MAS.S61: Emerging Wireless & Mobile Technologies

Lecture 4: Low-power communication, RFID

RFID (Radio Frequency IDentification)

Access Control

Inventory control

Security Sensitive Applications

Tracking & Localization

Long-Range Payment Systems

RFID (Radio Frequency IDentification)

Access Control

Inventory control

> 100 Billion in the world

Tracking & Localization

Long-Range Payment Systems

Basic Principle of Operation

RFID: cheap battery-free stickers

Reply to wireless reader
with a unique identifier

History of RFIDs

- WWII: Aircraft IFF Transponder
  - Identify Friend or Foe, Transmitter-Responder

- 1945: “The Thing” or “The Great Seal Bug”
  - “Gift” given by the Soviets to American ambassador

- 1980s: development of E-Toll transponders
- 2004: Auto-ID lab at MIT led to the birth of modern battery-free RFIDs
  - Goal: supply chain chain optimization
  - Paper: “Towards the 5 cent tag”

Types of RFIDs

Frequency Range

UHF (~900MHz)

HF (13.56MHz)

LF (120-150kHz)

long range (few m)

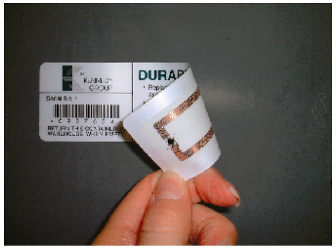
short range (few cm)

Range of Operation

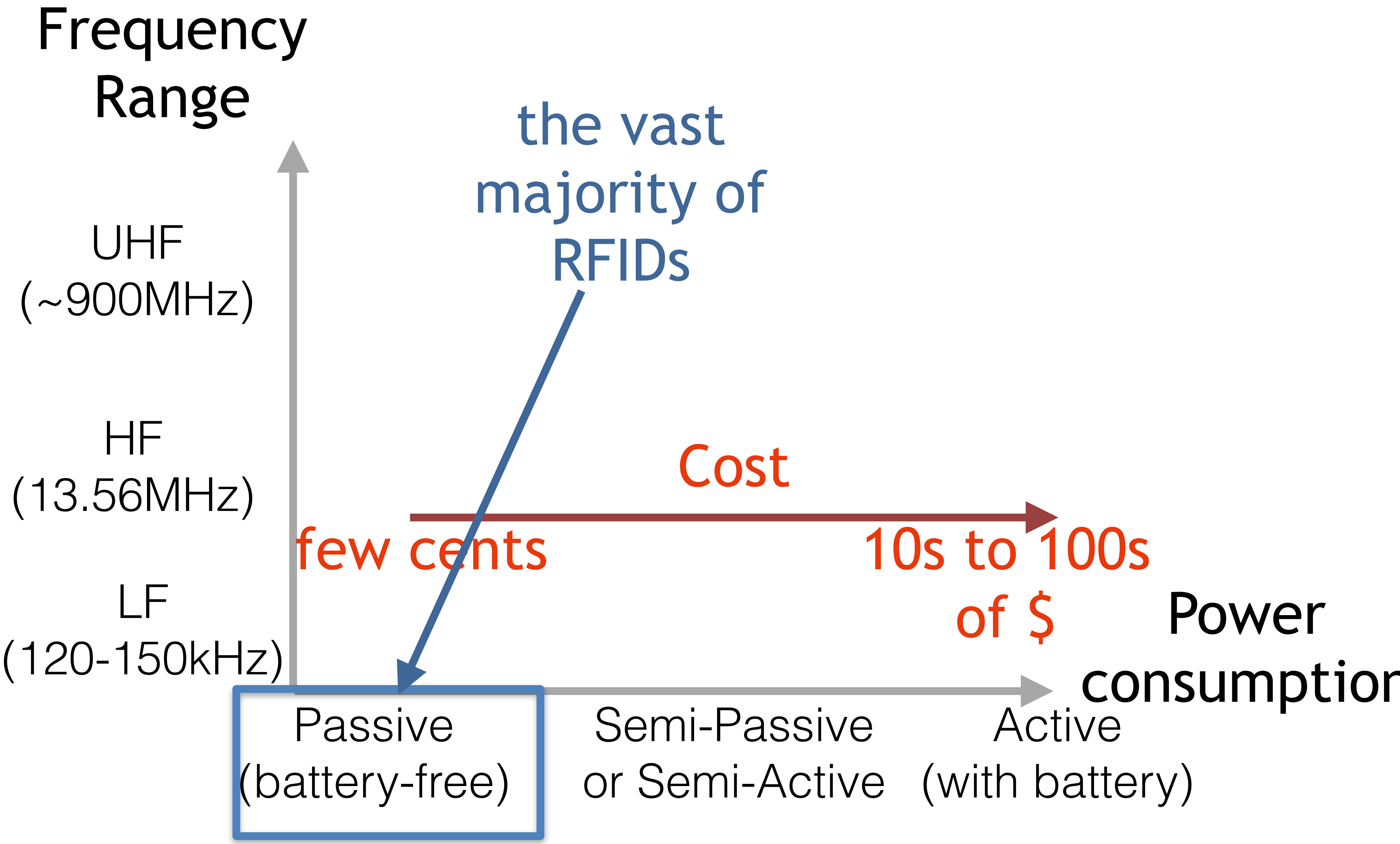
"need to tap"

Power consumption

Where do these fall?



Types of RFIDs



Other less common versions: 2.4GHz, UWB (3-10GHz), etc.

In The Rest of This Lecture..

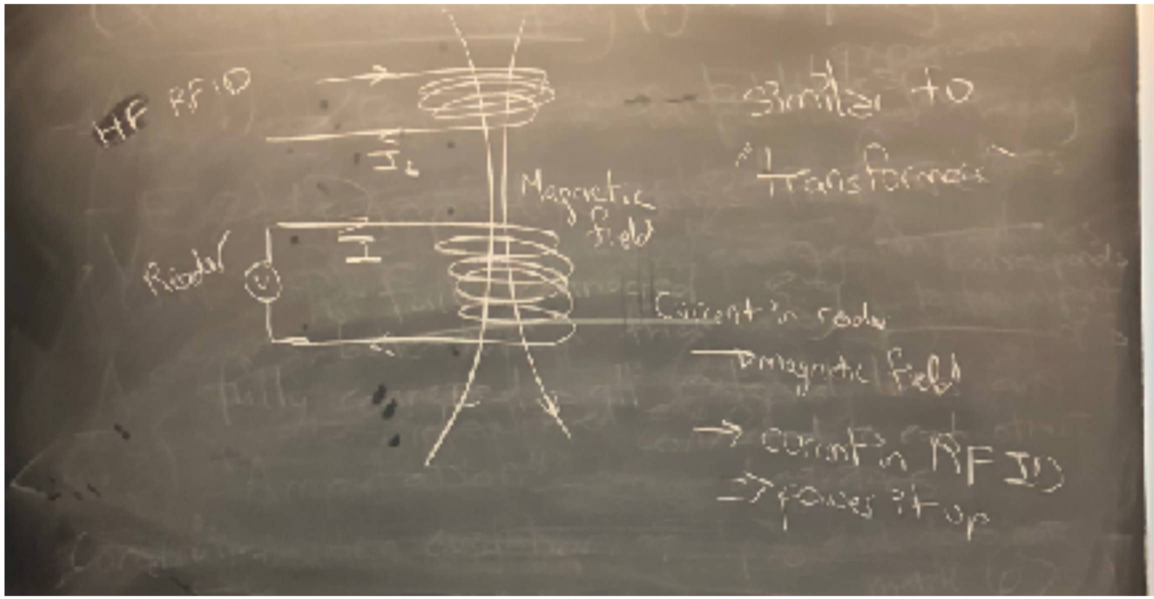
- LF/HF: Power-up / Communicate
- UHF: Power-up / Communicate
- Medium Access control

