Joint EC/EPoSS Expert Workshop 2008 Beyond RFID - The Internet of Things
Brussels, Belgium, 11 - 12 February 2008

RFID Sensing and Interacting Technology Fusion

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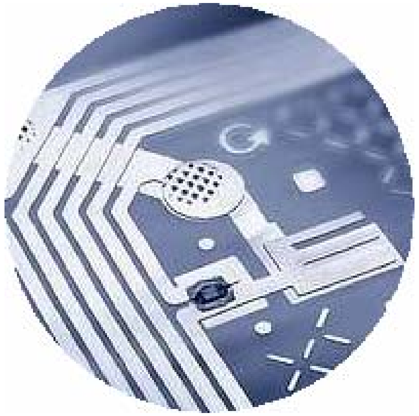
SINTEF, Norway

Outline

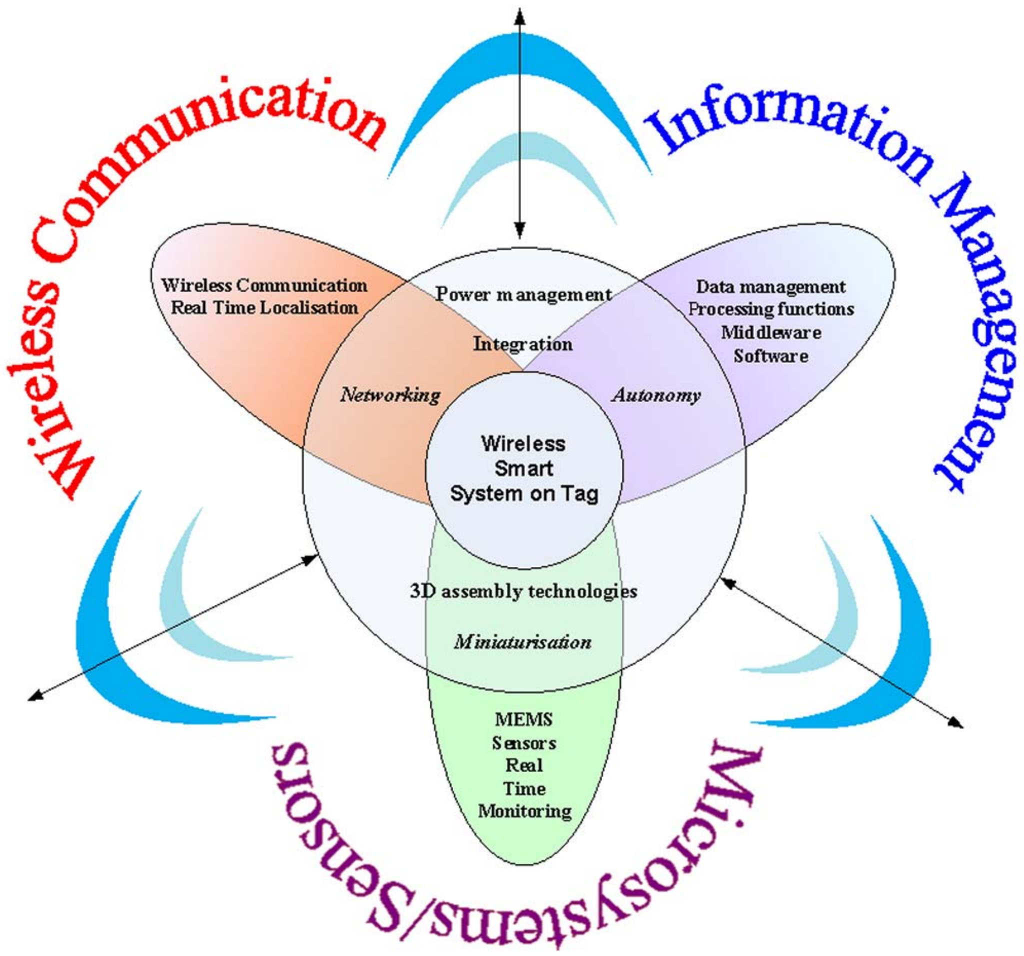
- Introduction
- Communication Technologies
- Smart Integrated Systems
- Hybrid Sensor Networks
- IntelliSense RFID
- Research Priorities
- RFID Technology Roadmap
- Future Scenarios



Smart Systems on Tags

Functions

- Sense
- Actuate
- Identify
- Interact
- Interface
- Communicate



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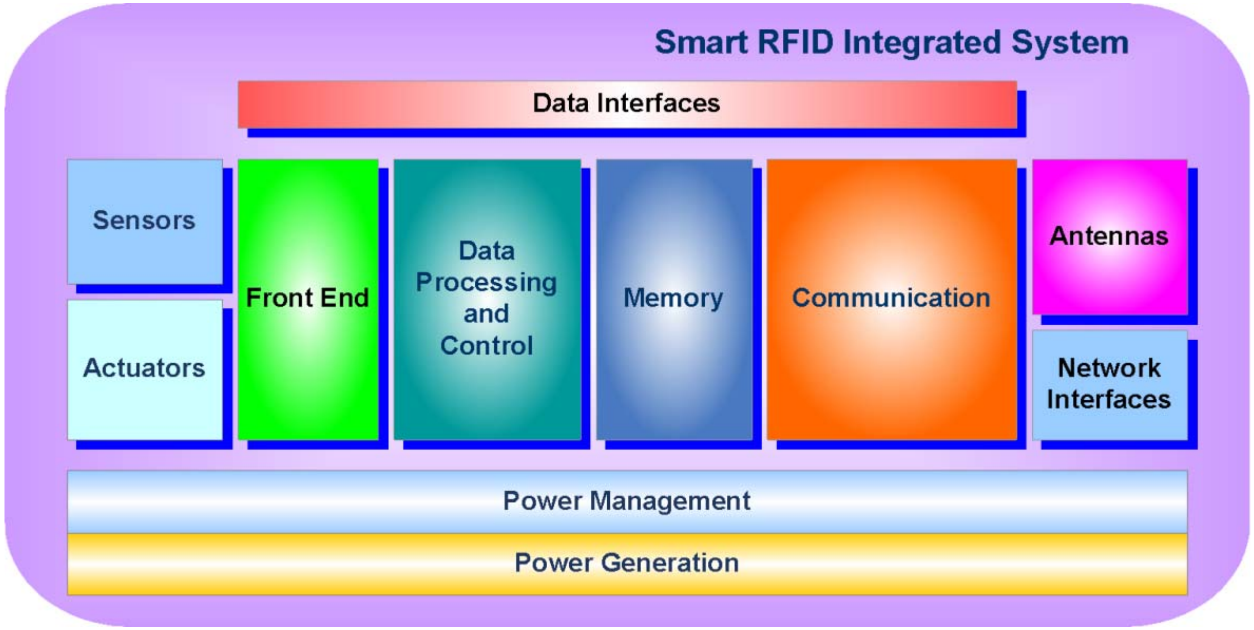
Smart Systems on Tags

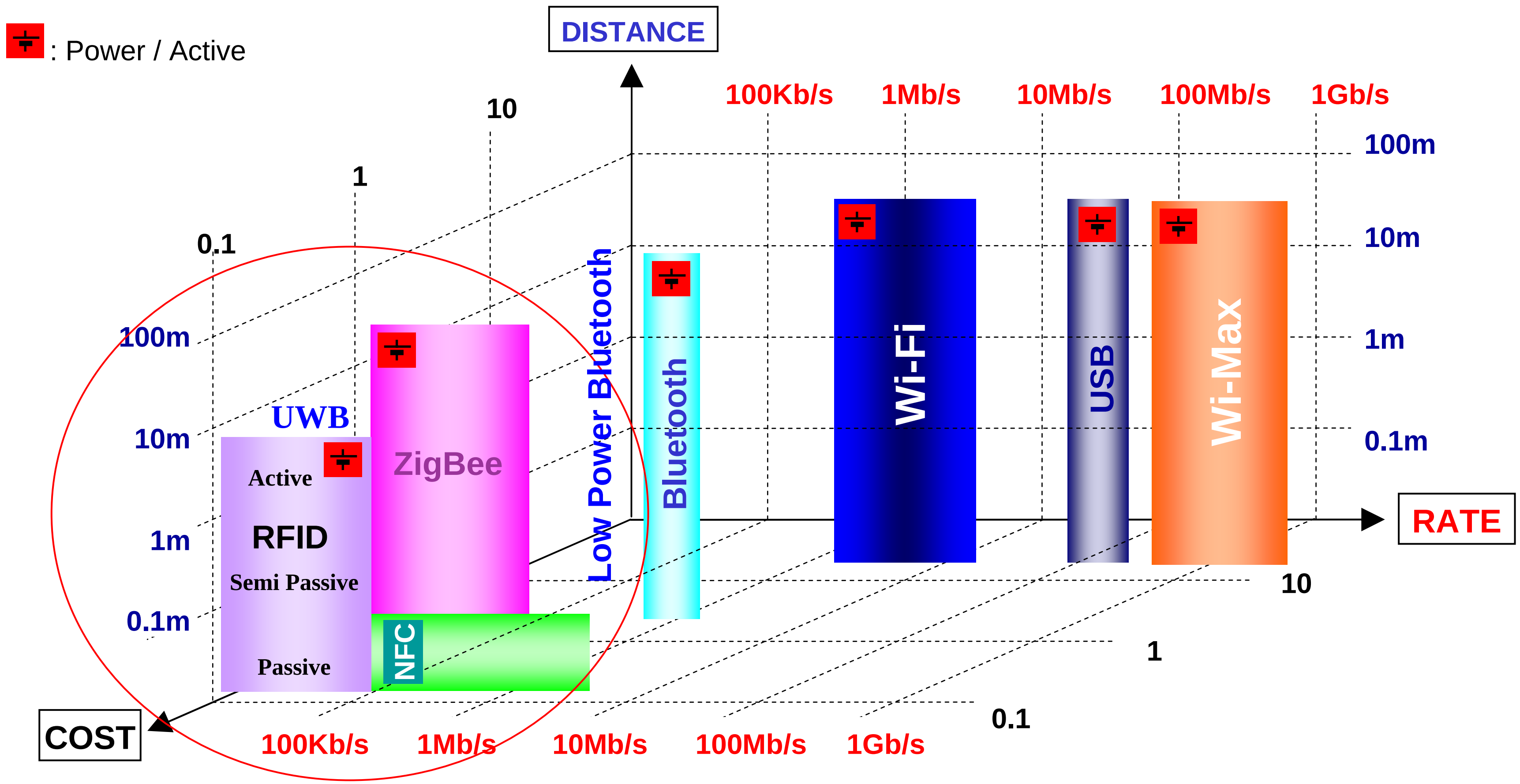
Modules

- Sensors
- Actuators
- Processing
- Memory
- Antennas
- Power
- Interface
- Communication



- Features:
  - Small size
  - Ultra low power
  - Very low cost
  - Autonoumus
  - ”Invisible”

Communication Technologies



Communication Technologies

M2M

RFID (424kb/s, 7m, 13.56MHZ, 866-960MHZ)
RFID (433MHz, 2.45GHz)

ZigBee* (250kb/s, 10m, 2.47GHz)
ZibBee*–a (20kb/s, 75m, 900 MHz)

H2M/H2H

Bluetooth (750kb/s, 10m, 2.47GHz)

