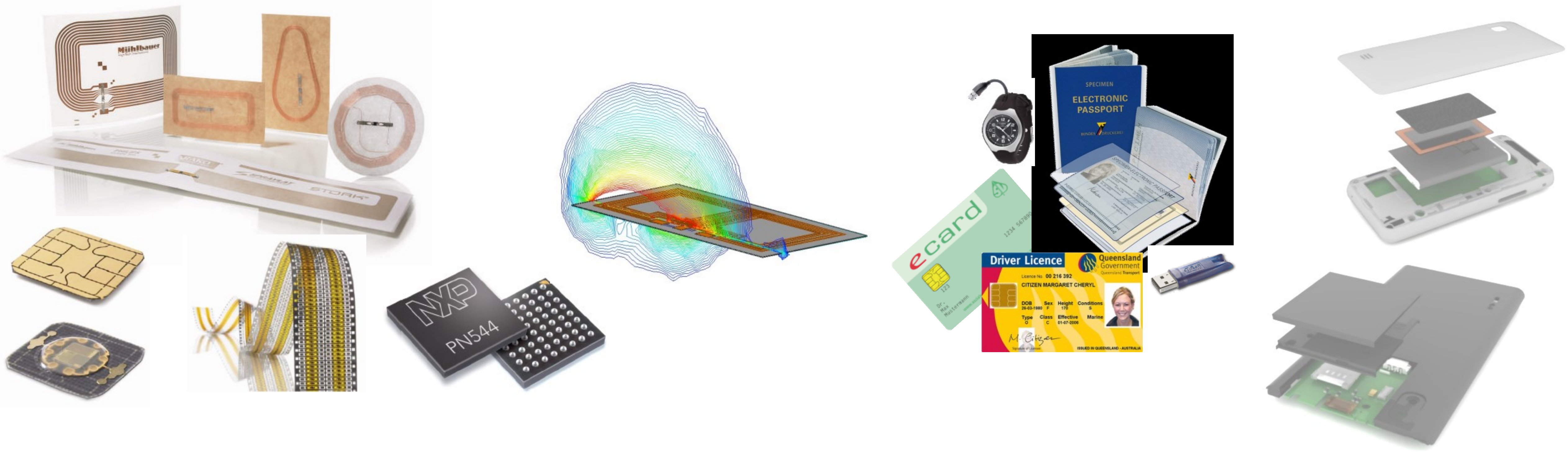


01 Introduction

1st unit in course 451.417, RFID Systems, TU Graz

Dipl.-Ing. Dr. Michael Gebhart, MSc

RFID Systems, Graz University of Technology
SS 2023, March 06st

rfid-systems.at
Advancing Technology

Content and Dates of Lectures

Date

- March 6th, 2023
- March 7th, 2023
- March 9th, 2023
- March 10th, 2023
- March 20th, 2023
- March 21st, 2023
- March 23rd, 2023
- March 24th, 2023
- Exam: 27th, 2023

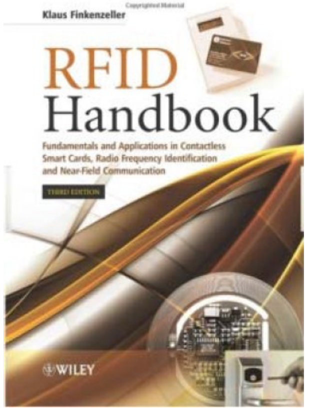
Content

- Introduction to RFID
- Standards and Frequency Regulation
- HF Basics, Elements and Components
- HF Reader Technology
- Protocols
- Loop antennas and transponders
- Contactless Measurement
- Practical Session
- LF Technology
- UHF Technology I and II

RFID Systems LV 451.417

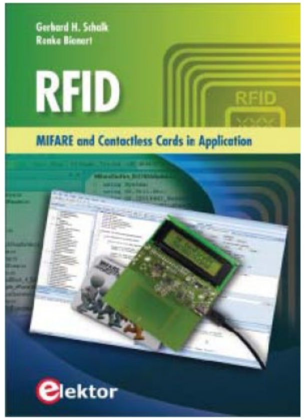
- Lecture notes available at www.rfid-systems.at

Some Literature



- RFID Handbook

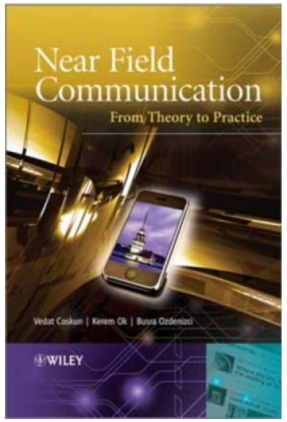
Fundamentals and Applications in
Contactless Smart Cards, Radio Frequency
Identification and Near Field Communication
Klaus Finkenzeller,
John Wiley & Sons
ISBN10 0470695064



- RFID:

  Mifare and Contactless Cards in Application

Gerhard Schalk and Renke Bienert
Elektor Publishing, April 2013
ISBN 978-1907920141
www.smartcard-magic.net



- Near Field Communication (NFC)

From Theory to Practice
Vedat Coscun, Kerem Ok, Busra Ozdenizci,
1st ed., John Wiley & Sons, 2012
ISBN10 1119971098

- Anwendungen und Technik von Near Field Communication (NFC)

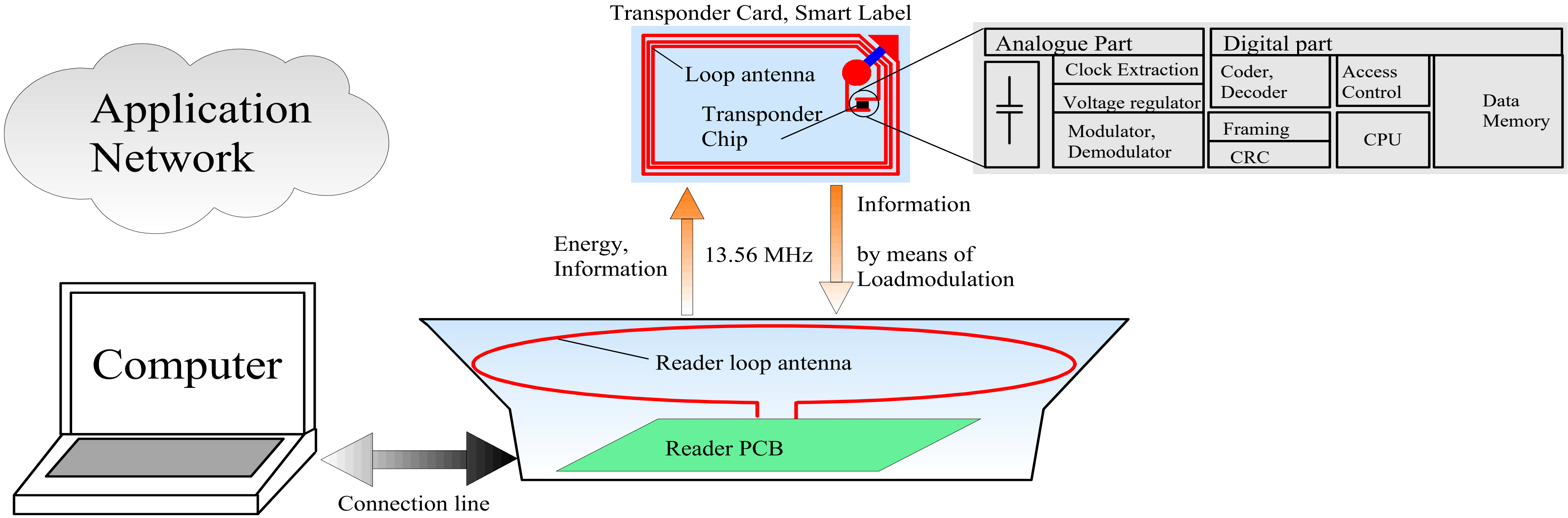
Josef Langer und Michael Roland
1. Auflage, Springer, Berlin, 2010
ISBN10: 978-3642054969

Introduction

What is RFID?

What is RFID?

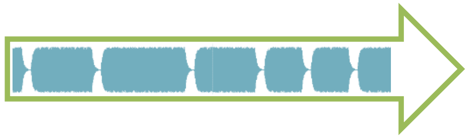
Typical application scenario



- The typical application is operated on a PC with a network in the background. Access to information on the **memory** of a contactless card is needed. This requires a reader, which provides at the Air Interface
  - **Power** to operate the transponder card,
  - **Commands** for the card to execute,
  - A **receiver** for the information coming from the card, which is transmitted via **load modulation**
- according to a standard for **Contactless Technology**.

Let´s take a first look to the signals…

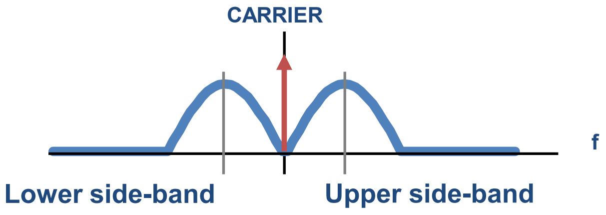
Reader sends out a continuous sine-wave carrier frequency, allowing transponder to harvest power & extract clock.

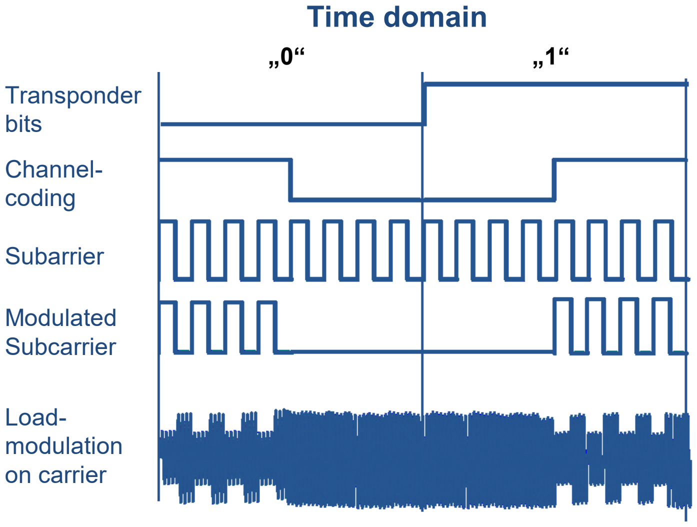


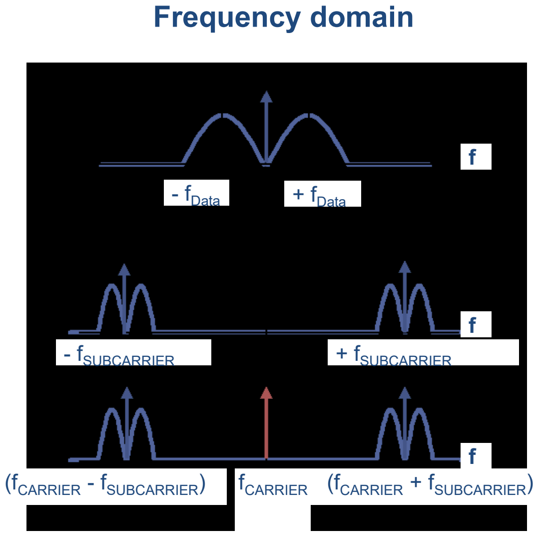
Transponder response data is transmitted by modulating the electrical load impedance on the loop antenna. This changes the impedance of the reader antenna, and can be detected by its receiver path.

Reader commands are transmitted by modulating this carrier (AM).

This requires a certain bandwidth around the carrier frequency.

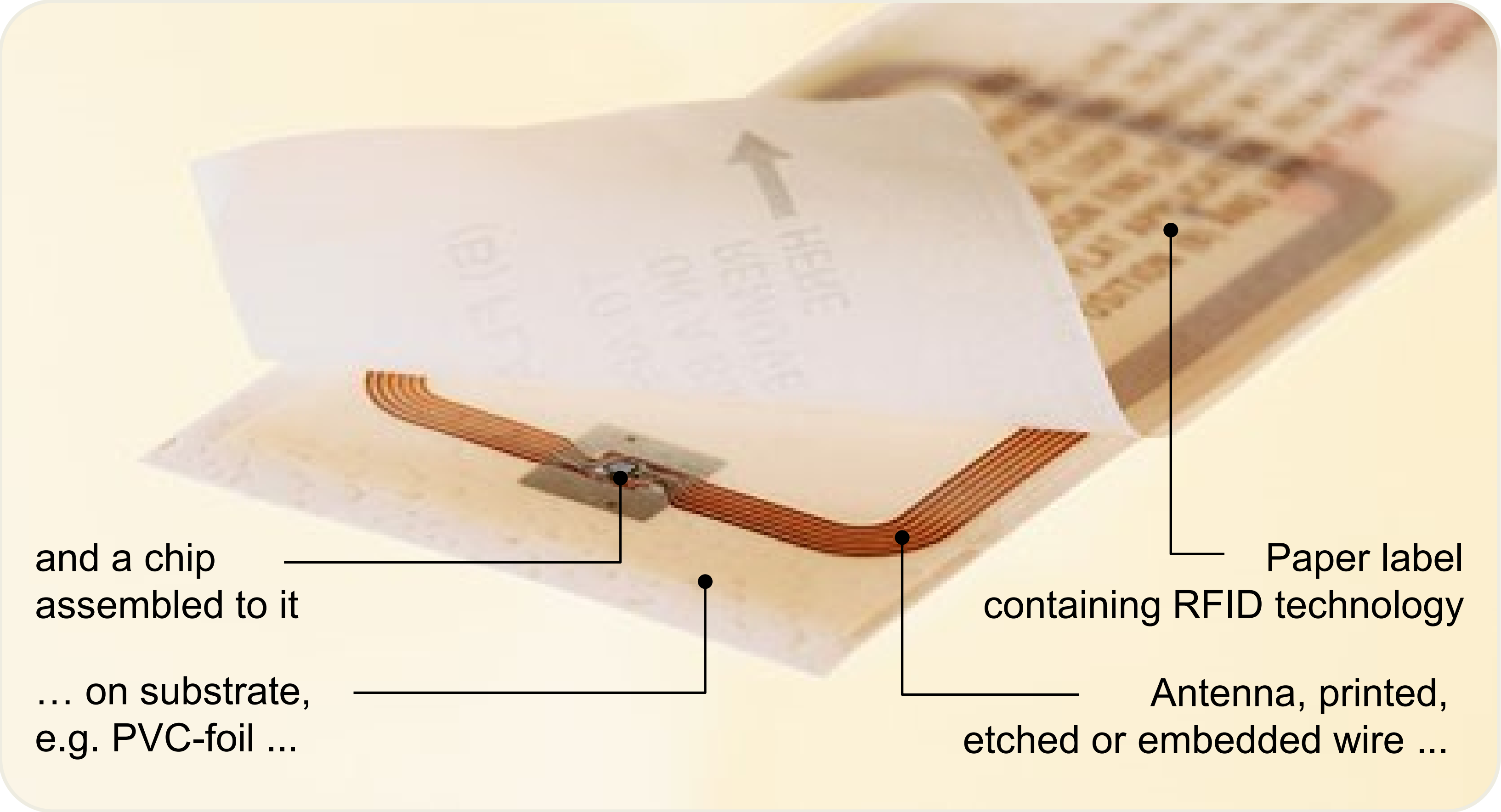






What is a “Smart Label”?

