Module IT.2301 - Internet of Things: Radio Frequency Identification RFID

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What is an RFID system? (1/)

- RFID (Radio Frequency Identification) is a means of identifying a person or object using a radio frequency transmission.
- The technology can be used to identify, track, sort or detect a wide variety of objects.
- Communication takes place between a reader (interrogator) and a transponder (Silicon Chip connected to an antenna) often called a tag.

What is an RFID system? (2/)

- Tags can either be active (powered by battery) or passive (powered by the reader field).
- Tags come in various forms including Smart cards, Tags, Labels, watches and even embedded in mobile phones.
- The communication frequencies used depends to a large extent on the application, and range from 125KHz to 2.45 GHz.

Commonly used RFID frequencies

	LF	HF	UHF	Microwave
Frequency	125 kHz	13.56 MHz	860 MHz	2.45 GHz
Range	< 0.5 m	1 m	4-5 m	600 m
Data rate	< 1 kbps	25 kbps	30 kbps	> 100 kbps
Tag	Passive	Passive	Active and Passive	Active and Passive
Tag size	Large	Medium	Small	Small
Antenna	Spiral	Spiral	dipole	dipole
Field	Near Field, Inductive Couling		Far Field, Electromagnetic Field	
Applications	Access Control Animal tagging	Smart Card Payment, ID Biomentrics transport	Supply Chain Baggage handling Box tagging	Real Time location of goods; Electronic toll

Outline: RFID

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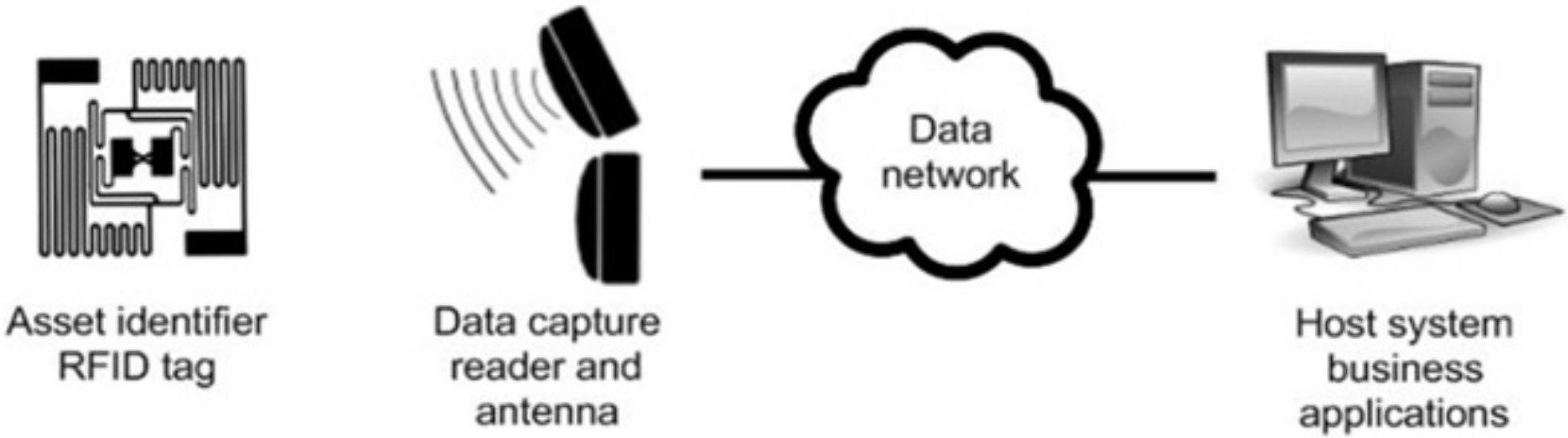
RFID System



☞ RFID Building Block:

- RFID Tag;
- RFID reader.

RFID system

- Tags are attached to objects and have internal memories known as Electrically-erasable programmable read-only memory (**EEPROM**) in which object information are stored.
- The stored information is the object unique ID (serial) number, or in some cases more details including manufacture date and product composition.
- When these tags pass through a field generated by a reader, they transmit this information back to the reader, thereby identifying the object.

Communication

- When the reader is switched on, it starts emitting a signal at the selected frequency band (typically 860 - 915MHz for UHF or 13.56MHz for HF).
- Any corresponding tag in the proximity of the reader will detect the signal and use the energy from it to wake up and supply operating power to its internal circuits.
- Once the Tag has decoded the signal as valid, it replies to the reader, and indicates its presence by modulating (affecting) the reader field.

Anti-Collision (1/)

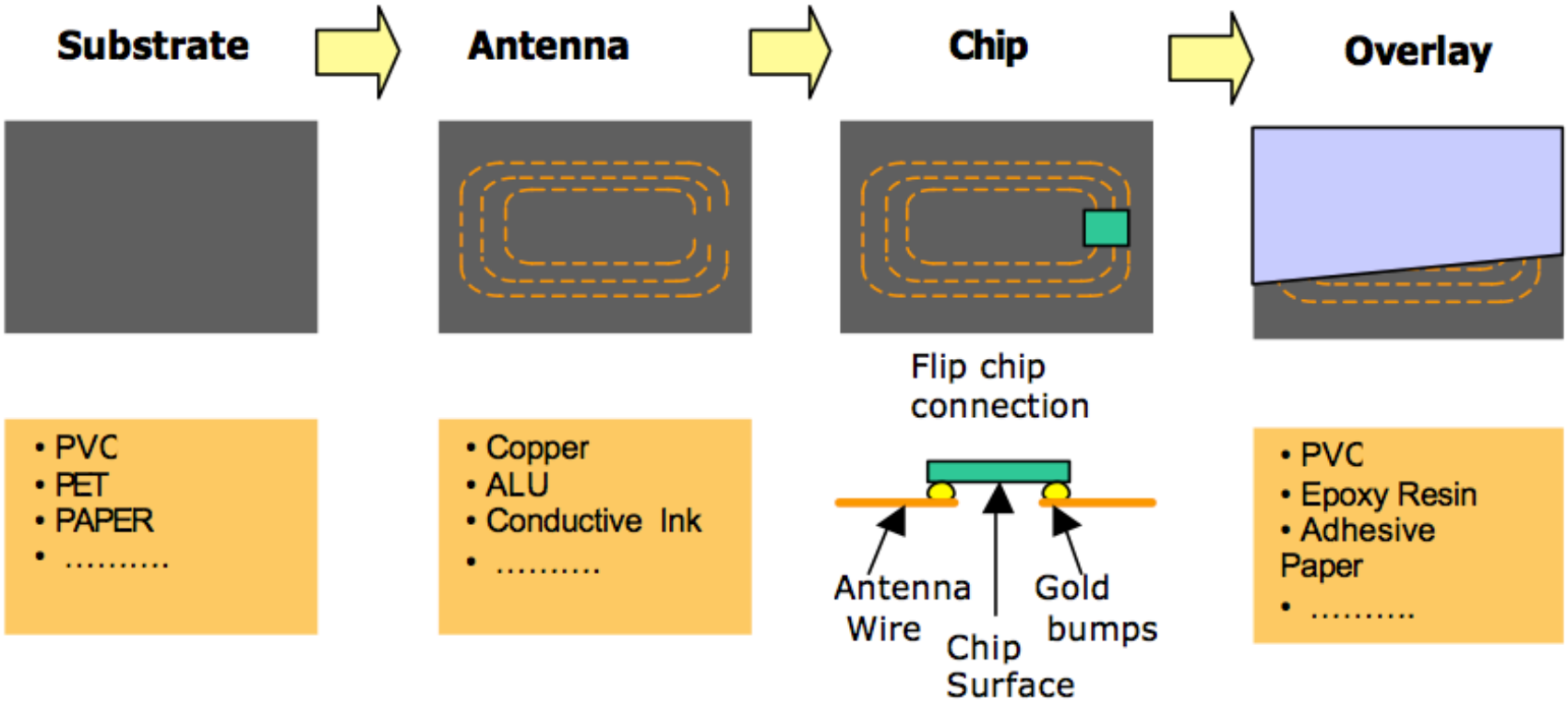
- If many tags are present then they will all reply at the same time, which at the reader end is seen as a signal collision and an indication of multiple tags.
- The reader manages this problem by using an anti-collision algorithm designed to allow tags to be sorted and individually selected.
- There are many different types of algorithms (Binary Tree, Aloha....) which are defined as part of the protocol standards.
- The number of tags that can be identified depends on the frequency and protocol used, and can typically range from 50 tags/s for HF and up to 200 tags/s for UHF.