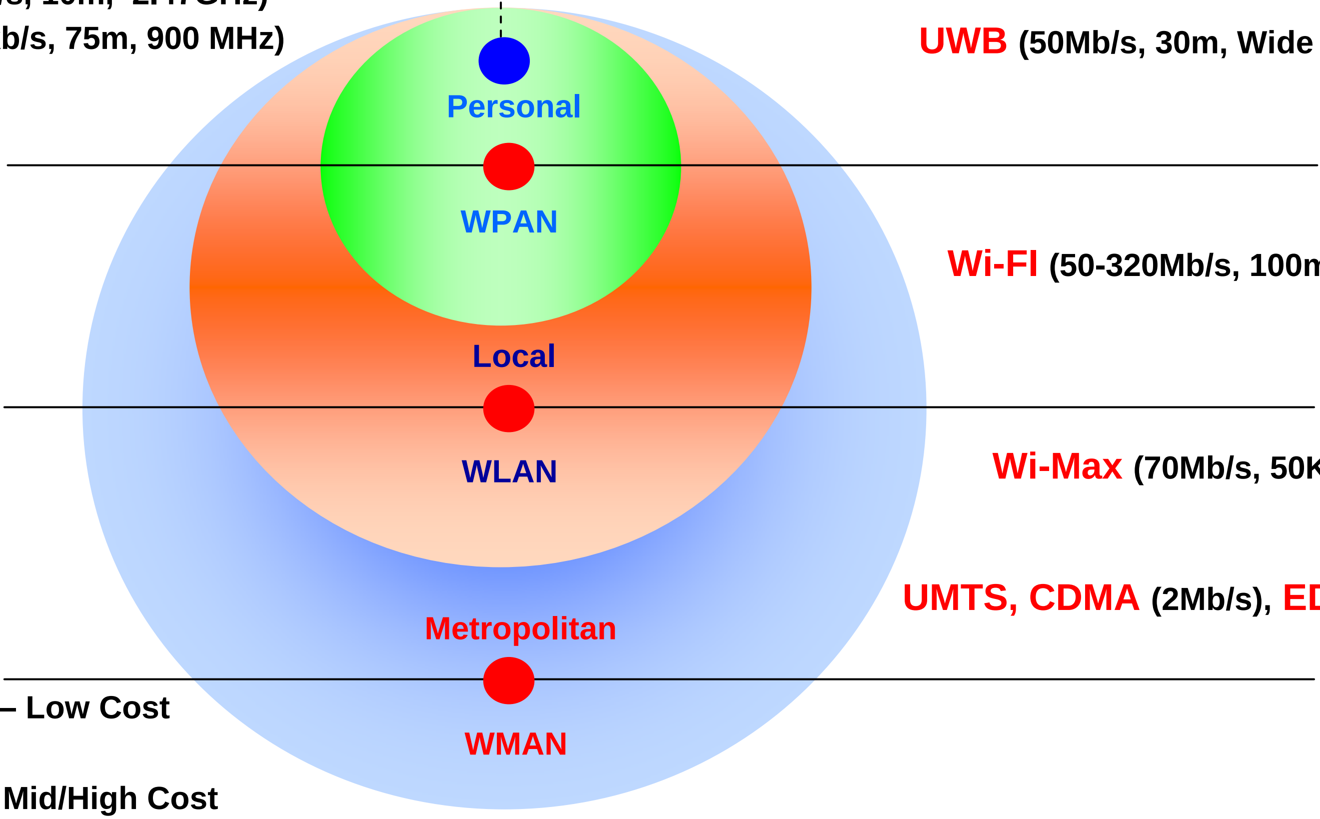
Low Power Bluetooth

UWB (50Mb/s, 30m, Wide Range)

Wi-FI (50-320Mb/s, 100m, 2.4-5.8GHz)

Wi-Max (70Mb/s, 50Km, 2-11GHz)

UMTS, CDMA (2Mb/s), **EDGE, MBWA**



Passive – Low Cost

Active – Mid/High Cost

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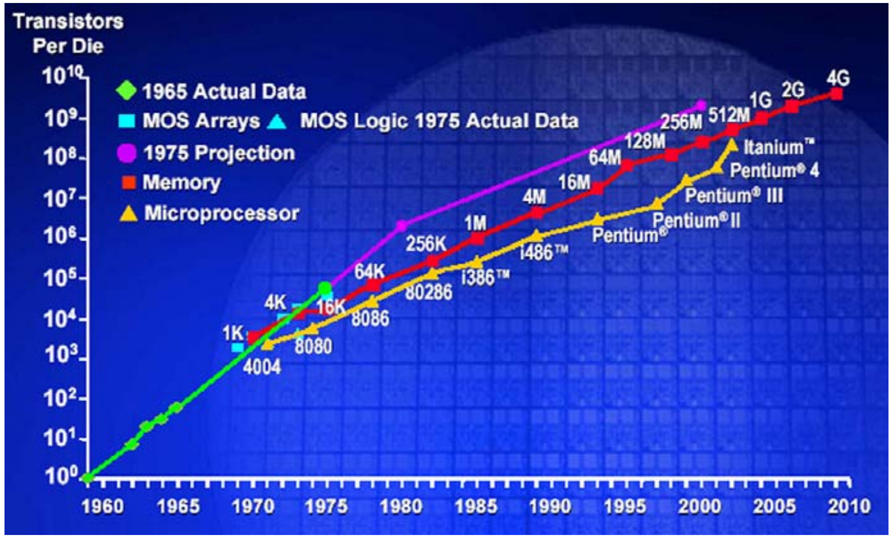
RFID Frequencies

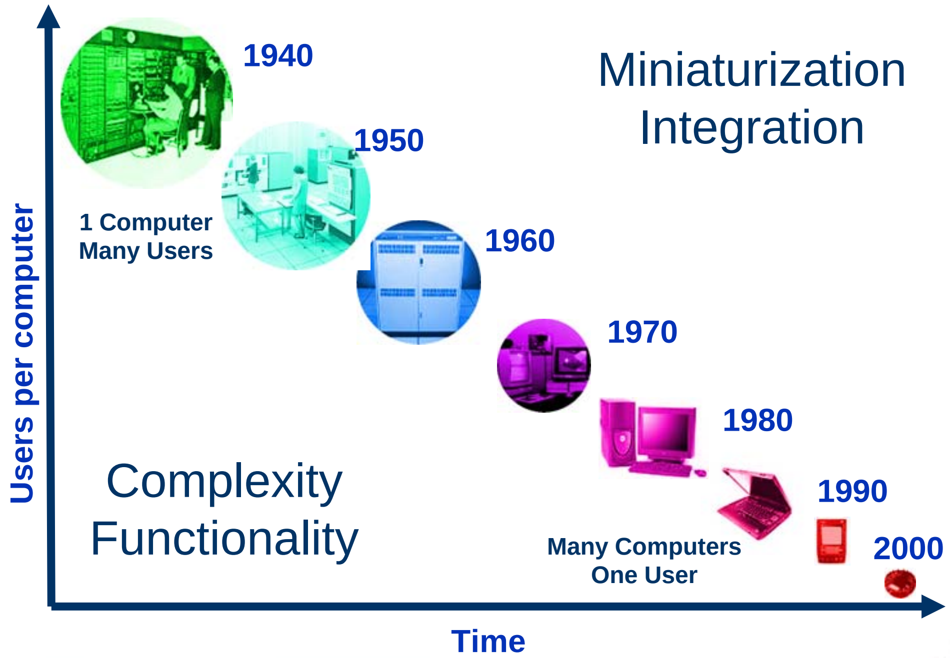
	135kHz	13.56MHz	900MHz	2.45GHz
RF Coupling	Magnetic	Magnetic	EM Field	EM Field
Antenna Features	Loop (>50turns)	Loop (5-8turns)	Folded Dipole (17cm)	Folded Dipole (5.5cm)
Water Influence	No	No	Medium	Large
Metal Influence	No (Except Iron)	No (Except Iron)	Large	Large
Communication Range	>50cm	>50cm	>3m	>1.5m

Frequency Range	Power Source	Data Transfer Speed	Energy Absorption	Energy Efficiency	ISO/IEC 18000 Part #
<135 KHz	Passive	Slowest - small amount of data	Lowest	Highest	2
13.56 MHz	Passive	Slow	Low	High	3
433 MHz	Active	Fast	High	Low	7
860-960 MHz	Passive	Faster	Higher	Lower	6
2.45 GHz	Passive or Active	Very Fast	Very High	Very Low	4

Technology Laws

- Moore’s Law
  - 1965: Number of Integrated Circuit components will double every year
  - 1975: Number of Integrated Circuit components will double every 18 months
  - Computing power doubles every 18 months
- Bell’s Law
  - New computing class every 10 years
- Metcalfe's Law
  - Value of network increases exponentially as number of participants increases
- Gilder's Law
  - Network bandwidth capacity doubles every 12 months

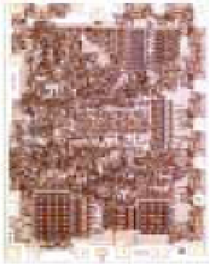




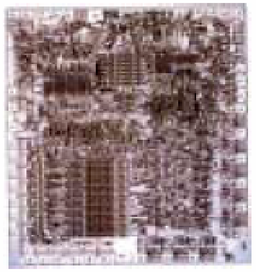
Technology Laws – INTEL μPs

4004
11 / 1971
2300
10 μm
108 KHz

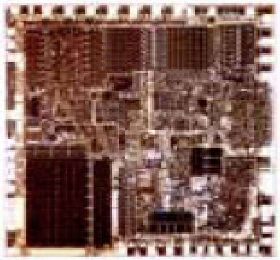
8008
04 / 1972
3500
10 μm
200 KHz



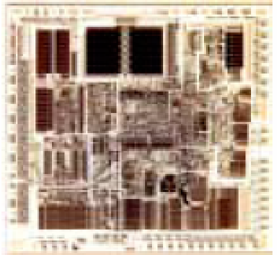
8080
04 / 1974
4500
6 μm
2 MHz



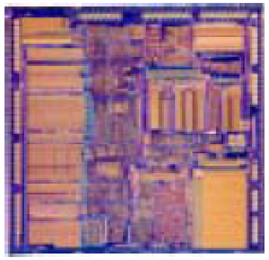
8088
06 / 1979
29000
3 μm
8 MHz



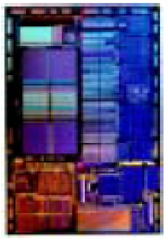
80286
02 / 1982
134000
1.5 μm
12 MHz



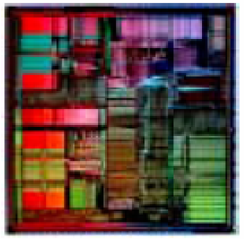
Intel386™
10 / 1985
275000
1 μm
16 MHz



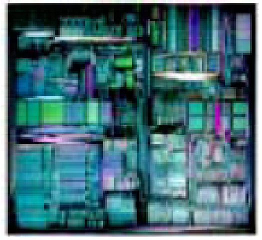
Intel486™ DX
04 / 1989
1.2 M
1 μm
25 MHz



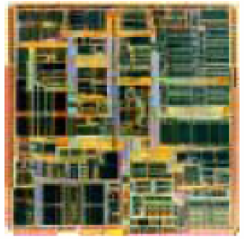
Pentium®
03 / 1993
3.1 M
0.8 μm
66 MHz



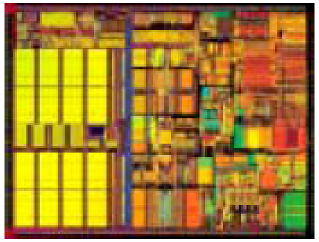
Pentium® Pro
11 / 1995
5.5 M
0.6 μm
150 MHz



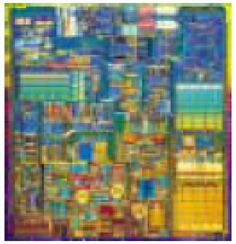
Pentium® II
05 / 1997
7.5 M
0.35 μm
233 MHz



