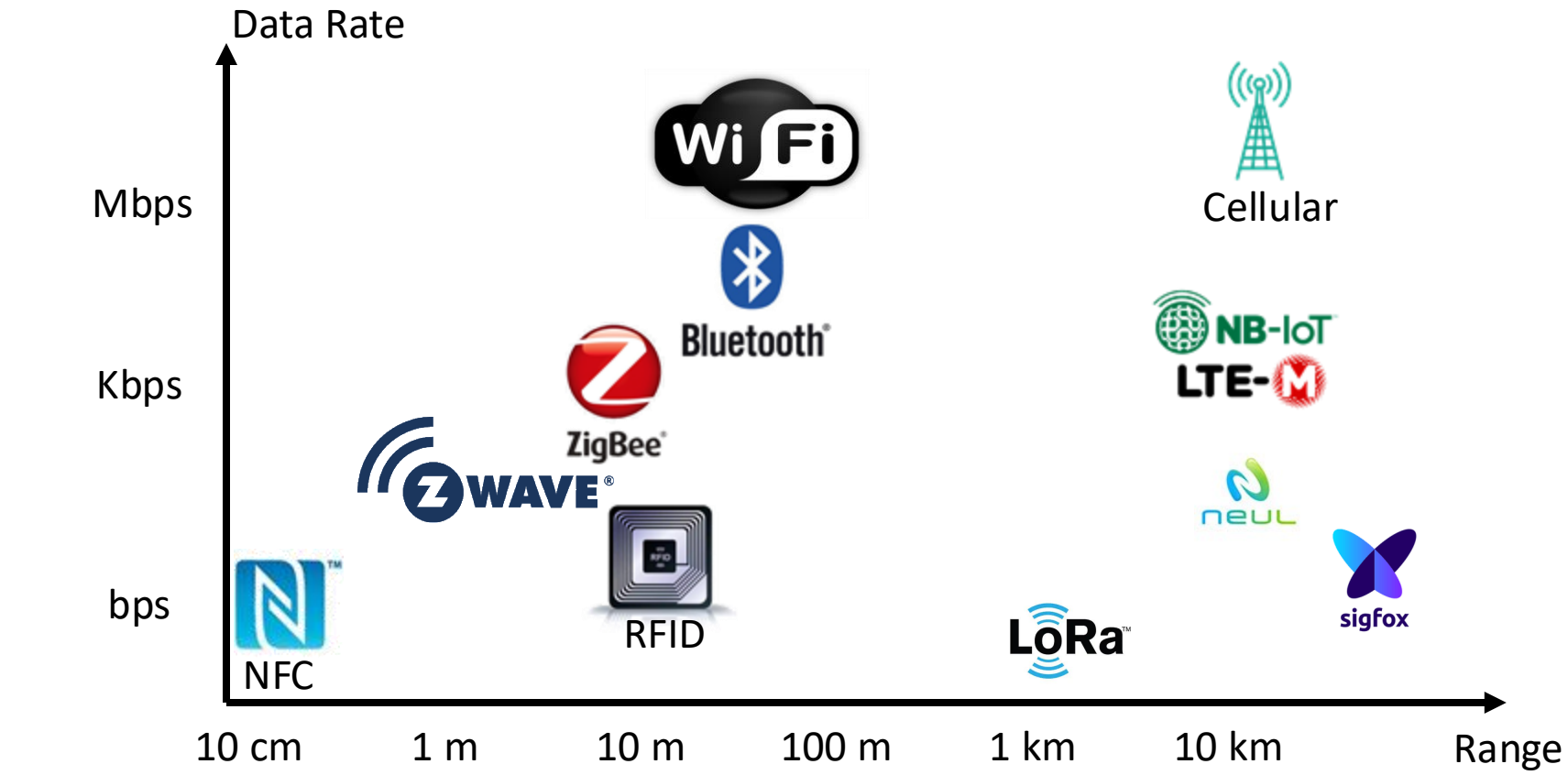
ZWAVE


ZigBee


# IoT Technologies

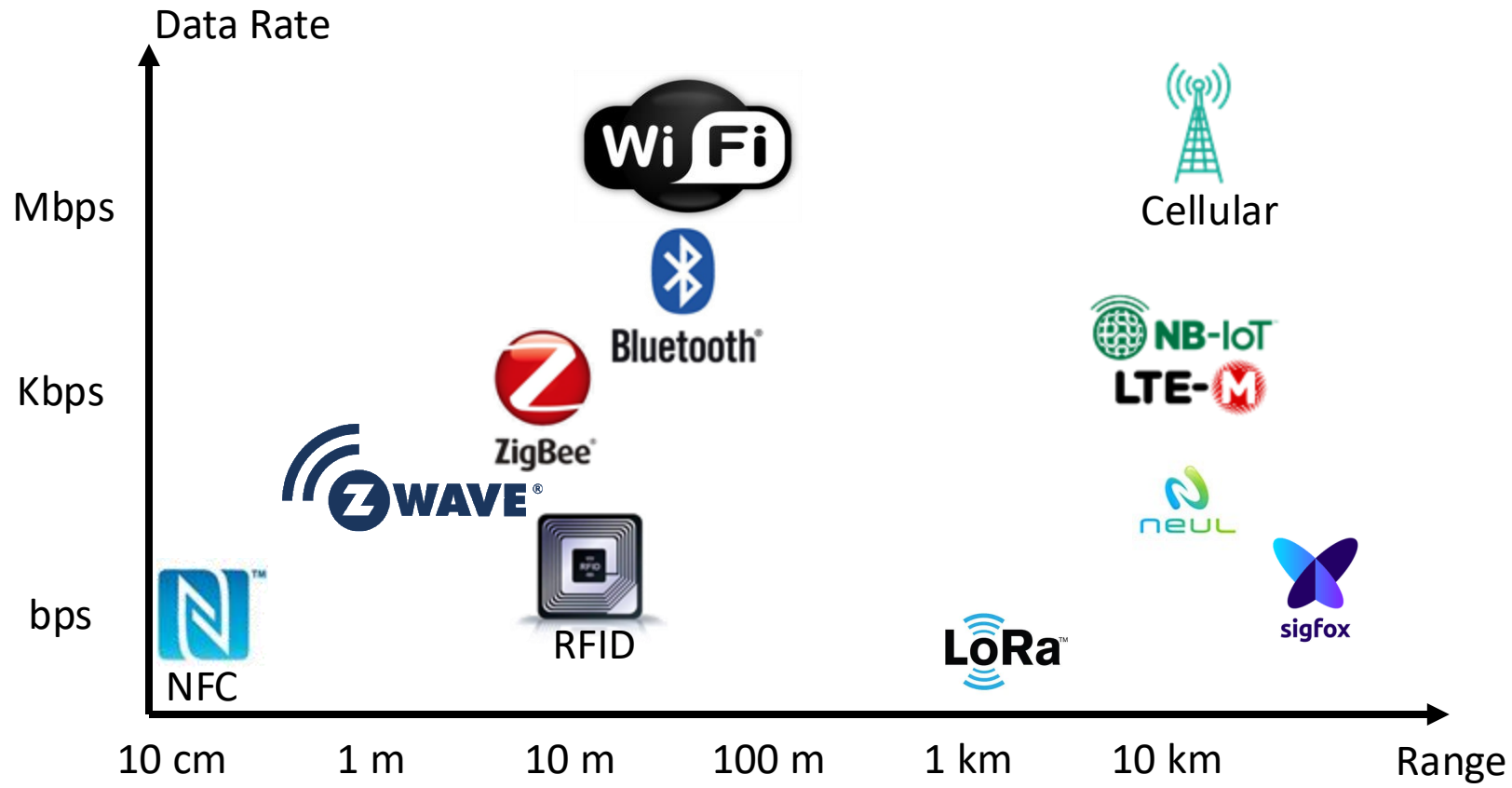


# IoT Technologies



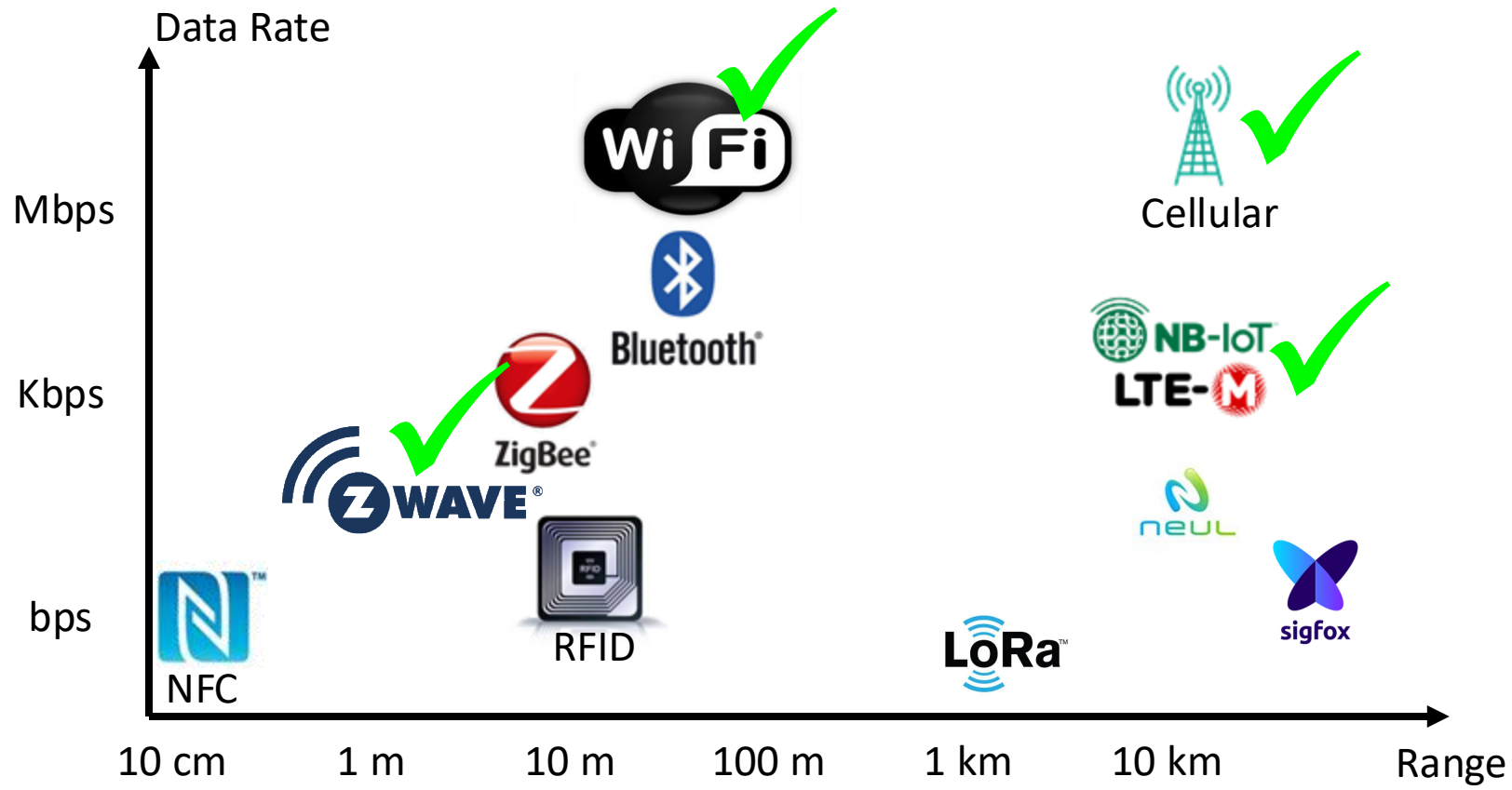
# IoT Technologies

Metrics to consider: Data Rate, Range,



# IoT Technologies

Metrics to consider: Data Rate, Range, Power (batter life), Cost



# IoT: Low Power Wide Area Networks




- Low power: battery lasts 5-10 years
- Low cost: $10-$20
- High range: 1 - 10 km
- Low Data rates: 100bps – 250 Kbps