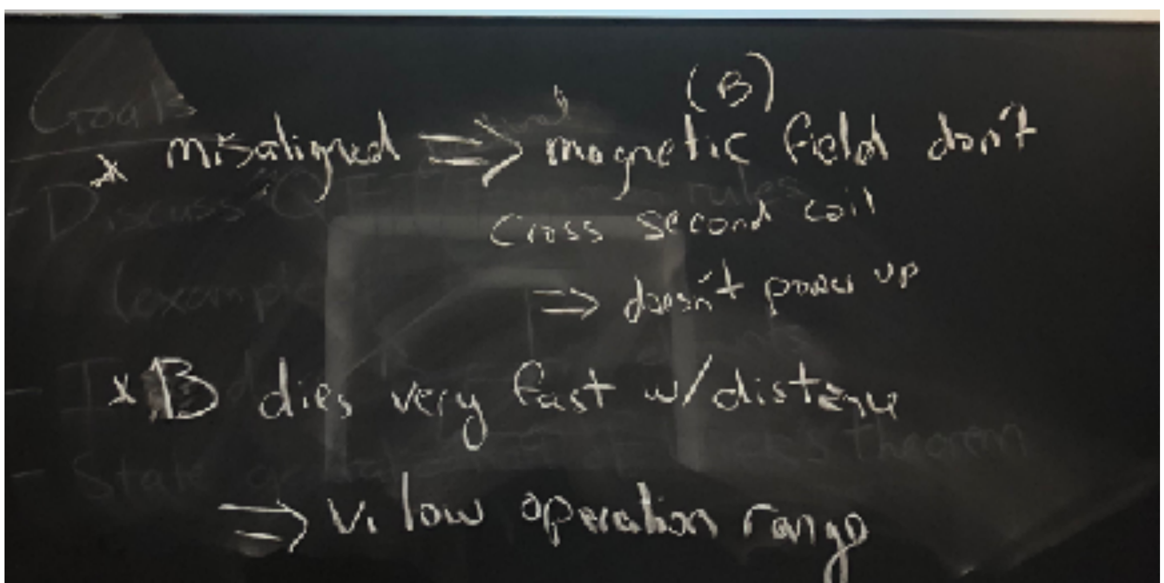
How does an RFID power up?

Harvests Energy from Reader's Signal

Inductive Coupling		Radiative
LF (120-150kHz)	HF (13.56MHz)	UHF (~900MHz)
Magnetic (Near Field)		Electromagnetic (Far Field)
Coil		Antenna

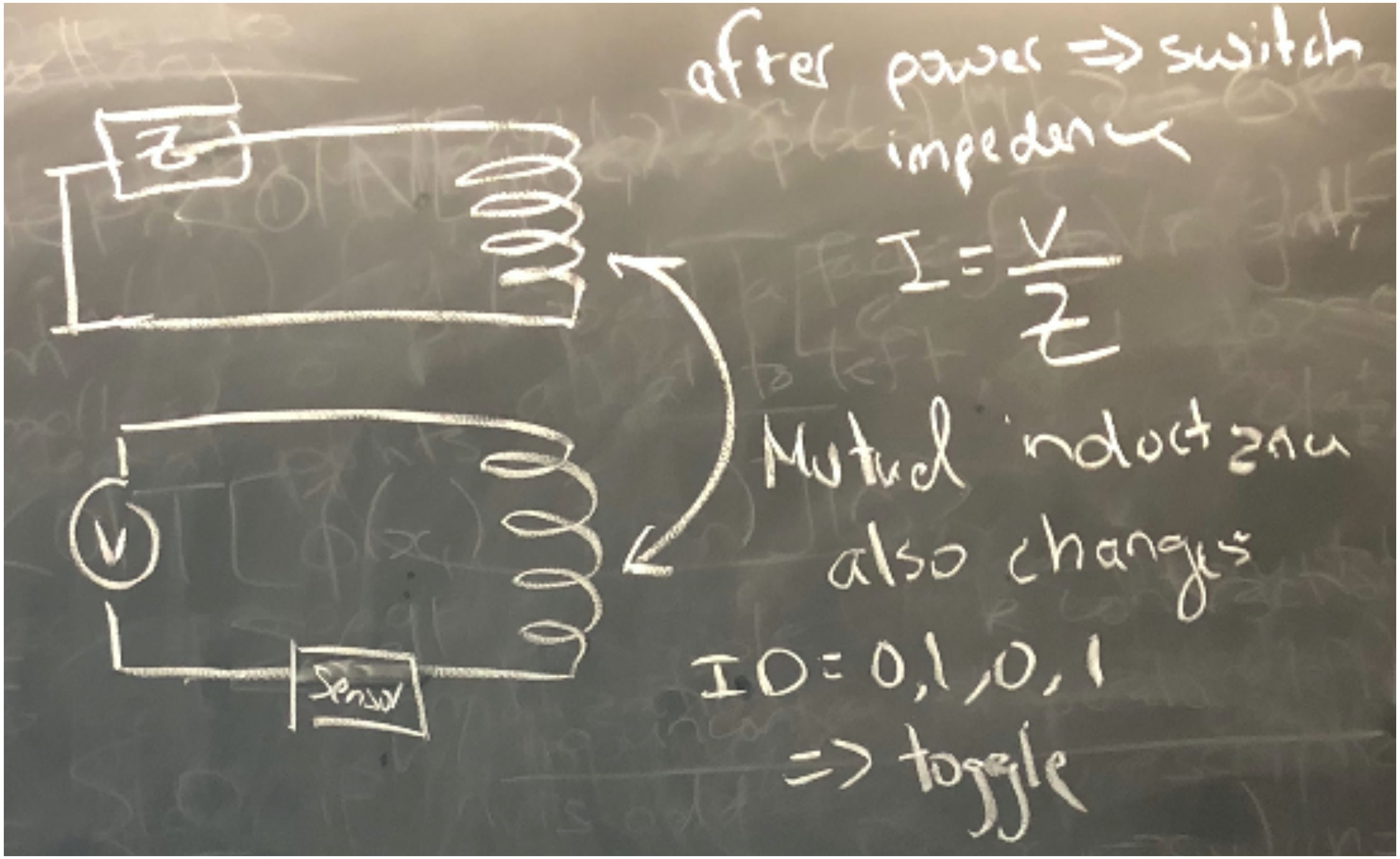
Inductive Coupling





Inductive Coupling

- Magnetic field also induced in the reverse direction
- By modulating its impedance, the tag can communicate bits that are sensed due to the mutual coupling



- Where else is this used?

How does the receiver decode?

- How does it know whether the high or the low is zero or one?

- Training sequence is sent at the beginning is used
- Any other type of Near filed operation?