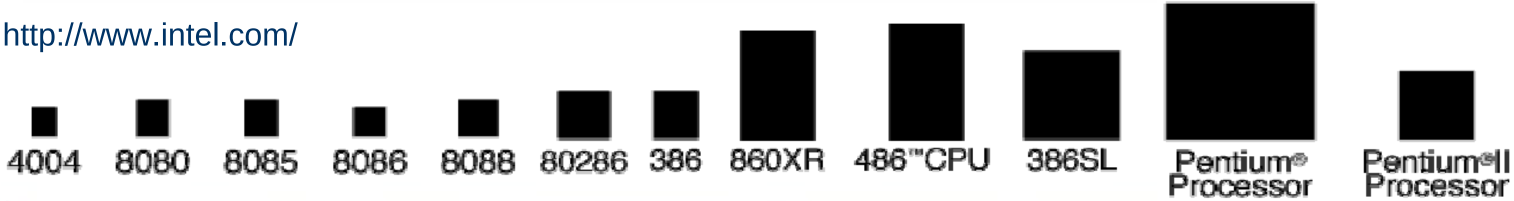
Pentium® III
02 / 1999
9.5 M
0.25 μm
500 MHz



Pentium® 4
11 / 2000
42 M
0.18 μm
1.5 GHz

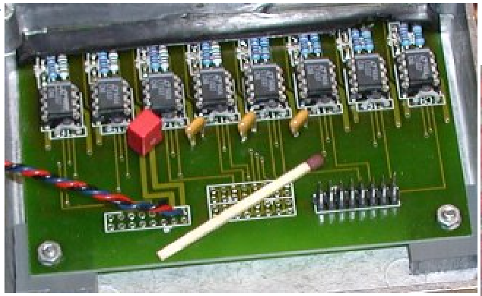


http://www.intel.com/



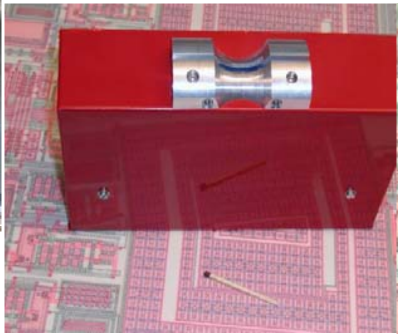
Fingerprint SINTEF Development

Size



8 channels 8 standard amplifiers

1997



1998

15x20 cm^2

256 channels 16 ASICs with 16 channels each - 0.8µm 2M CMOS

Miniaturization
Integration

Complexity
Functionality

2000

5x4 cm^2

256 channels 4 ASICs with 64 channels each - 0.8µm 2M CMOS)

2003

5x7 mm^2

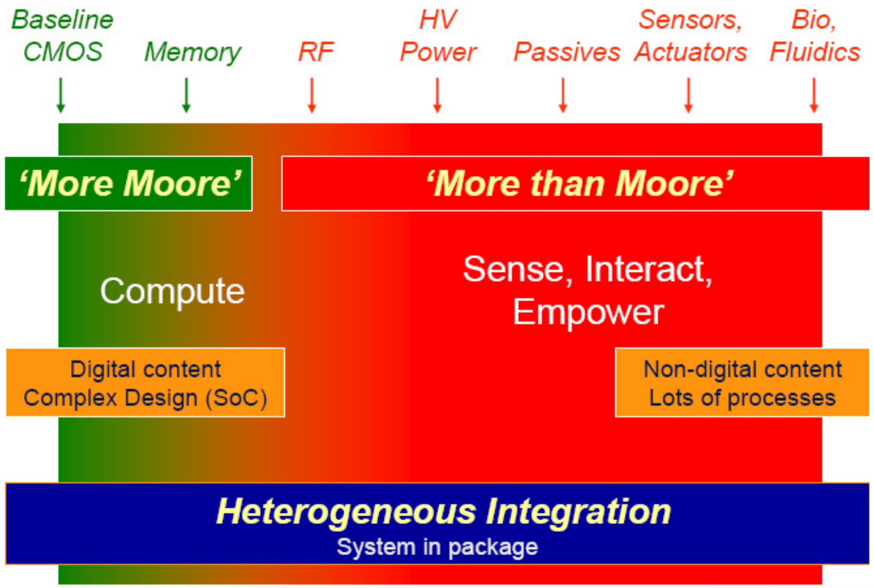
Hybrid solution: Fingerprint, Navigation and Pointer Detection

Silicon Substrate 7x15 mm^2
ASIC 4×4.5 mm^2 with 316 channels - 0.25µm 5M CMOS

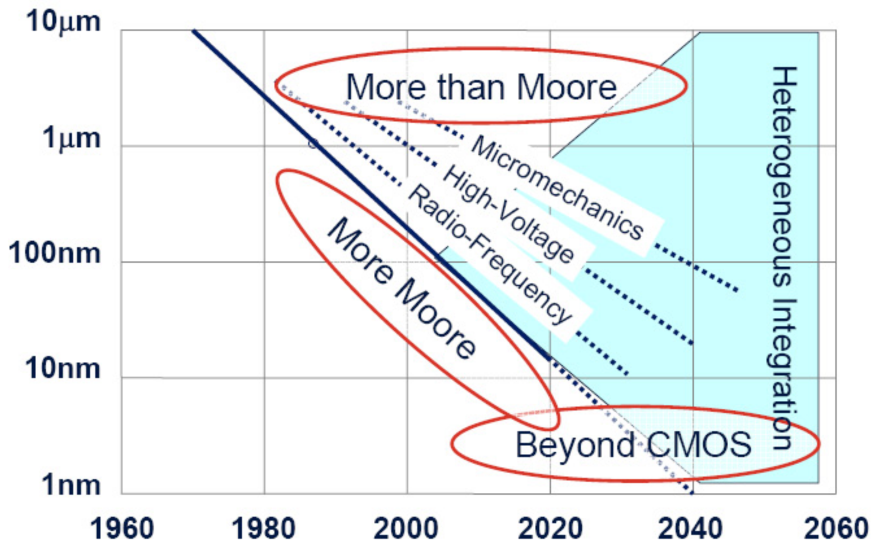
Time

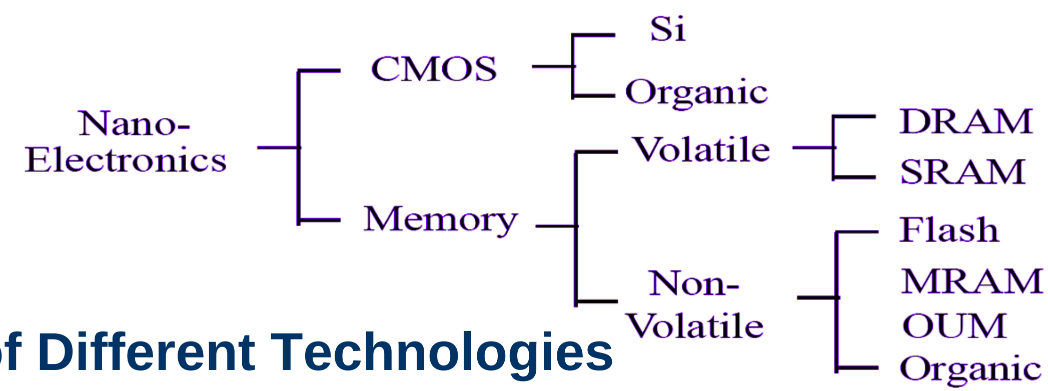
RFID Smart Systems on Tags

More than Moore and Heterogeneous Integration



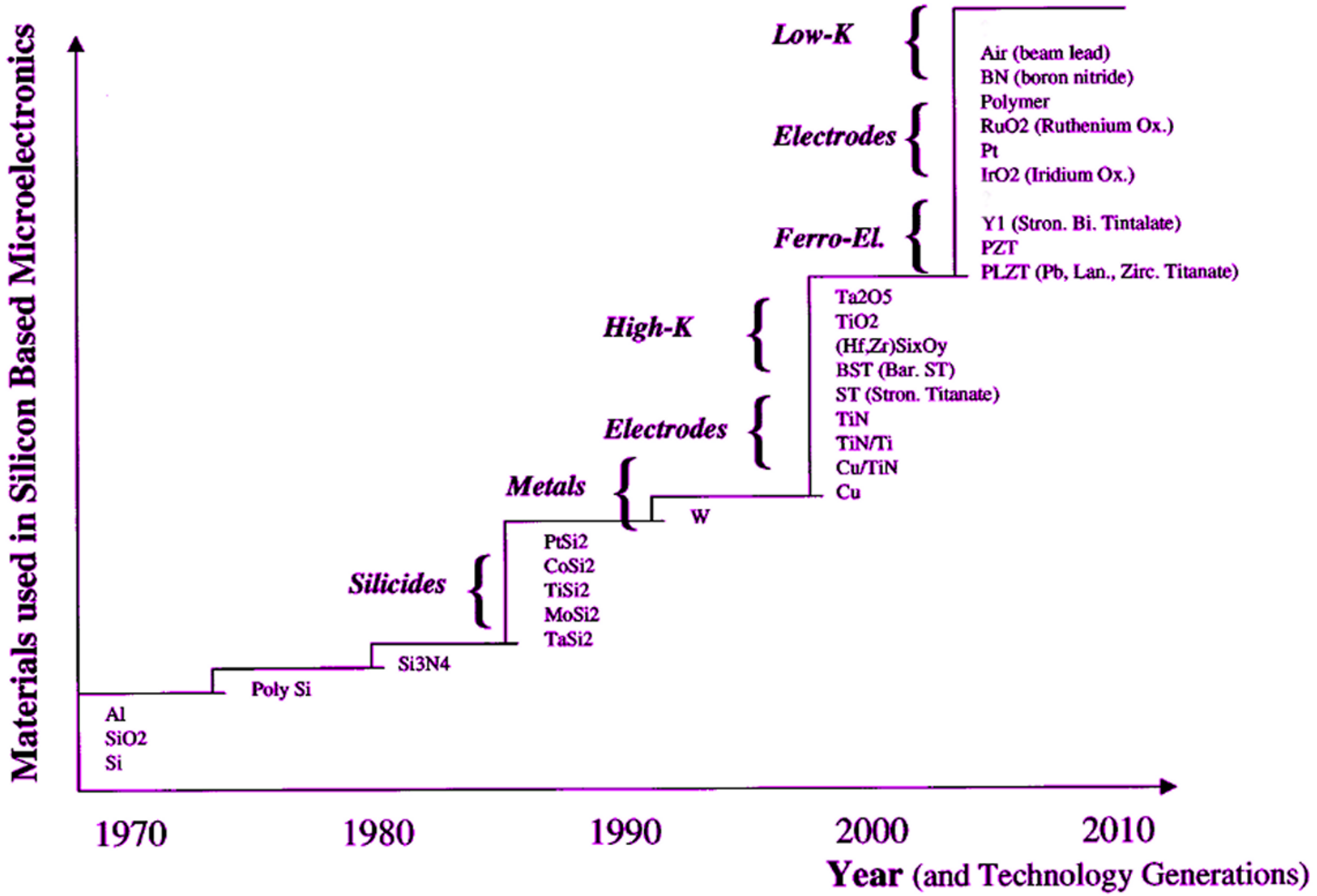
ENIAC technology roadmap





Heterogeneous Integration of Different Technologies

Quantum leaps in new materials



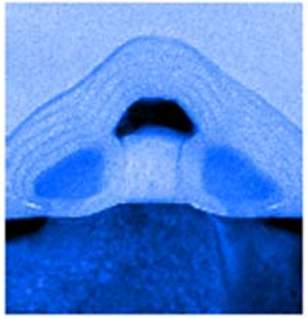
Source: R. W. Dutton,., *al.* IEEE TRANSACTIONS ON COMPUTER-AIDED DESIGN OF INTEGRATED CIRCUITS AND SYSTEMS, VOL. 19, NO. 12