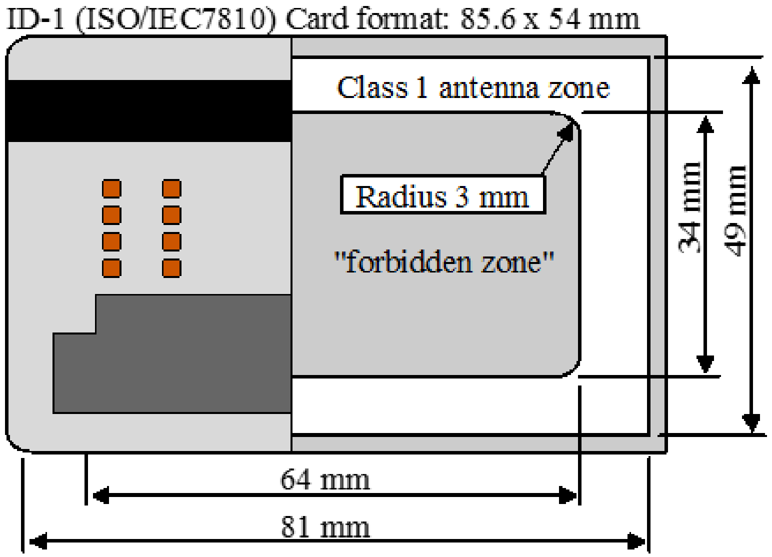
- The **contactless transponder** is the **electrically functional part**.
- “Label” refers to object-oriented tagging (e.g. logistics).



The world of Smartcards

- **ISO/IEC14443**.........The **Contactless Proximity Air Interface** for **person-related applications** was standardized 2 decades ago.
- Applications in **Government** (e-Passports, driver license, health card...), **Payment** (Contactless Credit Cards), **Public Transport** (Ticketing), **Secure Access Control**, etc. are successfully deployed.
- The **battery-less**, field-proven secure chip technology did migrate into objects e.g. SD-Cards, watches, USB-Sticks, which require small antennas. This requires **more accurate characterization and production tolerance consideration**.

- **Related ISO/IEC Standards**
  - 7810...........Card geometry (e.g. ID-1 format) and physical properties
  - 7811-3/-3...Embossing (letters raised in relief)
  - 7811...........magnetic stripe cards
  - 7812...........optical character recognition cards
  - 7813...........bank cards
  - 7816...........contact cards with ICs
  - 10373.........test methods



Card geometry specifications.

To differentiate...

- **Contactless Smart Label:** Transponder in an often flexible adhesive sticker, for object-oriented applications. Diverse form factors appear in the field, related to the properties of the object which they are attached to. Optimized rather for long distance operation, than for high data rates. NV memory is of rather low size (typical order is 2 kbit) and the protocols used are also optimized for long distance, to recognize and identify many smart labels around in short time, and for very low power on the transponder.

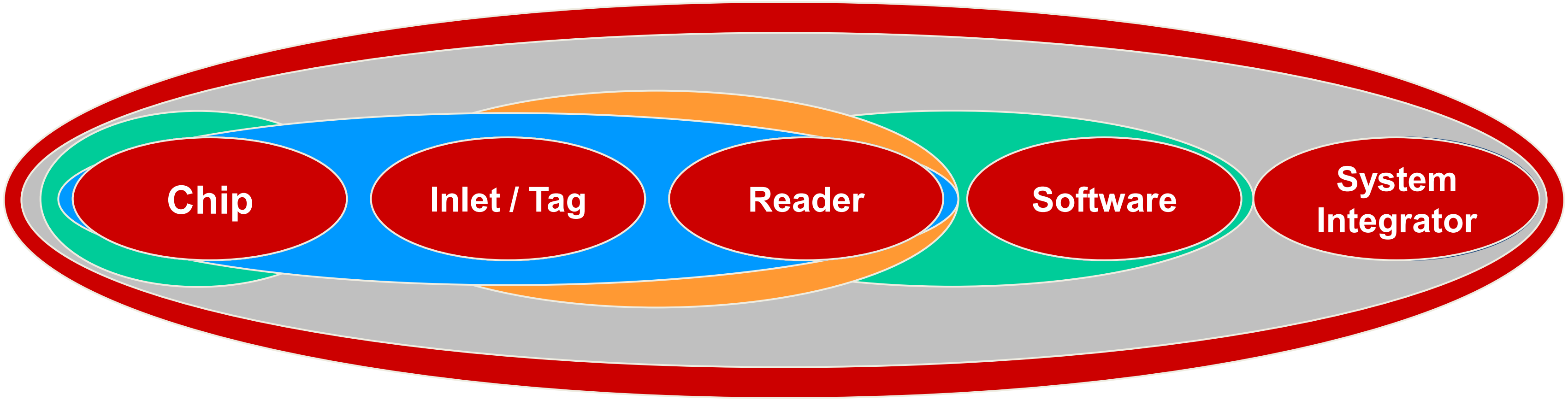
- **Contactless Smart Card:** Transponder card, containing person-related data. It allows to store more data (typical order is 200 kbytes) and operates with protocols which are optimized for high data rates (100 – 850 kbit/s) at rather short distances (a few centimeters). Security is an important aspect of quality, the stored (and transmitted) data is often protected by cryptography.

Partners in the RFID production value chain

Inlets, Labels and Tags need chips for their function

Readers, often based on integrated chips, must support standards by their periphery (antenna, matching network) and allow good operating conditions for contactless transponders.

System integrators must have a clear understanding of all parts in the chain to support standard conformance - starting with chip manufacturers, and including Readers, Software, Installation and Service.



Must work together to optimise performance for both sides, Reader & Transponder.

Software receives the input from the readers and so must have a good understanding of their properties regarding contactless function.

End user / Application

Context of RFID

Identification systems

Bar code systems (printed)

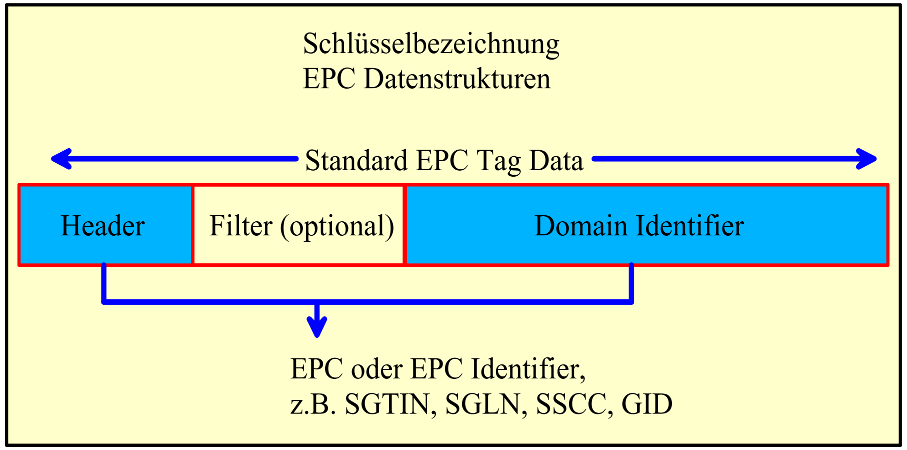
- Code using imprinted bars and spacers, which can be read out by optical laser scan.
- Contains clock and data information in a standardized format
  - UPC......Universal Product Code, USA ~ 1973
  - EAN......European Article Number, introduced 1976 for food
  - EPC......Electronic Product Code

(01) 1 0614141 007346 (21) 2

154257
(DAVE)(C1)(SL)(BLUE)

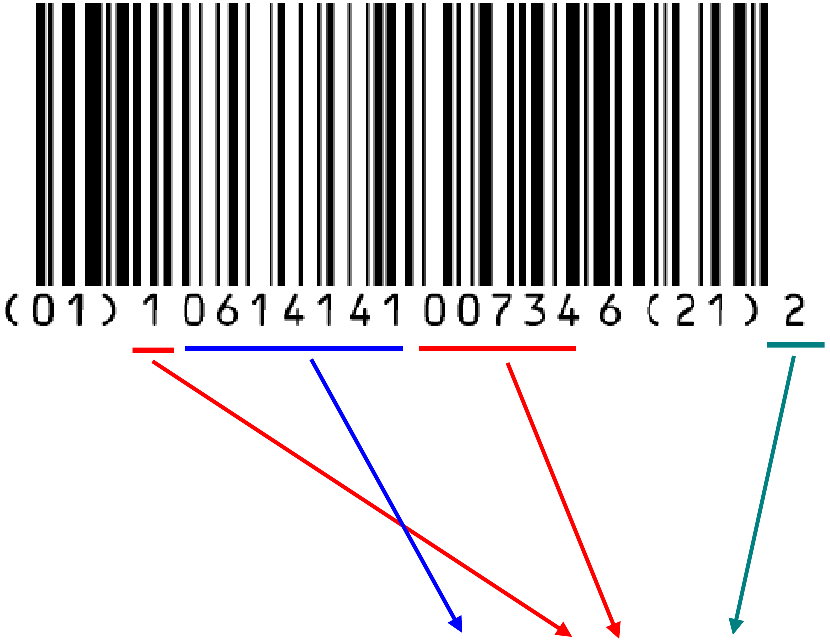
- More than 10 different major barcode systems are in use in parallel, today.
- Already in the early 1990ies the market volume for barcodes was 1,5 billion Euro, so it is a significant industry by itself.

Bar code – EPC



Schlüsselbezeichnung
EPC Datenstrukturen

EPC oder EPC Identifier,
z.B. SGTIN, SGLN, SSCC, GID



(01) 1 0614141 00734 6 (21) 2

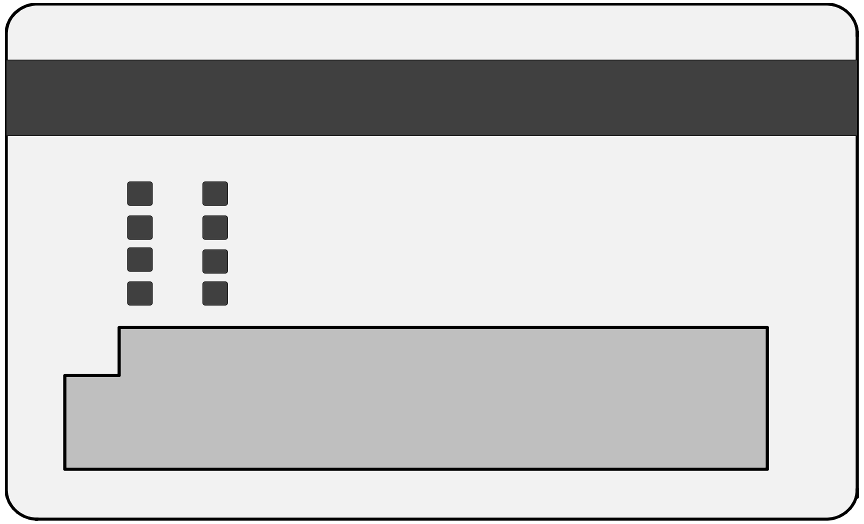
Header (binär)	Header (hexadezimal)	Codelänge (bit)	Code-Schema
0001100 - 0001111	0C – 0F	NA	Reserviert bis 64 bit Ende
00010000 - 00101110	10 – 2E	NA	RFU
00101111	2F	96	DoD-96
00110000	30	96	SGTIN-96
00110001	31	96	SSCC-96
00110010	32	96	SGLN-96
00110011	33	96	GRAI-96
00110100	34	96	GIAI-96
00110101	35	96	GID-96
00110110	36	198	SGTIN-198
00110111	37	170	GRAI-170

	Header	Filter	Partition	Company Prefix	Item Reference	Serial Number
SGTIN-96	8 bit	3 bit	3 bit	24 bit	20 bit	38 bit
	0011 0000 (binär)	7 (dezimal)	5 (dezimal)	0614141 (dezimal)	100734 (dezimal)	2 (dezimal)

http://www.epcglobalinc.org/standards/tds/tds_1_4-standard-20080611.pdf

World of Cards (I)

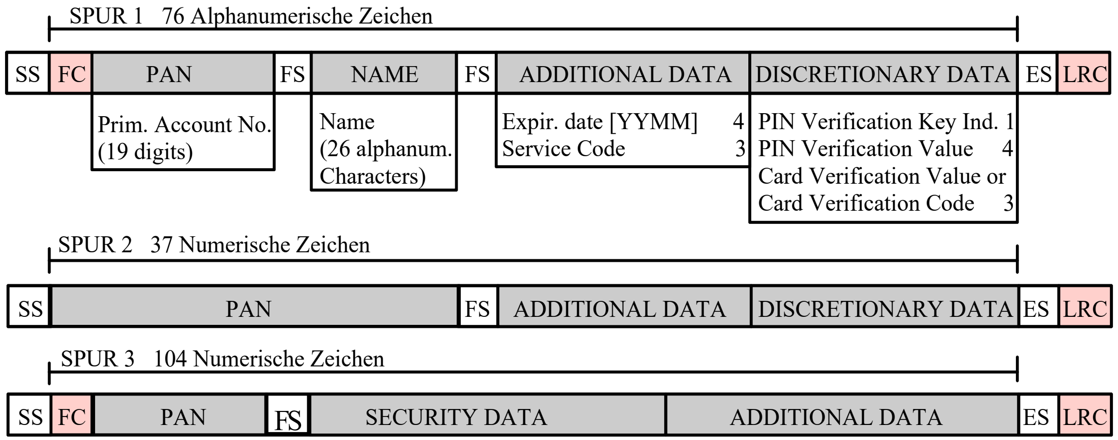
Standard (ISO/IEC)	Topics
7810	Card format and physical properties
7811-1/-3	Embossing (alphanumeric characters imprinted in relief)
7811-2 /-4/-5/-6	Magnetic stripe cards
7812	OCR Cards
7813	bank cards
7816	contact-based cards with integrated circuits
10373	Test methods



World of Cards (II)

Magnetic Stripe Cards

- Card Format **ID-1**: 85,6 x 54 x 0,76 mm



SPUR 1 76 Alphanumerische Zeichen

SS	FC	PAN	FS	NAME	FS	ADDITIONAL DATA	DISCRETIONARY DATA	ES	LRC
		Prim. Account No. (19 digits)		Name (26 alphanum. Characters)		Expir. date [YYMM] 4 Service Code 3	PIN Verification Key Ind. 1 PIN Verification Value 4 Card Verification Value or Card Verification Code 3		