Anti-Collision (2/)

- Once a tag is selected, the reader can perform a number of operations such as read the tags identifier number, or in the case of a read/write tag write information to it.
- After finishing dialoging with the tag, the reader can then either remove it from the list, or put it on standby until a later time.
- This process continues under control of the anti collision algorithm until all tags have been selected.

Outline: RFID

RFID Tag Packaging (1/)



RFID Tag Packaging (2/)

- Tags are manufactured in a wide variety of packaging formats designed for different applications and environments.
- The basic assembly process consists of first a substrate material (Paper, PVC, PET...), upon which an antenna made from one of many different conductive materials including Silver ink, Aluminum and copper is deposited.
- Next the Tag chip itself is connected to the antenna, using techniques such as wire bonding or flip chip.
- Finally a protective overlay made from materials such as PVC lamination, Epoxy Resin or Adhesive Paper, is optionally added to allow the tag to support some of the physical conditions found in many applications like abrasion, impact and corrosion.

Tag Cost

- The type of materials and assembly methods used to package tags impact directly on the final cost (around 30%), and to some extent on the communication performance.
- In the supply chain, the cost of tags is one of the main considerations for mass adoption, with the 5 cent tag being the much talked about target.

Tag Integrated Circuit (IC) (1/)

- RFID tag IC's are designed and manufactured using the most advanced and smallest geometry silicon processes. The size of a UHF tag chip is around 0.3 mm^2.
- In terms of computational power, RFID tags contain only basic logic and state machines capable of decoding simple instructions.
- IC design challenges consist in achieving very low power consumption, managing noisy RF signals and keeping within strict emission regulations.
- The amount of data stored ranges from just simple Identifier numbers of around 96 bits to more information about the product with up to 32 Kbits.

Tag Integrated Circuit (IC) (2/)

- Greater data capacity and storage (memory size) leads to larger chip sizes, and hence more expensive tags.
- The Electronic Product Code (EPC) is similar in concept to the UPC (Universal Product Code) used in barcodes today, and ranges from 64 to 256 bits.
- Having a simple code of up to 256 bits lead to smaller chip size, and lower tag costs.
- Tags that store just an ID number are often called **License Plate Tags**.

Tag Classes (1/)

Class 0 - Read Only- Factory Programmed

- Class 0 Tags are the simplest type of tags, where the data, which is usually a simple ID number, (EPC) is written only once into the tag during manufacture.
- The memory is then disabled from any further updates.
- Class 0 is also used for EAS (Electronic Article Surveillance) or anti-theft devices, with no ID, and only announce their presence when passing through an antenna field.

Tag Classes (2/)

Class 1 - Write once Read Only (WORM) - Factory or User programmed

- In this case the tag is manufactured with no data written into the memory. Data can then either be written by the tag manufacturer or by the user, one time.
- Following this no further writes are allowed and the tag can only be read. Tags of this type usually act as simple Identifiers

Class 2 - Read Write

- This is the most flexible type of tag, where users have access to read and write data into the tags memory.
- They are typically used as data loggers, and therefore contain more memory space than what is needed for just a simple ID number.

Tag Classes (3/)

Class 3 - Read Write - with on board sensors

- These tags contain on-board sensors for recording parameters like temperature, pressure, and motion, which can be recorded by writing into the tags memory.
- As sensor readings must be taken in the absence of a reader, the tags are either semi-passive or active.

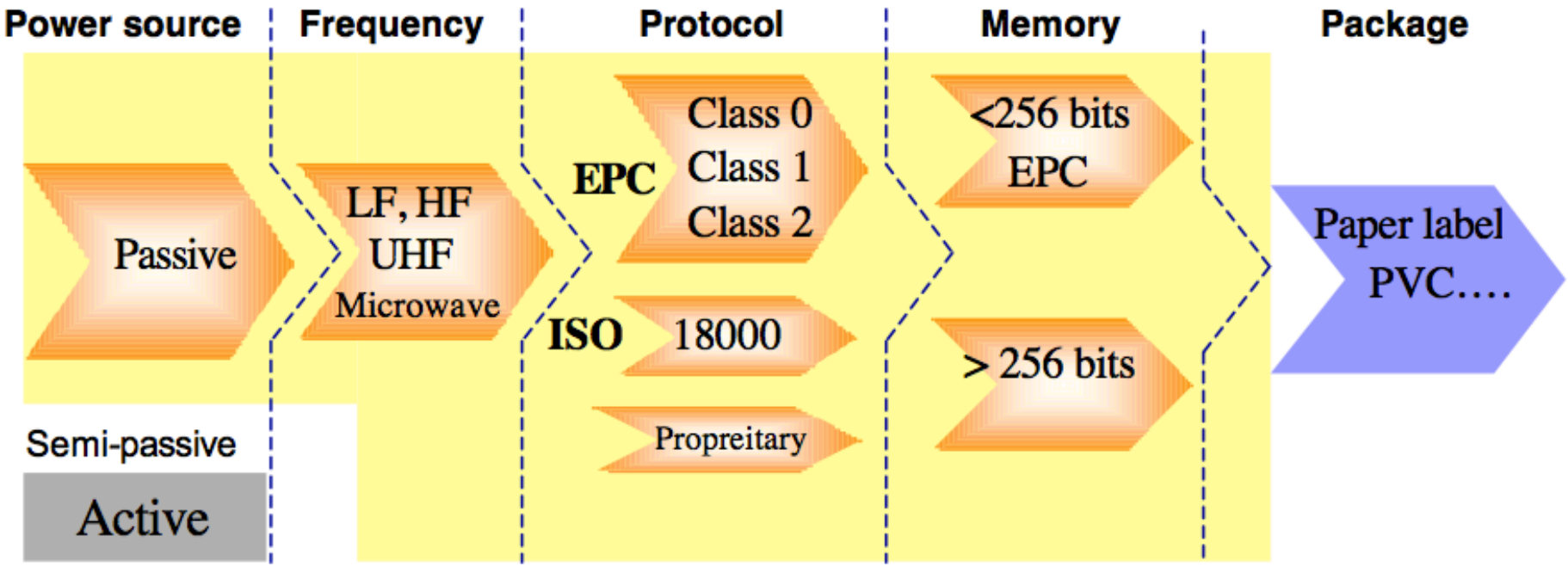
Class 4 - Read Write - with integrated transmitters