Silicon CMOS along ITRS

90 nm node
2003

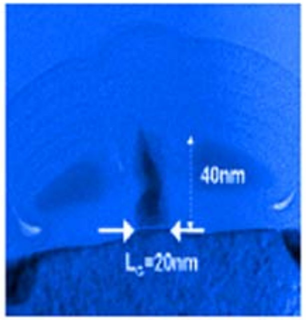
50 nm length
(IEDM 2002)

65 nm node
2005



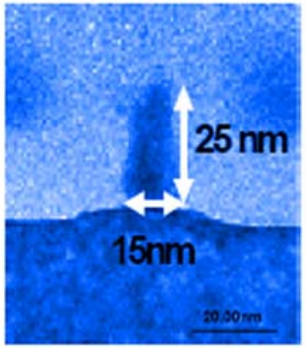
30 nm prototype
(IEDM 2000)

45 nm node
2007



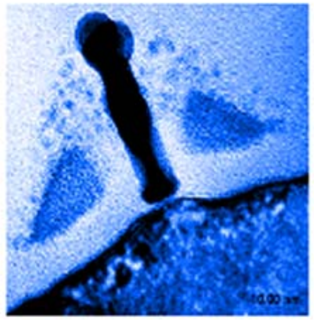
20 nm prototype
(VLSI 2001)

32 nm node
2009



15 nm prototype
(IEDM 2001)

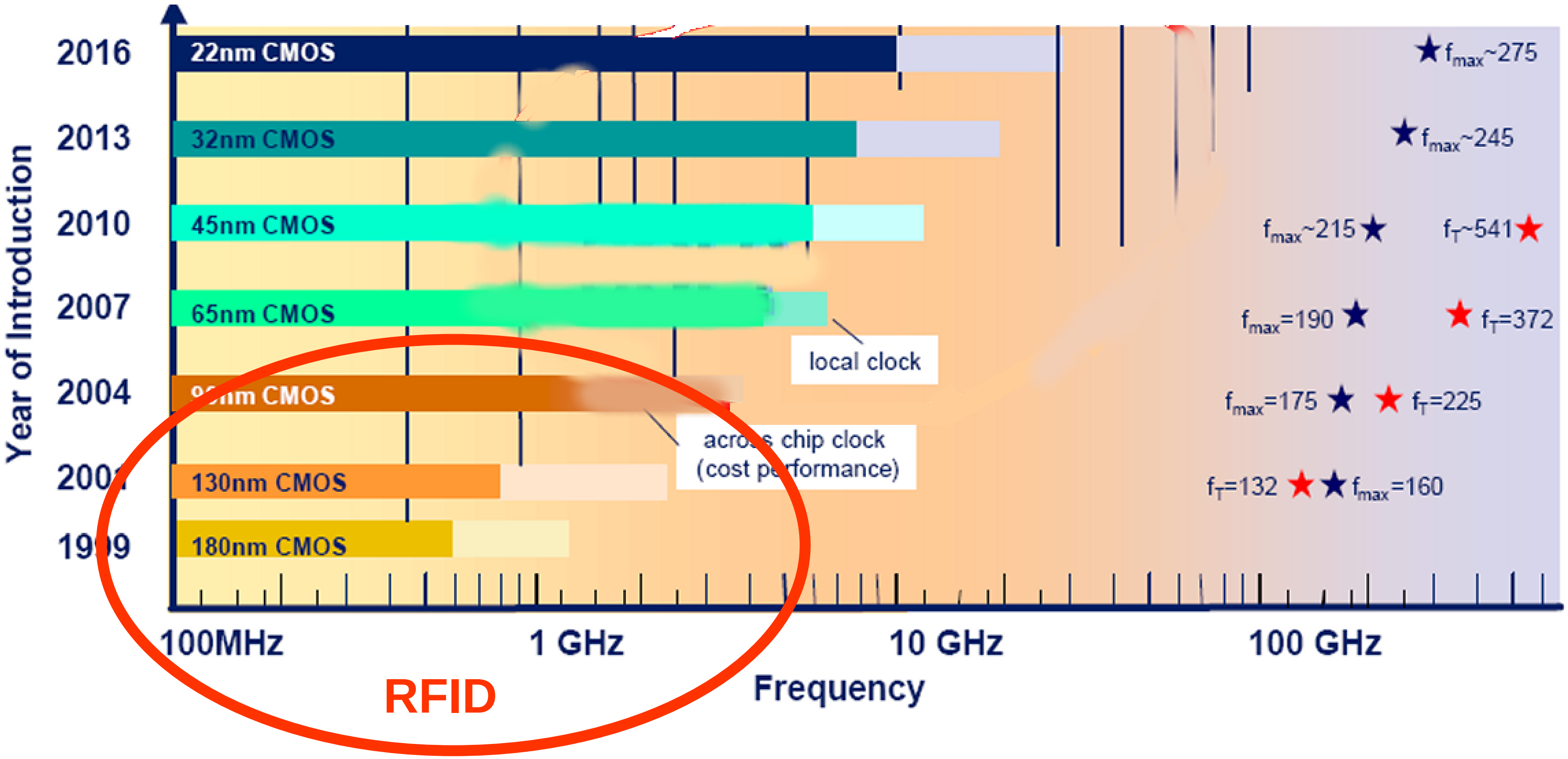
22 nm node
2011



10 nm prototype
(DRC 2003)

