The physics of RFID

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Overview

- A brief history of RFID
- Elements of an RFID system
- An ideal tag model and practical constraints
- An ideal reader model and practical constraints
- The basics of radio frequency propagation
- The basics of RF interaction with materials
- Conclusions

A brief history of RFID

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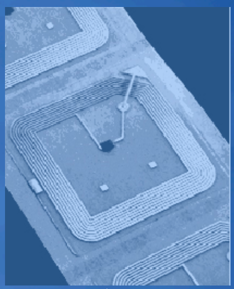
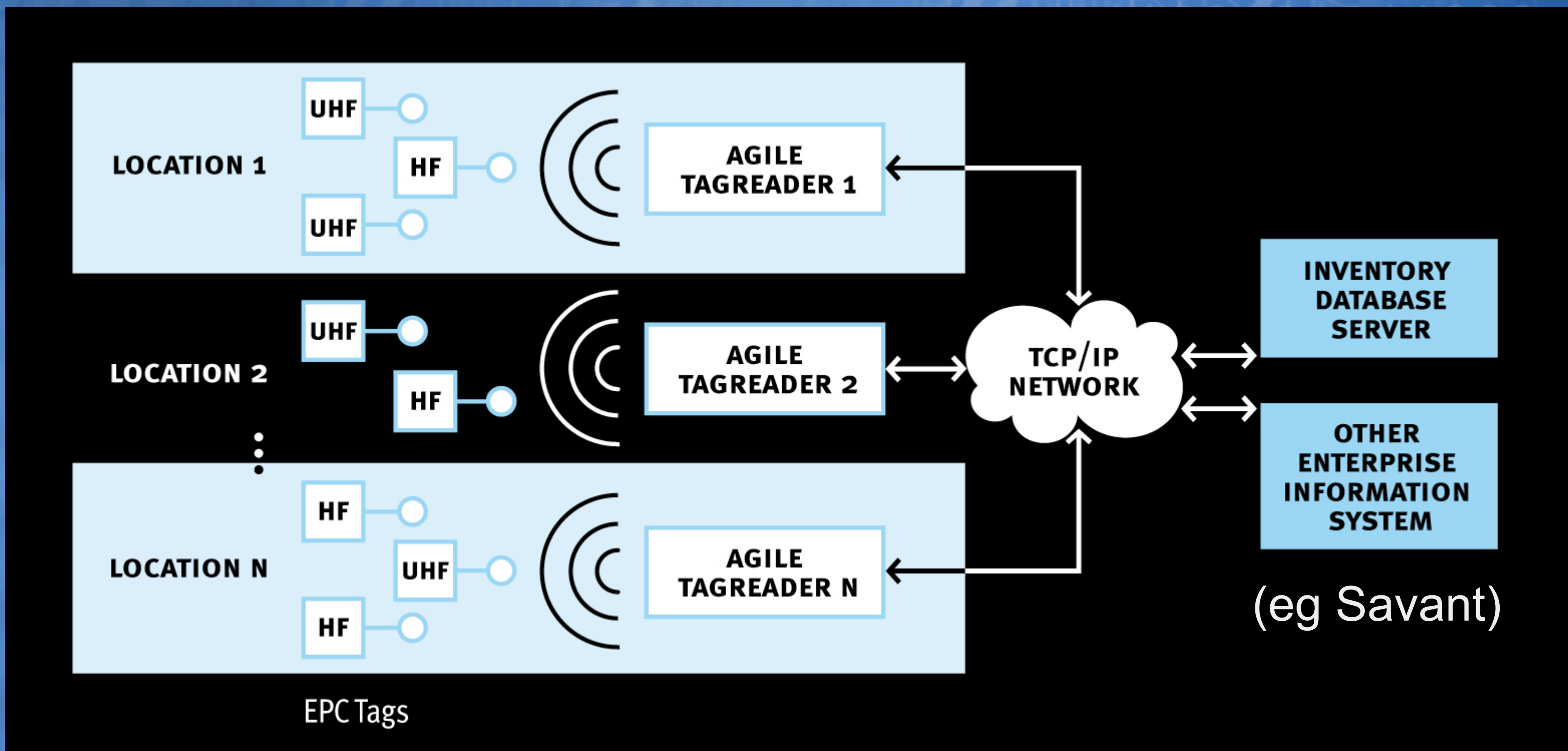
1862	1886	1942	1948	1972	2003



printing
lasers

IC / VLSI
networking
supply chain scaling

Elements of an RFID system



Four main elements: Tags, Readers, Antennas, and Network Systems

RF system variables

1. Choice of operating frequency
2. Tag IC, tag antenna design
3. Reader, reader antenna design
4. Proximate materials
5. Sources of external interference