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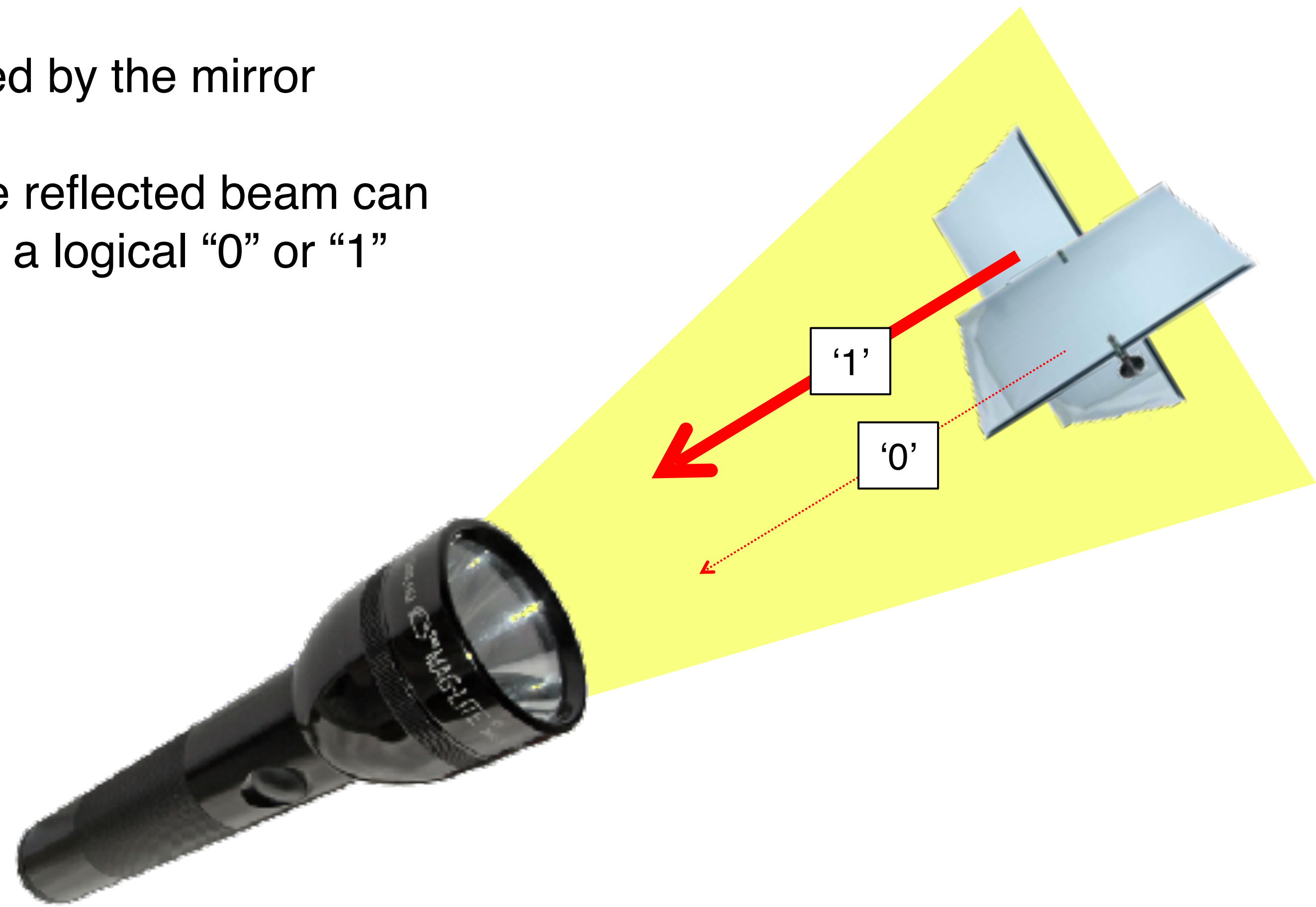
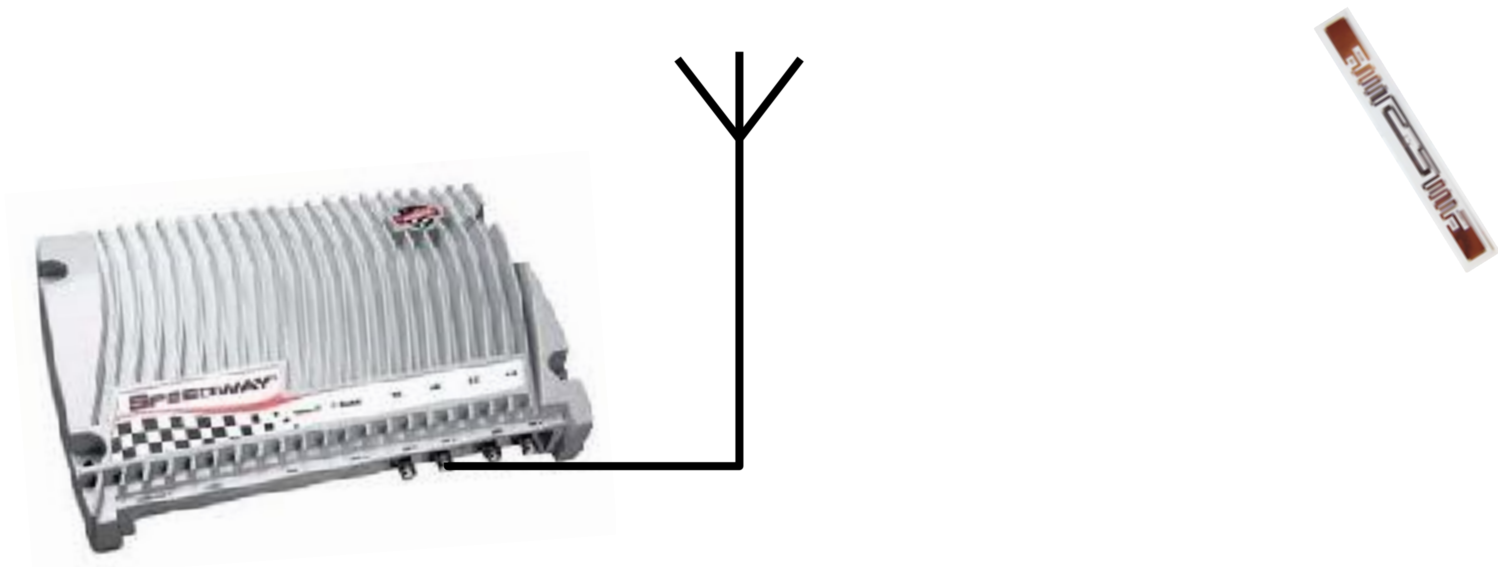
Backscatter Communication

- 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”