International Technology Roadmap for Semiconductors

Silicon CMOS along ITRS

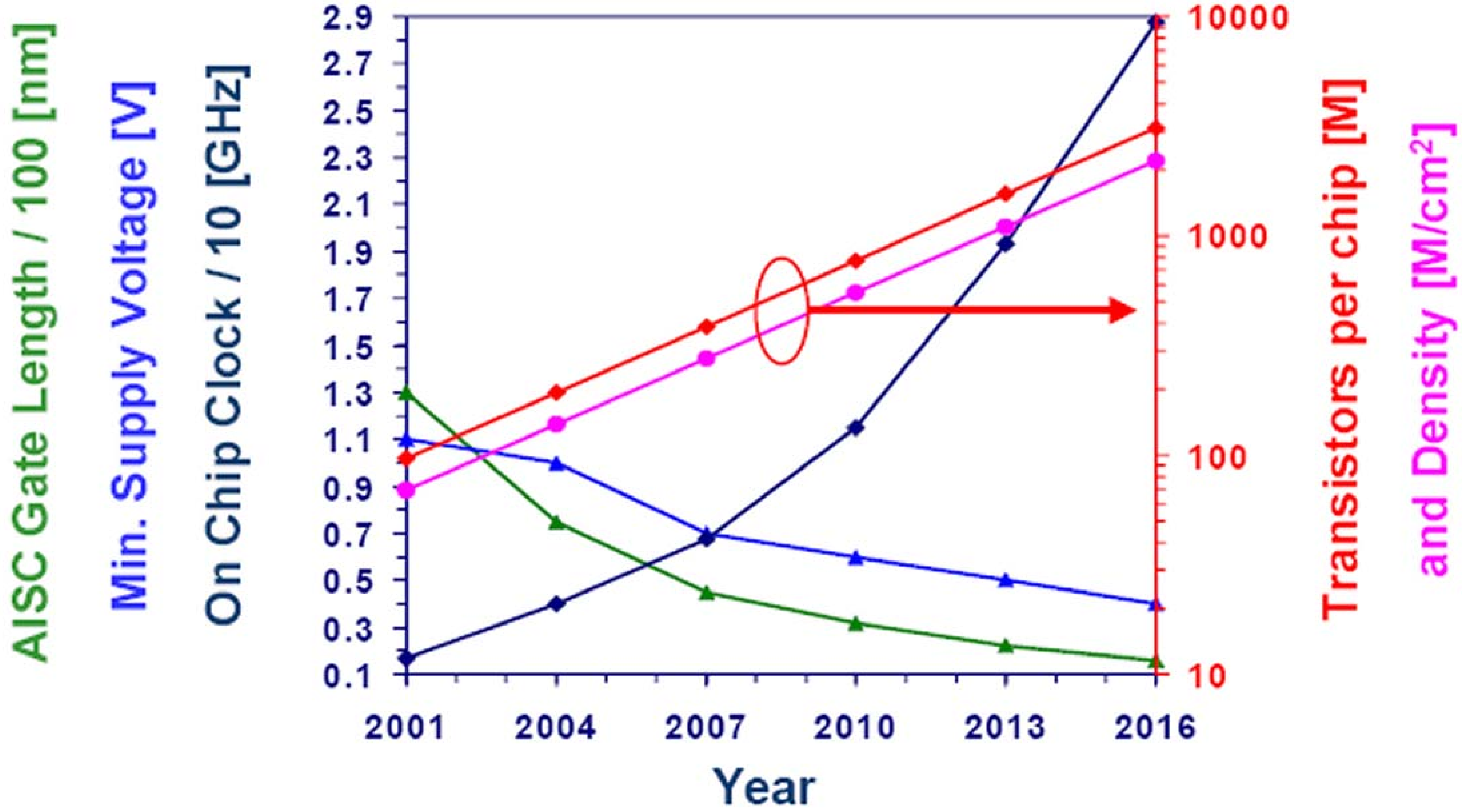


International Technology Roadmap for Semiconductors

Source: Infineon

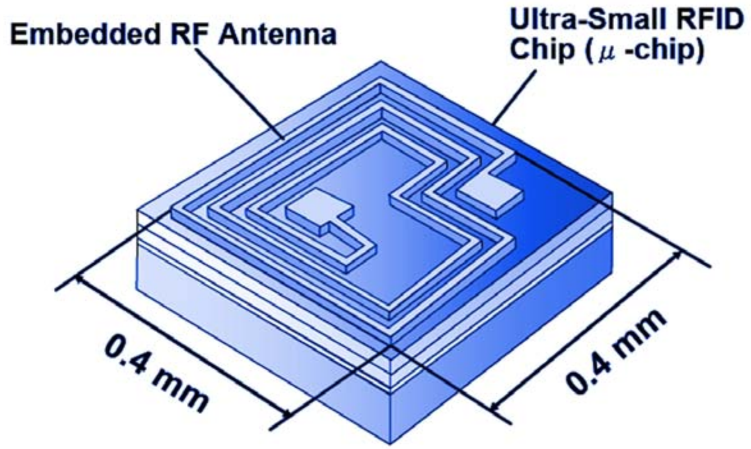
SINTEF

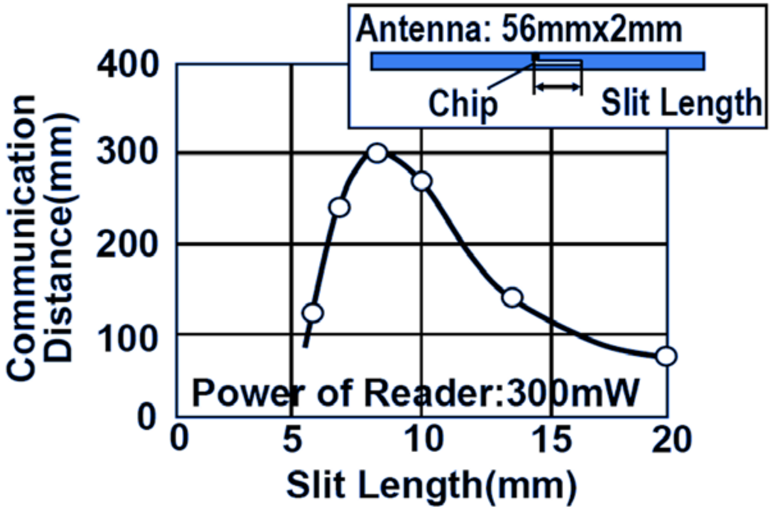
Silicon CMOS along ITRS

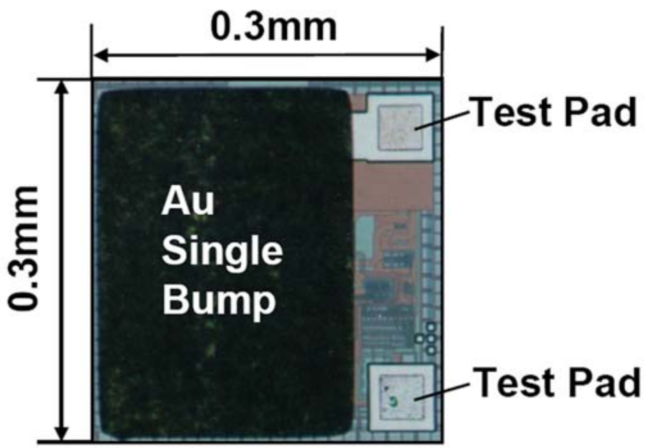


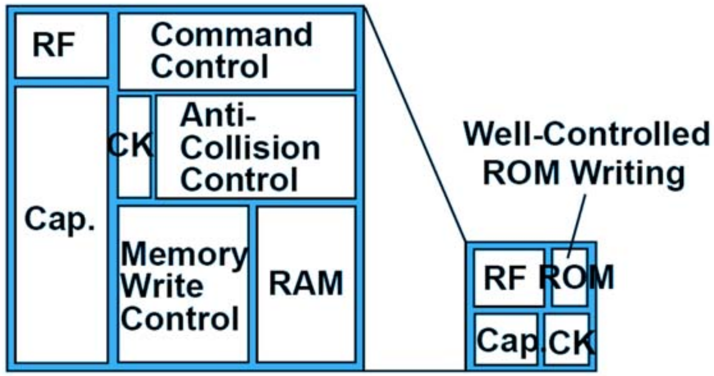
International Technology Roadmap for Semiconductors

RFID CMOS Devices







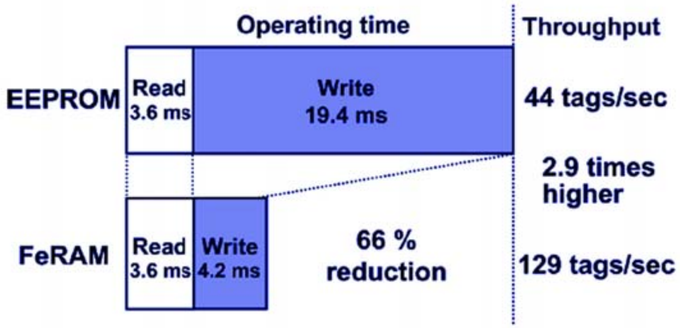


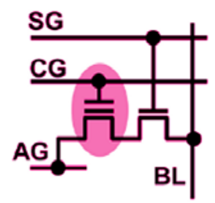
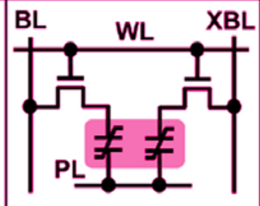
Source: Mitsuo Usam, *et., al.* ISSCC 2003

RFID Memory Devices

Operating Frequency	860 MHz – 960 MHz
Modulation Index (Forward)	15 % (Minimum)
Communication Range (4-W EIRP Forward 40 kbps / Return 40 kbps)	Read: 0 m - 4.3 m Write: 0 m - 4.3 m
Read/Write Throughput (Forward 40 kbps / Return 160 kbps)	129 tags/sec
Tag IC Power	80 µW
Anti-collision	Binary tree protocol
Technology	0.35-µm CMOS FeRAM
Die Size	1.23 mm x 1.50 mm

		Tag with EEPROM	Tag with FeRAM
Inventory (ID Search) Ability		~100 tags/sec	
Command Operation	Read	3.6 msec	
	Write	19.4 msec	4.2 msec
Read/Write Ability		44 tags/sec	129 tags/sec
Write Time Percentage		56.2 %	0.9 %



		EEPROM	FeRAM
Memory Cell Structure			
Programming principle		Charge injection	Polarization change
Read	CLK Speed	25 µsec	
	Power	12.5 µW	13.0 µW
Program (Write)	CLK Speed	3000 µsec	25 µsec
	Voltage	16 V	3.0 V
	Power	35.0 µW	15.7 µW
Read/Write Power difference		22.5 µW	2.7 µW

High speed Low power

Source: Hiroyuki Nakamoto *et., al.* IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 42, NO. 1

RFID Energy Generation Devices

Energy Harvesting

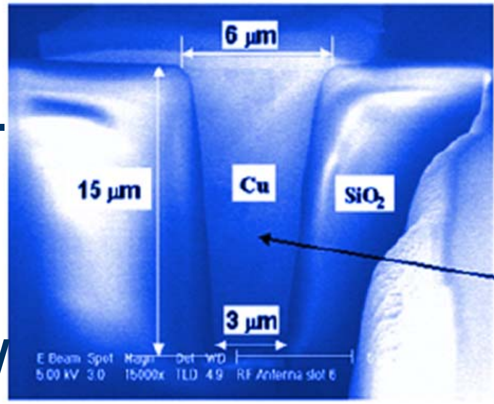
- Piezoelectric
- Micro Watt
- Vibration based
- MEMS Technology

Source: SINTEF

On Chip Antenna (OCA)

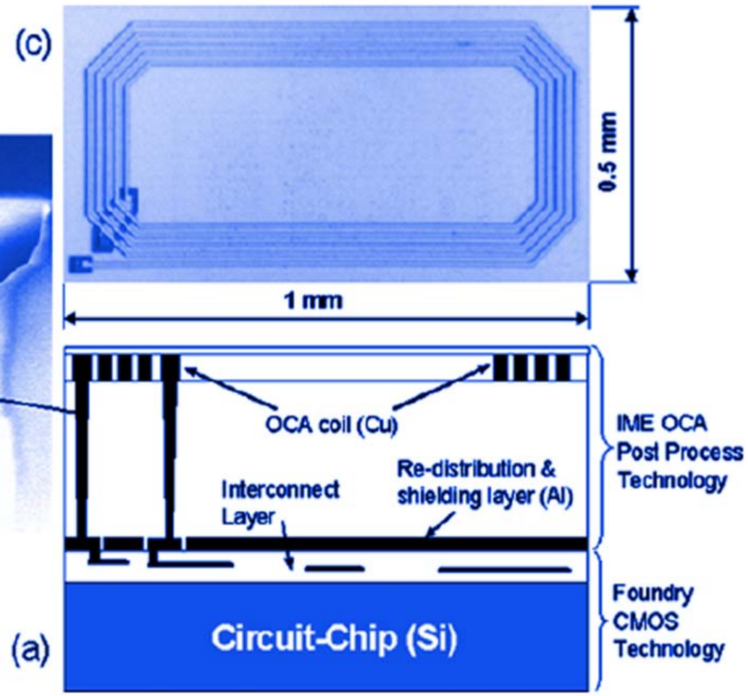
- On chip antenna with RFID tag chip area 1x0.5 mm^2.
- 2.45-GHz RFID tag
- Patterned Al shielding layer
- Inductor coils
- Cu based process.
- Distance 1-mm
- Power 617 µW
- Reader power 1 W

Top-view of the completed tag chip with OCA



(b)

Cross section of completed deep-via, and with



Cross section of OCA integrated on a tag chip

Source: L. H. Guo,*et., al.* IEEE ELECTRON DEVICE LETTERS, VOL. 27, NO. 2,

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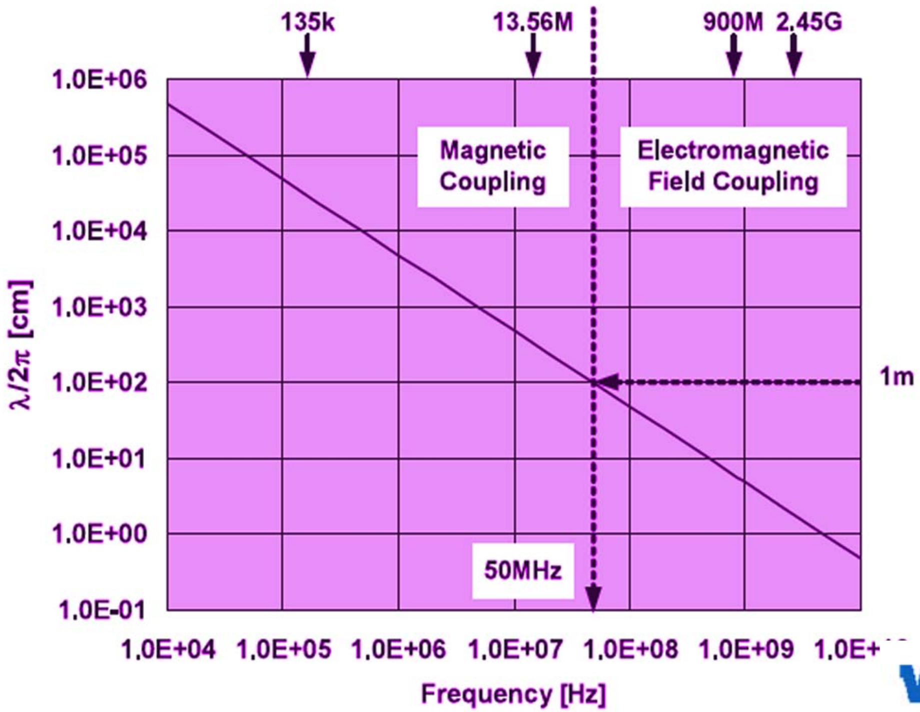
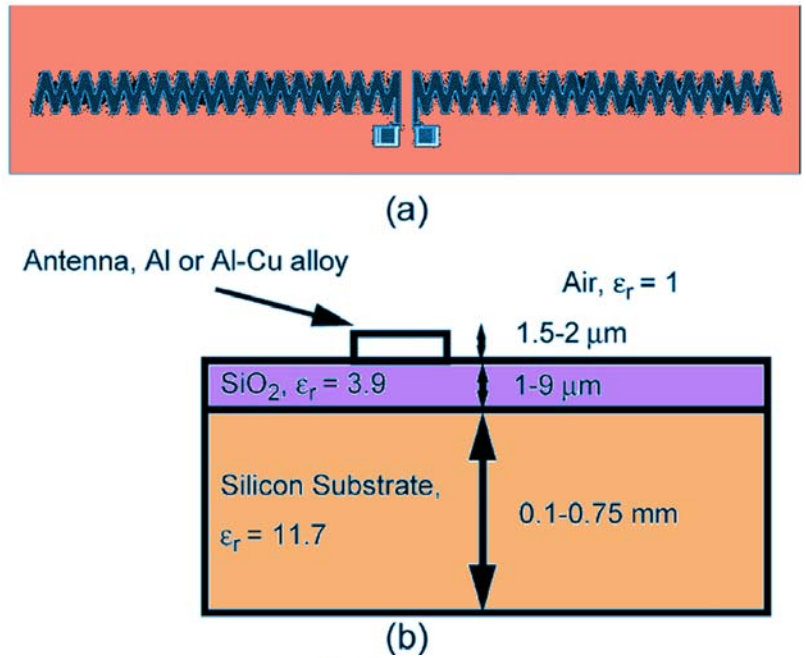
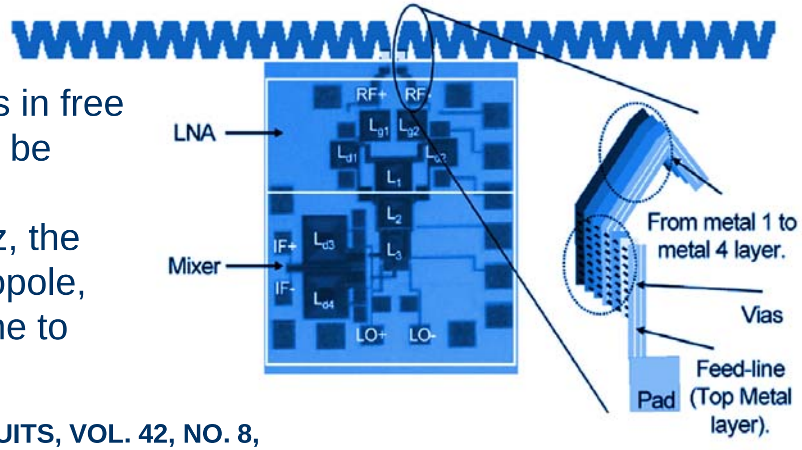
RFID Antennas (OCA)





At 24 GHz, the wavelength of electromagnetic waves in free space is 12.5 mm. A quarter-wave antenna needs to be only 3 mm.