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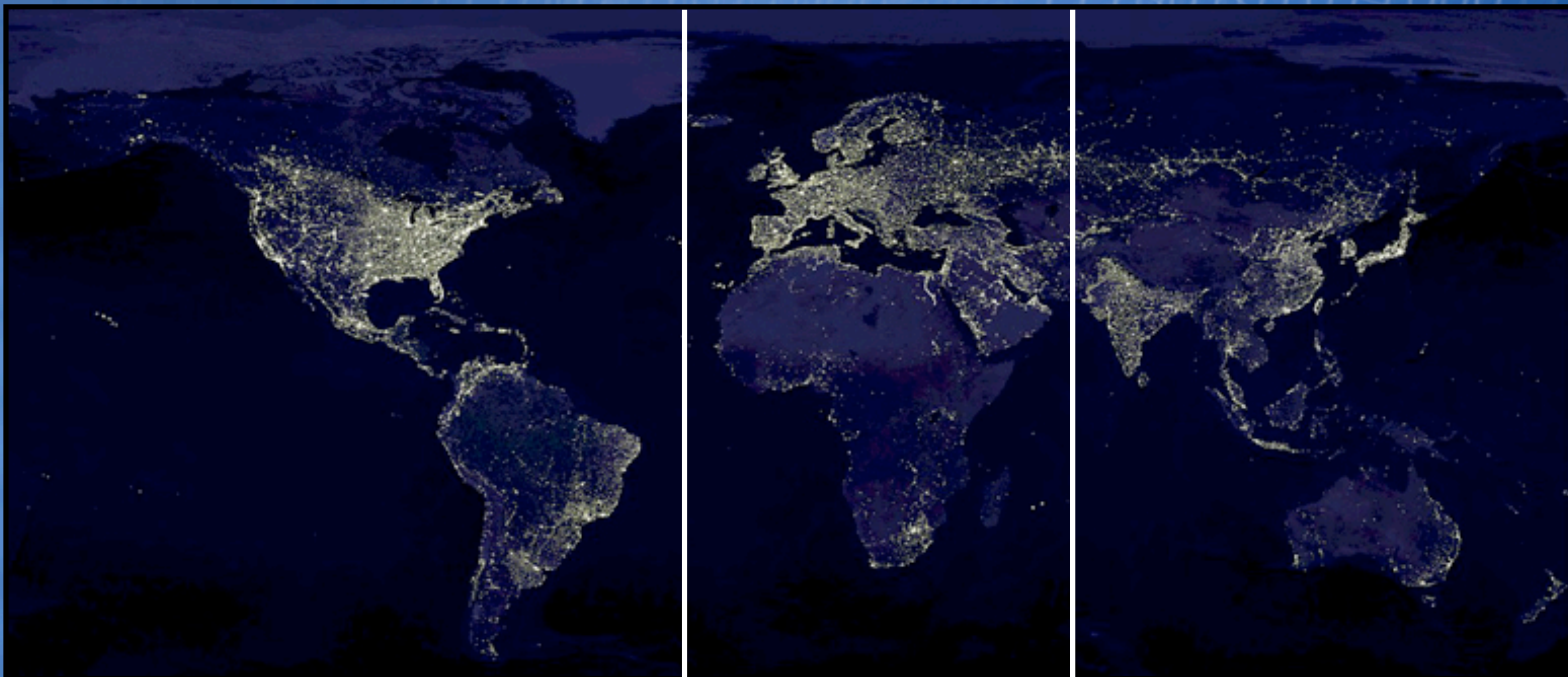
Major RFID markets by frequency