# IoT: Low Power Wide Area Networks

LoRa™ neul sigfox

# IoT: Low Power Wide Area Networks




Digital Communication Technology:

CCS: Chirp Spread Spectrum

# CSS: Chirp Spread Spectrum

- Chirp is signal that continuously sweeps frequency with time.
- For linear chirp: $f(t) = \alpha t + f_0$

$$\phi(t) = \int 2\pi f(t)\, dt = 2\pi \frac{\alpha}{2} t^2 + 2\pi f_0 t + \phi_0$$

$$s(t) = \exp\left(j2\pi \frac{\alpha}{2} t^2 + j2\pi f_0 t + j\phi_0\right)$$

# CSS: Chirp Spread Spectrum

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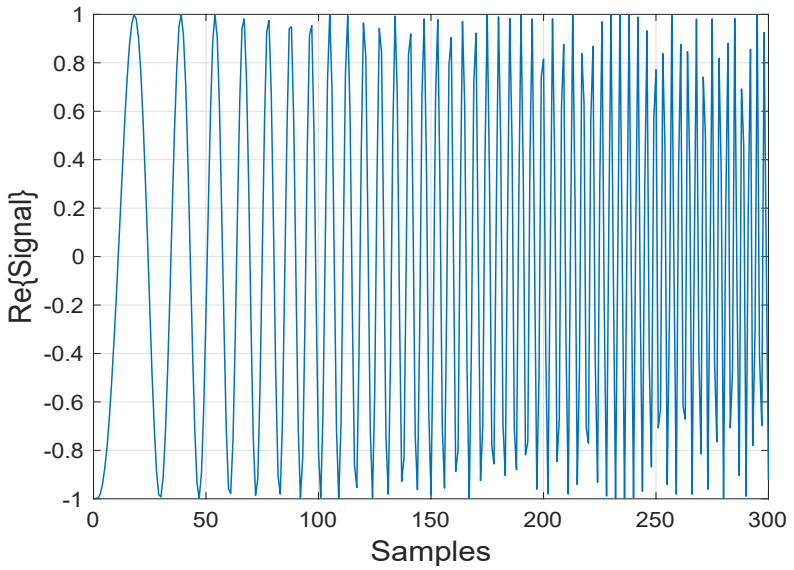
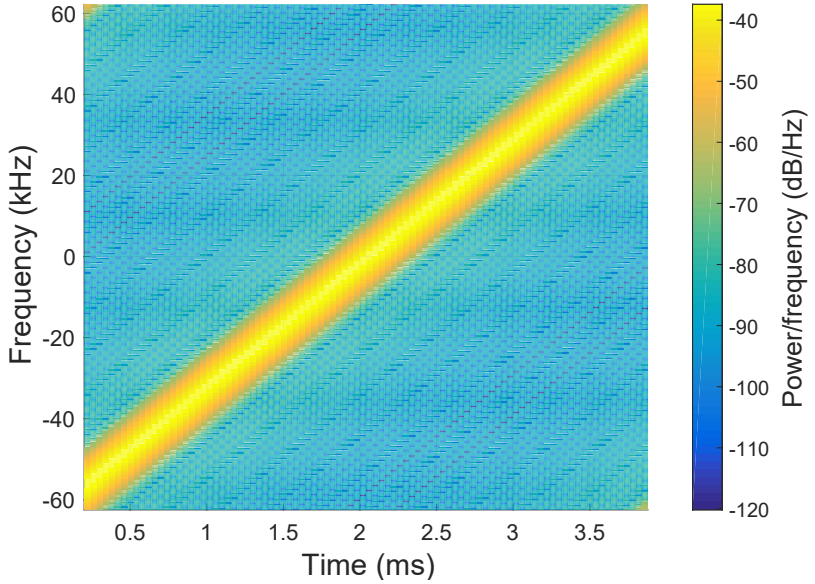
$$s(t) = \exp\left(j2\pi\frac{\alpha}{2}t^2 + j2\pi f_0 t + j\phi_0\right)$$

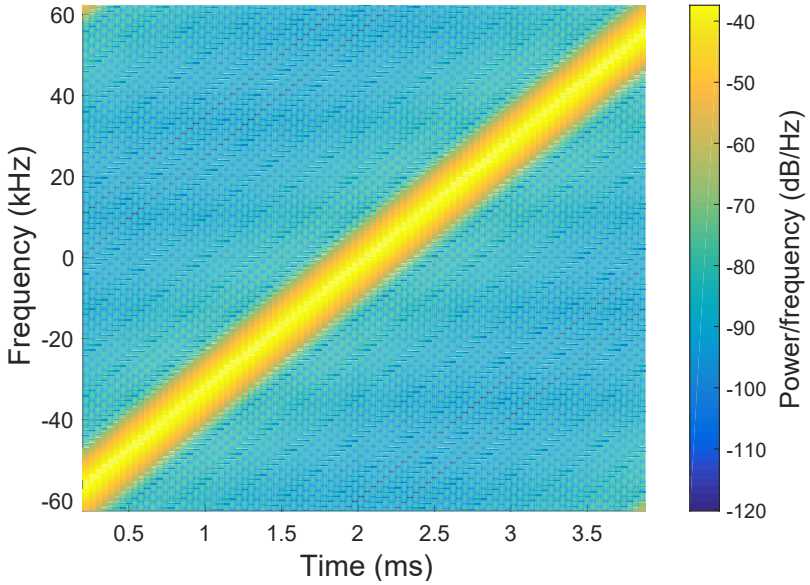


# CSS: Chirp Spread Spectrum

- For linear chirp: $f(t) = \alpha t + f_0$

$$s(t) = \exp\left(j2\pi\frac{\alpha}{2}t^2 + j2\pi f_0 t + j\phi_0\right)$$

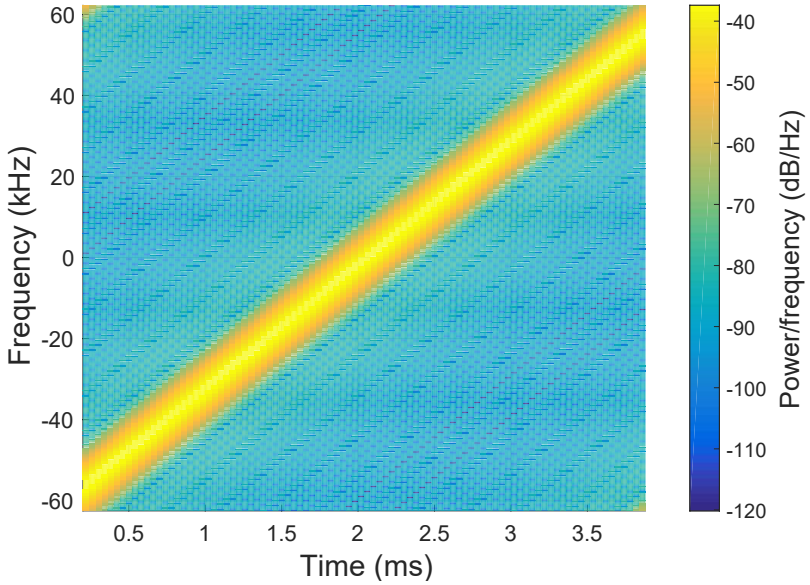



- Sweep from $-\frac{B}{2}$ to $+\frac{B}{2}$
- Sweep time is: $T_s$
- Sweep slope is: $\alpha = \frac{B}{T_s}$

# CSS: Chirp Spread Spectrum

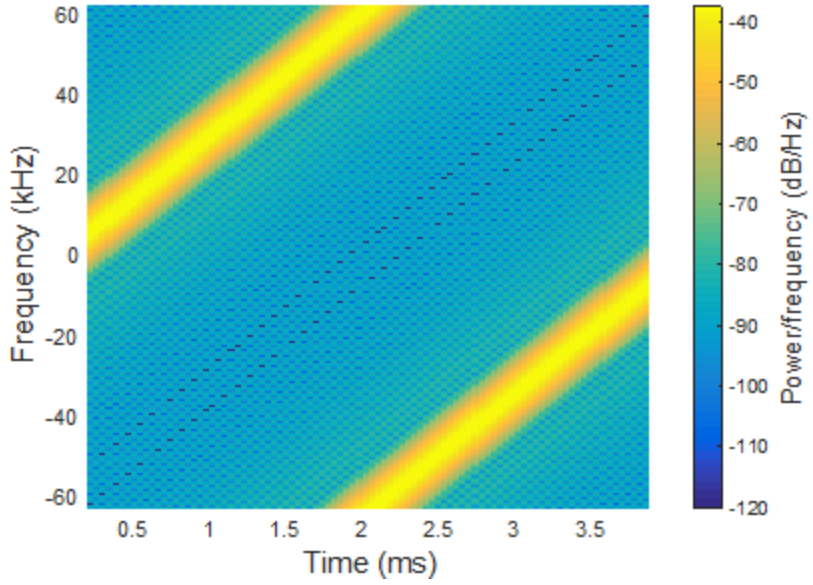
- Each symbol is sent as 1 chirp.
- Symbol time = Sweep time = $T_s$.
- Encode bits at sweep start.