SPUR 2 37 Numerische Zeichen

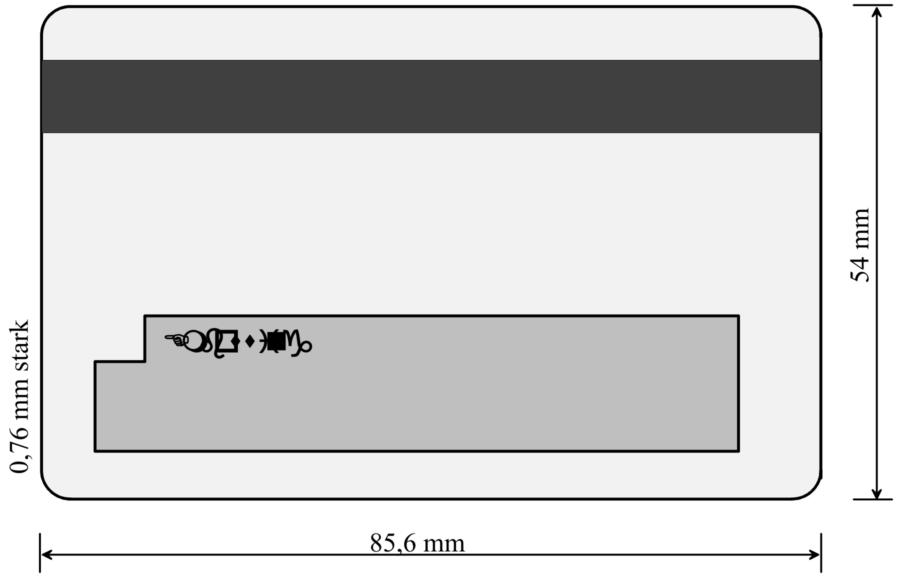
SS	PAN	FS	ADDITIONAL DATA	DISCRETIONARY DATA	ES	LRC

SPUR 3 104 Numerische Zeichen

SS	FC	PAN	FS	SECURITY DATA	ADDITIONAL DATA	ES	LRC

SS...Start Sentinel B(hex)
FS...Field Separator D(hex)
ES...End Sentinel F(hex)

LRC...Longitudinal Redundancy Check character
FC......Format Code

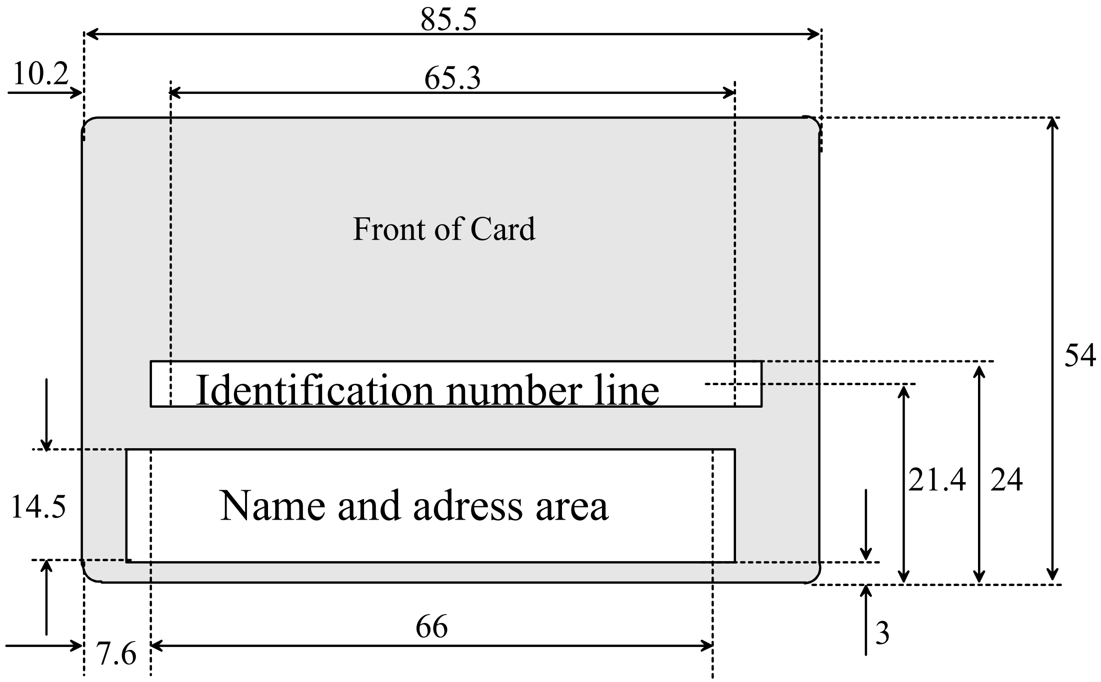


Track width	track	Code	Storage density	Character coding	Info content
			bits per inch	incl. parity bit	incl. control info
0,11" (2,8 mm)	1	IATA	210	7 bits / symbol	79 alphanum.
0,11" (2,8 mm)	2	ABA	75	5 bits / symbol	40 numeric
0,11" (2,8 mm)	3	THRIFT	210	5 bits / symbol	107 numeric

World of Cards (III)

Optical character recognition Cards (OCR)

- The use of Optical Character Recognition systems (OCR) started in the 1960ies. Special character types were designed, allowing to be read not only by humans but also automatically, by machines.
- Standardized e.g. in
  - ISO/IEC7811-1/-3 (Embossing).
- Applications in production, services and administration, or in the economy sector.



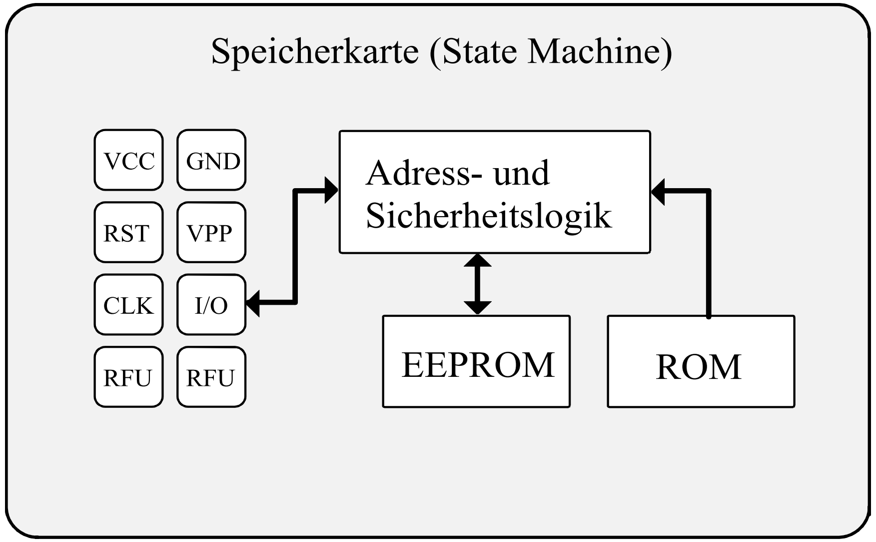
World of Cards (IV)

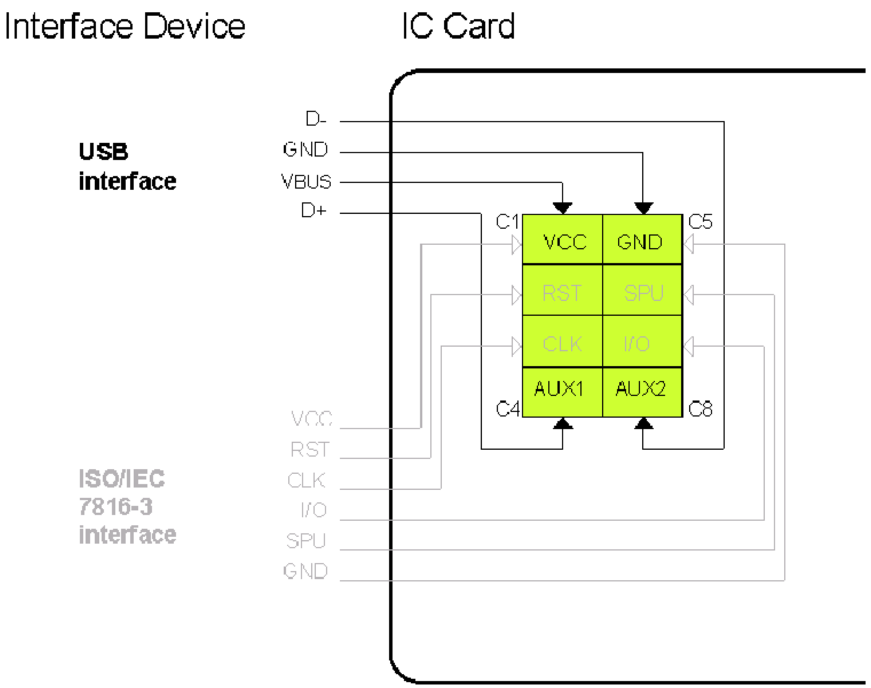
Chip-Disk

- The idea, to allow more data volume on a card, using available optical storage technology, led to the introduction of the chip-disc in 1999. Approximately 30 MB can be stored on the CD part.
- ISO/IEC 11693 / 11694 / 10373-5
- Meanwhile, the concept has disappeared from market, because more memory size can easily be implemented by an **Integrated Circuit Card** (ICC with contact interface).

Chip card – memory card (concept state machine)

- Memory cards operate with the sequential logic of a (usually **CMOS) state machine**.
- Supply power
  - Class A 4,5...5,5 V < 60 mA
  - Class B 2,7...3,3 V < 50 mA

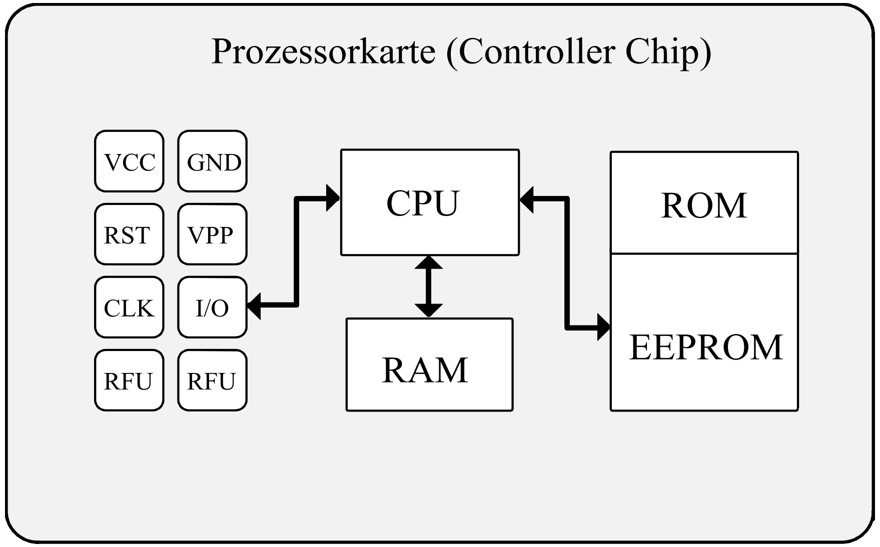




VCC......................	*Negative supply voltage*
GND......................	*Ground*
VPP......................	*Positive supply voltage*
RST......................	*Reset*
CLK......................	*Clock frequency*
I/O.........................	*Data interface*
RFU.......................	*Reserved for future use*

Chip card – controller card (concept processor)

- **Controller cards** operate using an integrated microcontroller, using a segmented memory (including ROM, RAM and EEPROM segments).
  - **ROM** may be mask-programmed in the wafer-based chip manufacturing process. It contains the operating system.
  - **EEPROM** contains application data which may be modified in operation. Access is only possible via the operating system.
  - **RAM** is the temporary, volatile operational memory of the controller. The data content is lost after supply power-down.



Some Identification Systems

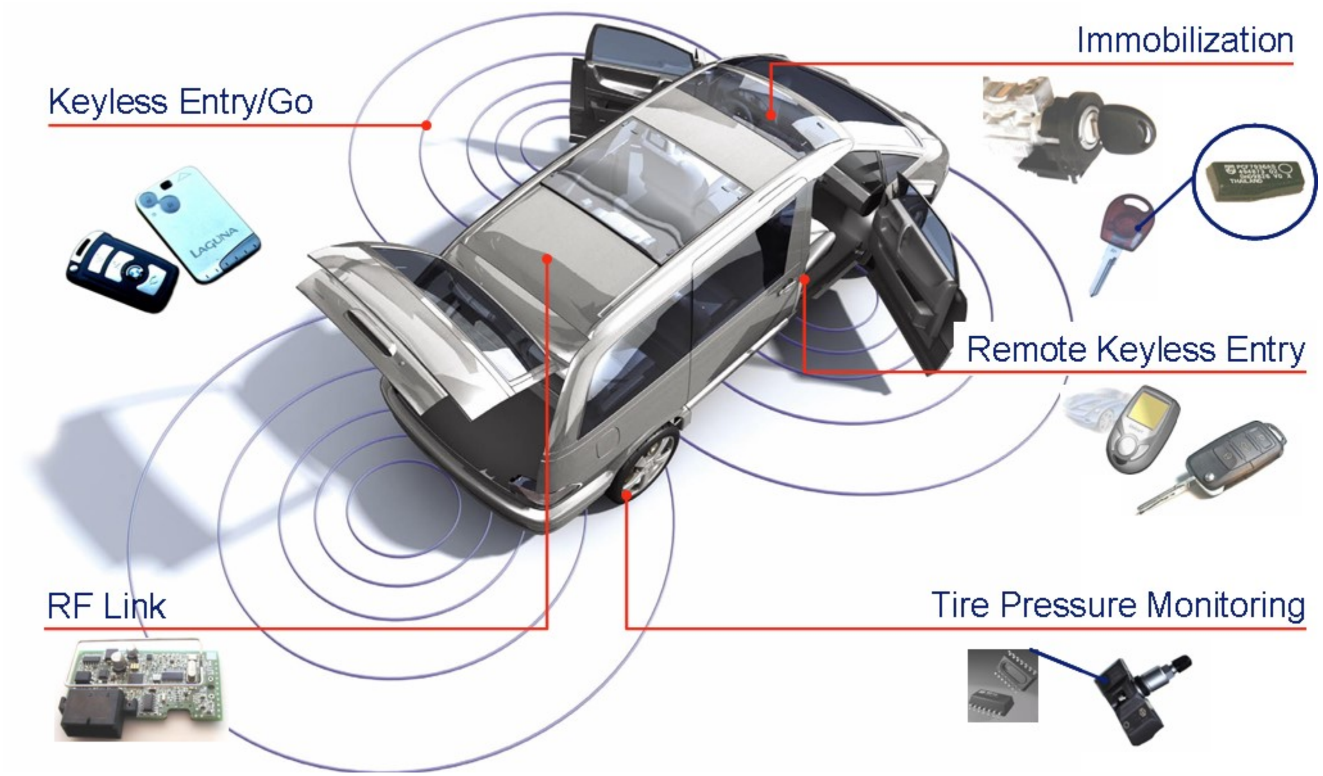
- Barcodes (=> labels, tags, object related)
- OCR Reader (Optical Character Recognition)
- Biometric methods (person-related)
  - Finger print
  - Iris-scan
  - Face recognition
- Speech identification
- Magnetic stripe cards
- Chip cards (=> cards, person-related)
  - Contact cards (SIM)
  - Contactless cards (RFID, NFC)

RFID related standards and application fields

RFID in Automotive applications

- **Immobilizers** were introduced early, in the mid 1980ies (LF RFID)
- Tire pressure monitoring (UHF)
- Passive key-less entry (UHF + HF)

- **High Reliability** and **very low drop-out rates** are essential for success in this market.
- One car key chip today often contains a combination of several technologies (active, passive, UHF, HF,...)