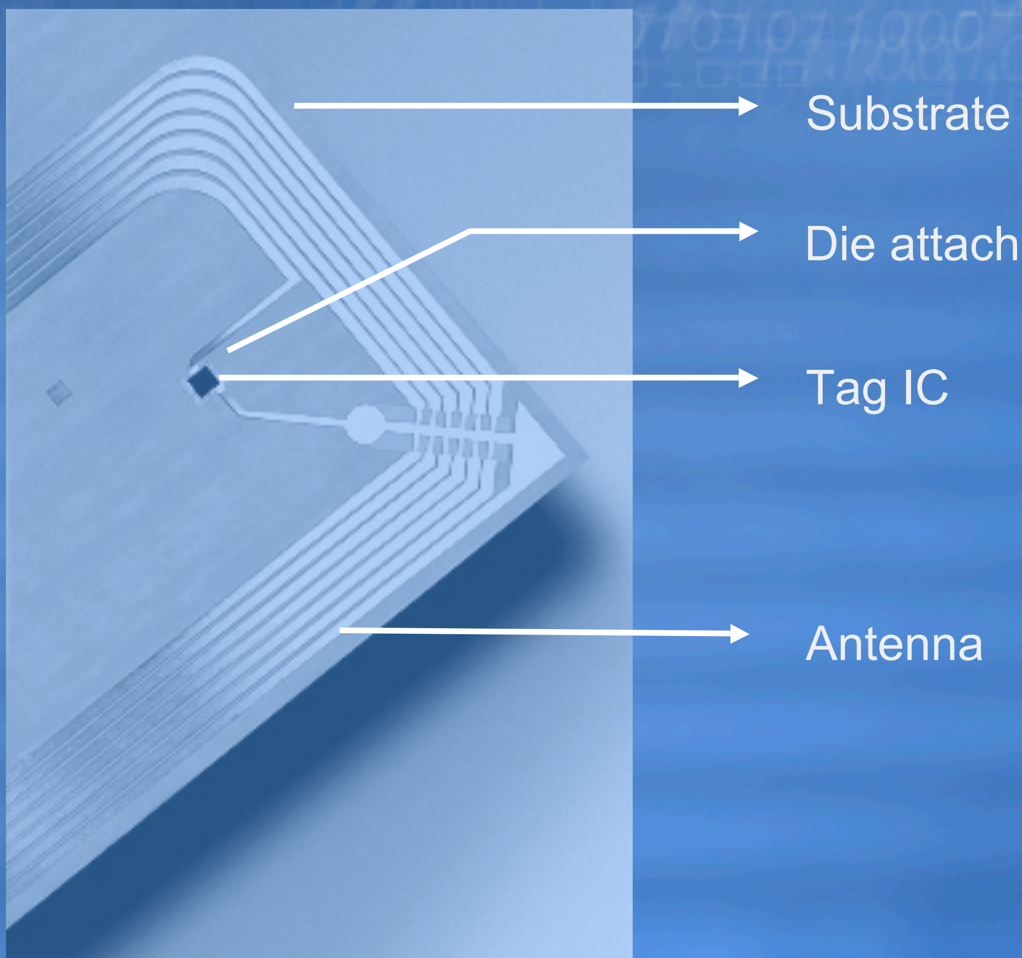


US, Canada	EU Countries	Japan
125KHz	125KHz	125KHz
13.56MHz	13.56MHz	13.56MHz
902-928MHz	868-870MHz	950-956MHz