bit = **'0'**




$$f(t) = \alpha t - B/2$$

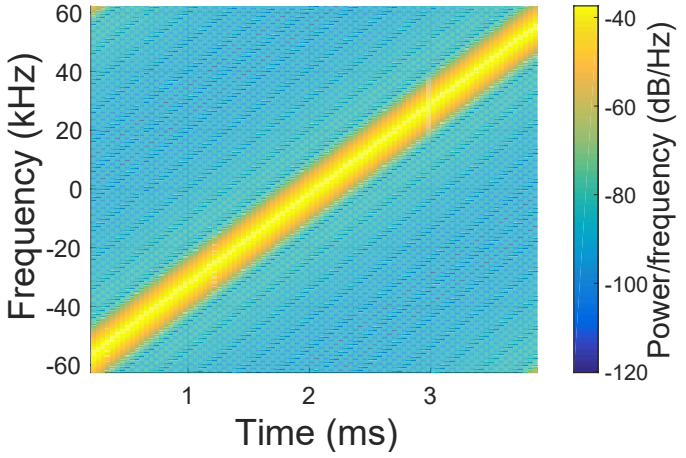
bit = **'1'**



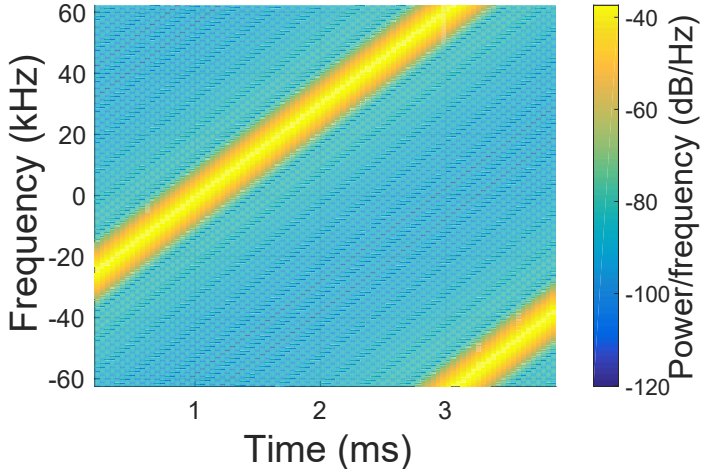

$$f(t) = \alpha t \bmod B$$

# CSS: Chirp Spread Spectrum

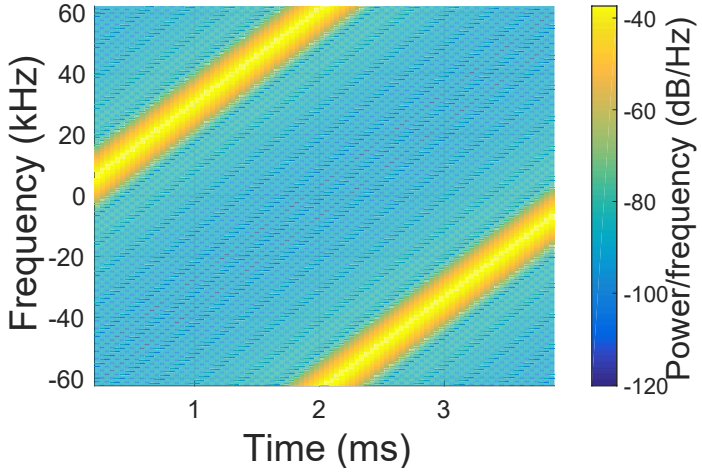
bits = **‘00’**



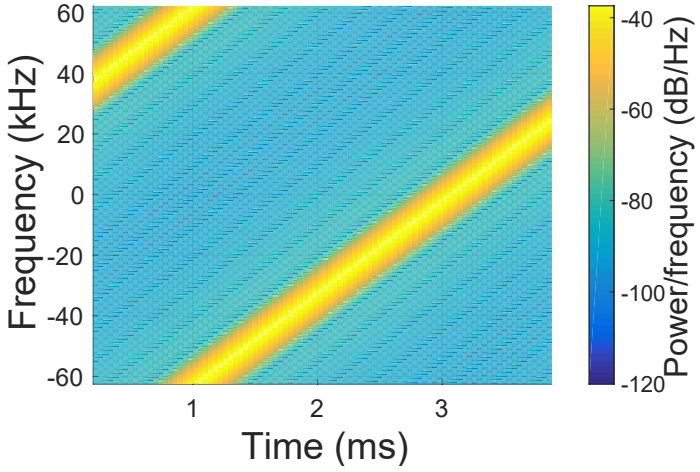

bits = **‘01’**




bits = **‘10’**




bits = **‘11’**



# CSS: Chirp Spread Spectrum

In general, to encode $n$ bits per symbol: $2^n$ shifts

But, How do we decode?

# But, How do we decode?

## At TX:

bit = **'0'** $s_0(t) = \exp\left(j2\pi\frac{\alpha}{2}t^2 - j2\pi\frac{B}{2}t + j\phi_0\right)$

bit = **'1'** $s_1(t) = \exp\left(j2\pi\frac{\alpha}{2}t^2 + j\phi_0\right)$

## At RX:

$$y(t) \times s_0^*(t) = y(t)\exp\left(-j2\pi\frac{\alpha}{2}t^2 + j2\pi\frac{B}{2}t\right)$$

bit = **'0'** $= \exp(j\phi_0)$

bit = **'1'** $= \exp\left(j2\pi\frac{B}{2}t + j\phi_0\right)$

FFT

Pulse at $f = 0$

Pulse at $f = \frac{B}{2}$

# But, How do we decode?

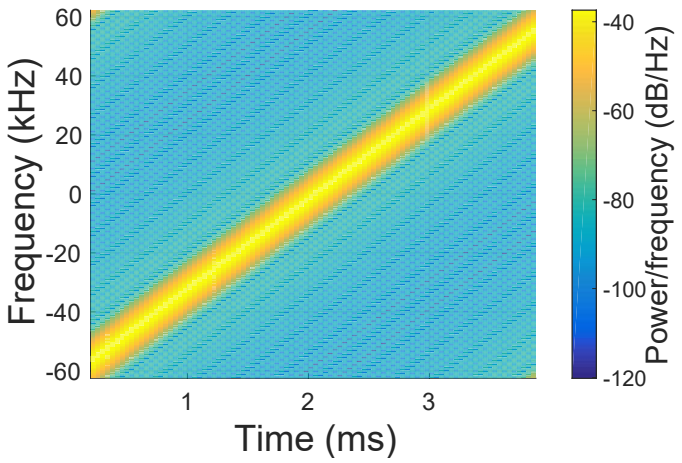
(1) Demodulate by multiplying with $s_0^*(t)$