Animal Tracking and Identification, food chain

- Includes identification, tracking and history from birth to slaughter, e.g. of cows.

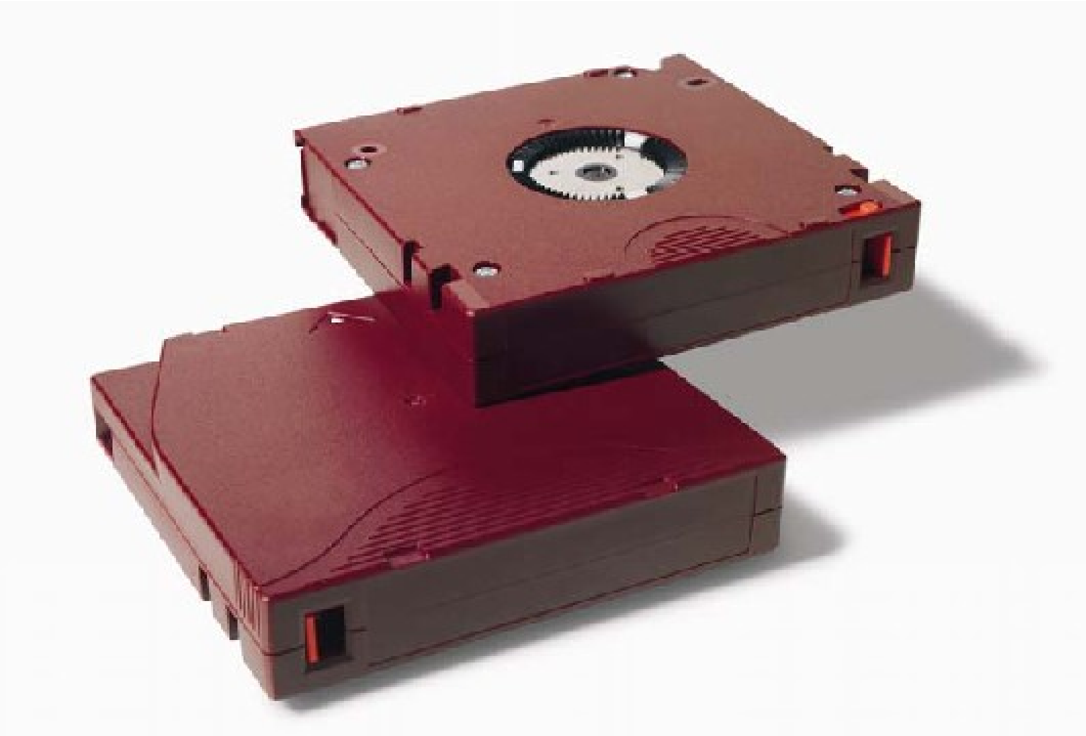
- Advantages are:
  - Improved awareness, that only animals in good health can enter the human food chain,
  - Allows to have overview and allows to control actions in case of animal diseas,
  - Individual treatment of individual animals is possible during the feeding,
  - Prevention of illegal sales
  - Simplifies the control for import and export,
  - Helps to prevent theft of animals.

Public Transport Ticketing

- Paper tickets with battery-less transponder technology are used in many cities, including London, Moscow, Warsaw, generally in the Netherlands and e.g. in 60 cities in China.
- 2007 were more than 3 billion Mifare transponder chips in field, and just Philips alone had sold more than 9 million reader chips for infrastructure.
- Low power chip design and low-cost (small chip area) are essential for success in this application area.
- Earlier, chips were mostly fabricated as state-machines, today most are fabricated as **controller-cards**, in **CMOS technology**.
- Mass market, tens of billions of devices in the field.

RFID as product index

- Magnetic tapes for back-up storage of data in IT, e.g. for banks, contain an HF-RFID transponder (LTO).
- It allows a robotic arm to select and identify one tape, and the memory saves a content of the tape. Furthermore, operational data (number of accesses, date and time-stamp, amount of use of the tape) can be saved.
- Specific niche market – single source, high margin.



Pharmacy market

Advantages in trademark protection and medicine distribution

- Verification
  - Every package marked with RFID has a serial number (**UID**), which allows an identification of the package by a search in a data base of all authentic medicine. This can easily be done at each step in the production chain.
- Back-tracking
  - This “**Unique IDentification number**” allows to get informations, where the medicine is, at this moment, about the history, the owners, packaging or configuration, storing conditions, for all partners in the production chain with access to the RFID system.
  - Knowledge about this history, as accessible via RFID, allows to track and find all distributors, e.g. if the medicine should be distributed, or if it should later be collected and destroyed.

Fashion industry

- Mass market for UHF-RFID
- A quick adoption of RFID has happened, because…
  - RFID-friendly environment (defined entry point is good for installation of gate antennas)
  - High costs and high margins per unit of clothing, which means a low percentage of costs of the RFID-tag in the sales price
  - Brand protection – 22 % of all world-wide sales of shoes are imitations
  - Short stay of the fashion in the shop (fashion trends change quickly) – lower transponder lifetime or data retention requirements
  - Inventory – accurate stock level

Electronic Passport – e-Government

- Introduction in 2005
- Typ. 70 - 100 million e-PP per year at beginning
- ~ 300 million chips in the field in 2008
- Philips had 70 - 80 % market share in the first years
- **ICAO** (civil aviation authority) had adopted **ISO/IEC14443** for world-wide standardized passport system
- Based on Mifare technology, which had been developed by Mikron in Gratkorn.

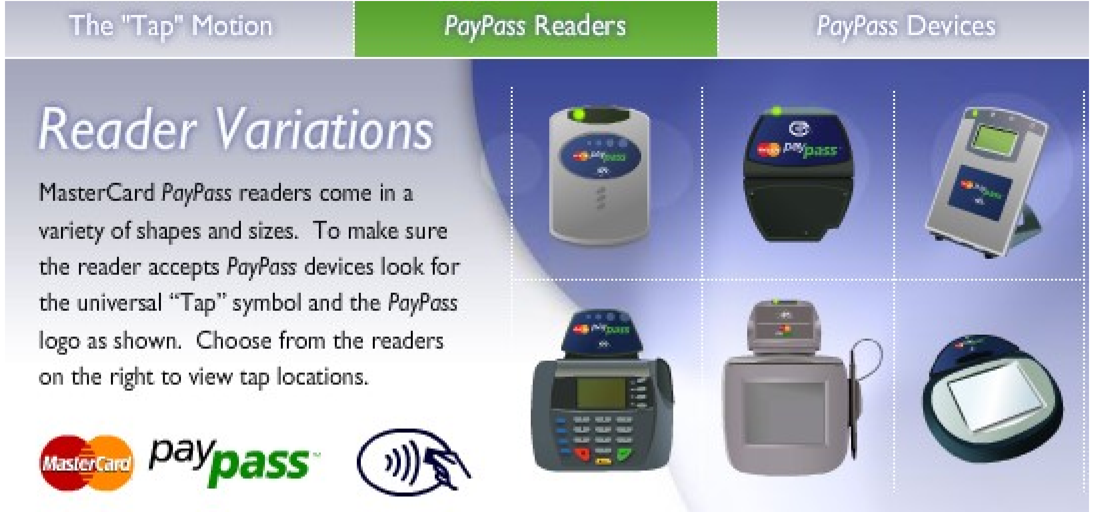
Contactless Credit Cards – e-Payment

- In the 1990ies, credit card companies had founded the EMVCo consortium (Europay, MasterCard, Visa Contactless).

- 6 billion cards for bank applications in the field in 2006
- 1,5 billion controller cards (mainly SIMCards)
- ~ 60 Million contactless credit cards in market in 2008, increasing trend.
- Vital for this application are **security** and low card production costs

Did You Know?

The innovative technology used in MasterCard *PayPass* extends payment convenience beyond traditional cards. Today your Credit, Debit, or Prepaid *PayPass* may come enabled within any of the following devices. Be sure to ask about these devices when you apply for a card.

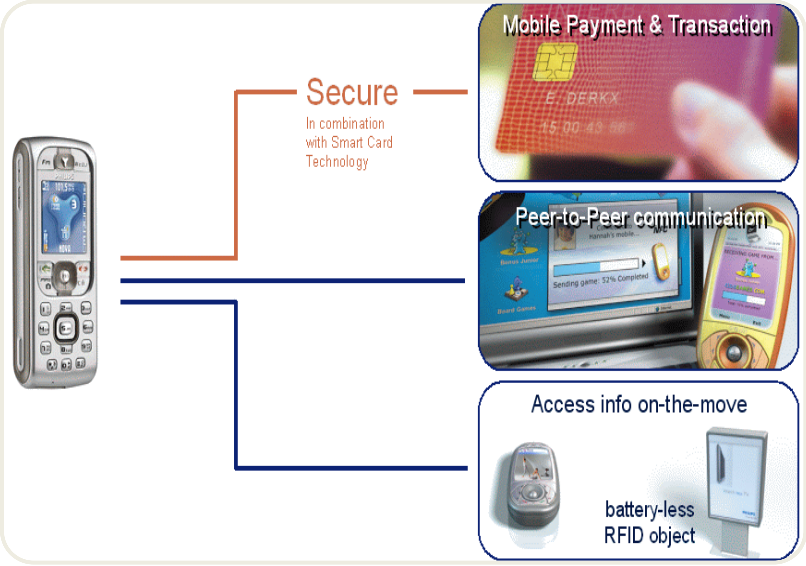


Reader Variations

MasterCard *PayPass* readers come in a variety of shapes and sizes. To make sure the reader accepts *PayPass* devices look for the universal "Tap" symbol and the *PayPass* logo as shown. Choose from the readers on the right to view tap locations.

Near Field Communication NFC

- Today, has become a roof standard for contactless technology in the 13,56 MHz HF frequency band.
- The name is used for protocols and function, does not actually mean the physical *near field* here.
- Originally, combines the function of a reader with a passive transponder
- Allows to implement / emulate several card applications in one device (mobile phone, tablet, handheld, etc.)
- Intuitive handling by very limited distance in near-field (compared to Bluetooth, WLAN, etc.)
- Personal, mobile multi-protocol reader.



Coil on Chip

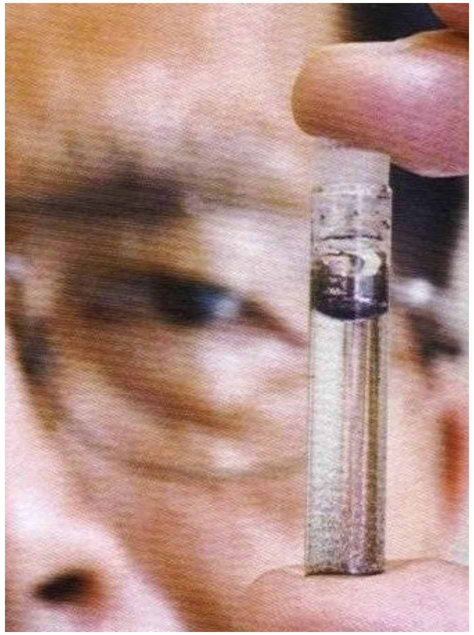
The concept to integrate a complete RFID transponder system including antenna on a silicon chip, was implemented by Hitachi.

RFID-„powder“ consisting of particles in size of 0,4 x 0,4 x 0,06 mm which contain a simple chip (ROM state-machine) operated at 2,45 GHz (small antenna).

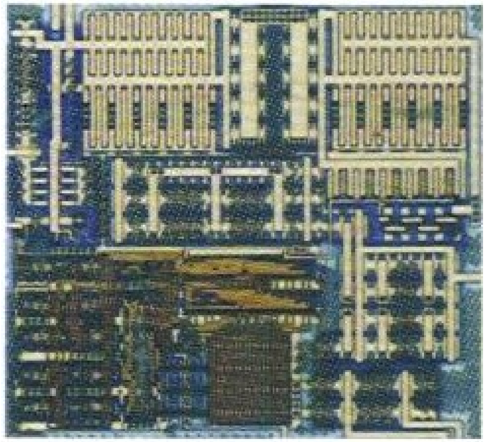
The intended application is a security feature for documents („chip in paper“).

Contracts, commercial papers, banknotes, or product eticettes.

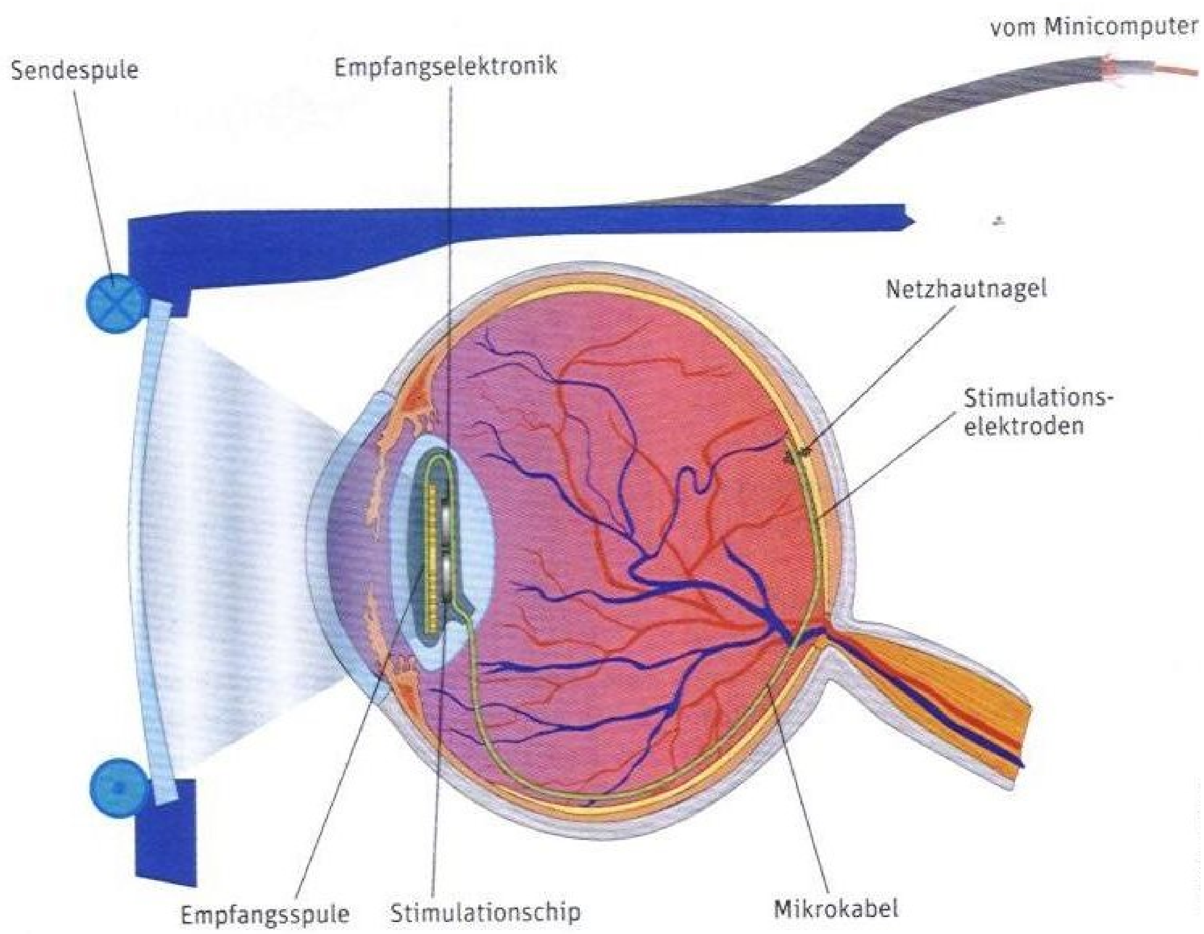
An immediate problem for „coil on chip“ appears in the size, which is determined by the antenna. The change to a smaller silicon process node is hard to implement – antenna size depends on operating frequency, and for the same system cannot be miniaturized.