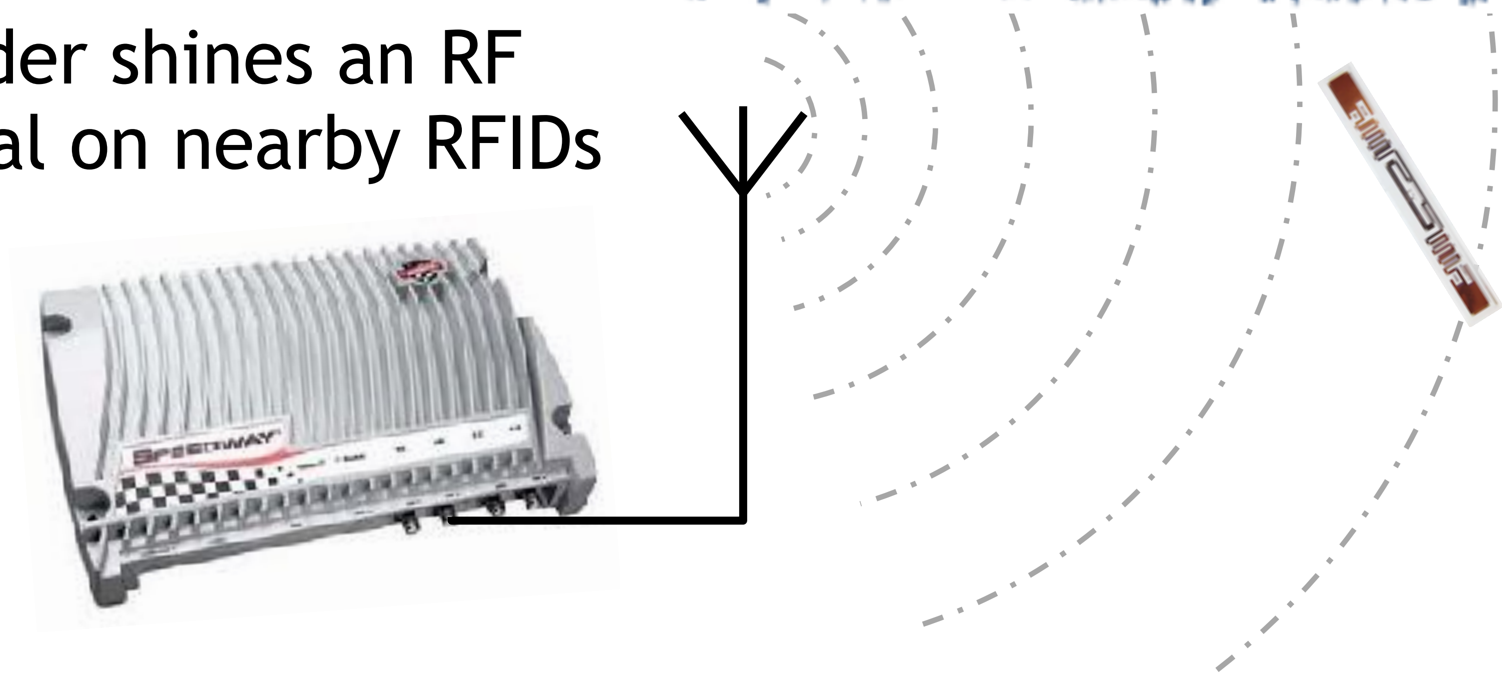
Backscatter Communication



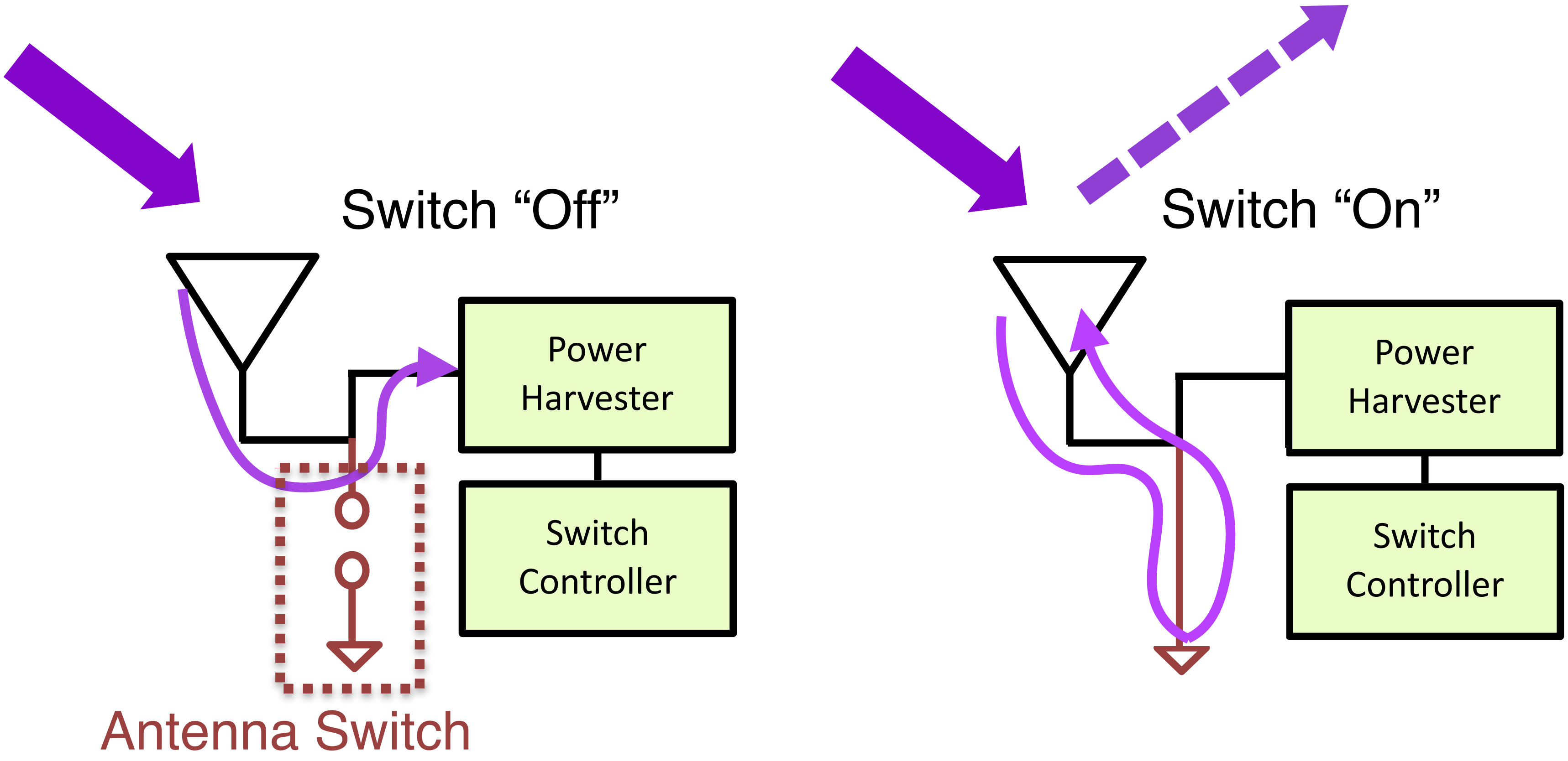
Backscatter Communication

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

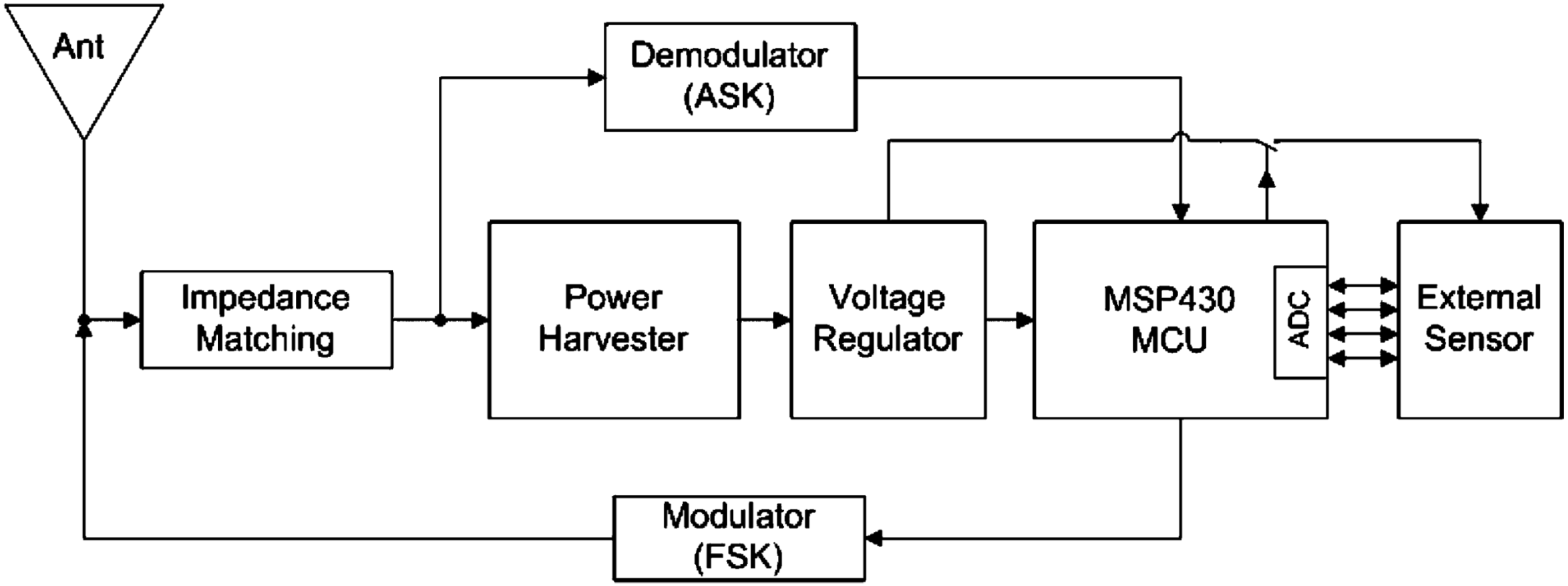
Reader shines an RF signal on nearby RFIDs