(2) Take and FFT over symbol time

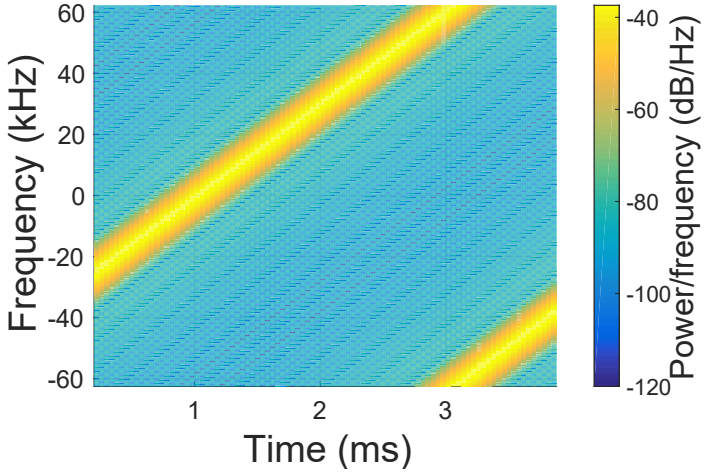
(3) Find position of the peak

# But, How do we decode?

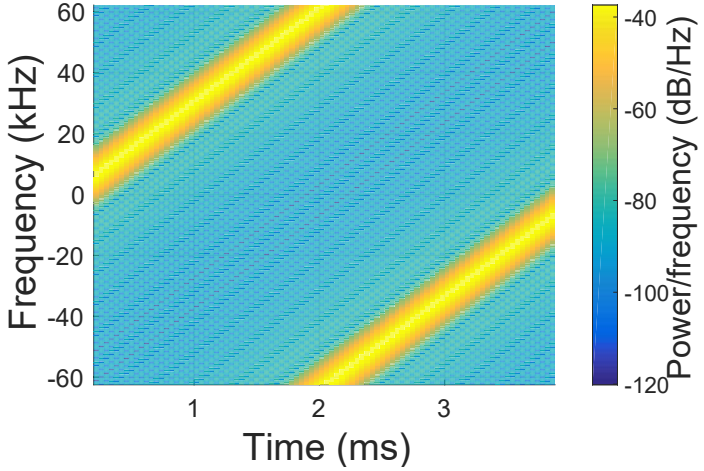
bits = **‘00’**



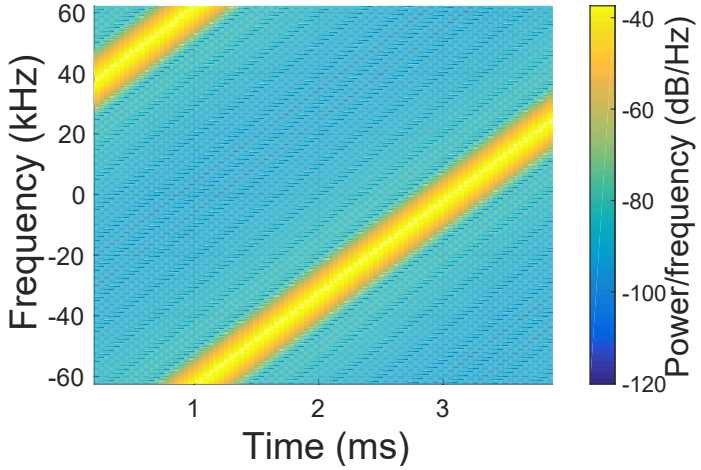

bits = **‘01’**




bits = **‘10’**

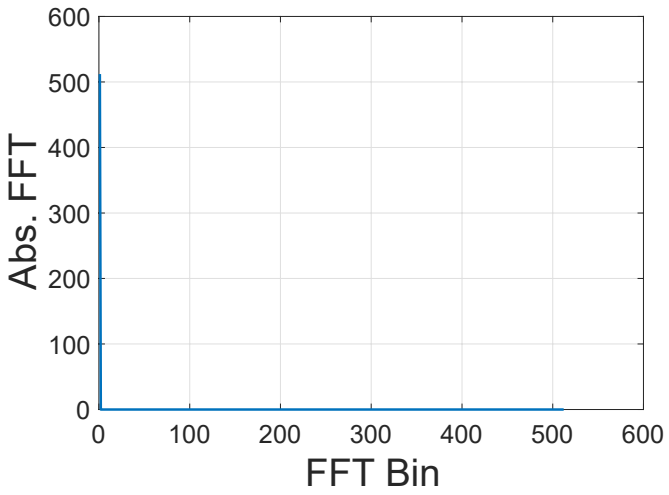



bits = **‘11’**

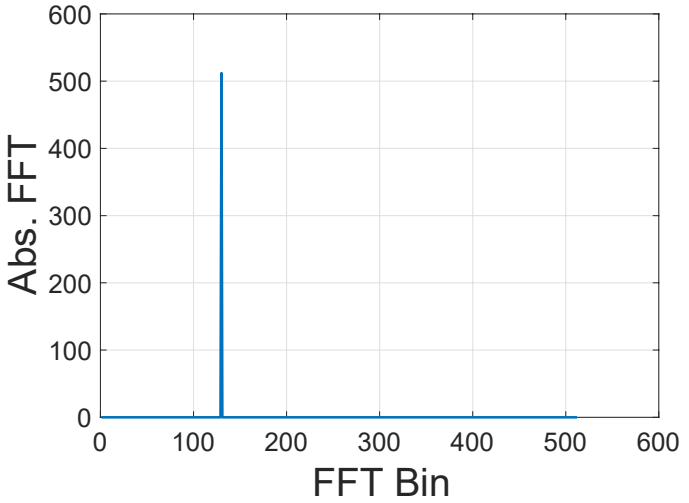


# But, How do we decode?

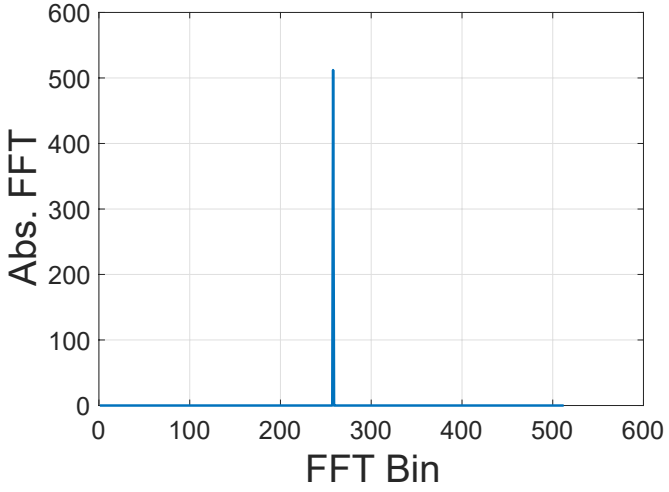
bits = **‘00’**




bits = **‘01’**




bits = **‘10’**

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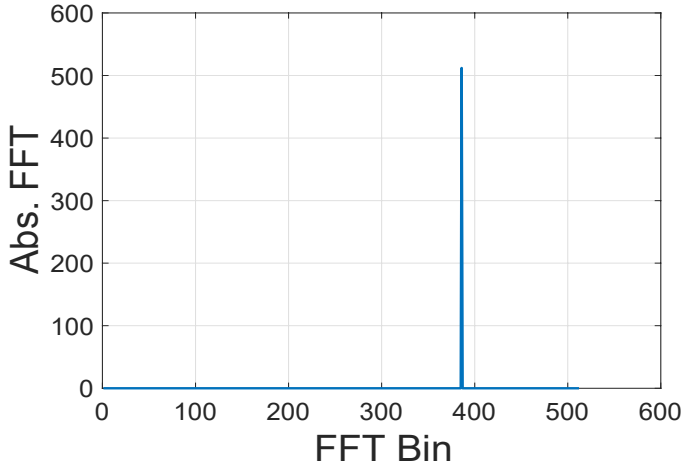


# What about the wireless channel?

LPWAN use low bandwidth (120kHz)

Narrow band channel

$$y(t) = h\, s_0(t) \times s_0^*(t)$$

bit = **'0'** $= h \exp(j\phi)$

bit = **'1'** $= h \exp\left(j2\pi \frac{B}{2} t + j\phi\right)$

FFT

Pulse at $f = 0$

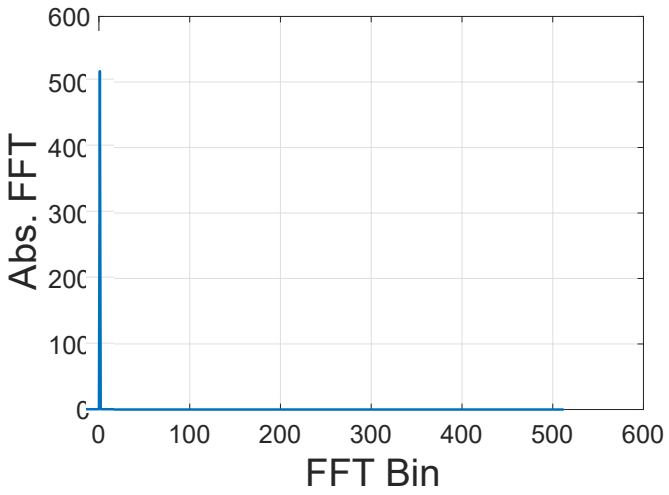
Pulse at $f = \frac{B}{2}$

Channel changes amplitude & phase but not position of pulse

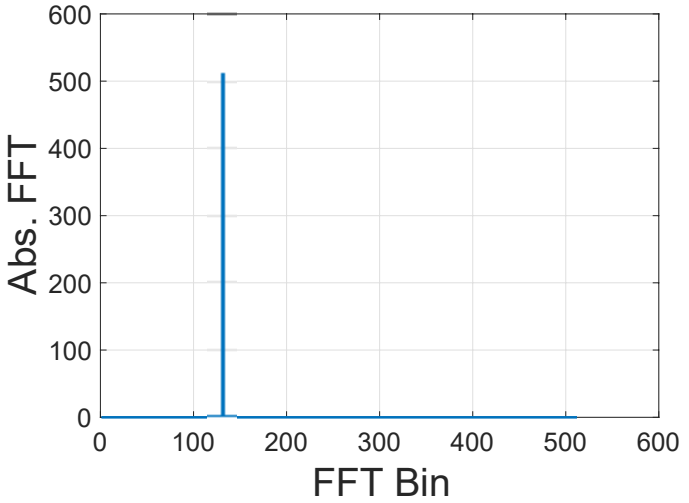
→ Can decode without correcting for channel

# What about CFO & Sampling offset?

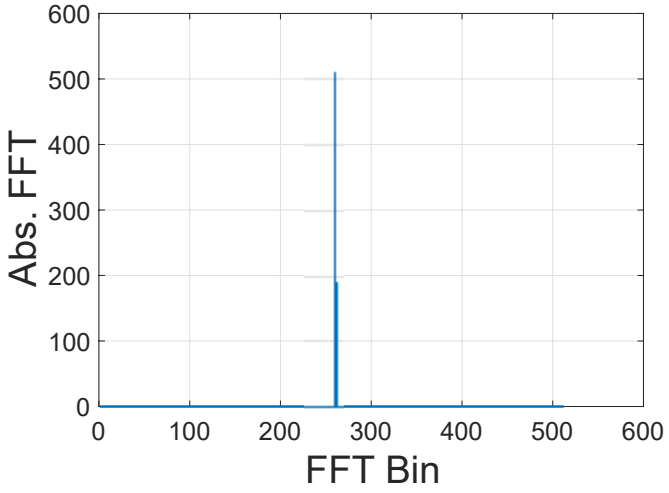
bits = **‘00’**



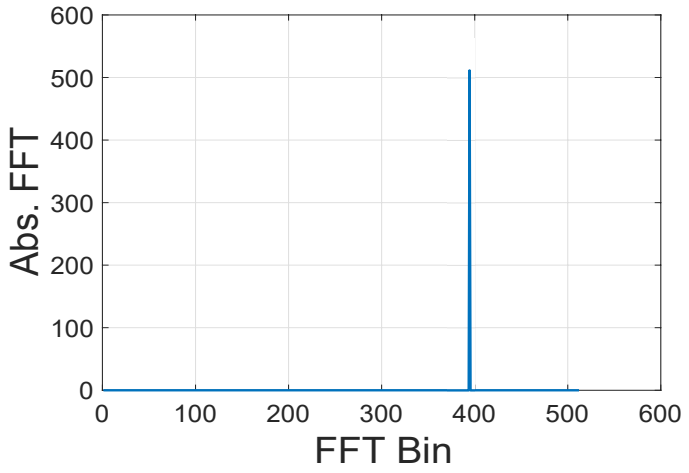

bits = **‘01’**




bits = **‘10’**




bits = **‘11’**



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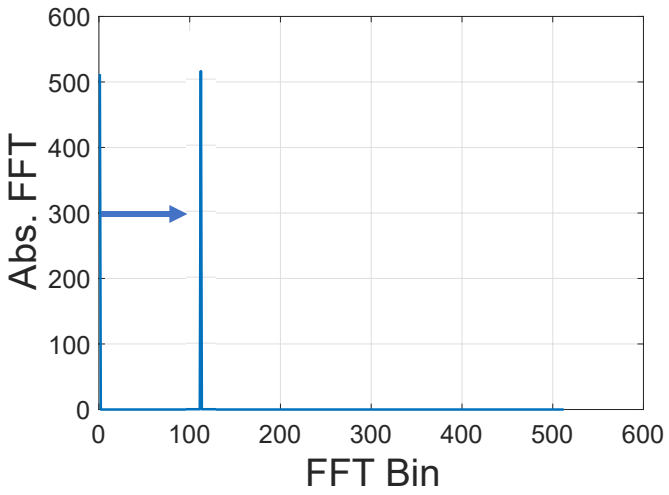
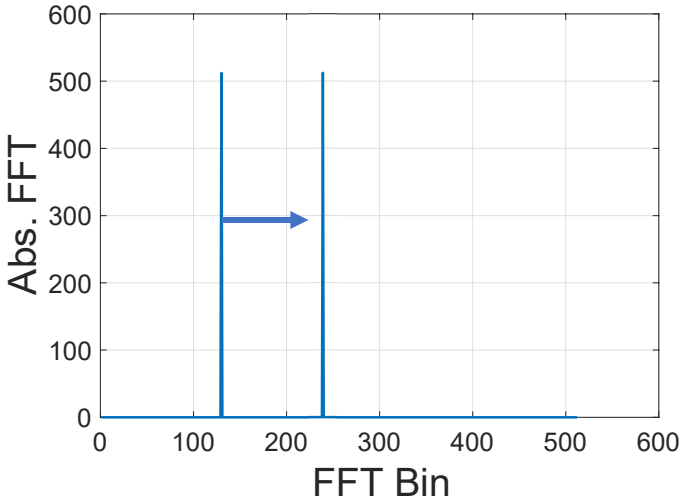
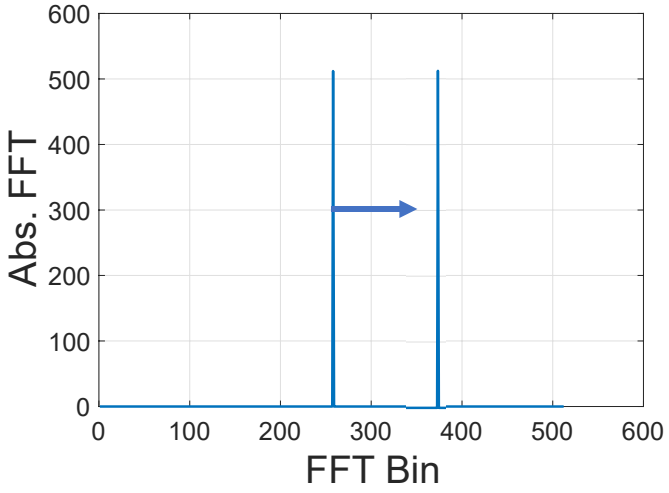