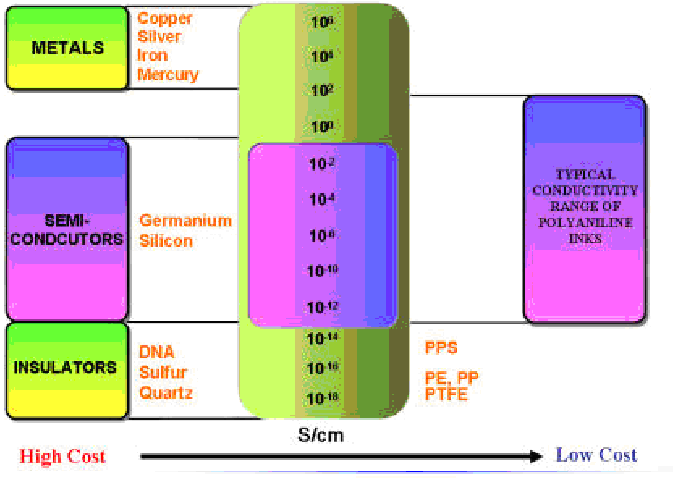
To make integration of antennas practical at 5.8 GHz, the size of on-chip antennas is reduced by using a monopole, which utilizes the virtual image below the round plane to make it behave as a dipole with twice the length.

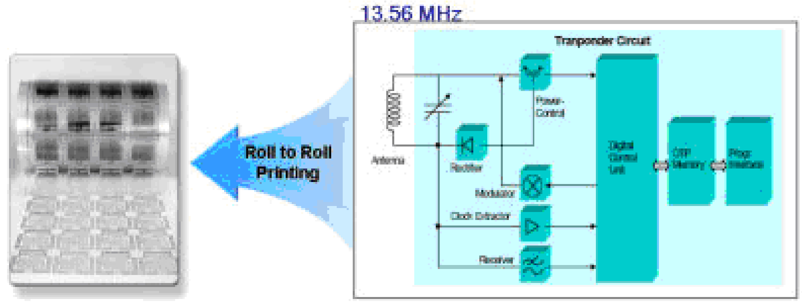


Source: Jau-Jr Lin *et., al.* IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 42, NO. 8,

Printed Electronics – Printed RFID

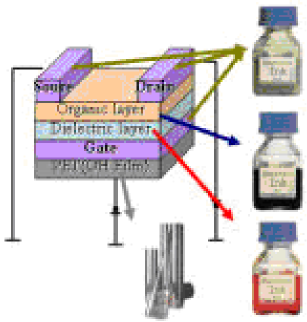
Conductive Inks





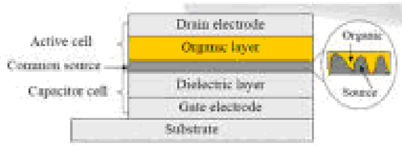
Materials

- Well researched
- Sufficient quality available
- Quality is in improving
- High volume production needed



Circuit Design

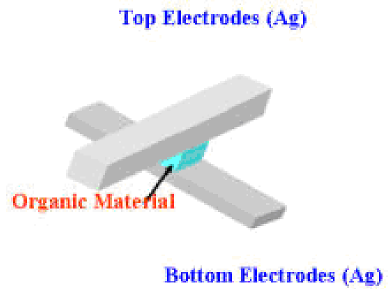
Adopt Si base design



Target Transistor Characteristics:
30μm channel length
1v-2v threshold
Power Supply: 5v
on/off ratio: 10^3
mobility 1 to 100 cm^2/Vs

Development Status

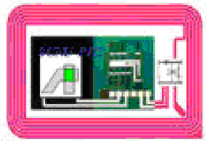
100% Printed Memory Cell



Electrode (Input Output)

- Silver : screen printing
- Organic Material

PEDOT : inkjet printing



Source: Sunchon National University

Printed Electronics – Printed RFID

- Large area, low cost, flexible electronics
- Displays
- Memories,
- Solar cells
- Applications:
  - Electronic book
  - Electronic paper
  - RFID tags
  - Sensors
  - Flexible solar cells

Lucent/E-Ink


Philips


Philips

SINTEF

RFID Display

Flex Display

- **APPLICATIONS**
  - Electronic display card
  - Smart active labels
  - Sensors and diagnostics
- **KEY FEATURES**
  - Low operating voltage (1.8V)
  - Low power (<3mA)
  - Ultra thin (450 micron)
  - High contrast (> 10:1)
  - Bright sunlight readable
  - Shock, vibration proof
  - Direct drive

Passive RFID tag (13.56MHz; ISO 15693) with a display. The display component is implemented by using E-ink's EP Sheet. The display works without batteries, by using the electrophoretic effect.

Source: Epson

Multi Standard Multi Sensing RFID

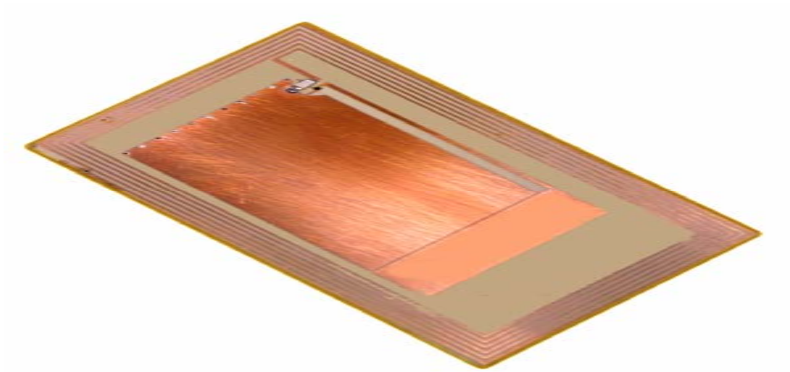
RFID Standards

Type	Standards	Applications	Frequency Band				
			LF (kHz)	HF (MHz)	UHF (MHz)	MW (GHz)	
			125/134	13.56	840-956	2.45	5.8
RFID Tags	ISO 18000	Any application	18000-2	18000-3 Mode 1 Mode 2	18000-6 Type A Type B Type C (EPC G2)	18000-4 Mode 1 Mode 2	18000-5
	EPC G2	Retail, logistics, healthcare and life sciences (HLS) industry			EPC C1G2		
	ISO/IEC 11784/5	Animal tagging					
RFID Contactless Cards	ISO/IEC 14443	Proximity cards, ticketing		ISO 14443 Type A Type B			
	ISO/IEC 15693	Vicinity cards, access control					
	ISO/IEC 10536	Contact less identification cards					

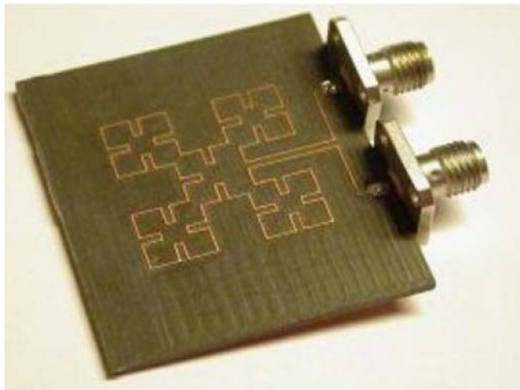
Multi Standard Multi Sensing RFID

Multi band antennas

- Coil combined with PIFA antenna (13.56 and 867MHz)
- Insensitive to metal environment at UHF frequencies
- 1.9 mm-thick substrate with credit card size



- UHF and MW (867MHz + 2.45GHz)
- Multi-band antenna
- Small size
- Reduced cost (one antenna for more frequencies/applications)

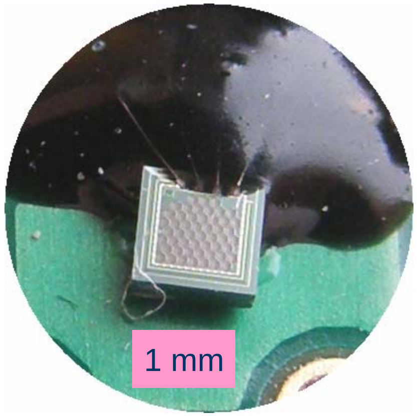


CHALMERS MC2 IMEGO Applied Micro Sensor Systems SINTEF VTT

Multi Standard Multi Sensing RFID

Sensors

- Pressure and Temperature
- Sensitivity of 1,3 fF/mbar and -5fF/K



- Humidity and pH
- Same geometry for both sensors: interdigitated microelectrodes with the specific polymer onto them