Source: Spektrum d. Wissenschaft, 5/08



Medical applications



Contactless communication technology also has medical applications:

- *Retina-implant is power-supplied and gets informations for the visual system via inductive near-field coupling,*
- *Implant in the human ear gets power and acoustic information to stimulate the nerves*

- *Advantage: cable connections can be avoided, and the replacement of batteries can also be avoided.*

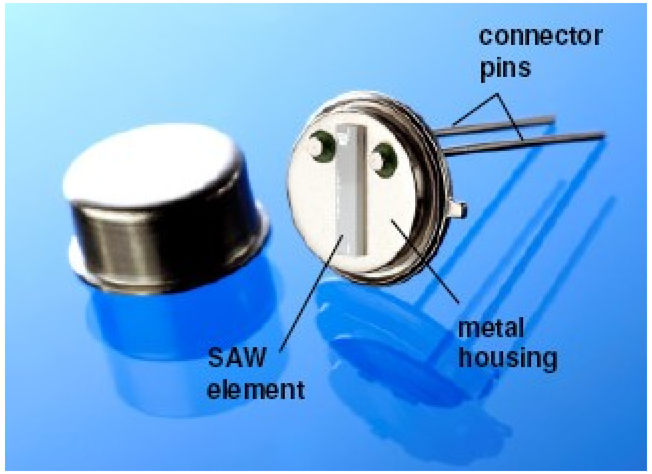
RFID & Sensors

- Interesting seems also the option, to connect sensors over distance to a data logging and evaluation system. Most relevant measures are
  - temperature
  - pressure
  - ph-value
  - orientation, acceleration, position,…
- Sensors are power supplied and can be configured and read-out over a standard protocol (e.g. ISO/IEC15693). To note: Also batteries could be integrated on silicon today.
- An early example is ZMD41211. It contains an integrated temperature sensor and data logger.
  - \- 30 °C ..... + 50 °C, +/- 0,5 °C
  - memory for 720 values, configurable timer
  - 1,3 V backup battery
  - ISO/IEC15693 interface (to program, read data)
  - I²C interface to connect other sensors or system

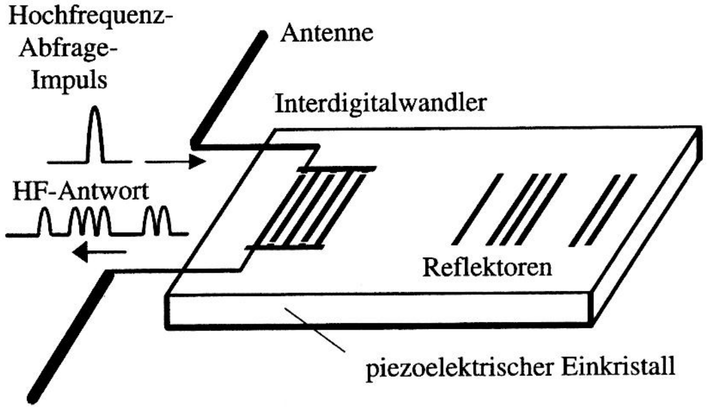
Si-integrierte Mikrobatterie, Source: elektronik report 10/2008

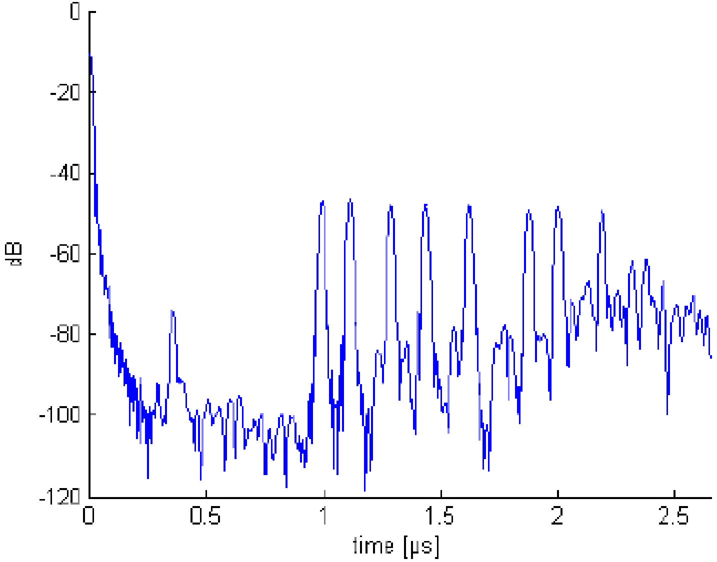
Surface Acoustic Wave for passive RFID-Sensor

- Electromagnetic waves are converted in surface-acoustic waves in the material, which propagate much slower. Dedicated regions of different material structure serve as reflectors which reflect a part of the incoming power back to the antenna. By choice of the reflectors, individual responses (only few bits identification) can be encoded.
- As the propagation time in certain substrate materials (e.g. LiNbO3) are linear correlated to temperature, this principle can be used for remote temperature sensing.



Source: [5]





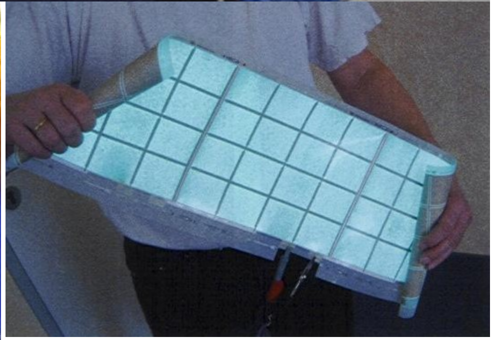
Polymer-Electronics

- RFID at the beginning was also sometimes mentioned as an application for polymer-electronics, using transistors based on organic chemistry. Circuits could then be printed on foils, together with the antenna.
  Though the life-time of such circuits was improved from hours to years, the rather young technology can hardly compare to a technically highly developed wafer-based silicon chip fabrication.
- Some aspects, silicon versus polymer:

– Structure size	~ 0,1 µm	~ 0,1 mm
– Data volume	~ 100 kB	~ 10 bit
– Lifetime	~ 100 yrs	~ 1 yr
– Threshold volt.	~ 0,7 V	~ 20 V

- So it will need very specific applications, to make this interesting technology competitive for market.

Source: elektronik report 4/2006

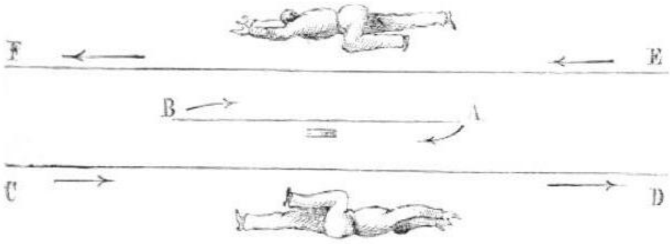


A subjective
history of semiconductor technology with focus on RFID and Contactless Communication

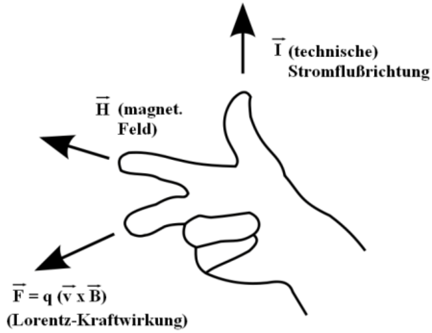
The Physicists (II)

- *In 1820* ***Hans Christian Oerstedt*** *found by chance during a University lecture in Copenhagen, that a current-carrying conductor can move a magnetic needle. Laboratories all over the world immediately started to investigate the effect, trying to explain it.*
- *As the concept of a field (amplitude, direction vector…) was not existing in that time, it was difficult to describe the experiment accurately (movement of the needle was defined relative to the sky…)*
- ***André-Marie Ampere*** *was the first to develop a reference, described in his “swimmer rule”. It defines, in which direction the north pole of the magnetic needle rotates, relative to a DC current. Later, this rule developed to the “three finger rule” used today.*
- *It is essential to note, at the beginning the most important point was to understand the phenomenon and to develop specific terms, to be able to describe it (phenomenologic view). However, this was achieved not just by random trials, but by defining clever experiments to find out the essential relations. And by systematic variation of parameters.*

Hans Christian Oerstedt,Source: [7]



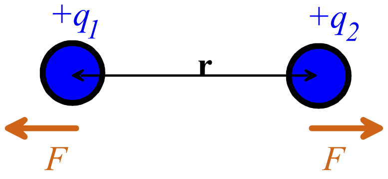
Swimmer rule, Source: Spektrum d. Wissenschaft 9/08 [7]

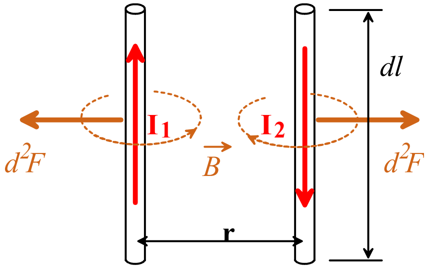


The Physicists (II)

- *1831: The principle of induction is – independent from each other – found by* ***Michael Faraday*** *in England, and* ***Joseph John Henry*** *in America. It accounts to Faradays particular qualities – by using explorative experiments – to have had a good sense to develop a new view and to find an appropriate concept and terms to describe the phenomenon.*
- *Led by theory and very different experimented* ***Jean Baptiste Biot*** *and his assistant* ***Felix Savart*** *in Paris. Biot already had a clear concept in mind, which form his law should have, when he determined in experiments with little flexibility the exact coefficients for it. Mathematical formulas were much higher regarded in Paris at that time, than experiments.*

Michael Faraday ~1840, Dagouerrotypie. Source: [7]





Coulomb force

$$F_{COULOMB} = \frac{1}{4\pi\,\varepsilon_0} \cdot \frac{q_1 \cdot q_2}{r^2}$$

Biot-Savart force

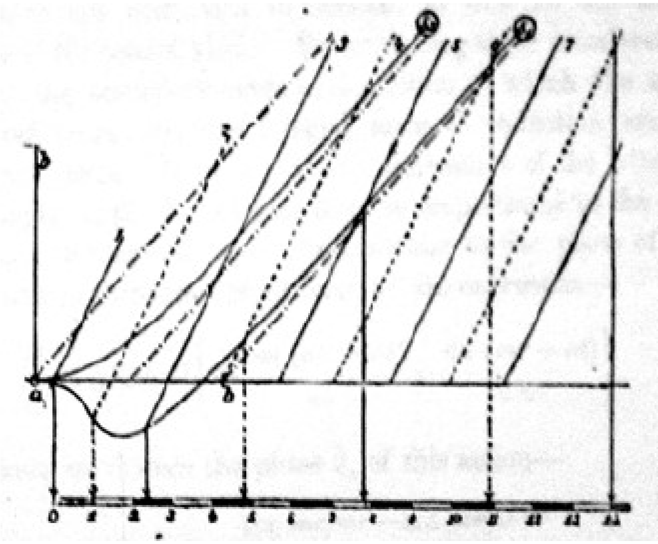
$$d^2F_{BIOT-SAVART} = \frac{\mu_0}{4\pi} \cdot \frac{I_2 dl \cdot I_1 dl}{r^2}$$

The Physicists (III)

- *1873: **James Clerk**, who´s father took over the name **Maxwell** after purchasing a manor house, could summarize the effects of electrotechnology which were known until then in a formal theory [8].*

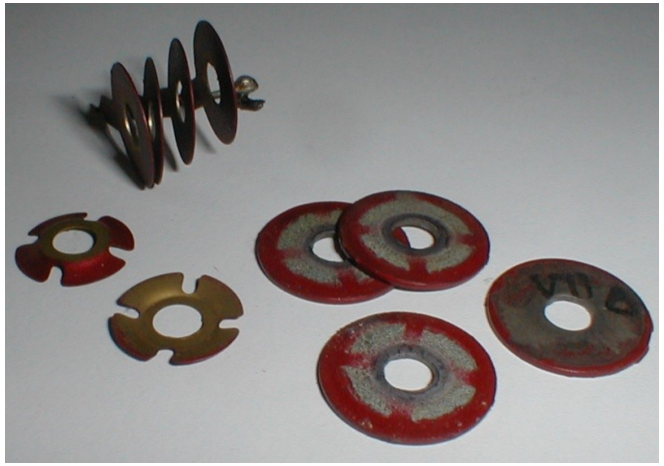
Maxwell 1855 ,Source: [7]

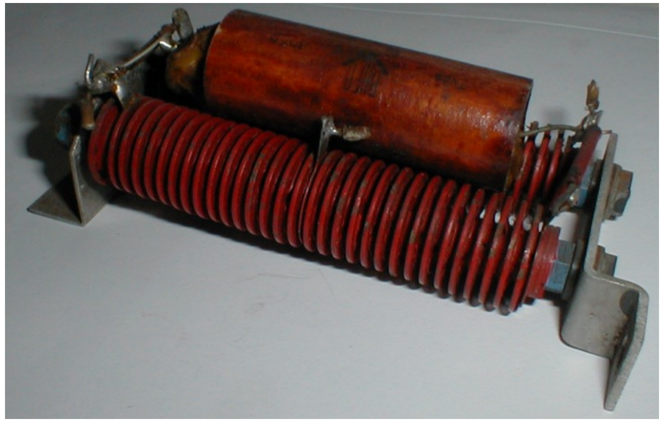
- *1886: **Heinrich Hertz** generates in Berlin experimentally electromagnetic waves and studies their emission and detection. He also investigates the border region from near-field to far-field and the behaviour of the electric and magnetic field. He develops the method of magnetic momentum as a theory for the propagation of the H-field (analogue to the electric dipole momentum).*
- *Theoretical foundations for a **system of absolute electric units** get highly required. A **congress** in Paris in 1881, later in Chicago in 1893, defines units like Volt, Ampere, Farad, Ohm.*