- These are like miniature radio devices which can communicate with other tags and devices without the presence of a reader.
- This means that they are completely active with their own battery power source.

Tag Classes (4/)

Class	Name	Memory	Power	Application
0	EAS (EPC)	None	Passive	Anti-Theft
1	EPC	Read-Only	Any	Identification
2	EPC	Read-Write	Any	Data logging
3	Sensor Tags	Read-Write	Semi-Passive	Sensors
4	Smart Dust	Read-Write	Active	Ad-hoc networking

Selecting a Tag



Active and Passive Tags (1/)

- Passive tags can be read at a distance of up to 4 to 5m using the UHF band; The semi-passive can achieve up to 100m and the active ones several kilometers.
- Passive tags use the reader field as a source of energy for the chip and for communication from and to the reader.
- The available power from the reader field, reduces very rapidly with distance and results in a limited communication distance of 4-5m for UHF band.

Active and Passive Tags (2/)

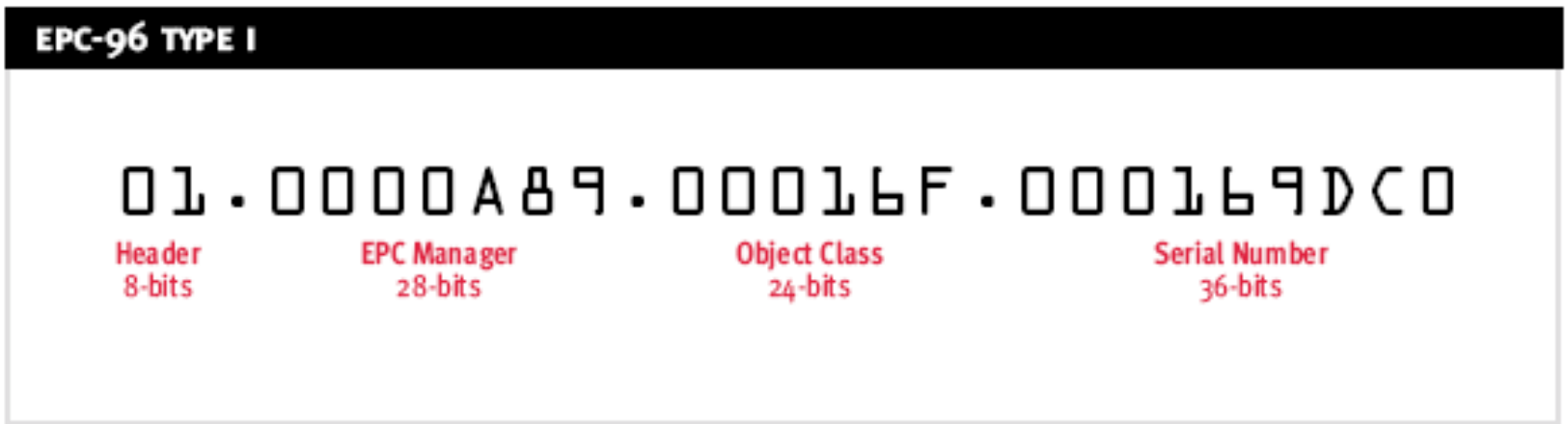
- Semi-Passive (battery assisted backscatter) tags have built in batteries and therefore do not require energy from the reader field to power the chip.
- This allows them to function with much lower signal power levels, resulting in greater distances of up to 100 meters.
- Distance is limited mainly due to the fact that tag does not have an integrated transmitter, and is still obliged to use the reader field to communicate back to the reader.
- Active tags are battery powered devices that have an active transmitter onboard. They generate RF energy and apply it to the antenna. This autonomy from the reader enable long range communication of over several kilometers.

Comparison of Passive and Active Tags

	Advantages	**Disadvantages**	**Remarks**
Passive	Longer life time Flexible Tags Low cost	Short range 4 to 5 m Local regulations control	Widely used Tags are LF, HF or UHF
Semi-Passive	Long range Can manage sensors	Expensive Reliability	real time systems tracking high values Tags are UHF
Active	Long range	Expensive	Logistics for tracking of containers on trains, trucks etc Tags are UHF or microwave

EPC code

- The code is similar to the UPC (Universal Product Code) used in bar codes, and ranges from 64 bits to 256 bits with 4 distinct fields.



RFID reader

- An RFID reader, known as an **interrogator**, is a device that provides the connection between the tag data and the enterprise system software that needs the information.
- The reader communicates with tags that are within its field of operation, performing any number of tasks including simple continuous inventorying, filtering (searching for tags that meet certain criteria), writing (or encoding) to selected tags, etc.
- The reader uses an attached antenna to capture data from tags. It then passes the data to a computer for processing.
- Readers can be affixed in a stationary position in a store or factory, or integrated into a mobile device such as a portable, handheld scanner. They can also be embedded in electronic equipment or devices, and in vehicles.

RFID reader antennas (1/)

- Reader antennas convert electrical current into electromagnetic waves that are then radiated into space where they can be received by a tag antenna and converted back to electrical current.
- The two most common antenna types are **linear** and **circular-polarized** antennas.
- Antennas that radiate **linear electric fields** have **long ranges**, and **high levels of power** that enable their signals to penetrate through different materials to read tags.
- Linear antennas are **sensitive to tag orientation**; depending on the tag angle or placement, linear antennas can have a difficult time reading tags.