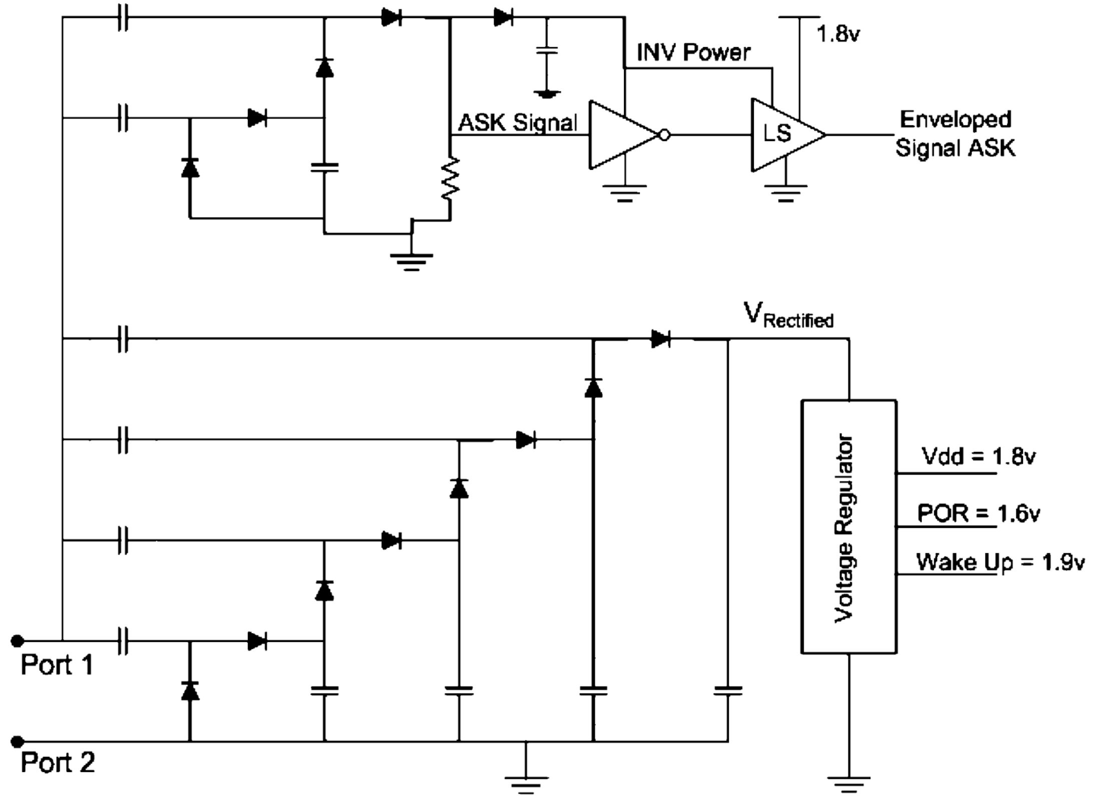
Uplink Communication



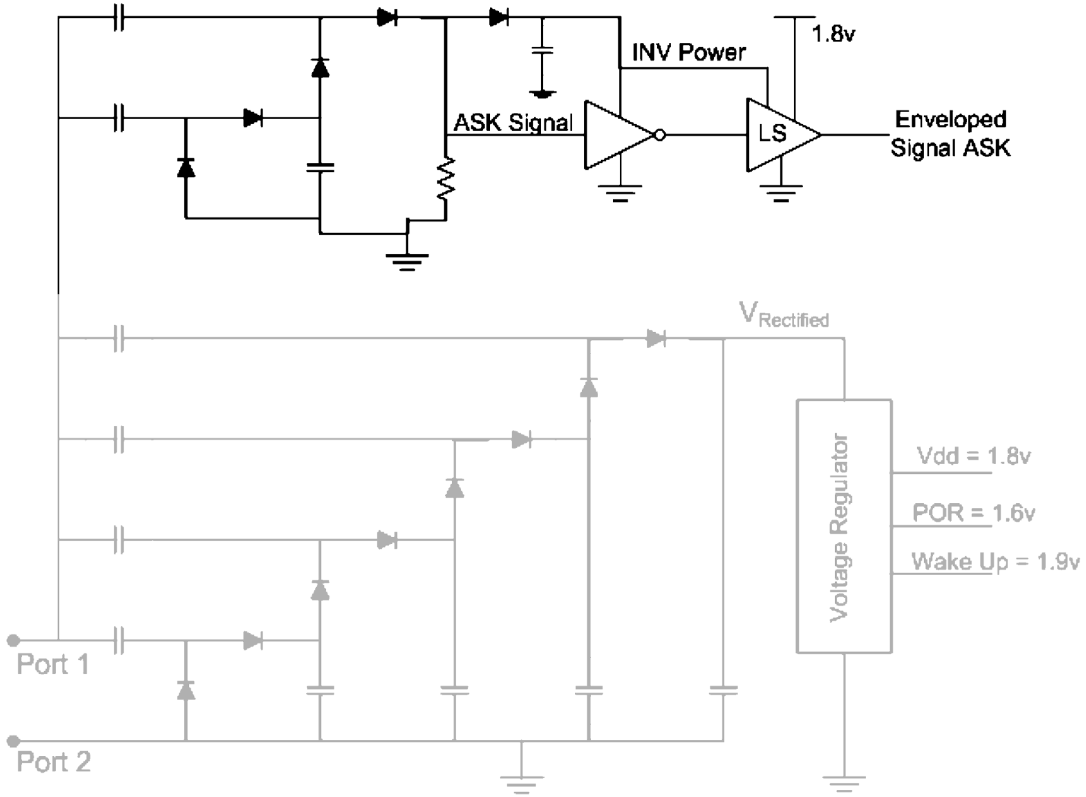
Backscatter Schematic



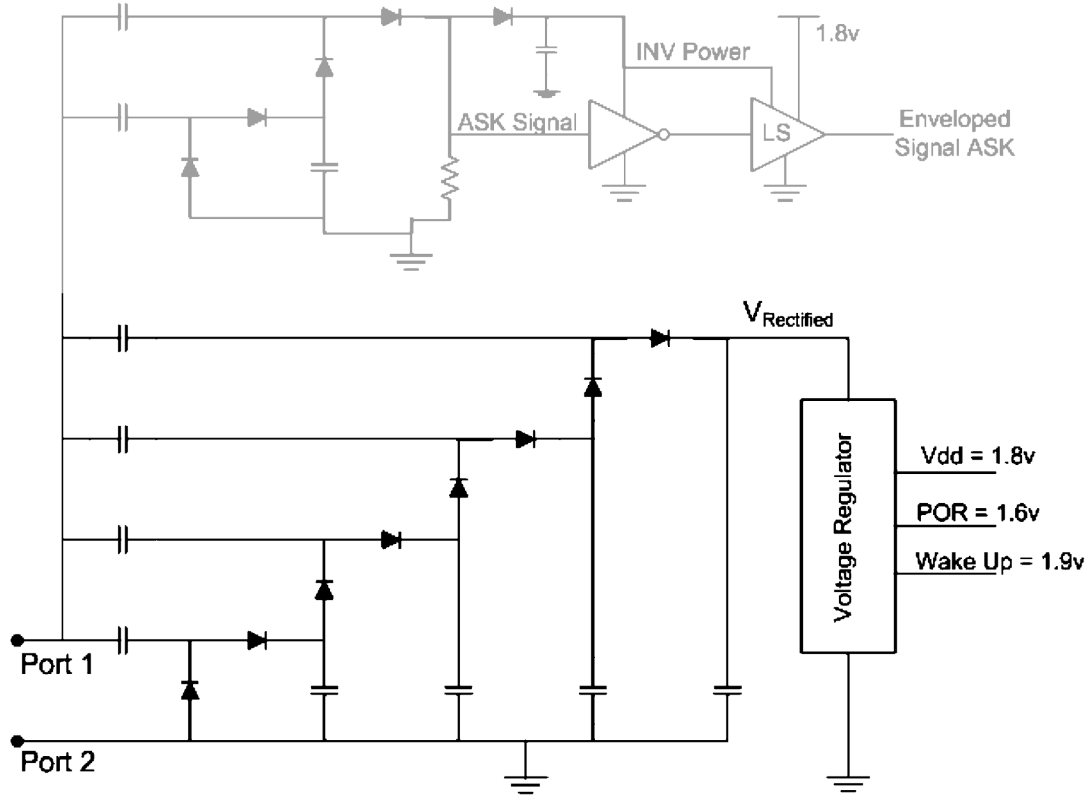
Demodulation/Harvesting



Demodulation

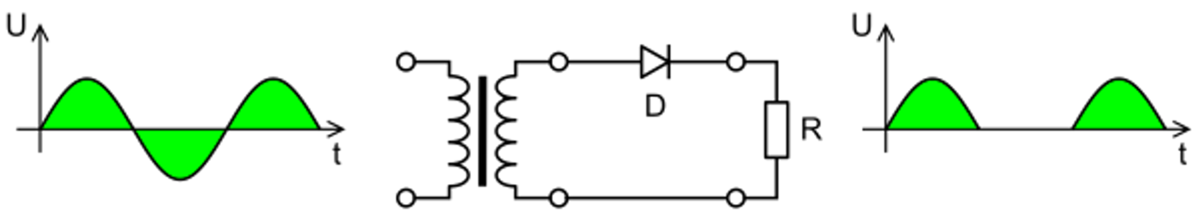


Power Harvester

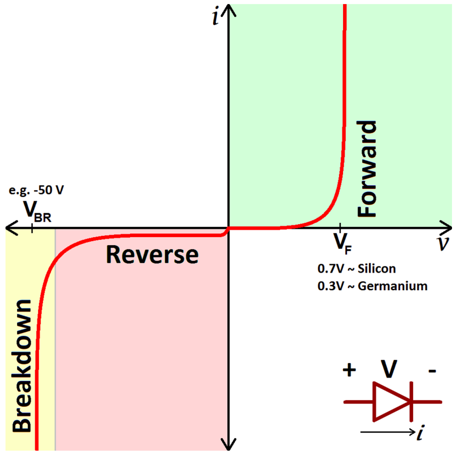


Voltage Rectification

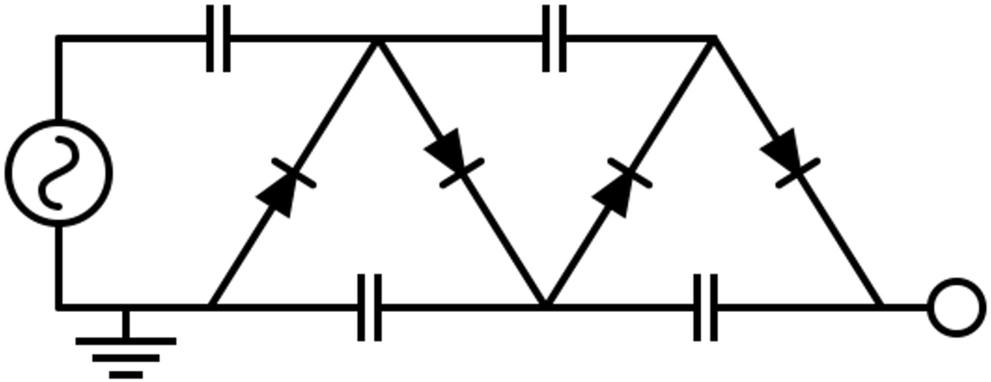
A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction.