CHALMERS MC2 IMEGO Applied Micro Sensor Systems SINTEF VTT

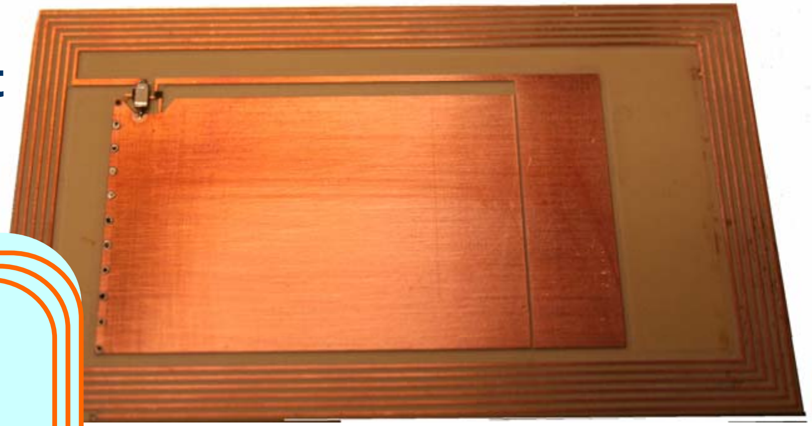
Multi Standard Multi Sensing RFID

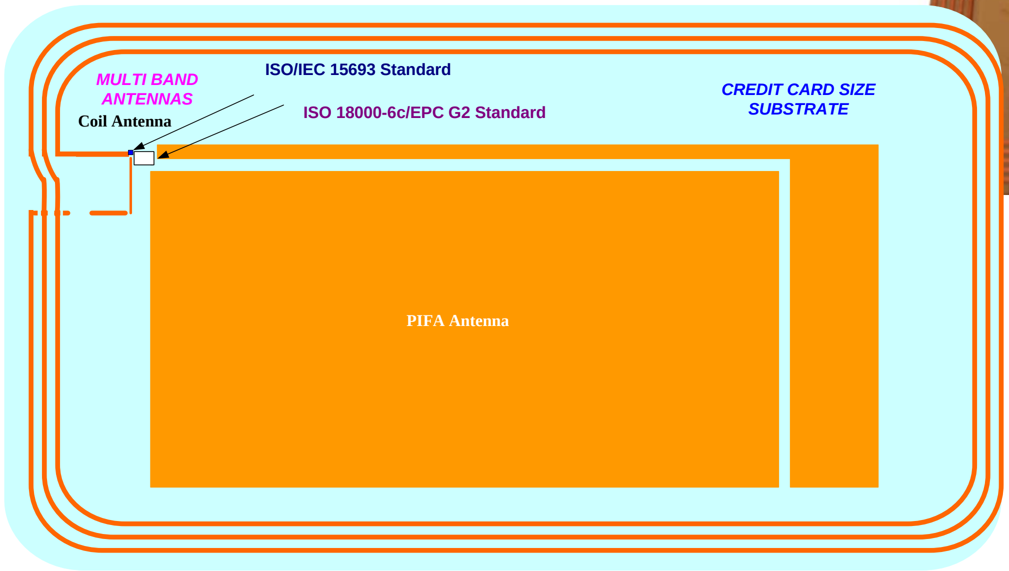
Multi Frequency Multi Standard RFID Tag

HF 13.56MHz ISO/IEC 15693 Standard

UHF 867/915 MHz ISO 18000-6c/EPC G2 Standard

Insensitive to metal environment

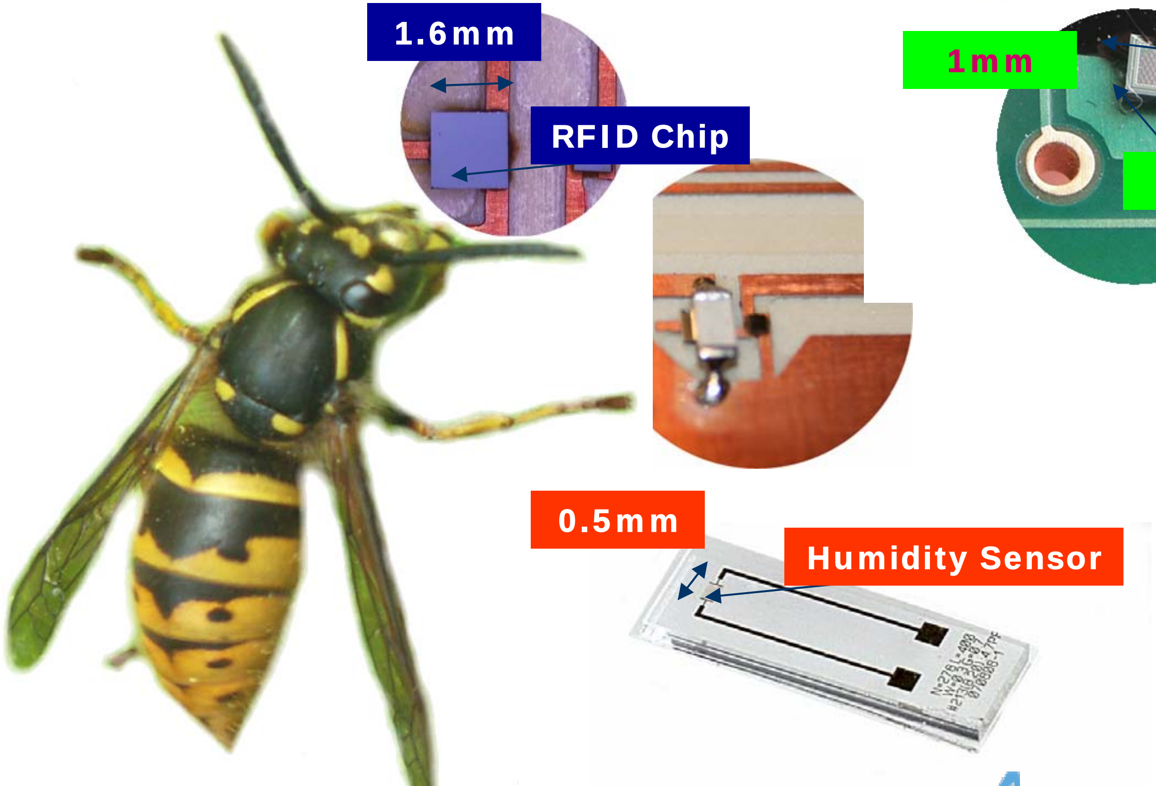




Multi Standard Multi Sensing RFID

Miniaturisation and integration

IntelliSense RFID



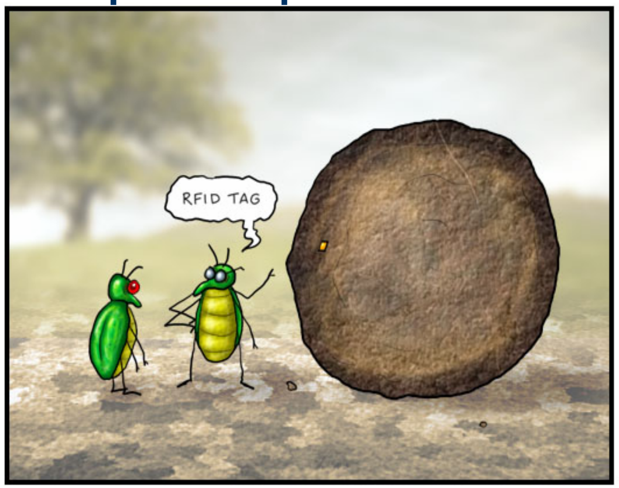
CHALMERS MC2 IMEGO Applied Micro Sensor Systems SINTEF VTT

Multi Standard Multi Sensing RFID

IntelliSense RFID

- Multi frequency multi band antennas
- Multi protocol RFID tags
- Metal insensitive tags
- Passive and active RFID technology
- Multi sensing: Temperature, pressure, humidity, pH sensors
- Mixed signal sensor interface
- UHF/HF data logger

- Small size
- Low power
- Low cost
- Simple calibration
- Simple implementation



Modern dung beetles

Sensing/Acting RFID

- **Smart RFID Tag Setup and Control**
  - Sensor/actuator identification (naming/address)
  - Reading (input) / writing (output) / control (states changes)
  - Network topology, power management, clustering, power management, quality of information
  - High level sensor/actuator control abstraction
- **Sensor/actuator data manipulation**
  - Sensor/actuator data format standard (data pair)
  - Sensor/actuator data translation
  - Sensor/actuator data description (prior-knowledge)
  - Sensor/actuator data operation (aggregation, value-added process)
- **Sensor/actuator heterogeneity**
  - Different sensor/actuator types, different operations

SINTEF

Sensing/Acting RFID

- **Smart tag network identification**
  - Identify each sensor/actuator tag, each sensor network and the network type
  - Multiple sensors/actuators on one tag
  - Multiple communication standards
- **Sensor/actuator data description**
  - Prior knowledge to use sensor/actuator data
- **Sensor/actuator data processing**
  - Sensor/actuator data:
  - Identification:
  - Localisation/Positioning:
  - Date/Time:

Sensing/Acting RFID

- **Communication protocol and standard**
  - RFID (eg. ISO 18000 6c EPC class 1 Gen 2)
  - IEEE 802.15.4 (ZigBee) IEEE 802.11 (Wireless Lan), IEEE 802.151.1 (Low Power Bluetooth)
- **Sensor/Actuator Tag communication**
  - Various communication protocol (c.f. ZigBee, Low Power Bluetooth, etc.)
  - Sensor/actuator RFID Tag is connected in multi-hop manner
  - Sensor/actuator data and control are forwarded from one Smart RFID Tag to other Sensor Tag from another sensor network
  - Internet of Things

Sensing/Acting RFID

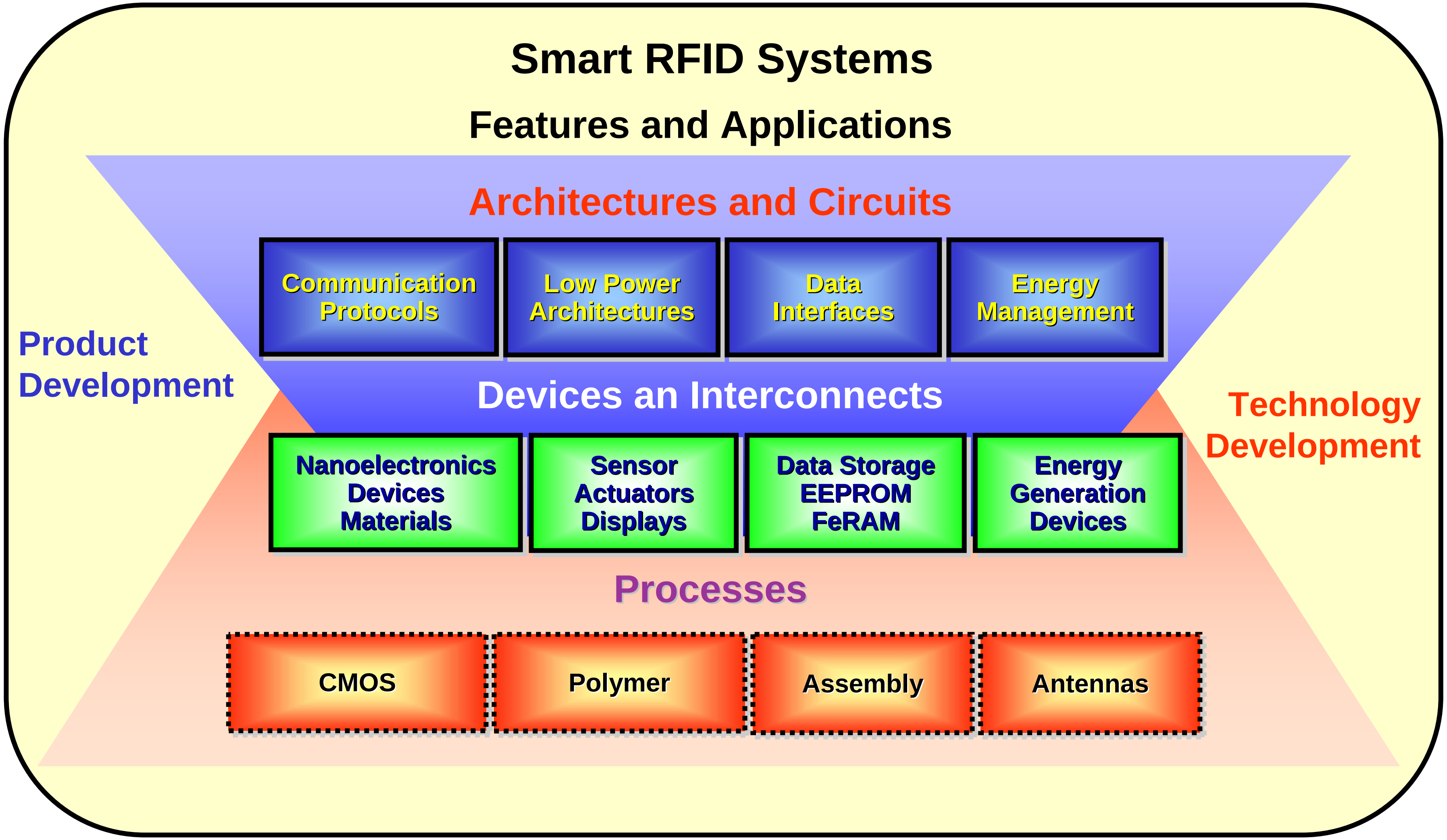
- **Reader**
  - Different application requirements and multiple communications standards and protocols
  - Mobile and fix
  - Sensor network shall be setup (on query period, threshold, topology)
  - Reader translates upper layer command to RFID/Ubiquitous sensor network command
  - Reader understands upper layer command
- **Reader management**
  - Reader management will control the operations of RFID sensor network
  - Application requirements are reflected to reader management