bits = **‘01’**




bits = **‘10’**

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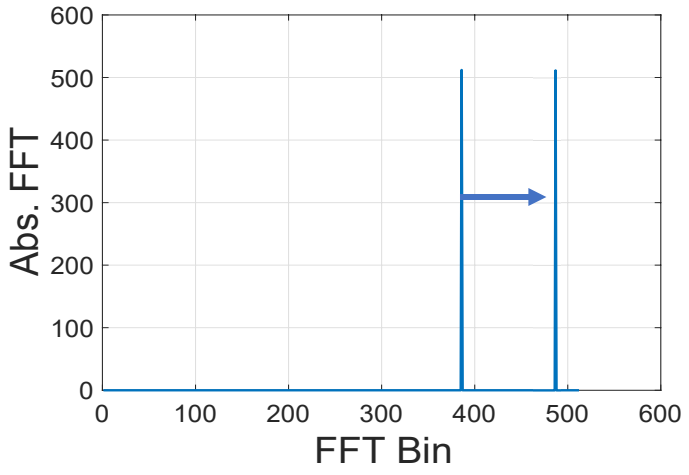
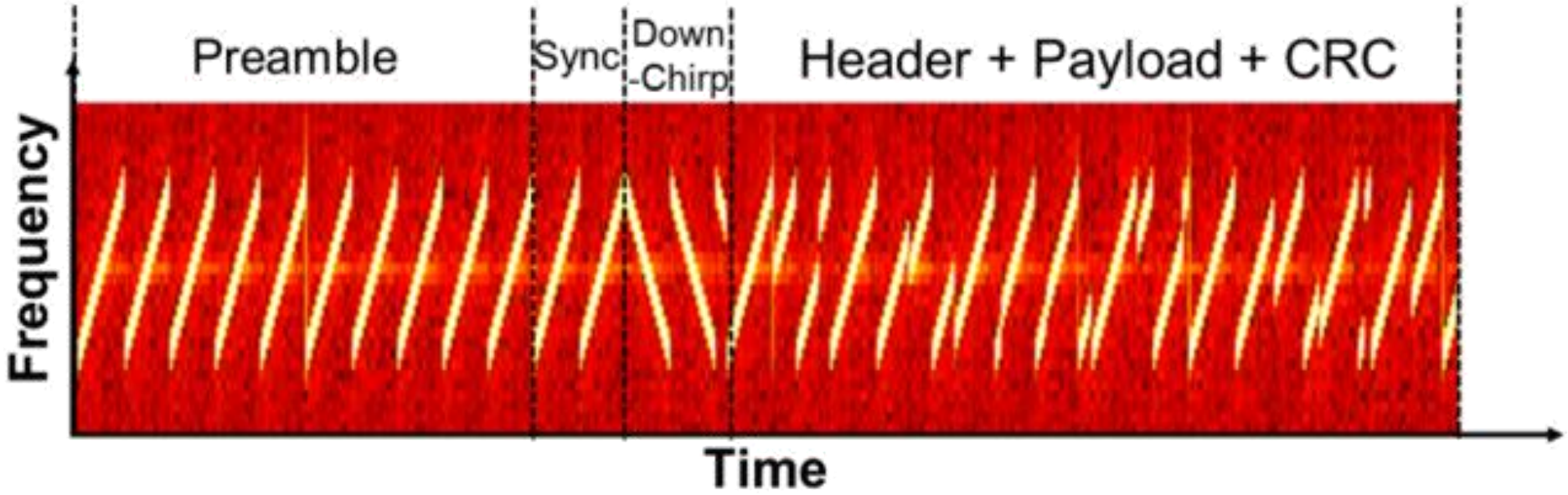
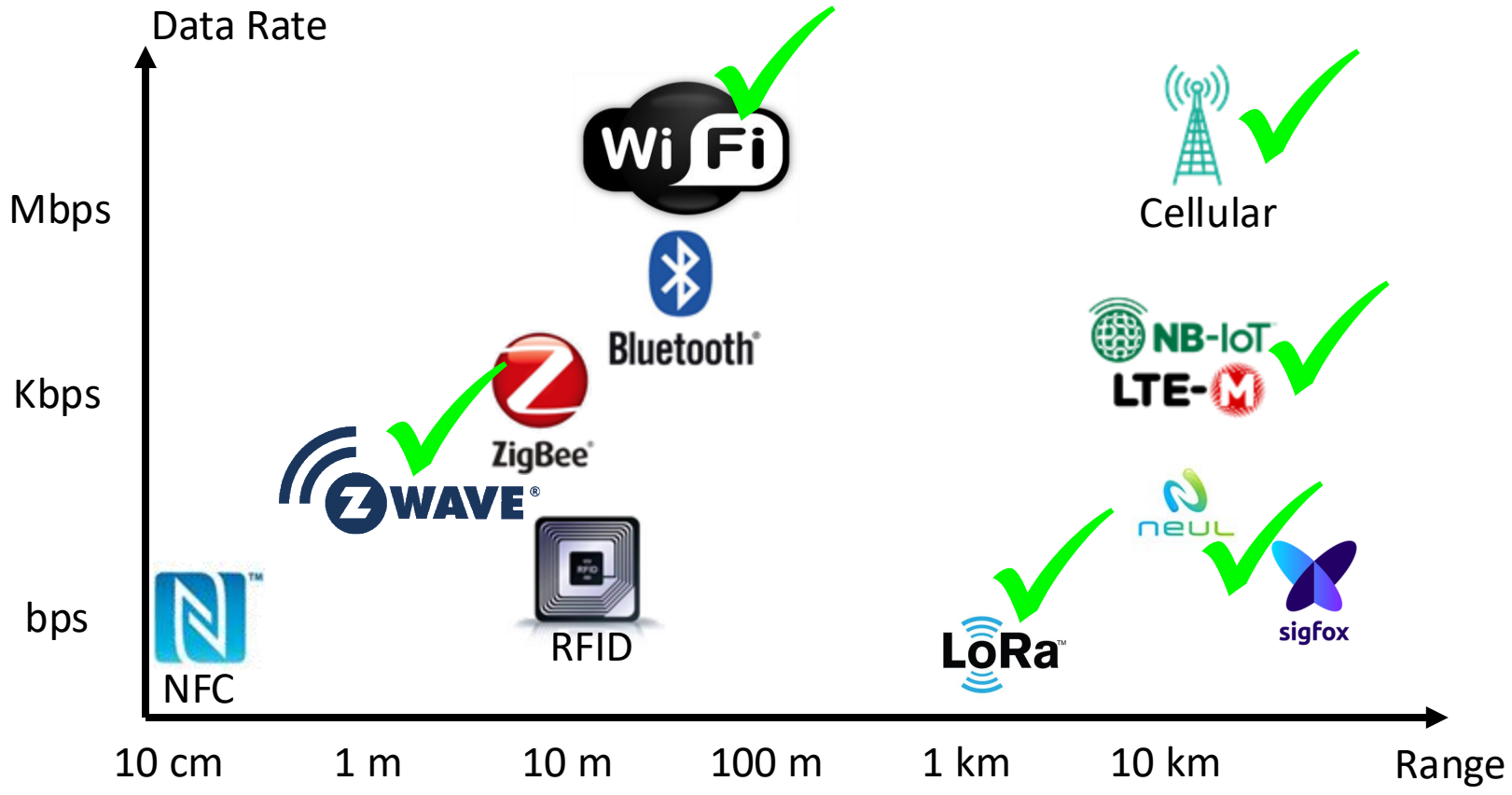


# LoRaWAN™: Packet Structure



# 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

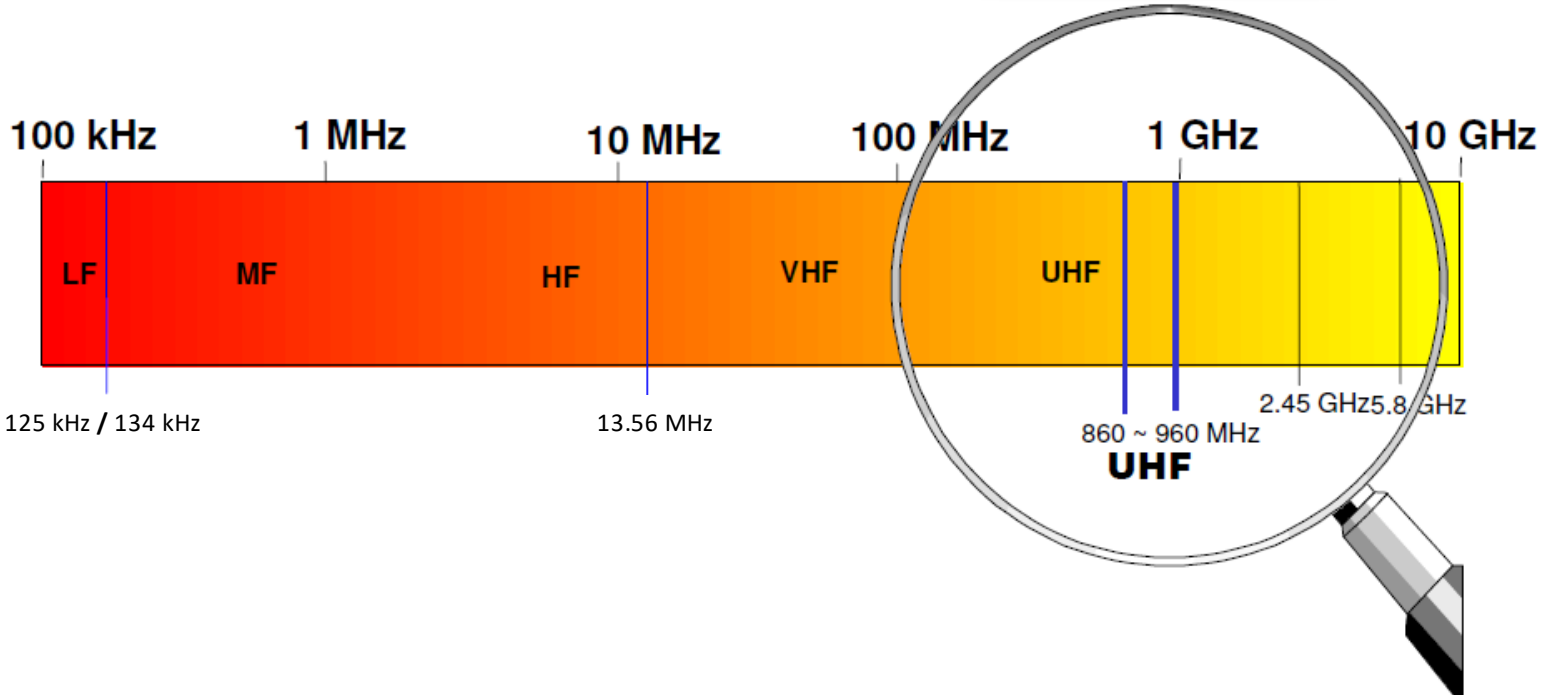
- No battery
- Short range
- Long life span
- Backscatters a reader's signal using OOK

# RFID: Radio Frequency IDentification

Passive RFID

HF (Same as NFC)