RFID reader antennas (2/)

- Antennas that radiate **circular fields** are **less sensitive** to orientation, but are not able to deliver as much power as linear antennas.
- Choice of antenna is also determined by the distance between the RFID reader and the tags that it needs to read. This distance is called read range.
- Reader antennas operate in either a **near-field** (short range) or **far-field** (long range).

RFID reader antennas (3/)

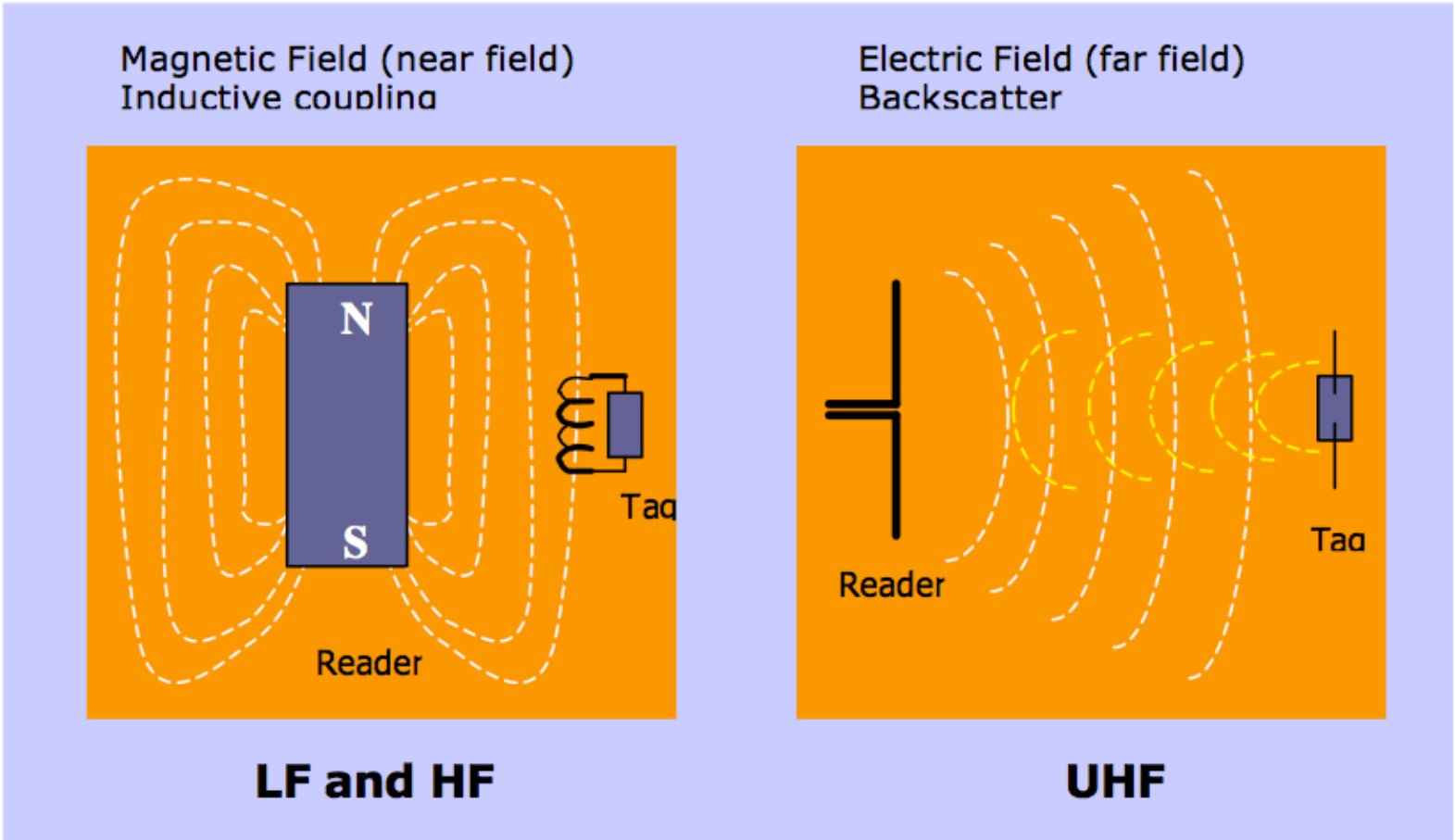
- In near-field applications, the read range is less than 30 cm and the antenna uses magnetic coupling so the reader and tag can transfer power.
- In near-field systems, the readability of the tags is not affected by the presence of dielectrics such as water and metal in the field.
- In far-field applications, the range between the tag and reader is greater than 30 cm and can be up to several tens of meters.
- Far-field antennas utilize electromagnetic coupling and dielectrics can weaken communication between the reader and tags.

Reader Control and Application Software

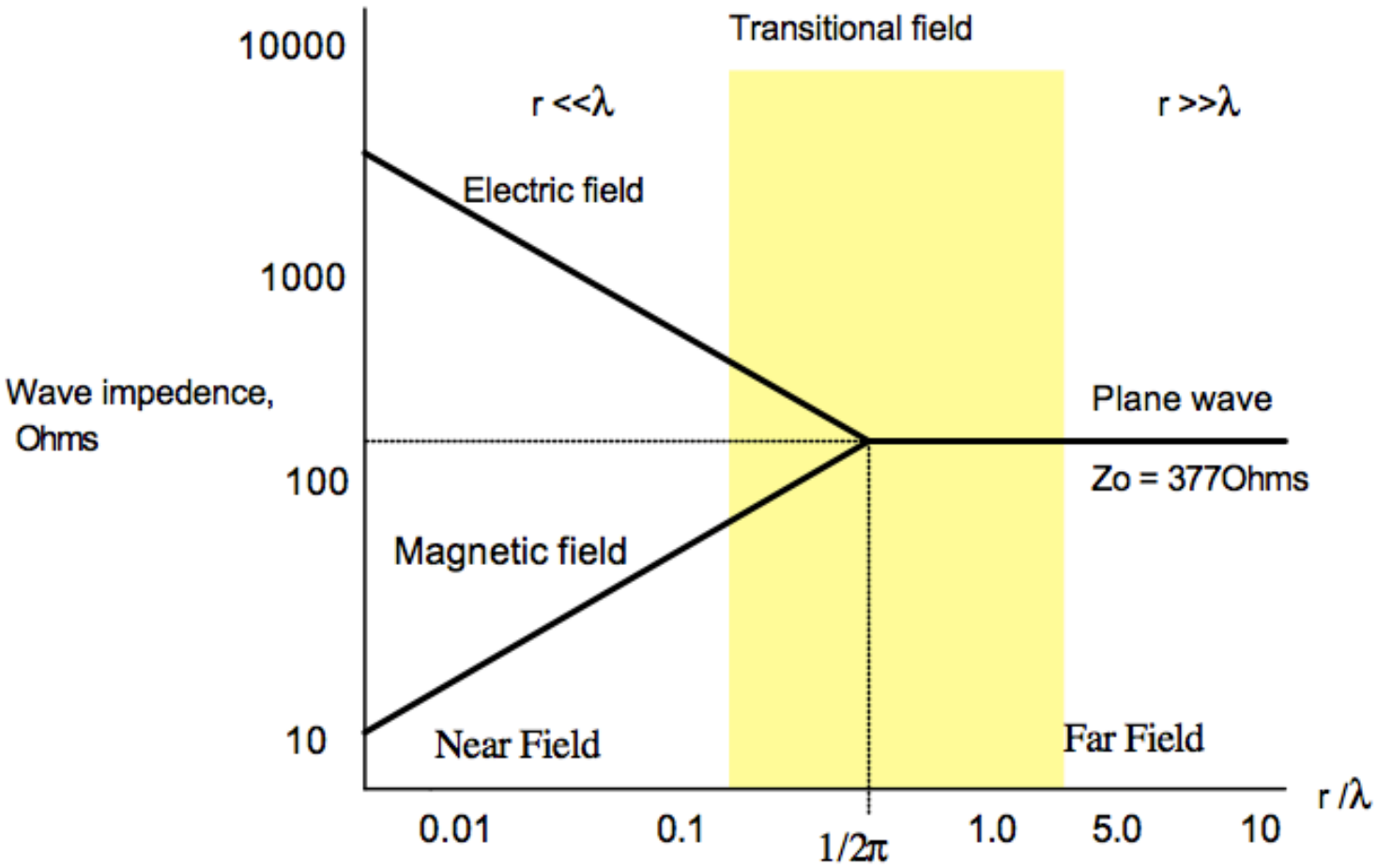
- Reader control and application software, also known as middleware, helps connect RFID readers with the applications they support.
- The middleware sends control commands to the reader and receives tag data from the reader.