Half-wave rectifier

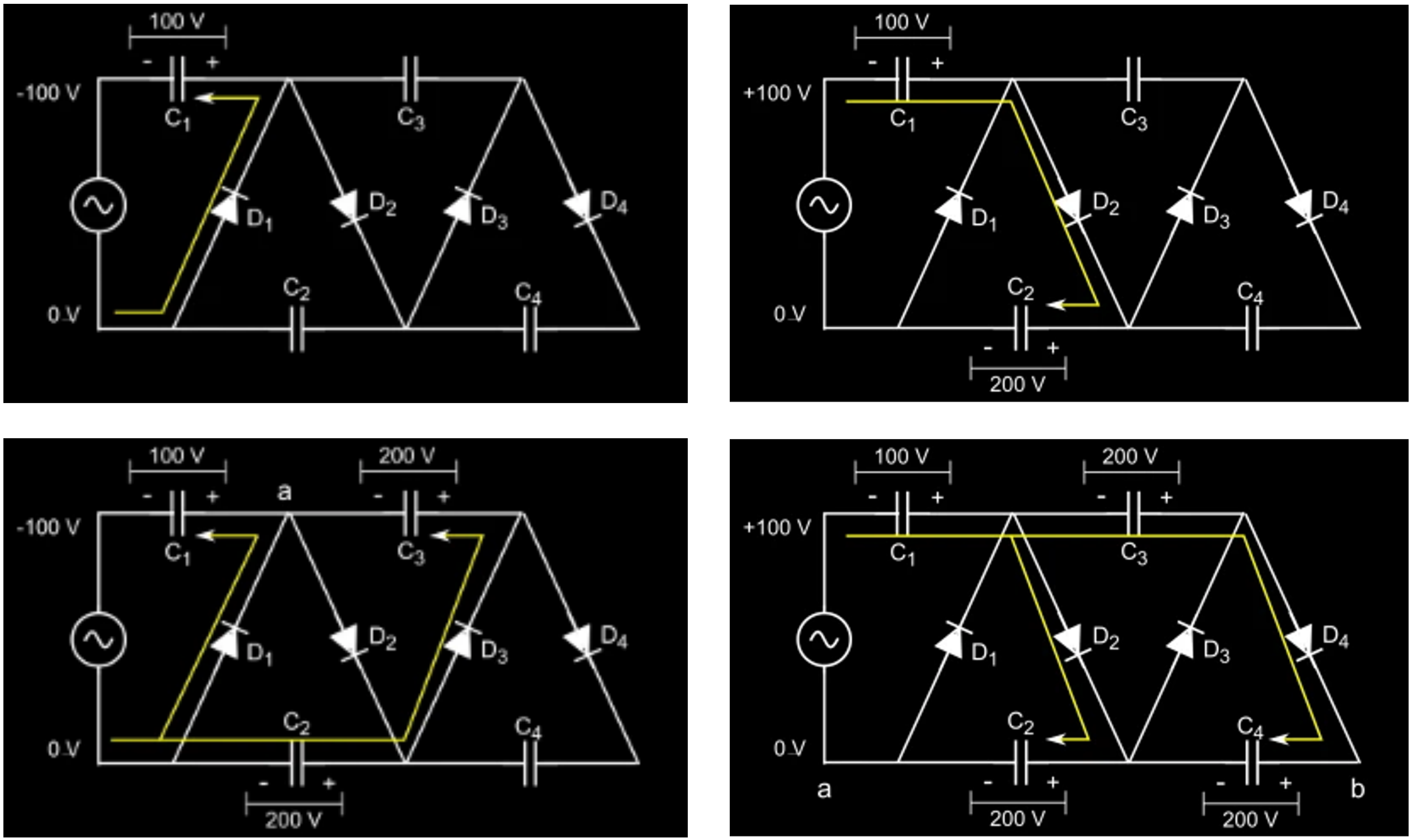


Diode

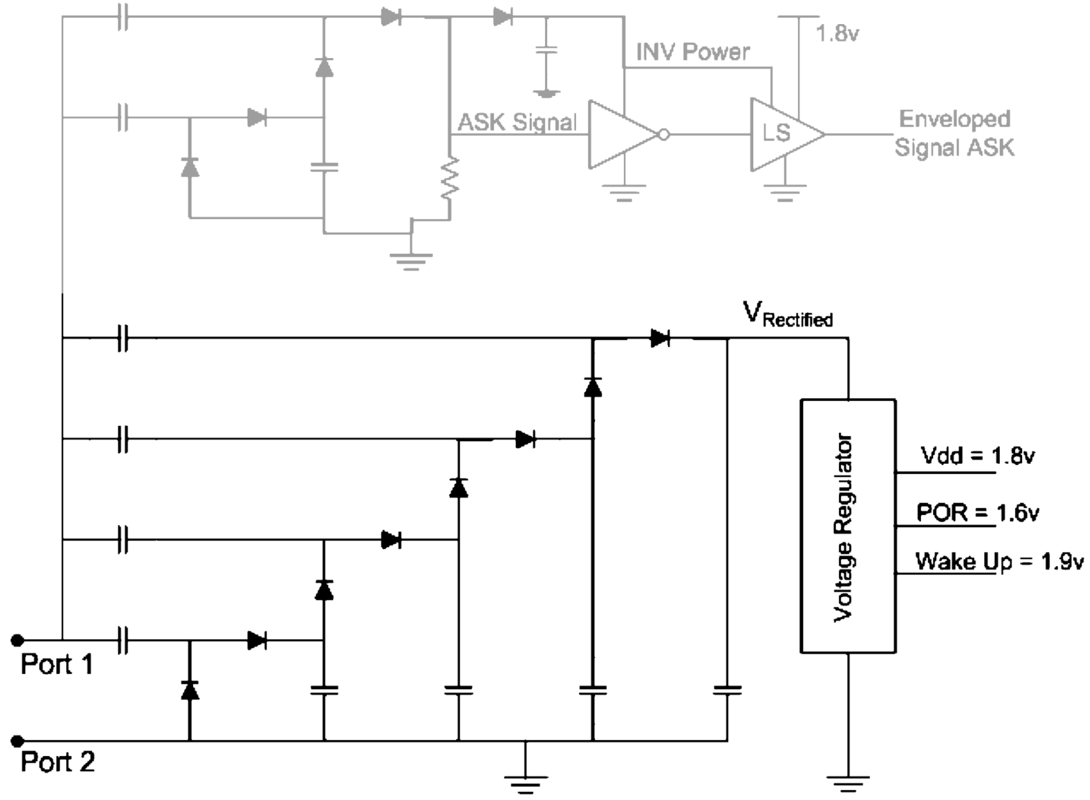


Voltage-multiplying rectifiers

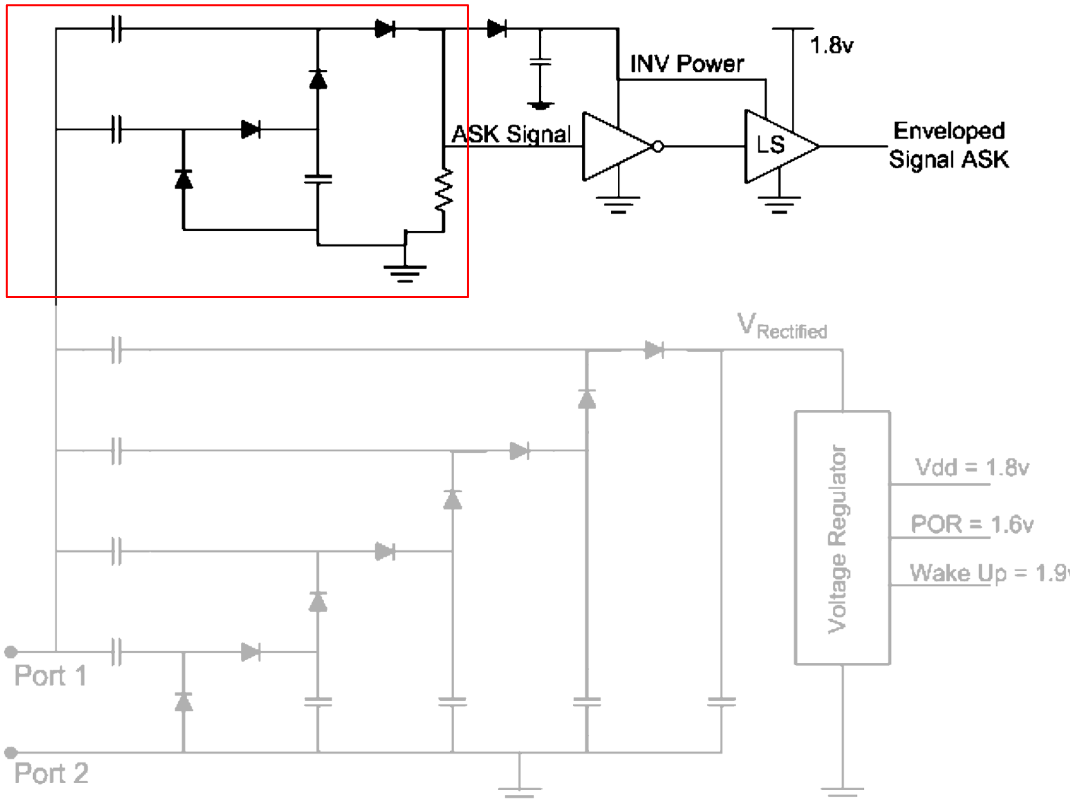
Voltage Rectification



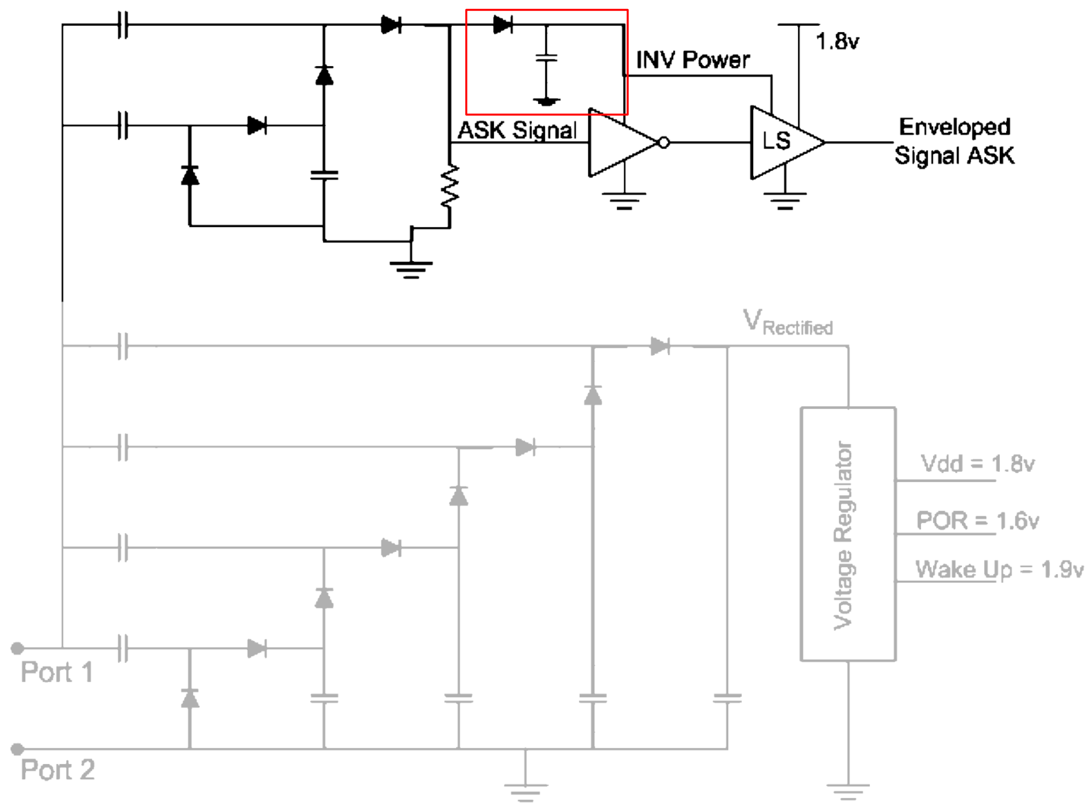
Power Harvester



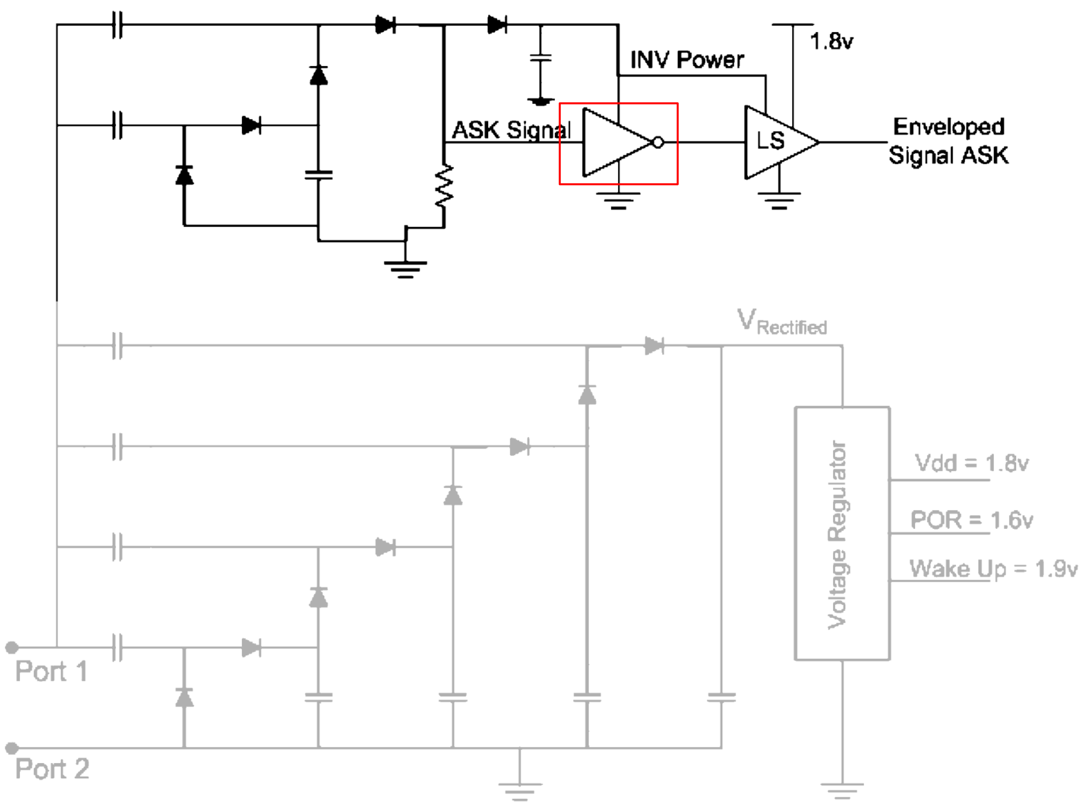
Demodulation

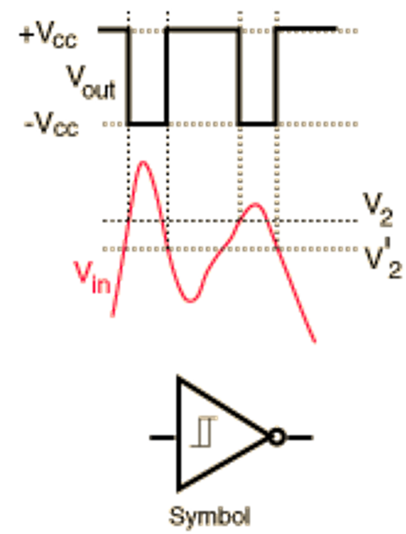


Demodulation



Demodulation





Schmitt Trigger

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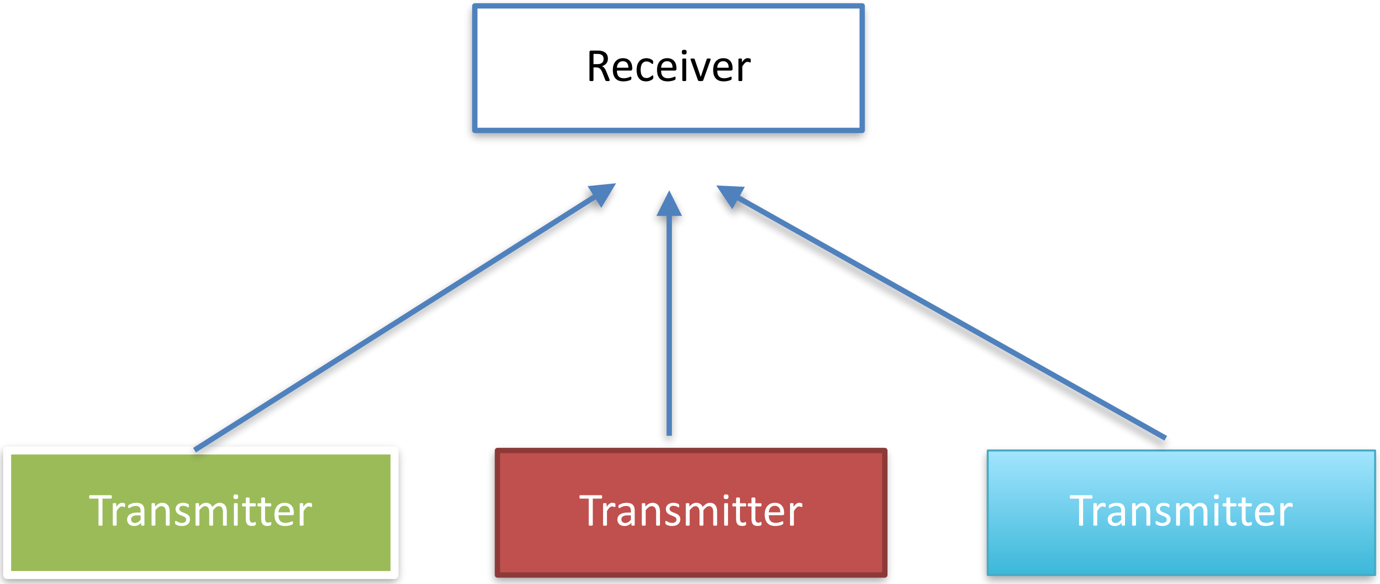
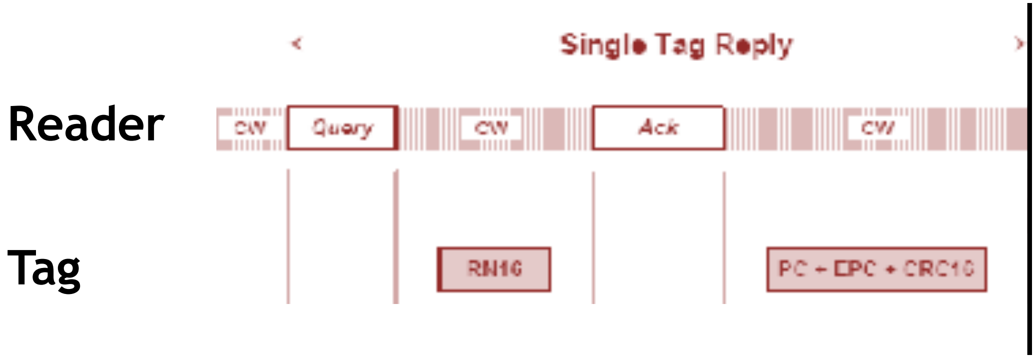
MAC