UHF



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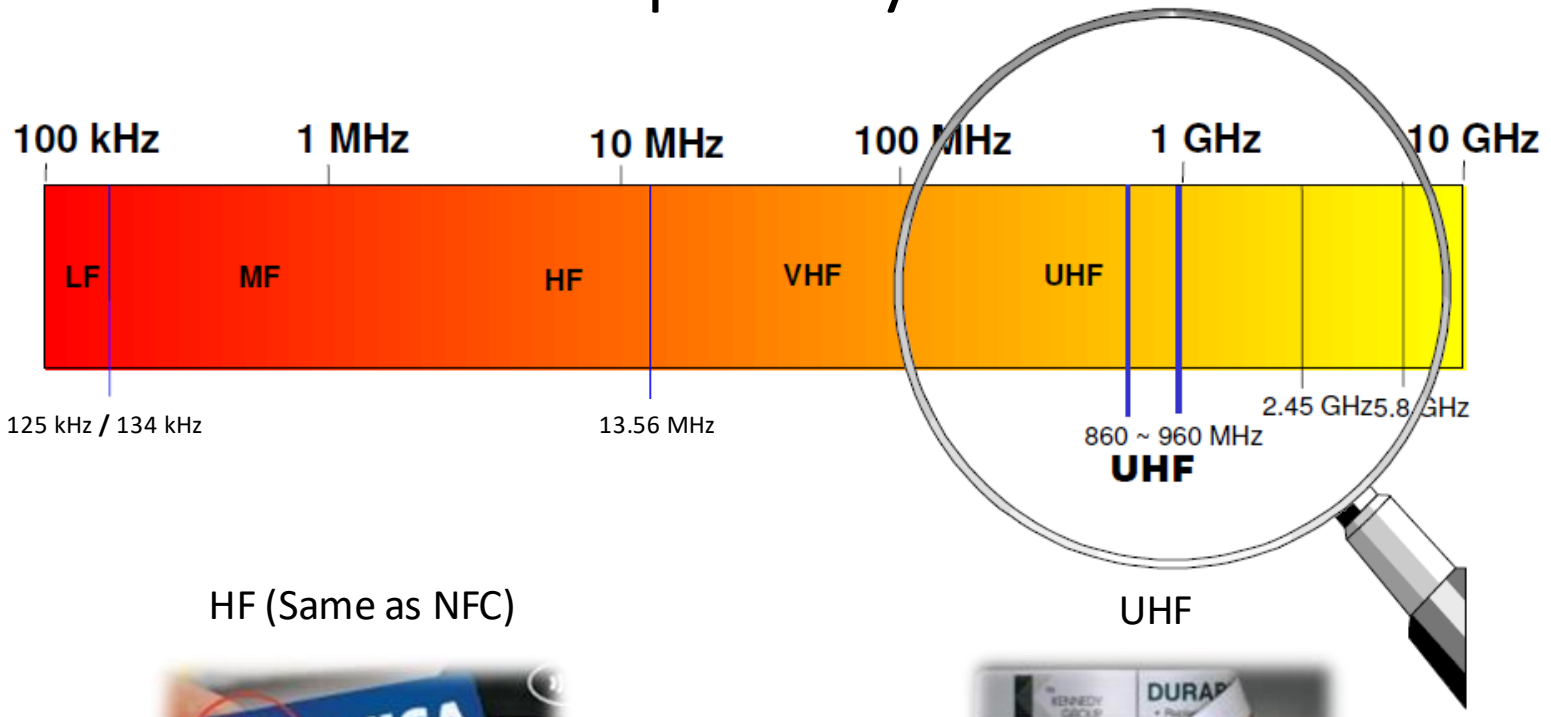
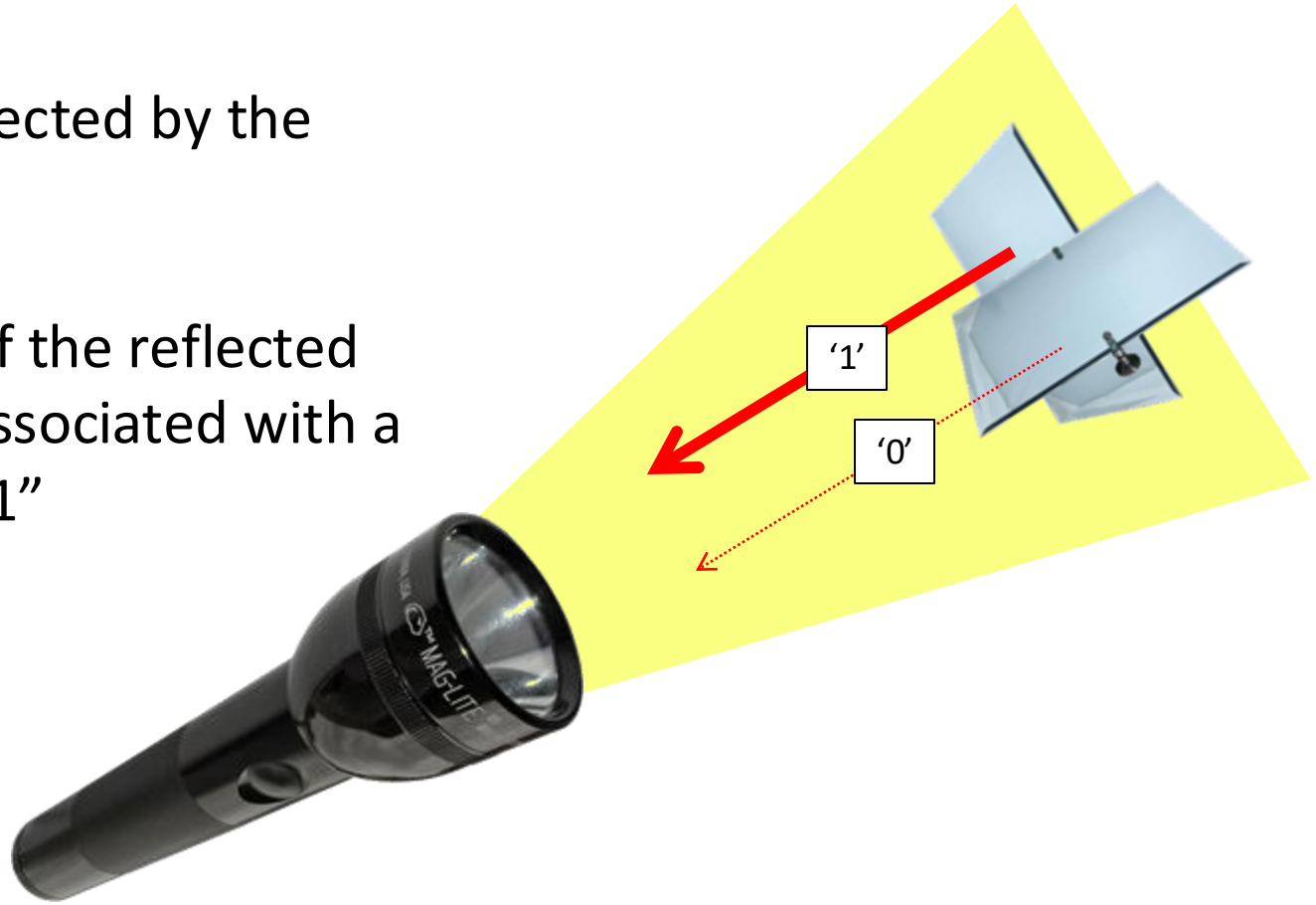


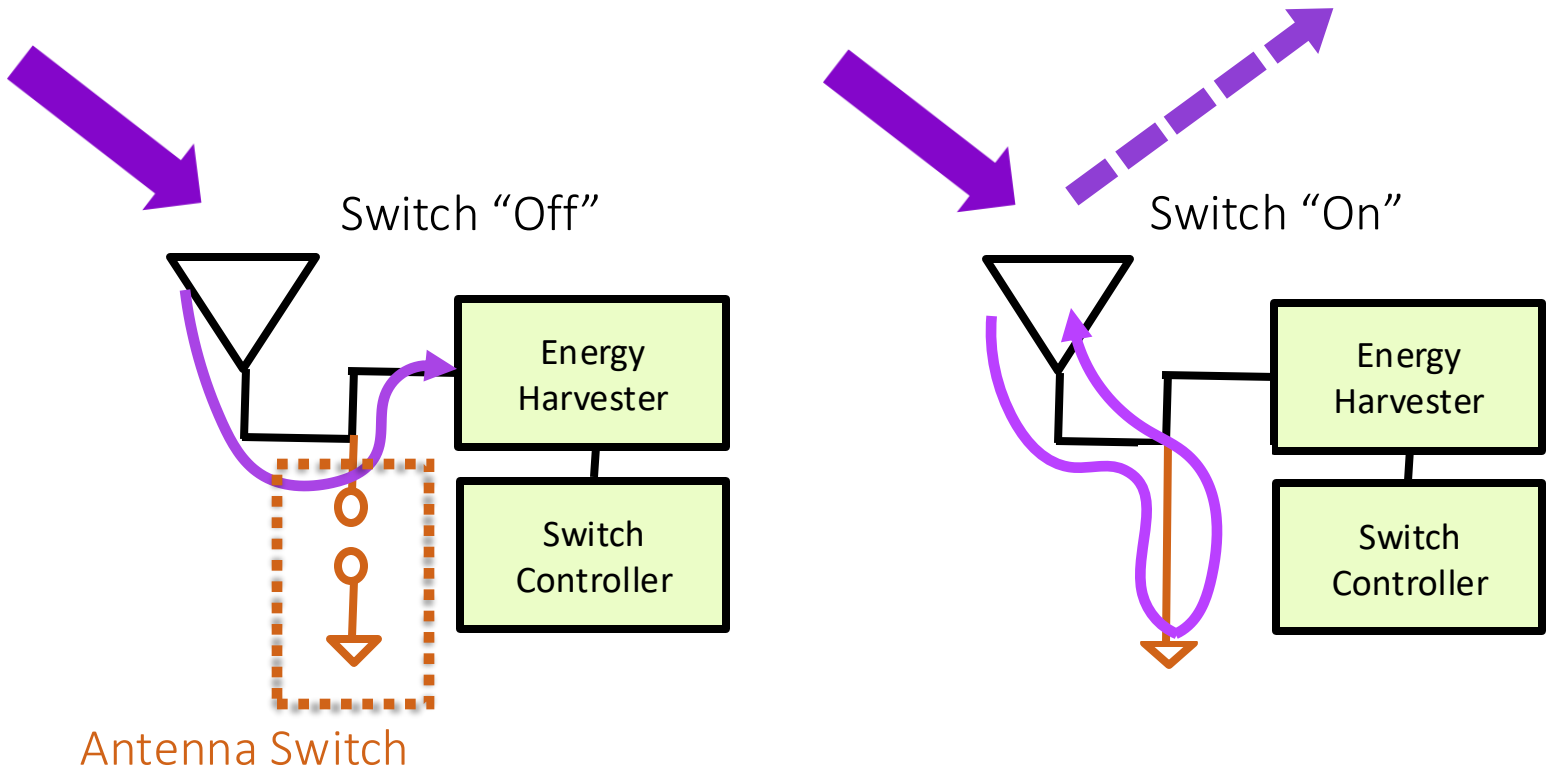

| | HF (Same as NFC) | UHF |
|---|---|---|
| |  |  |
| Range: | < 1cm | Few meters |
| Data Rate: | bps to few kbps | 100s kbps |
| Technology: | Backscatter over Inductive Coupling | Backscatter over RF |