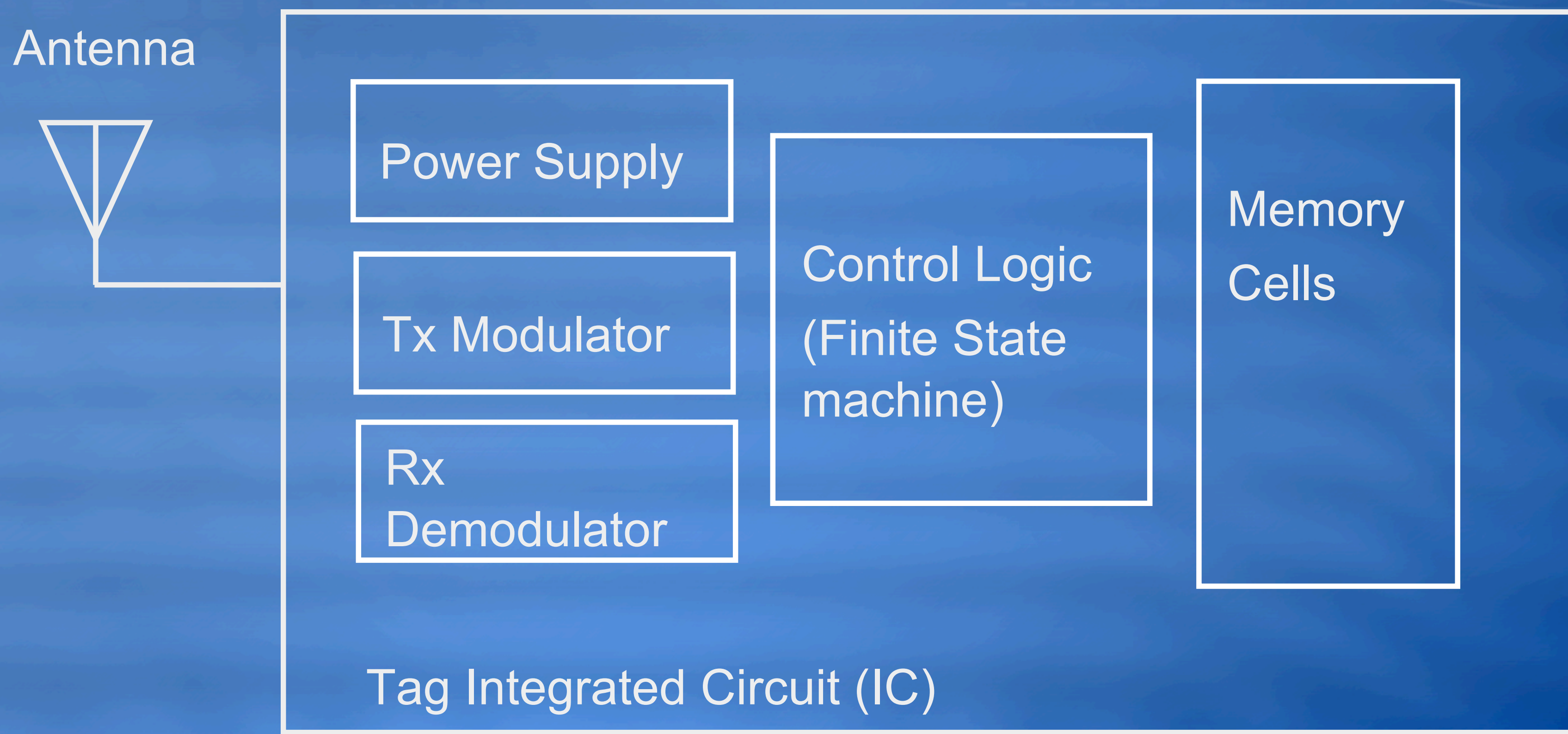
RFID tags at different frequencies

125 KHz	13.56 MHz	915 MHz	2.4 GHz
TI	Tagsys	Intermec	Intermec
Philips	Philips	SCS	SCS
Others	TI	Matrics	Hitachi
	Microchip	Alien	
	Others	Philips	
		TI	

Tag anatomy



Tag block diagram



What does a reader do?

- Primary functions:
  - Remotely power tags
  - Establish a bidirectional data link
  - Inventory tags, filter results
  - Communicate with networked server(s)

Reader anatomy

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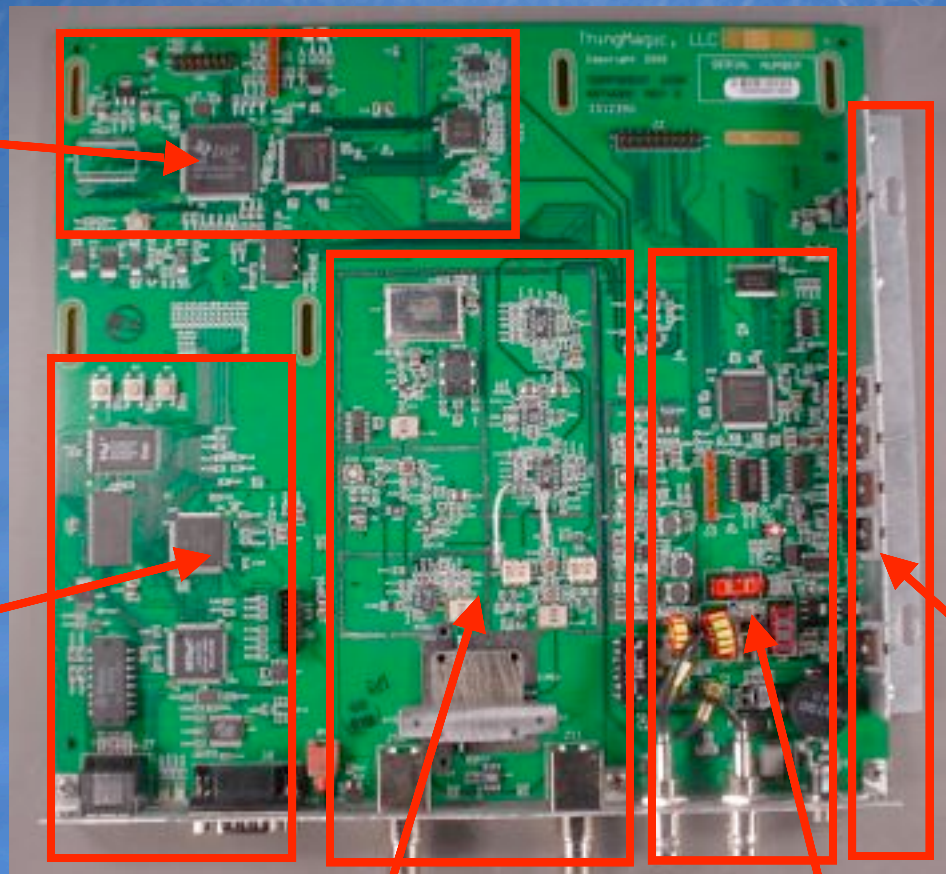
Digital Signal Processor (DSP)