First semiconductor technologies

- *1839* ***Alexandre Edmont Becquerel*** *found the photo-effect as an increased voltage at two electrodes consisting of different metals, which are immersed in acid (Volta´s cell).*
- *1875* ***W. Siemens*** *developed the Selenium cell as converter of optical power to electric current. Reasoning was the very low voltage of signals, transmitted over the transatlantic telegraph cable, which could be visualized only by a light-spot which was deflected by a mirror-galvanometer, which had been developed by Lord Kelvin for this specific purpose. Siemens´ electrical-mechanical-optical-mechanical amplifier allowed to record the data (using a relaise) on paper.*
- *Semiconductor diodes made of Selenium were in use until the 1950ies, mainly as rectifier for the voltage supply. Disadvantages were the low allowable reverse voltage of only 26 Volts (serial circuit of rectifiers necessary), high leakage current and aging caused by light.*
- *However, operated as solar cell the selenium cell achieves about 1 % efficiency. Cells of 6 cm diameter have about 1,6 V off-load voltage and 15 … 20 mA short-circuit current.*

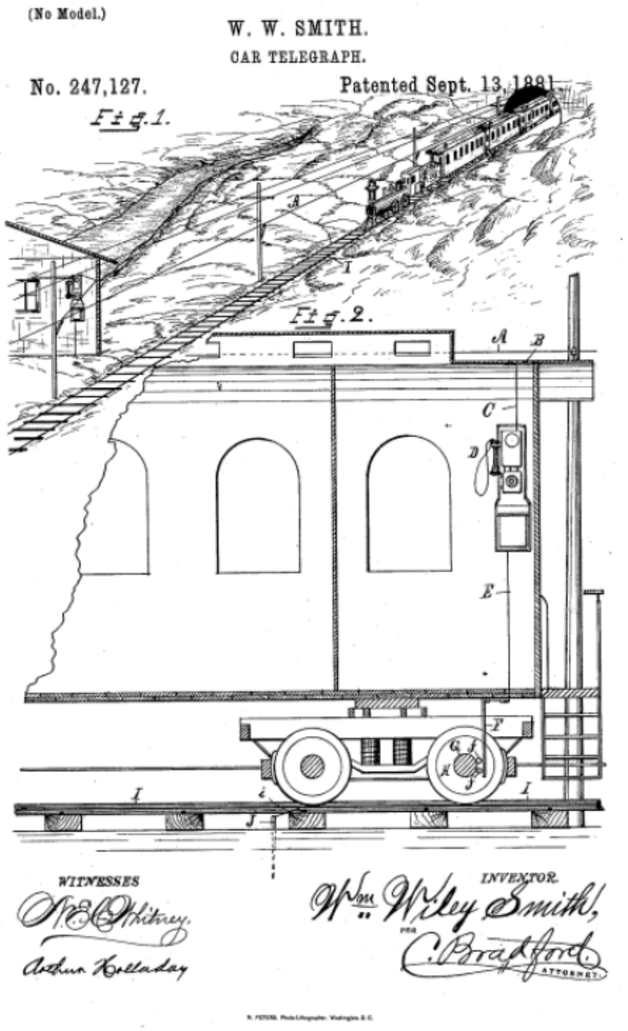




Source: Author, size approx. 8 cm.

Inductive near-field applications

- *First applications for inductive near-field coupling appeared already around 1880, e.g. in the context of connecting a Telephone to the movable railway (patents of Smith or Woods), however, without any practical relevance.*
- ***Harold Wheeler** introduced the classical definition of the "radian sphere" for the near-field region. Within a cylinder with a radius of $l/2\pi$ around the antenna conductor, induction dominates compared to radiation.*



Source: [4]

1916 – Czochralski process

- *1916 the Polish scientist **Jan Czochralski** had accidently immersed his feather pen in a crucible of hot liquid tin instead of his inkpot – and discovered a manufacturing process for Monocrystals and published it in 1918.*
- *In the Czochralski process a cleaned melt (e.g. of Silicon) is kept slightly below the melting point. A rotating slab containing a seed crystal in the right orientation is immersed and slowly pulled upwards. A mono-crystal develops, with a diameter which can be controlled very accurately by adjustment of temperature and velocity.*
- *The process is used in industry-scale applications since the late 50ies to produce the very pure raw material for Wafers to manufacture semiconductor devices, photovoltaic cells or similar. To date, more sophisticated processes like the zone melting technique are in practical use.*

Source: Wikipedia

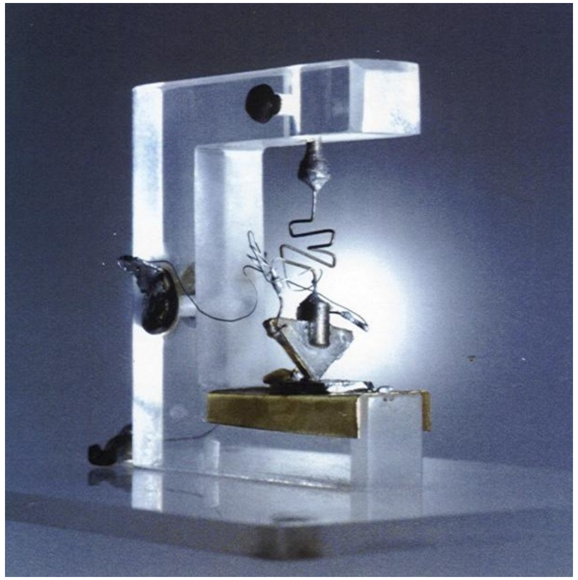
Source: elektronik report 3/05

~1930 Crystal systems

- *Semiconductors were mainly used as diode rectifiers, however, radio amateurs already knew in the late 1920ies that they can also be used for amplification.*
- *J. E. Lilienfeld filed a patent in Canada and the USA around 1930 for a device similar to the MOS transistor, made of the semiconductor material copper sulfide.*
- *The german physicist O. Heil had independently developed and patented in 1934 and -35 a similar principle (see S.d.W. 07/09 p94).*
- *At that time, the semiconductor material was contacted with metallic tips, but it was exposed to the air so isolating oxide layers formed within hours and degraded the device function. Main problem was the uniform purity and the doping level for the semiconductor (for silicon: < 1 impurity atom in a billion Si-atoms). Moreover, a theory for the function was missing.*
- *So, crystal systems had a bad reputation, compared to well-understood and reproducible electronic devices made of vacuum tubes. Thus, before the 2nd world war, crystal systems were no objects for serious research.*

1947 – Transistor (junction transistor)

The Bell Labs of the american telephone company AT&T was looking for practical amplifiers, and mobilized up to 6000 researchers. They were explicitly encouraged to leave trodden paths and not look for minor improvements, but for entirely new ways. The breakthrough came end of 1947 when 3 engineers, ***Walter Brattain, John Bardeen and William Shockley*** *succeeded with an arrangement around a germanium die.*
Shockley later improved the prototype and invented the bipolar junction transistor, which was more appropriate for mass production. AT&T issued licenses for transistor manufacturing to other companies like TI or Sony, which brought a few years later portable radios based on the new technology to market, and so leveraged these devices.
Some of Shockleys engineers founded in 1957 their own semiconductor company, Fairchild Semiconductors, and the scheme did repeat itself: ***Technicians, having the feeling to lose control of their own developments stepped out and founded their own enterprises – the well known "silicon valley" arised.***



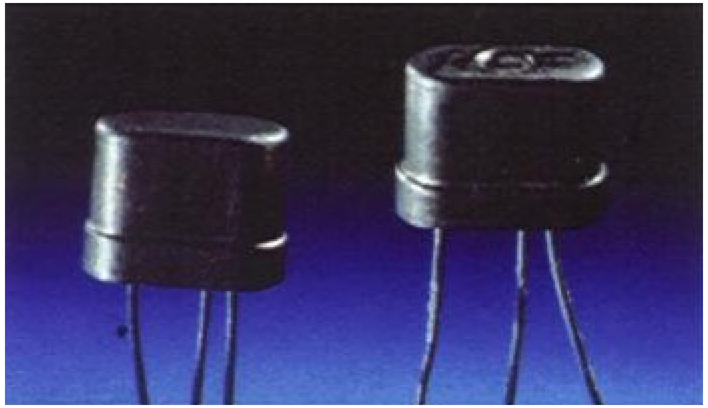
Source: elektronik report, 4/2006

1954 – silicon transistor

Since summer 1953 ***Gordon Teal****, lead engineer of an at that time rarely known semiconductor company named Texas Instruments, had intensively worked on the idea of a silicon transistor. On April 14, 1954, he finally succeeded with very pure material of* ***DuPont****. Following anecdote is reported about the publishing:*

Teal was the last speaker at a conference, where experts had forecasted the silicon transistor still several years ahead. At the end of his speech, Teal said "...I happen to have a few samples in my pocket...". Then he switched on a portable record player with a conventional audio amplifier consisting of germanium transistors. He dipped the transistors into a cup of hot oil, so everyone could hear how the music slowly died out. Then he replaced the amplifier by one containing his silicon transistors, made the same experiment, which then had no impact on the music.

Because of its higher allowable junction temperature of 150 °C compared to Germanium with only 70 °C, and other advantages like much smaller leakage currents, the silicon transistor is technically by far superior.



Source: elektronik report, 1/2005

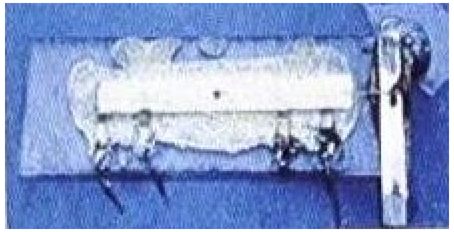
1959 – Integrated circuits

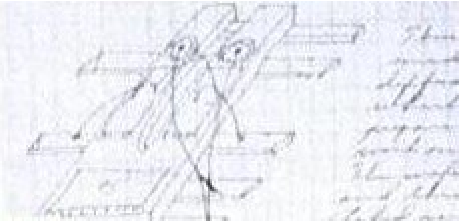
*The first "**Integrated Circuit**" was developed by **Jack Kilby** at Texas Instruments.*

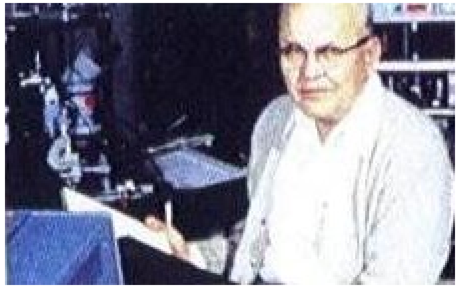
His circuit consisted of transistors, resistor and capacitance, to proof the concept.

He patented his idea under the title "Miniaturized Electronic Circuits" in 1959.

An integrated circuit is a piece of semiconductor, on which a number of electronic components are connected to a circuitry.



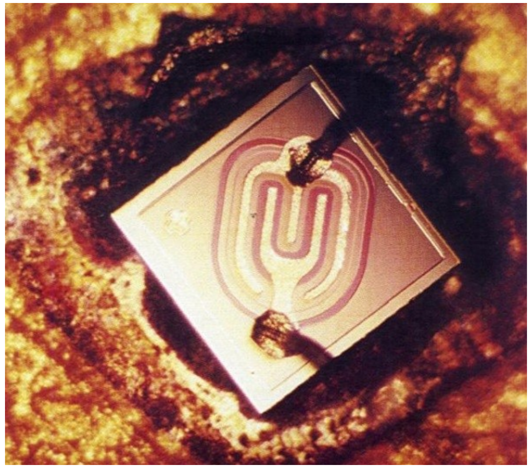




Source: Veendrick, [6]

Side remark:

Also the mass production of the still dominating vacuum tube technology discovered the concept. E.g. complete audio amplifier circuits were integrated in a glass tube.



Integrierter Bipolar-Flächen-Transistor BC107 (Philips)

1965 - Moore´s Law

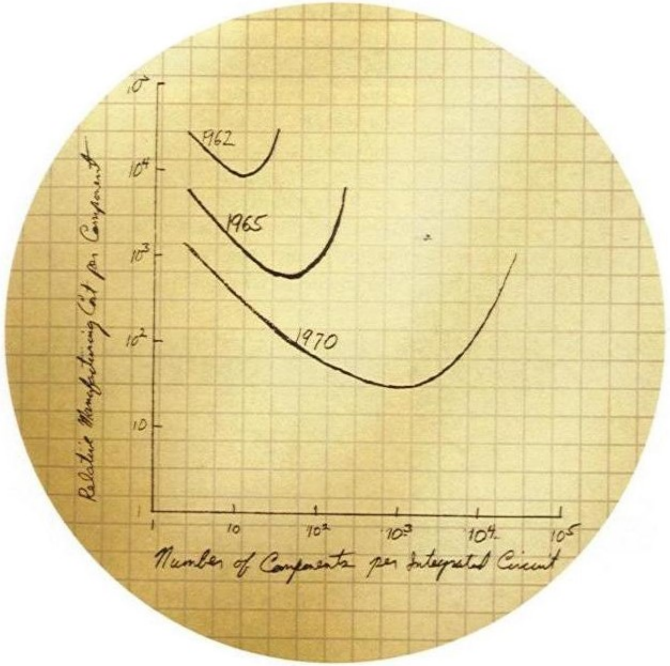
*For more than 40 years, the estimation of Intel co-founder **Gordon E. Moore**, postulated in 1965 and published in 1975, has been proven valid by reality:*

The number of transistors on an integrated circuit doubles between every 18 months and 2 years.

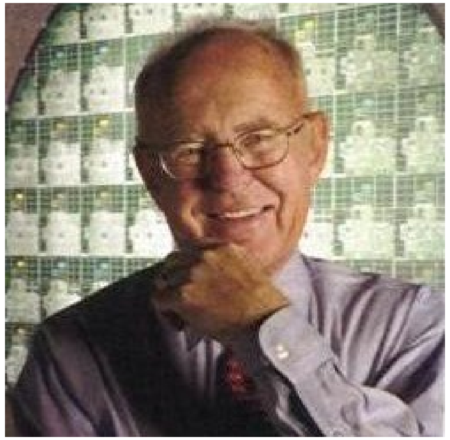
Moore related his growth prognosis to the relative increase of development costs per device. Increasingly powerful semiconductor devices need not only be technically producible, but have also to be available for a broad market at the right time. "Time to market" is essential for a successful product!

This is even more important for emerging markets, as have been microcontrollers, and as is RFID to date. Quick adaption to market needs is a key factor for success.

Project planning and risk assessment are today essential aspects for chip development (and may sometimes be contradicting to en engineers understanding of quality for a mature product).