# 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”



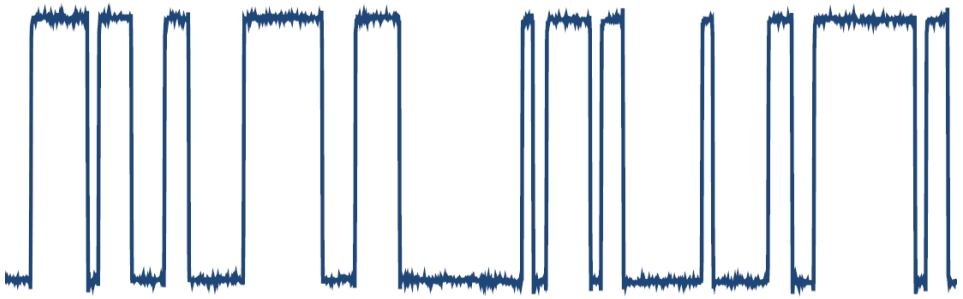
# Backscatter Communication



# Backscatter Communication


# Backscatter Communication

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



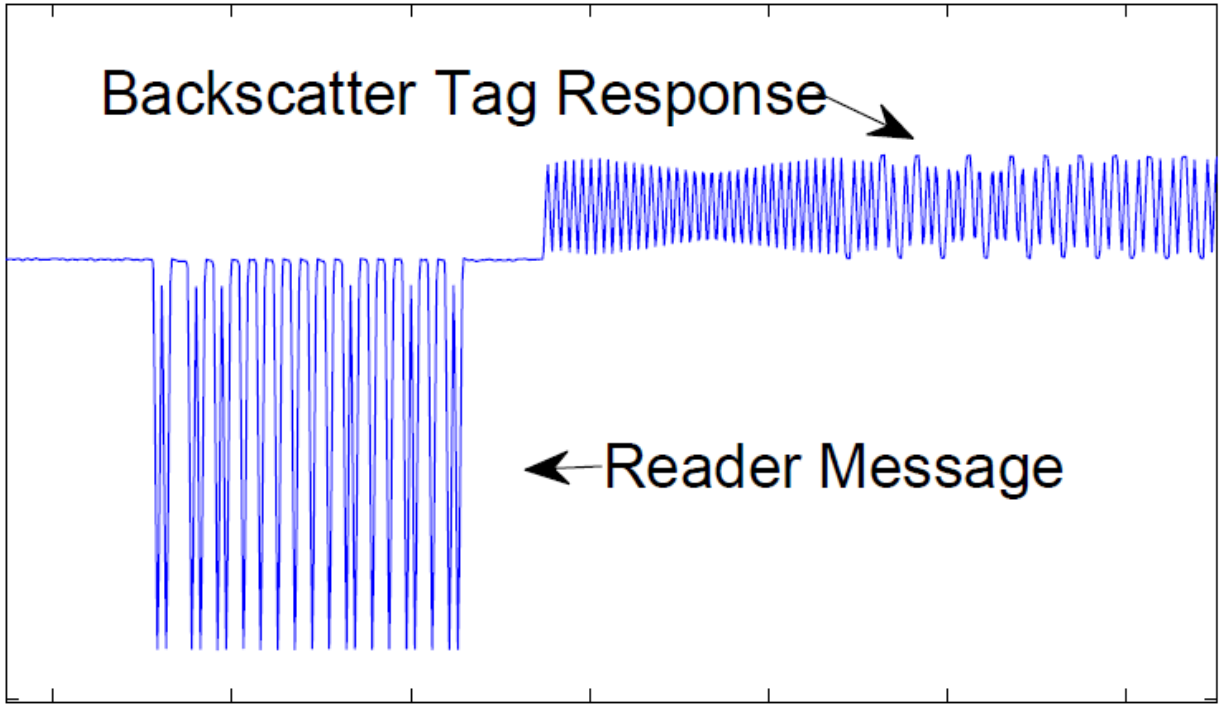
Reader shines an RF signal on nearby RFIDs

# Backscatter Communication

- Reader Transmits Continuous Sine Wave: $x(t) = \cos(2\pi f_c t)$

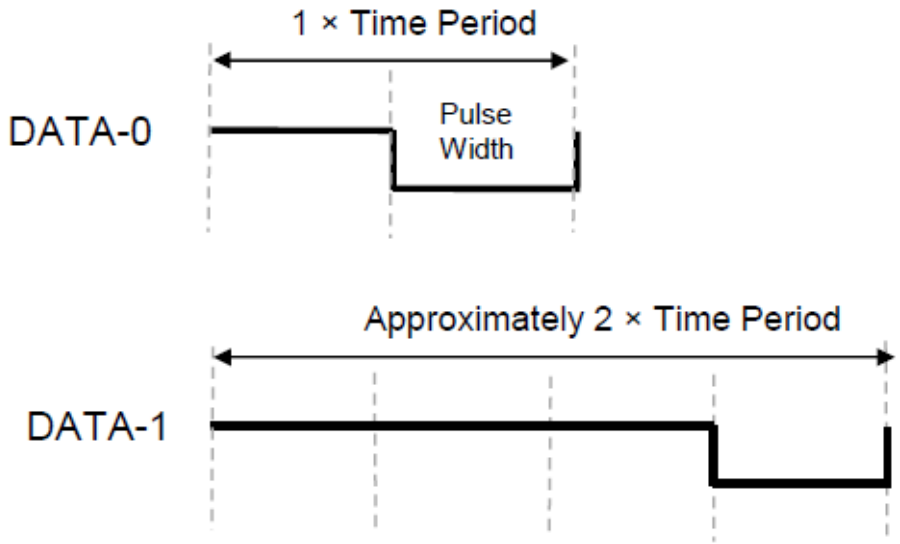
- Tag either reflect or doesn't reflect the signal

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



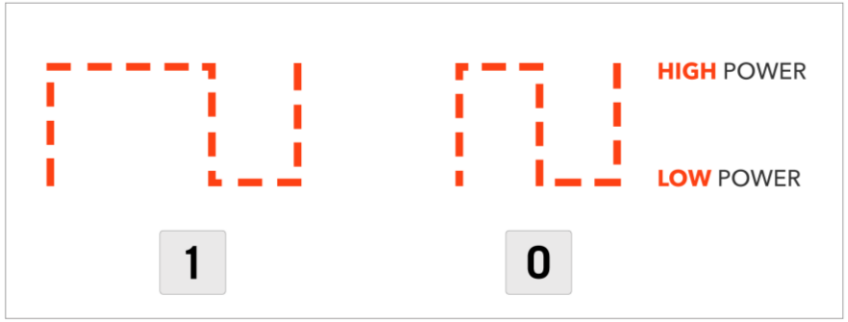
# Backscatter Communication

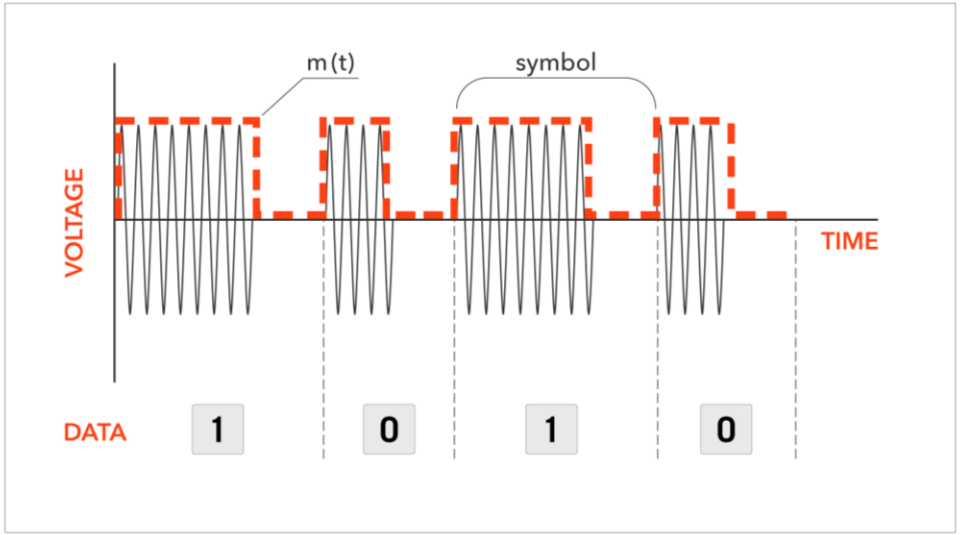
- Both Reader and Tag Use ON-OFF Keying for modulation
- Bit Encoding, however, can differ.
- Reader-to-Tag Encoding: Pulse Interval Encoding (PIE)



# Backscatter Communication

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



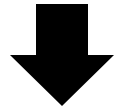



# Backscatter Communication

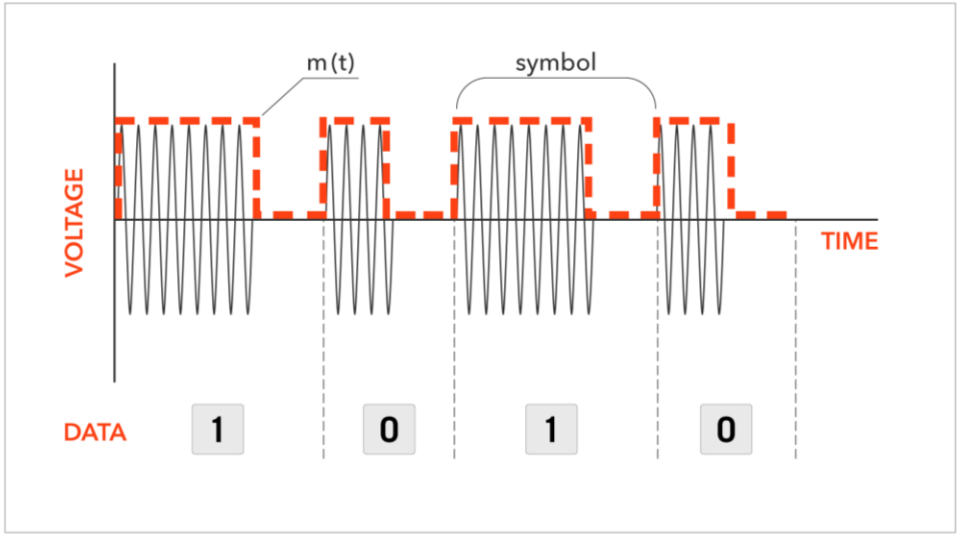
- Reader-to-Tag Encoding: Pulse Interval Encoding (PIE)

Why use PIE encoding?


Signal is on for longer time



Maximize energy harvesting at the tag.