Network Processor

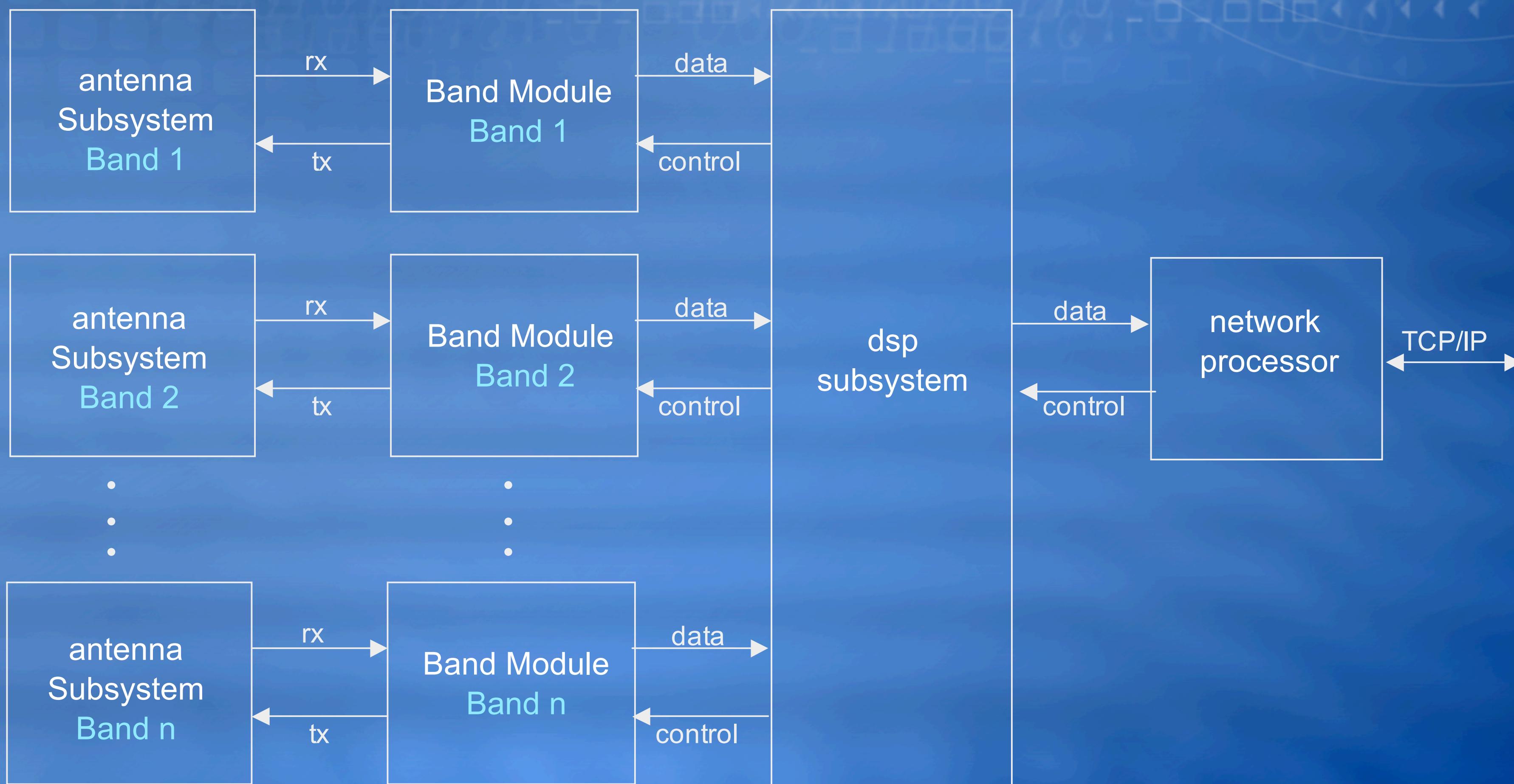


915MHz Radio

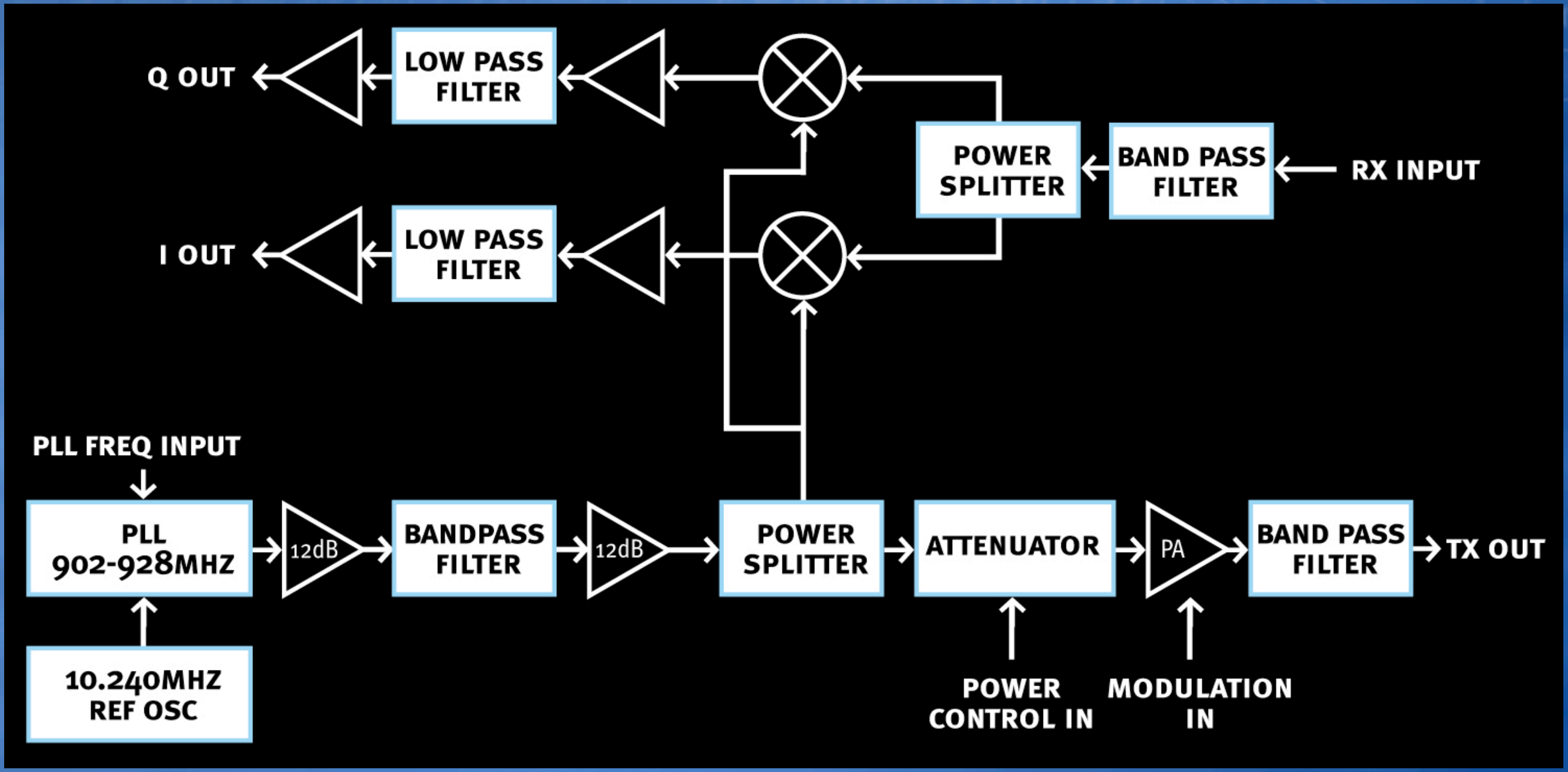
13.56MHz Radio

Power Supply

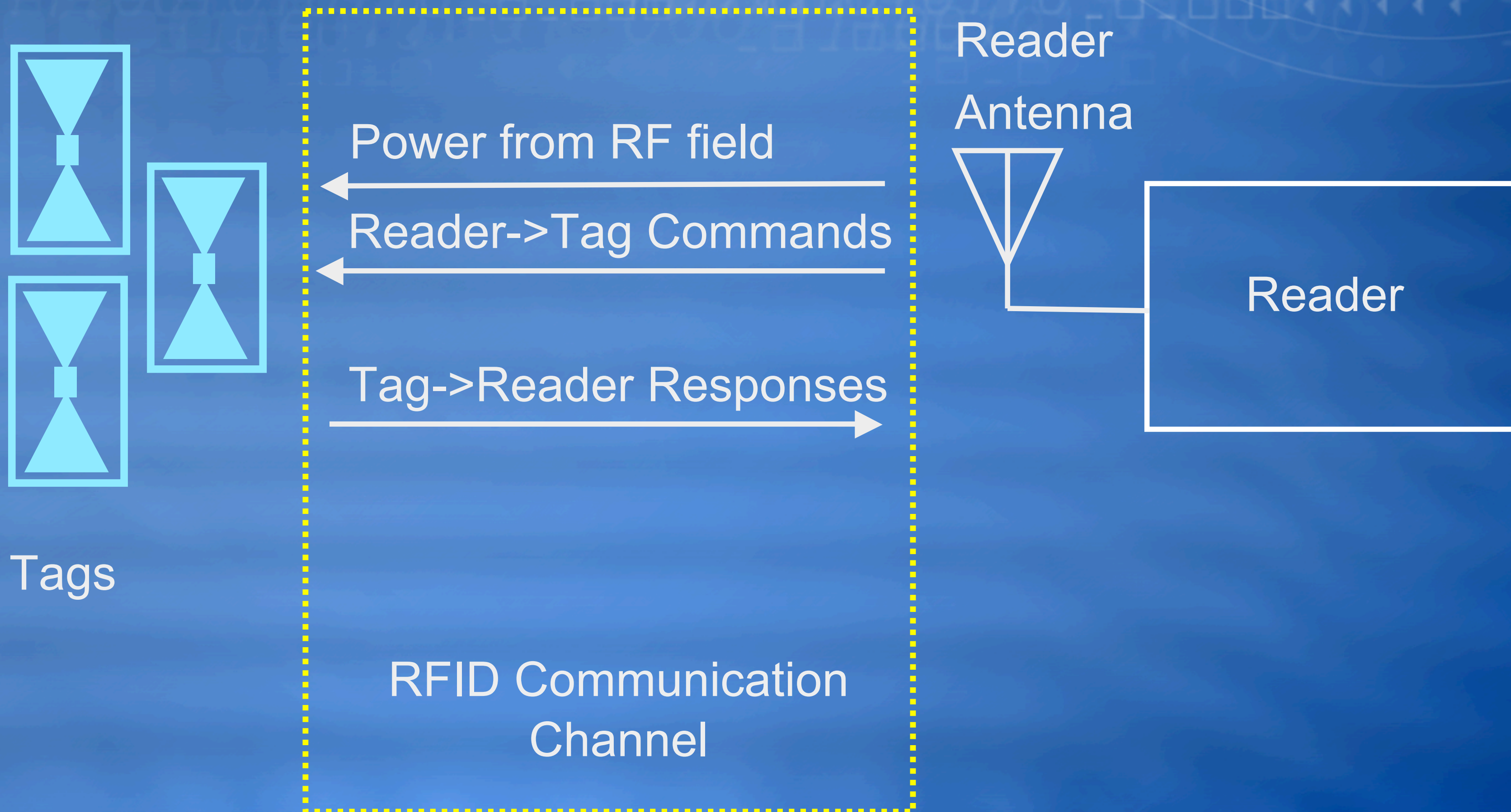
Reader block diagram



UHF (915MHz) reader RF section