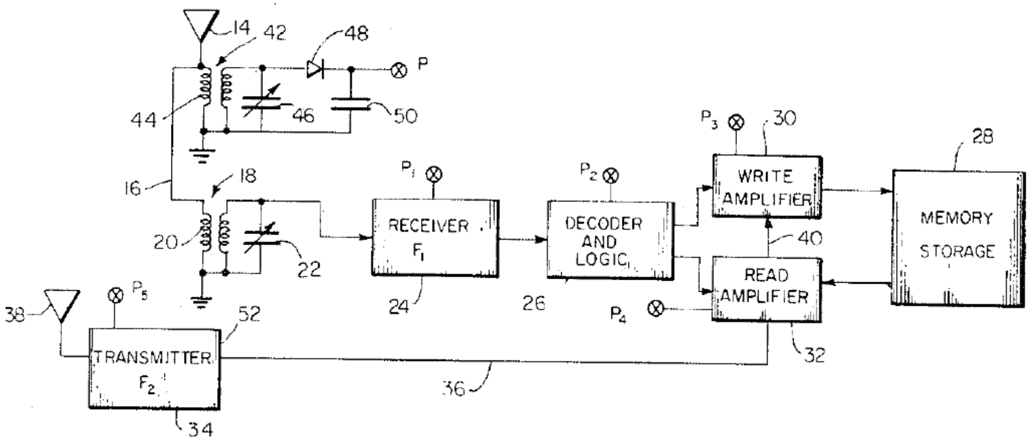


Source: elektronik report, 7/8/2005



First RFID concepts

- 1948 **Harry Stockman**, a swedish electrotechnicial, who had emigrated to the US and had worked in Radar development at Harvard University, published his report “Communication by Means of reflected power” and so did invent the principle of backscatter transponders, which are today used in UHF-RFID.
- ~ 1960 companies like Checkpoint Systems or Sensormatic introduced the 1-bit-transponder for Electronic Article Surveillance (EAS) as anti-theft protection. The working principle are magnetic resonance circuits (working e.g. at 8.2 MHz) and intentionally destroyable fuses or foil capacitors.
- 1973 **Martin Cardullo** patented a battery-less transponder, which could modulate a reflected electromagnetic wave signal, and thus could transmit stored data from a memory.

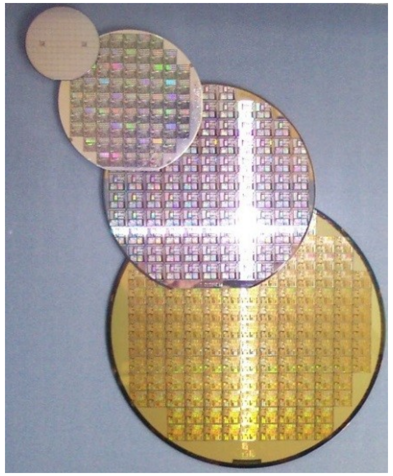


Source: Patent Cardullo, 1973

Chip production on silicon wafers

- **Wafers** are disks cut out of silicon mono-crystals, on which integrated circuits can be fabricated, using photo-chemical process steps. Size and thickness of wafers have the following standardized measures:

English name convention	Diameter in mm	Typical thickness in µm	Year of market introduction
2 inch	50,8	275	1971
3 inch	76,2	375	1973
4 inch	100	525	1976
5 inch	125	625	1982
6 inch	**150**	**675**	**1988**
8 inch	**200**	**725**	**1990**
12 inch	**300**	**775**	**1997**
18 inch	450	???	???



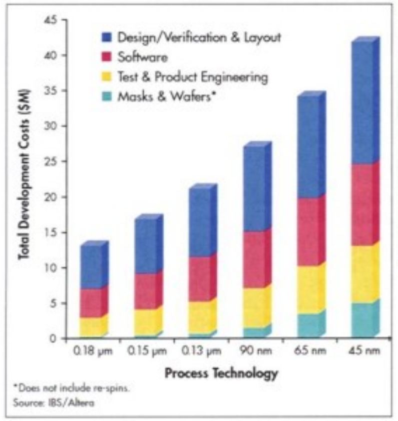
Source:Wikipedia

- **Dice** means an individual integrated circuit.
- **Lot**: A typical number of wafers is processed together in one run, e.g. 12,18 or 25 wafers. To note: For prototyping, it is also possible to take individual wafers our of the production, e.g. to shift a decision, e.g. on a mask-programmable operating system, and to save time (as only few steps are necessary to complete the wafer).
- **Batch** means a transport box for wafers, typ. can carry 32 wafers.

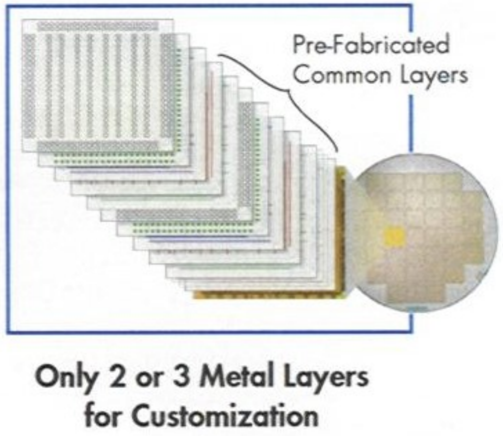
Chip development on silicon wafers

- **Masks** are necessary, to process individual layers in the vertical structure of an integrated circuit one after the other. Depending on process node (feature size) 15 ... 35 individual masks are necessary, at costs of 30.000 ... 800.000 €. Small feature sizes (processes) require masks of significantly higher costs. So, a complete and successful simulation of the product is becoming increasingly important, a “First Time Right” is the wish of the industry.
- Also application-oriented software can be programmed in non-volatile memory as ROM code by mask programming. Thus, different chip derivatives may not require complete mask sets, but only a few different masks to program the individual ROM code on the dice.
- Multiple Part Wafer or Shared Reticles are commonly used in the chip development phase, to produce several different ICs on one wafer (with one mask set), to share costs for the mask set in the development phase.

Quelle:elektronik report 5/2007



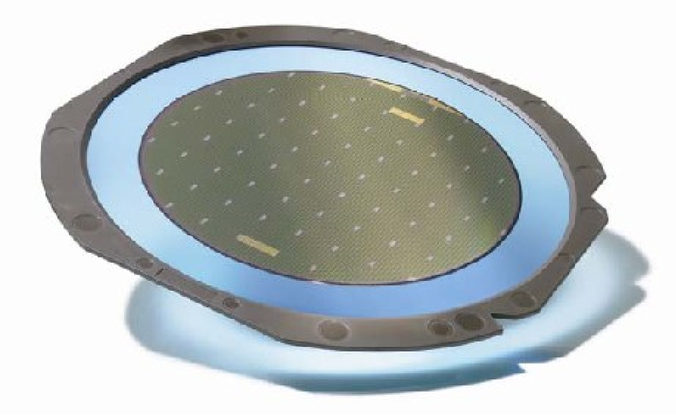
*Does not include re-spins.
Source: IBS/Altera



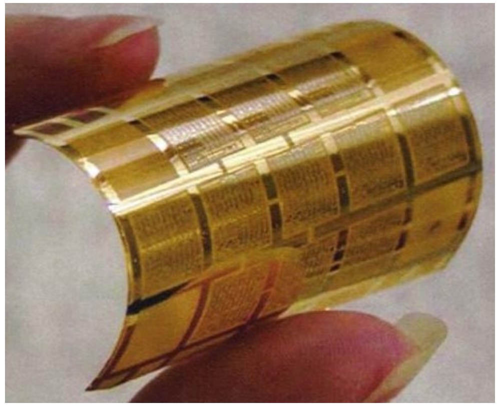
Source:elektronik report 12/2005

Chip development on silicon wafers

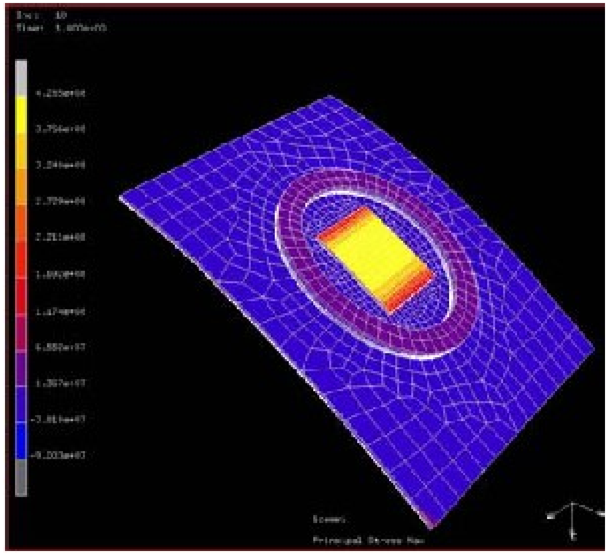
- Today, **wafer diameters** of 150... 300 mm are most commonly used.
- Thinning: After wafer processing, the wafers are thinned by grinning down the back side of the wafer (typically to 300, 150, 75 µm). Then the wafers are cut by separating diamond saws or by lasers. Individual dices are separately placed on a flexible foil.
- So-called Saw bows, connection bridges, which intentionally exceed the size limit of the dice and because of that, are cut in the sawing process, can be used, to determine the fabrication step on the chip. This way, e.g. it is possible to differentiate whether a test program (for wafer testing) should be used, or the final application program.



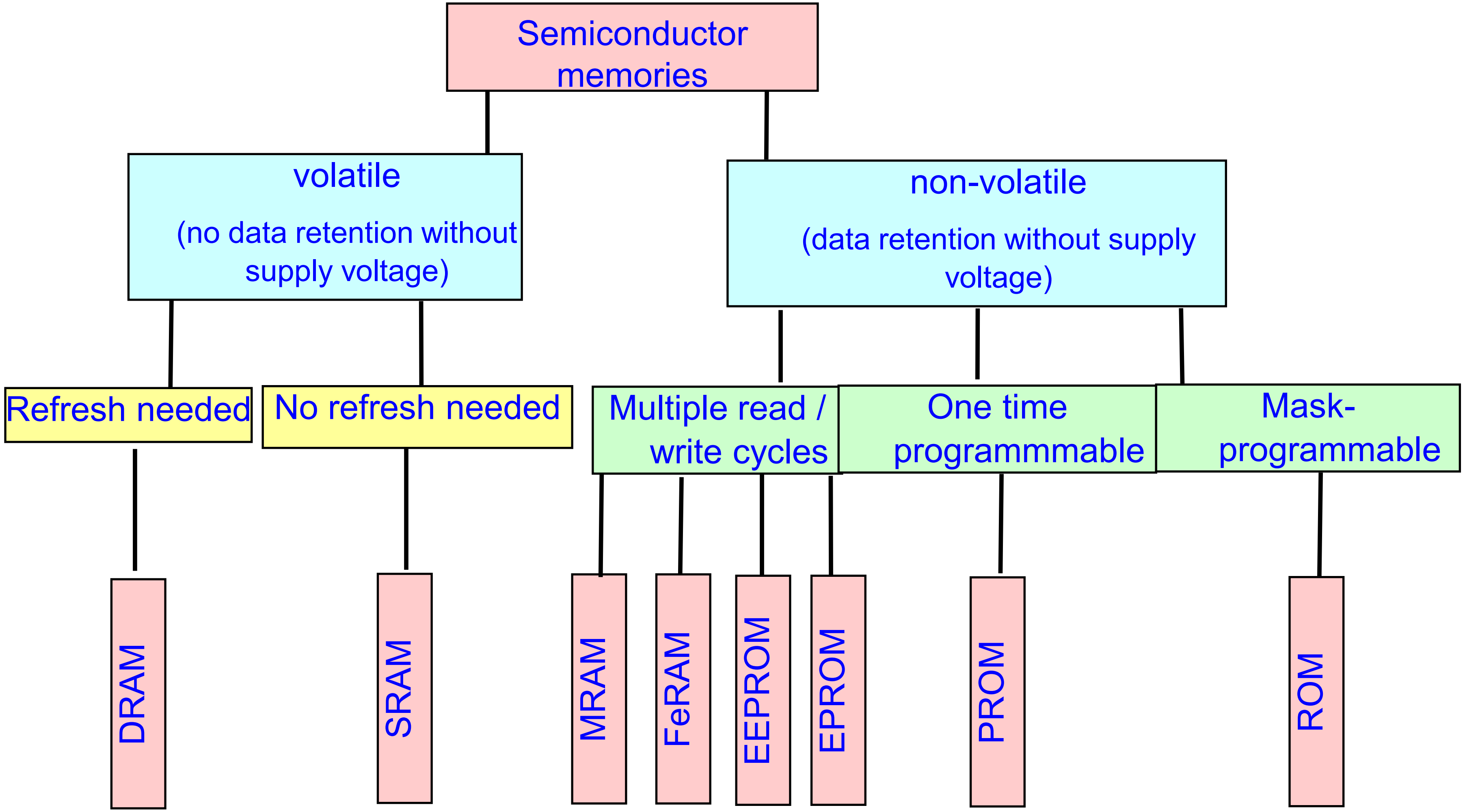
Source:Wikipedia



Source:elektronik report 12/2008



Semiconductor memory technologies



Semiconductor memories

volatile

(no data retention without supply voltage)

non-volatile

(data retention without supply voltage)

Refresh needed

No refresh needed

Multiple read / write cycles

One time programmmable

Mask-programmable

DRAM

SRAM

MRAM

FeRAM

EEPROM

EPROM

PROM

ROM

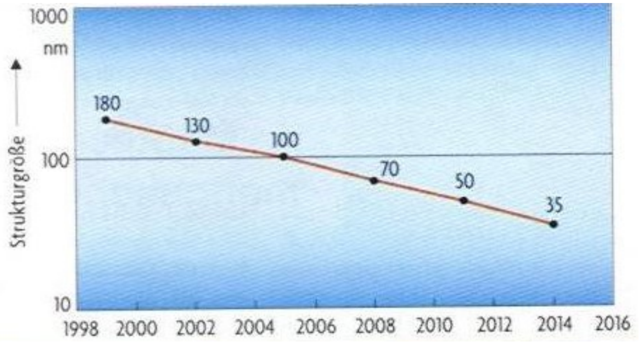
Source:Sikora [10].

Memory technologies

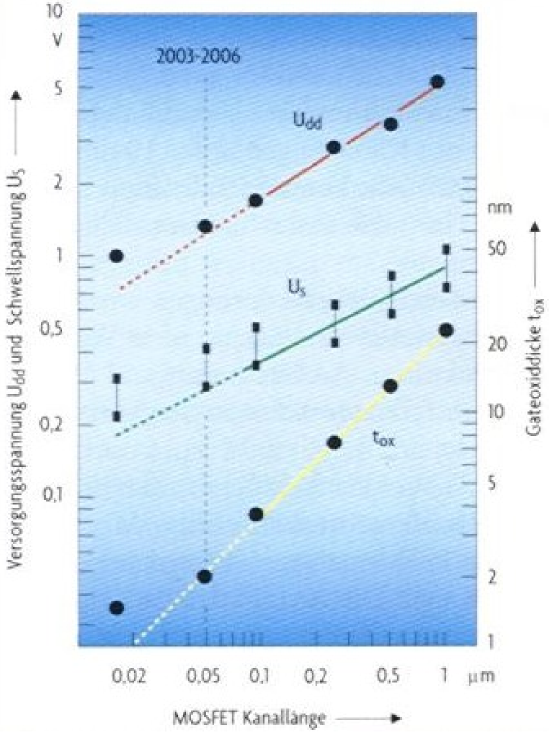
- **DRAMs:** Dynamic RAMs require continuous refreshment of the stored data, but require a minimum of silicon area per memory cell. They allow to achieve maximum storage density at low costs, a disadvantage is the continuous power required for he data refreshment in operation.
- **SRAMs**: Static RAMs can save data when the power supply is available, however, they require more silicon area per memory cell. Advantages are a lower supply power and short access times.