SINTEF

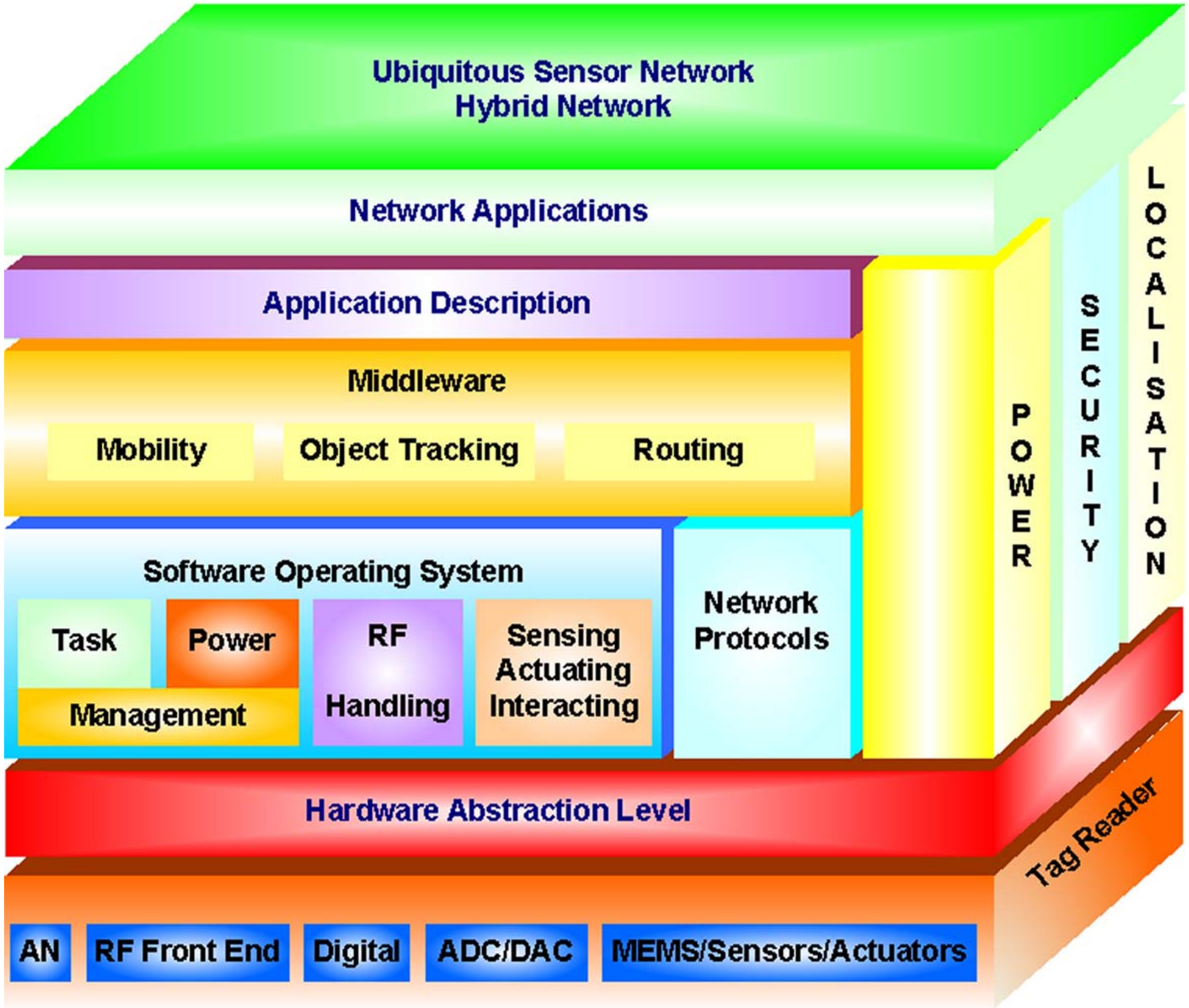
Sensing/Acting RFID

- **Environment conditions**
- Wireless sensor/actuator tags need to operate in conditions that are not encountered by typical computing devices:
  - Rain, snow, etc.
  - Wide temperature variations
  - High humidity
  - Saline or other corrosive substances
  - High wind speeds

Smart RFID Systems Development

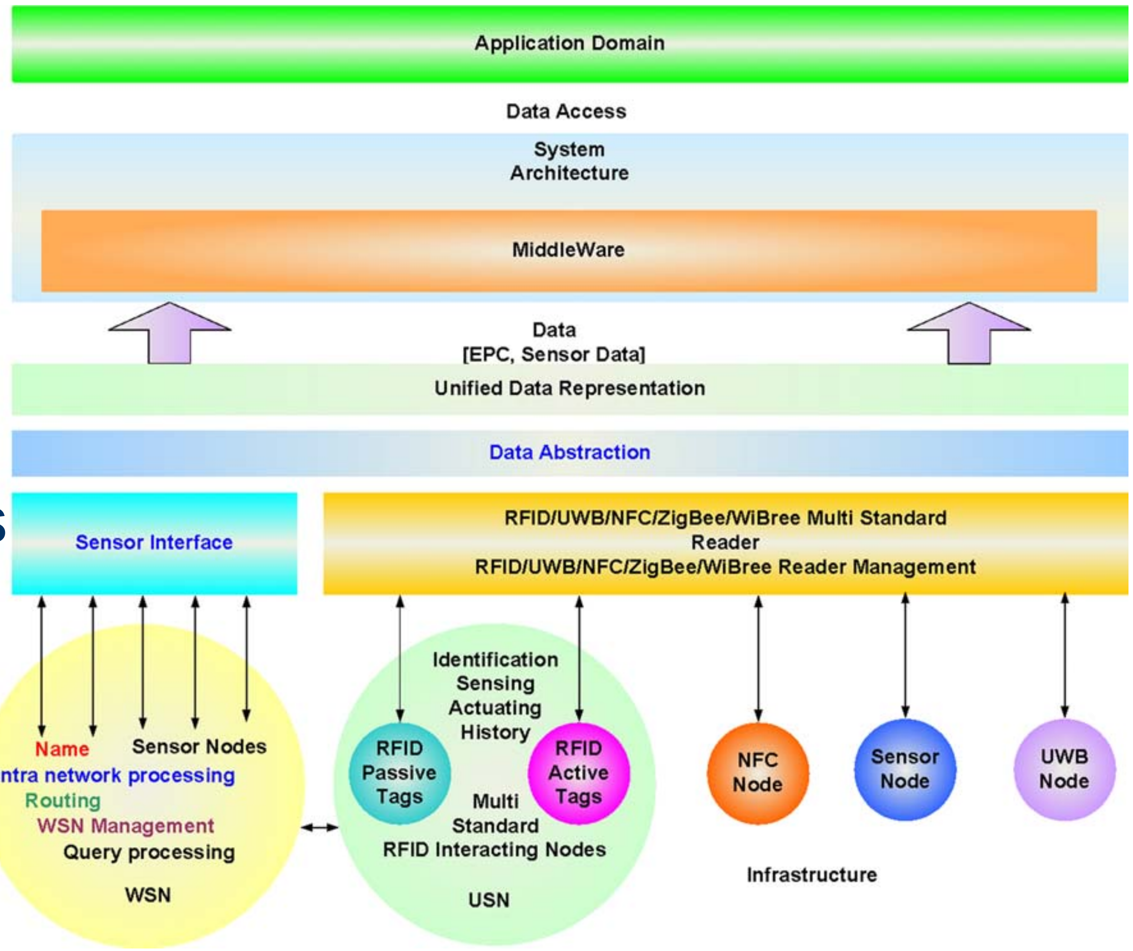


3D RFID Network Systems

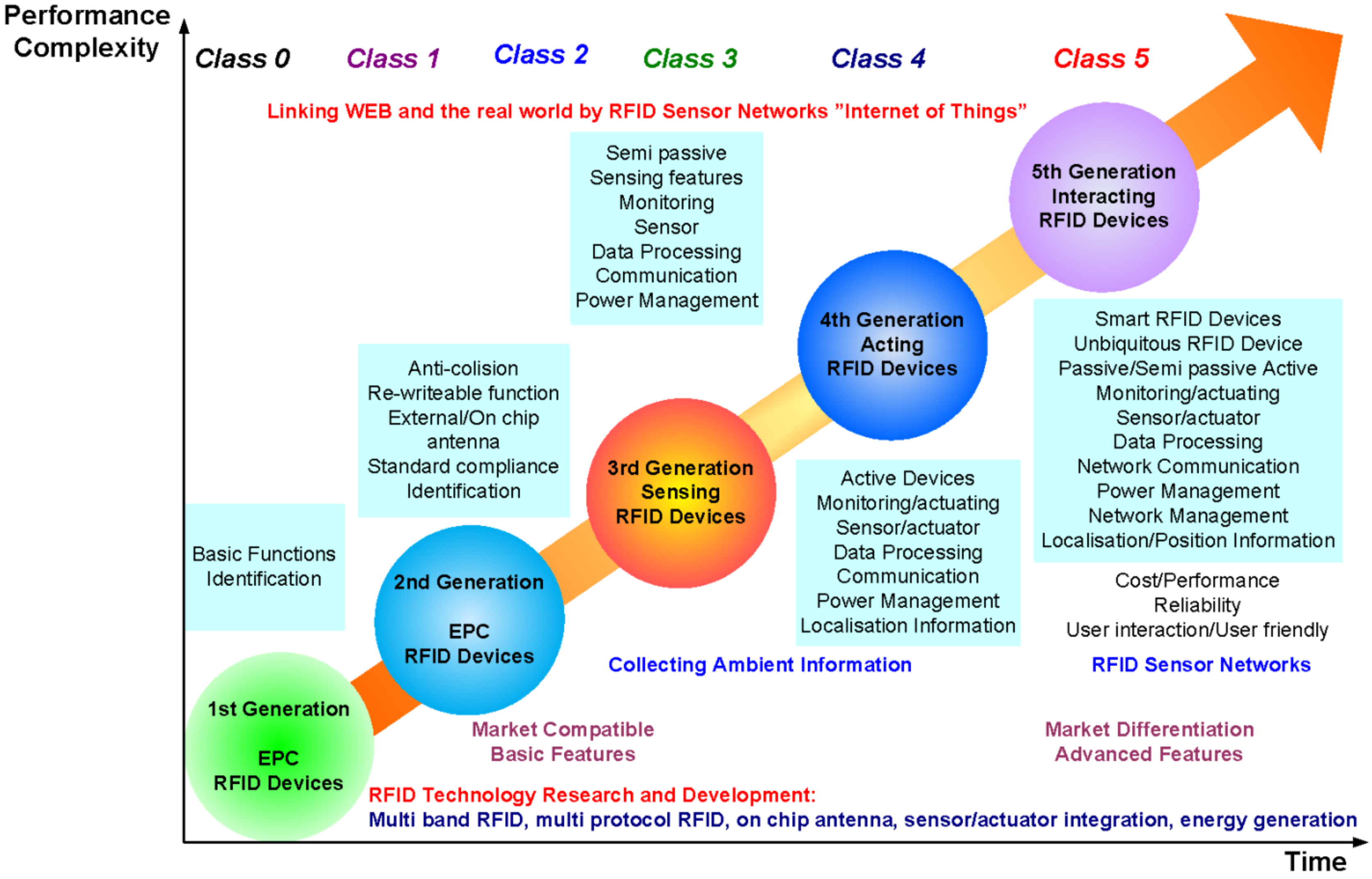


Hybrid Network Systems

- RFID systems integrated with other systems to obtain a networked infrastructure for different applications
- Combining standards RFID, WiFi, Zigbee, etc.
- Reconfigurability
- Scalability
- Modularity



Smart Integrated Systems



Challenges

http://www.flickr.com/photos/38869431@N00/424130402/