Single receiver, many transmitters



E.g., Satellite system, wireless

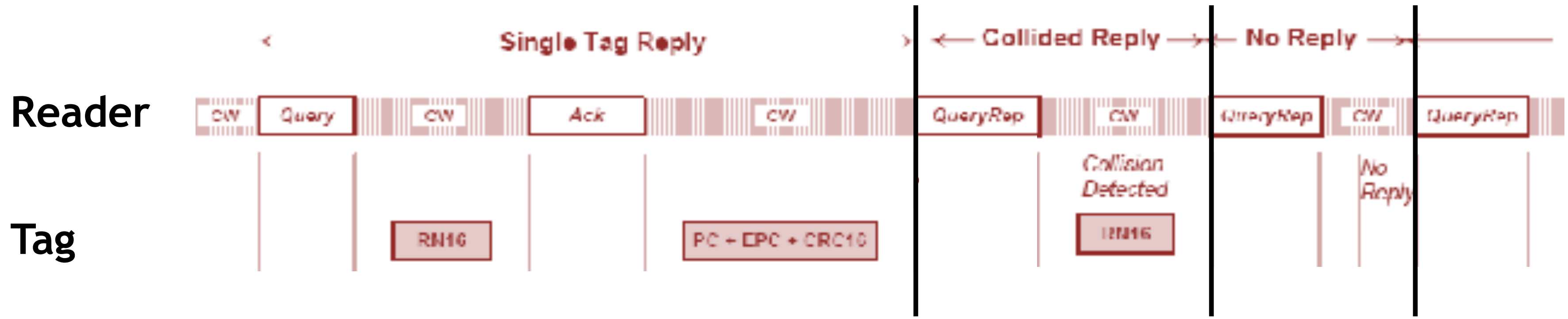
MAC (EPC-Gen 2)



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

MAC (EPC-Gen 2)



Inefficient:

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

Minimizing Collisions

- N RFID Tags & K Time slots
- Each tag picks a slot uniformly at random to transmit in
- *Let's assume the reader knows the number of tags N; how should it set K?*

- Probability that a tag transmits in a given slot:

$$p = \frac{1}{K}$$

- Probability that any tag transmits in a given slot without collision:

$$E = Np(1-p)^{N-1}$$

- To maximize E, set:

$$\frac{dE}{dp} = 0$$

- p=1/N => K=N

Minimizing Collisions

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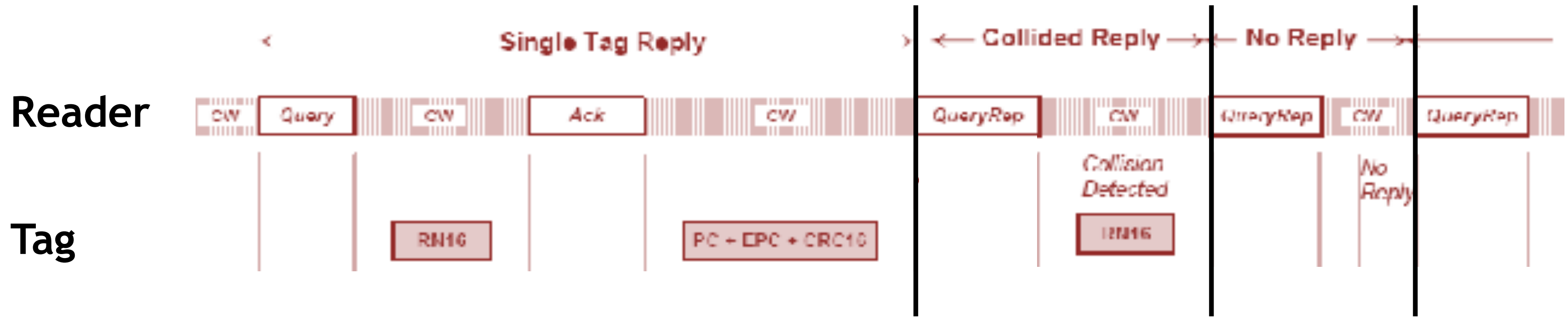
- p=1/N => K=N

$$\text{Efficiency} = E = \left(1 - \frac{1}{N}\right)^{N-1}$$

$$\text{Efficiency} \leq lim_{N \to \infty} E = \frac{1}{e} = 0.37$$

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

Significant work on "spanning trees", efficient scanning, decoding with collisions, etc.

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