Outline: RFID

How Tags Communicate?



Near and Far Field



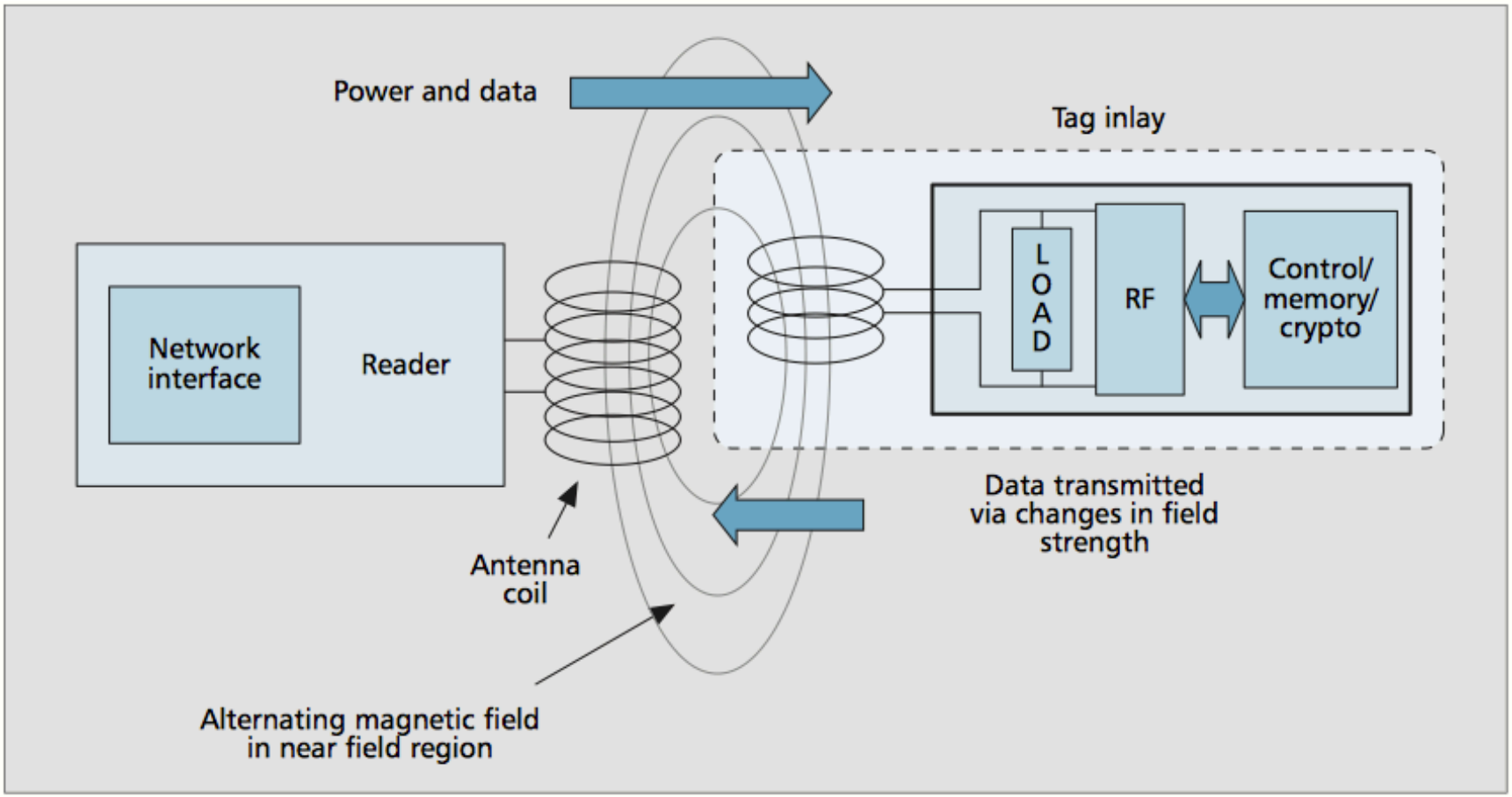
Tag Communication

- For distance $r \ll 0.16\lambda$, tags employs the near field inductive coupling of the tag to the magnetic field circulating around the reader antenna.
- For distance $r \gg 0.16\lambda$, tags use the far field similar techniques to radar (backscatter reflection) by coupling with the electric field.
- The near field is generally used by RFID systems operating in the LF and HF frequency bands, and the far field for longer read range UHF and microwave RFID systems.