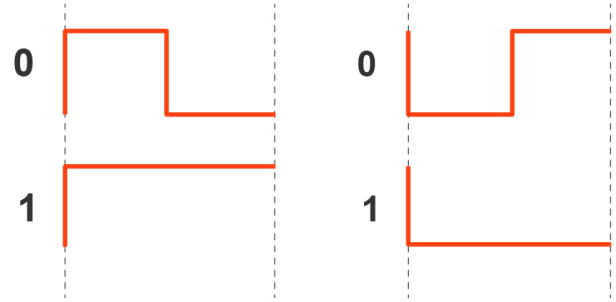


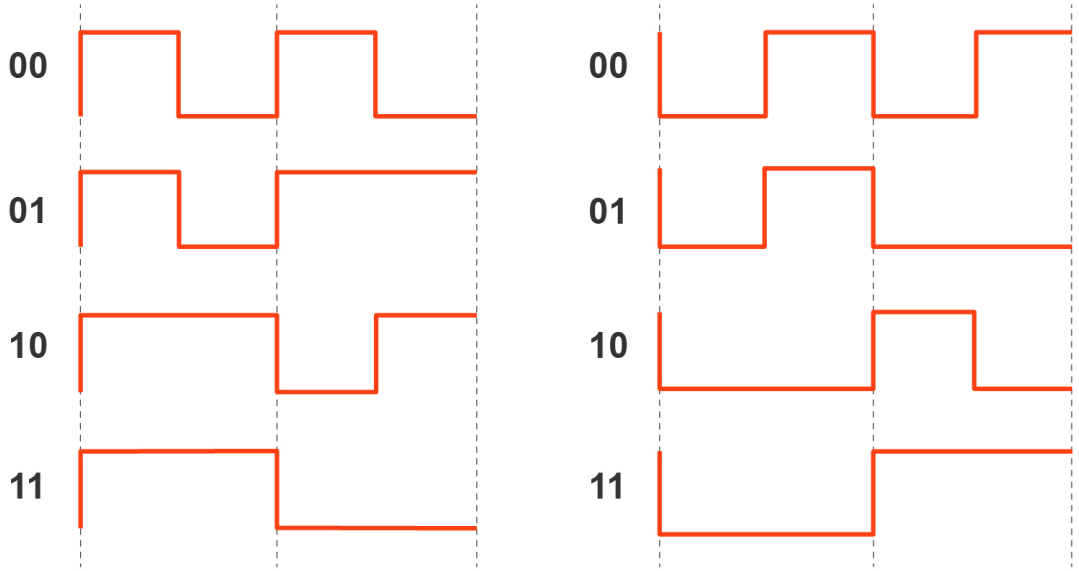
# Backscatter Communication

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

# Backscatter Communication

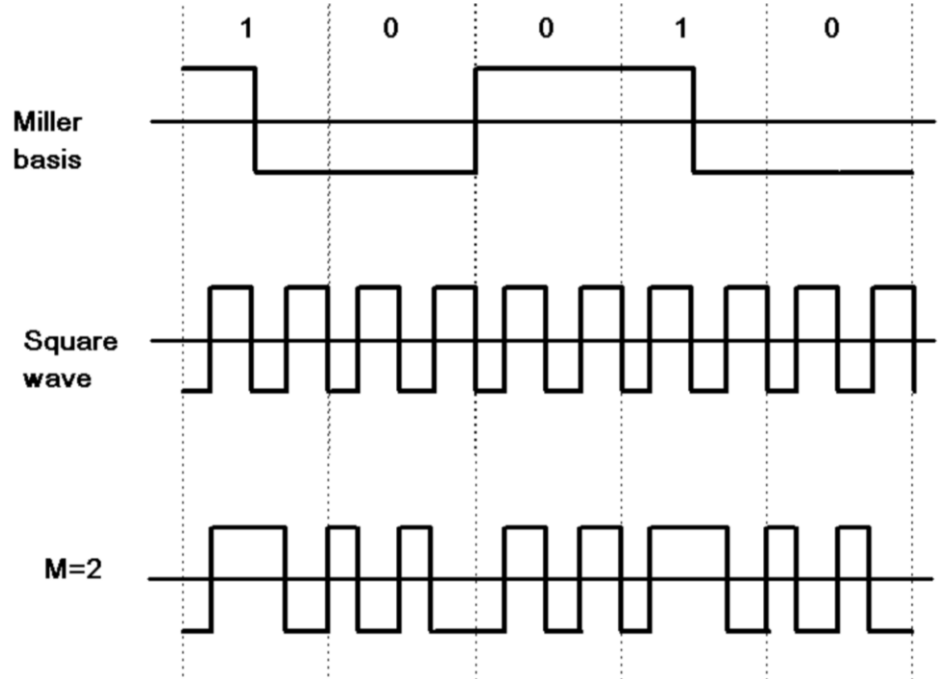
- Tag-to-Reader Encoding: FM0
- Inverts the switch at every symbol
- 0 bits has extra switch mid-symbol



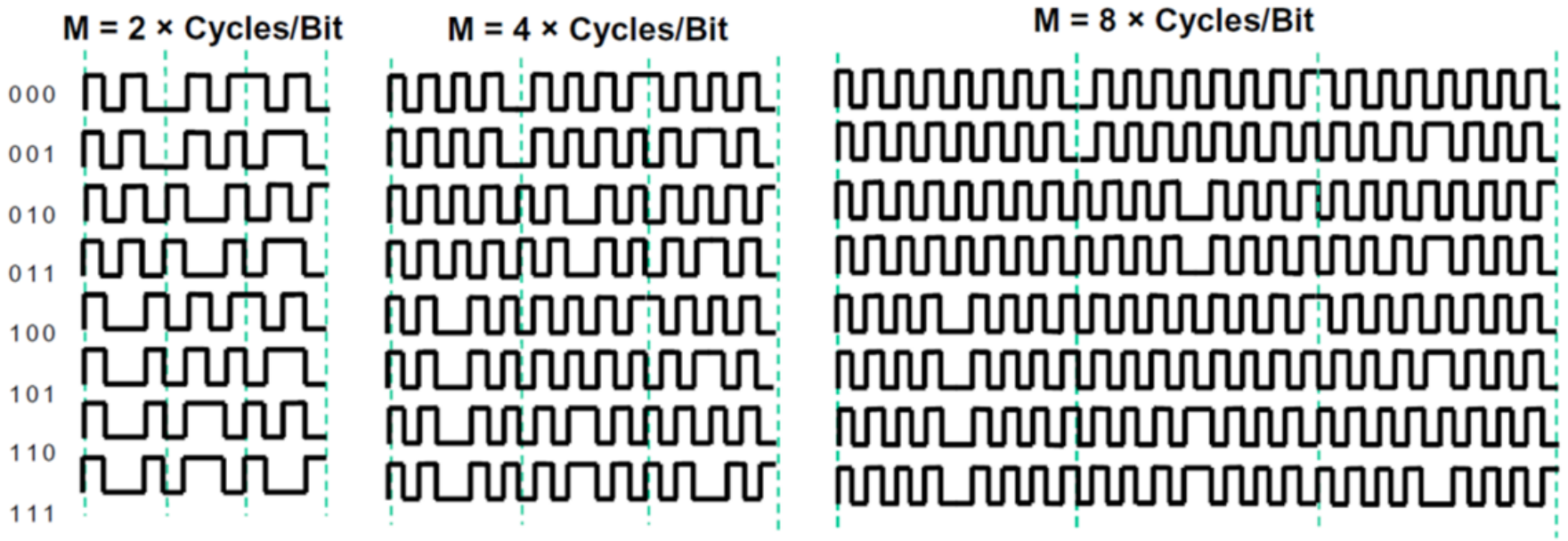
# Backscatter Communication

- 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



# Backscatter Communication

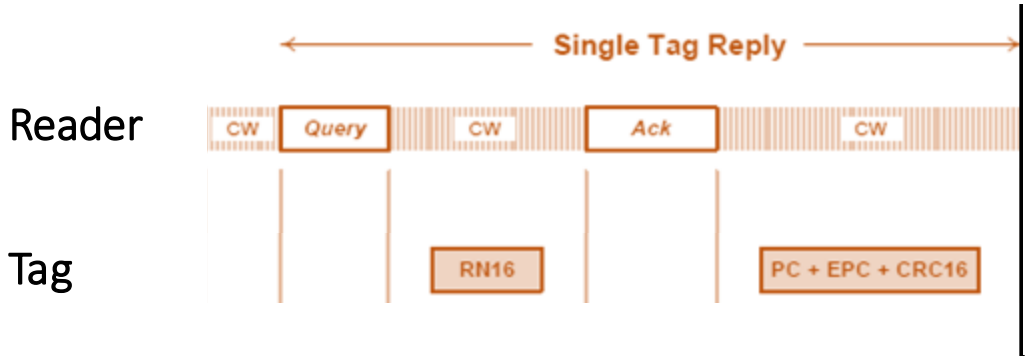
- Tag-to-Reader Encoding: Miller
- Inverts the switch between two consecutive 0 bit symbols
- Inverts the switch in the middle of 1 bit symbol
- Multiple by square wave of M times symbol rate for M=2,4,8



# 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

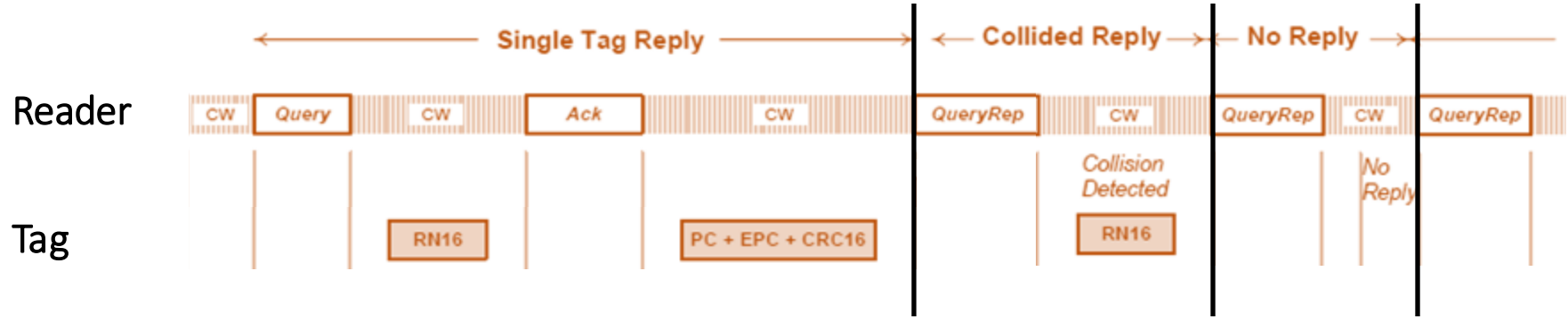
# EPC Gen2 Standard – MAC




Slotted Aloha:

- Reader allocates Q time slots and transmits a query at the beginning of each time slot
- Each tag picks a random slot and transmits a 16-bit random number
- In each slot:
  - RN16 decoded → Reader ACKs → Tags transmits 96-bit ID
  - Collision → Reader moves on to next slot
  - No reply → Reader moves on to next slot

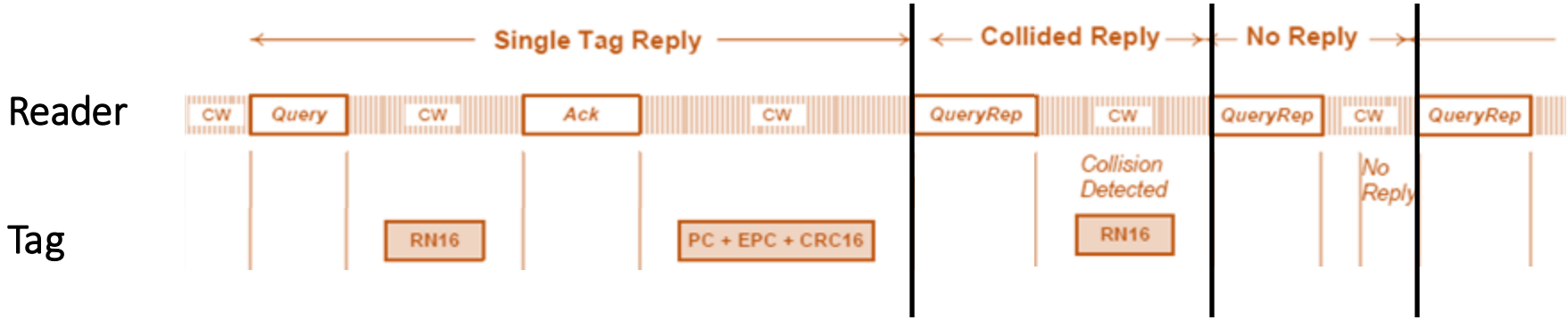
# EPC Gen2 – MAC




Inefficient:

- If reader allocates large number of slots → Too many empty slots
- If reader allocates small number of slots → Too many collisions

# EPC Gen2 – MAC




Inefficient:

- If reader allocates large number of slots → Too many empty slots
- If reader allocates small number of slots → Too many collisions
- If reader knows number of tags = N → Allocate K=N slots → 37% efficiency
- Downlink overhead