A passive RFID communication model

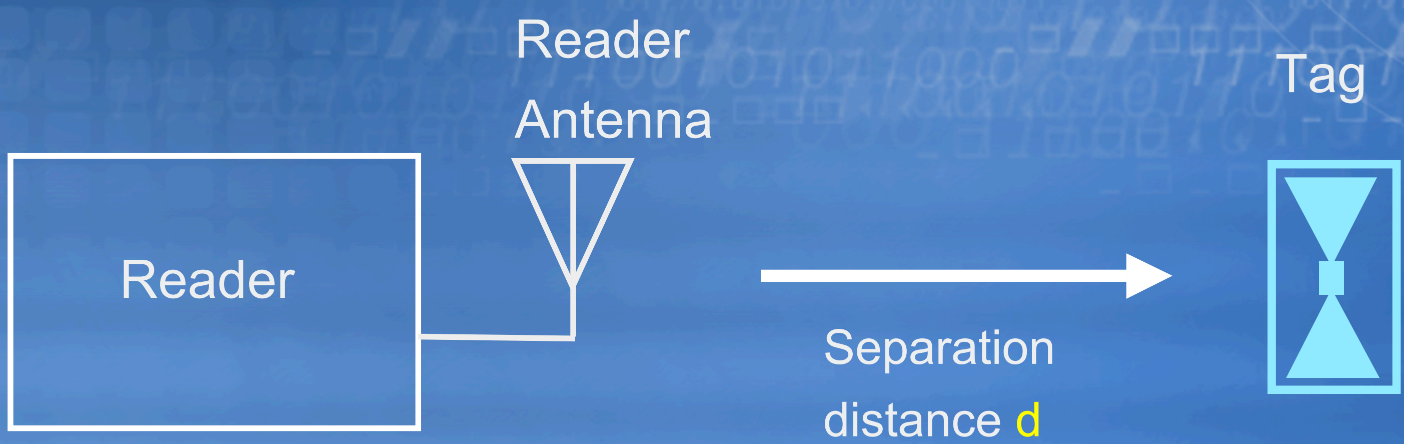


Limiting factors for passive RFID

1. Reader transmitter power Pr (Gov't. limited)
2. Reader receiver sensitivity Sr
3. Reader antenna gain Gr (Gov't. limited)

4. Tag antenna gain Gt (Size limited)
5. Power required at tag Pt (Silicon process limited)
6. Tag modulator efficiency Et

Reader->Tag power transfer



Q: If a reader transmits Pr watts, how much power Pt does the tag receive at a separation distance d?