Process nodes / structure scales in integration

- **Costs** per chip are an essential factor, urging for miniaturization. The chip area required for a certain chip functionality shall be as small as possible. Many dices shall be produced on one wafer.
- As different semiconductor manufacturers for efficiency reasons use the same equipment and process technology, de-facto standards have developed for so-called **process nodes** (meaning the minimum feature size).
  - 180 nm, 150 nm, 100 nm, 75 nm, 40 nm, etc.
- But the size reduction of the structures implies also changes of the electrical system parameters:
  - Supply voltage must be reduced (180 nm typ. 1,8 VDC),
  - max. allowable voltage has to be reduced => possibly requires completely new analog concepts,
  - Lead resistances increase (may cause smaller bandwidth),
  - Power loss per area increases, temperature may be critical,
  - Development costs for a mask set for wafer processing increases significantly

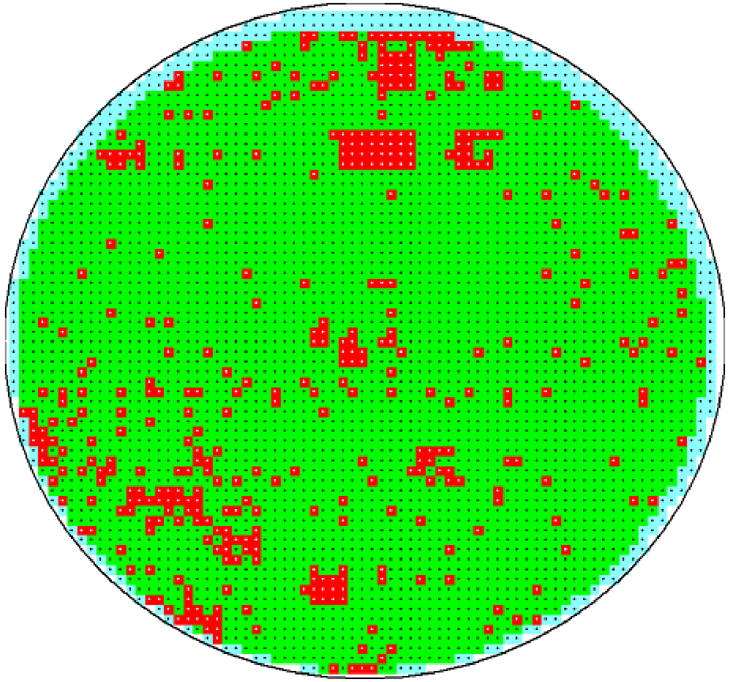


Source:elektronik report, 7-8/2000

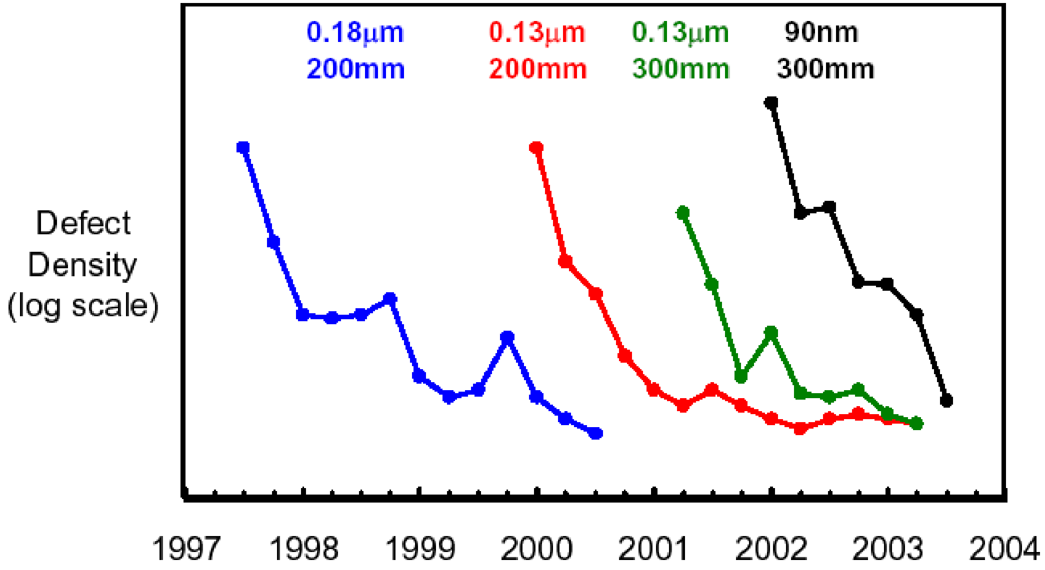


Chip fabrication on wafers

- **Yield** means the percentage of “good parts” out of production, these are the parts, which pass the wafer test at the end of production and thus are within the specification. During the wafer test, a **Wafer Map** is prepared, which identifies bad parts. In subsequent processing, after packaging, bad parts are marked by punched out holes, and are sorted out when a product is assembled.

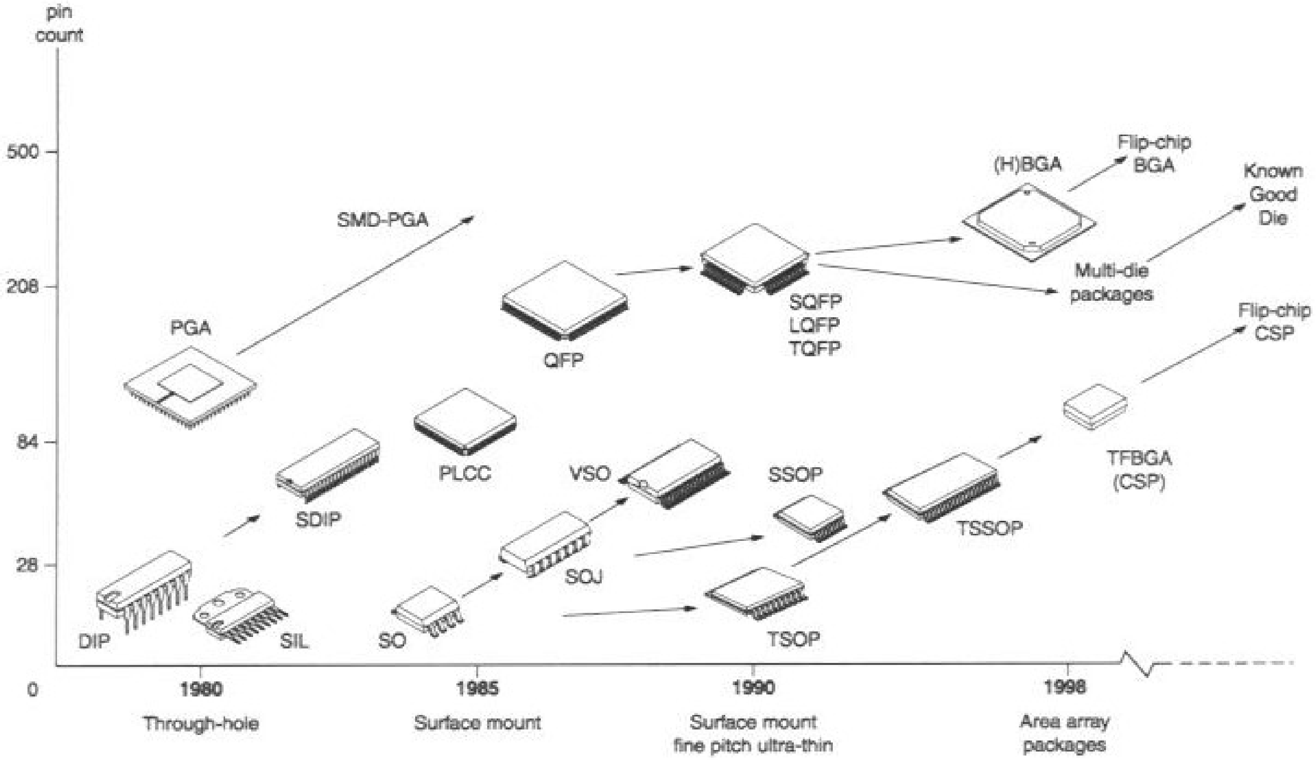


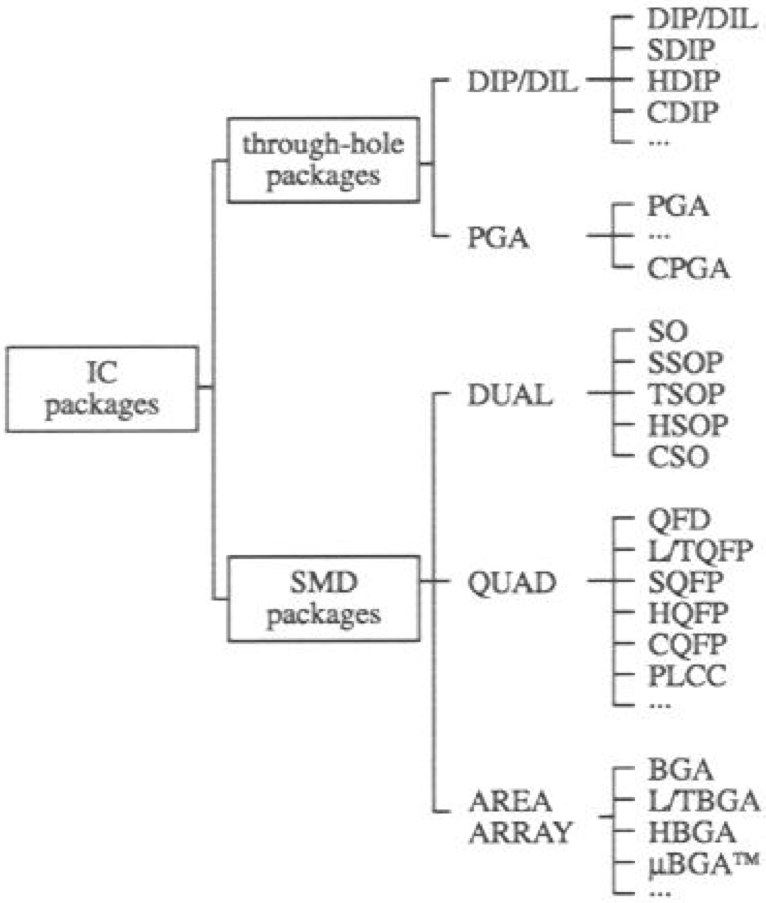
Yield Trend for Intel Logic Technologies



Packaging (I)

*Then, the die is integrated in a **package**. Classical packages with via-through plating or **Surface Mounted Devices (SMD)** are used in the RFID context for **Engineering Samples**. These are chip products in development, for which measurements need to be done also on individual module of the circuitry.*





Source:Veendrick [6]

Packaging (II)

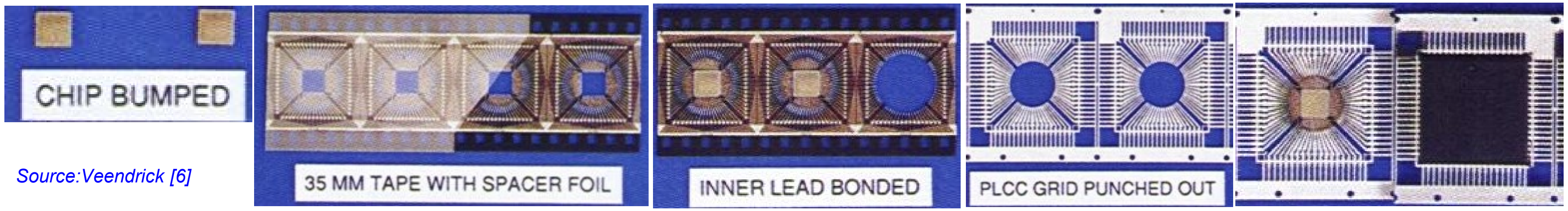
Packages for chips contribute costs in the range of 5 - 50% of the dies. Besides an improvement of electrical properties (lead inductance) it is worth especially for low-cost RFID transponder, to use leading technologies in this aspect. 3 technologies are of main relevance today:

- **Wire Bonding**: The die is glued on the bottom side with thermally conductive glue in the package. Then, gold wires (bond wires) of approximately 25 µm diameter are welded one after the other fro the die pad to the package connection. This is the older technology, still often used for large-scale industry production. Disadvantage: more time-consuming, higher lead inductance,…

Source:Veendrick [6]

Packaging (III)

- **Tape Automated Bonding**: A pre-fabricated “Lead Frame” from a tape is used. Gold ”bumps” are inserted on the contact pads of the die or on the contact pads of the inner Lead Frame of the package. A process step using pressure and high temperature is used to transform the bumps to solid connections between chip and Lead Frame (inner lead bonding). Then, this Lead Frame is punched out of the tape and connected to a Lead Frame which already is in the package (outer lead bonding). Die and connections are then sealed with epoxy resin. Advantage: Highly automated, shock-resistant, uniform distributed,…



Source:Veendrick [6]

- **Flip Chip**: The die is mounted flipped in the package, such that the side containing the functional elements is oriented towards the bottom of the package. Tin beads are deposited on the bond pads of the die – usually while the die is still on the wafer – and on the package board. Using temperature and pressure, the flipped die is connected to the package. Advantage: Very short lead connections, good mechanical stability, low space consumption.
  - Disadvantage: No visual inspection is possible

Packages for transponder chips

- Specific package developments are necessary, to satisfy the requirements of a complete transponder product. Critical aspects are
  - Tolerances in the assembly,
  - Height (especially critical for card products),
  - Heat dissipation (loss power),
  - Costs of the complete transponder (for low-cost products the package is even more relevant for the price).
- Some de-facto standards have evolved, which are shown below:

Thank you for your Audience!

Please feel free to ask questions...

Hinweise – Notizen

Questions for self-evaluation

- What is RFID?
- For which applications may RFID and NFC be used, and which properties are required for the technology in the specific application field? Mention advantages and disadvantages.
- Which parts and devices are required for a battery-less RFID system? How does the value-chain for production of RFID tags & readers look like?
- Think about the history and development of semiconductor technology and communication engineering. How and when did RFID develop? Which elements and aspects are required? Which alternative or competing technologies do exist?
- Think about the wafer-based silicon chip manufacturing process. How does RFID Chip development basically work? Which job functions are usually in a team? What is the meaning of “Time to market” and Moore´s law?
- Explain a few technical terms, e.g. what is a die, an engineering sample, a wafer mask, the yield, a wafer map, an MPW, a ROM code, bond wire, flip-chip technology?

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