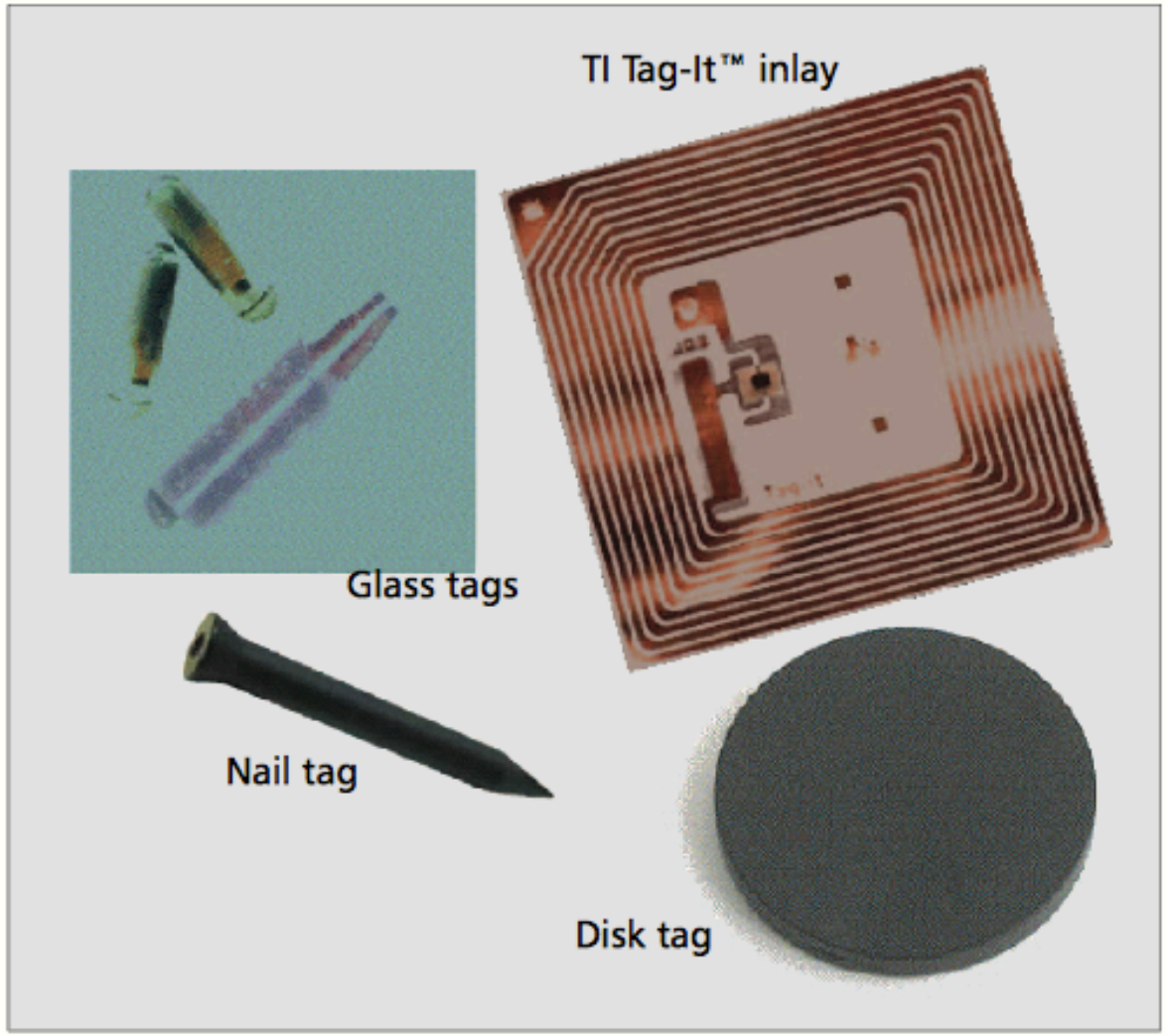
Near and Far Fields Limits

Band	Near Field Region	Far Field Region
LF	< 120m	>12Km
HF	<1m	>110m
UHF	<1.65cm	>1.65m
Microwave	<0.25cm	>0.25cm

Near Field Coupling (NFC)



NFC Tags



Near Field Communication

- The EM field in the near-field region is **reactive** in nature the electric and the magnetic fields are orthogonal and quasi-static.
- In this region, the fields E and H are out of phase by **90 degrees** to each other (recall that for propagating or radiating fields, the fields are orthogonal (perpendicular) but are in phase).
- Depending upon the type of antenna, one field (such as the electric field for a dipole or magnetic field for a coil) dominates the other.
- Most near-field tags rely on the magnetic field through **inductive coupling to the coil** in the tag.