A: It depends-

UHF (915MHz) : Far field propagation : $Pt \propto 1/d^2$

HF (13.56MHz) : Inductive coupling : $Pt \propto 1/d^6$

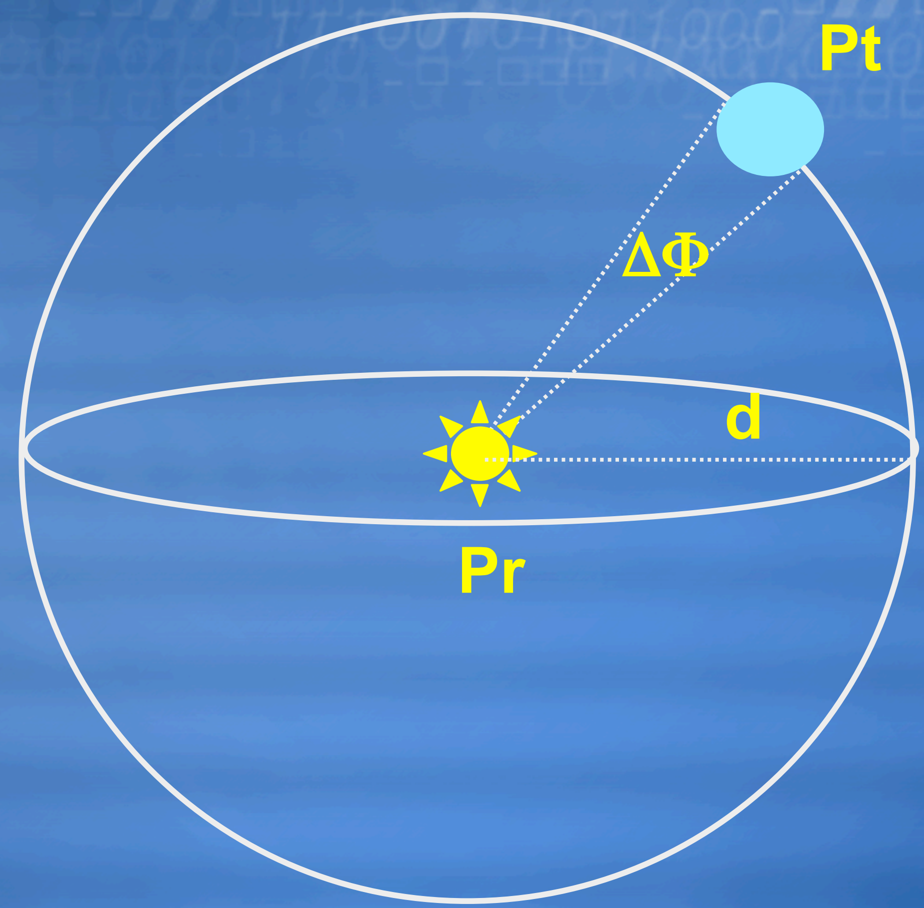
Typical UHF system parameters

- Reader Transmit Power Pr = 30dBm (1 Watt)
- Reader Receiver Sensitivity Sr = -80dBm (10^{-11} Watts)
- Reader Antenna Gain Gr = 6dBi

- Tag Power Requirement Pt = -10dBm (100 microwatts)
- Tag Antenna Gain Gt = 1dBi
- Tag Backscatter Efficiency Et = -20dB

- System operating wavelength λ = 33cm (915MHz)

Far field path loss



$$Pt = \frac{Pr \cdot Gr \cdot Gt \cdot \lambda^2}{(4\ \pi)^2\ d^2}$$

UHF read range estimation

- Two cases: Tag power limited, or reader sensitivity limited.

Well designed systems are tag power limited.

$$Pt = \frac{Pr \cdot Gr \cdot Gt \cdot \lambda^2}{(4\pi)^2 d^2}$$

$$d_{max} = \mathrm{sqrt}\left(\frac{Pr \cdot Gr \cdot Gt \cdot \lambda^2}{(4\pi)^2 Pt}\right)$$

d_{max} = 5.8 meters, theoretical maximum

Reader sensitivity limit

- Let's assume we can build a tag IC requiring 1 microwatt (100 times better than current practice)
- d_{max} = 194 meters tag power limit for this hypothetical IC.

$$P_{t\to r} = \frac{P_r \cdot G_r \cdot G_t \cdot E_t \cdot \lambda^2}{(4\pi)^2 d^4}$$

Pt->r = -99dBm

Noise power in 50 ohm resistor at 500KHz BW=4kTB=-109dBm.

With a practical receiver of NF=3dB, Pn=-106dBm, SNR=10dB.

This signal is at the edge of decodability.

Lessons from the simple model

- Since Pt $\propto 1/d^2$, doubling read range requires 4X the transmitter power.
- Larger antennas can help, but at the expense of larger physical size because $G\{t,r\} \propto$ Area.
- More advanced CMOS process technology will help by reducing Pt.
- At large distances, reader sensitivity limitations dominate.

RF signals and materials

Materials in the RF field can have several effects:

1. Reflection / refraction
2. Absorption (loss)
3. Dielectric effects (detuning)
4. Complex propagation effects (photonic bandgap)

RF effects of common materials

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Material	Effect(s) on RF signal
Cardboard	Absorption (moisture) Detuning (dielectric)
Conductive liquids (shampoo)	Absorption
Plastics	Detuning (dielectric)
Metals	Reflection
Groups of cans	Complex effects (lenses, filters) Reflection
Human body / animals	Absorption Detuning (dielectric) Reflection

Effective shielding of UHF signals

- Any conductive material exhibits a skin depth effect

δ = sqrt (2 ρ / (2 π f μ_0))

where $\mu_0 = 4 \pi \times 10^{-7}$ H/m.

For aluminum, $\rho = 2.65 \times 10^{-6}$ ohm-cm. An effective aluminum shield is only 27 microns thick.

For dilute salt water, $\rho = 10^{-2}$ ohm-cm. An effective salt water shield is 1 mm thick.

Conclusions

- There are serious practical limitations to passive RFID read range.
- It is not practical to read a passive UHF RFID tag from Earth orbit.
- Improvements to tag IC design will yield commercially helpful, but probably privacy-insignificant increase in read range.

- UHF RFID signals are easily shielded by common materials (aluminum foil, antistatic bags, or your hands).