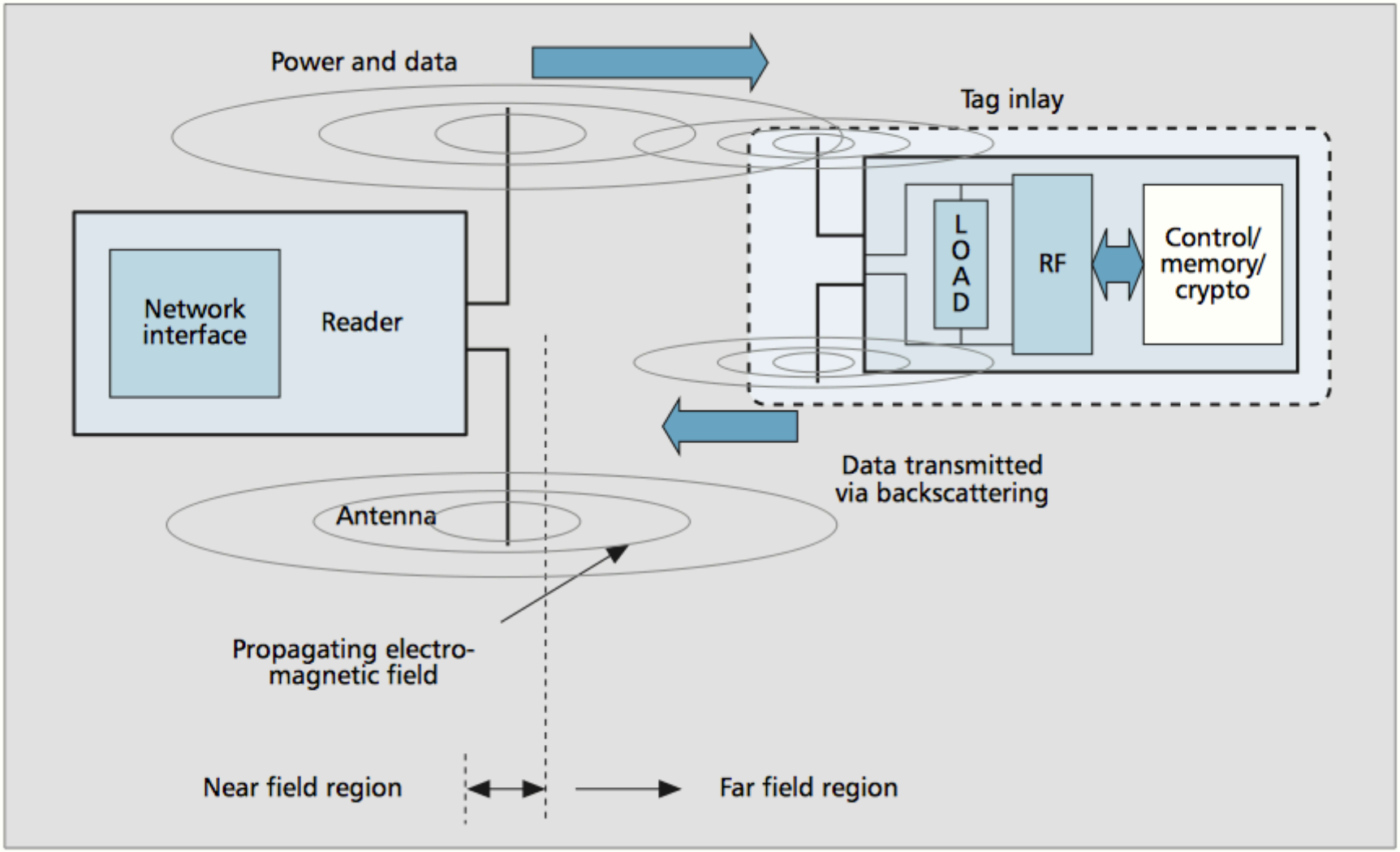
Magnetic Induction

- This mechanism is based upon **Faraday's principle** of magnetic induction. A current flowing through the coil of a reader produces a magnetic field around it.
- This field causes a tag's coil in the vicinity to generate a small current.
- Communication between a reader and a tag is through a mechanism called **load modulation**.
- Any variation of the current in a tag's coil causes a small current variation in a reader's coil due to the mutual inductance, and the variation is detected by reader.
- A **tag varies the current** by **changing the load** on its antenna coil, and hence the mechanism is called **load modulation**.

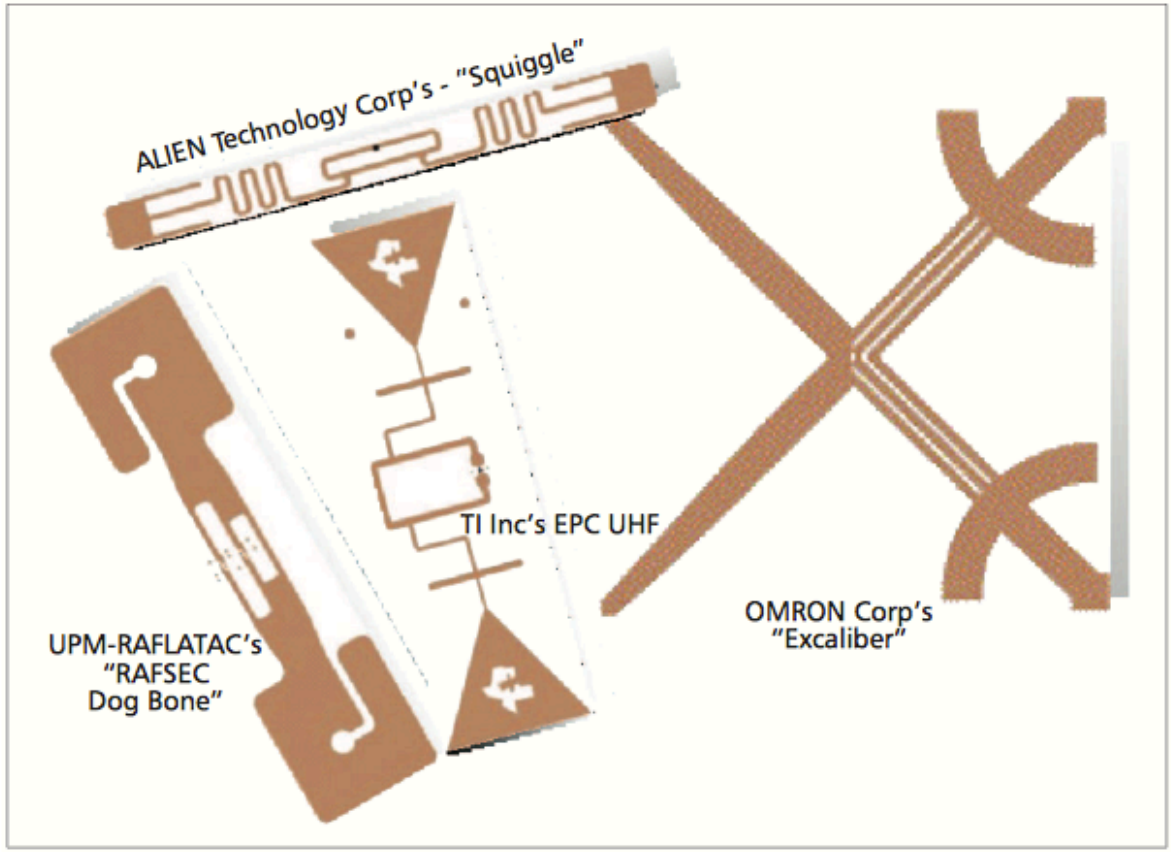
Magnetic Induction: LF and HF

- Because of its simplicity, inductive coupling was initially adopted for passive RFID systems. inductance between the two, and the variation is detected by reader.
- Only **low carrier frequencies** are used in **near-field coupling tags**; the two most common are 128 kHz (LF) and 13.56 MHz (HF).
- For example, the boundary distances are 372 m for 128 kHz and 3.5 m for 13.56 MHz.
- One problem with use of low frequencies is that a large antenna coil is required.
- Also, the power of magnetic field of a magnetic dipole loop drops as $1/r^6$ in the near-field region, where r is the distance between a reader and a tag.
- Another downside is the low bandwidth and, hence, the low data rate.

Far Field Communication Backscattering



Far Field Tags



Far Field Communication

- The EM field in the far-field region is radiative in nature.
- Coupling here captures EM energy at a tag's antenna as a potential difference.
- Part of the energy incident on a tag's antenna is reflected back due to an impedance mismatch between the antenna and the load circuit.
- Changing the mismatch or loading on the antenna can vary the amount of reflected energy, a technique called backscattering.

Far Field : UHF and microwave

- Far-field coupling is commonly employed for long-range (5-20 m) RFID, and, in contrast to near-field, there is no restriction on the field boundary for far-field RFID.
- The attenuation of the EM field in far-field region is proportional to $1/r^2$, which is smaller by orders of magnitude than in the near-field range (which is $1/r^6$).
- Far-field tags usually operate in the 860 MHz UHF band or in the 2.45 GHz Microwave band, and this results in a small antenna size and hence a low tag cost.
- UHF and Microwave far-field RFID magnetic signaling is highly subject to performance degradation near metal objects and water.

Outline: RFID

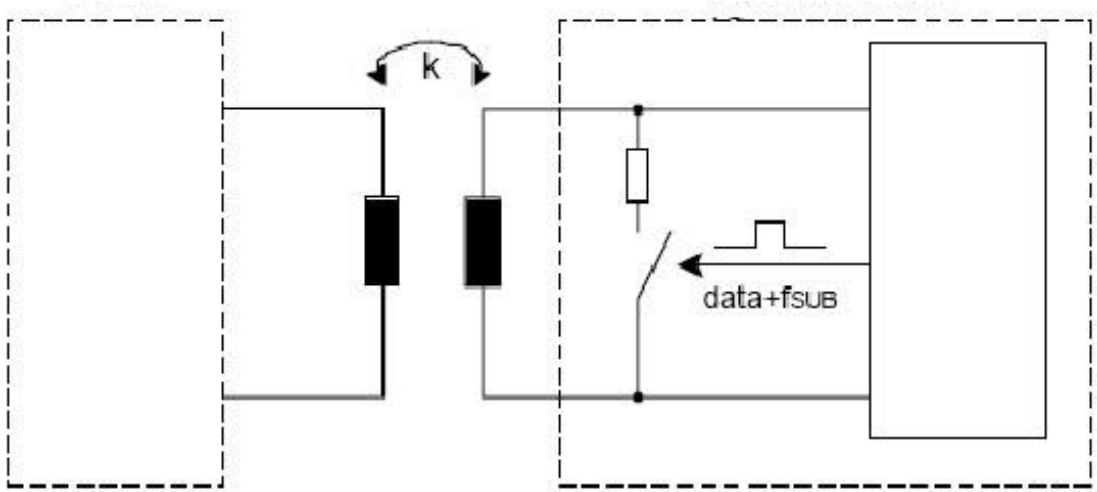
Load Modulation

- Applying the load modulation principles allows that the data from a passive target to be transmitted back to the reader.
- If a target with a resonant frequency equal to the transmission frequency of the reader is placed by the magnetic alternating field of the reader's antenna, the target will be powered by the magnetic field.
- If the load resistor is switched on and off at the target, the voltage changes at the reader's antenna because of the impedance changes in the target resulting in amplitude modulation at the reader's antenna.

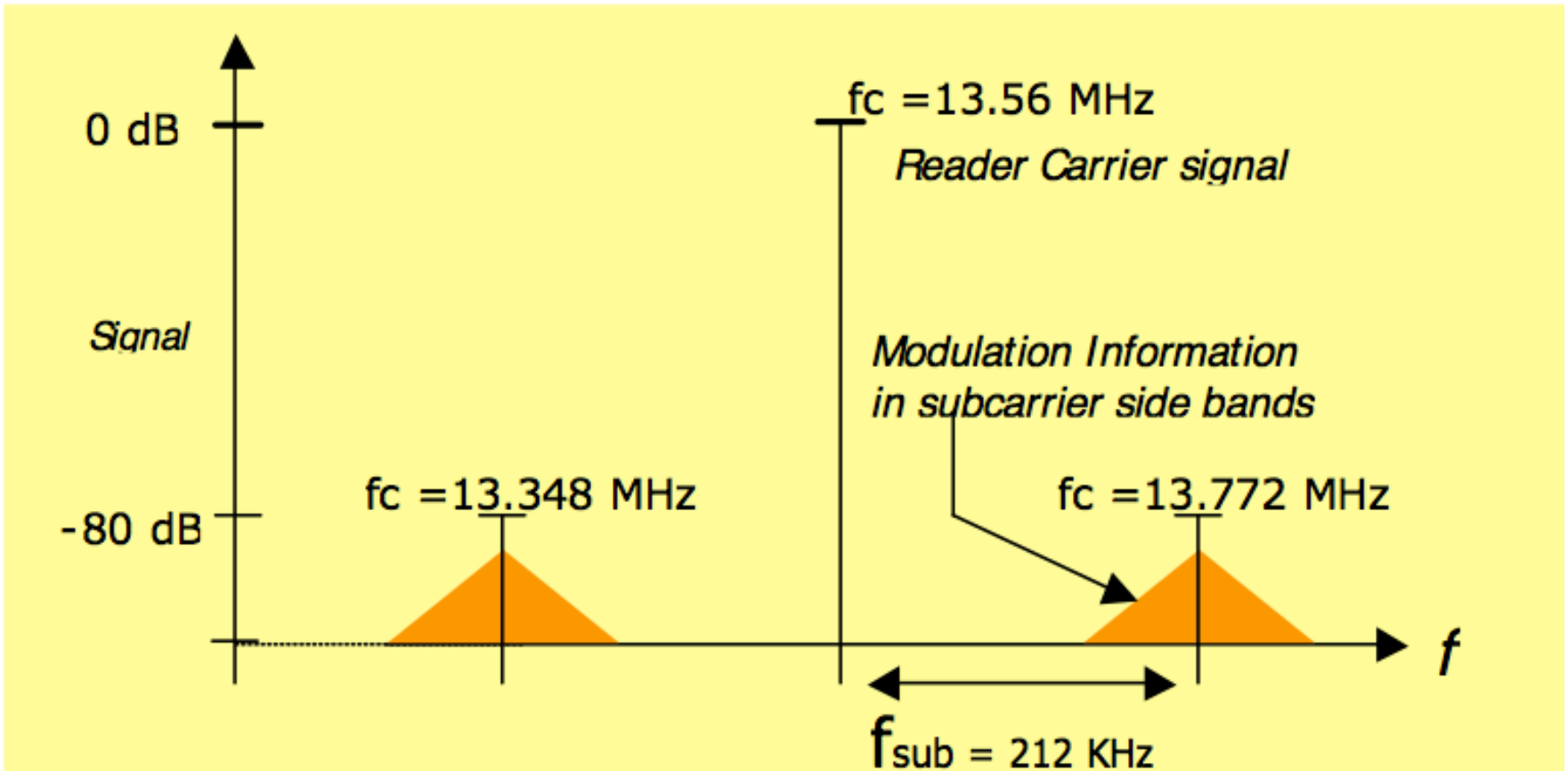
Subcarrier Load Modulation

- Instead of switching the load resistance on and off in time with a baseband coded signal, a low frequency subcarrier is first modulated by the baseband data signal.
- ASK, FSK or PSK modulation may be used as the modulation procedure for the subcarrier.
- The subcarrier frequency itself is normally obtained by the binary division of the operation frequency.
- For 13.56MHz systems, the subcarrier frequencies 847 kHz , 424 kHz or 212 kHz are normally used.
- The modulated subcarrier is now applied to switch the load resistor on and off.

Subcarrier Load Modulation



Advantage of the Subcarrier Load Modulation



Questions?